DEPARTMENT OF PHYSICS

January 2007 - December 2009

SCIENTIFIC REPORT

DIPARTIMENTO DI FISICA

SAPIENZA
UNIVERSITÀ DI ROMA

Sapienza Università di Roma

DEPARTMENT OF PHYSICS

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UNIVERSITÀ DI ROMA

Dipartimento di Fisica

Scientific Report

2007 - 2009

The Scientific Report has been edited by Daniele del Re, Marco De Petris, Leonardo Gualtieri, Fabio Sciarrino.

Cover graphics by Fulvio Medici:
Picture of Marconi Building
Department of Physics
Main Campus of Sapienza Università di Roma
Piazzale Aldo Moro 2, 00185 Roma

In the 1930s, a group of young architects, directed by Marcello Piacentini, created the new University Campus of Rome. The building which currently hosts the Department of Physics was designed by Giuseppe Pagano (1896-1945) between 1932 and 1935. After the death of Guglielmo Marconi, in 1937, it was given the name Istituto Guglielmo Marconi.

Originally Paganos building extended over 3400 square metres, and was divided into two main parts corresponding to Advanced Physics and Experimental Physics. It included workshops, a library and the guards houses. The two hundred and thirty-seven rooms that composed the building were organized following a functional scheme, related to the plant design and to the construction features of the building. The formal solutions, such as the mechanism of the windows, were defined with an aim to the maximal functionality; interior niches, colours, doors and windows were the same for all premises.

The innovative conception and use of leading-edge techniques make this building a masterpiece of aesthetics and functionality, mentioned in various Architecture textbooks. Indeed, it had a profound influence on the other architects who worked at the University Campus. The building plan is the result of a free articulation of the various parts, according to the different functions that should be carried out, harmoniously incorporated as well-defined volumes to which the vacuum corresponds as an essential complement of rhythm.

Guido Martinelli

Contents

Introduction

The Department of Physics of 'Sapienza', Università di Roma, is the natural heir of the tradition of Enrico Fermi, Franco Rasetti, Ettore Majorana, Edoardo Amaldi, Bruno Pontecorvo, Emilio Segrè (School of Rome), and is renown worldwide for its high quality research, international prestige and variety of teaching.

In this report all the activities of the Department from 2007 to 2009 are presented. During these three years the scientists of the Department of Physics have published approximatively 1500 articles on international refereed journals. Many of these publications appeared on journals with the highest Impact Factor (IF): 60% of them on journals with impact factor greater than 3 and 15 appeared on journals with IF>10. The high quality of the research carried out in our Department has led to a large number of funding grants from Italian and European funding agencies.

The scientific activity is organized in more than 100 research lines, grouped in six subject areas: Theoretical Physics, Condensed Matter Physics and Biophysics, Particle Physics, Astronomy & Astrophysics, Geophysics, History of Physics and Physics Education. For each area there is an introductive summary, followed by a one page report describing the main activities and lists of the involved scientists and the most relevant papers published in the considered time span. The detailed description of the Experimental and Computational Facilities of the Department is also included. To provide a complete insight on the Department activity, this book reports all the funded grants involving our institutions as well as Schools, Workshops and Conferences held in this period. The list of published papers in international referred journals divided by subject area and year completes the description.

In the considered triennium several highly recognized awards have been granted to members of our community, let me just mention the most relevant: the Dirac Medal to Luciano Maiani, the Lagrange-CRT Foundation Prize and the Microsoft European Science Award to Giorgio Parisi, the Dan David Prize Astrophysics-History of the Universe to Paolo de Bernardis, the Boltzmann Medal to Giovanni Gallavotti, the Enrico Fermi Prize to Miguel Angel Virasoro and to Luciano Pietronero. Such a high rate of prizes received by scientists of the Department testifies that the "School of Rome" is still lively.

The high quality of the research and educational activities of the Department draws the lifeblood of the commitment and passion of all members of the department itself. It is therefore both a pleasure and a duty to warmly thank all the administrative and technical staff, together with the whole body of scientists, for their personal effort to make things work. An effort that is more and more important in this very moment that sees a constant, dramatic reduction of resources, and the disownment of the value of research and culture.

I would like to conclude this brief Introduction by dedicating this report to the memory of Nicola Cabibbo. We had the privilege of having Nicola as a member of our Department. His works on the weak interactions are worldwide recognized. He has also been the president of the Italian National Institute of Nuclear Physics from 1983 to 1992, president of ENEA from 1993 to 1998 and since 1993 he has been the president of the Pontifical Academy of Sciences. At the time of publication of this report he has been awarded the Dirac Medal, a prize that he cannot receive personally due to his untimely death.

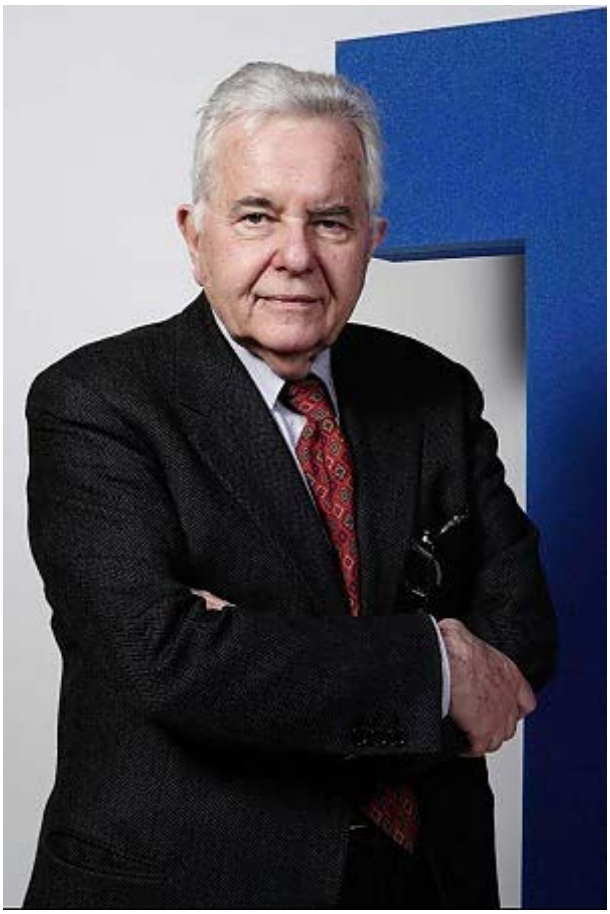
Giancarlo Ruocco

Director of the Department of Physics

In memory of Nicola Cabibbo

On the 16th of August, Nicola Cabibbo, Professor of Theoretical Physics in our Department and one of the world leading particle physicists, passed away.

At the beginning of his career, Cabibbo wrote with Raoul Gatto an exploratory paper on the physics that could be studied with e^+e^- interactions[1], which soon became a standard reference in the field.



In 1963, while at CERN, Cabibbo discovered a new fundamental constant of nature, named after him the Cabibbo angle[2]. In his theory, nuclear beta decay and strange particle decays are included in a unified picture. Building on previous ideas by Fermi, Feynman and Gell-Mann and others, the Universality concept thus formulated by Cabibbo opened the way to the Electroweak Unification, one of the highest achievements of modern Physics. The success of his theory[3] and his exceptional talent as teacher and conference speaker made soon Cabibbo an internationally known and influential figure.

Professor in Roma since 1966, he has promoted a school of theoretical physicists which had a world recognized impact on the field of fundamental particles and interactions. Among the most important results: the parton description of e^+e^- annihilations into hadrons[4], the computation of electroweak corrections to the muon magnetic moment[5], the study of the beta decay of heavy quarks[6], the prediction of the existence of a phase transition from hadronic to deconfined quark-gluon matter[7], the first lattice computation of weak parameters[8], the study of upper and lower bounds to the Higgs boson mass in Grand Unified Theories[9]. Together with Giorgio Parisi, Cabibbo proposed and devised a parallel supercomputer dedicated to lattice QCD studies[10].

Nicola Cabibbo has been President of INFN (1983-1992), of ENEA (1993-1998) and of Accademia Pontificia delle Scienze (since 1993). He was member of Accademia Nazionale dei Lincei and of the American Academy of Sciences. He received the High Energy and Particle Physics Prize of the European Physical Society (1991), the Sakurai Prize of the American Physical Society (1989) and the ICTP Dirac Medal (2010).

Luciano Maiani

President of CNR - Consiglio Nazionale delle Ricerche

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4. C.Swallow and R. Winston, *Semileptonic Hyperon Decays*, Ann. Rev. Nucl. Part. Sci. **53**, 39 (2003).
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Research areas and affiliations

The research activities have been divided in the following subject areas:

T- Theoretical Physics: T1-T23

C- Condensed matter physics and biophysics: C1-C46

P- Particle Physics: P1-P34

A- Astronomy & Astrophysics: A1-A16

G- Geophysics: G1-G4

H- History of physics and physics education: H1-H3

The authors of the Research Activities, as members of the Department of Physics, are reported at the end of each description. In the case of authors of other institutions affiliated to the Department of Physics, the following numbers have been adopted:

1 - INFN, Istituto Nazionale di Fisica Nucleare

2 - SOFT-INFM-CNR, Consiglio Nazionale delle Ricerche

3 - SMC-INFM-CNR, Consiglio Nazionale delle Ricerche

4 - Centro Studi e Ricerche Enrico Fermi

5 - INAF, Istituto Nazionale di Astrofisica

6 - ICRAnet, International Center for Relativistic Astrophysics

7 - CNISM, Consorzio Nazionale Interuniversitario per le Scienze Fisiche della Materia

8 - ENEA, Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile

List of research activities

T- Theoretical Physics:

T1. The New Hadrons
T2. B decay spectra in resummed QCD calculations
T3. Flavor, CP violation and Matter-Antimatter asymmetry
T4. The origin of Electroweak Symmetry Breaking and New Physics at the Electroweak scale
T5. Properties of hadron collisions at high energy
T6. Theory and phenomenology of quantum-spacetime symmetries
T7. Particles in Astrophysics: UHECR maps versus UHE Tau Neutrinos
T8. Physics of Gravitational Wave Sources
T9. Gamma-Ray Bursts
T10. Massive Nuclear Cores, Neutron Stars and Black Holes
T11. Quantum Cosmology
T12. Statistical mechanics of disordered systems and renormalization group
T13. The glassy state
T14. Optimization problems and message passing algorithms
T15. From Artificial Neural Networks to Neurobiology
T16. On static and dynamic properties of complex systems in statistical mechanics and quantum field theory
T17. Macroscopic fluctuation theory of irreversible processes
T18. Equilibrium statistical mechanics for one dimensional long range systems
T19. Markov chains on graphs
T20. Optical solitons in resonant interactions of three waves
T21. Propagation and breaking of weakly nonlinear and quasi one dimensional waves in Nature
T22. Towards a theory of chaos explained as travel on Riemann surfaces
T23. Discrete integrable dynamical systems and Diophantine relations associated with certain polynomial classes

C- Condensed matter physics and biophysics:

C1. Superconductivity in low-dimensional materials
C2. Strongly Correlated Superconductivity
C3. Charge inhomogeneities and criticality in cuprate superconductors
C4. Phase separation and spectroscopy of inhomogeneous and correlated functional materials
C5. Phenomenology of transport properties in matter
C6. Sub-Terahertz and Infrared studies of strongly correlated oxides
C7. Sympathetic cooling of Fermi-Bose atomic mixtures
C8. High Frequency Dynamics in Disordered Systems
C9. Soft Matter: Arrested states in colloidal systems
C10. Order in disorder: investigating fundamental mechanisms of inverse transitions
C11. Statistical physics of information and social dynamics
C12. Complex agents in the global network: selforganization and instabilities
C13. Understanding large scale collective three dimensional movements
C14. Statistical Biophysics
C15. Ordered and chaotic dynamics in molecules
C16. Fluctuation-dissipation relations in non equilibrium statistical mechanics and chaotic systems
C17. Chaos, complexity and statistical mechanics
C18. Stochastic convective plumes dynamics in stratified sea
C19. Mesoscopic solutes in water solvent
C20. Coarse Grained Molecular Dynamics Simulations: application to proteins and colloids
C21. Mixed quantum-classical dynamics for condensed matter simulations
C22. Computer simulation of rare events and non-equilibrium phenomena
C23. Polyelectrolyte-colloid complexes as innovative multi-drug delivery systems
C24. Nano-engineering of colloidal particles: Characterization of novel supra-molecular structures with hierarchical architecture for biotechnological applications
C25. Biopolymer Vesicle Interactions
C26. Biomolecules-lipid membranes interaction study : A contribution to gene therapy and drug delivery
C27. FT-IR spectroscopy of proteins
C28. Femtosecond Stimulated Raman Scattering: ultrafast atomic motions in biomolecules
C29. Quantum phenomena in complex matter
C30. Holographic optical tweezers: hands of light on the mesoscopic world
C31. Electronic properties of novel semiconductor materials investigated by optical spectroscopy under intense magnetic fields
C32. Hydrogen-mediated nanostructuring of the electronic and structural properties of nitrogen-containing III-V semiconductors
C33. Electron-phonon interaction and electron correlation effects in low-dimensional structures
C34. Design of electronic properties at hybrid organic-inorganic systems
C35. High-pressure optical spectroscopy on strongly electron correlated systems: the Metal Insulator transition
C36. Pressure tuning of charge density wave states
C37. Quantum engineering and self-organization in hybrid semiconductor/magnetic metal nanostructures: perspectives for spintronics
C38. Nonlinear electrodynamics in complex disordered systems: the SolarPaint project
C39. Nanomaterials for alternative energies. Solid-state hydrogen storage
C40. Molecular diffusion and Molecular imaging studies by means of NMR techniques in materials, tissues, animal models and humans
C41. The human brain: connections between structure, function and metabolism assessed with *in vivo* NMR
C42. Development of non-invasive methodologies for preservation,characterization and diagnostics of Cultural Heritage handworks
C43. Optical technologies for quantum information processing
C44. Quantum statistical mechanics and quantum information
C45. Experiments on Foundations of Quantum Mechanics
C46. Development of coherent terahertz radiation sources from third generation synchrotron machines and Free Electron Lasers

P- Particle Physics:

P1. Commissioning of the ATLAS detector and preparation for analysis
P2. Test and commissioning of the Muon Spectrometer of the ATLAS experiment
P3. Test and commissioning of the muon trigger system of the ATLAS experiment
P4. Supersymmetric Higgs search at hadron collider and perspectives towards the futures electron-positron linear colliders
P5. The CMS experiment at the CERN LHC
P6. The Lead Tungstate Crystal Calorimeter of the CMS experiment
P7. Precision measurements of CP violation and rare decays of B-hadrons at the CERN Large Hadron Collider LHC
P8. Interactions between nuclei at LHC: ALICE experiment
P9. Study of B-mixing and CP Violation with the CDF experiment
P10. Study of Standard Model processes at the high energy frontier with the CDF experiment
P11. Heavy Flavor and Spectroscopy with the CDF experiment
P12. Study of CP violation with the measurement of time-dependent CP asymmetries in B meson decays
P13. Observation of direct CP violation in B meson decays
P14. Measurement of the sides of the unitarity triangle
P15. Study of B meson rare decays and implications for new Physics
P16. Properties of the Charmed Particles Studied at BaBar
P17. NA62 experiment with at high-intensity charged kaon beam at CERN: search of Standard Model violations in the $K \to \pi\nu\bar{\nu}$ decay
P18. NA48/2 experiment at CERN with simultaneous $K^{\pm}$ beams: measurement of CP-violating asymmetries and $\pi\pi$ scattering lengths
P19. Kaon physics with the KLOE experiment
P20. Study of light hadron production and decay with the KLOE experiment
P21. Scintillator calorimeters for the detection of low energy photons, electrons and hadrons
P22. The ZEUS experiment at the HERA collider
P23. Dual readout calorimetry with crystals
P24. Study of proton channeling of bent crystals for beam collimation in high-energy accelerators
P25. Neutrinoless double beta decay search with CUORE experiment and scintillating bolometry developments
P26. Search for neutrino oscillations by the OPERA detector at Gran Sasso
P27. Neutrino oscillation in long baseline experiments
P28. Investigations on particle Dark Matter with DAMA/LIBRA at Gran Sasso
P29. Search of Dark Matter and Antimatter with AMS
P30. Experimental Search of Gravitational Waves
P31. ANTARES: a Čerenkov Neutrino deep-sea detector
P32. High Energy Neutrino astronomy in the Mediterranean Sea, NEMO and KM3NeT projects
P33. Quantum information with Josephson devices
P34. Results of SPARC Free Electron Laser Experiment

A- Astronomy & Astrophysics:

A1. Structure and Evolution of Galaxies
A2. Evolution of stellar systems and galactic nuclei formation and activity
A3. Advanced evolutionary phases of high mass stars
A4. Equilibrium and stability of relativistic stellar clusters and study of properties of systems with anisotropic distribution of stars velocities
A5. Search for periodicities in the solar energetic proton fluxes
A6. Measurement of the Galactic dust emission in the infrared and microwave bands
A7. Gravitational lensing and its cosmological applications
A8. Galactic and extragalactic sources of X and Gamma rays
A9. Spectral evolution and variability of Active Galactic Nuclei
A10. Search and analysis of galaxy clusters in the optical and X-ray bands
A11. Astronomical Databases: the Digitized First Byurakan Survey (DFBS) and the Roma Blazar Catalogue (BZCat)
A12. Ground-based observations of the Secondary Anisotropy of the Cosmic Microwave Background
A13. Balloon-borne and satellite measurements of the Cosmic Microwave Background and its interaction with Clusters of Galaxies
A14. Cosmic Microwave Background Polarization Measurements
A15. Kinetic Inductance Detectors for Measurements of the Cosmic Microwave Background
A16. Testing fundamental physics with cosmology

G- Geophysics:

G1. Theory and observations of climate and its changes
G2. Solar spectrophotometry to measure O_3, NO_2, UV irradiance and polysulphone dosimetry to quantify human UV exposure
G3. Atmospheric acoustical and optical remote sensing at middle latitudes
G4. Atmospheric optical remote sensing in Polar regions

H- History of physics and physics education:

H1. The early history of experimental physics at la Sapienza (1746-1930) and the development of physics in Italy after WWII
H2. Italy in Space
H3. Physics education: new perspectives on the problem of the transition from classical to quantum physics

The Theory Group

The Theory Group of the Physics Department at "La Sapienza" has produced, in the last many years, a large number of relevant results and, probably, among its main achievement there has been the ability to produce important and useful bridges, connecting different fields, unifying ideas and techniques and developing synergies that have allowed different parts of theoretical physics to progress fast.

Permanent members of the Theory group are 24 Full Professors, 9 Associate Professors and 11 Assistant Professors: many post-doctoral fellows and PhD students work with our group, and are supported both by Italian and by European funding.

Different historical developments of Renormalization Group that have been based here are probably the best example for qualifying this kind of developments: researchers working in particle physics have been talking to researchers trying to understand problems in condensed matter physics, finding common ground for important developments. On more general ground developments in Field Theory and Statistical Mechanics, for example, have been important, together with ideas whose reach has led, among others, to developments in computational physics and in biophysics.

In this sense I should start by making clear that I describe here only one part of the activities of our Department in Theoretical Physics: an equally important part is described in the Section about "Condensed Matter Physics and Biophysics", and the links among these different parts are really crucial. Let me quote, among other important subjects, the physics of strongly correlated systems, of high T_c superconductivity, of cooling and Fermi-Bose atomic mixtures of chaos and turbulence, of molecular dynamics, of self organized criticality and complexity (also applied to contexts far from the classical realm of the physics, as for example social dynamics or natural languages), and of different theoretical issue in biophysics. All these subjects are investigated in our Theory Group, and are discussed in this Report in the "Condensed Matter Physics and Biophysics" Section. The contributions C1-3, C7, C9-22, C38 and C44 that are described there and about which Francesco Sciortino comments are indeed, exactly as the ones on which we comment here, part of the work of the Theory group.

It is also important to note, before going to some detail, that the Theory Group researchers have been awarded a number of prestigious prizes and awards: I will only remind the reader, as a crucial example, that the group includes two Dirac medalists and that to its members have been awarded two Boltzmann medals.

I will describe here four main lines of research that, when considered together with the ones discussed in the Condensed Matter report, characterize well the large scope of the interest of our researchers. I will discuss here about our researches on the **Physics of Fundamental Interactions**, on **Theoretical Astrophysics**, on the **Physics of Disordered and Complex Systems** and on **Mathematical Physics**. There are a lot of ambiguities in this division, and many contribution span indeed more than one of these subsets, but I feel that this rough indexing (when, I repeat, seen together with the Theory researches described in the condensed matter section) is useful to give the lines of a short summary.

Let us start with our contributions to the **Physics of Fundamental Interactions**. The first part we want to stress is the phenomenological analysis of elementary particles. "The New hadrons" [T1] contribution to this report starts from noticing that although bound states of more than three quarks are in principle compatible with Quantum Chromodynamics, at today there is no clear evidence of the existence of such states. A collaboration of theorists and experimentalists has reanalyzed experimental data to produce a consistent picture. In particular this group has worked on trying to establish if there is evidence for tetra-quark, i.e. bound states of a di-quark (an agglomerate of two quarks) and an anti-di-quark. Two papers of this group have established

that experimental observations in different final states that were attributed to different exotic states by different research groups turn out indeed, when studied in a consistent frame, to be the same state. QCD calculations are used for understanding B decay spectra in [T2]. In order to measure the strength of the weak coupling of a beauty quark to an up quark (the CKM matrix element) one has to compute for example the lepton energy spectrum in the semileptonic decay $B \to X_u l \nu_l$, where X_u is a hadron state coming from the fragmentation of the u quark. The only analytic tool available at present to compute QCD effects is perturbation theory, but a fixed-order expansion is made unreliable by many-body effects related to infrared divergences. A modelization of non-perturbative effects has allowed to use experimental data from B fragmentation to derive resummed B spectra. A value for the CKM matrix element has been obtained, and it turns out to be smaller than the one obtained by other groups and in good agreement with estimates from lattice QCD.

The study of Flavor and of CP violation is at the root of [T3]: most of the processes relevant to the evaluation of CP violations at low energies have been computed in all known extensions of the Standard Model. The Rome group has given major contributions in these directions, discussing possible "New Physics" contributions to flavor and CP violations beyond the leading order in QCD. Among other results the $\Delta F = 2$ hadronic matrix element in Lattice QCD has been evaluated, including the computation of the next to leading order anomalous dimensions for the most general $\Delta F = 2$ operator basis. Here the role of the APE experiment [APE], a remarkable achievement of our Department, has been paramount. The group has also pioneered the phenomenology of non-leptonic decays, devising several strategies to estimate the Standard Model uncertainty in a reliable way. "The origin of Electroweak Symmetry Breaking" has been investigated by the same researchers of our Department in [T4], also looking for possible "New Physics at the Electroweak scale". Despite the abundance of experimental information we do not know much about the dynamics responsible for the spontaneous breaking of the electroweak symmetry. The group has worked on the formulation of realistic composite Higgs theories and on the investigation of their phenomenology. Recent progresses hint to a connection between gravity in higher dimensional curved spacetimes and strongly coupled gauge theories: this suggests that the dynamics that generates a light Higgs could be realized by the bulk of an extra dimension. The group has proposed a realistic five dimensional composite Higgs model, where the potential is calculable and predicted in terms of a few parameters. Particular care has been devoted to derive constraints implied by Flavor Changing Neutral Current effects and to analyze the best strategies to observe the new particles at the LHC. A further important field of study in this domain has been the analysis of the "properties of hadron collisions at high energy" [T5]. It is of large interest to study the evolution with energy of the cross-sections in hadron-hadron collisions and the properties of multiparticle production in these interactions. The researchers of the group have tried to determine the effects of fluctuations of the partonic configurations in colliding hadrons, and the relation between these fluctuations and the abundance of inelastic diffractive events: they have suggested that to describe the fluctuations in the number of elementary interactions at a given impact parameter in terms of a simple function, for which a parametrization was given.

We can summarize: this is an exciting period for particle physics, since LHC is proudly entering its full blossom period. It looks clear from what we have described that our Theory Group is ready to give an important contribution to the understanding of the new physics picture that will emerge out from a huge amount of data.

A different, but also crucial part of this research investigates "Theory and phenomenology of quantum-spacetime symmetries" [T6]. We go back here to the crucial role of symmetries, that has already played an important role in the work we have described up to here. Researchers of our group have been among the first advocates of centering on symmetry analysis the study of noncommutative spacetimes: one looks here both for a suitable frame for the problem and for tools to make the research program phenomenological in nature. For example the cases where the symmetries of a noncommutative spacetime are described by a Hopf algebra are of particular

interest. Some recent results provide a generalization of the Noether theorem that can be applied to the Hops algebra symmetries of non-commutative spacetime, and some recent studies of the phenomenology of the problem are using these results.

We hope, to make a long story short, that the research of our group will eventually help to shed light on the fascinating mystery of Quantum Gravity.

This last research argument is bringing us smoothly toward our **Theoretical Astrophysics** (here relation with the Astronomy and astrophysical group of our Department are strong and important: see the related report for useful additional information), and again we will start by describing a research that crosses over from phenomenology of elementary particles to astrophysics: "Particles in Astrophysics: UHECR maps versus UHE Tau Neutrinos" [T7]. There is not yet a proven correlation between cosmic rays and astronomical maps, mostly because of magnetic bending and blurring. Since more than half a century however the cosmic ray spectra extended up to ultra high energy regions, UHECR: at these energies Lorentz bending becomes negligible, and UHECR are no longer constrained in our own galaxy. Our group studies UHECR since two decades. This offers a natural window into the highest energy astronomy in the universe.

Gravitational waves are the (missing) crucial link to a consistent description of Quantum Gravity, and the work described in [T8], "Physics of Gravitational Wave Sources" moves in this direction. The first generation of interferometric detectors of gravitational waves is now operating at the design sensitivity: the European detectors VIRGO and GEO and the American experiment LIGO are taking data which will be analyzed in coincidence. Update of these detectors already started, and the second generation detectors will enhance their sensitivity by an order of magnitude: a design study for a further, third generation of detectors is in progress. The researchers of our group analyze various different theoretical aspects of the physics of gravitational waves astrophysical sources. The main topics are: (1) non radial oscillations and instabilities of neutron stars; (2) interaction of stars and black holes in binary systems; (3) structure and deformations of strongly magnetized neutron stars; (4) stochastic background of gravitational waves. These four research subjects are of crucial importance. In relation to point one our group has shown that a gravity wave detection from a pulsating star will enable researchers to establish whether the emitting source is a neutron star or a quark star. For the second issue our researchers have studied the tidal disruption of neutron stars by black holes in coalescing binars. For point three a general relativistic model of magnetars has been proposed. Last, for point four, the study of the gravitational wave stochastic background generated by Population III and Population II stars has been completed.

Detecting and understanding gravitational waves is, nowadays, one of the crucial goals of physics, and our group will surely continue giving important contributions in this direction.

Three other subjects are very important and are investigated by our group: (1) the "Gamma-Ray Bursts" [T9]; (2) the "Massive Nuclear Cores, Neutron Stars and Black Holes" [T10]; (3) "Quantum Cosmology" [T11]. As far as point one is concerned, using the observed gamma ray burst data the researchers of our group have progressed on the understanding of a theoretically predicted gamma ray burst structure, as composed by a proper gamma ray burst and an extended afterglow. For point two we are concerned with the study of nuclear cores, neutron stars and black holes. Here one wants to describe the process of gravitational collapse leading either to the formation of a neutron star or to the birth of a back hole. The researchers of the group establish that the electron density distribution deviates from the proton density distribution at the nuclear density: they find a stable and energetically favorable distribution of electrons. They study the energy states of electrons in the Coulomb potential and calculate the rate of the electron positron production. As far as the third issue is concerned, the center is the investigation of cosmological models with a minimal scale. The researchers of the group have analyzed the polymer representation of quantum mechanics for a particular homogeneous cosmological space-time. Also the Bianchi IX cosmological model (the Mixmaster Universe) has been studied within the framework of the generalized uncertainty principle. We also want to quote the problem of a background independent quantization of the gravitational field in a generic local Lorentz frame and the study

of generalized formulations of differential geometry.

Discussing now about our results in the **Physics of Disordered and Complex Systems** implies a sizable ideal jump (even if, obviously, complexity is potentially at the root of understanding of a large number of issues on the scale of the universe). When we discuss these researches we have to keep in mind strongly the tight relations with the work described in the condensed matter and biophysics section, since connections are, in this case, sometimes really strong. Our researches about the "Statistical Mechanics of disordered systems and renormalization group" are described in [T12]. In the last few years our researchers have performed several numerical studies of the three-dimensional Edwards-Anderson model, a prototypical finite dimensional spin glass. The use of the most advanced numerical techniques — the parallel-tempering method, multi-spin coding, cluster algorithms, etc. — and of very fast computers has allowed to address long-standing problems and to obtain several new and important results. A significant improvement of the quality of numerical simulations of random systems has been obtained by developing a new dedicated machine (JANUS) in collaboration with the University of Ferrara and several Spanish research groups. JANUS is a modular, massively parallel, and reconfigurable FPGA-based computing system. We only quote one further result among many: a new one-dimensional spin-glass model with long-range interactions has been introduced. The interaction between two spins a distance r apart is either ± 1 with a probability that decays with r as $1/r^\rho$, or zero. Depending on the exponent ρ, the model may or may not show mean-field behavior: for $\rho \leq 4/3$ the mean-field approximation is exact, for $\rho > 2$ no phase transition occurs, while in between the behavior is nontrivial.

Spin glass physics has received, with replica symmetry breaking and the understanding of the spin glass, many state phase, many crucial contributions from researchers of our group, and this study is progressing at a fast rate.

Our researchers have studied the physics of "The Glassy State" [T13]. A one-dimensional version of the Derridas Random Energy Model has been analyzed. The Random Energy Model, being a long range model, has a clear random first order transition. In the 1D model a length (proportional to the system size, as in the Kac limit) has been introduced, such that interactions are Random Energy Model-like on smaller scales. They have, as well, dedicated a large effort in recent years on the study of glasses of hard spheres. A system of monodisperse hard spheres is maybe the simplest showing most of the glass phenomenology and can be thus considered as a prototypical model: the interest to study it is very large. Similar ideas have been applied to "optimization problems and message passing algorithms" in [T14]. Among optimization problems, a quite general class is formed by Constraint Satisfaction Problems where a set of constraints is given, and where the constraints must be satisfied by a proper assignment of the variables. Our researchers have been able to solve this kind of models in the case where the constraints are generated independently, which actually correspond to defining the model on a random graph. A very important aspect of the message passing algorithms that our researchers have started to investigate recently is their use on non-random graphs, that is graphs with many short loops and topological motifs. An interesting example is given by the problem of ranking graphs nodes, i.e. to uncover which nodes are the most important in the graph topology (a straightforward application being the ranking of web pages). A new message passing algorithm that ranks nodes depending on how many loops pass through that node has been introduced. The last contribution to this research line is about neural networks: "From Artificial Neural Networks to Neurobiology", in [T15]. One main topic investigated by our group is synchronization. On one side neurons can be described by a set of first order linear differential equation with an interaction matrix with Gaussian distributed random elements: on the other side a more biological approach has led to the modeling of the behavior of oxytocin neurons of the hypothalamus when they emit the oxytocin hormone. Also the problem of the control of the movements of the eye (saccadic movements) has been considered.

Again smoothly, through the last research activity we have discussed, we can shift to the last of the four subjects we describe here, **Mathematical Physics**. We will see that also here we will encounter a large variety of interesting researches, developing a large number of new ideas in

different contexts. The first contributions is related to statistical mechanics and quantum field theory, and is connected to the rigorous investigation of the static and dynamic properties of complex systems [T16]. A large number of applications (to the physics of elementary particles, to the physics of condensed matter and to biological systems) have been investigated. The methods used for understanding spin glasses and neural networks let physical intuition merge with a rigorous mathematical treatment. The essential ingredients are given by powerful interpolation methods and sum rules. For neural networks of Hopfield type a characterization of the ergodic phase and a generalization of the Ghirlanda-Guerra identities have been given. Diluted systems have been studied in the cases of ferromagnetic, anti-ferromagnetic and general interpolating models. The theory of self-oscillating mechanical systems has been used for the study of speech formation. Simple models for the immunological system based on stochastic dynamical systems of statistical mechanics far from equilibrium have been studied.

The "Macroscopic fluctuation theory of irreversible processes" has been studied in [T17]. A macroscopic theory for a class of thermodynamic systems out of equilibrium has been proposed, funded on the analysis of a large family of stochastic microscopic models. The theory that has been proposed has many features of substantial improvement with respect to the theory developed long ago by Onsager and then by Onsager-Machlup which applies to states close to the equilibrium and does not really include the effect of non trivial boundary reservoirs. This treatment is based on an approach developed in the analysis of fluctuations in stochastic lattice gases. Developments in this field are of paramount importance, and the research of our group is giving an important contribution.

"Equilibrium statistical mechanics for one dimensional long range systems" has been analyzed in [T18]. The project is based on studying a one dimensional system of particles interacting via a long range attractive potential, and techniques developed for spins on a lattice are exploited. The one dimensional nature of the system allows to control the hard core contribution. "Markov chains in a graph" are analyzed in [T19]. Aldous conjecture about finite graphs claims that "The random walk and the interchange process on a finite connected simple graph have the same spectral gap". This conjecture has been proven for complete multipartite graphs by researchers of our group, using a technique based on the representation theory of the symmetric group. Also a further result has been obtained, with a similar proof valid for a different Markov chain called initial reversals.

A number of very interesting nonlinear problems complete the list of the ideas discussed in this report. We can identify four main issues: (1) "Optical solitons in resonant interactions of three waves" in [T20]; (2) "Propagation and breaking of weakly nonlinear and quasi one dimensional waves in Nature" in [T21]; (3) "Towards a theory of chaos explained as travel on Riemann surfaces" in [T22]; (4) "Discrete integrable dynamical systems and Diophantine relations associated with certain polynomial classes" in [T23]. As far as the optical solitons of point one are concerned our group has discovered a new multi-parametric class of soliton solutions of the model of the resonant interaction of three waves, that describe a triplet made of two short pulses and a background. As far as the quasi one dimensional waves of point two are concerned an inverse spectral transform has been developed for families of multidimensional vector fields, and it has been used to construct the formal solution of the Cauchy problem for non linear PDE's, and to give an analytic description of the breaking of multidimensional waves in Nature. For point three a new dynamical system has been introduced, interpretable as a 3-body problem in the complex plane, to improve the understanding of the role of movable branch points in the onset of chaotic motions in a deterministic context. At last (issue four) new Diophantine properties related to the integrable hierarchy of nonlinear PDE's associated with the KdV equation have been obtained, and new discrete integrable systems have been identified.

Enzo Marinari

T1. The New Hadrons

Ordinary matter is made of bound states of three quarks (baryons) or of two quarks (mesons). Although bound states of a larger number of constituents are possible in the theory describing strong interactions (QCD), there is hardly any evidence of such states.

Since decades the light scalar mesons are candidate four-quark states, but their experimental evidence has been questioned since recently. The situation was basically stalled until the B-Factories, followed by Tevatron experiments, started observing, in 2003, states containing at least an heavy quark anti-quark pair, that did not have the characteristics of mesons. Systems that include heavy quark-antiquark pairs (quarkonia) are an ideal laboratory for probing both the high energy regimes of QCD, where an expansion in terms of the coupling constant is possible, and the low energy regimes, where nonperturbative effects dominate. The detailed level of understanding of the quarkonia mass spectra is therefore such that a particle mimicking quarkonium properties, but not fitting any quarkonium level, is most likely to be considered to be of a different nature.

The activity of this group, composed of both theorists and experimentalists proceeded in parallel in a deeper theoretical understanding and in a reanalysis of experimental data to have a uniform and global picture of the observations. In particular, since the observed states have signatures which indicate the presence of four quarks, the group concentrated in understanding whether there is evidence of tetra-quarks: bound states of a diquark and anti-diquark, a diquark being an agglomerate of two quarks.

On the theoretical side the work has been concentrated on two fields: the prediction of the spectra of tetraquark states with a non-relativistic, quark constituent model for the calculation of the masses [1,2], and the understanding of the interaction between diquarks, with particular attention to the interpretation of the light scalar mesons [3]. There is also an ongoing discussion on whether the molecular option, where the four quarks mostly bind into quark-antiquark pairs, is to be preferred to the tetraquark one in particular cases [4]. Recent work of the group has gone in the direction of studying the production mechanism for the molecular option and showing its incompatibility with the data.

On the experimental side, a systematic study of the evidences has been carried out, with particular attention to states which are claimed as different in different publications because they are close but not identical in mass. In the case of states subject to strong interactions and therefore short-living, there is a significant uncertainty on their mass and width depending on the assumptions on the distribution of the invariant mass of the decay products. Recently we realized that experimental observations in different final states were attributed to different exotic states by different research groups although

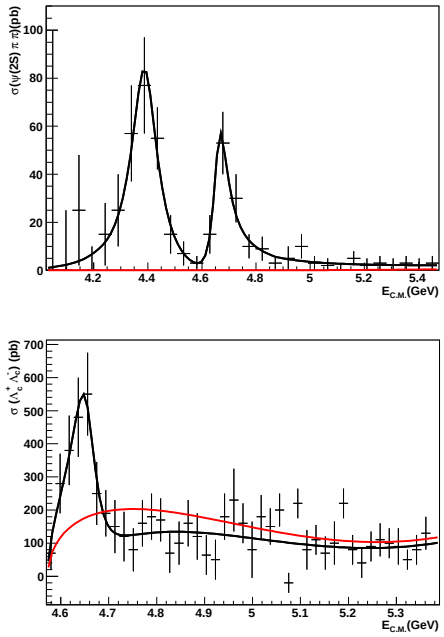

Figure 1: Invariant mass distributions and corresponding likelihood fits as evidence of baryonium, a bound state of two baryons and that therefore can decay both in $\psi(2S)\pi^+\pi^-$ (top) and in $\Lambda_c\bar{\Lambda}_c$ (bottom) with strong preference for the latter, baryonic, final state

they were indeed the same state if studied in a consistent frame. The most striking case is shown in Fig. 1: our reanalysis of the Belle data showed that the two states observed in the $\psi(2S)\pi^+\pi^-$ and $\Lambda_c\bar{\Lambda}_c$ final states were actually the same and that the ratio of the branching fraction is $BF(Y \to \Lambda_c\bar{\Lambda}_c)/BF(Y \to \psi(2S)\pi\pi) = 117 \pm 44$). This has very important implications because the smoking gun of tetraquarks is a strong preference for baryonic decay when kinematically allowed.

The group is now in the process of writing a review where all the measurements are treated uniformly, work that will allow indentifying analyses that need to be performed on existing data and areas where the next generation of experiments at higher luminosity is needed.

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T2. B decay spectra in resummed QCD calculations

At present, all experimental data in particle physics are compatible with the current theory of strong and electroweak interactions — the so-called standard model (SM). All the particles predicted by the SM have been discovered, with the exception of the Higgs boson, which will probably be discovered in the next decade at the Large Hadron Collider (LHC) at Cern, Geneve — currently in the first stages of operation. Apart from the Higgs search, a good fraction of present-day research in particle physics involves detailed comparison of experimental data with theoretical distributions of known particles with standard interactions. Weak and electromagnetic interactions of quarks are, in general, largely affected by the accompanying strong interactions effects, described by Quantum Chromodynamics (QCD). Even if someone is not primarily interested in strong interactions, he has to face them in any case as background effects, as for example in Higgs physics at LHC.

In order to measure the strenght of the weak coupling of a beauty quark to an up quark — the CKM matrix element V_{ub} — one has to compute for example the lepton energy spectrum in the semileptonic decay $B \to X_u l \nu_l$, where X_u is any hadron state coming from the fragmentation of the u quark. Let us note that at present there is no theory for any CKM element, but only some consistency relations among them coming from unitarity of the matrix itself, as implied by the SM. Such free parameters are therefore measured by comparing theoretical distributions containing them as unknown quantities, to experimental data. The only analytic tool available at present to compute QCD effects is perturbation theory: the corrections are computed with Feynman diagrams as truncated series in α_S, the strong coupling. The latter decreases logarithmically with the energy of the process — asymptotic freedom; for beauty decays $\alpha_S(m_b) \simeq 0.21$. In some regions of phase space of the above decays, experimentally relevant, many-body effects related to infrared divergencies become important: they manifest themselves in an enhancement of the coefficients of α_S^n in the perturbative series. This effect renders the fixed-order expansion completely unreliable and forces the resummation to all orders in α_S of the enhanced terms.

A general problem of all-order resummation is that an integration of the QCD coupling constant in the low energy region is involved, in which α_S is large and outside the perturbative domain — the old problem of the Landau ghost makes a specific appearence here. As shown in the eighties, this problem cannot be solved *inside* perturbation theory, because of missing dynamical input from the perturbative phase, and therefore it is necessary to introduce an arbitrary prescription from *outside* in order to have well-definite predictions for resummed spectra. These conclusions also apply to resummation in heavy flavor decays, as we explicitly found, but are in disagreement with those reached in the past few years by other groups (M. Neubert and coll. for instance). In our modelization of non-perturbative effects, we also equate the on-shell mass of the b quark to the mass of the B meson: $m_b = m_B$. That is consistent because the mass of a heavy quark has a much weaker physical meaning that is generally believed nowadays: quarks are confined. If one aims at describing *all* QCD dynamics at a fundamental level, he has to abandon perturbative QCD, because the latter has always to be supplemented with phenomenological models connecting the fictitious "parton world" with the real "hadron world". QCD can be computed exactly only with numerical Monte-Carlo methods after regularization on a lattice. In that case, one only deals with bare, regularization dependent, quark masses and with observable hadron masses. A renormalized beauty mass can certainly be defined but it is just conventional and bears to relation to dynamics. A consequence is that one has the freedom to fix m_b in a rather arbitrary way and a simple way to implement hadron kinematics in a parton computation is just to identify the unphysical b mass with the physical B mass. Also these assumptions are in disagreement with a large part of the B physics community (M. Neubert and E. Gardi). Many colleagues object that the Operator Product Expansion (OPE) involves m_b and not m_B and that identifying them would introduce non-vanishing $1/m_b$ corrections. Our reply is that implementing the OPE from first principles, i.e. on a lattice, would give similar problems in the definition of the quark mass as those discussed above, augmented by the specific ultraviolet power divergencies brought in by the small-momentum expansion.

We have used the accurate experimental data from B fragmentation to fix the prescription for the QCD coupling constant at low energy [1], from which we have derived our resummed B decay spectra [2]. By comparing the latter with experimental data, we have found some disagreement with electron spectra from the B-factories in the low-energy region, which we interpret as originating from an undersubtracted $b \to c l \nu_l$ background [2]. We have obtained for V_{ub} the value $(3.76 \pm 0.13 \pm 0.22)10^{-3}$ [3], smaller than the values obtained by the other groups and in good agreement with the determinations coming from lattice QCD (exclusive channels) or from global fits to the SM of the UTfit collaboration.

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T3. Flavor, CP violation and Matter-Antimatter asymmetry

The past decade has seen tremendous progress in the study of flavor and CP violation. B-factories have collected and analyzed an impressive amount of experimental data, that led to the confirmation of the Cabibbo-Kobayashi-Maskawa (CKM) mechanism for flavor and CP violation. While sizable New Physics (NP) contributions may still hide in $b \to s$ penguin decays [1], the bulk of CP violation in the K and B sectors can be correctly accounted for within the Standard Model (SM), with possible new sources of flavor and CP violation being confined to the level of 20-30% corrections [2]. If NP is of Minimal Flavor Violation (MFV) type, however, its contributions can be much larger without spoiling the consistency with experimental data. Until one year ago, MFV extensions of the SM seemed phenomenologically very appealing, although they give only a description of the NP flavor structure and not a solution to the origin of flavor. However, the recent Tevatron experiments presented their first measurement of CP violation in $B_s \to J/\Psi\phi$ decays, showing a discrepancy from the SM expectation at the level of three standard deviations. If this indication is confirmed, it will represent a major breakthrough in flavor physics and in model building, leaving behind MFV models and pointing to a more fundamental origin of flavor mixing. It would also open up very interesting perspectives for the LHCb experiment, which may become a primary source of indirect NP signals and a gold mine for the determination of NP flavor couplings. In any case, it is of the utmost importance to be ready to study in detail the possible signals of a non-MFV NP at the Large Hadron Collider (LHC) experiments.

Concerning the theoretical evaluation of hadronic flavor and CP violation at low energies, most of the relevant processes have been computed in all known extensions of the SM, including the Minimal Supersymmetric Standard Model (MSSM), extra-dimensional models, composite Higgs theories, etc. The Particle Theory Group (PTG) in Rome has given major contributions in these directions, pioneering the study of NP contributions to flavor and CP violation beyond the leading order in QCD. One of the fundamental results achieved by the PTG is the calculation of $\Delta F = 2$ hadronic matrix elements in Lattice QCD, with the computation of Next-to-Leading order (NLO) anomalous dimensions for the most general $\Delta F = 2$ operator basis and the calculation of the NLO matching for these operators in the MSSM.

Working in tight collaboration with experimental physicists, the UTfit collaboration, of which Guido Martinelli was one of the founders, has a world-leading role in performing combined analyses of flavor and CP violation in the SM and beyond. It has developed efficient tools to simultaneously constrain the CKM matrix and the NP contributions to $\Delta F = 2$ processes. These tools,

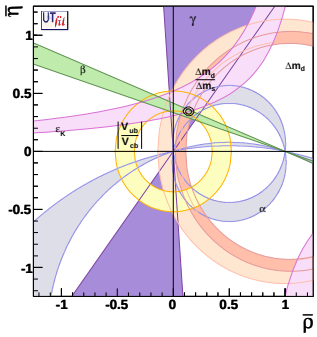

Figure 1: Constraints on the Wolfenstein parameters $\bar{\rho}$ and $\bar{\eta}$ from the Unitarity Triangle analysis [2].

combined with the model-specific ones for the known theoretical extensions of the SM, will form the starting point for the implementation of flavor and CP violation constraints on the NP Lagrangian. The missing ingredients (additional processes and/or new models) will be implemented in this framework. The PTG has also pioneered the phenomenology of non-leptonic decays, devising several strategies to estimate the SM uncertainty in a reliable, mostly data-driven way, as well as new methods to extract short-distance information from non-leptonic decays.

The extraction from experiments of useful phenomenological information on the SM and/or NP fundamental parameters may require an accurate knowledge of the relevant hadronic matrix elements of the effective weak Hamiltonian, which can be evaluated in Lattice QCD. The PTG in Rome is part of an important large-scale lattice collaboration, the European Twisted-Mass Collaboration. Thanks to the use of the ApeNext machines of INFN the PTG in Rome has a world-leading role in LQCD simulations and has provided accurate determinations of many important hadronic quantities, like: 1) light, strange and charm quark masses; 2) the decay constants of K-, D- and B-mesons; 3) the vector and scalar form factors relevant in the semileptonic decays of K-, D- and B-mesons relevant for the determination of the entries of the CKM matrix; 4) the bag parameters of the kaon relevant for the study of CP violation in the SM as well as in NP scenarios.

The future research activity of the PTG will continue along this lines, to keep up with the experimental results and to estimate the uncertainties in any NP model singled out by direct searches at the LHC.

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T4. The origin of Electroweak Symmetry Breaking and New Physics at the Electroweak scale

More than a century of experimental results and theoretical progress has led us to the formulation of an extremely elegant and compact theory of the fundamental interactions among particles. Despite their profoundly different manifestations on macroscopic scales, the electromagnetic, weak and strong forces are all described within the same mathematical framework of gauge theories. The electromagnetic and weak interactions are associated to the same $SU(2)_L \times U(1)_Y$ gauge invariance at short distances, although only electromagnetism is experienced as a long-range force. The rest of the electroweak symmetry is hidden at large distances or low energies, *i.e.* it is spontaneously broken by the vacuum. As a matter of fact, despite the abundance of experimental information, we do not know much about the dynamics responsible for such spontaneous breaking. An important clue comes from the results of the LEP experiments at Cern, which show strong evidence, although not yet conclusive, in favor of the existence of a light Higgs boson.

The Higgs mechanism of the Standard Model (SM) certainly gives the most economical formulation of the electroweak symmetry breaking (EWSB), as it requires the existence of just one new elementary particle: the Higgs boson. It has two main virtues: it is perturbative, hence calculable, and it is insofar phenomenologically successful, passing the LEP electroweak precision tests. On the other hand, a light elementary Higgs boson is highly unnatural in absence of a symmetry protection, since its mass receives quantum corrections of the order of the largest energy scale to which the theory can be extrapolated, which is the Planck scale in the case of the SM. In this sense the SM gives no explanation of why the Higgs is light, nor does it really explain the dynamical origin of the symmetry breaking. In fact, it should be considered as a parametrization rather than a dynamical description of the EWSB.

On the other hand, it is possible, and plausible in several respects, that a light and narrow Higgs-like scalar does exist, but that this particle be a bound state from some strong dynamics not much above the weak scale. Its being composite would solve the SM hierarchy problem, as quantum corrections to its mass are now saturated at the compositeness scale. As first pointed out by Georgi and Kaplan in the eighties, the composite Higgs boson can be naturally lighter than the other resonances of the strong dynamics – as required by the LEP precision tests – if it emerges as the (pseudo-)Nambu-Goldstone boson of an enlarged global symmetry of the strong dynamics. The phenomenology of these theoretical constructions is far richer than that of the SM, since an entire sector of resonances of the new strong dynamics is predicted and can be discovered at the Large Hadron Collider (LHC) experiments at Cern.

In the last years the Particle Theory Group (PTG) of Rome has actively worked on the formulation of realistic composite Higgs theories and on the investigation of their phenomenology at present and future colliders.

Much of the recent theoretical progress on the model building front has come from the intriguing connection between gravity in higher-dimensional curved spacetimes and strongly-coupled gauge theories. This correspondence suggests that the strong dynamics that generates the light Higgs could be realized by the bulk of an extra dimension. The research of the PTG has led to the formulation of the first realistic 5-dimensional composite Higgs models, resolving the long-standing problems of the original theories of Georgi and Kaplan. In the newly proposed constructions the Higgs is realized as the fifth component of a 5-dimensional gauge field and its potential is calculable and predicted in terms of a few parameters [1]. The phenomenology of these models has also been studied in details. Particular attention has been devoted to deriving the constraints implied by Flavor Changing Neutral Current effects [2] and to derive the best strategies to produce and observe the new particles at the LHC [3].

Whatever the form of New Physics is, a crucial issue that experiments should be able to settle is whether the dynamics responsible for the symmetry breaking is weakly or strongly coupled. If a light Higgs boson is discovered at the LHC or at Tevatron, the most important questions to address will be: what is its role in the mechanism of electroweak symmetry breaking ? Is it an elementary or a composite scalar ? Crucial evidence will come from a precise measurement of its couplings and a detailed study of the scattering processes that the exchange of the SM Higgs is assumed to unitarize, such as the scattering of two longitudinally polarized vector bosons. To address the above issues and thus unravel the origin of the electroweak symmetry breaking, much of the recent research activity of the PTG has focussed on the study of the properties of the Higgs bosons, ranging from the identification of new production channels at the LHC [4], to highlighting the best strategies to extract its couplings.

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T5. Properties of hadron collisions at high energy

The high energy frontier in particle physics is presently investigated by the experiments beginning to take data at the CERN Large Hadron Collider and by the Auger experiment, looking at the air showers produced by the highest energy cosmic rays. It is therefore of considerable interest to study the evolution with energy of the cross sections in hadron–hadron collisions and the properties of multiparticle production in these interactions. Given the composite nature of hadrons, it is natural to interpret the hadronic data in terms of elementary interactions between quarks and gluons; this is however a difficult task, which goes beyond the limits of perturbative QCD. A possible approach is provided by the so–called "mini–jet" eikonal models, that however in their original formulation did not include properly an important class of events, those due to inelastic diffraction. Following the old suggestion by Good and Walker based on an optical analogy, diffractive events can be introduced via a multichannel eikonal model, as it has been done already by several authors.

In our recent work [1] we addressed the problem of determining the effects of fluctuations of the partonic configurations in the colliding hadrons, and of investigating the relation between these fluctuations and the abundance of inelastic diffractive events. We suggested to describe the fluctuations in the number of elementary interactions at a given impact parameter in terms of a single function, and gave a simple parameterization for it. In the limit of negligible fluctuations the model coincides with the naïve mini–jet model of Durand and Pi. Such model does not include the inelastic diffraction, that is certainly present as it appears from Fig. 1. Moreover, this model requires the proton transverse dimension to increase with energy, in order to fit the data for total and elastic cross sections from center-of-mass energy $\sqrt{s} \sim 60$ GeV (ISR) up to $\sqrt{s} \sim 1800$ GeV (Fermilab Tevatron).

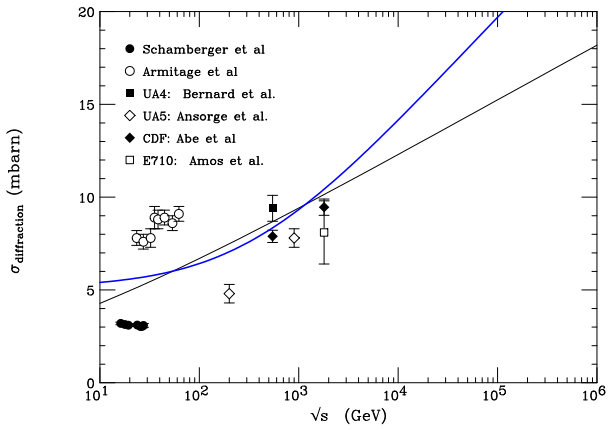

Figure 1: The points are measurements of the single diffraction pp and $p\overline{p}$ cross sections.

To describe at the same time total, elastic and diffractive cross sections we are forced to increase the variance of the fluctuations distribution, and in this way we were able to obtain reasonably accurate description of the data with transverse dimensions of the proton that stay constant with energy. The transverse radius turns out to be smaller than the electromagnetic one, suggesting that soft gluons have an impact parameter distribution narrower than valence quarks. The inclusion of fluctuations has also the consequence that the number of elementary interactions in an inelastic collision is larger (and more rapidly increasing) than in other models: this is a possibility that should be compared with data after including our formulae in a full Montecarlo code.

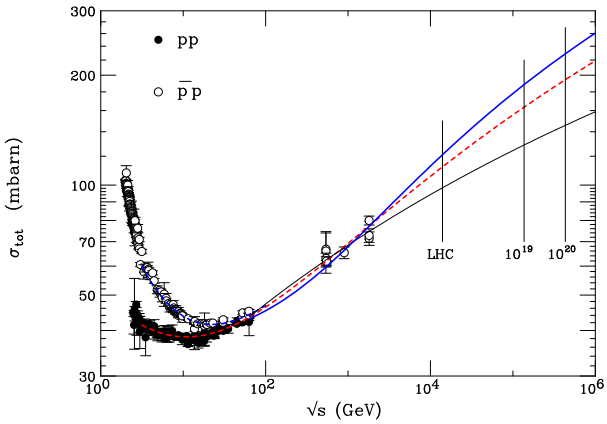

Figure 2: The points are measurements of the pp and $p\overline{p}$ total cross sections. The red [dashed] lines represent the fit of $\sigma_{\rm tot}(s)$ suggested in the Particle Data Group .

Two different, somehow extreme forms of the energy dependence of the parameters have been used to extrapolate to higher energies ($\sqrt{s} \sim 14$ TeV for LHC and $E_p = 10^{19}$ or 10^{20} eV for cosmic rays), giving rise to the blue [thick] and black [thin] curves in the figures. As it can be seen, the uncertainty in predicting the total cross section is still rather large.

Further investigations along these lines will be prompted by the upcoming data from the LHC experiments.

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T6. Theory and phenomenology of quantum-spacetime symmetries

The last century of physics has been primarily characterized by a long list of successes of the "quantum-theory paradigm". In a significant part of the literature on the search of a "quantum gravity", a theory providing a unified description of both quantum theory and general relativity, researchers are looking for ways to apply this quantum paradigm also to the description of spacetime. This effort is faced by significant conceptual challenges, and perhaps even more sizeable are the experimental challenges, since it is expected that the "spacetime quantization" should be characterized by a ultrasmall length scale, roughly given by the Planck length $\sim 10^{-35}m$.

One of the most popular attempted formalizations of spacetime quantization is "spacetime noncommutativity", a formalism that endows the spacetime coordinates of particles with intrinsically nontrivial algebraic properties, whose most studied examples introduce two model-dependent "noncommutativity matrices" $\theta_{\mu\nu}, \xi^{\alpha}_{\mu\nu}$:

$$[x_\mu, x_\nu] = i\theta_{\mu\nu} + i\xi^{\alpha}_{\mu\nu} x_\alpha \ .$$

Amelino-Camelia was one the first advocates of an approach to the study of noncommutative spacetimes which is centered on symmetry analysis, searching for both a suitable formalization and an associated phenomenology programme. Of particular interest are cases in which the symmetries of a noncommutative spacetime require a Hopf-algebra description. The core feature of this novel concept of a Hopf-algebra description of spacetime symmetries resides in the way in which the generators of the symmetries act on states of two of more particles, states which are therefore formalized as elements of a tensor product of multiple copies of the single-particle Hilbert space. For some of the most compelling choices of the noncommutativity matrices one finds an incompatibility between the noncommutativity of spacetime coordinates and the imposition of Leibniz law for the action of the generators T_α of spacetime symmetries on elements of the relevant tensor products,

$$T_\alpha[\Phi(x)\Psi(x)] \neq T_\alpha[\Psi(x)]\Phi(x) + \Psi(x)T_\alpha[\Phi(x)] \ .$$

Our most significant recent theory result [4] provides a generalization of the Noether theorem that is applicable to the Hopf-algebra symmetries of some noncommutative spacetimes. This had been a long-standing open issue for physical applications of Hopf-algebra spacetime symmetries, in which of course the conserved charges derived in the Noether analysis should play a key role.

Some of our recent studies on the phenomenology side have used in part this Noether-theorem result. In particular, there is strong interest in the community in the possibility to use observations of gamma-ray bursts, bursts of high-energy photons emitted by sources at cosmological distances, as an opportunity to gather indirect evidence on the short-distance quantum structure of spacetime and its symmetries. In most other contexts the new effects are too small to be observed, but some gamma-ray bursts have a rich structure of space/time/energy correlations and the fact that they travel cosmological distances allows for the minute quantum-spacetime/Hopf-symmetry effects to have in some cases a nonnegligible cumulative effect [1,3].

While for this gamma-ray-burst opportunity our recent results contribute to an established phenomenology programme, we also opened recently a completely new direction for quantum-spacetime phenomenology. This was inspired by theory results establishing that for some choices of the noncommutativity matrices one finds the novel effect of "infrared-ultraviolet mixing". This new scenario, which in just a few years was investigated in several hundred publications, is such that the effects induced by the short-distance quantum structure of spacetime, besides the normally expected implications for the ultraviolet sector of the theory, have implications which are significant in a dual infrared regime. Our proposal has been [2] to use the high accuracy of intereferometric techniques applied on "cold" (ultraslow) atoms as a way to look for signatures of these infrared manifestations of spacetime quantization. Our main result concerns measurements of the "recoil frequency" of atoms, and is summarized by the formula [2]

$$\Delta\nu \ \simeq \ \frac{2h\nu_*^2}{m}\left(1 + \lambda\frac{m^2}{2h\nu_*}\right) \ , \qquad (1)$$

where $\Delta\nu$ is the frequency difference of a pair of lasers used to induce the recoil, $h\nu_*$ is the energy of an excited level that plays a role in the recoil process, m is the mass of the atoms, and λ is a length scale characterizing the noncommutativity matrix. This relationship can be tested presently with accuracy of roughly 1 part in 10^9, and, also thanks to the fact that in the relevant experiments $m/(h\nu_*)$ is very large, allowed us to set a bound of $\lambda \lesssim 10^{-34}m$. And planned improvements of these atom-recoil experiments should comfortably provide sensitivity to values of λ as small as $\sim 10^{-35}m$, thereby reaching the desired "Planck length sensitivity".

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T7. Particles in Astrophysics: UHECR maps versus UHE Tau Neutrinos

Cosmic Rays is a very mature science based on charged cosmic particles raining on Earth from all directions at low (MeV) and high (EeV) energies. Their composition is known (mostly charged nucleon and nuclei) but their arrival direction, due to galactic magnetic fields, is lost. Their sources are suspected to range from Supernova shells or micro-quasars jet in our Milky Way to huge Active Galactic Nuclei or beamed Gamma Ray Burst Jets from outer cosmic space. But there is not yet a proven correlation between Cosmic Rays and astronomical maps, mostly because of magnetic bending and blurring. However, in the last decades, with the discover of wide and extensive air-showers, the Cosmic Ray spectra has been explored up to energies of tens and hundred EeV (UHECR). At those energies the Lorentz bending becomes negligible (for expected nucleons), UHECR are no longer constrained in our Galaxy, directionality is frozen offering (hopefully) a new particle Astronomy. Although UHECR event rate is low, their map should be easy to be correlated with other astronomical sources because UHECR suffer of a severe opacity by Microwave Radio Background: the so called GZK cut off, due to photonuclear pion production. This GZK cut leads to very bounded and well identified UHECR cosmic volumes (few tens Mega-parsec radius versus four Giga-parsec Universe size, a part over a million volume). Many experiments on CR, originated from P. Auger, B. Rossi, M. Conversi, J.Linslay , L.Scarsi, led to more recent ones like Fly Eyes, AGASA, Hires, and AUGER, to progress into UHECR Astronomy. In these three decades there have been many contradictions, but, since 2007 AUGER discovery, there is the hope to reveal the first anisotropy in AUGER UHECR map (discovering a clear or maybe apparent correlation between Local Universe, Super Galactic Plane, SGP, within GZK cut and UHECR nucleons arrival events). The very last AUGER maps are puzzling because (a) the AUGER UHECR composition signature is possibly favoring nuclei over nucleons; (b) it is favoring clustering mostly along an unique nearest AGN source, Cen_A, and no longer on SGP; (c) partially it is missing the nearest and rich Virgo cluster sources. In the last ten years we have been considering the well known Z-Burst model. Now we solve the AUGER puzzle [1] advocating a light nuclei nature of UHECR. The fragment clustering at lower energy may be soon discovered as a ten EeV tail in UHECR events. Also UHE neutrinos may reflect nuclei or nucleon UHECR composition producing mainly PeVs or EeVs UHE neutrino spectra, respectively. Because atmospheric neutrinos up to hundred TeV (secondaries of abundant CR in our atmosphere) rule and pollute, we proposed in the last decade to consider the (noise free) ν_τ made by ν_μ oscillation and mixing. (Tau neutrinos may also emerge at GeV regimes in largest Solar Flares [2]). Therefore UHE (GZK or cosmogenic) neutrinos may follow, testing UHECR origin and composition. The UHE ν_τ at tens PeV or at EeV may be revealed by their upward interaction on Earth crust and by consequent UHE tau escaping, decaying and air-showering in huge upward showers [3]. PAO fluorescence detectors may reveal these signals. Our DAF group of Rome studies UHECS since two decades, and it combines the physics of high energy particles, well above LHC regimes, their accelerations, their bending and blurring in Galactic and cosmic space. This study requires a multi-wavelength knowledge to be correlated with knowledge of wide nuclear and neutrino high energy physics. It offers natural windows into the highest energy astronomy in the Universe as well as into the deepest one, by neutrino astronomy. The probable tau neutrino discovery in near future will open a probe and a first spectacular appearance of the rare tau neutrino flavor.

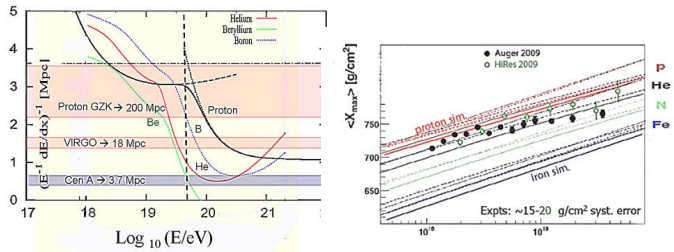

Figure 1: UHECR composition suppression distances with UHECR energies for nucleon and lightest nuclei; UHECR composition data favoring lightest nuclei [2]

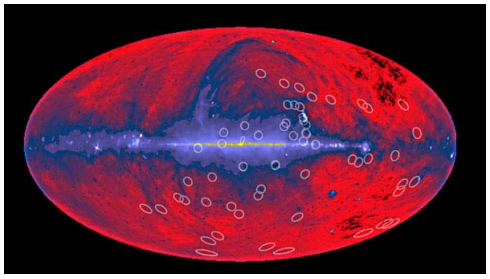

Figure 2: AUGER UHECR arrival map over radio map: note the main clustering correlation with Cen A bright jet

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T8. Physics of Gravitational Wave Sources

The first generation of interferometric detectors of gravitational waves (GWs) is now operating at the design sensitivity: the European detectors VIRGO and GEO, and the American project LIGO, are taking data which will be analyzed in coincidence. Upgrading of these detectors have already started and the second generation, the advanced (Virgo and LIGO) detectors, will have a sensitivity enhanced by an order of magnitude. Furthermore, a design study for an even more sensitive, 3rd generation of detectors is in progress. Theoretical and phenomenological studies of GW sources are strongly needed, since accurate templates of the expected signals enhance chances of detection, and provide an instrument to investigate the physics of the emitting source, establishing the basis for a gravitational wave astronomy.

Our research consists in studying various aspects of the physics of GW astrophysical sources. The main topics under investigation are: (i) non-radial oscillations and instabilities of young and old neutron stars, (ii) interaction of stars and black holes in binary systems, (iii) structure and deformations of strongly magnetized neutron stars, (iv) stochastic background of GWs.

(i) Compact stars like neutron stars (NSs) are expected to pulsate in damped oscillations (quasi-normal modes), which are associated to the emission of GWs. The detection of these signals will allow to measure the oscillation frequencies and damping times, which carry information on the structure of the star and on the equation of state (EOS) of matter in its core. This would offer a unique opportunity to study the behaviour of matter at supranuclear density. Considering a number of EOSs of nuclear matter recently proposed, and including the possibility that the compact star is composed of deconfined quark matter, we have carried out a systematic study on the star pulsation frequencies. We have shown that a GW-detection from a pulsating star will enable us to establish whether the emitting source is a NS or a quark star, and to constrain its EOS (see Fig. 1). In addition,

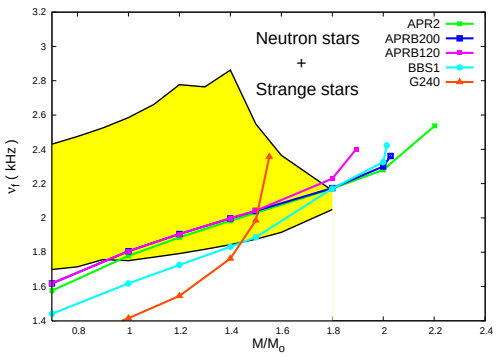

Figure 1: The frequency of the fundamental mode as a function of the mass of the star, for neutron stars described by different EOSs, and for quark stars (shadowed region).

we have studied the oscillations of rapidly rotating NSs. We have developed a new method to study the oscillation modes of rapidly rotating NSs [1], finding the effects of rotation on the frequencies of the quasi-normal modes.

(ii) We have studied the tidal disruption of NSs by black holes in coalescing binaries, evaluating the critical orbital separation at which the star is disrupted by the black hole tidal field, for several EOSs describing the NS matter and for a large set of the binary parameters. When the disruption occurs before the star reaches the innermost stable circular orbit, the gravitational wave signal emitted by the system exhibits a cutoff frequency, which is a distinctive feature of the waveform. We have evaluated this quantity and shown that, if found in a detected gravitational wave, this frequency will allow to determine the NS radius with an error of a few percent, providing valuable information on the EOS.

(iii) After the discovery of the Soft Gamma Repeaters and Anomalous X-ray Pulsars, it has been proposed that these sources are neutron stars with extremely strong magnetic fields; these *magnetars* would have a surface field as large as 10^{15} G, and internal fields up to 10^{16} G. A consistent fraction of the NSs should become magnetars at some stage of their evolution, and since a strong magnetic field induces a large deformation in the stellar structure, these stars could be strong sources of gravitational waves. We have constructed a general relativistic model of magnetars [2], finding the structure of the magnetic field, the stellar deformation it induces, and evaluating the expected GW emission.

(iv) Ten years ago, in a series of papers we studied the stochastic background of gravitational waves generated by cosmological populations of astrophysical sources. In the meantime, significant advances have been done in astrophysical observation, and a more accurate estimate of the star-formation rate history is available; moreover more accurate GW waveforms and estimates of formation rates for different sources have been produced by numerical relativity studies. Thus, we have started a research program to update our previous work on the subject. At present, we have completed the study of the GW stochastic background generated by Population III and Population II stars, determining the corresponding power spectral density and assessing whether these backgrounds might act as foregrounds for signals generated in the inflationary epoch [3].

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T9. Massive Nuclear Cores, Neutron Stars and Black Holes

One of the greatest challenges in theoretical physics is the description of the process of gravitational collapse leading either to the formation of a neutron star or to the formation of a Kerr-Newmann black hole [1]. We have reviewed our recent progresses in this field in Ref. [2]. Based on the Euler-Heisenberg-Schwinger mechanism for electron-positron pair productions and Ruffini-Christodoulou mass formula for black holes, we review the progresses in understanding the pair production region (Dyado-torus) outside a Kerr-Newmann black hole. The overcritical and undercritical values of the electric field are shown in Fig. 1. The optically thick plasma of electron-positron pairs and photons, formed in the Dyado-torus, after reaching thermal equilibrium (see Fig. 2), is bound to undergo an ultra-relativistic expansion, described by the conservations of energy-momentum and entropy. This accounts for the energy source of observed gamma-ray bursts. Using the relativistic Bolzmann-Vlasov and Maxwell equations to describe the motion of electron-positron pairs created by the Euler-Heisenberg-Schwinger mechanism and their back-reaction on the external electric field, as well as annihilation to photons, we study the time and spatial scales of plasma oscillation of electron-positron pairs and time scale for thermalization with photons. Comparing these time and spatial scales with the time and spatial scales determined by gravitational collapse process, it strongly implies that the Dyado-torus can be dynamically formed during gravitational collapse.

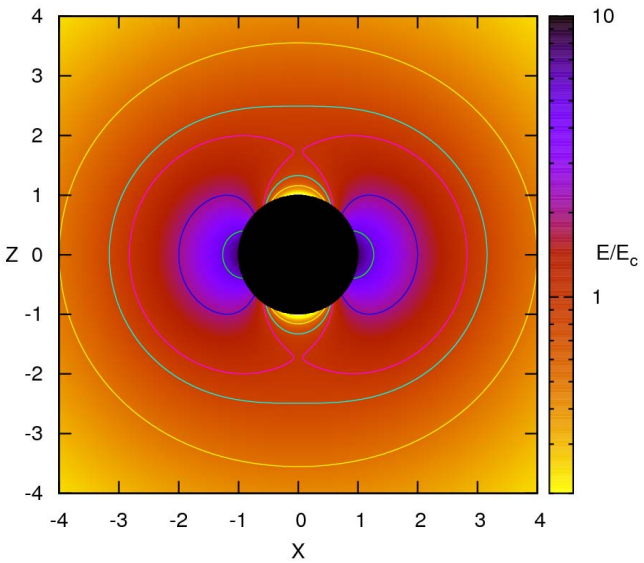

Figure 1: Dyado-torus. Details in Ref. [2].

This field has led to a critical analysis of the electrodynamics of neutron stars. Using the Thomas-Fermi model to describe degenerate electrons in the core of neutrons and protons, which is governed by gravitational, strong and weak interactions, we study the electrodynamics of neutron star cores. We find that the electron-density distribution deviates from the proton-density distribution at the nuclear density, due to the fact that protons are bound by the strong interaction, while electrons are free from it. As results, we find a stable and energetically favorable distribution of electrons, for which electric field on the surface of neutron star cores is about the critical value. We study the energy-states of electrons in the Coulomb potential and calculate the rate of electron-positron productions. This reveals the electro-dynamical properties of the core of neutron stars and massive stars before they gravitationally collapse to black holes.

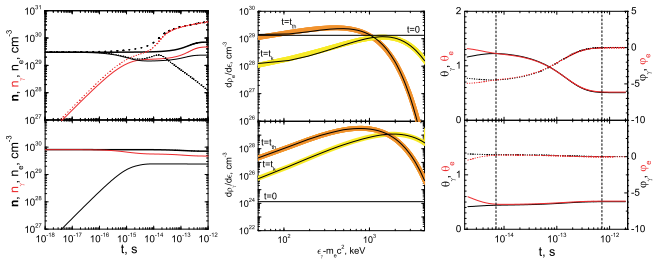

Figure 2: The density n of pairs and photons (left plot, with the total density in bold), their spectra $d\rho/d\varepsilon$ (center plot) and their temperatures $\theta = kT/(m_e c^2)$ along with chemical potentials $\varphi = \phi/(m_e c^2)$ (right plot) are shown. ε is the energy of particle in units of electron rest mass energy $m_e c^2$. Two different initial conditions were considered: when only pairs are present with negligible amount of photons, and the opposite case (upper and lower figures respectively). In both cases the pair plasma relaxes to thermal equilibrium configuration on a timescale $t_{th} < 10^{-12}$ s for our parameter range, i.e. much before it starts to expand on the timescale $t < 10^{-3}$ s. We also show by dashed lines (on the upper left panel) the evolution of pairs and photons concentrations when the inverse 3-body interactions are neglected. Further details are given in Ref. [3].

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T10. Gamma-Ray Bursts

After the great discovery of the black holes in our galaxy, following the identification of Cygnus-X1 [1], one of the greatest challenges has been to try to identify the moment of gravitational collapse and the extraction of the gravitational and electromagnetic energy in the process of black hole formation. It was clear, from the early work on the mass formula of the black hole, that up to 50% of the black hole mass-energy could in principle be extractable. In this way, the black hole would become, as recalled by Christodoulou & Ruffini in 1971, "the largest storehouse of energy in the universe". Soon after the discovery of Gamma-Ray Bursts, in 1975 Damour & Ruffini proposed that indeed vacuum polarization process occurring during a Kerr-Newmann black hole formation may lead to energy emission of $\sim 10^{54}$ ergs. The dynamics of the e^+e^- plasma formed in the dyadosphere and originating the GRB phenomenon can be divided into five fundamental phases: the self acceleration of the e^+e^- pair-electromagnetic plasma (PEM pulse); its interaction with the baryonic remnant of the progenitor star (PEMB pulse); the approach of the PEMB pulse to transparency, the emission of the proper GRB (P-GRB) and its relation to the "short GRBs"; the ultrarelativistic and finally the non relativistic regimes of the optically thin baryonic matter shell left over after the transparency and ballistically expanding in the Circumburst Medium (CBM). The best fit of the theory leads to an unequivocal identification of the "long GRBs" as extended emission occurring at the afterglow peak (see Fig. 1).

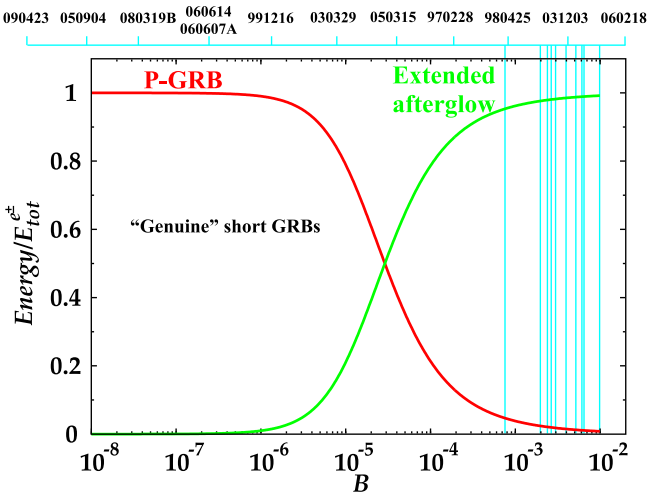

Figure 1: The energy radiated in the P-GRB and in the extended afterglow, in units of the total energy of the plasma ($E^{e^\pm}_{tot}$), are plotted as functions of the baryon loading B parameter. Also represented are the values of the B parameter computed for most of the GRBs we have analyzed.

The relative intensities, the time separation and the hardness ratio of the P-GRB and the extended afterglow are used as distinctive observational test of the theory and the excellent agreement between our theoretical predictions and the observations are documented. Using the observed GRB data, we progress on the uniqueness of our theoretically predicted GRB structure as composed by a proper-GRB (P-GRB), emitted at the transparency of an electron-positron plasma with suitable baryon loading, and an extended afterglow comprising the so called "prompt emission" as due to external shocks (see Fig. 2). We can theoretically fit detailed light curves for selected energy bands on a continuous time scale ranging over 10^6 seconds. The theoretically predicted instantaneous spectral distribution over the entire afterglow is presented, confirming a clear hard-to-soft behavior encompassing, continuously, the "prompt emission" all the way to the latest phases of the afterglow.

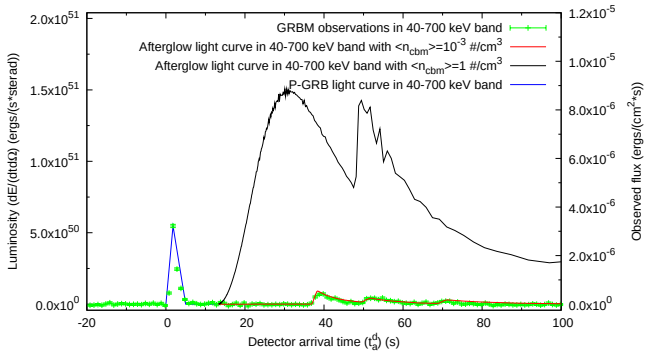

Figure 2: The theoretical fit of the *Beppo*SAX GRBM observations of GRB970228 in the 40–700 keV energy band. The red line corresponds to an average CBM density $\sim 10^{-3}$ particles/cm^3. The black line is the extended afterglow light curve obtained rescaling the CBM density to $\langle n_{cbm}\rangle = 1$ particle/cm^3 keeping constant its shape and the values of $E^{tot}_{e^\pm}$ and B. The blue line is the P-GRB. Details in Ref. [4].

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T11. Quantum Cosmology

The necessity for a quantum theory of gravity arises from fundamental considerations, and, in particular, from the space-time singularity problem. In fact, the classical theory of gravity implies the well known singularity theorems, among which the cosmological one. Several difficulties in implementing a quantum theory for the gravitational field can be overcome in minisuperspace models, for which some degrees of freedom are frozen out in view of the adopted symmetries. These models are still highly meaningful, since the most relevant case is a cosmological space-time.

The study performed within our group improves a research line centered in the investigation of cosmological models with a minimal scale. The introduction of a cut-off can be implemented by inequivalent approaches to quantum mechanics, which are expected to mimic some features of the final Quantum Gravity theory.

The polymer representation of quantum mechanics for a particular homogeneous cosmological space-time (the Taub Universe) was analyzed in [1] . This approach is based on a non-standard representation of the canonical commutation relations and it is relevant in treating the quantum-mechanical properties of a background-independent canonical quantum theory of gravity. The modifications induced by the cut-off scale on ordinary trajectories were studied from a classical point of view. Furthermore, the quantum regime was explored in detail by the investigation of the evolution of wave packets, unveiling an interference phenomenon between such wave packets and the potential wall. Nevertheless, the wave function of the Universe is not peaked far away from the singularity and falls into it following a classical trajectory; thus we have to conclude that the singularity is not removed on a probabilistic level.

A different intuitive approach to introduce a cut-off is based on deforming the canonical uncertainty relations leading to the so-called Generalized Uncertainty Principle (GUP). Such a modification appeared in perturbative string theory. In the work [2], the Bianchi IX cosmological model (the Mixmaster Universe) was studied within the GUP framework. To perform the analysis, two necessary steps, i.e. the study of the Bianchi I and II cosmological models, were necessary. The main results are: (i) The Bianchi I dynamics is still Kasner-like but is deeply modified since the GUP effects allow for the existence of two negative Kasner exponents. (ii) The Bianchi II model is no longer analytically integrable and therefore no BKL map can be obtained. (iii) The potential walls of Bianchi IX become stationary with respect to the point-Universe when the momentum of the latter is of the same order of the cut-off. We conclude that the deformed evolution of the Mixmaster Universe is still chaotic.

The comparison between the polymer- and the GUP-Taub model illustrates that the interference phenomena are produced in a complementary way. This feature appears both at classical level and in the quantum regime, as the behavior of the wave packets is investigated.

A further research line within our group deals with the definition of a background independent quantization of the gravitational field in a generic local Lorentz frame. This investigation is motivated by the standard requirement of Loop Quantum Gravity to restrict the local Lorentz frame by the so-called time gauge condition. The Hamiltonian formulation without such a gauge fixing is performed in [3]. The main technical issue is the emergence of a second-class system of constraints, which is reduced to a first-class one without fixing the local Lorentz frame but restricting to a suitable hypersurface in the full phase space. A privileged set of variables is selected out and is constituted by non-dynamical boost parameters and $SU(2)$ connections. Hence, the standard loop quantization in terms of holonomies and fluxes of the $SU(2)$ group is still well-grounded. Furthermore, boost invariance on a quantum level is reproduced by wave-functionals which do not exhibit any dependence on boost parameters. The results of this analysis outline the invariant nature of the discrete space structure proper of Loop Quantum Gravity and elucidates the fundamental role that the $SU(2)$ symmetry plays in the phase-space of gravity.

Finally, wide attention is devoted to study of generalized formulations of differential geometry in order to incorporate physical features of fundamental fields into a unified picture. In particular, in [4], a generalized connection, including Christoffel coefficients, torsion, non-metricity tensor and metric-asymmetricity objects, is analyzed according to the Schouten classification. The inverse structure matrix is obtained in the linearized regime, autoparallel trajectories are defined, and the contribution of the connection components are clarified at first-order approximation. The restricted sector in which is retained only a torsion field, is currently under investigation towards its implementation in the framework of a Lorentz gauge theory.

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T12. Statistical mechanics of disordered systems and renormalization group

The behavior of strongly disordered systems is very different from the one of pure, homogeneous systems. Experimentally, the most dramatic effects are observed in the dynamics. Very slow relaxation and aging, severe nonequilibrium effects, memory and oblivion, generalizations of the usual fluctuation-dissipation relations are all specific features of disordered systems. These dynamic effects have a static counterpart. For example, in spin glasses the onset of the slow relaxation is associated with the divergence of a static quantity, the nonlinear susceptibility.

Unfortunately, our understanding of the static behavior of strongly disordered systems is rather limited with the notable exceptions of the Sherrington-Kirkpatrick model and of Derrida's random energy model. In most of the cases, Monte Carlo simulations provide the only tool to determine the critical behavior and to sort out the different theories which have been proposed to describe these systems.

In the last few years we have performed several numerical studies of the three-dimensional Edwards-Anderson model. The use of the most advanced numerical techniques — the random-exchange or parallel-tempering method, multi-spin coding, cluster algorithms, etc. — and of very fast computers allowed us to address long-standing problems and to obtain several new and important results.

Numerical simulations of random systems are notoriously very difficult and, in spite of significant algorithmic progress, numerical simulations are limited to relatively small system sizes. A significant improvement has been obtained by developing a new dedicated machine (JANUS) in collaboration with the University of Ferrara and several Spanish research groups. JANUS is a modular, massively parallel, and reconfigurable FPGA-based computing system. JANUS is tailored for, but not limited to, the requirements of a class of hard scientific applications characterized by regular code structure, unconventional data manipulation instructions, and not-too-large database size. In particular, the machine is well suited for numerical simulations of spin glasses. On this class of applications JANUS achieves impressive performances: in some cases one JANUS processing element outperfoms high-end PCs by a factor of approximately 1000. Several simulations have been performed on Janus. The critical behavior of the four-state commutative random-permutation glassy Potts model in three and four dimensions and of the four-state three-dimensional Potts model have been carefully studied. More importantly, the use of JANUS allowed us to study carefully the relaxational dynamics in the three-dimensional Edwards-Anderson model [1], for a time spanning 11 orders of magnitude, thus approaching the experimentally relevant scale (i.e., seconds).

One of the most peculiar properties of the mean-field solution of the Edwards-Anderson model is the so-called ultrametricity: In the low-temperature phase thermodynamic states are organized in a hierarchical structure. One of the long-standing questions is whether such a structure also holds in the three-dimensional model or instead is a peculiarity of the mean-field solution as predicted by the droplet theory. In [2] we studied numerically the issue and found good evidence for the presence of an ultrametric structure also in the three-dimensional case.

Given the difficulty in obtaining clear-cut results for the three-dimensional spin glass, we also investigated several spin-glass models which share some of the properties of the finite-dimension Edwards-Anderson model, but, at the same time, are significantly simpler to simulate numerically. For this purpose we introduced a one-dimensional spin-glass model with long-range interactions. The interaction between two spins a distance r apart is either ± 1 with a probability that decays with r as $1/r^\rho$, or zero. Depending on the exponent ρ, the model may or may not show mean-field behavior: for $\rho \leq 4/3$ the mean-field approximation is exact, for $\rho > 2$ no phase transition occurs, while in between the behavior is nontrivial. Since this model is one-dimensional and, in spite of the presence of long-range interactions, each spin only interacts with a finite number of different (may be far) spins, it is possible to simulate quite large systems and carefully investigate finite-size effects. In [3] we studied numerically the model in the absence of magnetic field for values of p in the intermediate range, identified the paramagnetic-glassy phase transition, and characterized the low-temperature phase. We found both static and dynamic indications in favor of the so-called replica-symmetry breaking theory. In [4] we considered the behavior in an external magnetic field h. The results, obtained by means of a new analysis method, strongly suggest the presence of a finite-h transition, as also observed in the mean-field solution of the Edwards-Anderson model.

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T13. The glassy state

The glass is state of matter characterized by a very large viscosity. Consequently relaxational processes in a glass are extremely slow and the dynamics of the glass constituents takes place on a broad spectrum of timescales. The coexistence of fast and very slow processes makes the glass dynamics very interesting from the physical point of view, but also very difficult to treat analytically.

Experimental facts and analytical theories about the glass transition and the aging dynamics of glas-formers have been reviewed in a recent book [1] written by a member of our group. Thermodynamics of glasses poses interesting questions still largely unanswered, e.g., the existence of a thermodynamical phase transition to a glass state, lowering the temperature or increasing the density. Such a transition is predicted by mean field approximations and is called a random first order transition (RFOT), but its existence in finite dimensional systems is still a matter of debate.

It is well known that the free-energy barriers between states, that diverge in mean field approximation, are large but non-diverging in finite-dimensional models. Still, how much of the mean field scenario is maintained in low-dimensional models is unclear. Recently we have studied in Ref. [2] a one-dimensional version of the Derrida's Random Energy Model (REM). The REM, being a long range model, has a clear RFOT. In our 1D model we have introduced a length (proportional to the system size, as in the Kac limit) such that interactions are REM-like on smaller scales. We indeed find a limiting value for this crossover length between the REM-like and the 1D behavior, but corrections with respect to the mean field approximation are huge and would make hard to find the crossover length in actual glassy models.

Our group has, as well, dedicated quite a large effort in recent years on the study of glasses of hard spheres. A system of monodisperse hard spheres is maybe the simplest showing most of the glass phenomenology and can be thus considered as a prototypical model. Moreover, amorphous packings have attracted a lot of interest as theoretical models for glasses, because for polydisperse colloids and granular materials the crystalline state is not obtained in experiments. We have reviewed in Ref. [3] most of the recent results on systems of hard spheres obtained with the replica method.

At a first sight it could look strange to use the replica method, invented to average out the disorder, in systems with no disorder at all. But a closer look will reveal that a dense system of hard spheres is likely to be in one of the many amorphous packing configurations. Even if the original model has no disorder at all, the configurations dominating the high density phase are very many as if they were generated from a disordered Hamiltonian and the replica method is a natural tool to deal with such complexity.

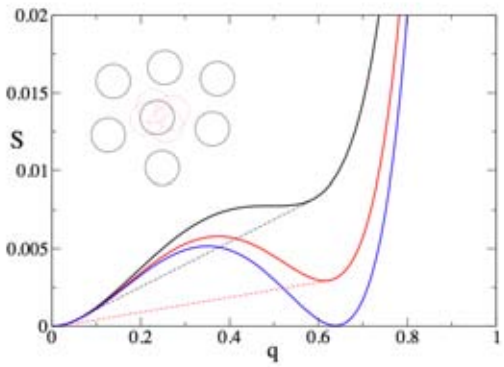

Figure 1: The replicated potential for estimating the number of states in a glassy phase.

In this context the replica method works more or less as follows. Given a reference equilibrium configuration, one can construct many replicated configurations, that interact with a small coupling term with the reference one. In the inset of Figure 1 we show with red dashed circle the replicas of the central molecule, which are free to evolve, but with a coupling ε with respect to the reference configuration. The main question is what happens when ε is sent to zero after the thermodynamical limit. In this limit, under mean field approximations, one can infer the existence of more than one state from the computation of the so-called replicated potential (which is shown with full lines in Figure 1). Actually in Figure 1 we are showing the entropy of configurations having a certain overlap q with the reference configuration.

In Ref. [4] we have also extended our theory of amorphous packings of hard spheres to binary mixtures and more generally to multicomponent systems. The theory is based on the assumption that amorphous packings produced by typical experimental or numerical protocols can be identified with the infinite pressure limit of long-lived metastable glassy states. We test this assumption against numerical and experimental data and show that the theory correctly reproduces the variation with mixture composition of structural observables, such as the total packing fraction and the partial coordination numbers.

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T14. Optimization problems and message passing algorithms

Optimization problems are widespread in scientific disciplines. The goal is typically to found the minimum of a given cost function defined in terms of a large number N of variables. In physical terms it corresponds to the computation of a ground state configuration. The problem may become very hard when the interacting terms in the cost function are in competition, i.e. the model is frustrated. In recent years our group has developed many statistical physics tools that allow to perform analytical computations in these models, even directly at zero temperature, such as to probe the structure of the ground states of the model.

Among optimization problems, a quite general class is formed by Constraint Satisfaction Problems (CSP) where a set is given of $M = \alpha N$ constraints, that must be satisfied by a proper assignment of the N variables. We have been able to solve this kind of models in the case where the constraints are generated independently, which actually correspond to defining the model on a random graph. Under this hypothesis, the Bethe approximation turns out to work in a certain range of model parameters (i.e. in the equivalent of the paramagnetic phase). When it fails, the replica symmetry need to be broken and we have obtained the solutions up to one level of replica symmetry breaking, that actually provide the exact answer for many well-known CSP.

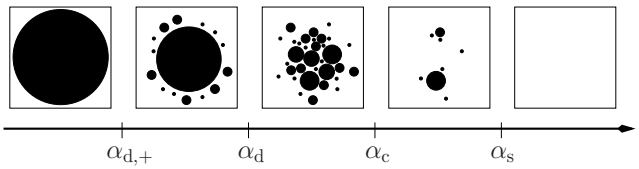

Figure 1: Phase transitions in the structure of solutions to random k-SAT problems [1].

While studying the structure of the space of solutions to random CSP we have uncovered many different phase transitions. In Figure 1 we show a schematic picture of how the structure of solution changes, e.g. forming clusters, while increasing the ratio α of constraints per variable. The picture is from Ref. [1] where we have presented the most general solution to important random CSP, like satisfiability and coloring. The random k-satisfiability problem has been further examined and solved in great detail in Ref. [2].

An important role of the phase transitions uncovered in this kind of problems relies on the fact that solving algorithms are typically affected by the drastic changes taking place at these thresholds: stochastic local search algorithms (like Monte Carlo) should get stuck at the dynamical threshold α_d, while Belief Propagation (BP) works up to the condensation threshold α_c and finally Survey Propagation (SP) should be able to go beyond α_c and get closer to the satisfiability threshold α_s.

The last two algorithms, BP and SP, are so-called Message Passing Algorithms (MPA) and are extremely efficient for making probabilistic inference on random graphs. These algorithms work by sending messages between the nodes of the graphs that represent the variables and the constraints in the problem. Messages leaving a node are updated according to the incoming messages to that node. For this reason the algorithm is easy to implement, fast to use and possibly distributed.

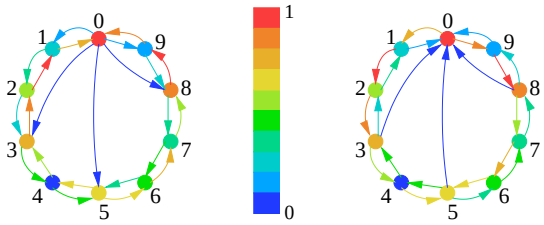

Figure 2: Examples of node ranking by counting loops [3].

A very important aspect of MPA that we have started to investigate recently is their use on non-random graphs, that is graphs with many short loops and topological motifs. An interesting example is given by the problem of ranking graphs nodes, i.e. to uncover which nodes are the most important in the graph topology (a straightforward application being the ranking of web pages). In Ref. [3] we have introduced a new MPA that ranks nodes depending on how many loops pass through that node. Typical rankings are shown in Fig. 2. The performances we obtain are comparable with those of widely used algorithms, like PageRank and betweenness centrality.

The effectiveness of our analytical approach to optimization problems is that we can deeply understand the physical origin of their hardness and thus explain why solving algorithms may fail to find solution to this problem. In Ref. [4] we have been able to solve analytically a stochastic search algorithm, which is based on BP and a decimation procedure. The analytical solution perfectly coincides with the outcome of the numerical algorithm and predicts a fail of the searching procedure due to the existence of a phase transition in the space of solutions. The resulting picture is somehow counter-intuitive: reducing the problem by fixing a certain fraction of variables does not simplify the problem, but rather makes it harder to solve.

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T15. From Artificial Neural Networks to Neurobiology

Neural networks have at least a double meaning. In one sense they are algorithms which solve certain tasks in the other they are models of realistic biological neurons. Our group works on the two approaches in this field since many years as well as in the application of mathematical methods to biology. The great variety of topics connected with the research on Neural Networks is the cause of a great spread of different mathematical tools used in the investigation. Neurons are very complex biological objects and there are many different ways to schematize them according to the aims that one wants to achieve. We describe only few aims of the many considered by us. One great topic is **sinchronization**. In the papers [1] and [3] this theme was analyzed from very different point of view. In [1] the neurons are described by a set of first order linear differential equations with an $n \times n$ interaction matrix with independent and gaussian distributed $N(0, 1/\sqrt{n})$ random elements. The problem of stability of the motion for large values of n has been solved in this paper using the cavity method of the theory of disordered systems. In this work it is assumed that many properties of a large system of neurons depend on the connections more than the biological structure of the neurons. This strategy involves a lot of mathematical tools in the theory, mainly nice and intriguing probability estimates. But this point is rather controversial and so we have developed also a more biological approach in the paper [3], where we have modeled the behavior of the oxytocin neurons of the hypothalamus when they emit the oxytocin hormone. In this model there are the ion currents characteristic of these neurons and all the interactions are through Poisson processes describing the synaptic inputs. This model cannot be solved analytically because of the large set of equations with many Poisson inputs, so it has been solved numerically with results in good agreement with the measures of electrical activity of these kind of neurons. These encouraging results convinced us that the best approach for finding general properties of large system of neurons are semi-phenomenological models where inputs are described by Poisson processes with activity found in the experiments and currents given by experimental measures of the patch-clamp type. Another good example of this approach is given in the paper [4] where the problem of the control of the movement of the eye (saccadic movements) is considered. The unexpected fact of the nature is that the smooth movements of any part of the body is controlled with the stochastic firing activity of the neurons! So the search for the minimimum of the variance of the motion becomes a problem of the theory of the stochastic control. In [4] it is shown that the control function can be found analytically by solving a simple differential equation, while usually the theory of stochastic optimization ends with the hard Hamilton-Jacobi equations which usually cannot be solved analytically. Another interesting fact is that the control function found in this paper gives the usual motion and velocity of the saccadic eye movement! Another interesting theme of our research has been connected with a pure biological question. Since we have developed the tools of extreme value theory of statistics we were able to apply it to biological questions, reinforcing the conviction that probability and statistics are the most useful instruments for dealing with the large complex systems of the biology. Thus in the paper [2] we applied this nice theory for finding the the motifs or the place in the precursor of the DNA, the set of blocks where the transcription factors of proteins that need to be reproduced bind starting the process of reproduction. These binding sites are the sites with maximal probability of binding. In the current literature the probability distribution of these sites was considered to be gaussian and so the distribution of the maximum was assumed to be a Gumbel distribution while we discovered using the statistic tools that the distribution of the maximum was a Weibull. This result brought to the identification of new binding sites and also to the distribution of couple of binding sites.

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T16. On static and dynamic properties of complex systems in statistical mechanics and quantum field theory

In the period under consideration, the research activities have been mainly oriented toward the study of the static and dynamic properties of complex systems, with applications to the physics of elementary particles, the physics of condensed matter, and biological systems. The methods and techniques refer to statistical mechanics, to the theory of stochastic processes, and dynamical systems. The methods at the basis of our study of spin glasses and neural nets let the physical intuition, accumulated through the use of the replica trick and numerical simulations, merge with the need for a rigorous mathematical treatment. The essential ingredients are given by powerful interpolation methods, and sum rules. These methods led in the past years to the proof of relevant results, in particular concerning the control of the infinite volume limit, and the mechanism of the spontaneous replica symmetry breaking.

We now give a concise review about the main results obtained.

For the neural nets of Hopfield type, we have given a characterization of the ergodic phase and the generalization of the Ghirlanda-Guerra identities. Moreover, a systematic interpolation method has been developed which allows the characterization of the replica symmetric approximation, and the possibility of introducing functional order parameters for the description of the replica symmetry breaking. Our method is based on the transformation of the neural net into a bipartite spin glass, where one of the party is given by usual Ising spin variables, and the other party is given by Gaussian variables. The quenched spin glass interaction is assumed to be Gaussian. It is immediate to realize that in general, for this kind of bipartite spin glass models, universality does not hold in general, in contrast with the Sherrington-Kirkpatrick model for a spin glass. The variational principle arising in the expression of the free energy in the infinite volume limit is of novel type, in that it involves a mini-max procedure, in contrast with the Sherrington-Kirkpatrick model for a spin glass. This seems to be a general property of a very large class of models. In particular, the mini-max variational principle has been found to hold for general bipartite models, of ferromagnetic and spin glass type. The replica symmetric approximation is ruled by two order parameters, connected with the values of the overlaps of the Ising spin variables and the Gaussian variables, respectively, connected by self-consistency relations. Obviously, the replica symmetric approximation looses its physical meaning at low temperatures, where the entropy becomes negative. However, by our interpolation methods, it is very simple to construct the full replica broken scheme, by a deep generalization of the methods developed for the spin glass case. The fully broken scheme is believed to give the true solution of the model.

Diluted systems have been studied in the cases of ferromagnetic, antiferromagnetic, and general interpolating models. Also in these cases, interpolation techniques, and the associated sum rules, have been found very useful. The interest of the diluted model is given by the fact that they give a kind of bridge between the mean field models and the models with short range interaction.

The theory of self-oscillating mechanical systems has been exploited for the study of speech formation, analysis and synthesis, and musical instrument functioning. It is possible to apply fully nonlinear schemes, by completely avoiding any kind of exploitation of the Fourier analysis. The role of the different peaks of the spectrum in the Fourier analysis is played by the intervention of successive Landau instability modes for the self-oscillating system. Moreover, with the same methods, we have studied tidal basins, and volcanic tremor of Stromboli type, in the frame of a recent collaboration with researchers at the Department of Physics at the University of Salerno.

Finally, in recent times, we have developed the possibility of giving simple models for the immunological system, based on stochastic dynamical systems of statistical mechanics far from equilibrium. The models are simple enough to allow practical evaluations, in connection with the known phenomenology, but they are very rich in the possibility of introducing all basic feature of the real system. This research is done in collaboration with researchers at the Department of Physics of the University of Parma.

Finally we would like to mention the study of the quantum field theory formulation of the relativistic Majorana equations, introduced in 1932 in a famous paper on Nuovo Cimento, and the study of slowing down, scattering and absorption of neutrons, by following the original methods of Fermi, Wick, Bothe, Heisenberg, with the purpose of a realistic assessment of the validity of the approximations introduced by them, in comparison with the modern methods of numerical simulations in the nuclear reactor theory.

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T17. Macroscopic fluctuation theory of irreversible processes

We have proposed a macroscopic theory for a certain class of thermodynamic systems out of equilibrium, which is founded on and supported by the analysis of a large family of stochastic microscopic models. Out of equilibrium the variety of phenomena one can conceive makes it difficult to define general classes of phenomena for which a unified study is possible. Furthermore the details of the microscopic dynamics play a far greater role than in equilibrium. Since the first attempts to construct a non equilibrium thermodynamics, a guiding idea has been that of *local equilibrium*, which means that locally on the macroscopic scale it is possible to define thermodynamic variables like density, temperature, chemical potentials... which vary smoothly on the same scale. Microscopically this implies that the system reaches local equilibrium in a time which is short compared to the times typical of macroscopic evolutions, as described for example by *hydrodynamic equations*. There are important cases however where local equilibrium apparently fails like aging phenomena in disordered systems due to insufficient ergodicity. These will not be considered in this paper. Also the case in which magnetic fields play a role is not covered by our analysis.

The simplest nonequilibrium states one can imagine are *stationary states* of systems in contact with different reservoirs and/or under the action of external (electric) fields. In such cases, contrary to equilibrium, there are currents (electrical, heat, matter of various chemical constitutions ...) through the system whose macroscopic behavior is encoded in transport coefficients like the diffusion coefficient, the conductivity or the mobility.

The ideal would be to approach the study of these states starting from a microscopic dynamics of molecules interacting with realistic forces and evolving with Newtonian dynamics. This is beyond the reach of present day mathematical tools and much simpler models have to be adopted in the reasonable hope that some essential features are adequately captured. In the last decades stochastic models of interacting particle systems have provided a very useful laboratory for studying properties of stationary nonequilibrium states. From the study of these models has emerged a macroscopic theory for nonequilibrium diffusive systems which can be used as a phenomenological theory.

A basic issue is the definition of nonequilibrium thermodynamic functions. For stochastic lattice gases a natural solution to this problem has been given via a theory of dynamic large deviations (deviations from hydrodynamic trajectories) and an associated variational principle leading to a definition of the free energy in terms of transport coefficients.

One of the main differences between equilibrium and nonequilibrium systems, is that out of equilibrium the free energy is, in general, a non local functional thus implying the existence of correlations at the macroscopic scale. These correlations have been observed experimentally and appear to be a generic consequence of our variational principle which can be reformulated as a time independent Hamilton-Jacobi equation for the free energy. This is a functional derivative equation whose independent arguments are the local thermodynamic variables and which requires as input the transport coefficients.

We believe that the theory we have proposed is a substantial improvement with respect to the theory developed long ago by Onsager and then by Onsager-Machlup which applies to states close to equilibrium, namely for linear evolution equations, and does not really include the effect of nontrivial boundary reservoirs. In principle, the theory we suggest should be applicable to real systems, i.e. with nonlinear evolution equations and arbitrary boundary conditions, where the diffusion is the dominant dynamical mechanism. We emphasize however that we assume a linear response with respect to the external applied field. Of course, the Onsager theory is recovered as first order approximation.

The basic principle of our theory is a variational principle for the nonequilibrium thermodynamic functionals. This principle has the following content. Take the stationary state as the reference state and consider a trajectory leading the system to a new state. This trajectory can be realized by imposing a suitable additional external field (in addition to the one already acting on the system). Then compute the work done by this extra field and minimize it over all possible trajectories leading to the new state. This minimal work is identified with the variation of the free energy between the reference and the final state. As well known in thermodynamics, in the case of equilibrium states this definition agrees with the standard one.

Our treatment is based on an approach developed in the analysis of fluctuations in stochastic lattice gases [1,2].

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T18. Equilibrium statistical mechanics for one dimensional long range systems

It is well known that one dimensional spin systems with long range interactions decaying as $|x-y|^{-\sigma}$ can give rise to a phase transition for $1 < \sigma \leq 2$. It is a conjecture suggested by Anderson that the range of the interactions (i.e. $1/\sigma$) should play the role of the dimensionality,so that , varying a , these models could mimic the properties of more realistic higher dimensional systems (e.g. the spin glasses where a satisfactory theory is still lacking). This is the motivation for a rigorous analysis of the models belonging to this class. Starting from a geometrical description of the energy fluctuations it is possible, when the interactions are ferromagnetic and the temperature is sufficiently small, to prove :

1) the existence of a phase transition and the convergence of a cluster expansion that allows to study the behaviour of the separation point between two coexisting phases

2) the persistence of a phase transition for $\sigma > 3/2$ when a stochastic magnetic field is present. (cfr. ref 1).

The actual project is to study a one dimensional system of particles interacting via long range attractive potentials. In this case the motivation is different but we plan to exploit the techniques developed for spin systems on a lattice. A central problem in equilibrium statistical mechanics is the derivation of the phase diagram of fluids where gas ,liquid and solid regions are present and separated by coexistence curves . The van der Waals theory gives a qualitative reasonable description of the liquid -vapour coexistence curve but the mean field assumed in this approach is far away from any realistic interaction and to get a result consistent with thermodynamics it is necessary to introduce the so called Maxwell construction. The first rigorous version of the van der Waals theory in statistical mechanics is due to Kac . Its main assumption is a sharp separation of the scales between the attractive and repulsive forces. In d dimensions the basic model has an attractive pair interaction of strenght γ^d and range $1/\gamma$ and an hard core of lenght 1. In the limit γ going to zero it is possible to obtain the van der Waals results with the Maxwell construction included. From a physical point of view this is not yet what desired as the phase diagram is only derived in the limit γ going to zero which does not correspond to any reasonable interaction among particles. The problem is to verify if the convergence of this limit is strong enough to ensure that before the limit (when γ is finite and the interaction is reasonable) this structure of the phase diagram is preserved. In the last decades this analysis has been successfully performed for spin systems on a lattice for dimensions larger than 1. The general strategy is to perform a coarse graining on a scale smaller then $1/\gamma$. The limit for γ going to zero of the effective hamiltonian is a non local functional where locally the interaction is mean field . The basic idea is to consider perturbations respect to the mean field equilibrium configurations rather then the original ground state. This allow to describe the configurations in term of contours and to prove a Peierls bound for all temperatures smaller than the mean field critical temperature and γ sufficiently small. This bound not only proves the existence of a phase transition but also the convergence of a cluster expansion that allows to fully describe the system for all temperatures smaller then the mean field critical temperature. The implementation of this strategy for a system of particles in the continuum for dimensions larger then one is so far not possible . The reason is technical and related to the actual control of the hard core component. In fact, in the region where we expect to have the transition, the liquid phase is "close" to an hard core system with an effective fugacity exceeding the value for which the convergence of the cluster expansion has been proved.

In one dimension this specific problem disappears because the hard core system is isomorphic to an ideal gas but it is necessary to add an attractive long range interaction to give rise to a phase transition.

We study one dimensional hard rods interacting via a finite range Kac potential plus a long range decreasing tail:

$$J(r) = \gamma\ 1_{r<\gamma^{-1}} + 1_{r>\gamma^{-1}} \frac{1}{r^\sigma} \tag{1}$$

The one dimensional nature of our system allows to control the hard core contribution. Coupling the coarse graining techniques developed for Kac potentials and a definition of contours suitable to describe the energy fluctuations in one dimensional long range systems , we expect to obtain ,via the Pirogov-Sinai approach , a Peierls bound and fully implement the strategy developed for spin systems on a lattice.

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T19. Markov chains on graphs

Let $\mathcal{G} = (V, E)$ be a connected finite graph with vertex set $V = \{1, 2, \ldots, n\}$. The *Laplacian* of $\mathcal{G}$ is the $n \times n$ matrix $\Delta_{\mathcal{G}} := D - A$, where A is the adjacency matrix of $\mathcal{G}$, and $D = \mathrm{diag}(d_1, \ldots, d_n)$ with d_i denoting the degree of the vertex i, *i.e.* the number of edges originating from i. Since $\Delta_{\mathcal{G}}$ is symmetric and positive semidefinite, its eigenvalues are real and nonnegative and can be ordered as $0 = \lambda_1 \leq \lambda_2 \leq \cdots \leq \lambda_n$. There is an extensive literature dealing with bounds on the distribution of the eigenvalues and consequences of these bounds. Of particular importance for several applications is the second eigenvalue λ_2 which is strictly positive since $\mathcal{G}$ is connected. The Laplacian $\Delta_{\mathcal{G}}$ can be viewed as the generator of a continuous-time random walk on V, whose invariant measure is the uniform measure on V. In this respect, λ_2 is the inverse of the "relaxation time" of the random walk, a quantity related to the speed of convergence to equilibrium. λ_2 is also called the *spectral gap* of $\Delta_{\mathcal{G}}$. There are several results which estabilish relationships between the spectral gap and various geometric quantities associated with the graph. Among these we should mention upper and lower bounds on λ_2 in terms of the Cheeger isoperimetric constant, a result closely related to the Cheeger's inequality dealing with the first eigenvalue of the Laplace–Beltrami operator on a Riemannian manifold.

One can consider, besides the simple random walk, more complicated Markov chains on the same graph $\mathcal{G}$. We mention two widely used processes: the exclusion process and the interchange process. In the interchange process each vertex of the graph is occupied by a particle of a different color (Fig. 1), and for each edge $\{i, j\} \in E$, at rate 1, the particles at vertices i and j are exchanged. The exclusion process is analogous but with only two colors, say k red particles and $n-k$ green particles (particles with the same color are considered indistinguishable).

The interchange process on $\mathcal{G}$ can be considered as a random walk on a larger graph with $n!$ vertices corresponding to the configurations of the process. This graph is nothing but the Cayley graph of the symmetric groups S_n with generating set given by the edges of $\mathcal{G}$, where each edge $\{i, j\}$ is interpreted as a transposition. We denote this graph with $\mathrm{Cay}(\mathcal{G})$. It is easy to show that the spectrum of $\Delta_{\mathcal{G}}$ is a subset of the spectrum of $\Delta_{\mathrm{Cay}(\mathcal{G})}$. By consequence

$$\lambda_2(\Delta_{\mathcal{G}}) \geq \lambda_2(\Delta_{\mathrm{Cay}(\mathcal{G})}) \,.$$

Being an $n! \times n!$ matrix, in general the Laplacian of $\mathrm{Cay}(\mathcal{G})$ has many more eigenvalues than the Laplacian of $\mathcal{G}$. Nevertheless, a neat conjecture due to David Aldous states, equivalently:

Aldous's conjecture (v.1). *If $\mathcal{G}$ is a finite connected simple graph, then*

$$\lambda_2(\Delta_{\mathcal{G}}) = \lambda_2(\Delta_{\mathrm{Cay}(\mathcal{G})}) \,.$$

Aldous's conjecture (v.2). *If $\mathcal{G}$ is a finite connected simple graph, then the random walk and the interchange process on $\mathcal{G}$ have the same spectral gap.*

Aldous's conjecture has been proven for trees in 1996. We have found a proof for complete multipartite graphs using a tecnique based on the representation theory of the symmetric group. This result will be published in a forthcoming issue of the Journal of Algebraic Combinatorics. Shortly after the appearence of our result, a general proof of the Aldous's conjecture was found by Caputo, Liggett and Richthammer.

In [1] we prove a similar result for a different Markov chain called *initial reversals*. Here the set of generators is given by the permutations

$$\{1, 2, \ldots k\} \longrightarrow \{k, \ldots, 2, 1\} \,,$$

where k is an integer between 2 and n. Again the interest of this result lies in the fact that it allows to compute the spectral gap of an $n! \times n!$ matrix, by considering a suitable (much smaller) $n \times n$ matrix.

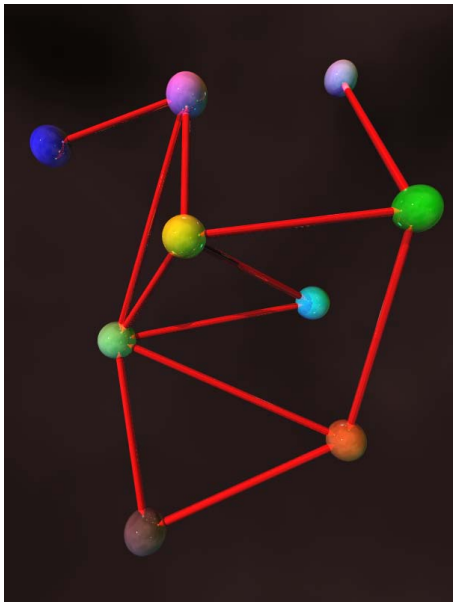

Figure 1: A configuration of the interchange process.

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F. Cesi

T20. Optical solitons in resonant interactions of three waves

In glass nonlinearity is cubic (Kerr effect) and solitons result from balance between dispersion (or diffraction) and nonlinear self-focusing. More recently both theoretical and experimental interest has been attracted by soliton propagation in media with quadratic nonlinearity (as in KTP crystals). In these media the most important and applicable effects arise in the resonant interaction of three waves, 3WRI. This interaction is modelled by a system of three dispersionless quadratic nonlinear partial differential equations for the envelopes of three quasi monochromatic plane-waves. Energy exchange between these three waves is possible because of the resonce condition $\omega_1 + \omega_2 = \omega_3$. These equations are integrable and their analytic investigation is made possible by the powerful tools of spectral theory. Since dispersion is missing, the mechanism of soliton formation is quite different from that in cubic material. In this case is rather the mismatch of group velocities and nonlinearity which gives rise to soliton propagation.

It is well known that parametric three-wave mixing provides a means of achieving widely tunable frequency conversion of laser light. Moreover the frequency conversion of short (bright) pulses may be significantly enhanced by means of optical solitons. Indeed, the collision of two bright input (soliton) pulses at different frequencies, with proper duration and input power, leads to a time-compressed pulse at the sum-frequency. However such pulse is unstable, since it rapidly decays into two time-shifted replicas of the same input pulses, with obvious limitation of the applicability of this technique to frequency conversion. In this context, a substantial advancement started in our group in Rome with the discovery of a new multi-parametric class of soliton solutions of the 3WRI model. The novelty of these solitons is that they describe a triplet made up of two short (localised) pulses and a cw background. Because of the persistent interaction with the background, the two b! right pulses propagate with dispersion whose balance with the quadratic nonlinearity causes a quite rich, and non standard, phenomenology of soliton behaviour. The distinction of these solitons with respect to those previously known is emphasised by referring to them as *boomerons* and *trappons*.

The most elementary solitons of this new family are bright-bright-dark triplets which travel with a common, locked velocity. Their velocity is different from any of the three characteristic group velocities. A soliton (simulton) of this type is stable if its velocity V is higher than a critical value V_{cr}. Unstable simultons move with velocity which is lower than V_{cr} but then eventually decay in an higher velocity stable soliton and a bump of the background moving with its own characteristic velocity. This implies that the initial and final velocities of unstable simultons are different from each other, namely they are accelerated. The time reverted process describes the excitation of a stable simulton by absorption of a background bump. These are analytic solutions of the 3WRI equations, the dynamical process being the boomeron solution. However the physical process consists of an excitation followed by decay (see Fig.1). Simultons may also couple together according

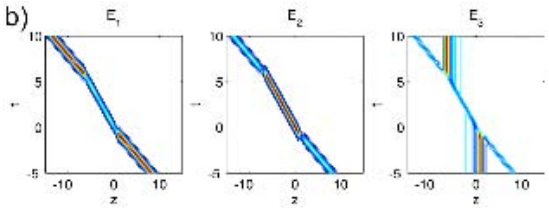

Figure 1: Numerical double boomeron process.

to their phase relations. For instance two in-phase simultons attract each other in a bound state in an even richer coherent structure (see Fig.2). A variety of

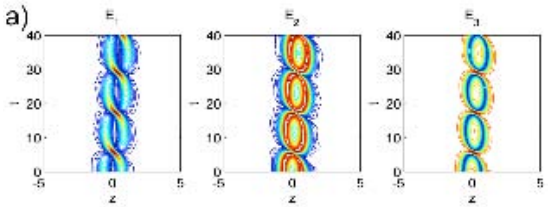

Figure 2: Two in-phase simultons with the same velocity.

potential applications are at hand by using the soliton behaviours of Bright-Bright-Dark triplet. For instance, an ultra short pulse (signal) interacting with the cw background (pump) generates a sum-frequency short bright pulse whose intensity, width and velocity can be controlled in a stable and efficient way by varying the background intensity. Moreover the trappon solution, a triplet of two bright and a dark pulses which are locked together to periodically oscillate, can lead to device a way to generate high-repetition rate pulse trains whose applicability and interest is in a broad range of domains [1]. On the experimental side, the first observation of solitonic decay in the case of three bright pulses has been reported quite recently [2] as the first step towards the observation of purely boomeronic and trapponic processes.

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T21. Propagation and breaking of weakly nonlinear and quasi one dimensional waves in Nature

Take any system of nonlinear PDEs i) characterized, for example, by nonlinearities of hydrodynamic type and ii) whose linear limit, at least in some approximation, is described by the wave equation. Then, iii) looking at the propagation of quasi one dimensional waves and iv) neglecting dispersion and dissipation, one obtains, at the second order in the proper multiscale expansion, the dispersionless Kadomtsev - Petviashvili equation in $n+1$ dimensions (dKP_n): $(u_t + uu_x)_x + \Delta_\perp u = 0$, $u = u(x, \vec{y}, t)$, $\vec{y} = (y_1, \ldots, y_{n-1})$, $\Delta_\perp = \sum_{i=1}^{n-1} \partial^2_{y_i}$. Therefore dKP_n arises in several physical contexts, like acoustics, plasma physics and hydrodynamics.

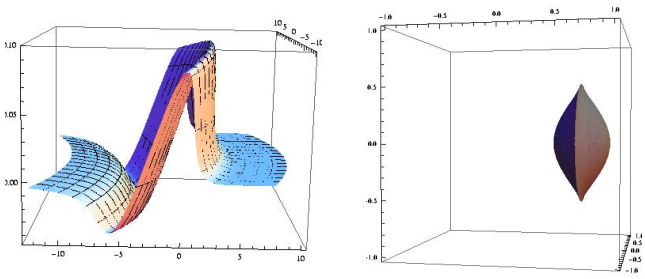
We remark that the $1+1$ dimensional version of dKP_n is the celebrated Riemann-Hopf equation $u_t + uu_x = 0$, the prototype model in the description of the gradient catastrophe (or wave breaking) of one dimensional waves. Therefore a natural question arises: do solutions of dKP_n break and, if so, is it possible to give an analytic description of such a multidimensional wave breaking?

It was observed long ago that the commutation of multidimensional vector fields can generate integrable nonlinear partial differential equations (PDEs) in arbitrary dimensions. Some of these equations are dispersionless (or quasi-classical) limits of integrable PDEs, having dKP_2 as prototype example, they arise in various problems of Mathematical Physics and are intensively studied in the recent literature.

We have recently developed the Inverse Spectral Transform (IST) for 1-parameter families of multidimensional vector fields, and used it to construct the formal solution of the Cauchy problem for distinguished examples of nonlinear PDEs of Mathematical Physics. This IST and its associated nonlinear Riemann-Hilbert Dressing scheme turn out to be efficient tools to study also other relevant properties of the solution space of the PDE under consideration: i) the characterization of a distinguished class of spectral data for which the associated nonlinear RH problem is linearized, corresponding to a class of implicit solutions of the PDE; ii) the construction of the longtime behaviour of the solutions of the Cauchy problem; iii) the possibility to establish whether or not the lack of dispersive terms in the nonlinear PDE causes the breaking of localized initial profiles and, if yes, to investigate in a surprisingly explicit way the analytic aspects of such a multidimensional wave breaking.

In this way it was possible to establish that localized initial data evolving according to dKP_2 generically break. This exact theory has been recently used to build a uniform approximation of the solution of the Cauchy problem for dKP_n, for small and localized initial data, showing that such initial data evolving according to dKP_n break, in the long time regime, if and only if $1 \leq n \leq 3$; i.e., in physical space. Such a wave breaking takes place, generically, in a point of the paraboloidal wave front, and the analytic aspects of it are given explicitly in terms of the small initial data.

The existence of a critical dimensionality above which small data do not break has a clear origin, since, in the model, two terms act in opposite way: the nonlinearity is responsible for the steepening of the profile, while the $n-1$ diffraction channels, represented by the transversal Laplacian, have an opposite effect; for $n = 1, 2, 3$ the nonlinearity prevails and wave breaking takes place (but at longer and longer time scales, as n increases), while, for $n \geq 4$, the number of transversal diffraction channels is enough to prevent such phenomenon, in the longtime regime.



(a) (b)

Figure 1: (a) A detail of the parabolic wave front of dKP_2 at breaking. (b) The compact region in 3D space in which the solution of dKP_3 is three valued, after breaking

We plan to investigate further such a theory and its applications, focusing, in particular, on the following topics. The mathematical aspects of the regularization of the multidimensional waves evolving according to dKP_n, for $n = 2, 3$, near breaking, using dispersion and/or dissipation. The rigorous aspects of the formalism. The construction of physically interesting explicit solutions. The applications of this theory to several physical contexts, like water waves, gas dynamics, plasma physics and general relativity.

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T22. Towards a theory of chaos explained as travel on Riemann surfaces

The fact that the distinction among integrable or non-integrable behaviors of a dynamical system is somehow connected with the analytic structure of the solutions of the model under consideration as functions of the independent variable "time" (considered as a complex variable) is by no means a novel notion. It goes back to classical work by Carl Jacobi, Henri Poincaré, Sophia Kowalevskaya, Paul Painlevé, and, in recent times, attracted the attention of Martin Kruskal and others. A simple-minded rendition of Kruskal's teachings on this subject can be described as follows: for an evolution to be integrable, it should be expressible, at least in principle, via formulas that are not excessively multivalued in terms of the dependent variable, entailing that, to the extent this evolution is expressible by analytic functions of the dependent variable (considered as a complex variable), it might possess branch points, but it should not feature an infinity of them that is dense in the complex plane of the independent variable. Many interesting results were obtained along this line of research, mainly by use only of numerical and local techniques (like the Painlevé analysis), which, albeit useful and widely applicable, provide no information on the global properties of the Riemann surfaces of the solutions (e.g. the number and location of the movable branch points and how the sheets of the Riemann surface are connected together at those branch points), a detailed analysis of which provides a much deeper understanding of the dynamics.

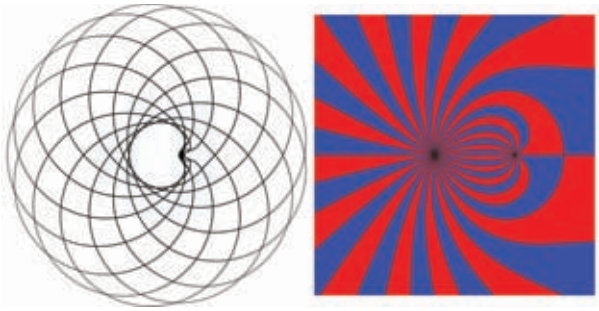

Figure 1: Example of locus of the roots (*left*) and branch-cut structure (*right*) of the algebraic equation that defines the Riemann surface associated to the solution of the 3-body model studied in [1] for a certain choice of the coupling constants and the initial data.

In the last few years people in our group, in collaboration with other researchers, have contributed to deepen the mechanism for the onset of irregular (chaotic) motions in a deterministic context by introducing a new dynamical system, interpretable as a 3-body problem in the (complex) plane, which is simple enough that a full description of the Riemann surface of its solution can be performed (via analytical, geometro-algebraic and combinatoric techniques), yet complicated enough to feature a rich behaviour, possibly including irregular or chaotic characteristics. It was shown in which sense the model displays sensitive dependence on the initial conditions and on the parameters, describing a mechanism to explain the transition from regular to irregular motions [1].

We have also studied the complexification of the one-dimensional Newtonian particle in a monomial potential, discussing cyclic motions on the associated Riemann surface, corresponding to a class of real and autonomous Newtonian dynamics in the plane. For small data, the cyclic time trajectories lead to isochronous dynamics. For bigger data the situation is quite complicated; computer experiments show that, for sufficiently small degree of the monomial, the motion is generically periodic with integer period, which depends in a quite sensitive way on the initial data. If the degree of the monomial is sufficiently high, computer experiments show essentially chaotic behaviour. We have suggested a possible theoretical explanation of these different behaviours. We have also introduced a one-parameter family of 2-dimensional mappings, describing the motion of the center of the circle, as a convenient representation of the cyclic dynamics; we call such mapping the center map. Computer experiments for the center map show a typical multi-fractal behaviour with periodicity islands [2]. Therefore the above complexification procedure generates dynamics amenable to analytic treatment and possessing a high degree of complexity.

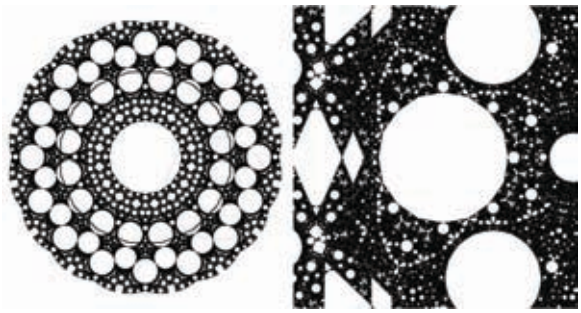

Figure 2: (*left*) Example of orbit generated by the center-map studied in [2]. (*right*) A magnification of the same orbit, showing the self-similarity of the geometrical structure.

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T23. Discrete integrable dynamical systems and Diophantine relations associated with certain polynomial classes

The main idea underlying the various research lines pursued under this heading originates from the following observation. If one knows a nonlinear dynamical system with an arbitrary number N of degrees of freedom that is isochronous — namely, that in an open region of its phase space features solutions all of which are completely periodic (i. e., periodic in all their degrees of freedom) with a fixed period (independent of the initial data, provided it falls within the isochrony region)—and if an equilibrium solution of this dynamical system can be explicitly found in the isochrony region, then standard linearization of the equations of motion of the system in the immediate neighborhood of this equilibrium configuration yields an $N \times N$ matrix whose eigenvalues must all be integer multiples of a common factor—because these eigenvalues yield the frequencies of the oscillations of the system in the infinitesimal neighborhood of its equilibrium, and if the system is isochronous, all these N frequencies must indeed be integer multiples of a common factor. So, by this roundabout way, one arrives at a Diophantine finding (i. e., an explicit matrix whose eigenvalues must all be integers)—a finding which may become a conjecture if one venture to guess the actual values of these N integers, or a theorem whenever such a conjecture can be proven.

This observation also opened a relatively vast area of research, because—contrary to what one might naively think—nonlinear isochronous dynamical systems are not rare, indeed there are techniques to manufacture a lot of them. For recent papers reporting results of this kind see [1,2,3]. The paper [3] is particularly remarkable inasmuch as it yielded new Diophantine properties related to the integrable hierarchy of nonlinear PDEs associated with the Korteweg-de Vries (KdV) equation, an item that has played a pivotal role in the major developments in theoretical and mathematical physics, and as well in several fields of pure mathematics, consequential to the discovery at the end of the 1960's of the integrable character of the KdV equation (the so-called "soliton revolution").

Moreover, to prove some of the conjectures arrived at in this manner, we pursued a research line leading to the identification of certain polynomials allowing Diophantine factorizations—including some polynomials belonging to the standard families of orthogonal polynomials classified according to the Askey scheme (for a recent instance of such results see [4]). And these developments have led to the identification of new discrete integrable systems [4], a finding whose ramifications are still under investigation. Indeed a new paper of this series, coauthored by the same group of authors (M. Bruschi, F. Calogero and R. Droghei), is in preparation.

Overall, the research line tersely outlined above seems susceptible of significant further developments, which we plan to pursue in the coming years. We also plan to promote the insertion of at least some of our findings in standard compilations of the properties of special functions, as was the case in the past for some analogous results: see section 15.823, entitled "Hermitian matrices and diophantine relations involving singular functions of rational angles due to Calogero and Perelomov", in the standard compilation of mathematical results originally due to I. S. Gradshteyn and I. M Rizhik ("Tables of integrals, series, and products", fifth edition, edited by Alan Jeffrey, Academic Press, 1980).

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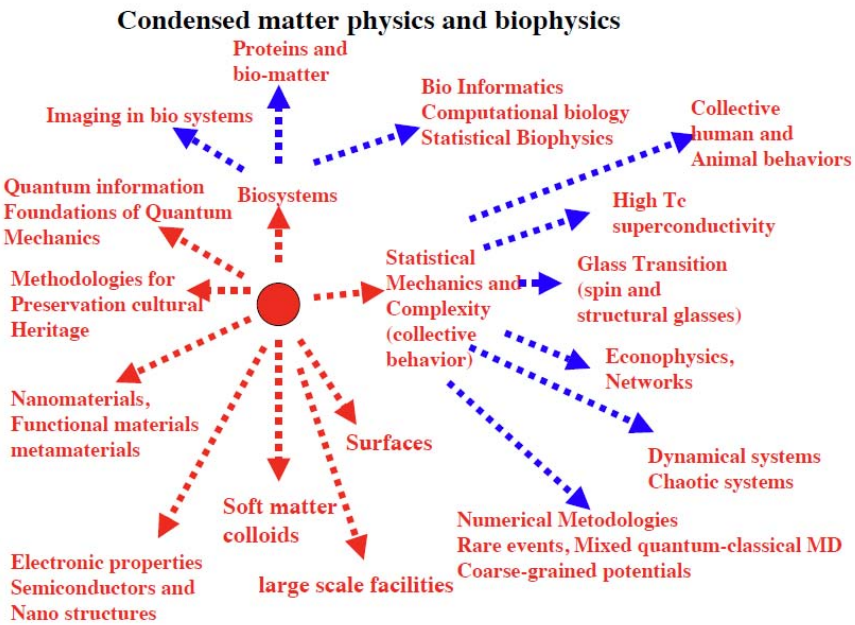
Condensed matter physics and biophysics

Condensed matter physics has a strong tradition in the Physics Department of *La Sapienza*. More than 50 scientists, with permanent positions (assistant, associate and full professors) and 30 affiliated researchers (mostly CNR staff) actively investigate different properties of hard, soft and bio matter, or export ideas developed in condensed matter to new frontiers. This group of scientist collaborates with about 20 post-docs and 25 Ph.D students enrolled in the Ph.D. school of the department.

Let me guide you, with the help of the map shown in Figure below, through the several research lines which are particularly active at the present time within the Physics Department.



One of the excellences of our Department is in statistical mechanics and physics of complex systems, a field which has developed from the ideas developed in the study of critical phenomena and self-similarty, back in the seventies. The science of complexity arises naturally from statistical mechanics after the fundamental change of paradigm with respect to the reductionist scientific vision stimulated by the critical phenomena studies. At the equilibrium point between order and disorder one can observe fluctuations at all scales and the system cannot be described any more with the usual formalism in which one tries to write simple equations for average quantities. From this conceptual grain many new concepts have developed which produced a revolution in our way of looking at nature and the offspring of these ideas are now blooming in the study of the most challenging open problems in statistical mechanic: scaling laws, renormalization group, fractal geometry, glassy and granular systems, complex liquids, colloids, high-T_c superconductivity and many others.

High T_c superconductivity is actively studied theoretically and experimentally (see C1,C2,C3,C4,C5,C6). Experimental studies focus on material aspects, on how it is possible to optimize physical parameters by changing external conditions as the pressure, temperature and magnetic field, in addition to the chemical pressure and atomic disorder to obtain new materials with possibly better superconducting function (C4) and on the anomalous transport properties which characterize high-T_c materials even in in their normal state (C5). Experimentalists also focus on the sub-THz, infrared and optical spectra of different oxide families, characterized by strong electron-electron and electron- phonon interaction to understand the exotic properties of these materials, which range from high-T_c superconductivity to the formation of charge density waves, from the appearance of pseudogaps at remarkably high T to Mott transitions (C6). Several theoretical groups work on new superconducting materials, with different approaches. Under investigation is the possibility that the superconductivity transition could share a Berezinsky-

Kosterlitz-Thouless (BKT) character, focusing on systems that are effectively low dimensional. To this category belong layered materials with weakly-coupled planes, like the high-temperature cuprate superconductors, as well as confined 2D structures, like thin films or conducting layers at the interface of artificial hetero-structures (C1). Under investigation is also the connection with "strong correlation" (C3). Indeed, superconductivity appears with highest critical temperatures in strongly correlated materials, and in particular by doping a Mott insulator, a state in which the carriers are localized by the mutual repulsive interactions. Such approach predicts a first-order transition between a superconductor and a anti-ferromagnet state as a function of pressure, and a bell-shaped superconducting region which reminds of the doping dependence of T_c in the copper oxides. A distinct, theoretical scheme is based on the idea that correlated materials are easily prone to charge instabilities. In this case the anomalous normal and superconducting properties naturally emerge from the abundance of soft charge fluctuations occurring when the system is close to the charge instability. Finally, another approach focuses on the common element of all exotic superconductors, the small value of the Fermi energy (or the Fermi velocities). From the point of view of the many body theory of superconductivity this situation requires a generalization which includes novel pairing channels beyond Migdal theorem.

Theoretical approaches are also applied to the study of quantum degeneracy in Fermi-Bose atomic mixtures, in the attempt to reach temperatures significantly smaller than the Fermi temperature to be able to observe the expected unconventional pairing mechanisms (C7).

A significant attention is devoted to the glass transition phenomenon. In the last years, interest has shifted from spin-glasses (after Parisi developed his replica-symmetry-breaking scheme for the infinite-range Ising spin glass) to structural and colloidal glasses, where disorder is self-generated by the system. Here the goal is to understand if there is an unconventional thermodynamic transition associated to the vanishing of the molecular mobility and how the temperature and pressure dependence of the dynamics can be properly described. Beside theoretical and numerical investigation of glass systems, interest is devoted to understanding peculiar phenomena taking place in disordered systems. One of these is the theoretical and experimental investigation of the nature of collective excitations in disordered solids, a topic reinvigorated by the discovery that disordered materials, such as glasses and liquids, support the propagation of sound waves in the Terahertz frequency region, made possible recently thanks to the development of the Inelastic X-ray Scattering (IXS) technique (C8) and the availability of specific beam lines at ESRF (Grenoble). Significant efforts are also made in the direction of understanding dynamic arrest with mechanism different from packing and the differences between gels and glasses (C9) and anomalous systems where dynamic arrest or crystallization take place on heating and/or decreasing packing (C10).

Statistical physics has proven to be a very fruitful framework to describe phenomena outside the realm of traditional physics. The last years have witnessed the attempt by physicists to study collective phenomena emerging from the interactions of individuals as elementary units in social structures. Our department is particularly active on a wide list of topics ranging from opinion, cultural and language dynamics (C11) to the dynamics of online social communities. In all these activities a crucial element is the information shared in specific groups and one is interested in understanding how this information emerges, spreads and gets shared, is organized and eventually retrieved. A similar knowledge transfer is taking place from Physics to Finance and Economics, a topic which, after the sub-prime crisis in the financial world, has attracted renewed interest. Indeed, standard risk analysis usually neglects concepts like collective behavior, contagion, network domino effect, coherent portfolios, lack of trust, liquidity crisis, and, in general psychological components in the traders behavior (C12). The research we develop is based on the introduction of suitable models with heterogeneous agents and a different perspective in which the interaction between agents (direct or indirect) is explicitly considered together with the idea that the system may become globally unstable in the sense of self-organized criticality.

Collective behavior is commonly found also in biology, occurring at several scales and levels of complexity. Animal groups - like insect swarms and bird flocks - are paradigmatic cases of

emergent self-organization. There is no leader to guide individuals towards the common patterns. Rather, collective behaviour arises spontaneously as a consequence of the local interactions between individuals, much as it happens in ordering phenomena in condensed matter systems. A crucial issue is therefore to understand how self-organization emerges in animal aggregations and how behavior rules at the individual level regulate collective efficiency and group function. Bird flocking is a striking example of collective animal behaviour which is currently under investigation in our Department (C13).

Statistical mechanics is also exploited to address fundamental biological problems in which the complexity of the living matter is relevant. Genes expressions, protein folding, metabolic pathways require understanding the connections and the interactions between a large number of components. For example, in a model system like the bacterium E.Coli, the estimated number of reactions composing the metabolic cycle is about 1100. Understanding the global organization of uxes at the cellular level, is thus fundamental both to predict responses to environmental perturbations, drugs, or gene knockouts, and to infer the critical epistatic interactions between metabolic genes (C14).

As a last example of offspring of statistical mechanics, we mention the ongoing research on dynamical chaotic systems (C15,C16,C17). Macroscopic systems are dynamical systems with a very large number of degrees of freedom and many characteristic times (e.g. application to climate and turbulence). In these cases, the usual indicators (Lyapunov exponents and Kolmogorov-Sinai entropy) are not very relevant. The innovative approach followed in Rome considers chaos a crucial requirement to develop a statistical approach to macroscopic dynamical systems (C16,C17). An application of stochastic processes to deep see convection processes is also currently investigated (C18).

Strongly connected to statistical mechanics is the numerical investigation (via molecular dynamics or Monte Carlo methods) of systems of different level of complexity, from the ab-inito quantum mechanics calculations, to atomistic studies of hard, soft and bio-matter, (including hydrated proteins (C19)), to coarse-grained methods (C20) for bridging the gap from the $\mathring{A}$-fs space-time scales to hydrodynamic behavior. Currently, we are working on a specific kind of mixed quantum-classical dynamics, the so-called non-adiabatic dynamics. In non-adiabatic situations, the coupling between nuclear (the bath) and electronic (quantum subsystem) motions in a molecular system, or the interactions with the environment, can induce transitions among the eigenstates of the electronic Hamiltonian that affects the (photo)chemistry and physics of non-adiabatic systems. Our work on developing efficient and rigorous MD algorithms for non-adiabatic simulations aims at controlling a number of interesting processes by understanding and modifying these transitions, for example via coupling to a control environment or via an appropriate pattern of excitations (C21). In the context of classical statistical mechanics, we are also active in the development of optimal methodologies for investigating rare events, i.e. events characterized by time-scales not accessible by brute force MD (e.g. chemical reactions, phase transformations, conformational changes related to the functionality of proteins), and the physics of systems out of equilibrium (C22). Rare events describe transitions over barriers higher than the thermal energy of the system, among metastable states of the free energy landscape and as such are characterized by time-scales much longer than those accessible by brute force MD. Chemical reactions, phase transformations, nucleation processes, and conformational changes related to the functionality of proteins are just a few examples of these events.

Next we move to the soft and bio matter studies. Here again, we build upon the developments which took place at the end of last century in the physics of simple and complex liquids and in the physics of disordered systems. Soft and bio matter have a twofold interest: one one side we need to understand the microscopic origin to the self-organization and the build up of structures at mesoscopic length scales. On the other side, we need to learn how to engineer nano and micro

sized particles to generate materials (and bio-materials) with controlled physical properties.

One of the model system investigated in Rome is made of interacting colloidal particles and oppositely charged polymers. These systems have recently attracted great interest, due to their relevance in a number of biological and technological processes, but even more to the fact that their dynamics and out-of-equilibrium properties offer unceasing challenges. These complexes show a rich and fascinating phenomenology yet poorly understood. Various novel core-particle aggregates have been prepared in Rome, by electrostatic self-assembly of polyelectrolytes (and nano particles) with oppositely charged lipid liposomes. The use of non-covalent forces provides an efficient method to position the polyelectrolyte chainin a well-defined supra-molecular architecture. In addition, it is possible to control the macroscopic properties of the assembly through an external environmental stimulus (C23,C24). We also investigate the interactions between biopolymers (proteins or nucleic acids) and self-assembled surfactants, a system which has raised increasing interest within the scientific community. Studies along these lines constitute an interdisciplinary approach of chemical/physical nature at the bio-molecular level. In addition these investigations contribute to important applications in biomedicine, as gene therapy. Our research focuses on a new class of self-assembled amphiphilic aggregates, called cat-anionic vesicles. The acronym cat-anionic defines surfactant aggregates formed by non-stoichiometric amounts of anionic and cationic surfactants coexisting with tiny amounts of simple electrolytes (C25).

We also investigate solid-supported lipid-films, considered as an attractive and useful model system for biological membranes. In particular, amphipathic lipid films on solid support allow the study of structural investigation of important biological model systems such as the vector like lipid membranes, in order to improve DNA transfection in non viral gene therapy and as a template for nanostructure construction (C26).

Structural properties of proteins are also carefully investigated with spectroscopic methods with the aim of connecting structural changes with the ability to catalyze specific chemical reactions or the relationship between structural properties of proteins of nutritional relevance, as examined by FT-IR spectroscopy, and nutrient utilization (C27). Using femtosecond stimulated Raman scattering spectroscopy (FSRS) we study the reaction of heme proteins with different biological functions (electron transfer , signaling, etc.). FSRS provides vibrational structural information with an unprecedented combination of temporal and spectral resolution, unconstrained by the Fourier uncertainty principle, i.e. in the < 100 fs time domain, unaccessible to conventional vibrational spectroscopy (C28). We also investigate via small angle X-ray scattering (SAXS), mass spectroscopy and light scattering techniques different proteins. In particular, we have recently investigated the protein ferritin , the main iron storage protein in living systems and τ-protein, one of the few proteins without a secondary structure. Ferritin is a stable complex forming an hollow sphere (apoferritin) filled with a Fe(II) oxide core and it is important to study since the ferritin core composition differs between pathological and physiological conditions. τ-protein is an interesting protein in which fluctuations are expected to be fast and to control the biological function (C29).

Soft and bio matter is also investigated to address fundamental problems in condensed matter. Indeed, colloidal suspensions have unambiguous advantages with respect to their atomic counterparts. Characteristic space and time scales are much larger, allowing for experimental studies in the light scattering regime and for a better time resolution. The size of the particles allows for direct observation with confocal microscopy techniques, down to the level of single-particle resolution. In addition, particle-particle interactions can be tuned by changing the solution conditions or by additives, as well as by synthesis of functionalized colloids. Colloidal suspensions, despite being very complex in nature and number of components, can often be well described theoretically via simple effective potentials. A significant effort is devoted to the investigation of the phase diagram and self-assembly abilities of patchy colloidal particles, in a combined theoretical, numerical and experimental study (C9,C20).

One powerful technique to investigate the motion and the interactions between colloidal particles

(or macromolecules attached to them) is offered by the so-called optical tweezers. Optical forces are indeed ideally suited to manipulate matter at the mesoscale which is characterised by length scales ranging from ten nanometers to hundreds of micrometers, femtonewton to nanonewton forces, and time scales from the microsecond on. In Rome we have built a set-up to perform holographic optical trapping (HOT), focusing an engineered wavefront into a tiny hologram image made of bright light spots in 3D, each spot serving as an independent point trap, providing contactless micromanipulation technique with many body, dynamic, 3D capabilities (C30).

A large effort is also devoted to investigation of electronic properties of novel materials, mostly semiconductor and organometallic compounds. Indeed, the synthesis of nanostructured semiconductors is incessantly boosting the number of opportunities in the field of electronics and photonics, as well as in the investigation of fundamental quantum phenomena in top-bench experiments. The control and modification of the physical properties of semiconductor heterostructures at nanometre scale lengths is thus crucial. In Rome, we presently focus on magneto-photoluminescence (m-PL) experiments, a powerful method to investigate fundamental properties of novel semiconductor materials such as Ga(As,N) (an example of a dilute nitrides), which feature surprising physical properties and qualitatively new alloy phenomena, e.g., a giant negative bowing of the band gap energy and a large deformation of the conduction band structure (C31). Moreover, we discovered that hydrogen irradiation of GaAsN completely neutralizes the effect of N and transforms GaAsN into virtual GaAs, with relevant changes in the energy gap and electron effective mass, among others. This has opened a novel way to the defect engineering of dilute nitrides, where it is possible to realize nanostructures on demand (C32).

Recently, organic molecules have been fruitfully exploited to develop devices with specific functionalities. Engineering of these devices requires an atomic level understanding of the parameters that control the structure and the function of these low-dimensional molecular architectures. A crucial issue for these organic-inorganic systems is the achievement of long-range order in exotic configurations (two-dimensional arrays, one-dimensional wires) such as to allow formation of exemplary hybrid structures with peculiar electronic properties associated to the reduced dimensions. We investigate organometallic molecules (like pentacene or metal-phthalocyanines, MPc) assembled on suitable crystalline surfaces in 1D chains or 2D ordered phases, with the final goal to design, control and optimize the electronic, transport and magnetic properties. In particular, a model to describe the interface dipole, the electronic state diagram, the bandwidth and the electronic state dispersion for the organic heterojunctions and organic-inorganic interfaces has been experimentally and theoretically proved (C33,C34). Furthermore, MPc formed by a magnetic central atoms are being used as chemical "cage" for anchoring the magnetic ion to a metal surface, such as the spin-state of the central atom could couple with the underlying magnetic or non magnetic metal.

Materials are not only studied under ambient conditions, but also under extreme perturbations. The development of modern pressure cells had made possible to investigate structural and electronic properties of materials under high pressure. One interesting case is offered by the possibility to modulate the electron-phonon coupling via modification of the lattice parameters, with the aim of investigating the physics of strongly correlated systems, which as we have discussed at the beginning represents one of the most challenging tasks of condensed-matter research (C35). Another case is offered by low-dimensional systems where the external variables (like temperature, magnetic field, and chemical and applied pressure) can affect the dimensionality of the interacting electron gas, and thus the intrinsic electronic properties, as well as the interplay among different order parameters, giving rise to rich phase diagrams (C36).

In many scientific fields considerable efforts are devoted to engeneering new materials with specific permittivity ϵ_{eff} and magnetic permeability μ_{eff}, to be able to control different properties of the electromagnetic radiation. A recent approach is based on artificial materials structures (metamaterials, MM) constituted of a macroscopic (periodic or aperiodic) arrays of single elements:

the size and the spacing between elements are much smaller than the wavelength of the e.m. field incident on them. By appropriate choice of materials and designs, is now possibile to control the behavior of ϵ_{eff} and μ_{eff}therefore to tailor the refractive index n of the MM. In this way, beside artificial magnetism, negative permeability and permittivity, a negative refractive index can be also obtained.

Activity is also ongoing on the integration of spintronics and conventional semiconductor technology, opening the way to wide-range applications. The discovery and exploitation of giant magnetoresistance in magnetic multilayers was the first remarkable achievement in spin electronics (spintronics). The second breakthrough was the observation of spin injection in structures containing layers of ferro-magnetic metal (FM) separated by a spacer of non-magnetic semiconductor (NS). Realization of both phenomena in the same FM/NS structures is currently investigated (C37).

The possibility of trapping light in disordered materials is expected to foster new applications in the field of energy and medicine, as well as novel fundamental discoveries in applied mathematics and the science of complex systems. A significant effort is devoted to the realization of advanced parallel codes for the analysis of light propagation in disordered materials characterized by various wavelengths, ranging from the Angstrom regime to the visible, Terahertz and the acoustic scale (C38).

A significant effort is also directed to the investigation of nanomaterials for alternative energies. Specifically we investigate hydrogen storage, a nodal point for the development of a hydrogen economy, attempting to understand the basic mechanisms of the hydrogenation/dehydrogenation process and the changes induced by nano-confinement, via anelastic spectroscopy and differential scanning calorimetry (C39).

We also focus on advanced NMR application to imaging in material, tissues and humans with a wide variety of methods. Molecular imaging offers the possibility of non-invasive visualization in space and time of cellular processes at molecular or genetic level of function. Specifically, we implement Diffusion Tensor (DTI) and Diffusion-weighted (DWI) imaging NMR techniques to provide information on biophysical properties of tissues which inuence the diffusion of water molecules (C40,C41).

Being located in Rome, it is inevitable to dedicate attention to the preservation of our cultural heritage. Physics can help significantly the development of non-invasive methodologies for preservation, characterization and diagnostics. Methods dealing with the study of works of art must be effective in producing information on a huge variety of materials (wood, ceramic, paper, resin, pigments, stones, textiles, etc.), must be highly specific owing to the variability of volume and shape of hand-works and must comply with the severe conditions that guarantee their preservation. Therefore, standard spectroscopic methods need to be properly modulated in order to fit such materials, while their application area must be enlarged to include structures and models which are unusual for physicists (C42).

Last but not least, we briefly recall the significant ongoing activity in quantum information (C43,C44) and computation. Quantum information is a new scientific field with origins in the early 90s, introduced by the merging of classical information and quantum physics. It is multidisciplinary by nature, with scientists coming from diverse areas in both theoretical and experimental physics (atomic physics, quantum optics and laser physics, condensed matter, etc.) and from other disciplines such as computer science, mathematics, material science and engineering. It has known a huge and rapid growth in the last years, both on the theoretical and the experimental side and has the potential to revolutionize many areas of science and technology. The main goal is to understand the quantum nature of information and to learn how to formulate manipulate, and process it using physical systems that operate on quantum mechanical principles, more precisely on the

control and manipulation of individual quantum degrees of freedom. On this perspective completely new schemes of information transfer and processing, enabling new forms of communication and enhancing the computational power, are under development (C43). Quantum optics, beside providing the basis for quantum computation, is also becoming a powerful tool for experiments on foundation of quantum mechanics. Experiments on multiple qubit (i.e., multiple quantum two-level systems) generated via nonlinear optical process, performed in Rome, are contributing to demonstrate genuine entanglement and persistency of entanglement against the loss of qubits, deeply testing the Bell inequality (C45).

The experimental research developed by members of the Physics Department is carried out not only in the laboratories located in Rome, but also in several international facilities (Grenoble, Trieste, Frascati). Very often, our scientists have been members of the groups which have designed and realized the beam lines of these facilities. For example, we have recently investigated the possibility to produce coherent THz radiation from our beamline SISSI (Synchrotron Source for Spectroscopy and Imaging) at the third generaton machine ELETTRA (Trieste) (C46). This range of the electromagnetic spectrum, which is roughly located between the infrared and the microwave region (0.1-20 THz), has been indeed scarcely investigated so far mainly because of the lack of intense and stable THz sources. THz radiation will disclose the ps and sub-ps scale dynamics of collective modes in superconductors and in exotic electronic materials, the ps-scale rearrangement dynamics in the secondary structure of proteins and biological macromolecules, early cancer diagnosis, and security applications.

Francesco Sciortino

C1. Superconductivity in low-dimensional materials

Large part of the experimental and theoretical research on new superconducting (SC) materials focuses nowadays on systems that are effectively low dimensional. To this category belong layered materials with weakly-coupled planes, like the high-temperature cuprate superconductors, as well as confined 2D structures, like thin films or conducting layers at the interface of artificial heterostructures. Besides the low dimensionality, a common characteristic of many of these systems is the low superfluid density, i.e. the energy scale which controls the phase fluctuations of the SC order parameter. Under these conditions, the SC transition could share a Berezinsky-Kosterlitz-Thouless (BKT) character, where vortex excitations play a crucial role.

The BKT transition has in principle very specific signatures, both below and above the SC transition temperature T_{BKT}. For example the superfluid density J_s vanishes with an "universal" jump approaching T_{BKT} from below, while the SC correlation length $\xi(T)$, that is probed by several quantities like paraconductivity, diamagnetism or Nerst effect, should diverge exponentially as $T \to T_{BKT}$ from above. This form would be in marked contrast with the typical power-law behavior of $\xi(T)$ due to Ginzburg-Landau (GL) SC fluctuations, where modulus and phase fluctuate simultaneously.

The observation of clear signatures of BKT physics in these new systems is still debated. In cuprates contradicting conclusions emerge from different probes: while Nerst effect and diamagnetism point towards a relevance of BKT physics, no clear signature of the would be universal jump of the superfluid density has been reported. Moreover paraconductivity in underdoped compounds provides evidence of a more traditional Aslamazov-Larkin GL-behavior [1]. This scenario calls for a deepr theoretical investigation of the additional effects that can affect the "universal" character of the BKT transition, mainly related to the quasi-2D structure and/or disorder. We have investigated these issues [2-3] using the sine-Gordon description of the BKT transition, which allows us to go beyond standard results derived in the XY model. First we discussed the role played by the energy μ of the vortex core in a weakly-coupled layered system. Here two ratios are relevant: μ/J_s, which fixes the temperature where vortices would like to unbind, driving the J_s to zero, and $J_\perp/J_s$, where $J_\perp$ is the interlayer Josephson coupling, which tends to keep J_s finite. While in the XY model μ/J_s has a fixed value, we showed that in the more general case the behavior of the system strongly depend on the ratio μ/J_s, the increasing of which effectively enhances $J_\perp/J_s$ [2]. As a consequence, even though the transition can ultimatively have a BKT character (i.e. vortex excitations are relevant) the jump of the superfluid-density J_s is reduced and smoothed, and does not occur any more at the "universal" temperature. A similar 'non-universal' μ/J_s dependence of the BKT transition was found in the analysis of the magnetic-field effect [3]. Indeed, we showed that the standard linear scaling of the field-induced diamagnetism $M \simeq -\xi^2(T)H$ above T_c is restricted to a range of fields that decreases as μ/J_s increases, accounting thus for the persistent non-linear effects reported in experiments in high-T_c superconductors.

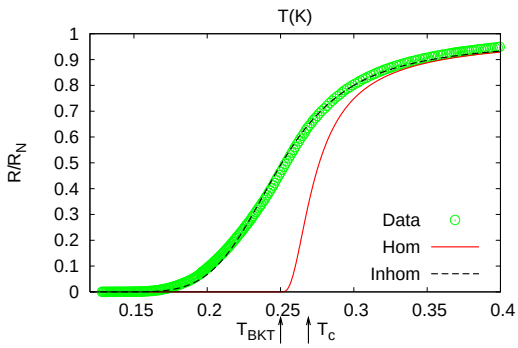


Figure 1: Resistivity in the presence of GL+BKT fluctuations, in the absence (Hom) and in the presence (Inhom) of inhomoegenity, compared to experimental data in SC heterostructures. [4]

Interestingly, a revised approach to the BKT transition can be necessary also in the case of low-temperature superconductivity, as it is shown by our recent analysis of 2D superconducting heterostructures [4]. Our work shows that the contribution of SC BKT fluctuations to the conductivity cannot be computed neglecting the prominent role of the intrinsic sample inhomogeneity (see Fig. 1). This result could give new insight also on the nature of the superconductor-insulator transition, that in these systems can be induced in field-effect devices, which represent a promising candidate for future technological applications.

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C2. Strongly Correlated Superconductivity

The origin of high-temperature superconductivity is one of the most elusive topics in modern solid-state physics. Superconductivity appears with highest critical temperatures in "strongly correlated" materials, and in particular by doping a Mott insulator, a state in which the carriers are localized by the mutual repulsive interactions. This is particularly surprising because superconductivity is associated to the formation of a coherent state of "Cooper pairs" in which the fermions are paired by an effective attractive interaction.

So, how can pairing be favoured by strong repulsion? The continuous advances of material science and experimental research are helping us to answer the question, through the design of new superconducting materials and an unprecedented accuracy in the investigation of their physics. These studies have shown that copper oxides are the most spectacular members of a wider class of strongly correlated superconductors including heavy fermion and organic molecular compounds.

During the last few years we have shown that trivalent fulleride superconductors of generic formula A_3C_{60} (A being an alkali-metal atom) belong to the same family [1], despite the fact that the pairing mechanism is the conventional electron-phonon coupling and the pair wave function has an isotropic s-wave symmetry.

In particular we have shown that a phononic pairing and correlations are not incompatible in fullerides, and indeed they can cooperate to provide high critical temperatures. The key observation is that phononic pairing of fullerides involves orbital and spin degrees of freedom, which are still active when charge fluctuations are frozen by the strong correlations and the system is approaching the Mott insulating state. As a consequence, an unrenormalized attraction is effective between heavy quasiparticles leading to an enhancement of superconductivity (with respect to a system with the same attraction and no repulsion).

Our approach predicted a first-order transition between an s-wave superconductor and an antiferromagnet as a function of pressure [1], and a bell-shaped superconducting region which reminds of the doping dependence of T_c in the copper oxides. These effects have been recently experimentally observed in a new expanded fulleride, Cs_3C_{60} with A15 structure, providing a crucial support to our theory. Further predictions of our approach include a superconducting transition which is associated to a gain of kinetic energy (as opposed to the standard BCS state, which is stabilized by potential energy gain) and a pseudogapped normal state [2].

Besides the remarkable success in describing the physics of expanded fullerides, this "Strongly correlated superconductivity" scenario that we briefly described has a more general validity. We expect indeed that different pairing mechanisms that involve spin or orbital degrees of freedom can coexist and even be favoured by strong repulsion. This is for example the case of superexchange interactions in the cuprates.

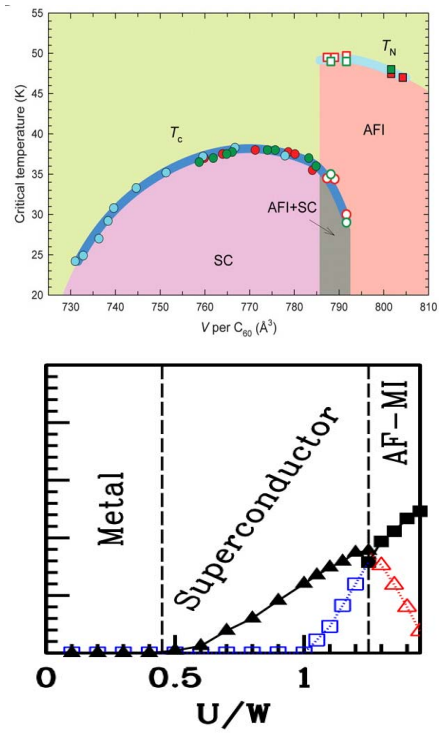

Figure 1: Theoretical and experimental phase diagram for Cs_3C_{60}

The surprising result that phonon-driven superconductivity can be favoured by repulsion depends crucially on the symmetry of the electron-phonon interaction. On the other hand in a model in which both repulsion and attraction are associated to the charge degrees of freedom [3,4] the two terms are competitive. In this case we have demonstrated that electron-phonon interaction is strongly reduced in correlated states, even if antiferromagnetic correlations revive its effect. Generically the depression is stronger at large transferred momentum than at small momentum. Interestingly, while phonon effects are reduced in the low-energy properties associated to quasiparticle motion, they are still present in the high-energy physics.

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C3. Charge inhomogeneities and criticality in cuprate superconductors

Strong correlations have the marked tendency to destabilize the metallic state. The formation of a Mott insulator is a "classical" case, but the breakdown of the metallic phase may also lead to superconductivity, competing phases, and inhomogeneities. Near these instabilities the metallic state can acquire an anomalous behavior and violate the standard Landau paradigm of Fermi liquids. Also superconductivity can be realized in unusual forms violating the standard BCS scheme. It is therefore of great interest to study strongly correlated systems in the proximity of their instabilities. This is the main framework of our investigation of new paradigms of the normal and superconducting states. This research regards fundamental concepts in solid-state physics, but it is also relevant for the understanding of physical systems of applicative interest like magnetic materials, spintronics, superconductivity, nano- and mesoscopic systems.

Since many years our group realized that strongly correlated systems are often prone to phase separation, although this may be prevented by Coulombic interactions. This is the so-called frustrated phase separation (FPS) giving rise to the general phenomenon of mesoscopic-, micro-, or nano-phase separation, which is by now a general chapter of condensed matter physics as it occurrs in many systems ranging from charged colloidal to two-dimensional electron gas, to ruthenates, manganites thin films, and high temperature superconductors (HTSC). In this last case FPS provides a mechanism of how attraction for pair formation can be generated by repulsive correlations. Recently we classified the transition to frustrated states in two universality classes [1] corresponding to the anomalies often found in a variety of strongly correlated electronic models: short range compressibility negative in a finite interval of density or delta like divergent due to the free energy crossing of two homogeneous phases. In this last case in 2D the system always breaks into domains in a narrow range of densities, no matter how big the Coulombic frustration is. For the case of negative compressibility, shown by our group to be relevant for the cuprates, we have provided [2] the phase diagram in three dimension in the density- frustration plane with transitions from the homogeneous phases to the different morphologies of clusters (from a bcc crystal of droplets, to a triangular lattice of rods, to a layered structure) (see Fig. 1). Inclusion of a strong anisotropy allows for second- and first-order transition lines joined by a tricritical point and for the discussion of the evolution from a sinusoidal charge density wave modulation to anharmonic stripes. These topics are strictly related to the physics of HTSC, according to our proposal that these systems are on the verge of a charge-ordering (CO) instability due to FPS. Although CO may not be fully realized because of low dimensionality, disorder, and Cooper-pair formation, there is a tendency to perform a second-order transition to a CO state with a transition line T_{CO} ending around optimal doping

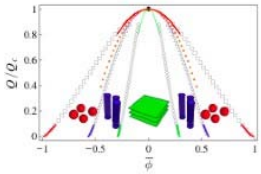

Figure 1: Schematic phase diagram of FPS in 3D isotropic systems (after Ref.2).

(for which the superconducting T_c is the highest) into a quantum critical point (QCP) at zero temperature (see Fig.2). Near this QCP the collective charge fluctuations

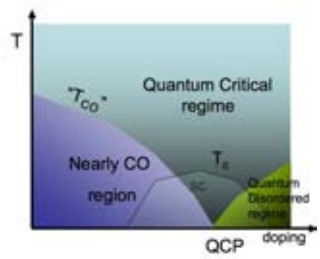

Figure 2: Schematic phase diagram of the HTSC focusing on the different CO regions and the CO-QCP

have an intrisically dynamic character and with their low energetic cost they provide an effective scattering mechanism for the metal quasiparticles possibly also leading to superconducting pairing. This "uncomplete criticality" makes it available low-energy quasi-critical fluctuations over extended regions of the phase diagram, whose effect on optical conductivity and Raman scattering[3], angle-resolved photoemission spectroscopy (ARPES) and STM [4] have been investigated. This analysis of spectroscopic signatures of the low-energy quasi-critical charge fluctuations has allowed to interpret several peculiar features of the spectra in HTSC and to identify the specific momentum and energy dependence of the collective excitations in these systems. More recently the dynamical character of the CO fluctuations has been exploited to account for the rather elusive character of CO in these materials: dynamic CO can substantially affect the ARPES and STM spectra at finite energy showing the 1D stripe self-organization, while leaving untouched the states near the Fermi level.

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C4. Phase separation and spectroscopy of inhomogeneous and correlated functional materials

Development of new materials with functional properties require knowledge of the physical parameters that control the structure-function relationship in the quantum matter. The first step is to identify these fundamental parameters, optimize them by controlling atomic and electronic properties exploiting advanced physical methods. An effective experimental approach is based on manipulation and control of phase separation in lamellar materials for developing new systems with desired application oriented quantum function. The approach is to bring the physical system in a fragile metastabile state, that could be characterized by an electronic topological transition of the Fermi surface, and manipulate the phase separation and self-organization at a nano-scale, determining the physical parameters and optimize them through changing external conditions, as the chemical pressure, charge density, magnetic field and temperature. The approach, combined with scattering and spectroscopic tools, provides key features on the structural-function relation, taking a step forward in designing new systems with desired functions for the future technology.

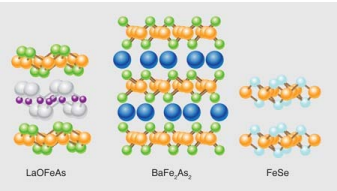

Figure 1: Structure of Fe-based superconductors with electronically active layers and the spacer blocks.

Mesoscopic phase separation and self-organization are common to the functional materials. The superstripes group on the functional materials is active in the field of heterogeneous materials with competing electronic degerees of freedom that control the basic functional properties. The complexity due to competing phases at the atomic scale drives the system to get electronically self-organized in textured states. A particular kind of self-organization in the superconducting systems is the so-called superstripes. This materials architecture show high T_c superconductivity in which the chemical potential is tuned near an ETT where the Fermi surface topology undergoes dimensionality change. In these conditions, the physical system is in an electronically/atomically fragile and one can manipulate its physical parameters by changing external conditions as the pressure, temperature and magnetic field, in addition to the chemical pressure and atomic disorder. Consequently, it is possible to optimize them to obtain new materials with possibly better superconducting function.

We have widely investigated the highly correlated transition metal oxides (TMOs) with nanoscale charge and lattice heterogeneities. Among these are the materials showing high T_c superconductivity, colossal magneto resistance (CMR), metal insulator transition and ferroelectricity. In addition to the TMOs, the highly correlated 4f systems also have been focus of spectroscopic studies to understand the underlying physics. Since the discovery of the Fe-based superconducting materials, the group has looked into their atomic scale structure, addressing the similarities with the copper oxide superconductors, not only from structural topology point of view but also for the mesoscopic inhomogeneties, in which the chemical pressure and the atomic scale disorder are found to be key ingredients. The group has routine excess to the most advanced international synchrotron radiation facilities for the characterization by scattering and spectroscopic methods. The in-house UHV facility permits to use photoemission method, in addition to permitting an epitaxial growth. The non-contact complex conductivity measurements down to He3 and an AFM/STM system further adds to the key facilities.

In the field, the group has organized a series of conferences with the specific topic, Stripes and High T_c Superconductivity. The group has also been part of recently concluded FP6-STREP EU project on the Controlling Mesoscopic Phase Separation.

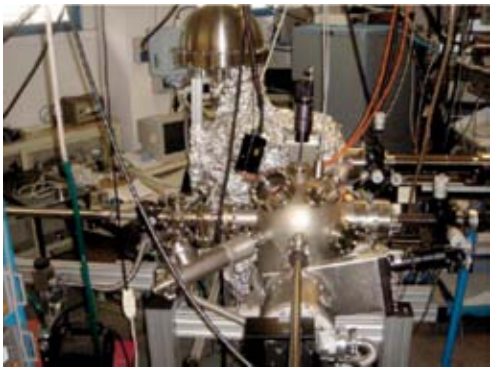

Figure 2: UHV system with MBE and photoemission spectroscopy chambers.

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http://superstripes.com/

C5. Phenomenology of transport properties in matter

Transport properties are among the most relevant properties for the study and characterization of matter. They may reveal fundamental informations on the electronic state in solids (such as bandwidth, mobility, localization effects) or on the mobility of particles in fluids.

Aimed to the study of transport phenomena under different conditions, our group has developed several experimental setups which allow us to measure electrical transport of different materials under a very wide range of external parameters: temperature (4.2 to 300 K and above), magnetic fields (up to 16 T), frequency (dc, rf and microwaves up to 65 GHz). We also developed *ad hoc* setups to study the resistivity tensor in anisotropic materials and microwave resistivity over a very wide, continuous spectrum.

During the last three years, our group has been using the measured transport properties to study the dynamical behaviour of several materials under different physical conditions. The research has been mainly devoted to the study of superconductors (both in the normal and in the superconducting state), while recently the attention has been also focused on other materials (conducting polymers, complex liquids).

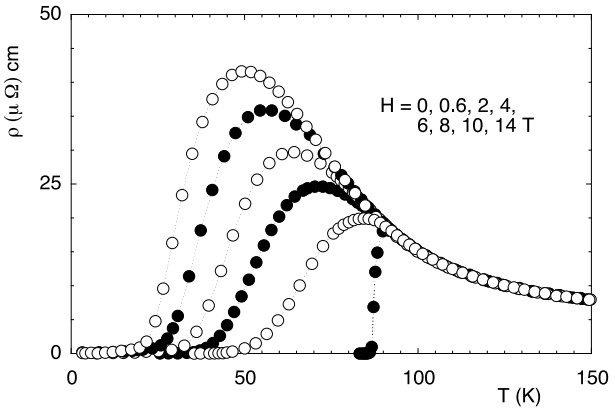

Figure 1: c-axis resistivity of HTSC as a function of temperature at different magnetic fields.

For what concerns superconductors, the research has been focused on the anomalous transport properties of High temperature superconductors (HTCS) even in their normal state (i.e. above T_c). The behaviour of resistivity as a function of temperature reveal several uncommon features, which are not fully explained by current theories. Some years ago we proposed a model for the description of the conductivity in HTCS in their normal state based on the role of internal barriers. In the last years, we exploited and extended this model to include other aspects of the measured properties of superconductors: charge confinement above T_c [1,2], nonlinearity (both above and below T_c) [4], to end up with the common interpretation of superfluid (below T_c) and pair formation (above T_c) within a single phenomenological frame. Parallel to this study, we studied the specific case of MgB_2 and in particular its characteristic double band. Using the measurements at microwave frequencies, we have been able to identify the contribution of each band and the contribution of thermal fluctuations to the obesrved resistivity below T_c [3].

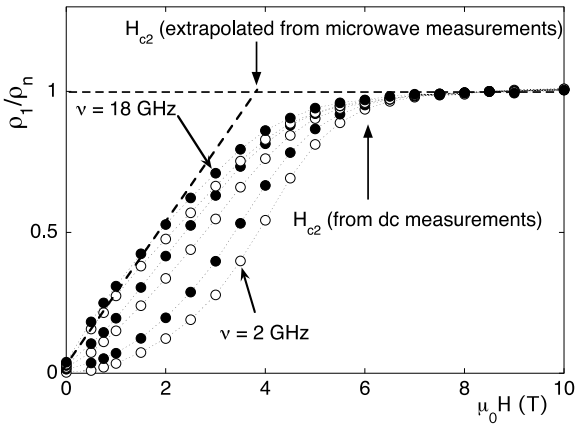

Figure 2: Microwave resistivity of MgB_2 as a function of magnetic field at T=15K. The difference between H_{c2} as determined by dc measurements and microwave measurements is explained in terms of thermal fluctuations.

Conducting polymers films has been studied both at low frequency (d.c.) and at microwave frequencies. The growth of these films is not as reproducible as in the case of common solids. A reliable study can thus be made only by measuring large sets of samples, in order to catch the mean behaviours. To this end, we developed a fast and reliable method to measure the conductivity of these samples. The combined structural and electrical characterization allowed us to understand several relevant aspects of the growing mechanism and the relevance of microscopic and mesoscopic scale transport (article submitted to Appl. Phys. A)

The study of complex liquids is still in a "work in progress" phase. We realized a cell for the measurement of the complex permittivity of liquid samples up to 40 GHz. After a relatively long setup procedure, a relevant data set has been collected (elaboration is in progress).

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https://server2.phys.uniroma1.it/doc/sarti/g20-group.html

C6. Sub-Terahertz and Infrared studies of strongly correlated oxides

In the last two years we have studied the sub-THz, infrared and optical spectra of different oxide families, characterized by strong electron-electron and electron-phonon interaction. Those studies were aimed at further investigating the exotic properties of these materials, which range from high-T_c superconductivity to the formation of charge density waves, from the appearance of pseudogaps at remarkably high T to Mott transitions.

In the cuprates we have measured the reflectivity of a number of single crystals belonging to the BSLCO family, in order to understand the mechanism of the insulator-to-metal transition. We have found that this this occurs when the Drude quasi-particle peak turns into a band at finite frequencies, which opens a gap in the density of states of just a few tens of meV [1]. This band has been identified as polaronic in nature, namely due to the charges undergoing weak localization due to a moderate electron-phonon coupling. This result confirms the importance of this interaction in the cuprates, at variance with several theoretical approaches where it is neglected.

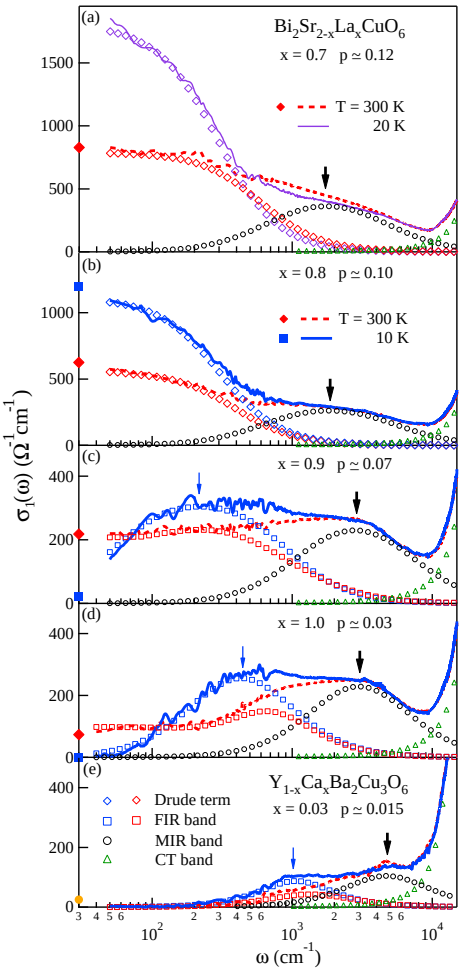

Figure 1: The metal-to-insulator transition induced in a superconductor by decreasing doping (from top to bottom) [1], as observed in the real part of the optical conductivity at two temperatures. The transition occurs through the change of the Drude peak (violet symbols) into a polaronic band peaked at finite frequency (blue symbols). A mid-infrared band, nearly insensitive to the transition is also detected (grey symbols). It is probably of magnetic origin.

In the newly discovered Fe-As pnictides, both the infrared and Raman phonon spectra of SmFeAsO have been determined [2]. Also the competition between superconductivity and spin-density wave at low doping has been approached by detecting infrared spectra vs. doping.

An extensive study of manganites with commensurate charge order has been performed in the sub-Terahertz spectral region [3] by using the coherent synchrotron radiation emitted by the storage ring BESSY-2 when working in the so-called α-mode. We have thus first revealed the collective modes of a charge density wave (CDW) in these materials. The collapse of the CDW induced by pressure has been observed by illuminating a single crystal of $Nd_{0.5}Sr_{0.5}MnO_3$, pressurized in a diamond anvil cell, with the far-infrared radiation of SPRING-8 (Japan).

We have also studied the Magnéli phases V_nO_{2n+1}, to understand the role played by strong electron-electron correlations in their transport and optical properties. In particular, the whole phase diagram of V_2O_3 has been probed in the infrared, and the opening of a pseudogap has been observed above 425 K. This loss of coherence has been explained by calculations taking into account the lattice expansion in a strongly correlated system [4].

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C7. Sympathetic cooling of Fermi-Bose atomic mixtures

Degenerate Fermi gases were first produced in 1999, and more recently Fermi superfluid behaviour has been conclusively evidenced through the generation of vortices and the onset of critical velocities in degenerate samples of ^{6}Li. Weakly interacting Fermi gases are difficult to bring to quantum degeneracy mainly due to fundamental obstacles in adapting cooling techniques successfully used for bosonic species. In particular, the Pauli principle inhibits efficient evaporative cooling among identical fermions as they reach degeneracy. This issue has been circumvented by developing two cooling techniques, namely mutual evaporative cooling of fermions prepared in two different states and sympathetic cooling with a Bose species.

In the former case, a selective removal of the most energetic fermions in both the hyperfine states is performed. Provided that the initial number of atoms in each state is roughly the same, efficient dual evaporative cooling can be performed throughout the entire process. Limits to the minimum reachable absolute temperature using dual evaporative cooling have been addressed. One has $T \gtrsim \mu/k_B$, where μ is the chemical potential of the Fermi gas. Moreover, the number of available atoms N_f progressively decreases over time with a corresponding drop in the Fermi temperature T_F proportional to $N_f^{1/3}$. The resulting gain in terms of a lower T/T_F degeneracy ratio is marginal, and the smaller clouds obtained at the end of the evaporative cooling are detrimental to detailed experimental investigations requiring a large number of atoms. In the case of sympathetic cooling through a Bose gas, the number of fermions is instead kept nearly constant and the cooling efficiency depends on the optimization of Fermi and Bose collisional properties, heat capacities, and, in the case of inhomogeneous samples, their spatial overlap.

To date, the smallest Fermi degeneracy achieved with both cooling techniques is in the $T/T_\mathrm{F} \geq 5 \times 10^{-2}$ range. This limitation has not precluded the study of temperature-independent features of degenerate Fermi gases, such as quantum phase transitions related to unbalanced spin populations or the effect of Fermi impurities in the coherence properties of a Bose gas. However, the study of more conventional phase transitions requires the achievement of degeneracy factors $T/T_F \simeq 10^{-3}$ or lower. Unconventional pairing mechanisms that are unstable at higher T/T_F could then be observed, and the phase diagram of Fermi atoms in the degenerate regime could be mapped in a wider range of parameter space.

Considering the novel physical insights that deeper Fermi degenerate gases and Fermi-Bose mixtures may provide, it is relevant to discuss the limitations to reaching the lowest T/T_F in realistic settings available by means of sympathetic cooling, and ways to overcome them. In [1] we have discussed two different techniques to overcome the apparent $T/T_F \simeq 10^{-2}$ limit observed so far, based on optimized heat capacity matching with species-selective traps or with lower dimensionality traps. The dynamics of evaporative cooling trajectories is analyzed in the specific case of bichromatic optical dipole traps also taking into account the effect of partial spatial overlap between the Fermi gas and the thermal component of the Bose gas. We show that large trapping frequency ratios between the Fermi and the Bose species allow for the achievement of a deeper Fermi degeneracy, confirming in a thermodynamic setting earlier arguments based on more restrictive assumptions. When the effect of partial overlap is taken into account, optimal sympathetic cooling of the Fermi species may be achieved by properly tuning the relative trapping strength of the two species in a time-dependent fashion. Alternatively, the dimensionality of the trap in the final stage of cooling can be changed by increasing the confinement strength, a technique that may be extended to Fermi-Bose degenerate mixtures in optical lattices.

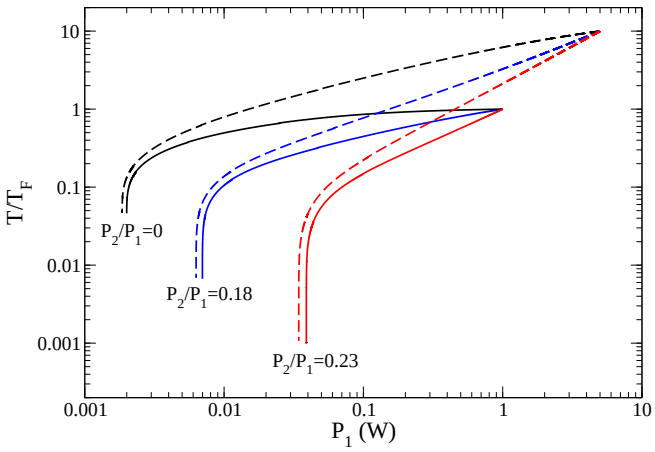

Figure 1: Theoretically obtainable degeneracy factor T/T_F versus the confining laser power P_1 during sympathetic forced evaporative cooling. The system is a mixture with N_f atoms of ^{6}Li and N_b atoms of ^{87}Rb trapped in a bichromatic optical dipole trap shaped by two lasers of power P_1 and P_2 at the wavelengths of $\lambda_1 = 1064$ nm and $\lambda_2 = 740$ nm for the ^{6}Li-^{87}Rb mixture. Two sets of curves are shown for different initial conditions and for different values of the ratio P_2/P_1. The minimum achievable T/T_F, corresponds to a fermion to boson heat capacity matching and is almost independent on the initial conditions.

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C8. High Frequency Dynamics in Disordered Systems

The discovery that disordered materials, such as glasses and liquids, support the propagation of sound waves in the Terahertz frequency region has renewed interest in a long-standing issue: the nature of collective excitations in disordered solids. From the experimental point of view, the collective excitations are often studied through the determination of the dynamic structure factor $S(Q,\omega)$, i.e. the time Fourier transform of the collective intermediate-scattering function $F(Q,t)$ which, in turn, is the space Fourier transform of the density self-correlation function. $S(Q,\omega)$ has been widely studied in the past by the Brillouin light scattering (BLS) and inelastic neutron scattering (INS) techniques. These techniques left an unexplored gap in the Q-space, corresponding to exchanged momentum approaching the inverse of the inter-particle separation a (the mesoscopic region, Q=1-10 nm^{-1}). This Q region is important, because here the collective dynamics undergoes the transition from the hydrodynamic behavior to the microscopic single-particle one.

Investigation of $S(Q,\omega)$in this mesoscopic region has become possible recently thanks to the development of the Inelastic X-ray Scattering (IXS) technique; many systems, ranging from glasses to liquids, have been studied with this technique. In addition to specific quantitative differences among different systems, all the systems investigated show some qualitative common features that can be summarized as follows:

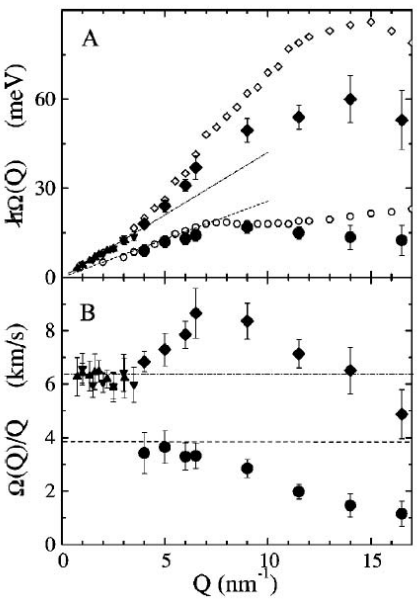

Figure 1: (A) Excitation energy $\Omega(Q)$ for vitreous silica from IXS (full dots) and Molecular Dynamics (open dots. The upper curve is for the L-mode, the lower one is for the T-mode.; (B) Apparent sound velocity from (A) defined as $\Omega(Q)/Q$.

(i) Propagating acoustic-like excitations exist up to a maximum Q-value Q_m ($aQ_m \approx$1-3 depending on the system fragility), having an excitation frequency $\Omega(Q)$. On increasing Q there exists a positive dispersion of the sound velocity (Fig. 1). (ii) $\Omega(Q)$ versus Q shows an almost linear dispersion relation, and its slope, in the $Q \to 0$ limit, extrapolates to the macroscopic sound velocity. (iii) The width of the Brillouin peaks, $\Gamma(Q)$, follows a power law, $\Gamma(Q)=DQ^{\alpha}$, with α=2 within the currently available statistical accuracy (Fig. 2). (iv) The value of D does not depend significantly on temperature, indicating that this broadening (i.e. the sound attenuation) in the high-frequency region does not have a dynamic origin, but is due to the disorder. (v) Finally, at large Q-values, a second peak appears in $S(Q,\omega)$ at frequencies smaller than that of the longitudinal acoustic excitations. This peak can be ascribed to the transverse acoustic dynamics, whose signature is observed in the $S(Q,\omega)$ as a consequence of the absence of pure polarization of the modes in a topologically disordered system.

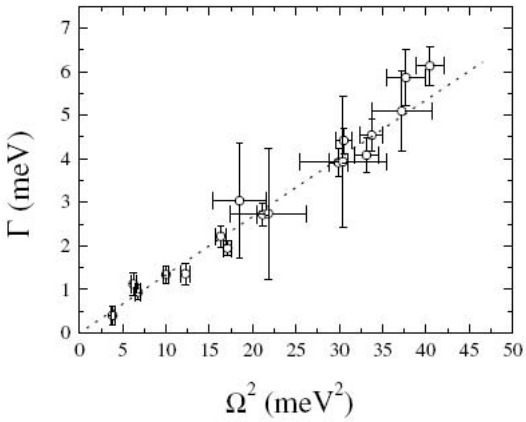

Figure 2: broadening (Γ) vs. excitation enegy position (Ω) square in glassy Selenium.

Recently, a theory for the vibrational dynamics in disordered solids [2], based on the random spatial variation of the shear modulus, has been applied to determine the Q-dependence of the Brillouin peak position and width, giving a sound basis to the whole set a features experimentally observed in the $S(Q,\omega)$ of glasses.

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C9. Soft Matter: Arrested states in colloidal systems

In recent years, dynamical arrest in colloidal systems, and more generally in soft matter, has gained increasing scientific attention. Colloidal suspensions have unambiguous advantages with respect to their atomic counterparts. Characteristic space and time scales are much larger, allowing for experimental studies in the light scattering regime and for a better time resolution. The size of the particles allows for direct observation with confocal microscopy techniques, down to the level of single-particle resolution. In addition, particle-particle interactions can be tuned by changing the solution conditions or by additives, as well as by synthesis of functionalized colloids. Colloidal suspensions, despite being very complex in nature and number of components, can be well described theoretically via simple effective potentials.

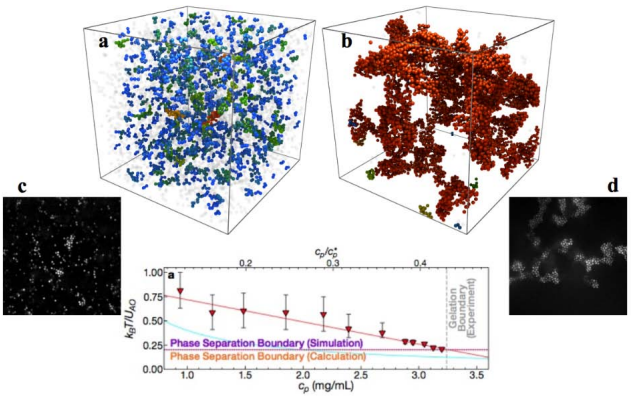

Figure 1: 3d reconstructions (a,b) of the fluid and gel states observed by confocal miscroscopy (c,d). The mapping of experimental onto numerical data (e) allows to identify that gelation takes place in coincidence with thermodynamic phase separation. From [2].

The variety of interactions reflects also in a variety of dynamically arrested states, which can be of gel or glass type. Gels are low density structures, stabilized by strong inter-particle bonds which create a percolating network, while glasses are generically found at larger density and stabilized by *caging*. The most famous colloidal glasses are certainly the so-called attractive and repulsive glasses observed in colloids with short-range depletion attractions, induced by the addition of non-adsorbing polymers in solution. The glass-glass interplay has been recently studied by simulations, showing that there is a long-time relaxation from the attractive to the repulsive glass [1].

At low densities the situation is more complex, and a variety of scenarios emerge when different inter-particle interactions are at hand. It has long been debated whether —for colloids with short-range attractions — the attractive glass line could extend continuously to lower densities, since a liquid-gas phase separation is encountered. To clarify the interplay between arrest and phase separation, we carried out a joint experimental/numerical work[2] in collaboration with Harvard University. Thanks to the single-particle resolution achieved by confocal microscopy, we compared the distribution of aggregates (clusters) in the fluid prior to gelation and built a mapping between the experimental control parameters and the thermodynamic parameters. In this way, we have provided unambiguous evidence that gelation occurs exactly at the spinodal threshold, as illustrated in Figure 1.

When depletion interactions are competing with electrostatic repulsion, the situation changes and phase separation can be suppressed. In this case, an equilibrium fluid of clusters exists at low densities. These clusters become the building blocks of dynamical arrest. As shown in Figure 2, with increasing packing fraction ϕ, clusters branch in a network gel structure, while at lower densities repulsive interactions dominate, originating a Wigner glass of clusters[3]. Wigner glasses are low-density disordered solids in which particles arrest despite being very far apart due to the soft repulsive cages[4].

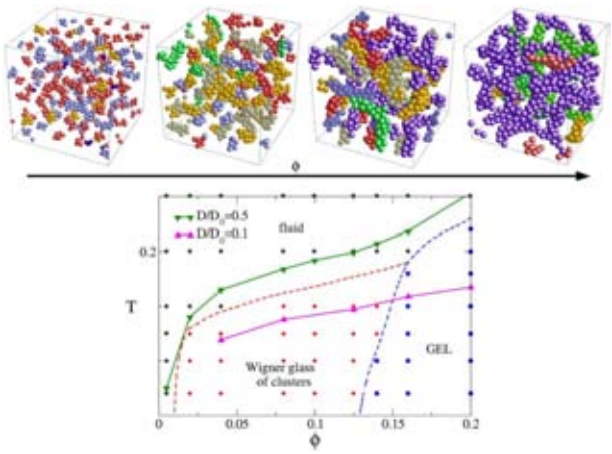

Figure 2: Simulation snapshots of Wigner glasses of clusters at low ϕ, turning into a percolating gel when ϕ increases, and related phase diagram. From [3].

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C10. Order in disorder: investigating fundamental mechanisms of inverse transitions

Reversible Inverse Transitions (IT) are rare phenomena recently observed in a widespread class of materials. The hallmark is that what is usually considered the "frozen" phase, that in standard systems appears as the temperature is lowered and is stable down to zero temperature, melt at low temperature. The typical case is the transition occurring between a solid and a liquid in the inverse order relation relatively to standard transitions. The case of "ordering in disorder", occurring in a crystal solid that liquefies on cooling, is generally termed *inverse melting*. If the solid is amorphous the IT is termed *inverse freezing* (IF).

For the definition of IT we stick to the one hypothesized by Tammann: a reversible transition in temperature at fixed pressure - or generally speaking, at a fixed parameter tuning the interaction strength externally, such as concentration, chemical potential or magnetic field - whose low temperature phase is an isotropic fluid. Generalizing to non-equilibrium systems one can address as IT also those cases in which the isotropic fluid is blocked in a glassy state. This occurs, e.g., in the poly(4-methylpentene-1) - P4MP1 as the temperature is very low and pressure not too large and in molecular dynamics simulations and mode-coupling computations of attractive colloidal glasses.

With this definition IT is not an exact synonym of reentrance. Indeed, though a reentrance in the transition line is a common feature in IT's, this is not always present, as, e.g., in the case of α-cyclodextrine or methyl-cellulose solutions for which no high temperature fluid phase has been detected. Moreover, not all re-entrances are signatures of an IT. In liquid crystals, ultra-thin films and other materials phases with different kind of symmetry can be found that are separated by reentrant isobaric transition lines in temperature without any occurrence of melting to a completely disordered isotropic phase. Also re-entrances between dynamically arrested states, aperiodic structures or amorphous solids of qualitatively similar nature, like liquid-liquid pairs are not considered as IT, since an a-priori order relationship between the entropic content of the two phases is not established and it cannot be claimed what is inverse and what is "standard". For the same reasons also re-entrances between equilibrium spin-glass and ferromagnetic phases do not fall into the IT category.

IT's are observed in different materials. The first examples were the low temperature liquid and crystal phases of helium isotopes He^3 and He^4. A more recent and complex material is methyl-cellulose solution in water, undergoing a reversible inverse sol-gel transition. Other examples are found in P4MP1 at high pressure, in solutions of α-cyclodextrine and 4-methypyridine in water, in ferromagnetic systems of gold nanoparticles and for the magnetic flux lines in a high temperature superconductor. A thourough explanation of the fundamental mechanisms leading to the IT would require a microscopic analysis of the single components behavior and their mutual interactions as temperature changes accross the critical point. Due to the complexity of the structure of polymers and macromolecules acting in such transformations a clear-cut picture of the state of single components is seldom available. For the case of methyl-cellulose, where methyl groups are distributed randomly and heterogeneously along the polymer chain, Haque and Morris proposed that chains exist in solution as folded hydrophilic bundles in which hydrophobic MGs are packed. As T is raised, bundles unfold, exposing MGs to water molecules and causing a large increase in volume and the formation of hydrophobic links eventually leading to a gel condensation. The polymers in the folded state are poorly interacting but also yield a smaller entropic contribution than the unfolded ones.

To model the folded/unfolded conformation bosonic spins can be used: $s = 0$ representing inactive state, $s \neq 0$ interacting ones. The randomness on the position of the "interaction carrying" elements is mimicked by quenched disorder.

In the latter years we have focused the study on the disordered spin models and the IF has been observed in the spin-glass mean-field Blume-Emery-Griffiths-Capel models with spin-1 variables. We have also considerd the random Blume-Capel model, whose mean-field solution predicts a phase diagram with both a spin glass/paramagnetic second order and a first order phase transition, i.e., displaying latent heat and phase coexistence. This model is characterized by the phenomenon of IT.

The connection of the mean-field solution with the finite dimensional case in spin glass models is still an open probles. This to go beyond the mean-field solution recently we have studied [1] the three dimensional version of the Blume-Capel model finding clear evidence for inverse freezing. The next step, taht we are taking, is studying a realistic computer model inspired to material for which experimental evidence has been collected in favour of an inverse transition, such as the poly(4-methylpentene-1) polymer. This work is still in progress.

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C11. Statistical physics of information and social dynamics

Statistical physics has proven to be a very fruitful framework to describe phenomena outside the realm of traditional physics. The last years have witnessed the attempt by physicists to study collective phenomena emerging from the interactions of individuals as elementary units in social structures [1]. Our group is particularly active on a wide list of topics ranging from opinion, cultural and language dynamics to the dynamics of online social communities. In all these activities a crucial element is the information shared in specific groups and one is interested in understanding how this information emerges, spreads and gets shared, is organized and eventually retrieved. Here we only summarizes a few examples.

Online social systems and human computing

The rise of Web 2.0 has dramatically changed the way we view the relation between on-line information and on- line users and prompts a new research agenda which complements the Web Science vision with analytical tools and modeling paradigms from the theory of complex networks. User-driven information networks in particular, i.e., networks of on-line resources built in a bottom-up fashion by Web users, have gained a central role and are regarded as an increasingly important asset. Understanding their structure and evolution brings forth new challenges because user-driven information networks entangle cognitive, behavioral and social aspects of human agents with the structure of the underlying technological system, effectively creating techno-social systems that display rich emergent features and emergent semantics [2]. These subjects have been investigated in the framework of EU STREP Project TAGora (www.tagora-project.eu).

Information Theory and Complexity One of the most challenging issues of recent years is presented by the overwhelming mass of available data. While this abundance of information and the extreme accessibility to it represents an important cultural advance, it raises on the other hand the problem of retrieving relevant information. Clearly the need for effective tools for information retrieval and analysis is becoming more urgent as the databases continue to grow. Recently we introduced a new automatic method for the extraction of information codified as sequences of characters. The method exploits concepts of information theory to address the fundamental problem of identifying and defining the most suitable tools to extract, in a automatic and agnostic way, information from a generic string of characters.

Phylogenetics While well established results are available for perfect phylogenies (i.e. evolutionary history that can be associated to a tree topology), when a deviation from a tree-like structure has to be considered very little is known, despite the efforts in this direction. Our activity on phylogeny reconstruction aims at providing methods to identify and to correctly take into account deviations from perfect phylogenies and also at providing the community with suitable benchmarks to test the validity of inferred phylogenies. One crucial problem, once a tree or a network is reconstructed, is to determine how reliable it is, i.e. how well it represents the true evolutionary history.

Language dynamics Language dynamics is an emerging field that focuses on all processes related to the emergence, change, evolution, interactions and extinction of languages [3]. Our activity in this area has been focused so far to the introduction of "simple" language games to investigate the emergence of names in a population of individuals. The *Naming Game* (NG) possibly represents the simplest example of the complex processes leading progressively to the establishment of human-like languages. More recently we introduced a promising modeling scheme to investigate the emergence of categories, the *Category Game* (CG) [4]. In this framework we addressed the open problem concerning the emergence of a small number of forms out of a diverging number of meanings, e.g., the basic color terms for colors (see Figure 1).

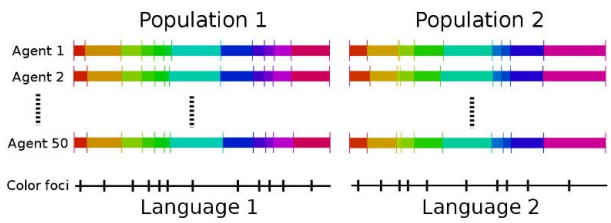

Figure 1: An example of the results of the Category Game. After 10^4 games, the pattern of categories and associated color terms are stable throughout the population. Different agents in one population have slightly different category boundaries, but the agreement is almost perfect (larger than 90%). As for each category, a focal color point is defined as the average of the midpoints of the same category across the population. Different populations may develop different final patterns.

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C12. Complex agents in the global network: selforganization and instabilities

The science of complex systems

The study of complex systems refers to the emergency of collective properties in systems with a large number of parts in interaction among them. These elements can be atoms or macromolecules in a physical or biological context, but also people, machines or companies in a socio-economic context. The science of complexity tries to discover the nature of the emerging behavior of complex systems, often invisible to the traditional approach, by focusing on the structure of the interconnections and the general architecture of systems, rather than on the individual components. For a general overview see Ref (1) and for all our activities the WEB page below.

The science of complexity arises naturally from statistical mechanics which, in the seventies, introduces a fundamental change of paradigm with respect to the reductionist scientific vision. At the equilibrium point between order and disorder one can observe fluctuations at all scales and the system cannot be described any more with the usual formalism in which one tries to write simple equations for average quantities. From this conceptual grain many new concepts have developed which produced a revolution in our way of looking at nature: scaling laws, renormalization group, fractal geometry, glassy and granular systems, complex liquids, colloids and many others. Also the understanding of Superconductivity as an emergent collective effect associated with symmetry breaking has been a very important element in the development of these ideas. An important implication of these ideas is about the complex properties of the large scale cosmic structures. This will probably lead to a major revision of the standard model of cosmology with deep implications on dark matter and dark energy (2). More recently it begins to be clear that these concepts can have much broader applications with respect to the physical systems from which they originated. This led to a large number of interdisciplinary applications which are sometimes surprising and which probably represent just the beginning of the many 7possible applications.

From Physics to Finance and Economics

After the sub-prime crisis in the financial world there have been many conjectures for the possible origin of this instability. Most suggestions focus on concepts like collective behavior, contagion, network domino effect, coherent portfolios, lack of trust, liquidity crisis, and, in general psychological components in the traders behavior (3). These properties are usually neglected in the standard risk analysis which is based on a linear analysis within a cause-effect relation. These new concepts require a novel approach to the risk problem which could profit from the general ideas of complex systems theory. This corresponds to the introduction of suitable models with heterogeneous agents and a different perspective in which the interaction between agents (direct or in direct) is explicitly considered together with the idea that the system may become globally unstable in the sense of self-organized criticality. The analysis is therefore shifted from the cause-effect relation to the study of the possible intrinsic instabilities. Our research project corresponds to a systematic analysis of these ideas based on agent models and order book models (4) together with the statistical analysis of experimental data. The final objective of these studies would be to define the characteristic properties of each of the above concepts from the models and then to identify their role and importance in the real financial markets.

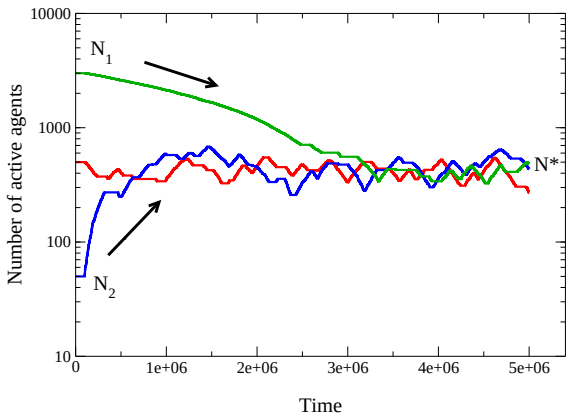

Figure 1: Self-organization towards the quasi-critical state of the market. Different populations of agents with a different starting number (3000 for the green line; 500 for the red and 50 the blue) evolve spontaneously and self-organize towards a state with an effective number of agents corresponding to the intermittent behavior with non-Gaussian properties. The state which is the attractor of the dynamics corresponds to the stylized facts observed in real markets.

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C13. Understanding large scale collective three dimensional movements

Collective phenomena are well known in physics, being at the core of phase transitions in condensed matter. They have been deeply investigated, providing with conceptual and methodological tools that can be usefully applied also in other fields. In biology, for example, collective behaviour is widespread, occurring at several scales and levels of complexity. Animal groups - like insect swarms and bird flocks - are paradigmatic cases of emergent self-organization. There is no leader to guide individuals towards the common patterns. Rather, collective behaviour arises spontaneously as a consequence of the local interactions between individuals, much as it happens in ordering phenomena in condensed matter systems. A crucial issue is therefore to understand how self-organization emerges in animal aggregations and how behavioural rules at the individual level regulate collective efficiency and group function.

Bird flocking is a striking example of collective animal behaviour. A vivid illustration of such phenomenon is provided by the aerial display of vast flocks of starlings gathering at dusk over the roost and swirling with extraordinary spatial coherence.

We have done for the first time a quantitative study of aerial display [1,2,3]. The individual three-dimensional positions in compact flocks of up to few thousands birds have been measured. We investigated the main features of the flock as a whole: shape, movement, density and structure.

We found that flocks are relatively thin, with variable sizes, but constant proportions. They tend to slide parallel to the ground, and during turns their orientation changes with respect to the direction of motion. Individual birds keep a minimum distance from each other; we measure such exclusion zone and find that it is comparable to the wingspan. The density within the aggregations is inhomogeneous, as birds are more packed at the border compared to the centre of the flock. These results constitute the first set of large-scale data on three-dimensional animal aggregations. Current models and theories of collective animal behaviour can now be tested against these data.

By reconstructing the three-dimensional position and velocity of individual birds in large flocks of starlings [4], we measured to what extent the velocity fluctuations of different birds are correlated to each other. We found that the range of such spatial correlation does not have a constant value, but it scales with the linear size of the flock. This result indicates that behavioural correlations are scale-free: the change in the behavioural state of one animal affects and is affected by that of all other animals in the group, no matter how large the group is. Scale-free correlations provide each animal with an effective perception range much larger than the direct inter-individual interaction range, thus enhancing global response to perturbations. Our results suggest that flocks behave as critical systems, poised to respond maximally to environmental perturbations.

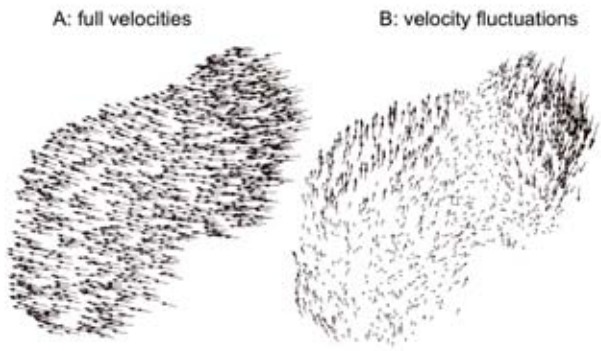

Figure 1: **Left**: Two-dimensional projection of the velocities of the individual birds within a starling flock at a fixed instant of time. **Right**: The velocity fluctuations in the same flock at the same instant of time (vectors scaled for clarity). Large domains of strongly correlated birds are clearly visible.

We found that the correlation is almost not decaying with the distance, and this is by far and large the most surprising and exotic feature of bird flocks. How starlings achieve such a strong correlation remains a mystery to us.

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C14. Statistical Biophysics

Cellular metabolism is to a large extent inaccessible to experiments. The best experimental technique available to date to probe intracellular reactions rely on C13-based flux analysis: basically, a population of cells (eg bacteria) is prepared to grow in a medium with a labeled carbon source (eg glucose). After a transient, the marker reaches a steady distribution over cells, and the mass-to-charge ratio distribution in certain target compounds (eg alanine) can be detected via mass or NMR spectroscopy. From this, reaction fluxes can be inferred. In a model system like the bacterium E.Coli, this allows to infer the values of a few tens of fluxes (all from the major carbohydrate-processing pathways) out of the roughly 1100 forming its metabolism. Much less is known about eukaryotic cells, and only a handful of data cover human cells (including the highly important red blood cells). The inherent difficulty of gathering experimental evidence makes theoretical approaches a necessary instrument to reconstruct the global organization of fluxes at the cellular level, both to predict responses to environmental perturbations, drugs, or gene knockouts, and to infer the critical epistatic interactions between metabolic genes. Several methods are currently available to compute reaction fluxes from the known stoichiometry, one prominent example being flux balance analysis. The pillars on which all of them rest are the assumptions that (a) metabolite concentrations and reaction fluxes are at a steady state, and (b) the cell's overall activity aims at maximizing the production and/or the consumption of a given set of metabolites. The latter condition is typically expressed via a linear optimization problem. Biomass maximization and ATP maximization, glucose consumption minimization or total flux minimization are all examples of this kind of approach.

Some experimental evidence indeed has shown that E. Coli under evolutionary pressure evolves towards states of maximal biomass production in nutrient rich environments. These models are able to reproduce the limited empirical evidence with a varying degree of success. In particular, if wild type cells in certain environments may be reasonably well described by a biomass optimization principle, after a knockout they are best described by a principle of minimal flux adjustment with respect to the wild type. Over the last few years, however, several limitations of the existing theories have emerged, most strikingly in the proliferation of objective functions that are needed to describe different cells, environments and cell mutants. By standard approaches it is not possible to predict the biomass composition given the cell and its environment: rather, the detailed biomass composition is a key input of the models. A further drawback of available theories is that by linear optimization they systematically reduce the space of feasible flux states to a single point (the optimum). Most of the biological features requiring high flexibility, like metabolic pathways coregulation or flux reorganization after knockouts or environmental changes, are unlikely to be captured by a simple optimization scheme.

Understanding the cell's response to perturbations at the metabolic level requires a deeper analysis of the existing data and theories, besides new heuristics to explore different directions. Our group has tackled such problem within Von Neumann's maximal producibility framework. The scientific novelty of our research lies essentially in the possibility to identify essential reactions (or genes) as dynamically stiff ones, thus linking directly to the genetic level. Results obtained so far reproduce the experimental evidence and allow to infer (rather than assume) the biomass composition. Many interesting extensions are currently being analyzed.

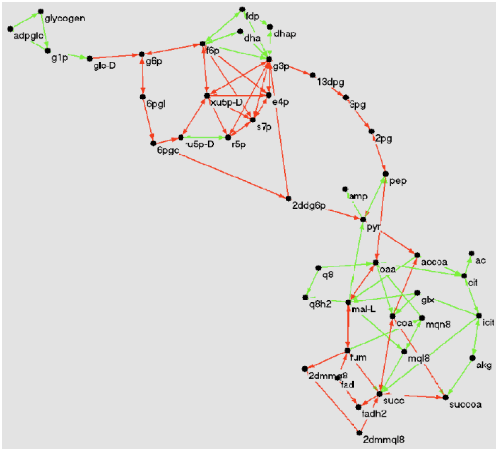

Figure 1: E. coli's central metabolism: nodes represent metabolites, an arrow joining two nodes is present when a reaction exists converting one into the other. Red reactions turn out to be "frozen", i.e. dynamically stiff.

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C15. Ordered and chaotic dynamics in molecules

The very first computer study of a condensed matter system that showed the (unexpected) existence of an ordered dynamical regime is a well known simulation by Fermi, Pasta, and Ulam, back in 1953. Since then, many papers have been published in this field, dealing with the dynamical behaviour of model or realistic systems. Larger systems have been usually found to be chaotic, while ordered behaviour has been found in some systems with few degrees of freedom (DOFs). The theoretical explanation of the appearance of ordered motions in nonlinear systems begun at the same time - but independently - as the FPU experiment, and is known as the KAM theorem. This theorem explained why a nonlinear system may be endowed with regular motions, provided the nonlinearity is not too strong; this property was attributed to the system as a whole. A later theorem by Nekhoroshev foresaw the possibility that within a chaotic system different DOFs may exhibit their chaotic behaviour on very different time scales. A computer simulation that yielded evidence of the type of dynamics foreseen by Nekhoroshev has been done for 2D and 3D lattices of particles interacting via a Lennard Jones potential; there, at low energy, the dynamics showed a mixed pattern, as different normal modes became chaotic over times that differed by several orders of magnitude for normal modes of different frequency.

In this framework we investigate the ordered and chaotic dynamics of molecules. We have simulated the dynamics of a butane molecule, and computed the time evolution of collective internal variables (three stretchings, two bendings, and the dihedral angle).

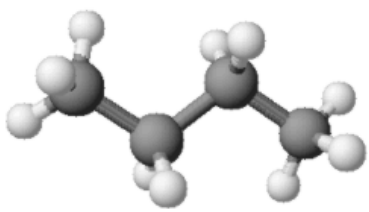

Figure 1: Model of the butane molecule.

The system is strongly nonlinear at high temperature because of the dihedral potential, as shown in Fig. 2.

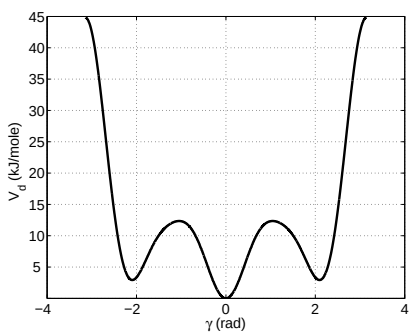

Figure 2: Torsion potential of the dihedral angle.

A chaotic system is usually characterized by a fast, exponential rate of divergence of trajectories beginning at near points in the phase space. This rate is measured by the maximum Lyapunov exponent λ_1. Coherence is the opposite of chaoticity, namely a slow divergence of near trajectories, and each collective variable can be characterized by a coherence time, the time needed to develop its chaotic behaviour. Table 1 shows the Lyapunov time λ_1^{-1} of the molecule and the coherence times $\widetilde{\tau}_c^{(l)}$ of the six internal coordinates: stretchings (b_i), bendings (θ_i), and dihedral angle (γ).

	$T = 54$ K $\lambda_1^{-1} = 222$	$T = 168$ K $\lambda_1^{-1} = 0.38$	$T = 250$ K $\lambda_1^{-1} = 0.26$
	$\widetilde{\tau}_c^{(l)}$	$\widetilde{\tau}_c^{(l)}$	$\widetilde{\tau}_c^{(l)}$
$\cos\theta_1$	3810	1.95	0
$\cos\theta_2$	3312	1.89	0.04
b_1	1596	6.79	0
b_2	0	0.87	0.87
b_3	1243	8.22	0
γ	697	0	0.04

Table 1: λ_1^{-1} and all coherence times are in ps. $\widetilde{\tau}_c$ is the coherence time relative to each DOF.

The coherence times diminish significantly when the temperature is raised above $T = 150$ K, where conformational transitions of the dihedral angle set in. Below this temperature the coherence times of some variables reach nanoseconds; moreover, there are large differences among variables, as their coherence times can be much larger or much smaller than the Lyapunov time of the whole molecule. This hierarchy of coherence reflects the prediction of Nekhoroshev' s theorem. Raising T above the transition region the coherence times drop to few picoseconds, and the differences among variables diminish, as the whole molecule becomes chaotic. At $T = 250$ K the central stretching b_2, which is the most chaotic at low temperature, becomes the most coherent.

We now aim at extending this analysis to larger molecules, where the coherence hierarchy may yield new insight into a variety of extended conformational transitions.

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C16. Fluctuation-dissipation relations in non equilibrium statistical mechanics and chaotic systems

One of the most important and general results concerning statistical mechanics is the existence of a relation between the spontaneous fluctuations and the response to external fields of physical observables (FDR). This result has applications both in equilibrium statistical mechanics, where it is used to relate the correlation functions to macroscopically measurable quantities such as specific heats, susceptibilities and compressibilities, and in nonequilibrium systems, where it offers the possibility of studying the response to time-dependent external fields, by analyzing time-dependent correlations. The idea of relating the amplitude of the dissipation to that of the fluctuations dates back to Einsteins work on Brownian motion.

The FDR result represents a fundamental tool in nonequilibrium statistical mechanics since it allows one to predict the average response to external perturbations, without applying any perturbation. In fact, via an equilibrium molecular dynamics simulation one can compute correlation functions at equilibrium and then, using the GreenKubo formula, obtain the transport coefficients of model liquids without resorting to approximation schemes.

Although the FDR theory was originally applied to Hamiltonian systems near thermodynamic equilibrium, it has been realized that a generalized FDR holds for a vast class of systems with chaotic dynamics of special interest in the study of natural systems, such as geophysics and climate. A renewed interest toward the FDR has been motivated by the study of the entropy production rate in systems arbitrarily far from equilibrium.

Recent developments in nonequilibrium statistical physics give evidence that the fluctuation-dissipation relations, which hold in systems described by statistical mechanics, have an important role even beyond the traditional applications of statistical mechanics, e.g. in a wide range of disciplines ranging from the study of small biological systems to turbulence, from climate studies to granular media, etc.

It is well known that in systems with aging and glassy behaviours there are non trivial relations among response functions and correlation funcion. Such a feature holds even for many systems which are ergodic and have an invariant phase space distribution, which is reached in physically relevant time scales. In particular in all the cases where there are strong correlations among different degrees of freedom.

In our research we study a generalized FDR which holds under rather general conditions, even in non-Hamiltonian systems, and in nonequilibrium situations. In addition, we discuss the connection between this FDR and the foundations of statistical mechanics, fluid dynamics climate, and granular materials.

As example we can cite the study of a multi-variate linear Langevin model, including dynamics with memory, which is used as a treatable example to show how the usual relations are recovered only in particular cases. This study brings to the fore the ambiguities of a check of the FDR done without knowing the significant degrees of freedom and their coupling. An analogous scenario emerges in the dynamics of diluted shaken granular media. There, the correlation between position and velocity of particles, due to spatial inhomogeneities, induces violation of usual FDRs. The search for the appropriate correlation function which could restore the FDR, can be more insightful than a definition of non-equilibrium or effective temperatures.

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C17. Chaos, complexity and statistical mechanics

The main aim of statistical mechanics is to describe the equilibrium state of systems with many degrees of freedom; while dynamical systems theory can explain the irregular evolution of systems with few degrees of freedom. Also macroscopic systems are dynamical systems with a very large number of degrees of freedom. However while the low dymensional systems have been largely investigated, and their basic features are well understood; the study of systems with many degrees of freedom and many characteristic times (e.g. climate and turbulence) is a difficult task. The reason of that is mainly due to the fact that, in these cases, the usual indicators (Lyapunov exponents and Kolmogorov-Sinai entropy) are not very relevant.

The Kolmogorov-Sinai entropy and the Lyapunov exponents quantify rather well the degree of time "complexity" in systems with few degrees of freedom. A complexity characterization is more difficult when many degrees of freedom and many time scales are present. For instance in developed turbulence this can be achieved using the ϵ-entropy, which measures the information content at different scale resolution. The climatic systems, where the fluctuations at different scales are comparable, are much more complicated. Other interesting situations arise in non chaotic systems (i.e. with zero Lyapunov exponent) but with irregular behaviour and in discrete-states systems, with regard to their continuum limit. The latter topic is tied up with the semiclassical limit and decoherence in quantum mechanics, and with deterministic algorithms to produce random numbers.

Perhaps in physics the most relevant example of high dimensional systems is the dynamics of macroscropic bodies studied in statistical mechanics. From the very beginning, starting from the Boltzmanns ergodic hypothesis, a basic question was the connection between the dynamics and the statistical properties.

The discovery of the deterministic chaos (from the anticipating work of Poincaré to the contributions, in the second half of the XX-th century, by Chirikov, Hénon, Lorenz and Ruelle, to cite just the most famous) beyond its undoubted relevance for many natural phenomena, showed how the typical statistical features observed in systems with many degrees of freedom, can be generated also by the presence of deterministic chaos in simple systems. For example low dimensional models can emulate spatially extended dynamics modelling transport and conduction processes.

Surely the rediscovery of deterministic chaos has revitalized investigations on the foundation of Statistical Mechanics forcing the scientists to reconsider the connection between statistical properties and dynamics. However, even after many years, there is not a consensus on the basic conditions which should ensure the validity of the statistical mechanics. Roughly speaking the two extreme positions are the traditional one, for which the main ingredient is the presence of many degrees of freedom and the innovative one which considers chaos a crucial requirement to develop a statistical approach.

One aim of our research has been to show how, for understanding the conceptual aspects of the statistical mechanics, one has to combine concepts and techniques developed in the context of the dynamical systems with statistical approaches able to describe systems with many degrees of freedom. In particular we discussed the relevance of non asymptotic quantities, e.g ϵ-entropy, and the role of pseudochaotic systems, i.e. non chaotic systems with a non trivial behaviour.

Vivid examples of such a feature is shown by numerical studies which evidenciate in a clear way that for high dimensional Hamiltonian systems chaos is not a fundamental ingredient for the validity of the equilibrium statistical mechanics. This happens for instance for the transport properties of systems with many degrees of freedom, e.g. diffusion coefficient, which are not sensitive to the presence of chaos. Such results support the point of view that to have good statistical properties chaos is unnecessarily demanding: even in the absence of chaos, one can have (according to Khichin ideas) a good agreement between the time averages and the predictions of the equilibrium statistical mechanics.

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C18. Stochastic convective plumes dynamics in stratified sea

The study of the deep sea convection processes is very important for climate comprehension. Their dynamics are very complex and far from being fully understood. Every year they occur in some specific sites of the world, allowing the deep water formation and oxygenation; their position is responsible of the general sea circulation and affects the earth climate. In particular the Mediterranean Sea Circulation is driven by a lot of these sites (MEDOC area, Adriatic Sea, Aegean Sea, and so on): each of them is characterized by strong yearly winds blowing over them and by not large sea stratification. During winter, this is slowly eroded by the wind stress in a finite sea region, so that an about circular isopycnal, geostrophic, cyclonic "doming", $\sim 50 - 100$ km large, quite homogeneous in its central area, appears; the stratification ($O(10^{-3} - 10^{-4} s^{-1})$) is vertically decaying and horizontally growing from the center to the boundary. At once, as a last violent wind proceeds on the late winter, a lot of $\sim 1km$ wide vertical down flows ($\sim 3 - 10cm/s$), so called "plumes", alternating with slower upward velocities, are visible at a depth of $100 - 550$ m, for a period $t \simeq 2h < f^{-1}$ (f is the Coriolis parameter); a decorrelation between plumes over a 2 Km horizontal range has been observed. These plumes are thought to be efficient water mixing agents as a large rotating "chimney" is forming on longer times.

The problem of the physical processes involved in formation and dynamics of these small plumes has been studied experimentally, numerically and theoretically for a long time. Laboratory experiments on a rotating tank cooled on a finite region of its upper surface, so as numerical and theoretical analyses have defined scale relations for the initial plume formation phase, relating the convective layer depth, its horizontal and vertical velocity and the reduced gravity to the time-space average surface buoyancy flux (due to surface cooling and evaporation caused by the wind), the time and the sea stratification. But the real plumes dynamics in the sea have to be still investigated.

In the last few years, my contribution to the comprehension of these processes has been given through the development of a stochastic three-dimensional analytical model describing the initial unsteady phase of convective plumes generation and dynamics (for times $\leq f^{-1}$). The hypothesis is that this kind of convection is not a collective phenomenon generated by bulk fluctuations, neither initially constrained by rotation. The analysis of field data suggests the above-mentioned observed turbulent plumes are likely generated by non uniformities of the cooling effects. So it is possible this kind of convection is due to external surface heterogeneous buoyancy forcing, in such a way that every plume is independent of the others.

The process is mathematically described by the complete set of the non viscous Navier Stokes equations (in Boussinesq and quasi-hydrostatic approximation) coupled to the non diffusive mass conservation equation in a rotating frame, by disregarding the wind stress. Very small sea stratification has been introduced as a perturbation. Still sea initial condition is given; the space and time stochastic buoyancy horizontal variability, driven by the transverse winds, is the source of a convective process. By recognizing two space scales (a small plume scale and a collective perturbed region scale) acting together, a multiple space scale method allows to decouple, in a stream function formulation, the vertical transverse plane, over which the plumes set is generated, from the winds direction line, along which the plume is deviated from the Coriolis force on longer times. Two time scales have been recognized; on the short time scale the plumes generation and first evolution can be described in a Lagrangian representation on a $2D$ plane; on the long time scale, shear horizontal instability allows a set of $3D$ small plumes to be defined: an enhanced region of perturbation can be recognized, due to stratification, driving to a different regime of scale laws. A kind of 'transformation' of the buoyancy allows the effect of the entrainment-detrainment to be analyzed. After all we have generation of a set of independent quasi periodical small scale plumes, whose distance is given by the horizontal correlation length in the surface buoyancy. Their evolution is described by an equation scalable with the penetration depth; it is ruled by time power 'one plume laws' depending on the statistics of the external events, their frequency, and by space-time buoyancy fluctuations power laws. The convective motion is driven by the mean horizontal in homogeneity of the surface buoyancy flux and its space-time variability. For short times a linear stability theory shows that the fastest growing in time internal perturbations take a very long time to grow. The analysis of the stability of the model, perturbed by vertical internal fluctuations on longer times, shows a weak intermittent behavior: but plume evolution and scaling laws are ruled by random external forcing leading to a higher time power behavior; this depends on the probability of the event, which hides slower internal randomness; if the air-sea interaction statistics is such that it is impossible to define it, no self-similar behavior is possible. Large internal fluctuations have a mixing and turbulence generation effect. Numerical simulation of the quasi-hydrostatic and not hydrostatic model shows that the not hydrostatic effect is not important.

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V. Bouché

C19. Mesoscopic solutes in water solvent

Water solutions with mesoscopic solutes represent still an open problem for what concerns both thermodynamic and statistical mechanic. The hydrogen bounds network in the solvent itself and, often, with the solute interface represent the undefined quantity. Must of the thermodynamic properties of these solutions depend on the extend of solute-solvent interface and on the overall solvent modification due to the presence of the solute (phase diagram, solute-solute interaction, eventual solute flocculation etc). To have an idea of the solute-solvent interfacial contribution we can evaluate the extent of the surface of 1 cc of solution, about 5 cm^2 surface, and the total surface of $10^{-6} molar$ solution of spherical solutes having $50\AA$ of radius, it results to be about 5 $10^4 cm^2$, quite a big number! My work has been developed in the last 5 years in collaboration with students graduated in my laboratory: Marco Maccarini, an experimentalist expert on SANS and SpinEcho neutron scattering now working at ILL Grenoble France, Fabio Sterpone, now working at the Dep. of Chemistry Ecole Normale Superiore, Paris France, and with Simone Melchionna, PhD fellow in my laboratory and now working at the Institute of Materials Ecole Polytechnique, Losanne Switzerland, the last two expert in M

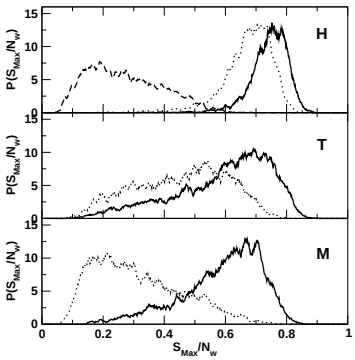

Figure 1: Maximum fully connected water cluster at different temperatures for Meso, Thermo and Hyperthermo organisms [2].

The first step of my study concerned the hydration properties of the G-domain of an omnipresent protein in all the living organisms by means of MD simulations in collaboration with Simone Melchionna. In this work we pointed out the fundamental role of water in the thermal stability of such a protein [1]. Afterward, with the help of Fabio Sterpone, we analyzed the same protein extracted by three different organisms, one having its optimal living condition (OLC) at 37 C a mesophile organism (M), the second a thermophile organism (T) having its OLT at 70 C, the third hyperthermophile (H) with OLT at 97 C, all of them present a high degree of sequence affinity. The main result of this work concerns the identification of a fully connected water network covering each of the organisms that shows an increasing thermal resistance going from M to H proteins (see Fig. 1). This result reinforcs the initial idea that water has a fundamental role in the protein thermal stability [2].

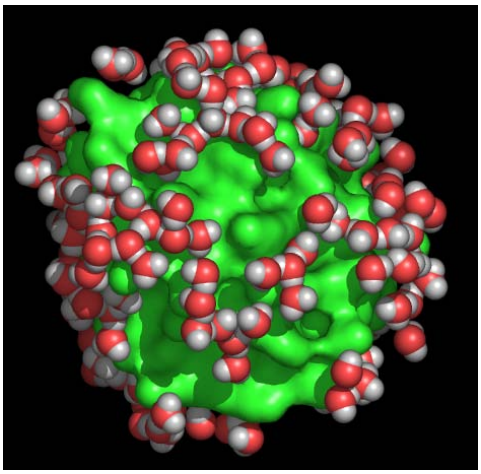

Figure 2: View of the (oil core)-water interface, the polymeric chains are hidden [3].

The second system we analyzed, in collaboration with Marco Maccarini, concerned solutions of nonionic surfactant belonging to the family $C_{12}E_j$, constituted by a tail of 12 hydrocarbon and j polyethylene units (E). This surfactants presents a very complex phase diagram generally associated to the interfacial degree of hydration. Up to now the main results we have obtained concern the effective exposure of the hydrophobic micellar core to the solvent: the distribution of the hydrophilic terminations is not uniform, thus living extended hydrophobic portion of surface in contact with water. Therefore the micellar equilibrium condition is characterized by a competing contributions between water-micellar core repulsion and the interfacial polymer-polymer attraction, an aspect not taken into account previously [3].

Recently Marco Maccarini and me start to work on gold nanoparticles (NP) activated with chemically bounded polymer chains of 45 E units. Preliminary results have shown that the NP is characterized by three shells: the first containing only the gold core, the second is polymer shell practically unhydrated, and the external shell with about 50 % by weight of water. Md simulation are now on going.

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G. Briganti, S. Melchionna, F. Sterpone, M. Maccarini

C20. Coarse Grained Molecular Dynamics Simulations: application to proteins and colloids

All atoms Molecular dynamics (MD) or Monte Carlo (MC) simulations of large systems, evolving on very long timescales, are very demanding in terms of computer resources. In these cases, it becomes important to develop coarse-grained (CG) models, i.e. a reduced representations of the interparticle interaction potential. Several systems in condensed matter physics and biophysics have been successfully modeled in this way. Protein folding and protein aggregation are often studied employing simplified CG. We have recently developed one of these models for the protein lysozime, to describe the clustering phenomenon which takes place in the absence of salt, as a result of a competition between hydrophobic attraction and screened electrostatic repulsion. CG models are also very relevant for testing state-of-the-art theoretical modeling, since they often allow for a one-to-one correspondence between the theoretical assumptions and the numerical realization. For example, the glass transition of rigid molecules where excluded volume interactions play a relevant role (e.g. lyotropic liquid crystals), can be conveniently modeled approximating their constituent particles as hard ellipsoids. We have investigate [1] the dynamic phase diagram of hard ellipsoids, employing event-driven MD, discovering, close to the isotropic-nematic transition clear indications of a new kind of glass transition, in agreement with recent theoretical predictions.

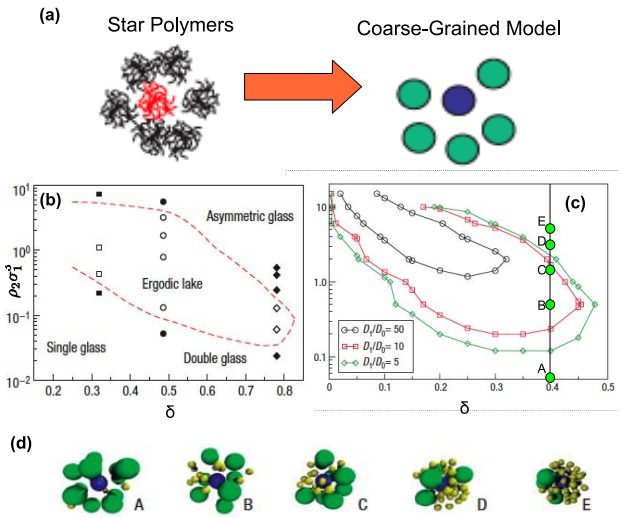

Figure 1: (a) Coarse-grained model of a star polymer mixture, constituted by large and small particles. The kinetic phase diagram (in the plane density-asymmetry) obtained by experiments (b) is qualitatively reproduced with simulations (c). (d) Snapshots of typical cages around a fixed large star (along the line in panel (c)).

CG models are also relevant in the investigation of soft-matter systems. Often, the interactions between colloidal particles can be modeled via an effective potential, by integrating out all solvent and internal degrees of freedom of the particles. One example is offered by star-polymers (SP), i.e. macromolecules containing a single branch point from which linear chains (arms) emanate. In [2], we reported the observation of several glass states in mixtures of SPs, modeled as simple spheres interacting with a suitable soft potential (see Fig.1 (a)). Another interesting example is offered by the chemical gelation of epoxy resins, which we have modeled as a mixture of two rigid ellipsoids forming permanent bonds through localized interaction sites[3]. MD allows us to follow the bonding process and study the structure and connectivity of the system in time (details in Fig. 2). More recently, we have studied the phase diagram of the recently synthesized Janus particles[4], i.e. spherical particles characterized by a surface divided into two areas of different chemical composition. The calculated phase diagram is very peculiar, showing competition between critical fluctuations and micelle formation.

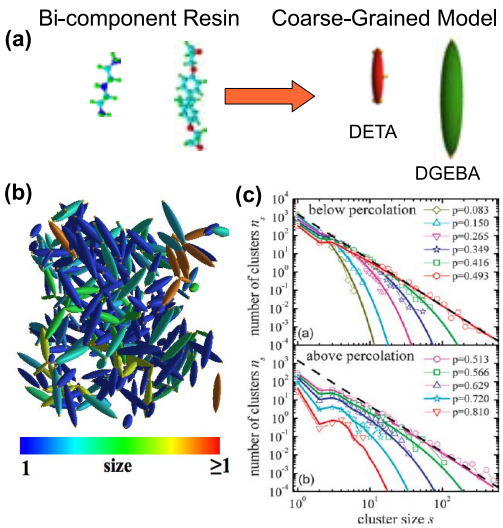

Figure 2: (a) Coarse-grained model of resins DGEBA and DETA. (b) Snapshot of sol phase (c) Cluster size distributions at various bond probability p (symbols) and corresponding theoretical predictions (continous lines).

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C21. Mixed quantum-classical dynamics for condensed matter simulations

The computational cost of quantum dynamic simulations scales exponentially with the number of degrees of freedom (DOF). This prevents a brute force solution of the problem and fosters research to find alternative, viable simulation methods. Large systems in which the quantum nature of just some DOFs is relevant can be studied with mixed quantum-classical methods. These methods start from a full quantum description of all DOFs and then partition them into two subsets: the quantum subsystem and the bath. A classical limit for the evolution of the bath alone is taken to substantially reduce the cost of the calculation while preserving, approximately, the quantum evolution of the subsystem. Taking this limit is non-trivial and part of our research explores using different approaches to analyze the formal properties of mixed quantum classical schemes [1]. We also study a specific kind of mixed quantum-classical problems: non-adiabatic dynamics. In non-adiabatic situations, the coupling between nuclear (the bath) and electronic (quantum subsystem) motions in a molecular system, or the interactions with the environment, can induce transitions among the eigenstates of the electronic Hamiltonian. A Born-Oppenheimer description of the nuclear dynamics is thus invalid and advanced simulation methods are necessary. Non-adiabatic transitions can affect the energy and charge distribution of a system, change the products of a chemical reaction by opening up different reaction channels, modify the relaxation path and the final state of a molecule excited by light and influence the time scale for its dissociation or recombination in the presence of solvent. Non-adiabatic simulations then open the possibility to control a wide range of interesting processes by suggesting how to modify the nature of the transitions, for example via coupling with a controlled environment or an appropriate pattern of excitations.

In collaboration with Ray Kapral (University of Toronto) and David Coker (Boston University) our group developed two approaches for simulating non-adiabatic mixed quantum-classical dynamics: the quantum-classical Liouville equation and the iterative linearized density matrix propagation. Both methods derive from well-defined approximations for propagating the density operator; the first exploits the Wigner-Liouville representation of quantum mechanics, the second the path integral formalism by Feynman. The approximation in both dynamics is controlled by the mass ratio of quantum and classical DOFs, and the coupling among the different dynamics arises naturally from a Taylor series expansion of the propagator in this parameter. The solution of the mixed-quantum classical equations can be expressed in an iterative form and solved by means of hybrid molecular dynamics - Monte Carlo algorithms whose accuracy increases with the order of the iteration. Tests on standard benchmark models (such as the spin-boson system) have proved that our methods are indeed capable of describing non-adiabatic processes [2,3]. Current research is focused on two technical fronts: improvements the algorithmic properties of the methods and further theoretical analysis to clarify their relationship and relative accuracy [4]. Progress in these areas is crucial for our goal of non-adiabatic applications to systems as complex as those that we have studied in the past with Born-Oppenheimer mixed quantum-classical methods (e.g. the diffusion of an excess electron in a metal-molten salt solution).

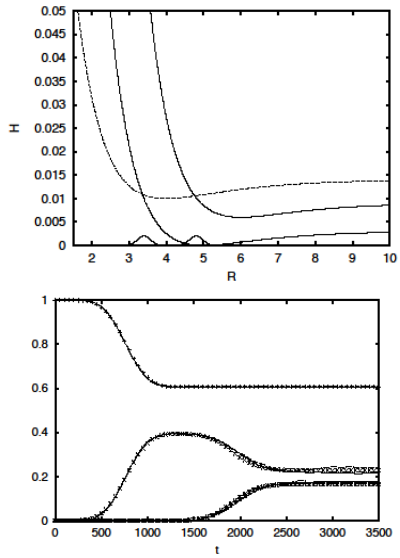

Figure 1: Simulation of a photodissociation experiment for a diatomic molecule [3]. Upper panel: schematic representation of 3 molecular electronic states and of the couplings among them plotted as a function of the internuclear distance. Bottom panel: time evolution of the probability to find the system on the different states (i.e. of the population of the states) after photoexcitation of the molecule on state 1 (solid line in the upper panel). The changes in the populations reflect the non-adiabatic transitions among the states.

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C22. Computer simulation of rare events and non-equilibrium phenomena

Computational physics, in particular molecular dynamics (MD), adopts an atomistic representation of matter, with model or ab initio interaction potentials, and solves numerically the evolution equations of the system. Statistical mechanics links the microscopic evolution to macroscopic properties and provides the framework to employ simulations to understand and control materials by acting at the nano-scale. Our group develops methods to make simulations more effective theoretical tools and applies them to investigate condensed matter. Two important areas of research are rare events and non-equilibrium MD.

Rare events are characterized by time-scales much longer than those accessible by brute force MD. In an appropriate set of collective variables, they can be described as transitions, over barriers higher than the thermal energy of the system, among metastable states of the free energy landscape. Chemical reactions, phase transformations, nucleation processes, and conformational changes related to the functionality of proteins are just a few examples of rare events. In collaboration with Eric Vanden-Eijnden (Courant Institute for Mathematical Studies), our group has contributed to establishing a set of methods that, appropriately combined, determine the most relevant aspects of rare events: free energy landscape, rate, mechanism. Recently, we used these methods to characterize the short-range diffusion of hydrogen in sodium alanates [1], prototypical materials for building safe and cost-effective storage devices for using hydrogen to fuel sustainable vehicles. The same

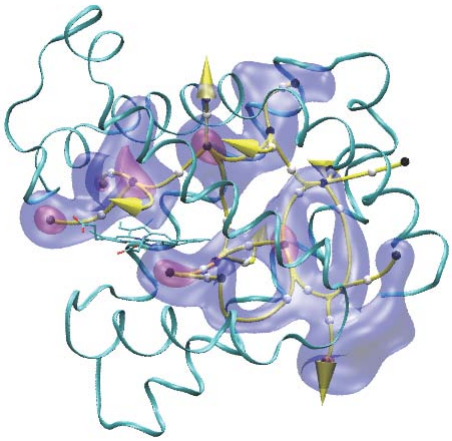

Figure 1: CO diffusion in myoglobin. The yellow curves are the most likely migration paths, while the arrows locate CO exits to the solvent. The white and black spheres indicate, respectively, the free energy barriers and minima along the pathways. The protein backbone is represented as ribbons and the heme as sticks.

methods were employed to map the exit pathways and the binding sites of CO in myoglobin and to study the kinetics of phase transitions in the Ising model [2].

Non-equilibrium MD. Perturbing a system from equilibrium is a common experimental method to study its properties. Transport coefficients (shear and bulk viscosity, thermal conductivities etc.) are often measured by creating a flow (of momentum, energy, etc.) in the material. Standard MD cannot be used directly to simulate a system in non-equilibrium conditions. A few years ago, we introduced a method, the dynamical approach to non-equilibrium (D-NEMD), that allows to obtain rigorous ensemble averages for properties of a non-stationary system out of equilibrium via MD trajectories. D-NEMD can be used to study both the steady state and the transient evolution of a system out of an initial stationary state and it can be applied also in the presence of a time-dependent perturbation that takes the system to a non-equilibrium final state. Calculations of the bulk viscosity of the triple point Lennard-Jounes fluid were performed [3] to prove the accuracy of the method compared with Green-Kubo estimates. More recently, the method has been applied

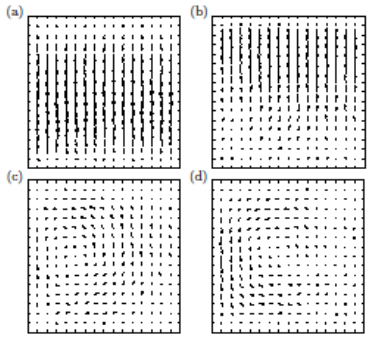

Figure 2: Snapshots of the velocity field in the 2d fluid at successive times during the D-NEMD simulation [4]. The development of the velocity roll in panel (d) reflects the response of the system, initially in a steady state under the effect of a thermal gradient (panel (a)), to the ignition of gravity. The system here is heated from below.

to study the transient leading to the formation of a convective cell which appears in a two dimensional fluid under the combined action of a thermal gradient and of gravity[4].

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C23. Polyelectrolyte-colloid complexes as innovative multi-drug delivery systems

Different charged colloidal particles have been shown to be able to self assemble when mixed in an aqueous solvent with oppositely charged linear polyelectrolytes, forming long-lived finite-size mesoscopic aggregates [1].
In fact, when a suspension of electrically charged colloidal particles and a solution of oppositely charged linear polyelectrolytes are mixed together, due to the long-ranged electrostatic interactions, and to the comparatively lower diffusivity of the bulkier particles, the polyelectrolyte chains rapidly diffuse in the whole solution and adsorb on the particle surface. The adsorption, due to the repulsion between the like charged chains, occurs in a 'correlated' manner. The resulting *polyelectrolyte-decorated particles* interact through a potential which is the superposition of a screened electrostatic repulsion due to the residual net charge of the pd-particles, of the attractive forces due to the non-uniform distribution of the surface charge, and of dispersion forces. The net result is an adhesive effect of the adsorbed polyelectrolytes, acting as an 'electrostatic glue'.

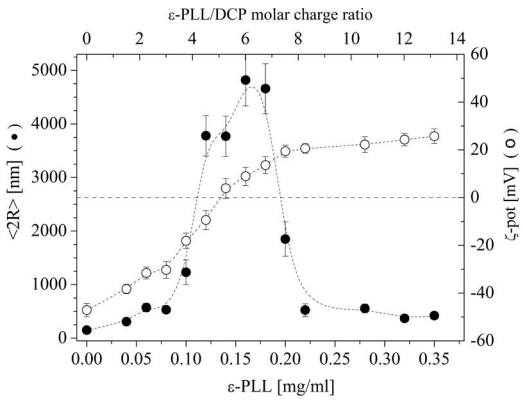

Figure 1: The typical 'reentrant' condensation of charged colloidal particles induced by an oppositely charged polyelectrolyte. The average hydrodynamic diameter $< 2R >$ and the average ζ- potential are shown as a function of polyelectrolyte concentration (bottom) or the corresponding polymer/particle charge ratio (top).

At increasing the polyelectrolyte content, with the progressive reduction of the net charge of the primary polyelectrolyte-decorated particles, larger and larger clusters are observed. Close to the isoelectric point the aggregates reach their maximum size, while beyond this point any further increase of the polyelectrolyte-particle charge ratio causes the formation of aggregates whose size is progressively reduced (Fig. 1). This 'reentrant' condensation behavior is accompanied by a significant 'overcharging', or charge inversion, i.e. more polyelectrolyte adsorbs than needed to neutralize the particle charge and eventually the sign of the net charge of the decorated particle is reverted.
Recently we proposed a model that takes into account the observed phenomenology in terms of a fine balance between long range repulsive and short range attractive interactions, both of electrostatic nature, and van der Waals forces [2,3].
This complex phenomenology has been observed for different polyelectrolytes in a variety of water dispersed colloids, such as micelle, latex particles and lipid vesicles.

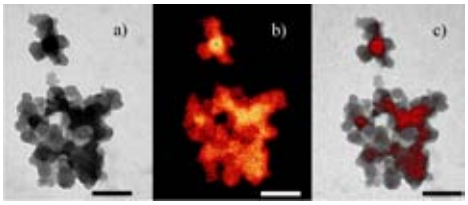

Figure 2: ESI-TEM image of a typical polyelectrolyte-liposome cluster. The cluster results from the polyelectrolyte induced aggregation of liposomes loaded with two different concentration of a Cs salt that gives a strong contrast in TEM images. Panel b) shows the 'Cs map' of the aggregate. In this image red-gold levels correspond to variations in the Cs concentration. Bars represent 100 nm.

In the last few decades, there has been a growing interest toward the use of delivery system for a more effective treatment of infectious diseases and cancer, and the interest of the scientific community increasingly focused on designing innovative solutions based on intra-cellular vectors. In this context, nano-technologies based on the self-assembly of macromolecules resulting in nano-sized complexes could play a key role, promising a tremendous potential for developing new diagnostic and therapeutic tools, as genuine 'nano-devices', able to interact with biological systems at molecular levels and with a high degree of specificity. Polyelectrolyte-colloid complexes appear a promising route to designing multi-compartment vectors for multi-drug delivery.

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C24. Nano-engineering of colloidal particles: Characterization of novel supra-molecular structures with hierarchical architecture for biotechnological applications

Systems of interacting colloidal particles and oppositely charged polymers have recently attracted great interest, due to their relevance in a number of biological and technological processes, but even more to the fact that their dynamics and out-of-equilibrium properties offer unceasing challenges. These complexes show a rich and fascinating phenomenology yet poorly understood. In the last few years, in our laboratory, various novel core-particle aggregates have been prepared by electrostatic self-assembly of polyelectrolytes (and nanoparticles) with oppositely charged lipid liposomes. The use of non-covalent forces provides an efficient method to position the polyelectrolyte chain in a well-defined supramolecular architecture. In addition, it is possible to control the macroscopic properties of the assembly through an external environmental stimulus.

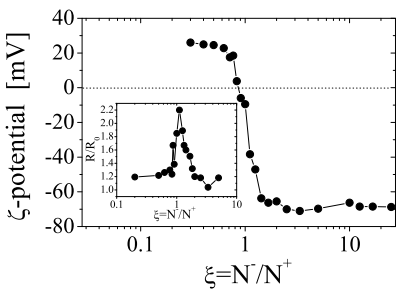

Figure 1: ζ-potential of PAA-induced lipoparticle aggregates as a function of the molar ratio $\xi = N^-/N^+$. The charge inversion effect changes the overall charge of the aggregates from positive(lipoparticles in the absence of PAA) to negative, after the adsorption in excess of PAA chains. The inset shows the ratio $R/R0$ of the radius of the aggregates normalized to the radius of the barelipoparticle as a function of the ratio $\xi = N^-/N^+$. This behavior is typical of the reentrant condensation effect.

In particular, we are dealing with polyelectrolyte-lipid complexes (lipoplexes) in aqueous solutions, consisting of linear, highly charged, anionic polyelectrolytes and oppositely charged (cationic) liposomes. We were able to demonstrate (by means of dynamic light scattering, laser Doppler electrophoresis, dielectric spectroscopy and TEM techniques) that three-dimensional structure can be created from polyelectrolyte-coated liposome described above. This system is characterized by the presence of a pronounced "charge inversion" effect that is responsible for the formation of large equilibrium clusters. Moreover, under certain conditions, this cluster phase seems to undergo a gelation process, exhibiting an aging behavior. "Charge inversion" occurs when at the surface of a mesoscopic charged particle more

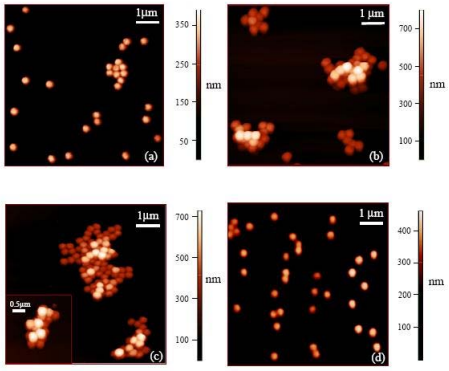

Figure 2: AFM images taken in air of mixtures of ϵ-PLL-polystyrene particle aggregates, induced by adding different amount of ϵ-PLL solution. (a): below the isoelectric condition; (b): close to the isoelectric point on the left side; (c) close to the isoelectric point on the rightside; (d): above the isoelectric condition. The inset in panel c) shows a detail of a single cluster.

counterions than necessary to neutralize it collapse. As a consequence, the resulting complex displays an overall charge, whose sign is opposite to the one the particle originally bears. This phenomenon, associated with the strong lateral correlation between adsorbed counterions, depends on counterion valence and size. When oppositely charged macro ions of comparable size and valence interact, as is the case of anionic polyelectrolytes interacting with cationic liposomes, charge inversion assumes a considerable extent ("giant" charge inversion). Concomitant to the charge inversion, as a print for the formation of a cluster phase, a reentrant condensation appears (Fig. 1). Our attempt is to use this approach to allow polyelectrolytes to adsorb onto an oppositely charged surface of the lipid vesicle in order to form highly structured aggregates. This new class of micron-scaled colloids with unusual properties adds to the array of existing hollow materials and expands the range of possibilities with respect to technological and drug delivery applications.

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C25. Biopolymer Vesicle Interactions

The interactions between biopolymers (proteins or nucleic acids) and self-assembled surfactants have raised increasing interest within the scientific community. Studies along these lines constitute an interdisciplinary approach of chemical/physical nature at the biomolecular level. In addition to so much intrinsic interest, the investigations contribute to important applications in biomedicine as gene therapy. Synthetic vectors, such as liposomes, represent an interesting alternative to viral delivery systems. However, they are rather difficult to prepare and generally have limited stability and shelf life duration. A new class of self-assembled amphiphilic aggregates, called cat-anionic vesicles, has been developed in recent years, and their chemical-physical properties have been exhaustively characterized. The acronym cat-anionic defines surfactant aggregates formed by non-stoichiometric amounts of anionic and cationic surfactants coexisting with tiny amounts of simple electrolytes. Cat-anionic vesicles are easily prepared and very stable.

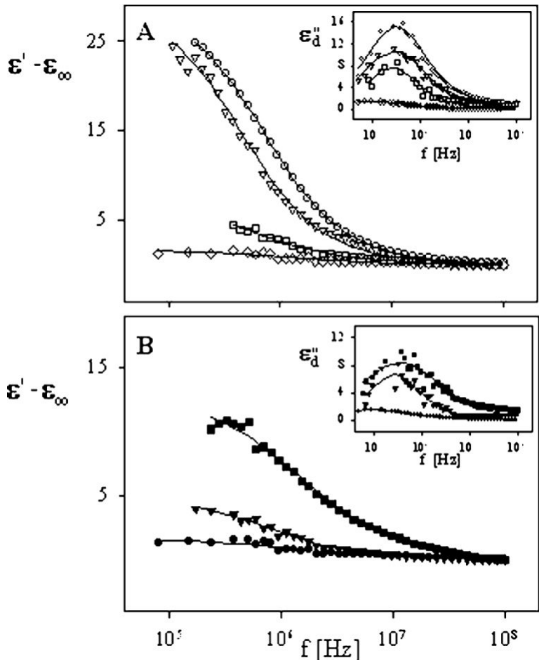

Figure 1: Dielectric dispersion of DDAB-SDS vesicle suspension with increasing DNA content. R is the molar ratio. Panel A: bare vesicles, R=0, (○); R=0.2, (▽); R=0.4, (□); R=0.6, (◊). Panel B: R=0.6, (●); R=1.2, (▼); R=1.5, (■). The insets show the dielectric relaxation loss.

The biophysical characterization of vesicle - biopolymer interactions may contribute to a better use of these surfactant aggregates in biotechnology. A biophysical approach, mainly based on the combination of biochemical assays, electrochemical and spectroscopic techniques, is used in our laboratory. Different surfactant systems interacting with proteins and DNA were investigated. A fully fluorinated surfactant, lithium perfluorononanoate, induces a molten globule conformation for lysozyme [1]. The formation of lipoplexes among proteins and SDS-CTAB vesicles was characterized [2]. Other work concerns studies of DNA interacting with several cat-anionic vesicles [3, 4]. In particular, an investigation on DNA, interacting with SDS-DDAB cat-anionic vesicles, was performed, mainly used dielectric relaxation (Fig. 1) and Zeta-potential (Fig.2) techniques.

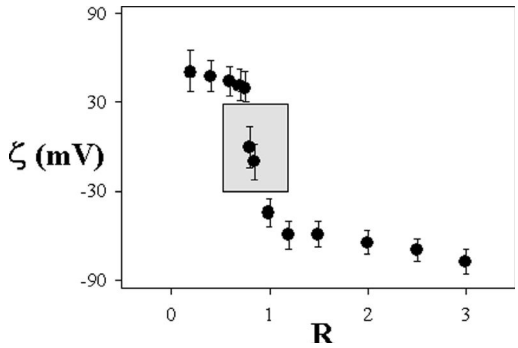

Figure 2: Zeta-potential as function of DNA in the vesicular pseudosolvent, expressed in terms of molar ratio R. The gray area indicates the region where complexes tend to flocculate.

The shift to near zero values of the dielectric increment and Zeta-potential, caused by the addition of DNA to the vesicular suspension and the occurence of a subsequent contribute of the nucleic acid, at higher concentrations, clearly demonstrates the electrostatic nature of the interactions (Fig. 1, 2). The conditions of saturation of the molecular bond were established. Important indications about the structural arrangement of DNA on the vesicle surface were achieved. Finally, the possibility of a controlled release of the bio-macromolecule was verified.

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C26. Biomolecules-lipid membranes interaction study : A contribution to gene therapy and drug delivery

Solid-supported lipid-films are considered as an attractive and useful model system for biological membranes and have been extensively studied as a peculiar class of materials due to their potential applications in various fields. In particular, amphipathic lipid films on solid support allow the study of structural investigation of important biological model systems such as the vector like lipid membranes, in order to improve DNA transfection in non viral gene therapy and as a template for nanostructure construction. In fact polyanionic DNA binds to cationic lipids to form electrostatic complexes, exhibiting, due to the amphipathic lipid structure, rich self-assembled ordered structures with different delivery efficiency through membrane cells. Moreover, the transfection efficiency of lipid-DNA complexes into cells can be increased by means of the inclusion of a neutral lipid which helps the cationic one in forming and maintaining lipid-DNA linkage. Selfassembled crystal-liquid phases of cationic and neutral amphipathic lipid molecules are very sensitive to the chemophysical properties present at the interface between the systemand the surrounding environment, such as theair temperature and relative humidity. By means of the use of flat semiconductor interface as solid substrate, to obtain an airbiofilm- slide system, which maintains the structural characteristic of the liposome aggregation, we are able to monitor the biofilm stereochemical arrangement controlling both temperature and relative humidity parameters of the air interface. We found [1-2] that the mixture of cationic/neutral lipid system which was deposited on silicon wafer by spin coating, was ordered as multiple bilayers with the presence of micron-sized clusters; DNA strand can influence such cluster formation without managing to organize itself within the mixture. Recently, by means of neutron reflectivity at the CRISP reflectometer at ISIS pulsed neutron source facility, we enlighten the lyotropic behaviour of silicon supported neutral lipid DOPC and cationic lipid DDAB with respect to the property shown by their mutual interaction under saturated deuterium oxide vapour, pointing out that the lipid mixture is organized in ordered domains composed of plane lamellar bilayers of non interactive DOPC and DDAB. Such biphasic arrangement weakens the helper role of DOPC thus favouring the DNA-lipid complex formation.

Other measurements we performed by in house X-ray diffractometer [3] devoted to stress the influence of the temperature on the lipid cluster formation in the mixture DOPC-DDAB, showed that at temperature higher with respect to the crystal gel-crystal liquid phase transition temperature of the DDAB, the mixture dissolves the biphasic structure on behalf of a single thermolyotropic mesophase. Furthermore DNA presence in the biphasic lipid structure lowers the temperature of the cluster dissolution and at $37°C$ is able to form single ordered structure.

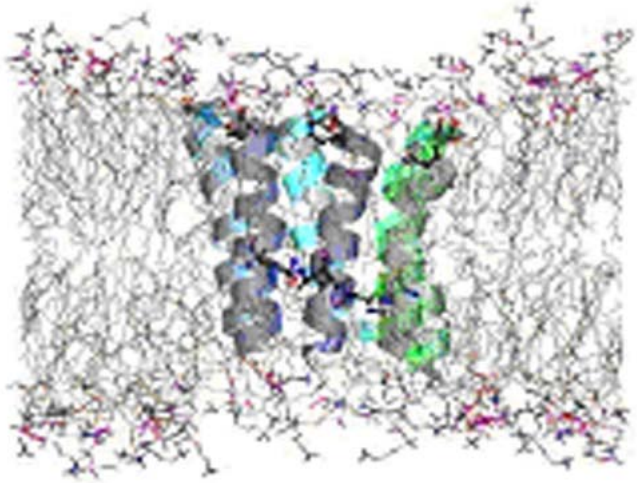

Figure 1: Peptide pore in lipid membrane.

Our research is now focused on other mechanisms able to delivery drugs, proteins, plasmid and genes into viable cells (tumoral or not). Recent studies show that the ultrasound can be used to deliver biomolecules into the cells offering attractive opportunities as non-invasive efficient therapy. By using a coordinate combination of FTIR Spectroscopy, Microscopy, EPR and Flow Cytometry techniques, we have analyzed the cellular processes (such as apoptosis and membrane poration) induced by different external agents [4].

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http://phys.uniroma1.it/gr/MOC-BIO/index.htm

C27. FT-IR spectroscopy of proteins

A. Nutritionally relevant proteins. A novel research line has recently been developed, aimed at the evaluation of the relationship between structural properties of proteins of nutritional relevance, as examined by FT-IR spectroscopy, and nutrient utilization. This research is in collaboration with the Istituto Nazionale di Ricerca per gli Alimenti e la Nutrizione (scientific responsible M. Carbonaro). Fourier-Transform InfraRed (FT-IR) spectroscopy has been recognized to have several advantages over other spectroscopic techniques for the study of proteins in biological systems. In particular, structure of food proteins with low solubility, such as plant proteins in denatured states, has been successfully determined by FT-IR [1]. The secondary structure of plant and animal proteins of nutritional relevance have been studied by Diffuse Reflectance FT-IR spectroscopy (DRIFTS). The results obtained on several proteins with different structures have been validated by a comparison with X-ray crystallographic and IR/Raman semiquantitative data available from the literature.

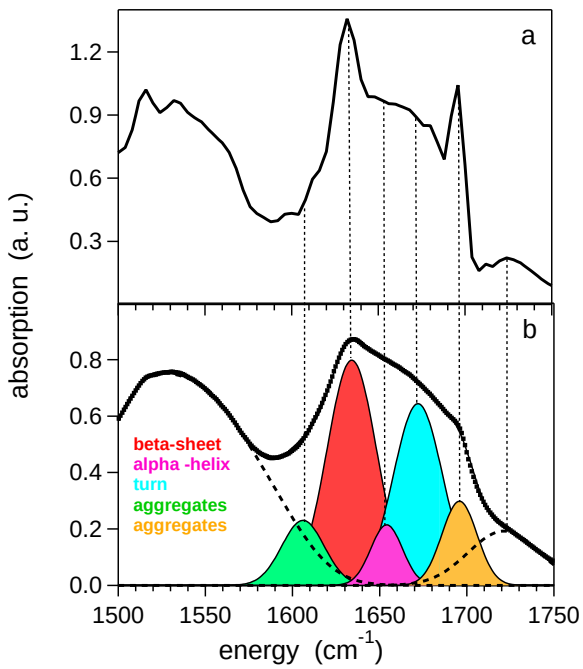

Figure 1: Absorption spectrum of *Concanavalin A* in the region of the Amide I. Panel(a): Fourier self- deconvolved amide band. Panel(b): single Gaussian contributions.

The same procedure has been applied to analysis of proteins in whole food matrix, and differences in the secondary structure of proteins between untreated and processed foods have been detected. Besides to major amide I contributions: β-sheets (1633-1638 cm^{-1}), random coil (1649 cm^{-1}), α-helix (1654-1658 cm^{-1}) and β-turns modes (1671-1678 cm^{-1}), minor contributions at 1606-1620 cm^{-1} and 1690-1696 cm^{-1} from antiparallel β-sheet structures have been quantified [2].

Application to legume seed flour analysis allowed to monitor changes in protein secondary structure that occurred upon heat processing of increasing intensity. Results have indicated that high amounts of multimeric complexes are formed from food proteins of plant origin with different mechanisms, depending on the initial content in β-sheet structure. Moreover, the higher the content in β-sheet structure, the higher was the stability of the complexes: this feature is likely to adversely affect protein utilization and may represent a detrimental factor on the overall nutritional quality [3].

B. Infrared Spectroscopy of Immobilized Enzymes on Nanostructured Polymers. Enzymes are biomolecules that catalyze the chemical reactions. Almost all processes in a biological cell need enzymes to occur at significant rates and biodegradable polymers such as poly(lactic acid) may often be utilized as drug delivery systems because their degradation products are metabolized in the human body. Suitable enzyme delivery supports should maintain a high level of enzyme activity, while preventing a possible leaching out during the reaction. Particles of nanoscopic size are very well-suited for the immobilization of enzymes as they provide large surface areas. In this research we have investigated Lipase which increases its specific activity when is immobilized on nanostructured polymers. We have shown by FT-IR spectroscopy through the study of amideI-II lipase bands, that this activity enhancement can be related to a modification of the α/β ratio [4]. Further investigations will be dedicated to improve the specific activity of Lipase, linking the α/β ratio to the size of the nano polymer.

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C28. Femtosecond Stimulated Raman Scattering: ultrafast atomic motions in biomolecules.

Chemical bonds form, break, and evolve with awesome rapidity. This ultrafast transformation is a dynamic process involving the mechanical motion of electrons and atomic nuclei. The speed of atomic motion is of the order of 1 km/s and, hence, the average time required to record atomic-scale dynamics over a distance of 1 $\AA$ is in the range of 100 femtoseconds (fs). Physiological bond formation, evolution and breaking between proteins and ligands occur on this timescale. Tracking each step of this process can provide significant insight on biological function, hence the need of a spectroscopic technique capable of revealing the structure of molecules on the timescale of atomic motion.

Femtosecond stimulated Raman scattering spectroscopy (FSRS) is a powerful method to study reaction dynamics as it provides vibrational structural information with an unprecedented combination of temporal and spectral resolution, unconstrained by the Fourier uncertainty principle. FSRS requires the generation of three synchronized pulses: (1) A femtosecond visible actinic pump that initiates the photochemistry of interest, (2) a narrow bandwidth picosecond Raman pulse that provides the energy reservoir for the amplification of the probe, and (3) a femtosecond continuum probe that is amplified at Raman resonances shifted from the Raman pulse.

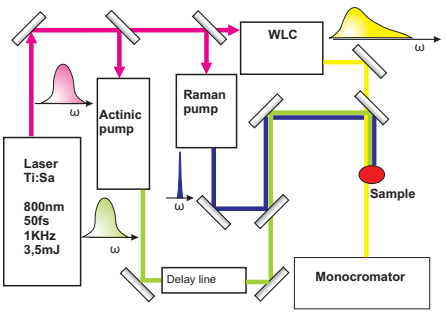

Figure 1: Schematic diagram of the FSRS setup.

Since 2009, the *Femtoscopy* group in the department of Physics in *Sapienza* has worked in the implementation of a FSRS experimental setup. In our setup, the actinic pulse is derived from an optical parametric amplifier system (TOPAS) that generates pulses with 10 $\mu J - 0.7$ mJ energy and tunability from 250 to 1200 nm. As Raman pulse, we have produced an 800 nm narrow bandwidth (0.5 nm) pulse by linear spectral filtering of the output of the titanium:sapphire (1 kHz, 3 mJ, 35 fs pulses at 800 nm) amplified (Legend, Coherent), by a custom grating filter. More recently, we developed a broadly tunable narrow band Raman Pulse, by means of a two-stage femtosecond visible-IR OPA which can generate pulses with $3-5$ μJ energy and linewidth ranging from $10-15$ cm^{-1}. Its tunability ranges from 330 to 510 nm which will allow us to exploit the resonance enhancement of various proteins that absorb in the visible.

In Fig.2 we show the results of our first experiments: the Stimulated Raman Scattering signal of a reference solvent (cyclohexane) obtained with both the grating ($\lambda = 800$nm) and the tunable ($\lambda = 480$nm) Raman pulse setup. The overlap of a Raman pump and a broadband continuum onto the sample allows the simultaneous detection of all the Raman active modes with a single 40fs laser shot, opening the possibility of time resolved studies in the $<$ 100fs time domain, unaccessible to conventional vibrational spectroscopies.

Our short term goal is to apply FSRS to study the dynamics of heme proteins with different biological functions (electron transfer , signaling, etc.). We are also working on multidimensional implementations of FSRS to study anharmonic coupling of small molecules as well as on imaging extensions of FSRS (CARS/SRS Microscopy).

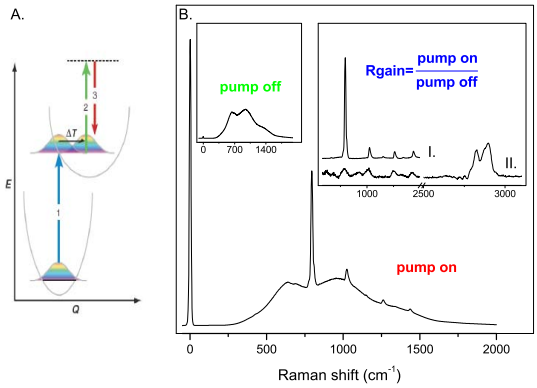

Figure 2: **A.**Energy-level diagram for a typical time-resolved FSRS experiment. **B.** FSR spectra of cyclohexane obtained with Raman pump at 800 nm (I) and 480 nm (II).

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C29. Quantum phenomena in complex matter

Our interest has been to study the role of quantum interference between different scattering channels driven by exchange interaction. This mechanism was introduced by Ugo Fano in the paper published in Nuovo Cimento in 1935 following a proposal of Sergio Segrè and Enrico Fermi. The topic was previously of interest to Ettore Majorana but he did not publish the work, that was left in his unpublished manuscripts. This resonance due to quantum interference was called Risonanza di Forma by Enrico Fermi, the Shape Resonance, that manifest itself in a negative and positive quantum interference between open and closed scattering channels. In 1955, the work of Fano was extended by Feshbach to many body systems for interpretation of interference between open and closed scattering channels in the nuclear physics.

Cooperative quantum phenomena have been proposed by some authors to be needed for understanding the cooperative phenomena observed in living matter and in its evolution. The key physical problem is that a quantum macroscopic condensate of interest for understanding cooperativity in living matter should occur at room temperature. This hypothesis is in contrast with all our knowledge. In fact, in a standard homogenous system it is known that the Bose-Einstein condensation for bosons, or the BCS condensation for fermions should appear only near the absolute zero temperature. It has been noted in 1993 by our group that this type of interference in a many body fermionic system, made of two distinguishable particles with attractive interaction between similar particles and repulsive interaction between different particles, could increase the critical temperature for the formation of superfluid condensates. This phenomenon could allow the formation of a superfluid like condensate at room temperature. In the same year it was independently proposed by Stoof in Leiden that an atomic Feshabach resonance for atomic association ad dissociation in a bosonic gas could increase the critical temperature for the Bose-Einstein condensation.

The work we have been doing these last 3 years focus on the fact that the Fano-Feshbach resonance take place a phase separation regime between the distinguishable particles in the proximity of a quantum critical point. We have investigated, first, how this type of phase separation can be manipulated by illumination, studying the simple case where photo-illumination induces a disorder to order phase transition [1]; second, the simple case of phase separation between a liquid and a striped-liquid driving in the presence of anisotropic interaction [2]. We have studied the Fano-Feshbach resonance and nanoscale phase separation in a polaron liquid near the quantum critical point for a polaron Wigner crystal [3]. Finally we have presented a scenario where the emergence of life in our universe is related with the onset a the mechanism based on Feshbach Resonance for association and dissociation of biological molecules [4].

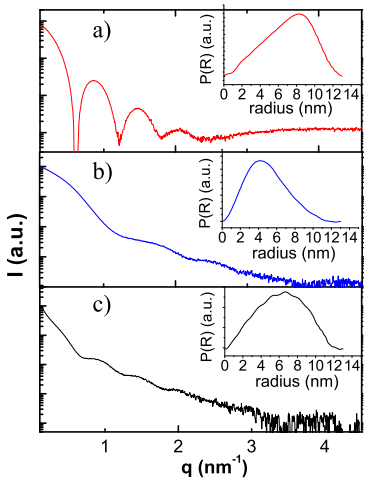

Figure 1: I(q) vs q for an apoferritin solution incubated in different concentration of Al(III) and Fe(II). a: apoferritin; b: apoferritin in Fe(II), c: apoferritin in Al/Fe. In the insets are distribution functions from the SAXS.

Recently we are working on two projects. The first concerns the conformation landscape of a protein without secondary structure: τ-protein where the dynamic fluctuations are expected to be fast and to control the biological function. The second project concerns the study of the ferritin , the main iron storage protein in living systems. Ferritin is a stable complex forming an hollow sphere (apoferritin) filled with a Fe(II) oxide core. The ferritin core composition differs between pathological and physiological conditions. In particular clinical conditions, plasma ferritin can be filled with metal other then Fe, such as Al. We are studying the shape and metal content variations of plasma ferritin extracted from different clinical patients, by means of small angle X-ray scattering (SAXS), mass spectroscopy and light scattering techniques. Moreover we are developing an in-vitro model of the aluminium uptake in ferritin. Fig. 1 an example of the pair distributions obtained from the SAXS, an effective technique to detect ferritin core variations.

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C30. Holographic optical tweezers: hands of light on the mesoscopic world

The mesoscopic world lies in between our macroscopic world and the microscopic world of atoms and molecules. Although phenomena are mainly governed by the laws of classical physics it looks much different than the world we live in. When shrinking the length scales from meters down to microns, the balance between forces changes dramatically: there is no inertia and viscous forces dominate, thermal agitation moves objects around in perpetual Brownian motion, surface forces are very strong and light pressure can exert a significant force. Optical forces are indeed ideally suited to manipulate matter at the mesoscale which is characterised by length scales ranging from ten nanometers to hundreds of micrometers, femtonewton to nanonewton forces, and time scales from the microsecond on. In 1986 Arthur Ashkin demonstrated that a tightly focused laser beam can stabily trap a micron sized dielectric object in 3D. Since their appearance optical tweezers have been applied to study mesoscopic phenomena in biology, statistical mechanics and colloidal science. The commercial availability of Spatial Light Modulators (SLM) opened new horizons to optical micromanipulation. SLMs are typically computer controlled liquid crystal minidisplays allowing to arbitrarily shape a wavefront by imposing a pixel by pixel phase shift on an incoming laser beam. Such an engineered wavefront can be focused into a tiny hologram image made of bright light spots in 3D, each spot serving as an independent point trap. What makes holographic optical trapping (HOT) very powerful is that it provides a contactless micromanipulation technique with many body, dynamic, 3D capabilities.

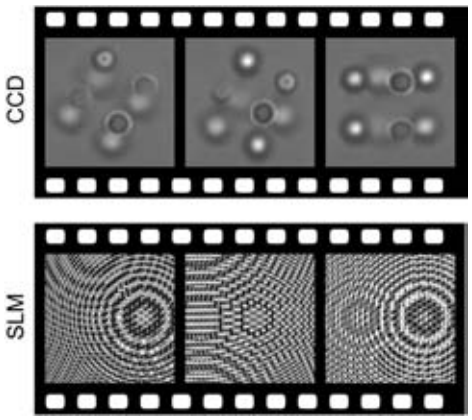

Figure 1: Frames from a movie† showing the interactive micro-manipulation of 8 silica beads (2 μm diameter) in water. The beads are arranged on the vertices of a 5 μm side cube which is then rigidly rotated. Bottom row shows the corresponding frames (holograms) displayed on the SLM.

We have contributed to HOTs technology by designing a novel iterative procedure for computer generated holograms with an unprecedented degree of efficiency and uniformity [1]. Using light as a tool for multi particle manipulation we have developed light driven devices and sensors for lab on chip applications such as an optical driven pump or multipoint velocity or viscosity probes for microfluidic channels [2]. When particle positions are tracked with digital video microscopy, light forces can be accurately calibrated so that HOTs also provide a unique tool to probe forces in controlled geometries. Trapping and isolating a pair of colloidal particles far away from other beads and confining walls, we could directly investigate very long ranged forces, such as the capillary or hydrodynamic interactions arising in thin fluid films [3]. HOTs also provide a very convenient tool to investigate the statistical mechanics of small systems by providing a reconfigurable optical energy landscape for Brownian motions. For example, trapping aerosol droplets with a time varying strength, we demonstrated that parametric resonance can be excited in a Brownian oscillator [4].

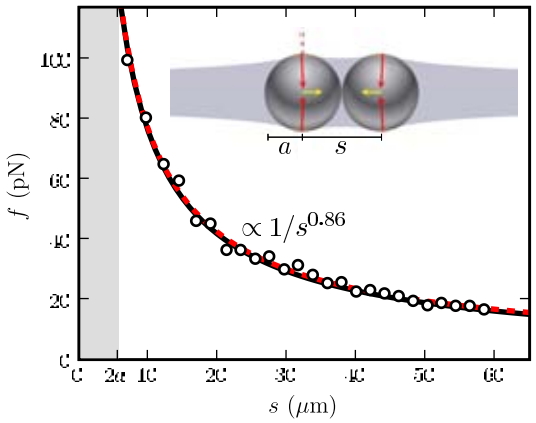

Figure 2: Two colloidal particles confined in a liquid film thinner then their diameter attract each other with a strong and long ranged capillary interaction.

Although single or dual trap optical tweezers have already boosted research in single cell and single molecule biophysics, we are only beginning to explore the full potential of 3D, multi-trap, dynamic holographic micromanipulation of biological structures.

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C31. Electronic properties of novel semiconductor materials investigated by optical spectroscopy under intense magnetic fields

The use of magnetic fields combined with optical spectroscopy techniques is a most powerful means to address the fundamental electronic properties of solids and, specifically, of semiconductor materials. Magnetic fields with relatively high intensity (B¡20 T) can be reached in small-scale laboratories, whilst large facilities are nowadays available worldwide to researchers for using fields up to 45 T (continuous) and up to 100 T (pulsed). As well-known from atomic physics, magnetic fields remove eigenstate degeneracy or uncover hidden symmetries. In bulk and nanostructured semiconductors, the electronic states in a magnetic field are arranged in Landau levels consisting of discrete eigenstates. These Landau orbits are the quantum mechanical analogue of classical cyclotron orbits and allow determining fundamental band structure parameters, such as the effective mass of charge carries. However, in optical experiments, the concomitant presence of (positively charged) holes and electrons leads to the formation of Coulomb-like bound pairs, referred to as excitons (the analogue of the hydrogen atom in solids). In semiconductors, excitons can be stable up to room temperature and dominate the emission properties of most materials and nanostructures. Thus, several model calculations have been developed in order to reproduce the field dependence of the recombination (or absorption) spectra of magneto-excitons.

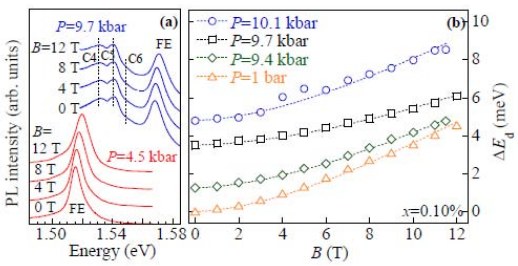

Figure 1: (a) PL spectra at T=90 K for different magnetic fields B and two hydrostatic pressures on a GaAs1-xNx sample (x=0.10%). FE and Ci indicate the free-exciton and N complex-related recombinations, respectively. (b) Dependence of the free-exciton diamagnetic shift ?Ed on magnetic field for different pressures in a GaAs1-xNx sample with x=0.10%. The dashed lines are a fit to the data by means of the model reported in [1]. The exciton reduced mass is the only fitting parameter.

To this regard, magneto-photoluminescence (m-PL) experiments are conveniently used whenever the fundamental properties of novel semiconductor materials or nanostructures are being investigated. This is the case of dilute nitrides, such as Ga(As,N), which feature surprising physical properties and qualitatively new alloy phenomena, e.g., a giant negative bowing of the band gap energy and a large deformation of the conduction band structure. This latter has been successfully investigated by combining a magnetic field (B up to 12 T) with hydrostatic pressure (P up to 10 kbar). P allows tuning the relative energy position between the conduction band minimum and nitrogen-cluster levels, while B permits to determine the electron effective mass for each relative alignment between those states (see Fig. 1). In this manner, it was discovered that the whole electronic properties of Ga(As,N) are indeed determined by a hierarchical distribution of N cluster energy levels [1]. Intriguing behaviors in other technologically relevant semiconductors have been revealed by m-PL under very intense fields (B up to 30 T). In Ga(As,Bi), an alloy of interest for spintronics and telecommunications, the exciton reduced mass value reveals an unexpected influence of Bi complexes on both the valence and conduction bands of the crystal [2]. In InN, a material having great importance for photovoltaics and transport applications, the Landau levels were measured for the first time by m-PL up to 30 T [3] in samples, whose electron concentration was tuned on-demand by post-growth hydrogen irradiation (see Fig. 2) [4]. This shed new light on the influence of native as well as of purposely incorporated hydrogen donors on the transport properties of InN.

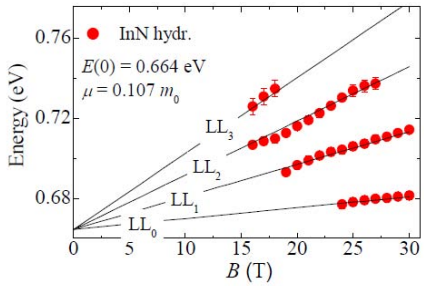

Figure 2: Energies of the Landau level, LLn, transitions measured in an InN sample treated with hydrogen. The value of the band gap energy at B=0 T, E(0), and the value of the carrier reduced mass, , are used as fit parameter.

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C32. Hydrogen-mediated nanostructuring of the electronic and structural properties of nitrogen-containing III-V semiconductors

The synthesis of nanostructured semiconductors is incessantly boosting the number of opportunities in the field of electronics and photonics, as well as in the investigation of fundamental quantum phenomena in top-bench experiments. The control and modification of the physical properties of semiconductor heterostructures at nanometre scale lengths can be obtained by several approaches. Layer-by-layer deposition of materials with different chemical composition and thickness, which is typical of modern epitaxial growth techniques, allows achieving carrier confinement in a two-dimensional potential (or quantum well). The attainment of nanostructures with lower dimensionality, such as quantum wires (QWRs) and quantum dots (QDs), is not as easy and mainly two approaches have been attempted, so far. Top-down methods achieve carrier lateral confinement by chemically removing small portions of quantum well heterostructures previously processed by lithography. This leads to QDs and QWRs characterized by a large degree of uniformity, flexibility, and reproducibility but at the expense of very lengthy and costly processes. Alternatively, bottom-up methods exploit the self-aggregation of QDs in highly-strained heterostructures or the spontaneous formation of colloidal nanocrystals. The resulting nanostructures have very high optical efficiency and thus are very attractive for the fabrication of optoelectronic devices, optical imaging in biological systems, or for the generation of single photon sources for quantum computation. However, the lack of a control in the spatial arrangement of the single nanostructure and the large dispersion in QD size have so far hindered a full exploitation of self-formed QDs.

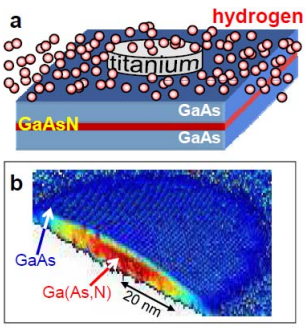

Figure 1: a. Schematic representation of the method leading to the formation of Ga(As,N) QD. b. Distribution of the N concentration (red: maximum; blue: minimum) in a Ga(As,N) QD. The vertical axis is 5 times exaggerated.

Dilute nitrides, such as Ga(As,N), are a new class of semiconductors with surprising physical properties and qualitatively new alloy phenomena, e.g., a giant negative bowing of the band gap energy (200 meV upon incorporation of 1% of N atoms in GaAs) and a large deformation of the conduction band structure [1]. This renders this alloy of high potential in several fields, such as optical fiber telecommunications, multi-junction solar cells, and Terahertz applications. Within this framework, we have developed a new method for achieving a band gap modulation in the sample growth plane without incurring in the main drawbacks of previous methods [2]. We showed that the incorporation of a suitable amount of hydrogen in Ga(As,N) modifies in a fully controllable and reversible way the band gap energy as well as the transport, spin and structural properties, which can be tuned on demand at any value intermediate between that of the as-grown material and that of the N-free lattice (GaAs) [3].

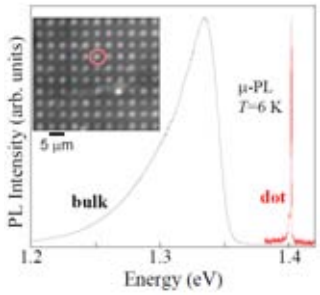

Figure 2: Comparison of the photoluminescence spectra of a bulk (black line) and a single Ga(As,N) QD (red line). Inset: Light emission from an ordered arrays of QDs. The red circle highlights the dot, whose emission spectrum is shown in the main part of the figure.

Hydrogen irradiation of these alloys performed through H stopping masks made of Ti and deposited by electron-beam lithography allows us to tailor the band gap in selected parts of the sample growth plane (see Fig. 1a). The size of the Ga(As,N)/GaAs heterostructures so achieved is limited only by H diffusion, whose front edge can be sharper than 5 nm thanks to the peculiar kinetics of H in these materials (see Fig. 1b) [4]. Finally, micro-photoluminescence shows that a true zero-dimensional confinement and an elevated degree of spatial ordering can be obtained by this approach (Fig. 2).

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http://chimera.roma1.infn.it/G29

C33. Electron-phonon interaction and electron correlation effects in low-dimensional structures

Low-dimensional structures present peculiar electronic properties associated to the reduced dimensions, where the electron-phonon interactions play a leading role. Exemplary low-D systems are the surfaces of single crystals when they present a reduced symmetry with respect the projected bulk-like geomtery or nanochains assembled on nanostructured templates. In the last few years we have analysed these systems, like interacting organic molecules on nanotemplates [1,2], or electron-phonon interaction in the prototypical semiconductor surfaces [3], and of reconstructued phases on metal surfaces [4]. Different phase structures in low dimensions systems can be a direct consequence of electronic instability versus lattice distortion, due to dimension reduction. Interplay between electronic properties and atomic geometry is then a key issue to characterize quasi-2D systems displaying charge density waves (CDW) and strong electron-phonon coupling, as for example sp-metals deposited on fcc(001) systems. Furthermore, strong electron-phonon coupling

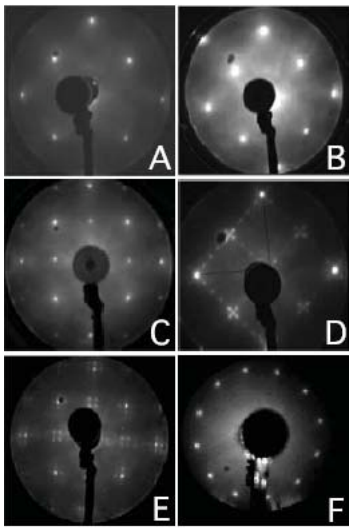

Figure 1: Electron diffraction patterns for Bi/Cu(100) system A) p(1×1) Cu(100); B) p(1×1) 0.2ML Bi; C) c(2×2) 0.5ML Bi; D) c($9\sqrt{2} \times \sqrt{2}$)R45° 0.7ML Bi; E) p(10×10) 0.8ML Bi; F) Bi bidomain hexagonal structure at about 140ML Bi.

(EPC) has been observed in Bi surfaces, where the competition between spin orbit effects and electron phonon interaction can inhibit the formation of a CDW. We have performed ARPES measurements in our LOTUS laboratory to characterize the electronic state dispersion of the Bi induced electronic states of the c(2×2), and p(10×10) phases, due to a strain-induced 2D array of dislocations. The periodicity in the different structural phases of a single layer of Bi deposited on the Cu(100) surface is reported in Fig. 1. The electronic state dispersion reproduces well the predicted band structure reported in Fig. 2, but we do not observe interface states crossing the Fermi level and the formation of a CDW. We observe a strong damping of the electronic features approaching the Fermi level due to a strong electron-phonon coupling. The transition from the c(2x2) phase to the p(10x10) phase strongly damps the Bi induced electronic states in the energy region close to the Fermi level, because of confinement effects induced by the domain wall formation (arrays of dislocations).

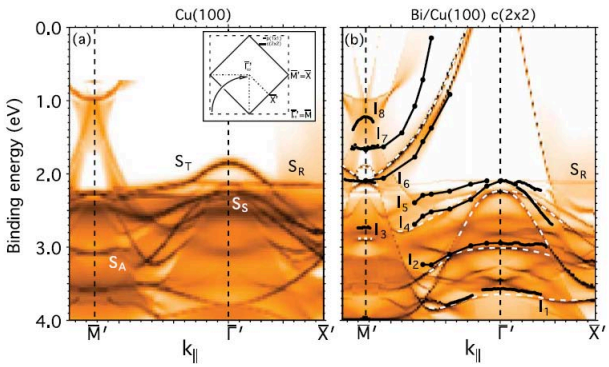

Figure 2: Theoretical electronic state dispersion for Cu(100) (a) and Bi/Cu(100) (b) along the $M'\Gamma'X'$ symmetry directions. S_i indicate the Cu surface states, I_i the Bi induced states. Comparison between measured (black lines) and theoretical I_i states (dashed lines) in the right panel.

A detailed analysis of the electron-phonon interaction has been performed from RT down to 8K. The results shows a linear dependence on the temperature, expected in a Debye model of phonon modes. By a linear fit of the electron mass enhancement parameter λ, as a function of temperature, we obtain equal $\lambda = 0.32$, much higher than the one reported for Cu either (bulk 0.14, surface 0.09) , thus indicating a stronger coupling due to the Bi overlayer. This is a prototypical example of a 2D system where the electron-phonon coupling is strongly enhanced with respect to the bulk value.

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http://server2.phys.uniroma1.it/gr/lotus/index.htm

C34. Design of electronic properties at hybrid organic-inorganic systems

The appealing optical, magnetic and transport properties of organometallic materials, the virtually unlimited choice of organic molecules and the processing flexibility of molecular films has led to exceptionally rapid progress in the development of organic devices over the past decade. Engineering of these devices requires an atomic level understanding of the parameters that control the structure and the function of these flexible molecular architectures. Today, several open questions enliven the scientific debate, primarily referred to organic/inorganic interface control (e.g. charge carrier injection, interaction at the interfaces, metal-semiconductor transition, spin coupling, etc.). Recent research has focussed on aromatic oligomers, whose pi-conjugation guarantees charge delocalization and electron mobility, an important issue for possible band-transport, and whose typical energy gaps lie in the visible energy range, with potential application in novel opto-electronic devices. A crucial issue for these organic-inorganic systems is the achievement of long-range order in exotic configurations (two-dimensional arrays, one-dimensional wires) such as to allow formation of exemplary hybrid structures with peculiar electronic properties.

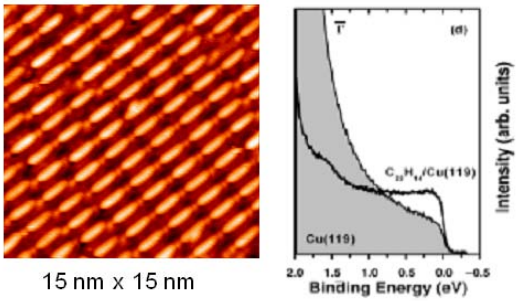

Figure 1: Pentacene nano-rails grown on Cu(119): (left) STM image; (right) electronic spectral density of states [1].

Within this appealing research field, in the LOTUS aboratory we have studied one-dimensional (1D) and two-dimensional (2D) highly-ordered structures of π-conjugated molecules assembled on single crystal metal surfaces, presenting nanometer-scale patterning. Well-ordered nano-rails of pentacene ($C_{22}H_{14}$) have been grown on the Cu(119) vicinal surface, whose electronic structure shows an enhanced density of electronic states at the Fermi level (Fig. 1), as confirmed by high-resolution angular-resolved photoemission (HR-ARUPS) and ab-initio calculations [1, 2]. The control of the electron/hole injection barrier has been determined using an organic buffer single-layer [3], whose mechanisms have also been explained by a theoretical model valid for a wide class of organic hetherojunctions[3].

Among the aromatic oligomers, metal-phthalocyanines (MPcs, M-$C_{32}H_{16}N_8$) are promising active elements for many optical, electronic and magnetic applications, and the central metal atom in MPcs can play a crucial role to establish the electronic/magnetic properties of the interface. A careful control of the nature and character of the induced electronic states at the interface with the metal substrate is a crucial issue. We have succeded in building-up highly-ordered MPc arrays on Au(110), and we determined the energy band diagram by HR-ARUPS (Fig. 2). In particular, by using alkali-metal intercalation we could tailor the energy gap, adjusting the hole-injection barrier and observing electron correlation effects due to the electron-injection into the localised states [4].

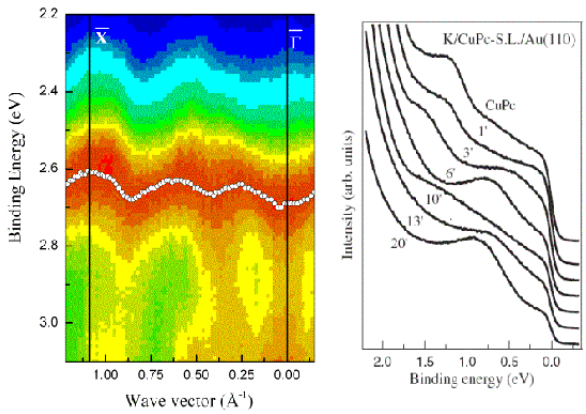

Figure 2: CuPc single-layer on Au(110): (left) interface band dispersion; (right) spectral density of electronic states as a function of K doping [4].

The control of the spin coupling of MPc molecules with a central magnetic atom with the underlying metal substrate can give rise to enhanced magnetic moments, with new 1D and 2D architectures for the fabrication of molecular spintronic devices. Objective of the on-going work is the study of MPcs formed by a magnetic central atom that can be used as chemical "cage" for anchoring the magnetic ion to a metal surface, so that the spin-state of the central atom could couple with the underlying magnetic or non magnetic metal.

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C35. High-pressure optical spectroscopy on strongly electron correlated systems: the Metal Insulator transition

A deep understanding of the physics of strongly correlated systems still represents one of the most challenging tasks of condensed-matter research. Generlly speaking, these systems show a variety extremely interesting physical behaviors (e.g. high temperature superconductivity or colossal magnetoresistance) and a high sensitivity of their properties to external parameters which makes them highly appealing for a wide range of technological applications. The latter characteristic is ascribed to the rather small extension of the electron bandwidth in comparison with other relevant energy scales as the electron correlation U or the charge-transfer (CT) energy gap. Under these conditions the independent electron approximation breaks down and, for example, materials at half filling can be insulators despite the opposite prediction of band theory. Materials at half-filling can become insulating also in the presence of electronphonon coupling triggered by spontaneous symmetry breaking such as Peierls and Jahn-Teller lattice distortions as in the cases of mixed-valence manganites and vanadium dioxide.

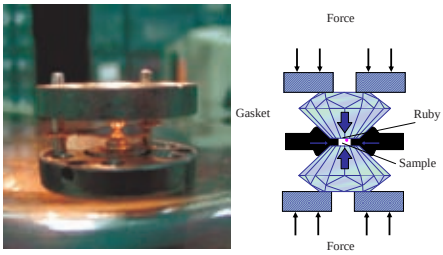

Figure 1: phase diagram of the vanadium oxides investigated

The Metal Insulator Transition (MIT) is thus one of the most important phenomena to be investigated in these systems. To this purpose infrared and Raman spectroscopy are the ideal tools since the former monitors the charge delocalization proces, and the latter provides information on the relevant lattice dynamic. Moreover both the techniques can be efficiently coupled with diamond anvil cells to carry out high pressure (HP) experiments which can be indeed very effective in shedding light on the complex physics lying behind the peculiar properties shown by these systems. Progressive and controlled lattice compression, indeed, tunes the strength of the interactions, simultaneously at work in these systems, at different extent. It becomes therefore possible to disentangle the interactions and, in some cases, to enhance the coupling mechanisms relevant to the physics of the system which are otherwise weak at ambient pressure. The research activity of our group in this field has focused in the last years on different vanadium oxides (V_3O_5,V_2O_3, VO_2 [1,2,3]) belonging to the Magneli phase and Ni pyrite compounds belonging to the $NiS_{2-x}Se_x$ family [4].

Vanadium oxides have attracted a considerable interest because of the abrupt and often huge change of conductivity at the MIT. In particular, we carried out Infrared and Raman measurements on HP VO_2 with the aim of clarifying the microscopic mechanisms at the origin of the spectacular temperature-driven MIT which involves a jump of five order of magnitude in conductivity and a simultaneous structural transition from a monoclinic (M1) insulating to rutile (R) metallic phase for T > 341 K. HP experiments show that the MIT is basically due to electron correlation and that, above 10 GPa, the onset of a metallization process accompanied by a sluggish structural transition to a new monoclinic Peierls dist

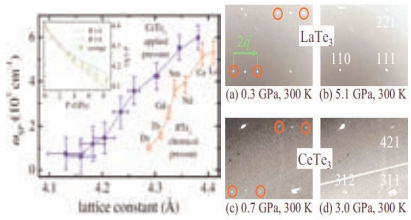

Figure 2: Left: Pressure dependence of the spectral weight of VO_2; a metallization proces is observed for P>10 GPa [1] . Right: spectral weight vs. lattice constant for $NiS_{2-x}Se_x$. A metallization process is observed either expanding (Se alloying) or compressing (Pressure) the NiS_2 lattice [4].

The cubic pyrite NiS2, is a CT insulator and is considered, together with vanadium sesquioxide V_2O_3, a textbook example of strongly correlated materials. NiS_2 easily forms a solid solution ($NiS_{2-x}Se_x$), with $NiSe_2$, which, while being isoelectronic and isostructural to NiS_2 is nevertheless a good metal. A MIT is thus observed at room temperature for x > 0.6 as well as in pure NiS_2 on applying hydrostatic pressure above P=4 GPa. We find that optical results are not compatible with the previously claimed equivalence between Se-alloying and pressure pointing out the different microscopic origin of the MIT.

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http://www.phys.uniroma1.it/gr/HPS/HPS.htm

C36. Pressure tuning of charge density wave states.

The study of low-dimensional systems has recently become one of the priorities in condensed matter physics. These systems not only experience remarkably strong quantum and thermal fluctuations, but also admit ordering phenomena that are difficult to obtain in three-dimensional materials, such as charge- and spin-density wave (CDW and SDW) states. CDW and SDW are broken symmetry ground states driven by the electron-phonon and electron-electron interactions, respectively. The intense theoretical and experimental efforts devoted to the investigation of the onset of density waves in one-dimensional system have provided a rather well established interpretation framework, although little is known about the two-dimensional case. External variables (like temperature, magnetic field, and chemical and applied pressure) can affect the dimensionality of the interacting electron gas, and thus the intrinsic electronic properties, as well as the interplay among different order parameters, giving rise to rich phase diagrams. Tuning the dimensionality by applying pressure can thus play a key role in developing a comprehensive theory. The di- and tri-chalcogenide RTe_n (R rare earth, n=2,3) are the latest paramount examples of low dimensional systems exhibiting the formation of an incommensurate CDW state. These materials are characterized by a layered structure where corrugated R-Te slabs alternate with planar Te square lattices (single layer for di- and double layer for tri-tellurides). Metallic conduction occurs along the Te sheets and unusually large CDW gap, depending on the rare earth, are observed also at ambient temperature. Owing to the 2D character of these compounds, the gap is not isotropic and shows a wave-vector dependence. In particular, since the vector q* does not nest the whole Fermi surface (FS), there are regions not gapped where free charge carriers lead to highly anisotropic metallic conduction. The study of these compounds could give an important insight into the interplay between the metallic state and the broken-symmetry CDW phase.

Through a close collaboraboration of our group with the ETH (Zurich, CH) and the Department of Applied Physics at the Stanford University (USA), a whole set of high-pressure measurements on RTe_2 and RTe_3 has been carried out. Using diamond anvil cells to pressurize the samp ering

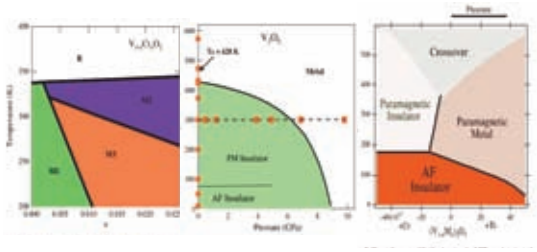

Figure 1: A picture and a schematic representation of a screw clamped diamond anvil cell.

(our lab), Infrared (IR) spectroscopy (SISSI beamline @ELETTRA, Trieste, IT) and x-ray diffraction (ID09A beamline @ESRF) [1,4].

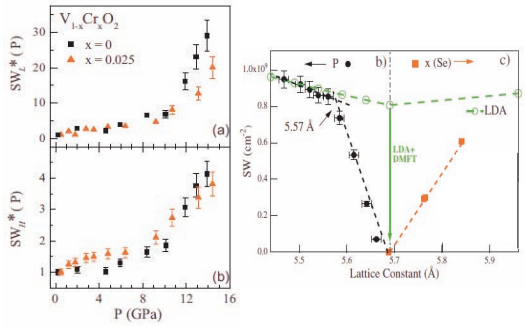

Figure 2: Left: Single particle excitation energy *vs.* lattice constant for CeTe3 under pressures and for the RTe3 series [1]. Right: X-ray diffraction pattern of single-crystal $LaTe_3$ and $CeTe_3$ single-crystal at different P and T. Red circles highlight the CDW satellite peaks and the modulation vector q*[4].

Our experiments clearly point out the CDW state and demonstrate the possibility of tuning and eventually suppress the CDW state by lattice compression [1,4]. We were able to establish a close equivalence between chemical (rare-earth substitution) and applied pressure in governing the onset of the CDW broken symmetry ground state and in tuning the gap. The reduction and the suppression of the CDW gap arises in both cases from internal changes of the effective dimensionality of the electronic structure, thus strengthening the link between CDWs and nesting of the FS [1,2]. We propose that broadening of the bands upon lattice compression in layered rare earth tellurides removes the perfect nesting condition of the FS thus diminishing the impact of the CDW transition on their electronic properties. The chemical/applied pressure equivalence is confirmed by Raman measurements, which, moreover, provides clear evidence for the tight coupling between the CDW condensate and the vibrational modes [3].

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C37. Quantum engineering and self-organization in hybrid semiconductor/magnetic metal nanostructures: perspectives for spintronics

Spin polarized electron transport is drawing increasing attention. The discovery and exploitation of giant magnetoresistance in magnetic multilayers was the first remarkable achievement in spin electronics (spintronics). The second breakthrough was the observation of spin injection in structures containing layers of ferromagnetic metal (FM), the so-called δ layers, separated by a spacer of non-magnetic semiconductor (NS). Realization of both phenomena in the same FM/NS structures will lead to an integration of spintronics and conventional semiconductor technology, opening the way to wide-range applications. The optimization of materials and geometry is crucial. Indeed, spin injection from transition (Fe,Co,Mn) or rare-earth (Gd) magnetic metals into common semiconductors (A_{IV}=Si,Ge; $A_{III}B_V$=GaAs,GaSb,GaN) is conditioned by the large difference of carrier concentration on the FM and NS sides, leading to a wide depletion region in the NS. The formation of spin-polarized local states reduces spin injection, even in an ideal contact, and the situation in real structures is even worse, due to the roughness of the interface. Various solutions were proposed to enhance spin injection, including a variety of tunnel barriers between FM and NS, or heavy doping of the surface region on the NS side, strongly narrowing the depletion region. Obviously, these methods have also significant drawbacks. Tunneling through an insulating layer may be the dominant transport mechanism only at low temperature, while heavy doping increases the recombination rate of injected carriers in the depletion region, reducing their lifetime. The simplest FM/NS layered system is a tunnel junction of two FM layers separated by a NS spacer. A periodic chain of tunnel junctions forms a multilayer [digital magnetic alloy (DMA)] with complicated transport and magnetic properties. Obviously, each FM/NS interface of the multilayer may be treated as almost magnetically independent [1,2] only in the case of a thick spacer. For a thin spacer, the different interfaces have to be considered as correlated, so the additional problem of their effective interaction and competition between parallel or anti-parallel configuration of their magnetic moments arises [3].

The promising way to avoid the above mentioned problems and improve spin injection consists in using a dilute magnetic semiconductor (DMS). Multiple studies reveal that magnetism may not be the intrinsic property of DMS, but rather arises from magnetic peculiarities of (self-organized) clusters enriched in transition metals contaminants containing, e.g., germanides or silicides of the transition metal in the NS matrix, which appear due to the phase separation [4]. Systems containing FM nanoparticles or layers incorporated inside DMS matrix (FM/DMS nanocomposites or multilayers) are the most promising candidates. Recently, a quite new approach to spin polarized electron transport has been opened using FM/NS and FM/DMS DMA, grown by molecular-beam epitaxy. The structure of these systems consists of alternated FM submonolayers built inside a NS matrix. Depending on the FM coverage and on the growing regime, an intra-submonolayer ferromagnetic ordering has been found with the Curie point far above room temperature. The study of DMA has just started and many problems, solved already for conventional FM/NS structures, are still under discussion for the DMA.

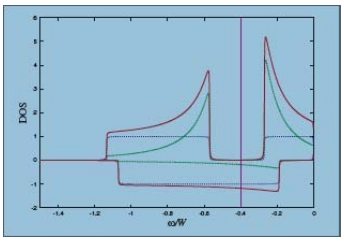

Figure 1: Density of states of the majority- and minority-spin two-dimensional bound-state bands formed in the vicinity of a δ layer, below the band edge of the semiconductor (located at $\omega > 0$), illustrating a half-metallic behavior [1].

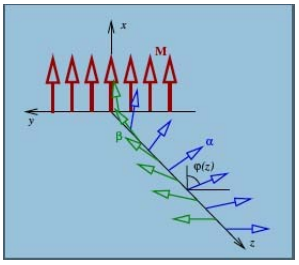

Figure 2: Structure of the domain wall in the case of antiferromagnetic order of impurity spins near a δ layer [(x, y) plane]. The ideal Néel structure for the sublattice magnetizations α and β is only recovered far off the δ layer [2].

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http://theprestige.phys.uniroma1.it/clc/

C38. Nonlinear electrodynamics in complex disordered systems: the SolarPaint project

The SolarPaint project is an interdisciplinary research aimed at mastering the link between complexity and light trapping mechanism in disordered systems, fostering new applications in the field of energy and medicine, as well as novel fundamental discoveries in applied mathematics and the science of complex systems. The project involves mathematical physics (solitons, shock waves, group theory, Lie algebras and symmetries of partial differential equations), theoretical physics (thermodynamics of chaos, statistical mechanics of disordered systems) and *ab-initio* computational science.

The term "ab-initio" means "from first principles, with no approximation" and identifies numerical integration schemes aimed at investigating phenomena stemming from first-principle equations of motion. The computational activity of SolarPaint is devoted to the realization of advanced parallel codes for the analysis of light propagation in disordered materials characterized by various wavelengths, ranging from the Angstrom regime to the visible, Terahertz and the acoustic scale. With reference to these different domains, the mathematical and theoretical portion of the project involves the study of:

X-ray Free Electron Laser (XFEL) beams interaction with molecular matter. XFEL are revolutionary photons sources, whose ultrashort, brilliant pulses are expected to allow single molecule diffraction experiments with interatomic length scales and femtosecond time resolutions.

Statistical description of a many-body solitons systems. A system of interacting solitons do exhibit interesting complex phenomena such as the generation of dispersive shocks and rogue waves. In the project we derive advanced theories able to provide simple thermodynamic interpretations of these phenomena.

Anderson localization of light. One of the most interesting effects of disorder is the trapping of light and the emergence of long living localized states, known as Anderson localizations, here studied in different configurations.

Disordered optical cavities. These systems do exhibit interesting links with spin-glasses with quenched disorder and the field of random matrices, here employed to provide a new perspective on these media.

Disordered photonic crystals and photon-plasmon polariton interactions. By exploiting interactions with photons and plasmon-polaritons in disordered photonic crystals, we study new concentrators for electromagnetic radiation in the terahertz regime for fundamental astrophysical studies.

Structural glasses, self assembly of dielectric scatterers. An important part of the project will be devoted to the study of the self-assembly properties of materials; an open problem, in fact, is how to realize a mean configuration of disorder necessary to observe, e.g. a specific property or a particular dynamics. To deal with this issue we here study self-assembled "photonic" colloids, in which optical components are first dispersed in a host medium and then assembled through the equilibrium configuration of the system.

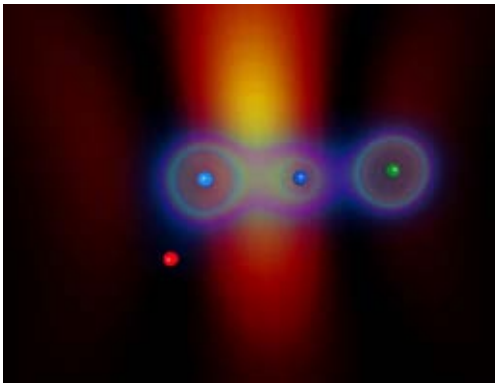

Figure 1: *Ab-initio* simulation showing the far-field scattered angular pattern (red to yellow colormap), nuclei position and electron density (blu to yellow colormap) time evolution of an $HNCO$ molecule irradiated by an ultrashort XFEL pulse.

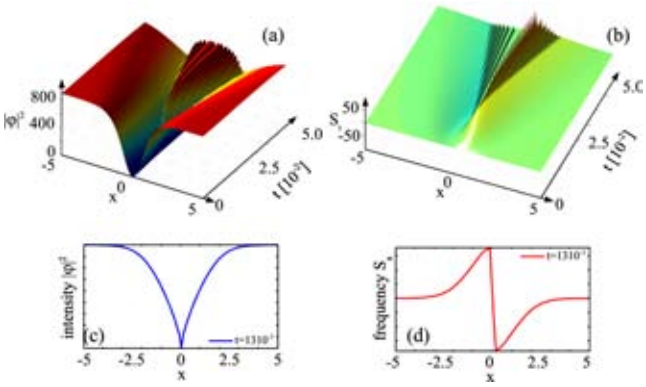

Figure 2: Intensity $|\psi|^2$, and frequency S_x evolution of an ensemble of solitons originating a dispersive shock at $t_{sk} = 0.0135$.

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http://www.solarpaintproject.org/

C39. Nanomaterials for alternative energies. Solid-state hydrogen storage

Hydrogen is attracting renewed interest as an energy carrier, due to the necessity of finding ecological energy media which may decrease the environmental pollution from fossil fuels. Hydrogen storage represents a nodal point for the development of a hydrogen economy. Of the three possible ways to store hydrogen, i.e. as high pressure gas, as a liquid (≃20 K at atmospheric pressure), or as hydrides in solids, the latter one appears as the most promising, due to the high mass and volume density and safety. The development of hydrogen storage media is currently considered as the most technologically challenging way for achieving a hydrogen-based economy. There are many compounds with promising hydrogen absorption capacities which, however, display serious drawbacks, like lack of reversibility, slow kinetics or deterioration with proceeding cycling. There is currently general agreement that adopting only traditional materials and methods will not lead to the achievement of the strict requirements necessary for the solid state hydrogen storage. At present, a considerable part of the international research efforts is devoted to the study of solid state hydrogen storage materials finely dispersed on artificial nanoporous supports. This approach is considered promising, since the use of thin layers of hydrogen absorbing compounds is expected to avoid sample compacting and to increase the surface to volume ratio to very high values. However the real interest in the dispersion of nanoparticles into nanoscaffolds resides in the possibility of obtaining a compound with better storage properties than the starting bulk material.

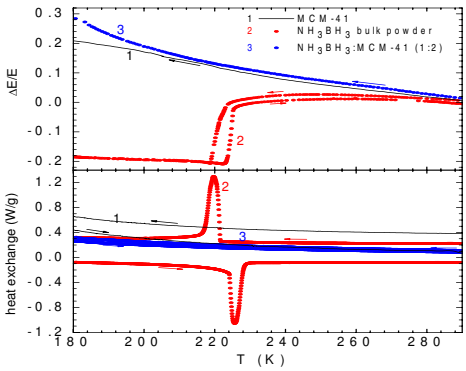

Figure 1: Effect on the Young modulus of the confinement of ammonia borane into mesoporous silica, MCM-41 [2].

An important task of the research conducted in our Laboratory is the understanding of the basic mechanisms of the hydrogenation/dehydrogenation process and the changes induced by the nanoconfinement. A combined study performed by anelastic spectroscopy and differential scanning calorimetry allowed us to show that one of the most promising compounds, ammonia borane (NH_3BH_3), finely dispersed in the channels of mesoporous silica does not undergo the structural phase transition present in the bulk, thus providing a clear indication that the basic physical properties of this material are strongly modified by such assembling on a nanoscale. The occurrence of different electronic and lattice interactions in nanostructured scaffolded hydrogen storage systems could provide an alternative approach to modify the thermodynamic features of bulk materials to obtain enhanced dehydrogenation properties and to accomplish reversibility. Finally anelastic spectroscopy has been proven to be a powerful tool, complementary to NMR and neutron scattering, in the study of the hydrogen dynamics. This information is highly demanded, because the hydrogenation/dehydrogenation of storage materials resides on the possibility for hydrogen atoms to perform short or long range diffusion processes. Anelastic spectroscopy investigations conducted in alanates allowed us to propose a model for the dehydrogenation process. The extension of the studies in ammonia borane lead us to identify the rotational and torsional dynamics of H atoms and to derive their activation energies [2]. Moreover, we used the measurements of the dynamic elastic modulus, which is very sensitive to the occurrence of phase transformations, to characterize the nature and the kinetics of the phase transition in NH_3BH_3 [3].

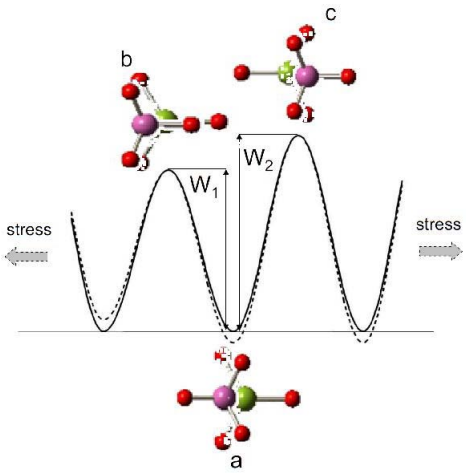

Figure 2: Schematic representation of the rotational and torsional dynamics of the NH_3BH_3 molecule with the corresponding energy profile [3].

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Authors

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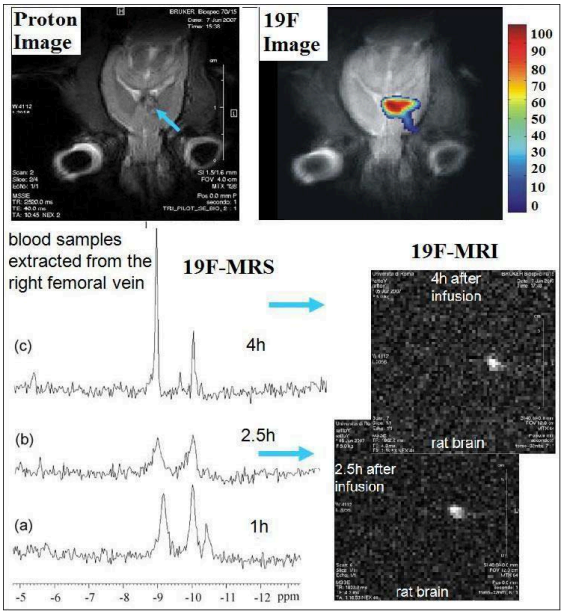
C40. Molecular diffusion and Molecular imaging studies by means of NMR techniques in materials, tissues, animal models and humans

Diffusion Tensor (DTI) and Diffusion-weighted (DWI) imaging NMR techniques are the only non-invasive tool available today to investigate molecular diffusion processes in vivo. DTI and DWI provide information on biophysical properties of tissues which influence the diffusion of water molecules [1]. Molecular imaging is the non-invasive visualization in space and time of cellular processes at molecular or genetic level of function. A key component in molecular imaging is the imaging probe which homes in on the specific target of interest in the body providing pharmacokinetic and tracking information. Using NMR spectroscopic and/or scanning methods (magnetic resonance spectroscopy, MRS and imaging, MRI), the probe is labeled with 19F atoms and it is visualized by 19F-MRS and /or 19F-MRI. Specifically, target molecules are marked by substitution of hydrogen atoms with one or more 19F atoms (usually -CF3 group). Due to the lack of endogenous background signal in vivo and the high MR sensitivity of the 19F atoms (83Within the framework of Molecular Imaging investigations we developed in our laboratory an in vivo 19F MR Imaging and Spectroscopy protocol for the optimization of BNCT (Boron Neutron Capture therapy). BNCT is an experimental binary radiation therapy based on the cytotoxic effects of high LET particles released from the 10B(n,alpha)7Li reaction that occurs when 10B captures a thermal neutron. For BNCT effectiveness a large amount of 10B atoms (at least 109 atoms of 10B per targeted cell) should be accumulated within tumour cells in order to obtain a maximum tumour-to-brain (T:Br) 10B concentration ratio. Currently, the therapy is mainly used to treat malignant brain glioma for which the conventional therapies do not provide any substantial benefit. The main limitations for BNCT effectiveness are: 1) the lack of efficient imaging methods to monitor the bio-distribution of 10B-labeled drugs in order to estimate the efficiency of the carrier and the optimal timing of neutron irradiation. This ideal time is when tumour-to-brain (T:Br) 10B concentration ratio achieves the maximum value at the lowest blood concentration; 2) the insufficient intake of 10B nuclei in the tumour cells. The aim of our study was to evaluate the boron bio-distribution and pharmacokinetics of 4-borono-2-fluorophenylalanine (19F-BPA) using 19F-MRI and 19F-MRS in animal model (C6-glioma rat brain). Moreover, the effect of L-DOPA as potential enhancer of BPA tumour intake was evaluated. 1H and 19F images were obtained using a 7T MR scanner, to assess 19F-BPA spatial distribution mapping in rat brain. Images (see upper panels in Figure) were processed in order to superimpose the 19F image (in colour levels of low=blue, high=red) on the corresponding anatomical 1H reference (in grey levels). To perform pharmacokinetics studies 19F spectra from rats blood samples were collected at 9.4 T at different time delays after BPA infusion (see a,b and c in Figure). The correlation between the results obtained by both techniques, showed the maximum 19F-BPA uptake in C6 tumour-bearing rats at 2.5h after infusion determining the optimal irradiation time [2].



Moreover, the effect of L-DOPA as potential enhancer of 19F-BPA tumour intake was assessed [3,4]. A significantly higher accumulation of BPA was found in the tumor tissue of rats pre-treated with L-DOPA as compared to the control group. Conversely, no significant difference was found in the normal brain and blood samples between the two animal groups. Our results suggest the presence of specific membrane antiport carriers with an high affinity for L-substrates, such as L-BPA and L-DOPA to explain the dramatic increase of BPA concentration in C6-glioma cells pre-treated with L-DOPA [4]. According to our results, these new strategies are expected to increase BNCT efficacy in absence of any additional risk of toxicity.

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http://lab-g1/

C41. The human brain: connections between structure, function and metabolism assessed with *in vivo* NMR

NMR has become the election technique for the *in vivo* study of brain structure and function, because of its exquisite multiparametrical properties. Our research focuses on human brain functional metabolism, both in healthy subjects and in some pathologies. The experimental work is performed on medium (1.5 T and 3 T) and high (7 T) field systems.

We studied the brain metabolic response to short stimulations, thus contributing to the debate on the link between brain metabolism, activity as seen with functional MRI (fMRI), and electrophysiology (neurovascular and neurometabolic coupling). By means of MR spectroscopy, it was shown that brain metabolism is aerobic from the very beginning [1]. Findings about metabolic alterations in epilepsy were obtained, as well as the first in vivo evidence that temporally resolved MR spectroscopy is sensitive to neuronal spiking (while it is well known that fMRI is sensitive mainly to postsynaptic potentials). In the last period, the work focused on the kinetic and thermodynamic modeling of metabolic events. A theoretical model was built, able to reproduce the main experimental findings about brain metabolism, These theoretical calculation showed that the intercellular nutrients trafficking, namely the flux of lactate between astrocytes and neurons (that can't be measured directly), is energetically negligible if compared to the direct uptake of glucose by cells, thus suggesting that the proposed metabolic partnership between neurons and astrocytes is not obligate [2].

A second important field is the study of the spinal cord function. The functional response to impulsive stimulation and the temporal dynamics of the signal were reported for the first time, thus assessing that the functional signal in the spinal cord is linear and time–invariant, similarly to what happens in the brain, but with different dynamics [3]. This study is essential for the knowledge of the biophysical mechanisms underlying the function of the the spinal cord.

Some important improvements of quantitative approaches were introduced. These improvements enhance the processing and facilitate the integration of structural and functional data, in order to gain more insights from the integrate analysis of several NMR derived parameters. As an example, functional data (areas activated by a given task) were combined with the knowledge of structural connectivity between those areas, assessed with tractographic techniques that exploit the directional properties of water diffusion in white matter. In this regard, a new and really promising field is the network organization of the human brain. We recently highlighted that the large scale brain networks observed at rest are affected, but not suppressed, by the execution of demanding cognitive tasks.

Finally, an exciting field is the direct observation of the magnetic effects of the tiny currents that flow across neurons during activity. We conducted some of the pioneering works aimed at observing these effects. We further investigated the issue by means of realistic simulations of neuronal networks. These theoretical calculations suggested that the neuronal currents are probably too tiny to be observable with the current technology. A possible improvement in this regard can be obtained by the use of ultra–low field MR, because with very low Larmor frequencies some spectral content of neuronal currents can be, in given conditions, on resonance, thus inducing direct excitation of the spin ensemble [4].

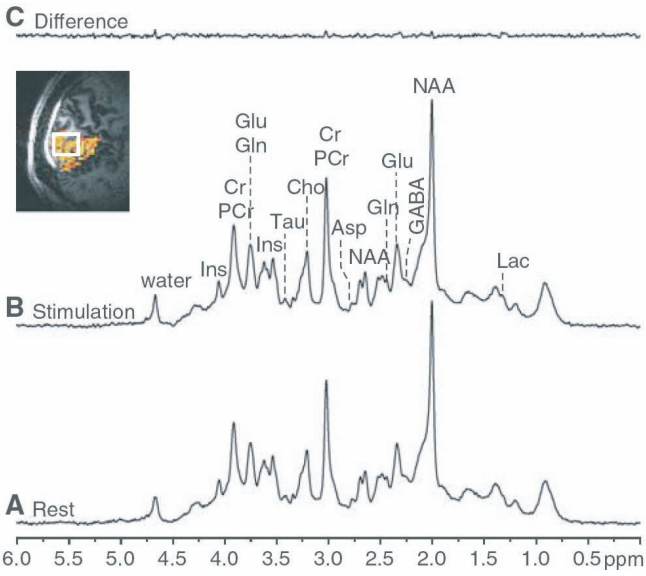

Figure 1: Example of functional spectroscopic experiment. Spectra are acquired in the region highlighted in the inset (colors code the activation identified by fMRI). Spectra are acquired at rest and during stimulation. Difference spectrum between resting and stimulated conditions (top) shows the relevant, tiny changes of metabolites [1].

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C42. Development of non-invasive methodologies for preservation, characterization and diagnostics of Cultural Heritage handworks

Development of non-invasive methodologies for preservation, characterization and diagnostics of Cultural Heritage handworks. Methods dealing with the study of works of art must be effective in producing information on a huge variety of materials (wood, ceramic, paper, resin, pigments, stones, textiles, etc.), must be highly specific owing to the variability of volume and shape of handworks and must comply with the severe conditions that guarantee their preservation. Therefore, standard spectroscopic methods need to be properly modulated in order to fit such materials, while their application area must be enlarged to include structures and models which are unusual for physicists. The contribution to this field by our group is based on the development and use of a surface NMR probe, which has proven highly effective for on-field and non-invasive measurements, with no significant limitations on sample volume and shape. What makes the surface NMR probe so peculiar is its strong magnetic field gradient (of the order of 10 T/m), as well as its low resonance frequency (about 18 MHz) and remarkable measurement depth from the sample surface (up to 8 mm). To date, several applications have been developed for paper, archaeological ceramic materials and wooden handworks. As to archaeological ceramics, a new model has been created, which can provide information on firing temperature of items, as well as on magnetic properties of their pore surface and their pore-size distribution. Such data - in the form of 2D Laplace correlation maps - have been presented as actual "fingerprints" of archaeological samples. These results return the NMR perspective on ceramics characterization in terms of firing technology and clay origin. As to wood, one major result concerns the possibility of assessing the moisture content by the surface probe, which now represents a suitable alternative to the gravity method, with the advantage of non-invasiveness and useful information on the moisture-content/strain relation associate to the microscopic state of water. This has improved the understanding of wood hydration mechanisms, so offering a chance of prediction on wood deformation according to environmental conditions. In addition, these features allow for the monitoring of wood deformation by direct check of the NMR relaxation-time distribution and, thus, may support operations of preservation of wooden objects of art placed in museums. Another important application has been developed in order to check the state of paper of historical documents, codices or printed book. The structure of paper and the role of water have been parameterized to get information on the state of cellulose polymerization, the distribution of water- cellulose bonds and the formation of interfibril water-clusters, on which many paper properties depend. Precisely, the analysis of Laplace correlation maps, which give information about water exchange between their microscopic localizations has provided growing understanding of the state of depolymerization and formation of cross-links between cellulose chains. A simple experiment performed by the NMR surface probe may detect early alterations of the structure of paper, which may act as a warning of paper degradation.

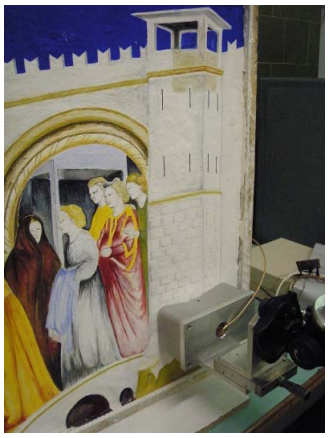

Figure 1: The mobile NMR probe examining a fresco surface.

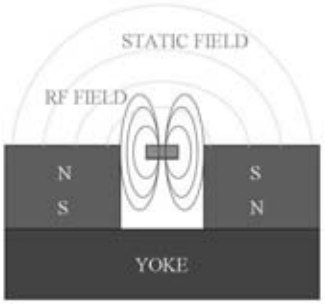

Figure 2: The static NMR magnetic field is produced by two permanent magnets joined by a yoke. The central coil produces the resonant radio frequency magnetic field perpendicularly to the static one.

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F. De Luca, C. Terenzi

C43. Optical technologies for quantum information processing

Quantum information (QI) is a new scientific field with origins in the early 90s, introduced by the merging of classical information and quantum physics. It is multidisciplinary by nature, with scientists coming from diverse areas in both theoretical and experimental physics (atomic physics, quantum optics and laser physics, condensed matter, etc.) and from other disciplines such as computer science, mathematics, material science and engineering. It has known a huge and rapid growing in the last years, both on the theoretical and the experimental side and has the potential to revolutionize many areas of science and technology. The main goal is to understand the quantum nature of information and to learn how to formulate manipulate, and process it using physical systems that operate on quantum mechanical principles, more precisely on the control and manipulation of individual quantum degrees of freedom. On this perspective completely new schemes of information transfer and processing, enabling new forms of communication and enhancing the computational power, will be developed.

Within the framework of QI theory, quantum optics represents an excellent experimental test bench for various novel concepts introduced. Photons are the natural candidate for QI transmission since they are practically immune from decoherence and can be distributed over long distances both in free-space and in low-loss optical fibres. Photons are also important for future quantum networks and are an obvious choice for optical sensing and metrology and, finally, they are a promising candidate for computing.

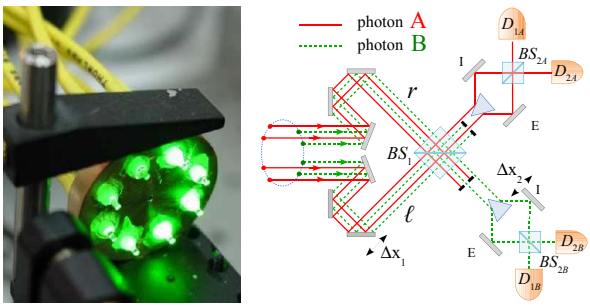

Figure 1: Schematic representation of the multiqubit source based on multipath entanglement [2].

In the last few years, the Quantum Optics group of Roma has contributed to develop different experimental photonic platforms to carry out quantum information processing based on different photon degrees of freedom (DOFs).

In our laboratory, by starting from a hyperentangled state, i.e. a two photon state built on two entangled DOFs, such as the polarization and the linear **k** momentum, we were able to generate four/six qubits cluster states to realize some basic computation algorithms. Cluster state are the fundamental resource for a new model of Quantum Computation, the so called one-way model. In this model the algorithms are simply realized by a sequence of single qubit measurements and feed-forward operations. The aim of our research has been to increase the dimensionality of the generated quantum states by using more degrees of freedom of the photons [1,2].

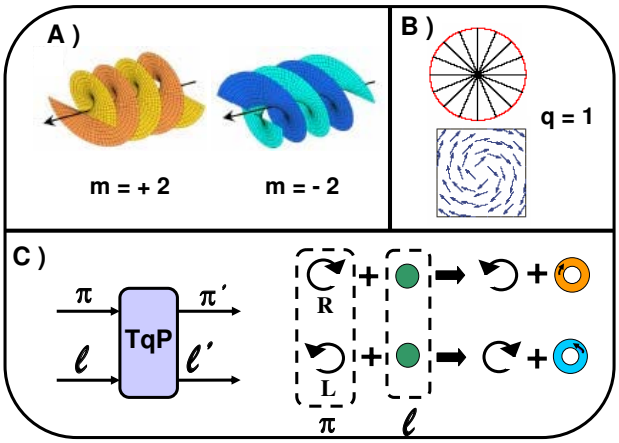

Figure 2: Schematic representation of the coupling between polarization (spin) and orbital angular momentum (OAM).

The standard encoding process of quantum information adopting the methods of quantum optics is based on the two-dimensional space of photon polarization ("spin" angular momentum). Very recently the orbital angular momentum (OAM) of light, associated to the transverse amplitude profile, has been recognized as a new promising resource, allowing the implementation of a higher-dimensional quantum space, or a "qu-dit", encoded in a single photon. Our research topic is based on the study of new optical devices able to couple the orbital and spinorial components of the angular momentum [3]. Such devices allow to manipulate efficiently and deterministically the orbital angular momentum degree of freedom, exploiting both the polarization and the OAM advantages [4].

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http://quantumoptics.phys.uniroma1.it/

C44. Quantum statistical mechanics and quantum information

The interest is in the quantum information (QI) properties of systems currently studied in quantum statistical mechanics like superfluids, itinerant magnetic and spin systems.

Some typical features of many-body theory, like the large-size limit, spontaneous symmetry breaking mechanisms and the mean field approximation need to be reconsidered from the point of view of a quantum information properties.

The obvious finite size of physical systems considered in QI is a difficulty not only from the point of view of accuracy of theoretical results valid performing the thermodynamic limit but also because some qualitative features of the theory like spontaneous symmetry breaking appear only in this limit.

Moreover, a generally accepted approximation, like the mean field, introduces new weakly interacting degrees of freedom and thus a "classical" (no entanglement) behaviour in terms of such degrees of freedom.

It is then difficult to introduce approximations which preserve nonlocal properties, and thus most of the work done is based on exact results or numerical methods. Using the Bogoliubov approximation, we studied analitically the time evolution of entanglement in a system of interacting bosons (Bose-Hubbard model) considering an initial coherent state. In Figure 1 we show how the linear entropy, an entanglement monotone as far as globally pure states are considered, grows in time for different size systems.

An alternative is to study either entanglement due to fluctuations with respect to mean field in the large size limit, or to modify the mean field approach to take into account the residual entanglement which arise from finite size effects. Recently the observation that some spin systems exhibit the mean field solution as the exact one for a particular value of a control parameter has led many people to study entanglement close to this particular point phase space in the large size limit.

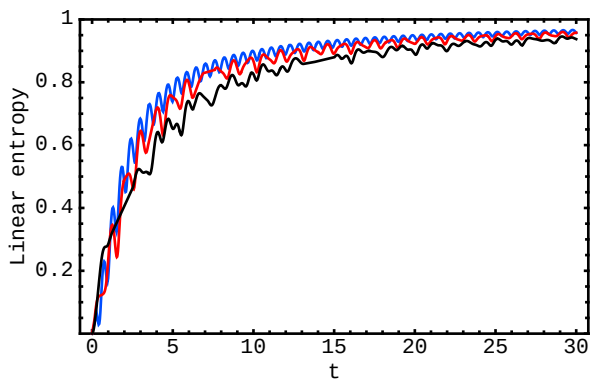

Figure 1: Linear entropy of the one-mode density matrix as a function of time. The curves correspond to three different values of the size of the system: the blue line describes a Bose-Hubbard model with $N = 2$, the red line is for $N = 8$, while the black line corresponds to $N = 20$.

One of us (G.G.) proposed and studied new spin systems which exhibit a dimerized phase where entanglement disappears. It has been also showed how a finite-size analysis of such systems allows one to predict the appearence of a magnetic symmetry breaking once the thermodynamic limit is performed.

To take into account size effects, we consider a generalization of mean-field superposition states originally introduced in the study of small superconductors and study the "residual" entanglement due to finite size effects.

The extension to strongly interacting electron systems is in progress.

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Authors

F. de Pasquale, G. Giorgi, S. Paganelli

C45. Experiments on Foundations of Quantum Mechanics

Einstein, Podolsky, and Rosen (EPR) showed that quantum mechanics cannot be simultaneously local, real, and complete, and were convinced that quantum theory should satisfy the reasonable assumption of locality and reality. Therefore, they concluded that quantum mechanics is incomplete. In 1964, John Bell discovered his famous inequality ruling out the possibility to introduce Local Hidden Variables (LHV). In his proof, he demonstrated that any LHV model cannot explain the statistical correlations present in two-qubit (i.e., a quantum two-level system) entangled states. The huge amount of experimental data obtained so far by Bells nonlocality tests, in particular with photons, confirms the quantum mechanical predictions and leads to the common belief that quantum mechanics cannot be simultaneously local and real. Indeed Bells inequality is nowadays exploited as a tool to detect entanglement in quantum cryptography and in quantum computation.

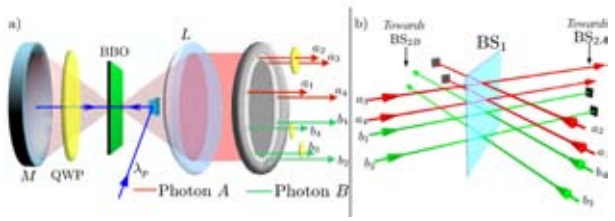

Figure 1: Generation of the six-qubit linear cluster state. a) Scheme of the entangled two-photon six-qubit parametric source: a UV laser beam (wavelength λ_p) impinges on the Type I BBO crystal after reflection on a small mirror. b) Spatial superposition between the left (ℓ) and right (r) modes on the common 50/50 beam splitter BS_1.) Spatial superposition between the internal I (a_2, a_3, b_2, b_3) and external E (a_1, a_4, b_1, b_4) modes is performed on BS_{2A} and BS_{2B} for the A and B photon, respectively.

Not so long ago, it was thought that the magnitude of the violation of local realism, defined as the ratio between the quantum prediction and the classical bound, decreases as the size (i.e., number n of particles and/or the number N of internal degrees of freedom) grows. Now it is clear that the ratio between the quantum prediction and the classical bound can grow as $2^{(n-1)/2}$ in the case of n-qubit systems. Mermins observation that the magnitude of the violation of local realism, defined as the ratio between the quantum prediction and the classical bound, can grow exponentially with the size of the system has been demonstrated using two-photon hyperentangled states entangled in polarization and path degrees of freedom, and local measurements of polarization and path simultaneously. Latter we reported on the experimental realization of a four-qubit linear cluster state via two photons entangled both in polarization and linear momentum. By use of this state we carried out a novel nonlocality proof, the so-called stronger two observer all-versus-nothing test of quantum nonlocality. Then we created a six-qubit linear cluster state by transforming a two-photon hyperentangled state in which three qubits are encoded in each particle, one in the polarization and two in the linear momentum degrees of freedom. For this state, we demonstrate genuine six-qubit entanglement, persistency of entanglement against the loss of qubits, and higher violation than in previous experiments on Bell inequalities of the Mermin type [2].

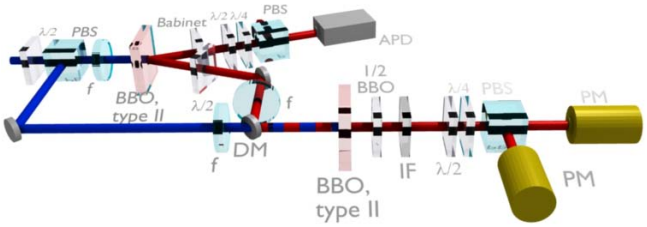

Figure 2: Generation of the microscopic-macroscopic state for non-locality tests in the multi-photon domain.

In 1981 N. Herbert proposed a gedanken experiment in order to achieve by the First Laser-Amplified Superluminal Hookup (FLASH) a faster-than-light (FTL) communication by quantum nonlocality. In Ref.[3] we reported the first experimental realization of that proposal by the optical parametric amplification of a single photon belonging to an entangled EPR pair into an output field involving a large number of photons. A theoretical and experimental analysis explains in general and conclusive terms the precise reasons for the failure of the FLASH program as well as of any similar FTL proposals. As following step a macrostate consisting of $N = 10^3$ photons in a quantum superposition and entangled with a far apart single-photon state (microstate) has been generated. Precisely, an entangled photon pair is created by a nonlinear optical process; then one photon of the pair is injected into an optical parametric amplifier operating for any input polarization state, i.e., into a phase-covariant cloning machine. Such transformation establishes a connection between the single photon and the multiparticle fields. We demonstrated the nonseparability of the bipartite system by adopting a local filtering technique [4].

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C46. Development of coherent terahertz radiation sources from third generation synchrotron machines and Free Electron Lasers

The last decade has witnessed a huge amount of experimental effort in order to fill the so-called Terahertz (THz) gap. This range of the electromagnetic spectrum, which is roughly located between the infrared and the microwave region (0.1-20 THz), has been indeed scarcely investigated so far mainly because of the lack of intense and stable THz sources. Scientific problems which could be addressed by THz spectroscopy and imaging include the ps and sub-ps scale dynamics of collective modes in superconductors and in exotic electronic materials, the ps-scale rearrangement dynamics in the secondary structure of proteins and biological macromolecules, early cancer diagnosis, and security applications.

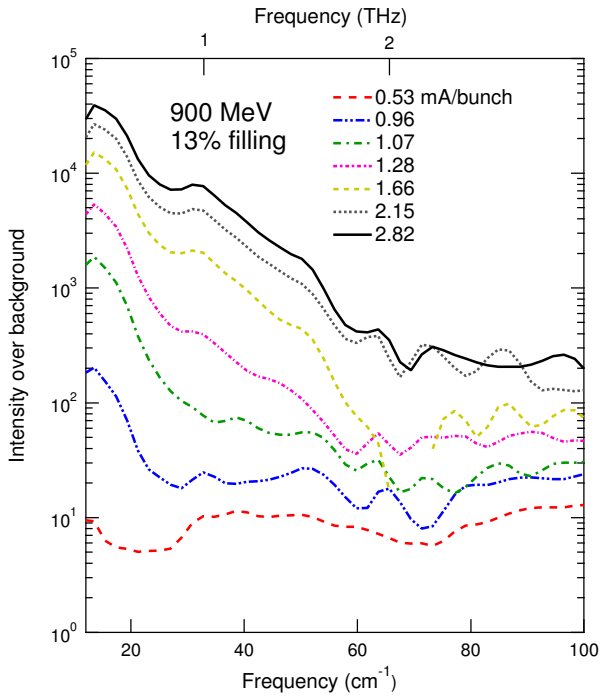

Figure 1: THz spectra for different currents stored in the ELETTRA ring and for an electronic energy of 900 MeV.

Short (sub-millimeter) electron bunches in storage rings and in Free Electron Laser (FEL) machines emit Coherent Radiation up to wavelengths of the order of the bunch length, i.e. in the THz range. As the coherent amplification scales with $N[1 + N * f(\omega)]$, with $f(\omega)$ being the Fourier Transform of the charge density in the longitudinal bunch profile and N the number of electron in the bunch, the brilliance gain with respect to most existing THz sources can be huge.

On this ground, we have recently investigated the possibility to produce coherent THz radiation from our beamline SISSI (Synchrotron Source for Spectroscopy and Imaging) at the third generaton machine ELETTRA (Trieste) [1]. Short bunches can be created by taking into account the strong bunch length energy dependence ($\sigma \approx E^{3/2}$), i.e. the bunch length can be reduced by lowering the machine energy [2]. In this way, strong pulse of THz radiation up to 1 THz have been obtained (see Fig.1). This radiation has been already used for linear spectroscopical applications [3].

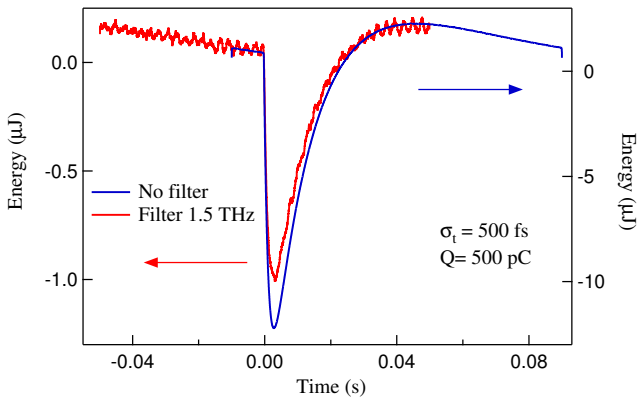

Figure 2: THz signal in μJ/pulse as measured by a pyroelectric detector at SPARC for a stored charge of 500 pC and for a bunch length of 500 fs. The red curve corresponds to the signal at 1.5 THz with a bandwidth of nearly 0.3 THz. The blue curve corresponds to the signal up to 3 THz.

Despite all efforts spent on THz research, the possibility of performing pump-probe time-resolved THz and infrared (IR) spectroscopy is instead basically unexplored. The difficulty lies in achieving an energy/pulse >10 μJ, which corresponds roughly to the electric field of 1 MV/cm at which the THz pulse becomes useful as a pump-beam. This task can be accomplished in FEL machines through ultra-short highly-loaded bunches. In this context, we are developing a new source which extracts pulsed THz and IR radiation from the SPARC FEL in Frascati (Italy). Preliminary measurements show that sub-ps radiation pulses can be obtained in the 10 μJ/pulse scale, a value which ranks SPARC among the best FEL THz sources worldwide (see Fig.2) [4].

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Authors

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Particle Physics

1 Particle Physics

Particle and Astroparticle Physics aim to give an answer to the most fundamental questions Nature has presented to us:

- does the Higgs Boson exist ?
- is there New Physics at the TeV scale ?
- how has the matter-antimatter asymmetry been generated ?

In connection with these questions there are other fundamental pieces missing:

- what is the Dark Matter ?
- is the neutrino a Dirac or a Majorana particle ?
- is CP violated in the neutrino sector and can this be the origin of the matter dominated universe ?

A comprehensive answer to these fundamental questions requires studies in a framework constituted by three interrelated frontiers of particle physics: the Energy Frontier, the Intensity Frontier and the Cosmic Frontier.

The experiments performed for this kind of searches are usually huge and require internationally coordinated efforts. They are carried on in large laboratories that offer first class infrastructure and finally they call for substantial resources, human and money-wise.

The Physics Department of Sapienza University, one of the largest in Italy, operates in this field in complete synergy with the Istituto Nazionale di Fisica Nucleare (INFN) local unit. The unit with its personnel, infrastructure and facilities is physically hosted in the Department buildings. People involved in High Energy Physics (HEP) experiments here are (approximately) 42 Faculty, 30 INFN research staff, 15 engineers and 20 technicians. Currently we have 10 post-docs and about the same number of PhD students. Just as an indication, the budget granted to the research group in this discipline can be evaluated at the level of 4.5 MEuro/year.

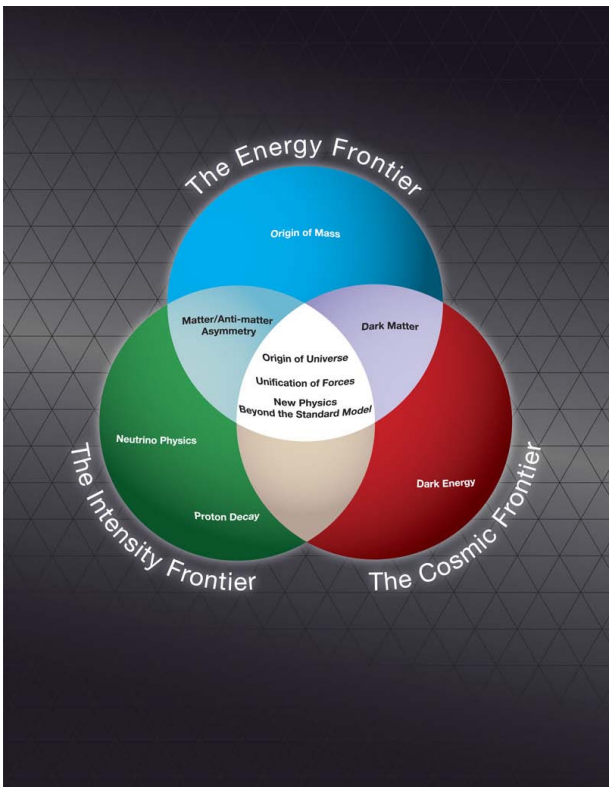

Figure 1: Courtesy of DOE

Although a lot of design, prototyping, preparation and even construction is carried on in the Department most of the experimental activity in the phase of experiment mounting, commissioning and running is worldwide spread in the main existing laboratories. Given the sizable dimension of the Department its research personnel is involved in many of the most prestigious laboratories in the world. We give a list here, associating experiments to laboratories.

- BaBar at PEPII at Stanford (USA)
- CDF at Tevatron in Fermilab, Chicago (USA)
- MEG at PSI, Villigen (Switzerland)
- ZEUS at DESY, Hamburg (Germany)
- UA9, NA62, ATLAS, ALICE, CMS, LHCb at the European laboratory of CERN, Geneva (Switzerland)
- KLOE at DAΦNE in Laboratori Nazionali di Frascati (INFN)
- VIRGO at EGO facility in Cascina (INFN-IN2P3)
- CUORE, DAMA, OPERA at Laboratori Nazionali del Gran Sasso (INFN)

There are also important activities in space (AMS) and underwater (ANTARES, NEMO)

1.1 Particle Physics with Accelerators

The search of new particles and new phenomena is the core of this field of activity. It is performed usually by large collaborations operating at large hadronic or e^+e^- colliders. After the success of the Standard Model validated by the precision measurements carried on at LEP two lines of research eventually developed. One is based on hadron colliders operating at the energy frontier (Tevatron at Fermilab, LHC at CERN) and the other is exploiting the intensity frontier (DAΦNE at LNF, PEPII at SLAC, the fixed target program at CERN SPS). The main goals of research at the energy frontier are the precision measurements of top quark parameters, the search for rare or new processes like the production of the Higgs boson and the 'Supersymmetry' (in an extended meaning). The intensity frontier is used to exploit the flavour physics studying the CP violation, both on K- and B-mesons and for precision measurements of the quark couplings (the CKM paradigm).

1.1.1 The Energy Frontier

The Tevatron collider has now collected almost 8 fb^{-1} of integrated luminosity and is expected to reach 10 fb^{-1} by the end of 2011. Members of the Physics Department of the Sapienza University, taking advantage of the large data sample available, have been involved within the CDF collaboration in searches of rare processes as like pair production of W and Z bosons and the production of heavy flavor jets in association with W or Z [P10]. Recently, the proton-proton collider LHC has successfully reached the center of mass energy of 7 TeV, the maximum energy ever reached by a particle accelerator (see Fig. 1). Such a high energy allows to significantly extend the capability to discover new phenomena at the TeV energy scale. The machine is now improving its intensity in order to match the luminosity requirement for studying rare phenomena like possible Higgs boson production and decay, and search for supersymmetric particle production.

Six experiments are operating in the four LHC interaction regions. The two main experiments, ATLAS and CMS, are detectors of unprecedented dimensions and complexity, aiming to exploit all what is connected to the energy frontier. They have been designed and realised to detect all particles produced in the interaction, and to reconstruct the kinematics of the interesting events. Due to the 40 MHz bunch crossing frequency, to the very large expected luminosity and to the total cross section of pp collisions, the trigger systems of these experiments have to identify the few interesting events (of the order of 100 Hz) in a very short time out of an interaction rate of more than 100 MHz. The project and realization of the trigger detectors and systems has been a particularly challenging enterprise.

The Physics Department of Sapienza University is involved in both ATLAS and CMS. A significant fraction of the precision chambers of the ATLAS muon spectrometer (namely the external part of the ATLAS apparatus aiming to detect and reconstruct the muons coming from the collisions) have been assembled and tested in the Rome Physics Department [P1, P2]. Moreover the logic of the muon trigger system, together with the electronics to realize it and the software to operate it has been also partly prepared in Rome [P3]. The CMS Rome group has been strongly involved in the project and realization of the electromagnetic calorimeter. This is a very large detector based on $PbWO_4$ crystals aiming to identify and measure high energy photons and electrons with excellent energy resolution [P6]. Both ATLAS and CMS groups are now participating to data taking at CERN and to data analysis. In particular the ATLAS group is involved in the Higgs search through its decay in four muons, in the study of Standard Model processes like W and Z production and in the search for a class of the so called "exotic" processes [P4]. The CMS Rome group is also involved in the search for the Higgs boson decaying in a pair of photons, and in supersymmetric particles decaying also in photons and electrons [P5]. Both searches are based on the performance of the electromagnetic calorimeter.

Two other groups from the Rome Physics Department are involved in the LHC experiments dedicated to more specific items: LHCb and ALICE. LHCb is designed to study flavour physics by detecting rare decays of the B mesons copiously produced in pp collisions [P7]. ALICE aims to study possible phase transitions in quantum fields at very high energy densities, the so called quark gluon plasma state of matter. This study is possible by exploiting the extremely large energy densities in high energy interactions of heavy ions, in particular Pb-Pb collisions [P8]. Both Rome groups have participated in the detector realization and commissioning. Another group of the Department has given an important contribution to the realization of the physics program of ZEUS, an experiment now completed at DESY. This experiment has studied in great detail the structure of the proton in electron-proton collisions at the highest energies ever reached [p22].

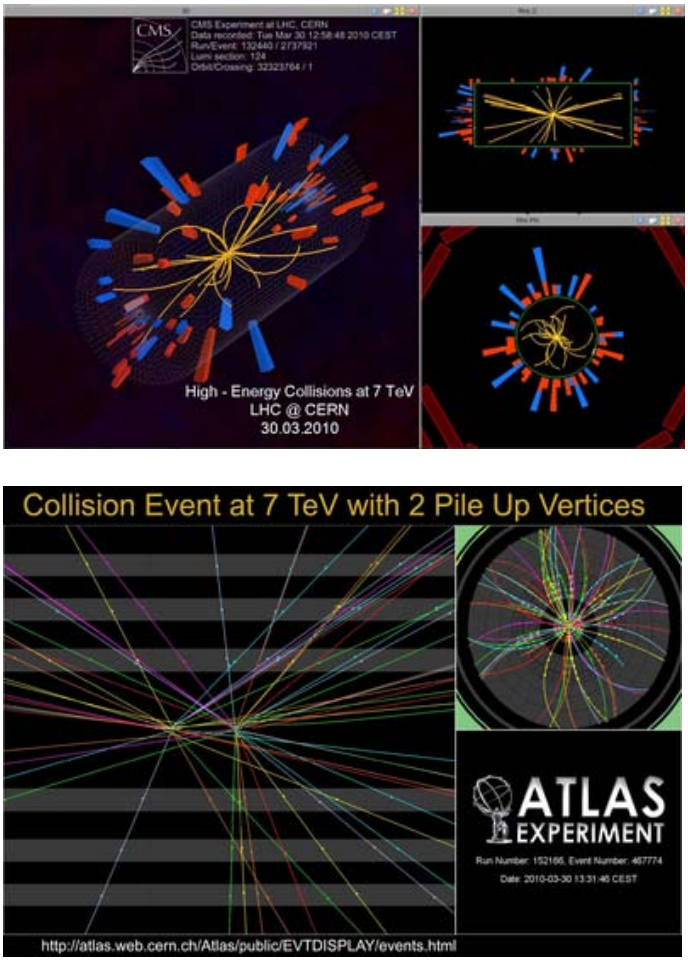

Figure 2: Top: one of the first 7 TeV collisions observed by CMS. Bottom: the first event with two overlapping p-p collisions observed by ATLAS. .

In all the activities presented here, a key ingredient is the computing power. For this reason we have set-up in Rome a computer center, a so-called Tier2 [F3]. The INFN Roma Tier2 centre is a shared facility among the ATLAS, CMS and VIRGO experiments. All the hosted resources are fully integrated with the worldwide Grid Computing Infrastructure and participate to the INFN and LCG/EGEE grids. At present a total of 1300 logical CPU cores and 500 TByte of storage space are available. The ATLAS, CMS and VIRGO Tier2 sites have a very important role in their respective experiments, for what concerns the Monte Carlo production and the user analysis. Each

Tier2 site is a national facility, used by either local or remote users of several physics groups of the experiments. The ATLAS and CMS facilities are also using their resources to compute the calibrations of the detector. The calibration data coming from CERN are collected in the Tier2 site and either analyzed in offline mode or automatically processed by the calibration agents, to provide prompt calibration constants back to CERN. The remote calibration infrastructure has been designed and realized in INFN Roma for the first time.

1.1.2 The Intensity Frontier

Detailed studies of known physics systems lead on one side to better understand their properties and interactions and on the other side to investigate deviations from the standard model which would represent an alternative path to new phenomena. This field is also known as "flavour" physics because its interest arises from the existence of three replicas of the leptons (e, μ, and τ and the corresponding neutrinos) and the quarks (u, c, and t, and d, s, and b). The open questions in this field are the level of mixing between the different replicas and the amount of violation of the Charge-Parity symmetry (CP). The latter is particularly relevant because on one side it is a key ingredient in understanding the current difference in abundance between matter and anti-matter, and on the other side one of the first effects of physics beyond the standard model would be alterations of the amount of CP violation in processes mediated by new particles. It is to be noted that the mixing between quarks is regulated by the so called "CKM" matrix, where "C" is the initial of Prof. Cabibbo, eminent member of this Department, as he was the first to introduce the concept of mixing in the early '60. The understanding of the generation of CP violation in the quark-mixing was awarded the 2009 Nobel Prize.

Concerning mixing measurements, groups of the Department have been recently involved in the first observation of the mixing between B_s [P9] and D_0 mesons [P16]. Mixing is a basic quantum-mechanics process, which was expected in these systems, but it has never been observed because of the extremely low expected rates. It is mediated by two virtual particles and therefore measurements of mixing parameters are critical because they could be affected if the particles exchanged are among those that are yet to be seen. Indeed, after the first low resolution measurement of the B_s mixing phase at Tevatron, a high precision determination of this phase is part of the mission of the LHCb experiment at LHC [P7] as a test of the Standard Model.

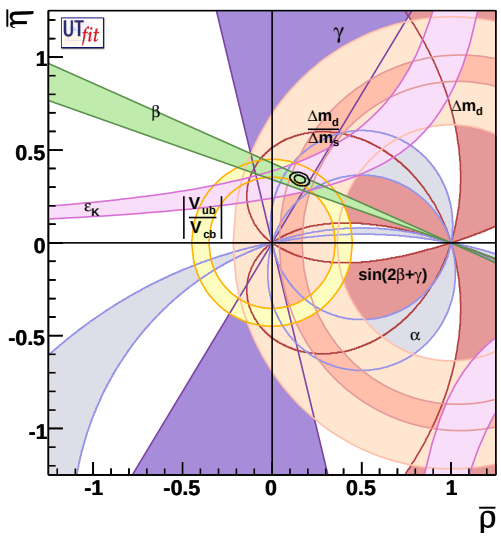

Figure 3: 68% C.L. contours of all the measurement of the apex of the Unitarity Triangle and the combined fit (black ellipses).

Mixing between lepton families would instead directly signal new physics: the MEG experiment, of which an INFN group is hosted in the Department, searches for $\mu \to e\gamma$ decays at a level of accuracy such that most models of new physics predict a signal. Searches sensitive to similar effects which can occur only if mediated by yet unseen particles have been performed in rare decays of the B mesons in BaBar [P15] and CDF [P11]. The future plans include searching for these effects in rare decays of the Kaon mesons with the NA62 experiment [P17], $K \to \pi\nu\bar{\nu}$.

The number of experiments contributing to the understanding of CP violation is very large since

this effect influences the interaction between any pair of quarks. The three couplings between the u, c and t quarks with the b are complex numbers that add to zero and that therefore can be represented as a triangle, called "Unitarity Triangle". All the numerous measurements sensitive to CP violation contribute to determining the apex of such a triangle (see Fig. 2).

The first system where CP violation was observed is the kaon mesons system. While the first experiments are dated in the '60s, the latest and more accurate measurements of CP violation were performed by the $NA48/2$ experiment [P18]. Similarly the KLOE experiment has recently measured with unprecedented accuracy the absolute value of the element of the CKM matrix governing the coupling between the s and u quark, thus yielding the currently most accurate measurement of the mixing matrix [P19]. Unfortunately the Kaon system suffers from large uncertainties in the understanding of the impact of strong interactions. In this respect the most sensitive system is constituted by the B meson. Members of this Department have worked on several aspects of such effects within BaBar (see [P12, P13, P14]) and CDF [P9]. Fig. 2, realized with a strong effort within this Department in phenomenological interpretation of a large number of data [T3], shows the combination of all available measurements. The good agreement between different measurements is a strong test of the Standard Model and a clear proof of the sensitivity of the data to possible new physics. Any new particle is extremely likely to alter at least one of the observables that are combined in the fit. It becomes therefore critical, even in the era of the Energy Frontier, to perform high precision measurements of the parameters of the "Unitarity Triangle". This is the goal of the LHCb experiment [P7] and is the basis of the proposal of a ultra-high luminosity machine producing B quarks (SuperB) which is being planned in Frascati, in close liaison with a group in this Department.

Finally the extremely large data sample collected to perform these precision measurement has been exploited also to investigate the spectroscopy of hadrons (states held together by strong interactions) with the appearance of new unexpected states. These states do not seem to fit with standard mesons and are indeed good candidates to belong to a new state of matter made of four quarks or two quarks and a meson. Such states are investigated in the low mass range [P20] and for heavy flavours [P16, P21, T1].

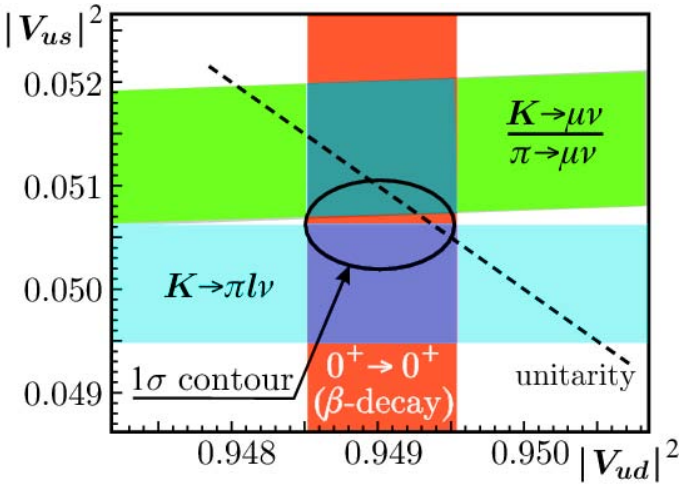

Figure 4: KLOE results for $|V_{us}|^2$, $|V_{us}/V_{ud}|^2$, and $|V_{ud}|^2$ from β decay measurements, shown as 2σ bands. The ellipse is 1σ contour from a fit. .

1.2 Astro-Particle Physics

The so-called Astro-Particle Physics is a field in great expansion. It includes the studies on neutrino properties, the sector where the most important discovery of the last decade comes from in the form of the demonstration of their massive nature. Search for the Dark Matter is the second pillar of this field. A fundamental role is played by the projects aiming at the detection of gravitational waves (GW). Our country is particularly blessed by the opportunity of having a superb facility, nearby located under Gran Sasso mountains for low background, low radioactivity experiments and by the interferometer built in the plain of Cascina near Pisa for GW search.

1.2.1 Neutrino Physics

In the field of fundamental particle physics the neutrino has become more and more important in the last few years, since the discovery of its mass. In particular, the ultimate nature of the neutrino (being a Dirac or a Majorana particle) plays a crucial role not only in neutrino physics, but in the overall framework of fundamental particle interactions and in cosmology. The only way to disentangle its ultimate nature is to search for the so-called Neutrinoless Double Beta Decay ($0\nu2\beta$). A group of the Department has participated in Cuoricino experiment and it is now fully engaged in the preparation of CUORE experiment at LNGS [P25]. CUORE is a 1 ton array of 988 crystals of TeO_2 that will be kept in a dilution refrigerator at a temperature of 10mK. By using the spectacular energy resolution in the measurement of the heat released by nuclear processes occurring inside the crystals, this experiment will cover an half-life of ^{130}Te for the ($0\nu2\beta$) up to 10^{26}y. The Roma group has taken, amongst others, the responsibility of procuring the crystals (done in RP China by SICCAS), by developing the entire chain of QC/QA of the crystal production that involves ICP-MS and Ge measurements at all levels and the final acceptance tests. A follow up of this activity has been the award of an ERC-AdG to one of the group member for a demonstrator for the next level of background reduction in this kind of experiments thanks to the combined read-out of heat and scintillation light in new materials (project LUCIFER).

On the sector of neutrino oscillations, a small but significative participation of the Department is in the OPERA experiment that exploits the CERN-LNGS neutrino beam. The search for ν_τ appearance will close the 3-neutrino picture of the oscillations and and is based on the emulsion scanning [P26], a technique which has seen our Department on the front line, since the antiproton search in cosmic rays by the E. Amaldi group in the '50s of the last century.

1.2.2 Dark Matter

Dark Matter (DM) is an hot subject nowadays. This elusive component of our Universe is searched at colliders, in space and underground. A group of this Department is active in the DAMA [P28] experiment at LNGS. This experiment has the aim of performing a direct detection of DM particles present in the galactic halo by using the annual modulation signature. It is based on ultra-pure, very low background NaI scintillator and thanks to its large mass has integrated an exposure in excess of 0.50 ton×y (the highest of this kind of experiments). The results, worldwide known, is an intriguing, statistically significant, presence of a modulation that could be explained by DM particles interacting with the detector. Improvements to the experiment (better quantum efficiency photomultiplier), with a crucial involvement, of the Roma group are being made.

AMS [P29] will soon fly to space and amongst other field of investigations will be sensitive to the product of annihilation of DM particles.

1.2.3 Gravitational Waves

Gravitational waves (GW) are space time-ripples such that the distance between free masses will alternately decrease and increase during their transit out of phase in two perpendicular directions. The VIRGO detector consists of a laser interferometer with two orthogonal arms each 3 km long. The sensitivity extends from 10 to 10000 Hz with a typical value of $h \sim 10^{-21}$ for the amplitude of the GW (see Fig. 4).

The VIRGO group of Rome plays a crucial role in VIRGO [P30]. The group mainly contributes to VIRGO:

- by designing , constructing and setting up the giant interferometric apparatus,
- by defining the strategy for the analysis of the collected data and developing the software needed to attain the scientific target of the detection of the gravitational waves

- by specifically being in charge for the last stage of the suspension system of the VIRGO mirrors

The improvement of the thermal noise limit is still a scientific target pursued during the construction of the detector payloads of the upgrade version of VIRGO, and it is a main issue of the design study of ET, the GW detector of third generation, a project financed by the European Union in the context of the Framework Program 7.

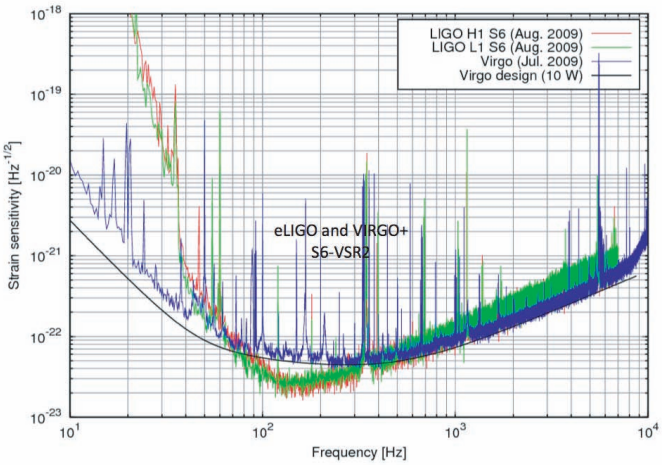

Figure 5: The spectral sensitivities of VIRGO and LIGO versus frequency, compared with the VIRGO design sensitivity curve.

1.2.4 Cosmic Rays

The last frontier for cosmic rays studies resides in UHE Neutrino detection. It will complement the one performed with muons, photons and primary hadrons. A Roma group [P31, P32] is participating both to ANTARES and NEMO with the final goal of an experiment of 1 km^3 to be performed in the Mediterranean sea. The group has participated actively in the characterization of deep-sea sites and has developed the electronics for such experiments. The project is partially financed by UE through the KM3NeT consortium.

Fernando Ferroni

P1. Commissioning of the ATLAS detector and preparation for the data analysis

The Large Hadron Collider (LHC) at CERN extends the frontiers of particle physics with its unprecedented high energy and luminosity. Inside the LHC, bunches of up to 10^{11} protons will collide every 25 ns with an energy of 14 TeV at a design luminosity of 10^{34} cm^{-2} s^{-1}.

ATLAS is a general-purpose experiment, which consists currently of 172 participating institutions with more than 2900 physicists and engineers, including 700 students. The detector, shown in Figure 1, consists of an inner tracker inside a 2 T solenoid providing an axial field, electromagnetic and hadronic calorimeters outside the solenoid and in the forward regions, and barrel and end-cap air-core-toroid muon spectrometers. The precision measurements for photons, electrons, muons and hadrons, and identification of photons, electrons, muons, τ-leptons and b-quark jets are performed over $\theta \geq 10°$. The complete hadronic energy measurement extends over $\theta \geq 1°$. The trigger is performed using a three-level system.

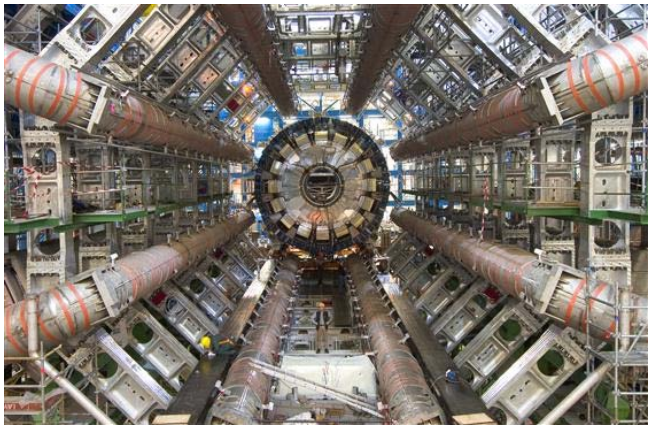

Figure 1: The ATLAS experiment.

The detector design [1] has been optimized to cover the largest possible range of LHC physics : searches for Higgs bosons and alternative schemes for the spontaneous symmetry-breaking mechanism; searches for supersymmetric particles, new gauge bosons, leptoquarks, quark and lepton compositeness indicating extensions to the Standard Model and new physics beyond it; studies of the origin of CP violation via high-precision measurements of CP-violating B-decays; high-precision measurements of the third quark family such as the top-quark mass and decay properties, and the decays of B-hadrons. The expected performances for the standard model Higgs boson search are shown in Figure 2.

In addition, to cope with the massive need for computing infrastructure a world-wide computing network, the World-wide LHC Computing Grid, has been built.

In the past the main contributions of our group have been in the design and construction of the precision detectors of the muon spectrometer, in the design and realization of the muon trigger, in the high level triggers, in data acquisition and in physics studies.

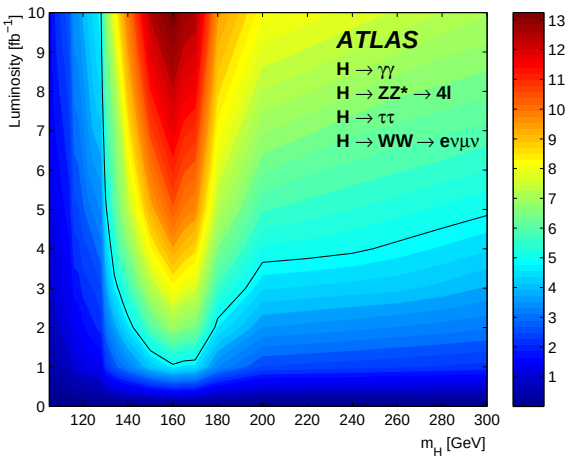

Figure 2: Significance contours for different Standard Model Higgs masses and integrated luminosities. The thick curve represents the 5σ discovery contour. In the region below 2 fb^{-1}, the approximations are less accurate, but conservative.

Currently, after an extensive programme of data acquisition with cosmics particles, ATLAS is exposed to the first LHC beams. Our interests now lie in the understanding and commissioning of the detector (expecially the parts built by us), in the calibration and processing of the data and, expecially, in the first physics analyses. We are engaged in Standard Model studies ([2], pag. 723), in the search for the Higgs boson in its 4-lepton decay ([2], pag. 1243) and in exotic processes ([2], pag. 1695).

At present our group hosts 10 students for their Thesis and 4 PhD students.

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http://www.roma1.infn.it/exp/atlas/

P2. Test and commissioning of the Muon Spectrometer of the ATLAS experiment

The detection and the precision measurement of leptons, in particular electrons and muons, is crucial for large part of the ATLAS physics program. The muon spectrometer of the ATLAS experiment is the part of the detector aiming to identify muons coming from proton-proton collisions, reconstruct their trajectory with high precision and measure their momenta. It consists of a barrel and two end-caps air-core toroids instrumented with three stations of precision chambers and trigger chambers. A schematic overview of the spectrometer is shown in Fig.1, where the names and the positions of the different detectors are shown. The aim of the spectrometer is to provide a measurement of the momentum for muons with transverse momenta between few GeV and 1 TeV. It is designed to cover all azimuthal angles and polar angles down to about 10° with respect to the proton beam direction. The expected momentum resolution of the muon spectrometer is evaluated by Montecarlo simulations and is shown in Fig.2.

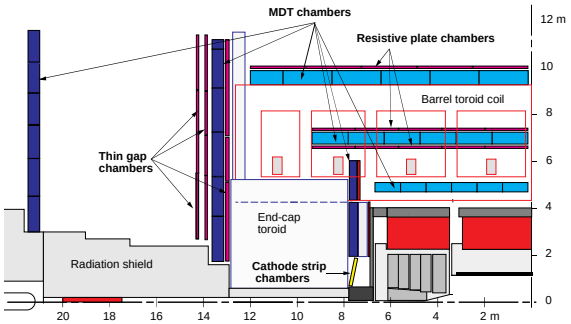

Figure 1: Side view of the ATLAS muon spectrometer. The p-p collision point is in the origin of the twp-coordinate system.

The Sapienza University group in collaboration with the INFN Sezione di Roma, has built and tested a significant fraction of the MDT (Monitored Drift Tubes) chambers composed by 3 cm diameter cylindrical drift tubes assembled in layers. These chambers that allow to measure the muon trajectories with a single-hit resolution of less than 100 μm have been installed and commissioned in the ATLAS detector and are now fully operational.

The Muon Spectrometer is completely working and taking data since 2007. Cosmic ray data allow to monitor the performance of the detector and to test the calibration and alignment methods.

As shown in Fig.2, the main contribution to the spectrometer resolution at high momenta comes from the single MDT tube resolution and calibration. For the continuous calibration of the MDT chambers, samples of muon tracks identified by the trigger are sent to three calibration centers where a complete calibration procedure is done. One of these calibration centers is in our University. In order to convert the raw time of

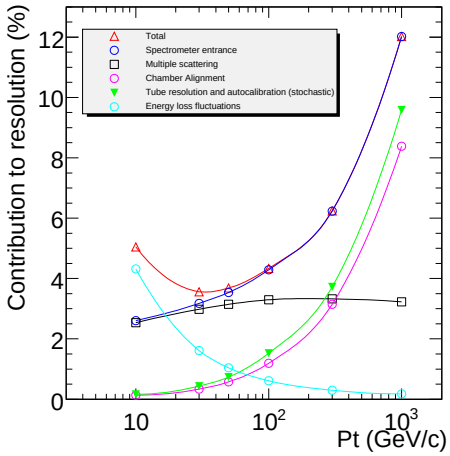

Figure 2: Contributions to the expected momentum resolution for muons reconstructed in the muon spectrometer as a function of transverse momentum.

each single tube to the hit position, one needs first to determine the t_0 of each tube and then to evaluate the space-to-time relation between the measured time and the drift distance. The calibration procedure allows to obtain the t_0 of all the tubes and the space-to-time relation for calibration regions where the tubes have the same properties. The full procedure has been extensively tested during the cosmic rays data taking and is ready to be used during the LHC run. At the same time the calibration data are used to study the quality of the data and contribute to the global quality assessment of the data taken.

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P3. Test and commissioning of the muon trigger system of the ATLAS experiment

The trigger system of the ATLAS experiment at LHC is organized in three hierarchical levels. The first trigger level (LVL1) is hardware based, implemented in custom programmable electronics, directly connected to the front-end of calorimeters and muon detectors. It uses coarse granularity data and has to reduce the event rate from 1 GHz (at the design luminosity of 10^{34} cm^{-2}s^{-1}) to 100 kHz within a latency of 2.5 μs. Level-2 (LVL2) and Event Filter (EF), composing the High Level Trigger (HLT), are software based and run on the on-line trigger farms. At LVL2 full granularity data, inside the Region of Interest (ROI) identified at LVL1 are available. The LVL2 selection reduces the event rate from 100 kHz to 2 kHz, with a latency time of 10 ms. The Event Filter makes use of the entire detector data, its total latency is $\sim$ 2 s and sofisticated algorithms are executed in order to refine the selection and reduce the data throughput to the $\sim$ 200 Hz of the event acquisition rate.
High p_T muons are important signatures of many processes predicted in various new physics scenarios. Moreover they allow to select Standard Model processes which are usually exploited for calibration and commissioning of the esperiment for physics. Therefore, the muon trigger performance has a strong impact on the physics reach of the experiment. The LVL1 selection is based on the definition of allowed geometrical roads, the Coincidence Windows shown in Fig. 1. Given a track that hits the middle trigger station (pivot plane), the algorithm searches for time-correlated hits in the confirm plane, inside a geometrical region around the η and ϕ of the hit on the pivot plane: the size of the (η, ϕ) intervals defines a specific p_T threshold for the muons originating from the Interaction Point. There are two confirm planes: one for low p_T triggers in the inner trigger plane (at a distance of about 70 cm from the pivot plane), and another located in the outer station, where hits are required, in addition to a low-p_T trigger, for high p_T muons.

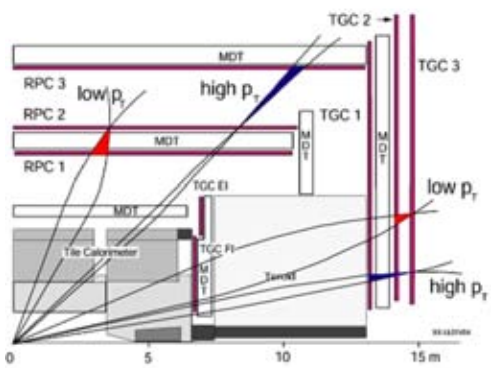

Figure 1: Schema of the L1 muon trigger coincidence windows. Low-p_T and high-p_T roads are shown.

The ATLAS group of the Physics Department and INFN section of the Sapienza Rome University has designed and built the electronics of the LVL1 muon barrel trigger. This system is based on about 800 electronic modules mounted on the RPC chambers where the trigger algorithms described above are implemented. In 2006 and 2007 the muon stations consisting of a sandwich of MDT and RPC chambers, with their trigger modules on, were mounted in the ATLAS experiment. The system was fully cabled in 2007 and 2008 and it was subsequently tested and calibrated with cosmic rays. The LVL1 trigger is now fully operational and it triggered the first muons coming from proton-proton interaction at the LHC start-up in Dicember 2009.

The Atlas Rome Group is also working in the LVL2 muon trigger algorithms development; at this stage high precision data from MDT chambers are used to identify good muon tracks and refine the p_T measurement. At LVL2 it is possible to combine the Muon Spectrometer (MS) tracks with the information coming from other detectors to further reduce the background. One algorithm combines the MS candidate with the Inner Detector tracks. The combination increases the sharpness of the threshold at low-p_T and helps to reject muons from in-flight decays of light mesons (π, K). The calorimetric information is used by another algorithm in order to tag isolated muons and increases the robustness of the standard muon triggers. These algorithms were developed using simulated data and have been tested with "real data" with cosmic rays. They proved to work in a reliable way and were operated in trasparent mode in the December 2009 LHC data taking and ready to filter the events in the upcoming LHC data taking.

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P4. Supersymmetric Higgs search at hadron colliders and perspectives towards the futures electron-positron linear colliders.

The Minimal Supersymmetric Standard Model (MSSM) is the most investigated extension of the Standard Model (SM). The theory requires two Higgs doublets giving origin to five Higgs bosons: two neutral scalars, h and H (h is the lighter of the two), one neutral pseudoscalar, A, and one pair of charged Higgs bosons, $H^{\pm}$. Their discovery is an irrefutable proof for physics beyond the SM. This is a key point in the physics program of future accelerators and in particular of the LHC. After the conclusion of the LEP program in the year 2000, the experimental limit on the mass of the Standard Model Higgs boson was established at 114.4 GeV with 95% CL. Limits were also set on the mass of neutral and charged MSSM Higgs bosons for most of the representative sets of model parameters.

The motivation [1] of the searches carried on in Rome in the last years is to explore the potential of the ATLAS detector at LHC for the discovery of neutral MSSM Higgs bosons in the parameter region not excluded by the LEP and Tevatron data. Two decays channel of MSSM Higgs have been explored one in μ pairs, the second in supersymmetric particles.

The first was focused on the search for h, the lightest of the neutral Higgs bosons decaying in μ pair. Its mass, taking account of radiative corrections, is predicted to be smaller than 140 GeV. The conclusion achieved can be summarized as that the discovery of a neutral h/A MSSM boson decaying into two muons, h$\rightarrow \mu^+\mu^-$ and A$\rightarrow \mu^+\mu^-$, accompanied by two b-jets is possible in a mass range of 100 to 120 GeV at tan$\beta > 15$, with an integrated luminosity $\int \mathcal{L}\,\mathrm{d}t = 10$ fb^{-1}, which corresponds to one year of data taking [2].

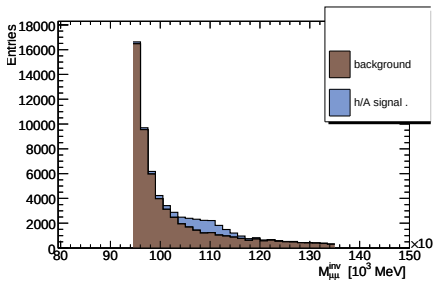

Figure 1: Distributions of the reconstructed $\mu^+\mu^-$ invariant mass, M_{inv}, for signal and backgrounds events,(tan$\beta = 45$, $m_{\mathrm{A}} = 110$ GeV, $m_{\mathrm{h}} = 110$ GeV) at $\int \mathcal{L}\,\mathrm{d}t$= 300 fb^{-1}. The h/A signal (light blue) emerge over the background (dark brown).

Moreover, to achieve an uncontroversial proof of the existence of models beyond SM, the discovery of the heavier bosons H and A is demanded, since the light h boson is indistinguishable from the SM Higgs boson. Many signatures of MSSM neutral Higgs bosons have been studied involving decays into known SM particles, in a scenario where it is assumed that sparticles are too heavy to participate in the process. If the MSSM Higgs decay into sparticles is kinematically allowed, decay channels involving neutralinos ($\tilde{\chi}^0$), charginos ($\tilde{\chi}^{\mp}$) and sleptons ($\tilde{\ell}$) can be considered, enlarging the possibilities of discovery.

In this second search, we have studied the potential for the discovery of neutral supersymmetric Higgs bosons, considering the decays of A/H into neutralino and chargino pairs, with subsequent decay into lighter neutralinos and leptons and an experimental final state signature of four leptons and missing energy (due to the presence of $\tilde{\chi}_1^0$-s), extending the search to charged Higgs boson. The analysis is performed in four different superymmetric model scenarios, two for MSSM and two for mSUGRA. With high luminosity, $\int \mathcal{L}\,\mathrm{d}t = 300$ fb^{-1}, a signal may be detected in three of the four supersymmetric scenario; in two of them discovery may be reached also with a lower luminosity, 100 fb^{-1}.

The Higgs discovery is expected to be achieved at hadron colliders, but its properties have to be studied at electron positron colliders (ILC,CLIC). The next generation of high energy colliders is intended to operate at a centre of mass energy ranging up to the TeV scale. The physics scope includes precise measurements of the triple- and quartic-gauge bosons interactions, as well as the characterisation of the Higgs-boson and top-quark sectors.

The final states are typically multiple hadronic jets, accompanied frequently by low-momentum leptons and/or missing energy. The signature of the final states of interest often relies on the identification of Z or/and W bosons by their decay modes into two jets. In order to distinguish them efficiently, a good jet energy resolution and a precise reconstruction of the jet direction is also required. These are among the main requirements driving the detector design in general and the calorimetry design in particular. The crucial point of this design is the choice of photodetectors. A novel photodector technology has been recently proposed, SiPM, SiliconPhotoMultipliers. In a laboratory in Rome, we have studied and characterized the response at different wavelenghts (380nm-650nm) of these innovative detectors [3,4].

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S. Gentile, F. Meddi

P5. The CMS experiment at the CERN LHC

The Large Hadron Collider at CERN, which started the operations in 2008-09, is the highest energy accelerator in the world and will be a unique tool for fundamental physics research for many years. The LHC will provide two proton beams, circulating in opposite directions, at an energy of 7 TeV each (centre-of-mass $\sqrt{s} = 14$ TeV). The CMS experiment is a general purpose detector to explore physics at this unprecedented energy scale. It is expected that the data produced at the LHC will elucidate the electroweak symmetry breaking, for which the Higgs mechanism is presumed to be responsible, and provide evidence of physics beyond the standard model such as supersymmetry or other unknown mechanisms. CMS will also be an instrument to perform precision measurements, e.g., of parameters of the Standard Model, mainly as a result of the very high event rates: the LHC will be a Z factory, a W factory, a b quark factory, a top quark factory and even a Higgs or SUSY factory if these new particles have TeV scale masses.

The CMS (Compact Muon Solenoid) detector, shown in Fig. 1, measures roughly 22 meters in length, 15 meters in diameter, and 12,500 metric tons in weight. Its central feature is a huge superconducting solenoid, 13 meters in length, and 6 meters in diameter. Its compact design is large enough to contain the electromagnetic and hadron calorimetry surrounding a silicon tracking system, and its high field (4 Tesla) allows a superb tracker detection system. Muon momenta are measured by gas chambers in the iron return yoke.

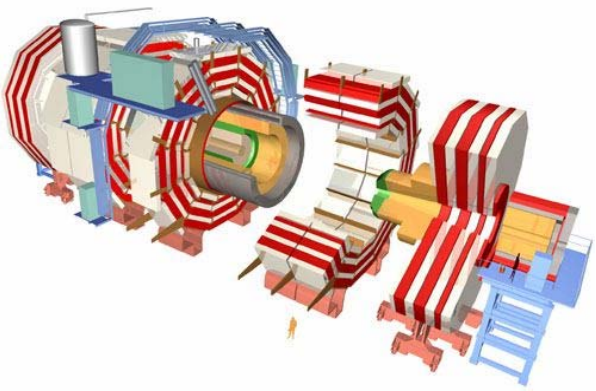

Figure 1: Schematic view of the CMS detector

Our group mainly contributed to the project and construction of the electromagnetic calorimeter, which is designed on the benchmark Higgs boson decay into two photons. The $H \to \gamma\gamma$ channel is crucial for the discovery of Higgs particles at masses beyond the upper reach of LEP (114 GeV/c^2) and below about 150 GeV/c^2. The challenge for discovery of a Higgs in this mode is the small branching fraction of about 0.002. The $\gamma\gamma$ decay mode can be well identified experimentally but the signal rate is small compared to the background. It has long been understood that $H \to \gamma\gamma$ can be detected as a narrow mass peak above a large background and then the resolution of the calorimeter is crucial. This led to the choice of high density scintillating $PbWO_4$ crystals, providing a compact, dense, fast and radiation resistant material with a resolution better than 0.5 % for high energy photons. Details of Rome contribution to the CMS calorimeter are given in "The Lead Tungstate Crystal Calorimeter of the CMS experiment" on this Report. The $H \to \gamma\gamma$ predicted signal is shown in Fig. 2.

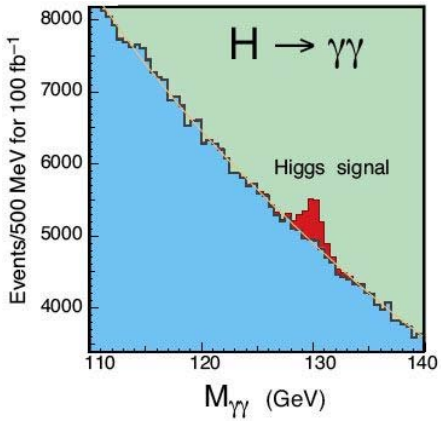

Figure 2: $H \to \gamma\gamma$ signal simulated in the CMS experiment for a Higgs mass of 130 GeV/c^2

Besides the Higgs search, our main interests in the physics analyses are the search of supersymmetric particles through electron and photon decays and of new, heavy Z bosons through their electron decays.

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http://www.roma1.infn.it/exp/cms/

P6. The Lead Tungstate Crystal Calorimeter of the CMS experiment

The Lead Tungstate crystal calorimeter is a key feature of the CMS experiment, described elsewhere in this report (The CMS experiment at the CERN LHC).

The calorimeter is made of 75 848 lead tungstate (PWO) scintillating crystals. Each crystal has a length of approximately 23 cm and a truncated pyramid shape with an average cross section of about 2.2×2.2 cm^2. Lead tungstate was chosen as scintillating medium after a long period of R&D, conducted in our laboratories together with several collaborators around the world. The choice was due to the fact that PWO has a very short radiation length ($X_0 = 0.89$ cm), allowing the construction of a compact detector, a fast response (most of its light is emitted in 25 ns), and is radiation tolerant, a fundamental requirement for LHC. On the other hand PWO has a relatively low light yield, demanding for an amplification of its signal. During the R&D phase our group contributed mainly in clarifying the effect of trivalent doping on crystals, studying the radiation damage, and in the definition of instruments and methods for a reliable measurement of both the light yield and transmission of PWO crystals. We also developed, in strict collaboration with italian manufacturers, both the main supporting structure for the ECAL and the transportation system. In the first case we had to face with the requirement of a very light structure to support a weight of about 100 tons. For the transportation we developed a dedicated dumped cage instrumented with accelerometers and a logging device, equipping the driver cabin with appropriate alarms.

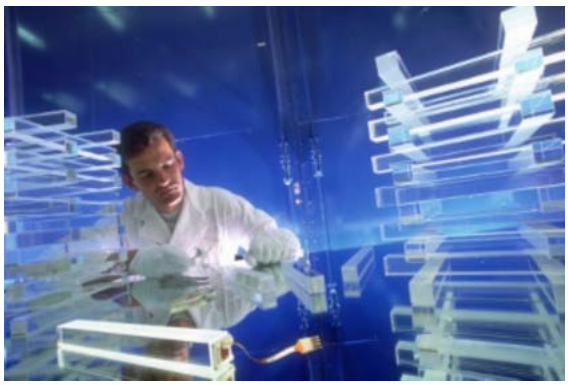

Figure 1: PWO crystals being labeled by a technician.

Crystals are arranged in such a way to form approximately a cylinder whose axis coincides with the beam axis. The lateral surface of the detector is called the *barrel*, while the two bases are called the *end–caps*. Crystals are organized in modular structures providing mechanical support for them. Half of the modules composing the ECAL barrel were built in dedicated laboratories in Roma, after a complex workflow during which all the parts used to realize the instrument were subjected to a careful quality control, by automatic machines designed and realized by us.

Photomultipliers cannot be used to measure the light emitted by PWO, because of the strong 3.8 T magnetic field produced by the CMS superconducting solenoid. To overcome this difficulty we employ avalanche photo–diodes (APDs) in the barrel region and vacuum photo–triodes in the endcaps (in these regions the predicted neutron flux is too high for APDs).

The calorimeter has an exceptionally good energy resolution. The resolution $\sigma(E)$ for photons whose energy is higher than about 100 GeV can be considered constant and is, for ECAL, better than 0.5 %. Such a result is very important for the discovery of any particle decaying into two photons, like the Higgs boson. This is the outcome of a careful design, appropriate machining of the crystals, good coupling between crystals and photodetectors, stability and calibration. Such a good resolution can only be maintained during the lifetime of the experiment thanks to continuos monitoring of the crystal transparency, achieved by laser light injected into each individual crystal by means of an optical fibre, and periodic calibrations using physics events. Stability is achieved keeping the whole detector at a constant temperature of about 18 °C, thanks to thermal screens and an appropriate cooling system, as well as operating the photo–detectors at stable voltages. In particular, the APD gain M is very sensitive to the magnitude of the bias voltage V, with $1/M\,(dM/dV)$ approximately equal to 3 %/V, requiring a stability of few tens of mV for biases of the order of 300 V. The stability of the bias voltage has been achieved working in strong collaboration with an italian firm, who developed a specially designed power supply that has been extensively tested by our group during the past years.

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http://www.roma1.infn.it/exp/cms

P7. Precision measurements of CP violation and rare decays of B-hadrons at the CERN Large Hadron Collider LHC

CP violation, discovered in neutral kaon decays, is still one of the outstanding mysteries of elementary particle physics. In the weak interactions CP violation is generated by the complex three by three unitary matrix known as the CKM matrix. In cosmology CP violation is one of the three ingredients required to explain the excess of matter over antimatter observed in our universe, but the level of CP violation that can be generated by the Standard Model is insufficient to explain this excess. This calls for new sources of CP violation beyond the Standard Model.

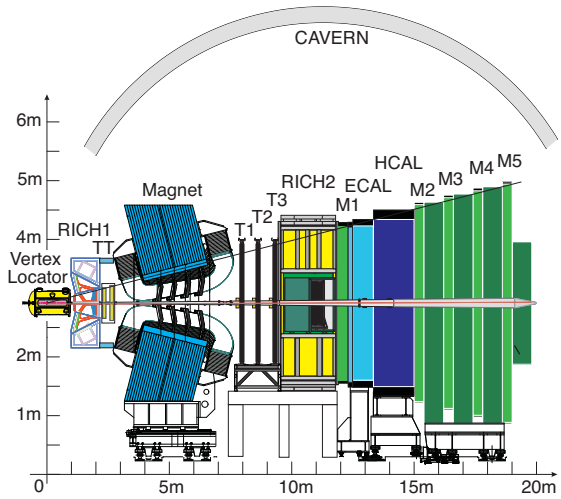

Figure 1: LHCb setup. M1−M5 are the muon detectors.

To search for such possibilities the LHCb experiment [1] at the CERN-LHC collider will precisely measure CP-violating effects and rare decays of B_d, B_s and D mesons. To reach these goals the LHCb detector (Fig. 1) must provide an excellent vertex and momentum resolution combined with very good particle identification.

Among the decay products of the B and D hadrons, muons are present in many final states as for example in the two CP-sensitive B decays, $B_d^0 \to J/\psi(\mu^+\mu^-)K_S^0$ and $B_s^0 \to J/\psi(\mu^+\mu^-)\phi$. In addition, the observation of the flavour-changing neutral current decays like $B_s^0 \to \mu^+\mu^-$ and $D^0 \to \mu^+\mu^-$ may reveal new physics beyond the Standard Model. Therefore a muon detector combined with a muon trigger and an offline muon identification are fundamental requirements of the experiment.

In the last years our laboratory has contributed to the design of the muon system comprising 1368 multi-wire proportional chambers (MWPCs) and to check their performance [2]. These chambers must have a time resolution lower than 4 ns (rms) and an efficiency of at least 99 % within a 25 ns time window. These stringent requirements where obtained by using, in most of the muon detector, four-gap MWPCs with a 5 mm gas gap and a 2 mm wire pitch. To check the long-term stability of the MWPCs in a high radiation environment an ageing test was performed [3] by exposing a few chambers to a 800 TBq ^{60}Co source during one month. Moreover the efficiency and the time resolution of a MWPC were measured as a function of the anode HV. The effect of a high radiation background on these two quantities was tested by exposing a chamber to a muon beam superimposed to the gamma flux of a 630 GBq ^{137}Cs radioactive source [4]. The results reported in Fig. 2, show that the MWPCs fulfill the requirements for HV larger than $\sim$ 2.6 kV.

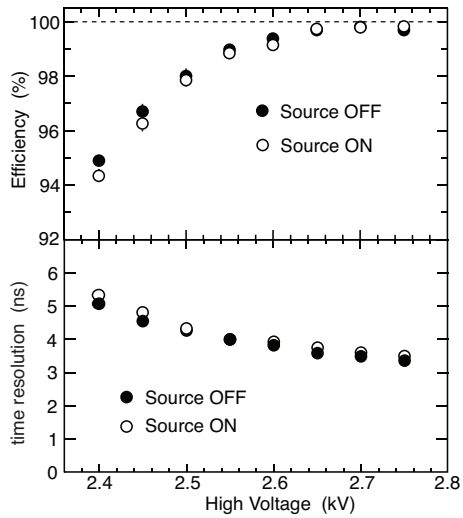

Figure 2: Efficiency and time resolution of a MWPC vs. the anode HV. The effect of the 630 GBq ^{137}Cs source is shown to be negligible.

In 2008 the entire setup was mounted on the p-p collider. The tests with the first proton beam show that the full setup and in particular the muon detector, reach the desired performance and are ready for data taking with the forthcoming machine runs.

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http://lhcb.web.cern.ch/lhcb/

P8. Interactions between nuclei at LHC: ALICE experiment

High-energy heavy-ion physics aims to study how collective phenomena and macroscopic properties, involving many degrees of freedom, emerge from the microscopic laws of elementary-particle physics. The most interesting case of collective phenomena is the occurrence of phase transitions in quantum fields at characteristic energy densities; this would affect the current understanding of both the structure of the Standard Model at low energy and of the evolution of the early Universe. In ultra-relativistic nuclei collisions it is expected to attain energy densities which reach and exceed the critical energy density 1 GeV fm^3, predicted by lattice calculations of Quantum Chromo Dynamics (QCD) for a phase transition of nuclear matter to a deconfined state of quarks and gluons, thus making the QCD phase transition the only one predicted by the Standard Model that is presently within reach of laboratory experiments.

ALICE is a general-purpose heavy-ion experiment primarily designed to study the physics of strongly interacting matter and the quark-gluon plasma (QGP) formed in nucleus-nucleus collisions at the LHC [1]. Its detectors measure and identify mid-rapidity hadrons, electrons and photons produced in the collision, and reconstruct particle tracks, including short lived ones, in an environment with large multiplicity of charged particles. A forward muon arm detects and identifies muons covering a large rapidity domain. Hadrons, electrons and photons are detected and identified in the central rapidity region by a complex system of detectors immersed in a moderate (0.5 T) magnetic field. Tracking relies on a set of high granularity detectors: an Inner Tracking System (ITS) consisting of six layers of Silicon Detectors, a large-volume Time-Projection Chamber (TPC) and a high-granularity Transition-Radiation Detector (TRD). Particle identification in this central region is performed by measuring energy loss in the ITS and TPC, transition radiation in the TRD, Time Of Flight (TOF) with a high-resolution array of multigap Resistive Plate Chambers, Cherenkov radiation with a High-Momentum Particle Identification Detector (HMPID), photons with a high granularity crystal photon Spectrometer (PHOS) and a low granularity electromagnetic calorimeter (EMCAL). Additional detectors located at large rapidities complete the central detection system to characterize the event and to provide the interaction triggers.

The ALICE Rome group is involved in the ultrarelativistic nuclei collisions study since 1994, participating to the WA97 and NA57 experiments at the CERN SPS. The aim was to obtain clear evidence of an enhancement of the (multi)strange baryons/antibaryons ratio production in the Pb-Pb collisions compared to p-Be collisions; this fact could represent a strong signal for a phase transition from ordinary matter to a Quark Gluon Plasma state. The results obtained in the NA57 experiment seem to confirm this important signature [2]. Since 2004 the ALICE Rome group participates to the realization of the Silicon Drift Detector (SDD) that constitutes the intermediate layers of the ITS [3]. The ITS consists of six coaxial cylinders: two innermost ones form the Silicon Pixel Detectors, two intermediate ones the Silicon Drift Detectors, two outermost ones the Silicon Strip Detectors. The number, position and segmentation of the layers are optimized for efficient track finding and high impact parameter resolution. The SDD front-end electronics is based on three types of ASICs, two of them, PASCAL and AMBRA, assembled on an hybrid circuit (see fig. 1) which is directly bonded to the sensor, and one, CARLOS, located at each end of a ladder. The Alice Rome group was responsible for the production and certification of the PASCAL and AMBRA chips since 2005. To this purpose a validation system was built up in the Rome laboratory using a semiautomatic Probe Station in a class 100 Clean Room equipped with hardware and software tools projected by the Rome group. In 2007, The Rome group collaborated to the assembly of the SDD modules and ladders in Torino, and finally to the installation inside the ITS in the ALICE site at CERN. During 2008 and 2009 the ALICE Rome group participated to the data taking in the cosmic rays runs used for the intercalibration of the whole ALICE detector. In december 2009, LHC machine started with p-p collisions at 900 and 2360 GeV and ALICE gave the first physics paper on the charged particles multiplicity in the detector [4].

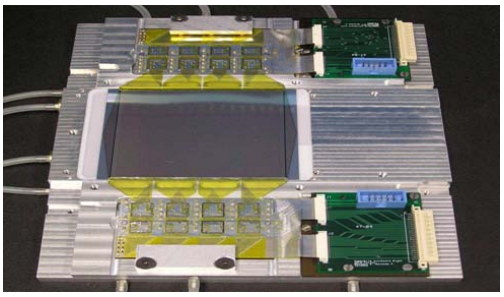

Figure 1: A Silicon Drift Detector on the assembly jig.

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P9. Study of B-mixing and CP Violation with the CDF experiment

The accurate determination of charge-conjugation-parity (CP) violation in meson systems has been one of the goals of particle physics since the effect was first discovered in neutral kaon decays in 1964. Standard model CP-violating effects are described through the Cabibbo-Kobayashi-Maskawa mechanism, which has proved to be extremely successful in describing the phenomenology of CP violation in B^0 and $B^{\pm}$ decays in the past decade. However, comparable experimental knowledge of B_s^0 decays has been lacking. In the B_s^0 system, the mass eigenstates are admixtures of the flavor eigenstates. This causes oscillations between the flavor states with a frequency proportional to the mass difference of the mass eigenstates (Δm_s). In the standard model this effect is explained in terms of second-order weak processes that provide a transition amplitude between the B_s^0 and $\bar{B}_s^0$ states. The magnitude of this mixing amplitude is proportional to the oscillation frequency, while its phase is responsible for CP violation in $B_s^0 \to J/\psi\phi$ decays. The presence of physics beyond the standard model could significantly modify the magnitude or the phase of the mixing amplitude. We have preformed the first time dependent analysis of the $B_s^0 \to J/\psi\phi$ decay, separating the time evolution of mesons produced as B_s^0 or $\bar{B}_s^0$ using flavor tagging tecniques. By relating this time development with the CP eigenvalue of the final states, which is accessible through the angular distributions of the J/ψ and ϕ mesons, we obtain direct sensitivity to the CP violating phase. With 1.35 fb^{-1} of data collected by the CDF experiment, we obtained the confidence bounds on the CP violation parameter $2\beta_s$ and the width difference $\Delta\Gamma$, shown in Figure 1. Assuming the standard model, the probability of a deviation as large as the level of the observed data is 15%, which corresponds to 1.5 Gaussian standard deviations.

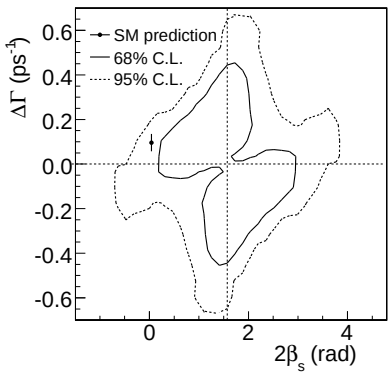

Figure 1: Feldman-Cousins confidence region in the $2\beta_s - \Delta\Gamma$ plane, where the standard model favored point is shown with error bars.

Since the discovery of the charm quark in 1974, physicists have been searching for the oscillation of neutral charm mesons between particle and anti-particle states. Such behavior is referred to as "mixing", as first explained in 1955 for the K^0 meson in terms of quantum-mechanical mixed states. Mixing was next observed for B_d^0 mesons in 1987. The years 2006 and 2007 have seen landmark new results on mixing: observation of B_s^0 mixing, and evidence for the D^0 mixing. The latter comes from two different types of measurements: direct evidence for a longer and shorter lived D^0 meson, from the decay time distributions for D^0 decays to the CP-eigenstates K^+K^- and $\pi^+\pi^-$ compared to that for the CP-mixed state $K^-\pi^+$, evidence for D^0 mixing in the difference in decay time distribution for $D^0 \to K^+\pi^-$ compared to that for the Cabibbo-favored (CF) decay $D^0 \to K^-\pi^+$. Such a difference depends on the combined effects of differences in the masses and lifetimes of the D^0 meson weak eigenstates. We have presented a new measurement based on this latter tecnique, performed for the first time at a hadron collider machine. We use a signal of 12.7×10^3 $D^0 \to K^+\pi^-$ decays recorded with the CDF detector at the Fermilab Tevatron, which corresponds to an integrated luminosity of 1.5 fb^{-1} for $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV. We search for $D^0 - \bar{D}^0$ mixing and measure the mixing parameters, finding that the data are inconsistent with the no-mixing hypothesis with a probability equivalent to 3.8 Gaussian standard deviations (see Figure 2), confirming the evidence obtained at the B factory experiments.

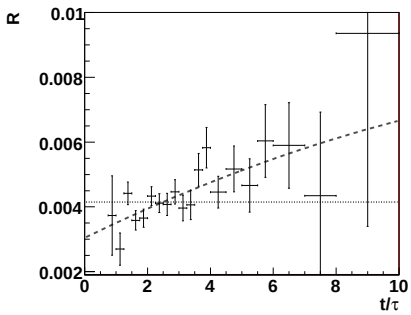

Figure 2: Ratio of prompt D^* "wrong-sign" to "right sign" decays as a function of normalized proper decay time. The dashed curve is from a least-squares parabolic fit. The dotted line is the fit assuming no mixing.

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P10. Study of Standard Model processes at the high energy frontier with the CDF experiment

The Standard Model of fields and particles is the theory that provides the best description of the known phenomenology of the particle physics. Since its formalisation at the end of the '60s, the Standard Model has been tested by many experiments. In this process a key role is played by the collision experiments in which elementary particles (tipically electrons and protons) interact at high energy, allowing precise tests of the theoretical models. In the latest years the TeVatron accelerator (located at the Fermi National Accelerator Laboratory, near Chicago) provided $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV, the highest available energy before the Large Hadron Collider at Cern will be fully operational. The CDF experiment runs one of the two multi-purpouse detectors installed at the TeVatron and is performing a wide range of measurements of SM processes generated by $p\bar{p}$ interactions with high tensferred momentum. In particular all the processes in which top quarks or Vector Bosons are produced require high energy partons interaction. The top quark has been discovered by the first run of the TeVatron experiments in 1996, exploiting the pair production process. After 13 years, in 2009, during the second run of the TeVatron, also the electroweak single top quark production has been observed.

The study of the associate production of Vector Boson and jets in $p\bar{p}$ collisions, is a fundamental tool to test the QCD in high transferred momentum regime, and can provide information on proton structure function.

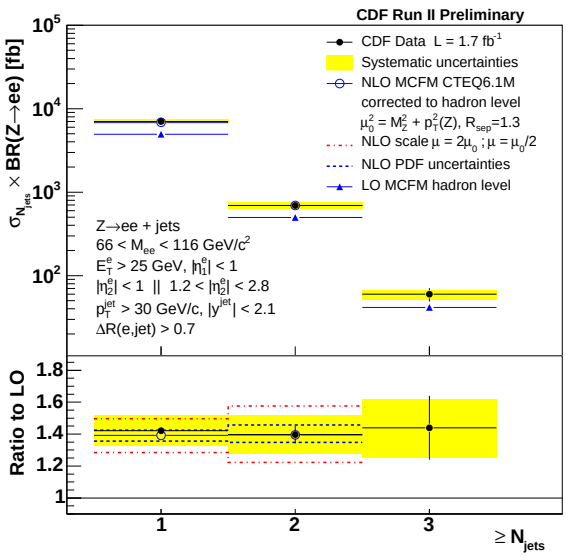

Figure 1: Measured cross section as a function of inclusive jet multiplicity compared to NLO QCD predictions [2].

In the latest years, with the increasing integrated luminosity collected by the CDF detector, differential measurements of the production cross sections of $Z/W + jet$ as a function of the number, momentum and rapidity of the jets have been performed. These results provide strong tests of the theoretical predictions and are also fundamental in order to tune the Monte Carlo generators for the next generation of experiments.

Exploiting techniques for the identification of the flavour of the parton which originates a jet, the production cross section of $W + b$, $W + c$, and $Z + b$ processes have been measured, providing results in good agreement with the SM expectations.

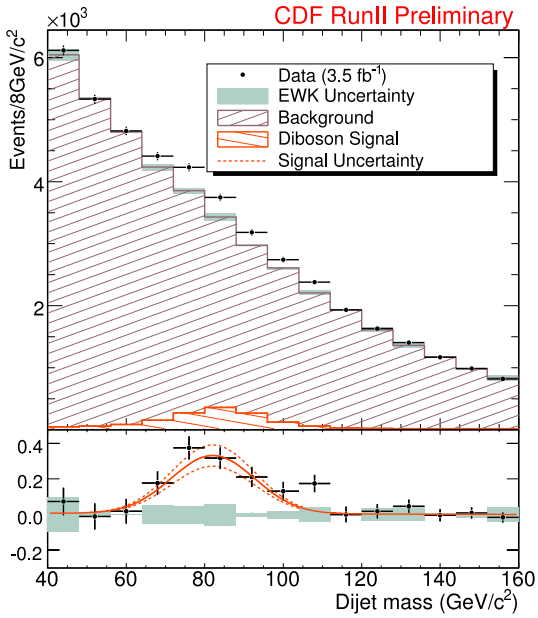

Figure 2: Dijet invariant mass distribution for candidates diboson events selected in the missing transvers energy and two jets final state [3].

The large statistic sample collected in the last years has allowed CDF experiment to reach competitive results also in the diboson sector, both in the cross section measurements and in the Triple Gauge Coupling limits. Several final states have been succesfully studied, including the hadronic ones, which are also relevant for the study of the low mass Higgs Boson.

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P11. Heavy Flavor and Spectroscopy with the CDF experiment

The Tevatron collider at Fermilab provides proton-antiproton collisions at $\sqrt{s} = 1.96$ TeV. The integrated luminosity collected until the end of 2009 was about 6 fb^{-1} corresponding to approximately $3 \cdot 10^{10}$ b-quarks produced in the acceptance of the CDF detector. The b-quarks hadronize in all sort of b-mesons and b-baryons, in contrast to e^+e^- machines operating at the Υ(4S) which can only study B^+ and B_d mesons, allowing thus the discovery and detailed spectroscopy of previously unseen b-baryons or other exotic states and the search for rare decays of the B_s^0 meson. Moreover the sophisticated trigger capability of the CDF detector allowed for the first time the online selection of events characterized by the presence of charged particles that do not point back to the primary collision point, a clear signature of the long lifetime of b-hadrons. The latter option has been made possible by the development of the Silicon Vertex Trigger (SVT), a custom hardware processor for fast pattern reconstruction and track fitting in the silicon vertex detectors ($< 20\ \mu$s) at the trigger level. The CDF group in Roma gave important contributions to the SVT deployment and operation. The sample collected by the SVT allowed the observation of several hadronic decay modes of the B_s^0 meson, like $B_s^0 \to \phi\phi$ that has been discovered by a team from Roma. Subsequently a detailed investigation of the polarization amplitudes in this channel has been performed in order to check the calculations made in the QCDf and pQCD theoretical frameworks. Other two body decay modes of the B_s^0 meson have been

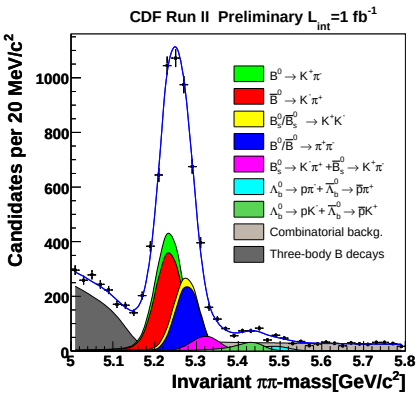

Figure 1: Invariant mass of two body B_d^0 and B_s^0 candidates showing the overlapping mass distribution of the four identified decay modes.

observed for the first time [1]. The $B_s^0 \to K^+K^-$ and $B_s^0 \to K^-\pi^+$ signals, shown in Figure 1, have to be disentangled from the overlapping two body modes of the B_d meson by a multidimensional fit to the mass, kinematics and specific ionization of the two tracks. The first measurement of direct CP violation in the B_s system has been performed using the $B_s^0 \to K^-\pi^+$ decay.

The rare decay mode $B_s^0 \to \mu^+\mu^-$ has a very suppressed Branching Ratio (BR) in the Standard Model due to helicity suppression. However, in many theories beyond the Standard Model this suppression is lifted and BR larger by factors as large as 100 are predicted. The CDF collaboration published[2] the most stringent upper limit on the $B_s^0 \to \mu^+\mu^-$ BR ($< 4.3 \cdot 10^{-8}$ @95%C.L.), severely constraining models of new physics.

The large yield of B-meson and the excellent momentum resolution provided by the central drift chamber and silicon detectors has allowed CDF to study in detail the resonance structure of the rare decay $B^+ \to J/\psi\phi K^+$[3]. In particular evidence for a near threshold resonant structure in the $J/\psi\phi$ mass spectrum has been shown, Figure 2. The significance of the peak is 3.8σ and its mass and width have been measured $M = 4143.0 \pm 2.9(\text{stat.}) \pm 1.2(\text{syst.})$ MeV, $\Gamma = 11.7^{+8.3}_{-5.0}(\text{stat.}) \pm 3.7(\text{syst.})$ MeV. Awaiting further confirmation speculations about this new exotic state include a $D_s^* D_s^*$ molecule or a 4 quark $[cs][\bar{c}\bar{s}]$.

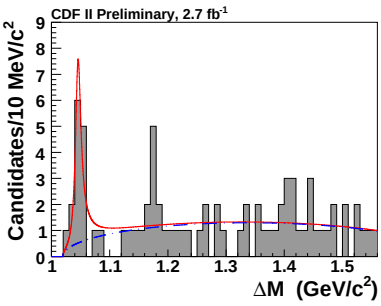

Figure 2: Invariant mass of $J/\psi\phi$ system (minus J/ψ mass) in $B^+ \to J/\psi\phi K^+$ decays showing the Υ(4140) resonance over a phase space background.

CDF has discovered in the last three years several new b-baryons. In particular the $\Sigma_b^\pm$ (with $[uud]$ and $[ddb]$ quark content respectively) have been discovered in the SVT samples by looking for their decay to $\Lambda_b\pi$. Additionally Ξ_b ($[dsb]$) and Ω_b($[ssb]$) have been identified respectively in the channel $\Xi_b \to J/\psi\Xi^-$, with $\Xi^- \to \Lambda\pi^-$ and $\Omega_b \to J/\psi\Omega^-$ with $\Omega^- \to \Lambda k^-$[4].

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P12. Study of CP violation with the measurement of time-dependent CP asymmetries in B meson decays

As far as one can see, our Universe is made of matter and no primordial anti-matter is evident. Whether this imbalance is a chance occurrence during the birth of the Universe or due to some fundamental difference between the behavior of matter and anti-matter under the charge-parity (CP) symmetry remains to be understood, and represents one of the biggest puzzles in Cosmology and Particle Physics. An elegant explanation of CP violation, within the framework of the Standard Model of Particle Physics, was proposed in 1973 by Kobayashi and Maskawa, and predicted large CP violation in B^0 mesons.

We have participated since 1993 in the design, detector commissioning and operation, and analysis of the data collected with the *BABAR* detector at the electron-positron collider PEP-II, located at the Stanford Linear Accelerator Center in California, USA, and operating at a center-of-mass energy of 10.580 GeV. In many of these

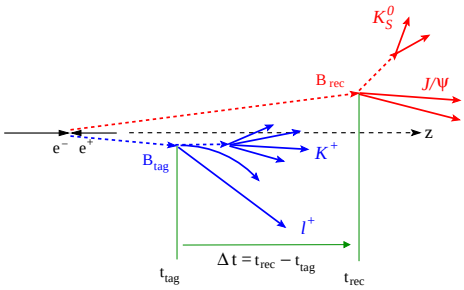

Figure 1: Production of a B^0–$\overline{B}^0$ pair where one B decays to a CP eigenstate, B_{rec}, and the other B to a flavor eigenstate, B_{tag}.

collisions, a pair of B^0 (particle) and $\overline{B}^0$ (anti-particle) mesons is produced in a quantum-entagled state: conservation of the quantum number known as *beauty* implies there is one particle and one anti-particle at any given time after their production, until one of the two mesons (B_{tag}) decays in a final state which allow us to determine whether it was a particle ($\overline{B}^0$ tag) or an anti-particle (B^0 tag). The other meson is then free to propagate and decay in a CP eigenstate (B_{rec}) accessible to both B^0 and $\overline{B}^0$ mesons. Thanks to the excellent performance of the silicon detector, we are able to identify the decay vertices of the two mesons and measure the distance between them that, in average, is $\sim 250\mu$m, with a precision of $\sim 150\mu$m. The knowledge of the relativistic boost of these particles allows us to determine the time interval Δt between the two decays, and finally count the number of observed $B^0 \to B_{rec}$ and $\overline{B}^0 \to B_{rec}$ decays as a function of the time interval Δt and the time-dependent asymmetry between them as illustrated in Fig. 2 for the final states $B_{rec} = J/\psi\, K_S^0$, $\psi(2S)K_S^0$, $\eta_c K_S^0$, $\chi_{c1} K_S^0$, and $J/\psi\, K_L^0$ [1,2]. The striking asymmetry between the particles and anti-particles is due to the excellent signal purity in these final states.

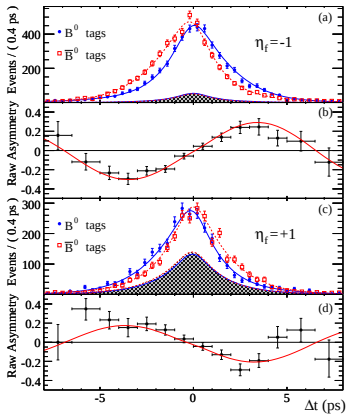

Figure 2: a) Number of $J/\psi\, K_S^0$, $\psi(2S)K_S^0$, $\eta_c K_S^0$, $\chi_{c1} K_S^0$ candidates in the signal region with a B^0 tag (N_{B^0}) and with a $\overline{B}^0$ tag ($N_{\overline{B}^0}$), and b) the CP asymmetry, $(N_{B^0} - N_{\overline{B}^0})/(N_{B^0} + N_{\overline{B}^0})$, as functions of Δt; c) and d) are the corresponding distributions for the $J/\psi\, K_L^0$ candidates. The solid (dashed) curves in (a) and (c) represent the fit projections in Δt for B^0 ($N_{\overline{B}^0}$) tags. The shaded regions represent the estimated background contributions to (a) and (c).

We have also studied these asymmetries in the more challenging final states $\eta' K_S^0$, ΦK_S^0, and $J/\psi\, \pi^0$ [3,4]. The expected probability of neutral B mesons decaying to these final states is rather small in the Standard Model. Hence the interest in these decays is twofold. Firstly, deviations of the measured decay probability could be a hint of New Physics beyond the Standard Model. Secondly, the measured time-dependent asymmetries should agree, within the experimental uncertainties, with the the $(c\bar{c})K_S^0$ channels, or else it could be another hint of New Physics phenomena. The measured asymmetry between the behavior of B^0 and $\overline{B}^0$ mesons contributed to the establishment of the theoretical model proposed by Kobayashi and Maskawa who were assigned the 2008 Nobel Prize in Physics.

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P13. Observation of direct CP violation in B meson decays.

Matter and antimatter were produced in equal amount according to the Big Bang theories on the origin of the Universe, but our experience tells us that the Universe is clearly matter-dominated. According to A.D. Sakharov one of the key element to understand the disappearance of antimatter is the nonconservation of the charge-parity (CP) symmetry in the fundamental forces governing the interactions of particles.

So far, two types of CP violation have been observed in the neutral K meson (K^0) and B meson (B^0) systems: CP violation involving the flavour mixing between the meson and its antiparticle (B^0 and $\bar{B}^0$) and direct CP violation in the decays of each meson. Direct CP violation effects are explained by the quantum interference of (at least) two competiting decay amplitudes. This interference has opposite sign for B^0 with respect to the $\bar{B}^0$ decays, resulting in a non-null difference of the decay rate for the B^0 and the $\bar{B}^0$.

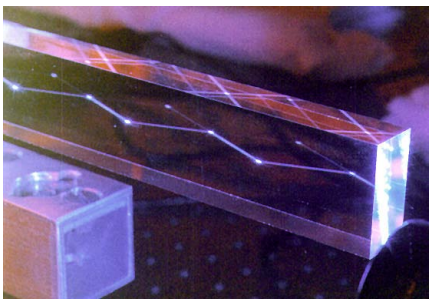

Figure 1: Quartz bar of the detector for internally reflected Cerenkov light of the BaBar experiment

In the last years the BaBar group of Roma was part of a large international collaboration that operated a detector at the Stanford Linear Accelerator Center (California) where a copious source of B meson was available at the PEP-II e^+e^- collider. The group was involved in data analysis with a special focus to rare decays of the B meson into light mesons. Combinations of rates measurements [1] of such decays are very sensitive to the CP parameters of the Standard Model (SM) of particle interaction.

One interesting channel is the B decay into the two-body final state $K^{\pm}\pi^{\mp}$ [2]. The identification of the mass of the final state particles was possible through an innovative apparatus able to detect the Cerenkov light emitted by the two particles crossing a quartz bar (shown in Fig.1). By measuring the ultraviolet light emission angles, kaon and pion were identified with very high precision. A careful analysis of the collected data led the Roma group to publish the first evidence of direct CP violation in the B meson system. This was in fact possible by counting the $B^0 \to K^+\pi^-$ decays versus the $\bar{B}^0 \to K^-\pi^+$ decays and finding a clear difference between the two samples (as shown in Fig.2).

The observed CP violation effects are large in the

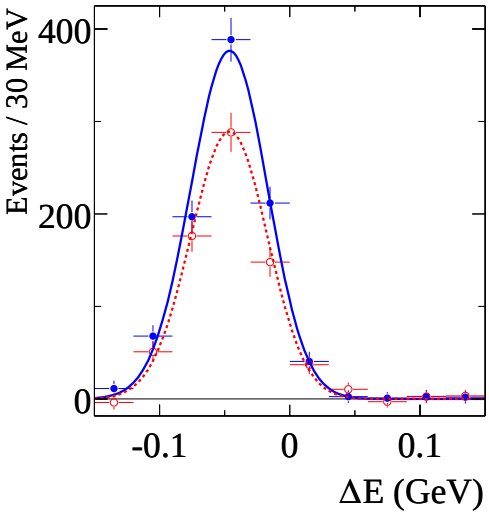

Figure 2: ΔE observable (equivalent to the invariant mass of the decay products) for the decays $B^0 \to K^+\pi^-$ (blue) and for $\bar{B}^0 \to K^-\pi^+$ (red). The direct CP asymmetry is given by the clear unbalance in the number of events.

B^0 meson system and they are consistent with the SM prediction, which has a unique source of CP violation. The theoretical mechanism generating such effect is known as the Cabibbo-Kobayashi-Maskawa model: the 2008 Nobel Prize in Physics was awarded to M. Kobayashi and T. Maskawa for this theory. Nevertheless the SM CP violation is too small to account for the matter-dominated Universe. Further investigations of such effects in several decays channels are therefore necessary to explain such dominance of matter. They have been started by the Roma BaBar group [3,4] but they may become conclusive only in future experiments with larger B meson data sets.

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P14. Measurement of the sides of the unitarity triangle

The weak force is responsible for the flavor transition of quarks which allows unstable particles made of heavy quarks and antiquarks to decay into lighter particles. The rates of these decays are related to a set of measurables called the Cabibbo-Kobayashi-Maskawa (CKM) matrix and can be represented in a graphical form as a triangle in the complex plane, called unitarity triangle (see Fig.1). The area of this triangle is a measure of the amount of charge-parity violation caused by the weak force. To check the consistency of the Standard Model

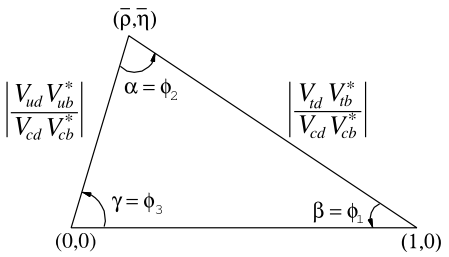

Figure 1: Unitarity triangle and CKM matrix elements.

it is important to determine not only the angles of the triangle but also the length of its sides. The measurement of the rate at which bottom quarks decay into up and charm quarks allows to determine the two elements of the CKM matrix called V_{ub} and V_{cb}.

The triangle's right side is instead connected to the mixing of neutral B mesons, i.e. the process where the B^0 meson spontaneously turn into a $\bar{B}^0$ meson, its antiparticle. The rate at which this transformation occurs constrains the length of the right side of the triangle.

The BaBar Rome group has been actively involved in the analyses aimed at determining both sides of the triangle using the BaBar detector. In particular, in the last three years important results have been achieved in the determination of the V_{ub} and V_{cb} matrix elements.

The semileptonic B meson decays to charm and charmless mesons ($B \to Xl\nu$) are the primary tools for measuring the CKM matrix elements V_{ub} and V_{cb} because of their simple theoretical description at the quark level and their relatively large decay rates. The measurement proceeds as follows. A relatively pure sample of $B\bar{B}$ events where one of the two B mesons decays semileptonically is identified by tagging a lepton and is reconstructed in a limited range of the phase space. In some analyses, to reduce the noise from B decays, additional requirements are applied. For instance, the other B meson produced in the event is fully reconstructed in hadronic modes, thus constraining to the kinematics of the whole event. The partial branching ratio is extracted and converted in V_{ub} and V_{cb} via theoretical correction factors. These factors introduce the largest systematic uncertainty which can range between 5% and 20%, depending on the analysis.

There are two main analysis methods which are complementary. The exclusive analysis focuses on the identification of a given final state, like $B \to \pi l\nu$ and $B \to D^* l\nu$ [1,2]. This approach is very clean but with the drawback of much larger theoretical uncertainties due to the determination of the form factors. The inclusive analysis, instead, integrates over all possible final state [3,4]. For example, for the V_{ub} extraction, the X meson in the $B \to Xl\nu$ decay is required to be compatible with a charmless state (π, ρ, ω, etc...). The charm contribution is subtracted using fits to the X mass spectrum, as shown in Fig.2. This approach is theoretically clean but it suffers of much larger experimental uncertainties.

The resulting measurements of V_{ub} and V_{cb} constraint the length of the left side of the triangle with an uncertainty of $\sim 10\%$. It is consistent with the expectations, confirming the success of the Standard Model. More stringent tests can be expected if there will be a deeper understanding of theory errors.

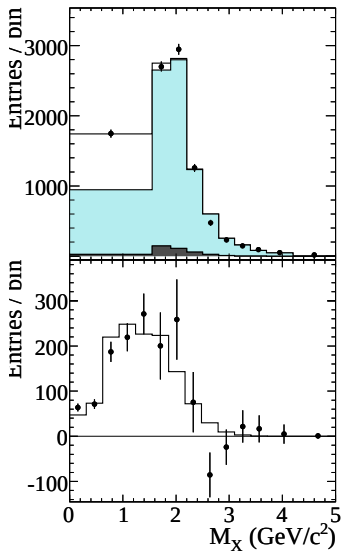

Figure 2: Charmless meson (X) mass spectrum in $B \to Xl\nu$. Top: before subtraction of charm contribution (light blue and black histograms). Bottom: after subtraction.

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P15. Study of B meson rare decays and implications for new Physics

The Standard Model (SM) of particle physics has been succefully tested in many experiments in the last 40 years. However solid arguments exist that it cannot be the final theory and great efforts for New Physics (NP) search are on-going. The study of rare B decays plays a unique role in such searches. B meson processes mediated by flavour-changing neutral-currents (FCNC) are forbidden at the leading order and NP contributions can be of the same order of magnitude of the SM contribution. Complementary information can be obtained from the study of the purely leptonic B decays which are often unaccessible with the present experiments, unless NP effects enhance the rate up to the current experimental sensitivity. For some of these decays, just the observation by itself would provide an unambiguous evidence of NP. We were part of the BaBar international collaboration that built and ran a detector at the Stanford Linear Accelerator Center where a copious amount of $B\overline{B}$ meson pairs was produced at the PEP-II e^+e^- collider. We were involved in data analysis with a special focus on the rare B decays. The study of these processes represent a big challenge for experiments due to the necessity of extraction of a small signal from a huge background ($>$ 1000 times bigger). We developed a novel technique in which one of the two B (B_{tag}) is reconstructed in a frequent mode, while the signal signature is searched for in the rest of the event (the *recoil*), composed by all tracks and neutral particles not associated to the B_{tag}. The method provides a pure sample of $B\overline{B}$ events and a clean environment to look for rare decays. This technique was applied to the measurement of the FCNC $B \to X_s\gamma$ branching ratio where more than 1000 fully hadronic $B \to DX$ decays for the B_{tag} were used [1]. This decay is an ideal framework for the study of flavour physics. The shape of the photon energy spectrum shape is used to infer theoretical parameters fundamental for the determination of the Cabibbo-Kobasyashi-Maskawa matrix element V_{ub} in $B \to X_u\ell\nu$ decays. The power of the recoil approach has been exploited for the search of the very rare FCNC $B \to K^*\nu\overline{\nu}$ decays where the two neutrinos escape detection. Using both semileptonic $B \to D^{(*)}\ell\nu$ and hadronic $B \to DX$ decays for the B_{tag} reconstruction, upper limits at 90% confidence level (CL) on the branching ratio have been set [2]:

$$\mathcal{B}(B^0 \to K^{*0}\nu\overline{\nu}) < 12 \times 10^{-5}\,, \quad (1)$$
$$\mathcal{B}(B^+ \to K^{*+}\nu\overline{\nu}) < 8 \times 10^{-5}\,. \quad (2)$$

Though they are a factor 10 above the SM expected values, those limits are used to constrain several NP scenarios. Complementary information can be obtained looking for purely leptonic B processes. According to the SM, they occur through annihilation diagrams and hence are highly suppressed. The only among them that is accessible at the present experiments is the $B^+ \to \tau^+\nu$ decay. In the search for $B^+ \to \tau^+\nu$ the recoil technique is adopted and both leptonic and hadronic τ decay modes are used. The measured branching ratio is [3,4]:

$$\mathcal{B}(B^+ \to \tau^+\nu) = (0.9 \pm 0.6 \pm 0.1) \times 10^{-4}\,, \quad (3)$$
$$\mathcal{B}(B^+ \to \tau^+\nu) = (1.8^{+0.9}_{-0.8} \pm 0.4) \times 10^{-4}\,, \quad (4)$$

for the semileptonic and hadronic B_{tag} reconstruction, respectively, in agreement with the expected SM value. $B^+ \to l^+\nu$ decays have been also studied by looking for one mono-energetic lepton and requiring the rest of event to be consistent with the decay of the other B meson. Upper limits are set at 90% CL :

$$\mathcal{B}(B^+ \to \mu^+\nu) < 1.0 \times 10^{-6}\,, \quad (5)$$
$$\mathcal{B}(B^+ \to e^+\nu) < 1.9 \times 10^{-6}\,. \quad (6)$$

No evidence of deviations from the SM in the rare processes has been found up to now. However these mesuraments are very important in order to discriminate among different New Physics scenarios. A typical example of exclusion "plot" is shwon in Fig.1. Future experiments, with larger B meson data sample will allow to test the SM at a deeper level.

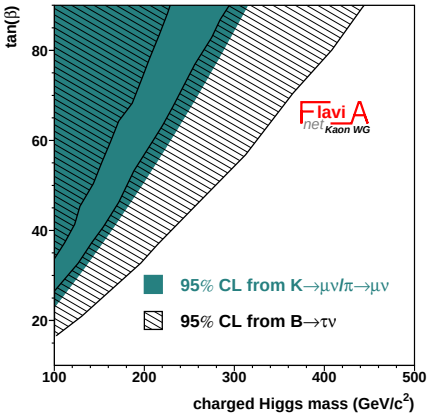

Figure 1: Excluded Region in Charged Higgs Boson models by the $B \to \tau^+\nu$ decay

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P16. Properties of the Charmed Particles Studied at BaBar

Members of the Physics Department of the Rome University "La Sapienza" are involved in the study of the properties of the charmed particles. These analyses have been carried out inside the B Collaboration, which used the BaBar detector for measuring events generated by e^+e^- interactions at the PEP-II asymmetric collider of the Stanford Linear Accelerator Center. The results obtained in the years 2007-2009 by the BaBar Collaboration in the field of the charmed particles are discussed below.

The D^0 and $\bar{D}^0$ mesons are generated as flavor eigenstates (containing a *charm* quark) and decays as mixture of two opposite CP eigenstates. Because of that, a pure beam of D^0 ($\bar{D}^0$) evolves in time becoming a mixture of both particles. This well known quantum-mechanical phenomena called *flavor mixing* is typical of self-conjugate pairs of neutral mesons, and has been previously observed in the K^0, B^0, and B_s^0 neutral-meson systems. It is expected to show a very tiny effect in the case if the neutral D meson, making its observation very difficult. Nevertheless, the BaBar collaboration produced the first evidence of the $D^0 - \bar{D}^0$ mixing by studying the D^0 and $\bar{D}^0$ decays into $K^+\pi^-$ and $K^-\pi^+$ [1]. Subsequent BaBar analyses have confirmed the evidence of the mixing. Overall the effect is extablished also if none channel has found an evidence of the mixing higher than 5 standard deviations.

As regard as the direct CP violation for D^0 mesons, hitherto the BaBar collaboration has not found any evidence for such violation.

The BaBar Collaboration has studied the properties of several charmed baryons. The most important results has been the first observation of the decay $\Lambda_c(2880)^+ \to D^0 p$ and the discovery of the $\Lambda_c(2940)^+$ baryon [2].

The BaBar Collaboration has studied the initial state radiation (ISR) production of heavy mesons decaying into pairs of D mesons. The study of the reactions $e^+e^- \to \gamma_{\rm ISR} D^{(*)}\bar{D}^{(*)}$ has shown evidence for several ψ excited states.

The BaBar Collaboration discovered in 2003 a narrow meson decaying to $D_s^+\pi^0$ at the mass of 2.32 Gev/c^2 [*Phys. Rev. Lett.* **90**, 242001 (2003)]. This discovery opened a new field in particle elementary physics: the study of the excited D mesons. The Collaboration has continued to study these excited mesons

The BaBar Collaboration has studied several D meson decays. The study of the $D_s^+ \to \mu^+\nu_\mu$ decay has allowed to obtain the most precise evaluation for the D_s^+ decay constant: $f_{D_s} = 283 \pm 23$ MeV [3].

Lastly, the BaBar collaboration has carried out several Dalitz plot analyses. An interesting result has been observed by the study of the $D^0 \to \pi^+\pi^-\pi^0$ decay [4]. Its Dalitz plot, shown in the figure, has the typical structure of a $\pi^+\pi^-\pi^0$ state with isospin zero. A phenomenological analysis, to which has partecipated one of the members of the Rome group of BaBar, has proved that the $I = 0$ amount in the final state is higher than 90%. This result is unexpected because the isospin is not a good quantum number for the weak interactions. It is also interesting because the final state has the exotic quantum numbers $I^G J^{PC} = 0^-0^{--}$. Furthermore, this result tell us that the decay $D^0 \to \pi^+\pi^-\pi^0$ is dominated by the $CP = +1$ eigenstate.

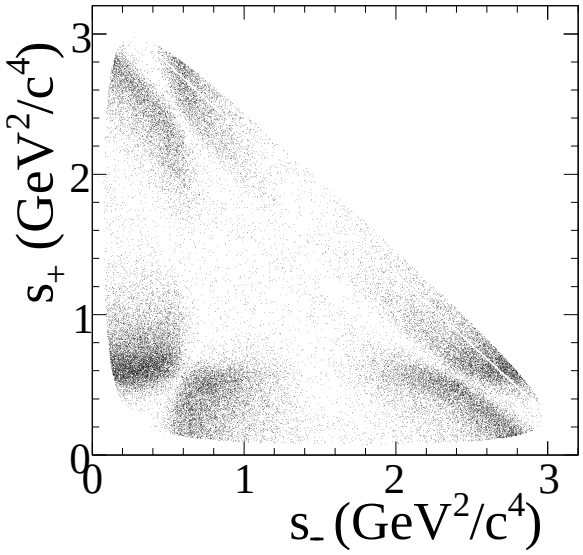

Figure 1: The Dalitz-plot of the $D^0 \to \pi^+\pi^-\pi^0$ decay. s_+ and s_- are respectively $m^2(\pi^+\pi^0)$ and $m^2(\pi^-\pi^0)$. The fine diagonal line at low $\pi^+\pi^-$ mass corresponds to the events removed by the cut $489 < M(\pi^+\pi^-) < 508$ MeV/c^2. The Dalitz-plot shows three diagonals with low density, indicating the dominance of the isospin zero.

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P17. NA62 experiment with a high-intensity charged kaon beam at CERN: search of Standard Model violations in the $K \to \pi\nu\bar{\nu}$ decays

The Branching Ratio (BR) $K^+ \to \pi^+\nu\bar{\nu}$ can be related to the CKM element V_{td} (the less well known one). The precise theoretical estimation in the Standard Model (SM) and in the SUper SYmmetry (SUSY) will allow us to have a probe of the flavour sector or the evidence of physics beyond the Standard Model, if deviation from the predicted SM value will be observed. The SM prediction is $(8.22 \pm 0.84) \times 10^{-11}$. Until now only seven events have been collected and the experimental value is $1.47^{+1.30}_{-0.89} \times 10^{-10}$. The NA62 experiment has been proposed and approved to detect $\approx$100 events with a signal to background of at least 10. The NA62 experiment will be housed in the CERN North Area, using the same SPS extraction line and target of the NA48 experiment. With a new high-acceptance beam-line, a secondary positive hadron beam 50 times more intense will be available.

The intense 400 GeV/c proton beam, extracted from the SPS, produces a secondary charged beam by impinging on a Be target. A 100 m long beam line selects a 75 GeV/c momentum beam with 1% RMS momentum bite and an average rate of about 800 MHz integrated over an area of 14 cm^2. The beam is positron free and is composed by 6% of K^+. A system of subdetectors placed about 100 m downstream to the beginning of the decay region provides the detection of the K^+ decay products: the decay rate in the 120 m long fiducial volume will be $\approx$11 MHz.

The success of the experiment depends crucially in obtaining the required level of background rejection. Key points of NA62 are: accurate kinematic reconstruction; precise timing to associate the π^+ with its K^+ parent; a system of efficient vetoes to reject events with γ and μ; a particle identification system to identify the kaons in the charged beam and to distinguish π^+ from μ^+ and e^+ in the final state. Indeed the main backgrounds to be rejected are: three-body K^+ decays, $K^+ \to \pi^+\pi^0$, $K_{\mu 2}$ and K_{e4}.

Due to the finite resolution of the reconstructed kinematic thresholds, low mass and high precision detectors placed in vacuum are required for the tracking. The very high rate in the beam detector (800 MHz) requires to associate the incoming kaon to the downstream pion track by means of tight spatial and time coincidences. Any mismatch between them, in fact, causes a loss of kinematic rejection power. A Cerenkov Threshold Counter (CEDAR) placed on the beam line, the beam tracker itself and a RICH, provide the timing of the experiment.

The beam tracker must reconstruct the beam tracks with at least 200 ps time resolution. The designed beam spectrometer (Gigatracker) consists of three Si pixels stations 60×27mm^2, made up by 300×300 μm^2 pixels each of them composed by a 200μm thick Si sensor. A readout chip 100μm thick constructed with a 0.13μm technology and bump-bonded on the sensor guarantees the required time resolution. The total material budget amounts to less than 0.5% radiation length per station. Dedicated radiation damage tests on prototypes proved the usage of this detector at an average rate of 60 MHz/cm^2.

The RICH is made of a 17 m long vessel placed after the pion spectrometer and filled with Ne gas at atmospheric pressure. A mosaic of mirrors at the end, having 17 m focal length, reflects the Cerenkov light towards two arrays of about 1000 phototubes each, placed on both the sides of the vessel at the entrance window.

Straw Tube is the building technology for the pion spectrometer. Four chambers placed in the same vacuum of the decay region form the detector. Each chamber includes four view-planes rotated by 45 degree one to another.

The main detector for the rejection of photons will be the quasi-homogenous liquid-Krypton calorimeter from the NA48 experiment, covering angles from 2 to 8.5 mrad. The decay fiducial volume is surrounded by 12 ring shaped detectors, in order to veto photons in the angular range from 8.5 to 50 mrad ("large angle" vetoes, LAV). In addiction, the LAV system must have a good energy and time resolution in order to define a precise energy threshold and to use the system in the trigger logic. For this purpose, each single detector station will be realized using the lead glass crystals formerly used for the OPAL barrel calorimeter, re-arranged in five staggered layers, radially arranged in order to ensure the required photon-detection efficiency.

In the three years 2006-2008, different test beams allowed the testing of the innovative detectors. In addition, 150 000 $K^+ \to e^+\nu$ decay candidates have been collected, in order to determine the ratio of $K_{e2}/K_{\mu 2}$ branching ratios to better than 0.5%, which is an interesting test of new physics, since it can be predicted with high accuracy within the Standard Model. The construction of the apparatus will start in 2010 and the beginning of the data taking is foreseen in 2012-2013.

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P18. NA48/2 experiment at CERN with simultaneous $K^{\pm}$ beams: measurement of CP-violating asymmetries and $\pi\pi$ scattering lengths

The primary goal of the NA48/2 experiment at the CERN SPS is the measurement of the slope charge asymmetries A_g in both $K^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}$ and $K^{\pm} \to \pi^{\pm}\pi^{0}\pi^{0}$ processes with a sensitivity at least one order of magnitude better than previous experiments. The new level of precision can explore effects, albeit larger than the SM predictions, induced by new physics, and is achieved by using a novel measurement technique based on simultaneous K^{+} and K^{-} beams overlapping in space.

The simultaneous K^{+} and K^{-} beams are produced by 400 GeV/c primary SPS protons impinging on a beryllium target. Charged particles with momentum (60±3) GeV/c are selected by an achromatic system which splits the two beams in the vertical plane and then recombines them on a common axis.

The beams then enter the fiducial decay volume housed in a 114 m long cylindrical vacuum tank. Both beams follow the same path in the decay volume: their axes coincide within 1 mm, while the transverse size of the beams is about 1 cm. With 7×10^{11} protons incident on the target per SPS spill of 4.8 s duration, the positive (negative) beam flux at the entrance of the decay volume is 3.8×10^{7} (2.6×10^{7}) particles per pulse, of which 5.7% (4.9%) are K^{+} (K^{-}). The K^{+}/K^{-} flux ratio is 1.79. The fraction of beam kaons decaying in the decay volume at nominal momentum is 22%.

The decay volume is followed by a magnetic spectrometer housed in a tank filled with helium at nearly atmospheric pressure, separated from the vacuum tank by a thin (0.31%X_0) Kevlar composite window. A thin-walled aluminium beam pipe of 16 cm outer diameter traversing the centre of the spectrometer (and all the following detectors) allows the undecayed beam particles and the muon halo from decays of beam pions to continue their path in vacuum.

The magnetic spectrometer, consisting of four drift chambers (two upstream and two downstream of a dipole magnet), allows to measure the momentum of charged particles with a resolution of $\sigma(p)/p$=$(1.02 \oplus 0.044 \cdot p)$% ($p$ in GeV/c). It is followed by a plastic scintillator hodoscope used to produce fast trigger signals and to provide precise time measurements of charged particles.

A liquid krypton electromagnetic calorimeter is used for photon detection and particle identification. It is an almost homogeneous ionization chamber with an active volume of 7 m^3 of liquid krypton, segmented transversally into 13248 projective cells, 27 X_0 deep, and with an energy resolution $\sigma(E)/E = 0.032/E \oplus 0.09/E \oplus 0.0042$ (E in GeV). The LKr is followed by a hadronic calorimeter and a muon detector.

Among the many interesting physics results obtained in the last three years, the measurement of the direct CP violating charge asymmetries of the Dalitz plot linear slopes $A_g = (g^{+} - g^{-})/(g^{+} + g^{-})$ in $K^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}$ and $K^{\pm} \to \pi^{\pm}\pi^{0}\pi^{0}$ decay. In particular, a new technique of asymmetry measurement involving simultaneous K^{+} and K^{-} beams and the large data sample collected, allowed a result of an unprecedented precision. The charge asymmetries were measured to be $A_g^{\pm} = (1.5 \pm 2.2) \times 10^{-4}$ with 3.11×10^{9} decays for the charged mode, and $A_g^{00} = (1.8 \pm 1.8) \times 10^{-4}$ with 9.13×10^{7} decays for the neutral mode, the precision being mainly limited by the statistics [1].

The distribution of the $K^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}$ decays in the Dalitz plot has been also measured with a sample of 4.71×10^{8} fully reconstructed events. With the standard Particle Data Group parameterization the following values of the slope parameters were obtained: $g = (21.134 \pm 0.017)$%, $h = (1.848 \pm 0.040)$%, $k = (0.463 \pm 0.014)$% [2]. This allowed an improvement in precision by more than an order of magnitude, allowing a more elaborate theoretical treatment, including pion-pion rescattering.

Using the full data-set, the $K^{\pm} \to \pi^{\pm}e^{+}e^{-}\gamma$ decay has been observed for the first time. 120 events have been selected over an estimated background of 7.3 ± 1.3 events. Using the $K^{\pm} \to \pi^{\pm}\pi^{0}_{D}$ as normalisation channel, the branching ratio has been measured in a model-independent way [3]: BR($K^{\pm} \to \pi^{\pm}e^{+}e^{-}\gamma$, $m_{ee\gamma} > 260\,\mathrm{MeV}/c^2$) $= (1.19 \pm 0.12_{stat} \pm 0.04_{syst}) \times 10^{-8}$, allowing comparison with ChPT predictions.

Another important result was a new measurement of the K_{e4} decay, based on a sample of more than 670 000 decays in both charged modes. The form factors of the hadronic current (F,G,H) and $\pi\pi$ phase difference ($\delta = \delta_s\delta_p$) have been measured in ten independent bins of the $\pi\pi$ mass spectrum to investigate their variation. Thanks to the sizeable acceptance at large $\pi\pi$ mass, low background and a very good resolution, the $\pi\pi$ scattering lengths have been measured with improved accuracy (under the assumption of isospin symmetry): $a_0^0 = 0.233 \pm 0.016_{stat} \pm 0.007_{syst}$, $a_0^2 = 0.0471 \pm 0.011_{stat} \pm 0.004_{syst}$ [4].

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http://www.cern.ch/na48/NA48-2/

P19. Kaon physics with the KLOE experiment

The KLOE experiment at the DAΦNE e^+e^- collider, the Frascati ϕ-factory, completed the first data-taking campaign in 2006, with a total integrated luminosity of $\sim$ 2.5 fb^{-1}, corresponding to $\sim 8\times10^9$ ϕ-mesons produced. At a ϕ-factory the $\phi \to K^0\bar{K}^0$ decay - with a branching fraction of $\sim$ 34% - produces the neutral kaon pair in a coherent quantum state with quantum numbers $J^{PC} = 1^{--}$:

$$|K^0\bar{K}^0\rangle = \frac{1}{\sqrt{2}}\{|K^0\rangle|\bar{K}^0\rangle - |\bar{K}^0\rangle|K^0\rangle\} = \frac{N}{\sqrt{2}}\{|K_S\rangle|K_L\rangle - |K_L\rangle|K_S\rangle\} \quad (1)$$

where $N \simeq 1$ is a normalization factor. Detection of a K_L thus signals the presence of a K_S, and vice-versa. This is a unique feature at a ϕ-factory, not possible at fixed target experiments, that can be exploited to select pure K_S and K_L beams of precisely known momenta (event by event) and flux.

The ϕ meson also decays 50% of the times into K^+K^- pairs. As for neutral kaons, the identification of a $K^\mp$ decay tags a $K^\pm$ beam. Therefore the clean selected samples of K_S, K_L, K^+, and K^- can be used to measure most, if not all, of the properties of the kaon system with high accuracy, e.g. lifetimes, masses, and absolute branching ratios (BR).

From the study of semileptonic decays the $|V_{us}|$ matrix element of the Cabibbo-Kobayashi-Maskawa (CKM) matrix has been measured with the best accuracy in a single experiment, and the lepton universality has been tested measuring the parameter $r_{\mu e} = 1.000 \pm 0.008$ [1], being the Standard Model (SM) prediction $r_{\mu e} = 1$. From the leptonic and semileptonic decays, combined with results from nuclear β decay and pion decays, it is possible to test with high precision a fundamental property of charged-current weak interactions in the SM, i.e. the unitarity of the CKM matrix, which results to be verified to $\mathcal{O}(0.1\%)$ (see Fig.1) [1].

At KLOE all the BRs for kaon dominant decays have been measured, as well as several rare kaon decays. For instance the BR for the $K_S \to \gamma\gamma$ decay, measured to a few percent precision, $BR(K_S \to \gamma\gamma) = (2.26 \pm 0.12 \pm 0.06) \times 10^{-6}$ [2], constituted an important test for Chiral perturbation theory predictions.

Another important example is the decay $K^\pm \to e^\pm\nu$, strongly suppressed in SM ($\mathcal{O}(10^{-5})$), which offers the possibility of detecting minute contributions from physics beyond the SM. In particular the ratio $R_K = \Gamma(K \to e\nu)/\Gamma(K \to \mu\nu)$ could deviate from SM prediction up to a few percent in minimal supersymmetric models. The measurement $R_K = (2.493 \pm 0.025 \pm 0.019) \times 10^{-5}$ [3] has been found in good agreement with SM expectations.

The state in eq.(1) has a quite straightforward formal analogy with the singlet state of two spin 1/2 particles.

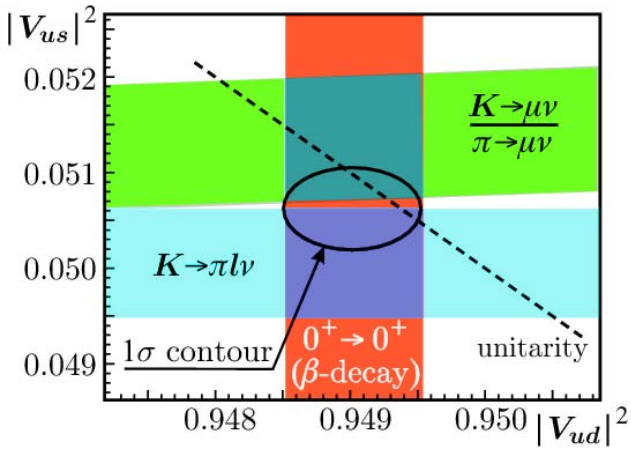

Figure 1: KLOE results for $|V_{us}|^2$, $|V_{us}/V_{ud}|^2$, and $|V_{ud}|^2$ from β decay measurements, shown as 2σ bands. The ellipse is 1σ contour from a fit. The unitarity constraint is illustrated by the dashed line [1].

It can be exploited to perform several tests of Quantum Mechanics (QM) and CPT symmetry [4]. For instance the decoherence parameter ζ in the $K^0 - \bar{K}^0$ basis, signalling a loss of coherence of the bipartite state and a departure from the standard QM time evolution, has been bounded at the level of $\mathcal{O}(10^{-6})$, being $\zeta = 0$ the QM prediction.

A second data-taking campaign (KLOE-2) is going to start at DAΦNE upgraded in luminosity. The KLOE detector has been upgraded with small angle electron taggers for $\gamma\gamma$ physics, while the installation near the interaction point (IP) of an inner tracker is planned for the next year. The KLOE-2 scientific program aims, among the several items, to further improve the experimental studies on kaon physics, and it will greatly benefit of the improved reconstruction with the inner tracker of charged tracks and decay vertices near the IP.

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http://www.roma1.infn.it/exp/kloe/

P20. Study of light hadron production and decay with the KLOE experiment

The KLOE experiment carried out at the Frascati $\phi-$factory DAΦNE has completed its first period of data-taking with an integrated luminosity of about 2.5 fb^{-1} collected at the peak of the $\phi(1020)$ resonance. This sample corresponds to about 8×10^9 ϕ mesons. Large samples of light hadrons have been produced, through the radiative decays $\phi \to M\gamma$, where M can be a scalar or pseudoscalar meson. Since the ϕ is a nearly pure $s\bar{s}$ state, these decays are unique probes of the properties and of the internal structure of the light hadrons.

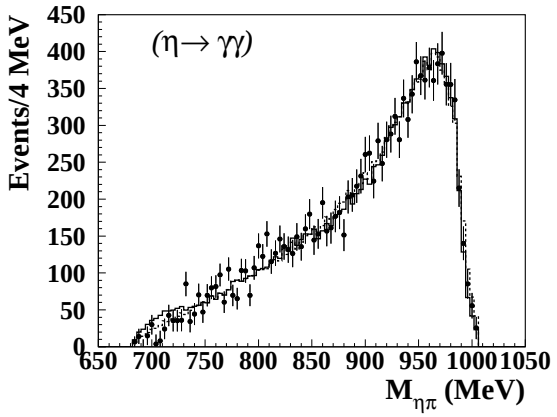

Figure 1: $a_0(980)$ shape from the $\eta\pi^0$ invariant mass [1].

It is not yet well understood whether the light scalar mesons ($\sigma(600)$, $f_0(980)$, $a_0(980)$) are ordinary $q\bar{q}$ mesons, $qq\bar{q}\bar{q}$ states, or bound states of a K and a $\bar{K}$ mesons. The scalar production dominates the radiative decays of the ϕ to two pseudoscalars, and the decay rates are expected to be sensitive to the internal structure of those resonances. Precise measurements of the branching ratios of $\phi \to f_0(980)\gamma \to \pi^0\pi^0\gamma$ and of $\phi \to a_0(980)\gamma \to \eta\pi^0\gamma$ have been performed and the parameters of the scalar resonances have been extracted respectively from a fit of the Dalitz plot or of the invariant mass distribution of the two pseudoscalars [1] (see Fig.1). The $f_0(980)$ production has also been studied in $e^+e^- \to \pi^+\pi^-\gamma$ events, in which a small signal from $e^+e^- \to f_0(980)\gamma \to \pi^+\pi^-\gamma$ has been extracted from a large background due to Initial State Radiation and Final State Radiation processes. We obtained branching ratios of the order of 10^{-4} and large couplings of the scalars to the ϕ meson: these results favour the $qq\bar{q}\bar{q}$ hypothesis, in which one of the pair is $s\bar{s}$, for the structure of the light scalar mesons. Moreover from the analysis of the Dalitz plot of the $\phi \to \pi^0\pi^0\gamma$ we obtained an indication of the presence of the decay $\sigma(600) \to \pi^0\pi^0$. We set also an upper limit to the branching ratio of $\phi \to K^0\bar{K}^0\gamma$ [2], which is expected to be dominated by the production of f_0/a_0 in the intermediate state.

About 10^8 η and $\sim 5 \times 10^5$ η' mesons have been produced during the first KLOE data-taking. These samples have been used to study rare η decays [3] and the $\eta - \eta'$ mixing angle, φ_P, and to investigate the η' structure, looking for a possible gluonium content in its wave fuction[4]. We measured the ratio $\Gamma(\phi \to \eta'\gamma)/\Gamma(\phi \to \eta\gamma) = (4.77 \pm 0.09 \pm 0.19) \times 10^{-3}$ and we fit our results together with other measurements of Vector $\to$ Pseudoscalar + γ and Pseudoscalar $\to$ Vector + γ decay rates obtaining the result shown in Fig.2, which indicates a gluonium content in η' (Z_G) different from zero at three standard deviation level.

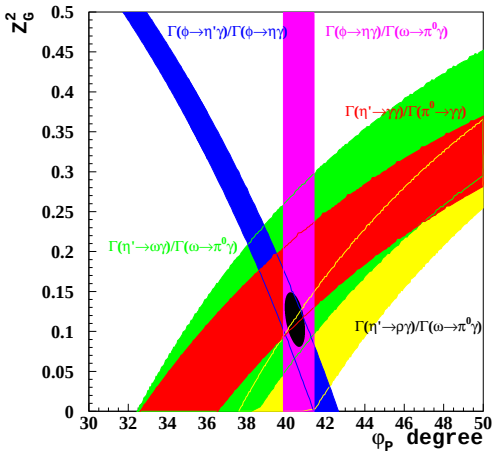

Figure 2: Fit result in the plane Z_G vs the $\eta - \eta'$ mixing angle: the black ellipse represents the 68% C.L. region [4].

A new data-taking is starting at DAΦNE with increased luminosity with the KLOE detector upgraded with the insertion of electron taggers for $\gamma\gamma$ physics. We plan to continue the study of the light hadrons by looking for $\gamma\gamma \to \sigma(600)$ in $e^+e^- \to e^+e^-\pi\pi$ events and by measuring the two-photon decay widths of π^0, η, η' and their transition form factors to $\gamma\gamma$.

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http://www.roma1.infn.it/exp/kloe/

P21. Scintillator calorimeters for the detection of low energy photons, electrons and hadrons.

The KLOE experiment has taken data at the e^+e^- accelerator DAFNE from 1999 to 2006. The results of this experiment are discussed elsewhere in this report. A program of detector and accelerator upgrade is in progress aiming to restart data taking in spring 2010 with improved luminosity and extended detection capability. We describe here the contributions to this program of the Sapienza University group.

An important part of the detector upgrade is the construction of the "electron taggers" at small angle. The aim of these detectors is the identification of the so called $\gamma\gamma$ annihilations, that is the process: $e^+e^- \to e^+e^-X$ where X is a generic hadronic state. In such events the two electrons in the final state are typically emitted at small angles with respect to the direction of the beams. Two pairs of detectors have been built: the HET (High Energy Tagger) designed to detect the electrons emitted at very small angle and with an energy very close to the beam energy (510 MeV), and the LET (see Fig.1) for electrons at intermediate angles and with energies approximately between 150 and 250 MeV. The Rome group has built the 2 LET detectors. Each LET is an array of 20 $1.5 \times 1.5 \times 12$ cm^3 LYSO crystals with the long dimension almost parallel to the electron arrival direction. Each crystal is read-out by a SiPM photo-detector placed on the bottom face. The LYSO + SiPM technology allows to have a compact detector with a good energy resolution and a sufficiently fast response. A prototype of the LET detector has been assembled and tested with electron beams in the energy range between 100 and 500 MeV.

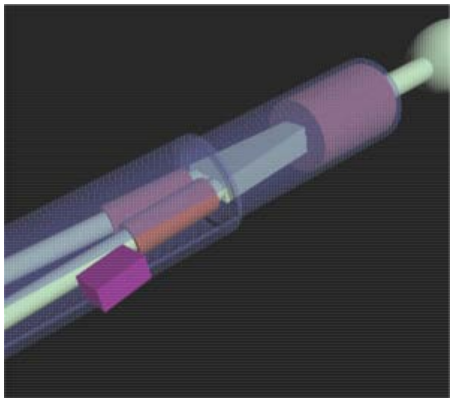

Figure 1: Schematic view of the KLOE interaction region including the beam pipe, the magnets and one of the LET detectors (the purple box in the left).

A second important study carried on by the Sapienza University group is the measurement of the response to neutrons of the KLOE calorimeter. In fact, part of the extended KLOE physics program requires the detection of neutrons with kinetic energies between few MeV and few hundreds MeV. The KLOE calorimeter is a lead-scintillating fibers calorimeter with a lead-fiber-glue ratio of 48-42-10 in volume. We have exposed a prototype of it to the neutron beam of the TSL Laboratory of the Uppsala University (Sweden). We have measured the calorimeter efficiency for neutrons of kinetic energies between 20 and 180 MeV. The results are shown in Fig.2. By comparing the efficiency of the KLOE calorimeter with the one of a bulk scintillator with the same scintillator equivalent thickness, we observe in average an efficiency enhancement of a factor 2.5. This somehow unexpected result opens the possibility to develop high efficiency and compact neutron detectors for this energy range with the lead-scintillating fibers technology.

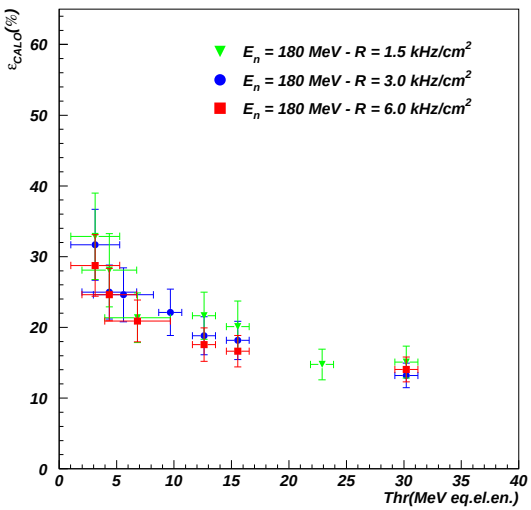

Figure 2: Neutron detection efficiency for 180 MeV neutrons as a function of the threshold, expressed in equivalent electron energy. The efficiency refers to a 16.5 cm thick calorimeter with about 8 cm equivalent scintillator thickness.

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http://www.roma1.infn.it/exp/kloe

P22. The ZEUS experiment at the HERA collider

The Zeus experiment (see Fig 1) was taking data at the electron-proton collider HERA at Desy, Hamburg, from 1992 to 2007. At present, data analysis is going on and will continue for several years. This general purpose detector was built by a large international collaboration, involving more than 40 experimental teams from 18 countries, for a total of about 400 physicists. There was a large Italian participation (funded by INFN, Istituto Nazionale di Fisica Nucleare), and the Rome group was responsible, together with groups from Bologna and Padova, of the muon detectors.

Since the famous 'Rutherford experiment' scattering has proven to be a very powerful tool to study the structure of atomic, nuclear and subnuclear matter. In particular, deep inelastic scattering (DIS) experiments at the end of the 60's, with a resolution power well below the the radius of the proton, were able to directly probe the elementary constituents of the nucleons. Deep inelastic scattering of leptons off nucleons has proved to be a key process in the understanding of the structure of the proton and testing of the Standard Model (SM). Neutral current (NC) DIS is mediated by the photon and the Z boson and is sensitive to all quark flavours. However, at leading order only up-type quarks and down-type antiquarks contribute to ep charged current (CC) DIS, mediated by a $W^{\pm}$ boson. Thus this process is a powerful probe of flavour specific parton distribution functions. The $e^{\pm}$-p collider HERA, unique of its kind and financed

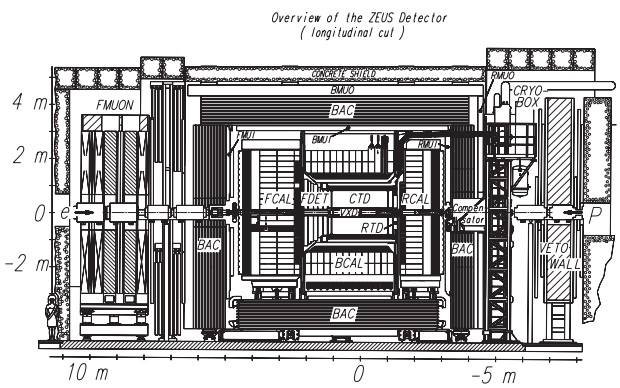

Figure 1: Schematic overview of the ZEUS detector (longitudinal cut)

with a substantial Italian contribution, became operational in 1992 and collided 27.5 GeV $e^{\pm}$ against 920 GeV p, thus providing an unprecedented resolution for probing the structure of the proton down to 1/1000th of its radius. In the second part of it's life (2002 - 2007) the accelerator allowed also for the use of polarised lepton beams. Due to the chiral nature of the weak interaction, the SM predicts a linear dependence of the CC cross section on the degree of longitudinal polarisation of the electron beam. The cross section is expected to be zero for a right-handed electron beam. Zeus has performed extensive studies with polarized beams [1]. The high energy particle beams of HERA allowed the exploration of a significant extension of the kinematic phase space in deep inelastic scattering and provided a very clean way of measuring the structure of the proton. The double differential charged current cross sections for lepton-nucleon scattering can be given in terms of three structure functions, F_2, F_L and xF_3. The longitudinal structure function, F_L, stems from the exchange of longitudinally polarised gauge bosons. The parity violating structure function, xF_3, arises from the interference between the vector and axial-vector couplings of the weak interaction. Results on the measurements of F_2 were extensively published in the past and are now part of particle physics textbooks. The term xF_3 could be evaluated by combining electron-proton and positron-proton scattering data[2]. More recently first measurements of F_L were made possible, taking data at different center-of-mass energies (Fig 2)[3].

Many other studies were performed with Zeus data, resulting in more than 200 published papers.

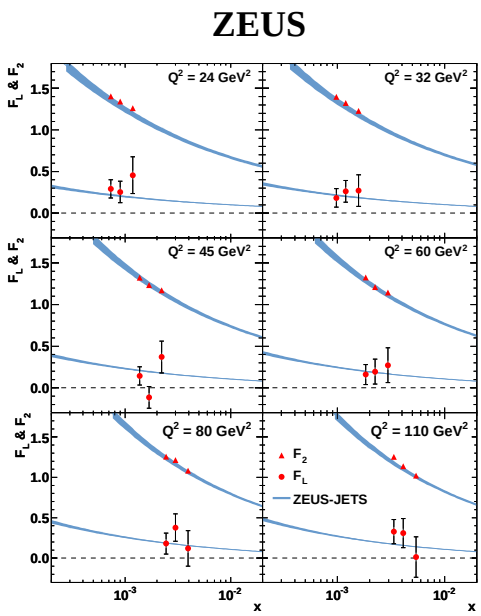

Figure 2: F_L and F_2 at 6 values of Q^2 as a function of x. .

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P23. Dual readout calorimetry with crystals

In recent years, dual-readout calorimetry has emerged as a promising new solution for the need to detect both leptons and hadrons with excellent accuracy in high-energy particle physics experiments [1]. The Dual Readout Method (DREAM) is based on a simultaneous measurement of different types of signals which provide complementary information about details of the shower development. It has been argued and experimentally demonstrated that a comparison of the signals produced by Čerenkov light and scintillation light makes it possible to measure the energy fraction carried by the electromagnetic shower component, f_{em}, event by event. Since the event by event fluctuation in f_{em} is the main limitation for the energy resolution in hadronic calorimeters, this may lead to an important improvement in the performance of hadron calorimeters. The first calorimeter of this type was based on a copper absorber structure, equipped with two types of active media. Scintillating fibers measured the total energy deposited by all the shower particles, while Čerenkov light, generated only by charged relativistic particles, was produced in undoped optical fibers.

The signals from certain high-density crystals ($PbWO_4$, BGO) can also be unraveled into Čerenkov and scintillation components; such crystals, when used in conjunction with the fiber calorimeter mentioned above, can offer in principle the same advantages for hadronic shower detection and, at the same time, provide accurate energy resolution for the electromagnetic component.

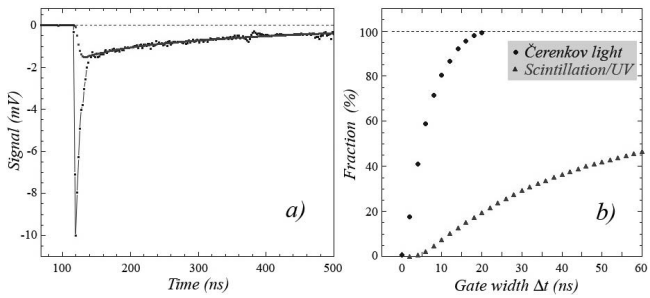

Figure 1: The average time structure of the UV signals from 200 GeV π^+ in BGO crystal. The long tail is due to the scintillation component,while the prompt peak represents the Cerenkov contribution(a). The "contamination" of scintillation light in a narrow time window Δt around the prompt peak (b).

We have performed a series of measurements in the H4 beam line of the SPS at CERN [2] providing a beam of high energy electrons and pions. Our detector was a high-density $Bi_4Ge_3O_{12}$ (BGO) crystal with a length of 24 cm mounted on a rotating table. The light produced by particles traversing this crystal was read out by two photomultiplier tubes Hamamatsu R5900U, 10-stage, bialkali photocathode, borosilicate window, located at the opposite ends. The light generated in the crystal was UV filtered at one side before being read out to reduce the scintillation contribution.

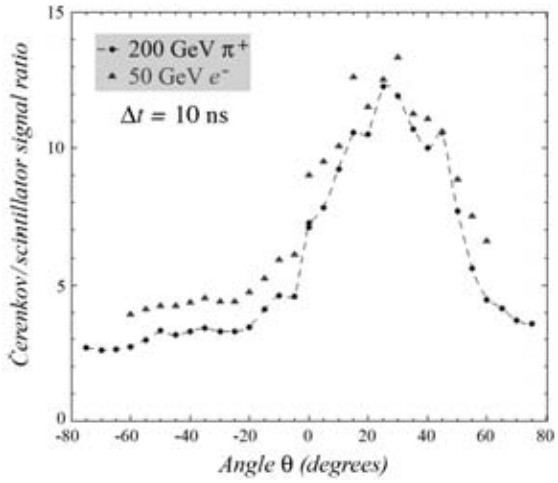

Figure 2: The Čerenkov/scintillation ratio in the UV signals from the BGO crystal, for a gate of 10 ns around the prompt peak, as a function of the orientation of the crystal with respect to the beam. Data for 50 GeV electrons and 200 GeV π^+.

The purpose of these tests was to split the crystal signals into their scintillation and Čerenkov components. We exploited the following differences between these components: 1) differences in *time structure*. Čerenkov light is prompt, while the scintillation mechanism is characterized by one or several time constants. 2) differences in *directionality*. Contrary to scintillation light, which is emitted isotropically, Čerenkov light is emitted at a characteristic angle by the relativistic (shower) particles that traverse the detector. We measured the signals for different orientations of the crystal with respect to the particle beam. In Figure 1 the prompt Čerenkov signal is superimposed to the slow scintillation component, allowing an easy separation of the two contributions. In Figure 2 the ratio between Čerenkov and scintillation light is plotted as function of the angle of the crystal with respect to the beam direction; the peak around the angle of Čerenkov emission is clearly visible. At present additional studies with a large BGO matrix [3] and with different type of crystals [4] are performed.

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P24. Study of proton channeling of bent crystals for beam collimation in high-energy accelerators

Collimation is an important component of particle accelerator technique, especially at the Large Hadron Collider LHC at CERN, where beam of high intensity and high energy will circulate in the collider ring. At LHC collimation system serves the purpose of eliminating the off-orbit particle (beam "halo" particles) to prevent damages to superconducting magnets. A traditional collimation system is made of a series of high-density materials that absorbe particles in the external region of the beam. A secondary beam halo is therefore generated with a larger divergence. Subsequent stages of collimation are needed to eliminate completely the unwanted particles. A new concept of collimation is such that instead of instrumenting the first stage of collimation with an amorphous material acting as absorber, a bent crystal could be used. Halo particles impinging on it would be trapped within the crystal planes and deflected to a well determined direction. In this way particle will not be scattered in any direction and the efficiency of collimation will improve. Using crystal would also help in enlarging the distance of traditional collimating absorber from the beam core, reducing the impedance of LHC and allowing higher currents and therefore a higher luminosity.

Crystal channeling has been observed since several years. In the 90s it was demonstrated that a proton beam of 120 GeV/c could be extracted at 8.5 mrad from the SPS at CERN using a silicon crystal mechanically bent with extraction efficiency of $10-20\%$. However it was foreseen that extraction efficiency through channeling could be brought to higher values by using shorter crystals, but the realization of the bent crystals of the requested size and bending was not simple. In the very last years many progresses were made in producing new higher quality silicon strip crystals with small length (down to 1mm) and curvature imparted at the level of 150 microrad.

In 2006 an internazional collaboration with phisicists from Russia, CERN and Italy has been formed to test new crystals with protons of 400 GeV/c from the SPS accelerator at CERN. The aim of the collaboration was to measure channeling efficiency through different kind of crystals. The Rome group partecipated to the 2006 PRIN funding to develop a tracking system to measure the proton deflection angle. The main results of the test are shown in Fig. 1. A channeling deflection of about (165 ± 2) μrad is observed when the proton beam hit the crystal axis with an angle of about 60 μrad with an efficiency of about 55%. Moreover, the high quality crystals used in the experiment allowed to discover new effects. Among those, it was observed the "volume reflection". A proton not channeled can pass transversly through the planes experiencing the periodic atomic potential. If the crystal has non-null bending, a centrifugal components adds up. In this way, whenever the transverse energy of the particle is lower than the potential barrier the transverse momentum of the particle gets reversed. This particle is therefore "reflected" (in a direction opposite to the center of curvature of the crystal) with an angle of about 13 μrad. The most relevant feature is that this effect is active for a larger range of relative angle between the particle direction and the crystal planes and has a very high efficiency (about 98%). This is therefore much appealing for beam collimation application. In general demonstrating the feasibility of using bent crystal to deflect beam it is an important step for future accelerator in which big dipole magnet could be substituted by tiny silicon bent crystal. Those crystal will be in fact the equivalent of several tens of Tesla magnetic fields!

The Rome group is currently involved in testing such concept of crystal collimation on a circulating beam at CERN SPS with preliminary encouraging results.

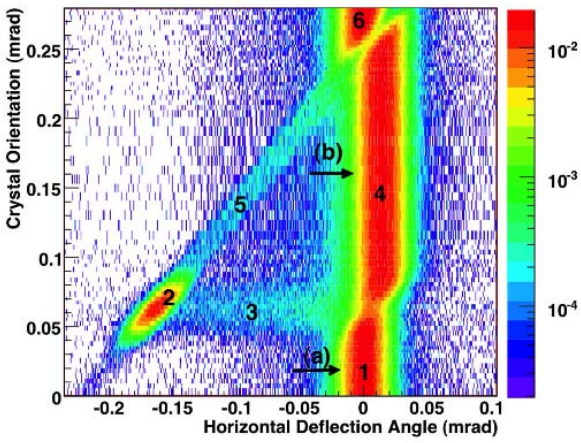

Figure 1: Beam intensity recorded by the silicon microstrip detector as a function of the horizontal deflection angle (x axis) and the crystal orientation (y axis) with respect to the incoming proton beam. Six regions can be identified: (1) and (6) non channeling mode; (2) channeling; (3) dechanneling; (4) volume reflection; (5) volume capture. The wider angular acceptance of volume reflection compared to channeling is clearly visible in the figure.

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P25. Neutrinoless double beta decay search with CUORE experiment and scintillating bolometry developments

In the field of fundamental particle physics the neutrino has become more and more important in the last few years, since the discovery of its mass. In particular, the ultimate nature of the neutrino (if it is a Dirac or a Majorana particle) plays a crucial role not only in neutrino physics, but in the overall framework of fundamental particle interactions. The only way to disentangle its ultimate nature is to search for the so-called Neutrinoless Double Beta Decay (DBD) $[(A,Z) \rightarrow (A,Z+2)+2e^-]$. The DBD is an extremely rare processes. In the two neutrino decay mode their halflives range from $T^{2\nu}_{1/2} \sim 10^{18}$ y to 10^{25} y. The technique used by our group to search this process is the bolometric one. A thermal detector is a sensitive calorimeter which measures the energy deposited by a single interacting particle through the corresponding temperature rise. This is accomplished by using suitable materials (dielectric crystals) and by running the detector at very low temperatures (in the 10 mK range) in a suitable cryostat (e.g. dilution refrigerators). In such a condition a small energy release in the crystal results in a measurable temperature rise. This temperature change can be measured by means of a proper thermal sensor, a NTD germanium thermistor. We have run a pilot experiment (CUORICINO) at Laboratori Nazionali del Gran Sasso and we are preparing a large mass (an array of 988 $5 \times 5 \times 5$ cm^3 TeO_2 crystals) experiment that will be sensitive to an halflife in excess of 10^{26} y. CUORICINO experiment, ended in 2008, has set an upper limit for the halflife of the process $T^{0\nu}_{1/2}(^{130}\text{Te}) \geq 3.0 \times 10^{24}$ y (90% C.L.) (Fig. 1).

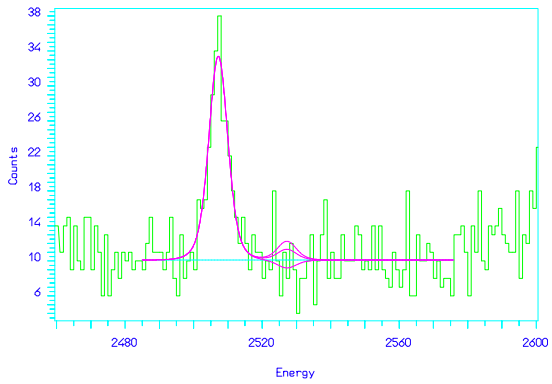

Figure 1: Background spectrum from 2470 to 2590 keV in CUORICINO. The solid lines are the best fit to the region and bounds (68% and 90%) CL on the number of candidate $0\nu\beta\beta$ decay events respectively.

In the preparation of CUORE (A Cryogenic Underground Observatory for Rare Events) experiment our group is on charge of several crucial tasks, from automatized detector assembly in ultrapure atmosphere to the software of the experiment. Our main expertise though is in the crystal developments. Our group is in charge of the entire process of crystal procurement from specifications to final acceptance tests through the qualifications of the materials. CUORE has the goal of probing the entire degenerate region of the neutrino mass spectrum being able to penetrate although partially the region of the inverted hyerarchy ($m_{\beta\beta} \sim 50$ meV). Our expertise has allowed to present to ERC-AdG program an innovative and extremely ambitious project (LUCIFER), a double readout (heat and scintillation) demonstrator composed of a few dozens ZnSe detectors with the goal of gaining two orders of magnitude with respect to present experiments in the background suppression. The principle of this detector is sketched in Fig. 2. The steps toward this experiments are the enrichment of about 15 Kg of ^{82}Se, the growth of ultrapure ZnSe crystals of about 500 grams each, the qualification of light detectors (Ge or Si wafers) with the resolution required, the assembly in the former CUORICINO cryostat and the developments of sophisticated analysis techniques for the background abatement. A success of this project would open the way for an experiment capable of exploring the entire region of the inverted hyerarchy of neutrino masses (O(10 meV)).

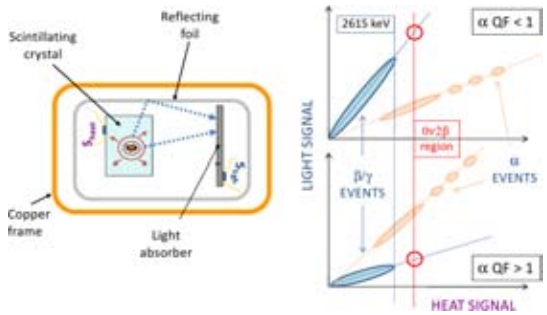

Figure 2: The concept of the detector (left) and of the analysis (right). The ability to tag α particles is a formidable asset in the search for $0\nu\beta\beta$ in high Q-value candidates.

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http://www.roma1.infn.it/exp/cuore/

P26. Search for neutrino oscillations by the OPERA detector at Gran Sasso

Increasing experimental evidence of neutrino oscillations has been collected in the last decades by several experiments, by exploiting both the natural neutrino sources, like the sun and the atmosphere, and the available reactor and accelerator facilities. However, a direct observation of neutrino flavor appearance, complementary to the widely reported flavor disappearance, yet remains among the missing tiles of the picture.

The OPERA neutrino detector was designed to perform the first detection of neutrino oscillations in the appearance mode trough the study of the ν_μ to ν_τ channel. The OPERA apparatus is installed in the underground Gran Sasso Laboratory (LNGS) in the high energy long-baseline CERN to LNGS neutrino beam (CNGS), 730 Km away from the neutrino source. The CNGS is an almost 'pure' ν_μ beam, so that the observation of ν_τ-induced events in the apparatus would be an unambiguous signal of in-flight oscillations.

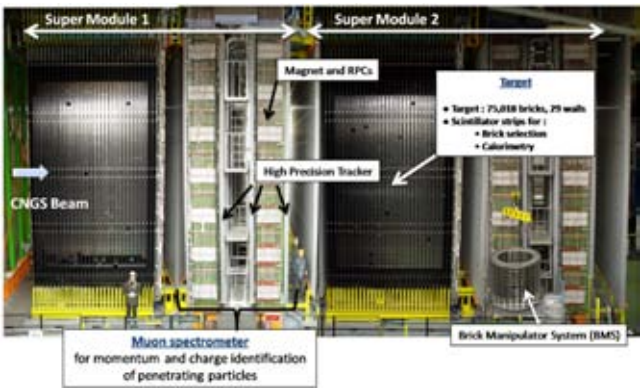

Figure 1: The OPERA neutrino detector.

OPERA is a hybrid detector made of two identical Super Modules, each consisting of a target section of about 625 tons made of emulsion/lead modules, of a scintillator tracker detector and a muon spectrometer. Details about the apparatus (fig. 1) can be found in [1].

The CNGS beam started to delivery neutrinos with a technical run in 2006. The physics program was initiated in 2007 with a very limited integrated intensity of 8.24×10^{17} protons on target (pot). Full-scale data taking took place in the next two years, with 1.78×10^{19} pot in 2008 and 3.52×10^{19} pot in 2009. Overall, $\simeq 5400$ beam-induced events were reconstructed till now in the OPERA target, by the pattern recognition of hits in the target tracker and spectrometer sections of the detector.

As for the hybrid technique deployed by OPERA, next steps after trigger are the extraction of selected target units candidate to contain the events[2], the development of photographic emulsion films therein, their fast automated scanning by computer-assisted optical microscopes [3], and, finally, the selection and study of peculiar decay topologies in order to unveal the ν_τ appearance tagged as charged-current (CC) interactions producing the short-lived massive τ lepton.

The location of beam-induced events in the emulsion films was successful since the beginning of data-taking, as reported in [4]. At the time of writing this note, $\simeq 1500$ neutrino events were located and studied, mostly from the 2008 run, while the 2009 run data will require some more months to be digested. The procedures for the selection and extensive study of events featuring decay topologies are under fine tuning. The production and decay of charmed particles was observed in ν_μ-induced CC interactions, at a rate compatible with the known production rate and the expected detection efficiency.

A few events with a prompt electron at a primary vertex were also observed, due to the known ν_e contamination of CNGS. The excellent space resolution of nuclear emulsions ($\simeq 1$ μm), particle identification and momentum measurements by multiple coulomb scattering were shown to allow full topological and kinematical study of interesting events.

In summary, OPERA is ready to detect the ν_τ appearance, and the analysis is in progress. The experimental program is expected to continue with data taking at higher intensity in 2010-2012 and consequent scanning and analysis of the emulsion target data.

According to the computed sensitivity, for an integrated intensity exceeding $2. \times 10^{20}$ pot the experiment is expected to observe over 10 oscillation events against less than 1 background.

As a member of the OPERA Collaboration spanning several countries in Europe and Asia, the Rome group, rooted in a long standing local experience with nuclear emulsions dating back to the early '50s, contributed to the design and construction of vital infrastructure for the emulsion handling at LNGS, as well as to the design, setting-up, test and exploitation of automated microscopes.

The group is now part of the 'European scanning team', having its partner in Japan. Contribution are also expected in the data handling (data-base) and in the physics analysis of selected events.

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Authors

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P27. Neutrino oscillation in long baseline experiments

The discovery of neutrino flavour oscillation allows to study neutrino mixing and masses. The story of neutrino oscillation starts with the detection of neutrinos from the Sun by the pioneering Homestake mine experiment led by Davis in the early 1970s. Bruno Pontecorvo was the first to interpret the deficit of the solar neutrino flux as a possible hint of neutrino oscillation. In the 80s and 90s a leading role in confirming the solar neutrino oscillation was played by the large water Cherenkov detectors Kamiokande (3 Kton mass) and its successor SuperKamiokande (50 Kton mass).

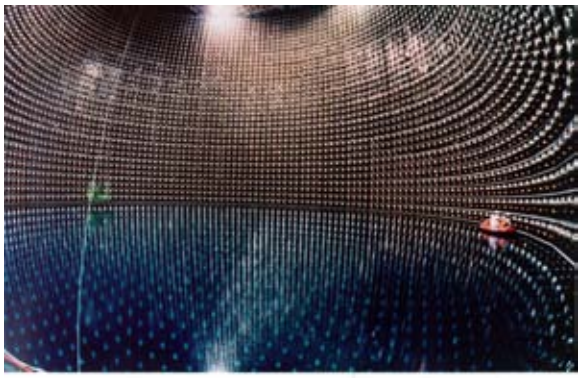

Figure 1: The SuperKamiokande detector.

In 1998 SuperKamiokande announced the discovery of oscillation of atmospheric neutrinos, i.e. the neutrinos produced by cosmic rays in the earth's atmosphere. This phenomenon can also be studied with man-made neutrinos produced by accelerators with a detector of suitable mass, located several hundreds kilometers away from the neutrino source. K2K is the first of these "long baseline" experiments. It uses the SuperKamiokande detector and a muon neutrino beam produced 250 Km away at KEK. K2K was the first to observe oscillation at an accelerator in 2005, thus confirming the discovery of atmospheric neutrino oscillation and improving the Δm^2 measurement. The Rome group has started its participation to K2K in 2002 proposing, assembling and operating the electromagnetic calorimeter used in the near detector.

To study neutrino oscillation the near detector plays a crucial role by measuring the flux before neutrino oscillate and by providing precision measurements of neutrino interactions properties and cross-sections [1,2].

Few experimental data exist for neutrino cross-sections at 1 GeV energy and some processes have never been measured. The present and next generation of neutrino oscillation experiments at accelerators require better experimental data. To this goal part of the K2K near detector has been used to assemble a new experiment, SciBooNE, at the Fermilab Booster neutrino beam. The Rome group has been responsible for the installation and operation of the electromagnetic calorimeter. The collaboration is now analysing the data taken from June 2007 to August 2008 both in neutrino and anti-neutrino mode. Several analysis are in progress and preliminary results have been presented at conferences. The first publication reports the search for coherent pion production in neutrino charged current interactions [3].

The Rome group is also participating to T2K, the first accelerator experiment searching for the subdominant ν_μ to ν_e oscillation, which has not been observed up to now. This process is related to a non zero θ_{13} neutrino mixing angle. The other two angles describing the neutrino mixing are known to be large from the oscillation of solar neutrinos and from the dominant ν_μ to ν_τ oscillation in atmospheric neutrinos. On the contrary we only know an upper limit on the angle θ_{13} and a measurement is needed in order to complete our understanding of neutrino oscillation. The observation of a non zero value may foster the measurement of leptonic CP symmetry violation in neutrino oscillation, since the CP violation effects are proportional to θ_{13} and leptonic CP violation can only exists if this angle is different from zero. T2K will also provide measurement at a few percent precision of the ${\Delta m_{23}}^2$ and θ_{23} parameters.

Figure 2: The layout of the T2K experiment.

As a successor of K2K, the T2K experiment uses again the SuperKamiokande detector and a new near detector. The neutrino beam is extracted from proton accelerated by the very high power (0.75 MW) accelerator complex now under commissioning at J-PARC in Japan. The Rome group proposed the adoption of a magnetised design for the near detector and the refurbishement of the large aperture dipole magnet built at CERN for the UA1 collaboration. The discovery of a non zero θ_{13} within a factor 20 with respect to the present upper limit is within reach of T2K after five years data taking. First results are expected in 2011.

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http://www.phys.uniroma1.it/gr/T2K/index.html

P28. Investigations on particle Dark Matter with DAMA/LIBRA at Gran Sasso

DAMA/LIBRA (Large sodium Iodide Bulk for RAre processes) is part of the DAMA project, which is mainly based on the development and use of low background scintillators. In particular, the former DAMA/NaI and the present DAMA/LIBRA set-ups, at the Gran Sasso National Laboratory, have the main aim to perform a direct detection of Dark Matter (DM) particles in the galactic halo using the model independent annual modulation signature. This signature exploits the effect of the Earth revolution around the Sun on the number of events induced by DM particles in a suitable low background set-up placed deep underground. In particular, as a consequence of its annual revolution, the Earth should be crossed by a larger flux of DM particles around roughly June 2nd (when its rotational velocity is summed to the one of the solar system with respect to the Galaxy) and by a smaller one around roughly December 2nd (when the two velocities are subtracted). The annual modulation signature is very distinctive since the effect induced by DM particles must simultaneously satisfy many peculiar requirements (see Ref. [1]).

The former DAMA/NaI experiment has pointed out a model independent evidence for the presence of DM particles in the galactic halo with high C.L. The DAMA/LIBRA set-up, now in data taking, is the result of a second generation R&D project to develop new highly radiopure NaI(Tl) detectors (250 kg total mass) to further investigate Dark Matter particles and other rare processes. The set-up, its main features and radiopurity have been discussed in Ref. [2]. After 4 annual cycles (exposure of 0.53 ton×yr) the model independent result achieved by the second generation DAMA/LIBRA set-up confirms the evidence of the presence of Dark Matter particles in the galactic halo with high confidence level; a cumulative C.L. of 8.2 σ is reached when considering the data of the former DAMA/NaI experiment and the ones of DAMA/LIBRA all together (exposure of 0.82 ton×yr) [1]. The collected DAMA/LIBRA data satisfy all the many peculiarities of the DM annual modulation signature. Neither systematic effects nor side reactions able to account for the observed modulation amplitude and to contemporaneously satisfy all the several requirements of this DM signature are available [1].

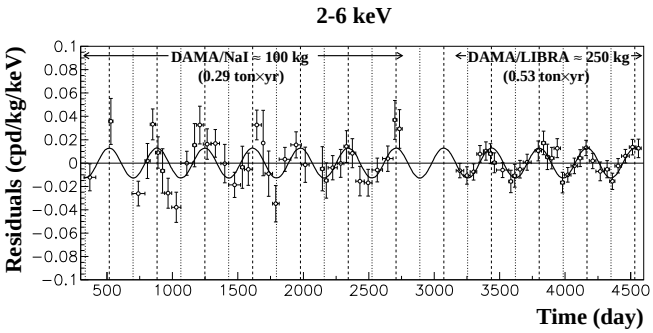

Figure 1: Model-independent residual rate of the single-hit scintillation events, measured by DAMA/NaI and the new DAMA/LIBRA experiments (exposure of 0.82 ton×yr) in the (2-6) keV energy interval as a function of the time (here keV is keV electron equivalent). The superimposed curves represent the cosinusoidal functions behaviors $A\cos\omega(t-t_0)$ with a period $T = \frac{2\pi}{\omega} = 1$ yr, with a phase $t_0 = 152.5$ day (June 2nd) and with modulation amplitudes, A, equal to the central values obtained by best fit over the whole data: (0.0129 ± 0.0016) cpd/kg/keV. The dashed vertical lines correspond to the maximum of the signal (June 2nd), while the dotted vertical lines to the minimum. The χ^2 test disfavors the hypothesis of unmodulated behavior ($A = 0$) giving a probability of 1.8×10^{-4} (χ^2/d.o.f. = 116.4/67).

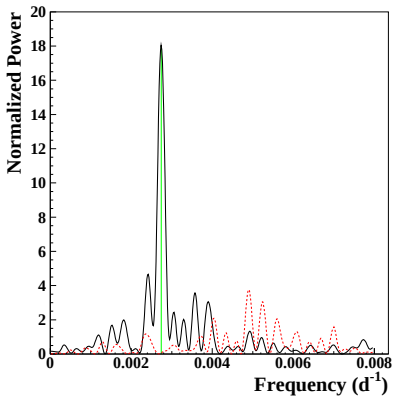

Figure 2: Power spectrum of the measured single-hit residuals for the (2-6) keV (solid line) and (6-14) keV (dotted line) energy intervals (exposure of 0.82 ton×yr). The principal mode in the (2-6) keV energy interval corresponds to a frequency of 2.737×10^{-3} d^{-1} (vertical line); that is to a period of $\simeq 1$ year. A similar peak is not present in the (6-14) keV energy interval just above.

The collection of a larger exposure with DAMA/LIBRA will allow the improvement of the corollary information about the nature of the candidate particle(s) and about various related astrophysical, nuclear and particle Physics scenarios as well as the investigation of the other DM features and of second order effects with very high sensitivity. Several rare processes other than DM will also be investigated (see e.g. Ref. [3]).

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P29. Search of Dark Matter and Antimatter with AMS

The Alpha Magnetic Spectrometer (AMS) is a high-energy particle physics experiment in space to be placed on the International Space Station (ISS). The main physics goals are the anti-matter and the dark matter searches [1]. Until now, a consistent theory of baryogenesis has not been yet proposed, as presently experimental data do not support these models. The last 20 years cosmic ray searches for antinuclei have given negative results. Detection of a few anti-He nuclei will be a clear evidence of existence of antimatter domains, since their formation in conventional processes is largely suppressed. Present limits on $\bar{He}$ search are at the level of 10^{-6} therefore to increase the sensitivity for antimatter up to very far distances, greater than 20 Mpc, AMS has to reach a rejection factor for He of 10^{-9}. High value of magnetic field B and large magnetic volume are first requirements for this goal, since momentum resolution is proportional to BL^2. Simulation by Monte Carlo method shows that no false candidates will be found in 10^9 He events, therefore we expect to reach the limit shown in figure 1.

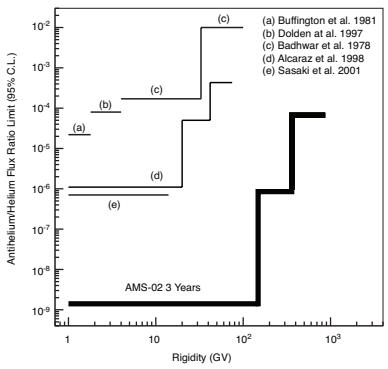

Figure 1: Projected AMS limits on $\bar{He}/He$ flux ratio compared to previous measurements (including AMS-01).

Several observations indicate that the Universe should include a large amount of unknown dark matter (DM). It should be composed of non-baryonic Weakly Interacting Massive Particles (WIMP). The Lightest Supersymmetric Particle in R-parity conserving SUSY models may be a WIMP candidate. SUSY dark matter can be searched in decay channels from neutralino annihilation. A simultaneous measurement of all channels will add confidence to the result. In the energy range 1 to 100 GeV of Cosmic Rays spectrum, ratio of proton/positron is of the order of 10^3 to 10^4, proton/antiproton ratio varies between 10^5 and 10^3 and electron/antiproton from 10^3 to 10^2. A detector aiming to search neutralino signal through annihilation products therefore needs an excellent proton and electron identification along with good charge sign determination, of the order of 10^5. Since AMS will take data for at least three years, it will record cosmic ray spectra with very high statistics and high precision, allowing possible discovery of new phenomena or new particles.

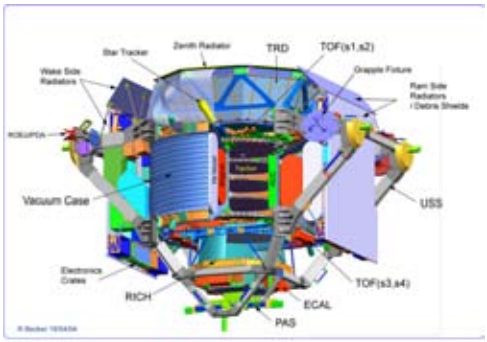

Figure 2: AMS detector in a cut-through view. USS is the support structure. See text for sub-detectors acronyms. Overall dimensions are 3m x 3m x 3m

The AMS main components are:

- Transition Radiation Detector (TRD) with capability to reject protons with a factor greater than 10^2 up to 250 GeV/c;
- the central spectrometer, magnet and silicon tracker;
- Time of Flight scintillation counters (TOF);
- Ring Imaging Cerenkov Counter (RICH) measuring independently speed and charge;
- Electromagnetic calorimeter (ECAL) with 3D sampling. It will reject protons with a factor greater than 10^3;
- Anticoincidence counters (ACC).

Figure 2 shows a cut-through view of the detector.

The Rome group, with INFN participation, has contributed mainly to the TRD construction and to the overall apparatus integration. The group will initiate data analysis on particle identification by TRD selection.

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P30. Experimental Search of Gravitational Waves

Gravitational waves (GW) are space-time ripples such that the distance between free masses will alternately decrease and increase during their transit out of phase in two perpendicular directions. For astrophysical events such as a supernova explosion at the galactic center, the GW amplitude, the dimensionless strain parameter h,could range between 10^{-19} - 10^{-21}. The observation of gravitational waves will complement the observation of electromagnetic waves and astro-particles (as cosmic rays and neutrinos). It will reveal aspects of the Universe not reachable by these means and will extend the observable domain even in the cosmic regions darkened by dust and masked by other phenomena.

With one large interferometer VIRGO (located near Pisa) and two cryogenic resonant antennas, EXPLORER installed at CERN and NAUTILUS at the INFN laboratory of Frascati, the G23 group is at the forefront of research on gravitational waves.

EXPLORER has been the first large-mass cryogenic GW antenna to perform long-term continuous operation. NAUTILUS is an ultracryogenic resonant-mass GW detector, cooled for the first time at 100 mK in 1991. The data produced continously by our detectors [1] are made available for the network analysis in the context of the International Gravitational Event Collaboration (IGEC). The typical detector sensitivities are of the order of $h \sim 10^{-19}$ in a bandwidth of few tens Hz around 900 Hz.

VIRGO is the result of an international effort of eleven research groups supported by INFN-Italy and CNRS-France. The detector consists of a laser interferometer with two orthogonal arms each 3 kilometers long[2]. In each arm, a two mirror Fabry-Perot (F-P) resonant cavity extends the optical length from 3 to about 100 km and therefore amplifies the tiny effect due to an impinging gravitational wave. VIRGO is sensitive to gravitational waves in a wide frequency range, from 10 to 10,000 Hz with a typical sensitivity of $h \sim 10^{-21}$. The remarkable low frequency sensitivity of VIRGO, only results from its peculiar suspension system. Since the beginning of its construction phase the G23 group keeps the responsability of the last suspension stage of the mirror, which plays a crucial role in defining the thermal noise limit of the interferometer and permits the mirror position control through the very small forces applied to the optical element [3]. Further improvement of this limit will require cooling the interferometer to very low temperatures, in order to minimize the thermal energy. This approach is under study in the context of the conceptual design of a third generation of gravitational wave detector (FP7-ET research program of European Union).

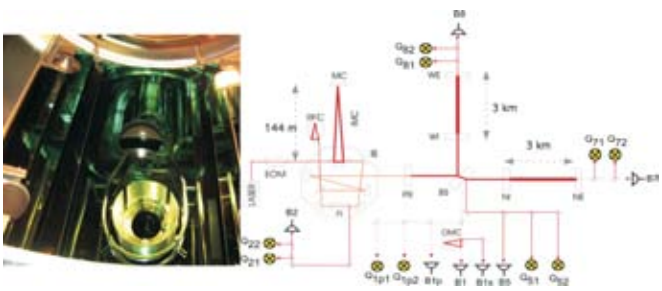

Figure 1: A F-P mirror suspended to its last stage (left). The VIRGO optical scheme (right).

The data taken by VIRGO are analysed in common with those of two similar instruments installed in USA, the LIGO interferometers sensitive in the frequency range 50 - 6,000 Hz.

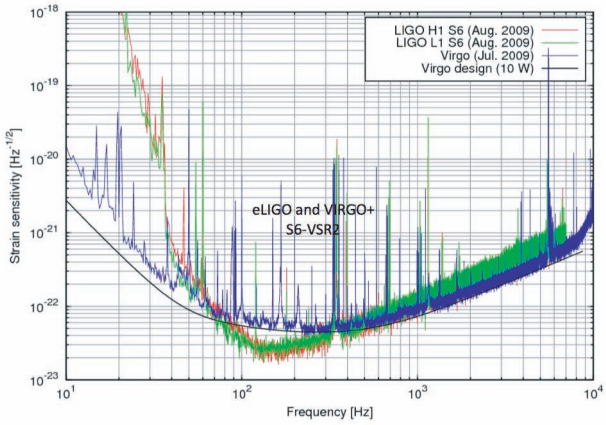

Figure 2: The spectral sensitivities of VIRGO and LIGO versus frequency, compared with the VIRGO design sensitivity curve.

Taking advantage of the larger bandwidth, these antennae should allow the detection of a large variety of GW signals, as those generated by the coalescence of binary systems (stars or black holes), supernovae and the stochastic GW [4]. In particular the Sapienza group is analysing the data for detecting continuous GW signals as those generated by pulsars, a data analysis challenge pursued using the GRID technology.

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P31. ANTARES: a Čerenkov Neutrino deep-sea detector.

The undisputed galactic origin of cosmic rays at energies below the so-called knee implies an existence of a non-thermal population of galactic sources which effectively accelerate protons and nuclei to TeV-PeV energies. The distinct signatures of these cosmic accelerators are high energy neutrinos and gamma rays produced through hadronic interactions with ambient gas or photoproduction on intense photon fields near the source. While gamma rays can be produced also by directly accelerated electrons, high-energy neutrinos provide unambiguous and unique information on the sites of the cosmic accelerators and hadronic nature of the accelerated particles. The original idea of a neutrino telescope based on the detection of the secondary particles produced in neutrino interactions is attributed to Markov [1] who invoked the concept in the 1950's. Events reconstruction is possible through the Čerenkov light induced by the path of the interaction products in transparent media. The Antares neutrino telescope, operating at 2.5 km depth in the Mediterranean Sea, 40 km off the Toulon shore, represents the world's largest operational underwater neutrino telescope, optimized for the detection of Čerenkov light produced by neutrino-induced muons. It is equipped with 885 optical sensors arranged on 12 flexible lines (Figure 1). Each line comprises up to 2 detection storeys each equipped with three downward-looking 10-inch photo-multipliers (PMTs), orientated at 45° to the line axis. The lines are maintained vertical by a buoy at the top of the 450 m long line. The spacing between storeys in 14.5 m and the lines are spaced by 60-70 m. An acoustic positioning system provides real-time location of the detector elements to a precision of a few centimeters. Antares is taking data in its full 12 lines configuration since May 2008.

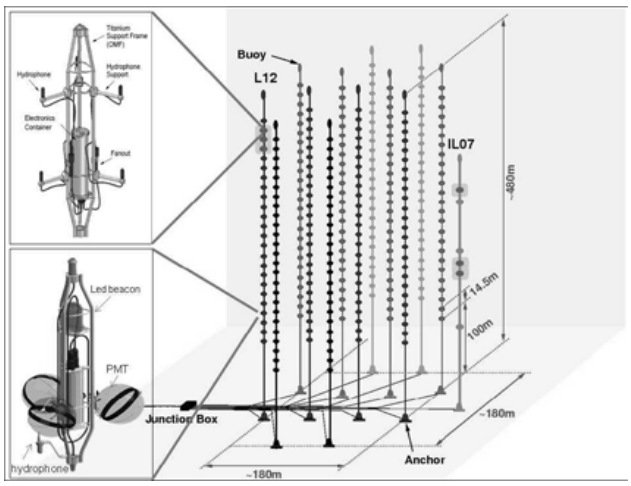

Figure 1: The layout of the completed ANTARES detector.

The main goal of Antares is the search of high energy neutrinos from astrophysical point or transient sources. There are numerous candidate neutrino sources in the cosmos; among them are Supernova Remnants, Pulsars and Microquasars in the Galaxy. Possible extragalactic sources include Active Galactic Nuclei and $\gamma - ray$ burst emitters. For such processes the neutrino energy scale is 10^{12} to $10^{16} eV$. Another important objective of neutrino telescopes like ANTARES is the search for dark matter in the form of WIMPs (Weakly Interacting Massive Particles). As an example in the case of supersymmetric theories with R-parity conservation, the relic neutralinos from the Big-Bang are predicted to concentrate in massive bodies such as the centres of the Earth, the Sun or the Galaxy. At these sites neutralino annihilations, and the subsequent decays of the resulting particles, may yield neutrinos with energies up to 10^{10} - $10^{12} eV$. Additionally the study of the diffuse neutrino flux, originating from sources that cannot be individually resolved or from interactions of cosmic rays with intergalactic matter or radiation, may yield important cosmological clues. Such measurements would be significant for neutrino energies in excess of $10^{15} eV$. The apparatus is well performing [2], [3], [4] and already allowed to reconstruct neutrino events (Figure 2).

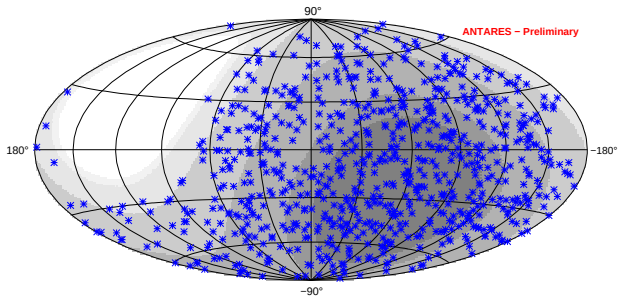

Figure 2: Sky map, in equatorial coordinates, of 750 neutrino candidates selected out of the 2007-2008 ANTARES data.

We participated to the construction of the detector and to data analysis with a special interest for the detection of "Sources in the Super-Galactic Plane".

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www.roma1.infn.it/people/capone/AHEN/index.htm

P32. High Energy Neutrino astronomy in the Mediterranean Sea, NEMO and KM3NeT projects.

The major scientific objective of this research is the study of the Universe by means of the observation of High Energy Neutrinos. Neutrinos are produced as secondary products of interactions of the accelerated charged cosmic rays in all models of cosmic sources of high-energy radiation. To have adequate sensitivity for the expected fluxes of astrophysical neutrinos, detectors with very large volumes, of the order of a km^3, are required. The construction of a km^3-scale Neutrino Telescope in the Mediterranean Sea is the goal of the European consortium KM3NeT of which we are between the promoters [1]. The Mediterranean Sea provides the large target mass necessary to enhance the detection rate and the transparency of its water makes it ideal to house a large array of light sensors to detect this Čerenkov light; it's geographic location is ideal since the region of the sky observed includes the bulk of the Galaxy. We did search and characterize the optimal deep-sea sites [2] for the detector installation and participated to the development of key technologies for the km^3 underwater telescope. As a prototype of the km^3 Čerenkov neutrino detector NEMO Collaboration did construct, install and operate a four floors detector (Figure 1) at $2100m$ depths close to Catania port.

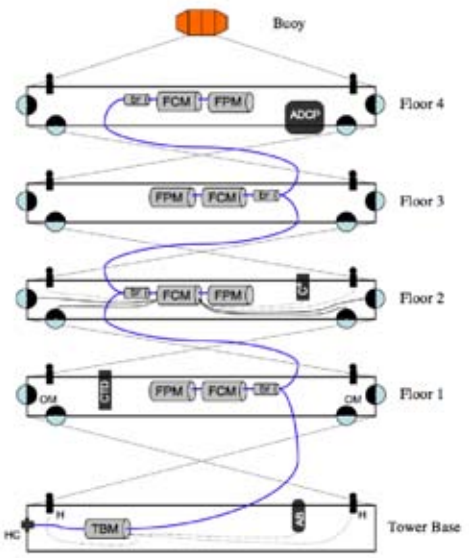

Figure 1: Scheme of the four floors prototype tower of the NEMO Phase-1 project.

The data analysis confirmed the expectations for detector resolutions and muon rates (Figure 2). The Roma group also developed, constructed and tested the whole electronics system for data acquisition and transmission [3] to the on-shore laboratory of all PMTs signals.

Recent AUGER results show that the spectrum of Ultra High Energy cosmic rays ($E > 10^{19}eV$) behaves

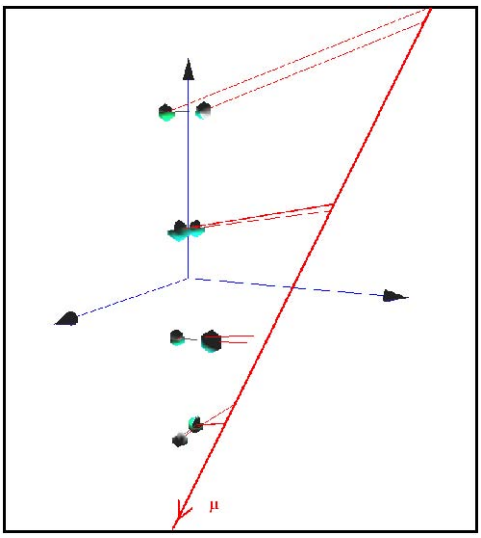

Figure 2: NEMO: reconstruction of a downgoing atmospheric muon track.

as foreseen if assuming the interaction between high energy protons and the microwave cosmic background radiation (the so called GZK effect). Neutrinos resulting from such interactions would have energies in the range $10^{17} - 10^{21}eV$ and their flux would be so faint that they could not be revealed by a Čerenkov Neutrino Telescope with a km^2 effective area. High-energy neutrino interactions can originate high-energy showers that deposit their energy in a limited volume of water. The shower energy is released in the medium through a thermal-acoustic mechanism that induces a local enhancement of the temperature. The consequent fast expansion of the heated volume of water generates a pressure wave which is detectable as an acoustic signal. We are developing technologies to exploit the acoustic detection, in deep-sea water, of UHE neutrinos [4].

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www.roma1.infn.it/people/capone/AHEN/index.htm

P33. Quantum information with Josephson devices

The first idea of a quantum computer (QC) can be traced back to R.P. Feynman that in 1982 said the quantum-mechanic description of a system of N particles may not be simulated by a normal computer (a Turing machine), the only possibility is to use a computer built with elements that obey the laws of quantum mechanics. In the following years the work of theoreticians led to define a universal QC, and in 1994 P.Shor found an algorithm for the prime factorization of a number. Zalka in 1996 then showed that problems of quantum chromodynamics could be traced back, in the case of a quantum computer, to the calculation of a FFT (Fast Fourier Transform) and then to prime factorization. It has to be stressed that an ideal QC could solve NP (non polynomial) problems, i.e. the class of problems whose solution can be found in polynomial time with a non-deterministic algorithm. In recent years a significant experimental work has begun to identify and develop the base elements (the qubits) necessary for the realisation of a quantum computer. This area or research is named QIPC: Quantum Information Processing and Communication. The Rome group is developing qubits and techniques to operate with Josephson based qubits operating at temperatures down to 10mK. The qubit prototypes rely on the use of microwave signals to manipulate and read out the qubits. When one thinks of a system of many, the complexity and the cost of the required instrumentation grows bigger and bigger. In Rome we have developed an alternative approach, namely controlling a flux qubit by means of fast pulses of magnetic flux, thus avoiding the use of radiofrequency. This method is appealing in the view of full integration of the control electronics on the qubit chip, by using RSFQ logic circuits to provide the pulses and synchronize them. The result would be a fully integrated system, scalable on a large scale, where both qubit and electronics are realized with the same technology.

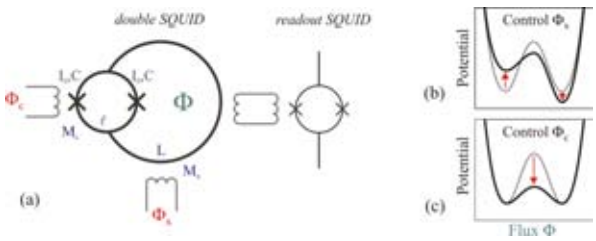

Figure 1: (a) Scheme of the double SQUID qubit coupled to the readout SQUID. (b) Effect of the control flux x on the potential symmetry. (c) Effect of the control flux c on the potential barrier..

The qubit used is based on a double SQUID namely a superconducting loop interrupted by a dc-SQUID with much smaller inductance, which behaves as an rf-SQUID whose critical current can be adjusted from outside by applying a magnetic flux. The schematic of the device is shown in figure 1. The main result of our measurements is the observation of the coherent free oscillations of the flux state populations as a function of the c pulse duration t for different values of ctop Figure 2 shows one of the best oscillations, at a frequency of 16.6 GHz; the experimental points are fitted by a continuous line (green online) as a guide for the eyes, while a dotted line (red online) marks the fit of the envelope to highlight the amplitude decay. This figure emphasize one of the advantages of our particular operating mode that, thanks to a very high oscillation frequency, allows to have many oscillation periods and perform several quantum operations even within a short decay time.

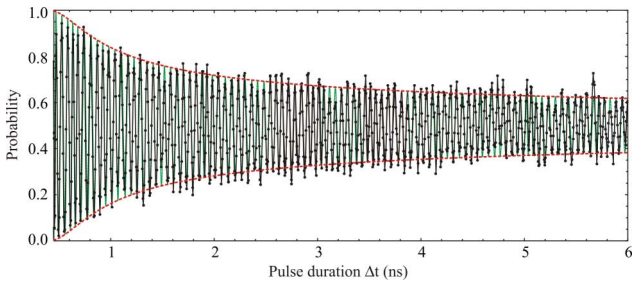

Figure 2: One of the best experimental curves showing coherent oscillations at a frequency of 16.6 GHz. The fit of the envelope is marked by a dotted line (red online).

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P34. Results of SPARC Free Electron Laser Experiment

The SPARC project is a Free Electron Laser (FEL) at the LNF, Frascati (Italy). The main components of the machine are showed in Fig.1 and is also the test and training facility for the recently approved VUV/soft X-ray FEL project named SPARX. The SPARC FEL is composed by a high brightness photo-injector providing a high-quality beam at energies up to 150 and 200 MeV (12 m), a transfer line for beam matching and diagnostic (6.8 m) and an undulator beam line (13 m) composed by six undulator sections with variable gap. The gun is a SLAC/BNL/UCLA 1.6 cell S-band RF photo-injector and its performances have been studied in a first phase, with a movable emittance meter. This instrument allowed the investigation of the beam parameters dynamic in the first meters after the gun, allowing to optimize the working point in order to minimize emittance (Ferrario working point). The final energy is reached with three SLAC-type linac sections at 2.856 GHz. The first two sections are surrounded by solenoids providing additional focusing during acceleration. This solution allows to work in *velocity bunching* regime that consists in exploiting a correlated velocity dispersion for obtaining the compression of the beam. The magnetic axial field properly tuned ensures the desired emittance preservation, i.e. high brightness electron source with short bunch length without the implementation of a magnetic chicane. The electron beam injected through the undulator generates high brilliance and tunable FEL radiation in the visible region around the fundamental wavelength (500 nm) and at VUV wavelengths with the harmonics.

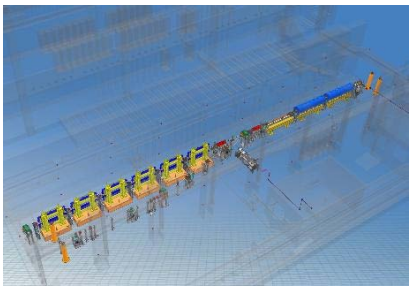

Figure 1: SPARC layout.

The first SASE FEL spectra was obtained on February 17th (Fig.2) and beam compression via velocity bunching with emittance compensation was demonstrated in April 2009. In July 2009 a substantial increase of the extracted radiation from the FEL source was obtained with a longitudinally flat top e-beam by increasing the bunch charge. The last stage of the commissioning has established the characterization of the FEL harmonics (200nm, 133nm) with SEED laser and the characterization of the spontaneous and stimulated radiation in the SPARC undulators with short electron beam (hundreds of fs) in the so-called single spike regime (full coherent laser pulses). The SPARC high brightness electron beam gives the possibility to develop multidisciplinary activities like coherent Terahertz radiation with OTR technique and moreover, in combination with the Terawatt laser of FLAME experiment at LNF, the Plasma acceleration (PLASMONX project) and coherent X-ray generation by the Thomson scattering. Experiments are being performed to generate and manipulate modulated electron bunches or bunch trains for possible uses in PWFA, pump and probe FEL experiments, narrow band THz source or enhanced SASE-FEL. The source's development of ultra-short x-ray pulses is both an impressive improvement for the accelerator and laser physics and it opens a new way of exploring the ultra-fast dynamics involved in matter physics (superconductivity, complex and strongly correlated system) and chemical-biological systems (crystallography, biomolecular organization, photosynthesis). In the last few years, the SPARC group of Roma1 has contributed to develop the high brightness photo-injector and the choice of machine parameters with some specific simulation tools for acceleration, transport of the beam and FEL interaction in the undulator.

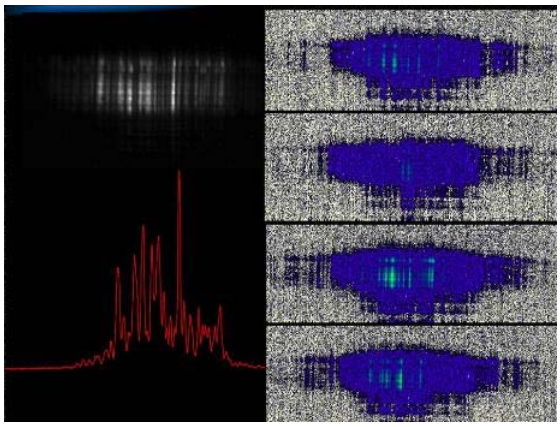

Figure 2: First 500 nm Self Amplified Spontaneous Emission (SASE) at SPARC on February 17th 2009.

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Astrophysics

The international year of astronomy just passed with flying colors, celebrating 400 years after the first scientific use of the telescope by Galileo Galilei, and his discoveries. Nowadays Astrophysics and Cosmology experience faster and faster growth worldwide, using the methods of experimental physics and the most advanced hardware and analysis technologies to study the universe, its content, its evolution and the physical phenomena happening in it. Our Department, located close to some of Galilei's sites, is a driving partner of this cultural adventure.

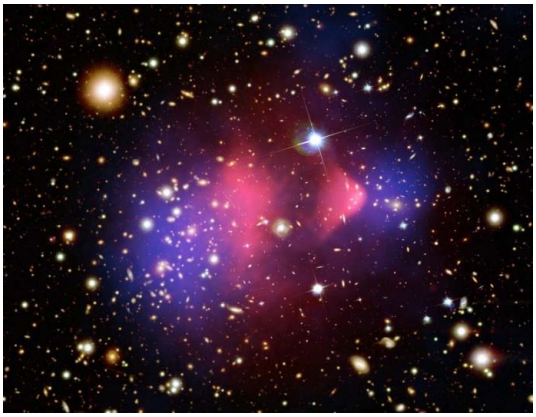

Figure 1: The "bullet cluster" of galaxies is a good example of an astrophysical system which must be studied in a variety of ways (dynamically, and with microwave, visible and X-ray observations), and can be used to constrain fundamental physics (dark matter). The figure is a composite of an optical image (showing the galaxies of the cluster), an image in X-rays (red, showing diffuse, ionized baryonic matter), and the density of dark matter (blue, as estimated by lensing of background galaxies). Future microwave observations of the Sunyaev-Zeldovich effect in this cluster will constrain the nature of dark matter. All these issues are investigated by astrophysicists in our Department. *credit: NASA/ESO*

Astrophysicists observe the universe to discover its structures and phenomena, and use the laws of physics to describe the observations. But also they use the universe as a laboratory, with physical conditions so extreme (e.g. near black holes, or near the big bang) that cannot be created on the Earth. So they take advantage of these observations to test new physical theories and laws, an evident the strong synergy among physics, astrophysics and cosmology. Our Department makes no exception.

The progress in Astrophysics and Cosmology has been very significant in the last 20 years. The highlights have been the discovery of gamma-ray bursts, the study of the large scale structure of the universe with galaxy surveys and with gravitational-lensing surveys, the detailed observation of structures in the cosmic microwave background, starting *precision cosmology*, and the discovery of the acceleration of the expansion of the universe. While all these are remarkable findings, they also pose fundamental questions, like:

- Did the universe undergo an inflation phase at ultra-high energies ?
- What is the nature of dark matter, and how does it affect the formation of structures ?
- What is the nature of dark energy, and does it really exist ?
- Is the estimated primordial abundance of ^{7}Li consistent with big bang nucleosynthesis ?
- How do supermassive black-holes form and how are they fed so as to shine as Quasars ?
- Which is the origin of gamma ray bursts ?
- Which are the sources of cosmic rays and ultra-high energy cosmic rays ?
- Which are the details of star formation and stars death ?

The Astrophysics research carried out in our Department covers a wide range of areas, facing many of the questions above:

- **Stellar and Galactic Astrophysics**, focusing on Astronomical Databases, Stellar systems structure, formation and evolution, Stability of relativistic stellar systems, Chemical evolution of galaxies, Measurements of the Galactic dust;

- **Extragalactic Astrophysics**, focusing on the spectral evolution and variability of Active Galactic Nuclei, Galactic and extragalactic X and gamma rays, Search and analysis of galaxy clusters in the microwave, optical and X-ray bands;

• **Cosmology**, focusing on measurements of the Cosmic Microwave Background (CMB) anisotropy and polarization, from ground and from space, development of Detectors for the CMB, Gravitational lensing, and tests of fundamental physics with cosmology.

The methods used to investigate these themes include theoretical studies, numerical simulations and data analysis with high-performance computers, development of original instruments and experiments carried from ground-based telescopes, stratospheric platforms, or deep space, in the full electromagnetic spectrum.

We have contributed and have access to the most important current space observatories (from Glast-Fermi for Gamma rays to Herschel in the far infrared and Planck in the millimeter range) and we are developing our own mm and submm stratospheric telescope (OLIMPO, with the Italian Space Agency). Moreover, we have developed and we run the MITO mm telescope at the Testa Grigia high mountain station, on the Italian Alps, and the optical telescope at Vallinfreda astronomical station. An optical telescope (TACOR) is available on the roof of the Department for education activities and optical instruments preparation/testing.

Figure 2: Artist view of an obscured Active Galactic Nucleus (AGN), a galaxy powered by a central supermassive black-hole. Our department is very active in the observation, analysis and physical interpretation of AGN data, both from ground based observations (with proprietary instruments at visible wavelengths) and from space observatories in X rays and gamma rays. *credits: ESA / NASA*

Additional infrastructure includes research laboratories for the development of advanced astronomical instrumentation, including CCD cameras, visible spectrographs, IR and mm-wave telescopes, spectrometers and detectors. The laboratories have advanced mechanical, electronics, optics and cryogenic instrumentation and expert technical support. We use large supercomputers in a national (CINECA) and european frame (DEISA, PRACE projects) for our simulations and analysis, but also medium-sized proprietary clusters. We are actively exploring the new approach to supercomputing, based on clusters of GPUs.

All this is accomplished by a staff of 15 academics, and by a larger number of students and Post-Doc, within a network of national and international collaborations. Our Department, in fact, offers a full specific curriculum in Astrophysics (the Bachelor's Degree in Physics and Astrophysics, the Master Degree in Astronomy and Astrophysics, and the Ph.D. in Astronomy), and we have a long-standing tradition of involving students of the two higher degrees quite deeply in research activities and in the related international collaborations.

Funds for these research activities (detailed in the following) come from MIUR (The Ministry of Education, University and Research), INAF (The National Institute for Astrophysics), ASI (The Italian Space Agency), INFN (The National Institute for Nuclear Physics).

Stellar and Galactic Astrophysics

This activity merges the heritage of the schools of Stellar Astrophysics (developed mainly in the 70s at the Laboratory of Space Astrophysics of Frascati) and of Astronomy (developed mainly at the Institute of Astronomy of our University and at the Observatory of Rome). Stars exist in a variety of forms and systems. They can be considered physics laboratories, where quantum mechanics and nuclear fusion, together with Newtonian dynamics, are the motors of evolution. Activities in our department are based on spectroscopic observations of stars, with focus on late high-mass stars, which are the key to understand the post-main-sequence evolution. Stellar systems represent very interesting dynamical systems, whose formation and evolution are studied in our department analytically, numerically and even thermodynamically, in the framework of galac-

tic dynamics and of general relativity **(A1, A2, A3 and A4)**. In particular, we advanced an original interpretation of galactic nuclei activity (Active Galactic Nuclei, AGN) as fed by decayed massive globular clusters in the central galactic regions. We also study the chemical evolution of spheroidal and largely-populated star systems (like globular clusters and elliptical galaxies), in order to produce models of sufficient accuracy to be compared to photometric and spectrometric observational data. Solar activity phenomena are also studied in terms of periodicities in the solar energetic proton fluxes (A5). Researchers are involved in studying our Galaxy by observing dust emission in the infrared and microwave bands using data from balloon-borne experiments (BOOMERanG) and from the Herschel satellite (A6).

Extragalactic Astrophysics

Clusters of galaxies are the largest gravitationally bound objects in the Universe. They form at the intersection of filaments and sheets of galaxies, as evident from large redshift surveys of galaxies and from numerical simulations. A large fraction of the mass of each cluster is in the form of a hot (millions of K), ionized tenuous gas, filling the potential well of the cluster, and producing X-rays. Most of the mass is in the form of dark matter, as evident from dynamical consideration and from lensing measurements on background sources. Researchers in our department estimate the redshift of distant clusters photometrically, using measurements of the spectral energy density from the ultraviolet to the near infrared. In this way they identify very distant clusters and can follow-up with X-ray observations, allowing studies of the evolution of galaxy populations in the clusters. We also study the gravitational lensing produced by clusters and in general by the distribution of dark matter (A7), and study clusters through the Sunyaev-Zeldovich effect (see next paragraph).

Figure 3: The cluster of galaxies Abell 1689, one of the most massive clusters known, is also a general relativity laboratory. Light from distant, background galaxies is deflected by the mass (visible and dark) present in the cluster, and produces characteristic arcs around the center of the cluster. *credits: NASA/ESA HST*

Active Galactic Nuclei are galaxies where the nucleus produces more radiation than the rest of the galaxy. This is due to a powerful supermassive black-hole located in the center of the AGN, with its ultra-hot accretion disk, surrounded by an obscuring torus and producing huge jets of relativistic particles. Depending on the orientation of the AGN with respect to the line of sight, we have different manifestations of the AGN, named radio loud and radio quiet quasars, blazars, broad line radio galaxies, narrow line radio galaxies, Seyfert galaxies. Researchers in our department study AGN mainly with optical and X-rays observations (A8, A9, A10 and A11). They use proprietary telescopes to contribute to a multi-wavelength network monitoring the variability of AGNs, which is the key to select AGN and understand the violent processes happening in the nucleus. They have contributed to large international missions for high-energy astrophysics, like Beppo-SAX, and more recently Swift and Fermi, and use the conspicuous flux of data to develop new and detailed models of these sources.

Cosmology

The Observational Cosmology Group (G31) was founded in our Department in 1981, by prof. Francesco Melchiorri, one of the Pioneers of Cosmic Microwave Background (CMB) research. The idea of studying the distant past of the Universe by measuring its photonic remnant (the CMB) resulted in a series of very successful experiments carried out by the group, to measure the spectrum of the CMB, its anisotropy, and its polarization. All these observables are sensitive

to different parameters of the cosmological model, and have produced compelling evidence for a homogeneous and isotropic background universe, where adiabatic inflationary perturbations have produced the large-scale structure we see today via gravitational instability.

Today, the activities of the group focus on the finest details of the Cosmic Microwave Background. We observe the interaction of CMB photons with the hot plasma in clusters of galaxies (the Sunyaev-Zeldovich effect) both from the MITO telescope (covering efficiently the frequencies in the atmospheric windows up to 240 GHz, and complemented by a performing atmospheric monitor, CASPER) (A12) and from the balloon-borne telescope OLIMPO (covering frequencies up to 480 GHz) (A13). There is a net energy transfer from hot electrons to CMB photons, so that the CMB spectrum shifts towards high frequencies in the direction of a cluster, with a very characteristic spectral signature. This effect allows to detect very distant clusters, using them as cosmological probes, and to study the peripheral regions of the intergalactic plasma, where the density is too low to produce significant X-ray emission. With the High Frequency Instrument on the Planck satellite, to which we contributed with the development of flight hardware (including all the cryogenic preamplifiers) of the calibrations and of data analysis, we study the primary anisotropy of the CMB with an unprecedented combination of angular resolution, sensitivity, and frequency coverage. The measurements of Planck will settle all the issues on CMB anisotropy, producing definitive maps of the microwave sky in a very wide frequency range, thus allowing reliable subtraction of foregrounds. Moreover, they will improve our knowledge of CMB polarization, and put significant constraints on the B-modes produced by inflation. We investigate CMB polarization with the BRAIN polarimeter, installed at the Concordia base on the high Antarctic plateau. This is a pathfinder for a large bolometric interferometer, the QUBIC experiment, in the framework of a large international collaboration. For the near future, we are developing new ultra-sensitive measurements of CMB polarization, to be carried out from a balloon platform, in preparation of a large post-Planck satellite mission (A14). In preparation of this, we are developing our own large format arrays of millimeter detectors, based on kinetic inductance resonators, and we are carrying out intensive technological research with the development of large cryostats for liquid helium in space (we have recently qualified porous plugs) and cryogenic polarization modulators with negligible heat load (A15). A new horizon opened recently with our proposal to study the wavelength spectrum of CMB anisotropy, by means of space-borne Differential Fourier Transform Spectrometers (DFTS). With the phase-A study of the SAGACE mission we have demonstrated the impact of this methodology in the study of the SZ effect, of the cooling lines in primeval galaxies (expecially [CII], of microwave emission from AGNs. All these experimental activities are complemented by a vigorous interpretation activity, based on the simultaneous analysis of different cosmological observables in the framework of the adiabatic inflationary model. This approach has been very successful in estimating and constraining several parameters of the cosmological model (like the average mass-energy density in the Universe Ω_o, the average density

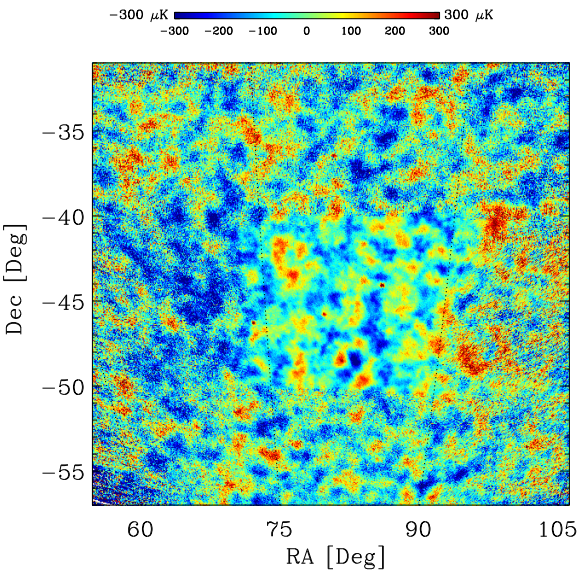

Figure 4: Map of the cosmic microwave background obtained at 145 GHz by the BOOMERanG experiment, built in our department, during its second fight devoted to the measurement of the polarization in the CMB (from Masi et al., 2006). The structures visible in the map are produced by density and velocity fluctuations in the primeval plasma, at redshift z $\simeq$ 1100. The angular power spectrum of this image constrains efficiently the cosmological parameters.

of baryons Ω_b, the density of dark energy Ω_Λ). The focus is now on the determination of the equation of state of dark energy, on the parameters of inflation, on neutrino masses, and in the forthcoming EUCLID satellite (ESA) to investigate dark matter: all these represent direct links between cosmology and fundamental physics (A16).

Paolo de Bernardis

A1. Structure and Evolution of Galaxies

This research is focused on the formation and evolution of spheroidal and largely-populated star systems, such as globular clusters and first-type elliptical galaxies, which cannot usually be "resolved" into individual objects. For elliptical galaxies the issues concern the progressive metal enrichment (owing to stellar nucleosynthesis and supernovae explosions) and the spatial distribution of the stellar populations, that were being formed in time (with corresponding increasing metallicities). The topic is relevant to the population synthesis, which consists in computing the integrated brightness, spectrum and colours, and allows the comparison of models with observational data. Observations are obtained through rectangular slits or concentric circular apertures. They can produce projected (on the disk image of a galaxy) radial profiles of photometric and spectral indices.

Information on the dynamical evolution of the stars in the various populations is not available in the literature at the levels needed to achieve an adequate comparison with observations, because of limits in the theoretical approach and difficulties in the numerical treatment. In order to reach a satisfactory spectro-photometric synthesis and compare the computed surface radial gradients with the observed profiles it is essential to account for the different galactic locations of the stars formed at different ages and with different metallicities and, hence, with differences in colours and spectra, Indeed, these data are produced by the cumulative contributions of all the stars of the galaxy located along the line of sight intersecting the disk at any specified projected radial distance.

Angeletti and Giannone (2003, 2008, 2010a, 2010b) bypassed the lack of information on the stellar dynamics by modelling the spatial radial distribution of the galactic mass, as deduced from the observed surface brightness, and the stellar metallicity, as derived from the central progressive concentration of the star forming gas. The strategy consisted in relating the stellar metal abundances to the stellar binding energies and angular momenta, in the scheme of a dissipative contraction of the proto-galactic gas accompanied by the simultaneous formation of stars with the metal abundances equal to that of the ambient gas at the time of the star formation. The approach combined a set of different schemes, in particular the "Concentration model" (CM) and the "Best Accretion Model" (BAM) by Lynden-Bell (1975), and the "Simple model" (SM) by Pagel and Patchett (1975). Models with a large set of choices for the free parameters (the exponent of the $R^{1/n}$ law for the radial surface brightness, the concentration index c, the metal yield p , and the amount of the accreted mass M) have been computed. The results have been then compared with the observations of four spectroscopic indices ($Mg_1, Mg_2, < Fe >, H\beta$) by Davies et al. (1993) and two photometric indices ($B - R_C$) and ($U - R_C$) by Peletier et al. (1990) for a sample of eleven galaxies.

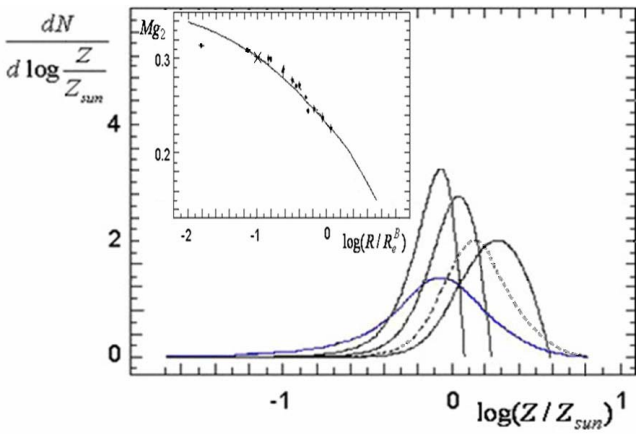

Figure 1: The distributions of the stellar metal abundances for the elliptical galaxy NGC 4278 from the CM+BAM (with $n = 4, c = 0.70, p = 1.0Z_{sun}, M = 3$) along the lines of sight through the projected radii $R_e^B, 0.5R_e^B$, and $0.1R_e^B$, from left to right (solid curves). The dashed curve gives the distribution within the circular aperture with projected radius $0.5R_e^B$, and the lowest solid curve the distribution integrated on the whole galaxy. The numbers of the stars are normalized to 1. In the inset, the model radial profile of Mg_2 is compared to the observations (dots; those on the right of the cross are unaffected by the seeing). The radius R is in unit of the effective radius $R_e^B = 32''.9$ in the Johnson B band.

The inset in Figure 1 shows how the observational data for index Mg_2 for the elliptical galaxy NGC 4278 are fitted by the model. In the figure the spatial (in the galaxy) radial distribution of the metal abundances Z is plotted for three surface radial distances, a circular aperture concentric to the galaxy image, and the whole galaxy. The best agreement of the models with the observational data of the studied galaxy sample indicates that the degrees of dissipation vary from moderate to large, the mean stellar metallicities range from the solar value to significantly oversolar values, the masses of the accreted matter can be relevant, the dispersions of velocities are isotropic in the majority of the selected galaxies, and their ages are not in disagreement with the age of 13 billion years. This is the age of the oldest globular clusters in our galaxy (estimated to be the lowest limit to the age of the Universe).

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Authors

L. Angeletti, P. Giannone

A2. Evolution of stellar systems and galactic nuclei formation and activity

Modern theoretical Astrophysics relies crucially on numerical methods. Actually, the strongly non-linear, out of equilibrium , physical stages that characterize the environment of galaxy and star formation, as well as the dynamics of star clusters in an external field are too complicated to be faced with analytic approximations. Gravity is the main engine of all the evolutionary astrophyical pass, and it is difficult to be taken properly into account without an overload of computational charge. Consequently, it is compulsory the use of efficient algorithms running on supercomputers. Our smal theoretical astrophysics group has been active since many years in the field of the study of the evolution of globular clusters in galaxies, and found that these stellar systems may be responsible for the structure and activity of the innermost galactic regions (see [1],[2]). To study at best the possibility that orbitally decaying massive stellar clusters form a super-star cluster in the central region of a galaxy, it is necessary to follow their motion in the potential of the parent galay, and to study the mutual galaxy-cluster feedback. This is possible only by mean of the integration of the complete N-body system equations. We approach this task in two ways: i) making use of the CINECA supercomputing facilities, running our own Tree-algorithm parallelized by mean of OpenMP and MPI libraries [1], and, ii) with our own hardware platform, based on 2 Graphic Processing Units (GPUs) used as supercomputers. Actually, a modern, cheap approach to supercomputing is through the use of 'hybrid' computational platforms, composed by a reliable multiprocessor host linked with an efficient 'number cruncher', like a GPU board. The structure of this computational platform is shown in Fig. 1. An optimal use of this platform required the implementation of a composite program, called NBSymple as ackronym for 'N Body Symplectic' (code), which exploits, thanks to OpenMP instructions, the power of multicore Intel CPUs and, thanks to the NVIDIA Computer Unified Architecture language, the high computational speed of the 240 threads of the individual TESLA C1060 GPU. The time integration is symplectic, i.e. time-reversible and avoiding secular term in the energy conservation error. The description of the code as well as its performances as computational speed and precision is found in [2]. Fig. 2 is a summary of the code performances of the NBSymple code in its various versions. The NBSymple code has presently 5 versions, each labeled with an alphabetic letter from A to E: NBSympleA is the, basic, fully serial code running on a single Quad core processor, while NBSympleE is the most performant version, uses CUDA on one or two GPUs to evaluate the total force over the system stars, i.e. both the all-pairs component and that due to the Galaxy, while the time integration is done by the OpenMP part of the code.

Figure 1: The scheme of the HW platform we installed to perform HP N-body simulations ([3]).

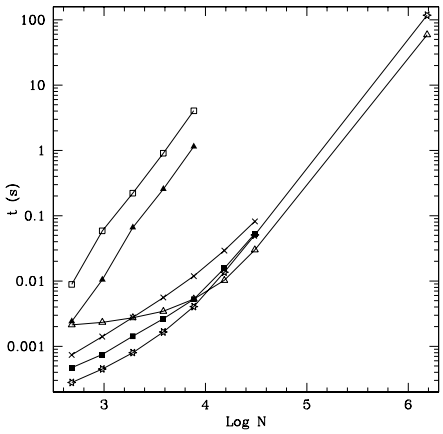

Figure 2: From [3]: the (averaged) solar time (in seconds) spent for one leap-frog integration step in single precision mode, as a function of N. Line with empty squares: NBSympleA code. Line with filled triangles: NBSympleB. Line with crosses: NBSympleC. Line with filled squares: NBSympleD. Line with stars: NBSympleE with a single GPU. Line with empty triangles: NBSympleE with two GPUs.

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Authors

R. Capuzzo-Dolcetta, A. Mastrobuono-Battisti, M. Montuori [3]

http://astrowww.phys.uniroma1.it/astro/dolcetta.html

A3. Advanced evolutionary phases of high mass stars

The details of post-MS evolution of massive stars are still poorly understood: the intermediate H-burning phases of an O-type star (typical mass up to 150 solar masses), are crucial as during them the star has to loose a huge quantity of its mass until it reaches its W-R phase (not in excess of 30 solar masses) during which it completely sheds its H envelope. This relatively short phase is thought to be represented by the extremely rare Luminous Blue Variables (LBVs) residing at the top of the HR diagram. The spectral and photometric characteristics of LBVs and related stars indicate that their evolution is driven by copious variable stellar winds. As a consequence their temporal light curves display irregular variability of 1-2 mag. Some of these stars have experienced ejection of significant shells with strong and rapid luminosity variations from the X-ray to the optical range. For most LBVs such events have been witnessed very rarely, but the presence of extended circumstellar nebulae suggests that they are a common aspect of LBV behavior.

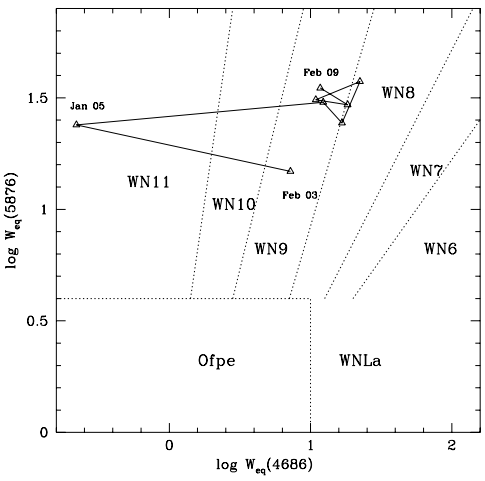

Figure 1: Spectral type oscillations of the LBV GR290 in the HeI vs HeII diagram

To date only about a dozen Galactic candidates have been confirmed, while there are more known extragalactic LBVs, in part thanks to the less obscured view of these extragalactic populations. As part of a spectrophotometric investigation of very massive stars we have studied the seven confirmed LBVs in the galaxy M33. May be the most intriguing is VarA, known to have formerly presented an M-type spectrum. Our most recent data indicated warmer color indexes successively confirmed by the spectral evolution towards an intermediate G-type . At the opposite edge of the temperature range, GR290 reached the hottest phase so far detected in an LBV [1]; If this phase would persist, we may be witnessing the rst case of transition from an LBV stage to a more stable WolfRayet one (see fig 1).

However, for apparent low luminosity levels there remain serious limitations in present instrumental capabilities, essentially in the X-ray range, so the narrow Galactic sample still remains the baseline for comparative characteristics and analysis of the class in general. For the prototype eta Car our observations with the X-ray satellite BeppoSAX revealed a constant non thermal excess luminosity between 13 and 20KeV in contrast with the variable thermal emission visible from the soft-X to the IR which is linked to the stellar wind. In a detailed spectroscopic analysis of AG Carinae, one of the galactic LBV prototypes, we unexpectedly found that the bolometric luminosity decreases as the star moves toward the maximum flux in the V band,contrary to the common assumption; this discovery allowed us to speculate about the amount of mass involved in the S-Doradus type instabilities which appear to be failed Giant Eruption, with several solar masses never becoming unbound from the star [2].

New discoveries would greatly advance the knowledge of evolutionary connection between LBV and other intermediate phases in the life of very massive stars, the duration of the LBV phase, the origin of their nebulae which show evidence for different wind regions. Puzzling is the presence of circumstellar dust, which has not been previously thought to exist around stars of this temperature and luminosity range. In a recent paper we presented a list of new members and candidates, for some of which we found evidence of binarity. Actually from a spectroscopic monitoring of an LBV candidate, apparently an intrinsecally very luminous B[e] star, we determined a periodical displacement of the photospheric absorption lines; the orbital period of about 30 days is compatible with a binary system composed by a massive B star and a collapsed object [3] We thus suggest that all the stars of this class are components of binary systems that have experienced strong mass transfer, responsible for the formation of extended gaseous and dusty envelopes. The spectroscopically confirmed LBV candidates discovered only require that variability be demonstrated to become actual LBVs. This last step can be achieved using both archival data and concerted long term monitoring .

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Authors

C.Rossi

A4. Equilibrium and stability of relativistic stellar clusters and study of properties of systems with anisotropic distribution of stars velocities

The study of compact objects like relativistic stellar clusters is considered one of the most important topics in General Relativity, being the collapse of dense stellar cluster one of the possible ways of formation of supermassive black holes in quasars and galactic nuclei. The structure and stability of such systems is strongly depending on energy cutoff which takes into account the evaporation of stars with large velocity. Also anisotropy in momentum space may appear during the possible rapid contraction of the cluster due to the preservation of angular momentum. Strong anisotropy is expected in dense clusters with a supermassive black hole at the center, where in the vicinity of the last stable orbit only stars with circular orbits can survive.

The study of the equilibrium configurations and their dynamic and thermodynamic stability for clusters has been systematically and deeply managed by constructing non collisional selfgravitating models with spherical symmetry and distribution function with a velocity cutoff. Stability of isotropic clusters is analyzed by constructing appropriate sequences of models by varying suitable parameters. Results of this analysis lead to conclusion that equilibrium configurations are dynamically stable in Newtonian regime, independently from the choice of distribution function while, in relativistic regime, a critical density showing the appearance of dynamical instabilities has been obtained. The general analysis of thermodynamical and dynamical stability can be performed by constructing a $z_c - T$ diagram of the equilibrium configuration (see Figure 1).

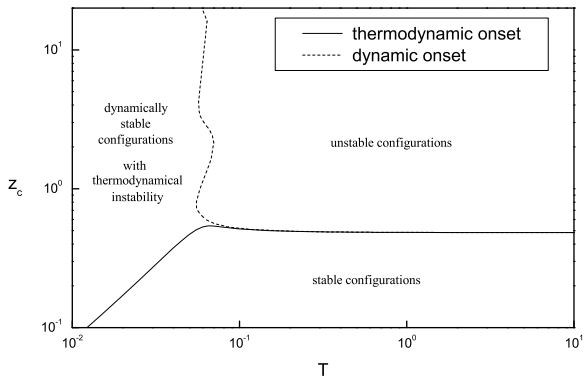

Figure 1: Regions of dynamical and thermodynamical stability in the plane (T, z_c).

The main result is the existence of dynamically stable solutions for arbitrarily large values of the central redshift z_c for sufficiently small values of the temperature T and the contemporary appearance of the onset of dynamical and thermodynamical instability for large values of temperature T [2]. Perspectives of this research is extending this analysis to anisotropic models. With the study of the equilibrium models with anisotropic distribution it is possible to see that these systems mantain the spherical symmetry if the total angular momentum is zero. The main characteristic of these models is the appearance of a hollow structure for which the density profile shows an increasing behavior at increasing values of radius at sufficiently large level of anisotropy [1,3].

The study of thermodynamical instabilities of selfgravitating systems is strictly connected with the problem of gravothermal cathastrophe first introduced by the well known paper of Lynden-Bell & Wood in 1968. In this model, the effect of the presence of region at negative thermal capacity leads the system towards the collapse of the core. The rough picture introduced by Lynden-Bell & Wood has been developed by constructing a selfconsistent model in which regions at negative thermal capacity coexists with positive ones (see Figure 2) on the basis of the application of statistical mechanics in presence of gravity. The general properties of these models are well fitting the main characteristics of globular clusters, by using the King distribution function, and give the possibility to analyze the dynamical evolution of the systems until the onset of the gravothermal catastrophe.

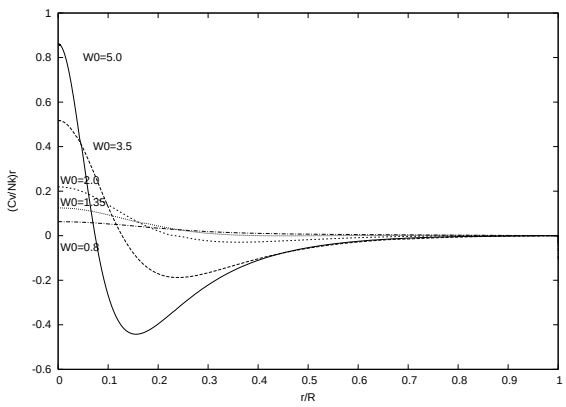

Figure 2: Values of thermal capacity in Nk units as a function of relative radius r/R for selected values of central potential W_0.

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Authors

M. Merafina

A5. Search for periodicities in the solar energetic proton fluxes

Past studies revealed that many solar activity phenomena undergo both periodic and quasi-periodic variations on different time scales. Nevertheless, only a few attempts were made so far to detect corresponding variations in the occurence frequency of solar energetic particle events. We tried to fill this gap searching for periodicities in the proton fluxes, measured in the interplanetary space, on time scales ranging from a few Bartels rotations (27 days) up the the Schwabe period (≈11 years).

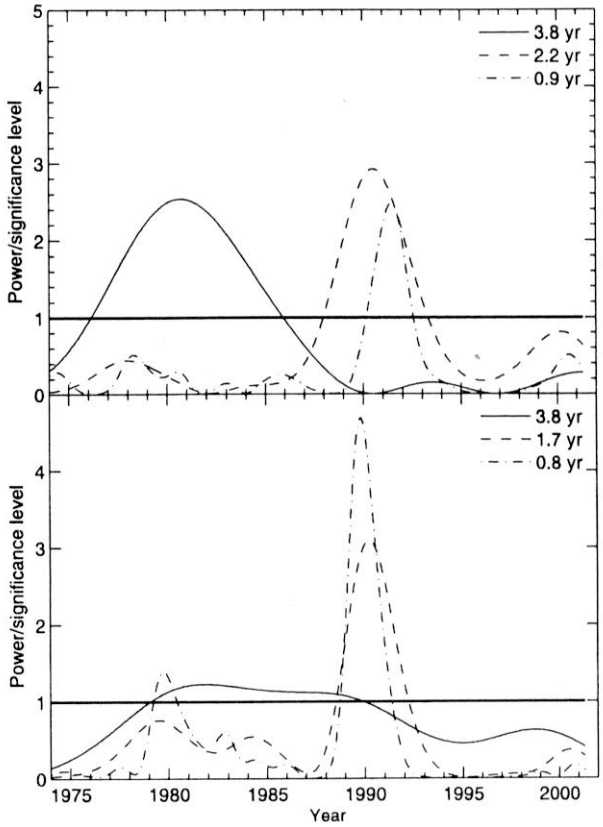

Figure 1: The wavelet power (normalized to the 95% significant level) corresponding to the most relevant periods (as reported in the legend) are plotted as a function of time for channel P2 (top) and channel P11 (bottom). An upper cutoff was applied to the data in order to smooth the discontinuities.

Our study was based on the data collected by the Charged Particle Measurement Experiment (CPME), aboard the satellite IMP 8, orbiting at ≈35 Earth radii in the period from 1974 to 2001. Measurements were performed in ten differential energy channels, but we used only those taken in channels P2 (0.50 - 0.96 MeV) and P11 (190 - 440 MeV), which were not affected by an experiment malfunction occurred in 1989. Data were analyzed using the wavelet transform (WT), a technique which offers an important advantage with respect to the Fourier transform, because it allows localization in time of possible periodicities which are not present continuously in the data set. It is known, however, that the WT may lead to erroneus results, when applied to discontinuous data, such as the proton fluxes considered in our study. We investigated this issue by applying the wavelet analysis to suitable test functions. It turned out that eventual spurious frequencies can be discarded by introducing an upper cutoff to reduce the amplitude of the stronger discontinuities present in the data set.

Discarded the spurious periods, our analysis revealed variations of the proton fluxes on the following time scales (see Figure 1):

T = 3.8 years. This period has been singled out in both the energy channels from 1977 to 1985 (the active phase of solar cycle 21). It closely resembles the 3.7 year period exhibited by the protospheric magnetic field in the same time interval.

T = 1.7 - 2.2 years. This modulation, also present in both the energy channels, is better observed from 1988 to 1993 (i.e., around the sunspot maximum of the cycle 22). It corresponds to the "quasi biennial oscillations" (QBO) which are known to characterize several features of the solar activity: e.g., the number of H flares, the total sunspot area, the 10.7 cm radio emission, and the flux of the energetic electrons. The common origin of all these phenomena is supported by the simultaneous disappearance of their modulation during quiet periods.

T = 0.8 - 0.9 years. This modulation is observed in shorter time intervals: its linkage with the variations of other solar parameters deserves other studies.

We also note the lack, in our data set, of significant modulations on time scales of 150 days and 5 - 6 years. However, the 150 day period (the so called "Rieger period"), revealed in several solar activity parameters, could have been hardly singled out in our analysis, as the proton fluxes were averaged over Bartels rotations (27 days). On the other hand, the absence of the 5.5 year modulation appear to be more significant. In fact it supports the hypothesis, advanced by some author, that this periodicity, observed, e.g., in the sunspot number, is an artifact produced by the asymmetric shape of the solar cycle.

We finally stress that the procedure we successfully introduced here to discard spurious periodicities may be useful when the WT is applied to other sets of data with strong discontinuities.

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Authors

G. Moreno

A6. Measurement of the Galactic dust emission in the infrared and microwave bands

Dust is the most robust tracer of the *Galactic ecology*, the cycling of material from dying stars to the ionized, atomic, and molecular phases of the ISM, into star forming cloud cores, and back into stars. While atoms, ions, and molecules are imperfect tracers because they undergo complex phase changes, chemical processing, depletion onto grains, and are subject to complex excitation conditions, dust is relatively stable in most phases of the ISM. It is optically thin in the Far Infrared (FIR) over most of the Galaxy, so that its emission and absorption simply depend on emissivity, column density and temperature. Cold dust in particular ($10\,\mathrm{K} \leq T \leq 40\,\mathrm{K}$) traces the bulk of non-stellar baryonic mass in all of the above "habitats" of the Galactic ecosystem.

Temperature and luminosity and, as their by-product, mass of cold dust measured over the Galactic Plane and at high Galactic latitudes, are the critical quantities needed to formulate a global predictive model of the cycling process between the Galactic ISM and star formation. This process drives the Galactic ecology in normal spirals as well as the enhanced star-formation rates of starburst galaxies and mergers and a quantitative understanding of it is needed in order to follow the formation and evolution of galaxies throughout the cosmos.

Figure 1: Herschel five-colour infrared images of cold gas in the constellation of the Southern Cross, located about 60° from the Galactic Centre, thousands of light-years from Earth. The images cover an area of $2° \times 2°$ on the sky

There is a long list of questions that the community has been addressing for some time, not finding satisfactory answers. Here is an abridged list:
- What is the temperature and density structure of the ISM? How do molecular clouds form, evolve, and how are they disrupted?
- What is the origin of the stellar initial mass function (IMF)? What is its relationship to the mass function (MF) of ISM structures and cloud cores on all scales?
- How do massive stars and clusters form and how do they evolve? What are the earliest stages of massive star formation and what are the timescales of these early phases?
- How do the Star Formation Rate (SFR) and Efficiency (SFE) vary as a function of Galactocentric distance and environmental conditions such as the intensity of the Interstellar Radiation Field (ISRF), ISM metallicity, proximity to spiral arms or the molecular ring, external triggers, and total pressure?
- Does a threshold column density for star formation exist in our Galaxy? What determines the value of this possible threshold?
- What are the physical processes involved in triggered star formation on all scales and how does triggered star formation differ from spontaneous star formation?
- How do the local properties of the ISM and the rates of spontaneous or triggered star formation relate to the global scaling laws observed in external galaxies ?

In particular using the Herschel telescope, the Open Time Key Project Hi-GAL (Herschel infrared Galactic Plane survey) will provide unique new data with which to address these questions. Hi-GAL will make thermal infrared maps of the Galactic Plane at a spatial resolution 30 times better than IRAS and 100 times better than DIRBE, from which a complete census of compact source luminosities, masses, and spectral energy distributions (SEDs) will be derived.

Figure 2: The Herschel and Planck spacecrafts

Our team has used the data from the BOOMERanG balloon missions to analyze dust properties at high galactic latitude, and will have access to data from the Planck HFI space mission and from the Hi-GAL Project. We have in the past developed techniques of map-making, component analysis [1]. We are expert in the study at millimeter wavelengths, see [2] and references therein, and we will make use of our expertise in the analysis and interpretation of the new extremely high quality datasets.

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A7. Gravitational lensing and its cosmological applications

Gravitational lensing uses the property of light to be deflected by the gravitational potential. The banding of light ray by a gravitational force is a direct consequence of the principle of equivalence but the amplitude of this effect can be exactly computed only using general relativity, in which the deflection is described by geodetic lines following the curvature of the space-time. The measuremt of a deflection of 1.75" for the stars behind the Sun during the 1919 solar eclipse was one of the main observational test that confirmed Einstein theory. Nevertheless it was only at the end the last century that gravitational lensing started to be an important reasearch subject in astrophysics and during the last ten years it became a fundamental tool for modern cosmology. The reason for this delay is mainly the very high quality images needed to observe this phoenomenon in most of the relevant cases: in what is called the "weak regime" the only observable consequence of light deflection is a tiny distortion in the shape of the lensed image.
In an international context were gravitational lensing is a leading research subject, Italy started with a serious delay comparing with the other countries. The group of Rome, the result of a close collaboration between the University "La Sapienza" and the astronomical observatory (OAR), is working very activily with Naples and Bologna to compensate this gap. The main interests of our group are the following:

Measurement of the cosmic shear: Cosmic shear is the gravitational distortion of the shape of background galaxies by the large scale structure of the universe. It is considered one of the most promising probe to determine the distribution of the dark matter in the universe.
Our group participated to the analysis of the Canada France Hawaii Legacy Survey (CFHTLS) data, up to now the most sensitive measurement of cosmic shear [1], that allowed to place tight constraints on two important cosmological parameters: the matter density $\Omega_{\rm m}$ and the normalization of the matter power spectrum σ_8.

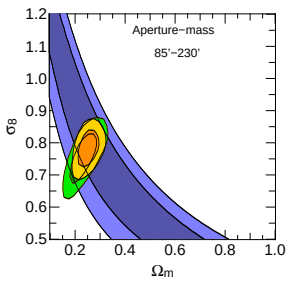

Figure 1: Comparison $(1, 2\sigma)$ between WMAP3 (green contours) and CFHTLS results (purple). The combined contours of WMAP3 and CFHTLS are shown in orange.

Participation to the space mission EUCLID: Euclid is a space mission selected for study within the ESA's Cosmic Vision framework. Euclid primary goal is to to place high accuracy constraints on Dark Energy, Dark Matter and Gravity using two independent cosmological probes: cosmic shear and baryonic acoustic oscillations. For this purpose, Euclid will measure the shape and spectra of galaxies over the entire extragalactic sky in the visible and NIR, out to redshift 2, thus covering the period over which dark energy accelerated the universe expansion. Our group participate to the development of the mission concept as a member of the Euclid Imaging Consortium [2].

Mass determination of galaxy clusters: The only direct method to estimate cluster mass, regardless of its composition or dynamical behavior, is therefore via measuring the distortion (*shear*) of the shapes of background galaxies that are weakly lensed by the gravitational potential of the cluster. Our group performed a weak lensing analysis of the $z = 0.288$ cluster Abell 611 on g-band data obtained at the Large Binacular Telescope (LBT) in order to estimate the cluster mass. The combination of the large aperture of the telescope and the wide field of view allowed us to map a region well beyond the expected virial radius of the cluster and to get a high surface density of background galaxies. This made possible to estimate an accurate mass for Abell 611, demonstrating that LBC is a powerful instrument for weak gravitational lensing studies. This project was completed performing a comparative study of the A611 mass results obtained with strong lensing and X-ray data.

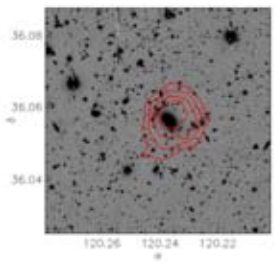

Figure 2: Projected mass map obtained from a weak lensing analysis of CCD images of the cluster Abell 611. The contour levels ($\sigma_{\rm min} = 3.5$, $\sigma_{\rm max} = 5$) are overplotted on a g-band greyscale image ($\sim 4'$) of the field of the cluster.

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Authors

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A8. Galactic and extragalactic sources of X and Gamma rays

Cosmic sources of high-energy electromagnetic radiation can be classified in two main classes: objects of stellar nature, which belong to our Galaxy, and Active Galactic Nuclei (AGN). The former objects are rotating neutron stars (pulsars), binary systems with a collapsed star (a neutron star or a black hole of stellar mass) and Supernova Remnants; the latter sources are believed to be supermassive black holes (10^6 - 10^9 solar masses) surrounded by an accretion disk and ejecting a jet of particles accelerated at relativistic energies.

The study of these sources had an impressive development after the launch of the space observatory Fermi-GST in June 2008. In the first year of operation, the LAT (Large Area Telescope, onboard F-GST) discovered about 1500 galactic and extragalactic sources whose emission extends up the GeV range. The majority of γ-ray sources with a well established counterpart are Blazars (BL Lac objects and Flat Spectrum Radio Quasars): these associations are mainly based on the positional coincidence. Our group is working from a few years in the compilation of a "Multifrequency Catalogue of Blazars" (Massaro et al. 2009), also known as Roma-*BZCAT*, which is a master list of sources of this class based on an accurate study of literature and new data. The last version of the Roma-*BZCAT* contains more than 2800 objects and can be accessed at the web site of the ASI Scientific Data Center. It is currently used by the FGST collaboration and allowed the identification of many new discovered γ-ray sources, particularly BL Lac objects. The catalogue will be also printed in four volumes: two of them, covering half of the sky, are already issued and the last two will appear before the end of 2010.

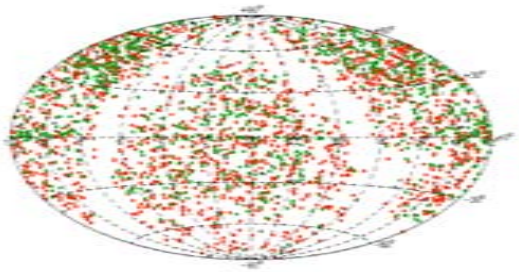

Figure 1: Sky distribution of the blazars in the Roma*BZCAT* (from E. Massaro et al. 2009).

We have also developed a numerical code based on the Minimal Spanning Tree (MST), a topometric algorithm for cluster analysis, for searching γ-ray sources in LAT sky images at energies above a few GeV. We defined and tested the criteria for the selection of candidate sources (Campana et al. 2008) and contributed to the preparation of the first catalogue of LAT γ-ray sources (1FGL, Abdo et al. 2010, submitted to ApJ). Presently, we are currently involved in the work of preparation of the two year LAT catalogue, which will be available before the end of 2010. We also contributed to the study of the high energy emission and to the analysis of multifrequency data of some bright blazars (3C 454.3, 3C 273, PKS 1502+106, PKS 1510-089) and these results are appearing in a number of papers.

We studied the X and γ-ray emission of some galactic sources, in particular isolated pulsars and their Pulse Wind Nebulae. We proposed a model for describing the phase and spectral evolution of the Crab pulsar based on the presence of two couples of emission components. This model gave a successful prediction (Campana et al. 2009) of the very high emission (> 25 GeV) of Crab discovered by the MAGIC team.

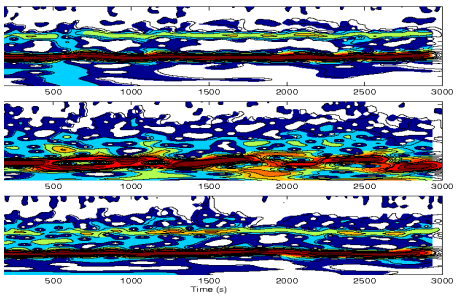

Figure 2: Wavelet spectra of three data series of the X-ray emission from GRS 1915+105 (from E. Massaro et al. 2010).

Another puzzling galactic source, that has been the subject of long and detailed researches, is the microquasar GRS 1915+105. It exhibits a very intense X-ray emission, characterised by a very complex variability. We are currently working on the analysis and interpretation of a large data set of X-ray observations, mainly performed by the BeppoSAX and Rossi-XTE satellites. The high flux of GRS 1915+105 allow us to investigate the instabilities of the accretion disk, which produce long series of recurring bursts. The time and spectral evolution of these bursts can be investigated by means of several linear and non-linear methods useful to describe the transitions from ragular to irregular modes, the latter ones characterised by rapidly chanche of the burst recurrence and shape. This source can be also useful to investigate the onset of possible chaotic processes in accretion disk systems.

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Authors

E. Massaro, R. Campana, A. Maselli

A9. Spectral evolution and variability of Active Galactic Nuclei

The general term 'active galactic nuclei' (AGNs) refers to the existence, in the central region of some galaxies, of energetic phenomena which cannot be attributed directly to stars. The spectral energy distribution of these sources, extends with comparable intensities from the Radio up to the Gamma ray band, implying that several physical mechanisms are involved, at variance with stars where the bulk of the emission comes from thermal black-body radiation. Their emission has been found to account for nearly the whole cosmic X-ray background radiation and their contribution is not negligible even for the cosmic Microwave background (CMB). The basic structure of an AGN is supposed to be a super-massive black hole (SMBH) (from 10^6 up to 10^9 solar masses) accreting matter from a surrounding disk: the conversion of gravitational potential energy into electromagnetic radiation powers the AGN emission. The mass of the central black hole is correlated with the mass of the host galaxy, indicating a physical connection between the processes of galaxy and AGN formation, which is one of the main subject of the present astrophysical research. While AGNs are present in about 1 % of all galaxies, most, if not all, galaxies are believed to host in their nucleus a SMBH with very low or null energetic activity for the absence of accretion processes. Most AGN show variability at all wave-lengths and time scales ranging from hours to years, which allow to investigate their internal structure. A small fraction of AGN, called Blazars, show particularly strong and rapid variability and are polarized. These properties are related with the presence of two opposite jets of material escaping at relativistic speed from the central region. The main emission processes in Blazars are a synchrotron component, due to the relativistic electron moving in the magnetic field of the jet, and an inverse Compton component, most likely due to interaction of the same electrons on the synchrotron photons, or to external photons. The two processes peak respectively at optical and X-ray frequencies, so that multi-wavelength, and therefore multi-instrument, observations must be simultaneously made to measure both components.

Since several years, our group is involved in these multiwavelength campaigns, which often imply large international collaborations using both ground based (optical, radio, TeV) and space based (X-ray, Gamma-ray) instruments: a recent example paper of this kind is reported below [1]. We are also involved in the study of the long term optical variability of Blazars, using our telescope at Vallinfreda and archive photographic plates from the Asiago Observatory [2]. The technique of digitization and data analysis has been mainly set up in the years 2002/04 by our group in the framework of a National Project.

Statistical samples of AGN, mostly quasars (QSOs) and Seyfert galaxies, can be detected through their variability. This makes possible the detection of faint AGNs, which cannot be selected on the basis of their colours, since they are affected by the light of the host galaxy. We created and analysed various samples of this type. For the sample of the Selected Area 57, observed in the optical band for more than 15 years at the Kitt Peak National Observatory to identify variable sources, we obtained observing time with the XMM-Newton X-ray Observatory [3]. Another sample of this type was created in the Chandra Deep Field South, where the deepest X-ray observations (2 Ms) exist. A third sample, which is one of the largest ever detected on the sole basis of variability, was obtained from the optical data collected by the ESSENCE international collaboration, which is devoted to the measure of the cosmological parameters through the analysis of deep supernova samples [4]. Variability-selected samples make possible a combined X-ray and optical analysis. The AGN nature of several variability-detected candidates has been confirmed by X-ray emission. We discovered some objects, whose AGN nature has been confirmed by optical spectroscopy, which are not detected in X-ray due to their particularly low X-ray to optical ratio.

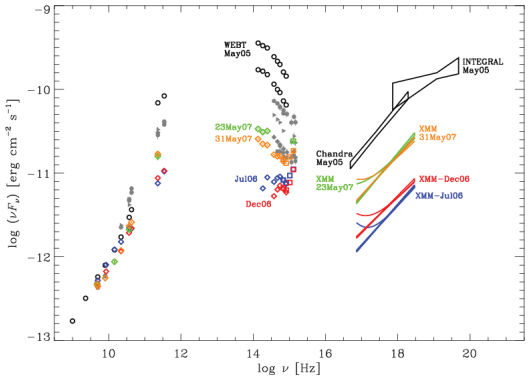

Figure 1: The time dependent spectral energy distribution of the Blazar 3C 454.3 resulting from multi-epoch observations, from the radio to the Gamma-ray band [1].

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http://astrowww.phys.uniroma1.it/scae.html

A10. Search and analysis of galaxy clusters in the optical and X-ray bands

Galaxy clusters are the largest and most massive gravitationally bound systems and represent a powerful tool to investigate dark matter, the evolution in cosmic time of the large scale structure of the Universe and galaxy formation and evolution. Originally selected as local enhancements of the galaxy number density on the celestial sphere, they were successfully modeled as hydrostatic equilibrium structures, once X-ray observations made the study of their intergalactic hot gas possible. Since the 80-ies, galaxy morphology and colour segregation in low redshift clusters were discovered, and quantified indicating the interaction of galaxies with the environment. For this reason, finding end studying high redshift cluster is the main way to understand the origin of the properties observed at low redshift, and the nature of the physical processes which determine the evolution of galaxies and their interaction with the environment. Studies of X-ray detected massive clusters up to redshift z 1.4 have shown little evolution of their properties, despite the large look back time (65 % of the age of the Universe). However, only very massive structures have been detected so far, due to the strong dependence of X-ray luminosity on the gas mass. Surveys based on the Sunyaev-Zeldovich (SZ) effect will open invaluable perspectives for the future, but do not reach yet the sensitivity to detect any of the known clusters at z¿1. Searching for Ly-alpha emitters near radio galaxies is limited to z¿2 for ground-based observations and other methods used at low redshift become unpractical for finding distant clusters in the range 1¡z¡2 where the first hints of colour segregation are expected to appear. The use of broad band images in several wavelength intervals, typically from the ultraviolet to the near infrared, makes it possible to derive a spectral energy distribution (SED), essentially equivalent to a low resolution spectrum, for all the galaxies in the observed field. Fitting the observed SEDs, with either empirical templates or with models derived from population syntheses, provides the determination of the so called photometric redshift. We developed the (2+1)D algorithm [1] which estimates a three-dimensional galaxy number density from the angular position and a radial distance determined from the photometric redshift obtained from multi-band photometry down to the deepest observational limits.

The application of this method in the GOODS field [2] allowed us to identify a galaxy cluster at redshift 1.6, to estimate its mass and to measure its the X-ray luminosity, from the deepest X-ray observation existing nowadays, obtained with the 2 Ms exposure of the Chandra X-ray observatory in the Chandra Deep Field South. This is the most distant galaxy cluster ever detected on the sole basis of an over-density in the galaxy distribution. While at low redshift the fraction of elliptical (red) galaxies is larger in regions of higher density, this effect tends to vanish at redshift greater than 1, due to a high fraction of star forming galaxies, which is present even in the over-dense regions. Our study of the segregation of galactic types for different environmental densities, as a function of cosmic time, has extended to redshifts grater than 2 [3] the evidence of this trend.

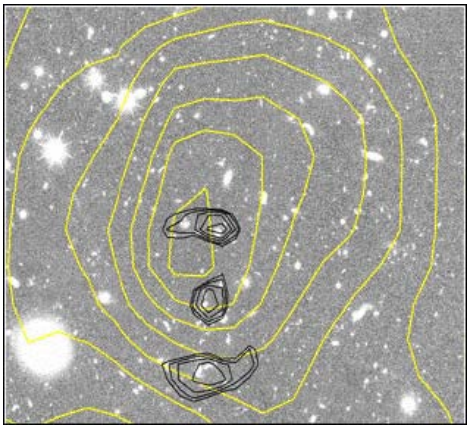

Figure 1: The highest redshift, z=1.61, galaxy cluster detected on the sole basis of galaxy overdensity [2]. Optical image in the z_{850} band from the ACS camera on board of the Hubble Space Telescope. Yellow lines: cluster iso-density contours; black lines 0.4-3 keV X-ray contours from Chandra X-ray Observatory data.

Thanks to the X-ray observations from Chandra and XMM-Newton satellites, at lower redshift ($0.1 < z < 0.5$) is now possible to study also the properties of relatively small ($10^{14} M_{\odot}$) and cool (kT $\lesssim$4 keV) clusters, which are more likely to display the effects of non-gravitational energy (star formation, active galactic nuclei) into the intra-cluster medium. One of these objects, Zw 1305.4+2941, has been observed with a medium-deep exposure of XMM-Newton and its properties were compared with those of other objects in the same range of parameters [4]. The study adds evidence in favour of a deviation of the main scaling relations, between X-ray luminosity, gas temperature and density and galaxy velocity dispersion, obtained for more massive galaxy clusters.

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Authors

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A11. Astronomical Databases: the Digitized First Byurakan Survey (DFBS) and the Roma Blazar Catalogue (BZCat)

Keeping the astronomical observations for the next generations of scientists is an important issue of science. The time scales of phenomena in astrophysical objects can indeed be very long and several decades or centuries of observations are sometimes required to discover them. Catalogues of astrophysical sources, including their position in the sky and their luminosity at several frequencies are therefore a key topic for research.
Our group is involved in two international projects of this kind:
1) the digitization of the First Byurakan Survey (DFBS);
2) the realization a Blazar catalogue (Rome BZCat).

The DFBS

The First Byurakan Survey is the largest (17000 square degrees) photographic spectroscopic survey of the northern sky made with the Schmidt telescope of the Byurakan Observatory, with a spectral coverage from 3400 to 7000 A. Originally the survey was designed by Markarian to discover Galaxies with Active Nuclei (AGN) or strong star formation; more than 1500 such galaxies were discovered by this survey.
The digitization of the plates and the automatic extraction of the spectra of the sources has been realized by our Group in collaboration with the Byurakan Observatory and the Cornell University. The database is hosted by the web server of our Group (http://byurakan.phys.uniroma1.it/), freely accessible by internet, containing the digitized plates of the FBS, the individual spectra of the sources and their B and R magnitudes. The technical details of the DFBS have been published in 2007 [1].

The web page allows to share the database informations with the astronomical community and to stimulate new ideas, extending the use of the database itself to study objects completely different from the targets of the original survey:
- after the realization of the DFBS a research project on asteroids has started, to improve their orbital parameters and to have a first estimate of their surface characteristics from their optical spectra;
- a new program has begun to search and study extremely red objects at high galactic latitudes. Nearly 1000 late M-type and carbon stars have been selected. Discovery of such objects is necessary for the study of the kinematics and chemical composition of the galactic Halo[2].
A general description of the FBS and the possibilities of its scientific applications can be found in a dedicated book where the future developments are also described[3]. We have started the integration of the DFBS database in the Astrophysical Virtual Observatories (AVOs) project, an International enterprise aiming to share observing materials and software tools to form a common research environment in which complex research programs can be conducted.

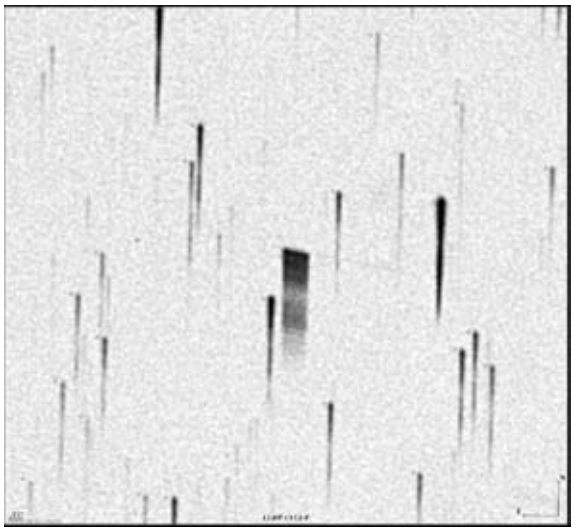

Figure 1: The spectrum of the asteroid 104 Klymene in the plate N. 126 taken on Nov 14, 1969, widened by the asteroid motion during the exposure.

The Roma BZCat

Our group also compiled a catalogue of blazars which is accessible at the web site of ASDC. This catalogue and its use is described in the section on X and gamma-ray sources.

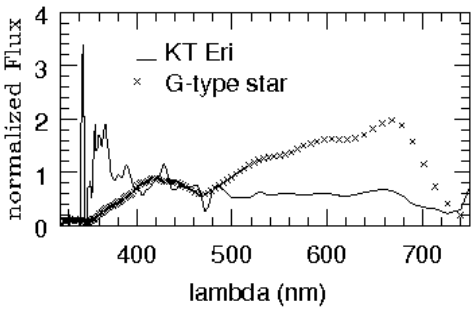

Figure 2: A pre-discovery (1971) spectrum of the Nova KT Eri (2009) in the DFBS, showing strong emission lines.

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A12. Ground-based observations of the Secondary Anisotropy of the Cosmic Microwave Background

The photons of the Cosmic Microwave Background (CMB), on their way towards us from the last scattering surface, interact with cosmic structures and their frequency, energy or direction of propagation are affected. These effects are included in the so called Secondary Anisotropies that arise from two major families of interactions. The first includes the interactions between photons and gravitational potential wells (*i.e.* gravitational lensing, the Rees-Sciama effect and the integrated Sachs-Wolfe effect). The second family incorporates the effects of scattering between CMB photons and free electrons such as inverse Compton interaction, the Sunyaev-Zel'dovich (SZ) effect, and velocity-induced scatterings, the Ostriker-Vishniac (OV) effect.

Observations of the SZ effect, developing instruments for this purpose, and the study of its implications in cosmology are the main goals of this research activity. The expected distortion in the CMB spectra is evident in the millimeter band and this allows its observation even from the ground. The Experimental Cosmology Group G31 has developed a 2.6 m in diameter on-axis aplanatic telescope mainly devoted to millimeter wavelength observations. The project, named MITO (Millimeter and Infrared Testagrigia Observatory) enjoys the logistical support of the IFSI/INAF laboratory on the Alps (Breuil-Cervinia 3480 m a.s.l.). The advantage of an observational cold and dry site is a stable and high atmospheric transmission in the mm-band. The cross-elevation modulation in the sky, for reducing the sky-noise, is ensured by a wobbling 41-cm in diameter subreflector. Several instruments have been installed at the telescope focal plane and new ones are almost ready (MAD, Multi Array of Detectors, a 3x3 pixels for 4 bands: 143, 214, 272 and 353 GHz) [1], or planned (WCAM, 7x7 arrays of TES in the W-band). An atmospheric spectrometer, CASPER2, has been designed and realised in order to continuously monitor the atmospheric opacity in the 2 mm ÷ 850 micron band. CASPER2 is a small (62-cm in diameter) telescope with a Martin-Puplett spectrometer and 2 detectors cooled down to 300 mK.

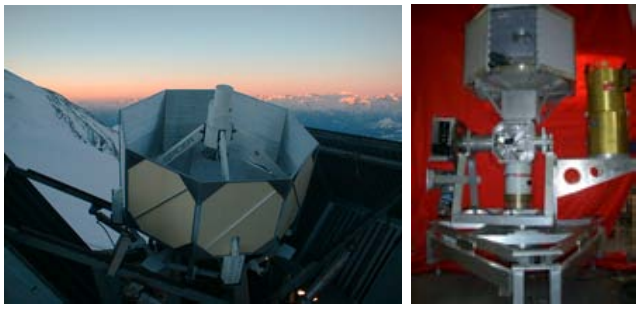

Figure 1: MITO telescope on the top of Testa Grigia mountain (left) and the atmospheric spectrometer CASPER2 (right).

The SZ effect has a continuous increasing number of applications in cosmology. Among the many, we have oriented our research on the possibility of constraining the scaling of the CMB temperature along the redshift, $T_{CMB}(z)$, deriving it from multifrequency observations of SZ effect towards cluster of galaxies [2,3]. Incoming all sky surveys collecting a large number of clusters will constrain better the temperature standard scaling law. So far, $T_{CMB}(z)$ has been only determined from measurements of microwave transitions in interstellar clouds due to atoms and molecules excited by CMB photons: an approach with substantial systematic uncertainties.

The clusters of galaxies are the main scatterers producing SZ distortion but the effect is generated by all the gas present along the line of sight. For this reason the SZ effect is also a useful challenging probe for detecting clusters having no detectable X-ray emission and for revealing the so-called missing baryons in the local universe. In fact half of the expected baryons are not yet counted mainly due to the difficulty of their detection due to their low gas density and temperature. Gasdynamical simulations suggest that these missing baryons could be accounted for in a diffuse gas phase with temperatures $10^5 < T < 10^7$ K and moderate overdensities ($\delta \leq 10 \div 100$), known as the warm/hot intergalactic medium (WHIM). The superclusters are suitable sky regions for this purpose as derived by gasdinamical simulations of the Universe: long filaments are present connecting cluster members.

We have performed observations of SZ effect towards Corona Borealis supercluster in collaboration with IAC in Tenerife and we studied in the MareNostrum Universe, a gasdynamical simulation provided us by a collaboration with UAM in Madrid, the expected SZ signal due to different gas components [4]. Incoming experiments, ground based or space missions in which the authors are involved, will allow to fully explore this topic reaching higher angular resolution and larger spectral range.

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A13. Balloon-borne and satellite measurements of the Cosmic Microwave Background and its interaction with Clusters of Galaxies

The measurement of cosmic microwave background (CMB) with experiments like BOOMERanG, WMAP, and currently Planck, has provided extraordinary images of the early universe, allowing a precise estimation of the cosmological parameters. The future of this research consists of the study of its detailed fine-scale and polarization properties.

Space missions allow the measurement of the spectral properties of the CMB. While the COBE satellite has measured very precisely the specific brightness of the CMB, the spectral distribution of CMB *anisotropy* is largely unexplored. Normally being the derivative of a Planck spectrum, its distribution is slightly modified by the interaction of CMB photons with matter along the path from recombination to here.

A well known effect is the inverse Compton scattering CMB photon undergo crossing the hot ionized plasma of clusters of galaxies (the Sunyaev-Zeldovich effect). Low frequency photons are boosted to higher frequencies, so that in the direction of cluster there is a deficit of brightness at frequencies lower than 217 GHz, and an excess at frequencies higher than 217 GHz. This is a very characteristic spectral feature, with an amplitude of the order of 10-100 ppm of the brightness of the CMB, allowing a clean separation from competing foregrounds. This effect can be used in a number of ways, ranging from the discovery of early clusters (this effect does not depend on the distance of the cluster) to the use of clusters as standard rulers for the determination of cosmological parameters (H_o, Ω_Λ), to the study of hidden baryons, or the study of the nature of non-baryonic dark matter in interacting clusters [1].

Other spectral features in the same frequency range are due to the interaction of CMB photons with early molecules, and the emission of lines (like the very strong [CII] line at 158 μm rest wavelength) from early galaxies.

A first important step in the measurement of these weak spectral features is the mission OLIMPO (fig.1), coordinated by our group and funded by the Italian Space Agency. This is a 2.6 m telescope featuring bolometer arrays at 150, 220, 340 and 450 GHz [2]. OLIMPO will produce maps of about 100 selected clusters in both hemispheres, significantly improving over the current Planck survey [3], due the longer integration time on clusters (by a factor >100), the larger number of detectors (by a factor ~ 3) and of the finer angular resolution (by a factor ~ 2). The first flight of OLIMPO is planned for 2011, in a circum-polar long-duration flight from Svalbard. In 2008 we have carried out a detailed phase-A study of a small satellite mission using a telescope similar to OLIMPO and a differential Fourier Transform Spectrometer with four with photon-noise limited bolometer arrays, to cover continuously the bands 100-450 GHz and 720-760 GHz, with spectral resolution tunable between 1 and 30 GHz. The instrument, called SAGACE (Spectroscopic Active Galaxies And Clusters Explorer), flies on a Molniya orbit, and can be built and operated within the tight budget of a small mission. This pathfinder mission can provide spectroscopic surveys of the Sunyaev-Zeldovich effects of thousands of galaxy clusters, of the spectral energy distribution of active galactic nuclei, and of the [CII] line of a thousand galaxies in the redshift desert. This would qualify the Italian community in view of the future large space-observatory Millimetron.

Figure 1: The OLIMPO payload, with the shields removed to display the 2.6 m Cassegrain telescope. The primary mirror can tilt, so that the focal plane arrays scan the sky in cross-elevation to make deep maps of the sky around selected targets (mainly clusters of galaxies).

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A14. Cosmic Microwave Background Polarization Measurements

The origin of primordial tiny fluctuations, about a perfectly homogeneous and isotropic universe, lies at the heart of both modern cosmology and high-energy physics. Inflationary theory offers today the most satisfying explanation for the origin of these fluctuations: within $10^{-35}s$ of the Big Bang, during a short phase of superluminal expansion of space, quantum fluctuations are stretched to cosmological scales.

Cosmic Microwave Background (CMB) measurements have shown that the basic predictions of this extraordinary theory are correct: the universe is almost spatially flat, and has a nearly Gaussian, scale-invariant spectrum of primordial adiabatic perturbations.

Another prediction, i.e. the production, during inflation, of a stochastic background of gravitational waves, can also be tested using precision measurements of the rotational component (B-mode) of the linear polarization field of the CMB. In fact these photons are last scattered by free electrons at recombination. In Thomson scattered radiation, linear polarization results if scattered radiation has a quadrupole anisotropy. At recombination, both scalar (density) perturbations and tensor (gravitational waves) perturbations produce quadrupole anisotropy, with different parity properties.

The difficulty of these measurements lies in the tiny amplitude of the polarized component (about 1 ppm of the CMB for the non-rotational component or E-mode, and even 10 ppb or less for the rotational component or B-mode).

Figure 1: Launch of the BOOMERanG-03 balloon-borne polarimeter from the McMurdo base in Antarctica. Our group has produced the telescope and the cryogenic system of the instrument, and coordinated the project, in cooperation with the Caltech group, since the very beginning.

Our group has developed technologies and methods to measure CMB polarization since long time ago, starting in the 70s with the pioneering efforts of Francesco Melchiorri.

We have recently measured the E-modes of CMB polarization with the BOOMERanG-B03 balloon-borne polarimeter, a follow-up of the extremely successful BOOMERanG-B98 balloon mission, which detected for the first time acoustic oscillations in the primeval plasma and measured the density parameter Ω_o to be close to 1.

To improve over that measurement, we have developed cryogenic polarization modulators, based on rotating waveplates [1,2] (see fig.2). These systems have been tested in the field in the framework of the BRAIN-QUBIC experiment, funded by PNRA: this is a bolometric interferometer devoted to sensitive CMB polarization surveys from the French-Italian Concordia Base, in Antarctica (Dome-C) [3].

In addition, we are developing large arrays of KID detectors (see below).

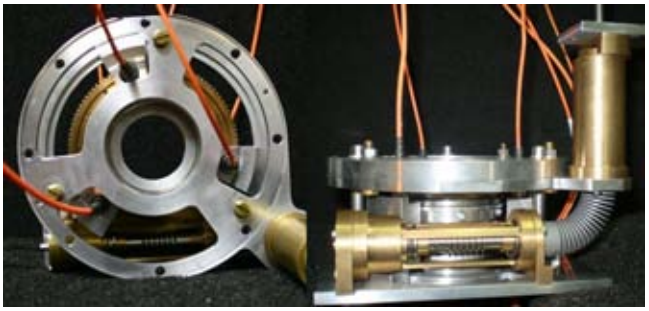

Figure 2: The cryogenic polarization modulator developed in our laboratory is able to rotate a waveplate in the focal plane of a polarimeter, with 0.01^o repeatability, and with negligible heat load on the 2K stage of the cryogenic system.

These developments are absolutely necessary in view of a future space-borne mission devoted to precision measurements of CMB polarization. In this framework our group has been the coordinator of the B-Pol proposal, in the framework of the ESA call Cosmic Vision 2015-2025 (see http://www.b-pol.org , and [4]).

Meanwhile we are now coordinating LSPE (Large Scale Polarization Explorer): a stratospheric balloon mission, funded by the Italian Space Agency. The payload consists of two instruments, covering the frequency bands around 40, 70, 140, 220 GHz, with angular resolution of the order of one degree. Using large throughput bolometers, the high frequency instrument reaches sensitivities of $\sim 35\ \mu K/\sqrt{Hz}$ per detector, with an array of about 100 detectors. The instrument will be flown during the arctic winter in a 15 days flight from Svalbard Islands, where our group has setup the Nobile-Amundsen launch facility in collaboration with ISTAR, ASI and ARR, and launched the first 800000 m^3 balloon on July 1st, 2009 .

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A15. Kinetic Inductance Detectors for Measurements of the Cosmic Microwave Background

Cosmic Microwave Background (CMB) observations are currently limited by background radiation noise, even for space-borne measurements. In this situation, the only way to improve the efficiency of CMB measurements is to boost the mapping speed of the experiment, using *arrays* of microwave detectors.

The Microwave Kinetic Inductance Detectors (MKIDs) are superconducting detectors providing detection of low energy photons (in the meV range) which can break Cooper pairs in a superconducting film, changing its surface impedance, and in particular the kinetic inductance L_k. This can be measured by letting the kinetic inductance be part of a superconducting resonator, which can have very high merit factor Q (up to $\simeq 10^6$), and thus be very sensitive to the variations of its components. Furthermore, the high Q makes MKIDs intrinsically multiplexable in the frequency domain: in a 1 GHz bandwidth it is possible to accommodate $\simeq 10^3 \div 10^4$ detectors, biased at different frequencies, all read simultaneously using a single coax cable, so that they can be easily implemented into large format arrays.

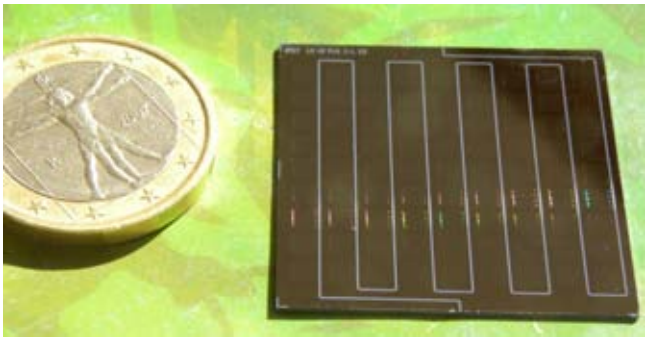

Figure 1: Picture of a 81 pixel array of lumped elements kinetic inductance detectors, built by the RIC-INFN collaboration and optimized for 140 GHz photons.

CMB photons with $\nu > 90$ GHz have enough energy to break Cooper pairs in Aluminum. We have thus focused in the last 4 years on the development of aluminum MKIDs [1]. Our resonators are distributed $\lambda/2$ ones; however their design follows an approach typical of lumped elements resonators (LEKID), varying the geometry of the circuit components in order for the resonator to match the impedance of free space. The resonator thus acts as a free absorber essentially on its whole area, without the need of antennas or quasi-particles traps. This makes the detectors easy to fabricate and to optimize for the specific experimental needs. We have optimized the geometry of the resonators with extensive use of 2-D and 3-D electromagnetic simulations.

Our detector chips have been made at the Bruno Kessler Foundation in Trento, and consist of a $40nm$ Aluminum film sputtered on a $400\mu m$ Silicon substrate.

We have setup a facility for test and optimization of these devices. It is composed of a 0.3K cryogenic system (pulse-tube cooler plus ^{3}He refrigerator), including two low thermal conductivity coaxial cables to bias the array. The facility includes a vector analyzer, frequency synthesizer, microwave sources (Gunn oscillators and antennas) and filter chains.

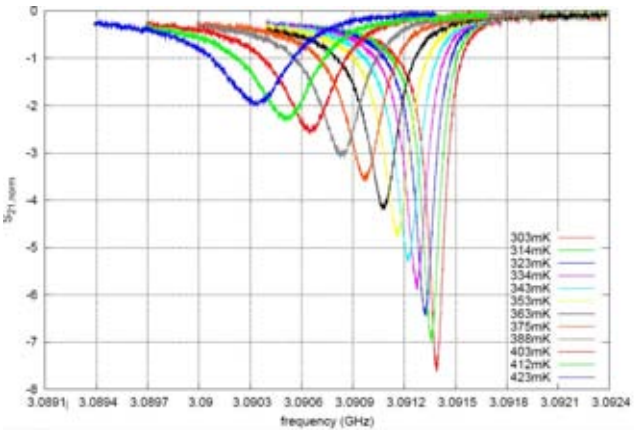

Figure 2: Resonance data (S_{12} in dB) versus temperature for one of our LEKID chips.

A thorough electrical characterization, also useful for calibration, can be achieved by making temperature sweeps and measuring the resulting variation in the amplitude and phase of the transmitted signal. The temperature increase induces an excess of quasiparticles N_{qp}in the material, from which we can estimate the responsivity in terms of deg/N_{qp}. To get optical data, we used a chopper alternating $300K$ and $77K$ blackbody sources, filling the field of view of the detector. A series of mesh-filters is placed on the windows on the cryostat shields at different temperatures. These remove high frequency radiation and define the transmission band, which in our case ranges from 100 to 185 GHz. We have measured typical optical NEPs $\sim 2 \cdot 10^{-16} W/\sqrt{Hz}$ ($1 \div 10Hz$ range). These detectors are already suitable for ground-based astrophysical measurements, where they are limited by the noise of the radiative background. Devices suitable for space-borne missions are currently under development.

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A16. Testing fundamental physics with cosmology

Our research interests are focused on theoretical cosmology, with a particular emphasis on the study of the Cosmic Microwave Background (herafter CMB). The CMB provides indeed an unexcelled probe of the early universe. Its close approximation to a blackbody spectrum constrains the thermal history of the universe. Its isotropy provides a fundamental probe of our standard theories for the origin of large-scale structure back to the effective 'photosphere' of the universe, when the universe was only one-thousandth of its present size. The future of cosmology as a mature and testable science lies in the realm of observations of CMB anisotropy and its polarization. Near future experiments as the Planck satellite (in which we are fully involved) will soon provide new data that will help in solving some key cosmological questions taht we list below.

Constraints on Dark Energy - A major goal of modern cosmology is to investigate the nature of the dark energy component, responsable for the current accelerated expansion of the Universe. Despite the fact that it accounts for about 70% of the total energy density of the universe, dark energy is largely unclustered and is typically measured just by its effect on the evolution of the expansion history (i.e. the Hubble parameter). Since the cosmic expansion depends on other key parameters as curvature or matter density, the nature of dark energy can therefore be revealed only by combination of different observables and/or observations over a wide redshift range.

A key parameter for determining the nature of dark energy is the equation of state. Recently, in collaboration with Asantha Cooray at the University of California Irvine and Daniel Holtz of Los Alamos Labs we performed a complete analysis of current cosmological datasets. The results, presented in [1], shows that current data are compatible with an equation of state as expected from a cosmological constant, showing no deviations from this simple, yet puzzling, model. In a recent paper in collaboration with Prof. George Smoot at the University of Berkeley (Nobel Prize 2006 in Physics) we studied the possibility of constraining dark energy with the CMB anisotropies weak lensing [2].

Cosmological Constraints on Neutrino Physics - Neutrinos play a relevant role in large scale structure formation and leave key signatures in several cosmological datasets. More specifically, neutrinos suppress the growth of fluctuations on scales below the horizon when they become non relativistic. if neutrinos have masses in the (sub)eV range would then produce a significant suppression in the galaxy clustering. It is therefore possible to derive strong, albeit indirect, constraints on the mass of the neutrino particle by analyzing cosmological data.

The nice aspect of this investigation is that neutrino masses in the (sub)eV range of energies can be probed directly in laboratory. A comparison of the cosmological constraints with those that will soon obtained from, for example, single or double beta decay experiments, could either provide a strong confirmation of the theory or reveal the presence of new physics.

In [3] we showed that future cosmological data could reach a sensitivity close to $\sim 0.01eV$, probing the neutrino mass hierarchy.

Cosmological Constraints on Inflation - Inflation has become the dominant paradigm for understanding the initial conditions for structure formation and for CMB anisotropies. In the inflationary picture, primordial density and gravitational-wave fluctuations are created from quantum fluctuations, "redshifted" beyond the horizon during an early period of superluminal expansion of the universe, then "frozen". Perturbations at the surface of last scattering are observable as temperature anisotropies in the CMB.
In the past years we made use of the most recent CMB data to discriminate among the various inflationary models.
More recently, we have investigated the ability of future experiments in constraining single field scenarios in [4].

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Geophysics and the Environment

The figures here included are an iconic display of the fundamental processes we are dealing with. Figure 1 shows the skyline of Santiago of Chile (similar to any other large city in the World) in a given day. The town-enveloping haze is a clear demonstration of air pollution.

Figure 2 is, instead, the time series of the global mean temperature anomaly (i.e., the departure from a given mean) as reported by IPCC (Intergovernmental Panel on Climate Change). A trend toward a warmer climate may be perceived. Despite the different spatial and temporal scales, these two phenomena may be the two sides of the same medal. Are, indeed, both phenomena likely caused by the interactions between Man and the environment? If this is the case, the following questions appear to be unavoidable. Are they an hazard for the Earth system? Can we monitor the system for identifying the phenomena? Can we predict these occurences with an useful skill? The answers are scientifically grounded only if we can rely upon the understanding of the physical causes of the observed phenomena. For instance, the polluting substances of Santiago are certainly due to human activities. The scarce atmospheric dispersion of these substances, however, are equally certainly concurring in shaping the effect. On the other hand the recent increase (or, better said, any change) of the Earth's surface global temperature is surely due to an unbalance of the global Earth's energy budget due to the difference between the incoming and the outgoing energy. Both depend, however, on the detailed atmospheric chemical composition and its physical state. While it is true that Mankind has changed at various degree this composition, it remains uncertain how much this has contributed to the unbalance of the Earth's energy budget.

Figure 1: Santiago of Chile skyline in a typical day.

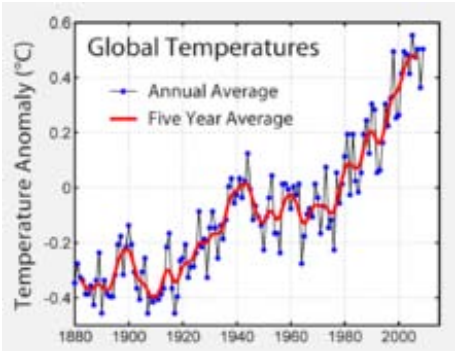

Figure 2: Global temperature anomalies of the Earth's surface.

Therefore, observational and theoretical studies are mandatory for preventing, mitigating and responding to the threats to the environment because of Man activities. The understanding of the Physics controlling the Earth system, in fact, is the unique method for a rational deployment of coutermeasures to avoid these hazards. As today, because the seamless interactions among the physical processes and their dynamics, only partial achievements succeeded in the disentanglement of this complicated net. We know, however, the road along which to move forward; we have the tools for measuring and modeling, we understand the need to be fully integrated in the scientific community.

We are, in fact, establishing methods and instrumentation for: modeling the Earth's system in its full complexity, monitoring from the ground Ultra Violet radiation, total Ozone and Nitrogen dioxide columnar contents, acoustically and optically remote sensing the thermodynamical state of the atmosphere and the presence of aerosol in populated regions and in Polar regions (within the Network for the Detection of Atmospheric Composition Change, NDACC).

Alfonso Sutera

G1. Theory and observations of climate and its changes

The main objective in Climate Dynamics is the understanding of the origin of the atmospheric general circulation, i.e. climatic zones. Aristotele devoted a volume to the description of atmospheric phenomena and climatic zones, while Galileo was the first who studied the origin of trade winds. Today, there are rational bases for an explanation of climatic zones, but the nonlinear character of the involved physical processes makes difficult the development of a comprehensive and established theory. Furthermore, nowadays the problem of future changes of the Earth's climate is attracting an increasing interest. However, the complex nature of the physical problem necessitates a major scientific effort to make possible assessments of likely future climate changes, regardless of whether these may be natural or man-made.

In this framework, the Climate Dynamics group of Roma carried out theoretical studies and numerical simulations to investigate the origin of the observed atmospheric general circulation features in relation to the role of the stratosphere, of the baroclinic eddies through their heat and momentum transports, and of changes in the imposed meridional temperature gradient in the troposphere. The formation and variability of tropospheric double-jet patterns observed in the Southern Hemispheres during the transition seasons (Fig. 1) has been investigated using a quasigeostrophic and a simplified general circulation model (GCM) [1].

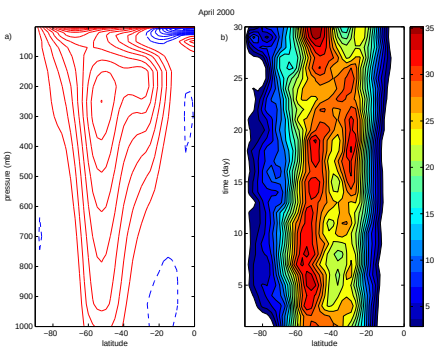

Figure 1: a) Latitude-pressure cross-section of the monthly mean zonal wind for April 2000, and b) latitude-time diagram of the zonal mean zonal wind at 200 mb [1].

The role of eddy heat fluxes in generating the observed double-jet pattern was ascertained using an analytical Eady model with stratospheric easterlies. Sensitivity of the results to the meridional temperature gradient in the troposphere showed a regime change from a prevailing subtropical jet to a midlatitude one. The intermittent nature of the tropospheric double jets has been also studied for the Northern Hemisphere winter and Southern Hemisphere summer [2]. The impact of baroclinic eddies on the mean tropopause height (a key parameter in climate change detection) has been assessed using NCEP reanalysis data for the last 50 years [3]. The analysis suggested the importance of baroclinic adjustment processes for midlatitude tropopause dynamics.

Using both NCEP reanalysis and observations space and time variability of drought and wetness at large-scale has been investigated also in relation to a changing climate. An updated analysis for the European area has been carried out computing the Standardized Precipitation Index (SPI) and applying the Principal Component Analysis (PCA) to the SPI field [4]. Linear and nonlinear trends of drought and wetness were compared for two time sections: 1949–1997 and 1949–2009 (Fig. 2).

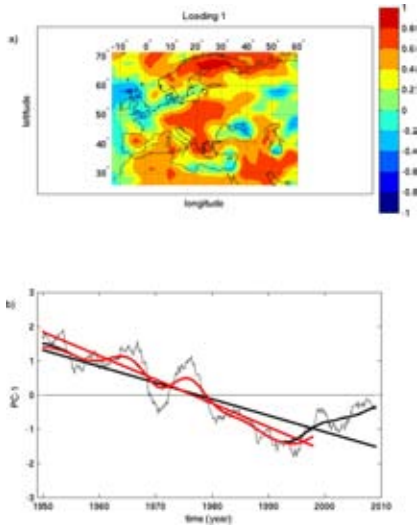

Figure 2: a) First loading of SPI field and b) first principal component score time series with the fitting linear and nonlinear trends for the whole period and the shorter period [4].

The study showed that the SPI time series are not stationary and have multi-year fluctuations. Linear trends highly depend on the time section considered and classical statistics, commonly used in hydrology, should be revised under the hypothesis of a varying climate. Finally, in the last 3 years the group is participating to the development of the ground segment of ASI ROSA satellite mission (launch occurred in September 2009 on board of OCEANSAT-2) that uses the radio occultation technique for sounding the atmosphere (http://www.asi.it/Rosa/RosaIT/ROSA.htm).

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I. Bordi, A. Sutera

http://romatm13.phys.uniroma1.it/

G2. Solar spectrophotometry to measure O_3, NO_2, UV irradiance and polysulphone dosimetry to quantify human UV exposure

The discovery of the Antarctic ozone hole in 1985 and the stratospheric ozone (O_3) downward trend at middle latitudes, observed since the 1970s, have hightened the interest within the scientific community on a possible increase of solar UV irradiance at the Earth' surface. Current evidence suggests that UV exposure is the major causative factor in several short and long term skin and eyes diseases, whereas the only well-established beneficial effect of solar UV radiation is the production of vitamin D3, essential for bones health. Although the stratospheric O_3 downward trend is well documented and its relationship to UV irradiance is established, the understanding of the global UV climate, including variability and trends, is still not easily detectable. The role of cloud cover, aerosol and pollutants which, in turn may have a time behavior, is still under study. Although the availability of UV measurements of high quality from ground-based instruments has increased in the last decades, reliable UV time series are shorter than the total O3 series.

In addition, most of ambient UV data consists of irradiance data while little is still known about UV exposure. The differently oriented body parts receive changing levels of radiation which is itself continuously changing, thus the quantification of human UV exposure is a complex issue being directly linked to the features of ambient UV irradiance under different conditions (i.e. urban, mountain, coastal sites), as well as to individual behavioural and cultural factors. As a result, even in areas of relatively low ambient UV radiation it is possible to experience relatively high personal exposure levels.

The Meteorology research group (GMET) has carried out, since 1992, high quality UV and total ozone and nitrogen dioxide (NO_2) measurements using Brewer spectrophotometry. The Rome UV series is the longest time series in Italy (Fig.1).

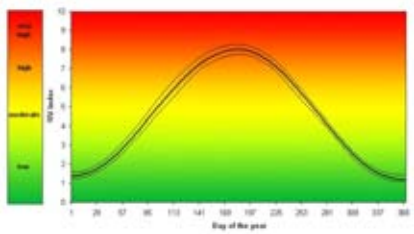

Figure 1: Climatological UV Index (thick line) at Rome (clear sky data 1992–2008) for each day of the year. The index is a measure of the intensity of UV radiation relevant to effects on the human skin. Thin line is 1 standard deviation. The color codes indicate exposure categories.

Erythemal Dose Rates (i.e. the incoming solar radiation on a horizontal surface convolved with the erythema action spectrum) have been also determined by YES UVB-1 broad-band radiometer operational since 2000. In the last few years the GMET group participated to the investigation of solar UV variability in Europe [1]. That study shows that changes in solar zenith angle are the major responsible, on a diurnal and annual basis, and that clouds play a significant role in modifying the UV pattern.

In addition the GMET group contributed to the validation studies of satellite-derived total O_3 and UV data from the Ozone Monitoring Instrument (OMI), investigating the possible sources of uncertainty in an urban site [2]. Besides the remote sensing activity, the GMET group is involved in studies on the quantification of UV exposure using polysulphone (PS) dosimetry (Fig.2).

Figure 2: PS dosimeters on the Brewer spectrophotometer during a calibration campaign (University Campus).

Two field experiments were carried out in mountainous areas on the Alps [3] and on the beach of a popular sea-side location in central Italy [4] involving volunteering skiers and sunbathers respectively. The studies yielded new important data resulting in a better understanding of UV exposure of outdoor occupational and leisure activities of Italians and providing information relevant to the future health policies regarding the potential detrimental effects from overexposure to UV radiation.

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http://www.phys.uniroma1.it/gr/gmet/index.html

G3. Atmospheric acoustical and optical remote sensing at middle latitudes

With climate and atmospheric pollution problems becoming a critical political and decision making issue, there is an increasing need for better monitoring the real changes affecting the atmosphere.

In particular, how much atmospheric aerosol affects the planetary radiative budget is acknowledged as being one of the major uncertainties in assessing the climate scenario.

In the Department of Physics there is a group involved in remote sensing of the atmosphere with acoustical and optical instruments.

The acoustical instrument is an active radar-like device (SOund Detection and Ranging, SODAR) that sends short sound bursts into the atmosphere and detects the echoes produced by the turbulence induced variations in the sound refraction index. The echo Doppler shift is used to compute the wind velocity profile. Sodar measurements can be carried out almost continuously and produce a very good description of the thermodynamical state of the atmospheric boundary layer displaying, for example, the time evolution of the mixing layer height above the instrument, the convective activity and the possible propagation of gravity waves (Figure 1).

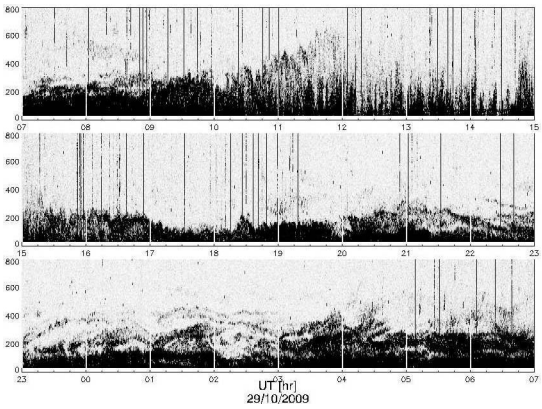

Figure 1: Facsimile output of the University of Rome sodar during a typical clear day. Dark regions show intense small-scale turbulence.

The optical instruments consist of active systems and passive radiometers in different wave bands.

The lidar (LIDAR, LIght Detection And Ranging), a radar-like instrument using a laser as radiation source and an optical telescope as receiver, is able to detect aerosol (by Mie scattering), minor constituents like water vapor (by Raman scattering), and temperature (by Rayleigh scattering) profiles through the troposphere and the stratosphere [1].

Passive radiometers in the visible and UV use the sun direct and/or diffuse radiation to measure the optical depth and other important parameters (Ångstrom coefficient and Single Scattering Albedo) of the atmospheric aerosol; radiometers in the IR use the terrestrial radiation to measure other atmospheric parameters (molecular species, temperature, etc) [2]. A successful experiment to measure aerosol optical depth was also carried out using a digital camera and star light [3].

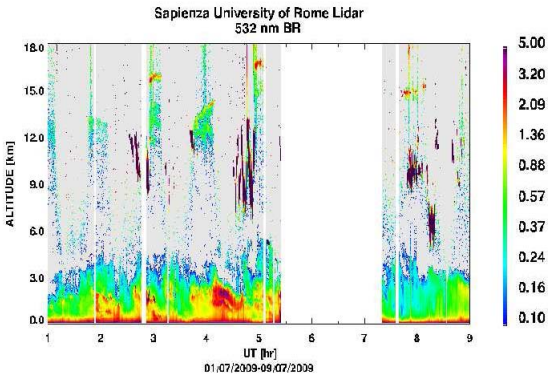

Figure 2: Example of sounding by lidar. Colors represent different backscatter ratio values. Boundary layer pollution is clearly visible while an aerosol layer probably produced by the eruption of a volcano is detected above 15 km.

The Group of Atmospheric Physics runs a lidar system (Stabile Rome Lidar, SRL) that performs systematic measurements from the university campus placed within the highly polluted city of Rome. SRL has been operational in the last years and the measurements, aimed at a wide range of scopes, cover the atmosphere up to the lower stratosphere. At the same time another somehow simpler lidar system (Mobile Rome Lidar, MRL), installed inside a mobile van, can be deployed to remote sites for special campaigns. MRL was recently deployed to the Valle del Biferno (41°56.8′N, 014°60.0E) for studying the atmospheric boundary layer height and performed two intensive campaigns coordinated with other international atmospheric groups during 2009 (Figure 2). In cooperation with ENEA, another lidar system is operated at the Station for Climate Observations located in the island of Lampedusa, a unique site for studying atmospheric aerosol (in particular desert dust) far from highly populated regions [4].

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http://g24ux.phys.uniroma1.it/

G4. Atmospheric optical remote sensing in Polar regions

With climate problems becoming a critical issue, there is an increasing need for better monitoring the real changes affecting the atmosphere. In particular the Polar zones are known to be among the most sensitive to global changes.

The Group of Atmospheric Physics runs a lidar system placed at Thule, Greenland, which is part of the international Network for the Detection of Atmospheric Composition Changes (NDACC) (http://www.ndsc.ncep.noaa.gov/). The network is composed of more than 70 high-quality, remote-sensing research stations for observing and understanding the physical and chemical state of the stratosphere and upper troposphere and for assessing the impact of stratosphere changes on the underlying troposphere and on global climate. The lidar (LIDAR, LIght Detection And Ranging), a radar-like instrument using a laser as radiation source and an optical telescope as receiver, is able to detect aerosol (by Mie scattering), minor constituents like water vapor (by Raman scattering), and temperature (by Rayleigh scattering) profiles from the ground up to the mesosphere (approximately 70 km).

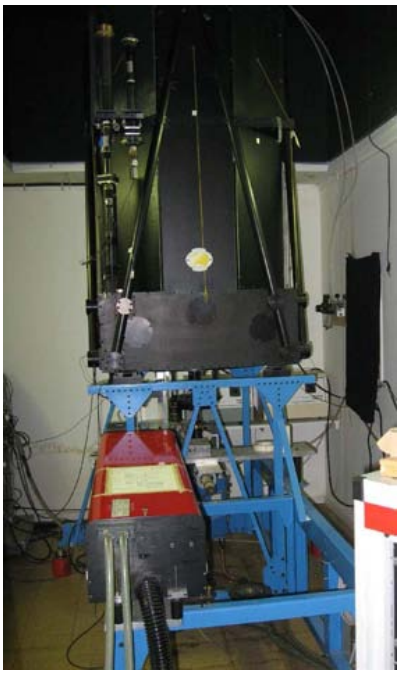

Figure 1: Lidar system at Thule. The black case contains the 800mm telescope pointing vertically; the Nd:YAG laser (red case) is placed in the lower part of the structure.

The lidar system was constructed at the University of Rome and installed in 1990 at Thule within a collaboration with the Danish Meteorological Institute (Figure 1). The system uses several receiving channels, which can be used to obtain vertical profiles of backscatter cross-section and depolarization of atmospheric particulate at two wavelengths (λ = 532nm and λ = 355nm). The depolarization provides information on the physical phase (solid or liquid) of the aerosol. In the absence of aerosol and clouds, the lidar can provide temperature profiles up to the mesosphere by molecular Rayleigh scatter (Figure 2). In the last twenty years the system has had the possibility to gather a wide statistics by operating in very different atmospheric conditions, such as during the stratospheric aerosol enhancement after the Pinatubo eruption in 1991, during conditions of extremely low temperatures and during Sudden Stratospheric Warming conditions. Moreover due to the high variability of the Polar vortex, Thule often passes from within to without the vortex and vice-versa with large temperature changes allowing the monitoring of peculiar polar thermo-dynamical phenomena like the ozone *laminae* [1]. Narrow band interference filters permit the operation also in high background illumination although only for aerosol profiles. Both aerosol and temperature data are continuously downloaded into the data base of NDACC. Presently the Thule station is run in collaboration with ENEA and INGV researchers who provide support and other complementary instrumentation.

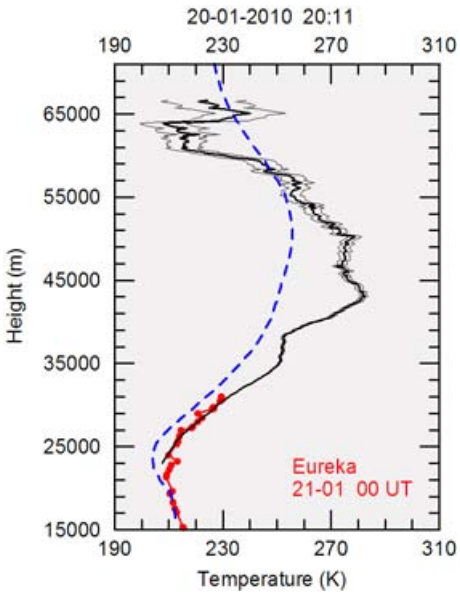

Figure 2: Atmospheric temperature profile at Thule measured by Rayleigh scattering lidar. Blue broken line: climatological temperature profile for January at latitude 75N. Red: radiosounding.

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History of Physics and Physics Education

Researches in history of physics have been pursued for a long time now in our department. Beside the direct interest and active role of a figure like Edoardo Amaldi, it is at least since the late seventies that a group of researchers has been engaged in the field as its main object of study. In the last decade efforts have been concentrated on the development of Italian physics in late 19th and 20th centuries, revisiting in a new light topics that had been already discussed (mainly through the protagonists recollections) and opening new vistas on subjects not yet explored by historians. This is largely due to the circumstance that in past years we have done a great deal of work locating, collecting, preserving and cataloguing a number of relevant sources, mainly personal papers of physicists who played a significant role in Italian science (in Rome and elsewhere); so that at the same time our department can easily claim to be the repository of the largest collection of primary sources for the history of contemporary Italian physics, and a wealth of previously unexplored documentation has been made available to researchers. These sources have been duly used, and a stream of studies has come out as a result, giving a fresh impetus to the reprisal of attention toward the history of modern physics in Italy (and its connections to the international context and to close disciplines).

In the last years these studies have been concentrated along three main directions: the transition from the early study of physics in the Papal university to the institutional development of physics in Rome after 1870, through the work of the first director of the Physics Institute of the new University built soon after the unification of the country, Pietro Blaserna [H1]; the role of Edoardo Amaldi in the years of reconstruction following WWII, both as a scientific leader and institutional organizer, and as an active researcher in cosmic ray and particle physics [H1]; and the early times of space science in Italy, from the late fifties to the early seventies, where again institutional themes are mixed with disciplinary developments, namely as a follow-up of the long standing Italian tradition in cosmic ray physics [H2]. The last line of research was born out of a wider international project, sponsored by ESA (European Space Agency), aimed at a full study of the history of the European effort in space science, in which De Maria and collaborators have been involved. Battimelli and Ianniello are presently working at bridging the gaps and linking their respective works and time periods of interest to produce a full history of the development of the physics school in Rome from the beginnings to the 1960s.

Research in physics education [H3] has for historical reasons a strong tie with studies in the history of the discipline, since the two fields of research have always been joined in the same disciplinary group for academic purposes. There is, however, more than just a formal reason for their proximity: most of the problems discussed at the educational level have their roots in foundational issues that can in turn be properly treated only if an historical perspective on the subject is considered. Such is certainly the case for the research topic in which Tarsitani is engaged: his present involvement in the pedagogical and conceptual problems raised by the effective teaching of introductory quantum physics stems naturally from his previous interest in the early history of quantum mechanics, and in the foundational problems connected to that development. This research is conducted in close collaboration with other groups both in Italy (Bologna and Udine) and abroad. It should be noted that, in spite of the large literature exisiting on the teaching of classical physics and relativity, very scarce attention has been paid in the field of physics education to the pedagogical problems poised by quantum mechanics; this line of research thus looks so much more promising as it is a field relatively untouched up to very recent times.

Giovanni Battimelli

H1. The early history of experimental physics at la Sapienza (1746-1930) and the development of physics in Italy after WWII

While the history of physics teaching at La Sapienza in post-unitary Italy is relatively known and there are several contributions on this subject, we have very scarce and fragmentary historical data related to the Papal States. Years ago I began to reconstruct this history from the concrete evidence preserved in the Museum of the Department of Physics (i. e. the oldest instruments kept in the Museum), from the small Archive of the Museum and from the documents in the Amaldi papers. A charming but very incomplete story came out which claimed closer attention, also based on input from scholars trained in the humanities who in the meantime had conducted a thorough research about the teaching of natural philosophy and mixed mathematics at the Sapienza; these courses are indeed the cultural roots of the course of physics in the modern sense.

It thus begun a long and patient research, particularly in the Archivio di Stato in Roma, which houses a rich collection of documents on the history of the Roman University, and this research led to clarify many unknown aspects. The questions to be answered concern the long process of the detachment of physics from the natural philosophy, the introduction of the first experimental practices in teaching, the establishment of the first chair of experimental physics at La Sapienza in 1746, and the first teachers (F. Jacquier, G.M. Fonda, B. Gandolfi, S. Barlocci) up to Paolo Volpicelli, which represents the transitional figure from the Papal Government to the new unified Italy. All along the research the comparison is considered with the Collegio Romano and the Accademia dei Lincei, trying to reconstruct the process of dissemination of physics. In this case the keystone for the understanding of the evolution of physics in Rome, no longer seen as the esoteric science of some isolated scholar but as a productive part of society, is the contribution of F. Scarpellini. Thanks to his activity physics was seen at last, from the time of the Enlightenment onwards, as an applied science bearer of progress. Scarpellini is the most important popularizer, between the eighteenth and the nineteenth century, of the experimental practice in physics, astronomy and mathematics, both for civilian and military purposes.

Along with the first chair of experimental physics at the Sapienza was created in Rome the new profession of the macchinista. In this connection the research has better outlined the hitherto almost unknown story of an important family of scientific instrument makers, the Luswergh, which accompanied the teaching of Physics at the Sapienza until the middle of the nineteenth century. From 1872 on, the management of the Istituto Fisico by Blaserna and later on by Corbino, as is well known, sets down the conditions for the rise of the Roman school of physics. Referring to this period a few minor histories have been investigated, bearing some relevance to the history of the emerging electrotechnics, of paleomagnetism and of the early studies of cosmic rays.

The prosecution of the historical investigation on Italian physics in the period following the second world War is a line of research started several years ago, which has already led to several results. Focusing on Edoardo Amaldi as the key figure (a choice dictated, beside his eminent role in the organization of physics in Italy, by the availability of the huge documentary source of his personal archive, deposited at the Physics department in Rome), the research aims at a further refinement of the overall picture of the development of physics in postwar Italy. An intrinsic part of the research work is the localization, collection and proper arrangement of archival sources. Thanks to the work done in past years in this respect, already now the Physics department in Rome can easily claim to host the largest repository of personal papers of 20th century Italian physicists. New sources of the same kind are in the process of being acquired and catalogued (papers of G. Gentile jr., G. Careri, C. Salvetti, V. Somenzi). The exploitation of these sources will allow to throw further light on key historical issues, such as the development of the Italian nuclear project in the fifties and sixties, and its relations with the research in fundamental nuclear physics, alongside with the institutional aspects of the question, which have already been the subject of an early investigation in the volume on the history of INFN published in 2001. A consistent fraction of the results of these enquiries will find its place as part of the reconstruction of the historical development of physics in Rome, which is the subject of a book to be completed shortly.

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G. Battimelli, M.G. Ianniello

H2. Italy in Space

During the last years I committed myself, together with my colleague Lucia Orlando, to develop a wide-ranging research programme on early Italian space activities, which led to the publication of a book, Italy in Space1, in December 2008. This research programme has been sponsored by the European Space Agency (ESA) and by the Agenzia Spaziale Italiana (ASI), and our book Italy in Space (with other three volumes on early space activities in Great Britain, Germany and Belgium) has been awarded with the Alexandre Koyr 2009 medal, considered the highest international distinction in history of science. The period covered in our book, ranging from 1957 to 1975, represents the pioneering phase of both Italys national space activities and European collaboration in the European Launcher Development Organization (ELDO) and The European Space Research Organization (ESRO).

Two professors of the University of Rome La Sapienza, the physicist Edoardo Amaldi and the aerospace engineer Luigi Broglio, were the main protagonists of the lift-off of Italys space activities. In 1959 Amaldi wrote a famous paper, Space Research in Europe, which had a huge impact in Europe and paved the way to the foundation of ESRO in 1962.

On Amaldis initiative, in 1959 the Commissione per le Ricerche Spaziali (CRS), chaired by Broglio, was set up within the Consiglio Nazionale delle Ricerche. Thanks to Broglio, who was also Colonel in the Italian Air Force, a number of sounding rockets with scientific payloads were launched in 1959, with the cooperation of the Aeronautica Militare Italiana, from the military base of Salto di Quirra, in Sardinia. The active collaboration between scientists and the military brought to the approval, in 1961, of the San Marco Project, a bilateral agreement between Italy and the United States, to build a sea-borne launching facility, to be installed near the Equator, facing the coast of Kenia, and to launch Italian satellites by means of a US Scout launcher. In 1964 the first Italian satellite, San Marco 1, was successfully launched by an all-Italian team. Thus Italy became the third country, after USSR and the US, to put a national satellite into orbit. In 1967, the successful launch of San Marco II satellite definitively qualified the Italian equatorial range for the launching of small satellites.

In the book we also analysed a an anomaly in the early development of Italian space activities: contrary to other European countries, such as France and Great Britain, where national space activitie and European collaboration reinforced each other, Broglios space programme soon vegan to conflict with Italys participation in ESRO and ELDO. Starting from these premises, our book sought to clarify the scientific, institutional and political reasons which prevented Italy from fully exploiting the San Marco miracle. In the late 60s the San Marco project entered its decline phase: Broglio did not succeed in his attempt to transform his Equatorial range into a European launch base for ESRO scientific satellites; consequently, between 1970 and 1975, only four American satellites and one British satellite were launched from the San Marco base. Moreover, Broglio was unable to break his gradual isolation at home, because of the lack of any real opening up to national industries in the concrete accomplishment of his space programme. The fate of the San Marco In the mid 1960s Italian industry had been charged with building the Test Satellite and the apogee motor for ELDO powerful launcher ELDO-PAS, later called Europa II. When the ELDO project was eventually cancelled, the Italian government, , in order to salvage the work already done by Italian industry decided to start a national programme for the realization of a telecommunication satellite called Sirio.This programme became the main focus of all Italian space efforts during the 1970s, both in terms of funding and the development of national aerospace industry. The principal aim of Sirio was to explore the possibilit of commercially exploiting a new frequency band, between 12 and 18 GHz. After a number of delays, Sirio was finally launched in August 1977, a few months bieore the launch by ESA of the first European telecommunication satellite. The successful launch of Sirio marked the first international success in the space sector for Italian firms such as Selenia, Aeritalia and Galileo. However, as in the case of the San Marco project, Italy did not fully exploit the success of the Sirio "miracle: it became a sort of missed opportunity for the development of an Italian R&D capability in the space telecommunicatio sector.

The San Marco and Siriostories highlight some weak features of ealry Italian space activities: namely, the somewhat artisanal approach of the San Marco project and the difficulties of national industries in exploiting the market potential f the space sector. Moreover, the lack of interest in space activitie on the part of Italian political leaders, and consequently the absence of a coherent national space policy prevented Italy from exploiting those activities as a leverfor industrial innovation and economic development for at least two decades.

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Authors

M. De Maria

H3. Physics education: new perspectives on the problem of the transition from classical to quantum physics

Its well known that the problem of teaching Quantum Physics at school, is of outstanding priority in the international research on Physics Education. Yet, the various groups of research dont share the same opinions. The debate is still open. The group of Rome is improving a path-proposal starting from substantial changes in the teaching of Classical Physics. Two aspects of the entire question are being stressed.

1. The links and the gaps between the Classical and the Quantum views of the physical world;
2. The formal structure of Quantum Physics;
3. The conceptual interpretation of the formalism.

As regards the first issue, we think that a meaningful teaching of Quantum Physics cannot be actuated if the main lines of the conceptual changes in the transition from the Classical to Quantum views would not explicitly treated. From this point of view, the research on teaching must be integrated with historical and epistemological knowledge. Our work is oriented towards the construction of a clear insight of the deep conceptual problems that emerge in the period 1890-1925, also by individuating some important experimental situations in which these problems appear in a form easy to understand.

As regards the second issue, its well known that the Quantum formalism has a conceptual meaning in itself. Our research aims to find strategies for a simple approach to Quantum formalism, which can be used also at school level. The research is oriented to create a logical-mathematical structure, based on a simplified form of the notion of Hilbert space. We develop the fact that Quantum Physics, at an elementary level, is based on a linear theory, which in turn finds its natural representation by means of vector spaces. The mayor obstacle to this development seems to be the use of complex numbers. We have developed a formal structure based on classical linear systems, that can be described in terms of the well-known Diracs notations. Therefore we are looking for a better integration between the teaching of Physics and the teaching on Mathematics.

As regards the third issue the research is oriented to the examination on the various misconceptions that infest many textbook introductions to Quantum Physics and are deeply impressed in the understanding of the subject of the majority of students. Obviouly this kind of research is based on an accurate analysis of the debates that followed the formulation of the new theoretical structure. A new line of research regards the impact of Quantum Field Theory on the conceptual issues raised by the above traditional debates. This last research is carried on in collaboration with the Group of the Department of Physics of the University of Bologna.

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Authors

C. Tarsitani

Laboratories and Facilities of the Department of Physics

Laboratories

L1. Quantum Optics Lab
L2. Cell Biophysics Lab
L3. Bio Macromol Lab
L4. LOTUS (LOw Temperature Ultarviolet photoelectron Spectroscopy) Laboratory
L5. Infrared Spectroscopy Lab
L6. Laboratory on "Nanomaterials for alternative energies: solid-state hydrogen storage"
L7. Nuclear Magnetic Resonance (NMR) Laboratory
L8. DECA NMR Laboratory
L9. Semiconductors and Optical Properties of Solids Lab
L10. Holographic Micromanipulation and Microscopy Lab
L11. Photon Correlation Lab
L12. High Pressure Spectroscopy Lab
L13. Inhomogenoeus and Correlated Functional Materials and Quantum Phenomena in Condensed Matter Lab
L14. Laboratory for Ultrafast Spectroscopy
L15. Macroscopic Quantum Coherence Lab
L16. Electronics and Silicon detectors Lab
L17. SCILab
L18. The Gravitational Wave laboratory VIRGO
L19. Laboratory of the KLOE-ROMA group
L20. The ATLAS-KLOE-DREAM laboratory
L21. Nuclear Emulsion Scanning Lab
L22. High Energy Astrophysical Neutrino Detection Laboratory
L23. Experimental Cosmology Lab
L24. Millimeter and Infrared Testagrigia Observatory
L25. Solar Radiometry Observatory
L26. The Vallinfreda astronomical Station
L27. Atmospheric Physics Lab

Facilities

F1. Departmental Library
F2. APE Laboratory
F3. The Tier2 Computing Centre for LHC
F4. The Electronics Lab LABE

L1. Quantum Optics Lab

The Quantum Optics laboratory has been engaged in experimental and theoretical researches on quantum information since almost 15 years. The group has contributed for many years to the quantum optics field with relevant experiments in ultrafast mode-locked and free-electron laser physics, QED microcavity physics, basic quantum interferometry and non-linear solid-state and molecular spectroscopy. This advanced know-how on linear and non-linear optics has been recently applied to several quantum information tasks: quantum teleportation, since the first realization in Rome to the implementation of active teleportation protocol and of teleportation of a quantum gate, optimal quantum cloning and U-Not gate, quantum process and state tomography, generation and detection of entanglement, amplification and purification of single qubits, frequency hopping of a single photon, generation of 2-photon hyper-entangled and cluster states, realization of polarization qutrits, implementation of the minimal disturbing measurement, manipulation of orbital angular momentum, generation of multiphoton entangled states.

Figure 1: Schematic representation of the multiqubit source based on multipath entanglement [2].

The laboratory in Roma is equipped with four optical experiments running independently. A first experimental activity is aimed at the generation of entangled states with large number of photons. The main optical source is a femtosecond laser (MIRA from Coherent) pumped by a 10W duplicated Nd:YAG laser (VERDI) further amplified by a regenerative amplifier (REGA from Coherent) pumped by a 18W Verdi.

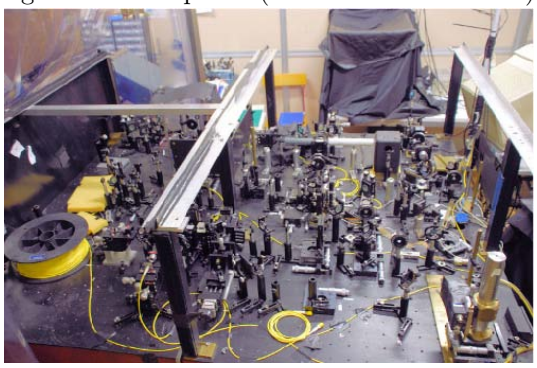


Figure 2: Schematic representation of the multiqubit source based on multipath entanglement [2].

The output field achieves an average power equal to 1.5 W, the repetition rate is 250 kHz and the pulse duration is equal to 250 fs. The second research activity is devoted to the generation and manipulation of multi qubit hyper-cluster entangled states and adopts a CW Argon laser and a femtosecond laser (MIRA from coherent pumped by a 10W Verdi).

A parallel third topic addresses the manipulation of orbital angular momentum, the main source is the second harmonic of a femtosecond laser (MIRA from Coherent pumped by a 10W Verdi). The achieved power is equal to 750 mW, the repetition rate is 76 MHz and the pulse duration is equal to about 180 fs.

The last research line concerns the generation of multipath and time-energy entangled state and integrated quantum circuits. It is based on a duplicated 2W Verdi laser (MBD266 from Coherent) delivering a single mode beam at 266 nm with power of 200 mW. A CW diode laser emitting 50 mW at 403 nm completes the available sources. All the experimental apparatus are based on nonlinear crystals, single-photon detectors, bulk and fiber optics elements, polarization manipulation, photomultipliers.

http://quantumoptics.phys.uniroma1.it/
Related research activities: C43, C45.

L2. Cell Biophysics Lab

The Cell Biophysics Laboratory is engaged in the characterization of the electrical and structural properties of biological objects of different complexity and different structural organization (nanoparticles, liposomes, micelles, biological cells, biological tissues), by means of different experimental techniques. The laboratory is equipped with a broad-band Frequency Domain Dielectric Spectroscopy set up (Hewlett-Packard Impedance Analyzers), covering the frequency range from 40 Hz to 2 GHz, which allows measurements of the permittivity $\epsilon^{'}(\omega)$ and dielectric loss $\epsilon^{"}(\omega)$ of biological suspensions in the temperature interval from -10 to 60 °C.

The technique spans over a wide range of characteristic times, providing information on different molecular mechanisms (Fig. 1).The size and size distribution of the biological objects at a nano- and mesoscopic scale is carried out by means of a Dynamic Light Scattering apparatus (Brookhaven FOQELS), measuring the decay of the intensity-intensity correlation functions in a temporal interval from 0.1 μs to some tens of minutes. The technique allows to follow the evolution of the characteristic size during the aggregation processes from simpler to more complex structures. The surface electrical charge distribution is investigated by means of the laser Doppler electrophoresis technique using a MALVER Zetamaster apparatus equipped with a 5 mW He-Ne laser.In biological samples, electrophoresis is ultimately caused by the presence of a charged interface between the particle surface and the surrounding fluid, which imparts the motion of dispersed particles relative to a fluid. In order to prepare a monolayer of amphiphilic molecules on the surface of a liquid, the Laboratory is equipped with a Langmuir-Blodgett [LB] trough, offering the possibilityto compress or expand these molecules on the surface, thereby modifying the molecular density. The monolayers effect on the surface pressure of the liquid is measured through use of a Wilhelmy plate. A LB film can then be transferred to a solid substrate by dipping the substrate through the monolayer.In addition, films can be made of biological materials to improve cell adhesion or study the properties of biofilms.

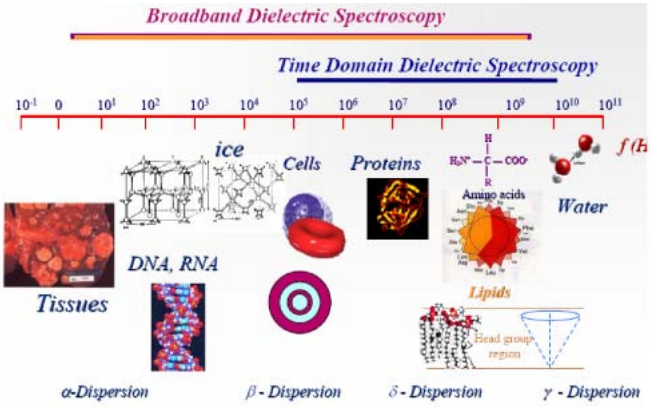


Figure 1: Broad-band dielectric spectroscopy opens unexpected potentiality in the investigation of biological colloidal systems.

Related research activities: C19.

L3. Bio Macromol Lab

The laboratory is used from about 30 years for researches devoted to characterize the physical properties of biopolymers and to study processes of interactions with amphifile molecules, in condition of self-aggregation. Other research involves studies on alterations in plasma membrane of cells, subjected to biochemical or physical stress.
The main techniques available in the Lab are as follows:
1)Dielectric set-up consisting in two HP Impedance Analyzers mod. 4194A and 4291A, that cover the frequency ranges 10 kHz - 100 MHz and 1MHz - 1.8 GHz respectively, equipped with thermostated dielectric cells.
2)Electrorotation set-up for measurements of specific capacitance and conductance of plasma membrane of cells.
3)Malvern Zeta Size Nano for measurements of Zeta Potential and Dynamic Light Scattering.
4)Luminescence Spectrometer Perkin Elmer LS50

Related research activities: C25.

L4. LOTUS (LOw Temperature Ultraviolet photoelectron Spectroscopy) Laboratory

The LOTUS laboratory has been established at the Department of Physics from year 2000, and it is mainly devoted in experimental researches on surfaces and nano-structures. The group has contributed for many years to the field with relevant experiments on the electronic state distribution of low-dimensional systems by state-of-the-art High-Resolution Angular-Resolved Ultraviolet Photoelectron Spectroscopy (HR-ARUPS). The research is mainly devoted to the study of the electronic spectral density of states of low dimensional systems and nanostructures, with particular attention to the low-binding energy region, close to the Fermi level. We can determine the most relevant band parameters of the nanostructures grown in-situ (band dispersion, effective mass, metal-insulator transition...). The ultra-high-vacuum (UHV) apparatus host also Low-Energy Electron-Diffraction (LEED), Thermal Desorption Spectrsocopy (TDS), Auger Electron Spectroscopy (AES) to study the long-range ordering, the energetics, the growth morphology of in-situ grown organic and inorganic architectures with specific functionalities. Recently, Organic-Molecular Beam Epitaxy (O-MBE) growth of hybid organic-inorganic ordered systems at the nano-scale has been performed exploiting self-assembling and template-driven aggregation. Experiments are also carried out by major synchrotron radiation sources, mainly for absorption (NEXAFS), photoemission (VUV-XPS), and diffraction (GIXD) characterization of the relevant physical systems preliminary studied in the laboratory. The main apparatus in the LOTUS laboratory (Fig. 1) contains the HR-ARUPS system, equipped with a Scienta SES-200 electron analyzer, containing a multi-channelplate (MCD) electron detector, with 0.1° angular and 4 meV energy resolution. In Fig. 2-a we show the system performances as determined on the $5p_{3/2}$-Xe core-level in the gas-phase

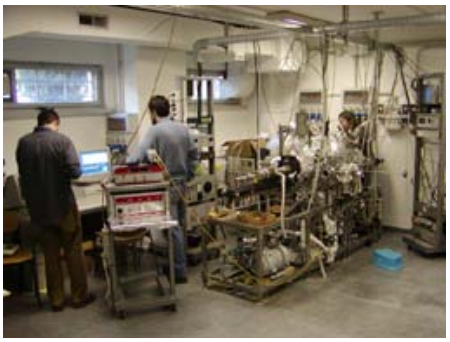
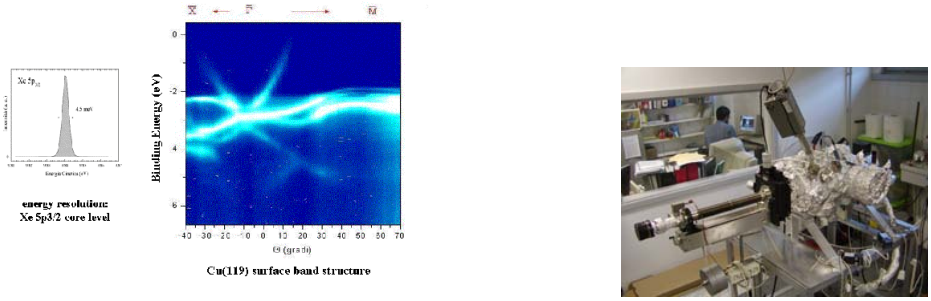


Figure 1: HR-ARUPS system, with two UHV chambers (preparation chamber, main chamber), also equipped with LEED, Auger, O-MBE, ion-gun and ancillary facility for surface preparation.



(a) (b)

Figure 2: (a) Measurements in the HR-ARUPS apparatus: (left) Xe-$5p_{3/2}$ core-level; (right) Cu(119) surface electronic band structure. (b) LEED, Auger, XPS system in an UHV chamber also containing TDS, O-MBE sources, and ancillary facility for surface preparation.

(energy resolution) and on the surface band structure of the vicinal crystalline surface Cu(119) (angular resolution). The photoemission system is equipped with a high-intensity He discharge source, emitting He_I and He_{II} main lines, with 21.218 and 40.814 eV photon energies, respectively. Samples can be inserted by an UHV-transfer chamber; the sample manipulator can be cooled to liquid He temperature and heated to several hundreds of °C. The UHV chamber hosts all ancillary facility for sample and surface preparation and cleaning (ion-gun, cleaver, etc.), and is also equipped with a LEED-AES system. In the UHV system there are O-MBE cells for clean, controlled and slow-rate (<0.1 Å/min) organic molecule deposition, and also several inorganic evaporation(sublimation) sources, and an all-UHV transfer chamber allowing deposition from liquid phase in controlled atmosphere. In the LOTUS laboratory, a second UHV chamber is present (Fig. 2-b), equipped with high-quality LEED apparatus, AES, and thermal desorption spectroscopy (TDS). An XPS system with un-monochromatized Al source is being mounted. It is also equipped with the same facility for sample cleaning, and series of O-MBE deposition sources of the first chamber. This second system is devoted to the study of growth morphology, surface symmetry, and energetics of the adsorbed species on surfaces. The presence of the same deposition facilities with the same geometry of the HR-ARUPS systrem, allows to easily fix the growth protocols, and to carefully characterise the recontruction symmetry, growth morphology, energetics and adsorption energy.

http://server2.phys.uniroma1.it/gr/lotus/Laboratory.htm
Related research activities: C33, C34.

L5. Infrared Spectroscopy Lab

The Infrared Spectroscopy (IRS) laboratory is working in the Sapienza Dept. of Physics since the end of the 1960's, when the first Fourier-transform Michelson interferometers appeared on the market. It was established by late Professor Salvatore Cunsolo, who had collaborated with Professor H. P. Gush to the development of one of such devices, during a sabbatical year at the University of British Columbia (Canada). That instrument after became the prototype of a performant series of interferometers produced by Bomem, a spin-off of British Columbia.

Figure 1: The Bruker 66V interferometer equipped with a liquid helium cryostat and with an infrared microscope.

Today, the IRS laboratory (permanent staff P. Calvani, S. Lupi, P. Maselli and A. Nucara) is focused on the spectroscopy of solids characterized by strong electron-electron correlation and/or electron-phonon interaction. Among them, there are novel superconductors like the high-T_c cuprates , the FeAs compounds, and metallic diamond. Also the colossal-resistance manganites, the vanadium oxides, the charge-ordered systems and the multiferroics have been widely investigated in the last years in a wide range of temperature and pressures. In those systems infrared spectroscopy, with its high spectral resolution and low perturbation, allows one to identify the low-energy excitations which are relevant to the electrodynamics of the solid, and to its phase transitions. Finally, an increasing activity is in progress in the domain of biophyisics. Immobilized enzymes (Lipase) on nanostructured polymers are being studied by Infrared spectroscopy, to understand the enhancement of their activity in such conditions. Another investigation concerns the study of proteins presnt in food, to find imprints of their different bio-availability by the human metabolism is related to easily identifiable spectral features.

The IRS Lab also routinely performs tests on infrared windows, filters, sources and detectors, as well as simulations and calculations, aimed at the development of new infrared sources, especially those synchrotron-based and the Fee-Electron Lasers (FEL). Presently the IRS group, in addition to the laboratory at the Dept. of Physics in Rome, manages an experimental station on the infrared beamline SISSI at ELETTRA (Trieste) and another one on the beamline SINBAD at DAFNE (Frascati). Moreover, the group collaborates to the exploitation of Terahertz coherent radiation from the FEL SPARC (Frascati). In this context, new activities started recently at the IRS Lab, concerning the applications of the metamaterials and of nanostructured materials - like Quantum Wells - to THz spectroscopy.

The IRS laboratory in Rome is instead devoted to spectroscopy with conventional black-body sources. Therein, we can perform virtually any kind of infrared/visible spectrum (transmittance, reflectance, diffuse reflectance, Attenuated Total Reflectance, Infrared Microspectroscopy) from the sub-Terahertz range to the Ultraviolet. To this aim, one can use two Michelson interferometers (a Bomem DA3 and a Bruker 66 V, shown in Fig. 1) coupled to nitrogen- and helium-cooled detectors, or a monochromator coupled to a CCD camera. These instruments are equipped with cryogenics for taking spectra down to 10 K, and with an optical oven which can heat the samples up to 550 K. The laboratory is also equipped with diamond anvil cells for collecting infrared spectra up to 20 GPa (200 Kbar) and with the necessary high-pressure technology. Finally, a small chemical laboratory is present for the treatment of solid samples and powders. It includes a system for polishing and washing the crystals, an oven, a diamond-wire saw for cutting the crystals, microscopes and other minor instrumentation.

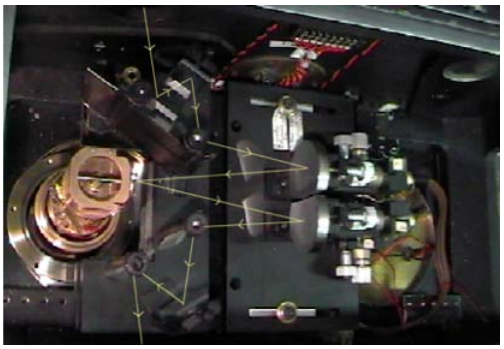


Figure 2: The remotely controlled set-up for high-precision reflectance measurements on small single crystals, mounted in the sample chamber of the Bomem DA3 interferometer.

http://www.phys.uniroma1.it/gr/irs/
Related research activities: C6, C46.

L6. Laboratory on "Nanomaterials for alternative energies: solid-state hydrogen storage"

The Lab has been active since 1968 in applying the anelastic spectroscopy, the acoustic emission, and the thermal analysis to study various solid systems, from the investigation of the motion of hydrogen in metals and of its quantum behaviour down to the liquid helium temperatures, to the high TC superconductors and manganites, to the lithium-ion batteries and the polymer electrolytes fuel cells. Over the last 8 years the activity has been focused on the novel complex hydrides for the solid-state hydrogen storage.

A large variety of experimental techniques is available. The Lab is equipped with four main experimental stations which can work independently. The anelastic spectroscopy facility allows measurements of elastic energy loss and dynamic modulus in high vacuum in the temperature range between 1.3 and 900 K. Anelastic spectroscopy is a well established experimental technique to quantitatively determine the dynamics and the diffusion parameters of mobile species in solids and the occurrence of phase transitions, including chemical reactions. An external stress, applied to a sample through its vibration perturbs the energy levels of atoms of fractions of meV and induces redistribution of mobile species in the material (defects or lattice atoms) among the perturbed levels. The motion parameters are measured while, by thermal activation, the new equilibrium is being attained.

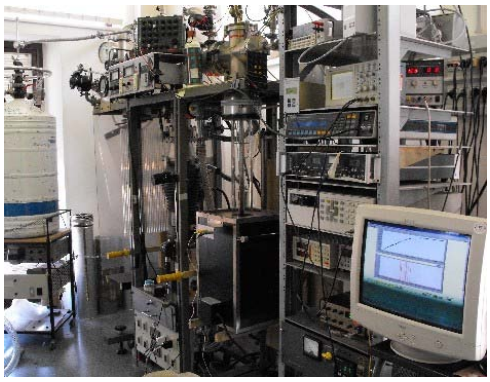


Figure 1: The experimental apparatus for anelastic spectroscopy measurements.

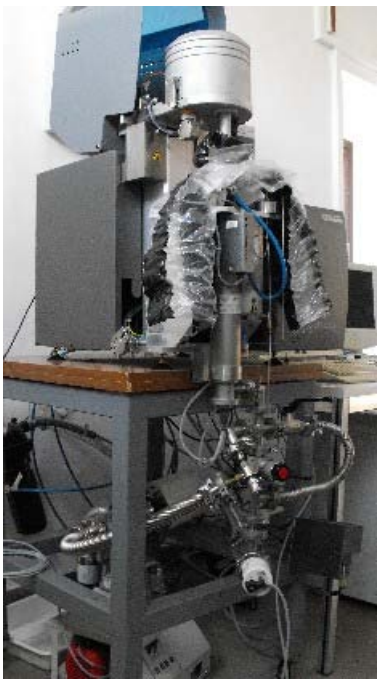


Figure 2: The system for concomitant thermogravimetry, differential scanning calorimetry and mass spectrometry.

The analysis of the data provides the parameters of the local or long range diffusion processes, like the relaxation rates and their pre-exponential factors, the activation energies for classical processes, or the splitting of the energy levels and the power laws of the relaxation rates for quantum tunnelling phenomena. Moreover, anelastic spectroscopy can sensitively detect structural and magnetic phase transitions through the dynamic elastic modulus, which is extremely sensitive to the formation of new phases or of atom complexes in materials. It has been shown that the dynamic Young modulus allows the monitoring of the evolution of the decomposition reactions in complex hydrides as a function of temperature and time. Anelastic relaxation gives essential information often not obtainable by other techniques and is complementary to neutron scattering, NMR, and NQR.

The group uses a flexible system for concomitant measurements of thermogravimetry and differential scanning calorimetry. This apparatus can operate both in inert gas atmospheres and in high vacuum, and the exploitable temperature range is between 300 and 1300 K. The system is complemented by a quadrupole mass spectrometer which allows the identification of the released gaseous species.

The thermal analysis Section is equipped with a commercial Dynamic Mechanical Analyzer, which is able to measure, also in liquid corrosive environments, but at a lower performance level, the elastic moduli and the elastic energy dissipation of solid samples in a wide temperature range, between 78 and 900 K. This system is particularly well suited for the study of polymers. By the home-made Sieverts apparatus, it is possible to determine the thermodynamic p-c-T curves of the various solid-hydrogen systems, through the volumetric measurement of absorbed/desorbed hydrogen. This system is operative in a wide range of temperatures (80-600 K) and pressures (0-200 bar).

Related research activities: C39.

L7. Nuclear Magnetic Resonance (NMR) Laboratory

Figure 1: 9.4T Bruker Avance

Figure 2: 7T Bruker Biospec

The NMR Laboratory in Physics Department of Sapienza University of Rome, has been engaged in developing researches on Nuclear Magnetic Resonance since almost 25 years. Research interests include theoretical speculation and experimental investigation in the field of Nuclear Magnetic Resonance. All the activities have been characterized by a specific orientation to applicative fields with a potentially high clinical impact. Some research lines are currently at the stage of basic research, some others are in a transitional stage between basic research and clinical application. The main research tools are NMR related techniques, including both Spectroscopy and Imaging. Investigation targets are: materials and biomaterials (confined water, gels, macromolecules) and living systems (cells, ex-vivo tissues, in-vivo animal models, humans).

In the laboratory are located : a 9.4T Bruker Avance MR spectrometer for in vitro experiments (equipped with a microimaging, multinuclear probe and high performance gradients) and a 7T Bruker Biospec MR Tomography (equipped with several coils to perform multinuclear experiments in vitro and in animal models). For in vivo diagnostic applications in humans, the NMR laboratory has strict interactions with the Neuroimaging Laboratory of Santa Lucia Foundation (equipped with a 3T head-dedicated Scanner) and with the department of Radiology of Tor Vergata University (equipped with a 3T and 1.5T whole body scanners. Specific research activities are: -MR investigations of skeletal system (spongy bone, cartilage, muscle) using multi-parametric approach: 1) conventional relaxation parameters and diffusion coefficient correlated to spectroscopic quantitative analysis (translational clinical research) 2) Non convention NMR technique, such as DTI or 23Na-triple-quantum (research activity) - MR investigations at high magnetic field (7T) of glioma animal model to optimize BNCT (Boron Neutron Capture Therapy) using: 1) Conventional and non conventional Diffusion Tensor Imaging (DTI) techniques 2) Imaging and Spectroscopic techniques performed on 19F nuclei to detect spatial distribution of fluorinated BNCT-carriers and to study their pharmacokinetics -Study and Development of new MR Multi Quantum coherences and anomalous diffusion approaches for 1) Materials application and investigation 2) Tissue investigation 3) Neuroradiological applications.

http://fslsrv3/default.aspx
Related research activities: C40, C41.

L8. DECA NMR Laboratory

The DECA NMR Laboratory is active from many years in different scientific areas regarding Magnetic Resonance Imaging, solid state NMR, diagnostic for Cultural Heritage, biomedicine, etc. The laboratory's activities have spread from the realization of methods for NMR imaging of low sensitivity nuclei and solid-state spin systems, to the development of original approaches for *in situ* non-invasive study of Cultural Heritage items.

The laboratory is provided with two main NMR experimental sets that may run independently each other. One is based on a high-resolution NMR spectrometer, a Bruker Avance 300 ultra-shield spectrometer, which utilizes a 7 T superconducting magnet tunable on a wide range of nuclei to make chemical-shift and relaxation measurements on a very large number of molecular species. The spectrometer is equipped with an ultra-intense magnetic gradient which can produce gradients as intense as 1250 Gauss/cm and it allows measuring molecular self-diffusion coefficient up to about 10^{-16} m^2/s. With this experimental apparatus, which posses also a controlling temperature capability, it has been performed research concerning transport properties on polymers and cell membranes. The second experimental apparatus is based on a single-sided mobile low-field NMR probe (Bruker NMR ProFiler) equipped with glass caskets and vacuum system for temperature and humidity specimens conditioning. This experimental set works at a Larmor frequency of about 18 MHz and utilizes a probe that includes permanent magnets. The electronics is based on the Bruker Minispec apparatus and may be used *in situ* since it is fully transportable. By this apparatus a number of application have been ideated to monitoring and characterizes Cultural Heritage items.

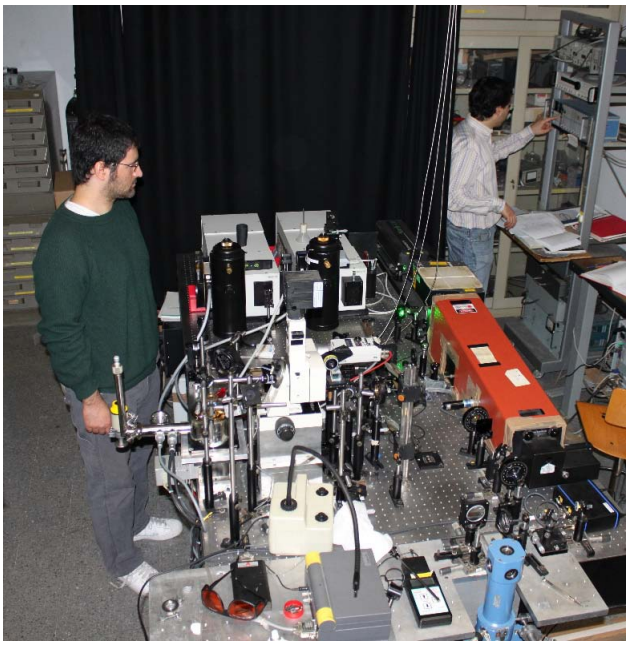
Figure 1: The high-resolution NMR Bruker Avance 300 ultra-shield spectrometer.

http://deca.phys.uniroma1.it/
Related research activities: C42.

L9. Semiconductors and Optical Properties of Solids Lab

Since its foundation, the laboratory of Semiconductors and Optical Properties of Solids has been engaged in research on the electronic and optical properties of semiconductors of interest in the fields of Information and Communication Technology and renewable energies. Si and III-V compounds under different type of external perturbations (e.g. high magnetic field, stress, excitation power density) have been the main objects of investigation. Either bulk material or heterostructures grown by molecular beam epitaxy (quantum wells wires) or self assembling (quantum dots) by national or international laboratories have been investigated. In the last ten years the interest of the laboratory has been focused on dilute nitrides and on the effect hydrogen has on the electronic and structural properties of these compounds. More recently, we have shown that the hydrogen induced effects can be exploited to achieve nanostructures with shape, size, and density arbitrarily designed in the sample growth plain by a novel technique, which avoids major drawbacks typical of standard top-down or bottom-up procedures.

A great variety of light sources, monochromators and detectors available in the laboratory permits to operate from the



(a)

(b)

Figure 1: (a) Optical table with apparatus for photoluminescence and Raman measurements (both micro and macro) in the near-UV to near-IR energy range. (b) Apparatus for irradiation with low-energy atoms of samples maintained at different temperatures.

near ultraviolet to mid-infrared energy range on two different optical tables.

Light sources are: a 2 W Coherent Ar laser, an 8 W Coherent Verdi diode laser, a 1 W Ti-sapphire tunable laser and a Coherent MBD 266 frequency doubler pumped by the Verdi laser, high pressure Hg and Xe lamps. A 1 m McPherson single monochromator, a 0.75 m Acton double monochromator, and a 0.3 m Jobin-Yvon single monochromator are also available, together with detectors including a Princeton Si CCD and an InGaAs linear array, a Hamamatsu photomultiplier with an UV extended GaAs cathode for single photon counting, an ADC ultrapure Ge detector, GaSb, InAs, PbS detectors, and related control electronics. Eventually, samples can be cooled down to liquid helium temperatures in two closed cycle cryostats or in two exchange gas cryostats, one of which equipped with magnetic fields up to 14 T. In order to measure the optical properties of single nanostructures, the laboratory has been recently equipped with a microscope for micro-photoluminescence and micro-Raman measurements and a He continuous-flow optical-cryostat whose piezoelectric movements permit to displace samples at liquid helium temperature by 8 mm maximum in the plane perpendicular to the microscope optical axis, with a resolution of a few nanometers. Finally, samples can be irradiated at temperatures ranging from room temperature to 600 C with beams of atomic hydrogen or other gases whose energy goes from a minimum of 50 eV to a maximum of 1500 eV.

Related research activities: C31,C32.

L10. Holographic Micromanipulation and Microscopy Lab

A mesoscopic object can be stably trapped in three dimensions by a tightly focused single laser beam. Computer-generated holograms displayed on liquid crystal spatial light modulators (SLM) offer a convenient way of producing large three dimensional arrays of dynamic optical traps. The ability to dynamically manipulate matter at the meso-scale opens the way to a wide range of applications in the physical and biological sciences. In our holographic optical tweezers (HOT) setup a TEM00 mode beam from a diode pumped, 532 nm, 2 W laser is expanded and reflected off a liquid crystal Spatial Light Modulator. Highly optimized holograms are generated in real time using custom parallel code running on state of the art Graphic Processing Units. The phase modulated wavefront is then focused onto a tiny trapping hologram by a 100x NA 1.4 objective lens mounted in an inverted optical microscope. The same lens is used to image trapped particles on a software controlled digital CMOS camera. 2D particle trajectories can be tracked by digital video microscopy with a spatial resolution of about 10 nm and up to 1 kHz framerate. A second setup combines HOT with Digital Holographic microscopy (DHM). The recorded hologram is a complex interference pattern produced by the propagation of a coherent laser beam through a thick sample. Numerical processing allows to obtain from a single shot hologram a full volumetric reconstruction with nanometer resolution. We are working on applications of holographic trapping and imaging to micro-fluidics, statistical mechanics, colloidal science and microbiology.

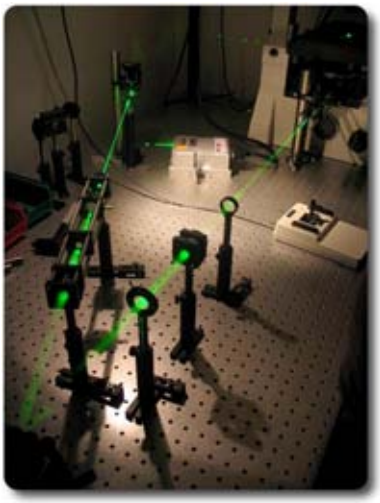


Figure 1: Holographic optical tweezers setup.

http://glass.phys.uniroma1.it/dileonardo/
Related research activities: C30.

L11. Photon Correlation Lab

In the last years the Photon Correlation laboratory has been engaged in experimental researches in Soft Matter. In particular the ageing phemonenon and the transitions towards arrested states both of gel and glass nature have been investigated.

The laboratory in Roma is equipped with two different photoncorrelation set-up running independently. Conventional Photon Correlation Spectroscopy set-up: a He-Ne laser (λ=632.8 nm) of 10 mW focused on the centre of a vat mounted on a goniometer. The temperature of the sample, sit in the centre of the vat, is controlled by a cooler-heater (HAAKE K35). The scattered light is focused, selected by a pinhole and revealed by a multimode fiber and a photomultiplier detector. A commercial ALV-5000 logarithmic correlator computes the autocorrelation functions. Measurements can be performed at various scattering vectors (moving the collecting arm and so varying the collecting angle) and in a correlation time window between 1 μs and 10 s. Advanced photon correlation spectroscopy set-up: a He-Ne laser of 35 mW is sent on a polarizing maintaining single mode fiber and is focused on the centre of a vat mounted on a goniometer. The temperature of the sample, sit in the centre of the vat, is controlled by a cooler-heater (HAAKE FUZZYSTARC35). A lens-collimator system couples the scattered intensity with a single mode fiber connected to a photodiode detector and a home made software provides a logarithmic correlation of the data. By means of the use of single mode fiber the coherence factor reaches the ideal value of 1 and therefore autocorrelation functions with a very high signal to noise ratio are obtained. Measurements at various scattering vectors (varying the collecting angle) and in a time correlation window between 1 μs and 2 s can be performed.

Figure 2: Photon correlation set-up.

Related research activities: C8.

L12. High Pressure Spectroscopy Lab

The research activity carried out at the High Pressure Spectroscopy Lab in the last ten years was mainly focused on the study of strongly correlated electron systems such as functional oxides for the electronic (manganites, multiferroics materials, spinels,...), charge density wave low dimensional materials (di- and tri-tellurides), and high T_C superconductors (e.g. Mgb_2 and oxypicnitedes). By combining the *in house* optical spectroscopy and the structural characterization (neutron and x-ray diffraction) carried out at the largest European large scale facilities a rather comprehensive experimental approach to these complex materials is obtained. Standard ancillary equipments allow to perform Raman and Infrared measurements over a wide temperature range (5-500 K by a Oxford cryostat) and the diamond anvil cell (DAC) technique is employed to compress the samples under equilibrium conditions up to very high pressure (40-50 GPa). Applying pressure help in disentangling the effects of the different interactions simultaneously at work in correlated materials and can cause interesting structural and magneto-electric transitions. In particular, spectacular insulator-to-metal transitions associated to conductivity jump of several order of magnitude can be induced. Owing to the diamond transparency to the electromagnetic radiation over a wide frequency range, DACs allow to study condensed matter with several spectroscopic techniques, such as optical spectroscopy, x-ray diffraction and spectroscopy. The HPS laboratory is equipped with a micro-Raman LabRAM Infinity spectrometer and a Bruker IFS66v Interferometer for infrared measurements. High pressure optical measurements are carried out *in house* and experiments are routinely performed by using also infrared and x-ray from synchrotron sources (mainly at ELETTRA and ESRF).

Figure 1: The micro-Raman LabRAM Infinity spectrometer.

The LabRAM spectrometer is a high-performance Raman microscope-spectrometer suitable for solid and fluid samples. The LabRAM is equipped with an He-Ne laser (632.81 nm), a notch filter and two diffraction gratings (1800 line/mm and 600 line/mm). The LabRAM incorporates state-of-the-art CCD detection and high efficiency optical construction to provide fast and reproducible analysis. The LABRam spectrometer works in backscattering geometry, using a notch filter to reject the elastic contribution. The confocal microscope is equipped with several high quality objectives with different working distances (from less then 1mm to very long working distance larger then 20 mm) and magnifications (from 10x to 100x). These allow to collect Raman spectra from very small portion of the sample: the laser spot on the sample is on the micron scale and the thickness of the scattering volume along the optical axes can be reduced to tens of microns or less exploiting the confocality. The very long working distance allows to collect measurements on the micron scale also on samples pressurized by DAC. A multiline air-cooled 100 mW Ar laser from Melles Griot coupled with an optical fiber system is also available for Raman measurements. This source can be used also on a second optical table where the availability of a new Peltier-cooled CCD (Symphony from Horiba), a Triax Monochromator (Jobin-Yvon), and a remote optical head equipped with interferential and notch filters and high magnification objective allow for a second conventional Raman setup.

Figure 2: Details of the LabRAM spectrometer.

The Bruker IFS66v Fourier Transform Infrared system allows measurements in over wide frequency range, from the far- to the near-infrared. The instrument can work in vacuum, with the advantage to avoid the strong absorption components due to water vapour. It is equipped vith different lamps (globar and Hg), beam-splitters (KBr and mylar), and detectors. The maximum resolution of the instrument is 0.1 cm^{-1}. Within the large sample compartment a focusing optical system (Cassegrain objectives) can be easily allocated.

Figure 3: IFS66v Interferometer

Several DACs (commercial from BETSA and DIACELL and home made for specific application) with different characteristic are available. Simple, efficient and portable gas-pressurizing systems can be used for the membrane DACs. Sample loading can be carried out at our laboratory for sample preparation. It is basically equipped with stereoscopic high-magnification optical microscopes, tools and machinery for handling very small samples, a micro spark-eroder for preparing gaskets for the DACs.

We finally notice that the availability of a Raman micro-spectrometer in our Lab allowed us to successfully carry out studies in the field of cultural heritage. Collecting Raman spectra from very small specimen allows us to study stratigraphic layers of polished cross-sections of paintings.

http://www.phys.uniroma1.it/gr/HPS/HPS.htm
Related research activities: C35, C36.

L13. Inhomogenoeus and Correlated Functional Materials and Quantum Phenomena in Condensed Matter Lab

The G4-Superstripes laboratory is engaged in the experimental research on the physics of complex materials with interplaying electronic degrees of freedom. The goal is to develop new materials by optimization of physical parameters through an experimental approach based on the control and manipulation of materials properties in the correlated and locally inhomogeneous systems. The group has provided a significant contribution in the field of mesoscopic phase separation in the complex matter with quantum phenomena as the superconductivity. Exploiting the high energy spectroscopy as a tool of fundamental electronic structure, combined with structural tools of mesoscopic structure, the group has been active in the frontier research with a direct implication of our understanding of complex condensed matter.

The G4 laboratory is specialized equipped with various instruments for the The G4 laboratory is specialized in the experimental research on quantum phenomena in complex matter. The research is addressed to unveil the complexity in known systems and in the synthesis of novel systems. The G4 laboratory is equipped with various instruments for the materials preparation and characterization. For the bulk preparation, in addition to several muffle furnaces, a furnace for Czochralski growth is available. Complex conductivity is frequently measured down to very low temperature using the Heliox3 cryostat. In addition, the group has a dedicated ultra high vacuum (UHV) facility equipped with a preparation chamber for layer by layer epitaxial growth of materials and the analysis chamber for spectroscopic analysis (Fig. 1). The preparation chamber has three e-beam evaporators, in addition to the RHEED facility. On the other hand, the analysis chamber is equipped with a dual anode X-ray source and an ultra violet radiation source, in addition to the high resolution multi channel Omicron EA 125 electron analyzer, permitting to perform XPS, AES and UPS measurements on complex materials. Surface structure and morphology can be studied using the LEED/Auger system mounted in the analysis chamber. All these measurements are possible down to about 20 K using liquid He cooled sample holder attached to the Omniax manipulator.

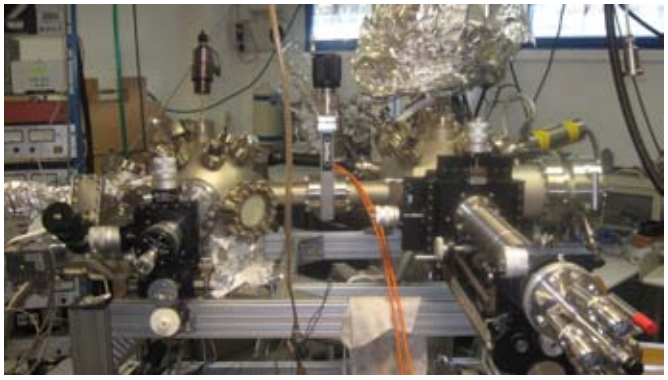


Figure 1: Schematic representation of UHV system equipped with the facility of sample preparation and electron spectroscopy.

The research in biological systems goes from metallo-proteins to metal nanoclusters and cellular organization. The G4 laboratory is equipped with an XE-120 atomic force microscope with combined capability of STM-AFM and is coupled with an optical microscope. The XE-120 permits Non-Contact mode imaging for both air and liquid imaging. The XE-120 is meant for studies of biological systems and for in-situ studies. The G4 laboratory is equipped with system for optical spectroscopy to study biological systems.

Figure 2: Atomic Force Microscope XE-120 coupled with an optical microscope.

http://www.superstripes.com/
Related research activities: C4, C29.

L14. Laboratory for Ultrafast Spectroscopy

The laboratory for Ultrafast Spectroscopy, inaugurated in March 2009, is a newcomer among the experimental facilities of the Physics Department. Built up from scratch thanks to an ERC-IDEAS Starting Grant project, the lab is powered by an ultrafast 80 Mhz Ti:Sa oscillator (Coherent MICRA) and a regenerative amplifier able to deliver 800nm, 1Khz pulses with dual option for 35 fs and 120 fs duration (Coherent LEGEND). The lab is currently involved in two main experimental activities based on Pump&Probe protocol applied in different time domains:

Femtosecond Stimulated Raman Scattering We study photoinduced effects in molecular and supra molecular structures such as isomerization reactions, ligand dynamics in proteins, vibrational energy redistribution. The system is pumped in an out of equilibrium state by an ultrashort tunable laser pulse produced with an Optical Parametric Amplifier (pump), and the wavepacket evolution is probed at variable time delays tracking ultrafast dynamics by means of Stimulated Raman Scattering. A combination of a narrowband, highly tunable (330 ÷ 520 nm and 790÷810 nm) pulse and a ultrashort white light continuum allows broadband stimulated Raman scattering resulting in a probe with sub ps time resolution and few wavenumbers frequency resolution.

Figure 1: Ultrafast Spectroscopy Laboratory

Picosecond acoustics We study acoustic properties (sound propagation) in disordered materials in the 10 ÷ 100 picosecond time domain (corresponding to 50-500 Ghz range), which is unaccessible ordinary frequency domain techniques such as light and neutrons/xrays scattering. The sample needs to be prepared as a film (100 ÷ 1000 nm thickness) with a 10nm metallic coating on a surface. An ultrashort 800nm pulse impinges in the metallic surface producing an impulsive thermal expansion launching a strain wave. A second broadband pulse (white light continuum) is reflected by the metallic surface and by the moving acoustic wave, resulting into a time dependent modulated signal with periodicity and damping related to sound velocity and attenuation.

http://femtoscopy.phys.uniroma1.it/
Related research activities: C28.

L15. Macroscopic Quantum Coherence Lab

The The Macroscopic Quantum Coherence (MQC) group aims to study the behaviour of macroscopic systems at very low temperatures, where the thermal effects are negligible, being dominated by quantum effects. In particular we study superconducting non linear systems realized with Jopsephson junctions in various configurations and topology. These systems are studied also in view of the realization of a Quantum Computer made of superconducting qubits. The laboratory is equipped with a Leiden Cryogenics He3-He4 dilution refrigerator, having a base temperature of 10mK and 200microW of power dissipation capability at 120 mK. The system is equipped with 36 low frequency filtered lines (dc-1 MHz) and very high frequency rigid coaxial lines (30 GHz).

For the high frequency signals we use two CW signal generators Anritsu Mg3694A 10 MHz-40 GHz and HP 8673G 2-26GHZ. For low frequency signal generators and the detection system we use low noise commercial equipments driven by lab View custom designed virtual instruments. Devices pre-test are performed using standard liquid helium immersion dewars and a Heliox He3 system with operating temperature of 0,3K (at IFN- CNR lab in Rome). The devices are designed by the low temperature group collaborating with the experiment (IFN-CNR) and realized in the CNR nano-micro fabrication facility, or by external factories.

Figure 2: Picture of the lower part of the dilution refrigerator.

http://www.roma1.infn.it/exp/webmqc/home.htm/
Related research activities: P33.

L16. Electronics and Silicon detectors Lab

The Laboratory of electronics and silicon detectors is primarily involved in the experiments of ultrarelativistic heavy ion and nuclear physics with particle beams: ALICE experiment at CERN and JLAB12 experiment at Jefferson Laboratory in the USA. The Laboratory is also involved in the R&D activities for PET use in medical applications with Silicon Photon Multiplier (SiPM) detectors: AX-PET Collaboration at CERN and TOPEM Collaboration in a R&D of INFN. In addition the Laboratory is developing a Fast Photometer System based on silicon detector SiPM for variable star measurements: collaboration with SCAE group of our Department.

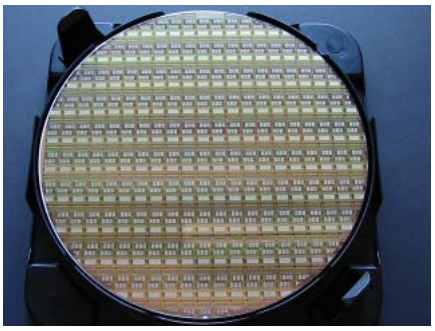


Figure 1: 8" wafer in 0.25 micron CMOS thecnology used for SDD ASIC in ALICE experiment.

The instrumentation allows the Laboratory to develop electronics on FPGA and allows testing FPGA and ASIC dedicated to the reading of silicon detectors using a logic analyzer and Pattern Generator both interfaced with a PC. A manual type Probe Station allows the test on wafers with diameter up to 8" (see Figure 1). It is available a data acquisition system via VME to PC using dedicated software (Labview). A climatic chamber allows tests on individual silicon detectors in the range between 10 $^{\circ}C$ and 70 $^{\circ}C$ with a current $I = I(V)$ measurement through Pico Ammeter. Finally, an optical pulsed system based on LED allows their characterization in terms of response to short pulses (down to 0.9 ns).

http:www.roma1.infn.it/exp/alice
Related research activities: P8.

L17. SCILab

In the SCI-Laboratory have been developed, in Collaboration with other Institutions and University since 10 years several prototypes of particle Detectors by collection of light emitted by scintillating plates. To optimize the light collection efficiency the Wave Length Shift fibers located on a side of a plate or in a groove of a tile were extensively studied. The Test results of these prototypes were used to build the muon time stamp Detector (CMP) and the Preshower Detector designed to separate the electron/pion. Both Detectors were installed into the 2 TeV Central Detector at Fermilab, CDF, USA. Application of commercial photomultiplier tubes with single anode or multi-anode were investigate by different light readout to maximize the amplification of the signal. Recently in the Laboratory we have started Tests of the Silicon Photomultipliers (SiPM),Fig. 1, for a new generation of Calorimetry Detectors (FACTOR Experiment, INFN), Muon Detector (T995 Experiment at FNAL) and track reconstruction of large zenith angle atmospheric showers. The Laboratory is equipped with a DAQ chain that uses fast VME electronics: Time Digital Converter with time resolution of few ps, Analog Digital Convertor to integrate the PMT signal, NIM Logic Units and a GHz Pulse generator used for the characterization of the scintillators. To test the performances of the prototypes we use a radioactive source (^{60}Co) or a muon telescope able to select cosmic rays. The telescope covers a solid angle of 1/64 stereo radians and is equipped with a low threshold discriminator (5 mV) that provides a TTL/NIM trigger sent to a 6 GS/s waveform Digitizing Board (DRS4) with 12 bit resolution, readout speed 30 MHz, jitter less than 100ps. The digitization is transmitted by USB2 cable to a PC and analyzed by Linux software, Fig 1.

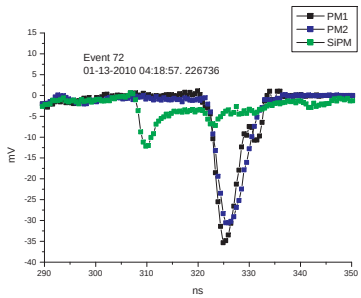


Figure 2: PMT signals (black and blue) of a muon track detected by the telescope and digitized by the DRS4 with 2GS/s. The 1x1 mm^2 SiPM signal (green) detected by a tile insert in the telescope is shown. The time difference between SiPM and PMT's is due to length difference of the cables. The telescope tiles are 10 cm apart along the vertical axis.

Related research activities: P9, P10, P11.

L18. The Gravitational Wave laboratory VIRGO

The Gravitational Wave laboratory of the university of Rome La Sapienza was founded by E. Amaldi and G. Pizzella almost 40 years ago and is still at the frontier of this research field. At the foundation time the activity was focused on the cryogenic resonant bar detectors. Here the first cryogenic GW antenna in the world was put in operation. Then the laboratory was devoted to the study of new strategies for the detection of weak forces setting new linear and back action evading transducers. Since 1996 the laboratory is devoted to support the VIRGO experiment and in particular to the design and test of the last stage suspension system of the mirrors for the GW VIRGO interferometer (the payload).
Recently, in order to reduce further the thermal noise associated to the suspended mirror, we developed a payload based on fused silica wires and we started to study the possibility to cool the mirror at cryogenic temperature. For this purpose we are developing a vibration free cryostat, an active system which compensate the vibrations generated by the pulse tube cryocooler operating at 5 K; we plan to use it also for testing the new cryo accelerometers for a very low frequency control.

The laboratory is equipped with a large variety of instrumentation and experimental facilities at the frontier of the present technology. Two optical tables are used to set up the opto mechanical transducers dedicated to the remote control of the payload degrees of freedom. High vacuum chambers and liquid helium cryostats of various dimensions, each one equipped with oil free turbo molecular pumps, are dedicated to the test of each payload component. Moreover, because of the severe constraint on the payload contamination, we set up for the final assembly phase a class 100 clean room inside which, thanks to the use of an extra filtered air flow, we are able to achieve up to the class 1 cleanness.

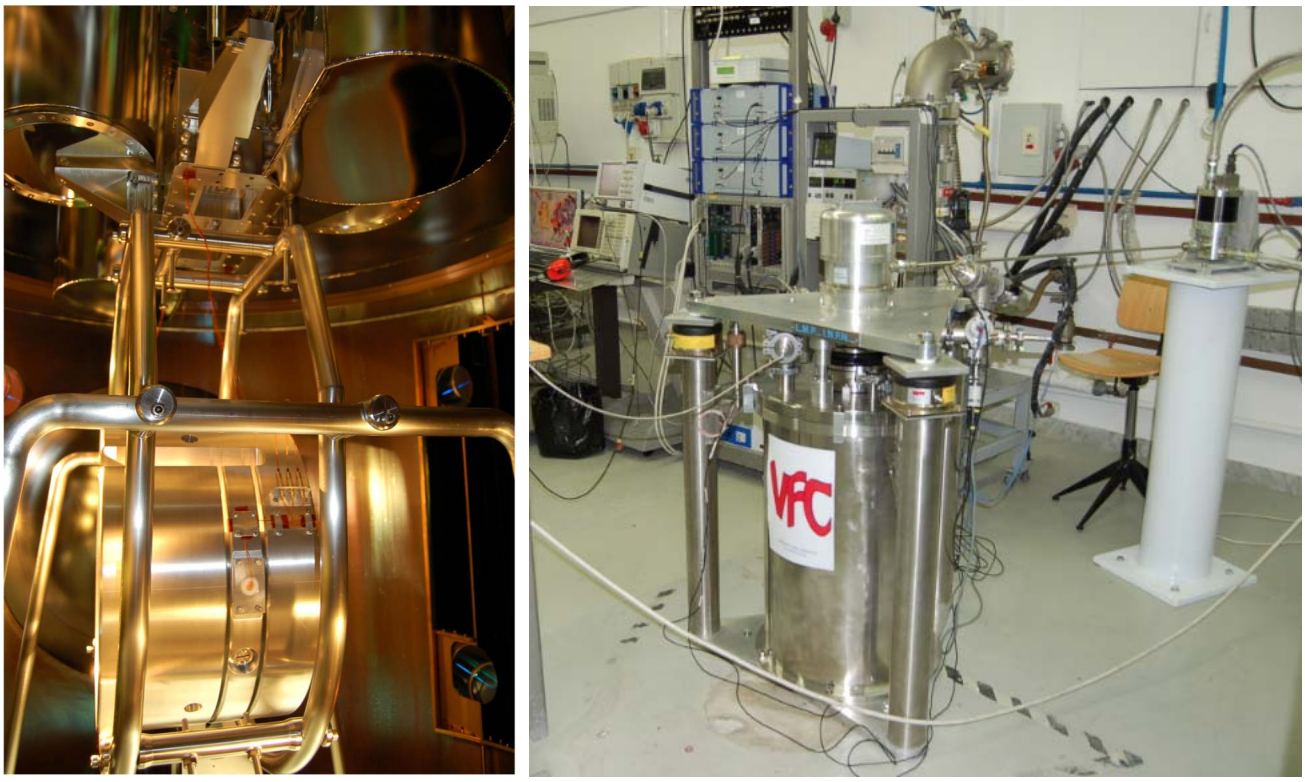


Figure 1: On the left a lateral view of the VIRGO payload constructed and tested in GW lab. On the right the vibration free cryostat installed in GW laboratory in Rome

Finally, for the VIRGO data analysis the laboratory installed the Tier 2 node of VIRGO: it consists of a LINUX farm of 416 cores and it includes a storage element of 16 TB spinning disks. This farm is the pilot of the VIRGO Virtual computing organization and it is integrated in the INFN-Grid infrastructure.

http://www.virgo.infn.it/
Related research activities: P30.

L19. Laboratory of the KLOE-ROMA group

The group of the Physics Department participates to the KLOE experiment at the DAΦNE e^+e^- collider of the Frascati Laboratories of INFN since 1992.

Recently the group has been involved in the intense activity for the KLOE-2 experiment, which will start its data taking data in 2010 with an upgraded detector. One of the main improvements is a small angle electron and positron tagger, made by a pair of compact calorimeters, called low energy taggers (LET). These calorimeters are made of LYSO scintillating crystals and read-out by silicon photomultipliers, and the Roma group has the responsability of their design, construction, installation and test. Among the several activities, it can be mentioned the test of the scintillating properties of the LYSO crystals performed inside a *black box* with a small ^{137}Cs source with the experimental set-up shown in Fig.1. The same set-up using a LED as a light source has been used to test the performance of the silicon photomultipliers, and also of other kinds of photodetectors (e.g. high quantum efficiency photomultipliers for a preliminary study of the KLOE upgrade.)

Figure 1: The experimental set-up for the test of scintillating crystals and photodetectors.

Another activity of the group focused on the study of the response of the lead-scitillating fiber calorimeters to neutrons of kinetic energy in the range between 20 and 180 MeV. A prototype calorimeter realized in the Roma Laboratory has been successfully tested at the neutron beam of the TSL Laboratory of the Uppsala University (Sweden), showing an enhanced detection efficiency with respect to equivalent bulk scintillator counters.

http://www.roma1.infn.it/exp/kloe/
Related research activities: P19, P20, P21.

L20. The ATLAS-KLOE-DREAM laboratory

The laboratory has been used in the past to prepare and test detectors for the particle physics experiment KLOE at the e+e- collider DAPHNE of the INFN Laboratori Nazionali di Frascati and for the experiment ATLAS at the LHC accelerator at CERN. In the next future some tests will be performed for the DREAM Collaboration studying a new approach (dual read out) to optimize hadronic calorimetry in high energy experiments.

For the KLOE experiment in the laboratory has been prepared a small prototype of the big central chamber before moving that in a test beam at CERN, where a full test of this drift chamber, operated with a helium - isobuthane mixture, has been performed also in a magnetic field. This small detector served also to study the final configuration of the wires in the chamber of the KLOE detector. For ATLAS in the laboratory has been prepared and operated the system used to test about 15000 drift tubes before they were assembled in the chambers, built in Rome, for muon detection in the big spectrometer of the experiment. The system is visible in the figure. For each tube the mechanical wire tension and the leakage current in HV (3080 V for a 4×10^4 gain at the wire) were measured. An accurate system checked the wire off-centerig in the tube with a 10 microns rms in projection. Also the gas leak of the tubes was measured (gas leaks smaller than 10^{-8} bar liter/s at 3 absolute bars were required). All these tests were controlled by a computer. A non invasive technique to replace broken wires in drift tubes glued in the chambers was then developed in this laboratory and used in other laboratories of the ATLAS Collaboration.

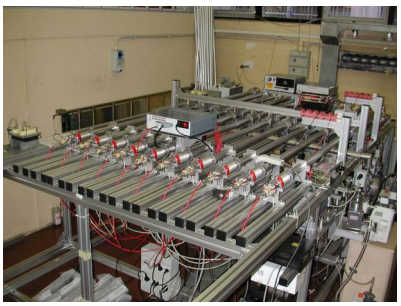


Figure 2: The system for the test of the drift tubes for the muon chambers of ATLAS.

Related research activities: P1, P2, P3, P19, P20, P21.

L21. Nuclear Emulsion scanning Lab

Since over 6 decades researchers in Rome are exploiting the emulsion technique applied to high-energy nuclear and particle physics, i.e. tracking ionizing particles in photographic films by high-magnification optical microscopes. As experiments evolved in complexity ("hybrid" detectors made of electronic devices and arrays of emulsion films) and scale (thousands of films to be scanned), the quest for fast, automated (computer-driven) optical microscopes, equipped with state-of-art TV cameras, stimulated an impressive evolution of the technique, particularly in Japan and in Europe.

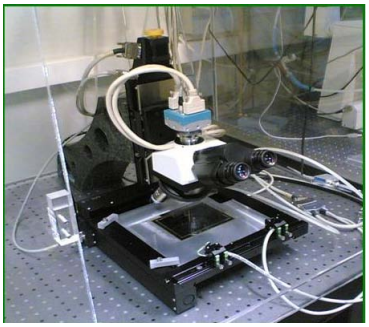


Figure 1: The European Scanning System, an automated optical microscope equipped with a fast, high resolution CMOS camera. Details in [3].

As a result, the still active "Emulsion scanning Lab" in Rome appears different from its early glorious age. Formerly, there were a lot of hand-operated optical microscopes, with many technicians ("scanners") busy to inspect by eye several optical fields per hour. At present, a fast microscope system (see Fig. 1) is operational under the full control of a computer, making "tomography" across photographic films. It could digest in real time some 200 bidimensional images per second, each of a few megapixel size, taken at different focal depth. In parallel, a 3-dimensional pattern recognition is performed, such that fully documented tracking data could be stored in a large data-base (terabyte scale).

The Emulsion scanning Lab in Rome is presently contributing to the data taking and event study of the OPERA experiment, searching for neutrino oscillations induced by the CERN-to-Gran Sasso neutrino beam (CNGS). The scanning Lab is a member of an european "federation", exploiting copies of the very same optical microscope system and a common software framework, spread over several reasearch centers in Italy and abroad. Other Labs in Japan are in joint venture, contributing to OPERA with different microscope systems of comparable performances.

Related research activities: P26.

L22. High Energy Astrophysical Neutrino Detection Laboratory

Our laboratory supported the several activities that, during the past decade, we have carried-out for the construction of the future deep-sea Cherenkov detector for the detection of high-energy astrophysical neutrinos. In our lab we have tested and calibrated the instruments for the measurement of the deep-sea environment in ANTARES site. We built special electronic cards for their setting and control. Also for the NEMO and the KM3NeT projects we have developed, built (mechanics, electronics and data acquisition system) and tested (before to operate them in deep sea) several "autonomous deep-sea measurement stations" to characterize the abyssal sites candidate for the Neutrino Telescope construction. All these activities needed conventional tools for electronics, mechanics and software development and construction. We performed careful studies of the characteristics of signals produced by the PMTs proposed for the construction of the Cherenkov undersea Neutrino Telescope (NEMO, ANTARES, KM3NeT), mainly PMTs with large photocathode area (8", 10", 13" diameter). We have built, for this work, in our lab a set-up that includes a blue laser for the PMT excitation and a full electronic chain for data acquisition.

The main activity of the lab is the development of the electronic system for the real-time acquisition of signals produced by the Neutrino Telescope system of PMTs located in deep-sea, about 100km far from the on-shore laboratory. This electronic system has to be reliable, redundant and has to require low power for it's operation. We developed and built the front-end electronic cards to digitize (at 200 MHz) the PMT's signals underwater ad to transmit "all data to shore". We also developed and built the electronic system for the serial, high-speed and synchronous, transmission of all PMT's data to shore. For this work we did develop several different transmission protocols and serializer-deserializer devices. For NEMO-Phase1 prototype (a four floors mini-tower operated for few months in 2007, at 2000m depths) and for NEMO-Phase2 (a whole tower deployed at 3500m depths in Capo Passero site) we built, tested and operated the full data acquisition/transmission system (based on GLink chipset). At present we are contributing, with the acquired expertise, to the definition of the data acquisition and transmission electronics system for KM3NeT. For these activities we used, in our lab, quite conventional instruments/devices for the design and test of the electronics and the related firmware: a LeCroy Wavepro 7100A oscilloscope, a logic analyzer Tektronix TLA714, a signal generator AGILENT 33250A, a PC farm. In our lab we also studied the basics for the detection of acoustic signal produced by the interaction in deep-sea water of Ultra High Energy astrophysical Neutrino. We characterised several hydrophones (specific for deep-sea use) in our lab and on a test beam; we developed and integrated the data acquisition cards, needed for these sensors, into the main electronics system built for NEMO. For these studies we can use a "silent room" in our "laboratory for acoustics".

http://www.roma1.infn.it/people/capone/AHEN/index.htm/
Related research activities: P31, P32.

L23. Experimental Cosmology Lab

The Experimental Cosmology laboratory produces and tests instrumentation for observations of the sky at submillimeter and millimeter wavelengths. The group is involved, since 1980, in many experiments with different observational sites: ground-based, balloon borne and satellite. In this laboratory has been developed and actually built hardware for the MITO observatory on the Alps, the BRAIN experiment in Antarctica, the BOOMERanG balloon and the High Frequency Instrument aboard of the Planck satellite of ESA.

The laboratory is equipped with facilities for: a) developing and assembling radiation filters and new technology detectors, like KIDs, specifically for mm-bands; b) testing and developing readout low noise electronics; c) cryogenic systems for ensuring low temperatures ($\leq$ 300 mK) for detectors and optical systems; d) calibrating photometers, polarimeters and spectrometers in the sub/mm spectral range.

Each facility is composed of:

a) an evaporation chamber (Jep 600 by RIAL Vacuum) with gauge controller, thickness monitor and pumping systems; an optical microscope (Leica Wild M3Z), a lapping and polishing machine (mod. 920 by South Bay Technology Inc.), a controlled atmosphere chamber (mod. 855 AC by Plas-Labs Inc.), hot press and wire saw.

Figure 1: Evaporation system RIAL used to produce resonant filters and mm-wave detectors

b) lock-in amplifiers (SR 850 and SR 830), oscilloscopes, AC and DC power suppliers, spectrum analysers, 24 bit data acquisition units. For the KIDs effort we have a 20 GHz vector analyzer, a 40 GHz CW synthesizer, and a dedicated cryogenic system with low-noise HEMT amplifiers.

c) Wet cryostats (Infrared Labs, QMC Ltd and self manufactured), cryogens transfer tubes, different size dewars for liquid nitrogen and liquid helium, 3 leak detectors (Alcatel and Pfeiffer). Three dry cryostats based on pulse tube refrigerators (Cryomec, Sumitomo, Vericold). Two of them include ^{3}He fridges for continuous operation at 0.3K without the need of ordering liquid Helium and liquid nitrogen, and one of them includes a dilution fridge for operation down to 55 mK.

Figure 2: Testbench for Kinetic Inductance Detector arrays, composed of synthesizer, vector analyzer for the 20 GHz band, lock-in amplifier, pulse-tube cryogenic system and ^{3}He refrigerator.

d) lamellar grating fourier transform spectrometer (mod. LR-100 by RIIC 50 mm stroke of the moving mirror); Large throughput Martin Pupplett Iterferometer (600 mm stroke of the moving mirror), 10-20 mW Gunn oscillators for the 90 and 150 GHz bands, 30 mW BWO source for the 350 GHz band, a 1-m in diameter off-axis parabolic f/2 mirror for generating plane mm-waves, cold and hot blackbody sources.

In the laboratory is also present a small machine shop including a combo mill-lathe and a drill press with accessory tools, for quick modification of mechanical parts.

For the integration of our large volume balloon payloads we have setup externally a large industrial tent with a usable internal volume of $10\times8\times6$ m^3. We have a 5 m Gantry-Crane with 2 Ton lift capability inside the tent, and a smooth concrete floor for moving the crane and carts with payloads. This is the largest volume integration facility of our Department. Both the BOOMERanG and OLIMPO payloads are integrated in this facility.

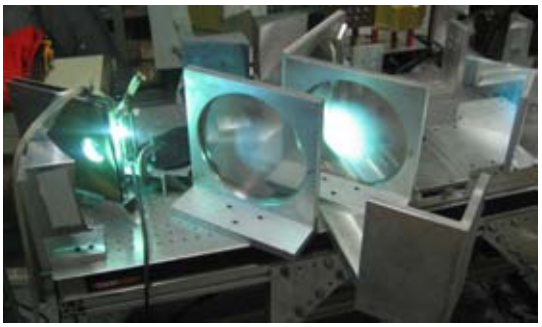


Figure 3: The large throughput interferometer, an imaging instrument with 0.5 cm^{2}sr throughput, able to analyze millimeter waves in the range 80-600 GHz, with resolution of 0.3 GHz.

http://oberon.roma1.infn.it/
Related research activities : A11, A12, A13, A14

L24. Millimeter and Infrared Testagrigia Observatory

MITO is an observing facility, developed and managed by the Experimental Cosmology Group, located in Valle dAosta (Northern Italy 45 56 03 North, 7 42 28 East) at an altitude of 3480 meter a.s.l. on the Italian-Swiss border.

The project was proposed by Francesco Melchiorri at the end of 70s and it become real with the effort of the Istituto di CosmoGeofisica, CNR in Turin (now Istituto di Fisica dello Spazio Interplanetario, IFSI/INAF - sezione di Torino) and by the availability of the existing laboratory on the top of Testa Grigia mountain.

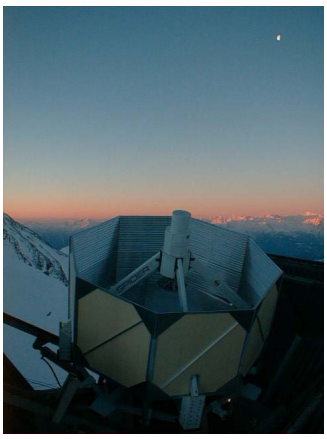


Figure 1: MITO telescope.

The telescope is mainly dedicated to intensity and polarization observations of Cosmic Microwave Background anisotropies at millimeter and submillimeter wavelengths.

The telescope has a f/4 Aplanatic Cassegrain (R-C) configuration with a 2.6 meter in diameter primary mirror and a subreflector of 41 cm in diameter. The focal plane scale is 25”/mm. The two monolithic mirrors have been manufactured in an aluminum alloy by Officine Ottico-Meccaniche Marcon (Italy): the primary mirror is only 115 kg in weight while the subreflector is 1.8 kg.

Atmospheric emission, mainly due to water vapor, and its fluctuations are minimized with the choice of an high altitude site and by performing differential measurements with a wobbling subreflector. An alt-azimuth mount allows a compact instrument and an horizontal sky modulation even during the tracking of a source in the sky. The telescope is protected from local environment background by a radiation shield with vanes in the inner surface.

The dome is connected to a laboratory where it is possible to communicate with all the instrument subsystems. Several photometers, mainly developed by the group with detectors cooled down to 300 mK, have been installed at telescope focal plane. The laboratory is also equipped for lodging a maximum of 6 researchers during observational campaigns.

http://oberon.roma1.infn.it/mito/
Related research activities : A13, A14

L25. Solar Radiometry Observatory

The research activities of the Meteorology group (GMET) intend to assess the influence of the decrease of ozone and its effect on UV radiation variability. The GMET equipment consists in a Brewer spectrophotometer MKIV n.067, installed in 1992 on the roof of the building of the Department of Physics in the University Campus. Direct sun measurements at 5 wavelengths in the UVB and VIS regions are carried out to retrieve total O_3 and NO_2 amounts, respectively.

Measurements of solar UV spectral irradiances in the spectral range from 290 to 325 nm, with a stepwidth of 0.5 nm, have been carried out since 1992. This long UV time series is necessary to assess the influence on ecosystems and on human health. In addition, erythemal dose rates have been obtained by the broadband UV radiometer (model YES UVB-1) in operation since 2000. The YES radiometer has a spectral response similar to that of skin erythema and values of erythemal dose rates are obtained using a calibration matrix as a function of solar zenith angle and total ozone amounts from Brewer spectrophotometer. Ambient UV radiation is also used in the quantification of human UV exposure by means of polysulphone dosimetry, this another research activity. Ancillary meteorological measurements of air temperature, relative humidity, and wind, are also available to characterize the UV field.

Figure 1: Solar Radiometry Observatory (University Campus).

http://www.phys.uniroma1.it/gr/gmet/index.html
Related research activities: G2.

L26. The Vallinfreda astronomical Station

The SCAE group has an observing facility near Vallinfreda, (a small town 50 km ENE of Rome), located at 850 m above the sea level with a rather low sky brightness (V=20.5 mag/arcsec2). Geographical coordinates are Long. 12o 58' 52" East, Lat. +42o 06' 01". Routine observations at Vallinfreda started by the end of Summer 1995.

The telescope is a Newtonian 50 cm f/4.5, built by GAMBATO, powered by an FS2 system, housed in a sliding-roof building (see fig. 1). A standard 12m-long container, provided by the italian Protezione Civile, gives logistical support.

The focal plane instrument is an Apogee ALTA AP47 CCD camera and a TrueTech filter wheel with standard BVRI Johnson-Cousins filters, provided by Astrodon-Schuler. Electric focuser is by MicroFocuser. Guiding is made with a 15 cm f/12 refractor telescope manifactured by ZEN and a StarLight Xpress MX916 camera.

All telescope operations (telescope pointing, filter wheel movements, image acquisition and guiding) are controlled by a PC with Windows XP operating system. The limiting magnitude, with a S/N ratio about 0.1 is 17.5 in the R band.

Figure 2: The Vallinfreda telescope in its sliding-roof building.

The telescope is mainly dedicated to monitoring of BL Lacertae objects, a subclass of Quasars with strong Radio and Gamma Rays emission, with special care for simultaneous observations with space-born instruments (Beppo-SAX, SWIFT, INTEGRAL, AGILE, FermiGST).

About 25 papers on refereed international journals have been made using (also) data obtained with the Vallinfreda telescope.

http://astrowww.phys.uniroma1.it/nesci/vallin.html
Related research activities: A9.

L27. Atmospheric Physics Lab

The Atmospheric Physics laboratory has been engaged in experimental and theoretical researches regarding radiative and thermodynamical properties of the Earth atmosphere for more than 25 years.

Most of the instruments are based on remote sensing techniques and are routinely run for probing the atmosphere above the campus location: several Rayleigh LIDARs (LIght Detection And Ranging) with different characteristics and able to measure the aerosol or the temperature through the stratosphere (Figure 1), a Raman Lidar able to measure the water vapor through the troposphere, a SODAR (SOund Detection And Ranging) able to measure the three components of the wind vertical profile and the turbulence structure up to 600 m, a MFRSR (MultiFilter Rotating Shadowband Radiometer) able to measure the total optical depth of the atmospheric aerosol in several visible bands, a microbarograph able to record the passage of pressure atmospheric disturbances. The instruments are used in conjunction with satellite overpasses for ground truth comparisons and calibration studies. They are used also in joint measurement campaigns for data assimilation in computer models. Very recently (April 2010) the measurements over the campus were used to monitor the presence of the Icelandic volcano eruption cloud above Rome.

During the years in some cases measurements of important geophysical quantities were carried on and prototipe instruments were tested within the lab at controlled conditions.

The know-how on remote sensing techniques has been applied for the design and development of an air born lidar (Air Born Lidar Experiment, ABLE) that flew during several international measurements campaigns aimed at monitoring the presence of aerosol in critical regions of the Earth (Antarctica, Tropical Regions and Actica). Presently a lidar of the group is operational at the Arctic station of Thule (Greenland) which is part of the Network for the Detection of Atmospheric Change (NDACC).

Figure 1: The Rayleigh Lidar with three channels for monitoring the atmospheric aerosol through the lower stratosphere.

Figure 2: The roof of the lab with 6 Sodar antennas and the astronomical dome for hosting lidars looking at zenith angles different from zero. The three Sodar antennas in the foreground are presently deployed elsewhere.

The lidar is able to measure the tropospheric arctic haze, aerosol profiles up to the stratosphere and temperature profiles through the mesosphere. All lidars were totally built in the lab using commercially available components. The optical sources are Nd:YAG lasers with second and third hamonic generators (the latter when needed). Some of the lasers are two stage systems: Q-switched oscillator and one-pass amplifier. Presently in the lab there are several Italian made pulsed lasers with outputs in the 10 MW power range.

The receivers are based on: 1) optical telescopes, 2) narrow band interference filters, 3) photmultipliers (for the visible) and avalance diodes (for near IR), 4) photon counting or analog sampling channels with bandpasses of the order of 20MHz or higher and 5) home developed computer programs.

The lab is placed at the last floor of the building where all the lidars usually sit. Access to the sky in a zenith only direction is obtained through hatches either manually or electrically controlled. The three antennas of the Sodar are sitting directly on the roof of the building (Figure 2) and a 4m astronomical dome allows the usage of remote instruments at different zenithal/azimuthal angles.

http://g24ux.phys.uniroma1.it/
Related research activities: G3, G4.

Servizio Progettazione Meccanica - Servizio Officina Meccanica

The **SPM (Servizio Progettazione Meccanica - Mechanical Engineering Service)** provides engineering and design skills to the experimental groups of the INFN Section and of the Physics Department, according to the Convention between INFN and the Department. The Service evolved with time, changing from the old drawing boards to modern CADs systems, and acquiring more and more competence as required by the more and more complex experiments in which physicist of INFN and Physics Department are involved. Today, the Service has a staff of one engineer and five technicians, under the direction of the Chief Engineer Corrado Gargiulo, and can provide skills regarding the dynamical analysis of complex structures, the design and realization of high precision mechanical parts, the engineering of parts compliant with the standards of the space industry, and also cryogenics, or high vacuum and high cleanliness systems. The design and simulation tasks are performed on a cluster of several workstation where all the most common CAD softwares are running: AutoCAD, INVENTOR, I-DEAS, CATIA. Moreover, also the ANSYS program is available for FEM simulation and analysis. The staff of the Service follows all phases of realization of a piece, from its design, to material procurement, to the tender for firms, to the actual construction, up to the integration and commissioning into the experimental system of the parts that have been produced. Since its birth the SPM participated to the most important experimental activities of INFN and gave its contribution also to many experiments carried by physicists of the Department. Currently, members of the staff play an important role in the engineering teams of experiments such as AMS, CUORE, and Virgo. For instance, since 2008 Corrado Gargiulo is responsible of the integration at CERN of the AMS experiment that will fly on the International Space Station.

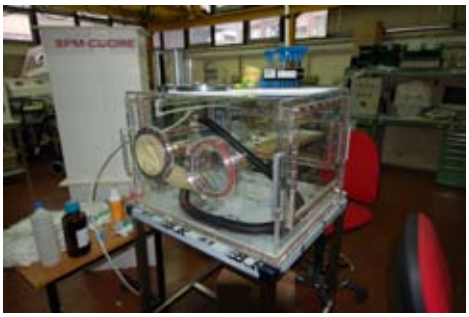


Figure 1: A clean box for the preparation of sensing crystals in CUORE experiment.

The **SOM (Servizio Officina Meccanica - Machine Shop Service)** of the INFN Section is an extended machine shop facility which is in charge of nine technicians that provide generic mechanical support to INFN and Department experiments and work also directly in building and commissioning parts of experimental systems, both on site and around the world.

The Servizio Meccanico is equipped with four milling machines, one of which, the C.B.Ferrari A15, has five axis with a CNC control and a precision of 20 microns over a range of 30 cm, four lathes, two of which are high precision tooling machines: the Shaublin 150 and the Shaublin 180 CCN. Moreover, a section of the machine shop is dedicated to metrology, with a Poly Galaxy Diamond 3D Measuring Machine (measuring volume: 0.5 m^3, precision $\simeq$ $2\mu m$), a Hommelwerke roughness meter and a Mitutoyo L.H. 600 linear height meter (precision $\simeq$ $1\mu m$, range 972 mm). Moreover, in the machine shop area two clean rooms are located: a class 10000 clean room which has been used to integrate parts of ATLAS, AMS and ALICE experiments, and a class 100 clean room, with a hut where the class 1 is reached. The class 100 room has been built to develop Virgo payloads and is used now to study new parts for second and third generation gravitational wave interferometers.

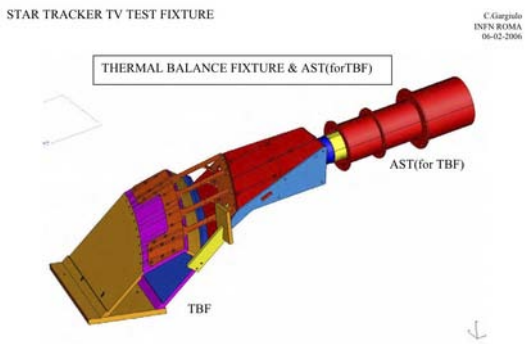


Figure 2: Design of the AMS Star Tracker.

The machine shop has also a room dedicated to a washing machine, equipped with a plant providing clean, demineralized water. A small unit providing ultrapure water is also placed in the class 100 clean room.

Other two services provided by the machine shop are a welding station (Plasma, T.I.G., soft welding) and two ovens for thermal treatments in air.

The Service participates in almost all the experimental activities of the INFN Section and gives important contributions also to the Department physicists, according to the convention between INFN and Department. For instance, the machine shop staff provided an important technical support to the Cosmic Microwave Background group in the Department.

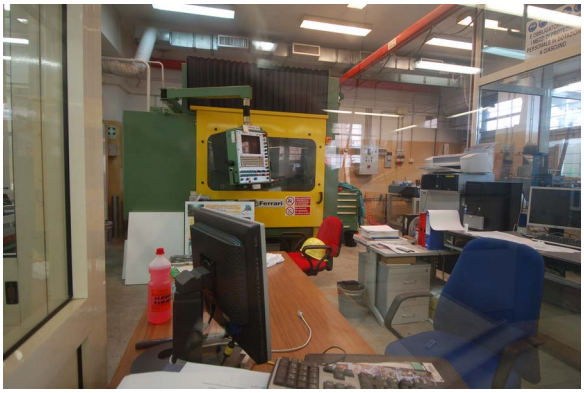


Figure 3: The C.B.Ferrari A15 milling machine

F1. Departmental Library

The Departmental Library has recently undergone a process of transformation both from the structural and logistic point of view, and a throughout modernization of the services.

The new location of the Departmental Library was inaugurated in 2005, and consists of a reading room with 46 places, 12 Personal Computers (one of which is specially equipped for the visually impaired) with direct access to the internet. The Library offers a series of services, from the traditional ones, like consulting and loan, to advanced ones, like reservation of work sessions on the PCs of the library or of the access to the wireless network with one's own laptop. These services are offered both to institutional users and to students that visit our University.

Figure 1: Main hall of the Departmental Library, with the front desk and the shelves displaying the latest issues of the subscribed journals. The reading room is located beyond the glass divider.

The catalogue of ancient and modern volumes (approximately 25000 books) is now fully automated. The catalogue of subscribed and historical journals (approximately 500 titles) is also automated. The bibliographic records are inserted into two important national databases (ACNP and SBN), so as to allow for the full on-line visibility of the heritage of our Library. The library provides document delivery (approximately 300 articles per year) within the interexchange circuit NILDE, and interlibrary loan with other libraries within the national circuit SBN and within international loan circuits. At the local level, the Library provides the following services: temporary loan for all students and institutional staff member of La Sapienza (approximately 5000 loans per year); reservation of internet accesses (12 PCs in the library) for research and consultation of on-line bibliographic resources; wireless connection of one's own laptop. All these services are accessible to all those that enroll as users at the Library (approximately 7000 enrolled users), providing their personal data. These data are stored in a database common to all the libraries of La Sapienza and of the territory of the Region Latium (Regione Lazio).

The Departmental Library takes active part to the national project of automation SBN, since 1990. This allows to share data and provide services to the users, without direct charges for the structure, but thanks to the centralized financial support of La Sapienza, via the SBN project. The automation process includes an experimental activity, aimed at improving the services offered to the users. It is already possible to access to the Library after the closing time, by means of a magnetic card which is currently released only to institutional users of the Department. Access to the Library is allowed to authorized enrolled users. The premises of the Departmental Library are controlled by a webcam circuit. Within the year, a new service will be made available, i.e., the automatic loan by means of the RFID technology. Thanks to the computer science competences of the Department of Physics, a software is being developed that will allow to download data from the database SEBINA/SBN and process them with the help of dedicated hardware, fully exploiting the RFID technology. Once tested, this software might be released and made accessible to other Departmental Libraries at La Sapienza. All volumes will be equipped with a RFID tag that will allow for full traceability and all users will be provided with an identifying card. Thanks to the association of these two elements, each user will be able to loan a book and register the operation in the loan database. The RFID technology will also allow to monitor the handling and recognition of the librarian material, making the procedure simpler, as compared to the long manual procedure of inventory control of the bibliographic material.

http://minosse.phys.uniroma1.it/web/home.html#

F2. APE Laboratory

The APE group is involved in research and development of High Performance Computing Architecture dedicated to theoretical physics applications (LQCD Lattice Quantum Chromodynamics, complex systems,...). Several generations of parallel supercomputers, known as "APE machines", have been built from the middle of 80's. The last APE supercomputer, APENEXT is installed in our department from 2006 and it shows a peak performance equal to 10 TeraFlops.

The APE group is currently composed of 4 staff people and 6 junior researchers with expertise ranging from hardware and software design to scientific applications coding and optimization. Current research activities focus on development of low latency and high bandwidth interconnection network for PC cluster (APENet+, 3-Dimensional Toroidal network optimized for LQCD computing platform), efficient use of (GP)GPU accelerators in theoretical physics (QUonG project) and design of specialized microarchitecture and systems optimized for scientific computing. Furthermore group members participate with leadership roles to EU FP7 project (SHAPES, EURETILE) in the area of embedded systems and high performance computing. The laboratory is equipped with storage and computing servers hosting CAD software to support ASIC and hardware design. Multiple high end PC clusters are also present to test and develop application software. A complete soldering station as well as test and measurement instruments, (high performances digital oscilloscope and logic analyzer) are used to test and verify hardware prototypes.

Figure 1: Laboratorio di Calcolo apeNEXT

http://apegate.roma1.infn.it
Related research activities: T3.

F3. The Tier–2 Computing Centre for LHC

The Tier–2 Computing Centre for LHC is a joint INFN–University effort, as most of the research activities in high energy physics in Italy. As a result most of the resources come from INFN–Sez. di Roma, while manpower is both from INFN and from University.

LHC experiments at CERN need large computing resources as well huge storage. In fact, each general purpose LHC experiment, such as ATLAS and CMS, is going to collect as much as 2–4 billions of events per year. Event size is of the order of 1 MB, resulting in a total of 2–4 PB of data to be stored. Data processing, moreover, is a CPU time–consuming activity for which the only solution is to parallelize jobs on many CPU cores. Taking into account that data analysis requires the comparison with simulated Monte Carlo events, and that the number of these events must be of the same order of magnitude of real data and is extremely costly in terms of CPU time, the figures given above almost double. Another factor 2–4 is required in order to guarantee some redundancy. Moreover, the experiments are expected to run for 10–15 years and data must be available for analysis for at least 20 years.

No single laboratory is able to concentrate enough computing power and enough storage in a single place, so that computing for LHC experiments is a distributed activity. We benefit from the existing GRID services, partly developed in Italy, to distribute both data and CPU load over several centres around the world, in a transparent way for the users. Resources are arranged hierarchically to make the system scalable. Data collected close to experiments are stored in the so–called Tier–0 at CERN, where they are initially processed as fast as possible. Once physics data have been reconstructed, events are distributed to few Tier–1 centres around the world, one of which is located in Bologna. Tier–1 centres have custodial responsibility of data and are in charge for data reprocessing, when needed.

From Tier–1's, data are distributed to Tier–2's that usually host a fraction of 20 % of data collected in a Tier–1. Tier–2's also provide computing power both for physicists' data analysis and for Monte Carlo production teams.

Users submit their jobs to a *Resource Broker* on the GRID which knows the location of data as well as the availability of computing power in each centre. It then distributes the jobs to many Tier–2's, close to target data, collects and merge all the results and returns them back to the user. Users, then, do not need to know about the exact location of data, nor those of computer centre. They do not need to know specific data file names, either. They just provide the *dataset name*, i.e. a conventional, human readable identifier of a large data sample: the system associates it to a set of files that can be distributed and/or replicated to few centres. Databases are used to keep track of data and their location.

One of the LHC Tier–2's is located in Roma, in the basement of the Department of Physics, serving both the ATLAS and CMS experiments. It hosts, in a dedicated room, seven innovative water cooled racks, each 42U high. All the racks are currently almost filled with rack CPU servers and storage units. The centre has been designed to host up to 14 racks.

Three tons of water are kept in a reservoir at 12°C by a redundant system of two chillers. A set of three computer controlled pumps makes the water flushing into a large pipe to which racks are attached in parallel. The racks, closed on all sides, contain a heat exchanger and three fans that produce a depression such that cool air from the bottom goes to the top of the rack creating a cool layer in front of the rack. Fresh air passes then through CPU's thanks to the fans contained in each server and goes to the back of the rack, where it is pushed to the bottom to be cooled down again. The usage of water instead of air to keep the units at the right temperature has many advantages: it consistently reduces power consumption, it makes the temperature much more stable (the temperature is stable around $(18 \pm 0.1)^\circ$C), it keeps the temperature of the environment comfortable and allows for some inertia in case of damages (the water stored in the reservoir is enough to keep the whole centre at a reasonable temperature for about 20 minutes, allowing for interventions).

All the racks are connected to a UPS protected power line up to 120 kVA that is able to maintain the system running for about 30 minutes in case of troubles on the electrical line. Moreover the centre is provided with sensors for floods and smoke detectors, as well as with an automatic fire extinguishing system, connected to sound and visual alarms.

Servers are internally connected by a 1 Gb LAN (to be upgraded to 10 Gb). The connection with the WAN is assured by two redundant connections to two different Garr POP's, via as many 10 Gb fibers.

A lot of effort has been spent to have the centre under full control. In particular we developed many monitoring tools that measure several quantities and report any anomaly to a centralized system from which we can check the current status and the history up to one year before of any monitored quantity. Every information is accessible via web even remotely and some intelligent agent has been deployed to automatically recover known problems. Moreover, the centre is equipped with a GSM interface that can be used either to send alarms to cell phones via SMS, or to receive commands from them in the form of an SMS. With this system we can remotely interrogate the databases as well as change some predefined configuration, even in the absence of any Internet access.

The centre runs almost smoothly since two years 7/24.

Related research activities: P1, P2, P3, P4, P5, P6.

F4. The Electronics Lab LABE

The LABE Laboratory is operated by the INFN unit in our Department. In the recent years it has been mainly engaged in building big electronics components for the LHC. In particular in the last decade was committed to design and assemble the Level 1 ATLAS muon trigger and to design and build the control Electronics of the LHCb experiment Muon Chambers. Moreover different experiments and projects like KLOE, Cuore, Opera and the student's laboratory received a useful support from LABE laboratory.

The Structure of LABE is mainly divided in three environments: the conceptual design of the architecture of the systems, the design and the project of sub-systems, the construction of electronic modules, and the test and debugs features of single modules.

The Laboratory is equipped with the state of the art of Electronic Design Automation (EDA) tools, a category of software tools dedicated to the design of electronic systems, such as printed circuit boards and integrated circuits. Using this facility we build inside the LABE different electronics modules with VLSI circuits: custom designed FPGA (Field Programmable Gate Array) and ASIC (Application specific Integrated Circuit) have been designed inside LABE.

Figure 1: Reworking system for High densiy electronics packages.

During the LHC design period we acquired competences to design Electronics for radiation environments, like space and high luminosity accelerators, an investigation that involves specific and different design techniques and technologies, like antifuse and Flash based FPGA. We also acquire abilities to test and to certificate electronics components using high intensity radiation sources and accelerator beams. In the context of the Cuore experiment, we have acquired competence in the modern battery powered detectors, based on Zigbee IEEE 802.15.4 wireless personal area networks, designing and realizing a network wireless pressure detectors.

Moreover the laboratory mantains some equipment for small productions of electronics prototype and for repairing, debugging and reworking modern electronics. A microscope,a Ball Grid Array reworking machine and two Surface Mounting reworking station are used to manage the modern electronics technology with High density pin out and a Printed Circuit Board (PCB) prototyping machine for fast prototyping of simple PCB. LABE is equipped with a small Mechanics workshop with a milling machine, drill press and a bending machine to provide the simple mechanics to support electronics. The LABE electronics instrumentations is equipped with the most advanced digital scopes, function generators, computers with VME, CANbus, I2c, SPI, and GPIB interfaces. An open space inside the LABE is provided to test instrumentation, measure and debug electronics. This space is now equipped with the system test for the LHCb muon chamber electronics, the system test for the Atlas Level 1 Muon electronics and test-bench for the SuperB Electromagnetic Calorimeter front-end Electronics.

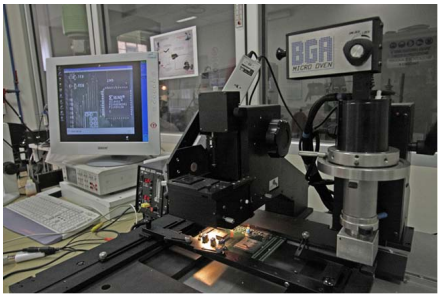


Figure 2: BGA(Ball Grid Array) packaging is commonly used to realize the huge number of connections between VLSI and multilayer PCB

http://maclabe.roma1.infn.it/
Related research activities: P3,P19,P20,P21,P25,P26.

Grants

1 European funding

FP6-NEST-PATH 2005-2008
"Extreme Events: Causes and Consequences (E2-C2)"
Local Responsible: A. Sutera
Local fund: 90,000 euro

European STREP project *TAGora* 2006-2009
European Responsible: V. Loreto
Local fund: 612,000 euro
http://www.tagora-project.eu

European Integrated Project ECAgents 2004-2008
Local Responsible: V. Loreto
Local fund: 280,000 euro
http://www.ecagents.org

European Project ATACD 2006-2009
Local Responsible: V. Loreto
Local fund 20,000 euro
http://www.atacd.net

ERC-IDEAS Senior Grant 2009-2014
"PATCHYCOLLOIDS"
Local Responsible: F. Sciortino
Local fund: 1,559,160 euro
http://pacci.phys.uniroma1.it/

ERC - IDEAS Starting Grant 2008-2013
"FEMTOSCOPY"
Local Responsible: T. Scopigno
Local fund: 1,544,400 euro

ECC Integrated Project EVERGROW 2004-2007
Local responsible: E. Marinari
Local fund: 400,000 euro
http://www.evergrow.org

European STREP project COMEPHS 2005-2008
Local Responsible: A. Bianconi
Local fund: 272,000 euro
http://www.physics.ntua.gr/comephs/

SOFTCOMP Network of Excellence 2008-2009
Local Responsible: F. Sciortino
Local fund: 24,000 euro
http://www.eu-softcomp.net/

Marie Curie Research/Training Network 2003-2008
"Dynamical Arrest"
Local Responsible: P. Tartaglia
Local fund: 250,000 euro
http://www.arrestedmatter.net/

2 Funding from Italian Ministry of Research (MIUR)

The Italian Ministry of Research (MIUR) supports fundamental research in Universities, mainly through the PRIN (Research Projects of National Interest)[1].

2.1 "PRIN 2005" (MIUR) Funding period: 2006-2008

"Meccanica statistica dei sistemi complessi"
National Responsible: V. Loreto
Local fund: 160,000 euro

"Nuove prospettive nella generazione e manipolazione di stati entangled e hyper-entangled"
Local Responsible: P. Mataloni
Local fund: 120,000 euro

"Dinamica e statistica di sistemi a molti e pochi gradi di libertà"
Local Responsible: A. Vulpiani
Local fund: 55,000 euro

"Stati arrestati in materia soffice a bassa densità: star polymers, laponite, liposomi, colloidi attrattivi"
Local Responsible: F. Sciortino
Local fund: 60,000 euro

"Studio di sistemi a forte correlazione elettronica"
Local Responsible: P. Calvani Local fund: 117,000 euro

"Metodi di simulazione per proprietà multi-scala di proteine immerse in matrici complesse"
Local Responsible: G. Ciccotti
Local fund: 32,442 euro

"Studio di strutture biocompativili mediante microscopia a forza atomica"
Local Responsible: C. Coluzza
Local fund: 32,000 euro

"Comunicazione quantistica sperimentale: nuovi metodi per la codificazione e il broadcasting dell'informazione quantistica"
Local Responsible: F. De Martini
Local fund: 128,000 euro

"Caratterizzazione di aerosol, nubi e specie chimiche minoritarie a supporto di modelli radiativi"
Local Responsible: G. Fiocco
Local fund: 48,550 euro

"Fisica statistica di sistemi con interazione a lungo raggio: studi analitici e numerici, dalla materia condensata alle strutture cosmologiche"
Local Responsible: A. Giansanti
Local fund: 32,000 euro

"Violazione di schemi e meccanismi standard dello stato metallico e superconduttivo nei sistemi fortemente correlati"
Local Responsible: M. Grilli
Local fund: 75,000 euro

"Interazione elettrone-reticolo ed effetti a molti corpi"
Local Responsible: L. Pietronero
Local fund: 138,000 euro

[1] Please note that the year appearing in the name of the grant ("PRIN 2005", "PRIN 2006" etc.) does not correspond to the actual funding period of the grant.

"La fisica nucleare e subnucleare nell'area romana: dai raggi cosmici agli acceleratori, 1930-70"
Local Responsible: F. Sebsatiani
Local fund: 20,250 euro

"Misura delle proprietà di non-equilibrio in sistemi elettroreologici tramite 'pinze ottiche"'
Local Responsible: G. Ruocco
Local fund: 51,352 euro

2.2 "PRIN 2006" (MIUR) Funding period: 2007-2009

"Cosmologia millimetrica con grandi mosaici di rivelatori"
National Responsible: P. de Bernardis
Local fund: 129,000 euro

"Sviluppo di cristalli scintillanti per rivelatori bolometrici per lo studio del doppio decadimento beta e di altri eventi fisici rari"
Local Responsible: E. Longo
Local fund: 35,600 euro

"Fasi della cromodinamica quantistica: teoria e fenomenologia"
Local Responsible: L. Maiani
Local fund: 72,000 euro

"Fisica dei sistemi complessi e disordinati: dai sistemi vetrosi ai modelli a molti agenti"
Local Responsible: G. Parisi
Local fund: 94,000 euro

"Raccolta di luce per un calorimetro a fibre scintillanti con ricostruzione di immagine e collaudo con fasci di particelle"
Local Responsible: G. DeZorzi
Local fund: 35,500 euro

"Sviluppo, caratterizzazione e ottimizzazione di rivelatori per fotoni, in termini di efficienza, uniformità di risposta e risoluzione temporale, realizzati con piombo, scintillatore e piombo, fibre scintillanti"
Local Responsible: G. D'Agostini Local fund: 23,000 euro

"Preparazione e messa a punto di un sistema di tracciatori per la misura degli effetti di channeling in cristalli curvi di silicio in vista del loro uso come collimatori di fasci adronici" Local Responsible: C. Luci
Local fund: 32,500 euro

"Interazioni fondamentali, unificazione e simmetrie di sapore oltre il modello standard nell'era del Large Hadron Collider"
National Responsible: G. Martinelli
Local fund: 43,500 euro

"Effetti radiativi degli aerosol nel mediterraneo centrale: integrazione di osservazioni e modelli di trasferimento della radiazione"
Local Responsible: A.M. Siani
Local fund: 34,000 euro

"Studio della stabilità dei vortici atmosferici isolati mediante sviluppi asintotici e predizione delle traiettorie dei tifoni"
Local Responsible: B. Tirozzi
Local fund: 15,185 euro

2.3 "PRIN 2007" (MIUR) Funding period: 2009-2011

"Superconduttivita' e fenomeni di coerenza in materiali non convenzionali e fortemente correlati"
Local Responsible: M. Grilli
Local fund: 72,632 euro

"Superconduttività e fenomeni di coerenza in materiali non convenzionali e fortemente correlati"
Local Responsible: L. Pietronero
Local fund: 83,970 euro

"Misure della distribuzione verticale, delle proprietà ottiche e degli effetti radiativi dell'aerosol artico troposferico dalla stazione di Thule (Groenlandia)"
Local Responsible: D. Fuà
Local fund: 29,500 euro

"Caratterizzazione della funzione del midollo spinale umano con risonanza magnetica nucleare"
Local Responsible: B. Maraviglia
Local fund: 29,146 euro

"Interferometri di terza generazione per la rivelazione delle onde gravitazionali"
Local Responsible: F. Ricci
Local fund: 61,800 euro

2.4 Other grants fron MIUR:

Progetto Lauree Scientifiche (MIUR) 2008-2009
Local Responsible: E. Longo
Local fund: 31,980 euro

3 Funding from other Italian Ministries

Ministero dell'Ambiente e della Tutela del Territorio e del Mare 2007-2009
"Hydrogen as an alternative ecological energy carrier: solid state hydrogen storage"
National Responsible: R. Cantelli
Local fund: 492,400 euro

4 Funding from other Italian agencies

ARPA Valle d'Aosta (Agenzia Regionale per la Protezione dell'Ambiente) 2006
"Valutazione dell'esposizione a radiazione solare ultravioletta in ambiente esterno presso una località montana della regione Valle d'Aosta"
Local Responsible: A.M. Siani
Local fund: 10.170 euro

Italian Space Agency 2007-2009
"BOOMERanG"
National Responsible: P. de Bernardis
Local fund: 309,860 euro

Italian Space Agency 2007
"Scientific Activity for the Programme: Planck HFI - Phase E"
Local Responsible: P. de Bernardis

Local fund: 100,990 euro

Italian Space Agency 2007
"Cosmology and Fundamental Physics from the Space - COFIS"
National Responsible: P. de Bernardis
Local fund: 554,265 euro

ARPA Valle d'Aosta (Agenzia Regionale per la Protezione dell'Ambiente) 2007
"Sorveglianza ozono, biossido di azoto e di irradianza UV con sistema spettrofotometrico Brewer"
Local Responsible: A.M. Siani
Local fund: 36.000 euro

Italian Space Agency 2008
"B-Pol"
National Responsible: P. de Bernardis
Local fund: 371,190 euro

Italian Space Agency 2007
"OLIMPO"
National Responsible: S. Masi
Local fund: 254,091 euro

Italian Space Agency, 2008-2010
"SW ROSA for OCEANSAT-2"
National Responsible: A. Sutera
Local Fund: 135,000 euro

Italian Space Agency 2008-2009
"HiGAL: Galactic Plane Survey with Herschel"
Local Responsible: F. Piacentini
Local fund: 58,742 euro

National Project for Antarctic Research 2008
"BRAIN"
National Responsible: S, Masi
Local fund: 90,000 euro

ARPA Valle d'Aosta (Agenzia Regionale per la Protezione dell'Ambiente) 2009
"Attività di sorveglianza e di studio dei dati di ozono totale e di irradianza ultravioletta tramite lo spettrofotometro Brewer"
Local Responsible: A.M. Siani
Local fund: 25.200 euro

Programma Vigoni, Ateneo Italo-Tedesco
"Teoria dei nuovi fenomeni negli spettri di fotoemissione dei superconduttori ad alta temperatura"
Local Responsible: M. Grilli
Local funds: 5,000 euro

5 Ph.D. Fellowships

Italian Space Agency 2007-2009
Ph.D. in Astronomy fellowship (M. Salatino)
Tutor: P. de Bernardis

VESF (Virgo-EGO) 2006-2008
Ph.D. fellowship for theoretical research on gravitational waves (S. Marassi)

Tutor: V. Ferrari

Università Italo Francese - Bando Vinci 2007-2010
PhD in Astronomy fellowship (A. Cruciani)
Tutor: P. de Bernardis

6 Funding from Private Companies

Kayser Italia 2008
"Phase-A Study for SAGACE satellite"
National Responsible: P. de Bernardis
Local fund: 190,000 euro

KAUST University
"The SolarPaint Project"
Local Responsible: A. Fratalocchi
Local fund: 300,000 USD

7 International Funding

Foundational Questions Institute 2008-2010
"Falsifiable Quantum-Gravity Theories of Not Everything"
Local Responsible: G. Amelino-Camelia
Local fund: 46,000 euro

8 Computational Time

DEISA Consortium
"Ab-initio Coulomb explosion simulation at x-rays (ACES-X)"
Local Responsible: A. Fratalocchi
Local fund: 360,000 CPU hours on power6 at Max-Planck

CINECA supercomputing Center, 2007
"Merging of globular cluster in the central galactic regions"
Local Responsible: P. Miocchi (in coll. with R. Capuzzo Dolcetta)
Local fund: 12,000 CPU hours

CINECA supercomputing Center, 2009
"Merging of globular cluster in the central galactic regions"
Local Responsible: P. Miocchi (in coll. with R. Capuzzo Dolcetta)
Local fund: 10,000 CPU hours

CINECA supercomputing Center, 2009
"Super-stellar cluster formation in the central galactic region"
Local Responsible: R. Capuzzo Dolcetta
Local fund: 12,000 CPU hours

Awards

Figure 1: left: Luciano Maiani, K.R. Sreenivasan and J. Iliopoulos; middle: Giorgio Parisi (second from the left) with (from left) Jean-Philippe Courtois, president of Microsoft International, Martin Taylor, vice president of the Royal Society, and Jules Hoffmann, president of the Acadmie des sciences.; right: Paolo de Bernardis

Luciano Maiani
Dirac Medal, International Center of Theoretical Physics (ICTP)(shared with J. Iliopoulos), 2007
"For their work on the physics of the charm quark, a major contribution to the birth of the Standard Model, the modern theory of Elementary Particles."

Giorgio Parisi
Microsoft European Science Award, 2007
"For his significant contribution to the advancement of science through computational methods"".

Giovanni Gallavotti
The Boltzmann Medal (shared with K. Binder), 2007
"For honoring outstanding achievements in Statistical Physics."

Luciano Pietronero
Enrico Fermi Prize, Società Italiana di Fisica, 2008
"For the demonstration of the presence of fractal structures in different self-organised phenomena"

Giorgio Parisi
Lagrange-CRT Foundation Prize, 2009

Paolo de Bernardis
Dan David Prize - Astrophysics-History of the Universe - (shared with A. Lange and P. Richards), 2009
"For their contribution to the study of cosmic microwave background with successful balloon borne experiments like BOOMERANG and MAXIMA."

Miguel Angel Virasoro
Enrico Fermi Prize, Società Italiana di Fisica, 2009
"For the discovery of a fundamental infinity-dimensions algebra to be applied to strings theory"

Figure 2: left: Giovanni Gallavotti; middle: Miguel Angel Virasoro; right: Luciano Pietronero (on the left) with G. Casati and L. Lugiato

Leonardo Gualtieri
Honorable Mention in the Gravity Research Foundation Essay Competition, 2007

Giuseppe Rocco Casale
C.I.S.B. Award (Centro Interdipartimentale di Ricerca per lo studio dei Modelli e dell'Informazione nei Sistemi Biomedici della Sapienza) for the best PhD thesis in Biophysics, 2007

Francesco Guerra
History of Physics Prize, Società Italiana di Fisica, 2008

Lucia Di Giambattista
Premio "Antonio Borsellino, XIX Congresso SIBPA, Rome September 17-20, 2008

Antonio Polimeni
Premio Tomassoni-Chisesi, Fondazione Sapienza, 2009

Riccardo Faccini
Premio Tomassoni-Chisesi, Fondazione Sapienza, 2009

Federico Ricci-Tersenghi
Premio Tomassoni-Chisesi, Fondazione Sapienza, 2009

Fabio Sciarrino
Medaglia Le Scienze per la Fisica and Medaglia della Presidenza della Repubblica, 2009

Nadeja Drenska
"Vito Volterra" Prize, Società Italiana di Fisica, 2009

Luca Lamagna
Award for the best communication at National Congress of Italian Society of Physics (SIF) - Section III: Astrophysics and Cosmic Physics, Bari, 2009

Michelangelo De Maria
Alexandre Koyr Medal, International Academy of the History of Science, 2009

Scientific Productivity

During the three years 2007-2009 the scientists of the Department of Physics of "Sapienza Università di Roma" have published 1488 articles on international referred journals. Many of these publications appeared on journals with the highest Impact Factor (I.F.): 60% of them on journals with I.F. greater than 3.

Impact Factor	0-1	1-3	3-5	5-10	> 10	Total
Theoretical Physics	36	96	41	30	4	207
Condensed matter physics and biophysics	52	255	181	55	10	553
Particle Physics	32	57	147	326	1	563
Astronomy Astrophysics	7	13	43	61	0	124
Geophysics	10	10	8	0	0	28
History of physics and physics education	13	0	0	0	0	13
Total	150	432	420	472	15	1488

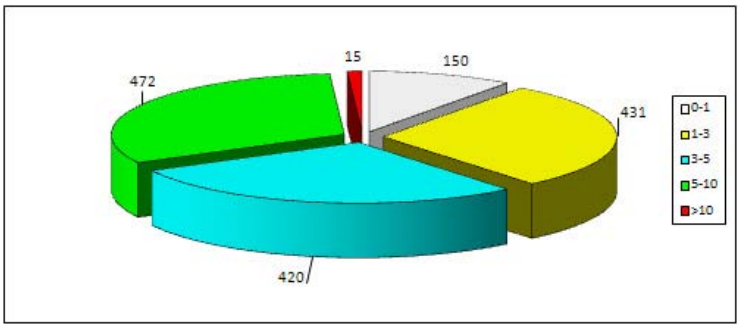


Figure 1: Published papers on international referred journals divided by Impact Factor ranges.

Among them, we published:

- 5 articles on Nature (I.F.=34.4)
- 2 articles on Reviews of Modern Physics (I.F.=33.1)
- 2 articles on Nature Materials (I.F.=29.5)
- 1 article on Nature Photonics (I.F.=22.9)
- 1 article on Phyiscs Reports (I.F.=17.7)
- 4 articles on Nature Physics (I.F.=15.5)
- 7 articles on Proceedings of the National Academy of Science of the U.S.A. (I.F.=9.4)
- 232 articles on Physical Review Letters (I.F.=7.3)
- 18 articles on Astrophysical Journal (I.F.=6.3)
- 9 articles on Journal of Cosmology and Astroparticle Physics (I.F.=6.3).

The research carried on in the Physics Department of Sapienza has indeed an high impact on the scientific community.

In the following we report the list of published papers in international referred journals divided by subject area and years. The papers are ordered by decreasing impact factor of the journal. Only the first author is listed to save space.

Theoretical Physics: 2007-2009

Publications 2009

[1] G. Amelino-Camelia, *Astrophysics: Burst of support for relativity*, Nat., **462**, (2009), pp. 291

[2] C. Martelli et al., *Identifying essential genes in Escherichia coli from a metabolic optimization principle*, Proc. Nat. Acad. Sci. U.S.A., **106**, (2009), pp. 2607

[3] I. Biazzo, *Theory of Amorphous Packings of Binary Mixtures of Hard Spheres*, Phys. Rev. Lett., **102**, (2009), pp. 195701

[4] L. Leuzzi et al., *Ising Spin-Glass Transition in a Magnetic Field Outside the Limit of Validity of Mean-Field Theory*, Phys. Rev. Lett., **103**, (2009), pp. 267201

[5] G. Seibold et al., *Model of quasiparticles coupled to a frequency-dependent charge-density-wave order parameter in cuprate superconductors*, Phys. Rev. Lett., **103**, (2009), pp. 217005

[6] E. Berti et al., *Comment on "Kerr Black Holes as Particle Accelerators to Arbitrarily High Energy"*, Phys. Rev. Lett., **103**, (2009), pp. 239001

[7] P. Contucci et al., *Structure of Correlations in Three Dimensional Spin Glasses*, Phys. Rev. Lett., **103**, (2009), pp. 017201

[8] G. Gubitosi et al., *A constraint on Planck-scale modifications to electrodynamics with CMB polarization data*, J. Cosmol. Astropart. Phys., **0908**, (2009), pp. 021

[9] G. Amelino-Camelia et al., *GAUGE: the GrAnd Unification and Gravity Explorer*, Exp. Astron., **23**, (2009), pp. 549

[10] R. Ciolfi et al., *Relativistic models of magnetars: the twisted-torus magnetic field configuration*, Mon. Not. R. Astron. Soc., **397**, (2009), pp. 913

[11] S. Marassi et al., *Gravitational wave backgrounds and the cosmic transition from Population III to Population II stars*, Mon. Not. R. Astron. Soc., **398**, (2009), pp. 293

[12] I. Flores-cacho et al., *The Sunyaev-Zeldovich effect in superclusters of galaxies using gasdynamical simulations: the case of Corona Borealis*, Mon. Not. R. Astron. Soc., **400**, (2009), pp. 1868

[13] K. Agashe et al., *Composite Higgs-Mediated FCNC*, Phys. Rev. D: Part. Fields, **80**, (2009), pp. 075016

[14] V. Cardoso et al., *Perturbations of Schwarzschild black holes in dynamical Chern-Simons modified gravity*, Phys. Rev. D: Part. Fields, **80**, (2009), pp. 064008

[15] C. Cherubini et al., *e^-e^+ pair creation by vacuum polarization around electromagnetic black holes*, Phys. Rev. D: Part. Fields, **79**, (2009), pp. 124002

[16] P. Lipari et al., *Multiple parton interactions in hadron collisions and diffraction*, Phys. Rev. D: Part. Fields, **80**, (2009), pp. 074014

[17] L. Caito et al., *GRB060614: a "fake" short GRB from a merging binary system*, Astron. Astrophys., **498**, (2009), pp. 501

[18] M. Ciuchini et al., *Searching For New Physics With B to K pi Decays*, Phys. Lett. B, **674**, (2009), pp. 197

[19] G. Amelino-Camelia et al., *A No-pure-boost uncertainty principle from spacetime noncommutativity*, Phys. Lett. B, **671**, (2009), pp. 298

[20] G. Amelino-Camelia et al., *Discreteness of area in noncommutative space*, Phys. Lett. B, **676**, (2009), pp. 180

[21] D. Fargion et al., *Detecting Solar Neutrino Flare in Megaton and km^3 detectors*, Nucl. Phys. B, **188**, (2009), pp. 142

[22] G. Parisi et al. *Phase diagram and large deviations in the free energy of mean-field spin glasses*, Phys. Rev. B: Condens. Matter, **79**, (2009), pp. 134205

[23] A. Cruz et al., *Spin Glass Phase in the Four-State, Three-Dimensional Potts Model*, Phys. Rev. B: Condens. Matter, **79**, (2009), pp. 184408

[24] V. Ferrari et al., *A semi-relativistic model for tidal interactions in BHNS coalescing binaries*, Classical Quantum Gravity, **26**, (2009), pp. 125004

[25] F. Leyvraz et al., *Short-time Poincare' recurrences in a broad class of many-body systems*, J. Stat. Mech: Theory Exp., **P02022**, (2009), pp. 1

[26] S. Franz et al., *Overlap interfaces in hierarchical spin-glass models*, J. Stat. Mech: Theory Exp., **-**, (2009), pp. P02002

[27] G. Parisi et al., *A replica approach to glassy hard spheres*, J. Stat. Mech: Theory Exp., **-**, (2009), pp. P03026

[28] F. Ricci-Tersenghi et al., *On the cavity method for decimated random constraint satisfaction problems and the analysis of belief propagation guided decimation algorithms*, J. Stat. Mech: Theory Exp., **-**, (2009), pp. P09001

[29] G. Amelino-Camelia et al., *Measurement of the spacetime interval between two events using the retarded and advanced times of each event with respect to a time-like world-line*, Gen. Relativ. Gravitation, **41**, (2009), pp. 1107

[30] M. Cassandro et al., *Phase transition in 1D random field Ising model with long range interactions*, Commun. Math. Phys., **228**, (2009), pp. 731

[31] M. Testa, *Identical particles, projectors and probabilities*, Phys. Lett. A, **373**, (2009), pp. 3624

[32] A. Pelissetto, *Coarse-Grained Models for Semi-Dilute Polymer Solutions under Good-Solvent Conditions*, J. Phys. Condens. Matter, **21**, (2009), pp. 115108

[33] G. Gallavotti, *On Thermostats: Isokinetic or Hamiltonian? finite or infinite?*, Chaos, **19**, (2009), pp. 013101

[34] D. Achlioptas et al., *Random Formulas Have Frozen Variables*, Siam J. Comput., **39**, (2009), pp. 260

[35] F. Calogero et al., *Towards a Theory of Chaos Explained as Travel on Riemann Surfaces*, J. Phys. A: Math. Theor., **42**, (2009), pp. 015205

[36] S. Manakov et al., *The dispersionless 2D Toda equation: dressing, Cauchy problem, longtime behavior, implicit solutions and wave breaking*, J. Phys. A: Math. Theor., **42**, (2009), pp. 095203

[37] M. Bruschi et al., *Integrability, analyticity, isochrony, equilibria, small oscillations, and Diophantine relations: results from the stationary Burgers hierarchy*, J. Phys. A: Math. Theor., **42**, (2009), pp. 454202

[38] F. Calogero et al., *Oscillatory and isochronous rate equations possibly describing chemical reactions*, J. Phys. A: Math. Theor., **42**, (2009), pp. 265208

[39] R. Droghei et al., *An isochronous variant of the Ruijsenaars-Toda model: equilibrium configuration, behavior in their neighborhood, Diophantine relations*, J. Phys. A: Math. Theor., **42**, (2009), pp. 445207

[40] A. Degasperis et al., *Multicomponent integrable wave equations: II. Soliton solutions*, J. Phys. A: Math. Theor., **42**, (2009), pp. 385206

[41] V. Alba et al., *Quasi-long-range order in the 2D XY model with random phase shifts*, J. Phys. A: Math. Theor., **42**, (2009), pp. 295001

[42] F. Calogero, *Comment on the paper entitled "Exact solution of N-dimensional radial Schroedinger equation for the fourth-order inverse-power potential, Eur. Phys. J. D 53, 123-125 (2009)"*, Eur. Phys. J. D, **53**, (2009), pp. 123

[43] F. Calogero et al., *New evolution PDEs with many isochronous solutions*, J. Math. An. Appl., **353**, (2009), pp. 481

[44] S. Dobrokhotov et al., *Behavior near the focal points of asymptotic solutions to the Cauchy problem for the linearized shallow water equations with initial localized perturbations*, Russ. J. Math. Phys., **16**, (2009), pp. 228

[45] G. Gallavotti, *Thermostats, chaos and Onsager reciprocity*, J. Stat. Phys., **124**, (2009), pp. 1121

[46] F. Belletti et al., *An in-depth view of the microscopic dynamics of Ising spin glasses at fixed temperature*, J. Stat. Phys., **135**, (2009), pp. 1121

[47] F.P. Toldin et al., *Strong-Disorder Paramagnetic-Ferromagnetic Fixed Point in the Square-Lattice $+/-$ J Ising Model*, J. Stat. Phys., **135**, (2009), pp. 1039

[48] L. Bertini et al., *Towards a Nonequilibrium Thermodynamics: A Self-Contained Macroscopic Description of Driven Diffusive Systems*, J. Stat. Phys., **135**, (2009), pp. 857

[49] G. Montani et al., *Linear Two-Dimensional MHD of Accretion Disks: Crystalline structure and Nernst coefficient*, Mod. Phys. Lett. A, **24**, (2009), pp. 2667

[50] G. Parisi, *The Mean Field Theory of Spin Glasses: The Heuristic Replica Approach and Recent Rigorous Results*, Lett. Math. Phys., **88**, (2009), pp. 255

[51] G. Amelino-Camelia et al., *On the 5D differential calculus and translation transformations in 4D κ-Minkowski noncommutative space-time*, Int. J. Mod. Phys. A, **24**, (2009), pp. 5445

[52] F. Guerra, *Coupled self-oscillating systems: theory and applications*, Int. J. Mod. Phys. B, **23**, (2009), pp. 5505

[53] F. Belletti et al., *JANUS: an FPGA-based System for High Performance Scientific Computing*, Comput. Sci. Eng., **11**, (2009), pp. 48

[54] B. Tirozzi et al., *Stability of the dynamics of an asymmetric neural network*, Commun. Pure Appl. An., **8**, (2009), pp. 655

[55] G. Corbò et al., *Magnetic dipoles and electric currents*, Am. J. Phys., **77**, (2009), pp. 818

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[57] F. Calogero, *Remembering Yakov Abramovich Smorodinsky*, Phys. At. Nucl., **72**, (2009), pp. 1

[58] R. Contino, *New Physics at the LHC: Strong versus Weak symmetry breaking*, Nuovo Cimento Soc. Ital. Fis., B, **32**, (2009), pp. 11

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[60] M. Bona et al., *First Evidence of New Physics in b s Transitions.*, PMC Phys. A, **A3**, (2009), pp. 6

[61] A. Degasperis et al., *Degasperis-Procesi equation*, Scholarpedia J., **4**, (2009), pp. 7318

Publications 2008

[1] G. Parisi, *Interaction ruling animal collective behavior depends on topological rather than metric distance: Evidence from a field study*, Proc. Nat. Acad. Sci. U.S.A., **105**, (2008), pp. 1232

[2] L. Leuzzi et al., *Dilute one-dimensional spin glasses with power law decaying interaction*, Phys. Rev. Lett., **101**, (2008), pp. 107203

[3] G. Parisi et al., *Large deviations in the free energy of mean-field spin glasses*, Phys. Rev. Lett., **101**, (2008), pp. 117205

[4] F. Belletti et al., *Nonequilibrium Spin-Glass Dynamics from Picoseconds to a Tenth of a Second*, Phys. Rev. Lett., **101**, (2008), pp. 157201

[5] E. Marinari et al., *Ranking by loops: a new approach to categorization.*, Phys. Rev. Lett., **101**, (2008), pp. 098701

[6] A. Pelissetto et al., *Nodal Quasiparticles and the Onset of Spin-Density-Wave Order in Cuprate Superconductors*, Phys. Rev. Lett., **101**, (2008), pp. 027005

[7] T. Jorg et al., *Entropic Effects in the Very Low Temperature Regime of Diluted Ising Spin Glasses with Discrete Couplings*, Phys. Rev. Lett., **100**, (2008), pp. 177203

[8] R. Contino et al., *Discovering the top partners at the LHC using same-sign dilepton final states*, J. High Energy Phys., **06**, (2008), pp. 026

[9] B. Tirozzi et al., *Emergent Synchronous Bursting in Oxutocin Neuronal Network*, PLoS Comput. Biol., **4, N7**, (2008), pp. 1

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[11] G. Amelino-Camelia et al., *Noether analysis of the twisted Hopf symmetries of canonical noncommutative spacetimes*, Phys. Rev. D: Part. Fields, **78**, (2008), pp. 0250051

[12] L. Gualtieri et al., *Transformation of the multipolar components of gravitational radiation under rotations and boosts*, Phys. Rev. D: Part. Fields, **78**, (2008), pp. 044024

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[32] R. Ruffini et al., *The Boundary Effect on Electron-Positron Pair-Productions*, Int. J. Mod. Phys. D, **28**, (2008), pp. 1231

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[40] F. Calogero et al., *Examples of isochronous Hamiltonians: classical and quantal treatments*, J. Phys. A: Math. Theor., **41**, (2008), pp. 175202

[41] S. Franz et al., *Mosaic length and finite interaction-range effects in a one dimensional random energy model*, J. Phys. A: Math. Theor., **41**, (2008), pp. 324011

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[49] G. Parisi, *On the survey-propagation equations in random constraint satisfiability problems*, J. Math. Phys., **49**, (2008), pp.125216

[50] F. Calogero, *A new class of solvable dynamical systems*, J. Math. Phys., **49**, (2008), pp. 052701

[51] A. Barra et al., *About the ergodic regime in the analogical Hopfield neural networks: Moments of the partition function*, J. Math. Phys., **49**, (2008), pp. 125217

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[53] D. Fargion et al., *Cherenkov Flashes and Fluorescence Flares on Telescopes: New lights on UHECR Spectroscopy while unveiling Neutrinos Astronomy*, Nucl. Instrum. Methods Phys. Res., Sect. A, **588**, (2008), pp. 146

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Publications 2007

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1st *Cesare Lattes Meeting*
Rio de Janeiro, Brazil, February 25-March 3, 2007
Members of the Physics Department in the Organizing Committee: R. Ruffini (co-Chair)
http://www.icranet.org/index.php?option=com_content&task=view&id=192&Itemid=295

Towards the B-POL mission for the cosmic vision program of ESA
CNR Headquarters, Rome, Italy, March 29-30, 2007
Members of the Physics Department in the Local Organizing Committee: P. de Bernardis

International meeting on Study of matter at extreme conditions (SMEC 2007)
Miami Beach, April 15-20, 2007
Members of the Physics Department in the Organizing Committee: N.L. Saini (co-Chair)

KAON '07
Frascati (Rome), Italy, May 21-25, 2007
Members of the Physics Department in the Local Organizing Committee: A. Di Domenico
http://www.lnf.infn.it/conference/kaon07/

Ab initio simulations in photochemistry: bringing together nonadiabatic dynamics and electronic structure theory
CECAM, Lyon, France; 23-25 May 2007
Members of the Physics Department in the Organizing Committee: Sara Bonella (co-Chair)
http://www.cecam.org/workshop-138.html

10th *Italian-Korean Meeting*
ICRANet, Pescara, Italy, June 25-30, 2007
Members of the Physics Department in the Local Organizing Committee: R. Ruffini
http://www.icranet.org/index.php?option=com_content&task=view&id=191&Itemid=773

Coherence and incoherence in strongly correlated systems
Sapienza University of Rome, Italy, July 3-7, 2007
Members of the Physics Department in the Local Organizing Committee: M. Grilli, S. Caprara, C. Castellani, G. Jona-Lasinio
http://gandalf.smc.infm.it/conference/ocs/

5th *Dynamics and thermodynamics of systems with long range interactions: theory and experiments.*
Assisi (Perugia), Italy, July 4-8, 2007
Members of the Physics Department in the Local Organizing Committee: Andrea Giansanti
http://pil.phys.uniroma1.it/ satlongrange/

STATPHYS23, the 23rd *International Conference on Statistical Physics of the International Union for Pure and Applied Physics (IUPAP)*
Genova, Italy, July 9-13, 2007
Members of the Physics Department in the Organizing Committee: L. Pietronero (Chair), V. Loreto (co-Chair)
http://www.statphys23.org/

International School on Complexity: Course on "Statistical Physics of Social Dynamics: Opinions, Semiotic Dynamics, and Language"
Ettore Majorana Foundation and Center For Scientific Culture, Erice, Italy, July 14-19, 2007 Members of the Physics Department in the Organizing Committee: V. Loreto (Chair)
http://pil.phys.uniroma1.it/ erice2007/

4th *Italian-Sino Workshop*
ICRANet, Pescara, Italy, July 20-29, 2007

Members of the Physics Department in the Local Organizing Committee: R. Ruffini
http://www.icranet.org/index.php?option=com_content&task=view&id=161&Itemid=234

2nd *Stueckelberg Workshop*
ICRANet, Pescara, Italy, September 3-7, 2007
Members of the Physics Department in the Local Organizing Committee: R. Ruffini, G. Montani, F. Cianfrani
http://www.icranet.org/index.php?option=com_content&task=view&id=220&Itemid=341

3rd *SRNWP Worksop on Short Range Ensemble Prediction Systems.*
Sapienza University of Rome, Italy, December 10-11, 2007
Members of the Physics Department in the Local Organizing Committee: A. Sutera, I. Bordi
http://www.meteoam.it/modules/newsPage/19072007/3rd_eps_ws_announce_111.htm

2nd*SRNWP-PEPS Workshop*
Sapienza University of Rome, Italy, December 12, 2007
Members of the Physics Department in the Local Organizing Committee: A. Sutera, I. Bordi
http://www.meteoam.it/modules/newsPage/19072007/3rd_eps_ws_announce_111.htm

Giornata per "Scienza 3"
Sapienza University of Rome, Italy, April, 2008

International Workshop on $e^+ e^-$ Collisions from phi to psi
Frascati (Rome), Italy, April 7-10, 2008
Members of the Physics Department in the Local Organizing Committee: C. Bini
http://www.lnf.infn.it/conference/phipsi08/

Workshop on the European Project: COMEPHS
University of Rome "La Sapienza", 9-11 April 2008
Members of the Physics Department in the Local Organizing Committee: Antonio Bianconi (Chair)

The XIV LNF Spring School "Bruno Touschek"
Frascati (Rome), Italy, May, 2008
Members of the Physics Department in the Local Organizing Committee: R. Faccini
http://www.lnf.infn.it/conference/lnfss/08/

Marie Curie School: Progress in simulating activated events
Valle Capore, Casaprota (RI), Italy 26-30 May 2008
Members of the Department in the Local Organizing Committee: Sara Bonella
http://www.cecam.org/workshop-209.html

5th *Italian-Sino Workshop*
Academia Sinica and National Dong Hwa University, Taipei-Hualien, Taiwan, May 28 - June 1, 2008
Members of the Physics Department in the Organizing Committee: R. Ruffini (co-Chair)
http://www.icranet.org/index.php?option=com_content&task=view&id=380&Itemid=235

1st *Workshop on Science and Technology through Long Duration Balloons*
Area Ricerca Tor Vergata, Rome, Italy, June 3-4, 2008
Members of the Physics Department in the Organizing Committee: S. Masi (Chair)
http://sait.oat.ts.astro.it/MSAIt790308/index.html

6th INTERNATIONAL CONFERENCE OF THE STRIPES (Stripes08) Quantum Phenomena in Complex Matter
ERICE-SICILY: 26 July - August 1, 2008
Members of the Physics Department in the Organizing Committee: Antonio Bianconi (Chair)

The 22nd Conference of the Condensed Matter Division of the European Physical Society (22-CMD-EPS)
Sapienza University of Rome, Italy, August 25-29, 2008
Members of the Physics Department in the Local Organizing Committee: C. Mariani (Co-Chair), M.G. Betti, C. Castellani, G. Parisi, G. Ruocco, S. Caprara, M. Grilli, C. Mariani, A. Polimeni, F. Ricci Tersenghi, F. Sciarrino,

T. Scopigno
http://www.cmdconferences.org/index1.html

CKM 2008: 5th International Workshop on the CKM Unitarity Triangle
Sapienza University of Rome, Italy, September, 2008
Members of the Physics Department in the Local Organizing Committee: R. Faccini
http://ckm2008.roma1.infn.it/

New opportunities and challenges for liquid and amorphous materials science
European Synchrotron Radiation Facility, Grenoble, France, September 2-5, 2008
Members of the Physics Department in the Organizing Committee: T. Scopigno (co-Chair)
http://www.esrf.eu/events/conferences/noclams

Wandering with Curiosity in Complex Landscapes: A scientific conference in honor of Giorgio Parisi for his 60th *birthday*
Sapienza University of Rome and Accademia dei Lincei, Rome, Italy, September 8-10, 2008
Members of the Physics Department in the Local Organizing Committee: E. Marinari, G. Martinelli, F. Ricci-Tersenghi, M. Virasoro.
http://chimera.roma1.infn.it/GIORGIO60/

The 11th *Management Committee Meeting of COST Action 726 "Long term changes and climatology of UV radiation over Europe"*
Sapienza University of Rome, Italy, September 18-19, 2008
Members of the Physics Department in the Local Organizing Committee: A.M. Siani

The legacy of "Edoardo Amaldi" in science society Sapienza University of Rome, Italy, October, 2008
Members of the Physics Department in the Local Organizing Committee: G. Pallottino
http://amaldi2008.roma1.infn.it/committee.htm

IEA Scientific Meeting of the Experts of Hydrogen Storage and Governments Representatives
Monte Porzio Catone, Rome, Italy, October 6-10, 2008
Members of the Physics Department in the Local Organizing Committee: R. Cantelli (Chair)
http://www.phys.uniroma1.it/gr/HYD/

International Conference on "FeAs High Tc Superconducting Multilayers and Related Phenomena" Superstripes 2008
Sapienza University of Rome, December 9-13, 2008
Members of the Physics Department in the Organizing Committee: Antonio Bianconi (Chair)

Conference on Dark Matter
Galileo Galilei Institute for theoretical Physics, Florence, Italy, February 9-11, 2009
Members of the Physics Department in the Organizing Committee: A. Melchiorri (Chair)
http://www.ggi.fi.infn.it/index.php?p=events.inc&id=34

Rare event in high-dimensional systems
Place and Time: UCLA, Los Angeles, USA; 23-27 February 2009
Members of the Department in the Local Organizing Committee: Giovanni Ciccotti
http://www.ipam.ucla.edu/programs/re2009/default.aspx

Workshop on New Horizons for Modern Cosmology
Galileo Galilei Institute for theoretical Physics, Florence, Italy, January 19 - March 13, 2009
Members of the Physics Department in the Organizing Committee: A. Melchiorri (co-Chair)
http://www.ggi.fi.infn.it/index.php?p=workshops.inc&id=23

Galileo Galilei Institute for theoretical Physics
Conference on Dark Matter
Galileo Galilei Institute for theoretical Physics, Florence, Italy, March 3 - April 4, 2009
Members of the Physics Department in the Organizing Committee: A. Melchiorri (Chair)

http://www.ggi.fi.infn.it/index.php?p=events.inc&id=40

International meeting on Study of matter at extreme conditions (SMEC2009)
Miami - Western Caribbean. March 28 - April 2, 2009
Members of the Physics Department in the Organizing Committee: N.L. Saini (co-Chair)

The International Conference in Honor of Ya. B. Zeldovich 95th *Anniversary*
Minsk, Belarus, April 20-23, 2009
Members of the Physics Department in the Organizing Committee: R. Ruffini (co-Chair)
http://www.icranet.org/zeldovich

Neutron Stars as Gravitational Wave Sources
Astronomical Observatory of Rome, Monte Porzio Catone (Rome), Italy, April 21-23, 2009
Members of the Physics Department in the Organizing Committee: V. Ferrari (Chair), L. Gualtieri (co-Chair)
http://www.neutronstars.net78.net/

The XIV LNF Spring School"Bruno Tousche"
Frascati (Rome), Italy, May, 2009
Members of the Physics Department in the Local Organizing Committee: R. Faccini
http://www.lnf.infn.it/conference/lnfss/09/

La Sapienza di Darwin
Sapienza University of Rome, Italy, May, 2009
Members of the Physics Department in the Local Organizing Committee: C. Cosmelli (Chair)
http://agenda.infn.it/internalPage.py?pageId=0&confId=1344

Sobral Meeting
Sobral, Brazil, May 26-29, 2009
Members of the Physics Department in the Organizing Committee: R. Ruffini (co-Chair)
http://www.icranet.org/index.php?option=com_content&task=view&id=435&Itemid=814

EPSRC symposium workshop on molecular dynamics
Warwick mathematics institute, Warwick, UK; 1-5 June 2009
Members of the Department in the Organizing Committee: Giovanni Ciccotti (co-Chair)
http://www2.warwick.ac.uk/fac/sci/maths/research/events/$2008_2$009/symposium/wks5/

TAGora workshop at the Hypertext 2009 conference
Torino, Italy, June 29 - July 1, 2009
Members of the Physics Department in the Organizing Committee: V. Loreto (Chair).
http://www.tagora-project.eu/blog/2009/03/27/ht09-workshop-semiotic-dynamics-in-online-social-communities/

6th *Italian-Sino Workshop*
Pescara, Italy, June 29-July 1, 2009
Members of the Physics Department in the Local Organizing Committee: R.Ruffini, C. L. Bianco
http://www.icranet.org/index.php?option=com_content&task=view&id=458&Itemid=825

12th *Marcel Grossmann Meeting*
UNESCO headquarters, Paris, France, July 12-18, 2009
Members of the Physics Department in the Organizing Committee: R. Ruffini (Chair)
http://www.icra.it/MG/mg12/en/

EPSRC Network mathematical chellenges of molecular dynamics
University of Bath, Bath, UK: 13-15 July 2009
Members of the Physics Department in the Organizing Committee: Giovanni Ciccotti (co-Chair)
http://www.md-net.org.uk/events/$bath_ju_2$009.htm

International meeting onLocal distortions and Physics of Functional materials (LPF09)
Frascati (Roma), Italy, 22-24 July, 2009

Members of the Physics Department in the Local Organizing Committee : N.L. Saini

Searching for New Physics at the LHC
The Galileo Galilei Institute for Theoretical Physics, Florence, Italy, August 31 - October 30, 2009
Members of the Physics Department in the Organizing Committee: R. Contino (co-Chair)
`http://ggi-www.fi.infn.it//index.php?p=workshops.inc&id=26`

6th *International workshop on relaxation in complex systems (IDMRCS)*
Sapienza University of Rome, Italy, September 1-5, 2009
Members of the Physics Department in the Local Organizing Committee: G. Ruocco (Chair)
`http://denali.phys.uniroma1.it/ idmrcs6/`

QIPC09 - Quantum Information Processing and Communication
Sapienza University of Rome, Italy, September 21-25, 2009
Chairman: F. De Martini and P. Mataloni, Members of the Physics Department in the Local Organizing Committee: C. Cosmelli, F. Sciarrino, G. Vallone
`http://qipc09.phys.uniroma1.it/`

1st *Galileo-XuGuangqi meeting*
Shanghai, China, October 26-30, 2009
Members of the Physics Department in the Organizing Committee: R.Ruffini (co-Chair)
`www.icranet.org/galileo-xuguangqi`

11th *Italian-Korean Meeting*
Sogang University, Seoul, South Korea, November 2-4, 2009
Members of the Physics Department in the Organizing Committee: R.Ruffini (co-Chair)
`http://cquest.sogang.ac.kr/`

Algorithms in macromolecular modeling
University of Texas, Austin, USA; 11-15 November 2009
Members of the Department in the Local Organizing Committee: Giovanni Ciccotti (co-Chair)
`http://www.ices.utexas.edu/am3/`

7th *Progress Meeting (PM7) of the ASI project "Software ROSA for OCEANSAT-2"*
Sapienza University of Rome, Italy, December 2-3, 2009
Members of the Physics Department in the Local Organizing Committee: A. Sutera, I. Bordi

5th *Australasian Conference on General Relativity*
Christchurch, New Zealand, December 16-18, 2009
Members of the Physics Department in the Organizing Committee: R.Ruffini (co-Chair)
`http://www2.phys.canterbury.ac.nz/ACGRG5/`