Presentation of the research activities
Dipartimento di Fisica, 30 Sept 2019

from the cosmic microwave radiation to the hunt for exoplanets: a cosmic journey through the research activities in astrophysics

Raffaella Schneider
On behalf of the Astrophysics faculty members

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the cosmic history in 1 slide…

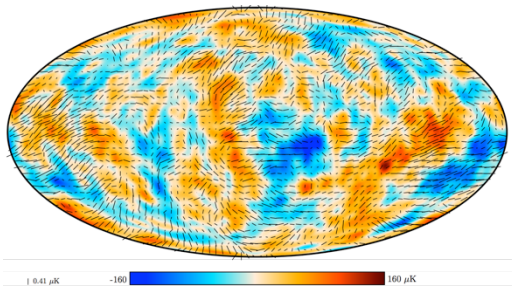
observational and theoretical cosmology
de Bernardis, Battistelli, De Petris, Melchiorri, Masi, Maoli, Lamagna, Piacentini

extragalactic astrophysics
Schneider, Pascale

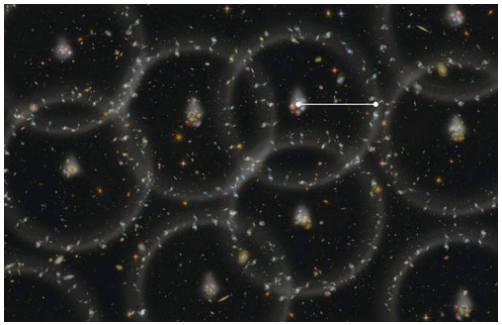
Stellar and Galactic astrophysics
Capuzzo-Dolcetta, Meddi, Merafina, Pascale

Observational and theoretical cosmology

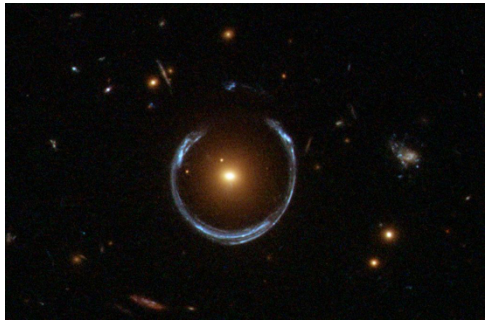
What is the physics of the very early Universe ?
What is driving the current accelerated expansion of the Universe ?
What formed the observed structure at large scales as galaxy clusters and super-clusters ?



CMB



BAO



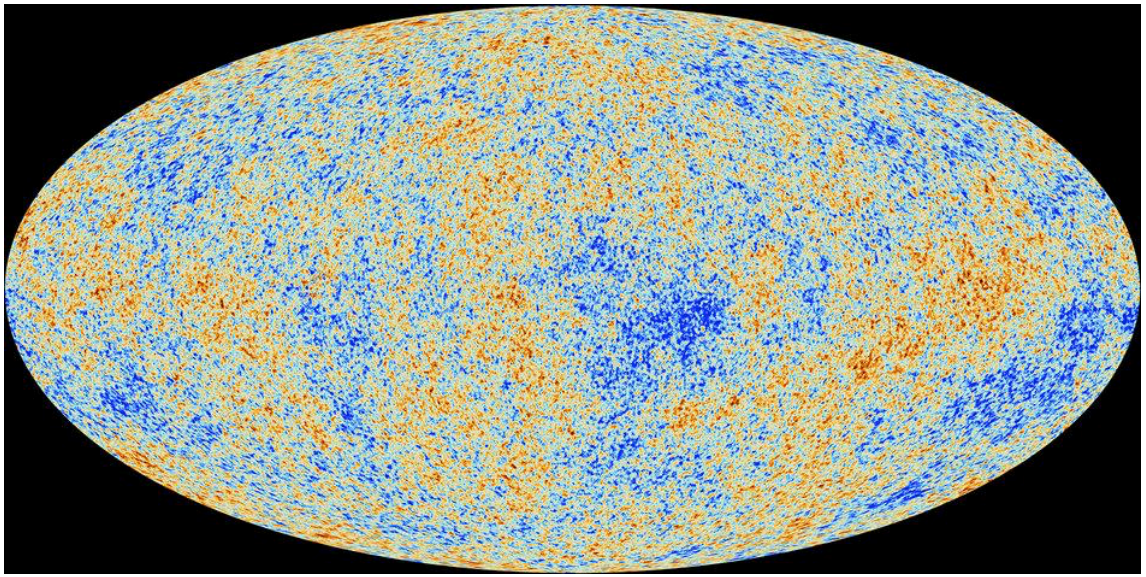
Lensing

The current answers to these questions are, respectively, Inflation, Dark Energy and Dark Matter. However, we simply don't know what these things are and we never detected them in laboratory. Cosmology is currently the only place where new physics is needed. We consider three major observables: Cosmic Microwave Background (CMB) anisotropies, Baryon Acoustic Oscillation (BAO) in galaxy surveys and weak lensing.

Observational and theoretical cosmology

In our department we mainly focus on the cosmic microwave background radiation that was emitted only 380.000 years after the Big Bang and it provides a picture of the infant Universe

temperature anisotropies map measured by the Planck satellite



Credits: ESA and the Planck Collaboration

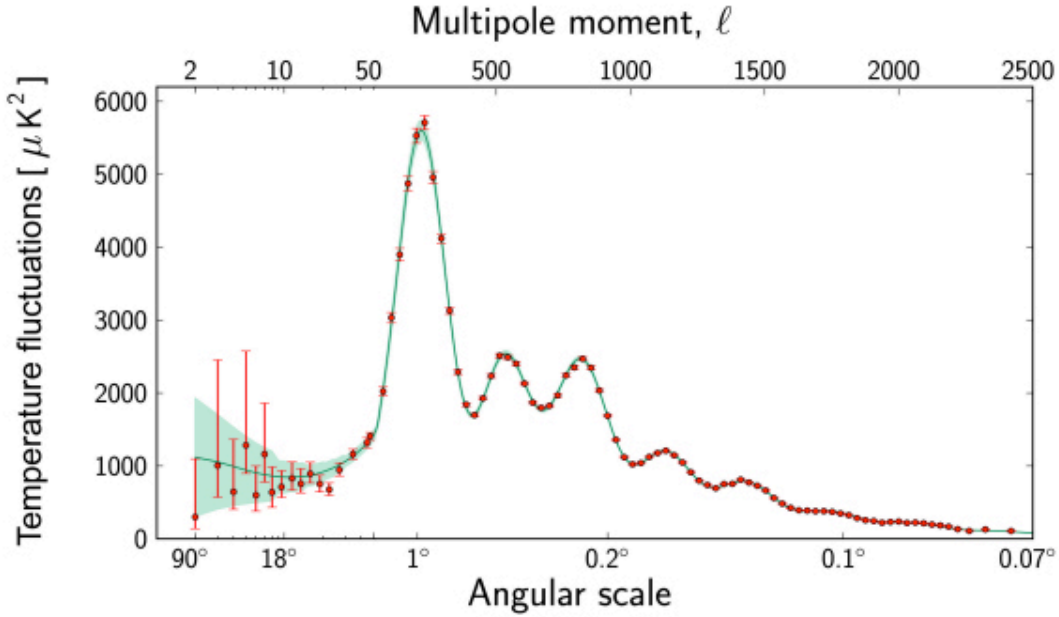
Gruber Prize for cosmology 2018

observational and theoretical cosmology
de Bernardis, Battistelli, De Petris, Maoli, Masi, Melchiorri, Lamagna, Piacentini

Observational and theoretical cosmology

These observations have allowed to infer the age of the Universe, its geometry, the mass fraction in ordinary and dark matter, and many more properties

power spectrum of temperature anisotropies measured by Planck



Credits: ESA and the Planck Collaboration

observational and theoretical cosmology
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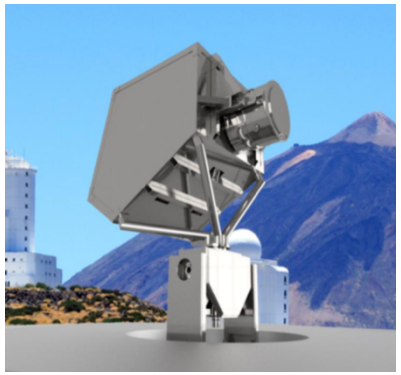
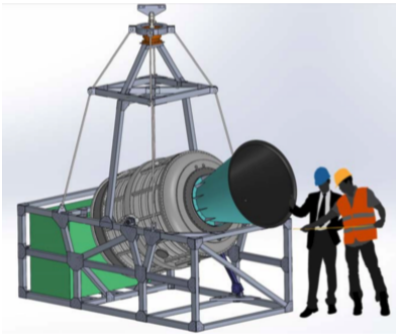
Observational and theoretical cosmology



Cosmic Microwave Background polarization
The Large Scale Polarization Explorer LSPE

Designed to measure the **primordial gravitational waves** imprinted in the **polarization of the Cosmic Microwave Background**

Composed by
- a Ground based telescope in Tenerife (lead by University of Milano)
- A balloon based telescope, for a polar long duration flight. 15 days at 40 km altitude.
  (lead by Sapienza)



observational and theoretical cosmology
de Bernardis, Battistelli, De Petris, Melchiorri, Masi, Lamagna, Piacentini

Observational and theoretical cosmology

Cosmic Microwave Background polarization
LiteBIRD

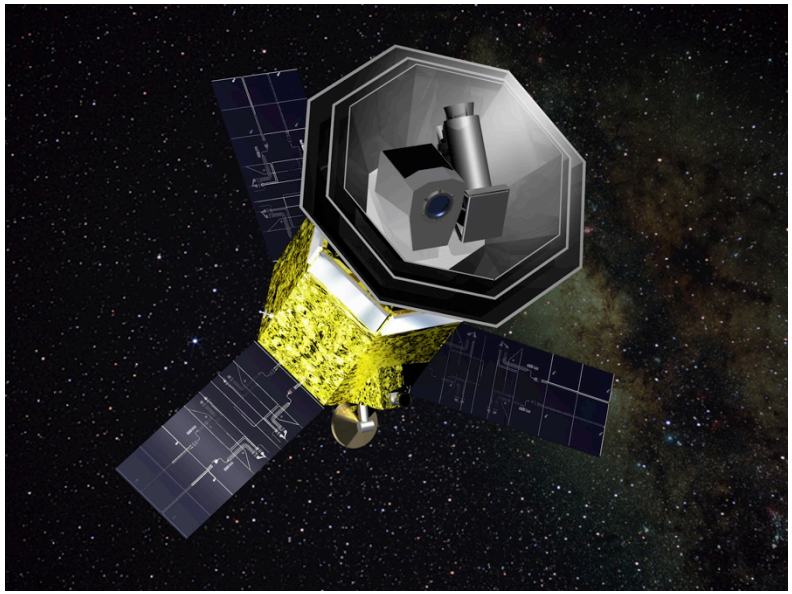
LiteBIRD is a Space Telescope for the Cosmic Microwave Background polarization.
With respect to Planck:

- increased sensitivity
- Increased accuracy and control of systematic effects in polarization
- Reduced angular resolution (most of the signal is at large scales)

International collaboration:

- Lead by Japan Space Agency (JAXA)
- Contributed by NASA
- Contributed by ESA and European Space Agencies, ASI (Italy) and CNES (France) in particular
- Mission selected by JAXA and planned for 2028

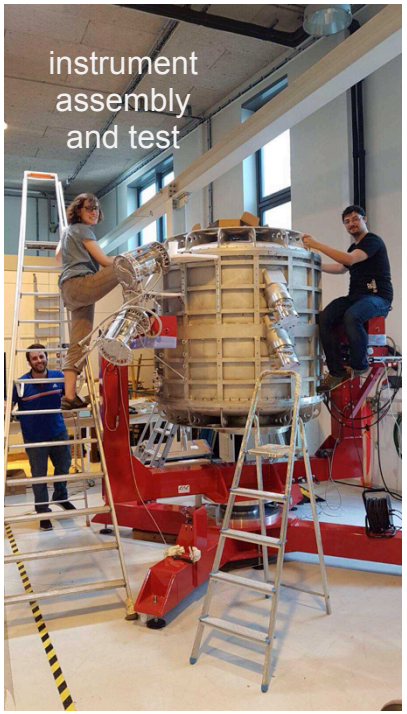
Members of the Observational Cosmology Group in Sapienza have leading role in the collaboration

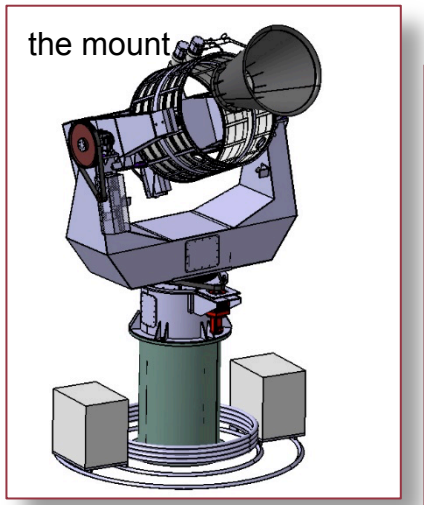


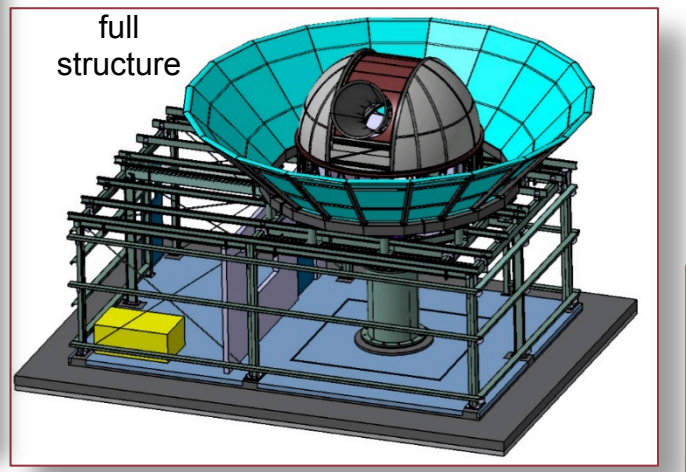
observational cosmology
de Bernardis, De Petris, Masi, Lamagna, Piacentini

QUBIC

Bolometric interferometer dedicated to B-modes polarization measurements
To be installed in Argentina
P.I. Prof. Silvia Masi







observational cosmology
Masi, de Bernardis, Battistelli, De Petris, Lamagna, Piacentini

Observational and theoretical cosmology

Along its long journey, the cosmic microwave radiation interacts with different structures: galaxies and galaxy clusters, that leave imprints on its spectrum through the Sunyaev-Zel'dovich (SZ) effect

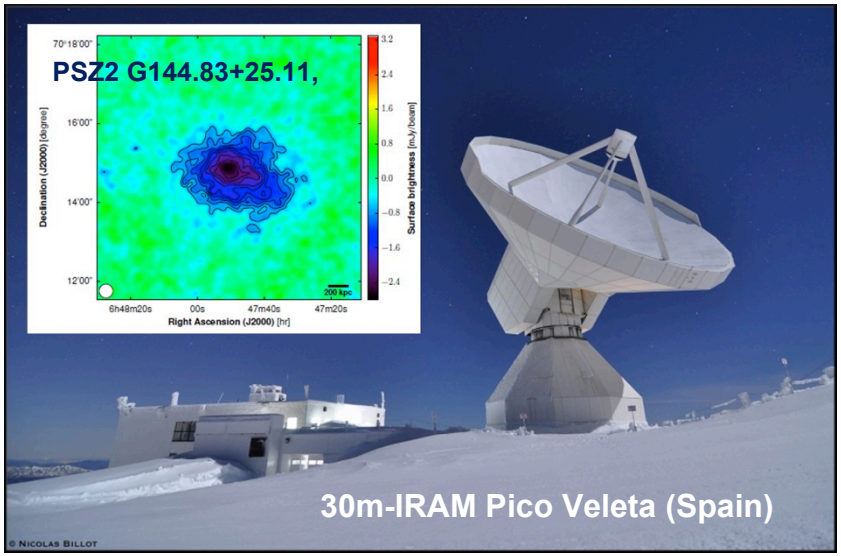
Credits: Silvia Masi and the Olimpo collaboration

observational and theoretical cosmology

de Bernardis, Battistelli, De Petris, Melchiorri, Masi, Lamagna, Piacentini

Observations and simulations of clusters of galaxies

Clusters of galaxies are powerful target to provide useful cosmological information

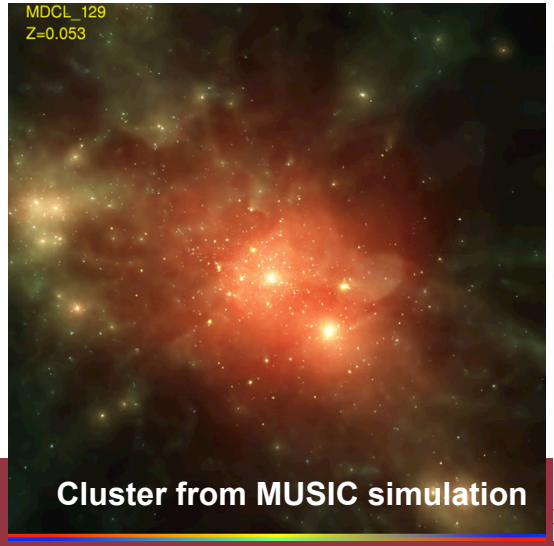


Ground-based observations of thermal Sunyaev-Zel'dovich effect at microwaves towards tens of clusters are ongoing with NIKA2, the kilo-pixel KIDs camera at focus of 30-m IRAM telescope in Spain.

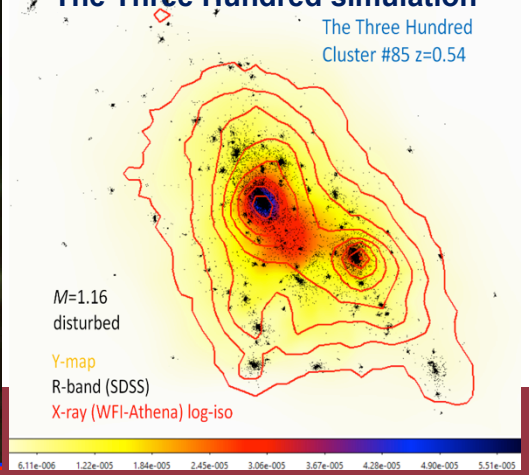
The reconstruction of baryons distribution with high angular resolution minimizes dangerous biases on cosmological application.

State-of-art hydrodynamical simulations allow us to "play" with synthetic clusters.

Optical, X-ray and SZ effect maps to compare with real observations and/or to check instruments observational capabilities.



Optical/X/SZ maps of a cluster from The Three Hundred simulation



Microwave/millimetric observations with 100 m-class telescopes

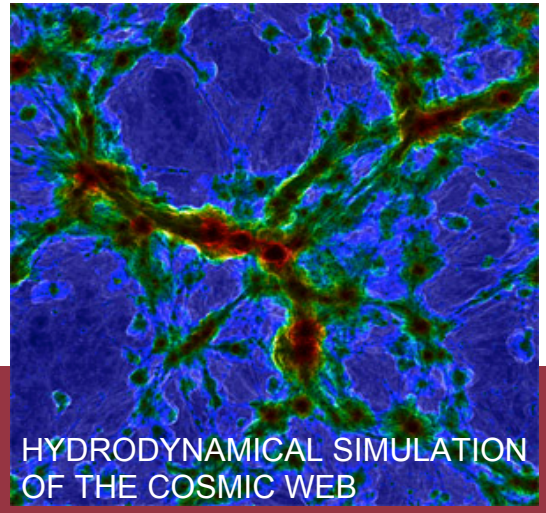
- Anomalous Microwave Emission (a.k.a Spinning Dust) from extragalactic sources is still a question for modern astrophysics

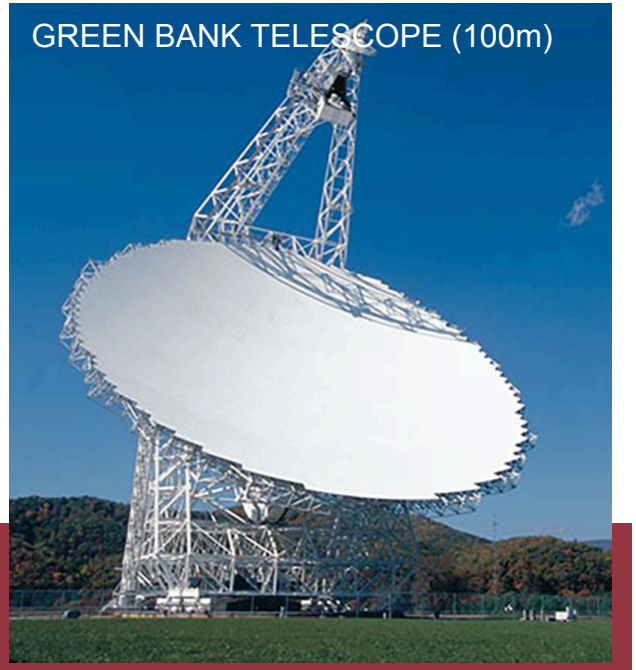
- 64m Sardinia Radio Telescope observations on M31 at 6.7GHz and 22GHz are being carried-on through a large observational project led by Sapienza

  (PI: E. Battistelli)

- Filamentary structures between galaxy cluster (cosmic web) can be studied through high resolution Sunyaev Zel'dovich effect
- 100m Green Bank Telescope is being used for this goal

  (PI: E. Battistelli)





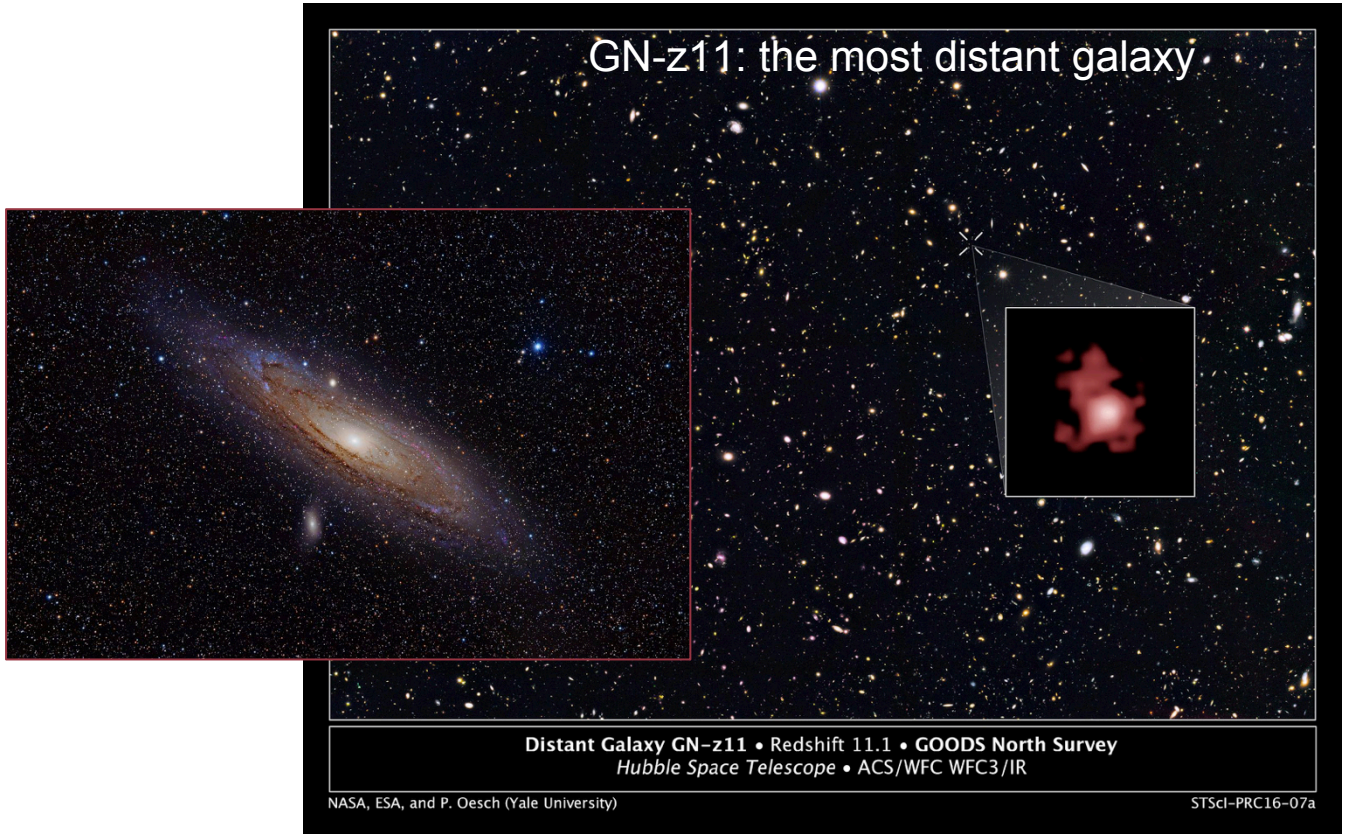
Extragalactic Astrophysics

The FIRST group studies the formation and evolution of the galaxies and their nuclear black holes, starting from the first stars that form 200 Myr after the Big Bang

The Extremely Deep Field of the Hubble Space Telescope

Credits: NASA, ESA, HUDF09

Extragalactic Astrophysics

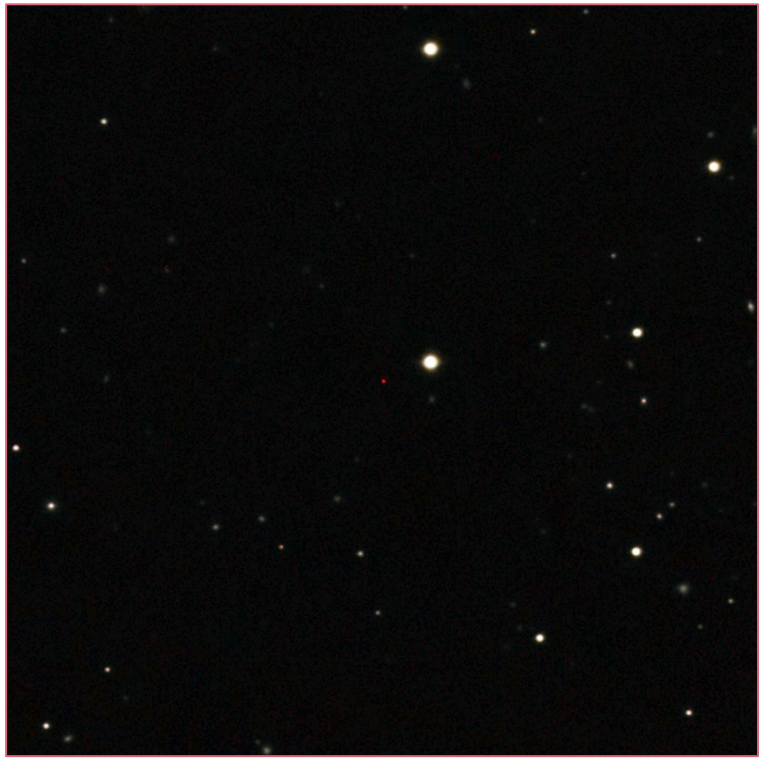


We aim to understand how galaxies like GNz-11 can evolve into galaxies like the Milky Way or Andromeda and if GN-z11 is one of the first galaxies or if there is something else that has formed at even earlier cosmic times and that it is still beyond our observational frontier.

Extragalactic Astrophysics

the existence of supermassive black holes with masses of billion of solar masses when the Universe was less than 1 Gyr old is one of the most important open problems in extragalactic astrophysics.

ULAS J1120: a 2 10^9 M_{sun} black hole, 770 Myr after the Big Bang

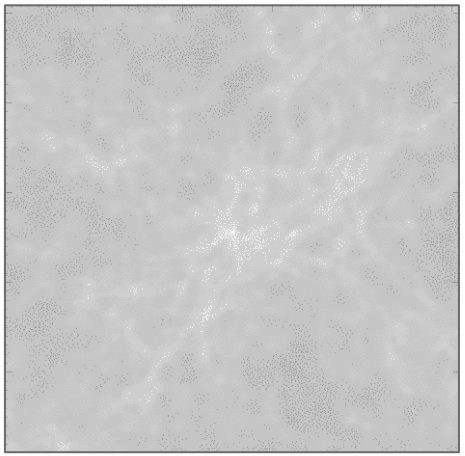


Extragalactic Astrophysics

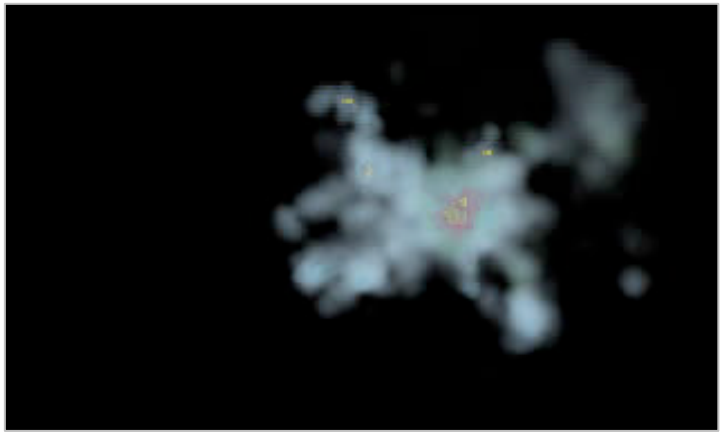
We follow a multi-band approach comparing our theoretical models with observations in different bands of the electomagnetic spectrum (X-rays, UV, optical, IR and radio) and predicting the gravitational wave signals produced by merging compact binaries and supermassive black hole binaries

AMALDI
RESEARCH CENTER

Graziani+2015,2017



Graziani+2019

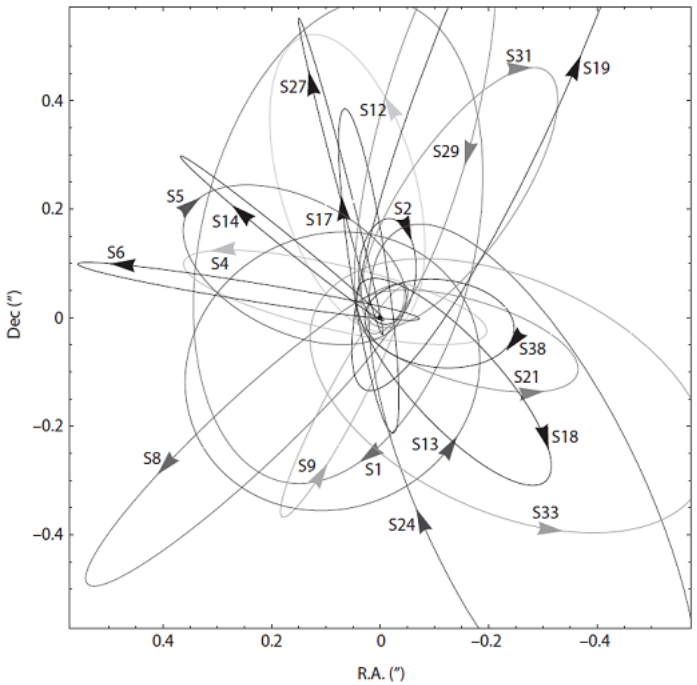


numerical simulations of evolving galaxies
Left panel: Milky Way-like galaxy Right panel: primordial galaxy

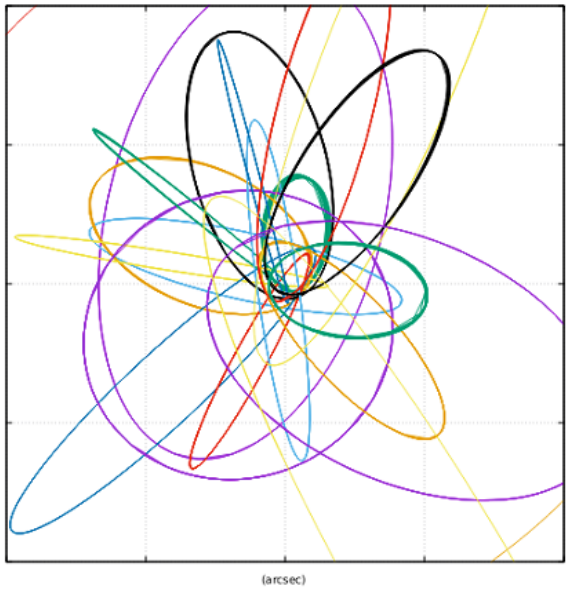
Stellar and galactic astrophysics

By means of detailed theoretical models and numerical simulations, a research group (ASTRO group, lead by R. Capuzzo Dolcetta) in our Dep. has reached important results about a series of topics concerning the Physics in galactic environment, over many length and time scales (from planets to supermassive black holes, SMBHs).

The observed orbits of S-stars in the Galaxy central region



Numerical simulation of star orbits in the field of a SMBH



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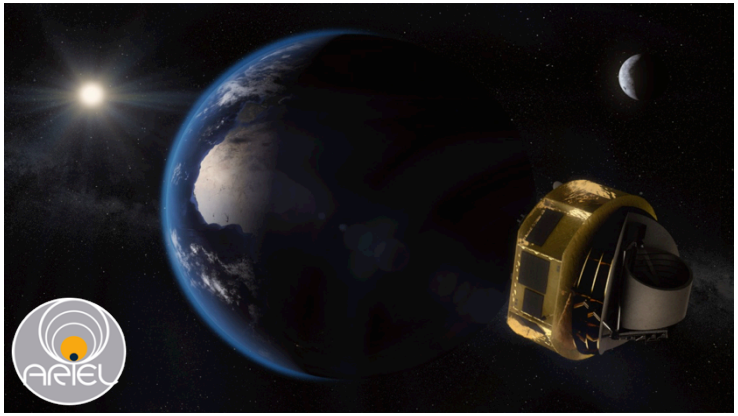
Exoplanets

Every star in the Milky Way has on average one planet. Today, we have detected more than 4,000 exoplanets. We still know little about the true nature of these worlds: mass, radius and little spectroscopy. How do exoplanets form? And, most importantly, how common is our own Solar System?

Known planets are very different from those in our Solar System. K2 18b is a temperate planet with water vapour traces detected, but with mass 8x that of Earth. There are many more with temperatures spanning from cold to 1000K and above

We want to understand the exoplanet diversity.

We'll do this with ARIEL, an ESA space mission that will characterize the atmospheres of 1000 exoplanets.



Collaboration with other research institutions in Rome

- Istituto Nazionale di Astrofisica (INAF)

Osservatorio Astronomico di Roma – Monteporzio Catone (OAR)
Istituto di Astrofisica e Planetologia Spaziale (IAPS)

- Istituto Nazionale di Fisica Nucleare (INFN)
- Agenzia Spaziale Italiana (ASI)
- ESA/ESRIN
- CNR
- Tor Vergata, Roma 3

Future perspectives

- Data science
- Space industries
- Research and Industrial software developer
- Financial services
- PhD program in Astronomy, Astrophysics and Space Science

Joint program between Sapienza (4+1 ARC), Tor Vergata (4) and INAF (3) = 12 grants
https://phd.uniroma1.it/web/ASTRONOMY-ASTROPHYSICS-AND-SPACE-SCIENCE

- Master in scienza e tecnologia spaziale (Tor Vergata University)

https://www.mat.uniroma2.it/masterst

Master degree in Astronomy and Astrophysics

Reference person: Prof. M. de Petris

7 compulsory courses (42 CFU) and 5 additional courses (2 with no constraints) (30 CFU)

1st semester

Processi e plasmi astrofisici (T)

Relatività generale (T)

Fisica superiore (T)

Astrophysics Laboratory

2nd semester

Physical Cosmology (T)

Astrofisica stellare (T)

Theoretical astrophysics (T)

Astrophysics Laboratory

Observational cosmology

Ottica astronomica

Dinamica dei sistemi stellari (T)

Astrofisica delle Alte energie (T)

Astrofisica extragalattica

Planets and exoplanets

1st semester

Cosmologia teorica (T)

Sistemi autogravitanti (T)

Evoluzione chimica dell'Universo (T)

Particle and astroparticle physics

Experimental gravitation

Introduzione alla gravità quantistica (T)

Methods of space astrophysics

Laboratorio di calcolo avanzato

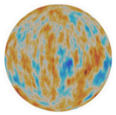
Additional information on research in astrophysics

https://www.phys.uniroma1.it/fisica/ricerca/aree-tematiche-e-gruppi-di-ricerca/astronomia-astrofisica-e-geofisica

ASTRONOMY, ASTROPHYSICS AND GEOPHYSICS

We are living exciting times for Astrophysics and Cosmology, being able to measure electromagnetic signals produced during all phases of the evolution of the Universe. Our Department is giving key contribution to this scientific exploration in several areas.

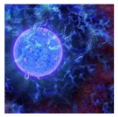
- **Cosmology**



Cosmic Microwave Background (CMB) Science. CMB photons cross most of the universe, in space and time, before reaching us. So their observational properties (spectrum, anisotropy, polarization, statistics) allow to study directly the evolution of the universe in its earliest phases. We are active in the measurement of CMB anisotropy in the direction of clusters of galaxies, building original experiments and developing new, custom technology and methods as specified below. The **OLIMPO** experiment is aimed at measuring the spectral-spatial anisotropy of the mm-wave sky. The **QUBIC** and **LSPE** experiments are aimed at measuring CMB polarization at large and itermediate scales from the high Argentinian Andes and from the Arctic winter stratosphere, respectively. The **COSMO** experiment is aimed at measuring spectral distortions of the CMB from Dome-C (Antarctica) using a cold Fourier Transform Spectrometer. We are also developing new detector arrays exploiting the Kinetic Inductance Detector technology, in collaboration with IFN-CNR. These detectors have been selected to operate on OLIMPO (140, 200, 340, 480 GHz) and COSMO (140, 220 GHz). Future applications at larger telescopes at lower frequency are under study. The **BOOMERanG** and **Planck** surveys, where our group gave very important contributions, produced a wealth of new information, which is still being analyzed with original techniques, in optimal data fusion with other cosmological data, constrianing the details of the cosmological model.

Membri: De Bernardis, Battistelli, De Petris, Melchiorri, Masi, Maoli, Lamagna, Piacentini

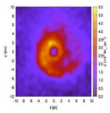
- **Extragalactic Astrophysics**



Understanding the nature of the first stars, the first galaxies and black holes is one of the most pressing questions in modern astrophysics. These are also amongst the key science goals of ongoing campaigns, with cutting-edge instruments including the Hubble Space Telescope (HST), the Atacama Large Millimetre Array (ALMA), the forthcoming James Webb Space Telescope (JWST, 2019), and the new generation of millimetre wave cameras such as MUSCAT and TolTEC. We investigate the physical processes that shape the infant Universe through a combination of theoretical models, numerical simulations and detailed comparison with observational data. We follow a multi-wavelength approach that aims to model the properties of the first galaxies in different bands of the electromagnetic spectrum (X-rays, UV, IR, radio) as well as the gravitational wave luminosities of the compact remnants and nuclear black holes that they host.

Membri: Pascale, Schneider

- **Stellar and Galactic Astrophysics**



We developed theoretical and numerical modelling, including high level parallel codes, and applies it to: the dynamics of stars in dense stellar systems, the formation and evolution of nuclear star clusters, super massive black hole formation in galactic centers, extrasolar planetary systems dynamics, merging compact objects in star clusters and GW emission. Another scientific activity is related to the study of the dynamical evolution of stellar systems on different scales, from globular clusters up to clusters of galaxies, dealing with theoretical and numerical approaches, including for instance the study of thermodynamical instabilities of selfgravitating systems, with relevant results on the onset of thermodynamic instability, improving previous works on the same subject. Another research area is related to exoplanets. Thousands of exoplanets have been detected so far, and the list will be extended to tens of thousands in the next decade by dedicated space missions and ground instrumentation. However, little is known about the true nature of these far away worlds. Do atmospheres exist? What are they made of? What kinds of climate do they have? Can biosignatures be detected? What does all this tell us about planetary formation and evolution, and the uniqueness or otherwise of the solar system? Our experimental activities directly address these questions through spectroscopical observations of exoplanet atmospheres from space, with the ARIEL mission, and using instrumentation on ground and balloon borne observatories.

Membri: Capuzzo-Dolcetta, Meddi, Merafina, Pascale

scientific report

https://www.phys.uniroma1.it/fisica/node/9991

astroseminars

https://lists2.roma1.infn.it/mailman/listinfo/astroseminar

astrophysics research activities and reference persons

observational and theoretical cosmology
de Bernardis, Battistelli, De Petris, Melchiorri, Masi, Maoli, Lamagna, Piacentini

extragalactic astrophysics
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Stellar and Galactic astrophysics
Capuzzo-Dolcetta, Meddi, Merafina, Pascale