

MASTER IN PHYSICS

Curriculum in BioSystems

General information on the different curricula can be found at

<https://corsidilaurea.uniroma1.it/it/corso/2021/30055/programmazione>

where available courses and the detailed programs of each course can be found

New info on 2022/23 a.y will appear in the future

Curriculum in BioSystems

The curriculum provides a **comprehensive knowledge of the principles and applications of physical modelling in biology**. Besides a core background in physics (RQM and Condensed Matter) the student will develop a deep understanding of the physical mechanisms driving biological systems at all levels and scales, and of the techniques to analyze them.

- ➡ the origin of intra and inter molecular forces, of the self-assembly processes, the physics of polymers and of colloidal solutions.
- ➡ the basic principles of response theory and the main techniques in spectroscopy and microscopy to investigate biological systems at the microscopic scale.
- ➡ the theory of low Reynolds number hydrodynamics and how to study - through various experimental techniques - dynamical processes in cells and living systems.
- ➡ theoretical concepts in stochastic processes and the statistical physics of interacting systems and how to use them to describe signal amplification, regulation and collective phenomena in multi-scale biological processes, from neural networks to animal groups.
- ➡ computational methods to analyze data and make sense of them

| Corso di laurea in Fisica (LM-17) - Curriculum Biosistemi | | | | | | | |
|---|---|-----|-------|-------|--------|-----|-----------|
| N. | Insegnamenti | CFU | anno | sem. | SSD | eng | ambito |
| 1 | Condensed Matter Physics | 6 | 1 | 1 | FIS/03 | Y | caratt. |
| 2 | Soft and Biological Matter | 6 | 1 | 1 | FIS/03 | Y | caratt. |
| 3 | Physics Laboratory I (propedeutico a Physics Laboratory II) | 6 | 1 | 1 | FIS/01 | Y | caratt. |
| 4 | Physics Laboratory II | 9 | 1 | 2 | FIS/01 | Y | caratt. |
| 5 | Theoretical Biophysics | 6 | 1 | 2 | FIS/02 | Y | caratt. |
| 6 | Biophysics | 6 | 1 | 2 | FIS/03 | | caratt. |
| 7 | English language | 4 | 1 | 2 | | Y | AAF |
| 8 | Gruppo A | 6 | 1 / 2 | 1 / 2 | | | aff.-int. |
| 9 | Gruppo A | 6 | 1 / 2 | 1 / 2 | | | aff.-int. |
| 10 | Corso a scelta | 6 | 1 | 2 | | | |
| 11 | Relativistic Quantum Mechanics | 6 | 2 | 1 | FIS/02 | Y | caratt. |
| 12 | Gruppo A | 6 | 1 / 2 | 1 / 2 | | | aff.-int. |
| 13 | Corso a scelta | 6 | 2 | 1 | | | |
| 14 | Internship | 3 | 2 | 1 | | Y | AAF |
| 15 | Thesis Project | 38 | 2 | 2 | | Y | AAF |

| Gruppo A (aff.-int.) | | | | | | | |
|----------------------|--|---|---|---|--------|---|--|
| 1 | Biochimica | 6 | 1 | 1 | BIO/10 | N | |
| 2 | Computational Biophysics | 6 | 1 | 1 | INF/01 | Y | |
| 3 | Computing Methods for Physics | 6 | 1 | 1 | INF/01 | Y | |
| 4 | Statistical Mechanics and Critical Phenomena | 6 | 1 | 1 | FIS/02 | Y | |
| 5 | Nonlinear and Quantum Optics | 6 | 1 | 1 | FIS/03 | Y | |
| 6 | Molecular biology | 6 | 1 | 2 | BIO/11 | Y | |
| 7 | Mathematical Physics | 6 | 1 | 2 | MAT/07 | Y | |
| 8 | Advanced Machine Learning for Physics | 6 | 1 | 2 | INF/01 | Y | |
| 9 | Nonlinear Waves and Solitons | 6 | 1 | 2 | FIS/02 | Y | |
| 10 | Neural Networks | 6 | 1 | 2 | FIS/02 | Y | |
| 11 | Meccanica statistica del non equilibrio | 6 | 1 | 2 | FIS/02 | N | |
| 12 | Photonics | 6 | 1 | 2 | FIS/03 | Y | |
| 13 | Physics of Liquids | 6 | 1 | 2 | FIS/03 | Y | |
| 14 | Spectroscopy Methods and Nanophotonics | 6 | 1 | 2 | FIS/03 | Y | |
| 15 | Many-Body Physics | 6 | 2 | 1 | FIS/02 | Y | |
| 16 | Medical Applications of Physics | 6 | 2 | 1 | FIS/01 | Y | |
| 17 | Physics of Complex Systems | 6 | 2 | 1 | FIS/03 | Y | |
| 18 | Statistical Mechanics of Disordered Systems | 6 | 2 | 1 | FIS/03 | Y | |
| 19 | Surface physics and nanostructures | 6 | 2 | 1 | FIS/03 | Y | |
| 20 | Statistical Physics and Machine Learning | 6 | 2 | 1 | FIS/02 | Y | |

CFU = number of credits
 Anno = year (first or second year)
 Sem. = semester in which the course is taught
 Eng = in English (Y) or in Italian (N)

SSD:
 FIS: Physics course
 CHIM: Chemistry course
 BIO: Biology course
 INF: Computer science course
 MAT: Mathematics course

7 Mandatory Courses

4 common to all curricula
 3 specific to the Biosystem CV

3 Courses from Group A

2 Elective Courses

Constraints:
 2 courses must be NON-FIS
 (BIO, INF, MAT etc)

Mandatory Courses specific to the Biosystem curriculum

- Soft and Biological Matter (Prof. Sciortino, year 1- sem 1)

intramolecular forces, the role of water, polymers (structure and self-assembly), micelles, membranes, gels, colloidal suspensions, structure of DNA and proteins

- Biophysics (Prof. Di Leonardo, year 1 – sem 2)

What's inside: genetic parts and circuits (gene expression – single molecule exp techniques – genetic editing)

What's outside: single cell movements (flagella, cytoskeleton, cell substrate - exp technique to probe movement)

Multicellular dynamics (growth and division, branching, tissue dynamics, quorum sensing – exp techniques)

- Theoretical Biophysics (Prof. Giardina, year 1 – sem 2)

The role of noise: signal detection, signal amplification and statistical reliance

(background in stochastic processes, bio cases: from chemoreception to chemotaxis; fotoreception)

The role of interactions and collective phenomena

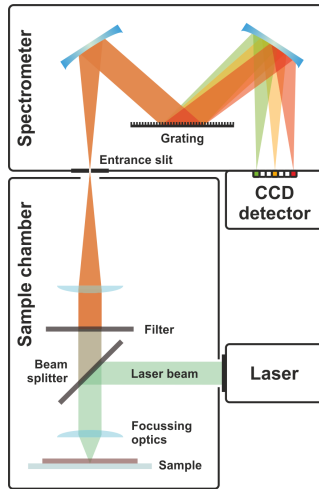
(background in critical phenomena, bio cases: proteins, neural networks, animal groups and living active matter)

- LAB II- BioSystems (Prof. Nucara, year 1 – sem 2)

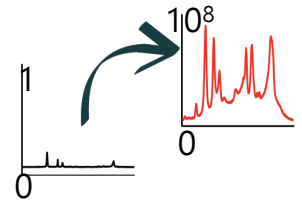
linear response theory/scattering/spectroscopy/microscopy/imaging/NMR

Investigation of bio macromolecules with vibrational spectroscopy

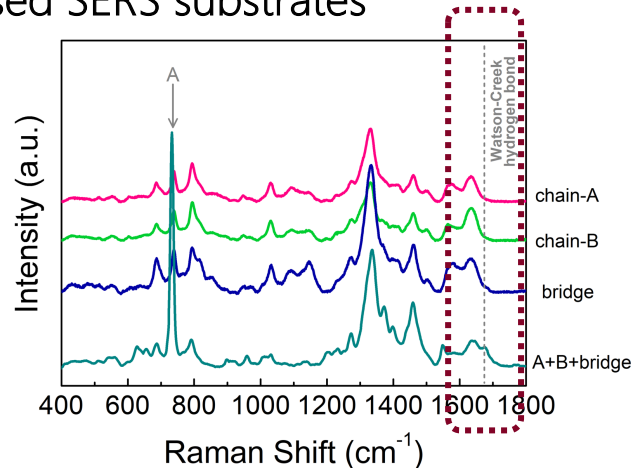
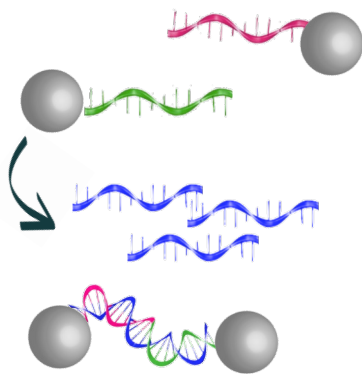
1) Surface Enhanced Raman Scattering: DNA self-assembly



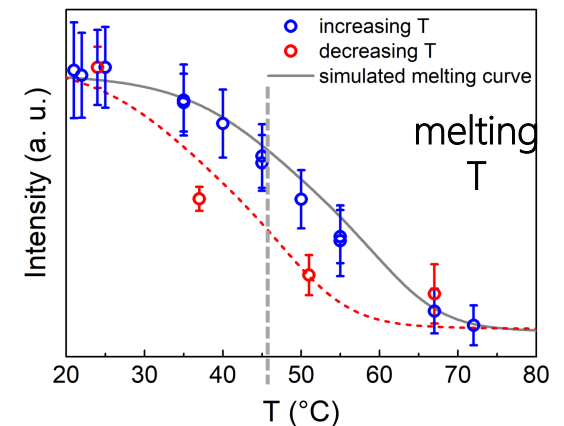
- ✓ enhancement of Raman signal coming from molecules bound/located very close to metallic (gold, silver) nanostructures
- ✓ "super-resolution" spectroscopic imaging



self-assembly of DNA-based SERS substrates

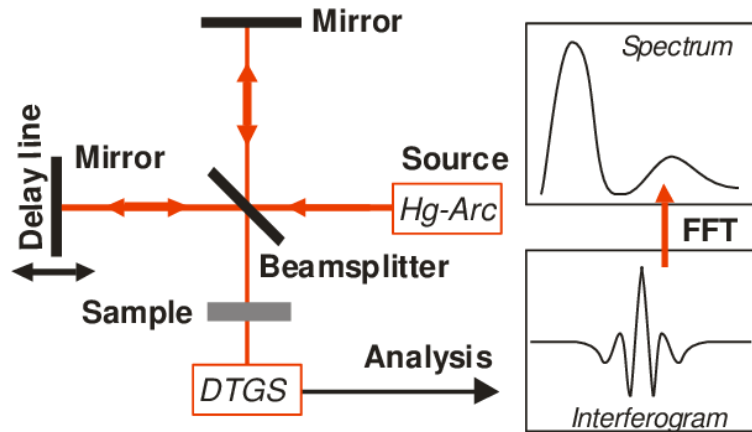


reconstruction of DNA melting profile

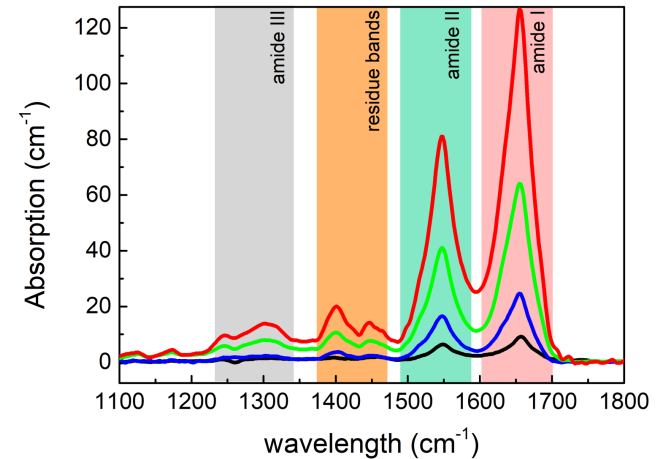


Investigation of bio macromolecules with vibrational spectroscopy

2) Infrared spectroscopy of proteins

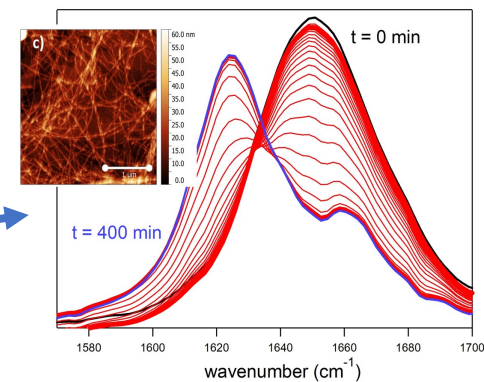


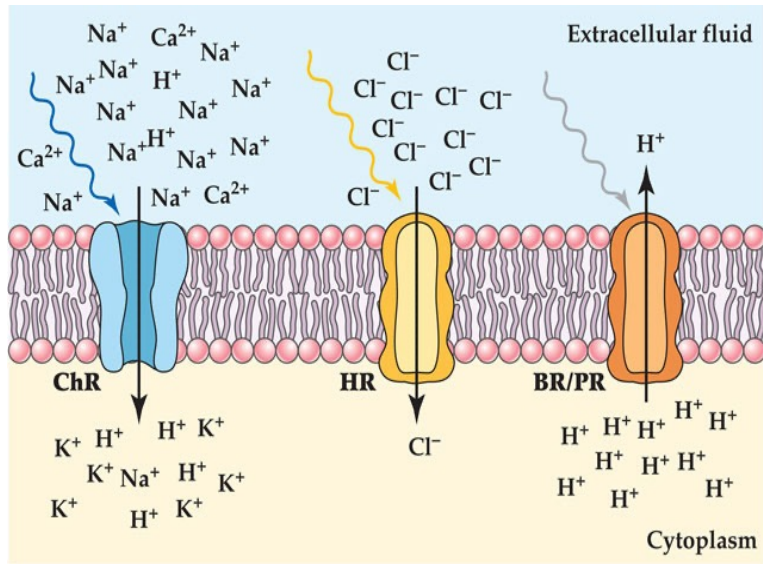
access to main vibrational modes
(stretching, in and out of plane bending)



Infrared spectrum is well suited to characterize protein changes, as:

- secondary structure alteration
- presence of intra- and inter-molecular aggregates
- kinetics of the aggregate/fibril formation
- binding between biomolecules



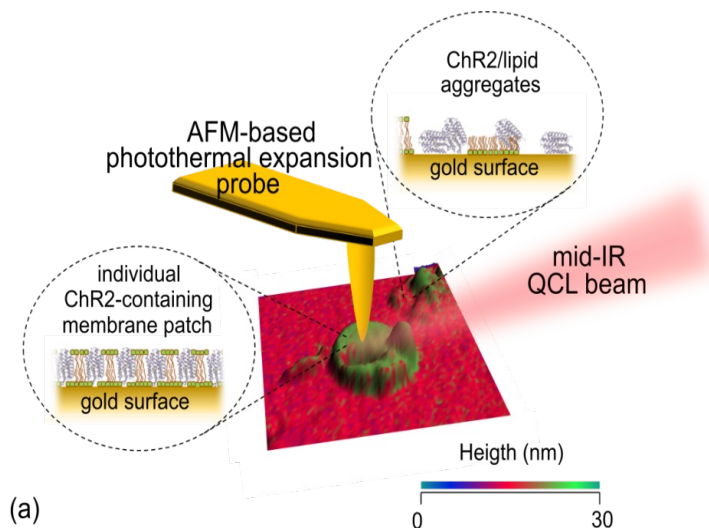


Light-induced conformational changes of proteins for optogenetics

Mid-infrared (IR) spectroscopy applied to the study of conformational changes of optogenetic transmembrane proteins

From 10^{23} molecules (laboratory IR) to 10^6 molecules (synchrotron micro-IR) to 10^2 molecules (AFM-IR nanospectroscopy).

Single-membrane-layer spectra achieved, prerequisite for simultaneous IR and electrophysiology measurements



(a)

Prof. Michele Ortolani (infrared spectroscopy group)
Dr. Valeria Giliberti (Istituto Italiano di Tecnologia)

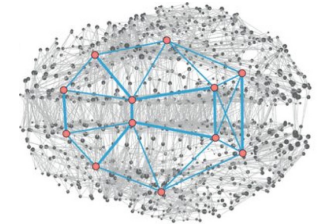
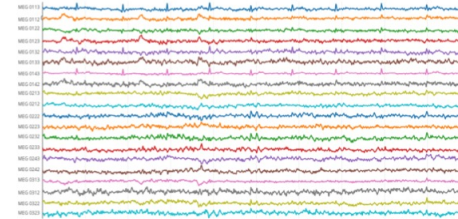
Theoretical and Computational methods in biophysics

Prof. Giancarlo Ruocco

Giorgio Gosti, Edoardo Milanetti, Lorenzo Di Rienzo e Mattia Miotto (IIT)

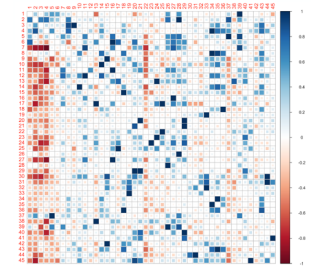
Effective brain connectivity estimation from Magneto-encephalograph (MEG) Data

The purpose is to infer from MEG data the effective connectivity matrix, which describes the relationship between the different functional areas of the brain, through the development of a new machine learning based method which uses the Hopfield model for characterizing the dynamics of brain states.

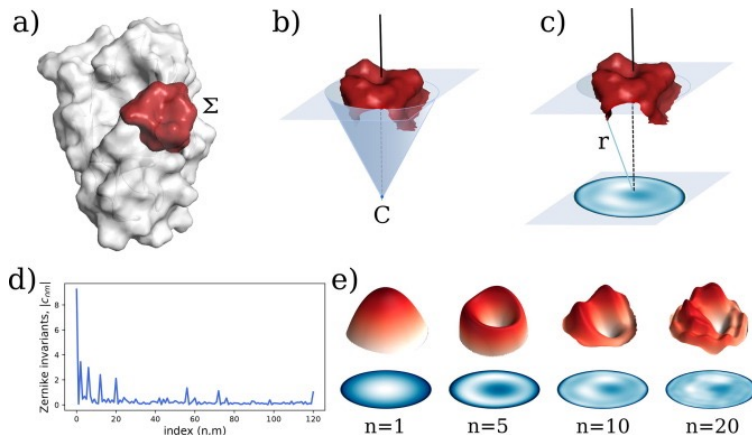


$$s_i(t) = \theta \left[\sum_{j=1}^n J_{ij} s_j(t - \Delta t) \right]$$

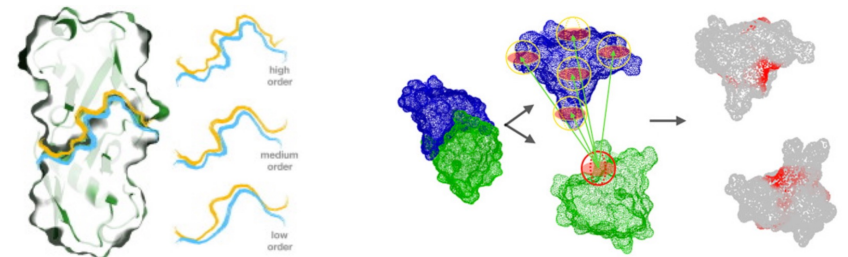
$$E(s_i(t), \bar{s}_i(t)) = \frac{1}{2} \sum_{t \in T} \sum_{i=1}^n (s_i(t) - \bar{s}_i(t))^2,$$



2D Zernike polynomial expansion: Finding the protein-protein binding regions

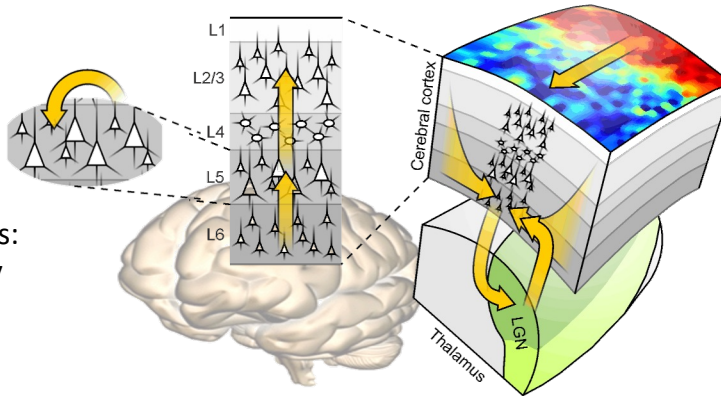


Our method is able to rapidly and quantitatively measure the geometrical shape complementarity between interacting proteins, comparing their molecular iso-electron density surfaces expanding the surface patches in term of 2D Zernike polynomials. We then apply the method for the blind recognition of binding sites

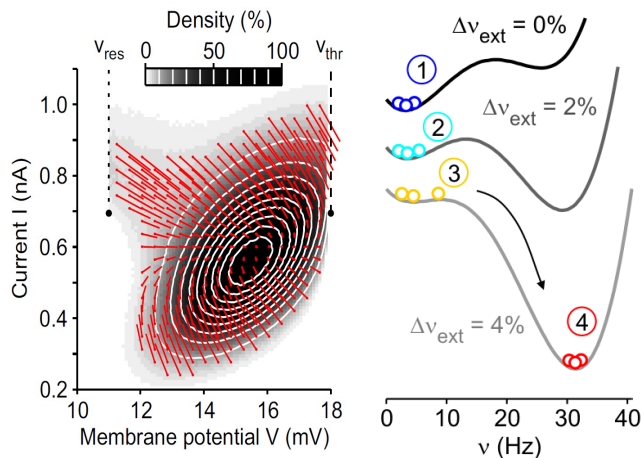


Neural networks: the physics of the brain

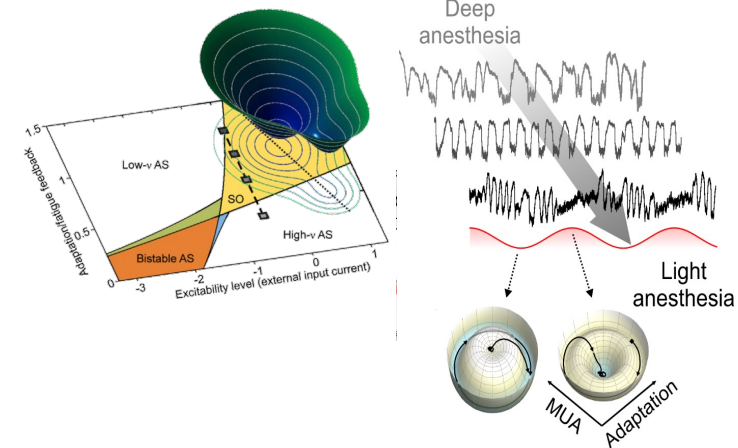
- Bridging the gap between theory and experiments aiming at quantitatively describing the multiscale dynamics of brain networks: open systems permanently out of equilibrium.



- Dynamics of finite-size networks of neurons to model spontaneous activity and cognitive functions.



- Focus on the sleep-wake cycle: synchronization phase transition of the brain.



Maurizio Mattia (ISS)

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Statistical mechanics of memory, of learning and of neural networks.

Paradigm:

Hopfield model, based on Parisi theory of spin glasses.

$$H = -1/2 \sum J_{ij} \sigma_i \sigma_j \quad \sigma_i = -1, +1 \quad J_{ij} = \sum_{\mu} \xi^{\mu}_i \xi^{\mu}_j$$

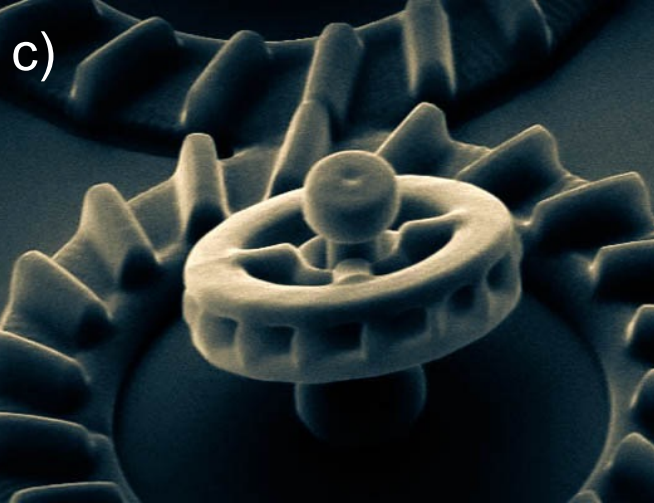
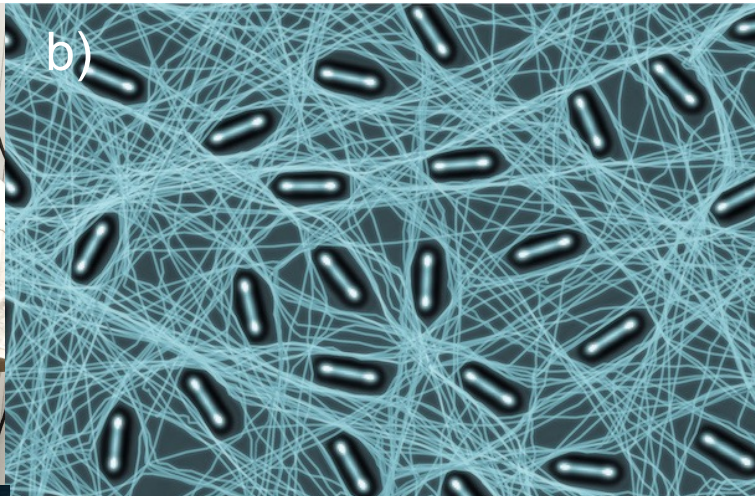
Principal research directions of our groups in this moment:

1. Realistic statistical models of memory.
2. Learning correlated information.
3. Forgetting memories: the dreaming protocol and the palimpsest schemes.

Prof. Enzo Marinari & the Chimera Group

<https://chimera.roma1.infn.it/>

Active Matter and Synthetic Biology Lab



Prof.
Roberto Di Leonardo

www.dileonardolab.it

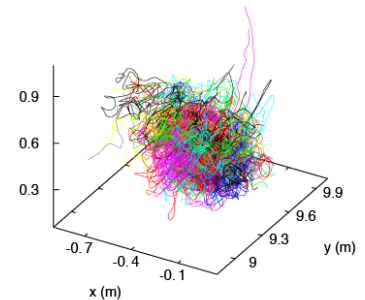
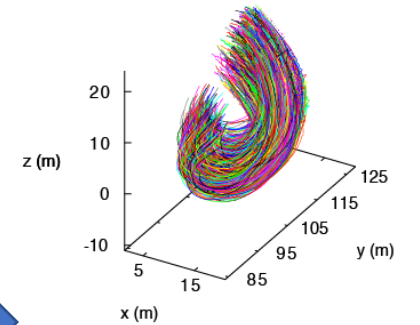
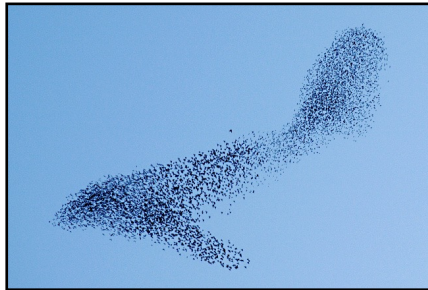
We combine optics, computers and molecular biology to study the statistical and fluid mechanics of microswimmers.
a) By combining virtual reality and holography we can use light to grab and manipulate swimming bacteria as if they are right in front of us.

b) using light we can 3D print complex microstructures and study how bacteria can escape from them

c) or build bio hybrid micro-machines that use swimming bacteria as tiny propellers.

d) we can use light to control the internal state of genetically modified bacteria

Collective behaviour in living groups: flocks, swarms and cells



- Statistical analysis of collective motion: structure, correlations, info-propagation
- Statistical inference: from data to models
- How do coordination arises in living interacting groups?
- What features regulate robustness/adaptation/response?
- Can we define behavioral classes?

MORE INFORMATION:

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More info

<https://sites.google.com/uniroma1.it/irene-giardina/teaching/curriculum-biosistemi>