Il Gruppo IV: Fisica Teorica

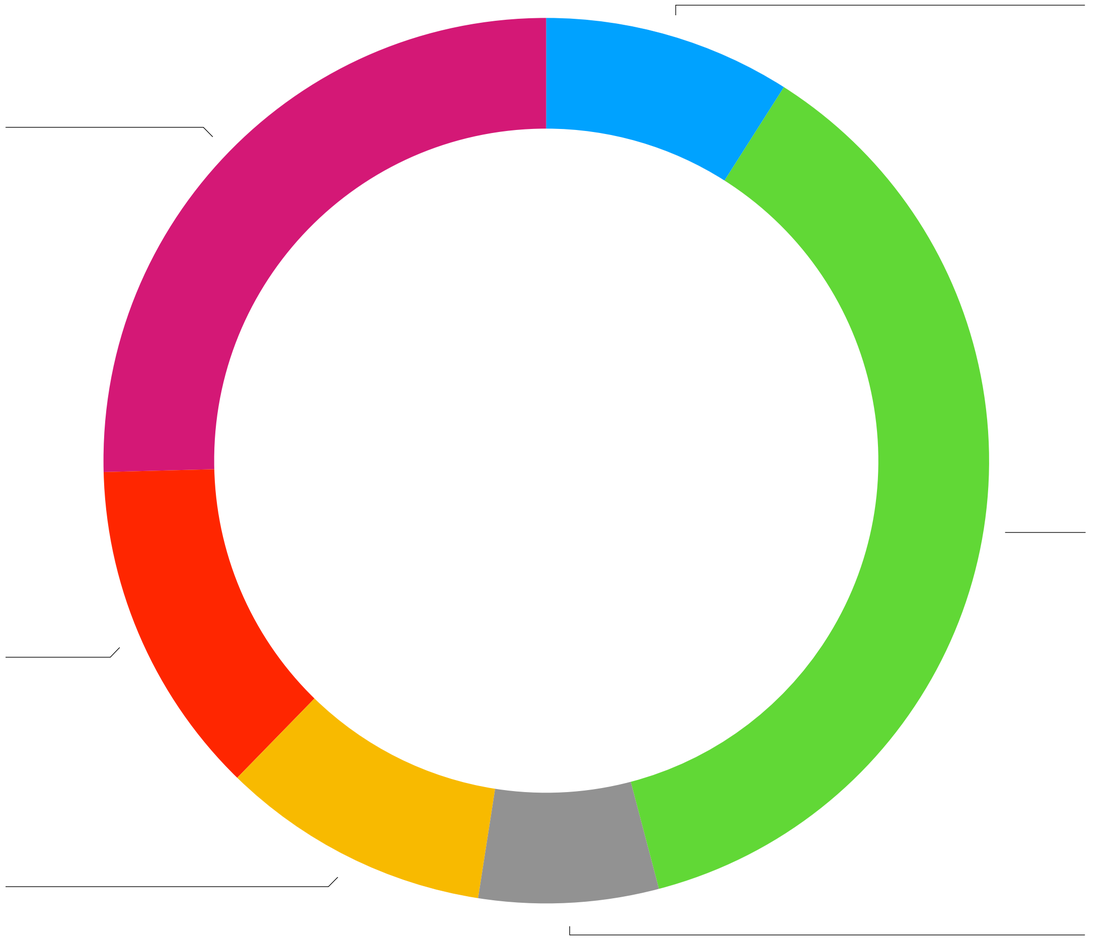
Domenico Orlando
(INFN, Sezione di Torino)

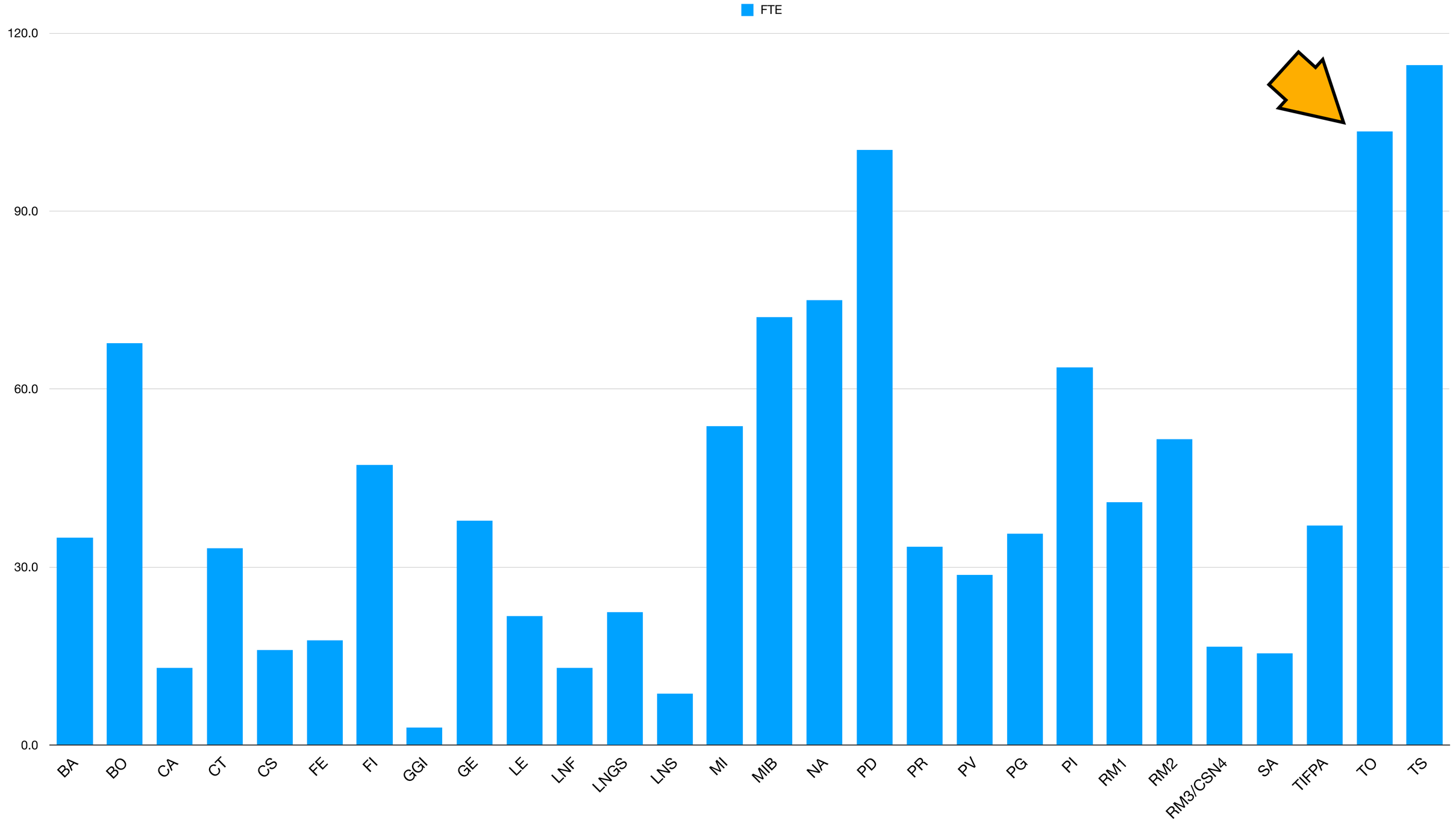
Consiglio di Sezione | Torino, 13 Giugno 2025

I Numeri

Composizione
122 membri (109 FTE)

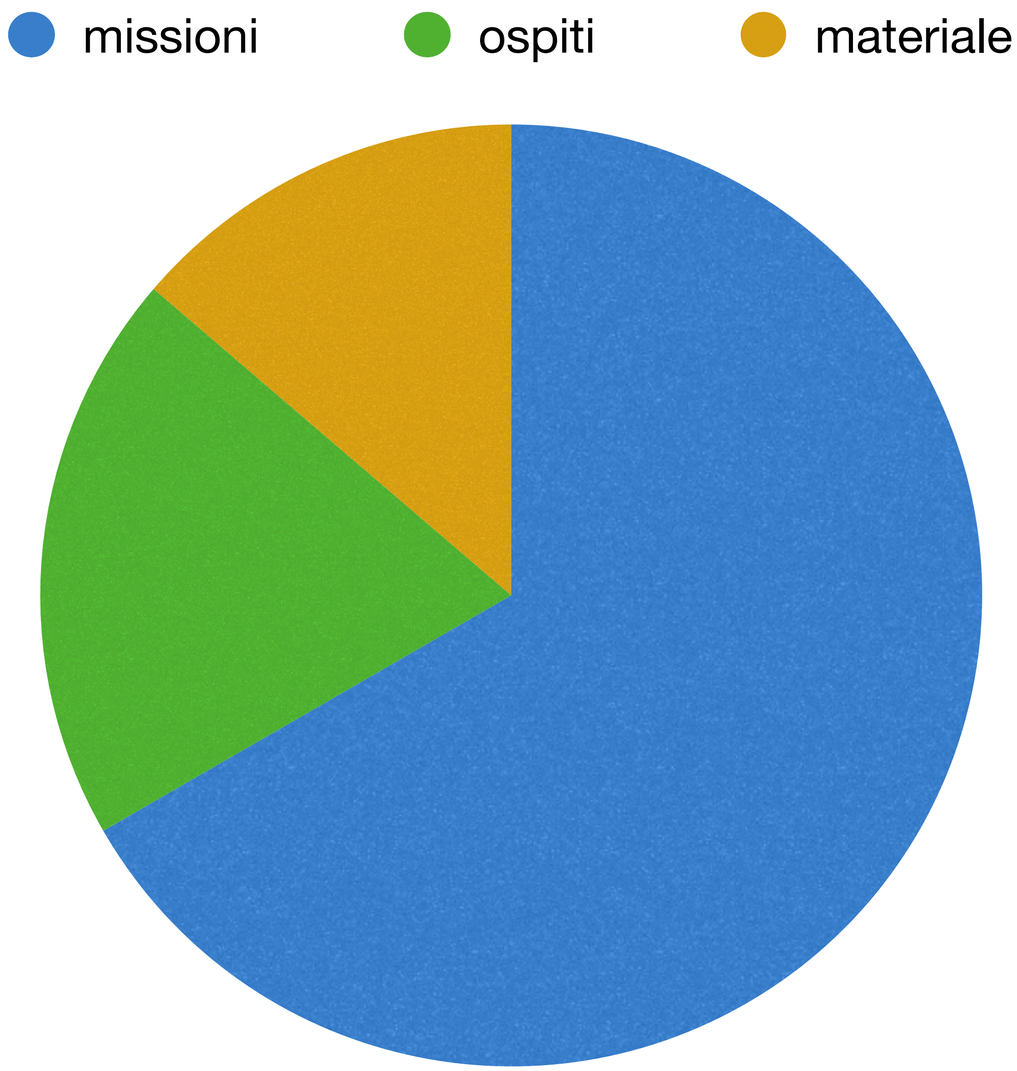
- 11 dipendenti
- 45 associati UniTO
- 8 associati UPO
- 12 associati PoliTO
- 15 postdoc
- 31 PhD




FTE
120.0
90.0
60.0
30.0
0.0
BA
BO
CA
CT
CS
FE
FI
GGI
GE
LE
LNF
LNGS
LNS
MI
MIB
NA
PD
PR
PV
PG
PI
RM1
RM2
RM3/CSN4
SA
TIFPA
TO
TS

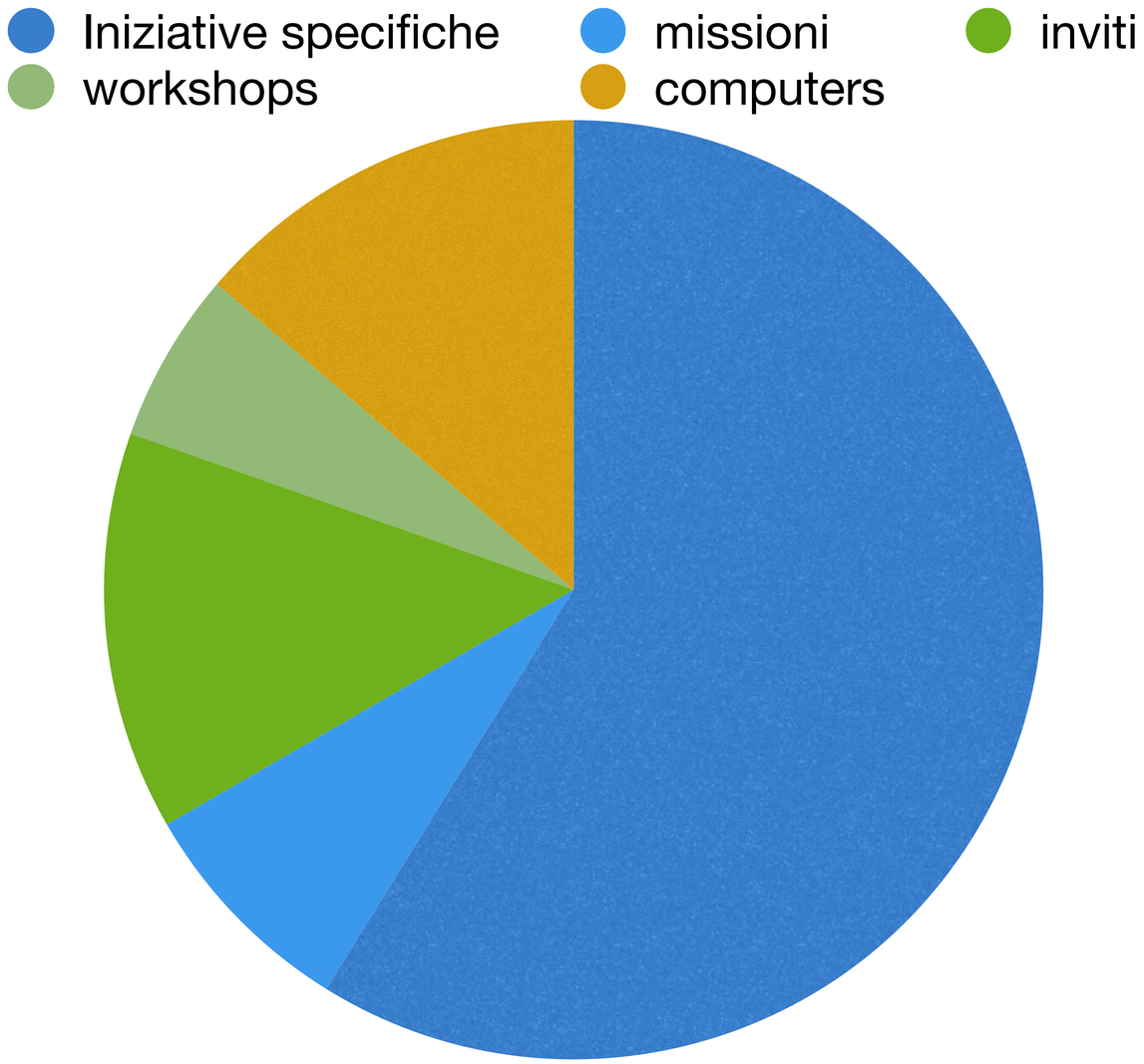
Budget 2024

missioni	170 k€
ospiti	50 k€
materiale	35 k€
Totale	**255 k€**



Budget 2024

Iniziative specifiche	150 k€
missioni	20 k€
inviti	35 k€
workshops	15 k€
computers	35 k€
Totale	**255 k€**



Le Iniziative Specifiche

A grandi linee

1. **Teoria dei campi e delle stringhe**
GSS Orlando | **STEFI** Pesando | SFT Tateo

2. **Fenomenologia delle particelle**
AMPLITUDES Badger| **SPIF** Torrielli |
TEONGRAV Nagar

3. **Fisica nucleare e adronica**
NINPHA Boglione | NUCSYS Barbaro |
SIM Nardi

4. **Metodi matematici**
MMNLP Ortenzi

5. **Fisica delle astroparticelle**
INDARK Diaferio | **TASP** Donato

6. **Fisica statistica e applicata**
BIOPHYS Osella | ENESMA Pagnani |
FIELDTURB Boffetta

GSS (Gauge Theories, Supergravity and String Theories)

Nodes: TO-GE-MI-MIB-PD-PI-RM3-LE-TO

Quantum Field and String Theories for the unification of
Quantum Gravity and Gauge interactions

Applications to phenomenology and cosmology;
mathematical methods (geometry), supergravity

Main themes:

- The space of consistent theories of Quantum Gravity
- Holography and dualities
- Black Hole Entropies and Microstate Counting
- Supersymmetry breaking
- SUGRA, black hole scattering and gravitational waves

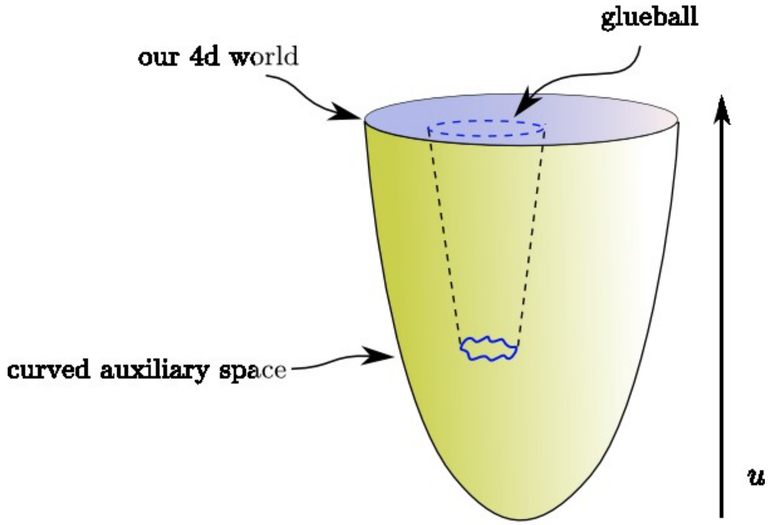
ST&FI 2024 Highlights

SF&TI is a multifaced IS whose research subjects are in formal theoretical physics and range from CFT to supersymmetric gauge theories to string theory in various forms.

1) Supersymmetric gauge theories

Focus: non-perturbative aspects of strongly coupled 4d N=2 SCFTs using supersymmetric localization and the validity of the AdS/CFT correspondece in a non-maximally supersymmetric set-up.

(Marco Billò, Maialuisa Frau, Alberto Lerda)

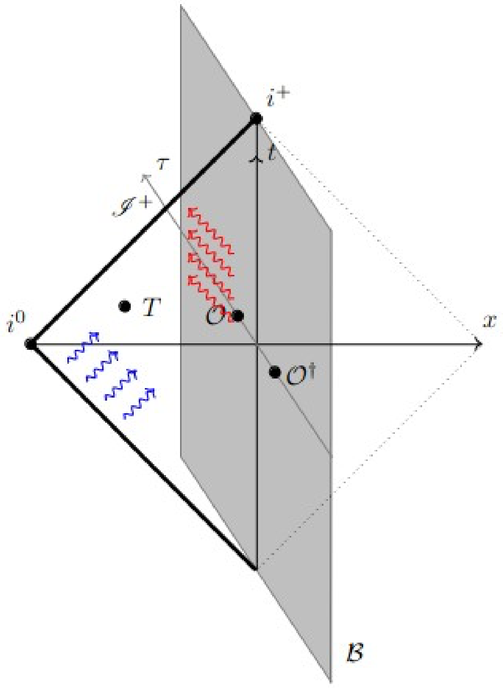


2) CFT and defects

Focus: strongly coupled quantum field theories with bootstrap methods.

These QFT are relevant for condensed matter systems such as doped quantum antiferromagnets

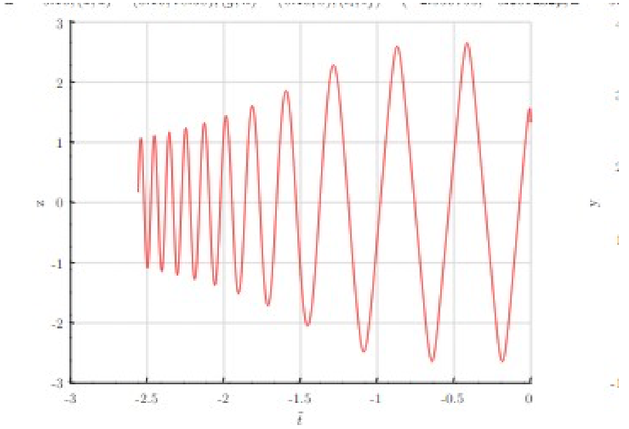
(Lorenzo Bianchi, Marco Meineri)



3) String theory and String Field theory

Focus: formal aspects of string theory, especially of open/closed interactions which can lead to a better understanding of quantum gravity effects in Big Bang and Black Holes

(Carlo Maccaferri, Igor Pesando)



Statistical Field Theory (SFT) scientific initiative – I

The Turin members of the SFT scientific initiative work in the fields of integrable models and lattice field theory

The most recent results by the members working on integrable models (Cavaglià, Sakamoto and Tateo) concern:

- ★ Extension of the Classical/Quantum correspondence in integrable systems deformed by operators related to the stress-energy tensor
- ★ Exact study of Regge trajectories in holographic 3D conformal gauge theory (in progress)
- ★ Integrability for string and gauge theories: new non-perturbative method to solve spectrum of strings in AdS_3 with Ramond-Ramond flux
- ★ Conformal bootstrap and integrability hybrid approach: new constraints on the Wilson line defect CFT in Super-Yang-Mills theory
- ★ Discretization of integrable 1+1D quantum field theories from 4D Chern-Simons theory (in progress)

Statistical Field Theory (SFT) scientific initiative – II

The Turin members of the SFT scientific initiative work in the fields of integrable models and lattice field theory

Recent research activities of the members working in lattice field theory (Caselle, Nada and Panero) include:

- ★ Simulation of quantum field theory through machine-learning techniques
- ★ Numerical and analytical investigation of the Nambu–Gotō string model for confinement
- ★ Monte Carlo study of the entanglement entropy
- ★ Numerical reconstruction of spectral functions in lattice field theory

Amplitudes

analytic structure, loop methods and pertubative gravity

LNF (Del Duca, RN)

TO (Badger)

NA (Tramontano)

BO (Peraro)

PA (Mastrolia)

RO (Bonciani)

"**Modern amplitude methods** have made a huge impact on our **understanding of quantum field theory** and our ability to make precise predictions for physical observables. Their remarkable **mathematical structure** has led to new results in an enormous range of subjects from gravitational waves, condensed matter systems and collider experiments.

Our team members have contributed to cutting-edge computations of amplitudes, and our aim is to keep INFN to the forefront of amplitude evaluations both for **collider** and for **gravitational-wave observables**."

Precision studies of fundamental interactions (SPIF)

Nodes: Bari (Fulvia De Fazio), Genova (S. Marzani), Milano (A. Vicini), Roma 3 (D. Meloni), Torino (P. Torrielli)

Keywords: LHC and collider physics, precision tests of the Standard Model (SM), flavour physics, higher-order perturbative calculations, Monte Carlo event generators

Phenomenology of elementary particle physics at present high-energy experiments such as the LHC, B-factories, neutrino-oscillation experiments, and at future facilities

Precision tests of the SM at colliders through precise predictions for observables relevant to Higgs boson, gauge bosons, and hadronic final states

Deeper understanding of the proton structure, including QCD and electroweak effects and their uncertainties, with modern machine-learning techniques

Flavour physics: analysis of the rare decays of heavy quarks, and the determination of the CKM matrix elements

Formulation of explicit SM extensions to investigate fundamental questions: Dark Matter, strong CP problem, precise phenomenology of the neutrino sector

TEONGRAV & Virgo (Prometeo)

Gravitational wave modeling from coalescing compact binaries

Towards numerical-relativity informed effective-one-body waveforms for dynamical capture black hole binaries
T. Andrade, J. Trenado, **S. Albanesi**, R. Gamba, S. Bernuzzi, **A. Nagar** et al. , to appear

Faithful effective-one-body waveform of small-mass-ratio coalescing black hole binaries: the eccentric, nonspinning, case,
S.Albanesi, S. Bernuzzi, T. Damour, **A. Nagar**, A. Placidi, arXiv:2305.19336

2.5PN accurate waveform information for generic-planar-orbit binaries in effective one-body models,
A.Placidi, G. Grignani, T. Harmark, M. Orselli, S. Gliorio, **A. Nagar**, arXiv:2305.14440

TEOBResumS: Analytic systematics in next-generation of effective-one-body gravitational waveform models for future observations,
A. Nagar, **P. Rettegno**, R. Gamba, A. Albertini and S. Bernuzzi, arXiv:2304.09662

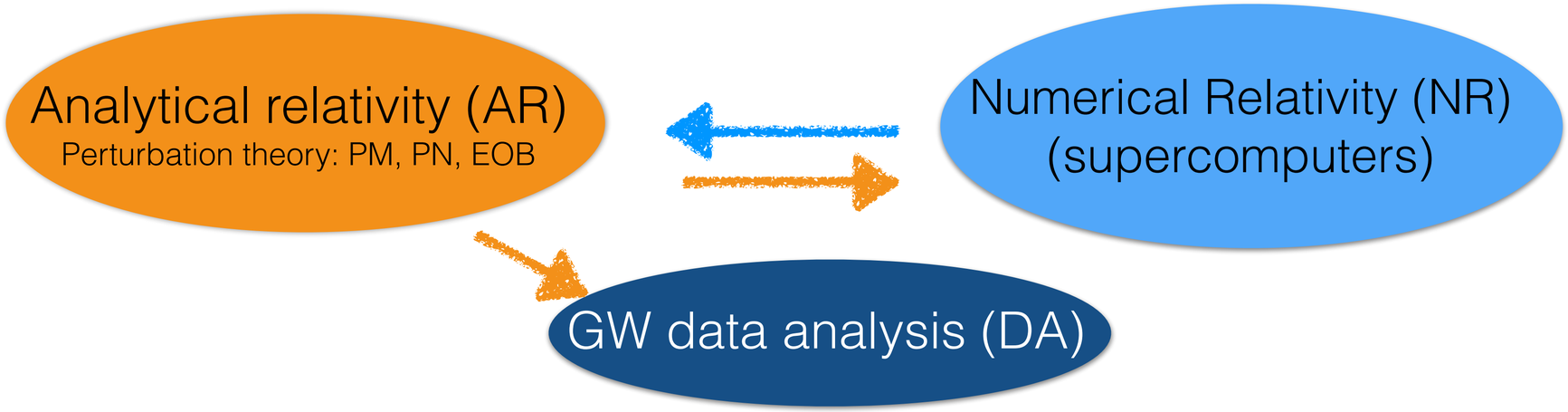
Effective-one-body Hamiltonian in scalar-tensor gravity at third post-Newtonian order,
T. Jain, **P. Rettegno**, M. Agathos, **A. Nagar** and L. Turco, Phys. Rev. D 107 (2023) 8, 084017, arXiv:2211.15580

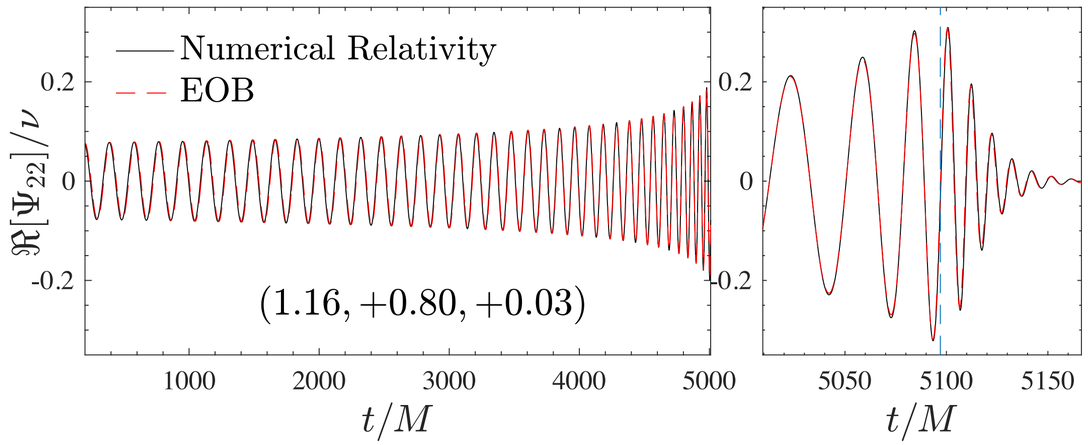
Strong-field scattering of two black holes: Numerical relativity meets post-Minkowskian gravity,
T. Damour and **P. Rettegno**, Phys. Rev. D 107 (2023) 6, 064051, arXiv:2211.01399

Comparing second-order gravitational self-force and effective one body waveforms from inspiralling, quasi circular and nonspinning black hole binaries II.The large mass ratio case
A. Albertini, **A. Nagar**, A. Pound et al., Phys. Rev. D 106 (2022) 8, 084062, arXiv:2208.02055

THEORY for CompactBinaryCoalescence

- Interface between Analytical & Numerical Relativity for GW data-analysis
- 2-body problem in General Relativity



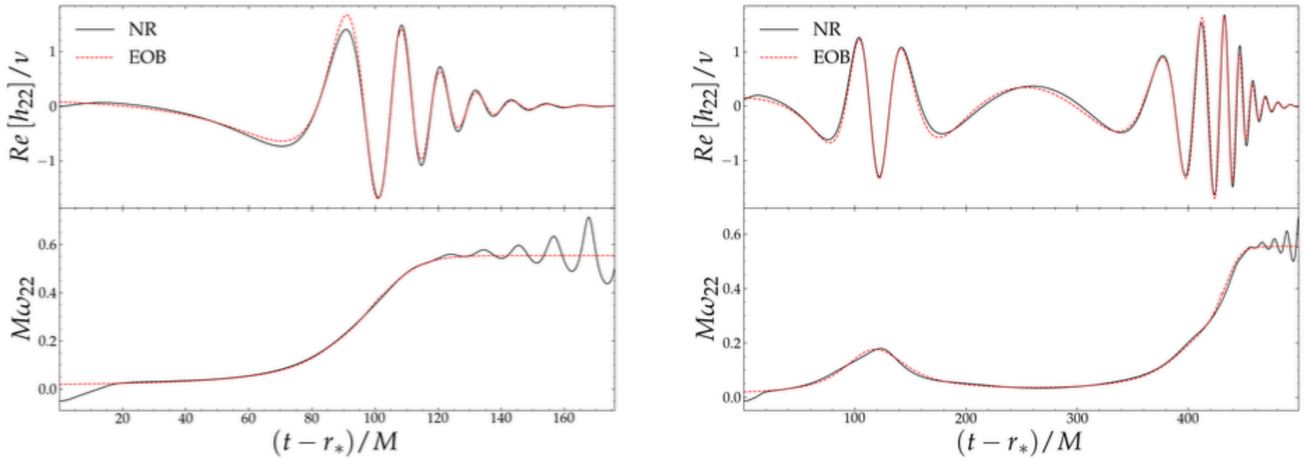


Challenges:

- physical completeness (spin, tides, eccentricity)
- accuracy
- efficiency (AR vs NR)
- 10^7 templates needed for a single event

The physics you can infer depends on your ability at modeling it!

- Waveform modeling for various sources (BBHs, BNS)
- Focus on noncircular configurations (> 2020)
- Making sense to PM & PN expansions using EOB theory.



Andrade et al. 2023, to appear

Damour & Rettegno 2022

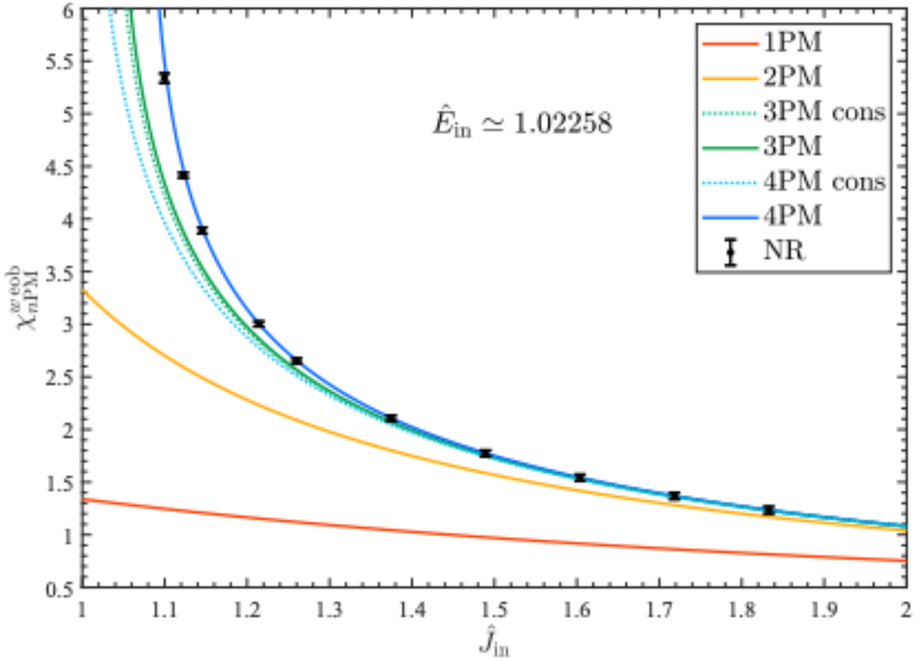
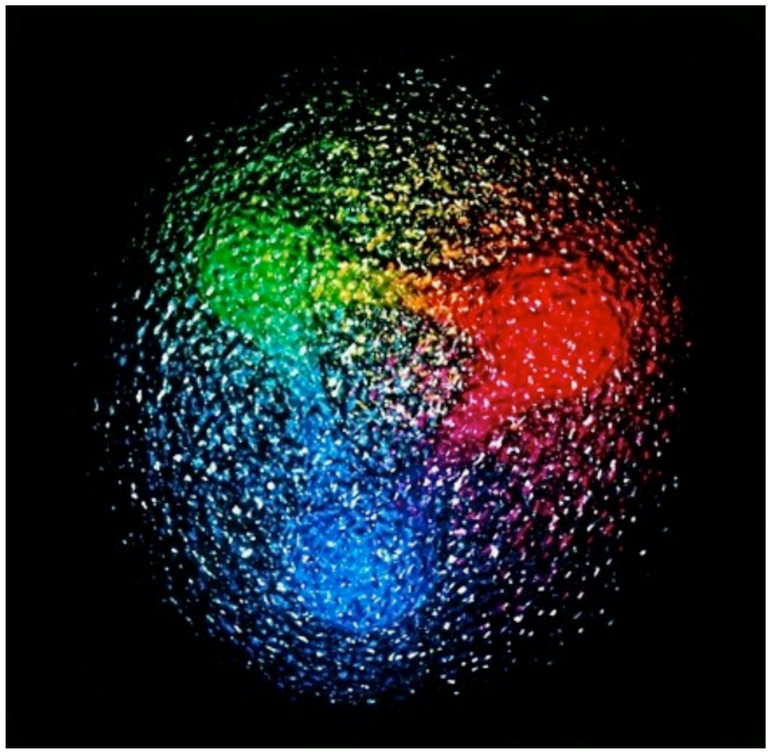


FIG. 3. Same comparison as Fig. 2 using the $w^{\rm eob}$-resummed scattering angles $\chi^{w\,\rm eob}_{n\rm PM}$ derived through the use of the EOB radial potentials $w_{n\rm PM}$. The agreement using 4PM results including radiation-reaction terms is excellent.

NINPHA (National Initiative on Physics of Hadrons)

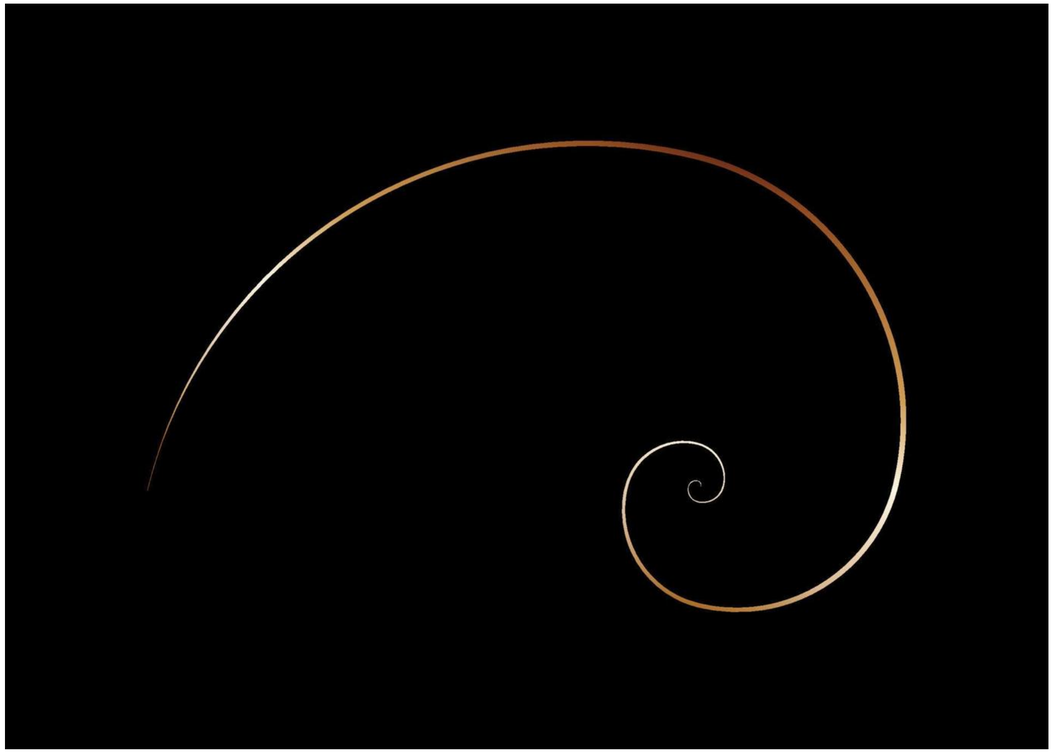
RN: Mariaelena Boglione . Nodi: TO-GE-PV-PG-CA

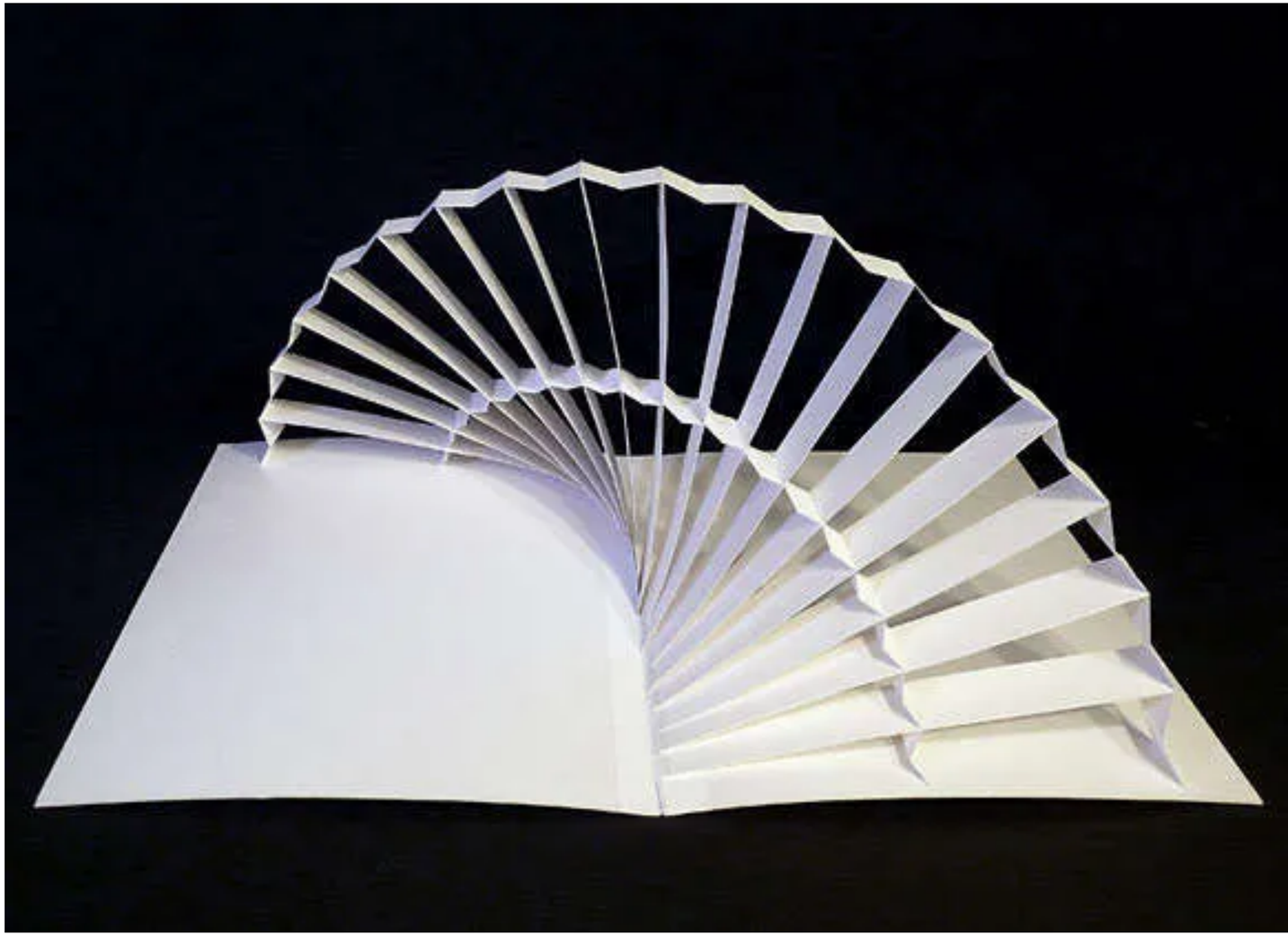
- The goal of the NINPHA project is to study the inner structure of hadronic matter
- The focus is on how hadron phenomenology emerges from the interactions generated by the **symmetries of QCD**, and from the breaking of these symmetries.
- Building accurate maps of the **internal dynamics of partons** and of their **mutual interactions** will shed light on the composition of hadronic masses and spins in terms of elementary constituents, and will eventually lead to a **microscopic understanding of confinement.**
- Shaping these maps in momentum and coordinate space requires advanced non-perturbative techniques, as well as highly accurate perturbative computations.



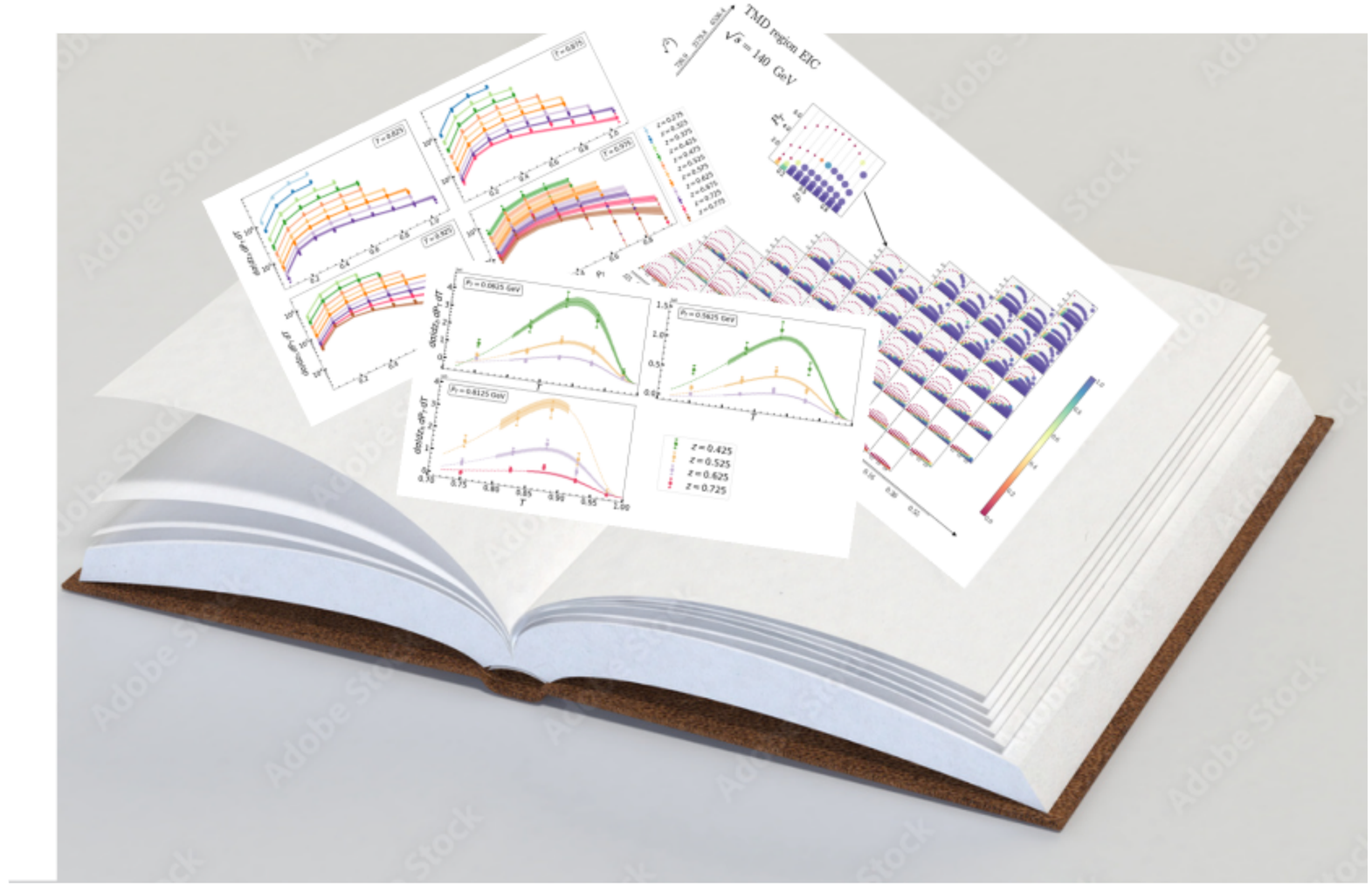
… to 3D nucleon structure

From collinear approximation





Data analyses have much to say about the dynamical inner structure of nucleons



Strongly Interacting Matter

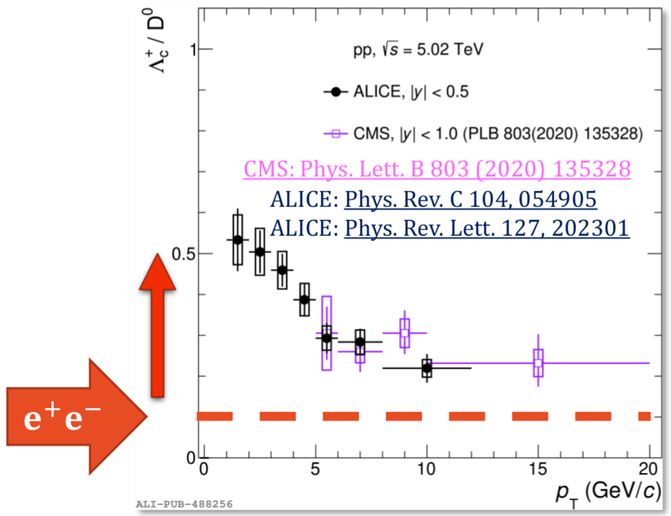
Permanent staff:
Marzia Nardi (INFN, local coordinator)
Arturo De Pace (INFN)
Andrea Beraudo (INFN)
Marco Monteno (INFN)

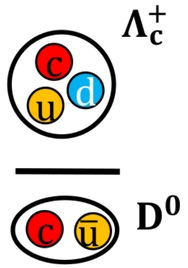
Fellini researcher:
Daniel Pablos

PhD students:
Jorge Manuel Martinez Vera

Master students:
Ferdinando Frascà

Heavy-flavor production in hadronic collisions





Strong evidence for breaking of factorization even *pp* collisions

$$d\sigma_h \neq \sum_{a,b,X} f_a(x_1)\, f_b(x_2) \otimes d\hat{\sigma}_{ab\to c\bar{c}X} \otimes D_{c\to h_c}(z)$$

Fragmentation functions and fractions from e^+e^- collisions *not universal*

Strongly Interacting Matter

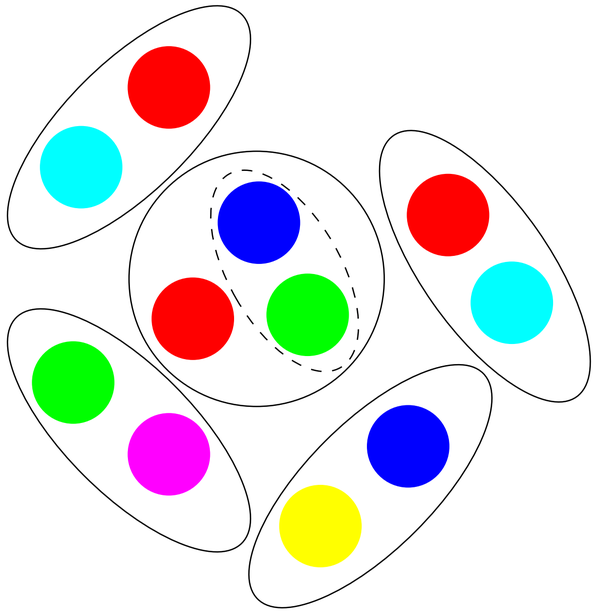
Permanent staff:
Marzia Nardi* (INFN)
Arturo De Pace (INFN)
Andrea Beraudo (INFN)
Marco Monteno (INFN)

Fellini researcher:
Daniel Pablos

PhD students:
Jorge Manuel Martinez Vera

Master students:
Ferdinando Frascà

Development of a new hadronization model

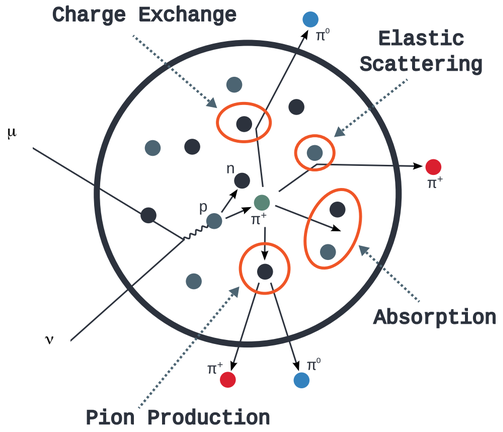


Assuming the production of a hot deconfined fireball (of gluons, quarks and diquarks) both in pp and in nucleus-nucleus collisions allows us to develop a new model of hadronization based on the formation of color-singlet clusters from the *recombination of the closest opposite-color charges*.

Iniziativa Specifica NucSys (LE-PD-PI-TIFPA-TO)
Staff: M.B. Barbaro, A. De Pace; PhD students: V.Belocchi; C.Giusti (PV)

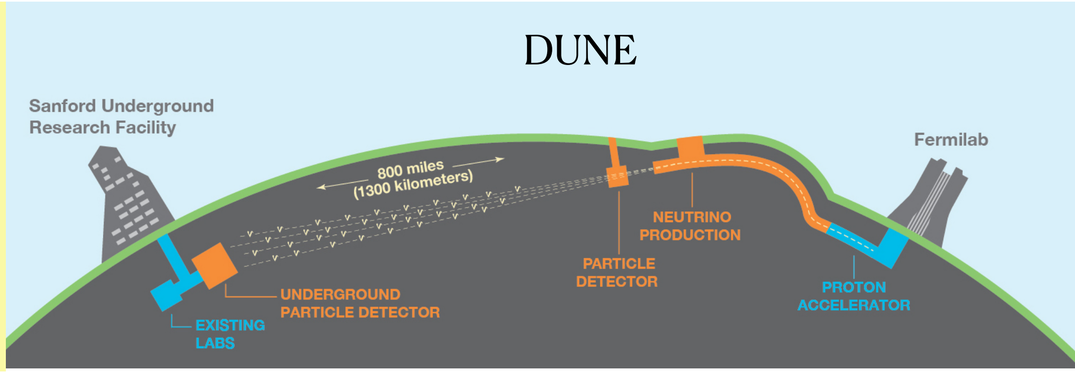
Nuclear theory, Electroweak interactions in medium/heavy nuclei

We work at developing and improving **nuclear models** to be used in the description of **lepton-nucleus scattering** in the **relativistic regime** (1-10 GeV): mean-field models, nucleon-nucleon correlations, final-state interactions, two-body currents, meson production, DIS, etc.



Main application: theoretical support to long-baseline neutrino experiments

Next-generation **long-baseline neutrino experiments** (DUnE, T2K/HyperK), aimed at the precise determination of the oscillation parameters and search for leptonic CP violation, require **accurate modelling of nuclear effects** to minimise systematic errors.



Main collaborations

Universities of Seville, Granada, Complutense de Madrid; Université Paris/Saclay and LPNHE Paris; NuSTEC (Neutrino Scattering Theory-Experiment Collaboration)

Main achievements in the last 12 months

V. Belocchi, M.B. Barbaro, A. De Pace, M. Martini,
Relativistic meson-exchange currents in semi-inclusive lepton scattering
Accepted for publication in Phys. Rev. C, e-Print: 2401.13640 [nucl-th]

J.M. Franco-Patino et al.,
New model comparison for semi-inclusive charged-current electron and muon neutrino scattering by Ar40 in the energy range of the MicroBooNE experiment
Phys. Rev. D 109 (2024) 1, 013004, e-Print: 2304.01916 [hep-ex]

J. Gonzales-Rosa et al,
Superscaling in the resonance region for neutrino-nucleus scattering: The SuSAv2-DCC model
Phys.Rev.D 108 (2023) 11, 113008, e-Print: 2306.12060 [nucl-th]

S.F. Pate et al.,
Global fit of electron and neutrino elastic scattering data to determine the strange quark contribution to the vector and axial form factors of the nucleon
Phys.Rev.D 109 (2024) 9, 093001, e-Print: 2402.10854 [hep-ph]

P. Rodriguez Casale, J.E. Amaro, M.B. Barbaro,
Meson-Exchange Currents in Quasielastic Electron Scattering in a Generalized Superscaling Approach
Symmetry 15 (2023) 9, 1709, e-Print: 2307.15783 [nucl-th]

Mathematical Methods in Non-Linear Physics

Unità di Torino (M. Onorato, G. Ortenzi)

- Stratified fluids and integrable and near-to-integrable models.

  Stratification is inherent to all near-equilibrium states of both the ocean and the atmosphere. Displacement of fluid parcels from their neutral buoyancy position within a density stratified flow can result in internal wave motion, thus providing a key mechanism for energy exchange over a wide range of scales in geophysical fluid dynamics.

- Study of Anomalous Waves.

  Extreme phenomena such as anomalous waves in fluid dynamics or classical optics are ubiquitous and their characterization is crucial to fully understand the behavior of the physical systems where they appear.

- Gradient singularities in multidimensional systems.

  The largest part of the classical literature on this singularities involves one-dimensional and/or integrable cases (NLS, KP). Non-integrable multidimensional systems are less known, and the study of extreme phenomena in this case is an active and open field of research.

Theoretical Astroparticle Physics

Current members in Torino: A. Cuoco - M. Di Mauro - F. Donato - N. Fornengo - S. Gariazzo - C. Giunti - M. Regis - A. Rubiola - M. Taoso - B. Thakore - E. Todarello

INFN Iniziativa Specifica **Theoretical Astroparticle Physics (TAsP)**
(roughly 100 participants)

PI: Fiorenza Donato (UniTo)

12 nodes: Bari, Bologna, Ferrara, Lecce, LNF, LNGS, Napoli, Padova, Pisa, Roma1, Torino, Trieste

Research lines

Current members in Torino: A. Cuoco - M. Di Mauro - F. Donato - N. Fornengo - S. Gariazzo - C. Giunti - M. Regis - A. Rubiola - M. Taoso - M. Garramone, I. John, J.Koechler, J. Terol-Calvo, B. Thakore - L. Stefanuto

Main research lines of our group in Torino:

Dark Matter

Cosmic-rays and multi-messenger astrophysics

Neutrino Physics

Particle cosmology

Events recently organised by our group:

Dark Tools (Torino, June 2025). International workshop

XSCRC2024: cross-sections for cosmic-ray physics (CERN, October 2024). International workshop

BAM: Axions in the sky (Barolo, June 2024). International workshop on axions and dark matter

TAsP national meeting (Torino, January 2024)

Cross sections for Galactic CRs: a step forward

https://indico.cern.ch/event/1377509/ @ CERN, 10/2024

(D. Maurin, FD, S. Mariani)

Precision cross-sections for advancing cosmic-ray physics and other applications: a comprehensive programme for the next decade

D. Maurin[a,*], L. Audouin[b], E. Berti[c], P. Coppin[d], M. Di Mauro[e], P. von Doetinchem[f], F. Donato[e,g,h], C. Evoli[i,j], Y. Génolini[k], P. Ghosh[l], I. Leya[m], M. J. Losekamm[n,o], S. Mariani[h], J. W. Norbury[p], L. Orusa[q,r], M. Paniccia[d], T. Poeschl[h], P. D. Serpico[k], A. Tykhonov[d], M. Unger[s], M. Vanstalle[t], M.-J. Zhao[u,v], D. Boncioli[w,j], M. Chiosso[e,g], D. Giordano[e], D. M. Gomez Coral[x], G. Graziani[c], C. Lucarelli[h], P. Maestro[y,z], M. Mahlein[n], L. Morejon[aa], J. Ocampo-Peleteiro[ab], A. Oliva[ab], T. Pierog[t], L. Šerkšnytė[h]

D. Maurin et al. 2503.16173, subm. to Physics Report

InDark: Inflation, Dark Matter and the Large-scale Structure of the Universe

PI Massimiliano Lattanzi (INFN – Ferrara)

INFN Units: BO-FE-GE-LNGS-MI-PD-PR-RM2-**TO**-TS

MAIN TOPICS

1. Inflation and primordial universe

2. Dark matter and light relics

3. Dark energy and modified gravity

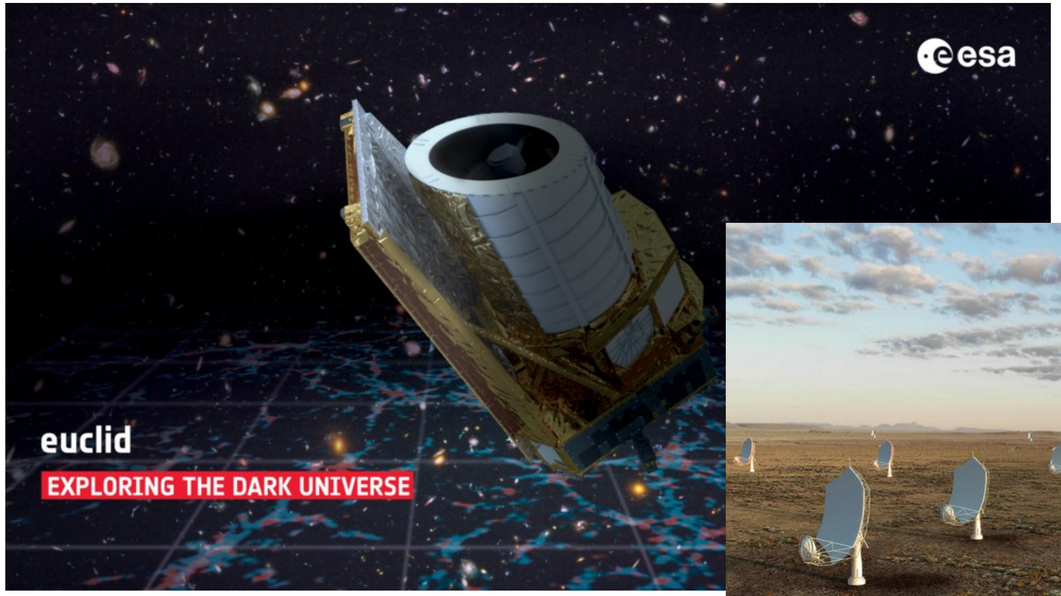
4. Cosmological observables as a probe of fundamental physics

- ***4.1 Cosmic microwave background***
- ***4.2 Cosmic structures***
- ***4.3 Cosmological gravitational waves***

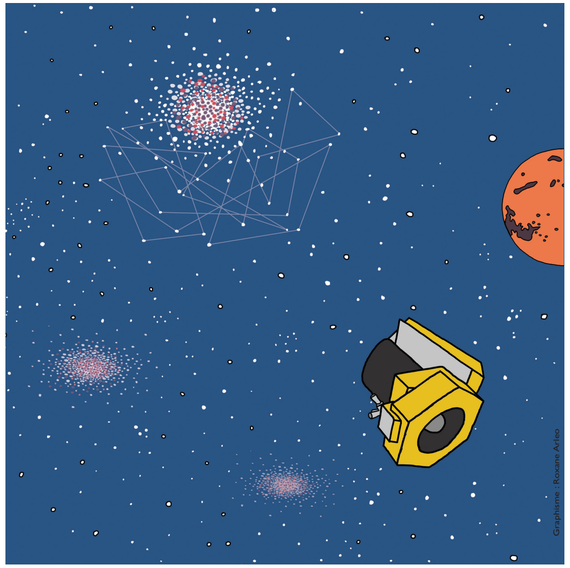
InDark Torino

Involved in

- **Theia**: the next generation astrometric space mission (after Gaia) [Ostorero, Diaferio]
- **Euclid space telescope** [Camera, Pace] **Launched on July 1st 2023**
- **Square Kilometer Array** [Camera]
- **HectoMAP redshift survey** [Diaferio]



THEIA
Microarcsecond Astrometric Observatory



Faint objects in motion : the new astrometry frontier
Proposal for a medium size mission opportunity in ESA's science programme (M5) mission

Theia lead proposer : Prof Céline Bœhm

MAIN RESULTS in 2024-25

- ***Dark energy and modified gravity***

  - **Outer regions of galaxy clusters as new probe to test modifications to gravity** (Butt, Diaferio, ... 2025)

  - **The CosmoVerse White Paper: Addressing observational tensions in cosmology with systematics and fundamental physics** (Di Valentino, … Pace, … 2025)

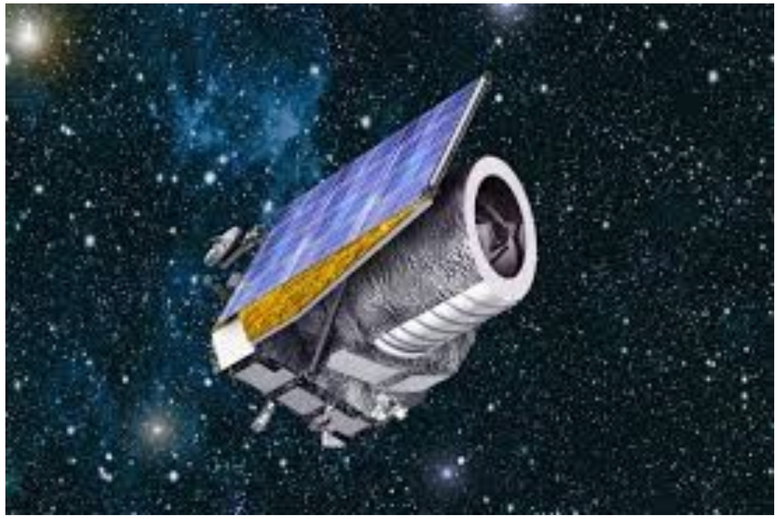
MAIN RESULTS in 2024-25

- ***Cosmological observables as a probe of fundamental physics***

- **Cluster lensing mass inverstion (CLUMI+): Combining dynamics and weak lensing around galaxy** (Umetsu, Diaferio, ... 2025)

- **Euclid: Early Release Observations – A preview of the Euclid era through a galaxy cluster magnifying lens** (Atek, …, Camera, ... 2025)

- **Cosmology with ESO-SKAO synergies** (Santos, Camera, ... 2024)



BioPhys Group

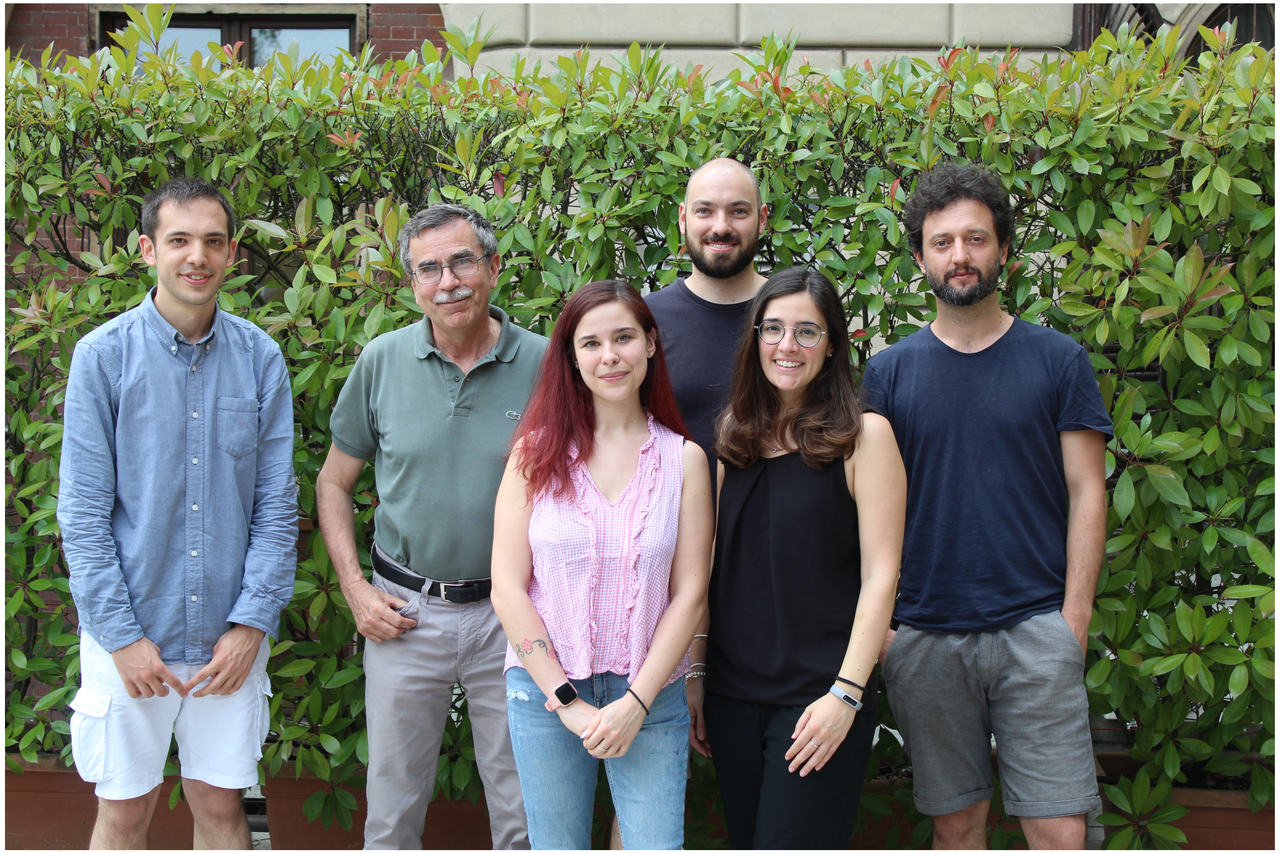
Staff:

Michele Caselle

Matteo Osella

Keywords:

Statistical Physics,
Complex Systems,
Precision Medicine



PhD Students in Complex Systems for Life Sciences:

Filippo Valle (Postdoc)

Marta Biondo (Postdoc)

Silvia Lazzardi (III year)

Francesco Zirattu (II year)

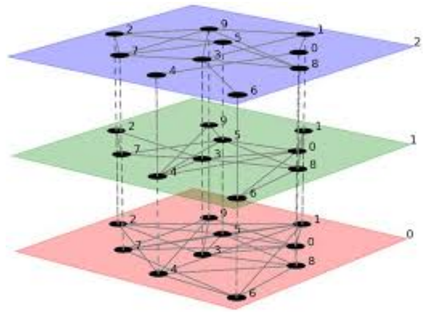
Letizia Pizzini (II year)

Research topics

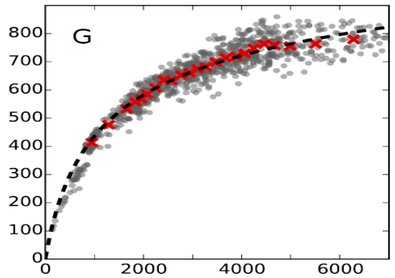
Different research topics:

Gene regulatory networks

Structure and function of recurrent regulatory circuits;
Integration of different layers of regulation to identify disease markers;
Tissue/cell-type/disease-type from RNA sequencing data

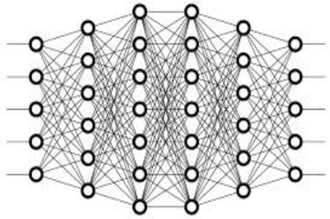


Universal Statistical laws in Molecular Biology



Machine Learning

Role of data structure and neural network architecture for performance



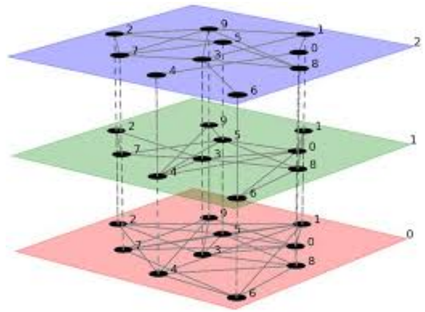
Common denominator is the application of tools from stat phys and stoch process theory to large-scale data analysis.
Main keyword: "Personalized Medicine"
Use of molecular data to fine tune therapeutic protocols

Research topics

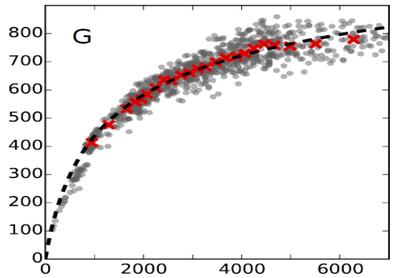
Different research topics:

Gene regulatory networks

Structure and function of recurrent regulatory circuits;
Integration of different layers of regulation to identify disease markers;
Tissue/cell-type/disease-type from RNA sequencing data

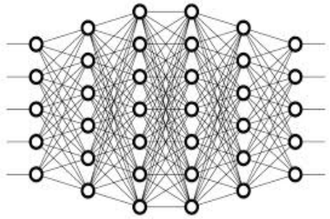


Universal Statistical laws in Molecular Biology



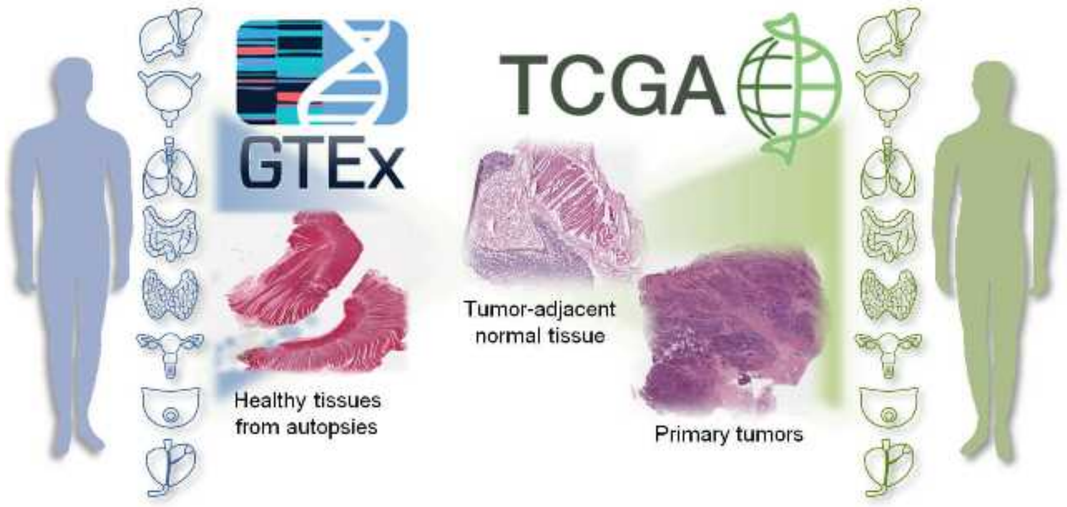
Machine Learning

Role of data structure and neural network architecture for performance



Common denominator is the application of tools from stat phys and stoch process theory to large-scale data analysis.
Main keyword: "Personalized Medicine"
Use of molecular data to fine tune therapeutic protocols

ML approach to the classification of expression patterns

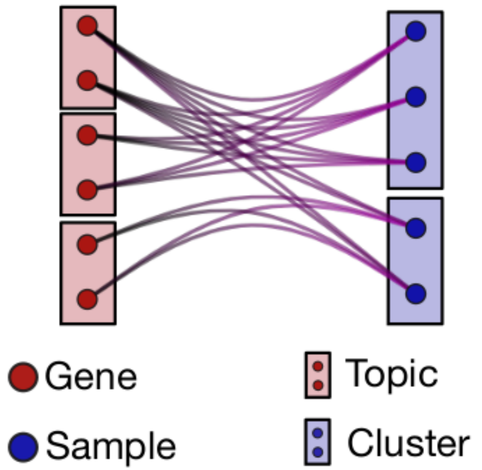


samples

genes	P1	P2	P3	P4	P5
	100	10	0	36	21
	45	0	6	124	0
	163	6	0	72	0
	43	32	12	0	2
	0	0	0	0	80

Classical questions:

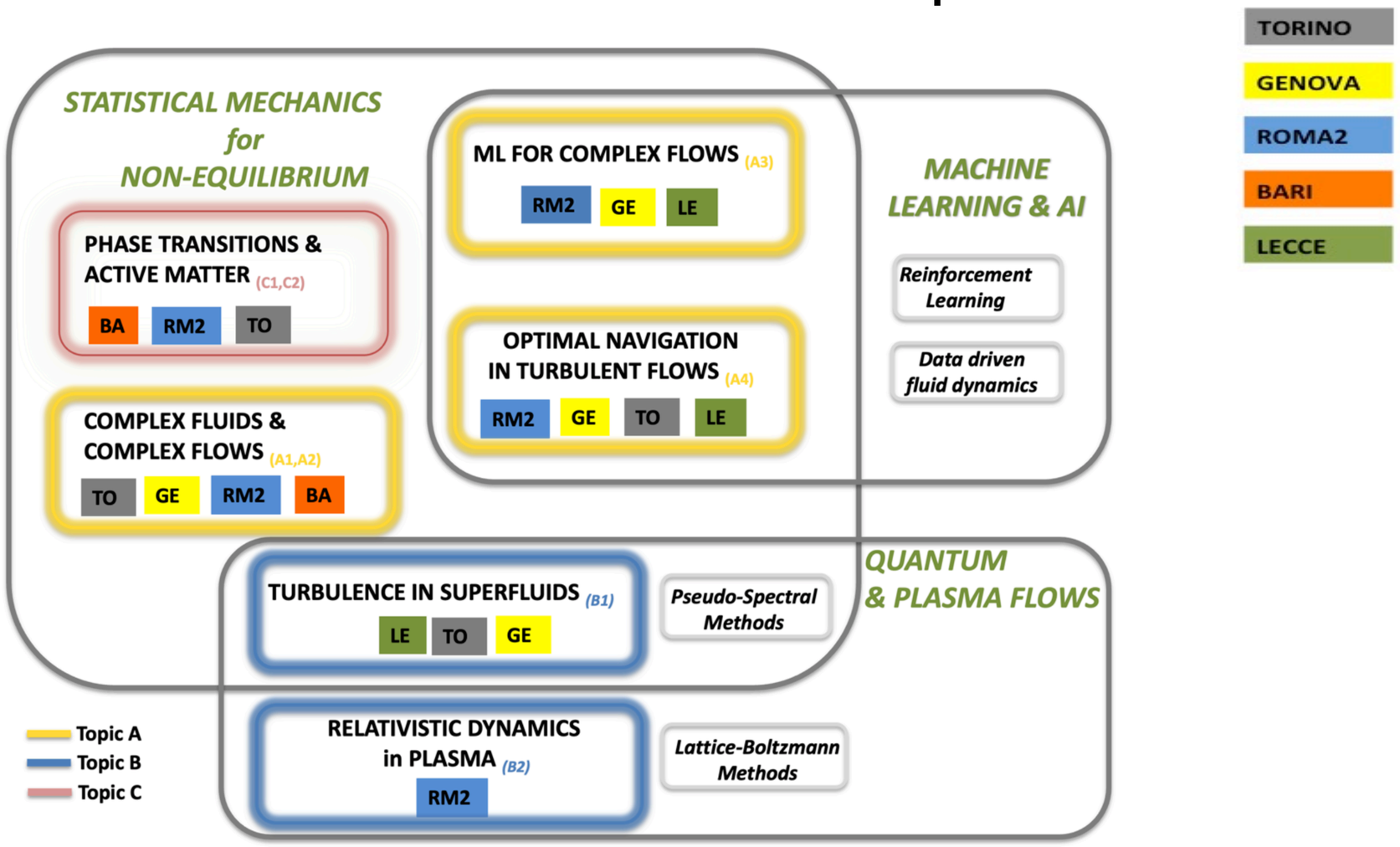
Classify samples (e.g., healthy vs cancer)
Identify marker genes for classification



F. Valle, M. Osella and M.Caselle ***Cancers 2020, 12, 3799.***
F. Valle, M. Osella and M.Caselle ***Cancers 2022, 14, 1150.***

FIELDTURB (2016-2022) (2023-2025 under review)

Particles and Fields in Turbulence and in Complex Fluids

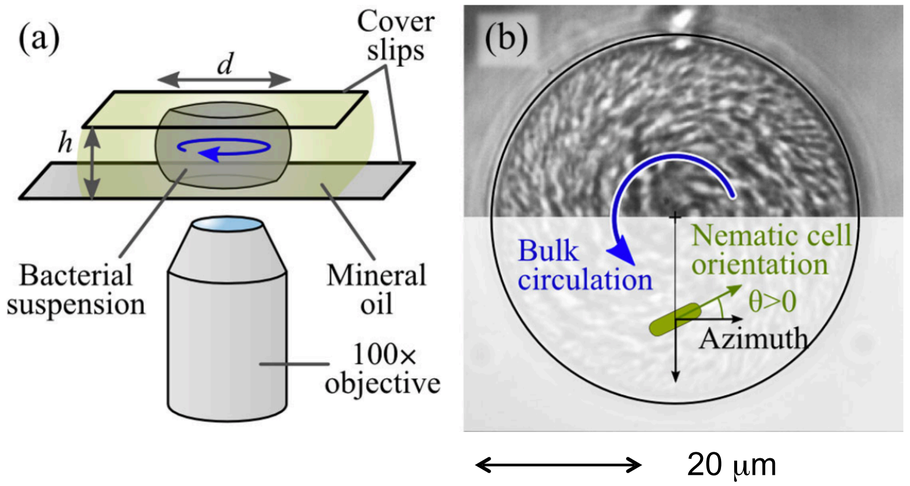


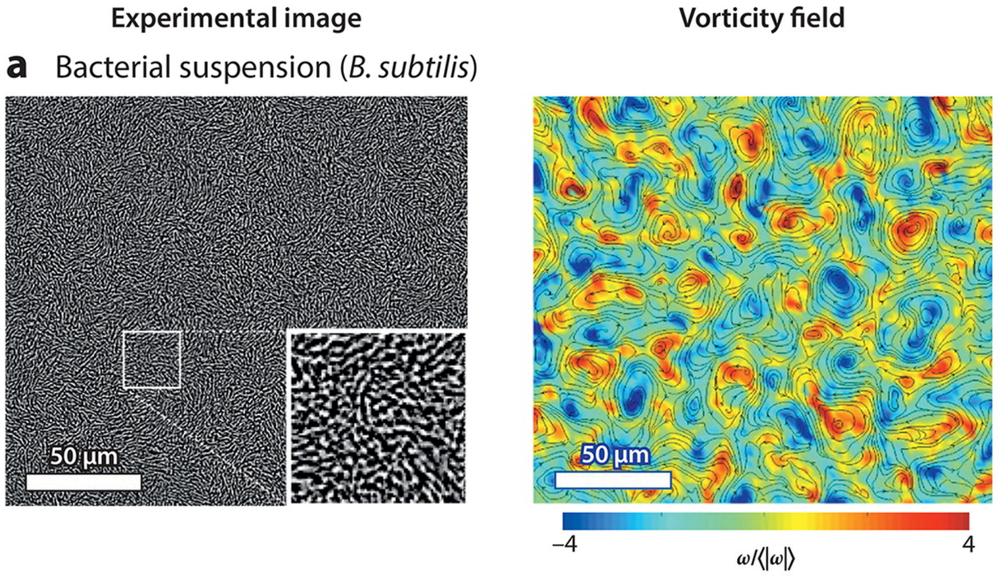
5 units, about 22 permanent staff
Theoretical approaches + numerical methods (on supercomputers and GPUs)

A new, turbulent-like state of active matter model for bacteria
(Torino unit)

Active biological matter, as two-dimensional suspension of motile bacteria, can produce coherent motion at scales much larger than the single cell

Experiment with Bacillus subtilis from R.E. Goldstein's group
Phys. Rev. Lett. **110**, 268102 (2013)



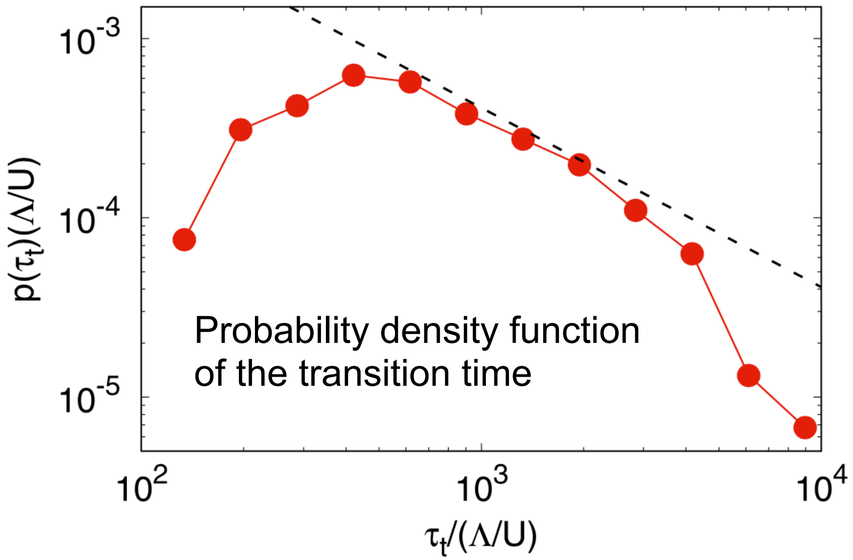


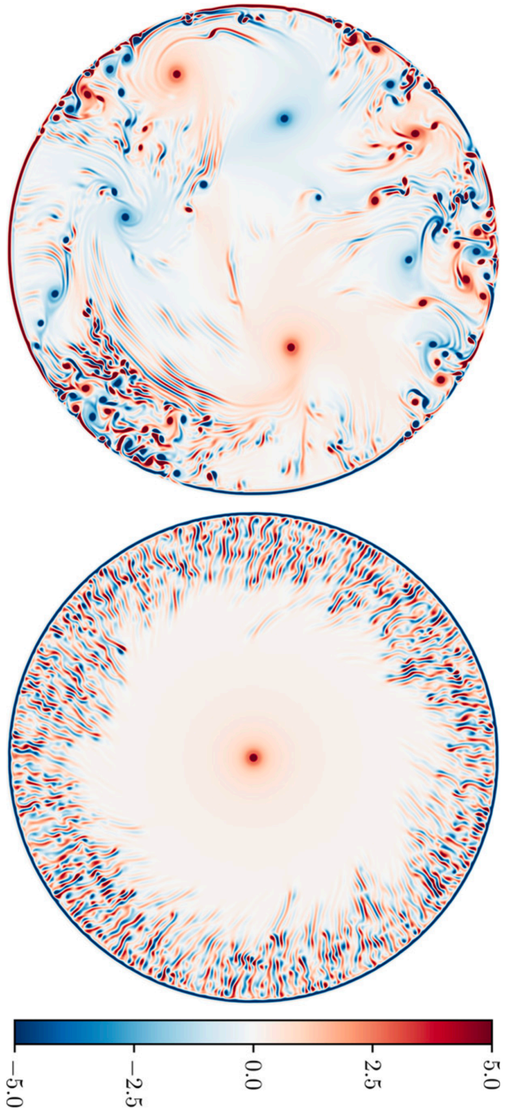
At sufficiently large scale the motion becomes turbulent-like (e.g. power-law energy spectra)

A new, turbulent-like state of active matter model for bacteria
(Torino unit)

We performed extensive numerical simulations of a standard active matter model in confined (circular) geometry where we found the transition from a “turbulent” state to a single, coherent vortex of the size of the domain.

The transition time to the single vortex has a large variability with a PDF which has a simple power-law behavior for long times which is presently under investigation



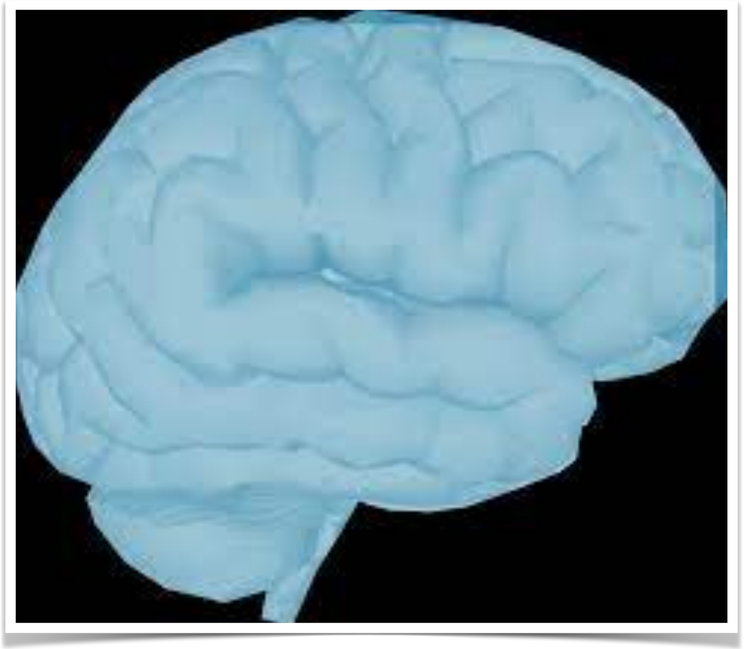


L. Puggioni, G. Boffetta, S. Musacchio, *Phys. Rev. E* **107** 055107 (2023)
L. Puggioni, G. Boffetta, S. Musacchio, *Phys. Rev. E* **106** 055103 (2022)

ENESMA : Equilibrium and Non-Equilibrium Statistical Mechanics of **complex and disordered systems**. [1.5 FTE]

Applications: the amorphous state, systems biology and brain functioning

RM1-TO (Andrea Pagnani, PoliTO) 3 staff, 2 AdR, 2 PhD 30%

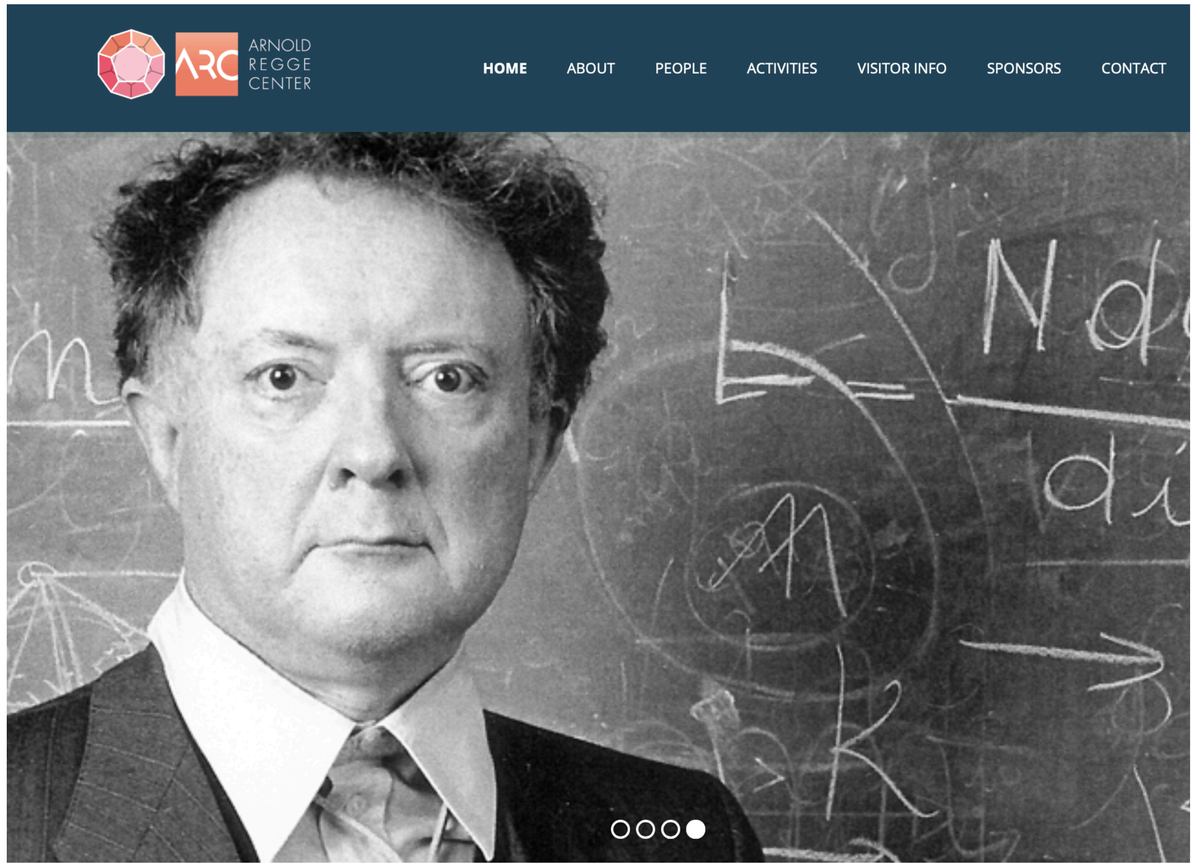


Keywords:
Complex and disordered systems (vetri di spin, random field models), Theoretical neuroscience, Statistical inference

Abstract
Study fundamental problems in equilibrium and non-equilibrium statistical physics with applications in system biology and brain functioning ; realistic brain modelling and machine learning

Altre Attività

Il Regge Center



Previously **“Arnold-Regge Center for Algebra, Geometry and Theoretical Physics”**

in rinnovo per altri 4 anni , non più bilaterale Italia-Russia ma aperto a qualsiasi collaborazione internazionale

RelativitApp : Rinnovo di uno strumento didattico interattivo ancora unico nel suo genere, ideato da Regge-Tibone

https://aulascienze.scuola.zanichelli.it/blog-scienze/science-news/einstein-a-cartoni-animati-omaggio-a-tullio-regge

La Forza nascosta

http://laforzanascosta.to.infn.it

Opera teatrale sul ruolo femminile nelle grandi rivoluzioni scientifiche del ‘900 e progetto didattico per le scuole.

(INFN-TO: Ceresole, De Marco, Marcello, Pastrone)

https://www.youtube.com/watch?v=oGLQvmET6Cg

Cosa ci serve

- Supporto per **calcolo** (cloud) per TASP, SPIF e altri
- Supporto in **segreteria** per **postdoc** e **AdR**
- Supporto per le **missioni**
- Supporto nella gestione degli **ospiti**
- Supporto per gli **ordini** (materiale, eventi)