

Gruppo 4 - Fisica Teorica



Istituto Nazionale di Fisica Nucleare

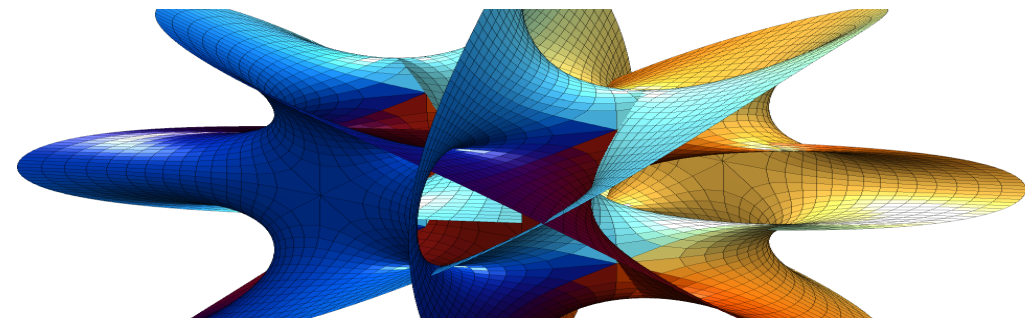
Sezione di Pisa

Coordinatore: Dario Buttazzo

e-mail: dario.buttazzo@pi.infn.it

Pisa, 07.07.2025

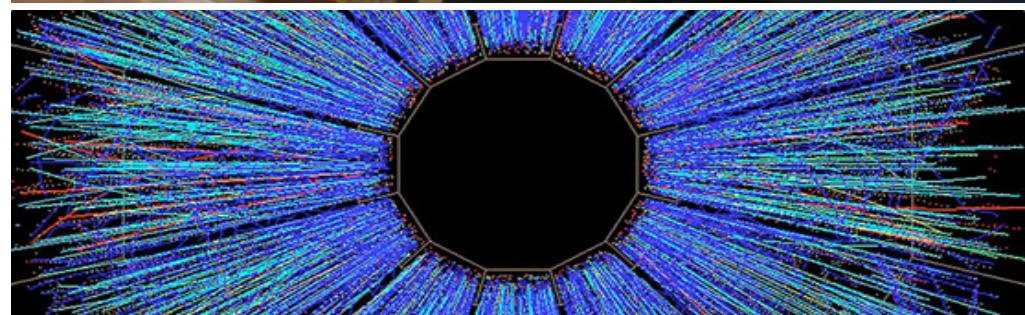
Le linee scientifiche della CSN4



Linea 1: Campi e stringhe



Linea 2: Fenomenologia delle interazioni fondamentali



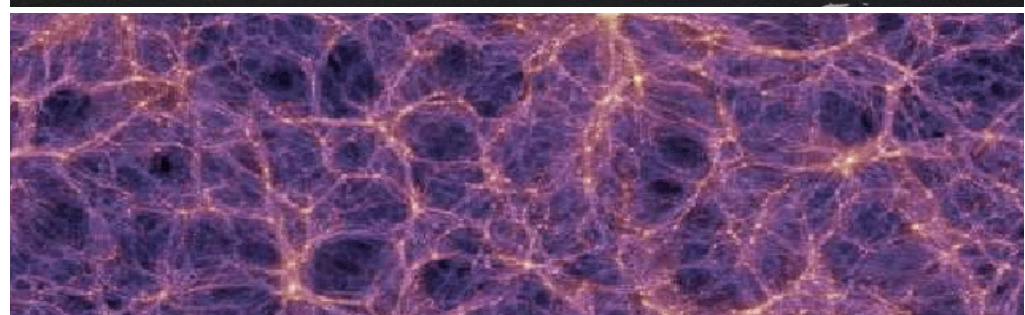
Linea 3: Fisica nucleare e adronica

$$\mathcal{L} = D_\mu \Phi^\dagger D^\mu \Phi - \mu^2 \Phi^\dagger \Phi - \lambda |\Phi^\dagger \Phi|^2$$

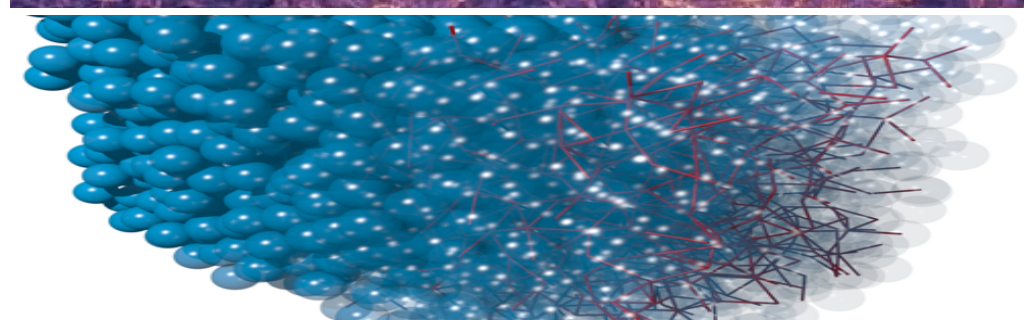
Doublet

$$\mathcal{L} = \partial_\mu \Phi^\dagger \partial^\mu \Phi - \mu^2 \Phi^\dagger \Phi - \lambda (\Phi^\dagger \Phi)^2$$

Linea 4: Metodi matematici



Linea 5: Astroparticelle

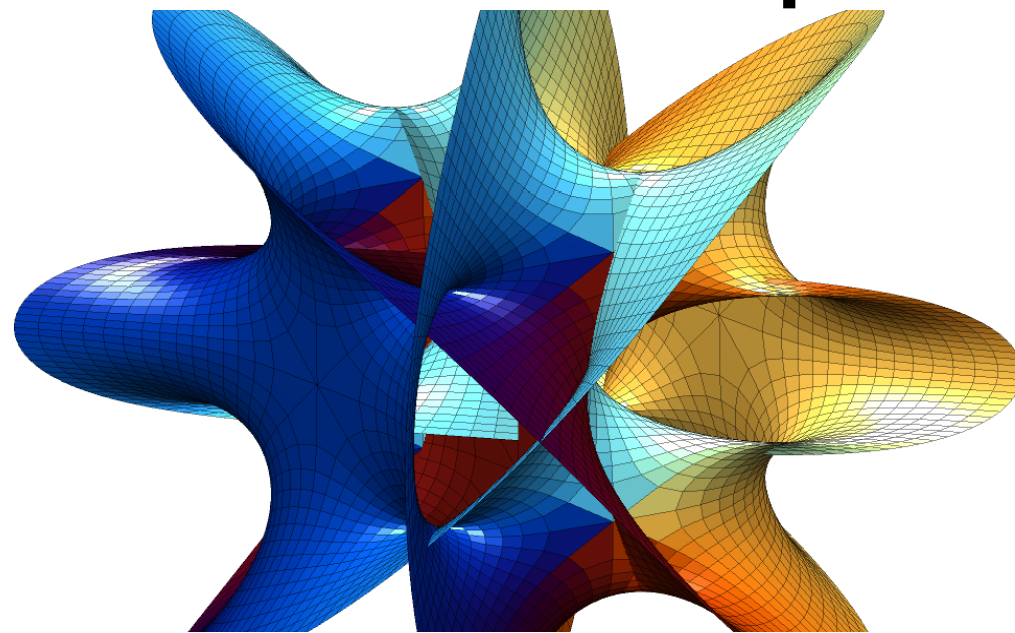


Linea 6: Fisica statistica e applicata

Linee scientifiche: Sezione di Pisa

- Linea 1 (Campi e Stringhe)
 - **FLAG** – Fields and Gravity (Responsabile locale: [Omar Zanusso](#))
 - **GAGRA** – Gauge Theories and Gravity (Responsabile locale: [Damiano Anselmi](#))
 - **GAST** – Gauge and String Theories (Responsabile locale: [Stefano Bolognesi](#))
 - **GSS** – Gauge Theories, Strings and Supergravity (Responsabile locale: [Augusto Sagnotti](#))
 - **NPQCD** – Non-Perturbative QCD (Responsabile locale: [Enrico Meggiolaro](#))
 - **SFT** – Statistical Field Theory (Responsabile locale: [Davide Rossini](#))
- Linea 2 (Fenomenologia)
 - **TPPC** – Theoretical Particle Physics and Cosmology (Responsabile locale: [Dario Buttazzo](#))
- Linea 3 (Fisica Nucleare e Adronica)
 - **NUCSYS** – Strongly Correlated Nuclear Systems (Responsabile locale: [Michele Viviani](#))
- Linea 5 (Fisica astroparticellare)
 - **NEUMATT** – Neutron star Matter Theory (Responsabile locale: [Ignazio Bombaci](#))
 - **TASP** – Theoretical Astroparticle Physics (Responsabile locale: [Daniele Gaggero](#))
 - **TEONGRAV** – Gravitational Wave Emission from Astrophysical Sources (Responsabile locale: [Leonardo Gualtieri](#))
- Linea 6 (Fisica Statistica e Teoria di Campo Applicata)
 - **BIOPHYS** – Biophysics (Responsabile locale: [Giuseppe Brancato](#))

Linea 1: Teoria dei campi e stringhe



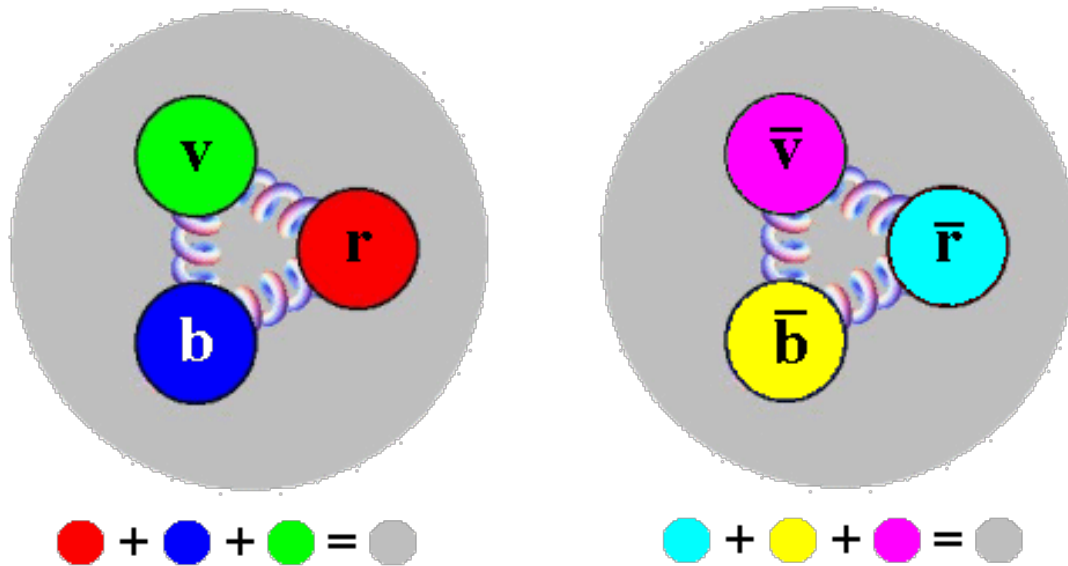
NPQCD (Non-Perturbative properties of QCD)

- **Sezioni partecipanti:** Bari, Cosenza, Ferrara, Pisa
- **Responsabile nazionale:** C. Bonati (Sez. INFN di Pisa)
- **Associati presso Pisa:**
 - B. Alles Salom (Primo Ricercatore INFN, 100% NPQCD)
 - C. Bonati (Prof. Associato, 100% NPQCD)
 - G. Clemente (RTDA [PNRR], 100% NPQCD)
 - M. D'Elia (Prof. Ordinario, 100% NPQCD)
 - A. Di Giacomo (Prof. Emerito [associato eminente], 0% NPQCD)
 - E. Meggiolaro (Prof. Associato [responsabile locale], 100% NPQCD)
 - D. Bitnaya, R. Dionisio, A. Giorgieri, M. Intini (Dottorandi, 100% NPQCD)
 - M. Naviglio, I. Soler, K. Zambello (Assegnisti PRIN, 100% NPQCD)

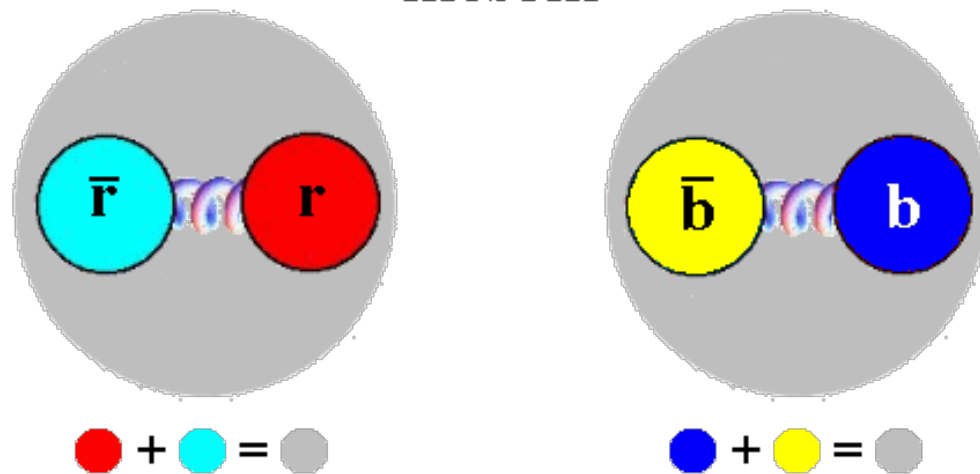
Attività di ricerca

- **Proprietà non-perturbative della QCD:** confinamento del colore, simmetrie chirali, proprietà topologiche, proprietà dell'assione, etc.

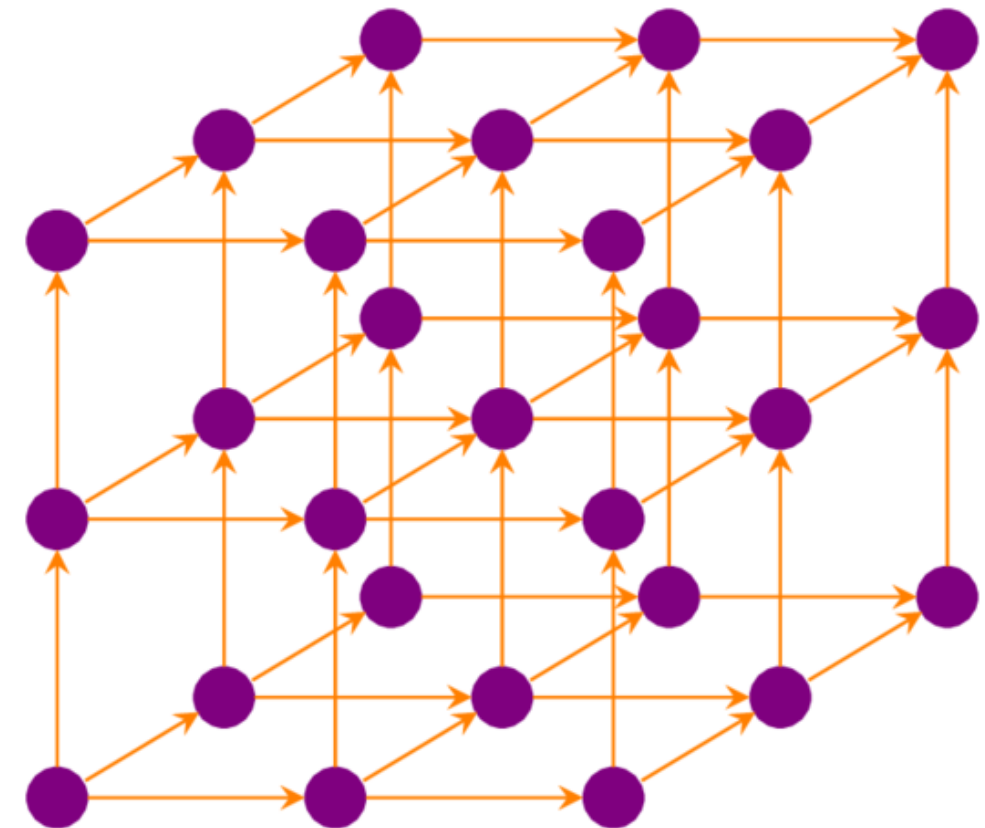
barioni



mesoni

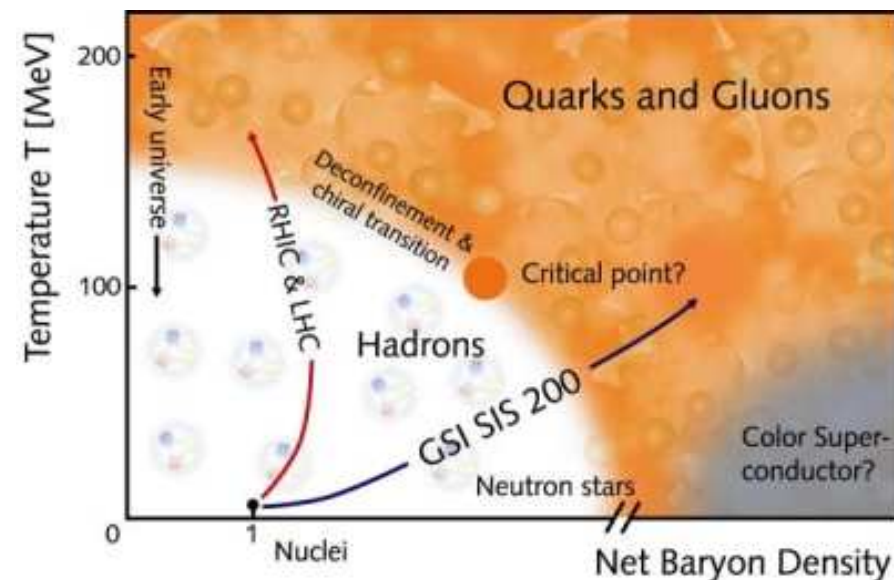


● quark
→ gluon



Attività di ricerca

- **Proprietà non-perturbative della QCD:** confinamento del colore, simmetrie chirali, proprietà topologiche, proprietà dell'assione, etc.
- **Studio delle interazioni forti in condizioni estreme:** diagramma di fase della QCD, QCD in campi esterni, etc.



- **Simulazioni numeriche e teorie efficaci.**
- **Connessioni fenomenologiche:** collisioni fra ioni pesanti, scattering adrone-adrone, transizione di QCD cosmologica, fenomenologia dell'assione.
- **Connessioni tecnologiche:** sviluppo di codici su architetture parallele standard ed ibride (CPU+GPU o altro), algoritmi per “Quantum Computing”.

GAST

(Gauge and String Theories)

Sezione di Pisa

Stefano Bolognesi (UniPi Professore Associato, Incarico di ricerca INFN)

Kenichi Konishi (UniPi, Associato Senior INFN)

Hengyuan Guo (PostDoc)

Rocco Pellegrino, Salvatore Santoro (laureandi magistrali)

Matteo Orso* (laureato magistrale 2024)

Andrea Luzio* (perfezionato sns 2025)

Attività di Ricerca 2024-2025

Non-perturbative aspects of gauge theories. Symmetries and generalized symmetries. Chiral gauge theories at strong coupling. Topological solitons, Skyrmions e Magnetic Skyrmions. Quantum measurement problem. Callan-Rubakov effect for chiral theories. Holography, vortices and black holes.

GSS: Gauge theory, Strings, Supergravity

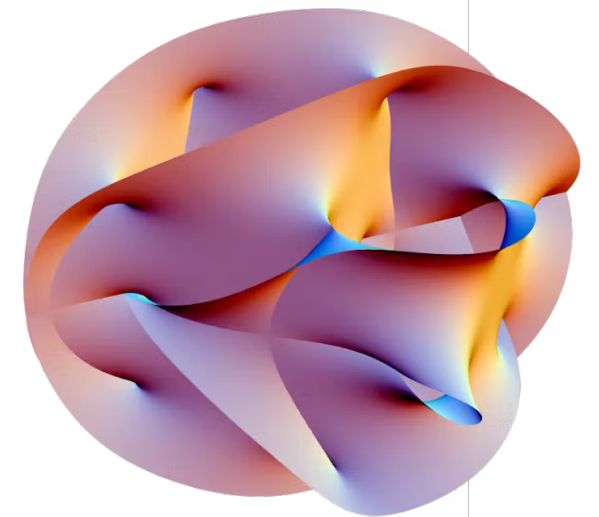
- **Staff members**

- Augusto SAGNOTTI (Professor)
- Guilherme PIMENTEL (Professor)

- **Other participants (1 PhD student and 3 Postdocs arriving in 2025)**

- Craig CLARK (PhD student, 2022-)
- Ipak FADAKAR (PhD student, 2024-)
- Rajat SHARMA (PhD student, 2024-)
- Tom WESTERDIJK (PhD student, 2022-)
- Chen YANG (PhD student, 2022-)
- Carlos DUASO PUEYO (Post-doc, 2024-, SNS fellowship)
- Laura ENGELBRECHT (Post-doc, 2024-, paid by ERC)
- Sumer JAITLEY (Post-doc, 2024-, paid by ERC)
- Giorgio LEONE (Post-doc 2024-2025, paid by PRIN) — going to Padova in the fall
- Chrysoula MARKOU (Post-doc, 2024-, SNS fellowship)
- Emine SEYMA KUTLUK (Post-doc, 2024-, SNS fellowship)

- **Supersymmetry breaking by fields and branes**
- **String Perturbation Theory**
- **Cosmological Correlations and Inflation**
- **Formal aspects of de Sitter Space**
- **Gravitational Radiation and Asymptotic Symmetries**
- **Gravitational Collapse and Black Holes**
- **Twistors and their applications to Cosmology**



GSS: Gauge theory, Strings, Supergravity

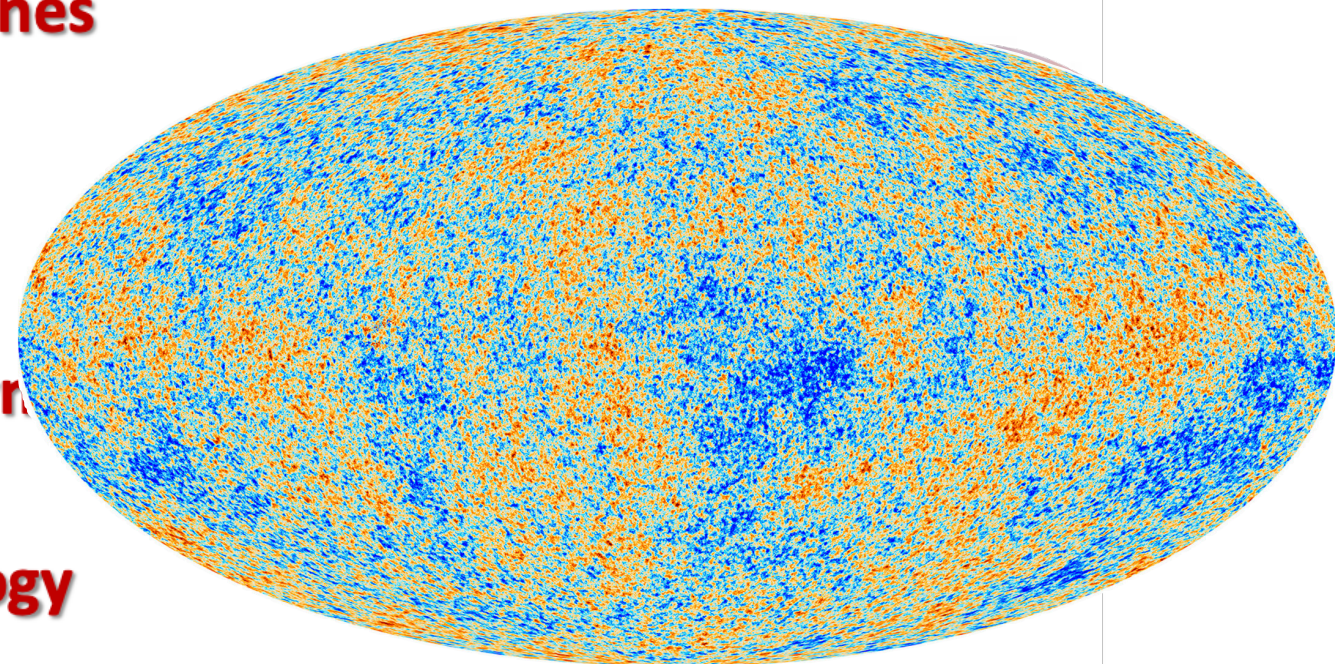
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- **Supersymmetry breaking by fields and branes**
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- **Gravitational Radiation and Asymptotic Symmetry**
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L'attività dell'IS è principalmente rivolta allo studio dei **fenomeni quantistici** in presenza di un **campo gravitazionale** con particolare attenzione a quelli derivanti dalla **quantizzazione della gravità**.

Partecipanti Locali

Strutturati:

- Giovanni Marozzi (PA - 40%)
- Omar Zanusso (RTDB - 100%)

Dottorato:

- Luca Parente (100%)
- Lorenzo Benfatto (100%)
- Pierre Bechaz (20%)

Gauge Theories and Gravity (without relying on supersymmetry)

D. Anselmi **Particelle puramente virtuali e virtualità cosmica**

La gravità quantistica può essere definita modificando le tecniche diagrammatiche usuali per incorporare particelle “puramente virtuali”. Si ottiene così una teoria unitaria e rinormalizzabile, che fornisce predizioni testabili in cosmologia primordiale, tra cui il valore del rapporto tensore-scalare r delle fluttuazioni primordiali, in corso di misurazione, previsto nell'intervallo $4/10000 < r < 3/1000$.

Le proprietà delle particelle puramente virtuali sono state studiate in vari contesti, tra cui le teorie dei campi in intervalli di tempo finiti, dove l'operatore di evoluzione temporale U è unitario ma perde la proprietà di gruppo e non ammette un'Hamiltoniana in senso standard

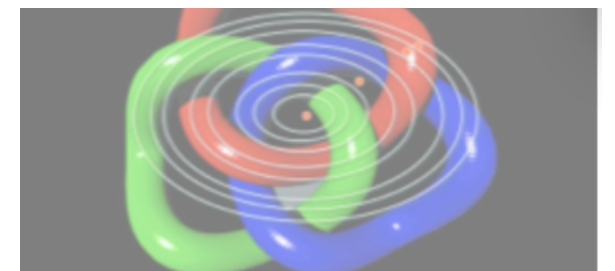
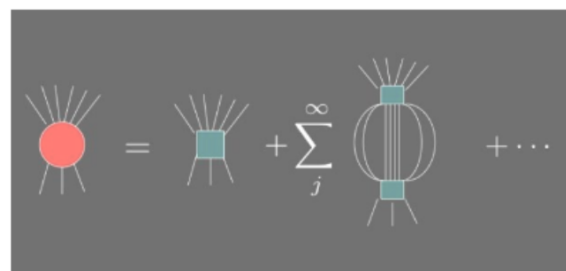
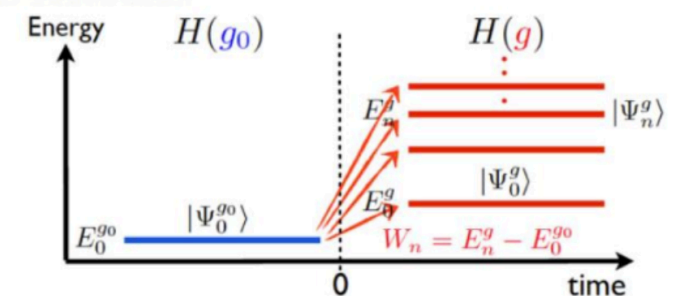
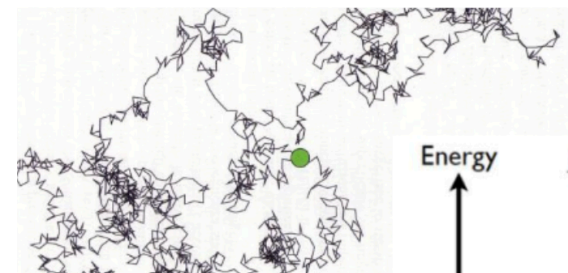
Iniziativa specifica INFN

Statistical Field Theory (SFT)

Sede di Pisa

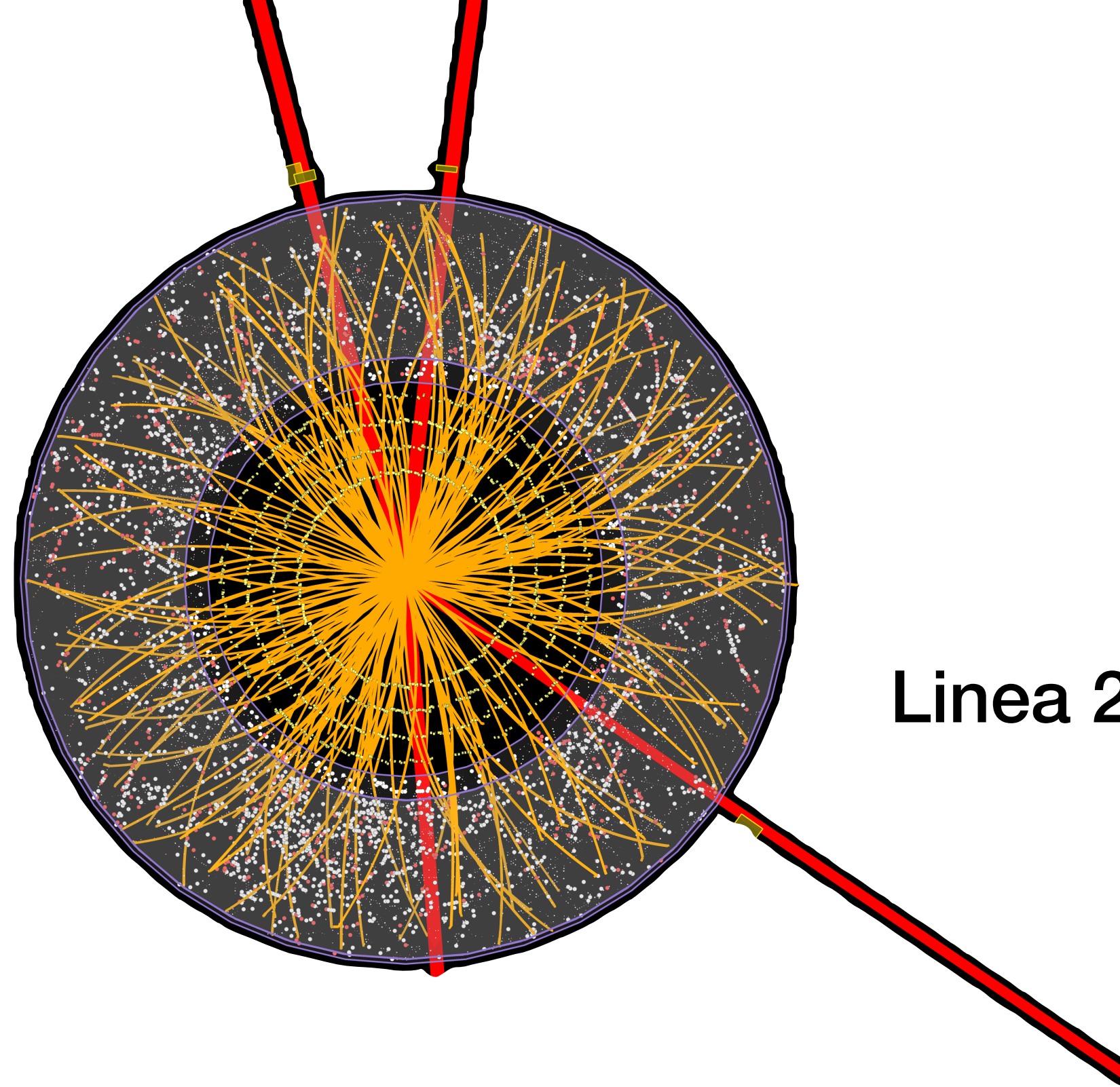
Vincenzo **Alba** (UNIPi, PA, 100%)
Michele **Burrello** (UniPi, PA, 100%)
Davide **Rossini** (UniPi, PO, 100%)
Alessandro **Vichi** (UniPi, PA, 100%)
Mihail **Mintchev** (INFN, senior, —)
Sanam **Azarnia** (INFN, assegno, 100%)
Fabio **Caceffo** (UniPi, PhD, 100%)
Federico **Rottoli** (UniPi, postdoc, 100%)

8 ricercatori, **7** FTE



Principali argomenti di ricerca

- **Quantum field theories out of equilibrium**
 - > low-dimensional QFTs for integrable models and deformations
 - > bound-state confinement through generalized hydrodynamics
 - > hydrodynamics of the quantum Mpemba effect
 - **Entanglement and quantum complexity**
 - > hydrodynamics of entanglement in open quantum systems
 - > entanglement transitions under quantum monitoring
 - > magic (nonstabilizerness) in fermionic and quantum spin systems
 - **Conformal field theories and conformal invariance**
 - > CFT approaches to study phase transitions and scattering amplitudes
 - > conformal bootstrap methods in higher dimensions (eg. 3D and 4D)
 - **Quantum simulation of many-body systems**
 - > quantum transport in Rydberg-atom platforms
 - > analog quantum simulations of CFTs with Josephson-junction arrays
 - > hybrid quantum dot—superconductor systems for topological quantum computing
-



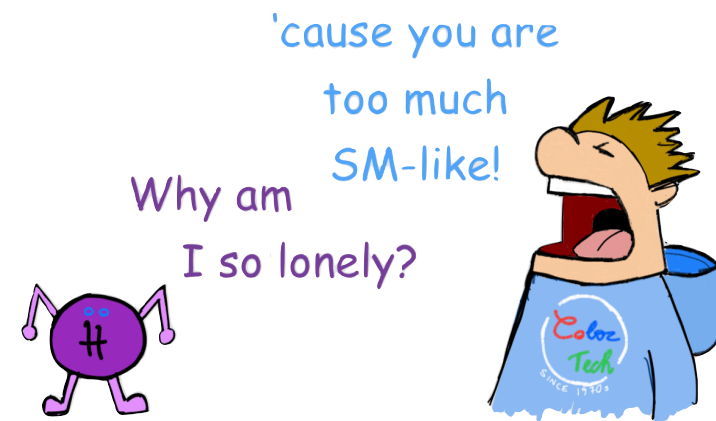
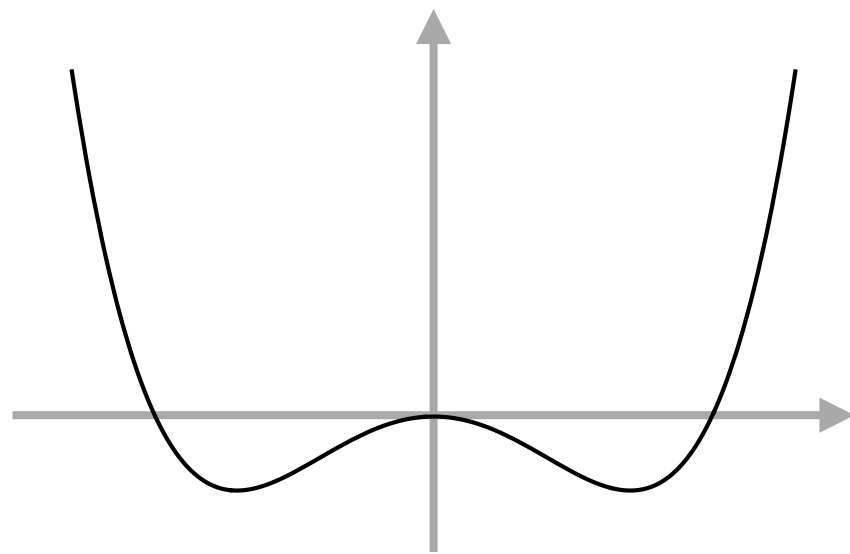
Linea 2: Fenomenologia

New phenomena at the TeV scale

♦ What causes EWSB?

we don't know...

is it the SM up to any (experimentally accessible) energy scale?



$$M_{\text{NP}} \lesssim 4\pi v \approx 3 \text{ TeV}$$

New phenomena at the TeV scale

♦ What causes EWSB?

we don't know...

is it the SM up to any (experimentally accessible) energy scale?

♦ What is Dark Matter??

we have no idea...



can have EW interactions: WIMP

$$g_{\star} \approx g_{\text{EW}} \quad \Rightarrow \quad M_{\text{DM}} \approx \text{few TeV}$$

New phenomena at the TeV scale

♦ What causes EWSB?

we don't know...

is it the SM up to any (experimentally accessible) energy scale?

♦ What is Dark Matter??

we have no idea...

♦ What is flavor?

we have no idea...

$$m_u \sim \begin{pmatrix} \cdot & \cdot & \text{large red circle} \end{pmatrix}$$
$$m_d \sim \begin{pmatrix} \cdot & \cdot & \text{small green circle} \end{pmatrix}$$

$$V_{\text{CKM}} \sim \begin{pmatrix} \text{large purple circle} & \text{small purple circle} & \text{tiny purple circle} \\ \text{small purple circle} & \text{large purple circle} & \text{tiny purple circle} \\ \text{tiny purple circle} & \text{small purple circle} & \text{large purple circle} \end{pmatrix}$$

$$m_\ell \sim \begin{pmatrix} \cdot & \cdot & \text{small blue circle} \end{pmatrix}$$

**Theoretical implications for direct and indirect searches
at present and future colliders (LHC, FCC, muon collider)**

TPPC — Theoretical Particle Physics and Cosmology

Pisa, Firenze, Roma 1

Responsabile Nazionale:

Michele Redi (sezione di Firenze)

e-mail: michele.redi@fi.infn.it

Responsabile Locale:

Dario Buttazzo (sezione di Pisa)

e-mail: dario.buttazzo@pi.infn.it

Staff: Dario Buttazzo (PR INFN, 80%), Paolo Panci (PA UniPi, 90%),
Enrico Trincherini (PA SNS, 90%), Daniele Barducci (RTDA UniPi, 90%)

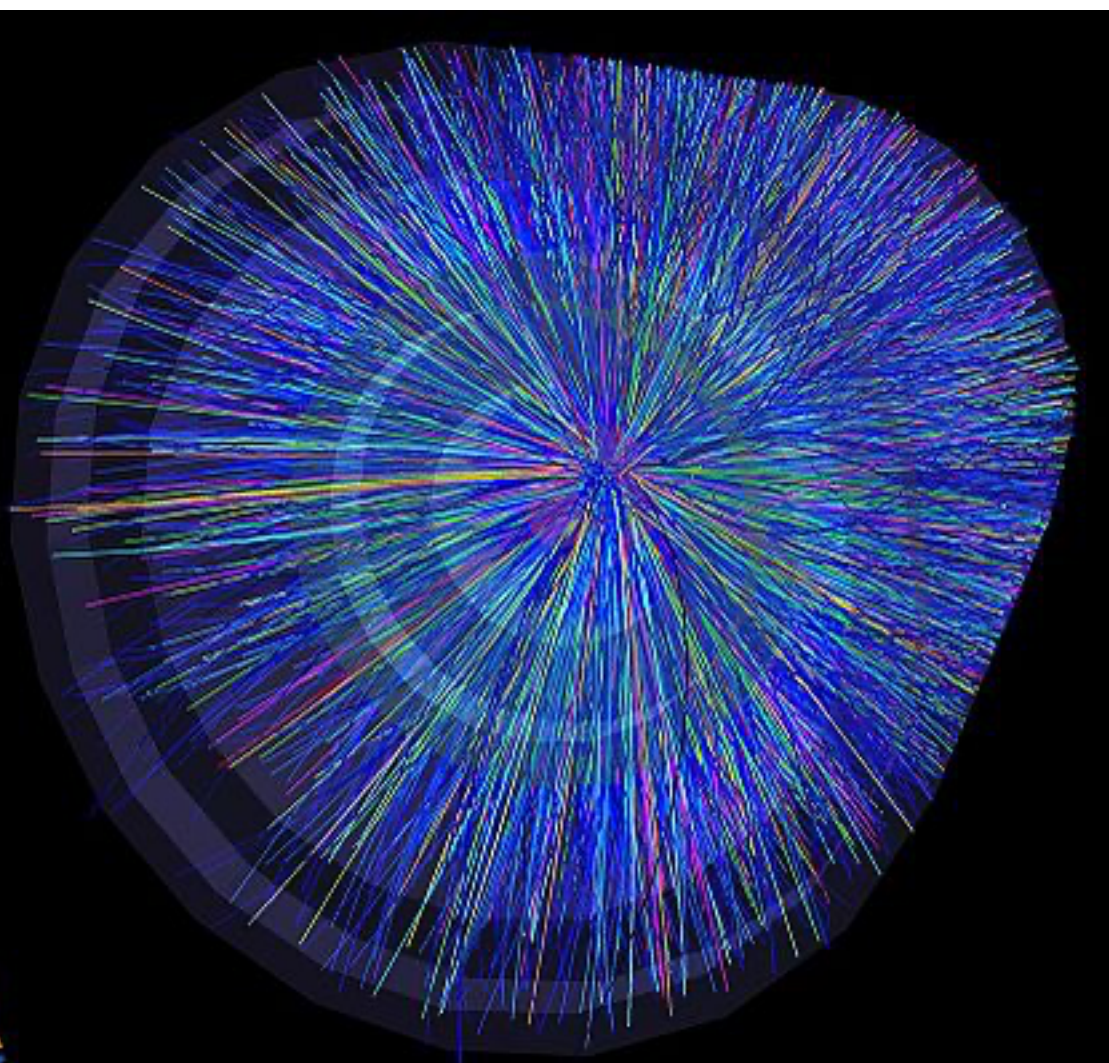
Postdoc: ➡ Michael Zantedeschi (INFN), Arman Korajac (INFN), Mateusz Duch (UniPi)
Florentin Jaffredo (INFN), Arsenii Titov (UniPi) ➡

Studenti PhD: Mohammad Aghaie (UniPi), Bruno Bucciotti (SNS), Andrea Di Lecce (SNS), Leonardo Juliano (SNS), Giulio Marino (UniPi), ➡ Keshav Chaudhary (UniPi)
Alessandro Dondarini (UniPi) ➡

TPPC — Theoretical Particle Physics and Cosmology

Pisa, Firenze, Roma 1

- ✦ **Beyond the Standard Model:** extended Higgs sectors, composite Higgs, dark sectors, unified models [[Barducci](#), [Buttazzo](#), [Zantedeschi](#), [Di Lecce](#), [Marino](#)]
- ✦ **Collider physics:** LHC & future colliders, FCC, muon collider; EFT, Higgs and EW physics, ... [[Buttazzo](#), [Korajac](#), [Barducci](#), [Marino](#), [Chaudhary](#)] (sinergia con Gruppo 1)
- ✦ **Flavour physics:** rare B, K, D decays; fundamental models of flavour; lepton flavour [[Buttazzo](#), [Korajac](#), [Barducci](#)] (sinergia con Gruppo 1)
- ✦ **Dark Matter**
 - ✦ Indirect searches [[Panci](#), [Marino](#), [Aghaie](#)] (sinergia con TASP + Gruppo 2)
 - ✦ Direct searches [[Panci](#), [Marino](#)] (sinergia con fisica della materia)
 - ✦ Models of DM: WIMPs, axions, composite DM, etc [[Buttazzo](#), [Di Lecce](#), [Panci](#)]
- ✦ **Black holes & fundamental physics** [[Trincherini](#), [Juliano](#), [Bucciotti](#) + [Panci](#), [Zantedeschi](#), [Marino](#), [Dondarini](#)]
- ✦ **Gravitational waves (as signatures of BSM)** (sinergia con Virgo, ET, Flash) [[Trincherini](#), [Juliano](#), [Bucciotti](#) + [Panci](#), [Zantedeschi](#), [Marino](#), [Dondarini](#)]



Linea 3:
Fisica nucleare e adronica

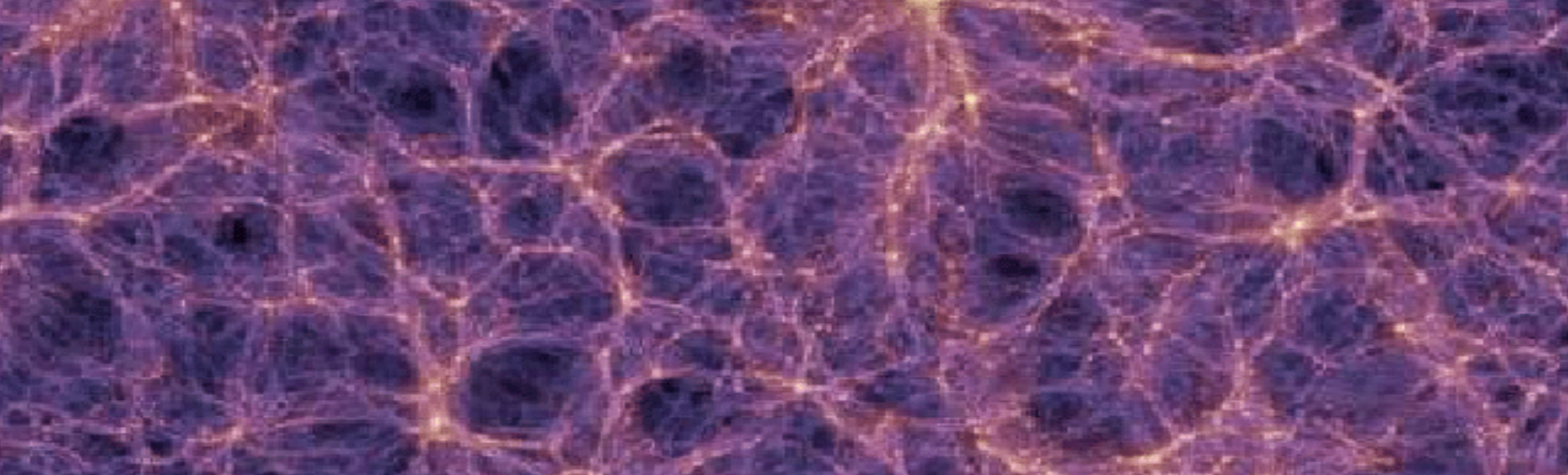
NUCSYS

- **Staff:** A. Kievsky, L. E. Marcucci, M. Viviani
- **Post-doc:** E. Filandri (ECT*, Trento, associata su Nucsyst-PI)
- **PhD:** E. Proietti (3° anno), M. Sagina (2° anno), V. Barlucchi (1° anno, in condivisione con Mainz U.)
- **Laureandi:** Lorenzo Vaccari (TBC)

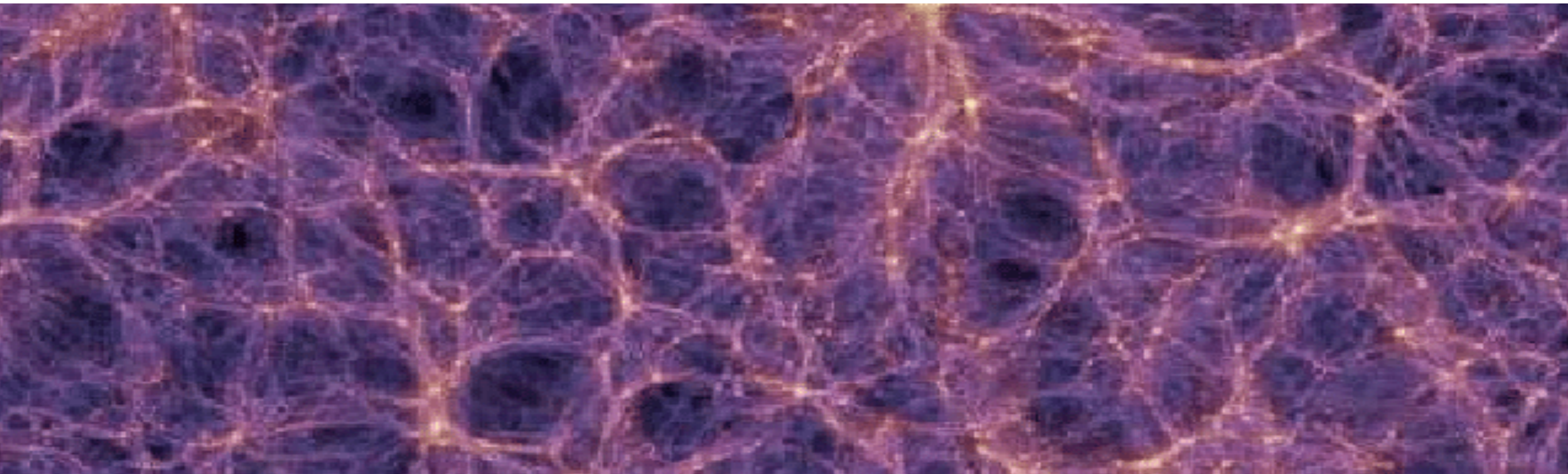
Temi di ricerca 2026:

→ synergy with ALICE experiment

- Femtoscopy studies in collaboration with the Alice experiment (p-p-Lambda correlation functions and the NNLambda three-body force)
- Universality in few-nucleon systems (consequences of the large values of NN scattering lengths on various observables)
- Study of the alpha-particle monopole transition form factor (study of energy and width first excited state of ^4He)
- Beyond Standard Model Physics in few-nucleon systems (dark-matter scattering and evidence of the X17 particle in few-nucleon transitions)
- Reactions of astrophysical interest (p-d, p- ^3He , and d-d fusions, consequences for the BBN and for the energy production)
- Study of new three-nucleon interaction in p-d scattering observables (development of sophisticated models of three-nucleon interactions)
- Study of hyperon-nucleon interactions, within contact and chiral Effective Field Theory (development of interaction improvable order-by-order)
- Study of short-range correlations in light nuclei (comparison w/ electron scattering exp. at Jefferson Lab.)



Linea 5: Astroparticelle, gravità, cosmologia



Neutron star matter

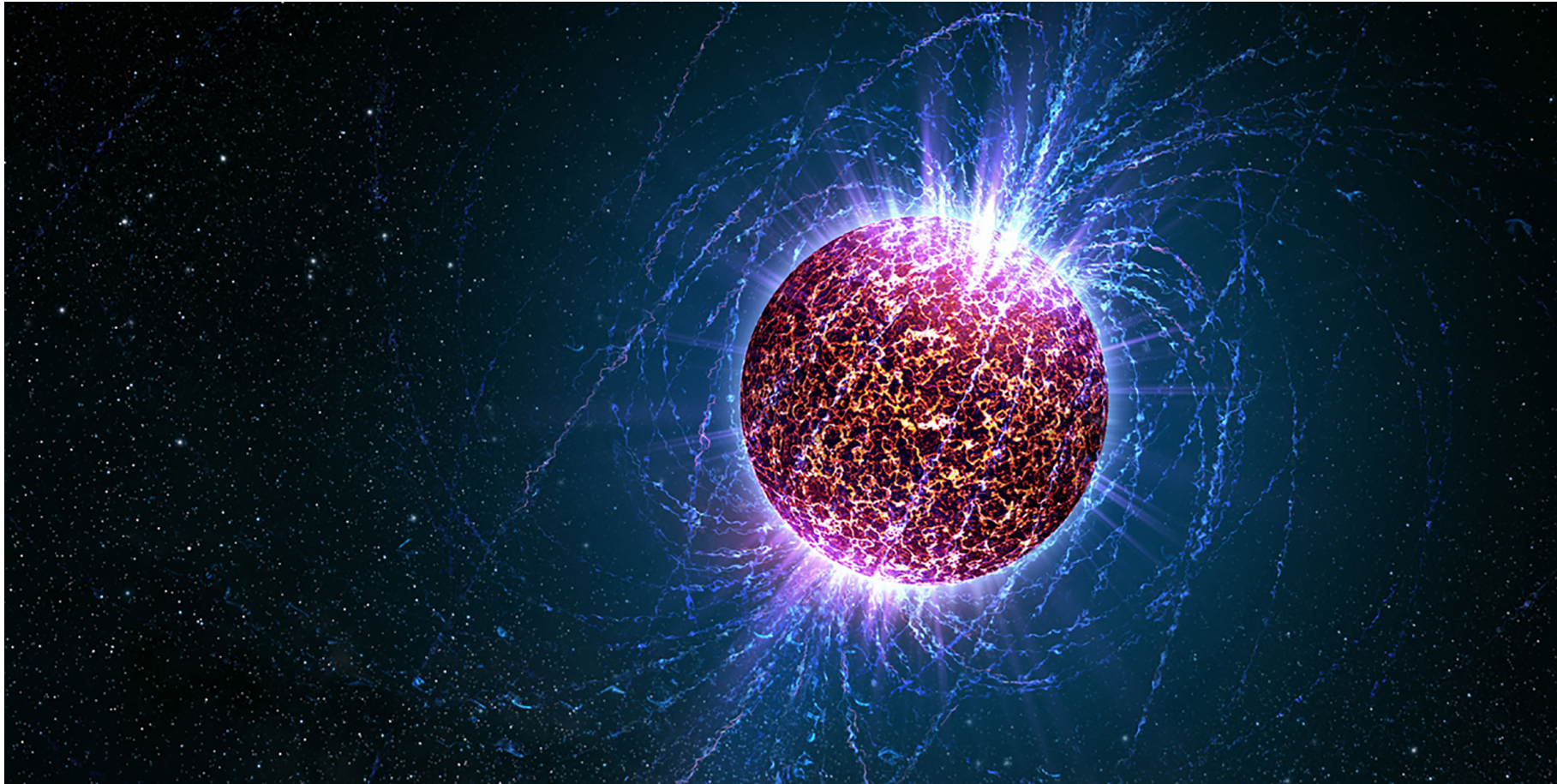
Research line: **Astro-Particle Physics**

Topics: Dense Matter, Neutron Star Physics, Dark Matter in Compact Stars, and Quantum Many-Body Physics

The research on dense matter and Neutron Star Physics is of paramount interest and topicality, especially after the discovery of **gravitational waves from the merging of binary neutron star systems** and the birth of **multimessenger astrophysics**.

Partecipanti sezione di Pisa

- Ignazio Bombaci, 100% (resp. locale)
- Vishal Parmar, 100% postdoc borsa INFN non-italiani
- Maria Luisa Chiofalo, 40% (Prof. Univ. Pisa)
- Michele Barsanti, 30% (Prof., Dipart. Di Ingegneria, Univ. Di Pisa)
- Sebastiano Bresolin, 30% (Ass. Ric., Dipart. di Fisica, Univ. di Pisa)



➤ **Dark Matter in compact stars (Neutron Stars and White Dwarfs)**

Study of the effects of fermionic **dark matter** on the properties of **neutron stars**.

➤ **General Relativistic simulations of binary Strange Star mergers.**

➤ **Equation of State for strong interacting matter at high density and temperature**

➤ **Equation of state of strongly interacting fermionic neutral atoms** with potentials characterized by long effective range and tunable strength.

➤ **Quantum atom technologies for fundamental physics, astrophysics and cosmology problems.**

TASP - Theoretical AstroParticle Physics

• Linee di ricerca del gruppo di Pisa

Fisica stellare: caratterizzazione delle popolazioni e delle proprietà stellari e delle loro caratteristiche mediante modelli numerici e confronto con dati astrometrici, fotometrici, spettroscopici. Studio delle popolazioni stellari in galassie vicine.

Cosmologia teorica: descrizione delle osservabili in modo gauge-invariante. Definizione perturbativa e non-perturbativa della dinamica cosmologica.

Fisica dei raggi cosmici e astronomia multi-messenger: Studio della propagazione dei raggi cosmici nella Galassia. Studio della radiazione non termica (radio, raggi gamma, neutrini diffusi) mediante codici numerici.

Ricerca indiretta della materia oscura: segnature astronomiche e cosmologiche di nuova fisica (CMB, 21cm, dati astronomici multi-messenger). Fenomenologia dei buchi neri primordiali e della fisica dell'accrescimento su buchi neri.

Fisica dei plasmi: Studio dei fenomeni dissipativi e del trasporto di energia nei plasmi in regime turbolento, studio delle proprietà delle strutture magnetizzate turbolente osservate nello spazio mediante simulazioni numeriche.

Formazione ed evoluzione di galassie: Caratterizzazione delle proprietà delle galassie e del mezzo intergalattico nell'epoca della reionizzazione attraverso la modellizzazione e l'implementazione di simulazioni numeriche in ambiente cosmologico, con idrodinamica, auto gravità, chimica, e trasporto radiativo per predizioni e interpretazione di dati osservativi.

• Staff:

- Francesco Califano [Prof. Associato, universitario] 80%
- Santi Cassisi [Dirigente di ricerca INAF] 80%
- Michele Cignoni [Prof. Associato, universitario] 100%
- Scilla Degl'Innocenti [Prof. Ordinaria, universitario] 100%
- Daniele Gaggero [Ricercatore INFN] 80%
- Dario Grasso [Primo Ricercatore INFN distaccato presso l'ambasciata d'Italia nei Paesi Bassi]
- Giovanni Marozzi [Prof. Associato, universitario] 55%
- Andrea Pallottini [RTDB, universitario] 100%
- Pier Giorgio Prada Moroni [Prof. Associato, universitario] 60%

Assegnisti: Matheus Rodrigues Medeiros Silva, Giada Valle. **Dottorandi:** Pierre Béchaz

TEONGRAV: Gravitational waves sources

- 4 faculty/staff members:

- Leonardo Gualtieri (100%),
- Walter Del Pozzo (10%),
- Angelo Ricciardone (20%),
- Daniele Gaggero (20%)



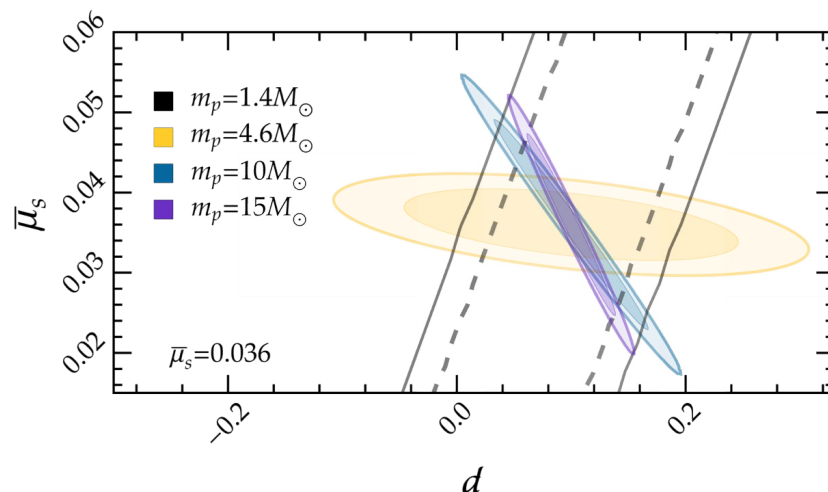
- 4 PhD students:

- Matteo Della Rocca (100%),
- Ilaria Caporali (50%),
- Dario Rossi (100%),
- Joachim Pomper (50%)

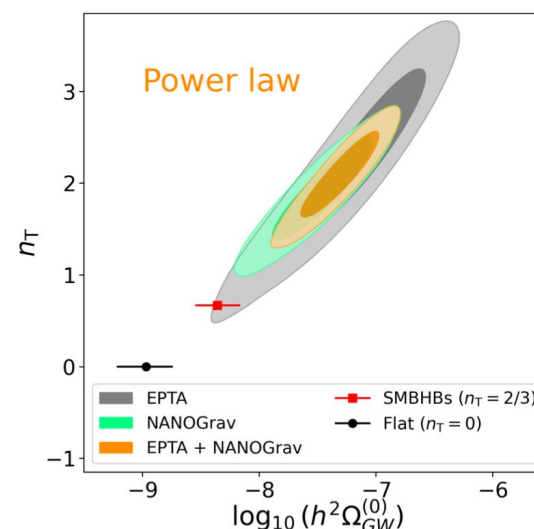


TEONGRAV: Gravitational waves sources

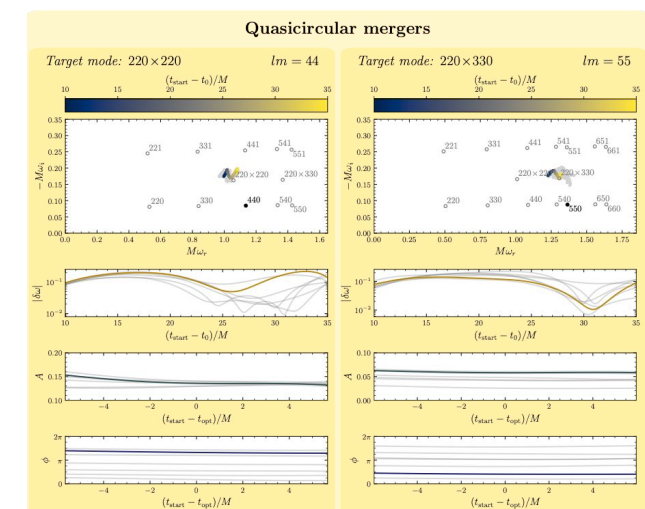
- Modelling of black hole binaries and of the emitted GW signals beyond GR
 - comparable mass binaries: inspiral, merger, ringdown
 - extreme mass-ratio inspirals
- Gravitational wave sources as probes of dark matter
- Modelling of the GW stochastic background
- Data analysis techniques to extract signatures of new physics from GW signals (inspiral, ringdown)
- Binary neutron stars as probes of the neutron star equation of state
- Inference of astrophysical and cosmological models



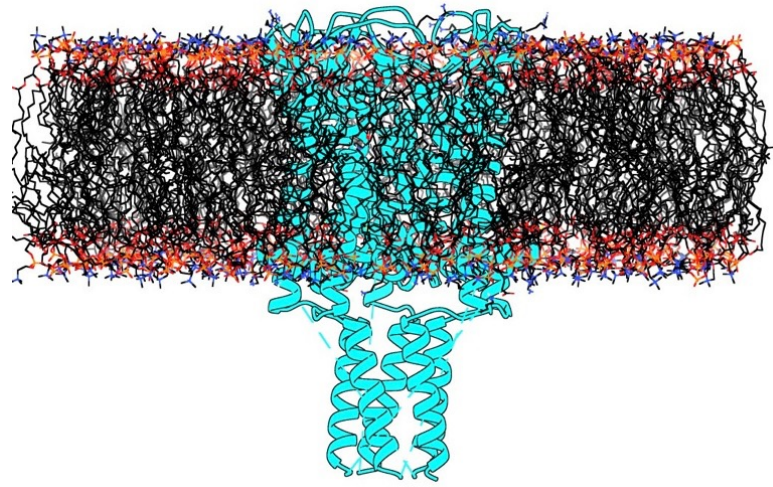
PRL
2023



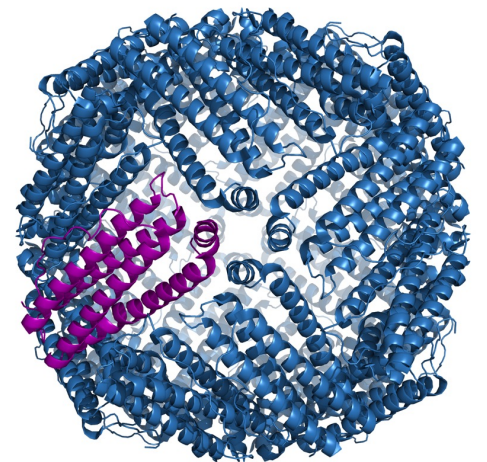
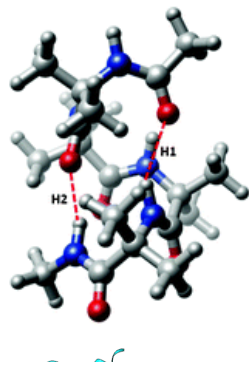
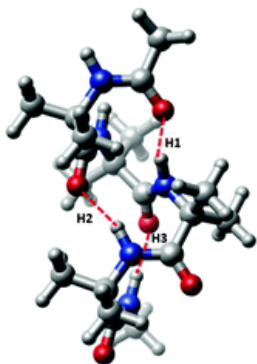
PRL
2024



PRL
2023

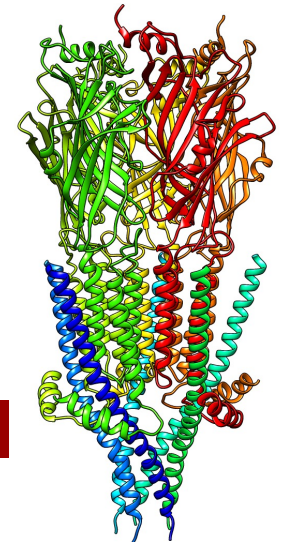


Linea 6: Fisica applicata e statistica



Activity

The activity of the Pisa group is focused on the developments and applications of numerical simulation methods of complex systems of biological interest.



Members (FTE: 4.0)

Name -- Position -- INFN Position

Giuseppe Brancato – Professore Associato 100%

Vincenzo Barone -- Professore Ordinario 0% (Ass. senior)

Luca Benedetti – Dottorando 100%

Alfonso Ferretti – Dottorando 100%

Simone Grandinetti – Postdoc 100%

Sebastiano Stramaglia INFN section: Bari

Mario Nicodemi INFN section: Napoli

Guido Tiana INFN section: Milano

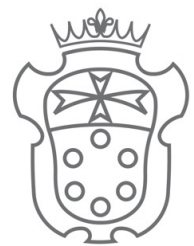
Giuseppe Brancato INFN section: Pisa

Velia Minicozzi INFN section: Roma II

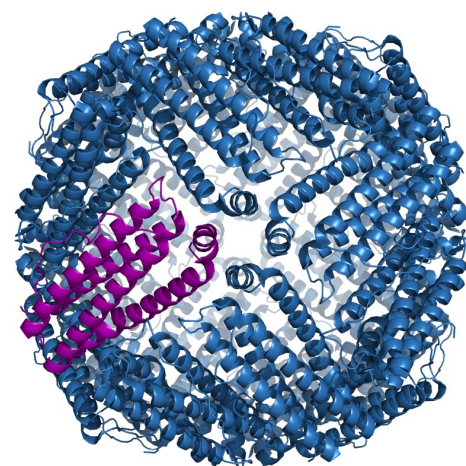
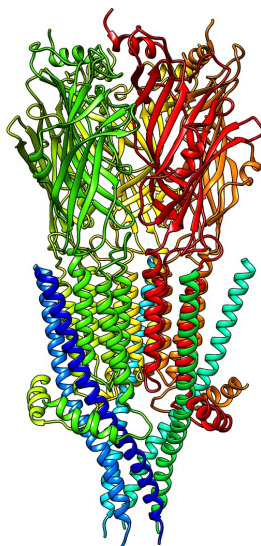
Silvia Scarpetta INFN section: Salerno

Michele Caselle INFN section: Torino

Luca Tubiana INFN section: Trento

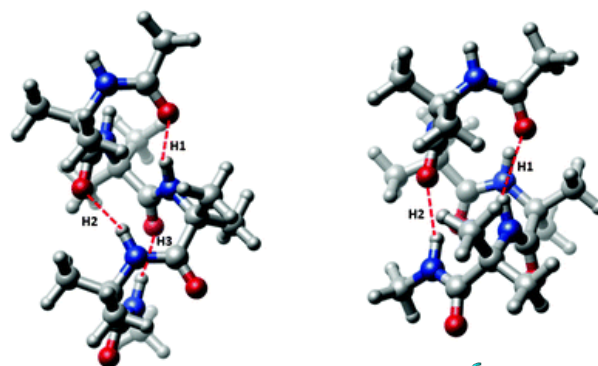


5HT3 Serotonin Receptor

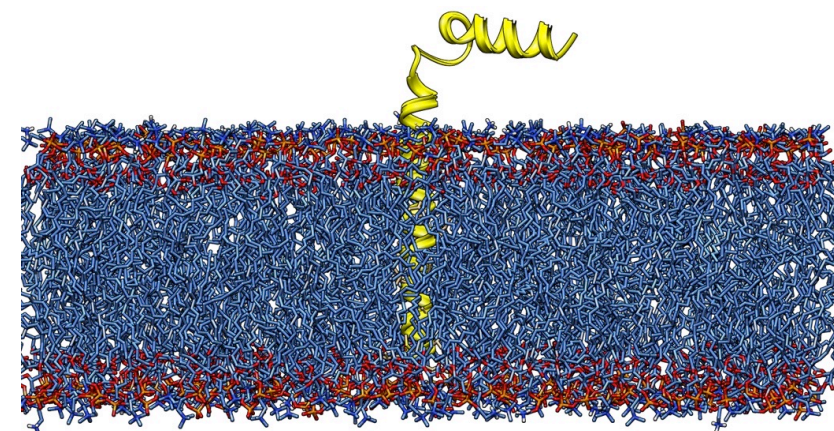


Ferritin

Aib-based peptides

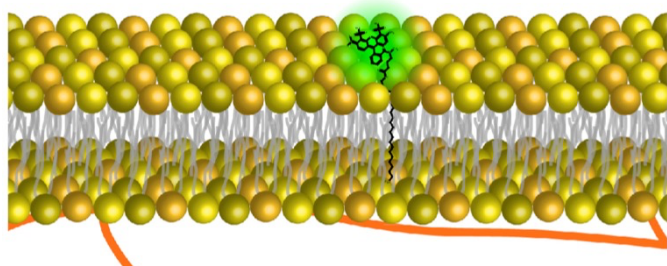


Phospholamban

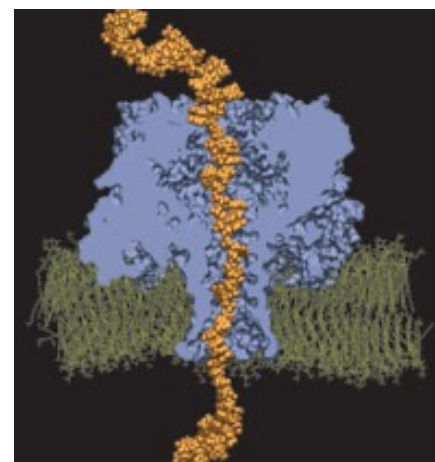
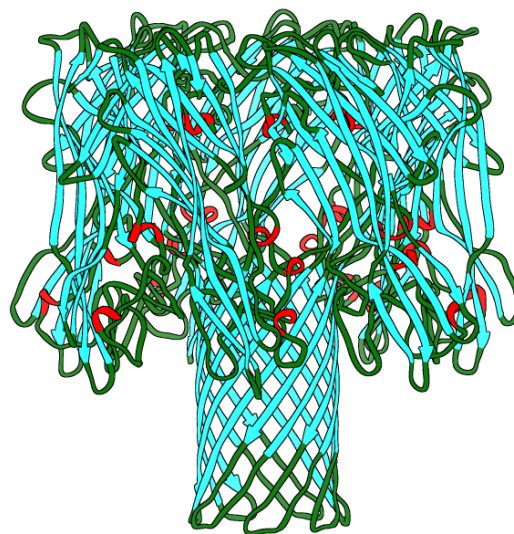


Fe-S cluster biosynthesis (IscS-IscU system)

Lipid Membranes



Hemolysin



MscL channel

