2026 SPACE day

Book of Abstracts

Scuola Superiore Meridionale

23 JUNE 2026

SCUOLA SUPERIORE MERIDIONALE

1st-Year PhD Students

Virginia Cardillo

Title: Next-Generation Lunar Laser Ranging: Sub-Millimeter Precision for PNT Infrastructure and Fundamental Physics

As we enter a transformative phase of lunar exploration marked by the ESA Moonlight initiative, establishing a robust "Lunar Galileo" system requires unparalleled precision in Positioning, Navigation, and Timing (PNT). First-generation lunar laser ranging arrays deployed during the Apollo era are fundamentally limited to an accuracy of 2-3 centimeters. This is due to "pulse spreading" caused by the physical extent of the multi-reflector arrays combined with the Moon's natural libration.

To overcome these limitations, this presentation introduces the second-generation INFN-LNF MoonLIGHT device, which utilizes a single, large 100mm Corner Cube Retroreflector. Because it possesses a single optical center, MoonLIGHT's performance is invariant under rotation, effectively eradicating pulse spreading and targeting an unprecedented accuracy of less than 1 millimeter.

This 100-fold technological leap not only unlocks operational advancements but also carries an incredibly high scientific potential. Operationally, laser positioning acts as the critical "Ground Truth" for future PNT infrastructure, offering a reliable method to validate radio-frequency navigation orbits and verify crucial relativistic clock corrections. Scientifically, sub-millimeter lunar laser ranging offers the unprecedented opportunity to probe the deep lunar interior, which could eventually determine the state of its core. Furthermore, this next-generation technology holds the potential to establish the tightest constraints on fundamental physics: future applications could include testing the Strong Equivalence Principle to a targeted accuracy of 10^{-15}, measuring the Geodetic Precession of the Earth-Moon system to further test General Relativity, and probing the Dark Sector by constraining the Yukawa potential. Ultimately, the MoonLIGHT project exemplifies the synergy between advancing autonomous deep-space navigation and paving the way for groundbreaking fundamental discoveries.

Mauro Fioravanti

Title: Sequential Data Processing for Lunar Laser Ranging Tests of Gravity

Lunar Laser Ranging (LLR) is one of the most accurate tools for testing General Relativity at Solar System scales, relying on the measurement of the round-trip travel time of laser pulses between the Earth and the Moon with millimeter precision. Standard analyses of LLR data are mainly based on global least-squares adjustments, which provide parameter estimates but offer limited access to the temporal dynamics of the errors.

In this talk, I propose an alternative approach based on sequential data processing methods, in particular the Extended Kalman Filter, with the aim of using LLR data as a tool for validating the underlying dynamical models. By analyzing the temporal structure of the innovations and the evolution of the covariance matrix, it is possible to identify inconsistencies between the model and the observations, revealing systematic effects, parameter degeneracies, and potential signatures of new physics.

Particular attention is devoted to the consistent propagation of uncertainties in nonlinear regimes, where standard covariance evolution based on local linearization may become inadequate. In this context, differential-geometric methods are investigated as a natural framework for describing the evolution of uncertainties on the underlying state space and for improving the robustness of sequential estimation in high-precision LLR analyses.

Amedeo Gaudio

Title: The diversity of planetary systems and the search for Earth-like worlds with PLATO

The search for worlds beyond our Solar System is one of the most exciting, and technologically challenging, frontiers of modern astrophysics. Over the past three decades, since the first discovery of an exoplanet orbiting a Sun-like star in 1995 (51 Pegasi b), more than 6,000 extrasolar planets have been identified, with countless others still awaiting detection.

These discoveries have revealed an astonishing diversity in planetary system architectures, many of which differ significantly from our own. In our Galaxy, we find planets larger than Earth yet smaller than Neptune, the so-called super-Earths, as well as gas giants comparable to Jupiter orbiting much closer to their host stars than Mercury does to the Sun. This variety naturally leads to key open questions: How common is our Solar System in the Milky Way? How many planetary systems host Earth-like planets? And ultimately, are habitable worlds widespread, or is life a rare phenomenon in the Universe?

My PhD project is motivated by these questions. Today, addressing them is no longer a matter of science fiction. On January 1st, 2027, the European Space Agency (ESA) will launch the PLATO (PLAnetary Transits and Oscillations of stars) mission, a space telescope specifically designed to detect and characterize Earth-sized planets orbiting Sun-like stars. PLATO will monitor the brightness of hundreds of thousands of stars with unprecedented precision, enabling the discovery of terrestrial planets in the habitable zone and providing accurate measurements of stellar and planetary properties through a combination of transit photometry and asteroseismology.

Within this framework, my research will focus on the analysis of PLATO data and on conducting demographic studies of planetary systems. By statistically characterizing the population of exoplanets and their host stars, my goal is to contribute to a deeper understanding of how planetary systems form and evolve, and to place our own Solar System in a broader Galactic context.

Andrea Iacobellis

Title: Decay, Stability, and Cosmological Effects of Oscillons

Oscillons are metastable, spatially localized configurations that arise generically in nonlinear scalar field theories and are expected to form abundantly in the early Universe via parametric-resonance fragmentation. Their longevity is associated with suppressed radiation and non-perturbative decay, as described by small-amplitude/quasi-breather methods and effective field theory approaches. Despite this progress, it remains unclear whether oscillon stability admits a universal, model-independent description, particularly in cosmological settings where expansion and gravitational couplings can alter their dynamics. Ultra-light and axion-like scalar field models provide a concrete framework in which to investigate these effects. This project aims to identify the mechanisms controlling oscillon decay and lifetime, and how these compete with gravitational effects. The goal is to determine whether a small set of parameters, such as tail amplitudes, frequency evolution, and compactness, can characterize stability across models. This competition determines whether oscillons disperse, remain long-lived, or undergo gravitational collapse, with possible consequences including localized overdensities, primordial black hole formation, or solitonic structures.

Chiara Niccolai

Title: Quasars as standard candles: extending the Hubble diagram

Quasars are among the most luminous Active Galactic Nuclei (AGN), with bolometric luminosities exceeding 10 erg/s. Thanks to their extreme brightness and abundance in modern surveys, they offer a promising opportunity to probe the high-redshift Universe. In recent years, a non-linear relation between their X-ray and UV luminosities has been identified, suggesting that quasars could be used as standardizable candles to measure cosmological distances and extend the Hubble diagram well beyond the reach of supernovae. However, their use as reliable distance indicators requires a deeper understanding of the physical processes governing their emission, in particular the accretion of matter onto the central supermassive black hole and possibile mechanisms arising in different conditions. During my Master's thesis, I investigated the reliability of the standard accretion disk model using samples of quasars with multi-epoch optical observations, comparing the observed relationship between line and continuum luminosities with theoretical predictions. Building on this work, my PhD research aims to further constrain the physics of quasar emission and assess their effectiveness as cosmological probes. Ultimately, the goal is to use quasars to extend the Hubble diagram to higher redshifts and test different cosmological models.

Francesca Scrivano

Title: Exploring Dark Matter with the LHC

In the standard ΛCDM cosmological framework, visible baryonic matter constitutes about 5% of the total energy content of the Universe, while dark matter accounts for approximately 27% of the total energy density and about 85% of the total matter content.

Dark Matter (DM) is a non-baryonic and non-luminous form of matter, whose existence is inferred from its gravitational effects on astrophysical systems, such as galactic rotation curves, the dynamics of galaxy clusters, gravitational lensing, and anisotropies in the cosmic microwave background. Despite the remarkable success of the Standard Model (SM) in describing fundamental interactions, it does not provide a viable dark matter candidate, thus motivating extensions beyond the Standard Model (BSM).

One of the most promising experimental approaches to probe dark matter is its direct production at the Large Hadron Collider (LHC). In this scenario, dark matter particles would escape detection, leading to an imbalance in the transverse energy of the event, commonly referred to as missing transverse energy (MET).

This project focuses on the production of dark matter in association with one or two top quarks in proton–proton collisions, considering fully hadronic final states reconstructed with the CMS detector. The signal is described within simplified models that assume the existence of a scalar or pseudoscalar mediator ϕ, which couples Standard Model particles to dark matter candidates χ.

Paola Simone

Title: Hawking radiation as a probe of physics beyond the Standard model

Hawking radiation from primordial black holes provides a unique link between particle physics and black hole physics. In this work, we investigate the phenomenology of black hole evaporation, focusing on photon and neutrino signals produced through secondary emission processes. Particular attention is given to potential signatures arising in Beyond Standard Model scenarios, such as supersymmetric extensions. Using Monte Carlo simulations, we assess whether these effects lead to observable features, providing an astrophysical probe of new physics complementary to current collider searches.

4th-Year PhD Students

Filippo Bouché

Title: Higher-order statistics in Euclid: towards the analysis of the DR1 weak lensing data

I will provide an overview of weak lensing higher-order statistics and their relevance to the Euclid mission. The talk will draw on the results of the latest paper from the HOWLS group in Euclid, which employed the Fisher formalism to explore the constraining power of non-Gaussian statistics on cosmological parameters. Emphasis will be placed on the key lessons learned from this preparatory project, highlighting how it informs the development of robust methodologies for the analysis of the Data Release 1. I will conclude by outlining the plans for the Data Release 1, with a particular focus on the strategies for probing modified gravity models.

Simone Cepollaro

Title: Stabilizer Entropy in Subspaces, Gauge Theories, and Spacetime Geometry

The classical simulability of quantum systems and the realization of quantum advantage are closely tied to the quantum resource known as nonstabilizerness (or magic). In this talk, we present a unified framework to quantify this resource in constrained quantum systems using Stabilizer Entropy (SE). We first examine the impact of embedding quantum states within larger systems, introducing the "magic gap" and demonstrating how specific symmetries can minimize the computational cost of quantum simulation. We then apply this formalism to several physical scenarios: quantum error correction, discrete lattice gauge theories, and the SU(2) gauge-invariant subspace — a key object in different quantum gravity theories. Our results suggest that a judicious choice of embedding can lead to greater efficiency in both classical and quantum simulations on NISQ-era quantum hardware.

Carmen Ferrara

Title: Primary constraints of newer general relativity

We study the primary constraint structure of newer general relativity, a gravity theory based on a torsionless teleparallel geometry. The gravitational action consists of a scalar built from quadratic combinations of the nonmetricity tensor with arbitrary coefficients \$c_i\$ in the Lagrangian. We perform a decomposition on the Lagrangian and compute the canonical momenta associated with the metric. We characterize the primary constraints coming from the metric conjugate momenta by analyzing when the map between momenta and velocities becomes non-invertible, and organize the outcome through a fully nonlinear decomposition into scalar, vector and tensor sectors. Comparing our results with previous results the literature, we find five and three primary constraints coming from the tensor and vector sectors, but we notice a degeneracy in the scalar sector that produces 1 or 2 scalar primary constraints depending on the conditions on the parameters c_i. We also obtain the primary constraint coming from the covariant formulation of symmetric teleparallel gravity.

Giuseppe Meluccio

Title: On the emergence of gravity from a pre-geometric spacetime

In Pre-geometric Gravity the geometry of spacetime and its gravitational dynamics are emergent from a more primitive configuration. In particular, Einstein gravity arises as an effective field theory from a mechanism of spontaneous symmetry breaking formulated in a more fundamental Yang–Mills-like gauge theory without an underlying metric structure. This theoretical framework can accommodate both the dynamical and the topological sectors of gravity. The dynamical sector consists of the Einstein–Cartan theory and the cosmological constant term. The topological sector yields the complete set of four-dimensional topological invariants, i.e. the Gauss–Bonnet, Pontryagin and Nieh–Yan terms (with the latter containing the Holst term). All coupling constants of gravity (the Planck mass, the cosmological constant, the Barbero–Immirzi parameter etc.) are generated dynamically from the free parameters of the original pre-geometric theory. This emergence mechanism does more than reproduce the gravitational interaction in the low-energy regime: it establishes non-trivial connections between the different energy scales of gravity, opening new perspectives for Quantum Gravity and high-energy phenomenology.

Andrea Boccia

Title: Asteroid-mass Primordial Black Holes from Supersymmetry

In this talk, we discuss the formation of asteroid-mass Primordial Black Holes (PBHs) as a dark matter candidate within supersymmetric extensions of the Standard Model. In particular, we show that the presence of heavy particles predicted by the Minimal Supersymmetric Standard Model (MSSM) can induce a temporary softening of the equation of state of the early Universe during their transition to the non-relativistic regime, significantly enhancing PBH production. We compute the effective equation of state for different realizations of the MSSM mass spectrum, described by three characteristic mass scales, and evaluate the resulting PBH mass functions assuming a broad and approximately scale-invariant primordial curvature power spectrum. Comparing our results with current observational constraints, we find that for supersymmetric masses above $\sim 10^5$ GeV the PBH abundance is strongly enhanced in the asteroid-mass window, allowing PBHs to account for the total dark matter density while remaining consistent with existing bounds.

Laura Antonia Cerbone

Title: Prototyping DXA4A: first proof-of-concept for bone densitometry with Timepix detectors

DXA4A is a compact Dual X-ray Absorptiometry (DXA) scanner based on Timepix detectors, designed to enable in-flight assessment of bone density loss in astronauts due to skeletal deconditioning in microgravity. The system is conceived to be lightweight and portable, addressing the constraints of space missions. Conventional DXA systems rely on dual acquisitions with tube voltage switching to obtain low- and high-energy images. In contrast, DXA4A exploits the spectral capabilities of Timepix detectors to generate energy-resolved images from a single acquisition, potentially simplifying the system design and reducing dose and acquisition time. In this seminar, I will present the first proof-of-concept tests for bone densitometry performed with Timepix3 and Timepix4 detectors. The results demonstrate the feasibility of energy separation and quantitative measurements, representing a first step towards the development of the DXA4A scanner. Finally, the final design of DXA4A will be presented, together with the expected sizes, functionality and power consumption.

Mariam Abdelaziz

Title: Can primordial gravitational waves leave a trace in galaxy clustering?

Primordial gravitational waves provide a direct probe of the physics of the very early Universe, but their observational detection remains challenging. In this talk, I will discuss an indirect route to probing such tensor perturbations through their imprints non-Gaussianityale structure of the Universe. At second order in cosmological perturbation theory, primordial tensor modes can source scalar density perturbations. Since the induced density contrast is quadratic in the tensor field, it is intrinsically non-Gaussian, even if the primordial gravitational waves themselves are Gaussian. I will first review how this mechanism generates a tensor-induced matter power spectrum and bispectrum, and then show how the resulting non-Gaussianity affects the clustering of dark matter halos. In particular, I will present the scale-dependent correction to halo bias sourced by the bispectrum of the induced density field. The resulting signal has a characteristic scale dependence that is not captured by standard primordial non-Gaussianity templates, suggesting that galaxy clustering may offer a complementary window onto primordial gravitational waves and the inflationary epoch.