PhD program in
Astronomy, Astrophysics and Space Science

Cycle 41 - Call 2025

Available theses at Sapienza, Tor Vergata and INAF

June 27, 2025

Introduction

This is the list of thesis proposals for the 2025 joint PhD program in Astronomy, Astrophysics and Space Science organized by Sapienza and Tor Vergata Universities, in collaboration with National Institute of Astrophysics (INAF).
For this year, all students will be enrolled in Tor Vergata University.
The following table summarizes the list of fellowships offered by the different institutes.

Institution	Funds	Number of fellowships	Number of proposals	Thesis topics
TorVergata	University	5	21	Section 1
	Space It Up	1	1	Section 1.22
Sapienza	University	5	32	Section 2
INAF	INAF-OAR	2	9	Section 3.1
	INAF-OAR ERC	1	1	Section 3.1.10
	INAF-OAAb	1	11	Section 3.2
	INAF-IAPS	2	16	Section 3.3
	IAPS (project funds)	1	1	Section 3.4
TOTAL		18	92	

Contents

1 University of Rome Tor Vergata

Five (5) fellowships are granted for students to carry out their research in Tor Vergata.
One extra fellowship is funded by SpaceItUp project, is section 1.22.

1.1 Finding the needle in the haystack with machine learning - Eleonora Troja

Supervisor (Name, Institution and e-mail):
Eleonora Troja, University of Rome Tor Vergata, eleonora.troja@uniroma2.it
Co-Supervisors (Name, Institution and e-mail): TBD

Scientific Case: Kilonovae are a new class of astrophysical transients resulting from the merger of two neutron stars. Their detection provides key insights into the formation of heavy elements, relativistic outflows, and the nature of extreme gravity environments. Wide-field surveys, such as those conducted by the upcoming Vera C. Rubin Observatory (LSST), and future space missions such as the Nancy Grace Roman Telescope, will generate vast amounts of imaging data, making the identification of kilonovae a significant challenge. Their spectral and temporal signatures overlap with a variety of other astrophysical transients, such as supernovae, cataclysmic variables, and active galactic nuclei. The difficulty lies in distinguishing kilonovae from this "haystack" of common transients within wide-field survey data. Additionally, their low occurrence rate requires robust methods capable of filtering through massive datasets with high precision and recall. Traditional methods struggle with the overwhelming number of transient sources, prompting the need for machine learning (ML) approaches to efficiently identify these rare events.
Outline of the Project: ML techniques offer a powerful means to enhance the detection and classification of kilonovae in real-time survey pipelines. The student will learn and test deep learning models, such as convolutional neural networks (CNNs) and recurrent neural networks (RNNs), which can be trained on simulated and archival datasets to recognize kilonova signatures. Bayesian inference and anomaly detection methods will be used to help quantify uncertainties, ensuring reliable identifications. Ensemble learning approaches combining multiple classifiers will be developed to improve robustness. By integrating ML-based classifiers into LSST's Alert Stream, potential kilonovae can be rapidly identified and relayed to follow-up observatories, such as the James Webb Space Telescope (JWST) and Very Large Telescope (VLT). Adaptive learning systems can continuously improve detection accuracy by incorporating new observations.
Planning of the activities:
Year 1: acquisition of the scientific background and state-of-the-art techniques; strenghtening programming skills (e.g. Python); gather archival datasets and simulated light curves as training set; thesis write-up. Year 2: development of neural networks and anomaly detection algorithms; test and validate models on labeled datasets; thesis write-up.
Year 3: assess model performance using real survey data; presentation of the results via publications and attendance to 1-2 conferences; thesis write-up.
Institution(s) where the research will be carry out:
University of Rome Tor Vergata

1.2 Spotting the Unseen: Unveiling Off-axis Afterglows in Transient Surveys - Eleonora Troja

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Co-Supervisors (Name, Institution and e-mail): TBD

Scientific Case: Gamma-ray bursts (GRBs) are among the most energetic cosmic explosions, typically detected by their prompt high-energy emission. However, many GRBs go undetected in gamma-rays due to their jets being misaligned with our line of sight. These so-called off-axis afterglows manifest as late-peaking X-ray, optical or radio transients, making wide-field transient surveys a crucial tool for detecting them. Studying off-axis GRB afterglows provides key insights into their explosion mechanism, jet structure, and the true rate of GRBs, essential for understanding their role in stellar evolution and multimessenger astrophysics.
The challenge lies in distinguishing these transients from other variable sources, such as supernovae, active galactic nuclei, and tidal disruption events. With the advent of new X-ray facilities, such as Einstein Probe, and next-generation radio surveys, such as those conducted by the Square Kilometre Array (SKA), the Very Large Array Sky Survey (VLASS), and ASKAP's Variables and Slow Transients (VAST) survey, we now have unprecedented opportunities to identify and study off-axis GRBs.
Outline of the Project: This thesis will focus on identifying and characterizing off-axis GRB afterglows using wide-field surveys. The student will design and implement advanced search strategies, which include developing and optimizing AI-driven machine learning models for automated transient classification, as well as statistical techniques for distinguishing off-axis afterglows from other variable radio sources. The student will lead multi-wavelength follow-up to confirm the nature of the transients, and model the data with state-of-the-art theoretical models. The detected events will be used to refine estimates of GRB rates, jet structures and opening angles, contributing to multimessenger astrophysics.
Planning of the activities:
Year 1: acquisition of the scientific background and state-of-the-art techniques; strenghtening programming skills (e.g. Python); training in data analysis techniques; development of pipelines for data processing and transient candidate selection; thesis write-up. Year 2: apply search algorithms to survey datasets; cross-match candidate events with multi-wavelength databases; model light curves and spectral evolution for confirmed candidates; thesis write-up.
Year 3: derive constraints on rates and jet structure; presentation of the results via publications and attendance to 1-2 conferences; thesis write-up.
Institution(s) where the research will be carry out:
University of Rome Tor Vergata

1.3 Exploring Active Galactic Nuclei through Multi-Wavelength and Multi-Messenger Observations - Prof. Francesco Tombesi

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Scientific Case:
Active Galactic Nuclei (AGN) are among the most luminous and dynamic objects in the Universe, driven by the accretion of matter onto supermassive black holes. Their intense electromagnetic radiation, relativistic jets, and energetic outflows not only illuminate the cores of their host galaxies but also affect galactic evolution through feedback processes. Recent advances in multi-wavelength observations—from radio and X-ray to optical/infrared—have significantly deepened our understanding of AGN physics. Multi-messenger astronomy, which integrates electromagnetic signals with gravitational waves, neutrinos, and cosmic rays, offers an unprecedented way to probe the most extreme environments in AGN. By combining these diverse observational channels, we can gain new insights into AGN accretion, outflow formation, and feedback mechanisms, providing a more complete understanding of the processes that shape galaxies.

Outline of the Project:
The project will utilize a combination of proprietary and archival multi-wavelength data along with state-of-the-art multi-messenger observations. Key components include:

- **Spectral Analysis:** Explore the spectral energy distributions and emission features from the accretion disk, corona, and outflows using data from multi-wavelength observatories.
- **Outflow Studies:** Investigate the physics and dynamics and AGN-driven outflows, assessing their impact on the host galaxy.
- **Multi-Messenger Observations:** Incorporate the latest multi-messenger evidence to explore the connection between AGN activity and high-energy photon/particle/GW production.
- **Theoretical Modeling:** Compare observational results with theoretical models of AGN winds, outflows, and particle acceleration.

Planning of the activities:

- **Year 1:** Conduct a literature review on AGN physics and multi-messenger techniques; acquire and process multi-wavelength data.
- **Year 2:** Perform detailed spectral analysis of AGN accretion disks, jets, and outflows; cross-correlate electromagnetic observations with available multi-messenger results; develop theoretical models.
- **Year 3:** Synthesize the multi-wavelength and multi-messenger results to assess AGN physics and feedback on host galaxies; publish key findings in peer-reviewed journals; write and defend the PhD thesis.

Institution(s) where the research will be carried out: Tor Vergata University of Rome; INAF.

1.4 Search for massive objects closely orbiting supermassive black holes with repeating transients in galactic nuclei - Prof. Francesco Tombesi

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Scientific Case:
The LIGO-Virgo detection of gravitational waves (GW) in conjunction with electromagnetic (EM) signals has opened a new era in multi-messenger astronomy. Recent theoretical studies suggest that extreme/intermediate mass ratio inspirals (E/IMRIs) — systems involving a supermassive black hole (SMBH) and a stellar-mass or intermediate-mass black hole — and Massive Black Hole Binaries (MBHBs) can produce gravitational waves detectable by ESA's Laser Interferometer Space Antenna (LISA). When these systems are embedded in an accretion disk, such as in an Active Galactic Nucleus (AGN) or a Tidal Disruption Event (TDE), they are expected to emit prolonged EM signals, observable by missions like ESA's Athena X-ray Observatory. This project is timely, especially with the forthcoming LISA mission and the development of low-latency GW data pipelines that will enable rapid response and coordinated follow-up with EM facilities, along with new survey instruments like Rubin LSST and Einstein Probe.

Outline of the Project:
Over the last decade, several classes of repeating transients in galactic nuclei, with periods ranging from minutes to days, have been uncovered in optical and X-ray surveys. The student will:

- Perform detailed time-resolved X-ray spectral and timing analysis of repeating transients using data from XMM-Newton, NICER, eROSITA, and possibly Einstein Probe to detect quasi-periodic variability, characterize outflows, and conduct photo-ionization modeling.
- Compare the observed outflow properties with detailed numerical simulations to constrain the mass of the secondary object, thereby building a census of mass ratios and inspiral rates in these systems.
- Develop and implement a low-latency pipeline for processing LISA gravitational wave triggers, integrating them with EM observations to rapidly identify candidate extreme/intermediate mass ratio inspirals (EMRI/IMRIs) and/or massive black hole binaries (MBHBs) in galactic nuclei.
- Utilize the latest sensitivity curves from LISA and Athena to simulate the expected GW and EM signals, thereby assessing the multi-messenger science potential and refining detection strategies.

Planning of the Activities:

- **Year 1:** Conduct a comprehensive literature review on AGN physics, multi-messenger astronomy, and low-latency GW data processing. Identify and analyze repeating transients in archival data from existing monitoring campaigns.
- **Year 2:** Perform detailed spectral and timing analyses on a selected sub-sample of repeating transients to extract key physical parameters. Begin simulations to constrain the secondary mass from outflow properties.

- **Year 3:** Apply a low-latency pipeline for LISA gravitational wave trigger processing. Integrate GW and EM simulation results to refine detection and follow-up strategies for MBHBs, EMRI/IMRIs. Publish findings in peer-reviewed journals and complete the PhD thesis.

Institution(s) where the research will be carried out: Tor Vergata University of Rome; INAF.

1.5 Properties of Exoplanetary Systems - Luigi Mancini

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Scientific Case: Exoplanets
Outline of the Project: The detection of extrasolar planets and their subsequent characterization are among the most exciting fields of modern astrophysics. Observations of the astonishing diversity of a) internal structures of both small and giant exoplanets, b) properties of their atmospheres, and c) global architectures of planetary systems continuously challenge our knowledge of planet formation, evolution, and interiors. By using instruments and telescopes like TESS, LBT, HARPS-N, ESPRESSO, GIANO-B, Gaia, JWST, this PhD project aims at furthering our understanding of key aspects of planet formation and evolution processes focusing on a three-fold, highly synergistic, multi-technique observational approach: I) the characterization of hot, warm, and temperate transiting small-size planets (Super-Earths and Neptunes) to determine their orbital (period, semi-major axis, eccentricity) and physical (radius, mass, density) parameters, and thus investigate their internal structure, formation, and evolution via a combination of high-sensitivity photometric and spectroscopic measurements; II) the study of the atmospheres of hot planets at high spectral resolution to determine their composition, investigate atmospheric dynamics, and possibly reconstruct their formation and migration history; III) studies of the architectures of planetary systems by considerably refining the occurrence rates and properties (e.g., distributions of mass, semi-major axis, eccentricity, multiplicity, dependence on stellar parameters) of both small/low-mass and gas giant planets to provide observational constraints to models of planet formation and migration; IV) searches for correlations between different exoplanet populations, for instance inner low-mass planet and outer gas giants, to investigate the role of outer giant planets in the formation and migration of the inner small ones and measure occurrence rates of planetary systems with mass and orbital separation hierarchy similar to that of our Solar System.
Planning of the activities:
Year 1: Observations, participation in conferences and schools, team meetings, data analysis and modeling, writing papers.
Year 2: Observations, participation in conferences and schools, team meetings, data analysis and modeling, visiting period at a foreign institute, writing papers.
Year 3: Team meetings, participation in conferences, data analysis and modeling, writing papers, writing thesis.
Institution(s) where the research will be carry out:
- Department of Physics, University of Rome ”Tor Vergata”;
- Short-term visit to the Turin Astrophysical Observatory.

1.6 Millimetre observations of galaxy clusters - Hervé Bourdin

Supervisor :
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Co-Supervisors:
Pasquale Mazzotta, Università degli Studi di Roma Tor Vergata (mazzotta@roma2.infn.it)
Scientific Case: Being the largest and last matter inhomogeneities that collapsed across cosmic times, galaxy clusters occupy a unique place at the crossroads of astrophysics and cosmology. Complementary with X-ray observations, the thermal Sunyaev-Zel'dovich (tSZ) effect allows us to probe the hot gas content of galaxy clusters from their core to their peripheries. The tSZ signal being mixed up with CMB or (extra)-Galactic thermal dust anisotropies, we developed component separation algorithms using sparse representations (wavelet and curvelet transforms) to detect and map galaxy clusters from Planck data. **Outline of the Project**: Using these tools to analyse millimetre observations in combination with X-ray data (XMM-Newton, Chandra), the PhD student will perform research works such as:
a) measuring the Hubble constant from combined X-ray and SZ observations of clusters of the Planck catalogue;
b) extracting hot gas pressure profiles to investigate the physics of cluster atmospheres from nearby ($z < 0.5$) to distant clusters ($z > 0.5$) of the Planck catalogue;
c) developing new algorithms to combine Planck data with observations performed at higher angular resolutions (e.g. SPT) and detect more distant clusters ($z > 1$).
Planning of the activities:
Year 1:
(i) Study of recent reviews of galaxy clusters and related work
(ii) Familiarise with the software for data reduction and data analysis
Year 2:
(iii) Training in parallel programming with CPU, GPU and High Performance Computing
(iv) Millimetre data Analysis of Planck and SPT Data
Year 3:
(v) Interpretation of the data analysis using current and models **Institution(s) where the research will be carry out**:
Università degli studi di Roma Tor Vergata

1.7 Witnessing the culmination of structure formation in the Universe from X-ray observations of clusters of galaxies - Pasquale Mazzotta

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Co-Supervisors:
Hervé Bourdin, Università degli Studi di Roma Tor Vergata (bourdin@roma2.infn.it)
Scientific Case: Clusters of galaxies provide valuable information on cosmology, from the physics driving galaxy and structure formation, to the nature of dark matter and dark energy. Their observable spatial distribution of mass components, that reflects the cosmic distribution of matter (85% dark matter, 12% X-ray emitting gas and 3% galaxies), their internal structure and their number density as a function of mass and redshift are powerful cosmological probes as their growth and evolution depends on the underlying cosmology (through initial conditions, cosmic expansion rate and dark matter properties). Clusters form at the nodes of the Cosmic Web, constantly growing through accretion of matter along filaments and via occasional mergers. Part of the gravitational energy dissipated during their grow is channeled, via shocks and turbulent motions, into the amplification of magnetic fields and acceleration of relativistic particles. These non-thermal components manifest themselves as diffuse cluster-scale radio emission. Clusters are thus excellent laboratories for probing the physics of the gravitational collapse of dark matter and baryons, as well as for studying the non-gravitational physics that affects their baryonic component.
Outline of the Project: Using a large, unbiased, signal-to-noise limited Planck sample of clusters of galaxies observed in X-Ray with Chandra and XMM we will plan to: (i) obtain an accurate vision of the statistical properties of the local cluster population, and in the highest mass regime; (ii) measure how their gas is shaped by the collapse into dark matter haloes and the mergers that built today's clusters; (iii) uncover the provenance of non-gravitational heating; (iv) resolve the major uncertainties in mass determinations that limit cosmological inferences.
Planning of the activities:
Year 1:
i) Study of recent reviews of galaxy clusters and related work
(ii) Familiarise with the software for data reduction and data analysis
Year 2:
(iii) Training in parallel programming with CPU, GPU and High Performance Computing
(iv) X-ray data Analysis of 120 Clusters of Galaxies observed with the XMM-Newton and Chandra observatories
Year 3:
(v) Interpretation of the data analysis using current and models

Institution(s) where the research will be carry out:
Università degli studi di Roma Tor Vergata

1.8 Investigating the Atmospheric Response of Earth and Exoplanets to Solar/Stellar Grand Minima Events - Francesco Berrilli

Supervisor: Francesco Berrilli, University of Rome Tor Vergata, francesco.berrilli@roma2.infn.it
Co-Supervisors: Simona Bordoni (TBC), University of Trento, Italy
Scientific Case: The Sun's magnetic activity, characterized by sunspots, faculae, and networks, leads to variations in its irradiance across diverse timescales. Cosmogenic radionuclide analysis reveals the presence of extended periods of reduced (Grand Minima) and enhanced (Grand Maxima) solar activity, spanning multiple solar cycles. The variations in solar spectral emission, particularly in the ultraviolet (UV) band, induced by Grand Minima and Maxima, result in significant alterations to Earth's atmospheric conditions. It is hypothesized that similar radiative processes govern the interactions between solar-like stars and their respective exoplanetary atmospheres. Specifically, UV variations affect thermospheric density, influencing satellite deorbiting and space debris, and alter ozone content, potentially impacting Earth's climate. A team of solar physicists and climatologists will use space data, radionuclides, and climate models, including the ISCA 3D climate framework, to study Earth's atmospheric response to solar minima. ISCA is designed for modeling global atmospheric circulation on Earth and other planets.
Outline of the Project: During the thesis, historical time series of total and spectral solar temperature and irradiance, derived from the analysis of cosmogenic isotope abundance data, will be examined to study the effects of the two terms on the global and regional climate of planets such as Earth, Mars or Venus, and possible exoplanets.
Planning of the activities:
Year 1: Literature and Stae-of-the-Art, Data acquisition and model design;
Year 2: Data analysis and model development and validation;
Year 3: Refining the model and assessing its impact and Thesis writing and dissemination of research findings.
University of Rome Tor Vergata, University of Trento, University of Exeter (UK), National Solar Observatory (Co, USA).

1.9 Synergistic Use of Space and Ground-Based Instrumentation in Sun-as-a-Star Research - Francesco Berrilli

Supervisor: Francesco Berrilli, University of Rome Tor Vergata, francesco.berrilli@roma2.infn.it
Co-Supervisors: Gianni Mainella, Fundación Galileo Galilei - INAF, mainella@tng.iac.es
Scientific Case: The availability of continuous full-disk solar data, obtained from either ground-based robotic telescopes (e.g., GATES telescopes) or space-based imagers, is indispensable for establishing a direct correlation between induced Radial Velocity (RV) variations and solar magnetic (bright and dark) regions. By synchronizing and correlating future or available high-precision solar RV measurements (e.g., LOCNES, HARPS-N) with solar data, it becomes possible to construct refined models that mitigate the impact of solar and stellar activity, thereby significantly enhancing the reliability of exoplanet detection.
Outline of the Project: the synergistic use of available and planned solar full-disk observations (e.g., GATES/TSST) and high-resolution observations (e.g., EST, DKIST), in conjunction with dedicated sun-as-a-star spectroscopy's instruments such as LOCNES or HARPS-N-solar at the TNG, facilitates an in-depth exploration of the correlation between solar Radial Velocity (RV) fluctuations and the emergence of magnetic structures on the solar disk. This comprehensive data analysis enables the study of the fundamental physical processes that govern solar/stellar magnetic variability, which is a significant contributor to the 'stellar noise' observed in astronomical data.
Developing advanced solar instrumentation and analyzing its data requires sophisticated experimental and data analysis techniques. This thesis investigates optical, mechanical and detector technologies for solar instruments (e.g, TSST MOF filters or characterization of LOCNES NIR absorbing cells) aiming to improve our understanding of solar phenomena and their effect on solar RV fluctuations.
Planning of the activities:
Year 1: Literature Review; Scientific Research Plan: Develop a detailed scientific research plan outlining the specific astrophysical questions. This includes defining observation strategies and data analysis;
Year 2: Collaborating with existing observatories that can accommodate solar instruments is a potential approach for site selection in building robotic solar telescopes;
Year 3: Instrumentation/data pipeline qualification and testing. Scientific Papers and Presentations: Prepare and publish scientific papers in peer-reviewed journals based on the research findings. Present your research at scientific conferences and workshops. Thesis Writing, presenting the research objectives, methodology, results, and scientific contributions.
Possible Location: University of Rome Tor Vergata, Telescopio Nazionale Galileo (La Palma, Isole Canarie), EST facilities (La Palma, Isole Canarie)

1.10 Non-linear Dynamics of Astrophysical Magnetic Fields - Dario Del Moro

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Scientific Case: Planetary and Solar Physics
Outline of the Project: During the last decades, significant progress has been made in understanding astrophysical and planetary magnetic fields, thanks to the development of new observational techniques, space missions, and increasingly sophisticated numerical models. These advances have stimulated a growing interest in investigating the physical mechanisms that govern magnetic field generation in natural systems such as stars as our Sun and/or planets like the Earth. Despite these developments, crucial aspects remain unexplained. In both stars and planets, magnetic fields are thought to originate from self-sustained dynamo processes driven by convective flows of electrically conducting fluids in rotating systems. However, the detailed mechanisms underlying the dynamo action, the transitions between different magnetic configurations, and the conditions leading to polarity reversals are still open questions. Improving our understanding requires coordinated efforts on two complementary fronts: the development and analysis of theoretical and numerical models that capture the essential dynamics of convective dynamos, and the interpretation of observational data (e.g., spectro-polarimetric measurements for the Sun, and geomagnetic and paleomagnetic records for the Earth). Within this project, the PhD candidate will gain a solid grounding in dynamo theory, magnetohydrodynamics (MHD), and nonlinear dynamics. Depending on the candidate's interests and background, the work may focus on numerical simulations of dynamo processes, on the study of simplified theoretical models (e.g., involving bifurcations or stochastic resonance), or on the interpretation of observational data in the framework of dynamo theory.
Planning of the activities:
Year 1: Strengthening the background in MHD by attending 1-2 dedicated conferences and/or schools; training in Python and parallel programming through specific courses; enhancing communication skills by attending relevant workshops.
Year 2: Deepening the knowledge of MHD by attending 1-2 dedicated conferences and/or schools; publishing first results in peer-reviewed journals.
Year 3: Publishing main results in peer-reviewed journals; networking opportunities; writing and defending the PhD thesis.
Institution(s) where the research will be carry out: University of Rome Tor Vergata

1.11 Physics Informed Machine Learning for Space Weather - Dario Del Moro

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Co-Supervisors (Name, Institution and e-mail):
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Scientific Case: Planetary and Solar Physics - Space Science Techniques
Outline of the Project: The primary source of Space Weather is the Sun. Variations in the electromagnetic radiation and particle flux of solar origin affect the whole Solar System. Heliophysics has evolved from an exploratory and discovery-driven discipline to a mature, explanatory science in the last decades. The importance of predicting the changes induced by the Sun in the Heliosphere (and the effects that those changes have on humankind's activities) has become a significant priority within the programs of national space agencies worldwide, and it presents physicists with new challenges and opportunities in the areas of theory, modelling, data analysis and instrumentation development. Recent studies have demonstrated that combining AI with physics-based approaches holds great promise offering reliable tools for space weather forecasting. This project aims to leverage physics to inform the machine learning methods and apply machine learning to better estimate key parameters in MHD deterministic equations. Depending on the candidate's interests and capabilities, this project may expand towards the investigation and the modelling of the processes of the energy release on the Sun and the energy deposition on the planet's magnetosphere-atmosphere system, the analysis of datasets and with state-of-the-art techniques, or the development of new instrumentation for the acquisition of relevant, data.
Planning of the activities:
Year 1: Strengthening the background in the Sun-Earth Relationship by attending 1-2 dedicated conferences and/or schools; training in Python and Machine Learning through specific courses; enhancing communication skills by attending relevant workshops.
Year 2: Deepening the knowledge of space weather by attending 1-2 dedicated conferences and/or schools; publishing first results in peer-reviewed journals.
Year 3: Publishing main results in peer-reviewed journals; networking opportunities; writing and defending the PhD thesis.
Institution(s) where the research will be carry out: University of Rome Tor Vergata

1.12 The time evolution of magnetic activity in solar-like host stars and its consequence on the exoplanetary environment - Luca Giovannelli

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Co-Supervisor (Name, Institution and e-mail):
Maria Pia Di Mauro, INAF IAPS, maria.dimauro@inaf.it
Scientific Case: The extreme efficiency of asteroseismology in supporting the exoplanetary program has been demonstrated by recent results obtained by the high-precision photometric space missions Kepler/K2 and TESS, which have allowed not only to reveal thousands of new exoplanets but also to disclose the structural and dynamical properties of many host stars. However, to progress in this field, a detailed assessment of the interaction between the host star and its planets is needed. In order to investigate how a star influences conditions on an orbiting exoplanet it is necessary to know and understand the evolution of the magnetic and dynamical properties of the host star.
Outline of the Project: This thesis aims to combine asteroseismic methods with photospheric and chromospheric activity analyses to characterize, not only the main stellar and planetary parameters such as the dimensions, the density, and the age but also to study how the internal rotation obtained by inversion techniques and the magnetic activity of a star evolve with age and with the changes of the internal structure. In particular, knowing how a magnetic dynamo fueled by internal rotation might produce structured magnetic cycles will allow us to reconstruct the history of magnetic interaction between a star and its hosted planet.
This study will be of cornerstone importance to connect the historical dataset of stellar activity (Mount Wilson) with big data on millions of stars provided by Gaia and Vera Rubin observatories. In fact, magnetic fields are key actors in the evolution of all stellar objects, through their ability to influence the angular momentum evolution and the mass-loss of stars.
Planning of the activities:
Year 1: Analysis of long-term variability of a suitable sample of solar-like targets studying stellar activity measurements from ground-based observatories and reconstruction of magnetic activity cycle.
Year 2: Use of asteroseismic tools to gain an accurate characterisation of host stars and, hence, of the exoplanets orbiting around them. Use of asteroseismic inversion techniques to determine the internal rotation from observed splittings of oscillation frequencies.
Year 3: Understanding how internal rotation and magnetic activity of a star evolve with age .
Institution(s) where the research will be carry out: University of Rome Tor Vergata, INAF-IAPS

1.13 Solar Physics in the CubeSat Era: Compact Instrumentation for UV to Gamma-Ray Space Observations - Luca Giovannelli

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Co-Supervisor (Name, Institution and e-mail):
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Scientific Case: The study of high-energy photons from the Sun is crucial for understanding solar variability and space weather, which impact both Earth's climate and technological infrastructure. Traditional large-scale observatories provide detailed observations but are costly and limited in number. The emergence of CubeSat constellations and distributed space architectures offers a disruptive approach to continuous solar monitoring. By miniaturizing advanced UV imaging and X/Gamma-ray spectroscopy instruments, we can enhance real-time space weather prediction and fundamental heliophysics research. This project contributes to this paradigm shift by optimizing compact payloads for scientific CubeSat missions.
Outline of the Project: This PhD project focuses on the development and optimization of compact payloads for CubeSat missions dedicated to solar and space weather studies. Specifically, the research will enhance UV imaging and X/Gamma-ray spectroscopy techniques for detecting high-energy photons from the Sun. The project is closely linked to the Sun cubE onE (SEE) mission, set to launch in late 2027, with at least one year of science operations. The candidate will work on the design, testing, and integration of miniaturized instrumentation, optimizing data acquisition and analysis pipelines. The research also includes simulations to evaluate performance under real-space conditions and will contribute to the development of observation strategies within CubeSat missions.
Planning of the activities:
Year 1: Review of the relevant state of the art science in satellite solar missions, with a focus on CubeSat missions deployed and planned. Review of payload design and selection of optimal components for UV imaging and X/Gamma spectroscopy. Strengthening the background in solar physics by attending 1-2 dedicated conferences and/or schools;
Year 2: Prototype development and laboratory testing of key payload subsystems. Integration and calibration of detectors with focus on optimizing signal-to-noise ratio. Development of simulation models to predict instrument performance in orbit.
Year 3: Final payload validation, environmental testing, and software integration. Preparation for deployment in the SEE mission, including mission operation planning and data analysis strategy. Analysis of the first scientific data provided by SEE.
Institution(s) where the research will be carry out: University of Rome Tor Vergata, INFN Roma Tor Vergata.

1.14 Title: Nearby dwarf galaxies as cosmological laboratories - Giuseppe Bono

Supervisor:
G. Bono, UNITOV, bono@roma2.infn.it
Co-Supervisors:
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V.F. Braga, INAF/OAR, vittorio.braga@inaf.it, INAF/OAR
Scientific Case: Currently, one of the greatest open questions of modern astrophysics and cosmology involves the so-called Hubble tension, i.e. the discrepancy between the Hubble constant (H0) based on Supernova (SN) Ia and on the Cosmic microwave background (CMB) temperature data from Planck assuming λCDM cosmology. The current measurements of SN Ia point to the approximate value of 73 km/s/Mpc while those based on CMB indicate values that are 5 sigma smaller (68 km/s/Mpc). One way of dealing with the discrepancy is the revision of measurements for the SN Ia which are based on the direct and late-time universe method better known as the cosmic distance ladder. This requires having precise and robust ways of obtaining distances for primary and secondary distance indicators. The main of this project is to use old distance indicators (RR Lyrae, Tip of the red giant branch) and AGN as secondary distance indicators to constrain possible systematics.
Outline of the Project: Analysis of multi-band optical/near-infrared/mid-infrared data (mean magnitudes) and/or spectroscopic data (elemental abundances) to constrain the metallicity dependence of the primary distance indicators. New distance estimates based on primary distance indicators of nearby galaxies hosting AGNs.
Planning of the activities: Planning of the activities: The first year will be mainly devoted to the analysis of field RR Lyrae for which we already collected NIR photometric and spectroscopic data. The second year will be mainly devoted to the calibration of new diagnostics for the estimate of RR Lyrae distances (Period-Luminosity, Period Wesenheit relations) and to a sample of AGNs in Local Volume galaxies. The research activity in the 3rd year will be focussed on the estimate of H0.
Institution(s) where the research will be carry out:
University of Rome Tor Vergata, INAF-OAR, ESO (Munich, Santiago)

1.15 Title: Identification of streams in the Galactic halo by using RR Lyrae as stellar tracers - Giuseppe Bono

Supervisor:
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Co-Supervisors:
M. Monelli, matteo.monelli@inaf, INAF/OAR; M. Fabrizio, michele.fabrizio@inaf.it, INAF/OAR
Scientific Case: The most popular theories concerning the formation of the Galactic halo date back to Eggen+62 who suggested a dissipative collapse and to Searle+78 who suggested a dissipationless mechanism. The latter scenario is supported by Cold Dark Matter cosmological simulations suggesting that the Halo formed from the aggregation of protogalactic fragments (Monachesi+19). The discovery of stellar streams and the merging of a massive dwarf galaxy like Sagittarius (Ibata+94) provided further support to this hierarchical mechanism. Now in the Gaia era, the fine structure of the Halo is clearly emerging (Das+16; Iorio+19). New signatures of major/minor mergers have been found in the inner Halo: Gaia Enceladus (Helmi+18) and Sequoia (Myeong+19). The main aim of this thesis is to characterize the streams by using kinematic (proper motions, Gaia) and spectroscopic (radial velocities, elemental abundances, ESO telescopes) observables. The approach we plan to adopt will allow us to investigate the 3D structure and the origin of the stellar streams recently identified.
Outline of the Project:
Planning of the activities:
Institution(s) where the research will be carry out:
University of Rome Tor Vergata, INAF-OAR, ESO (Munich, Santiago).

1.16 Title: Classical Cepheids as beacons to estimate stellar extinction - Valentina D'Orazi

Supervisor:

V. D'Orazi, valentina.dorazi@roma2.infn.it, UNITOV

Co-Supervisors:

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Scientific Case:

Classical Cepheids play a fundamental role in modern Astrophysics, because they are the most popular primary distance indicators and also solid tracers of young stellar populations. Moreover and even more importantly, they are also fundamental laboratories to investigate several long-standing astrophysical problems. The main aim of this project is to use the steady periodicity of classical Cepheids to estimate the interstellar extinction by using diffuse interstellar bands. We have already collected a huge data set of high resolution optical spectra of Galactic and Magellanic Cepheids and they will be adopted to derive new reddening maps to improve the accuracy of Cepheid distance scale.

Outline of the Project:

Planning of the activities:

Institution(s) where the research will be carry out:

University of Rome Tor Vergata, INAF-OAR, ESO (Munich, Santiago), Univ. of Bologna.

1.17 Unveiling Chemical Abundances in Variable Stars: Advanced Statistical Methods for Large-Scale Spectroscopic Surveys - Valentina D'Orazi

Supervisor (Name, Institution and e-mail):
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Co-Supervisors (Name, Institution and e-mail):
Giuseppe Bono, University of Rome Tor Vergata, bono@roma2.infn.it
Scientific Case: We are currently in the golden age of spectroscopic surveys, with millions of high-resolution spectra set to be collected by projects such as WEAVE and 4MOST. Traditional physical modelling approaches are no longer feasible for such large datasets. Therefore, advanced statistical methods are essential to expedite the process of deriving stellar parameters and chemical abundances for large samples of stars. This project aims to develop a dedicated approach for analyzing helium-burning variable stars (HBVs), including classical Cepheids, Type II Cepheids, and RR Lyrae stars. These excellent tracers, located in all Galactic components (disk, bulge, and halo), allow us to infer detailed information about the formation and evolution of the Milky Way and its satellites.
Outline of the Project: The project will begin with the acquisition and exploitation of mock template spectra developed within the 4MOST consortium. These spectra, representing a few thousand objects, will serve as the foundation for training and testing our algorithms. The initial focus will be on developing advanced statistical methods capable of accurately deriving stellar parameters such as temperature, surface gravity, and chemical composition from these high-resolution spectra. Once the algorithms are adequately trained and validated using the mock template spectra, they will be applied to a larger dataset. Specifically, the project will target over 10,000 variable stars included in the S4 survey of the 4MOST consortium. This survey is dedicated to high-resolution chemical studies of the disk and bulge regions of our Galaxy. This project is conducted in close collaboration with Maria Bergemann's group at the Max Planck Institute for Astronomy in Heidelberg. Multiple visits to the institute are expected throughout the duration of the PhD program, facilitating close interaction and knowledge exchange with leading experts in the field.
Planning of the activities:
Year 1: Acquisition and preparation of mock template spectra from the 4MOST consortium; Development of preliminary statistical methods for deriving stellar parameters; Initial training and testing of algorithms using mock template spectra.
Year 2: Refinement and optimization of statistical methods based on initial results; Extensive validation of algorithms using a larger subset of mock spectra; Application of algorithms to a pilot sample of variable stars from the S4 survey.
Year 3: Full-scale application of refined algorithms to the entire S4 survey sample of variable stars; Detailed analysis of derived chemical abundances and stellar parameters; Integration of results to infer the formation and evolution history of the Milky Way.
Institution(s) where the research will be carry out:
University of Rome Tor Vergata; Max Planck Institute for Astronomy

1.18 Cosmology from the cross-correlation of CMB and large-scale structure observables - Marina Migliaccio

Supervisor (Name, Institution and e-mail):
Marina Migliaccio, University of Rome "Tor Vergata" (migliaccio@roma2.infn.it)
Co-Supervisors (Name, Institution and e-mail):
Giulio Fabbian (IAS-CNRS), Carmelita Carbone (INAF IASF-MI)
Scientific Case: The recent launch of the ESA Euclid space mission marks the onset of a new era in galaxy surveys. Euclid will map the positions, distances and shapes of billions of galaxies out to redshift $z \sim 2$ across more than a third of the sky. The combination and correlation of these data with Cosmic Microwave Background (CMB) measurements will allow to explore an unprecedented range of physical scales and cosmic epochs, ranging from recombination to structure formation and the late-time accelerated expansion of the Universe. Given this, it is crucial and timely to investigate the interplay of these diverse probes to maximise the return of information in constraining both the cosmological model and the properties of the large-scale structure tracers.
Outline of the Project: We propose to investigate cross-correlations of CMB anisotropies and lensing with observations from Euclid. Several studies can be pursued within this research field. One possibility is represented by cross-correlations with Euclid primary probes, which are galaxy clustering and weak-lensing, to test structure growth, dark energy/modified gravity scenarios, and primordial non-Gaussianity through scale-dependent galaxy bias. In these studies, the key advantage of using cross-correlations resides in their ability to break degeneracies between cosmological and astrophysical parameters, while allowing control of uncorrected systematic effects which do not correlate across independent observations. Another avenue involves investigating the reconstruction of cosmic filaments from Euclid data and analyzing their cross-correlation with CMB probes. This presents a highly innovative method for characterizing the distribution of dark matter, testing the fundamental nature of gravity, and probing neutrino masses.
Planning of the activities:
The initial phase of the project will center on gaining an in-depth understanding of state-of-the-art observations and theoretical modelings for both cosmology and large-scale structure tracers. Following this, the focus will be on refining theoretical predictions and data analysis pipelines. Finally, there will be the application of these methodologies to realistic N-body simulations and Euclid data, along with CMB data from Planck, ACT and SPT. Several Euclid data releases are expected during the PhD project, notably the first internal data release DR1 at the end of 2025, followed by DR2 in 2027. Throughout the PhD course, the student will work within a highly international environment, directly contributing to the activities of the CMBX Science Working Group of the Euclid Consortium.
Institution(s) where the research will be carry out:
University of Rome "Tor Vergata" with possibility of long-term visits at foreign institutions (e.g. IAS-CNRS).

1.19 Data analysis challenges for future CMB observations - Marina Migliaccio

Supervisor (Name, Institution and e-mail):
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Co-Supervisors (Name, Institution):
Alessia Ritacco (Univ. Grenoble Alpes, CNRS, Grenoble INP, LPSC-IN2P3); Mathieu Remazeilles (IFCA Santander)
Scientific Case: In the coming years, a number of experiments will collect cutting-edge measurements of the Cosmic Microwave Background (CMB) polarisation hunting for primordial B-modes. These B-modes are a distinctive signature of cosmic inflation and promise to be a unique probe of the physics of the early universe. However, their detection remains challenging, primarily due to the need of very high sensitivity and exquisite control of instrumental systematic effects, as well as foreground contamination from microwave emissions originating in our own Galaxy. To achieve the ambitious objectives of future experiments, it is crucial to develop advanced data analysis techniques able to effectively address these challenges.
Outline of the Project: The project will focus on improving data analysis techniques in preparation for future experiments, with the possibility to work on mitigation and separation of foreground emissions; realistic simulations; angular power spectrum estimates; and modelling of likelihood functions to constrain cosmological parameters. Taking advantage of simulations, the interplay between Galactic polarised emission and instrumental effects will be analysed in-depth, propagating their impact to cosmological targets and specifically to constraints on early universe models. Additionally, the new techniques can also be used to produce improved analyses of polarization data already available, such as those delivered by Planck.
Planning of the activities:
The thesis project will be carried out in an extremely international environment, where the student will play an active role in the preparatory work for next-generation CMB experiments, like the LiteBIRD space mission. In its initial phase, the project will prioritize acquiring a comprehensive understanding of the research field and developing specific skills in data analysis techniques, foreground modelling, simulation of realistic datasets. Subsequently, the project will shift focus towards the development and implementation of algorithms and statistical methods, which will be optimised using both simulations and available data.
Institution(s) where the research will be carry out:
University of Rome "Tor Vergata" with the possibility of long-term visits abroad (e.g. at Univ. Grenoble Alpes or IFCA Santander).

1.20 Adaptive optics for gravitational wave interferometers in the Einstein Telescope era - V. Fafone

Supervisor (Name, Institution and e-mail):
Prof. V. Fafone, viviana.fafone@roma2.infn.it, University of Roma Tor Vergata
Co-Supervisors (Name, Institution and e-mail):
Dott. M. Lorenzini, matteo.lorenzini@roma2.infn.it, University of Roma Tor Vergata
Scientific Case: Gravitational-wave (GW) detections have fostered a new exploration of the Universe. Einstein Telescope (ET) is being proposed as the European project for next generation GW observatories. ET will be an unprecedented resource to address open questions in fundamental physics and cosmology. It will probe the physics near the black-hole horizon, help understanding the nature of dark energy and possible modifications of general relativity at cosmological scales. The ET sensitivity and wide frequency band will make it possible to access the entire population of stellar and intermediate mass BH (up to 10^3 solar masses) back to the early Universe.
Outline of the Project: The possibility of reaching the ET science goals depends on the improved performance of adaptive optical systems necessary for optimizing the interferometer's operation. This project will focus on the development of advanced sensors and actuators to be implemented for wavefront sensing and control in ET. The thesis will be carried on within the Virgo-Einstein Telescope Tor Vergata group, responsible for the development of the adaptive optical system both in Virgo and in ET.
Planning of the activities:
Year 1: First year: acquire/improve knowledge of the state-of-the-art instrument science of GW observatories, gain experience with simulation tools and start modeling activities.
Year 2: develop dedicated models, design the optical set up and start measurements and characterization.
Year 3: complete the characterization measurements; thesis writing.
Institution(s) where the research will be carry out:
University of Roma Tor Vergata, European Gravitational Observatory

1.21 Modeling performances of future gravitational wave detectors - V. Fafone

Supervisor (Name, Institution and e-mail):
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Co-Supervisors (Name, Institution and e-mail):
Dott. A. Rocchi, alessio.rocchi@roma2.infn.it, INFN Sezione di Tor Vergata
Scientific Case: Plans for upgrading current detectors (Virgo_nEXT in Europe and A# in the US) are being developed alongside future projects such as Einstein Telescope and Cosmic Explorer. These initiatives will foster the exploration of the Universe throughout its cosmic history, reaching back to the cosmological dark ages. The future of gravitational wave astronomy hinges on the detection capabilities of next-generation interferometers in the Hz-kHz frequency range, where very interesting phenomena involving neutron star and black hole binary systems occur.
Outline of the Project: The aim of this project is to develop tools to model the performances of present and next generation detectors with the goal of assessing their operability and science return. The thesis activity will be focused on the optimization of simulation codes to investigate the behavior of the instrument under several operating conditions. The thesis will be carried on within the Virgo-Einstein Telescope Tor Vergata group.
Planning of the activities:
Year 1: First year: acquire/improve knowledge of the state-of-the-art instrument science of GW observatories, gain experience with simulation tools and start modeling activities.
Year 2: develop dedicated models, simulate performances of the instrument as designed.
Year 3: complete the simulation activity with the addition of deviations from design configuration; thesis writing.
Institution(s) where the research will be carry out:
University of Roma Tor Vergata, European Gravitational Observatory

1.22 The Role of Innovative Instrumentation in Advancing our Understanding of Solar Activity and its Terrestrial/Lunar Impact and modelling improvements - Francesco Berrilli - SpaceItUp funds

Supervisor: Francesco Berrilli, University of Rome Tor Vergata, francesco.berrilli@roma2.infn.it
Co-Supervisors: Roberto Ronchini, Telespazio S.p.A., Italy, roberto.ronchini@telespazio.com

Project Space It Up (bando di finanziamento ASI D.N. 687/2022 - deliberaz. N. 71/2022 - CUP E83C24000530001 – UPB MurPE15-SpaceItUp2022PNRR-WP6 - Spoke 6 *Protection of Critical Structures and Space Weather*

Scientific Case: While solar activity impacts the entire Earth-Moon system, Earth's magnetosphere provides crucial protection for human spaceflight in Low Earth Orbit. The Moon lacks this vital shielding, presenting significant obstacles for future human exploration, the deployment of lunar satellite networks, and the establishment of long-term lunar bases. This research will detail the fundamental differences in the physical conditions of circumterrestrial and lunar space as they respond to solar activity. Additionally, it will analyze how the lunar environment interacts with Earth's magnetotail under different solar conditions to guide the development of mitigation strategies against space weather hazards for future human lunar settlements.
Outline of the Project: During the thesis, three main topics are investigated: Develop and evaluate novel spaceborne instrumentation for key solar/heliospheric measurements; Improve coupling models between solar events and their effects on Earth and the Moon; Enhance predictive capabilities of space weather models using new data streams.
Planning of the activities:
Year 1: Literature and State-of-the-Art for LSW and specialized satellites for the monitoring of the high energy radiation and particles environment in the Eart/lunar deep space, Data acquisition;
Year 2: Develop and evaluate novel spaceborne payloads and models for solar/heliospheric physics;
Year 3: Refining the P/L and models and Thesis writing and dissemination of research findings.
University of Rome Tor Vergata, Telespazio S.p.A. (Rome)

2 Sapienza University of Rome

A total of five (5) fellowships are granted for students to carry out their research in Sapienza.

2.1 Cosmic Microwave Background polarization with the QUBIC experiment - SIlvia Masi

Supervisor (Name, Istitution and Contact):
Silvia Masi, Sapienza University, silvia.masi@roma1.infn.it
Co-Supervisor (Name, Istitution and Contact):
Jean-Christophe Hamilton, APC-Paris, jchamilton75@gmail.com
Scientific Case: Cosmic Microwave Background (CMB) polarization at large angular scales represents the best way to test the cosmological inflation hypothesis. Due to the extremely faint B-mode polarization signal, it is mandatory that the search and detection is obtained by very different experiments. At variance with all other CMB polarization experiments, the Q and U Bolometric Interferometer for Cosmology (QUBIC) is an innovative polarimeter for the Cosmic Microwave Background, combining the excellent beam-forming capabilities of interferometers and the extreme sensitivity of bolometers. QUBIC uses Fizeau interferometry to synthesize the instrument beam by a reconfigurable array of apertures. It is composed by three modules (97, 150 and 220 GHz) operating from Alto Chorillo (Argentina) at 5000 m *asl* to beat atmospheric contamination.
Outline of the Project: The first module of QUBIC has been installed in Alto Chorrillo in November 2023 and is currently being commissioned. The Thesis work will consist in the optimization of the observation program, participation in the measurements (sky and calibration measurements) and in the data analysis.
Planning of the activities: first year: study of the theory of CMB polarization - study of the measurement methods involving bolometric interferometry with cryogenic detector arrays - Contribution to the instrument calibration second year: simulation of systematic effects, development of mitigation methods, contribution to sky survey and calibration measurements third year: Data Analysis and Thesis writing.
Institution(s) where the research will be carry out: G31 Laboratory - Physics Department - Sapienza University of Rome; APC Paris (visits of Hamilton's group).

2.2 Polarimetric measurements of the Cosmic Microwave Background: looking for signals from cosmic inflation - Paolo de Bernardis

Supervisor (Name, Institution and e-mail):
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Co-Supervisors (Name, Institution and e-mail):
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Scientific Case: The measurement of Cosmic Microwave Background (CMB) polarization at large angular scales represents the best way to investigate the first split-second after the big-bang, and the cosmological inflation hypothesis. The Large-Scale Polarization Explorer (LSPE) is a mission to measure inflation-originated CMB polarization, significantly improving both the sensitivity and the control of systematic effects with respect to current experiments. LSPE-SWIPE is a balloon-borne polarimeter for the Cosmic Microwave Background, featuring a small aperture (50 cm diameter) cryogenic telescope feeding two large arrays of multi-mode TES bolometers. Polarization modulation is obtained using a rotating half-wave plate (HWP) as the first optical element of the instrument. The HWP is cooled cryogenically, levitated and rotated by means of a superconducting magnetic bearing.
Outline of the Project: The thesis will focus on the development and calibration of the polarimeter and its cryogenic system, including the development of a custom calibration source. In addition, an in-flight calibration procedure will be devised and validated. The work will be completed with the participation in the flight campaign and data analysis, with a key role in the in-flight calibration data reduction. The experience gained with the development of the LSPE polarimeter will be extremely useful for the development of the future LiteBIRD satellite, which uses the same polarimetry methods as LSPE, and the thesis work will be instrumental for the student to contribute to the LiteBIRD mission as well. See also http://lspe.roma1.infn.it and http://litebird.jp/eng/ .
Planning of the activities:
Year 1: Study of the theory of CMB polarization, polarized foregrounds, advanced measurement methods, participation in instrument development
Year 2: instrument development, calibration measurements, simulations and mitigation of systematic effects
Year 3: completion of the data analysis, thesis writing, defense
Institution(s) where the research will be carry out: G31 Laboratory, Physics Department, Sapienza University of Rome

2.3 Preparation of the LiteBIRD space mission for CMB polarization: instrument definition, requirements, and data analysis - Francesco Piacentini

Supervisor (Name, Institution and e-mail):
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Co-Supervisors (Name, Institution and e-mail):
Giampaolo Pisano, Sapienza University, giampaolo.pisano@uniroma1.it
Scientific Case: Accurate measurements of the polarization of the Cosmic Microwave Background (CMB) allow us to detect the presence of gravitational waves in the early universe, at the recombination epoch. These gravitational waves carry information about the inflationary mechanism in the very early universe. Polarization measurements in the microwave band also allow us to constrain the re-ionization history of the Universe associated with the formation of the first stars, to measure the topology of the Universe and possible anomalies, to characterize the matter distribution in the Milky Way, and more.
LiteBIRD, is a Japanese-led space mission, with significant contributions from the US and EU countries, dedicated to measuring CMB polarization with degree-scale angular resolution between 40 and 400 GHz. It is scheduled for launch in mid 2030s.
For more information, see: LiteBIRD; Probing cosmic inflation with the LiteBIRD cosmic microwave background polarization survey, Progress of Theoretical and Experimental Physics; 2023; 042F01 (2023), `https://doi.org/10.1093/ptep/ptac150`
Outline of the Project: The candidate will contribute to the mission preparation, in particular to the definition of the instrument requirements, to the development of next generation algorithms for instrument simulation, calibration, control of systematic effects, polarization extraction, component separation, measurement of cosmological parameters, measurement of statistical anomalies, and much more. The candidate will work in a very international environment, with links and contacts worldwide. A period of 2-12 months abroad (Japan, US or Canada) is foreseen and funding is secured.
Institution(s) where the research will be carry out:
The main institution will be Sapienza University of Rome, Physics Department.
Possible hosting institutions for periods abroad are: The Kavli IPMU (the University of Tokyo Kashiwa campus), Tokyo, Japan.

2.4 Preparation of the LSPE-SWIPE balloon instrument for CMB polarization: data acquisition system and data analysis - Francesco Piacentini

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Francesco Piacentini, francesco.piacentini@uniroma1.it, Sapienza University
Co-Supervisors (Name, Institution and e-mail):
Paolo de Bernardis, Sapienza University
Scientific Case: Accurate measurements of the polarization of the Cosmic Microwave Background (CMB) allow us to detect the presence of gravitational waves in the early universe, at the recombination epoch. These gravitational waves carry information about the inflationary mechanism in the very early universe. Polarization measurements in the microwave band also allow us to constrain the re-ionization history of the Universe associated with the formation of the first stars, to measure the topology of the Universe and possible anomalies, to characterize the matter distribution in the Milky Way, and more.
Large Scale Polarization Explorer (LSPE), a program dedicated to the measurement of the CMB polarization. LSPE is composed of two instruments: LSPE-Strip, a radiometer-based telescope on the ground in Tenerife-Teide observatory, and LSPE-SWIPE (Short-Wavelength Instrument for the Polarization Explorer) a bolometer-based instrument. For more information, see: The large scale polarization explorer (LSPE) for CMB measurements: performance forecast, The LSPE collaboration, Journal of Cosmology and Astroparticle Physics, Volume 2021, August 2021, `https://iopscience.iop.org/article/10.1088/1475-7516/2021/08/008`.
Outline of the Project: The participant will work within the LSPE collaboration and will contribute to the final development of the LSPE-SWIPE instrumentation, in particular to the software of the data acquisition system. He/she will participate to the integration, calibration and operation campaign. The activity will be completed by the analysis of the retrieved data, consisting in the production of maps of the CMB polarization and the extraction of the encoded cosmological information.
The activity is strongly related to the parallel development of the LiteBIRD space mission for the observation of the CMB polarization, on a longer time-scale. The participant can join the LiteBRID international collaboration, and contribute to the LiteBIRD mission as well.
Institution(s) where the research will be carry out:
The main institution will be Sapienza University of Rome, Physics Department.
International collaborations are set for both LSPE and LiteBIRD and periods abroad are envisaged.

2.5 Study and optical characterisation of the millimetre-wave polarisation modulator for the LiteBIRD MHFT instrument - Giampaolo Pisano

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Co-Supervisor (Name, Institution and Contact):
Fabio Columbro, Sapienza University, fabio.columbro@roma1.infn.it; Francesco Piacentini, Sapienza University, francesco.piacentini@roma1.infn.it
Scientific Case: Measurements of the polarisation of the Cosmic Microwave Background (CMB) radiation is currently one of the hottest topics in Cosmology. The G31 group is involved in many CMB projects world-wide including the LiteBIRD satellite mission. The B-mode signals are extremely weak and require extraordinary sensitivity, exquisite control of the optical systematics and polarisation modulation. The latter is achieved by means of cryogenically cooled Half-Wave Plates (HWPs) rotated by using a superconductive bearing based on a magnetic levitation system. The group has developed many types of HWPs: from those based on crystalline plates to others based on metamaterials.
Outline of the Project: In the context of a project funded by the European Space Agency (ESA), we will study two types of metamaterial HWPs: transmissive mesh-HWPs and embedded reflective HWP. We will characterise their optical performance both at room and cryogenic temperature and feed back the data in order to optimise their design.
Planning of the activities: PhD project tasks: - Metamaterials e-m modelling using finite-element analysis software (HFSS). - Optimisation HWP designs based on metamaterials - Assistance to the devices manufacture, performed within our international collaboration network. - Device testing with Fourier Transform Spectrometers (FTSs), Vector Network Analysers (VNAs) and cryogenic instrumentation. - Data analysis and impact on study of the systematics.
Institution(s) where the research will be carry out: Sapienza University

2.6 Development of quasi-optical components based on metamaterials for millimetre-wave astronomy instrumentation and for Cosmic Microwave Background polarisation experiments - Giampaolo Pisano

Supervisor (Name, Institution and Contact):
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Co-Supervisor (Name, Institution and Contact):
Luca Lamagna, Sapienza University, luca.lamagna@roma1.infn.it
Scientific Case: Metamaterials are artificial materials with properties not always available in natural materials. They can be realised with 3D periodic structures, with sub-wavelength unit elements, and used to invent novel and exotic quasi-optical (QO) devices.
Outline of the Project: This project will focus on the development of one of the following devices: a) Mesh half-wave plates: to modulate the polarisation of light in CMB instruments. b) Mesh-lenses: flat, thin surfaces to replace massive standard plastic lenses. c) Mesh-absorbers: thin surfaces to absorb stray light over large bandwidths and angles. d) Mesh correcting surfaces: surfaces to correct optical aberrations or polarisation systematics. e) Mesh transmissive dichroics: surfaces to split beams with different frequencies. f) Mesh Spiral-Phase- or Q-plates: surfaces to manipulate the Orbital Angular Momentum of light. These devices are targeted to mm/sub-mm astronomy instrumentation, in particular that related to the detection of the Cosmic Microwave Background (CMB) B-Modes. The G31 group is involved in many projects worldwide including the LSPE balloon experiment and the Japanese LiteBIRD satellite mission. Devices a)-c) find direct application in the LiteBIRD MHFT and the LSPE SWIPE instruments. These developments can also find applications in other fields, such as telecommunications.
Planning of the activities: PhD project tasks: - Metamaterials e-m modelling using finite-element analysis software (HFSS). - Design of a novel quasi-optical device. - Assistance to the device's manufacture. - Device testing with FTSs and VNAs. - Data analysis.
Institution(s) where the research will be carry out: Sapienza University

2.7 Galaxy clusters and cosmic web study with medium and high angular resolution at millimetric wavelenghts - Elia Battistelli

Supervisor:
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Co-Supervisor:
Matteo Murgia, INAF, matteo.murgia@inaf.it

Scientific Case: The cosmic web and its filamentary structures connecting galaxy clusters represent a fundamental prediction of hierarchical structure formation through gravitational accretion. These large-scale features hold particular significance for resolving key questions in modern cosmology, including the nature of the missing baryon problem and the potential existence of baryonic dark matter components. The most promising observational probe of these diffuse structures is the Sunyaev-Zel'dovich (SZ) effect, which arises from the inverse Compton scattering of cosmic microwave background (CMB) photons by hot electrons in the intergalactic medium. This same physical mechanism serves as a powerful tool for studying the intracluster medium (ICM) physics in galaxy clusters when observed with sufficiently high angular resolution to resolve their internal structure.

Outline of the Project: During the PhD program, the candidate will conduct observations and perform data analysis of microwave-frequency data obtained from major radio telescopes, particularly utilizing the MISTRAL receiver on the Sardinia Radio Telescope (SRT). This research aims to investigate the nature of the cosmic web through precise measurements of the Sunyaev-Zel'dovich effect and other relevant phenomena. Additionally, the student will have the opportunity to join the Atacama Cosmology Telescope and the Simons Observatory collaboration, where they will work on cross-correlating high angular resolution data (10 arcseconds) with moderate resolution observations (2 arcminutes). This comparative analysis will enable studies of the cosmic web across different spatial scales, from fine structures in galaxy clusters to larger-scale filamentary networks.

Planning of the activities:
Year 1: The student will develop the observational strategy and detailed observation plan for the MISTRAL experiment, the 90GHz camera developed at Sapienza University for the Sardinia Radio Telescope (SRT). They will participate in the final commissioning phase of this instrument. MISTRAL offers an angular resolution of 12 arcseconds and a field of view of 4 arcminutes, making it an ideal facility for studying galaxy clusters and their outskirts through millimeter-wave observations. The student will gain hands-on experience with instrument calibration, observation planning, and initial data reduction.
Year 2: The student will cross-correlate MISTRAL's galaxy cluster observations with data from the Atacama Cosmology Telescope (ACT) and Simons Observatory (SO). They will develop a unified analysis pipeline capable of extracting both small-scale (cluster substructures) and medium-scale (filamentary connections) features. This multi-instrument approach will enable comprehensive studies of the thermal and kinematic properties of the intracluster and circumcluster medium across different angular scales.
Year 3: The student will focus on in-depth data analysis, physical interpretation of results, and preparation of scientific publications. They will:
-Characterize the thermodynamic properties of galaxy clusters and their surrounding environments;
-Investigate potential connections between cluster properties and large-scale structure filaments;
-Lead the preparation of publications for international scientific journals;
-Present findings at international conferences.
Institution(s) where the research will be carried out: Physics Department, Sapienza University of Rome

2.8 Study of the polarization of the Cosmic Microwave Background from high altitude ground based experiments - Elia Battistelli

Supervisor:
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Co-Supervisors:
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Scientific Case: The polarization of the Cosmic Microwave Background (CMB) encodes fundamental information about the early universe, primarily through two distinct signatures: E-modes (generated by scalar density perturbations) and B-modes (produced either by primordial gravitational waves from cosmic inflation or by gravitational lensing of the CMB). Current state-of-the-art experiments aim to detect these faint polarization signals with the following key scientific objectives:
-Probing cosmic inflation, which would test theories of quantum gravity and provide evidence for energy scales approaching 10^{16} GeV;
-Constraining the epoch of reionization;
-Mapping dark matter distribution through the statistical analysis of CMB lensing.
-Characterizing foreground contamination by analyzing multi-frequency polarization data to separate Galactic emissions from the cosmological signal.

Outline of the Project: The PhD candidate will have the opportunity to actively participate in international CMB polarization experiments, including QUBIC (Q&U Bolometric Interferometer for Cosmology), a novel bolometric interferometer designed for precision measurements of primordial B-modes, and Simons Observatory, a next-generation CMB experiment featuring both small-aperture and large-aperture telescopes. Both instruments are taking data from high altitude south American observational sites. The student's involvement will include:
-Instrument characterization and calibration;
-Observational campaigns participating in data acquisition at high-altitude sites (e.g., Atacama Desert or Alto Chorrillo);
-Data analysis: developing pipelines for map-making, power spectrum estimation, and systematic error characterization.
This hands-on experience with cutting-edge CMB technology will provide complete training in both instrumental astrophysics and cosmological data analysis.

Planning of the activities:
Year 1: During the first year of the PhD program, the student will familiarize and train with the instrument:
-Acquire in-depth knowledge of CMB polarization instruments through hands-on training in instruments (self-)calibration, simulations of observational strategies, and analysis of pilot data sets;
-Develop expertise in polarimetry fundamentals (E/B-mode separation, systematic effects) and instrument-specific software pipelines;
-Begin preparatory work for future observations.
Year 2: The second year will be focused on active participation in observational activities and data acquisition. Thus the student will focus:
-Conduct and participate to observations;
-Responsibilities will include real-time data quality assessment, instrument performance monitoring, and coordination with international teams;
-Contribute to calibration measurements (e.g., with celestial or artificial sources) and mitigation of ground/atmospheric contamination.
Year 3: The final year will emphasize scientific exploitation of collected data, data analysis and scientific dissemination:
-Capitalize on acquired datasets to extract cosmological parameters and characterize foregrounds

(dust/synchrotron) via multi-frequency analysis;
-Lead the preparation of publications for international scientific journals;
-Present findings at international conferences and collaboration meetings. .

Institution(s) where the research will be carried out: Physics Department, Sapienza University of Rome

2.9 Optical Design and Instrumental Systematics for Next-Generation CMB Polarization and Spectral Distortion Experiments - Luca Lamagna

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Co-Supervisors (Name, Institution and e-mail):
Alessandro Paiella, Physics Department, Sapienza University of Rome
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Scientific Case: The study of the Cosmic Microwave Background (CMB) remains one of the most powerful tools in observational cosmology. Over the past two decades, increasingly sensitive experiments have refined our understanding of the early universe, confirming the predictions of the standard cosmological model. Yet, some of the most profound questions remain open, such as the nature of inflation and the presence of new physics beyond the standard model.
Polarization measurements of the CMB, particularly the elusive B-modes, offer a unique window onto the physics of inflation. At the same time, precise characterization of the CMB spectral distortions could reveal processes that occurred during the thermal history of the Universe, including energy injection from decaying particles, primordial black holes, or large-scale structure formation. These signals are extremely faint and demand unprecedented control of instrumental effects, calling for a new generation of experiments with highly optimized optical systems and deeply characterized systematics.
Outline of the Project: This PhD project will take place within the context of the next generation of CMB experiments—LiteBIRD, CMB-S4, and FOSSIL—which aim to explore the early universe with high precision through measurements of polarization and spectral distortions. The student will also interact with current and near-future experiments such as QUBIC, LSPE/SWIPE, and COSMO, contributing to both development and validation phases.
This PhD will provide the candidate with a solid foundation in the design and analysis of CMB experiments, offering the opportunity to contribute to some of the most ambitious and scientifically promising missions of modern cosmology. The work will be carried out in collaboration with leading international teams and will combine theoretical, computational, and experimental approaches in a balanced and highly interdisciplinary environment.
Planning of the activities:
Year 1: The candidate will become familiar with the fundamentals of CMB instrumentation and systematics, with particular focus on optical and quasi-optical design. The first phase will involve simulation of optical systems, including telescope assemblies, reimaging optics, and polarization modulators. State-of-the-art electromagnetic modeling tools (such as GRASP, Zemax, and physical optics simulators) will be used to design and optimize optical subsystems under realistic operational constraints.
Year 2: The second year will be dedicated to the integration of optical models into full-instrument simulation frameworks. These simulations are critical to assess the impact of optical design choices on systematic effects, such as beam asymmetries, polarization leakage, side lobes, and cross-polarization, which can limit the sensitivity to primordial signals. The student will contribute to the development and validation of these frameworks, working in close coordination with the international consortia of LiteBIRD and CMB-S4.
Year 3: In the final phase, the student will focus on experimental validation of the models. This includes participation in laboratory test campaigns to measure optical properties of components and subsystems, and in the analysis of data from ongoing experiments like QUBIC, LSPE/SWIPE and COSMO.
Institution(s) where the research will be carried out: Physics Department, Sapienza - University of Rome

2.10 Integration and Performance Verification of the COSMO Interferometer for CMB Spectral Distortion Measurements - Luca Lamagna

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Co-Supervisors (Name, Institution and e-mail):
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Alessandro Paiella, Physics Department, Sapienza University of Rome
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Scientific Case: Spectral distortions in the cosmic microwave background (CMB) offer a unique and largely untapped probe of the early universe. Detecting these faint signals requires instrumentation of exceptional sensitivity and control over systematic effects. The COSMO (COSmic Monopole Observer) experiment is designed to meet this challenge through the development of a cryogenic Fourier Transform Spectrometer (FTS), paired with a reference blackbody source of unprecedented emissivity, surpassing even that of FIRAS, the benchmark experiment in this field.
Outline of the Project: This PhD project is centered on the assembly, integration, and performance verification of the COSMO interferometer, with particular attention to identifying and mitigating instrumental systematics that could compromise the measurement.
By the conclusion of this thesis, the COSMO FTS will have undergone rigorous verification, positioning it as a next-generation instrument capable of revealing the subtle spectral fingerprints of the early universe. The candidate's work will represent a foundational step toward enabling the precise detection of CMB spectral distortions.
Planning of the activities:
Year 1:
Design Refinement and Pre-Assembly Validation.
Initial efforts will focus on finalizing the design of the interferometer based on prior optical and electromagnetic simulations. The candidate will assess component compatibility, define alignment tolerances, and prepare detailed procedures for cryogenic integration. Early laboratory tests on key subsystems (lenses, mirrors, beamsplitters, and cryogenic delay lines) will validate their functionality and robustness under controlled conditions.
Year 2:
Assembly and Cryogenic Integration.
The FTS and the reference blackbody will be integrated in a cryogenic environment, with precise alignment and thermal control systems in place. The candidate will develop and execute the integration workflow, carry out alignment verification tests, and ensure system stability through initial cooldown cycles. Performance will be evaluated using calibrated sources, establishing a baseline for spectral response and instrumental noise.
Year 3:
Performance Testing and Systematics Characterization.
The final phase focuses on full-system testing. The candidate will perform detailed spectral measurements to characterize the interferometer's sensitivity, resolution, and stability. Advanced simulations will guide the identification and modeling of systematic effects (thermal drifts, optical misalignments, beam asymmetries) that could bias the results. Mitigation strategies, both in hardware and data analysis, will be explored and quantified.
Institution(s) where the research will be carried out:
Physics Department, Sapienza - University of Rome

2.11 Tracing the birth and fate of the first black hole seeds - Raffaella Schneider

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Co-Supervisors (Name, Institution and e-mail):
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Scientific Case:
The origin of the first supermassive black holes (SMBHs) formed in the early Universe remains one of the unsolved questions in extragalactic astrophysics. The existence of hundreds of quasars at $z \geq 6$ indicates that $10^9 - 10^{10} M_\odot$ SMBHs can form within $\simeq 700$ Myr by efficiently accreting mass onto smaller black hole (BH) seeds. However, the nature of these BH seeds remains largely unconstrained. Theoretical models have attempted to link the properties of BH seeds to the physical conditions in their birth environments, especially gas metallicity (Z) and the intensity of the illuminating radiation field in the Lyman-Werner band ($J_{\rm LW}$). As a result, three distinct families of BH seeds are predicted to form: light BH seeds (masses up to a few hundred $M_\odot$) from massive Population III star remnants, heavy BH seeds ($\simeq 10^4 - 10^5 M_\odot$) from the direct collapse of a Super Massive Star (SMS), and intermediate-mass BH seeds ($\simeq 10^3 M_\odot$) from runaway stellar or BH collisions in dense clusters. The advent of JWST has revealed a previously unknown population of AGNs at $2 < z < 11$, significantly fainter than known quasars and with unexpectedly large BH-to-stellar mass ratios. These AGNs show unique nuclear properties, including being X-ray faint, radio-quiet, and surrounded by very dense gas. These observations suggest we may be witnessing an early evolutionary stage of BH growth, potentially linked to the formation of BH seeds. The goal of this PhD project is to use high-resolution and N-body simulations to investigate BH seed formation and interactions in their birth environments, leveraging JWST's discoveries and preparing for future gravitational wave observations.

Outline of the Project:
Recent high-resolution simulations have shown that BH seed formation depends on the interplay between gas fragmentation, accretion, and stellar collisions (Chon & Omukai 2020). The final outcome of this so-called super-competitive accretion mechanism is the formation of a continuous BH mass distribution spanning the range between light, intermediate-mass, and heavy BH seeds (Chon & Omukai 2024). Based on these preliminary findings, the PhD candidate will explore new initial conditions for BH seed formation (moderate to low values of the illuminating UV radiation field, different values of the initial gas metallicity). This part of the work will be done in collaboration with Dr. Sunmyon Chon (Max Planck Institute for Astrophysics, Garching) and Prof. Kazuyuki Omukai (Tohoku University). These simulations will be used to characterize the stellar/BH mass distribution within each different BH seed formation site and to investigate the subsequent dynamical interactions among newly formed BH seeds (in-situ mergers) using direct N-body codes. This part of the work will be done in collaboration with Dr. Manuel Arca Sedda (GSSI). As a result, we will estimate the BH coalescence rates, retention fraction, and gravitational wave luminosity. Finally, we will incorporate the above findings in a simplified analytical framework and elaborate a new simulation-guided model for BH seed formation that can be adopted in larger-scale galaxy evolution models. For each of the above steps, we plan to make extensive comparison with new data from JWST available through participation to current and future observational proposals.

Planning of the activities:
Year 1: Simulations of early BH seed formation, exploring different BH birth environments selected from cosmological initial conditions
Year 2: N-body simulations of the subsequent interactions between stars and newly formed BH seeds.
Year 3: Deveolpment of a simulation guided model for BH seed mass function.

Institution(s) where the research will be carry out: Sapienza University of Rome, Max Planck Institute for Astrophysics/Tohoku University, and the GSSI.

2.12 Exploring stellar populations at cosmic dawn - Raffaella Schneider

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Co-Supervisors (Name, Institution and e-mail):
Luca Graziani, Sapienza University of Rome
Scientific Case: Our understanding of the formation history of cosmic structures relies on the LCDM standard cosmological model, according to which the primordial gas cooled and formed the first stars a few hundred million years after the Big Bang. For the first time in cosmic history, stellar nucleosynthesis was ignited, and the light emitted by the first stars transformed their birth environments by heating and ionizing the surrounding gas. The onset of stellar evolution led to the first supernova explosions and to the formation of the first black holes. Heavy elements and dust grains released by supernovae enriched the primordial gas, with dramatic consequences on the cooling efficiency of star forming regions, and on the mass spectrum of second-generation stars. The formation of the first black holes and their mass growth by gas accretion or through mergers with other black holes is tightly linked to the physical conditions prevailing in their host galaxies. These complex and intertwined sequence of events marks the emergence from the cosmic dark ages into cosmic dawn. The launch of the JWST has enabled an epochal leap forward in our understanding of these remote cosmic epochs. As of today, more than 20 galaxies with spectroscopic redshift > 10 have been detected, with detailed characterization of their physical properties in terms of chemical enrichment, energy source, stellar populations, morphologies, and environment. These amazing observations have opened new compelling questions, among which an overabundance of UV bright galaxies at $z > 10$ which may point to a different nature of the stellar populations hosted in these galaxies and/or to a change in the mode of star formation at early cosmic times.
Outline of the Project: The aim of the PhD project is to develop new feedback models that capture the unique properties of stellar populations and black hole seeds formed at cosmic dawn, and predict star formation and chemical enrichment histories of $z > 10$ galaxies by running high-resolution hydrodynamical simulations on different scales. This part of the work will be done in collaboration with Ataru Tanikawa (Fukui Prefectural University). We will devise observational strategies to look for Population III stars and guide the interpretation of JWST observations. The project will make use of the state-of-the-art galaxy evolution model dustyGadget, a cosmological hydrodynamics code where we have implemented an on-the-fly description of dust formation and evolution. DustyGadget has been recently moved to Gadget4 and extended to include new physical processes tailored to the first galaxies. The PhD candidate will be involved in dustyGadget development and in running new cosmological and zoom-in simulations. Post-processing of the simulation output with customised photoionization and radiative transfer codes will also be part of the project, to allow extensive comparison with JWST and ALMA observations. This part of the work will be carried out in collaboration with Laura Pentericci at INAF/Astronomical Observatory of Rome, and Roberto Maiolino at Cambridge University. For each of the above steps, we plan to write one (or more) papers.
Planning of the activities:
Year 1: development and testing of new physical modules in dustyGadget;
Year 2: cosmological and zoom-in simulations;
Year 3: post-processing of simulations with Cloudy and SKIRT.
Institution(s) where the research will be carry out:
The project will be carried out at Sapienza University of Rome, but a secondment can be foreseen at Cambridge University during the third year of the project.

2.13 Modeling collisions of massive stars: implications for the origin of supermassive black holes - Dominik Schleicher

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Co-Supervisors (Name, Institution and e-mail):
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Scientific Case:
Collisions between massive stars are considered to play a very relevant role in collision-based scenarios for the origin of supermassive black holes. Large N-body simulations have shown that efficient runaway-collisions can occur, and observational data of nearby Nuclear Star Clusters support a possible collision-based origin of the supermassive black holes. Nonetheless important parts of the stellar evolution during the runaway mergers are not sufficiently understand and include strong uncertainties, especially regarding the mass loss during the stellar mergers, which could even become prohibitive and prevent the formation of a very massive object. Within this project, the goal is to directly simulate mergers of massive stars, including the possibility of multiple subsequent collisions, as well as the mergers of very high mass and low mass stars, to understand their possible implications for mass loss. In this way we will contribute in a very relevant manner to understand whether the formation of very massive objects via collisions can be feasible or not.
Outline of the Project: During this project, we will pursue 3D hydrodynamical simulations using the moving-mesh hydrodynamics code AREPO (https://github.com/dnelson86/arepo), a code that allows for an accurate treatment of hydrodynamics on a grid that moves along with the flow. The project will include the implementation of initial conditions employing models of massive main-sequence stars, and the subsequent modeling and analysis of the stellar collisions, focusing particularly on the mass loss as well as stellar rejuvenation processes as a result of the collisions. A relevant aspect will concern also the modeling of mergers between low-mass stars and very massive objects, as in those cases particularly the possible mass loss could become higher than the mass gain. The project will be carried out in collaboration with the group of Prof. Ralf Klessen at the University of Heidelberg, including experts on the AREPO code.
Planning of the activities:
Year 1: Implementation of the initial conditions and first simulations of mergers of massive main-sequence stars.
Year 2: Systematic suite of merger simulations of massive stars; investigation of multiple merger events and effect on stellar evolution.
Year 3: Modeling of mergers between low mass stars and very massive objects and investigation of mass loss.
Institution(s) where the research will be carry out:
Sapienza University of Rome (with possibility of a research stay at University of Heidelberg, Germany)

2.14 A two-component Fokker-Planck model for the co-evolution of Nuclear Star Clusters and Supermassive Black Holes - Dominik Schleicher

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Scientific Case: Nuclear Star Clusters and supermassive black holes are known to frequently co-exist, and models and simulations suggest that the processes and evolution of Nuuclear Star Clusters may also be closely related to the formation and origin of supermassive black holes. Particularly in dense enough clusters a central massive object may form via runaway collisions of massive stars, or alternatively stellar mass black holes could also sink to the center and create a massive black hole as a result of post-Newtonian interactions. Such black hole mergers can be detected and probed via gravitational wave observations, and the stellar mass black holes may play a relevant in deciding the present-day properties of the Nuclear Star Clusters.
Within this project, we will build up on the semi-analytical model by Leigh et al. 2022, MNRAS, 517, 3838, where a two-zone Fokker-Planck model is being employed to describe the time evolution of binary orbital parameter distributions in dense stellar environment. During the project proposed here, this model will be significantly extended and applied to Nuclear Star Clusters with and without supermassive black holes.
Outline of the Project: We will build up on the statistical mechanics-based model by Leigh et al. 2022, MNRAS, 517, 3838, where the Fokker-Planck equation is being employed to describe the time evolution of binary orbital parameters. During the project proposed here, this framework will be extended developing and implementing a description considering two mass components (low-mass and high-mass stars), as well as to incorporate source terms to describe mergers and star formation as well as loss terms describing escapers from the star cluster. The model will be compared and cross-checked with numerical simulations and applied to Nuclear Star Clusters with and without supermassive black holes. As reference models, we consider the large N-body simulations DRAGON I and II and Monte-Carlo simulations of Nuclear Star Clusters.
Planning of the activities:
Year 1: Development of a two mass-component model (low-mass and massive stars) based on the Fokker-Planck equation for star cluster evolution.
Year 2: Integration of new sink and source terms to account for, for example, removal of massive stars due to collisions.
Year 3: Confront the analytic calculations with numerical N-body simulations (DRAGON I, II), plus Monte-Carlo simulations. Systematic application of the model to Nuclear Star Clusters with and without supermassive black holes.
Institution(s) where the research will be carry out:
Sapienza University of Rome (with possibility of a research stay at University of Concepción, Chile)

2.15 Cosmic Microwave Background polarization with the LSPE-SWIPE experiment: Mission simulations and data analisys - Giancarlo De Gasperis

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Co-Supervisors (Name, Institution and e-mail):
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Scientific Case: Detection of primordial B-mode polarization within the Cosmic Microwave Background (CMB) offers a direct probe of gravitational waves generated during cosmic inflation. This measurement constitutes a primary avenue for validating inflationary cosmology. The Large Scale Polarisation Explorer (LSPE) aims to characterize CMB polarization through two complementary instruments: LSPE-STRIP, a ground-based radiometer deployed at the Tenerife-Teide observatory, and LSPE-SWIPE, a stratospheric balloon-borne bolometer. LSPE-SWIPE employs a small-aperture cryogenic telescope coupled to multi-mode Transition Edge Sensor (TES) bolometer arrays. Polarization modulation is achieved via a rotating half-wave plate (HWP) situated at the instrument's optical input.
Outline of the Project: The proposed Ph.D research will be dedicated to the completion and validation of the LSPE-SWIPE data processing and simulation pipeline. This includes the analysis of foreseen observational data, the reconstruction of (foreground-cleaned) Stokes parameter maps of the CMB, and the derivation of cosmological parameters.
Planning of the activities:
The proposed work plan for the candidate's three-year Ph.D. program can be divided roughly in the following manner:

1. Study of CMB polarisation theory, and polarised foregrounds, data analysis methods, study and development of the data analysis pipeline;
2. HWP systematics studies and mitigation, Pipeline integration, sky map reconstruction and foreground removal aiming to B-mode detection;
3. Study of the effect of instrumental noise and systematics on Cosmological parameters estimates, thesis writing and defense.

and cosmological parameters estimation.
Institution(s) where the research will be carry out:
Physics department – Sapienza University of Rome. The candidate will collaborate with the LSPE collaboration and periods abroad are envisaged

2.16 Cosmic Microwave Background polarization with the QUBIC experiment - Giancarlo De Gasperis

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Scientific Case: QUBIC is a novel kind of polarimeter optimized for the measurement of the B-mode polarization of the CMB, which is one of the major challenges of observational cosmology. The signal is expected to be of the order of a few tens of nK, prone to instrumental systematic effects and polluted by various astrophysical foregrounds which can only be controlled through multichroic observations.
Outline of the Project: The PhD work will focus on QUBIC calibration, commissioning, data taking and analysis. The course duration allows one to start from raw data up to the extraction of cosmological information. The work will be supervised by G. De Gasperis for data analysis, spectro-polarimetry and components separation, and by S. Masi for calibration and data taking. The research will include work in Argentina for hands-on data taking and calibration, and in Paris for data analysis activities.
Planning of the activities:
The research activity will start with hands-on work on the data analisys pipeline (developed at APC-Paris and available to the QUBIC collaboration), analisys and characterisation of the QUBIC focal plane noise properties. The core of the research projet will be interferometric self-calibration of sky data taken at 150 and 220 GHz from Alto Chorillo site, sky map reconstruction and foreground removal, aiming to B-mode detection and cosmological parameters estimation.
Institution(s) where the research will be carry out:
Physics department – Sapienza University of Rome. The candidate will collaborate with the international QUBIC collaboration and periods abroad are envisaged.

2.17 Cosmology with 3x2pt Euclid DR1 data - Roberto Maoli

Title:
Cosmology with 3x2pt Euclid DR1 data

Supervisor (Name, Institution and e-mail):
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Co-Supervisor (Name, Institution and e-mail):
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Scientific Case:
Constraning dark energy models and modified gravity theories with the 3x2pt statistics of the first data release of Euclid

Outline of the Project:
The Euclid satellite mission is safely approaching a keystone moment of its life with the first internal release of data expected for the Fall 2025. The unprecedented quality of the weak lensing data, and the high number density of galaxies with measured photometric redshift will allow to perform a tomographic 3x2pt analysis (i.e., the 2pt correlation of shear–shear, shear–position, and position–position) hence tracing both the universe evolution and the growth of structures. This dataset will represent a goldmine for constraining dark energy models, and discriminate among rival theories of gravity (either GR or modified ones). The present project aims at first modeling the observables taking into accoun the most important systematics, and then use the actual DR1 data to investigate the nature of dark energy, and look for signatures of deviations from GR.

Planning of the activities:
Year 1: development and test of observables modeling including the effect of systematics.
Year 2: constraning dark energy models with DR1 Euclid data.
Year 3: constraining modified gravity theories with DR1 Euclid data.

Institution(s) where the research will be carry out:
Dipartimento di Fisica - Sapienza Università di Roma
I.N.A.F. - Osservatorio Astronomico di Roma

2.18 The topology of weak lensing convergence field in Euclid DR1 data - Roberto Maoli

Title The topology of weak lensing convergence field in Euclid DR1 data

Supervisor (Name, Institution and e-mail):
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Co-Supervisor (Name, Institution and e-mail):
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Scientific Case:

Measurement and modelling of topological probes to constrain cosmological models using weak lensing as measured from Euclid DR1 data

Outline of the Project:
Stage IV weak lensing surveys have promised to deliver weak lensing data of such a high quality to make it possible to probe the non Gaussiaity of the convergence field. Topology is one of the way this characteristics can be probed with Minkowski Functionals (MFs), Betti Numbers (BNs), and persistent homology (PH) standing out as most promising probes. Aim of the present project is to develop the theoretical modelling, and the numerical tools to use them on the first release of Euclid data, expected to be delivered internally in Fall 2025 (the public one being one year later). The candidate will have access to the expertise developed by the HOWLS team of the Euclid Collaboration with key members in Rome (both Observatory and Physic Department). The access to the data in advance with respect to the public release will allow to perform this frontier research in a leading position.

Planning of the activities:
Year 1: development of emulators for MFs, BNs, PH including the effect of systematics.
Year 2: Bayesian likelihood analysis of the Euclid DR1 data to constrain dark energy models.
Year 3: development of emulators in the modified gravity framework.

Institution(s) where the research will be carry out:
I.N.A.F. - Osservatorio Astronomico di Roma
Dipartimento di Fisica - Sapienza Università di Roma
Laboratoire d'Astrophysique de Marseille

2.19 Galaxy Clusters Mass inference with X-ray and millimeter band high-resolution observations supported by hydrodynamical simulations - Marco De Petris

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Scientific Case: Clusters of galaxies: unbiased total mass inference is mandatory for accurate cosmological applications.
Outline of the Project: The project focuses on the study of the Intra-Cluster Medium (ICM) diffused inside clusters of galaxies using multiwavelength observational approaches with real and simulated images. Thus, the ultimate goal is to achieve an accurate knowledge of their total mass to make them a powerful cosmological tool. The observations at X-ray and millimeter band, to detect the Sunyaev-Zel'dovich (SZ) effect, allow us to reconstruct, due to their complementarity, the thermodynamics of the intracluster medium, such as pressure, density and temperature, the dynamical state of those objects and then their total mass by applying physical models or Machine Learning techniques. Current high resolution SZ imagers, such as NIKA2 and the forthcoming MISTRAL camera, would integrate XMM-Newton data to accurately map ICM thermodynamics, avoiding the simple simmetric halo shape assumption. The candidate will investigate this topic joining The Three Hundred collaboration to study synthetic clusters, provided by large volume hydrodynamical simulations. He/she will try to validate the best methodology for the reconstruction of the thermodynamics of the ICM, in particular the gas temperature in the case of distant clusters, combining only intensity SZ and X-ray data. The presence of gas turbulence could be more deeply investigated and gas motions explored by the kinetic SZ effect. A more precise hydrostatic mass will be studied with constrained bias by including possible non-thermal pressure components.
Planning of the activities:
Year 1:
- acquire the necessary knowledge to handle large hydrodynamic simulation data; - summarize the current cluster mass estimates, with related uncertainties and biases; - recover ICM temperature distribution from tSZ and X-ray, without spectroscopy, after method validation with synthetic clusters; - periodically report activities during collaboration meetings and/or seminars and/or conferences;
Year 2:
- map ICM turbulence from Compton parameter, gas density and temperature maps and ICM motions by kSZ; - study the dynamical state by different indicators; - periodically report activities during collaboration meetings and/or seminars and/or conferences;
Year 3:
- estimate cluster total mass with hydrostatic equilibrium assumption and/or Machine Learning models; - periodically report activities during collaboration meetings and/or seminars and/or conferences; - present the results in publications and write the Thesis
Institution(s) where the research will be carry out:
Sapienza University of Rome and Universidad Autonoma de Madrid

2.20 Cosmic Tensions - Alessandro Melchiorri

Supervisor (Name, Institution and e-mail):
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Co-Supervisors (Name, Institution and e-mail):
Scientific Case:
The standard ΛCDM model has been remarkably successful in describing the evolution of the Universe. However, growing observational tensions suggest it may be incomplete. In particular, the discrepancy between early-Universe (e.g., CMB) and late-Universe (e.g., supernovae, galaxy surveys) measurements of the Hubble constant (H_0) points to possible new physics beyond ΛCDM. This project aims to explore whether these tensions arise from unknown systematics or represent signatures of new phenomena such as early dark energy, modified gravity, or novel neutrino physics. Addressing these issues is essential to test the foundations of modern cosmology and guide the interpretation of next-generation surveys.
Outline of the Project:
Recent advances in observational cosmology have led to high-precision measurements of key cosmological parameters. However, persistent discrepancies—known as cosmological tensions—have emerged between early- and late-Universe observations. The most notable among these are the Hubble tension and the S_8 tension, which challenge the standard ΛCDM model. This PhD project will systematically study the origin, implications, and possible resolutions of these tensions. The student will begin by analyzing current datasets including Planck, ACT, SPT, DESI, KiDS, SH0ES, and others. Emphasis will be placed on understanding potential systematics versus new physics.
Planning of the activities:
Year 1 will focus on laying the groundwork for the project. This includes a thorough review of the existing literature to identify open questions and define the specific scope of the research. During this time, the necessary analytical and computational tools will be developed or adapted. Preliminary work will begin, such as early-stage simulations or data analysis, depending on the nature of the project. Initial findings will be shared at workshops or internal meetings to gather feedback and refine the approach.
Year 2 will be dedicated to the core development of the research. Building on the tools and insights gained during the first year, the focus will shift to the systematic analysis of the problem. This may involve running extended simulations, comparing theoretical predictions with data, or developing new models. Collaborations with other researchers or groups will be strengthened to validate and expand the work. The results obtained will be presented at national and international conferences, and the first major publication will be submitted for peer review.
Year 3 will concentrate on finalizing and consolidating the research. The most significant results will be refined and prepared for publication in high-impact journals. Broader implications of the findings will be explored, including possible extensions or applications. The work will be presented at conferences and seminars to maximize dissemination. If relevant, a final report or thesis will be completed, outlining the achievements of the project and potential directions for future research.
Institution(s) where the research will be carried out:
Mainly at the University of Rome Sapienza. Collaborations with other European institutions will be included.

2.21 Future Constraints from Measurements of CMB Polarization - Alessandro Melchiorri

Supervisor (Name, Institution and e-mail):
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Co-Supervisors (Name, Institution and e-mail):
Scientific Case:
The polarization of the Cosmic Microwave Background (CMB) encodes an enormous amount of information about the early Universe. While temperature anisotropies have already been measured with high precision, polarization measurementsÑespecially on large and intermediate angular scalesÑare still improving rapidly. High-sensitivity polarization data can shed light on crucial questions in cosmology, such as the sum of neutrino masses, the number of relativistic degrees of freedom, the nature of inflation, and the presence of primordial gravitational waves. Future ground-based experiments (such as Simons Observatory and CMB-S4) and space missions (such as LiteBIRD) are expected to significantly reduce the uncertainties on cosmological parameters. This project aims to forecast and analyze how these upcoming polarization datasets can improve our understanding of fundamental physics.
Outline of the Project:
This PhD project will focus on the theoretical and computational study of constraints on cosmological parameters using future CMB polarization data. The student will start by performing a comprehensive analysis of current datasets, such as Planck and ACT, to build a baseline. Using this as a starting point, they will employ Markov Chain Monte Carlo (MCMC) and Fisher matrix techniques to simulate future measurements and assess their potential for discovery. Special emphasis will be placed on investigating the impact of polarization on parameters such as the tensor-to-scalar ratio r, the effective number of neutrino species $N_{\rm eff}$, the total neutrino mass $\sum m_\nu$, and possible deviations from standard recombination or reionization scenarios. The work will also include an evaluation of systematic effects and foreground contamination, crucial to ensure reliable parameter estimation. The results will provide a roadmap for interpreting the next generation of CMB data and for planning complementary observations.
Planning of the activities:
Year 1 will be dedicated to building the theoretical background and familiarizing with the tools necessary for data analysis and simulation. The student will replicate standard results from current datasets to validate the analysis pipeline and gain hands-on experience with codes such as `CLASS`, `CAMB`, and `MontePython`. Initial forecasts using Fisher matrix methods will be carried out to explore the sensitivity of future missions to various cosmological parameters.
Year 2 will focus on a detailed simulation of future experiments, using realistic noise and beam models from projects like Simons Observatory, LiteBIRD, and CMB-S4. The student will perform full MCMC analyses to study degeneracies among parameters, test extensions to the standard model, and incorporate possible astrophysical foregrounds such as polarized dust and synchrotron emission. Interaction with international collaborations and potential research stays abroad may take place during this phase.
Year 3 will involve refining the simulations, producing final forecasts, and preparing the results for publication. The student will explore how combining CMB polarization with other observables (e.g., BAO, lensing, large-scale structure) can break degeneracies and enhance parameter constraints. The most promising theoretical models will be tested against simulated data, and the broader implications for particle physics and early-Universe cosmology will be investigated. A final thesis will be written, summarizing the contributions and suggesting future research directions.
Institution(s) where the research will be carried out:
Mainly at the University of Rome Sapienza, with potential collaborations and visits to European and international institutions involved in CMB experimental efforts.

2.22 Characterisation of the atmospheres of extrasolar planets with the Ariel space mission - Enzo Pascale

Supervisor (Name, Institution and e-mail):
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Co-Supervisors (Name, Institution and e-mail):
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Scientific Case: Planets orbiting stars other than our Sun, known as exoplanets, have been detected in large numbers through dedicated surveys conducted by ground-based telescopes and space observatories. Despite this achievement, their atmospheric properties remain largely unknown. To address this gap, the Ariel space mission has been selected as the fourth medium-class mission in ESA's Cosmic Vision program, with a planned launch in 2029 (http://arielmission.space). Ariel aims to conduct the first large-scale spectroscopic survey of exoplanet atmospheres, significantly advancing our understanding of planetary diversity in the Galaxy.
Outline of the Project: The successful candidate will join the Ariel mission consortium, which is responsible for the design and provision of the Ariel science payload. As part of this collaboration, the candidate will contribute to optimizing the mission's scientific objectives, particularly in the spectroscopic characterization of approximately 1000 exoplanet atmospheres across visible and infrared wavelengths. The primary goal is to obtain statistically representative measurements of their chemical composition and thermal structures. The candidate will have the opportunity to work on optimizing observational strategies, refining data analysis techniques, and improving atmospheric retrieval methods to maximize the mission's scientific output.
Planning of the activities:
As a member of the Ariel consortium, the PhD student will work under the guidance of the Ariel Mission Scientist and Ariel Telescope Scientist, taking an active role in the international collaboration. Depending on their research interests and expertise, the candidate may choose to focus on one or more of the following areas: optimizing the instrument's observational strategy, evaluating science performance and the accuracy of retrieved atmospheric parameters, developing data reduction and science analysis pipelines, or characterizing instrument and astrophysical systematics. The specific project topics will be tailored to the candidate's personal interests and scientific curiosity, ensuring a fulfilling and engaging research experience.
The project also offers opportunities for travel to meet collaborators, participate in workshops, conferences, and attend post-graduate schools, contributing to the candidate's professional development.
Institution(s) where the research will be carry out: Department of Physics, Sapienza University of Rome

2.23 Search for continuous and long transient gravitational wave signals - Paola Leaci

Supervisor (Name, Institution and e-mail):
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Co-Supervisors (Name, Institution and e-mail):
Pia Astone (INFN), Cristiano Palomba (INFN), Marco Serra (INFN)
Scientific Case: Continuous and long transient gravitational waves (GWs) are possibly emitted by asymmetric spinning neutron stars (either isolated or in binary systems), primordial black holes or dark matter particles. These sources are among the most interesting targets of the Advanced LIGO-Virgo detectors. No signals of this kind have been detected yet, although stringent upper limits have been placed.
Outline of the Project: The LIGO-Virgo-KAGRA (LVK) Collaboration is currently taking data for the fourth observing run, and the analysis of this data could open new opportunities for the first detection of continuous or long transient signals. Several research projects are available on these topics.
Planning of the activities:
The PhD fellow will be involved in the development of advanced data analysis techniques, ranging from matched filtering, to semi-coherent time-frequency methods, image processing and machine learning. The PhD fellow will work with real GW data and become a member of both the Virgo and Einstein Telescope Collaborations.
Institution(s) where the research will be carried out: Sapienza University and LVK laboratory sites and institutions.

2.24 Bridging infinite-duration Continuous and Stochastic background gravitational-wave searches - Paola Leaci

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Co-Supervisors (Name, Institution and e-mail):
Pia Astone (INFN)
Scientific Case: Continuous gravitational waves (CWs) from asymmetric spinning neutron stars, both isolated and in binary systems, are among the most interesting targets of the Advanced LIGO-Virgo detectors. To date no CW signal has been detected yet, although stringent upper limits have been placed on the CW strain amplitude. The search for such class of signals is, however, quite difficult due to their expected weakness, and can be very computationally expensive when the source parameters are not known or not well constrained. The stochastic background of gravitational waves (SGWB), on the other hand, is being searched over using cross-correlation techniques, and can be generated by the superposition of a wide variety of independent and/or unresolved both astrophysical and cosmological sources, or persistent gravitational waves in specific directions. Recent investigations have shown that stochastic directional searches have the ability to detect CWs, with less sensitivity than CWs searches, but with small computing requirements. Hence, it is timely to establish the basis for a common approach consisting of using SGWB algorithms to quickly identify CW signals, which will be then properly followed up with ad hoc CW pipelines, analyzing the most recent observational advanced LIGO-Virgo-KAGRA data set.
Outline of the Project: So far, the CW and SGWB groups have been working independently, but due to the high potential of detecting CWs with the upcoming sensitivity improvement that can be achieved with the advanced LIGO-Virgo detectors, it has become timely to establish the basis for a common project consisting of using SGWB algorithms to quickly identify CW signals, which will be then properly followed up with ad hoc CW pipelines.
Planning of the activities:
In a first stage, the student will become familiar with both the data-analysis tools and the scientific case. Subsequently, they will test existing code through Monte-Carlo software simulations. This will set up the grounds for an efficient joint analysis that uses the fast and consolidated SGWB cross-correlation algorithm to quickly identify CW signals, which can then be properly followed up with ad hoc CW pipelines. At this point, the whole pipeline will be ready to run on the latest LIGO-Virgo-Kagra O4 run, which is currently still in data taking."
Institution(s) where the research will be carried out: Sapienza University and LVK laboratory sites and institutions.

2.25 Real-time searches for high energy neutrinos with KM3NeT/ARCA - Silvia Celli

Supervisor (Name, Institution and e-mail):
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Co-Supervisors (Name, Institution and e-mail):
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Scientific Case: KM3NeT is a growing infrastructure of deep-sea neutrino telescopes located in the Mediterranean Sea, devoted to fundamental physics studies as well as to the exploration of cosmic neutrinos. These detectors have a wide field of view and high duty cycle, making them extremely suitable to monitor the occurrence of extreme non-thermal phenomena in the Universe. Particularly, the geometry of the KM3NeT/ARCA detector is ideal for the detection of high-energy events, allowing for the investigation of the origin of the diffuse astrophysical neutrino flux, observed since a decade but whose origin still today remains a mystery. The analysis of real-time neutrino data is of paramount importance in the context of the identification of transient and variable sources, whose high-energy emission is limited to a short temporal window (few seconds or less).
Outline of the Project: In this context, the Rome group has been developing since many years the ARCA online alert system, providing a fast reconstruction of the energy and direction of the events interacting within and around the detector, as well as their classification as signal or background. Multi-messenger searches are extremely promising, in that the observation of neutrinos coincident with a given population of sources allows to constrain the fraction of accelerated protons, and hence possible connections with Ultra-High Energy Cosmic Rays (UHECRs), the most energetic particles ever observed.
Planning of the activities:
The student will characterize promising neutrino sources within a variety of emission models, including Gamma-Ray Bursts, Gravitational Wave sources, and Active Galactic Nuclei. Moreover, within the context of the online alert system of ARCA, they will implement dedicated algorithms for the identification of their possible neutrino emission, e.g. through dedicated real-time catalog source monitoring. This activity will allow the student to handle both phenomenological models and data, participating to the vibrant activities of the online group of KM3NeT, possibly being author of public alerts that are released in case of significant detections.
Institution(s) where the research will be carry out: Physics Department of Sapienza University of Rome

2.26 Investigating the origin of the highest energy neutrino ever detected - Silvia Celli

Supervisor (Name, Institution and e-mail):
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Co-Supervisors (Name, Institution and e-mail):
Massimo Mastrodicasa, Massimo.Mastrodicasa@uniroma1.it; Sapienza University of Rome
Scientific Case: The KM3NeT/ARCA detector has recently achieved a milestone in neutrino astronomy, namely the observation of the highest energy neutrino ever measured, KM3-230213A, at 220 PeV. This remarkably discovery opens the window to an unexplored domain with neutrinos, far beyond the reach of current colliders. While several extra-galactic accelerators are known to be located in the uncertainty region of KM3-230213A, no direct association could be identified, and the origin of this particle remains to date unknown. Alternatively, this particle could have been produced by the interaction of an ultra-high-energy cosmic-ray (UHECR) with the background radiation fields permeating the Universe, during its propagation towards Earth, in what is known as the cosmogenic hypothesis.
Outline of the Project: Cosmogenic neutrinos have so far eluded experimental confirmation; however their existence was long ago theorized as guaranteed by the simultaneous presence of UHECRs and radiation fields, e.g. the Cosmic Microwave Background (CMB) and the Extragalactic Background Light (EBL). KM3-230213A might hence constitute the first detection of this long-searched for component in the cosmic neutrino flux. The project will be devoted to investigating such a scenario in a twofold approach, involving both simulations of UHECR photohadronic interactions and analysis of a novel KM3NeT data sample.
Planning of the activities:
The student will work with public codes simulating the propagation of UHECRs through the Universe, exploiting the impact of their mass composition on the expected neutrino flux as well as of different EBL models. The results of these simulations will be adopted as input for an optimized search of cosmogenic neutrinos in the KM3NeT dataset, taking advantage of the entire exposure accumulated so far.
Institution(s) where the research will be carry out: Physics Department of Sapienza University of Rome

2.27 Multi-messenger search for core collapse supernovae with KM3NeT- Irene Di Palma

Supervisor (Name, Institution and e-mail):
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Co-Supervisors (Name, Institution and e-mail):
Massimo Mastrodicasa, Massimo.Mastrodicasa@uniroma1.it; Sapienza University of Rome
Scientific Case: Core collapse supernovae (CCSN) are among the most energetic explosions in the modern Universe and one of the long-standing riddles of stellar astrophysics. According to the standard paradigm, the energy transfer by the intense neutrino flux can be the decisive agents for powering the supernova outburst. We expect the next generation of neutrino telescopes (KM3NeT, Icecube-Gen2, HyperKamiokande) to be able to discriminate the CCSN signal from the noise with high accuracy. The collapse of the iron core of a massive star is expected to produce also gravitational waves in addition to neutrinos. While neutrinos carry information about the mode amplitude in the outer region of the core, gravitational waves probe deeper in.
Outline of the Project: A new analysis concept has been recently developed to enhance the detection efficiency of CCSN signals. In fact, it is necessary to consider a multi-messenger method that takes advantage of the information coming from both the neutrino and gravitational wave signal from detectors like Advanced LIGO, Advanced Virgo and KAGRA.
Planning of the activities:
The student will review the developed analysis using neutrino information. Then, he/she will estimate the detection prospects of the current and next generation detectors both in gravitational waves and neutrinos. The student will also exploit the complementary information coming from the different probes to implement a dedicated algorithm. Year 1: During the first year of activity, the student will first study the known astrophysical discoveries in the gravitational wave catalogues and in neutrinos astronomy in the multimessenger framework to understand the possible joint signals that can be detected. The aim is to build a theoretical astrophysical model for the emission mechanisms of different probes.
Year 2: In the second year the student will develop and implement an algorithm to enhance the detection efficiency of common signals from sources like CCSN.
Year 3: During the third year, there will be the application of the implemented algorithm to the real detector data and to simulated data for the discovery of neutrinos and gravitational waves in the contest of current and next generation detectors.

Institution(s) where the research will be carry out: Physics Department of Sapienza University of Rome

2.28 Comprehensive Observations of Supernovae via Multimessenger Investigations - Irene Di Palma

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Co-Supervisors (Name, Institution and e-mail):
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Scientific Case: Supernovae are among the most interesting multi-messenger sources in the universe, since the entire process can produce electromagnetic, neutrino and gravitational waves. The information provided by the different signals are complementary and a complete picture of the astrophysical event could be provided only through a combined analysis. However, the detection horizon for the various instruments of these messengers can be very different. In particular, gravitational waves from supernovae have not been detected yet. A joint analysis combining information from all the messengers could enhance the confidence for a supernova detection.
Outline of the Project: This thesis project wants to investigate the Supernova discovery potential of a network of different detectors, gravitational waves, neutrinos and electromagnetic telescopes.
Planning of the activities:
The student will study the literature regarding the supernova detection using a multimessenger approach, exploiting the strengths and weaknesses of each method. Then, after the examination of the emission processes of electromagnetic, neutrino and gravitational waves, she/he will first estimate the detection prospects of the new generation of detectors (gravitational waves, neutrino and electromagnetic). Then the student will explore the possibility to exploit common information and correlations from different messengers to perform a joint analysis. The student will take advantage of the expertise of co-supervisors, each one for any messenger. The project will end with a workflow/algorithm for a joint analysis of Supernova source.
Institution(s) where the research will be carry out: Physics Department of Sapienza University of Rome

2.29 Cryogenic payload developments for ET - : Ettore Majorana

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Co-Supervisors (Name, Institution and e-mail):
Paola Puppo, INFN, paola.puppo@roma1.infn.it
Scientific Case: Low frequency sensitivity of Einstein Telescope (ET-LF) is an unprecedented target in GW research concerning cosmology and implies cryogenics implementation to enhance cosmological results. The realisation of payloads and cryostats for the 3rd generation (3D) detectors and related prototyping is the theme of this research. To this purpose, an EC granted project, driven by INFN, is being carried on in the Rome physics department at the ARC-ETCRYO lab. Viable solutions, identified though specific prototyping, will be the core activity for the next 3-5 years. The concept being based upon two main concepts: 1) the seismic isolation system performance foreseen for ET should not be spoiled by the mechanical interface of cryogenic system at the level of the payload and 2) the mechanical dissipation of the cold payload should not exceed the one achieved with a room-temperature system. 3) advanced material solutions, based upon Sapphire and Silicon, are being developed through worldwide exchanges in the context of ET collaboration.
Outline of the Project: Design of the mock prototyping to be tested in Rome and active collaboration on the main themes dealt by the ET Instrument Science Board (ISB) Payload and Cryogenics divisions. In this context a close collaboration with KAGRA (Kamioka-KEK-NAOJ; Japan), KIT (Karlsruhe; Germany) and Kelvin Inst. (Glasgow, GB) is already active. The PhD student will be directly involved and expected to play a key role in this vibrant context. A long-timed experience was matured in Rome concerning thermal noise modelling and the experimental developments to design suitable solutions for the cryogenic payloads must be conducted in according to that. The highest internationalisation context is expected, and stages abroad are foreseen.
Planning of the activities:
During the first two years major activity will be focused on designing the crucial tests to delineate and validate solutions, working on materials, sapphire and silicon crystals and mechanical modelling concerning thermal noise (driven by Fluctuation Dissipation Theorem related and FEA). During the third year the finalised solutions will be object of revising towards actual design implementation in the ET design.
Institution(s) where the research will be carry out:
Sapienza and INFN-Roma1

2.30 Virgo payload local controls - Ettore Majorana

Supervisor (Name, Institution and e-mail):
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Co-Supervisors (Name, Institution and e-mail):
To be defined.
Scientific Case: The upgrade and low noise optical lever sensing system of Virgo (OpLev) is a key activity for both Advanced GW detectors and next generation detectors The involved sensors are considered as "the factory of water" for the interferometers. They are in operation h24/d for years and, without them global signals, including the GW detection, would not exist. The system is multipurpose, as it is used during the deployment and integration of payloads, and then for real time pre-alignment the mirrors, and is integrated in the overall global angular control of the mirror set. In perspective, the low frequency noise affecting these devices will be improved and the results of this research will be adopted for both Virgo and ET. Indeed, Virgo represents a unique testbed for improving the system. In synthesis: OpLevs are essential for Virgo, and Virgo operation is essential for ET as it provides GW signals for the network until ET will not be operational. Moreover, any development of local controls system will be reflected on ET implementations.
Outline of the Project: Long stages at the site are foreseen including involvement in the Virgo control room is foreseen. Looking actual data is essential. In parallel, tabletop tests meant crosscheck the performance will be performed. The effects of air turbulence on the in-air path will be studied. Also, basic electronics development concerning low noise Position Sensor Device (PSD) amplifiers and source (SLED) modulation will be object of this crucial activity for the future.
Planning of the activities:
During the first year the student will be trained at the Virgo site, meanwhile the design of specific tests will be gradually performed, and the related hardware components will be purchased. The second year will be dedicated to experimental activity (Rome and Virgo site). During the third year the new system will be tested in Virgo and the results projected towards ET applications.
Institution(s) where the research will be carry out:
Sapienza and INFN Roma1

2.31 Guidance, Navigation, and Control Architecture for the Multi-Wavelength CubeSat Mission SEE for High-Cadence Solar Flare Monitoring - Fabio Curti

Supervisor (Name, Institution and e-mail): Fabio Curti (School of Aerospace Engineering - Sapienza University of Rome, The University of Arizona),email: fcurti@arizona.edu, fabio.curti@uniroma1.it
Co-Supervisors (Name, Institution and e-mail):
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Scientific Case: The Sun cubE onE (SEE) is a 12U CubeSat microsatellite mission in Low Earth Orbit (LEO), designed to operate during solar cycle 25, SEE aims to investigate solar activity and its effects on Sun–Earth interactions and Space Weather through a multi-wavelength observational approach. SEE's primary objective is to monitor solar flares across a wide energy spectrum—from soft X-rays to gamma rays—as well as capture ultraviolet (UV) images of the Sun in the Fraunhofer Mg II doublet at 280 nm. To meet its scientific goals, SEE is equipped with two payloads:
1. A gamma and X-ray instrument
2. A UV imager for Mg II emissions.
The gamma and X-ray instrument will explore flare emissions over a broad photon energy range, spanning from a few keV to several MeV—covering over three decades in energy. Utilizing a combination of silicon photodiodes and silicon photomultiplier (SiPM)-based detectors, it will achieve unprecedented temporal resolution. Notably, the use of SiPM technology—applied for the first time in solar physics—will enable a detection cadence exceeding 10^6 Hz, offering new insights into the rapid dynamics and underlying mechanisms of solar flares. The payload includes two primary detectors to ensure full spectral coverage across the keV to MeV range. Complementing this, the UV telescope will image solar disk activity in the Mg II doublet, enabling studies of both long-term solar variability and rapid flare-associated UV emissions throughout part of the solar cycle.
Outline of the Project:
• To design the complete GNC architecture suited for SEE's scientific requirements.
• To select and size the attitude determination sensors and control actuators.
• To define and simulate attitude maneuvers needed during science operations, calibration, and safe modes.
• To validate pointing accuracy, maneuverability, and system responsiveness.
• To evaluate constraints and requirements: payload field of view (FoV), pointing stability,attitude tracking maneuver agility.
• To define Functional mode (e.g.,operational mode, sun-pointing, maneuvering, idle, safe mode).
Planning of the activities:
Year 1: Sun-pointing strategy: continuous tracking of the Sun for both UV and X-ray instruments; Minimizing jitter and maximizing pointing stability.Targeted slews and flare response: slews to active regions for real-time flare monitoring, agile reorientation without payload disruption.
Year 2: Safe mode and anomaly recovery; Autonomous reconfiguration to stable attitude with low power consumption . Recovery path to operational mode. Develop a high-fidelity spacecraft simulator for closed-loop GNC validation.
Year 3: Simulation environment; Tools such as MATLAB/Simulink, GMAT, or STK.
Test cases:
Nominal science operation:
- Slew maneuvers to flare locations;
- Momentum dumping cycles;
- Transition to safe mode under sensor/actuator failure;
- Pointing accuracy;
- Response time for maneuvers;
- Stability during long-duration observations.
The PhD activities include attending the progress meeting of the project. The study is in collaboration

with the Italian aerospace companies Argotech, Next, Neat and Optec.

Institution(s) where the research will be carry out:

The research will be carried out at the School of Aerospace Engineering (Sapienza University of Rome), at the Department of Systems and Industrial engineering (The University of Arizona, Tucson) and the Solar Physics and Space Weather group at the Department of Physics of (University of Tor Vergata).

2.32 Machine Learning-Driven Position and Orientation Estimation of Lunar Spacecraft via Crater Feature Analysis - Fabio Curti

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Co-Supervisors (Name, Institution and e-mail):
Gilberto Goracci, European Space Agency, email: gilberto.goracci@esa.int
Scientific Case:
Absolute navigation on the Moon is vital—overcoming inertial drift during the orbital, descent, and landing phases enables precise, autonomous position and orientation (pose) estimation. Crater-based visual terrain-relative navigation (TRN) is a promising method to correct this drift using onboard optical sensors and crater databases.Crater features are abundant and uniquely distributed on the lunar surface, making them robust landmarks for localization. Classical methods (e.g., edge detection, template matching) are susceptible to lighting variations and background clutter. Machine Learning (ML), especially CNN-based detectors or Mask R-CNN architectures, can offer greater robustness to variable conditions (illumination, crater scale) and produce more reliable crater detections.
However, ML/crater-based visual pose estimation has primarily been tested on rovers; its full application to a orbiting and descending spacecraft higher speeds, diverse viewpoints, and real-time constraints—remains underexplored. Previous research has shown that matching detected craters to an orbital catalog can yield global positioning accuracy within a few meters and attitude estimation within a few degrees.
This project applies modern ML crater-detection methods to spacecraft pose estimation with high safety and precision requirements. It bridges a critical gap between rover-focused research and orbiting/landing-phase autonomy, with the potential to set new standards for real-time, ML-driven lunar navigation systems. Proven real-time crater detection and pose estimation would directly enable precise and autonomous navigation, supporting future missions such as NASA Artemis.
Outline of the Project:

1. Design and train a machine learning model for robust crater detection under varying lighting and terrain conditions.
2. Develop an algorithm for crater matching to a preloaded lunar crater map/database.
3. Integrate crater-based localization into a pose estimation pipeline (e.g., using an Extended Kalman Filter).
4. Evaluate system performance in simulation and/or using real lunar imagery.

Planning of the Activities:
Year 1:
Select lunar image datasets and crater databases (e.g., LROC, LOLA, Kaguya);
Train initial ML models (e.g., Mask R-CNN, YOLO) for crater detection;
Evaluate detection performance under varying lighting and viewing angles;
Develop a feature-based crater matching algorithm.

Year 2:
Optimize ML models for generalization and onboard suitability (e.g., compression, inference speed);
Integrate detection results with inertial navigation data using Kalman or particle filters;
Enhance robustness to noise, resolution degradation, and occlusions.

Year 3:
Test the complete pipeline on simulated trajectories (using lunar terrain models);
Validate results against known pose data (ground truth or simulated);

Conduct Hardware-in-the-Loop (HIL) testing at the Moon Optical Navigation Simulation Test Environment for Robotics (MONSTER), located at the ARCA Laboratory, School of Aerospace Engineering, Sapienza University of Rome.
The terrain is a high-fidelity replica of the Mare Serenitatis landing site (23°N, 14°E), scaled 1:2000. The 3 m × 4 m terrain model corresponds to 6000 m × 8000 m on the lunar surface. A robotic Cartesian manipulator simulates orbiting or descending phases by moving along the X-Y-Z axes using stepper motors. The robot platform is equipped with a camera for vision-based navigation and a LiDAR sensor for measuring spcecraft distances from the surface.

Institution(s) Where the Research Will Be Carried Out:
The research will be conducted at the School of Aerospace Engineering (Sapienza University of Rome) and the Department of Systems and Industrial Engineering (University of Arizona, Tucson).

3 INAF

3.1 INAF-OAR

Two (2) fellowship are granted to carry out research at INAF-OAR, among the following thesis proposals.
One third fellowship is supported by the ERC project RECAP. See [**?**].

3.1.1 JWST and MOONS@VLT observations of star-forming regions across the Local Group - Katia Biazzo

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Co-Supervisors (Name, Institution and e-mail):
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Scientific Case: The formation of planets is strictly tied to the evolution of protoplanetary disks. Timescales for disk evolution depend on different factors, related to both the properties of the central young stellar object (e.g., star and disk parameters, mass accretion rate) and those of the environmental conditions of the clouds in which the star-disk system forms (e.g., metallicity, density, external intense radiation fields).
Outline of the Project: The thesis aims at investigating the disk evolution and lifetime of young stellar populations in different star-forming regions. To this aim, key parameters related to disk evolution, such as mass accretion rates and mass ejection rates from jets and winds, will be measured for samples placed at different galactocentric distances (from the solar vicinity to the outer Galaxy) and in the Large and Small Magellanic Clouds, to understand how these parameters depends from the environment.
Planning of the activities:
Year 1: The PhD student will be involved in the analysis of optical/near-infrared photometric data acquired with the NIRCam and MIRI instruments on the James Webb Space Telescope (JWST). These datasets will be mainly focused on star-forming regions in the the outer Galaxy and in the Large and Small Magellanic Clouds, so to study young stellar objects with wide ranges of metallicity.
Year 2: In the second year of the project, the student will work on NIRSpec spectroscopic data acquired with JWST on samples of young stellar objects to analyze the accretion and ejection properties in different environmental conditions.
Year 3: During the third year, the student will also work on infrared spectra that will be acquired with the MOONS@VLT instrument in Chile (start of operations: 2026). These observations are in the framework of the MOONS Guaranteed Time Observation (GTO) program for Galactic studies, in which our group is actively involved. The sample of the MOONS GTO comprises observations in star-forming regions spanning different properties (distance, mass, density).
Institution(s) where the research will be carry out:
The PhD student will carry out the work at the INAF Astronomical Observatory of Rome and at the Tor Vergata University. Interactions with collaborators at the European Space Agency (ESA-ESTEC; The Netherlands) and at the Astrophysical Observatory of Arcetri, together with exchange visits, are foreseen.

3.1.2 High order weak lensing statistics from Euclid DR1 to go beyond GR - Vincenzo Cardone

Supervisor (Name, Institution and e-mail):
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Co-Supervisor (Name, Institution and e-mail):
Roberto Maoli, Dipartimento di Fisica - Sapienza Università di Roma, roberto.maoli@roma1.infn.it

Scientific Case:
Going beyond 2nd order summary statistics of weak lensing fields as measured from the first data release of Euclid data with the aim of constraining dark energy models and looking for signatures of modified gravity.

Outline of the Project:
Stage III weak lensing surveys have relied on 2nd order summary statistics (such as the angular power spectrum in harmonic space and the 2pt correlation functions in configuration space) which however only extract the information contained in the Gaussian part of the signal. The increased quantity and quality of the data Stage IV surveys will release make it possible to go to higher order probes which have access to the non Gaussian features of the signal. It is this additional information that allows to strengthen the constraints on the cosmological parameters, and discriminate among dark energy models and modified gravity theories. Aim of this project is to develop theoretical, and computational tools to go from measurement to constraints. To this aim, the candidate will have access to the simulations developed within the Euclid Collaboration to test theoretical models of high order probes (such as 3pt correlation function, peaks count, and topological indicators), and to create accurate emulators to take into account also observational systematics. These tools will then be used on the actual data that Euclid will make accessible to the collaboration members one year before the public release. All this work will be carried out in close collaboration with the Euclid HOWLS Key Project members so that part of the project will be executed at the Laboratoire d'Astrophysique de Marseille where collaborators of the Rome team are. The candidate will therefore have the opportunity to perform frontier research at exactly the right moment when forecasts will be replaced by actual constraints.

Planning of the activities:
Year 1: Development of theoretical models, and test against simulations;
Year 2: Refinement of models, and development of emulators;
Year 3: Fit of actual DR1 Euclid data to constrain cosmological models.

Institution(s) where the research will be carry out:
INAF - Osservatorio Astronomico di Roma
Dipartimento di Fisica - Sapienza Università di Roma
Laboratoire d'Astrophysique de Marseille

3.1.3 Unveiling the physics of jets in X-ray binaries with the MeerKAT SKA precursor - Piergiorgio Casella

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Co-Supervisors (Name, Institution and e-mail):
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Giampaolo Pisano, Sapienza University of Rome, giampiero.pisano@uniroma1.it
Scientific Case: Black-hole X-ray binaries (BHXBs) are binary systems in which a stellar-mass black hole accretes matter from a low-mass companion star. These systems are the best laboratories for studying extreme gravitational fields. In recent years, it has been established that the dissipation of gravitational energy in the accretion process of BHXBs results in both radiation and collimated jets, carrying a large amount of kinetic energy, just as in active galactic nuclei (AGN). However, in AGN, because of the long dynamic timescales, we are limited in performing population statistics studies to understand the evolution of our observations. This is at variance with BHXBs, where the accretion rate varies on timescales accessible to our studies, ranging from years to fractions of a second. One of the most interesting aspects of these sources is the production of discrete jet ejecta that propagate at apparent superluminal speeds far from the central BH. Covering the full trajectory of these jets allows us to model their dynamics with great accuracy and hence to measure their physical properties, while, at the same time, effectively using them as invaluable probes of the surrounding environment. While these jets are historically difficult to detect, the MeerKAT radio-interferometer (a precursor of the Square Kilometre Array, SKA) is now revolutionizing the field with its exceptional sensitivity at GHz frequencies.
Outline of the Project: The project will focus on the reduction and analysis of MeerKAT BHXB data taken as part of the X-KAT collaboration, including new and archival observations with the presence of discrete jet ejecta. The full propagation at large (parsec) scales will be tracked and then modelled with blast-wave dynamical models derived from the physics of gamma-ray bursts. These models will be improved by including the time evolution of the jet emission, which can give information on the jet magnetic field strength and the particle acceleration process. Moreover, by exploring the radio polarization properties of the jet radiation throughout their propagation, the student will be able to map the evolution of the jet structure, shock front and magnetic field, and then probe its interaction with the surrounding medium with unprecedented detail.
The PhD student will have the opportunity to join the MeerKAT X-KAT collaboration and the SKAO science working groups for Transients, to participate in schools for radio astronomy in Europe and Italy, and to carry out a period of activity in top European institutions such as the University of Oxford and CEA Saclay near Paris for studies of BHXBs jet physics.
Planning of the activities:
Year 1: Data reduction and analysis of BHXBs monitored regularly by MeerKAT. Identification of transient jets, measuring their path in the sky as they travel away from the launching BH.
Year 2: Extraction of the polarimetric properties of the radio emission from the detected transient jets.
Year 3: Expansion of existing dynamical model, with the inclusion of radiative transfer, including polarised emission calculation. Application to the best data sets.
Institution(s) where the research will be carry out:
INAF-Osservatorio Astronomico di Roma, Monteporzio Catone, with foreseen (3-4 month) visits at the University of Oxford (prof. Rob Fender) and the Université Paris-Cité / CEA-Saclay (prof. Stéphane Corbel)

3.1.4 Intra Cluster Light from Euclid DR1 data as a probe of dark matter haloes - Paola Dimauro

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Co-Supervisors (Name, Institution and e-mail):
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Scientific Case:

Constraining dark matter halo of cluster galaxies and its evolution with redshift by modeling the Intra Cluster Light measured from Euclid DR1 data

Outline of the Project:
The IntraCluster Light (ICL) is a probe of the underlying dark matter profile of the galaxy cluster being related to the stripping of stars due to the tidal effect of the cluster as a whole on its smallest member galaxies. Its formation process, correlation with cluster properties, and evolution with redshift allows it to constrain galaxy formation scenarios, and trace the radial profile of cluster halos along the cosmic epochs. The candidate will explore both observational aspects related to its measurement, and constrain theoretical models by comparing models and data. To this end, he will have access to the analysis pipeline developed by our team as part of our activities within the Euclid Collaboration. The project will be at the right time given that the first internal release of Euclid data will take place at the same exact moment the candidate will start the PhD project.

Planning of the activities:
Year 1: Testing different methods for the measurement of ICL;
Year 2: Measurement of the ICL profile and properties from an optimally selected sample of galaxy clusters;
Year 3: comparison of formation models, and dark matter haloes profile with ICL measurements, and study of the evolution with redshift of the results.

Institution(s) where the research will be carry out:
INAF - Osservatorio Astronomico di Roma
Dipartimento di Fisica - Sapienza Università di Roma

3.1.5 GRBs as probes: investigating the high redshift Universe with the most energetics phenomena - Andrea Melandri

Supervisor (Name, Institution and e-mail):
Andrea Melandri, Silvia Piranomonte (INAF-Osservatorio Astronomico di Roma)
Co-Supervisors (Name, Institution and e-mail):
Gianpaolo Pisano (Università Sapienza, Roma)
Scientific Case: One of the primary objectives in modern astrophysics is to enhance our comprehension of the chemical enrichment and evolution of the Universe at high redshifts. To achieve this, extensive surveys have been conducted to detect distant galaxies based on their drop-out characteristics, either through wide field surveys of bright quasars or deep field analyses. Another valuable perspective on the remote Universe comes from the identification of high-redshift gamma-ray bursts (GRBs). GRBs offer several advantages over other investigative methods: (i) they are observed at greater redshifts, (ii) they are unaffected by galaxy brightness, (iii) they are not subject to the biases typically present in optical and/or near-infrared surveys, and (iv) they predominantly occur in average cosmic regions. High-redshift GRBs can provide crucial insights into the early stages of structure formation and the properties of the galaxies in which they occur, offering fundamental and sometimes exclusive information.
Outline of the Project: This thesis project aims to investigate the properties of the population of GRBs detected at high-redshift. To date, less than 15 events have been detected (and spectroscopically confirmed) at a redshift larger than 5. A detailed analysis of this sample will give us additional information about the high redshift Universe with respect to other distance markers.
Planning of the activities:
Year 1: The selected candidate will be responsible for gathering and conducting a comprehensive analysis of all the existing data pertaining to the chosen sample of high-redshift GRBs
Year 2: The project will also encompass the analysis of data for potential new events that may come to light in the coming months or years
Year 3: Finally, the project will also benefit from secured access to multiple observatories in the upcoming semesters, which will enable the observation of potential new events.
Institution(s) where the research will be carry out:
INAF-Osservatorio Astronomico di Roma, Dipartimento di Fisica Università Sapienza, Roma

3.1.6 MHD processes in the lower solar atmosphere - Mariarita Murabito

Supervisor (Name, Institution and e-mail):
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Ermolli Ilaria, INAF - OAR, ilaria.ermolli@inaf.it
Co-Supervisors (Name, Institution and e-mail):
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Scientific Case:
Observation and analysis of the MHD processes occurring in the solar atmosphere are fundamental to understanding the dynamic behavior of the Sun's atmosphere, where magnetic fields play a crucial role in shaping plasma's motion and evolution. Various MHD processes involving magnetic reconnection, wave propagation, and turbulence are responsible for the dynamic features observed in the Sun's atmosphere, including energetic flares and coronal mass ejections (CMEs). Advancing on the understanding these processes is essential for the knowledge of the solar magnetic activity, as well as for improved forecasting of space weather events. Several existing (DKIST, SST, GREGOR, Solar Orbiter, Solar Dynamic Observatory, IRIS) and new solar facilities planned for operations in 2026-2028 (IBIS2.0, MUSE and Solar-C) will allow to observe and study these processes to understand the origin and evolution of instabilities in the solar atmosphere, as well as the mechanisms heating the solar corona and driving the solar wind.
Outline of the Project:
The project aims to investigate the interplay between magnetic fields, plasma dynamics, and instabilities in the solar atmosphere on state-of-the-art observations of the Sun's lower atmosphere, to derive new deeper insights into the fundamental mechanisms driving solar eruptive and impulsive events, such as flares and CME. In addition the project aims to contribute to the design of new observations for the study of the MHD processes in the Sun's atmosphere with existing and upcoming solar facilities.
The activities will focus on the analysis of state-of-the-art high-resolution spectro-polarimetric observations, including both new and archival data from several ground-based facilities (DKIST, SST, GREGOR, IBIS2.0). Special focus will be given to data of the lower solar atmosphere, where the footpoints of strong magnetic flux bundles reside and MHD processes are generated. Physical properties of the solar plasma in these regions will be derived using data inversion techniques, together with specific tools for the identification of MHD processes (such as phase-lag analysis and power maps). The upper solar atmosphere will be investigated using UV spectra and imaging from current and future missions (IRIS, Solar Orbiter, and Solar Dynamic Observatory, MUSE, Solar-C) and from numerical simulations.
Planning of the activities:
Year 1: Identification of case studies that can exploit coordinated observations (either publicly available or available to the supervisors) of the solar atmosphere under different plasma conditions (e.g., solar flares, evolving magnetic regions, quiet plage regions) obtained with ground- and space-based facilities. Study of inversion techniques and solar instrumentation. Request for and execution of new coordinated observations with state-of-the-art telescopes.
Year 2: Study of the MHD processes observed in the Sun's atmosphere, with focus on the energy and mass transport from the lower (photosphere, chromosphere) to the upper (transition region, corona) solar atmosphere, and identification of plasma properties in the studied processes. Processing and analysis of the new observations performed in Year 1.
Year 3: Further analysis of the new observations performed in Year 1 to improve the understanding of the origin and evolution of solar plasma instabilties. Definition of best strategies for new observations with upcoming telescopes (IBIS2.0, MUSE, Solar-C).
Institution(s) where the research will be carry out:
INAF - Osservatorio Astronomico di Roma; Universita Tor Vergata; foreseen visits at Istituto de Astrofisica de Canarias (Spain) and Lockheed Martin's Solar and Astrophysics Laboratory (USA)

3.1.7 Searching for population III stars in the environment of massive, merger galaxies at the epoch of reionization - Laura Pentericci

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(Adriano Fontana, INAF Osservatorio Astronomico di Roma, email: adriano.fontana@inaf.it)

Co-Supervisors (Name, Institution and e-mail):
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Antonello Calabrò, INAF Osservatorio Astronomico di Roma,
email: antonello.calabro@inaf.it

Scientific Case: Searching for population III stars in the environment of massive, merger galaxies at the epoch of reionization

Outline of the Project: The project consists of analyzing a sample of galaxies at redshifts between 7 and 10 (in the reionization epoch), observed by JWST using integral field spectroscopy (NIRSpec-IFU). Part of the data is already publicly available, while another part (10 galaxies) is proprietary and comes from a recently accepted program. The goal will be to study the environment of the observed galaxies and search for star-forming clusters dominated by Population III stars, which are metal-free and very massive stars, similar to the first stars formed in the Universe. Taking advantage of the interacting state of most of the sample, a detailed study will also be conducted on how interactions and mergers influence the physical properties of galaxies in their early evolutionary stages, and the activity of the central supermassive black hole (SMBH). Specifically, the spatial distribution of dust, star formation rate (SFR), and metallicity will be analyzed to understand how morphological transformation occurs, how galaxies grow, and how AGN and the host galaxy influence each other. The final goal will be to study the gas kinematics to test the effects of stellar and AGN feedback, and to predict the ultimate fate of these systems. In the entire project, the student will compare the observed properties of mergers and Pop III clusters with the cosmological simulations made by the extragalactic group in the University of 'Sapienza'.

Planning of the activities:
Year 1: Study of the reduction pipeline and analysis of publicly available IFU spectroscopic data from JWST. Analysis of additional data (10 galaxies) from the new JWST accepted program. The first goal of the study will be the search for Population III star clusters in the environment of the observed galaxies, and the comparison with predictions from theoretical models.
Year 2: Study of the effects of interactions and mergers on the physical properties of galaxies at redshifts above 7. The student will produce 2D maps of stellar mass, SFR, dust attenuation, and metallicity of the observed sample, and interpret the results.
Year 3: Identification of stellar clumps in the galaxies studied before, and a more detailed analysis of their properties. The final part of the project will be dedicated to defining the best strategies for identifying Pop III clumps in the early Universe with upcoming telescopes, such as ELT.

Institution(s) where the research will be carried out:
INAF Osservatorio Astronomico di Roma, and Università Sapienza, Roma

3.1.8 STARLIGHT: Shedding Light on the Formation and Fate of Stellar Remnants in view of Einstein Telescope - Silvia Piranomonte

Supervisors (Name, Institution and e-mail):
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Co-Supervisors (Name, Institution and e-mail):
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Scientific Case: Recently, INAF has been actively involved in developing multi-messenger science for the 3rd generation interferometer Einstein Telescope (ET). In this context, one of the important scientific aspects to be tackled for the forthcoming ET era, is to improve our knowledge of the formation and evolutionary pathways of both single and binary neutron stars (BNS) by providing an up-to-date theoretical framework for the astrophysical characterization of the population of transients that will be detected by ET and associated EM follow-up facilities
Outline of the Project: This thesis project wants to investigate the formation and evolution of BNS systems by means of theoretical models and numerical simulations focusing the attention on the following tasks: 1. studying the pre-supernova evolution of stars that may produce NS after their explosion; 2. investigating the formation of the compact object during the explosion; 3. studying the formation and evolution of BNS.
Planning of the activities:
Year 1: The candidate will be responsible for carrying out a study of the evolution of stars in the mass range 8-25Mo with unprecedented resolution and accuracy using a stellar evolution code that couples an extended nuclear network to the equations of the stellar structure and chemical mixing.
Year 2: Then, using a new HDM code she/he will simulate the explosion of the up-to-date progenitor stars to characterize in detail the population of NSs.
Year 3: Finally, she/he will couple the obtained results to a binary population-synthesis code to study the populations of merging BNSs across cosmic time and their implications on the populations of short GRBs and heavy elements enrichment through r-processes.
Institution(s) where the research will be carry out: INAF Osservatorio Astronomico di Roma

3.1.9 A Universal theoretical framework for black holes and galaxies - Rosa Valiante

Supervisor (Name, Institution and e-mail):
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Co-Supervisors (Name, Institution and e-mail):
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Scientific Case: A Universal theoretical framework for black holes and galaxies: modelling the BH formation, growth and dynamics from the cosmic dawn (z 30) to the present day ($z = 0$).
Black Holes (BHs) play a key role in the process of galaxy evolution, yet the mechanisms regulating their formation, growth and feedback are still poorly understood. The relation between the BHs and their host galaxies, observed at different cosmic epochs, reveals a complex interplay and the role of BH feedback in regulating star formation and galaxy growth is difficult to assess. In addition, the James Webb Space Telescope (JWST) recently revealed previously unexpected features of distant Active Galactic Nuclei (AGN). The detection of ”overmassive” BHs, with a BH-to-stellar mass ratio up to two orders of magnitude larger than that expected from the well-established local scaling relation, and the discovery of a brand new class of objects, dubbed ”Little Red Dots”, peculiar compact red galaxies, presumably hosting obscured accreting BHs possibly representing a transient phase in the galaxy cosmic evolution history, further challenges our understanding of BH growth. On the one hand, the discovery of these peculiar AGN at z¿6 enhance our ability to constraint their origin. On the other hand, reconciling their properties with those of AGN and galaxies observed at lower redshift, down to the present day, is a major issue.
Outline of the Project: Insert text here The goal of the proposed project is to significantly advance in our understanding of the formation and evolution of BHs and galaxies across cosmic times, from the Cosmic Dawn (z 30) to the present day (z=0), suggesting a consistent picture to interpret/predict AGN properties and demographics. The PhD fellow will work mainly with the semi-analytic ”Cosmic Archaeology Tool” (CAT), a state-of-the art model for the formation and evolution of BHs and galaxies. We will extend CAT, so far limited to the first billion years of the cosmic evolution (z¿4), to the local Universe (z=0), investigating the evolutionary connection among the AGN observed by JWST at $z > 10$, luminous quasars at $2 < z < 7$ and the quiescent galaxies at $z = 0$. With this tool we will bridge the gap between local and high-redshift AGN populations exploring their key signatures across cosmic epochs. This study will establish critical benchmarks—new diagnostics and strategies—for future observational campaigns with next-generation electromagnetic facilities (e.g., JWST, Athena, Euclid, AXIS) and gravitational wave detectors (e.g., PTA, LISA, ET).
Planning of the activities:
Year 1: analytic reconstruction of high mass-resolution ($10^5 - 10^6\, M_\odot$) cosmological merger trees for a large sample of ”parent” dark matter halos with Monte Carlo techniques based on the Extended Press-Schechter theory. Comparison with state-of-the art numerical, large-volume, N-body simulations to validate the halo mass function in the high-mass end ($> 10^8\, M_\odot$).
Year 2: Runs of the new version of CAT and analysis of the outcomes. Exploration of the AGN/galaxy mass and luminosity functions, in different spectral bands, at different cosmic epochs. Comparison with observations of single and dual/multiple AGN.
Year 3: detectability studies and predictions for the binary BH merger rates and gravitation al wave (GW) signal in the frequency domain of different GW observatories, like ET, LWGA, LISA and PTA. preparation of a (public) catalogue of GW sources.

Institution(s) where the research will be carry out:
The project will be carried out at INAF-Astronomical Observatory of Rome (Monte Porzio Catone), in close collaboration with Sapienza University of Rome.

3.1.10 Probing the epoch of reionization with high redshift galaxies - Laura Pentericci (ERC funding TBC)

Supervisor (Name, Institution and e-mail):
Laura Pentericci, INAF-OAR, laura.pentericci@inaf.it
Co-Supervisors (Name, Institution and e-mail):
Scientific Case: Probing the epoch of reonization with Lyalpha galaxies within the RECAP project.
Outline of the Project: Within the RECAP synergy grant project, the student will work on different scientific topics related to the epoch of reionization as probed through high redshift galaxies and in particular Lyalpha emitting galaxies. The student will use both JWST spectroscopic surveys which are being carried out (or have just been completed) and also future data from the GTO MOONS survey which will start at the end of 2026, and will thus be available during the third year of the thesis.A very close collaboration with the theory group at MPA Garching is also foreseen since the project will involve extensive comparison between observational results and simulations.
Planning of the activities:
Year 1: Study the visibility of Lyalpha emitters in the fields observed by the CAPERS and RUBIES JWST surveys. Study field to field variations (also including previous results from our group). Search and analyse early ionized regions.
Year 2: Extensive comparison of the results to the simulations provided by the theory group of RECAP. Inferences on the evolution of the neutral hydrogen fraction during reionization.
Year 3: Use data from the first part of the MOONS GTO survey to extend the visibility analysis to large areas. Study the topology of reionization. Compare to large scale simulation from RECAP team.
Institution(s) where the research will be carry out:
Astronomical Observatory of Rome, with foreseen 2x3 months visits at MPA Garching during the second/third year.

3.2 INAF-OAAb (Ossevatorio Astronomico di Abruzzo)

One (1) fellowship is granted for a student to carry out his/her research at INAF-OAAb, among the following thesis proposals.
Research activity will be carried out in the Observatory located in the city of Teramo https://maps.app.goo.gl/4VSuf1w91YLmEsh76.

3.2.1 Compact Stellar Systems with Euclid - Michele Cantiello

Supervisor (Name, Institution, and E-mail):
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Co-Supervisors (Name, Institution, and E-mail):
Oscar Straniero, INAF Oss. Astr. d'Abruzzo (oscar.straniero@inaf.it)

Scientific Case:
The study of extragalactic compact stellar systems—namely globular clusters (GCs) and ultracompact dwarfs (UCDs)—provides a valuable opportunity to constrain the evolutionary history of their host galaxies and, on a broader scale, the surrounding galaxy group or cluster environment.
These stellar systems possess several intrinsic and observational characteristics that make them ideal tools for testing current models of galaxy formation and evolution. They exhibit a narrow range of ages and chemical compositions, with most older than 10 Gyr. Their high luminosity allows them to be observed at significant distances, up to several hundred megaparsecs. Additionally, GCs can number in the thousands around a single galaxy, particularly in the halos of massive brightest cluster galaxies.
The advent of telescopes such as Euclid, JWST, and LSST, which have recently begun or are soon to start observations, has opened an era of unprecedented discoveries. The depth, resolution, and coverage of these instruments will enable the analysis of vast galaxy samples, significantly advancing our understanding of galactic evolution and the complex physical mechanisms—both internal and external—that govern it.
This Ph.D. thesis project aims to leverage the extensive datasets from these missions, both proprietary and accessed through participation in specific consortia, to refine models of galaxy formation and evolution through the study of GCs and UCDs. The selected Ph.D. student will analyze the properties of GC and UCD candidates within observed galaxy systems—including their spatial distribution, colors, and luminosity functions—and use them as fossil tracers of past interaction events between galaxies and their environments.
Outline of the Project:
Preliminary studies of Euclid observations and LSST precursors have shown that GC systems can be analyzed in galaxies up to distances of 100 Mpc, with even larger distances achievable for UCDs. The wide survey area of these experiments makes them ideal for mapping the properties of GC and UCD systems in and around galaxies, galaxy groups, and clusters with unprecedented coverage and uniformity. To complement the extensive but relatively shallow survey data, JWST observations provide an opportunity to study compact stellar systems in exquisite detail for galaxies located well beyond the local Universe.
The student will be introduced to the SPoT research team at the INAF Observatory of Abruzzo, gaining access to data from these and potentially additional observational datasets. They will learn methods to identify extragalactic GCs and UCDs from photometric samples and analyze their spatial and photometric properties. The results of these studies will be placed in the broader context of modern galaxy formation and evolution models to assess their consistency with theoretical predictions.
Planning of the Activities:

- **Year 1:** Introduction to the properties of GCs and UCDs; analysis techniques for identifying and characterizing compact stellar systems; familiarization with Euclid, LSST (precursors), and/or JWST data.

- **Year 2:** Study of GC and UCD systems in the local Universe.

- **Year 3:** Finalization of the study and comparison with model predictions.

Depending on the student's skills, we expect one or more papers to be published in peer-reviewed journals.

Institution(s) where the research will be carried out:

INAF Astronomical Observatory of Abruzzo (Teramo, Italy); Other European Research Institutes and Universities involved in the missions of interest for the project.

3.2.2 Nuclear uncertainties in r-process abundances and kilonova light-curves - Sergio Cristallo

Supervisor (Name, Istitution and e-mail):
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Co-Supervisors (Name, Istitution and e-mail):
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Scientific Case: The rapid neutron-capture process, or r-process, is invoked in order to explain the existence of roughly half of the elements heavier than iron observed in nature. Nuclear network calculations simulating the occurrence of the r-process in different astrophysical scenarios require the knowledge of the properties of thousands of exotic nuclei, most of which nowadays cannot be measured in laboratory. Therefore, nuclear structure calculations are essential to address the quest of the origin of heavy elements in nature.
Outline of the Project: In this thesis, the PhD candidate will employ the nuclear density functional theory and perform large-scale nuclear structure calculations. By estimating nuclear properties such as binding energies and fission rates using mean-field and beyond mean-field approaches, the candidate will assess the impact of nuclear uncertainties in r-process abundances and kilonova light-curves, and provide useful guidance to future experiments at radioactive ion-beam facilities (as the SPES-INFN experiment), exploring the neutron-rich side of the nuclear chart.
Planning of the activities:
The candidate is expected to spend a substantial amount of time visiting the theoretical nuclear physics group in Madrid (Spain), in order to get acquainted with the nuclear structure and nuclear network codes employed in this thesis. Then, nucleosynthesis calculation of the r-process will be performed at INAF-OAAb, under the supervision of researcher belonging to the theoretical stellar evolution and nucleosynthesis group.
Institution(s) where the research will be carry out:
INAF-Osservatorio Astronomico d’Abruzzo (INAF-OAAb)
Universidad Autonoma de Madrid (Spagna)

3.2.3 Kilonovae spectra in the Einstein Telescope era - Sergio Cristallo

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Scientific Case: The production of elements heavier than iron via the rapid neutron capture process has been demonstrated to occur during Neutron Star Mergers. In the next years a pletora of these events is expected to be triggered by the Einstein Telescope interferometer and some of their electromagnetic counterparts (termed kilonovae) will be observed by worldwide facilities. However, a clear identification of heavy element spectral features is a kilonova is still an extremely difficult task and hot debated topic.
Outline of the Project: In this thesis, the PhD candidate will get aqquainted with radiative transfer codes (e.g. TARDIS and POSSIS) to model the UV/optical/NIR spectra of those explosive transients. The computed theoretical spectra will be made available on a dedicated web platform, together with r-process yields and kilonova light-curves.
Planning of the activities:
The candidate will work on the TARDIS code in strict collaboration with researchers belonging to the theoretical stellar evolution and nucleosynthesis group of INAF-OAAb. Moreover, she/he will collaborate with staff members of the Università degli Studi di Ferrara to get familiar with the POSSIS code.
Institution(s) where the research will be carry out:
INAF - Osservatorio Astronomico d'Abruzzo
Universitá degli Studi di Ferrara.

3.2.4 The final destiny of stars that develop a degenerate CO core: from type Ia supernovae to low-mass X-ray binaries - Oscar Straniero

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Scientific Case: After the H and the He burning phases, intermediate-mass stars ($5 < M/M_\odot < 10$) form a compact core, made of a mixture of carbon and oxygen, whose density is large enough that free electrons are partially or fully degenerate. Beside of the relatively small range of stellar masses, these stars are of pivotal importance in understanding several astronomical phenomena, such as various of supernova types, classical and recurrent novae, low-mass X-ray binaries. Those with the smallest mass, never rich the conditions for the carbon burning and, after evolving on the asymptotic giant branch, they lose the envelope enriched with the yields of the internal nucleosynthesis and, later on, become CO white dwarfs. In interactive binaries, a CO WD may accreted material lost by a companion star, giving rise to explosive phenomena, such as cataclysm variables, novae, and type Ia supernovae. However, in more massive stars, the core mass eventually exceeds a critical value (about 1.05 $M_\odot$), so-that a carbon ignition takes place and, due to the degenerate equation of state, it gives rise to a thermonuclear runaway. As a result of this degenerate C burning, the core is enriched in O and Ne. Later on, the star enters a super-AGB phase. The final fate of these stars is not clear. As single stars, they can either attain the Chandrasekhar mass limit during the super-AGB phase or produce a massive ONe WDs. In the former case, they give rise to a so-called electron-capture supernova. On the other hand, a massive WDs that receives mass from a companion in a close binary, may also produce Novae and/or Supernovae, or undergo an accretion-induced core collapse, after which they appear as low-mass X-ray binaries. Finally, stars in the upper portion of the mass range (10-11 $M_\odot$) can ignite Ne and proceed through the advance burning phases, up to the formation of a Fe-rich core. In this case, the stellar evolution end is a classical core-collapse supernova.
Outline of the Project: The objective of this project is to shed light on the possible evolutionary scenarios above described, by combining theoretical predictions and observational constraints. Calculation of theoretical stellar models in the mass range ($5 < M/M_\odot < 10$), both as single objects and in binary systems, will be the main task of the PhD fellow. In particular, we aim to understand:

- **Composition of the core after the C burning and how it can determine the final fate (thermonuclear explosion or accretion-induced core collapse).** Indeed, if an ONe core attaining the Chandrasekhar mass likely will undergo a core-collapse, even a small amount of unburned carbon in the core may trigger a thermonuclear explosion (through a carbon deflagration).
- **The response of the compact accretor to a mass transfer from a companion star filling its Roche lobe.** The heating and the compression produced by the mass accretion onto the surface of a WD can induce violent thermonuclear runaways of the burning shells (H, He and C burning shell), whose result is a limitation, and even a stop, of the net mass accretion. So far, these phenomena have been poorly understood.

Planning of the activities:

- **Year 1:** Comprehension of the state of the art and familiarization with the stellar evolutionary code in both single and binary configurations.
- **Year 2:** Calculations a complete evolutionary sequences of selected stellar models in the intermediate-mass range.
- **Year 3:** Calculation of complete evolutionary sequences of selected binary systems hosting CO or ONe WD.

All the calculations will be carried on with the FuNS evolutionary code, developed and maintained by the proponents. The High-Performance-Computing facilities provided by INAF will be employed. At the end of this PhD program, the fellow should acquire new scientific competences, in the field of theoretical stellar astrophysics, and a skill in computational science and HPC.
Institution(s) where the research will be carried out:
INAF - Osservatorio Astronomico d'Abruzzo.

3.2.5 Machine Learning for sensing, control and post-processing in Adaptive Optics: novel techniques for the next generation of space and ground-based observing facilities - Gianluca Di Rico

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Scientific Case:
Machine Learning applied to Adaptive Optics Systems.
Adaptive Optics (AO) brings together all the technologies that allow removing the images degradation due to wavefront aberrations. Its application ranges from bioscience to optical telecommunication, and in particular in astrophysics, where AO is of paramount importance for the present and future largest ground-based observing facilities, like the Extremely Large Telescopes (ELTs), and recently also for space instrumentation. Its classical approach is based on the usage of one or more wavefront sensors, one or more multi-actuators (deformable mirror, DM) and a real-time computer (RTC) to realize a closed-loop system for the compensation of wavefront distortions.
On the other hand, the use of Machine Learning (ML)in photonics is opening new possibilities for developing innovative and high-performance techniques in wavefront sensing and correction, as well as in the post-processing of astronomical data. In fact, ML is expected to play a key role in advancing mission science and operations in future space facilities, such as the Habitable World Observatory (HWO).

Outline of the Project:
The research activity will focus on studying ML algorithms and Neural Networks (NN) to reconstruct the relationships among measured aberrations, instrumental patterns, scientific images, and incoming wavefronts. This is a key aspect for optimizing control loops, accelerating post-processing operations, and enhancing scientific output. The work will also include collaborative development of prototypes and test benches, the use of dedicated hardware for real-time & cloud computing, laboratory and on-sky verification.
The candidate will have the opportunity to participate in cutting-edge scientific and technological activities within a multidisciplinary and international team of engineers and scientists. The student will acquire expertise in the following items:
- Machine Learning, wavefront sensing, and correction techniques;
- Key challenges and limitations of current AO instrumentation;
- The application of Machine Learning to future AO systems for the ELTs ;
- Hands-on laboratory experience: setting up optical benches and NN training, laboratory and on-sky verification of prototypes.

Planning of the activities:
Year 1: the first year will focus on the study of existing literature and explore the scientific applications of ML and AO technologies to future space and ground-based instrumentation. The main objective will be to identify the most promising ML and AO applications.
Year 2: the second year will be dedicated to further investigating the applications identified in the first year through simulations, theoretical analyses, and models. A subsequent phase will include laboratory activity on test benches and protoypes to validate the proposed innovative solutions.

Year 3: The final year will focus on the completion of laboratory activities, analyzing the acquired data, and consolidating the results. The candidate will then write the Ph.D. thesis, summarizing the findings from the entire research process.

Institution(s) where the research will be carried out:
INAF - Osservatorio Astronomico d'Abruzzo, in collaboration with other INAF institutes and international teams. Visiting and short periods abroad for collaboration activities, on-sky testing campaigns, meetings and conferences are desirable.

3.2.6 Adaptive Optics observations with ORCAS satellites: transformative technologies for unprecedented angular resolution and sensitivity - Dr. Gianluca Di Rico

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Scientific Case:
Adaptive Optics (AO) has led to fundamental advances in our understanding of several astrophysical processes, enabling ground-based astronomical instrumentation to overcome the limitation imposed by the atmospheric turbulence and allowing the largest existing telescopes to provide superior spatial resolution with respect to current space telescopes at VIS/NIR wavelengths. In the last two decades, the INAF scientific and technological community played a decisive role in the development of new AO technologies that pushed the capability to sense and correct the incoming wavefront closer to the diffraction. They have been adopted in the majority of the main international projects for AO instrumentation.
Nevertheless, the full potential of these ground-based observatories is still not completely exploited, while new giant facilities, namely the Extremely Large Telescope (ELTs) are under construction. In fact, despite the use of Laser Guide Stars (LGS) effectively increases the total sky coverage (providing artificial reference stars close to the scientific targets), due to their limited altitude and shape, there are still severe limitations to the nominal performance that ground telescopes could effectively achieve.
Artificial reference sources aboard satellites outside the atmosphere can overcome these limitations, providing the largest ground-based AO facilities with suitable Satellite Guide Stars (SGSs), that are needed to acquire data at the highest resolution, ideally for every scientific target on the sky.
With the aim to achieve these outstanding capabilities, INAF is collaborating with NASA at the ORCAS (Orbiting Configurable Artificial Star) mission in the definition of the science goals and technological requirements for the design of the satellite and new AO instrumentation optimized for this innovative observing technique.
ORCAS will enable new science, providing outstanding quality data with unprecedented angular resolution, superior sensitivity and a unique absolute flux calibration, from the Near Infrared (NIR) up to Visible bands (VIS). Observations will be carried out with large ground facilities as the W.M. Keck and LBT and VLT observatories, and in future with the ELTs. A wide variety of scientific cases can be impacted, including Solar System object, exoplanets, galaxy evolution, black holes, extreme stellar dynamics, general relativity, dynamics of the galactic center, dark matter and dark energy, while also complementing and extending the science of HST, JWST, and Roman, as well as other future missions.
The student will have the opportunity to take part this cutting-edge project, participating to the definition of the ORCAS mission, from the science cases to the small satellite requirements (orbit and payload), from the possible modification of existing AO instrumentation to the design of new innovative instruments to maximize the scientific return.

Outline of the Project:
The PhD student will be part of the INAF/ORCAS research group, which collaborates with NASA and LBT Observatory at the development of the space and ground segment of the ORCAS mission, within the framework of the INAF-ADONI National Lab.

The student will develop skills in:
- space missions, design and development phases, including resource management and operational control;
- design and engineering of small satellite scientific payload, optics and electronics systems;
- Adaptive Optics most innovative technologies for the compensation of the atmospheric effects on transmitted signals, in the visible and infrared wavebands;
- developing new AO instruments and observing strategies specifically tailored for the ORCAS case;
- contributing with new ideas to science cases for the ORCAS-assisted observations with largest ground-based AO facilities.
The main aim of the proposed PhD project is to prepare a young researcher that will be able to lead outstanding technological projects, for both space and ground-based observing facilities, with a strong and synergical connection with the scientific team.

Planning of the activities:
The research activities will be carried out within the INAF/ORCAS international collaboration, a large multi-disciplinary team of engineers and scientists.

- Year 1: The significant part of the work in the first year, will be dedicated to the study of existing literature and explore the scientific applications of SGSs to ground based AO observations.
- Year 2: The student will take part in the feasibility studies aimed at evaluating the use of existing instrumentation and possible upgrade/modifications (through simulations and/or prototyping), to carry out the first ORCAS-assisted observations with large existing facilities as the LBT, ESO telescopes and future ELTs.
- Year 3: The last year will be dedicated to the verification of proposed technologies and methodologies (in the laboratory and possibly on-sky), and to consolidate the analyses on acquired data. He/she will also contribute to the official reports and documentation, necessary for the system engineering and the management of the project. Writing of the thesis. One/two conference or peer-review papers are also expected.

Institution(s) where the research will be carried out:
INAF - Osservatorio Astronomico d'Abruzzo, in collaborations with other INAF institutes and international teams. Visiting and short periods abroad for collaboration activities, on-sky testing campaigns, meetings and conferences are desirable.

3.2.7 Novae Contribution to Galactic Chemical Evolution: a Theoretical Study - Dr. Luciano Piersanti

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Co-Supervisors (Name, Institution and e-mail):
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Scientific Case: Novae are powerful explosions occurring on the top of white dwarfs (WDs) embedded in interacting binary systems. Due to the transfer of matter from the companion, a hydrogen-rich layer is piled up on the top of the degenerate component, thus determining the ignition of a violent flash which turns into a thermonuclear runaway. Observations suggest that such a flash can reproduce the overall properties of Novae only if the accreted material is enriched in heavy elements by partial mixing with the most external layers of the accretor. Many numerical computations have been performed in the past in order to put firm constraints on the physical processes driving the development of the dynamical event, even if no definitive answer has been obtained so far.
Outline of the Project: The proposed work will be devoted to implement the treatment of hydrodynamical evolutionary phases in the FuNS code, used up to now to investigate in detail the physical processes and the produced nucleosynthesis during the hydrostatic phases of stars, both single or in binary systems. The work is aimed to investigate both the physical processes driving to the onset of a Nova event and the produced nucleosynthesis. The computation of Nova outburst will be performed by varying the mass transfer rate and the WD total mass and its chemical composition. The obtained nucleosynthesis for the ejecta will be made available on a web database as input for the computation of galactic chemical evolution models.
Planning of the activities:
Year 1: Implementation of the hydrodynamic mode into the FuNS code.
Year 2: Development of a full nuclear network suitable to study nucleosynthesis produced in a Nova outburst.
Year 3: Computation of a grid of models by varying the mass transfer rate and the chemical composition and mass of the accreting WD.
Institution(s) where the research will be carried out:
INAF - Osservatorio Astronomico d'Abruzzo.

3.2.8 Morphology and photometry of high- and intermediate-redshift galaxies: high-res simulations and observations for the next generation ground-based observatories - Dr. Elisa Portaluri

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Co-Supervisors (Name, Istitution and e-mail):
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Gianluca Di Rico, INAF - OAAb, gianluca.dirico@inaf.it

Scientific Case: To date, the study of distant galaxies and a detailed morphological analysis of their sub-structures are hampered by the faint magnitudes and, even more so, by the small angular sizes. Several astronomical surveys that investigate the galactic structures over a wide range of morphology were carried out and have revealed other important observational evidences, such as the evolution of the mean effective radius for passive (i.e. early-type) galaxies, the existence of a mean sequence for star-forming galaxies, and color gradients in elliptical galaxies at high redshifts. Moreover, despite of previsions, at high redshift very massive galaxies are already present, but they are smaller than nowadays ellipticals. This suggests that they can not be the direct precursors of local galaxies and interaction phenomena may play a fundamental role for their evolution. At this point, a direct chance to discriminate the more plausible formation scenario and to understand their evolution is to look for spheroids and discs at $z > 1$ and compare their characteristics with those of local galaxies: studying the photometric properties of galaxies at different ages gives us the chance of understanding their assembling history and can provide important insight into the evolutionary history of galaxies.
Next generation instrumentation will provide unprecedented sharpness and depth view of high- and intermediate-redshift galaxies, allowing to fully characterize the properties and shed light on the mechanisms of galaxy formation and evolution. Thanks to the enhanced capabilities of such new technologies, the study of spatially-resolved galaxy properties will be possible with great details providing a fundamental piece of information to recover the assembly history of galaxies.
The student will work both on numerical simulations and on precursor data to pave the way of this scientific case for future AO-assisted instruments.
Outline of the Project: The PhD student will be part of our research group, which is deeply involved in the science and development teams of the first generation instruments for ELT (MICADO and MORFEO) and of third generation instruments of VLT (MAVIS). He/she can also take part in the feasibility studies of SHARP and PCS, both proposed for the next phase of ELT. Participation in the definition and development of more new instruments to be proposed for already employed facilities, like LBT, but also very new concepts, like the NASA/ORCAS project, are possible and desirable.
We expect the student will develop skills in:

- manipulating astronomical imaging data in optical and near-IR passbands;
- adapting and upgrading existing numerical codes for the specific aims of her/his thesis project;
- developing new procedures specifically tailored for the AO case
- contributing with new ideas to science cases feasible at existing AO-assisted facilities.

The main aim of the proposed PhD project is to prepare a scientist that will be able to lead scientifically outstanding projects fully exploiting the capabilities of the ELT and also have a strong and synergical connection with the technological team that is developing the instrumentation.

Planning of the activities:
Year 1: The significant part of the work, starting from the first year, will be dedicated to explore the future scientific applications of ELT instruments, via simulations, using official software already available and also implementing the code to the use case. The student will take part in the feasibility

studies aimed at preparing the first observations with these instruments, interacting with several research groups and actively collaborating to the extension of the White Book we have planned, taking into account the outcome of JWST science. He/she will also contribute to the official reports and documentation, necessary for the instrumentation management.
Year 2: The student will have access to the GTO data of our research group, and the second year will be devoted to conduct the analysis on the morphology and photometry of the galaxies at high and intermediate redshifts. He/she will also be asked to propose new observations with existing AO-assisted instrumentations (e.g. LUCI@LBT, ERIS@VLT), to lead their analysis. All the results will be published in international refereed papers.
Year 3: At this stage there should be also the possibility to contribute to other proposed instrumentation, taking part to the feasibility study of them. In fact, with the gained experience in both the fields of simulations and analysis of real data, the student will be able to conduct a detailed analysis and comparison of the capabilities of the new generation of instrumentation with respect to the current ones in the field of the high-redshift galaxies. All the results will be published in international refereed papers.

Institution(s) where the research will be carried out: INAF - OAAb mainly, but collaborations with both different INAF institutes and international science instrument teams will be possible and desirable.

3.2.9 Decoding Interacting Transients: From Circumstellar Media to High-Energy Astrophysics - Dr. Leonardo Tartaglia

Supervisor: Leonardo Tartaglia, INAF – OAAb Teramo; leonardo.tartaglia@inaf.it
Co-Supervisors: Giorgio Valerin, INAF – OAPd Padova; Accademic co-supervisor to be defined.

Scientific Case: Interacting transients provide a unique opportunity to study the final evolutionary stages of massive stars, their mass-loss mechanisms and the shaping of their circumstellar environments. Massive stars often undergo significant episodic or continuous mass loss prior to explosion, creating dense circumstellar structures that may interact with supernova ejecta. This collision generates forward and reverse shocks converting kinetic energy into radiation and producing distinctive observational signatures such as narrow emission lines, multi-peaked light curves, and thermal transients. Unveiling the nature of their progenitor systems, reconstructing their pre-explosion evolution and characterising the mechanisms driving circumstellar mass loss are crucial for addressing fundamental questions in modern stellar Astrophysics. Interacting transients also play a crucial role in high-energy astrophysics. The shocks can accelerate particles to relativistic speeds, leading to the production of high-energy neutrinos through hadronic processes. Observations by IceCube have detected a diffuse high-energy neutrino flux, but the astrophysical sources remain unidentified. Interacting transients, with their energetic environments and prolonged interaction phases, are promising candidates for producing these neutrinos. Understanding these processes bridges the fields of stellar astrophysics and particle physics, addressing key questions about the evolution of massive stars and the Universe's most energetic phenomena.
Outline of the Project: This PhD project focuses on unraveling the progenitor properties of optical transients interacting with dense circumstellar media – phenomena that offer unique insights into the final evolutionary stages of massive stars. Combining multi-wavelength observational data with theoretical models, the project will investigate progenitor properties, mass-loss mechanisms, and their influence on circumstellar environments. Additionally, it will explore how interacting supernovae contribute to the high-energy neutrino flux observed by IceCube, addressing fundamental questions in stellar evolution and multi-messenger Astronomy. The candidate will gain essential skills in managing multi-wavelength follow-up observations of optical transients, performing data reduction, and developing advanced analysis and modelling codes – key competencies for a competitive academic career. Active participation in international collaborations such as SOXS, GRAWITA, and ENGRAVE will provide invaluable opportunities to engage with leading researchers in transient astrophysics. This project promises to advance our understanding of massive star evolution and supernova interactions while equipping the candidate with expertise vital for a successful career in Astrophysics.

Planning of the activities:
Year 1: **Foundation and initial data analysis.** Preliminary steps include training in observational techniques, data reduction and coding, review of the literature on interacting transients and neutrino production and first analysis of available archival data on interacting transients. Unpublished data are also available, including top-quality spectra obtained with VLT X-Shooter. The candidate will also join international collaborations such as SOXS, GRAWITA and ENGRAVE.
Year 2: **Advanced analysis and theoretical modelling.** Existing datasets will be expanded with observations of newly discovered transients (provided by ongoing surveys such as ZTF and ATLAS). Advanced analysis of spectral features and bolometric light curves of interacting transients will be performed using existing analytical and numerical models and new codes will be developed to improve modelling on ejecta-CSM interactions and predict neutrino fluxes. Initial results will be presented at main conferences such as the annual EAS meeting.
Year 3: **Synthesis and dissemination.** Data analysis will be finalised along with neutrino flux predictions for the considered sample of interacting transients and results published in the main peer-reviewed journals such as Astronomy & Astrophysics, Monthly Notices of the Royal Astronomical

Society and the Astrophysical Journal. The final part of the project will focus on the PhD thesis as well on exploration of postdoctoral opportunities.

Institution where the research will be carry out: mainly INAF – Osservatorio Astronomico d'Abruzzo; regular collaboration with INAF – Osservatorio Astronomico di Padova.

3.2.10 Probing Extragalactic High-Energy Neutrino Sources - Leonardo Tartaglia

Supervisor: Leonardo Tartaglia, INAF – OAAb Teramo; leonardo.tartaglia@inaf.it
Co-Supervisors: Accademic co-supervisor to be defined.

Scientific Case: High-energy neutrinos are among the most enigmatic particles in astrophysics, offering a direct probe into the extreme environments where cosmic rays are accelerated. Unlike photons, neutrinos travel vast cosmic distances unaffected by magnetic fields, carrying unaltered information about their sources. Observations from IceCube and other neutrino observatories have confirmed their existence at extraordinary energies, yet their astrophysical origins remain largely unknown. Identifying these sources is a fundamental challenge in modern Astrophysics. Potential extragalactic sources include interacting supernovae, flaring blazars, and tidal disruption events (TDEs). These systems host relativistic outflows and shock regions capable of accelerating particles to ultra-high energies. In these environments, hadronic interactions between cosmic rays and surrounding matter or radiation produce neutrinos. For example, active galactic nuclei (AGN) jets and TDEs have been proposed as sites of particle acceleration due to their dense cores and relativistic flows. Similarly, interacting supernovae provide prolonged shock activity due to ejecta colliding with dense circumstellar material. Despite significant progress in multi-messenger Astronomy, pinpointing neutrino sources remains elusive. Advanced techniques such as stacking analysis – combining signals from multiple events – are critical for enhancing sensitivity to faint or rare sources. By integrating observational data with theoretical models, this project aims to refine predictions of neutrino fluxes and uncover the physical processes driving their production.
Outline of the Project: This project aims to physically characterise potential extragalactic sources of these neutrinos, including interacting supernovae, flaring blazars, and tidal disruption events. By combining cutting-edge observational data with advanced theoretical models, the research will study in detail the physical processes driving neutrino production in these extreme environments, such as particle acceleration and interactions in relativistic outflows. The candidate will develop codes to compute predicted neutrino fluxes and apply stacking analysis techniques to enhance sensitivity to faint or rare sources. Additionally, the PhD student will gain expertise in managing multi-wavelength follow-up observations of optical transients, performing data reduction, and developing analysis and modelling tools - essential skills for a competitive academic career. Participation in international collaborations focused on "multi-messenger" Astronomy, such as GRAWITA, ENGRAVE and ET, will provide invaluable connections within the global transient astrophysics community. This project promises to advance our understanding of high-energy neutrino sources while equipping the candidate with the tools to excel in the field.

Planning of the activities:
Year 1: **Foundation and initial data analysis.** Preliminary steps include training in observational techniques, data reduction and coding, review of the literature on neutrino production mechanisms and candidate sources (supernovae, blazars, TDEs) and first analysis of available archival data to identify potential neutrino sources. The candidate will also join international collaborations such as GRAWITA, ENGRAVE and ET.
Year 2: **Advanced analysis and theoretical modelling.** Multi-wavelength data of newly discovered transients (provided by ongoing surveys such as ZTF and ATLAS) will be acquired. Stacking techniques along with simulation codes will be explored to enhance sensitivity to faint or rare neutrino sources and to predict neutrino fluxes from various astrophysical sources. Observational findings will be compared with theoretical predictions to constrain source properties. Initial results will be presented at main conferences such as the annual EAS meeting.
Year 3: **Synthesis and dissemination.** Data analysis will be finalised along with the integration of observations with models to refine neutrino flux predictions. The results will be published in the main peer-reviewed journals such as Astronomy & Astrophysics, Monthly Notices of the Royal Astronom-

ical Society and the Astrophysical Journal. The final part of the project will focus on the PhD thesis as well on exploration of postdoctoral opportunities.

Institution where the research will be carried out: INAF – Osservatorio Astronomico d'Abruzzo.

3.2.11 Netron-capture processes studies with nuclear reaction networks - Dr. Diego Vescovi

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Co-Supervisors (Name, Istitution and e-mail):
Sara Palmerini - Università degli Studi di Perugia - sara.palmerini@unipg.it
Scientific Case: It has been known for more than 60 years that the slow and rapid neutron capture processes (s- and r-process) are each responsible for creating about half of the elements heavier than iron in the Universe. In addition, an intermediate neutron capture process (i-process) with neutron concentrations halfway between the s- and the r-processes was also identified. To understand how these processes operate in different astrophysical scenarios and what relative abundance patterns they produce, detailed nuclear reaction network calculations are needed that track thousands of isotopes and tens of thousands of nuclear reactions.
Outline of the Project: In this thesis, the PhD candidate will develop a novel general-purpose nuclear reaction network that can evolve an arbitrary list of nuclear species with an arbitrary set of nuclear reactions. The candidate will use the new code to systematically investigate neutron capture nucleosynthesis processes for different astrophysical scenarios and nuclear inputs. Special attention will be paid to the sensitivity of the heavy elements production to the beta decay rates of the nuclei involved, as they compete with neutron capture rates. This kind of study is of key importance for future experiments aimed at measuring nuclear beta-decay rates in stellar-like conditions, such as the PANDORA experiment.
Planning of the activities:
Year 1: The candidate will develop the code at INAF-OAAb, under the guidance of a researcher belonging to the theoretical stellar evolution and nucleosynthesis group. Moreover, she/he will learn the basis of stellar modelling, in particular the Asymptotic Giant Branch (AGB) phase, which are among the candidates to host the s- and the i-processes.
Year 2: She/he will conduct sensitivities studies for the s- and the i-processes occurring AGB stars for varying nuclear inputs, such reation rates and decay rates. This task will be pursued in close collaboration with researchers from the nuclear astrophysics group of the University of Perugia.
Year 3: She/he will conduct studies aiming at understanding the dependence of the i-process occurrence on varying stellar initial masses and metallicities and the effects of different mixing mechanisms.
The candidate will join the PANDORA collaboration during the PhD project.
Institution(s) where the research will be carry out:
INAF-Osservatorio Astronomico d'Abruzzo and Università degli Studi di Perugia.

3.3 INAF-IAPS

Two (2) fellowship is granted for a student to carry out his/her research at INAF-IAPS, among the following thesis proposals.

3.3.1 Understanding the nature of the high energy emission of accreting low mass X-ray binaries. - Fiamma Capitanio

Supervisor (Name, Institution and e-mail)
Fiamma Capitanio, INAF-IAPS, fiamma.capitanio@inaf.it
Co-Supervisors (Name, Institution and e-mail):
Francesco Tombesi, UNITOV, francesco.tombesi@roma2.infn.it
Scientific Case: Accreting low-mass X-ray binaries (LMXBs) host a compact object (either a non-pulsating neutron star or a black hole) that accretes matter via Roche-lobe overflow from a low-mass companion star. They are highly variable objects, both in spectral and timing properties.
Although extremely variable, these objects exhibit a spectrum that can be roughly described as a combination of a soft thermal component, originating from the accretion disk, and a harder component produced by electron scattering, with reflection from a cold medium. However, the nature and origin of the scattering electron plasma responsible for the harder spectral component remain elusive, as do the spectral and timing variability of these systems.
Thanks to the NASA/ASI Imaging X-ray Polarimetry Explorer (IXPE), X-ray polarimetry has finally become an extraordinary tool for investigating the physics of accretion in LMXBs. While X-ray spectroscopy provides information about the physical parameters of the emitting regions, polarimetry offers insights into geometrical properties, such as the shape and extent of the scattering region. The IXPE energy band-pass (2–8 keV), although primarily covering the direct emission from the accretion disk, also partially intercepts the low-energy boundary of the inverse Compton emission in NS/BH LMXBs. The first IXPE results suggest that polarization is higher than expected, ruling out certain electron corona geometries.
Outline of the Project: INAF-IAPS and UTOV are ideal institutions for this type of research. Researchers at IAPS-INAF are experts in LMXBs, X-ray data analysis, and have extensive knowledge of IXPE detectors. Meanwhile, researchers at UTOV specialize in both theoretical X-ray astrophysics and data analysis. Scientists from both institutions are part of the IXPE collaboration and are also deeply involved in a large multi-frequency observational campaign carried out in coordination with IXPE and major X-ray telescopes. A vast amount of data has been collected to simultaneously study the physical parameters and geometry of the emitting regions. These data have not yet been fully exploited and hold significant potential for new discoveries.
Planning of the activities:

Year 1: The candidate will begin by studying the scientific case and learning data reduction and analysis techniques for IXPE and other X-ray missions, such as INTEGRAL, Swift, NICER, and NuSTAR. The candidate will investigate the spectral and polarimetric characteristics of LMXBs and their relation to individual spectral components in different spectral states.

Year 2: the candidate will work on collected data, including archive data, to find and interpret the results

Year 3: will involve further analysis and consolidation of work into the PhD thesis, providing a comprehensive view of the polarization properties of NS and BH LMXBs.
Institution(s) where the research will be carry out: INAF-IAPS and UNITOV

3.3.2 Gamma-ray astronomy and the search of lost Pevatrons (with a little help from neutrinos) - Martina Cardillo

Supervisor: Dr Martina Cardillo, INAF-IAPS, martina.cardillo@inaf.it

Co-Supervisor: ????

Scientific Case: Cosmic particle acceleration and the origin of Cosmic Rays (CRs) are one of hottest topics in High Energy (HE) astrophysics. Non thermal g-ray emission is the main investigation channel: it is produced by either accelerated electrons (leptonic processes) and protons (hadronic processes). The discrimination between leptons and hadrons is at the base of the CR origin search, but this is very challenging. The recent data collected in the VHEs have stressed this complexity supporting sources other than the standard candidates, Supernova Remnants (SNRs), can accelerate Galactic CRs, but have also given to us a large amount of information to study and understand. For this reason, CRs and their sources will be one of the main topics of future Cherenkov Telescopes like ASTRI Mini-Array and CTA.

Outline of the Project: Through literature study, develop (in python language) and manage theoretical models, constant comparison with present and future g-ray and neutrino data, g-ray data interpretation and analysis, the student will carry on a comprehensive study of SNRs, computing their g-ray and joint estimated neutrino emission with existing code re-adaptation, exploiting the multi-wavelength and multi-messenger approaches applied to SNRs, and subsequently to other types of sources. The active collaboration with the ARIES team of prof Jagdish Joshi, involved in neutrino models development and Pulsar Wind Nebulae studies, and the Memorandum of Understanding existing between the IceCube and ASTRI Mini-Array collaboration, will be an important support to these activities.

Planning of the activities:
Year 1: Involvement within the team and knowledge of the current activities. Introduction to the CR origin issue, comprehension of existent theoretical models of g-ray emission from SNRs, study of the Science Tool Gammapy to manage and analyse experimental data from the VHE instruments like ASTRI Mini-Array but also LST-1 and CTA.
Year 2: modification and improvement of the SNR acceleration model based on the recent developments, study and introduction of the neutrino emission expected from analysed sources, comparison of the results with other acceleration models applied to other kinds of sources, Gammapy application on available simulated or real VHE data from ASTRI Mini-Array but also LST-1 and CTA. There is the possibility of a period abroad at the ARIES institute.
Year 3: application of the developed models on recent experimental data that will be obtained by all the available VHE and neutrino experiments and future planning.

Every year there will be chances to participate to meeting/conferences/schools and a little percentage of the time will be used to develope outreach capabilities in order to disseminate the work.

Institution(s) where the research will be carry out: Istituto di Astrofisica e Planetologia Spaziali (IAPS-INAF), Via del Fosso del Cavaliere 100, Roma

3.3.3 Hyperspectral data analysis of Meteorites and Small Bodies – Cristian Carli & Alessandra Migliorini

Supervisor (Cristian Carli, IAPS-INAF and cristian.carli@inaf.it):

Co-Supervisors (Alessandra Migliorini, IAPS-INAF and alessandra.migliorini@inaf.it):
Co-Supervisors (Enzo Pascale, Univ. La Sapienza, Roma and enzo.pascale@uniroma1.it):

Scientific Case: Understanding the evolution of the Solar System passes through the comprehension of the small bodies which formed in its first million years. They can be considered as the best witness of the planetesimals present in the early Solar System formation stages, and a more in-depth study of their mineralogy will improve our knowledge on the formation of a planetary system. A way to achieve that information is to consider spectroscopic investigation in the visible and near-infrared (VNIR) retrieving compositional information from the surface properties of these asteroids. On the other hand, each year about 40,000 tons of extraterrestrial material from asteroids across the Earth's atmosphere, sometimes arriving to the surface as meteorites. This extraterrestrial material can correlate with their parental bodies by using the VNIR reflectance properties, even if nowadays only a few meteorites have been firmly linked to asteroids. Several reflectance measurements of meteorites have been obtained in the past even if recently the number of recovered stony meteorites is strongly increasing, but several meteorite families are spectrally underinvestigated. Moreover, at the same time, VNIR spectra of small bodies acquired with terrestrial telescopes as well as dedicated space missions (e.g. HERA) towards small bodies are growing in numbers. In particular, the investigation of stony asteroids(e.g. S-,A-,Q-,V- types) characterized by clear absorption bands attributable to mafic mineralogy can be an important goal since those bodies could be often spectrally related to both early formed differentiated or undifferentiated objects, with a different correlation to achondrite or chondrite meteorites.

Outline of the Project: To accomplish this result we will perform VNIR reflectance spectroscopy on both achondrite or chondrite meteorites, dominated by mafic mineralogy, focusing on poorly investigated families. We will also consider spectra of meteorites already present in the databases to have a large and variegate dataset for data analysis and statistical clustering. Similarly, asteroid spectra, obtained from ad-hoc, recent, ground-based observations of S-,A-,Q-,V- types and from the available datasets, will be compared to meteorites in order to identify a possible parental body. Considering the large number of spectra for meteorites and small bodies, the work will focus on hyperspectral data. Spectral indicators and other hyperspectral classificator and clustering techniques, considering more recent approaches, will be derived for a comparison with asteroid properties. This will support a deep investigation of spectral properties from meteorite groups to asteroid types.

Planning of the activities:
Year 1:
1) Reviewing the public meteorites VNIR spectra datasets and small bodies spectra 2) Define possible meteorites to be investigated on VNIR and request them to the owner institution 3) Investigate and test different classificator and cluster techniques

Year 2:
1) Acquired reflectance spectra of the meteorites (possibly with a period abroad at institution with strong collaboration) 2) Reviewing small bodies spectra datasets 3) Investigate the different datasets taking into account the previously selected techniques 4) Preparing a first manuscript

Year 3:
1) Finalizing data analysis and preparing a second manuscript 2) Writing the Thesis

Institution(s) where the research will be carry out:
IAPS-INAF (abroad institution e.g. DLR Berlin, IAS Orsay, IPAG Grenoble)

3.3.4 Development and Application of ATR-FTS Spectroscopy for the Detection of Biomolecules and Volatiles in Mars-Analog Environments: Implications for Future Space Missions – F. G. Carrozzo

Supervisor (Name, Institution, and e-mail):
F. Giacomo Carrozzo, INAF-IAPS, giacomo.carrozzo@inaf.it
Co-Supervisors (Name, Institution, and e-mail):

Scientific Case: The detection of traces of past or present life, together with the characterization of in situ available resources, plays a crucial role in understanding the evolution of the Red Planet and in planning future human missions to Mars and the Moon. One of the fundamental aspects of this research is the development of innovative instruments capable of performing direct and non-destructive analyses of Martian soil.
In this context, ATR-FTS (Attenuated Total Reflection - Fourier Transform Spectroscopy) emerges as an innovative and potentially revolutionary technology. This technique, never before employed in planetary sciences, offers a highly effective method for analyzing the chemical composition of planetary materials, detecting biomolecules, and identifying the presence of water and other volatiles. The present study aims to develop a portable prototype of an ATR-FTS spectrometer, with the objective of validating its effectiveness in terrestrial analog environments and assessing its potential for future space missions.
Outline of the Project:
• Miniaturization and optimization of the ATR-FTS spectrometer for space applications.
• Characterization of planetary analog materials to evaluate the instrument's capability to identify relevant compounds.
• Detection and analysis of biomolecules and volatiles potentially indicative of past or present biological activity.
• Study of implications for space exploration missions, with particular attention to the instrument's use on Mars and the Moon.
Planning of the activities:
Year 1:
• Review of the existing scientific literature on ATR-FTS spectroscopy and its application in planetary sciences.
• Design of a portable prototype with a wavelength range between 1-2.5 μm for spectral acquisition of planetary-relevant materials.
Year 2:
• Experimental tests to evaluate the device's capability to identify minerals and materials analogous to Martian and lunar ones.
• Development of a methodology for the detection of biomolecules under controlled conditions.
Year 3:
• Assessment of the ATR-FTS spectrometer's effectiveness in identifying organic molecules potentially indicative of biological processes.
• Validation of the device in terrestrial analog environments, simulating Martian conditions to test the instrument's robustness and reliability.

Institution(s) where the research will be carried out:
INAF-IAPS via del Fosso del Cavaliere, 100 Roma

3.3.5 Statistical Analysis and Modeling of Magnetic Field Topologies in Turbulent Space Plasmas - Giuseppe Consolini

Supervisor (Name, Institution and e-mail):
Dr. Giuseppe Consolini, INAF-IAPS, Email: giuseppe.consolini@inaf.it
Co-Supervisors (Name, Institution and e-mail):
Dr. Giuseppina Nigro, Università degli Studi di Roma "Tor Vergata", Email: giuseppina.nigro@roma2.infn.it
Scientific Case: The majority of visible matter in the universe exists in a plasma state, and in many astrophysical environments, plasma dynamics is dominated by turbulence. This is particularly true for heliospheric plasmas, such as the solar wind and the circumterrestrial space. In this context, the turbulent solar wind serves as a natural laboratory for studying astrophysical turbulence, as it is directly accessible to space missions. In the past, ESA and NASA missions, such as ESA's Cluster and NASA's MMS, have provided a unique opportunity to investigate turbulent plasma dynamics using multipoint measurements. For the first time, these missions enabled the study of statistical properties of magnetic and velocity field gradient tensors, along with their SO(3) invariant quantities, across different plasma regions. This has led to a better characterization of the morphological and topological properties of velocity streamlines and magnetic field lines, spanning from magnetohydrodynamic (MHD) scales down to ion and sub-ion scales, where the single-fluid approximation is no longer valid. Understanding the structure of magnetic and velocity flow fields is crucial for unveiling the mechanisms behind particle acceleration, plasma heating, and dissipation in collisionless plasmas. However, a complete theoretical framework for describing the statistical properties of gradient tensor invariants across MHD to sub-ion scales is still lacking, particularly when non-ideal effects, such as the Hall term and pressure gradient terms, are considered. Addressing this challenge requires further theoretical and observational studies, especially in light of the proposed ESA-Plasma Observatory multipoint mission.
Outline of the Project: The aim of this thesis is to use both recent and past observations from multipoint space missions, such as ESA's Cluster and NASA's MMS, to study the statistical properties of the morphology/topology of magnetic field lines and velocity streamlines in various circumterrestrial and near-Earth solar wind regions, as characterized by the SO(3) invariants of the associated gradient tensor. Specifically, the research will focus on analyzing magnetic field morphologies at ion and sub-ion scales in the solar wind, the magnetosheath, and Earth's central plasma sheet. In parallel with the statistical study, the thesis will also involve the development of an MHD/Hall shell model to describe the evolution of magnetic and velocity field gradient tensors. This modeling will be highly relevant for investigating the statistical properties of the associated SO(3) gradient tensor invariants across different scales. If available, the results on statistics of gradient tensor invariants will also be compared with numerical simulations of turbulent plasmas.
Planning of the activities:
Year 1: To study the literature related to the space plasma turbulence and the theoretical/observational approaches/methods to the investigation of gradient tensors. To start a statistical analysis of the features of the magnetic field gradient tensor in different regions of the near-Earth space and solar wind using data from available multipoint space missions.
Year 2: To develop a simple MHD/Hall shell-model for the dynamics of the magnetic and velocity field gradient tensors. To investigate the scale-to-scale evolution of the statistical features of the magnetic field gradient tensor as it results from the MHD/Hall shell model, comparing the results with the actual observations.
Institution(s) where the research will be carried out:
INAF-Istituto di Astrofisica e Planetologia Spaziali, Via del Fosso del Cavaliere 100, 00133 Roma, Italy.
Dip. di Fisica, Universita' di Roma Tor Vergata, Via della Ricerca Scientifica 1, 00133 Roma, Italy

3.3.6 Development of the Lunar Electromagnetic Monitor in X-rays (LEM-X) – Ettore Del Monte

Supervisor (Name, Institution and Contact):
Ettore Del Monte, INAF-IAPS, ettore.delmonte@inaf.it
Co-Supervisor (Name, Institution and Contact):
Eleonora Troja, Department of Physics University of Rome Tor Vergata, (eleonora.troja@uniroma2.it)
Scientific Case: The Lunar Electromagnetic Monitor in X-rays (LEM-X) project aims at developing an X-ray (2-50 keV) all-sky monitor for the observation of Gamma-ray bursts and other X-ray transients from the Moon surface. LEM-X is led by the Istituto di Astrofisica e Planetologia Spaziali (IAPS-INAF) in the context of the Earth-Moon-Mars (EMM) project (INAF-ASI-CNR) of the Italian ”National Recovery and Resilience Plan” (PNRR). With respect to in-flight and already flown wide-field X-ray monitors, the LEM-X modularity, detection plane technology and coded aperture design will allow for a continuous and simultaneous monitoring of the whole sky, enabling a complete and direct association of electromagnetic transients with multimessenger events.
Outline of the Project: The successful PhD candidate will join the LEM-X team and will be involved in the instrument development and optimisation. During the three years, the candidate will participate to all the key activities of the LEM-X study, from the optimisation of the coded-aperture imaging system to the measurement of the detector performance, from the study of the background components to the optimisation of the LEM-X architecture and the definition of the mission profile.
The following methods will be used to carry out the research activity:

- Experimental science techniques and standards for space-borne instrumentation
- Scientific data analysis methods for solid-state X-ray detectors
- Numerical methods (e.g. analytical, MonteCarlo) for instrument performance simulation and assessment of the environmental conditions
- Graphical development of instrument testing platform and virtual instruments

Planning of the activities:
Year 1: Training through the study of the relevant scientific literature in the fields of: Moon environment, Solid-state radiation and particle detectors, Coded-aperture imaging, Transient high-energy astrophysics and Gravitational Waves astrophysics
Year 2: Development, experimental characterization and optimisation of the LEM-X detectors; Definition of the LEM-X mission profile;
Year 3: Simulation and analysis of astrophysical data finalized at the optimization of the overall LEM-X architecture;
Institution(s) where the research will be carry out:
Istituto di Astrofisica e Planetologia Spaziali (IAPS) di Roma – Istituto Nazionale di Astrofisica (INAF) Via del Fosso del Cavaliere 100, I-00133 Rome.

3.3.7 Use of Artificial Intelligence for Particle Background Subtraction in X-ray Astronomy - Simone Lotti

Supervisor (Name, Institution and Contact):
Simone Lotti, INAF/IAPS Roma, simone.lotti@inaf.it

Co-Supervisor (Name, Institution and Contact):
Luigi Piro, INAF/IAPS Roma, luigi.piro@inaf.it
Elia Battistelli, Physics Department, La Sapienza University of Rome, elia.battistelli@roma1.infn.it

Scientific Case:
The PhD proposal is embedded in the context of background estimation and subtraction for X-ray satellites, where accurate removal of the particle background is a critical challenge for the observation of faint and/or diffuse sources.
This proposal is framed within the context of the upcoming Athena X-ray Observatory—an ESA flagship mission scheduled for adoption in 2027 and flight in the late '30s. Athena (Advanced Telescope for High-ENergy Astrophysics) is designed to investigate key questions in Astrophysics, such as:

- How and why does ordinary matter assemble into the large-scale structures (galaxies, galaxy groups, and galaxy clusters) that we see today?
- How do black holes grow and shape their environment, as well as the cosmological evolution of the galaxies hosting them?

Athena will be the most powerful X-ray observatory ever flown and, in addition to addressing the above mentioned questions, will provide important results for virtually all classes of astrophysical objects, from high-Z gamma-ray bursts at the edge of the observable Universe, to the closest planets in our solar neighborhood.
One of its key instruments, the X-ray Integral Field Unit (X-IFU), is based on a large array of Transition Edge Sensor (TES) microcalorimeters and will be the most powerful spectrometer in its class, capable to perform simultaneous high-grade energy spectroscopy ($\sim$34 eV @ 7 keV) and imaging over the 4' FoV. INAF/IAPS has the co-PI ship of the X-IFU instrument and is also responsible for the particle background estimate and reduction.
In this context, the proposed research aims to develop an artificial intelligence (AI) model that can predict the level and spectral shape of the background by integrating data from instrument calibrations, onboard cross-calibrations (including anticoincidence sensor data), and external cosmic-ray monitors. The enhanced background correction is expected to improve the sensitivity of the instrument and, thereby, our ability to explore high-energy phenomena, further pushing the frontiers of our knowledge of black hole evolution to the redshifts where the first galaxies are forming, and the understanding of the physics of intra-cluster gas out to the boundaries with the Warm Hot Intergalactic Medium (WHIM).

Outline of the Project:
The project is structured into three interconnected phases, ensuring a pathway from initial research to final validation and application. In the first phase, a comprehensive literature review will be conducted to survey current methods in particle background subtraction and to review state-of-the-art AI techniques applied to astrophysical data. Concurrently, training data will be compiled from Monte Carlo simulations, including instrument calibration data, cross-calibration data with onboard sensors (such as anti-coincidence systems), and external cosmic-ray flux measurements, alongside the development of initial data preprocessing and normalization protocols. A feasibility study will assess the existing computational infrastructure in INAF/IAPS.

The second phase focuses on the development and training of the AI model. A multilayered AI architecture, potentially incorporating convolutional and/or recurrent neural networks, will be designed to address the specific challenges of X-ray background prediction. A simulation environment will be constructed to mimic various background conditions, utilizing archival data from missions like XMM-Newton and Chandra for testing, training, and fine-tuning the model. Optimization processes, including cross-validation, hyperparameter tuning, and error analysis, will be employed to ensure the model's robustness and generalizability across different observational scenarios. The predictive accuracy and reliability of the model will be benchmarked against archival X-ray data, with comparisons made to conventional background subtraction techniques. Feedback from these validation tests will inform iterative refinements to enhance model performance.
In the final phase, the AI model will undergo testing and validation against simulated data for Athena, to prepare for its integration within the mission framework. The culmination of this phase will involve the preparation of detailed reports and scientific publications that summarize the methodology, results, and implications for future X-ray observatories. Possibly collaborative sessions with Athena and related research groups will be organized to discuss integration strategies.

Planning of the Activities:
Year 1: Comprehensive review of the literature on existing methods and similar approaches for background extraction in astrophysical data; feasibility study based on existing infrastructures at IAPS; study of applicable artificial intelligence techniques.
Year 2: Development and training of the AI model with simulated and existing data; execution of tests to verify the reliability of the model.
Year 3: Model optimization, final validation, and writing of the thesis.

Institution(s) where the research will be carried out:
INAF/IAPS Roma

3.3.8 Development of cryogenic particle detectors based on Transition Edge Sensors (TES) for ATHENA and future ground-breaking experiments - Claudio Macculi

Supervisor (Name, Institution and Contact):
Claudio Macculi, INAF/IAPS Roma, claudio.macculi@inaf.it
Matteo D'Andrea, INAF/IAPS Roma, matteo.dandrea@inaf.it
Co-Supervisor (Name, Institution and Contact):
Luigi Piro, INAF/IAPS Roma, luigi.piro@inaf.it
Elia Battistelli, Physics Dpt. La Sapienza University of Rome, elia.battistelli@roma1.infn.it
Scientific Case: Cryogenic detectors are a cutting-edge technology for ground-breaking experiments in astrophysics and particle physics. In this context, Transition Edge Sensor (TES) microcalorimeters are a core element in the next generation of X-ray astrophysical instruments, due to their unparalleled sensitivity and energy resolution,

The proposed PhD work is framed in a double context: the Athena mission, the next ESA Large X-ray observatory, flagship one, to be launched in 2037 at L1 orbit, and a Reserch&Development (R&D) project for setting up a new production chain of TES microcalorimeter in the Rome ArTov research area.

Athena will address key questions in Astrophysics, such as: - How and why does ordinary matter assemble into the structures (galaxies, galaxy groups and galaxy clusters) that we see today? - How do black holes grow and shape their environment, as well as the cosmological evolution of the galaxies hosting them? One of the two on board instruments is the X-IFU (X-ray Integral Field Unit), a cryogenic spectrometer based on a large array of TES (Transition Edge Sensor) microcalorimeters able to perform simultaneous high grade energy spectroscopy (about 3eV@7keV) and imaging over the 4' FoV. INAF/IAPS has the co-PI ship of the X-IFU instrument and, from the technological point of view, it is also responsible for the delivery of the CryoAC (Cryogenic AntiCoincidence) which is a detector necessary to lower the particle background detected by the main detector: the lower the residual background, the higher the instrument sensitivity. The CryoAC is a 4 pixels detector made of Silicon suspended absorbers sensed by Ir/Au TES working at 50 mK, and placed at a distance less than 1 mm below the TES-array.

Building on the expertise acquired on ATHENA, our team is also leading an R&D activity in collaboration with the CNR Institute for Photonic and Nanotechnologies (CNR/IFN) Roma, aimed at developing a new in-house production chain for TES detectors. This research line allows fundamental studies on TES detectors, and opens the possibility to explore new applications for the TES anticoincidence technology (i.e. use in dark matter/rare event search experiments or in different electromagnetic bands).

Outline of the Project:
The PhD student will participate in the ATHENA X-IFU CryoAC development, and simultaneously will have the possibility to perform more fundamental studies on TES detectors design and fabrication being involved in the ArToV R&D project.

As far as the Athena project is concerned, the next major X-IFU milestones relevant in the PhD time-frame is the delivery of the Engeneering Model CryoAC cold stage having the shape of the Flight one. The PhD student will follow all the phases of this activity by interfacing with all the relevant Italian team (INAF, Genova Univ., CNR/IFN) and company, and foreign partners (SRON-NL, CNES-FR). In more details, the student will set up experiments in a cryogenic environment, carry out tests of the detector and its readout electronics, analyze measurements while doing simulations of the CryoAC instrument aimed at understanding the test results. The PhD student will work in a team with recognised expertise in the field of cryogenic microcalorimetry for high-energy observations from space (INAF/IAPS), the manufacturing of cryogenic detectors (Phys. Dpt, Genoa university), and the cryogenic readout electronics (CNR/IFN Roma). The activity will be mainly performed in INAF/IAPS Roma but, due to the X-IFU international context, activity related to integration and test of the above mentioned detectors are planned at SRON (NL) and CNES (Toulouse, FR) laboratories, and the PhD student will be fully involved in.

As far as the R&D project is concerned, the PhD student will be involved in the TES manufacturing activity at the CNR Nano-Microfab facility at ArTov Roma, in the context of an INAF/IAPS lead project. He/she will work in a clean room environment, working on the processes underlying the fabrication of superconducting and nano/micro devices (optical and electron-beam lithography, metal and superconducting materials evaporation and sputtering, deep reactive ion etching of silicon, ...). The PhD student will then be in charge of testing its own produced devices.

Planning of the activities:

Year 1: acquisition of basics on TES detectors (fabrication, integration and test), clean room and cryogenic laboratory techniques. EM CryoAC chip integration and test.

Year 2: EM CryoAC assembly activity made of the chip, cryogenic electronics and metallic support (participation in integration, characterization and functional test). Participation in the definition of procedures for TES detector manufacturing.

Year 3: Closure of the activity related to the delivery of the EM CryoAC. Production and test of TES devices besides ATHENA.

Institution(s) where the research will be carry out: INAF/IAPS Roma

3.3.9 Study of Jupiter's Main Aurora from Images and Spectra of NASA's Juno Mission - Alessandro Mura

Supervisor (Name, Institution and e-mail): Alessandro Mura, INAF - Istituto di Astrofisica e Planetologia Spaziali (IAPS), alessandro.mura@inaf.it **Co-Supervisors (Name, Institution and e-mail)**: Chiara Castagnoli, INAF - Istituto di Astrofisica e Planetologia Spaziali (IAPS), chiara.castagnoli@inaf.it
Scientific Case: Jupiter's aurora is the most powerful in the Solar System, driven by high-energy precipitating electrons that dissociate H2 molecules, leading to the formation of H3+, which emits strongly in the infrared. The Jovian Infrared Auroral Mapper (JIRAM) onboard NASA's Juno spacecraft provides unprecedented imaging and spectral data of Jupiter's auroral phenomena. This PhD project aims to exploit the extensive dataset acquired by JIRAM to analyze the structure and dynamics of Jupiter's main auroral oval and polar auroras. By mapping the spatial and spectral properties of H3+ emissions, this study will enhance our understanding of electron acceleration mechanisms and their impact on Jupiter's magnetosphere-ionosphere coupling.
Outline of the Project: The project will focus on the morphological structures of Jupiter's main auroral oval and polar aurora, utilizing JIRAM's imaging and spectroscopic capabilities. The key objectives include: - Mapping auroral images onto the 1-bar reference level to obtain a consistent spatial framework. - Identify recurrent sub-structures at the auroral oval at both poles. - Investigating the relationship between auroral morphology and electron precipitation processes.
Planning of the activities: Year 1: - Data processing: data selection, noise removal, image mapping, and auroral structure identification. - Preliminary analysis of the spatial and temporal distribution of H3+
Year 2: - Development of mathematical models to investigate the auroral precipitation. - Comparative analysis of auroral structures across multiple Juno orbits. - Establishing collaborations with international research groups, including an internship abroad. - Preparation / submission of scientific articles
Year 3: - Finalization of data analysis and interpretation. - Writing of the PhD thesis and submission of scientific articles.
Institution(s) where the research will be carried out: INAF - Istituto di Astrofisica e Planetologia Spaziali (IAPS) International institutions during the internship period.

3.3.10 S-type asteroids: insights from the HERA Mission through remote sensing spectroscopy and laboratory analogues - Ernesto Palomba

Supervisor (Name, Institution and e-mail):
Ernesto Palomba (INAF-IAPS, ernesto.palomba@inaf.it)
Co-Supervisors (Name, Institution and e-mail):
Marianna Angrisani (INAF-IAPS, marianna.angrisani@inaf.it)
Scientific Case: S-type asteroids are among the most common in the inner asteroid belt, characterized by rocky compositions rich in silicates, iron, and magnesium. As remnants of the early solar system, they offer insights into planetary formation and the primordial materials that shaped terrestrial planets, including Earth. The HERA mission of the European Space Agency launched in 2024, presents a unique opportunity to study the S-type binary asteroid system Didymos and its moon Dimorphos. The mission is primarily focused on Planetary Defense, evaluating the impact of NASA's Double Asteroid Redirection Test (DART) on Dimorphos. By integrating remote sensing spectroscopy with laboratory analogues, HERA aims to significantly advance our understanding of S-type asteroids in several key areas such as surface composition and mineralogy, space weathering effects (understanding how solar wind and micrometeorite impacts alter spectroscopic signatures) and impact processes and regolith properties to investigate the changes in surface material and internal structure to refine planetary defense strategies. Laboratory measurements of extraterrestrial analogues (meteorites) and terrestrial regoliths play a crucial role in validating remote sensing data. For instance, simulating space weathering through laser irradiation and ion bombardment on these samples helps distinguish between primary compositional features and weathering-induced spectral alterations. Additionally, using for example, the spectra of ordinary chondrite meteorites (which closely resemble S-type asteroids) enables the calibration of remote sensing data. This approach allows for accurate mineral identification and abundance estimates on Didymos and Dimorphos, supporting the comprehensive interpretation of data collected by HERA.
Outline of the Project: Review of the state of the art - Training on spectroscopic and hyperspectral image data exploitation techniques. Learn the main techniques (spectrometer and microscope) , space weathering simulation techniques and programming languages, such as Python. Data Analysis and comparison of the remote sensing data with laboratory data - Application of radiative transfer models and machine learning techniques - Discussion of the achieved results
Planning of the activities:
The doctoral research will span three years, featuring collaborations with the international HERA space mission Team and opportunities for international stays for some weeks. Year 1: Study of relevant literature and of the needed analysis techniques, including radiative transfer models. First approaches to laboratory and experimental activites
Year 2: Application to spectroscopy data from HERA space mission (Hyperscout, Aspect, TIRI intruments). Application of spectroscopic analysis, radiative transfer models and machine learning techniques
Year 3: Achieved results discussion and comparison between the study cases. Presentation of results to national and international conferences
Institution(s) where the research will be carry out: Istituto di Astrofisica e Planetologia Spaziali (IAPS) di Roma Via del Fosso del Cavaliere 100, I-00133 Rome. Possibility for short stays in other International Institutions, e.g. Aalto University, Helsinki, Finland. Jaxa,Japan Aerospace Exploration Agency, Sagamihara, Japan. ESTEC, European Space Agency, Noordwijk, The Netherlands

3.3.11 A mass-scaling approach to the physics of jets from accreting black holes - Francesca Panessa

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Co-Supervisors (Name, Institution and e-mail):
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Scientific Case: Relativistic jets appear as an ubiquitous feature among accreting black holes (BH) at all mass scales, from supermassive BHs in active galactic nuclei (AGN) to stellar-mass BHs in galactic X-ray binaries (XRBs). In particular, jets from AGN represent some of the most energetic known phenomena in the universe, and they played a key role in regulating galaxy formation at early epochs via feedback processes. These BHs can form and accelerate discrete jet ejecta that propagate at apparent superluminal speeds far from the core, and one of the most powerful tools for investigating these outflows is the Very Long Baseline Interferometry (VLBi), which can be used to provide sub-milliarcsecond scale imaging at radio wavelengths and track the kinematics of the jets. Covering the jet full trajectory allows us to model their dynamics with great accuracy and hence to measure their physical properties (mass, speed, energy), while, at the same time, effectively using them as probes of the surrounding environment. However, a physical model for the dynamics of these ejecta has been developed only for small-scale XRBs jets, and it has not been yet directly applied to AGN jets. On the other hand, jets have been historically difficult to detect in BH XRBs, while jet ejecta in AGN have been detected since the 70s, and we now have an immense VLBI dataset on which to test and apply our physical models to learn something new on the central engine.
Outline of the Project:
The project will be focused on the study of the dynamics of jets present in hundreds of radio-loud AGN observed at 15 GHz with the Very Long Baseline Array (VLBA). These data have been obtained between 1994 and 2016 as part of the 2 cm VLBA survey and Monitoring Of Jets in Active galactic nuclei with VLBA Experiments (MOJAVE) programs. The full propagation at large (pc) scales will be tracked and then subsequently modelled with blast-wave dynamical models derived from the physics of gamma-ray bursts, which will have to be adapted to the AGN scenario. This dynamical modeling will be used, in tandem with core monitoring in UV, optical and radio, to infer information about both the central engine – such as the total ejected energy, the connection to disc variability and potentially even the composition of the ejected plasma, as well as the ambient medium surrounding the XRB. The kinematical models will also be improved by including the time evolution of the jet emission, which will give crucial information on the jet magnetic field strength and on the particle acceleration process. The project itself will evolve from the extension of the model to the typical conditions of jets in AGN to an entirely new jet population study which will provide new insights on the formation, on the energetics and on the overall evolution of these outflows.
Planning of the activities:
Year 1: Development and adaptation of the existing blast-wave dynamical model for the AGN jet scenario
Year 2: Application of the ad-hoc dynamical model to the a subset of jets from the MOJAVE sample
Year 3: Automatization of the modeling framework, with the application to the entire MOJAVE jet sample and consequent large jet population study
Institution(s) where the research will be carried out:
INAF-IAPS, Rome, with foreseen (3-4 month) visits at the University of Oxford (prof. Rob Fender) and the Instituto de Astrofisica de Andalucia (Prof. Josè Luis Gomez Fernandez)

3.3.12 The multimessenger and transient Universe with Gravitational Wave observatories and High-energy space satellites - Luigi Piro

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Co-Supervisor (Name, Institution and Contact):
Francesco Pannarale, Sapienza University, francesco.pannarale@roma1.infn.it
Scientific Case: Electromagnetic observations of Gamma-Ray Bursts (GRBs), including those connected with Gravitational Wave (GW) sources, carry fundamental information on their stellar progenitors (NS binary mergers or collapsar) and on the properties of the relativistic outflow produced after the collapse/merging of their progenitors. With the recent launch of two satellites, Einstein Probe and SVOM, breakthrough observations of GRBs, including those associated with GW events, are being carried out, timely placed to exploit the present and future GW observations by Virgo and LIGO.
Outline of the Project: The project aims at tackling fundamental questions such as the origin of the progenitors of various populations of GRBs, either in the close and in the high-z universe, and to exploit the multimessenger GW observations of the events produced by binary mergers, either neutron star- neutron star or neutron star - black hole, including those with a mass-gap candidate. The PhD student will work on broad band observations of GRBs, from radio to gamma-rays, aimed at characterizing their progenitors through various observational features related with the intrinsic properties as well as with the progenitor environment. By joining these data with GW analysis, the student will characterize the geometry and physical properties of the merger by joint modeling of gravitational waves and electromagnetic data, that offers an unique way of constraining the properties of the event.
Planning of the activities:
The group at IAPS has a long standing expertise in follow-up observations from radio to hard X-rays on GRBs and on the GW sources detected by Virgo and LIGO and is part of the most important international collaborations in this field. The student will have the opportunity to work on the broadband observations of GRBs and GW counterparts that are being currently gathered, and to work on data sets from some of the key facilities from radio (ATCA, VLA, E-Merlin, Meerkat), optical (Vera-Rubin/LSST, ESO telescopes through the Engrave and STARGATE collaboration, and GCT telescope in Canarie Islands) and X-rays (Einstein Probe, SVOM, Chandra, NUStar, XMM-Newton), including GW associated events. He/she will also analyze the rich data base of GW data available after the end of the O4 observing run, taking advantage of the unique experience on GW offered by the group at Sapienza University, directly involved in VIRGO/LIGO. The project will also include analysis with a state of the art time-evolving photoionized X-ray model (TEPID) of the close environment of the GRB. The candidate will be offered to develop key theoretical aspects regarding the kilonova. Moreover, he/she will also elaborate the perspectives offered by future instrumentation in the field, including the next generation of GW antennas and high energy satellites, with particular regard to the large X-ray observatory Athena and the future generation of GW experiment, Einstein Telescope.
Year 1: Introduction to the different electromagnetic facilities and data. Acqusition of the basic skills for data analysis. Key scientific background on GRBs properties and modelling (afterglow, kilonova). Progenitors. GW-data analysis and first introduction to joint EM-GW analysis. Application to selected events
Year 2: Direct involvement in observing runs in selected EM facilties. Participation to observing proposal preparation. Joint analysis of the O4 GW sample of GW-EM events.
Year 3: Exploitation of a selected sample of GRBs (e.g. high-z GRBs/ sGRBs/ X-ray Flashes with Einstein Probe with associated broad band observation and detailed modelling of the afterglow and the ionized environment of the GRB. Simulations and predictions for future EM and GW experiments, such as Athena and Einstein Telescope
Institution(s) :
INAF/IAPS; Sapienza University

3.3.13 Advanced Tool for Space Mission Planning - Roberto Sordini

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Co-Supervisors (Name, Institution and e-mail):
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Scientific Case: Modern space missions rely on highly sophisticated scientific instruments to explore planetary bodies, moons, and other celestial targets. These instruments must operate under strict constraints, including limited onboard storage, power consumption, and communication windows for data transmission.
Efficient observation planning is essential to maximise scientific return while ensuring mission constraints are met.

To achieve this, automated planning tools play a crucial role in optimising observation sequences, predicting resource usage, and preventing conflicts in command execution. Upcoming missions, such as Juice , BepiColombo and Europa Clipper, highlight the growing need for adaptable scheduling tools capable of handling different spacecraft architectures, orbital dynamics, and scientific objectives. A versatile observation planning framework will support scientists and mission teams in efficiently managing complex observational campaigns across various missions.

Outline of the Project: Building on past experience with mission planning tools, the PhD student will develop a flexible and scalable tool designed to support observation planning for multiple missions and instruments. This innovative will be adaptable to various mission profiles, ensuring its applicability beyond a single spacecraft or instrument.
This tool will be developed in MATLAB or Python, utilising SPICE Kernels to model observation geometries, spacecraft trajectories, and instrument fields of view. Its core functionalities will include:

- Observation timeline generation, ensuring optimal execution sequences.
- Command sequence validation, preventing conflicts and operational errors.
- 3D and 2D visualisation, offering real-time assessments of observation opportunities.
- Impact analysis of orbital and attitude changes, optimising scientific output.
- Data volume estimation, crucial for mission planning and downlink prioritisation.

The tool will generate command sequences in mission-compatible formats, facilitating direct integration into spacecraft operations.
Planning of the activities:
Year 1: Initial Development & Proof of Concept

- Define system architecture and key functionalities based on mission requirements.
- Get familiar with the use of SPICE Kernels.
- Develop core modules for trajectory modelling and observation visualisation.
- Implement preliminary timeline generation and data estimation functions.
- Validate performance using simulated datasets.

Year 2: Advanced Functionality & Testing

- Expand tool's capabilities for multi-instrument support.

- Develop command validation and error-checking mechanisms.
- Enhance 3D/2D visualisation for user interaction.
- Perform validation tests with real mission data.
  During the second year, a period of work could be planned to be carried out abroad at the European Space Astronomy Centre (ESAC) of ESA.

Year 3: Finalisation & Deployment

- Optimise the tool for operational use with space agencies and scientific teams.
- Conduct extensive validation with input from active mission teams (e.g., Juice, Europa Clipper, BepiColombo).
- Provide training, documentation, and user support.
- Explore integration with future mission ground segment infrastructures.

By providing a robust, adaptable, and mission-agnostic planning tool, the developed tool will enhance the efficiency of space mission operations and contribute to maximising the scientific return of current and future planetary exploration missions.
Institution(s) where the research will be carry out:
Istituto di Astrofisica e Planetologia Spaziali (IAPS), Via del Fosso del Cavaliere 100, 00133, Roma

3.3.14 The ALMAGAL large project: investigating the accretion mechanisms in high-mass star-forming regions - Alessio Traficante

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Co-Supervisors (Name, Institution and e-mail):
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Scientific Case: One of the open topics in modern astrophysics is understanding the formation mechanisms of the most massive stars in our Galaxy. In particular, how the nursery home of these stars, the protoclustetrs, accrete from their large-scales environment, in a complex interplay between gravity and turbulence. In this context we have recently presented the first results from the ALMAGAL survey, the largest survey of massive star-forming regions observed with the ALMA telecope.
The goal of this PhD project is to investigate the accretion onto the ALMAGAL protoclusters and contribute to the understanding of the massive star-formation mechanism in our Galaxy.
Outline of the Project: The PhD candidate will become familiar with the ALMAGAL dataset and the algorithms required to produce science-ready datasets. In particular, the candidate will learn tow to identify the best molecular lines that will be used to trace the gas dynamics in the ALMAGAL protoclusters, how to extract the information to determine the accretion rates and infall motions in these star-forming regions and how to interpret the results in the general context of the actual massive star-formation theories.
Planning of the activities:
Year 1:
The candidate will learn how to read and extract spectral lines information from the ALMAGAL dataset, how to model these spectra and derive the scientific properties such as the velocity peak and the velocity dispersion of the selected molecular lines Year 2:
The candidate is expected to publish his/her/they first work about the accretion properties of the ALMAGAL protoclusters.The candidate will also start to investigate the correlation with the large-scales environment of these protoclusters. Year 3:
The candidate will fully investigate the properties of the large-scales dynamics from the ALMAGAL parental clouds and the protoclusters. Such molti-scale work will lead to the production of at least a second paper by the end of the PhD project.
Institution(s) where the research will be carry out:
INAF-IAPS, Via Fosso del cavaliere, 100 00133 Roma

3.3.15 Study of Io surface using infrared images and spectra, within the framework of the Juno/JIRAM research projects - Francesca Zambon

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Co-Supervisors (Name, Institution and e-mail):
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Scientific Case
Io, the most geologically active body in the Solar System, features hundreds of volcanic calderas (named pateræ) across its surface. The distribution and activity of Io hotspots are closely linked to its internal structure and subsurface layers. Additionally, the gases emitted by Io's volcanic activity contribute to its atmosphere, highlighting the role of these emissions in atmospheric escape processes and their impact on Jupiter's magnetosphere. Given this, studying the distribution, morphology, and temporal variability of Io's hotspots is crucial for gaining a comprehensive understanding of the satellite, from its innermost layers up to its atmosphere.

Research Activity Description
Analysis of data (images and spectra of Jupiter's moon Io) acquired by the JIRAM instrument onboard NASA's Juno spacecraft.

Outline of the Project

- Study of the distribution, morphology, and temporal variability of Io's volcanic hotspots, with particular focus on thermal emission processes and the composition of ejected material.
- Comparison of hotspot distribution with the geological characteristics of Io's surface to identify possible correlations with tidal heating mechanisms and crustal tectonics.
- Analysis of the interaction between Io's volcanic activity and its atmosphere and exosphere, assessing the role of emitted gases in atmospheric escape processes and their contribution to Jupiter's magnetosphere.

Planning of the activities
Year 1: Familiarize with the JIRAM instrument, data, tools and techinique of analysis.
Year 2: Data analysis and interpretation of the results.
Year 3: Finalization of the scientific objectives of the project. Preparation of the PhD thesis.

Institution(s) where the research will be carry out
The selected candidate will carry out their activities at the INAF – Institute for Space Astrophysics and Planetology, collaborating with the project leaders and the personnel assigned to Juno/JIRAM.

3.3.16 Mission and and space segment development for the METRIC mission - Francesco Santoli

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Co-Supervisors (Name, Institution and e-mail):
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Scientific Case: The METRIC (Measurement of EnvironmenTal and Relativistic In-orbit preCessions) mission concept envisages a compact satellite in a highly eccentric and high-inclination Earth orbit, to pursue three different scientific objectives: mapping of atmospheric density through accelerometric measurements, verification of the theory of General Relativity in the weak field, contribution to the maintenance of the Earth reference system through space geodesy measurements. The scientific measurements would be performed by means of compact on-board instrumentation, in particular a high-sensitivity accelerometer (derived from ISA - Italian Spring Accelerometer, of the ESA Bepi-Colombo mission), and geodetic instrumentation (laser telemetry retroreflectors and GNSS receiver). The orbital profile and the type of envisaged instrumentation foster relevant advances in the three scientific areas indicated above.
Outline of the Project: The PhD student will address the multiple engineering aspects related to the development of the METRIC mission concept. In particular: definition of a compact space platform compatible with the scientific, operational and instrumental requirements; high-precision metrological calibration of the platform itself; optimization of the positioning of the on-board instruments; study of a mission profile allowing to achieve the challenging scientific goals.
Planning of the activities:
Year 1:
Consolidation of the mission scientific requirements and review of the state-of-the-art of the involved systems and concepts Year 2:
Development of the mission concept and definition of the system requirements Year 3:
Analysis of the critical items for the mission implementation and study of the development and calibration plan at mission level. **Institution(s) where the research will be carry out**:
INAF-IAPS

3.4 INAF, fellowships funded by specific projects

One fellowship is granted for students to carry out their research on the following proposal.

3.4.1 Development and Application of ATR-FTS Spectroscopy for the Detection of Biomolecules and Volatiles in Mars-Analog Environments: Implications for Future Space Missions – F. G. Carrozzo

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Co-Supervisors (Name, Institution, and e-mail):

Scientific Case: The detection of traces of past or present life, together with the characterization of in situ available resources, plays a crucial role in understanding the evolution of the Red Planet and in planning future human missions to Mars and the Moon. One of the fundamental aspects of this research is the development of innovative instruments capable of performing direct and non-destructive analyses of Martian soil.
In this context, ATR-FTS (Attenuated Total Reflection - Fourier Transform Spectroscopy) emerges as an innovative and potentially revolutionary technology. This technique, never before employed in planetary sciences, offers a highly effective method for analyzing the chemical composition of planetary materials, detecting biomolecules, and identifying the presence of water and other volatiles. The present study aims to develop a portable prototype of an ATR-FTS spectrometer, with the objective of validating its effectiveness in terrestrial analog environments and assessing its potential for future space missions.
Outline of the Project:
• Miniaturization and optimization of the ATR-FTS spectrometer for space applications.
• Characterization of planetary analog materials to evaluate the instrument's capability to identify relevant compounds.
• Detection and analysis of biomolecules and volatiles potentially indicative of past or present biological activity.
• Study of implications for space exploration missions, with particular attention to the instrument's use on Mars and the Moon.
Planning of the activities:
Year 1:
• Review of the existing scientific literature on ATR-FTS spectroscopy and its application in planetary sciences.
• Design of a portable prototype with a wavelength range between 1-2.5 μm for spectral acquisition of planetary-relevant materials.
Year 2:
• Experimental tests to evaluate the device's capability to identify minerals and materials analogous to Martian and lunar ones.
• Development of a methodology for the detection of biomolecules under controlled conditions.
Year 3:
• Assessment of the ATR-FTS spectrometer's effectiveness in identifying organic molecules potentially indicative of biological processes.
• Validation of the device in terrestrial analog environments, simulating Martian conditions to test the instrument's robustness and reliability.

Institution(s) where the research will be carried out:
INAF-IAPS via del Fosso del Cavaliere, 100 Roma