PhD program in
Astronomy, Astrophysics and Space Science
XXXIX cycle

Available theses @ Tor Vergata, Sapienza, INAF, and ASI

Introduction

This is the list of thesis proposals for the 2023 joint PhD program in Astronomy, Astrophysics and Space Science organized by Tor Vergata and Sapienza Universities, in collaboration with National Institute of Astrophysics (INAF) and Italian Space Agency (ASI).
The following table summarizes the list of fellowships offered by the different institutes.

Institution	Funds	Number of fellowships	Number of proposals	Thesis topics
Tor Vergata	University	5	21	Section 1
Sapienza	University	3	30	Section 2
	PNRR[1]	2	30	Section 2
INAF	INAF-OAR	1	16	Section 3.1
	INAF-OAAb	1	11	Section 3.2
	INAF-IAPS	1	17	Section 3.3
	IAPS (projects funds)	4	4	Section 3.4
	PNRR CTA+ project	3	3	Section 3.5
	PNRR HPC project	1	1	Section 3.6
	PNRR STILES project	1	5	Section 3.7
ASI	ASI	3	3	Section 4
TOTAL		25	111	

[1]PNRR stands for "Piano Nazionale di Ripresa e Resilienza" meaning National Recovery and Resilience Plan (NRRP). It is a post-COVID recovery plan, part of the European Next Generation EU (NGEU) programme.

Contents

1 University of Rome Tor Vergata

A total of five (5) fellowships are granted for students to carry out their research in Tor Vergata on the following proposals.

1.1 Space Weather and Space Science

Supervisor (Name, Istitution and Contact):
Dario Del Moro, Tor Vergata University, dario.delmoro@roma2.infn.it
Co-Supervisor (Name, Istitution and Contact):
Luca Giovannelli, Tor Vergata University, giovannelli@roma2.infn.it
Scientific Case: Planetary and Solar Physics and 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. Solar and space physics 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 increasingly apparent. Space Weather has become a major 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. Depending on the candidate's interests and capabilities, this project may expand towards the investigation and the modelling of the physical processes triggering the energy release on the Sun and the energy deposition on the planet's magnetosphere-atmosphere system, the analysis of new and existing datasets with state-of-the-art techniques, the definition of the potentialities of new remote or in-situ measures, or the development of new instrumentation for the acquisition of relevant, multi-messenger data.
Planning of the activities: 1 year: Strengthening the background in Sun-Earth Relationship 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.
2 year: Deepening the knowledge of space weather by attending 1-2 dedicated conferences and/or schools; publishing first results in peer review journals.
3 year: Publishing main results in peer review journals; networking opportunities; write and defend the PhD thesis
Institution(s) where the research will be carry out: Tor Vergata University

1.2 The Magnetic Field and the Dynamics of the Solar Convection

Supervisor (Name, Istitution and Contact):
Dario Del Moro, Tor Vergata University, dario.delmoro@roma2.infn.it
Co-Supervisor (Name, Istitution and Contact):
Giusy Nigro, Tor Vergata University, giuseppina.nigro@roma2.infn.it
Scientific Case: Planetary and Solar Physics
Outline of the Project: During the last decades, new observational and numerical techniques have provided significant advances in the knowledge of our star and the physical processes occurring in its interior and the space around it. Recent space missions devoted to observing the Sun further stimulate this increasing research field. Despite recent advances, the remaining discrepancies between theoretical models and solar observations imply that something still needs to be added to our understanding of the Sun and the physical mechanisms governing its activity. The advancement of our knowledge must progress on two fronts. On one side, we need to develop further theoretical and numerical models for a deeper understanding of the solar interior, namely the regions below the solar surface that are not directly observable and are the site of the regenerating source of the solar activity (i.e., convection zone), as well as models of the solar atmosphere to address unresolved problems concerning essential manifestations of its activity as solar eruptions. On the other side, we are still striving to get reliable information on the thermodynamic and magnetic properties of the solar atmosphere via spectro-polarimetric observations due to the intrinsic difficulty of the calibration and analysis of the data. Within this project, the PhD candidate will achieve a deep knowledge of the fields of Solar Physics and spectro-polarimetry and, depending on the candidate's interests and capabilities, may acquire the skills and methodologies necessary for decoding the information hidden in the polarization of the solar spectrum, and/or to perform MHD numerical simulations of the solar convection zone and solar atmosphere.
Planning of the activities: 1 year: Strengthening the background in solar physics 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.
2 year: Deepening the knowledge of solar physics by attending 1-2 dedicated conferences and/or schools; publishing first results in peer review journals.
3 year: Publishing main results in peer review journals; networking opportunities; write and defend the PhD thesis
Institution(s) where the research will be carry out: Tor Vergata University

1.3 Changes in the solar irradiance and planetary climatic effects

Supervisor (Name, Istitution and Contact):
Francesco Berrilli, University of Rome Tor Vergata, francesco.berrilli@roma2.infn.it
Co-Supervisor (Name, Istitution and Contact):
Simona Bordoni, UNiversity of Trento, simona.bordoni@unitn.it
Scientific Case: Solar/stellar irradiance and planetary climatic effects
Outline of the Project: the Sun is a magnetic active star whose surface activity, in terms of the coverage of sun-spots, faculae and networks, modulates the irradiance on small-medium (day-years) time scales. Secular variations of solar irradiance (hundreds of years) have a less clear origin but are believed to be present. Since changes in irradiance have a global effect, there must be a global climate solar forcing impact. However, in the energy balance relation for the Earth's climate system, in addition to the direct forcing term which can be easily determined, there is a non-linear term describing the indirect influences on the surface temperature. 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, and possibly Mars or Venus.
Planning of the activities: 1 year: study of the state-of-the-art literature and formation of the scientific background in solar/stellar activity and star/planet interaction especially the context of climate forcing and its variations. Applications on simple case studies of 3D climate models in response to total and spectral variations of solar emission. Relationship by attending 1-2 dedicated conferences and/or schools.
2 year: modifications of the 3D simulation codes of planetary atmosphere models to take into account variations in the emission spectrum of the host star and non-linear response processes.
3 year: study of climatic responses in the face of secular variability of the TSI and SSI or stellar equivalent. Publishing main results in peer review journals.
Institution(s) where the research will be carry out: Tor Vergata University, Trento University and (possibly) University of Exeter

1.4 The dynamic Sun observed with state-of-the-art ground and space-based instrumentation

Supervisor (Name, Istitution and Contact):
Francesco Berrilli, University of Rome Tor Vergata, francesco.berrilli@roma2.infn.it
Co-Supervisor (Name, Istitution and Contact):
Luca Giovannelli, Tor Vergata University, giovannelli@roma2.infn.it
Scientific Case: Dynamic Sun and state-of-the-art instrumentation for space/ground-based astrophysics
Outline of the Project: recent heliospheric space missions that allow to study the dynamics of the solar plasma near our star, such as Parker Solar Probe or Solar Orbiter, and ground-based telescopes with very high spatial and temporal resolution, such as DKIST or GREGOR, allow to study the physical processes underlying the solar variability and Space Weather events with unprecedented observing details. The development of such instrumentation and the analysis of the data available from remote and in-situ instrumentation require advanced experimental capabilities and appropriate data mining and data analysis techniques. The topic of the thesis is solar dynamics which will be investigated with the most recent instruments and data available to the heliophysics community.
Planning of the activities: 1 year: study of the state-of-the-art literature and formation of the scientific background in dynamic Sun and experimental techniques and instruments for space/ground-based spectro-polarimetry. Relationship by attending 1-2 dedicated conferences and/or schools.
2 year: panoramic spectroscopy based on interferometry, data analysis for measurements from space and ground-based. Advanced techniques of Big Data, data mining, ML, etc in Python.
3 year: participation in stationary/ground-based projects in the field of heliophysics and space weather. Publishing main results in peer review journals.
Institution(s) where the research will be carry out: Tor Vergata University, Italian Space Agency and (possibly) Instituto Astrofísica Andalucía (IAA) / Department of Physics and Astronomy at Georgia State University

1.5 DRAGON - Advanced X-ray modeling of powerful black hole winds

Supervisor (Name, Istitution and Contact):
Francesco Tombesi, Tor Vergata University, francesco.tombesi@roma2.infn.it
Co-Supervisor (Name, Istitution and Contact):
Enrico Piconcelli, INAF, enrico.piconcelli@inaf.it, Fabrizio Nicastro, INAF, fabrizio.nicastro@inaf.it, Alfredo Luminari, INAF, alfredo.luminari@inaf.it
Scientific Case: Virtually every galaxy in the universe hosts a supermassive black hole (SMBH) at its center, whose mass is tightly related to the properties of its host. Winds driven by their quasar phase are thought to play a key role by regulating the growth of both the SMBH and the galaxy's stellar component. Key open questions are: 1) How do SMBHs trigger and launch outflows? 2) What is their physical state and geometry? 3) Do they affect SMBH growth and feeding? 4) How are energy and metals transferred out to ISM/CGM scales?
Outline of the Project: X-ray observations are key to address these questions as they probe the innermost, hot phase of the outflow, which carries most of the kinetic energy. We developed a novel, physically-motivated model called "Winds in the Ionized Nuclear Environment" (WINE) that overcomes the major limitations of the current models and represents the best trade-off between physical accuracy and versatility (Luminari+ 2018,2020; Laurenti+ 2021). The student will join our "aDvanced X-RAy modelinG of black hOle wiNds" (DRAGON) project, performing the most advanced spectral analysis of powerful quasar winds in the largest X-ray database currently available in order to derive the physical parameters of the outflows in a homogeneous and self-consistent way.
Planning of the activities: The research activities will be divided in three main sections, with the following objectives: (i) data collection and model set-up, spectral analysis of the DRAGON sample; (ii) detailed estimates of the wind physical parameters; (iii) detailed comparison to theoretical models. The student will join international projects and proposals for the upcoming JAXA/NASA/ESA's X-ray Imaging Spectroscopy Mission (XRISM) to be launched in 2023, which will provide an unprecedented hyper-energy resolution view of AGN X-ray spectra. Opportunities for the student to travel or longer-term internships in international institutes, such as NASA/GSFC and University of Maryland, are expected.
Institution(s) where the research will be carry out: Tor Vergata University of Rome; INAF (OAR Rome, IAPS Rome, OAS Bologna); NASA - Goddard Space Flight Center (USA); University of Maryland (USA)

1.6 Studies of objects closely orbiting supermassive black holes with repeating extragalactic X-ray transients

Supervisor (Name, Istitution and Contact):
Francesco Tombesi, Tor Vergata University, francesco.tombesi@roma2.infn.it
Co-Supervisor (Name, Istitution and Contact):
Dheeraj Pasham, Massachusetts Institute of Technology-MIT, drreddy@mit.edu; Eleonora Troja, Tor Vergata University, nora@roma2.infn.it
Scientific Case: The LIGO-Virgo detection of Gravitational waves (GW) and electromagnetic (EM) emission from an extragalactic object has recently opened up the field of multi-messenger astronomy. Currently, several works have suggested that extreme mass ratio inspirals (EMRIs) containing a supermassive black hole (SMBH) and a stellar-mass/intermediate-mass black hole should produce GWs detectable by ESA's Laser Interferometer Space Antenna (LISA) and also emit EM signals detectable by an X-ray observatory for months/years prior to their merger.
Outline of the Project: Over the last decade multiple classes of repeating, extragalactic nuclear transients with periods ranging from 2 minutes to 20 days have been uncovered in X-rays. This project will be particularly focused on the new phenomenon of quasi-periodic outflows (QPOuts). The student will: i) perform detailed time-resolved X-ray spectral analysis of the entire sample of repeating X-ray transients to search for outflows and perform photo-ionization modeling; ii) based on the estimated strengths of the outflows from X-ray data, compare the results with detailed simulations generated by our group to constrain the mass of the secondary, which will allow us to build a census of mass ratios and rates of such systems; iii) use the latest LISA and Athena X-ray observatory sensitivity curves to simulate the expected GW signals from such systems and the expected multi-messenger science.
Planning of the activities: The thesis work will be based at the Tor Vergata University of Rome, but the student will join an international team and there will be opportunities to travel or long-term internships in top-level international institutes, such as the Massachusetts Institute of Technology (MIT). Besides providing new avenues for discovering EMRIs with current and upcoming facilities (such as NICER, XMM-Newton, XRISM), the project will have important repercussions for future space missions, such as ESA's LISA and Athena.
Institution(s) where the research will be carry out: Tor Vergata University of Rome; Massachusetts Institute of Technology (MIT)

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

Supervisor (Name, Istitution and Contact):
Pasquale Mazzotta, Tor Vergata University, pasquale.mazzotta@roma2.infn.it
Co-Supervisor (Name, Istitution and Contact):
Hervé Bourdin, Tor Vergata University, herve.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: (i) Study of recent reviews of galaxy clusters and related work (ii) Familiarise with the software for data reduction and data analysis (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 (v) Interpretation of the data analysis using current and models
Institution(s) where the research will be carry out: University of Rome ”Tor Vergata”

1.8 Millimetre observations of galaxy clusters

Supervisor (Name, Istitution and Contact):
Hervé Bourdin, Tor Vergata University, herve.bourdin@roma2.infn.it
Co-Supervisor (Name, Istitution and Contact):
Pasquale Mazzotta, Tor Vergata University, pasquale.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: (i) Study of recent reviews of galaxy clusters and related work (ii) Familiarise with the software for data reduction and data analysis (iii) Training in parallel programming with CPU, GPU and High Performance Computing (iv) Millimetre data Analysis of Planck and SPT Data (v) Interpretation of the data analysis using current and models
Institution(s) where the research will be carry out: University of Rome ”Tor Vergata”

1.9 The Galactic thin disk and its chemical enrichment

Supervisor (Name, Istitution and Contact):
Valentina D'Orazi, Tor Vergata University, valentina.dorazi@roma2.infn.it
Co-Supervisor (Name, Istitution and Contact):
Giuseppe Bono, Tor Vergata University, bono@roma2.infn.it; Ronaldo da Silva, INAF, ronaldo.oliveira@inaf.it
Scientific Case: Dating back to more than half a century ago, classical Cepheids (CCs) have been widely used to trace the variation of iron as a function of the Galactocentric distance. The key advantage of using CCs to trace young stellar populations is manifold: i) CCs are very solid primary distance indicators and their individual distances can be estimated with accuracy better than 3%; ii) They are associated with central helium burning phases (blue loop) of intermediate-mass stars. This means that they are quite common and ubiquitous across the Galactic thin disk; iii) CCs have low surface gravities and their spectra are quite rich in absorption lines. Radial metallicity gradients are crucial diagnostics to trace the chemical enrichment history of individual galactic components. The radial variation of different heavy elements, produced either by SN Ia or by massive and AGB stars or by more exotic objects (neutron star mergers), provides fundamental constraints on chemical evolution models. Moreover, the use of CCs will allows us to investigate the role that galaxy mergers, stellar migrations, and kinematics plays in the formation and evolution of galaxies. In addition to these indisputable advantages, radial metallicity gradients allow us to trace the coupling among star-forming regions spiral structure and geometrical complexity (warps, flares, streams).
Outline of the Project: This PhD project will take advantage of new and accurate high resolution optical and near-infrared spectra collected with a variety of spectrographs. Our team was awarded with dopzen of observing nights at medium and large telescopes. The new spectrascopic abundances provide firm constraints on the chemical enrichment history of the thin disk by using neutron capture elements (s- and r- process elements). The same spectra will also be adopted to constrain the kinematics across the spiral arms, and in particular across the disk flare.
Planning of the activities: The 1st year will be mainly devoted to the measurements of atmospheric parameters and the computation of the grid of atmosphere models. The 2nd year will be mainly devoted to the analysis of the neutron captiure elements and to the comparison with chemical evolution models. The research activity in the 3rd year will be focussed on the global view of the chemical enrichment of the thin disk and to the chemical tagging, i.e. to the coupling between chemistry, proper motion (Gaia) and kinematics.
Institution(s) where the research will be carry out: Tor Vergata University, INAF-OAR, ESO (Munich, Santiago).

1.10 The Galactic Bulge: Stellar populations across the Galactic center

Supervisor (Name, Istitution and Contact):
Giuseppe Bono, Tor Vergata University, bono@roma2.infn.it
Co-Supervisor (Name, Istitution and Contact):
Manuela Zoccali, PUC, mzoccali@astro.puc.cl; Vittorio Braga, INAF, vittorio.braga@inaf.it
Scientific Case: The Galactic Bulge is a fundamental laboratory to investigate the early formation and evolution of the Galactic spheroid and its interactions with the thin disk and the Halo. The Bulge is the ideal playground to constrain evolutionary and pulsation properties of old and metal-rich stellar populations. Indeed, similar populations are located well beyond the Local Group (the closest elliptical galaxy is Maffei 1). The formation and evolution of the Bulge is still debated.
Outline of the Project: This PhD project will take advantage of new and accurate near-infrared (H,K) and mid-infrared (L-band) images that will be collected with ERIS at VLT (ESO). Our team was awarded with a Large Programme (100 hours) to perform photometry and spectroscopy of selected Bulge fields. ERIS is a spectro-imager assisted by a Single Conjugated Adaptive Optics (SCAO) that will allow us to perform accurate and deep photometry of the regions across the Galactic center (Sgr A*). The new photometry will provide firm constraints on the star formation history approaching the Galacticv center and their interaction with Sgr A*. Moreover, the same images will be adopted to constrain the impact of stellar crowding on the RR Lyrae distance scale.
Planning of the activities: The first year will be mainly devoted to the analysis of the photometric catalog based the very first images of the Galactic center. The second year will be mainly devoted to the analysis of the bulge fields located above the Galactic plane to investigate stellar populations beyond the Galactic center. The research activity in the 3rd year will be focussed on the global view of the stellar population and geometry of the regions located acrosds the Bulge, the Galactic center and the regions beyond the Galactic center.
Institution(s) where the research will be carry out: University of Rome Tor Vergata, INAF-OAR, ESO (Munich, Santiago).

1.11 The Galactic Bulge and its chemical enrichment

Supervisor (Name, Istitution and Contact):
Valentina D'Orazi, Tor Vergata University, valentina.dorazi@roma2.infn.it
Co-Supervisor (Name, Istitution and Contact):
Giuseppe Bono, Tor Vergata University, bono@roma2.infn.it; Michel Fabrizio, INAF, michele.fabrizio@inaf.it
Scientific Case: The Galactic Bulge is a fundamental laboratory to investigate the early formation and evolution of the Galactic spheroid and its interactions with the thin disk and the Halo. The Bulge is the ideal playground to constrain evolutionary and pulsation properties of old and metal-rich stellar populations. Indeed, similar populations are located well beyond the Local Group (the closest elliptical galaxy is Maffei 1). The formation and evolution of the Bulge is still debated.
Outline of the Project: This PhD project will take advantage of new and accurate near-infrared (J,H,K) low and medium resolution spectra that will be collected with ERIS at VLT (ESO). Our team was awarded with a Large Programme ($\sim$ 100 hours) to perform photometry and spectroscopy of selected Bulge fields. ERIS is a spectro-imager assisted by a Single Conjugated Adaptive Optics (SCAO) that will allow us to provide accurate iron and alkpha-element abundaces of old (RR Lyaree) and intermediate age (red clump) stellar tracers across the Bulge and the Galactic center (Sgr A*). The new spectrascopic abundances provide firm constraints on the chemical enrichment history and the role played by in situ and acrreted stellar populations. The same spectra will also be adopted to constrain the kinematics of both old and intermediate age stellar populations.
Planning of the activities: The first year will be mainly devoted to the measurements of the iron abundancxe and the comparison with similar estimates in the literature. The second year will be mainly devoted to the analysis of alpha elements and to the comparison with chemical evolution models. The research activity in the 3rd year will be focussed on the global view of the chemical enrichment of the Bulge and the analysis of NIR high resolution spectra collected with WINERED at Magellan of Bulge stars.
Institution(s) where the research will be carry out: University of Rome Tor Vergata, INAF-OAR, ESO (Munich, Santiago).

1.12 The cosmic distance scale and the H0 tension

Supervisor (Name, Istitution and Contact):
Giuseppe Bono, Tor Vergata University, bono@roma2.infn.it
Co-Supervisor (Name, Istitution and Contact):
Giuliana Fiorentino, INAF, giuliana.fiorentino@inaf; Vittorio Braga, INAF, vittorio.braga@inaf.it
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 sdistance indicators (RR Lyrae, Tip of the red giant branch) and AGN as secondary distance indicators to constrain possible systematics.
Outline of the Project:
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).

1.13 Physical Properties of Transiting Planetary Systems

Supervisor (Name, Istitution and Contact):
Luigi Mancini, Tor Vergata University, lmancini@roma2.infn.it
Co-Supervisor (Name, Istitution and Contact):
Alessandro Sozzetti, INAF, alessandro.sozzetti@inaf.it
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, TESS, 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 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 architecture of planetary systems with inner small/low-mass planets and outer gas giants to investigate the role of outer giant planets on 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: Observations, Data analysis and modellization
Institution(s) where the research will be carry out: Department of Physics, University of Tor Vergata

1.14 Multimessenger searches in the Einstein Telescope era

Supervisor (Name, Istitution and Contact):
Viviana Fafone, Tor Vergata University, viviana.fafone@roma2.infn.it
Co-Supervisor (Name, Istitution and Contact):
Sabrina D'Antonio, INFN, sabrina.dantonio@roma2.infn.it
Scientific Case: GravitationalWave-GW observations have recently started a new exploration of the Universe. Einstein Telescope (ET) is being proposed as the European project for third generation GW interferometers. ET will be an unprecedented resource to address open questions of 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: ET will operate in synergy with a new generation of innovative electromagnetic (EM) observatories. This project will focus on GW- very high energy GRBs joint observations, with the aim of developing tools to study joint GW-EM strategies making also use of machine-learning algorithms. Previous studies have in fact shown that machine-learning-based classifiers may prove valuable to infer source properties of electromagnetically bright gravitational-wave transients. The thesis will be carried on within the Einstein Telescope Tor Vergata group, in collaboration with EM partners.
Planning of the activities: First year: acquire/improve knowledge of the state-of-the-art searches for joint GW-HE GRBs detections and of data analysis tools. Second year: develop dedicated models and algorithms. Third year: apply the tools to some specific science case e.g. subthreshold searches; thesis writing.
Institution(s) where the research will be carry out: University of Roma Tor Vergata, European Gravitational Observatory

1.15 Adaptive optics for gravitational wave interferometers

Supervisor (Name, Istitution and Contact):
Viviana Fafone, Tor Vergata University, viviana.fafone@roma2.infn.it
Co-Supervisor (Name, Istitution and Contact):
Alessio Rocchi, INFN, alessio.rocchi@roma2.infn.it
Scientific Case: Future GW astronomy will rely on the detection capabilities of next generation interferometers in the low-mid frequency range (Hz-hundreds Hz). The upgraded versions of the Virgo interferometer and the future projects such as Einstein Telescope will foster the exploration of the Universe along its cosmic history back to the cosmological dark ages. The sensitivity to signals from NS and BH coalescing binary systems will be limited by the performances of the optical systems.
Outline of the Project: The aim of this project is to develop new strategies for the improvement of the quality of the core optics, through the reduction of thermal noise and the implementation of cutting-edge adaptive optics. The thesis will be carried on within the Virgo-Einstein Telescope Tor Vergata group, responsible for the development of the adaptive optical system and member of the international coating R&D collaboration.
Planning of the activities: 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. Second year: develop dedicated models, design the optical set up and start measurements and characterization. Third year: complete the characterization measurements; thesis writing.
Institution(s) where the research will be carry out: University of Roma Tor Vergata, European Gravitational Observatory

1.16 The component separation challenge for future CMB observations

Supervisor (Name, Istitution and Contact):
Marina Migliaccio, Tor Vergata University, migliaccio@roma2.infn.it
Co-Supervisor (Name, Istitution and Contact):
Mathieu Remazeilles, IFCA Santander, remazeilles@ifca.unican.es; Alessandro Carones, Tor Vergata University, alessandro.Carones@roma2.infn.it
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 foreground contamination from microwave emissions originating in our own Galaxy. This foreground contamination is expected to surpass the primordial signal across all areas of the sky. To achieve the ambitious objectives of future experiments, it is crucial to develop sophisticated component separation methods that can effectively separate the primordial signal from the astrophysical foregrounds.
Outline of the Project: Building upon existing frameworks, the project will focus on improving the foreground separation techniques in preparation for future experiments. This requires developing algorithms and statistical methods able to effectively handle complex foreground emissions. In addition, taking advantage of realistic simulations, the project will investigate the interplay between Galactic polarised emission and instrumental effects on the CMB B-modes reconstruction. Ultimately, the aim is to assess how these contaminants impact the ability to constrain models of the early universe.
Planning of the activities: The project will be carried out jointly at Tor Vergata and IFCA. The cosmology groups of both institutes are actively involved in planning future observational campaigns from space (LiteBIRD, PICO) and from the ground (Simons Observatory, CMB-Stage4), and the project will be carried out in an extremely international environment. The initial phase of the project will be devoted to acquiring a comprehensive understanding of the research field and developing specific skills in data analysis techniques, foreground modelling and simulation of realistic datasets. The project will then focus on optimising the foreground cleaning methods for upcoming experiments and implement approaches based on simulations to assess how the performance of these methods impacts cosmological constraints.
Institution(s) where the research will be carry out: University of Rome “Tor Vergata” and IFCA Santander Spain

1.17 Cosmology from the cross-correlation of Cosmic Filaments and Cosmic Microwave Background observations

Supervisor (Name, Istitution and Contact):
Marina Migliaccio, Tor Vergata University, migliaccio@roma2.infn.it
Co-Supervisor (Name, Istitution and Contact):
Carmelita Carbone, INAF, carmelita.carbone@inaf.it; Javier Carron-Duque, INFN, javier.carron@roma2.infn.it

Scientific Case: In the coming years, deep and wide galaxy surveys will collect a wealth of new data, covering a wide range of physical scales and different cosmic epochs. This presents the opportunity to achieve an unprecedented reconstruction of the Cosmic Web, combining both high accuracy and a wide cosmological volume. By mapping the evolution of cosmic filaments and investigating their cross-correlation with complementary measurements of the CMB temperature anisotropies and gravitational lensing, we can design a novel approach to constrain the cosmological model and its extensions. This project is especially timely, given the imminent launch of the ESA Euclid mission scheduled for July 2023.

Outline of the Project: The project will involve designing innovative methods to reconstruct cosmic filaments starting from the observed galaxy distribution. The work will build upon existing frameworks (Carron-Duque, Migliaccio et al. 2022) and take advantage of Machine Learning techniques. Testing on realistic large simulations in different cosmological scenarios (Parimbelli, Carbone et al. 2022) will allow us to characterise the cross-correlation with CMB observables and the dependence on different cosmological models, the distribution of dark matter, the nature of gravity, and neutrino masses.

Planning of the activities: The initial phase of the project will be devoted to acquiring a comprehensive understanding of the reconstruction techniques and the simulated datasets. Subsequently, the focus will be on optimising and forecasting the performance of the reconstruction in preparation for upcoming photometric and spectroscopic surveys, especially in view of the Euclid internal data releases DR1 (2025) and DR2 (2027). Finally, cross-correlations of filaments with CMB and weak-lensing simulated and/or real data will be studied.

Institution(s) where the research will be carry out: University of Rome “Tor Vergata”

1.18 A multi-messenger study of relativistic jets from compact binary mergers

Supervisor (Name, Istitution and Contact):
Eleonora Troja, Tor Vergata University, eleonora.troja@uniroma2.it
Co-Supervisor (Name, Istitution and Contact):

Scientific Case: Jets are ubiquitous phenomena across all scales of black hole (BH) mass. Understanding their formation, composition, and propagation is a key objective of high-energy astrophysics. This thesis will focus on jets produced by the collision (or merger) of two compact objects, either two neutron stars (NSs) or a NS and a BH. These systems are loud sources of gravitational waves and produce the most powerful explosions in the Universe, known as gamma-ray bursts. The student will be directly involved in the observations of gamma-ray bursts and gravitational wave counterparts discovered during the on-going observing run O4. The properties of their jets will be characterized through gamma-ray (Swift, Fermi, INTEGRAL), X-ray (Swift, Chandra, XMM-Newton, NuSTAR) and radio (VLA, ATCA, EVN) data, and compared to state-of-the-art theoretical models incorporating complex angular structures. By using complementary streams of data from gravitational wave and electromagnetic observations, the thesis will explore how the fate of the relativistic jet depends on the intrinsic properties of the merger, and the nature of its remnant (BH vs. NS).
Outline of the Project:
Planning of the activities:
Institution(s) where the research will be carry out: Tor Vergata

1.19 Mapping the diversity of kilonova emission from compact binary mergers

Supervisor (Name, Istitution and Contact):
Eleonora Troja, Tor Vergata University, eleonora.troja@uniroma2.it
Co-Supervisor (Name, Istitution and Contact):

Scientific Case: Kilonovae are a new class of astrophysical transients powered by the radioactive decay of heavy nuclei, freshly synthesized after the collision (or merger) of two neutron stars (NSs). Building a sample of well-studied kilonovae is the next crucial step to advance our understanding of these mergers and assess their role in the production of metals heavier than iron, such as gold, platinum, and uranium. The PhD student will be directly involved in the observations of new kilonovae, selected along three different channels: gravitational wave sources, gamma-ray bursts, and wide-field sky surveys. Observations will be mostly carried out at ultraviolet, optical and IR wavelengths, and will involve both imaging and spectroscopy with ground-based (GTC, Gemini, VLT) and space-based (Swift, HST, JWST) observatories. Any new kilonova will be compared to state-of-the-art simulated light curves and spectra of varying input parameters to infer the ejecta morphologies, compositions, masses, and velocities. The thesis will explore how the colors of the kilonova emission depends on the observer's viewing angle, the intrinsic properties of the merger, and the nature of its remnant (BH vs. NS).
Outline of the Project:
Planning of the activities:
Institution(s) where the research will be carry out: Tor Vergata

1.20 Probing the equation of state of hot dense matter with multi-messenger observations

Supervisor (Name, Istitution and Contact):
Eleonora Troja, Tor Vergata University, eleonora.troja@uniroma2.it
Co-Supervisor (Name, Istitution and Contact):

Scientific Case: The behavior of matter at supra-nuclear densities is unknown and represents one of the fundamental open questions of modern astrophysics. These extreme physical conditions are beyond the capabilities of laboratories on Earth and cannot be calculated from first principles but can only be probed observing astrophysical phenomena involving neutron stars (NSs) and black holes (BHs). This thesis will focus on multi-messenger observations of compact binary mergers, formed by either two NSs or a NS and a BH, and explore how they can be employed to constrain the nuclear equation of state (EoS). The student will be directly involved in the observations of gravitational wave counterparts discovered during the on-going run O4. The lessons learned will be used to outline the scientific prospects for the next generation observatories, such as the Einstein Telescope and NewAthena.
Outline of the Project:
Planning of the activities:
Institution(s) where the research will be carry out: Tor Vergata

1.21 Exploring the transient universe in the era of multi-messenger astronomy and Big Data

Supervisor (Name, Istitution and Contact):
Eleonora Troja, Tor Vergata University, eleonora.troja@uniroma2.it
Co-Supervisor (Name, Istitution and Contact):

Scientific Case: Modern telescopes revealed to us a dynamic and ever-changing sky, populated by a myriad of stellar explosions, eruptions, and collisions. In recent years, wide-field sky surveys have enormously increased the quantity and variety of known astrophysical transients, and these numbers are expected to sky-rocket with the advent of the Vera Rubin Observatory. At the same time, gravitational wave (GW) detectors have ushered in a new era of multi-messenger astrophysics, in which GW and light can be combined to open new windows onto the extreme Universe. However, the electromagnetic counterpart of a GW source often needs to be painstakingly searched sifting through hundreds of possible candidates. This thesis will address the open questions and challenges of transient discovery and classification in the new era of data-driven multi-messenger time-domain astrophysics. It will develop new observing strategies and methods for the discovery of kilonovae at optical and near-infrared wavelengths, paving the way to their identification with the Nancy Grace Roman Space Telescope.
Outline of the Project:
Planning of the activities:
Institution(s) where the research will be carry out: Tor Vergata

2 Sapienza Universtity of Rome

A total of five (5) fellowships are granted for students to carry out their research in Sapienza on the following proposals. Three (3) of the five theses are funded by Sapienza and two (2) of the five theses are funded by Sapienza with PNRR support, and require to spend a period of 6 months abroad during the three years of activity.

2.1 Extreme physics in the galactic center environments

Supervisor (Name, Istitution and Contact):
Roberto Capuzzo Dolcetta, Sapienza University, Roberto.capuzzodolcetta@uniroma1.it
Co-Supervisor (Name, Istitution and Contact):
TBD
Scientific Case: The central region of our Galaxy and of other galaxies are very densely populated by stars whose number density can reach up to 10^7 stars per cubic parsec. Moreover, galactic centers almost always host a super massive black hole. Such environment represents a unique opportunity to study gravity in the strong field regime, testing General Relativity and investigating interesting mechanisms of gravitational wave emission. This thesis is in the theoretical/numerical side of this scientific context.
Outline of the Project: Galactic centers are site of strong gravitational fields where classical Newtonian mechanics shows to be insufficient to provide a clear understanding of the phenomena, from the observed gravitational redshifts and star movement precession The thesis indeed aims to have a good modelization with sophisticated N-body codes which includes both regularization of strong interactions and the inclusion of the approximation of General relativity by means of Post Newtonian treatment. The scope of the thesis is indeed the evaluation of the role of deviation from Newtonian physics in such peculiar environments with subsequent feedback on star dynamics and gravitational wave emission.
Planning of the activities: In the first months of his activity the student should improve his knowledge of classical and relativistic gravitation to be able to model the dynamical physics of galactic nuclei in presence of super massive black holes. After this he will operate on existing sophisticated simulation codes and he is expected to be able to implement with new physics their structure in order to perform modern and accurate estimates of the consequences of the physical processes in such very dense environments. All this is expected to happen in the three years of the PhD program.
Institution(s) where the research will be carry out: The project will be mainly developed at the dep. of Physics in Sapienza in strict collaboration with the group of the Max Planck Inst. fuer Extraterrestrial Physic lead by the Nobel laureate prof. R. Genzel which will provide us with the data coming from the GRAVITY project active at the VLT facility operated by ESO. Collaboration is planned also with prof. R. Spurzem at the Heidelberg university and prof. F. Antonini at the Gravity Exploration Institute of the Cardiff university.

2.2 Study and optical characterisation of the millimetre-wave polarisation modulator for the LiteBIRD MHFT instrument

Supervisor (Name, Istitution and Contact):
Giampaolo Pisano,
Sapienza University, giampaolo.pisano@uniroma1.it
Co-Supervisor (Name, Istitution 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

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

Supervisor (Name, Istitution and Contact):
Giampaolo Pisano,
Sapienza University, giampaolo.pisano@uniroma1.it
Co-Supervisor (Name, Istitution 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

2.4 Cosmology in the JWST era

Supervisor (Name, Istitution and Contact):
Alessandro Melchiorri, Sapienza University, alessandro.melchiorri@uniroma1.it
Co-Supervisor (Name, Istitution and Contact):
...
Scientific Case: The James Webb Space Telescope (JWST) offers unique capabilities to constrain cosmology. It can probe the early 'dark ages' of the Universe and the epoch of reionization, providing insights into dark matter, inflation, and primordial density fluctuations. Furthermore, its high-resolution imaging and spectroscopy enable the study of galaxy formation and evolution. By combining these observations, JWST will provide crucial constraints on cosmological models, possibly revolutionizing our understanding of the Universe's origin and evolution.
Outline of the Project: The goal of this project is to utilize the high-resolution imaging and spectroscopic capabilities of the James Webb Space Telescope (JWST) to study high-redshift galaxies and constrain cosmological models. We will identify and observe a sample of high-redshift galaxies using JWST's near-infrared instruments. By analyzing their properties, including stellar populations, star formation rates, and spatial distributions, we aim to obtain key measurements that can be used to constrain cosmological models, such as the expansion rate of the Universe, the nature of dark energy, and the growth of cosmic structures.
Planning of the activities:We plan to a) select a sample of high-redshift galaxies based on existing surveys and observational data. b) Collect and analyze data from JWST observations, including measurements of galaxy properties and redshifts. c) Conduct statistical analysis and compare the observed galaxy properties with predictions from cosmological models. d) Refine and constrain cosmological models based on the comparison between observations and theoretical predictions. e) Publish the results in scientific journals and present findings at relevant conferences.
Institution(s) where the research will be carry out: Sapienza University Physics Dept.

2.5 Modelling for Tensions of Precision Cosmology

Supervisor (Name, Istitution and Contact):
Alessandro Melchiorri, Sapienza University, alessandro.melchiorri@uniroma1.it
Co-Supervisor (Name, Istitution and Contact):
Giovanni Montani, Sapienza University, giovanni.montani@uniroma1.it
Scientific Case: In the era of precision cosmology the physical parameters, characterizing the Universe evolution, are measured with a high level of accuracy and, in recent years tensions emerged in data coming from independent source studies. The most important discrepancy in data is the so-called Hubble tension, which outlines, at 5 sigma, the incompatibility between the value of the Hubble constant as measured by the Planck Satellite and by the SNIa Pantheon+ sample.
Outline of the Project: The proposed study aims at developing theoretical models to interpret the Hubble tension via modified gravity theories, with particular attention to the metric f(R)-Lagrangian. The basic ingredient, able to account for the Hubble constant scaling, is the scalar field, non-minimally coupled to standard gravity, emerging in the Jordan frame and which potential term reflects the form of the considered f(R)-model.
Planning of the activities: The study will start by a critical analysis of the existing literature and will then be dedicated to set up a specific theoretical framework for the Universe dynamics in extended gravity. Furthermore, the constructed models have to be validated by comparison with data and, in order to conciliate the Hubble tension with other data discrepancies, the modified gravity theory has to be combined to other effects, like local Universe inhomogeneities and quintessence formulations with varying equation of state parameter.
Institution(s) where the research will be carry out: Sapienza University Physics Dept.

2.6 Polarimetric measurements of the Cosmic Microwave Background: looking for signals from cosmic inflation

Supervisor (Name, Istitution and Contact):
Paolo de Bernardis,
Sapienza University, paolo.debernardis@roma1.infn.it
Co-Supervisor (Name, Istitution and Contact):
Fabio Columbro, Sapienza University, fabio.columbro@roma1.infn.it
Scientific Case: 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: first year: study of the thory of CMB polarization, polarized foregrounds, advanced measurement methods, participation in instrument development second year: instrument development, calibration measurements, simulations and mitigation of systematic effects third year: 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

2.7 Cosmic Microwave Background polarization with the QUBIC experiment

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).

2.8 Sunyaev Zel'dovich effect study of galaxy clusters and cosmic web with medium and high angular resolution

Supervisor (Name, Istitution and Contact):
Elia Battistelli, Sapienza University of Rome, elia.battistelli@roma1.infn.it
Co-Supervisor (Name, Istitution and Contact):
Adam Hincks, University of Toronto, adam.hincks@utoronto.ca
Scientific Case: The Cosmic Web and filaments between clusters are a clear prediction of the process of hierarchical formation via continuous accretion and have the potential to unveil the open question of Baryonic Dark Matter. This can be probed observationally using the interaction of hot electrons in the predicted filaments with the CMB photons: the Sunyaev Zel'dovich (SZ) effect. The same effect can be used to study Galaxy Clusters and their astrophysics through high angular resolution observation.
Outline of the Project: During the PhD period, the student will perform observations and data analysis of microwave data from large radio telescope like the Green Bank Telescope (projects GBT/19B-095 PI: Battistelli) with the goal to unveil the nature of the cosmic web. In addition, the student will be proposed to join the Atacama Cosmology Telescope collaboration to cross correlate high angular resolution (10 arcsec) data with moderate angular resolution ones (2 arcmin).
Planning of the activities: The student will prepare the observational strategy and observational plan, and participate to the commissioning, for the MISTRAL experiment, a millimetric camera built at Sapienza University for the Sardinia Radio Telescope. MISTRAL, with an angular resolution of 12 arcsec and a Field of View of 4 arcmin, is an ideal facility instrument for millimetric observation of the Galaxy Clusters and their outskirts.
Institution(s) where the research will be carry out: Physics Department, Sapienza Univeristy of Rome

2.9 Anomalous Microwave Emission: observations and data analysis with the Sardinia Radio Telescope and the Atacama Cosmology Telescope

Supervisor (Name, Istitution and Contact):
Elia Battistelli, Sapienza University of Rome, elia.battistelli@roma1.infn.it
Co-Supervisor (Name, Istitution and Contact):
Matteo Murgia, INAF, matteo.murgia@inaf.it
Scientific Case: Anomalous Microwave Emission (AME) is an astrophysical emission that still lacks a full theoretical comprehension. The most updated models predict that AME is dominated by electric dipole emission from rapidly rotating dust grains: the Spinning Dust. Of great interest is the possibility to detect AME from extragalactic sources as it represents a unique possibility to study astrophysical processes so far only studied in our Galaxy. Past and ongoing projects at the Parkes telescope, Sardinia Radio Telescope (SRT), and the Green Bank Telescope (GBT) are showing the importance of high angular resolution (arcmin level) measurements.
Outline of the Project: The SRT is undergoing a renewal of the receiver suite that will include, besides the up-to-date existing facilities, a new 19-beam Q-band (33-50 GHz) heterodyne receiver for SRT Gregorian focus. In the range 33-50GHz, AME is supposed to be decreasing with frequency, a peculiar feature that will allow astronomers to disentangle its emission from thermal dust emission and to disentangle models.
Planning of the activities: During the PhD, the student will analyze existing data, and will propose and make high angular resolution observations with existing facilities. Among others, the student will analyze data from the Atacama Cosmology telescope which recentily underwent an upgrade with 30GHz and 40GHz channels.
Institution(s) where the research will be carry out: Physics Department, Sapienza Univeristy of Rome

2.10 Cosmological parameters from Euclid probes

Supervisor (Name, Istitution and Contact):
Roberto Maoli, Sapienza University, roberto.maoli@roma1.infn.it
Co-Supervisor (Name, Istitution and Contact):
Vincenzo Cardone, INAF, vincenzo.cardone@inaf.it
Scientific Case: Determination of cosmological parameters for Dark Energy and Modified Gravity models using the data from Euclid survey
Outline of the Project: The Euclid satellite will carry on spectroscopic and imaging survey of 15000 sq deg providing both galaxy clustering and weak lensing data. As additional probes, Euclid will also detect a large sample of galaxy clusters and allow cross – correlation of the galaxy field with CMB. In order to make the best profit of the whole dataset, it is of paramount importance to investigate the correlation among these different probes both at the level of the theoretical signal and the data covariance. This will not only increase the accuracy on the cosmological parameters (making the total larger than the sum of the parts), but also look for any systematics which can bias the results from a single probe. The proposed thesis aims at developing a self – consistent approach to Euclid data relying on a likelihood analysis which correctly takes into account the covariance among each individual dataset. The work will be carried out in close interaction with the likelihood work packages of the Euclid Consortium, and with the cosmological simulations group in order to validate the method against realistic mock data. Moreover, the timeline of the PhD cycle nicely matches those of Euclid whose first data release will be available in time to use the developed methods on true data.
Planning of the activities: The proposed project can be carried on in three steps approximately matching the three years of the PhD course duration as follows.
Step 1 (1st year): development of theoretical framework and of the code infrastructure; Step 2 (2nd year): development of the code and validation against benchmark codes; Step 3 (3rd year): test against simulations and use on real data (if available).
Institution(s) where the research will be carry out: Dipartimento di Fisica - Università La Sapienza I.N.A.F. - Osservatorio Astronomico di Roma

2.11 Realtime searches for high energy neutrinos with KM3NeT/ARCA

Supervisor (Name, Istitution and Contact):
Irene Di Palma, Sapienza University, Irene.DiPalma@uniroma1.it
Silvia Celli, Sapienza University, Silvia.Celli@uniroma1.it
Co-Supervisor (Name, Istitution and Contact):
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. The geometry of the KM3NeT/ARCA detector is particularly suited for the detection of high-energy events, allowing for the investigation of the origin of the diffuseastrophysical neutrino flux, observed since a decade now but whose origin still remains a mystery. The analysis of real-timeneutrino data is of paramount importance in the context of the identification of transient sources, as Gamma-Ray Bursts and flaring blazars, whose high-energy radiation 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, e.g. the observation of neutrinoscoincident with a given population of gamma-ray sources is of paramount importance to constrain the fraction of protons that are accelerated in these sources, and hence their possible connection with Ultra-High Energy Cosmic Rays (UHECRs).
Planning of the activities: In the online alert system framework, the student will characterize possible neutrino sources within a variety of emission models, and also implement dedicated algorithms for the identification of their possible neutrino emission in the online alert system of ARCA.
Institution(s) where the research will be carry out: Physics Department of Sapienza University of Rome

2.12 Multi-messenger search for core collapse supernovae with KM3NeT

Supervisor (Name, Istitution and Contact):
Irene Di Palma, Sapienza University, Irene.DiPalma@uniroma1.it
Co-Supervisor (Name, Istitution and Contact):
Silvia Celli, Sapienza University, Silvia.Celli@uniroma1.it
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 thecore, gravitational waves probe deeper in.
Outline of the Project: A new analysis concept has been recently developed to enhance the detection efficiency ofCCSN signals. In fact, it is necessary to consider a multi-messenger method that takes advantage of the informationcoming 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. Physics Department of Sapienza University of Rome
Institution(s) where the research will be carry out: Physics Department of Sapienza University of Rome

2.13 Characterisation of the atmospheres of extrasolar planets with the Ariel space mission

Supervisor (Name, Istitution and Contact):
Enzo Pascale, Sapienza University of Rome, enzo.pascale@uniroma1.it
Co-Supervisor (Name, Istitution and Contact):
Giusi Micela, INAF, giuseppina.micela@inaf.it
Scientific Case: Planets orbiting stars other than our Sun, known as exoplanets, have been successfully detected in large numbers through dedicated surveys conducted by ground-based telescopes and space observatories. Despite this remarkable achievement, our understanding of these alien worlds remains limited. To address this gap in knowledge, 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). The mission aims to revolutionize our understanding of exoplanets in the Galaxy.
Outline of the Project: In this exciting project, you will have the opportunity to join the consortium responsible for designing Ariel to conduct a spectroscopic survey of approximately 1000 exoplanet atmospheres across visible and infrared wavelengths. The primary objective of the Ariel sample is to obtain statistically representative measurements of the chemical composition and thermal structures of hundreds of transiting exoplanets. This comprehensive dataset will enable groundbreaking advancements in planetary science, extending our knowledge beyond the boundaries of our own Solar System.
Planning of the activities: As a member of the Ariel consortium, you will work under the guidance of the Ariel Mission Scientist and assume a leading role in the international Ariel collaboration. Your involvement may encompass one or more of the following areas of investigation: optimizing instrument design, evaluating science performance, developing data reduction and science analysis pipelines, and characterizing instrument and astrophysical systematics. The specific project topics will be tailored to your personal interests and scientific curiosity, ensuring a fulfilling and engaging research experience. The project also offers opportunities for travel to meet collaborators and attend workshops, conferences, and post-graduate schools, further enhancing your professional development.
Institution(s) where the research will be carry out: Sapienza University of Rome

2.14 Exploring the black hole landscape at cosmic dawn

Supervisor (Name, Istitution and Contact):
Raffaella Schneider, Sapienza University, raffaella.schneider@uniroma1.it
Co-Supervisor (Name, Istitution and Contact):
Rosa Valiante, INAF, rosa.valiante@inaf.it; Luca Graziani, Sapienza University, luca.graziani@uniroma1.it; Tommaso Zana, Sapienza University, tommaso.zana@uniroma1.it
Scientific Case: Hundreds of quasars have been discovered and characterized at $z > 5$, with the most distant found at only 670 million years after the Big Bang. The super massive black holes (SMBHs) that power these sources have masses of order, $10^8 - 10^9 M_\odot$, raising the question of how such systems were built in such a short amount of cosmic time. Most theories involve Eddington-limited or possibly super-Eddington accretion onto seed BHs that are predicted to form at $10 < z < 30$, and have masses that range from $\simeq 100 M_\odot$ to over $\simeq 10^5 M_\odot$. The relative contribution of each seed type and their dominant growth mode remain largely unconstrained by observations.
Outline of the Project: JWST is starting to be a game changer by pushing observations to lower SMBH ($\simeq 10^6 M_\odot$) and to higher redshifts ($z \simeq 11$), into a regime where BHs are expected to keep memory of their initial seed mass (Valiante et al. 2018). Understanding to what extent present and future JWST data are capable of constraining BH seeding and growth requires self-consistent models that are capable to explore the rich BH landscape at cosmic dawn across a broad range of physical scales and redshifts, from the formation sites of the first stars to the most massive galaxies hosting SMBHs at $z > 6$, from the innermost nuclear regions where BHs grow by accreting gas, to the large scales where galaxies exchange gas with their surrounding environment.
Planning of the activities: We propose to base our analysis on a complementary set of theoretical tools. We will make extensive use of the semi-analytical model CAT (Cosmic Archaeology Tool, Trinca et al. 2022, 2023) to explore different BH seeding prescriptions and the impact of more sophisticated modeling of BHs dynamical evolution, gas feeding and feedback. In addition, we will run ultra-high resolution hydrodynamical simulations of dense nuclear disks to explore BH feeding and feedback, and to develop motivated prescriptions for BH accretion to be incorporated in CAT. The results will be compared to JWST observations, by simulating BH/host galaxy emission spectra with photoionization models and will provide state-of-the-art candidates for third generation gravitational wave telescopes such as LISA and ET.
Institution(s) where the research will be carry out: Sapienza University, with a tight collaboration with the extragalactic group at INAF/Rome Astronomical Observatory. Long-term visit to a foreign institution (Institute for Astronomy – Cambridge University, or the University of Zurich, depending on the development stage of the project) is envisaged.

2.15 Understanding the formation of the first galaxies in the JWST era: the growth of metals, dust, and stellar mass at early cosmic times

Supervisor (Name, Istitution and Contact):
Raffaella Schneider, Sapienza University, raffaella.schneider@uniroma1.it
Co-Supervisor (Name, Istitution and Contact):
Luca Graziani, Sapienza University, luca.graziani@uniroma1.it; Tommaso Zana, Sapienza University, tommaso.zana@uniroma1.it
Scientific Case: We are witnessing an exciting revolution in our understanding of the first billion years of cosmic history. The launch of the JWST has already enabled the discovery of galaxies in the first few hundred million years, and their detailed characterization in terms of chemical enrichment, stellar populations, morphologies, and environment is ongoing. In addition, there have also been recent probes of the dust content of galaxies in the first billion years with ALMA. This wealth of data has the potential to paint a picture of unprecedented clarity of the first billion years of cosmic evolution, if we have robust theoretical models with which to interpret them.
Outline of the Project: The ultra-high redshift galaxies being discovered and studied in detail by JWST are unprecedented laboratories for testing our theories of how stars form out of dense gas, how feedback from massive stars and supernovae impact galaxy formation, how galaxies are enriched with heavy elements, and how dust is formed and destroyed in their interstellar medium. The proposed PhD project aims to address the following main astrophysical questions: what is the nature of the stellar populations inhabiting the first galaxies? What are their star formation and chemical enrichment histories? Do we understand the key physical processes that shape their evolution?
Planning of the activities: We propose to address the above questions by developing, testing, and running a new set of cosmological hydrodynamical simulations with the code dustyGadget (Graziani et al. 2020, Di Cesare et al. 2023), a modified version of the Gadget code which accounts for the production of dust by stellar populations and its evolution in the interstellar medium, where we plan to include a more detailed physical description of star formation and feedback in early galaxies. Detailed analysis of the simulations results will be carried out, including postprocessing with radiative transfer codes to provide multiwavelength spectra of synthetic galaxies. These will be extensively compared to observational data, thanks to ongoing collaborations with teams involved in JWST and ALMA observational programs.
Institution(s) where the research will be carry out: Sapienza University, with a tight collaboration with the extragalactic group at INAF/Rome Astronomical Observatory. Long-term visit to a foreign institution (Institute for Astronomy – Cambridge University, or University of Texas at Austin, depending on the development stage of the project) is envisaged.

2.16 Analysis and Validation of Electromagnetic Simulations for Cosmic Microwave Background (CMB) Polarization Observations.

Supervisor (Name, Istitution and Contact):
Luca Lamagna, Sapienza University of Rome, luca.lamagna@uniroma1.it
Co-Supervisor (Name, Istitution and Contact):
Giampaolo Pisano, Sapienza University of Rome, giampaolo.pisano@uniroma1.it; Alessandro Paiella, Sapienza University of Rome, alessandro.paiella@uniroma1.it
Scientific Case: The CMB, a remnant radiation emitted approximately 13.8 billion years ago after the Big Bang, represents one of the most powerful sources of information to probe the early stages of the universe. The polarization of the CMB provides valuable insights into the structure and evolution of the primordial universe, including processes like cosmic inflation and the formation of the first structures. To fully harness the informational potential of the CMB and its polarization, an accurate and detailed understanding of the quasi-optical components used in observations is necessary. Electromagnetic simulations play a crucial role in this process, as they allow for the study and optimization of the response of these components to CMB radiation.
Outline of the Project: The proposed project will focus on the analysis and validation of electromagnetic simulations, with the aim of ensuring that the models used accurately represent real observational conditions. An interdisciplinary approach will be required, combining knowledge from physics, cosmology, electromagnetism, and instrumentation, to critically analyze simulation results and compare them with experimental data of breadboard models designed and built for validation purposes. During the development of the project, candidates will have the opportunity to work with data from prominent ground-based and space missions in the field of CMB cosmology and collaborate with recognized experts in this field. Through this experience, they will acquire advanced skills in data modeling and analysis, the use of sophisticated computational tools, and an understanding of the technical challenges associated with cosmological observations.
Planning of the activities: Identification of reference designs and acquisition of the expertise for electromagnetic modeling; case studies of interest for specific CMB experiments of the current and next generation, including LSPE, COSMO, QUIJOTE and LiteBIRD; prototype/breadboard construction and laboratory characterization; comparison of predictions and experimental results.
Institution(s) where the research will be carry out: Physics Department, Sapienza University of Rome; ancillary activities may be carried out with the collaboration of foreign institutions in France, UK, Japan, and may require activity in different laboratories in these countries.

2.17 Optical modeling and validation for the next generation CMB satellite LiteBIRD.

Supervisor (Name, Istitution and Contact):
Luca Lamagna, Sapienza University of Rome, luca.lamagna@uniroma1.it
Co-Supervisor (Name, Istitution and Contact):
Marco De Petris, Sapienza UNiversity of Rome, marco.depetris@uniroma1.it; Francesco Piacentini, Sapienza University of Rome, francesco.piacentini@uniroma1.it
Scientific Case: The polarization of the Cosmic Microwave Backgorund (CMB) carries invaluable information about the early universe and its fundamental properties. Understanding the origin and evolution of cosmic structures, as well as the nature of dark matter and dark energy, relies heavily on precise measurements of CMB polarization. The LiteBIRD mission, currently planned for launch in 2030, aims to revolutionize our understanding of these cosmic puzzles by mapping the polarization patterns of the CMB with unprecedented sensitivity and resolution.
Outline of the Project: In order to achieve the ambitious target sensitivity of LiteBIRD, it is essential to have a thorough understanding of the optical properties of its instruments. The optical modeling carried out in this PhD thesis will play a crucial role in accurately predicting and interpreting the measurements obtained by the LiteBIRD Middle and High Frequency Telescope. By simulating the behavior of light within the instrument's optical system, taking into account the effects of various components and their interactions, we can optimize the instrument's performance, assess potential systematic effects, and ensure the reliability and accuracy of the scientific data and inform the critical requirements for the Assembly and Instrument Verification phase of the project. The successful candidate will benefit of the opportunity to work within an international and collaborative research environment, access state-of-the-art facilities and resources for optical modeling and data analysis, supervision and mentorship from leading experts in cosmology and instrument development, and the possibility of contributing to scientific publications and attending international conferences and collaboration meetings.
Planning of the activities: Develop and implement advanced optical design techniques tailored to the LiteBIRD MHFT dual telescope; simulate and analyze the propagation of light through the instrument, including optical elements, polarization modulator, detectors, and filters; investigate and optimize the performance of the instrument by analyzing key parameters such as spectral response, efficiency, and polarization properties. collaborate closely with experts in the field and actively contribute to the LiteBIRD instrument design finalization. Validate the optical models using existing breadboard calibration data and participate in the development of strategies for systematics mitigation.
Institution(s) where the research will be carry out: Physics Department, Sapienza University of Rome; ancillary activities may be carried out with the collaboration of foreign institutions in France, UK, Japan, and may require activity in different laboratories in these countries.

2.18 Advancing Observational Cosmology through CMB Polarization Measurements: calibration Strategies for the LiteBIRD Mission.

Supervisor (Name, Istitution and Contact):
Francesco Piacentini, Sapienza University of Rome, francesco.piacentini@uniroma1.it
Co-Supervisor (Name, Istitution and Contact):
Luca Lamagna, Sapienza University of Rome, luca.lamagna@roma1.infn.it

Scientific Case: Accurate measurement of the Cosmic Microwave Background polarization allows to detect the presence of gravitational waves in the early Universe, at the recombination epoch. These gravitational waves carry information on the inflation mechanism in the very early Universe. Polarization measurements in the microwave band also permit to constrain the re-ionization history of the Universe, linked to the formation of first stars; to measure the topology of the universe and possible anomalies; to characterise the matter distribution in the Milky way, and more. LiteBIRD, is a Japanese-lead space mission, with relevant contribution from the US and EU countries, devoted to the measurement of the CMB polarization with degree-scale angular resolution, in 15 frequency bands between 40 and 410GHz. It is scheduled for a launch in 2030. The spacecraft hosts three instruments, LFT, MFT and HFT covering low, mid and high frequency ranges respectively. The supervisor of the proposed thesys is the Instrument Scientist of the MFT and HFT instruments, which are contributed by Europe. 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 goal of the project is to address the challenges realted to calibration of the instruments of the LiteBIRD mission. Specific research objectives include:
a. Evaluate and analyze the calibration requirements of the LiteBIRD instruments.
b. Develop calibration techniques to achieve high precision and accuracy in the polarization measurements.
c. Contribute to the definition of the calibration plan.
d. Investigate potential sources of systematic errors and develop mitigation strategies.
e. Perform extensive simulations and develop data analysis tools to be used for LiteBIRD's instrument calibration.
f. Contribute to the LiteBIRD mission by providing calibration requirements and techniques.
The applicant 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.

Planning of the activities: The proposed activity consists of the following steps:
a. Conduct literature review to gain an understanding of existing calibration techniques and the challenges specific to CMB polarization measurements.
b. Analyze the LiteBIRD mission requirements and review calibration needs and constraints.
c. Develop novel calibration methods for the LiteBIRD instruments.
d. Implement simulations of the LiteBIRD observations to assess the performance of the calibration strategies under realistic in-lab and in-flight conditions.
e. Validate the proposed calibration techniques using mock data and simulations, comparing the results with known input parameters and established benchmarks.
f. Analyze calibration data from the LiteBIRD prototypes.

Institution(s) where the research will be carry out: Sapienza university of Rome, Physics Department. Possible hosting institutions for periods abroad are: The Kavli IPMU (the University of Tokyo Kashiwa campus), Tokyo, Japan; QUP: Quantum-field Measurement Systems for Studies of the Universe and Particles, Tokyo, Japan; University of California Berkeley, USA

2.19 Cosmic Microwave Background polarization with the QUBIC experiment

Supervisor (Name, Istitution and Contact):
Giancarlo De Gasperis, Sapienza University, giancarlo.degasperis@uniroma1.it
Co-Supervisor (Name, Istitution and Contact):
Silvia Masi, Sapienza University, silvia.masi@roma1.infn.it
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

2.20 The PILOT balloon borne experiment: Measurement of polarised emission of dust in the intergalactic medium at THz frequencies

Supervisor (Name, Istitution and Contact):
Giancarlo De Gasperis, Sapienza University, giancarlo.degasperis@uniroma1.it
Co-Supervisor (Name, Istitution and Contact):
Paolo de Bernardis, Sapienza University, paolo.debernardis@roma1.infn.it
Scientific Case: PILOT is a balloon-borne experiment to study the polarisation of dust emission in the diffuse Interstellar medium in our Galaxy. It aims to: reveal the structure of dust in the intergalactic medium and the magnetic field structure in our and nearby galaxies at a resolution of $\simeq 2$ arcmin; characterise the geometric and magnetic properties of dust grains; understand polarised foregrounds, and finally complement Planck observations at higher frequencies.
Outline of the Project: The Research aims at understanding and characterising the instrumental properties and the dataset of PILOT flights, the analysis for the third flight, focusing on instrument calibration, real and simulated data analysis, the science behind the ISM emission and finally to better understand the galactic dust foreground polarised emission, an essential step to CMB B-mode detection.
Planning of the activities: The research aims to analyse and reduce PILOT data, taking into consideration the effect of cross-correlated noise among detectors due to residual atmospheric emission and produce far infrared dust emission polarization map of the observed extended sources. These will be compared with the latest Planck polarization data to characterise the polarization of the dust continuum emission in the diffuse interstellar medium. A period of work on the project at IRAP-Toulouse is envisaged.
Institution(s) where the research will be carry out: Physics department – Sapienza University of Rome

2.21 Inferring the dynamical state of galaxy clusters by classifying their morphology with high-resolution multi-wavelength images

Supervisor (Name, Istitution and Contact):
Marco De Petris, Sapienza University of Rome, marco.depetris@roma1.infn.it
Co-Supervisor (Name, Istitution and Contact):
Gustavo Yepes, Universida Autonoma de Madrid, gustavo.yepes@uam.es; Antonio Ferragamo, Istituto de Astrofisica de Canarias, ferragamo@iac.es
Scientific Case: Clusters of galaxies: dynamical status classification
Outline of the Project: Clusters of galaxies reveal ideal astrophysical laboratories to study Universe composition and evolution. Moreover, an accurate knowledge of their mass has useful cosmological implications. Unfortunately, the mass is not an observable and its estimate is likely affected by a bias, mainly due to observational issues and to the not-always fulfilled applied physical models. Among the possible sources of mass bias that has been thoroughly investigated up to now, such as the presence of IntraCluster Medium non-thermal pressure support, due to turbulence and/or bulk gas motions, we focus on the dynamical state of clusters, inferred by different morphological indicators. This project will address the different approaches to infer the dynamical state of clusters using multi-wavelength observations and hydrodynamical simulations. Going beyond the simple definition of a single status of a cluster, we would like to expand the classification at all the radial distances and matter components and different observables. Using the large dataset of synthetic clusters extracted from one of the largest hydrodynamical simulation with available mock images at different spectral bands, suc as The Three Hundred project, the candidate would compare the existing indicators of the dynamical state based on morphological parameters and will investigate the new ones based on the Zernike polynomials. The validated indicators will be applied on high-resolution multi-wavelength images of clusters, such as NIKA2 SZ and XMM-Newton X-ray maps, to study the impact of the dynamical state on mass estimates. The candidate will join The Three Hundred collaboration, working in an international team with colleagues at the Universida Autonoma de Madrid and Notthingam University.
Planning of the activities: 1- acquire the necessary knowledge to handle large hydrodynamic simulation data; 2- summarize the state of the studies on the morphology of the clusters made through simulations; 3- collect all available dynamic state classifications based on observational data; 4- compare and validate existing indicators on multi-wavelength mock images; 5- extend the recent application of Zernike Polynomials to images at different bands after a correct tuning on simulations; 6- periodically report activities during collaboration meetings and/or seminars and/or conferences; 7- present the results in publications.
Institution(s) where the research will be carry out: Sapienza University of Rome, Universida Autonoma de Madrid and Istituto de Astrofisica de Canarias

2.22 Galaxy Clusters Mass inference by Intra-Cluster Medium investigation with X-ray and millimeter band high-resolution observations supported by hydrodynamic simulations

Supervisor (Name, Istitution and Contact):
Marco De Petris, Sapienza University of Rome, marco.depetris@roma1.infn.it
Co-Supervisor (Name, Istitution and Contact):
Gustavo Yepes, Universida Autonoma de Madrid, gustavo.yepes@uam.es; Weiguang Cui, Universida Autonoma de Madrid, weiguang.cui@uam.es
Scientific Case: Clusters of galaxies: total mass inference
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 more 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, 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, possibly 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 hydrodynamic 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. A more precise hydrostatic mass of distant clusters will be studied with constrained bias.
Planning of the activities: 1- acquire the necessary knowledge to handle large hydrodynamic simulation data; 2- summarize the current cluster mass estimates, with related uncertainties and biases; 3- recover ICM temperature distribution without X-ray spectroscopy after method validation with synthetic custers; 4- map ICM turbulence from Compton parameter, gas density and temperature maps; 5- estimate cluster total mass with hydrostatic equilibrium assumption and/or Machine Learning models; 6- periodically report activities during collaboration meetings and/or seminars and/or conferences; 7- present the results in publications.
Institution(s) where the research will be carry out: Sapienza University of Rome and Universida Autonoma de Madrid

2.23 Exploiting the correlation between neutrino and gravitational wave in core-collapse supernovae.

Supervisor (Name, Istitution and Contact):
Marco Drago, Sapienza University of Rome, marco.drago@uniroma1.it
Co-Supervisor (Name, Istitution and Contact):
Irene Di Palma, Sapienza University of Rome, irene.dipalma@uniroma1.it
Scientific Case: Core-collapse supernovae are among the most interesting sources of multi-messenger astronomy and a joint detection between neutrino and gravitational waves is one of the future challenge of astronomical physics. The current gravitational wave detectors have indeed a horizon distance of gravitational wave detection from supernovae limited to our galaxy. Given that neutrino detectors can see further distances, using information from neutrino flux could enhance the possibility to detect a gravitational wave from the same source
Outline of the Project: A new analysis concept has been recently developed to use neutrino information to feed a specific gravitational wave search, based on a matched filter method, which have been historically used for the detection of compact binary coalescences. This method is promising but it is still a beginning state and it need further exploration and improvements, so that it could be used for the next analyses of the gravitational wave detectors of the present generation (LIGO-Virgo-KAGRA) and the futue (ET).
Planning of the activities: The student will review the developed analysis using neutrino filter for gravitational wave search from supernova signal. He/She will then compare the method with other results from the literature works about multimessenger analysis. After this review, the student will perform new strategies to improve the detection capability of the method, in order to expand the horizon of detection, in order to apply the method in future data.
Institution(s) where the research will be carry out: Physics Department of Sapienza University of Rome

2.24 Entangled states of light for quantum noise reduction in gravitational wave detectors

Supervisor (Name, Istitution and Contact):
Ettore Majorana, Sapienza University of Rome, ettore.majorana@uniroma1.it
Co-Supervisor (Name, Istitution and Contact):
Sibilla Di Pace, Sapienza University of Rome, sibilla.dipace@uniroma1.it
Scientific Case: Quantum noise (QN) is one of the main limiting contributions to gravitational wave GW detectors' sensitivity. Virgo and LIGO already employ frequency-independent squeezing (FIS) setups reducing QN in the high-frequency range (200Hz). Nevertheless, for a broadband QN reduction (10Hz-1kHz), the upgrade to a frequency-dependent squeezing (FDS) setup is necessary. The FDS technique currently adopted consists of a FIS source coupled with a 300m long detuned Filter Cavity (FC). Looking forward, especially to the 3rd generation detectors, such as the Einstein Telescope (ET), developing more compact FDS setups is crucial.
Outline of the Project: The most promising alternative FDS technique is based on the production of two squeezed Einstein Podolsky Rosen (EPR) quantum-entangled beams. This setup has the advantage of being more compact and flexible versus the interferometer optical configuration, with respect to the technology employing the FC. EPR technique, before being implemented in large-scale GW detectors, needs to be tested in a suspended interferometer limited by radiation pressure quantum noise and working in the same frequency range of GW detectors. This is the novelty of this project: testing the broadband QN reduction due to EPR squeezing injection in a small scale suspended interferometer, called SIPS.
Planning of the activities: During these years the PhD student will carry on the development of both the EPR setup and the SIPS interferometer and will participate in their integration at the R&D squeezing laboratory of EGO (European Gravitational Observatory), Virgo site. The EPR setup installation is currently ongoing, and by the end of 2023 we expect to be ready for a first EPR squeezing measurement in a single test cavity. Whereas, for the test in SIPS more time is needed. The finalisation of the SIPS interferometer in Rome, before the installation at EGO, will be carried out in parallel, and will be completed during this PhD project. The student will be also involved in the simulation activities necessary to demonstrate the positive effect of EPR squeezing on QN in the sensitivity curve of Virgo and ET. The final goal of this project will be to validate the EPR technology for GW detectors.
Institution(s) where the research will be carry out: Virgo G23 Laboratory at Physics Department of Sapienza University of Rome

2.25 Development of new technologies for reducing thermal noise in next generation Gravitational Wave Detectors

Supervisor (Name, Istitution and Contact):
Piero Rapagnani, Sapienza University of Rome, piero.rapagnani@uniroma1.it
Co-Supervisor (Name, Istitution and Contact):
Paola Puppo, INFN, paola.puppo@roma1.infn.it
Scientific Case: After the first observation of gravitational waves in 2015, gravitational wave astronomy is now becoming more and more important. Currently, the three available detectors, (the 2 LIGO interferometers and Virgo), are at the beginning of a new observation run (O4). Since a few years, we are preparing the contruction of the new generation of instruments, with sensitivities improved by at least a factore ten with respect to the current ones. In Europe, we shall build the Einstein Telescope, a third generation gravitational wave interferometer that will use new tecnologies to reduce the intrinsic noises that limit the sensitivities of gravitational wave detectors. The Thesis we propose deals with the development of new methods to reduce the thermal noise of the test mass of the interferometer by means of cryogenics and the use of new low dissipation materials for the suspensions, to be applied to the mirrors of the Einstein Telescope.
Outline of the Project: The student will be introduced into the study of thermal motion in material bodies in connection with their anelastic properties. This theortical approach will be the base to the study of new techniques to reduce the thermal motion of mirrors and their suspensions in third generation gravitational wave interferometers, that will operate at about 10 K. The student will also gain experience in the design, simulation and test of elements of the new mirror suspension and in several cryogenic sensing and actuation technique needed.
Planning of the activities: During the first year the student will be guided to acquire a good level of knowlwdge on the subject of thermal noise, Design and simulations of elements of the mirror suspension to be tested will be carried out in the second year, while during the third year esperimental tests will be carried out. Tests will be carried out in the new Amaldi Center Lab in Sapienza, at Virgo in Cascina.
Institution(s) where the research will be carry out: Sapienza University, Rome, Virgo, Cascina (Pisa) (IT)

2.26 The Large Mass payload implementation in AdvancedVirgo+ Phase-2

Supervisor (Name, Istitution and Contact):
Ettore Majorana, Sapienza University of Rome, ettore.majorana@uniroma1.it
Co-Supervisor (Name, Istitution and Contact):
In AdvancedVirgo+ project large mirrors will be installed at the terminal position on the 3-km-long Fabry-Pérot optical cavities, to reduce the coating thermal noise, a mechanical dissipation related to the presence of the thin layer deposited on the test masses to let them operate as high reflectivity mirrors. The coating thermal noise is expected to limit future sensitivity improvements and reach 2-4 10-24 1/sqrt(Hz) in the range 50-500 Hz allowing a significant improvement of the detection horizon (above 200-250 Mpc for BNS events with SNR=8). The large mirrors (or test masses), made of high purity fused silica, have 550 mm diameter, allowing to host a beam 60% larger. The overall mass will be 105 kg. A prototype payload, suitable to host and control such a big test mass has been developed and reviewed by the Virgo Collaboration, and two units are nowadays under construction. Several aspects have still to be tackled, and a significant amount of studies will be related to the actual implementation, foreseen by 2025 to join the observation run 05.
Scientific Case: One relevant aspect of interferometric gravitational-wave detectors is the symmetry of both optical and mechanical plants. In case of AdV+ Phase-2, due to a trade-off of feasibility versus investment, large mass mirrors will be installed only on one side of the cavities. Then the inertial asymmetry of the payloads along each arm requires a deep study of radiation pressure-induced coupling between the test masses, which turns into a more advanced strategy to properly reconstruct the laser beam degrees of freedom into the cavities. Studying Large mass payloads is a step forwards ET payload developments and this project is a suitable path to envisage the development focussed on third generation detectors.
Outline of the Project: This project is three folded: a) auto-alignment studies on inertially-asymmetric Fabry-Perot arm cavities dominated by radiation pressure, b) setting-up and installation of actual parts of the detector, c) study of technical noise introduced by controls. All of them are crucial for the Observation run 05 (2025).
Planning of the activities: This project is three folded: a) auto-alignment studies on inertially-asymmetric Fabry-Perot arm cavities dominated by radiation pressure, b) setting-up and installation of actual parts of the detector, c) study of technical noise introduced by controls. All of them are crucial for the Observation run O5 (2025). The activity will be organized in coordination within the subsystems of the Virgo Collaboration. The thesis is definitely experimental. Provided that the student will contribute on all of the three themes mentioned above, upon the basis of the student's attitudes, he/she may focus on one specific theme, gradually acquiring major responsibility. The study of the complex optomechanical system of suspended test masses will accompany the overall period of the thesis.
Institution(s) where the research will be carry out: Long periods at the Virgo site at the European Gravitational Observatory (Cascina, Pisa), supported by INFN funding could be required especially in the phases of payload assembling and actual implementation of payload controls. In Rome, at the Dep. of Physics (G23), the student will focus on modeling and simulation tools learning, always in close interface with experts at the site and in other laboratories affiliated to the international collaboration Virgo. The student will be involved as well in Observation run O4, and in the analyses concerning sensitivity improvements during which he/she will learn about the actual operation of the gravitational-wave interferometer.

2.27 Mission analysis and design of the multi-wavelength synoptic solar microsatellite SEE.

Supervisor (Name, Istitution and Contact):
Fabio Curti, Sapienza University, fabio.curti@uniroma1.it
Co-Supervisor (Name, Istitution and Contact):
Dario Spiller, Sapienza University, dario.spiller@uniroma1.it
Scientific Case: SEE is a microsatellite mission that has been selected by the Italian Space Agency (ASI) in the framework of the Call "Future CubeSat Missions". The SEE mission during solar cycle 25 will provide multiwavelength data of Space Weather events. To meet the scientific requirements two scientific payloads are foreseen for the SEE mission: 1. the gamma and X-ray instrument; 2. the UV Imager for the Mg II doublet at 280 nm. The SEE gamma and X-ray instrument will study flare emission in an extended range of photon energies, from few keV to few MeV, covering three decades in energy and exploring flare variability with unprecedented temporal resolution. The use, for the first time in solar physics, of SiPM technology will ensure cadence as high as 106̂ Hz, opening a new window on flare dynamics and on the mechanisms at their base. The gamma and X-ray payload has two main detectors to provide extended energy range from few keV to few MeV.
Outline of the Project: The research activities concern two main topics:
1. The orbit and perturbations analysis according to the payload's requirements. The analysis includes doppler shift, eclipse duration, ground station visibility, and CubeSat lifetime. The results of this activity will provide the drivers for the design of the mission.
2. Guidance, Navigation and Control (GNC). The study deals with the preliminary design of the GNC architecture. The results of this activity will provide the GNC system of the microsatellite in the selection of actuators and sensors. Moreover, the activity will focus on the maneuvers design and pointing accuracy analysis for the development of the on-board algorithms.
Planning of the activities: During the first year , the research focuses on mission analysis. The second year and the third year are devoted to the design and simulator development of the spacecraft GNC according the payload requirements. The PhD activities could include attending the progress meeting of the project. The study is in collaboration with ASI and Italian aerospace companies Argotech, Next, and Optec.
Institution(s) where the research will be carry out: The research will be carried out at the School of Aerospace Engineering (Sapienza) and the Solar Physics and Space Weather group at the Department of Physics of (University of Tor Vergata).

2.28 Artificial intelligence applied to Space Domain Awareness.

Supervisor (Name, Istitution and Contact):
Fabio Curti, Sapienza University, fabio.curti@uniroma1.it
Co-Supervisor (Name, Istitution and Contact):
Dario Spiller, Sapienza University, dario.spiller@uniroma1.it
Scientific Case: Space Domain Awareness (SDA) includes Space Situational Awareness (SSA), Space Surveillance and Tracking (SST) and Space Traffic Management (STM). As more and more spacecraft use space in increasingly dense orbital regimes, coordination and tracking of spacecraft is needed to operate safely by avoiding collisions, and to reduce debris populations. The activity focuses on the optical observations from ground sensors and orbit sensors to track resident space objects with the aim at estimating the orbit, the shape, and the attitude motion. The other aspect of the study is the estimation of the shape and attitude dynamics of the observed objects. The collection of photometric measurements (the light curves - flux of photons through a wavelength reflected by the space object), can provide the estimation of the spin attitude dynamics, shape, and the surface parameters.
Outline of the Project: The following topics will be addressed in the study:
1. Initial Orbit Determination (IOD) by means of small arcs optical measurements. Classical IOD methods (such as Gauss's method, Double-R iteration, or Gooding's method) are not applicable to the case of small arcs (observations less than 60 sec). Therefore, the study will be directed towards the application of recent techniques in the field of Artificial Intelligence such as the Physics Informed Neural Networks (PINNs), that can solve direct and inverse problems governed by parametric differential equations.
2. The estimation of the shape, angular velocity, and attitude of observed space objects through "light curves". In particular, the Light Curve Inversion (LCI) approach, commonly used for asteroid shape estimation, aims to roughly determine the shape of a satellite and it is one of the key aspects of the ongoing research efforts in the SDA. AI approaches will be investigated to estimate the shape, and the dynamics of resident space objects.
Planning of the activities: During the first year and the second year, the research focuses on the study and the development of AI-based techniques. The third year the activities will exploit the real observed data acquired by the telescope facility at the University of Arizona to test and validate the proposed methods.
Institution(s) where the research will be carry out: The research is conducted at the School of Aerospace Engineering (Sapienza University of Rome) and in collaboration with the Space 4 Center of the University of Arizona (Tucson, USA).

2.29 Data-analysis techniques for continuous gravitational-wave searches from neutron stars in binary systems

Supervisor (Name, Istitution and Contact):
Paola Leaci, Sapienza University, paola.leaci@uniroma1.it
Co-Supervisor (Name, Istitution and Contact):

Scientific Case: The gravitational-wave astronomy field has been resolutely founded seven years ago, thanks to the first direct detection of transient gravitational waves from the collision of two black holes. The first detection of continuous gravitational waves from fastly rotating neutron stars has yet to be done, and it may be around the corner, representing a further revolutionary big discovery. Scorpius X-1 is a neutron star in a binary system with a low-mass companion star. It is believed to be rapidly spinning and is considered a very promising source of contiuous gravitational waves. The signal received on Earth depends on the (almost unknown) system parameters, and a search for that signal loses sensitivity if incorrect values are used for those parameters. From this arises the need to develop novel techniques to carry out the search for such a class of signals targeting the brightest low-mass X ray binary we know so far, i.e. Scorpius X-1.
Outline of the Project:
Planning of the activities:
Institution(s) where the research will be carry out:

2.30 Bridging infinite-duration Continuous and Stochastic background gravitational-wave searches

Supervisor (Name, Istitution and Contact):
Paola Leaci, Sapienza University, paola.leaci@uniroma1.it
Co-Supervisor (Name, Istitution and Contact):

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

3 INAF

3.1 INAF-OAR

One (1) fellowship is granted for a student to carry out his/her research at INAF-OAR, among the following thesis proposals.

3.1.1 Compact objects at their extremes

Supervisor (Name, Istitution and Contact):
Gian Luca Israel, INAF, gianluca.israel@inaf.it
Co-Supervisor (Name, Istitution and Contact):
Francesco Tombesi, Tor Vergata University, rancesco.tombesi@roma2.infn.it
Scientific Case: Recent studies show the emergence of different classes of accreting X-ray binaries hosting neutron stars (NSs) or black holes, and isolated NSs with extreme physical properties. In binaries, besides the accretion disk, are present different components such as coronae, magnetospheres, winds and fast jets. Flux variations on timescales down to millisecond provide diagnostics of their physics: the X-ray spin period and its derivative in ultra-luminous X-ray NSs inform models of super-Eddington accretion; aperiodic fast variation delays in the radio, infrared, optical and X-rays encode information on emission mechanisms and disk/jet interplay in black holes; millisecond pulsations in both the optical and the X-rays yield insight on the different accretion regimes. Magnetars, isolated NSs hosting the strongest magnets in the Universe, are discovered and studied through Gamma/X-ray bursts and outbursts. Their observations are fundamental to the study of the interaction between radiation and matter under extreme conditions, the magneto-thermal evolution of NSs, etc.
Outline of the Project: The fellow will take part in the discovery and/or study of new members of the different classes of compact objects and will exploit/develop a wealth of state of the art, time-resolved observations and data analysis algorithms to address one of the open problems in this area of research.
Planning of the activities: The student will exploit data carried out with fast-time detectors (able to sample the emission down to micro-seconds timescales) and will make use of different tools, including AI algorithms (genetic, evolutionary and machine-learning) in order to constrain the current theoretical models.
Institution(s) where the research will be carry out: The institution where the research will be carried out: INAF Osservatorio Astronomico di Roma (sede di Monte Porzio Catone)

3.1.2 Probing inhomogeneous reionization with Ly-alpha emitters clustering

Supervisor (Name, Istitution and Contact):
Laura Pentericci, INAF, laura.pentericci@inaf.it
Co-Supervisor (Name, Istitution and Contact):
Manuela Magliocchetti, INAF, manuela.magliocchetti@inaf.it
Scientific Case: The epoch of reionization is a still largely unexplored domain: we do not have a precise picture of when it happened, how it proceeded spatially, and which sources were the main responsible for the ionizing photon budget. The MOONS-MOONRISE GTO survey of which INAF is part will start at the beginning of 2024 and will observe large areas of the sky where we will identify Lyα emitting galaxies (LAEs)at $z > 5$. We will derive LAE clustering and its evolution with cosmic time, to constrain the topology of reionization. The student will also search and analyze very high redshift over-densities to investigate the physics of early sites of reionization.
Outline of the Project: The student will first familiarize with clustering analysis techniques and spectroscopic data analysis. He/she will then apply the techniques to available data in the CANDELS fields where observations from many surveys are already available. The new MOONS data are expected to start coming in from beginning of 2024. Most likely the student will also be able to participate to the MOONS data acquisition and spectroscopic analysis. As soon as the first MOONS field is completed the clustering analysis will be applied.
Planning of the activities: Year 1 clustering techniques, spectroscopic analysis. Start of MOONS data acquisition: Year 2 MOONS data acquisition. Application of clustering analysis to CANDELS fields: Year 3 MOONS data acquisition continues. Application of clustering analysis to MOONS observations
Institution(s) where the research will be carry out: Sapienza and INAF

3.1.3 JWST and VLT/MOONS observations of star-forming regions across the Local Group

Supervisor (Name, Istitution and Contact):
Katia Biazzo, INAF, katia.biazzo@inaf.it
Co-Supervisor (Name, Istitution and Contact):
Brunella Nisini, INAF, brunella.nisini@inaf.it; Luigi Mancini, Tor Vergata University, lmancini@roma2.infn.it
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 central young star properties (e.g., atmospheric and global parameters, mass accretion rate, UV field) and environmental conditions of the clouds in which the star is forming (e.g., metallicity, density, external radiation fields).
Outline of the Project: The thesis aims at investigating the disk evolution and lifetime of young 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/Small Magellanic Clouds, to understand how these parameters depends from the environment.
Planning of the activities: The PhD student will be initially involved in the analysis of optical/near-infrared spectra already acquired both from the NIRSpec instrument on the James Webb Space Telescope (JWST) and from the Large Binocular Telescope (LBT) in Arizona. These datasets will be mainly focused on star-forming regions in the Large/Small Magellanic Clouds and outer Galaxy so to study young stellar objects with wide ranges of metallicity. In the second part of the project, the student will also work on the IR spectra acquired with the MOONS@VLT instrument in Chile (start of operations: 2024), in the framework of the MOONS GTO on Galactic studies. This second sample will comprise 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 European Space Agency (ESA-ESTEC; The Netherlands) and at the Astrophysical Observatory of Arcetri are foreseen.

3.1.4 Direct imaging and characterization of wide-orbit exoplanets with LBT/SHARKs

Supervisor (Name, Istitution and Contact):
Simone Antoniucci, INAF, simone.antoniucci@inaf.it
Co-Supervisor (Name, Istitution and Contact):
Valentina D'Orazi, Tor Vergata University, vdorazi@roma2.infn.it
Scientific Case: Understanding how planets form within the protoplanetary disk of their host star is one of the major challenges of current astrophysical research. The formation of massive gaseous planets is particularly important, as they are believed to play a fundamental role in shaping the final configuration of the planetary system.
Outline of the Project: We propose a thesis aimed at discovering and characterizing very young wide-orbits gaseous planets still in formation within the protoplanetary disk of their host star, using high-contrast imaging with the new INAF PI-instruments SHARK-VIS and SHARK-NIR at the Large Binocular Telescope. The aim is to derive the main physical parameters of the protoplanet (NIR data) and its gas accretion rate (VIS data) and put them in relation with the properties of the host star and disk to constrain the formation process.
Planning of the activities: the PhD student will reduce and analyze data taken with both instruments, thus acquiring expertise in high-contrast imaging techniques and planet/star characterization. They will also be involved in planning and execution of SHARK observations at LBT.
Institution(s) where the research will be carry out: Università di Roma Tor Vergata, INAF-Osservatorio Astronomico di Roma (VIS), INAF-Osservatorio Astronomico di Padova (NIR), LBT

3.1.5 Characterization of the scientific performance of the ASTRI Mini-Array during its Science Verification Phase

Supervisor (Name, Istitution and Contact):
Saverio Lombardi, INAF, saverio.lombardi@inaf.it
Co-Supervisor (Name, Istitution and Contact):
Ciro Bigongiari, INAF, ciro.bigongiari@inaf.it; Aldo Morselli, INFN, aldo.morselli@roma2.infn.it; Roberta Sparvoli, Tor Vergata University, roberta.sparvoli@uniroma2.it
Scientific Case: Very high-energy (VHE, O(100) GeV ¡ E ¡ O(100) TeV) gamma rays of cosmic origin are associated to the most violent phenomena of the Universe and can reveal unique information on open issues of modern astrophysics, particle physics, and cosmology. The ASTRI Mini-Array will represent in the next few years an important instrument for deep observations of galactic and extra-galactic targets in the energy range between 1 TeV and 100 TeV and beyond. The ASTRI Mini-Array is under construction at the Observatorio del Teide (in the Canary Island of Tenerife, Spain) and will be fully operational within the next few years. It will be composed of nine small-sized (4-meter in diameter) making it the largest facility of IACTs until the CTA Observatory will start operations. The first telescope (”ASTRI-1”) will be fully deployed by fall 2022, while the second and third telescopes (”ASTRI-8” and ”ASTRI-9”) by mid 2023. The completion of the array with all nine telescopes will be incrementally achieved by the next few years.
Outline of the Project: Each individual telescope, as well as the stereoscopic system consisting of an increasing number of telescopes, will undergo a dedicated scientific verification phase. The scientific capabilities of the system will be verified in detail through dedicated simulations and astrophysical observations. We propose a PhD fellowship research program focused on defining and implementing optimized strategies for characterizing the scientific performance of the ASTRI Mini-Array telescopes during its science verification phase. The project aims to characterize the first real data collected by the ASTRI Mini-Array, starting from the first three telescopes, and to assess the performance of the system in different array configuration and observational conditions.
Planning of the activities: The PhD candidate is expected to widely contribute to several aspects of this research program, in particular to: - the definition of optimal observation strategies during the Science Verification Phase; - perform a complete Monte-Carlo simulation campaign to characterize the instruments; - the development of efficient software tools for the data analysis of the collected data, including new machine and deep learning methods; - the generation and fine-tuning of the Monte Carlo simulations needed to analyze the collected data; - the data analysis of astrophysical source observed by the ASTRI Mini-Array telescopes, both in single-telescope and stereoscopic mode; - on-site technical activities and astronomical data taking; - the scientific interpretation and the publications of the main achieved results.
Institution(s) where the research will be carry out: INAF’s Rome Astronomical Observatory (INAF-OAR) and ASI’s Space Science Data Center (ASI-SSDC), which is responsible for the ASTRI Mini-Array data processing system.

3.1.6 Rubin LSST: enabling early science with pulsating stars

Supervisor (Name, Istitution and Contact):
Marcella Di Criscienzo, INAF, marcella.dicriscienzo@inaf.it
Co-Supervisor (Name, Istitution and Contact):
Giuseppe Bono, Tor Vergata University, Giuseppe.Bono@roma2.infn.it
Scientific Case: During the first 10 years of operations, Rubin Observatory will conduct the Legacy Survey of Space and Time (LSST) of the entire southern sky and provide the widest, fastest, and deepest views of the night sky ever observed. On-sky commissioning of the Rubin telescope will start in mid-2024 while the first LSST public releases are expected by 2025. The student will focus his/her project on the preparatory phase of Rubin LSST. The main goal of his Ph.D. project will be to enable early science with LSST focusing on different types of Local Group pulsating stars (RR Lyrae, Cepheids Long Period Variables) and their use as distance indicators and tracers of stellar populations. The student, during his/her Ph.D. work, will have the unique opportunity to work on the very first Rubin images in collaboration with the LSST team working on image quality.
Outline of the Project:
Planning of the activities: AA 2023/2024 (I year) Immediate participation in the work of LSST LSST Science collaborations TVS and SMWL (weekly teleconferences, meetings, surveys).Training on Rubin Science Platform through the analysis of DC2 data and on MAF metrics including those developed in OAR (Di Criscienzo et al. 2023). Technical study and production of notebooks dedicated to SC1 using Gaia light curves template. Writing and submission of the first paper on the methodological approach. AA 2024/2025 (II year) Support of working package WP2.2 (PI Marcella Di Criscienzo) of S22 in-kind work on the first images taken by the telescope during the commissioning. Technical study and production of notebooks dedicated to SC2 focusing on few interesting dwarf galaxies. Writing and submission of the second paper, concerning the application to synthetic data. AA 2025/2026 (III year) Use of the first Rubin LSST observations and Data Release for the scientific cases identified in previous years. The results will be presented at international conferences and LSST internal meetings and published in referred papers. Writing and submission of the third paper based on real data.
Institution(s) where the research will be carry out: INAF-Osservatorio Astronomico di Roma (main) Università di Tor Vergata

3.1.7 Studying the Cosmological evolution of Galaxies' Gaseous phases in dustyGadget Hydrodynamical simulations integrated with state-of-the-art Time-Evolving Photoionization Physics

Supervisor (Name, Istitution and Contact):
Fabrizio Nicastro, INAF, fabrizio.nicastro@inaf.it
Co-Supervisor (Name, Istitution and Contact):
Raffaella Schneider, Sapienza University, raffaella.schneider@uniroma1.it; Luca Graziani, Sapienza University of Rome, luca.graziani@uniroma1.it; Alfredo Luminari, INAF, alfredo.luminari@inaf.it
Scientific Case: Current hydrodynamical simulations for the formation and evolution of structure in the Universe, use snapshots of external equilibrium photoionization code computations to picture the frozen physical state of the gaseous components of galaxies at different times during the simulation.
Outline of the Project: The project will consist in integrating the code TEPID within cosmological hydrodynamical simulations run with the dustyGadget code, a modified version of the Gadget code, which accounts for the production of dust by stellar populations and its evolution in the interstellar medium. The results will be compared with previous runs based on "on-the-spot" equilibrium photoionization, and the outputs of the simulations will be used to study the evolution of the gaseous components of galaxies and their surroundings with particular emphasis on (a) the physical state of the hot and photoionized components of the circum-galactic medium, and (b) the evolution of the ionization degree of star-forming regions undergoing explosions of young and massive stars in the galaxy's disks. The outputs will be also used to produce mock optical-UV and X-ray spectra along random lines of sight, to be compared with observations of, e.g. GRBs, and background quasars crossing the halos of intervening galaxies.
Planning of the activities: The research activities will be divided in four main parts: (i) revision and adaptation of TEPID for its integration into the dustyGadget hydrodynamical simulation code; (ii) detailed tests of the new simulations and comparison of the outputs with previous runs based on equilibrium-photoionization snapshots; (iii) detailed studies of the gaseous ionization state in the simulations, especially in the surroundings of galaxies and in bright star-forming regions at different stage of the evolution, and (iv) production of mock optical-UV and X-ray spectra as extracted from random lines of sight through the simulated galaxy environments, to be compared with archival and new observations. The student will join international projects and proposal for observations, at both ground and space facilities (e.g. the upcoming JAXA/NASA/ESA's X-ray Imaging Spectroscopy Mission XRISM, to be launched in August 2023). Opportunities for the student to travel or longer-term internships in international institutes (e.g. the Harvard-Smithsonian Center for Astrophysics in the USA), are expected.
Institution(s) where the research will be carry out: INAF (OAR and IAPS, Rome), University of Rome "La Sapienza"

3.1.8 The long lasting GRBs-SNe relationship: 25 years and counting

Supervisor (Name, Istitution and Contact):
Andrea Melandri, INAF, andrea.mleandri@inaf.it
Co-Supervisor (Name, Istitution and Contact):
Sivlia Piranomonte, INAF, silvia.piranomonte@inaf.it; Giampaolo Pisano, Sapienza University of Rome, giampaolo.pisano@uniroma1.it
Scientific Case: The detection of a rare broad-lined Type Ic supernova (SN) emission linked to a gamma-ray burst (GRB) event (GRB980425/SN1998bw) has yielded valuable understanding regarding the properties of numerous long-duration GRBs. The association between GRBs and SNe at small distances (z¡0.3) is strongly confirmed thanks to spectroscopic observations. At large redshifts a SN component has been detected for many long GRBs in the form of a "bump" in the light curve of the optical counterpart. In any case, this association seems to hold true irrespective of the event's distance and brightness. However, the specific attributes of the SNe currently identified and spectroscopically linked to GRBs may exhibit slight variations. Conducting a statistical and systematic analysis of the presently confirmed events will offer crucial insights for future observations across various distances and energy ranges.
Outline of the Project: This thesis project aims to investigate the properties of the SNe population associated with long GRBs. To date, fewer than 20 SNe have been spectroscopically linked to GRB events spanning a broad high-energy emission range. A comprehensive examination of the confirmed events will provide additional information for forthcoming observations at different energy levels and distances.
Planning of the activities: The selected candidate will be responsible for gathering and conducting a comprehensive analysis of all the existing data pertaining to the chosen sample of SNe associated with long GRBs. The project will also encompass the analysis of data for potential new events that may come to light in the coming months or years. 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 La Sapienza, Roma

3.1.9 STARLIGHT: Shedding Light on the Formation and Fate of Stellar Remnants in view of Einstein Telescope

Supervisor (Name, Istitution and Contact):
Silvia Piranomonte, INAF, silvia.piranomonte@inaf.it;
Marco Limongi, INAF, marco.limongi@inaf.it;
Andrea Melandri, INAF, andrea.melandri@inaf.it
Co-Supervisor (Name, Istitution and Contact):
Raffaella Schneider, Sapienza University, raffaella.schneider@uniroma1.it;
Marco Limongi, INAF, marco.limongi@inaf.it;
Andrea Melandri, INAF, andrea.melandri@inaf.it;
Mario Spera, SISSA, mario.spera@sissa.it
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: 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. 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. 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; Dipartimento di Fisica, Univ. La Sapienza; Scuola Internazionale Superiore di Studi Avanzati (SISSA), Trieste.

3.1.10 Comparing observations of the high-redshift Universe with models predictions

Supervisor (Name, Istitution and Contact):
Emiliano Merlin, INAF, emiliano.merlin@inaf.it
Co-Supervisor (Name, Istitution and Contact):
Laura Pentericci, INAF, laura.pentericci@inaf.it
Scientific Case: Comparing theoretical predictions with observations is crucial to assess both the accuracy of the models and the robustness of the algorithms used to analyse the data. To obtain a fully consistent comparison, forward-modeling of cosmological simulations is required. The code FORECAST (Fortuni et al. 2023, subm.) will be used to simulate current and future high-redshift observations (JWST, HST, Euclid, Rubin/LSST, ELT).
Outline of the Project: Together with our team at Inaf-OAR, the PhD student will: (i) add new algorithms to FORECAST, to take into account physical phenomena (e.g. AGN emission, local dust absorption, simulation of spectroscopic data); (ii) produce simulated images from various instruments, filters, depths and resolutions, mimicking the corresponding real datasets; (iii) analyse such images, retrieving photometric and/or spectroscopic data, and inferring redshifts and physical properties of the simulated sources; (iv) compare the results with both the input values of the simulations (to assess the robustness of the adopted techniques, highlighting possible biases introduced by them) and the observational data (e.g. number counts, luminosity and mass functions, inferred star formation histories, etc.), to check the accuracy of theoretical predictions and to provide forecasts for future observations.
Planning of the activities: 1st year - Study of the code FORECAST and of the scientific literature; implementation of algorithms in the code; 2nd year - simulations of datasets; 3rd year - analysis of the results; publication of the results in one or more refereed papers; writing of the thesis.
Institution(s) where the research will be carry out: INAF-Osservatorio Astronomico di Roma

3.1.11 Investigating the first quasars in the early Universe with world-class observatories

Supervisor (Name, Istitution and Contact):
Luca Zappacosta, INAF, luca.zappacosta@inaf.it
Co-Supervisor (Name, Istitution and Contact):
Laura Pentericci, INAF, laura.pentericci@inaf.it
Scientific Case: The formation of luminous quasars (QSO) powered by heavy ($> 10^9$ Msun) supermassive black-holes (SMBH) when the Universe was only 1 Gyr old (z¿6) is a hot topic in modern astrophysics. Their existence seriously challenges theoretical models as it implies a period of extremely rapid mass growth followed by a fast feedback phase of slow down of the accretion likely due to large mass ejections by QSO-driven winds. The advent of large observing programs with world-class observatories is rapidly revolutionizing our understanding of these sources.
Outline of the Project: Our project aims to shed light on the nuclear properties of z¿6 QSO according to their SMBH mass growth. Specifically, it will primarily focus on the HYPerion quasars at the Epoch of ReionizatION (HYPERION) sample which we selected to have SMBH which had the most rapid mass growth in their formation history. These QSO, powered by SMBH with huge masses ($10^9 - 10$ Msun), benefit from high-quality rest-frame X-ray/UV/optical data taken with world-class telescopes, such as our 700 hours Heritage XMM-Newton X-ray programme and rest-frame UV/optical spectra from large ground-based and space telescopes (VLT, Magellan and James Webb).
Planning of the activities: The student will analyze: - the X-ray-to-optical spectral continuum using physical models for the QSO emission to estimate the SMBH mass accretion rate; - the UV/optical emission lines to characterize nuclear/host-galaxy scales QSO-driven ionized winds. The nuclear accretion and wind properties will then, be related to each other to shed light on the accretion and feedback phases of these sources.
Institution(s) where the research will be carry out: INAF-Osservatorio Astronomico di Roma in collaboration with the large international team of HYPERION scientists

3.1.12 The interplay between AGN radiative output and physics of nuclear winds

Supervisor (Name, Istitution and Contact):
Enrico Piconcelli, INAF, enrico.piconcelli@inaf.it
Co-Supervisor (Name, Istitution and Contact):
Francesco Tombesi, Tor Vergata University, francesco.tombesi@roma2.infn.it; Alfredo Luminari, INAF, alfredo.luminari@inaf.it; Fabrizio Nicastro, INAF, fabrizio.nicastro@inaf.it
Scientific Case: AGN-driven winds are considered the most promising mechanism to set the SMBH-Host galaxy scaling relation and explain the evolution of massive galaxies. The study of AGN winds is therefore one of the growing hot topics in extragalactic astronomy and is ubiquitously considered in the core science of current and future major astronomical facilities. We developed a novel Time Evolving PhotoIonisation Device (TEPID) to accurately model the temporal evolution of UV and X-ray circum-nuclear, outflowing gas and to readily compare its spectrum to observations.
Outline of the Project: Photoionisation codes currently available in the literature only model time-steady, equilibrium gas; as such, they only allow limited diagnostics on the data and cannot constrain the energy of AGN winds and their impact on the host galaxy evolution. This program aims to use our time-evolving photoionization code TEPID to analyze: (a) X-ray spectroscopic data of current (XMM, Chandra) and upcoming (XRISM, launch Summer 2023) observatories of nearby AGN, (b) multi-epoch UV spectra of high-z AGN containing the imprint of high-ionization relativistic outflows.
Planning of the activities: The research activity will start by learning how to use TEPID by applying it to high-quality XMM and Chandra spectra of a well-selected sample of 20 AGN. The analysis will be extended to both first-year XRISM data of AGN as soon as they are released and to multi-epoch VLT/SDSS UV spectra. Thanks to our physically-based analysis, we foresee innovative results that will be published in a series of peer-reviewed papers led by the student. The student will also be encouraged to submit X-ray and optical/UV observing proposals.
Institution(s) where the research will be carry out: INAF-Osservatorio Astronomico di Roma and University of Tor Vergata, with long-term visits to our collaborators at Harvard-Smithsonian Center of Astrophysics (Boston, USA), NASA-Goddard and Universidad Autonoma de Mexico (UNAM).

3.1.13 Tackling the Challenge of optical millisecond pulsars

Supervisor (Name, Istitution and Contact):
Filippo Ambrosino, INAF, filippo.ambrosino@inaf.it
Co-Supervisor (Name, Istitution and Contact):
Alessandro Papitto, INAF, alessandro.papitto@inaf.it; Gian Luca Israel, INAF, gianluca.israel@inaf.it
Scientific Case: Millisecond pulsars in compact binary systems (MSPs) are prime targets to study the interaction between the matter in-flowing towards a neutron star (NS), its rotating magnetosphere and the outgoing radiation and particle wind. Either the rotation of their magnetic field or the in-fall of matter lost by a companion star powers their electromagnetic emission. Coherent pulsations of the emitted radiation are essential diagnostics to identify the mechanism powering the emission. Recently, the fast optical photometer SiFAP2 - managed by our group (PI: Papitto, Ambrosino) and operated at the INAF Galileo Telescope - has observed for the first time surprisingly bright optical pulses from two MSPs surrounded by an accretion disk. Hardly fitting in the standard paradigm, these findings demand new unconventional solutions.
Outline of the Project: The fellow will aim at discovering optical MSPs in the different states accessible to these systems and measuring the emission properties (e.g., emission region, efficiency). The results will be used to test models that assume that optical and X-ray pulsations might originate at the shock boundary between the relativistic pulsar wind and the disk plasma, suggesting the coexistence of accretion and particle acceleration.
Planning of the activities: The fellow will exploit SiFAP2 proprietary data of MSPs, using dedicated fast algorithms to search and characterise optical pulsars. Simultaneous multi-wavelength observations at radio, X-ray and gamma-ray energies will also be used to measure the broadband spectral energy distribution and constrain the emission geometry.
Institution(s) where the research will be carry out: INAF Osservatorio Astronomico di Roma

3.1.14 Higher order statistics in weak lensing from the Euclid survey

Supervisor (Name, Istitution and Contact):
Vincenzo Cardone, INAF, vincenzo.cardone@inaf.it
Co-Supervisor (Name, Istitution and Contact):
Roberto Maoli, Sapienza University, roberto.maoli@roma1.infn.it
Scientific Case: Development and use of emulators for the estimate of higher order probes in weak lensing
Outline of the Project: The unprecedented quality and quantity of Euclid weak lensing data opens up the road to a characterisation of the statistical properties of the convergence field which goes beyond the present day standard. Rather than relying on second order statistics, one can indeed extract information from the field non Gaussianity through higher order statistics. This includes both global estimators (e.g., higher order moments), topological indicators (such as Minkowski functionals, and Betti numbers), and local probes (as the 3pt correlation function). A comprehensive analysis based on Fisher matrix forecasts has been recently performed as first step of the HOWLS project within the Euclid collaboration. The present PhD thesis will be carried on as part of the next step of HOWLS aiming at developing fast methods for the computation of high order statistics probes to efficiently sample the parameter space in a MCMC analysis. The project will address theoretical and observational aspects relying on Euclid - like simulations. The work will be carried on within the Euclid HOWLS hence allowing the student to work in a highly formative environment.
Planning of the activities: The proposed project can be carried on in three steps approximately matching the three years of the PhD course duration as follows. Step 1 (1st year): analysis of the simulated convergence maps and production of training sample; Step 2 (2nd year): development of an emulator for the theoretical estimate of high order probes; Step 3 (3rd year): test against simulations and use on real data (if available).
Institution(s) where the research will be carry out: I.N.A.F. - Osservatorio Astronomico di Roma; Dipartimento di Fisica - Università La Sapienza

3.1.15 HigherConstraining cosmology with dark sirens and Euclid cross-correlation

Supervisor (Name, Istitution and Contact):
Roberto Scaramella, INAF, roberto.scaramella@inaf.it
Co-Supervisor (Name, Istitution and Contact):
Matteo Martinelli, INAF, matteo.martinelli@inaf.it; Roberto Maoli, Sapienza University, roberto.maoli@roma1.infn.
Scientific Case: Constraining cosmological parameters using gravitational waves and Euclid data
Outline of the Project: Next generation gravitational waves (GW) surveys, such as Einstein Telescope, have the potential to provide catalogues with large number of observed events. Most of these events will not have an associated redshift making the use of such catalogues not straightforward. While statistical tools can be used to extract valuable cosmological information, a most promising approach is to cross-correlate GW surveys with Large Scale Structures (LSS) surveys, such as Euclid. This can both provide an estimate for the redshift of the GW events, and cosmological information on its own. The present PhD project will aim at investigating the best approaches to combine future GW observations with Euclid, studying the possible systematics and the analysis methods needed to fully extract cosmological information. The student will have access to the activities of multiple Euclid Science Working Groups, with the possibility to join the activities of the Theory Working Group and apply the methods developed also to non-standard cosmological models. They will gain experience in both observational and theoretical aspects, and overall increase their expertise on cutting-edge cosmological investigations.
Planning of the activities: The proposed project can be carried on in three steps approximately matching the three years of the PhD course duration as follows. Step 1 (1st year): analysis of the possible ways to combine GW and Euclid data; Step 2 (2nd year): development of a code implementing the approach identified as optimal in year 1; Step 3 (3rd year): test against simulated data and correction of systematics.
Institution(s) where the research will be carry out: I.N.A.F. - Osservatorio Astronomico di Roma; Dipartimento di Fisica - Università La Sapienza

3.1.16 Stellar populations of the Local Group galaxies in the JWST era

Supervisor (Name, Istitution and Contact):
Flavia Dell'Agli, INAF, flavia.dellagli@inaf.it
Co-Supervisor (Name, Istitution and Contact):
Raffaella Schneider, Sapienza University, raffaella.schneider@uniroma1.it
Scientific Case: The recent launch of the James Webb Space Telescope will allow the census of the stellar populations of the Local Group galaxies with an unprecendented accuracy. A significant fraction of the data will regard the stars evolving through the asymptotic giant branch (AGB), whose spectral energy distribution (SED) is affected by the presence of dust formed in their winds. Interpreting these observations requires the set up of a methodology based on stellar and dust formation modelling, to be potentially extended to the study of more distant galaxies, whose stellar population is unresolved.
Outline of the Project: The description of dust formation in the stellar winds will be updated, to consider the effects of the shocks triggered by large amplitude pulsations and to model the formation of PAH. These results will be applied to the library of stellar models maintained by the proponent, to calculate the dust production rate across the evolution of the star. Stellar evolution and dust formation modelling will be used to develop a library of synthetic spectra, to represent the evolution of the SED of stars of various mass and metallicity.The final step will be the development of a tool based on population synthesis, able to describe the stellar population of galaxies, based on the star formation history and age-metallicity relation.
Planning of the activities: year 1: implementation of the effects of the shocks and of the network to describe the formation of PAH in the chemo-dynamical description of stellar winds. year 2: calculation of the spectral library and of the stellar isochrones. year 3: development of the tool to make population synthesis
Institution(s) where the research will be carry out: INAF-Osservatorio Astronomico di Roma

3.1.17 Understanding multiple populations in Globular Clusters

Supervisor (Name, Istitution and Contact):
Paolo Ventura, INAF, paolo.ventura@inaf.it
Co-Supervisor (Name, Istitution and Contact):
Flavia Dell'Agli, INAF, flavia.dellagli@inaf.it
Scientific Case: Results from phometry and high-resolution spectroscopy outlined a surprising diversity in the stellar populations of Galactic Globular Clusters. The chemical patterns traced by the stars, the peculiar morphology of the horizontal branch and the splitting of the main sequence indicate that more stellar populations co-exist, with part of the stars having formed from material processed by proton-capture nucleosynthesis.
Outline of the Project: The project aims at interpreting the observational data set of globular clusters stars, by mean of a self-enrichment scenario, where the main actors of the pollution of the intra-cluster medium, releasing the gas from which the new generations of stars formed, are stars of intermediate mass, evolving through the asymptotic giant branch (AGB) phase. The project will stars with the calculation of updated yields from AGB mass of different mass and metallicity, to check consistently between the theoretical expectations and the chemical patterns observed. Particular care will be devoted to understand the morphology of the horizontal branches of the globular clusters examined.
Planning of the activities: year 1: implementation of the network to follow the Ar-K-Ca nucleosynthesis, required to interpret the observed abundances of potassium and calcium. year 2: calculation of the chemical yields of stars of different mass and metallicity. year 3: reconstructing the star formation history of the multiple populations, based on the chemical composition of the ejecta of AGB stars.
Institution(s) where the research will be carry out: University of Roma "La Sapienza"; Osservatorio Astronomico di Roma

3.2 INAF-OOAb (Ossevatrio Astronomico di Abruzzo)

One (1) fellowship is granted for a student to carry out his/her research at INAF-OOAb, among the following thesis proposals.

3.2.1 Look up at the stars to understand the new physics.

Supervisor (Name, Istitution and Contact):
Oscar Straniero, INAF, oscar.straniero@inaf.it
Co-Supervisor (Name, Istitution and Contact):
Alessandro Mirizzi, University of Bari, ...; Cristina Pallanca, UNiversity of Bologna, ...
Scientific Case: Does the neutrinos have a non-zero magnetic moment? Why don't strong interactions violate CP symmetry? What is dark matter made of? Answers to these and other fundamental questions may be found looking at stars as laboratories of physics. By comparing observable stellar properties (luminosity, effective temperature, composition. . . .) to predictions of stellar models that incorporate theories beyond the Standard Model, we may constrain the new physics paving the route toward a better comprehension of the fundamental laws of nature.
Outline of the Project: Depending on the student's skill and interest, the thesis may be either observational (multi-wavelength stellar photometry) or theoretical (stellar models and physics of stellar interiors). The immediate objective of the thesis is to obtain astrophysical constraints to possible theoretical proposals about physics beyond the standard model. The strategy is straightforward: 1. identification of stellar properties much sensitive to the new physics ingredient, and 2. comparisons between theoretical predictions (from stellar models) and astronomical observations. To be competitive with laboratory experiments, both the precision of the astronomical data and the accuracy of the stellar models should be improved as much as possible. The long-term objective is to exploit this new knowledge in the framework of a multi-messenger astrophysics. The PhD student will be incorporated in a multi-disciplinary team that boast a widely recognized experience in observing stars of different mass, age and composition, in modelling their interior and in modify the stellar structure equations in order to incorporate new physics ingredients. Important results have been already obtained, see, e.g., Straniero et al. 2019 (ApJ 881, 158), Menjiao et al 2021 (Ph.Rv.L. 126, 1101), Straniero et al. 2020 (A&A 644, 166).
Planning of the activities: Since the beginning, the student is expected to collaborate to the ongoing scientific program of the research team. During the first years of his activity, he should improve his knowledge of stellar evolution, standard and non-standard stellar physics and astronomical data handling. In addition to the mandatory courses offered by the PhD program, the participation to schools and workshops will be strongly encouraged. In the second year we expect the student could take the responsibility to carry-on the selected science case. The third year will be dedicated to writing the thesis and to presentation of the results, both trough the publication of one or two papers on referee journals and the presentation of the results in specific workshop or conferences.
Institution(s) where the research will be carry out: INAF-Osservatorio Astronomico d'Abruzzo

3.2.2 Carbon burning in massive stars and accreting white dwarfs: impact on supernova progenitors.

Supervisor (Name, Istitution and Contact):
Oscar Straniero, INAF, oscar.straniero@inaf.it
Co-Supervisor (Name, Istitution and Contact):
Gianluca Imbriani, University of Naples ”Federico II”, ...; Luciano Piersanti, INAF, ...
Scientific Case: Recently, theoretical and observational evidences revealed the importance of the progenitor evolution in our comprehension of supernova events. This is true for core-collapse supernovae, whose progenitors are single or binary massive stars, as well as for thermonuclear supernovae, whose progenitors are accreting white dwarfs. In both cases, the hydrostatic C burning phase plays a relevant role for the final explosion. In thermonuclear SNe, a hydrostatic C burning (simmering phase) precedes the dynamical breakdown, and determines the physical and chemical conditions at the onset of the explosion. In massive stars, is the shell C burning that controls the growth rate of the core and, in turn, the internal physical and chemical stratification within the collapsing core. In spite of its importance, the leading nuclear process that activates the C burning, the 12C+12C reaction, is poorly known. The available measurements for the 12C+12C cross-section barely attains 2 MeV, while the C burning in stars occurs at much lower thermal energies. The new 3.5 MV facility for nuclear astrophysics at the INFN-Gran Sasso laboratory has been specifically designed to significantly improve the knowledge of this important stellar nuclear process, by exploiting the background suppression provided by the 3000 m of rocks above the underground laboratory. Next year (2024)m the LUNA collaboration will start new low-energy measurements of the 12C+12C reaction with the 3.5 MV machine.
Outline of the Project: The aim of these thesis is to exploit the new low-energy measurements of the 12C+12C cross-section to better constrain the stellar rate of the C burning and, in turn, to definitely fix one of the major uncertainties affecting our knowledge of supernova progenitors. The student will become member of the LUNA (Laboratory for Underground Nuclear Astrophysics) collaboration and part of the stellar evolution team of the INAF-Osservatorio d’Abruzzo. His main contribution will be: 1. the calculation of updated reaction rates for the C burning phase and 2. The development of new models of supernova progenitors. The PhD student will be incorporated in a multi-disciplinary team that boast a widely recognized experience in nuclear astrophysics, stellar physics, stellar evolution, stellar nucleosynthesis, and, more specifically, in modelling supernova progenitors.
Planning of the activities: Since the beginning, the student is expected to collaborate actively to the ongoing scientific program of the research team. It includes activities related to the experimental program and to the stellar evolution computational theory. During the first years, he should improve his knowledge of stellar evolution, standard and non-standard stellar physics and nuclear astrophysics. In addition to the mandatory courses offered by the PhD program, the participation to schools and workshops will be strongly encouraged. In the second year we expect the student could take the responsibility to carry-on the main science case. The third year will be dedicated to the writing of the thesis and to the presentation of the results, both trough the publication of one or two papers on referee journals and the presentation of the results in specific workshop or conferences.
Institution(s) where the research will be carry out: INAF-Osservatorio Astronomico d’Abruzzo

3.2.3 Galactic archaeology: adjusting the clock(s) to unveil the formation and evolution of the Milky Way.

Supervisor (Name, Istitution and Contact):
Santi Cassisi, INAF, santi.cassisi@inaf.it
Co-Supervisor (Name, Istitution and Contact):
Giuseppe Bono, Tor Vergata University, bono@roma2.infn.it

Scientific Case: Galactic archaeology is the study of the history of the nearby universe, with a focus on our own Galaxy. Like classical archaeologists studying fossils to understand the history of humanity, Galactic archaeologists study the most ancient structures observable today, specifically the stellar fossils, to learn about the earliest phases of the Milky Way. In this context, ongoing observational surveys such as Gaia ESA mission, APOGEE, etc., are producing an extremely detailed view of the chemo-kinematic properties of the Milky Way. To fully exploit the potential of this wealth of information, and constrain MW formation and evolution models, it is crucial to retrieve an additional, fundamental information: the age of large samples of stars in Galactic fields and clusters. In such a way, a detailed chrono-chemo-dynamical map of the MW can be obtained.

Outline of the Project: Outline of the Project: The aim of the project is to obtain a homogeneous age scale appropriate for the whole parameter space in terms of age and metallicity. Various chronometers will be applied to stars in different evolutionary stages, all of them calibrated homogeneously on a stellar model set. To this purpose, the first step is to provide an updated theoretical evolutionary framework whose uncertainties have to be properly evaluated. To set the various stellar clocks to the same age scale, one needs to use a suitable observational benchmark, whose age dating can be simultaneously performed by using different age indicators. To this aim, we will adopt a sample of MW open clusters, carefully investigated in the context of high-precision, observational surveys.

Planning of the activities: During the thesis's work, the student will have the opportunity to develop his/her skills in stellar modelling as well as in deriving from the theoretical evolutionary framework all the relevant tools/information needed to estimate the age of star clusters and field stars. In the same time, the student will learn how to apply the theoretical framework to the most recent and updated observational datasets concerning the astrometric, photometric and spectroscopical properties of both cluster stars and field ones. As a consequence, the doctoral fellowship will allow the student to acquire a significant expertise and competence in different, but still complementary, research fields. The research will be carried out at the INAF - Osservatorio Astronomico d'Abruzzo (Teramo); however due to the long standing scientific collaboration that our research group established on this topic with the Galactic archaeology group at the Instituto Astrofisico de Canarias (Tenerife - Spain), it will be also possible for the student to spend some periods of his/her research activity at this international institution.

Institution(s) where the research will be carry out: INAF Astronomical Observatory of Abruzzo

3.2.4 Neutron-capture processes studies with nuclear reaction networks

Supervisor (Name, Istitution and Contact):
Diego Vescovi, INAF, diego.vescovi@inaf.it
Co-Supervisor (Name, Istitution and Contact):
Sara Palmerini, University of 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 as a function of the physical 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: The code will be developed at INAF-OAAb, under the guidance of a researcher belonging to the theoretical stellar evolution and nucleosynthesis group. The candidate will conduct the sensitivity study in close collaboration with researchers from the nuclear astrophysics group of the University of Perugia. 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 (INAF-OAAb) and Universita' degli Studi di Perugia

3.2.5 Magnetic fields and heavy elements nucleosynthesis in asymptotic giant branch stars

Supervisor (Name, Istitution and Contact):
Diego Vescovi, INAF, diego.vescovi@inaf.it
Co-Supervisor (Name, Istitution and Contact):
Gabriele Cescutti, University of Trieste, gabriele.cescutti@units.it
Scientific Case: Low- to intermediate-mass thermally pulsing asymptotic giant branch (AGB) stars are predicted to contribute to about half of the cosmic abundances of elements heavier than iron in the Galaxy, via the slow neutron-capture process (s-process). In these objects, the formation of the 13C neutron source requires extensive mixing that goes beyond the simple convection adopted in canonical stellar models. Recently, magnetic instabilities have been suggested as possible causes of this mixing. Stellar models including such magnetic mixing were shown to reproduce common observational constraints from s-process enriched sites in the Galaxy. Their expected contribution to the Galactic Chemical Evolution is, however, uncertain due to the lack of a homogeneous set of heavy element theoretical yields.
Outline of the Project: In this thesis, the PhD candidate will master the fundamentals of stellar modeling and perform detailed AGB evolutionary models that include magnetic mixing. He/she will then compute the relative stellar yields and use them to conduct a galactic chemical evolution study.
Planning of the activities: The candidate will work in strict collaboration with researchers belonging to the theoretical stellar evolution and nucleosynthesis group of INAF-OAAb for the stellar nucleosynthesis and stellar yields calculations. The part concerning the galactic chemical evolution study will be performed in collaboration with staff members of the University of Trieste.
Institution(s) where the research will be carry out: INAF - Osservatorio Astronomico d'Abruzzo and Universita' degli Studi di Trieste

3.2.6 Neutron capture nucleosynthesis process: the third wheel

Supervisor (Name, Istitution and Contact):
Sergio Cristallo, INAF, sergio.cristallo@inaf.it
Co-Supervisor (Name, Istitution and Contact):
Gabriele Cescutti, University of Trieste, gabriele.cescutti@inaf.it; Cristian Massimi, University of Bologna, cristian.massimi@bo.infn.it; Devika Kamath, Macquarie University, devika.kamath@mq.edu.au
Scientific Case: The nucleosynthesis of elements heavier than iron requires the presence of free neutrons in stellar plasmas. The two main neutron capture processes, the slow (s-) and rapid (r-) processes, have been recently joined by a third process, the so-called intermediate neutron capture process (i-process). The effective contribution of this process to Galactic Chemical Evolution is currently very uncertain, with some stars belonging to the Galactic halo showing its typical fingerprint.
Outline of the Project: In this thesis, the PhD candidate will get acquainted with network calculations involving neutron captures. 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 i-process. A comparison between models and stellar spectra stars showing the fingerprint of the i-process will be performed. Finally, the candidate will perform a Montecarlo sensitivity study on theoretical neutron capture rates, in order to determine the effects on their variations on i-process nucleosynthesis. This study will be of guidance for future experimental measurements at the recently installed NEAR station of the n_TOF experiment (CERN). Depending on neutron beam and target sample availability, first measurements may be performed before the end of the PhD project.
Planning of the activities: The candidate will work in strict collaboration with researchers belonging to the theoretical stellar evolution and nucleosynthesis group of INAF-OAAb. The part concerning observations will be performed in collaboration with staff members of the Macquarie University in Sydney. The part concerning the sensitivity study will be performed in collaboration with staff members of the Università degli Studi di Trieste. During the whole PhD project, the candidate will join the n_TOF experiment, becoming familiar with its experimental facilities.
Institution(s) where the research will be carry out: INAF - Osservatorio Astronomico d'Abruzzo, Università degli Studi di Trieste, CERN - France

3.2.7 Nuclear uncertainties in r-process abundances and kilonova light-curves

Supervisor (Name, Istitution and Contact):
Sergio Cristallo, INAF, sergio.cristallo@inaf.it
Co-Supervisor (Name, Istitution and Contact):
Samuel Giuliani, Universidad Autonoma de Madrid, samuel.giuliani@uam.es
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)

3.2.8 Making the way through the mists of massive star remnants with a multimessenger drill

Supervisor (Name, Istitution and Contact):
Leonardo Tartaglia, INAF, leonardo.tartaglia@inaf.it
Co-Supervisor (Name, Istitution and Contact):
Francesco Villante, University of L'Aquila, francescolorenzo.villante@univaq.it
Scientific Case: While multi-messenger astronomers are mainly focusing on electromagnetic counterparts of GWs, equally significant efforts need to be devoted to the origin of the astrophysical high-energy neutrinos (in the Tev-Pev range) which are being discovered by IceCube. Despite being the (so far) favoured sources, blazars cannot account for the whole neutrino flux we are detecting. Interacting supernovae are expected to play a role, as their shocked regions are favourable environments to efficient particle acceleration. Exploring their role in the population of possible particle emitters, is hence crucial to our understanding of the origin of both high-energy neutrinos and cosmic rays.
Outline of the Project: This project aims at characterising extragalactic transients occurring within a dense circumstellar medium (CSM), providing estimates of key parameters to tackle still unsolved problems of multi-messenger astronomy, such as linking high-energy neutrinos observed by IceCube to their astrophysical sources and the nature of massive black holes discovered by LIGO/VIRGO.
Planning of the activities: Activities will involve obtaining and analysing data of transients showing excesses in their luminosity output, possibly due to interaction of their ejecta with a dense pre-existing CSM. These will help detailing properties of transients from the most massive stars and explore links to high-energy neutrinos. The applicant will learn how to plan and manage observations of transients, reduce both spectroscopic and photometric data in the widest possible range of wavelengths (ideally from UV to radio) and analyse them with dedicated modeling tools. Activities will also include nights at telescopes of different classes (including those of the Campo Imperatore observatory and the NTT at the La Silla Observatory in Chile) and participation in national and international projects such as GRAWITA, ENGRAVE and SOXS. Existing collaborations with research group will provide opportunities to visit European or national institutes.
Institution(s) where the research will be carry out: INAF - Osservatorio Astronomico d'Abruzzo and Universita' di L'Aquila

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

Supervisor (Name, Istitution and Contact):
Elisa Portaluri, INAF, elisa.portaluri@inaf.it
Co-Supervisor (Name, Istitution and Contact):
Michele Cantiello, INAF, michele.cantiello@inaf.it; Gianliuca Di Rico, INAF, gianluca.dirico@inaf.it; Roberto Ragazzoni, University of Padua, roberto.ragazzoni@unipd.it
Scientific Case: Photometric and morphological study of the distant galaxies to understand their formation and evolution. 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. 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.
Outline of the Project: A significant part of the work will be dedicated to explore the future scientific applications of ELT instruments, via simulations and also in the perspective of having access to the *guaranteed time observations* (GTO), and to exploit scientific data from precursor instruments. The student will take part in the feasibility studies aimed at preparing the first observations with these instruments, collaborating with several research groups, from different INAF institutes and Universities, and of international science instrument teams. In particular, the student will be asked to propose new observations with existing AO-assisted instrumentation (e.g. LUCI@LBT, ERIS@VLT), to lead their analysis and to publish the results in international refereed papers. 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. In a nutshell: - Introduction: the high- and intermediate Universe; a literature study; - Exploiting VLT data to investigate the properties of a sample of galaxies; - Simulation and analysis of mock images of high redshift galaxies as seen from next generation of new instrumentation (VLT and ELT); - Discussion on the improvements we can expect from next instrumentation and what we will be able to discover; - Conclusion: what we learned and the contribution to the extragalactic astrophysics from next instrumentation.
Planning of the activities: - The first year will be devoted to study the existing literature and to make the first tests with the data collected to the team and eventually propose new observations for the next cycle. A paper on a peer-review journal is expected;
- The second year will be dedicated to study the new instrumentation exploring the future scientific applications via simulations to understand the incoming potentiality and how they can contribute to the extragalactic astrophysics. The applicant will participate to the team responsible to the feasibility study of MORFEO and MICADO (and/or MAVIS and SHARP) and will participate to the various Consortium meetings contributing to the Science Operational Teams;
- The last year will be devoted to write a paper on the simulations and discussion of the scientific results with the next instrumentation. The last semester will be dedicated to write the thesis. 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).
Institution(s) where the research will be carry out: INAF Osservatorio Astronomico d'Abruzzo and possibly other INAF institutes. Visiting and short periods abroad for meetings, conferences and work will be desirable.

3.2.10 Machine Learning methods for sensing, control and post-processing in Adaptive Optics: novel techniques for the next generation of instruments for the Extremely Large Telescopes.

Supervisor (Name, Istitution and Contact):
Gianluca Di Rico, INAF, gianluca.dirico@inaf.it
Co-Supervisor (Name, Istitution and Contact):
Marco De Petris, Sapienza University of Rome, marco.depetris@roma1.infn.it; Stefano Bonora, CNR, stefano.bonora@cnr.it; Matteo Di Carlo, INAF, matteo.dicarlo@inaf.it
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 bio-science to optical tele-communication, and in particular in astrophysics, where AO is of paramount importance for the present and future largest telescopes, like the ELT. 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 the atmospheric turbulence during observations. The use of Machine Learning in photonics is opening up new perspectives in the development of highly performing techniques for wavefront sensing, DM control and post-processing of astronomical data. The research activity will consist in the study of algorithms and neural networks for the reconstruction of the relationship between wavefront aberrations and phase compensation, for both the optimization of real-time control loops, and the speed-up of post-processing operations. The work foresees the development of laboratory test benches and the usage of dedicated hardware for real-time & cloud computing.
Outline of the Project: - Literary review on Machine Learning, wavefront sensing and correction techniques;
- Review on major criticalities and limitations of existing AO instrumentation;
- ML for AO systems: application of novel technologies in future ELT instrumentation;
- Laboratory activities: test bench setup, Neural Network (NN) training and verification;
- Conclusion: lesson learned, advancements and achievements for the development of future AO instrumentation.
Planning of the activities: - The first year will be devoted to the study of existing literature and to identify novel ML applications in AO systems;
- The second year will be dedicated to the definition of activities and procedures. Moroeover, the candidate will contribute to the setup of a laboratory test bench, needed for the NN training and the verification of required innovative technologies and methodologies;
- The last year will be dedicated to complete the laboratory activities and to consolidate the analyses on acquired data. Writing of the thesis. One/two conference or peer-review papers are also expected.
Institution(s) where the research will be carry out: INAF Osservatorio Astronomico d'Abruzzo and possibly other INAF institutes. Visiting and short periods abroad for meetings, conferences and work will be desirable.

3.2.11 Final Design, Test and Verification of the Calibration Unit of the Multiconjugated adaptive Optics Relay For ELT Observations (MORFEO)

Supervisor (Name, Istitution and Contact):
Gianluca Di Rico, INAF, gianluca.dirico@inaf.it
Co-Supervisor (Name, Istitution and Contact):
Marco De Petris, Sapienza University of Rome, marco.depetris@roma1.infn.it; Elisa Portaluri, INAF, elisa.portaluri@inaf.it; Roberto Ragazzoni, UNiversity of Padua, roberto.ragazzoni@inaf.it
Scientific Case: Development of visible and near infrared instrumentation for the calibration of advanced Adaptive Optics systems. The thesis will concern the final phases of the development of VIS/NIR instrumentation for extremely large telescopes. INAF-Abruzzo is in charge of the design and construction of the MORFEO Calibration Unit, a highly complex and advanced subsystem that will allow to calibrate the largest and challenging Adaptive Optics module currently under development, to be mounted on the 39m diameter European Extremely Large Telescope (ELT).
Outline of the Project: - Introduction: the calibration of Adaptive Optics systems and components; a literature review;
- The MORFEO Adaptive Optics Module for ELT: calibration requirements and functional analisys;
- MORFEO Calibration Unit: analysis of the performance and design optimization;
- Definition of the instrument integration, test and verification procedures
- Prototyping and laboratory verification of critical components.
- Discussion on the technologies and methodologies proposed for the Final Design and MAIT phase;
- Conclusion: lesson learned, advancements and achievements.
Planning of the activities: The candidate will have the unique opportunity to take part this cutting-edge project by carrying out system engineering, performance and verification analysis during the Final Design Review phase of the project, and significantly contribute to the definition of the activities of the Manufacturing Assembly Integration and Test (MAIT) phase. The research activities will include the development of laboratory test benches - for showcasing new technologies and methodologies - and will be carried out within the MORFEO international collaboration, a large multi-disciplinary team of engineers and scientists. - The first year will be devoted to the study of existing literature and to identify solutions to minimize instruments criticalities.
- The second year will be dedicated to the definition of activities and procedures to be carried out during the MAIT phase, verification of technologies and methodologies by mean of a laboratory test bench.
- The last year will be dedicated to complete the laboratory activities and to consolidate the analyses on acquired data. Writing of the thesis. One/two conference or peer-review papers are also expected.
Institution(s) where the research will be carry out: INAF Osservatorio Astronomico d'Abruzzo and possibly other INAF institutes. Visiting and short periods abroad for meetings, conferences and work will be desirable.

3.3 INAF-IAPS

One (1) 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

Supervisor (Name, Istitution and Contact):
Fiamma Capitanio, INAF, fiamma.capitanio@inaf.it
Co-Supervisor (Name, Istitution and Contact):
Francesco Tombesi, Tor Vergata University, francesco.tombesi@uniroma2.it
Scientific Case: Accreting Low-mass X-ray binaries (LMXBs) host a compact object (non-pulsating Neutron Star or a Black Hole)accreting via Roche-lobe overflow from a low mass star companion. They are strong X-ray emitters and highly variable objects. Their spectral and timing behaviours generally follow the same pattern of transition between two alternating main states roughly described as a combination of a soft thermal component, coming from the accretion disk, plus a harder electron scattering one with reflection by a cold medium. However, the nature and the origin of the scattering electron plasma (also called ìcoronaî) that causes the harder spectral component remain elusive. X-ray polarimetry is a powerful tool in investigating the physics of accretion in LMXBs. In fact, the X-ray spectroscopy provides information on the physical parameters of the emitting regions, while polarimetry, about geometrical properties such as the shape and extension of the region where the scattering occurs. With the NASA/ASI Imaging X-ray Polarimetry Explorer (IXPE) is now possible to observe polarization of the X-ray emission at energes that could intercept the low-energy boundary of the emission due to electron scattering. the IXPE first results show a polarization higher than expected that is not always easy to explain.
Outline of the Project: The candidate will work in synergy with researchers of both IAPS and UTOV that are experts in X-ray data analysis, theoretical X-ray astrophysics and they have a deep knowledge of the IXPE detectors. They are part of the IXPE collaboration and are also deeply involved in a massive multi-frequency observation campaign has been carried in coordination with IXPE and the principal X-ray telescopes. The thesis work will take the advantage of the data to study the physics of the accretion together withs the geometry of the emitting regions.
Planning of the activities: The thesis work will follow the above scheme: The candidate will start to study the scientific case and will learn the data reduction of IXPE and other X-ray missions (INTEGRAL, Nicer,Nustar). She/he will have access to the data collected by the multi-frequency observation campaign. The work will be focalised on the origin and the evolution of the hot electron corona in both NS and BH LMXB
Institution(s) where the research will be carry out: INAF-IAPS and UToV

3.3.2 Gamma-ray astronomy and the search of lost Pevatrons

Supervisor (Name, Istitution and Contact):
Martina Cardillo, INAF, martina.cardillo@inaf.it
Co-Supervisor (Name, Istitution and Contact):
Marco Tavani, INAF, marco.tavani@inaf.it
Scientific Case: Cosmic particle acceleration and the origin of Cosmic Rays (CRs) are one of hottest topics in High Energy (HE) astrophysics. Non thermal gamma-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.
Planning of the activities: 1 Year: 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 2 Year: 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. 3 year: application of the developed models on recent experimental data that will be obtained by all the VHE and neutrino experiments
Institution(s) where the research will be carry out: INAF-IAPS

3.3.3 Study of Solar Wind Fluctuations from MHD down to kinetic scales

Supervisor (Name, Istitution and Contact):
Giuseppe Consolini, INAF, giuseppe.consolini@inaf.it
Co-Supervisor (Name, Istitution and Contact):
Raffaella D'Amicis, INAF, raffaella.damicis@inaf.it
Scientific Case: Planetary and Solar Physics
Outline of the Project: The solar wind is a turbulent plasma medium that represents a natural laboratory to study turbulence in astrophysical plasmas, providing a unique environment, easily accessible to interplanetary probes. This kind of observations allow to investigate the turbulent dynamics of a plasma medium from MHD fluid scales down to kinetic scales, where the single fluid approximation is no longer valid. The aim of this thesis work is to take advantage of novel observations from recent space missions, such as the ESA/NASA-Solar Orbiter, the NASA-Parker Solar Probe, etc., to gain a deeper understanding of the dynamical changes of the solar wind features from MHD to kinetic scales. In particular, the chaotic/turbulent nature of fluctuations and the occurrence of dissipation beyond the spectral break near the ion scales is a central issue of the proposed study. Approaches based on standard spectral analysis, dynamical system analysis (such as fractal and/or multifractal analysis) and statistical mechanics will be implemented and applied to unveil and characterize the different nature of kinetic fluctuations with respect to MHD scales.
Planning of the activities: 1 year: Strengthening knowledge of space plasma physics. Deepening of the topics to be investigated through a bibliographic study; possible participation in schools and congresses dedicated to the topics of the thesis project; enhancing communication skills by attending relevant workshops. 2 year: Deepening the knowledge of turbulence analysis methods; data selection and analysis; publishing first results in peer review journals. 3 year: Publishing main results in peer review journals; networking opportunities; write and defend the PhD thesis
Institution(s) where the research will be carry out: INAF-IAPS

3.3.4 Complexity in weakly-collisional space plasmas at fluid and kinetic scales

Supervisor (Name, Istitution and Contact):
Giuseppe Consolini, INAF, giuseppe.consolini@inaf.it
Co-Supervisor (Name, Istitution and Contact):
Simone Benella, INAF, simone.benella@inaf.it
Scientific Case: Planetary and Solar Physics
Outline of the Project: Heliospheric and near-Earth space plasmas represent a weakly-collisional medium in a far-from-equilibrium state showing complex collective behaviors and turbulent dynamics over a wide range of scales. Great advances in the understanding of the main properties of space plasma dynamics have been recently made by taking advantage of increasingly accurate in-situ satellite measurements. However, several aspects of weakly-collisional space plasmas are still not understood, especially at scales where the separation between ion and electron inertial lengths occurs (kinetic scales) and the fluid-like approximation does not apply. The aim of this PhD thesis project is to make a contribution in the characterization of both turbulent and kinetic fluctuations by investigating the topology of velocity and magnetic field structures through the scale-to-scale evolution of coarse-grained gradient-tensor invariants. Since the scale-to-scale evolution of turbulent and kinetic fluctuations can be envisioned as a stochastic process, information obtained from analysis based on in-situ satellite measurements and numerical simulations will be interpreted in the traditional framework of kinetic plasma physics, but also using recent, innovative and multidisciplinary theoretical approaches, such as the stochastic thermodynamics.
Planning of the activities: 1 year: Strengthening knowledge of space plasma physics. Deepening of the topics to be investigated through a bibliographic study; possible participation in schools and congresses dedicated to the topics of the thesis project; enhancing communication skills by attending relevant workshops. 2 year: Deepening the knowledge of nonlinear and stochastic analysis methods; data selection and analysis; publishing first results in peer review journals. 3 year: Publishing main results in peer review journals; networking opportunities; write and defend the PhD thesis
Institution(s) where the research will be carry out: INAF-IAPS

3.3.5 The quest for dual supermassive black holes

Supervisor (Name, Istitution and Contact):
Alessandra De Rosa, INAF, alessandra.derosa@inaf.it
Co-Supervisor (Name, Istitution and Contact):
Raffaella Schneider, Sapienza University, raffaella.schneider@uniroma1.it; Cristian Vignali, DIFA, ...; Paola Severgnini, INAF, ...
Scientific Case: Searching for AGN signatures in dual super-massive black holes (SMBHs) and characterizing their nuclear activity in the multi-messenger era.
Outline of the Project: There is growing evidence that galaxy mergers are the way through which SMBHs grow and also form, especially at the highest luminosities. Numerical simulations have shown that strong inflows in a galaxy merger feed gas to the SMBH, thus powering accretion and triggering the AGN. Merging SMBHs are among the loudest sources of gravitational waves in the Universe. The connection between AGN triggering and galaxy merger is not clear yet, despite several observational campaigns carried out in this field. The apparently different results may be a consequence of different sample selection, observational biases and numerical techniques.
Planning of the activities: The project is dedicated to multi-wavebands studies of multiple SMBHs, with emphasis on the best strategies for detections, applicable to the current and upcoming observatories, and the most updated and comprehensive numerical simulations and theories on the pairing and merging of SMBHs. Through the analysis of multi-wavelength data (optical, radio, mm, IR, X-rays) the work aims at investigating (a) the occurrence of dual and offset AGN by cross-matching large-area optical/near-IR survey galaxy pairs/multiplets with X-ray catalogs and infer the level of nuclear activity; (b) the properties of nuclear emission and SMBH environment in merging galaxies such as: BH mass ratio, AGN Luminosity, absorption, accretion rate, star formation activity. These characteristics will be compared with those found in SMBH hosted in isolated systems with the main goal of understanding the parameters that most drive the AGN triggering. The derived source demography and physical properties obtained through multi-wavelength data will be interpreted and placed in a coherent picture using state-of-the-art numerical simulations.
Institution(s) where the research will be carry out: INAF-IAPS

3.3.6 Analysis of the bright areas on Ceres searching for organics and other components

Supervisor (Name, Istitution and Contact):
M. Cristina De Sanctis, INAF, cristina.desanctis@inaf.it
Co-Supervisor (Name, Istitution and Contact):
TBD
Scientific Case: The thesis will be focused on the analysis of visible and infrared data taken by the Dawn mission at Ceres. The dwarf planet has been recognized as one of the most interesting ìAstrobiological targetsî for the next missions searching for life, being rich of ice, organics and minerals derived from aqueous alteration. These materials are distributed on the surface irregularly, with many bright areas showing different characteristics. Those bright areas are likely to be residua of extruding salty fluids circulating into the subsurface. Aim of the doctoral project is to better understand the materials and processes characterizing the bright areas in the framework of their potential for being ìhabitable nichesî.
Outline of the Project: ï Analysis of the Dawn mission Camera and Spectrometer data: revision of the catalogue of the bright areas, searching for differences and common characteristics. ï Analysis of the spectra and camera colors of the bright areas. ï Analysis of the spectral parameters of the bright areas. ï Investigation of the correlations and trends between the parameters, emphasizing parameters indicative of organics. ï Mapping of the parameters linked to the identified main constituents in the bright areas and characterization of the distribution of the unknown species. ï Spectral unmixing of the data using radiative transfer models and mapping the distribution of the different species. ï Reproduction in laboratory of the inferred mixture to verify the interpretation. ï Investigation of the processes responsible for the formation and emplacement of the bright materials, using the results from this study
Planning of the activities: 1st year: Data analysis (camera and spectrometer); identification of valuable parameters, the study of correlations and trends, mapping of the parameters 2nd year: the study of the spectral unmixing methods and applications to the spectra of the bright areas; mapping of the results from the unmixing procedures 3rd year: laboratory activity measuring natural mixtures based on the results from the spectral unmixing and comparison with the Dawn data; Identification of the possible processes responsible for the bright areas on Ceres.
Institution(s) where the research will be carry out: INAF-IAPS

3.3.7 Galactic archaeology combining asteroseismic and spectroscopic analysis of open clusters and globulars

Supervisor (Name, Istitution and Contact):
Maria Pia Di Mauro, INAF, maria.dimauro@inaf.it
Co-Supervisor (Name, Istitution and Contact):
Valentina D'Orazi, Tor Vergata University, valentina.dorazi@inaf.it
Scientific Case: Stellar clusters, including open and globular clusters, provide valuable insights into the evolutionary history of the Galaxy's disk and halo, respectively. These clusters consist of stars born from the same molecular cloud, sharing common attributes such as age, kinematics, and initial chemical composition. Consequently, their properties can be measured with greater precision compared to individual stars. Globular clusters, in particular, exhibit multiple stellar populations whose origins remain elusive.
Outline of the Project: This thesis project aims to enhance our understanding of red-giant stars in well-observed open and globular clusters within the Kepler and TESS fields by combining asteroseismic data from photometric space missions with observational parameters obtained from spectroscopic campaigns such as GALAH and Gaia-ESO. The asteroseismic analysis of red-giant stars has proven to be a powerful technique for characterizing their internal structure and accurately determining their age, mass, and radius, surpassing other available methods. To fully leverage the potential of asteroseismology, precise measurements of atmospheric stellar parameters such as effective temperature, surface gravity, luminosity, and metallicity are essential and can be obtained through high-resolution spectroscopy. By providing an innovative and critical contribution to large spectroscopic surveys, this project aims to deepen our understanding of the Galactic stellar disc and enable a more comprehensive analysis of its properties.
Planning of the activities: The student will learn to analyze high-resolution spectra in order to characterize the stellar atmosphere of observed red-giant stars. In addition, the student will learn asteroseismic techniques based on the use of observed oscillation frequencies of red-giant stars, and accurate stellar modelling.
Institution(s) where the research will be carry out: INAF-IAPS

3.3.8 On-ground validation and in-orbit scientific observations of the HERMES nano-satellites constellation for GRB studies and Gravitational Wave counterparts

Supervisor (Name, Istitution and Contact):
Yuri.Evangelista, INAF, yuri.evangelista@inaf.it
Co-Supervisor (Name, Istitution and Contact):
Eleonora Troja, Tor Vergata University, eleonora.troja@uniroma2.it
Scientific Case: HERMES (High Energy Rapid Modular Ensemble of Satellites) is a space borne mission of the Italian Space Agency, with contribution by the Horizon 2020 EU program. The project is based on a constellation of 6 nanosatellites, hosting innovative, miniaturized detectors to localize and probe the timing properties of the emission of Gamma-Ray Bursts and other high-energy transients. With a launch date in 2024, the HERMES transients monitoring represents a keystone capability to support the new generation of gravitational wave interferometers, which will observe a sky volume 100 times larger than what explored to date. INAF, in collaboration with INFN, University of Tubingen, Politecnico di Milano, University of Pavia, Bruno Kessler Foundation, University of Udine and University of Cagliari, has developed the modular X/gamma-ray monitor to be integrated on-board 3U CubeSat spacecrafts.
Outline of the Project: The successful PhD candidate will join the HERMES team during the satellite integration and on-ground calibration and validation activities, learning the fundamental notions and skills needed for the development, assembly, integration and test of space-borne instrumentation. After the launch of the HERMES constellation in mid-2024, the PhD work will be focused on the in-flight instrument operation and on the reduction, analysis and scientific interpretation of the HERMES in-flight data. The candidate will take part to the mission commissioning phase, scientific verification phase and data analysis and exploitation, in a project which is perfectly suited for a PhD thesis and will provide the student a complete view of both the theoretical and experimental aspects of a space-borne high energy astrophysics mission. The PhD candidate will work in collaboration with the HERMES team and collaborators network, that counts both Academic Institutions in Italy and abroad (INAF, Politecnico di Milano Aerospace Department, INFN, University of Nova Gorica, Pavia, Cagliari, Tubingen, and others), and private companies (FBK, DEIMOS, Skylabs, C3S). We are committed to provide a stimulating and caring work environment, supporting personal growth and professional development.
Planning of the activities: The activity planning will follow the HERMES project schedule which foresees the payload-spacecraft integration and test in 2023-2024. After the launch campaign, planned to take place in late 2024, the PhD candidate will take part to the satellite constellation commissioning phase and science verification phase. Starting from 2025, the activities will be mostly focused on the scientific data reduction and analysis, with special focus on GRB inner engine modelling and multi-messenger astrophysics.
Institution(s) where the research will be carry out: The activities will be mainly carried out at the INAF-IAPS laboratories in Rome. Validation and post-integration tests will be carried out at Politecnico di Milano, in charge of the HERMES spacecraft development and integration. Scientific data analysis and GRB emission modelling will be carried out in University of Rome ”Tor Vergata” and INAF-IAPS.

3.3.9 X-ray polarimetry of solar flares, from Heliophysics to Space Weather

Supervisor (Name, Istitution and Contact):
Sergio Fabiani, INAF, sergio.fabiani@inaf.it
Co-Supervisor (Name, Istitution and Contact):
Francesco Berrilli, Tor Vergata University, francesco.berrilli@roma2.infn.it
Scientific Case: Solar flares (SF) and Coronal Mass Ejections pose a serious risk to technological activities in space and on ground. Both phenomena are often correlated, especially the more intense eruptive ones. X-ray polarimetry of SF allows to obtain information about magnetic reconnection that originates the eruptive events, the configuration of the magnetic field and the acceleration of the particles towards the Sun and interplanetary space. Thanks to technological advances new instruments are under development and new space missions are in preparation (CUSP - Italy, PhoENiX (Japan), Sapphire and GRIPS (USA), promising to open a new observational window.
Outline of the Project: The PhD student will join the team at INAF-IAPS which leads the development of X-ray polarimeters based on Compton scattering (CUSP mission) and photoelectric effect (for imaging polarimetry of SF). The assessment of the scientific case will be carried out in collaboration with the Solar Physics Group at University of Tor Vergata. The activity will also include collaboration with international teams.
Planning of the activities: This PhD project is aimed at assessing the scientific case of X-ray polarization of SF in Heliophysics and Space Weather. The student will perform feasibility studies of SF observations with Compton and photoelectric polarimeters based on the simulations of the detector performance with the input of spectral, timing and imaging archival data from other missions (i.e RHESSI). The student will also have the possibility to contribute to the experimental activity at INAF-IAPS.
Institution(s) where the research will be carry out: INAF-IAPS, Univ. Tor Vergata

3.3.10 Development of high-throughput Silicon-based detection systems for X-ray Astronomy

Supervisor (Name, Istitution and Contact):
Marco Feroci, INAF, marco.feroci@inaf.it
Co-Supervisor (Name, Istitution and Contact):
Paolo De Bernardis, Sapienza University, paolo.debernardis@roma1.infn.it
Scientific Case: The nature of the most extreme Galactic compact objects (neutron stars and black holes, the end-point of stars) is still largely unknown, as well as the physics of light and matter in their vicinity, where density and gravity are at their most extreme in the Universe and the effects predicted by General Relativity (GR) dominate. Progresses require a quantum leap in the sensitivity of investigations, able to detect the effects of GR and provide new diagnostics. This is planned to be achieved by future missions, like the Sino-European eXTP or the US-European STROBE-X missions, in which the proposing team plays a major role. Further, the same technologies are being developed for wide-field imaging instruments, with their planned application to the Moon experiment LEM-X, recently funded by the PNRR national program. These missions require new enabling detector technologies, which are indeed being developed by a collaboration among IAPS, INFN, FBK, Polytechnic of Milan and University of Pavia.
Outline of the Project: The successful candidate will participate in the development of innovative Silicon detector technologies for space applications. The team composed by IAPS and its collaborators at INFN, FBK and Universities have unique design, technology, manufacturing, test, qualification and calibration capabilities and facilities. The research activity will be primarily spent in understanding the science drivers, their flow down to instrument requirements and their verification through laboratory tests, data analysis and test campaigns at local and external facilities (e.g., irradiation facilities). This research experience will provide a rare opportunity for real hands-on contribution to future space missions for X-ray Astronomy, in a broad international context, ranging from European, to Chinese to US institutions.
Planning of the activities: The core of this PhD thesis will be the understanding of the scientific requirements and the consequent development of innovative Silicon detector systems (detector and electronics). 2024: the first PhD year will be centered on the development of the large-area detectors for the eXTP, STROBE-X and LEM-X projects, with special focus on the definition of the instrumental requirements as flown-down from the mission scientific requirements. 2025: the second year will be invested in interfacing the prototype detectors with the back-end of the instruments, verifying the compatibility with the experiment design and providing a preliminary performance budget of the integrated system; 2026: the final year will be spent in the space qualification and X-ray characterization of the detectors, concluding with the thesis compilation and finalization.
Institution(s) where the research will be carry out: INAF-IAPS

3.3.11 Acceleration and forecasting of solar energetic particles

Supervisor (Name, Istitution and Contact):
Monica Laurenza, INAF, monica.laurenza@inaf.it
Co-Supervisor (Name, Istitution and Contact):
Dario Del Moro, Tor Vergata University. dario.delmoro@roma2.infn.it
Scientific Case: Space Science
Outline of the Project: The acceleration of high-energy (¿1 MeV) particles at the Sun is both an intriguing unsolved problem in Astrophysics and a key aspect of the Space Weather science. The acceleration of the so-called solar energetic particles (SEPs) is believed to occur during solar eruptions at flare sites and at shock waves driven by coronal mass ejections. SEPs also represent extreme Space Weather events posing the most hazardous condition in the Heliosphere, e.g., for space exploration, life and human activities. The proposed thesis is intended to address the two closely related problems of the SEP acceleration and their forecast. The project aims to produce a unified picture of SEP events, by considering all the relevant aspects such as the features of the solar source and the full dynamics of solar atmosphere, the solar wind plasma conditions and the interplanetary magnetic field (IMF) configuration, the properties of energetic particles in the Heliosphere. The most favourable conditions for the development and propagation of SEP events will be identified mainly by combining multi-wavelength solar observations, in-situ measurements of energetic particles and solar wind plasma and magnetic field, especially by exploiting the potential offered by the most recent space missions. The ground-based networks of neutron monitors will complement the study of SEPs at relativistic energies. Moreover, the obtained information about the SEP solar sources will be used in a more direct space weather perspective to design an innovative operational model, possibly based on machine learning techniques, to provide early and reliable forecasts of SEP events. This research will allow us to get new insights on the physical processes at the origin of SEP events and will favour advances in the Space Weather science and more generally in the field of Astrophysics.
Planning of the activities: The first year will be devoted to data retrieval, identification and selection of SEP events, characterisation of the SEP event properties and the status of the interplanetary medium at different heliographic locations. The second year will be dedicated to the study of the SEP associated solar sources and comparison with expectations from theoretical models and simulation. The third year will be devoted to consolidation/interpretation of results and the setup of an SEP forecasting scheme.
Institution(s) where the research will be carry out: INAF - IAPS

3.3.12 Cold stage design of the Cryogenic AntiCoincidence detector (CryoAC) for the Athena/X-IFU instrument

Supervisor (Name, Istitution and Contact):
Claudio Macculi, INAF, claudio.macculi@inaf.it
Co-Supervisor (Name, Istitution and Contact):
Elia Battistelli, Sapienza University, elia.battistelli@roma1.infn.it; Luigi Piro, INAF, luigi.piro@inaf.it
Scientific Case: Athena
Outline of the Project: The proposed PhD work is inserted in the context of the Athena mission, the next ESA Large X-ray observatory to be launched on the 2nd half of 2030s at L1 orbit. 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? The mission is now under a re-definition phase aimed at proposing a design compliant to the cost cap stated by ESA. 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 a TES (Transition Edge SensorTES microcalorimeters) able to perform simultaneous high grade energy spectroscopy (3eV@7keV) and imaging over the 4í FoV. INAF/IAPS has the co-PI ship of the X-IFU instrument and, from the technological point of view, 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 TESes working at 50 mK, and placed at a distance ¡ 1 mm below the TES-array. The next major X-IFU milestone relevant in the PhD timeframe is the Athena mission adoption on early 2027, at which it is requested by ESA that critical subsystems must reach the Technology Readiness Level TRL5. In the context of the CryoAC activity, it translates in consolidating the technologies by the following main activities: 1) pre-EM (pre - Engineering Model) having the shape of the Flight one, but only one readout channel instrumented 2) A structural model necessary to test the pre-EM geometry in relevant environment (i.e., mechanical vibrations test) The PhD student will follow all the phases of these activities 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.
Planning of the activities: - 2023/2024 new Demonstration Model (single pixel device) based on revised ”TES layout” vs ”G thermal conductance” design - 2023/2024 structural model activity based on hexagonal shape geometry - 2024/2026 pre-EM activity
Institution(s) where the research will be carry out: INAF-IAPS

3.3.13 Atmospheric tracers of exoplanet formation in the JWST era

Supervisor (Name, Istitution and Contact):
Sergio Molinari, INAF, sergio.molinari@inaf.it
Co-Supervisor (Name, Istitution and Contact):
Enzo Pascale, Sapienza University, enzo.pascale@uniroma1.it; Diego Turrini, INAF, diego.turrini@inaf.it
Scientific Case: Giant planets form and migrate in circumstellar disks rich in gas, dust and ices. The distribution of the chemical elements across these three carriers is not fixed throughout the disk, but is shaped by the disk decreasing temperature moving away from the central star and evolves over time as the disk cools down. Recent evidence from ALMA suggests that planets may form at much larger distances from the star (larger than 100 au) and much earlier time (during the early protostellar Class-0 phase) than previously thought. As such, as they migrate to their final orbits planets will grow their mass from a much larger number of disk regions with radically different chemical make-ups than considered by the previous generation of models. Recent works from our team at INAF investigate how different physical and chemical conditions in protoplanetary disks, as well as different initial formation distances, will produce planets with very different chemical and atmospherical compositions, and demonstrate how the disk and planet compositions can be reliably connected. These results introduce new and improved ways to use spectroscopy of exoplanetary atmospheres to infer the formation history of planets, tracing back their atmospheric composition to the properties of the progenitor disk and the distance from the star where they formed. The new methods developed at INAF by our team are being validated observationally with exoplanets atmospheric data from high-resolution spectra from the ground, demonstrating their high potential for their applications to James Webb Space Telescope (JWST) and, in perspective, the ESA mission Ariel.
Outline of the Project: The launch of JWST marked the beginning of the era of systematic exoplanet characterization. The exoplanetary compositions being gathered by JWST's first observational campaigns promise to revolutionize our view of how planetary systems are born. Fully tapping into their potential, however, requires us to first fill the gaps in our understanding of the links between the native circumstellar disks, the formation of planets and the composition of their atmospheres. To this aim the candidate, jointly supervised by the exoplanets team at La Sapienza and the planet formation team at INAF, will investigate which atmospheric species can both be reliably quantified in exoplanetary atmospheres and best inform us on the formation environments of their planets taking advantage of the suite of scientific codes developed by the two teams. To study the observational signatures of the planet formation process, the candidate will combine astrochemical models of circumstellar disks, n-body simulations of the formation and migration of planets, and atmospheric chemical models with the suite of tools created by the INAF team to produce realistic atmospheric compositions and their associated synthetic spectra, whose analysis and comparison with JWST public-domain data, as well as from ground-based high-resolution spectroscopy in collaboration with HOT-ATMOS and GAPS INAF projects, will allow to identify and validate the most diagnostic atmospheric features.
Planning of the activities: Year 1) Under the supervision of the planet formation team at INAF the candidate will generate synthetic exoplanets atmospheric spectra using equilibrium and non-equilibrium models, starting from the planet chemical composition resulting from the combination of different protoplanetary disk structures and compositions, and different planet formation histories. Year 2) Under the supervision of the exoplanet team at La Sapienza, the candidate will use spectral retrieval codes integrated with instrument simulators to infer the intensity of observable signatures of key molecular species that can uniquely trace the dominant carriers of main chemical elements. The candidate will combine these results with predictions from planet formation and migration models to characterize their diagnostic power. The candidate will test the methodology on JWST data in the public domain and will assess the opportunity for JWST follow-up observations. Year 3) The candidate will produce grids of planet formation predictive models for the interpretation of ground-based exoplanets atmosphere spectra gathered through high-resolution spectroscopy by the INAF project GAPS to contribute to their interpretation and support the preparation of the Ariel mission. Finaliza-

tion of papers and write-up of thesis.
Institution(s) where the research will be carry out: INAF-IAPS

3.3.14 Development of the next generation of X-ray Polarimeters

Supervisor (Name, Istitution and Contact):
Fabio Muleri, INAF, fabio.muleri@inaf.it
Co-Supervisor (Name, Istitution and Contact):
Giampaolo Pisano, Sapienza University, giampaolo.pisano@roma1.infn.it

Scientific Case: After 60 years of wait, the recent launch of the NASA-ASI mission IXPE has allowed the measurement of X-ray polarization of tens of galactic and extragalactic celestial sources and has confirmed the expected great potential of this technique to investigate their geometry and processes at work in these objects. IXPE was designed as an explorer mission, intended to perform a survey of the field and identify the directions for future projects.

Outline of the Project: This PhD project is aimed at building on top of the IXPE experience the next generation of instrumentation able to pursue the most compelling scientific questions that IXPE started to tackle. This includes the polarimetry at higher energies to study the reflection component known to be present in the spectra of X-ray binaries and AGN, high-angular resolution polarimetry of extended sources like Pulsar Wind Nebulae and Supernova Remnants, or polarimetry of bright transient sources like Gamma Ray Bursts. The PhD student will join the team at INAF-IAPS which led the development of the Italian contribution to the IXPE mission and has developed over the last 20 years the gas photoelectric polarimeters now on-board IXPE.

Planning of the activities: Activities will include the development and characterization with X-rays of detectors based on cutting-edge technologies which are being ported for the use as X-ray polarimeters of celestial sources with the financial support by MIUR and INAF. Measurements with the X-ray test facility at IAPS, data analysis and simulations will be carried out as needed during the project, in collaboration with an international team which the student will join.

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

3.3.15 Shedding light on the central remnant of gravitational wave counterparts: broad-band electromagnetic observations and gravitational-wave joint analysis

Supervisor (Name, Istitution and Contact):
Luigi Piro, INAF, luigi.piro@inaf.it
Co-Supervisor (Name, Istitution and Contact):
Francesco Pannarale, Sapienza University, francesco.pannarale@roma1.infn.it
Scientific Case: Electromagnetic observations of gravitational-wave counterparts, in particular those related to mergers of two neutron stars or a neutron star with a black hole, pin down the properties of the relativistic outflow produced after the collapse of the two compact objects and carry fundamental information on the origin of the remnant.
Outline of the Project: The project aims at tackling fundamental questions such as the nature of the merger remnant, whether a black hole or a massive neutron star, or the geometry and physical properties of the merging system. The candidate will work on joint data sets and joint modeling of gravitational waves and electromagnetic domains, which offers an essential and 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 of gravitational-wave sources detected by Virgo and LIGO. The candidate will have the opportunity to take part to the broad-band observations of gravitational-wave counterparts during the O4 run (which is ongoing), and to work on data sets gathered following gravitational-wave events by some of the key radio (ATCA), optical (LSST and data through the Engrave collaboration) and X-ray facilities (Einstein Probe). He/she will also jointly analyze the electromagnetic and gravitational-wave (once public) data sets, taking advantage of the experience in gravitational waves offered by the Sapienza University. The analysis will also include the use of a state of the art time-evolving photoionized X-ray model (TEPID). 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 gravitational-wave antennas and high-energy satellites, with particular regard to the large X-ray observatory Athena.
Institution(s) where the research will be carry out: INAF-IAPS

3.3.16 From close-by black-holes binaries to distant Active Galactic Nuclei: Improving the sensitivity to polarization of the Imaging X-ray Polarimetry Explorer

Supervisor (Name, Istitution and Contact):
Paolo Soffitta, paolo.soffita@inaf.it
Co-Supervisor (Name, Istitution and Contact):
Francesco Tombesi, Tor Vergata University, francesco.tombesi@roma2.infn.it

Scientific Case: IXPE a NASA-ASI mission, successfully launched in December 2021, is revolutionizing X-ray Astronomy. After 50 years, a new window is opened. Polarization is being detected from all X-ray emitting sources. Angular resolved polarization is revealed in Supernova Remnants, Pulsar Wind Nebulae and Molecular Clouds. Time and energy resolved polarization is measured in neutron star and black-hole binaries. Polarized radiation is detected from molecular torus and from jets in AGNs. Notwithstanding this IXPE sensitivity can improve.

Outline of the Project: From 2024 IXPE will operate with targets chosen by the astrophysics community. Data becomes soon public. Currently 20-years old algorithms are being used and polarization variability in Active Galactic Nuclei or Neutron star binaries are often barely detected. The energy dependence of the polarization angle, the signature of black-hole spin, is poorly detected. We propose to enhance IXPE sensitivity for past, current and future observations. The candidate will work in the group that developed and calibrated the polarization sensitive detectors and will be included in the international collaboration analyzing and interpreting the data.

Planning of the activities: The planned activity is the study celestial X-rays source with improved algorithms, including machine learning techniques, to be assessed during this thesis. The interested candidate will access to both astrophysical and calibration data and to current analysis algorithms. We expect that the outcome of the thesis will foster the knowledge on how X-ray emitting celestial sources work.

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

3.4 INAF-IAPS, fellowships funded by specific projects

Four (4) fellowships are granted for students to carry out their research on the 4 following proposals, funded by the 4 projects.

3.4.1 Calibration of the MIST-A instrument

Supervisor (Name, Istitution and Contact):
Gianrico Filacchione, INAF, gianrico.filacchione@inaf.it
Co-Supervisor (Name, Istitution and Contact):
Silvia Masi, Sapienza University, silvia.masi@roma1.infn.it
Scientific Case: MIST-A is the MWIR Imaging Spectrometer for Target-Asteroids to be launched in 2028 aboard the UAESA mission to the Main Belt. The mission will observe 6 asteroids during fly-bys before arriving in orbit on (269)Justitia, a 50 km diameter object with peculiar spectral properties similar to outer solar system bodies. Current telescopic observations indicate that the asteroidís composition is compatible with the presence of organic matter and hydrated minerals, useful resources for in situ extraction. MIST-A goal is to identify the asteroidsí surface composition and physical properties (regolith grain size, porosity, temperature, thermal inertia) by means of spectrophotometric models and to realize surface maps necessary to correlate this information with morphological units. The reliability of the process will depend on the accuracy of the instrumentís calibration.
Outline of the Project: The candidate will participate in the instrumentís calibration campaign, including the characterization of the spectral, spatial, geometric and radiometric performances, and the characterization of the experimental setups to be employed in the measurements. The activity will include the testing and evaluation of the performances of key subsystems, such as the IR detector, the internal calibration unit and the steerable mirror mechanism used to acquire hyperspectral images.
Planning of the activities: 2024: Intro to imaging spectrometers calibration and asteroidís IR spectroscopy, thesis compilation; 2025: Preparation and calibration of the experimental setups, subsystems characterization, thesis compilation; 2026: Calibration measurements of the MIST-A space model, data processing, thesis compilation and finalization.
Institution(s) where the research will be carry out: INAF-IAPS, Leonardo Company, Campi Bisenzio (FI)

3.4.2 Thermophysical characterization of Mars' interior and surface through numerical codes

Supervisor (Name, Istitution and Contact):
Michelangelo Formisano, INAF, michelangelo.formisano@inaf.it
Co-Supervisor (Name, Istitution and Contact):
TBD; Cristina De Sanctis, INAF, ...; Francesca Altieri, INAF, ...
Scientific Case: The study of Marsí interior and surface reveal important information about the physical and chemical processes that shaped the planet. In this regard, the ESA ExoMars Rover mission, which launch is scheduled in 2028, will investigate the Martian soil down to 2 meters, providing a physical and chemical characterization, for the first time, of the shallow subsurface by means of an extensible drill, and searching for ancient traces of life. In the past, several missions investigated Mars so a large quantity of orbital and landed robotic mission data are available, in particular in the visible and near infrared through spectroscopic investigations. All these data can still be exploited in order to prepare the ExoMars Rover data analysis. For this purpose and to better depict plausible physical scenarios, numerical models are required. Both Eulerian (e.g., finite-element-method codes) and Lagrangian (e.g., discrete-element-method) methods could be used in synergy to characterize the surface and the shallow subsurface (with the presence of volatile) of Mars from a thermophysical point of view, in particular in presence of the drilling operations.
Outline of the Project: The candidate will contribute to develop and validate a Lagrangian code in order to investigate the soil of Mars (for example the mechanical and thermal response of the soil to the drilling) and/or to investigate the dynamics of the possible volatiles in the soil. Several different scientific cases will be explored during the project with the aim to build reference scenarios for a correct interpretation of the data taken by the ExoMars mission as well as other missions.
Planning of the activities: - Validation of the code comparing it with other codes, yet developed by other researchers; - Application to different scientific cases of Mars to investigating the red planet surface, shallow subsurface; - Application of the code to simulate the interaction with the drilling activities for different scenarios
Institution(s) where the research will be carry out: INAF-IAPS

3.4.3 Early star formation in Galactic protoclusters: evolutionary study of fragmentation, dynamics and chemistry with the ALMAGAL Survey

Supervisor (Name, Istitution and Contact):
Sergio Molinari, INAF, sergio.molinari@inaf.it
Co-Supervisor (Name, Istitution and Contact):
Raffaella Schneider, Sapienza University, raffaella.schneider@uniroma1.it; Alessio Traficante, INAF, alessio.traficante@inaf.it
Scientific Case: Clustered star formation involves breaking up of molecular clumps (linear scales of 0.5-1.0 pc) into cores (linear scales < 0.05 pc), as indeed observed at high spatial resolution at mm wavelengths. A full understanding of the fragmentation process and its role in allowing high-mass stars to collect material up to their final mass is still elusive. ALMAís transformational power makes it now possible to investigate statistically significant samples of young embedded clusters containing high-mass stars in-the-making. As part of the ERC Synergy ìECOGALî project, IAPS coordinate the "ALMAGAL" ALMA Large Project, in which we observe in millimeter continuum and spectroscopy more than 1000 sites of Galactic high-mass star formation at a 1000AU-scale distributed on a variety of evolutionary stages, from infrared dark clouds to ultracompact HII regions, and locations in the Galaxy.
Outline of the Project: Under the supervision of the ECOGAL-ALMAGAL PI Team at IAPS, the selected candidate will analyse the ALMAGAL interferometric maps in millimeter continuum and high-resolution spectral lines to study: i) the process of clump-to-core fragmentation, ii) the evolution of the chemical and dynamical state of the dense gas in the star-forming cores, and iii) the modes in which clump material is accreted onto the cores as a function of evolution. An important and qualifying aspect of the work will be the comparison of the analysis results with the predictions from numerical simulations developed in the Saclay ECOGAL node, with frequent visits to CEA-Saclay and the participation in the ECOGAL Consortium activities.
Planning of the activities: Year 1) Analysis of clump fragmentation properties from ALMAGAL continuum source catalogs, characterization of hierarchical structure, number of fragments and mass function, relationship with chemical tracers (CH3OH, H2CO, CH3CN) and dynamical state of core and clump gas from ALMAGAL spectral cubes. Year 2) Similar analysis on libraries of post-processed numerical simulations for different environmental conditions (clump surface densities, turbulent Mach number, magnetic field etc.) and different line-of-sight projections, etc. Year 3) Papers finalized, preparation of follow-up proposals with ALMA and/or other facilities, Thesis writing.
Institution(s) where the research will be carry out: INAF-IAPS

3.4.4 Measurements of IR optical properties of gases at atmospheric planetary conditions, in particular for the Collision Induced Absorption bands of H2-H2, H2-He and others

Supervisor (Name, Istitution and Contact):
Giuseppe Piccioni, INAF, giuseppe.piccioni@inaf.it
Co-Supervisor (Name, Istitution and Contact):
Enzo Pascale, Sapienza University, enzo.pascale@uniroma1.it; Davide Grassi, INAF, davide.grassi@inaf.it; Stefania Stefani, INAF, stefania.stefani@inaf.it
Scientific Case: A large data set of molecular data and a well developed theoretical framework is available for the analysis of absorption and emission spectra recorded for various gases. However, when atmospheres of real planets are concerned some important data are lacking and theory is insufficient. Laboratory experiments can overcome these problems and provide new data that can be used for the analysis of molecular spectra and can also shed light on hitherto not understood phenomena occurring in the atmosphere of planets. In particular, collision induced absorption (CIA) bands are symmetry forbidden in the vibrational (or rototranslational) spectra of molecules, but can become allowed when collisions occur between molecules of the same or different kinds. CIA causes the thermal opacity of the giant planets, as H2 and He radiate most of the absorbed sunlight and internal heat to space. CIA may also influence climate and thus habitability of terrestrial planets.
Outline of the Project: The study will be mainly experimental and it will be performed at the INAF-IAPS laboratory. A special custom cell named PASSxS (Planetary Atmosphere Simulation System for Spectroscopy), existing at the PLAB of INAF-IAPS, will be used for the measurements of transmittance of the gases under controlled environmental conditions. The gas cell is optically coupled with a Fourier transform spectrometer (FTIR).
Planning of the activities: The planning of the thesis activities will be in agreement with the PhD rules and timing, allowing to accomodate activities related to the PhD formation (courses, workshops, summer or winter schools, etc.).
Institution(s) where the research will be carry out: Mainly INAF-IAPS Rome, via del Fosso del Cavaliere 100, 00133 Rome but also with possible visits of other Universities or Research Centers abroad.

3.5 INAF – CTA+ Program

Three (3) fellowships are granted for students to carry out their research on the 3 following proposals, funded by PNRR – CTA+ PROGRAM (NextGenerationEU – CUP C53C22000430006).

3.5.1 A multi-messenger study of starburst and active galaxies in the new era of Cherenkov Telescopes

Supervisor (Name, Istitution and Contact):
Alessandra Lamastra, INAF, alessandra.lamastra@inaf.it
Co-Supervisor (Name, Istitution and Contact):
Silvia Celli, Sapienza University, silvia.celli@uniroma1.it
Scientific Case: Starburst galaxies and galaxies hosting active galactic nuclei (AGN) are unique astrophysical laboratories characterized by different possible environments where particles can be accelerated. The investigation of the gamma-ray and neutrino emission produced by the interaction of the accelerated particles with matter and radiation in the AGN and host galaxy environments can be effectively used to unveil the acceleration mechanisms in these astrophysical objects.
Outline of the Project: The thesis project will be aimed to: 1) gain knowledge about gamma-ray and neutrino production processes in starburst and active galaxies; 2) perform analysis of data collected by current Imaging Atmospheric Cherenkov telescopes (IACTs), such as the Large-Sized Telescope prototype of the future Cherenkov Telescope Array (CTA) and the MAGIC telescopes; 3) perform simulation-based studies for observation with CTA.
Planning of the activities: In the first two years the PhD candidate will develop a theoretical model for the multi-messenger emission from starburst and active galaxies, and in parallel will analyze data from Cherenkov telescopes. In the third year the PhD candidate will use the developed theoretical model to draw detailed predictions for the gamma-ray and neutrino emission in individual active and starburst galaxies that will be used for the interpretation of the data from current telescopes, and for the simulations of the observations with next-generation Cherenkov telescopes.
Institution(s) where the research will be carry out: INAF-Osservatorio Astronomico di Roma

3.5.2 Insights into the physics of very high energy transient events with Imaging Atmospheric Cherenkov Telescopes”

Supervisor (Name, Istitution and Contact):
Alessandro Carosi, INAF, alessandro.carosi@inaf.it
Co-Supervisor (Name, Istitution and Contact):
Ciro Bigongiari, INAF, ciro.bigongiari@inaf.it; Antonio Stamerra, INAF, antonio.stamerra@inaf.it; Roberta Sparvoli, Tor Vergata University, roberta.sparvoli@uniroma2.it
Scientific Case:VHE Astrophysics, Cherenkov Telescopes, Gamma-ray Bursts, GW-counterparts, VHE transients
Outline of the Project: The research project proposed for this thesis will focus on the study and characterization of transient events such as Gamma-ray Bursts (GRB) and Gravitational Waves (GW) in the very high energy (VHE - beyond few tens GeV) band. The main project's science goals are related to the investigation of the different emission scenarios and the physical processes able to produce VHE radiation in these extreme cosmic accelerators. To this end, the student will make use of broadband observational data including the VHE data of the MAGIC Telescopes, the CTA/LST-1 prototype and the ASTRI-Mini Array. The student will actively participate in the VHE follow-up campaigns and data reduction, by also taking an important role in the development of a set of dedicated simulations. The development of new analysis methods based on image recognition and machine learning techniques specific for transient events might be envisaged. The PhD student will be part of the CTA and MAGIC collaborations.
Planning of the activities: We plan to prepare a solid interpretative framework for the forthcoming follow-up campaigns of transient events with current- and next-generation Cherenkov telescopes, focussing specifically on GRB and GW observations. We plan to explore the GRB micro-physical parameters space by model lepto-hadronic emission in on- and off-axis GRBs by means of theoretical emission models.
Institution(s) where the research will be carry out: INAF-Osservatorio Astronomico di Roma

3.5.3 Particle Acceleration in our Galaxy in the new era of Cherenkov Telescopes

Supervisor (Name, Istitution and Contact):
Martina Cardillo, INAF, martina.cardillo@inaf.it
Co-Supervisor (Name, Istitution and Contact):
Marco Tavani, INAF, marco.tavani@inaf.it
Scientific Case: Gamma-ray astronomy plays a fundamental role in the understanding of very high energy tricky and outstanding sources in our own Galaxy and their role in particle acceleration. In this context, despite the enormous efforts done in very recent years, both theoretically and experimentally, Cosmic Ray (CR) origin remain without clear answers. The recent detection of 12 gamma-ray Galactic sources well above E¿100 TeV by the LHAASO observatory has been a breakthrough in the context of CR origin search. Although most of these sources are unidentified, they are often spatially correlated with leptonic accelerators, like pulsar and pulsar wind nebulae (PWNe). This dramatically affects the paradigm for which a gamma-ray detection at E¿100 TeV implies the presence of a hadronic accelerator of PeV particles (PeVatron). Moreover, the LHAASO results supports the idea that sources other than the standard candidates, Supernova Remnants, can accelerate Galactic CRs. In this context, the good angular resolution of future Cherenkov telescopes, such as the ASTRI Mini-Array and CTA, and the higher sensitivity of future neutrino detectors, such as KM3NeT and IceCube-Gen2, will be of crucial importance.
Outline of the Project: The student will be involved in several activities in the development of ASTRI Mini-Array and CTA (LST, SSTs etc), especially in scientific simulation and soon in the real-data analysis; through theoretical model study and development, parameters understanding, multi-wavelength comparison, he/she will contribute to understand the nature and the role of different kind of accelerated particle sources in our Galaxies.
Planning of the activities: First year: introduction in the CR acceleration issue through literature studies, first approach with the ASTRI Mini-Array and CTA realities, introduction to the Science Tool Gammapy, fundamental in order to manage and analyze experimental data and to NAIMA in order to create gamma-ray emission models for the interested sources; Second year: data simulation for ASTRI Mini-Array and CTA collaboration in the context of CR acceleration, entrance in the commissioning activities, data analysis and comparison between simulated and first real experimental data Third year: understanding new experimental data and of their role in the CR acceleration context, active participation in future pointing plan for the instruments.
Institution(s) where the research will be carry out: INAF-IAPS

3.6 INAF - HPC Program

One (1) fellowship is granted for a student to carry out his/her research on the following proposal, funded by PNRR – National Centre For Hpc, Big Data And Quantum Computing" PROGRAM (CUP: C53C22000350006).

3.6.1 Exploring Novel Algorithms for data Reconstruction and Operations in high energy astrophysics through innovative machine learning techniques

Supervisor (Name, Istitution and Contact):
Francesco Visconti, INAF, francesco.visconti@inaf.it
Co-Supervisor (Name, Istitution and Contact):
Antonio Stamerra, INAF, antonio.stamerra@inaf.it;
Pasquale Mazzotta, Tor Vergata University, pasquale.mazzotta@uniroma2.it
Scientific Case: Analysis and interpretation of observations on gamma-ray sources through the development of novel algorithms for machine learning applied at data reconstruction and event classification from Cherenkov telescopes.
Outline of the Project: The PhD student will be engaged in the development and application of the most advanced computing techniques for data analysis and simulation in the gamma-ray Astrophysics. She/he will be part of a team actively involved in the analysis and interpretation of observations on gamma-ray sources emitting giga- and tera-electronvolt radiation, such as AGN/blazars, gamma-ray burst, starburst galaxies, gravitational waves counterparts, and in their impact on cosmological and fundamental physics, such as dark matter searches and intergalactic magnetic field studies. The activity will be carried out in the framework of the novel ICSC, the Italian Center for Supercomputing https://www.supercomputing-icsc.it
Planning of the activities: Development of software for Image Processing and Analysis of astrophysical images and catalogs. Extraction, characterization and classification of astrophysical objects and events such as those observed by Cherenkov telescopes (e.g. Cherenkov Telescope Array (CTA) and its precursors: MAGIC, LST, SST, ASTRI Mini-array) through the development of algorithms for Machine Learning operations and deployment of models exploring the best suitable architecture (diffusive denoising models, autoencoders, convolutional neural networks, recurrent networks, graph networks and so on). Integration of the developed codes in existing astronomical software and implementation on hardware infrastructure both CPU and GPU cluster oriented.
Institution(s) where the research will be carry out: INAF-Osservatorio Astronomico di Roma

3.7 INAF – STILES Program

One (1) fellowship is granted for a student to carry out his/her research on one of the following proposals, funded by PNRR – STILES PROGRAM (NextGenerationEU – CUP: C33C22000640006).

3.7.1 Observations of proto-planets and connected phenomena in planet forming disks

Supervisor (Name, Istitution and Contact):
Simone Antoniucci, INAF, simone.antoniucci@inaf.it
Co-Supervisor (Name, Istitution and Contact):
Biazzo, INAF, katia.biazzo@inaf.it; Valentina D'Orazi, Tor Vergata University, vdorazi@roma2.infn.it
Scientific Case: The thesis will focus on the analysis of GO and GTO data from current and future AO-assisted imagers and spectro-imagers (MUSE/ERIS at VLT and SHARK-VIS/NIR at LBT) aiming at detecting proto-planets still in their accretion phase, and at studying phenomena correlated with the evolution of proto-planetary disks, such as jets and winds.
Outline of the Project: The student will also be involved in the preparatory work to define the requirements of the science related to proto-planetary disks for the near-IR IFU module of the future high resolution spectrograph on ELT (ANDES), which has just entered its Phase-B of development.
Planning of the activities: The thesis foresees strong interactions with other institutes belonging to the JEDI (Jets and Disks at INAF) collaboration, and in particular with researchers of the collaboration working on ALMA data of proto-planetary disks, to establish a link between the disk structures observed at sub-mm wavelengths and the presence of proto-planets imaged in the VIS/NIR.
Institution(s) where the research will be carry out: INAF-Osservatorio Astronomico di Roma

3.7.2 Exploring the epoch of reionization with Euclid, MOONS, SKA and their precursors

Supervisor (Name, Istitution and Contact):
Marco Castellano, INAF, marco.castellano@inaf.it
Co-Supervisor (Name, Istitution and Contact):
TBDThe forthcoming launch of the Euclid satellite will provide a great opportunity to investigate galaxies in the first Gyr after the Big Bang
Scientific Case:
Outline of the Project: Thanks to its sensitivity and large field of view, Euclid observations in Deep and Calibration fields will yield large samples of bright galaxies at z 6-9 that will allow mapping the topology of the process of reionization of the HI in the inter-galactic medium (IGM). The PhD student will work in the context of the Primeval Universe Science Working Group of the Euclid Consortium to investigate galaxies in the epoch of reionization.
Planning of the activities: She/he will prepare forecasts on how to combine Euclid high-redshift samples with future 1) VLT-MOONS large field-of-view near-IR spectroscopy and 2) SKA observations of the HI line at 21cm, in order to constrain the role of galaxy clustering in the IGM reionization. The first Euclid data will become available during the PhD duration, meanwhile the student will have the opportunity to work with public and proprietary JWST, ALMA and VLT observations of high-redshift galaxies to constrain galaxy clustering in the epoch of reionization and the ionizing properties of distant galaxies.
Institution(s) where the research will be carry out: INAF-Osservatorio Astronomico di Roma

3.7.3 A new eye on the Galactic Bulge with ERIS@VLT: advanced data reduction to pave the road for ELT exploitation”

Supervisor (Name, Istitution and Contact):
Giuliana Fiorentino, INAF, giuliana.fiorentino@inaf.it
Co-Supervisor (Name, Istitution and Contact):
Giuseppe Bono, Tor Vergata University, Giuseppe.Bono@roma2.infn.it; Marcella Di Criscienzo, INAF, marcella.dicriscienzo@inaf.it; Michele Fabrizio, INAF, michele.fabrizio@inaf.it; Laura Schreiber, INAF, laura.schreiber@inaf.it
Scientific Case: The successful candidate will have the opportunity to explore new data of the Bulge taken with the Adaptive Optics (AO) assisted ERIS@VLT. We have been successfully allocated almost 100 hours of photometry and spectroscopy with ERIS within the project ”Rr lyrae In and Beyond the galactic Bulge Survey (RIBBS)” (GTO time). When the PhD will start we will already have data in our hands (first observation run scheduled in June 2023).
Outline of the Project: The aim of RIBBS is to use photometry and spectroscopy of old (RR Lyrae, type II Cepheids) and intermediate age (red clump) stellar tracers to constrain stellar populations in and beyond the Galactic center and to identify a sizable sample of new variable stars in the anti-center. The spectroscopic survey will allow us to investigate the Bulge kinematics and to constrain its chemical enrichment at the early epochs of formation. These data will constrain current galaxy formation models, and in particular, will improve our knowledge of the connection between Bulge, Halo, Bar and thin disk dynamical instabilities. As a technological by-product of our project, an appropriate analysis of these data is crucial to understand our current ability in managing AO data and it is a unique opportunity to test and validate new software tools to make real the diffraction limit potential of Extremely Large Telescopes (ELTs).
Planning of the activities:
Institution(s) where the research will be carry out: INAF-Osservatorio Astronomico di Roma

3.7.4 Joint analysis of Euclid and SKA weak lensing data

Supervisor (Name, Istitution and Contact):
Vincenzo Cardone, INAF, vincenzo.cardone@inaf.it
Co-Supervisor (Name, Istitution and Contact):
Roberto Scaramella, INAF, roberto.scaramella@inaf.it; Roberto Maoli, Sapienza University, roberto.maoli@roma1
Scientific Case: Aim of the project is the modeling of second and high order statistics of weak lensing observables (in both the harmonic and configuration space) taking into account large scales effects and the differences in the intrinsic alignment properties of the populations observed in the optical through Euclid and the radio with SKA.
Outline of the Project: Particular emphasis must be dedicated to the cross - correlation between the two datasets which can help to constrain the intrinsic alignment description. These models will be initially tested against the already available mock data for Euclid and SKA, but the candidate will also have access to the first Euclid data release and possibly to SKA precursor datasets.
Planning of the activities:
Institution(s) where the research will be carry out: INAF-Osservatorio Astronomico di Roma

3.7.5 Unveiling the nature of Fast Optical Bursts (FOBs) with SiFAP2@TNG: from the origin to their characterisation.

Supervisor (Name, Istitution and Contact):
Piergiorgio Casella, INAF, piergiorgio.casella@inaf.it
Co-Supervisor (Name, Istitution and Contact):
Filippo Ambrosino, INAF, filippo.ambrosino@inaf.it
Scientific Case: In the next years, large surveys will provide a wealth of data at many wavelengths and on different timescales, opening the so-called "synoptic Astronomy" era. This revolution has already started, especially in the radio band, for example with MeerKAT and other pathfinders of the Square-Kilometer Array (SKA). Fast Radio Bursts (FRBs) are among the most puzzling unresolved mysteries, on which large and increasing observational efforts are concentrated worldwide.
Outline of the Project: Recent observations strongly suggest extremely magnetised neutron stars (magnetars) as the central engines, and the identification of an optical/X-ray counterpart has emerged as the missing link to eventually prove the scenario. However, light pollution due to the increase of space debris and satellite constellation launches has stunningly raised the rate of spurious artefacts in scientific data, especially in the optical band. Therefore, the search for unknown optical counterparts of fast transient phenomena has become more difficult. This Ph.D. thesis is focused on the analysis of the large and growing archive of very high time resolution lightcurves collected with the Silicon Fast Photometer and Polarimeter (SiFAP2) mounted at the INAF 3.6 m Telescopio Nazionale Galileo (TNG, La Palma, Canary Islands, Spain). The candidate will characterise the population of the thousands of fast optical events (Fast Optical Bursts, FOBs) that are present in the SiFAP2 data and might include the long-sought-after FRB optical counterparts. This will be done by performing statistical analyses and developing custom-dedicated algorithms based on machine/deep learning. As the FOBs population is plausibly composed of different types of events, this Ph.D. project will potentially lead to multi-disciplinary scientific results.
Planning of the activities: The candidate will develop a broad set of competencies (computational, statistical and astrophysical), that will place her/him on the frontier of modern Astrophysics.
Institution(s) where the research will be carry out: INAF-Osservatorio Astronomico di Roma

4 ASI

Three (3) fellowships are granted for students to carry out their research on the 3 following proposals, funded by Italian Space Agency (ASI).

4.1 Study of Kinetic Inductance Detectors (KID) at millimeter wavelengths for future space missions

Supervisor (Name, Istitution and Contact):
Angela Volpe, ASI, Angela.Volpe@asi.it;
Co-Supervisor (Name, Istitution and Contact):
Silvia Masi, Sapienza University, silvia.masi@roma1.infn.it, Alessandro Paiella, Sapienza University, alessandro.paiella@roma1.infn.it
Scientific Case: The millimeter band is rich of cosmological and astrophysical information, and deep sky surveys have been identified in the ESA Voyage 2050 program. KID provide comparable or better performance (in terms of time constant, radiation hardness, robustness) and significant fabrication and readout simplifications with respect to the current standard, Transition Edge Superconductors. They have recently been validated for operation in near space with the OLIMPO mission and represent very appealing candidates for future space missions.
Outline of the Project: The activity will focus on the optimization of mm-wave KID for space missions, implementing methodologies to increase the density of detectors in the large-format focal planes required to maximize the mapping speed of large sky surveys. Designs to implement multi-chroic dual polarization pixels will be devised and implemented in prototypes. In a paraller activity, the scientific case and the optimization of the observation of galaxy clusters in Sunyaev-Zeldovich effect will be studied, in theory and through the analysis of data taken with KID-based detectors, like the ones used in the OLIMPO mission and in the MISTRAL imager, in order to optimize the new focal planes for the OLIMPO mission.
Planning of the activities: First year: study of the Sunyaev-Zeldovich effect and its use to investigate the intracluster density and temperature distributions, its dynamics, and to use the clusters as cosmological probes. Study of Kinetic Inductance Detectors theory and first laboratory measurements. Second year: design of dual polarization and multi-chroic KID pixels. Requirements for the new OLIMPO focal planes. Analysis of data obtained from KID and optimization of the photometric accuracy. Third year: Fabrication and test of new dual polarization and multi-chroic KID pixels. Thesis and main paper writing.
Institution(s) where the research will be carry out: Dipartimento di Fisica, Sapienza Università di Roma; Agenzia Spaziale Italiana; collaboration with Arizona State University.

4.2 Spectroscopy studies at millimeter wavelengths

Supervisor (Name, Istitution and Contact):
Gemma Luzzi, ASI, gemma.luzzi@asi.it
Co-Supervisor (Name, Istitution and Contact):
Paolo de Bernardis, Sapienza University, paolo.debernardis@roma1.infn.it; Gianluca Polenta, ASI, Gianluca.polenta@asi.it
Scientific Case: The ESA Voyage 2050 report highlights the need for a large space mission on high-precision spectroscopy of the CMB. The Italian cosmological community is active in the CMB spectral distortions sector, with the ground-based pathfinder COSMO under construction. In the field of PNRR, the study proposal of an atmospheric spectrometer for CubeSat was approved by the Physics Department of the Sapienza University. SSDC is carrying out a scientific research program on the cosmological implications of the Sunyaev-Zeldovich (SZ) spectrum with data of the ESA Planck satellite. A member of SSDC - ASI is co-lead of the project study group "LiteBIRD: Mapping the Hot Gas in the Universe". The thesis proposal fits into this context.
Outline of the Project: 1. Study of on-chip spectrometers at mm and submm frequencies for CubeSats. 2. Study of the SZ spectrum and its cosmological implications. Data analysis of current datasets (e.g. Planck legacy) and forecasts for LiteBIRD.
Planning of the activities: 1. Study of on-chip spectrometers at mm and submm frequencies for CubeSats, whose current application is designed for the spectral study of the atmosphere, but which in the future, with further developments, could potentially be used for the study of spectral distortions of the CMB. 2. Constraints on CMB temperature evolution and CMB monopole y-distortions from the SZ effect.
Institution(s) where the research will be carry out: SSDC-ASI, Sapienza

4.3 A twilight sky survey: catching near-Sun asteroids

Supervisor (Name, Istitution and Contact):
Alessio Giunta, ASI, alessio.giunta@asi.it
Co-Supervisor (Name, Istitution and Contact):
Francesco Berrilli, Tor Vergata University, francesco.berrilli@roma2.infn.it; Davide Perna, INAF, davide.perna@inaf.it
Scientific Case: The low solar elongation region is an extremely important but poorly explored area. A large number of interesting Near-Earth Objects (NEOs), such as Atiras, Earth co-orbitals and Earth Trojans, all have orbital dynamics or photometric behaviours that restrict their observability to this region of the sky. These small bodies hold clues to the dynamical history of the inner solar system, as well as the physical evolution of asteroids in extreme environments. Unfortunately, the current generation of sky surveys either don't focus on these low-elongation regions, or they do it with small meter-class telescopes, barely able to reach magnitude 20 under challenging twilight conditions. As a result of this lack of coverage, a corresponding gap exists in our knowledge of these populations of objects.
Outline of the Project: - discovery and physical characterization by multiband photometry and high resolution spectroscopy of NEOs at low solar elongations using worldwide telescopes such as LBT, VST, NTT, TNG, NEOSTEL and Dragonflyeye; - feasibility study of a new CubeSat mission with the aim of discovering and physically characterizing low solar elongation asteroids.
Planning of the activities: Within a new Coordination Centre for the physical characterization of NEOs to be developed in ASI-SSDC, the candidate will be required to write and submit observing proposals with worldwide telescopes, plan and perform new observations, reduce data, develop new algorithms for the detection and taxonomic classification of new moving objects using synthetic tracking techniques and artificial intelligence. In the final year the candidate will also be required to participate in the feasibility study of a new CubeSat mission identifying mission needs, defining technical requirements specifications and comparing between the different configurations.
Institution(s) where the research will be carry out: Tor Vergata, ASI-SSDC, INAF-OAR