PhD program in Astronomy, Astrophysics and Space Science XXXVIII cycle

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1 University of Rome Tor Vergata

1.1 Shedding Light on the First Billion Solar Masses Black Holes at the Epoch of Reionization

Supervisor: Francesco Tombesi (Tor Vergata)
Co-Supervisor: Luca Zappacosta (INAF-OAR)
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Abstract: The existence of billion solar masses supermassive black holes (SMBH) powering luminous quasars (QSOs) already within one billion years from the Big Bang, in the Epoch of Reionization (i.e. z¿6; EoR), is one of the most debated topics in modern astrophysics and spurred intensive multi-band investigations to understand their properties. So far however, the faint fluxes of high-z QSOs and the limited sensitivity of X-ray observatories hampered a reliable view of the nuclear properties of these outstanding objects. To overcome these limitations, we have been awarded a large Multi-Year Heritage Programme with the XMM-Newton X-ray observatory on the HYPerluminous quasars at the Epoch of ReionizatION (HYPERION), a sample of 17 QSOs at z=6-7.5 characterized by their fast SMBH mass assembly. This thesis project will exploit the high-quality XMM-Newton HYPERION dataset and the rich complementary multi-band observations from flagship observatories at rest-frame UV/optical bands (VLT, LBT, JWST). The aim of the thesis is an unprecedented investigation of the nuclear and accretion/ejection properties of the most extreme QSOs at the EoR.

1.2 Advanced X-ray modeling of powerful black hole winds

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Abstract: 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 during their active galactic nucleus (AGN) phase are thought to play a fundamental role in this regard by regulating the growth of the SMBH and the stellar component. X-ray observations are key to probe

the innermost and fastest outflows, which carry most of the power. Despite their importance, a conclusive picture of the physical properties of AGN outflows is still lacking, mostly because of modeling limitations. To overcome this, we developed a unique wind model called "Winds in the Ionized Nuclear Environment" (WINE). In this thesis project we will carry out an extensive, time-resolved X-ray spectral analysis of powerful outflows in a large database of AGNs observed with major X-ray satellites. The resultant estimates of the mass outflow rate and energy budget will be fundamental for understanding the physics of accretion and ejection onto SMBHs and AGN feedback. This work will also represent a fundamental stepping stone in preparation for the imminent launch of hyper-resolution X-ray space observatories, such as XRISM.

1.3 Space Weather processes connected to the Sun-Planet interaction and focused on the coupling between the solar plasma and Earth magnetosphere / ionosphere

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Abstract: The Space Weather studies the physical status of the Sun, of the interplanetary space and of the circumterrestrial environment. Space Weather Events (SWEs) can affect satellite operations and technology on Earth, or put the health of astronauts at risk, especially in thof deep space. The physical processes related to the interaction of the solar magnetized plasma with the circumterrestrial environment are particularly important. A significant role in these processes is played by the solar plasma-magnetosphere / ionosphere coupling. This coupling is responsible for the transfer of energy and moment to magnetosphere / ionosphere system and which originates physical complex and not yet fully understood processes. The thesis project aims to improve the understanding of the dynamic properties of plasma and electromagnetic fields in the solar plasma-magnetosphere/ionosphere coupling through satellite measurements acquired from flying missions in LEO, such as Swarm and CSES, from the heliophysical missions (i.e., Solar Orbiter and Parker Solar Probe) and possibly with the support of data acquired on Earth.

1.4 The Solar Synoptic Telescope project: MOF-based spectroscopy, Telescope optical design and robotization

Supervisor: Francesco Berrilli (Tor Vergata)
Co-Supervisor: Stuart Mark Jefferies (GSU)
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Abstract: The study and forecasting of Space Weather Events (SWEs) need the simultaneous observation of different features of the Sun. Multilayer observation of solar magnetic field and photospheric velocity, transient solar event detection, and SW-Space Situational Awareness support are provided by multi-line, continuous, high cadence synoptic telescope surveys. In the past years, MOF-based telescopes demonstrated their ability to produce calibrated datasets of such data (e.g., Mees Observatory, Antarctic campaign 2016-18, TSST telescope). This thesis project aims to take the final step necessary to realize the first network of MOF-based synoptic telescopes. It has two objectives: i) the development of a helium-based MOF instrument for multilayer observation and 3-D reconstruction of solar dynamics; ii) the automation and robotization of the telescope to transfer the telescopes to high-quality sites for seeing (i.e., La Palma, Maui, South Pole, etc.). This is a jointly supervised Ph.D. thesis (cotutelle) between the universities of Rome Tor Vergata and Georgia State University and involves 18 months of work at Tor Vergata and 18 months at GSU.

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

Supervisor: Pasquale Mazzotta (Tor Vergata)
Co-Supervisor: Herve' Bourdin (Tor Vergata), Marco De Petris (Sapienza)
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Abstract: 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 cos-

mological 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. 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.

1.6 Millimetre observations of galaxy clusters

Supervisor: Herve' Bourdin (Tor Vergata)
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Abstract: 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. 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).

1.7 Space Weather and Space Science

Supervisor: Dario Del Moro (Tor Vergata)
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Abstract: 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, 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.

1.8 The Magnetic Field and the Dynamics of the Solar Convection

Supervisor: Dario Del Moro (Tor Vergata)
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Abstract: The solar magnetic field couples the solar interior with the visible surface of the Sun and with its atmosphere. It is also responsible for all solar activity in its numerous manifestations. The polarized electromagnetic spectrum of the Sun encodes a wealth of information on the thermodynamic and magnetic properties of its atmosphere. In order to recover such information, scientists perform critically sensitive spectro-polarimetric observations

of the Sun, and then carefully reduce, analyze, and interpret the observed data. Within this project, the PhD candidate will achieve a deep knowledge the fields of solar Physics and spectro-polarimetry, will acquire the multiple skills and methodologies necessary for decoding the polarization of the solar spectrum, and will understand both the instrumentation used to acquire the observations and the limitations that arise from the observed data quality.

1.9 Planetary habitability in the galactic context

Supervisor: Amedeo Balbi (Tor Vergata)
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Abstract: The project aims at assessing the dependence of planetary habitability (defined, minimally, as the capability of a planetary environment to sustain life as we know it) on the astrophysical context, with a focus on the temporal and spatial frequency and distribution of habitable planetary systems in the galaxy. This goal will be pursued through the use of numerical codes of exoplanetary climates and atmospheres, with a particular emphasis on the interaction with ionizing radiation from astrophysical sources. A by-product of the project will be the definition of ranges of survivability for different classes of organisms at various galactic locations, and of signatures produced by biological activity that might be detected by future astronomical observations.

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

Supervisor: Giancarlo De Gasperis (Tor Vergata)
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Abstract: PILOT (Polarized Instrument for the Long-wavelength Observations of the Tenuous ISM) is a balloon-borne experiment to study the polarisation of dust emission in the diffuse Interstellar medium (ISM) 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;
- Complement Planck observations at higher frequencies.

The third flight has been performed at the end of 2019; flight analysis and data cleaning is ongoing.

The thesis work 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.

A period of work on the project at IRAP (Toulouse) is envisaged.

For more info see also:

- http://pilot.irap.omp.eu and https://arxiv.org/abs/1410.5760
- https://arxiv.org/abs/1804.05645 and https://arxiv.org/abs/1901.06196
- https://arxiv.org/abs/2205.03668

1.11 Multi-wavelength cubesat to study solar variability: science goals and mission profile

Supervisor: Luca Giovannelli (Tor Vergata)
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Abstract: Sun CubE OnE (SEE) is a micro satellite for multispectral synoptic observation of the Sun. The SEE mission is in the shortlist of the "Future missions for Cubesat" call of the Italian Space Agency (ASI), and it is expected to start its phase A study in 2023. SEE is a 12U CubeSat

mission in LEO whose main objective is the study of solar variability from UV to gamma. The Gamma and X-ray fluxes will be studied with unprecedented temporal resolution and with a multi-wavelength approach thanks to the combined use of silicon photodiode and silicon photomultiplier (SiPM) -based detectors. The flare spectrum will be explored from the keV to the MeV range of energies by the same payload, and with a cadence ¿ 10 kHz to unveil the sources of the solar flares. Given its UV imaging capabilities, SEE will be a key space asset to support detailed studies on solar activity, especially in relation to ultraviolet radiation which strongly interacts with the upper layers of the Earth's atmosphere, and in relation to space safety, included in the field of human space exploration. During the Nominal Mission, SEE shall constantly point the Sun, except during manoeuvres, eclipses or contingencies. A detailed study of a suitable Sun-synchronous orbit, with details on the maximum allowed doppler-shift and orbit decay will be part of the mission profile definition in the thesis.

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

Supervisor: Eleonora Troja (Tor Vergata)
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Abstract: 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. 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).

1.13 Mapping the diversity of kilonova emission from compact binary mergers

Supervisor: Eleonora Troja (Tor Vergata)
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Abstract: 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: follow-up searches of gravitational wave sources, follow-up observations of gamma-ray bursts, and through serendipitous 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).

1.14 Development of adaptive optical systems for the next generation gravitational wave detectors

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Abstract: A key element in multimessenger astronomy is represented by the precision in the sky localization of the gravitational wave source, which is directly related to the detector sensitivity. In particular, observational capabilities of future gravitational wave detectors rely on highly performing optical systems. The aim of this project is to develop new strategies for the

correction of optical aberrations in the test masses of future interferometric detectors through the implementation of cutting-edge adaptive optics. The thesis will be carried out at the Tor Vergata Physics Department and the European Gravitational Observatory.

1.15 Optimization of the performances of Virgo in the next observational runs

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Abstract: Precise modelling of interferometric gravitational wave detectors is a crucial step toward the achievement of the target sensitivity. This thesis project is focused on the analysis of the data collected by Virgo to characterize its behavior and optimize its performances, and to develop simulation tools in view of the forthcoming upgrades toward the third-generation observatory Einstein Telescope. The thesis will be carried out at the Tor Vergata Physics Department and the European Gravitational Observatory.

1.16 GPU Optimization of data-analysis and simulation code for CMB experiments

Supervisor: Giuseppe Puglisi (Tor Vergata)
Co-Supervisor: Nicola Vittorio (Tor Vergata)
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Abstract: The cosmology group at Tor Vergata is actively involved in planning future observational campaigns targeting cosmic microwave background (CMB) polarization from space (LiteBIRD, PICO) and from ground (Simons Observatory, CMB-Stage4). One of the major challenges in the context of the CMB radiation is to detect a polarization pattern, the so called B-modes thought to be directly linked to the energy scale of the inflationary era. This project aims at improving and optimizing the data analysis and simulation frameworks adopted in the forthcoming CMB experiments. We devote a particular focus on the code optimization given the latest hardware architectures of computing facilities where a hybrid version of CPU and GPU nodes have been already deployed. The student will be involved in an international network of experts from prestigious institution around the world so that transfer

of knowledge is ensured.

1.17 Challenges for future CMB observations: modelling of Galactic microwave emission and component separation techniques

Supervisor: Giuseppe Puglisi (Tor Vergata)
Co-Supervisor: Marina Migliaccio (Tor Vergata)
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Abstract: The cosmology group at Tor Vergata is actively involved in planning future observational campaigns targeting cosmic microwave background (CMB) polarization from space (LiteBIRD, PICO) and from the ground (Simons Observatory, CMB-Stage4). One of the major challenges in the context of CMB studies is to detect a polarization pattern, the so-called primordial B-modes, thought to be directly linked to the inflationary era. To date, primordial B-modes are yet to be detected, partly because the microwave emission from our own Galaxy acts as a foreground contamination. This project will be carried out in an extremely international environment and it will mainly focus on the development of novel techniques based on supervised and unsupervised learning in order to improve the modeling and characterization of the Galactic polarized emission at sub-mm wavelengths. On the other hand, the activity will also tackle the challenge to improve the methodologies of foreground cleaning aimed at separating the primordial signal from the astrophysical emissions. These are, in fact, essential to achieve the ambitious goals of future experiments, for which high sensitivities are expected to be reached.

1.18 Physical Properties of Transiting Planetary Systems

Supervisor: Luigi Mancini (Tor Vergata)
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Abstract: 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 archi-

tectures of planetary systems continuously challenge our knowledge of planet formation, evolution, and interiors. By using instruments and telescopes like TESS, LBT, HARPS-N, ESPRESSO, GIARPS, this PhD project aims at furthering our understanding of key aspects of planet formation and evolution processes focusing on a two-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.

1.19 Observing gaseous exoplanets in formation around young stars

Supervisor: Luigi Mancini (Tor Vergata)
Co-Supervisor: Katia Biazzo (INAF-OAR), Simone Antoniucci (INAF-OAR)
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Abstract: One of the most exciting topics for exoplanet studies is understanding how the planets form within the protoplanetary disks of their parent stars. Crucial targets to be investigated for this science case are gaseous giants on wide orbits, as such planets play a fundamental role in sculpting the final architecture of planetary systems. We propose a thesis aimed at studying giant exoplanets in formation within disks of young stars, based on direct imaging data to be acquired with SHARK-VIS, the new high-contrast imager of the Large Binocular Telescope (LBT; Arizona), built at the INAF-OARoma. SHARK-VIS will be employed to search and characterise gaseous exoplanets still in accretion phase, while high-dispersion optical/near-infrared spectra of the hosting star, acquired with GIARPS at the Telescopio Nazionale Galileo (Spain), will be used to characterise the parent star. Data from other facilities placed at the LBT or at the European Southern Observatory will be also analysed. The PhD student will carry out the work at the Tor Vergata University and INAF-OARoma. He/She will

also be actively involved in the observations at the LBT and also in projects from space missions (JWST, Ariel)

1.20 The impact of primary and secondary distance indicators on the cosmic distance scale

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Co-Supervisor: R. da Silva (INAF-OAR)
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Abstract: The main of this PhD project is to provide a new calibration of primary distance indicators associated with young (classical Cepheids) an old (RR Lyrae, Tip of the Red Giant Branch) stellar populations. The canidate will take avantage either of theoretical (stellar pulsation and evolution) or empirical (Gaia, OGLE) calibrations based on both optical and NIR diagnostics. Moreover, the candidate will have the opportunity to use a huge data set of metal abundances collected by our group to constrain on a quantitative basis the impact of the metallicity on the cosmic distance scale. The primary distance scales will be applied to both gas-poor an gas-rich stellar systems to provide new calibrations of secondary distance indicators (SNIa, AGN, GCLF). The candiate will split her/his time among Nice, Garching (Germany, ESO) and Rome.

1.21 Nearby dwarf galaxies as astrophysical and cosmological laboratories

Supervisor: Giuseppe Bono (Tor Vergata)
Co-Supervisor: Michele Fabrizio (INAF-OAR)
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Abstract: Nearby dwarf galaxies appear to be strongly dark matter dominated, and indeed their Mass-to-Light ratios are of the order of several hundreds. Our group collected detailed and homegenous multiband photometric data with wide field imagers available at the 4-8m class telescope to investigate their stellar populations and their variable star content. Moreover, we have also collected spectroscopic data using multi-object (slit, fiber) spectrographs to estimate the radial velocity and the metallicity distribution of both old and intermediate-age stellar populations. This empirical scenario will be used to estimate the ML ratios and their chemical enrichment history.

The candidate will also provide new constraints the impact of the environment on advanced evolutionary phases (HB, AGB) in very metal-poor stellar systems. The candiate will split her/his time among Victoria (Canada), Garching (Germany, ESO) and Rome.

1.22 Cosmology from the cross-correlation of CMB and large-scale structure observables

Supervisor: Marina Migliaccio (Tor Vergata)
Co-Supervisor: Nicola Bartolo (Padua University)
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Abstract: Only recently cosmology has undergone a renaissance, transforming from a data-starved to a data-driven science. While observations supply strong evidence in favour of the standard model of cosmology (ΛCDM), some tensions have been found which could be hinting at new physics beyond the standard model. With the advent of wide galaxy surveys, such as the ESA mission Euclid, and the high sensitivity maps of the microwave sky delivered by Planck and expected from future experiments, it is crucial and timely to investigate the interactions and complementarities of these diverse probes of the Universe. In particular, as different observations can be sensitive to the same physics, studying their cross-correlation appears as a unique tool to maximise the scientific outcome of each probe. Cross-correlating observables of the Cosmic Microwave Background, such as temperature and lensing data, with galaxy distribution and weak leansing data can allow us to reconstruct the evolution of the large-scale structure across cosmic time and derive novel constraints on the nature of the dark side of the Universe.

2 Sapienza Universtity of Rome

2.1 Probing the epoch of reionization with the first galaxies

Supervisor: Laura Pentericci (INAF-OAR)
Co-Supervisor: Emiliano Merlin (INAF-OAR)
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Abstract: The epoch of reionization is still a largely unexplored domain: we still 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. Through JWST observations (which will be available from autumn 2022) and MOONS observations of shallower but much larger areas (starting from 2023), the student will identify galaxies at z¿5 and characterize their nature and physical properties. We will put particular emphasis on the study of the Lyman alpha emitting galaxies, also through machine learning and deep learning techniques, to investigate the contribution of these very first galaxies to the re-ionization process. The student will also search and analyze z¿5 over-densities to investigate the topology of the reionization

2.2 Dynamical evolution and stellar evolution in globular clusters

Supervisor: Marco Merafina (Sapienza)
Co-Supervisor: Oscar Straniero (INAF-OAAb)
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Abstract: Current numerical simulations support the understanding of the dynamical evolution of Globular Clusters. In particular, these models were used to check the validity of the effective potential theory (POS-MULTIF2017, 004). However, they were developed assuming a single or constant stellar mass. With more realistic models, in which GCs are populated with stars of different mass according to a continuous spectrum, there is a concrete possibility to obtain a more accurate reproduction of the observed distribution of stellar velocities, which now also includes the transverse component (HST, Gaia). Furthermore, with the support of N-body simulations, it will be possible to verify both the degree of equipartition of energy between the stars of the cluster, which is a debated problem and does not yet know a definitive answer, and the effects of mass segregation. In addition to the mass spec-

trum and the presence of the galactic tidal field, the study of the effects of the dynamical evolution on stellar evolution (and viceversa) constitutes the real novelty of this research that may give additional effects, such as the presence and formation of binary or ternary systems, stellar multi-populations and the formation of compact objects (WDs, neutron stars and black holes). Thus, a study of multi-mass theoretical models can provide important results useful for understanding the coupling between stellar evolution and dynamics in globular clusters.

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

Supervisor: Paolo de Bernardis (Sapienza)
Co-Supervisor: Fabio Columbro (Sapienza)
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Abstract: The measurement of Cosmic Microwave Background (CMB) polarization at large angular scales represents the best way to investigate the first split-second after the big-bang, and the cosmological inflation hypothesis. The Large-Scale Polarization Explorer (LSPE) is a mission to measure inflation-originated CMB polarization, significantly improving both the sensitivity and the control 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. In both experiments, 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. 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 con-

tribute to the LiteBIRD mission as well. See also *http://lspe.roma1.infn.it* and *http://litebird.jp/eng/*

2.4 Inference of the mass of clusters of galaxies by hydrodynamic simulations and multi-wavelength observations and its cosmological implications

Supervisor: Marco De Petris (Sapienza)
Co-Supervisor: Gustavo Yepes (Universida Autonoma de Madrid - Spain) and/or Frederic Meyet (LPSC, Universite' Grenoble Alpes - France)
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Abstract: 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. All possible sources of mass bias will be thoroughly investigated: the presence of IntraCluster Medium non-thermal pressure support, due to turbulence and/or bulk gas motions, the dynamical state of the clusters, inferred by different morphological indicators, and the impact of filaments in their outskirts. This project will address different approaches to infer the mass of clusters using multi-wavelength observations and hydrodynamical simulations. The candidate will join: 1- the NIKA2 Large Program Sunyaev-Zel'dovich team, participating in the millimeter observations with the kilo-pixels camera at 30-m IRAM telescope in Spain and then in the data reduction and analysis, and 2- The Three Hundred collaboration, working with synthetic clusters extracted from one of the largest hydrodynamical simulation with available mock images at different spectral bands.

2.5 Black hole spectroscopy with effective one-body models: waveforms, rates, and tests of gravity

Supervisor: Paolo Pani (Sapienza)
Co-Supervisor: Raffaella Schneider (Sapienza)
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Abstract: The study of the ringdown emission of gravitational waves from binary black holes is one the most promising paths to test gravity in the

strong field regime. Effective one-body models can extend the ringdown up to the merger by modelling early times non-linearities. This is crucial to overcome the problem of determining the starting time of the ringdown in the linear regime, and to build reliable waveforms that include in the analysis a high-SNR part of the signal that is hitherto excluded. This framework can also be adapted to different scenarios beyond general relativity and is excellent to characterise higher multipolar modes in the gravitational wave signal, whose detection could lead to the first authentic test of the no-hair theorem with current and future detectors, with possible profound implications for both astrophysics and fundamental physics. On the other hand, the quality of these tests also depends on the abundance and mass distribution of binary black holes in the universe. We plan to construct analytical waveform approximants useful for parameter estimation, and interface them with population studies aimed at estimating event rates for ringdown tests with current and future interferometers.

2.6 Spectral distortions of the Cosmic Microwave Background : the COSMO experiment

Supervisor: Silvia Masi (Sapienza)
Co-Supervisor: Jens Chluba (University of Manchester, UK) - Paolo de Bernardis (Sapienza)
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Abstract: Spectral distortions (SD) of the CMB monopole are now recognized as a unique way to study several processes happening at different epochs during the evolution of the universe. Only upper limits exist for the SD at mm wavelengths, of the order of 100 ppm of the peak CMB brightness. While the final measurement certainly requires a space mission, pathfinders are needed to develop and test the instrument configuration, and to detect the largest distortion. This is the so called "y distortion", due to the presence of ionized matter in the post recombination universe, and expected at a level about 50 times smaller than the current upper limits. One staged experiment, called COSMO (COSmic Monopole Observer) is being assembled and integrated to be operated from Dome-C, Antarctica, with a proposed follow-up mission on a stratospheric balloon. The PhD student would work both on the experiment integration and calibration together with our group, and on

simulations and optimization of the data analysis pipeline in collaboration with the Manchester group directed by prof. Jens Chluba.

2.7 Cosmic Microwave Background polarization with the QUBIC experiment

Supervisor: Silvia Masi (Sapienza)
Co-Supervisor: Jean-Christophe Hamilton (APC Paris) - Giancarlo De Gasperis (Tor Vergata)
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Abstract: 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. The 150 GHz one has been demonstrated in the laboratory. QUBIC, integrated and calibrated in Salta (Argentina) during 2021, will be shipped to Alto Chorillo by October 2022. The data analysis and simulation pipeline developed at APC-Paris is available to the collaboration. The PhD work will focus on 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 S. Masi for calibration and data taking, G. De Gasperis for data analysis and J.C. Hamilton for spectro-polarimetry and components separation. The thesis will include work in Argentina for hands-on data taking and calibration, and in Paris for data analysis activities.

2.8 Preparation of the LiteBIRD space mission for CMB polarization: instrument definition, requirements, and data analysis.

Supervisor: Francesco Piacentini (Sapienza)
Co-Supervisor: Luca Lamagna (Sapienza)
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Abstract: Accurate measurement of the Cosmic Microwave Background polarization allows to measure the presence of gravitational waves in the early Universe, at the recombination epoch. These gravitational waves carry information on the inflation mechanism in the early Universe. Polarization measurements in the microwave band also permits 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 late 2020s. The spacecraft hosts three instruments, LFT, MFT and HFT covering low, mid and high frequency ranges respectively. The supervisor is the Instrument Scientist of the MFT and HFT instruments, which are contributed by Europe. The applicant will contribute to preparation of the mission, in particular in the definition of the instruments requirements, in the development of next generation algorithms for instrument simulation, calibration, control of systematic effects, polarization extraction, component separation, measurement of the cosmological parameters, measurement of statistical anomalies, and much more. The applicant will work in a very international environment, with links and contacts worldwide. A period of 2-12 months abroad (US, Japan or Canada) is foreseen and funding is secured. For more information, see: Probing Cosmic Inflation with the LiteBIRD Cosmic Microwave Background Polarization Survey, submitted to PTEP (2022) https://arxiv.org/abs/2202.02773

2.9 Design, Optimization and Characterization of Kinetic Inductance Detectors for Cosmic Microwave Background radiation experiments

Supervisor: Alessandro Paiella (Sapienza)
Co-Supervisor: Francesco Piacentini (Sapienza)
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Abstract: Kinetic Inductance Detectors (KIDs) are low-temperature superconductive resonators easily multiplexable in large-format (thousands of independent detectors) arrays. This characteristic and their intrinsic high

sensitivity make them very attractive for precision measurements of the Cosmic Microwave Background (CMB) radiation. The thesis work concerns the design, the optimization and the characterization, through laboratory measurements, of the detector arrays of CMB experiments such as MISTRAL and COSMO, and for premiale ASI. MISTRAL (Millimetric Sardinia Radio Telescope receiver based on array of lumped element KIDs) is a cryogenic camera which will be installed at the Sardinia Radio Telescope and will allow continuum, high angular resolution observations of the mm-wave sky in the W-band. COSMO (Cosmic Monopole Observer) is a ground-based telescope aimed at the spectral measurements of CMB monopole isotropic spectral distortions (in two bands centered at 150 and 250 GHz) from Dome-C in Antartica. Premiale ASI is a R&D activity for the development of polarization sensitive KIDs in the frequency range 120-550 GHz, for experiments aimed at the measurement of CMB primordial B-modes.

2.10 Development of advanced data analysis techniques for the search of periodic gravitational waves and their application to the data of Virgo and LIGO detectors

Supervisor: Piero Rapagnani (Sapienza)
Co-Supervisor: Pia Astone (INFN)
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Abstract: Spinning neutron stars, both isolated and in a binary system, are expected to emit periodic gravitational waves if asymmetric respect to the rotational axis. Such signals are very weak and their detection poses relevant challenges from the analysis and computational point of view. The Thesis work we propose is about the application of advanced data analysis techniques to develop a robust and computationally efficient pipeline for the search of periodic gravitational waves, and its application to the data produced by the LIGO and Virgo detectors. This work will be carried on within the Rome group of the Virgo Collaboration which is one of the world-wide leaders in this field. As part of the LIGO-Virgo collaboration we are guaranteed immediate access to the full data set. The detection of periodic signals, thanks to their long time duration and very specific features, will transform neutron stars in true laboratories for relativistic astrophysics and for nuclear physics, allowing unprecedented studies on high density matter and opening

a new outstanding window on the study of neutron stars.

2.11 Development of new technologies for sensitivity improvements in next generation Gravitational Wave Detectors

Supervisor: Piero Rapagnani (Sapienza)
Co-Supervisor: Ettore Majorana (Sapienza)
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Abstract: 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 (O3), started on April 1st 2019. Just in one month, we have observed one signal from black coalescence every few days, and one signal coming from the coalescence of a binary neutron star. Of course this is only the beginning: 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.

2.12 Cosmological parameters from Euclid probes

Supervisor: Roberto Maoli (Sapienza)
Co-Supervisor: Vincenzo F. Cardone (INAF-OAR)
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Abstract: The Euclid satellite will carry on a spectroscopic and imaging survey over 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 $\tilde{n}$ correlation of the galaxy field with the CMB. In order to make the best profit of the whole dataset, it is of paramount importance to investigate the cross $\tilde{n}$ correlation among these different probes. This

will not only increase the accuracy on the cosmological parameters (being the total more than the sum of the parts), but also to look for any systematics which can bias the results from a single probe. The proposed thesis will investigate a self $\tilde{n}$ consistent approach to the Euclid data developing a likelihood analysis which correctly takes into account the covariance among each individual dataset. Validation of the proposed tools will be possible against Euclid $\tilde{n}$ like simulations. A close interaction with the likelihood work packages present in the Euclid collaboration is foreseen putting the student in contact with a large community performing frontier research in cosmology.

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

Supervisor: Enzo Pascale (Sapienza)
Co-Supervisor: @
Contact: enzo.pascale@uniroma1.it
Abstract: Planets orbiting stars other than our Sun (exoplanets) are now detected in large numbers by dedicated surveys from the ground and from space. Despite this impressive achievement, our knowledge of these alien words remains limited to what can be learned from a measurement of the planet radius and mass, and from some sparse near-IR spectroscopy and broad band photometry from space. In this decade, spectroscopic observations extending to the mid-IR with the Ariel space mission (http://arielmission.space) will reveal us the chemical composition and thermodynamics of the transiting planet atmospheres, unveiling their true nature, and allowing us to link planetary formation to evolution. In this project you join the consortium that is designing Ariel to perform a spectroscopic survey of about 1000 exoplanet atmospheres, yielding the first statistically significant mapping of exo-atmospheres. Under the supervision of the Ariel Mission Scientist, you will assume a leading role in the Ariel consortium on one or more of the following lines of investigation: optimisation of instrument design; estimates of science performance; development of data reduction and science analysis pipelines; characterisation of instrument and astrophysical systematics. Detailed project topics will depend on your personal interests and curiosity. Visit http://www.roma1.infn.it/ pascalee for additional information and contacts.

2.14 Deciphering current tensions in cosmologica data.

Supervisor: Alessandro Melchiorri (Sapienza)
Co-Supervisor: @
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Abstract: Most recent cosmological data show tension on the value of different derived parameters (Hubble constant, matter clustering, curvature of the Universe and so on...). Goal of the thesis will be to investigate the nature of current tensions and to provide possible explanations either in the form of systematics, or in the form of new physics. Another fundamental aspect will be to identify the utility of future experiments in solving the current issues.

2.15 Investigating dark matter properties from cosmology

Supervisor: Alessandro Melchiorri (Sapienza)
Co-Supervisor: @
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Abstract: While a fundamental part of the current cosmological model, the nature and the physical properties of the dark matter remain elusive. We plan to perform a systematics analysis of current and future cosmological data to constrain several aspects of the dark matter paradigm. Is the dark matter just cold or we see evidence for different particles? What is the neutrino mass hierarchy? is dark matter interacting with itself or other components as neutrinos or dark energy?

2.16 Exploring star formation and stellar black holes at cosmic dawn with numerical simulations

Supervisor: Luca Graziani (Sapienza)
Co-Supervisor: Rosa Valiante (INAF-OAR)
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Abstract: Thanks to modern observational facilities, such as ALMA and to the long-awaited James Webb Telescope, a revolutionary set of observations of the early stages of cosmic star formation and on the first galaxieswill be available soon. Modern numerical methods based on hydrodynamical simulations and radiative transfer will require further improvements on various physical mechanisms regulating star formation, to finally reveal the missing

link between metal poor binary stars and compact binaries generating gravitational waves. This project aims at developing a new version of the dustyGadget code to predict the first generation of stars and their stellar black holes, with a focus on massive black hole binaries and their gravitational wave events. These predictions will be relevant in view of the next generation of GW observatories like ET and LISA. The ideal candidate should combine his/her interests in the above astrophysical problems with a keen aptitude and a strong curiosity in developing numerical codes, in applying advanced programming techniques, and finally in advancing his modeling skills with techniques of parallel, distributed and GPU-accelerated computing.

2.17 Understanding the ISM of the first dusty galaxies in the Epoch of Reionization

Supervisor: Luca Graziani (Sapienza)
Co-Supervisor: Marco Castellano (INAF-OAR)
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Abstract: Chemically evolved, dusty galaxies evolving during the first gigayear of our Universe, the so called Epoch of Cosmic Reionization (EoR, z ¿6), are nowadays observed both as single objects and in high redshift surveys. This dataset will certainly boost in the next years thanks to the JWST observational programs, and relevant ALMA follow-up observations in the sub-mm. A statistically reliable dataset to constrain hydrodynamical simulations and poorly constrained feedback effects, will be available. This project aims at interpreting the new generation of observations and inferring the origin of cosmic dust in the ISM of the first galaxies by specifically designed hydrodynamical simulations performed with the dustyGadget code, and post-processed by radiative transfer runs. The interested candidate will develop strong scripting skills necessary to analyze the outputs of numerical simulations and the capability to independently perform 'had hoc' hydrodynamical runs targeted at interpreting specific observed objects. In collaboration with Marco Castellano at INAF-OAR he/she will access data from several JWST surveys and learn how to analyze and properly interpret them with numerical simulations.

2.18 Using Quantum Machine Learning to Explore New Analysis Perspective in Remote Sensing

Supervisor: Fabio Curti (Sapienza)
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Abstract: Quantum computing (QC) is starting to demonstrate advantageous features with respect to classical computing, and interesting applications are now investigated related to Quantum Machine Learning (QML). Potential benefits of QML include the possibility to explore more data in shorter amount of time and the improvement of the learning process. Preliminary applications of QML to remote sensing data coming from Earth observation satellites or interplanetary missions around other celestial bodies have already been considered in literature. However, further investigation is needed to consider the rapid growth of QC and the development of new machine learning paradigms designed for QC. This PhD project will investigate how the current QC technology can help the development of new analysis techniques for the exploitation of big data in remote sensing. This research activity is developed in the framework of the agreement between the School of Aerospace Engineering, Sapienza University of Rome and the ?-lab, ESA-Esrin.

2.19 Edge Computing with Artificial Intelligence Algorithms to Enhance Satellites Autonomy

Supervisor: Dario Spiller (Sapienza)
Co-Supervisor: Fabio Curti (Sapienza)
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Abstract: Improving satellites autonomy in terms of in-orbit operations and data elaboration could revolutionize the design of future missions with important advantages in terms of offered satellite-based services. Artificial intelligence (AI) can help in different ways, e.g., in terms of controlling the satellites to perform the required maneuvers by using reinforcement learning or neural networks classification models to process remote sensing data directly on-board. Using hardware accelerators such as graphics processing units (GPUs), tensor processing units (TPUs), or Field Programmable Gate Array (FPGA) is a requirement to properly run AI algorithms. When considering edge computing to deploy AI algorithms directly on-board, inference

time and power consumption are fundamental features to be considered. This PhD project will investigate new applications of AI algorithms for on-board deployment to foster the increase of satellite autonomy. This activity is developed in the framework of the agreement between the School of Aerospace Engineering, Sapienza University of Rome and the ?-lab, ESA-Esrin.

2.20 Exploring the black hole mass spectrum throughout cosmic times

Supervisor: Raffaella Schneider (Sapienza)
Co-Supervisor: Rosa Valiante (INAF-OAR)
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Abstract: The detection of gravitational waves (GW) emitted by black hole (BH) binary systems have started a new era of exploration of the Universe with far reaching astrophysical implications. The very existence of stellar-mass BHs with masses of several tens of solar masses, up to the pair-instability gap, has questioned our current understanding of massive stellar evolution and its dependence on metallicity. The exploitation of this vast scientific potential requires new advanced theoretical models that are capable of linking star formation, stellar evolution, and BH formation in a full cosmological context, where galaxy evolution is described in a self consistent manner. This is particularly true in light of the stepwise increase in sensitivity expected for future third-generation GW detectors, that will be capable of discovering binary BHs over the entire history of the Universe, up to the beginning of star formation, at r$z \sim 20 - 30$, when the Universe was only 150 - 200 Myr old. At the same time, super-massive black holes (SMBHs) are observed up to redshift $z = 7.54$ as quasars, at lower redshift as active galactic nuclei, and today in massive galaxies in their quiescent state, and cover a mass range from $\sim 10^4\, M_\odot$ to $\sim 10^9 - 10^{10}\, M_\odot$. Understanding the assembly of the first massive BHs in the Universe stands on the determination of the nature of their BH seeds and how they grow, and hence the role they play in the evolution of their host galaxies. But even more challenging is to explore whether a single thread exists that connects the formation of stellar-mass and super-massive BHs. This project aims at using and advancing state-of-the-art semi-analytical and numerical models to explore the BH mass spectrum as a function of redshift and how this correlates with massive star formation, metallicity, and galaxy evolution. The

models will be benchmarked with multi-band electromagnetic observations (proprietary data available through collaborations and/or published data) and will be used to make detailed forecasts for future GW detectors.

2.21 Study and optical characterisation of millimetre-wave polarisation modulators for Cosmic Microwave Background instruments

Supervisor: Giampaolo Pisano (Sapienza)
Co-Supervisor: Fabio Columbro (Sapienza)
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Abstract: 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. In this project 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. 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.

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

Supervisor: Giampaolo Pisano (Sapienza)
Co-Supervisor: Silvia Masi (Sapienza)
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Abstract: 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. 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 Japanese LiteBIRD satellite mission. Devices a)-c) find direct application in the LB MHFT instrument. These developments can find also applications in other fields. 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.

2.23 Sunyaev Zel'dovich effect study of galaxy clusters and cosmic web with Atacama Cosmology Telescope and higher angular resolution instruments

Supervisor: Elia Battistelli (Sapienza)
Co-Supervisor: Francesco Piacentini (Sapienza)
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Abstract: The Cosmic Web and filaments between clusters are a clear pre-

diction 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. 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 data with moderate angular resolution ones. Also (s)he will prepare the observational strategy and observational plan, and do the commissioning, for the MISTRAL experiment, a millimetric camera being 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.

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

Supervisor: Elia Battistelli (Sapienza)
Co-Supervisor: Matteo Murgia (INAF-OA Cagliari)
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Abstract: 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. 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 recently underwent an

upgrade with 30GHz and 40GHz channels. Also, it should be noted that 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.

2.25 Development and validation of the optical system for the LiteBIRD Medium and High Frequency Telescope

Supervisor: Luca Lamagna (Sapienza)
Co-Supervisor: Alessandro Paiella (Sapienza)
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Abstract: LiteBIRD is the next-generation satellite for the observation of the microwave sky in polarization. It is planned for a launch within the next decade, and it aims at constraining the signature of primordial gravitational waves in the Cosmic Microwave Background (CMB) through the search for the large-scale (degree and above) curly component of the CMB polarization anisotropy (primordial B-mode). A detection of such a signal is highly regarded as the "smoking gun" of the inflationary phase of the early evolution of the universe, and it is largely informative of the features and energy scales of the processes triggering the inflationary phase transition. The level of the primordial B-mode signal is unknown, and current upper limits set its amplitude at most at a fraction of a percent with respect to the CMB intensity anisotropies. With such an ambitious scientific target, the requirements on sensitivity, polarimetric calibration accuracy, detection chain stability and systematics control are unprecedented. Most of the efforts related to hardware design and prototyping are driven by the need to develop modeling, testing and validation methods consistently with the subsystem- and system-level requirements. The aim of this PhD thesis is the refined study of the optical system of the LiteBIRD Medium and High frequency telescope, i.e. the onboard instrument devoted to the polarimetry of the microwave sky in the 100-400 GHz band. The candidate is expected to work with dedicated simulation and analysis software to model the system and its subsections, and to investigate the issues related to thermal, mechanical and

electromagnetic systematics and tolerancing. Such issues, and the related uncertainties affecting their characterization, propagate into the detection chain with nontrivial interplay with the rest of the aspects of the instrument, and ultimately determine the low-level systematics breakdown. The Ph.D. candidate is also expected to participate to the experimental validation activities related to the optical and quasioptical subsystem caharacterization (including, as an example, the broadband characterization of the microwave absorber coating on the optical tube walls). As a part of an international coordinated effort, this project will also help the candidate to establish a rich network of links and collaborations with the worldwide CMB community.

3 INAF

3.1 Adjusting the clock(s) to unveil the chrono-chemo-dynamical structure of the Milky Way.

Supervisor: Santi Cassisi (INAF-IAPS)
Co-Supervisor: Giuseppe Bono (Tor Vergata)
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Abstract: Ongoing observational surveys 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. 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.

3.2 Understanding R-process and Kilonovae aspects in the multi-messenger era

Supervisor: Sergio Cristallo (INAF-OOAb)
Co-Supervisor: Francesco Pannarale (Sapienza)
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Abstract: Half of the heavy elements in the Universe are synthesized via the rapid neutron capture process in stars (the r-process), proved to be at work during Neutron Star Mergers (NSMs) by observing and interpreting the kilonova explosion following the gravitational event GW170817. An in-depth understanding of the r-process and kilonovae events is therefore crucial to fully exploit the potentiality of the newly born multi-messenger astronomy. This thesis aims to unveil fundamental information on the nucleosynthesis

expected by NSMs. The candidate will focus on the prediction of r-process yields in the different components of NSMs. Taking advantage of heavy element opacities by the PANDORA-INFN facility, she/he will develop a new tool to model kilonovae lightcurves, a key chance to understand the observations of the kilonova discovered after gravitational wave detections by LIGO/Virgo/KAGRA.She/he will work together with worldwide recognized researchers, with a long-lasting tradition in stellar modelling and related nucleosynthesis, and will have the opportunity of being member of leader collaborations in the field (GRAWITA, ENGRAVE, Einstein Telescope). Stages at foreign institution are foreseen.

3.3 The impact of magnetic fields on M dwarf stars

Supervisor: Adriano Pietrinferni (INAF-OOAb)
Co-Supervisor: Giuseppe Bono (Tor Vergata)
Contact: adriano.pietrinferni@inaf.it - bono@roma2.infn.it
Abstract: M dwarfs are the lowest mass stars, occupying the bottom of the main sequence. These stars dominate the local stellar population. It has become clear that M dwarf stars should host Earth- and Neptune-size planets. As a consequence, they are receiving a lot of attention in the present and future spatial surveys -such as PLATO- aimed at the search of Earth-like exoplanets. Several M dwarfs exhibit surface activity (flares and coronal emission in X-rays, UV, and radio) correlated with the presence of intense magnetic fields. Despite the interior structure of these stars is relatively simple, several studies demonstrated that measured radii of M dwarfs tend to be larger than those predicted by the stellar evolution theory. This discrepancy correlates with the magnetic activity. The main aim of this work is to modify the Stellar Evolutionary code FRANEC in order to take into account the contribution of the magnetic field on the M Dwarf stellar structures. The theoretical predictions will be constrained by exploiting the exquisite photometry and asteroseismological observations from space missions and high-resolution spectroscopy ground based observation devoted to the exoplanet search.

3.4 Self-consistent description of mass transfer in interacting binary systems with degenerate accretors (CO WDs)

Supervisor: Luciano Piersanti (INAFOAAb)
Co-Supervisor: Marco Merafina (Sapienza)
Contact: luciano.piersanti@inaf.it - marco.merafina@roma1.infn.it
Abstract: CO WDs accreting matter from their companions in binary systems are the progenitors of many eruptive phenomena (Novae and He-novae), as well as of SNe Ia. Up to now the response of the accretor to mass deposition has been investigated by adopting constant mass transfer rate, but in real systems the latter changes during the evolution due to GW emission and variations in the stars masses. Recently, under simplified assumptions, few simulations have been performed by accounting for the evolution of both the interacting stars and the binary systems parameters. These studies demonstrated that the mass transfer history plays a pivotal role in determining the final outcome of binary systems. The proposed work will be carried out by using the FuNS evolutionary code, already used in the past to study mass transfer process on degenerate accretors. The code will be implemented to follow the evolution of both the two stars as well as that of the binary system parameters. The new version of the code will be employed initially to study the properties of AM CVn systems with a He-star donor with particular attention to the effects of rotation on the thermal properties of the CO WD.

3.5 Managing software development activity for large, complex scientific projects with the safe methodology. problems, optimization and future perspectives

Supervisor: Matteo Canzari (INAF-OAAb)
Co-Supervisor: Carlo Baffa (INAF-OA Arcetri), Amedeo Balbi (Tor Vergata)-TBD
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Abstract: Software development is playing an increasing role in astronomical research, spanning from data science to instrument control and artificial intelligence. Current astronomical large projects are characterized by a great complexity that reflects into the software to be developed. Efficient man-

agement appears therefore crucial to deliver a reliable product. The Agile approach, widely used in industry, is currently adopted in the Scaled Agile Framework (SAFe) for the development of the control software of the SKA Project. The application of SAFe to a science project represents a novelty and shows problems not fully investigated. The candidate will work in a "SAFe team" devoted to developing the SKA graphical user interfaces, training with the Agile/SAFe methodology and investigating its necessary criticalities and optimizations. The final aim will be the definition of a new dedicated framework for the software development of a scientific project, taking into account the peculiarities and the large values of the scientific environment.

3.6 Development of new vis/nir instrumentation for the electromagnetic follow-up on gw detections

Supervisor: Mauro Dolci (INAFOAAb)
Co-Supervisor: Fabio La Franca (Roma Tre), Gabriele Rodeghiero (INAF)
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Abstract: The thesis is oriented to the design and development of new visible and near infrared (NIR) instrumentation for multi-messenger astronomical facilities. INAF-Abruzzo, as a member of the GRAWITA collaboration, is developing new visible and infrared cameras for the AZT-24 telescope at the Campo Imperatore Observatory (L'Aquila, Italy) to follow up on the optical and NIR counterparts of gravitational wave detections. The candidate will have the unique opportunity to take part in this cutting-edge project by carrying out optical engineering, simulations, performance and verification analysis for this facility. The candidate shall be willing to work and travel frequently to the Campo Imperatore Observatory (2200 amsl).

3.7 Look up at the stars to understand the new physics

Supervisor: Oscar Straniero (INAFOAAb)
Co-Supervisor: Alessandro Mirizzi (Univ. Bari) - Cristina Pallanca (Univ. Bologna)
Contact: oscar.straniero@inaf.it
Abstract: Does the neutrino 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. Our team 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). 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).

3.8 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: Elisa Portaluri (INAF-OAAb)
Co-Supervisor: Roberto Ragazzoni (Univ. Padova) - Gianluca Di Rico (INAF-OAAb)
Contact: elisa.portaluri@inaf.it - roberto.ragazzoni@inaf.it - gianluca.dirico@inaf.it
Abstract: 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 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 foresee the development of laboratory test benches and the usage of dedicated hardware for real-time & cloud computing.

3.9 Design and development of visible and near infrared instrumentation for the calibration of advanced Adaptive Optics systems: the case of the Multi-conjugated Adaptive Optics RelaY (MAORY) for the European Extremely Large Telescope (ELT)

Supervisor: Gianluca Di Rico (INAF-OAAb)
Co-Supervisor: Marco De Petris (Sapienza) - Roberto Ragazzoni (Univ. Padova)
Contact: gianluca.dirico@inaf.it - marco.depetris@roma1.infn.it - roberto.ragazzoni@inaf.it
Abstract: The thesis will concern the development of optical and near infrared (NIR) instrumentation for the new generation of extremely large telescopes. INAF-Abruzzo, is in charge of the design and construction of the MAORY Calibration Unit for the ELT telescope, a highly complex and advanced subsystem that will allow to calibrate MAORY, the largest and challenging Adaptive Optics module currently under development, to be mounted on the 39m diameter European Extremely Large Telescope (ELT). 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 in preparation 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 MAORY international collaboration, a large multi-disciplinary team of engineers and scientists.

3.10 Characterisation of the counterparts of gravitational wave events by present and future GW interferometers through its gamma-rays and broadband emission

Supervisor: Antonio Stamerra (INAF-OAR)
Co-Supervisor: Pasquale Mazzotta (Tor Vergata)
Contact: antonio.stamerra@inaf.it - mazzotta@roma2.infn.it
Abstract: This PhD project aims at identifying and describing the gamma-ray emission at energies beyond few GeV associated to the gravitational wave (GW) counterparts. The immediate goal of the project is twofold: the estimation of the joint gamma-ray and GW emission rates, and the association of the electromagnetic (e.m.) emission in other wavelengths. The estimated gamma-GW rates will be carried on through the simulation of the expected signals from the present GW interferometers LIGO-VIRGO-KAGRA and the future Einstein Telescope (ET), and of the expected gamma-ray signal in the present and future Cherenkov telescopes, like the Cherenkov Telescope Array. The association of the multifrequency signal will be done through the development of a dedicated pipeline collecting and analyzing the data from different space- and ground-based observatories. The resulting broadband spectral energy distribution will be compared with the expected emission from GW counterparts, such as off-axis short-GRB from binary neutron star mergers, providing a characterisation and classification of the GW event and its associated e.m. emission. The PhD student will be part of the CTA collaboration and of the ET research unit at INAF. Institution where the PhD student is expected to carry out his/her research: Osservatorio Astronomico di Roma

3.11 Characterization of the actual performance of the ASTRI Mini-Array and study of very-high energy transient phenomena

Supervisor: Saverio Lombardi (INAF-OAR), Alessandro Carosi (INAF-OAR)
Co-Supervisor: @
Contact: saverio.lombardi@inaf.it - alessandro.carosi@inaf.it
Abstract: The goal of the project proposed for this thesis is twofold. First,

it aims to characterize the first real data collected by the ASTRI Mini-Array telescopes (a ground-based gamma-ray facility of nine 4-m class Imaging Atmospheric Cherenkov Telescopes under implementation at the "Observatorio del Teide" in Tenerife, Spain) and to assess the performance of the system in different array configuration and observational conditions. Second, it aims to explore the ASTRI Mini-Array capabilities to study transient phenomena - such as gamma-ray bursts (GRBs) and multi-messenger sources (gravitational waves and high-energy neutrinos) - at the TeV energy scale and to define efficient pointing strategies and criteria for alert follow-ups. The student shall develop dedicated software tools for both the data analysis and the handling of external alerts, with the aim of optimizing the fast pointing strategies and the transient follow-up observations in a multi-wavelength and multi-messenger context. Applications to other Cherenkov facilities, like MAGIC and CTA-LST, will also be possible.

3.12 Study of the gamma-ray and neutrino production in AGN and star-forming galaxies

Supervisor: Alessandra Lamastra (INAF-OAR)
Co-Supervisor: Silvia Celli (Sapienza)
Contact: alessandra.lamastra@inaf.it - silvia.celli@uniroma1.it
Abstract: Many star-forming galaxies and those hosting active galactic nuclei (AGN) show evidence of massive outflows of material in a variety of gas phases (ionized, neutral atomic, and molecular) and at different spatial scales. As the material is ejected from the core of the galaxies, interactions of accelerated particles with the interstellar medium and radiation field can produce high-energy gamma rays and neutrinos. For the XXXVIII cycle, we propose a PhD fellowship research program on the observational and theoretical studies on the non-thermal electromagnetic and neutrino emission in AGN and starburst galaxies. The PhD candidate will develop the theoretical framework related to the modeling of the gamma-ray and neutrino emission from AGN-driven and starburst-driven outflows. The PhD candidate will also make use of real data of astrophysical targets at very high energy, exploiting the synergies between the MAGIC and KM3NeT Cherenkov telescopes, in order to pursue a remarkable scientific program. Furthermore, detailed simulation-based studies for observations with next-generation Cherenkov telescopes (CTA, ASTRI-MA) will be performed for several astrophysical

targets in order to evaluate future prospects.

3.13 Time-Resolved UV and X-ry Spectroscopy of Quasar Relativistic Outflows and Gamma-Ray-Burst high-z Galaxy ISM, with our in-house Time-Evolving Photo-Ionization Device (TEPID)

Supervisor: Fabrizio Nicastro (INAF-OAR)
Co-Supervisor: Luigi Piro (INAF-IAPS)
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Abstract: Modelling single-epoch spectra of high-ionization Active-Galactic-Nuclei (AGNs) outflows with equilibrium photo-ionization models can only provide average estimates of the product between the gas density and its distance from the ionizing source. This hampers the estimate of outflow mass and thus energetic. Analogously, equilibrium photoionization models fail to model the transient spectra of X-ray Gamma-Ray-Burst afterglows, most likely due to the dramatic ionizing-flux variations following the explosion. Time-evolving photoionization models, instead, can efficiently break the density-distance degeneracy in AGN outflows, and possibly enable proper characterization of transient X-ray spectra following an explosive event. This program aims to use our time-evolving photoionization code TEPID to model both: (a) multi-epoch SDSS (Sloan Digital Sky Survey) spectra of moderate-z Quasars displaying high-ionization relativistic outflows (BALs), and (b) GRB X-ray afterglow spectra. This will enable unprecedented characterization of both the energetic of AGN outflows and their impact on the evolution of the host galaxy, and the gaseous environment of star-forming regions in high-z galaxies.

3.14 Unveiling red galaxies in the young Universe

Supervisor: Paola Santini (INAF-OAR)
Co-Supervisor: Raffaella Schneider (Sapienza)
Contact: raffaella.schneider@uniroma1.it
Abstract: The launch of the James Webb Space Telescope (JWST) opens unprecedented discovery space, thanks to its enormous gain in sensitivity, spatial resolution and spectral coverage compared to its predecessors. It will allow us to investigate the nature of elusive galaxy populations that are still

poorly understood. This project aims at using JWST data, as well as the ALMA (Atacama Large Millimeter Array) public archive, to characterize the two-fold nature of high redshift red galaxies: dust-obscured star-forming galaxies and passive galaxies. The former are vigorously forming stars, while the latter have ceased their star formation. These two challenging (and often misclassified) populations are commonly missed by current observations despite playing key roles in galaxy evolution. JWST will enable their accurate separation and a proper characterization of their physical properties and their role in galaxy evolution.

3.15 Galaxies at the cosmic frontier

Supervisor: Marco Castellano (INAF-OAR)
Co-Supervisor: Laura Pentericci (INAF-OAR)
Contact: marco.castellano@inaf.it - laura.pentericci@inaf.it
Abstract: The advent of JWST will soon allow us to perform a thorough exploration of the first billion years after the Big Bang and to individuate the first sources of light. The PhD student will have the opportunity to exploit newly acquired JWST spectroscopic and photometric data on extra-galactic legacy fields to constrain the physical and statistical properties of star-forming galaxy populations at the highest observable redshifts (z 7-15). He/she will exploit recently developed spectro-photometric fitting techniques to measure the properties of their stellar populations (intrinsic luminosity and SFR, mass, age, metallicity, ionizing efficiency) in order to ascertain their role in the reionization of the Universe and the presence of primordial (popIII) stellar populations.

3.16 Higher order statistics in weak lensing from the Euclid survey

Supervisor: Vincenzo Cardone (INAF-OAR)
Co-Supervisor: Roberto Maoli (Sapienza)
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Abstract: The unprecedented quality and quantity of Euclid weak lensing data opens up the road to a characterization 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 ñ 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 ñ like simulations. The work will be carried on within the Euclid High Order Statistics Work Package hence allowing the student to work in a highly formative environment.

3.17 Constraining cosmology with dark sirens and Euclid cross-correlation

Supervisor: Matteo Martinelli (INAF-OAR)
Co-Supervisor: Roberto Maoli (Sapienza)
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Abstract: 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.

3.18 Characterizing massive exoplanets and their host stars

Supervisor: Katia Biazzo (INAF), Simone Antoniucci (INAF-OAR)
Co-Supervisor: Luigi Mancini (Tor Vergata)
Contact: katia.biazzo@inaf.it - simone.antoniucci@inaf.it - lmancini@roma2.infn.it
Abstract: Understanding how planets form within the protoplanetary disk of their host star is one of the challenges of current astrophysical research. The formation of massive planets is particularly important, as they are believed to play a fundamental role in shaping the final configuration of the planetary system. We propose a thesis aimed at characterising young stars and their massive planets, which are still in formation within the protoplanetary disks. Host stars will be characterised in terms of atmospheric parameters and chemical abundances through optical/near-infrared high-resolution spectra acquired with the GIARPS facility at the Telescopio Nazionale Galileo (Spain) or with other facilities (PEPSI at the Large Binocular Telescope, LBT, and HARPS at the European Southern Observatory). Exoplanets will be searched and characterised through direct imaging with SHARK-VIS, the new high-contrast imager of the LBT (Arizona) built at the INAF-OARoma. The PhD student will carry out the work at the INAF-OARoma and at the Tor Vergata University. He/She will be also involved in future ground-based spectroscopic/photometric observations and projects from space missions (e.g. JWST, Ariel).

3.19 Stellar populations across the Sagittarius dwarf spheroidal galaxy and the Galactic bulge

Supervisor: Manuela Zoccali (Chile)
Co-Supervisor: Michele Fabrizio (INAF-OAR)
Contact: mzoccali@astro.puc.cl - michele.fabrizio@inaf.it
Abstract: This PhD project is focussed on the multiband analysis of stellar populations in the Sagittarius dwarf spheroidal galaxy an in the Galactic Bulge by using astrometric, photometric and spectroscopic data released by Gaia DR3. The key idea is to use homogeneous and accurate proper motion measurements to separate field and Sagittarius stars. Radial velocity data provided by Gaia will be complemented with proprietary low- and medium resolution spectra we plan to collect with the Enhanced Resolution Imager

and Spectrograph (ERIS) assisted by the Adaptive Optics Facility (AOF) at the Very Large Telescope (ESO). Furthermore, we also plan to fully characterise Sagittarius RR Lyrae variables, already detected by OGLE, by using near-infrared photometry collected by the public survey VVV-X. The student will spend her/his scientific activity at the INAF – Rome Astronomical Observatory and at the Pontificia Universidad Católica de Chile. The double affiliation will allow the student to apply for reserved observing time to the telescopes available in Chile.

3.20 Deep into the crowding of the Galactic Center

Supervisor: Giuliana Fiorentino (INAF-OAR), Elena Valenti (ESO)
Co-Supervisor: Giuseppe Bono (Tor Vergata)
Contact: giuliana.fiorentino@inaf.it - evalenti@eso.org - giuseppe.bono@uniroma2.it
Abstract: This project is focused on the analysis of old stellar populations across the Galactic center. Recent photometric and spectroscopicinvestigations across the nuclear stellar disk have been limited to bright stellar tracers (red giants, supergiants, O and B-type stars). Only recently, Contreras-Ramos et al. 2018 succeeded in the identification of a few RR Lyrae located within a few arcmin from the Galactic center. However, we still lack accurate and deep near-infrared (NIR)/mid-infrared (MIR) color-magnitude diagrams approaching the turn off of the old stellar population. To accomplish this goal we plan to take advantage of the Enhanced Resolution Imager and Spectrograph (ERIS). This unique instrument is Adaptive Optics assisted and it will allow us to collect NIR/MIR (J,H,K,[3.6]) images with exquisite spatial resolution. The observing and reduction strategy will provide accurate and deep photometry across Sgr-A* to identify RR Lyrae. Moreover, we also plan to use the integral field spectrograph to collect medium resolution NIR spectra to estimate the metallicity of evolved old, low mass stars. This means the unique opportunity to investigate, for the first time, the 3D structure of the innermost galaxy regions and its interaction with the central black hole at the early epoch of bulge formation. The student will spend her/his research activity at the INAF Rome Astronomical Observatory.

3.21 The present Solar System: a reservoir of prebiotic material

Supervisor: Elisabetta Dotto (INAF-OAR), Elena Mazzotta Epifani (INAF-OAR), Davide Perna (INAF-OAR)
Co-Supervisor: Amedeo Balbi (Tor Vergata)
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Abstract: The population of small bodies of the Solar System is considered responsible for the release of the organic material and of the onset of life on Earth. Pristine material, almost unprocessed, is still observable nowadays: it is contained in the primitive comets, Trans-Neptunian Objects, Centaurs, Trojans, asteroids, and Near-Earth Objects. The study of these bodies is crucial for their astrobiological value. The proposed research consists in the physical characterisation of the most primitive small bodies in our Solar System, mainly by means of: i) spectroscopic investigation in the visible and near-infrared range, to constrain the composition, and ii) statistical analyses to retrieve the global properties of the populations. Data obtained with large on-ground telescopes and with space missions (e.g. OSIRIS-REx, Hayabusa 2, DART/LICIACube) will be compared with numerical simulations and laboratory spectra of meteorites and analogue minerals, in order to model composition and structure of targets and investigate the presence of molecules important for life.

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

Supervisor: Maria Pia Di Mauro (INAF-IAPS)
Co-Supervisor: Luca Giovannelli (Tor Vergata)
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Abstract: The extreme efficiency of asteroseismology in supporting the exoplanetary program has been demonstrated by several recent successful space programs (Kepler and TESS). The aim of this thesis is to go beyond these results and to combine asteroseismic methods with photospheric and chromospheric activity analyses to characterize, not only the main stellar and planetary parameters such as the dimensions, the density, and the age, but also to study how the internal rotation and the magnetic activity of a star

evolve with age and with the changes of the internal structure. This study will be of cornerstone importance to connect the historical dataset of stellar activity (Mount Wilson) with big data on millions of stars provided by Gaia and Vera Rubin observatories. In fact, magnetic fields are key actors in the evolution of all stellar objects, through their ability to influence the angular momentum evolution and the mass-loss of star. In particular, the knowledge of how a magnetic dynamo fueled by internal rotation might produce structured magnetic cycles will allow us to reconstruct the history of magnetic interaction between a star and its hosted planet.

3.23 Lunar Laser Ranging (LLR) Science: The Moon as a proof-mass to test Gravitational Physics and Selenophysics

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Abstract: LLR has been, and still is, a powerful tool for testing gravitational physics and lunar science since 1969 with NASA's Apollo 11 mission. The retroreflector arrays installed on the Moon have allowed to obtain a series of significant measurements on the gravitational interaction and a first insight on the internal structure of the Moon. The technological developments of the terrestrial segment of the last years, in terms of laser systems and time measurements, have reached a point where further progress in the precision of the measurement of the Earth-Moon distance and, consequently, in the verification of the gravitational interaction, are limited by the various errors associated with current retroreflectors arrays. Next missions to the Moon are expected to locate on our satellite a new generation of single laser retroreflectors and transponders that will act as active laser ranging systems. This will allow a significant improvement in the precision of laser measurements and in the final accuracy of the physical quantities object of the investigations. These improvements will be more significant if further development of the dynamic model of the Moon's motion is provided. The thesis aims to investigate firstly whether the current models are compliant to guarantee the declared improvement in the literature by a factor of 10 in the accuracy of the Earth-Moon distance, i.e. from the current cm level to the mm one, with the intended use of next generation retroreflectors. A second goal is to

understand which models should be further improved to take a step up from the mm level in accuracy.

3.24 Characterization of terrestrial analogues in the Visible and Near-Infrared for the study of martian surface materials

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Abstract: The study of Mars benefits from large amounts of orbital and landed robotic mission data. In particular, spectroscopic investigations in the visible and in the near-infrared, where surface materials show several diagnostic absorption bands, are crucial to infer the Red Planet composition and thus understand how minerals formed and evolved. Libraries of mineral spectra of astro-materials are an important reference for characterizing martian surface composition and offer a unique opportunity to maximize the scientific understanding of the huge amount of information which is being made available from space missions in this decade and in the next one.

3.25 Unveiling the origin of radio emission in radio-quiet AGN

Supervisor: Francesca Panessa (INAF-IAPS), G. Bruni (INAF-IAPS)
Co-Supervisor: @
Contact: @
Abstract: The problem of how accretion and ejection phenomena are related to each other in AGN has been one of the hot topics of extragalactic astrophysics since the first discoveries of active galaxies and it has been probed to be crucial in order to build more physically-motivated AGN-host galaxy evolutionary models. We propose a PhD thesis project to perform an investigation on AGN activity taking advantage of new proprietary data, in particular of one radio large program that we recently obtained at the European VLBI Network. This PhD project aims at probing the physical radiation mechanisms in the vicinity of the supermassive black holes in moderately luminous Active Galactic Nuclei. New radio data acquired from the SKA pathfind-

ers and precursors (e.g, LOFAR, MeerKAT, ASKAP, etc.) will complement the radio information at different frequencies, sensitivities and spatial scales. Eventually, a multi-frequency analysis of data at optical and X-rays will lead to a comprehensive study of the accretion/ejection phenomenon.

3.26 Gamma-ray astronomy and the search of lost Pevatrons

Supervisor: Martina Cardillo (INAF-IAPS)
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Abstract: G-ray astronomy plays a fundamental role in the Cosmic Ray (CR) origin understanding, one of the most debated issues in High-Energy Astrophysics (HEA). Indeed, this will be one of the main topic of future Cherenkov Telescopes like ASTRI Mini-Array and CTA. Both relativistic protons and electrons can emit g-rays with different processes but only the detection of hadronic g-ray emission can probe CR acceleration. Distinguishing leptonic and hadronic components is a tricky issue in HEA; in principle, only a g-ray detection at about 100 TeV would be a direct proof of the hadronic origin of the emission. However, collected data asked new questions. E.g., LHAASO observed unexptected PeV emission from Pulsars Wind Nebula while we didn't see yet the expected one from Supernova Remnants. Through literature study, develop (python language) and manage theoretical models, constant comparison with present and future HE data, g-ray data interpretation and analysis, the student will carry on a parallel study of different candidates "pevatrons" to understand why accelerated particle presence translates into different spectral features.

3.27 Investigations of the Large-Scale Structure of the Universe as traced by radio galaxies

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Abstract: Extragalactic radio sources (both Active Galactic Nuclei and star-forming galaxies) constitute an extremely interesting mix of populations, not only because of their intrinsic value, but also for their fundamental role

in shaping our Universe the way we see it today. Furthermore, thanks to the possibility of being observed up to very high redshifts, they can also provide crucial information on both the star-formation history of our Universe and on its Large-Scale Structure (LSS) properties and their evolution with time. The proposed PhD project aims at investigating the LSS as traced by galaxies observed in a radio frequency range only very poorly probed before. Indeed, results from this analysis will be amongst the first ones to be obtained by the astronomical community. The proposed work will make use of proprietary data from one of the deepest surveys performed with the LOFAR (LOw Frequency ARray) instrument. The results will then be matched to the available theoretical models in order to provide a comprehensive picture that spans from the early universe up to the current epoch.

3.28 Characterization of aerosols in the Jupiter's troposphere from NASA/Juno's infrared spectral data

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Abstract: The upper troposphere of Jupiter hosts a variety of cloud types, ultimately caused by the condensation of minor gaseous components of the atmosphere (such as ammonia, water and hydrogen sulphide) or by-products of photochemical reactions. These aerosols have been characterized by past studies on the basis of a large number of ground-based or space-based telescopic observations, ranging from UV to mid-infrared. However, the large body of high spatial resolution data being currently collected by the JIRAM-Juno instrument (a spectro-imager operating between 2 and 5 ?m) further demonstrated the large variety of cloud structures (in terms of opacities, shapes, etc) as well as their spatial variability down to very small scales (few kilometers). Moving from the preliminary analysis presented in Grassi et al. 2021, this work aims to: • refine the study adopting more advanced algorithms for the treatment of multiple scattering in the solar region, • improve the cloud modelling, with a specific focus on assumed aerosol scattering properties (to be ultimately derived from shape, size distribution and composition hypothesis) • implement a self-consisten analysis covering simultaneously the solar (2-3.2 ?m) as well as the thermal region (3.5-5 ?m) • integrate information offered by limb-darkening curves derived from JIRAM IR images The

study will explore also the further information content on aerosol properties offered by extension of spectral range between 0.5 and 5.5 ?m, as expected from the measurements of the forthcoming MAJIS-JUICE instrument.

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

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Abstract: 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 2023, 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, University of Udine and University of Cagliari, has developed the modular X/gamma-ray monitor to be integrated on-board 3U CubeSat spacecrafts. The successful PhD candidate will join the HERMES team during the instrument integration and on-ground calibration activities. After the launch of the HERMES constellation in mid-2023, 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.

3.30 Atmospheric tracers of exoplanet formation

Supervisor: Sergio Molinari (INAF-IAPS)
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Abstract: The incoming data from the James Webb Space Telescope will mark the beginning of the era of exoplanet characterization. The exoplane-

tary compositions we will soon be able to unveil will 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 formation and composition of planets. 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 to produce realistic atmospheric compositions and their associated synthetic spectra, whose analysis will allow to identify their most diagnostic features.

3.31 Dynamical complexity in space plasmas

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Abstract: Heliospheric and near-Earth space plasmas are characterized by a complex dynamics that manifests itself through the turbulent features, scale invariant fluctuations over a wide range of scales and multiscale processes. The understanding of this inherent complexity, which is fundamental to correctly model transport processes and the interaction between different plasma regions, is still incomplete. For instance, the solar wind turbulent nature at the sub-ion scales is still not understood. The aim of this thesis work is to investigate the dynamical features of the magnetic field and plasma parameters from MHD scales to sub-ion ones in the heliosphere using data from some recent interplanetary space missions, such as NASA-MMS, NASA-Parker Solar Probe, ESA-Solar Orbiter, ESA-Cluster mission, etc.

3.32 Impact of solar activity in the near-Earth plasma environment and Space Weather

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Abstract: The solar activity is well known to have a significant impact on the geospace. This impact causes different phenomena, as particle precipitation, magnetospheric substorms and magnetic storms. These phenomena can have a very relevant effect on the anthropic and technological systems, causing, for instance, problems on the radio communications, GPS systems and power distribution networks. Although great advances have been done in the comprehension of the general macro scale scenario of the interaction between the interplanetary disturbances, due to the solar activity, and the geospace plasma environment, several phenomena occurring at mesoscales and microscale are still not fully understood. The work proposed in this thesis consists in studying the small-scale dynamics of geospace plasmas in the high-latitude regions and the short-timescale dynamics of the magnetosphere-ionosphere system in response to changes of the interplanetary conditions. The proposed work will require to analyze data from both interplanetary, magnetospheric and ionospheric space missions (e.g., NASA-Themis, ESA-Cluster, ESA-Swarm, etc.), and ground-based measurements from magnetic observatories and Super-DARN.

3.33 Analysis of cometary and asteroidal dust in view of future space missions

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Abstract: Dust is the smallest building block of our Solar System and encodes its history and evolution and has been extensively studied especially in the last years, thanks to space missions to asteroids and comets. Other missions will be launched in the next years, i.e., ESA/Hera (to an asteroid), ESA/Comet Interceptor (to a primitive comet), CNSA/ZhengHe (asteroid+comet). The PhD candidate will deal with scientific issues concerning asteroidal and cometary dust. On one side, he/she will analyse data from past and ongoing missions (e.g., Rosetta) to investigate unresolved key-questions about dust properties (e.g., how does its composition varies temporally on comets? How are dust and ice activity related? How do dust properties change with depth?): this will give the student an opportunity to interact with the planetary science international community. On the other side, he/she will collaborate to the development of instruments (e.g., dust

detectors) that will be on board the three space missions listed above, basing on scientific requirements identified, giving him/her the opportunity to actively participate in the phases preceding the launch of an international space mission.