PhD program in
Astronomy, Astrophysics and Space Science
XXXVII cycle

Available theses @ Tor Vergata, Sapienza, INAF

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1 University of Rome Tor Vergata

1.1 Planetary habitability in the galactic context

Supervisors: Amedeo Balbi (Tor Vergata University)
Contact: balbi@roma2.infn.it
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.

1.2 Physical Properties of Transiting Planetary Systems

Supervisors: Luigi Mancini (Tor Vergata University); Co-Supervisor: Alessandro Sozzetti (Turin Astrophysical Observatory)
Contact: lmancini@roma2.infn.it
Abstract: he detection of extrasolar planets and their subsequent characterization are among the most exciting elds of modern astrophysics. Observations of the astonishing diversity of a) internal structures of both small and giant exoplanets, b) properties of their atmospheres and c) global architectures of planetary systems continuously challenge our knowledge of planet formation, evolution, and interiors. By using instruments and telescopes like TESS, LBT, HARPS-N, ESPRESSO, 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.

1.3 Observing gaseous exoplanets in formation around young stars

Supervisors: Luigi Mancini (Tor Vergata University), Katia Biazzo, Simone Antoniucci (INAF-OAR)
Contact: lmancini@roma2.infn.it, katia.biazzo@inaf.it, simone.antoniucci@inaf.it
Abstract: One of the most exciting topics at the forefront of 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 are believed to 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 that will be acquired with SHARKVIS, the new high-contrast imager of the Large Binocular Telescope (Arizona), built at the INAF-Osservatorio Astronomico di Roma. SHARK-VIS images will be employed to search and characterise gaseous exoplanets still in accretion phase, while complementary high-dispersion optical and near-infrared spectra of the hosting star, already acquired with the GIARPS spectrograph at the Telescopio Nazionale Galileo (Spain) in a parallel programme, will be analysed to characterise the parent star. The PhD student will carry out his/her work at the Tor Vergata University and INAF-OAR. The student will also be actively involved in the observations at LBT with the SHARK team.

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

Supervisors: Pasquale Mazzotta, Hervé Bourdin (Tor Vergata university)
Contact: mazzotta@roma2.infnf.it, herve.bourdin@roma2.infn.it
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 cosmological probes as their growth and evolution depends on the underlying cosmology (through initial conditions, cosmic expansion rate and dark matter properties). Clusters form at the nodes of the Cosmic Web, constantly growing through accretion of matter along filaments and via occasional mergers. Part of the gravitational energy dissipated during their grow is channeled, via shocks and turbulent motions, into the amplification of magnetic fields and acceleration of relativistic particles. These non-thermal components manifest themselves as diffuse cluster-scale radio emission. Clusters are thus excellent laboratories for probing the physics of the gravitational collapse of dark matter and baryons, as well as for studying the non-gravitational physics that affects their baryonic component. 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.

1.5 Millimetre observations of galaxy clusters

Supervisors: Hervé Bourdin, Pasquale Mazzotta (Tor Vergata University)
Contact: herve.bourdin@roma2.infn.it, mazzotta@roma2.infn.it)
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 ($z > 1$).

1.6 Advanced X-ray modeling of quasar winds

Supervisors: Francesco Tombesi (Tor Vergata University); Co-Supervisors: Dr. Enrico Piconcelli, Dr. Fabrizio Nicastro, Dr. Alfredo Luminari (INAF)
Contact: francesco.tombesi@roma2.infn.it
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 novel wind model called "Winds in the Ionized Nuclear Environment" (WINE). In this thesis project we will perform an extensive X-ray spectral analysis of powerful outflows in a large database of AGNs with WINE. 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. Moreover, this work will also represent a fundamental stepping stone in preparation for the next generation XRISM (to be launched in 2022) and Athena space observatories.

1.7 Illuminating the Universe with the Cosmic Microwave Background

Supervisors: Marina Migliaccio (Tor Vergata University)
Contact: migliaccio@roma2.infn.it
Abstract: The cosmology group at Tor Vergata is actively involved in planning future observational campaigns targeting cosmic microwave background (CMB) polarization and, in particular, the JAXA-LiteBIRD space mission. We also participate in the soon to be launched ESA Euclid survey, which will

map the position, redshift and shape of billions of galaxies. In this context, the thesis project will aim at identifying novel ways to address open questions in cosmology with future CMB data in combination with complementary observables. Two fundamental aspects will be investigated: a) Study of cosmic reionization, the epoch at which the first sources formed. This will require developing novel techniques to reconstruct the universe ionization history. b) Constraining the nature of the dark sector, i.e. dark energy and dark matter, by exploiting the correlations between CMB observables (temperature, polarization, lensing) and data from galaxy surveys. These diverse probes provide a large lever-arm of cosmic epochs, from recombination to structure formation across the entire past light cone, and the candidate will acquire high-level skills in both CMB and large-scale structure theory and data-analysis.

1.8 Unveiling the accretion mechanisms of pulsating ultraluminous X-ray sources

Supervisors: GianLuca Israel (INAF); Co-Supervisor: Francesco Tombesi (Tor Vergata University)
Contact: gianluca.israel@inaf.it
Abstract: The discovery of ultraluminous X-ray sources (ULXs) hosting X-ray pulsars with luminosity well in excess of the Eddington one has changed our understanding of ULX as a class and has posed new questions on standard accretion theory. The thesis will comprise two different approaches: searching for new members of this elusive class, and studying the pulsating ULX (PULX) in M51 with an unprecedented detail. The search for new PULXs will rely upon algorithms which increase the sensitivity to pulsations by removing the effects of the strong pulse period derivative characteristic of these systems and the Doppler effect due to the orbital motion. The use of proprietary (accepted Large Program) and archival XMM datasets of M51 ULX-7 will allow us to measure the orbital period derivative in order to prove whether PULXs do emit radiation at super-Eddington rates as a result of a very strong magnetic fields or are instead beamed-emitters with sub-Eddington luminosity, a long standing open problem in the field. The student is expected to work on the detection algorithms, on the development of pipelines, on the physics of super-Eddington accretion, and on the orbital period decay models.

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

Supervisors: Giancarlo De Gasperis (Tor Vergata University); Co-Supervisor: J.P. Bernard (IRAP, Toulouse)
Contact: giancarlo.degasperis@roma2.infn.it
Abstract: PILOT (Polarized Instrument for the Long-wavelength Observations of the Tenuous ISM: see also *http://pilot.irap.omp.eu*) is a a balloon-borne astronomy experiment to study the polarization 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) galaxy at a resolution of $\simeq 2'$;
- 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, and preliminary flight analysis and data cleaning is ongoing (see *https://www.irap.omp.eu/en/success-of-the-3rd-flight-of-the-pilot-stratospheric-balloon-experiment/*).
Preliminary results are in *https://arxiv.org/abs/1901.06196* and in Mangilli A., et al., 2019, A&A, 630, A74.
The thesis work aims at understanding and characterising the instrumental properties and the dataset of the flights of PILOT and the analysis for the third flight, with a strong focus 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.

1.10 The early chemical enrichment of the Galactic Bulge using old stellar tracers

Supervisors: Manuela Zoccali (Universidad Catolica de Chile); Co-Supervisor: Giuseppe Bono (Tor Vergata University)

Contact: mzoccali@astro.puc.cl
Abstract: This PhD project is focussed on the use of old, low-mass primary distance indicators (RR Lyrae, Type II Cepheids) to constrain the metallicity distribution (alpha, iron peak neutron capture elements), kinematics and radial metallicity gradients. The project is based both on both low- and high-resolution spectra already collected with 4-8m class telescopes. Moreover, we also plan to provide accurate estimate of the barycentric velocity by using radial velocity templates for both metallic and Balmer lines already developed by our group. The project might also include the analysis of high-resolution NIR spectra, collected with WINERED at NTT (ESO).

1.11 Cosmic distance scale: from primary to secondary distance indicators

Supervisors: Giusepe Bono (Tor Vergata University)
Contact: bono@roma2.infn.it
Abstract: We are facing a stark discrepancy between the estimate of the Hubble constant based on the CMB (Planck collaboration) and on primary (Classical Cepheids) plus secondary (SN Type Ia) distance indicators. The current determinations indicate a difference at the 3 sigma level. The idea is to attack the problem fully exploiting novel distance determinations based either on Gaia or on theoretical Period-Luminosity relations. Moreover, it is also planned to follow a different path by using old distance indicators (RR Lyrae, Tip of the Red Giant Branch) to constrain possible systematics affecting the Cepheid distance scale. The project might also include the analysis of NIR time series images collected with a broad range of 4-8m class telescope of nearby stellar systems (globulars, dwarf galaxies).

1.12 Improving detection capabilities of coalescing compact binary systems in the next generation interferometric gravitational wave detector Einstein Telescope

Supervisors: Viviana Fafone (Tor Vergata University); Co-Superivos: Alessio Rocchi (INFN)
Contact: viviana.fafone@roma2.infn.it
Abstract: Future GW astronomy will rely on the detection capabilities of

next generation interferometers in the low-mid frequency range (Hz-hundreds Hz). Einstein Telescope (ET) is the pioneer project for the next generation GW observatory, which will allow us for the first time to explore the Universe along its cosmic history back to the cosmological dark ages. The sensitivity for detection of NS and BH coalescing binary systems will be limited by the performances of its optical systems. In particular, ET observational capabilities will be strongly affected by thermal noise and optical aberrations. The aim of this project is to optimize the ET sensitivity in the low-mid frequency band through developments of new techniques for thermal noise reduction and/or adaptive optics. The thesis will be carried on within the Einstein Telescope Tor Vergata group, responsible for the development of the adaptive optical system and member of the international thermal noise R&D collaboration

1.13 Fostering multimessenger techniques in the Einstein Telescope era

Supervisors: Viviana Fafone (Tor Vergata University)
Contact: viviana.fafone@roma2.infn.it
Abstract: Gravitational-wave (GW) observations have recently started a new exploration of the Universe. Einstein Telescope (ET) is being proposed as the European project for third generation GW interferometers. ET will be an unprecedented resource to address open questions of fundamental physics and cosmology. It will probe the physics near the black-hole horizon, help understanding the nature of dark energy and possible modifications of general relativity at cosmological scales. The ET sensitivity and wide frequency band will make it possible to access the entire population of stellar and intermediate mass BH (up to 10^3 Mo) back to the early Universe. ET will operate in synergy with a new generation of innovative electromagnetic (EM) observatories. This project will focus on GW- very high energy GRBs joint observations, with the aim of developing tools to evaluate the prospects for future detections on the basis of the current EM instrument capabilities and to study joint GW-EM detection rates for threshold and sub-threshold events. The thesis will be carried on within the Einstein Telescope Tor Vergata group, in collaboration with EM partners.

1.14 The solar activity and Sun-Earth System

Supervisors: Francesco Berrilli (Tor Vergata University)
Contact: francesco.berrilli@roma2.infn.it
Abstract: The Sun is an active star on time scales ranging from evolutionary time scales to the rapid fluctuations associated with the evolution of convective and magnetic structures on its surface. Solar activity can be studied by means of measurements from space, relating to the last solar cycles, from ground based instruments or through historical reconstructions by means of isotopes such as Be10 or C14. The study of solar activity and the response of the circum-terrestrial (Space Weather) or terrestrial (upper atmosphere, troposphere, etc.) environment allows a better understanding of the complex Sun-Earth system. The development of the thesis will be based on the application to Solar Activity Models the most recent data concerning the variations of the solar potential obtained from geophysical data of isotopic abundances and from recent observations with the major ground-based telescopes or in space. In the case of specific interest, an experimental work related to instrumentation for the measurement of solar activity both from ground-based and from space (for example on CubeSat satellites) instruments is also possible.

1.15 The Sun: Magnetic Field and the Turbulent Convection

Supervisors: Dario Del Moro, Luca Giovannelli (Tor Vergata University)
Contact: dario.delmoro@roma2.infn.it, luca.giovannelli@roma2.infn.it
Abstract: Many key topics of the Sun do not yet have a definitive explanation, such as the generation of the Sun's magnetic field, the superhot corona, the differential rotation shape, the origin of the solar wind, and the causes of the magnetic eruptions and of the solar flares. Important steps ahead have been obtained in the latest years through the analysis of spectropolarimetric datasets at high spatial and spectral resolutions, more are expected in the next years, with the upcoming new generation of Solar Telescopes. This project is centred on the studies of the magnetic coupling between the deep photosphere and upper chromosphere and aims at the formation of a young researcher in Solar Physics, capable of using and developing new instrumentation and diagnostics of the thermal, dynamic and magnetic properties of the solar plasma over many scale heights, by using multiple wavelength imaging,

spectroscopy and spectropolarimetry.

1.16 Extreme Space Weather Events: Advances in Understanding and Forecasting

Supervisors: Dario Del Moro (Tor Vergata University), M. Laurenza
Contact: dario.delmoro@roma2.infn.it
Abstract: The dynamics of the Sun is the driver of a wide number of processes that take place in the heliosphere and that affect the planetary bodies and their environments. The study of such processes and how the solar-driven disturbances interact with the planetary magnetospheres, ionospheres and atmospheres, has become one of the main scientific topics all over the world, which is generally addressed with the term "Space Weather". This project is devoted to analyse and model solar-driven disturbances for a deeper understanding of the underlying physical mechanisms and prediction of the arrival in the interplanetary and planetary environments. These analyses may also be employed to forecast and now-cast the possible impacts on technological systems and humans in space. The challenge is to fully exploit data from the recently launched missions such as Parker Solar Probe, Solar Orbiter and BepiColombo, equipped with unprecedented sensitive instrumentation at new suitable vantage points in the inner heliosphere. This can be achieved by applying state-of-the-art data assimilation techniques to the new, extensive datasets, and by updating and developing models that reproduce the complexity, turbulence and dynamics of the solar wind and interplanetary perturbations and their role in the acceleration of energetic particles.

1.17 Imaging Spectropolarimetric Instruments for Solar Physics

Supervisors: Luca Giovannelli
Contact: luca.giovannelli@roma2.infn.it
Abstract: Multi-heights datasets of plasma velocities and vector magnetic field are pivotal to understand the complex magnetic nature of the solar atmosphere and the source of space weather events. For this reason, several projects in progress involves the development of Imaging Spectropolarimeters working at different wavelength range and spatial scales. The Tunable Imager Spectropolarimeters (TIS) for the European Solar Telescope (EST)

is a foreseen focal plane instrument for the future 4-m class solar telescope that will investigate the finest spatial scales in the solar atmosphere (30 km). TIS is based on Fabry Pérot etalons, that will allow for a spectral resolution as high as 120 000. The development of large aperture etalons is a technological challenge that will be exploited in collaboration with private companies. The Tor Vergata Synoptic Solar Telescope (TSST) is a full disk telescope in assembly phase based on magneto optical filter, that will produce full disk magnetograms and dopplergrams. Validation of the TSST at Tor Vergata is required before the deployment at Canary Islands. Part of the thesis work include analysis of already available spectropolarimetric datasets.

2 Sapienza Universtity of Rome

2.1 Search for the origin of the cosmic neutrino flux with ANTARES and KM3NeT

Supervisors: Silvia Celli (Sapienza University); Co-Supervisor: Irene Di Palma (Sapienza University)
Contact: Silvia.Celli@uniroma1.it; Antonio.Capone@uniroma1.it
Abstract: The origin of the diffuse astrophysical neutrino flux remains so far elusive. While both Galactic and extragalactic accelerators are likely to contribute to it, it is important to recall that both accelerator and target is needed for neutrino production. Such a target might be in the form of dense radiation ($p\gamma$ interactions) or matter (pp collisions) fields. The former scenario is expected to be realized e.g. in Gamma-Ray Bursts (GRBs), promising candidates to search for neutrino emissions because of their transient nature. The latter scenario is likely taking place in the Plane of the Milky Way, where SuperNova Remnants (SNRs) are surrounded by dense molecular clouds, which provide ideal conditions for neutrino emissions. The PhD activity is linked to the search for the sources of the neutrino flux, by exploring one of the suggested scenarios and investigating possible spatial and temporal correlations between high-energy neutrino telescope data (ANTARES and KM3NeT) and multi-messenger/multi-wavelength catalogs of sources (GRBs, SNRs/clouds). Observation of neutrino events coincident with a source population would allow to establish the connection between neutrinos and cosmic rays.

2.2 Multi-messenger search for core collapse supernovae with ANTARES and KM3NeT

Supervisors: Irene Di Palma (Sapienza University)
Contact: Irene.DiPalma@uniroma1.it
Abstract: Core collapse supernovae (CCSN) are among the most energetic explosions in the modern Universe and one of the long-standing riddles of stellar astrophysics. According to the standard paradigm, the energy transfer by the intense neutrino flux can be the decisive agents for powering the supernova outburst. We expect the next generation of neutrino telescopes (KM3NeT, Icecube-Gen2, HyperKamiokande) to be able to discriminate the CCSN signal from the noise with high accuracy. The collapse of the iron core

of a massive star is expected to produce also gravitational waves in addition to neutrinos. While neutrinos carry information about the mode amplitude in the outer region of the core, gravitational waves probe deeper in. To enhance the detection efficiency of CCSN signals it is necessary to consider a multi-messenger method that takes advantage of the information coming from both the neutrino and gravitational wave signal from detectors like Advanced LIGO, Advanced Virgo and KAGRA. This is a unique opportunity to develop strategies and create techniques for locating the sources on the sky, extracting their signals from noisy data, and fitting them to simulations and theoretical models.

2.3 LSPE-SWIPE instrumentation and data acquisition development

Supervisors: Francesco Piacentini (Sapienza University)
Contact: francesco.piacentini@uniroma1.it
Abstract: LSPE-SWIPE is a balloon-based telescope for the measurement of the CMB polarisation at large angular scales. Accurate measurement of the CMB polarization allows to measure the presence of gravitational waves at the recombination epoch, thus measuring the inflation mechanism in the early Universe. Polarization measurements in the microwave band also allow to constrain the re-ionization history of the Universe, related 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. The participant will work within the LSPE collaboration, participating to the final development of the instrumentation, and in particular to the software of the data acquisition system. He/she will participate to the integration, calibration, and operation campaign. The activity will be completed by analysis of the retried data, consisting in producing maps of the CMB polarization and extractive the cosmological information encoded.

2.4 Preparation of the LiteBIRD space mission for CMB polarization: data analysis and systematic effects

Supervisors: Francesco Piacentini (Sapienza University)
Contact: francesco.piacentini@uniroma1.it

Abstract: Accurate measurement of the CMB polarization allows to measure the presence of gravitational waves at the recombination epoch, thus measuring the inflation mechanism in the early Universe. Polarization measurements in the microwave band also allow 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 US and EU countries. The applicant will contribute to preparation of the mission, in particular by 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 link and contacts worldwide.

2.5 Polarimetric measurements of the Cosmic Microwave Background: looking for signals from the very early universe

Supervisors: Paolo de Bernardis (Sapienza University)
Contact: paolo.debernardis@roma1.infn.it
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. 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 PhD thesis will focus on the development and calibration of the polarimeter and of 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 the 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. See also *http://lspe.roma1.infn.it* and *http://litebird.jp/eng/* .

2.6 The Large-Scale Polarization Explorer: attitude control system implementation, calibration, and flight-data analysis

Supervisors: Paolo de Bernardis (Sapienza University)
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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 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. The polarimeter will fly on a stratospheric balloon during the polar night, and will spin in azimuth, at a limited set of fixed elevations, to cover a large fraction of the sky. The attitude control system (ACS) is composed of an azimuth pivot and a linear actuator for elevation chenges. Pointing reconstruction is based on GPS, fast star sensors, and laser gyroscopes. The thesis work will start from the setup of the star sensors, the development of their readout system, the interface towards the flight control computer. Will then plan and perform the ACS system calibration and validation during the launch campaign, and contribute to the data analysis, leading the pointing reconstruction effort, an extremely important step of the process. This will also involve the analysis of pointing-related systematic effects, propagating all the way to cosmological parameters estimates. See also *http://lspe.roma1.infn.it* .

2.7 High angular resolution Sunyaev Zel'dovich effect study of galaxy clusters and cosmic web

Supervisors: Elia Battistelli (Sapienza University); Co-Supervisor: Luigi Piro (INAF)

Contact: elia.battistelli@roma1.infn.it

Abstract: The Cosmic Web and filaments between clusters are a clear prediction of the process of hierarchical formation via continuous accretion and have the potential to unveil the open question of Baryonic Dark Matter. This can be probed observationally using the interaction of hot electrons in the predicted filaments with the CMB photons: the Sunyaev Zel'dovich (SZ) effect. The same effect can be used to study Galaxy Clusters and their astrophysics through high angular resolution observation. 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 and GBT/21B-101, PI: Battistelli) with the goal to unveil the nature of the cosmic web. 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.

2.8 Extragalactic study of Anomalous Microwave Emission: observations and data analysis

Supervisors: Elia Battistelli (Sapienza University)
Contact: elia.battistelli@roma1.infn.it

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. 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.

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

Supervisors: Alessandro Paiella (Sapienza University)
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Abstract: Kinetic Inductance Detectors 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 radiation. The thesis work will concern the design, the optimization and the characterization, through laboratory measurements, of the detector arrays of CMB experiments such as MISTRAL, COSMO, premiale ASI and OLIMPO-2. MISTRAL is a cryogenic camera which will be installed at the Sardinia Radio Telescope and will allow continuum observations of the mm-wave sky in the W-band; COSMO is a ground-based telescope devoted to the measurements of CMB monopole spectral distortions from Dome-C in Antartica; premiale ASI is a balloon-borne experiment aimed at the measurements of the primordial B-modes of the CMB polarization; and OLIMPO-2 is the second flight of the balloon-borne OLIMPO experiment devoted to the measurement of the spectrum of the Sunyaev-Zel'dovich effect in galaxy clusters.

2.10 First stars and the seeds of galaxies

Supervisors: Raffaella Schneider (Sapienza University); Co-Supervisor: Luca Graziani (Sapienza University); Collaborators: Marco Castellano (INAF-OAR), Roberto Maiolino (University of Cambridge), Laura Pentericci (INAF-OAR)
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Abstract: The transition from the "dark ages" in the history of the Universe to "cosmic dawn" saw the formation of the first autonomous sources of radiation, stars and black holes. The project aims to address the following

three key questions: (i) What is the nature of the first stars to shine through the Universe? (ii) What is the best observational strategy to observe the first stars? (iii) What was the contribution of the first stars to cosmic reionization? Excitingly, we are at the verge of a revolution of research into the transition from the dark ages to cosmic dawn. The launch of the JWST in October 2021 will enable an unprecedented epochal leap forward. JWST will offer the very first opportunity to find and fully characterize the first galaxies and to explore the nature of the sources of reionization, with the ultimate goal of detecting the signatures of the very first generation of stars. Determining these physical properties will rely heavily on comparison with models and simulations tailored to the data. In this project, we propose to perform dedicated hydrodynamical cosmological simulations to guide the interpretation of these complex data sets, allowing to extract at best their physical content. Close collaboration with observers involved in current and future high-z galaxy surveys with JWST is envisaged.

2.11 Stellar dynamics around massive and super massive objects in dense galactic environments

Supervisors: Roberto Capuzzo Dolcetta (Sapienza University)
Contact: roberto.capuzzodolcetta@uniroma1.it
Abstract: This thesis aims at progressing towards the understanding of mechanisms of mergers giving rise to bursts of gravitational wave emission and to the growth of massive black holes up to the supermassive black hole scale. The methods and tools for such investigations are those of preliminary study of the wide literature, followed by planning of a set of sophisticated numerical N-body simulations which account of General Relativity in the frame of Post Newtonian approximation.The work is inserted in an international context (collaborations with Univ. of Heidelberg (NL) are on the way). The proper numerical codes and related expertise are available to the group of research (see https://sites.google.com/uniroma1.it/astrogroup/home).

2.12 From black hole seeds at large red shifts up to supermassive black holes

Supervisors: Roberto Capuzzo Dolcetta (Sapienza University)
Contact: roberto.capuzzodolcetta@uniroma1.it

Abstract: The existence of super massive black holes in galactic centers is an ascertained feature. Observational evidence indicates that at high redshifts, corresponding to an age of the universe about 1 Gyr, central galactic black holes have already reached values of mass of the order of billion solar masses. Anyway, the modes of formation and growth up to millions or even billion solar masses is an open issue, still. A possibility is that relatively high mass black holes (called 9́3seeds9́4) can come from rapid evolution and collapse of Pop III stars. To grow of several orders of magnitude in mass, these seeds need a super (or even hyper) Eddington accretion. It is also possible a sequence of black hole seeds mergers with subsequent growth of the merger result. In such case, the dynamics is an important engine for the fate of black hole seeds. Dynamics determined by the peculiar, high density environment, that necessarily should take into account relativistic effects. In such frame, this thesis aims to the study of the first evolution fo a system of primordial black hole seeds in an inner galactic environment, still embedded in residual gas contained by the strong gravitational potential. This will be done by coupling results coming from large scale hydrodynamical simulation with the local, strong, dynamical interaction among the black hole seeds. This work will give significant hints on the rates of black hole mergers at high redshift, as well as on the integrated power in form of gravitational waves. Things which will likely find observational counterpart with the new generation GW telescopes. This work stands in a collaborative frame with experts of astrophysical relativity (p. Amaro Seoane) and hydrodynamical simulations (L. Mayer, UZH, CH).

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

Supervisors: Enzo Pascale (Sapienza University)
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://arielmis-

sion.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/ for additional information and contacts.

2.14 Spectral distortions of the Cosmic Microwave Background: Integration and calibration of the COsmic Monopole Observer

Supervisors: Silvia Masi (Sapienza University)
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Abstract: The COsmic Monopole Observer (COSMO) is a staged effort to measure deviations of the Cosmic Microwave Background spectrum from a perfect Planckian. Deviations at low level (1 ppm) are expected due to physical processes happening before and after recombination. The COSMO instrument is a differential Fourier Transform Spectrometer comparing the brightness of the sky to that of an internal blackbody. In its first implementation, COSMO will be operated from the Concordia station in Dome-C (Antarctica), with installation on site and starting measurements on the sky in 2023. The experiment will be exploiting the fast response of Kinetic Inductance Detectors to perform fast sky-dips: this will allow the separation between atmospheric emission and sky monopole, strongly mitigating the effects of 1/f atmospheric noise. The target accuracy / sensitivity in the measurement of the spectral brightness is < 1 ppm, so that the instrument should be able to detect for the first time y-like spectral distortions due to ionized matter in the cosmic web and at reionization. A further implementation on a stratospheric balloon will allow us to get a sensitivity improvement of a factor ~ 10. The thesis work will focus on instrument integration and

calibrations, with the opportunity to participate in the commissioning and first data taking and analysis. See also *cosmo.roma1.infn.it*

2.15 Cosmic Microwave Background polarization with the QUBIC experiment

Supervisors: Silvia Masi (Sapienza University), Giancarlo De Gasperis (Tor Vergata University)
Contact: silvia.masi@roma1.infn.it , giancarlo.degasperis@roma2.infn.it
Abstract: The Q and U Bolometric Interferometer for Cosmology (QUBIC) is an innovative polarimeter for the Cosmic Microwave Background, combining the beam control of interferometers and the sensitivity of bolometers. QUBIC uses (Fizeau) interferometry to synthesize the beam of the instrument by means of a reconfigurable array of input apertures: this approach allows a number of very interesting features, like self calibration and correction of systematic effects. The QUBIC final instrument will be composed of three modules operating at 97, 150 and 220 GHz from Alto Chorillo (Argentina) at an altitude of $\sim$ 4900 meters *asl* to beat atmospheric emission and its fluctuations. The operation of the first module at 150 GHz of the instrument has been recently demonstrated in the laboratory, and the instrument is ready for shipment (it will be in Argentina in July, 2021, and, after integration and further tests in Salta, it will reach the operation site for data taking during the end of 2021). Several codes are available to the members of the collaboration through github, and have been specifically developed for the QUBIC experiment simulations and data analysis. The PhD thesis work will focus on instrument calibration, commissioning, data taking and data analysis. The PhD thesis will also focus on the use and further development of custom analysis methods, needed to fully exploit the potential of the instrument. See also *http://qubic.in2p3.fr/wordpress/*

2.16 Stellar and dynamical evolution of Globular Clusters

Supervisors: Oscar Straniero (INAF); Co-Supervisor: Marco Merafina (Sapienza University)
Contact: oscar.straniero@uniroma1.it
Abstract: Globular Clusters (GC) are building blocks of galactic halos.

They are found in any galaxy type, spirals, ellipticals, dwarfs. Typically, they contain millions of stars tied by the reciprocal gravitational glue. GCs and their stars have been used to date the Galaxy and to understand the early phases of the Milky Way history. Recently, new exciting discoveries, such as the existence of multiple stellar populations and the association with tidal streams, revealed a more complex scenario for the GC formation. Beside these challenging studies, GCs provide a natural laboratory to investigate fundamental physics. The proposed thesis concerns the development of theoretical tools to investigate the interplay of stellar evolution and stellar dynamics in GGs. The main goal is the search of hints of missing physical processes at different scales, from the long scale of the gravitational interactions among stars, to the nuclear and sub-nuclear scales of the weak and strong interactions that operate in hot and dense stellar cores of the most evolved GC stars. The hunt for new physics will proceeds through accurate comparisons of numerical simulation results with extant observational data.

2.17 Development of advanced data analysis techniques for the search of periodic gravitational waves emitted by spinning neutron stars and their application to the data of Virgo and LIGO detectors

Supervisors: Pia Astone (INFN), Piero Rapagnani (Sapienza University)
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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.

2.18 Development of new technologies for mirror suspension and control for Third Generation Gravitational Wave Detectors

Supervisors: Piero Rapagnani (Sapienza University), Paola Puppo (INFN)
Contact: piero.rapagnani@roma1.infn.it
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.

2.19 Development of technologies for quantum noise broadband reduction in ground-based gravitational wave interferometers

Supervisors: Ettore Majorana (Sapienza), Luca Naticchioni (INFN)
Contact: ettore.majorana@uniroma1.it
Abstract: In 2015, after more than 5 years of R&D by the LIGO-Virgo scientific collaboration for the upgrade to the second generation of ground based gravitational wave detectors, the first direct observation of a GW signal has been possible. Thus, a new window of observation on the Universe has been opened and many other events have been detected by Virgo and LIGO in the following scientific observing runs O1-O2 and O3. Thanks to

the technology upgrades, the sensitivity of the second generation of GW detectors has reached the limit due to the quantum nature of light, the so-called Standard Quantum Limit (SQL). Quantum noise in a GW detector is given by two contributions: radiation pressure noise, dominating at low frequency and shot noise, dominating at high frequency. SQL occurs only when these two contributions are uncorrelated. During the last observing run O3, with the implementation of frequency independent squeezing, the sensitivity of the detector has been improved in the high frequency range (200Hz-3kHz) where shot noise is dominant. Nevertheless, frequency independent techniques, where a phase squeezed vacuum state is injected in the dark port of the interferometers, improves the sensitivity curve only in the high frequency at the expenses of an increasing noise in the low frequency. Therefore, any project aiming at a broadband reduction of quantum noise all over the sensitivity curve of ground-based GW detectors should imply a technique that overcomes SQL, such as frequency dependent squeezing. The present project aims at the realisation of an instrument capable to produce frequency dependent squeezing, starting from an existing mechanical prototype of table-top experiment SIPS: suspended interferometer for ponderomotive squeezing In the short term, SIPS will be used as a test bench for another frequency dependent squeezing table-top experiment based on the Einstein Podolsky Rosen (EPR) quantum entanglement, before a possible integration of the EPR setup in Advanced Virgo.

2.20 Searches for gravitational waves from dark matter candidates

Supervisors: Paola Leaci (Sapienza), Cristiano Palomba (INFN)
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Abstract: Ultra-light bosons in the mass range [1E-14, 1E-11] eV, like the QCD axions or the dark photons, are a possible components of dark matter and have been recently predicted to be a source of long-lasting gravitational waves, which are potentially detectable by the Virgo and LIGO detectors.This Thesis is devoted to the study, development, testing and application of robust data-analysis methods to search for such signals using real interferometer data. These signals are emitted by bosons with masses that are several orders of magnitude smaller than what can be probed by particle detector experiments. The work will be carried out in the framework of a col-

laborative and competitive international environment, where several groups in the world are making efforts to detect such gravitational-wave signals as they can convey crucial information on dark matter, and shed light on the fascinating connection among astrophysics and particle physics.

2.21 The outskirts of clusters of galaxies by hydrodynamic simulations and observations and their cosmological implications

Supervisors: Marco De Petris (Sapienza University); Co-Supervisors: Gustavo Yepes (Universida Autonoma de Madrid - Spain), Frederic Mayet (LPSC Université Grenoble Alpes - France)
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Abstract: Clusters of galaxies reveal useful astrophysical laboratories to study Universe composition and evolution. They reside at the nodes of the Cosmic Web, the filamentary structure filling our Universe with the smallest volume fraction and the largest mass fraction being populated by the so called missed baryons. This project is focused on studying the impact of small scale filaments (a few virial radii) on clusters evolution and dynamical state. In fact, the filaments funnel matter onto cluster possibly perturbing the hydrostatic equilibrium even at smaller radii resulting in a biased mass. Several attempts are on-going to shed some light on this topic investigating it by simulations and observations. The study is supported by N-body hydrodynamical simulations, such as The Three Hundred project, with multi-wavelength maps (X-ray, SZ signal and optical) of regions around synthetic clusters. We plan to study 1- the statistics of filaments, based on some properties (such as length, thickness and gas/star components and mass and dynamical state of the clusters), 2- the spatial correlation of different components in the filaments (stars and gas), 3- the impact of filaments on clusters conditions, such as their dynamical state, non-thermal pressure component, gas fraction and 4- the possibility of constraining the best observational conditions and/or targets for high resolution SZ observations.

2.22 Self-similarity of cluster of galaxies properties and observables by employing hydrodynamic simulations

Supervisors: Marco De Petris (Sapienza University); Co-Supervisors: Gustavo Yepes (Universida Autonoma de Madrid - Spain), Weihuang Cui (University of Edinburgh, UK)
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Abstract: Clusters of galaxies constitute a self-similar population under the assumption of the simplest models of structure formation, based on simple gravitational collapse. Therefore, scaling relations between their mass and global IntraCluster Medium properties, such as the X-ray luminosity, Sunyaev-Zel'dovich (SZ) signal, and galaxy richness and velocity dispersion, among the others, can be applied on large catalogues derived from surveys but only after their validation along different mass, redshift and dynamical state ranges. The study of these scaling laws on a limited number of objects, a representative sample, is mandatory to tune the calibration and the scatter. This Thesis project takes advantage of the availability of state-of-the-art N-body hydrodynamical simulations such as The Three Hundred project. Synthetic clusters have already proven to be a useful and efficient testbed to increase our theoretical understanding even to explore scaling laws. In this project we plan to study such relationships for multi-wavelength observations by using mock images of clusters in X-ray, SZ and optical band and to check the validity of the self-similarity

2.23 Weak Lensing Cosmology with Euclid

Supervisors: Roberto Maoli (Sapienza University), Vincenzo Cardone (INAF-OAR)
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Abstract: The Euclid satellite is the next ESA cosmology mission which will perform a spectroscopic and imaging survey over 15000 sq deg. Galaxy clustering and weak lensing data will be provided also allowing detection of clusters and cross – correlation with CMB. The unprecedented quality and quantity of weak lensing data will moreover open up the road to non Gaussianity through higher order statistics including both global estimators (e.g., high order moments), topological indicators (e.g., Minkowski functionals), and local probes (e.g., bispectrum). In order to make the best use of the

whole dataset, it is of paramount importance to both develop techniques for the estimate of Euclid observables, their cross – correlation, and the likelihood function, and develop algorithms for their measurement from simulated dataset. Accounting for the presence of systematics is critical for both aspects. The student will become a member of the Euclid collaboration hence having access to mock data and interacting with a large world community performing frontier research in cosmology. The thesis is also timely tuned so that the results will be ready at the launch of the satellite.

2.24 Addressing problems in the physics of accreting compact objects with variable emission from X-ray binaries

Supervisors: Luigi Stella (INAF)
Contact: luigi.stella@inaf.it
Abstract: X-ray binaries host a compact object (neutron star, NS, or stellar mass black hole, BH) which accretes matter from a donor star, leading to the emission of radiation in different bands. Besides the accretion disk proper, they comprise different components such as coronae, magnetospheres, winds and fast jets. Luminosity variations, reflecting variability in the accretion flow on timescales down to millisecond, provide a powerful diagnostic of the physics of these systems. For instance the X-ray spin period and period derivative of ultra-luminous accreting NSs inform models of super-Eddington accretion; the delays between aperiodic fast variation in the infrared, optical and X-rays encode information on emission mechanisms and disk/jet interplay of accreting BHs; periodic millisecond pulsations in both the optical and the X-rays yield key insight on the different physical regimes of transient, fast spinning NSs. The student will exploit a wealth of state of the art, time-resolved observations of X-ray binaries to address one or more of the open problems in this area of research.

2.25 Artificial intelligence techniques for the GNC system design of autonomous spacecraft for interplanetary missions

Supervisors: Fabio Curti (Sapienza University)
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Abstract: The research focuses on Artificial Intelligence (AI) techniques to design the Guidance Navigation and Control (GNC) system of spacecraft for interplanetary missions, in order to improve the performances, flexibility, autonomy and capability to handle failures and performance degradation. Currently, unmodeled effects or uncertain parameters (e.g. dynamics, sensor/actuator, etc.) limit the GNC performances. AI techniques based on machine learning could be integrated in GNC systems to enable on-line learning of the properties of dynamics, environment, sensors and actuators. Such AI-assisted GNC system would increase both the performance and the degree of autonomy on-board in terms of robustness, adaptability and awareness. However, typical AI techniques do not meet the reliability standards (e.g. reproducibility, robustness, convergence, etc.). Thus, it is needed to investigate the criticalities and challenges of the use of AI techniques for the GNC design, by integrating techniques based on physical system and architectural configuration, with data-based on-line learning. The research is conducted in collaboration with the University of Arizona (Tucson, USA).

2.26 Modeling and characterization of optical systematics for the Litebird Medium and High Frequency Telescope

Supervisors: Luca Lamagna (Sapienza University); Co-Supervisor: Alessandro Paiella (Sapienza University)
Contact: luca.lamagna@roma1.infn.it, alessandro.paiella@roma1.infn.it
Abstract: LiteBIRD is the next generation CMB satellite approved by JAXA for launch by the end-2020s. It will perform high precision measurements of the Cosmic Microwave Background polarization anisotropies from the Earth-Sun L2 point in a nominal 3-years mission, hunting for the elusive signal from primordial gravitational waves, encoded in the B-modes of the CMB polarization pattern at large angular scales. This tiny cosmological signal will be buried into a plethora of astrophysical and instrumental sources of contamination, demanding careful and unprecedented accuracy in tracking the instrumental systematic effects which leak into the measurement chain, potentially yielding false detections. The successful candidate will actively participate to the advanced phase of the design of the MHFT, the dual on-axis telescope on-board the satellite, covering the 90-450 GHz frequency band. He will devote most of his effort to the modeling and the experimental

verification of optical and quasi-optical systematics due to non-ideal behavior of the optical and quasi-optical elements (including lenses, microwave absorbers, filters and anti-reflection coatings)

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

Supervisors: Giampaolo Pisano (Sapienza University)
Contact: giampaolo.pisano@uniroma1.it
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 develop novel and exotic quasi-optical devices. This project will focus on the development of one of more of the following devices:

- Mesh half-wave plates: to modulate the polarisation of light in CMB instruments.
- Mesh-lenses: flat, thin surfaces to replace massive standard plastic lenses.
- Mesh-absorbers: thin surfaces to absorb stray light over large bandwidths and angles.
- Mesh correcting surfaces: surfaces to correct optical aberrations or polarisation systematics.
- Mesh transmissive dichroics: surfaces to split beams with different frequencies.
- 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-b-c) find direct application in the LB MHFT instrument and, all of them, in many other areas related to the microwave engineering field. 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

2.28 Development of metamaterial lenslet arrays for Cosmic Microwave Background experiments

Supervisors: Giampaolo Pisano (Sapienza University)
Contact: mpaolo.pisano@uniroma1.it
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 and exquisite control of the optical systematics. High sensitivity can be achieved by using thousands of detectors coupled to very compact arrays of pixels/antennas. Current coupling solutions based on ëlensletí arrays rely on small silicon lenses requiring sophisticated manufacturing procedures and specifically designed anti-reflection coatings to work efficiently. In this project we propose to develop compact lenslet arrays for detector coupling based on metamaterials. We have developed flat ëmesh-lensesí able to mimic the behaviour of thicker standard lenses. These lenses can be 'miniaturised' and coupled to an array of detectors. A mesh-lens array will be a simple flat device. PhD project tasks:

- Metamaterials e-m modelling using finite-element analysis software (HFSS).
- Design and optimisation of a novel lenslet array based on metamaterials.

- Assistance to the devices manufacture, performed within our international collaboration network.
- Device testing with Fourier Transform Spectrometers (FTSs) and Vector Network Analysers (VNAs).
- Data analysis.

2.29 The first generation of galaxies from James Webb Space Telescope observations

Supervisors: Laura Pentericci (INAF-OAR); Co-Supervisor: Marco Castellano (INAF)
Contact: laura.pentericci@inaf.it
Abstract: The frontier of the observable universe has been constantly pushed towards earlier and earlier epochs, finally reaching, during the last ten years, the epoch of hydrogen reionization. The detection of a few hundreds of galaxies at z 7- 10 (1-0.5 Gyr after the Big Bang) has enabled constraints on the timeline of reionization, the cosmic star-formation rate density and the physical properties of the most distant sources. However, significant uncertainties remain. First of all, z¿4 galaxies are usually detected from imaging observations sampling the rest-frame ultra-violet (UV), which is very sensitive to dust extinction. The star- formation rates and the corrections for dust extinction are themselves determined from the luminosity and slope of the UV continuum. Physical quantities such as mass, age, and star-formation histories, whose estimate relies on the optical-rest frame, largely suffer from the limited sensitivity and resolution of currently available near and mid-IR data. Finally, at the highest redshifts (z¿8) spectroscopic redshift confirmation is limited to a handful of sources, and very little is known on the physical conditions (metallicity, stellar populations, ionizing efficiency) of the faint galaxies that are believed to be the main sources of ionizing radiation. The James Webb Space Telescope (JWST), scheduled for launch in october 2021, has the potential to transform our knowledge of the distant universe thanks to deep, high-resolution images and spectra in the IR/mid-IR, corresponding to the optical rest-frame at high-z. This project takes advantage from the participation to two planned JWST Early Release Science surveys which will obtain imaging and spectroscopy of many tens of galaxies deep into the epoch of reionization. The goal of the thesis is to carry out the analysis of the first

sample of distant sources in JWST images and spectra, in order to determine the physical properties and the contribution to reionization of faint, dwarf galaxies at z 6-12. A comparison to the predictions of theoretical models will also be carried out by the student.

2.30 Deciphering current anomalies in cosmological data

Supervisors: Alessandro Melchiorri (Sapienza University)
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Abstract: The Lambda Cold Dark Matter model provides a very good fit to most of current cosmological observables. However, it is based on several assumptions (CDM, Inflation, and the cosmological constant) that have still to be measured in laboratory and/or experimentally verified. Alternatives to the LCDM model do exist that can provide an equally good fit to current data. Moreover, anomalies and tensions with a statistically significance ranging up to four standard deviations (as in the case of the Hubble tension) are emerging. Scope of the project will be to identify and quantify current tensions between cosmological data, to estimate the impact of systematic effects and to search for possible theoretical explanations

2.31 CMB polarization and new physics

Supervisors: Alessandro Melchiorri (Sapienza University)
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Abstract: Future measurements of CMB polarization B modes are expected to open a window to the physics of extreme high energies. Moreover, several new mechanisms such as the presence of an early dark energy component can induce a birefringence signal in polarization. Magnetic fields can also induce and modify the polarization spectra and leave characteristic imprints. The goal of this thesis will be to identify all possible physical mechanisms that could affect future polarization measurements and to quantify possible degeneracies between them in order to answer the crucial question: what can we learn from future CMB polarization data?

3 INAF

3.1 Time domain astrophysics with current- and next-generation arrays of Cherenkov Telescopes in the context of multi-wavelength and multi-messengers astronomy

Supervisors: Saverio Lombardi (INAF-OAR), Marco Tavani (Tor Vergata University and INAF); Collaborator: Antonio Stamerra (INAF-OAR)
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Abstract: The detection of the Teraelectronvolt (TeV, $10^{1}2$ eV) counterparts to transient events has proved fundamental to constrain radiative processes, particle acceleration, and the physics of mechanisms responsible for the most extreme astrophysical sources, such as gamma-ray bursts and active galactic nuclei. Examples of recent, major advances in this field are the discovery of TeV radiation from gamma-ray bursts (MAGIC coll., Nature, 2020, 575, 455) and the observation of TeV radiation from the blazar TXS 0506+056 in association with the detection of a high-energy astrophysical neutrino by the IceCube observatory (IceCube, Fermi coll., MAGIC coll et al., Science, 2018, 361,146). The search of TeV emission associated to gravitational waves (GW) signals, represents the next frontier. The Cherenkov telescopes are the most performant instruments to exploit the fast variable gamma-ray emission from these transients. These observations, complemented by multi-wavelength campaigns proved effective in the description of the astrophysical processes, either complementing or challenging the exiting scenarios, and opening a new window in the exploration of astrophysical transients. The project proposed for this thesis aims at studying the TeV gamma-ray emission with current- and next-generation Cherenkov telescope systems, emitted by multi-messenger sources (GW and high energy neutrinos) and from gamma-ray bursts. The student shall propose and carry out observations with the MAGIC Cherenkov telescopes, currently operating on the Canary Island of La Palma (Spain). She/he will develop dedicated simulation to investigate the scientific prospects of the next-generation ground-based gamma-ray observatories, such as the ASTRI Mini-Array, which is being deployed on the Canary Island of Tenerife (Spain), and the Cherenkov Telescope Array (CTA). She/he will also contribute to the fast pointing

strategies and to the development of the relevant software tools. The recipient will be a full member of the MAGIC, CTA and ASTRI collaborations.

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

Supervisors: Alessandra Lamastra (INAF-OAR)
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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 cosmic rays with the interstellar medium can produce high-energy gamma rays and neutrinos. For the XXXVII cycle, we propose a PhD fellowship research program on the observational and theoretical studies on the non-thermal electromagnetic and neutrino production in AGN and starburst galaxies. The PhD candidate will develop the theoretical framework related to the modelling of the gamma-ray and neutrino emission from AGN-driven and starburst-driven outflows. The PhD candidate will also exploit real data of astrophysical targets at very high energy, which will be taken by the MAGIC 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, LST) will be performed for several astrophysical targets in order to evaluate future prospects.

3.3 Searching for optical millisecond pulsars to probe particle acceleration and to boost continuous gravitational waves searches

Supervisors: Alessandro Papitto (INAF OAR)
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Abstract: Millisecond Pulsars (MSPs) in compact binary systems are unique laboratories to study the interaction between the matter in-flowing towards a Neutron Star (NS), its rotating magnetosphere and the outgoing radiation, particle wind and jets. Coherent pulsations of the emitted radiation are critical diagnostics to measure the NS properties. The fellow will use

dedicated fast timing algorithms to search for optical MSPs exploiting a new observing window opened by the observations of unexpectedly bright optical pulsations from two MSPs with the fast photometer SiFAP at the INAF Galileo Telescope. The fellow will discuss the results to understand how particles accelerated by the pulsar field interact with the surrounding plasma to produce the unexpectedly bright pulsations observed. On the other hand, observations of continuous gravitational-wave candidate sources will significantly improve the available spin and orbital ephemerides. For the first time, high sensitivity searches for yet undetected continuous periodic signals in LIGO-VIRGO-KAGRA new data sets would be allowed, which would turn crucial to unveil the internal mass and field distribution of NSs.

3.4 Stellar winds and dust formation of stars

Supervisors: Paolo Ventura (INAF-OAR), Francesco Berrilli (Tor Vergata University)
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Abstract: The stars not undergoing core collapse, accounting for 95% of the global stellar population, during the late evolutionary phases are efficient dust manufacturers and extraordinary polluters of the interstellar medium. A full comprehension of the mechanism leading to the formation of dust particles in their wind proves important to interpret their spectral energy distribution and to assess their contribution to the overall dust budget in the Universe. The proposed research project is aimed at overcoming the current uncertainties connected to the present-day description of dust formation, by developing a self-consistent model, which takes into account nucleation and stellar pulsations, to determine the mineralogy and quantity of dust formed in the wind of stars of different mass during their lifetime also with the possible connection to Sun-like stars and interactions with the hosted planets. The results of this study will be of great support for the incoming observations from the James Webb Space Telescope, which will sample all the galaxies of the Local Group, and beyond. The comparison between the theoretical expectations and the observations will allow the characterization of the evolved stars populations and assess how these stars can be used to reconstruct the star formation history of the host galaxy.

3.5 Characterization of gargantuan quasars at the Epoch of Reionization

Supervisors: Luca Zappacosta (INAF-OAR), Raffaella Schneider (Sapienza University)
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Abstract: The rapid mass growth of Supermassive Black Holes (SMBH) powering luminous quasars (QSOs) at the Reionization Epoch (EoR, $z > 6$) is a hot topic in modern astrophysics and spurred extensive multiwavelength campaigns with flagship observatories. Although X-rays are the most direct evidence of the processes responsible for the energy generation in the innermost regions surrounding accreting SMBHs, the observation of QSOs at EoR in this spectral band are still sparse. To overcome this limitation we have been awarded a Multi-Year Heritage Programme on the XMM-Newton X-ray observatory. This will ensure the deepest ever view (a total of 700 hours) of the 17 most massive HYPerluminous quasars at the Epoch of ReionizatION (HYPERION). The thesis project will be aimed at delivering the first panchromatic study of the QSOs at EoR, taking advantage of the upcoming X-ray observations combined with many UV-to-millimeter archival data. In addition, the student will be involved in the data-driven refinement of cosmological semi-analytic models and simulations, developed by members of the HYPERON Team, to investigate SMBH formation history/channels in the earliest stages of cosmic evolution.

3.6 A Systematic Study of the Largest Reservoir of Baryons and Metals in the Universe: the Circum Galactic Medium of Galaxies

Supervisors: Fabrizio Nicastro (INAF-OAR); Co-Supervisor: Pasquale Mazzotta (Tor Vergata University)
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Abstract: At all epochs, the gaseous medium surrounding galaxies (CGM) is thought to contain significant fractions of the galaxies' baryons and metals and thus to play a fundamental role in the process of galaxy-Intergalactic-Medium (IGM) co-evolution throughout the Universe's life. Yet, no systematic study of this important component of the Universe's has been performed so far. The proposed project (selected as a PRIN-INAF in 2021) aims to ex-

ploit the richness of UV-X-ray archives to address two fundamental and yet unanswered questions: (a) how many baryons and metals are hidden in hot halos of galaxies in the local Universe? and (b) how are they redistributed throughout the Universe during its lifetime. Main objectives of the proposed study are: (1) to secure multiple detections of one of the most hunted, and still elusive, metal-enriched baryonic components of the local Universe: the hot CGM of galaxies at $z < 1$; (2) to use state-of-the art hydro-dynamical simulations for the formation of structures in the Universe, to gain insights on the physical and chemical properties of the hot CGM and trace back its co-evolution with virialized structures.

3.7 Characterizing massive exoplanets and their host stars

Supervisors: Katia Biazzo, Simone Antoniucci (INAF-OAR); Collaborator: Luigi Mancini (Tor Vergata University)
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Abstract: Understanding how planets form within the protoplanetary disk of their host star is one of the major challenges of current astrophysical research. The formation of massive planets is particularly important, as they are believed to play a fundamental role in shaping the final configuration of the planetary system. Here, we propose a thesis aimed at characterizing young stars and their massive planets, which are still in formation within the protoplanetary disks. Host stars will be characterized in terms of atmospheric parameters and elemental abundances through high-resolution spectra from optical to near-infrared wavelengths already acquired with the GIARPS facility at the Telescopio Nazionale Galileo (Spain). Exoplanets will be searched and characterized through high-contrast direct imaging data taken with SHARK-VIS, the new high-contrast imager of the Large Binocular Telescope (Arizona) built at the INAF-Osservatorio Astronomico di Roma. The PhD student will carry out the work at the INAF-OARoma and at the Tor Vergata University. He/She will be also actively involved in future spectroscopic and photometric observations.

3.8 Multi-wavelength studies of active galaxies in VANDELS

Supervisors: Angela Bongiorno (INAF-OAR); Co-Supervisor: Laura Pentericci (Sapienza University and INAF-OAR)
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Abstract: VANDELS is an ultradeep spectroscopic survey of high redshift galaxies and AGN in the well known fields: UDS and CDFS. From the massive observational campaign, a final sample of 80 AGN up to z=5.5 have been selected by using a combination of their spectral and X-ray properties. The PhD project will consist in studying the multi-wavelength properties of these objects, by combining the high S/N VANDELS spectra with the multi-wavelength data already available for these sources (e.g. X-ray, radio, HST). Examples of such studies are (1) the investigation of the outflow properties for high-z AGN (using UV interstellar absorption lines) as a function of the host properties (e.g. stellar mass, SFR) and the comparison to normal galaxies; (2) the study of the $M_{BH} - sigma$ relation where the galaxy velocity dispersion will be measured from the galaxy UV absorption line width while the M_{BH} will be computed from the broad emission lines (e.g. CIV & MgII) redshifted in the optical spectra at $z > 1$.

3.9 Cosmology and galaxy evolution with the Euclid Survey: discover and study of extreme galaxies

Supervisors: Roberto Scaramella (INAF-OAR), Roberto Maoli (Sapienza University)
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Abstract: Regular spiral and elliptical galaxies so far have been the main focus of galaxy samples used to study the intertwined astrophysical and cosmological aspects of galaxy evolution. But the existence of nonstandard galaxies such as Low Surface Brightness galaxies, dwarves, and ultra diffuse galaxies poses crucial questions on the differences in the formation and evolution of these objects. This has important consequences on the low end of luminosity and mass function of the galaxies, which depend on the Dark Matter characteristics. The census and characterisation of these objects is now at the forefront of research. Therefore Euclid, the next ESA mission for Cosmology to be launched at the end of 2022, will allow a crucial step in this topic. The Euclid Local Universe Science Working Group is starting

its activities right now with a large Italian participation. The timing for a 3 year PhD program is excellent: the student will be able to study the first data from the satellite and there will be numerous opportunities for subsequent post-doc positions within the large Euclid Consortium. The work is planned to be carried on in stages (details upon request). Collaborations are ongoing with groups in Rome and Neaples observatories, Salento University plus others in Spain and France.

3.10 The Imaging X-ray Polarimetry Explorer: analysis of flight data from black holes and neutron stars from commissioning phase to the operative life.

Supervisors: Paolo Soffitta (INAF-IAPS)
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Abstract: The Imaging X-ray Polariemtry Explorer, a NASA-ASI mission, is expected to be launched on 30th november 2021 with a Falcon-9 rocket on an equatorial low-earth orbit. Starting from the commissioning phase, observation of celestial sources will provide a wealth of data consisting of energy, timing and angular resolved polarimetry from basically all the classes of celestial sources. Observation will span from relatively bright Active Galactic Nuclei to X-ray binaries hosting, white dwarves, neutron stars or black holes. They also include angularly resolved polarimetry from Supernova Remnants and Pulsar Wind Nebulae The successful candidate will be engaged in the group that devised and built the instrument and which is leader in its calibration. The dottoraro di ricerca is particularly timely for exploring polarization data from this discovery mission.

3.11 Extragalactic Globular Clusters with the Vera Rubin Observatory: unresolved old stellar systems for mapping the history of galaxy interactions

Supervisors: Michele Cantiello (INAF-OAAb)
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Abstract: The Vera Rubin Observatory (VRO, previously LSST), will be

a factory of excellent optical data that will revolutionize many fields of Astronomy. With this thesis project we aim at using precursory VRO data and simulations to identify extragalactic globular clusters (GCs) around massive galaxies out to 100Mpc. GCs are among the oldest structures in the Universe, fossil tracers of the earliest evolutionary stages of a galaxy and its host environment. The student will take advantage of data and simulations -and of the first VRO images- to study the characteristics of GCs populations in the local Universe for constraining the properties of the host galaxy and its environment. This project will give the student the opportunity to participate in one of the most challenging and exciting astronomical experiments of the decade.