Galassie e Cosmologia

Super-Eddington Accretion onto Supermassive Black Holes (Paola Marziani M. D'Onofrio)

In recent years, growing observational evidence has pointed to phases of super-Eddington accretion as a key mechanism in the early, rapid growth of supermassive black holes. This thesis aims to contribute to our understanding of these extreme accretion episodes by combining multi-wavelength diagnostics and detailed spectral analysis. The first objective will be to define robust, multi-frequency selection criteria—based on spectral energy distributions, emission line properties, and variability—to identify super-Eddington candidates in large surveys such as SDSS and DESI. The student will then focus on three core aspects of super-Eddington accretion: (1) accurate estimation of accretion parameters: refining black hole mass and Eddington ratio estimates through multi-component spectral fitting and empirical correlations, with particular attention to viewing-angle effects; (2) dynamics of the wind: analyzing velocity shifts and profiles of optical and UV emission lines to characterize radiation-driven outflows; (3) chemical composition of the line-emitting gas: exploring metallicity-sensitive diagnostics to trace enrichment and test scenarios involving nuclear star formation in the outskirts of an advection-dominated accretion flow. The research will be based on a carefully selected “gold” sample of several tens of super-Eddington candidates, combining proprietary observations (e.g. ESO/VLT XSHOOTER, GTC/Osiris) with archival survey data. Depending on the student’s background and interests, the work may emphasize observational analysis, dynamical and photoionization modeling, or even the role of accretion-modified stars in the central regions through dedicated simulations. The project is part of an active collaboration involving researchers at Gemini/NOIRLab, the Belgrade Astronomical Observatory and University, the Instituto de Astrofísica de Andalucía, and the Instituto de Astronomía of UNAM.

Characterizing the mechanisms affecting galaxies with spatially resolved observations (Alessia Moretti Benedetta Vulcani, Marco Gullieuszik)

It is currently assumed that galaxy evolution in the general field is mostly regulated by internal mechanisms (e.g. winds due to stars or AGN) and that environmental effects play a major role only in galaxy clusters, the most massive structures in the Universe. Nonetheless, even galaxies living in non-cluster environments can be significantly affected by external processes connected to the position of galaxies within the cosmic web. Currently, though, there is no consensus on the importance of such mechanisms in galaxy evolution and a complete census of their impact and incidence in the different non-cluster environments is lacking. We propose a project to obtain the definite answer on the relative importance and effectiveness of different mechanisms in affecting galaxy properties in low density environments in the local universe ($z<0.05$).

The PhD student will be involved in the scientific exploitation of the new MAGNET survey that will tackle the following questions: i) to which extent do field galaxies feel environmental processes? ii) what is the relative importance of internal and external factors in regulating galaxy evolution in the field? iii) are gas accretion and removal significant? iv) how is star formation affected by the different mechanisms? The keystone of the survey will be the analysis of spatially resolved maps of different galaxy properties, including those of the different gas phases. We are currently gathering data with the VST telescope on the ionized gas emission, and we will gather observations at many different wavelengths (examples

include Meerkat (HI), ALMA (H2), MUSE (ionized gas), UVIT and HST (compact star forming regions), JWST (dust), LOFAR (high energy cosmic rays) and the student could contribute to their preferred spectral range.
The student will be inserted in an international context and spend at least a few months in foreign institutes, where our collaborators are based.

Positive and negative feedback from AGNs in GASP ram-pressure stripped galaxies (Alessia Moretti)
The role of AGN feedback is of paramount importance when trying to reproduce the overall contribution of massive galaxies to statistical properties of galaxy population in the Universe. At the high mass end of the luminosity function, in fact, the star formation must be somehow suppressed to reconcile observations and simulations of galaxy evolution.
From the observational point of view, though, recent literature has demonstrated that both negative (i.e. suppressing star formation) and positive feedback are at play in active galaxies.
In particular the mechanism behind the promotion of star formation in correspondence of AGN outflows is the mechanical compression of the cold gas reservoir present in the galaxy cores.
GASP galaxies subject to ram-pressure stripping (RPS) show an anomalous cold gas content, coupled with an increased star formation activity with respect to undisturbed galaxies with the same mass.
Moreover, some of the GASP galaxies show distinct signatures of negative feedback manifesting as ionized and cold gas holes.
This effect is also predicted by numerical state-of-the-art high resolution simulations devised on purpose for the GASP project.
We propose a PhD project aimed at using the spatially resolved data from MUSE, HST and ALMA to study the combined effect of the ram-pressure and AGN feedback on the star formation properties of galaxies evidencing signatures of negative feedback, as traced by ionized/cold gas cavities.
The work will be done in collaboration with the entire GASP team, both in Padova and abroad.
For a full description of the GASP project, including team composition and publication record please visit the dedicated webpage https://web.oapd.inaf.it/gasp/.

The extra-planar gas properties of observed and simulated galaxy discs. (Antonino Marasco prof F. Marinacci (Univ. of Bologna, IT), prof. F. Fraternali (Groningen University, NL))
This project is focused on the disc-halo gas cycle in nearby galaxy discs triggered by stellar and AGN feedback. The student will use sophisticated 3D modelling tools to characterise the main properties (mass, 3D distribution and kinematics) of the extra-planar gas in a) nearby galaxy discs as revealed by the deepest HI and optical IFS observations available (e.g. MHONGOOSE, GECKOS); b) simulated galaxy discs from cosmological, zoom-in and dedicated hydrodynamical simulations using synthetic HI and Halpha observations.
The results of the analysis will be used to deepen our understanding of the gas circulation physics at the disc-halo interface and to provide robust guidelines for theoretical models of stellar and AGN feedback. This project will benefit from a close collaboration with the Univ. of Bologna (IT) and Groningen (NL).

A new software to infer the mass distribution in rotating galaxy discs (Antonino Marasco prof F. Fraternali (Univ. of Groningen, NL))
This project is focused on relation between baryons and dark matter in galaxies at various redshifts.
The student will assist the development of a new software package to model parametric, multi-component mass distribution models to emission line observations of rotating galaxy discs. This software will provide a direct and robust estimates of the physical properties (mass, scale-length, etc) of different mass components (stellar and gaseous disks, stellar bulge, dark matter halo), and of their associated uncertainties. The software will be tested on mock data from hydrodynamical simulations of galaxy evolution (e.g. TNG50, FIRE2) and applied to a variety of observational dataset (HI from MeerKAT, optical from MUSE and WEAVE, IR from JWST, CO and [CII] from ALMA) to quantify the relation between baryonic and DM component at different cosmic epochs. This project will benefit from a close collaboration with the Univ. of Groningen (NL).

The environment and the morphology of Active Galactic Nuclei Hosts along the Eigenvector 1 sequence (Paola Marziani M. D'Onofrio)
The thesis will address the host galaxy morphology and environment of spectroscopically selected samples of AGN organized along the Eigenvector 1 (E1) sequence. The project focuses on the physical link between the nuclear properties of quasars — such as Eddington ratio, occurrence and power of relativistic ejections, chemical enrichment and the large-scale features of their host galaxies and surroundings. A particular emphasis will be placed on the interaction between radio jets and the ambient interstellar medium (ISM). The student will examine how radio morphology, jet orientation, and feedback signatures appear in special classes of type-1 AGN, and correlate with position along E1, using archival radio maps (e.g., VLA FIRST) and spectroscopic indicators of outflows or shocks, part of them already available from SOAR dedicated observations. In parallel, the host galaxy morphology and color will be investigated across the E1 sequence using multi-band imaging data (e.g., SDSS, Pan-STARRS). Tricolor composite maps will be used to trace dust lanes, star-forming regions, and structural asymmetries, helping to infer merger signatures, tidal features, or gradients in stellar population. A dedicated survey might be planned as part of the Ph.D. project. The project is oriented toward image analysis and classification, as well as toward interpreting physical correlations across the AGN parameter space. The thesis will contribute to understanding how AGN activity — especially radio-mode feedback, due to weakly active supermassive black holes — is shaped by and shapes its galactic environment.

Stelle, popolazioni stellari e mezzo interstellare

The Faintest and Coolest Stars in the Nearest Globular Clusters Using the James Webb, Hubble, and Euclid Space Telescopes (Luigi (Rolly) BEDIN carraro/libralato/nardiello)

Globular clusters (GCs) are among the oldest known objects in the Universe for which accurate ages can be determined. They serve as ideal astrophysical laboratories, as their stars are, to a first approximation, coeval, equidistant, and chemically homogeneous. Stellar

color-magnitude diagrams (CMDs) of GCs are powerful tools for studying stellar evolution and dynamics. We have secured observing time with the James Webb Space Telescope (JWST) using NIRCam and NIRISS in direct-imaging mode to obtain high-precision photometry and astrometry of the faintest stellar populations in several key clusters: M4, NGC 6397, NGC 2808, NGC 5139 (Omega Centauri), and 47 Tucanae (second epoch). Proper motion studies will also be extended to explore the internal kinematics of a larger sample of 34 GCs using both new JWST data and archival Hubble Space Telescope (HST) images. This program has three primary goals:
a) Brown Dwarfs and the Hydrogen-Burning Limit – We aim to map the transition in the CMD and luminosity function between hydrogen-burning stars and non-fusing brown dwarfs (BDs). Observing BDs in GCs provides a unique opportunity to test and calibrate models of metal-poor BD atmospheres, as well as theories of their formation and evolution.
b) White Dwarf Cooling Sequences - Our data will capture the full infrared white dwarf (WD) cooling sequence, extending the legacy of HST observations. This will enable fundamental studies of WD physics and the search for signs of ancient planetary systems through the detection (or absence) of infrared excesses in hot WDs.
c) Precision Astrometry and Internal Kinematics - The candidate will use JWST and archival HST data to compute proper motions across 34 globular clusters. This will refine source membership classifications and allow for detailed investigation of internal kinematic structures.

A key component of the program is the assessment and mitigation of field-star contamination. The existing HST data, taken approximately 15 years ago and reaching the star/BD boundary, will serve as the first epoch for proper motion measurements. Future JWST epochs will extend membership studies deeper into the BD regime. All reduced datasets and high-precision astrometric and photometric tools will be made publicly available in a timely manner.

These high-quality proper motions will empower the candidate to investigate the internal kinematics of globular clusters with unprecedented precision. In particular, the project will enable direct measurement of how internal velocity dispersion varies with stellar mass, providing key insights into the degree of energy equipartition—a fundamental yet poorly understood aspect of globular cluster dynamics. The scientific and technical skills acquired through this research will be highly valuable for a successful career in astrophysics beyond the PhD.

Astrometric Search for Planets with the Hubble, James Webb, Kepler, and Euclid Space Telescopes (Luigi (Rolly) BEDIN carraro/nardiello/libralato)

The 25,000-Lightcurve HST–Kepler Treasury Survey---

The Kepler database holds an important, yet largely untapped, opportunity. Two "super-aperture" fields—centered on the open star clusters NGC 6791 and NGC 6819—contain thousands of stars that have been monitored almost continuously over more than four years. If their stellar populations can be reliably disentangled, these Kepler datasets could revolutionize our understanding of planet occurrence rates in large, coeval, and chemically homogeneous stellar groups.

We are using high-resolution HST imaging of these two fields, combined with a proven method that integrates Kepler light curves with HST source data. The unparalleled image quality of HST enables the creation of a homogeneous, complete, and color-calibrated input catalog, making it possible to extract Kepler light curves for all detectable sources in the field. Moreover, HST astrometry allows us to derive proper motions aligned with the Gaia reference frame, enabling accurate membership determinations for every star.

This effort will yield approximately 25,000 light curves, increasing the total Kepler sample by about 15%. Based on current planet occurrence rates, we anticipate detecting over 70 transiting exoplanets—approximately 40 in NGC 6819 (solar metallicity), and 30–50 in NGC 6791 (super-solar metallicity).

Our program will significantly extend the scientific legacy of the Kepler mission by increasing the known population of transiting exoplanets and enabling a direct test of the planet occurrence–metallicity relationship in stellar populations that are uniquely well-characterized. In addition, the data will support a wide range of astrophysical investigations and provide an exceptional resource for selecting targets for future observations with JWST, ARIEL, and other missions.

Characterization of the Gap Transients in the Era of Large Surveys (Lina Tomasella Andrea Pastorello)

In 2018 the Padova-Asiago SN Group began a systematic monitoring project of all transients in the "Gap" discovered by the main panoramic surveys (Pan-STARRS, the Zwicky Transient Facility, ATLAS, ASAS-SN, the Catalina Sky Survey). Our work has allowed us to identify three main categories of transients in the "gap": the giant eruptions of massive stars (mainly Luminous Blue Variables and Wolf-Rayet stars), the coalescences of non-degenerate stars (luminous red novae), and intrinsically faint supernovae. These latter, in particular, are interesting because they could provide the observational counterparts of "core-collapse" supernovae that are predicted from a theoretical point of view, but which have not been identified with certainty: the "electron-capture" supernovae from super-AGB stars and the fall-back SNe from very massive stars.
Although the various categories of transients in the "Gap" show surprising similarities from an observational and energetic point of view, the study of the physical parameters and the comparison with theoretical models have highlighted that these events can be produced by radically different physical processes, as well as by stars that cover a wide range of evolutionary phases and masses. The proposed doctoral thesis project consists of analysing and interpreting in detail the data of a category of transients in the "gap". The doctoral student will have to manage the following activities:
1. The candidate will personally coordinate the observational campaigns based on data collected from ground-based and space telescopes, and will be responsible for telescope observations, the reduction and analysis of photometric and spectroscopic data, in the ultraviolet (SWIFT/UVOT), optical and infrared domains. The doctoral student will have wide access to observational facilities (in Asiago, Spain, Chile, China), through guaranteed time on various telescopes. In particular, our team leads the international scientific collaboration on the study of "Gap Transients" with the SOXS spectrograph mounted on the ESO-NTT telescope. This spectroscopic survey will start in June 2025. Furthermore, we are among the

founders of the Large Programme "NOT Unbiased Transient Survey-2" at the Nordic Optical Telescope (NUTS2), born as a collaboration between researchers from various European institutes and active without interruption for a decade.
2. Analyse the data prior to the discovery of the transient available in public archives (especially the Hubble Space Telescope and the James Webb Space Telescope). The main purpose of this work is the characterisation of the progenitor in its quiescent phase and/or its history of variability in the years preceding the discovery. 3. Compare the observational data with theoretical models with the aim of determining the parameters of the explosion and the progenitor (in particular the mass of the progenitor). Our group is developing theoretical models that will be widely used and refined by the doctoral student. 4. Carry out statistical studies and rate estimates, using the large database of similar objects available in a data archive that we are implementing (https://sngroup.oapd.inaf.it/ gap.html). The comparison will allow us to identify various subgroups of transients in the "gap" and to construct "template" light curves and spectral sequences, which are essential tools for a rapid identification of potential new candidates discovered by the surveys. The doctoral student's activity will also be aimed at the upcoming use of data provided by one of the most innovative astronomical projects of the next decade: the Legacy Survey of Space and Time (LSST) at the Vera Rubin Observatory.

Unveiling the peculiar type Iax thermonuclear supernovae (Lina Tomasella)
In the last decade, the discovery of several peculiar Type Ia SNe has drawn the attention to the photometric and spectroscopic diversity in this class formed by otherwise homogeneous transients. SNe Iax are the largest class of peculiar thermonuclear SNe (with over 50 members known so far), whose main characteristics are:- a lower luminosity than normal SNe Ia (-13 > MV > -19), and a fast rise (~10 to 20 days) to the maximum light;- lower velocity for the ejected material (~2000-6000 km/s) compared to classical Type Ia SNe;- early spectra dominated by Fe-group elements (strong FeII, FeIII; CoII in the JHK-bands); IMEs, such as Si, S, and Ca are identified, but these features are weaker than those observed in normal SNe Ia.
Type Iax are unique among all SNe in their late-time spectral properties. These spectra show both permitted and forbidden emission features, never becoming fully nebular. Regarding the progenitors, pre-explosion HST deep images for SN 2012Z (McCully et al. 2014, Nature, 512) show a luminous and blue source consistent with an He-star companion to a C/O WD system; progenitor non-detection for 2014ck (Tomasella et al. 2016, MNRAS 459), SNe 2008ge and 2014dt (Foley et al. 2010, AJ, 140; 2015, ApJ, 798) rules out the most luminous/massive stars. However, the diversity within this class of transients cannot be reduced to a one-parameter description and this may imply that distinct progenitors and/or explosion mechanisms are involved, despite the overall similarity of the main observables.

The proposed doctoral thesis project consists of analysing and interpreting a set of data for a sample of type Iax SNe. The doctoral student will have to manage the following activities:
1. coordinating the observational campaigns for a selection of type Iax SNe, and the reduction and analysis of photometric and spectroscopic data, in the ultraviolet (SWIFT/UVOT), optical and infrared domains. The student will have wide access to observational facilities (in Asiago, Spain, Chile, China), through guaranteed time on various telescopes.
2. searching in the public archives (Gemini, HST, JWST, …) pre-explosion images. The main purpose of this work is the characterisation of the progenitor (up till now only the progenitor

of SN 2014Z was identified as a blue luminous object compatible with a helium-star donor and an accreting near-Chandrasekhar mass WD, McCully+ 2014).
3. Carry out statistical studies, rate estimates, host environments characteristics of type Iax SNe, in order to investigate how different environments influence the diversity of peculiar type Ia SNe.

High-contrast imaging of forming planetary systems with SHARK (Dino Mesa Domenico Barbato)
The high-contrast imaging (HCI) technique is becoming more and more important for the detection and characterization of new exoplanetary systems and it will become even more important with the instrumentation of the future extremely large telescopes. SHARK-NIR is a new exoplanet imager designed and builded under the supervision of scientists of the Observatory of Padova and it is currently installed at the Large Binocular Telescope (LBT) in Arizona. It has recently started its scientific observations and the first results have been published at the beginning of this year. In the near future it is planned a survey of targets in the Taurus-Auriga region with the aim to image young forming planets and the exoplanetary disks where they are forming. A PhD student participating to this program would be requested to help in the target selection and in the preparation and execution of the observations. He/she will also have the possibility to participate to the observations directly at the telescope. Finally, he/she will help in the data reduction and in the full process for the exploitation of the science data retrieved ending with the participation to the scientific publications of the results.

Looking for binary planets and exomoons through spectroscopic monitoring of directly imaged planets (Silvano Desidera C. Lazzoni (INAF-OAPD), L. Malavolta (UniPD), A. Zurlo (Univ. Diego Portales, Chile))
The number of exoplanets detected with various techniques is continuously increasing. Several of these planets were detected with high-contrast imaging at wide separations from the central star. Very recent instrument developments allow us to observe these objects at high spectral resolution, up to R=100000, coupling high resolution spectrographs with adaptive optics modules. This opens the possibility of detecting companions to these planets through radial velocity monitoring of the planets themselves or spectroscopic identification of features belonging to different components in the case of a binary planet. Satellites are a signpost of the interaction of the planets with the primordial circumstellar disk, therefore they give fundamental insights into the formation channel of exoplanets. These observations will also permit the analysis of high-resolution spectra of the directly-imaged planets to study their atmospheres and other physical properties. Pilot programs providing significant amounts of data to carry out the project are on-going or already approved and additional observing time will be requested. This PhD project is connected to on-going international collaborations, with natural perspectives for a few-months stays working in other institutes and chances for co-supervision.

The role of the environment on young stars and disk population (Elisabetta Rigliaco Raffaele Gratton, Dino Mesa, Silvano Desidera)
Star formation is a continuous process that lasts for periods as long as tens of million years. During this time the star-forming cluster forms stars, surrounded by their circumstellar/protoplanetary disks, and multiple systems. The environment where stars form and the mass of the primaries in multiple systems have a strong influence on the

frequencies, semi-major axis, mass distribution of stellar companions, and survival of their protoplanetary disks. It is recently becoming clear that most young clusters in the solar neighbourhood were not born in isolation, but they were originated in massive star-forming complexes with hundreds of parsec long chains of star formation that show well defined age and velocities gradients, from massive/older clusters to smaller/younger clusters. In this context, the analysis of the stellar and disk population in different environment is crucial for the understanding of the survival of stars, multiple systems and disks. In this thesis we propose to investigate multiplicity of stars and presence of disks in different environment with the aim of understanding how the environment impacts on the frequency, mass ratio, and separation of binaries, and the survival of protoplanetary disks.

Benchmark for the hunting of supernovae progenitors (Nancy Elias-Rosa S. Simón Díaz (IAC, Spain))

Massive stars are predicted to end their lives as core-collapse supernovae (SNe). However, these SNe exhibit a notable diversity in their observed properties, reflecting the varied evolutionary states of their progenitor stars at the moment of explosion. A key question in stellar astrophysics is: How can we accurately determine the mass of a supernova progenitor star?

This project addresses this challenge by developing a comprehensive framework to characterise supernova progenitors.
-Mapping the Parameter Space: The student will create a robust database of photometric information for a large sample of at least a few hundred spectroscopically confirmed massive post-main-sequence stars in the Milky Way and the Magellanic Clouds. This database will include key parameters such as masses, metallicities, and extinction. To efficiently analyse this rich dataset, the student will utilise and develop machine learning techniques for statistical analysis.
-Connecting Stars to Supernovae: The project will then apply this database to: (i) establish a clear connection between the statistical properties of supergiant stars and those of SNe, (ii) validate and refine existing and newly derived estimates of SN progenitor masses, and (iii) compare the observed progenitor masses with predictions from stellar evolution models.

The outcome of this project is to create a reference benchmark for identifying supernova progenitors and accurately estimating their fundamental stellar physical parameters.

This multidisciplinary PhD project offers the opportunity to gain expertise in several exciting areas of astrophysics, including stellar evolution (particularly in the massive star regime), supernova explosion mechanisms, photometric and spectroscopic techniques, and advanced data analysis using machine learning. The student will also develop skills in handling new and archival astronomical data.

The project will be conducted in collaboration with Dr. S. Simón Díaz at the Instituto de Astrofísica de Canarias (Spain) and Dr. I. Negueruela at the University of Alicante (Spain). The student will also actively participate in international collaborations, such as the NOT Unbiased Transient Survey (NUTS2) and the new spectroscopic survey of transients using the Son of X-Shooter (SOXS). This offers excellent opportunities for attending conferences and workshops and visiting collaborating institutions.

Exploring the Explosive Deaths of Massive Stars: Correlating Optical and Radio Transients Properties (Nancy Elias-Rosa Maria Teresa Botticella (INAF-Osservatorio Astronomico di Capodimonte))
This doctoral project lies at the forefront of multi-messenger astronomy through the analysis of time-domain observations of stellar death. By combining data from wide-field transient surveys with multi-wavelength studies, the project aims to connect the explosive endpoints of stellar evolution with the properties and evolutionary pathways of massive stars, thereby determining the underlying physical mechanisms shaping this evolution.

Specifically, this project will correlate optical and radio transient properties to address key questions about how massive stars evolve and eventually explode.

The project is structured in two interconnected parts:
1.-Bridging the Gap: Supernova and Star Formation Rates: We will reconcile supernova rates with star formation rates by determining the fraction of supernovae obscured by dust. This involves a cutting-edge approach: cross-matching optically detected supernovae with radio emission. This analysis will serve as a basis for future radio studies, optimising synergies with upcoming facilities such as the Vera C. Rubin Observatory's Legacy Survey of Space and Time (LSST) and the Square Kilometre Array (SKA).
2.-Decoding Circumstellar Interactions: Probing Progenitor Stars: Radio observations are a powerful tool to characterise the progenitors of supernovae, allowing us to measure crucial properties like mass-loss rates, pre-supernova wind density and structure, and even magnetic field formation. By analysing radio light curves of synchrotron self-absorbed supernovae, we can directly probe the shock radius and magnetic field strength.

This project offers the opportunity to join an international community and develop research skills in stellar evolution and transient astronomy. You will collaborate directly with leading researchers, including Dr Maria Teresa Botticella at INAF-Osservatorio Astronomico di Capodimonte, an expert on supernova rate studies, and Dr Mattia Vaccari at the University of Cape Town, who is deeply involved in radio astronomy.

Preparing for the Roman imaging of nearby galaxies (Leo Girardi Michele Trabucchi, Giada Pastorelli)
The Nancy Grace Roman Space Telescope (Roman for short) will be launched next year, adding a fantastic facility for the study of nearby galaxies in the near-infrared. It will be able to image an area 100 times larger than the Hubble SpaceTelescope, in just one shot and with similar spatial resolution. Leo Girardi is deeply involved in the preparation for the “nearby galaxies” part of the Roman surveys, together with colleagues at University of Washington, Seattle. Present work is concentrated on making detailed simulations of the Roman data, but soon it will change to the exploration of real Roman data. Particularly interesting will be the improvements in the determination of space-resolved star formation histories, and dust mapping in galaxies, provided by the combination of Roman and already-available Hubble Space Telescope data. Another important possibility will be the simultaneous measurement of thousands of light curves for long-period variables in galaxies, hence improving their calibration as standard candles. The PhD student will develop the tools needed to model and interpret such new data, starting from our libraries of stellar

evolutionary tracks, isochrones, and pulsation models.

Asteroseismology in the PLATO era (Leo Girardi Diego Bossini (Uni Padova), Andrea Miglio (Uni Bologna))

Asteroseismology has become a fundamental tool to obtain direct information about the main stellar parameters (mass, radius) and their internal structure. A mine of asteroseismic data of unprecedented precision and richness is now available due space missions like CoRoT, Kepler, and TESS, and it will be further enhanced with ESA's mission PLATO. In this context, red giant stars have proven to be excellent laboratories to test asteroseismic techniques. Unraveling the physics behind them is essential for their correct characterization, whether our intent is to study stellar populations, or the history of the Milky Way.

This PhD project focuses mainly on the asteroseismic modelling of low-mass, metal-poor red giant stars, and alpha-enhanced stars, which serve as valuable probes of Milky Way halo and thick disk populations. The student will use both the PARSEC code to compute stellar evolution models, and the optimisation tool PARAM to determine the fundamental stellar properties.

The student will then apply those tools to data from space missions such as Kepler and TESS which have provided high-quality asteroseismic data for thousands of stars, including Galactic red giants. The aim is to calibrate stellar models of red giant stars and set the stage for the upcoming PLATO mission.

Spectroscopic Investigation of Stellar Populations in Globular Clusters (Anna Fabiola Marino Emanuele Dondoglio)

The discovery of multiple stellar populations within globular clusters has reshaped our understanding of these ancient systems. Once thought to be simple, chemically homogeneous stellar populations, globular clusters are now known to host a rich variety of stars with complex chemical signatures and evolutionary histories. Yet, the physical mechanisms behind their formation remain one of the major open questions in stellar astrophysics.

This PhD project is focused on high-resolution spectroscopy as the primary tool to investigate the chemical composition of these multiple populations. The candidate will lead a detailed spectroscopic campaign to perform chemical tagging of the various stellar populations revealed by advanced photometric diagrams. These chemical abundances serve as powerful diagnostics—acting as a chemo-dynamical clock—to trace the sequence of star formation events and the nature of the polluters that enriched the interstellar medium across different evolutionary timescales.

While the core focus will be on spectroscopic analysis, the project will also benefit from synergies with high-precision photometry and astrometry, combining complementary datasets to provide a more complete picture of globular cluster formation. The candidate will work at the frontier of observational capabilities, maximising the potential of current telescope facilities.

The ideal candidate will have a strong interest in stellar astrophysics, spectroscopy, and data analysis. This is a unique opportunity to join a vibrant field at the forefront of Galactic archaeology and stellar evolution.

Spectroscopic Investigation of Stellar Populations in Globular Clusters (Anna Fabiola Marino Emanuele Dondoglio)
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Chemical Signatures of Planet Engulfment in Sun-like Stars (Lorenzo Spina Giovanni Carraro, Sara Lucatello)
Planet engulfment events occur when a star accretes rocky planetary material, typically as a result of orbital decay or instabilities within the planetary system. When this material falls into the star, it dissolves in the stellar envelope, leaving behind detectable chemical signatures that reflect the composition of the engulfed bodies. This PhD project aims to identify and characterize these signatures in Sun-like stars using high-resolution spectroscopy and stellar modelling. Detecting the chemical fingerprints of engulfed planets can offer valuable insights into the diversity of planetary compositions beyond our Solar System, providing a new way to explore the building blocks of other worlds through stellar chemistry.

Galactic astronomy with machines (Lorenzo Spina Giovanni Carraro, Sara Lucatello)
Galactic astronomy is entering a new era, shaped by the rapid growth in the volume and quality of stellar data. In the coming years, massive datasets will become increasingly available, offering an unprecedented opportunity to study the formation and evolution of our Galaxy in exquisite detail. This PhD project is focused on developing and applying innovative

data-driven methodologies - such as advanced statistical tools and machine learning techniques - to extract meaningful insights from complex, high-dimensional data. By participating in this project, the student will gain hands-on experience at the intersection of astrophysics and data science, building a skill set that is highly valuable both in academic research and beyond.

Peculiar objects in globular clusters: key elements to understand multiple populations? (Simone Zaggia Simone Zaggia, Yazan Al Momany, Leo Girardi)
The study of Galactic globular clusters (GGCs) has long been a cornerstone in understanding stellar evolution and the formation history of the Milky Way. Among the various stellar populations within GGCs, peculiar stars with various variability properties have been seldom studied in a systematic way to understand their properties, evolution and origin. This PhD project aims to investigate the characteristics and distribution of such stars in GGCs which could be key to shed light on the complex phenomenon of multiple populations problem within these clusters. With the availability of more than 10 years of VLT Survey Telescope continuous monitoring and the imminent starting of the scientific operations of the Large Synoptic Survey Telescope (LSST), this research will aim at the study of all peculiar stars present in a diverse sample of GGCs. The project will focus on identifying and characterizing the various subpopulations, their variability characteristics and possible compositions. These will include stars in the Horizontal Branch which harbours the presence of exotic variables like the "Padua" variable discovered by Momany et al. in the year 2020. By examining their spatial distribution, chemical composition, and evolutionary pathways, we aim to uncover the underlying mechanisms driving the formation of multiple populations in GGCs. Special attention will be given to the role of helium enrichment, age differences, and stellar rotation in shaping the observed properties of such peculiar stars. Through a combination of observational data and theoretical modeling, this research will contribute to a more nuanced understanding of the multiple population problem in GGCs. The findings are expected to have broader implications for the study of stellar evolution, the chemical enrichment history of the Milky Way, and the formation processes of globular clusters. Ultimately, this project seeks to bridge the gap between observational evidence and theoretical predictions, providing new insights into the intricate dynamics of GGCs and their stellar constituents.

The Milky Way galaxy revealed by Rubin/LSST first data (Simone Zaggia Simone Zaggia, Leo Girardi, Giada Pastorelli)
The Rubin/LSST survey will soon start creating the deepest-and-widest photometric catalogue ever, containing about 19 billion stars over half of the sky, in six different wavelengths, and with rich variability information. This will be a treasure trove for studies of stellar evolution and of the Milky Way structure and evolution. Our team is deeply involved in the preparation of the survey and in developing the tools to interpret the stellar data. In this PhD project, we will develop the tools needed to exploit the star counts in the Rubin/LSST data. They include: 1) to estimate the incompleteness and real photometric errors on the data from LSST First-Light and Science Verification images (to become available before May 2026); 2) to compare the star counts revealed by these images to our predictive models that generate synthetic LSST data starting from grids of stellar evolutionary tracks, spectral models, spatial densities and star formation histories; 3) to improve the latter prescriptions

so that we gain a better description of the Milky Way components, and their stars. Particularly interesting will be the application of these methods to the star clusters and nearby dwarf galaxies to be imaged during the Science Verification phase. The PhD student will be inserted into Rubin/LSST – the most ambitious astrophysical project of the next decade – with full data rights, and will be expected to interact with our main collaborators in the USA (Seattle and Tucson) and in Croatia (Zagreb and Rijeka).

Sole e Sistema Solare

Surface investigation of icy satellites in the Outer Solar System (Alice Lucchetti Luca Penasa, Maurizio Pajola)
The exploration of the icy satellites in the outer Solar System shows a stunning variety in these bodies' surface geology. In addition, they are also interesting from an astrobiological perspective because they are "ocean worlds", hosting or possibly hosting a subsurface salty ocean underneath their cold icy surface. Understanding both the geological processes that shape the icy satellites' surfaces and the link between the subsurface ocean and the surface itself is pivotal to give new insights into their current states and geological histories and/or evolution.
The aim of the PhD project is to make a comparative analysis between the icy satellites of the outer Solar System to identify the common and different geological processes affecting them through the usage of data acquired by space missions, e.g. Voyager at Uranus, Galileo at Jupiter, Cassini-Huygens at Saturn and New Horizons at Pluto-Charon. The PhD project foresees a geomorphologic mapping of icy satellites, a structural analysis of the surface features, and a spectral and compositional analysis using images acquired by visible cameras onboard past space missions. This will be done to understand how these surface observations can lead to implications for the subsurface or evolution of the body. In particular, a special attention will be given to Jupiter icy moons, Europa, Ganymede and Callisto considering the upcoming ESA JUpiter Icy Moon Explorer (JUICE) mission in which the PhD candidate will be involved fostering international collaborations.

Surface properties of Near-Earth Asteroids (Maurizio Pajola Alice Lucchetti)
Researching asteroids furthers our understanding of the formation and evolution of our Solar System. Indeed, such bodies are considered to be among the most pristine objects which formed before the planets and can therefore be used to find out how the early stages of planet formation and evolution looked like. In addition, different processes such as impacts and thermal fatigue might have partially/totally modified the asteroids' uppermost layers. For this reason, studying the geomorphological properties of asteroidal surfaces, such as craters size-frequency distribution (SFD), boulders SFD, the occurrence of mass movements, lineaments, fractures as well as their spectroscopic returns pivotal clues about how such bodies formed and might have evolved.

The aim of this PhD Thesis is to analyze the huge imagery, topographical and spectral dataset we obtained of NEAs in general, and of binary asteroid (65803) Didymos-Dimorphos (target of the NASA/ASI DART-LICIACube and of the coming ESA/Hera missions) and of (101955) Bennu (target of the NASA OSIRIS-REx mission) to study their surfaces

properties, focusing on the identification of i) multiple geological units, ii) crater and boulder SFD, iii) global lineaments and localized fractures and iv) mass movements. By merging such analysis with their spectral properties, the PhD Candidate will be able to provide the most complete picture of these two bodies returning a state-of-the art framework of Didymos-Dimorphos prior to the arrival of Hera in 2027, as well as the widest possible context of Bennu as the parent body of the samples that returned back to Earth in September 2023.
Last but not least, the PhD candidate will have the unique opportunity to become part of the mentioned missions, working in a thrilling, young and international environment.

Supervisors: Maurizio Pajola, Alice Lucchetti – INAF Astronomical Observatory of Padova, Italy

Calibration and performance evaluation of the stereo cameras for space missions. (CRISTINA Re Emanuele Simioni)
The Phd will be focused on stereo cameras calibration applied to the field of planetary sciences. The calibration procedures of stereo camera systems on planetary missions is a critical process to ensure the accuracy of 3D surface reconstructions and topographic mapping. The study will consider the development and refinement of routines concerning the calibration procedures and performance evaluation of stereo camera systems designed for at least two different space mission contexts (in-orbit remote sensing context and in-situ rover-based mapping). The BepiColombo mission to Mercury will be one of the main scenarios and the in-flight calibration of the stereo imaging channel (STC) will be studied. An hyperspectral stereo camera for a future lunar rover will be also considered. For what is concerning the BepiColombo data, the PhD will have the opportunity to test the procedures with real images since the starting of the nominal mission phase will occour in the middle of the PhD period.
The project will consider the development of routines for in-flight calibrations to correct geometrical shifts that may be affected by mechanical stress or thermal deformation. Star field imaging will be, in fact, used periodically to verify absolute pointing accuracy and refine boresight alignment in order to ensure accuracy of data products such as digital terrain models (DTMs), orthoimages, and geological maps. Procedures will be also developed to perform radiometric and spectral calibrations in order to translate the raw sensor output (DNs) into absolute physical measurements. The calibration activities of a rover hyperspectral stereo camera will be planned for the validation of the capability of the a prototype system to reconstruct a 3D surface for each waveleghts.

<u>Tecnologie avanzate e strumentazione</u>

Imaging and photogrammetric techniques for the PANCAM System on ESA's DAEDALUS Mission: Enabling 3D mapping of lunar Lava Tubes (Emanuele Simioni claudio.pernechele@inaf.it)
The European Space Agency's DAEDALUS mission aims to explore the subsurface environment of the Moon through the robotic descent into lunar lava tubes—potential sites for future human habitation and valuable archives of the Moon's geological history.
At the core of this mission is the PANCAM system, a hyper-hemispherical imaging camera designed to operate in GPS-denied, low-light environments. This PhD research focuses on

the development and application of advanced imaging and photogrammetric methods tailored to the unique characteristics and constraints of the PANCAM system. A key objective is to adapt and extend the image processing pipeline developed for the CaSSIS stereo camera on Mars to the extreme field of view (FoV) and optical geometry of the PANCAM. The research will involve the design and validation of novel algorithms for image correction, 3D reconstruction, and spatial analysis, applicable both to lunar conditions and terrestrial analog cave environments. Through a combination of simulation and experimental field testing, this work aims to improve spatial awareness, autonomous navigation, and scientific interpretation within lunar lava tubes, delivering essential capabilities for the success of DAEDALUS and future robotic exploration missions.

The Lunar Panoramic camera PANCAM (Emanuele Simioni claudio.pernechele@inaf.it)
The PANCAM Camera

This payload was designed at the National Institute for Astrophysics (INAF) to integrate the capabilities of a high-resolution camera with those of a hyper-hemispherical imaging system. Thanks to its extremely wide field of view, PANCAM was selected for the European Space Agency's DAEDALUS mission, aimed at exploring lunar lava tubes. These structures, confirmed by the GRAIL mission, represent thermally stable and protected environments that could serve as potential sites for human settlement on the Moon. The PhD project will focus on the development and application of photogrammetric methods tailored to the unique optics of PANCAM, with the goal of supporting autonomous navigation and scientific exploration within lunar cave environments.

EKARUS - Design optimization and implementation of an Adaptive Optics system for the Asiago Copernico telescope (Davide Greggio Gabriele Rodeghiero)
This PhD project will focus on the design adaptation, optimization, and commissioning of the Adaptive Optics (AO) system Papyrus for integration with the coudé focal station of the Copernico Telescope at Cima Ekar, Asiago. Papyrus is an AO system based on a pyramid wavefront sensor, currently installed at the Observatoire de Haute-Provence. Due to ongoing maintenance and upgrades at its current site, there are plans to temporarily relocate the system to the Copernico Telescope, where it will be operated under the name EKARUS.

This relocation presents a valuable opportunity for research and development in adaptive optics, as well as hands-on training for students and early-career researchers in advanced AO technologies. The main objectives of the project include: 1)Adapting and optimizing the Papyrus system for the Copernico telescope, 2)Carrying out its installation and on-site commissioning.

The activity will provide the candidate with optical design skills, as well as alignment and integration techniques. The position requires the availability to spend periodic shifts at the Cima Ekar Asiago Observatory.

The project will be conducted in collaboration with the Laboratoire d’Astrophysique de Marseille (current owner of Papyrus), the University of Durham, and various INAF institutes in Italy.

MATTO - Integration and optimization of a Multi-Conjugate Adaptive Optics facility (Luca Marafatto Alessandro Ballone)

This PhD project will focus on the integration, alignment and optimization of MATTO, a Multi-Conjugate Adaptive Optics (MCAO) facility, to be developed at INAF-OAPD premises. MCAO systems are in use, planned or evaluated for most of the current and future largest ground telescopes; MATTO will serve as a test bench for feasibility study, validation and comparison of next generation MCAO techniques. The bench is modular and includes both point-like (natural sources like) and elongated (laser like) reference sources, together with 3 Deformable mirrors, which can allow a variety of control scheme implementations.
The candidate will be involved in the:
integration of the bench: optical alignment of the components, verification of the configurations
implementation of the control scheme and real-time computing system
optimization of the full system
The project will make full use of the wide range of opto-mechanical resources provided by the PNRR STILES project, enabling the implementation of a system that currently has no competitors in the European landscape.
Such laboratorial setup will provide the candidate with the opportunity of facing all the different aspects behind the assembly and operation of a complex Adaptive Optics instrument, as well as the challenges for reaching the highest instrument performance for different scientific goals.