INAF2 projects
PhD Cycle 38

INAF2 – Project 1

Stellar clusters in the era of Gaia and large spectroscopic surveys

Supervisor: Dr. Angela Bragaglia

Contact: Dr. Angela Bragaglia, angela.bragaglia@inaf.it

PhD project in ASTROPHYSICS

Title of the Project: *Stellar clusters in the era of Gaia and large spectroscopic surveys*

INAF-OAS Supervisor : *Angela Bragaglia*

Co-Supervisors : *none*. Collaborators: E. Carretta, E. Dalessandro, A. Sollima (INAF-OAS Bologna); F.R. Ferraro, A. Miglio, A. Mucciarelli (DIFA Bologna); V. D'Orazi, S. Lucatello, A. Vallenari (INAF-OA Padova), *plus WEAVE and 4MOST Consortium members*.

Scientific Case: *Stellar clusters* are important constituents and tracers of the Galactic structure. They reside in the halo (the globular clusters), in the bulge and in the disk (where we see predominantly open clusters). Most stars form in associations and clusters which later dissolve, dispersing their constituents. Understanding the *connection between field stars and their parent cluster* is fundamental to figure out the cluster formation and dissolution mechanism and the contribution to the general chemical and dynamical evolution of the Galaxy. Stellar clusters are also the ideal site where to *test stellar evolutionary models*, by studying e.g. the presence and relevance of element diffusion, mixing, etc. Stellar evolutionary models are the best way to derive *ages*, on whose accuracy ultimately rests most of our understanding of galaxy evolution. We are now in a privileged era, with large surveys from the ground and space missions providing a wealth of information. *Gaia*, the ESA astrometric, photometric, and spectroscopic mission, is revolutionizing our understanding of the Milky Way and of galaxies in general, with its exquisite precision and accuracy for more than 1.5 billion objects. The 5-d map (coordinates, proper motions, and parallaxes) of the Milky Way provided by *Gaia* is complemented by photometric and spectroscopic large surveys from the ground, which add radial velocity, metallicity, and detailed chemical composition for a significant fraction of *Gaia* stars of all Galactic components and in particular for clusters of all ages. The full exploitation of *Gaia* and ground-based spectroscopic data to describe our Galaxy requires a precise and homogenous analysis of the stellar clusters, in combination with stellar models. *We mention in particular three projects which will provide the data and framework for the PhD project : the Gaia-ESO Survey (with FLAMES on the ESO VLT), the WEAVE survey (at the WHT on Canary Islands) and 4MOST (ESO public survey at VISTA, for which I am co-PI of the Community Survey "Stellar Clusters in 4MOST").*

Outline of the Project: The Bologna DIFA, INAF-OAS Bologna and INAF-OA Padova are involved in *Gaia*, *Gaia*-ESO, WEAVE, and 4MOST. The PhD project main steps are: 1) familiarization with the subject of stellar clusters and stellar populations; 2) analysis of data already in hand, both from large surveys and space missions; 3) interpretation and publication of results. The PhD project will center on (at least) one of the following topics: a) Globular clusters and the link between their chemistry and structural properties; b) Finding dispersed clusters stars using chemical and dynamical tagging; c) Using stellar clusters as test of evolutionary models; d) Using open cluster as chemical tracers of the disk. *Further developments or projects can be devised in agreement with the PhD student.*

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INAF2 – Project 2

Galaxy evolution with distribution functions of physical properties on the way to Euclid

Supervisor: Dr. Micol Bolzonella

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PhD project in ASTROPHYSICS

Title of the Project: Galaxy evolution with distribution functions of physical properties on the way to Euclid

INAF-OAS Supervisor : Micol Bolzonella (micol.bolzonella@inaf.it)

Co-Supervisors : Elena Zucca (elena.zucca@inaf.it), Lucia Pozzetti, Olga Cucciati, Sandro Bardelli + Euclid team (local and international)

Scientific Case: Distribution functions, like stellar mass, star formation rate and luminosity functions, allow us to derive statistical constraints on galaxy evolution, e.g. on the stellar populations in galaxies, on the history of mass assembly, and on feedback mechanisms affecting star formation. These functions for different galaxy classes and different environments (from voids to groups and clusters) are increasingly crucial for the analyses of the present and future galaxy surveys.
This thesis project aims at deriving distribution functions from available datasets, and then applying the acquired knowledge to the Euclid survey, starting in 2023.

Outline of the Project: Our group is involved in most of the largest state-of-the-art spectroscopic and photometric surveys carried out up to now (VVDS, COSMOS, VIPERS, VANDELS, VUDS, CFHTLS, ELAIS, HSC-SSP, SXDF, and others): the first step of the project is to combine them taking into account the different depths and characteristic observational uncertainties affecting the estimates of physical parameters. The homogeneous derivation of distribution functions from low to high redshift will provide a reference point for all the future studies and theoretical models of galaxy evolution. These distribution functions are also as a fundamental ingredient of the emerging technique of empirical models and machine learning techniques adopted to produce large mock samples of galaxies. The PhD candidate will be involved in the Euclid Collaboration, and will make use of the acquired expertise to optimally exploit the first Euclid data, actively collaborating to the determination of physical properties of galaxies, the selection of potentially interesting subsamples, and the derivation of their distribution functions and redshift evolution, using classical methods and machine learning algorithms.
Euclid (ESA Cosmic Vision mission, with launch planned in the first semester of 2023 and observations in the following 7 years) is designed to survey 15,000 deg^2 with visible (VIS) and near-infrared (Y, J, H) imaging to H_{AB}=24 with near-infrared slitless spectroscopy ($1.25<\lambda<1.85\mu m$), plus smaller and deeper fields observed about two magnitudes fainter.
The PhD candidate will be involved in this large international collaboration that will open the way to various future collaborations in different topics related to cosmology, simulations, galaxy evolution, big data mining.

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INAF2 – Project 3

Development, integration, testing and exploitation of high energy astrophysics satellite missions

Supervisor: Dr. Riccardo Campana

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PhD project in ASTROPHYSICS

Title of the Project:
Development, integration, testing and exploitation of high energy astrophysics satellite missions

INAF-OAS Supervisor
Riccardo Campana

Co-Supervisors:
Enrico Virgilli, Ezequiel J. Marchesini

Scientific Case:
High energy astrophysics, Experimental astrophysics, Space science, Instrumentation, Gamma-ray bursts, High energy transients

Outline of the Project:
The INAF/OAS "Laboratorio Gamma" group is playing a major role in many major space-based experiments, proposed or in development, aiming to vastly increase the discovery space of the high energy transient phenomena over the entirety of cosmic history. Currently, the main space projects with our involvement are:

- HERMES (*High Energy Rapid Modular Ensemble of Satellites*, http://www.hermes-sp.eu) that is an ASI-led project developing a constellation of nanosatellites, with a first launch around 2022, that aims to study the Gamma-Ray Bursts (GRBs) and high energy transient events like the electromagnetic counterparts of gravitational waves.
- eXTP (enhanced X-ray Timing and Polarimetry https://www.isdc.unige.ch/extp/), a Chinese-led mission with a large European participation, that is a science mission designed to study the state of matter under extreme conditions of density, gravity, and magnetic field. The launch is planned around 2030.

For the scientific objectives of these missions, a description of their on-board instruments, and the international context in which they operate the reader is invited to visit the related websites. For all these missions in an active realization phase, and in several other proposed missions and concept studies, INAF/OAS "Laboratorio Gamma" has a main role in conceiving, developing, realizing, and testing the relevant X and gamma-ray instrumentation, thanks also to several years of experience developed for missions currently operating (e.g., INTEGRAL, AGILE) or proposed (e.g., LOFT, THESEUS)
The proposed PhD project will take place in this framework, with specific activities that can be tailored on the candidate main interests and capabilities, in one or all of the following areas:

- Space-borne X-gamma instrumentation design, development, and test.
- Satellite assembly, integration, and testing (AIV) activities
- Simulation and optimization activities.
- Scientific data exploitation.

The ideal candidate should have:

1. Flexibility and willingness to learn
2. Willingness to work in large national and international interdisciplinary teams.
3. A reasonable knowledge of high-energy astrophysics main scientific themes and open issues.
4. Knowledge of basic electronics and computer programming is not necessary but useful.

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INAF2 – Project 4

Mass assembly at z>2: galaxy and structure formation in protoclusters

Supervisor: Dr. Olga Cucciati

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Osservatorio di Astrofisica e Scienza dello Spazio
OAS – Bologna

PhD project in ASTROPHYSICS

Title of the Project: ***Mass assembly at z>2: galaxy and structure formation in protoclusters***

INAF-OAS Supervisor : Olga Cucciati (olga.cucciati@inaf.it)

Co-Supervisors and collaborators: Margherita Talia (DIFA), Roberto Decarli (INAF-OAS), Sandro Bardelli (INAF-OAS), Micol Bolzonella (INAF-OAS), Lucia Pozzetti (INAF-OAS), Cristian Vignali (DIFA), Elena Zucca (INAF-OAS) + VUDS and VANDELS international teams

Scientific Case: Protoclusters of galaxies are crucial sites for studying how mass builds up in high-density regions of the early universe. The Cosmic Star Formation Rate Density, i.e. the average rate at which stars are formed at all epochs in the universe, rises from the early universe up to z~2, and then falls at z<2. The hierarchical formation of dark matter structures plays a role in both the rise and fall of the Cosmic Star Formation Rate Density. Indeed, there are physical processes taking place in high-density regions of the universe which are able to enhance or to quench the star formation in galaxies. We expect to observe signatures of both kinds of processes in the redshift range 2<z<4, given the evolutionary state of dark matter structures at these epochs and the time scales for these processes to have effect.

Outline of the Project: The main focus of this project is the study of proto-clusters identified in the VUDS and VANDELS spectroscopic surveys at 2<z<4. Both these surveys come with high-quality multi-wavelength data (from radio, to IR, optical and X-ray), used and to be used to derive galaxy properties. In particular, the interested student will 1) characterise the identified protoclusters (total mass, shape, 3D distribution…), infer their evolution with simulations and theoretical models, and find candidate "descendants" in the literature; 2) analyse galaxy properties (star formation rate, stellar mass, gas content, spectral features, presence of AGN...) as a function of environment. This double approach will allow the student to constrain the evolution of both structures and galaxies. The analysis will also include comparisons with simulations and models of galaxy evolution, to constrain how mass, from dark matter to stars, assembles in the universe.

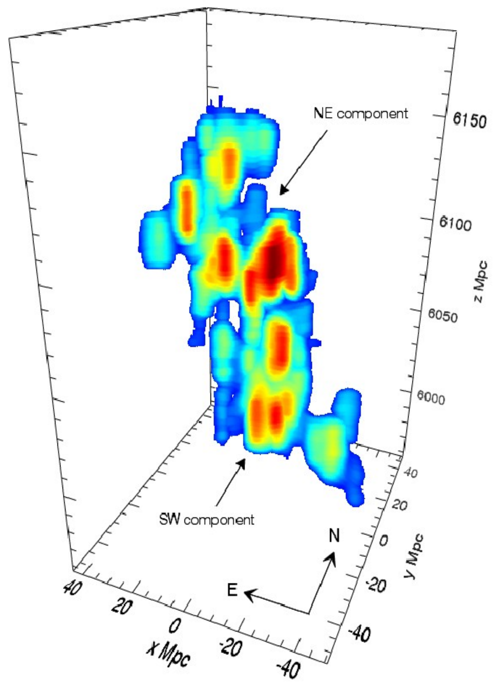

Fig. 1 - *The 3D shape of the Hyperion proto-supercluster at z=2.45 (Cucciati+2018)*

The interested student will work on data from the VUDS and VANDELS surveys and their ancillary data-sets, together with recently acquired follow-up data (e.g. from NOEMA, ALMA, KECK, HST), and will collaborate to prepare and apply for new observations with state-of-the-art instruments.

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INAF2 – Project 5

Studying ultra fast outflows in AGN using physical models

Supervisor: Dr. Mauro Dadina

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Osservatorio di Astrofisica e Scienza dello Spazio
OAS – Bologna

PhD project in ASTROPHYSICS

Title of the Project: Studying ultra fast outflows in AGN using physical models

INAF-OAS Supervisor : Mauro Dadina

Co-Supervisors : Gabriele Matzeu, Massimo Cappi, Paola Grandi, Eleonora Torresi, Giorgio Lanzuisi

Scientific Case:

All the galaxies in the Universe host a supermassive black hole (SMBH) at their center and the mass of their bulge correlates with that of the SMBH. This implies that they had coevolved across cosmic times. The discovery of ultra-fast outflows (UFOs) in the X-ray spectra of AGN indicated one of the best candidates to explain this tight correlation. AGN driven winds, being potentially able to sweep apart the interstellar dust, may act as medium to install self-regulating feedback mechanisms able to explain both the AGN feeding and the star formation history of the host galaxy ecosystems. We will use physically motivated models for the launching of these winds on existing XMM-Newton data to study UFOs and their energetics. This should allow a reliable estimation of the real impact that UFOs may have on the hosting galaxies.

Outline of the Project:

The proposing group may have access to the state-of-the art radiation- and magnetically-driven models explaining the UFOs launching and driving mechanisms.

AGN are a large family of objects. As such, it is fundamental to understand which of the two proposed mechanisms is dominating in different subsample of sources and/or if there are commonalities among the different classes of AGNs. Having this in mind and considering the three years duration of a PhD project, it is therefore fundamental to individuate samples of objects that may be considered as representative for one or more of the subclasses of AGN. The spectral analysis of the available X-ray data will be then used to infer: 1) which of the two scenarios is able to best describe the data (i.e. we will try to identify the best launching mechanism): 2) what is the energetic inputs into the host galaxies to estimate the real impact of these winds on the galaxy evolution. It is worth noting that these aspects are often inspected using very crude assumptions on the geometry and mass outflow rates of the UFOs. Some of these unknowns are indeed parameters of the fitting using the physical models and this will represent a huge step forward in this respect.

Finally, the obtained results will be used to simulate AGN observations with the XRISM (Jaxa and NASA) and Athena (ESA, NASA and Jaxa) X-ray observatories. They will carry new developed microcalorimeters that will couple unprecedented energy resolution (7 and 2 eV respectively) and collecting area. XRISM will be launched in 2022, in perfect timing with the proposed project, while INAF-OAS is deeply involved in the Athena project (launch ~2034).

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INAF2 – Project 6

Quasars at the dawn of cosmic time

Supervisor: Dr. Roberto Decarli

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PhD project in ASTROPHYSICS

Title of the Project: ***Quasars at the dawn of cosmic time***

INAF-OAS Supervisor : Roberto Decarli

Co-Supervisors : Marcella Brusa (DIFA)

Scientific Case: Quasars at z>6 (when the universe is <1 Gyr old) are arguably the most active objects in the early Universe. The high luminosity of a quasar is powered by rapid accretion of gas (>10 M_o yr^{-1}) on a central black hole with mass M_{BH}>10^8 M_o. Their host galaxies are forming stars at humongous rates (100-1000 M_o yr^{-1}). Copious reservoirs of gas sustain both star formation and nuclear accretion. The very presence of such compact concentrations of matter suggests that high-z quasars reside in the extreme peaks of the cosmic density distribution, so quasars could be used to pin-point the first galactic overdensities. These extreme properties make quasars unique laboratories of the birth and early formation of black holes and massive galaxies.

Outline of the Project: The project of this PhD thesis focuses on the search for and characterization of the first quasars, their host galaxies and their environment at cosmic dawn (z>6). The advent of sensitive, large-area optical/NIR surveys has propelled the discovery of new quasars at higher and higher redshift, recently breaching the z=7.5 frontier. The imminent launch of the Euclid satellite is poised to further boost the search for new quasars at even higher redshifts. At the same time, observations at mm and sub-mm wavelengths using Atacama Large Millimeter Array (ALMA) and Northern Extended Millimeter Array (NOEMA), coupled with sensitive optical/NIR photometry and spectroscopy from ground facilities, shed new light on the gas that fuels black hole accretion and that is the vehicle of any feedback mechanism. The James Webb Space Telescope (JWST) will revolutionize our view of quasar host galaxies and their environment, by exposing rest-frame optical gas tracers (such as hydrogen Balmer lines, and [OIII] lines). These observations will provide us with new diagnostics of the gas physics and kinematics, and of the stellar population of the quasar host galaxies.

The perspective student will have the opportunity to work on data collected through on-going observational campaigns using ESO/NTT, Nordic Optical Telescope, GranTeCan, ALMA, NOEMA, HST, and most notably, a dedicated JWST Cycle 1 General Observer project; and will design and implement new observational campaigns, with the goal of searching for new quasars at cosmic dawn and characterizing the formation and early evolution of the first quasar host galaxies. The project will take place in the framework of a well-established international collaboration (with main partners in Germany, France, the Netherlands, Spain, the USA, and China), that will naturally insert the student in a vibrant network of world-leading experts in the study of high-z quasars.

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INAF2 – Project 7

Tracing the cosmic web in X-ray and radio bands

Supervisor: Dr. Stefano Ettori

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PhD project in ASTROPHYSICS

Title of the Project: *Tracing the cosmic web in X-ray and radio bands*

INAF-OAS Supervisor : S. Ettori

Co-Supervisors : F. Vazza (DIFA)

Scientific Case: On scales larger than tens of millions light years, the Universe is self-organised by gravity into a spiderweb pattern filled by baryonic and dark matter: the "Cosmic Web". While the distribution of galaxies tracing the skeleton of the Web has been observed for decades in optical and infrared wavelengths, only a partial detection of its dominant mass component -the Warm Hot Intragalactic Medium/WHIM- has been possible so far, and only in its coldest component at ~1e6 K (e.g. Nicastro+18). The vast majority of the WHIM at hotter temperatures, that should be detectable in X-rays, is still missing a firm detection not to mention a proper characterization. Galaxy clusters form in the high density regions corresponding to the knots of this Cosmic Web, and their outskirts are the regions where WHIM filaments intertwine in the process of collapsing onto the main halo, identifying the transition volume between the virialized intracluster medium (ICM) and the in-falling material. These regions are thus suitable targets to locate the hottest component of the WHIM and to study the processes that regulate the formation of the collapsed structures (e.g. Ghirardini+19, Simionescu+21).

Outline of the Project: The PhD candidate will run and explore datacubes from cosmological hydrodynamical simulations produced in Magneticum (PI: Dolag, Munich Univ; these simulations cover large cosmological volumes and include many physical processes) and within the MAGCOW project (PI: Vazza; the simulations include the effects of magnetic fields and gas metallicity, allowing to predict the expected synchrotron radio emission from the shocked accreting regions), and will employ state-of-art tools (e.g. SIXTE) to obtain spectral-imaging products of the expected emission mostly at X-ray and radio wavelengths. These products will be compared with the sensitivity reachable with the present (X-ray: XMM-Newton, eROSITA; radio: LOFAR, MWA) and future (X-ray: XRISM/2023, Athena/2032; radio: SKA/2023) observatories to define the best strategy to constrain and characterize any emission associated with the WHIM at these energies, as pioneered in our recent work (Vazza, Ettori +19). An observational follow-up will be considered to look for filamentary X-ray emission associated to the WHIM around the most massive halos of the Universe out to z~0.6 that will be observed with dedicated XMM-Newton exposures as part of our 2018-2021 CHEX-MATE project (PI: Ettori), also using available lensing and radio information. The candidate will thus have the chance to apply an innovative and synergetic approach between multi-band observations and simulations to provide guidelines on the most efficient way to identify and measure the properties of the hottest part of the WHIM in emission.

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INAF2 – Project 8

The future of the cosmic microwave background through anisotropies and spectral distortions

Supervisor: Dr. Fabio Finelli

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PhD project in ASTROPHYSICS

Title of the Project: *The future of the cosmic microwave background through anisotropies and spectral distortions*

INAF-OAS Supervisor : Fabio Finelli

Co-Supervisors : Daniela Paoletti

Scientific Case: The spectral perfection and spatial imperfection of the Cosmic Microwave Background (CMB) were established by the COBE satellite in the early 90's. Anisotropies have been charted in intensity and polarisation at a finer and finer resolution with increasing sensitivity through the years by several experiments from space, balloons and ground and will be further measured by CLASS, Simons Observatory, LiteBIRD, CMB-S4. The measurement of spectral distortions instead had little progress since COBE FIRAS, but are targeted by different concepts of experiments from space (Pixie, PRISM, Pristine, Voyage 2050, FOSSIL). How cosmology could be constrained by the interplay of anisotropies and spectral distortions of CMB is the subject of this Ph. D. thesis.

Outline of the Project: The first year will be devoted to the learning of CMB science and of the public/private tools for theoretical predictions and data analysis. This will happen through interaction with the supervisors, attending cosmology schools and hands-on schools -previous Ph.D students of our group had greatly benefit from these hand-on schools. The second year will be dedicated to the use of spectral distortions dedicated codes for theoretical predictions and corresponding constraints which could be obtained by future experiments. Important scientific cases for spectral distortions studies are Early Universe physics and inflation (by opening a new window on density perturbations on small scales), black-hole formation scenarios, nature of dark matter, structure formation, cosmic magnetism and reionisation.
In the third year the student will study the cross-correlation between CMB anisotropies and CMB spectral distortions which will complete the combined constraints achievable by anisotropies and spectral distortion with future experiments. This activity will consist in developing new codes which could then be released in the public domain. The student will profit off the Marco Polo program within the University of Bologna. The student might use this opportunity to visit Jens Chluba, Univ. of Manchester, UK, who is a long-term collaborator in the field of CMB anisotropies and is probably the most renowned expert in the field of CMB spectral distortions at international level. The student will also profit from our involvement in projects such as LiteBIRD (also at the national level through the program under the ASI-UniRM2 agreement "Partecipazione italiana alla fase A della missione LiteBIRD") and in concepts for future measurements for CMB spectral distortions submitted to ESA (such as the ESA M7 proposal Fossil – FTS for CMB spectral distortion exploration - or the previous ESA F1 proposal Pristine – Polarised radiation interferometer for spectral distortions and inflation exploration).

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INAF2 – Project 9

The Milky Way assembly as traced by its stars and globular Clusters

Supervisor: Dr. Davide Massari

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PhD project in ASTROPHYSICS

Title of the Project: The Milky Way assembly as traced by its stars and globular clusters

INAF-OAS Supervisor : Davide Massari

Co-Supervisors : Alessio Mucciarelli (UniBO); Michele Bellazzini (OAS); Donatella Romano (OAS)

Scientific Case: The recent data release from the Gaia mission has triggered a revolution in our understanding of the assembly history of the Milky Way (MW). Leveraging this unprecedented dataset of nearby stars and globular clusters, a plethora of past merger events between the MW and dwarf galaxies have been discovered (Helmi et al., 2018, Massari et al.2019). Globular clusters have proven so effective in this respect, that the investigation of their chemistry has also opened the way to investigate the assembly of MW satellites, such as the LMC (Mucciarelli et al. 2021, Nature Astronomy). The next step to understanding the assembly history of the MW and its siblings is to characterise these merger events, in particular their star formation histories. The PhD candidate will pursue this ambitious objective by working first with state-of-the-art Gaia DR3 kinematic data, to associate the known Galactic globular clusters with their former galaxy progenitor based on their orbital properties. Then, they will reconstruct the progenitors chemical properties by using proprietary high-resolution spectroscopic data of both stars and globular clusters, to be compared with chemical evolutionary models to reconstruct each galaxy star formation history.

Outline of the Project:
Year 1: dynamical classification of retrograde field stars and globular clusters based on Gaia DR3 and proprietary spectroscopic data;
Year 2: Chemical analysis of inner-halo globular clusters and retrograde field stars;
Year 3: Comparison with theoretical models and reconstruction of the star formation history of past merger events

Dataset:
-52 hours of proprietary data taken with PEPSI@LBT (field stars)
-107 hours of proprietary data taken with UVES@VLT (field stars + globular clusters)
-Gaia DR3 kinematic data

External collaborations (possible Marco Polo destinations):
Prof. A. Helmi (University of Groningen, NL)
Prof. P. Bonifacio (Observatoire de Paris, FRs)

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INAF2 – Project 10

Machine learning techniques applied to the Gaia, TESS and LSST datasets.

Supervisor: Dr. Tatiana Muraveva

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PhD project in ASTROPHYSICS

Title of the Project: Machine learning techniques applied to the *Gaia*, TESS and LSST datasets.

INAF-OAS Supervisor: Tatiana Muraveva

Co-Supervisors: Alessia Garofalo (INAF-OAS), Gisella Clementini (INAF-OAS), Andrea Miglio (DIFA-UniBO)

Scientific Case: Astronomy is entering a new era of Big Data science thanks to exponentially growing data volumes from large surveys, such as *Gaia,* Transient Exoplanet Survey Satellite (TESS) and the Legacy Survey of Space and Time (LSST) at the Vera Rubin Observatory (VRO). The *Gaia* Data Release 3 will be published on 13 June 2022. In addition to the astrometry and broad-band photometry already available for about 1.8 billion sources in the Milky Way and beyond, it will provide information on large sets of variable stars, galaxies, asteroids, as well as astrophysical parameters, radial velocities, epoch photometry and spectra. TESS is an all-sky photometric survey providing exquisite high-cadence high-precision light curves for hundreds of thousands of bright stars. While TESS' primary aim is the detection of exoplanetary transits, it has proven to be a goldmine for studies of stellar variability. Finally, these datasets will be complemented by a 500 petabyte set of images and data products from the LSST@VRO that is expected to become fully operational in 2023. The extraordinary volume of these data will pose novel challenges as data volumes at these scales have never been encountered by the scientific community before. Thus, application of the advanced machine learning (ML) techniques, which can provide the level of accuracy and automation required to exploit large datasets efficiently, becomes highly needed and timely.

The PhD candidate will exploit state-of-art ML algorithms to (1) explore the whole data parameter space, searching for hidden correlations in the *Gaia* DR3 and, lately, LSST datasets; (2) infer the missing data (e.g. radial velocity, metallicity, age) from the available dataset (e.g. Dropulic et al 2021); (3) train the models used to classify variable stars on a combined sample of the time-series data from *Gaia* DR3, LSST and TESS. The PhD candidate is also expected to contribute to the research projects based on the *Gaia* and LSST data proposed for the Centro Nazionale High Performance Computing (HPC) and Big Data. With support from the Marco Polo fellowship program, he/she will spend periods abroad at Dipartimento de Inteligencia Artificial, UNED, in Madrid and at the DPAC data processing centre of the Geneva Observatory.

Outline of the Project:
YEAR 1: Investigation of the *Gaia* DR3, TESS and the LSST-simulated datasets. Application of the ML algorithms to *Gaia* DR3 data in order to explore the hidden correlations.
YEAR 2: Application of the ML algorithms to *Gaia* DR3 and LSST data to infer the missing parameters.
YEAR 3: Training the models used to classify variable stars on a combined sample of the time-series data from *Gaia* DR3, LSST and TESS.

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INAF2 – Project 11

Physical properties of galaxies over cosmic time: from present to future perspectives.

Supervisor: Dr. Lucia Pozzetti
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Osservatorio di Astrofisica e Scienza dello Spazio
OAS – Bologna

PhD project in ASTROPHYSICS

Title of the Project: Physical properties of galaxies over cosmic time: from present to future perspectives.

INAF-OAS Supervisor: Lucia Pozzetti (INAF-OAS Bologna)
Co-Supervisors & collaborators: M.Moresco (UniBo), M.Talia (UniBo), O.Cucciati (INAF-OAS), M.Bolzonella (INAF-OAS)+ WEAVE+STePs, MOONS, Euclid, 4MOST, MOSAIC teams

Scientific Case:

We propose a PhD thesis to derive physical properties of ISM and stellar populations in galaxies (such as the age, star formation history, metallicity of gas and stars, velocity dispersion, dust content and ionization state) at different masses and redshift, focusing mainly on full-spectrum modelling of their stellar continuum and of nebular emission using single or stacked high S/N spectra of galaxies.
We propose, using an archaeological approach, to start from the properties derived from the spectra of various existing surveys from low to high redshifts (from SDSS to VANDELS, LEGA-C), to analyse them in different environments, from field to groups/clusters. Spatially resolved galaxy spectra can be also analyse when available (using MUSE and MANGA public data). Finally, we propose in particular to study the possible application of this analysis to future instruments and surveys in which we are involved (MOONS, WEAVE, 4MOST, MOSAIC, Euclid). This study will allow to place constraints on the evolutionary paths of different stellar and gas properties in various galaxy types.

Outline of the Project:

Considerable progress has been made over the last several decades toward understanding the formation and assembly histories of galaxies. On the observational front, two complementary techniques are widely used. On the one side, lookback studies aim to study the evolution of galaxies in a statistical manner by comparing snapshots of the galaxy population at different cosmic epochs. On the other side, in the archaeological approach, one infers past evolution through detailed studies of z=0 galaxies and their stellar populations. This method of extrapolating back in time is enabled by high quality data of nearby galaxies. From previous surveys, it is well established that galaxy evolution proceeds with cosmic time, driven mainly by the quenching of the star formation, from blue/star-forming galaxies to red/passive galaxies, within a ''downsizing scenario'', from the most massive to the less massive galaxies. However, the detailed mechanisms driving this evolution, and the corresponding timescales are not yet fully understood. A possible way forward is to follow the archaeological approach at different epochs, constraining the possible evolutionary paths of passive galaxies, and removing some of the degeneracies between star formation histories and halo/galaxies assembly histories. Another fundamental and complementary ingredient is also the information about the chemical enrichment of both star and gas, providing information about how happened the gas exchange between the galaxy, its halo and the surrounding environment, and at the same times of the corresponding feedback processes responsible for the star formation quenching. Such detailed information can be only achieved through deep spectroscopy providing reliable measurements (SNR >>10) of the absorption features and of the stellar continuum. Combined with accurate multi-wavelength photometry in the optical and NIR bands, this approach allows to estimate accurate galaxy stellar masses as well as stellar ages, star formation rate, metal abundances, velocity dispersion, but also star formation history. On the other hand nebular emission will provide information on the gas-phase metallicities and ionization state of star forming galaxies through photoionization models (CLOUDY).

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INAF2 – Project 12

Chemical enrichment of the Milky Way and its satellites in the Large Survey Era.

Supervisor: Dr. Donatella Romano
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Osservatorio di Astrofisica e Scienza dello Spazio
OAS – Bologna

PhD project in ASTROPHYSICS

Title of the Project: ***"Chemical enrichment of the Milky Way and its satellites in the Large Survey Era"***

INAF-OAS Supervisor: Dr. Donatella Romano

Co-Supervisors: Prof. Alessio Mucciarelli (UniBO-DIFA)

Scientific Case: We have entered an exciting era for Galactic Archaeology studies, one in which astrometric data – from the ESA Gaia mission – and high-resolution spectroscopic data – from large past, ongoing, and forthcoming surveys, such as the Gaia-ESO Survey, APOGEE, GALAH, WEAVE, and 4MOST – can be effectively combined for thousands of stars to unravel the past star formation and chemical enrichment histories of our own Galaxy and its satellites. This wealth of data is revealing complex substructures as well as the existence of stars with peculiar chemical compositions; both these facts require a revision of current chemical evolution models.

Outline of the Project: During the first year of his/her PhD, the successful candidate will get familiar with data mining and will learn how to use packages such as `astropy` and `galpy` to obtain kinematic and dynamical properties of the stars from Gaia DR3 data, or aussieq2 to obtain stellar ages (see Romano et al. 2021, A&A, 653, A72). He/she will construct homogeneous data samples for different Galactic components comprising detailed chemical abundances, kinematic and dynamical data for the sample stars, as well as their ages. He/she will start to get familiar with the chemical evolution code for the Galaxy.
The second year will be dedicated to the calibration of the Galactic chemical evolution model against the Milky Way data. New stellar yields will be implemented in the code, updating and extending the work of Romano et al. (2010, A&A, 522, A32) and Romano et al. (2019, MNRAS, 490, 2838).
During the third year, the chemical evolution model will be extended to the closest Milky Way satellites (the Large and Small Magellanic Clouds) as well as to other interesting systems, such as Sagittarius (which is the relic of an ancient accretion episode).

Part of this PhD Thesis work will be done in collaboration with foreign experts (Marco Polo period); possible partners include Dr. Elisabetta Caffau (Observatoire de Paris, France) and Dr. Cristina Chiappini (AIP Potsdam, Germany).

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INAF2 – Project 13

Investigating the properties of kilonovae.

Supervisor: Dr. Andrea Rossi
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PhD project in ASTROPHYSICS

Title of the Project: Investigating the properties of kilonovae

INAF-OAS Supervisor : Andrea Rossi

Co-Supervisors : Giulia Stratta, Eliana Palazzi, Elena Pian

Scientific Case: The simultaneous detection of the gravitational wave (GW) source GW170817 and the short Gamma-ray burst GRB 170817A has provided the first direct evidence that at least a fraction of short GRBs is associated with the merging of two neutron stars (NSs). At the same time, the discovery of AT2017gfo, the optical counterpart of GW170817, allowed us, for the first time, to follow-up spectroscopically the elusive astrophysical phenomena known as "kilonova", associated with r-process nucleosynthesis in the ejecta of the NS-NS merger. Their studies are of fundamental importance to understand the nature of the progenitor of GRB, the equation of state of neutron stars, and the heavy element chemical enrichment of the Universe.
In Rossi et al., 2020 (MNRAS 493, 3379), we investigated the range of kilonova luminosity comparing the optical/NIR light curves of all short GRBs (sGRBs) with known redshift with those of the kilonova AT2017gfo. This study indicated a large diversity between the blue (optical) and red (near-infrared) components of the kilonova, with the first one covering at least 2 orders of magnitudes, while the second component is very similar in luminosities. To further understand the kilonova event, it is of fundamental importance to consider i) the contaminating GRB afterglow light ii) physically motivated kilonova models and iii) the possible energy injection from a magnetar.

Outline of the Project:

1) Simultaneous optical and X-ray analysis of the afterglow of short GRBs using *afterglowpy* Python package. Already existent data archive at OAS (<2019) should be updated with early epoch optical afterglow and X-ray light curves from Swift/XRT repository, and with new short GRBs with known redshift;
2) KN identification as extra feature with respect of the best fit afterglow, using model deviations in optical and NIR ;
3) Comparison of KN signal with AT2017gfo as well as with KN models tailored on each GRB with z and *afterglowpy* best fit parameters;
4) Comparison of KN models with afterglow luminosity when KN is not detected to constrain KN model parameter space;
5) Involvement in the GRAWITA and ENGRAVE collaborations, which are respectively the Italian and the European consortium dedicated to the follow-up and study of the counterparts of GW signals.

In addition to the scientific knowledge on the KN and short GRB, the candidate will learn the skills and experience necessary in data analysis and software development.

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INAF2 – Project 14

Thunderstorms, lightning, and gamma-rays: terrestrial gamma-flashes (TGF)observations from ground, from aircraft, and from the top of a volcano.

Supervisor: Dr. E. Virgili
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Osservatorio di Astrofisica e Scienza dello Spazio
OAS – Bologna

PhD project in ASTROPHYSICS

Title of the Project
Thunderstorms, lightning, and gamma-rays: terrestrial gamma-flashes (TGF) observations from ground, from aircraft, and from the top of a volcano

INAF-OAS Supervisor: E. Virgilli

Co-Supervisors: R. Campana, E. J. Marchesini (OAS-Bologna), Alessandro Ursi (IAPS-Roma), M. Marisaldi (UIB, Bergen, Norway)

Scientific Case
Terrestrial Gamma-ray Flashes (TGFs) are typically revealed during intense lightning episodes, which are phenomena of potential impact both on the atmospheric environment and on electronic instrumentation in flight and on ground. Risk mitigation strategies are currently under investigation by several groups in Europe and in the USA.
These events have been studied in depth in the last decade by the Fermi observatory and the Italian AGILE satellite, now joined by several other instruments, including the ESA's ASIM experiment on the International Space Station (ISS). The emission phenomenon, which includes gamma-rays and neutrons, is not yet fully understood. For this reason, in addition to and in synergy with observations from satellites in space, it is crucial to obtain local measurements on ground and on aircraft with dedicated instrumentation.

Outline of the Project
Within the Gamma-FLASH project, INAF/OAS develops a suite of scintillator detectors to be installed in terrestrial and in aircraft experiments for TGF detection during thunderstorms. Energy and thermal calibration must be performed on these detectors.
High lightning rate locations have been identified both for terrestrial observations and flight campaigns. The activities are in collaboration with INFN, Universities of Roma and Padova, ISAC and the Italian Air Force. Further activities are foreseen with the execution of extended flight campaigns, and with the installation of scintillator detectors on the slopes of the Etna volcano, where an INAF observatory is also present. These activities will combine the detection of gamma-ray radiation in the relevant environment, rich in volcanic dust that increases the lightning rate, and with the monitoring of the electric field within the thunderstorms. In the proposed PhD project, the following activities will be assigned: A) critical interpretation of the physical origin of the TGFs, B) definition of the scientific requirements for their detection, C) design, development and set-up of X-/gamma-ray instrumentation, D) Installation in situ of the instrumentation and test. E) Data analysis of the obtained ground-based measurements, possibly in connection with lightning data.
The ideal candidate must have 1) good disposition to work in a team, 2) high motivation in undertaking outdoor experimental campaigns, 3) flexibility in working on different aspects, from the experimental activity to the data analysis, 4) analytical skill in the interpretation of the results.

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