3 INAF

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

Supervisor: Santi Cassisi (INAF-IAPS)
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Abstract: Ongoing observational surveys are producing an extremely detailed view of the chemo-kinematic properties of the Milky Way. To fully exploit the potential of this wealth of information, and constrain MW formation and evolution models, it is crucial to retrieve an additional, fundamental information: the age of large samples of stars in Galactic fields and clusters. In such a way, a detailed chrono-chemo-dynamical map of the MW can be obtained. The aim of the project is to obtain a homogeneous age scale appropriate for the whole parameter space in terms of age and metallicity. Various chronometers will be applied to stars in different evolutionary stages, all of them calibrated homogeneously on a stellar model set. To this purpose, the first step is to provide an updated theoretical evolutionary framework whose uncertainties have to be properly evaluated. To set the various stellar clocks to the same age scale, one needs to use a suitable observational benchmark, whose age dating can be simultaneously performed by using different age indicators. To this aim, we will adopt a sample of MW open clusters, carefully investigated in the context of high-precision, observational surveys.

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

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

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

3.3 The impact of magnetic fields on M dwarf stars

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

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

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

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

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

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

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

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

3.7 Look up at the stars to understand the new physics

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Co-Supervisor: Alessandro Mirizzi (Univ. Bari) - Cristina Pallanca (Univ. Bologna)
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Abstract: Does the neutrino have a non-zero magnetic moment? Why don't strong interactions violate CP symmetry? What is dark matter made of? Answers to these and other fundamental questions may be found looking

at stars as laboratories of physics. By comparing observable stellar properties (luminosity, effective temperature, composition. . . .) to predictions of stellar models that incorporate theories beyond the Standard Model, we may constrain the new physics paving the route toward a better comprehension of the fundamental laws of nature. Our team boast a widely recognized experience in observing stars of different mass, age and composition, in modelling their interior and in modify the stellar structure equations in order to incorporate new physics ingredients. Important results have been already obtained, see, e.g., Straniero et al. 2019 (ApJ 881, 158), Menjiao et al 2021 (Ph.Rv.L. 126, 1101), Straniero et al. 2020 (A&A 644, 166). Depending on the student's skill and interest, the thesis may be either observational (multi-wavelength stellar photometry) or theoretical (stellar models and physics of stellar interiors).

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

Supervisor: Elisa Portaluri (INAF-OAAb)
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Abstract: Adaptive Optics (AO) brings together all the technologies that allow removing the images degradation due to wavefront aberrations. Its application ranges from bio-science to optical tele-communication, and in particular in astrophysics, where AO is of paramount importance for the present and future largest telescopes, like the ELT. Its classical approach is based on the usage of one or more wavefront sensors, one or more multi-actuators (deformable mirror, DM) and a real-time computer (RTC) to realize a closed loop system for the compensation of the atmospheric turbulence during observations. The use of Machine Learning is opening up new perspectives in the development of highly performing techniques for wavefront sensing, DM control and post-processing of astronomical data. The research activity will consist in the study of algorithms and neural networks for the reconstruction of the relationship between wavefront aberrations and phase compensation, for both the optimization of real-time control loops, and the

speed-up of post-processing operations. The work foresee the development of laboratory test benches and the usage of dedicated hardware for real-time & cloud computing.

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

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Abstract: The thesis will concern the development of optical and near infrared (NIR) instrumentation for the new generation of extremely large telescopes. INAF-Abruzzo, is in charge of the design and construction of the MAORY Calibration Unit for the ELT telescope, a highly complex and advanced subsystem that will allow to calibrate MAORY, the largest and challenging Adaptive Optics module currently under development, to be mounted on the 39m diameter European Extremely Large Telescope (ELT). The candidate will have the unique opportunity to take part this cutting-edge project by carrying out system engineering, performance and verification analysis, during the Final Design Review phase of the project, and in preparation of the Manufacturing Assembly Integration and Test (MAIT) phase. The research activities will include the development of laboratory test benches - for showcasing new technologies and methodologies - and will be carried out within the MAORY international collaboration, a large multi-disciplinary team of engineers and scientists.