**Fenomeni estremi in astrofisica**

***Extreme phenomena in astrophysics***

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| These theses are aimed at studying in detail rare astrophysical objects (supernovae, optical transients associated to gravitational waves, extreme QSO, binary neutron stars and other high energy galactic sources, as well as peculiar galaxies). |

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| Andrea Pastorello | **Interacting Supernovae and supernova impostors.**<br>"Supernova impostors" are a family of eruptive variables with observed properties resembling those of true supernovae. However, as a major difference with genuine supernova explosions, impostors reach fainter absolute magnitudes (below -15), and - most importantly - the progenitor stars survive the eruptive episodes. Recent studies suggest that several types of massive stars may experience luminous outbursts, including different classes of super/hypergiants, luminous blue variables and early-type Wolf-Rayet stars. And major outburst can be also observed as a consequence of coalescence of two stars.<br>The discrimination between impostors and real supernovae is sometimes a tricky issue. Observational evidences suggest a tight correlation between impostors and a class of supernovae whose ejecta interact with dense circum-stellar medium (CSM), that can be either hydrogen-rich or helium rich (and, hence, hydrogen-poor).<br>The former transients have been linked with massive, hydrogen-rich precursors (primarily luminous blue variables, but also A to K-type hypergiants or even red supergiants), the latter with Wolf-Rayet stars (mostly WNE).<br>More interestingly, the progenitors of interacting supernovae experienced enormous mass-loss events a very short time (weeks to a few years) before the terminal supernova explosion. In other words, real supernovae have been occasionally observed to be heralded by an outburst (i.e. a supernova impostor).<br>The PhD thesis project consists in analyzing data of recent supernova impostors and/or genuine ejecta-CSM interacting supernovae. This includes the follow-up of the transient event (SN/impostor), as well as the inspection of pre-discovery archive Hubble Space Telescope images with the aim of recovering the pre-burst variability history of the progenitor star. The PhD student is expected to perform observation at the telescopes (Asiago, La Palma, La Silla), to gain expertise in the reduction and analysis of ultra-violet to infrared photometry and spectroscopy, and manage theoretical tools.<br>The PhD student is expected to lead projects on major international collaborations, including the running "Extended-Public ESO |

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| | Spectroscopic Survey for Transient Object" (ePESSTO+), which is awarded by 90 nights in the next 18 months at the 3.56-m New Technology Telescope at La Silla and a 2-years lasting Large Program at the 2.5-m Nordic Optical Telescope (NOT, in collaboration with researchers from institutions of North Europe Countries) to study peculiar stellar transients, and the newly born Fast and Dark Side of Transient experiment, which will study rapidly evolving transients with the Liverpool Telescope.<br><br>All the above projects provide a bunch of observational time to monitor a large number of interesting transients, including interacting SNe and SN impostors. The proposed supervisor is co-leading an ePESSTO+ science team aimed at studying interacting SNe, SN impostors and stellar mergers, and the PhD candidate is expected to actively join the team activities. Most importantly, the supervisor is the PI of one of the INAF-approved proposals to study stellar transients with the Large Synoptic Survey Telescope (LSST). As the LSST consortium is now requesting to provide templates for rare stellar transients, the activities of the PhD student will be in the framework of the LSST preparatory phase. |
| Enrico Cappellaro | **Optical counterparts of gravitation wave transients**<br><br>A new era of multi-messenger astronomy began on 2017 Aug 17 with the LIGO/Virgo discovery of gravitational waves from the coalescence of two neutron stars (GW170817) and the subsequent detection of electromagnetic radiation at all wavelengths from gamma ray to radio wavelengths.<br>The prompt identification and the detailed photometric and spectroscopic follow-up of the associate optical transient (AT2017gfo) lead to confirmation of long standing conundrums for the outcome of BNS mergers in particular with respect to the nucleosynthesis of very heavy (r-process) elements.<br>The Ligo/Virgo interferometers are resuming their operations in March 2019 with improved sensitivity. New exciting discoveries are expected in the forthcoming months.<br>In this context our group is giving a major contribution to the Italian (GRAWITA) and European (ENGRAVE) collaborations for transient search, observational follow-up and data analysis of GW-associated optical transients.<br>Each of these themes offer plenty of opportunities for original researches in observational astrophysics using top instrumentation facilities ranging from wide field imagers to optical and infrared photometry and spectroscopy. |
| Paola Marziani<br><br>w. | **Extremely accreting quasars and cosmology**<br><br>Quasars are among the most luminous sources in the Universe. There are still many enigmas on their inner workings; in addition, a large |

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| P. Mazzei<br>M. D'Onofrio | spread in luminosity has hampered their use for cosmological studies. However, several very recent works suggest that it may be possible to exploit a particular class, extremely accreting quasars, as cosmological distance indicators. The student will start from the definition and analysis of a large sample of highly accreting quasars in terms of optical UV and soft-X-ray properties from survey and archival data (SDSS, BOSS, MAST, etc.) and already collected Gran Telescopio Canaries observations. The project will first lead to results on the physical and structural parameters of extremely accreting quasars that are presently poorly understood and that are at the basis of luminosity estimates. Results will then be applied to derive estimates of the principal cosmological parameters with a proper analysis of statistical and systematic effects. The project involves collaborations with researchers at IAA (Spain) and UNAM (Mexico). In 3 years the student will acquire a culture on important theoretical and phenomenological aspects of quasars, the ability to analyze and measure spectroscopic multifrequency data as well as to apply methods commonly used in observational cosmology. The prospect of the thesis is to give a relevant contribution to a frontier field that will open further lines of research on AGNs and in observational cosmology. |
| Luca<br>Zampieri | **High Energy and Time Resolution Astrophysics of Galactic sources**<br><br>The development and construction of arrays of Cherenkov imaging telescopes, in which INAF is technologically involved through the ASTRI Mini-array project, opens up unprecedented opportunities for the study of very high energy (VHE) Galactic sources. In addition, our team is engaged in the design, construction and operation of instruments with very high time accuracy in the optical band for applications to the High Time Resolution Astrophysics (HTRA) of variable sources (Aqueye+, Iqueye). These investigations have the ultimate goal to move significantly closer to an understanding of the mechanisms for particle acceleration at the highest energies, and of the physical processes at work close to neutron stars and black holes.<br><br>The proposed PhD project is devoted at the simulation/observation and modelling of Galactic sources with compact objects using CTA, the ASTRI Mini-array, and Aqueye+Iqueye, with the aim of improving our knowledge of the VHE emission and of the fast variability of these sources. The plan is to use also the available archival X-ray and Fermi data to complement the information at VHE and in the optical band. The PhD activity will include a partial involvement in the technological development of our HTRA instrumentation. |
| Riccardo<br>Ciolfi | **Short gamma-ray burst jets from binary neutron star mergers**<br><br>The recent gravitational wave detection of a binary neutron star (BNS) merger in coincidence with a short gamma-ray burst (SGRB) proved the long-standing hypothesis connecting the two phenomena. The post- |

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| | merger dynamics leading to the formation of a SGRB jet remains however uncertain.<br>The interested PhD student will employ special relativistic magneto-hydrodynamics simulations performed with the PLUTO code to investigate how the properties of the system affect the ultimate jet observables, i.e. the energetics and the angular structure. While previous studies assumed simple hand-made initial conditions for the matter distribution in the environment surrounding the merger site, here the student will directly import, for the first time, the results of state-of-the-art BNS merger simulations.<br>The results will be crucial to interpret the prompt and afterglow emission of past and upcoming SGRB events. In particular, this work will directly contribute to the efforts of the GRAWITA project in a multimessenger context and to reinforce the science case of the THESEUS space mission. |
| Laura Greggio | **Identifying the progenitors of Supernovae from LSST data**<br><br>Supernovae come in two main flavours, thermonuclear explosions (Type Ia) and Core Collapse explosions. Within each of these classes there are many subtypes, with a variety of photometric and spectroscopic display. The various subtypes are related to the mass range and to the specific evolutionary path of the progenitors. The rate of events of the various types, and its correlation with the properties of the parent galaxy lead to important constraints on the nature of the progenitors. To investigate on this problem one needs to collect data for a large sample of galaxies, determining the rates of Supernovae of the various kinds, and to accurately characterize the stellar populations in the sample galaxies. The Large Synoptic Survey Telescope, which will start operations in 2022, will provide the ideal database for this research. This study is the subject of a project currently part of LSST - Italia (financed by INAF), which grants access to data and products of the LSST international collaboration. A large amount of preparatory work is needed to be able to fully exploit the data from the survey. The thesis work will consist in performing simulations of the observations under different assumptions for the cadence and observing conditions, using codes provided by the LSST collaboration. The light curves measured on the simulated data will be analyzed in order to assess the capabilities of different survey strategies with respect to the determination<br>of the Supernova subtype. With this in hand it will be possible to proceed with a thorough discussion of the potential of the LSST survey with respect to investigating on the progenitors of Supernovae of the different kinds.<br><br>The results of the simulations will be important for the whole community of researchers involved in the study of transients in LSST, like the Transient and Variable Stars and the Dark Energy Science |

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| | Collaboration. The thesis work will also allow the development of a number of other applications, like computing the expected detection of kilonova events, or studying new classification schemes, which may be more effective for the astrophysical interpretation of the observations. The project includes the collaboration with researchers in Naples, and may generate an international collaboration within the LSST community. |
| Alessia Moretti | **Mapping the molecular gas phase of peculiar galaxies in nearby clusters with ALMA**<br><br>In the context of galaxy evolution clusters of galaxies play a special role, as they are the places where star formation gets quenched more efficiently, even if it is still largely unclear what is the main mechanism that induces the quenching.<br>Among the various physical processes proposed so far, the ram pressure stripping (i.e. the stripping of gas from the galaxy disk due to the interaction with the hot intra-cluster medium, producing "jellyfish" galaxies) has been extensively studied recently here in Padova thanks to the GASP survey that makes use of the excellent spatial resolution of MUSE data. This has allowed to map the distribution of ionized gas out to large distances from the galaxies on a scale of ~ 1 kpc.<br>The size and spatial resolution of this dataset is unique in the world.<br>To understand where and how new star formation is happening or is quenched, one needs to be able to map the molecular gas content on the same spatial scale. This spatial resolution at sub-mm wavelengths is nowadays available thanks to the ALMA interferometer, but was impossible to achieve with single dish telescopes at the median redshift of GASP (z~0.05).<br><br>The PhD student will work on the analysis of the (already acquired) ALMA data of 4 cluster stripped galaxies to a) map the extent of the molecular gas, b) analyze the relation, if any, with the ionized gas phase, c) derive the resolved Star Formation Efficiency to ultimately understand both how the gas stripping acts on the different gas phases, and how the physics of the star formation process proceeds in the peculiar environment of a stripped tail.<br>This work will be one of the first attempting to resolve extragalactic star formation on scales comparables with the ones of our Galaxy.<br>The student will be involved in an international team of young researchers both within INAF and abroad (Chile, Mexico, Netherlands, US). |
| Benedetta Vulcani | **Hunting for jellyfish galaxies in the early universe**<br><br>Clusters of galaxies are important laboratories for the study of the physical processes that drive galaxy evolution. In clusters galaxy formation proceeded at an accelerated pace compared to the rest of the universe. The physical mechanisms responsible for these effects are, |

however, still very much debated. A variety of processes have been proposed in the literature, ranging form slow-acting gravitational interactions such as galaxy–galaxy harassment to potentially extremely rapid interactions of galaxies with the gaseous intracluster medium (ICM). The latter process is called ram-pressure stripping (RPS) and is expected to be especially efficient in massive galaxy clusters.

In the recent years, the physics and observational signature of RPS have been the subject of extensive numerical simulations and observational campaigns, in the local universe. In contrast, very little is known on RPS events at $z>0$. At high redshift clusters are not only intrinsically more massive, but they are also dynamically less evolved and more likely to be undergoing mergers than systems in the local Universe, a critical requirement as extreme RPS events are most likely triggered by merger-driven shocks.

To date, only sparse RPS candidates have been identified beyond the local universe, based on morphological asymmetries detected on multi band imaging. Only one statistically significant sample of RPS candidates at z= 0.3-0.7 has been published, and only the basic information on the position of these galaxies within the clusters has been discussed.

The proposed project will detect and investigate RPS candidates using the data of the Reionization Lensing Cluster Survey (RELICS) of the Hubble Treasury Program, which observed 41 massive galaxy clusters at $0.2<z<1$. Ancillary data will be used to obtain a first characterisation of the galaxies, including spectroscopic redshift, stellar mass and colors. Dedicated campaigns will follow up the most striking RPS cases to characterise the spatially resolved properties of the objects, with the intent of understanding how, where and why gas is removed from galaxies, and at measuring the timescale and efficiency of gas stripping as a function of galaxy mass and environment.

The detailed comparison of the observed morphological, kinematic and age information with simulations will also provide constraints for the physical recipes adopted in simulations. Comparisons with RPS candidates in the local universe (e.g. form the survey GASP, PI Poggianti) will allow to characterise the evolution of the strengths of the RPS across cosmic time.

The student will be inserted in an international context and spend at least few months in foreigners institutes, where the collaborators to this project are based.