Nuove tecniche e “big data” in astrofisica

New techniques and big data in astrophysics

These theses are devoted to the development of new instrumentation/investigation techniques or to the statistical analysis of big data samples. All of them require the development of advanced computer skills (for numerical simulations/machine learning codes).

Riccardo Ciolfi	**Short gamma-ray burst jets from binary neutron star mergers** 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-merger dynamics leading to the formation of a SGRB jet remains however uncertain. 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. 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** 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 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. 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 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.
Antonella Vallenari w. M. Pasquato	Gaia is an ambitious mission to map more than one billion stars in the Milky Way to unprecedented levels of accuracy, and is revolutionizing our views on the Galaxy formation and evolution. As more data pours in, several unsolved puzzles in the formation and evolution of our Galaxy can finally be addressed. Gaia gave us clear-cut memberships, astrometry, and proper motions for 1200+ Open Clusters (OC; Cantat, Vallenari et al 2018; Soubiran,...Vallenari et al. 2018). Meanwhile Gaia-ESO, APOGEE, WEAVE (first light 2020), the SPA and OSTTA projects at TNG and NOT telescopes complement GAIA with spectroscopy. The scale of these datasets is well into the big-data regime, and proper tools are needed to dissect them. The Ph.D. student will mine OC data with unsupervised machine learning -from simple clustering approaches to cutting-edge representation learning via deep neural nets- to unearth the answer to the following questions: 1) are all stars born in clusters, and what is the relation between clusters and the field? (Bouy et al. 2018) 2) why is the Galactic disk out-of-equilibrium (Gaia Collabration, Katz et al 2018) and what is perturbing it: spiral arms and bar, or satellites? (Antoja et al 2018) 3) how is stellar migration shaping the disk (e.g. see Freeman & Bland-Hawthorn 2002) and how are mergers affecting its evolution? The end goal is the statistical characterization of OC global properties in terms of chemical abundances, kinematics, and

	structural parameters. In particular: - are there distinctive groups of OCs corresponding to competing modes of formation and/or stage of dynamical evolution? How many groups and how strongly divided? (see e.g. Pasquato & Chung 2019) - are there OCs that are clear outliers with respect to this pattern, possibly corresponding to accreted OCs as opposed to OCs formed in-situ? - what is the intrinsic dimensionality of the OC dataset, i.e. the minimal number of independent parameters that define OC properties? A further goal is the characterization of individual stars in terms of chemistry, using abundance patterns to reveal OC stars lost to the field (chemical tagging). In the first year the Ph.D. student will gain the relevant skillset (Python with Astropy, Scikit-Learn, Keras+Tensorflow running on GPUs) and theoretical knowledge in cluster analysis (Kaufman & Rousseeuw 2009) and nonlinear dimensionality reduction (Lee & Verleysen 2007). The second year will be spent training autoencoders (see e.g. Goodfellow et al. 2016) on raw spectral data of stars from e.g. APOGEE, WEAVE, GES public data complemented with photometry and kinematics. Cluster analysis in the autoencoder latent variable space will improve on the state-of-the-art of chemical tagging, currently based on linear techniques (see e.g. Leung & Bovy 2019). The third year will see the application of similar techniques to OC global properties, astrophysical interpretation in terms of origin (e.g. in situ VS accreted) and determination of the number of subgroups in the OC dataset in latent space. Expected scientific products: papers, sharing of trained models/codebase in the spirit of reproducible research, and thesis. The student will be involved in the WEAVE, GAIA, and LSST international collaborations and spend part of the time working abroad. In addition to the supervisors (expert in open clusters/disk kinematics and machine learning techniques, respectively) the student will interact with other team members based at INAF/OaPD (Ricardo Jimenez Carrera, Rosanna Sordo) and with collaborators in Barcelona (Carme Jordi, Tristan Cantat) and Bordeaux (Caroline Soubiran). This is a young, dynamic and international team, with members involved in GAIA, WEAVE, and LSST.
Carmelo Arcidiacono w. M. Gullieuszik, B. Vulcani	**Image analysis and PSF-Reconstruction for MAORY MICADO** Novel investigation methods that take advantage of astronomy synergies with different branches of science, like Mathematics, Information Technology (IT), big data, and Statistics among the others, offer the opportunity to derive a significant gain from Adaptive Optics (AO) assisted observations. The case of the Point Spread Function (PSF) reconstruction (PSF-R) is paradigmatic. PSF is a key parameter for the morphologic and photometric analysis of

	galactic (i.e. globular cluster) and extra-galactic (i.e. properties of high-z galaxies) objects. The adaptive optics improved the energy concentration at the cost of more complex and elaborated PSF, that makes the analysis demanding. Actually, the true level of contrast offered by the new class of instruments may be reached only with a good knowledge of the response of the system. Here the point: existing data reduction tools use just a limited part of the information made available by new observing techniques, such as the telescope telemetry and Wave Front Sensor (WFS) data of the Adaptive Optics (AO) systems. And the obvious consequence: the maximum exploitation of all the data available allows not only pushing forward current magnitude and resolution limits, but it also paves the road to investigate a new class of scientific cases (i.e. looking to high temporal variability phenomena). Being able to build a reliable PSF model from telemetric data only has a substantial impact on many scientific cases. The case of extragalactic observations is paradigmatic: all extragalactic surveys target fields have a low density of bright stars; the PSF-R modeling allows the data interpretation, otherwise limited by the lack of suitable reference stars within the science frame. INAF OaPd is currently involved in the MAORY and MICADO, the major high-resolution imaging instrument for the ELT, and in MAVIS, the most advanced MCAO instrument foreseen on 8-10 meter class telescope. In this framework, on a three years timeline, the PhD student will: ● undertake data reduction and data simulation activities on AO assisted instruments; ● study novel concepts for observing strategies; ● produce optimal data reduction pipeline; ● evaluate the scientific impact of PSF-r on a few key science cases
Caterina Boccato w. G. Cremonese, S. Pastore, S. Zaggia, V. Zanini	**The study of ICT applications, starting from the use of scientific data in the realm of virtual reality, augmented reality and the Internet of Things for the enhancement of research, specifically for Planetary Sciences.** The scholarship will focus on technologies and applications of virtual reality, augmented reality and 3D visualization that, on the one hand could provide the acquisition of skills for a specialized Public Outreach, and on the other, a substantial contribution to the analysis and simulation of data in the field of Planetary Sciences and Solar System Exploration. The thesis involves the research and use of complex software and programming for coding languages. The work will therefore focus on the synergy between specialized Outreach and Research, and will

	involve the doctoral student in national events with the aim to "immerse" the public in new projects and evaluate their effectiveness. The third mission has effectively become an institutional task for every research organisation, therefore, it needs to be studied thoroughly and systematically in order to be developed in the most effective way and to be evaluated at its best. In this context it is important to consider the possibility of starting a doctoral scholarship in the specific field of Planetary Sciences (Solar System, Exoplanets and Space Exploration in general) that are well suited to the use of scientific data for purposes other than pure scientific research. It is also worth noting that virtual reality and augmented reality are now considered key technologies for the development of a European digital infrastructure, and that an Inter-Commission B2-C1-C2 Working Group has been established within the International Astronomical Union entitled: Data Driven Astronomy Education and Public Outreach (DAEPO), which denotes how the international astronomical community is very attentive to these aspects. The person who will receive the scholarship will not only have to study which technological solutions and contents to convey, but also how to transmit them, in order for them to be truly effective in the context of Third Mission activities. These activities being research promotion, public engagement activities (Public and School) and the enhancement of cultural heritage.
Luca Zampieri	**High Energy and Time Resolution Astrophysics of Galactic sources** 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. 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.