Stabilization of calibration light sources for High Accuracy Photometry Instruments

Advisors: Manuel Abreu (DF/FCUL & IA U.Lisboa), Alexandre Cabral (DF/FCUL & IA U.Lisboa)

Abstract: Transit spectroscopy and multi-band photometry has been so far conducted using general-purpose, space-based instruments. These measurements however suffer from a high level of systematic error due to issues such as pointing jitter, thermal and opto-mechanical stability, wavelength and photometric calibration, and detector stability. Testing and calibration of high precision photometers for the detection of planetary transits requires a light source which photometric stability must be better than the goal stability of the photometer to be tested.

In case test, integration and calibration of these sensors, it will be required highly radiometrically stable light sources, both in flux and spectra.

The proposed project aims to research and develop a device that senses the light source fluctuations and modulates the beam, both in flux and in spectra, to produce a sufficiently stable source, a truly impressive challenge when stabilization levels of few ppm are required over long periods of observation.

University: Lisboa

Novel software for state-of-the-art spectrographs: stellar radial velocity extraction

Advisors: Sérgio Sousa (IA U.Porto), Pedro Viana (DFA/FCUP & IA U.Porto), Nuno Santos (DFA/FCUP & IA U.Porto)

Abstract: The detection of an increasing variety of exoplanets, planets orbiting other stars, and in particular the derivation of their masses, has been possible thanks to the continuous development of high-resolution, stable spectrographs, and making use of the Doppler radial-velocity method. Over the past two decades, technological progress together with significant advances in data reduction and analysis techniques already allowed this method to detect and characterize a thousand or so exoplanets. Now, the dawn of a novel generation of ground and space-based instruments and missions promises to bring us close to the discovery and characterization of temperate Earth-like worlds, similar to Earth in both mass and composition and thus potential islands of life in the Universe.

Several interesting challenges remain, however. In particular, a new data analysis paradigm is needed to significantly improve the extraction of radial velocity information from stellar spectra. Therefore, we propose as the main objective of this project the development and implementation of a novel data processing and analysis software for the precise estimation of stellar radial velocities from state-of-the-art spectra. This software should be developed using high-performance programming and computing techniques, in order to optimize its speed. It will be used to analyze data taken with instruments such as ESPRESSO (ESO-VLT), NIRPS (ESO-3.6m) and SPIROU (CFHT), where our team has a leading participation.

The candidate will have the opportunity to apply the algorithm to existing data in collaboration with the team, namely in the search for temperate Earth-like exoplanets. By the end of the project, the candidate will have acquired expertise on the reduction and analysis of high-resolution stellar spectra, pipelines for astronomical instrumentation, as well as on general-purpose advanced programming, computational, statistical and machine-learning techniques.

University: Porto

Mitigate stellar activity to characterize Earth-size planets

Advisers: Susana Barros (IA U.Porto)

The detection of terrestrial mass planets is a major goal in astrophysics. This has recently become possible due to two space-based transit surveys, namely CoRoT and Kepler and improvements in the precision of radial velocity measurements. Future space based missions (e.g. CHEOPS, PLATO) and new high-resolution spectrographs such as ESPRESSO (Pepe+2010) and NIRPS (Wildi+2017) are being planned to detect and characterize Earth-like planets around bright nearby stars. This research project aims to improve the accuracy and precision of planetary parameters derived from transits and radial velocities obtained with these future facilities, which our institute has privileged access.

One of the project goals is to develop tools and methods that are essential to explore the data from these missions. A second more general goal of this project is to study the effect of stellar activity in observations of small sized planets. The student will investigate how the stellar activity biases planetary parameter measurements and develop methods to correct for it. The corrections will be implemented in an already existing tool to derive mass and radii of exoplanets. Then he/she will apply the new tool to new observations of exoplanets obtained with CHEOPS, EXPRESSO and NIRPS. This is crucial to improve the accuracy of the measurements of mass and radii of planets in the range from Earth-Neptune size. Accurate masses and radii are essential to derive the composition of very low mass planets and gain insight into planetary structure. This will provide constrains on planetary formation and evolution theories. Moreover, bright systems allow further characterization of the planets. Optionally the student can also be involved in developing stellar activity corrections for observations of Rossiter–McLaughlin effect to measure the relative angle between the planet orbit and the stellar spin or observations of planetary atmospheres.

University: Porto

Composition of Earth-size planets

Advisers: Susana Barros (IA U.Porto), Olivier Demangeon (IA U.Porto)

Many transiting small exoplanets where found and are waiting to be found by the K2 mission (Barentsen+2018). Our group has developed tools to reduce K2 data, compute high precision light curves and search for planetary transits. Using these tools, we already discovered multiplanetary systems (Barros+2017) and a planet smaller than the Earth (Santerne+2018).

This project consists in optimizing and using these tools to create a complete list of transiting planetary candidates from K2 data; prioritize them for follow-up observations and confirm them using state-of-the-art spectrographs: HARPS, ESPRESSO, NIRPS. The recently launched TESS satellite is also providing transiting candidates, which can also be included in the priority list for follow-up. The student will thus have the unique opportunity to discover and characterize new exoplanets. One important part of the project is the development of tools to prioritize the planetary candidates using all the available information.

The second part of the project involves combining the transit observations from K2 and TESS with the radial velocity observations taken with HARPS, ESPRESSO and NIRPS. This will allow deriving the mass and radii of the planets and hence constrain their composition. Our group already has its own code to derive the planetary parameters but the student is expected to optimize it.

The tools developed here will also be important for future surveys like PLATO. Our group is responsible for their development for the ESA mission PLATO giving the opportunity for the student to be involved in this extra-ordinary mission which gather most of the European exoplanet community.

Possible developments of this project are:

- Optimizing the photometry of TESS data
- Detecting exoplanet of prime-interest for atmospheric characterization: exoplanet with extended atmospheres, in the verge of evaporation or rocky planet around very bright stars.
- Statistical studies about the occurrence rate of different types of planets as a function of stellar properties.

University: Porto

Unveiling the composition of exoplanets atmospheres with CHEOPS and ESPRESSO

Advisers: Olivier Demangeon (IA U.Porto), Nuno Santos (DFA/FCUP & IA U.Porto), Gabriella Gilli (IA U.Lisboa)

Although several thousands of exoplanets have already been detected (see exoplanet.eu), our understanding of their atmospheres is still very limited. In most of the cases, our knowledge of an exoplanet can be reduced to its mass and radius (see Demangeon+2018). The last years have, however, seen considerable developments in terms of instrumentation. New missions like the ESA-CHEOPS satellite (Fortier+2014), the ESA-ARIEL project (Tinetti+2016) and the high resolution spectrograph ESPRESSO@ESO-VLT (Pepe+2014) will shed new lights on exoplanets and their atmospheres.

CHEOPS, ARIEL and ESPRESSO will provide complementary information. On one side, CHEOPS will probe the atmosphere of “hot jupiters” providing broad spectral measurement of the light reflected by these planets. ARIEL will complement that with low resolution spectra in the infra-red. On the other side, ESPRESSO will provide high resolution observation of these planets and their host stars, from which transmission spectra and specific spectral signatures can be extracted.

For this PhD project, the laureate will be involved in CHEOPS, ARIEL and ESPRESSO science team activities. The first objective will be to focus on the interpretation of CHEOPS and ESPRESSO data. A second step will be to participate to the scientific definition of the ARIEL mission whose launch is planned for 2028. Using state-of-the art models, inspired from those used to simulate the atmosphere of Solar System planets, the laureate will infer several properties of the observed atmospheres: their reflective properties (albedo, presence/characteristics of clouds, e.g. Demory+2013, Martins+2018), their temperature, the molecules and atoms which compose them (e.g. Birkby+2017). Due to the unprecedented precision and flexibility offered by CHEOPS and ESPRESSO on one side and the importance of the ESA-ARIEL mission for the future of exoplanet sciences. The results from this thesis will constitute landmarks in the field of exoplanetary atmospheres and help to shape the future of the field.

The supervisors of this project, along with the team which will host the laureate, has a deep involvement and expertise in both CHEOPS, ARIEL and ESPRESSO. They will guarantee the laureate access to the data, to sophisticated 3D atmospheric models and involvement in the science team’s activities.

University: Porto

Emission and transmission spectra of exoplanet atmospheres

Advisers: Olivier Demangeon (IA U.Porto), Nuno Santos (DFA/FCUP & IA U.Porto)

With more than 3800 extra-solar planets discovered so far, one of the main focus of exoplanet research is the detailed characterization of exoplanets, and specifically their atmospheres. This represents a first effort that should ultimately lead the detection of life signatures in other worlds.

ESPRESSO, NIRPS and SPIROU are a new generation of high-resolution spectrographs dedicated to exoplanet research. Installed at ESO's VLT, ESPRESSO (Pepe+2014) started its observations in September 2018 and for the next 4/5 years will dedicate 1/3 of its guaranteed observation time (or about 70 nights) to exoplanetary atmosphere studies. NIRPS (Bouchy+2017) and SPIROU (Simon+2012) will start observation within the next year and will also reserve a significant fraction of their time to exoplanetary atmosphere sciences. ESPRESSO observes at visible wavelengths, while NIRPS and SPIROU observe in near infra-red. The observations from these different facilities will thus be complementary, and allow to approach the study of exoplanet atmospheres from a unique perspective.

Different observational strategies can be used for this objective depending on the exoplanet studied. When the exoplanet transits in front of its parents star, we are able to observe the minute color dependent changes in the spectra produced by the different fractions of the stellar light passing through the exoplanet's atmosphere (Wyttenbach+2017). From such observation a low resolution transmission spectra of the atmosphere can be extracted. In some cases, the detection of strong absorption lines of molecules like CO is also possible (Désert+2009). For hot exoplanets orbiting close to their parent stars, the spectra of the light emitted by the atmosphere can also be detected (Stevenson+2010).

The main objective of this PhD project is to extract robust observational constraints on the atmospheres of exoplanets as observed with ESPRESSO, NIRPS, and SPIROU. For this, the candidate is expected to perform and optimize the data analysis processes to extract the minute planetary signal and derive the properties of exoplanet atmospheres.

The supervisor and co-supervisor of this project are deeply involved in ESPRESSO, NIRPS, and SPIROU. They will offer to the laureate both access to the data and science teams, as well as expertise on the instrument and the observational techniques required for this project.

University: Porto

New insights into stellar physics from the NASA-TESS survey on A-type stars

Advisors: Margarida Cunha (IA U.Porto), Daniel Holdsworth (University of Central Lancashire)

Abstract: The study of stellar pulsations – or *Asteroseismology*- provides the only means to directly probe the interior of a star and constrain its physical and dynamical properties. Among the different types of stars exhibiting stellar pulsations, the Ap stars are unique for their strong magnetic fields and for their chemical peculiarity. These properties make them laboratories for studying the physical processes taking place inside stars that are currently most challenging to our understanding, such as macroscopic mixing, microscopic diffusion, and magnetic fields. The high- precision photometric time-series that the NASA TESS mission will acquire on several hundred Ap stars offer a key opportunity to make definitive tests to the modelling of the physical processes mentioned before. To explore that opportunity, the project proposes an end-to-end approach where the student will start by analyzing the data from this satellite and then use the results of that analysis to infer information about the properties of the stars through modelling. The ultimate goal is to take advantage of the TESS data to raise to a new level the modelling of one of the richest classes of stellar pulsators, as well as our understanding of key physical mechanisms operating inside stars.

University: Porto

Type: This topic may correspond to a mixed fellowship with up to 1 year abroad.

EnsemProbing inside stellar cores with ultra-precise, space-borne data

Advisors: Margarida Cunha (IA U.Porto), Benoît Mosser (LESIA - Observatoire de Pari), Mathieu Vrard (IA U.Porto)

Abstract: As a result of the launch of the CoRoT and *Kepler* satellites, the astronomical community has, today, exquisite asteroseismic data on thousands of stars. Moreover, in a decade this number will increase by orders of magnitude as a result of the launch, in 2026, of the ESA mission PLATO. A large fraction of these stars exhibits variability associated to the presence of gravity waves or waves of mixed nature (gravity and acoustic). These waves offer a unique opportunity to probe the conditions in stellar cores. The goal of this project is to explore the opportunity offered by the ultra-precise space-borne data made available by *Kepler* to constrain physical processes that shape the chemical gradients in stellar cores and that are, thus, decisive for stellar evolution. This will be achieved through the development and application of diagnostic tools aimed specifically at extracting the information contained in gravity and mixed-mode pulsations. By doing so, the project will also make a key contribution to the preparation of the future PLATO mission.

University: Porto

Type: This topic may correspond to a mixed fellowship with up to 1 year abroad.

The physics of high-mass star formation: Zoom-in on MaCProS

Advisors: Nanda Kumar (IA U.Porto), Pedro Palmeirim (IA U.Porto), Doris Arzoumanian (IA U.Porto)

Abstract: In the early 70's, theoretical considerations of the radiation feedback on gravitational collapse led to the prediction of an upper limit on the stellar mass that can form via accretion process. The subsequent three decades has gone by in much debate in an effort to resolve this problem, however, without success. It has also led us to identify other feedback processes that might set an upper limit on the stellar mass, namely, fragmentation, stellar winds, ionization pressure and magnetic fields. Some theoreticians have now settled upon a resolution of these issues and agree that there is no upper limit on the maximum stellar mass. However, observational studies have so far been unable to test, confront or have a say on how nature has produced the most massive stars that one finds in our Milky Way galaxy, or, if there is an upper limit on the stellar mass that can form via accretion.

Palmeirim & Kumar (2019, in preparation) have assembled the most massive and compact proto-and-pre-stellar cores (dubbed as MaCProS) based on a careful analysis of the physical properties of the star forming cores such as surface density, luminosity, mass, temperature and so on. This analysis is based on exploiting a wealth of new information from the Milky Way Galactic Plane legacy surveys Herschel Hi-Gal and ATLASGAL. This is unlike the brightness limited samples that are currently popular.

The goal of this thesis project is to conduct a wide variety of infrared and sub-millimetre high-spatial resolution observations to zoom-in on the best MaCProS. Dedicated tests will be conducted to examine them to enable our understanding of the physics of high-mass star-formation. The approach here will especially focus on tests devised in the light of the filament-hub paradigm of star formation and specially aimed to probe sub-100s of AUs in physical size. Observations using ALMA, SOFIA, JWST and VLTI are foreseen.

The candidate student should demonstrate a solid understanding of undergraduate level physics, chemistry and mathematics, a flair to study star formation, a willingness to undertake scientific adventures behind computer displays and on top of the worlds high-rise mountain observatories. During the PhD, the student will specialize in reduction and analysis of sub-millimetre and infrared data, both from single telescopes and interferometric arrays. Several collaborative visits to the UK, Spain, and Germany are also expected.

University: Porto

The physics of stars: building the next generation suite of tools to explore seismic data acquired from space

Advisors: Margarida Cunha (IA U.Porto), Tiago Campante (IA U.Porto), Pedro Avelino (IA U.Porto)

Abstract: A dramatic change in stellar astrophysics research is taking place thanks to the launch and planning of space missions capable of detecting stellar oscillations in thousands of stars. The analysis of these oscillations provides information on the stars' radius, mass, and age, which are key elements in other areas of astrophysics, such as exo-planetary research and the study of our own Galaxy. However, current methodologies to infer the stellar properties are subject to systematic errors that, if not correctly accounted for, will compromise all studies that are based on the inferred stellar parameters. The main goal of the project is to develop the next generation suite of tools for forward modelling, that will consider and quantify the impact of important short-comings associated to state-of-the-art methodologies, translating them into realistic uncertainties in the inferred stellar properties. The tools will be further applied by the student in the characterization of hundreds of solar-like pulsators observed from space.

The project will be organized in four steps: (1) A thorough analysis of the dependence of the oscillation frequencies on stellar properties and physics; (2) The definition of a hierarchy of the physical unknowns in the problem, followed by the implementation of a statistical analysis that considers that hierarchy in the derivation of the stellar parameters and their uncertainties; (3) The parameterization of the uncertainties, aimed at quantifying the biases in the inferred stellar parameters;(4) The application of the new suite of tools to a large sample of solar-like pulsators observed from space.

University: Porto

The magnetic environment of Young Stellar Objects

Advisors: Jorge Filipe Gameiro (IA, U. Porto), João Lima (IA, U. Porto)

Abstract: It has been demonstrated in the last decade that magnetic fieds play a central role throughout the star formation. In the Pre-Main-Sequence (PMS) phase the stellar magnetic fields have a larger impact on the stellar evolution and likely control accretion processes and trigger outflows/jets. The Young PMS star hosts a large-scale magnetic field that disrupt the inner circumstellar disk and the accretion proceeds from the inner disk rim to the stellar surface through the magnetic funnels (star/disk magnetospheric interaction). The production of high energy photons are responsible for heating and ionizing the disk and likely originate disk winds. However, the star/disk interaction and its connection to the outflow is still an open question. Also, understanding the disk dispersal is important to constrain the star and planet formation.

SPIRou is a near Infrared (nIR) spectropolarimeter instrument mostly aimed at detecting and characterizing Earth-like planets and at investigating how magnetic fields impact star/planet

formation. The stronger polarimetric sensitivity of the instrument will be important to improve our knowledge of magnetic field topology in PMS Object, which are far less obscured in the nIR than in the optical.

This PhD project will be done under the SPIRou Legacy Survey in which we are participating. The main goal is to undertake an intensive survey of magnetic fields in PMS stars and inner accretion disks. The project aims to understand how the young star magnetically interacts with the circumstellar disk, in order to obtain a more quantitative description on the star and planet formation. The modeling of the large-scale stellar magnetic fields can be later used to constrain the numerical simulations we are currently working on and understand the connection between accretion and outflows.

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University: Porto

Density amplification at filament junctions and massive star formation

Advisor: Nanda Kumar (IA, U. Porto)

Abstract: Gravitational collapse of cold, dense gas in the interstellar clouds lead to star formation. How does this collapse produce low mass stars is fairly well understood. A prototypical star forming region such as the Orion Nebula or Rosette Nebula will display a spectrum of objects from 0.1 to 100Msun. How does the same cloud produce this spectrum of objects, especially those stars that are 50-100 Msun is the main puzzle that is yet to be understood.

We have recently shown that all known massive star formation take place in pockets of highly amplified densities and mass, that occur at junctions of filaments. There is much evidence that these density amplified pockets are capable of driving longitudinal flows of gas, allowing gravity to dominate over turbulence. Magnetic fields are expected to further aid and modify the physical conditions within these pockets.

The goal of this thesis project is to investigate the properties of the density amplified regions, to understand its physics and how it impacts the formation of the most massive monstrous stars of our Galaxy. Using a variety of observational tools and methods, we want to understand the density and kinematic structure, role of magnetic field and turbulence, and the mass function of objects that such regions produce.

The candidate student should demonstrate a solid understanding of undergraduate level physics, chemistry and mathematics, a flair to study star formation, a willingness to undertake scientific adventures behind computer displays and on top of the worlds high-rise mountain observatories. During the PhD, the student will specialize in reduction and analysis of sub-millimeter and infrared data, both from single telescopes and interferometer arrays.

University: Porto

ESPRESSO’s look at fine structures of stellar surfaces using exoplanets transits

Advisers: Vardan Adibekyan (IA, U. Porto), Nuno C. Santos (IA, U. Porto)

Abstract: Stellar surfaces are full of inhomogeneities (due to the presence of stellar granulation, magnetic spots, etc.) which cause different types of difficulties for exoplanet related studies (e.g. exoplanet detection, bulk and atmospheric characterization etc.). Ironically, exoplanet transits can provide enormous information about the nature of these inhomogeneities, and stellar surfaces, in general.

Transiting planets consecutively block the light coming from different segments of the stellar disk. High-resolution differential spectroscopy will provide the spectra of these small surface segments temporarily covered by the transiting planet. Studying center-to-limb variations of asymmetric profiles and wavelength shifts of spectral lines with different properties (different strengths, excitation potential, ionization level), and comparing them with the predictions of the 3D models of stellar atmospheres will unable to characterize the fine structures of these atmospheres. Understanding and characterizing the 3-dimensional and time-dependent properties of stellar atmospheres is crucial for accurate determinations of stellar properties and for the properties of planets orbiting them.

The detection of very subtle changes in line profiles and wavelength shifts requires ultra high signal-to-noise (S/N) ratio. This will be only possible by averaging many spectral lines of similar properties and taken from very high-resolution and high-S/N spectra. The new ESPRESSO spectrograph, installed at the VLT, perfectly fits the aforementioned requirements and provides a unique possibility to perform such an unprecedented study.

Note: It is important to note that both supervisors are science team members of the ESPRESSO consortia (N. Santos is the Co-PI of the instrument) and have access to 270 nights of GTO observations. All the observations needed to conduct this project are or will soon be available.

University: Porto

The build-up of metals within galaxies with cosmic time

Advisors: Jarle Brinchamnn (IA U.Porto)

Abstract: With the MUSE instrument on the VLT we are producing the deepest spectroscopic observations of the Universe with an unprecedented sensitivity and spatial resolution. In this project the student will develop a method to combine the data from MUSE with spectra from HST and in the future the Euclid satellite. With this in hand he/she will carry out the largest survey of how metals are distributed in galaxies as a function of cosmic time – constraining the physics of galaxy formation.

University: Porto

Self-consistent spectral modeling of quasars and its implication to the mass assembly history galaxies

Advisors: Jean Michel Gomes (IA U.Porto), Luis Vega Neme (IATE – OAC, Córdoba)

Abstract: Quasars are thought to be hosted by a supermassive black hole (SMBH) capable of producing an energy release due to matter accretion that easily outshines the whole host galaxy, leading to this featureless *quasi-stellar object* appearance the most massive and luminous galaxies in the early Universe. Over the past few years, it was discovered several quasars even at early times (redshift ~7). We propose a new spectral fitting code for fitting the UV-optical range in a self-consistent manner to be applied to quasars. This code will include a standard accretion disk model (Shakura & Sunyaev 1973) and a more realistic UV-optical model from, e.g., Kubota & Done (2018). We will tie these prescriptions together in order to energetically reproduce both the observed continuum plus emission- lines in quasars considering internal attenuation. This new fitting code

will be publicly available and additionally applied to ~500 000 quasars from the SDSS DR15. We will produce a full database catalog for the astronomical community. This is a preparatory work for the MOONS spectrograph in which IA co- leads also it will add value when the modules for fitting quasars are incorporated in the population synthesis code FADO (Gomes & Papaderos 2017).

This project provides an excellent combination of astrophysical theory with observations, and it will lead to valuable expertise on the field of spectral synthesis and AGN phenomenon. Several publications will support the future career of the student. Preferable computing languages are Fortran, Python or IDL.

University: Porto

Spatial distribution of α-elements in galaxies

Advisors: Jean Michel Gomes (IA U.Porto), Polychronis Papaderos (IA U.Porto)

Abstract: A long-standing puzzle in extragalactic research concerns the anomalous abundances of so- called α-elements (e.g., C, N, O, Ne, Si, S, Mg and Na) relative to iron (Fe) in early-type galaxies (ETGs). These elements are generally enhanced relative to Fe by an "enhancement- ratio" [E/Fe] correlating with the stellar velocity dispersion (hence, the total stellar mass) of an ETG. The dominant physical mechanism responsible for this trend is still unknown yet fundamental to the understanding of the chemo-dynamical evolution of ETGs across their entire mass spectrum.

Three main scenarios have been proposed for these discrepancies: a) a varying star-formation rate efficiency in massive ETGs, b) a non-universality of the stellar initial mass function (IMF) in the sense of a "top- heavy" IMF and c) selective loss of elements due to galactic winds. All these scenarios attempt reproducing the observed [E/Fe] ratios as essentially the result of chemical enrichment by Type II and Type Ia Supernovae, each acting on different timescales, and with a relative frequency closely linked to the galaxy star formation history.

Studies of stellar populations in galaxies have dramatically advanced in the last decade. Instead of using a few hand-picked Lick indices, fluxes and integral colours to constrain the star formation- and chemical enrichment history of galaxies, modern spectral synthesis codes and computing facilities now permit a detailed modelling of the full optical spectrum of a galaxy in a pixel-by-pixel approach. These modelling tools and the availability of high-quality data sets (e.g., 2dF, 6dF, SDSS and GAMA surveys) offer a promising avenue for a better understanding on how galaxies form and evolve through time. However, all spectral synthesis studies carried out over the past decade on the basis of these single-fibre spectroscopic surveys lack the necessary spatial coverage and resolution to study the radial trends in galaxies (cf e.g. Gomes et al. 2016b&c).

Only recently spatially-resolved data from Integral Field Spectroscopy (IFS) has become available, permit- ting the study of radial abundance patterns of α-elements in galaxies with unprecedented detail. An innovative aspect of this PhD research project is the use both the IFS data for 667 local Hubble-type galaxies from The Calar Alto Legacy Integral Field spectroscopy Area survey (CALIFA – http://califa.caha.es) and Mapping Nearby Galaxies at APO (MaNGA) survey (last release ~5k galaxies) to determine the 2D α- element distribution in a spatially resolved pattern. This observational input will be combined with the derived Star-Formation Histories and structural properties of ETGs from CALIFA with the goal of developing new evolutionary diagnostics for ETGs and shedding light into the origin of the α-element enhancement in these systems.

University: Porto

Dark matter and metal poor stars in Ultra Faint Dwarfs

Advisors: Jarle Brinchamnn (IA U.Porto)

Abstract: Ultra-faint dwarfs are the most dark matter dominated objects we know – in some there is 1000 times more dark matter than baryonic. They are also the faintest and lowest mass galaxies we know with the entire galaxy less bright than a single star. These facts combine to make these systems excellent places to look for dark matter and to explore the effect of stellar feedback on galaxy evolution in low mass dark matter halos. To that end I am carrying out a survey of 100hrs with MUSE on the VLT to study the make-up of these ultra-faint satellites and constrain their metal enrichment history and dark matter content. The student will be involved in both of these aspects, with a particular focus on the metal enrichment history and stellar make-up of the ultra-faint dwarfs.

University: Porto

Investigating Structure Formation around Massive Galaxies through a Radio-Infrared Synergy

Advisors: José Afonso (DF/FCUL & IA U.Lisboa), Hugo Messias (Joint ALMA Observatory)

Abstract: One of the greatest challenges facing observational cosmology is understanding the formation of large scale structure in the Universe. Hierarchical models for structure formation developed over the last few years, achieving the high degree of predictive success that they do, are however still unconstrained, in particular in helping to understand how the light (galaxies) traces the underlying (dark) matter and how this relation evolves over time. We will address this problem by performing a systematic study of the evolution of the densest regions of the Universe, as traced by the most massive galaxies and their environments, improving our understanding of how the most massive regions of the Universe form and evolve. This will only be possible by using data from a deep mid-infrared wide-field survey, the extended Spitzer Extragalactic Representative Volume Survey (SERVS), now including over 2700 hours of deep mid-infrared observations and capable of finally overcoming long-standing observational limitations.

University: Lisboa

The First Radio Galaxies in the Universe

Advisors: José Afonso (DF/FCUL & IA U.Lisboa), Israel Matute (IA U.Lisboa), Hugo Messias (Joint ALMA Observatory)

Abstract: Recent observations of the highest redshift quasars and radio galaxies pinpoint the early growth of supermassive black holes (SMBH) that trigger the formation of active galactic nuclei (AGNs) at redshifts greater than 7. It is anticipated that radio emission can be detected from such early AGN, although its characteristics are still quite indeterminate. The importance of such detection, however, is extremely high. It will: (a) provide us with a lighthouse that reveals the physics of the first accretion episodes to the first SMBHs in the Universe; (b) allow the direct study of the neutral gas throughout the Epoch of Reionisation itself with the next generation of radio telescopes, through the observation and study of the HI 21cm forest against such early AGN; (c) allow us to trace the early growth of Large Scale Structure in the Universe. After decades of laborious work, trying to understand the deepest radio observations, the conditions are now finally right to develop a project that can make us understand where are the “first radio galaxies” and how to find them with upcoming radio telescopes.

University: Lisboa

Type: This topic may correspond to a mixed fellowship with up to 1 year abroad.

Fitting galaxies with MANGA

Advisors: Ciro Papparlardo (IA U.Lisboa)

Abstract: One of the biggest open questions of Astrophysics is to establish a comprehensive picture of galaxies evolution. This is a complicated task, and despite the huge effort of scientists, large uncertainties related to the interpretation of the observations are still present, together with oversimplification in the models. One of the largest projects in the world tackling the issues related to the evolution of galaxies is the Sloan Digital Sky Survey (SDSS, Eisenstein et al.2011). It started twenty years ago and recently, in December 2018, the data taken by the fourth phase of SDSS have been released, Data Release Fifteen (DR15). The main difference with respect to the previous releases is that for the first time the database contains also the spectra of about 5000 galaxies obtained with the revolutionary instrument MANGA, the integral field spectrograph unit mounted on the 2.5 m optical telescope at Apache Point Observatory (New Mexico). This is a unique database, where instead of a spectrum collecting the light from the entire galaxies, as it was for the previous releases, 17 different 'integral field unit' (IFU) extract simultaneously different spectra from the same regions of the sky. The possibility to place the different IFU at small distances allows detailed studies of the chemical composition, the kinematic, and the stellar age distribution of each galaxies investigating its internal structure.

As already mentioned, previous SDSS releases extracted from each observed galaxy a single spectrum, sampling mostly the centre of target galaxies. Despite these limitations, the SDSS data have been crucial to discover the fundamental relations between the stellar mass of a galaxy and its star formation rate, the so-called 'main sequence', and the link between the stellar mass and the mass of heavy elements available in a galaxy, also known as 'mass-metallicity relation'.

This project proposes a deep analysis of the 'MANGA' extended data-set in DR15, in order to investigate the physical processes that determine the galaxy scaling relations mentioned above, considering also the internal structure of the galaxies, available for these 5000 objects. For such a purpose, different spectral fitting tools will be compared and mutually validated, to clarify possible bias and strengthen the conclusions of the work. In particular, the student will use a specific software developed within the IA (Porto node), FADO, which is an optimized spectral fitting algorithm able to disentangle the stellar and gaseous emission of medium resolution optical spectra, and for this reason suitable for the goal of the project.

University: Lisboa

Spectro Photometric Analysis of MOONS Galaxy Evolution Legacy

Advisors: Ciro Papparlardo (IA U.Lisboa)

Abstract: Galaxy evolution is one of the biggest open question in Astrophysics but, despite the huge effort of scientists, there are still large uncertainties in the observations and oversimplification in the models. The reasons for the lack of a comprehensive theory in this field, are twofold:

- on one side instrumental limitations have biased our knowledge of galaxies towards most luminous object, preventing then a statistical significance at higher distances. Most of the studies are focused on nearby galaxies, missing then the most relevant part of the Universe history.
- on the other side there are strong theoretical limitations to the information that we can extract from the light that we observe. Most of the effort up to now focused on two distinct parallel paths: photometric approaches develop fitting methods to extract physical parameters from sparse data points sampling the galaxy spectral energy distribution; the other approach is spectroscopy, and in this direction different spectral fitting tools have become the more and more efficient in recovering reliable results from the analysis of moderate resolution spectra.

The combined action of these two factors hampered big step forwards in this field of Astrophysics. It is clear that in order to have really relevant improvement we must tackle the problem in two ways:

1. build instruments able to observe galaxies at larger distances, where the Universe was younger;
2. improve the efficiency of both spectroscopic and photometric approach.

The instrumental gap mentioned above will soon be challenged by the MOONS (Multi-Object Optical and Near-infrared Spectrograph) instrument, a spectrograph that will be mounted on the Very Large Telescope (VLT) in Chile and will trigger a step forward in our knowledge of the assembly history of galaxies. The Institute of Astronomy and Space Sciences (IA) in Portugal is strongly involved in the project, being part of the scientific consortium, and participating to the construction of the instrument.

This project proposes to participate to MOONS through two complementary actions, strongly related with the expertise grown within the IA:

1. investigate the galaxies spectra provided by the MOONS consortium through specific spectral fitting tools developed within the IA: i.e. FADO.
2. build a photometric data set for the same galaxies observed with MOONS in order to investigate the properties of their Spectral Energy distribution (SED).

University: Lisboa

Reconstruction of the mass assembly history of Active Galactic Nuclei with FADO

Advisors: Jean Michel Gomes (IA U.Porto), Polychronis Papaderos (IA U.Porto)

Abstract: Fitting Analysis using differential evolution Optimization (FADO) is a conceptually novel, publicly available spectral population synthesis (PS) code (www.spectralsynthesis.org), which employs for the first time genetic optimization and artificial intelligence to identify the star--formation and chemical evolution history (SFH and CEH, respectively) that self-consist- ently reproduce the main nebular characteristics of star-forming (SF) galaxies. This unique concept allows us to alleviate and even overcome, degeneracies in spectral synthesis studies, thereby opening new avenues to the investigation of galaxy formation and evolution.

However, a large fraction of emission-line galaxies hosts an Active Galactic Nucleus (AGN) powered by accretion of matter onto a central super-massive black hole of several million solar masses. Depending on our viewing angle to the galaxy nucleus and its surrounding obscuring torus, the strong non-stellar radiation from the AGN can provide an important fraction, or even outshine, the spectral continuum of the underlying galaxy host. Even a low-to-moderate (~20%) contribution of the AGN to the optical continuum emission of a galaxy can strongly bias conclusions drawn from state-of-the-art purely-stellar PS codes, as demonstrated in Cardoso, Gomes & Papaderos (2016, 2017).

The work tasks and main objectives of this PhD thesis are to use FADO in order to:

1. Quantify its accuracy with benchmark tests in retrieving the SFH & CEH in the presence of an AGN. Additionally, compare the results from FADO with those from purely stellar codes (e.g., STARLIGHT, STECKMAP, ULySS, FIREFLY). In this task, the student will make use of fictitious datasets created with the REBETIKO evolutionary synthesis code under the presence of an AGN;
2. Disentangle the star-forming component from the non-thermal AGN component and estimate the AGN luminosity emission in various spectral bands;

3. Test distinct recipes in modeling the spectral energy distribution of the AGN, like the inclusion of multi-component continuum (e.g., Ferland et al. 2017 - Big Blue Bump and distinct power-law slopes in the X-ray, UV and optical). The student will make use of the FADO AGN module;
4. Fit galaxy spectra data sets from SDSS & GAMA surveys as well as Integral Field Spectroscopy data from MUSE, MEGARA, MaNGA to investigate the SFH & CEH of galaxies hosting an AGN.

This project provides an excellent combination of astrophysical theory with observations, and it will lead to valuable expertise and several publications that will support the future career of the student. Preferable computing languages are Fortran, IDL and/or Python.

University: Porto

Studying extended gas associated with distant AGN using MUSE observations of extended Lyman-alpha emission

Advisors: Andrew Humphrey (IA U.Porto)

Abstract: This project will use VLT MUSE observations of extended Lyman-alpha emitting gas to study the co-evolution between the interstellar medium, star formation activity and the outputs of the active nucleus itself, thereby obtaining new pieces of the jigsaw puzzle that is our understanding of the formation and evolution of galaxies. The student will process and analyze archival VLT MUSE integral field spectroscopy observations of high-redshift radio galaxies and/or quasars, and study in detail the morphological, kinematic, ionization and chemical enrichment properties of extended (>10 kpc) Lyman-alpha emitting gas halos associated with the active galaxies. Observational information will be compared with models from the literature, and the ionization and chemical enrichment properties will be modeled using state of the art ionization modeling codes. Important new information on cluster (or protocluster) environment will also be obtained.

University: Porto

Diffuse ionized gas and Lyman continuum photon escape in spiral galaxies

Advisors: Polychronis Papaderos (IA U.Porto), Jean Michel Gomes (IA U.Porto)

Abstract: Diffuse ionized gas (DIG) is a ubiquitous component in the disk and halo of late-type galaxies (LTGs). The excitation mechanisms and ionization conditions of the DIG pose a long-standing enigma. The prevailing picture though is that the DIG originates from Lyman continuum (LyC) photons escaping from sites of ongoing star formation and their reprocessing into nebular emission on scales of ~1 kpc away from HII regions. The mechanisms facilitating escape and transport of LyC radiation are unclear, it is yet likely that a key role is played by injection of energy and momentum by stellar winds and SNe into a porous multi- phase interstellar medium. Various lines of evidence indicate that the diffuse, low-surface brightness DIG contributes ~20-50% of the total Hα emission in late-type galaxies, a fact that may introduce a substantial observational bias on estimates of star formation rates in high-redshift galaxies where DIG emission is barely detectable. This project aims at a detailed investigation of the physical properties of the DIG in a representative sample of nearby face-on spiral galaxies using image processing techniques, spatially resolved integral field spectroscopy and advanced spectral synthesis models. A central question to be addressed concerns the relation between the fractional contribution of the DIG to the total Hα luminosity and the star formation history and structural properties of LTGs.

University: Porto

Uncovering the mass assembly history of late-type galaxies in different environments with IFS data

Advisors: Jean Michel Gomes (IA U.Porto), Catarina Lobo (DFA/FCUP & IA U.Porto), Tom Scott (IA U.Porto)

Abstract: Galaxy clusters and groups are gravitationally bound structures that contain hundreds to thousands of galaxies bonded by gravity and embedded in a dense medium. They are excellent laboratories for studying the impact of the environment on the mass assembly history of their member galaxies. As such, there is abundant literature on how several processes such as ram pressure stripping, strangulation, tidal effects and merging can lead to significant changes in the secular evolution of galaxies. A combination of these mechanisms is expected to explain some of the morphological transformations of galaxies and the quenching of their star formation activity. Pinning down the dominant mechanism responsible for these evolutionary trends is one of the key-questions in extragalactic astronomy, that is likely linked to the process of in fall of galaxies into clusters occurring within the framework of the hierarchical growth of large scale structure. The cold gas medium of galaxies is expected to be tightly connected with their capacity to keep forming stars and is extremely sensitive, in small timescales, to the mechanisms mentioned above. It should thus provide indications of the relevant processes acting on galaxies located at different cluster centric radii and in the field. Recent studies that show abnormally strong and frequent cold gas interstellar medium interactions signatures in the late-type galaxies in merging clusters seem to indicate that this phase of the galactic content carries the signatures of the physical processes occurring in different environments.

This project proposes a systematic study of 2D integral field spectroscopy (IFS) from the MaNGA (Mapping Nearby Galaxies at APO) survey combined with HI and molecular gas ancillary data for a large sample of galaxies inhabiting different environments. In order to reconstruct the spatially resolved star-formation and chemical enrichment history of galaxies in distinct environments, the student will make use of the FADO population synthesis code and Porto3D post-processing IFS analysis pipeline.

This project provides an excellent combination of astrophysical theory with observations, and it will lead to valuable expertise in the field of spectral synthesis and environment of galaxies, i.e. cluster as compared to field galaxies. Several publications will support the future career of the student. Previous knowledge on one of the following computing languages is desirable: ESO-MIDAS script language, Fortran 77/2008+, C, C++, IDL or Python.

University: Porto

Cosmological tests of gravity theory beyond General Relativity

Advisors: Francisco Lobo (IA U.Lisboa), Noemi Frusciante (IA U.Lisboa)

Abstract: An outstanding problem faced by modern cosmology concerns cosmic acceleration, i.e. the phase of accelerated expansion recently entered by the Universe, for which we still lack a satisfactory theoretical explanation. Within the context of General Relativity, an accelerated expansion can be achieved adding an extra ingredient in the energy budget of the Universe, commonly referred to as dark energy. A different approach is to modify the law of gravity describing the Universe at large scales. A plethora of modified gravity models addressing the phenomenon of cosmic acceleration have been proposed and analyzed. The astronomical community has embarked on an intense observational effort to help exploring the real nature of the cosmic acceleration. Up and coming missions will deliver highly accurate data, offering an unprecedented insight into gravity on cosmological scales. This observational effort is not yet balanced by an equally focused effort at theoretical modeling. The ability to constrain various properties of cosmological models using observational data, such as the anisotropies of the cosmic microwave background, the large scale structure of the galaxy distribution, the expansion and acceleration rate of the universe and other such quantities, has become an essential part of modern cosmology.

The goal of the PhD project will be to unveil the real nature of the theory of gravity. To achieve this, the student will apply theoretical modeling and numerical methods to the best data available and perform forecasts for future next generation surveys.

Development of this project is required for several reasons 1) new theoretical models need to be built; 2) new numerical patches need to be developed which serve to test models against cosmological observations. The analysis tools developed by the student are expected to be used in the upcoming ESA Euclid mission in which the host institution has a leading role. In order to ensure a successful PhD, this project contains theoretical and numerical elements that are flexible such that they can fit with the student's skills and expertise.

University: Lisboa

Testing cosmology in the non-linear regime in the Euclid era

Advisors: Ismael Tereno (IA U.Lisboa), Alberto Rozas-Fernandez (IA U.Lisboa)

Abstract: Physical cosmology relies on two unknown substances – dark matter and dark energy – to provide a description of the Universe that is consistent with current observations. Many dark matter and dark energy hypotheses will soon become testable with data from the Euclid space mission. This project addresses one of those hypotheses: the unification of dark matter and dark energy (UDM).

The goals of this project are: (i) derive structure formation properties in UDM class of models and other related models, (ii) derive their signatures in Euclid's gravitational lensing observables and (iii) forecast Euclid's ability in testing this hypothesis. The theoretical derivations need to be done with high precision and accuracy to match the data quality. In particular, they need to address structure formation in the non-linear regime. To achieve these goals, this project will use existing numerical tools and develop new ones. In particular the project aims at producing N-body simulations of UDM models and the first detailed study of non- linear structure formation under the UDM hypothesis. Other tasks include assessment of model-dependent systematics, creation of lensing maps and statistical inference of model parameters.

University: Lisboa

Restriction: This is a closed topic.

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2 Fast 2 Furious Universe

Advisors: Nelson Nunes (IA U.Lisboa), Tiago Barreiro (IA U.Lisboa)

Abstract: The realization that the Universe is accelerating propels the idea of dark energy. This project aims to understand its nature and how it interacts with the other particles: dark matter, baryons, radiation and neutrinos. The crucial starting point is the most general scalar-tensor theory that leads to viable theoretical cosmologies. The student will test the free functions of the theory against current and forthcoming observational data (ESPRESSO, Euclid, Lisa). This is both a theoretical and hands on data project.

University: Lisboa