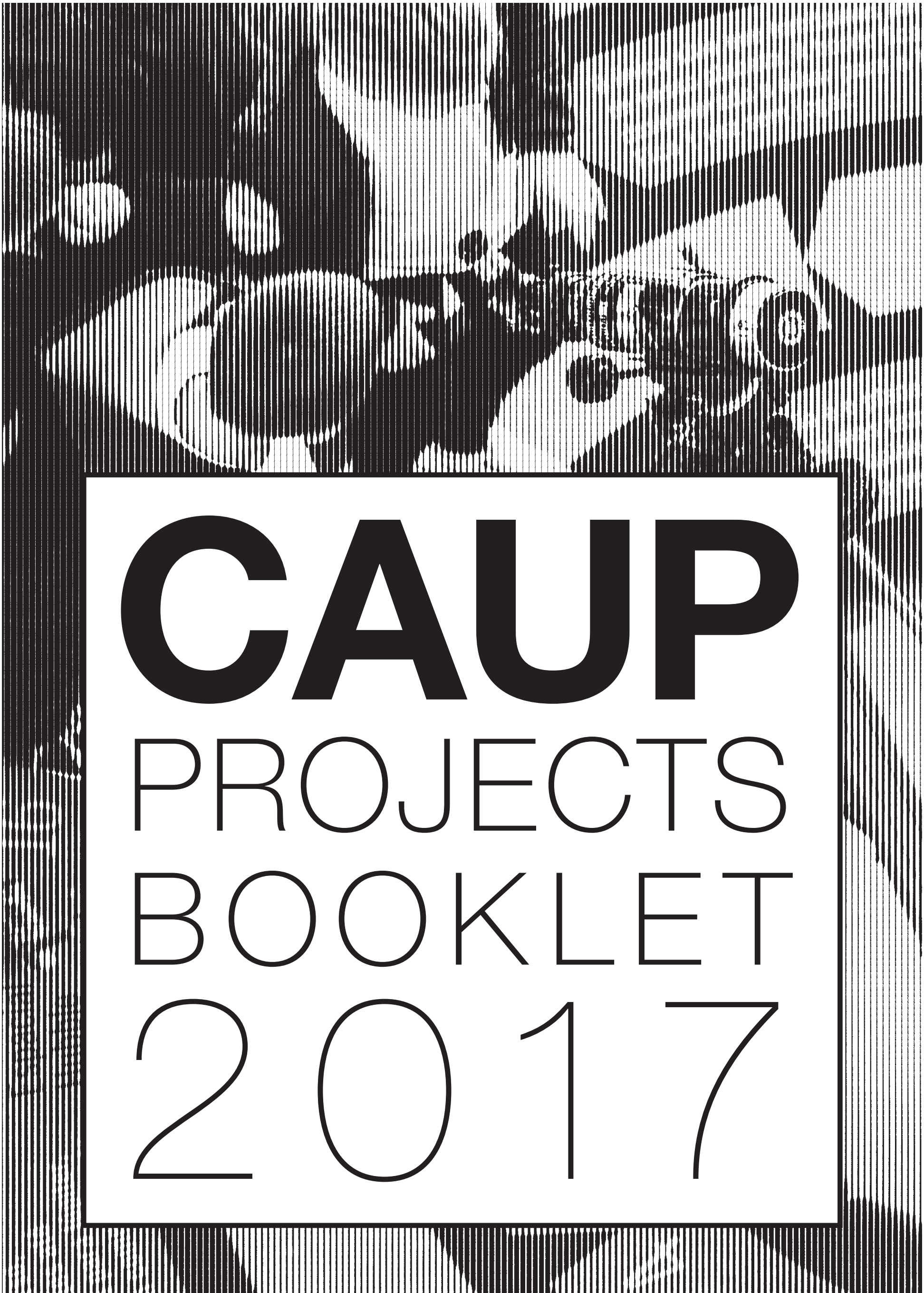

CAUP

PROJECTS BOOKLET 2017

INDEX

Introduction

CAUP has a strong commitment to providing training opportunities for the next generation of astrophysicists, and we are the only research center in the country with a training activities portfolio that spans all levels from Secondary School to Doctoral Programmes – and entails significant amounts of funding and human resources. As part of our commitment to leadership and excellence, we hereby release a list of research projects offered by CAUP members, for various training levels, in the academic year 2017-18.

We start by listing PhD/MSc projects within our participation in ESA and ESO consortia, as leading the national participation in such consortia is one of our key strategic priorities. These are followed by other astrophysics PhD/MSc projects. These tend to represent more specific interests of individual members, although in some cases they also involve non-CAUP collaborations (and external co-supervision). At the PhD level, many of these projects are eligible for funding through our PhD::SPACE doctoral program in the context of IA.

Finally we list education/outreach projects and projects for undergraduate students. In the latter case these are listed in Portuguese, since they are almost always offered through the Faculty of Sciences' PEEC internship program. As an appendix we also list the current CAUP team, including both the researchers and the PhD and younger students.

In the cases where the project has several co-supervisors, the contact person for the project is the one whose e-mail is listed, and you should approach him/her for any enquiries on the project. Although the list is representative of current interests and priorities, it is by no means exhaustive. Many CAUP members have sufficiently broad interests and expertise to be able to supervise other projects. Potentially interested students are encouraged to contact us to explore further possibilities.

Carlos Martins

(Head of the CAUP Training Unit)

March 2017

ESA and ESO related projects

Astrophysical and Local Tests of the Einstein Equivalence Principle

Level: PhD or MSc

Supervisor: Carlos.Martins@astro.up.pt

Notes: Available in PhD::SPACE, foreign co-supervisor to be appointed (at PhD level)

The Einstein Equivalence Principle (EEP, which Einstein formulated in 1907) is the cornerstone of General Relativity (only formulated in 1915) but also of a broader class known as metric theories of gravity. Although they are often confused, the two are conceptually distinct, and different experiments optimally constrain one or the other. Recent developments, including quantum interferometric tests and dedicated space missions, promise to revolutionize the field of local tests of the EEP and dramatically improve their current sensitivity.

In this thesis the student will explore new synergies between these imminent new local tests of the EEP and ongoing or planned astrophysical and cosmological tests: some of these directly test the EEP, while others only test the behaviour of GR on various scales. We will explore relevant paradigms (including scenarios with and without screening mechanisms), develop a taxonomy for the current and new model classes, and study how they are further constrained by experiments such as MicroSCOPE and ACES, in combination with astrophysical data from ESPRESSO, ALMA and other facilities. The work will also be directly relevant for the science case of several E-ELT instruments, as well as Euclid and the SKA.

Key relevant references are: Dimopoulos et al. PRL 98 (2007) 111102, Leite & Martins PRD 94 (2016) 023503, Martins GRG 47 (2015) 1843, Martins et al. JCAP 1508 (2015) 047, Martins et al. PRD 93 (2016) 023506, Uzan LRR 14 (2011) 2 and Will LRR 17 (2014) 4.

Characterizing exoplanet atmospheres with CHEOPS: combining theory and observations

Level: PhD

Supervisor: Nuno.Santos@astro.up.pt

Co-supervisors: Antonio García Muñoz (TU Berlin), O. Demangeon

Notes: Available in PhD::SPACE (mixed fellowship with up to 1 year abroad)

With the number of exoplanets increasing at a fast pace, the attention of exoplanetology is progressively focusing on their detailed characterization. This characterization effort will receive a major boost in the coming years, as a number of new telescopes both in space and on the ground become operative. To fully exploit the potential of the data to arrive, it is critical that similar efforts are spent on the development of theoretical tools that will enable the interpretation of the observations.

CHEOPS is a new ESA space mission (to be launched in 2018) jointly developed by an European consortium whose goal is to characterize planets using high precision photometry. The exquisite photometric precision of CHEOPS will allow us to derive accurate radii for planets orbiting nearby bright stars, thus constraining with unprecedented accuracy their physical properties. Furthermore, CHEOPS' photometric precision will allow to detect the occultation signals of several planets. Occultations occur when the planet passes behind the star as seen by us. During that moment the light emitted/reflected by the planet does not arrive to the observer. The amount of light that is lost in such an event is deeply related to various atmospheric physical properties (e.g. composition, temperature, presence of clouds/hazes). The detection of occultations is currently one of the best avenues to study the atmospheres of exoplanets.

The present project proposes a combined theoretical and observational approach to use data from new instruments (and in particular from CHEOPS) to study the atmospheres of exoplanets. The student is expected to analyze CHEOPS' data to detect and interpret the occultation signals (and maybe phase curves) for a variety of planets orbiting stars with different properties. A statistical analysis of the data, coupled with the model predictions, will allow him to explore new physical processes in the atmospheres of exoworlds. During the project the student is expected to get involved in the exploration of CHEOPS data.

Fundamental cosmology from precision spectroscopy: from ESPRESSO to the E-ELT

Level: PhD or MSc

Supervisor: Carlos.Martins@astro.up.pt

Notes: Available in PhD::SPACE, foreign co-supervisor to be appointed (at PhD level)

ESPRESSO is the next generation spectrograph, combining the efficiency of a modern Echelle spectrograph with extreme radial velocity and spectroscopic precision, and including improved stability thanks to a vacuum vessel and wavelength calibration done with a Laser Frequency Comb. ESPRESSO will be installed in the Combined Coudé Laboratory of the VLT in late 2017, and linked to the four Unit Telescopes (UT) through optical Coudé trains, allowing operations either with a single UT or with up to four UTs for about a 1.5 magnitude gain. One of the key science drivers of ESPRESSO is to perform improved tests of the stability of nature's fundamental couplings, and in particular to confirm or rule out the recent indications of dipole-like variations of the fine-structure constant, alpha.
In this thesis the student will be directly involved in the analysis and scientific exploration of the ESPRESSO fundamental physics GTO data, as well as in the preparation of any follow-up observations. Apart from its obvious direct – and very significant – impact on cosmology and fundamental physics, the ESPRESSO data will also be important as the first reliable precursor of analogous high-resolution spectrographs for the next generation of Extremely Large Telescopes, and in particular of ELT-HIRES (in whose ongoing Phase A we are directly involved). Thus a second goal of the thesis is to use the ESPRESSO data to carry out detailed realistic simulations to assess the cosmology and fundamental physics impact of ELT-HIRES, inter alia exploring the feasibility of novel tests which are beyond the sensitivity of ESPRESSO, such as redshift drift measurements and molecular tests of composition-dependent forces.

Key relevant references are: Avgoustidis et al. PRD 93 (2016) 043521, de Martino et al. PRD 94 (2016) 083008, Evans et al. MNRAS 445 (2014) 128, Leite et al. PRD 94 (2016) 123512 Martins GRG 47 (2015) 1843, Martins et al. JCAP 1508 (2015) 047, PRD 93 (2016) 023506, PRD 94 (2016) 043001 and Martins & Pinho PRD 95 (2017) 023008.

Looking for rings and tides in transiting planets

Level: PhD
Supervisor: Susana.Barros@astro.up.pt
Co-supervisor: Nuno Santos
Notes: Available in PhD::SPACE

Recent years have seen a revolution in our knowledge of exoplanetary systems including many surprising discoveries. In contrast, several expected results have not yet been observed or confirmed. Among these is the existence of moons and rings, as well as of tidal deformations of the exoplanets that orbit very close to their parent star. This project aims at detecting these extreme systems taking advantage of the unprecedented precision of the ongoing and future transit missions K2, TESS, CHEOPS and Plato, as well as of new high--resolution spectrographs such as ESPRESSO.
In this project we propose to upgrade a state of the art Bayesian transit and radial velocity fitting code to include rings, planetary occultations, Rossiter-McLaughlin effect, and tidal effects. Rings have never been detected around extra-solar planets, but their signature should be present in both the transit light and radial-velocity curves (through the Rossiter--McLaughlin effect). The tidal star-planet interactions deform the planets, producing also significant deformation in the light curve (never detected, but expected for some short period planets). Hence, the code will allow searching for the signature of rings, planetary occultations, and tidal effects. All these effects have been predicted by theory but they were never observed: the new set of instruments will allow us to make a breakthrough in this domain.

Our team has privileged access to CHEOPS data hence the student will be able to access this unique dataset. Furthermore, the tools developed during this project we may also use for other datasets: NASA K2, TESS missions and in the future for ESA PLATO mission. The results of this project will increase the scientific exploitation of these state of the art missions and lead to a better understanding of planetary systems.

Reflections from other worlds: detecting the atmospheres of other planets with high resolution spectroscopy

Level: PhD
Supervisor: Nuno.Santos@astro.up.pt
Co-supervisor: Cláudio Melo (ESO)
Notes: Available in PhD::SPACE

Are we alone in the Universe? To answer this question, several high-impact instruments and space missions are in current development, guaranteeing that exoplanetology will be in the front-line of astronomical research for many years to come. With the number of exoplanets increasing at a fast pace, the focus in this field is also starting to focus significant efforts towards the detailed characterization of these alien worlds. In particular, a number of different techniques have enabled the detection of the signature from exoplanet's atmospheres for already a dozen of cases. The advent of a whole new generation of high-resolution spectrographs working both in the optical and near-IR is promising a bright future for this line of research, allowing to characterize increasingly smaller planets at larger distances.

ESPRESSO is a new high-resolution spectrograph for the ESO-VLT telescopes (the start of the operations is expected for early 2018). Its unique stability and resolution, coupled with the high collecting area of the VLT telescopes, will allow us to detect and characterize exoplanets with masses similar to that of the Earth. Furthermore, ESPRESSO is expected to give us the possibility to detect the reflected light signal from distant exoplanets. A new window towards the study of exoplanet atmospheres will thus be open. Our team is deeply involved in ESPRESSO, having thus a unique access to this instrument and to its data.

In the present PhD offer the student the opportunity to lead the development of a methodology to detect the spectra of exoplanets using high-resolution spectroscopy, and in particular to study the reflectance of the exoplanet as a function of wavelength. The developed methods will be used with new data from ESPRESSO. Together with planet atmosphere models, the observations will allow us to probe and understand in unique detail the physical and chemical conditions of the observed planets, and shed new light into the physics of these distant worlds.

Small planets around small stars: characterizing M-dwarfs in CHEOPS

Level: PhD
Supervisor: Sergio.Sousa@astro.up.pt
Co-supervisor: Nuno Santos, Elisa Delgado Mena
Notes: Available in PhD::SPACE

This project will be focused on the precise characterization of low mass stellar/planetary systems observed with CHEOPS. The characterization of the planets in these systems are strongly dependent on the correct knowledge of the host stars. Therefore the goal of this topic is strongly connected with the precise characterization of M stars. Although these cool M stars are the most common stars in our Galaxy they still represent an outstanding challenge in what regards their characterization and are currently the most crucial step for an accurate study of low mass stellar/planetary systems.
To achieve this goal we will use ground-breaking spectroscopic analysis of near-infra-red (NIR) spectra of M-dwarf stars with the goal of deriving precise and homogeneous stellar parameters. The knowledge of the stellar parameters of planet-hosts, in particular their radii, is essential for the derivation of the properties of the discovered planets. The goals of the present project will have important impact in the scientific community and are of great importance for the full success of future space missions like CHEOPS for which we have direct access to private/consortium data (80% of the telescope time), but also for TESS, which will have immediate public data, and later for PLATO.
With this in mind, the goal of the proposed project is to use methodologies for the spectroscopic analysis of near-IR high resolution spectra that are/will soon be available from new instruments such as SpiRou, CARMENES, and CRIRES+. Moreover, we intend to develop a method based on spectral synthesis that could be used as an alternative for this kind of stars. These methods will be applied to M stars hosting planets observed with CHEOPS/TESS. Besides the determination of precise stellar (and thus planetary) properties, one important side project will be to further explore possible correlations between the properties of the stars and the presence of the planets, which can give important clues for planet formation models.

Other astrophysics projects

Advanced statistical data analysis methods for the detection of other Earths

Level: PhD
Supervisor: Pedro Viana (viana@astro.up.pt)
Co-supervisor: Nuno Santos
Notes: Available in PhD::SPACE

For the past two decades, the radial velocity technique has been extremely successful, leading to the detection and characterisation of hundreds of exoplanets. In the process, its limits have been continuously challenged by a combination of new instrumentation and data analysis methods. The main objective has been to reach the precision needed to detect Earth-analogs, planets with mass and orbital period close to that of Earth, moving around a star similar to the Sun. This goal may become a reality within the next few years, as third-generation spectrographs become operational, e.g. ESPRESSO@VLT in 2018. However, it will only be accomplished through the implementation of more advanced statistical data analysis methods, capable of identifying a planetary-induced radial velocity signal in the presence of confounding signals an order of magnitude higher in amplitude, be they of instrumental origin or produced by stellar activity.

In this project we propose to tackle these problems through the development of a new data analysis computational tool for the purpose of exoplanet detection and characterization using the radial velocity technique, built within the framework of Bayesian statistics and using the power of Gaussian Processes. This tool should be capable of jointly taking into account the information contained in any number of time-series, extracted from spectroscopic and photometric data, that may help disentangle the impact on radial velocity data of planetary motion and stellar activity, based on existing and newly developed indicators for the latter. As a result, it is expected the student will be at the forefront with respect to the detection and characterization of low-amplitude (e.g. below one meter per second) signals produced by the orbital motion of exoplanets. This could lead to the publication of high-impact papers, based on the analysis of HARPS and/or ESPRESSO data.

Analytic Methods for Astrophysical Defect Fingerprinting

Level: PhD or MSc

Supervisor: Carlos.Martins@astro.up.pt

Notes: Available in PhD::SPACE, foreign co-supervisor to be appointed (at PhD level)

Cosmic strings arise naturally in many proposed theories of new physics beyond the standard model unifying the electroweak and strong interactions, as well as in many superstring inspired inflation models. In the latter case, fundamental superstrings produced in the very early universe may have stretched to macroscopic scales, in which case they are known as cosmic superstrings. If observed, these objects thus provide a unique window into the early universe and possibly string theory.

Recent progress in CMB polarization and gravitational wave detection shows how some of these scenarios can be constrained by high-resolution data. However, to fully exploit the potential of ESA facilities such as CORE and LISA, one needs matching progress both in high-resolution HPC numerical simulations of defect networks and in the analytic modelling of key physical mechanisms underlying their evolution. This thesis will address the latter, using a series of mathematical and statistical techniques to develop more accurate analytic models for general defect evolution (building upon the successes of the current canonical VOS model) as well as for their astrophysical fingerprints, which is able to match the sensitivity of ongoing and future observational searches.

A recent introduction to the field can be found in Martins, Defect Evolution in Cosmology and Condensed Matter: Quantitative Analysis with the Velocity-Dependent One-Scale Model (Springer, 2016). Other relevant references are Lazanu et al. PLB B747 (2015) 426, Martins & Cabral PRD 93 (2016) 043542, Martins et al. PRD 93 (2016) 043534 & PRD 94 (2016) 116017, and Vieira et al. PRD 94 (2016) 096005.

Coding the Cosmos: A New Generation of Superstring Simulations

Level: PhD or MSc

Supervisor: Carlos.Martins@astro.up.pt

Notes: At PhD level, this is a closed project

Cosmic strings arise naturally in many proposed theories of new physics beyond the standard model unifying the electroweak and strong interactions, as well as in many superstring inspired inflation models. In the latter case, fundamental superstrings produced in the very early universe may have stretched to macroscopic scales, in which case they are known as cosmic superstrings. If observed, these objects thus provide a unique window into the early universe and possibly string theory.

Recent progress in CMB polarization and gravitational wave detection highlights how some of these scenarios can be constrained by high-resolution data. However, they also show that the current bottleneck is the lack of accurate high-resolution simulations of defect networks that can be used as templates for robust statistical analysis. This is expected to be an even bigger problem for next-generation facilities such as CORE and LISA. This thesis will go significantly beyond the state-of-the-art and develop and implement a new generation of high-scalability HPC defect codes that will be able to match the sensitivity of ongoing and forthcoming observational searches.

A recent introduction to the field can be found in Martins, Defect Evolution in Cosmology and Condensed Matter: Quantitative Analysis with the Velocity-Dependent One-Scale Model (Springer, 2016).

Cosmic strings and other defects as probes of the (very) early universe

Level: PhD
Supervisor: Lara.Sousa@astro.up.pt
Co-supervisor: Pedro Avelino
Notes: Available in PhD::SPACE

The recent discovery of the Higgs Boson at the Large Hadron Collider appears to support the idea that the universe underwent, in its early history, a series of symmetry-breaking phase transitions and that, as a consequence, networks of topological defects could have been generated. These defect networks, although formed in the early universe, are expected to survive throughout the cosmological history, potentially leaving behind a plethora of observational signatures. The study of cosmic defects and their signatures, then offers an insight into the physics of the early universe. Compellingly, the recent suggestion that fundamental strings and 1-dimensional Dirichlet branes – the fundamental objects of Superstring theory – may play the role of cosmic strings, extends this possibility towards very early cosmological times into energy scales far beyond the reach of current particle accelerators.
The computation of the specific signatures left behind by topological defects is essential to use the data of present and upcoming observational infrastructures to their full potential. This project aims at improving the current estimates of these signatures, by making use of realistic semi-analytical and numerical models for the evolution of cosmic defect networks, with a particular emphasis on cosmic (super)string and domain wall networks. In particular, the associated gravitational wave background and its impact on the B-mode polarization of the Cosmic Microwave Background, their signatures on the reionization history of the universe and the 21cm background, and their potential role as seeds of variations in fundamental couplings, shall be investigated in detail. Detailed forecasts for upcoming probes, including eLISA (as part of our participation in the eLISA Cosmology Working Group), COrE+, SKA, ESPRESSO and E-ELT HIRES will be central to this PhD project.

Detection of phase-curves in the K2 data

Level: MSc

Supervisor: Olivier.Demangeon@astro.up.pt

The NASA-Kepler satellite has revolutionized the field of exoplanetology in many aspects. One of them is the detection of tens of exoplanet phase-curves, see Esteves et al 2015 (ApJ 804, 150). Phase-curves are particularly interesting since, when they are produced by a planet, they constitute a manifestation of the exoplanet atmosphere. After the loss of two reaction wheels, the Kepler satellite pointing accuracy was severely damaged but cleaver engineering allowed the continuation of the mission in a new configuration named K2. Our team developed a software called POLAR (see Barros, Demangeon et al. 2016: A&A 594, A100) to reduce the data coming from K2 and retrieve a photometric precision close to the original Kepler mission.

Thanks to the retrieved photometric precision, a phase-curve has been recently observed in the light-curve of the exoplanet WASP-157 b observed with K2 (see Mocnik et al. 2016, arxiv:1603.05638). The objective of this project is to look for phase-curves in the light-curve provided by the POLAR software. The student will first go through the list of planets detected in the K2 data and announced for example in Barros, Demangeon et al. 2016. From these lists, he will select the planets which have the best chances of displaying a phase-curve in their light-curve (shorter periods and bigger radius). Finally, he will analyze the selected light-curves to extract the phase-curve variations. Depending on the result of the analysis this work could lead to a publication.

Galaxy interactions at Infrared wavelengths

Level: MSc
Supervisor: Tom.Scott@astro.up.pt
Co-supervisor: Catarina Lobo

Galaxies, especially in galaxy clusters and galaxy groups, can tidally interact with one another and these interactions produce characteristic distortions in the galaxy's shape, e.g. tidal tails. During their orbits in galaxy clusters, spiral disk galaxies like the Milky Way can also interact with a hot X-ray emitting gas, which pervades galaxy clusters and is known as the intra-cluster medium (ICM). This interaction, known as ram pressure stripping, can remove the galaxy's gaseous interstellar medium. During ram pressure stripping it is only the galaxy's interstellar medium which interacts with the ICM leaving the galaxy's old stellar population unaffected. Ram pressure stripping can however affect the location of young stars. So to distinguish between tidal and ram pressure-stripping interactions we need to understand which wavelength best traces a spiral galaxy's old stellar population. We can then see whether the old stellar population has been disturbed or not by the interaction, thus allowing us to distinguish between tidal and ram pressure interactions. In turn this will help understand how the cluster environment drives the evolution of its galaxies.
In general, infrared wavelengths are better tracers of old stellar populations than optical wavelengths, but there remain questions about which infrared wavelength bands optimally reflect a galaxy's old stellar population. The project's aim is to compare the emission from a sample of spiral galaxies in a few nearby clusters imaged in different infrared wavelength bands and with different telescopes, including the Spitzer space telescope (all data is available and in archives). The study will investigate the differences between emission in different infrared bands and the reasons for these differences based on theories of the emission detectable in each band, with the aim of determining which band best reflects the emission from the old stellar population. Resolving this question is a step in understanding more fundamental issues of galaxy evolution.

Gas flows around high-mass binary stellar systems in formation

Level: PhD or MSc

Supervisor: Nanda Kumar (nanda@astro.up.pt)

Notes: Available in PhD::SPACE

O- and early B-type stars are commonly found in binary and multiple systems. A study of ca. 400 OB stars shows that 70% of all O-stars and 50% of early B stars display binarity or multiplicity. Yet we do not know why.

Two mechanisms are known to produce binary systems with mass ratios close to unity (M2/M1~1) and typical separations of 3 to 1000 AU: first, gravitational instability in a massive accretion disk; and second, N-body interactions in a proto-cluster. In the first case, if mass flows onto a centrifugally supported disk faster than it can be accreted onto the star, the disk may grow to rival the mass of the star and fragment by gravitationally instability to form a second star, possibly of near equal mass. Numerical hydrodynamic simulations of massive accretion flows have produced such an outcome.

The goal of this project is to examine the nature of accretion flows and outflowing gas in four young binary systems that have been discovered by us through adaptive optics observations. This project will employ observations primarily in the (sub)mm and infrared bands using ALMA and VLT.

New Maps of the Dark Side: Euclid and beyond

Level: PhD or MSc

Supervisor: Carlos.Martins@astro.up.pt

Notes: Available in PhD::SPACE, foreign co-supervisor to be appointed (at PhD level)

The growing amount of observational evidence for the recent acceleration of the universe unambiguously demonstrates that canonical theories of cosmology and particle physics are incomplete—if not incorrect—and that new physics is out there, waiting to be discovered. The most fundamental task for the next generation of astrophysical facilities is therefore to search for, identify and ultimately characterise this new physics. The acceleration is seemingly due to a dark component whose low-redshift gravitational behaviour is very similar to that of a cosmological constant. However, currently available data provides very little information about the high-redshift behaviour of this dark sector or its interactions with the rest of the degrees of freedom in the model.

It is becoming increasing clear that tackling the dark energy enigma will entail significantly extending the redshift range where its behaviour can be accurately mapped. A new generation of ESA and ESO facilities, such as Euclid, the E-ELT, and the SKA have dark energy characterization as a key science driver, and in addition to significantly increasing the range and sensitivity of current observational probes will allow for entirely new tests. The goal of this thesis will be to carry out a systematic exploration of the landscape of physically viable dark energy paradigms and provide optimal discriminating observational tests. The work will initially focus on Euclid (whose launch is fast approaching) and will gradually broaden to explore synergies and probe combination with the SKA and relevant ELT-HIRES instruments.

Key relevant references are: Amendola et al. (2016) arXiv:1606.00180, Calabrese et al. PRD 89 (2014) 083509, Martins et al. PRD 93 (2016) 023506 and Martins et al. PRD 94 (2016) 043001

Orbital evolution of planetary systems: from formation to today

Level: PhD
Supervisor: Vardan.Adibekyan@astro.up.pt
Co-supervisors: Alexandre Correia (U. Aveiro), Pedro Figueira
Notes: Available in PhD::SPACE

The field of extrasolar planets research is teeming with activity. Very recently we celebrated the 20th anniversary of the discovery of the first planet outside our system, and yet we count already over 3000 confirmed planets and thousands of candidates to confirm. With a fast-growing discovery pace and a bright future ahead guaranteed by large number of ongoing and planned projects, it presents itself as the emerging astronomy topic of the new century.

As the planetary zoology continues, recent studies have shown that stellar properties (like mass, evolutionary stage, and metallicity) also play a very important role not only on the formation of planets, but also on the orbital evolution. Several remarkable observational results can be outlined from these studies, that are still waiting for a solid explanation: planets in the metal-poor systems form/evolve differently appear to form farther out from their central star and/or they form later and do not migrate far; low-metallicity stars have a deficit of eccentric planets between 0.1 and 1 AU when compared to their metal-rich counterparts, because of either a less effective planet-planet interactions or due to the self-shadowing of the disk by a rim located at the dust sublimation radius (approx. 0.1 AU). Planet-planet and planet-disk gravitational interactions during the formation process emerge as important orbit-shaping to be explored for a better understanding of the evolution of planetary systems. With this application we propose to study the impact of stellar metallicity on the orbital evolution of planetary systems from the observational point of view and to develop new simulations in which we consider the effect of disk and/or a companion planet's presence on the planetary parameters. A linkage between theory and observations as presented here is uncommon, but crucial to understand our picture of extrasolar system. The different expertise of the supervisors will allow for a more encompassing work than before.

Physical properties of VIPERS galaxies

Level: MSc
Supervisor: Jean Michel Gomes (jean@astro.up.pt)
Co-supervisor: Catarina Lobo

VIPERS, the VIMOS Public Extragalactic Survey (http://vipers.inaf.it), has recently made its second and final data release of ca. 90 000 galaxy spectra in the redshift range $0.5 < z < 1.2$ over a total area of 24 square degrees. Multi-wavelength ancillary data is available as well. These new data provide the currently unique opportunity to extend to medium redshift, with similar statistics, all the analyses already carried out for SDSS local galaxy spectra, namely by deriving several physical properties of galaxies such as stellar and gas masses, extinction, chemical abundances, mean stellar age and metallicity, star-formation histories, gas ionization parameters, among others. Comparisons with the local sample results will allow us to shed light on how galaxies evolve through time.
In this project, the student is expected to learn how to work with existing spectral synthesis and emission-line analyses tools, and apply them to the already fully reduced VIPERS spectra to extract the physical properties of galaxies outlined above. During this work, he/she will have to develop some programming routines and achieve a good management of the dataset. The student will then compare his results with the ones already obtained at low redshift, contributing to a better understanding of the possible evolutionary pathways of galaxies. In particular, some astrophysical relations (e.g. the mass-metallicity relation) will be investigated for the first time at higher redshifts with similar statistical significance as already achieved in the local Universe.

Planning observations for the detection and characterization of exoplanets

Level: PhD
Supervisor: Pedro Viana (viana@astro.up.pt)
Co-supervisor: Sérgio Sousa
Notes: Available in PhD::SPACE

The detection and characterization of planets around stars other than the Sun, also known as exoplanets, has been one of the most rapidly developing research topics within Astronomy for the past two decades. With third-generation spectrographs becoming operational in the next few years, e.g. ESPRESSO@VLT in 2018, and with the launch of space missions like CHEOPS (also in 2018), our knowledge of the exoplanet population will expand significantly, in particular towards the regime occupied by Earth analogs. However, in order for these instruments to be used in the most efficient way, it will be very important to carefully plan the sequence of observations to be made of any given star. The objective is to extract the maximum amount of information about any exoplanet orbiting the stars observed. This is most naturally achieved within the framework of Bayesian optimal experimental design, where the utility function to be maximized measures the expected information gain with the planned observations.
In this project we propose the development of a computational tool for planning observations aimed at the detection and characterization of exoplanets, using the radial velocity or transit techniques, and built within the framework of Bayesian experimental design. This tool should be capable of implementing batch and sequential planning, and take into account different types of prior data and information about the physical phenomena that affect the observables, namely when and in what conditions the stars that could be the targets of observation are visible. As a means of using existing transit data to inform the planning of radial velocity observations, and vice-versa, it is also proposed the characterization of the relation between exoplanet mass and radius using Gaussian Processes as part of a hierarchical Bayesian model. As a result, the student is expected to participate in the planning and execution of observations using the HARPS and/or ESPRESSO instruments, as well as by the CHEOPS satellite. The publication of several papers is expected, describing the planning methods developed, the derived relation between exoplanet mass and radius, and on the characteristics of the exoplanets discovered or re-observed based on the data acquired through the planned observations.

Probing the architecture of multi-planetary systems

Level: PhD
Supervisor: Susana.Barros@astro.up.pt
Co-supervisor: Olivier Demangeon
Notes: Available in PhD::SPACE

The Kepler satellite has revealed that a large percentage of the known transiting exoplanets are in multi-planetary systems (ca. 40%). Multi-planetary systems are great laboratories to test theories of formation and migration of planetary systems. Many interesting systems found by Kepler and others recently found by the K2 mission are still awaiting detailed modelling due to the extracomplexity that the gravitational interaction between the different planets of the system introduces. This project aims at the study of the architecture of multi-planetary systems using detailed state of the art n-body simulations coupled with a Bayesian modelling.

The project is built on a photodynamic transit and radial velocity (RV) fitting tool developed by our group to study interesting known Kepler multi-planetary systems and/or new multi-planetary systems discovered by the K2 and TESS new surveys. A photodynamical analysis, accounting for the dynamical interactions between the planets of the system at the earliest stage of the data analysis, achieves a better precision and accuracy on the determination of the system parameters than usual methods. It is also more sensitive to the low masse planets. The goal of this project is to focus on the lowest mass planets (super-Earths and mini-Neptunes), for which it is not possible to determine masses with current RV instruments alone and will probe this fascinating population of planets.

Our group has developed a pipeline to reduce K2 data and compute high precision light curves combined with a transit search algorithm to search for planetary transits. Hence we have a competitive advantage to discover knew interesting systems from K2 or even TESS data. We are also involved in a collaboration to obtain precise radial velocities with the HARPS spectrograph to confirm and characterise these candidates. The student will study the most promising know systems and is also expected to be involved in the search and characterisation of these new multi-planetary systems.

Search for transiting planets in K2 light curves

Level: MSc
Supervisor: Olivier.Demangeon@astro.up.pt
Co-supervisor: Susana Barros

The K2 satellite is a gold mine for exoplanets science. Every 6 months, it offers to the community tens of thousands of light-curves in which already hundreds of transits have been detected, see for e.g. Barros, Demangeon, et al. 2016 (A&A 594, A100), thereafter BD16. The goal of this project is to improve the code described in BD16 and search for exoplanetary transits in the new data coming from the K2 satellite. In particular, we will focus the development in improving the detection of systems with multiple planets. Those systems are indeed particularly interesting for their implication on the processes of formation and evolution of exoplanets in general.
Depending on the progress, the project can also include a participation to the follow-up of the detected transits. In this case the student will be involved in the vetting and prioritisation of the detected transits. The most promising ones will then be observed in radial velocities with the HARPS and/or SOPHIE high-resolution spectrograph (through or collaboration) to confirm the planetary nature of the transits and measure the mass of the planets. The student will be involved in the resulting publication(s).

Stellar noise and stellar ‘signals’

Level: MSc
Supervisor: Vardan.Adibekyan@astro.up.pt
Co-supervisor: Mahmoudreza Oshagh (U. Gottingen)

Understanding the stellar magnetic activity phenomena (such as spots, faculae, plages) is very important for different fields of stellar and exoplanetary astrophysics, and for planetary climate studies. Studying magnetic activity on stars of different stellar parameters and activity levels provides an opportunity for detailed tests of stellar/solar dynamo models. From the exoplanetary sides, it is well known that stellar active regions combined with the stellar rotation can induce signals in high-precision photometric and radial velocity observations. These activity-induced signals may lead to masking or mimicking exoplanets signal. Moreover, these signals are one of the main limitations for the detection and the precise characterization of low mass/small radii planets, which is the major goal of future instruments.

The ultimate goal of this project is to explore novel ways to estimate the stellar variability (new proxies). By using lines of different excitation and ionization potentials the student will explore the link between photospheric variability and chromospheric activity. It is also of great interest (and part of the project) to study the impact of these variations on the the derivation of stellar parameters and chemical abundances of the stars.

This work will be carried out in collaboration with Pedro Figueira and other members of the EXOEarths team <http://www.astro.up.pt/exoearths>. The student will join our team that has very strong experience in the studies of stellar activity, planet detection and stellar characterization. There is also possibility for the student to participate in the observational programs of our team with the telescopes in Chile.

The Nature of High-Mass Proto-Stellar Seeds

Level: PhD or MSc

Supervisor: Nanda Kumar (nanda@astro.up.pt)

Notes: Available in PhD::SPACE

In the formation of stars, the Kelvin-Helmholtz time scale becomes shorter than the free-fall time-scale, for a mass approximately 7-8 solar masses. Therefore, the stellar seed reaches a thermal equilibrium, start-off nuclear fusion and begin to contract to the main-sequence even while it goes through the main phase of accreting matter. Consequently, the luminosity of the massive stellar seed derives both from accretion luminosity and nuclear fusion. This leads to high internal entropy of these proto-stellar objects allowing them to swell in radius.

At a later stage this entropy is radiated away through intense radiation (ionizing the surroundings), allowing the proto-star to contract and become a main sequence OB star. Depending on the instantaneous mass and the evolutionary time-scale (<50000 years), these high mass stellar seeds are known in the literature as massive young stellar objects, infrared counterparts to high mass proto-stellar objects or the ionizing sources of compact HII regions.

The goal of this project will be to analyse the zYJHK band (0.8 micron to 2.4 micron) spectroscopy of a systematic sample of the high mass stellar seeds to understand the physics that theory predicts to be different from that of lower mass sun-like stars.

Unveiling the composition of exoplanets with atmosphere spectroscopy

Level: PhD
Supervisor: Olivier.Demangeon@astro.up.pt
Co-supervisor: Susana Barros
Notes: Available in PhD::SPACE

With already more than 3000 exoplanets detected, we know that exoplanets are ubiquitous in the galaxy. However, for most of them, their composition and atmospheric conditions (temperature, pressure, clouds, hazes, rain) are poorly known. The goal of this project is to delivering insights in the composition of exoplanets through an homogenous modeling of dataset obtained with different observational techniques.
The student will have to confront the PHOENIX-BT-Settl atmospheric models to data from several instruments enabling atmospheric characterization and extract robust information regarding the composition of exoplanets' atmosphere. He will first start with archive and already published data from transit photometry (Sing et al. 2016 from WFC3@HST) and high-angular resolution and high-contrast data (Bonnefoy et al. 2016 SPHERE@VLT). Then he will analyse high-spectral resolution data using the cross correlation technique (Snellen et al. 2010 from CRIRES@VLT). An homogenous analysis of datasets coming from these different observational techniques has never been done before and will open new doors for atmospheric studies. The final step of this project will be to apply the developed analyses to different types of newly discovered planets and to explore trends in the atmospheric composition with respect to the characteristic of the observed planets, stars and observing techniques.

Weather forecast on exoplanets through the modeling of phase-curves

Level: MSc
Supervisor: Olivier.Demangeon@astro.up.pt

Accessing the conditions in exoplanets' atmospheres is the new focus of the exoplanet community. During the past ten years, the space missions CoRoT, Kepler and K2, based on the high-precision photometry technique, have provided us with exquisite light-curves allowing the detection of thousands of exoplanets. In favorable cases where the detected planet orbits very close to its parent star, those light-curves can provide additional information regarding the planet's atmospheric conditions through the observation of phase-curves (see Esteves et al. 2015).
This project proposes to implement the model described in Esteves et al 2015 (ApJ 804, 150). The student will then plug this model into an existing software developed by our team to analyse the light-curve of exoplanets. Finally, the software will be used to interpret the phase-curve of known exoplanets and look for variability in the phase-curve of already know planets as recently done by Armstrong et al 2016 for HAT-P-7 b (Nature Astronomy 1, 0004). Such variability constitutes the first observed signs of weather evolution in an exoplanets atmosphere. In case a new variability is discovered in the phase-curve an exoplanet, the student will be involved in the resulting publication.

Education/ outreach and undergraduate projects

Scientific literacy and astronomy teaching

Level: PhD or MSc

Supervisor: Carlos.Martins@astro.up.pt

We have recently carried out a survey of high-school students (from 7th to 12th grade) in Portuguese schools, aiming to determine the degree of understanding of some basic astronomy concepts which are supposedly part of the national schools curriculum. The main result of the survey was that most students do not in fact meet the set national standards. The goal here is to take advantage of our privileged contacts with schools to extend this study, ideally reaching several tens of thousands of students and possibly also extending it to university students. The increased population will enable a more detailed statistical analysis that should allow meaningful comparisons between different sub-samples. Although the focus will be on astronomy, in the case of a PhD project we will also aim to quantify the degree of scientific literacy of the students, either by implementing in Portugal methodologies previously developed in other countries or by designing and implementing our own, optimized to the specific context of Portuguese schools. Finally we will seek to quantify the degree of scientific literacy of the school teachers themselves, and how that may impact some of the knowledge (and the possible misconceptions) acquired by the students during their school years.

Cartografando o lado escuro do universo

Orientador: Carlos.Martins@astro.up.pt
Local do Estágio: CAUP; dependendo do desempenho, o estágio incluirá também visitas de trabalho a colaboradores no estrangeiro e/ou deslocações a conferências para apresentação dos resultados.

Perfil do Candidato:
Experiência prévia de programação, análise e visualização de dados é essencial. Experiência anterior com projectos deste tipo é valorizada. Espera-se uma dedicação mínima de 6 horas de trabalho por semana, parcialmente presenciais. Serão disponibilizados um espaço de trabalho no CAUP e acesso a recursos computacionais apropriados. Poderá ser realizada uma entrevista aos candidatos.

Objectivos e Actividades:
Os alunos serão integrados em colaborações internacionais que desenvolvem estratégias observacionais optimizadas para a caracterização das propriedades da energia escura em todo o intervalo de redshifts de 0 a 5, utilizando o satélite Euclid (ESA) e os vários instrumentos previstos para o E-ELT (ESO).

Actividades específicas incluem:
1) Estudo semi-analítico de modelos cosmológicos com campos escalares para a aceleração do universo e a variação das constantes fundamentais da natureza;
2) Desenvolvimento e análise de simulações numéricas para modelos representativos, e comparação com os dados observacionais existentes ou futuros;
3) Desenvolvimento de catálogos simulados de observações para os instrumentos em causa (Euclid, ESPRESSO, HIRES e outros) e optimização das respectivas estratégias observacionais;
4) Organização e apresentação dos resultados obtidos.

Exemplos de bibliografia relevante: arXiv:1412.0108, arXiv:1503.05068, arXiv:1505.05529, arXiv:1601.02950 e arXiv:1606.07261.

Paleontologia cósmica: à procura de fósseis do universo primitivo

Orientador: Carlos.Martins@astro.up.pt

Local do Estágio: CAUP; dependendo do desempenho, o estágio incluirá também visitas de trabalho a colaboradores no estrangeiro e/ou deslocações a conferências para apresentação dos resultados.

Perfil do Candidato:
Experiência prévia de programação, análise e visualização de dados é essencial. Experiência anterior com projectos deste tipo é valorizada. Espera-se uma dedicação mínima de 6 horas de trabalho por semana, parcialmente presenciais. Serão disponibilizados um espaço de trabalho no CAUP e acesso a recursos computacionais apropriados. Poderá ser realizada uma entrevista aos candidatos.

Objectivos e Actividades:
Os alunos serão integrados em colaborações internacionais que estudam a evolução de supercordas e outras n-branas. Estes objectos formaram-se necessariamente no universo primitivo, e a sua caracterização dá-nos pistas cruciais sobre a física fundamental. O estudo da evolução destes objectos inclui a análise das suas consequências observacionais, no contexto dos dados do satélite Planck e de possíveis missões futuras da ESA (CORE e LISA).

Actividades específicas incluem:
1) Estudo de modelos analíticos para a evolução de redes de supercordas e outros defeitos topológicos;
2) Desenvolvimento de novos modelos (analíticos ou numéricos) simplificados para estudar aspectos específicos da dinâmica da rede;
3) Processamento, análise e visualização de resultados de simulações numéricas de alta resolução destas redes;
4) Organização e apresentação dos resultados obtidos.

Exemplos de bibliografia relevante: arXiv:1312.2123, arXiv:1405.7722, arXiv:1407.3905, arXiv:1602.01322 e arXiv:1602.08083.

Testes da universalidade das leis da física

Orientador: Carlos.Martins@astro.up.pt
Local do Estágio: CAUP; dependendo do desempenho, o estágio incluirá também visitas de trabalho a colaboradores no estrangeiro e/ou deslocações a conferências para apresentação dos resultados.

Perfil do Candidato:
Experiência prévia de programação, análise e visualização de dados é essencial. Experiência anterior com projectos deste tipo é valorizada. Espera-se uma dedicação mínima de 6 horas de trabalho por semana, parcialmente presenciais. Serão disponibilizados um espaço de trabalho no CAUP e acesso a recursos computacionais apropriados. Poderá ser realizada uma entrevista aos candidatos.

Objectivos e Actividades:
Os alunos serão integrados em colaborações internacionais que desenvolvem novos métodos astrofísicos para testar o modelo cosmológico padrão e procurar indícios da presença de nova física para além deste. Em particular, pretende-se estudar a possibilidade de as leis da física a que estamos habituados não serem válidas em regiões diferentes do universo.

Actividades específicas incluem:
1) Estudo do impacto da variação das constantes fundamentais da natureza em processos ou objectos astrofísicos específicos, e do seu impacto observacional;
2) Exploração dos testes astrofísicos da estabilidade das constantes fundamentais como ferramentas para testes mais precisos do Princípio de Equivalência de Einstein;
3) Desenvolvimento de novos testes de consistência do modelo cosmológico padrão, no contexto da instrumentação da próxima geração (incluindo o Euclid e os vários instrumentos previstos para o E-ELT);
4) Organização e apresentação dos resultados obtidos.

Exemplos de bibliografia relevante: arXiv:1409.1923, arXiv:1412.0108, arXiv:1511.04335, arXiv:1603.04498 e arXiv:1607.01677.

APPENDIX

The CAUP Team, March 2017

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