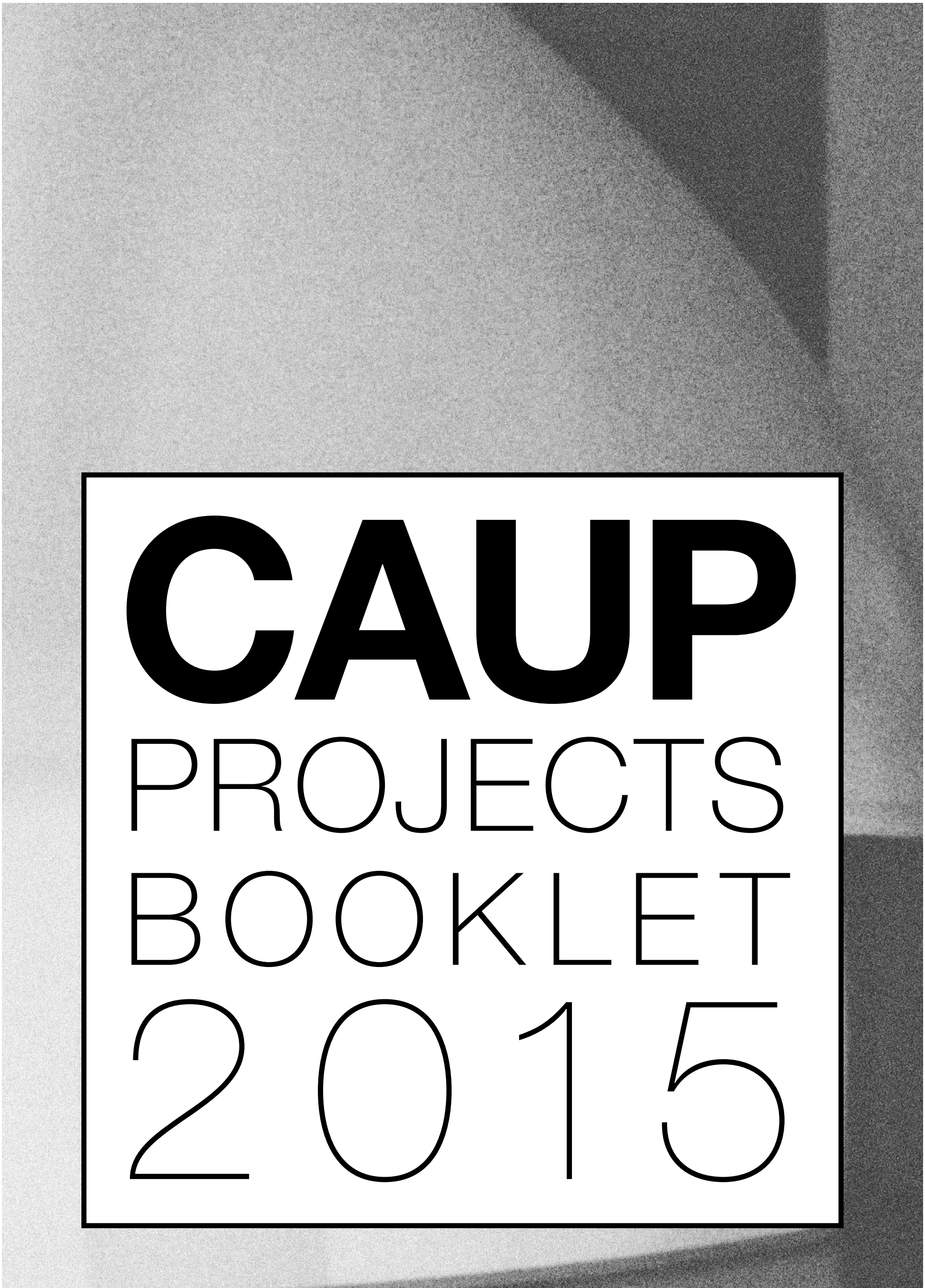

CAUP PROJECTS BOOKLET 2015

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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 2015-16.

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.

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 research team and a 'Funding ID' of current research grants.

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 2015

ESA and ESO related projects

From ESPRESSO to Plato: detecting and characterizing Earth-like planets in the presence of stellar noise

Level: PhD
Offered in PhD::SPACE: Yes
Supervisor: Nuno.Santos@astro.up.pt

While the number and variety of discovered extra-solar planets is still an important asset for exoplanet research, the focus of extrasolar planet researchers is now moving towards two main lines: 1) the detection of lower and lower mass planets, with the goal of finding an Earth sibling, and 2) the finest characterization of planets orbiting other stars, including their interior structures and atmospheres.

Despite the development of a whole new generation of instruments and space missions (like ESO's ESPRESSO and ESA's CHEOPS and PLATO missions, on which our team is deeply involved), these goals are not easy to achieve. In particular, the noise introduced by stellar activity has been shown to be a strong source of difficulties for planet search and characterization programs using both high precision radial velocity or photometric transit observations.

The present project proposes to investigate the impact and role of stellar activity in precise planet search and characterization projects. For this, we expect the student to develop a tool to simulate the effects of stellar activity on precise photometric (transit) and radial velocity measurements. The tool will then be applied to real data (e.g. HARPS and Kepler). The impact of stellar activity on the derivation of precise planet parameters will be investigated in detail. The results of this project have crucial consequences for the full success of instruments like ESPRESSO, CHEOPS, and PLATO.

Galactic stellar populations and planet formation with the Gaia--ESO Survey data

Level: PhD
Offered in PhD::SPACE: Yes
Supervisor: Sergio.Sousa@astro.up.pt
Co-supervisor: Vardan Adibekyan (CAUP)

The on-going Gaia-ESO Survey is a very ambitious project which uses ESO/VLT to obtain detailed spectra of about 100000 stars from all the Galactic stellar populations. We propose to use the data from this survey (for which we have privileged access) to study the chemical and kinematic properties of stellar populations. The goal is to understand the formation and evolution of the distinct populations that we can identify with the data.

In addition, we propose to investigate the observed planet hosting stars to understand possible links between the different stellar populations and planet formation processes. This latter study should help us to better estimate the frequency of the different type of planets for each stellar population and in our Galaxy in general.

New Maps of the Dark Side

Level: PhD or MSc
Offered in PhD::SPACE: Yes
Supervisor: Carlos.Martins@astro.up.pt

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 (in which the Dark Side team is more directly involved) and will gradually broaden to explore synergies with other facilities.

Recent relevant works include arXiv:1202.4364, arXiv:1206.1225, arXiv:1311.5841, arXiv:1412.0108 and arXiv:1503.05068.

The ESPRESSO Road to Fundamental Cosmology

Level: PhD
Offered in PhD::SPACE: Yes (Closed topic)
Supervisor: Carlos.Martins@astro.up.pt

The full cosmological impact of astrophysical tests of fundamental physics, including those of the spacetime stability of nature's fundamental couplings, has only emerged recently. In part this was due to the work done within CAUP's 'Dark Side' project, and these tests are now being included in studies for ESA and ESO's next-generation of facilities.

While a detection of variations of fundamental couplings will be direct evidence of Equivalence Principle violations and a fifth force in Nature, any such measurements (even null results) can provide tight constraints on additional dynamical degrees of freedom (such as fundamental scalar fields) that are now known to be among Nature's building blocks.

This thesis will explore the role of these astrophysical tests on cosmology and fundamental physics, with some emphasis on dynamical dark energy. Starting with the experience gained from a recent UVES Large Program, the work will concentrate on the ESPRESSO fundamental physics tests, contributing both to the GTO preparation and its subsequent exploitation. The ESPRESSO experience will also lead to more detailed and realistic feasibility studies for ELT-HIRES.

Recent relevant works are arXiv:1409.1923 and arXiv:1409.3963, and a roadmap for the field is in arXiv:1412.0108.

Other astrophysics projects

Accretion versus outflow regions around Young Stellar Objects

Level: PhD
Offered in PhD::SPACE: Yes (Closed topic)
Supervisor: João Lima (jlima@astro.up.pt)
Co-supervisors: Jorge Filipe Gameiro (CAUP), Christophe Sauty (Paris)

The evolution of young stellar objects (YSO's) is critically dependent on the balance between the accretion of matter coming from their surrounding disks and the collimated jets outflowing around their poles. The magnetic field plays a crucial role in both channelling these flows of plasma and controlling their dynamics and energetics.

Modelling the overall stellar formation on all scales from the global collapse and jet feedback down to the inner disk star interaction is presently out of reach. Thus, we concentrate on the central magnetospheric accretion connected to the stellar outflow in class II objects like classical T Tauri stars.

T Tauri stars are well observed objects. In such evolved protostars, observational evidences suggest that jets originate in the inner regions of the accretion disk or even closer in the magnetosphere of the central source. Thus it is crucial to understand the connection between these two regions, one controlling accretion and the other responsible for the jet.

In this project we aim firstly, at modelling the structure of the magnetosphere of the YSO in which accretion takes place using existing numerical codes like PLUTO. This approach will enable a blending between accretion and outflow regions around YSO's. The advantage of such numerical approach is to enable the study of time dependent solutions. Secondly, the solutions found will be used in a separate radiative transfer model to compute line profiles and test the consistency of the MHD solutions with observations.

A new tool for the asteroseismic characterization of large samples of pulsating stars

Level: PhD
Offered in PhD::SPACE: Yes
Supervisor: Margarida Cunha (mcunha@astro.up.pt)
Co-supervisors: Pedro Avelino (CAUP), Dennis Stello (Sydney)

As a result of the launch of the CoRoT and Kepler satellites, the astronomical community has, today, exquisite asteroseismic data on thousands of red giant stars. The analysis of just a fraction of these data has already led to a number of very exciting new results, published in high-impact journals, such as Nature and Science. Moreover, given the recent approval by ESA of the mission PLATO2.0 (launch around 2023), it is expected than in a decade the number of red giants with detected oscillations will increase by orders of magnitude. To exploit this large observational sample of stars, further development of asteroseismic theoretical tools is required. In particular, it is imperative that we have tools capable of modelling the pulsations in large grids of red giant models, covering a wide parameter space (in mass, age, metallicity), in a reasonable amount of time.

In this context, the main goal of this project is to develop a new linear adiabatic pulsation code, significantly more efficient than those currently available, that may be applied to large grids of red giant models, necessary to fully exploit the available data. Along with the characterization of the red giant populations based on the data already available, the proposed tool will constitute a magnificent step forward towards the preparation for the exploitation of the data that will be acquired by the PLATO2.0 mission.

Asteroseismic characterization of exoplanet-host stars in preparation for NASA's TESS and ESA's PLATO space missions

Level: PhD
Offered in PhD::SPACE: Yes
Supervisor: Mario.Monteiro@astro.up.pt
Co-supervisor: Tiago Campante (Birmingham)

New insights on stellar evolution and stellar interiors physics are being made possible by asteroseismology, the study of stars by the observation of their natural, resonant oscillations. Asteroseismology is proving to be particularly significant for the study of solar-type stars, in great part due to the exquisite data that have been made available by NASA's Kepler space telescope. The future looks even brighter, with NASA's TESS and ESA's PLATO space missions promising to revolutionize the field and increase the number of stars with detected oscillations by several orders of magnitude. The information contained in stellar oscillations allows the internal stellar structure to be constrained to unprecedented levels, while also allowing fundamental stellar properties (e.g., mass, radius, and age) to be precisely determined.

In anticipation of the flood of observations from future space missions, the main goal of this project is to develop and test state-of-the-art asteroseismic techniques for the estimation of fundamental stellar properties. Particular attention will be focused on calibrating the determination of age, due to the strong dependence this quantity has on stellar physics. The goal is to address the critical requirement to obtain precise estimates of age for stars at different phases of evolution and/or with planetary systems where signatures of life are to be observed. A very important component of this project will be to understand the systematics on the derived properties that arise from changes in the input physics and the effects introduced by different evolutionary and pulsation codes.

The implications of this project will be far-reaching. Not only should it provide important contributions to theories of stellar structure, stellar dynamics and evolution, but it will also play an important role in the characterization of planet-candidate host stars and their planetary systems.

Coding the Cosmos: A New Generation of Superstring Simulations

Level: PhD or MSc
Offered in PhD::SPACE: Yes
Supervisor: Carlos.Martins@astro.up.pt

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.

The recently released Planck results highlight 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 detailed statistical analysis. This is expected to be an even bigger problem for next-generation facilities such as COrE+ and eLISA. The goal of this thesis will thus be to 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 forthcoming observational searches.

Recent relevant works include arXiv:1206.6043, arXiv:1310.3614, arXiv:1312.2123, arXiv:1405.7722 and arXiv:1407.3905.

Correlations between atmospheric parameters of exoplanets and properties of their host stars

Level: MSc
Supervisor: Pedro.Figueira@astro.up.pt
Co-supervisor: João Lima (CAUP)

The correlation between the surface gravity of an exoplanet and the stellar activity of the host star is probably one of the most puzzling in the field of exoplanets. In a recent work we demonstrated the correlation is real and not the result of small-number statistics as claimed before, and a contemporary work proposed a first explanation for it. The time has come to understand it with a well-defined sample of stars and from a sound theoretical background. We aim at extending the previous work using HARPS and SOPHIE data on transiting planets, and revisit the correlation.

We propose to the student to do this analysis work and to expand it by compiling from the literature the currently available observation information about exo-planetary atmospheres, including the observed fluxes and derived albedos and temperatures. The data will then be used to search for correlations between the different planetary atmospheric parameters, and stellar properties. The results of this study may have important impact for the understanding of planet formation and evolution.

The student is expected to be fluent in programming languages, and to develop this work in python.

Determination of stellar parameters for M-dwarf stars: the NIR approach

Level: PhD
Offered in PhD::SPACE: Yes (Closed topic)
Supervisor: Sergio.Sousa@astro.up.pt
Co-supervisor: Nuno Santos (CAUP)

This project is focused on the 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 correct 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 are thus of great importance for the full success of future space missions like TESS, CHEOPS, and PLATO.

With this in mind, the major goal of the proposed project is to adapt current methodologies, well established for the analysis of high resolution optical spectra of FGK dwarfs, to be used with near- IR high resolution spectra that will soon be available from new instruments such as SpiRou, CARMENES, and CRIRES+. In this context the student is expected to implement an automatic code to estimate stellar parameters directly from the measurement of line equivalent widths, and to apply it to M stars hosting planets. Besides the determination of precise stellar (and thus planetary) properties, the student will then 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.

Diffuse ionized gas and the Lyman continuum photon escape fraction

Level: PhD or MSc
Offered in PhD::SPACE: No
Supervisor: Polychronis Papaderos (papaderos@astro.up.pt)
Co-supervisor: Jean Michel Gomes (CAUP)

Diffuse ionized gas (DIG) is an ubiquitous component in star-forming galaxies that permeates their disk and halo. The excitation mechanisms and ionization conditions of the DIG pose a long-standing problem. The prevailing picture though is that the DIG originates from ultraviolet ionizing photons (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 transport of LyC photons are unclear, it is yet likely that bubbles created by stellar winds in a turbulent medium with a fractal/porous 3D structure play a key role. Shocks, photoelectric heating, turbulent mixing layers and a diffuse floor of gas ionization from hot evolved post-AGB stars could add a further contribution to the formation of the DIG. Various lines of evidence indicate that 20-50% of the total Halpha emission in galaxies can be in diffuse DIG form, a fact that introduces an observational (surface brightness) bias with obvious consequences on estimates of star formation rates both in the local universe and in high-redshift galaxies. The goal of this project is twofold:

1) Using spatially resolved integral field spectroscopy (IFS) data from CALIFA (http://califa.caha.es) and other IFS surveys, in combination with higher-spatial resolution imaging data, to isolate the DIG and study its spatial and spectroscopic characteristics. A central question behind the study of nearby Hubble-type galaxies from CALIFA is how the DIG fraction (consequently, the LyC escape fraction from HII regions) is related to the star formation history of galaxies.

2) The second goal of this project is to explore the LyC escape fraction in starburst galaxies using archival IFS data and single-fiber spectra from Sloan Digital Sky Survey.

Forward modelling of space- -based asteroseismic data: Kepler, TESS and PLATO missions

Level: PhD
Offered in PhD::SPACE: Yes
Supervisor: Isa Brandão (isa@astro.up.pt)
Co-supervisor: Margarida Cunha (CAUP)

This project consists on the forward modelling of pulsating stars that were or will be, in the near future, observed by space-based missions. The main goal is to derive their fundamental parameters, such as the mass and age, as accurately as possible. The accurate knowledge about these two parameters is of extreme importance for instance, in the exoplanetary science, in order to derive the mass of planets and the age of planetary systems. Moreover, a detailed modelling of stars will improve our knowledge regarding the physics of stellar interiors, which, in turn, will allow for the derivation of even more accurate stellar parameters.

In order to derive accurate stellar parameters, the project will be focused on the study of an innovative method for the forward modelling of stars that is based solely on seismic diagnostics that are insensitive to the stars' outermost layers. These layers are extremely difficult to model, and their incorrect treatment induces errors in the inferred stellar parameters. By concentrating on seismic diagnostics that are only sensitive to the deepest regions of the stars, the tool will allow for better determinations of stellar masses and, particularly, stellar ages. The new method will be applied to real data of stars observed by the Kepler mission and possibly the TESS mission (with launch expected in 2017) and will be a key tool for the preparation of the future ESA's mid-class mission, PLATO.

Identifying real siblings within FGK+M common proper motion pairs

Level: MSc
Supervisor: Bárbara Rojas-Ayala (babs@astro.up.pt)

Stars in binary systems are believed to be born at the same time from the same material and, therefore, it is assumed that they share the same metallicity. Observationally, it is easier to identify common proper motion (CPM) groups of stars than gravitationally bound binary objects. CPM stars, as their name states, are objects that share noticeable and very similar proper motion. These objects are usually treated as wide binaries if their chance-alignment probability is low. CPM pairs have been used widely in the literature to calibrate metallicity relations for M dwarfs by assigning the metallicity of the FGK star to the CPM pair. However, there are no studies corroborating independently if the assumption of coevality holds for FGK+M CPM pairs by studying each component separately.

This project, which has Sérgio Sousa as co-supervisor, aims to test if the coevality assumption holds for 26 FGK+M CPM pairs observed with the KPNO-4m echelle and APO-TSPEC spectrographs. The main tasks of the project are:

1) the extraction, reduction and spectroscopic parameter analysis for the FGK high-res spectra

2) compare metallicity results from the spectroscopic analysis of the FGK stars to the M dwarf metallicities estimated from photometric and nIR methods in the literature, and iii) estimate the probability of CMPs being real siblings by metallicity and kinematical informations, and test the reliability of M dwarf metallicity estimation methods.

Influence of magnetic fields on stellar spectra and radial velocity surveys to search for planets

Level: MSc
Supervisor: Elisa.Delgado@astro.up.pt

The analysis of stellar spectra is very important to characterize the atmospheres of stars and their possible planetary companions. The determination of accurate chemical abundances relies on the use of high resolution spectra while fundamental parameters (effective temperature, gravity and metallicity) can be determined in a very precise way using the same data.

The shape of the spectral lines are affected by several properties of the stars, such as its rotation or the motions of the photospheric gases. These effects are taken into account when doing spectral synthesis (derivation of synthethic spectra to fit the observed spectra). However, the presence of magnetic fields may affect the profiles of spectral lines. This effect is stronger in the infrared than in the optical spectrum since the broadening due to the Zeeman effect is proportional to the square of the wavelength while non-magnetic broadening increases only linearly in wavelength. As expected, the effect is also stronger when the magnetic fields are more intense, as in the case of some active M dwarfs.

The aim of this project is to analyze different kind of stars making use of MOOG-Stokes, a spectral synthesis code which considers the effects of magnetic fields, and to identify the most affected lines by the Zeeman splitting both at infrared and optical wavelengths. The results of this project will be important not only for the spectroscopic characterization of stars in the infrared region but for the search of planets around active stars with the radial velocity technique. This work will be done in collaboration with other members of the Exo-Earths team.

Investigating the Potential Impact of Kappa-Distributed Electron Energies on the Emission Line Spectra of Quasar Nebulae

Level: MSc
Supervisor: Andrew.Humphrey@astro.up.pt

Powerful quasars are often surrounded by giant (10-100 kpc) halos of gas, which are photoionized predominantly by the intense radiation emitted by the active galactic nucleus. Line emission can be used to determine the physical conditions (such as chemical abundances, density, temperature) in these halos, in conjunction with photoionization model calculations which simulate the relevant microphysics within the halos.

The assumption of a Maxwell-Boltzmann (MB) electron energy distribution (EED) has long been central to photoionization models and abundance analyses of ionized nebular regions. However, direct measurements of EEDs in various Solar system plasmas have revealed that non-equilibrium electron energy distributions, with a suprathermal excess compared to a MB EED, are commonplace. These distributions are usually represented by a generalized Lorenztian known as the kappa-distribution (KD). It is, therefore, long overdue to consider whether KD EEDs may be present in extrasolar photoionized nebulae, and to study how this might impact on spectral modeling and abundance analyses for such regions. Quasar nebulae are particularly promising sites to test for the presence of KD EEDs.

The aim of this project is to compute and compare KD and MB EED photoionization models for quasar ionized nebulae, and to perform a comprehensive inter-comparison of models with the observed line spectra for a variety of quasar types, in order to determine (a) whether KD EEDs (or more generally, non-equilibrium EEDs) are present in quasar ionized nebulae; (b) the impact of using one EED instead of the other, when using emission lines to derive the physical conditions of the nebulae; (c) which emission line diagnostics are least susceptible to choice of EED.

Orbital evolution of planetary systems: from formation to today

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

The field of extrasolar planets research is teeming with activity. This year we will celebrate the 20th anniversary of the discovery of the first planet outside our system, and yet we count already over 1700 confirmed planets and hundreds 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 continue, 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)

VIPERS(*) has just made its first data release of ~50 000 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. The student will be working closely not only with the supervisor but also with Catarina Lobo.

(*) VIPERS is the VIMOS Public Extragalactic Survey (http://vipers.inaf.it)

Probing fundamental physics with scalar fields and cosmic defects using state of the art cosmological observations

Level: PhD
Offered in PhD::SPACE: Yes
Supervisor: Pedro.Avelino@astro.up.pt
Co-supervisor: Lara Sousa (CAUP)

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.
Surveys of the cosmological 21cm signal – using SKA and LOFAR – will probe the matter distribution of the universe during the dark ages, potentially unveiling the role of small-scale density perturbations generated by cosmic strings and other cosmic defects in structure formation. On the other hand, the gravitational wave background will be probed with unprecedented sensitivity by a new generation of gravitational wave experiments (eLISA, LIGO) and the Cosmic Microwave Background B-mode polarization power spectrum will be determined with unprecedented precision by present and future missions such as Planck and CMBPol. Together these provide new observational windows for the study of cosmic defects and their associated vector and tensor perturbations which will be extensively explored in this project. The opportunities to gain information about the physics of the early universe through the search for topological defects are, thus, manifold.
This PhD project aims at significantly improving current constraints on cosmic defects, by making use of the latest data and realistic numerical and semi-analytical models for defect network evolution. Particular emphasis will be given to the gravitational wave background generated by cosmic strings and domain walls and its potential impact on the B-mode polarization of the Cosmic Microwave Background (CMB), as well as to the characterization of specific string signatures on the 21cm background and their impact on reionization history.
The potential role of domain walls as seeds of space-time variations of fundamental couplings shall also be investigated, taking full advantage of the window opened by a new generation of high-resolution ultra-stable spectrographs such as ESPRESSO.

Spatial distribution of alpha--elements in CALIFA galaxies

Level: PhD
Offered in PhD::SPACE: Yes
Supervisor: Jean Michel Gomes (jean@astro.up.pt)
Co-supervisor: Polychronis Papaderos (CAUP)

A long-standing puzzle in extragalactic research is the anomalous abundances of so-called alpha-elements (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 enhanced-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 (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 resolution to study the radial trends in galaxies.

Only recently spatially-resolved data from Integral Field Spectroscopy (IFS) has become available, permitting the study of radial abundance patterns of α-elements in galaxies with unprecedented detail. An innovative aspect of this project is the use of IFS data for 600 local Hubble-type galaxies from The CALIFA survey 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.

Starburst activity and structural properties of Blue Compact Dwarf galaxies

Level: PhD or MSc
Offered in PhD::SPACE: No
Supervisor: Polychronis Papaderos (papaderos@astro.up.pt)
Co-supervisor: Jean Michel Gomes (CAUP)

Blue Compact Dwarf (BCD) galaxies are the best local analogues of the low-mass protogalactic units that rapidly formed out of almost metal-free gas in the early Universe. These galaxies undergo vigorous star-forming activity over a spatial extent of ~1 kpc, producing thousands of massive stars in a brief starburst episode. The release of energy and momentum from stellar winds and SNe is expected to lead to a large-scale thermalization of the gas component of BCDs, and the ejection of hot (several millions K), metal-enriched gas into their halo in form of fast (a few 100 km/s) galactic winds.

This project will center on the analysis of broad-band (B,R,I) and narrow-band (Halpha) data for a sample of approximately 100 BCDs. Its main goals are

1) to investigate starburst-driven galactic outflows using Halpha imaging data (with the option of supplementing this analysis with longslit and integral field spectroscopy data, if selected as a PhD project)

2) to carry out a systematic investigation of the structural properties of the starburst component and underlying host galaxy of the sample BCDs using surface photometry and profile decomposition techniques.

Towards new worlds by portraying the tiny stars

Level: PhD
Offered in PhD::SPACE: Yes
Supervisor: Bárbara Rojas-Ayala (babs@astro.up.pt)
Co-supervisor: Nuno Santos (CAUP)

The search and characterization of new worlds has a strong dependance on the characterization of the host stars. A large number of the most interesting rocky planets found until date orbit the smallest stars. The characterization of M dwarf stars has been a one of the hottest topics in the past 10 years, and it has been quite challenging, involving new and creative techniques based on empirical data of nearby M dwarfs.

The goal of this project is to provide not only reliable measurements of the fundamental parameters for the tiny stars, but also provide consistency and estimate the real precision of the different methods involving photometry, spectroscopy and evolutionary models. This comprehensive study is fundamental for the M dwarf targets of the PLATO 2.0 mission, and the proper characterization of their likely planetary companions.

Toward the statistical validation of Earth-like planets

Level: PhD
Offered in PhD::SPACE: Yes
Supervisor: Alexandre.Santerne@astro.up.pt
Co-supervisor: Nuno Santos (CAUP)

Detecting a planet like the Earth is one of the main challenges of the next decade. To find such planets, new outstanding instrumentations are going to be built with an unprecedented precision (such as the ESPRESSO spectrograph for the ESO – VLT and the PLATO space mission from ESA). Their precision will make possible the detection of an exoearth signal. However, other astrophysical scenarios are able to mimic the signal of an Earth signal, like stellar variability (stellar activity, magnetic cycle), or multiple stellar systems.

The announcement of the first Earth-twin planet will thus require strong evidence that the detected signal is indeed of planetary origin. This can be done by statistically validating the planet signals. In this context, the PASTIS software is a unique, fully-Bayesian, tool that is able to validate small-size planets. However, today, the PASTIS tool is not able to statistically validate an Earth-analog planet without relying on their occurrence rate and statistics of physical properties. Statistics of such planets are however extremely poor since only one is known so far (the Earth).

The goal of this PhD will be to improve the capabilities of PASTIS to validate planets, down to Earth-size ones. This can be done by improving the constraints from the data on the various astrophysical scenarios. This will require to develop and/or implement more accurate models of the scenarios, especially of stellar activity. Then, the improved PASTIS software will be used by the PhD student to validate Earth-size planets already detected by the Kepler space telescope or small planets that are first to be detected in existing HARPS data. Then, it will also be used to prepare the validation of other Earth in the context of the ESPRESSO spectrograph, which will be commissioned at the end of the PhD.

Unveiling the Dark Side of the Universe

Level: PhD
Offered in PhD::SPACE: Yes
Supervisor: Pedro.Avelino@astro.up.pt

Unveiling the nature of dark matter and dark energy, the main constituents of the Universe, is one of the most ambitious challenges of fundamental physics. The main goal of this project is to provide a contribution towards this major objective through the parameterization, characterization and constraining of coupled dark matter/dark energy models.

This project contemplates both theoretical and numerical tasks, including the computation of the cosmological implications of coupled dark matter/dark energy models taking into account nonlinear back reaction effects. Numerical simulations and semi-analytical methods will be employed in the modeling of the dark matter/dark energy interaction both at microscopic and macroscopic levels. State of the art cosmological observations, using type Ia supernovae, large scale clustering (including baryon acoustic oscillations), cosmic microwave background temperature and polarization anisotropies, and weak lensing, will be used to constrain the parameter space of coupled dark matter/dark energy scenarios. Forecasts of the results to be obtained with future missions, such as EUCLID and ESPRESSO, will also be performed.

Was Einstein right?

Level: MSc
Supervisor: Carlos.Martins@astro.up.pt

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 project the student will explore new synergies between these new local tests of the EEP and current 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 consider relevant benchmark scenarios (including models with and without sceening mechanisms) and study how they will be further constrained by experiments such as MicroSCOPE and ACES, in combination with extant astrophysical data. This study will also be relevant to further develop the science case of some of the E-ELT instruments, in particular ELT-HIRES which is strategically relevant for CAUP.

Education/outreach and undergraduate projects

Scientific literacy and astronomy teaching

Level: PhD or MSc
Offered in PhD::SPACE: No
Supervisor: Carlos.Martins@astro.up.pt

During the International Year of Astronomy 2009, a survey was done to more than 3200 students (from 7th to 12th grade) in Portuguese schools, aiming to determine the degree of understanding of some basic astronomy concepts which are supposedly +art 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 the enhanced contacts with schools provided by IYL 2015 to repeat and extend this earlier 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, 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 (and for a PhD project only), 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 misconceptions) acquired by the students during their school years.

Atividade solar e clima espacial

Orientador: Mario.Monteiro@astro.up.pt

Local do Estágio:
CAUP

Perfil do Candidato:
Estudantes do curso de Licenciatura em Astronomia

Objectivos e Actividades::
Pretende-se com este projeto modelar a atividade solar usando alguns os seus indicadores e relacionar o nível dessa atividade com a irradiação solar. A partir dessa análise procura-se caracterizar a influência do nível de atividade solar na
climatologia espacial e no clima na Terra. As atividades a desenvolver, com a colaboração adicional do investigador do CAUP João Lima, incluem:

1) Modelar a variação do número de manchas solares com base em diferentes modelos matemáticos e usando dados relativos a diferentes períodos de tempo

2) Modelar a variação do número de outros fenómenos relacionados com o ciclo solar (por exemplo, proeminências solares, explosões solares) de forma a obter correlações entre esses dados

3) Correlacionar a atividade solar com a irradiação solar

4) Investigar a influência da ocorrência destes fenómenos com o clima espacial e com os fenómenos climáticos à superfície da Terra.

Energia escura dinâmica, de alfa a ómega

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:

É dada preferência a alunos de astronomia, física ou engenharia física. Experiência prévia de programação, análise e visualização de dados é essencial. Espera-se uma dedicação ao projecto de 1 dia de trabalho por semana. A experência anterior com projectos deste tipo é valorizada. Poderá ser realizada uma entrevista aos candidatos.

Objectivos e Actividades:

Os alunos serão integrados em colaborações internacionais cujo objectivo é o desenvolvimento de estratégias observacionais optimizadas para a caracterização das propriedades da energia escura em todo o intervalo de redshifts de 0 a 5, em particular utilizando o satélite Euclid (ESA) e os vários instrumentos previstos para o E-ELT (ESO). Entre outros serão explorados métodos astrofísicos que testam a estabilidade das constantes fundamentais da natureza. Actividades específicas incluem:

1) Estudo (semi-)analítico de alguns modelos cosmológicos para a aceleração do universo e a variação das constantes fundamentais da natureza.

2) Desenvolvimento e análise de simulações numéricas para alguns modelos representativos, e comparação com os dados observacionais já 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

Estudo da dinâmica e consequências cosmológicas de redes de defeitos topológicos

Orientador: Pedro.Avelino@astro.up.pt

Local do Estágio:
CAUP

Perfil do Candidato:
Candidato com o primeiro e segundo ano completos da licenciatura em Física ou Astronomia, ou a frequentar o mestrado em Física ou Astronomia, ou a frequentar o Mestrado Integrado em Engenharia Física e com o primeiro e segundo ano completos. Bons conhecimentos de Física, Matemática e Computação. Poderá ser solicitada uma entrevista com o candidato para aferir se este possui as competências e motivação necessárias para uma boa execução do projecto.

Objectivos e Actividades::
Derivação das equações macroscópicas para a evolução de redes de defeitos topológicos num universo homogéneo e isotrópico, usando conhecimentos de relatividade restrita e argumentos termodinâmicos. Determinação de consequências observacionais associadas à possível existência destas redes no Universo. Estudo da dinâmica de redes de defeitos topológicos usando modelos analíticos e/ou simulações numéricas.

Estudo do impacto da energia escura na formação de estruturas cosmológicas

Orientador: Pedro.Avelino@astro.up.pt

Local do Estágio:
CAUP

Perfil do Candidato:
Candidato com o primeiro e segundo ano completos da licenciatura em Física ou Astronomia, ou a frequentar o mestrado em Física ou Astronomia, ou a frequentar o Mestrado Integrado em Engenharia Física e com o primeiro e segundo ano completos. Bons conhecimentos de Física, Matemática e Computação. Poderá ser solicitada uma entrevista com o candidato para aferir se este possui as competências e motivação necessárias para uma boa execução do projecto.

Objectivos e Actividades::
Cálculo das alterações ao colapso linear e não linear de matéria escura em diferentes modelos de energia escura. Determinação das respectivas implicações observacionais, em particular no contexto da missão Euclid recentemente aprovada pela ESA. Estudo da dinâmica linear e não linear de flutuações de densidade em modelos cosmológicos com matéria e energia escura.

Literacia científica e ensino da astronomia

Orientador: Carlos.Martins@astro.up.pt

Local do Estágio:

CAUP; os resultados do projecto poderão ser apresentados no Encontro Nacional de Astronomia de 2016. Poderão também ser úteis algumas deslocações a escolas.

Perfil do Candidato:

É dada preferência a alunos de mestrado de ensino, e em igualdade de circunstâncias às áreas de astronomia e física. Será dada preferência a candidatos com alguma experiência prévia na àrea. Experiência em programação, análise e visualização de dados é importante. Poderá ser realizada uma entrevista aos candidatos.

Objectivos e Actividades::

O estagiário participará no desenvolvimento e implmentação de um estudo sobre literacia científica (em particular na área da astronómica) no ensino secundário (e possivelmente superior) em Portugal. Actividades específicas incluem:

1) Pesquisa bibliográfica sobre a área relevante

2) Planeamento do estudo (dirigido aos alunos), e análise da viabilidade de um possível estudo complementar para professores do ensino secundário, e para alunos do ensino superior

3) Implementação do estudo

4) Organização e apresentação dos resultados obtidos

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:
É dada preferência a alunos de astronomia, física ou engenharia física. Experiência prévia de programação, análise e visualização de dados é essencial. Espera-se uma dedicação ao projecto de 1 dia de trabalho por semana. A experência anterior com projectos deste tipo é valorizada. Poderá ser realizada uma entrevista aos candidatos.

Objectivos e Actividades::
Os alunos serão integrados em colaborações internacionais cujo objectivo é o estudo da evolução de supercordas e de outros defeitos topológicos. 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 ainda a análise das respectivas consequências observacionais, no contexto dos dados do satélite Planck e de possíveis missões futuras da ESA como o COrE+. 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 do problema

3) Processamento, análise e visualização de resultados de simulações numéricas de alta resolução destas redes

4) Organização e apresentação dos resultados obtidos

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:
É dada preferência a alunos de astronomia, física ou engenharia física. Experiência prévia de programação, análise e visualização de dados é essencial. Espera-se uma dedicação ao projecto de 1 dia de trabalho por semana. A experiência anterior com projectos deste tipo é valorizada. Poderá ser realizada uma entrevista aos candidatos.

Objectivos e Actividades::
Os alunos serão integrados em colaborações internacionais cujo objectivo é desenvolver novos métodos astrofísicos para testar o modelo cosmológico padrão e procurar indícios da presença de nova física para além deste modelo. 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 nas propriedades de vários objectos astrofísicos, e das suas consequências observacionais

2) Estudo do impacto de testes astrofísicos da estabilidade das constantes fundamentais da natureza e do Princípio de Equivalência na física fundamental

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

APPENDIX

The CAUP Team, March 2015

Researchers [40]
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Elsa M. P. S. Moreira
Inês S. A. B. Mota
André A. M. Pereira
Luís F. R. Pereira
Ana M. M. Pinho
Maria P. L. P. Ramos
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Pedro M. T. Vianez
José P. P. Vieira

Funding ID: Currently funded grants active in the 2015-16 academic year.

Doctoral Network in Space Sciences (PhD::SPACE)
PI: Mário Monteiro

Exploitation of Space Data for Innovative Helio- and Asteroseismology (SPACEINN)
PI: Non-CAUP (CAUP contact Mário Monteiro)

Optimization of ESPRESSO Fundamental Physics Tests
PI: Carlos Martins/Ana Catarina Leite

Planet Analysis and Small Transit Investigation Software (PASTIS)
PI: Nuno Santos/Alexandre Santerne

Sounding Stars with Kepler (ASK)
PI: Non-CAUP (CAUP contact Mário Monteiro)

Stellar parameters of M dwarfs: investigating the star-planet connection
PI: Elisa Delgado

Study of Emission Line Galaxies with Integral Field Spectroscopy
PI: Non-CAUP (CAUP contact Polychronis Papaderos)

The future of Extrasolar Planets: new intrumentation for new science
PI: Pedro Figueira

The study of stellar activity for the search and characterization of extrasolar planets
PI: Alexandre Santerne

CAUP

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