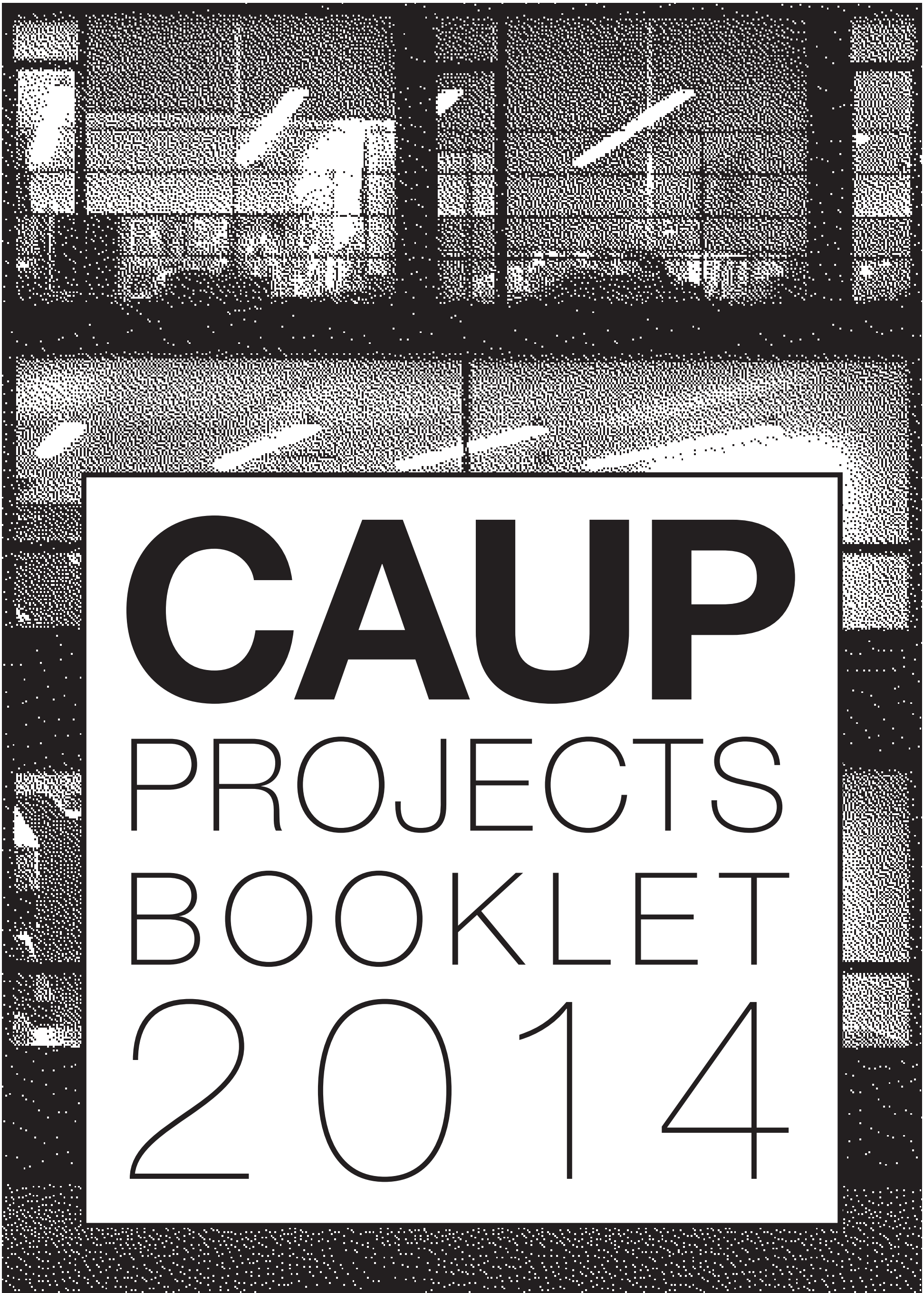

CAUP
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INTRODUCTION

CAUP is the largest Astrophysics research institute in Portugal, with maximum marks in the International Research Assessments in the last 10 years. In its relatively short existence we have provided several world-leading contributions to Astronomy, Fundamental Physics and Space Sciences. We have a strong commitment to providing key training opportunities for the next generation of astrophysicists, and are (to the best of our knowledge) 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 proposed by CAUP members as undergraduate research projects in the academic year 2014-15. We start by listing projects done in the context of our participation in ESA and ESO consortia, since leading the national participation in such consortia is one of our long-term strategic priorities. Other astrophysics and education/outreach projects are listed subsequently. These tend to represent more specific interests of individual members, although in some cases they also involve non-CAUP collaborations (and external co-supervision).

As an appendix we also list the current CAUP research team and a list of grants that are expected to provide the backbone of our research funding in the next academic year. Additional information, including the research interests and recent publications of CAUP members and the scientific goals of the research grants, can be found online at http://www.astro.up.pt.

Although the list is representative of our current interests and priorities, it's by no means exhaustive. Many CAUP members have sufficiently broad interests and expertise to be able to supervise other projects. Any potentially interested student is therefore encouraged to contact us to explore further possibilities.

Carlos Martins

(Head of the CAUP Training Unit)

March 2014

A New Generation of Fundamental Cosmology Tests with Euclid and the E-ELT

Level: Masters or PhD
Supervisor: Carlos Martins (Carlos.Martins@astro.up.pt)
Co-supervisor (at PhD level): TBA (member of Euclid Cosmology Theory SWG, non-CAUP)

Euclid is an ESA medium-class mission, currently due to be launched in 2020, whose main goal is to understand the physical origin of the accelerated expansion of the universe. CAUP is an affiliated institute of the Euclid Consortium and is actively involved both in the technical preparation and in the scientific exploitation of the mission. This project will enable the student to contribute to the latter.

The main goal will be to carry out a detailed assessment of Euclid as a tool for a new generation of precision consistency tests of the LambdaCDM paradigm and for searches for new physics. Particular attention will be given to dynamical dark energy and modified gravity models. Possible synergies with the various E-ELT instruments with science drivers relevant for fundamental cosmology. The work will be done in the context of the Euclid Science Working Groups and, at the PhD level only, the student will also be a member of the Euclid Consortium.

Examples of two studies recently carried out within the Euclid Cosmology Theory SWG, and now part of the Euclid Theory Review document, can be found at arXiv:1305.7031 and arXiv:1311.5841.

Detecting the signatures of exoplanet atmospheres: the high resolution spectroscopy approach

Level: Masters or PhD
Supervisor: Nuno Santos (Nuno.Santos@astro.up.pt)
Co-supervisor: Pedro Figueira (Pedro.Figueira@astro.up.pt)

The detection of exoplanetary atmospheres is one of the holy grails of planetary sciences. Its relevance is often driven from the fact that their detection represents a determinant step towards for the discovery of possible life signatures in an alien world. Unfortunately, although some successes have been achieved (e.g. Brogi+2012, Nature 486, 502), the direct detection of exoplanet atmospheres using spectroscopy (in any wavelength region) remains a difficult and mostly unexplored domain.

In this project we propose to explore the possibility of detecting planetary atmospheres using both optical and near-IR high resolution spectroscopy. The methodologies developed will be of strong importance for the exploitation of data from future instruments, including the ESPRESSO (ESO, VLT) and HIRES (E-ELT) spectrographs (our team is strongly involved in both projects).

Estimating the false-positive probability of the future exoplanet space missions PLATO and TESS

Level: Masters

Supervisor: Alexandre Santerne (alexandre.santerne@astro.up.pt)

The future space missions TESS and PLATO will look for hundreds of thousands of bright, nearby stars to find transiting Earth-like planets in the habitable zone. However, other astrophysical false-positive scenarios (such as eclipsing binaries) might also mimic the signal of such exoplanets.

The objective of this master thesis is to simulate exoplanets and astrophysical false-positive populations as they will be observed by TESS and PLATO to estimate their false-positive probability. This false-positive probability will then have direct implication on the observing strategy of both missions as well as the ground-based follow-up observations. It will also be a key value for all statistical analysis based on the transit detections of both missions.

For this project, the student will use existing tools developed at CAUP to simulate planets and false-positive scenarios (i.e. PASTIS) as well as public tools (e.g. Besancon Galactic Model). The result of these simulations might led to a publication in a peer-reviewed journal.

Optimized Observational Strategies for ESPRESSO and HIRES

Level: Masters or PhD
Supervisor: Carlos Martins (Carlos.Martins@astro.up.pt)
Co-supervisor (at PhD level): TBA (non-CAUP)

ESPRESSO (under construction) and HIRES (under study) are two ESO spectrographs, respectively for VLT and the E-ELT, which have as one of their key science goals the search for evidence of spacetime variation of the fundamental constants of nature. In the case of HIRES, a further goal is to carry out a first measurement of the cosmological redshift drift (a.k.a. the Sandage-Loeb test).

This project will carry out an assessment of the requirements and sensitivity of the two spectrographs for these purposes, and of the impact that these measurements will have as probes of fundamental physics, including the key conundrum of dark energy. This analysis will then be used to derive optimized observational strategies for both instruments. The student may also have the opportunity to exploit data from the ongoing ESO UVES Large Program for Testing Fundamental Physics.

The project may have a more theoretical or a more observational focus, depending on the background and interests of the student. In the case of a PhD project a co-supervisor will be chosen accordingly in due course. One such recent study can be found at arXiv:1109.6793, and the road ahead is outlined in arXiv:1309.7758 and arXiv:1309.7770.

The ESPRESSO Catalog, or the ultimate extrasolar planets shopping list

Level: Masters
Supervisor: Pedro Figueira (pedro.figueira@astro.up.pt)

The ESPRESSO spectrograph, now under construction, has as one of its main science drivers to find an Earth twin orbiting around a solar-type star. All extrasolar planets detected until now have either a larger mass, a shorter orbital period, or orbit around stars lighter than our own; these properties make their detection easier and thus feasible with today's instrumentation. With ESPRESSO we will reach a precision of 10 cm/s, permitting the detection of a planet with one Earth-mass orbiting inside the habitable zone of a G-type star.

It is now up to us to choose carefully which stars to observe. The project proposed here will consist in studying the different stellar properties that have an impact on the detection of extrasolar planets and define the catalog of stars to observe with ESPRESSO. For that the student will study ESPRESSO's detection capabilities and the impact of stellar noise as a limiting factor on extrasolar planet's detection. The work will provide an excellent introduction to the subject of extrasolar planets and to the most efficient detection method we know, detection by radial velocity measurement.

The student will work closely not only with the supervisor but with Barbara Rojas-Ayala, an expert on the study of M-dwarfs and who will be a de-facto supervisor for the definition of the M-dwarf counterpart of the catalog.

Application of spectral analysis optimization methods to asteroseismic data of classical pulsators

Level: Masters
Supervisor: Michael Bazot (bazot@astro.up.pt)

Asteroseismology is a powerful technique that yield data sensitive to the stellar interior. It is extremely useful in stellar physics since many important physical characteristics of stars (e.g. their mass, their age) depend strongly on their innermost regions. The seismic quantities used to constrain theoretical stellar models are the eigenfrequencies of the various pulsation modes of the stars. These modes are extracted from time series representing the variations of either the radial velocity or luminosity of stars. The number of pulsation modes, their typical frequency range, their amplitude and even their form (harmonic signals, damped harmonic signals) vary from one star to the other. With the advent of the space missions CoRoT and Kepler, very long time series have offered the possibility to measure oscillation frequencies with great precision.

A common problem in asteroseismology is the study of the so-called classical pulsators and in particular delta-Scutis. These stars are known to have vary stable harmonic pulsation modes, which have been observed for a very long time using ground-based facilities. However, the study of space-mission data led to the extraction of a large number of modes, sometimes several hundreds, many of low amplitude, whose physical interpretation is difficult. The goal of this project is to reanalyze some of these time series using various optimization techniques for spectral analysis .In particular, we will rely on the progresses offered by the use of the sparse signal modelling (i.e. considering that the signal is zero almost everywhere except at some discrete frequencies) in order to explore the possibility that different solutions to the problem of the extraction of the frequency from time series of classical pulsators exist. The project will be done in collaboration with A. Garcia-Hernandez and H. Carfantan (Toulouse).

Cosmic Paleontology: Searching for Superstrings

Level: Masters or PhD
Supervisor: Carlos Martins (Carlos.Martins@astro.up.pt)
Co-supervisor (at PhD level): TBA (non-CAUP)

Topological defects necessarily form at phase transitions in the early universe. Being non-linear objects, their study requires a combination of phenomenological analytic modeling and complex HPC numerical simulations. Among the possible defects, superstring networks are particularly interesting, and recent work suggests their unavoidable formation at the phase transition that ends inflation. Characterizing their evolution and consequences can provide us with unique clues on fundamental physics and the dynamics of the early universe.

Although cosmic superstrings share many of the properties of standard strings that have been extensively studied in the past, there are important differences: they don't always intercommute when they intersect and the formation of junctions occurs naturally as a result of string interactions. Hybrid networks with various types of defects can also form, with non-trivial dynamics. Understanding such realistic networks is an open problem that warrants further study, since it has a direct impact on the observational signatures of (and searches for) these objects. The availability of high-precision data from the ESA Planck Surveyor makes this study particularly timely. This work may also help define the science case of the planned COrE/PRISM satellite.

The project may have a more theoretical or a more numerical/observational focus, depending on the background and interests of the student. In the case of a PhD project a co-supervisor will be chosen accordingly in due course. Examples of recent work in the area include arXiv:1201.5064 for analytic modelling and arXiv:1206.6043 and arXiv:1312.2123 for numerical work, while arXiv:1310.3614 provides a brief overview of the area.

Earth-mass planet detection and characterization in the presence of stellar noise

Level: Masters or PhD
Supervisors: Nuno Santos (Nuno.Santos@astro.up.pt)
Co-supervisor (at PhD level): Alexandre Santerne

The detection and characterization of exoplanets using the photometric transit technique has seen a recent enormous success with missions like Kepler and CoRoT. Stronger expectations now come from future space missions like TESS (NASA), CHEOPS and Plato (ESA), which will be able to precisely characterize the composition and internal structure of thousands of low radius, Earth and Super-Earth sized planets. However, a strong difficulty for their success will come from the fact that stellar activity (and associated surface features) are strong sources of noise (e.g. Oshagh+2013, A&A 556, A19).

In this project we propose to develop a series of new tools to model the effects of stellar activity in high precision time series photometry of solar type stars, including young stellar objects, and improve the characterization of known planets and future planet detections. The results of this project will strongly contribute to the full exploitation of data from future missions like Plato and CHEOPS.

Field Theory applications to Astrophysics, Cosmology and High Energy Physics

Level: Masters or PhD

Supervisor: Pedro Avelino (Pedro.Avelino@astro.up.pt)

The student will be expected to work on one or more of the following topics: evolution and cosmological consequences of cosmic defects including domain walls, (super)strings and other p-brane networks; non-gaussian models for structure formation; reionization history of the Universe; interacting dark energy models; modified gravity; extra dimensions and variation of fundamental couplings; inflationary models and viable alternatives as a solution to the problems of the standard cosmological model; abundance of primordial black holes; interface dynamics in cosmology, condensed matter and biology; mass inflation inside black holes.

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

Level: Masters
Supervisor: Elisa Delgado Mena (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.

Modelling the interaction between the accretion and outflow regions around YSO's

Level: Masters or PhD
Supervisor: João Lima (jlima@astro.up.pt)
Co-supervisor (at PhD level): TBC (from Observatory of Paris – LUTh)

The evolution of young stellar objects 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 channeling these flows of plasma and controlling their dynamics and energetics.

In this project we aim firstly, at modelling the structure of the magnetosphere of the YSO in which accretion takes place with very simple MHD analytical models. Secondly, we aim at blending such models with existing self-similar MHD models for jets around these objects. These later ones have been developed by a long standing collaboration between CAUP and Paris researchers.

There is the possibility of extending the analytical approach presented here to a numerical one, using existing numerical codes like PLUTO. The advantage of such numerical approach is to enable the study of time dependent solutions. Paris researchers have a long expertise on the use of such codes for modelling MHD flows. Thus, this will be a joint project between CAUP and LUTh (Observatory of Paris).

Near-IR high precision radial velocities: towards precise mass determination for planets around late type stars

Level: Masters or PhD
Supervisors: Nuno Santos (Nuno.Santos@astro.up.pt)
Co-supervisor (at PhD level): Pedro Figueira

Presently existing optical spectrographs routinely allow to derive RVs with precisions of 1m/s or better (e.g. HARPS@ESO). However, the best NIR instruments are still one step behind with attainable precisions only slightly better than 5 m/s (Figueira+2010, A&A, 515, A106; Bean+2010, Nature 468, 669). The problem of deriving high precision RVs in the IR is becoming more and more important as several present and future photometric planet search projects (e.g. NGTS) are concentrating their efforts on late type stars. Moreover, the soon-to-be-launched GAIA mission is expected to detect thousands of new planetary systems, many of which around M-dwarfs (Sozzetti et al. 2011, EPSC-DPS Joint Meeting 2011, 1071).

With this in mind, several teams are now proposing to build new IR high resolution spectrographs that will be able to achieve RV precisions of the order of 1 m/s. The derivation of precise RV in the IR is, however, a difficult task. In particular, when observed from the ground, the NIR spectrum is filled by large numbers of absorption lines and bands produced by our own atmosphere (telluric lines). These lines blend with those of the celestial body whose spectrum we want to measure and study. In this project we propose to develop new tools to analyze high resolution near-IR spectra, with the goal of achieving high precision radial velocies. These include the modeling of telluric lines, the identification of the best IR stellar absorption lines to derive precise velocities, and the study of stellar activity diagnostics in the IR.

Parametric stellar convection model for the exploration of helio- and asteroseismic eigenfrequencies properties

Level: Masters or PhD
Supervisor: Michael Bazot (bazot@astro.up.pt)
Co-supervisor (at PhD level): Mário João Monteiro

Helioseismology and asteroseismology are powerful observational methods that allow to drill the interiors of stars. Measuring oscillation frequencies allows one to constrain theoretical stellar models, i.e. estimate the mass of a star, its age, initial chemical composition or other related physical characteristics. The use of observational constraints sensitive to its interior is of the uttermost importance since i) some fundamental characteristics (e.g. the mass or the age) are mostly determined by the central physical state of the star, ii) the modelling of the surface layers is difficult and our models are much cruder (and hence unlikely to reproduce observations depending mostly on these regions). This second issue is at the heart of a long-standing problem in helio- and asteroseismology. Even though the stellar oscillations are sensitive to the stellar interior, they are still affected by the surface layers. It has long been recognized that there exist systematic differences between computed frequencies, based on our best solar models, and observed solar frequencies.

It it this issue we want to investigate in this program. Since it is believed that these differences arise from an improper treatment of the upper layers (top of the surface convective zone, interior/atmosphere boundary, atmosphere) of stars, we want to test alternative physical models that might reinstate an agreement between theory and observations. This would in turn be extremely useful in order to calibrate properly theoretical models using solar data and then apply them to other stars. It has been often conjectured that the current modelling of convection could the a most important factor leading to the exiting disagreement. Therefore, we will explore some parametric models for convection that will allow to tune finely the efficiency of the process, as well as its characteristic length scales. To that effect, we will use Bayesian computational methodologies in order to explore the multi-dimensional spaces of parameter underlying these convection model.

Probing inside strongly magnetic stars

Level: Masters or PhD

Supervisor: Margarida Cunha (mcunha@astro.up.pt)

The study of stellar oscillations provides a unique way to see inside stars and study their physics and dynamics. In the case of strongly magnetic stars, the study of the interaction between the magnetic field and the oscillations allows us, in addition, to learn about the stars' magnetic field properties. Recently, significant amounts of excellent asteroseismic data of magnetic stars have been acquired both in dedicated space-based campaigns with satellites such as WIRE, MOST and Kepler and in ground-based campaigns with high-resolution spectrographs, such as UVES at VLT. Nevertheless, theoretical studies of pulsations in magnetic stars still lack the level of detail that is needed to effectively compare with the observational data.

In this project the student will develop analytical and numerical tools for studying the coupling between magnetic fields and pulsations and apply them to real data. The ultimate aim is to make realistic comparisons between the theory and the observations possible and, thus, confidently extract information about the magnetic fields and internal structure of these stars.

The role of alpha elements on the formation of planets

Level: Masters

Supervisor: Vardan Adibekyan (vadibekyan@astro.up.pt)

The correlation between the occurrence of giant planets and the metallicity of host stars is now well established, with metal-rich stars being more likely to harbor gas giants. Interestingly, the same correlation is weakened as one moves toward Neptune-size planets, ultimately vanishing as we enter the regime of terrestrial planets. These correlations lend support to the core-accretion model, where the planet formation starts with the accretion of dust particles and later planetesimals. Latter, if the metallicity of the system is high, the rocky or icy core can form very fast and after accreting a gaseous envelope a massive planet will be formed. If the amount of heavy elements (metals) is not enough the core will grow in a longer timescale and will be no time to accrete enough gas – the planet will be terrestrial. In most of the studies the results were obtained using the iron abundance as a proxy of overall metallicity. However, recent studies showed that metal-poor planet host stars are enhanced by other elements, which means that the total amount of metals in these stars is not small.

In this Master project the student will derive chemical abundances of the stars from the Coralie sample using the Cross-Correlation Function, with the ultimate goal to study the correlation between the frequency of planets and "total" metallicity. This work will be carried out with the collaboration of Pedro Figueira, Sergio Sousa and other members of the EXOEarths team.

Towards the precise characterization of planets around M-dwarfs

Level: Masters or PhD
Supervisors: Nuno Santos (Nuno.Santos@astro.up.pt)
Co-supervisor (at PhD level): B. Rojas-Ayala/S. Sousa

M-dwarfs are the most abundant stars in our Galaxy. However, due to the complexity of their spectra, the derivation of precise parameters for M-dwarf stars (e.g. effective temperature, chemical abundances) is one of the most challenging tasks of stellar astrophysics. The precise characterization of these stars is, however, of utmost importance for several domains. In particular, the derivation of precise parameters for the discovered exoplanets, including their masses and radius (and thus their mean density, a critical parameter for the determination of the bulk composition), is critically dependent on the knowledge of the stellar parameters.

In this project we propose to approach the problem of M-dwarf parameters by exploring the use of both optical and near-IR high-resolution spectroscopy (e.g. Neves+2013, A&A 552, A36; Onehag+2012, A&A 542, A33).

Validating small exoplanets using the Rossiter-McLaughlin effect

Level: Masters
Supervisor: Alexandre Santerne (alexandre.santerne@astro.up.pt)

Future space missions like TESS or PLATO will have the precision to find small, Earth-size, exoplanets transiting nearby stars. The signal of those small exoplanets might be also mimicked by various astrophysical scenarios, like eclipsing binaries. Therefore, those small exoplanet detections should be first validated. One of the technique to validate a transiting exoplanet is to measure its mass by observing the reflex motion of the host star caused by the planet. However, in the case of low-mass exoplanets in the habitable zone, measuring their mass can really be challenging and telescope time consuming. Another technique has been proposed by Gaudi & Winn (2007). This technique consists in observing the Rossiter-McLaughlin effect to validate their nature. In the case of small exoplanets in the habitable zone, they have shown that the Rossiter-McLaughlin effect should be more easily detected than the reflex motion of the host star. This technique requesting observations only during the few hours of a transit, it would be also much less telescope time consuming than looking for the reflex motion of the host star during several years.

The objective of this master thesis is to explore the performances of the Rossiter-McLaughlin technique to validate small exoplanets in the habitable zone, in the context of future instruments like PLATO and ESPRESSO. For that, the student will adapt and use different tools already developed at CAUP such as Arome, SOAP-T and PASTIS to simulate Rossiter-McLaughlin effects of transiting exoplanets and eclipsing binaries. Depending on the results obtained, the student will then test this validation technique on real data already obtained by the Kepler space telescope and the SOPHIE spectrograph. The result of this thesis might led to at least one publication in a peer-reviewed journal.

Scientific literacy and astronomy teaching

Level: Masters or PhD
Supervisor: Carlos Martins (Carlos.Martins@astro.up.pt)
Co-supervisor (at PhD level): TBA

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 opportunities to interact with schools provided by the International Year of Light 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.

APPENDIX

The CAUP Team, March 2014

Researchers [39]
Vardan Zh. Adibekyan
Pedro P. Avelino
Michaël Bazot
Isa M. Brandão
Carlos M. Correia
Margarida S. Cunha
António C. da Silva
Paulo Maurício de Carvalho
Elisa Delgado Mena
Lokesh K. Dewangan
Alexandre D. A. Fernandes
João M. T. S. Ferreira
Pedro Figueira
Mercedes E. Filho
Daniel F. M. Folha
Jorge F. Gameiro
Antonio García Hernández
Jean Michel Gomes
Jorge M. C. Grave
Andrew J. Humphrey
M. S. Nanda Kumar
Maria Teresa V. T. Lago
Patricio Lagos
João J. G. Lima
Catarina Lobo
Carlos J. A. P. Martins
Marco Montalto
Mário J. P. F. G. Monteiro
Annelies Mortier
Breezy Ocaña Flaquer
Giancarlo Pace
Polychronis Papaderos
Nathan Roche
Bárbara Rojas Ayala
Alexandre Santerne
Nuno C. Santos
Sérgio A. G. Sousa
Lara G. Sousa
Pedro T. P. Viana

Ph.D. Students [18]
Daniel T. Andreasen
Lisa Benamati
Lupércio B. Bezerra
Leandro S. M. Cardoso
Diana Cunha
Leyla Ebrahimpour
João P. S. Faria
Rui A. A. Fernandes
João N. T. Gomes da Silva
Jorge H. C. Martins
Mahmoudreza Oshagh
Raphael Peralta
Elsa P. R. G. Ramos
Ana C. S. Rei
Ângela R. G. Santos
Arlindo M. M. Trindade
Maria Tsantaki
Pauline E. Vielzeuf

Undergraduate/Masters Students [13]
Rui F. C. Alves
Rui P. L. Azevedo
Ana S. C. Brandão
Manuel M. P. V. P. Cabral
Simão M. João
Ana C. O. Leite
Inês S. A. B. Mota
Ana M. M. Pinho
José A. C. Sá
Guilherme D. C. Teixeira
Joel A. C. Teixeira
Pedro M. T. Vianez
José P. P. Vieira

Funding ID: Currently funded grants active during all or most of the 2014-15 academic year.

An exploration of the assembly history of galaxies with the novel concept of self consistent spectral synthesis
PI: Polychronis Papaderos

Cosmic Superstrings in the Planck Era
PI: Carlos Martins/João Pedro Vieira

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)

ESPRESSO: a new spectrograph for the VLT (part V) – control electronics and the ADC subsystem
PI: Nuno Santos

Gaia Research for European Astronomy Training (GREAT-ITN)
PI: Non-CAUP (CAUP contact Nuno Santos)

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 Dark Side of the Universe
PI: Carlos Martins

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

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Centro de Astrofísica da Universidade do Porto

Centro de Astrofísica da Universidade do Porto

U. PORTO

Rua das Estrelas
4150-762 Porto, Portugal
T. +351 226 089 830
geral@astro.up.pt

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