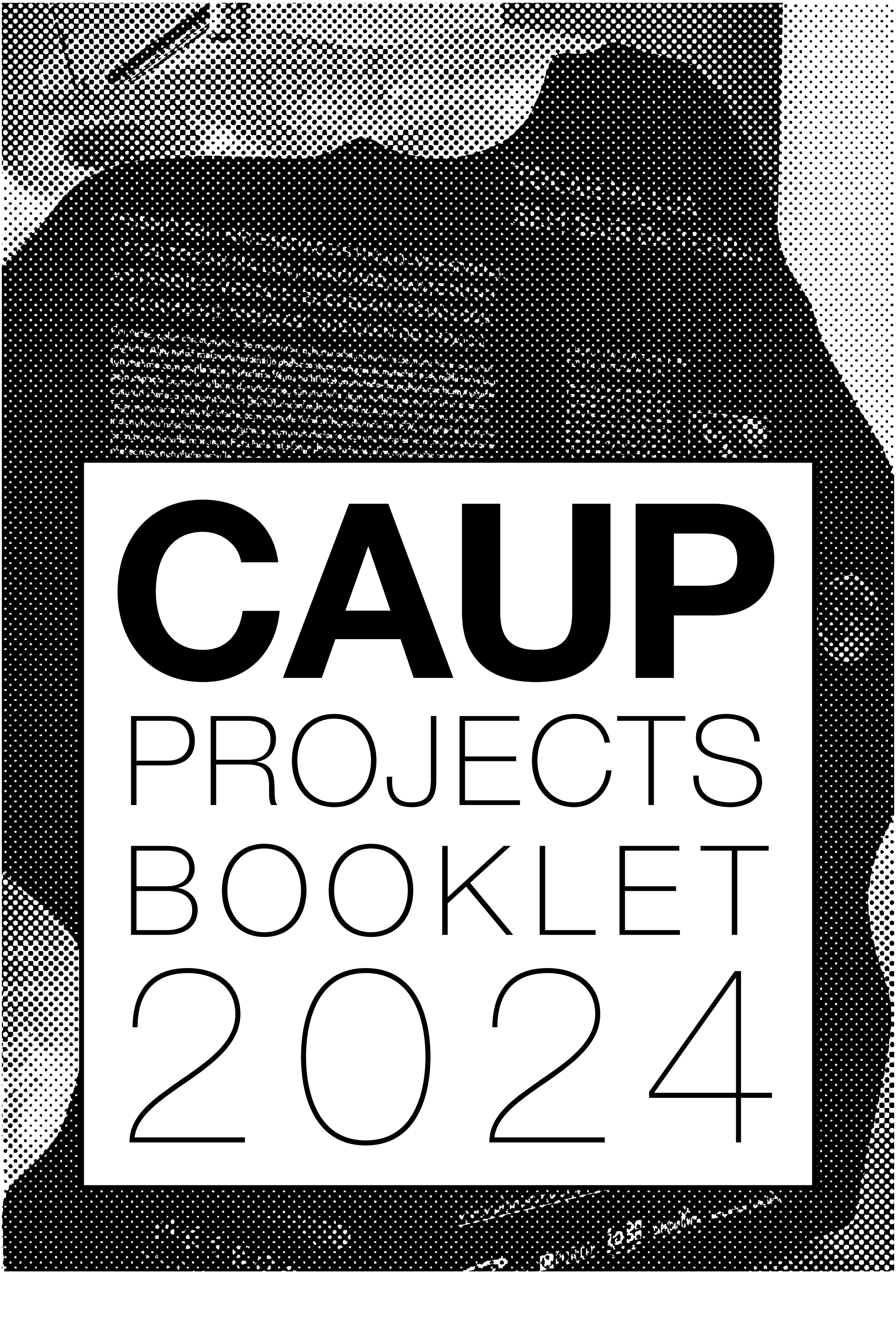

CAUP

PROJECTS BOOKLET 2024

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 2024-25.

We start by listing PhD/MSc projects within our participation in ESA and ESO consortia, which is one of our key strategic priorities. These are followed by other astrophysics PhD/MSc projects, and then by junior (undergraduate) projects and education & outreach projects. These tend to represent more specific interests of individual members, although in various cases they also involve non-CAUP collaborations and external co-supervision. At the PhD level, these projects are eligible for funding through regular FCT PhD grants. Local funding is sometimes also available for MSc and junior projects. Some projects are listed in Portuguese, since they are mainly offered through the PEEC internship program. In each section the projects are listed alphabetically by title. As an appendix we also list the current CAUP team, including both the researchers and the PhD and younger students.

The project contact person's e-mail is listed, and should be approached for any enquiries on the project. The list is representative of current interests and priorities, but it is not exhaustive. Many CAUP members can devise additional projects at shorter notice, and have sufficiently broad interests and expertise to be able to supervise projects on further topics. Potentially interested students are encouraged to contact us to explore further possibilities.

Carlos Martins

(Head of the CAUP Training Unit)

Apbril 2024

CAUP PROJECTS BOOKLET 2024

INDEX

ESA and ESO related projects

Challenging Lambda in the Euclid era

Level: PhD or MSc
Supervisor: Carlos.Martins@astro.up.pt
https://cienciavitae.pt/portal/en/4D17-61B5-3A0C

The growing amount of observational evidence for the acceleration of the universe 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 of forthcoming astrophysical facilities is 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 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 (active), the ELT, and the SKAO (both under construction) 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 of the key assumptions underlying LambdaCDM. The goal of this thesis will be to carry out a systematic exploration of the landscape of physically viable theoretical dark energy paradigms and provide optimal discriminating observational tests.

The project is suitable for those with a scientific interest in the interface between theoretical cosmology/fundamental physics and cosmological observations. The work will be done in the framework of the FCT Phi in the Sky grant (which may provide an MSc grant), including several international collaborations. Key relevant references are Alves et al. MNRAS 488 (2019) 3607, Amendola et al. LRR21 (2018) 2, Marques et al. MNRAS 527 (2023) 9918, Martinelli et al. A&A 644 (2020) A80 & A&A 654 (2021) A148, Martins et al. PRD 94 (2016) 043001, Pinto et al. PRD 107 (2023) 083514, and Schoneberg et al. JCAP 10 (2023) 039.

Fundamental physics with the ANDES spectrograph

Level: PhD or MSc

Supervisor: Carlos.Martins@astro.up.pt

https://cienciavitae.pt/portal/en/4D17-61B5-3A0C

A key science driver of the state-of-the art ESPRESSO spectrograph is to improve tests of the stability of nature's fundamental couplings such as the fine-structure constant, but the first dedicated redshift drift experiment is also in progress. The ESPRESSO data is also important as the first reliable precursor of the analogous ELT spectrograph, ANDES (in whose Phase B the supervisor is the Chair of the Cosmology and Fundamental Physics WG), which will enable tests beyond the sensitivity of ESPRESSO, such as redshift drift measurements and molecular tests of composition-dependent forces.

The goal of the thesis is to develop and consolidate the ANDES cosmology and fundamental physics science cases, especially tests of the stability of fundamental couplings such as alpha and the detection of the redshift drift or Sandage test signal. Specifically, the student will build upon our ESPRESSO scientific and technical expertise, and on our privileged access to its data, to develop fully realistic end-to-end ANDES simulations and forecasts for its fundamental physics science goals. These will enable a full assessment of the ANDES capabilities, inform any necessary tradeoffs, and enable us to start outlining possible observational strategies.

The student, who should have a genuine interest (and, ideally, some previous experience) in experimental spectroscopy and astrophysical data analysis, will work in the general framework of the ESPRESSO and ANDES science teams, and will also join the FCT Phi in the Sky project team (which may provide an Msc-level grant). Key relevant references are Alves et al. MNRAS 488 (2019) 3607, Cristiani et al. MNRAS 522 (2023) 2019, Marques et al. MNRAS 522 (2023) 5973, Martins Rep.Prog.Phys. 80 (2017) 126902, Martins et al. PLB 827 (2022) 137002, PRD 105 (2022) 123507 & Exper.Astron. 57 (2024) 5, Murphy et al. A&A 658 (2022) A123, Schmidt et al. A&A 646 (2021) A144 and Vacher et al. PRD 106 (2022) 083522.

Looking at the Sun, Finding other Earths

Level: PhD
Supervisor: Nuno.Santos@astro.up.pt
https://cienciavitae.pt/portal/481A-63F9-5CFA

More than 5000 extrasolar planets have been announced until today orbiting other stars. In this line, strong hopes to detect "Earth-like" systems, rocky planets in the habitable zone of solar type stars, come from new state-of-the-art instruments and missions by the main international agencies (ESO, ESA, NASA). Ground based high-resolution spectrographs such as ESPRESSO (Pepe et al. 2020, A&A 645, A96), represent relevant steps in this effort (see e.g. results from our team - Demangeon et al. 2020, A&A 653, A41; Faria et al. 2022, A&A 658, A115).

Physical phenomena associated with the presence of stellar magnetic regions (e.g. spots, faculae), stellar granulation, and stellar oscillations, are able to produce "signals" in the spectra that can mislead planet search efforts (e.g. Santos et al. 2014, A&A 566, A35). Stellar "noise" is presently seen as the major obstacle in the quest for other Earths.

Having this in mind, our team has recently seen approved an ERC Advanced Grant project to build a new facility: the Paranal solar ESPRESSO Telescope (PoET - http://poet.iastro.pt). PoET will be a small solar telescope, that will link with ESO's state-of-the-art ESPRESSO spectrograph to obtain disk resolved and disk integrated spectra of our Sun. The whole goal is to use the unique solar observations as a proxy to understand how to diagnose and correct the stellar "noise" in exoplanet research data (for other solar-type stars).

The successful PhD student will be involved in the development and exploitation of PoET data, with the scientific goal of understanding how to model and correct "stellar noise" in data from high precision exoplanet research. In parallel, the student may be involved in state-of-the-art planet search and characterization projects (e.g. ESPRESSO, NIRPS). The outcomes of this project will have an important impact on the characterization of Earth-like planets with future facilities at the new generation of giant telescopes (e.g. the ELT).

The physically resolved properties of distant galaxies with MUSE, HST and Euclid

Level: PhD
Supervisor: Jarle Brinchmann (jarle@astro.up.pt)
https://cienciavitae.pt/portal/2018-ADE7-51C9

The spectra of galaxies are replete with emission lines that provide essential information on the physical conditions in the (mostly ionized) gas within galaxies. The modeling of these emission lines has a long history and the technique of photoionization modeling has become a cornerstone of astrophysics. These models rely on knowing the far-UV (20-90nm) ionizing spectra of the sources lighting up the gas, but this part of the spectrum of a star has only been observed directly for only 3-4 stars and it is a major uncertainty for the interpretation of the spectra of distant galaxies. In this project you will develop methods to place strong constraints on the shape of the ionizing spectrum of stars from the observation of the emission lines they give rise to, basically see the invisible, and help settle this debate.

The basis for this project is that we now have a wide range of galaxies with spectra covering both the UV (120-300nm) and optical (350-1000nm) regions which originate from transitions that require different energies for the excitation or ionization. In this project you will develop methods, building on previous work in the literature such as e.g. Zastrow, Oey & Pellegrini (2013, APJ, 769), but now combining optical and UV data and aimed to tackle not only HII regions but also galaxies.

The models will be used to constrain the ionizing spectrum in nearby galaxies from the CLASSY survey with HST, as well for the future interpretation of data on higher redshift galaxies, combining MUSE, Euclid, MOONS and 4MOST data (all of which the supervisor is heavily involved in). The end result of the thesis will be a systematic study of the ionizing spectra of stars & galaxies as a function of metallicity and redshift.

Tides that shape planetary systems

Level: PhD
Supervisor: Susana.Barros@astro.up.pt
https://cienciavitae.pt/portal/4B13-5BDD-FF3E

Recent years have seen a revolution in our knowledge of exoplanetary systems. Recently we have been able to detect the deformation of the shape of a planet, made for the first time by our group. We found that the giant planet orbiting the star WASP-103 was extremely deformed due to tides. Another effect, tidal decay (a shrinking of the planet's orbit), has also been detected recently for one system. However, its strength is much higher than expected, which remains a mystery.

In this context, this project aims at detecting tidal decay and tidal deformation of exoplanets taking advantage of the unprecedented precision of the ongoing and future transit missions like TESS, CHEOPS, and PLATO, in which our team is deeply involved. In particular, this project will take advantage of the extreme precision of CHEOPS to investigate tides in planetary systems. The student will be officially involved in the CHEOPS mission and may also be involved in other science cases of the CHEOPS science team.

Tides have stronger influence in some exoplanetary systems than in our solar system and they can significantly shape the architecture of some systems, such as Hot-Jupiters. For planets that are very close to the parent star, we propose to measure the variation of transit times that would be due to the tidal interaction with the host star. We have been obtaining data for the past 3 years and new observations are planned in the next two years. These will allow to detect tidal decay for a few systems or meaningfully constrain its strength. We will also aim to detect the deformation of planets due to tides for some exoplanets following our recent breakthrough for WASP-103b (Barros+2022). We will use both new CHEOPS data possibly together with JWST observations to attempt to detect the tidal deformation in other systems.

Other astrophysics projects

Analytic Methods for Realistic Cosmic Strings and Superstrings

Level: PhD or MSc
Supervisor: Carlos.Martins@astro.up.pt
https://cienciavitae.pt/portal/en/4D17-61B5-3A0C

Cosmic strings arise naturally in many extensions of the standard model, including 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 provide a unique window into the early universe and possibly string theory. Recent progress in CMB and gravitational wave observations shows how some of these scenarios can in principle be constrained by high-resolution data, but also highlight bottlenecks which make current constraints unreliable. To fully exploit the potential of facilities such as the SKAO 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, especially additional degrees of freedom on the defect worldsheets, e.g. charges and currents.

This thesis will address the latter, using novel mathematical and statistical techniques, informed by the world's most accurate defect simulations (being done by our team) to build upon the successes of the canonical VOS and CVOS models to develop a new generation of accurately calibrated analytic models for general defect evolution as well as for their astrophysical fingerprints, which is able to match the sensitivity of ongoing and future observational searches and yield reliable constraints.

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 Almeida & Martins PRD 104 (2021) 043524 & PRD 106 (2022) 083525, Correia & Martins PRD 100 (2019) 103517, PRD 104 (2021) 063511 & PRD 106 (2022) 043521, Martins & Cabral PRD 93 (2016) 043542, Martins et al. PRD103 (2021) 043538 & PRD 104 (2021) 103506, and Rybak et al. PRD107 (2023) 123514.

Characterise observationally the GNSS signal and remove it from HI IM surveys

Level: PhD or MSc

Supervisor: Jose.Fonseca@astro.up.pt
https://www.cienciavitae.pt/E81E-0EC5-9741

A source of contaminants in HI intensity mapping (IM) are satellites around Earth. One subset of satellites that lie within the frequency range we pretend to do HI IM is the Global Navigation System Satellites (GNSS). A mitigation strategy is to consider frequency ranges far away from the allocated satellite transmission band which are set by the International Telecommunications Union. Still, out-of-band transmission can leak out of these allocations making it necessary to understand how satellite RFI propagates into the frequencies we wish to do science. Harper & Dickinson (2018) estimated the impact of GNSS on a future SKAO-MID band 2 HI IM survey. Attempts to model the observed satellite signal for the MeerKAT's HI IM data has been done, reproducing it when the telescope response is still linear. The out-of-band impact is residual but non-negligible and impacts the largest scales we seek. Hence it is of utter importance to improve the modeling of the satellite signal, including more prior information, and clean it from all bands before any cosmology study. Our goal is to improving the satellite statistical model we fit to the data and assess which one is better in removing or minimizing its impact in the estimation of the HI power spectra.

After improving the GNSS model and well carachterising the satellite contamination with MeerKAT's observational data we should clean the satellite signal from the data. We will also test if any residual satellite emission is still present. The student is then expected to quantify the residual impact of GNSS in the cosmology band by estimating the HI power spectrum and cross-power spectrum as done in Cunnington et al 2023. We will do the same power spectra estimation when the out-of-band satellite signal is not removed. We will then compare both and quantify the improvement brought by cleaning satellite contamination. We will then assess to which extent data, previously masked because of the presence of GNSS radio interference, can now be used in cosmology.

Relevant references are Cunnington et al., MNRAS 518 (2023) 6262; Harper & Dickinson, MNRAS 479 (2018) 2024; Santos et al., arXiv:1709.06099; Wang et al., MNRAS 505 (2021) 3698.

Detecting stellar magnetic cycles through latitudinal migration of starspots

Level: MSc
Supervisor: Angela.Santos@astro.up.pt
https://cienciavitae.pt/portal/en/621E-7A29-78F9
Co-Supervisor: Ricardo Gafeira (U. Coimbra)

Dark magnetic spots on stars' surfaces are a manifestation of stellar magnetic activity. In the Sun, as the 11-year solar cycle progresses, sunspots gradually form at lower latitudes, a phenomenon called spots' latitudinal migration. As the Sun is differentially rotating, the rotation rates associated with spots vary. Similar behavior is expected in other solar-like stars. However, one cannot directly observe their spots, we can only detect their indirect effect, namely on the stellar brightness. Starspot signals are complex with multiple spots of different sizes and lifetimes at different latitudes. Moreover, there are other sources of brightness variations including instrumental artifacts. Therefore, the detection and characterization of magnetic cycles through the brightness of stars has been challenging and tainted with false-positive detections.

In this project, the student will investigate whether spots' latitudinal migration can be detected through integrated solar brightness (Sun-as-a-star observations from ESA/NASA's VIRGO). To that end, the student will compare the unresolved Sun-as-a-star observations with the resolved sunspot observations. This will allow us to better understand Sun-as-a-star data and, consequently, better interpret the data of other stars, for which only unresolved data is available. The learnings acquired with solar data will then assist the analysis of the stellar data collected by NASA's Kepler. This project will facilitate the detection and consequent characterization of stellar magnetic cycles. These observational constraints are key to understanding the physical processes in stars and inform dynamo theory.

Estimation of the effect of lensing in photometric surveys

Level: PhD or MSc

Supervisor: Jose.Fonseca@astro.up.pt
https://www.cienciavitae.pt/E81E-0EC5-9741

The observed distribution of matter in the universe carries important information about the early stages of the universe, as well as its composition and evolution. To understand the clustering of the universe one needs to measure the positions of galaxies in the universe. But these distances and angular locations in the sky are slightly altered by the matter in the universe leaving imprints in the observed statistical distribution of galaxies. Such imprints are exquisite new probes to Einstein's theory of Gravity.

This project's goal is to determine the effect of weak lensing in the observed angular clustering of photometric galaxy surveys at wide redshift separations. The student will review how space-time affects the path and observed energy of photons arriving from distant galaxies and how it affects the observed power spectrum. Prior programming knowledge would be beneficial (Python or/and C/C++ and/or Fortran).

Relevant references are Fonseca et al., MNRAS 466 (2017), 2780; Tansella et al., JCAP 10 (2018) 032; Chisari et al., ApJS 242 (2019) 2; Jelic-Cizmek et al., JCAP 04 (2021) 055.

Exploring the red side of the most abundant stars in the Galaxy

Level: PhD
Supervisor: Elisa.Delgado@astro.up.pt
https://cienciavitae.pt/portal/DE16-C677-9895
Co-Supervisor: Sérgio Sousa

The determination of accurate and precise stellar parameters and chemical abundances of cool stars, and in particular M dwarfs, is of prime importance to study the Galactic chemical evolution since they are the most abundant in the Galaxy. Moreover, M dwarfs are excellent targets for the quest of other Earths due to their lower mass and size. However, to characterize a planet we need to have highly accurate estimates of parameters and chemical composition of its host star. Despite the recent advancements in the study of these faint stars, different techniques lead to significant differences in the obtained parameters. The main goal of this project is to achieve a higher precision in the characterization of this population of poorly known stars.

Opposite to the crowded optical spectra of M dwarfs, the near-infrared (NIR) is significantly less blended. In addition, the spectral energy distribution of M dwarfs makes them more than one order of magnitude brighter in the NIR than in the visible. Therefore, we propose to use the data from NIRPS, a new high-resolution NIR spectrograph that will observe hundreds of M dwarfs in order to search for planets, and for which we will have priviledged access to its Guaranteed Time Observations (GTO). The quality of the data will allow us to have a large library of M dwarfs spectra with high signal to noise and a broad range of stellar parameters. During the project, the student will apply spectral synthesis methods to derive the stellar parameters and obtain chemical abundances of different kind of elements (alpha, iron peak, s-process). The results of this project will serve to make a better characterization of the planets orbiting those stars, to have a better understanding of the star-planet connection and to study the chemical evolution in the Galaxy using one of the largest homogeneous samples of M dwarfs to date.

Extracting cosmological information from the distribution of neutral hydrogen

Level: PhD or MSc
Supervisor: Jose.Fonseca@astro.up.pt
https://www.cienciavitae.pt/E81E-0EC5-9741

The radio telescope MeerKAT, a precursor of the future Square Kilometer Array Observatory (SKAO), will probe the large-scale distribution of matter in the Universe using the radio emission of neutral hydrogen (HI). It, therefore, has the potential to make a statistical measurement of the HI power spectrum using intensity mapping. With it one can detect the elusive Baryon Acoustic Oscillations (BAO) that can constrain Dark Matter and Dark Energy, as well as understand the evolution of neutral hydrogen through cosmic time (important for the formation of galaxies and stars).

This project aims to participate in the building of pipelines for the data analysis of HI maps using state-of-the-art statistical techniques. We will use Monte Carlo Markov Chains (MCMC) for parameter estimation of the composition and evolution of the universe. No prior knowledge of astronomy is required. The student should be an enthusiast in Bayesian statistical techniques and programming (Python or/and C/C++ and/or Fortran).

Relevant references are Tanidis & Camera, MNRAS 489 (2019) 3385 (2019); Spinelli et al., MNRAS 509 (2022) 2048; Cunnington et al., MNRAS 496 (2020) 415; Berti et al., MNRAS 521 (2023) 3221.

Measuring primordial non-Gaussianity with photometric galaxy surveys

Level: PhD or MSc
Supervisor: Jose.Fonseca@astro.up.pt
https://www.cienciavitae.pt/E81E-0EC5-9741

Understanding the very early universe and the physics of Inflation is one of the most important quests in cosmology. Primordial fluctuations in the gravitational potential from the inflaton field provide a mechanism to source the large-scale distribution of matter in the Universe. In the simplest model of Inflation such primordial fluctuations are taken to be Gaussian with very small non-Gaussian deviations, but it is not necessarily true in other inflationary scenarios. A particular type of primordial non-Gaussianity (PNG), called “local type”, gives rise to a scale-dependent bias of galaxies. Therefore, a non-zero PNG changes the bias of DM tracers on the largest cosmological scales and offers a unique late universe window onto the primeval one.

Here we focus on how well can we measure PNG with photometric galaxy surveys and how sensitive is this measurement with respect to systematics. Additionally, we will optimise the binning of the data to understand the trade-off between precision and density. To quantify the impact of observational systematics on the best fit and error of PNG we will simulate mock catalogs with codes like, introduce systematics in the known mocks and use a cosmological parameter inference likelihood pipeline.

Relevant references are Alonso et al., MNRAS 484 (2019) 4127; Challinor & Lewis, PRD84 (2011) 043516; Pocino et al., A&A 655 (2021) A44; Ramírez-Pérez et al., JCAP 05 (2022) 002; Torrado & Lewis, JCAP 05 (2021) 057.

Probing very large cosmological scales with the distribution of neutral hydrogen

Level: PhD or MSc
Supervisor: Jose.Fonseca@astro.up.pt
https://www.cienciavitae.pt/E81E-0EC5-9741

HI (neutral hydrogen) intensity mapping is a new and challenging way of using radio telescopes, such as the Square Kilometre Array Observatory (SKAO), to map the large-scale distribution of matter in the universe. These will probe ever larger scales of the universe crucial to open new windows into the very early universe and test theories of Inflation. But the calibrated maps contain not only the neutral hydrogen emission but also residual emission from galactic and extra-galactic sources. Traditional approaches use blind foreground subtraction methods to clean them from the observed signal. While successful in recovering the cosmological information on sub-horizon scales, these cannot reconstruct the large angular scales, important to probe the very early universe. In addition, at such large-scales, the observed clustering has relativistic corrections which can be used to test Einstein's theory of gravity. Therefore understanding clustering to high precision on such scales is required to probe the early universe and further test the fundaments of General Relativity.

This project aims to explore new approaches on how to deal with residual foreground contamination. In particular, study how feasible is to jointly infer the cosmological parameters and foreground parametrisations. We aim to learn when and how such an approach can be taken with future datasets using simulations and standard Monte Carlo Markov Chains (MCMC). No prior knowledge of astronomy is required. The student will learn the basic principles of Bayesian statistical techniques. Prior programming knowledge would be beneficial (Python or/and C/C++ and/or Fortran).

Relevant references are Fonseca & Liguori, MNRAS 504 (2021) 267; Alonso et al., MNRAS 447 (2015) 400; Loureiro et al., MNRAS 485 (2019) 326; Fonseca et al., ApJ 812 (2015) L22.

Shedding light on the complexities of stellar rotation

Level: MSc
Supervisor: Angela.Santos@astro.up.pt
https://cienciavitae.pt/portal/en/621E-7A29-78F9
Co-Supervisor: Rafael García (CEA, Saclay), Margarida Cunha

Magnetic activity is ubiquitous in stars and its characterization is of paramount importance in the context of both stellar and (exo)planetary research. A crucial ingredient for the generation of stellar magnetic activity and magnetic cycles is differential rotation. To improve our understanding of the physical processes leading to stellar magnetic activity, developing efficient methods to measure differential rotation in solar-like stars is, thus, of utmost importance. This can be achieved by analyzing stellar brightness and its temporal variation. In a differentially rotating star, the brightness variations are quasi-periodic. Still, average rotation periods have been measured with success for a large number of solar-like stars. However, discerning the contribution of spots at different latitudes and quantifying differential rotation has, so far, been nontrivial.

In this project, the student will develop techniques to constrain differential rotation from the stellar brightness variations. The rotational analysis to be carried out will be designed to preserve the properties of signal components with slightly different rotation rates. Those techniques will be tested and validated with solar data, as well as artificial data, which will be produced by the student. Artificial data will allow the student to explore the parameter space and perform control tests, determining the requirements for reliable estimates and the efficiency of each method across the parameter space.

This project will be an important step forward in obtaining reliable differential rotation estimates for extended samples of stars, particularly those observed by NASA's Kepler and future ESA's PLATO. These estimates are also highly demanded for advancing our knowledge of the dynamo processes.

Signatures of magnetic activity in differentially rotating solar-like stars

Level: PhD

Supervisor: Angela.Santos@astro.up.pt

https://cienciavitae.pt/portal/en/621E-7A29-78F9

Co-Supervisor: Savita Mathur (IAC), Rafael García (CEA, Saclay)

Active regions in the surface of magnetically active stars lead to stellar brightness variations. Indeed, such brightness variations provide constraints on both surface rotation and magnetic activity of stars. Planet-hunting space-based high-precision photometric missions, particularly Kepler, opened a new window of opportunity for stellar physics by collecting the light of hundreds of thousands of stars. While the average rotation and the average magnetic activity have been measured for more than 55,000 stars, discerning the contribution of spots at different latitudes and quantifying differential rotation from integrated stellar light is non trivial. Simultaneously, differential rotation is a key ingredient in dynamo theory (i.e. generation of magnetic fields) and an observational constraint that theoreticians long for.

The first main goal of this project is to characterise surface latitudinal differential rotation of Kepler solar-like stars and, consequently, understand how differential rotation varies across the Hertzsprung-Russell diagram. Furthermore, characterising differential rotation can also help detect magnetic cycles analogous to the 11-year cycle of the Sun. In the Sun, spots emerge at gradually lower latitudes where the rotation rates are higher. This phenomenon leaves a signature in the stellar integrated light. With this in mind, the second main goal of the project is to detect and characterise magnetic cycle candidates.

The student will investigate the latitudinal differential rotation of Kepler solar-like stars, as well as detect and characterise magnetic cycles. Accurate measurements of such stellar properties are scarce and polluted by false-positive detections. However, those properties are both crucial for the development of dynamo theory and for the subsequent understanding of stellar magnetism and evolution. Therefore, constructing efficient methods to retrieve those properties is essential.

Starburst-driven galactic winds and the evolving topology of gas in local analogs of the first galaxies

Level: PhD
Supervisor: Polychronis Papaderos (papaderos@astro.up.pt)
https://cienciavitae.pt/portal/7718-0C12-5613

Chemically unevolved starburst galaxies (SGs) in the nearby Universe are unique laboratories of extragalactic astronomy, as they constitute the best local analogs of the first galaxies formed in the Universe at the Epoch of Reionization (EoR). Photometric studies of these systems indicate that they experienced the dominant phase of their formation at a late cosmic epoch through strong starburst episodes that gave rise to the nearly coeval formation of thousands of massive stars and strong, spatially extended nebular emission associated with fast (several 100 km/s) galactic winds.

Understanding starburst-driven galactic winds is fundamental to the understanding of how the first galaxies have emerged and evolved at the EoR. Various lines of theoretical evidence imply that energetic radiation and momentum-driven winds from massive stars, and the ensuing supernovae explosions have rapidly led to the disruption of the maternal gas halo of these proto-galaxies, facilitating escape of Lyman continuum radiation and the reionization of the Universe. However, little is quantitatively known about the time evolution of the 3D topology and kinematics of neutral and ionized gas in the presence of a strong central energy source (the starburst and ebentually also an AGN powered by matter accretion onto a massive black hole) in early phases of galaxy evolution. With the revolutionary James Webb Space Telescope (JWST), Euclid and ALMA, and the MUSE@VLT integral field spectroscopy unit it is now possible to carry out for the first time a spatially resolved study of the starburst-gas interaction in SGs.

This PhD project will use high-quality data from the above mentioned observing facilities and instruments to investigate for the first time the connection between the energy production history and the physical properties of galactic winds in a representative sample of SGs.

Stellar rotation and magnetic activity of solar-like stars observed by Kepler/K2 mission

Level: MSc
Supervisor: Angela.Santos@astro.up.pt
https://cienciavitae.pt/portal/en/621E-7A29-78F9
Co-Supervisor: Savita Mathur (IAC), Rafael García (CEA, Saclay)

The angular momentum transport in solar-like stars is still not completely understood. This concerns the internal rotation but also the surface rotation for stars of the same age or older than the Sun. NASA's K2 mission (that succeeded the nominal Kepler mission) has observed several tens of thousands of solar-like stars for 3 months, including several hundreds of planet-host stars. With such photometric data, it is possible to study surface rotation through the passage of spots/active regions on the visible disk of the stars.

The goal of the project is to determine average rotation periods of solar-like stars observed by K2 with a 30-minute cadence that is enough to look for rotation modulation as it has already been done for more than 55,000 stars observed by Kepler. The student will analyze the photometric data with an existing automatic code that measures surface rotation and a magnetic activity proxy based on the photometric data. This pipeline is also associated with a machine learning code to help the classification of the spectral type of the stars and classify them into rotating or non-rotating categories. If time permits, the student will look at the planet-host stars of the K2 mission and the planet orbital period to study the star-planet interactions. This project will help to better understand the evolution of stellar rotation and magnetic activity.

Testing General Relativity with the Eddington experiment

Level: MSc
Supervisor: Carlos.Martins@astro.up.pt
https://cienciavitae.pt/portal/en/4D17-61B5-3A0C

The Eddington experiment, carried out on 29 May 1919 and replicated in the 1920s, is one of the canonical tests of General Relativity (GR), and clearly the one with the largest historical and societal impact. Not only did it prove decisively that light (i.e., photons) gravitate, but it also provided strong supporting evidence for a GR prediction, falsifying the analogous Newtonian physics one.

Although more stringent tests of GR can now be obtained by other techniques, the historical importance of the Eddington experiment is a clear motivation for a modern replication. The total solar eclipse of 12 August 2026, whose path of totality includes Spain and Portugal, provides a unique opportunity, compounded by the fact that the date will be within AstroCamp 2026. While the eclipse conditions are not ideal by comparison to the 1919 one (e.g., there no bright stars near the Sun's limb), these might be partially offset by advances is astrophysical instrumentation.

The goal of the thesis is to provide a quantitative assessment of the circumstances of the eclipse and a feasibility study of its use for an Eddington test with sufficient precision and accuracy to distinguish between the GR and Newtonian predictions - ideally, through a methodology which AstroCamp 2026 students can understand, and to which they can directly contribute. The thesis should also provide a detailed implementation plan (including a timeline and budget), to be implemented in the 2025-26 academic year. In addition to a good understanding of GR, the student should have a genuine interest in astrophysical instrumentation and data analysis.

Undergraduate projects

Física fundamental, do ESPRESSO ao ANDES

Orientador: Carlos.Martins@astro.up.pt
https://cienciavitae.pt/portal/en/4D17-61B5-3A0C

Perfil do Candidato:
O aluno deve ter interesse em astrofísica observacional e análise de dados. Experiência de programação, análise e visualização de dados é essencial. Espera-se uma dedicação ao projecto de pelo menos 6 horas de trabalho por semana.

Objectivos e Actividades:
O aluno será integrado num projecto internacional que usa o espectrógrafo ESPRESSO, e o seu sucessor, ANDES, 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 que conhecemos não serem válidas em regiões ou épocas diferentes do universo, e definir e prioritizar testes futuros. Possíveis actividades incluem:
1) Exploração dos testes de física fundamental em curso, feitos pelo ESPRESSO, como ferramentas para testes mais precisos de modelos de energia escura e do Princípio de Equivalência de Einstein;
2) Análise das restrições a classes específicas de modelos, impostas por testes de consistência, incluindo a nucleossíntese primordial e a evolução da temperatura da radiação cósmica de fundo, e por outros dados observacionais contemporâneos;
3) Planeamento e design experimental de futuros testes mais precisos, no contexto do ANDES, incluindo o redshift drift, e criação de catálogos de dados simulados para optimização de estratégias observacionais;
4) Organização e apresentação dos resultados obtidos. O estágio poderá incluir visitas de trabalho a colaboradores externos e/ou deslocações a conferências para apresentação dos resultados, e.g. espera-se que os resultados sejam apresentados no Encontro Nacional de Astronomia 2025.

Bibliografia relevante, disponível em https://arxiv.org: 1709.02923, 2012.10505, 2203.02781, 2305.01446, 2311.16274, 2404.05037.

Simulação computacional e visualização de supercordas com GPUs e CUDA

Orientador: Carlos.Martins@astro.up.pt
https://cienciavitae.pt/portal/en/4D17-61B5-3A0C

Perfil do Candidato:
O aluno deve ter interesse em programação, física computacional e data science. Experiência de programação, análise e visualização de dados é essencial. Experiência de programação paralela e/ou em GPUs será útil. Espera-se uma dedicação ao projecto de pelo menos 6 horas de trabalho por semana.

Objectivos e Actividades:
O aluno será integrado num projecto internacional que estuda a evolução de vários tipos de defeitos topológicos, incluindo paredes de domínio, cordas cósmicas e supercordas. Estes objectos formaram-se necessariamente no universo primitivo, e a sua caracterização dá-nos pistas cruciais sobre a física fundamental, que serão exploradas pelo SKAO e LISA. O objectivo do estágio é a simulação computacional da evolução de alguns destes modelos cujo comportamento não foi ainda estudado em detalhe, recorrendo a programação em CPUs e/ou GPUs, e o pós-processamento e análise destas simulações. Actividades específicas podem incluir:
1) Estudo de modelos analíticos para a evolução de redes de defeitos topológicos;
2) Desenvolvimento, optimização e/ou validação de códigos numéricos de evolução de redes;
3) Processamento, análise e visualização de resultados de simulações numéricas de alta resolução destas redes (incluindo o desenvolvimento de videos destas simulações);
4) Organização e apresentação dos resultados obtidos. O estágio poderá incluir visitas de trabalho a colaboradores externos e/ou deslocações a conferências para apresentação dos resultados, e.g. espera-se que os resultados sejam apresentados no Encontro Nacional de Astronomia 2025.

Bibliografia relevante, disponível em https://arxiv.org: 1602.08083, 1911.03163, 2005.14454, 2108.07513, 2208.01525, 2304.00053.

Testes de modelos de energia escura e gravitação modificada

Orientador: Carlos.Martins@astro.up.pt
https://cienciavitae.pt/portal/en/4D17-61B5-3A0C

Perfil do Candidato:
Experiência de programação, análise e visualização de dados é essencial. Espera-se uma dedicação ao projecto de pelo menos 6 horas de trabalho por semana.

Objectivos e Actividades:
O aluno será integrado num projecto internacional que desenvolve estratégias observacionais optimizadas para a caracterização das propriedades da energia escura. Em particular, pretende-se estudar as consequências observacionais de modelos cosmológicos inspirados em teoria de cordas ou gravitação quântica, usando novos instrumentos como o Euclid, o SKAO, e o ANDES, que alargarão a gama de redshifts para os quais o comportamento gravitacional da energia escura é bem conhecido e possibilitarão testes completamente novos. Actividades específicas incluem:
1) Estudo semi-analítico de modelos de física fundamental baseados em campos escalares ou outros graus de liberdade para a aceleração do universo e das suas consequências observacionais;
2) Desenvolvimento de ferramentas estatísticas de comparação desses modelos com dados observacionais (cosmológicos e astrofísicos) actualmente existentes;
3) Aplicação destas ferramentas a modelos de energia escura e gravitação modificada, e modelação de estratégias observacionais para o estudo estes modelos com instrumentos futuros;
4) Organização e apresentação dos resultados obtidos. O estágio poderá incluir visitas de trabalho a colaboradores externos e/ou deslocações a conferências para apresentação dos resultados, e.g. espera-se que os resultados sejam apresentados no Encontro Nacional de Astronomia 2025.

Bibliografia relevante, disponível em https://arxiv.org: 2204.08016, 2301.13500, 2304.02522, 2307.15060, 2312.09702, 2404.05037.

Understanding the observational biases in measuring stellar rotation

Supervisor: Angela.Santos@astro.up.pt
https://cienciavitae.pt/portal/en/621E-7A29-78F9

Goals and activities:
Rotation is a key property of stars, influencing for example their lifespan by mixing their chemicals. Simultaneously, rotation evolves as the stars age, with older stars exhibiting a gradual slowdown. This relationship offers a promising avenue to infer the ages of stars. However, first, we must understand the observational biases. In this project, the student will obtain and analyze synthetic data to explore the intricate interplay between stellar inclination (the angle between the observer's line of sight and the stellar spin axis) and other stellar properties. This will help to understand the observation biases affecting the accuracy of rotation measurements, a crucial step toward accurate stellar ages.

Education and outreach projects

Astrofísica, programação e análise de dados para o ensino secundário

Orientador: Carlos.Martins@astro.up.pt
https://cienciavitae.pt/portal/en/4D17-61B5-3A0C

Perfil do Candidato:
É dada preferência a alunos de mestrado de ensino. Experiência prévia de programação, análise e visualização de dados é útil. Espera-se uma dedicação mínima de 6 horas de trabalho por semana.

Objectivos e Actividades:
Os estagiários participarão no desenvolvimento de conteúdos de astrofísica e áreas afins apropriados para alunos do ensino secundário (de áreas científicas), no âmbito do projecto Phi in the Sky, incluíndo conteúdos relacionados com o eclipse total do Sol que será visível em Portugal a 12 de Agosto de 2026. Actividades específicas incluem:
1) Pesquisa bibliográfica sobre a área relevante;
2) Desenvolvimento de conteúdos de astrofísica (incluindo programação e análise de dados) apropriados para alunos do ensino secundário, em colaboração com os investigadores e alunos de doutoramento da equipa e com professores de escolas secundárias parceiras do projecto;
3) Implementação destes conteúdos em pequenos grupos de alunos do ensino secundário das escolas parceiras (incluindo visitas a estas escolas);
4) Organização e publicação destes conteúdos, e dos resultados obtidos.

Espera-se que os resultados do estudo sejam apresentados, entre outros locais, no Encontro Nacional de Astronomia 2025.

Citizen science: from an investigative technique to a method of equity in access to astronomy communication and education

Level: PhD or MSc
Supervisor: ilidioandrecosta@astro.up.pt
https://www.cienciavitae.pt/portal/en/7F17-E317-A0DF
Co-Supervisor: Carla Morais (FCUP)

The citizen science (CS) concept is now summarized in a simple common idea: the public engagement in different stages of scientific processes. If the view of CS as a scientific technique is very consensual, its use as a science communication and education (SCE) method is not. However, accomplishing science communication goals is one of the most common purposes of CS, highlighted by both scientists and CS project managers alike. Indeed, the advantages of associating science communication and science education have long been known, namely through CS projects, helping to bridge the gap between scientific research and science education. Thus, engaging teachers in CS processes is a natural path, enhanced by the "school effect" and the "teacher effect" in students, but also in the effect these have in student's families and the surrounding school community. This "multiplier effect" of influences which schools provide is unique and highly positive.

Supported by data of our previous research and in a synergistic context between science education, science communication to non-interested audiences and scientific research in astronomy, that "CoAstro: @n Astronomy Condo" project emerges. In it we have as objectives: i) to structure, implement and evaluate the effects of a co-designed CS project by primary teachers (from regions with low spontaneous involvement with science), astronomers and science communicators; ii) to evaluate knowledge, attitudes and beliefs towards science, of teachers and its changes, as a result of participation in CoAstro; iii) perceive the impact of CoAstro on the dissemination of astronomy among school communities; iv) to improve a CS design for a public with low interest in astronomy and inregions far away from science centres.

Contributos para a investigação em ensino e divulgação das ciências

Orientador: ilidioandrecosta@astro.up.pt
https://www.cienciavitae.pt/portal/en/7F17-E317-A0DF

Perfil do candidato:
Dar-se-á preferência a candidatos com bom domínio da língua inglesa (especialmente escrita) não sendo, contudo, um critério de exclusão a falta de domínio desta língua.

Objectivos e actividades:
O candidato deverá estar motivado para a realização de projetos investigativos exploratórios na área do ensino ou divulgação das ciências (biologia, geologia, matemática, astronomia, física ou química).Estes partirão de dados já coletados pelo Planetário do Porto - Centro Ciência Viva (PP-CCV) ou, em alternativa, poderão resultar de novas propostas investigativas apresentadas pelos candidatos.
Assim propõe-se:
1) Definição do campo de intervenção ou, em alternativa, seleção dos dados, já existentes no PP-CCV, a trabalhar.
2) Tratamento/análise dos dados.
3) Discussão dos resultados e estabelecimento de conclusões.
4) Apresentação do projeto investigativo exploratório, sob a forma de artigo e/ou comunicação em congresso.

Scientific literacy and astronomy teaching

Level: PhD or MSc
Supervisor: Carlos.Martins@astro.up.pt
https://cienciavitae.pt/portal/en/4D17-61B5-3A0C

We have previously carried out surveys of high-school students in Portuguese schools, aiming to determine the degree of understanding of some basic astronomy and other science 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 general scientific literacy of the students, focusing on contemporary issues such as global warming. These studies can be done 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 also 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. The goal will be to use our findings to propose a detailed and specific actin plan that schools and teachers can implement locally.

Appendix

The CAUP Team, April 2024

Researchers [35]
Vardan Zh. Adibekyan
Pedro P. Avelino
Susana C. C. Barros
Jarle Brinchmann
Tiago J. L. C. E. Campante
Vítor M. M. Costa
Ilídio André P. M. Costa
Margarida S. Cunha
Paulo Maurício de Carvalho
Elisa Delgado Mena
Olivier D. S. Demangeon
William Dethier
Pedro Figueira
Daniel F. M. Folha
José Carlos Fonseca
Jorge Filipe Gameiro
Jean Michel Gomes
M. S. Nanda Kumar
Maria Teresa V. T. Lago
Patricio Lagos
João J. G. Lima
Catarina Lobo
Carlos J. A. P. Martins
Jorge H. C. Martins
Mário J. P. F. G. Monteiro
Polychronis Papaderos
Ana S. Paulino Afonso
L. Filipe Pereira
Nuno C. Santos
Ângela R. G. Santos
Tom C. Scott
Sérgio A. G. Sousa
Lara G. Sousa
Clara Sousa Silva
Pedro T. P. Viana

Ph.D. Students [29]
Alexandros Antoniadis Karnavas
Alba Barka
Ana F. S. Barros
Thibault Boulet
Abhishek Chougule
Miguel T. Clara
Ana Rita Costa Silva
Eduardo A. S. Cristo
Pedro Alexandre C. Cunha
Tomás de Azevedo Silva
João D. F. Dias
David Grüber
Ricarda Heilemann
Catarina M. J. Marques
Nuno A. M. Moedas
Sandy G. Morais
Sergei Mukovnikov
Andreas W. Neitzel
Jennifer Peralta Lucero
José Rodrigues
Nuno M. Rosário
Carmen San Nicolás Martinéz
Maya Shemesh
André Miguel A. C. V. Silva
Bárbara M. T. B. Soares
Abderahmane Soubkiou
Daniel A. D. Vaz
Clara Marie Winckler
Paulina M. Zaworska

Other Students [25]
Carlos M.F. António
Pedro B. Barbosa
Pedro Miguel H. Branco
Martim Carvalho
Bruno B. Cerqueira
António M.B. Correia
Rúben Costa
Yuri C. Damasceno
Maria Inês M.F.S. Ferreira
Diogo S.V.B. Gomes
Eduardo Campos Gonçalves
Gabriela Lapa
Joana C. Leite
José Lino
Mariana A.F. Melo e Sousa
Paulo A.G. Monteiro
Pedro A.A. Nogueira
João D.C.M. Pestana
André S.A. Pinheiro
Mariana I.C. Reis
David S. Santos
Pedro Miguel M. Silva
Rodrigo P. Silva
Eva L. Silva
Joana Raquel A. Teixeira

1989-2024

35 ANOS
DE EXCELÊNCIA
EM INVESTIGAÇÃO,
FORMAÇÃO E
DIVULGAÇÃO EM
ASTRONOMIA

CAUP **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

www.astro.up.pt
www.facebook.com/astro.up.pt
www.twitter.com/astro_up
www.youtube.com/cauptv