Sample of PhD Topics at IA for 2018

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March 2018

instituto de astrofísica e ciências do espaço

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PhD Topics for 2018 :: Planets

"Towards the detection and characterization of other Earths"

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

Advisers: Nuno C. Santos (IA U.Porto & DFA/FCUP), Cláudio Melo (ESO Chile)

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

ESPRESSO is a new high-resolution spectrograph for the ESO-VLT telescopes (the start of the operations is expected for late 2017/early 2018). Its unique stability and resolution, coupled with the high collecting area of the VLT telescopes, will allow us to detect and characterize exoplanets with masses similar to that of the Earth. Furthermore, ESPRESSO is expected to give us the possibility to detect the reflected light signal from distant exoplanets. A new window towards the study of exoplanet atmospheres will thus be open. Our team is deeply involved in ESPRESSO, having thus a unique access to this instrument and to its data.

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

University: Porto

Characterizing exoplanet atmospheres with CHEOPS: combining theory and observations

Advisers: Nuno C. Santos (IA U.Porto & DFA/FCUP), Antonio García Muñoz (TU Berlin), Olivier Demangeon (IA U.Porto)

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

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

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

During the project the student is expected to get involved in the exploration of CHEOPS data.

University: Porto

Type: This may correspond to a mixed fellowship (up to 1 year abroad).

Orbital evolution of planetary systems: from formation to today

Advisers: Alexandre Correia (CIDMA U. Aveiro), Vardan Adibekyan (IA U.Porto), Pedro Figueira (IA U.Porto)

The field of extrasolar planets research is tee-ming with activity. Very recently we celebrated the 20th anniversary of the discovery of the first planet outside our system, and yet we count already over 3000 confirmed planets and thausand 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.

University: Porto

Probing the architecture of multi-planetary systems

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

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

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

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

University: Porto

Unveiling the composition of exoplanets with atmosphere spectroscopy

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

With already more than 3000 exoplanets detected, we know that exoplanets are ubiquitous in the galaxy. However, for most of them, their composition and atmospheric conditions (temperature, pressure, clouds, hazes, rain) are poorly known. Models exist which, given the density of the planet, assume the most likely composition and compute the most likely structure and temperature-pressure profile (Valencia et al 2007, 2010, Guillot et al. 1996). Unfortunately, all these models are degenerate with respect to the exact composition (Alibert 2016). The goal of this project is to raise some of those degeneracies by delivering insights in the composition of exoplanets.

If detecting exoplanets is already a challenging task due to the high contrast and low angular separation between a planet and its host star, obtaining their spectra requires state-of-the art instrumentation. The past decades have seen the emergence of three techniques capable of obtaining spectral informations of exoplanet: high-angular resolution and high contrast imaging (Marois et al 2008 , Lagrange et al. 2010), high-precision photometry (Charbonneau et al. 2002, Stevenson et al. 2014), and high-spectral resolution cross correlation techniques (Snellen et al. 2010, Martins et al. 2015).

For the ambitious objective of constraining exoplanet atmospheres, high-precision instruments are not enough. Extracting reliable spectral information on the observed exoplanet atmosphere requires advanced data reduction and analysis techniques coupled with state of the art modeling. This project proposes to the student, to benefit from the unique conditions offered by IA and our collaborators, to be at the junction between observation and theory. He will have to confront the data from several instruments enabling atmospheric characterization to the PHOENIX-BTSettl atmospheric models and extract robust information regarding the composition of exoplanets' atmosphere. He will first start with archive and already published data from transit photometry (Sing et al. 2016 from WFC3@HST) and high-angular resolution and high-contrast data (Bonnefoy et al. 2016 SPHERE@VLT). Then he will analyze high-spectral resolution data using the cross correlation technique (Snellen et al. 2010 from CRIRES@VLT). An homogenous analysis of datasets coming from these different observational techniques has never been done before and will open new doors for atmospheric studies. The final step of this project will be to apply the developed analyses to different types of newly discovered planets and to explore trends in the atmospheric composition with respect to the characteristic of the observed planets, stars and observing techniques.

University: Porto

Characterization of Giant Planets Atmosphere Dynamics with Doppler Velocimetry and Cloud Tracking Techniques

Advisers: Pedro Machado (IA U.Lisboa), Agustin Sánchez-Lavega (Escuela Técnica Superior de Inginiaria de Bilbao)

The scientific objective of this PhD proposal is to help constrain the atmospheric dynamics of the Giant Planets (Saturn and Jupiter), detect and study atmospheric planetary waves, storms, measure wind velocities and their spatial and temporal variability.

Major objectives are:

1) to measure the latitudinal profile of the zonal winds and to search for wave motions through ground-based spectroscopic observations, using Doppler techniques;

2) to complement in-situ observations made by space missions (JUNO and CASSINI using cloud tracking techniques);

3) to better understand the nature of the processes governing the overall dynamics in the atmosphere of Saturn and Jupiter, in particular waves and wave-mean flow interactions;

4) to understand the atmosphere dynamics of Solar System Giant Planets as a case study in order to help constrain atmospheric models of gaseous-type exoplanets.

University: Lisboa

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

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PhD Topics for 2018 :: Stars

"Towards a comprehensive study of stars"

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Ensemble asteroseismology of solar-type stars with the NASA TESS mission

Advisors: Tiago Campante (IA U.Porto), Mikkel N. Lund (Aarhus University), Margarida Cunha (IA U.Porto)

The Transiting Exoplanet Survey Satellite (TESS) is a NASA space mission, with launch scheduled for March 2018, that will perform an all-sky survey for planets transiting bright nearby stars. Furthermore, TESS's excellent photometric precision will enable asteroseismology, the detailed study of stars by the observation of their natural, resonant oscillations. Asteroseismology is proving to be particularly relevant for the study of solar-type stars (i.e., low-mass, main-sequence stars and cool subgiants), in great part due to the exquisite photometric data made available by NASA's Kepler space telescope and, more recently, by the repurposed K2 mission. In extending the legacy of Kepler/K2, the main goal of this project will be to perform an ensemble asteroseismic study of bright solar-type stars that reside in the solar neighborhood, making use of data collected by TESS during its 2-year primary mission. To that end, we propose an end-to-end PhD project that will provide the student with skills in photometric time-series preparation from pixel data, asteroseismic data analysis and stellar modeling techniques. The implications of this project are far- reaching. The proposed research will provide a well characterized sample of benchmark solar-type stars to be used in studies of exoplanetary systems and of the chemical evolution of the solar neighborhood, the latter of which will impact on Galactic archaeology studies.

University: Porto

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

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

Advisors: Margarida Cunha (IA U.Porto), Pedro Avelino (IA U.Porto & DFA/FCUP), Dennis Stello (Univ. of New South Wales)

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 approval by ESA of the mission PLATO2.0 (launch around 2024), it is expected that 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 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, a primary 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. The code will then be applied in the characterization of the red giant populations for which space-based data are already available, and in the study of particular aspects of the physics of these stars. 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.

University: Porto

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

Magnetic activity and its impact on stellar physics and exoplanets research

Advisors: Margarida Cunha (IA U.Porto), Nuno C. Santos (IA U.Porto & DFA/FCUP)

The study of magnetic activity in stars is now at the center of the attention of the astrophysical community. Its relevance is clear in the context of stellar physics, where there is an effort to understand the necessary conditions for the development of dynamos capable of explaining the observations of the sun and other stars. But its relevance is also evident in the context of the study of sun-earth interactions and in the search for and characterization of earth-like exoplanets. In this project it is proposed that the student develops a new tool capable of simulating more realistically than what is currently done, observables of the greatest importance in the context of the study of stellar activity and of its impact on exoplanets' research. Based on this tool, the student must first determine the conditions necessary for a robust inference of information about the rotation and activity of stars, as well as about the presence and characteristics of exoplanets. In a second phase, the student should make such inferences from actual data. This tool will be instrumental for a more robust extraction of the information contained in the Kepler (NASA) light curves and in preparing for the exploration of data from future NASA, ESA, and ESO instruments.

University: Porto

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PhD Topics for 2018 :: Galaxies

"The assembly history of galaxies resolved in space and time"

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

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

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

University: Lisboa

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

The First Radio Galaxies in the Universe

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

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

University: Lisboa

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

Objective criteria for the selection of the most distant radio galaxies

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

Studies of the high redshift Universe have relied on a number of methods to identify increasingly distant and, consequently, younger galaxies. Radio selection has been reborn as one of the most promising methods, as powerful radio AGN can currently be detected at radio frequencies at essentially any redshift. Using the next generation of deep radio surveys, these searches are now being pushed to new sensitivity levels, to find radio AGN at the highest distances and at the earliest formation stages, presumably well within the Epoch of Reionization. Using multiwavelength data (x-rays, optical, infrared and millimetre, besides the radio itself), the faint radio population has started to be characterized, contributing not only to a better understanding of the radio sky, but, even more interestingly, selecting elusive, more extreme sources that can only be understood with the upcoming full capabilities of the Atacama Large Millimetre Array. These studies are exciting, but can only currently be performed over very small areas. Extending such studies to virtually the whole sky is a prime objective of the next generation of radio surveys, and this project aims to play a pivotal role in such expansion.

The host institution for this project is involved (with co-Is and co-PIs) in two of the most ambitious projects in the pre-Square Kilometre Array era, surveys that will map the entire sky at 1.4GHz at microJansky levels. The Evolutionary Map of the Universe (EMU), to be performed with the Australia Square Kilometre Array Pathfinder, will cover the sky at declinations below 30deg, while the Westerbork Observations of the Deep APERTIF Northern-Sky (WODAN) will cover the northern regions. Both surveys should start producing data from 2017. Together, the EMU and WODAN surveys will produce a unique dataset that, together with other multiwavelength data being obtained or soon to be obtained, will be able to find the most extreme and unique radio galaxies, including the first-generation of powerful AGN in the Universe, in the Epoch of Reionization. This project proposes to (a) establish a set of objective criteria for the selection of very high redshift radio galaxies; (b) find and analyse candidates for very high redshift radio galaxies, including the preparation of follow-up observations of particularly interesting candidates with ALMA; (c) play an active role in the optimization of the next generation of ultra-deep whole-sky radio surveys, the EMU and WODAN projects, in order to explore more efficiently the highest redshift Universe.

University: Lisboa

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

Diffuse ionized gas and Lyman continuum photon escape in spiral galaxies

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

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

University: Porto

Spatial distribution of α-elements in CALIFA galaxies

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

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

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

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

Only recently spatially-resolved data from Integral Field Spectroscopy (IFS) has become available, permitting the study of radial abundance patterns of α-elements in galaxies with unprecedented detail. An innovative aspect of this PhD research project is the use of IFS data for ~600 local Hubble-type galaxies from The Calar Alto Legacy Integral Field spectroscopy Area survey (CALIFA – http://califa.caha.es) to determine the 2D α-element distribution in a spatially resolved pattern. This observational input will be combined with the derived Star-Formation Histories and structural properties of ETGs from CALIFA with the goal of developing new evolutionary diagnostics for ETGs and shedding light into the origin of the α-element enhancement in these systems.

University: Porto

The importance of star-formation, black-hole accretion and other physical mechanisms into the Far-IR – radio correlation

Advisors: Cirino Pappalardo (IA U.Lisboa), Israel Matute (IA U.Lisboa), Jose Afonso (IA U.Lisboa)

One of the most challenging astrophysical questions is to determine when and how stars form throught the history of the Universe. One of the best indicators of this so-called star formation rate is the far infrared (FIR) emission of galaxies. The interstellar dust present in galaxies is the responsible for the absorption of the UV energy coming from the radiation field of young (and massive) stars that is later re- emitted thermally in the FIR. The infered number of massive stars is then a good proxy of the current star-formation rate of the galaxies. The contribution to this emission from the older stellar population present in the galaxy is still a matter of debate and, depending on their contributing fraction, could strongly affect our star-formation estimates. In this context, we observe in galaxies a strong connection between the radio and the FIR emission. Although radio emission can be related to the current star formation, the apparent direct connection between them is far from obvious due to the contribution (as in the case of the FIR) of additional physical processes not directly linked to star-formation. In the radio, electrons accelerated to relativistic energies in jets coming from the accretion of matter into a super massive blackhole (SMBH) in Active Galactic Nuclei (AGN), can in many cases overshine the emission from young stellar populations. Despite all these different emission mechanisms, the relation is surprisingly tight and universal for galaxies over several orders or magnitude in mass and luminosity. Nowadays, a complete theoretical understanding for the tightness of this correlation is still missing. An invaluable insight into the physics of this correlation could be gain by considering a statistical large sample of galaxies were we can precisely measure both the radio continuum and FIR properties. With modern radio continuum surveys and with the large FIR database produced by the Herschel Space Observatory, such samples can be built and explored.

The goal of this project is to investigate the influence of the average dust mass and dust temperature into the FIR-radio correlation as well as the significance of the AGN contribution. With this objective in mind, the student will build a large sample of galaxies with high quality data both in the radio and at FIR wavelengths. We will investigate the scatter in the FIR-radio correlation as a function of different dust mass bins, and as a function of redshift. The multi-wavelength coverage available for a large fraction of the sources will allow us to investigate in detail the physics related to the different dust heating mechanisms. This study will shed light on which conditions the FIR-Radio correlations is still reliable. The data sample and results obtained during the thesis will be crucial for future studies of star-forming galaxies. In particular the proposed analysis will be important to understand the faint radio population that will be uncovered by the future radio continuum survey, such as the SKA pathfinder and precursor radio continuum surveys from ASKAP (Norris et al. 2011), LOFAR (Rottgering et al. 2011), MeerKAT (Jarvis 2012), and the Jansky Very Large Array (JVLA).

University: Lisboa

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PhD Topics for 2018 :: Cosmology

"Unveiling the dynamics of the Universe"

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Origin of the arrow of time of the Universe

Advisors: Marina Cortês (IA U. Lisbon/Perimeter Institute) and Lee Smolin (Perimeter Institute for Theoretical Physics – Canada)

Time always moves in the same direction, it always increases and never decreases: we always remembre the past and never the future. This asymmetry of time is universal, from scales on Earth up to cosmological scales. We receive light that galaxies emitted long ago in the past and never receive light they emitted in the future.

This time asymmetry is not reflected in the majority of physics laws which are time symmetric, they work in the same way if time is increasing or decreasing. In fundamental physics time is symmetric, and we attribute the cosmological arrow of time to very unusual initial conditions in the beginning of the universe. These conditions are so special that their probability is of order 1 in 10^90. Why the universe started in such an unlikely state is a question we have no answer for in cosmology.

In this work we investigate whether the time asymmetry may already be present in the fundamental laws, which would avoid having to attribute it to very special initial conditions at the Big Bang. We construct models that simulate such a time asymmetry and the student will run simulations with these models from existing code. The code for the simulations is already in place, so the student can directly start working on it. The goal is to infer from the results of the simulations what are the properties of physics if its are fundamentally time asymmetric. This project is co-supervised by Prof. Lee Smolin of the Perimeter Institute for Theoretical Physics in Canada.

University: Lisboa

Spacetime singularities, cosmology and black holes beyond General Relativity

Advisors: Diego Rubiera-Garcia (IA U.Lisboa), Francisco Lobo (IA U.Lisboa)

Einstein's deep insight on the relation between gravitation and geometry represents the culmination of scientific thinking on the nature of gravitation initiated with the pioneering works of Galileo. The idealization of a body as a point particle moving along geodesics of a spacetime determined by matter distributions leads to a number of astrophysical and cosmological predictions which are in excellent agreement with observations. There are, however, several issues that cast serious concerns on the limits and validity of this theory. From the observational side, we find the inability of General Relativity (GR) and the standard model of particle physics to account for astrophysical and cosmological observations, forcing the need to add dark matter/dark energy into the theory, of which we have no directly experimental evidence so far. From the theoretical side, the unavoidable existence inside GR of spacetime singularities deep inside black holes as well as in the early Universe, breaks the predictability and determinism of our physical theories. In this project, we shall address these questions from a broader perspective, where GR is taken as just an approximate theory that requires modifications both in the large curvature and large distance regions. More specifically, we will consider generalizations of GR by including additional geometrical elements not considered there, and study in detail the modifications in the predictions in astrophysics and cosmology with respect to the standard lore in the field. One fundamental goal of this project is the understanding of spacetime singularities, both inside black holes and in cosmology (early and late-time), as well as studying mechanisms for their resolution.

University: Lisboa

Analytic Methods for Astrophysical Defect Fingerprinting

Advisors: Carlos Martins (IA U.Porto)

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

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

University: Porto

Astrophysical and Local Tests of the Einstein Equivalence Principle

Advisors: Carlos Martins (IA U.Porto)

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

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

University: Porto

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

Advisors: Carlos Martins (IA U.Porto)

ESPRESSO is the next generation spectrograph, combining the efficiency of a modern Echelle spectrograph with extreme radial velocity and spectroscopic precision, and including improved stability thanks to a vacuum vessel and wavelength calibration done with a Laser Frequency Comb. ESPRESSO will be installed in the Combined Coudé Laboratory of the VLT in late 2017, and linked to the four Unit Telescopes (UT) through optical Coudé trains, allowing operations either with a single UT or with up to four UTs for about a 1.5 magnitude gain. One of the key science drivers of ESPRESSO is to perform improved tests of the stability of nature's fundamental couplings, and in particular to confirm or rule out the recent indications of dipole-like variations of the fine-structure constant, α.

In this thesis the student will be directly involved in the analysis and scientific exploration of the ESPRESSO fundamental physics GTO data, as well as in the preparation of any follow-up observations. Apart from its obvious direct – and very significant – impact on cosmology and fundamental physics, the ESPRESSO data will also be important as the first reliable precursor of analogous high-resolution spectrographs for the next generation of Extremely Large Telescopes, and in particular of ELT-HIRES (in whose ongoing Phase A we are directly involved). Thus a second goal of the thesis is to use the ESPRESSO data to carry out detailed realistic simulations to assess the cosmology and fundamental physics impact of ELT-HIRES, inter alia exploring the feasibility of novel tests which are beyond the sensitivity of ESPRESSO, such as redshift drift measurements and molecular tests of composition-dependent forces.

University: Porto

New Maps of the Dark Side: Euclid and beyond

Advisors: Carlos Martins (IA U.Porto)

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

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

University: Porto

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

Advisors: Lara Sousa (IA U.Porto), Pedro Pina Avelino (IA U.Porto & DFA/FCUP)

The recent discovery of the Higgs Boson at the Large Hadron Collider appears to support the idea that the universe underwent, in its early history, a series of symmetry-breaking phase transitions and that, as a consequence, networks of topological defects could have been generated. These defect networks, although formed in the early universe, are expected to survive throughout the cosmological history, potentially leaving behind a plethora of observational signatures. The study of cosmic defects and their signatures, then offers an insight into the physics of the early universe. Compellingly, the recent suggestion that fundamental strings and 1-dimensional Dirichlet branes – the fundamental objects of Superstring theory – may play the role of cosmic strings, extends this possibility towards very early cosmological times into energy scales far beyond the reach of current particle accelerators.

The computation of the specific signatures left behind by topological defects is essential to use the data of present and upcoming observational infrastructures to their full potential. This project aims at improving the current estimates of these signatures, by making use of realistic semi-analytical and numerical models for the evolution of cosmic defect networks, with a particular emphasis on cosmic (super)string and domain wall networks. In particular, the associated gravitational wave background and its impact on the B-mode polarization of the Cosmic Microwave Background, their signatures on the reionization history of the universe and the 21cm background, and their potential role as seeds of variations in fundamental couplings, shall be investigated in detail. Detailed forecasts for upcoming probes, including eLISA (as part of our participation in the eLISA Cosmology Working Group), COrE+, SKA, ESPRESSO and E-ELT HIRES will be central to this PhD project.

University: Porto

Dark energy interactions

Advisors: Nelson Nunes (IA U.Lisboa)

This project tries to understand the nature of dark energy and how it interacts with the other particles, being dark matter, baryons, radiation or neutrinos. The crucial starting point is the most general scalar-tensor theory that leads to viable theoretical cosmologies. The student will test the free functions of the theory against current and forthcoming observational data. This is both a theoretical and hands on data project.

University: Lisboa

Unveiling the Dark Side of the Universe

Advisors: Pedro Avelino (IA U.Porto)

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 backreaction 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.

University: Porto

Restriction: This is a closed topic.

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PhD Topics for 2018 :: Instrumentation

"Space and Ground Systems and Technologies"

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Atmospheric Dispersion Correction for High Resolution Astronomical Instruments

Advisors: Alexandre Cabral (IA U.Lisboa), Gerardo Ávila Soberanes (ESO)

This proposal is focused on the development of Atmospheric Dispersion Correctors for current astronomical instruments where the recent developments in the field of adaptive optics systems, improving considerably the performances of telescope resolution, and the arrival of large telescopes with diameters up to 40 m, reinforce the need to revisit the way differential atmospheric dispersion is corrected and how it influences the performances of high resolution spectrographs.

The work for this proposal will cover both the Study of the atmospheric dispersion phenomena and how it influences astronomical observations and the analysis and development of Atmospheric Dispersion Correctors (ADC). All will be supported by the work on three case studies, each one on a different astronomical instrument: the already installed Espresso ADC, the current NIRPS ADC and the future E-ELT HIRES ADC(s)

University: Lisboa & Porto

Restrictions: This is a closed topic.

Metrology of stabilized laser sources for gravitational wave detectors

Advisors: Manuel Adler Abreu (IA U.Lisboa & FCUL), Alexandre cabral (IA U.Lisboa & FCUL)

This proposal is focused on the development of metrology concepts and testbeds for testing and verification of noise characteristics of highly stabilised laser sources. These laser sources have critical importance on the global uncertainty of high precision interferometry techniques being implemented for the gravitational wave detectors, but also play a major role for nanoscale dimension metrology and other high accuracy measurement techniques. The work to be implemented by the student comprises the evaluation of the current lasers sources with such stringent requirements, the assembly of experimental setup for the stabilisation of a suitable laser source and the development of tools that will allow to verify the performance of such device.

University: Lisboa