CENTRO DE ASTRONOMIA E ASTROFÍSICA
FACULDADE DE CIÊNCIAS DA UNIVERSIDADE DE LISBOA

Topics offered for PhD applicants 2013-2014

Centro de Astronomia e Astrofísica da Universidade de Lisboa (CAAUL)

Departamento de Física - FCUL

CAAUL, Observatório Astronómico de Lisboa, Tapada da Ajuda, 1349-018 Lisboa - Tel: 213616739/30 - http://caaul.oal.ul.pt

Page intentionally left blank

Team support and research environment

The Centre for Astronomy and Astrophysics of the University of Lisbon (CAAUL) is a research centre with a strong national and international role, with active collaborations with institutions in over twelve countries. It also plays an important role in teaching, being involved in the graduate and post-graduate education programs in Astronomy and Astrophysics at the University of Lisbon.

CAAUL's research is currently grouped under three main scientific topics:

1) "**Origins and Evolution of Stars and Planets**": this group focuses on star formation and the interstellar medium, and on the characterization of the circulation of Solar-System atmospheres. Recent research has been focused on wind measurements in the atmospheres of Titan and Venus using Doppler velocimetry techniques. Observations with the Visible and Infrared Thermal Imaging Spectrometer (VIRTIS) onboard ESA's Venus Express mission, and with the VLT UVES (UV and Visual Echelle Spectrograph) instrument have been used. The group has also experience in general circulation modeling and on radiative transfer studies of planetary atmospheres.

2) The "**Galaxies and the Evolution of the Universe**" group has a strong emphasis in observational studies of galactic evolution using and contributing to the development of the deepest astronomical surveys (e.g., GOODS, SERVS, ASKAPEMU, WODAN), observational studies of modified gravity and dark energy with cosmological weak lensing, study of systematics in preparation of upcoming weak lensing surveys (e.g. EUCLID) and theoretical cosmology and gravitation (e.g., modified gravity, dark energy). The student will be part of a group of researchers at the Centre for Astronomy and Astrophysics (currently 7 researchers and 4 students) dedicated to the study of galaxy formation and evolution. Using a range of multiwavelength datasets, amongst the deepest ever obtained, the student will become acquainted with data processing techniques, physical processes in galaxies, and how to confront observational evidence obtained in this thesis work with the most recent theoretical models. The student will also become involved in the development of the next-generation of whole-sky radio surveys, with the upcoming radio telescopes ASKAP, MeerKAT and the upgraded WSRT-APERTIF, and be part of the development of new proposals for observing time with ESO telescopes (namely VLT and ALMA) and other state-of-the-art astronomical facilities.

3) The "**Optical Instrumentation for Astrophysics**" group, the Portuguese scientific group with the largest number of ESA projects, focuses on astronomical and space optical and laser instrumentation, encompassing concept, simulation, project, integration and testing and data processing, an activity largely supported by ESA and ESO, fundamentally in the areas of optical metrology, optical design and optical guidance and control.

Page intentionally left blank

Multi-wavelength 3D mapping of the atmospheric circulation of Venus using Venus Express and ground-based observations

Supervisor: David Luz (dluz@oal.ul.pt)

Abstract: Venus and the Earth are considered to be the twin planets of the Solar System: both formed in the same region of the solar nebula and reached the end of the planetary accretion stage with very similar masses and compositions. Venus and the Earth, however, followed very different evolutionary paths. Their atmospheres, in particular, display striking contrasts in thermal structures, compositions and circulation mechanisms. Venus is covered with a thick layer of clouds, which is optically thick in the visible and prevents direct observation of the surface. These clouds are formed by H2SO4 droplets and reflect most of the incoming solar radiation back to space. The atmosphere is characterized by rapid circulation, the so-called superrotation, seen in fast cloud motions at ultraviolet, visible and near and thermal infrared wavelengths. The mechanisms at the origin of superrotation, however, and the atmospheric circulation and variability between 75 and 100 km altitude remain largely unknown, due to a lack of adequate techniques for measuring winds in that region. Moreover, the recent detection of long-term variations in the amount of atmospheric SO2, a crucial trace component of the atmosphere, led to the hypothesis that atmospheric oscillations similar to terrestrial phenomena may occur on Venus. The causes of such variations, which may be related with active volcanism at the surface, remain to be understood.

In this project the student will utilize observations made during the last 6 years by the Venus Express spacecraft, currently orbiting Venus, with the objective of measuring the winds in the Venus mesosphere. This work will be based on the techniques of Doppler velocimetry and cloud tracking developed by the planetary atmospheres group at CAAUL. High-resolution infrared spectroscopy data from Venus Express, together with ground-based observations from the VLT (Chile) and CFHT (Hawaii), will be analyzed in order to directly measure Venus winds between 70 and 100 km altitude and to characterize atmospheric superrotation, detect wave phenomena and monitor long-term variability of the atmospheric dynamics. A full characterization of this region of the atmosphere is crucial for understanding the behavior of terrestrial-type exoplanets in the habitable zone and to design and prepare for future missions to Venus.

The planetary atmospheres group of CAAUL collaborates with a large number of international teams in space sciences. The selected candidate is expected to be proficient in written and spoken English, have excellent communication skills and availability to travel. Short stays in collaborating research centers in Europe may be necessary. Applications to PhD theses in association with other European universities or to European PhD theses are encouraged. Candidates will have support from CAAUL for applying to research studentships.

Characterizing atmospheric composition and trace species variability in the atmosphere of Venus with ALMA

Supervisor: David Luz (dluz@oal.ul.pt)

Abstract: The surface of Venus is covered with volcanic features and most of its crust is of volcanic origin. Despite many signs that volcanoes may be active in the present on Earth's twin planet, no direct evidence of present volcanic activity has been found thus far. On the one hand, the surface of Venus is hidden from direct observation by its thick cloud layer. The clouds are formed by H_2SO_4 droplets and reflect most of the incoming solar radiation back to space. Clouds, their effect on the radiative balance of the atmosphere, and the sulfur cycle are thus intimately related. SO_2, SO and CO are some of the gases that may originate in active volcanism and which, combined with water vapor, intervene in the cloud formation process. Recent detections of long-term variability of atmospheric SO_2, in particular, are indicative that there may be active sources at the crust in the present.

In this project the student will carry out and analyze observations with the ALMA (Atacama Large Millimetre Array), with the objective of characterizing variations of atmospheric composition between 70 and 100 km altitude, in particular for water vapor and trace species of possible volcanic origin. Mapping the atmospheric composition of the Venusian mesosphere and its variability using the high spatial resolution allowed by ALMA (up to 1 arcsec), will allow to characterize the water and sulfur cycles and to infer possible volcanic activity or other phenomena with a direct influence on atmospheric composition.

The planetary atmospheres group of CAAUL collaborates with a large number of international teams in space sciences. The selected candidate is expected to be proficient in written and spoken English, have excellent communication skills and availability to travel. Applications to PhD theses in association with other European universities or to European PhD theses are encouraged. Candidates will have support from CAAUL for applying to research studentships.

The growth of supermassive black holes via secular processes

Supervisors: José Afonso (jafonso@oal.ul.pt), Elvira Leonardo

Abstract: Over the last few years, models for galaxy formation and evolution have improved significantly, driven by the constrains imposed by deeper and more comprehensive observations of the high-redshift Universe. The current Lambda Cold Dark Matter structure formation (hierarchical) models, with prescriptions for feedback from Starformation and AGN processes, have been successful in explaining much of the observations, leading to an image of galaxy growth mostly by merging and interaction between galaxies. However, one element still remains absent from the entire picture - pure disk or bulgeless galaxies. These galaxies are simply too difficult to produce in a merger dominated Universe, and would be quickly destroyed by interactions with even low-mass halos. Furthermore, they should not be able to host supermassive black holes, something which has been contradicted by the discovery of handful of bulgeless galaxies with AGN in the local Universe.
In the last few years, the group has assembled a sample of thousands of bulgeless galaxies at intermediate to high redshifts (z~0.4-1.0) and, using the deepest X-ray observations available, has identified about 30 bulgeless galaxies with AGN. While the phenomena is obviously rare in the Universe, it is likely a key ingredient to the understanding of galaxy formation and evolution throughout the whole Universe History.

In this thesis, the student will analyse the characteristics of the sample of bulgeless AGN, and compare those to the examples found in the local Universe. Using some of the deepest astronomical observations ever made, in fields that include COSMOS and Chandra Deep Field South, he will try to understand how these supermassive black holes can grow in bulgeless galaxies, which have presumably avoided mergers with neighbouring galaxies (growth by secular processes), and use this knowledge to constrain the current galaxy formation and evolution models.

Infrared properties of faint radio galaxies

Supervisors: José Afonso (jafonso@oal.ul.pt), Marco Grossi

Abstract: The most recent radio surveys and multiwavelength follow-up observations have revealed a complex picture for the faintest radio galaxy population observed. At the limit of the current radio telescopes capabilities, most sources are either starforming or AGN galaxies, going through a substantial amount of evolution. The relative weight of these populations at the faint (sub-mJy) radio flux level is still largely unknown, as is the mechanism responsible for the radio emission in these different populations. Also, recent results indicate that ultra high redshift galaxies will also be detected at these faint radio flux levels.

By using recent mid- and far-infrared observations of some of the most extensively studied regions in the sky, and in preparation for the next generation of whole-sky radio surveys, the student will look at the infrared properties of this population, trying to estimate the relative weight between star formation and AGN processes in these sources.

A comparative FIR study of radio loud and radio quiet AGN

Supervisor: José Afonso (jafonso@oal.ul.pt)

Abstract: One of the most important phases in the evolution of a galaxy is that when the galaxy hosts an Active Galaxy Nuclei. The infall of matter to a supermassive black hole in the center of a galaxy, often accompanied by intense starformation which is expected to be terminated by the AGN action itself at some point, is a complex phenomena still poorly understood. In particular, there appears to be an observational split between the so-called “Radio-Loud AGN”, where the ratio of radio to optical light is considerable, and the “Radio-Quiet AGN”, where the radio emission is small or even undetected. These AGN are arguably distinguished by different accretion modes, but the observational data hasn’t been able to provide a definite answer. Understanding the Radio-Loud vs. Radio-Quiet AGN problem is of fundamental importance to (a) understand the AGN phenomena itself; (b) predict what will be the outcome of the next generation of radio surveys currently being planned and (c) understand how to look for the highest redshift radio galaxies, the first AGN in the Universe that should already be detected by current deep radio surveys.

In this thesis, the student will look into the Far-Infrared properties of a large sample of Radio-Loud and Radio-Quiet AGN, using the deepest observations from the Herschel Space Observatory to characterise these sources. Their dust (mass, temperature, distribution) and star formation content, as well as the quantification of both the FIR and the radio emission from SF and AGN activity will be obtained. The results will then be used to predict the observability of very high redshift AGN in current and future deep radio surveys such as the EMU and WODAN.

Objective criteria for the selection of very high redshift radio galaxies

Supervisors: José Afonso (jafonso@oal.ul.pt), Silvio Lorenzoni

Abstract: The Epoch of Reionization (EoR), when the first stars and galaxies formed and transformed the Universe from being almost completely neutral to almost completely ionised (z~7-11) is one of the major frontiers in the knowledge of galaxy and structure formation. Identifying the most distant galaxies is a difficult and time-consuming procedure, as one is pushing the most powerful observational facilities to the limit of their capabilities. Radio selection methods have recently gained an increased interest for the selection of the most distant galaxies, as powerful radio-AGN at very high redshifts are well within the sensitivity limits of current deep radio surveys and, with the advent of the next generation of radio telescopes, like ASKAP, MeerKAT and LOFAR, there is a potentially large number of very high redshift sources that will be detected. However, objective criteria for the efficient selection of these sources still require development. Radio-based criteria, like the Ultra Steep Spectrum criteria, seem to be less efficient as radio-driven multiwavelength criteria, such as the recent Infrared Faint Radio Source criteria.

In this thesis, the student will seek do develop new, efficient ways to select high redshift radio galaxies, studying the properties of those already known (z~4-5.2) in the infrared and millimetre wavelengths, and of the substantial amount of high-redshift candidates waiting for confirmation. Consideration of the characteristics of the EoR and their effect on the observability of the radio emission of extremely high-redshift radio galaxies will be necessary, via a theoretical treatment of the emission mechanisms in radio galaxies under the effect of an increasingly hot background of photons. The results of this project will then be used to (a) find and analyse robust candidates for very high redshift radio galaxies in current deep radio surveys, in particular using the unique capabilities of ALMA and (b) optimise the design of the next generation of whole-sky radio surveys such as EMU and WODAN, which are currently being developed with the participation or the leadership of CAAUL members.

The KMOS/VLT revolution: rotation curves, metallicities, dust extinction and galaxy formation and evolution with hundreds of galaxies at 0.8 < z < 2.23

Supervisors: David Sobral (sobral@strw.leidenuniv.nl), Mark Swinbank (Durham), José Afonso

Abstract: By conducting very large 5-10 deg^2 narrow-band surveys to search for emission-line sources with WIRCam/CFHT and WFCAM/UKIRT, we have found thousands of individual distant Hα emitters at z=0.8 ,0.84, 1.47 and 2.23. These are ideal samples to study the metallicities, dust extinction and rotation curves of star-forming galaxies and how these have evolved from the peak of the star-formation history (z~2.5) till today. By using KMOS (a second-generation VLT instrument that is starting observations at the end of 2013), the student will be able to gain unprecedented detailed information on a large sample of galaxies. KMOS, with its 24 Integral Field Units (IFUs) allows to target up to 24 galaxies at the same time, obtaining an image and a near-infrared spectrum for each pixel. This is a unique opportunity to map the distribution and intensity of star formation, dynamics and metallicity on ~4 kpc scales and address: (i) What is the fraction of primitive disks, spheroids and mergers; (ii) Is the distribution of star formation at high-z more centrally concentrated than comparably luminous/turbulent galaxies at z~0? and iii) Are chemical abundance gradients weaker or stronger than local spiral galaxies and do those change with time? Answers to these questions using our well selected samples will address whether stellar mass assembly at z~1-2 is dominated by secular isolation or via merger-induced growth and will provide some of the strongest tests/constraints to the most sophisticated models of galaxy formation and evolution. By selection, all of the targets have known Hα fluxes and all are sufficiently bright so their resolved properties can be recovered and the survey efficiency will be ~100%.

One unique aspect of this project is that there are significant over-densities in the very large samples of Hα emitters, and thus, with KMOS, the student will be able to confirm and characterise the high redshift structures, derive accurate metallicities, measure the mass-metallicity relation, obtain Balmer decrement extinctions and identify AGN for a sample of hundreds of Hα-selected galaxies and investigate if the environment plays a role in setting these galaxy properties. This project's approach is unique: not only will it advance our knowledge at z=2.2, 1.47, 0.8 with robust, Hα selected samples that can be built very quickly and used to access evolution, but it will also unveil any dependence on environment of SFRs, dust extinction, metallicities, and AGN fraction for the first time even at z > 2.

Facilities: VLT/KMOS, VLT/SINFONI, ALMA, CFHT/WIRcam, Subaru/FMOS

Finding, confirming and studying the most distant (first) galaxies at z>7 before JWST and E-ELT: a (very) wide-field approach

Supervisors: David Sobral (sobral@strw.leidenuniv.nl), José Afonso, Bahram Mobasher (UC Riverside)

Abstract: When did the first stars and galaxies form? Over the last decade, galaxies have been robustly identified out to z~7.2, just ~700 Myr after the Big Bang, and a GRB has been confirmed at an even earlier epoch (z~8.2). The refurbished HST/WFC3 has opened a window to even earlier epochs, allowing the selection of z~7-10 very faint candidates. Despite the great progress, all z>7.3 candidates are simply too faint to be spectroscopically confirmed, a consequence of them being found by very deep, very small-area surveys. A very effective approach towards overcoming the current limitations is to look for relatively luminous Lyα emitters at wavelengths which are easily accessible from the ground. The reasons are simple: it opens the possibility of targeting very large volumes required to find the most luminous sources at z~7-9, but also because, by selection, it will find sources with relatively luminous Lyα emission, enabling the spectroscopic confirmation and detailed study of such distant sources for the first time. With the advent of near-infrared wide-field cameras, this can now be done very effectively, and our group has just completed by far the largest contiguous narrow-band near-infrared survey (~20x larger than the previous largest one) for Lyα emitters at z~8.8. The student will be able to work on both the follow-up of the current best candidates for the highest redshift galaxies, but also to participate in extending the survey to both lower luminosities, but also to even larger areas and different redshifts by using different telescopes/instruments. The results will allow for the most accurate determination of the evolution of the Lyα luminosity function up to z~9, with extremely important consequences to studying the re-ionisation of the Universe.

The confirmation of even a single z~8.8 Lyα emitter will allow for completely unprecedented science and follow-up observations, because any confirmed source will be bright enough to be studied by the largest telescopes/facilities available right now. This would be a fantastic opportunity to explore ALMA, Keck, the VLT(SINFONI/KMOS) and HST to unveil the nature of z~9 galaxies, many years before the next generation of large telescopes allows this to be done for the much fainter sources.

Facilities: CFHT/WIRcam, VISTA/VIRCam), VLT/SINFONI

Unveiling the 3-D structure of a remarkable distant super-cluster and the roles of environment, mass and galaxy properties at z~0.8

Supervisors: David Sobral (sobral@strw.leidenuniv.nl), José Afonso, Philip Best (Edinburgh)

Abstract: Why were galaxies in the distant Universe so efficient at producing new stars? What were the roles of "nature" (stellar mass) and "nurture" (environment) in the past, how did they change with cosmic time and is there a connection between those and the declining star formation activity? Is our current view of how galaxies form and evolve correct? By probing a very wide range of environments (from fields to clusters of galaxies) and masses, we are now obtaining a much better picture of the roles and inter-dependences of mass and environment in the distant Universe. However, there are significant limitations in current studies, due to the small sample sizes, lack of multi-wavelenght data in cluster fields, projection effects, and the dilution/confusion of environments (e.g. filaments vs small groups). In order to obtain the sharp view that we need, overcoming current limitations (from the use of photometric redshifts), the student will use the VLT (with VIMOS, 40 hours of observations already conducted at the VLT, all in excellent conditions) to accurately map in 3-D a unique super-structure at $z = 0.84$ in the COSMOS field (10×13 Mpc). This massive, large structure contains 3 confirmed massive X-ray clusters/groups and shows a striking filamentary structure of star-forming galaxies. By targeting > 1000 galaxies residing in such structure, the student will measure accurate redshifts (from both emission and absorption lines) and make a detailed/accurate 3-D map of the complex structure, identifying filaments, fields, outskirts, small groups and the cluster cores. The student will obtain independent mass estimates from the absorption lines, and map SFRs down to even the least active galaxies, but also detect post-starburst galaxies (K+As) and map their fraction in the cluster, group, filament and field environments over the entire structure. The results of this project will reveal exactly where star formation activity is being enhanced/quenched, clearly disentangling the roles of mass and environment in the distant Universe in a robust way for the first time.

Moreover, due to the fact that this super-structure is in the COSMOS field, the student will be able to fully explore the rich multi-wavelenght data-set to detail and expand the conclusions of the study, particularly by investigating the morphologies (with Hubble Space Telescope imaging), but also to look at radio, near- (Spitzer) and far-infrared (Herschel) properties of galaxies residing in the various environments within the super-structure.

Facilities: VLT/VIMOS, HST, Subaru/Suprime-cam, Herschel

Lyα wide-field surveys at z=2-3 and matched Lyα - Hα: what does Lyα really tell us?

Supervisors: David Sobral (sobral@strw.leidenuniv.nl), Huub Röttgering (Leiden), José Afonso

Abstract: Many studies rely on the Hydrogen Lyα (Lyα) emission line to survey, study and understand the distant Universe (z>2-3), as it is often the only feature available to spectroscopically confirm/study such galaxies. However, its escape fraction (f_escape) is highly uncertain at z>2, and much is unknown about what Lyα actually traces. How much are we missing in/how biased is our current view of the very high redshift, almost completely based on Lyα? In order to answer such questions, the student will conduct and work on very large (~5-10 deg^2) Lyα surveys at z~2-3 (the likely peak of the star-formation history). This includes a perfectly matched Lyα-Hα survey at z=2.23 by using a costume-made narrow-band filter specifically designed for this project (delivered to the INT in May 2013). By measuring Lyα/Hα ratios for a sample of hundreds of galaxies at z=2.23, the student will robustly measure f_escape and the Lyα/Hα ratio as a function of mass, colour, environment and SFR and empirically calibrate Lyα for the first time, with very important applications/consequences for z>2 studies.

Furthermore, while deep Lyα (Lyα) surveys at 3<z<7 have been extremely successful at detecting a relatively high number of Lyα emitting sources, and show that there is little evolution at 3<z<6 at faint luminosities, there are big discrepancies at the bright end, as surveys simply lack the volume to constrain it. By conducting by far the largest survey (>2-4 orders of magnitude larger in volume than any other) for the most luminous Lyα emitters at z~2-3, the student will also detect >3000 powerful Lyα emitters and >100 Lyα "blobs" (the largest ~contiguous objects found in the Universe, many times the size of a single galaxy), determine their Luminosity Function for the first time and measure their correlation function and evolution. This will provide the first robust sample that can be directly compared with the highest redshift samples, to directly test whether there is evolution in the bright end of the Lyα luminosity function. This project will allow the student to observe on large telescopes to obtain the data directly (~20 nights over the first years), but also to do follow-up studies with e.g. VLT or ALMA to unveil and detail the nature of Lyα blobs.

Facilities: INT/WFC, UKIRT/WFCAM, VLT

Light in the Inhomogeneous Universe

Supervisor: José Pedro Mimoso (jpmimoso@fc.ul.pt)

Abstract: The standard model of cosmology has been remarkably successful in accounting for the main observed features of
the Universe. A basic pillar of the model is the so-called Cosmological Principle which assumes that the universe is spatially homogeneous and isotropic. This hypothesis found strong support in the discovery of the cosmic microwave background (CMB) and, subsequently, in the increasingly precise measurements of this relic radiation that confirm the extreme smoothness of the Universe at large scales, of the order of the Gpc.

However at smaller scales the Universe we observe is inhomogeneous. Indeed, we see a plethora of structures such as galaxies, clusters of galaxies, and we even know that there are collapsed objects that we do not directly see. We also detect the peculiar motions that these structures exhibit which are of the order of hundreds of km/s.

The importance of this evolved, inhomogeneous universe has been underestimated until recently. The recent discovery of an unexpected late time behavior of the Universe drawn from the surveys of the Supernovae of the type Ia (Sn Ia), has stimulated a variety of different approaches to explain the observations. At present the best interpretation is that the universe close to us ($z \sim 0.5 - 1$) undergoes a phase of accelerated expansion. This viewpoint is derived by comparing the actual apparent luminosities of the Sn Ia with those that would be expected from a decelerating Einstein-de Sitter universe. It does assumes that the universe is homogeneous, and this underlies all redshift, and subsequent distance observations.

In the present research proposal for a Phd work we aim at investigating whether this procedure is justified, and under which conditions. For that purpose we will consider inhomogeneous models, namely those that are spherically symmetric to retain the local isotropy, and will carefully analyze all the quantities that are derived from the local collection of light. The fact that the universe is inhomogeneous means that concepts as redshift, angular and diameter distances, and horizons will depend on the spatial locations of source and not just on the look back time. So all the concepts of observational cosmology have to be redefined within this extended cosmological setting, and this is what we set to do in the present research work. We will use a blend of geometrical and analytical methods, and numerical simulations to be contrasted with the latest data from combined observations.

The present work plan inscribes itself in the goals pursued by the project CERN/FP/123618/2011 to which it is hence related.

Resumo: O modelo padrão da cosmologia tem sido extremamente bem sucedido na explicação das principais observações do Universo. Um pilar básico do modelo é o chamado princípio cosmológico que assume que o universo é espacialmente homogéneo e isotrópico. Esta hipótese encontrou um decisivo apoio na descoberta da radiação cósmica de fundo (CMB) e, posteriormente, nas medições cada vez mais precisas desta radiação que confirmaram a regularidade extrema do Universo a grandes escalas, da ordem do Gpc.

No entanto, em escalas menores do universo que observamos é inhomogénea. De fato, podemos ver uma infinidade de estruturas como galáxias, aglomerados de galáxias, e sabemos que existem também objectos extremamente compactos não vemos diretamente. Além disso detectamos os movimentos peculiares que estas estruturas exibem e que são da ordem das centenas de km / s.

A importância deste universo mais perto de nós e inhomogéneo tem sido subestimada até há pouco tempo. A surpreendente descoberta de um comportamento inesperado do universo mais próximo a partir das observações de supernovas do tipo Ia (Sn Ia), desencadeou uma variedade de diferentes abordagens para explicar as observações. Actualmente, a melhor interpretação é que o universo perto de nós ($z \sim 0,5$-1) passa por uma fase de expansão acelerada. Este ponto de vista é obtido através da comparação dos luminosidades aparentes das Sn Ia com aquelas que seriam de esperar num universo de Einstein-de Sitter em desaceleração. Assume-se porém que o universo é homogêneo, e isso está subjacente a todas as determinações de redshifts, e de indicadores de distância derivados.

Na presente proposta de investigação para um trabalho de doutoramento pretendemos investigar se esse procedimento é justificado, e em que condições. Para este efeito, consideram-se modelos não homogéneos, nomeadamente os que são simétricas esfericamente, de modo a conservar a isotropia local, e pretende-se analisar cuidadosamente todas as quantidades que são derivadas a partir da recolha local da luz. O fato do universo ser inhomogéneo significa que conceitos como redshifts, distâncias angulares e distancia diametral, e horizontes dependem agora das localizações espaciais das fontes e não apenas dos tempos de emissão na fonte e de detecção. Assim, todos os conceitos da cosmologia observacional têm de ser cuidadosamente redefinidos dentro deste cenário cosmológico estendido, e isso é o que se propõe fazer no presente trabalho de investigação. Para esse efeito exploraremos técnicas analíticas e geométricas em simultâneo com métodos numéricos e contrastar-se-ão as definições com dados observacionais recentes.

Este programa de trabalho inscreve-se nos objectivos do projecto CERN/FP/123618/2011 com o qual se relaciona.

Acceleration of the late universe: Modified gravity theories and Backreaction

Supervisors: Francisco Lobo (fsnlobo@gmail.com), José Pedro Mimoso

Abstract: The proposed research plan aims at the search for an explanation of the late accelerated expansion of the Universe, looking beyond the standard theory of gravity, and at the implications of inhomogeneities of the spacetime. Instead of assuming the existence of some sort of exotic matter, we focus of the alternative approaches which corresponds to question the gravitational theory itself and the assumption of spatial homogeneity. We will investigate a possible degeneracy between the predictions arising from modified gravity theory and those of the so-called back-reaction prescription. We will test extended models from modified gravity and back-reaction against astrophysical and laboratory measurements, as well as laboratory and space-based Equivalence Principle experiments. The present work plan inscribes itself in the goals pursued by the project CERN/FP/123615/ 2011 to which it is hence related.

Resumo: A presente proposta de investigação busca uma explicação para a recente expansão acelerada do universo, considerando extensões da teoria da gravitação padrão, bem como as implicações de inhomogeneidades do espaço-tempo. Em vez de admitirmos a existência de alguma forma de material exótica, concentramo-nos na alternativa que consiste em questionar a teoria da gravitação e a habitual hipótese de homogeneidade espacial. Investiga-se a possível degenerescência entre as previsões derivadas destas duas possibilidades, i.e, da modificação da gravitação e da “backreaction”. Usaremos as observações astrofísicas, experiências de laboratório, bem como experiências do Princípio de Equivalência no espaço para testar os modelos estudados. Este programa de trabalho inscreve-se nos objectivos do projecto CERN/FP/123615/2011 com o qual se relaciona.

Dark matter halos in the era of Euclid

Supervisors: Ismael Tereno (tereno@oal.ul.pt), António da Silva

Context: The present proposal is made in the framework of Euclid. ESA's Euclid space mission for cosmology will complete a half-sky survey of the deep sky in optical and near infra-red bands, measuring the shapes of over a billion galaxies and obtaining accurate redshifts of tens of millions of galaxies. The data will be used for weak gravitational lensing and galaxy clustering studies, which are the primary cosmological probes to investigate the nature of dark energy, dark matter and gravity.
The Euclid space telescope is scheduled to launch on 2020. In the meantime the various science working groups of the Euclid Consortium are setting the standard for the state-of-the-art in Cosmology. The topic of the present proposal is one of the many tasks relevant for the scientific preparation of Euclid, namely the modelling of astrophysical correlations between the shapes of galaxies, which contaminate the weak gravitational lensing signal that Euclid will measure.
Portugal is a member state of the Euclid Consortium and CAAUL and CAUP are Euclid affiliated institutes. The supervisors of the present proposal are the two national coordinators of Euclid. The candidate will thus become a member of the consortium and benefit from an international working environment.

Abstract: The so-called intrinsic alignment is a correlation between the orientations of pairs of galaxies at highly separated redshift. It is due to a physical correlation between the foreground galaxy of the pair and the dark matter halo responsible for lensing the background galaxy. This effect is a major contaminant of the cosmological weak lensing signal that Euclid aims to detect.
This project will contribute to model this astrophysical systematic effect and propose ways to correct it. The student will investigate the process of angular momentum acquisition of galaxies by tidal torquing using dedicated N-body simulations of Large Scale Structure. The first step is to quantify the correlation between tidal shears of dark matter proto-halos at early times and study the dependence of tidal shearing on the environment. The simulations will be carried out with the public code Gadget 2 including only Dark Matter (DM) particles in a boxsize of 512 Mpc/h on the side and a total number of about 1 billion particles. The simulation is run from an initial condition at high redshift down to the present time storing the gravitational potential information. We then tag all particles in each halo, and trace back their properties at early times, which allows to compute the centre of mass, momentum of inertia, tidal shear tensor, and consequently the angular momentum for all proto-haloes at high z.
The next step is to place galaxies in the dark matter halos, according to a semi-analytic model, with orientations given as function of the halos angular momentum. The student will then produce a ray-tracing code, to be applied through the simulation in order to obtain 2D maps of projected ellipticities. The ellipticities will be correlated as a result of the angular momentum correlations acquired in the process of galaxy formation.

The final step will be to measure the correlation as function of redshift and use it as a template to correct a weak lensing signal. This can be done either by direct subtraction or in a parameterized way using nuisance parameters in an MCMC analysis.
Finally, the produced catalogue of dark matter halos can be used as a sub-product for other applications, such as constraining theoretical models for dark matter halo profiles with the method of galaxy-galaxy lensing.

Further reading:

"Intrinsic alignment-lensing interference as a contaminant of cosmic shear", Hirata C. M., Seljak U., Phys. Rev. D, 70, 063526 (2004), http://arxiv.org/abs/astro-ph/0406275

"Intrinsic galaxy shapes and alignments II: Modelling the intrinsic alignment contamination of weak lensing surveys", B. Joachimi, et al., submitted to MNRAS (2013) http://uk.arxiv.org/abs/1305.5791v1

"Review: galactic angular momenta and angular momentum correlations in the cosmological large-scale structure", Bjoern M. Schaefer, Int. J. Mod. Phys. D, 18, 173 (2009), http://arxiv.org/abs/0808.0203v1

"Euclid Mission: building of a Reference Survey", J. Amiaux (including I. Tereno and A. da Silva), SPIE Astronomical Telescopes and Instrumentation Proceedings, Volume 8442, id. 84420Z-84420Z-11 (2012), http://arxiv.org/abs/1209.2228

"Euclid Definition Study Report", R. Laureijs et al, ESA/SRE(2011)12, http://arxiv.org/abs/1110.3193

Polarisation of the Cosmic Microwave Background

Supervisors: C. Sofia Carvalho (cscarvalho@oal.ul.pt), António da Silva

Introduction: Cosmology is presently a very active field because of the large number of observations that are becoming available and that will allow us to characterize with great precision the nature and physical origin of the primordial cosmological perturbations, as well as of dark matter and dark energy.

The first objective consists in developing and implementing a novel estimator of the primary polarisation signal of the cosmic microwave background (CMB). This signal can be measured from the gravitational lensing field to be extracted from CMB maps. This type of analysis will be particularly important in the sequence of the public release of CMB polarisation data by the Planck Collaboration (due beginning of 2014) and in the context of the tasks of the CMB Cross-Correlations Science Working Group of the Euclid Consortium.

The second objective consists in assessing the robustness of the estimator of the primary CMB with respect to contamination by secondary CMB polarisation effects, which is not being considered in the current CMB data analysis. This requires the development of a detailed model of the secondary polarisation signals, such as the CMB quadrupole and double-scattering induced polarisations, which act as contaminants in the detection of the primary signal. This topic is related to the detection of CMB secondary polarisation by galaxy clusters with the ALMA interferometer.

Description: The CMB radiation is supposed to originate from the last scattering surface (the time when radiation decoupled from matter) and to have propagated almost unperturbed until today. The CMB is a unique source of information about the physics of the primordial Universe and its subsequent evolution. In particular, the CMB polarisation (Hu & Dodelson 2011, Aghanim et al. 2011) is becoming a key observational tool for cosmology and large scale structure formation studies. It allows to probe the early universe and to tighten constraints and/or break degeneracies on cosmological parameters (Planck collaboration 2003 XVI, XXIII). Whereas the temperature maps produce by Planck have already been extensively analysed, the polarisation analysis has been postponed to the next series of papers.

1st Objective: Primary polarisation induced by CMB lensing

Photons travelling along the line of sight between the last scattering surface and an observer today were deflected by intervening dark matter distribution by means of gravitational lensing. This process conserves surface brightness and polarisation; consequently it does not generate fluctuations in the temperature or polarisation of the CMB, but instead smoothes them and shifts them to smaller scales. This process distorts the temperature-temperature (TT) correlation power spectrum coherently over scales of 2 arcmin. It also mixes and distorts the EE and BB polarisation power spectra (Seljak 1996).

The relevance of the CMB lensing reconstruction for cosmology is twofold.

By distorting the E-mode polarisation, the CMB lensing induces a B-mode polarisation which is a major contaminant in the measurement of the primordial B-mode polarisation predicted by some inflationary models. CMB lensing is also a powerful cosmological probe of the matter distribution integrated from the last scattering surface to the present time. Thus, *delensing* the CMB will allow to recover the primordial B-mode and probe the full-sky large scale structure distribution with a maximum efficiency at z~3 (Lewis & Challinor 2006), thus having the potential to distinguish among models of gravity (Sherwin et al. 2011).

Effort has been devoted to developing an optimal reconstruction of the lensing potential in harmonic space, which implicitly assumes full-sky, coverage without cuts or uneven sky coverage. For a reconstruction based on the temperature anisotropy alone, it bas been shown how to construct an optimal quadratic estimator in this idealized context (Okamoto and Hu 2003). For the exploitation of polarised anisotropies, at a high sensitivity where the B signal is entirely due to lensing, the quadratic estimator underperforms and the higher-order corrections to the quadratic estimator present in the maximum likelihood estimator are no longer negligible (Hirata & Seljak 2003).

Since weak lensing is manifested essentially at very small scales, all the information relevant to lensing reconstruction lies on angular scales close to the resolution scale of the sky map. As an alternative to the conventional harmonic-space estimator (Wu 2001), an estimator has been proposed (Carvalho & Moodley 2010) that is slightly less optimal and modified to have a finite range and a kernel in real space. The prospective candidate will extend the implementation of the real-space estimator to the CMB polarisation in order to optimize the extraction of the lensing information from high-precision CBM polarisation maps.

2nd Objective: Secondary polarisation induced by galaxy clusters and filaments

In addition to the primary CMB polarisation, signals arising from secondary polarisation effects significantly contribute to the observed polarisation. In particular the scattering of CMB photons by reionized (mostly primordial) gas produces polarised radiation, which carries invaluable information about the scattering medium as well as the primordial CMB signal. Among the strongest effects are: a) the polarisation induced by the CMB quadrupole (which couples the primary CMB quadrupole anisotropy to the electron density fluctuations of the reionized gas), b) the transverse-motion induced polarisation (which is related to the transverse motion of the gas cloud), c) the double-scattering polarisation (due to an induced anisotropy at the second scattering event) and d) the Faraday rotation polarisation (which arises in the presence of magnetic fields). Although preliminary studies exist on some of these effects (e.g. Ramos et al. 2012, Liu et al. 2005 and references therein), a thorough characterization of the aforementioned polarisation signals is presently missing while it is crucial for the preparation and exploitation of high-precision CMB observations, such as those of Planck, ALMA and the future PRISM satellite.

The prospective candidate will engage in this characterization using state-of-the-art numerical simulation methods and will apply them to existing tools (e.g. the Planck Sky Model) that are used within international consortia, such as Planck and PRISM, to predict survey yields and test methods to maximise the scientific return from polarisation observations. Emphasis will be given to the detection of secondary polarisation in galaxy clusters with the ALMA interferometer. An important part of the work will be focused on the separation between primordial and secondary polarisation components, and in assessing the constraining power of the different types of polarisation information on cosmological and structure formation parameters. An interesting extension of this work is the development of methods for the separation of the different polarisation components at the ALMA frequencies.

This proposal aims to work on a key issue of observational cosmology in order to provide tools that meet the unprecedented level of significance and accuracy required by PLANCK and forthcoming probes such as PRISM, for a successful treatment and interpretation of the new data sets.
In particular, we propose the student to:

- extend the implementation of the real space estimator to the CMB polarisation.
- model contaminants of the CMB polarisation signal so as to extract the primary signal.
- analyse the cosmological implications and constrain gravity theories with weak lensing.