Astronomy & Physical Cosmology
speciality of the official
Master in Theoretical Physics

Offers
for

MSc Theses
2023/24

On the following pages the possible projects for a MSc thesis are listed. Please note that the MSc thesis is not restricted to be selected from this list; this list simply reflects research interests within the Department and its associated members. You always have the option to talk to the members and come up with a new project.

Note that each project has to be a work worth 12 ECTS which translates to 300 hours (ca. 8 weeks) of work. The work will primarily be undertaken during (and after) the third trimester, but you are free to start as early as possible.

There will be two calls to present the master thesis: one in end-June/early July and another one in early-September.

The list provided here is ordered by the surnames of the supervisor.

Javier Álvarez Marquez (CAB) and Luis Colina (CAB), Daniel Ceverino (UAM tutor)

Galaxies at redshifts beyond z > 6

The nature of the sources that reionize the universe is still unknown. Imaging surveys have concluded that galaxies are detected as increasingly strong [OIII]-line emitters at high redshifts. Recent studies argue that extreme [OIII] emitters (EW[OIII]5007Å>1000Å) at redshifts above 6 should be common, and be responsible for the reionization of the universe (so called Epoch of Reionzation, eoR). However, their physical properties, especially Lyman continuum emissivity, are not firmly established yet. The group at CAB has recently been awared a medium-size program with the James Webb Space Telescope (JWST) to investigate a complete sample of galaxies (LAEs/LBGs) at redshifts above 6, and identified as [OIII]88um emitters with ALMA. These data will establish i) the age and mass of the stellar population, ii) the structure of the stellar population and ionized gas nebula, iii) the physical conditions, kinematics and ionization status of the ISM, and iv) the LyC escape fraction. The combination of JWST's deep, high-angular resolution multiwavelength imaging and spectroscopy, and ancillary ALMA data, will provide key information on the early stellar mass and galaxy assembly during the yet unexplored Epoch of Reionization.

The potential candidate will work with the PI (Javier Álvarez), and coI (Luis Colina) of the JWST proposal to establish the age and stellar mass of the sample galaxies based on simulated spectral templates and the combination of existing data (HST, Spitzer, ALMA), and future JWST data (to be taken during 2022 and 2023). *The potential candidate could extend these studies beyond the MSc thesis into a PhD project, depending upon final qualifications and available funding*.

A good knowledge of english at all levels is required, as well as knowledge of programming in python.

Rafael Alves Batista (UAM-IFT)

Probing Intergalactic Magnetic Fields

The origin of cosmic magnetic fields in the universe is an open problem in cosmology. There are essentially two classes of models to explain the cosmological magnetogenesis: primordial and astrophysical mechanisms. The existence of non-zero intergalactic magnetic fields (IGMFs) permeating the whole universe can favour the former process, suggesting the existence of an all-pervasive field since early times.
High-energy gamma rays can probe the universe up to relatively large distances as they are electrically neutral and their arrival directions can be approximately traced back to their source. The interaction of the high-energy gamma rays with ambient photons from the cosmic microwave background and the extragalactic background light can produce electromagnetic cascade, whose short-lived charged component is affected by intervening magnetic fields, allowing us to study these fields. The goal of this project is to model the development of gamma-ray-induced electromagnetic cascades in the intergalactic medium in order to constrain properties of IGMFs.

This TFM will be carried out within the boundaries of the DArk Matter, AStroparticles and COsmology (DAMASCO) group at the UAM Theoretical Physics Department and the Institute for Theoretical Physics (IFT UAM-CSIC). DAMASCO's current main research interests include the indirect search for dark matter, with special care to gamma rays; the analysis of numerical cosmological simulations, mainly to shed light on the smallest scales; high-energy neutrino astrophysics; cosmic-ray astrophysics; multi-messenger astronomy. DAMASCO belongs to the Fermi-LAT Collaboration, the Cherenkov Telescope Array (CTA) Consortium, the Giant Radio Array for Neutrino Detection (GRAND) Collaboration, the Global Cosmic-Ray Observatory (GCOS) Collaboration, and the DESI Collaboration. The group has also an excellent network of collaborations with (local, national, international) experts in astroparticle physics and cosmology.

Further info about the team and research activities: https://projects.ift.uam-csic.es/damasco/

Desirable skills (optional):

- Good level of programming (preferably Python or Julia).
- Good command of English.
- Good communication skills.

References:

- R. Alves Batista, A. Saveliev, Universe 7 (2021) 223 [2105.12020]
- R. Alves Batista, A. Saveliev, Astrophys. J. Lett. 902 (2020) L11 [2009.12161]
- R. Alves Batista et al., PRD 94 (2016) 083005 [1607.00320]

Contact and questions: rafael.alvesbatista@uam.es

Rafael Alves Batista (UAM-IFT)

Origin of ultra-high energy cosmic rays

The origin, nature, and mechanisms of acceleration of the most energetic particles in the Universe, the ultra-high energy cosmic rays (UHECRs), are unknown. During their propagation from their sources to Earth, they can interact with ambient photons from the cosmic microwave background and the extragalactic background light, and also be deflected by intervening magnetic fields (both Galactic and extragalactic). Many models have been proposed to explain how cosmic rays are accelerated to such extreme energies, and common candidates for sources include active galactic nuclei, tidal disruption events, and magnetars, among others.

In this project the student will use catalogues of astrophysical sources to simulate the propagation of UHECRs from possible sources to Earth, considering all relevant energy loss processes as well as deflections in magnetic fields. This will help shed light on the origin of the highest-energy particles in the universe. These simulations will ultimately be used to interpret current measurements of UHECRs and to improve the design of future observatories currently under construction.

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Further info about the team and research activities: https://projects.ift.uam-csic.es/damasco/

Desirable skills (optional):
- Good level of programming (preferably Python or Julia).
- Good command of English.
- Good communication skills.

References:

- R. Alves Batista et al., Front. Astron. Space Sci. 6 (2019) 23 [1903.06714]
- R. Alves Batista et al., PRD 96 (2017) 023010 [1704.05869]
- R. Alves Batista and J. Silk, PRD 96 (2017) 103003 [1702.06978]

Contact and questions: rafael.alvesbatista@uam.es

Rafael Alves Batista (UAM-IFT)

Probing the Cosmos with Multiple Messengers

The origins of the most energetic particles in the Universe has been a long-standing puzzle. In the quest to identify their astrophysical sources, it is essential to understand how these particles are accelerated, how they can escape the sites wherein they are produced, and which roads they can take on their journey to Earth. The multimessenger framework is a powerful tool for unveiling the Universe at extremely high energies, far beyond the reach of Earthly particle accelerators such as the Large Hadron Collider. Each astrophysical messenger provides direct information on specific properties of cosmic accelerators, thus justifying the multimessenger approach. Conversely, it is possible to use these messengers to probe the Universe, from its radiation content to the magnetic fields that permeate it, as well as to search for signatures of the elusive dark matter and to search for physics beyond the standard model.

This TFM will be carried out within the boundaries of the DArk Matter, AStroparticles and COsmology (DAMASCO) group at the UAM Theoretical Physics Department and the Institute for Theoretical Physics (IFT UAM-CSIC). DAMASCO's current main research interests include the indirect search for dark matter, with special care to gamma rays; the analysis of numerical cosmological simulations, mainly to shed light on the smallest scales; high-energy neutrino astrophysics; cosmic-ray astrophysics; multi-messenger astronomy. DAMASCO belongs to the Fermi-LAT Collaboration, the Cherenkov Telescope Array (CTA) Consortium, the Giant Radio Array for Neutrino Detection (GRAND) Collaboration, the Global Cosmic-Ray Observatory (GCOS) Collaboration, and the DESI Collaboration. The group has also an excellent network of collaborations with (local, national, international) experts in astroparticle physics and cosmology.

Further info about the team and research activities: https://projects.ift.uam-csic.es/damasco/

Desirable skills (optional):
- Basic programming skills.

References:

- A. Addazi et al., Prog. Part. Nucl. Phys. 125 (2022) 103948 [2111.05659]
- R. Alves Batista, A. Saveliev, Universe 7 (2021) 223 [2105.12020]
- R. Alves Batista et al., Front. Astron. Space Sci. 6 (2019) 23 [1903.06714]

Contact and questions: rafael.alvesbatista@uam.es

Rafael Alves Batista (UAM-IFT), Miguel A. Sánchez-Conde (UAM)

A search of axion-like particles with high-energy gamma rays

Axion-like particles (ALPs) are hypothetical entities often invoked to solve various problems in particle physics to cosmology. They are one of the most promising candidates to account for the elusive dark matter, responsible for a quarter of the universe's energy density.
A way to search for ALPs is by looking for their effects in photons. In the presence of external magnetic fields, they can convert into one another leading to measurable signals. Over cosmological scales, this phenomenon is more prominent for photons with gamma-ray energies. This project consists in the search for ALPs using high-energy gamma rays.
The work will have a theoretical/computational component involving simulations. Depending on the interests of the student, it is also possible to use data by the Fermi Large Area Telescope (Fermi-LAT) to look for these signatures.

This TFM will be carried out within the boundaries of the DArk Matter, AStroparticles and COsmology (DAMASCO) group at the UAM Theoretical Physics Department and the Institute for Theoretical Physics (IFT UAM-CSIC). DAMASCO's current main research interests include the indirect search for dark matter, with special care to gamma rays; the analysis of numerical cosmological simulations, mainly to shed light on the smallest scales; high-energy neutrino astrophysics; cosmic-ray astrophysics; multi-messenger astronomy. DAMASCO belongs to the Fermi-LAT Collaboration, the Cherenkov Telescope Array (CTA) Consortium, the Giant Radio Array for Neutrino Detection (GRAND) Collaboration, the Global Cosmic-Ray Observatory (GCOS) Collaboration, and the DESI Collaboration. The group has also an excellent network of collaborations with (local, national, international) experts in astroparticle physics and cosmology.

Further info about the team and research activities: https://projects.ift.uam-csic.es/damasco/

Desirable skills (optional):
- Good level of programming (preferably Python or Julia).
- English knowledge.
- Good communication skills.

References:

- M. Sánchez-Conde et al., PRD 79 (2009) 123511 [0905.3270]
- I. Irastorza & J. Redondo, Prog. in Part. and Nuclear Phys., 102 (2018) 89 [arXiv:1801.08127]
- R. Alves Batista, A. Saveliev, Universe 7 (2021) 223 [2105.12020]
- M. Doro, M. Sánchez-Conde, M. Hütten, Adv. in VHE Astrophysics (2022) [arXiv:2111.01198]

Contact and questions: rafael.alvesbatista@uam.es and miguel.sanchezconde@uam.es

Santiago Avila (UAM)

Large-Scale Structure of the Universe with galaxy surveys

The Large-Scale Structure (LSS) of the Universe if one of the pillars of the LCDM model. Galaxy clustering is one of the main probes by recent, ongoing and forthcoming galaxy surveys (BOSS, DES, DESI, Euclid, LSST, SKA). Some of the main observables are:

- **Baryonic Acoustic Oscillations**. These primordial waves in the baryon-photon plasma left imprinted a preferred scale in the Universe, corresponding to the sound horizon at decoupling. This scale can be seen as a peak in the separation of galaxies: the BAO peak. The peak of known size is used as a standard ruler to constrain the expansion history of the Universe and is one of the most robust cosmological probes.
- **Redshift Space Distortions**. The velocities of nearby galaxies are correlated due to the action of local gravity. This leaves a distinct pattern in the galaxy clustering that can be used to measure the strength of gravity at cosmological scales as a test to GR.
- **Primordial Non-Gaussianities**. The initial conditions of the Universe leave distinct patterns in the abundance of clusters and the clustering of galaxies at large scales. Hence, the LSS is a powerful tool to constrain the physics of inflation.
- Combined probes. Galaxy clustering is also very powerful when combined with other probes such as weak lensing, CMB lensing, cluster counts, radio intensity mapping, etc.

I work on all those topics using data from the above-mentioned experiments, state-of-the-art cosmological simulations and theoretical modelling of the LSS. We could discuss further possible projects, but I propose one example here:

- **Redshift Space Distortions with the DES**. The **Dark Energy Survey** could be the first photometric galaxy survey to detect the presence of RSD due to its unique statistical power and good control of photometric redshifts. The work will consist of measuring 2-point correlation function from DES simulations and run MCMC fits for the RSD parameters. This will serve to understand the viability to detect RSD in DES and assess the expected precision and accuracy. In the future this could be continued (in a PhD) to perform the analysis on real data.

References

[1] "Completed SDSS-IV extended Baryon Oscillation Spectroscopic Survey: Cosmological implications from two decades of spectroscopic surveys at the Apache Point Observatory" arXiv:2007.08991

[2] "Dark Energy Survey Year 3 Results: A 2.7% measurement of Baryon Acoustic Oscillation distance scale at redshift 0.835" arXiv:2107.04646

[3] "The Completed SDSS-IV extended Baryon Oscillation Spectroscopic Survey: measurement of the BAO and growth rate of structure of the luminous red galaxy sample from the anisotropic power spectrum between redshifts 0.6 and 1.0" arXiv:2007.08994

[4] "HI intensity mapping correlation function from UNIT simulations: BAO and observationally induced anisotropy" Ávila et al. arXiv:2105.10454

Daniel Ceverino (UAM)

Protocúmulos de galaxias en el Universo primitivo

Los cúmulos de galaxias con cientos o miles de miembros constituyen los mayores objetos del Universo. Los astrofísicos se preguntan cómo se pudieron formar estos gigantes cuando el universo era joven.

Las simulaciones cosmológicas de formación de galaxias pueden ayudar a aclarar este misterio. Este trabajo utiliza la base de datos del proyecto “The Three Hundred” para identificar y caracterizar protocúmulos así como las galaxias que albergan.

El estudiante se familiarizara con algoritmos de “data mining” y tendrá que extraer información científicamente relevante para componer un modelo de formación y evolución de protocúmulos.

Mínimos requisitos: conocimientos de programación en python, C or Fortran.

Daniel Ceverino (UAM)

Getting ready for the James Webb Space Telescope:
mock images from cosmological simulations of first galaxies and the effect of dust attenuation

This fall we are expecting the launch of the James Webb Space Telescope (JWST), the successor of the Hubble Space Telescope. We need to be ready for the amazing images from the first galaxies that formed in the early Universe. This is one of the main objectives of this telescope (https://jwst.nasa.gov/content/science/firstLight.html).

The goal of this project is the generation of mock images of first galaxies that can be compared directly with JWST observations. From a large set of existing images from the FirstLight database, the student will add the effect of the dust attenuation.

Tentative observations suggest that dust attenuation is less severe in small, faint galaxies and it increases in more massive galaxies with higher gas (and dust) column densities. Due to the large sample of galaxies with different masses, the student will be able to test different models of dust attenuation and address the importance of dust as a function of galaxy mass and redshift.

The student will use the FirstLight database, a large number of cosmological simulations of first galaxies (N-body + hydro). More information on the project website: http://odin.ft.uam.es/FirstLight/index.html

Requirements: Good programming skills in any of the following languages: Fortran, C, Python

Daniel Ceverino (UAM)

The formation of globular clusters in giant clumps in the early Universe

Globular clusters are the oldest stellar systems in our galaxy. They must have formed in extreme conditions of densities and pressures in the early Universe. One of the formation theories suggests that giant clumps of gas in early galaxies may host such conditions. The goal of this project is to use a catalog of giant clumps extracted from cosmological simulations of galaxy formation, the VELA simulations (https://www.nirmandelker.com/the-vela-simulation-suite). The student will populate these clumps with globular clusters according to different formation scenarios.

Requirements: Good programming skills in any of the following languages: Fortran, C, Python

Laura Colzi (CAB)

Unveiling the origin of nitrogen fractionation

The study of isotopic ratios, like the 14N/15N and 12C/13C, of molecules towards star-forming regions in our Galaxy gives important information about the chemical history of the molecular cloud itself and of the entire Milky Way, including our Solar system. However, the chemical processes that cause the spread of 14N/15N values (N-fractionation) within the same molecular cloud are still not fully understood. Only recent chemical models proposed a dependence of the 14N/15N ratios on the UV field exposure of the molecular cloud, which however needs to be confirmed observationally.

In this thesis project the student will perform a direct test to the dependence of N-fractionation values with the UV field, measuring the 14N/15N ratio of HCN and HNC towards the Monoceros R2 photo-dominated region. In particular, we have recently obtained observations with the IRAM 30m radiotelescope in Pico Veleta (Granada, Spain) towards two regions, the ionization front exposed to a strong UV field, and a northern embedded region where photons could not arrive. These observations are decisive in testing the importance of UV field to local N-fractionation processes.

The student will learn how to use the astrophysical analysis software GILDAS and MADCUBA to analyse spectra in the millimeter wavelengths, will identify the rotational transitions of the molecules, and derive the molecular abundances and abundance ratios. Then, the student will compare the results with observations and chemical models in the literature and will discuss about the possible implications on local N-fractionation.

This work will be used for the preparation of a publication in an astrophysical journal.

This project will be conducted within the "Chemical complexity in the ISM and star formation" group of the Centro de Astrobiología (website: https://cab.inta-csic.es/astrochem/index.html).

For more information contact: lcolzi@cab.inta-csic.es

Weiguang Cui (UAM)

The difference between observed and simulated galaxies -- the effect of galaxy finder

Understanding the galaxies, i.e. their properties, requires identifying them in the first place from both observation and theory sides. However, galaxy finding in observation is driven by geometry methods, while simulated galaxies are normally identified based on their physical property – a gravity-bound object. Are they the same? Apparently not. The main purpose of this project is to quantify the differences between observational defined galaxy and theoretical defined galaxy. This can be only done in one way – analysing the simulated galaxy with observational methods, because getting the physical quantities, such as star velocity, of observed galaxies is very hard.

In this project, the student will work with the simulated galaxies from the 300 project. He/She will first identify the galaxy from mock images of galaxy cluster with PhotoUtil (https://github.com/astropy/photutils). Then, he/she will crossmatch these identified galaxies with the theoretical identified galaxies, study their property differences, and present the result statistically.

Prerequisite Knowledge and Skills
python, knowledges of galaxy finding software (desired) and numerical simulation (desired)

References
The 300 project: Cui et al. 2018, https://doi.org/10.1093/mnras/sty2111
PhotoUtil: Bradley et al. 2019, https://doi.org/10.5281/zenodo.2533376

Weiguang Cui (UAM), Daniel de Andres (UAM) & Gustavo Yepes (UAM)

Learn to predict the initial conditions

Reproducing the observed Universe is a huge project with many benefits. However, it is not easy to make accurate simulations to precisely mimic the Universe we see, see the CLUES project for example. One of the difficulties lie in the so-called constrained initial condition, with which the simulations start and finally can out put the analogue of the observed Universe, for example, SDSS survey. This project is aiming at using the advanced ML techniques to train from the simulation output at z=0 and to make predictions of their initial conditions.

Angeles Diaz (UAM), Sandra Zamora (UAM)

Derivation of abundance gradients in the face-on spiral galaxy NGC 1058.
Implications for the formation and evolution of galactic discs.

The importance of the knowledge of abundance distributions in spiral galaxies is widely recognized as a probe of their chemical evolution and star formation histories. The observation and analysis of HII regions provide excellent means for deriving chemical abundances of different elements, both primordial and by-products of stellar nucleosynthesis. This information is central to guide theoretical models of the formation and evolution of galaxies. Among the different abundance-related parameters employed in the study of spirals are: the radial metallicity gradient, the average metallicity at a given fiducial galactic radius, and the central metallicity value, where metallicity usually refers to oxygen abundance. In fact, the two latter parameters rely on the determination of the first, since they are determined either by interpolation and extrapolation respectively.

Chemical evolution models have shown that: (1) abundance ratios between elements depend mostly on stellar nucleosynthesis and the initial Mass Function (IMF); (2) the slope of any abundance gradient is not sensitive at all to the adopted nucleosynthesis; and (3) the predicted absolute abundance of any element depends on all adopted parameters and hence it does not represent by itself a good test of any theory although it should be reproduced by any self-consistent model.

However, the determination of accurate abundance gradients is not an easy task. In nearby galaxies, abundances have been found to decrease with galactocentric distance and, since these abundances control the cooling of the ionised gas, different techniques implying direct, empirical or semi-empirical methods, are needed to derived abundances throughout galactic discs.
We have secured long slit spectrophotometric data along the disc of the face-on spiral galaxy NGC 1058 obtained with the ISIS spectrograph attached to the 4.2m WHT telescope in La Palma Observatory. The spectral range covers from 3500 to 10000 Å simultaneously. These observations will allow the determination of unambiguous elemental abundance gradients thus providing a clear picture of the true metallicity distribution in the galaxy, either giving support or rejecting the hypothesis of the multi- component abundance gradients for normal spiral galaxies, compared to the classic scenario of a well- behaved smooth linear negative logarithmic gradient throughout all galactocentric distances, with important implications for the formation and chemical evolution of these objects.

Contact and questions: angeles.diaz@uam.es

Violeta Gonzalez Perez (UAM)

Exploring the recently discovered fast radio bursts with galaxy models

Fast Radio Bursts (FRB) are extremely bright radio pulses dispersed by ionised gas. They were serendipitiously discovered just in 2007 (Lorimer et al. 2007) and their origin is yet unkown. Some of the reported possible origins are: magnetars, mergers of stars and mergers of compact objects, susch as black holes.

There are about 90 known FRBs, with redshifts up to 3, and it is expected that the JWST telescope might be able to detect them up to redshift 10. This long range of cosmic time detection range makes them a very promising independent cosmological probe.

FRBs are expected to be able to constrain the mass of neutrinos, the primordial spectrum of fluctuations and the epoch of reonisation.

The current theories on the origin of FRB connect them to stellar populations. In this work we propose to explore this connection and its cosmological implications using a semi-analytical model of galaxy formation (GALFORM and SHARK) and evolution run on a large dark matter simulation (UNIT).

The starting point for this work will be to explore the proposed theories on the origin of FRBs (e.g. Platts et al. 2018) and their connection to galaxies and their environments (e.g. Fialkov et al. 2018)

References:

* Discovery of FRBs: Lorimer et al. 2007 ()
* UNIT: Chuang et al. 2019 (https://ui.adsabs.harvard.edu/abs/2019MNRAS.487...48C/abstract)
* GALFORM: Gonzalez-Perez et al. 2020 (https://ui.adsabs.harvard.edu/abs/2020MNRAS.498.1852G/abstract)
* SHARK: Lagos et al. 2018 (https://ui.adsabs.harvard.edu/abs/2018MNRAS.481.3573L/abstract)
* Theories compilation: Platts et al. 2019 (https://ui.adsabs.harvard.edu/abs/2019PhR...821....1P/abstract)
* Fialkov et al. 2018 (https://ui.adsabs.harvard.edu/abs/2018ApJ...863..132F/abstract)

Maria J. Jimenez-Donaire, Antonio Usero (OAB)

Characterizing dense gas emission in the center of NGC 3627

Stars are observed to form in the densest parts of local clouds. Thus, estimating gas density across galaxies is crucial in order to test predictions from star formation theories. The HCN(1-0) and HCO+(1-0) transitions have proven key to extragalactic studies of cold, dense gas, directly linked to star formation. The emission coming from these dense gas tracers is however found to be optically thick, and therefore can be excited at lower densities. This has a clear impact on line ratios tracing dense gas fractions, and the efficiency of star formation, as any changes in the measured line ratios (e.g., HCN-to-CO) could potentially arise as a consequence of optical depth variations, rather than density variations in the ISM. Our new ALMA Band 3 data simultaneously measures the emission coming from dense gas tracers, HCN and HCO+, and their isotopologues, H13CN and H13CO+, in the center, bar, and off-nuclear star forming regions of the nearby galaxy NGC 3627. NGC 3627 is a barred spiral with inner structures that resemble those in the Milky Way.

The key goals for the student will be to:

(1) Explore and analyze the new ALMA data, learning the basics of interferometry. The student will also get familiar with handling data cubes and producing moment maps of each transition.

(2) Analyze the dense gas emission and derive for the first time reliable HCN/H13CN and HCO+/H13CO+ intensity ratios in the galaxy center, southern bar edge and along the bar, to determine the dense gas optical depths.

(3) Compare the results to our previous observations and calibrate how these line ratios (HCN/H13CN and HCO+/H13CO+) change as a function of the dense gas fraction HCN/CO in different environments.

(4) Derive column densities and dense gas masses in a normal, star-forming galaxy center in the outer in the disk, using RADEX. The mass of dense molecular gas will be key to understand the star formation efficiency of the gas.

Given the large amount of radio data, it would be desirable that the student has good computing skills.

Alexander Knebe (UAM)

Galaxy Clusters: (4 offers, each 12 ECTS)

Galaxy clusters are the largest gravitational bound objects in the Universe and lie on the cross-roads of astrophysics and cosmology. On the one hand, by studying their masses and number density they provide insights of the cosmological background. On the other hand they constitute an ideal astrophysical environment to study all the processes that take place during the formation of galaxies. We have used 11 different simulation codes for modelling the same galaxy cluster in a cosmological context in- and excluding all the relevant physical processes. For some of the proposed MSc projects this existing and unique dataset should be used to investigate various scientifically interested topics. But we also have at our disposal a suite of cosmological simulation that allow the study of galaxy clusters in a statistical sense.

Please note that each of the points listed below is for *one* single MSc thesis of 12 ECTS.

Signing up for one of these projects will further open the possibility to join an existing international group of researchers working on both this comparison and galaxy clusters, respectively; see http://popia.ft.uam.es/nIFTyCosmology/week1.html for more details.

<u>MSc thesis #1: cluster outskirts</u>
The plan for this project is to study differences in the properties of the brightest cluster galaxy (i.e. the central galaxy), the luminosities of the satellite galaxies as well as any intra-cluster light. For this purpose it appears adequate to make use of the single cluster simulation performed with aforementioned 11 different simulation code: how stable are results with respects to the numerics?

<u>MSc thesis #2: the influence of baryons</u>
This project aims at investigating how the baryons included in the simulation affect the shape, angular momentum, and general distribution of matter when compared against dark matter only simulations. For this project we should again use the suite of single cluster simulations as this is available to us with and without gas physics.

<u>MSc thesis #3: Intra-Halo Light</u>
Galaxies falling into and then orbiting a larger host galaxy experience tidal forces which will tear them apart (see, for instance, the two Magellanic clouds are orbiting our Milky Way). First their dark matter halo will be stripped, but eventually also stars will be removed and deposited into the halo of the host galaxy. These stars are then free-floating and constitute the so-called "intra-cluster light". The aim of this project is to investigate how different semi-analytical models for galaxy formation treat and predict these halo stars. Will we be able to distinguish different models via the intra-cluster light? Or will we be able to even improve models?

<u>MSc thesis #4: Mbh-sigma Relation</u>
The Mbh–sigma (or simply M–sigma) relation is an empirical correlation between the stellar velocity dispersion of a galaxy bulge and the mass M of the supermassive black hole at the galaxy's centre. Here we plan to study how this relation differs amongst the various semi-analytical models of galaxy formation. There have recently been claims that this relation is different at higher redshift. As different SAMs might use different prescriptions on the growth of BH and bulge (AGN FB, merger, starburst prescriptions, etc) we can check how this very important relation varies with redshift in all the models available to us. Will we be able to use this rule out or confirm some of the models?

Alexander Knebe (UAM)

Galaxy Formation: (2 offers, each 12 ECTS)

Understanding galaxy formation within a full cosmological context is one of the prime fields of research in astrophysics. While a lot of effort is going into directly modeling galaxies by means of hydrodynamical simulations, another route to the subject is to defer to dark matter only cosmological simulations, and then populating the haloes emerging in them with galaxies in a semi-analytical fashion. And there are currently various such models out there all aiming at producing the same observational predictions.

Besides of performing direct simulations of galaxies, we have also used 13 different semi-analytical codes (basically all existing) for running their model over the same cosmological simulation. The question now is whether they all give the same results when compared amongst each other or against direct simulations. For some of the proposed MSc projects the existing and unique dataset of galaxy catalogues should be used to investigate various scientifically interested topics. But we also have at our disposal a suite of cosmological simulation that allow the study of galaxies in a statistical sense.

Please note that each of the points listed below is for *one* single MSc thesis of 12 ECTS.

Signing up for one of these projects will further open the possibility to join an existing international group of researchers working on both this comparison and galaxy clusters, respectively; see http://popia.ft.uam.es/nIFTyCosmology/week2.html for more details.

<u>MSc thesis #1: Environmental Effects - 12 ECTS</u>
We aim to study the difference (between different SAMs) in the degree of environmental effects on galaxy properties. Environmental effects are observed and predicted, but whether its degree is in quantitative agreement with SAM prediction and how robust the SAM prediction is have not been addressed in good detail. This is part of the goal of this project.

<u>MSc thesis #2: Cold/Hot Gas in Galaxies - 12 ECTS</u>
Gas cooling and heating are competing processes during the formation of galaxies: cool gas is able to form stars, but feedback mechanisms heating part of the gas again are required to prevent an overproduction of stars. For this project the evolution of hot and cold gas shall be studied in the various different semi-analytical models.

Elias Lopez Asamar & David Cerdeno (UAM)

The Migdal effect: a new channel to search for dark matter

Nearly 80% of the total mass content of the universe can be detected only by gravitational effects. The composition of such matter contribution, called dark matter (DM), is unknown, and there are strong evidences supporting that it is made of a new type of elementary particles. In this context, direct detection experiments aim to find DM particles that might populate the Solar System, by searching for their interactions with a dedicated detector on Earth.

Recently it has been proposed to use the Migdal effect, namely the ionization of an atom when the respective nucleus is perturbed, as a new approach to search for DM in direct detection experiments [1]. However, the Migdal effect currently stands as a theoretical prediction that has not been experimentally verified yet.

This project offers an opportunity to develop some research on the Migdal effect, balancing both theory and experiment. On one hand, the student will review the theory of the Migdal effect, and will work on applying it to DM experiments based on semiconductor detectors, where a proper treatment of the valence electrons is still incomplete. And on the other hand, the student will have the possibility to work in the development of an array of photomultiplier sensors, carried out at the UAM high energy physics laboratory, for the experimental confirmation of the Migdal effect with the MIGDAL experiment [2].

References:
[1] M. Ibe, W. Nakano, Y. Shoji and K. Suzuki, J. High Energ. Phys. 2018, 194 (2018)
[2] H. Araújo et al. (MIGDAL Collaboration), arXiv:2207.08284 (2022)

Ignacio Mendigutía & Jorge Lillo-Box (Centro de Astrobiología CAB, CSIC-INTA)

Looking for exoplanets around hot stars from high precision light curves

Context and objectives:
Although thousands of exoplanets have been detected during the last decades, observational approaches are biased towards solar-type stars and colder sources. Thus, our knowledge on planet frequencies around hotter stars with spectral types A and B is practically absent. Fortunately, high-precision light curves obtained with NASA's Transiting Exoplanet Survey Satellite (TESS) show that hundreds of such hot stars could be potentially hosting planets. TESS lightcurves of these candidates will be carefully analyzed during this master thesis project, with the final goal of confirming their presence and providing a first statistical approach on planetary frequencies around A and B stars. In a second step, the previous results on mature, main sequence stars will be connected to the sites where those planets form: the protoplanetary disks around young, pre-main sequence “Herbig Ae/Be” stars.

Working place and Supervisors:
The selected candidate will have the opportunity to interact with astrophysicists and engineers in a vibrant, international environment at the facilities of the European Space Agency in Spain (ESA-ESAC, Madrid), working at the Centro de Astrobiología (CAB-CSIC/INTA) building. Such an environment is ideal to get perspective on astrophysics-related career paths, inside or outside academia.

Ignacio Mendigutía has expertise on star and planet formation, with particular focus on Herbig Ae/Be stars.
Personal webpage: https://ignaciomendigutia.wixsite.com/astro
Contact email: imendigutia@cab.inta-csic.es

Jorge Lillo-Box has expertise on the search and characterization of exoplanets and the analysis of TESS data.
Personal webpage: https://www.jlillobox.com/
Contact email: jlillo@cab.inta-csic.es

Student's skills:
Real interest and commitment to work on the proposed topic is the only requirement. Very basic knowledge on star/planet formation and/or exoplanets combined with minimum computing skills are desiderable, but the student will be guided in all steps during the process.

Useful links:
Centro de Astrobiología (CAB-CSIC/INTA): https://cab.inta-csic.es/
European Space Astronomy Centre (ESA-ESAC): https://www.esa.int/About_Us/ESAC
TESS mission: https://www.nasa.gov/content/about-tess

Francisco Najarro, Lee Patrick y Raul Castellanos (Centro de Astrobiología)

Variability of the most massive stars in the Centre of the Galaxy

Massive stars shape their surrounding environments via intense stellar winds throughout their lives and as they explode as supernovae at the end of their lives, which provides chemical and energetic feedback for future generations of stars. Once the most massive stars exhaust their supply of hydrogen in their cores, they go through a variety of short lived stellar phases. Luminous blue variable (LBV) stars represent such a transitional phase in the life cycle of massive stars, which experience large eruptions from their atmospheres expelling large amounts of material in short bursts, and are thought to be progenitors to some of the most energetic supernova explosions known. LBVs are so rare that only a handful are known in the Milky Way and despite their importance, much remains unknown about their evolution. The known examples of LBVs in the Galaxy are often found in extreme environments such as the Central and Quintuplet clusters at the centre of the Galaxy.
Using observational data from the K-band Multi-Object Spectrograph on Very Large Telescope (KMOS/VLT), Chile, the student will study the three LBVs in the Quintuplet cluster and assess how the spectroscopic appearance of LBVs vary over time. The binary nature of the LBVs will be investigated and the consequences of the variability of lack thereof will be put into context in the overall evolutionary cycle of massive stars.
Requirements: This project will involve data reduction and analysis of KMOS/VLT spectroscopic data using well developed recipes. Radial velocities of the stars will be determined and a spectroscopic variability analysis will be performed.

This project will be conducted as part of the Massive Stars research group of the Torrejón site of the Centro de Astrobiología.

For more information contact: najarro at cab.inta-csic.es, lrpatrick at cab.inta-csic.es

Nataly Ospina & Luis Labarga (UAM)

Search of the DSNB with Super-Kamiokande

Core-collapse Supernovae (CCSNe) are among the most catastrophic phenomena in the Universe and are essential elements of the Cosmos. However, their underlying mechanism is not understood; characterizing it would require complex knowledge of the core of the collapsing star. This information could be accessed by detecting neutrinos emitted in the Supernova, whose luminosity and energy spectra closely follow the different steps of the CCSNe mechanism.

The existing neutrino experiments are mostly sensitive to SNe occurring in our galaxy and its immediate surroundings, but, nevertheless, these events are extremely rare (a couple of times per century in our galaxy). An alternative way to learn about the properties of SNe in the Universe is to study the neutrinos that have been emitted by each SNe since the beginning of the formation of the Universe. The integrated flux of these neutrinos forms the "Diffuse Supernova Neutrino Background" (DSNB), also known as "Supernova Relic Neutrinos" (SRN). If they could be detected, they would provide a steady stream of information on stellar collapse, nucleosynthesis, formation of the heavier elements, and determination of the rate of optically failed SNe by comparison with optical measurements. Also, as the DSNB is composed of neutrinos of all flavors whose energies have undergone a redshift during their propagation toward the earth, on the size and nature of the evolution of the Universe itself.

The student will be involved in the analysis of the search of the DSNB with the Super-Kamiokande (SK) Gadolinium (Gd) data. SK is one of the most important neutrino experiments in the world and, since 2020 started the Gd phase. It consists in the addition of Gd salt to the SK water to improve the sensitivity of the detector. There are several theoretical models for the DSNB; their predictions for the flux vary within a factor 10; now according to the most widely accepted modern analyses (Horiuchi et al. 2009, Beacom 2010), SK with Gd2(SO4)3 (2% solution) should detect up to six such SNe events each year.

<u>References:</u>

The Super-Kamiokande Collaboration; Harada, M. et al. 2023; Search for astrophysical electron antineutrinos in Super-Kamiokande with 0.01wt% gadolinium-loaded water, eprint arXiv:2305.05135.

Giampaolo, A. et al. 2022; Diffuse Supernova Neutrino Background search at Super-Kamiokande with neutron tagging, 37th International Cosmic Ray Conference. Online, published March 18, 2022, id.1154.

The Super-Kamiokande Collaboration; Abe, K. et al. 2021; Diffuse Supernova Neutrino Background Search at Super-Kamiokande, Physical Review D, 104, 12, article id.122002

Lee Patrick (Centro de Astrobiología)

Studying the runners:
Characterising the Red supergiant runaway stars in the Magellanic Clouds using Gaia DR3

How massive stars interact with companions in a binary system is a key ingredient of stellar evolution and dictates how massive stars end their lives. Runaway stars are those that have been kicked out from binary systems after e.g. a supernova explosion. We see many such stars in early evolutionary phases, but at the final evolutionary stage - the red supergiant phase - no confirmed runaway has been identified outside of the Milky Way.

This is partly because until the most recent Gaia data release (DR3; June 2022) such stars have been very difficult to identify. With Gaia DR3, proper motions from earlier releases have been supplemented with an additional radial velocity component, which allows one to study the dynamics of these galaxies in greater detail. Given what we know about the evolution of massive stars, how does binary evolution contribute to the dynamics of the red supergiant population of the Magellanic Clouds?

In this project the student would make use of the most recent Gaia data release to study the dynamics of the Large and Small Magellanic Clouds using red supergiant stars and build on recent work to identify candidate RSG runaway stars in the Large Magellanic Cloud. A dynamical model will be obtained for these galaxies and compared with other tracers of dynamical evolution in these galaxies.

The student will then use this model to identify outliers. In this sense, this will be the first homogenous study of runaway red supergiant stars in the Magellanic Clouds. Using simulations, the student will estimate the total number of red supergiant runaways in the Magellanic Clouds. Time permitting, the student may compare these results to evolutionary models to test the physics of binary evolution.

Requirements: This project will be based on Gaia DR3 data which will be downloaded and analysed by the student.

This project will be conducted as part of the Massive Stars research group of the Torrejón site of the Centro de Astrobiología.

For more information contact: lrpatrick at cab.inta-csic.es

Lee Patrick (Centro de Astrobiología)

A chemical map of Red supergiant stars in the Perseus OB-1 association

Red supergiant stars are the final evolutionary stage of the majority of massive stars before a supernova explosion. These stars are extremely useful to test theories of stellar evolution, particularly when they occur in star forming associations of fixed ages. The Perseus OB-1 association is one of the closest such examples to Earth and therefore acts as an excellent laboratory for detailed studies of red supergiant stars.

We have recently obtained high-resolution spectroscopic observations from the Mercator Telescope of all 20 of the red supergiants in Perseus OB-1 association with the aim of searching for binary systems and determining chemical abundances for the targets.

The observations are fully reduced. The student will lead the analysis to determine stellar parameters by developing and applying chemical analysis routines (based on existing routines) using state-of-the-art stellar evolutionary models. The student will generate a grid of models that cover the range of expected parameters and use a minimisation technique to determine the stellar parameters that best describe the observations.

The student will compare the results with abundance measurements in the literature and quantitatively assess the recent claims of extreme chemical homogeneity (Fanelli et al. 2022), which needs to be independently verified.

This project will be conducted as part of the Massive Stars research group of the Torrejón site of the Centro de Astrobiología.

For more information contact: lrpatrick at cab.inta-csic.es

Lee Patrick & Miriam Garcia (Centro de Astrobiología)

Bi-modal metallicity distribution of the IC 1613 galaxy

IC 1613 is a low-metallicity dwarf irregular galaxy with a controversial metal abundance. Recent studies using Blue Supergiant stars suggest that this galaxy contains an intriguing, bimodal metallicity distribution. By determining metallicities of ~40 Red Supergiant Stars (RSGs), using the well tested J-band analysis technique, the student will independently estimate the metallicity distribution of IC 1613 and examine the hypothesis of bimodality.

Spectroscopic observations using the K-band Multi-Object spectrograph on the Very Large Telescope have been obtained. The student will reduce and analyse these data, using a well defined reduction recipe. Using a grid of stellar models the student will determine the effective temperature, metallicity and surface gravity of each star and study the metallicity distribution of IC1613.

Requirements: This project will involve data reduction of near-infrared spectroscopic observations, which require a basic level of coding ability. Coding scripts to perform the spectral fitting may also be developed within python.

This project will be conducted as part of the Massive Stars research group at the Centro de Astrobiología.

For more information contact: lrpatrick at cab.inta-csic.es

Lee Patrick (Centro de Astrobiología) & Jesús Maíz Apellániz (Centro de Astrobiología, ESAC)

Photometric variability of RSGs in the MCs

Red supergiant stars (RSGs) are the final evolutionary stage of the majority of massive stars before a supernova explosion. When a massive star stops burning hydrogen into helium in its core, the star drastically expands its outer envelope and appears as an RSG. Despite their importance for understanding the diversity of observed supernovae, the physics of the atmospheres of RSGs is incomplete, which has implications for our understanding of how much mass massive stars lose throughout their lives and ultimately what the final supernova explosion looks like. Studies of the physics of RSGs have previously focused on individual systems and a complete picture of how variable the atmospheres of RSGs is lacking.

New results from the Gaia mission (DR3; June 2022) allows the study of stellar variability in different evolutionary phases for entire populations of stars in the Magellanic Clouds: two of our nearest neighbour galaxies. In this project the student will study the variability of RSGs in the Magellanic Clouds using a new catalogue of variability based on Gaia DR3. Global trends will be studied and a relationship between evolutionary phase and variability will be developed. The student will analyse this large dataset and use this to place in context the recently observed Great Dimming of Betelgeuse.

Requirements: This project will be based on Gaia DR3 data which will be downloaded and analysed by the student.

This project will be conducted as part of the Massive Stars research group at the Centro de Astrobiología.

For more information contact: lrpatrick at cab.inta-csic.es

Enrique Perez & Ruben Garcia-Benito (IAA), Angeles Diaz (UAM)

Re-evaluating the evolution of the mass-metallicity relation in the VIPERS survey

The mass-metallicity relation (MZR) is one of the most fundamental relations for star-forming galaxies and implies that there is a correlation between the integrated stellar mass and the metal content of these objects. Among the different aspects still under investigation in relation with the MZR are its evolution with redshift and the secondary dependence with star formation rate (SFR).

For this reason, there are an increasing number of deep surveys intended to enlarge the number of galaxies at different cosmological epochs to find more precise answers to these issues.

Among these surveys, VIPERS have compiled spectroscopic information about around 10k objects in the redshift range $0.3 < z < 1.0$.

Metallicity is usually estimated in most works deriving the total oxygen chemical abundance from very simple relations between the flux of certain emission-lines in the local Universe. We have proposed a new method based on photoionization-models that makes use of all available information in a consistent way. The proposed work consists of a re-evaluation of the conclusions made by the VIPERS collaboration in what regards to the evolution of the MZR, using our new method to derive the metal content of the analyzed VIPERS galaxies. The new method will use as input the available information of the main lines emitted by the ionized gas, comparing the results with what has been already published by this collaboration.

Enrique Perez & Ruben Garcia-Benito (IAA), Angeles Diaz (UAM)

Statistical Study of the Radial Variation of the Effective Temperature of Ionizing Clusters in MaNGA Sample Galaxies

MaNGA (Mapping Nearby Galaxies at Apache Point Observatory) is a survey of over 2000 galaxies in the nearby universe, conducted in the optical part of the spectrum using the technique of integral field spectroscopy. This technique allows for obtaining maps with a spatial resolution of about 2.5 arcseconds of all the spectral features.

In this work, we propose to use the database containing the main emission lines produced in the brightest star-forming regions of MaNGA's disk galaxies and utilize a Python-based code to transform that observational information into characteristics of these regions, including their metal content, ionization parameter, and the equivalent effective temperature of the ionizing clusters. The aim is to analyze whether the radial variation of these properties along the galaxies' disks is correlated with other integrated properties, such as their brightness, mass, or morphological type. The study of these characteristics in a large sample is crucial for understanding the formation and evolution mechanisms of these objects.

Given the large amount of data to be processed, as well as the need to use Python to execute the necessary codes for deriving part of the information, it is required that the student has knowledge of Python or similar programming languages.

Isabel Rebollido (CAB)

Delivery of volatile materials in planetary systems with JWST

The presence of water on Earth challenges the models of planet formation, as volatiles are expected to be depleted in the inner regions of planetary systems in the early years of their evolution. Multiple hypothesis suggest an external origin, as comets and asteroids bombarded the surface of rocky planets while the system was dynamically unstable. If this were the case, we can search for similar mechanisms taking place in young forming exoplanetary systems.

Exocomets that can be polluting the surfaces and atmospheres of planets have been detected for decades, but it is now, with the advent of JWST, that we can observe volatile materials in the warm and hot regions of planetary systems, including CO and H2O.

The tasks in this project will include data reduction and analysis of a JWST NIRSpec spectra of a exocomet host star, to search for volatiles and establish upper limits. If the analysis is completed, the results could be submitted to a scientific journal.

The student is required to have a good level of English (both in speaking and writing), and programming skills in python.

Miguel Ángel Sánchez Conde (UAM)

Investigating unidentified Fermi-LAT sources as potential dark matter subhalos

The nature of the dark matter (DM) in the Universe is one of the greatest mysteries of our time, and its quest of utmost relevance for the whole scientific community. This DM has not been directly detected in the laboratory, yet its gravitational effects have been observed at all astrophysical scales. Among the preferred DM candidates, the so-called weakly interacting massive particles (WIMPs) are, undoubtedly, the ones most intensely searched for. Different yet complementary approaches for their detection are possible. Among them, indirect detection techniques aim at detecting WIMP annihilation/decay products, such as gamma rays, neutrinos or antimatter [1,2]. In this Project, the student will analyze data from the NASA Fermi Large Area Telescope (Fermi-LAT) to look for these signatures. We will focus on the most promising unidentified sources in Fermi-LAT point-source catalogs. Indeed, these sources could be DM subhalos annihilating to gamma rays and just awaiting a proper classification [3,4]. In a later step, we will use this information to set constraints on the nature of the WIMP as the DM particle.

This TFM will be carried out within the boundaries of the DArk Matter, AStroparticles and COsmology (DAMASCO) group at the UAM Theoretical Physics Department and the Institute for Theoretical Physics (IFT UAM-CSIC). DAMASCO's current main research interests include the indirect search for dark matter; the analysis of numerical cosmological simulations; high-energy neutrino astrophysics; cosmic-ray astrophysics; multi-messenger astronomy. DAMASCO belongs to the Fermi-LAT Collaboration, the Cherenkov Telescope Array (CTA) Consortium, the Giant Radio Array for Neutrino Detection (GRAND) Collaboration, the Global Cosmic-Ray Observatory (GCOS) Collaboration, and the DESI Collaboration. The group has also an excellent network of collaborations with (local, national, international) experts in astroparticle physics and cosmology.
Further info about the team and research activities: https://projects.ift.uam-csic.es/damasco/

Desirable skills (optional):

- Good English knowledge.
- Good communication skills.
- Good level of programming.

References:

1. G. Bertone, D. Hooper and J. Silk, Physics Reports 405 (2005) 279–390 [arXiv:0404175]
2. E. Charles, M. Sánchez-Conde, et al., Physics Reports, 636 (2016) 1 [arXiv:1605.02016]
3. J. Coronado-Blázquez, M. Sánchez Conde, et al., JCAP 07 (2019) 20 [arXiv:1906.11896]
4. M. Doro, M. Sánchez-Conde, M. Hütten, Adv. in VHE Astrophysics (2022) [arXiv:2111.01198]

Contact and questions: miguel.sanchezconde@uam.es and mwechakama@gmail.com

Miguel Ángel Sánchez Conde (UAM) y Maneenate Wechakama (U. Kasetsart)

Constraining axion-like particle dark matter models with magnetars in gamma rays

One of the greatest mysteries in cosmology, astrophysics and, more in general, in theoretical physics today is the nature of dark matter. Some of the most popular models are based on massive particles called axions or some generalizations like axion-like particles (ALPs), that could be indirectly detected via their coupling with photons [1,2]. Indeed, In the presence of external magnetic fields, they can convert into one another leading to measurable signals. Different magnetized astrophysical environments could be optimal for this ALP-photon mixing. In this project, we will explore a novel target for ALP searches, namely Fast Radio Bursts (FRBs), supposed to be originated by magnetars, i.e., fast-rotating, highly magnetized neutron stars that emit intense beams of energy all across the spectrum. We will focus on high-energy gamma rays. First, we will predict the effect of ALP on MeV-GeV gamma-ray photons coming from these objects. Then, we will use data (already analyzed or not, depending on the interest of the student) from the NASA Fermi Large Area Telescope (Fermi-LAT) to look for these signatures. In the absence of a signal, we will set constraints on the ALP parameter space.

This TFM will be carried out within the boundaries of the DArk Matter, AStroparticles and COsmology (DAMASCO) group at the UAM Theoretical Physics Department and the Institute for Theoretical Physics (IFT UAM-CSIC). DAMASCO's current main research interests include the indirect search for dark matter; the analysis of numerical cosmological simulations; high-energy neutrino astrophysics; cosmic-ray astrophysics; multi-messenger astronomy. DAMASCO belongs to the Fermi-LAT Collaboration, the Cherenkov Telescope Array (CTA) Consortium, the Giant Radio Array for Neutrino Detection (GRAND) Collaboration, the Global Cosmic-Ray Observatory (GCOS) Collaboration, and the DESI Collaboration. The group has also an excellent network of collaborations with (local, national, international) experts in astroparticle physics and cosmology.
Further info about the team and research activities: https://projects.ift.uam-csic.es/damasco/

Desirable skills (optional):

- Good English knowledge.
- Good communication skills.
- Good level of programming.

References:

1. M. Doro, M. Sánchez-Conde, M. Hütten, Adv. in VHE Astrophysics (2022) [arXiv:2111.01198]
2. I. Irastorza & J. Redondo, Prog. in Part. and Nuclear Phys., 102 (2018) 89 [arXiv:1801.08127]
3. M. Ajello et al., PRL, 116 (2016) 161101 [arXiv: 1603.06978]
4. M. Sánchez-Conde et al., PRD, 79 (2009) 123511 [arXiv:0905.3270]
5. V. M. Kaspi & A. Beloborodov, Annu. Rev. Astron. Astrophys, 55 (2017) 261 [arXiv:1703.00068]
6. C. Bochenek et al., Nature, 587 (2020) 59 [arXiv:2005.10828]
7. G. Principe et al., A&A, 675 (2023) A99 [arXiv:2305.09428]

Contact and questions: miguel.sanchezconde@uam.es and maneenate.w@ku.th

Miguel A. Sánchez-Conde (UAM) & Pedro de la Torre Luque (Escuela politécnica, Universidad CEU San Pablo)

Compatibility of Galactic synchrotron emission with current astrophysical predictions

The detected flux of positrons and electrons is still a subject of intense debate nowadays given the problems to understand the sources of these particles and their spatial distribution in the Galaxy. Although we expect them to be mainly produced in cosmic-ray collisions and powerful pulsars, other sources might be at play as well, included exotic sources such as dark matter (DM) annihilation. However, cosmic-ray observables only allow us to probe their emission close to the Solar System, losing the information about their spatial distribution. Since these particles interact with the Galactic magnetic field, they produce synchrotron radiation that our radio-telescopes can observe, thus mapping the distribution of these particles in the full sky. This project aims at understanding the compatibility of the most recent measurements of synchrotron emission in the Galaxy with the current models for the production of positrons and electrons in the Galaxy, looking for possible signatures of exotic sources of these particles, included DM.

This TFM will be carried out within the boundaries of the DArk Matter, AStroparticles and COsmology (DAMASCO) group at the UAM Theoretical Physics Department and the Institute for Theoretical Physics (IFT UAM-CSIC). DAMASCO's current main research interests include the indirect search for dark matter; the analysis of numerical cosmological simulations; high-energy neutrino astrophysics; cosmic-ray astrophysics; multi-messenger astronomy. DAMASCO belongs to the Fermi-LAT Collaboration, the Cherenkov Telescope Array (CTA) Consortium, the Giant Radio Array for Neutrino Detection (GRAND) Collaboration, the Global Cosmic-Ray Observatory (GCOS) Collaboration, and the DESI Collaboration. The group has also an excellent network of collaborations with (local, national, international) experts in astroparticle physics and cosmology.

Further info about the team and research activities: https://projects.ift.uam-csic.es/damasco/

Required skills:

- Good programming skills (C++ and python)
- Good English level

References:

- Di Bernardo et al. Journal of Cosmology and Astroparticle Physics 03 (2013) 036
- Manconi et al. Physical Review Letters (2022) 129, 111103
- De la Torre et al. ArXiv:2307.13731 (2023)
- E. Orlando, Monthly Notices of the Royal Astronomical Society, 475, 2, (2018)
- Evoli et al., JCAP 02 (2017) 015 [1607.07886]
- Evoli et al., JCAP 07 (2018) 006 [1711.09616]

Contact, questions: pedro.delatorreluque@fysik.su.se and miguel.sanchezconde@uam.es

Luis Velilla Prieto (Dept. of Molecular Astrophysics. Instituto de Física Fundamental, CSIC)

Molecular complexity in the rapidly evolving star V Hydrae

Stars in their late stages of evolution play an important role in the enrichment and replenishment of synthesized material in terms of gas and dust. In particular, Asymptotic Giant Branch (AGB) stars are amongst the top contributing sources to the chemical complexity growth and the enrichment of the interstellar medium. These stars produce vast amounts of molecular gas and dust grains that form dense circumstellar envelopes that are further processed due to photochemical processes, shocks, gas-grain interactions, and more. Interestingly, a rapid evolution seems to take place once they evolve through the post-AGB stage in their way to form a planetary nebula.

Recently, we have found an increasingly complex chemistry in the outflows of these post-AGB stars which is probably caused by shocks as a consequence of binary interaction. In order to advance our understanding about this chemical complexity, we aim to investigate the molecular content of post-AGB objects using spectra of these outflows in the millimeter wavelength range. In this work, we propose to study a spectral line survey carried out with the Atacama Pathfinder Experiment (APEX) antenna of the carbon rich post-AGB star V Hydrae. We will use standard reduction and analysis techniques with the software CLASS (GILDAS https://www.iram.fr/IRAMFR/GILDAS/) to identify spectral lines and characterize the circumstellar envelope of this puzzling object.

A good command of English is highly recommended as well as programming skills (any language is good, Fortran, Python, or even knowledge with Matlab).

References:

[1] https://arxiv.org/abs/1412.2074

[2] https://arxiv.org/abs/1609.01904