# Anexo I

## Listado de proyectos de formación

**PlanFormacion-2023-ICE-01**

**Title:** Improving H0 measurement reducing systematic uncertainties of Cepheid distances

**PI:** Lluís Galbany (lgalbany@ice.csic.es)

**Project summary:**

The expansion rate of the universe parameterized by the Hubble-Lemaitre parameter H(z) has been a major endeavor in cosmology since the discovery of the expanding Universe. H(z) is not constant, but rather varies over cosmic time following the deceleration and acceleration of the Universe. In the last years, significant effort has been put forth to measure with high precision the local value of the Hubble-Lemaitre parameter known as the Hubble constant (H0), and today H0 is estimated from the distance ladder with an uncertainty of ~1%. Perplexingly, these findings have revealed a dramatic discrepancy dubbed the Hubble tension: the estimation of H0 from the local distance ladder is in strong disagreement (at 5 sigma or 99.99% level) with the value inferred at high-redshift from the angular scale of fluctuations in the cosmic microwave background (CMB), possibly hinting towards new physics beyond the standard model. This discrepancy represents the most urgent puzzle of modern cosmology, and it is nowadays one of its hottest topics.

One of the ways to alleviate the Hubble tension is to reduce the systematic uncertainties of the methods used to determine H0. For the distance ladder method, one of the main contributors to the systematics is the standardization of Cepheids and type Ia supernovae (SNe Ia). In particular, Cepheids calibration takes into account the known Period-Luminosity relation with a correction based on metallicity. However, the SHOES team assigned to each Cepheid a metallicity based on the radial distance and a metallicity gradient measured from HII regions. To address this possible leading systematic, the student will use integral field spectroscopy (IFS) from 29 of the 37 SH0ES Cepheid and SN Ia galaxies, to measure local metallicities at positions where Cepheid stars are found, and compare them with those used in the SH0ES work. With this exquisite dataset, the student will also map their local environmental properties (star formation rate, stellar age and dust extinction) to explore the environment effects in Cepheid distance estimation and in the determination of the current expansion of the universe H0.

**PlanFormacion-2023-ICE-02**

**Title:** Radio emission from giant planets and brown dwarfs

**PI:** Daniele Viganò (vigano@ice.csic.es)

**Project summary:**

Exoplanetary sciences are living a boom, mostly thanks to the traditional transiting and radial velocity detection methods, and the increasingly improving atmospheric characterization. A more unusual way to study them is their emission at low radio frequencies (below GHz), where actually both Jupiter (the most magnetized Solar planet) and some brown dwarfs (big cousins to giant planets) emit. Intense campaigns to detect such dim but informative emission are on-going, to have direct insights on the magnetic properties of the system, which are very important but still highly unconstrained for exoplanets.

The project consists on one side to identify among these sub-stellar objects the most promising radio-emitter candidates in order to propose radio observations with different international radio interferometers: VLA, GMRT, MeerKAT. A throughout investigation of the existing literature and analysis of archival data will be also performed, together with the understanding of the basic mechanism and flux estimation.

**PlanFormacion-2023-ICE-03**

**Title:** Shear viscosity of electromagnetic plasmas in extreme conditions

**PI:** Cristina Manuel (cmanuel@ice.csic.es)

**Project summary:**

Neutron stars are formed when a massive star runs out of fuel and collapses. With an average of ten kilometers and almost two solar masses, they are the densest objects in the Universe. It is not yet clear what the internal composition of these stars is, and there are different proposed models about their composition. This is an active field of research, which involves the study of matter under the extreme conditions which cannot be attained in terrestrial laboratories.

Understanding the physics of neutron stars, such as their cooling and the dynamics of their hydrodynamical modes, requires knowledge of their transport coefficients, like conductivities and viscosities. On the other hand, the value of the transport coefficients depends on the composition and interaction of the microscopic constituents of the medium.  Thus the computation of transport coefficients and their possible measure can establish a link between the macroscopic and microscopic physics of the star, revealing information about the content and composition of the star. The shear and bulk viscosities are particularly important for assessing damping rates of hydrodynamical modes of the star.  In particular, undamped hydrodynamical r modes could render rotational neutron stars unstable, and this fact is used to put some constraints on the value of the viscosities. The shear viscosity in the core of neutron stars is assumed to be dominated by the collisions of electrons.

In this project we will focus on the computation of the shear viscosity in electromagnetic plasmas under extreme conditions. Computing transport coefficients in plasmas, such as shear viscosity, can be tricky due to potential infrared divergencies from electromagnetic interactions. It is known how to properly assess these problems. One must take into account how the medium modifies the electromagnetic interactions. These techniques have been developed and used so far for ultrarelativistic plasmas. This project aims to compute how the shear viscosity in electromagnetic plasmas is affected when the ultrarelativistic condition is relaxed. The techniques for these computations are known, and only a generalization of some computations will be required. The final computation will have to be carried out numerically. Thus good analytical and numerical skills are necessary to carry out this project.

**PlanFormacion-2023-ICE-04**

**Title:** Analysis of the coincidences between ROHP-PAZ observations and GPM-constellation radar and radiometers

**PI:** Ramon Padullés (padulles@ice.csic.es)

**Project summary:**

The Radio Occultations and Heavy Precipitation aboard PAZ satellite (ROHP-PAZ) is an experiment that had the objective to test, for the first time, the capability of the Global Navigation Satellite System (GNSS) Polarimetric Radio Occultation (PRO) technique to sense precipitation. Led by the Institute of Space Sciences (ICE-CSIC) and on orbit since February 2018, the results of the analyses of first years of data have demonstrated that PRO are not only able to sense rain, but also to provide information of the vertical cloud structures.

The PRO concept represents an enhancement of the standard radio occultation technique, that consists on tracking the signals emitted by GPS satellites from a low Earth orbit satellite occulting behind the Earth's horizon. These signals cross lower and denser layers of the atmosphere as the occultation advances. The augmentation that the polarimetry provides consists on collecting these signals using two linearly and orthogonal polarized antennas (H and V), instead of the circularly polarized one used in the standard technique. Comparing the phase of the signals received at the two antenna ports (ϕH - ϕV), we can infer the presence of hydrometeors along the ray paths. These hydrometeors range from large raindrops to horizontally oriented snowflakes.

With the objective to continue with the validation of the PRO technique and exploit its applications, the aim of this project is to analyze the numerous coincident measurements between the ROHP-PAZ observations and radars and radiometers. The NASA's Global Precipitation Measurement (GPM) core satellite flies a precipitation radar that provides detailed information about rain and, partially, of its associated cloud structure. A significant number of coincidences have been identified between our ROHP-PAZ observations and GPM-core satellite, which are complemented by the microwave radiometer also aboard GPM (GMI). Furthermore, these set of collocations can be extended using all the radiometers from the GPM-constellation.

This project will consist on analyzing the coincidences and infer relationships between the different observables, with special focus on the characterization of the vertical structure of the ROHP-PAZ and radiometer observations, and with the help of machine learning and statistical programming tools.

**PlanFormacion-2023-ICE-05**

**Title:** Radar Signal Processing for ocean current measurements

**PI:** Serni Ribó (ribo@ice.csic.es)

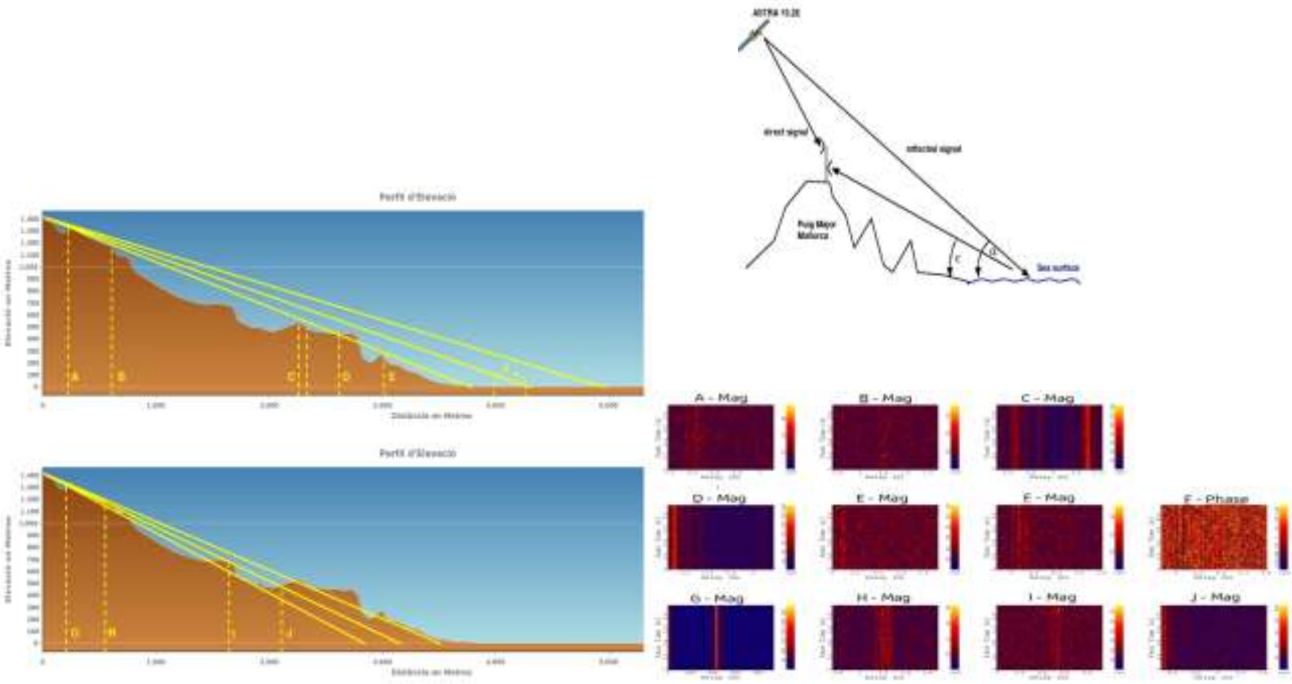
**Project summary:**

In August 2021 an experimental campaign was carried out at the island of Mallorca. On top of its highest mountain, the Puig Major, a set of dish antennas were pointed towards the sea surface to collect digital satellite TV signals reflected from the sea surface. These signals were recorded using a high speed (320 MBytes/s) data recorder.

Later, the signals were processed digitally with the objective to detect the echoes of the signals in a bi-static radar configuration. This preliminary analysis has shown the echos of the signals when they are reflected by nearby hills and mountains.

The objective is now to refine the signal processing and detect the echos from the sea surface. These echos are also affected by the moving wave at the sea surface and by the sea current, which results in a Doppler shift on the frequency of the received echos. We aim at measuring the speed of the waves through the measurement of the Doppler frequency.

This activity requires the use of digital processing techniques and knowledge on radar concepts.



**PlanFormacion-2023-ICE-06**

**Title:** Galaxy Surveys, cosmological parameter constrains from weak lensing and clustering

**PI:** Martin Crocce (crocce@ice.csic.es)

**Project summary:**

The discovery that the expansion of the Universe is accelerating has turned into one of the main mysteries in Physics today, with explanations that range from a new type of "repulsive" energy: the dark energy, or the failure of General Relativity on cosmological scales. Moreover, there is overwhelming evidence of a Dark Matter sector, unseen directly but essential to explain the observed large-scale structure. Seeding light into the nature of these dark components, and establishing a consistent cosmological model from the early Universe until today, is fundamental to turn cosmology into a strongly rooted discipline. Hence, European and American funding agencies have placed the study of Dark Energy through extragalactic surveys at the top of their priority list.

These massive astronomical surveys scan the way millions of galaxies distribute across huge volumes. Several surveys are ongoing or will start in the near future and their common denominator is the unprecedented level of precision at which they will render the large-scale structure of the Universe1. Of particular relevance for ICE is the Euclid/ESA space mission, that is due to be launched in July 2023 and will scan 15,000 deg2 of sky and billions of galaxies, with the main goal of understanding the dark sector. These surveys trace the growth of structure by correlating the position and shapes of galaxies across huge distances and look-back times.

One key aspect of their analysis is being able to compare theory predictions with the direct measurements, in particular in scales dominated by nonlinear physics, where most of the information exists. This is typically done using Markov Chain Monte Carlo techniques, and complex pipelines exist or are being built that incorporate at the same time, the model predictions, the estimation of covariance and errors, the data measurements, to produce posterior predictions for cosmological parameter values after sampling over the likelihood of these parameters. One such pipeline used by the Dark Energy Survey is CosmoSIS, while EUCLID is developing CLOE (a team effort co- coordinated by M. Crocce). In this JAE-ICU we will first overview the field of observational cosmology, aspects such as galaxy clustering or weak gravitational lensing, and then get familiar with the use of one of these pipelines (in collaboration with students and postdocs from the observational cosmology group) with the concrete goal of producing forecast predictions for what Euclid can achieve in terms of constraining power in relevant parameters of the dark sector.

A key requirement for cosmological analysis is that the theory prediction calculations for any parameter are fast (well less than a second). As a spin-off we will also investigate and use a state-of-the-art technique that is being widely used in different areas of cosmology called Emulators, which are basically a machine learning method of high-dimensional interpolation based on Gaussian process that allows to produce such predictions very fast after training the software at specified points in parameter space (e.g. a latin hypercube).

1 https://www.ice.csic.es/research/missions-experiments

**PlanFormacion-2023-ICE-07**

**Title:** Dynamics of Black Holes and their Gravitational Wave emission

**PI:** Carlos F. Sopuerta and Michele Lenzi (sopuerta@ice.csic.es, lenzi@ice.csic.es)

**Project summary:**

Black Holes are becoming a central object in Astrophysics, Cosmology, and in Fundamental Physics (understood in this context as the study of the laws of physics, in particular of gravity). Black Holes are expected to be the end state of the life of compact stars and, according to General Relativity, they can have any mass, which is why they can be relevant in different physical scenarios: Early Universe: primordial black holes formed out of quantum fluctuations; Astrophysics: The fact that they are the endpoint of stellar evolution, tells us about the history and details of star formation; Cosmology: Supermassive black holes sitting at the galactic centers can trace the formation and evolution of galaxies; Fundamental Physics: The way in which Black Holes emit gravitational waves is a precise tool for testing their nature and the nature of gravity.

In this project, we propose to study one of the most distinctive properties of Black Holes: Their quasinormal modes. These are the "natural" modes of oscillation of Black Holes, and they are called quasinormal because, apart from an oscillatory evolution, they are exponentially damped in time since the Black Hole is part of an open system. Quasinormal modes are also the end stage of the evolution and gravitational-wave emission of the coalescence of binary black holes, which is what mostly ground-based gravitational wave detectors as LIGO and Virgo have detected so far (> 90% of the detections). It turns out that General Relativity is telling us that astrophysical Black Holes should be characterized only by two quantities, their mass and their intrinsic rotation, the spin. Therefore, the complex quasinormal frequencies of Black Hole should only depend on these two quantities, which constitutes an ideal situation to make experimental tests.

The main idea behind this project is to use recent developments in the study of perturbed Black Holes, related with the study of quasinormal modes and scattering processes, to revisit properties of the quasinormal modes of spinning Black Holes (Kerr Black Holes). This can provide a deeper understanding of the structure of quasinormal modes and their dependence on the physical parameters, as well as to study their stability under modifications of the theory of gravity or other type of modifications of the standard paradigm.

**PlanFormacion-2023-ICE-08**

**Title:** New approach to identify AGN in large-scale spectroscopic surveys

**PI:** Mar Mezcua (mezcua@ice.csic.es) and Małgorzata Siudek

**Project summary:**

Active galactic nuclei (AGN) are powered by massive black holes and play a key role in galaxy formation and evolution. From an observational point of view, the black hole mass correlates with the properties of the host galaxies, but the origin of this relationship is still largely unexplored and our understanding of the feedback process between black holes and galaxies is still incomplete. Large-scale spectroscopic surveys provide a unique opportunity to study the co-evolution of black hole and host properties. However, the selection of AGN is still a challenging task. The standard selection methods based on emission line ratios result in incomplete and contaminated AGN samples. The goal of this JAE project is to identify AGN based on an unsupervised machine learning method. The high-dimensional nature of galaxy spectra makes it challenging for humans to detect features associated with AGN, but not for advanced machine-learning algorithms. In this project, we aim at developing a new approach to identify AGN using the full information from the galaxy spectra and machine-learning techniques. Such an approach promises unbiased AGN selection and will be of interest for planning future AGN observing strategies. A good knowledge of python and basic knowledge of machine-learning methods is advisable.

**PlanFormacion-2023-ICE-09**

**Title:** The VLA Orion A Large Survey (VOLS): understanding the accretion-ejection connection during the early stages of star formation

**PI:** Josep M Girart (girart@ice.csic.es)

**Project summary:**

The VLA Orion A Large Survey (VOLS) large project has been granted with 306 hours of observing time with the Karl G. Jansky Very Large Array to perform the deepest survey at subarcsecond resolution of the Orion A molecular cloud. By May 25, he VLA has observed more than 60 hours of the project. Initial assessment of the data quality in one of the execution blocks has been done by our group at the ICE (see attached image).

The goal of the VOLS project is to build a census of the stellar population to investigate how the mass accretion rate and the mass-loss rate proceed with the protostellar evolution and how they depend on the birth environment and on the mass of the star. To answer these questions, VOLS will observe at two frequency bands (6 cm and 2 cm) the northern part of the Orion A molecular cloud covering an area of ~0.5 deg 2. Orion A is the nearest star-forming complex containing a broad range of environments populated by protostars and Young Stellar Objects (YSOs) with different masses and evolutionary stages, representing a testbed for star formation theories. The observations at 6 cm will start in March 2022.

The JAE-ICE project is focused to have a first contact with the VOLS data and to learn the data reduction and analysis techniques in aperture synthesis.

The student will work with the C-band (6 cm) data obtained with most extended configuration of the VLA and will be involved in the data reduction and imaging process. The initial tasks to conduct are: i) Learn the data reduction techniques with the CASA package. ii) identify radio sources using source identification algorithms; and, iii) identify emission from radio jets.

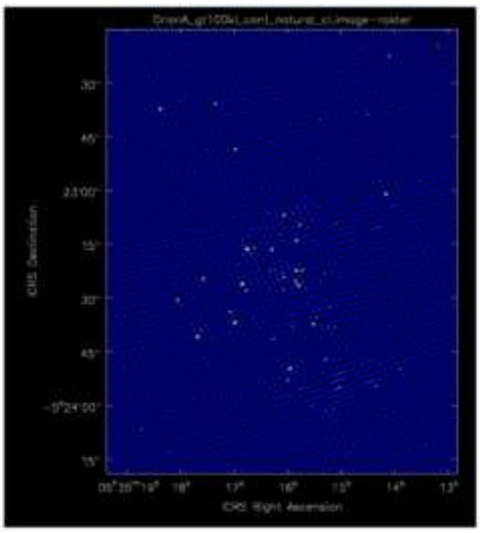


**IMAGE:** The image shows a small portion of the Orion A full image obtained by the Very Large Array on May 5, 2022. The full image has a size of 1.2deg x 0.5deg, and it is composed by more than 1 Giga pixels. The region shown is Orion KL/Irc2 nebula, which is associated with a clusters of low to high-mass Young Stellar Objects (YSO). The image shows the radio emission of some of these YSOs.

PlanFormacion-2023-ICE-10

**Title:** Unveiling the Core Mass Function in star-forming clusters

**PI:** Álvaro Sánchez-Monge (asanchez@ice.csic.es)

**Project summary:**

Most stars do not form in isolation, but in clusters containing hundreds of stars that are initially found deeply embedded inside molecular clouds. Therefore, understanding star and stellar cluster formation requires characterizing the fragmentation process of the molecular cloud into dense cores out of which stars will eventually form. The number of newly-formed stars with a given mass, the so-called IMF (initial mass function), is a key parameter in the study of the formation and evolution of clusters that transcends all astrophysical fields. During the last decades, some theories have claimed that the IMF is related to the masses of the dense cores that fragment out of the molecular cloud, the so-called CMF (core mass function). The first observational results supported this possible connection, however biases and limitations on the spatial resolution and the accuracy of core mass determination may have affected the results obtained so far.

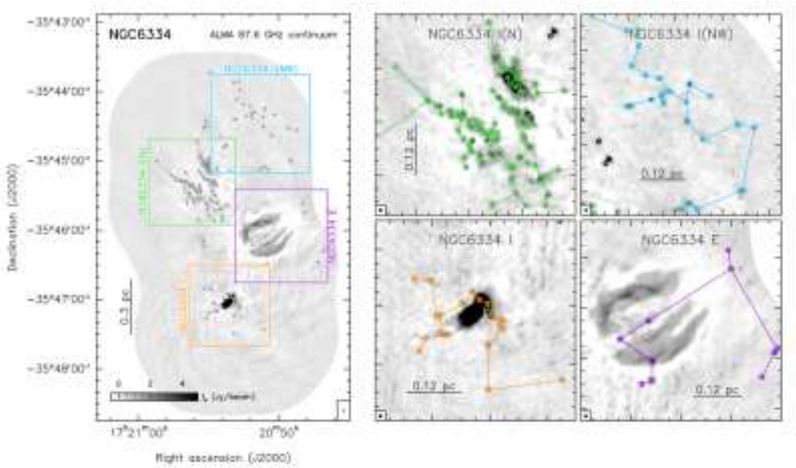



**Figure.** *Previous ALMA band 3 (87.6 GHz) image of the four clusters (marked with colored boxes) in NGC6334. The positions of the cores are marked with circles. The lines in the right panels denote the connection of the cores through a minimum spanning tree. The new ALMA band 6 data provides a resolution and sensitivity 10 times better, allowing us to resolve and detect all the cores in these four clusters.*

We seek to overcome these known observational biases and perform a detailed study of the CMF in four embedded clusters at different evolutionary stages, emerging from the same molecular cloud (see Figure). For this, we have acquired ALMA band 6 (220 GHz) observations, reaching a spatial resolution of 200 au and a mass sensitivity of 0.1 Msun, which will allow us to resolve all the members in the cluster and probe the CMF from low to high core masses. The student will work with new high-quality ALMA data to produce images of the dust continuum emission of the dense cores in these four clusters. Following the generation of the astrophysical images, the student will use automatic procedures to identify and extract all the detected cores. This will permit to determine properties such as their masses, sizes and location within the cluster. With the masses, the CMF of these clusters will be constructed and compared to the IMF. The main tasks to conduct are: (i) to learn data reduction and image generation techniques common in radio-interferometry; (ii) to identify dense cores using source identification algorithms; and (iii) to calculate key physical parameters such as the masses of the cores, which permit to generate the CMF.

**PlanFormacion-2023-ICE-11**

**Title:** Numerical study of magnetic star-planet interaction

**PI:** Fabio Del Sordo (delsordo@ice.csic.es)

**Project summary:**

The study of star-planet interaction has gained momentum in recent years as a consequence of the discovery of exoplanetary systems with architectures very different from that of our own Solar System. In general, though, the observation of this kind of interaction in exoplanetary systems remains somewhat controversial, because so far any tentative detection could not be clearly connected with the orbital motion of an exoplanet. Consequently, a comprehensive theoretical investigation of magnetic interaction is essential. The modeling of magnetic star-planet interaction has blossomed in the past 15 years, making it one of the newest and most active fields in exoplanetary science. Due to the complexity of the problem, the use of state-of-the-art numerical tools is necessary.

With this project we want to simulate the interaction between a potentially magnetized Hot Jupiter and its host star. The model will be based on the case of HD189733b, which is a hot Jupiter orbiting its host star in 2.2 days. This system has been extensively studied with observations aimed at characterizing the planet and its atmosphere. What is really missing in the picture is to say something about its magnetic properties. We propose to simulate the interaction between a stellar wind, consistent with that of the host star, and a magnetized body moving on a 2.2 days orbit. The goal is to make prediction on the shape and size of the magnetosphere of HD189733b, depending on crucial parameters such as its mean magnetic field, its atmospheric evaporation rate, and the mean stellar wind density and magnetization.

In order to do so, we will use the PLUTO code, which is a very versatile numerical tool built to simulate both subsonic and sub-alvenic and supersonic and super-Alfvenic flows.

Finally, this project will provide therefore predictions for the possibility to observe radio emission triggered by star-planet interaction both for the case of HD189733 and for other similar systems.

**PlanFormacion-2023-ICE-12**

**Title:** Development of a magnetic diagnostic subsystem for LISA

**PI:** Miquel Nofrarias (nofrarias@ice.csic.es)

**Start date:** Anytime between September 2023 and January 2024

**Project summary:**

Gravitational waves are a prediction of Einstein's General Relativity recently detected by the on-ground laser interferometers LIGO. LISA (Laser Interferometer Space Antenna) is an ESA mission with expected launch in 2034 aiming to detect gravitational radiation by putting three satellites in heliocentric orbit separated 2.5 million km one from each other, forming a triangle. The Gravitational Astronomy group at the Institute of Space Sciences (ICE) provided the Data and Diagnostics Subsystems of LISA Pathfinder, a precursor mission launched in December 2015 that successfully proved the key technologies to reach the purest free-fall in space to the date, i.e. down to the sub-femto-g [1].

Our group is now leading the Spanish contribution to LISA. The mission in now in its phase B1 (detailed design phase). A particular interesting challenge is the magnetic diagnostic subsystem, which requires to reach sensitivities below 10nT/sqrt(Hz) down to the very stable measuring bandwidth of 0.1 mHz [2]. On top of that, the sensors need to be located close to the free-falling test mass —a condition that cannot be achieved with fluxgate sensors. For that reason, our group already started the development of a magnetic diagnostic subsystem by means of an Anisotropic Magnetoresistors (AMR) [3]. This would allow several improvements when compared to fluxgate sensors. The current baseline for the LISA magnetic diagnostics subsystem is composed by five AMRs distributed around each test mass of the space-craft.

The candidate will join the team developing the LISA magnetic diagnostic subsystem at ICE. He/she will get familiarized with high precision magnetic measurements working in the development of a prototype magnetic diagnostic subsystem and its experimental validation in a test bench. The prototype is composed by a network of AMR sensors with the corresponding high precision acquisition electronics. The test bench includes a mu-metal structure to isolate the sensor from the Earth magnetic field and Helmholtz coils to generate controlled magnetic fields and gradients.

References


[1] M. Armano et al. (2016) Sub-Femto-g Free Fall for Space-Based Gravitational Wave Observatories: LISA Pathfinder Results. Phys. Rev. Lett. 116, 231101

[2] M. Armano et al. (2020) Spacecraft and interplanetary contributions to the magnetic environment on-board LISA Pathfinder. MNRAS. 494, 3014-3027

[3] Mateos, I et al. (2015). Low-frequency noise characterization of a magnetic field monitoring system using an anisotropic magnetoresistance. Sensors and Actuators A: Physical 235. 57 –63.

**PlanFormacion-2023-ICE-13**

**Title:** Machine learning for precision exoplanet studies

**PI:** Guillem Anglada-Escudé, Ignasi Ribas, Manuel Perger, Juan Carlos Morales, Fabio del Sordo (anglada@ice.csic.es, iribas@ice.csic.es, perger@ice.csic.es, morales@ice.csic.es)

**Project summary:**

The current noise floor for exoplanet detection is set by intrinsic astrophysical variability. Among other things, spots, granulation, and localised magnetic fields cause distortion in spectroscopic line profiles that mimic Doppler shifts, and also produce wavelength dependent effects that perturb precision transit photometry. In this project we will use the StarSim tool developed by our group to generate realistic time series of exoplanet measurements and use machine learning methods to produce the inverse solution, that is, the time-series without the contributions from stellar noise. In the project the student will deal with simulated observations, high resolution spectra, photometry, and will involve developing code to use ML tools such as pytorch or tensor flow. The intern will also use real observations from the HARPS/N and CARMENES spectrograph and from photometric surveys such as TESS and ground-based facilities that are publicly available and/or accessible to the group via consortium participation. An outcome of the project can be a research paper and/or contribution to an observing time proposal to apply the developed methodologies. As part of the project, the student shall also contribute to updating and improving modules of the StarSim tool (also in Python). A good understanding of the physical processes involved in producing observable effects is desirable. The student shall participate in all weekly group meetings where s/he will present progress over time.

**PlanFormacion-2023-ICE-14**

**Title**: Orbital evolution of large meteoroids, and their link with asteroids using Python codes

**PI**: Josep M. Trigo-Rodríguez (trigo@ice.csic.es)

**Project summary**:

This research project focuses on the exploitation and comprehensive analysis of the Fireball and Meteorite Research Network (SPMN-CSIC) fireball database with the aim of identifying large meteoroids associated with Near Earth Objects (NEOs) and with potential to produce meteorite falls. The study aims to introduce the candidate in the techniques used to reconstruct fireball trajectories and to infer the pre-atmospheric heliocentric orbits of the meteoroids. At the same time, once the orbits are computed, we plan to answer intriguing questions about the origin of these rocks in dynamic processes delivering these large meteoroids to the Earth region (collisions between Main Asteroid Belt objects, asteroid disruptions in the Near Earth Region, cometary-like outgassing activity, etc…). For the development of this work, some previous knowledge on celestial mechanics, propagation of orbits with numerical methods and Python is required.