Proposals for Master Thesis 2017/2018

Using galaxy correlations to understand the acceleration of the Cosmos

Advisor: **Dr. Martín Crocce** martincrocce@gmail.com

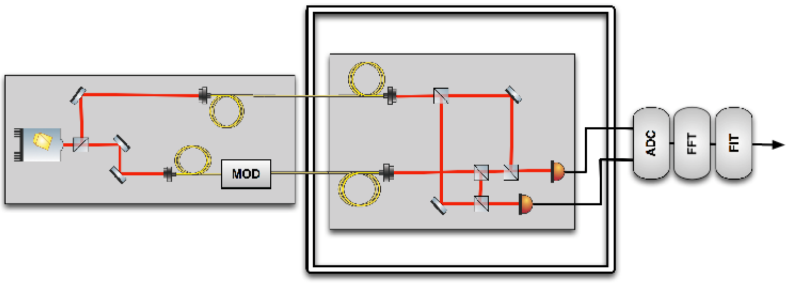
The discovery of the accelerated expansion of the Universe has turned into of the main puzzles in Cosmology, with explanations that range from the need to modify Einstein's theory of Gravity to the existence of new forms of energy. The Dark Energy Survey (DES) is the largest galaxy survey currently operating, scanning millions of galaxies over 1/8 of the full sky, with the goal of understanding why the Universe expands with increasing speed, what is the exact contribution of dark-matter, and many other exciting questions in Cosmology. Our group is strongly involved in DES (https://www.darkenergysurvey.org) with the analysis of the third year of data (out of 5), mainly studying the large-scale distribution of galaxies and their cross-correlation with CMB and weak gravitational lensing. We are also very involved in other surveys such as European ESA/Euclid satellite and the Physics of the Accelerated Universe (PAU). Working in such surveys is at the same time exciting and timely. We propose to develop tools to measure galaxy correlation functions on large scales, and deepen into the theoretical knowledge to interpret that signal through the use of numerical simulations.

Optical metrology noise reduction techniques for space-based gravitational wave detectors

Advisor: **Dr. Miquel Nofrarias** nofrarias@ice.csic.es

Gravitational waves are a prediction of Einstein's General Relativity recently detected by on-ground laser interferometers. LISA (Laser Interferometer Space Antenna) is an ESA mission designed to detect gravitational waves in space, aiming to detect gravitational radiation by putting three satellites in heliocentric orbit separated 1 million km one from each other, forming a triangle. The Gravitational Astronomy group at the Institut de Ciències de l'Espai (IEEC-CSIC) has provided the Data and Diagnostics Subsystems of LISA Pathfinder, a precursor mission launched in December 2015 which has successfully measured the residual acceleration of two free-falling test masses in space down to the $5 \times 10^{-15}\,\mathrm{m/s^2/Hz^{1/2}}$ in the mHz band [1].

Our group is currently developing the techniques required for the future LISA mission. In particular the design of an ultra-stable thermostat able to create a space-like environment allowing high precision optical metrology experiments in the mHz band. The setup consists of an interferometer implementing the deep phase interferometer scheme [2] in a ultra-stable CFRP (Carbon Fiber Reinforced Polymer) bench. The phase measuring system is a FPGA with LEON3 soft-core processor while the temperature read-out subsystem is a replica of the control unit currently flying in the LISA Pathfinder satellite.



Schematic of the setup with the modulation bench (left), the Mach-Zhender interferometer inside the vacuum chamber (middle) and the post-processing taking place in the FPGA (right).

The candidate will work in the implementation of optical metrology noise reduction techniques in the very low-frequency band, i.e. the mHz. This includes the implementation of phase stabilization loops based on optical path-length difference, frequency noise [3] and environment temperature disturbances [4].

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

[2] G Heinzel et al. Deep phase modulation interferometry Optics express 18 (18), 19076-19086 (2010)

[3] G Hechenblaikner et al. Digital laser frequency control and phase-stabilization loops in a high precision space-borne metrology system. IEEE Journal of Quantum Electronics 47 (5), 651-660 (2011).

[4] M Nofrarias et al. Subtraction of temperature induced phase noise in the LISA frequency band. Physical Review D 87 (10), 102003 (2013).

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Theoretical studies of the pulsar / pulsar wind nebula complex

Advisor: **Dr. Diego Torres** dtorres@ice.csic.es
https://sites.google.com/view/dft-research

Pulsars are compact objects at the end of the stellar evolution. They are small and rotate very fast. In doing so they generate high energy phenomenology, perhaps the most interesting of which is the appearance of outflows of particles, a wind. These are called pulsar wind nebulae, and emit all along the electromagnetic spectrum. I have ongoing research projects in this area, studying how the pulsar wind nebula evolve in time and what do they emit while doing so. This is a theoretical research, and its aim is to produce models to compare with multi-frequency observations. I propose you to embark into modelling high-energy astrophysics of compact objects, in particular how the pulsar's evolution may affect the nebulae properties.

You should be interested in using codes, and being willing to produce some bits of codes yourself. You should not fear some paper - pencil computations, nor studying difficult concepts that mix radiation physics, cosmic-rays, hydrodynamics, and some particle physics. I offer dedicated training sessions with introduction to the topics and the codes to be used.

Neutron stars as a laboratory for dense matter

Advisor: **Dr. Cristina Manuel** cmanuel@ice.cat
Advisor: **Dr. Laura Tolos** tolos@ice.csic.es

Compact stars, and more particularly neutron stars, are a unique laboratory for testing matter under extreme conditions. Over the past years a particular effort has been invested in studying different scenarios for the dense phases of matter in the core of neutron stars, from quarks to hadrons at high densities. The final aim is to understand neutron star observables, such as the mass, radius, magnetics fields or rotation, in terms of a plausible scenario for its interior.

For this purpose, theoretical approaches based on effective field theories for hadronic and quark matter have been developed in our group. The master thesis proposed aims at following the study of the interior of neutron stars by applying the previously developed theoretical frameworks to obtain the equation of state and transport properties of dense matter in the core of neutron stars. With these ingredients, we will be able to address the mass and radius of neutron stars as well as the dynamic properties of neutron stars, going from rotation to the effect of magnetic fields onto neutron stars.

Reflectometry of GNSS signals: new opportunities from spaceborne missions

Advisor: **Dr. Estel Cardellach** estel@ice.csic.es

The Earth planet is a complex system with many processes and interactions yet to be characterized. As other planets in the Solar System, relevant bits of information can be obtained from remote measurements taken from the Space or using Space infrastructures. The reflectometry using signals transmitted by the Global Navigation Satellite Systems (GNSS) has been investigated since the late 90s as an opportunistic Earth remote sensing technique. The ICE-CSIC/IEEC is one of the pioneering groups in Europe, as it got involved in 1998. Since then, the group has developed hardware instruments, processing and analysis techniques, performed ground-based, air-borne and stratospheric experiments and has contributed to space-borne GNSS-R mission definitions and assessment studies.

Until recently, most of the experimental work in the field was from low altitude platforms, as no GNSS-Reflectometry (GNSS-R) missions were orbiting and/or providing extensive data sets. With the launch of UK's TechDemoSat-1 (TDS-1) satellite in 2014, NASA's CYGNSS constellation of small satellites (December 2016), the opportunities to prove the GNSS reflectometry techniques from space have increased. GNSS-R data from these missions are already available, opening the chance to test novel analysis techniques and check new scientific applications.

GNSS-R is known to serve for Ocean altimetric applications, Ocean sea roughness characterization (wind and waves, also called scatterometry), land applications such as soil moisture and vegetation indexes, wetland monitoring, and sea-ice and snow measurements. We suggest a few possible topics for the master thesis, all based on analysis of space-borne GNSS-R data sets available at the time of the mater thesis research:

- Image-like analysis techniques of spaceborne GNSS-R data for Ocean scatterometry;
- Novel Ocean altimetric techniques of spaceborne GNSS-R data;
- Wetland monitoring with spaceborne GNSS-R data;
- Characterization of Antarctic sheets with spaceborne GNSS-R data.

The project expects to get publishable results, both/either in conferences and/or in international conferences.

GNSS polarimetric Radio-Occultations for rain characterization

Advisor: **Dr. Estel Cardellach** estel@ice.csic.es

The Earth planet is a complex system with many processes and interactions yet to be characterized. As other planets in the Solar System, relevant bits of information can be obtained from remote measurements taken from the Space or using Space infrastructures.

The ICE-CSIC/IEEC leads a space-borne experiment aboard the PAZ Low Earth Orbiter to conduct, for the first time ever, polarimetric Radio-Occultation (RO) measurements of the Earth atmosphere using Global Navigation Satellite Signals (GNSS). GNSS RO is a well-known technique that originated decades ago to sense other planets' atmospheres. Since mid 90s it has been implemented around the Earth using signals from the navigation satellite systems, and it has been proven to provide accurate profiles of the refractive index of the atmosphere, which can be further inverted into temperature, pressure and humidity, as well as electron content of the ionosphere.

Unlike the existing standard GNSS RO missions, the Radio-Occultation and Heavy Precipitation aboard PAZ (ROHP-PAZ) experiment will use a 2-polarimetric antenna, collecting linear components of the GNSS signals, essentially transmitted at circular polarization. The measurement concept is based on the ancillary delay suffered by the horizontal component of the signal with respect to the vertical one, when crossing tangentially the flattened drops of intense rain.

In preparation for the PAZ launch and ROHP-PAZ operations, the ICE-CSIC/IEEC is putting together a set of synthetic data and inversion algorithms. The master student, with the help of the tools developed at the ICE-CSIC/IEEC, is asked to"

- generate a particular set of polarimetric RO events,
- analyze the goodness of the current inversion algorithms,
- identify the weaknesses of the algorithm, under which circumstances it fails and to which degree, and to contribute suggesting improvements.

The outcome of this master thesis would represent a valuable contribution to the potential success of new opportunistic remote sensing technique and its in-orbit demonstration, the ROHP-PAZ experiment.

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Chemical differentiation in the high-mass protocluster IRAS 20293+395

Advisor: **Dr. Gemma Busquet** busquet@ice.cat
Advisor: **Dr. Josep Miquel Girart** girart@ice.cat

The aim of this project is to investigate the chemical differentiation of the gas in the high-mass star-forming region IRAS 20293+3952 using high angular resolution observation of the $H^{13}CO^+$ (1–0) molecular transition and including data available from the literature of other species (N_2H^+ (1–0), NH_3 (1,1), and NH_2D ($1_{11} - 1_{01}$)).

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Modeling the kinematics of very young protoplanetary disks

Advisor: **Dr. Gemma Busquet** busquet@ice.cat
Advisor: **Dr. Josep Miquel Girart** girart@ice.cat

ALMA superb angular resolution, image fidelity and sensitivity is revealing for the first time a very detailed pictures of the physical and chemical structure of protoplanetary disks. The goal of this project is to use ARTIST, a radiative transfer code, to model the expected kinematics of standard protoplanetary disks models by combining the expected (Keplerian) rotation and infall velocities. The output from these models would be a useful template for comparing with ALMA observations.

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Reflectance properties of asteroids and primitive meteorites

Advisor: **Dr. Josep Maria Trigo** trigo@ice.cat

The ICE is the only Spanish repository of NASA Antarctic meteorites, and is currently analyzing the reflectance properties of pristine chondrites to identify their progenitor asteroids. This minor thesis will compare the reflectance spectra of chondrites and asteroids in order to identify possible links among them. As a significant outcome the asteroids identified could be future targets for sample-return and we could test the reliability of performing asteroid mining.

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Compact radio emission in X-shaped radio galaxies

Advisor: **Dr. Mar Mezcua** marmezcua.astro@gmail.com

Galaxy mergers are known to play a key role in galaxy evolution. Mergers impact strongly both the galaxy morphology and kinematics, and can trigger/fuel the activity of the nuclear supermassive black hole (or active galactic nucleus, AGN). The detailed mechanisms driving this process are however not clearly understood, and further studies are required to constrain and understand the evolution of supermassive black holes in merging or post-merger galaxies. X-shaped radio sources possibly reside in post-merger galaxies and exhibit a peculiar morphology characterized by two pairs of misaligned radio lobes: the high-surface-brightness or active lobes, similar to the pair of jets of 'normal' radio galaxies, plus an additional pair of low-surface-brightness lobes. One possible explanation for this unusual structure is that X-shaped radio galaxies host two unresolved AGN with one pair of jets associated to each of them. Because of the small separation (of a few parsecs) expected between the two AGN, high-resolution radio observations are required to detect them. You will analyze EVN (European Very Long Baseline Interferometry Network) and MERLIN radio observations of a sample of X-shaped radio galaxies showing compelling evidence of a recent merger event. The aims are to detect compact, AGN-like components and to trace weak, existing or relic jets. So far only one binary black hole has been found at parsec-scales, so the discovery of another parsec-scale binary AGN would constitute a major breakthrough.

Seeking for the seeds of supermassive black holes

Advisor: **Dr. Mar Mezcua** marmezcua.astro@gmail.com

How supermassive black holes form and grow is still one of the long-standing questions in astronomy. Supermassive black holes of more than 1 billion solar masses already existed when the Universe was only 0.8 Gyr old. To reach this mass in such a short time, they should have started as seed intermediate-mass black holes (IMBHs) of less than 1 million solar masses and grow very fast via accretion and mergers. Such IMBHs are the missing link between stellar and supermassive black holes and they should be present in the nucleus of dwarf galaxies resembling the first galaxies formed in the early Universe. This is the case of extremely metal-poor dwarf galaxies, whose intense star formation and highly sub-solar metallicities make them ideal laboratories for searching for the seed black holes or IMBHs that populated the early Universe. The combination of high-resolution radio and X-ray observations offer the best tool for detecting such IMBHs in these galaxies. You will analyze EVN (European Very Long Baseline Interferometry Network) radio observations and Chandra X-ray observations of a sample of extremely metal-poor dwarf galaxies whose optical spectra indicate the possible presence of an active black hole. The project will thus allow you to gain experience in two different observational regimes as well as in starting to write a scientific paper on the detection of IMBHs in extremely metal-poor dwarf galaxies.

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Cosmological evolution in phantom cosmologies

Advisor: **Dr. Diego Sáez** saez@ice.csic.es

Since 1998 when two groups independently detected deviations in the brightness distance of supernovae Ia, together with other independent tests as the CMB, the scientific community has mostly accepted that there is a hidden component whose equation of state has a peculiar form, and which has been known as Dark Energy. Within this term a large number of candidates have been proposed, including modifications of Einstein's General Relativity, and fluids with an exotic equation of state, which may be even less than -1, called "phantom" fluids and which mostly lead the evolution of the universe into a singularity. Nowadays we know that the formation of the great structures we observe, as galaxies, clusters, etc ... are the consequence of the gravitational perturbations that occur along the cosmological evolution, and which have their origin in the primordial fluctuations produced during inflation. The distribution of these structures was once one of the first quantitatively accurate tests of modern cosmology and its greater precision with the collection of data that several large projects are carrying out will shed light on how they evolute, and specifically how that mysterious component dark energy behaves. This work is aimed at the student becoming familiar with the treatment of cosmological perturbations, and their effects on the formation of the structure and at the CMB. As main novelty, the student will analyse the effects that unconventional state equations for the dark energy, as the phantom fluids, may have on the equations of (classic) perturbations, and possibly on the distribution of galaxies, giving rise to a better understanding of the nature of dark energy.

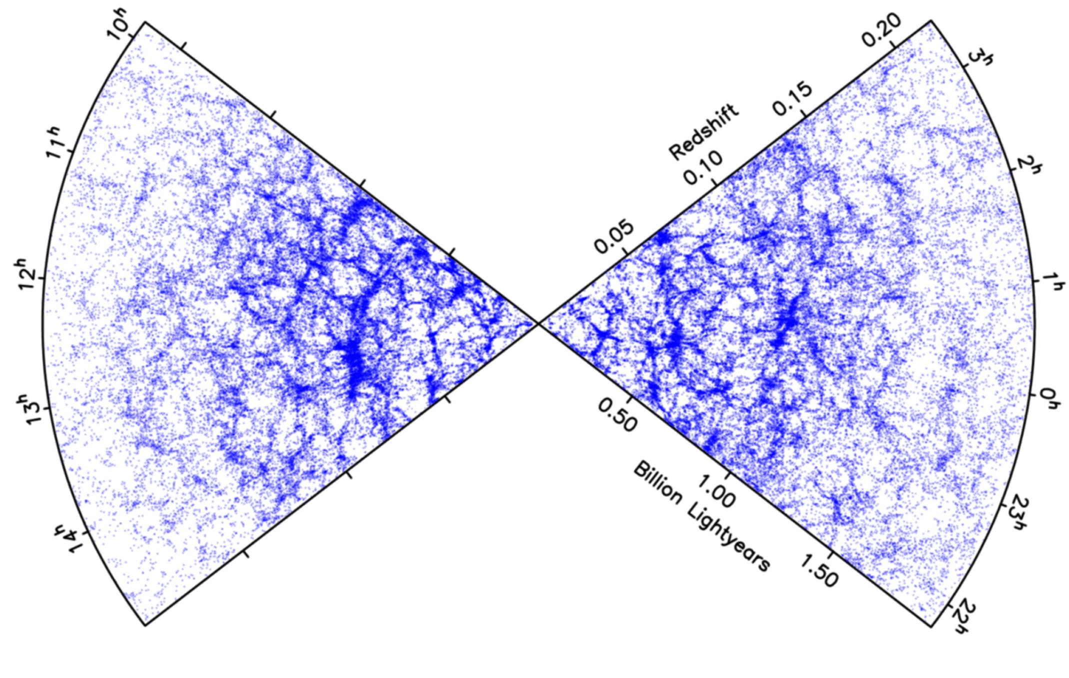

Figure 1: The 2dF Galaxy Redshift Survey

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Rain detection using digital satellite TV signals

Advisor: **Dr. Serni Ribó** ribo@ice.csic.es

Digital satellite TV signals are broadcast from geostationary satellites to reach the dish antennas at our homes. But these signals do also reach clouds and rain clusters, from which they are scattered. By acquiring these scattered signals and processing them appropriately, properties of the scattering volume can be derived, as for instance rain intensity. ICE has developed and advanced scientific digital satellite TV signal receiver (PARIS-MB) capable of acquiring such signals.

The proposed activity consists of using the PARIS-MB receiver to obtain signals reflected from rain events. The tasks to be carried out are:

- Definition and preparation of the instrumental set-up.
- Planning and execution of the experimental campaign to collect TV-sat signals scattered by rain.
- Processing and analysis of the collected data.

Sea-surface wave measurement using digital satellite TV signals

Advisor: **Dr. Serni Ribó** ribo@ice.csic.es

Digital satellite TV signals are broadcast from geostationary satellites to reach the dish antennas at our homes. But these signals do also reach the surface of the earth, and in particular the surface of the sea, from which they are reflected. By acquiring these reflected signals and processing them appropriately, properties of the reflecting surface can be derived, as for instance the sea-surface roughness. ICE has developed and advanced scientific digital satellite TV signal receiver (PARIS-MB) capable of acquiring such signals.

The proposed activity consists of using the PARIS-MB receiver to obtain sea-surface wave measurements. The tasks to be carried out are:

- Definition and preparation of the instrumental set-up.
- Planning and execution of the experimental campaign to collect TV-sat signals reflected on the sea-surface.
- Processing and analysis of the collected data.

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Primordial power spectra in f(R) models of inflation

Advisor: **Dr. Emili Elizalde** elizalde@ice.cat
Advisor: **Dr. Sergei Odintsov** odintsov@ice.cat

The power spectra of f(R) inflation using a new technique in which the norm-squared of the mode functions is evolved will be studied. Results will be confronted with analytic approximations for how the spectra depend upon the function f(R). The spectra will be numerically compared in the Jordan and Einstein frames for the same wave number k, and the dependence upon the geometries of these frames in quite different ways, will be discussed. In particular, in terms of the number of e-foldings until end of inflation. Techniques to distinguish f(R) inflation from scalar-driven inflation will be implemented.

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New gravity models deviating from R^2 inflation

Advisor: **Dr. Emili Elizalde** elizalde@ice.cat
Advisor: **Dr. Sergei Odintsov** odintsov@ice.cat

New inflationary scenarios in theories beyond the Starobinsky model, in particular a class of theories described by arbitrary functions of the Ricci scalar and the K-essence field will be studied in detail. The pathologies associated with higher-order equations of motion, which are known to constrain the stability of this class of theories, will be further investigated. A general framework to calculate the slow-roll parameters and the corresponding mappings to the theory parameters will be developed. For some new gravitational models within the class of theories under consideration we want to illustrate the power of the Planck/Bicep2 latest data in order to constrain such gravitational Lagrangians.

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Stellar migrations and their impact in the chemical evolution of the Galaxy

Advisor: **Dr. Jordi Isern** isern@ice.csic.es

Besides moving around the center of the galaxies, stars experience radial and vertical movements in such a way that there is mixing between the different populations of stars. All in all results in a chemical evolutionary scenario different from the classical one. In this TFM we propose to examine the problem, to build simple semianalytical models and to check the impact of such migrations in the galactic populations of stars.

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Modeling galaxy surveys with cosmological simulations

Advisor: **Dr. Pablo Fosalba** fosalba@ice.csic.es

The new generation of galaxy surveys will probe the 3D distribution of galaxies and dark-matter with exquisite detail over a large volume of the universe. Mining this big datasets we will be able to constrain cosmological parameters with unprecedented accuracy. But in order to extract this wealth of cosmological information in an optimal way we need to model the observables with a great level of realism. This requires modeling the non-linear growth of structure in the universe under dark-matter self-gravity, what is only possible with the use of numerical (N-body) simulations.

We offer the possibility to run state-of-the art numerical simulation codes, in collaboration with the MICE team (http://maia.ice.csic.es/mice/), in one of the largest supercomputers in the world, the Marenostrum4 (https://www.bsc.es/marenostrum). These simulations model the growth of the large-scale structure, known as the "cosmic web", and they are a key ingredient to build realistic galaxy mocks. The student will also have the opportunity to contribute to the development of tools to construct synthetic galaxy catalogs that will be used for the scientific preparation and exploitation of leading galaxy surveys, in which our group is actively involved, such as DES, DESI, Euclid, PAU and LSST.

X-ray emission from classical novae as observed with the NASA Swift satellite

Advisor: **Dr. Margarita Hernanz** hernanz@ice.csic.es

Since its launch in 2014, the NASA Swift satellite has detected X-ray emission (in the soft energy range) in several classical nova explosions, happening on accreting white dwarf stars in binary systems. The soft X-rays originate on the hot white dwarf photosphere. These observations have a strong impact on the understanding of the remaining nuclear burning on top of the white dwarf after the explosion and on the nova explosion process itself.

A census of the novae discovered by the Swift/XRT instrument will be performed. In addition, a detailed study of the observations of one of the novae (spectra and X-ray light curve) by means of standard data reduction techniques will be done. Finally, data will be fitted with both analytical and numerical models of hot white dwarfs atmospheres, and the relevance for the understanding of the nova phenomenon will be analyzed.

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<u>**Asteroseismic characterization of stars with solar-like oscillations**</u>

Advisor: **Dr. Aldo Serenelli** aldos@ice.csic.es

Solar like-oscillations are ubiquitous in stars with convective envelopes. Based on space missions such as Kepler and K2, it is now possible to characterize stellar properties by modeling their oscillation spectrum with numerous applications: characterization of stellar populations for studies of galactic structure, studies of internal stellar structure, determination of properties of exoplanet-host stars, and more. These studies rely on asteroseismic data in combination with stellar evolution models and statistical Bayesian methods to determine stellar properties.

Different possibilities are offered for a master thesis: application of existing codes to Kepler/K2 datasets for modeling giant and/or dwarf stars, development of new generation of analysis tools and stellar models to apply to Kepler/K2 asteroseismic data and in preparation for the NASA mission TESS (to be launched in December 2017) that will provide asteroseismic data for about one million stars.

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