Master Thesis Proposals

2023-2024

Space Sciences

Faculty of Sciences

Liège University

Important notice!

The present catalogue is especially relevant for master theses in the ***Research focus***.

Its content **is not exhaustive**, and students are encouraged to contact specific teachers/researchers to ask them about potential alternatives if they are interested in other topics.

For the ***Professional focus***, the master thesis must mainly consist of an internship and there is no specific offer prepared in advance. Students are encouraged to search for opportunities out of the AGO Department. To do so, contacting other institutes is highly recommended, including

- Liège Space Centre (Sart-Tilman) : http://www.csl.uliege.be (or via S. Habraken, C. Barbier, M. Georges)

- Belgian Institute for Space Aeronomy (Brussels) : http://www.aeronomie.be/en/

- Royal Observatory of Belgium (Brussels) : https://www.astro.oma.be/en/

- Royal Institute for Meteorology (Brussels) : https://www.meteo.be/en/

- The AMOS company (Sart-Tilman) : https://www.amos.be/

- The Aerospacelab company (Mont-Saint-Guibert): https://www.aerospacelab.be/

… or any other company involved in space activities.

About master theses out of ULiège...

Students involved in internships (abroad, in Belgium, and even at the Centre Spatial de Liège) have to fill in an internship agreement and a risk analysis sheet. These documents must be completed in consultation with the person responsible for the internship at the host institution, with the agreement of the teacher/academic supervisor in ULiège.

For any question or request for assistance, the contact person for the Faculty of Sciences is Mrs Kristel Karremans: Kristel.Karremans@uliege.be

In addition, for a stay abroad it is mandatory to follow an on-line procedure to officially request the authorization to the Rector of the University (MODUS platform). This is necessary for the validation of the activity abroad in the student's master program and for benefiting of an insurance coverage. The request should be introduced at least one month (sooner is better!) before the expected date of departure.

Astroparticles, Dark matter and Gravitational waves

Contact person : J.R. Cudell

e-mail : jr.cudell@uliege.be

Tel : 04 366 3654

Office: 4/44 (B5a)

Availability: most afternoons in May or June. Check via e-mail if you want to be sure,

Thematics : Cosmology and astroparticles

Description:

A number of possibilities exist (in particle physics, astroparticle physics, dark matter, gravitational waves,…), and I encourage interested students to come and see me.

Gravitational microlensing by primordial black holes

Contact person : Dominique Sluse

e-mail : dsluse@uliege.be

Tel : 043669797

Office: B5c, +1/10

Availability: The interested student(s) should contact me by email to organise a meeting.

Thematics : Cosmology, Astrophysics

Description:

Large separation gravitationally lensed quasars are rare systems constituted of quasar images separated on the sky by several tens of arcseconds. They are generally found behind strong lensing clusters of galaxies which produce multiple images of a background quasar and of other distant galaxies. Because of these characteristics, the line-of-sight towards those lensed images is expected to be dominated by dark matter. If a small fraction of the dark matter is constituted of primordial black holes, or if low mass dark matter “clumps” are present, one may expect microlensing to occur and modify the apparent brightness of the background lensed image. This master thesis aims at forecasting microlensing by primordial black holes in known large separation systems. The impact of the source size on the expected occurrence of microlensing will also be studied.

These forecasts may be compared to real data. For several systems, it is possible to derive observational constraints on the presence of microlensing from spectra and lightcurves of lensed images available in the group or in the literature. This work could constitute a first step before a PhD thesis related to microlensing.

Prerequisites: Experience with python programming (e.g. via SPAT0002-1: Programming techniques, numerical methods and machine learning) is needed. Other recommended courses: Extragalactic astrophysics (SPAT0011-1).

Searching for strongly lensed galaxies in large sky surveys

Contact person : Dominique Sluse and Ludovic Delchambre

e-mail : dsluse@uliege.be, ldelchambre@uliege.be

Tel : 043669797

Office: B5c, +1/10

Availability: The interested student(s) should contact us by email to organise a meeting.

Thematics : Cosmology, Astrophysics; Instrumentation and methods

Description:

Strongly lensed galaxies and quasars are used for a variety of astrophysical applications. Less than a thousand of them are currently known but several tens of thousands will be hiding in the images of upcoming large surveys such as the Euclid space mission to be launched in July (https://sci.esa.int/web/euclid) and the Large Synoptic Survey Telescope Corporation's mission. Finding those systems among the billions of galaxies present in the data is like searching a needle in a haystack. Machine learning plays a key role in finding new systems but the purity of the sample is not yet sufficient.

We propose to expand the preliminary development of a new search method which consists in performing non-parametric modeling of galaxies and identify lenses using a combination of machine-learning techniques applied on the space of non-parametric indices representing the image. This project will build on this previous work and apply the method to an existing survey (CFIS-r - UNIONS) to search for new gravitationally lensed system candidates. This work could constitute a first step before a PhD thesis related to strong-lensing.

Other projects related to extragalactic astrophysics and/or gravitational lensing are possible. Contact us for more information

Prerequisites: Experience with python programming (e.g. via SPAT0002-1: Programming techniques, numerical methods and machine learning) is needed. Other recommended courses: Extragalactic astrophysics (SPAT0011-1), Astrophysical observations (SPAT0068-1), Traitement de données (PHYS0931-1).

The dark matter content of strongly lensed galaxies

Contact person : Dominique Sluse

e-mail : dsluse@uliege.be

Tel : 043669797

Office: B5c, +1/10

Availability: The interested student(s) should contact us by email to organise a meeting.

Thematics : Cosmology, Astrophysics; Instrumentation and methods

Description:

Strong gravitational lensing provides the most accurate measurement of the total mass of galaxies. By comparing the total and the stellar mass of lensing galaxies it is possible to derive the dark matter content of those systems. The proposed project aims at studying in detail several gravitational lensing galaxies to infer their stellar mass, measure their kinematics, and hopefully dark matter content, based on multiple data sets:

· Photometry derived from Hubble Space Telescope imaging data

· Spectroscopy from ESO-MUSE integral field spectroscopy data

The photometry will be used to infer accurate morphological information on the lensing galaxy: effective radius, ellipticity, evidence for isophotal twists, color gradients, ... while the spectroscopy may be used to infer the lens velocity dispersion and stellar mass. Those results will be combined with existing strong lensing models to infer the dark matter distribution in those galaxies.

This work may be the building block of several follow-up studies. One of them consists in using lensed quasars for measuring the expansion rate of the Universe (i.e. the Hubble constant H0). Another application consists in probing the structure of the lensed quasar using gravitational microlensing. This work could constitute a first step before a PhD thesis dedicated to one of those topics.

Prerequisites: Experience with python programming (e.g. via SPAT0002-1: Programming techniques, numerical methods and machine learning) is needed. Other recommended courses: Extragalactic astrophysics (SPAT0011-1), Astrophysical observations (SPAT0068-1), Traitement de données (PHYS0931-1).

Gravitational lensing aided study of the variability of AGNs

Contact person : Dominique Sluse

e-mail : dsluse@uliege.be

Tel : 043669797

Office: B5c, +1/10

Availability: The interested student(s) should contact me by email to organise a meeting.

Thematics : Cosmology, Astrophysics; Instrumentation and methods

Description:

The stochastic variability of quasars has been recognized and studied since the discovery of the active galactic nucleus (AGN) phenomenon. While long term lightcurves of millions of quasars are expected to be obtained in the next decade thanks to the Large Synoptic Survey Telescope Corporation's mission, there is evidence that the current cadence and observing strategy of the survey is sub-optimal for recovering the statistical properties of the AGN lightcurves.

This project proposes to use multiply imaged AGNs to reconstruct a more densely sampled lightcurve and partly fill inter-season gaps. The student will simulate the variability of gravitationally lensed quasars, and characterizing the statistical properties of the signal for various plausible lensed AGN configurations. In the second part of the project, the student will self-consistently emulate the presence of microlensing in the lightcurve and evaluate how much the latter affects the recovered intrinsic statistical properties of the lightcurves. A related project aiming at discovering lensed AGNs from blended light curves may be envisioned.

This work could constitute a first step before a PhD thesis dedicated to micro-/strong-lensing.

Prerequisites: Experience with python programming (e.g. via SPAT0002-1: Programming techniques, numerical methods and machine learning) is needed. Other recommended courses: Extragalactic astrophysics (SPAT0011-1), Astrophysical observations (SPAT0068-1), Traitement de données (PHYS0931-1)

New methods for dissecting integral field spectroscopy observations of gravitationally lensed quasars

Contact person : Dominique Sluse

e-mail : dsluse@uliege.be

Tel : 043669797

Office: B5c, +1/10

Availability: The interested student(s) should contact me by email to organise a meeting.

Thematics : Instrumentation and methods

Description:

The observation of strongly lensed quasars with integral field spectroscopy provides invaluable insights on those systems. They enable one to measure the lensing galaxy redshift, the lens velocity dispersion, as well as the properties of the lensed quasars and sometimes also of its host galaxy.

One of the observational challenges in analyzing such data arises from the fact that the atmospheric seeing blends the flux of the quasar images and of the host galaxy.

This project aims at exploring how a standard machine learning technique, the principal component analysis (PCA), can be used to de-blend spectra using both the spatial and the color information of the data encoded in integral field spectroscopy data. After reviewing existing literature on the topic, the student will simulate ideal integral field spectroscopy data similar to state-of-the art one. Then, PCA decompositions will be applied to those data, for various levels of observational complexity.

Depending on the student's interest and skills, alternative methods may also be considered. In particular, one may consider the development of state-of-the-art deep learning techniques for achieving the same task.

This work could constitute a first step before a PhD thesis analyzing large samples of integral field spectroscopy data of gravitationally lensed quasars.

Prerequisites: Experience with python programming (e.g. via SPAT0002-1: Programming techniques, numerical methods and machine learning) is needed. Other recommended courses: Astrophysical observations (SPAT0068-1), Traitement de données (PHYS0931-1).

Line profile variability in peculiar massive stars

Contact person : Gregor Rauw & Yaël Nazé, High-Energy Astrophysics Group

e-mail : g.rauw@uliege.be

Tel : 04/366 9740

Office: Institut d'Astrophysique & Géophysique, Bât B5c, Allée du 6 Août, 19c, room 2/2

Availability: interested students are invited to contact the coordinator by e-mail to arrange an appointment

Topic: stellar astrophysics

Description:
Some massive OB-type stars display variations of their spectral lines that hint either at (non-radial) pulsations at their surface or structures inside their circumstellar environment. Studying these phenomena opens new avenues to learn more about the fundamental properties of these stars. Indeed, the properties of pulsations reflect the internal structure of the star, whilst the structures in the circumstellar environment bear information about its dynamics and the possible impact of a companion star on this environment. Observationally studying these phenomena requires long series of high-quality spectroscopic observations. Over recent years, our team has collected such data for several peculiar massive stars.
The student is asked to

- get acquainted with the properties of the target stars and with the general subject of spectral line profile variability in massive stars,
- normalize and analyse the spectroscopic observations that have been collected for the target stars,
- apply a series of tests to the time series of spectra of each of the stars to search for variability, specify its significance level and to establish possible periodicities,
- and finally, compare the results with what is known about the targets in the literature and discuss the implications of the results.

Remarks: attending or having attended the course on “Variable Stars” is clearly an advantage.

Evolution of orbital parameters of binary systems during a mass transfer episode

Contact person : Gregor Rauw, High-Energy Astrophysics Group

e-mail : g.rauw@uliege.be

Tel : 04/366 9740

Office: Institut d'Astrophysique & Géophysique, Bât B5c, Allée du 6 Août, 19c, room 2/2

Availability: interested students are invited to contact the coordinator by e-mail to arrange an appointment

Topic: stellar astrophysics, celestial mechanics

Description:
Many (massive) OB-type stars are members of close binary systems where the stars will fill up their Roche lobe at some point of their evolution and transfer mass and angular momentum to their companion. An important question related to this interaction is how it impacts the parameters of the orbit such as its eccentricity and semi-major axis. In the literature, it is frequently assumed that a Roche lobe overflow episode will circularize the orbit almost instantaneously, but more recent work indicates that this is not necessarily true, at least not for binaries where the mass gainer is a compact object (white dwarf or neutron star). It is less clear though whether these conclusions also hold for binaries containing non-degenerate mass gainers.
The student is asked to

- get acquainted with the subject of mass and angular momentum exchange in general and the theoretical work on compact object mass gainers in particular,
- formulate the expression of the perturbing force created by the mass transfer and express the associated secular perturbations of the osculating orbit by means of the Gauss equations,
- implement a numerical scheme to integrate the equations of the perturbations of the parameters of the osculating orbit and apply it to several specific configurations,
- compare with the results for compact mass gainers and discuss the implications of the results.

Remarks: attending or having attended the course on “Celestial Mechanics and Space Trajectories” is a pre-requisite, attending or having attended the course on “Variable Stars” is an advantage.

Eclipses in massive star binaries

Contact person : Yaël Nazé & Gregor Rauw, High-energy astrophysics group

e-mail : ynaze@uliege.be

Tel : 04/366 9720

Office: B5C, +2/12

Availability: interested students are invited to contact the coordinator to arrange an appointment

Thematics : stellar astrophysics

Description:

Massive OB stars often reside in binary systems. When such systems are seen under a high inclination, eclipses may occur. The analysis of these events helps pinpointing the fundamental properties of the stars. To this aim, high-quality photometric data are required, but the TESS satellite now provides such data for nearly the whole sky. The student will examine light curves of a large sample of OB stars, to detect the eclipsing cases, then analyze these curves with a specific software to derive the physical parameters, and finally see how the results fits into the knowledge of massive star systems.

Remarks: attending or having attended the course “variable stars” is clearly an advantage

The age of an Ancient: systematic study of Methuselah's star / HD 140283

Contact person : Gaël Buldgen & Marc-Antoine Dupret

e-mail : gbuldgen@uliege.be, ma.dupret@uliege.be

Tel : 04 366 97 32

Office: B5c +1/12

Availability: Anytime from mid-May to mid-july

Thematics : Astrophysics: Stellar physics, Asteroseismology

Description:

Context: HD 140283 is a low mass subgiant branch star that has often been dubbed "the oldest star in the Universe" and some of its age determinations have challenged cosmological models (providing an age of the Universe of 13.7Gy). Indeed, numerous studies have attempted at determining precisely its age and have provided values between 14.5 and 12 billion years. So far, no systematic study of the uncertainties entering the computation of stellar evolution models has been carried out, meaning that these age estimates are still subject to debate.

Method: The student will be introduced to the Liège Stellar Evolution Code (CLES) and to the Stellar Parameters INferred Systematically (SPInS) software. Grids of models will be computed with CLES to study systematically the variations of the age of HD140283 with physical ingredients such as the transport of chemicals, the opacity tables and nuclear reaction rates. If time allows it, the student will also investigate the potential impact of seismic constraints on the determined age and the lifting of degeneracies on the determinations of the stellar parameters.

Recommended courses and prerequisites: A good knowledge of stellar physics is required (Stellar evolution I and II), introduction to asteroseismology is recommended (Stellar stability and Asteroseismology). Introduction to Python and Fortran programming languages is recommended.

Seismic probing of subgiant stars with mixed modes

Contact person : Marc-Antoine Dupret

e-mail : ma.dupret@uliege.be

Tel : 04 366 97 32

Office: B5c +1/12

Availability: Anytime from May to mid-july

Thematics : Astrophysics: Stellar physics, Asteroseismology

Description:

Context:
Once their central hydrogen is exhausted, low-mass stars leave the main sequence, become subgiants and next red giants. At this evolutionary stage, stars are composed of a small-sized helium core in contraction located below a thin hydrogen-burning shell, all surrounded by a diluted expanding envelope. Due to their core-envelope structure, they exhibit a peculiar kind of stochastically-excited oscillations called mixed modes. These modes can propagate in the central radiative region, where they behave as gravity modes, and in the convective envelope, where they behave as acoustic modes. Unlike pure acoustic modes in main-sequence stars, the frequency pattern of mixed modes in the subgiant and red giant phase gives us the unique opportunity of probing the properties not only of their outer envelope, but also of their inner layers. Space missions like CoRoT and *Kepler* revealed such very rich spectra of oscillation including mixed modes.

Proposed work:
In the team ASTA, we have very recently developed the software EGGMiMoSA, a unique tool for the asteroseismic probing of subgiants and red giants with mixed modes. We also have our own stellar evolution code CLES and stellar adiabatic oscillation code LOSC. The aim of this Master Thesis project is to use these tools for the first seismic probing of well-chosen subgiants with very rich oscillation spectra observed by the *Kepler* spacecraft. The work of the student will first consist in determining the set of relevant seismic indicators and measure their observational values for the selected targets. Next, he/she will compute a grid of stellar models encompassing these targets and study how the seismic indicators depend on the global parameters of these models. Finally, he/she will use EGGMiMoSA for an automatic search of the stellar models best reproducing the seismic observations. As key results of this study, the mass, age, chemical composition, extra-mixing (the so-called overshooting) of these stars will be accurately determined for the first time. This work could constitute a first step before a PhD thesis dedicated to the detailed seismic study of numerous subgiants observed by *Kepler*.

Recommended courses: Stellar structure and evolution I SPAT0044-1 (& II SPAT0045-1) & Stellar stability and asteroseismology SPAT0005-1

Impact of He-burning cores on pulsation spectra and application to observations in the case of hot subdwarfs and red clump stars

Contact person : Valerie Van Grootel and Marc-Antoine Dupret

e-mail : valerie.vangrootel@uliege.be and ma.dupret@uliege.be

Tel : +32 4 366 97 30 et +32 4 366 97 32

Office: B5c, +1/13 et +1/12

Availability: any time by email for a first contact. We'll then convene for an appointment to discuss the topic in more detail.

Thematics : Astrophysics

Description:

In advanced stages of evolution, stars burn Helium into Carbon and Oxygen in their cores. The structure of this core is complex, because of the onset of convection and associated processes (semi-convection, overshooting, etc.) and the growth of the core as long as Helium burns.

The first step of this master thesis is to study, from stellar evolution models (in particular computed with CLES, the Liège stellar evolution code), the impact on the pulsation spectra of the structure and the evolution of He-burning cores.

The second step is to make links between these theoretical pulsation spectra with the observed pulsation spectra for core-He burning stars. Many core-He burning stars pulsate (subdwarf B stars or Extreme Horizontal Branch stars; Red giant stars of the Red Clump), and their observed pulsations are well constrained thanks to recent space missions (Kepler, TESS, etc.).

This master thesis is in the field of asteroseismology and is well suited for a student who likes theoretical modelling, as well as making links between theory and observations.

Recommended courses: SPAT0005-1 *Stellar Stability and asteroseismology,* SPAT0045-1 *Stellar structure and evolution II* (Pr. M.A. Dupret)

Modeling TESS data of extreme horizontal branch stars by asteroseismology

Contact person : Valérie Van Grootel

e-mail : valerie.vangrootel@uliege.be

Tel : +32 4 366 97 30

Office: B5c, +1/13

Availability: Any time by email for a first contact. We'll then convene for an appointment to discuss the topic in more detail.

Thematics : Astrophysics

Description:

The TESS satellite from NASA gathers since December 2018 high-quality photometric data on various stars, for searching transiting exoplanets but also for asteroseismology. Asteroseismology is the study of stellar oscillations in order to tightly constrain the physics inside stars and hence, to refine the models of the structure and the evolution of stars. Among these stars, TESS observes each month (one Sector of the sky each 27 days) dozens of extreme horizontal branch stars, and discovers/confirms pulsations in a few of them. Extreme horizontal branch stars, also known as subdwarf B (sdB) stars, represent an advanced stage of stellar evolution. These hot (T_{eff}=20,000-40,000 K) and compact (log g=5.2-6.2) objects burn helium in their cores into carbon and oxygen and are surrounded by an extremely thin H-rich envelope. Understanding the formation of sdB stars is one of last big mysteries of stellar evolution.

The proposed master thesis concerns the asteroseismic modeling of sdB stars observed by TESS. First step will consist in selecting the most promising targets for asteroseismic modeling: presence of a rich pulsation spectrum, availability of good spectroscopic constraints. The second step is preliminary asteroseismic analyses on the most promising targets, in order to select one that will be studied in depth during this master thesis in the third step. The asteroseismic modeling consists in quantitatively comparing the computed oscillation periods for large sets of stellar models to the observed periods. By optimizing this comparison (through genetic algorithms that have been developed for this purpose) to find the best-fitting model to the observations, the seismic modeling will yield the global parameters (e.g. stellar mass and radius) and internal structure and composition (e.g. envelope layering, core composition) of the star. Results will then be exploited, by comparing them to those of other sdB stars modeled by asteroseismology and by interpreting them in a context of sdB formation. All the tools are available and ready for a direct application to these TESS data.

This subject is well-suited for a student who like to work on practical applications of asteroseismology and space-based observations.

Recommended courses: SPAT0005-1 *Stellar Stability and asteroseismology*, SPAT0045-1 *Stellar structure and evolution II* (Pr. M.A. Dupret)

Finding the orbital period of the system PB 8783 by the O-C method

Contact person : Valérie Van Grootel

e-mail : valerie.vangrootel@uliege.be

Tel : +32 4 366 97 30

Office: B5c, +1/13

Availability: any time by email for a first contact. We'll then convene for an appointment to discuss the topic in more detail.

Thematics : Astrophysics

Description:

PB 8783 is a system composed of a subdwarf O (sdO) star and a main-sequence F star, of unknown orbital period (of the order of years, a priori, from what we know on the formation of such systems). The sdO star is pulsating (one of the very few known sdO pulsators), which means the arrival of pulsations is slightly delayed when the star is moving away from us and is slightly advanced when the star approaches us, as long as it moves around the center of mass of the system. This is the pulsation timing, or O-C method, and is well known to constrain binary systems, or to discover exoplanets around stars. A nice example of obtaining the orbital period of an sdB+F system can be found in Otani et al. 2018, ApJ, 859, 145.

The pulsations in PB 8783 have been discovered in 1997, and are regularly observed since then, including by the space mission TESS these last years.

The first step would be to analyse the observations, extract the properties of the pulsations, and measure the phase shift of the pulsations. The orbital period will be deduced. In a second step, the orbit of the system will be modelled. If we have time, we will use these constraints to carry out a seismic modelling of the sdO pulsator. It would be the first sdO star modelled by asteroseismology.

Validation and characterization of the two-planet system TOI-1453

Contact person : *Manu Stalport ; Laetitia Delrez*
e-mail : manu.stalport@uliege.be ; ldelrez@uliege.be

Tel :

Office: B5c, office 1/15 (floor +1)

Availability: Interested students should contact us by email to arrange a meeting.

Thematics : Astrophysics; Planetology and planetary systems

Description:

The formation and evolution of planetary systems remains an open question of astrophysics, and an active field of research. With the detection of exoplanets - planets that orbit other stars than the Sun - new families of planets were discovered, among which the super-Earth and sub-Neptune planets. These planets, absent from the Solar System and yet likely the most abundant in our Galaxy, span the transition between rocky and volatile-rich planets. Therefore, their study is crucial to understand the conditions needed to retain a large atmosphere or not. Multi-planet systems represent particularly valuable laboratories. Indeed, their exoplanets formed in the same environment, and as such their comparison sets strong constraints on formation and evolution processes.

The two-planet candidate system TOI-1453 is one of these valuable systems. Two super-Earth/sub Neptune exoplanet candidates orbit the central K-dwarf star with orbital periods of 4.3 and 6.6 days. The two candidates were announced by the Transiting Exoplanets Survey Satellite (TESS) mission, which currently scrutinizes the whole sky in search for transiting exoplanets around bright stars. The transit of an exoplanet is defined by its passage in front of the host star as seen from Earth, which happens under favorable geometric configurations. This event repeats periodically after each revolution of the exoplanet. The decrease of incoming stellar flux during the transits informs us about the size of the exoplanet relative to that of the star. Furthermore, the mutual gravitational interactions between the planets of a same system can induce anomalies in the times of transit from the exact periodicity. This effect, referred to as transit timing variations (TTV), depends on the mass of the planets. Both the mass and radius are fundamental parameters to constrain the composition of the exoplanets, notably their fraction of volatiles.

This Master thesis project has two goals. 1) Validate the two planet candidates (i.e. confirm their planetary nature) and refine the estimation of their size. 2) Constrain the TTV in the system, and if possible, set constraints on the planet masses. To achieve these goals, the student will learn the necessary concepts of dynamics and data analysis, and will apply them in a numerical approach.

Facilities, tools, and supervision: The student will be provided with a workstation in the students' office (+1 floor) and all the tools needed to analyse the TESS data. The student will meet with the supervisor(s) ideally every week or every 2 weeks to perform a progress review of the project, where he/she will be able to discuss difficulties, new ideas, etc.

Recommended course: SPAT0063-1 *Introduction to exoplanetology*

Transit transmission spectroscopy of TRAPPIST-1 planets with JWST

Contact person : Michaël Gillon

e-mail : michael.gillon@uliege.be

Tel : 043669743

Office: B5c, -1/1

Availability: 15-19 + 22-25 May from 13h to 15h.

Thematics : Planetology and planetary systems

Description:

The TRAPPIST-1 system is composed of seven Earth-sized rocky planets in short orbits around a very-low-mass (~0.09 M_{sun}) star 40 light-years away. Thanks to their transiting nature and to the small size (~0.12 R_{sun}) and infrared brightness of their host star, these planets are particularly well-suited for the detection and characterization of compact secondary atmospheres around them with JWST. In theory, such atmospheric characterization could reveal traces of habitability, and even of biological activity. It is thus no surprise that TRAPPIST-1 has been the most observed exoplanet target in JWST Cycle 1. Notably, transit transmission spectroscopic observations have been (or will soon be) performed for its seven planets with the NIRSPEC and/or NIRISS instruments. Many of these observations have been (or will be) performed in the framework of a community initiative [1] and have no proprietary period. The goal of this Master thesis will be to perform a global reduction and analysis of these public data and to use the resulting transmission spectra to draw inferences on the presence/absence of significant atmospheres around the planets and on the photospheric structure of the star.

The candidates to this Master thesis should have followed the course SPAT0063 'Introduction to exoplanetology'.

[1] Gillon M., Meadows V., Agol E., et al. 2020, *The TRAPPIST-1 JWST Community Initiative*, Bulletin of the AAS, Vol. 52, Issue 2. DOI: 10.3847/25c2cfeb.afbf0205

Direct imaging of forming planets and their birth environment

Contact person : Valentin Christiaens, Olivier Absil

e-mail : valentin.christiaens@uliege.be

Tel : 04 366 9739

Office: +2/18

Availability: Interested students should contact me by email to arrange a meeting.

Thematics : (Exo)Planetology and planetary systems. Data processing and analysis.

Description:

The *indirect* discovery of thousands of exoplanets with different masses, radii and orbital separations suggests a variety of pathways for planetary system *evolution*. But do giant planets share common *formation* mechanisms? The advent of a new generation of sub-mm and high-contrast infrared instruments have recently provided direct images of protoplanetary discs, the birth cradle of planets, revealing a wealth of structures potentially related to embedded planets (gaps, spiral arms, asymmetries). However, in only two systems have protoplanets been unambiguously confirmed so far, limiting our understanding of the mechanisms involved during planet formation.

In this project, the student will use ESO archival data obtained with the SPHERE high-contrast imager on a sample of protoplanetary discs showing strong hints of planet presence, with the goal of confirming new protoplanets. Priority targets for this project would consist of discs with identified kinematic deviations from Keplerian rotation in their gas flow (i.e. *kinks*). These kinks, inferred from sub-mm interferometric data, are supposedly tracing embedded protoplanets. Since their measured amplitude depend on the mass of the planet, any direct imaging confirmation of such kink could lead to the first independent estimate of the luminosity and mass of a forming giant planet, hence would provide the strongest constraints to date on giant planet formation mechanisms (mass estimates being not available for the directly imaged protoplanets to date). In practice, the project will rely on routines already implemented in VIP, the largest open-source package of high-contrast imaging routines, which has been developed and maintained at ULiège. The student will further test novel image processing techniques developed in the team to remove the bright emission from the star and produce higher fidelity images of protoplanetary discs than currently available, with the goal of identifying new direct (point source) or indirect evidence (e.g. spiral arms) of embedded protoplanets.
Depending on the results, the project may lead to a publication, and the student would be highly valued for a PhD in the field of high-contrast imaging.

Recommended background:
- (SPAT0067-1) Atmospheric and adaptive optics (O. Absil);
- (SPAT0063-1) Introduction to exoplanetology (M. Gillon);
- *Programming experience with python is also recommended.*

Search for OH Prompt emissions lines in high resolution comet spectra obtained with UVES at the ESO Very Large Telescope (VLT)

Contact person: Jehin Emmanuël (ULiège)

E-mail: ejehin@uliege.be

Tél: (0)4 3669726

Office: B5c 1/9

Thematic: Astrophysics (small bodies of the solar system)

Description:

Comets are among the best preserved specimens of the primitive solar nebula. This status of "fossils" gives them a unique role in understanding the origins of the solar system. The success of the Rosetta space mission was very important and is changing our knowledge about comets. But it showed also that observations from the ground continue to be important: they make it possible to supplement the data in situ by obtaining information on larger scales of the coma and tails, and for a much larger number of comets, which is necessary to extrapolate the results to the entire cometary population. The link between the composition of comets and their dynamic history must still be clarified and a complete comet classification and surface composition of nuclear ices is still missing. To pursue this goal a complete inventory of the emission lines present in cometary spectra is for instance needed to characterize comet composition at best and as strange as it might seems, in the high resolution spectra of comets, hundreds emission lines are still to be identified.

Laboratory studies predict that the photo-dissociation of H_2O by solar Lya photons in the comae of comets should lead to a small percentage of OH in high rotational states of its principal electronic state. These states should promptly emit a near-ultraviolet photon in a transition to a lower state. From there, the radicals decay to the lowest rotational states by direct rotational transitions and via ro-vibrational cascade in the 1-0 vibrational band, all within the lower state. Normally in Earth-based observations these lines are extremely weak compared to the fluorescence of OH radicals in th sunlight. Since the prompt emission rate is directly proportional to the column density of water, whereas the fluorescent emission of OH is proportional to the column density of OH, the lines due to prompt emission are strongest very close to the nucleus, a region not often accessible from Earth (A'Hearn et al. 2015).

In this context, we propose for this master thesis a search of the elusive OH prompt emissions in the Near-UV region of the spectrum (310-350 nm) of a sample of very high quality comet spectra obtained in the last 20 years by our team with UVES, the high resolution spectrometer of the ESO Very Large Telescope (VLT).
No new data reduction of the spectra will be requested but the student needs to work with several software of his choice to display the spectra, search for the OH lines based on line tables, to measure their positions, widths and intensities, to be able to make detailed graphics. The procedure will follow the discovery paper of A'Hearn et al. (2015).

The work will be done in the comet group of the OrCa Service (+1)
https://www.orca.uliege.be/cms/c_5012867/fr/orca-cometes

Asteroid light curves from TRAPPIST telescopes archived images

Contact Person: Jehin Emmanuël

e-mail: ejehin@uliege.be

Tél: (0)4 3669726

Office: B5c 1/9

Availability: please contact me

Thematics: Astrophysics (small bodies of the solar system)

Description:

The TRAPPIST telescopes installed at the la Silla observatory in Chile in 2010 and at the Oukaimeden observatory in Morocco in 2016 by our team are dedicated to the research and the study of exoplanets in transit and the study of the small bodies of the Solar System (comets and asteroids). Each night, since 10 years in Chile and 5 years in Morocco we collect hundreds of images of one or two fields during several hours to search for exoplanets in transit. This constitutes a unique dataset of about 2.5 million images to be explored to search for asteroids and comets.
In this work we propose to search the huge database of TRAPPIST to identify the known asteroids present in the images using their well known orbits. As some fields are observed several nights in a row and for many hours per night it will be possible to build high density light curves for many of these objects and measure their rotation period.
Objectives: Find the known asteroid present in the TRAPPIST archive. Measure and collect the photometric measurements for each target found and build their light curves with time to try to find the asteroid rotation period. Most of these rotation light curves will be new and will be published in a paper. This will be useful to better understand the evolution of small bodies via Yarkovsky/YORP effect by comparing the distribution of the properties of spins (period, longitude, latitude) to the dynamical families.

https://www.trappist.uliege.be/

Jupiter's UV aurora: Polar dawn spots

Contact persons : Denis GRODENT, B. BENMAHI, B. BONFOND

e-mail : d.grodent@uliege.be bilal.benmahi@uliege.be b.bonfond@uliege.be

Tel :

Office: B5c – 0/LPAP

Availability: Please contact us by email to set a meeting date

Thematics : Planetology

Description:

Several master thesis topics are available at the Laboratory for Planetary and Atmospheric Physics (LPAP). The proposed topics can be adapted and refined to better fit the tastes and skills of the student.

Polar dawn spots in Jupiter's aurora (Bertrand BONFOND)
This master thesis topic is about polar spots located in Jupiter's dawn auroral region which are commonly observed in HST and Juno-UVS datasets.
A previous study (Radioti et al., 2008) analyzed the mapping of these features in the equatorial plane as well as their time scales and periodicities. It was shown that these polar dawn spots are a frequently observed feature located just pole. Additionally, they can reoccur quasi-periodically every 2 – 3 days, a periodicity observed for the first time in auroral features. Because of their mapped location and their periodic cycle, the polar dawn spots were interpreted as signatures of internally driven magnetic reconnection in the Jovian magnetotail. However, this study was restricted to a series of images taken between February 21 and June 11, 2007.

A similar analysis, based on more recent observations of HST-STIS and Juno-UVS should confirm/infirm/complement these findings. Contrary to HST data, Juno-UVS observations make it possible to consider a possible local time dependency.

Jupiter's UV aurora: Relativistic electron burst above Jupiter’s poles

Contact persons : Denis GRODENT, B. BENMAHI, B. BONFOND

e-mail : d.grodent@uliege.be bilal.benmahi@uliege.be b.bonfond@uliege.be

Tel :

Office: B5c – 0/LPAP

Availability: Please contact us by email to set a meeting date

Thematics : Planetology

Description:

Several master thesis topics are available at the Laboratory for Planetary and Atmospheric Physics (LPAP). The proposed topics can be adapted and refined to better fit the tastes and skills of the student.

Relativistic electron burst above Jupiter’s poles (Bertrand BONFOND)
The UVS instrument is an ultraviolet spectrograph designed to study the auroral emissions on Jupiter. However, its detector is also sensitive to relativistic electrons (E>7MeV) and can thus be used as a radiation monitor. A previous study of this radiation noise above the pole (Bonfond et al. 2018), based on data gathered during Juno’s 12 first orbits, demonstrated the existence of radiation micro-bursts, with a typical timescale of ~10 ms when Juno was flying over specific regions of the polar auroras. In this work, the student will expend this study to the current 50 orbits, in order to confirm or invalidate the trends identified in the preliminary study and further investigate this mysterious phenomenon.

Ganymede's UV aurora

Contact persons : Denis GRODENT, B. BENMAHI, B. BONFOND

e-mail : d.grodent@uliege.be bilal.benmahi@uliege.be b.bonfond@uliege.be

Tel :

Office: B5c – 0/LPAP

Availability: Please contact us by email to set a meeting date

Thematics : Planetology

Description:

Several master thesis topics are available at the Laboratory for Planetary and Atmospheric Physics (LPAP). The proposed topics can be adapted and refined to better fit the tastes and skills of the student.

Juno’s observations of Ganymede’s aurora (B. Bonfond)

The NASA Juno orbits around Jupiter since August 2016. Now that its prime mission is over, it entered an extended mission, which allows the spacecraft to perform close encounters with some of the planet’s major moons. The objective of this master thesis is to adapt the codes used to process auroral images of Jupiter’s aurorae in the ultraviolet domain to the latest data from Ganymede (Greathouse et al. 2022). This work will pave the way for the future observations of the Galilean moons by JUICE.

Jupiter's UV aurora: Spectral analysis of Jupiter's aurora

Contact persons : Denis GRODENT, B. BENMAHI, B. BONFOND

e-mail : d.grodent@uliege.be bilal.benmahi@uliege.be b.bonfond@uliege.be

Tel :

Office: B5c – 0/LPAP

Availability: Please contact us by email to set a meeting date

Thematics : Planetology

Description:

Observations of Jupiter in the UV range have revealed the existence of extremely intense polar aurora phenomena. These observations have answered many questions about these phenomena and revealed some of their mysteries. However, in spite of the innumerable studies on the Jovian auroral phenomena, certain questions still remain unanswered, such as the shapes of the distributions of the electron energy flows at the origin of the auroral emissions.

Spectral analysis of Jupiter's aurora (Bilal BENMAHI)
One of the possible studies focuses on two parts:
- Firstly, to perform a colour ratio adjustment to map the characteristic energy of electrons precipitating in the auroral regions by modelling the transport of a mono-energy electron flow using an electron transport model that
- The second part of this study consists of a comparison of the characteristic energy maps obtained with different electron flux distribution models (mono-energy, Maxwellian and kappa distributions).
- Bonus: Depending on the progress of the work, the results obtained in the previous point can be used to make a comparison with the electron energy distributions measured by the Juno/JEDI instrument.

Climate projections on the North-Western continental Shelf

Contact person: Marilaure Grégoire MAST (Modelling for Aquatic Systems)

e-mail: mgregoire@ulg.ac.be

Tel:

Office: B5a, 2nd floor

Description :

The aim of the master thesis is to implement the hydrodynamical model NEMO (already implemented in the Black Sea) over the northwestern continental shelf to simulate the hydrodynamics at seasonal and interannual scales. The model will be validated with in-situ and satellite data. Multidecadal simulations will be realized 40 years in the past and at the end of the 21st century under two scenarios of change SSP1 (Sustainability, Paris agreement) and SSP5 (Fossil-fuel development). The impact of climate change on the North Sea circulation, tidal dynamics and stratification will be assessed by comparing past and future predictions.

Specific method, material used: 3D modelling

Preconditions and/or important information: **to want to work with modelling** (in 3D)

Impact of small scales atmospheric processes on the physical and biogeochemical state of the Black Sea.

Contact: Marilaure Grégoire MAST (Modelling for Aquatic Systems) and Xavier Fettweis (Laboratory of climatology)

e-mail: mgregoire@ulg.ac.be, xavier.fettweis@uliege.be

Tel:

Office: B5a, 2nd floor

Description:

The dynamic of the ocean is strongly governed by its interactions with the atmosphere at the air sea interface which constitutes a dominant forcing. Yet, the quality of the atmospheric forcing in terms of resolution is not always adequate to simulate the ocean physics and biogeochemistry, in particular, (sub)-mesoscale processes. Moreover, in the majority of cases, there are no retroactions from the ocean to the atmosphere. In this master thesis, the student will run a coupled physical biogeochemical model forced by different types of atmospheric forcings for past reconstructions and projections. These simulations will be compared and their quality assessed by comparison with observation. Then, some experiments using a two-way coupled system will be realized and results will be compared with forced simulations (without feedback). In particular, the simulations of extreme events (e.g. tropical cyclones, heatwaves) will be assessed in both configurations.

Specific method, material used: 3D modelling

Stay abroad, financial conditions:

Preconditions and/or important information: **to want to work with modelling** (in 3D) and use/build new codes (mainly in python).

Assessing the impact of modelling the radiative transfer on the physics and biogeochemistry

Contact: Marilaure Grégoire MAST (Modelling for Aquatic Systems)

e-mail: mgregoire@ulg.ac.be

Tel:

Office: B5a, 2nd floor

Description:

The in-water-irradiance is a key variable in oceanography that governs the heat distribution, primary production and photo-chemical reactions. An accurate representation of the ocean physics and biogeochemistry by ocean numerical models hence requires an accurate calculation of the in-water irradiance. However, if marine ecosystem models become more and more sophisticated in terms of food chain representation, the optical calculation is still very often oversimplified. The aim of the master thesis is to assess the impact of a better representation of light penetration on the physics (e.g. thermocline position) and biogeochemistry by comparison with Biogeochemical Argo and in-situ data.

Specific method, material used: 3D modelling

Stay abroad, financial conditions:

Preconditions and/or important information: **to want to work with modelling** (in 3D)