Master Thesis Proposals

2025-2026

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, 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/

- Space Applications : https://www.spaceapplications.com/

… 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 (IFPA)

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.

Study of kilonovae with current and future detectors

Contact person : Marion Pillas

e-mail : marion.pillas@ligo.org

Tel : +33642431161

Office: Bât. B5A - 4th floor

Availability: The student can contact me by email to we organize a meeting anytime in May and June.

Thematics : Astrophysics & Gravitational-Wave Physics

Description:

Kilonovae are optical - infrared transients, witness to the nucleosynthesis of heavy elements during the merger of neutron stars. These optical counterparts are crucial to study the environment of the merger as they come from the ejected matter during the coalescence. The only confirmed event that has been detected in coincidence with a neutron star merger so far is the kilonova associated with the gravitational wave GW170817 from a binary neutron star mergers and seen in coincidence with electromagnetic counterpart across the entire spectrum, on 2017, August 17. This joint detection started the era of multi-messenger astronomy with gravitational waves. However, we do not have a complete knowledge about these events yet. In this master thesis, we will study the properties of kilonovae associated to these mergers and explore their detectability with future telescopes. The student will be involved in a kilonova population study and will explore how they can be detectable with future instruments such as Vera Rubin Observatory and indirectly with Einstein Telescope or LISA, especially from the ordinary memory effect that could come from the neutron star merger aftermath and in particular from the ejected matter during the merger. We will start from a estimation of a neutron star merger population to infer the associated kilonova properties and explore the detectability regarding the sensitivity of the instruments.

The candidate will have an interest in fundamental astrophysics and data analysis along with programming skills in Python. We are looking for someone with enthusiasm for exploring and implementing algorithms, as well as curiosity and willingness to learn about new topics, like gravitational waves and astroparticle physics. Having taken some introductory gravitational-wave physics/astrophysics courses would be beneficial.

The proposed master thesis is valid for both 27 credits and 15 credits.

Observing Active Galactic Nuclei with the Extremely Large Telescope

Contact person : Dominique Sluse

e-mail : dsluse @uliege.be

Tel : 04 366 9797

Office: B5c, +1/10

Availability: Contact D. Sluse by email for an appointment.

Thematics : Extragalactic Astrophysics, Instrumentation and methods

Description:

The European Extremely Large Telescope (ELT) is set to become the world's largest optical and near-infrared telescope, boasting a colossal 39-meter segmented main mirror and advanced adaptive optics that will deliver the sharpest images of the sky. With a first light expected in by 2030, the ELT will very soon be on Sky. The METIS instrument, short for Mid-infrared ELT Imager and Spectrograph, is one of the first-generation instruments designed for the ELT. It is the only ELT instrument to cover wavelengths beyond 3 microns offering a spatial resolution better than the current James-Webb Space telescope.

We propose you to play an active role in preparing the exploitation of METIS for AGN science. Specifically, we will propose you to work on designing one or two observing science programs with METIS: this will start with understanding the science case, explore the state-of-the-art on the topic, understand the observational constraints, and simulate observations. The detailed workflow will depend on your scientific and technical interest, as well as of the chosen science case. The project can be adapted for 15 or 27 credits. Possible science cases encompass: Mapping of the dust in the inner regions of AGNs, improve the understanding of changing-look AGN, map coronal line emission in AGNs, probe the inner regions of binary AGNs, measure astrometric displacements of gravitationally lensed AGNs during a microlensing event.

Recommended lectures for this project: SPAT0002-1 (Statistical Methods and data analysis), SPAT0011-1 (Extragalactic astrophysics), SPAT0086-1 (Advanced data analysis in python and introduction to machine learning), SPAT0068-1 (Astrophysical observations), SPAT0033-1 (Astrophysics).

The dark matter content of strongly lensed galaxies

Contact person : Dominique Sluse

e-mail : dsluse@uliege.be

Tel : 043669797

Office: B5c, +1/10

Availability: Contact D. Sluse by email for an appointment.

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 H_0). 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

(27 credits project)

Recommended lectures for this project: SPAT0002-1 (Statistical Methods and data analysis), SPAT0011-1 (Extragalactic astrophysics), SPAT0086-1 (Advanced data analysis in python and introduction to machine learning), SPAT0068-1 (Astrophysical observations), SPAT0033-1 (Astrophysics).

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

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. 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 (deep-learning, image mirroring, …)

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

(15 or 27 credits project)

Recommended lectures for this project: SPAT0002-1 (Statistical Methods and data analysis), SPAT0011-1 (Extragalactic astrophysics), SPAT0086-1 (Advanced data analysis in python and introduction to machine learning), SPAT0068-1 (Astrophysical observations), SPAT0033-1 (Astrophysics).

Gravitational microlensing by primordial black holes — forecasting and detecting signals in large-separation lensed quasars

Contact person : Dominique SLUSE & Guillaume MAHLER

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Tel :

Office: B5c 1/10 - B5c 1/11

Availability: make appointment via email

Thematics : Extragalactic astrophysics

Description:

The proposed master thesis is valid for 27 credits, but can be adapted to 15 credits as well

Large-separation gravitationally lensed quasars are rare but highly informative systems, where multiple images of a background quasar are produced by the gravitational potential of a foreground galaxy cluster. These image separations can span several tens of arcseconds, indicating that the lensing is dominated by the smooth dark matter component of the cluster. However, if a fraction of this dark matter is composed of compact objects—such as primordial black holes (PBHs)—they can act as microlenses, introducing additional variability in the brightness of the quasar images through gravitational microlensing.

This project aims to investigate the possibility of detecting microlensing signals in these unique systems as a probe of small-scale dark matter structure. The student will focus on modelling the expected microlensing effects induced by a population of primordial black holes or other low-mass compact dark matter clumps along the line of sight. Simulations will explore a range of parameters including lens mass distribution and source size, the latter being a key factor in determining the observability of microlensing fluctuations.

A second phase of the project will involve comparison with real data: several large-separation lenses already have high-quality spectral and photometric observations available, either within our group or in the literature. These datasets may show flux anomalies or variability patterns consistent with microlensing, allowing preliminary constraints to be placed on the abundance of compact dark matter.

This project provides an opportunity to explore one of the most intriguing dark matter candidates and offers a novel observational window into small-scale structure. It is ideally suited for a student with an interest in gravitational lensing, dark matter physics, and data-model comparison. This work could constitute a first step before a PhD thesis related to microlensing.

Prerequisites: Experience with python programming (e.g. via SPAT0002-1: Statistical Methods and data analysis) is needed. Other recommended courses: Extragalactic astrophysics (SPAT0011-1).

Galaxy-galaxy strong lensing in clusters — quantifying cluster-induced shear and its impact on lens modelling

Contact person : Guillaume MAHLER & Dominique SLUSE

e-mail : dsluse@uliege.be & Guillaume.mahler@uliege.be

Tel :

Office: B5c 1/10 - B5c 1/11

Availability: make appointment via email

Thematics : Extragalactic astrophysics

Description:

The proposed master thesis is valid for 27 credits, but can be adapted to 15 credits as well

Galaxy-galaxy strong lensing is a powerful tool to probe the mass distribution of individual galaxies, including their dark matter halos, by analysing the multiple images of background sources they produce. However, when these galaxies reside within massive galaxy clusters, the lensing signal is modulated by the cluster's overall gravitational potential. In these environments, the cluster acts as a macro-lens, often introducing an external shear or convergence that can bias the interpretation of the galaxy-scale lens model if not properly accounted for. While the effect is commonly approximated as a simple external shear, the actual cluster-induced perturbation can be more complex, especially in dense regions or near the cluster core.

This project will investigate how galaxy-galaxy lenses behave when embedded in cluster environments, with the goal of systematically comparing the induced shear from the cluster potential to the external shear typically inferred in blank-field lensing studies. The student will work with a sample of galaxy-galaxy lenses identified within known clusters, and build detailed lens models that include both the small-scale lensing galaxy and the surrounding cluster mass distribution as a macro-model. Public data from strong lensing surveys, supplemented by spectroscopic and photometric information, will be used to characterise both the galaxy lenses and their host clusters. A key outcome will be a statistical comparison of the inferred shear components, and whether their amplitude and orientation follow the trends observed in isolated galaxy-galaxy lensing systems.

The project will also assess whether the prevalence of such systems in clusters can be robustly quantified in a complete sample — a step that is essential for using these lenses to constrain cosmological models or test theories of structure formation. This work offers a novel angle on galaxy and cluster-scale lensing and provides a valuable testbed for future studies of environmental effects on lensing.

This project is well-suited for a motivated student interested in gravitational lensing, galaxy evolution, and cosmology and could constitute a first step before a PhD thesis.

Prerequisites: Experience with python programming (e.g. via SPAT0002-1: Statistical Methods and data analysis) is needed. Other recommended courses: Extragalactic astrophysics (SPAT0011-1).

Galaxy groups as gravitational lenses — building a reference sample to probe their mass-to-light ratio

Contact person : **Guillaume MAHLER**

e-mail : Guillaume.mahler@uliege.be

Tel :

Office: B5c 1/11

Availability: make appointment via email

Thematics : Extragalactic astrophysics

Description:

The proposed master thesis is valid for 27 credits, but can be adapted to 15 credits as well

Galaxy groups, occupying the intermediate mass range between isolated galaxies and massive galaxy clusters, are an essential but relatively understudied population in the study of cosmic structure formation. Despite being key environments where galaxies evolve through interactions and mergers, their dark matter content and mass distribution remain poorly constrained. In particular, the mass-to-light ratio (M/L)—a fundamental quantity that links luminous matter to the underlying dark matter—has yet to be robustly established for this regime. This project aims to address this gap using strong gravitational lensing, which offers a direct and assumption-free probe of the total projected mass.

The work will proceed in two phases. First, the student will construct a curated reference sample of confirmed or candidate group-scale strong lenses. This will involve mining public lensing surveys and databases, applying group identification criteria, and assembling photometric and redshift data to characterise both the lenses and the lensed sources. In the second phase, detailed lens modelling will be carried out on a selected subset using established software tools to reconstruct the total mass distribution of each system. These mass measurements will then be compared to the optical light content, allowing us to derive M/L ratios and examine their dependence on group properties (e.g. richness, redshift). The results will help assess whether galaxy groups behave as scaled-down clusters or if they exhibit distinct signatures, providing new constraints on hierarchical structure formation.

This project is well-suited for a motivated student interested in gravitational lensing, galaxy evolution, and cosmology and could constitute a first step before a PhD thesis.

Prerequisites: Experience with python programming (e.g. via SPAT0002-1: Statistical Methods and data analysis) is needed. Other recommended courses: Extragalactic astrophysics (SPAT0011-1).

Kinematics of the molecular torus of an active galaxy with ALMA data

Contact person : Violeta Gámez Rosas

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Tel : **+32 (0)4 366 9768**

Office: Quartier Agora Allée du 6 Août, 19C - Bât. B5c Office: +2/14

Availability: May 21-23 and June 2-6

Thematics : Astrophysics, kinematics, computer models.

Description:

Active Galactic Nuclei (AGNs) are among the most energetic phenomena in the universe, powered by accretion onto supermassive black holes. A key component in the unified model of AGNs is the presence of a dusty torus, which obscures or reveals the central engine depending on the viewing angle. In addition to warm dust, this torus also contains molecular gas that can be traced and resolved with the Atacama Large Millimeter/submillimeter Array (ALMA) at sub-parsec resolution.

In this project, the student will use archival ALMA observations of the nearby active galaxy NGC 1068 to study the molecular counterpart of the torus. The goal is to model the gas kinematics and test two competing scenarios: (1) a rotating disk with an outflow, and (2) an inner rotating disk surrounded by a counter-rotating outer disk.

To analyze the data, the student will use Canubi, a Python-based MCMC wrapper that interfaces with the kinematic modelling software 3DBarolo, to estimate the geometrical and kinematic parameters of the molecular disk. Optionally, a machine learning approach may also be explored depending on the student's experience.

The project involves working with existing software tools rather than developing code from scratch, therefore basic familiarity with python will be sufficient. This is an excellent opportunity for students interested in AGN physics, data analysis, computational modelling, and astronomical applications of interferometry. The proposed master thesis work will be valid for 27 credits.

Two is a charm

Contact person: Yaël Nazé & Gregor Rauw, High-Energy Astrophysics Group
e-mail: ynaze@uliege.be
Tel: 04/366 9720
Office: Institut d'Astrophysique & Géophysique, Bât B5c, Allée du 6 Août, 19c, room 2/12
Availability: interested students are invited to contact the coordinator by e-mail to arrange an appointment
Thematics: stellar astrophysics

Description:

Massive OB-type stars often belong to binary systems. This multiplicity impacts their evolution, as mass and angular momentum transfer may occur. In this work, the student will analyze several binaries, characterize their properties and their evolutionary state. This will be done through a joint analysis of high-quality spectroscopic and photometric data.

The student is asked to

- get acquainted with the properties of massive binaries and the general knowledge of the targets,
- process spectroscopic and photometric data,
- analyze these spectra and light curves to derive the physical parameters of the stars and their orbit,
- and finally, compare the results with other massive binaries, discuss the results and their implications.

Remarks: attending or having attended the course on "Variable stars" is clearly an advantage.

This project is first intended for a full, 27 ECTS, thesis.

X-ray emission in short period interacting wind eclipsing massive binaries

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

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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

Thematics: stellar astrophysics, X-ray astrophysics

Description:

Most massive OB-type stars reside in binary or higher multiplicity systems. As these stars feature highly energetic stellar winds, the collision between those winds is expected to generate a strong and relatively hard X-ray emission. Furthermore, the level of observable X-ray emission is expected to vary with orbital phase as the stars revolve around their common centre of mass. Yet, detailed investigations with modern X-ray satellites showed that many O-star binaries, especially those with short orbital periods, lack a strong X-ray emission and rather display a level of emission that is consistent with the typical intrinsic emission arising from the individual winds (i.e., without any significant additional emission from a wind-wind collision). We propose here to investigate the X-ray properties of a sample of well-known O-star binaries observed with XMM-Newton at several orbital phases.

The student is asked to:

- get acquainted with the properties of the target stars and with the general subject of wind interactions in massive binaries,
- process all available XMM-Newton observations of the target system,
- analyse the EPIC and RGS spectra using the xspec software,
- establish the variations of the X-ray emission as a function of orbital phase, and compare them with ROSAT data
- and finally, discuss the results obtained, compare them with what is observed in other colliding wind binaries, and discuss the implications.

Remarks: attending or having attended the course on “High-Energy Astrophysics” is clearly an advantage.

The g-mode spectra of core-He burning stars: influence of He-flash and chemical transitions

Contact person : Valerie Van Grootel

e-mail : valerie.vangrootel@uliege.be

Tel : +32 4 366 9730

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:

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. Asteroseismology has the potential to unveil the internal structure of the stars through the study of stellar pulsations.

In a master thesis done in the year 2023-2024, we investigated the theoretical pulsation spectra of subdwarf B (sdB) stars, which are core-He burning objects having lost most of their envelope during previous stages of evolution. General pulsation patterns emerged, as a function of the features in stellar models and their various physical prescriptions for their thermal and chemical structures. These results have been published in Guyot, Van Grootel, Charpinet et al. 2025, A&A, 696, A13.

In order to complete this investigation and make the necessary link with the observations (many sdB stars have pulsations observed by the NASA Kepler and TESS satellites), two main influences remain to be investigated: the pollution by Carbon in the otherwise pure He stellar mantle and the profiles of chemical transitions in the star, which were kept fixed in the first study. These two features have potentially a high impact on the pulsation spectra.

The second step of this master thesis is to make links between these theoretical pulsation spectra with the observed pulsation spectra for sdB stars. Qualitative comparison will be carried out first, before completing quantitative seismic modelling, by fitting observation pulsation periods with theoretical ones computed from models and identifying the optimal model.

This master thesis is in the field of asteroseismology and is well suited for a student who likes investigation on theoretical models, as well as making links between those models and observations. The proposition is valid for both 15 (first part) or 27 credits (first and second parts).

Recommended courses: SPAT0005-1 *Stellar Stability and asteroseismology,* SPAT0044-1 and SPAT0045-1 *Stellar structure and evolution I and II* (Pr. M.A. Dupret)

Close binaries with compact stars and gravitational waves

Contact person : Valerie Van Grootel

e-mail : valerie.vangrootel@uliege.be

Tel : +32 4 366 9730

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:

Close binaries with compact stars (hot subdwarfs, white dwarfs) are known sources of gravitational waves (GWs) in the mHz, a frequency domain that will be accessible to future space-based GW detectors like LISA. In recent years, two master theses at ULiege have explored this topic: (1) the identification of hot subdwarf+white dwarf binaries that could be detected by LISA; (2) a theoretical investigation of the orbital evolution of white dwarf+white dwarf binaries under the action of GW emission and dynamical tides.

Building on these studies, several master theses in that direction are proposed for the 2025-2026 academic year:

- **Modeling the foreground noise from hot subdwarf binaries**: While a few hot subdwarf+white dwarf systems were identified as individually detectable with LISA in the first thesis, most of them will not be resolved and will contribute to a "stochastic foreground noise". This noise will add to the well-known galactic foreground noise (mainly originating from double white dwarf binaries) and the extragalactic foreground noise. Unlike these, the contribution from hot subdwarf binaries have been overlooked so far. This thesis will focus on studying, modeling and determining the importance of this "hot subdwarf binary noise".

- **Identifying known white dwarf binaries in the relevant parameter space**: This project involves surveying the literature to identify known white dwarf + white dwarf binaries that fall within the parameter space (in terms of mass and orbital separation) deemed promising in the second thesis mentioned above. Their detectability with LISA will also be assessed.

- **Exploring the asteroseismic potential of white dwarf binaries**: This topic focuses on identifying known white dwarf + white dwarf binaries in the literature that exhibit pulsation. Their detectability with LISA will then be assessed. The aim is to evaluate their asteroseismic potential and determine how asteroseismic modeling could complement studies based on GW emission.

The first proposition is valid for a 27-credit master thesis, while the second and third topics are more dedicated for a 15-credit master thesis (or, be combined into a 27-credit thesis).

Can solar neutrino fluxes be reproduced by models with revised abundances?

Contact person : Gaël Buldgen & Marc-Antoine Dupret

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Tel : +32 (0)4 366 9751

Office: B5C +1/15

Availability: From May 12th to May 16th and from June 9th to June 13th

Thematics : Stellar physics, asteroseismology

Description:

Context: The revision of the solar abundances in 2005, which was confirmed in 2009 and 2021 by additional spectroscopy analyses and independent helioseismic methods, has started a crisis in solar modelling. The observed disagreements with helioseismology and measured solar neutrinos fluxes of models computed with these new abundances have divided the community over the question of a revision of the physics of solar models. Recent Borexino measurements of the so-called CNO neutrinos further complicated the issue. Various processes, including radiative opacities, electronic screening of the nuclear reactions but also protosolar accretion phases have been shown to significantly impact the conclusions we draw from solar models. In this context, a simple case study of the dominant physical contributors to variations of the neutrino fluxes is required to fully grasp the degeneracies at hand.

Method: The student will be introduced to the Liège Stellar Evolution Code (CLES). A simple parametric toy-model of the solar core will be developed using existing routines of CLES. The student will compare the results of his model to the observed neutrino fluxes and identify the dominant physical parameters that affect their predicted values. First, a detailed study of the degeneracies at play will be required, before an actual inference of the potential solution using an MCMC software will be used. The study will be purely theoretical.

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

stability and asteroseismology SPAT0005-1 (Pr. M-A Dupret). Having followed the course on Statistical methods and data analysis SPAT0002-1 is a plus.

This master thesis subject is intended to be of 27 credits.

Transitory convective cores in low-metallicity stars

Contact person : Gaël Buldgen & Marc-Antoine Dupret

e-mail : gbuldgen@uliege.be

Tel : +32 (0)4 366 9751

Office: B5C +1/15

Availability: From May 12th to May 16th and from June 9th to June 13th

Thematics : Stellar physics, asteroseismology

Description:

Context: The modelling of convection is one of the most uncertain aspect in the theory of stellar structure and evolution. The shortcoming of the currently used simplified theories lead to uncertainties regarding extra-mixing processes acting at the border of convective layers. In the case of stellar cores, additional mixing at the border of convective layers is considered to be the main driver of uncertainties on stellar ages, often associated with stars above 1.2 solar masses. However, another physical regime leads to the apparition of fully-mixed cores in the early evolutionary stages of all solar like stars, linked with the out-of-equilibrium burning of Helium 3. Constraining the properties of such cores can only be achieved using new seismic indicators in the era of high-quality space-based photometric surveys.

Method: The student will be introduced to the Liège Stellar Evolution Code (CLES) and to the Liège Adiabatic Oscillation Code (LOSC). Grids of models will be computed with CLES to study the apparition of convective cores due to out-of-equilibrium burning of Helium 3 and their evolution with time. Oscillation frequencies will be computed to determine whether some well-chosen seismic indicators may provide a hint of the detectability of these cores, as well as the characterize their size or duration of their lifetime. The study will be purely theoretical and involve detailed analysis of the internal structure of low mass stars (between 0.8 and 1.1 solar masses).

Recommended courses: Stellar structure and evolution I SPAT0044-1 (& II SPAT0045-1) & Stellar stability and asteroseismology SPAT0005-1 (Pr. M-A Dupret)

This master thesis subject is intended to be of 27 credits.

Detailed seismic probing of a unique K-dwarf hosting exoplanets

Contact person : Marc-Antoine Dupret and Martin Farnir

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:

The K-dwarf HD 219134 is a wonderful system hosting at least five exoplanets including two super-Earths detected in 2017 by the EXOTIC team of the Liège university. In September 2024, it was observed by the Keck Planet Finder by an international team, leading to the detection of numerous solar-like oscillation modes. These results have just been published and make a detailed seismic probing of this star fully possible. This is the core of the proposed work. Solar-like stars have been core targets of recent space missions such as CoRoT, Kepler and TESS, some of them showing very rich oscillation spectra, constituting e.g. the so-called Kepler legacy sample. But such detections were not possible for K-dwarfs from space because of their lower amplitudes and higher granulation in photometry.

Proposed work:

In the ASTA team, we recently developed the WHOSGLAD and PORTECLES codes enabling to exploit all the information contained in solar-type oscillation spectra and find the stellar internal structure models that best account for the observed oscillation frequencies. We are also developing the stellar evolution code CLES. The beginning of the work will consist of a detailed and critical reading of the literature on HD 219134. The core of this master thesis is to use the above tools to characterize HD 219134 and its super-Earths with the highest possible precision and accuracy. It will also be a question of evaluating as completely as possible the impact on the results of measurement errors and uncertainties in the models: opacities, equation of state, convection model, chemical composition and atmosphere model essentially. This study will not only allow for a better global characterization of this star: mass, radius, and especially its age. But in doing so, it will also allow for more precise and accurate measurements of the masses and radii of the two transiting super-Earths.

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

Impact of dynamical tides on the evolution of planetary orbits.

Contact person : Marc-Antoine Dupret

e-mail : MA.Dupret@uliege.be

Tel : 04 366 97 32

Office: B5c, room 1/12

Availability: Anytime from May to mid-July

Thematics : Astrophysics: stellar physics

Description:

Context:

Tidal forces produced by close planets can deform their hosting star and produce tidally excited oscillations of the star. As a result of the tidal deformation, the planets exert a moment of force on the star modifying its rotation and producing a variation over time of the orbital parameters of the planets. This can lead, among other things, to a progressive decrease or increase in the semi-major axis of the orbit. The final fate of planets (engulfment, increase of the distance or stabilization of the orbit) is of course a key question.

Proposed work:

We have just developed in the ASTA team a new model of dynamical tides including for the first time a full account of the energetic aspects and the Coriolis force. We propose in this master thesis to apply it to star-planets systems. The student will model with this tool tidally excited oscillations of different types produced by planets in intermediate mass stars. The first part of the work consists of delving into the theory of dynamic tides and their impact on the orbit and rotation. This will then be followed by a familiarization to the modelling tools required for this study. Finally, a detailed analysis of the impact of dynamical tides on the evolution of planetary orbits in the stellar mass regimes where our models apply ($M > 1.4\ M_{sun}$) will be performed. The student will explore in details the parameter space (stellar and planetary mass, initial distance, eccentricity, stellar rotation rate) and identify how the evolution of the planet-star system depends on these parameters.

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

Investigating the properties of the galactic population of pulsars

Contact person : Michaël De Becker (MEGA)

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Office: 1/8, 1st floor of building B5c

Availability: Please send an e-mail to organize an appointment

Thematics : Astrophysics

Description:

There are more than 3,500 known pulsars in the Milky Way galaxy. Most of them are revealed by their typical radio light curve, which shows clear pulses with a time interval corresponding to their rotation period.

Within the framework of the standard model for pulsar radio emission, the measurement of light curves of pulsars can be used to determine some of their main properties, such as the lower limit of their magnetic field, their lifetime and their braking index. An important part of the thesis will consist in a critical discussion of the distribution of parameters characterising the population of Galactic pulsars. The discussion should also include a significant bibliographic component.

This Master's thesis topic requires the processing of data collected from the main pulsar catalogue using tools that will be developed by the student. To this end, any interested student should express some affinity for programming (with any language of their choice).

This proposed master thesis is valid for 15 credits.

Recommended courses:

SPAT0069-1 Radio astrophysics

SPAT0002-1 Statistical methods and data analysis

Investigating the capability of interstellar clouds to produce molecules of prebiotic interest using recent astrochemical codes

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Availability: Please send an e-mail to organize an appointment

Thematics : Astrophysics

Description:

With more than 300 different molecules identified in dense interstellar clouds, the study of interstellar physico-chemical processes has become a major research theme in astrophysics.

The core of this dissertation is the study interstellar astrochemistry using models that allow us to follow the evolution of abundances of multiple species over time, and to identify the main routes of molecule formation. In addition to open access models used by the astrochemical community, the student will have the opportunity to use a new model currently in development in the MEGA group.

The first stage of the work will involve getting familiar with the appropriate modelling tools. The main focus of the work will be set on the abiotic synthesis of molecules of prebiotic interest. Within this framework, the student will be free to define, in discussion with the supervisor, which specific aspect of these interstellar processes will be developed in the master's thesis.

The student will also carry out an extensive bibliographical exploration with a view to ensuring a good connection between his work and the research being carried out in this area.

This proposed master thesis is valid for 27 credits.

Required course:

SPAT0020-2 Astrochemistry

Recommended course:

SPAT0008-1 Interstellar medium

Modeling the cometary spectrum of the CH radical

Contact person: Jehin Emmanuël (ULiège) & Philippe Rousselot (Observatoire de Besançon)

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Tél: 043669726

Office: B5c 1/9

Availability: please contact me

Thematic: Astrophysics (small bodies of the solar system)

Description:

The CH radical appears in the constituents of the gas present in the coma of a comet. It is a dissociation product of molecules release by the ices of the nucleus or dust grains. This radical has two emission bands in the visible range at 389 and 430 nm. Although not the brightest in the emission spectrum of comets, these bands make it possible to measure the quantity of this radical but also the 12C/13C or even D/H isotopic ratios in this radical, provided that spectra with high spectral resolution and a high signal-to-noise ratio are available. To achieve this, it is necessary to model this emission spectrum, which is possible thanks to the data available in the scientific literature (energy levels and transition probabilities).

An initial approach to modeling this spectrum (Kim et al., 1997; Meier et al., 1998) showed that it could not be modeled as an equilibrium spectrum—like other radicals present in cometary comas, for example OH or CN—due to its very short lifetime (about a hundred seconds at 1 AU from the Sun). However, a model based on a Boltzmannian distribution of energy levels can provide a correct result.

The goal of this work is to model this emission spectrum (CH and its isotopologue 13CH), using molecular data available in the ExoMol database. These data are based on more recent work: Masseron et al. 2014, and Bernath 2020. Such a model will be compared with the high-resolution cometary spectra available in the team and obtained with the VLT UVES instrument.

The student should be comfortable with programming (at least Python) and have a basic knowledge of molecular spectroscopy. Knowledge of astrophysics on the solar system would be a plus but is not essential.

The work will be done within the COMETA Service (+1), and a stay of at least two weeks at the Besançon observatory to work with prof. Philippe Rousselot will be planned.

https://www.cometa.uliege.be/

References :

Bernath P.F., 2020, JQSRT 240, 106687
Masseron T., et al., 2014, A&A 571, A47
Meier R., et al., 1998, Icarus 136, 268
Kim S.J., et al., 1997, J. Geomag. Geoelectr. 49, 1165

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

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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 COMETA Service (+1) : https://www.cometa.uliege.be/

Photometric analysis of Near-Earth Asteroids (NEA) using TRAPPIST telescopes

Contact persons: Jehin Emmanuël (Université de Liège)

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Tél: 043669726

Office: B5c 1/9

Availability: please contact me

Thematic: Astrophysics (small bodies of the solar system)

Description:

The TRAPPIST 0.6m telescopes installed at the la Silla observatory in Chile in 2010 and 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) (Jehin et al. 2011).

The main goal of this master thesis is the physical characterization of NEAs through the analysis of new and/or archived observations obtained with the TRAPPIST telescopes.

NEAs are asteroids that possess a semi-major axis smaller than 1.3 astronomical units. This means that these objects can potentially come close to the Earth, cross its orbit and even impact it. As of today, more than 35,000 NEAs have been discovered and about 2,000 new NEAs are discovered each year. Among those about 2500 are considered as potentially dangerous for the Earth. Their study is then important to better understand their population, their formation and their physical properties (size, albedo, composition, and rotation period, densities) to develop mitigation strategies in the case of the discovery of an NEA on an Earth impact trajectory.

During the master thesis, the student will familiarize with the observations with TRAPPIST telescopes, schedule new observations and then reduce and analyze the new data. The main datasets will be photometric observations that will allow to derive light curves and derive the rotation period of the asteroids, get information on its shape. A rotation light curve of an asteroid is indeed produced by the fact that an asteroid is an irregularly shaped object that is spinning around a rotation axis. As the asteroid rotates, the total surface area visible from Earth is changing, producing the variation of its intensity. Analysis of asteroid light curves provides information about its rotation period, its spin axis orientation and shape.

https://www.cometa.uliege.be/

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

Study of a meteor shower using radio data from the BRAMS network

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Availability: If possible a Friday, for example Friday 17, 24, 31 May or 7 June.

Thematics: Planetology and planetary systems; Instrumentation and methods.

Description:

Millions of tiny solid particles called meteoroids fall daily into the Earth's atmosphere and form the meteor background. In addition, every year, when Earth encounters a stream of meteoroids released by comets or sometimes asteroids, a meteor shower occurs. When these small dust particles hit the atmosphere at very high speeds, they disintegrate and produce an ionized trail along their path, with a local electron density high enough to temporarily reflect radio waves sent from the ground. The reflected signal is called a meteor echo. Most of these reflections are specular meaning that most of the power of the meteor echo comes from a small region (a few km or less) along the meteoroid path, whose position depends on the locations of the transmitter and of the receiver.

The BRAMS network (Belgian RAdio Meteor Stations) aims at detecting and studying these meteoroids by using forward scattering of radio waves, i.e. with the transmitter and the receiver not being co-located like in a traditional meteor radar. A dedicated beacon emits a signal at a frequency of 49.97 MHz with a constant power of 340 W which is reflected off the meteor ionized trail and recorded continuously by about 50 receiving stations in Belgium, which makes the BRAMS network unique worldwide. Recently, algorithms to compute the trajectory and speed of a meteoroid using data from multiple BRAMS stations have been developed and tested (Balis et al. 2023, 2025).

In this project, we propose to use the BRAMS data and these algorithms during a selected meteor shower to test whether shower meteors can be efficiently separated from those pertaining to the background. To discriminate the meteors, we will rely on the position of their radiant and on their speed. The selected meteor shower will be an active one with a peak well marked above the background. Also, meteor showers such as the Perseids should be avoided initially since their particles are more fluffy leading to meteor echoes that do not strictly follow the specularity condition and hence for which the developed algorithms might fail. The Quadrantids in January with a pronounced and relatively short (a few hours) peak is a good starting candidate.

References :

Balis, J. et al., Reconstructing Meteoroid Trajectories Using Forward Scatter Radio Observations From the BRAMS Network, Radio Science, 58, 2023. https://doi.org/10.1029/2023RS007697

Balis, J. et al., Enhanced meteoroid trajectory and speed reconstruction using a forward scatter radio network: pre-t0 phase technique and uncertainty analysis, submitted to Radio Science, 2025

Identifying Low Earth Orbit satellites in SPECULOOS South observations

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Availability: Tuesday and Thursday from 14hrs to 16hrs

Thematic: Instrumentation and methods

Description:

SPECULOOS (Search for habitable Planets EClipsing ULtracOOl Stars) aims to detect exoplanets using the so-called transit method on the nearest (<40 pc) ultracool (<3000K) dwarf stars. SPECULOOS is a project led by the University of Liege (project leader: Michaël Gillon) and carried out in partnership with the University of Cambridge, the University of Birmingham, the Massachusetts Institute of Technology, the University of Bern, and the University of Zurich. It is based on a network of robotic telescopes distributed on two main observatories, SPECULOOS-South in Chile (4 telescopes, see Figure on the right) and SPECULOOS-North in Tenerife (1 telescope, soon 2), complemented by the SAINT-Ex telescopes (1 telescope in Mexico). The project was born in 2011 as a prototype on the TRAPPIST-South telescope in Chile. This prototype discovered the extraordinary planetary system TRAPPIST-1 (= SPECULOOS-1) composed of seven Earth-like planets in orbit around an ultra-cold dwarf star located at 40 light years. After this prototype phase, the project itself started its operations in 2019. In 2022, it discovered a new potentially habitable planet around another ultra-cold dwarf named SPECULOOS-2 (Delrez et al. 2022). More recently, the project discovered SPECULOOS-3b, an Earth-sized planet in a 17-hour orbit around an M6.5-type ultracool dwarf located 16.8 parsecs away (Gillon et al. 2024).

The rapid development in low Earth orbit (LEO) satellites brought with it a variety of new challenges, including an increased probability of collisions, increased pollution of space in the form of space debris, increased complexity in tracking space objects, impacts on ground- and space-based astronomy, and even concerns about atmospheric pollution due to launch emissions and re-entry of satellite bodies. SPECULOOS observations are not immune to this problem. We have recently found at least 10 LEO satellite traces per night. The goal of this project is to assess the impact of this contamination, not only for our project but also for the Paranal site, in collaboration with the Atmospheric Scientist of ESO Paranal.

For satellites trace detection we will use *prose* (Garcia et. al 2022), a Python package to build image processing pipelines for Astronomy. For each image that we detect a satellite trace source, we will save the position, orientation and maximum flux of the trace. Additionally, we will save the julian date of the detection, the image center RA and DEC position, filter, exposure time and FoV of the observation. This information will be helpful for later try to identify the satellite that produced the streak. The next step would be to run our detection and identification codes for all our data from 2019-2024. We will discuss the better way to store and analyse these data to produce valuable statistics as well as to produce useful information for the community.

Characterization of tight binaries from long baseline interferometry observations

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Availability: Tuesday and Thursday from 14hrs to 16hrs

Thematic: Astrophysics

Description:

Within the SACY collaboration, we have identified spectroscopic binaries (Elliott et al. 2014, Zuniga-Fernandez et al. 2021a), close visual binaries (Elliott et al. 2015) and wide and extremely wide binaries (Elliott et al. 2016a,2016b) in young associations. Elliott et al. 2015 analysed Adaptive Optics (AO) imaging data for 113 members of the young associations and identified 44 companions around 38 stars. Since then, we have collected data from 27 other AO imaging surveys targeting these young associations, reaching over 2000 AO observations of about 190 individual objects. Similarly, as a part of the multiplicity studies within the SACY project, two VLTI/PIONIER observing runs (Programs 097.C-0587 and 099.C-0195, PI: P. Elliott) were conducted in 2016 and 2017. The combination of the AO-imaging and VLTI observations can “bridge the gap” between spectroscopy and direct imaging, covering the angular separation range of ~1-10,000 mas. This combination of techniques can yield comprehensive multiplicity statistics over a continuous range of projected separations with single-epoch observations, and inclinations, orbits and dynamical masses with multi-epoch observations.

Long baseline interferometry allows us to spatially resolve components in close binaries, providing astrometric positions at $\sim 2-60$ mas scale with micro-arcsecond accuracy. We used the VLTI with the four-telescopes combiner PIONIER. From these observations, we retrieved all the science ready data from the ESO archive. For each binary candidate detection, we searched in the literature whether the multiple nature of the system was known using other observation techniques. We detected a companion in two objects that were flagged as non-confirmed SB candidates in our last update of SBs in the SACY sample.

In this project you will analyse interferometric data taken with PIONIER, get the astrometry and search in public catalogues for new observations for these binary candidates. These observations open the possibility to refine the orbital inclination of previously identified systems and help us to obtain preliminary orbital solutions for newly identified systems.

Mirror mode waves in Jupiter's magnetosheath

Contact person : Bertrand BONFOND

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Office: B5c 0/2

Availability: Please contact me via email.

Thematics : Planetology

Description:

Formed by the interaction of the super-sonic solar wind and a planetary magnetosphere, the magnetosheath is the transition layer comprised between the bow shock and the magnetopause. The compression of the plasma in this region favours the growth of a variety of plasma waves among which are the mirror mode waves. These mirror mode waves are fluctuations in plasma density and magnetic fields that move with the bulk flow. These waves can transfer energy between particles and electromagnetic fields and they can also influence magnetic reconnection on the magnetospause.

You will analyse the magnetic field measurements of the various probes that explored the Jovian magnetosphere, including the Juno spacecraft currently orbiting Jupiter, and you will identify and characterize the mirror mode structures in the magnetosheath. All the data required for this analysis are archived on NASA's Planetary Data System.

27 credits – following SPAT0028-2 and SPAT0001-1 is highly recommended

Polar dawn spots in Jupiter's aurora

Contact person : Bertrand BONFOND

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Availability: Please contact me via email.

Thematics : Planetology

Description:

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) showed the location of these features in the equatorial plane as well as their time scales and periodicities. It was shown that the majority of polar dawn spots magnetically map to the dawn sector. Additionally, they occur 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.

27 or 15 credits – following SPAT0028-2 is highly recommended

Exploring the plasma source of Jupiter's magnetosphere: using in-situ ultraviolet observations to monitor the Io plasma torus

Contact person : Alessandro Moirano, Bertrand Bonfond

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Availability: After May 20th (please, consider sending an email beforehand anyway)

Thematics : Planetology and planetary systems

Description:

The Jovian moon Io is a celestial body that hosts constant volcanic activity, which is ultimately driven by the tidal stress imparted by Jupiter. The ejected material ultimately supplies a donut-shaped plasma cloud around Jupiter – called the Io plasma torus - made primarily of oxygen and sulfur ions. The Io plasma torus is the main source of plasma for the entire Jovian magnetosphere, and its structure, dynamics, chemistry and variability have been the focus of Jupiter's exploration for decades.

Since 2016, the Juno spacecraft has been orbiting around Jupiter, using its ultraviolet spectrograph (UVS) to monitor the auroral emission around the poles. Although the instrument was not designed to observe the Io plasma torus, its wavelength range incidentally includes some emission lines of the oxygen and sulfur. Additionally, the geometry of Juno's orbit provides a unique, global view of the torus when the spacecraft is far below the southern pole of Jupiter.

In this master thesis, we propose to estimate the UV emission from the Io torus using Juno's unique dataset, which has not been extensively explored for this purpose. The student will acquire and develop a number complementary skills, such as spectrometric processing and analysis, an understanding of how a deep space instrument works, and an understanding of the physics involved in magnetospheric processes. Depending on the findings in Juno's dataset, the student will also learn to determine the direction of the study (for example, it may be possible to carry out a statistical analysis, or a single-case study work), which makes this subject good for either a 15- or 27-credits thesis.

Partial Melting of Mercury's Fertile Mantle

Contact person: Bernard Charlier

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Office: B20 – 1/12

Availability: Available in May-June, except June 6 to 22

Thematics: Planetology and planetary systems

Description:

The planet Mercury has been extensively studied by the MESSENGER spacecraft and will be explored again in 2026 by the European BepiColombo mission. Measurements have revealed that its surface is covered with rocks of magmatic origin. This crust, with a varied composition, results from partial melting of the mantle between 4.2 and 3.5 billion years ago. Major magmatic activity and the formation of Mercury's secondary volcanic crust were therefore limited to the first billion years of the planet's evolution, before ceasing and giving way to a much more limited, explosive volcanism.

To study the geochemical diversity of the crust and the origin of the cessation of volcanism, the mantle melting processes must be better understood. This Master's project thus proposes to study the partial melting of Mercury's fertile mantle through an experimental approach. Experiments will be carried out at high pressure (1 GPa, corresponding to the base of the lithosphere) and high temperature (1300–1500 °C) to simulate the melting process and understand phase equilibria (mineralogy, chemistry of silicate melts).

The candidate will be trained in experimental petrology methods and in situ analytical techniques (microscopy and electron microprobe) required for the project.

The proposed master thesis is valid for 27 credits.

Mantle Melting Properties in the Mg_2SiO_4–SiO_2–CaS System and Implications for Reduced Planets

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Availability: Available in May-June, except June 6 to 22

Thematics: Planetology and planetary systems

Description:

Olivine (forsterite) and orthopyroxene (enstatite) are common minerals in planetary mantles. These ultramafic rocks (harzburgites) are highly refractory and can only melt at very high temperatures. They are therefore generally considered as depleted sources, incapable of contributing to the production of lavas and crust formation through partial melting. However, the mantles of ultra-reduced planets (such as Mercury) may also contain exotic sulfides such as CaS, which could significantly affect the mantle's melting properties.

In this project, the Mg_2SiO_4–SiO_2–CaS system will be studied to better understand the melting behavior of ultra-reduced planetary mantles. Experiments will be conducted at high pressure (1 GPa) and high temperature (1400–1800 °C) to simulate the melting process and investigate phase equilibria (mineralogy, silicate melt chemistry, sulfur solubility).

The candidate will be trained in experimental petrology methods and in situ analytical techniques (microscopy and electron microprobe) required for the project.

The proposed master thesis is valid for 27 credits.

Adsorption Processes in MEDUSA

Contact person: Guy Munhoven (LPAP)

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Availability: by appointment

Thematics: climate, environment and oceanography

Description:

Solute transport in porous media such as seafloor surface sediments is mostly by molecular or ionic diffusion in porewater. However, for some nutrients, such as ammonium or phosphate ions, transport by adsorption onto solid particles is another important mechanism.

Adsorption processes are currently not represented in the Model of Early Diagenesis in the Surface Sediment with Adaptable complexity, MEDUSA (Munhoven, 2021). While a reasonably realistic steady-state representation of adsorption processes (by diffusion coefficient enhancement) can be realised by code patching, it is unclear if this approach allows for selective adsorption on special types of solid particle (e. g., clay particles only). As a result, it would be more consistent to extend the code generator to allow for the explicit inclusion of adsorption processes.

Here, I propose to implement both approaches in MEDUSA and to perform a comprehensive sensitivity analysis of the two methods, and of the relative importance of transport by adsorption in general.

Requirements and prerequisites. This thesis project requires advanced programming skills. The code generator for MEDUSA is written in Fortran 95 and needs to be adapted. Introductory training in Fortran 90/95 can be provided if required.

Basic knowledge of biogeochemical cycles (carbon, phosphorus, nitrogen) would be useful, but is not indispensable, as this can be easily acquired from textbooks and scientific literature (rich collection available in the lab).

Infrastructure. Usual developments and test simulations can normally be done on the student's own computing devices (laptop, desktop PCs), but a computing server is available in the lab if required.

Stays abroad. This work can be completely done in Liège.

Special terms and conditions. This subject is ***not suitable for a 15-credit thesis***.

Carbon Dioxide Removal with MBM-MEDUSA (or *i*LOVECLIM-MEDUSA)

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Office: B5c building – room 0/13

Availability: by appointment

Thematics: climate, environment and oceanography

Description:

Due to the painfully slow progress in reducing atmospheric CO_2 emissions, Carbon Dioxide Removal (CDR) has over the years become a firm component in the cocktail of measures riquired to reduce atmospheric CO_2: fulfilling the requirements of the Paris agreement, i. e, keeping the mean global warming well below 2 °C above pre-industrial levels, and preferably below 1.5 °C by the year 2100, will at this stage require some form of CDR. CDR encompasses all kinds of processes that remove CO_2 from the atmosphere, be this by afforestation or reforestation, bioenergy with carbon capture and storage (BECCS), direct air capture and storage (DACS) or ocean alkalinization. The net efficiency of CDR methods is, however, subject to debate: positive emissions seem to be more efficient in increasing global temperature than negative emissions in decreasing them.

Here, I propose to adapt the coupled ocean carbon cycle-sediment model MBM-MEDUSA (Munhoven, 2007, 2021) so that it can be used to carry out the standard experiments of the Carbon Dioxide Removal Model Intercomparison Project (CDRMIP). The analysis will then also focus on the impact of CDR techniques and scenarios on the future evolution of the distribution se-floor carbonates. Alternatively, the Earth System Model *i*Loveclim which already includes all of the necessary carbon cycle related components, and which would furthermore allow to take into account the climate feedback, could also be used.

Requirements and prerequisites. This thesis project requires programming skills. MBM-MEDUSA is written in Fortran 95 and needs to be adapted. Introductory training in Fortran 90/95 can be provided if required. Processing and analysis of the results has so far been done with IDL, but is progressively transiting to Python.

Basic knowledge of the carbon cycle would be useful, but is not indispensable, as this can be easily acquired from lecture notes, textbooks and scientific literature (rich collection available in the lab).

Infrastructure. Developments on MBM-MEDUSA can be done on the students own computing devices (laptop, desktop PCs). A dedicated computing server is nevertheless available if required.

Stays abroad. It should normally be possible to carry out this work completely in Liège.

Special terms and conditions. This subject can be adapted for a 15- or a 27-credit thesis.

Development of a coupled coral photosynthesis-respiration-calcification model

Contact person: Guy Munhoven (LPAP)

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Phone: (+32) (4) 366 9771

Office: B5c building – room 0/13

Availability: by appointment

Thematics: climate, environment and oceanography

Description:

The World oceans' coral reefs are important carbon sinks in the ocean and they contribute to regulate atmospheric CO_2 levels on time scales of a few centuries to tens of millennia.

Here, I propose to develop a model of coupled carbon alkalinity and oxygen fluxes as a result of photosynthesis, respiration and calcification by the different components of a coral. We are at first basing our developments on previously published models, such as those of Hohn and Merico (2012, DOI:10.5194/bg-9-4441-2012) or Nakamura et al. (2013, DOI:10.1007/s00338-013-1032-2).

Requirements and prerequisites. This thesis project will obviously require programming skills. Once tested and validated, the model is meant to be included in ocean biogeochemical cycle models (multi-box models, EMICs or full 3D models). Accordingly, programming work would best to be done in Fortran 90 or better, as this is the source language of those models. I will provide introductory training in Fortran 90/95 if required. However, as early development stages of a new model generally require a lot of exploration tests, developments for this thesis can also be done in Python.

Furthermore, basic knowledge of biogeochemical cycles is recommended. Students must furthermore not be afraid of mathematics (differential equations, basic numerical methods, etc., at bachelors' level).

Infrastructure. Early stage developments can be done on the student's own computing devices (laptop, desktop PCs). For computationally intensive work, a dedicated computing server is available.

Stays abroad. It should normally be possible to carry out this work completely in Liège.

Special terms and conditions. This subject can be adapted for a 15- or a 27-credit thesis.

Climate Change Impacts on Temperate Forest Trees

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Availability: Many available slots on Monday (starting from May 19), Tuesday (starting from May 20) and Wednesday (starting from May 28). However, the best is to send a e-mail to fix an appointment.

Thematics : Climate, environment and oceanography

Description:

Climate change may have severe impacts on land vegetation. For instance, droughts, which are projected to become more frequent and more intense in the future in many parts of the world, may seriously decrease crop growth and productivity with potential threats on food security. Forests are also impacted with a reduction of growth, but also enhanced vulnerability and mortality of some tree species. An example is Norway spruce which became more susceptible to insect attack following the droughts of the 2018, 2019 and 2020 summers in Wallonia. This led to the mortality of many spruce tree stands in Wallonia. Other temperate tree species, such as beech, are also at risk.

The impact of climate change on plant species depends on the morphophysiological traits of the species, i.e., physical, chemical or biological properties characterizing different plant organs (e.g., specific leaf area, or leaf area per unit leaf mass, is an important trait for photosynthesis). The trait values vary among species, as well as among individuals within a single species. They result from acclimation to the environment and the climate in which the individual has grown, as well from genetic adaptation. Traits data are gathered in a global database: TRY (https://www.try-db.org/TryWeb/Home.php).

The objective of this master thesis is to collect leaf trait data from the TRY database for several temperate tree species, and knowing locations and years of the sampling, put the trait values in correspondence with climate data, to identify the climate variables that are controlling the traits, and establish statistical relationships allowing to predict the trait values from meteorological data. Optionally, trait data may also be measured in the field (field campaigns in Ardenne forests or abroad) or from remote sensing hyperspectral sensors.

The inferred relationships will be introduced in the CARAIB dynamic vegetation model (developed in our research unit) to improve the simulation of temperate forests with this model, by using traits that dynamically respond to climate variables (instead of being constant in the current version of the model). Then, simulations will be performed for the future according to climate scenarios of the Intergovernmental Panel on Climate Change (IPCC) to investigate the acclimation potential of the studied species against climate change, and the impact on productivity and growth, as well as on mortality rate whenever possible.

Master thesis valid for 27 credits or 15 credits.

Variable Redfield-Ratio Organic Matter

Contact person: Guy Munhoven (LPAP)

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Phone: (+32) (4) 366 9771

Office: B5c building – room 0/13

Availability: by appointment

Thematics: climate, environment and oceanography

Description:

Most existing ocean biogeochemical models adopt a comparatively simple approach to represent the coupling of the nutrient (essentially nitrate and phosphate) and carbon cycles that arise from the production, transport and remineralization of organic matter: they adopt fixed C:N:P ratios, generally called Redfield ratios, to quantify the stoichiometry of organic matter. While this approach is justified to first order, there are regional deviations from these global average characteristics, and it seems that these ratios may also change in time, e. g., in response to the ongoing ocean acidification and global warming, or in relation to past climate changes, such as the Pleistocene glaciations. Hence, more and more biogeochemical models start to adopt variable organic matter stoichiometry to take into account this improved understanding of the coupled nutrient-carbon cycles.

Here, I propose to go one step further with these improvements, by also analysing the impact on the ocean-sediment exchange of nutrients, carbon and oxygen, using the the coupled ocean carbon cycle-sediment model MBM-MEDUSA (Munhoven, 2007, 2021): the ocean carbon cycle part will have to be extended to allow for variable C:N:P compositions of organic matter and a compatible MEDUSA configuration to be set up. Applications can address scientific questions of the past or the future evolution of the global carbon cycle.

Requirements and prerequisites. This thesis project requires programming skills. MBM-MEDUSA is written in Fortran 95 and needs to be adapted. Introductory training in Fortran 90/95 can be provided if required. Processing and analysis of the results has so far been done with IDL, but is progressively transiting to Python.

Basic knowledge of biogeochemical cycles (carbon, phosphorus, nitrogen) would be useful, but is not indispensable, as this can be easily acquired from textbooks and scientific literature (rich collection available in the lab).

Infrastructure. Usual developments and test simulations can normally be done on the student's own computing devices (laptop, desktop PCs). For computationally demanding work, a dedicated calculation server is available.

Stays abroad. It should normally be possible to carry out this work completely in Liège.

Special terms and conditions. This subject is ***not suitable for a 15-credit thesis***.

Classification of Phytoplankton Blooms in Model and Satellite data

Contact person : Marilaure Grégoire, Mathurin Choblet (MAST group)

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Office: B5 2/52

Availability: After June 9, 2025 (I am on a research cruise without internet in May)

Thematics : Climate, environment and oceanography;

Description:

Are you interested in doing data science that is relevant for climate change research, apply cool algorithms to big environmental datasets, become an expert in a topic that is new for you? Then the MAST group might have a master thesis topic of interest for you. Phytoplankton plays a crucial role in Earth's carbon cycle and produces a significant portion of our planet's oxygen. Surface chlorophyll concentration, observable as "ocean color," serves as a key indicator of phytoplankton blooms and is recognized as an Essential Climate Variable (ECV) due to its importance in monitoring marine ecosystem health and productivity. This parameter can be measured via satellite remote sensing or estimated through biogeochemical ocean models. Changes in phytoplankton bloom patterns affect the entire marine food web, with shifts potentially signaling important ecosystem changes. However, current analysis of phytoplankton blooms is often limited to simple time series methods, which don't fully capture its complex dynamics.

This thesis aims to advance beyond traditional analyses by:

Establishing robust criteria for identifying and classifying different types of phytoplankton blooms ; Characterizing bloom occurrence patterns across temporal and spatial dimensions ; Investigating the physical and biogeochemical drivers behind different bloom types ; Comparing satellite observations with biogeochemical model outputs for the Black Sea region.
The student will apply data science techniques to both remote-sensing data and model-generated chlorophyll estimates, including: Connected component analysis for bloom identification. Self-organizing maps for pattern recognition, Hierarchical clustering for bloom classification, spectral analysis to quantify the variability of chlorophyll… (to be adapted according to the interests of the student).

Research Environment

The MAST research group at the University of Liège develops an operational biogeochemical model of the Black Sea, a unique marine environment characterized by strong seasonal blooms. The student's work will contribute directly to improving our understanding of chlorophyll dynamics and help evaluate the strengths and weaknesses of the current model. Close supervision and support will be provided throughout the research process. The candidate will have an interest in environmental data science along with programming skills, particularly in Python. We're looking for someone with enthusiasm for exploring and implementing algorithms, as well as curiosity and willingness to learn about new topics, like the biogeochemistry of the ocean. While having taken some introductory oceanography courses would be beneficial, it is not mandatory for starting the project.

The proposed master thesis can be valid for both 27 credits and 15 credits.

Advancing high contrast imaging techniques for rocky exoplanet detection

Contact person : Gilles Orban de Xivry (PSILab group of Olivier Absil)

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Tel : 04/3669712

Office: B5c 2 / 13

Availability: will be given based on first email contact

Thematics : Instrumentation and methods

Description:

The next generation of ground-based and space-based high contrast imaging instruments will have the potential to image and characterize rocky exoplanets for the first time. This exciting prospect comes with significant technological challenges, particularly in achieving the necessary contrast at the smallest angular separation from the parent star.

In the pursue of this objective, high contrast imaging instruments employ coronagraphs, that is an optical device designed to suppress the on-axis starlight while allowing the off-axis planet light to pass through. However, beyond the design of the coronagraph, atmospheric and instrumental aberrations present major limitations. Therefore, advanced aberration control and post-processing techniques are crucial for obtaining the highest performance and improving detection limits.

The student project will involve performing advanced Fourier optics simulations of a high-contrast imaging instrument to explore either advanced aberration sensing or new post-processing techniques.

In the first case, the objective is to better understand our ability to measure aberrations within the coronagraphic instrument, simulate the impact of those diverse aberrations on the final image, and possibly apply machine learning techniques to try and measure them.

In the second case, the objective is to use instrumental telemetry to reconstruct the image of the starlight and optimally subtract it from the science image to improve the detection limit. This new approach would be compared to more standard post-processing techniques.

The project will involve Python programming, utilizing pre-existing libraries developed at the PSILab. The exact scope will be discussed with potential candidates, with options for both 27-credit and 15-credit.

Research Environment

The research will be done within the PSILab group at the University of Liège. The group has a long-standing expertise in high contrast imaging and the use of the vortex coronagraph. The group is part of the development team of the Mid-infrared ELT Imager and Spectrograph (METIS), one of the first-generation instruments for the Extremely Large Telescope (ELT), bound to see light in 2030.

Change detection from SAR imagery and Machine Learning techniques

Contact person : Murielle Kirkove

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Office: B29 (Centre Spatial de Liège (CSL)), 2.29

Availability: May, June

Thematics : Climate, environment and oceanography

Description

Change detection techniques based on imagery analysis have applications in many different areas including in the socio-ecological domain of detection and monitoring of human activities asdeforestation and buildings constructions or the study of soil quality for agricultural purposes. Theincreasing number of Synthetic Aperture Radar (SAR) satellites observing the earth on a regularbasis provides image time series that can be used to analyze changes. The manual analysis of SARimages to detect changes is a tedious task. However, the progress in Artificial Intelligence (AI) andin particular, in Machine Learning (ML), offers fast ways to perform change detection.We developed a theoretical methodology based on ML techniques to detect changes from SARsatellite image time series. Most change detection algorithms are supervised and need thus a largeamount of labeled data. Finding labeled SAR data is difficult since it results from a costly and time-consuming task. The proposed methodology is based on a self-supervised approach; it does notrequire any labeled data. Self-supervised approaches are typically divided in two stages: a pre-training (unsupervised) stage providing pseudo-labeling procedure to derive labeled data and a fine-tuning (supervised) stage for learning a model on pseudo-labeled dataset. The unsupervised stagehas been developed and assessed. It is based on a joint convolutional Auto-Encoder (AE) combiningtwo convolutional AEs that are able, for each images-pair, to reconstruct each of the images from theother one. The pseudo-labeling is based on the reconstruction errors allowing to segment images-pairs with classes including high-probability of non-change and high-probability of change classes.Two Neural Network models have been proposed for the supervised step respectively based on thePCBA-Net and the U-Net architectures.

The Signal Processing lab of the CSL has a long expertise in SARimagery and is currently studying the exploitation of SAR imagery by ML techniques for diverseapplications as detection of land changes. In this context, this lab is looking for a motivated masterstudent to explore the proposed ML method. This work will be carried out for a specific targetapplication, as part of an ongoing project with the purpose of detecting spatio-temporalenvironmental changes induced by mining activities in the Democratic Republic of Congo.Concerning the proposed ML change detection methodology, the student will be responsible forunderstanding its theoretical concepts, developing it, proposing and developing a technique toassess it and analyzing its performances. The outcomes of the master thesis are expected tocontribute to the field of automatized detection of changes from SAR imagery.

Regular meetings (every week or every two weeks) will be organized during the year.

Recommended skills/courses : SPAT0032-1: Remote sensing ; INFO8004-1: Advanced machine learning ; INFO8010-1: Deep learning• Programming (Python langage)

Number of credits: 15 or 27

Analysis of XRF spectra with Machine Learning techniques for sorting non-ferrous metal alloys

Contact person : Dr. Murielle Kirkove
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Availability: May, June

Thematics : Instrumentation and methods

Description

Based on a technology developed by the ULiege department “Gemme” for recycling non-ferrous metal scraps by families of alloys, the industry “Comet” developed an industrial line, MULTIPICK using 16 robots taking their sorting instructions from a bench of sensors (3D, hyper-spectral and X-ray Topography (XRT)). The metal sorted by MULTIPICK are mixtures of different alloy grades generally remelted for low-end applications. Sorting specific alloys permits thus to generate added economic and environmental value. The objective of a new project is thus the integration in the MULTIPICK line of Laser Induced Breakdown Spectroscopy (LIBS) and X-Ray Fluorescence (XRF) analytical sensors and data processing algorithms to sort specific alloys, in this case, aluminum and stainless-steel alloys. These algorithms will exploit the most recent developments in Artificial Intelligence (AI) and in particular in Machine Learning (ML) to process the data generated by all the sensors and provide identification of elements of the alloys of interest. The Electronics and the Signal Processing labs of the Centre Spatial de Liège (CSL) contribute to this project, the Electronics lab, by developing a new analytical XRF setup dedicated to stainless-steel and aluminum alloys, the Signal Processing lab by developing an ML method to process the XRF data, *i.e.* spectra.

To conceive this ML method, different ML models with Neural Network (NN) architectures proposed in the literature for the analysis of XRF spectra will be studied. The two first and simplest models have Fully-Connected Neural Network (FCNN) and Convolutional Neural Network (CNN) architectures that return from a single XRF spectra a vector of elements concentrations. The third model is based on the combination of an Auto-Encoder (AE) that represents the data in the form of compact information (a code) and a mapping module that transforms the code into a vector of concentrations of elements. The AE is composed of an “encoder” that generates the code and a “decoder” that synthesizes the data from this code. The proposed models have never been employed for the application field of the current project. In this context, the Signal Processing lab is looking for a motivated master student to explore one or more of the proposed ML models for the current project application. The student will be responsible for understanding the theoretical concepts of the chosen ML methods, developing them, proposing and developing a technique to assess them with respect to a set of labeled XRF spectra, and analyzing their performances. The outcomes of the master thesis are expected to contribute to the field of automatized identification of metal alloys from XRF data.

Regular meetings (every week or every two weeks) will be organized during the year.

Recommended skills/courses : INFO8004-1: Advanced machine learning; INFO8010-1: Deep learning; Programming (Python language)

Number of credits: 15 or 27