

Master Thesis Proposals

2026-2027

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 (in Belgium or abroad).

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 (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.

Coprime sampling for continuous gravitational-wave detection

Contact person : Maxime Fays (OGrav)

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Tel : +32 (0)4 366 3643

Office: B5a +4/41

Availability: Please make an appointment via email

Thematics : Gravitational waves; Data analysis; Signal processing

Description: Continuous gravitational waves are among the most elusive signals searched for in gravitational-wave astronomy. They are expected to be produced, for example, by rapidly rotating neutron stars with tiny deformations. Unlike the spectacular merger signals already detected by LIGO and Virgo, continuous waves would be extremely weak but present over very long observing times. Their detection would open a new way of studying neutron-star interiors and dense matter. The difficulty is computational as much as observational. A weak periodic signal can be buried deep below the detector noise, and standard searches may require scanning very large parameter spaces. This project explores a lighter and more original approach: using coprime sampling to identify persistent frequency signatures without relying on a full matched-filter search. The central idea is to look for narrow spectral features that remain compatible across several carefully chosen downsampled views of the same data. A real astrophysical tone should leave a structured and reproducible imprint, while random noise peaks are less likely to remain consistent under these different views. The project will test whether this structure can be used to improve sensitivity compared with simple peak-picking methods, while keeping the search computationally affordable.

The student is asked to:

- Study the basic physics and data-analysis challenges of continuous gravitational-wave searches
- Simulate weak nearly monochromatic signals embedded in realistic noise
- Implement and test coprime sampling strategies in the frequency domain
- Develop detection scores based on persistence and consistency across data segments
- Compare the method with simpler frequency-domain detection strategies

Ideal student profile: This project is well suited to a student interested in gravitational-wave data analysis and signal processing. It has a strong computational component, but remains close to clear physical intuition: finding a very weak periodic signal hidden in noisy data. Good Python programming skills are required. Familiarity with Fourier analysis, statistics, or numerical methods is an asset.

Recommended courses: Theory of gravitational waves; Advanced data analysis in Python and introduction to machine learning.

This master thesis is intended for 27 credits.

Open project on the Einstein Telescope

Contact person : Maxime Fays (OGrav)

e-mail : maxime.fays@uliege.be

Tel : +32 (0)4 366 3643

Office: B5a +4/41

Availability: Please make an appointment via email

Thematics : Gravitational waves; Einstein Telescope; Data analysis; Detector physics

Description:

The Einstein Telescope will be a third-generation gravitational-wave observatory designed to observe the Universe with much improved sensitivity, especially at low frequencies. This new frequency window will bring major scientific opportunities, but also new challenges in detector modelling, data analysis, and interpretation of the signals. This master thesis is proposed as an open project around the Einstein Telescope. Rather than defining a single fixed topic in advance, the precise subject will be chosen through discussion with the student, depending on their interests and background. Possible directions include the impact of Newtonian noise on low-frequency observations, the use of null streams to identify or veto non-astrophysical signals, the detection prospects for specific gravitational-wave sources, or the development of analysis tools adapted to third-generation detectors. The goal is to define a project that is scientifically relevant and aligned with the student's profile. Students interested in gravitational-wave physics, detector limitations, or data-analysis methods for future observatories are encouraged to come discuss possible directions.

The student is asked to:

- Review the scientific goals and data-analysis challenges of the Einstein Telescope
- Identify, together with myself, a focused research question
- Develop a theoretical, numerical, or data-analysis approach to address this question
- Test the method on simulations, sensitivity curves, or simplified detector models
- Interpret the results in the context of third-generation gravitational-wave astronomy

Ideal student profile: This project is well suited to a student interested in gravitational-wave science who would like to help shape the exact topic of their thesis. Depending on the chosen direction, the project may involve theoretical modelling, numerical simulations, signal processing, or data analysis. Good Python programming skills are strongly recommended, and curiosity for future gravitational-wave detectors is essential.

Recommended courses: Theory of gravitational waves; Advanced data analysis in Python and introduction to machine learning.

This master thesis is intended for 27 credits.

Response-informed detection of long-duration gravitational-wave bursts

Contact person : Maxime Fays (OGrav)

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Office: B5a +4/41

Availability: Please make an appointment via email

Thematics : Gravitational waves; Data analysis; Machine learning

Description: Most gravitational-wave detections so far have come from compact binary mergers, where the expected signal shape is relatively well modelled. However, the gravitational-wave sky may also contain longer and less predictable transient signals. These long-duration bursts could be associated with complex astrophysical phenomena, for which accurate waveform models are not yet available. Searching for such signals is difficult because one cannot simply compare the data with a precise theoretical template. Existing methods often look for regions of excess energy in time-frequency maps, but weak signals can be hard to distinguish from instrumental noise. This project explores whether additional physical information can make these searches more powerful. The guiding idea is that a real gravitational-wave burst should not appear as an arbitrary bright patch in the data. It should carry a coherent structure related to the detector network, the time-frequency evolution of the signal, and the geometry of the source on the sky. The goal of the project is to build and test a response-informed detection method that uses this structure to separate weak long-duration signals from noise more efficiently than standard excess-power approaches. The student will work with simulated burst signals injected into noisy data, construct physically motivated features, and evaluate how much these features improve detectability. Depending on progress, the project may also include machine-learning tools to learn the difference between structured gravitational-wave candidates and ordinary noise fluctuations.

The student is asked to:

- Review the main challenges of long-duration gravitational-wave burst searches
- Generate or analyse simulated time-frequency data containing weak burst signals
- Build physically motivated features using detector response and signal morphology
- Develop a detection strategy for identifying structured signal candidates
- Compare the method with standard excess-power searches

Ideal student profile: This project is suited to a student interested in gravitational-wave astronomy, data analysis, and machine-learning-inspired methods. It combines physical modelling with numerical experimentation, and is appropriate for someone who enjoys developing and testing new ideas. Good Python skills are required. Experience with statistics, signal processing, or machine learning is an asset.

Recommended courses: Theory of gravitational waves; Advanced data analysis in Python and introduction to machine learning.

This master thesis is intended for 27 credits.

Simulating the lensing environment for gravitational waves: from clusters to Einstein Telescope and LISA

Contact person : Guillaume Mahler (MEGA) & Maxime Fays (OGRAV)

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Office: B5c 1/11

Availability: Please make an appointment via email

Thematics : Astrophysics; Cosmology; Gravitational lensing; Gravitational waves

Description: Gravitational waves, like light, can be deflected, magnified, and time-delayed by intervening mass structures — a phenomenon known as gravitational lensing of gravitational waves. As the sensitivity of current and future detectors increases, lensed gravitational wave events are expected to become scientifically rich targets. Next-generation facilities — the Einstein Telescope on the ground and LISA in space — will open entirely new windows where lensing effects may be frequent and highly informative.

Interpreting these lensed events requires a detailed understanding of how the astrophysical environment of the lens — the substructure of galaxy clusters, line-of-sight mass contributions, and the complexity of “microscopic” potentials — shapes the expected signal. Building on previous theoretical work carried out in the group, this project will develop a simulation framework to model realistic lensing environments for gravitational waves. The framework will be built from the ground up; its precise scope will be defined in close and progressive discussion between the student and the supervisor. The student will connect their predictions to the detection prospects and sensitivity curves of both current and future facilities (e.g. the Einstein Telescope and LISA).

The student is asked to:

- Review the theoretical framework of gravitational wave lensing, including wave-optics effects
- Develop a simulation framework for realistic astrophysical lensing environments (scope to be refined with supervisor)
- Explore the impact of mass substructure and line-of-sight complexity on the gravitational wave lensing signal
- Connect predictions to the sensitivity and detection horizon of the Einstein Telescope and LISA

Ideal student profile:

A student with a strong theoretical physics background and genuine curiosity for gravitational wave science. This project carries a heavy programming component alongside substantial theoretical work and requires both a rigorous analytical mindset and the patience to develop new numerical tools. Prior exposure to general relativity or gravitational wave physics is strongly recommended.

Recommended courses:

SPAT0002-1 (Statistical Methods and data analysis); prior exposure to gravitational wave physics or general relativity is strongly recommended.

This master thesis is intended for 27 credits. A 15-credit version can be defined focusing on a specific, more restricted aspect of the simulation framework, to be agreed with the supervisor.

Wide-separation lensed quasar lens models and time-delay cosmography

Contact person : Guillaume Mahler & Dominique Sluse (MEGA)

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Tel : --

Office: B5c 1/11 & B5c 1/10

Availability: Please make an appointment via email

Thematics : Extragalactic astrophysics; Cosmology; Gravitational lensing

Description:

Wide-separation gravitationally lensed quasars are rare systems in which a background quasar is multiply imaged by the combined gravitational potential of a foreground galaxy cluster and its member galaxies. Their image separations, often spanning several tens of arcseconds, make them unique probes of the total mass distribution in clusters on large scales. Beyond their value as mass tracers, these systems offer an independent route to measuring the Hubble constant H_0 through time-delay cosmography — the measurement of the arrival-time differences between the quasar images.

This project builds on the work of Napier et al. and aims to construct detailed lens models of wide-separation systems. The primary goal is to model the mass distribution of the underlying lensing galaxy and cluster using available imaging and spectroscopic data. As an explicit second phase, the student may explore time-delay measurements and their cosmological implications with a possible extension to group-scale lenses in the context of the Euclid telescope observations.

The student is asked to:

- Familiarise themselves with the literature on wide-separation lensed quasars and existing models
- Construct strong lensing mass models for one or more systems, characterising the mass distribution of the lensing galaxy and cluster
- Compare results with independent mass estimates where available
- As a second phase: explore time-delay constraints and their implications for H_0

Ideal student profile:

A student with a strong interest in observational cosmology and gravitational lensing, comfortable working with real observational data and motivated by connecting lensing models to broader cosmological questions. Python programming is required. Prior exposure to extragalactic astrophysics or lensing formalism is a strong asset.

Recommended courses:

SPAT0002-1 (Statistical Methods and data analysis), SPAT0011-1 (Extragalactic astrophysics).

This master thesis is intended for 27 credits. A descoped 15-credit version focuses on the lens modelling of a single system without the time-delay phase.

Star formation in brightest cluster galaxies: building a spectroscopic pipeline for the Indian DOT telescope

Contact person : Guillaume Mahler (MEGA)

e-mail : Guillaume.mahler@uliege.be

Office: B5c 1/11

Availability: Please make an appointment via email

Thematics : Extragalactic astrophysics; Instrumentation and methods

Description:

Brightest cluster galaxies (BCGs) are the most massive galaxies in the universe and sit at the gravitational centres of galaxy clusters. BCGs residing at the centres of cool-core clusters (where the intracluster gas cools and condenses) can host residual star formation fed by the cooling flow. Measuring this star formation is a key probe of the baryon cycle in massive clusters and of the feedback processes that regulate it.

This project will use long-slit spectroscopic observations obtained with the Devasthal Optical Telescope (DOT) based in India to measure star formation rates in a handful of carefully selected BCG targets. A central component of the project is the construction of a spectroscopic data reduction pipeline for DOT long-slit data. While nearly all the necessary routines exist in the group, no unified pipeline is yet in place. The student will assemble, integrate, test, and document this pipeline before applying it to the science targets. This pipeline will become a lasting resource for the group.

The student is asked to:

- Assemble existing reduction routines into a coherent, documented pipeline for DOT long-slit spectroscopy
- Reduce and flux-calibrate the spectroscopic observations of the BCG targets
- Measure emission line fluxes (e.g. H α , [OII]) and derive star formation rates
- Interpret the results in the context of cool-core cluster physics and BCG co-evolution with the cluster

Ideal student profile:

Training in astronomical spectroscopic data analysis is a firm prerequisite. At ULiege, this is provided by the observational astronomy techniques course of Prof. Jehin (SPAT0068-1). This project suits a student who enjoys both the craft of instrument data reduction and the astrophysical questions that motivate it. An interest in extragalactic astrophysics and cluster physics is key.

Recommended courses:

SPAT0068-1 (Astrophysical observations — prerequisite), SPAT0011-1 (Extragalactic astrophysics).

This master thesis is intended for 27 credits. A 15-credit version focuses on the pipeline construction and the analysis of a reduced set of targets.

Surface brightness profiles of brightest cluster galaxies across the SLICE survey

Contact person : Guillaume Mahler (MEGA)

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Office: B5c 1/11

Availability: Please make an appointment via email

Thematics : Extragalactic astrophysics; Cosmology

Description:

Brightest cluster galaxies are built through a continuous process of mergers and accretion that leaves a distinct imprint on their stellar distribution. In particular, the extended, low surface brightness envelopes accumulated through repeated minor mergers carry direct memory of the mass assembly history at cluster centres. Comparing BCG profiles across a well-defined, cosmologically distributed sample is therefore a powerful way to track how stellar mass accumulates over cosmic time.

The SLICE survey (Survey of Lensing Clusters in JWST Epoch) provides deep JWST imaging of 124 galaxy clusters evenly distributed in redshift from $z = 0.2$ to $z = 2.0$. This project will focus on fitting and characterising the surface brightness profiles of BCGs in at least 20 clusters within a single cosmologically relevant redshift bin. The full sample of 124 clusters is available for extension if the student progresses well.

The student is asked to:

- Develop or adapt profile fitting tools (e.g. Galfit or equivalent) for JWST imaging data
- Fit BCG surface brightness profiles for at least 20 clusters in one redshift bin
- Characterise profile parameters: Sérsic index, effective radius, position angle, and ellipticity
- Discuss results in the context of BCG assembly history and their evolution with redshift
- Extend to additional redshift bins or the full SLICE sample if time permits

Ideal student profile:

A student with a clear interest in photometric data analysis and galaxy evolution, who enjoys systematic large-sample analysis of imaging data. Comfort with Python and image analysis tools is required. Prior exposure to extragalactic astrophysics is strongly recommended.

Recommended courses:

SPAT0011-1 (Extragalactic astrophysics), SPAT0002-1 (Statistical Methods and data analysis).

This master thesis is intended for 27 credits. A 15-credit version focuses on a well-defined subsample within a single redshift bin.

Source reconstruction in gravitational lenses: comparing parametric, pixel-based, and direct methods

Contact person : Guillaume Mahler (MEGA)

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Office: B5c 1/11

Availability: Please make an appointment via email

Thematics : Extragalactic astrophysics; Instrumentation and methods

Description:

One of the central challenges in strong gravitational lensing is recovering the true morphology of the lensed background source, which is distorted and magnified by the foreground mass distribution. Several complementary reconstruction approaches exist: direct inversion methods, parametric modelling of clumpy sources, and pixel-based reconstruction techniques. Each carries different assumptions, different sensitivities to noise and model errors, and different computational demands. A rigorous and systematic comparison of these methods within a single consistent framework, applied to real data, is rarely done and constitutes a valuable methodological contribution to the field.

This project will develop a source reconstruction pipeline within the Lenstool framework, building on custom routines already available in the group. The student will learn to use and integrate all three approaches and will rigorously compare their performance. The pipeline will be tested directly on at least one real arc using JWST data, with the possibility of extending the analysis to additional systems as the student progresses.

The student is asked to:

- Learn and implement the three source reconstruction methods within the Lenstool framework using existing group routines
- Develop a coherent, documented pipeline integrating all three approaches
- Test and compare the methods on a selected arc from the JWST SLICE survey
- Evaluate performance in terms of recovered source morphology, residuals, and computational cost
- Extend to additional arcs if time permits

Ideal student profile:

A student with strong programming skills and genuine comfort with numerical methods and inverse problems. This project is particularly well suited to students coming from a technical or computational background who wish to direct these skills towards astrophysical data.

Recommended courses:

SPAT0002-1 (Statistical Methods and data analysis), SPAT0011-1 (Extragalactic astrophysics). This master thesis is intended for 27 credits. A 15-credit version focuses on implementing and comparing two of the three methods on a single arc.

The mysterious flux ratio in J0924+0219

Contact person : Dominique Sluse (MEGA)

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Tel : 04366 9797

Office: B5c 1/10

Availability: Please make an appointment via email

Thematics : Extragalactic astrophysics; Gravitational lensing, Cosmology

Description:

The object J0924+0219 is a strongly gravitationally lensed system producing four images of a single background active galactic nucleus (AGN). While its global lens configuration is well constrained, the system displays an unusually extreme anomaly: two images that should have comparable brightness differ in flux by more than a factor of ten. There is no consensus on the origin of this anomaly.

Most interpretations attribute this anomaly to small-scale gravitational perturbations in the lensing galaxy, such as low-mass substructures (“milli-lensing”), possibly combined with microlensing by stars. However, despite extensive modelling efforts, no lens-based scenario has succeeded in reproducing all observational constraints simultaneously, especially across different wavelengths. This persistent failure suggests that a key physical ingredient may be missing.

This master thesis proposes to explore an **alternative and largely unexplored direction**: the role of the internal structure of the AGN itself. In particular, emission from extended regions on tens-of-parsecs scales, whose size, morphology, and wavelength dependence vary across the AGN, may modify the lensed image appearance in non-trivial ways. Surprisingly, this impact of realistic AGN structure on the lensed images has received little attention in the literature, despite its potential to affect observed flux ratios.

The student will revisit and synthesize the available **multi-wavelength data** for J0924+0219 and critically analyze the assumptions underlying standard interpretations. Different AGN source configurations will be tested to evaluate whether source-structure effects can naturally account for the observed anomalies. If time permits, these results may be combined with alternative microlensing scenarios.

The student is asked to:

- Compile and synthesize existing multi-wavelength observations of J0924+0219
- Identify and critically assess the shortcomings of standard flux-ratio interpretations
- Simulate lensed images for realistic AGN source structures using pre-computed lens models
- Compare predictions across wavelengths and confront them with observations

Ideal student profile:

This project suits a student interested in physical interpretation, hypothesis testing, and exploratory research. The work involves investigating poorly charted territory. Comfort with Python programming is required. Prior exposure to extragalactic astrophysics is recommended.

Recommended courses:

SPAT0011-1 (Extragalactic astrophysics), SPAT0002-1 (Statistical Methods and data analysis), SPAT0033-1 (Astrophysics).

This master thesis is intended for 27 credits.

Students interested in related topics are encouraged to inquire about additional projects.

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

Contact person : Dominique Sluse (MEGA)

e-mail : dsluse@uliege.be

Tel : 04366 9797

Office: B5c 1/10

Availability: Please make an appointment via email

Thematics : Extragalactic astrophysics; Gravitational lensing, Instrumentation and methods; Data analysis and machine learning

Description:

Integral field spectroscopy (IFS) has become a powerful observational tool for the study of strongly lensed quasars, as it simultaneously provides spatially resolved and spectrally resolved information. Such data enable key measurements, including the redshift and velocity dispersion of the lensing galaxy, as well as the spectral properties of the quasar and of its host galaxy.

A major challenge in analyzing IFS data of lensed quasars arises from atmospheric seeing, which spatially blends the light from the multiple quasar images and of the lensing galaxy. This blending complicates the extraction of clean spectra and limits the scientific return of these datasets.

This project aims to explore how a standard machine-learning technique, principal component analysis (PCA), can be used to de-blend spectra by jointly exploiting the spatial and spectral information encoded in IFS data cubes. After reviewing existing approaches in the literature, the student will simulate idealized integral field spectroscopy observations of strongly lensed quasars. PCA-based decompositions will then be applied to these simulated datasets under progressively more realistic observational conditions (e.g. increasing noise levels, reduced spatial resolution, complex source configurations).

Depending on the student's interest and technical skills, alternative or complementary approaches may also be explored, such as deep-learning methods, image mirroring techniques, or other data-driven decomposition strategies.

The student is asked to :

- Review existing methods for spectral and spatial de-blending in IFS data
- Simulate idealized IFS observations of strongly lensed quasars
- Implement and apply PCA-based decomposition techniques to these data
- Test the robustness and performance of the method under increasingly realistic conditions

Ideal student profile :

This project is designed for a student with a strong interest in data analysis, numerical methods, and machine-learning techniques applied to astrophysical data. The emphasis is on method development rather than on detailed astrophysical interpretation. Comfort with Python programming is required.

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).

This master thesis can be carried out as a 15- or 27-credit, with the scope adapted accordingly.

Students interested in related topics are encouraged to inquire about additional projects.

Study of radio shells in the Galactic plane using MeerKAT data

Contact person : Michaël De Becker (MEGA)

e-mail : Michael.DeBecker@uliege.be

Tel : 04 366 9717

Office: B5c 1/8

Availability: Please make an appointment via email

Thematics : Astrophysics, Galactic sources, Stellar and interstellar physics

Description:

The mapping of the radio emission from the Galactic plane by the MeerKAT observatory revealed a wealth of sources, including many associated to stellar objects and due to the stellar feedback on the surrounding interstellar medium. Among these sources, several display a ring-like morphology that is typical of the shells produced by the interaction of strong stellar winds with their surroundings. These shells result from the compression of interstellar matter by winds of massive stars, leading to favorable conditions for significant radio emission. This topic thus combines shock physics and radiative process considerations.

This master thesis topic consists of the analysis of some of these ring-like sources. The main tasks of this master thesis include:

- getting familiar with the radio techniques, including appropriate flux density measurements in irregular background regions using dedicated tools
- exploring and understanding the physical interpretation framework of these sources
- developing dedicated tools for data analysis and/or image production
- developing dedicated tools for the physical interpretation of the measurements

Radio images are available and ready to be used, without the need to proceed with all the upstream data processing.

This proposed master thesis is valid for 27 credits, and may be adapted for 15 credits.

Required courses:

SPAT0008-1 Interstellar medium

SPAT0069-1 Radio astrophysics

Recommended course:

SPAT0002-1 Statistical methods and data analysis (or equivalent)

Investigating the nature of point sources in the Galactic plane using MeerKAT radio data

Contact person : Michaël De Becker (MEGA)

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Tel : 04 366 9717

Office: B5c 1/8

Availability: Please make an appointment via email

Thematics : Astrophysics, Galactic sources, Stellar and interstellar physics

Description:

The mapping of the radio emission from the Galactic plane by the MeerKAT observatory revealed a wealth of sources, including many point sources very likely of stellar origin. Although radio emission can be measured from quite long distances across the Galactic disk due to a low attenuation (apart from geometric flux dilution), extinction can be severe in the optical domain. It is thus likely that a significant number of these radio sources do not have a well-identified counterpart in the visible domain. However, potential counterparts in the infrared or in X-rays are likely to help constraining their nature.

This master thesis topic includes the following main tasks :

- getting familiar with the radio techniques, including appropriate flux density measurements in irregular background regions using dedicated tools
- defining Galactic regions of interest, focusing on stellar clusters harboring young stellar populations
- cross-correlating the radio point source positions with various catalogues in different spectral domains
- combining the multi-wavelength information on selected objects to constrain their nature
- developing dedicated tools for data analysis and/or image production
- developing dedicated tools for the physical interpretation of the measurements

Radio images are available and ready to be used, without the need to proceed with all the upstream data processing.

This proposed master thesis is valid for 27 credits, and may be adapted for 15 credits

Required courses:

SPAT0033-1 Astrophysics

SPAT0069-1 Radio astrophysics

Recommended course:

SPAT0002-1 Statistical methods and data analysis (or equivalent)

SPAT0008-1 Interstellar medium

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. This project is intended for 27 credits thesis but can be adapted for a 15 credits thesis.

Spectroscopic and photometric variability of Be stars

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

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

Thematics: stellar astrophysics, variable stars, stellar evolution

Description:

Be stars are rapidly rotating B-type stars that exhibit emission in the H I lines of their spectrum. The emission lines arise in viscous disc surrounding the star and containing material ejected by the star. The physical mechanism that drives the mass ejection is unknown. It has been suggested that the beating of pulsation modes could provide the necessary kick to eject the material. Nowadays, it is thought that the Be star gained their rapid rotation via mass and angular momentum transfer from a companion star which would now appear as either a stripped hot subdwarf, or a compact object (white dwarf, neutron star or black hole). For most configurations, the companion would be much fainter than the Be star in the optical.

The goal of this study is to combine data from a spectroscopic monitoring campaign of a sample of Be stars, to study the variability of the emission lines which traces the status of their discs (outbursts, disc dissipation, disc formation, etc.) and to search for the signature of orbital motion of the Be star. Ground-based and space-borne photometric data will also be analysed to search for pulsations and to supplement the spectroscopic data in the study of the disc's long-term variations.

The student is asked to:

- get acquainted with the properties of Be stars in general, and of the target stars in particular,
- reduce and normalize the spectroscopic observations that have been collected to study the variability of both targets,
- measure the properties of the emission lines and search for variability and orbital motion,
- analyse photometric time series notably to search for the signature of pulsations
- and finally, discuss the results obtained in the context of the general knowledge of Be stars.

Remarks: attending or having attended the course on “Variable Stars” is clearly an advantage. This project is intended for 27 credits thesis but can be adapted for a 15 credits thesis.

Detailed investigation of convective/radiative transition in He-burning cores

Contact person : Valerie Van Grootel

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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 details of the core structure have impact on the total amount of Helium burnt, and hence on the time stars spend in this evolutionary stage. Fortunately, some core-He burning stars show stellar oscillations, with detailed and rich spectra observed by Kepler and TESS, which allow us to use asteroseismology to unveil their internal structure through the study of their pulsations. In this master thesis we will focus on subdwarf B (sdB) stars, which are core- He burning objects having lost most of their envelope during previous stages of evolution. They exhibit g-mode oscillations that precisely probe the convective/radiative regions in He-burning cores.

To carry out a detailed theoretical investigation on these regions, we will use static (parametric) models, which are in their 5th generation. These 5G models incorporate a detailed parametrization of the convective/radiative regions, to mimic different configurations possible according to different prescriptions encountered in evolutionary models and 3D hydrodynamical situations: presence or not of a semiconvection zone (and its extension of present), chemical transitions, thermal stratification. This variety of possible configurations has a profound impact on the stellar pulsations, which we will model thanks to 5G models. In a second step, we will aim to make link between these theoretical pulsation spectra with the observed pulsation spectra for sdB stars by Kepler and TESS. Qualitative comparison will be carried out first, before completing quantitative seismic modelling, by fitting observation pulsation.

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)

3D helioseismic probing of the solar helium abundance

Contact persons : Gaël Buldgen & Marc-Antoine Dupret

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Availability: Anytime from May to mid-July

Thematics : Astrophysics: stellar physics

Description:

Context:

On the one hand, the tens of thousands of oscillation modes observed in the Sun constitute a wealth of information on its internal structure, at the heart of the discipline called helioseismology. On the other hand, 3D hydrodynamic simulations give us a completely new perspective on the solar convective envelope. The abundance of helium in the solar envelope (the second most abundant element in the universe !) cannot be deduced from its solar spectroscopy, and helioseismology provides the most accurate current measurements. However, current global seismic probing methods assume a spherically symmetric internal structure. The core of this master thesis project consists of moving away from this hypothesis to measure the abundance of solar helium more accurately.

Proposed work:

The signature of envelope helium abundance mainly appears through the depletion of the so-called adiabatic index $\Gamma_1 \equiv \partial \ln P / \partial \ln \rho|_s$ in the second partial ionization zone of helium. The novelty of the project lies in taking into account the fact that the thermodynamic state and therefore Γ_1 depends on the 3 spatial coordinates, with in particular a very marked asymmetry between the up and down flows. The first part of the project will be to analyse it in a high resolution 3D hydrodynamic simulation of the upper solar envelope. Next, the main part of the project will consist of adapting the seismic inversion method to take into account the horizontal distribution of the thermodynamic quantities and more specifically Γ_1 . Finally, a new more accurate seismic measurement of the envelope helium abundance will be performed with the improved method. This work would certainly warrant publication in an international scientific journal.

Recommended courses: SPAT0045-1 Stellar structure and evolution I and II & Stellar stability and asteroseismology SPAT0005-1 (can be taken the 2nd year)

Transitory convective cores in low-metallicity stars

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

Thematics : Stellar physics, asteroseismology

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.

Impact of new opacities on massive stars' evolution and oscillations

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Availability: Anytime from May to mid-July

Thematics : Astrophysics: stellar physics

Context:

Radiative transport and the temperature profile within stars are entirely dependent on their opacity. Behind this opacity lies the full complexity of the interaction between matter and radiation in the extreme conditions of stellar interiors. Through the precise information that stars transmit to us about themselves, they therefore constitute a natural laboratory for studying this interaction. The pulsation driving processes of massive stars are extremely dependent on this interaction, and slight changes can have significant consequences. Furthermore, the timescale of stellar evolution (and thus the measurement of stellar ages) depends entirely on their luminosity and therefore on their opacity. New opacities have recently been calculated by one of the few groups capable of doing so (at Los Alamos, USA). The aim of this project is to explore the many consequences of this update on the evolution and pulsations of massive stars in the core hydrogen burning phase (main sequence).

Proposed work:

The first task will be to calculate, using the Liège Stellar Evolution Code, a grid of models with the new OPLIB opacity tables. Next, the impact of these new opacities on isochrones, the extension of convective cores and the various global parameters: luminosities, effective temperatures, ... will be examined in detail and compared to the models with old opacities. A close examination of the opacity profiles within the models will also help to identify where the changes are most significant.

The second task will consist of calculating the relevant oscillation modes of this model grid using our team's non-adiabatic oscillations modelling code. A detailed analysis of the results will then be carried out: impact on the extent of the instability strips, on the period intervals of the excited oscillations modes, detailed analysis of the thermodynamic cycle that drives the oscillations, ... This work would certainly warrant publication in an international scientific journal.

Recommended courses: SPAT0045-1 Stellar structure and evolution I and II & Stellar stability and asteroseismology SPAT0005-1 (can be taken the 2nd year)

Impact of dynamical tides on the evolution of planetary orbits

Contact person : Marc-Antoine Dupret

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Availability: Anytime from May to mid-July

Thematics : Astrophysics: stellar physics

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 ($M > 1.4 M_{\text{sun}}$) 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

High-resolution images of the UV aurora on Jupiter

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Availability: From Monday to Thursday afternoon. Please send an email in advance.

Thematics : Planetology and planetary systems

Description:

Juno is a NASA mission dedicated to exploring the planet Jupiter. It orbits around the giant planet in an eccentric polar orbit since July 2016, bringing a wealth of discoveries and unprecedented observations. Among its instruments is an imaging spectrograph (Juno-UVS), which is dedicated to the observation of the Jovian aurorae. The spatial resolution of the instrument projected on the planet strongly depends on the altitude of the spacecraft, which varies widely. Previous studies have focused on the global morphology of the aurora, paying a particular attention to the large-scale features. This thesis project aims to produce high-resolution maps of the UV aurora, focusing on the data gathered at low-altitude. The first part of the proposed project will therefore involve producing such images, which are expected to reveal many understudied morphological details. The second part of the work will involve characterizing the shape, size, brightness and variability of a selection of these small-scale features. The student will then compare them to similar features at Earth in order to discuss potential explanations, but keeping in mind the fundamental differences between the planets.

The proposed master thesis project corresponds to a 27 credit thesis, but topic can be tailored down to fit a 15 credit thesis.

Robustness of transmission spectra of terrestrial exoplanets: impact of baseline modeling and limb darkening assumptions — application to SPECULOOS-2c

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Availability: To be discussed after first contact

Thematics: Astrophysics; Planetology and planetary systems; Instrumentation and methods

Description:

The detection and characterization of transiting exoplanets rely on the precise modeling of photometric light curves. In the case of terrestrial planets orbiting ultracool dwarfs, such as those targeted by the SPECULOOS survey, transit signals are typically shallow and highly sensitive to systematic effects. With the advent of high-precision space-based observations from the James Webb Space Telescope, transmission spectroscopy has become a key tool to probe exoplanetary atmospheres. However, the robustness of the derived spectra critically depends on methodological choices made during the data analysis.

This master thesis aims to assess the impact of baseline modeling and limb darkening assumptions on the retrieval of transmission spectra. The study will focus on the terrestrial exoplanet SPECULOOS-2c, discovered within the SPECULOOS survey and observed by JWST. Publicly available JWST data will be analyzed to extract spectroscopic light curves across multiple wavelengths.

The student will implement and compare different baseline models describing instrumental and astrophysical systematics, using statistical criteria such as the Bayesian Information Criterion (BIC) or marginal likelihood estimates. In parallel, the influence of various limb darkening prescriptions will be investigated, considering both fixed coefficients and informed priors derived from stellar atmosphere models. The analysis will explore how these assumptions affect the inferred transit depths and the resulting transmission spectrum.

Additional tests will include the comparison between global multi-wavelength fits and independent fits per spectral channel. The goal is to evaluate the reliability of spectral features and to identify possible degeneracies between physical and methodological parameters.

This project will provide the student with strong expertise in exoplanet data analysis, statistical modeling, and interpretation of high-precision observations. It may lead to a scientific publication. Recommended courses include astrophysics (SPAT0033), introduction to exoplanetology (SPAT0063), stellar atmospheres (SPAT0006), planetary and exoplanetary atmospheres (SPAT0056), and statistical methods and data analysis (SPAT0002).

The proposed master thesis is valid for 27 credits.

Study of the chemical composition of comets atmospheres using the TRAPPIST telescopes

Contact person: Jehin Emmanuël (COMETA)

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Availability: please contact me

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 is still missing.

In this context, we propose the observation and analysis of the coma of two or three bright comets with the TRAPPIST telescopes network. These robotic telescopes installed by our team in Chile (in 2010) and in Morocco (in 2016) are equipped with narrow band filters to isolate the emissions of different gases and dust contained in the atmosphere of comets. The student will have to prepare the observations, calibrate the data and calculate the production rates of the different gases using the so-called Haser model (1957). The necessary tools for this kind of measure have already been developed in our team. The student will have to become familiar with the various techniques, adapt and improve, if necessary, the reduction procedures and scripts and run the models. The results might lead to the publication of a short article.

The work will be done in the comet group of the COMETA Service (+1) and the TRAPPIST team

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

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

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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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 seem, in the high-resolution spectra of comets, hundreds emission lines are still to be identified.

Laboratory studies predict that the photo-dissociation of H₂O by solar Ly α 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 radical’s 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 the 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 online tables, 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

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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

Contact person: Hervé Lamy (IASB) & Emmanuel Jehin (COMETA)

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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 specular 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

Exploring the performance of ELT/METIS high-contrast imaging

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Availability: May 11-13, May 18-22, June 9-12

Thematics : Instrumentation and methods; Planetology and planetary systems

Description:

The Mid-infrared ELT Imager and Spectrograph (METIS) will be one of the two first light instruments for the European Extremely Large Telescope (ELT), with an expected scientific first light in 2030. One of the prime scientific goals of METIS is to study extrasolar planetary system at an unprecedented angular resolution and sensitivity through high-contrast imaging (HCI). The instrument is therefore equipped with a vortex coronagraph, developed and built in Liège, which is expected to be key in achieving some of the most ambitious science goals of METIS, such as the first direct image of a temperate rocky planet. Observations with a newly commissioned infrared vortex coronagraph on the ERIS instrument at the Very Large Telescope (VLT) have however recently shown that, due to instrumental imperfections and image processing limitations, the vortex coronagraph may not deliver significantly better performance than non-coronagraphic imaging.

The goal of this master thesis is therefore to explore whether a similar situation may arise in the context of METIS and identify the potential sources of performance degradation for the METIS vortex coronagraph. In particular, we will focus on the effect of high-frequency pointing jitter, which is known to be a significant source of performance limitation for vortex coronagraphs. We will also investigate how the choice of an image processing algorithm may or may not help recover the intrinsic performance of the vortex coronagraph.

The proposed analysis will be based on an end-to-end software simulator for the ELT/METIS instrument, using a python package (HEEPS) developed at PSILab that is routinely used to predict the HCI performance of the instrument. Within this project, various sources of instrumental errors will be introduced in the end-to-end simulations and the resulting mock observations will be processed with various image processing algorithms (ranging from simple ones to the most advanced ones) to explore their combined effect on the METIS HCI performance.

Injection and recovery of various extrasolar objects (exoplanets, circumstellar disks) will be attempted to illustrate the scientific potential of METIS.

The proposed master thesis is valid for both 27 credits and 15 credits. It requires a working knowledge of python programming. Following the course SPAT0067 (Atmospheric and adaptive optics) is strongly recommended, as well as SPAT0063 (Introduction to Exoplanetology).

Variable Redfield-Ratio Organic Matter

Contact person: Guy Munhoven (LPAP)

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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*.

Development of a coupled coral photosynthesis-respiration-calcification model

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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 CO₂ 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.

Carbon Dioxide Removal with MBM-MEDUSA (or iLOVECLIM-MEDUSA or UVic_ESCM-MEDUSA)

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Availability: by appointment

Thematics: climate, environment and oceanography

Description:

Due to the painfully slow progress in reducing atmospheric CO₂ emissions, Carbon Dioxide Removal (CDR) has over the years become a firm component in the cocktail of measures required to reduce atmospheric CO₂: 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 CO₂ from the atmosphere, be this by afforestation or reforestation, bioenergy with carbon capture and storage (BECCS), direct air capture and storage (DACs) or ocean alkalization. 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 Models iLoveclim or Uvic_ESCM which already include 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.

Adsorption Processes in MEDUSA

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Phone: (+32) (4) 366 9771

Office: B5c building – room 0/13

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*.

Mantle Melting Properties in the $\text{Mg}_2\text{SiO}_4\text{-SiO}_2\text{-CaS}$ System and Implications for Reduced Planets

Contact person: Bernard Charlier (Dep. of Geology)

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Office: B20 – 1/12

Availability: May 12-13, May 20-22, and June

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 and Mercury-like exoplanets) may also contain exotic sulfides such as CaS, which could significantly affect the mantle's melting properties.

In this project, the $\text{Mg}_2\text{SiO}_4\text{-SiO}_2\text{-CaS}$ 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.

Mercury's Smooth Plains : The Last Pulse of Major Volcanism before Shutdown

Contact person: Bernard Charlier (Dep. of Geology)

e-mail: b.charlier@uliege.be

Tel: 04/366.22.50

Office: B20 – 1/12

Availability: May 12-13, May 20-22, and June

Thematics: Planetology and planetary systems

Description:

Mercury's Smooth Plains represent some of the youngest volcanic surfaces on the planet and provide key insights into its late-stage thermal and magmatic evolution. These plains are thought to result from widespread effusive volcanism that occurred after the formation of large impact basins, marking the final phases of internal geological activity.

This thesis aims to investigate the distribution and origin of Mercury's smooth plains in order to better constrain the timing and mechanisms of the final volcanic activity. Using high-resolution datasets from the MESSENGER mission and previous work on the mapping of Smooth Plains, the study will specifically focus on combining geological mapping and X-Ray compositional mapping to understand the diversity of their compositions and the implications for the interior of the planets (the mantle sources) and the melting conditions.

Depending on the specific interests of the student, the project could pay particular attention to the thermal evolution of the planet to understand changes in magma supply and mantle dynamics, or to geological features and impact structures to understand formation processes (impact melt, impact-triggered melting of the interior).

The results will contribute to a broader understanding of planetary cooling processes and volcanic shutdown on small terrestrial bodies. It will also provide new perspectives for the BepiColombo mission that will enter into orbit in late 2026.

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

Contact person : Dr. Murielle Kirkove

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Tel : 04.382.46.41

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

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. For this work, a XRF simulator has been developed, a dataset made of simulated XRF spectra has been created and a theoretical supervised ML methodology was designed. This method 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” obtained by the developed XRF simulator synthesizing the spectra from this code. This method has been developed and assessed with the help of a master student. Its performances can be improved through some techniques as data augmentation, replacement in the decoder of the XRF simulator by a ML model and replacement of the AE model by a Variational AE (VAE) model.

In this context, the “Signal Processing” lab is looking for a motivated master student to explore the proposed improvements for the current project application. The student will be responsible for understanding their theoretical concepts, developing them, proposing and analyzing their performances. The outcomes of the internship / master thesis are expected to contribute to the field of automatized identification of metal alloys from XRF data.

Supervision

The internship / master thesis will be carried out under the supervision of Murielle Kirkove du laboratoire “Signal Processing” du CSL. 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 (principles, algorithmic, Python language)

Number of credits: 15 or 27

Change classification from SAR imagery and Machine Learning techniques

Contact person : Dr. Murielle Kirkove

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Tel : 04.382.46.41

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

Availability: May, June

Thematics : Climate, environment and oceanography

Description

Change detection and classification techniques based on imagery analysis have applications in many different areas including in the socio-ecological domain of detection and monitoring of human activities as deforestation and buildings constructions or the study of soil quality for agricultural purposes. The increasing number of Synthetic Aperture Radar (SAR) satellites observing the earth on a regular basis provides image time series that can be used to detect and classify changes. The manual analysis of SAR images for this purpose is a tedious task. However, the progress in Artificial Intelligence (AI) and in particular, in Machine Learning (ML), offers fast ways to perform change detection and classification

The “Signal Processing” lab of the Centre Spatial de Liège (CSL) has a long expertise in SAR imagery and has studied for a few years the exploitation of SAR imagery by ML techniques for diverse applications as detection of land changes. Currently, this lab is contributing to a research project targeted a specific application with an ongoing initiative aimed at detecting spatio-temporal environmental changes induced by mining activities in the Democratic Republic of Congo (DRC). For this work, with the help of two master students, a dataset made of SAR images times series selected from a spatio-temporal Area Of Interest (AOI) covering numerous mining sites in the Kivu Lake region of DRC has been created and a self-supervised ML methodology of change detection from SAR imagery has been developed. These developments allowed to produce an inventory of changes in the selected AOI. In addition, a labeling work will soon be done to provide for the same AOI labeled SAR data with labels indicating different types of changes among which the ones to be identified, that is the ones induced by mining activities.

In this context, this lab is looking for a motivated master student to develop an supervised ML methodology in order to classify the changes of the created inventory with the use of the labeled SAR data. The student will be responsible for making a literature survey to propose a theoretical approach of classification of changes (with special attention to Deep Learning classifiers based on a CNN architecture, in particular the popular ML object detection algorithms as YOLO and Mask-RCNN) and developing it. The outcomes of the internship / master thesis are expected to contribute to the field of automatized detection and classification of changes from SAR imagery.

Supervision

The internship / master thesis will be carried out under the supervision of Murielle Kirkove from the “Signal Processing lab” of CSL. 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 (principles, algorithmic, Python language)

Number of credits: 15 or 27

Change detection from SAR imagery and Machine Learning techniques

Contact person : Dr. Murielle Kirkove

e-mail : M.Kirkove@uliege.be

Tel : 04.382.46.41

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 as deforestation and buildings constructions or the study of soil quality for agricultural purposes. The increasing number of Synthetic Aperture Radar (SAR) satellites observing the earth on a regular basis provides image time series that can be used to detect changes. The manual analysis of SAR images for this purpose is a tedious task. However, the progress in Artificial Intelligence (AI) and in particular, in Machine Learning (ML), offers fast ways to perform change detection.

The “Signal Processing” lab of the Centre Spatial de Liège (CSL) has a long expertise in SAR imagery and has studied for a few years the exploitation of SAR imagery by ML techniques for diverse applications as detection of land changes. Currently, this lab is contributing to a research project targeted a specific application with an ongoing initiative aimed at detecting spatio-temporal environmental changes induced by mining activities in the Democratic Republic of Congo (DRC). For this work, with the help of one master student, a dataset made of SAR images times series selected from a spatio-temporal Area Of Interest (AOI) covering numerous mining sites in the Kivu Lake region of DRC has been created and a theoretical unsupervised ML methodology was designed. It based on a joint convolutional Auto-Encoder (AE) combining two convolutional AEs that are able, for each images-pair, to reconstruct each of the images from the other one. This method has been developed and assessed with the help of a second master student. The performances of this method can be improved trough some techniques as integration of additional data and data augmentation and trough extension to a self-supervised approach. Such 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. For the proposed methodology, 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 and two architectures for the Neural Network model used in the supervised step have been proposed: the PCBA-Net and the U-Net architectures.

In this context, this lab is looking for a motivated master student to explore the proposed methodology. The student will be responsible for understanding its theoretical concepts, developing it and analyzing its performances. The outcomes of the internship / master thesis are expected to contribute to the field of automatized detection of changes from SAR imagery.

Supervision

The internship / master thesis will be carried out under the supervision of Murielle Kirkove from the “Signal Processing lab” of CSL. 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 (principles, algorithmic, Python language)

Number of credits: 15 or 27