Master Thesis Proposals

2022-2023

Space Sciences

Faculty of Sciences
Liège University

Important notice!

The present catalogue is especially relevant for master theses in the ***Research focus***.
Its content is not exhaustive, and students are encouraged to contact specific teachers/researchers to ask them about potential alternatives if they are interested in other topics.

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

- Liège Space Centre (Sart-Tilman) : http://www.csl.uliege.be (or via S. Habraken, C. Barbier, M. Georges)
- Belgian Institute for Space Aeronomy (Brussels) : http://www.aeronomie.be/en/
- Royal Observatory of Belgium (Brussels) : https://www.astro.oma.be/en/
- Royal Institute for Meteorology (Brussels) : https://www.meteo.be/en/
- The AMOS company (Sart-Tilman) : https://www.amos.be/
- The Aerospacelab company (Mont-Saint-Guibert): https://www.aerospacelab.be/

… or any other company involved in space activities.

About master theses out of ULiège...

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

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

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

Astroparticles, Dark matter and Gravitational waves

Contact person : J.R. Cudell

e-mail : jr.cudell@uliege.be

Tel : 04 366 3654

Office: 4/44 (B5a)

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

Thematics : Cosmology and astroparticles

Description:

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

Modeling strongly lensed systems observed with Euclid

Contact person : Dominique Sluse

e-mail : dsluse@uliege.be

Tel : **043669797**

Office: B5c, +1/10

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

Thematics : Cosmology, Astrophysics; Instrumentation and methods

Description:

The upcoming Euclid mission (https://sci.esa.int/web/euclid) will image about one third of the whole sky with exquisite image quality and depth. Astronomers expect to discover several thousands of new strongly lensed galaxies and quasars over the whole mission. There are multiple challenges that need to be tackled to extract scientific information from those systems: (1) quantify the precision and accuracy achievable from Euclid observations of lensed systems, (2) quantify how/if inaccuracies in subtraction of the “sky” background affect strong lens models; (3) automatically model multiply imaged quasars based only on astrometric information.
The proposed master thesis aims at addressing one of those challenges depending of the student’s interest and skills. The student will either work with simulated lensed systems or “Euclidize” existing Hubble Space Telescope data, and subsequently use standard lens modelling tools to extract information on the matter distribution of the lensing galaxy. Project (1) consists in comparing lens models obtained with HST and Euclid. For project (2), simulated lens systems will be generated and modelled, including various levels of low-surface brightness contamination, to identify how low surface brightness features affect the modelling. Project (3) aims at setting up an automatised framework for modelling gravitationally lensed quasars. The students are strongly encouraged to contact me to discuss these projects. Other projects related to extragalactic astrophysics and/or gravitational lensing are possible. Contact me for more information.

Prerequisites: Experience with python programming (e.g. via SPAT0002-1: Programming techniques, numerical methods and machine learning) is needed. Other recommended courses (not mandatory): Extragalactic astrophysics (SPAT0011-1), Astrophysical observations (SPAT0068-1), Traitement de données (PHYS0931-1).

Characterizing the line of sight towards strongly lensed quasars

Contact person : Dominique Sluse

e-mail : dsluse@uliege.be

Tel : 043669797

Office: B5c, +1/10

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

Thematics : Cosmology, Astrophysics; Instrumentation and methods

Description:

Gravitationally lensed quasars are used for a variety of astrophysical applications: measurement of the expansion rate of the Universe, micro-lensing based estimate of the size of the accretion disc around supermassive black holes, study of the dark matter content of galaxies, …
For this master thesis project, the student will have to analyze integral field spectroscopy data of gravitationally lensed quasars. The data, obtained with the MUSE integral field spectrograph mounted on one of the Very Large Telescopes of the European Southern Observatory in Paranal, will be used to automatically identify galaxies in the field of view of a lens system and measure their redshifts. The student will first use standard methods for this task, and subsequently be invited to develop a framework enabling a more automatic redshift measurement. The ensemble of redshifts gathered will be used to search for the presence of group(s) along the line of sight towards the lens. This is a key step for achieving accurate cosmographic analyses from time-delay lens systems. The students are strongly encouraged to contact me to discuss this project. Other projects related to extragalactic astrophysics and/or gravitational lensing are possible. Contact me for more information

Prerequisites: Experience with python programming (e.g. via SPAT0002-1: Programming techniques, numerical methods and machine learning) is needed. Other recommended courses (not mandatory): Extragalactic astrophysics (SPAT0011-1), Astrophysical observations (SPAT0068-1), Traitement de données (PHYS0931-1).

Innovative techniques to find strongly 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 : Cosmology, Astrophysics; Instrumentation and methods

Description:

Strongly lensed galaxies and quasars are used for a variety of astrophysical applications. Less than a thousand of them are currently known but several tens of thousands will be hiding in the images of upcoming large surveys such as the Euclid space mission and the Large Synoptic Survey Telescope Corporation's mission. Finding those systems among the billions of galaxies present in the data is like searching a needle in a haystack. Machine learning plays a key role in finding new systems but the purity of the sample is not yet sufficient.
I propose to explore one (or several) new direction for improving the detectability of strongly lensed systems. The first approach consists in performing non-parametric modeling of galaxies and compare the space of non-parametric indices for samples of normal galaxies and of lensing galaxies. For this purpose, galaxies with and without simulated background sources will be created and modeled with parametric and non-parametric methods. Machine learning techniques will then be applied in the abstract space of non-parametric coefficients to disentangle normal galaxies from gravitationally lensed systems. A second approach consists in exploring the ability of some machine learning techniques (such as active learning) in improving the purity and completeness of lensed samples identified with deep learning methods. The students are strongly encouraged to contact me to discuss this project. Other projects related to extragalactic astrophysics and/or gravitational lensing are possible. Contact me for more information

Prerequisites: Experience with python programming (e.g. via SPAT0002-1: Programming techniques, numerical methods and machine learning) is needed. Other recommended courses (not mandatory): Extragalactic astrophysics (SPAT0011-1), Astrophysical observations (SPAT0068-1), Traitement de données (PHYS0931-1).

Gravitational lensing aided study of the variability of AGNs

Contact person : Dominique Sluse

e-mail : dsluse@uliege.be

Tel : 043669797

Office: B5c, +1/10

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

Thematics : Cosmology, Astrophysics; Instrumentation and methods

Description:

The stochastic variability of quasars has been recognized and studied since the discovery of the active galactic nucleus (AGN) phenomenon. While long term lightcurves of millions of quasars are expected to be obtained in the next decade thanks to the Large Synoptic Survey Telescope Corporation's mission, there is evidence that the current cadence and observing strategy of the survey is sub-optimal for recovering the statistical properties of the AGN lightcurves.
This project proposes to use multiply imaged AGNs to reconstruct a more densely sampled lightcurve and partly fill inter-season gaps. The student will simulate the variability of gravitationally lensed quasars, and characterizing the statistical properties of the signal for various plausible lensed AGN configurations. In the second part of the project, the student will self-consistently emulate the presence of microlensing in the lightcurve and evaluate how much the latter affects the recovered intrinsic statistical properties of the lightcurves. A related project aiming at discovering lensed AGNs from blended light curves may be envisioned.
The students are strongly encouraged to contact me to discuss this project. Other projects related to extragalactic astrophysics and/or gravitational lensing are possible. Contact me for more information

Prerequisites: Experience with python programming (e.g. via SPAT0002-1: Programming techniques, numerical methods and machine learning) is needed. Other recommended courses (not mandatory): Extragalactic astrophysics (SPAT0011-1), Astrophysical observations (SPAT0068-1), Traitement de données (PHYS0931-1).

The influence of gravitational microlensing on the linear UV and optical polarization of accretion disks in active galactic nuclei

Contact person: Dorde SAVIC

e-mail: dsavic@uliege.be

Tel: +32465480496

Office: B5c 2/10

Availability: Every Friday afternoon would be available for the meeting.

Thematics: Cosmology and astropaticles

Description:

A few percent of galaxies show an enhanced emission from the nucleus that typically surpasses the stellar emission from the rest of the galaxy. This phenomenon, known as an active galactic nucleus (AGN), is assumed to have a central supermassive black hole, surrounded by an accretion disk which emits mostly in the X-ray from the inner part, but also in the UV/optical continuum in the outer disk (Shakura & Sunyaev 1973). The UV/optical polarized emission is due to Thomson scattering (Chandrasekhar 1950) and it is affected by several accretion disk parameters: size, accretion rate, mass of the supermassive black hole, viscosity and the viewing inclination of the system. Linearly polarized radiation introduces two more quantities - Stokes parameters Q and U, from which the polarization degree and the polarization angle can be inferred. The latter two provide us with additional informations and are highly sensitive to the geometry of the observed system.

Gravitational microlensing (Chang & Refsdal 1979) allows us measure the size of accretion disks. Strongly lensed AGNs images are magnified by a complex field of stellar-mass objects in the lens galaxy located between the observer and the AGN. As the AGN moves relative to our line of sight, the magnification changes, generating a significant uncorrelated variability between images on timescales of months to years. Microlensing variability is computed by convolving the intensity map of the source with the microlensing map followed by an extraction of values for a point source that is moving along a given direction for a given length (time) over the convolved map.

The proposed project consists of three steps. The first one is to model the accretion disk polarization using the 3D Monte Carlo radiative transfer code SKIRT[1], developed at the University of Gent (Camps & Baes 2015), that is publicly available and user-friendly. Successful models will produce 2D polarization maps in different wavebands after running SKIRT for a grid of accretion disk parameters. The second step is to convolve the polarization maps Q and U with the microlensing maps generated for different lensing parameters. The convolved maps will be used for extracting the polarization time series. The final step is performing a simple analysis how the microlensing affects the polarization signal for a small grid of accretion disk and lensing parameters that were used.

Programming skills required: basic-intermediate knowledge of C++, Python/Matlab/R/other software for data manipulation and analysis. A considerable amount of models could be run on several remote high performance computing servers operating under similar Linux distributions which require a basic knowledge on using Linux terminal. The preference for the operating system e.g. Linux/Windows/macOS for carrying out the project is up to the candidate.

[1] https://skirt.ugent.be

Investigating cosmic engines

Contact person: Gregor Rauw, Yaël Nazé

e-mail: g.rauw@uliege.be ynaze@uliege.be

Tel: 04 366 97 40

Office: B5C, +2/2

Availability: Please send an email to make an appointment.

Thematics: Astrophysics

Description:

Massive stars are true cosmic engines in galaxies. Indeed, their bright ionizing radiation and strong stellar winds, complemented by their deaths as supernovae, result in a huge impact on their environment. However, these stars are short-lived and few in number in star-forming regions. Many aspects of these important objects thus remain unexplained.

The Groupe d'Astrophysique des Haute Energies has acquired a great expertise in the analysis of multiwavelength data of massive stars. This led to its involvement in several space missions, and to the regular selection of its observing programs by ESA, ESO, or NASA. The GAPHE also has a private access to a high-quality spectrograph installed on a robotic telescope, as well as to original analysis tools.

As a consequence, several topics are possible for master theses, notably:

- improvement of eclipse analyses
- detailed characterization of specific binaries
- variability study of peculiar massive stars

(this list is not exhaustive - additional subjects are possible, and even tailored subjects may be discussed)

As a direct illustration of what can be done in such theses, here are some examples of past studies:

- **Mernier F.** & Rauw G., An XMM-Newton view of the M17 nebula, 2013, New Astronomy, 20, 42
- **Cazorla C.**, Nazé Y., Rauw G., Wind collisions in three massive stars of Cygnus OB2, 2014, A&A, 561, A92
- Rauw G., **Rosu S.**, et al., Apsidal motion in the massive binary HD152218, 2016, A&A, 594, A33
- Rauw G., **Mossoux E.**, Nazé Y., FeXXV line profiles in colliding wind binaries, 2016, New Astronomy, 43, 70
- Nazé Y., Gosset E., **Marechal Q.**, New X-ray detections of known Wolf-Rayet stars, 2021, MNRAS, 501, 4214

Investigation of interstellar chemistry on the basis of chemical network modelling

Contact person : Michaël De Becker, Guy Munhoven

e-mail : Michael.DeBecker@uliege.be

Tel : 04 366 97 17

Office: B5c +1/8

Availability: First contact by e-mail

Thematics : Astrophysics, astrochemistry

Description:

The invetigation of physico-chemical processes in astrophysical environments is a very active field of research. To date, more than 200 molecules have been identified in dense interstellar clouds. The investigation of this science topic proceeds notably by making use of models able to solve for rate equations for a high number of chemical species identified – or likely present – in the environment being considered.

This master thesis will consist in the study of a subset of chemical network that will be selected following a discussion with the supervisors. Among various possiblities, one may consider to evaluate the formation rate of selected species depending on the complexity of the network, and on the physical conditions of the environment.

All results will have to be critically discussed in the framework of our current knowledge in interstellar astrochemistry.

Required courses:
- SPAT0020 Astrochemistry(M. De Becker)
- SPAT0008 Interstellar medium (M. De Becker, V. Van Grootel)

Seismic probing of helium burning stars with mixed modes

Contact person : Marc-Antoine Dupret

e-mail : ma.dupret@uliege.be

Tel : 04 366 97 32

Office: B5c +1/12

Availability: Anytime from May to mid-july

Thematics : Astrophysics: Stellar physics, Asteroseismology

Description:

Context:
Once their central hydrogen is exhausted, low-mass stars leave the main sequence, become subgiants and next red giants. Hydrogen is now burnt in a thin shell and when T~10^8 K is reached in the core, the phase of core helium burning considered for this work starts. Due to their core-envelope structure, these stars exhibit a peculiar kind of stochastically-excited oscillations called mixed modes. These modes can propagate in the central radiative region, where they behave as gravity modes, and in the convective envelope, where they behave as acoustic modes. Unlike pure acoustic modes in main-sequence stars, the frequency pattern of mixed modes in the red giant phase gives us the unique opportunity of probing the properties not only of their outer envelope, but also of their inner layers. Space missions like CoRoT and *Kepler* revealed such very rich spectra of oscillation including mixed modes.

Proposed work:
In the team ASTA, we have very recently developed the software EGGMiMoSA, a unique tool for the asteroseismic probing of subgiants and red giants with mixed modes. We also have our own stellar evolution code CLES, which is now able to model the helium burning phase just after the helium flash, and the stellar adiabatic oscillation code LOSC. The aim of this Master Thesis project is to use these tools for the first seismic probing of core helium burning red giants with very rich oscillation spectra observed by the *Kepler* spacecraft. The work of the student will be to compute a grid of stellar models encompassing these targets and study how the seismic indicators depend on the global and internal characteristics of these models. Finally, he/she will use EGGMiMoSA for an automatic search of the stellar models best reproducing the seismic observations. As key results of this study, the core characteristics of some of these stars, including the so-called overshooting, will be accurately determined for the first time. This work could constitute a first step before a PhD thesis dedicated to the detailed seismic study of numerous red giants observed by *Kepler*.

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

Tidal deformations in binary stars and impact on their orbit

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:
Binary systems are very frequent in the stellar world, which involve strong tidal interactions when the components are close enough. Tides deform the shapes of stars and thus modify their observable characteristics. This can be seen typically in the light curves of eclipsing binaries. They also affect the internal structure of stars and significantly affect the transport of angular momentum and chemicals in them. Finally, tidal interactions produce secular changes of the orbital parameters such as a motion of the periastron (called the apsidal motion) that can be observed and provides an important constraint on their internal structure. However, these effects are usually neglected or inaccurately modelled.

Proposed work:
We have just developed in our team a code which, for the first time, accurately models the tidal deformation of stars from their core to their surface. We propose in this thesis to explore numerous applications of it. First, a grid of representative binary models with different masses, evolutionary stages, relative distance, rotation period and eccentricities will be computed. Next, these models will be examined in detail and compared to simpler models: tidal and centrifugal deformation, gravity-darkening and rate of apsidal motion. Finally, the application to the observed massive binary HD 152248 will be explored.
This subject could also constitute a first step before a PhD thesis, which would focus on the impact of binarity on stellar evolution.

Recommended courses: SPAT0044-1/45-1 Stellar structure and evolution I and II (Pr. M.A. Dupret)

Seismic probing of subgiant stars with mixed modes

Contact person : Marc-Antoine Dupret

e-mail : ma.dupret@uliege.be

Tel : 04 366 97 32

Office: B5c +1/12

Availability: Anytime from May to mid-july

Thematics : Astrophysics: Stellar physics, Asteroseismology

Description:

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

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

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

3D interaction between convection and pulsations in white dwarfs

Contact person : Marc-Antoine Dupret

e-mail : ma.dupret@uliege.be

Tel : +32 4366 9732

Office: B5c, room 1/12

Availability: Anytime in May or June

Thematics : Astrophysics: stellar physics, asteroseismology

Description:

This master thesis concerns white dwarfs, the final stage of the evolution for the vast majority (97%) of stars in the Universe. White dwarfs exhibit several classes of pulsations, which allow us to apply the tools of asteroseismology in order to tightly constrain the physics inside these stars and hence, to refine the models of their structure and their evolution. It also focuses on the most important problem in current modelling of stellar oscillations: their coupling with convection.

In these stars, the mechanism that drives pulsations is concentrated in the upper (envelope+atmosphere) thin convective layers. Two key ingredients are therefore required to accurately model white dwarfs and their pulsations: interaction between pulsations and convection, and accurate modelling of the upper layers. For the accurate modelling of the upper layers, full 3D hydrodynamical simulations are available since recently (see the work of P.-E. Tremblay, one of our collaborators) and will be used for this project. On the opposite, accurately modelling the interaction between pulsations and convection is still a major problem, particularly towards the red edges of white dwarfs' instability strips.

In our team, we have just developed a ground-breaking 3D hydrodynamical model of the coupling between stellar convection and oscillations. In the current version, it is specifically designed for solar-like acoustic oscillations. The objective of this master thesis is to adapt it to white dwarfs' gravity mode oscillations, and explore first applications to representative models of these stars. Through this master thesis, the student will plunge into the hydrodynamics of the superficial turbulent layers of white dwarfs and their interaction with oscillations.

This will constitute a first look to this major problem achievable within this master project, but a full investigation of this problem would constitute an excellent topic for a subsequent PhD thesis, with the goal of unveiling the energetic aspects of white dwarf's oscillations and solving the discrepancies currently encountered with their observed instability strips.

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

Modeling TESS data of extreme horizontal branch stars by asteroseismology

Contact person : Valérie Van Grootel

e-mail : valerie.vangrootel@uliege.be

Tel : +32 4 3669730 but contact preferably by email.

Office: B5c, room 1/13.

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

Thematics : Astrophysics

Description:

The TESS satellite from NASA gathers since December 2018 high-quality photometric data on various stars, for searching transiting exoplanets but also for asteroseismology. Asteroseismology is the study of stellar oscillations in order to tightly constrain the physics inside stars and hence, to refine the models of the structure and the evolution of stars.

Among these stars, TESS observes each month (one Sector of the sky each 27 days) dozens of extreme horizontal branch stars, and discovers/confirms pulsations in a few of them. Extreme horizontal branch stars, also known as subdwarf B (sdB) stars, represent an advanced stage of stellar evolution. These hot (T_{eff}=20,000-40,000 K) and compact (log g=5.2-6.2) objects burn helium in their cores into carbon and oxygen and are surrounded by an extremely thin H-rich envelope. Understanding the formation of sdB stars is one of last big mysteries of stellar evolution.

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

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

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

Stellar parameters for exoplanet-hosting stars

Contact person : Valérie Van Grootel

e-mail : valerie.vangrootel@uliege.be

Tel : +32 4 3669730 but contact preferably by email.

Office: B5c, room 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:

Both for the transit and radial velocity methods of exoplanet detection, the planetary mass and radius are only measured relative to those of their host star. It is therefore crucial to model the star as accurately as possible, in particular in vision of ultra-high precision space-borne photometry such as the ESA mission CHEOPS (launched in 2019), PLATO (2026) and ARIEL (2029): the errors on the planetary mass and radius mainly come from the errors on the stellar mass and radius. Concerning the age of the star, it is the best proxy for the age of its planets, since they are formed together. Age is also essential information to constrain evolution of planetary systems (dynamical evolution, evolution of their atmospheres, etc.).

At ULiège we are involved in both CHEOPS and ARIEL missions for stellar modeling of the exoplanet hosts, which are in majority FGK stars. We have state-of-the-art models of these stars and proven optimization methods, with and without asteroseismology, in order to derive mass, radius and age of exoplanet hosts. We propose in this traineeship to participate to this stellar modeling effort for CHEOPS and ARIEL missions. This concerns stellar evolution modeling of current CHEOPS targets, as well as detailed seismic modeling on some Kepler Legacy targets (66 FGK targets observed by Kepler with very high-precision asteroseismology) and other benchmark stars in the context of the preparation of the ARIEL mission.

Unveiling the fate of planetary systems I:
Searching for survivor exoplanets

Contact person : Valerie Van Grootel, Francisco J. Pozuelos

e-mail : valerie.vangrootel@uliege.be ; fjpozuelos@uliege.be

Tel : Valerie: +32 4 3669730; Fran: +32 4 3669738

Office: B5c +1/13 & /17

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

Thematics : Planetology and planetary systems

Description:

Theories concerning the formation and evolution of planetary systems are, at a certain level, well understood. However, little is known about how planetary systems end their lives. Indeed, the evolution of a given planetary system depends upon its host star, including when the star leaves the main sequence and starts the red giant branch (RGB) phase, when it expands and may engulf close-in planets. The question of what happens to these engulfed planets is of vital importance for understanding the fate of planetary systems. The most promising targets to address this question are hot subdwarfs, which are hot and compact post-RGB stars with typical sizes of 0.1-0.3R_sun and masses of 0.47M_sun.

In this research project the student will join our team and contribute to our transit survey in the search for transiting disintegrating exoplanets. After the RGB phase of its host star, an underlying hot rocky exoplanet may suffer a body-disruption event, which could produce an elongated tail of dusty material. This research makes use of data collected by space telescopes such as TESS (Transiting Exoplanet Satellite Survey), Kepler and K2. We now have a performing tool to detect the transits of evaporating bodies, which will be used by the student to scrutinize a pre-existing target list in the search for signals which might hint at the presence of disintegrating exoplanets. For each event that overcomes the vetting process, a ground-based follow-up campaign with the TRAPPIST telescopes will be proposed and executed to rule out potential sources of false positives and strengthen the evidence of their nature. More information on the project can be found in this paper : http://arxiv.org/abs/2104.10462

Recommended course: SPAT0063-1 *Introduction to exoplanetology* (Pr. M. Gillon)

Unveiling the fate of planetary systems II:
Searching for disintegrating exoplanets

Contact person : Valerie Van Grootel, Francisco J. Pozuelos

e-mail : valerie.vangrootel@uliege.be ; fjpozuelos@uliege.be

Tel : Valerie: +32 4 3669730; Fran: +32 4 3669738

Office: B5c +1/13 & /17

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

Thematics : Planetology and planetary systems

Description:

Theories concerning the formation and evolution of planetary systems are, at a certain level, well understood. However, little is known about how planetary systems end their lives. Indeed, the evolution of a given planetary system depends upon its host star, including when the star leaves the main sequence and starts the red giant branch (RGB) phase, when it expands and may engulf close-in planets. The question of what happens to these engulfed planets is of vital importance for understanding the fate of planetary systems. The most promising targets to address this question are hot subdwarfs, which are hot and compact post-RGB stars with typical sizes of 0.1-0.3R_sun and masses of 0.47M_sun.

In this research project the student will join our team and contribute to our transit survey in the search for transiting disintegrating exoplanets. After the RGB phase of its host star, an underlying hot rocky exoplanet may suffer a body-disruption event, which could produce an elongated tail of dusty material. This research makes use of data collected by space telescopes such as TESS (Transiting Exoplanet Satellite Survey), Kepler and K2. We now have a performing tool to detect the transits of evaporating bodies, which will be used by the student to scrutinize a pre-existing target list in the search for signals which might hint at the presence of disintegrating exoplanets. For each event that overcomes the vetting process, a ground-based follow-up campaign with the TRAPPIST telescopes will be proposed and executed to rule out potential sources of false positives and strengthen the evidence of their nature. More information on the project can be found in this paper : http://arxiv.org/abs/2104.10462

Recommended course: SPAT0063-1 *Introduction to exoplanetology* (Pr. M. Gillon)

Searching for multi-planet systems in TESS data
to be followed up with CHEOPS

Contact person : Laetitia Delrez, Francisco J. Pozuelos

e-mail: ldelrez@uliege.be, fjpozuelos@uliege.be

Tel: Laetitia Delrez: +32 4 366 97 63 / Francisco Pozuelos: +32 4 366 97 38

Office: Laetitia Delrez: B5c -1/2 / Francisco Pozuelos: B5c +1/15

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

Thematics: Planetology and planetary systems

Description: Exoplanets transiting bright and nearby stars are key objects for advancing our knowledge of planetary formation and evolution. Thanks to their special geometry and the brightness of their host star, we can indeed measure their radius, mass (in combination with radial velocity measurements or via transit timing variations), and orbital parameters, and we can also study their atmosphere. In particular, multi-planetary systems with several planets transiting the same bright star are targets of paramount importance, as they make it possible to compare several planets in the same system and better constain their properties and histories.
Launched in April 2018, NASA's Transiting Exoplanet Survey Satellite (TESS) is searching the whole sky for small planets transiting bright nearby stars. As of April 2022, TESS has identified 5637 planet candidates, also known as TESS Objects of Interest (TOIs), of which 205 have been confirmed so far. The detection of a transiting planet around a given target enhances the probability that other planets in the system - if any - are also transiting (assuming small mutual inclinations between the orbital planes of the planets). However, these extra planets may have been missed by the TESS automatic detection pipeline if they produce transit signals that are below the set detection threshold. This can happen for planets with long orbital periods (with only a few transits covered by the TESS data) and/or small radii (shallow transits).
The goal of this project is to scrutinize the TESS light curves of a selected number of targets for which the TESS pipeline detected at least one TOI, to search for possible signals that may hint at the presence of other planets. We will focus here on bright Sun-like stars that could be followed up with ESA's new Characterizing ExOPlanets Satellite (CHEOPS, launched in December 2019). Unlike previous exoplanet detection missions, like TESS, CHEOPS is an exoplanet follow-up mission, designed to collect ultra-high precision photometry of known transiting planets (or candidates) around bright stars (a single star observed at a time). Thanks to its high precision and versatility, CHEOPS is perfectly suited to follow up and confirm the promising low signal-to-noise TESS candidates that may be found in the framework of this project.

Facilities, tools, and supervision:
The student will be provided with a workstation in the existing students' office and all the tools needed to analyse the TESS data. The student will meet with the supervisors ideally every week to perform a weekly progress review of the project, where he/she will be able to discuss difficulties, new ideas, etc. The student will be invited to join meetings of the ExoTIC group (Exoplanets in Transit: Identification and Characterization), where other exoplanet-related topics are discussed.

Recommended courses:
SPAT0063-1 *Introduction to exoplanetology* (lecturers: Michaël Gillon and Olivier Absil)
SPAT0002-1 *Programming techniques, numerical methods and machine learning* (lecturer: Dominique Sluse)

Imaging giant planet formation

Contact person : Valentin Christiaens (main supervisor), Olivier Absil (co-supervisor)

e-mail : valentin.christiaens@uliege.be

Tel : +32 4 3669739

Office: B5c - 2/18

Availability: Most week days during May and June between 9am and 6pm, apart from Monday and Tuesday mornings. Safer to confirm by email first.

Thematics : Planetology and planetary systems

Description:

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

In this project, the student will use archival data obtained with the SPHERE high-contrast imaging instrument of the Very Large Telescope on a sample of discs showing hints of planet presence. The student will learn how to reduce data using the supervisor's pipeline, and test novel image processing techniques developed in the team to model and subtract the bright emission from the star in order to produce high-fidelity images of protoplanetary discs, and potentially identify new direct (point source) or indirect evidence (e.g.: spiral arms) of embedded protoplanets. The project will involve testing and optimisation of specific aspects of the image processing pipeline, such as:

- the effect of proper centering of the star in the images;
- the effect of flux variations during the observing sequence, and inclusion of this information to improve the sensitivity towards exoplanets;
- the use of a new criterion to build better stellar PSF models for subtraction, and hence optimise the sensitivity towards exoplanets.

The project will heavily rely on routines already implemented in VIP, an open-source python package of high-contrast imaging routines developed in Liège and maintained by the main supervisor.

Recommended background (albeit non-exclusive):

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

Using a novel method to retrieve the direct spectrum of exoplanets

Contact person : Valentin Christiaens (main supervisor), Olivier Absil (co-supervisor)

e-mail : valentin.christiaens@uliege.be

Tel : +32 4 3669739

Office: B5c - 2/18

Availability: Most week days during May and June between 9am and 6pm, apart from Monday and Tuesday mornings. Safer to confirm by email first.

Thematics : Planetology and planetary systems

Description:

Although thousands of exoplanets have been identified with *indirect* methods of detection, only a few dozens of exoplanets have been *directly* imaged. Despite low in numbers, direct spectroscopy of these planetary-mass companions has provided invaluable information on their atmosphere and physical properties, and have enabled to refine atmospheric models of giant planets. While current instrumentation only allows for the direct detection and characterisation of young giant planets at large separation, the future generation of high-contrast imagers on extremely large telescopes may significantly increase that sample, by probing shorter separations and potentially enabling the first direct image of a (super-)terrestrial exoplanet. Parallel development of better post-processing algorithms to disentangle exoplanet signals from the bright stellar glare in high-contrast images is required to further optimise detection sensitivity. In this context, a novel method labelled *spectral unmixing* has recently been proposed to leverage the power of medium-resolution integral field spectrographs to boost the sensitivity towards faint planets. The principle relies on the fact that stellar glare dominates most of the field such that most spaxels measure a modulated version of the stellar spectrum. Since exoplanets present a distinct spectrum and are localised in the image, they can be singled out after filtering of the stellar spectrum, allowing for reliable spectral extraction.

In this project, the student will use 4 archival datasets obtained with the SINFONI integral field spectrograph instrument of the Very Large Telescope on a sample of young stars showing hints of planet presence. The data are calibrated and ready for the application of *spectral unmixing*. Some coding is expected from the student in order to implement the algorithm, which is expected to heavily rely on existing routines implemented in VIP, a large open-source python package of high-contrast imaging routines developed in Liège, and maintained by the main supervisor. Among the 4 sources that will be considered in this project, 3 companions have been confirmed (2 planets and a low-mass binary) and an additional low-mass candidate has been identified. These datasets thus make for ideal testbeds to refine and apply the *spectral unmixing* algorithm.

Recommended background (albeit non-exclusive):

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

Application of neural networks to PSF photometry

Contact person : Lionel Garcia

e-mail : lgarcia@uliege.be

Office: B5C -1/3

Availability: end of May - beginning of June

Thematics : Photometry, PSF modeling, Neural Networks

Description:

Due to its simplicity and robustness, aperture photometry is the dominant choice to extract photometry from ground and space-based observations. Point-spread-function (PSF) photometry, on the other hand, is slow and highly dependent on model selection and parameterization. But recent developments in the field of cosmic shear measurements might give PSF photometry a brighter future. By using a deep convolutional neural network (CNN) trained on simulated PSFs, Herbel et al. 2018 were able to accurately fit for a 10-parameter model of SDSS stars in a fast and highly scalable way. We propose to explore this subject in two ways. First, the development of a linear based method based on polar shapelets to perform fast and scalable PSF photometry. Second, by reproducing Herbel et al. 2018 model (with potential help from their team and based on a smaller model developed and tested by our team) and applying it to PSF photometry.

Asteroid light curves from TRAPPIST telescopes archived images

Contact Person: Jehin Emmanuël

e-mail: ejehin@uliege.be

Tél: (0)4 3669726

Office: B5c 1/9

Availability: please contact me

Thematics: Astrophysics (small bodies of the solar system)

Description:

The TRAPPIST telescopes installed at the la Silla observatory in Chile in 2010 and at the Oukaimeden observatory in Morocco in 2016 by our team are dedicated to the research and the study of exoplanets in transit and the study of the small bodies of the Solar System (comets and asteroids). Each night, since 10 years in Chile and 5 years in Morocco we collect hundreds of images of one or two fields during several hours to search for exoplanets in transit. This constitutes a unique dataset of about 2.5 million images to be explored to search for asteroids and comets.
In this work we propose to search the huge database of TRAPPIST to identify the known asteroids present in the images using their well known orbits. As some fields are observed several nights in a row and for many hours per night it will be possible to build high density light curves for many of these objects and measure their rotation period.

Objectives: Find the known asteroid present in the TRAPPIST archive. Measure and collect the photometric measurements for each target found and build their light curves with time to try to find the asteroid rotation period. Most of these rotation light curves will be new and will be published in a paper. This will be useful to better understand the evolution of small bodies via Yarkovsky/YORP effect by comparing the distribution of the properties of spins (period, longitude, latitude) to the dynamical families.

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

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

Contact person: Jehin Emmanuël (ULiège)

E-mail: ejehin@uliege.be

Tél: (0)4 3669726

Office: B5c 1/9

Thematic: Astrophysics (small bodies of the solar system)

Description:

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

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

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

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

The brightness/colour ratio relationship in the different zones of the aurora based on Juno-UVS observations

Contact person : Bertrand BONFOND

e-mail : b.bonfond@uliege.be

Tel : 04/366.9772

Office: B5c 0/2

Availability: Please send an email to schedule a meeting.

Thematics : Planetology

Description:

Juno is a NASA mission dedicated to the exploration of the planet Jupiter. It orbits around the giant planet since July 2016, bringing a wealth of discoveries and unprecedented observations. Among its instruments sits an imaging spectrograph (Juno-UVS) dedicated to the observations of the Jovian aurorae. As an imaging spectrograph, the Juno-UVS instrument provides 2 key pieces of information about the UV aurora, its brightness and its colour. The colour of the aurora can be used as a proxy for the energy of the precipitating particles.

The student will use the image processing tools developed at the Laboratory for Planetary and Atmospheric Physics (www.lpap.uliege.be) to derive the relationship between the brightness and the colour ratio of different regions of the Jovian aurora in order to identify and characterize the different processes accelerating the charged particle leading to the auroral emissions.

The courses SPAT0028-2 and/or SPAT0023-1, as well as SPAT0032-2 are highly recommended.

The temporal variations of Jupiter's auroral signatures of injections based on UV observations

Contact person: Denis GRODENT

e-mail: d.grodent@uliege.be

Tel: 04/366.9773

Office: B5c 0/5

Availability: Please send an email to schedule a meeting.

Thematics: Planetology

Description:

Jupiter permanently displays several types of auroral emissions, which can be observed in the ultraviolet with instruments like the STIS camera on board the Hubble Space Telescope or Juno's UVS spectrograph. The process of plasma injection taking place in Jupiter's enormous magnetosphere produces typical signatures, some of which are easily identified by their location, but also by their temporal evolution. However, so far, the temporal behaviour of such emissions has been relatively overlooked while it contains interesting information on the injection process itself.

The student will use the available databases and image processing tools developed at the Laboratory for Planetary and Atmospheric Physics (LPAP) to infer the temporal characteristics of such auroral emissions and relate them to the magnetospheric plasma injection process.

Carbon sequestration in the Black Sea: the biological carbon pump. Assessing the relative importance of the organic and inorganic carbon export.

Contact person : Marilaure GREGOIRE

e-mail : mgregoire@ulg.ac.be

Tel : please contact her by e-mail

Office: B5a (please contact her by e-mail)

Thematics : Environment and Oceanography

Description:

The Biological Carbon Pump (BCP) is mediated by the marine foodweb that converts Dissolved Inorganic Carbon (DIC) into Particulate Organic and Inorganic Carbon (respectively POC and PIC). These POC and PIC are heavier than water density and then gravitationally sink to the bottom. During their transfer to depth, POC is degraded by bacteria and converted back into DIC and, under some conditions PIC is chemically dissolved. Understanding the mechanisms that govern the importance of the BCP, from primary production to export at depths is crucial for assessing the role of the ocean in the mitigation of climate warming. The aim of the master thesis consists in using an existing biogeochemical model to investigate the BCP in the Black Sea and the contribution of POC and PIC export.

The tasks are as follows:
1) Run the current version of the model (implemented in the Black Sea), understand the basics equations, interpret the results;
2) Extend the model by adding an explicit representation of the calcification process performed by coccolithophorids, one of the dominant Plankton Functional Types, not yet represented in the model;
3) Investigate model performances by comparison with BGC Argo floats data as concerns the dynamics of Chla and backscattering coefficients (+ literature analysis);
4) Run sensitivity studies by changing the atmospheric forcing to mimic the effect of climate change.

Specific method, material used: The student will work with an existing biogeochemical model that would need to be extended. This model is coupled with a physical model of the Black Sea water column.

Preconditions and/or important information: to want to work with modelling

MAST (Modelling for Aquatic Systems, (http://labos.ulg.ac.be/mast/)

Nitrogen cycling in the Black Sea: how does nitrogen fixation combine the nitrogen loss due to denitrification and anammox?.

Contact person : Marilaure GREGOIRE

e-mail : mgregoire@ulg.ac.be

Tel : please contact her by e-mail

Office: B5a please contact her by e-mail

Thematics : Environment and Oceanography

Description:

The Black Sea is one of the largest anoxic marine environments in the world. Dissolved oxygen does not penetrate below ~100-150m and 87% of it's the Black Sea volume is euxinic. In anoxic conditions, bacteria use nitrate and sulfate as alternate oxidants for the degradation of organic matter. Denitrification and the ANaerobic AMMonium OXidation (anammox) consume large amounts of fixed nitrogen (i.e. nitrate, ammonium). This is not yet known if this loss can be compensated by the input from the river discharges and nitrogen fixation. Nitrogen fixation can be realized by autotrophic and heterotrophic organisms and a previous master thesis evidenced that the heterotrophic part could be significant.

The tasks are as follows:
1) Run the current version of the model (implemented in the Black Sea), understand the basics equations, interpret the results;
2) Extend the model by adding an explicit representation of heterotrophic nitrogen fixation;
3) Investigate model performances by comparison with BGC Argo floats data as concerns the dynamics of Chla (+ literature analysis). Check the N2 dynamics;
4) Assess the relative importance of autotrophic versus heterotrophic nitrogen fixation as well as the consequences for the Black Sea nitrogen budget.

Specific method, material used: The student will work with an existing biogeochemical model that would need to be extended. This model is coupled with a physical model of the Black Sea water column.

Preconditions and/or important information: to want to work with modelling

MAST (Modelling for Aquatic Systems, (http://labos.ulg.ac.be/mast/)

Offshore windfarm impact on biogeochemistry: a model approach.

Contact person : Marilaure GREGOIRE

Name of the Supervisor: Marilaure Grégoire (MAST) and Xavier Fettweis (Laboratory of climatology)

e-mail : mgregoire@ulg.ac.be

Tel : please contact her by e-mail

Office: B5a please contact her by e-mail

Thematics : Environment and Oceanography

Description:

The North Sea, and in particular, the Belgian Coastal Zone (BCZ), have been submitted to various human activities with for instance, the deployment of offshore wind farms (OWFs), dredging, aquaculture and eutrophication. In particular, OWFs are colonized by biofouling communities, mainly mussels. These mussels filter particles in the water column and produce fecal pellets. Through this biodeposition process, fouling mussels have the possibility to modify the distribution of carbon flux to the sediment with consequences for the biogeochemical cycling of the coastal zone. The aim of the master thesis is to couple a simplified ecosystem models to simulate the impact of the biodeposition process on the biogeochemical cycling. The impact of aquaculture development on the particle fluxes to the bottom will also be evaluated.

Specific method, material used: 3D modelling

Stay abroad, financial conditions: Ghent university (to be defined)

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

MAST (Modelling for Aquatic Systems, (http://labos.ulg.ac.be/mast/)

Linking patterns in phylogeny, traits, abiotic variables and space:
Black Sea Fisheries

Contact person : Marilaure GREGOIRE

Name of the Supervisor: Marilaure Grégoire, Bruno Frederich, Camille Albouy
(Ifremer)

e-mail : mgregoire@ulg.ac.be

Tel : please contact her by e-mail

Office: B5a please contact her by e-mail

Thematics : Environment and Oceanography

Description:

The aim of the master thesis is to estimate the functional and phylogenetic diversity of fish assemblages in connection with environmental gradients. The master student will have to compile a data set on Black Sea fishes and in particular,

1) to estimate morphological, physiological, life history and behavioral traits,
2) Creation of species ranges from Obis and habitat data,
3) Creation from the species list of a set of phyogenetic trees,
4) Collecting spatialized information on the area, coastline/ bioregions/MPA.

From data analysis, he/she will define the geographical distributions of dominant fish species using a grid cell at a resolution of 0.01° by 0.01°. Then, for those species, the candidate will compute several indicators from the matrix of pairwise functional distances between species.

Such matrix will permit to mix different types of functional traits and to compute several indicators describing the various facets of the functional diversity. The graphical representation of the distance matrix (i.e., functional space) will be done through a Principal Coordinates Analysis (PcoA). As an example, the Fric index that represents the extent of the functional differences among species based on the distinction of their morphological, physiological and ecological traits will be estimated. To characterize the phylogenetic diversity the student will use classical measure, namely the PD index that only relies on the amount of evolutionary history and could be calculated on dated phylogeny based on a recently published molecular tree (Rabosky et al 2018).

Specific method, material used: Statistical analysis in R.

Stay abroad, financial conditions: Ifremer, Camille Albouy

Preconditions and/or important information - Field campaigns, diving, ... : None (a profile of biologist is more appropriate for this topic).

MAST (Modelling for Aquatic Systems, (http://labos.ulg.ac.be/mast/)

Nutrient budget of the Calvi Bay (Corsica, France).

Contact person : Marilaure GREGOIRE

e-mail : mgregoire@ulg.ac.be

Tel : please contact her by e-mail

Office: B5a please contact her by e-mail

Thematics : Environment and Oceanography

Description:

Marine seagrasses are considered as an important ecosystem for carbon sequestration (blue carbon). The Calvi Bay hosts a large Posidonia Oceanica seabed whose sequestration potential has been estimated by punctual measurements collected in mooring established since 2006 in Stareso. The upscaling of this sequestration potential at the scale of the Bay requires the use of modelling approach that takes into account the variability of environment conditions on seagrass photosynthesis. In the frame of this master thesis, the role of Posidonia oceanica in carbon sequestration and nitrogen removal will be investigated using a mathematical model that couples a description of the carbon and nitrogen cycling. Model outputs will be validated from existing and newly collected field data. Model results will be scaled up for assessing the role of the bay in carbon sequestration.

Specific method, material used: An existing biogeochemical model coded in R. The student may need to extend the model.

MAST (Modelling for Aquatic Systems, (http://labos.ulg.ac.be/mast/)

Assessing the impact of using a regional atmospheric model on the physical and biogeochemical state of the Black Sea.

Contact person : Marilaure GREGOIRE

Name of the Supervisor: Marilaure Grégoire (MAST) and Xavier Fettweis (Laboratory of climatology)

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

Tel : please contact them by e-mail

Office: B5a, please contact them by e-mail

Thematics : Environment and Oceanography

Description:

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

Specific method, material used: 3D modelling

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

MAST (Modelling for Aquatic Systems, (http://labos.ulg.ac.be/mast/)

Testing of a spectral radiative module for oceanographic models.

Contact person : Marilaure GREGOIRE

e-mail : mgregoire@ulg.ac.be

Tel : please contact her by e-mail

Office: B5a please contact her by e-mail

Thematics : Environment and Oceanography

Description:

The in-water-irradiance is a key variable in oceanography that governs the heat distribution, primary production and photo-chemical reactions. An accurate representation of the ocean physics and biogeochemistry by ocean numerical models hence requires an accurate calculation of the in-water irradiance. However, if marine ecosystem models become more and more sophisticated in terms of food chain representation, the optical calculation is still very often oversimplified. The aim of the master thesis is to improve the representation of light penetration in an existing ocean numerical model and to assess how it improves model performances. The master thesis is targeted towards the testing of a computationally efficient radiative transfer model (RTM, already implemented and running) describing the distribution of in-water irradiance (the diffuse and direct parts) along the vertical and in different spectral bands corresponding to those typically used in remote sensing and in particular in the Sentinel 3 Ocean and Land Color Instrument (OLCI). The penetration of spectral irradiance will be described considering its absorption and scattering at different wavelengths by various optically active components. State of the art formulations that link absorption and scattering properties to the biomass of optically active constituents will be used. The main purposes here are 1) to validate the model using radiometric measurements provided by remote sensing and field data like BGC-ARGO, AERONET-OC and BIOMAP products, 2) to refine the representation of optically active constituents, and, in particular the Coloured Dissolved Organic Matter (CDOM) whose current representation is oversimplified, 3) to assess the impact of a better representation of the light field on the thermocline postion.

Specific method, material used: 3D modelling

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

MAST (Modelling for Aquatic Systems, (http://labos.ulg.ac.be/mast/)

Modelling biogeochemical cycles in the Global Ocean

Contact person : Marilaure GREGOIRE

e-mail : mgregoire@ulg.ac.be; a.mouchet@uliege.be

Tel : please contact them by e-mail

Office: B5a, please contact them by e-mail

Thematics : Environment and Oceanography

Description:

Ocean deoxygenation has the potential to alter the global cycling of essential biogeochemical elements like carbon (C), nitrogen (N) and phosphorus (P) with consequences of the Earth Climate and life that we hardly know. The expansion of Oxygen Minimum Zones (OMZs) and Anoxic Marine Zones (AMZs) in the global and coastal ocean in response to climate change and eutrophication is intensifying the loss of fixed N through denitrification. Mathematical modelling allows to investigate the mechanisms implied in the modifications of our ocean and allows to assess their relative importance. In this master, thesis, the student will run an existing biogeochemical model (BAMHBI) to simulate the cycling of nitrogen, phosphorus and oxygen in the Global Ocean. The biogeochemical model is forced by the outputs of an existing physical model of the ocean (i.e. NEMO) that solves the hydrodynamical fields with a resolution of 2°. The coupling between the biogeochemical and physical model is already done.

The student will have to
1) run the configuration for the Global Ocean,
2) analyze the results using appropriate statistical tools,
3) based on the results analysis and comparison with observations, improve selected model formulations,
4) when the results will be satisfactory, compute diagnostics (e.g. primary production, denitrification, oxygen consumption).

Specific method, material used: An existing biogeochemical model coded in R or in Fortran.

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

MAST (Modelling for Aquatic Systems, (http://labos.ulg.ac.be/mast/)

Prediction of the amplitude of the Chandler wobble mode of Mars from atmospheric excitation.

Contact person: Promotors: Ozgur Karatekin, Sébastien Le Maistre, Orkun Temel

E-mail: karatekin@oma.be lemaistre@oma.be and temel@oma.be

Tel: 02 373 0211 (ROB General)

Office: Royal Observatory of Belgium

Availability: Any time by teleconf; please email to decide when.

Thematic: Planetology

Description:

The Martian atmosphere is very thin but participates in the process of sublimation and condensation of the polar caps. A quarter of this atmosphere condenses in the poles according to the seasons. These mass movements induce variations in the rotation of Mars and a polar motion. This movement has seasonal components. There is also a free oscillation mode, the Chandler wobble, which would be excited by the atmosphere. The master thesis consists in calculating the amplitudes of the polar motion linked with the Chandler wobble using the outputs of a general circulation model of the Martian atmosphere.
This work can lead to a scientific publication and extend into a doctoral thesis.

Task description:

- Get familiar with GCM of the Martian atmosphere
- Compute polar motion excitation
- Compute CW excitation

Phobos gravity field from MEX flyby.

Contact person: Promoter: Sébastien Le Maistre, co-promotor: Alfonso Caldiero, reader: V. Dehant

E-mail: sebastien.lemaistre@oma.be ; alfonso.caldiero@oma.be ; v.dehant@oma.be

Tel: 02 373 0266 (V. Dehant)

Office: Royal Observatory of Belgium

Availability: Any time by teleconf; please email to decide when.

Thematic: Planetology

Description:

Many space missions have targeted the Martian system, but the nature of the Martian moons is still unclear, their origin still a mystery. Phobos, the larger of the two, was approached several times by the ESA Mars Express (MEX) mission. In these encounters, the spacecraft flew by the moon while in its orbit around Mars, at a distance as low as the 60km of the 2013 flyby - the most recent one to date dedicated to radio-science. Since then, no spacecraft has ever come this close to Phobos.

Doppler radio-tracking of MEX during its flybys allowed to improve the accuracy on the standard gravitational parameter of the moon and to estimate the J_2 and C_{22} coefficients of its extended gravity field. These coefficients depend on the mass distribution within the body, and therefore their values can help constrain the interior structure of Phobos. However, these estimated values may be biased due to the effect of systematic errors which are not easy to remove, the most prominent being the uncertainty in the position of Phobos at the moment of the flyby. Other sources of error are the modelling of non-gravitational forces on the spacecraft, and the whitening of the Doppler data.

In this thesis, the effect of these systematics on the least-squares solution for the Phobos gravity parameters will be gauged, in order to then provide more reliable uncertainty bounds for the estimates. The work will start from simulated parameter-estimation campaigns, replicating the conditions of the real flybys but with synthetic Doppler data. In addition to helping weight the biases on the solutions, these simulations should provide a strategy for the parameter estimation (in terms of type and number of parameters to estimate and the set of a priori constraints) which minimizes correlations and errors in the solution.

The resulting estimation strategy will then be employed to process the real Doppler data from the MEX flybys. The corresponding uncertainties for the estimated parameters will eventually be increased based on scaling factors determined in simulation. Special attention will be paid on the degree-1 gravity coefficients that position the center of mass with respect to the center of figure. Because of their large correlation with the errors in the Phobos positions over time, these coefficients have not been estimated so far, while their detection could put strong constraints on the mass distribution inside the body.

The parameter estimation will be performed using the orbit determination software available at ROB: GINS (CNES/GRGS) or MONTE (NASA/JPL).
This master thesis may lead to a publication.

Task description:

- Get familiar with radioscience data processing
- Application to Phobos
- Orbit determination and parameter estimation for science results

Processing of Planetary Radio Interferometry and Doppler Experiment (PRIDE) experiment.

Contact person: Promotors: Sébastien Le Maistre, Dominic Dirkx

E-mail: lemaistre@oma.be and D.Dirkx@tudelft.nl

Tel: 02 373 0211 (ROB General)

Office: Royal Observatory of Belgium

Availability: Any time by teleconf; please email to decide when.

Thematic: Planetology

Description:

The Planetary Radio Interferometry and Doppler Experiment (PRIDE) technique exploits the radio transmitting capabilities of spacecraft from the most modern space science missions. A very high sensitivity of Earth-based radio telescopes (see Figure) involved in astronomical and geodetic Very Long Baseline Interferometry (VLBI) observations and an outstanding signal stability of the radio systems allow PRIDE to conduct precise tracking of planetary spacecraft. The data from individual telescopes are processed both separately and jointly (involving correlators) to provide Doppler and VLBI observables, respectively. The accurate examination of the changes in phase of the radio signal propagating from the spacecraft to each of the ground radio telescopes on Earth make the “open-loop” Doppler observables derived from each telescope very useful for different fields of planetary research. The Doppler data are called “open-loop” as the receiving ground station does not lock on the signal but receives the signal as it is in a frequency band around the expected received signal. “Closed-loop” Doppler data obtained by deep space tracking networks, such as the NASA Deep Space Network (DSN) and the ESA tracking station network (ESTRACK), are routinely used for navigation and science applications. The Doppler data are called “closed-loop” as the receiving ground station has the technical capability to lock on the signal.
For the future LaRa (Lander Radioscience) experiment that will be launched to Mars in 2022, we envisage to use this “open-loop Doppler” technique in order to increase the precision on the data. By tracking the LaRa signal, Earth-based radio telescopes involved in the PRIDE experiment can provide open-loop Doppler tracking data. The technique of processing the data is very different for “open-loop Doppler” compared to “closed-loop” Doppler, and will have to be fully developed. The partnership with JIVE (Joint Institute for VLBI ERIC) and the Technical University Delft will help us to use existing codes and not to start from scratch.

Task description:

- Get familiar with open-loop data processing
- Application to LaRa
- Compute of the improvement

Titan gravity field from lakes' equipotential and geological maps.

Contact person: Promotors: S. Le Maistre, co-promotors: Valerio Filice, Alfonso Caldiero
E-mail: sebastien.lemaistre@oma.be
Tel: 02 373 0211 (ROB General)
Office: Royal Observatory of Belgium
Availability: Any time by teleconf; please email to decide when.

Thematic: Planetology

Description:

NASA's Cassini mission to Saturn and its moons has been one of the most incredible feats of robotic space exploration, and even after its final plunge into the planet's atmosphere the data it collected continue to reveal more and more about the system. This project aims at improving our knowledge of Titan's gravity field, using a combination of data from different instruments onboard Cassini. The largest of Saturn's moons, Titan is the only body in the solar system (other than the Earth) to have stable liquid seas observed on its surface. These hydrocarbon reservoirs can help constrain the gravitational field of the moon, since all the points of a fluid surface have the same gravity potential - save for small variations due to waves.

The gravity potential at each point on the surface depends on its elevation, which is provided by Cassini's altimetry and SARtopo data. The other parameters modelling the gravity potential can instead be retrieved from radio science. Cassini performed more than a hundred close flybys of Titan, of which 9 were entirely dedicated to the determination of its gravity field. Ka- and X-band Doppler data from these flybys can be inverted to estimate the gravitational field of the moon. The latest gravitational model determined from these data includes coefficients of its spherical harmonic expansion up to degree 5. However, preliminary studies using this model have shown significant departures of the gravity potential along the lake's shorelines from that of an equipotential surface. This might hint at biases in the estimated gravity coefficients, or at large density anomalies below the lakes.

Hence, a new gravity field model should be produced as part of this study, from the joint least-squares inversion of Doppler and shorelines elevation data. Eventually, along with the spherical harmonics coefficients, the use of mascons will be considered to model possible local density anomalies. The data inversion will be performed using the orbit determination program (ODP) available at ROB: GINS (CNES/GRGS) or MONTE (NASA/JPL).

A correct modelling of the gravity field of a body is key to the understanding of its interior structure, and in the case of Titan, this may go beyond its current state. Morphological maps have shown the presence of empty lakes on the surface of the moon. Comparison between the equipotential surfaces containing the shorelines of these dry seas with the surfaces of the filled lakes could then provide information about the evolution of Titan's gravity, and therefore its interior.

Task Description:

- The student will develop a new software able to determine the shoreline's coordinates of filled/empty lakes from morphological maps and/or from the raw altimetry and SARtopo data
- The student will then translate the elevation of the shorelines into a priori constraint to be used by the ODP
- Finally, a new least-squares inversion of the Doppler data from the 9 Cassini flybys will be performed, including the constraints given by the shorelines elevation

This work can lead to a publication and can be continued in a PhD thesis.

Titan gravity field from lakes' equipotential and geological maps.

Contact person: Promotors: S. Le Maistre, co-promotors: Valerio Filice, Alfonso Caldiero

E-mail: sebastien.lemaistre@oma.be

Tel: 02 373 0211 (ROB General)

Office: Royal Observatory of Belgium

Availability: Any time by teleconf; please email to decide when.

Thematic: Planetology

Description:

This research topic aims at providing a new method to assess the quality of the rotation model of an atmosphere-less small body. Other approaches enabling the determination of rotation parameters of small bodies already exist. They are based on radiometric data, astrometric data and photogrammetric observations, all sensitivities to errors in the ephemeris of the celestial body. Here we propose to use as observable the images of the shadows projected on the surface of the body. Differently from the other kind of observations, the shadows are not sensitive to the errors in the body's ephemeris, which are very large for most of the small bodies of the solar system. The shadows depend mostly on the topography of the body and on its rotation. In the frame of this study, we will focus on Phobos, the largest moon of Mars, because its topography is accurately known while its libration amplitude (i.e. the amplitudes of the periodic variations in its rotation) is controversial and of great interest for constraining the interior structure of Phobos.

The work will consist first in creating fake images of Phobos surface with different rotation models proposed in the literature, and then compare them to real pictures as those provided by the ESA Mars Express mission, identifying thereby which model is best. Besides assessing the published models of Phobos rotation, one could go further by determining a new rotation model from the shadow data. Given the fact that the difference between the shadow areas in the real and fake pictures is the error, at the time of the picture, of the rotation model used to create the artificial image, it is possible to adjust the rotation parameters by minimizing that difference in the least squares sense.

The generation of the computed observable, i.e. the fake image, is crucial in this methodology. Currently, the software used is "FLOW", that is a Field Of View (FOV) visualizer for SPICE users, which creates an FOV image in JPEG/PNG/FITS formats using SPICE kernels developed by JAXA, the Japan Aerospace Exploration Agency.

Task Description:

The student will assess the accuracy of the image generated by FLOW and develop a tool to compare the fake and the real pictures, defining a strategy for the crater selection and for the quantification of the good matching of the real and fake images.

Fig: MEX-HRSC real picture of Phobos (left) juxtaposed with an artificial picture produced via the FLOW software (right)

General Circulation Modeling (GCM) of Martian dust and water cycles.

Contact person: Promoter: Ozgur Karatekin, co-promotors: Cem Berk Senel, Orkun Temel, Reader: V. Dehant
ozgur.karatekin@oma.be, cem.berk@oma.be, orkun.temel@oma.be, v.dehant@oma.be
Observatoire royal de Belgique et UCLouvain Tel: 02 373 0266 (V. Dehant)

Office: Royal Observatory of Belgium

Availability: Any time by teleconf; please email to decide when.

Thematic: Planetology

Description:

The dust cycle is the most profound driver of the Martian climate; thus, capturing the time-evolving dust distribution correctly is vital for simulating a realistic climate. The proper modeling of the dust cycle is closely coupled with water cycle dynamics, as both affect the radiative state of the atmosphere as well as general circulations.
Better understanding of the dust-water cycle feedback is key to solve numerous mysteries in Martian climate system, from polar cap evolution towards the dust storm-water escape interaction and the formation of extremely elongated water ice clouds in the wake of a volcano. Therefore, this master thesis aims to develop a novel interactive dust-water cycle model to be built within the ROB version of MarsWRF GCM. The new model will be verified with in-situ observations of NASA's MSL rover and InSight lander as well as orbiter observations from Mars Climate Sounder (MCS) and Nadir and Occultation for *MArs* Discovery (NOMAD) instruments. Following the development phase, the new model will be assessed to solve latest scientific questions seeking the exploration of red planet's atmosphere. This work may lead to a scientific publication as a follow-up of recently published works at ROB and extend into a doctoral thesis.

Task description:

- Perform high-resolution GCM of the Martian atmosphere.
- Comparison with the recent in-situ lander/rover and orbiter observations.
- Model and algorithm development for dust, water ice & vapor microphysics in Fortran.

Hypervelocity impact modeling of the solar system bodies.

Contact person: Promotor: Ozgur Karatekin, co-promotor: Cem Berk Senel, reader: V. Dehant
ozgur.karatekin@oma.be, cem.berk@oma.be, v.dehant@oma.be
Observatoire royal de Belgique et UCLouvain Tel: 02 373 0266 (V. Dehant)

Office: Royal Observatory of Belgium

Availability: Any time by teleconf; please email to decide when.

Thematic: Planetology

Description:

The impact processes are ubiquitous in the solar system, as one of the primary mechanisms driving the evolution of asteroids and comets. From small meteorite impacts to gigantic Moon-forming collisions, the impact cratering formation holds key insights pointing out the dynamical history of our solar system from 4.6 billion years ago. Meanwhile, thanks to the rapid advance in numerical modeling as well as computational resources, high-resolution numerical models offer a powerful framework assisted by either ground-based or spacecraft observational studies.

Within this context, this master thesis deals with the numerical modeling of impact processes by making use of state-of-the-art iSALE shock physics code as well as an N-body smoothed particle hydrodynamics (SPH) model. Performed simulations aim to resolve the aftermath of impacts on a variety of solar system bodies from asteroids to main belt comets and planetary moons, such as Phobos and Europa. This study offers a unique opportunity to better understand the solar system impact processes, ranging from cratering morphology towards the ejecta dynamics, volatile exchange, momentum transfer and interior dynamics. This work may lead to a scientific publication and can be extended through a doctoral thesis.

Task description:

- Perform shock physics model and N-body SPH model simulations.
- Implementing ANEOS/Tillotson equation of state (EOS) models.
- Comparison with the analytical, laboratory or in-situ scaling relations.
- Post-processing of simulation results by in-house and new algorithms in Python.

Planetary defense & planetary exploration of binary asteroid.

Contact person: Promotor: Ozgur Karatekin, co-promotor: Birgit Ritter, reader: V. Dehant
ozgur.karatekin@oma.be, birgit.ritter@oma.be, v.dehant@oma.be
Observatoire royal de Belgique et UCLouvain Tel: 02 373 0266 (V. Dehant)

Office: Royal Observatory of Belgium

Availability: Any time by teleconf; please email to decide when.

Thematic: Asteroids

Description:

Understanding the origin and evolution of near-Earth asteroids (NEAs) is an issue of scientific interest and practical importance because NEAs are potentially hazardous to the Earth. However, when and how NEAs formed and their evolutionary history remain enigmas. The asteroid surface and interior evolve in response to forces and effects from their environment. The asteroids are subject to a number of different physical effects, including surface acceleration (self-gravitation, rotation and tides), small non-gravitational forces and changing environments over time.

This master thesis is dedicated to understand the physical and dynamical properties on the binary asteroid Didymos, target of NASA's DART (Double Asteroid Redirection Test) and ESA's HERA missions. This planetary defense-driven collaboration, in addition to evaluate the kinetic impactor technique to change the motion of an asteroid in space, will greatly contribute to better understand the formation of binary asteroids as well as Solar System history.

The study will include modelling and simulations of relevant asteroid environment (i.e. surface forces, thermophysical properties and mechanical properties) to available (DART) and planned (HERA) observations. The study includes also preparations of scientific operations such CubeSat landing, and surface operations with the gravimeter as well as HERA thermal camera observations. This work may lead to a scientific publication as a follow-up of recently published works at ROB and extend into a doctoral thesis.

Geocenter determination by VT observations.

Contact person: Promotor: Ozgur Karatekin, co-promotor: Hakan Sert, reader: V. Dehant
ozgur.karatekin@oma.be, hakan.sert@oma.be, v.dehant@oma.be
Observatoire royal de Belgique et UCLouvain Tel: 02 373 0266 (V. Dehant)

Office: Royal Observatory of Belgium

Availability: Any time by teleconf; please email to decide when.

Thematic: Orbit determination

Description:

Traditional VLBI method solely has a geometrical nature by observing distant celestial sources -quasars-to access the quasi-inertial reference frame. Hence, it is not sensitive to the center of the Earth that is the origin for terrestrial reference systems, which is currently determined by geodetic techniques such as the Satellite Laser Ranging and GNSS.

New ESA missions such as GENESIS with VLBI tracking of satellite with an onboard VLBI Transmitter (VT) mimicking quasar signals would open new possibilities for the improvement and unification of reference frames, and determination of the movement of the geocenter of the Earth.

This master thesis is dedicated to assessment of VT observations to determine the geocenter position. By considering different geometrical configurations (positions of the VT and ground stations), and observation durations, accuracy of the geocenter position will be investigated compared/combined with SLR accuracies and contribution of VT will be investigated. This work may lead to a scientific publication as a follow-up of recently published works at ROB and extend into a doctoral thesis.

Task description:

- Preparing the Earth orbiting satellites for VT observation on Bernese GNSS Software
- Perform VT simulations with different configurations
- Comparison/combining of the results with other techniques like SLR/GNSS.

VLBI Observations Lunar Satellites/stations.

Contact person: Promotor: Ozgur Karatekin, co-promotor: Hakan Sert, reader: V. Dehant
ozgur.karatekin@oma.be, hakan.sert@oma.be, v.dehant@oma.be
Observatoire royal de Belgique et UCLouvain Tel: 02 373 0266 (V. Dehant)

Office: Royal Observatory of Belgium

Availability: Any time by teleconf; please email to decide when.

Thematic: Orbit determination

Description:

Moon is the objective of future European missions, which demands adaptation of modern navigation and geodetic techniques. ESA's Moonlight initiative involves expanding satnav coverage and communication links to the Moon. A dedicated lunar navigation satellite constellation and lunar surface beacons providing additional ranging sources and extended coverage is planned with new GNSS receivers, laser retro-reflector and novel VLBI transmitters.

This master thesis is dedicated on the investigation of these geodetic technics with emphasis on VLBI and includes orbit propagation/determination of lunar satellites and/or precise positioning of lunar lander/rover positions. Different orbits and geometrical configurations between the VLBI ground stations and lunar satellites/beacons will be considered. This work may lead to a scientific publication as a follow-up of recently published works at ROB and extend into a doctoral thesis.

Task description:

- Precise positioning and Moonlight satellites/beacons using GNSS and VLBI stations
  - Visibility analysis
  - Error analysis
  - Optimization

Quantum telecom in space

Contact person : Serge Habraken

e-mail : shabraken@uliege.be

Tel :

Office: CSL + B5a

Availability: to be scheduled by e-mail

Thematics : Instrumentation and methods

Description:

The constellations of earth observation satellites have opened a field for secure and high flux communications. Optical space telecoms are now maturing fast and answer the high flux demand. However, the security and confidentiality of the data are not ensured.
The solution will come from Quantum Key Distribution (QKD). This data transfer protocol starts to be standardized for fiber optics telecom but it remains unmature for free space optics telecom, even if prove of concept is demonstrated.

QKD is based on quantum physics such as Heisenberg Uncertainty Principle and Quantum Entanglement. **A first Master thesis** is proposed to survey the principles and cover the limitations with a focus on the satellite optical telecom.
It is especially dedicated to students with a good background in quantum physics + optics and interested to space technology challenges. An experimental demonstration is foreseen (production of entangled photons with laser source) through a collaboration with a Belgian research center.

A second master thesis is proposed to highlight the solutions for improving the KQD protocol in space. It is especially dedicated to students with a good background in space environment and optics. An experimental demonstration is foreseen through a collaboration with a Belgian research center.

Both subjects have the potential to be continued, ideally with a Ph. D. Thesis.
They receive an external financial support.