Master Thesis Proposals

2017-2018

Space Sciences

Faculty of Sciences
Liège University

Unveiling the internal structure of massive stars through their locations in the HR diagram

Contact person : Marc-Antoine Dupret, Melanie Godart, Arlette Noels

e-mail : dupret@astro.ulg.ac.be; mgodart@astro.ulg.ac.be; noels@astro.ulg.ac.be

Tel : 04 366 97 25 / 04 366 97 32

Office: B5c +1/4 / +1/12

Availability: May-June 2017 [please contact us for making an appointment]

Thematics : Astrophysics (stellar structure and evolution; massive stars)

Description:
1. The vast majority of the stars visible in our night sky are continuously burning Hydrogen into Helium: this is called the 'main sequence phase' of the evolution. For massive stars (with masses larger than 10 times the mass of the Sun), this phase lasts for a few million years whereas the following phases of nuclear burning are much shorter (10^6 years for Helium burning to a few days for Silicon burning).
2. Castro et al. (2014, A&A, 570) plotted in the spectroscopic Hertzsprung-Russel (sHR) diagram a large number of observed massive stars. Assuming that the majority of the observed stars are indeed in their main sequence phase, this density map suggests an observational boundary for the beginning (ZAMS) and the end (TAMS) of the main sequence depending on the stellar mass. This observational TAMS boundary reaches low effective temperatures (logTe ~ 4.2 for 30 Msun stars).
3. However, no standard theoretical models are able to reproduce this observational TAMS limit: the TAMS models are located at higher effective temperature than what is expected from observations.

Therefore, we propose that the student investigates (1) how it would be possible for massive star tracks to reach such low effective temperatures during their Hydrogen burning phase or, (2), how a large number of stars could be located at those effective temperatures without being burning Hydrogen into their core (as, e.g. during their Helium burning phase).

For this purpose, we will guide the student through the following steps:
1. Get acquainted with CLES, the stellar evolution code from Liege (Scuflaire et al. 2008, Ap&SS, 316). The student will compute stellar models with the standard input physics, and learn how to represent the results obtained in an HR diagram, in a spectroscopic HR diagram and by building structure profile figures.
2. Investigate the effect on the stellar structure of varying different parameters in the physics of the models. For this point, we propose 3 main directions:
- the use of different assumptions for the extension of the convective core
- the use of different mass loss rates
- the use of a turbulent diffusion

(or a combination of some of these effects).
3. Finally, the student will be asked to investigate the other scenario: that these stars, located in the cold side of the sHR diagram are in their core Helium burning phase.

Recommended master courses: Stellar Structure and Evolution I and II (M.-A. Dupret)

Simulations of photometric performance of a CubeSat

Contact person : Valérie Van Grootel & Sébastien Salmon

e-mail : valerie.vangrootel@ulg.be ; sebastien.salmon@ulg.ac.be

Tel : +32 4366 9730/9765

Office: B5c, room 1/13 or 1/14

Availability: Anytime in May or June except 15-17 May, 24 May, 30 May, and 12-16 June.

Thematics : Instrumentation and methods

Description:

CubeSats are a class of standardized nanosatellites (spacecrafts that weigh 1-10 kg) by unit “U” of 10x10x11 cm^3. They are an expanding space activity, with several hundreds of CubeSats forecasted for a launch in the coming years, including for scientific purposes. In particular, thanks to huge technical progress in satellite pointing stability and attitude control, high-precision photometry for astrophysics is now achievable.

NANESSE[1] is a Liege-led project of a 3U CubeSat dedicated to high-precision photometry of Alpha Centauri, our closest stellar neighbour. Alpha Cen is composed of two stars similar to the Sun, and a more distant, but thought to be gravitationally bound, faint red dwarf, Proxima.

NANESSE has 3 scientific purposes: (1) to measure stellar oscillations of Alpha Cen A (1-10 ppm amplitudes); (2) to monitor the stellar activity of both components (~100 ppm amplitudes); and (3) to search for Earth-sized transiting planets (~60-100 ppm amplitudes) around Alpha Cen A, B, or both. The most interesting low-Earth orbits to ensure optimal visibility of Alpha Cen are sun-synchronous dawn/dusk (6h/18h) orbits, where a satellite rides the terminator between day and night.

The goal of this master thesis project is to characterize the photometric performance of a 3U CubeSat in a dusk/dawn orbit like NANESSE. Several solutions for the design of the payload and the platform will be quantified and tested for their photometric performance. This will allow us to dimension the optical design in order to meet the scientific objectives. The performance simulator for the CHEOPS space mission (http://sci.esa.int/cheops/), for the preparation of which the promoters of this master thesis are implied, will be used as the tool to carry out the simulations.

Recommended courses: SPAT0035-1 *Space Exploration* (Pr. G. Rauw), AERO0018-3 *Space experiment development* (J. Loicq)

[1] Nanosatellite for Asteroseismology and activity of the NEarest Stellar System with Exoplanets

Modeling extreme horizontal branch stars by asteroseismology

Contact person: Valérie Van Grootel

e-mail: valerie.vangrootel@ulg.ac.be

Tel: +32 4366 9730

Office: B5c, room 1/13

Availability: Anytime in May or June except 15-17 May, 24 May, 30 May, and 12-16 June.

Thematics: Astrophysics: stellar physics

Description:

This master thesis concerns asteroseismology, 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. The proposed project spans from observational data reduction and analysis, to theoretical modeling by comparison between observed and theoretical oscillation properties of various stellar models.

The stars studied in this master project are extreme horizontal branch stars, also known as subdwarf B (sdB) stars. They represent an advanced stage of stellar evolution, after the main sequence where the stars spend most of their lives and after the first red giant phase. 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 PG 1336-018, a pulsating sdB star member of an eclipsing binary that has been observed with the 1.6-m Mount Bigelow telescope from January to June 2017. Because the PG 1336-018 sdB star is member of an eclipsing binary, its mass and radius are accurately and precisely known from orbital modeling, providing the most stringent test for sdB models and asteroseismology of evolved stars in general. First step will consist in cleaning and reducing observational data, and second step in extracting the frequencies of stellar oscillations. The third step is the asteroseismic modeling itself, by 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. The final objective will be to model the rotation period and internal rotation profile of the sdB star, by interpreting frequency multiplets associated to stellar rotation. This is particularly interesting for stars in close binaries such as PG 1336-018, which experience strong tidal interaction with its companion star. This is thought to lead to full spin-orbit synchronism (equality of orbital and rotation periods throughout the star). Determining internal rotation profile will provide stringent constraints for poorly constrained tidal friction theories.

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

Convection in pulsating white dwarfs

Contact person : Valérie Van Grootel & Marc-Antoine Dupret

e-mail : valerie.vangrootel@ulg.ac.be; ma.dupret@ulg.ac.be

Tel : +32 4366 9730/9732

Office: B5c, room 1/13 or 1/12

Availability: Anytime in May or June except 15-17 May, and 12-16 June. In particular, we are both available the two first weeks of May.

Thematics : Astrophysics: stellar physics

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.

The objective of this master thesis is to improve our understanding of the pulsation properties in white dwarfs. In these stars, the mechanism that drives pulsations is concentrated at the base of the upper (envelope+atmosphere) 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. The first ingredient is now taken into account thanks to the non-adiabatic MAD pulsation code (developed by Pr. Marc-Antoine Dupret) and fully implemented in our (1D) standard models of white dwarfs. For the accurate modelling of upper layers, full 3D hydrodynamical simulations are now available (see the recent work of P.-E. Tremblay, one of our collaborators), and their results has now to be exploited.

The first objective of this master thesis is to build patched models of white dwarfs, which will be 1D models with upper layers deduced from 3D simulations. This will consist in computing temporal and horizontal averaged quantities from 3D simulations, and calibrating convection free parameters for a continuous connection between interior and 3D averaged upper layers.

The second objective is to compute the pulsation properties of these patched models. The first step will be to compute adiabatic pulsations (this should be an excellent approximation for pulsations periods, since they are mainly determined in adiabatic regions). By comparing these periods with those obtained from standard 1D models, the objective is to assess for the first time the systematic errors coming from the approximate modeling of the superficial layers, the so-called surface effects. This is crucial for all structure modeling studies of white dwarfs. The second step is to compute non-adiabatic pulsations of these patched models, by using the MAD code. The objective is to assess the importance of an accurate upper layers modeling on the range of excited pulsations and on the instability strips of pulsating white dwarfs. For this last non-adiabatic objective, a first look is achievable within this master project, but a full investigation constitutes an excellent topic for a subsequent PhD thesis, with the goal to solve the discrepancies currently encountered with the observed instability strips of pulsating white dwarfs.

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

Diagnosing and calibrating the multi-century sunspot number series

Contact person : Frédéric Clette (+ co-supervisor to be defined)

e-mail : frederic.clette@oma.be

Tel : 02/373.02.33

Office: Observatoire Royal de Belgique, Physique solaire, 3 avenue Circulaire, 1180 Bruxelles

Availability: Mon 21 may (10-12h), Tue 6 june (10-12h), Tue 19 june 2017 (10-12h)

Thematics : Astrophysics (Solar physics, solar cycle, data mining, time series and error analysis)

Description:

Visual sunspot observations are at the base of the single longest scientific record of solar activity, spanning four centuries. The primary reference index, called sunspot number, was recently submitted to a full revision and re-calibration. A new significantly modified series was released in July 2015, shedding new light on our understanding on the long-term variations and instabilities of the 11-year solar cycle. However, uncertainties remain and errors in past historical data need to be established using the present state-of-the-art statistical and data mining techniques. A good overview of the ongoing effort was the theme of a recent special issue of the Solar Physics journal (Vol 291, N° 9-10: http://link.springer.com/journal/11207/291/9/page/1). This revival of long-term studies aims at addressing our current inability to predict the future evolution of the solar cycle, a key quest in solar physics, at constraining the latest physical models of the solar dynamo, and at improving our understanding of the solar influence on Earth climate change.

In the framework of this thesis, we will exploit the full database of raw sunspot counts maintained by the World Data Center SILSO (sidc.be/silso), which contains more than 500.000 observations spanning several centuries, in order to derive a better understanding of the scale differences between past observers, by exploiting modern data from the current worldwide SILSO observing network. Indeed, a key issue when building such a long-term record is to bring all observations to the same normalization scale, by diagnosing and compensating various inhomogeneity factors (instrumentation, observing practices, etc.). The abundance of modern data (280 stations) allows to implement statistical techniques to derive the noise properties of past data (often loosely documented) and advanced data mining techniques (multi-variate analysis) to address e.g. data gaps in sparse series or to identify “families” of observers sharing common characteristics. This analysis will help shedding light on remaining discrepancies in past sunspot observations (direct indicator of solar activity level) and also between sunspot data and parallel solar and geomagnetic records.

For this thesis, the solar team at the ROB will provide guidance based on years of world-recognized expertise. The World Data Center SILSO, hosted at the ROB, is indeed at the core of the current on-going research in this field. Although this is a time-limited master thesis, this training period may thus directly lead to useful results supporting current ongoing research, and it can perfectly be expanded later on as a full PhD research project. Although our team is based in Brussels, a significant part of the work can be carried out remotely, as the base data are accessible or storable off-site. However, for the good progress of the daily work, we assume that the student would spend one day in Brussels at least twice per month to interact directly with the promoter at the ROB. The main pre-requisites are a good base knowledge of time series and statistical error analysis, and an interest in astronomical data processing and data mining techniques, and in long-term solar activity.

Numerical simulation of the influence of the Earth's magnetic field on the global dynamics of the Earth.

Contact person: Véronique Dehant (Co-Promoter: Emmanuelle Javaux)

E-mail: v.dehant@oma.be

Tel: 02 373 0266

Availability: take a rendez-vous per email

Thematics: Planetology and planetary systems

Description:

The Earth's magnetic field is generated by the dynamo effect. In the same way that a bicycle dynamo generates light from the mechanical energy provided by the cyclist, the Earth generates a magnetic field thanks to the mechanical energy present within the movements of the conductive fluid contained in the liquid part of its core: the legs of the cyclist are then replaced by gravity. The influence of this magnetic field on the dynamics of the Earth's mantle and that of the solid part of the core is still poorly known. This influence, also called electromagnetic coupling, constitutes an essential point in our understanding of terrestrial dynamics and is part of a wider problem of the interaction between the different layers that make up the Earth and other celestial bodies such as Mercury or Ganymede. In order to carry out this project, a 3D computer code is made available to the student (SFEMaNS, Spectral Finite Element for Maxwell and Navier Stokes). On the basis of simple flows from the literature and thus known for their dynamogenic properties, it will be possible to study, on the one hand, the effects of the solid core of the Earth (modifying its conductivity and its radius) on the dynamogenic properties of the flow and, on the other hand, the mechanical influence of the magnetic field, through the Lorentz forces, on the solid core and on an outer layer, modeling the Earth's mantle. Minimal code changes will have to be made and the entire simulation process will be discussed with the ROB team: meshing of the different geometries, modification of the Input files and processing of the results.

This project can lead to a scientific publication and can be continued within a PhD thesis.

Investigation of Mars surface H_20 and CO_2 ice and atmosphere-surface interactions with Trace Gas Orbiter

Contact person: Véronique Dehant, co-promoter: Emmanuelle Javaux

E-mail: v.dehant@oma.be

Tel: 02 373 0266

Availability: take a rendez-vous per email

Thematics: Planetology and planetary systems

Description:

Understanding ongoing processes related to the temporal and spatial variations of surface H_20 and CO_2 ices, presence of liquid water, and exchange of trace species between the subsurface and the atmosphere are among the key open scientific problems, challenging our current understanding of the fundamental behavior of the Martian climate. Subsurface processes may produce emission of volatiles as well as trace gases into the atmosphere. The destabilization of subsurface ice and/or clathrates has been proposed as a mechanism for the formation of apparently present-day active fluid features on the surface and as a source for atmospheric trace gases such as methane. There is also recent evidence that liquid water may flow intermittently on present-day Mars probably due to the presence of perchlorate and other salts as sources of ions that can lower the freezing point of aqueous solutions. ESA's Trace Gas Orbiter (TGO, see figure) which has recently entered in Mars orbit will monitor the spatial and temporal variations of Mars atmosphere with emphasis on volatiles and trace gases.

In this Master thesis study, Mars surface atmosphere interactions will be carried out based on NOMAD (Nadir and Occultation for MArs Discovery) spectral observations in collaboration with scientists from Royal Observatory of Belgium and Royal Belgian Institute for Space Aeronomy (PI-Institute of the NOMAD). NOMAD is a spectrometer suite onboard TGO that can measure the spectrum of sunlight across a wide range of wavelengths (infrared, ultraviolet and visible). This broad coverage of the instrument enables the detection of the components of the Martian atmosphere and surface, even in low concentrations.

During the study, spectral data will be studied in terms of composition of surface properties. Bidirectional reflectance and the related photometric parameters will be considered in order to characterize the Martian surface. Models will be fitted to the observed data, which may include a spatial mixture of regolith, H_20, CO_2 ices, brines (mixture of water and salts) and clathrates. Since the NOMAD science phase is foreseen to start in early spring 2018, the spectra from previous Mars missions (Fourier spectrometer (PFS) and OMEGA onboard Mars Express and Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) onboard the Mars Reconnaissance Orbiter) will be first used to validate the proposed approach before applying to newly acquired NOMAD data set. Moreover, the proposed study will help to characterize also the variations in angular momentum due to the redistribution of masses in global scale, such as the migration of ice from the polar caps to the atmosphere and temporal and spatial variations of surface ices. These phenomena are critical for the forthcoming radio science experiments RISE onboard 2018 InSight mission (see figure on the right) and LaRa (Lander radio-science experiment, PI institute is ROB) onboard ExoMars 2020.

This work can lead to a publication and to a continuation into a PhD thesis.

Study of water on Mars in the frame of ExoMars mission

Contact person: Véronique Dehant, co-promoter: Emmanuelle Javaux

E-mail: v.dehant@oma.be

Tel: 02 373 0266

Availability: take a rendez-vous per email

Thematics: Planetology and planetary systems

Description:

Recently, observations of the HIRISE camera on board the Mars Reconnaissance Orbiter (MRO, see figure) have provided solid evidence on the intermittent presence of salt-saturated liquid water on the surface of the planet Mars at present. Space missions had already revealed traces of water in the past of Mars (riverbeds and deltas, flow channels, etc.), proving that liquid water had flowed at the surface of the planet in the distant past (3.5 billion years ago and before). The current presence of liquid water is of great interest as it represents an essential criterion in the study of the habitability of a planet. MRO observations showed narrow and dark flows observed on the slopes of Mars that appear and grow during warm seasons and disappear during the cold seasons. The detection of hydrated salts suggests that these flows would consist of brines made of chlorate and magnesium perchlorate and sodium perchlorate. Current conditions of temperature and pressure at the surface of Mars do not allow the pure liquid water to remain stable. However, the presence of salt keeps the liquid water up to -70°C.

The number of recent space missions to the Red Planet is particularly important and will remain so in the coming years. In particular, the ExoMars mission (launched in 2016) consists of the entry-descend-landing module Schiaparelli and the Trace Gas Orbiter (TGO) probe, which is aiming, among other things, to identify gases and isotopes present as trace elements in the Martian atmosphere. The Royal Belgian Observatory (ORB) is participating in this mission and the Belgian instrument NOMAD (Nadir and Occultation for MArs Discovery), a spectrometer that characterizes temporal variations and spatial distribution of trace gases and water ice on the surface is developed at the Institute of Space Aeronomy (IASB), neighbor and privileged partner of the ORB in the framework of this research.

The master thesis consists of studying the presence of saline liquid water in the Martian subsoil and on the surface of Mars. A sub-surface model including the transport of water vapor is available at the ROB. This model takes into account the vapor, ice and absorption phases. First, the work will consist in adding the liquid phase of the water to the model. The latter will then be used locally in places capable of accommodating the temperature and pressure conditions necessary for maintaining the liquid water. The stability of the water will be studied in particular according to the thermal properties of the soil and the presence of different salts.

This work can lead to a scientific publication and possibly to a doctoral thesis.

Mars rotation from SBI (Same Beam Interferometry) radio science measurements

Contact person: Véronique Dehant, co-promoter: Denis Grodent

E-mail: v.dehant@oma.be

Tel: 02 373 0266

Availability: take a rendez-vous per email

Thematics: Planetology and planetary systems

Description:

The SBI (Same Beam Interferometry) technique can provide very accurate measurements of the distance difference between two spacecraft or landing probes. It is a matter of simultaneously tracking in a coherent manner two or more landers having identical transponders from a single antenna on Earth. The transmitted radio signals are relayed by the lander transponder back to the Earth station, where they are recorded and then combined in an interferometric mode to form a differential phase measurement. Since the media traversed by the two signals (e.g. interplanetary plasma or the atmosphere of the Earth) are the same, these sources of error cancel out largely in the case of an SBI measure.

These measurements will make it possible to precisely observe the deformations of the surface of Mars due to the tides and its rotation, which will add precise constraints on the interior of Mars (such as the state and size of the core for example), as well as on the mass exchanges between the polar ice caps and the atmosphere.

For the proposed work, simulations will be carried out to quantify the contribution of this type of measure on our knowledge of the parameters of the rotation and tides of Mars. Measurements will be generated and then used to extract interesting information and assess the level of accuracy that will be achievable. This allows testing different mission configurations and seeing which is most conducive.

It will also be asked to test new configurations such as for example a lander on Mars, the second being on Phobos, one of the moons of Mars.

The software used was developed at the Royal Observatory of Belgium in the case of Doppler and SBI measurements between a Martian lander and the Earth. The orbital movement of Phobos around Mars will have to be added to the software and simulations will have to be carried out and analyzed for many configurations, in order to see which is the best mission strategy.

This work can lead to a scientific publication.

Whitening of Doppler data in Radio Science

Contact person: Véronique Dehant, co-promoter: Denis Grodent

E-mail: v.dehant@oma.be

Tel: 02 373 0266

Availability: take a rendez-vous per email

Thematics: Planetology and planetary systems

Description:

The Deep Space Network (NASA) and ESTRACK (European Space Tracking - ESA) ground stations communicate directly with space probes using uplink radio signals (Earth → Transponder) and downlink signals (Transponder → Earth). The frequency band used is often the X band or the S band.

When the Earth is in the field of the antennas of the probes and if the programmatic allows it, the probes transmit for a limited period of time telemetry data (navigation or sensors data) and / or scientific data (binary data or pure modulated tones). The scientific data of interest to us in this case are the Doppler data produced by the DSN and ESTRACK antennas after receiving the descending signals (One-Way path: Probe → Earth or Two-Way path: Earth → Probe → Earth).

The data stored in flat files are often temporally correlated and therefore require pre-processing so as not to overestimate the quality of the Doppler data with artificially small formal errors.

The objective of this master thesis is to apply a suitable data-whitening algorithm that will de-correlate and normalize the components of the Doppler signal embedded in background noise (Gaussian white noise).

Description of tasks:

- Examine the different whitening algorithms that allow to process highly noisy data and compare their respective performances.
- Implement under Matlab the algorithm of whitening that will minimize the amplification of the noise present in the Doppler data (files from DSN and ESTRACK ground stations).

This work can lead to a publication and cab be continued in a PhD thesis (application to real data).

Effect of charged particles on Doppler tracking

Contact person: Véronique Dehant, co-promoter: Emmanuelle Javaux

E-mail: v.dehant@oma.be

Tel: 02 373 0266

Availability: take a rendez-vous per email

Thematics: Planetology and planetary systems

Description:

The aim of this study is to analysis the effects of plasma turbulence in the solar wind on Doppler radio measurements from interplanetary spacecraft
A spacecraft receives an uplink signal at X-band (7.3 GHz), and transmits data (telemetry or science data) to Earth at X-band (8.4 GHz). In addition, a small amount of downlink power is transmitted at S-band (2.3 GHz) for evaluating the link performance. The two-way communication involves a 34-m ground station on the Earth that is equipped to emit an X-band signal and to receive both X- and S-band signals. At the ground station a loop tracker records carrier phase at both downlink carriers and this data is analyzed to examine the effect of charged particles, from solar plasma and the Earth's ionosphere, on Doppler passes typically used for tracking and navigation of interplanetary spacecraft. The Doppler tracking data allows, for example, calculating the gravitation field of the planet around which the spacecraft is orbiting. The experimental data set that will be used in this study are dual-frequency tracking of the European Space Agency's (ESA) Mars Express (MEX) spacecraft.

Task Description:

Based on the power spectral analysis of the dual-band data, the objective of this work is to determine an appropriate model for treating charged particles in single-band Doppler tracking. The statistic of phase variations will be described in terms of Allan variances (root-mean-square differenced-phase variations) and classical frequency variance. A realistic modelling of the charged particle variations should be adopted in good agreement with current models developed to estimate the solar plasma variations as a function of SEP angle.

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

Observation and analysis of transits of TRAPPIST-1 planets

Contact person: Michaël Gillon

e-mail: michael.gillon@ulg.ac.be

Tel: 043669743

Office: Institute of Astrophysics, B5c, 1/10

Availability: 1st to 19th May, 19 to 30 June

Thematics: Planetology and planetary systems; Instrumentation and methods

Description:
In 1992, the discovery of the first exoplanets opened a new domain of modern astronomy. 25 years later, more than three thousands exoplanets have been detected at an ever increasing rate. In parallel to this galore of detections, many projects aiming to *characterize* exoplanets have reached success in the last decade, bringing notably first pieces of information on the atmospheric properties of giant exoplanets. These pioneer results have paved the way for future atmospheric studies of habitable terrestrial exoplanets able to reveal the existence of life around another star. In this exciting context, the recent discovery of a compact system of seven temperate Earth-sized planets around the nearby ultracool dwarf star TRAPPIST-1 is a game-changing result. Indeed, not only these seven planets could harbor some liquid water on a fraction of their surface, especially the three of them that orbit within the so-called habitable zone of the star, but they are all seven extremely well-suited for a detailed atmospheric characterization with existing and upcoming facilities (especially JWST), which makes TRAPPIST-1 a first (multiple) opportunity to probe the atmospheric composition of temperate Earth-sized exoplanets in a search for chemical traces of life.

The proposed Master Thesis will focus on the observation of transits of the TRAPPIST-1 planets with the robotic telescopes of the ULg-led projects TRAPPIST and SPECULOOS, and in their detailed analysis. The main goal of these observations will be to enable improving the precision on the planets' masses, which is crucial to thoroughly constrain their compositions and interpret the upcoming atmospheric measurements. These improved masses will be obtained with the Transit Timing Variation (TTV) method, which rely on the gravitational interactions between the planets. Indeed, the TRAPPIST-1 system form a unique resonant chain that results in strong mutual interactions leading to significant changes in the periodicity of the planets' transits. Monitoring at high-precision the transits of the planets enables thus to constrain their mutual dynamical perturbations and their masses.

The student will learn to manage all the parts of the project, from the scheduling and preparation of the observations to the scientific exploitation of the resulting transit light curves (the complex TTV analysis will be performed by external collaborators). This work will provide her/him with a first-class expertise in robotic telescope operation, high-precision time-series photometry, exoplanet transit light curve analysis, and planetary system dynamics. These results will be presented in a peer-reviewed scientific article, eventualy first-authored by the student.
The only prerequisite to this Master Thesis work is the successful completion of the course 'Introduction to exoplanetology' (SPAT0063-1).

Design and scientific optimization of a small-scale spacebased interferometer to study exoplanets

Contact person: D. Defrère , O. Absil , J. Loicq

e-mail: defrere@astro.ulg.ac.be , absil@astro.ulg.ac.be , j.loicq@ulg.ac.be

Tel: 043669758

Office: B5c, -1/1

Availability: any day (please contact us to agree on a time slot)

Thematics: Planetology and planetary systems; Instrumentation and methods

Description:

The detection and characterization of exoplanets is one of the major science cases of modern astronomy. In particular, the recent discovery of planetary systems around the nearest stars represents a formidable scientific opportunity for a small-scale space-based interferometer. An interferometer combines very precisely the light from different mirrors to synthetize a virtual telescope that has an angular resolution much larger than that of the individual mirrors. This technique provides the necessary sensitivity and angular resolution to observe the terrestrial planet zone around nearby stars and particularly around Proxima Cen, our nearest star located at only 4.2 light-years and hosting a small rocky planet recently discovered in the habitable zone (i.e., the zone around a star which is compatible with surface liquid water).

Under the supervision of the department of Astrophysics, Geophysics, and Oceanography (AGO), and in collaboration with the Centre Spatial de Liège (CSL), the goal of the master thesis will be twofold. The first goal will be to define the science case of such a small-scale space-based interferometer with scientists of the AGO department. To achieve this goal, the master student will gain knowledge in various areas of exoplanetology and develop computer codes to maximize the scientific return of the concept (based on different instrumental assumptions). The second goal will be to define a functional design that use space-ready technologies and can fit on a small space platform. To achieve this goal, the master student will collaborate closely with CSL which leads the instrumental design.

Recommended master courses :
- SPAT0063-1 : Introduction to exoplanetology
- PHYS0124-1 : Instrumental optics I
- PHYS0125-3 : Instrumental optics II

Taming the error growth in a multi-scale ocean model

Contact person : Alexander Barth (Eric Deleersnijder, UCL, co-promoter)

e-mail : a.barth@ulg.ac.be

Tel : 043663664

Office: B5a, 2.56

Availability: 22 May, 29 May (please confirm per email)

Thematics : Oceanography

Description:
Ocean models are affected by errors of various origins, including uncertainties in the initial conditions, open ocean boundary conditions and sub-grid scale processes. Data assimilation aims to reduce the inevitable growth of these errors by the constraining the model's state variables by means of observations. Data assimilation schemes rely on the estimation of the expected errors affecting model and observations and combine model and observations by minimising the expected error of the combination.

The error growth is closely linked to the resolved scales in an ocean model. The errors associated with small-scale processes (like mesoscale eddies or submesoscale filaments) tend to grow much faster than the errors related to the large-scale process (e.g. the general circulation in a basin). Ideally observations should cover the whole spectrum of the scales represented in a model. However, it is clear that only a small part of the variability spectrum can be directly constrained by observations. Through the dynamical coupling of scales, data assimilation can propagate in theory the information from the measured scale to the non-measured scales. It is unclear however if coupling is sufficiently strong so that e.g. large-scale information can also improve the representation of small-scale processes.

The aim of this MSc thesis is to assess how observations at one scale can be used improved the model result at a different scale. The question will be addressed using the multi-scale model SLIM (www.climate.be/slim_flyer) and the Ensemble Kalman Filter (e.g. Canter et al. 2016, Barth et al. 2015) in the context of a twin experiment. A twin experiment is a controlled numerical experiment where the « true » ocean state is a reference simulation and thus assumed to be known and the observations are extracted from this reference simulation.

By the end of this MSc thesis, the student will have gained insight into the predictability of ocean processes and data assimilation, and will have become familiar with a complex C++/python model and a Fortran-90 data assimilation package.

Suivi du stress végétal par télédétection

Contact person : Christian Barbier; Bernard Tychon

e-mail : cbarbier@ulg.ac.be; Bernard.Tychon@ulg.ac.be

Tel :

Office: Laboratoire Traitement du Signal, Centre Spatial de Liège; Eau-Environnement-Développement, Campus d'Arlon

Availability: Contact by e-mail

Thematics : Climate, environment and oceanography ; Instrumentation and methods

Description:

Il existe de nombreux types de stress pour les végétaux (sécheresse, salinité, anaérobie, rayonnement UV, gel, excès de chaleur, polluant dans l'air et dans les sols, carences minérales, maladies, pestes,…). Ces stress entrainent des réponses du végétal (fermeture stomatique, gel, réduction de la photosynthèse,…) qui peuvent être détectées par différents types de capteurs spatiaux ou aériens (voir Jones and Schofield, Gen. Appl. plant physiology, 2008, special issue, 34 (1-2), 19-32).

L'objet de l'étude serait de déterminer quelles combinaisons de capteurs seraient les plus appropriées pour un suivi global du stress végétal à l'échelle de la planète.
Cette étude fera le point (état de l'art) sur le suivi des différents types de stress observables par différents capteurs (recherche bibliographique avancée).
A partir de là, il sera demandé à l'étudiant de proposer une (ou plusieurs) combinaison(s) de capteurs à même de suivre avec une précision suffisante (à définir) pour un usage opérationnel, un certain nombre de stress végétaux (on ne pourra pas les suivre tous) avec des capteurs à bord de satellite.

Idéalement, des essais avec des capteurs manuels portables devraient être réalisés pendant le TFE.
Selon l'emphase que l'on apportera, ce travail convient aussi bien à un profil d'étudiant en sciences spatiales que d'étudiant en agronomie.

Development of a test facility for radiation testing of electronic components used in space: low energy electron beam

Contact person : Alain Carapelle

e-mail : A.Carapelle@ulg.ac.be

Tel : 04 382 46 24

Office: CSL (Bât B29 room 2.17)

Availability: Monday to Thursday 3 PM to 6 PM

Thematics : Instrumentation and methods

Description:

In the frame of the study of radiation effects on electronics, Single Event Effect (SEE) tests are done with heavy ions beams (or sometime Laser testing). The purpose of this work would be to modify an existing facility to produce low energy (<100 keV) electron beam using β^- sources. The setup will be a sort of energy selection (monochromator) device.

The work will be divided in the followings points:

- Design of a magnetic deflector taking into account energy spectrum of sources and achievable power supply, entrance and exit collimator
- Modification of one of the chamber input to fit the deflector
- Test with the 4 sources and different settings
- Measurement of results with the spectrometer

Candidate:

- Should have strong experimental background
- Following abilities are useful :
    - experience in nuclear spectroscopy (amp, MCA …)
    - knowledge of vacuum technics
    - knowledge of liquid nitrogen usage

Development of a polarization scrambler for earth observation spectrometers

Contact person : Serge Habraken

e-mail : shabraken@ulg.ac.be

Tel : 04 3663649 / 043824635

Office: Building B5a (Phys) Local 0/52 / Centre Spatial de Liège.

Availability: to be agreed by e-mail

Thematics : Instrumentation and methods

Description:

For earth observation, efficient diffraction gratings are used as wavelength separators for spectrometry. However, the efficiency of these gratings is highly dependent of the incident polarization. To mitigate the polarization sensitivity of the optical setup, polarization scramblers are used. We propose to design a polarization scrambler based on gratings with a period smaller than the incident wavelength.

The master thesis will consist in:

- Design of the gratings parameters to achieve both half-wave plate condition and high transmission over the desired bandwidth
- Numerical simulations of the performances as a depolarizer
- Tests and characterization of the first prototypes as half-wave plates on a polarimetric bench
- Adapt the design of the grating geometry to achieve polarization scrambling
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Candidate:

- Must have polarization and diffraction notions (seen in Instrumental Optics I & II or coherent and incoherent optics)
- Must have an interest in experimental and numerical work
- Must have an interest in programming with Matlab and interfacing with Labview