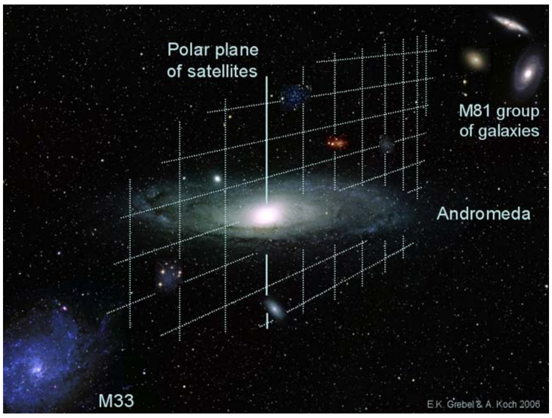
A search for faint satellites around isolated galaxies



SUMMARY.
An isolated galaxy is a galaxy that does not have any nearby massive and luminous neighbors. However, they may be accompanied by small satellite galaxies. A satellite galaxy is a smaller companion that travels on bound orbits within the gravitational potential of their host galaxy, in the same way that planets within the Solar System are gravitationally bound to the Sun. Our galaxy, the Milky Way (MW), has several satellite galaxies, being the more massive the Large and Small Magellanic Clouds (LMC and SMC). However the MW is not an isolated galaxy, it belongs to the Local Group with the Andromeda (M31) galaxy, which also has a system of satellites, and the Triangulum (M33) galaxy. Are satellite galaxies only related to group galaxies or there is a population of satellites around isolated galaxies?

OBJECTIVES

- ***Knowledge:*** *Students will gain knowledge on the topic of extra-galactic astrophysics, in particular on how the environment affects galaxy formation and evolution.*
- ***Skills:*** *Students will learn to manage large databases and to use SDSS and DESI data.*

INSTITUTE

The project will be developed in the Galactic Astrophysics Group of the Department of Theoretical Physics and Cosmology at the Faculty of Sciences of the University of Granada (UGR), Spain.

- University of Granada
- Galactic Astrophysics Group
- Edificio Mecenas, Campus Universitario de Fuentenueva, Universidad de Granada, 18071-Granada, Spain.

THEORY

by M. Argudo-Fernández

Detecting satellite galaxies is a difficult task, since they are small and faint, and therefore their detection is mostly limited to very nearby galaxies, as M31. The Dark Energy Spectroscopic Instrument (DESI) Bright Galaxy Survey (BGS) is producing the most detailed map of the nearby Universe, providing optical spectra for millions of galaxies brighter than 19.5–20.2 r-band magnitude.

The objective of this project is to look for faint satellites around a sample of isolated galaxies, with the aim of identifying satellites similar to the LMC and the SMC.

If such population exists, their distribution carries important information for the underlying cosmology, dark matter properties and galaxy formation processes. In this sense, studying the faint small-scale structure of isolated galaxies therefore provides a valuable test for ΛCDM.

APPLICATIONS

by M. Argudo-Fernández

To carry out this project, we will use the Sloan Digital Sky Survey (SDSS) catalogue of isolated galaxies (SIG). The galaxies in the SIG are brighter than 15.7 r-band magnitude and are isolated, with no physically bound neighbours brighter than 17.7 r-band magnitude.

If we confirm that, on the other hand, this population of faint satellites is simply a line–of–sight coincidence, these results would confirm the SIG as the sample of the most extremely isolated galaxies in the local Universe. Such a sample would be the most ideal laboratory to test models of galaxy formation and evolution. Besides, the SIG would offer the opportunity to start statistically significant studies of galaxy properties and interpret them in light of their relations with their local and large-scale environments.

MAIN PROGRESSION STEPS

- Tier 1: Python course completion and review of relevant references.
- Tier 2: Sample selection, data analysis, interpretation of the results.
- Tier 3: Preparation of written project and presentation.

EVALUATION

- Theory grade [30%]
  Comprehension of theoretical background as part of the written report.
- Practice grade [30%]
  [20%]: Project development, progress, analysis, and conclusions, as detailed in the report.
  [10%]: Initiative, pro-activity, teamwork.
- Defense grade [40%]
  - Oral and slides quality
  - Context
  - Project / Personal work
  - Answers to questions

BIBLIOGRAPHY & RESOURCES

- Argudo-Fernández et al. 2015
- Hahn et al. 2023
- SDSS webpage
- DESI webpage

CONTACT

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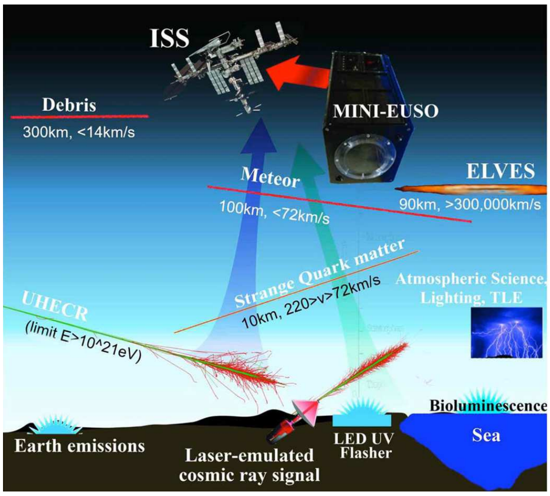
Modelling of space & ground-based observations of meteors and exotic matter



SUMMARY.

Objective of the METEOR is a full immersion in the topic of transient luminous events of extraterrestrial origin. Different kinds of phenomena will be investigated, ranging from meteor events to the detection of the transit of exotic matter in the atmosphere. Approximately one week will be devoted to lectures covering the theoretical background of the covered topics. A significant fraction of the time will be devoted to numerical simulations and data analysis. Whenever possible, some time will be devoted to laboratory experiment activities. The methodology will be applied to the analysis of Mini-EUSO, PRISMA or DIMS data. Mini-EUSO is a space experiment on board the ISS, PRISMA is a network of ground-based full-sky cameras in Italy while DIMS is a set of CCD camera in Japan and US. The three experiments aim at detecting meteors and/or fireballs, and search for interstellar meteoroids and exotic matter.

OBJECTIVES

- ***Knowledge***, *understand planetary science, learn about the dark matter problem and observational methodologies*
- ***Skills*** *run numerical simulations, process Mini-EUSO, PRISMA or DIMS data*

INSTITUTE

- Department of Physics, University of Turin
- Institute URL
- Via P. Giuria 1, Turin, Italy

THEORY

by BERTAINA Mario Edoardo

Explain the theoretical aspects covered in the METEOR and the observational methodology.

by BARGHINI Dario

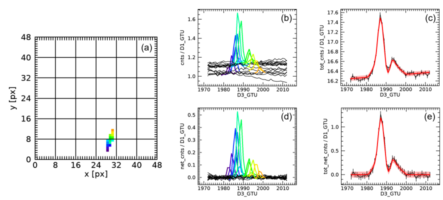
Presentation of the meteor observation techinques and the importance of meteor studies in the framework of planetary science.

APPLICATIONS

by D. Barghini/ M. Bertaina

The trainee will use and possibly improve available numerical codes to analyze the data acquired by Mini-EUSO, PRISMA or DIMS projects as well as simulate the expected signals in the detector by meteors or exotic matter.

The figure shows an example of extraction of the meteor signal from the data after polishing the background noise



Example of processing a meteor signal.

MAIN PROGRESSION STEPS

- Week 1-2: lectures on the covered topics and bibliographic studies
- Weeks 3-8: project
- Week 9: preparation of the final presentation and discussion

EVALUATION

The students will be examinated by means of a final presentation which will be delivered on the last week. This presentation should include all the items discussed in the following.

- Theory grade [30%]
  - 50%: theoretical questions, base calculus from lectures
  - 50%: critical spirit
- Practice grade [30%]
  - Project-related exercices (10%): thought-process and results
  - Project (90%): initiative, progress, analysis
- Defense grade [40%]
  - Oral and slides quality
  - Context
  - Project / Personal work
  - Answers to questions

BIBLIOGRAPHY & RESOURCES

Any reference or web page that students can read to have a better idea of the topic

- Bertaina-webpage
- Mini-EUSO-project
- Mini-EUSO-video
- Mini-EUSO-paper
- PRISMA-website-ITALIAN
- PRISMA-paper
- DIMS-paper

CONTACT

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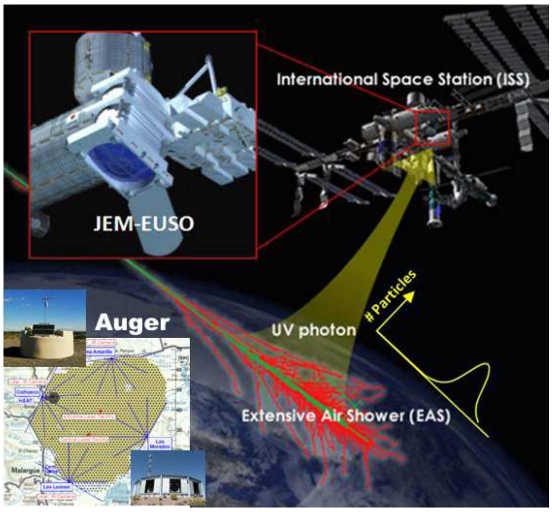
Modelling of space & ground-based observations of Ultra-High Energy Cosmic Rays



SUMMARY.

One of the key open questions in the field of astroparticle physics concerns the origin of the so-called Ultra-High Energy Cosmic Rays (UHECRs). They consist of protons and nuclei traveling through the universe with macroscopic energies, reaching 10^{20} eV and beyond, which makes them by far the most energetic particles known in the universe. However, their sources and acceleration mechanism(s) are still to be identified. A major challenge is the very low flux, namely about 1 particle per km^2 per millennium at the highest energies! For this reason, detectors with a huge field of view must be developed to study UHECRs with reasonable statistics. Objective of the METEOR is a full immersion in the topic of UHECRs, with lectures on cosmic rays science and detection tecniques. A significant fraction of the time will be devoted to conduct data analysis, simulation studies or experiments in the framework of the Pierre Auger Observatory or JEM-EUSO projects.

OBJECTIVES

- ***Knowledge***, *understand cosmic ray science, learn about astroparticle physics and observational methodologies*
- ***Skills*** *run numerical simulations, process AugerPrime or JEM-EUSO data*

INSTITUTE

- Department of Physics, University of Turin
- Institute URL
- Via P. Giuria 1, Turin, Italy

THEORY

by BERTAINA Mario Edoardo

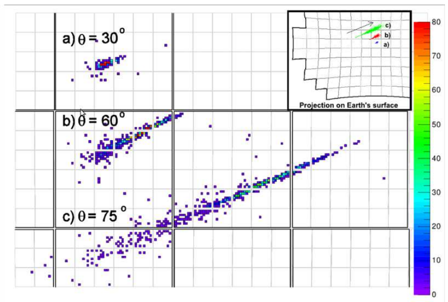
Explain the theoretical aspects covered in the METEOR and the observational methodology. Presentation of the cosmic ray observation techinques and the importance of cosmic ray studies in the framework of astroparticle science.

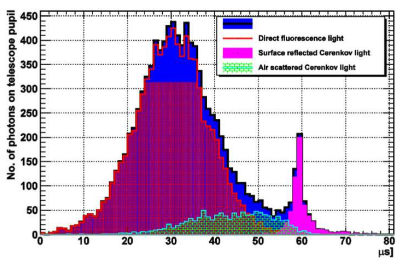
APPLICATIONS

by M. Bertaina

The trainee will use and possibly improve available numerical codes to analyze the data acquired by JEM-EUSO or AugerPrime projects as well as simulate the expected signals in the detector by UHECRs.

The figure shows an example of the signal generated in the atmosphere by the extensive air shower produced by an UHECR colliding with the atmosphere and detected by the JEM-EUSO space telescope





Example of the signal generated by an UHECR on the JEM-EUSO focal surface.

MAIN PROGRESSION STEPS

- `Week 1-2`: lectures on the covered topics and bibliographic studies
- `Weeks 3-8`: project
- `Week 9`: preparation of the final presentation and discussion

EVALUATION

The students will be examinated by means of a final presentation which will be delivered on the last week. This presentation should include all the items discussed in the following.

- `Theory grade [30%]`
  - 50%: theoretical questions, base calculus from lectures
  - 50%: critical spirit
- `Practice grade [30%]`
  - Project-related exercices (10%): thought-process and results
  - Project (90%): initiative, progress, analysis
- `Defense grade [40%]`
  - Oral and slides quality
  - Context
  - Project / Personal work
  - Answers to questions

BIBLIOGRAPHY & RESOURCES

Any reference or web page that students can read to have a better idea of the topic

- Bertaina-webpage
- JEM-EUSO-program
- JEM-EUSO-paper
- PierreAugerObservatory
- Auger-paper
- UHECR-science

CONTACT

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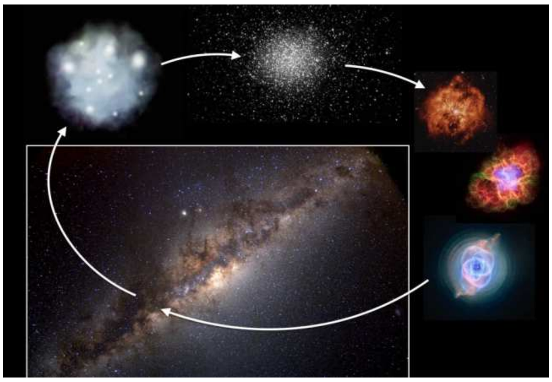
Galactic chemical evolution



SUMMARY.
Galactic Chemical Evolution models can trace element evolution from the early Universe, integrating nuclear physics, stellar evolution, and cosmology. By combining detailed stellar observations with sophisticated chemical evolution models that link nuclear physics and stellar evolution, we can unravel the processes of element creation and the complex story of how our Galaxy formed and evolved over cosmic time.

OBJECTIVES

- **Knowledge**
  Drivers of chemical enrichment in our Galaxy.
  Timescales of enrichment for different elements.
  Chemical signatures to look for and their implications.
- **Skills**
  Work with numerical simulations of chemical evolution.
  Compare stellar abundances to synthetic results.
  Minimize model parameters within a bayesian approach.

INSTITUTE

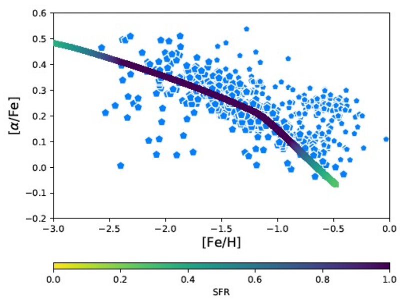
- Osservatorio Astronomico di Trieste, INAF.
- website INAF OATS
- INAF-Osservatorio Astronomico di Trieste Via G.B. Tiepolo, 11, 34143 Trieste, Italy

THEORY

Fundamental ingredients of chemical evolution: initial conditions, star formation, initial mass function, gas flows (infall and winds) and stellar nucleosynthesis. Analytic solutions (closed box) and their limitations. How to extend to an numerical model. Implementation of a standard homogenous model and a stochastic evolution model. Stellar evolutons models with nucleosynthesis, the most recent sets.

APPLICATIONS

Comparison the GCE model results with chemical abundances measured in Galactic stars. From the classic case of the alpha-knee to the dispersion of the neutron capture elements. How to adopt a Bayesian approach to contrain Galaxy evolution and evaluate stellar nucleosynthesis.



[α/Fe] as a function of [Fe/H]. The cyan pentagons are stars measured by APOGEE, which belong to Gaia-Enceladus. The model is shown as a line and it is colourcoded according to the SFR (see colorbar).

MAIN PROGRESSION STEPS

- `Tier 1`: Theoretical basis of chemical evolution
- `Tier 2`: How to develope a numerical model
- `Tier 3`: Comparison with the data

EVALUATION

The student will be evaluated according to the capability to solve practical problems and based on the final project presentations. At this stage theoretical knowledge will be also investigated.

- `Theory grade [30%]`
  – Questions during the final presentation
- `Practice grade [30%]`
  – Based on the capabilities of the student to indendently solve some scientific problems and to use, modify, and implement new features in a Galactic chemical evolution code
- `Defense grade [40%]`
  – Oral and slides quality
  – Context
  – Project / Personal work
  – Answers to questions

BIBLIOGRAPHY & RESOURCES

- Matteucci 2012
- Rizzuti et al. 2021
- Spitoni et al. 2020
- Cescutti et al. 2020

CONTACT

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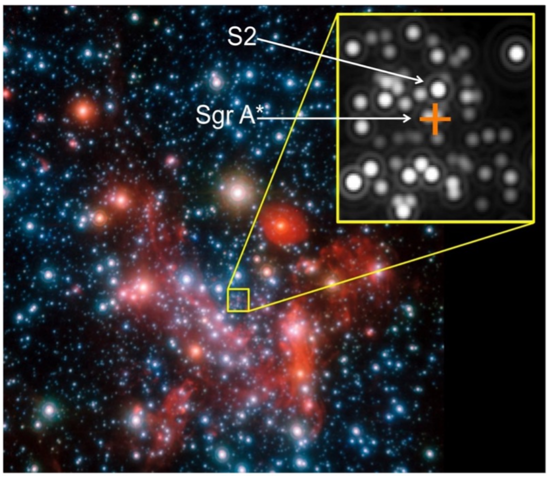
Source Detection and Extraction from Infrared Deep Space Observations



SUMMARY.

The METIS instrument is an advanced infrared camera operating in the 3 to 10 micron wavelength range, soon to be installed on the European Extremely Large Telescope (ELT), which boasts a 40-meter primary mirror. This project focuses on building a robust software pipeline to evaluate METIS's imaging capabilities, particularly for observing the Galactic Centre. The core challenge lies in simulating and accurately placing astrophysical sources on a pixel grid of the infrared detector, then analyzing the resulting synthetic images. This involves combining physical models with computational tools to assess how well METIS can perform key measurements like source localization (astrometry) and brightness estimation (photometry). By leveraging and extending existing simulation codes and data analysis packages, this work sits at the intersection of astrophysics, computational modeling, and software engineering.

OBJECTIVES

- *Master and extend the METIS simulation pipeline (ScopeSIM), focusing on wrapping and integrating it into a modular, automated software workflow.*
- *Generate realistic synthetic images of the Galactic Centre by automating ScopeSIM simulations and accurately mapping sources onto the detector grid.*
- *Integrate the classical source extraction tool StarFinder into the pipeline for automated astrometric and photometric analysis, ensuring smooth data exchange and batch processing capabilities.*
- *Develop new source extraction algorithms or tools tailored to METIS data characteristics, improving detection and measurement accuracy beyond existing solutions.*
- *Build a cohesive, scalable pipeline that combines simulation, extraction (both existing and newly developed tools), and performance evaluation with emphasis on reproducibility, modularity, and software engineering best practices.*

INSTITUTE

- Faculdade de Engenharia da Universidade do Porto
- https://www.up.pt/feup/en/
- Rua Dr. Roberto Frias s/n, Porto 4200-465, Portugal

THEORY

by Carlos M. Correia

The work focuses on astrometry and photometry techniques simulated images from adaptive-optics-corrected observations. Understanding image formation and source detection algorithms for precise location and flux determination are key development the students will learn and improve during the internship.

APPLICATIONS

by Carlos M. Correia

Adaptive optics performance simulations. Evaluation of Strehl ratio and residual wavefront error. Use of state-of-the-art techniques for photometry and astrometry. Deep understanding of the challenges of performing precision astrometry and photometry with ELT instruments. Scientific writing, plotting and interpretation of advanced astrophysical metrics.

MAIN PROGRESSION STEPS

- `Weeks 1-2:` Introduction to METIS, ELT instrumentation, and adaptive optics.
- `Weeks 3-4:` Training on StarFinder and ScopeSim
- `Weeks 5-7:` Performance evaluation in terms of astrometry and photometry.
- `Weeks 8-9:` Result interpretation and preparation of final report.

EVALUATION

- `Theory grade [30%]`
  Comprehension of theoretical background as part of the written report.
- `Practice grade [30%]`
  [20%]: Project development, progress, analysis, and conclusions, as detailed in the report.

  [10%]: Initiative, pro-activity, teamwork.
- `Defense grade [40%]`
  - Oral and slides quality
  - Context
  - Project / Personal work
  - Answers to questions

BIBLIOGRAPHY & RESOURCES

noindent

- Brandl et al, (2021): METIS: The Mid-infrared ELT Imager and Spectrograph, (2021)
- Monty et al.. (2023): "Astrometry with MAVIS: Pushing Past the Limits of Gaia to the Crowded Centres of Globular Clusters. Adaptive Optics for Extremely Large Telescopes 7th Edition

CONTACT

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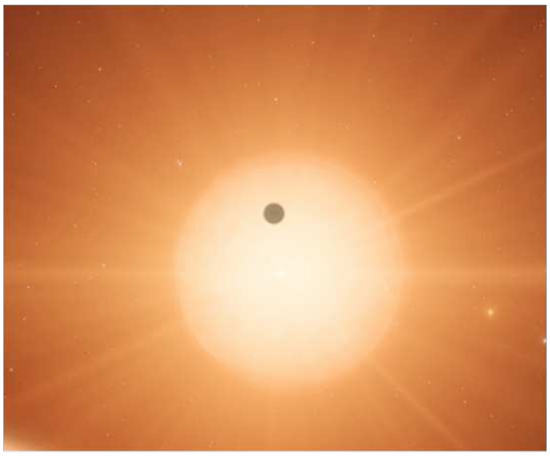
Exoplanet Hunter Instruments Performance Prediction



SUMMARY.
The Extremely Large Telescope (ELT) will provide unprecedented capabilities for high-angular-resolution astronomy and exoplanet characterisation. One of its future instruments, the Planetary Camera and Spectrograph (PCS), is designed to directly image and spectroscopically characterise exoplanets and circumstellar environments at extremely high contrast levels. This project focuses on predicting and evaluating PCS scientific performance using analytical and simulation-based tools. Particular emphasis is placed on adaptive optics performance estimation through analytical frameworks such as TipTop. The work includes the study of atmospheric turbulence, wavefront correction, coronagraphic performance, and resulting science metrics

OBJECTIVES

- *Understand the scientific objectives and architecture of PCS.*
- *Study high-angular resolution techniques and in particular extreme adaptive optics and how they are used in direct exoplanet imaging systems.*
- *Learn analytical performance prediction methodologies.*
- *Use TipTop to estimate PCS extreme adaptive optics performance metrics (contrast, Strehl, wavefront error, etc).*
- *Analyse observing scenarios and performance trade-offs.*

Particular emphasis is placed on adaptive optics performance estimation through analytical frameworks such as TipTop.

INSTITUTE

- Faculdade de Engenharia da Universidade do Porto
- https://www.up.pt/feup/en/
- Rua Dr. Roberto Frias s/n, Porto 4200-465, Portugal

THEORY

by Carlos M. Correia

The work includes the study of atmospheric turbulence, wavefront correction, coronagraphic performance, and resulting science metrics.

APPLICATIONS

by Carlos M. Correia

Adaptive optics performance simulations. Evaluation of Strehl ratio and residual wavefront error. Performance analysis under different atmospheric conditions. Comparison between analytical and simplified numerical approaches. Scientific plotting and interpretation of PCS performance metrics.

MAIN PROGRESSION STEPS

- `Weeks 1-2:` Introduction to PCS, ELT instrumentation, and adaptive optics.
- `Weeks 3-4:` Training on TipTop and analytical prediction methods.
- `Weeks 5-7:` Performance studies and observing scenario analysis.
- `Weeks 8-9:` Result interpretation and preparation of final report.

EVALUATION

- `Theory grade [30%]`
  Comprehension of theoretical background as part of the written report.
- `Practice grade [30%]`
  [20%]: Project development, progress, analysis, and conclusions, as detailed in the report.
  [10%]: Initiative, pro-activity, teamwork.
- `Defense grade [40%]`
  - Oral and slides quality
  - Context
  - Project / Personal work
  - Answers to questions

BIBLIOGRAPHY & RESOURCES

noindent

- Neichel et al, "TipTop: toward a single tool for all ELT instrument's PSF prediction," Proc. SPIE 13097, Adaptive Optics Systems IX, 130972Y (27 August 2024)
- Kasper, et al "PCS — A Roadmap for Exoearth Imaging with the ELT" The Messenger 182 (March 2021): 38–43.

CONTACT

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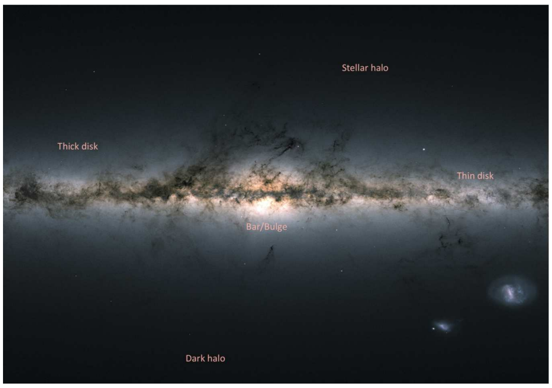
On the evolutionary history of the Milky Way and its building blocks



SUMMARY.
How galaxies form and evolve is one of the most important open questions in astronomy. There is evidence that galaxies are formed hierarchically, with low-mass galaxies merging over cosmic time and forming more massive systems. With the advent of large surveys such as Gaia and APOGEE, thousand of stars that were likely born in dwarf galaxies and later accreted to the Milky Way (MW) were found. However, the detailed mass assembly of the Milky Way as well as the evolutionary histories of its building blocks are still unknown. In this METEOR, we will explore the properties of a sample of stars which likely were accreted to the Milky Way in the past, deriving their chemical compositions and dynamical properties, in order to better understand the evolutionary history of the Milky Way and its building blocks.

OBJECTIVES

- **Knowledge**: The student will learn about how stellar atmospheric properties (e.g. effective temperature, surface gravity, metallicity and elemental abundances) affect the spectrum of a star, how to derive these properties from real stellar spectra obtained using one of the largest telescopes in the world (Clay Telescope at Las Campanas Observatory, Chile) and how these properties are used to understand the history of the Milky Way.
- **Skills**: The student will learn basics of stellar spectroscopic analysis, manipulation and analysis of large datasets, statistical methods and quality assessment of large datasets, and communication and collaboration within an international research group.

INSTITUTE

- Uppsala University, Uppsala, Sweden (Website).
- Box 256, SE-751 05 Uppsala, SWEDEN

THEORY

In this METEOR, the topics that will be covered will be:

- Optical stellar spectroscopy.
- Galactic chemical evolution.
- Milky Way assembly history.
- Large dataset statistical analysis.

APPLICATIONS

The student will work with a library of high-resolution spectra of over 150 metal-poor stars observed using the Mike Spectrograph at Clay Telescope at Las Campanas Observatory in Chile. These stars were chosen to represent the building blocks of the Milky Way. In this project, the student will develop relevant skills to execute Galactic Archaeology studies and also contribute to a detailed study on the dwarf galaxies that merged with the Milky Way in the past, connecting the chemical patterns of stars to the evolution of disrupted dwarf galaxies and the Milky Way's mass assembly history.

MAIN PROGRESSION STEPS

- Step 01: Learn how chemical abundances and dynamical properties of stars can unveil information about the evolution of the Milky Way and its building blocks.
- Step 02: Investigate a sample of metal-poor stars and understand their possible origins according to their orbital properties using Gaia survey data.
- Step 03: Learn how stellar atmospheric parameters and elemental abundances are calculated from stellar spectra.
- Step 04: Develop a pipeline to calculate stellar parameters and chemical abundances of a sample of metal-poor stars and analyze their findings in the context of Galactic Archaeology.
- Step 05: Document their findings, prepare a written report and give an oral presentation to be delivered to the Stellar Elemental Abundances group at the end of their stay.

EVALUATION

- Theory grade [30%]
  - Written report
- Practice grade [30%]
  - Participation in Stellar Elemental Abundances meetings (30%): which will include a presentation of their results.
  - Project (70%): initiative, progress, analysis.
- Defense grade [40%]
  - Oral and slides quality
  - Context
  - Project / Personal work
  - Answers to questions

BIBLIOGRAPHY & RESOURCES

- Freeman & Bland-Hawthorn., 2002, Annual Review of Astronomy and Astrophysics, v. 40, n. 1, p. 487-537.
- Helmi, 2020, Annual Review of Astronomy and Astrophysics, v. 58, n. 1, p. 205-256.

CONTACT

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Understanding the interaction of bars and spirals

SUMMARY.

More than half of all spiral galaxies, including our own Milky Way, host bars. This METEOR will seek to understand one of the least understood aspects of bars, which is their interaction with spirals. This project will use numerical simulations to explore how bars and spirals interact, with a goal of providing diagnostics of their co-evolution that can be used in future studies. The results of the project will have applications to several current large surveys, including from ESA's *Euclid* satellite, and ground-based surveys such as REDWAY.

OBJECTIVES

- Students will learn about the dynamics of bars and of spirals. They will explore how their interactions can be observed in the Milky Way, setting the stage for applications to REDWAY data.
- Students will develop skills in using simulations to answer detailed questions about the evolution of galaxies. They will also learn how to project simulations into the space of Milky Way observables, to provide predictions for future observations.

INSTITUTE

- University of Lancashire
- https://www.lancashire.ac.uk/
- Preston, United Kingdom

THEORY

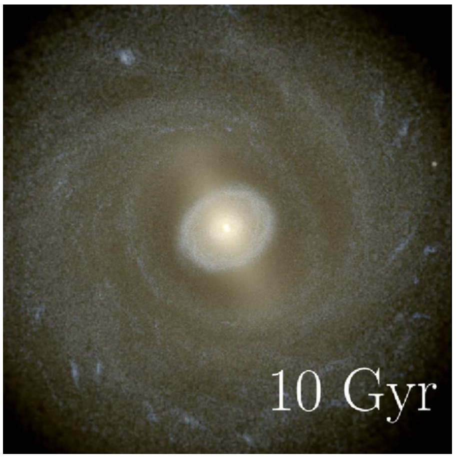
by Victor P. Debattista

Bars in galaxies are very common in the nearby universe and have been found to already be present in galaxies as early as redshift $z \sim 4$. Bars drive evolution within the galaxy by transferring angular momentum from the bar to stars further out, and to the dark matter halo. The effect of the bar on the evolution of galaxies is amplified by the presence of spiral arms, which comprise density waves travelling through the stellar disc. At the ends of bars, the spirals often appear to be connected to the bar, giving the impression that the bar is driving the spirals. But in general spirals and bars rotate with different angular frequencies. Instead, what seems to happen is that spirals repeatedly detach and re-attach to the ends of the bar as the two rotate relative to each other.

While this behaviour has been known for some time, what this means for the velocities of stars, star formation and stellar chemistry is not known. This project will use high time-resolution simulations to follow the motions of stars and gas, and the properties of star formation at the interface of bars and spirals to understand their interaction better. Results of this work can form the basis of followup work in either the Milky Way or external galaxies to confirm that this complex behaviour is taking place.

APPLICATIONS

by Victor P. Debattista



Students will first follow the evolution of a bar and spirals in a simulation, such as the one above, tracing their attachments and detachments. The students will then measure the kinematics of gas and stars, the star formation rate, and the chemistry of new stars. These properties will then be stacked across time as a function of the relative state of the bar and spirals. In the last step the observables will be viewed as in the Milky Way. This will permit future data, from the REDWAY survey using the newly built MOONS instrument for the VLT, to unravel the interplay between bars and spirals.

MAIN PROGRESSION STEPS

- Weeks 1-9: Follow course in Galaxies, if desired
- Week 1: Understanding Python code for simulation analysis
- Week 2: Preliminary analysis of simulations
- Weeks 3-9: Project work

EVALUATION

- Theory grade [30%]
  - Oral presenation of results (80%): Weekly
  - Presentation of an article (20%): critical spirit
- Practice grade [30%]
  - Project (80%): initiative, progress, and applications
  - Code development (20%): clear and reusable code
- Defense grade [40%]
  - Oral and slides quality
  - Context
  - Project / Personal work
  - Answers to questions

BIBLIOGRAPHY & RESOURCES

- Sellwood & Sparke 1988
- Ardèvol et al. 2026

CONTACT

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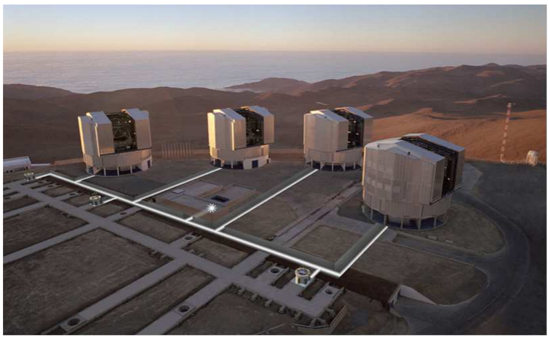
☎ +44 1772 893568
✉ vpdebattista@gmail.com

Exoplanet science with nulling interferometry



SUMMARY.
This METEOR project introduces students to the field of high-contrast interferometry, with a particular focus on nulling techniques for the detection and characterization of exoplanets. Students will explore the physical and instrumental limitations affecting ground-based observations, including atmospheric turbulence, optical aberrations, and operational constraints. The project combines theoretical concepts, numerical simulations, and data analysis using state-of-the-art tools such as SCIFYSim and the GRIP nulling pipeline. Students will gain hands-on experience in modelling interferometric instruments, reducing realistic datasets, and linking instrumental performance to scientific outcomes.

SCIENTIFIC CONTEXT

This project is directly relevant to current challenges in exoplanet detection and characterization. High-contrast interferometry is a key technique for detecting faint companions and studying circumstellar environments. The methods explored in this project are applicable to current and future facilities, including VLTI instruments and concepts for future space missions. Students will gain insight into how instrumental design choices translate into scientific performance and discovery potential.

OBJECTIVES

The main goal of this METEOR is for students to become familiar with the field of high-contrast interferometry and its application to exoplanet science. More specifically, students will:

- Understand the principles of high-contrast imaging and interferometry, including nulling techniques
- Identify the main limitations to performance, such as atmospheric turbulence, wavefront errors, and instrumental constraints
- Learn how to simulate the behaviour of a ground-based high-contrast interferometer
- Use simulations to optimise instrument design and observing strategies
- Become familiar with nulling data reduction using dedicated pipelines (e.g. GRIP)
- Develop skills in scientific programming, data analysis, and interpretation

INSTITUTE

- Institute of Astronomy (KU Leuven)
- Celestijnenlaan 200D, 3001 Leuven

THEORY

by Denis Defrère

Students will be introduced to the fundamental concepts of high-contrast interferometry. This includes the basics of optical interferometry, the principles of nulling interferometry, and the challenges associated with the star-planet contrast problem. The course will cover the impact of atmospheric turbulence (phase noise, piston errors), optical aberrations, and instrumental limitations on performance. Students will also be introduced to current and future interferometric instruments, and to the role of simulations in instrument design and science preparation.

by Thomas Mattheussen

Students will be introduced to interferometric observations and to nulling data reduction techniques. They will learn how to use dedicated software such as the GRIP pipeline, including calibration strategies, bias correction, and the extraction of astrophysical signals from noisy data.

APPLICATIONS

by Denis Defrère

The practical work will consist of a hands-on project combining simulation and data analysis.Students will first use simulation tools (e.g. SCIFYSim) to model the behaviour of a ground-based interferometric instrument, including the impact of instrumental parameters and noise sources (e.g. phase errors, transmission maps, atmospheric perturbations).They will then apply the GRIP nulling data reduction pipeline to simulated (and optionally real) datasets. This will include calibration, estimation of null depths, and error analysis. Students will develop diagnostic tools to evaluate instrument performance, compare simulated and reduced data, and investigate detection limits. Finally, they will interpret their results in a scientific context, assessing the detectability of exoplanets or circumstellar material and proposing possible optimisations of the instrument or observing strategy.

MAIN PROGRESSION STEPS

- Weeks 1-2: theory, getting familiar with simulation tools
- Weeks 3-4: first data reduction and results
- Weeks 5-6: development of diagnostic tools and analysis of results
- Weeks 7-8: data reduction optimization
- Week 9: project presentation

EVALUATION

- Theory grade [30%] The theory part will be evaluated based on the written report.
- Practice grade [30%] The practical grade will be based on the output of the project, i.e., through the written report.
- Defense grade [40%]
  - Oral and slides quality
  - Context
  - Project / Personal work
  - Answers to questions

BIBLIOGRAPHY & RESOURCES

- Laugier et al. 2023
- SCIFYSim
- GRIP

CONTACT

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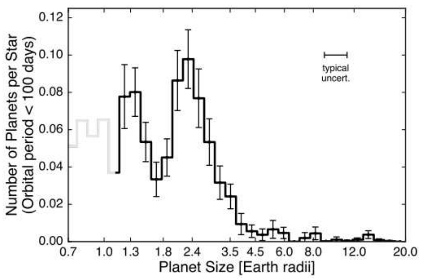
Chemical evolution of sub-Neptunes



SUMMARY.

This METEOR project will teach you about interior modeling of planets, evolution modeling as well as atmospheric loss. You will improve the calculation of sub-Neptune evolutions and explore their evolution tracks. We aim to understand how sub-Neptunes atmospheres change chemically as we approach those sub-Neptunes in the radius valley (see Figure).

OBJECTIVES

- *What will student learn?: learn about sub-Neptune population, their atmosphere diversity and how we anticipate their evolution over time, learn about fractionated mass-loss*
- *What will students learn to do?: run numerical simulations, use python, use Fortran-wrapped codes, interface existing codes*

INSTITUTE

ETH Zurich, Departement of Physics, Honggerberg Zurich, Switzerland

- ETH Zurich
- Institute URL
- Wolfgang-Pauli Strasse 27, Zurich, Switzerland

THEORY

Sub-Neptunes cool and contract over time. After formation, they can host deep magma oceans that can easily last over Gyrs. Magma oceans inherently interact with gases from overlying envelopes. There are chemical interactions and compositional coupling (i.e., the dissolution of gases). The extent of those chemical reactions are unknown, but we can map out end-members of assuming either no chemistry or full global chemical equilibrium states. As sub-Neptunes cool, their equilibrium states also shift and thus they chemically evolve. At the same time, sub-Neptunes are shaped by photoevaporative mass loss, which can preferentially remove light atoms. In this project all three major processes will be combined: thermal and chemical evolution and fractionated mass loss to space. Our group has developed models to account for all aspects individually. The combination of some of the processes are already done (Steinmeyer et al. 2026, Valatsou et al. 2026).The combination of all three processes and the exploration of resulting diversity of sub-Neptunes is at the heart of this project.

APPLICATIONS

You will explore the diversity of sub-Neptunes as they approach the radius valley. Existing models predict a clear trend of higher oxidation states of atmospheres (Cherubim et al. 2025), however they generally do not account for interior-atmosphere coupling and the replenishment of volatiles from the deep interior. Here, you will combine interior-atmosphere coupled models with fractionated mass loss models in an evolution framework. All individual components are readily developed, however not all aspects are fully coupled in the framework. You will first couple mass loss to the thermo-chemical-evolution framework and than explore how atmosphere composition of sub-Neptunes changes as they approach the radius valley and eventually become super-Earths.

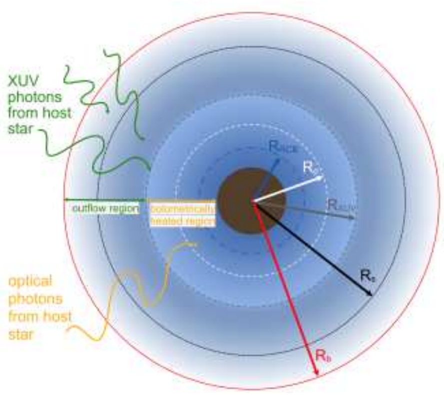


Illustration of BOREAS - the fractionated mass loss model from Valatsou et al. (2026), recently expanded to C-H-N-O-S species.

MAIN PROGRESSION STEPS

- Week 1: literate study
- Weeks 2-8: project & report writing
- Weeks 9: finishing report & talk

EVALUATION

Your work will be evaluated based on your progress during the project, your written report to present and summarize your results, and the final oral defense, in which you give a talk about your project and answer questions to the audience.

- Practice grade [60%]
  - Report (50%): writing structure, clarity of thought, and presentation of results
  - Project (50%): initiative, progress, analysis
- Defense grade [40%]
  - Oral and slides quality
  - Context
  - Project / Personal work
  - Answers to questions

BIBLIOGRAPHY & RESOURCES

- Group website
- Prof. Dorn website

CONTACT

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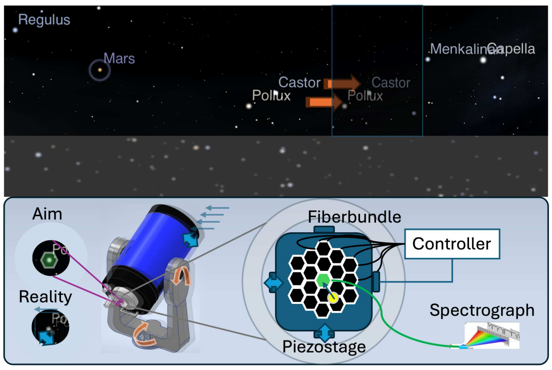
Telescope-Fiber-Spectrograph interface for Spectroscopy on bright Stars



SUMMARY.

Fiber-fed spectrographs are widely used in stellar astrophysics due to their ability to provide stable and repeatable illumination of the spectrographs slit. A compact fiber-fed interface intended for seeing-limited stellar spectroscopy with a ground-based telescope has been developed but needs further testing.
The system is designed to couple a seeing-broadened stellar image into a multimode optical fiber using a mechanically stable and optically robust assembly. A 19-fiber hexagonal bundle was developed, consisting of a central science fiber surrounded by identical fibers used for alignment feedback. To maintain stable coupling under atmospheric and mechanical disturbances, the fiber bundle is mounted on a bi-axial piezoelectric positioning stage. The logic ensures that for small-scale corrections, the piezo-stage moves the fiber bundle, while for large-scale drifts, the telescope mount is adjusted. This "dual-stage" approach keeps the science fiber aligned with the target star throughout the exposure

OBJECTIVES

What will student learn?

- Astrophysical Instrumentation
- Theory of seeing and its effect on fiber-coupling
- Theory of fiber-coupled spectrographs

What will students learn to do?

- Set up a fiber-coupling
- Stabilize the coupling of starlight into the fiber
- Coupling to a spectrograph
- Analyze spectra generated with the telescope-fiber-spectrograph setup

INSTITUTE

University of Applied sciences Emden / Leer
Institute for Lasers and Optics
https://ILO-Emden.de
Constantiaplatz 4, 26725 Emden, Germany

The working group develops components for calibration of (astrophysical) spectrographs. Prof. Huke is responsible for the design and development of the Calibration Unit(s) for ANDES, the Armazones high Dispersion Echelle Spectrograph.

THEORY

by Philipp Huke

Light guiding with fibers seems to be a convenient choice for modern astrospectroscopy. Large telescopes (ELT, VLT, KECK to be named a few) sport fiber-fed spectrographs like ESPRESSO, HIRES and in the future ANDES. CARMENES is also an example. To build a fiberlink requires a detailed knowledge about light (coherence) and light guiding, telescopes, spectrographs and their targeted sciences..

APPLICATIONS

by Philipp Huke

We will work on
- Coupling light with different étendu into fibers
- Light-guiding
- Observation of modal noise
- Using a small-scale (10") telescope to couple starlight into fibers
- Spectroscopic measurements.

MAIN PROGRESSION STEPS

- **Week 1-3**: courses Light Guiding & Advanced Metrology, Introduction into the laboratories, simulation software, starting the project
- **Weeks 4-9**: project

EVALUATION

- **Theory grade [30%]**
  - Simulation project (70%)
  - Presentation of an article (30%)
- **Practice grade [30%]**
  - Exercises (20%)
  - Project (80%)
- **Defense grade [40%]**
  - Oral and slides quality
  - Context
  - Project / Personal work
  - Answers to questions

BIBLIOGRAPHY & RESOURCES

Any reference or web page that students can read to have a better idea of the topic

- SPIE Telescope & Instruments 2026: Watch-out for the respective publication (we can show it to you after the conference

CONTACT

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Photometric analysis of Near-Earth Asteroids using TRAPPIST telescopes


Science Photo Library - ANDRZEJ WOJCICKI // Getty Images

SUMMARY.
Near-Earth Asteroids (NEAs) constitute a complex dynamical population whose proximity to Earth ($\leq$ 1.3 au) necessitates rigorous characterization for both solar system evolution studies and impact hazard assessment. This METEOR explores the rotational physics and morphology of NEAs using time-series photometry from the TRAPPIST telescope network. The student will master CCD signal processing and differential photometry to quantify periodic flux variations caused by the rotation of non-spherical bodies. By applying rotational dynamics and mathematical light-curve inversion, the aim will be to derive fundamental physical parameters including rotation periods, 3D shape models, and spin-axis orientations.

OBJECTIVES

- **Knowledge**, Observe and analyze light curves using the TRAPPIST telescopes, derive fundamental physical parameters including rotation periods, 3D shape models, and spin-axis orientations of NEAs.
- **Skills** Preparing observations, data calibration, how to analyse them, and how to interpret them.

INSTITUTE

The work will be done at the STAR Institute of the University of Liège and the TRAPPIST team.

- STAR Institute
  University of Liège
  Allée du 6 Août 19C,
  B-4000 Liège 1, Belgium

APPLICATIONS

by Emmanuel Jehin

The TRAPPIST 0.6m telescopes installed at the la Silla observatory in Chile in 2010 and in Morocco in 2016 by our team are dedicated to the research and the study of exoplanets in transit and the study of the small bodies of the Solar System (comets and asteroids) (Jehin et al. 2011). The main goal of this METEOR is the physical characterization of NEAs through the analysis of new and/or archived observations obtained with the TRAPPIST telescopes.

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

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

EVALUATION

- Theory grade [30%]
  - Student will be asked to write a report and prepare an oral presentation, followed with questions.
- Practice grade [30%]
- Defense grade [40%]
  - Oral and slides quality
  - Context
  - Project / Personal work
  - Answers to questions

BIBLIOGRAPHY & RESOURCES

- Jehin et al. (2011)
- https://www.cometa.uliege.be/
- https://www.trappist.uliege.be/

CONTACT

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Chemical composition of comets atmospheres using the TRAPPIST telescopes

SUMMARY.
Comets are among the best preserved specimens of the primitive solar nebula. This status of "time capsules" gives them a unique role in understanding the origins of the solar system. The success of the Rosetta space mission was very important and is changing our knowledge about comets. But it showed also that observations from the ground continue to be important: they make it possible to supplement the data in situ by obtaining information on larger scales of the coma and tails, and for a much larger number of comets, which is necessary to extrapolate the results to the entire cometary population. The link between the composition of comets and their dynamic history must still be clarified and a complete comet classification is still missing.

OBJECTIVES

- **Knowledge**, Observing and analyzing the coma of bright comets using the TRAPPIST telescopes, focusing on gas and dust emissions and in particular the gas production rate calculations.
- **Skills** Preparing observations, data calibration, how to analyse them, and how to interpret them.

INSTITUTE

The work will be done in the STAR Institute of the University of Liège and the TRAPPIST team.

- STAR Institute
  University of Liège
  Allée du 6 Août 19C,
  B-4000 Liège 1, Belgium

APPLICATIONS

by Emmanuel Jehin

We propose the observation and analysis of the coma of two or three bright comets with the TRAPPIST telescopes network (Jehin el al. 2011). These robotic telescopes installed by our team in Chile (in 2010) and in Morocco (in 2016) are equipped with narrow band filters to isolate the emissions of different gases and dust contained in the atmosphere of comets. The student will have to prepare the observations, make plans to send to the robotic telescopes, calibrate the data and calculate the production rates of the different gases using the so-called Haser model (1957). The necessary tools for this kind of measures have already been developed in our team. The student will have to become familiar with the various techniques, adapt and improve if necessary the reduction procedures and scripts and run the models with our help. The results might lead to the publication of a short article with our group.

EVALUATION

- Theory grade [30%]
  - Student will be asked to write a report and prepare an oral presentation, followed with questions.
- Practice grade [30%]
- Defense grade [40%]
  - Oral and slides quality
  - Context
  - Project / Personal work
  - Answers to questions

BIBLIOGRAPHY & RESOURCES

- https://www.cometa.uliege.be/
- https://www.trappist.uliege.be/
- Jehin et al. (2011)

CONTACT

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Optical polarization analysis of supermassive black holes

SUMMARY.
Optical polarimetry of supermassive black holes provides an invaluable diagnostic for the geometry and physical mechanisms driving accretion flows, jets, and the acceleration of high-energy particles. Astrophysicists from the Skinakas observatory have pioneered the field with observations using RoboPol - a unique 4-channel polarimeter. This METEOR provides the unique opportunity to get hands-on experience in optical polarimetric observations and data analysis within the framework of the Black hOle Optical polarization TimEdomain Survey - BOOTES. BOOTES aims to understand particle acceleration in astrophysical jets through high-cadence observations of blazars and uncover the mechanism of accretion disk formation through observations of tidal disruption events.

OBJECTIVES

The student will learn the basics of polarimetry and optical polarimetric data analysis, basics of observing planning, and data acquisition.

INSTITUTE

The METEOR will take place at the Institute of Astrophysics and the Skinakas observatory located in the island of Crete in Greece.

- Institute of Astrophysics
- https://www.ia.forth.gr/
- N. Plastira 100, Vassilika Vouton, Heraklion, Crete, Greece
- Skinakas Observatory

THEORY

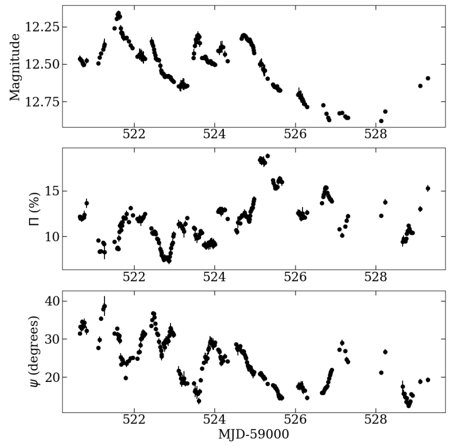
by Yannis Liodakis

Supermassive black holes create beautiful structures like accretion disks and jets through magnetized plasma. Polarimetry allows us to trace the magnetic fields embedded in the plasma and trace their evolution with time. The student will be acquainted with the physics of accretion disks and jets, and how polarization observations can help us differentiate between competing models. They will also be acquainted to the basics of polarimetry and optical polarimetric data analysis.

APPLICATIONS

by Yannis Liodakis

The student will be working on the data analysis of optical polarization observations of blazars and tidal disruption events from RoboPol at the 1.3m telescope. They will be acquainted with the data calibration, analysis as well as the survey strategy, monitoring program, data acquisition, and telescope operations.



High-cadence optical polarization observations of blazar BL Lacertae. The observations we taken using 15 telescopes across the world (incl. Skinakas) to test particle acceleration in black hole jets. The top panel shows the evolution of optical brightness over time. The middle panel shows the evolution of the polarization degree, and the bottom panel the evolution of the polarization angle.

MAIN PROGRESSION STEPS

- Tier 1: Theory of polarimetry and black hole physics
- Tier 2: Optical polarization data analysis
- Tier 3: Interpretation of the results and comparison to theoretical models

EVALUATION

- Theory grade [20%]
  - Presentation of an article at the journal club (100%).
- Practice grade [40%]
  - Project (100%): initiative, understanding, overall data analysis performance
- Defense grade [40%]
  - Oral and slides quality
  - Context
  - Project / Personal work
  - Answers to questions

BIBLIOGRAPHY & RESOURCES

- Van Velzen et al., 2020
- Gezari 2021
- Blandford et al., 2019
- Hovatta & Lindfors 2019
- King et al., 2014
- Ramaprakash et al., 2019
- Blinov & Pavlidou 2019
- Liodakis et al., 2023
- Liodakis et al., 2024
- Stokes parameters
- RoboPol
- BOOTES

CONTACT

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Orbital parameters of binary stars

SUMMARY.

Stars like company and, unlike the Sun, half of the stars in the Milky Way have stellar companions which could significantly affect the physico-chemical properties of stellar evolution. Binarity allows to explain many astrophysical observations thanks to interactions between stellar components, such as type Ia supernovae or chemically peculiar stars. It also allows the determination of stellar masses, radii and luminosities, much more precisely than for single stars. Among binary stars, Spectroscopic Binaries (SB) are those that are detected by spectrography. In this METEOR the student will familiarise him/herself with the Radial Velocities (RV) method widely used for orbital characterization.

OBJECTIVES

The main objective is to introduce the student to the modeling of spectroscopic binaries by means of the radial velocities method to derive the orbital parameters (period, eccentricity, RV amplitude, etc.) of close binary stellar systems.

INSTITUTE

The METEOR will take place at Université Libre de Bruxelles, on the 'La Plaine' campus, in the Institut d'Astronomie et d'Astrophysique located at Bd du Triomphe, 2, 1050, Brussels. Accomodation can be find here or here.

THEORY

by Thibault Merle

The gravitational two-body problem – Observing binaries (with focus on spectroscopic binaries and the method of radial velocities) – Fundamental parameters derived from binaries

APPLICATIONS

by Thibault Merle

The project will consist in deriving orbital solutions of spectroscopic binaries with 2 visible components (SB2). The student will familiarize him/herself with data reduction and analysis of high resolution spectra for some SB2 obtained with the HERMES and HRS spectrographs at Mercator (North hemisphere) and SALT (South hemisphere) telescopes. He/she will determine the RV of each component by computing cross-correlation functions of spectra with templates and compute orbital solutions for inner and outer pairs. Comparison of orbital parameters with other SB2 may also be performed.

MAIN PROGRESSION STEPS

- **Tier 1**: theory and exercices
- **Tier 2**: research project
- **Tier 3**: project+oral preparation

EVALUATION

The student's production will be evaluated according to the completion of intermediate goals defined during the development of the project.

- **Theory grade [30%]**

  The student will solve about 8 practical exercises related to the theoretical parts studied.
- **Practice grade [30%]**

  The student will write a report of the project in a research article style and will be evaluated on its initiative, progress, analysis and critical assessement of his/her results.
- **Defense grade [40%]**
  - Oral and slides quality
  - Context
  - Project / Personal work
  - Answers to questions

BIBLIOGRAPHY & RESOURCES

- Spectroscopic binary star simulator
- Pourbaix et al., A&AS (1998)
- Merle, Bull.SteRo.Sc. Liège (2023)

CONTACT

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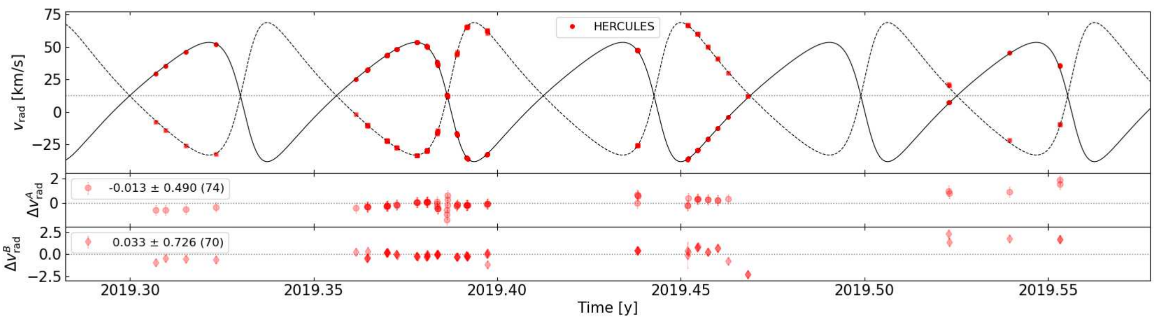


Example of the RV curves fitting of an SB2 (solid and dashed black lines).
Red points are the measured RVs.
Lower panels show the residuals (observed − calculated).

TESS observations of intermediate-mass stars

SUMMARY.

Intermediate-mass stars are fascinating objects: they spin rapidly, which flattens stars at the equator, induces internal mixing, and generally makes observations hard to interpret. They also often harbour oscillations, whose analysis is challenging but allows us to infer their parameters and open a window on their internal structure.

The stay will include lectures on stellar structure, evolution and oscillations, and training on frequency analysis tools. This will allow the student to analyze TESS observations for a sample of intermediate-mass pulsating stars at different rotation rates. Starting from luminosity variations measured from space, they will put together a strategy to extract oscillation frequencies accurately and derive stellar parameters for at least a few stars in the sample. By comparing their results with theoretical expectations, Gaia parameters, and other stars from the literature, they will asses the impact of rapid rotation and discuss sources of uncertainty.

OBJECTIVES

- The student will learn the evolution of stars, as well as strategies to characterize the parameters and structures of stars, with a focus on their rotation.
- The project consists in analyzing TESS data, extracting the frequencies of the oscillations propagating for stars in our sample, link oscillation properties with stellar parameters and compare these with Gaia estimates.

INSTITUTE

- Group of stellar evolution and nucleosynthesis
- Theoretical and Cosmos physics department, Universidad de Granada (Spain)
- Edificio Mecenas, campus de Fuentenueva, Granada, Spain

THEORY

by G. Mirouh, A. García Hernández

This METEOR will complement the lectures in Nice by introducing advanced aspects of stellar physics, such as the impact of rotation on the stellar structure and evolution, and asteroseismology [1]. Data analysis techniques such as frequency extraction and pattern search will also be at the core of the lectures and project, with a tutorial for the Granada-developed tool MultiModes [2].

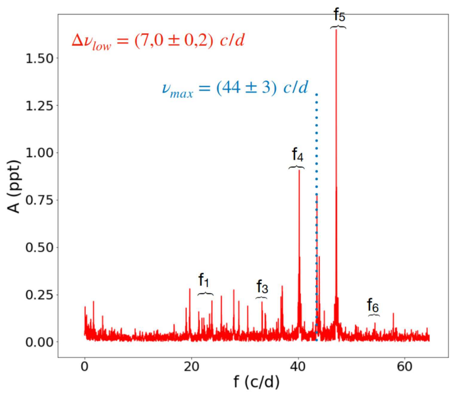
APPLICATIONS

by G. Mirouh, A. García Hernández

This METEOR consists in the study of a sample of intermediate-mass stars rotating at different speeds and observed by the TESS mission.

Frequencies will be extracted from photometric time series with MultiModes, the regular patterns they follow will be derived and related to stellar parameters through well-known scaling relations [3]. The parameters thus inferred will be compared with Gaia estimates, compared with similar targets, and used to assess the impact of rotation.

We expect the student to offer a modelling strategy, identify sources of uncertainties, and apply it to at least a few stars in the sample. Applications to more stars will obviously be valued positively.



Oscillation spectrum obtained using [2] for a TESS target, along with mode identification (in black) and seismic indicators (in red and blue).

MAIN PROGRESSION STEPS

- `Week 1-2`: Stellar physics and asteroseismology courses.
- `Week 3-4`: Frequency extraction techniques and exercices.
- `Weeks 5-9`: Project.

EVALUATION

- `Theory grade [30%]`
  - Written exam: stellar physics (50%)
  - Presentation of an article (50%)
- `Practice grade [30%]`
  - Practical exercice: frequency extraction and discussion (30%)
  - Project (70%)
- `Defense grade [40%]`
  - Oral and slides quality
  - Context
  - Project / Personal work
  - Answers to questions

BIBLIOGRAPHY & RESOURCES

- [1] Mirouh G. M., 2022, FrASS, 9, 2296
- [2] Pamos Ortega D. et al., 2022, MNRAS, 513, 374
- [3] García Hernández A. et al., 2015, ApJL, 811, 29

CONTACT

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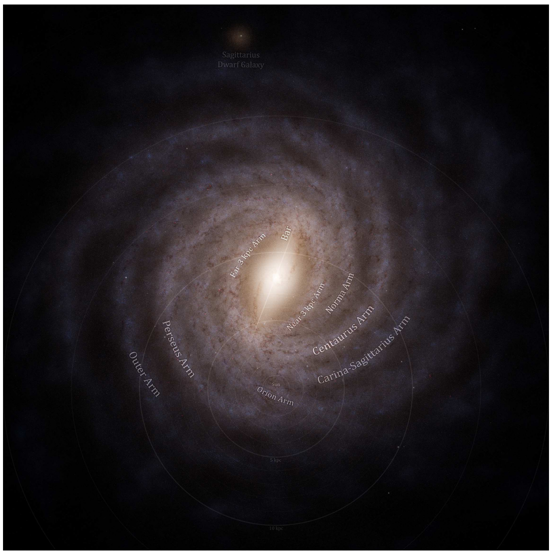
Young Stellar population in the Milky Way



SUMMARY.
Understanding the formation of stellar populations in the Milky Way is fundamental to address some of the main open questions in contemporary astronomy: from the origin of the solar system to the physical processes driving the evolution of galaxies. In the last decade the field has been revolutionized by the *Gaia* space mission and several ground-based spectroscopic surveys. In this METEOR hosted at the Arcetri Observatory, we will review the properties of young stars in the Milky Way and the spectroscopic techniques used to analyse them. We will introduce the student to the main galactic surveys and teach them how analyse the spectra of young stars and mine large data catalogs.
The figure on the left shows an artistic impression of the Milky Way based on data from the *Gaia* space mission (Credit: ESA/Gaia/DPAC, Stefan Payne-Wardenaar)

OBJECTIVES

- *The student will learn the basis of the pre-main sequence evolution and the formation and evolution of young stellar population as well as the main open issues on this topic.*
- *The student will learn the properties of the main past and current stellar galactic survey (e.g., Gaia, Gaia-ESO, APOGEE, 4MOST, WEAVE) and the main techniques for data mining.*
- *The student will learn spectroscopic techniques used to analyse spectra of young stars.*

INSTITUTE

- INAF-Osservatorio Astrofisico di Arcetri
- www.arcetri.inaf.it
- Largo E. Fermi, 50125, Firenze, Italy

THEORY

by G.G. Sacco

Theoretical lessons will be divided in two parts: In the first part, we will discuss the properties of young stars and young stellar populations, while in the second part, we will discuss main techniques used to analyse spectroscopic data.

SURVEYS AND DATA MINING

by G.G. Sacco

We will discuss in details the Gaia mission and its catalogue as well as recent and future ground based spectroscopic surveys. Then, we will describe the main techniques to retrieve data from public catalogue and analyse them.

APPLICATIONS

by G.G. Sacco

The supervisors will design a research project that will be carried out using data from the large galactic surveys and will allow the student to delve in one of the open issues in galactic astronomy discussed during the theory lessons.

MAIN PROGRESSION STEPS

- Week 1: Lessons on Theory and bibliographic research.
- Week 2-3: Lessons on Surveys, data mining and spectroscopy
- Week 4: Oral presentaion and discussion of a research paper
- Week 5-8: Research project
- Week 9: Final exam with presentation of the research project

EVALUATION

The evaluation will be divided in two steps. After the first four weeks the student will give an oral presentations based on one or more papers on the topics presented in the first weeks, while during the last weeks he or she will prepare a presentation on the research project.

- Theory grade [30%]
  - Literature (70%): Oral exam on a research paper after the first four weeks
  - Research project (30%): Discussion of the research project in a broader scientific context
- Practice grade [30%]
  - Data mining (50%): Capability to select and retrieve data from archives of large surveys
  - Data analysis (50%): Data analysis capabilities
- Defense grade [40%]
  - Oral and slides quality
  - Context
  - Project / Personal work
  - Answers to questions

BIBLIOGRAPHY & RESOURCES

- Sacco et al. 2023
- Magrini et al. 2023
- Gaia Archive
- The 4MOST spectrograph

CONTACT

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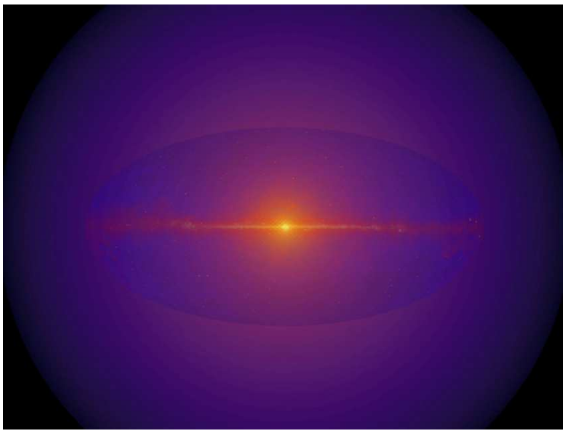
Hunting for dark matter with gamma rays



SUMMARY.
The nature of dark matter (DM) in the Universe is one of the greatest mysteries of our time, and its discovery is of utmost importance. While DM has not been directly detected in laboratories, its gravitational effects are evident at all astrophysical scales. Among the leading DM candidates, weakly interacting massive particles (WIMPs) are the most extensively studied. Indirect detection seeks to identify WIMP annihilation or decay products, such as gamma rays, neutrinos, or antimatter. In this project, the student will get an introductory yet complete view of state-of-the-art DM research in gamma rays. (S)he will i) compute predicted gamma-ray DM signals for a promising astrophysical source; ii) learn to download and analyze gamma-ray data collected by the NASA's Fermi satellite from that sky region; iii) search for DM signals in the Fermi data and, if absent, use it to constrain the DM particle's nature.

OBJECTIVES

- **Knowledge:** astroparticle physics; state-of-the-art DM research; theoretical modeling of astrophysical DM distributions; computation of DM-induced photon fluxes; γ-ray emission/absorption mechanisms in the Universe; γ-ray detection from space.
- **Skills:** Use of *CLUMPY* for DM modeling and DM-induced photon flux computations; retrieval and analysis of γ-ray data with *Fermipy*; standard likelihood data analyses for the search of DM signals; constraints on the DM parameter space if no signal.

INSTITUTE

- Instituto de Física Teórica (IFT UAM-CSIC) & Universidad Autónoma de Madrid (UAM).
- IFT URL & UAM URL.
- C/ Nicolás Cabrera 13-15, Campus Cantoblanco, Madrid, SPAIN.

THEORY

by Miguel Á. Sánchez-Conde

The student will review the DM problem, its observational evidence, and the most used recipes to model DM distributions. S(he) will get familiar with the WIMP as the preferred DM particle candidate and its expected standard model signatures, with emphasis in WIMP-induced γ-ray signals [1,2]. For the latter, the student will review γ-ray emission and absorption mechanisms in the Universe, and will get to know the NASA Fermi satellite, the most advanced γ-ray detector currently in operation (see figure below).

Illustration of the NASA Fermi satellite currently in orbit.

APPLICATIONS

by Miguel Á. Sánchez-Conde

The student will use the *CLUMPY* software to model the underlying DM distribution in a promising astrophysical source (to be chosen by the time of the project) and to compute its WIMP-induced γ-ray flux. With these predictions at hand, the *Fermipy* software will be used to analyze actual data collected by the NASA Fermi γ-ray satellite, and to search for DM signals from the source sky direction. Should no signal be detected, already available scripts will be utilized to set constraints on the nature of the DM particle using that information.

MAIN PROGRESSION STEPS

- Weeks 1-2: Lectures on astroparticle physics and DM.
- Weeks 3-4: Project - DM modeling and flux predictions (*CLUMPY*).
- Weeks 5-7: Project - *Fermipy* gamma-ray data analysis.
- Weeks 8-9: Project - Results' interpretation and DM constraints.

EVALUATION

- Theory grade [30%]
  - Oral exam (50%): basic questions on lectures' content.
  - Presentation of an article to the host group (50%): concepts digestion, critical spirit.
- Practice grade [30%]
  - Computing (30%): use of *CLUMPY* and *Fermipy*.
  - Project (70%): initiative, progress, interpretation.
- Defense grade [40%]
  - Oral and slides quality
  - Context
  - Project / Personal work
  - Answers to questions

BIBLIOGRAPHY & RESOURCES

(1) Bertone et al. 2005.
(2) Charles et al. 2016.
(3) Host group webpage.
(4) CLUMPY and Fermipy.

CONTACT

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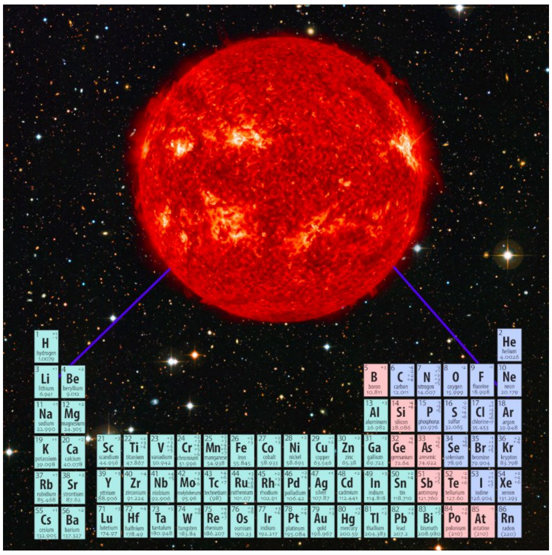
Chemical composition of very metal-poor stars



SUMMARY.
Very metal-poor stars, those that have chemical elements in amounts that are 100 times or less than what is found in the Sun, are among the oldest stars in the Galaxy. Such old stars are fossils that can reveal details about the early stages of the Milky Way formation and evolution. In particular, the chemical elements in some of these extant metal-poor stars may come from a single or from very few nucleosynthetic sources, including the explosion of the first stars to form in the Universe (the so called Population III stars) and mergers of neutron stars. Interestingly, some of these very old stars have been found to be enriched in r-process elements. The rapid neutron capture process (r-process) is a nucleosynthetic mechanism that produces the heaviest elements in the periodic table, but that is still not well understood. In this METEOR, the student will perform the analysis to determine the detailed chemical abundance pattern of a sample of very metal-poor stars candidates of being rich in r-process elements. The results will then be used to investigate the origins of the potential enrichment based on stellar nucleosynthesis models. Gaia data will also be used to determine to which stellar population the stars belong.

OBJECTIVES

- **Knowledge**
  Introduction to the physics of stellar spectra and spectral line formation; fundaments of stellar nucleosynthesis and stellar populations;
- **Skills**
  Practical and critical use of tools for the analysis of high-resolution stellar spectra; use of Gaia data to compute kinematics and stellar orbits; comparison to theoretical models of stellar nucleosynthesis.

INSTITUTE

- Nicolaus Copernicus Astronomical Center, Polish Academy of Sciences
- https://www.camk.edu.pl/en/
- Bartycka 18, Warsaw, Poland
- SAGA (Stellar Abundances and Galactic Archaeology) Team
- Research at the SAGA Team

THEORY

by Rodolfo Smiljanic

- **Stellar spectra**

First, we will have an introduction to the physics of stellar spectra formation, including an overview of continuous opacities, model atmospheres, and the formation of absorption lines. This will include a look into how the overall spectra and selected lines change as a function of stellar parameters and chemical composition.

- **Stellar populations**

Second, we will discuss the different stellar populations of the Milky Way (thin and thick discs, bulge, and halo). We will look into the main differences of their stars in terms of ages, chemical composition, kinematics, and orbits. This will then be contextualized in terms of their most probable histories of chemical enrichment.

APPLICATIONS

by R. Smiljanic and team

The student will learn to use tools for the analysis of stellar spectra and work to determine the chemical composition of a sample of metal-poor stars. The main focus will be on spectral lines of elements heavier than Fe. The resulting abundances will be compared to models of stellar nucleosynthesis. The student will also use Gaia data (proper motions, parallaxes, and radial velocities) to compute stellar orbits and investigate to which Galactic stellar population the stars belong.

MAIN PROGRESSION STEPS

- `Week 1-3`: Lectures on stellar spectra and stellar populations
- `Week 4-8`: Research project
- `Week 9`: Project presentation

EVALUATION

- `Theory grade [30%]`
  - Oral exam (50%): theoretical questions based on reading material
  - Discussion of an article (50%): critical spirit, clarity, answering questions
- `Practice grade [30%]`
  - Project: initiative, progress, analysis
- `Defense grade [40%]`
  - Oral and slides quality
  - Context
  - Project / Personal work
  - Answers to questions

BIBLIOGRAPHY & RESOURCES

- da Silva & Smiljanic 2025
- Giribaldi & Smiljanic 2023
- Bonifacio et al. 2025

CONTACT

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Stars, Transits & Habitability

SUMMARY.
Astrobiology aims to understand the conditions that allow life to exist in the Universe, which makes it essential to study stars and their planets as possible habitats. This project introduces these conditions by learning the key physical and chemical factors that shape planetary systems in our Galaxy. Students will apply theoretical concepts of stellar evolution, planet formation and habitability together with practical analysis of ground-based and space-based NASA TESS light-curve data and stellar spectra from the Molėtai Astronomical Observatory and archives. The work focuses on detecting and modelling planetary transits, determining essential star and planet parameters and evaluating the potential habitability of the studied system. Through this METEOR, students will gain experience in star and planet data analysis and in linking astrophysical measurements with astrobiological interpretation.

OBJECTIVES

- *The student will understand the key concepts of astrobiology, including the Galactic Habitable Zone, planet characterisation, habitability, and the chemical and organic components relevant to life, as well as the main open issues on these topic.*
- *The student will learn to analyse light-curves and stellar spectra to model planetary transits, determine basic system parameters.*

INSTITUTE

- Vilnius University, Faculty of Physics, Institute of Theoretical Physics and Astronomy
- Institute URL
- Saulėtekio av. 3, LT-10257 Vilnius, Lithuania

THEORY

by R. Minkevičiūtė

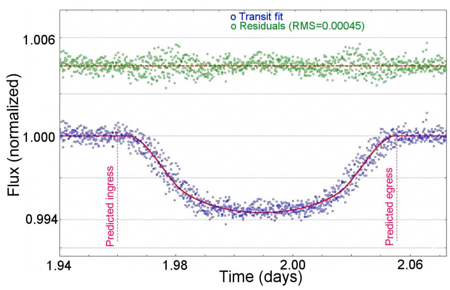
Are we alone in the universe? The question of whether there is life beyond Earth has captivated us for thousands of years. During the METEOR, the student will learn the key theoretical concepts of astrobiology, including star formation, protoplanetary disks, exoplanet detection and characterisation, the habitable zone around stars, and the distribution of chemical elements and organic molecules in the Universe. The theoretical part will also address the geological history of Earth and the origins of life on our planet.

APPLICATIONS

The students will pick a project with a focus on exoplanet transit or on planet-hosting star analysis.

by E. Pakštienė

The student, with guidance from the supervisor, will analyse ground-based and NASA TESS light-curve data to detect and model planetary transit, determine orbital period and planet radius, and combined with stellar data evaluate the potential habitability of the studied system.



Phase-folded light curve of the hot Jupiter HD 201033 b transit, observed with the TESS space telescope in Sector 56 at a 2-minute cadence.

by E. Stonkutė

The student, with guidance from the supervisor, will run a research project based on observational data of a planet-hosting star, using spectra from the Molėtai Astronomical Observatory archive together with Gaia data. From these datasets, the student will determine the stellar parameters and the abundances of key chemical elements (e.g., C, N, O, S, Mg, Si, Fe), as well as the star's mass, age and kinematics.

MAIN PROGRESSION STEPS

- `Week 1-2`: Project introduction
- `Week 1-4`: Lessons & Seminars on Theory
- `Week 3-8`: Research project
- `Week 9`: Final exam with presentation of the research project

EVALUATION

- *`Theory grade [30%]`*
  - *Presentation of an article*
  - *Participation in seminars*
- *`Practice grade [30%]`*
  - *Initiative, progress, analysis*
  - *Oral presentation*
- *`Defense grade [40%]`*
  - *Oral and slides quality*
  - *Context*
  - *Project / Personal work*
  - *Answers to questions*

BIBLIOGRAPHY & RESOURCES

- *Pakštienė et al. 2026*
- *Huber et al. 2022*
- *Stonkutė et al. 2020*
- *NASA Exoplanet Archive*
- *Madhusudhan 2026, "Habitability and biosignatures"*
- *Molėtai Astronomical Observatory*

CONTACT

Edita Stonkutė, Erika Pakštienė & Renata Minkevičiūtė
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The chemical fingerprints of exoplanet-host stars

SUMMARY.

Understanding how planets form and evolve across our Galaxy requires uncovering the link between planets and their host stars. In this project, the student will explore this relationship by investigating how stellar parameters correlate with planetary properties such as mass, radius, multiplicity, and orbital characteristics. The student will gain experience in analyzing high-resolution stellar spectra using a variety of techniques, with a particular focus on determining the abundances of key chemical elements important for planet formation. The data used in this work are part of the scientific preparation for the Ariel space mission and will contribute directly to its goals.

OBJECTIVES

- **Knowledge**: understanding of stellar atmospheres via spectroscopy and the fundamental principles of the chemical evolution of our Galaxy
- **Skills**: hands-on analysis of high-resolution stellar spectra to derive stellar parameters and chemical abundances, statistical interpretation of planet-host star relations and Galactic stellar populations

INSTITUTE

The METEOR will take place at the Osservatorio Astrofisico di Arcetri part of the Istituto Nazionale di Astrofisica in Florence, Italy.

- INAF - Osservatorio Astrofisico di Arcetri
- www.arcetri.inaf.it
- Largo Enrico Fermi 5, I - 50125 Firenze, Italy

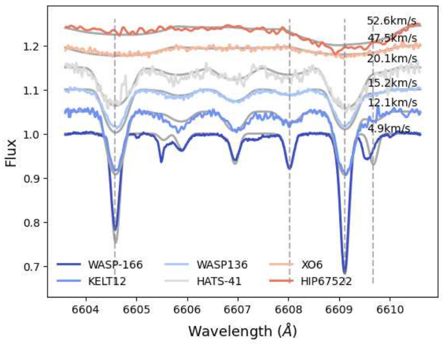
THEORY

by Maria Tsantaki, Laura Magrini

During the METEOR stage, the student will learn the principles of line absorption mechanisms and how stellar atmospheric parameters (temperature, gravity, metallicity) affect the line strength. The properties of planetary systems as a population will be introduced, along with the key quantities that place constraints on models of planetary formation and migration, in particular those related to stellar chemical abundances. The key processes driving the chemical evolution of the Galaxy will be discussed, along with how chemical abundances change over time and across different regions of space.

APPLICATIONS

by Maria Tsantaki



Example spectra of planet-host stars analysed with the spectral synthesis technique from the Ariel mission candidate sample.

The student will analyze spectra of planet-host stars, with the goal of preparing the target list for the Ariel space mission, a mission dedicated to study the atmospheres of their planets. These spectra obtained from state-of-the-art spectrographs by our own observations and archival data will be analysed with specific analysis methods –such as the spectral synthesis with fasma– tailored to each spectral type. The student will first determine the atmospheric parameters, and then measure the abundances of key elements important for planet formation. These measurements will allow us to study correlations between stellar properties and the presence of planets. The student will use the theoretical knowledge of the chemical evolution of the Galaxy to infer its role in shaping planetary systems.

MAIN PROGRESSION STEPS

- `Tier 1`: Theory on stellar spectroscopy and star-planet relations
- `Tier 2`: Analysis of spectroscopic data
- `Tier 3`: Interpretation of the results

EVALUATION

- `Theory grade [20%]`
  - Presentation of an article (60%)
  - Participation in seminars (40%)
- `Practice grade [40%]`
  - Project (100%): initiative, performance
- `Defense grade [40%]`
  - Oral and slides quality
  - Knowledge of the scientific framework
  - Project / Personal work
  - Answers to questions

BIBLIOGRAPHY & RESOURCES

- Tsantaki et al., 2025
- da Silva et al., 2024
- Magrini et al., 2022
- fasma
- Ariel stellar characterization
- Ariel space mission

CONTACT

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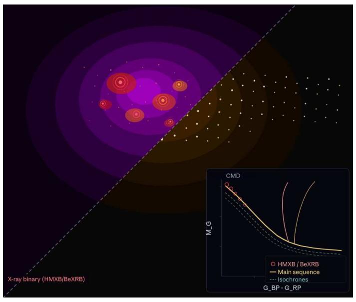
From Star Birth to X-ray Binaries: Mapping the Magellanic Clouds with Gaia DR4



SUMMARY.
The Small Magellanic Cloud (SMC) is a disrupted dwarf disk galaxy actively being tidally stripped by the Milky Way and the LMC, producing extended structures — the Magellanic Bridge, Wing, and Stream — that overlap with the SMC main body on the sky but are kinematically distinct. The forthcoming Gaia DR4 catalogue will provide precise photometry and proper motions for millions of SMC stars, enabling a detailed map of its three-dimensional structure and kinematic substructure. Depending on the student's interests, the project can be extended to investigate the connection between SMC, star-formation history, and the population of High-Mass X-ray Binaries — linking the disruption history of the galaxy to the formation of its most extreme stellar systems.

OBJECTIVES

- **Knowledge:** galaxy structure and tidal interactions, stellar evolution, star formation history, proper motions, the Magellanic System; optionally: X-ray binary populations
- **Skills:** Python, color-magnitude diagram (CMD) analysis, proper motion measurements, machine-learning clustering, probabilistic population classification

INSTITUTE

- Department of Physics, National and Kapodistrian University of Athens (NKUA)
- Dr. G. Vasilopoulos, Prof. D. Hatzidimitriou

THEORY

by G. V. & D. H.

The SMC is a disrupted dwarf disk galaxy at ~60 kpc with an exceptionally large line-of-sight depth of ~20 kpc [1], so stars at very different distances are projected onto the same sky region. Combined with distinct kinematic components — the SMC disk, Bridge, and tidal Wing — this produces broadened and blurred features in the CMD [2] that cannot be decomposed from photometry alone. *Gaia* proper motions [3] are key to separating these populations, as structures overlapping on the sky remain kinematically distinguishable. A natural extension concerns the SMC population of HMXBs and BeXRBs, which trace recent star formation [4] and may preferentially associated with specific kinematic components, connecting the galaxy's disruption history to the formation of its most extreme stellar systems.

APPLICATIONS

by G. V. & D. H.

***Gaia* structure and kinematics.** Using *Gaia* DR4 photometry and proper motions the student will: (a) map the SMC line-of-sight depth using CMD morphology across its full extent, accounting for reddening and population mixing; (b) identify kinematically distinct populations by combining proper motions with CMD position; (c) apply unsupervised machine-learning (e.g. GMM, HDBSCAN) in the 4D space of sky position and proper motion (μ_α, μ_δ) to assign probabilistic membership to the SMC disk or tidal structures.

HMXBs and star-formation history. Cross-matching kinematic maps with SMC HMXB/BeXRB catalogues [4,5] to test whether X-ray binary surface density correlates with recent star formation in specific kinematic components. All analysis in Python with reproducible, well-documented code.

MAIN PROGRESSION STEPS

- Tier 1: Stellar evolution, galaxy structure & tidal interactions; introduction to *Gaia* data products and the Magellanic System; CMD, proper motion and clustering exercises; line-of-sight depth mapping and 4D kinematic analysis
- Tier 2 *(optional)*: Cross-matching with HMXB/BeXRB catalogues; SFH comparison per kinematic component; statistical analysis of the HMXB–SFH association
- Other: We also offer the opportunity to participate in the *Gaia* Doctoral Network workshop (Athens, January 2027) for advanced training and networking with the European *Gaia* community

EVALUATION

- Theory grade [20%]
  Exercises based on lectures (50%), journal club article presentation (50%)
- Practice grade [40%]
  Project: clarity of code, understanding of context, written report, presentation skills
- Defense grade [40%]
  - Oral and slides quality
  - Context
  - Project / Personal work
  - Answers to questions

BIBLIOGRAPHY & RESOURCES

- [1] Ripepi, V. et al. 2017, MNRAS, 472, 808
- [2] Dhanush, S. R. et al. 2025 ApJ, 980, 73
- [3] Zivick, P. et al. 2018, ApJ, 864, 55
- [4] Antoniou, V., Zezas, A., Hatzidimitriou, D., & Kalogera, V. 2010, ApJL, 716, L140
- [5] Haberl, F. & Sturm, R. 2016, A&A, 586, A81
- [6] Gaia Collaboration, Prusti, T., et al. 2016, A&A, 595, A1

CONTACT

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Orbital Dynamics of Multiplanet Systems

THEORETICAL MECHANICS & ASTRODYNAMICS LAB
ΕΡΓΑΣΤΗΡΙΟ ΘΕΩΡΗΤΙΚΗΣ ΜΗΧΑΝΙΚΗΣ & ΑΣΤΡΟΔΥΝΑΜΙΚΗΣ

SUMMARY.

The long-term dynamical stability of multiplanet systems is a fundamental question in planetary science. This project investigates the orbital dynamics of exoplanetary systems hosting three or more planets, selected from current observational catalogs. The equations of motion are integrated numerically. Chaos indicators — including the Fast Lyapunov Indicator (FLI), the Mean Exponential Growth factor of Nearby Orbits (MEGNO), and Lagrangian Descriptors (LD) — are computed to characterize the orbital dynamics and assess the long-term stability of the observed configurations.

Scientific Context

The discovery of thousands of exoplanetary systems has revealed a rich diversity of multiplanet architectures. Understanding whether these systems are dynamically stable over gigayear timescales — and what orbital configurations allow long-term coexistence — is a central problem of modern planetary science. Analytical and semi-analytical methods (e.g. mean-motion resonances, secular theory) provide important insights, but direct numerical exploration of the phase space remains indispensable, particularly for compact or near-resonant systems.

Objectives

Upon completion of this project the student will be able to:

- retrieve and interpret orbital data from exoplanet catalogs (NASA Exoplanet Archive, `exoplanet.eu`);
- formulate and implement the gravitational N-body equations of motion in a suitable reference frame;
- apply high-accuracy numerical integrators (e.g. `REBOUND`, custom RK78 or symplectic schemes) to long-term orbital simulations;
- compute and interpret variational chaos indicators: FLI, MEGNO, and Lagrangian Descriptors;
- present results in the form of a scientific report and oral defence.

Work Programme

Phase 1 — Bibliographic study *(weeks 1–3)*. Review of the literature on N-body dynamics, mean-motion resonances and chaos indicators. Selection of target systems from the exoplanet catalogs according to criteria of scientific interest

Phase 2 — Numerical tools *(weeks 4–6)*. Implementation or adoption of a suitable N-body integrator. Learn to use Python for numerical inegration and computation of chaos indicators. Use particular C-code software.

Phase 3 — Dynamical mapping *(weeks 7–11)*. Numerical integrations for various undetermined parameters and estimation of survival times. Identification of resonant configurations and phases of stability or instabillity.

Phase 4 — Analysis & writing *(weeks 12–16)*. Writing of the thesis report; preparation of the oral presentation.

Prerequisites

- Classical and analytical mechanics (Lagrangian/Hamiltonian formalism).
- Ordinary differential equations; basic numerical analysis.
- Programming proficiency in Python or C++.
- Basic knowledge of celestial mechanics (orbital elements, Kepler's laws) is an advantage.

Deliverables

- Written thesis report (∼30–50 pages).
- Oral defence presentation (20 min + questions).

Key References

- Murray & Dermott, *Solar System Dynamics*, Cambridge UP, 1999.
- Dvorak R. (ed), *Extrasolar Planets*, Wiley-VCH, 2008.
- Foutzopoulos K., *MSc-thesis* `voyatzis.webpages.auth.gr/SeniorThesis/mfoutzopoulos2023.pdf`, 2023

Supervisor

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Research interests: Celestial mechanics, orbital dynamics, dynamical systems, chaos indicators, N-body simulations, ESA Hera mission.