Hunting for planet-hosting discs

Project description:
Planet-forming discs, discs of gas and dust orbiting young stars, are the birthplaces of planets. Thanks to its ability to resolve small details in these objects, the Atacama Large Millimeter/submillimeter Array (ALMA) revolutionised our understanding of planet formation, showing that most planet-forming discs display sequences of "gaps and rings", thought to be due to ongoing interactions between a population of young planets and their forming disc (Fig. 1a). However, direct evidence of the presence of embedded planets is only available in one disc, PDS 70 (Fig. 1b and 1c), where two Jupiter-like young planets were detected. It is common belief that the uniqueness of PDS 70 stands in its large cavity (cf. Fig. 1a and 1c), almost completely devoid of dust and gas, thus ideal to search for planetary emission well distinguished from the background disc one. The aim of this project is to search for PDS 70 analogues, building a complete census of planet-forming discs with broad and deep cavities, as a first step to identify possible planet-hosting discs. This will be done by combining optical to mm photometry available for hundreds of sources in nearby star-formation regions. If time allows, by searching the ALMA archive, the student will complement their sample with sub-mm images of these discs, when available, and identify the best planet-hosting candidates.
The student will learn to search multi-wavelength photometry catalogues and combine them to identify disc-bearing stars and the presence of cavities in these sources. If time allows, they will also learn how to search for data in the ALMA archive and reconstruct images (e.g., Fig 1a, 1c) from these observations. The main tools will be open-source software to search and cross-match online catalogues (e.g., Topcat) and to image ALMA data (CASA).

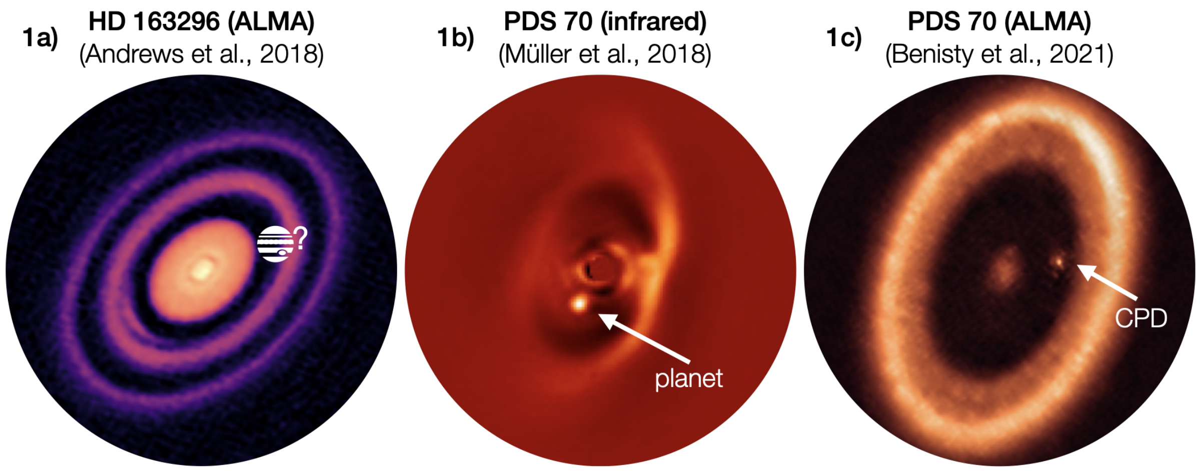

Figure 1: a) ALMA image of HD 163296, a planet-forming disc rich in gaps (dark areas) and rings (bright areas). b) Planetary emission from PDS 70 b in the infrared. c) ALMA image of PDS 70, showing a wide and empty cavity. Circumplanetary emission (CPD) around PDS 70 c is also visible.

Desired skills:
Some knowledge of coding with Python is desirable, but not indispensable.

Example reading materials
References: Andrews et al. (2018), Benisty et al. (2021), van der Marel et al. (2023)

Studying ionization bubble topology during the Epoch of Reionization

Project description:
The Epoch of Reionization (EoR) represents a critical phase in the Universe's evolution, marking the shift from a neutral to an ionized state of the intergalactic medium (IGM). During this period, the topology of the IGM i.e. the distribution of ionized regions, or "bubbles", reveals valuable insights into the phenomena and sources driving this transition. The characteristic size of these ionized bubbles affects both the amplitude and position of the peak in the 21 cm signal arising from neutral hydrogen fluctuations in the IGM. Observationally, these are relevant for upcoming telescopes like the Square Kilometre Array (SKA), which aims to detect the 21 cm signal. This project will focus on studying the bubble size distribution during EoR using realistic semi-numerical reionization models, exploring various model aspects to gain a deeper understanding of this fascinating cosmic epoch.
Throughout the project, the intern will gain exposure to semi-numerical reionization modeling and associated techniques. They will primarily work with the photon-conserving reionization model SCRIPT, which utilizes Python-wrapped Fortran. Other relevant tools may also be employed, depending on the project's progress.

Desired skills:
It is desirable to have preliminary experience with Python programming and handling Python based packages. Apart from this, an introduction to basic cosmology can be useful (although not necessary).

Example reading materials

- A Short Introduction to Reionization Physics: *T.R. Choudhury, 2022*
- Photon number conservation and the large-scale 21 cm power spectrum in semi-numerical models of reionization, *Choudhury & Paranjape, 2018*
- The Distribution of Bubble Sizes During Reionization, *Lin et al, 2015*

Exploring the Birth of Directly Imaged Exoplanets: Revising Thermal Evolution Models with GASTLI

Project description:
Gas giant exoplanets that are far enough from their star can be ”photographed” using a technique called direct imaging. This method allows us to study exoplanets that are very young, which still retain information about their formation conditions, particularly their formation entropy (a measure of the heat of formation). To determine the entropy, we compare the planet’s emitted light (its emission spectrum or fluxes) to numerical models. These models, known as thermal evolution models, predict how a planet’s radius and emitted light change over time. However, recent studies have found that there are discrepancies between different models, especially in their predictions of a planet’s radius. One possible explanation for these differences is that many widely used models rely on outdated data for entropy and density (known as equation of state or EOS). The aim of this project is to revisit thermal evolution models using the GAS gianT modeL for Interiors (GASTLI), a state-of-the-art interior and evolution model that uses the latest EOS data. By using GASTLI, you will generate updated calculations of planetary radius and emission flux. These new calculations will help us better interpret recent observations of directly imaged planets and address the current discrepancy between existing models.
You will gain experience with numerical simulations of exoplanet interiors and atmospheres, learning how these models are used to interpret observations of exoplanet atmospheres and masses. The main tool for this project is GASTLI, which is written in Python. You will also work with other Python packages, such as matplotlib, numpy, scipy, pandas and h5py, for model management and data visualization.

Desired skills:
Knowledge of Python. Previous experience with matplotlib and numpy will be useful.

Example reading materials

Zhang et al. (2024), *Disequilibrium Chemistry, Diabatic Thermal Structure, and Clouds in the Atmosphere of COCONUTS-2b,* arXiv: 2410.10939, accepted in Astrophysical Journal.

Cooking the Pizza Crust: Investigating Edge Rings in Protoplanetary Disks

Project description:

Rings and gaps are among the most prominent substructures in protoplanetary disks observed in the ALMA continuum. These rings represent radial concentrations of pebble-sized particles, often associated with planet formation processes. They may indicate the presence of forming planets carving the structures or regions where accumulated pebbles aid planet assembly. A peculiar subset of disks, some extremely young, exhibit smooth profiles with a single dip/bump at the disk's outer edge–resembling a "pizza crust." The origins of these edge rings, and their connection to planet formation and disk evolution, remain unclear. This project will investigate the possibility that these rings are formed due to radiative transfer effects at the disk edge. Specifically, the steep dust surface density gradient at the outer edge of the dust disk enhances irradiation efficiency, producing a temperature bump. This bump creates a pressure maximum, trapping pebbles and forming a "first-generation" ring that could initiate planet formation at the disk edge.

The student will gain foundational knowledge about ALMA continuum observations and imaging analysis. They will also develop skills in using radiative transfer tools (e.g., RADMC-3D) and dust evolution codes (e.g., DustPy), which are widely applied to disk evolution and planet formation studies.

Desired skills:

- Basic programming skills (e.g., Python)
- Enthusiastic and motivated in radiative transfer and planet formation
- Familiarity with numerical tools (any) is a plus, but not required

Example reading materials

Dullemond, C. P., Birnstiel, T., Huang, J., et al. (2018) "The Disk Substructures at High Angular Resolution Project (DSHARP). VI. Dust Trapping in Thin-ringed Protoplanetary Disks," ApJL, 869, L46 - 2018ApJ...869L..46D

Kim, S., Takahashi, S., Nomura, H., et al. (2020) "The Detection of Dust Gap-ring Structure in the Outer Region of the CR Cha Protoplanetary Disk," ApJ, 888, 72 - 2020ApJ...888...72K

Maureira, M. J., Pineda, J. E., Liu, H. B., et al. (2024) "FAUST: XVIII. Evidence of annular substructure in a very young Class 0 disk," A&A, 689, L5 - 2024A&A...689L...5M

Dullemond, C. P., Juhasz, A., Pohl, A., et al. (2012) "RADMC-3D: A multi-purpose radiative transfer tool," ascl.soft, ascl:1202.015 - 2012ascl.soft02015D

Stammler, S. M., & Birnstiel, T. (2022) "DustPy: A Python Package for Dust Evolution in Protoplanetary Disks," ApJ, 935, 35 - 2022ApJ...935...35S

Clouds in exoplanetary atmospheres:
impact of particle mixing and size distributions

Project description:

Clouds present a challenge to understanding the atmospheres of extrasolar planets as they can often hide spectral features of the gaseous components of atmospheres. We have now entered an era where JWST's unprecedented resolution allows us to test and refine our understanding of cloud microphysics in extrasolar atmospheres.

Despite these advances, current self-consistent forward models struggle to reproduce observations of self-luminous objects such as directly imaged exoplanets and brown dwarfs. This highlights the urgent need to improve our modelling techniques and identify the underlying causes of the discrepancies between models and observations.

In this project, you will have the opportunity to explore how different assumptions about clouds affect the synthetic emission spectra of self-luminous objects. Specifically, you will investigate:

1. **The impact of different cloud particle size distributions** in the synthetic emission spectra of self-luminous objects;
2. **The effect of different material mixing treatments within cloud particles** on cloud opacities and the resultant spectra.

Through this project you will learn about self-consistent forward modelling of planetary atmospheres and gain a deep understanding of cloud formation and properties in exoplanetary atmospheres. You will be using the `MSG` model for cloudy substellar atmospheres.

Desired skills:

Familiarity with programming is desired (in any language). Knowledge of Python and/or Fortran is a plus.

Example reading materials

- Review paper on clouds/hazes in exoplanet atmospheres: Gao et al. 2021
- Paper on the effect of different mixing treatments in transmission spectra (not self-consistent!): Kiefer et al. 2024
- The `MSG` model paper: Jørgensen et al. 2024

Python tools for the analysis of massive binary stars

Project description:
This project consists of two primary components: (1) Enhancing the Python repository MINATO (Massive bINaries Analysis TOols), a comprehensive suite of Python-based tools. MINATO supports various aspects of massive binary star research, including radial velocity measurements (Fig. 1), orbital period determination, atmospheric analysis, and spectral energy distribution (SED) fitting (Fig. 2). (2) Applying the MINATO tools to analyze high-resolution spectroscopic data obtained with the FEROS spectrograph at the 2.2m telescope at La Silla Observatory, Chile.
The internship offers hands-on experience with key methodologies in stellar astronomy relevant to both binary and single stars. Emphasis is placed on developing programming skills essential for contemporary astronomical research. The student will utilize GitHub for version control and collaborative development, contributing to the project's codebase. The main objective is to refine MINATO into a user-oriented Python package, thereby enhancing its utility and accessibility for the astronomical community.

Desired skills:
Proficiency in Python and familiarity with GitHub are advantageous but not required. Candidates with a background in massive or binary stars are encouraged to apply, even if their programming experience is limited.

Example reading materials
MINATO has been used in the following works:
2021MNRAS.507.5348V, 2023MNRAS.525.5121V

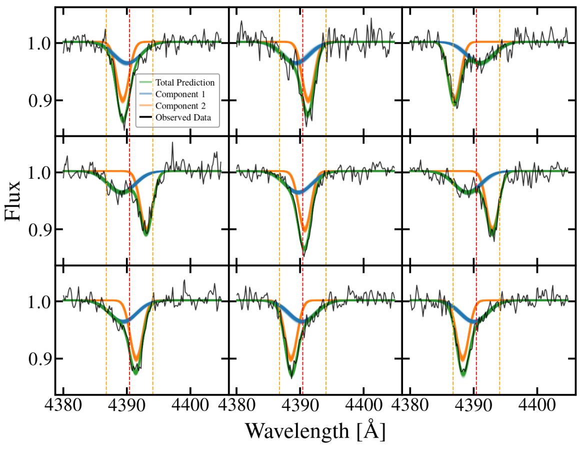

Figure 1: Gaussian fitting to the spectral lines of a double-lined spectroscopic binary for radial velocity measurements, from Villaseñor et al. submitted.

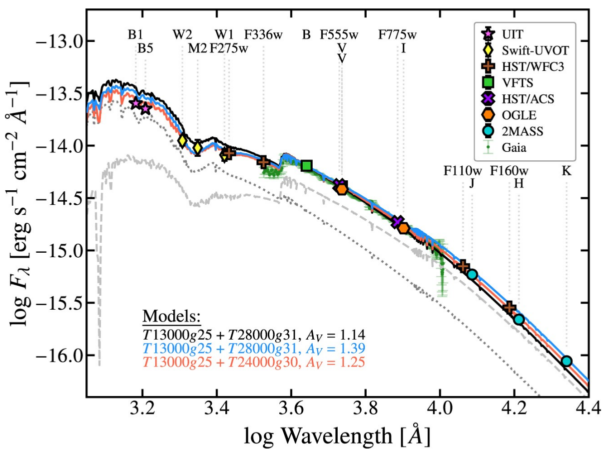

Figure 2: SED fitting of the stripped star VFTS 291 from Villaseñor+2023.

Integration and testing of the MICADO calibration assembly

Project description:

The summer project in astronomical instrumentation allows to contribute to the development of the ELT camera MICADO. We are currently building up and test the hardware of the calibration assembly, and the candidate is expected to be interested in practical lab work, data analysis and goal-oriented thinking. Moderate python expertise is an asset. No need for engineering level CAD skills. A more software and calibration concept oriented direction is also possible, since we develop the calibration pipeline and data reduction principle at the same time to the hardware. Goal is to provide the ELT first light camera MICADO with 0.1% level calibration tools for its main science modes imaging, differential astrometry, and long-slit spectroscopy from 0.8.-2.4 μm.

Desired skills:
Moderate Python knowledge would be helpful.

Exploring the Diverse Universe of Dwarf Galaxies

Project description:
Dwarf galaxies are the smallest, faintest, and most numerous galaxies in the Universe, containing only a fraction of the stars found in larger systems like the Milky Way. Despite their small size, they play a key role in understanding galaxy formation, the influence of dark matter, and the conditions of the early Universe. These galaxies are thought to serve as the building blocks of larger systems in hierarchical structure formation.

This project focuses on studying the physical properties of a sample of dwarf galaxies identified in surveys with the James Webb Space Telescope and Hubble Space Telescope. By determining their distances, masses, and star formation rates, we aim to explore how these galaxies evolve and interact with their environments. The analysis will provide insights into their role in the assembly of cosmic structures and their place in the broader context of galaxy evolution.
The student will learn about galaxy evolution. They will work with data from Hubble and JWST, using open source Python software packages.

Desired skills:
Some Python knowledge would be highly beneficial.

Example reading materials
Zaritsky D. et al., 2024, AJ, 168, 69. doi:10.3847/1538-3881/ad543f