# Exoplanet sytem characterization Internal Structure and Evolution of Exoplanets and their Parent Stars

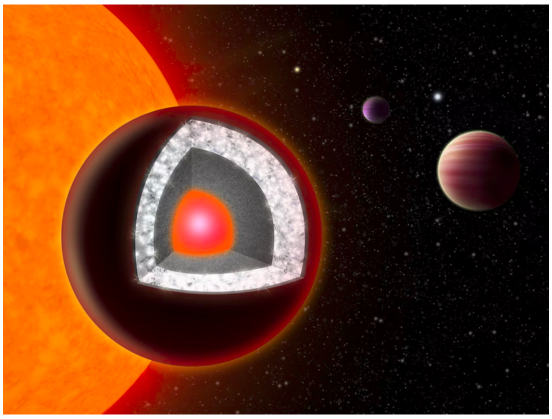


*Illustration credits: Haven Giguere, Yale*

SUMMARY.
Exoplanets are new windows into our Universe. We want to know what they are made of, how they were formed and ultimately whether they may harbour life. Characterizing exoplanets i.e., measuring their physical parameters and atmospheric properties to infer their structure and composition is key. They are part of systems including one or several stars and therefore the combined evolution of stars and planets is essential to learn more about these objects. We propose a course that combines expertise on stellar and planetary structure and evolution with the goal to characterize exoplanetary systems. This modern approach of characterizing simultaneously stars and planets is the essence of the forthcoming ESA space mission PLATO.

## OBJECTIVES

- The students will learn the physical principles behind the internal structure and evolution of stars and planets. Both standard and modern concepts will be presented.
- Theoretical and numerical approaches are proposed. The first part will be dedicated to the derivation of the fundamental equations and the understanding of the general concepts in the fields of stellar physics and planetology. With this background, the students will have the opportunity to use state-of-the-art numerical codes based on these principles to approach current hot topic problems in exoplanetology and interpret recent observed data.

## PREREQUISITES

☒ S2. Stellar physics

## THEORY

### Basics of stellar evolution.

by O. Creevey, L. Bigot, R. Ligi

Classical Stellar Evolution: Main concepts and equations of stellar structure and evolution with a particular emphasis on nuclear energy production and energy transports to understand evolution and the HR diagram. Topics on determining planet-host parameters (radius, mass, age) focussing also on the sources of uncertainties. Exploration of the properties with age.

Modern developments like granulation will be over-viewed to present their consequences for the detection and characterization of transiting exoplanets.

### Basics of planet evolution

by T. Guillot

Classical Planetary Evolution: Solid & gas planets, importance of EOSs, atmospheric boundary conditions, importance of stellar irradiation. Evolution, heat transport, an HR diagram for gaseous planets.

Modern developments: Atmospheric dynamics, tides, Ohmic dissipation.

## APPLICATIONS

by L. Bigot, T. Guillot

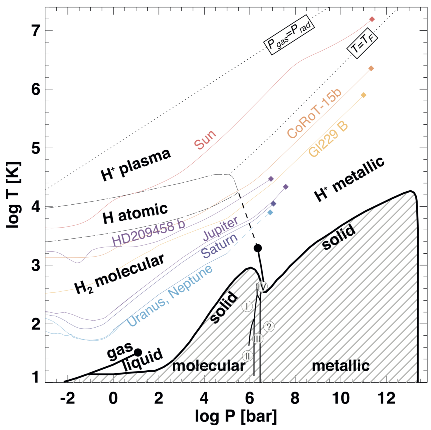
Hands-on course: The students will learn how to use the stellar and planet evolution codes CESAM and CEPAM. This will give the ability to predict physical parameters as a function of input mass, composition, and age. They will first calculate evolution tracks for the Sun and for Jupiter. They will test how a change in atmospheric boundary condition (e.g., including irradiation for a hot Jupiter) affects the evolution.

The students will then perform individual projects based on recent research in the fields of stellar evolution and exoplanet research. Possible topics are:

Quantify the inflation of hot Jupiters: Giant exoplanets very close to their parent stars (hot Jupiters) are found to be on average larger than predicted by standard evolution models. Using CEPAM and comparing with existing observations, the student will quantify the effect and test possible solutions (tides, ohmic dissipation, warmer atmosphere...).

Measure planetary core sizes: Some giant exoplanets are denser than average. This may indicate the presence of a dense central core. Using CEPAM and existing observations, the student will calculate possible core mass values for these exoplanets.

Combined star and planet fit: Star and planets have properties that change simultaneously with age. To understand the evolution of the system, both stellar (CESAM) and planetary (CEPAM) evolution codes will be used to reproduce multiple observational data relative to the host star and, using existing data analysis tools and hand made procedures, will extract the radius, mass, density, age, temperature of the star and the planet. Special attention will be given to the uncertainties and the correlations among the parameters.




*Structure and hydrogen profiles for the Sun and giant planets.*

## MAIN PROGRESSION STEPS

- `Week 1 - 3`: theoretical courses, hands-on work and exercises
- `Week 4 - 6`: individual project
- `Week 7`: preparation for presentation

## EVALUATION

- `Theory grade [30%]`
  - Written exam (70%): theoretical questions and numerical applications based on lectures
  - Theoretical exercises (30%)
- `Practice grade [30%]`
  - Practical exercises (40%): thought-process and results
  - Project (60%): initiative, progress, analysis
- `Defense grade [40%]`
  - Oral and slides quality
  - Context
  - Project / Personal work
  - Answers to questions

## BIBLIOGRAPHY & RESOURCES

- Stellar Astrophysics (LeBlanc)
- Lecture notes in Stellar Structure and Evolution (Christensen-Dalsgaard)
- Useful link for exoplanet talks and seminars

## CONTACT

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