# Modeling of Exoplanets Interiors

## in the Framework of Future Space Missions

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## Introduction

Despite the huge number of **discovered exoplanets**, our knowledge regarding their compositions remains extremely limited. Modeling the interior of such bodies is necessary to go further than the first approximation given by their **mean density**. Their precision allows to efficiently constrain the internal structure of a body, given the uncertainties on its **fundamental parameters**. However, current models are still limited by a **degeneracy** on the input composition.

Here we present a model able to handle **various planetary compositions**, from terrestrial bodies to ocean worlds. Using the **elemental abundances** of an exoplanet's host star, we significantly reduce the existing degeneracy. From this, it is possible to infer the type and state of material present at the **planet's surface**.

## Model

Our model is based on the physical properties of the Earth and other solar system bodies. A planet in our model is made of various **concentric layers** (see **Figure 1**). Their respective proportions are controlled by the **core mass fraction** (CMF) and **water mass fraction** (WMF) of the planet, whose variations form a parameters space that can be explored.

Knowing the bulk **Fe/Si** and **Mg/Si** ratios of the planet allows to break the degeneracy on its composition. As these parameters cannot be measured, we assume them to **reflect those of the planet's host star** [1], which are estimated via high-resolution spectroscopy.

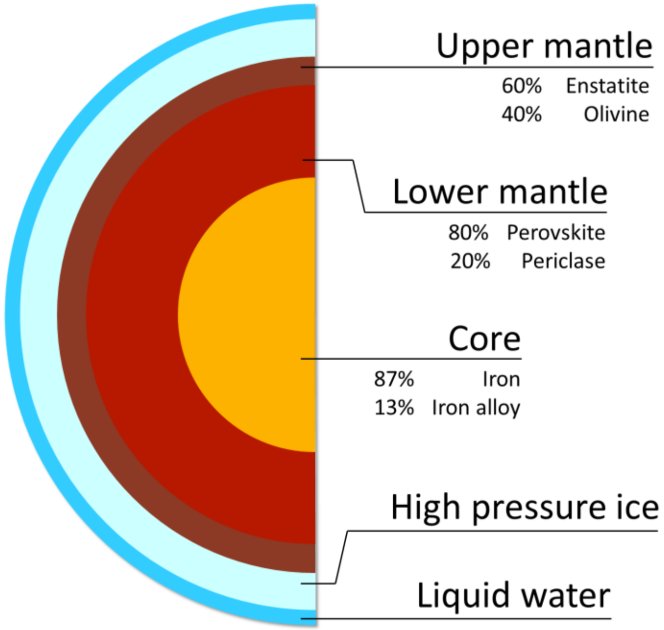


Figure 1. Internal structure of an ocean planet, with five concentric layers: metallic core, silicate mantles (lower and upper), and water layers (solid and liquid). Our model is able to handle any combination of these layers.

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# The Case of Kepler-10b

## Results

Kepler-10b is the **first rocky planet** that has been detected by the Kepler mission. Its mass was estimated by **[2]** with a precision of 12%, but its radius is known with an **unrivaled precision** of 2% **[3]**. Combined to the elemental abundances of Kepler-10 **[4]**, this allows to greatly constrain the planet's composition.

Applying our model to this case shows that Kepler-10b is likely to be a **terrestrial planet**, compatible with an **Earth-like composition**. For this planet, we derive a range of 10-33% for the CMF, and 0-14% for the WMF.

Table 1. List of physical and orbital parameters of the exoplanet Kepler-10b, and its host star Kepler-10 **[2,3]**.

| Planet parameters | |
|---|---|
| Orbital distance (AU) | $0.017^{+0.008}_{-0.002}$ |
| Equilibrium temperature (K) | $2169^{+96}_{-44}$ |
| Planet Radius ($R_\oplus$) | $1.47^{+0.03}_{-0.02}$ |
| Planet Mass ($M_\oplus$) | 3.72 ± 0.42 |
| **Stellar parameters** | |
| Effective temperature (K) | 5627 ± 44 |
| Star Mass ($M_\odot$) | 0.913 ± 0.022 |
| Star Radius ($R_\odot$) | 1.065 ± 0.009 |

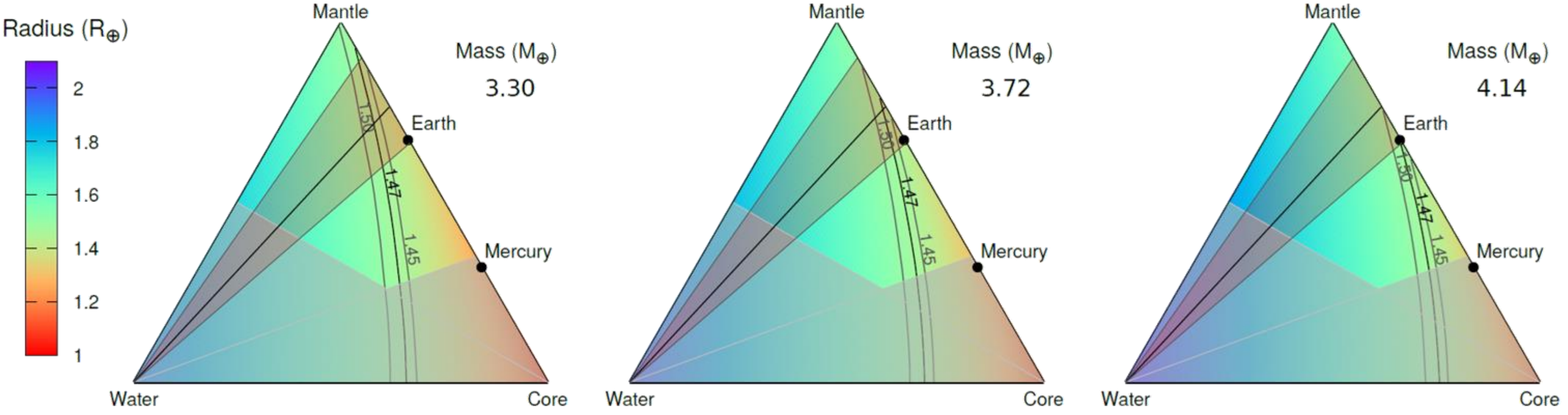


Figure 2. Ternary diagrams displaying the investigated compositional parameter space of Kepler-10b for three values of the planet's mass: the minimum, central, and maximum values inferred by **[2]**, using 1-sigma uncertainties. Also shown are the isoradius curves denoting the planet radius measured by **[3]** with the 1-sigma extreme values. Two areas of the diagrams are excluded from the study, based on assumptions on the solar system formation. The Fe/Si ratio of Kepler-10, with its uncertainties **[4]**, delimits an area in the diagram represented as a red triangle

# Challenges from future Space Missions

Kepler-10b, with the very low uncertainty on its radius, is a **great example** of what models of planetary interiors are capable of when coupled to observational data with **a great precision**. Also, the importance of **determining elemental abundances** of exoplanet-hosting stars cannot be neglected, as it allows to break the degeneracy of such models.

For now, the precision on fundamental parameters of most exoplanets is not reaching that of Kepler-10b's, and **stays far** from the internal uncertainties of models of planetary interiors. However, upcoming space missions dedicated to the characterization of known exoplanets, as **CHEOPS or PLATO** (see **Figure 3**) will provide these parameters with an unrivaled precision **[5]**, reaching that of interior models. Therefore, the next step in modeling the interior of exoplanets is to **improve models** with more precise descriptions of the behavior of used materials.

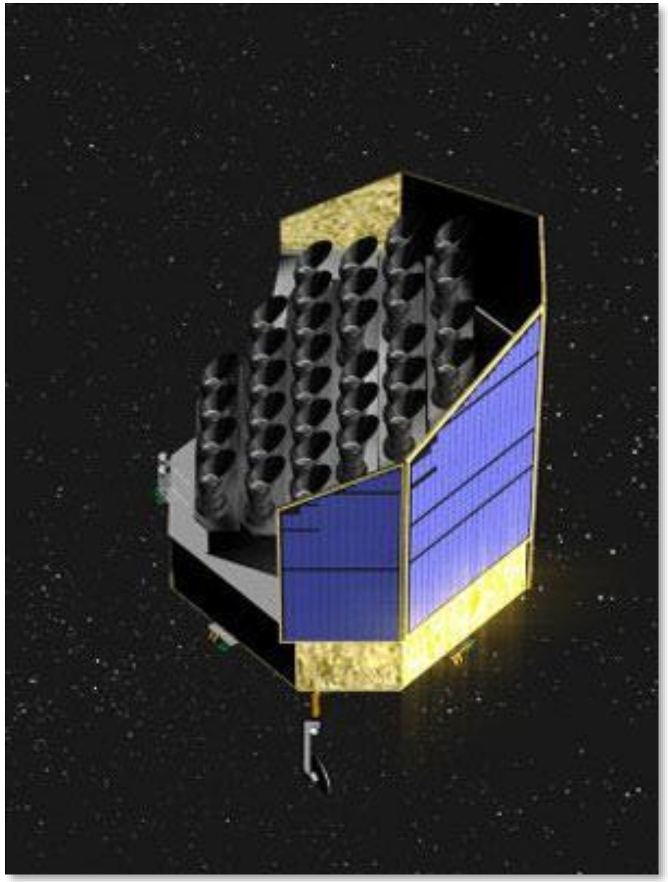

Figure 3. The PLATO space mission is developed by ESA, and set to be launched in 2026. It is dedicated to precise characterization of known exoplanets.

*Image credits: CNES*

## References

**Constraints on low mass Exoplanets Interiors from Stellar Abundances**

by Brugger B., Mousis O., Deleuil M., and Deschamps F. – *Submitted to The Astrophysical Journal*


**[1]** Thiabaud A. et al. (2015) – *A&A, 580, A30*

**[2]** Weiss L.M. et al. (2016) – *ApJ, 819, 43*

**[3]** Dumusque X. et al. (2014) – *ApJ, 789, 154*

**[4]** Santos N.C. et al. (2015) – *A&A, 580, L13*

**[5]** Rauer H. et al. (2014) – *Experimental Astronomy, 38, 249R*