Modeling Small Exoplanets Interiors

A Numerical Scheme to Explore Possible Compositions

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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. This work aims at overcoming this limitation with the development of a **numerical model**: knowing the planet's mass and radius, it computes its **internal structure**. Coupled to an adapted numerical scheme, it provides a range of compositions compatible with the exoplanet's fundamental parameters. The final aim of this work is to develop a tool to **constrain the composition and structure** of new discovered exoplanets, and eventually their formation scenarios.

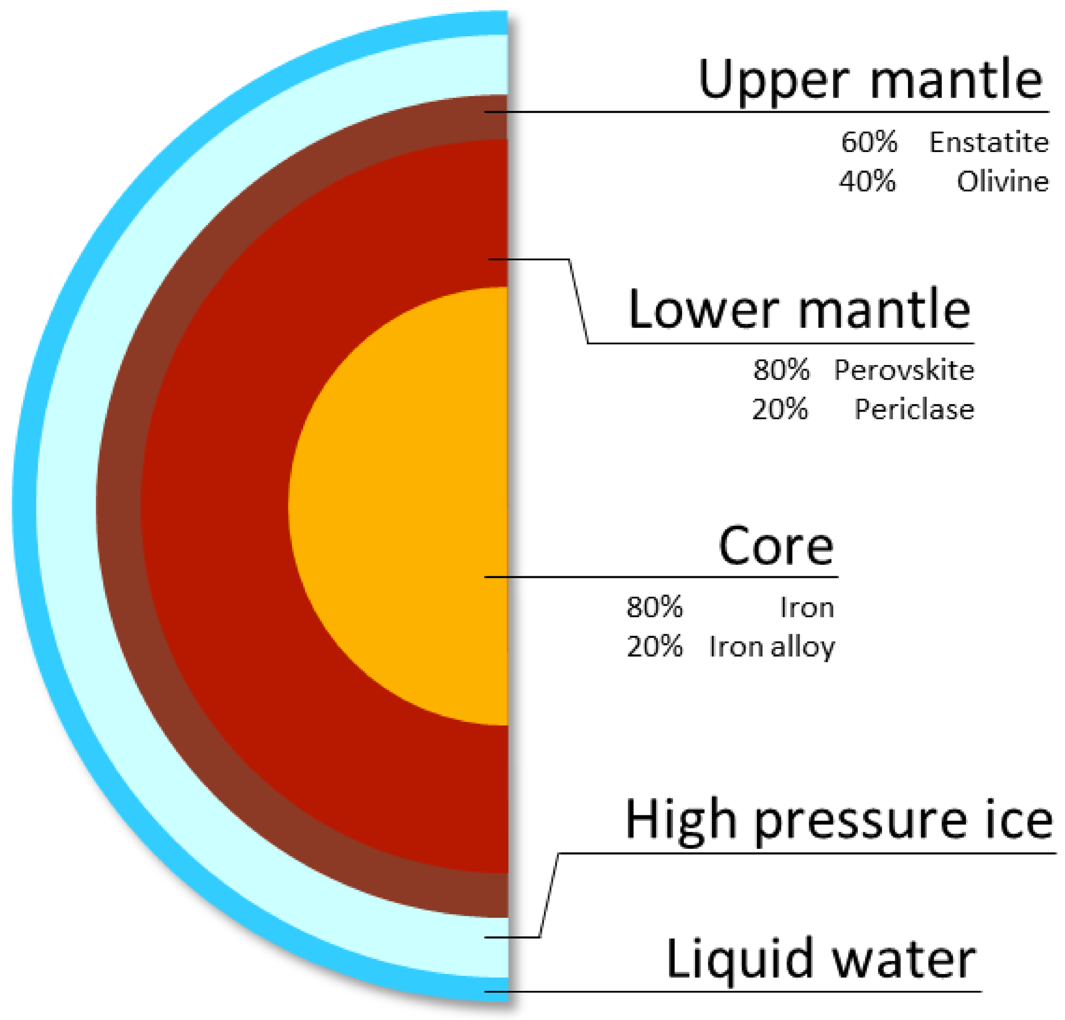

Figure 1. Internal structure of an ocean planet, with five concentric layers: metallic core, silicate mantles (lower and upper), and water layers (solid and liquid). Our model is able to handle any combination of these layers.

Model and Parameters

Similarly to existing models **[1, 2]**, 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, forming a parameters space that is explored in this work.

The **Super-Earth CoRoT-7b**, discovered by **[3]**, is considered here as a test case for our model (see **Table 1**).

We first assumed that this planet shares a composition similar to that of the Earth, namely a **rocky planet** with a 33% CMF. **Figure 2** shows the variations of four physical quantities as a function of the planet's internal radius: gravity acceleration, pressure, temperature and density. We then **repeated** the simulation for all compositions allowed by the variations of the CMF and the WMF (see **Figure 3**).

Table 1. List of physical and orbital parameters of CoRoT-7b and its parent star CoRoT-7 **[5, 6]**.

Planet parameters	
Orbital period (day)	0.853585 ± 0.000024
Orbital distance (AU)	0.0172 ± 0.00029
Planet Mass (M_E)	4.73 ± 0.95
Planet Radius (R_E)	1.585 ± 0.064
Stellar parameters	
Effective temperature (K)	5259 ± 58
Star Mass ($M_\odot$)	0.913 ± 0.017
Star Radius ($R_\odot$)	0.820 ± 0.019

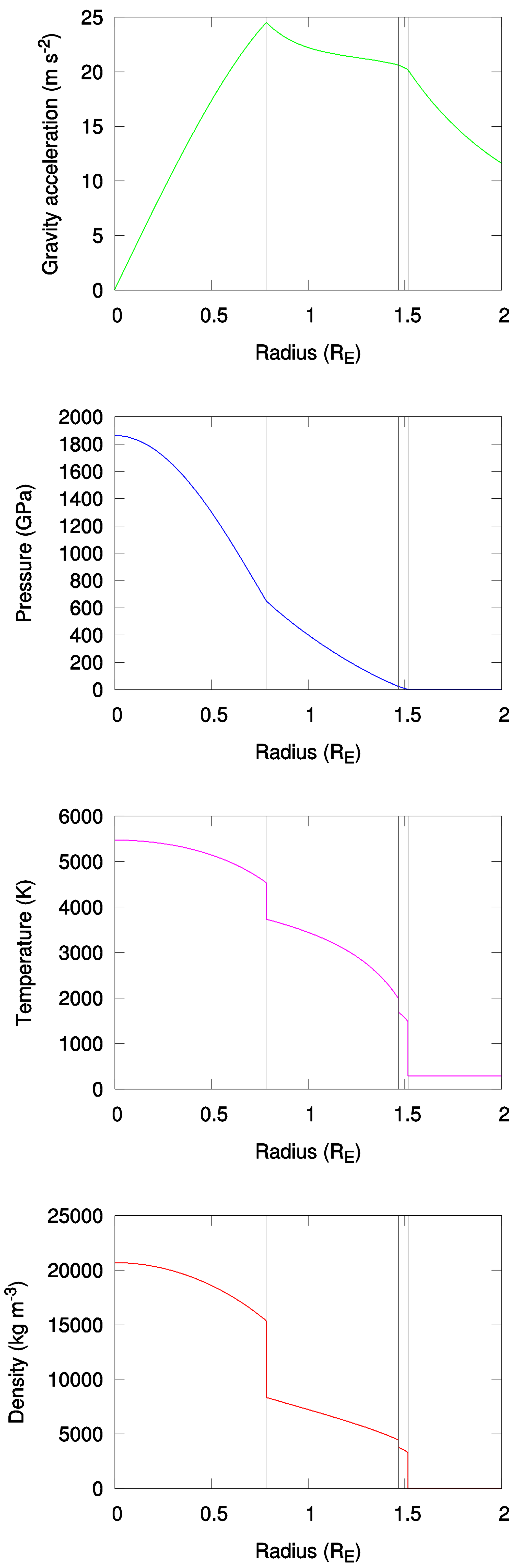

Figure 2. From top to bottom: gravity acceleration, pressure, temperature and density radial profiles inside CoRoT-7b, for an Earth-like composition (33% CMF, 0% WMF). Vertical lines show the boundaries between the layers (from left to right: core, lower mantle and upper mantle).

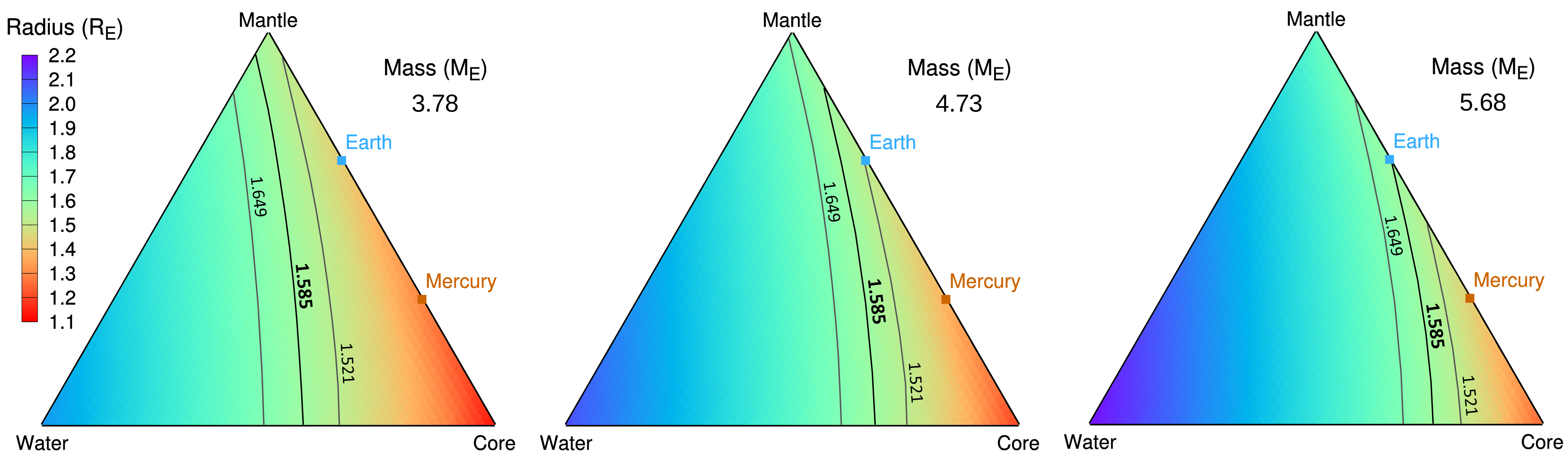

Figure 3. Ternary diagrams displaying the investigated compositional parameters space: each point corresponds to a unique composition. The three corners correspond to planets which are 100% silicate mantle, 100% water or 100% metallic core. From left to right, diagrams correspond to the minimal, central, and maximal masses inferred for CoRoT-7b. Each diagram shows a colored map of the planet radii obtained for the corresponding compositions. Also shown are isoradius curves denoting the minimal, central, and maximal radii measured for CoRoT-7b.

Results and Discussion

Based on early mass and radius measurements, previous studies **[4]** concluded that CoRoT-7b presented a significant depletion in iron comparatively to the Earth. Indeed, only one set of mass and radius was compatible with an Earth-like composition. Here, using the **latest estimates** of the planet's parameters, we show that the same composition can be obtained more easily. Moreover, CoRoT-7b can present a CMF up to 50% while keeping a complete **rocky structure**, eliminating the need of an iron depletion. In addition to confirming its **Super-Earth status**, our results enlarge the range of compositions allowed for CoRoT-7b.

All possible compositions are not considered in this study: in addition to water, CoRoT-7b could possess an **atmosphere**, enriched in various volatile species. Adding such cases is essential to develop a self-consistent model. However, in its current form, our numerical model is already capable to explore a large range of compositions, and can be used as a tool to **check the planetary likelihood** of exoplanet candidates in the small size domain.

References

[1] Sotin et al. 2007 – *Icarus 191, 337*

[2] Valencia et al. 2006 – *Icarus 181, 545*

[3] Léger et al. 2009 – *A&A 506, 287*

[4] Valencia et al. 2010 – *A&A 516, 20*

[5] Barros et al. 2014 – *A&A 569, 74*

[6] Haywood et al. 2014 – *MNRAS 443, 2517*