EPSC Abstracts
Vol. 13, EPSC-DPS2019-1771-3, 2019
EPSC-DPS Joint Meeting 2019

EPSC
EPSC-DPS Joint Meeting 2019
15–20 September 2019 | Geneva, Switzerland

Water-rich (exo)-planets: formation and interior structure

Oliver Shah (1,2), Yann Alibert (1) and Ravit Helled (2)
(1) Universität Bern, Switzerland (2) Universität Zürich, Switzerland (contact: oliver.shah@space.unibe.ch)

Abstract

We are developing structure models of planetary interiors in the earth and super-earth regime. A key focus of our research lies in assessing, from a modelling approach, to what extent the presence of high water mass fractions in the interior and on the surface of planets can be linked to observable quantities.

1. Introduction

Even with increasing precision in the observations of extrasolar planets it will remain a difficult task to infer a planets interior composition from the measurement of external quantities alone. But it is possible to pose additional constraints on the bulk structure of a planet by combining the astrophysical aspects with knowledge from different areas such as chemistry, material sciences or geology. Therefore, our theoretical models require the input from observational and experimental data to constrain and refine certain model assumptions. With these models we are aiming for providing a considerable contribution to classification and characterization of observed planets in the solar and other stellar systems. This endeavor includes but is not restricted to: More refined inference of interior properties from observed quantities, possible constraints on the interactions between interior and atmosphere and linking to the evolutionary history of planets. Furthermore, as all of the aforementioned aspects are connected to a planets potential for habitability, our research might provide useful means to ascertain interesting candidates for future observations in this regard.

2. Model

In the first stage of our project we combine a one dimensional structure model (e.g. Seager 2007, Sotin 2007) with experimental and theoretical studies on the behavior of different hydrated materials. To this end we build hydration models for silicate and magnesium containing compounds to investigate in a firs step the effects of hydration on the equation of

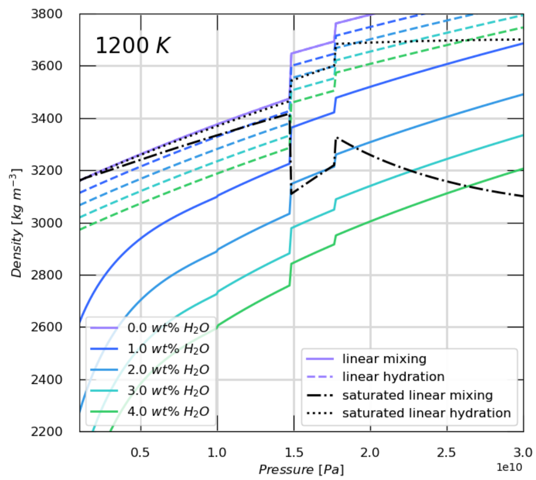

Figure 1: Hydration effect on Mg_2SiO_4 using our hydration model (dashed curves) vs. a simple linear mixing law (solid curves). Also shown is the maximum hydration effect (black curves) for both cases which is constraint by the water saturation in the material.

state and the resulting influence on the mass-radius relation for different compositions. The hydration model is based on experimental data that have been performed for a variety of materials under pressure and temperature conditions relevant for planetary modelling. Figure 1 shows a first visualization of the effect of hydration on the example of Mg_2SiO_4 (Olivine). Shown is the density at different pressures at T = 1200 K and for different water contents X_{H2O} in wt% denoted as "linear hydration". Also shown is the maximum hydration effect which is restricted by the saturation hydration given by our model, denoted as "saturated linear hydration". For the sake of comparison we performed the same calculations but instead of using the linear hydration model we use a simple linear mixing law, denoted as "linear mixing".

3. First results

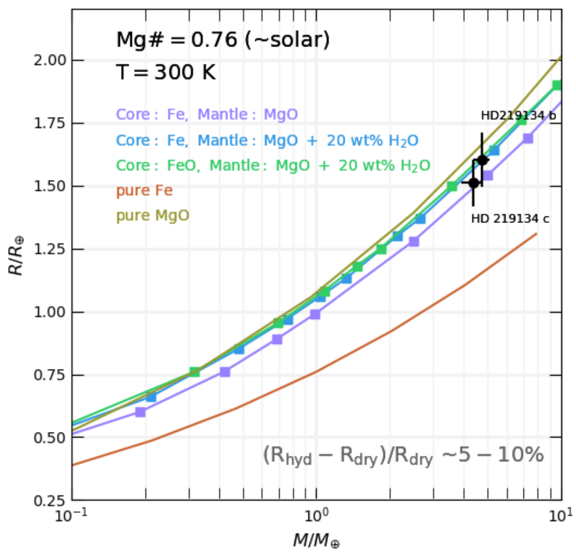

Figure 2: Mass-radius relation curves for isothermal planets at 300 K and fixed Mg# = 0.76. The planets consist of a Fe core and a MgO mantle. Hydration effects are accounted for by exchanging Fe with FeO and MgO with $Mg(OH)_2$. (different colors, see inset legend or text for details).

As a first application of our simple hydration model we compute the mass-radius curves for different scenarios (Fig. 2). We consider isothermal planets at 300 K and fix the magnesium number, given by Mg# = Mg/(Mg+Fe), to roughly solar. Mg and Fe here denote the total molar abundance in the interior of magnesium and iron respectively. Fixing Mg# has been achieved by iteratively alter the core mass fraction to match the desired value of Mg# = 0.76. The first scenario (purple curve) corresponds to completely anhydrous planets. The core is assumed to be pure Fe and the mantle pure MgO (Periclase). The choice of MgO for the mantle composition is motivated by the fact, that it is one of the simplest minerals relevant in planetary science and can store considerable amounts of water (e.g. Hermann 2016). In the second scenario (blue curve) we introduce 20 wt% water into mantle but not in the core. As a result, the reduced density of $Mg(OH)_2$ (Brucite) with respect to MgO leads to an increase of the radius at a given mass by ~5-10%. The third scenario (green curve) now includes the hydration of the iron core by replacing Fe with FeO, assuming that the hydrogen produced by this reaction will be outgassed and can either be lost to space or form a hydrogen envelope during planetary evolution, which we have not taken into account at this stage. An interesting feature that is imminent from Fig. 2 is that exchanging Fe with FeO has seemingly a negligible effect on the resulting radius at a given mass. This is an inherent consequence of the fact that the magnesium number has been held constant. By exchanging Fe with FeO the core mass fraction of the planets must become larger in order to maintain the Mg#. As FeO still has a larger density than $Mg(OH)_2$, this means, that the average bulk density increases. The effect of decreasing the density in the core by exchanging Fe with FeO and the effect of increasing the core mass fraction more or less balance each other in the present case, leading to almost no net effect.

4. Discussion

In Fig. 2 we have also plotted the observed mass and radius for the planets HD219134 b and HD219134 c. Our calculations show that the ~10% difference in bulk density of planet b compared to planet c (Dorn et al. 2018) could possibly be explained by hydration effects in the interior. However, the obtained mass-radius curves for the different scenarios were obtained by assuming a likely oversimplified bulk composition. Furthermore it must be noted, that $Mg(OH)_2$ as a pure substance has a very narrow stability field in the PT-plane (e.g. Hermann 2016). Treating the entire pressure range in the mantle with the equation of state for the stable $Mg(OH)_2$ phase can therefore be expected to introduce considerable errors on the computed density. Nevertheless, our current efforts show, that hydration can significantly affect the radius of a planet and that this effect is in principle large enough to be accessible by observations.

References

[1] Dorn, Caroline, et al. "A new class of Super-Earths formed from high-temperature condensates: HD219134 b, 55 Cnc e, WASP-47 e." *Monthly Notices of the Royal Astronomical Society* 484.1 (2018): 712-727.

[2] Hermann, A., & Mookherjee, M. (2016). High-pressure phase of brucite stable at Earth's mantle transition zone and lower mantle conditions. *Proceedings of the National Academy of Sciences of the United States of America*, *113*(49), 13971–13976. doi:10.1073/pnas.1611571113

[3] Seager, Sara, et al. "Mass-radius relationships for solid exoplanets." *The Astrophysical Journal* 669.2 (2007): 1279.

[4] Sotin, Ch, O. Grasset, and A. Mocquet. "Mass–radius curve for extrasolar Earth-like planets and ocean planets." *Icarus* 191.1 (2007): 337-351.