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Interior characterization in multiplanetary systems: Trappist-1

Caroline Dorn (1), Klaus Mosegaard (2) and Simon Grimm (3)
(1) University of Zurich, Institut of Computational Sciences, Switzerland (2) Niels-Bohr-Institute, Copenhagen, Danmark, (3) University of Bern, Center for Space and Habitability, Switzerland

Abstract

There are available data specific to multi-planetary systems which have not yet been considered for interior characterization of planetary interiors. For Trappist, the specific data are the correlations of masses between different planets as derived from TTV analysis. Furthermore, we demonstrate that the rocky interior of planets in a multi-planetary can be preferentially probed by studying the most dense planet being an analogue for a rock-dominated interior.
Our methodology includes a Bayesian inference analysis that uses a Markov chain Monte Carlo scheme. In addition, we develop a new resampling method that allows us to account for the correlations of masses between different planets.

For the interiors of Trappist-1 planets, we find that possible water mass fractions generally range from 0-25%. No clear trends in the amount of water and orbital period are observed. Our results suggest that planetary water budgets originate from the accretion of material with limited bulk volatile content (below 30 %) and from fairly well-mixed regions in the protoplanetary disk that blurred any trend of increasing volatile fraction with orbital period.

1. Introduction

The Trappist-1 planets do not follow a single mass-radius trend, but there is some scatter among the bulk densities of planets. Previously characterized by [4], the most recent and more precise mass and density estimates from [5] provide new insights into the planet bulk compositions. They find that purely rocky interiors are likely for planets c and e, while planets b, d, f, g, and h require envelopes of volatiles. The outer planets f–h have cold enough equilibrium temperatures such that common volatile species CO_2 and H_2O are condensed out. The high bulk density and temperature conditions of planet e may allow for Earth-like surface conditions.

The volatile layers are unlikely to be hydrogen-dominated, since their lifetimes are limited by the large EUV irradiation [1], which is supported by transit spectroscopic observations [3]. Thus, previous atmospheric investigations strongly suggest the presence of terrestrial-type atmospheres.

Here, we quantify the origin of the scatter in bulk densities of the planets and investigate the value of different data types for an improved interior characterization.

2. Method

We employ a Bayesian inference analysis that uses a Markov chain Monte Carlo scheme. In addition, we develop a new resampling method that allows us to account for the correlations of masses between different planets.

Our interior estimates account for the anticipated variability in the compositions and layer thicknesses of a pure iron core, a silicate mantle of general composition, pure-water ice and ocean layers, and terrestrial-type atmospheres, and thermal state of the planets.

The data comprise planetary masses and radii and their correlations, stellar irradiation, and different abundance proxies (i.e., no proxy, a stellar proxy, a proxy based on the most dense planet of the system). In addition, we account for the correlation between the masses of different planets, which has not been consiedered in previous characterization studies.

3. Results

Our results show that there are significant influences on interior estimates given (1) different abundance proxies on rock-forming elements and (2) the correlations of masses between different planets. In comparison, observational uncertainties on mass and radius have only limited influence on interior estimates.

Different abundance proxies can lead to differences in the median predicted water mass fraction that range from 25% up to 50%. This is because different proxies allow differently dense rocky interiors, which affect the amounts of possible water in order to fit mass and radius.

The improvements gained by accounting for the correlations of masses between different planets are large. For planets b, c, e and h thay vary between 50-70 %, while they range from 0-30% for d, f, and g. The level of improvements depend on the abundance proxies and how compatible they are with the individual measured masses and radii of the planets.

In Figure 1, we show a summary of predicted water mass fractions for all planet that account for the anticipated variability in structure and composition of Super-Earths. For the shown Figure, water mass fractions range up to 20-30% for b and d. Lowest values are found for planet e, but also c and h with few percents of water mass fractions.

There is no clear trend of increasing water mass fraction with orbital period which can be explained with mixing of planetesimals from ice-rich and ice-poor regions of a disk. The fact that the Trappist-1 planets are much more volatile-rich compared to the terrestrial Solar System planets is in line with predictions from planet formation [6].

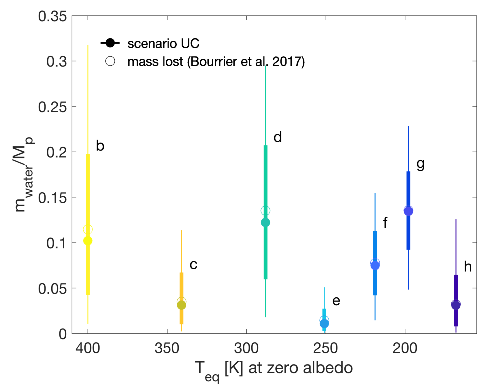

Figure 1: Marginalized water mass fractions as a function of equilibrium temperature T_{eq} (at zero albedo). No obvious trend of increasing water mass fraction with larger orbital distance and thus cooler T_{eq}. For the water mass fractions, the 3th-16th-84th-97th-percentiles are depicted by the thin and thick error bars. How much water mass fraction there could have been after formation (open circles) is calculated by adding the amount of possibly lost water [2] to our inferred median estimates (filled circles).

4. Summary and Conclusions

Trappist-1 planets are not scale-up analogs of each other but have variable bulk densities. Here, we have quantified the origin of this variability, that is mostly due to different amounts of water, but also to some extent the sizes of rocky interiors and the thicknesses of gas envelopes. There is no clear trend of volatile fraction with orbital period. This suggests that accreted planetesimals were sufficiently mixed such as to blur otherwise expected increases of water fraction with distance from the star.

With our study on Trappist-1, we have explored the data types that are specific to multi-planetary systems. Such data will be relevant for the interior characterization of planets in other systems as well, for which our study provides new pathways for an improved interior characterization.

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