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Two terrestrial exoplanet families with different origins

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Abstract

We examine the trends for small planets in the three-dimensional radius-insolation-density space and find that the Earth-size planets divide into two distinct families based on insolation. The lower insolation family merges with terrestrial planets and small bodies in the solar system. The higher insolation terrestrial planet family forms a bulk-density continuum with the sub-Neptunes, and is thus likely to be composed of remnant cores produced by photo evaporation.

1. Introduction

One of the important questions in the study of exoplanets is: “Are terrestrial exoplanets Earth-like, Venus-like, or the remnants of gas- or ice giants?” [1]. With the original sub-Neptune envelope largely or completely removed through photoevaporation or another process, the planet radius is determined by the size of a rocky, or possibly icy, core. Recent work [2] demonstrated the presence of a deficit in the planet occurrence rate around 1.75 Earth-radius and provided a compelling observational motivation for invoking the loss of sub-Neptune H/He envelopes as a formation mechanism for super-Earths. To improve our understanding of the processes that shape the bulk properties of small planets, we explore the relationships between radius, insolation, and density for exoplanets and small bodies in our solar system.

2. Results

For this study, we used data from the NASA Exoplanet Archive and restricted the sample to confirmed planets with radius values less than 3.5 Earth-radius augmented with planets from [3] and recent results for the Trappist-1 system [4]. Kepler target radii were updated with GAIA-derived values [5]. We removed planets with anomalously large densities (ρ>15 g/cm3), a planet pair thought to have survived stellar engulfment [6], and a planet pair with an anomalously large inclination difference, potentially indicating an unusual dynamical history [7]. The resulting sample contains 107 exoplanets (Fig. 1).

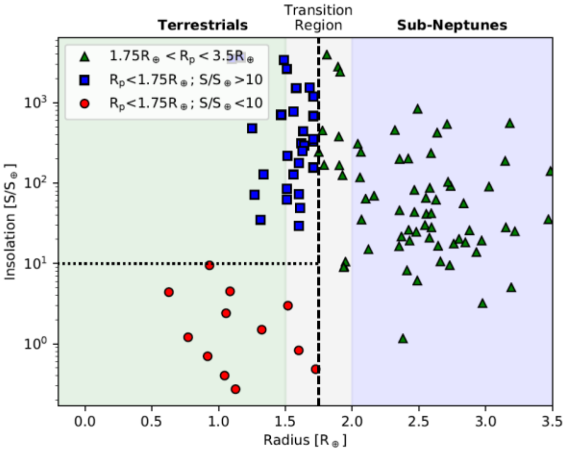

Figure 1: *An insolation gap divides the terrestrial planets into two categories which are the Earth-like planets (red circles) and the naked cores of sub-Neptunes (blue squares)***.**

Terrestrial exoplanets are defined as planets having a radius lower than 1.75 Earth-radius where there is a gap [2]. This group of exoplanets can be separated into two families according to their insolation with a clear separation around 10 times Earth-insolation (Fig. 1). The T1 family has low insolation and includes objects in the solar system whereas the T2 family has insolation more than 10 times larger than Earth. Interestingly, the separation between the T1 and T2 terrestrial exoplanets remains largely true in a radius-density plane (Fig.2).

Excluding the T1 family, a general trend with decreasing density with increasing radius emerges. We modeled this trend with a bilinear piecewise continuous function and retrieved the model posterior distributions using a Markov Chain Monte Carlo method [8]. The average slope of the radius-density function is larger for the T2 terrestrial exoplanets than for the sub-Neptunes. The T1 family follows a completely different trend with a positive slope with the density increasing with radius. The linear trend obtained without any assumption is very close to the theoretical prediction for Earth-like planets [9].

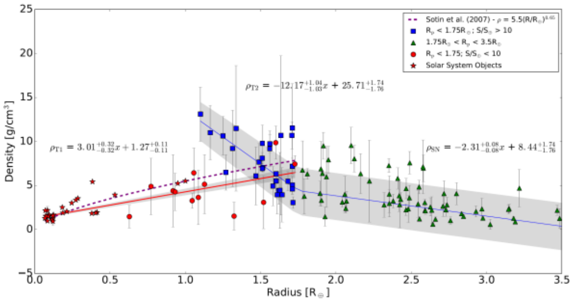

Figure 2: *Three family of exoplanets can be defined in a radius-density plot suggesting that the terrestrial planets are either Earth-like (red circles) or the naked core of sub-Neptunes (blue squares).*

The T2 terrestrial exoplanets family is also characterized by an increase in density with increasing mass (Fig. 3). This trend is not compatible with photo evaporation since removing the lighter component would lead to larger density while decreasing mass. It is however compatible with mass enhancement by collisions and accretion of denser material. The T2 family would therefore be the result of the evolution of sub-Neptunes that would loose their atmosphere by photo evaporation and would increase their density by late collisions as they migrate towards their star.

3. Summary and Conclusions

Terrestrial exoplanets divide into two families. First, the Earth-like exoplanets show low levels of insolation. They likely formed by collisions like the inner planets of the solar system. The second family is marked by high level of insolation. It shows a continuity with the sub-Neptunes in the density-radius trend. The strong implication is that T2 super-Earths are the remnant cores of gas giant planets and were created by photoevaporative stripping of sub-Neptunes. However, the T2s are created not only by photoevaporation/stripping; the T2 mass-density correlation implies a process which increases mass with increasing density, potentially late bombardment of naked cores.

This study suggests that the number of Earth-like exoplanets with known radius and mass is limited to less than a dozen. Future work will investigate the potential habitability of this subset of exoplanets.

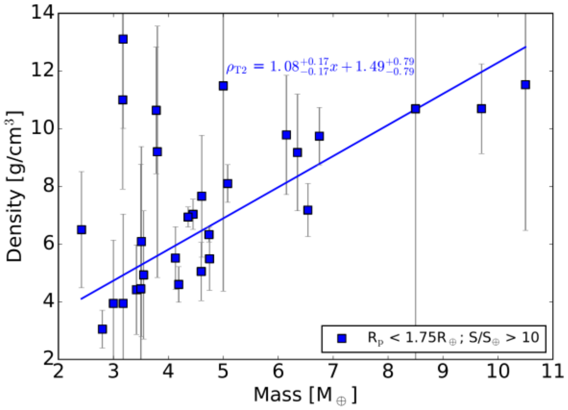

Figure 3: *The positive slope of the mass-density relationship for the T2 terrestrial exoplanets is consistent with mass enhancement by collisions.*

Acknowledgements

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References

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