Similarity of multi-planetary systems

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Introduction

It was suggested that planets orbiting the same star tend to have similar sizes and masses. However, these results are based in Kepler data. Due to the faintness of the stars, only a few of the planets were also detected with radial velocity followups and, therefore, the planetary masses were mostly unknown.

Goal: In this work we revisit several aspects of the "peas in the pod" pattern (i.e. the radius, mass and period ratio correlation) in detail by accounting for observational biases and using different exoplanet catalogs.

Similarity in mass and radius

The Sample

We use the NASA Exoplanet Archive on July 2021. We exclude the less accurate data by considering only planets with uncertainties smaller than $\sigma_M/M = 50\,\%$ $\sigma_R/R = 20\,\%$, which leaves us with 48 systems.

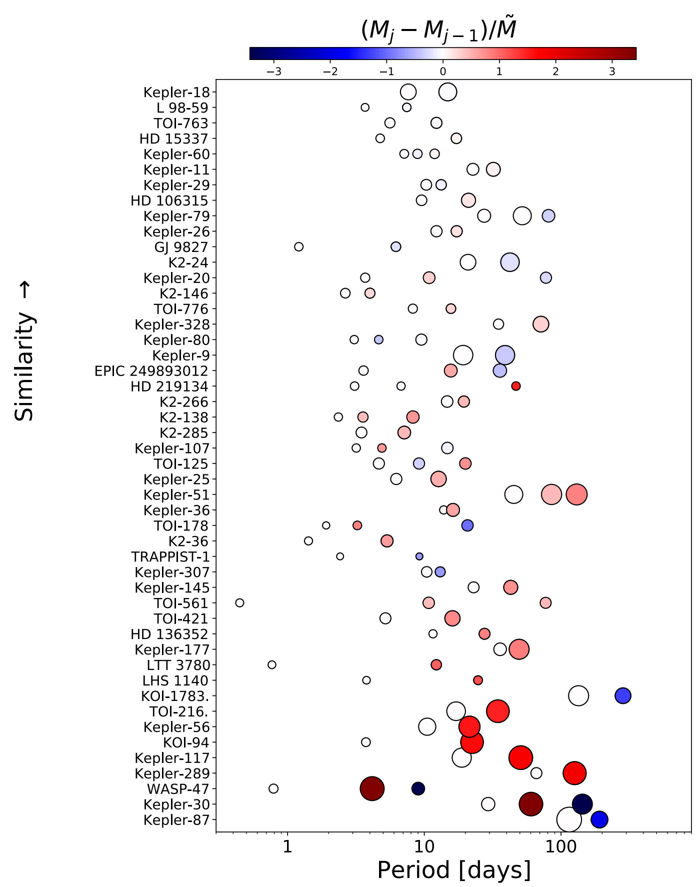

Figure 1: Orbital architecture of the 48 multi-planetary systems in our sample. They are ordered by similarity in mass. The size of the points is proportional to the size of the star, and the color represents the change of mass of a planet with respect to the previous one, normalised by the median in the system. The systems are ordered by similarity in mass.

Comparing diversity in mass and radius

We quantify the similarity of the systems considering the distance in the log M_p space, which can be expressed as:

$$\mathscr{D}_M = \sum_{\substack{i=1 \\ P_i < P_{i+1}}}^{N_{pl}-1} \left| \log \frac{M_{i+1}}{M_i} \right| \Big/ N_{pl} - 1$$

With an equivalent expression for $\mathscr{D}_R$.

Figure 2 shows an histogram of the $\mathscr{D}_M$ and $\mathscr{D}_R$. It shows that systems tend to be more similar in mass than in radius. We remind that this metric is not sensitive to the size of the range in mass and radius. We also find that the most similar systems in match do not match the most similar systems in radius. None of the ten most similar systems in mass match any of the ten most similar systems in radius.

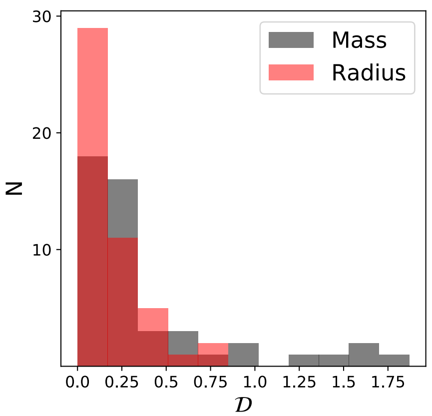

Figure 2: Histograms of $\mathscr{D}_M$ (black) and $\mathscr{D}_R$ (red).

Analysis of the "peas in the pod" pattern

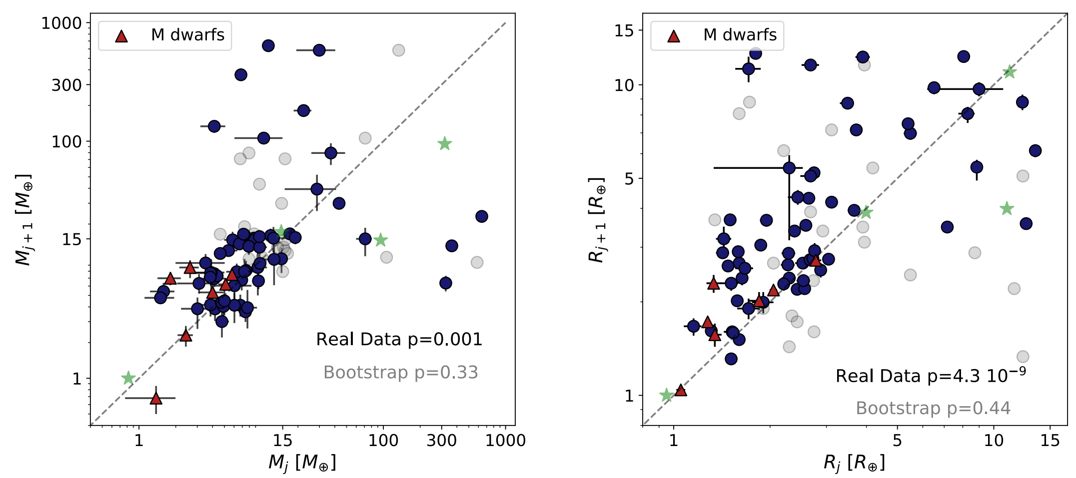

Figure 3: The mass (left) or radius (right) of a planet against the mass or radius of the next planet farther from the star. The red triangles correspond to pairs of planets around M-dwarfs. The green star shaped markers correspond to the Solar System planets and the grey points to a bootstrap trial.

We investigate the "peas in the pod" pattern of the systems in our sample, as shown in Figure 2. In order to asses the role of detection biases we perform a series of bootstrap tests. We confirm that the "peas in the pod" trend found in our sample cannot be explained by observational biases, and that there is a sharp transition in the uniformity of planets at $\sim 100 M_p$ and $\sim 10 R_p$. Systems below this limits tend to be much more uniform.

We also find a clear dependency of the with the stellar mass. Systems around more massive stars tend to be less uniform in mass and radius. Note in Figure 2 that systems around M-dwarfs follow closely the 1:1 line.

Systems with less precise mass and radius measurements tend to be less uniform, probably due to the high proportion of low mass and radius planets among planets with high uncertainties.

Similarity in density:

We also investigate the "peas in the pod" pattern in other quantities. The planetary density for instance, show strong correlation between adjacent planets.

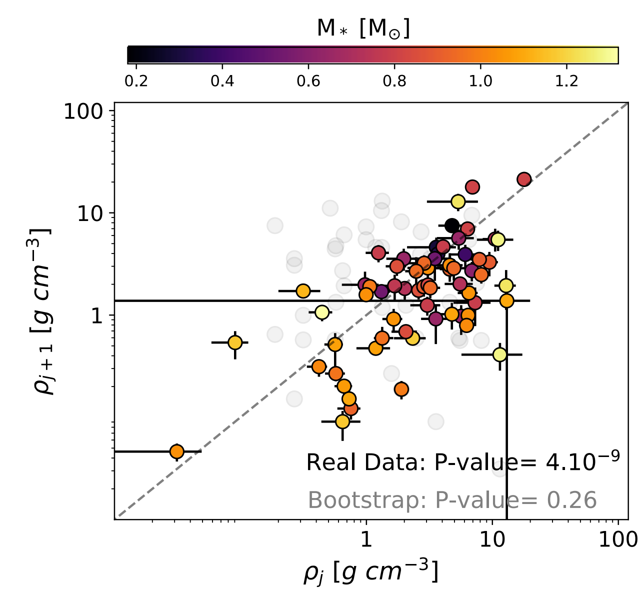

Figure 4: The planetary density against the densities of the next planet farther from the star. The colors of the dots represent the effective temperature of the host star, and the gray dots correspond to a bootstrap trial.

Summary & Conclusions:

Our main findings are the following:

- Systems tend to be more similar in radius than in mass, and the most similar systems in radius do not match the most similar in mass.
- There is a sharp transition in the "peas in the pod" pattern of planets at $\sim 100 M_p$ and $\sim 10 R_p$. Systems with planets below these limits are significantly more uniform.
- Even if so far only basic physical quantities as planetary mass or radius have been studied in detail, other quantities as the density may be important to fully understand the nature of planetary systems.

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