

On the origin and time evolution of the period ratio distribution of super-Earths and sub-Neptunes

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Observations by Kepler and other telescopes such as TESS have revealed detailed orbital information for super-Earths and sub-Neptunes (SEs). In particular, the distribution of orbital period ratios between neighboring SEs is important because it reflects the formation and dynamical evolution processes of planetary systems. The most notable feature of the period ratio distribution is that most SE pairs are not in mean-motion resonances. Additionally, recent observations of planetary systems suggest a decreasing trend in the fraction of pairs that are in resonances over time. It is also known that the period ratios of pairs in resonances are not exact integer ratios, but are often slightly shifted outward. These features of the period ratio distribution have been extensively studied, both observationally and theoretically, as one of the most important characteristics of SEs since the Kepler mission. However, the physical processes that determine these features in the period ratios—particularly the fact that most pairs are not in resonances—still require further theoretical investigation.

In this study, we simulate the formation of SEs from a ring of solids, following the planet formation scenario from rings that has recently gained attention in general planet formation theory. Specifically, we investigate the formation of SEs from a ring of planetary embryos in an evolving protoplanetary disk using *N*-body simulations that account for collisional accretion and orbital migration. A large number of simulations are conducted under a variety of conditions, including variations in the initial solid distribution and its mass, disk evolution, and the rate of orbital migration. By analyzing the simulation results, we aim to gain a deeper understanding of how the characteristics of SE orbital period ratios are determined. We also discuss to what extent the planet formation scenario from the ring can explain the origin of SEs.

The results of the simulations so far are as follows: First, the characteristic feature that the fraction of SE pairs in mean-motion resonances decreases over time, with most SE pairs falling out of resonance in older systems, can be explained by the process of convergent migration during formation followed by resonant breaking due to orbital instability. We also find that the orbital instability is influenced by the material remaining near the ring region where the SEs formed. Additionally, it is suggested that the formation scenario considered in this study can explain the feature that SE pairs in resonance tend to pile up slightly outside of exact commensurability. In this presentation, we will present these latest results and discuss how the ring-based planet formation scenario can account for the observed features, including the time evolution of the period ratio distribution of SEs.

Keywords: Super-Earths, Sub-Neptunes, Period-ratio distribution, Mean-motion resonances, Planet formation