There might be giants: Companions to compact planetary systems

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Abstract

The limited completeness of the Kepler sample for planets with orbital periods greater than ~1 yr leaves open the possibility that some exoplanetary systems may host as-yet undetected extra planets. Should such planets exist, their dynamical interactions with the inner planets may prove vital in sculpting the final orbital configurations of these systems. Using an N-body code with additional forces to emulate the effects of a protoplanetary disc, we perform simulations of the migration of systems of super-Earth mass planets with unseen giant companions. The systems formed in these simulations are analogous to Kepler-11 or Kepler-32, containing 3-5 inner planets, with giant companions which are unlikely to have been detected by Kepler. We use the results of these simulations to explore the effect that unseen giant companions would have on mean-motion resonances between the innermost planets in such systems.

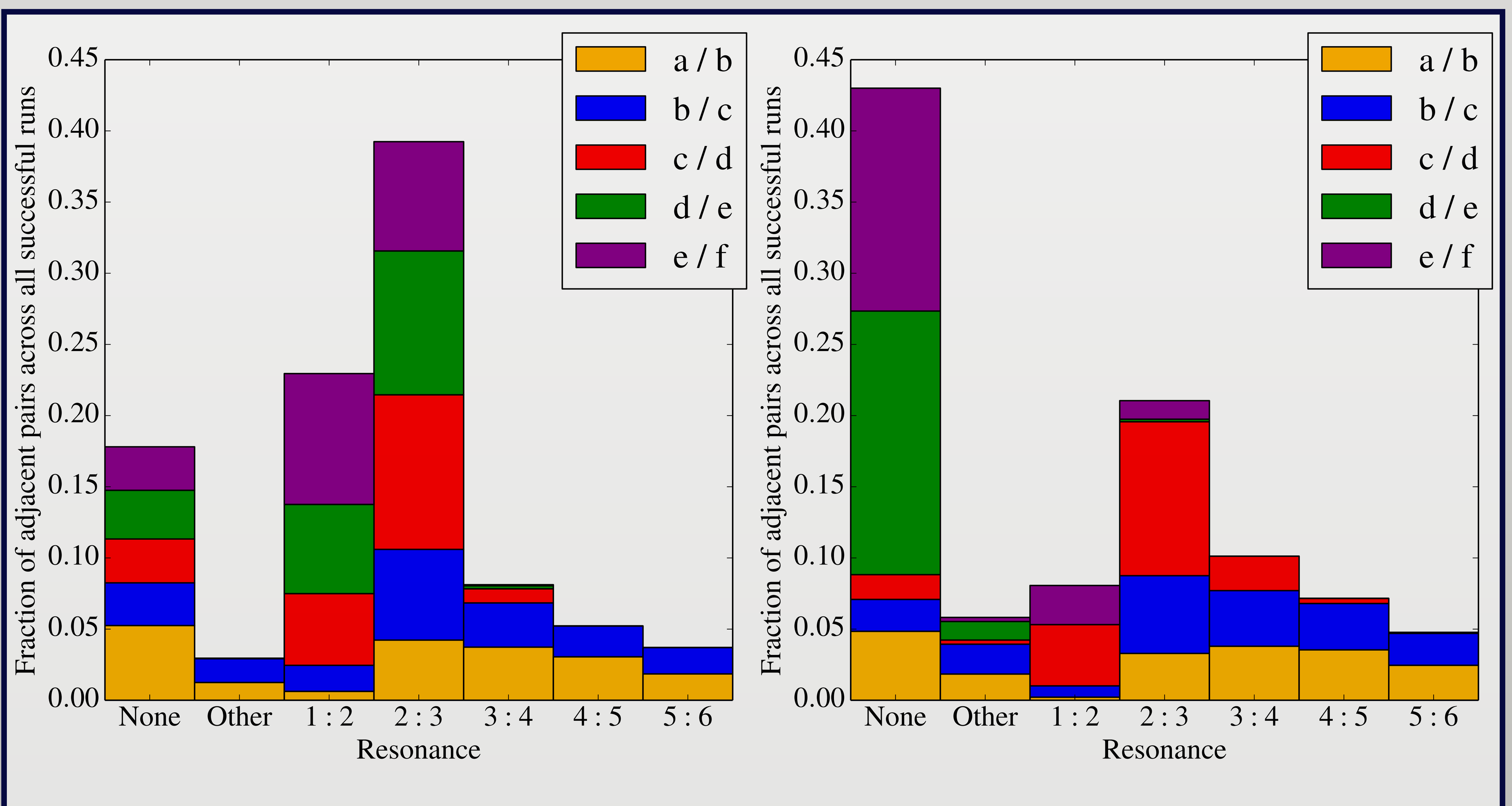

Figure 1 - The difference in the occurrence of mean-motion resonances between the control case (left) and the case where planet 5 grows to a 3 Jupiter-mass giant (right).

Motivation

Recent advances in the discovery of exoplanets have revealed several distinct populations, with the Kepler mission highlighting a large number of extremely compact systems of super-Earths (e.g. Kepler-11, Lissauer et. al. 2011), and radial velocity surveys discovering many Jupiter-analogues outside of 1AU. In spite of the relative abundance of both populations, there has not yet been a detection of a system of compact super-Earths with an exterior giant companion, largely due to a lack of overlap between the 2 discovery methods. Thus there remains the possibility that compact systems sculpted by giant companions may exist.

In our previous work (Hands et. al. 2014), we explored the possibility of assembling compact Kepler systems via traditional, disc-driven migration, finding it to be a viable method that somewhat over-predicts the occurence of mean-motion resonances. Here we investigate the dynamical effect of adding an unseen Jupiter-mass planet during this process.

Method

We follow the method of Rein and Papaloizou (2009), following the inward migration of a system of super-Earths using an N-body code with 3 parametrized forces representing migration, eccentricity damping and disc turbulence. These forces are controlled by 3 free parameters. We additionally introduce a toy model for runaway growth, letting the mass of one of the super-Earths increase exponentially (on a prescribed time-scale) to become a (gas-)giant once it reaches 1AU. Each simulation begins with the same 6-planet system of super-Earths, which increase in mass with distance from the star (analogous to Kepler-11 and Kepler-32). We ran 4 sets of 1000 simulations, varying which planet (5th or 6th from the star) undergoes runaway growth and the final mass that it attains (1 or 3 Jupiter-masses). A 5th set of simulations in which no planet undergoes runaway growth is treated as a control.

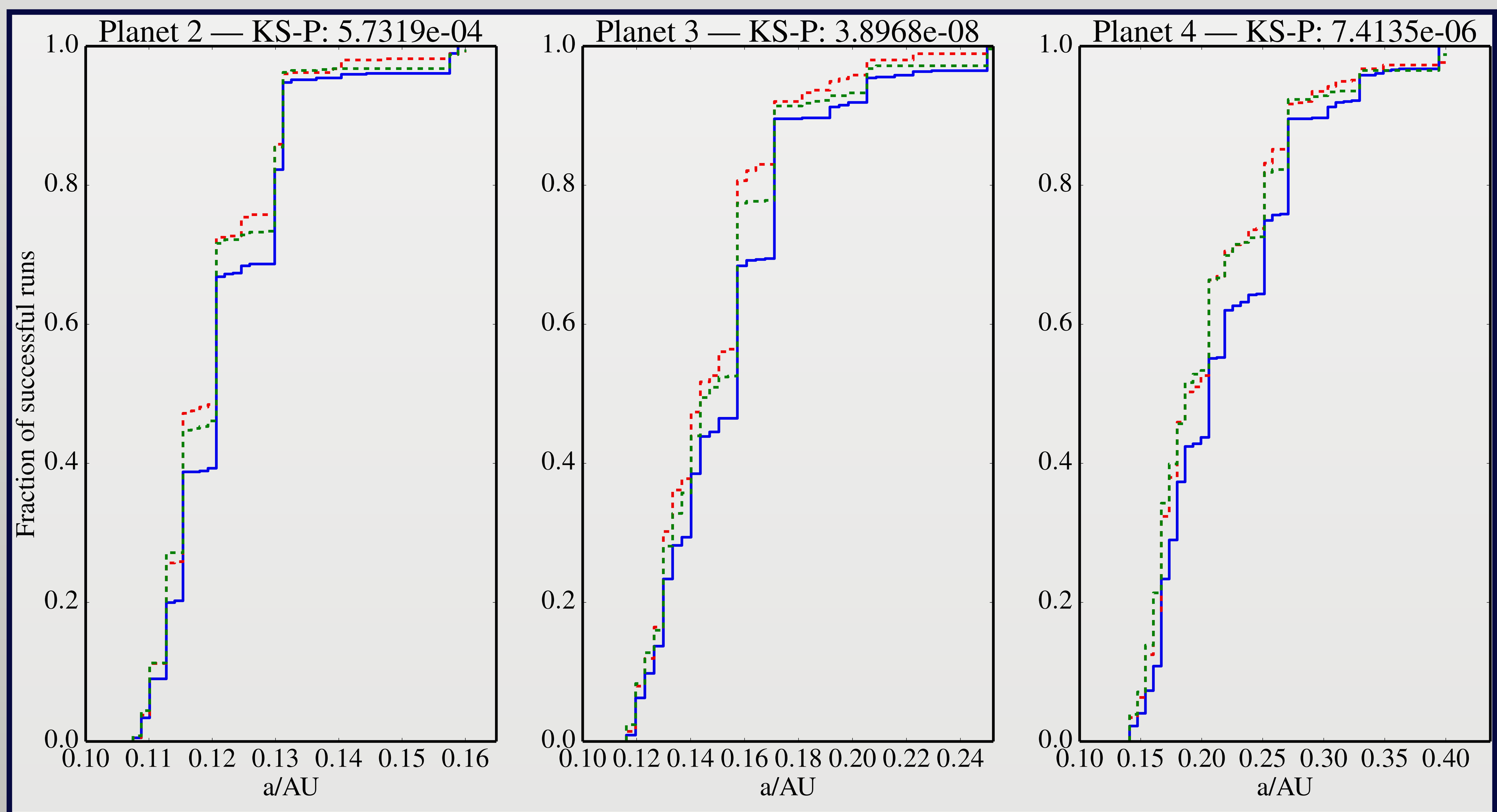

Figure 2 - Position distributions of planets 2-4 (from left to right) in the control case (blue) and the case where planet 5 grows to a 3 (red) and 1 (green) Jupiter-mass giant. Probabilities from a K-S test are shown above each panel. Note the large differences between the distributions.

Results & Conclusion

The growth of either the 5th or 6th planet to a giant during the migration phase can significantly perturb the innermost super-Earths compared to the control case. Figure 1 shows the effect that this has on the preferred mean-motion resonances, with more of the interior planets being out of resonance in the case with a giant planet, and also generally preferring higher-order, weaker resonances. Figure 2 shows that this effect is also reflected in the final locations of the interior planets, with giant companions allowing interior planets to occupy more tightly-packed orbits. The magnitude of the effect depends sensitively upon the final mass of the giant and the number of interior planets.

We find that unseen Jupiter-mass companions could have a significant dynamical effect on compact planetary systems, altering the final locations and preferred resonant configurations.

References

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