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Infrared Excesses in Kepler Multiplanet Systems Using WISE

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Abstract

The newly-announced Kepler multiplanet systems are suddenly the best candidates to host undetected hot asteroid belts. Low mutual inclinations and over-stable orbits make it likely there has not been large-scale planet migration, and thus several Earth masses of planet-building material were (and perhaps still are) present within 1 AU of these stars. Because of this location close to the star, planetesimal belts between these planets would be hot asteroid belts with equilibrium temperatures measured in hundreds of Kelvin. Mid-infrared data from WISE is used to constrain the amount of dust present in these systems. Beyond analyzing valuable multi-wavelength data on these exciting new planetary systems, these dust measurements help address the puzzle of how some mature stellar systems currently have massive dust disks, despite models finding very low probability of their existence.

1. Introduction

Planetesimal belts may be used as a diagnostic of stability. The resonant features in our Kuiper Belt are likely best explained by outward migration of Neptune in the final stages of planet formation. Many hot Jupiter systems have excesses at long wavelengths, indicating dust that orbits at Kuiper Belt distances from the host star (Bryden et al. 2009). Were the inner (asteroidal) planetesimal belts of these systems destroyed by the hot Jupiters migrating inwards? Because of Kepler's transit detection technique, all of the discovered planets are coplanar to within a few degrees; additionally, Latham et al. (2011) find that among the Kepler-discovered systems, multiplanet systems are less likely to host a giant planet than single planet systems. If this pattern holds with future Kepler data releases containing longer period planets, these are systems that have not been disrupted, and the planets may still be orbiting at the distance where they formed. This implies that any leftover planetesimal belts may still be intact, making these Kepler multiplanet system the best candidates for finding stable extrasolar small body belts.

2. Stability in Multiplanet Systems

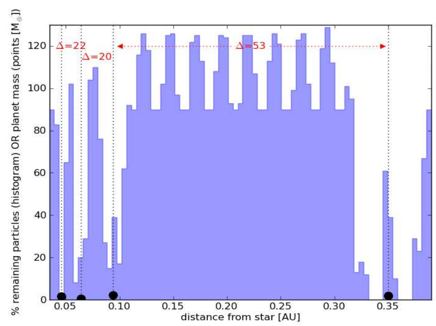

Figure 1: This histogram shows the percentage remaining test particles after a 10^7-orbit integration. Particles are swept up by nearby planets, forming gaps, but remain stable between these planets because $\Delta \geq 20$ for all three planet pairs. Circles show the planets' semimajor axes, and the y axis gives their masses in $M_\oplus$.

Lissauer et al. (2011) discuss the ∼170 known Kepler multiplanet systems, and point out that most of these systems are overstable. This stability is measured in terms of the mutual Hill radius, $R_H = (\frac{M_i+M_o}{3M_*})^{1/3}(\frac{a_i+a_o}{2})$, where M_i and M_o are the masses and a_i and a_o are the semimajor axes of the inner and outer planets. Δ is used to measure the separation of the two planets: $\Delta = \frac{a_o-a_i}{R_H}$. Gladman (1993) proves that when Δ is greater than 3.5 for two planets of similar mass on initially circular orbits, those planets can *never* have their orbits cross. Because of the perturbations from other planets in the system, this criterion rises empirically to $\Delta = 9$ for multiplanet systems (Lissauer et al. 2011). We take this a step further and postulate that for two-planet systems with $\Delta \geq 20$, stable orbits can exist between these planets and there is a possibility for a planetesimal belt there.

Figure 1 shows the results of an orbital integration for KOI 70, which has four planets, each separated by $\Delta \geq 20$. Particles remain between each of the planets as predicted.

3. WISE Data

The Wide-field Infrared Survey Explorer mission (WISE) released its preliminary survey in mid-April 2011. The released data covers about half of the Kepler field, including ~80 multiplanet hosts. These systems are all detected in WISE's 3.4 and 4.6 μm bands, most are detected ($>3\sigma$) in the 12 μm band, while only one is detected in the 22 μm band. These wavelengths are where emission from hot dust would peak, and matches quite well with the equilibrium temperatures of the known Kepler planets from Lissauer et al. (2011). We place upper limits on the amount of dust in the inter-planet gaps in each of these systems.

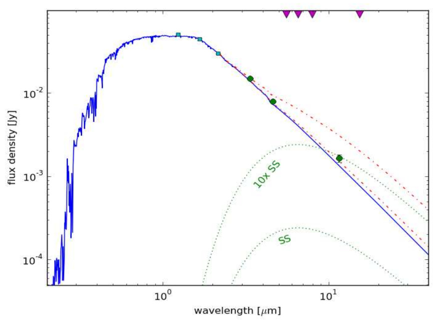

Figure 2: Spectral energy distribution with dust rings of two different masses. See text for explanation.

Figure 2 shows the model spectrum of KOI 70 (blue line; model from Castelli & Kurucz 2004). Squares show data from the 2 Micron All-Sky Survey (2MASS; Skrutskie et al. 2006) which is used to scale the stellar model. The purple triangles at top show the wavelength peak of the blackbody resulting from the equilibrium temperature calculated for each of the 4 planets in this system. The green dotted curves shows the blackbody flux resulting from a ring of 10 μm-diameter dust grains placed between the 3rd and 4th planets of the system, one with a mass equal to the approximate dust mass in our solar system ($\sim 10^{-8}$ $M_{\oplus}$), and one ten times higher. The red dash-dotted lines show the sum of the stellar and dust fluxes. Finally, the green circles show the WISE measurements. In this case, it appears that the WISE data rules out dust masses as high as ten times the solar system value.

4. Summary and Conclusions

We use WISE data to constrain the presence of interplanetary dust rings within Kepler multiplanet systems. The presence of dust in these systems lends support to the idea that Kepler multiplanet systems have not undergone large-scale migration, and that these are very different from systems that host a giant planet. Future Kepler data will help support or refute this idea.

Acknowledgements

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