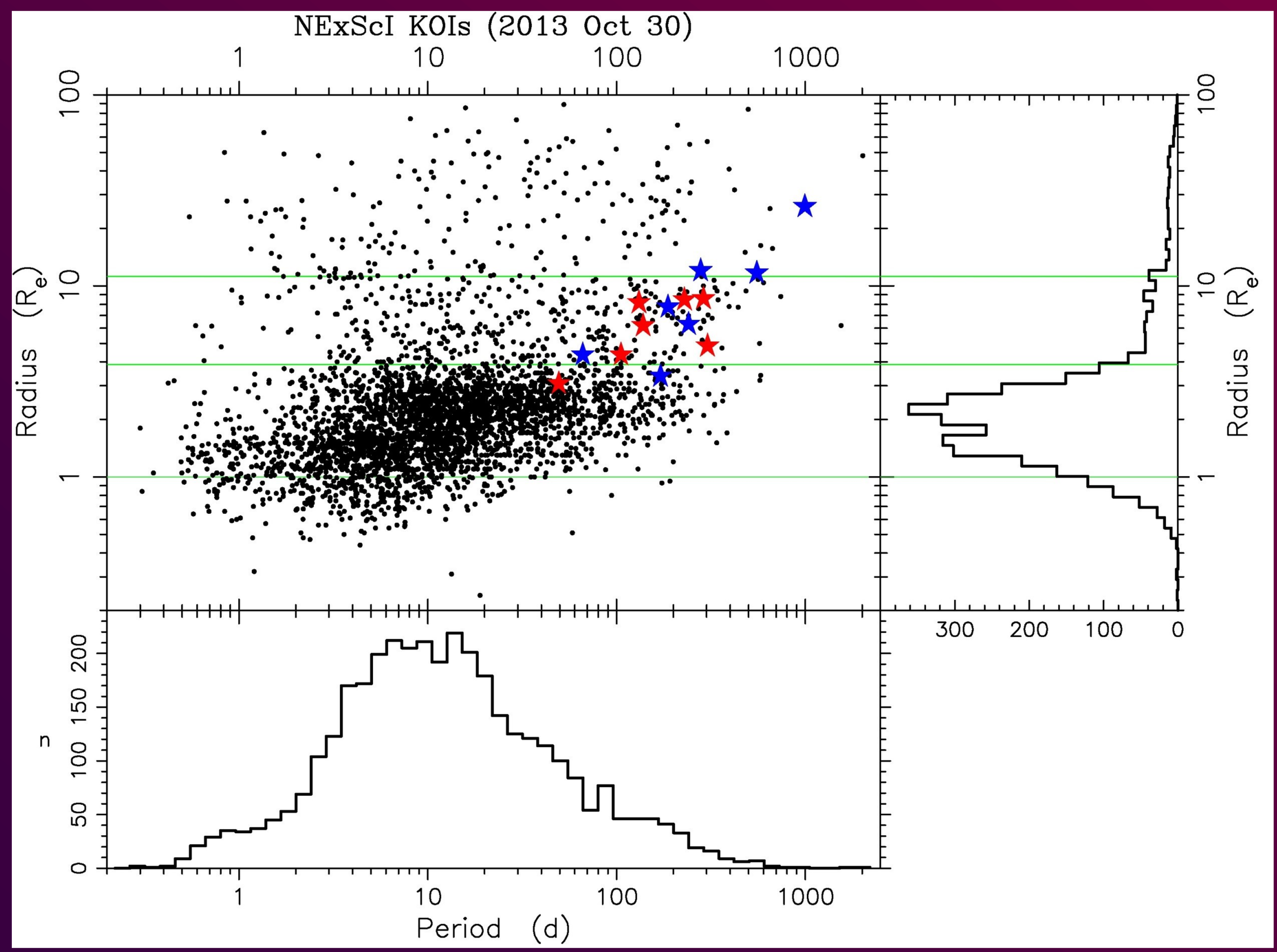
Kepler Circumbinary Planets: Emerging Trends

William F. Welsh and Jerome A. Orosz, San Diego State University

Currently there are 7 confirmed Kepler circumbinary planets (CBPs), and an additional 7 more candidates. While still few in number, the sample is now large enough that some intriguing trends are emerging.

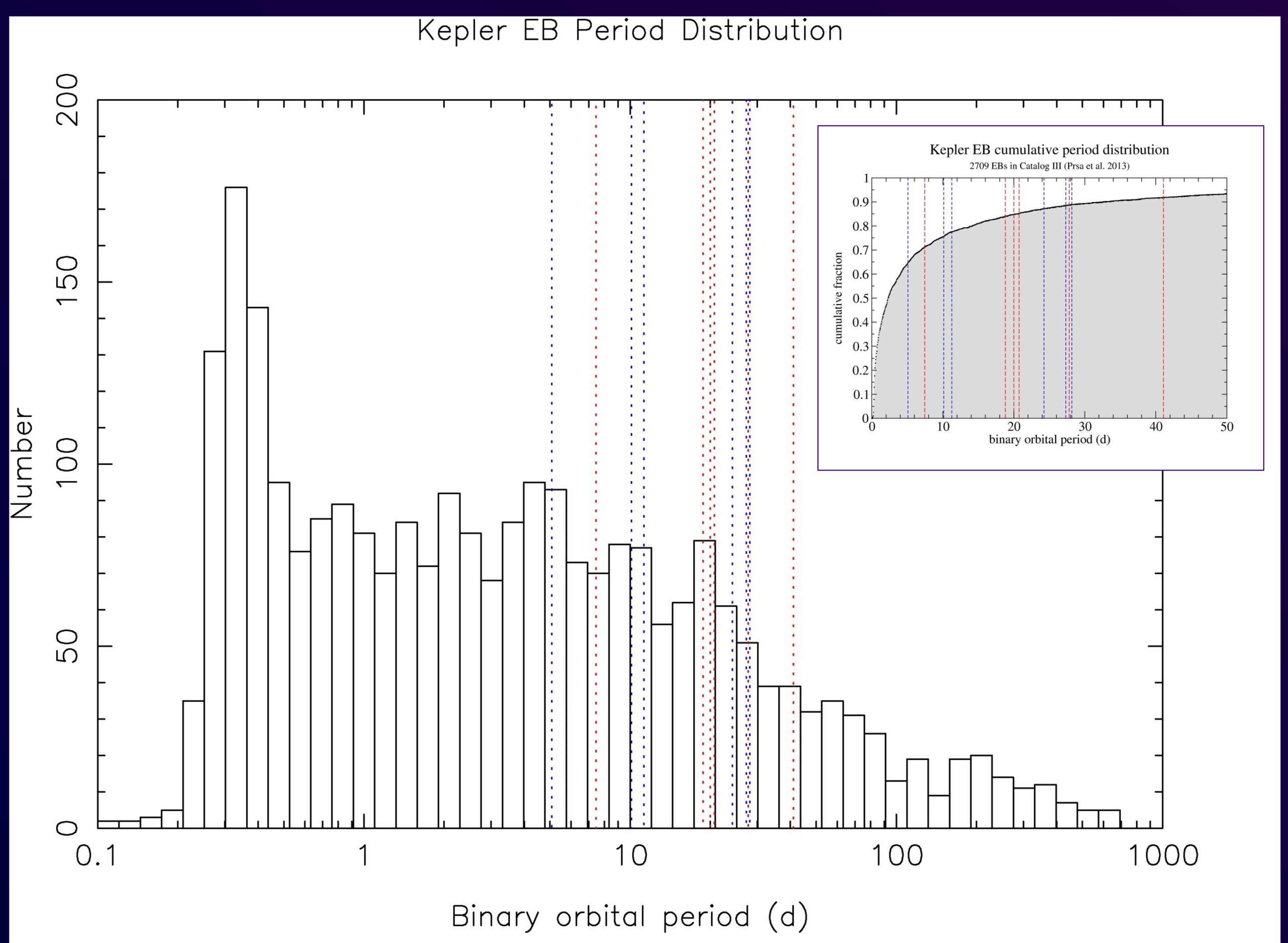
The CBP Population

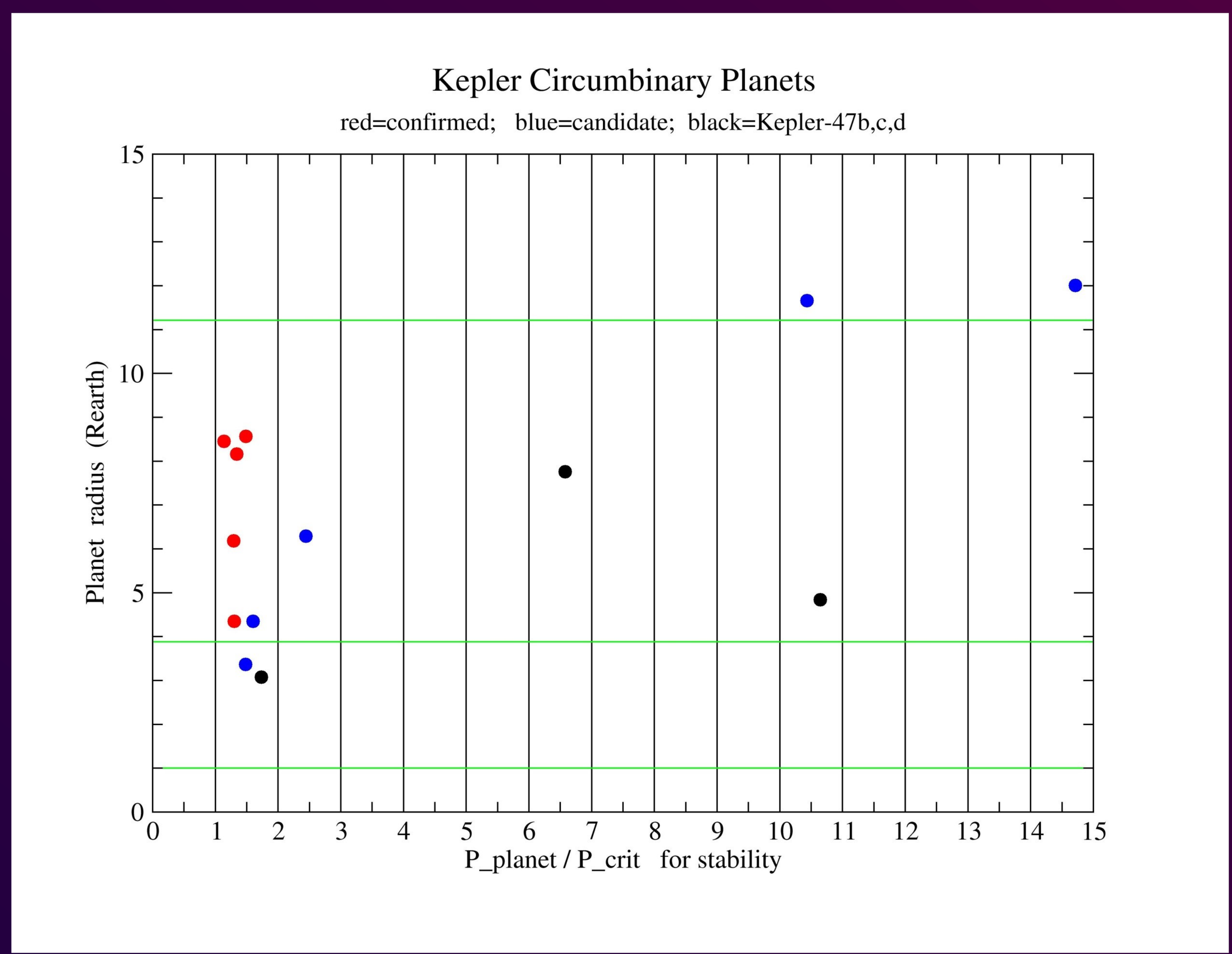
The period and radius distribution of the current set of KOIs is shown in the figure on the right (on a log-log scale). Also shown are the circumbinary planets, with the red symbols denoting the confirmed CBPs and the blue marking the candidate cases. Two differences in these samples are immediately apparent: (i) the CBPs are on average larger than the KOIs, and (ii) the CBPs have longer orbital periods. The size difference could be due to observational bias: for a variety of reasons, CBPs are much harder to detect than planets around single star, so smaller-size planets are easy to miss. Also, the longer periods on average mean fewer transits are present in the data. Perhaps more interesting, notice that in 13 of the 14 cases the planet's radius is Jupiter-size or smaller, even though larger planets are easier to find. (The largest CBP in the upper-right part of the figure is in fact non-transiting and does not have a radius measurement – this is the expected radius based on its mass.) It seems CBPs prefer to be smaller than Jupiter, which may not be unusual, as the same is true for the KOIs. The longer periods for the CBPs compared to the KOIs might naively be seen as simply due to the planets needing to be further from the barycenter for stability, since there are two stars the planet is orbiting. But as shown below, there is a great deal of room available for short-period CBPs, yet such planets are not detected.



Orbital Periods of EBs hosting CBPs

As illustrated in the figure below, the orbital periods of Kepler EBs range from 0.07 to 671 days, with a median of 2.63 days (see Kirk et al. 2013 and the on-line Kepler EB Catalog V3 maintained by Andrej Prsa). In comparison, those EBs that host planets have a median orbital period of 20.4 days. Even the shortest CBP binary has a period of 5.08 days, nearly twice that of the median of the binaries without planets. In the figure below, the dotted vertical lines show the periods of the CBPs. CBPs are not seen in short period systems. Why? It is unlikely an observational bias, since the shorter EB periods would allow for shorter period planets which would exhibit more transits. Perhaps the death of planets around short-period binaries is due to the mechanism that created the tight binary in the first place.





Tendency to be Near-Critical

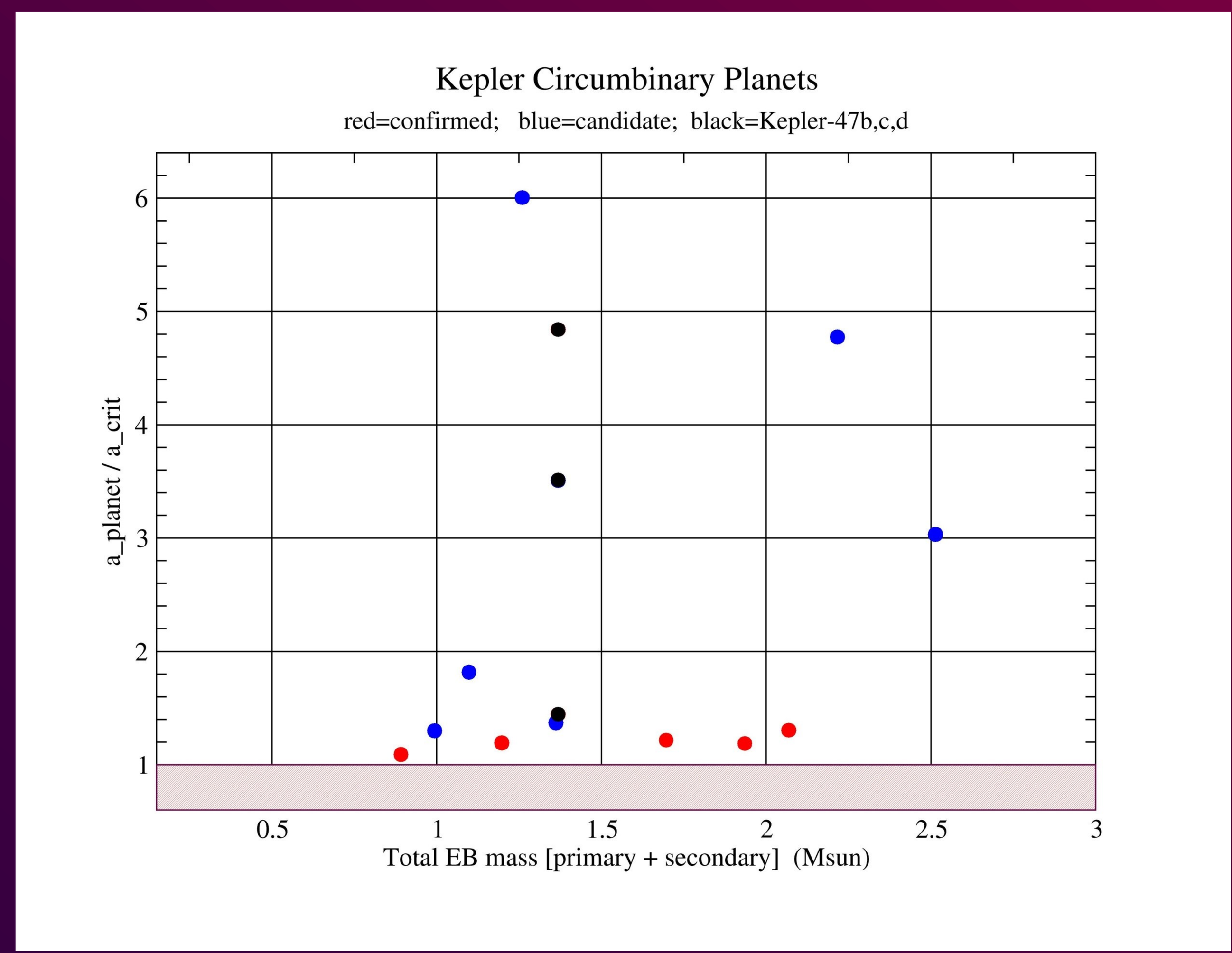
The first transiting CBP discovered, Kepler-16b (Doyle et al. 2011), orbits its host stars in a remarkably tight orbit. Its semi-major axis is only 9% larger than the critical radius within which the gravitational perturbations from the stars could render the planet's orbit unstable (Holman & Weigert 1999). But is this "living on the edge" a feature of CBPs or just a peculiarity of Kepler-16? The above figure reveals the answer – excluding the outer planets of the Kepler-47 system, 8 of 12 CBPs have an orbital period within a factor of 2 of the minimum period needed for stability. See the clumping of points near the P/P_{crit} =1 value on the left hand side of the figure above What is this telling us about CBP formation and migration?

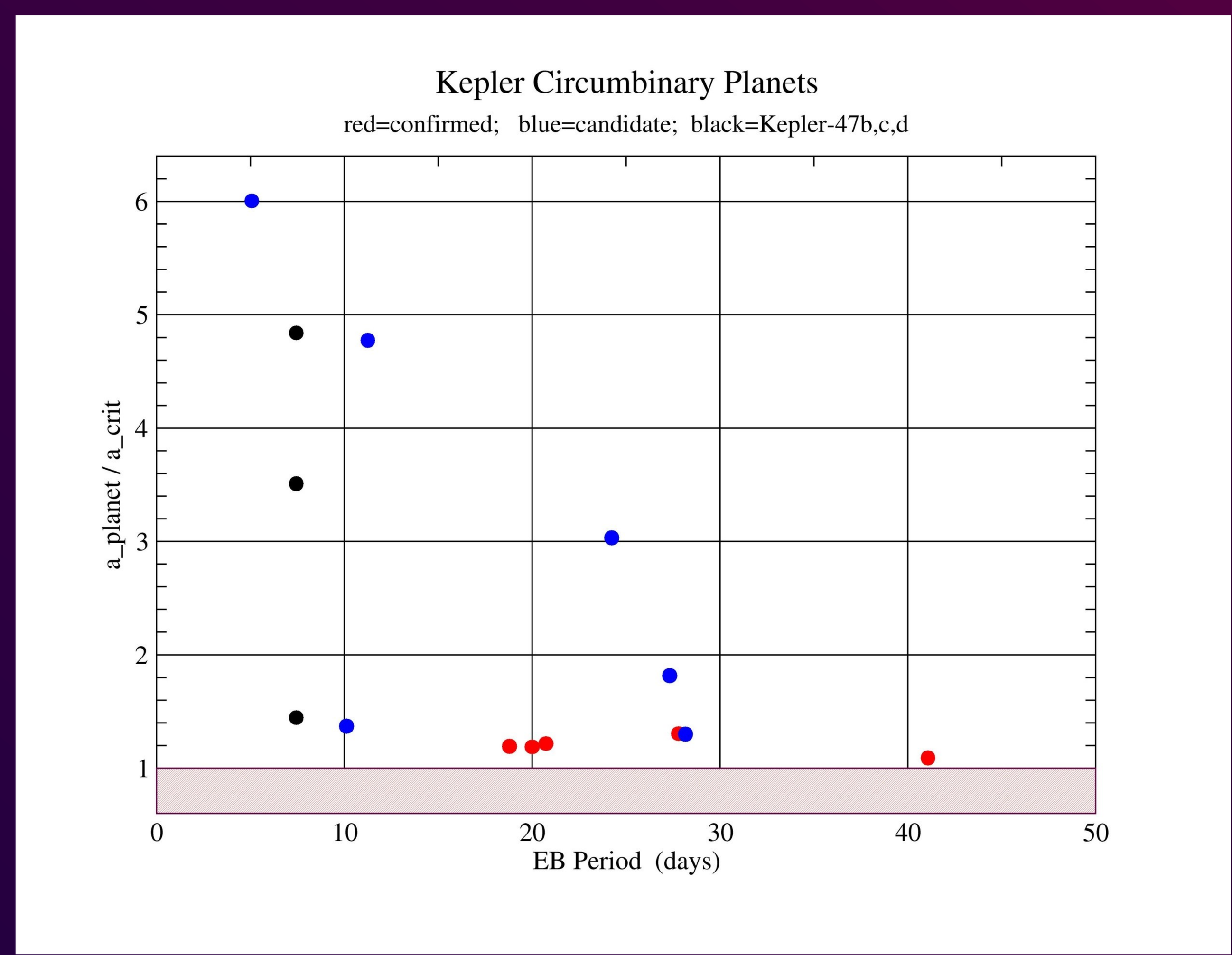
The figure also shows that 11 of 13 CBPs with a measured radius have radii that are Saturn-size or smaller. The green horizontal lines indicate the radii of Earth, Neptune, and Jupiter. The two largest planet candidates are also the furthest from the critical radius, offering a suggestive but very tentative hint that planets of Jupiter size and larger may not lie close to the stability radius, as was found in numerical planet-planet scattering simulations by Pierens & Nelson (2008). But the figure also suggests that there maybe non-transiting planets interior to the one seen to be transiting – there is plenty of room dynamically, as the Kepler-47 system proves (Orosz et al. 2013).

CBPs in the Habitable Zone

The proximity of the planet's orbit to the critical radius for (in)stability can be expressed in either orbital period or in semi-major axis. In the figures below we show the ratio a/a_{crit} versus total mass of the binary and versus the orbital period of the binary. The tendency for CBPs to lie near the unstable region (shaded region) is readily apparent. The fact that some planets are detected far from the critical zone undermines the argument that the pile-up is purely an observational bias (this is where a planet has the highest probability of transiting). The sample of EBs observed by Kepler contains mainly G and K stars, and those with CBPs have periods on the order of tens of days. To be stable, the planet must have a period 3-8x larger than the binary (Holman & Weigert 1999). As a consequence, the Kepler sample of CBPs lie close to the habitable zone: 2 of 7 confirmed planets and 3 of 7 candidates are in the HZ, yielding the remarkable rate of roughly a third of all Kepler CBPs fall in the HZ.

The figures below show no correlation between distance from a_{crit} and the total mass of the binary. There is an apparent lack of planets at large distances from longer-period binaries. But this is likely an observational selection effect – such systems have orbital periods of ~500 – 2000 d, so are less likely to transit and will yield at most only 1-3 transits in the Kepler data.





Acknowledgments

We thank the Kepler EB and TTV Working Groups, with special thanks to Josh Carter. We gratefully acknowledge support from the Kepler Participating Scientists Program via NASA grant NNX12AD23G, and from the NASA Origins Program via grant NNX13AI76G.

References

Doyle, L. R., et al. 2011, Science, 333, 1602
Holman, M.J. & Weigert, P.A. 1999, AJ, 117, 621
Kirk, B. et al. 2013, in preparation
Orosz, J.A. et al. 2013, in preparation
Pierens, A. & Nelson, R. P. 2008, A&A, 483, 633