Testing the Titius-Bode law predictions with Kepler

Chelsea X. Huang & G. Á. Bakos
xuhuang@princeton.edu

PRINCETON UNIVERSITY

Background

The architecture of our solar system was proposed to follow the Titius-Bode (hereafter TB) relation, which describes the semi-major axes of solar system planets in a logarithmic form as a function of their sequences in the system.

Bovaird & Lineweaver (2013) (hereafter BL13) tested the applicability of TB relation on all of the known extrasolar high multiplicity planetary systems ($N_{\rm planets} \geq 4$).

$$log\, P_n = P_0 + n * log\, \alpha, \quad n = 0, 1, 2, ...N-1.$$

1. They found that 94% of the complete systems favor the general TB relation.
2. They predicted 114 additional planets in the 60 Kepler high multiplicity planetary systems.

Method

We search for planets in the high multiplicity Kepler planetary systems based on our previous experience on Kepler data (Huang et al. (2013)). We use a method that includes:

1. Initial de-trending of the data;
2. The reconstructive Trend Filtering Algorithm (TFA);
3. The Box Least Squares method;
4. Removal of the detected signal from the raw light curve and then repeat step 1,2,3 and 4.

Conclusions

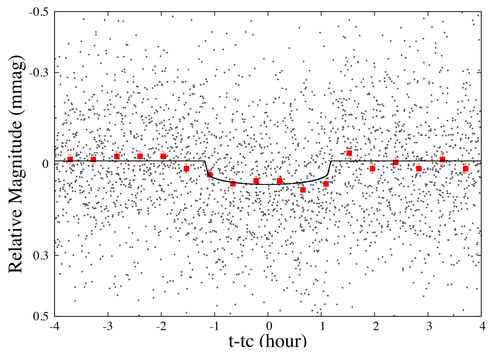
- We did not find the majority of the predicted planets in BL13.
- We have higher detection rates in the sparse systems that required insertion.
- We found out the small number of detections are hard to be explained by observational bias.
- We suggest a possible over-prediction of the occurence rate of planet pairs near the 3:2 NMMR by BL13.

Result

We detected five planetary candidates around 97 predicted periods in 56 systems.

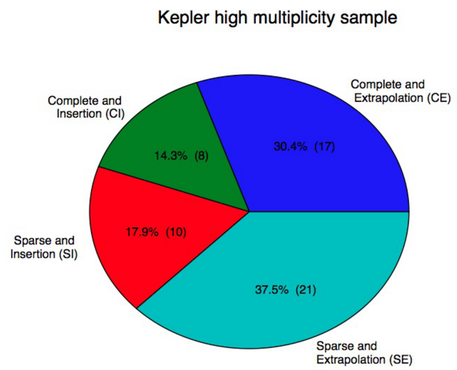
We also found an additional transit signal and two single transits which were not predicted in these systems.

Folded light curve of KOI-2859



Detected period: $P = 5.43$ **days.**
Predicted period $P_{\rm predict} = 5.2 \pm 0.3$ **days.**

Sample



- 'S" stands for dynamically sparse systems.
- "C" stands for dynamically complete systems.
- "E" stands for extrapolated - for systems originally have a better fit to the TB relation than the solar system, only one "extrapolated" prediction is made in each of them.
- "I" stands for insertion - insertions of planets are made so that the systems can fit a tighter TB relation.

Detection Summary

Catagory	Num. Predictions (star/planet)	Num. Expectations	Num. Detections (star/planet)
SI	10 (39)	5^{+7}_{-4}	4 (4)
CI	8 (20)	2^{+3}_{-1}	0 (0)
CE	17 (17)	1^{+3}_{-1}	1 (1)
SE	21 (21)	1^{+2}_{-1}	0 (0)

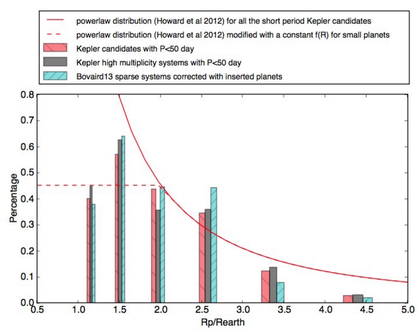
Bias Analysis

Inclination bias ($\sigma_i = 1.8^{+0.5}_{-0.8}\,^\circ$, Fabrycky et al. (2012)): Expected detections

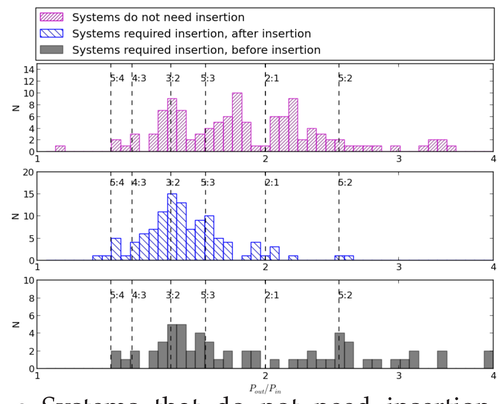
$$E(N) = \sum_{i=1}^{n} (1 - \exp\,[-\frac{1.06^2}{2\sigma_i^2}(\frac{P_i}{50\rm day})^{-4/3}]).$$

Radius bias :

We compute the lower (upper) limit of the expected detections using the solid (dashed) line as shown in the figure:



Adjacent pair ratios



- Systems that do not need insertion have strong NMMR peaks.
- Systems needing insertion (after insertion) have excess in 3:2 NMMR but are lack of 2:1 NMMR.
- Systems needed insertion (before insertion) have less pronounced NMMR peaks.

References

[1] Bovaird, T., & Lineweaver, C. H. 2013, MNRAS, 435, 1126
[2] Fabrycky, D. C., Lissauer, J. J., Ragozzine, D., et al. 2012, arXiv:1202.6328
[3] Howard, A. W., Marcy, G. W., Bryson, S. T., et al. 2012, ApJS, 201, 15
[4] Huang, X., Bakos, G. Á., & Hartman, J. D. 2013, MNRAS, 429, 2001