

THE FREQUENCY OF PLANETS IN THE CIRCUMSTELLAR HABITABLE ZONE: USING THE TITIUS-BODE RELATION TO CORRECT FOR INCOMPLETENESS. Charles. H. Lineweaver¹, Timothy Bovaird¹, ¹Planetary Science Institute, Research School of Astronomy and Astrophysics and Research School of Earth Sciences, Australian National University, charley.lineweaver@anu.edu.au, timothy.bovaird@anu.edu.au

The Titius-Bode (TB) relation's successful prediction of the period of Uranus was the main motivation that led to the search for another planet between Mars and Jupiter. This search led to the discovery of the asteroid Ceres and the rest of the asteroid belt. The TB relation can also provide useful hints about the periods of as-yet-undetected planets around other stars. In Bovaird & Lineweaver (2013) [1], we used a generalized TB relation to analyze 68 multi-planet systems with four or more detected exoplanets. We found that the majority of exoplanet systems in our sample adhered to the TB relation to a greater extent than the Solar System does. Thus, the TB relation can make useful predictions about the existence of as-yet-undetected planets in Kepler multi-planet systems. These predictions are one way to correct for the main obstacle preventing us from estimating the number of Earth-like planets in the universe. That obstacle is the incomplete sampling of planets of Earth-mass and smaller [2-5] (summarized in Fig. 1).

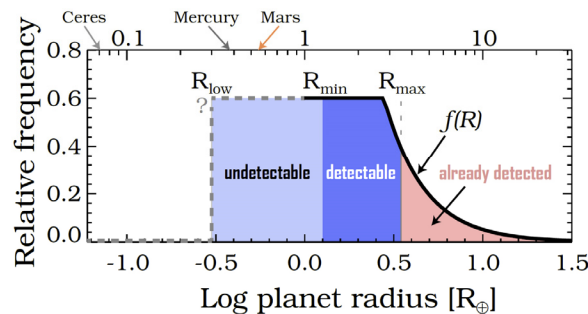


Fig. 1: Relative frequency of exoplanet radii.

In [6], we use a generalized Titius-Bode relation to predict the periods of 228 additional planets in 151 of these Kepler multiples. These Titius-Bode-based predictions suggest that there are, on average, 2 ± 1 planets in the habitable zone of each star. See the planets in the green vertical band in Fig. 2.

We also estimate the inclination of the invariable plane for each system and prioritize our planet predictions by their geometric probability to transit. We highlight a short list of 77 predicted planets in 40 systems with a high geometric probability to transit, resulting in an expected detection rate of ~ 15 per cent, ~ 3 times higher than the detection rate of our previous Titius-Bode-based predictions.

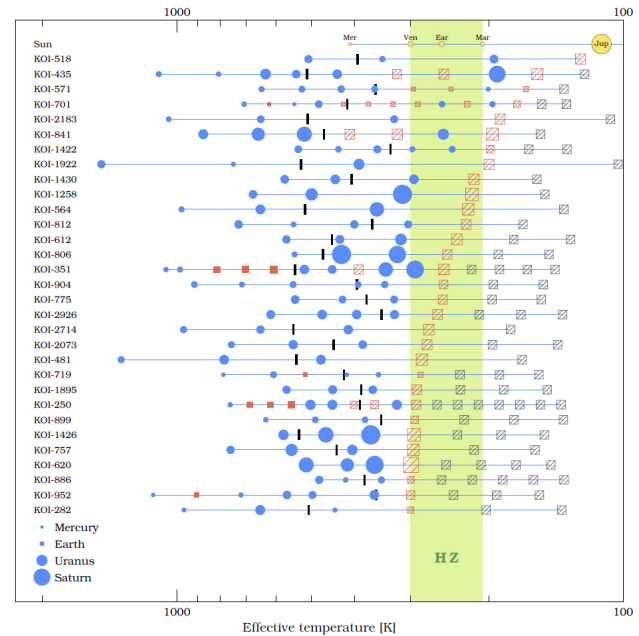


Fig. 2: Blue dots are exoplanets detected by Kepler. Red and gray squares are our TB-based predictions.

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References: [1] Bovaird, T. & Lineweaver, C.H. (2013) *MNRAS*, 435, 1126-1138. [2] Dong S. & Zhu Z. (2013) *ApJ*, 778, 53 [3] Fressin F. et al. (2013) *ApJ*, 766, 81 [4] Petigura E. A. et al. (2013) *PNAS*, 110, 19273 [5] Silburt A. et al. (2014), *ApJ* (arXiv:1406.6048v2) [6] Bovaird, T., Lineweaver, C.H. & Jacobsen, S.K. (2015, in press) *MNRAS*, arXiv:14126230v3.