Building a Predictive Model for the Detection of Possible Outer Planets in Known 2-body Resonant Systems

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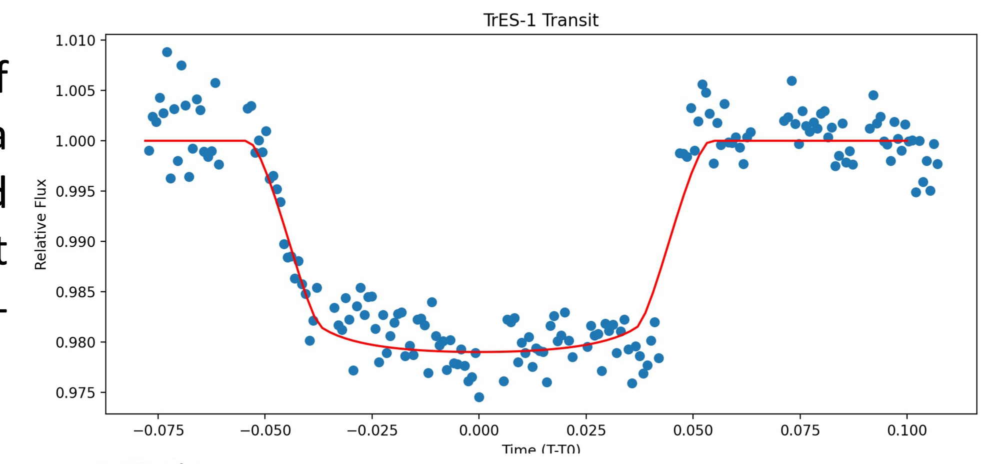
Abstract

This project has found evidence of trends in known 3-planet systems with inner planets in a Mean Motion Resonance to construct a predictive model with the ability to propose periods of possible outer planets in currently known 2-planet MMR systems. Using light curve data collected from the *Kepler/K2* mission, periodograms and transit curves can be constructed and analyzed to develop such a model as to provide ranges for outer extant planets' periods, with the known 3-planet systems as the training dataset and the 2-planet systems having the prediction applied to them. The distribution of period ratios in known 3-planet systems are examined considering each different integer resonance to evidence more specifically for each system of interest. This model creates a framework for further mass-based analyses of orbital trends, as well as laying the foundation for future prospective n-body dynamical simulations in systems with known classified period relationships and MMRs. This will serve as a mode to find new exoplanets in currently known and classified transiting systems and give justification to possible new planets discovered given that they build on noted observed trends of inner planet resonances. This model should be applied to all *Kepler/K2* and *TESS* 2-planet systems in an MMR to use these trends and find new exoplanets in such known systems.

Transiting Exoplanets/The Model

Figure 1a. Transit light curve of TrES-1b, a Hot Jupiter transiting a K0V star, overlayed with expected transit curve model. This transit was taken using Wesleyan's 24-Inch Perkin Telescope



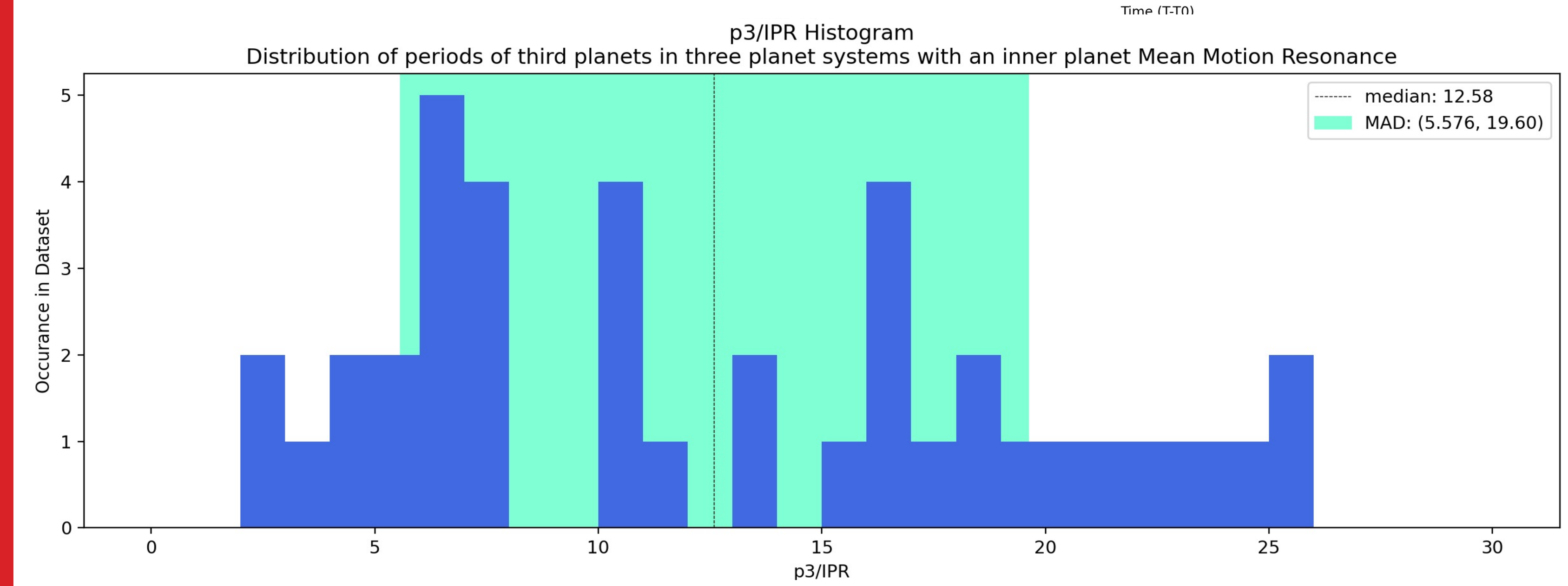


Figure 1b. Distribution of p3/(p2/p1) where p2/p1 is labelled "inner planet resonance" or IPR.

Building the Model

- The Predictive Model was constructed by taking the orbital periods of known 3-planet resonant systems and comparing them to 2-planet resonant systems. This is done with the goal of being able to postulate a range of possible third planet periods in these two-planet resonant systems through comparing them to known three-planet systems with the inner two planets in an MMR.
- IPR represents "inner planet resonance" and represents p2/p1, or the period ratio of the inner 2 planets in a 3-body system. For two planet systems, this is essentially the input for the model, which returns a range of possible periods provided the orbital periods are in an MMR.
- Dataset sampled all 3-planet systems with inner planets in a 2:1, 3:1, 3:2, 5:2, or 4:3 MMR ±0.05

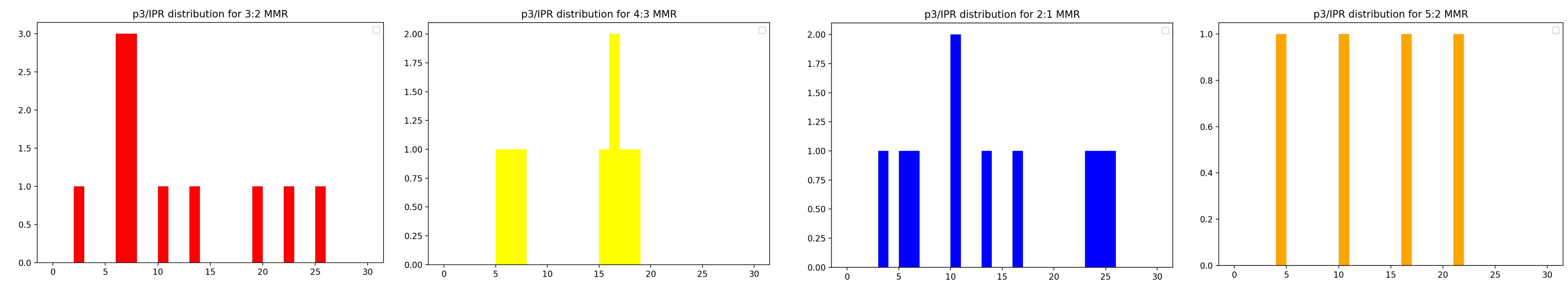


Figure 2. Distribution of p3/(p2/p1) within 3:2 MMR (red), 4:3 MMR (yellow), 2:1 MMR (blue), and 5:2 MMR (orange). Note tendency for part of 3:2 and 4:3 MMRs to remain in specific close ranges, wherein if a transit-like curve were to be found in such a range its existence could be further justified as a possible planet.

Applying the Model

- The model constructed by the period distributions is applied through periodogram and light curve analysis[3]
- Periodograms are a way to visualize periodic events in a signal, and a periodic transit will cause a spike at the transiting planet's orbital period
- Folding light curves around known periods and peaks within the possible range determined by which MMR is found can be used to find transit signals of possible outer planets

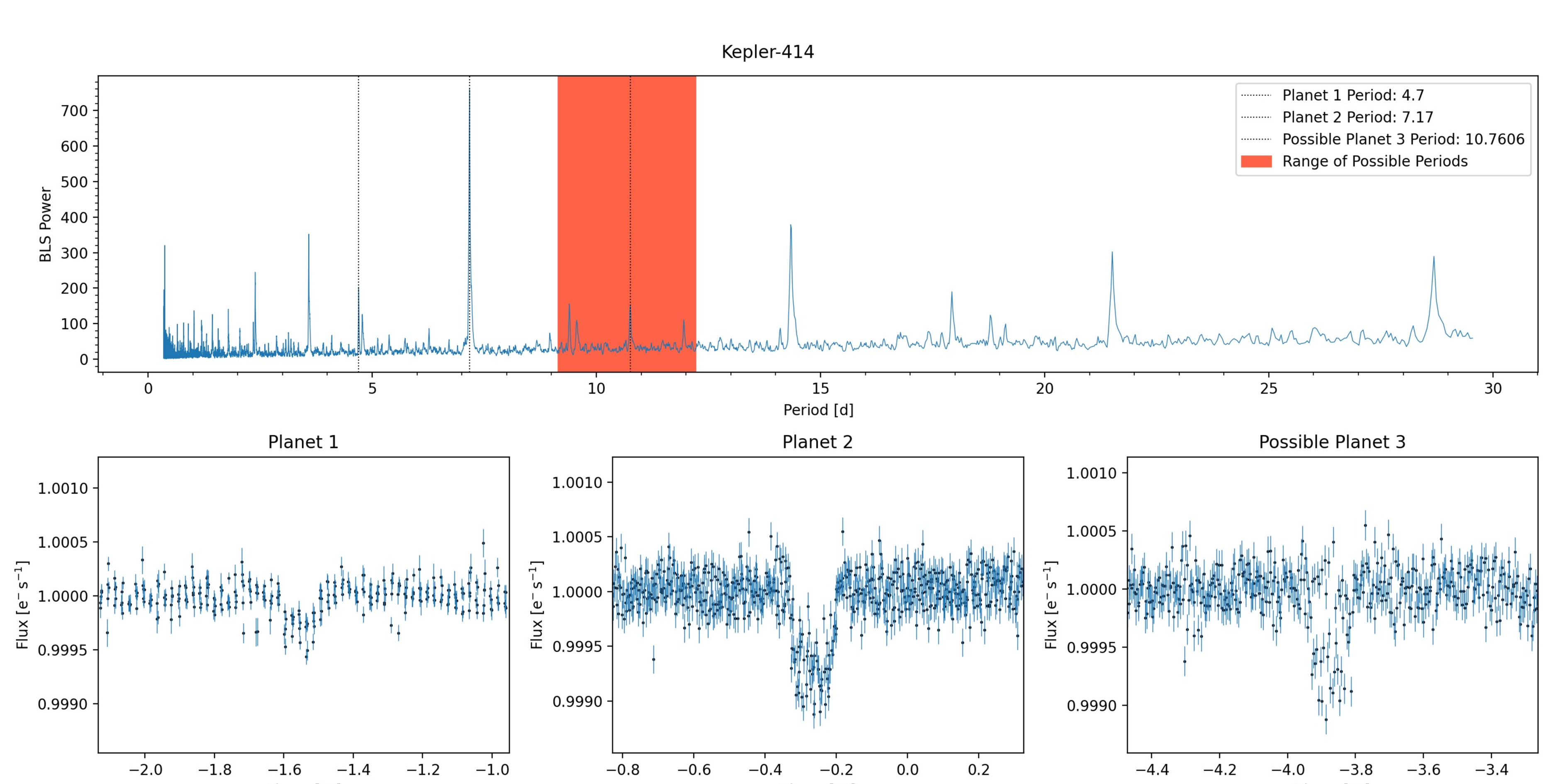


Figure 3. Application of model to Kepler-414, a transiting 2-planet system with a super-Earth and Neptune-like planet orbiting a G-type star discovered using Transit Timing Variations[1]. Note transit light curves for Kepler-414b and Kepler-414c. Possible planet d light curve is also included, folded for period spike in periodogram within range modelled by the 3:2 MMR histogram, though much follow-up must occur before conclusions can be drawn.

Conclusions/Future Work

- This model has found trends in the periods of third planets relating to inner planet MMRs.
- *The Kepler/K2* mission revealed a great dynamical breadth of transiting exoplanet systems, of which resonant systems are common.[4] The next step is to apply this model to all *Kepler/K2* 2-planet resonant systems.
- Dynamical evolution of Hot Jupiter systems have been found to disturb photometric searches for companion planets[5], therefore limitations on detecting transiting hot Jupiter companions may necessitate the inclusion of planet size and semi-major axis as limiting dimensions to the model.
- Transit Timing Variations (TTVs) tend to be amplified in resonant systems. Follow-up ground-based TTV analysis should also be performed to further corroborate systems of interest[2]. This is very much a longer-term goal to expand the model.

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