APPLYING THE METHOD OF TRANSIT TIMING VARIATIONS TO KEPLER: PHASE 2

Matthew Holman
Smithsonian Astrophysical Observatory

Measuring the masses of Kepler planet candidates presents a daunting challenge. Most of the target stars are relatively faint. Most of the planets have small radii and thus are expected to have low masses. And some of the candidate planets have distant, long- period orbits. Thus, the radial velocity signatures are small and difficult to measure. Although some of planetary masses can be measured with high-precision spectrographs on large aperture telescopes, given ample amounts of observing time, in most cases an alternative means of establishing the planetary nature of these candidates must be used. The method of transit timing variations (TTVs) is just such a technique. For a single transiting planet, the variation in the interval between transits, produced by gravitational interactions with additional planets, allows for the detection of those perturbing planets. And detailed observations of those variations can, in principle, allow the orbital period and mass of the perturbing planets to be determined from transit observations alone (Holman & Murray 2005, Agol et al. 2005). Holman and Murray (2005) predicted that systems with multiple planets transiting the same star would be observed by Kepler. They noted that for some such systems the masses of all the planets could be measured from their mutual timing variations alone. The Kepler-9 (Holman et al. 2010) and Kepler-11 (Lissauer et al. 2011a) systems confirmed this prediction. In the case of Kepler-9, the larger two of its three known planets show substantial, anticorrelated TTVs. We measured the masses of Kepler-9b and Kepler-9c by modeling the transit times, along with six Keck HIRES RV observations (Holman et al. 2010). Kepler-9d was validated using a BLENDER analysis (Torres et al.2011). In the case of Kepler-11, with its closely packed configuration, the masses of five of its six transiting planets could be estimated from their TTVs, and the sixth planet was again validated with BLENDER (Lissauer et al. 2011a). Kepler has discovered an abundance of systems with multiple transiting planet candidates (Borucki et al. 2010, Steffen et al. 2010, Ragozzine and Holman 2010, Borucki et al. 2011, Lissauer et al. 2011b, Ford et al. 2011). A significant number of these are amenable to TTV analyses that will yield mass estimates with future Kepler data (Ford et al. 2011). In addition, some single transiting systems show significant TTVs; future data may permit us to establish the masses and orbits of the perturbers in these systems. I propose to continue contributing to the theoretical and analytical interpretation of the transit timing data from the Kepler mission. The specific scientific objectives of this proposal are: 1) to apply the TTV method to Kepler candidate systems that have not yet been confirmed; 2) to re-analyze currently known multiple planet systems, such as Kepler-9 and Kepler-11, as new data become available; and 3) to place upper limits on the masses of possible additional planets in systems with single and multiple confirmed planets or planet candidates.