Orbital Reconstruction and Discovery of Hidden Circumbinary Planets Through Eclipse Timing Residuals and N-Body Dynamics

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Prior to the first unambiguous discovery in 2011, circumbinary planets (CBPs), planets orbiting two stars or eclipsing binaries (EBs), were considered unlikely to exist due to the perturbations of binary stars. Now with 35 confirmed CBPs, they serve as natural laboratories in complex three-body environments and probes for planet formation or stability. However, the catalog lags behind the 6,000+ known single-star exoplanets because conventional phase-folding detection architectures cannot accommodate CBPs' inconsistent transits or longer orbital periods. I report the discovery of two CBP candidates previously not listed in the NASA Exoplanet Archive and the independent recovery Kepler-1660b. To address these challenges, I developed a pipeline leveraging eclipse timing variations (ETVs) to quantify the gravitational influence of CBPs in Kepler data without requiring planetary transits. EBs were modeled with Bayesian nested sampling to extract precise mid-eclipse times. Periodic structures in the residuals were fitted with a light-travel-time effect (LTTE) model to evaluate third-body effects, with parameters initialized by a trust-region reflective optimization. Dynamical viability of the candidate systems was tested with N-body simulations. The reduced chi-squared and false alarm probability tests indicate robust LTTE fits, and N-body simulations placed the LTTE solutions in regions beyond the critical stability boundary in configurations consistent with those predicted by the inward migration theory. This ETV method enables detection of non-transiting, longer-period CBPs previously inaccessible and tests for proposed three-body models, expanding the known CBP population and deepening our understanding of planet formation in multi-stellar environments.

Awards Won:
Second Award of $2,400
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