AN ANALYSIS OF THE FIXED STAR APPROXIMATION IN TRANSIT LIGHT CURVE MODELS

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Introduction and Goals

Many extrasolar planet transit light curve models use the approximation of a massless planet. They approximate the planet as orbiting elliptically with the host star at the orbit’s focus (Figure 1) instead of depicting the planet and star as both orbiting around a common center of mass (Figure 2). This approximation should generally be very good because the transit is a small fraction of the full-phase curve and the planet to stellar mass ratio is typically very small. However, to fully examine the legitimacy of this approximation, it is useful to perform a thorough comparison of the fixed star and wobbling star transit models over all parameter space.

Figure 1: the fixed star orbit model

Figure 2: the wobbling star orbit model

Goals

We set out to answer two questions:

1) In what domains of parameter space is the discrepancy between the two models largest?

2) If one were to characterize an exoplanetary system in one of these domains, what error would be obtained in the parameter estimates when using the fixed star model?

Project Outline

To examine the first question, we used a Monte Carlo sampling method to generate a sample distributed according to a measure of deviation between the two models. We then applied a density clustering algorithm to extract the high-density domains. As for the second question, we fit curves generated by the wobbling star model using the fixed star model and examined the disagreement between the two parameter sets to yield specific information about which regions of parameter space must be avoided.

Step 1: Metropolis within Gibbs Sampling

- Sampled according to the sum of squares between the fixed star and unfixed star models
- Free parameters: semi-major axis a, eccentricity e, argument of periastron \( \omega \), orbital inclination i, stellar mass \( M_\star \), and radius \( R_\star \), and planet mass \( M_p \) and radius \( R_p \)

Examples of marginal distributions

Step 2: Density Clustering

- Used the Ordering Points to Identify the Clustering Structure (OPTICS) algorithm to identify high-density regions
- OPTICS generates an ordering of the points in the dataset from which variable-sized clusters may be extracted

Example of OPTICS applied to noisy bivariate Gaussian samples

Step 3: Curve Fitting and Thresholding

- Sampled points in high-density regions and generated transit curves using the wobbling star model
- Fit the curves with the fixed star model and evaluated the percent errors in the parameter sets
- Applied thresholds on the semi-major axis and planet radius percent error and used bootstrapping to evaluate the uncertainty

Results

Conservative parameter “danger zone”:

\[
\frac{M_p}{M_\star} > 0.00092 \pm 0.00008
\]

All points with planet radius error greater than 1% and semi-major axis error greater than 1.8% lie within the boundary defined by the planet to stellar mass ratio greater than 0.00092 ± 0.00008.

Further Research

The techniques used in this work could be used to compare other more advanced models, such as transit models that account for asymmetric transits due to gravity darkening or planetary bow shocks.

References


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