Transit detection on eclipsing binary systems

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Since the beginnings of the transit method, the potential for the detection of transiting planets around close eclipsing binary systems (EB) has received special attention (Schneider & Chevreton, 1990). The major reason is given by the increased probability to detect planets with transits around these systems, due to the intrinsic alignment of the binary components' orbital plane with the observer. A strong correlation between the orbital planes of the binary components and any circumbinary planets may be assumed, and hence, the probability that planets produce transits should be significantly higher than in randomly oriented systems. Also, non-aligned planetary systems will precess around the EB orbital axis, and periodically exhibit transits as well (Schneider, 1994). Also, the detection of circumbinary planets would be a significant extension to the variety of known planets, with important repercussions on existing models of planet development.

The major difference in planet transit detection around EB's, compared to single stars, results from the dependence of the transits' durations, times of occurrence and shapes on the phase of the EB during the planet crossing. A planet may cause one, two, or even multiple transits for each orbital period. Detection algorithms are therefore required to consider all possible planetary periods and EB-phases in order to take into account the full variety of transit lightcurves. (The phase of an EB at a given time is of course known, unknown is however the time of the crossing, which may be expressed by a planet's epoch). Such an algorithm was described first by Jenkins at al. (1996), then based on the matched-filter approach. An implementation for the TEP project, which observed the CM Draconis system for over 1000 hrs from 1994-2001 (Deeg et al., 1998, Doyle et al., 2000), was performed with optimizations for the analysis of ground based data with varying extinction. In these, a detection statistical values for the two hypothesis 'transit-present' and 'transit-absent' are being compared. This work led to the definition of several 'planet-candidates', some of them based on rather elevated numbers - up to 11 - of 'transit-candidates' that were identified by the algorithm. None of the planet-candidates could be verified in follow-up observations, however.

The algorithms used in TEP, or the one described by Jenkins et al., are not fundamentally different from single star detection algorithms (and hence can be adapted to single stars, see Tingley 2003). The major steps are: 1) removal of the binary eclipses, 2) the modeling of transits for all configurations of planetary period and epoch (also possible: inclination, eccentricity) which give significantly different transit signals, and 3) the comparison of transit models and data, with the derivation of detection statistical values for all configurations. Detection statistical values above some threshold indicate then planet candidates, with the threshold being given by the noise of the lightcurve and the *number* of configurations that had to be searched. Only the first of these steps is specific to EB detection. Transit detection of EBs is however a significantly larger computational problem as for single star transits, on the order of the number of planet epoch (or EB phase) steps that give significantly different transit models. In single star transit detection, the duration and shape of a transit is invariant against a planet's epoch, and transit models depend on only the period (and inclination), with very simple representations, such as box-shaped transits, being possible.

The number of transit configurations that have to be tested in a lightcurve of equally-spaced data is being given by:

$$N_{op} = k\, 2\, t_d^{-2}\, (P_{max}-P_{min})\, t_{obs}^{2}\, t_{inc}^{-1}$$

where P_{max} and P_{min} define the period range to be searched, t_{obs} is the duration of observation (150 days in the case of COROT), t_{inc} the time increment between data points, t_d a 'mesh-size' based on the typical duration of a transit (0.5 - 2hrs may be used for most EB's), and k an efficiency factor (k~1 for unoptimized algorithms). For the different projects analyzed (TEP, COROT, Eddington, Kepler), this gives values of $N_{op} = 10^{12}$ to 10^{14}, with differences being dominated by the quadratic term t_{obs}^2.

Considering that $O(N_{op})$ tests need to be performed for the analysis of only one *lightcurve*, this is a very demanding computing problem. A method to reduce N_{op} is presented, based on the independent analysis of smaller sections of a lightcurve. If a long lightcurve is divided into $n = t_{obs}/t_{obs,s}$ equal sections, were $t_{obs,s}$ is the length of each section, it can then be shown that N_{op} increases only linearly with t_{obs}. After the creation of arrays or 'maps' of detection statistical values for each section, these arrays can be co-added to find potential detection statistics maxima in the entire lightcurve. As there is a danger of promoting false transit candidates in co-adding, all resulting maxima need to be further evaluated by performing a transit detection in a fine-meshed parameter space around them, based on the entire lightcurve. Maxima from this second step may then, if above some given threshold, become final planet candidates. A related version of this 'slicing method' was already used in the analysis of the TEP project (Doyle et al. 2000), were a division of a 5 year long lightcurve into 5 seasonal sections reduced the computing time to about 1/7,5. Another advantage of this method is the ability to add new data to an existing, and already analyzed lightcurve, with the basic transit detection being needed only on the newly added data. This is of particular interest for long-running space missions and ground-based projects, lowering computing demands and allowing more flexible analysis strategies.

References:

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