Transiting Planets
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An algorithm for the detection of transits of planets around eclipsing binaries in CoRoT

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Abstract. We present a matched filter algorithm to detect transits of planets that orbit both components of close eclipsing binaries in CoRoT targets. The formation of binary systems surrounded by disks is one of the most common outcomes of stellar formation; their detection would therefore constitute an important discovery. In an eclipsing binary system, the binary-planet alignment gives raised transit probabilities and the special transit shapes from circumbinary planets provide a unique identifier for their planetary nature; the problems of false alarms are largely avoided. CoRoT data have unprecedented time coverage and photometric precision that make them especially suitable for the search of transits of planets across eclipsing binaries. No reliable detections of circumbinary planets have been reported yet, and their discovery would constitute a new class of planets.

1. Planet transits in Eclipsing Binaries

More than half the main-sequence stars in the solar vicinity belong to multiple systems. The possibilities of detecting transits of planets around eclipsing binaries are high, because such planets, if they exist, will probably be orbiting in the same plane of the stars.

There are differences between planet transits on individual stars and around eclipsing binaries. In the first case, the transits are periodic and their shape and duration are constant. For the binary, the transits are semi-periodic; when they take place, the shape and the duration depend on the binary orbital phase. For these reasons a specific transit-search algorithm must be used to detect transits of planets around binaries.

2. Matched filter algorithm

We use a modified version of the matched-filter algorithm by Jenkins, Doyle & Cullers (1996) that consists in modeling the transits for a trial planet with a set of periods and epochs and to compare them to the data resulting in some detection statistic for each period and epoch. To calculate the model, some information about the binary is needed. Thus, for each component it is important to know the radius, the semi-major axis and its contribution to the system luminosity, apart from the total mass of the system and the inclination of the orbit of the binary. The model is compared with the observations. To simplify the model the mutual eclipses of the binary (Fig. 1) are first subtracted from the data. A value of the fit model-data is then calculated for each trial period and epoch.

The detection value, $C - C0$, is given by:

$$C0 = \frac{1}{\sum_i |D_i|} \qquad C = \frac{1}{\sum_i |D_i - M_i|} \tag{2.1}$$

Where D_i are the data points and M_i are the model points. The initial fit-model uses a very small planet radius. Most of these models result in values of $C - C0 < 0$ and are not considered further. However, if $C - C0 > 0$, there might be a planet at that period and epoch. The algorithm then increases the planet radius and recalculates $C - C0$, repeating this until the $C - C0$ value diminishes. The radius at maximum $C - C0$ then gives an estimation of the radius of the planet. The highest points in the map of $C - C0$ values against period and epoch (Fig. 2) are thus candidates for a transit detection.

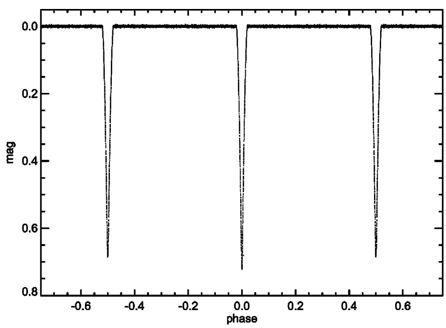

Figure 1. Simulated light curve of the eclipsing binary CM Dra. Both components have spectral class M4.5, a near edge-on inclination of 89.82 ° and a period of 1.268 days. A light curve of CM Dra with a planet with the radius of the Earth has been simulated with the characteristics of a CoRoT target with 14 magnitudes (1.4 mmag white noise) in a "Long Run" (150 days of observations, 8 min sampling).

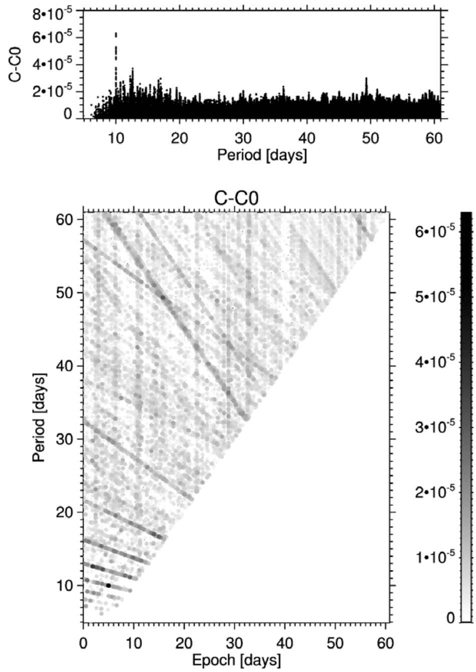

Figure 2. Lower panel: map of detections, $C - C0$. 44 million models are calculated and compared with the observations. Most of these models result in values of $C - C0 < 0$; only cases were $C - C0 > 0$ are plotted. Upper panel: the maximum value for $C - C0$ at each period. The simulated planet with a period of 10 days, an epoch at 5 days and a radius of one Earth corresponds to the maximum point.

3. Detection tests in simulated CoRoT data

We performed detailed simulations with a CM Dra like binary and the noise characteristics of the CoRoT data. CM Dra is a M4.5/M4.5 binary with an inclination of 89.82 °

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and a period of 1.268 days. We include transiting planets with 3, 2 and 1 radius of the Earth, a period of 10 days and an epoch of 5 days. In these simulations the algorithm is able to detect a planet with the radius of the Earth around a CM Dra system. The simulated planet is located at the maximum of C-C0 (Fig. 2).

4. Application to real CoRoT data

In a first application to real CoRoT data, we selected an observed binary with a very clean light curve, and added an artificial planet to it. This binary (Fig. 3) has a period of 3.667 days, an orbital inclination of 86.67 ° and its components have 8352 K and 4466 K, which imply sizes of 1.86 and 0.76 $R_{\odot}$. The simulated planet has the radius of Jupiter, a period of 15 days and epoch of 7.5 days (Fig. 5). The algorithm detects clearly the simulated planet (Fig. 4). This test was performed on a fairly large planet due to the size of the binary; tests with different binaries and planets are currently under way.

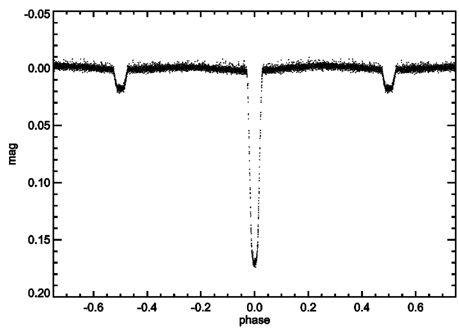

Figure 3. CoRoT light curve from the binary used in detection tests.

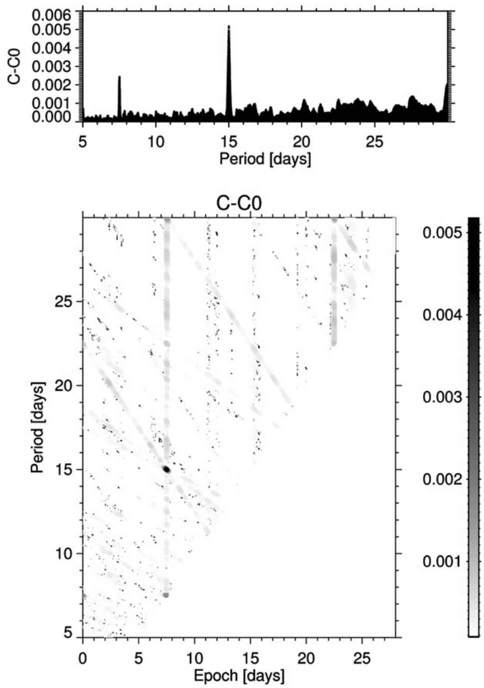

Figure 4. Analog to Fig. 2, for the real binary with a simulated planet, period = 15 days, epoch = 7.5 days and a radius of Jupiter. 7 million models are calculated and compared with the observations.

The most suitable binaries for the detection of circumbinary planets are those that are relatively bright and have low mass, an inclination close to 90 ° and a short period. In order to improve the reliability of the planet detections, good knowledge of the stellar parameters is important; especially their total mass, which affects the distance to the planet (and hence the moment of transits) for a given orbital period. Together with the CoRoT Eclipsing Binary working group, results from radial velocity observations

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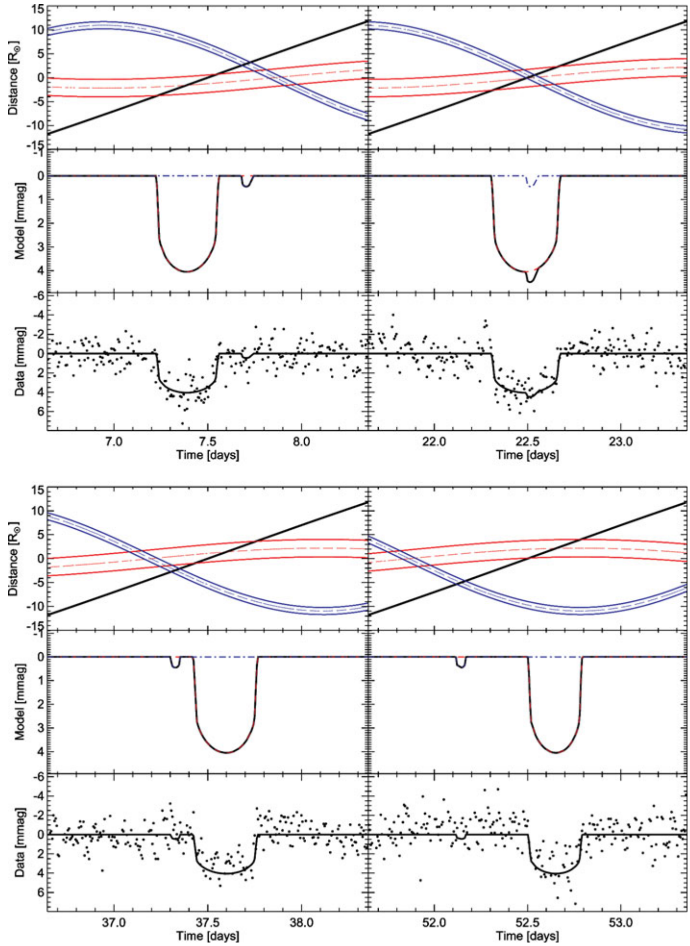

Figure 5. The modeled light curve and the CoRoT observational data with the Jupiter radius simulated planet. For each window, the upper panel shows the elongation from the system barycenter for binary component A (red), binary component B (blue) and the planet (grey). The middle panel is the modeled light curve of planet transits after removal of the mutual A/B eclipses. Finally, the lower panel is the data with the simulated planet (dots) with the clean model curve (line) for comparison.

obtained with the IDS spectrograph on the Isaac Newton Telescope (La Palma, Spain) are currently being combined with the CoRoT light curves for their characterization. In each CoRoT run, more than a hundred eclipsing binaries are detected and we hope that their analysis will reveal the first planet with the expected unusual transits.

Acknowledgements

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