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Characterization of eclipsing binary systems from the CoRoT mission

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Abstract. In this paper, we analyze 28 eclipsing binary systems observed during the CoRoT mission. Our aim was to remove the systematic effects present in the light curves and to calculate the orbital periods and initial epochs of all the targets. In addition, we modeled the light curves of the detached system CoRoT ID 0651331676 and the supercontact systems CoRoT ID 0310144545, CoRoT ID 0223934244 and CoRoT ID 0224009552 to obtain the following physical parameters: mass ratio, orbital inclination, temperature of the secondary star and potential of both components.

Resumo. Neste artigo, analisamos 28 sistemas binários eclipsantes observados durante a missão CoRoT. Nosso objetivo foi remover os efeitos sistemáticos presentes nas curvas de luz e calcular os períodos orbitais e as épocas iniciais de todos os alvos. Além disso, modelamos as curvas de luz do sistema destacado CoRoT ID 0651331676 e os sistemas de supercontato CoRoT ID 0310144545, CoRoT ID 0223934244 e CoRoT ID 0224009552 para obter os seguintes parâmetros físicos: razão de massa, inclinação orbital temperatura da estrela secundária e potencial de ambos os componentes.

Keywords. Binaries – Eclipsing

1. Introduction

A binary system consists of two gravitationally bound stars that orbit around a common center of mass. If the inclination i of the orbit is 90º or close to it, the system is said to be an eclipsing binary. The dynamic description of this type of system is based on equipotential surfaces, as described by Kopal (1955) and presented in the following equation:

$$\Omega = \frac{1}{\sigma} + q\left(\frac{1}{\sqrt{\sigma^2 - 2\sigma\lambda + 1 - \sigma\lambda}}\right) + \frac{1}{2}(1+q)(1-\nu^2)\sigma^2,$$

where q is the mass ratio (M_2/M_1), σ is the ratio between the distance r and the separation a between the components, and λ is a relation between zenithal and azimuthal angles.

The determination of the mass and other physical parameters of binary systems is possible due to the mutual gravitational influence between the components.

In this work, we analyze 28 light curves of eclipsing binary systems observed during the CoRoT space mission, which operated from January 2007 to October 2011. Through the analysis, we obtained: initial epoch, orbital period, mass ratio, orbital inclination, temperature of the secondary component, and the potential of both components.

2. Metodology

For the analysis of light curves, it was necessary to undergo a data processing step to remove as many systematic effects as possible. For this purpose, we employed an algorithm called Periodic Detrend. written in the `Python` language that is based on the Savitzky-Golay filter, which can be considered a generalization of the moving average. This filter uses local polynomials within predefined windows for curve smoothing. In summary, this is a good technique for removing trends in time series. Integrated into the algorithm is also the PDM technique (Phase Dispersion Minimization), which evaluates the total dispersion of a particular curve when folded at the phase of a specific test period. These two tools work in an integrated and iterative manner within the algorithm, testing various periods until the one generating the smallest dispersion in the light curve is found.

For modeling, we employed the algorithm developed by Wilson & Devinney (1971), whose technique is based on the concept of equipotential surfaces, originally developed by Kopal (1955). This approach models systems ranging from detached to overcontact systems. To optimize the fitting statistics and better explore the parametric space, we utilized the `emcee` library, which is based on the Markov Chain Monte Carlo method.

3. Results and Discussions

In this study, we will discuss, as an example, the results of the eclipsing binary system CoRoT ID 0223934244.

This system has a primary component with a temperature of 5862 ± 190 K and is part of the open cluster NGC 2264, situated in the direction of the Monoceros Constellation.

In the first plot of Figure 1, the original light curve data is displayed (black points) along with the corresponding moving average (in red). On the x-axis, time is expressed in terms of Modified julian date (Mjd). In the subsequent plot, the filtered data is shown, i.e., without the trend or signal due to systematic effects. Finally, the periodogram plot indicates the value of the optimal period obtained by the algorithm, i.e., the value that resulted in the smallest dispersion of the folded light curve. For this system, the obtained orbital period was 1.202 ± 0.001 days.

Upon visual inspection of the moving average, certain low-frequency variations in the data can be observed. By removing this unwanted component from the signal, we obtain a light curve that is smoother in the upper region, making it suitable for modeling.

In Figure 2, the results obtained from modeling the light curve are presented.

Through visual inspection of the curve, it is apparent that the start and end of the eclipses are not well defined. Additionally, the depths of the primary and secondary minima are very similar, indicating a contact binary system where the temperatures of

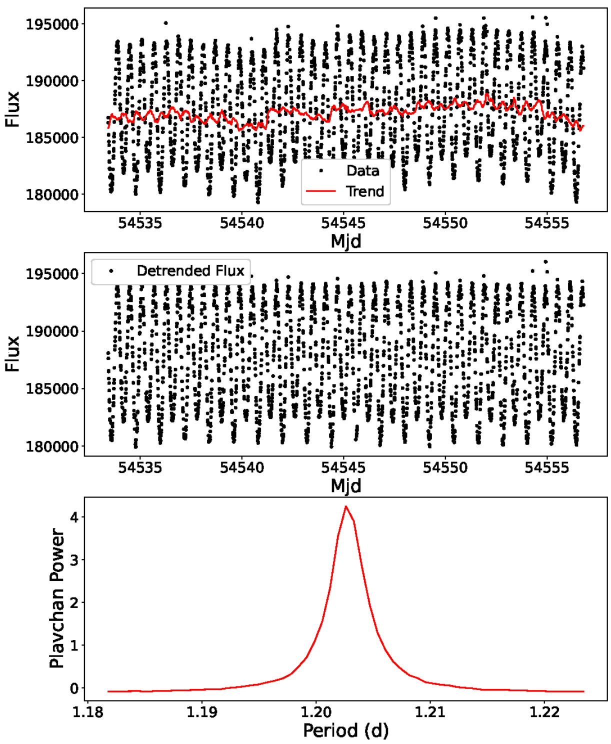

Figure 1. Results provided by the Periodic Detrend algorithm.

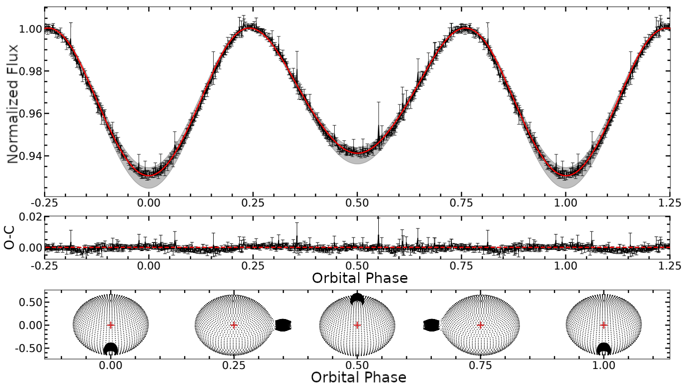

Figure 2. Light curve modeled with the Wilson-Devinney algorithm.

both stars are very close. In such systems, both components exceed the Roche lobe limit and exchange matter with each other. The O-C diagram shows the residual of the fit. Lastly, in the same figure, the system's morphology is graphically represented. The elongated shape of the components is typical of contact systems, as they are under intense tidal forces. Another observed characteristic in the morphology is that the primary component is much more massive than its companion. In fact, the mass ratio M_2/M_1 found for this system is 0.017 ± 0.001.

In supercontact systems, the exchange of matter between the components can lead to a change in the matter distribution, such that the potentials Ω of both components become equal. This condition was set as an initial condition in the modeling code, and the best value found for the potentials was 1.62 ± 0.04.

The low orbital inclination, 56.8°, indicates that only a small fraction of each star is eclipsed during each half cycle. This explains the small percentage of brightness decrease (approximately 0.05%) observed in the light curve.

Figure 3 presents the posterior distributions of the fits. The Gaussian shape of the distributions indicates the convergence of

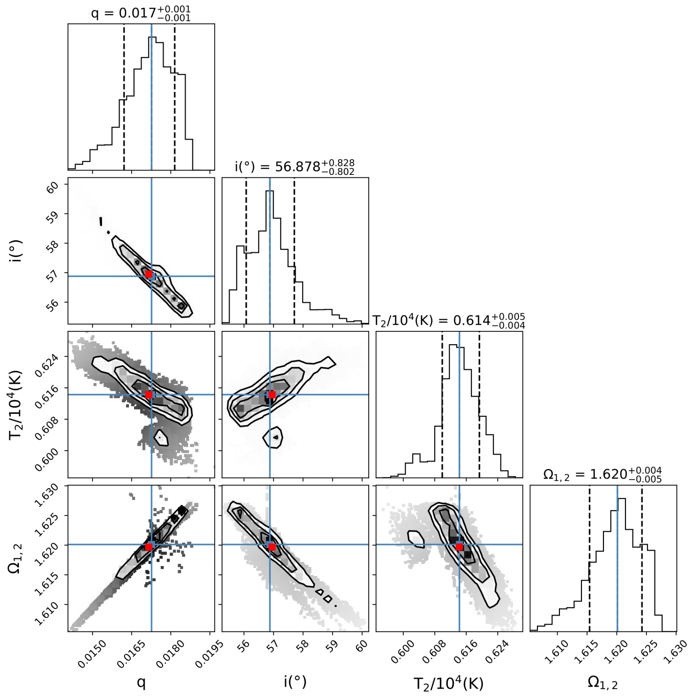

Figure 3. Posterior distribution generated by the `emcee`.

the fit. In all cases, the Markov Chain stabilized around a most probable value for each parameter (red points in the figure).

In Table 1, the results obtained from the fitting are presented.

Table 1. Parameters obtained from the fitting.

CoRoT ID 0223934244	
$P(d)$	1.202 ± 0.001
$q = M_2/M_1$	0.017 ± 0.001
$i(deg)$	56.8 ± 0.8
$T_1(K)$	6143^{+51}_{-44}
Ω_1	1.62 ± 0.04
Ω_2	1.62 ± 0.04
$T_1(K)$	5862 ± 190
$Epoch(Mjd)$	$54\,534.776 \pm 0.001$

4. Conclusions

The parameters obtained uniquely in this study may contribute to a more comprehensive characterization of the studied systems in the future.

The initial epoch and orbital period were calculated for all 28 systems. The modeling was performed for the targets CoRoT ID 0651331676, CoRoT ID 0310144545, CoRoT ID 0224009552, in addition to the system discussed in this work.

Of the targets analyzed, 85.7% correspond to the supercontact classification, with periods of less than 1.2 days. The CoRoT target ID 0651331676 is the only one detached, with a period of 3.5836 ± 0.0002 days.

References

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