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Research Note

Analysis of a photoelectric light curve of the W UMa-type binary ST Ind

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Abstract. Modelling of Walter and Duerbeck's photoelectric observations of ST Ind is performed. The Wilson-Devinney model along with a Monte Carlo method as the search procedure, was used to derive the physical parameters of this contact system. One dark spot on the surface of the primary component was introduced to explain the observed difference in the heights of the maxima.

Key words: binary stars: eclipsing binaries – star-spots – individual: ST Ind

1. Introduction

The first person who noticed the variability of ST Ind (CoD -48° 13615, α=20^h 35^m 22^s, δ=-48° 18$'$ 45$''$ (2000.0), V=11.2-11.7) was Hoffmeister (1956). He classified it as a W UMa-type binary with equal depths of the minima and estimated its period to 0.401888 d.

Mugherli and Cerruti (1982) applied a least squares fit and obtained light curve elements with higher accuracy, where 0.40188233 d was a new period value. The original Hoffmeister's data (24 times of minima) as well as six new ones (obtained with the 60cm Lowell telescope at Cerro Tololo Interamerican Observatory) were taken into account.

In the late 70s and early 80s Walter and Duerbeck conducted photoelectric monitoring of light curve fluctuations among W UMa-type systems, using the 50cm and 61cm Bochum telescopes operating within the European Southern Observatory. During this program they succeeded to gather a complete light curve of ST Ind with Johnson B and V filters. The ephemeris of the system was further improved (Walter, Niarchos and Duerbeck 1989, hereafter WND):

$$\text{Min I} = \text{JDH } 2442661.7113 + 0.4019155 \text{ E}$$

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WND noticed the presence of periodic fluctuations in certain parts of the light curve of ST Ind, interpreting them as being the result of the precessional motion of the rotation axis of the brighter component. On the other hand, no significant differences were found among light curves gathered in different years.

In order to evaluate preliminary geometric and photometric parameters of the system, they engaged an automated Fourier technique, separately for yellow and blue data. The most important results published by WND were: inclination i=76$\stackrel{\circ}{.}$4, the mass ratio q=0.24 and B-V=0.50. The brighter component contributes 80 percent to the total light. They found ST Ind to be a W UMa system of W-type (primary minimum caused by a partial occultation). The observations revealed also an asymmetry of the light curve of ST Ind, particularly seen by the difference of levels of the maxima.

In this paper we present results of modelling of ST Ind B and V light curves published earlier by WND. The Wilson-Devinney model (Wilson 1993) was deployed along with a Monte Carlo search procedure to find the best solution.

2. Light curve modelling

In order to obtain physical parameters for ST Ind we used the latest (1993) version of the Wilson-Devinney code. We performed simultaneous computations in both filters. Initially, we check how good a fit would be when we adopted the parameters derived by WND. The primary component's temperature was estimated to 6150K, by using the B-V colour of ST Ind determined by WND and making use of the calibration published by Popper (1981). The mass ratio was set to 0.24 and the contact configuration was assumed. All other parameters were allowed to be adjusted. It occurred that the quality of such a fit is rather poor (χ^2= 0.96) The synthetic light curves obtained in such a way are presented in Figs. 1 and 2 by the dashed lines. Next, we made a search for a better fit, also for other values for the mass ratio q between 0.10 and 5.0. In this procedure, we still assumed

Table 1. Parameters derived from the Wilson-Devinney model

configuration	contact
phase shift	0.0000 ±0.0000
i	71°.3 ±0.5
$g_1 = g_2$	*0.320
$A_1 = A_2$	*0.50
T_1	**6430K
T_2	6414K ±50
q	**0.602 ±0.005
Ω_1=Ω_2	2.999 ±0.020
L_1 (B)	7.25 ±0.11
L_1 (V)	7.27 ±0.10
L_2 (B)	*4.550
L_2 (V)	*4.571
l_3 (BV)	*0.0
χ^2	0.2023
	dark spot
$longitude$	107°.2 ±2.5
$lattitude$	257°.0 ±5.5
$radius$	15°.6 ±2.0
$temperature$	0.897 ±0.022

* - not adjusted
$**$ - adjusted only within the CRS method

q to be fixed, and used the original Wilson-Devinney differential correction (DC) algorithm as the searching procedure. In order to save computer time, 60 normal points in each filter were calculated from the observations gathered by WND. We adopted also the original phases as listed in their paper. It turned out that a better fit could be obtained for some intermediate values of q. However, for q between 0.5 and 1.0 the quality of the fit is about the same (χ^2 in the range: 0.59-0.64). For any of the obtained solutions a contact configuration was reached eventually. Additionally, there was still a remarkable discrepancy between the observed and theoretical light curves, particularly around the maxima.

In order to improve the solution we assumed that the difference in height between maxima is due to the presence of a dark spot on the surface of the primary component. Introducing one dark spot requires four additional parameters: two concerning the spot location on the stellar surface and two ones describing the spot size and temperature. To ensure that the best fit (global minimum) is found, we switched to the Price algorithm (CRS) as the searching procedure (Price 1977, Barone et al. 1989). In this step, we also used all data published by WND - altogether 109 points in each filter.

The CRS method does not require starting values for the searched parameters. It is able to locate the global minimum within the set domain. The ranges for parameters were set up as follows: inclination between 50 and 90 degrees, temperatures of the components between 5000K and 7000K, the mass ratio in the range of 0.2-3.0 and components' luminosities between 1.0-12.56. During all computations no third light was assumed to be present. The whole surface of the primary was searched as a plausible spot location. Its radius was expected to fall between 10 and 60 degrees, while the spot temperature factor between 0.7 and 1.0 (temperature factor exceeding unity means that the spot is hotter than the surrounding stellar surface).

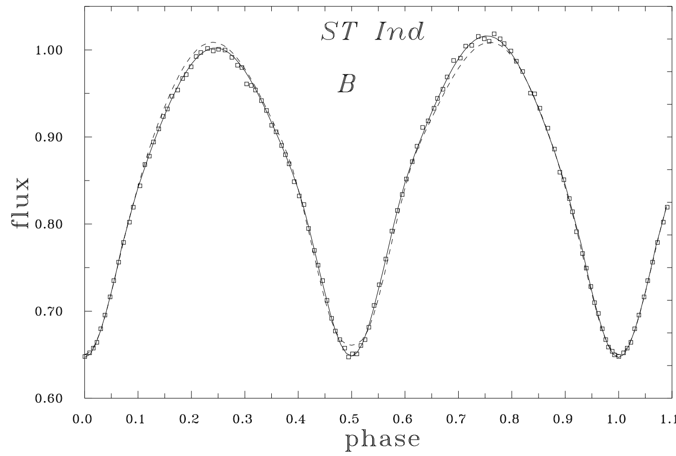

Fig. 1. Observed and theoretical light curves of ST Ind in B filter

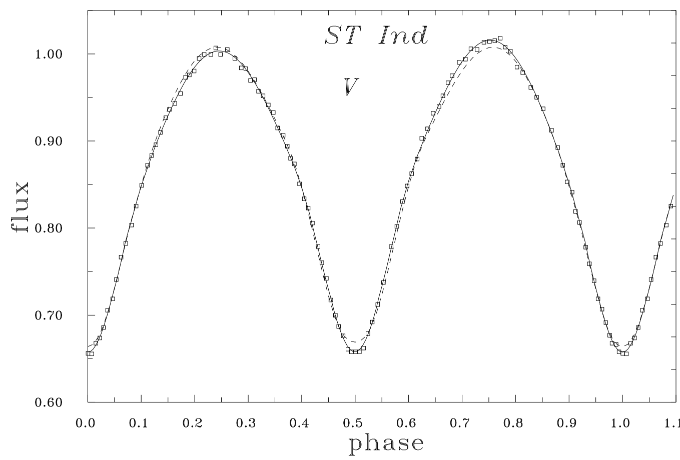

Fig. 2. Observed and theoretical light curves of ST Ind in V filter

We proceeded with the CRS search examining the search array every several thousands of iterations. Iterations were stopped when the difference between the best and the worst elements of the search array was less than 1 percent. To check the stability of the derived solution we switched to the original Wilson's DC method and set all the physical parameters resulting from the previous step as the starting values. The primary star's temperature was set to the value derived from the CRS computations and was not adjusted. Convergence was achieved in a few iterations. The parameters corresponding to the best fit are listed in Table 1, while theoretical light curves (continuous lines) along with the observed ones (squares) for B and V filters are shown in Figs. 1 and 2, respectively. The errors listed in Table 1 are those calculated within the DC procedure.

3. Conclusions

We have obtained a model for ST Ind using the Wilson-Devinney code for computing light curves of a binary system. The mass ratio in our model is not so extreme as that derived by WND, thus the components of equal temperature, are more comparable in mass. It should be noted that in spite of the small formal error of q (see Table 1), the root-mean-square value manifests a very moderate dependence on a mass ratio for q between 0.5 and 1.0. Models for the mass ratio larger than one, give a noticeably worse fit to the observations.

We conclude that the mass ratio could not be determined from the photometry alone. Measuring radial velocity curves would give a reliable mass ratio for ST Ind. If good spectroscopy is available, combined with results of the present modelling, would give the absolute dimensions of the components of ST Ind.

All attempts to exclude the contact configuration from the scope of calculations, (i.e. limitation to semi-detached) were leading to significant grow of the rms error.

As it was noticed by different authors (Krzesinski et al. 1991, Milone et al. 1987), modelling light curves of contact systems with spots, strong correlations between selected spot parameters exist. Among them, the most correlated are temperature and size of the spot. The same situation was found for ST Ind. We checked the correlations by introducing a small 'perturbation' to the parameters derived from the final fit. Careful analysis of the rms error indicates that slightly smaller spot radius together with higher temperature of the spot would give also a satisfactory solution.

Solutions with a hot spot on the primary component were also considered. For such a case, however, the fit is worse than for a cool spot but the rms error is only about 1 percent higher.

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