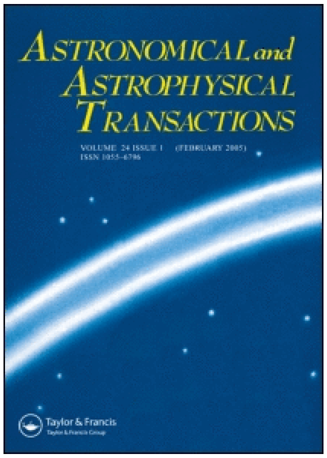

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NEW PHOTOMETRIC STUDY OF THE RS CVN TYPE BINARY *SZ PSC*

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Visual (BV) light curves of the RS CVn type binary system SZ Psc are presented. The light curves show a period change towards decreasing phases. New parameters for the system are found based on an analysis of the observed light curves using a Djuraševič's inverseproblem method. The observed light curves of SZ Psc, in both observational bands, can be successfully interpreted within the Roche model with three spotted areas on the surface of the more massive component. Characteristics of the spots and a genera discussion of the observed light curves and the results are given.

KEY WORDS Binary systems, light curves, SZ Psc

1 INTRODUCTION

SZ Psc (HD 219113, $\alpha_{2000} = 23^h13^m23^s.8$, $\delta_{2000} = +02°40'32''$, $m_v = 7.2$–7.7) is a totally eclipsing double line spectroscopic binary, of the RS CVn type. The system consists of a K1 IV with a radius of $5.1R_\odot$ and mass $1.62M_\odot$ that fills 85% of its Roche lobe and an F8 V companion with a radius of $1.5R\odot$ and a mass $1.28M_\odot$ at a distance of 125 pc (Popper, 1988).

Few photometric observations of the system exist, as its period is very close to four days (Jakate *et al.*, 1976; Tunca, 1984). Period changes have been observed not only from photometric (Jakate *et al.*, 1976; Tunca, 1984) but also from spectroscopic data (Doyle *et al.*, 1994), while Kalimeris *et al.* (1995) have made a detailed study of the orbital period variation of the system. In this paper we present new optical (BV) light curves of the system and new parameters based on an analysis of the observed light curves using a spot model.

2 OBSERVATIONS

The BV observations presented in this paper were carried out with the 1.2 m telescope at the Kryonerion Astronomical Station from July 1993 to September 1994. The optical photometer used is a single channel photon counting photometer described by Dapergolas and Korakitis (1987).

The photometer employs a high gain 9789 photube and conventional UBV filters. The star HD 219018 ($\alpha_{2000} = 23^h12^m38^s.6$, $\delta_{2000} = +02°41'10''$, $m_v \sim 7.7$) was used as comparison. Jakate suspected it was a variable but this was not confirmed in later studies. The filters used are in close accordance to the international UBV system. Each observation is the average of four succesive measurements, and the corresponding phases were calculated using the linear ephemeris by Tunca (1984):

$$\min I = 2444827.0047 + 3^d.9657889 \times E.$$

3 PHOTOMETRIC ANALYSIS: PROCEDURE AND RESULTS

The model used to describe the SZ Psc system is based on the Roche geometry (Djurašević, 1992a), according to which the size of the two components is described by filling coefficients $F_{1,2}$ of their critical Roche lobes. They are expressed through the ratio of stellar polar radii, $R_{1,2}$, and the corresponding polar radii of the Roche lobes, i.e., $F_{1,2} = R_{1,2}/R_{\mathrm{Roche}_{1,2}}$, telling us to what degree the stars in the system fill their Roche lobes.

In a spherical coordinate system the surfaces of the components were divided into a large number of elementary cells ($72 \times 144 = 10368$). Intensity and angular distribution of the cell's radiation were determined by stellar effective temperatures, limb and gravity darkening and by reflection effects.

The presence of spotted areas on the system components enables us to explain the asymmetry and depressions on the light curves. In the model, these active regions are approximated by circular spots, characterized by the temperature contrast of the spot with respect to the surrounding photosphere $A_s = T_s/T*$), by the angular dimension (radius) of the spot (θ) and by the longitude (λ) and latitude (φ) of the spot centre. The longitude (λ) is measured clockwise (as viewed from the direction of the $+Z$-axis) from the $+X$-axis (the line connecting star centres) in the range 0–360°. The latitude (φ) is measured from 0° at the stellar equator (orbital plane) to +90° at the "north" ($+Z$) pole and −90° at the "south" ($-Z$) pole.

In order to use the above described model in the analysis of B and V light curves of *SZ Psc*, some of the model parameters were fixed to standard values to reduce the number of free parameters. So in the present study the mass-ratio of the components was fixed to the value of $q = m_2/m_1 = 1.2656$ as was estimated by Popper (1988) from spectroscopic data. The primary's temperature was consistent with its spectral type (F5 IV; $T_1 \sim 6650$ K). Gravity darkening coefficients and bo-

Table 1. Results of the light-curve analysis obtained by solving the inverse problem within the Roche model with three spotted areas on the coler secondary for the *SZ Psc* system

Quantity	*B – filter*	*V – filter*
$\Sigma(O-C)^2$	0.0969	0.1068
θ_1	33.0 ± 0.5	36.2 ± 0.5
λ_1	15.0 ± 1.0	15.1 ± 0.9
φ_1	58.3 ± 0.8	60.0 ± 0.7
θ_2	40.0 ± 0.4	41.5 ± 0.4
λ_2	123.7 ± 1.1	123.9 ± 1.0
φ_2	-12.4 ± 0.8	-12.9 ± 0.8
θ_3	35.3 ± 0.5	37.3 ± 0.4
λ_3	243.9 ± 0.8	244.1 ± 0.8
φ_3	6.2 ± 2.6	3.9 ± 2.0
T_2	4657 ± 11	4689 ± 18
F_1	0.322 ± 0.004	0.327 ± 0.004
F_2	0.998 ± 0.002	0.998 ± 0.003
i	69.84 ± 0.06	69.77 ± 0.08
u_1	0.69	0.62
u_2	0.81	0.73
Ω_1	10.472	10.338
Ω_2	4.176	4.177
R_1 $[D=1]$	0.109	0.110
R_2 $[D=1]$	0.375	0.375

Note. Fixed parameters: $q = m_2/m_1 = 1.2656$ – mass ratio of the components, T_1=6650 K – temperature of the primary, $A_s = T_s/T_2 = 0.7$ – spot temperature coefficients, $\beta_1 = \beta_2 = 0.08$ – gravity-darkening coefficients of the components, $f_1 = f_2 = 1.00$ – non-synchronous rotation coefficients of the components. $\Sigma(O-C)^2$ is the final sum of squares of residuals between observed (LCO) and synthetic (LCC) light curves, $\theta_{1,2,3}$ are the spot's angular dimensions, $\lambda_{1,2,3}$ are the spot's longitude and $\varphi_{1,2,3}$ are the spot's latitude (all in arc degrees), $F_{1,2}$ are the filling coefficients for critical Roche lobes of the primary and secondary, T_2 is temperature of the secondary, i the orbit inclination (in arc degrees), $u_{1,2}$ are limb-darkening coefficients of the components, $\Omega_{1,2}$ are dimensionless surface potentials of the primary and secondary and $R_{1,2}$ are the polar radii of the components in units of the separation (D) between the component centres.

lometric albedos were put equal to their theoretical values of 0.08 and 0.5, respectively, which are appropriated for stars with convective envelopes (Lucy, 1967; Rucinski, 1969; Raffert and Twigg, 1980), while limb-darkening coefficients were derived using the polynomial proposed by Diaz-Cordoves *et al.* (1995).

Optimum model parameters were obtained through the minimization of the sum $S = \Sigma(O-C)^2$, where $O-C$ is the residual between observed (LCO) and synthetic (LCC) light curves at every given orbital phase. The minimization of S is done in an iterating cycle of corrections of the model parameters to achieve the best agreement between observed and synthetic light curves. This method, created by modifying Marquardt's (1963) algorithm, also gives standard errors of the parameters. The obtained results allow an interpretation of photometric observations of the system.

Large asymmetry of the light curves required spotted areas on the components to be added in the model if we want a good description of the light curves. Since the results of the light-curve analysis strongly depend on the choice of the working hypothesis, the analysis was carried out within the framework of several hypotheses with dark spotted areas on the surfaces of both components. Rejecting those which produced discrepant values of the parameters of the system and its active spotted areas for the B and V observational bands, we finally chose the Roche model with three spotted areas on the cooler secondary component as the optimum solution. These active regions on the chromospherically active K1 IV subgiant are of the same nature as solar magnetic spots (Mullan, 1975). In this case the light-curve analysis yielded mutually well consistent parameters (see Table 1.). The errors in parameter estimation had an origin in the non-linear least-squares method, on which the inverse-problem method is based.

According to our solution the hotter primary is very deep within its Roche lobe ($F_2 \sim 0.325$), while the cooler secondary almost completely fills its critical Roche lobe ($F_2 \sim 0.998$). Following from Table 1 we have polar radii of the components of $R_1 \sim 1.68R_{\odot}$ and $R_2 \sim 5.74R_{\odot}$ with the separation between the components $D \sim 15.3R_{\odot}$ as a unit measure. Large spotted areas on the secondary cover an extended part of the surface of the star. This suggests a high activity in the system during these observations.

Following from the inverse-problem solutions for individual light curves, Figure 1 (top) presents the best fit of observations (LCO) by the optimum synthetic light curves (LCC).

The next three rows in this panel present the view of the system SZ Psc with the parameters estimated by analysing B and V light curves, respectively. On these plots one sees how a CB system would look at a noted orbital phase, chosen so that the spots are visible.

Finally, Figure 1 (bottom) presents also the changes of the $B - V$ colour index with the orbital phase. They are calculated from the best synthetic light curves (LCC) obtained by solving the inverse problem. We can see some changes around the minima of the light curves that may be attributed to the difference in the temperature of the components and to the spot-effects.

4 DISCUSSION AND CONCLUSIONS

In the present study we used a spotted model to fit our observations of *SZ Psc*. From the light-curve analysis of the system, new estimates of its parameters were made, and the positions as well as dimensions of active regions were found. The analysis yielded a semidetached configuration ($F_1 \sim 32.5\%$; $F_2 \sim 99.8\%$), with a significant temperature difference ($\Delta T \sim 1980$ K) between the two components.

Having in mind the large changes in the shape of the light curves, future photometric observations of this interesting system are of great interest.

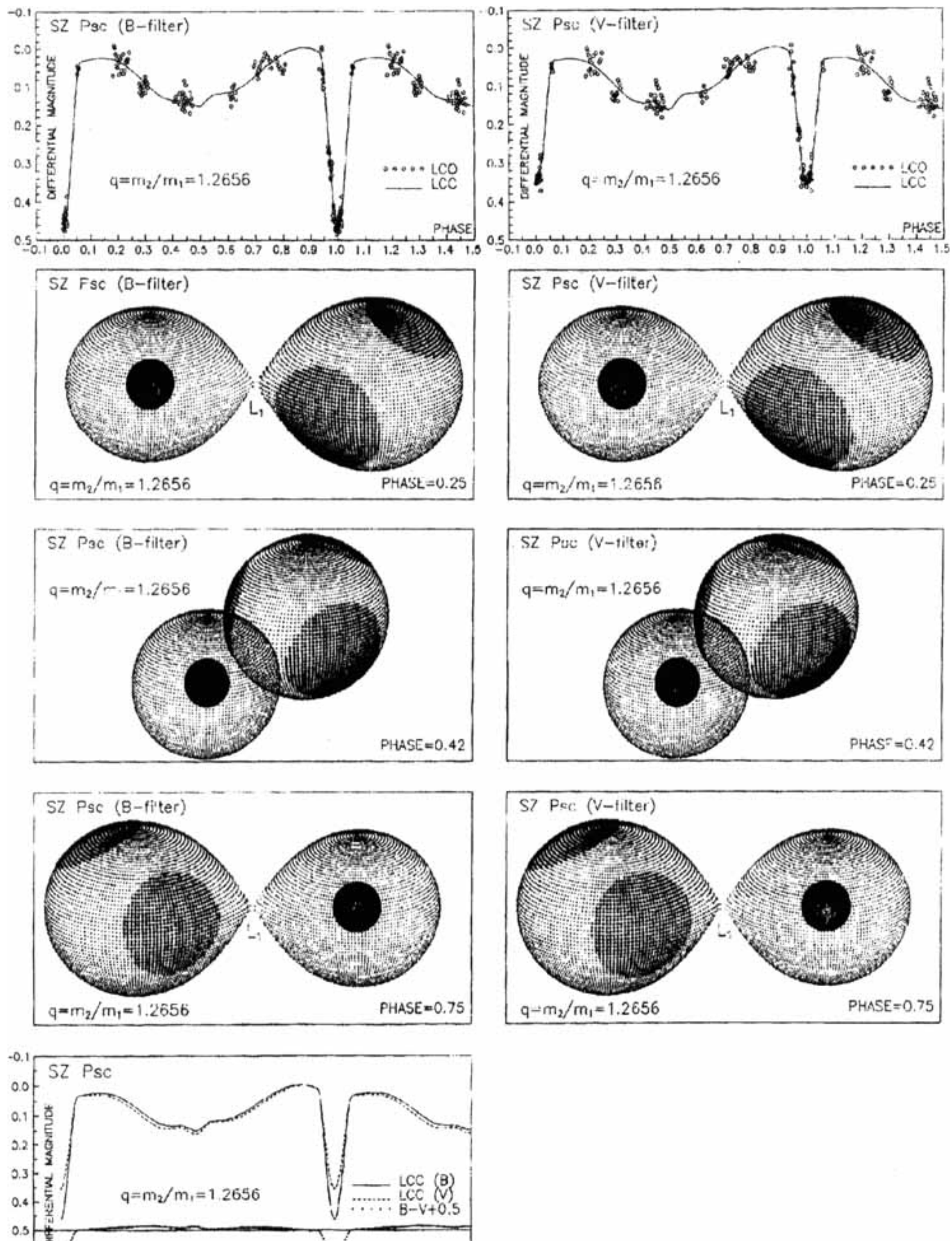

Figure 1 Observed (LCO) and final synthetic (LCC) light curves of *SZ Psc* with final $O - C$ residuals obtained by analysing B and V observations; the view of the system *SZ Psc* at corrseponding orbital phases, obtained with the parameters estimated by analysing observations; the changes of the $B - V$ colour-index with the orbital phase.

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