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APPLICATION OF THE BaSeL ATMOSPHERIC MODELS IN THE LIGHT-CURVE ANALYSIS

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1. THE STELLAR ATMOSPHERE APROXIMATIONS AND THE LIGHT-CURVE ANALYSIS

In previous versions of our programme for light-curve analysis in eclipse CB systems (Djurašević, 1992a), generalized for the case of an overcontact configuration (Djurašević, *et al.*, 1998), there were two different possibilities in the application of the model with respect to the treatment of the radiation law: the simple black-body theory, or the stellar atmosphere models by Carbon & Gingerich (1969, hereafter CG), the latter giving a more realistic spectral energy distribution than the black-body approximation. In some cases (as B-type systems) the Planck option gives better fits than the CG approximation, with solutions that are more consistent in different photometric passbands. Further improvement of the progamme is possible if we introduce a third option: the use of tables of model atmospheres that are quite modern and more reliable. Here we present our current version of the programme for the light-curve analysis which uses the new promising Basel Stellar Library (hereafter "BaSeL") with empirically colour-calibrated flux distributions over a large domain of effective temperatures (Lejeune *et al.* 1997, 1998). This library combines theoretical stellar energy distributions, which are based on several original grids of blanketed model atmospheres.

To compute synthetic colours from the BaSeL models, we need effective temperature (T_{eff}), surface gravity ($log\ g$) and metallicity ($[Fe/H]$). The surface gravities can be derived very accurately from the masses and radii of the CB stars by solving the inverse problem of the light-curve analysis, but the temperature determination is related to the assumed metallicity and strongly depends on photometric calibration. Consequently, the BaSeL library has been corrected in such a way as to provide synthetic "corrected" flux distributions, consistent with extant empirical calibrations at all wavelengths from near-UV through the far-IR (see Lejeune *et al.* 1997, 1998).

In our programme for the light-curve analisys, we have explored the "corrected" BaSeL model flux distributions, within a large range of stellar parameters: $2000K \leq$

$T_{eff} \leq 35000K$, $-1 \leq [Fe/H] \leq 1$ and $3 \leq log\ g \leq 5$. In the inverse-problem the fluxes are calculated in each iteration for current values of temperatures and $log\ g$ by interpolating in the both of these quantities in the atmosphere tables, as an input, for a given metallicity of the CB components. The metallicity of the involved CB components can be different. Because of that we can use individual, different tables as an input, for each star, and, in that way, choose the best calculations for its particular atmospheric parameters. Compared to Vaz *et al.* (1995) our two-dimensional flux interpolation in T_{eff} and $log\ g$ is based on the application of the *bicubic spline* interpolation (Press *et al.*, 1992). This proved itself to be a good choice.

By choosing and fixing the particular input switch, the programme for the light-curve analysis can be simply redirected to the Planck or CG approximation, or to the more realistic BaSeL model atmospheres. Parallel tests of these programme modifications proved that the implementation of the BaSeL models option in the light-curve analysis gave solutions for different passbands light curves that were more mutually consistent than in the case of the CG or black approximation. If an independant spectroscopic sources could give us an estimate of the metallicity of the CB components, the application of the BaSeL models option in the light-curve analysis could really give more reliable solutions, and thereby better estimates of the parameters of the CB system, as well. A change in the assumed metallicity causes a noticable change in the predicted stellar effective temperature. Lastennet *et al.'s* (1999) analysis supports this conclusion.

2. APPLICATION TO THE LIGHT-CURVE ANALYSIS OF THE RY SCT

The present study deals with the problem of estimating the orbital and physical parameters for the early-type eclipsing binary RY Sct. This peculiar system has the orbital period of $P \sim 11^d.125$ and its optical spectrum, classifed as around B0pe, is characterised by strong [FeIII], [SiIII] emission lines and emission lines of hydrogen, helium, etc. Radio emission (Hughes and Woodsworth, 1973) and infrared excess (Geisel, 1970), dominated by extremly large stellar silicate excess (Grasdelen *et al.*, 1979), suggested that the massive binary system of RY Sct is surrounded by an extensive peculiar circumstellar nebula containing gas and dust. A shallow and asymmetrical emission feature observed in the core of H_α indicated the presence of the material expanding at high velocities (de Martino *et al.*, 1992). These authors suggested a multiple shell nebula and an asymmetrical mass outflow from the system.

While the same authors found that RY Sct is in the overcontact phase with the more-massive cooler star and less-massive hotter one, Cowley and Hutchings (1976), King and Jameson (1979), Giuricin and Mardirossian, Cherepashchuk (1988) and Antokhina and Kumsiashvili (1999) proposed a β Lyrae model, in which the secondary was hotter (O5) but under-luminous because of an obscuring disc. In the last two papers, for the mass ratio the authors used the new value of $q = m_2/m_1 \sim 3.3$ (Skul'skij, 1985, 1992).

Our own new observations of RY Sct were obtained at Maidanak Observatory (Uzbekistan) by using 0.6 m aperture telescope with standard UBVR filters. In this paper we explored these light-curves in order to improve our present knowledge of this binary.

To estimate the parameters of this system we analysed our new light curves by using our current version of the programme for the light-curve analysis in which we explored the "corrected" BaSeL model flux distributions. For the metallicity of the RY Sct's components we used $[Fe/H]_{h,c} = 0.1$. The indexes $_{\mathrm{h,c}}$ correspond to the hotter and cooler component of the system respectively. Since our analysis gave the overcontact configuration of the system, we expected mutual tidal effects to synchronise stellar rotational and orbital periods ($f_{h,c} = 1.0$ - nonsynchronous rotation coefficients). The temperature of the less-masive (hotter) star was fixed at the value $T_h = 28000K$, appropriate for an B0 star. The gravity-darkening coefficients were set at $\beta_{h,c} = 0.25$ according to the stars' temperature. This value corresponds to von Zeipel's law for fully radiative envelopes. Consequently, for the components' albedos we adopted the values $A_{h,c} = 1.0$, corresponding to full reradiation. The limb-darkening coefficients ($u_{h,c}$) were derived according to stellar effective temperature and surface gravity via the polinomial proposed by Díaz-Cordovés *et al.* (1995). During the optimisation process, according to the temperature changes, we performed an automatic recomputation of the limb-darkening. In the R-filter the limb-darkening was taken from the tables published by Al Naimy (1977).

With the mass ratio of the components $q = m_2/m_1 \sim 3.3$ (Skul'skij, 1985, 1992), the iterating process of optimisation converges very fast to the overcontact configuration, with the orbit inclination of about $i \sim 84^o.5$ and with significantly low temperature of the more-massive (cooler) primary component ($T_c \sim 23900K$).

Since our light curves are asymmetrical around the secondary minima and have a small difference in the heights of successive maxima, after achieving the first convergence we included free parameters related to active spotted areas ($A_S = T_S/T_*$)-the temperature contrast of the spots with respect to the surrounding photosphere, θ_S-spot's angular dimensions - radius, λ_S-longitude and φ_S-latitude of its centre) into the iterative process.

High fitting quality was obtained under the assumption of a relatively large hot area on the more-massive (cooler) star, near the neck region between the components ($A_{S1} = T_{S1}/T_c \sim 1.22$, $\theta_{S1} \sim 47^o.5$ and $\lambda_{S1} \sim 169^o$). This solution and the value of the mass ratio suggested significant mass and energy transfer from the less-massive (hotter) star onto the cooler one, and such an effect can produce hot area around the neck region on the more-massive primary. Such a physical nature of the spot allowed us to fix its latitude ($\varphi_S = 0^o$) and thereby to reduce the number of free parameters. The optimum fitting of the observations was obtained after introduction of an additional hot region on the more-massive (cooler) star, located in the equatorial zone of the star, near the external Lagrange point L_3 ($A_{S2} = T_{S2}/T_c \sim 1.29$, $\theta_{S2} \sim 27^o$ and $\lambda_{S1} \sim 327^o$). It is very probable that from this region we have an intensive gas outflow, which can be one of the possible ways to form the circumstellar nebula around the system. We suggest that matter is emanating near the L_3 point, which implies that material is flowing from the less-masive primary towards the secondary. After having passed through the neck region, the material is accelerated very likely by radiation presure and it is lost for the system. From high-resolution spectroscopic observations de Martino *et al.* (1992) found that three mechanisms could be responsible for the existence of the nebula around RY Scuti: mass loss by stellar wind, mass outflow from the external Lagrange point or a major expulsion phase from the system. The study of Milano *et al.* (1981) indicates that the system is in a high degree of overcontact ($f_{over} \sim 41\%$), which also could favour a mass loss from the external Lagrange point during the mass exchange phase as the main mechanism.

The parameters derived in the light-curve analysis are listed in Table 1. Resulting from the inverse-problem solutions for individual light curves, Fig. 1. (Left) presents the optimum fit of the observed light curves (LCO) by synthetic ones (LCC). The light curves are normalised to the brightness at the orbital phase of 0.25. The final residuals (O-C) between the observed (LCO) and optimum synthetic (LCC) light curves are given, too. The right-hand column in these Figures shows the view of RY Sct's Roche models, obtained with the parameters estimated by analysing the corresponding light curves. Thanks to such plots, one sees how would a CB model look like at a noted orbital phase, chosen so that the active bright regions are visible. Finally, the bottom row of this panel gives the observed new UBVR light curves, drawn together, and the changes of the colour indexes $U-B$, $B-V$ and $V-R$ with the orbital phase.

3. CONCLUSIONS

The summary of our results, given in Table 1, proved that the Roche model with two hot regions on the more-massive (cooler) component of RY Sct can successfully simulate the observed light curves. Without these active regions the fitting was much poorer. Our analysis shows that the implementation of the BaSeL models in the programme for the light-curve analysis gave solutions that are more mutually consistent for different UBVR passband curves than the CG or the black-body approximation.

The results describe Ry Sct's system as an overcontact configuration with a high degree of overcontact ($f_{over} \sim 31.4\%$), and with the temperature difference between the components $\Delta T = T_h - T_c \sim 4100K$. With the mass ratio $q = m_c/m_h \sim 3.3$, these solutions suggest a significant mass and energy transfer from the less-massive (hotter) star onto the more-massive (cooler) component. The hot area on the cooler star in the neck region, can be taken as a consequence of this mass and energy exchange between the components. Another hot area (near the external Lagrange point L_3) is probably the zone of an intensive mass outflow from the system. This mechanism, together with mass loss by stellar wind, could be responsible for the existing nebula around RY Scuti.

Formerly the light-curves analysis was performed in the frame of the Roche model with an acretion disc around the more-massive component, also. That model was developed for the W Ser-type of systems (Djurašević, 1992c). Since the obtained fitting quality within that model was of a much poorer quality we think that such a model can be rejected as a less probable.

Table 1. Results of the analysis of the RY Sct light curves obtained by solving the inverse problem for the Roche model with two hot areas on the more-massive (cooler) component.

Quantity	U-filter	B-filter	V-filter	R-filter
$\Sigma(O-C)^2$	0.6108	0.3775	0.2929	0.2379
A_{S1}	1.224±0.004	1.219±0.004	1.231±0.004	1.222±0.003
θ_{S1}	45.8±0.6	47.9±0.6	46.9±0.6	49.3±0.5
λ_{S1}	170.7±0.7	167.7±0.6	168.3±0.5	168.7±0.5
A_{S2}	1.280±0.004	1.283±0.004	1.305±0.004	1.287±0.003
θ_{S2}	26.6±0.4	27.9±0.4	26.0±0.3	28.0±0.3
λ_{S2}	330.6±1.7	324.7±1.5	327.0±1.5	326.2±1.2
T_c	23799±94	23950±118	23792±106	24065±79
F_c	1.051±0.002	1.048±0.002	1.051±0.001	1.054±0.002
i	84.7±0.9	84.4±0.7	84.7±0.7	84.3±0.6
u_h	0.34	0.36	0.32	0.22
u_c	0.36	0.39	0.34	0.22
$\Omega_{h,c}$	6.8147	6.8257	6.8147	6.8037
Ω_{in}	7.0106	7.0106	7.0106	7.0106
Ω_{out}	6.3875	6.3875	6.3875	6.3875
$f_{over}[\%]$	31.45	29.67	31.45	33.21
R_h	0.275	0.274	0.275	0.276
R_c	0.468	0.467	0.468	0.468
$L_h/(L_h+L_c)$	0.338	0.310	0.310	0.307

FIXED PARAMETERS:
$T_h = 28000K$ - temperature of the less-masive (hotter) star,
$f_h = f_c = 1.00$ - nonsynchronous rotation coefficients of the components,
$q = m_c/m_h = 3.3$ - mass ratio of the components,
$\beta_{h,c} = 0.25$ - gravity-darkening coefficients of the components,
$A_{h,c} = 1.0$ - albedo coefficients of the components.
$\varphi_{hs} = 0^o$ - hot spot latitude (ekvatorial zone of the star)
$[Fe/H]_{h,c} = 0.1$ - accepted metallicity of the components

Note: $\Sigma(O-C)^2$ - final sum of squares of residuals between observed (LCO) and synthetic (LCC) light curves, $A_{S1,2} = T_{S1,2}/T_2$ - spot temperature coefficient, $\theta_{S1,2}$ - spot angular dimensions and $\lambda_{S1,2}$ - spot longitude, (both in arc degrees), F_h - filling coefficient for critical Roche lobe of the hotter less-masive star, T_c - temperature of the more-massive cooler star, i - orbit inclination (in arc degrees), $u_{h,c}$ - limb-darkening coefficients of the components, $\Omega_{h,c}$ - dimensionless surface potentials of the primary and secondary, Ω_{in}, Ω_{out} - the potentials of the inner and outer contact surfaces respectively, $f_{over}[\%] = 100 \cdot (\Omega_{h,c} - \Omega_{in})/(\Omega_{out} - \Omega_{in})$ - degree of overcontact, $R_{h,c}$ - polar radii of the components in units of the distance between the component centres and $L_h/(L_h + L_c)$ - luminosity of the hotter star (icluding spots on the cooler one).

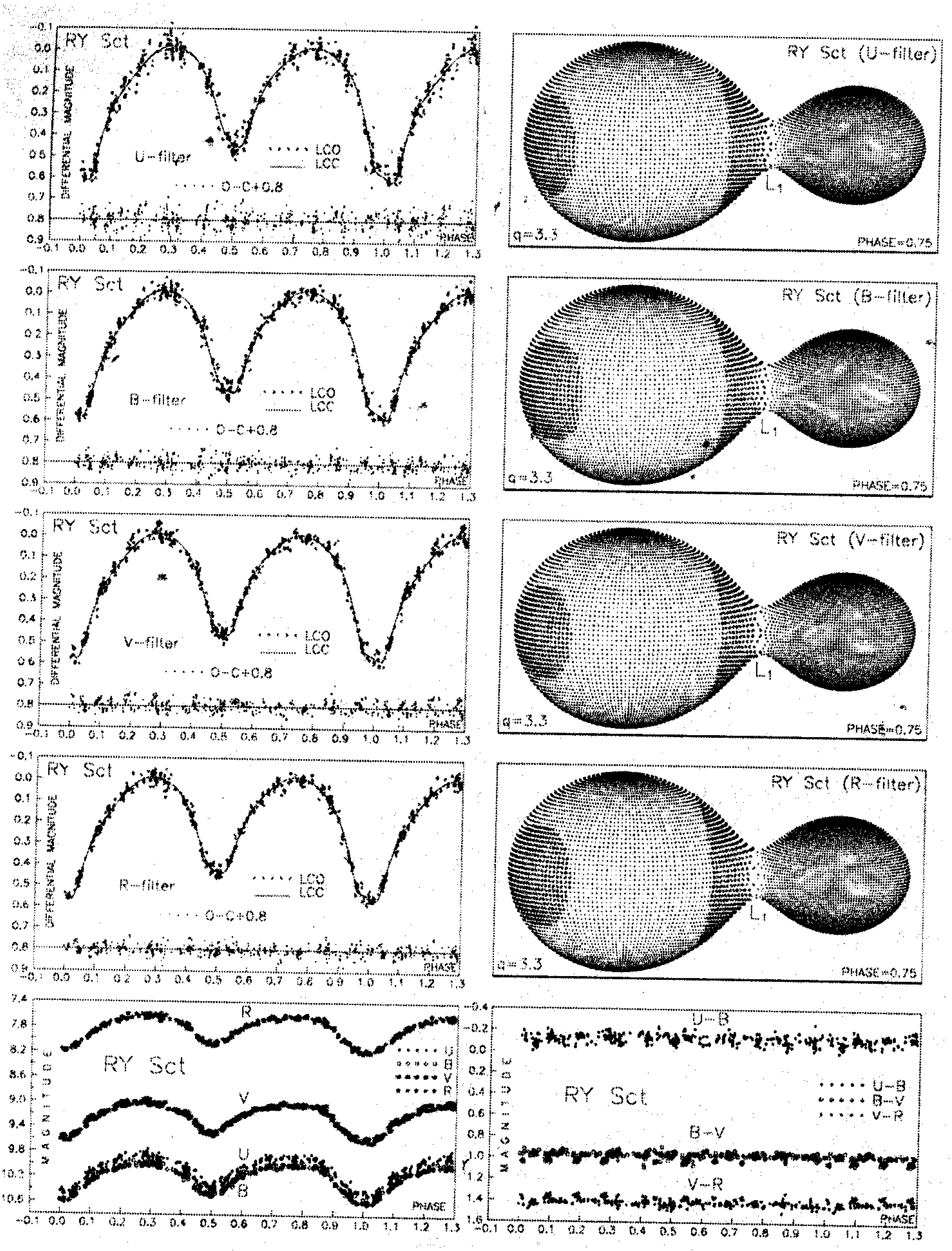

Fig. 1. Left: Observed (LCO) and final synthetic (LCC) light curves of RY Sct with O-C residuals obtained by solving the inverse problem within the framework of the Roche model with two hot areas on the more-massive cooler star; Right: The view of the Roche model for the RY Sct at the orbital phase 0.75 with parameters estimated by solving the inverse problem; Bottom row: Left: the observed new UBVR light curves; Right: The changes of the colour indexes $U - B$, $B - V$ and $V - R$ with the orbital phase.

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