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PRELIMINARY ANALYSIS OF THE LIGHT CURVES OF CB *OO Aql*

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Abstract. The paper is devoted to the problem of the determination of the orbital and physical parameters of active CB *OO Aql* on the basis of the interpretation of photometric observations made by Lafta and Grainger (1985). The problem is solved in two stages: by obtaining a synthetic light curve in the case when the parameters of the corresponding CB model (Djurašević, 1992a) are given *a priori* (direct problem) and by determining the parameters of the given model for which the best fit between the synthetic light curve and the observations is achieved (inverse problem) (Djurašević, 1992b). The light curves are analysed in the frame of several working hypotheses among which the hypothesis including a hot spot on the secondary proved to be the probable one. Within the last hypothesis the basic parameters of the system and of the active region are estimated.

1. INTRODUCTION

CB *OO Aql* is a short-period ($P = 0^d.506796$) W Uma-type system. Binnendijk (1986) performed the first analysis of the light curves based on his own observations in B and V passbands. Demircan and Güdür (1981) observed this system from 1968 to 1974 and suggested that plausible explanation of the periodic fluctuations of times of minima is the presence of a third body in the system or nodal regresion.

Lafta and Grainger (1985) analysed the observations obtained in B and V passbands by using Kopal's Fourier method and by the optimisation method. Details concerning this procedure of light curves analysis can be found in the mentioned paper and references therein. These methods are not based on the Roche model, and due to the asymmetry of the light curve the optimum model fit substantially deviates from observations in some parts of the light curve.

For the spectroscopic mass ratio based on the analysis of radial velocities Hrivnak (1989) gave the value $q = m_2/m_1 = 0.843$. In the analysis of Binnendijk's light curves Hrivnak applied Wilson's (1979) programme for overcontact configurations and estimated the system parameters. Due to the asymmetry of the light curves near the curves' maxima obtained fit deviates from observations.

The most striking feature of these light curves is their asymmetry arising from the unequal height of successive maxima. This variation can be explained by assuming the existence of active dark or hot spot regions on some of the system's components. On stars with convective envelopes, as in this case (spectral type G5 V), one may expect the presence of spots. Therefore, the hypothesis of RS CVn-type activity appears justifiable. However, due to mass and thermal energy transfer between components on W UMa-type systems one can expect also the occurrence of regions with higher temperatures in equatorial zone on the cooler secondary towards which the transfer is directed.

For the purpose of analysing the asymmetric light curves, deformed by the presence of spots on the components, a model (Djurašević, 1992a) has been developed, which is based on the principles originated in the Wilson and Devinney (1971) model. Fig. 1 graphically presents the model.

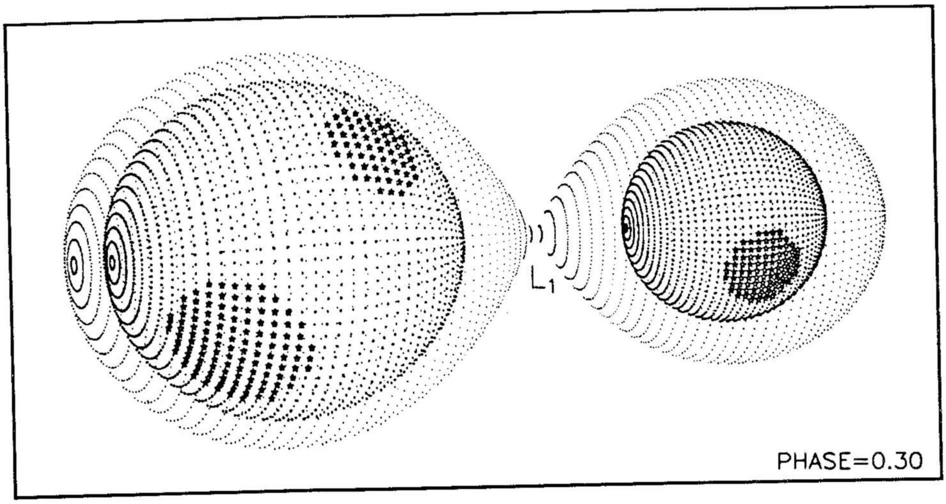

Fig. 1. The Roche model of an active CB with spots on the components.

For a successful application of the realized CB model in analysing the observed light curves, an efficient method unifying the best properties of the gradient and the differential-corrections method into a single algorithm (Djurašević, 1992b) is proposed. This method is realized by modifying the Marquardt (1963) algorithm. The inverse problem is solved in an iterative cycle of corrections to the model elements based on a nonlinear least-square method.

The interpretation of photometric observations is based on the choice of optimal model parameters yielding the best agreement between the observed light curve and the corresponding synthetic one. Some of these parameters can be determined *a priori* in an independent way, while the others are found by solving the inverse problem.

2. ANALYSIS

In this paper we present the analysis of light curves of *OO Aql* obtained in B and V passbands (Lafta and Grainger, 1985) based on the model of CB system with spots on components (Djurašević, 1992a). The asymmetry of these light curves is more profound than in Binnendijk's observations, which indicates the higher level of activity in the system.

A preliminary analysis of light curves showed that both components in this system fill their critical Roche lobes, therefore we expected that tidal effects cause the sinchronisation between of rotational and orbital periods. We treated the gravity-darkening coefficients as free parameters in the inverse-problem method and we adopted $\beta_{1,2} = 0.08$ as their initial values. Lucy (1967) and Osaki (1970) regard this value as justifiable in stars with convective envelopes. In the programme which solves the inverse problem, the linear limb-darkening coefficients are determined on the basis of the temperature of the components and of the stellar-surface gravity, according to the given spectral type, by using the polynomial proposed by Díaz-Cordovés *et al.* (1995). The temperature of the primary component T_1, was set at 5700 K based upon the spectral type (G5 V) (Roman, 1956) and colour of the system (B-V)=0.76 (Eggen, 1967).

The results of the light curve analysis for these systems highly depend on the chosen working hypothesis. Within the hypothesis of a RS CVn-type spot we considered a single- and double-spot model with the possibility of spot occurrence on both, primary and secondary, components in the system. Double-spot model with spots on the primary gives a good fit to the observations, but the spot parameters are somewhat divergent in B and V light curves. This may indicate this hypothesis as being inappropriate in the analysis of observational light curves. Therefore, we looked for the possible explanation of the observed deformation on the light curves in the frame of a second mechanism in active region formation.

The obtained results show that system's components fill their critical Roche lobes, having approximately the same temperature. The system is in the contact or mildly overcontact configuration, which is implied by somewhat higher values of gravity-darkening coefficients. The used model does not predict an overcontact configuration which is compensated by increasing the gravity-darkening coefficients. Overcontact configuration is possible since the equality of temperatures of main-sequence stars with different masses can be explained through the exchange of thermal energy. In the system the stars are in physical contact in the vicinity of the Lagrangian equilibrium point L_1. Lucy (1967,1968a,1968b) showed that the contact of adiabatic parts of two convective envelopes necessarily leads to the exchange of thermal energy. We can expect that this exchange produces a region of enhanced luminosity on the cooler secondary, therefore it is sensible to test the model with a hot spot in the equatorial zone. The temperature contrast of the spot with respect to the surrounding photosphere (A_s), the longitude (λ) and the angular dimensions of the spot (θ) are treated as free parameters.

Within this hypothesis the analysis of light curves yields mutually well consistent parameters of the system and of the active regions in B and V passbands. Consequently, the presence of a hot spot on the secondary can be taken as possible. Approximate equality of the temperatures for components being in physical contact suggests the exchange of thermal energy that is in favour of the last hypothesis.

Because of the limited space here we present in Table I only the results for the V passband curve.

TABLE I

Results of analysis (RES) observed light curve for the active CB *OO Aql*.

RES: (V-filter)

0.1302E-01 - final sum of square deviations $\sum(O-C)^2$

FREE PARAMETERS AND ERRORS:

0.997E+00 ± 0.19E-02 - filling coeff. for the primary's critical lobe ($S_1 = R_1/R_{Rc}$)
0.998E+00 ± 0.14E-02 - filling coeff. for the secondary's critical lobe ($S_2 = R_2/R_{Rc}$)
0.862E+02 ± 0.10E+00 - orbit inclination (i)
0.560E+04 ± 0.55E+01 - temperature of the secondary (T_2)
0.844E+00 ± 0.91E-02 - mass ratio of the components ($q = m_2/m_1$)
0.304E+02 ± 0.34E+00 - angular dimensions of the bright spot (θ)
0.845E+02 ± 0.12E+01 - longitude of the bright spot (λ)
0.109E+01 ± 0.15E-02 - bright spot temperature coefficient ($A_s = T_s/T_2$)
0.101E+00 ± 0.43E-02 - gravity-darkenning coefficient of the primary (β_1)
0.800E-01 ± 0.46E-02 - gravity-darkenning coefficient of the secondary (β_2)

FIXED (*) AND CALCULATED PARAMETERS:

* 0.570E+04 1.00 1.00 - temperature of the primary T_1 and nonsynchronous rotation coefficients f_1, f_2
* 0.50 0.50 - albedo coefficient for the components (A_1, A_2)
0.66 0.67 - limb-darkening coefficient for the components (u_1, u_2)
0.369 0.341 - polar radii of the components (R_{p1}, R_{p2}) [D=1]
[D=1] - data are given in units of the distance between the component centres.

The components of the system fill their critical Roche lobes. The mass-ratio of the components, estimated by the light curve analysis, is in good agreement with its spectroscopically estimated value ($q = 0.843$), (Hrivnak, 1989). The longitude of the active region amounts to about 90°, and the temperature contrast with respect to the surrounding photosphere amounts to about 1.09. This means that the spot is by about 500 K warmer than the surrounding photosphere. In solving the inverse-problem spot dimensions are anticorrelated to the temperature contrast and this can affect these results. Namely, a smaller spot with a higher temperature contrast deforms the light curve in the similar way as a larger spot with a lower temperature contrast does.

The quality of the obtained results can be graphically presented. Fig. 2 shows the fit of the observed light curve (LCO) by synthetic model curve (LCC) and the final (O-C). Through a specially developed programme (Djurašević, 1991) it is possible to present the view of the system in a selected orbital phase on the basis of the parameters obtained by solving the inverse problem. Fig. 3 give the view of the system for the orbital phase 0.30.

The analysis of the light curves presented in this paper allows the estimation of parameters for *OO Aql* and for the active region.

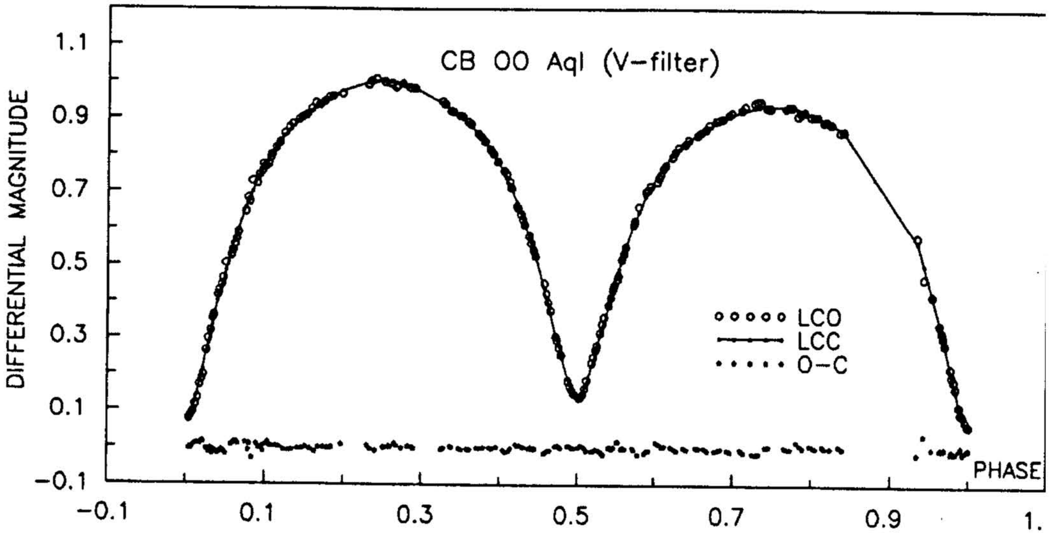

Fig. 2. Observed (LCO) and final synthetic (LCC) light curves with final O-C obtained by solving the inverse problem of active CB *OO Aql* (V- filter).

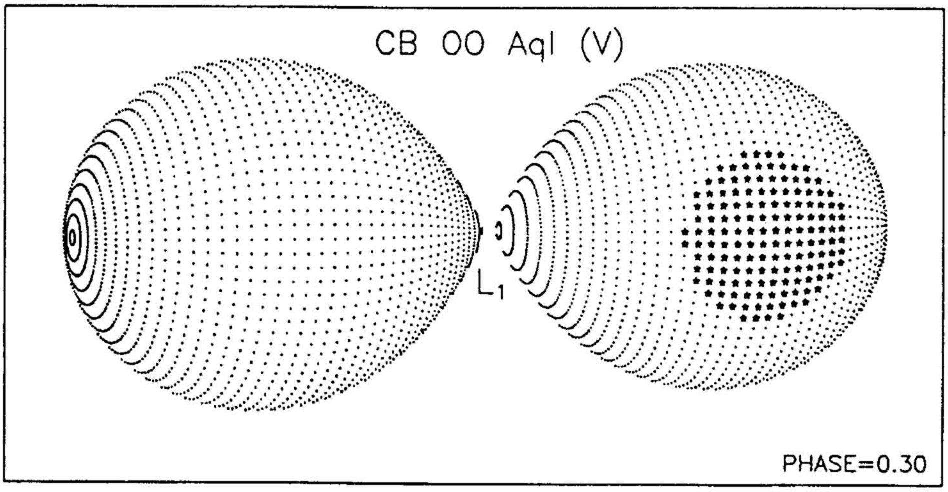

Fig. 3. The view of the CB *OO Aql* at the orbital phase 0.30 with parameters obtained by solving the inverse problem.

Acknowledgements

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