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AN INTERPRETATION OF CB LIGHT CURVE OF ACTIVE CATACLYSMIC VARIABLE OY Car BY USING THE INVERSE-PROBLEM METHOD

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Abstract. In the paper considered is a model synthesizing the light curves of novae and novae-like stars, as well as of active close binaries (CB) in the phase of an intensive matter exchange between the components with accretion onto a white dwarf. The model considers the radial and azimuthal temperature distributions in the disc allowing a successful interpretation of asymmetric deformed light curves characteristic of these systems. The analysis of the observed light curves is performed by using the inverse-problem method (Djurašević, 1992b) adapted to this model. In the particular case the parameters of the dwarf-nova $OY Car$ are estimated on the basis of observations (Wood et al., 1989).

1. INTRODUCTION

In the modern theory of accretion in CB it is important to determine from observations the physical characteristics of the system and accretion disc for the cataclysmic variables such as the novae and novae-like stars. The luminosity of majority of these stars in the quiescent phase (between outbursts) is due to the accretion disc located around the white dwarf and the hot spot on the disc edge. The disc is formed due to a gas stream flowing from the secondary. In the region where the stream touches the disc the temperature is increased and this is known as the hot spot. On account of a relatively low accretion-disc luminosity in the quiescent phase the hot spot in these systems contributes significantly, sometimes dominantly, to the total system luminosity. For this reason the light curves are significantly deformed and they have a characteristic form caused by the ellipse geometry, as well as by the radial and azimuthal temperature distributions in the disc. The CB model (Djurašević, 1992a) developed earlier for the W Ser type systems and the inverse-problem method (Djurašević, 1992b) are adapted for analyzing the light curves of these systems. This particular case comprises the analysis of the observational material (Wood et al., 1989) referred to the dwarf nova $OY Car$. The system's orbital period is about 91 minutes. In the quiescent phase (between outbursts) the light curve has a relatively stable form so that it becomes possible to estimate the basic system's parameters by means of an adequate analysis.

2. THE MODEL

The canonical model of a cataclysmic variable is a Roche lobe-filling cool main sequence star which looses matter into the Roche lobe of the white dwarf. The transferred material has too much angular momentum to fall onto the surface of the white dwarf. Because of the tiny dimensions of the primary, this material flies along its trajectory inside the white dwarf's Roche volume forming a ring around the central object. As viscous forces are at work, the matter gradually looses angular momentum, and this ring spreads out to form a disc which lies in the orbital plane of the system, extending down to the white dwarf. On the disc lateral side, in the zone where the gas stream falls on the disc, there is an intensive hot-spot radiation. The position, size, and temperature of a hot-spot are dependent on the gas-stream parameters, on the forces in the system and on the disc size. A hot-spot causes deformations on a CB light curve, which becomes asymmetric with a characteristic hump, which is due to the intensive hot-spot radiation.

When the matter is approaching the white dwarf it has to get rid of excess gravitational energy, half of which, according to the Virial Theorem, is converted into kinetic energy of the disc material, while the other half is transformed into radiative energy, causing the disc to shine as a luminous object. At the interface between the innermost disc area and the white dwarf (in the nonsynchronous rotation) the motion of disc material will have to be broken down to the velocity of the white dwarf, in the process of which additional radiative energy will be liberated and the boundary layer will be formed.

For the purpose of analyzing light curves of this active CB with an accretion disc around white dwarf, being at the evolutionary phase of an intensive matter exchange between the components, a model for light-curve synthesis has been realized by modifying the model (Djurašević, 1992a), developed for the systems like W Ser. The system components are considered in the framework of nonsynchronous Roche model and the accretion disc of a constant thickness lies in the orbital plane around white dwarf capturing the matter of the neighbouring component.

The primary surrounded by the disc is situated relatively well within the Roche oval, and its rotation can be significantly nonsynchronous. Near the Lagrange equilibrium point L_1 flows from the secondary (which fills the Roche limit) the gas stream 'nourishing' the disc. In the zone where the stream touches the lateral side of the disc a hot spot is formed (Fig.1.). In all details, the model is explained in Djurašević, 1992a. Here only the changes in the details concerning the temperature distribution along the disc radius, which is characteristic for the accretion onto a white dwarf, will be presented.

Without a model of the light distribution in the disc, it is not possible to perform a correct analysis of the eclipse curves for deriving the geometric properties of the system.

The viscosity of the disc material determines how much energy is liberated at any point in the disc, i. e. the temperature distribution along disc radius. With the assumption that the whole disc is stationary, i.e. mass transfer rate $\dot{M}$ is constant throughout the disc, the effective temperature distribution $T_{eff}(r)$ can be described

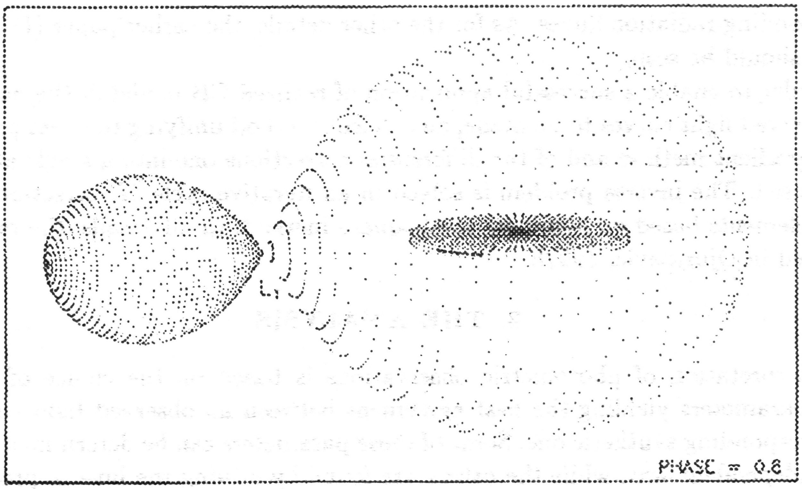

Fig. 1. The Roche model for cataclysmic variables.

by simple analytical formula (Verbunt, 1982) :

$$T^4_{eff}(r) = \frac{3GM_{wd}\dot{M}}{8\pi\sigma r^3}\left(1 - \sqrt{\frac{R_{wd}}{r}}\right), \tag{1}$$

where G and σ are Newton's and Stefan's constants, and R_{wd} is the inner radius of the disc. The assumption is that the disc with its internal side has a contact with the surface of the white dwarf. In the case of magnetic white dwarf, the exact value of disc inner radius is at some distance from the surface, depending on the mass of the star, the field strength, and the mass accretion rate.

The term in brackets accounts for the transfer of angular momentum between the disc and the white dwarf and imposes a certain, though in practice probably unimportant, uncertainty on the value of the effective temperature.

In our model the temperature on the edge of the disc $T_d(r = R_d)$ appears as a parameter. Expressed through this quantity, the temperature distribution in steady state models for optically thick blackbody discs, based on (1), has the form :

$$T_{eff}(r) = \frac{T_d}{C_{fr}}\left(\frac{R_d}{r}\right)^{3/4}\left(1 - \sqrt{\frac{R_{wd}}{r}}\right)^{1/4}, \tag{2}$$

where

$$C_{fr} = \left(1 - \sqrt{\frac{R_{wd}}{R_d}}\right)^{1/4}.$$

In order to include this temperature distribution in the CB-light-curve-synthesis model the disc is divided uniformly into concentric isothermal annuli whose temperature is determined by relation (2) and the radius is determined as the middle of the corresponding annulus. In such a procedure the area of an elementary cell on the disc depends on the radius and it is calculated for each annulus separately, as well as the corresponding radiation fluxes. As for the other details, the earlier paper (Djurašević, 1992a) should be seen.

In order to enable a successful application of realized CB model in the analysis of the observed light curves to be made, an efficient method unifying the best properties of the gradient method and of the differential-corrections one into a single algorithm is proposed. The inverse problem is solved in an iterative cycle of corrections to the model elements based on nonlinear least-square method. In all details, the method is explained in Djurašević, 1992b.

3. THE ANALYSIS

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

The above procedure is applied to analyzing light curves of dwarf nova OY Car. For this system, the eclipse light curves clearly show the presence of two eclipsed objects which are identified with the white dwarf and the hot spot on the edge of the accretion disc.

For the analysis the mean light curves in the U and B filters obtained on March 9, i. e. March 10, 1984 (Wood et al., 1989) are used, when the system was in a quiescent state following a superoutburst that began on 1983 July 28 and preceding a normal outburst that began on 1984 April 1. The physical parameters of OY Car's two stars and the structure of the quiescent disc and hot spot can all be found from detailed analysis of the light curve. Since the difference between the two solutions (U and B curves) is small and the text is limited, here will be presented only the results of the analysis concerning the U-observations.

The mean light curve is shown in Fig. 2, where the measurements are denoted by the symbol (o), and the final synthetic light curve obtained by solving the inverse problem by symbol (∗).

In the inverse-problem solving one assumes for the temperature of the secondary T=3000 K based on the spectral type (dM7-dM8). The mass ratio, the dimensions and the temperature of the primary are assumed to be free parameters. The same is valid for the orbit inclination and for the parameters of the disc and of the hot spot.

The obtained results are presented in Table I and in Fig 2. The view of the system at some orbital phases is shown in Fig 3. with parameters obtained by solving the inverse problem.

The results of the present analysis show that for the mass ratio of the components a value of $q = 0.102$ can be assumed, whereas for the orbit inclination $i = 83^\circ.7$ is obtained.

The white dwarf in the center of accretion disc is possibly surrounded by a spherical boundary layer, and in addition by a luminous ring of material around its equator.

The effective temperature of the central object surrounded by the disc in the quiescent phase is about 15 000 K. As can be seen from the analysis, the possible radius of the central sphere is about 0.018 [R=1], whereas for the disc radius one obtains a value of 0.334 [R=1], i. e. 0.01 [R=1] for its thickness. For the temperature on the

TABLE I

Light curve analysis for CB OY Car
1984. Mar 9, 10.

RES (U filter) :
0.3642E − 01 - final sum of square deviations $\sum(O-C)^2$

FREE PARAMETERS AND ERRORS :
0.336E − 01 ± 0.107E − 02 - filling coefficient for the primary's critical oval
0.837E + 02 ± 0.981E − 01 - orbit inclination
0.514E + 04 ± 0.966E + 02 - disc temperature
0.100E − 01 ± 0.324E − 03 - disc thickness [R=1]
0.148E + 05 ± 0.501E + 03 - primary's temperature
0.561E + 00 ± 0.176E − 02 - disc dimension coefficient ($S_d = R_d/R_{yk}$)
0.323E + 03 ± 0.363E + 00 - hot-spot longitude
0.929E + 01 ± 0.468E + 00 - hot-spot angular dimensions
0.257E + 01 ± 0.335E − 01 - hot-spot temperature coefficient ($A_d = T_s/T^d$)
0.102E + 00 ± 0.212E − 03 - mass ratio of the components ($q = m_2/m_1$)

FIXED (*) AND CALCULATED PARAMETERS :
* 0.300E+04 1.0 1.0 - temperature of the secondary T_2 and nonsynchronous rotation coefficients f_1, f_2
* 0.25 0.08 - gravitational-darkening coefficient for the components (1,2)
0.3884 1.0000 - limb darkening coefficient for the components (1,2)
0.9966 0.4050 - limb darkening coefficient (disc, hot spot)
0.0179 0.1910 - polar radii of the components (1,2) [R=1]
0.0179 0.3335 - inner and outer radii of the disc [R=1]

[R=1], the data are expressed in the units of the distance between the centres of the components.

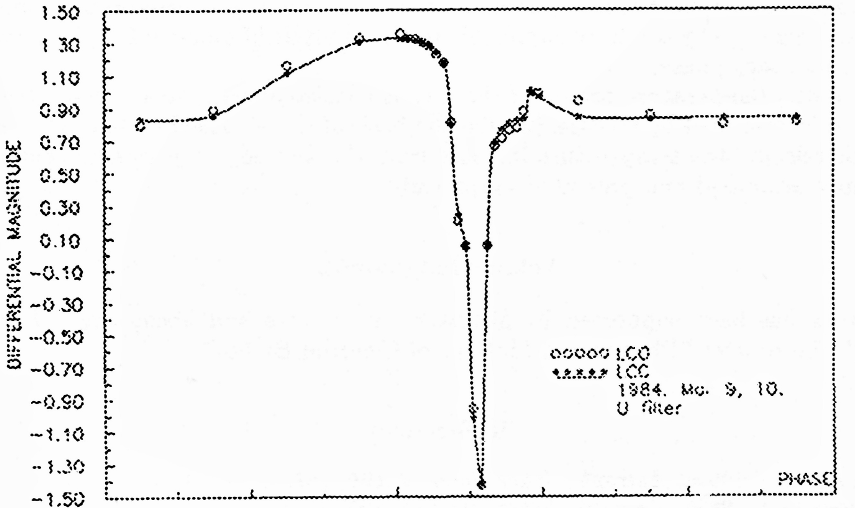

Fig. 2. Mean observed (LCO) and final synthetic (LCC) light curves in solving the inverse problem of active CB OY Car.

disc edge one obtains about 5100 K and the temperature coefficient of the hot spot with respect to the surrounding disc edge temperature is about 2.6, i. e. the temperature in the hot spot can attain 13 000 K. For the hot-spot longitude one obtains 323° and about 9° for its angular dimensions. The analysis shows that more than 50% of the corresponding Roche oval is filled by the disc.

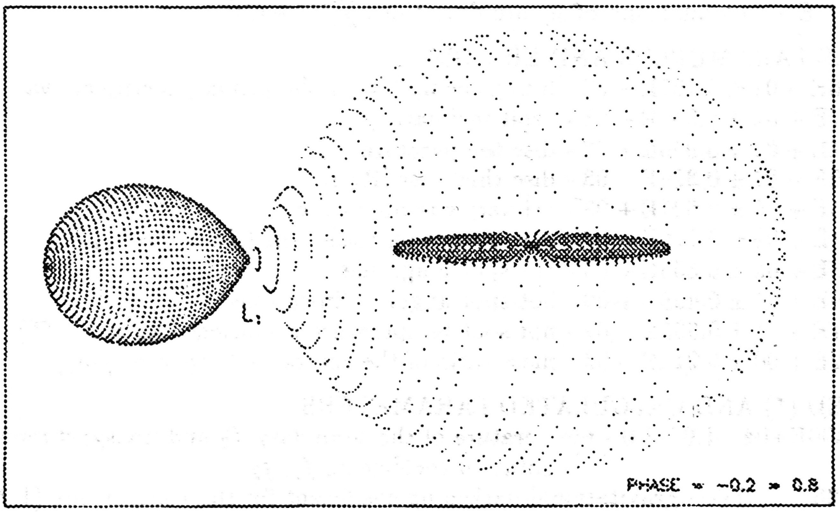

Fig. 3. The view of the CB OY Car at the orbital phase 0.80 with parameters obtained by solving the inverse problem.

The obtained results are in a relatively good agreement with the system parameters estimated earlier (Wood et al., 1989) and found in an independent way. This indicates that the proposed model of the system and the corresponding inverse-problem method presented here briefly are fully applicable to the analysis of active CB light curves in this evolutionary phase.

The radial temperature profile of the disc is consistent with steady mass transfer rate, and is described by relation (2). On the basis of the obtained system parameters and this relation the temperature increase from the disc edge towards its center can be simply estimated and presented graphically.

Acknowledgements

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