Publ. Astron. Obs. Belgrade No. 54 (1996), 105 – 110 *Contributed paper*

AN INTERPRETATION OF THE LIGHT CURVE OF THE ACTIVE CB *AR Pav*

G. DJURAŠEVIĆ
Astronomical Observatory, Volgina 7, 11050 Belgrade, Yugoslavia
E-mail gdjurasevic@aob.aob.bg.ac.yu

Abstract. The paper contains a model synthesizing the light curves of active close binaries (CB) *AR Pav* in the phase of an intensive matter exchange between the components, with accretion onto the primary star. The model considers the radial and azimuthal temperature distributions in the disk enabling a successful interpretation of asymmetrically deformed light curve characteristic of this system. The analysis of the observed light curves is performed by using the inverse-problem method (Djurašević, 1992b) adapted to this model. The parameters for the *AR Pav* are estimated on the basis of photographic observations (Mayall, 1937).

The synthetic light curves obtained through the inverse-problem solving, as a whole, fit the observations well which suggests that existence is possible of accretion disk around *AR Pav* primary.

1. MODEL

On the basis of light curve analyses of this symbiotic object we discuss the possibility of existence of accretion disk. Light curve of this long period ($P = 604^d.6$) eclipsing CB system has characteristic shape that is similar to the light curves of dwarf novae in quiescence phase. This similarity suggests intense exchange of matter between components. For light curve interpretation we suggest the model in which secondary is a Roche lobe-filling cool giant star (M3III), which loses matter into the Roche lobe of the primary (Oe). The primary surrounded by the disk is situated relatively well within the Roche lobe, and its rotation can be significantly non synchronous. Near the Lagrange equilibrium point L_1 the gas stream flows from the secondary (which fills the Roche lobe) 'nourishing' the disk. The lateral sides of the disk are approximated by a cylindrical surface. In the zone where the gas stream touches the lateral side of the disk, a hot spot is formed.

In order to give a successful description of the light curve in this phase of the system activity, another active disc region is added, named "bright spot". Its apparition can be explained by the gas dynamics in the system and by the gas-stream penetration and the hot-spot influence toward the disk interior. The model does not consider the gas-stream radiation. If in reality the accretion disk form deviates from the model idealization more significantly, this increased-luminosity region may be interpreted also as a purely geometrical consequence. For example, any possible disk elipticity would require in our model an increased output radiation flux for individual elementary disk cells appearing in fact as an increased-temperature region at certain disk longitudes.

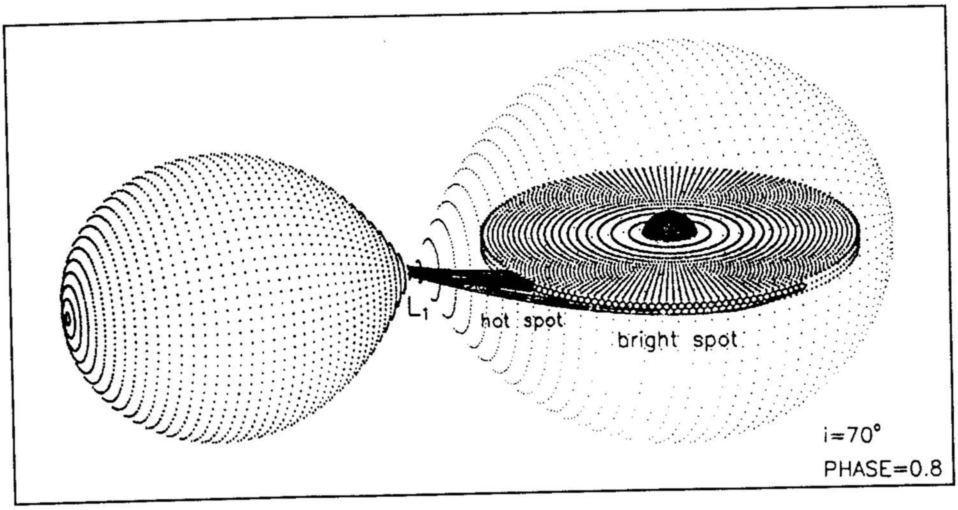

Fig. 1. The Roche model for active CB with accretion disk.

In the model these spots are described through their angular dimensions, center longitude and the temperature contrast of a spot with respect to the unperturbed temperature on the disk edge. Due to the intensive gas-stream infall the disk surface in the central part of the hot spot can be deformed resulting in a certain local radiation concentration which deviates from the global azimuthal distribution. In the model this effect is described by an angle φ_{rad} between the lines perpendicular to the elementary cells and the corresponding azimuth. In another bright spot, this effect is negligible.

Other essential model elements are described in details elsewhere (Djurašević, 1992a).

The viscosity of the disk material determines how much energy is liberated at any point in the disk, i.e., the temperature distribution along the disk radius. For the radial temperature profile of the disk, in analogy with the model for dwarf novae (Djurašević, 1996) an approximate relation is applied:

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

where

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

In our model the temperature on the edge of the disk $T_d(r = R_d)$ appears as a parameter. $R_{prim.}$ is the inner radius of the disk. The assumption is that the disk with its internal side has a contact with the surface of the primary star.

The parameter a_T has a dominant role in the radial-disk-temperature-profile determining. For relatively small a_T values, about 0.15, the temperature is nearly constant, whereas with a_T increasing the temperature gradient becomes steeper, to achieve the steady-state configuration for the case $a_T = 0.75$. The other term with the exponent value of 1/4 describes the temperature distribution in the primary's immediate surroundings so that its influence on the global picture is insignificant.

In order to include this temperature distribution in the CB-light-curve-synthesis model the disk is divided into concentric isothermal annulars (of constant area), whose temperature is determined by relation (1).The model involves a Planck-type radiation for the elementary cells into which the areas of the components and of the accretion disk are divided. The details of the synthesis procedure concerning light curve have been given elsewhere (Djurašević, 1992a), where the model was considered for the W Ser-type systems.

Such a model concept enables light-curve synthesizing for the parameters given *a priori* where the obtained light curve can describe all the essential elements of the observed ones for the case CB *AR Pav*. By varying the free model parameters it is possible to achieve a good fit to real observations and consequently to estimate the system parameters.

2. APPLICATION

The interpretation of the 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 priori* in an independent way, while the others are found by solving the inverse problem method (Djurašević, 1992b).

The above procedure is applied to analyzing the photographic light curve (Mayall, 1937) of *AR Pav*. These observations are obtained in the period between 1895 and 1935. Because the model is made for U, B and V light curves analyses, the photographic light curve is considered as B filter curve. This possibly introduces some uncertainties in parameter estimating.

In the inverse-problem solving one assumes for the temperature of the secondary $T_2 = 3530K$ based on the spectral type (M3III). Due to the reduction in the number of free parameters the mass ratio is here fixed at the value $q = m_2/m_1 = 0.48$ (follows from Thackeray and Hutchings, 1974).

The dimensions and the temperature of the primary are assumed to be free parameters. The same holds for the orbit inclination, for the parameters of the disk (thickness, radius, edge temperature and temperature distribution along disk radius) and of the hot spot (angular dimensions, longitude, temperature contrast). For the hot spot also one calculates the angle φ_{rad} between the maximum direction of the hot-spot radiation and the corresponding azimuth. For another bright spot characteristic are temperature contrast, angular dimensions and longitude of the center.

The obtained results are presented in Table I.

TABLE I

Results of analysis of (RES) observed light curve for the active CB *AR Pav.*

RES (B filter):
$0.1433E+01$ - final sum of square deviations $\sum(O-C)^2$

FREE PARAMETERS AND ERRORS:
$0.140E+00 \pm 0.20E-02$ - filling coef. for the primary's critical lobe ($S_1 = R_1/R_c$)
$0.129E+05 \pm 0.27E+03$ - disk-edge temperature (T_d)
$0.358E+00 \pm 0.68E-01$ - disk temperature distribution coefficient (a_T)
$0.271E-01 \pm 0.66E-03$ - disk thickness (d) [D=1]
$0.100E+01 \pm 0.83E-02$ - disk dimension coefficient ($S_d = R_d/R_{yc}$)
$0.188E+01 \pm 0.19E+00$ - hot-spot temperature coefficient ($A_{hs} = T_{hs}/T_d$)
$0.352E+03 \pm 0.35E+01$ - hot-spot longitude (λ_{hs})
$0.601E+01 \pm 0.12E+01$ - hot-spot angular dimensions (θ_{hs})
$0.253E+02 \pm 0.83E+01$ - angular departure of maximum hot-spot radiation (φ_{rad})
$0.157E+01 \pm 0.13E-01$ - bright-spot temperature coefficient ($A_{bs} = T_{bs}/T_d$)
$0.255E+03 \pm 0.14E+01$ - bright-spot longitude (λ_{bs})
$0.653E+02 \pm 0.20E+01$ - bright-spot angular dimensions (θ_{bs})
$0.874E+02 \pm 0.15E+00$ - orbit inclination (i)
$0.320E+05 \pm 0.90E+03$ - primary's temperature (T_1)

FIXED (*) AND CALCULATED PARAMETERS:
* 0.353E+04 1.0 1.0 - temperature of the secondary T_2 and nonsynchronous rotation coefficients f_1, f_2
* 0.48 - mass ratio of the components ($q = m_2/m_1$)
* 0.25 0.08 - gravity-darkening coefficient for the components (β_1, β_2)
0.25 1.00 - limb-darkening coefficient for the components (u_1, u_2)
0.41 0.33 - limb-darkening coefficient (disk - u_d, hot spot - u_{hs})
0.059 0.297 - polar radii of the components (R_{p1}, R_{p2}) [D=1]
0.059 0.444 - inner and outer radii of the disk (R_{di}, R_d) [D=1]
[D=1], data are given in units of the distance between the component centres.

These results, obtained with specially developed softwer, are represented graphically. The normalized light curve (LCO) is shown in Fig. 2, where the measurements are denoted by the symbol (o), and the final synthetic light curve (LCC) obtained by solving the inverse problem is presented by asterix (*) connected with solid line. The final, difference between the observed and optimal synthetic light curve (O-C), which is the result of inverse problem solution, is represented with asterix (*) connected by dashed line. Fig. 3 gives the view of the system for the orbital phase 0.80 obtained on the basis of the system parameters contained in Table I.

For the mass ratio of the components $q = 0.48$ one finds for the orbit inclination about $87^o.4$. The analysis shows that the disk radius is equal tu the corresponding Roche lobe radius (see disk dimension coefficient $S_d = R_d/R_{yc}$ in Table I). Roche lobe radius R_{yc} was calculated in orbital plane in the direction normal to the line that connects centers of both components.

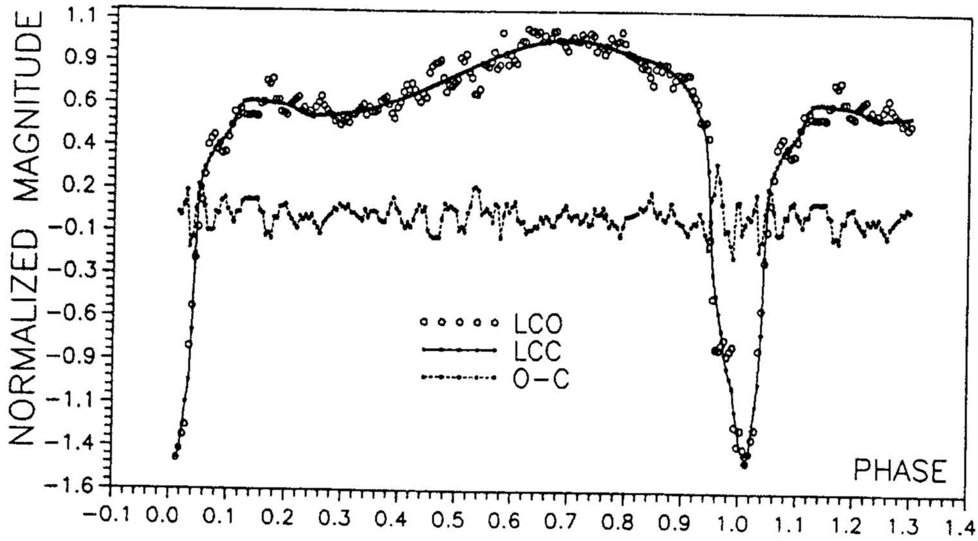

Fig. 2. Observed (LCO) and final synthetic (LCC) light curves with final O-C obtained by solving the inverse problem of active CB *AR Pav*.

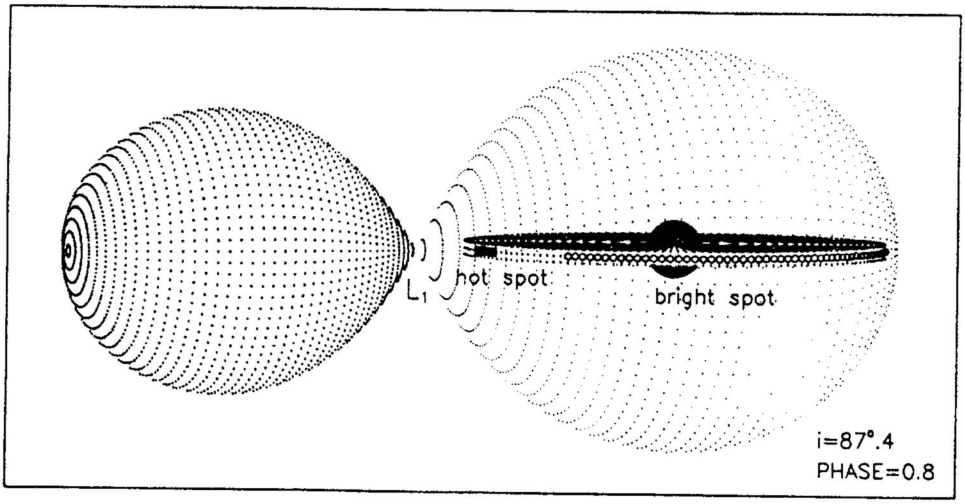

Fig. 3. The view of the CB *AR Pav* at orbital phase 0.80 with parameters obtained by solving the inverse problem.

The obtained results indicate a complex structure of the active regions aside of the acccretion disc, which is approximated in the model with two components - a hot spot and a larger bright spot, with lower temperature. The hot-spot (temperature about $24000K$) has the angular dimension about 6^o and longitude of about 352^o. The radiation of the hot spot is "beamed" forward by about 25^o. The angular size of the larger bright spot is about 65°, and the longitude of the centre about 255°. The temperature of this spot is estimated at about $20000K$.

Based on the B light curve analysis, we estimated that the disk-edge temperature is about $12900K$. The disk-radial-temperature profile is considerably flatter than in the steady-state-approximation case. Beginning from the edge towards the disk centre the temperature increases attaining about $17000K$ near the primary.

Expressed in the units of the distance between the component centres [D=1] the disk size is estimated at about 0.444 [D=1], its thickness at 0.027 [D=1], and the primary radius at about 0.059 [D=1]. The primary temperature is about $32000K$.

From the results given in the Table I and from the given Figures one can conclude that the model proposed here offers a good global fit to the observations.

The obtained results indicate that the proposed model of the system and the corresponding inverse-problem method briefly presented here are fully applicable to the analysis of active CB light curve *AR Pav* in this evolutionary phase.

Though the model given here includes a number of approximations, it allows an independent procedure in the observational-material analysis based on the light-curve synthesis and on the application of the inverse-problem method. The obtained results indicate that in *AR Pav* existence of the accretion disk around primary is possibly real.

Acknowledgements

This work has been supported by Ministry for Sciences and Technology of Serbia through the project "Astrometrical, Astrodynamical and Astrophysical investigations".

References

Djurašević, G.: 1992a, *Astroph. Space Science*, **196**, 267.
Djurašević, G.: 1992b, *Astroph. Space Science*, **197**, 17.
Djurašević, G.: 1996, *Astroph. Space Science submited.*
Mayall, M. W.: 1937, *Harvard Ann.*, **105**, 491.
Thackeray, A. D., and Hutchings, J. B.: 1974, *M.N.R.A.S.*, **167**, 319.