THE SOLUTION OF THE X-RAY HEATING LIGHT CURVE FOR 4U2129+47/V1727 CYG

K. PAVLOVSKI
Hvar Observatory, Faculty of Geodesy, Zagreb, Yugoslavia

ABSTRACT: The X-ray heating light curve of the binary X-ray source 4U2129+47/V1727 Cgy is synthesized. A reliable solution is obtained only after accounting for the influence of an accretion disk. Model parameters achieved by the best fit are discussed. The solution is also discussed in the context of an extended OFF state.

1. Introduction

The X-ray source 4U2129+47/V1727 Cyg was discovered in the UHURU X-ray survey (Forman et al., 1978), and since then it was observed until the EXOSAT epoch. The fourth UHURU catalogue gives a flux in the 2 to 10 keV band varying between 11 to 22 μJy. Thorestensen et al. (1979) identified V1727 Cyg as its optical counterpart. Moreover, their observations revealed a distinguished X-ray source with a large amplitude orbital X-ray heating light curve (ΔB 1.5 mag). In the optical spectrum they find X-ray generated emission features and photospheric absorption features which were simultaneously present.

In the detailed UBV photometric study McClintock et al. (1981) confirmed their findings. Subsequent EINSTEIN X-ray observations revealed the very important discovery of a partial X-ray eclipse with shapes independent of energy (McClintock et al., 1982). These data imply that the binary X-ray source 4U2129+47 contains an extended X-ray emitting region, very probably an accretion disk corona.

Horne, Verbunt and Schneider (1986) - in their timeresolved high resolution spectroscopy of V1727 Cyg - concentrated on the accretion disk around the compact object. The mass, which they derived for it, is in discrepancy with neutron star masses. EXOSAT failed to detect 4U2129+47 (Pietsch et al., 1983) and in subsequent work Pietsch et al. (1986) dealt with the optical and X-ray behavior of this source in an OFF state.

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2. Computational procedure and input parameters

It is assumed in the present computations that the optical companion fills its critical Roch lobe. Hence, its shape is described by the Roche equipotential surface (c.f. Kopal, 1978). For a grid of surface elements the von Zeipel gravity-darkening theorem is used to calculate local gravity and effective temperature. X-ray heating is treated in an approximate way supposing that a fraction $\kappa = 1-\eta$, where η is the X-ray albedo, of the infalling X-rays is absorbed by the atmosphere of the optical companion and reprocessed as UV and optical radiation. In this sense, X-ray heating is manifested as an increase of the local effective temperature. Besides pure geometrical factors (i.e. distance of the surface element from the X-ray source and the angle of incidence of X-rays on it), this additional term strongly depends on the X-ray albedo and the ratio of luminosities of the X-ray source and optical companion L_x/L_o. The duration of the X-ray eclipse provides a constraint on input parameters. If it is assumed that the duration at half-depth represents the duration of the X-ray eclipse of the compact object then for fixed orbital inclination, the mass ratio $q = M_x/M_o$ is determined, where M_x and M_o are the masses of the compact object and optical companion, respectively. The approximate fractional radius of the Roch lobe filling component is also determined in this way. $M_x > M_o$ cases for $q < 1$ are not considered. Calculations are performed for temperatures of the optical companion in the range between 4000 and 8000 K.

3. Light curve analysis in X-ray ON state

The optical light curve of 4U2129+47/V1727 Cyg in the X-ray ON state is caracterized by a large amplitude single wave with a broad and rounded maximum and V-shaped minimum. In Fig. 1, amplitudes of synthesized X-ray heating light curves are compared with the observed ones. The amplitudes shown are differences between the magnitudes at phases 0.0 and 0.50. Observed level of amplitudes are marked by M for McClintock et al. (1986) and H for Horne et al. (1986). It is clearly seen that no solution exists, which simultaneously fits both amplitudes. However, the importance of a X-ray heating in the system ON state is clearly demonstrated.

It seems that an additional light source is needed which would on one side reduce the X-ray heating effect and increases the amplitude of the light curve on the other side. Since Horne et al. (1986) find evidence for an accretion disk around the compact object, it was only natural to include its influence in the present calculation. A very simple model of an accretion disk is assumed, similar to that used by Balog et al. (1981). The disk is taken to be of infinitesimal thickness and is located in the orbital plane. Mutual eclipses of the disk and optical companion are taken into account. This would substantially decrease the effect of X-ray heating.

The best fit is obtained in a trial and error procedure and is shown in Fig. 2. Parameters derived for the optical companion

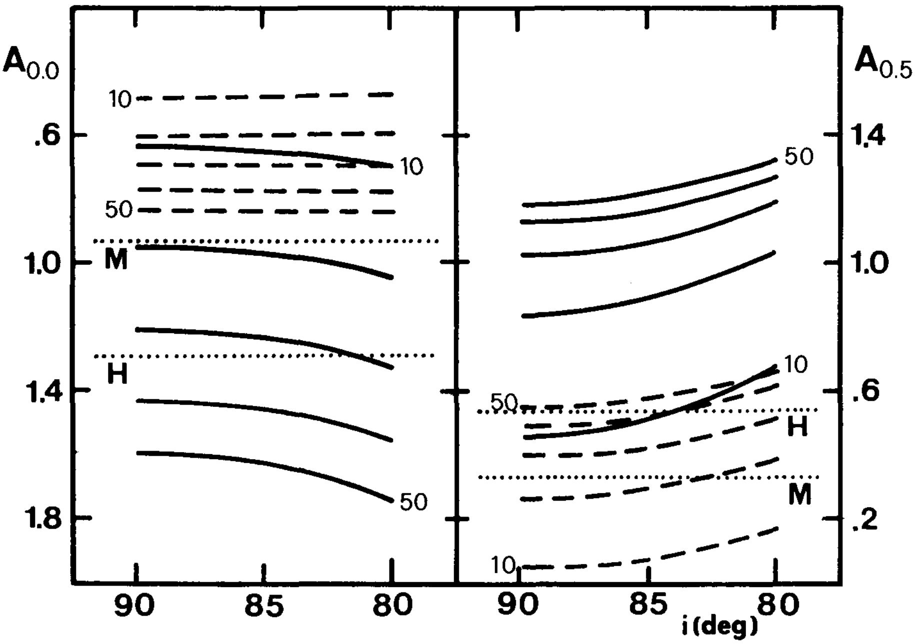

Fig. 1 Amplitudes of synthetic X-ray heating light curves as a function of orbital inclination for the various $\kappa.L_x/L_o$ factors. Solid lines are for temperature 4000 K, and dashed lines for 8000 K. Observed amplitudes are indicated by dotted lines (see text).

and accretion disk are given in Table I. It should be noted that the fit is not perfect, and while the amplitude of the light curve, and its ascending branch from phases 0.25 to 0.50 are satisfactorily matched, the problem with the shape of the minimum still remains. The amplitude of the B-V color curve is 0.32, and roughly corresponds to the observed one. The asymmetry in the light curve suggests an uneven brightness distribution in the accretion disk. In their spectroscopic study Horne et al. find differences in the approaching and receding parts of the disk. A more elaborate accretion disk model is needed to account for the V-shaped minimum and overall asymmetry in the light curve.

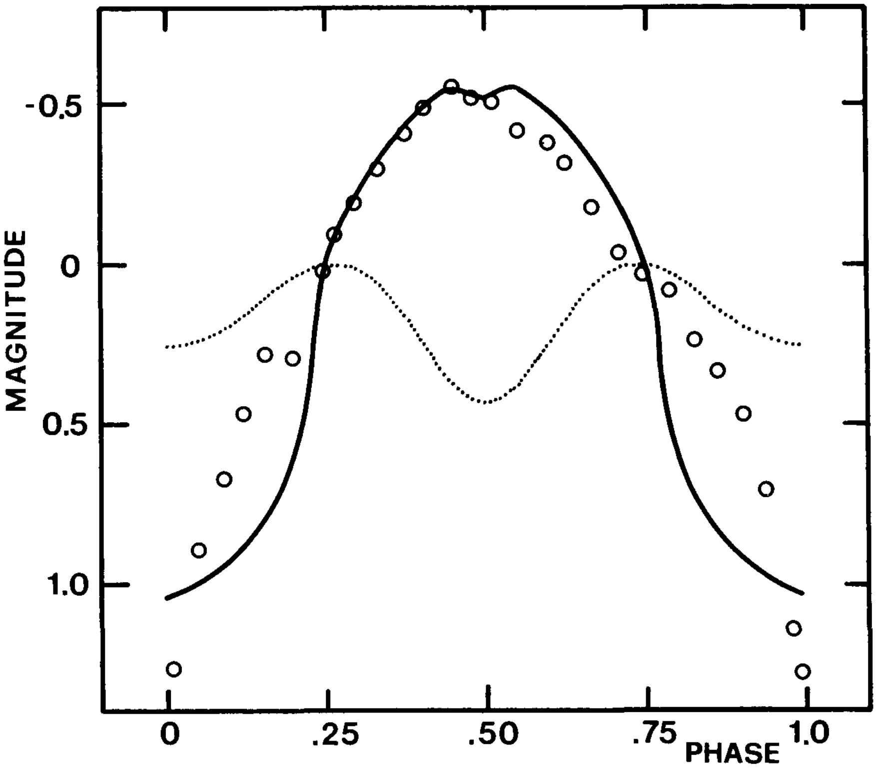

Fig. 2 Comparison of observed light curve with the synthetic one (λ = 4200 A). Effects of X-ray heating and an accretion disk are included. The best fit parameters are given in Table I, where the duration of the X-ray eclipse θ_x is also indicated. Open circles represent observations by Horne, Verbunt, and Schneider (1986). The dotted line shows a pure ellipsoidal variation.

Table I

q	1.413	T_o	4000 K
i	80^o	T_d	15000 K
M_x	0.93 $M_\odot$	R_d	0.4 $R_\odot$
M_o	0.66 $M_\odot$	v_d	650 km/s
R_o	0.62 $R_\odot$	K_o	240 km/s
θ_x	36^o	d	0.9 kpc
a	1.78 $R_\odot$	$\varkappa L_x/L_o$	10

4. Discussion

From the assumptions and start parameters given in Table I some constraints on the model of 4U2129+47/V1727 Cyg could be given. Values for the optical companion are taken from Allen (1973), and they assume a main-sequence star. From the mass ratio a mass of the compact object of $M_x = 0.93\ M_\odot$ is implied. This again differs from the standard model which assumes that the compact object is a neutron star. With the above mass and disk parameters, predictions for the velocities of the companion star and the outer edge of the disk could be made. The values derived are in the range of the observed quantities tiven by Horne et al. (1986).

The distance to the source is calculated after correction of the V magnitude for the influence of a luminous disk, which is 0.35 mag. Taking the X-ray flux to be 10 μJy during the observations (see Fig. 3 of Pietsch et al., 1986), and with the distance estimate it follows that $L_x/L_o = 22$. This means that the X-ray albedo is η 0.5.

If calculations are performed with no X-ray heating, an amplitude of pure ellipsoidal variations amounts to 0.45 mag. With disk parameters, the synthetic light curve gives even larger amplitudes. The range of B observations published by Pietsch et al. (1986) in an extended quiescent period is not larger than 0.2 mag, while their analysis of CCD images however shows variability in the range of 0.35 mag in V band. It should be noted here that the presence of X-ray heating fills the secondary minimum which substantially decreases the amplitude of the light curve. The analysis of light variations in the OFF state can give a further constraint for the model of this system.

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