THE CONTINUUM ENERGY DISTRIBUTION OF THE OLD-NOVA GK PER (1901)

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ABSTRACT The observed X-ray to IR continuum energy distribution of the old-nova GK Per, corrected for the contribution of the late-type secondary and for i.s. extinction,is found to be consistent with the model of an accreting magnetic white dwarf. Furthermore, we discuss plausible modifications of the standard disc structure caused by the presence of magnetic field lines threading the disc and evaluate the contribution to the observed radiation field from several physical mechanisms.

1. INTRODUCTION

Amongst classical old-novae, GK Per(1901) can be considered an exceptional object (Bianchini and Sabbadin 1982, Bianchini et al. 1981, Bianchini et al. 1982, Rosino et al. 1982). In a recent paper Bianchini and Sabbadin (1982), hereafter called BS, showed that the continuum energy distribution of the nova is peaked at λ 3600 and demonstrated that this can be explained by the presenceof a magnetic field sufficiently strong to disrupt the hotter inner parts of the accretion disc thus leading to radial inflow along the field lines on to the magnetic poles of the white dwarf. The observed UV continuum of the nova shortward of λ 2000 was interpreted as the low energy tail of black-body radiation from the surface of the white dwarf heated by thermal conduction inside the accretion column. Here we analyze the continuum energy distribution of GK Per from X-ray to infrared wavelengths and discuss the relative importance of the different physical mechanisms responsible for the observed radiation field. In what follows we will adopt the GK Per binary system parameters given by BS. The UV and optical fluxes given in this paper are twice as much as those derived by BS as they considered only one hemisphere around the star.

2. ACCRETION DISC MODELS

The emergent spectrum from an optically thick accretion disc having inner radius $R_i > R_{WD}$ can be derived by applying a modification of the standard disc model of Shakura and Sunyaev (1973), Bath et al. (1974), Lynden-Bell and Pringle (1974) and Bath (1976) in which the disc does not extend to

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the star but maintains at any radius the original radial temperature distribution. The best fit to the observed UV to visual flux distribution, corrected for the contribution of the K2 IV secondary (Gallagher and Oinas 1974), is obtained at $\dot{M}=1\times10^{18}$g s^{-1} and $R_i=1.3\times10^{10}$cm (hereafter called solution A); the resulting magnetic field at the surface of the star is $B=2.5\times10^{8}$G. A second solution (solution B) is obtained following Ghosh and Lamb (1979) who demonstrated that, due to threading of magnetic field lines across the disc, the temperature decreases in the inner parts of the disc whilst it increases in the outer regions compared to the standard disc model. For a white dwarf of moderate "rotation fastness" ($\omega_s=0.3$) the best fit to the corrected UV to visual continuum is obtained for $\dot{M}=2\times10^{16}$g s^{-1} and $R_i=1.2\times10^{9}$cm; this yields $B=5\times10^{5}$G.

3. DISCUSSION

To discriminate between solutions A and B it is necessary to analyze the continuum energy distribution of the old-nova from X-ray to infrared wavelengths. The spectrum produced by an accreting magnetic degenerate dwarf generally has six components (King and Lasota 1979, Kylafis and Lamb 1979):

1) the spectrum produced by the accretion disc
2) a black-body limited UV, visual or infrared cyclotron component produced by the hot, post-shock emission region
3) a hard X-ray bremsstrahlung component also produced by the hot emission region
4) a hard UV or soft X-ray black-body component produced by cyclotron and bremsstrahlung photons which are absorbed by the stellar surface and re-emitted
5) a hard UV or soft X-ray black-body component emitted by the white dwarf polar caps which are heated by thermal conduction of the electrons inside the accretion columns
6) a hard UV or soft X-ray black-body component emitted by polar caps heated by collision of the infalling matter

In general we have:

$$L_{acc} = L_D + L_{ff} + L_{Cyc} + L_{BB} \qquad (1)$$

L_{acc} being the total luminosity of the system due to accretion; L_D the luminosity of the disc; L_{ff} the luminosity of the bremsstrahlung emission; L_{Cyc} the luminosity of the cyclotron component ; L_{BB} the sum of components 4,5 and 6. The observed UV, optical and infrared (work in preparation) fluxes indicate that L_D is of the order of 1×10^{34}erg s^{-1}. The X-ray luminosity, L_{ff}, obtained by folding a 100 KeV (for a 1.3 $M_\odot$ white dwarf) bremsstrahlung spectrum having a column density $NH=7\times10^{20}$cm^{-2} through the Einstein instrument response (Cordova et al. 1981), is 6.6×10^{33}erg s^{-1}. The cyclotron luminosity will strongly depend on the values of B and $\dot{M}$ (King and Lasota 1979). The black-body emission from polar caps must satisfy the following conditions:

a) Flux at λ 1300 $\cong 6\times10^{28}$erg s^{-1} A^{-1}
b) Flux at λ 10 $\leq 5.6\times10^{30}$erg s^{-1} A^{-1}

Condition a) is derived from the difference between the observed and the calculated (disc models) fluxes at λ 1300; condition b) means that the black-body flux at λ 10 (where extinction is negligible) must not exceed that expected from a 100 KeV bremsstrahlung thermal spectrum having $L_{ff}=6.6\times10^{33}$ erg s^{-1}. Fig. 1 compares the observed continuum of GK Per with that predicted by solutions A and B.

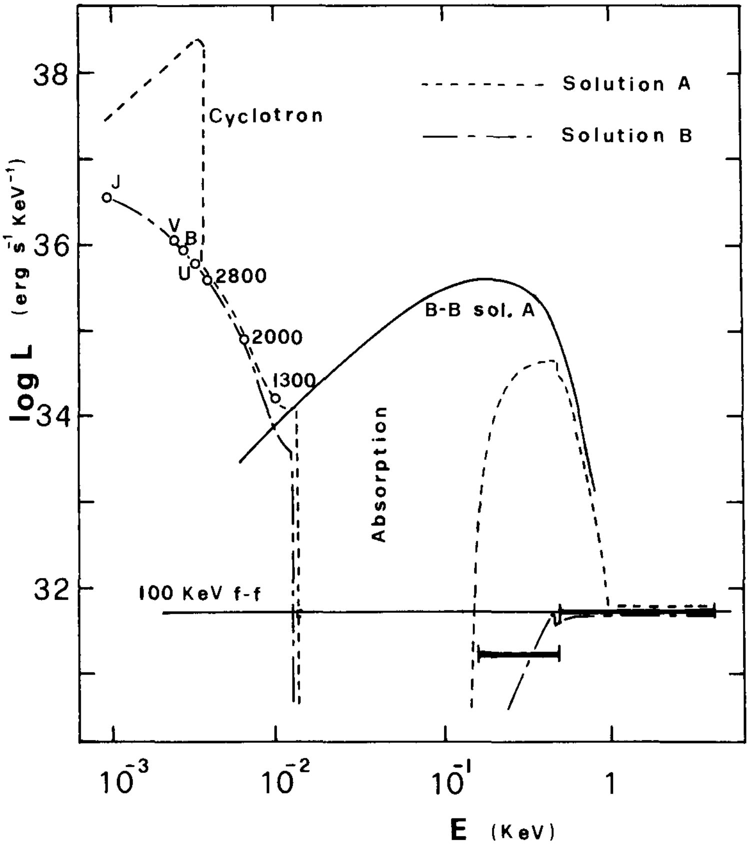

Figure 1. Comparison of the observed X-ray to infrared continuum energy distribution of GK Per with that predicted by solutions A and B. Open circles indicate fluxes at UBVJ and selected UV wavelengths; bars refer to the mean fluxes observed in the two spectral ranges of the Einstein instrument. Both maximum BB and minimum Cyc components are indicated. The extinction in the far UV and X-ray region is for a column density $NH=10^{20}cm^{-2}$. UV and UBVJ data are corrected as indicated by BS.

In solution A $L_{acc}=5.8\times10^{35}$erg s^{-1} and conditions a) and b) are satisfied only for $L_{BB}<0.4L_{acc}$. From equation (1) we obtain $L_{Cyc}>0.6L_{acc}$, but this is impossible since the Rayleigh-Jeans tail of the black-body component produced by self-absorbed cyclotron emission would be in this case (i.e. with $B=10^{6}$ G) limited at λ 3500, which corresponds to three times the fundamental cyclotron frequency (King and Lasota 1979). This would then produce much larger fluxes than observed in the optical region. In the case of solution B we have $L_{acc}=1.2\times10^{34}$ erg s^{-1} and, for the given $\dot{M}$ and B values, $L_{Cyc} \ll L_{ff}$. From equation (1) we obtain $L_{BB}\cong0$. Thus, solution B is not completely satisfactory since a hot black-body component is very likely present in our spectra.

Our results suggest that disc models involving mass transfer rates and magnetic fields which are intermediate between those of solutions A and B should be discussed. While steady, optically thick disc models adequately represent the spectrum of a number of cataclysmic variables, there are many cases in which the observed UV continua are better interpreted as the superposition of two black-body sources. In conclusion, the observed deviations from a "steady-disc distribution", which often take the form of optical and/or IR excess, might be due to the contribution from the bright spot as well as to the presence of magnetic fields sufficiently strong to modify the geometry and the radial temperature distribution of the "standard disc".

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DISCUSSION FOLLOWING A. BIANCHINI'S TALK

MEYER: I wonder whether somebody could perhaps comment on the following point in Ghosh and Lamb's model. If you pick out angular momentum, of course you do work against the torque by the differential motion in the disk and since this is differential work I guess it probably has to be dissipated and it might well be that a part of that dissipation would come back into the disk. That could be a source of heating the disk, so it might matter in the model whether you include such terms or not.

BIANCHINI: No, what we really did is just an attempt, more qualitative than quantitative. Just considering Ghosh and Lamb's work you can find the temperature distribution is changing in that way.

LAMB: I would also like to try to respond to that, noting, of course, that this is Fred Lamb's work and not my own, so I am not an expert on it. Your point is well taken, but is already reflected in what has been done here. Namely, the dissipation has been moved from the innermost part of the disk to further out by the magnetic field lines that thread the disk. For that reason, the temperature is lower than usual in the innermost part and then somewhat higher farther out. But the dissipation is still there.

SHAVIV: If I understood you correctly the main effect is that you have an R_i, you cut off the disk from touching the star. So if someone would have come to you with a different type of boundary layer between the disk and the star, your result would not really reject it immediately. Then, the model leading to an on pole accretion by the star, rather than along the equator is not really absolutely compulsory out of your results, is that correct?

BIANCHINI: Yes. I can say one more thing, the solution B which seems the best one, needs a fractional area of 0.02 which is quite large it is larger than the 10^{-3} which you get from the theory for a magnetically driven accretion column.

LAMB: What you are just discussing concerns more the black body tail, and what the spectrum is like in the hard X-rays and the soft X-rays. However, if we consider just the optical and near UV energy distribution, there may still be a significant difference. If the disk is disrupted fairly far out from the white dwarf, then it will strongly affect the energy distribution in the blue and near UV. The effect is more than just changing the boundary layer, which presumably mostly affects much shorter wavelengths. Instead of comparing models A and B, what does the flux distribution look like if you take just a normal disk flux distribution?

BIANCHINI: If you take a normal disk you don't get the peak of the energy distriubtion, which is at 3600 Å, this is the problem. I want to mention one more point, IUE spectra of the star during the outburst in 1981 have been taken, I saw the spectra and actually the peak is moving to the UV, to near 1000 Å and I don't know if these models will fit such data, qualitatively speaking everything is going in the right direction, you just increase the accretion rate.