ENERGY DISTRIBUTION OF HARD X-RAY EMITTING CATACLYSMIC VARIABLES

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ABSTRACT

We present the energy distribution of three hard X-ray sources H2252-035, 4U1849-31 and 2A0526-328 identified with intermediate polars. The ultraviolet and optical continuum can be well described by the standard disc model but this requires rather large discs and high accretion rates. Other possible contributions to the energy distribution are estimated. The predicted high accretion rates as well as the amplitude of the optical pulsations are in disagreement with the observed X-ray luminosity suggesting the existence of an unseen soft X-ray or extreme UV component.

1. INTRODUCTION

Among the hard X-ray sources recently identified with cataclysmic variables, three of them: H2252-035 (AO Psc), 4U1849-31 (V1223 Sgr) and 2A0526-328 (TV Col) exhibit a class of common properties. They were optically identified on the basis of their spectra showing blue continuum and strong hydrogen and helium emission lines. They differ from normal dwarf novae, being in a persistent high state without recorded outbursts.

These sources are multiperiodic systems. H2252-035 shows three optical periodicities: 3.59 hours, 805s and 859s (Patterson and Price, 1981). The longest one is interpreted as the orbital period. The 805s period being also present in the X-ray flux is likely to be associated with the rotation of the compact star. The second pulsation is the beat period between 805s and 3.59h and can be explained by the reprocessing of X-rays on a disc bulge or on the secondary in a prograde system. 4U1849-31 shows an optical pulsation (P = 794s) similar to those observed in H2252-035 but up to now no orbital period is known[1] (Steiner et al., 1981). 2A0526-328 displays two photometric periods, 5.2h and 4.02 days (Motch, 1981). A spectroscopic period of 5.5h has been discovered by Hutchings et al. (1981). The 4.02 day period appears to be the beat-

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ing period of the two short ones. Essentially two models have been proposed: Hutchings et al. (1981) identify the spectroscopic period with the orbital one, the 5.2h photometric period corresponding to the rotation of the white dwarf. Watts et al (1981) assume that the orbital period is the 4 days period and the spectroscopic one is the period of the rotation of the white dwarf. This last model requires a retrograde orbit.

These sources differ from the AM Her type systems in several aspects: no soft X-rays are detected and they do not exhibit polarisation, the systems are non synchronized and the corotation radius is probably smaller than the Roche lobe of the compact star allowing the formation of an accretion disc. We have attempted to test the presence of such a disc from the energy distribution in ultraviolet and optical.

2. OBSERVATIONS

The ultraviolet observations were made with the IUE satellite using the low dispersion mode and the large aperture. They were collected by ourselves or from the data bank of the ESA station. They were reduced using the revised calibration (ESA newsletters no. 11). The ultraviolet and optical data of H2252-035 used here were already published by Hassall et al. (1981). A first presentation of the ultraviolet spectrum of 4U1849-328 is in Bonnet-Bidaud et al. (1982). We added in this study three other spectra (two at short wavelengths and one at long wavelengths) obtained in January 81. The optical UBVRI colours are those given in Bonnet-Bidaud et al. (1982). Ultraviolet observations of 2A0526-328 were presented by Coe and Wickramasinghe (1981) and Mouchet et al. (1981). We present here average ultraviolet fluxes obtained from 8 short wavelength spectra and 5 long wavelength ones.

3. ACCRETION DISC FIT TO THE ENERGY DISTRIBUTION

The three sources exhibit a strong UV continuum with emission lines superimposed on it. Indication of an interstellar reddening is present in the average long wavelength (LWR) spectra around 2200Å. The colour excess was determined by fitting the LWR spectra with a power law reddened according to the near galactic extinction law given by Seaton (1979). The best values for E_{bv} are respectively 0.11, 0.16 and 0.06 for H2252-035, 4U1849-31 and 2A0526-328. The result for H2252-035 is in disagreement with the evaluation given by Hassall et al. (1981) who neglected reddening.

A standard optically thick disc model described by Bath et al. (1980), and references therein, was fitted to the UV and optical data (including IR for H2252-035). The shape of the disc continuum is determined by two parameters: a characteristic temperature T_* and the ratio R_0/R_1 of the outer and the inner radii of the disc, while the normalization factor is related to the distance, the inner radius and the inclination angle of the system.

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The best fits determined by a minimum χ^2 routine are plotted in Figure 1. The corresponding parameters are given in Table 1. We did not use optical data of 2A0526-328 because of their great variability. The fitted disc from the UV data leads to a B-V colour slightly redder than observed. Assuming that the disc fills about 90% of the Roche lobe of the primary we can compute the inner radius, then the accretion rate and the luminosity of the disc are derived from T_*. An orbital period of 5.5h was assumed for 2A0526-328. The inner disc radius of 4U1849-31 must be small (~5 10^8 cm) in order to be compatible to an orbital period of a few hours. The deduced parameters are given in Table 1. As no eclipse is observed in these systems a reasonable upper limit for i is 70°.

A standard disc model can reasonably well fit the energy distribution of the three sources. The required temperatures are high implying a strong accretion rate and the inner radius of the disc is found to be very close to the white dwarf. This leads to a disc luminosity greater than the hard X-ray luminosity and would indicate the presence of an unseen soft X-ray or extreme UV component. Moreover, the resulting distance of 2A0526-328 is definitively too large.

Source	T_*(K)	R_0/R_1	R_0(10^9cm)	R_1(10^9cm)	d(pc)/$\sqrt{\cos i}$	$\dot{M}$(10^{16}gs^{-1})	L_D/L_X(2-10keV) (d = 300 pc)
H2252-035	140 000	75	30	0.4	460	9	44
4U1849-31	170 000	82	41[1]	0.5	625	37	50
2A0526-328	200 000	46	55	1.2	3650	978	1264

[1] Assuming an orbital period of 4h.

Table 1. Accretion disc fits parameters and deduced parameters

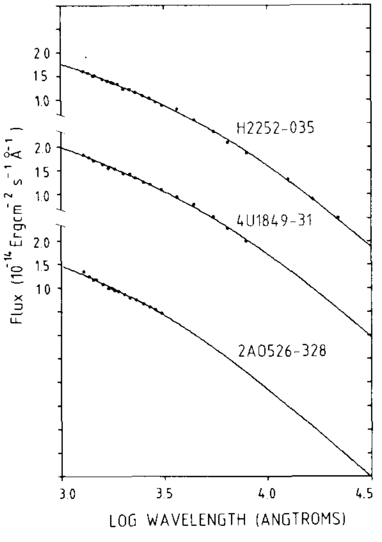

Figure 1: Energy distribution of H2252-035, 4U1849-31 and 2A0526-328. Drawn lines are the best fitted disc spectra with parameters given in Table 1.

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4. OTHER POSSIBLE EMITTING COMPONENTS

The disc parameters derived in the previous section may be modified if the ultraviolet and optical fluxes are not entirely due to the accretion disc. In this paragraph we discuss other possible contributing emission regions.

4.1 The Secondary Star

Low mass red dwarf secondaries are expected to contribute at long wavelengths yielding an overestimation of the R_0/R_1 radii ratio. Assuming that the secondary is a main sequence star we can compute the contribution of this star in H2252-035 and 2A0526-328 using the relations given by Robinson (1976) and Warner (1976). In H2252-035 the secondary has a negligeable contribution in V but accounts for half of the observed K flux at a distance of 300 pc. The secondary in 2A0526-328 would contribute to 1/10 of the V flux at 500 pc for an orbital period of 5.5h. IR observations are required to determine the nature of this secondary more accurately. Though no precise estimate of the R_0/R_1 ratio can be made due to the unknown distance, a decrease of this ratio would be compatible with the presence of a magnetized white dwarf which prevents the disc from extending down to this object. Nevertheless, changes in the optical-IR part leave unchanged the temperature estimates.

4.2 Pulsating Light

A detailed study of the energy distribution of the two optical pulsations of H2252-035 is presented in Motch and Pakull (1981). They found a different colour behaviour for the direct pulsation (at the X-ray period) and for the reprocessed one.

<u>905s Pulsations (X-ray Period)</u>. The energy spectrum of the pulsated light at this period is in λ^{-4} consistent with the Rayleigh Jeans tail of a hot blackbody possibly emitted by a polar cap on the white dwarf or by the inner edge of the disc. This contribution could be due to steady nuclear burning of accreted matter in the envelope of the degenerate dwarf or to reemitted thermalized bremsstrahlung. Assuming that this blackbody accounts for less than 20% at 1 keV (no soft X-ray having been detected) and considering that it represents 12% of the flux at 3250Å (Motch and Pakull, 1981) we derived a maximum temperature of about $4.5\ 10^5$K for an X-ray pulsed fraction of 40% to 100%. The corresponding emitting areas are respectively 18% to 45% of the surface of the white dwarf for a typical radius of 10^9 cm and a distance of 300 pc. Considering a typical temperature of 10^5K the corresponding blackbody luminosity is about $5\ 10^{33}\ (d/100pc)^2$ $ergs^{-1}$ consistent with the disc luminosity inferred from the parameters given above ($1.5\ 10^{34}$ $ergs^{-1}$). Substracting this 10^5K blackbody from the observed energy spectrum yields a new disc model fit of similar quality with a characteristic temperature of 65000K and a smaller ratio R_0/R_1 of 32. These new parameters do not affect significantly the accretion rate and the disc luminosity which remains in disagreement with the X-ray observed luminosity.

959s Pulsations. These optical pulsations probably arise from the reprocessing of the X-ray beam on a bulge or in the atmosphere of the secondary. The theoretical energy distribution of such a reprocessed flux is not well established, so that this contribution cannot be easily removed. We can reasonably estimate from the optical observations that about 10% of the flux in the 1200-7000Å range is due to heating. The studies of the low mass X-ray binaries have shown that 1% to 5% of the X-ray flux is reprocessed (Van Paradijs, 1982). These two assumptions lead to an expected X-ray luminosity ranging from 10^{34} to $5\ 10^{34}$ $ergs^{-1}$ for a distance of 300 pc. This value is consistent with the strong X-ray luminosity predicted from the disc model. This conclusion is also valid for 4U1849-31.

4.3 Hot Spot

Although the hot spot is a feature often observed in cataclysmic variables, such a signature is absent in the light curves of H2252-035 and 4U1849-31, possibly due to a moderate inclination angle or to a large extension of the disc. We cannot however exclude the presence of a bright spot in 2A0526-328 as it was shown in the study of UV spectra near the photometric maximum (Mouchet et al, 1981).

4.4 Influence of the Magnetic Field

The influence of the compact object magnetic field on the disc must be taken into account. Ghosh and Lamb (1979) showed that this magnetic field modifies the temperature distribution of a standard disc in a region whose size is essentially a function of the rotation of the degenerate star and which can extend up to the outer parts of the disc for reasonable rotational velocities. This new distribution in radial temperature can lead to a very different energy spectrum in shape as well as in absolute flux (for more details see A. Bianchini (these proceedings)). Such an effect can be expected for the three sources in which an indication of an anisotropic X-ray emission is suggested.

5. VARIABILITY

The study of the energy distribution variability especially in the UV range is a key for understanding the nature of the different spectral contributions.

5.1 4U1849-31

Strong variations in the intensities of the four short wavelength IUE spectra are observed without any significant change in their slopes. An increase of 23% occurred between the two spectra taken in May 81 at 1.5h interval while the V magnitude deduced from the fine error sensor remained constant. This suggests the presence of at least two emitting regions. The study of spectral variations with the orbital period will certainly be valuable.

5.2 2A0526-328

The large number of available ultraviolet spectra made possible the study of the UV continuum variations with the different periods. The fluxes around 1770Å and 2700Å are plotted in Figure 2 versus the three phases using the ephemerides given by Hutchings et al. (1981). We have corrected the 5.2h photometric phase from the variation of the maximum of the optical light curve with the 4.02 days period (Motch 1981). No correlation of the UV flux is observed with both photometric periods but a regular variation is present versus the spectroscopic one showing a maximum around phase 0.6. This behaviour is consistent with the gradual decrease of the amplitude of the photometric 5.2h period with decreasing wavelength (B and U passbands) and with the presence of a modulation with the 5.5h spectroscopic period in the U band only, showing the same phasing as in the UV (Motch, private communication). None of the proposed models gives a clear explanation of this result.

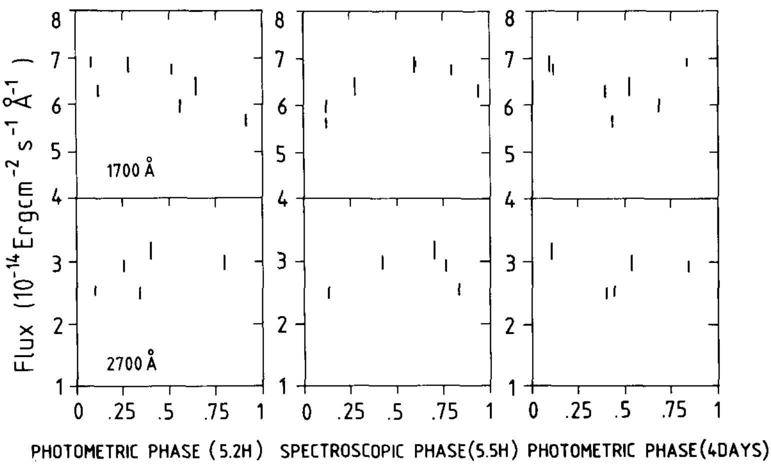

Figure 2: Ultraviolet fluxes of 2A0526-328 averaged in 50Å interval around 1770Å (upper part) and 2700Å (lower part) plotted versus the three optical phases.

CONCLUSION

Though a standard accretion disc can well fit the energy distribution of the three sources presented here, the presence of other emitting components is suggested both from optical and ultraviolet variability. The magnetic field of the compact star may also change the disc continuum. The amplitude of the optical pulsations and the evaluated disc parameters both lead to a predicted high energy luminosity larger than the hard observed X-ray luminosity.

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NOTE

1. A possible orbital period of 3.22h is proposed by B. Warner (see these proceedings).

REFERENCES

Bonnet-Bidaud, J.M., Mouchet, M., Motch, C., 1982, Astron. Astrophys., 112, p.355
Coe, M.J., Wickramasinghe, D.J., 1981, Nature, 290, p.119
Ghosh, P., Lamb, F.K., 1979, Astrophys. J., 232, p.259
Hassall, B.J.M., Pringle, J.E., Ward, M.J., Whelan, J.A.J., Mayo, S.K., Echevarria, J., Jones, D.H.P., Wallis, R.E., Allen, D.A., Hyland, A.R., 1981, M.N.R.A.S., 197, p.275
Hutchings, J.B., Crampton, D., Cowley, A.P., Thorstensen, J.R., Charles, P.A., 1981, Astrophys. J., 249, p.680
Motch, C., 1981, Astron. Astrophys., 100, p.277
Motch, C., Pakull, M.W., 1981, Astron. Astrophys., 101, L9
Mouchet, M., Bonnet-Bidaud, J.M., Ilovaisky, S.A., Chevalier, C., 1981, Astron. Astrophys. 102, p.31
Patterson, J., Price, C.M., 1981, Astrophys. J., 243, L83
Robinson, E.L., 1976, Ann. Rev. Astron. Astrophys. 14, p.119
Seaton, M.J., 1979, M.N.R.A.S., 187, 73p
Steiner, J.E., Schwartz, D.A., Jablonski, F.J., Busko, I.C.,
Watson, M.G., Pye, J.P., McHardy, I.M., 1981, Astrophys. J., 249, L21
Van Paradijs, J., 1982, in "Accretion-driven Stellar X-ray Sources", in press
Warner, B., 1976, IAU Symposium 73, p.85
Watts, D.J., Greenhill, J.G., Hill, P.W., Thomas, R.M., 1982, M.N.R.A.S., 200, 1039

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DISCUSSION FOLLOWING M. MOUCHET'S TALK

BIANCHINI: Do you think that the Ghosh and Lamb temperature distribution is a better explanation for what we observe, so that we need smaller inner radii and smaller accretion rates?

MOUCHET: The problem is that the standard disk model, without magnetic fields, already fits well, but we need to include other contributions as I have described, so it is difficult to conclude whether the Ghosh and Lamb model fits better.

LANGER: Do you think that you have seen, between the optical, UV and X-ray emission, most of the luminosity that you refer to as present in the system or do you actually think that there is a fair bit that is missing, that you have not seen?

MOUCHET: We need to observe maybe in very soft X-rays, because we don't observe soft X-rays, or in extreme UV, you must have energy there, but it is not observed.

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