X-RAY EMISSION FROM NON-MAGNETIC CATACLYSMIC VARIABLES

H. VAN DER WOERD
Laboratory for Space Research Utrecht,
Utrecht, The Netherlands

ABSTRACT

EXOSAT observations of a large sample of non-magnetic cataclysmic variables have led to the detection of VW Hyi and OY Car as strong soft X-ray sources during superoutburst. The spectral characteristics of the X-ray emission of these SU Uma systems are compared. It is proposed that both systems have, besides a cool, optically thick boundary layer, an extended hot, optically thin corona.

1. INTRODUCTION

In non-magnetic cataclysmic variables the white-dwarf magnetic field has no influence on the mass-accretion flow from the inner disc into the white-dwarf atmosphere. This inner region, the boundary layer, has a structure and temperature which is determined by the accretion rate and white-dwarf mass (Pringle and Savonije, 1979; King and Shaviv, 1984). For high accretion rates ($\dot{M} > 10^{16}$ g s^{-1}) the accretion energy is

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radiated by an efficiently cooling, optically thick inner disc and boundary layer (Pringle, 1977). The expected temperature is a few times 10^5 K, which implies that most radiation comes out in the EUV and soft X-ray band. The Low-Energy telescope aboard the EXOSAT observatory is sensitive to soft X-ray radiation between 8 and 300 Å. During the 3 years life time of this satellite we have observed 16 non-magnetic systems, in order to detect this expected soft X-ray component.

2. OBSERVATIONS AND ABSORPTION

Most systems were not, or only weakly detected, which is likely due to the strong absorption of the extremely soft X-ray flux by a relatively small amount of interstellar matter (e.g. Patterson and Raymond, 1985). The three brightest novalike variables (IX Del, RW Sex and V3885 Sgr) were observed, but only the first system showed an appreciable and variable soft X-ray flux. Dwarf novae in outburst are, in principle, ideally suited to study the soft X-ray generation as function of the varying mass-accretion rate. Observations of four systems during outburst (TT Boo, EM Cyg, AY Lyr and KT Per) were not successful. However, both the SU Uma systems OY Car and VW Hyi were detected as strong soft X-ray sources during superoutburst.

3. OY CARINAE

The EXOSAT observations were part of a large multi-wavelength study of the May 1985 superoutburst by the Oxford group (Naylor et al., 1986;

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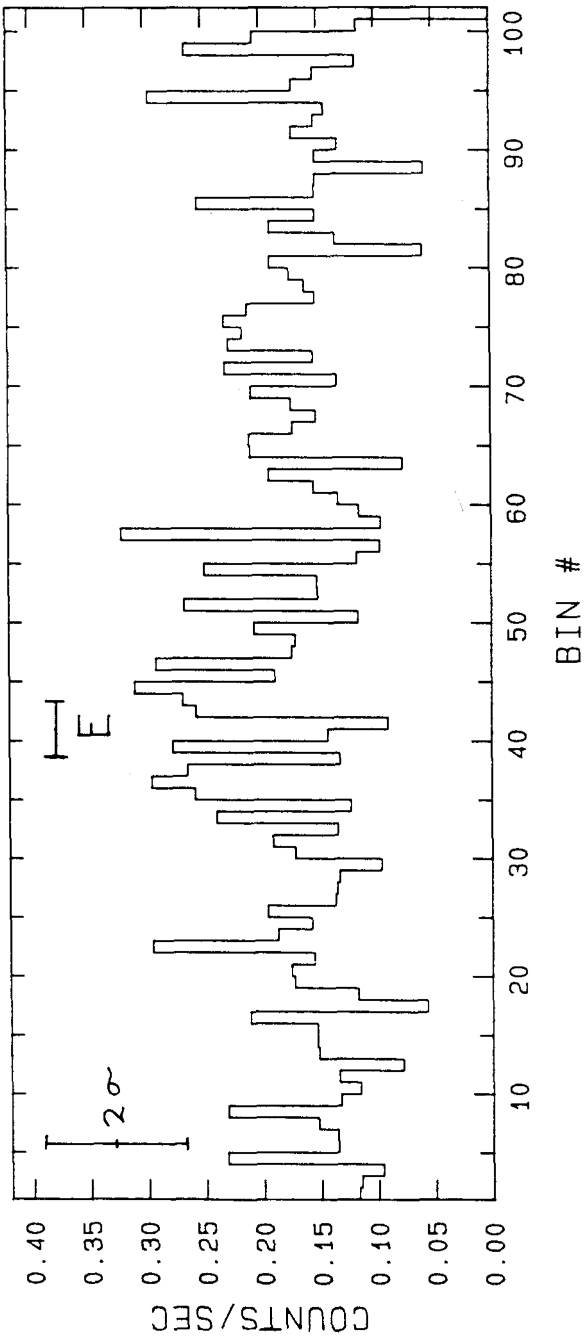

Fig. 1. *The soft X-ray (3000-Lexan filter) light curve of one orbital cycle on 3 May 1985. The predicted total eclipse of the white dwarf (E) should cover more than four bins (one bin is 54.54 s). The typical error bar is indicated.*

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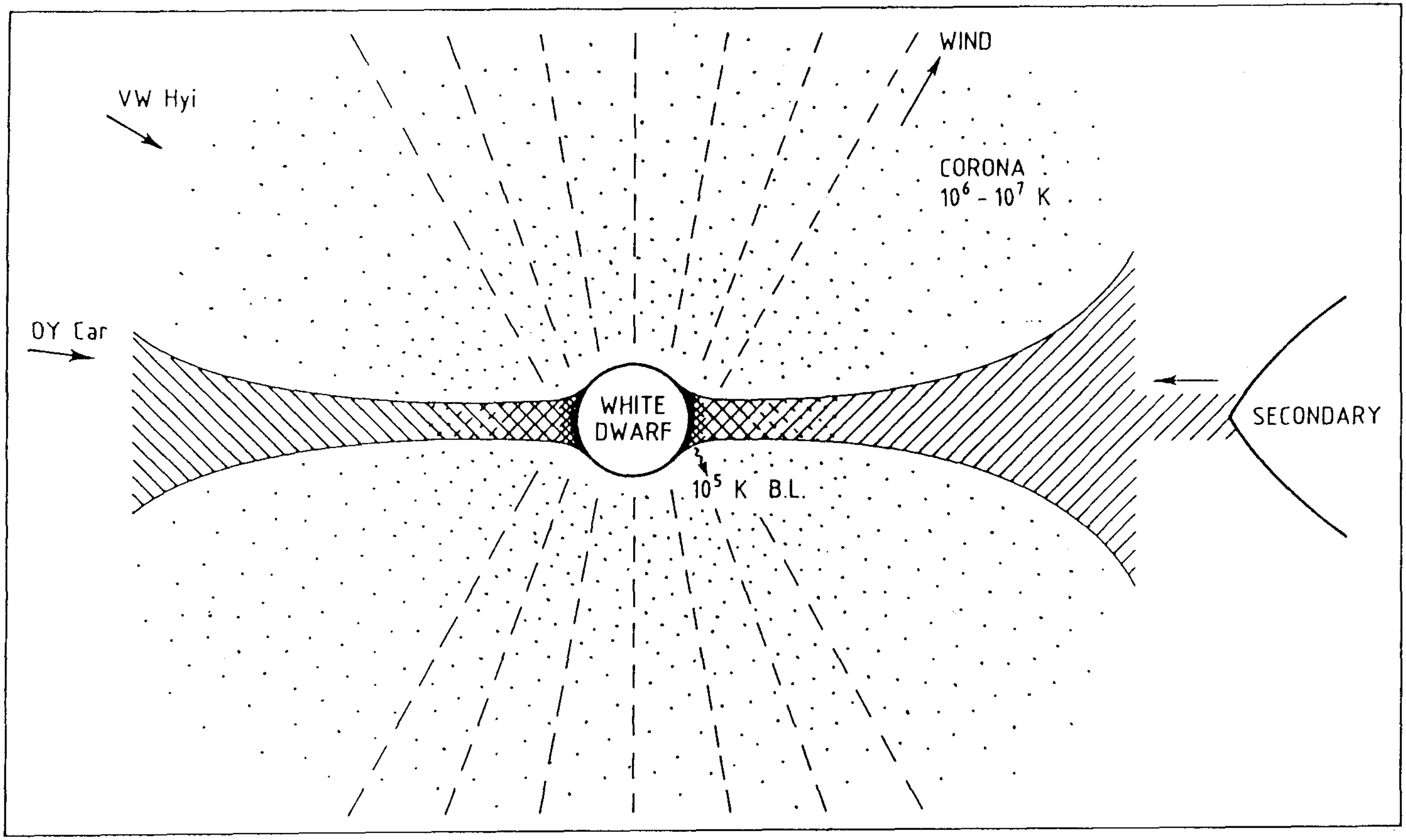

Fig. 2. *Schematic representation of an SU Uma system during superoutburst. The X-ray emission comes from a cool (≈10^5 K) boundary layer and a hot (10^6 - 10^7 K) optically thin corona. Note the extended, asymmetric rim of the disc, which, in OY Car, hides the boundary layer from view and introduces the UV orbital modulation. In reality the white-dwarf radius is a factor of 2 - 4, and the height of the inner disc a factor of ≈50 smaller.*

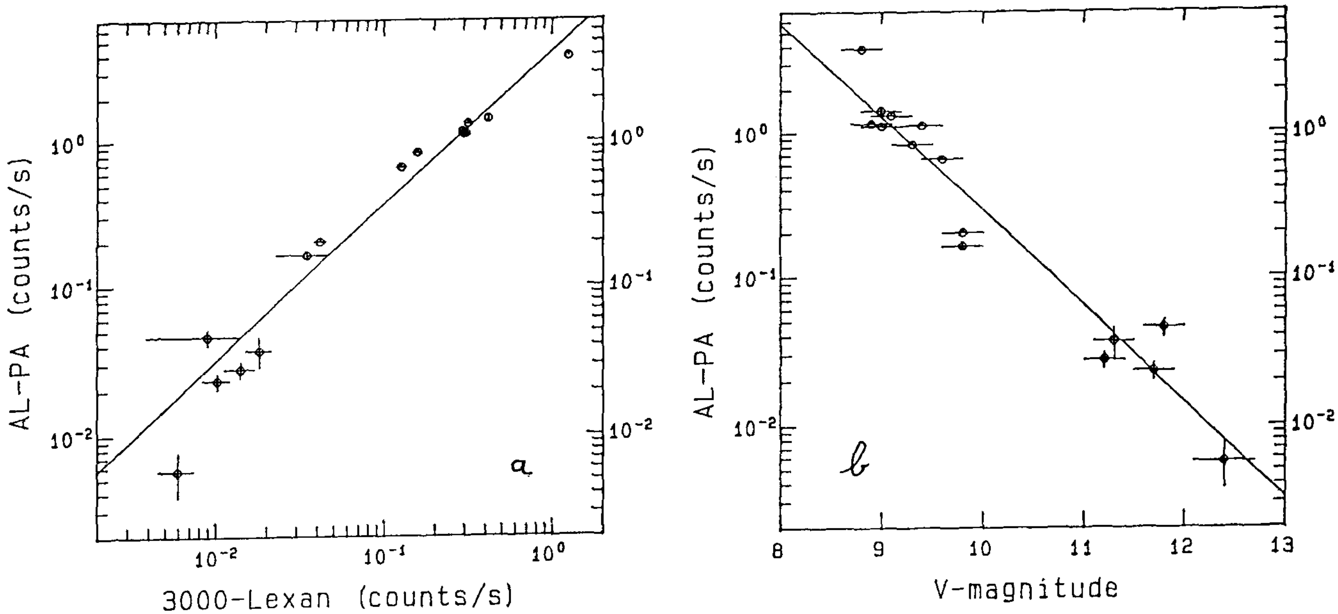

Fig. 3. *During maximum and decline of normal- and super-outbursts in VW Hyi the Al-Pa count rate is correlated with the 3000-Lexan count rate (a) and V-magnitude (b). A best linear fit in (a) gives a constant softness ratio of 3.9 over two orders of magnitude in count rate.*

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Hassall et al., 1986). OY Car is a highly inclined system ($i \approx 83^{\circ}$) in which the white dwarf and boundary layer are totally eclipsed by the secondary for ≈4 minutes (Cook, 1985). The soft X-ray light curve (Fig. 1) shows no indication for an eclipse. The eclipsed flux can be at most 30 % (5σ). The fact that there is in the X-ray band no orbital modulation (Fig. 1) and no eclipse, like observed in the UV, indicates that probably the inner disc and boundary layer are hidden from view by an extended wall at the rim of the disc (Hassall et al., 1986).

The ratio of the flux in the Al-Pa over the 3000-Lexan filter (softness ratio) is ≈0.4. This ratio is very sensitive to the jump in flux at the Lyman HeII edge at 228 Å. Pure He model atmospheres (Wesemael et al., 1980) with $T \lesssim 1.0\ 10^5$ K show a large jump and have a softness ratio of order 10. Models with $T \gtrsim 1.5\ 10^5$ K show a small jump, and the softness ratio is of order 1 or less. The softness ratio of OY Car therefore indicates that $T > 1.5\ 10^5$ K. However, a boundary layer with this temperature must have a radial extension a factor 40 smaller than the disc scale height near the white dwarf, to fit with the observed count rate. This is much smaller than expected (Pringle, 1977).

This fact, combined with the absence of eclipses, points to the presence of a hot, optically thin, X-ray emitting corona. I have calculated the characteristics of such a corona, using the code of Mewe, Gronenschild and van den Oord (1985) for optically thin plasmas with temperatures between 10^5 and $3\ 10^7$ K. The plasma remains optically thin for $T > 10^6$ K. For $T > 2\ 10^7$ K the plasma would lead to detection in the EXOSAT ME experiment, in contrast to observations. In this temperature interval ($10^6 - 10^7$ K) and for typical values of the interstellar absorption column ($N_h = 10^{18} - 10^{20}\ cm^{-2}$), the observed count rate corresponds to an emission measure ($\int N_e^2\, dV$) of 10^{53} to 10^{54} cm^{-3}. The softness ratio lies between 0.3 and 0.5 (like observed), and the emitted energy is typically 10^{31} erg s^{-1}. A schematic representation of OY Car during superoutburst is shown in Fig. 2.

4. VW HYDRI

This system is during superoutburst an extremely soft X-ray source, which radiates most of its energy at wavelengths above 170 Å (van der Woerd et al., 1986). Monitoring of this system during several outbursts has led to the conclusion (Van der Woerd and Heise, 1986) that the softness ratio remains almost constant (≈3.9), while the count rate changes by a factor of 100 (Fig. 3). This would indicate, for an optically thick boundary layer, that the temperature remains constant between 1.0 and 1.5 times 10^5 K (see above), while we expect changes in temperature by a factor 2 to 3. A two component model with an optically thick hot ($T > 1.5\ 10^5$ K) boundary layer plus an optically thick cool ($T < 10^5$ K) inner disc is also ruled out. The 3000-Lexan count rate implies an extremely small boundary layer, like in OY Car.

This problem can be solved when also in VW Hyi an extended hot corona surrounds the system. In contrast to OY Car, we now can observe both the boundary layer and corona (see Fig. 2), because VW Hyi has an inclination of ≈60^0. The boundary layer is cool (≈10^5 K), and radiates most of its flux in the Al-Pa band (softness ratio ≈10). The hot corona provides most of the 3000-Lexan flux. The bolometric flux flux of the soft component depends heavily on the exact temperature and absorption column density (10^{32} to 10^{34} erg s^{-1}).

5. DISCUSSION

The X-ray flux from OY Car during superoutburst is non-eclipsed, and probably comes from an extended (much larger than the white dwarf) hot ($10^6 - 10^7$ K) corona. The presence of a similar corona in VW Hyi during superoutburst, would give an elegant solution to the problem of the observed spectral shape in this system. The implied extension of the corona excludes that the corona is in hydrostatic equilibrium around the white dwarf. I mention the analogy between cataclysmic variables in outburst and the early type O and B stars. Both have strong winds; and now both are believed to have a hot corona. The connection between wind and X-ray emission, as proposed by Lucy and White (1980) and Lucy (1982), might also exist in SU Uma systems during superoutburst.

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