Non-Magnetic Cataclysmic Variables in the *ROSAT* WFC Survey

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Six non-magnetic cataclysmic variables were detected during the *ROSAT* WFC survey; four dwarf novae and two nova-like variables. In two dwarf novae (VW Hyi & SS Cyg) the flux evolution through outburst was followed across a broad wavelength range. The two other detections (Z Cam & RX J0640–24) also suggest the presence of distinct luminous EUV emission components; supporting the view that such components are a ubiquitous feature of dwarf nova outbursts. Two bright nova-like variables were detected, but these detections are found to be consistent with the soft tail of the X-ray emission.

1. Introduction

1.1. *Cataclysmic Variables (CVs)*

X-rays in non-magnetic cataclysmic variables are thought arise in the boundary layer between the disk and white dwarf; where material settles onto the surface from its Keplarian velocity. Assuming the white-dwarf is not rotating close to breakup, one half of the total accretion luminosity must be released in this transition. If the boundary layer is thin, i.e. the transition from Keplarian to white-dwarf velocity is sudden, one would expect the entire boundary-layer luminosity to be emitted as X-rays.

In most non-magnetic CVs the boundary layer emission is optically thin and hard ($kT \sim 1$–10 keV); as such they are not promising EUV sources. The exceptions are systems with a high accretion rate: dwarf novae in outburst and nova-like variables. In these the boundary layer density becomes high enough to make it at least partly optically thick to its own radiation (Pringle & Savonije 1979); the hard X-rays are thermalised and emitted in the EUV ($kT_{eff} \sim$ 10's eV). Pre-ROSAT these soft emission components had been observed only in three systems, all bright dwarf novae in outburst: SS Cyg, VW Hyi and U Gem (Jones & Watson 1992; Pringle et al. 1987; Mason et al. 1988).

EUV emission should be a ubiquitous feature of high $\dot{M}$ CVs if this simple picture is correct. The luminosity should also be comparable with that of the disk (optical/UV). Van Teeseling & Verbunt (1994) show that there is a deficiency of boundary-layer luminosity (hard X-rays compared with optical/UV) which is an increasing function of $\dot{M}$; perhaps indicating the increasing importance of an unobserved EUV component. However, several observations now suggest that the luminosity of the EUV component, where detected, is also lower than that of the disk.

1.2. *ROSAT WFC Survey*

The *ROSAT* Wide Field Camera (WFC) surveyed entire sky in two EUV bandpasses† during the second half of 1990 (Sims et al. 1990). Of the 382 sources detected in the initial survey analysis (Pounds et al. 1993), 17 were identified as CVs. A systematic search for all magnetic CVs, dwarf novae in outburst and the brightest nova-like variables revealed a further four high significance detections (Wheatley 1995a,b).

Six non-magnetic systems were detected, of which four are dwarf novae: VW Hyi, SS Cyg, Z Cam and RX J0640–24; and two are nova-like variables: IX Vel and V3885 Sgr.

† S1a, 90–206 eV; S2a 62–110 eV

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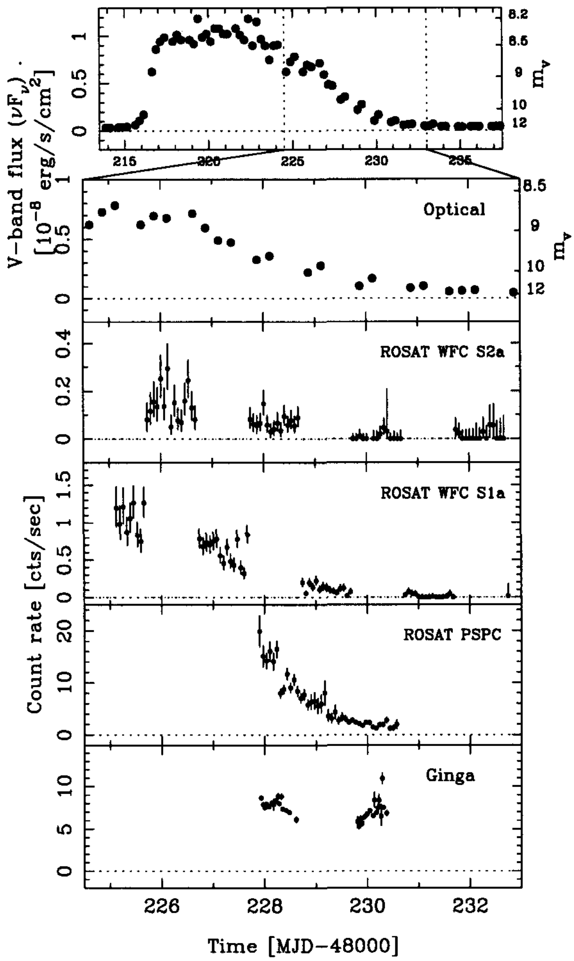

FIGURE 1. Multi-wavelength lightcurves of an outburst of the dwarf nova SS Cygni.

2. Dwarf Novae

Of the four WFC detections of dwarf novae, three were made at the time of outburst (SS Cyg, VW Hyi & Z Cam, Figs. 1–3). There is no simultaneous optical light curve of RX J0640–24, but EUV/optical ratios strongly suggest that it too was detected in outburst.

SS Cyg and VW Hyi are the brightest dwarf novae, in optical and X-rays, and have both been seen as strong EUV sources during outburst. As such they were chosen as targets for a detailed multi-wavelength study, made at the time of the *ROSAT* surveys.

2.1. *SS Cyg*

SS Cyg was observed during decline from ordinary outburst (Fig. 1). The *ROSAT* WFC and PSPC light curves clearly show a bright EUV component ($kT \sim 20$ eV), which declines more quickly than the optical (e-folding timescales of one and three days respectively). The luminosity of this component is $\sim 10^{33}\, d^2_{100\,pc}\, erg\, s^{-1}$, which is at

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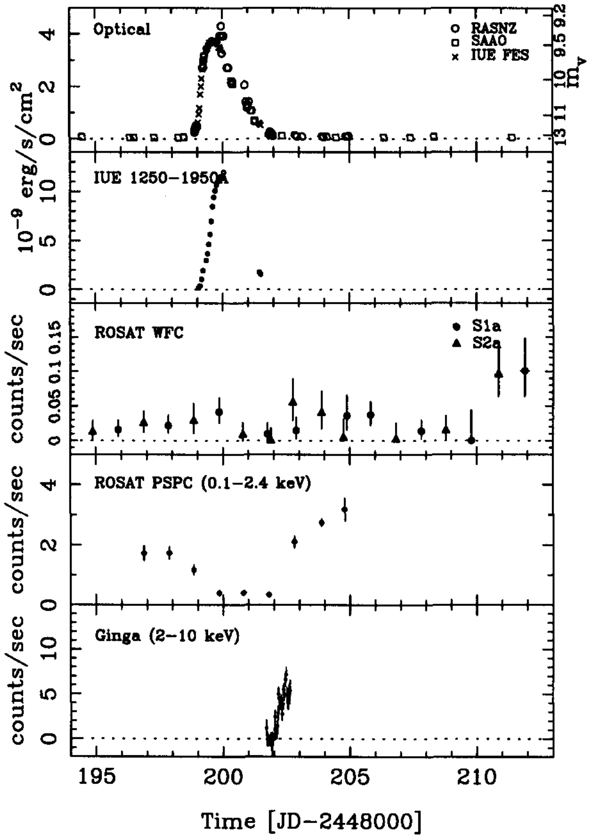

FIGURE 2. Multi-wavelength lightcurves of an outburst of the dwarf nova VW Hydri.

least an order of magnitude less than that of the disk. The hard X-ray light curve, measured with *Ginga* (2–20 keV), remains constant throughout this decline, and at a level below that of an observation of quiescence (40 cts/s). Ponman et al. (1995) discuss these observations in detail.

2.2. *VW Hyi*

The multi-wavelength observations of VW Hydri (Fig. 2) are discussed by Wheatley et al. (1995). Here the suppression of the hard X-rays during outburst is well defined by the *ROSAT* PSPC and *Ginga* light curves. Crucially, the *Ginga* observation catches the recovery to the quiescent level; placing it firmly at the end of the optical outburst. This unambiguously associates the X-ray emission with the boundary layer, since models agree that the accretion disk returns to quiescence from the outside in. This probably holds for SS Cyg, since the hard X-rays remain at their apparently suppressed level until very late in the outburst (Fig. 1).

The WFC light curves show no evidence for an EUV component replacing the hard X-rays, but at outburst maximum the survey scans were made with the hard filter (S1a). *EXOSAT* LE observations, in which an EUV component was detected, suggest a best blackbody temperature around 90 000 K (Van Teeseling et al. 1993), which would have been detected with the soft filter (S2a). The non-detection one day later with S2a

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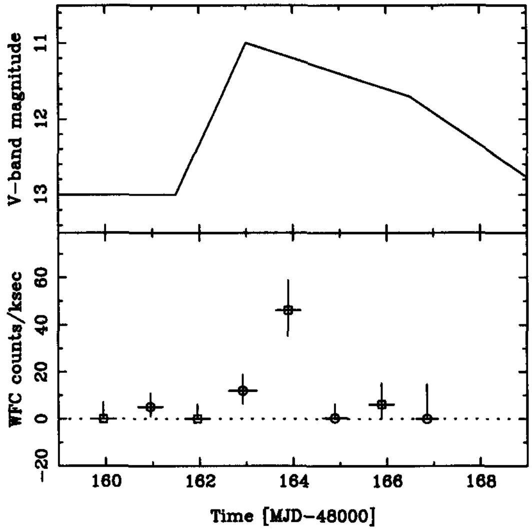

FIGURE 3. Optical and WFC light curves of Z Cam through an outburst (S1a: o, S2a: □).

suggests that the EUV component declines more quickly than the optical in VW Hyi, as in SS Cyg. Upper limits to WFC countrates during outburst limit the blackbody luminosity to $10^{33}\,d^2_{65\,pc}\,\mathrm{erg\,s^{-1}}$ for any temperature; which is substantially below that of the disk ($> 6 \times 10^{33}\,d^2_{65\,pc}\,\mathrm{erg\,s^{-1}}$).

2.3. *Z Cam*

Z Cam is the third brightest of the eleven other dwarf novae caught in outburst during their survey observations, and is the only one detected. Figure 3 shows a clear EUV enhancement at outburst maximum. The outburst evolves more rapidly than the WFC filters were changed, so little spectral information is available, but for the S2a count rate at MJD 48164 to be so much higher than S1a at MJD 48163 requires either a very soft spectrum or that S1a caught the EUV rise. The low EUV flux at the beginning of the optical decline (S1a at MJD 48165 and S2a at MJD 48166) clearly indicates that the EUV component declines more quickly than the optical, as is seen in SS Cyg and VW Hyi.

2.4. *RX J0640–24*

RX J0640–24 was discovered through the optical follow-up to the PSPC galactic-plane survey (Beuermann & Thomas 1993). It was detected only in S1a and with a low count rate (10 ± 3 cts/ks) and the light curve is consistent with that of a constant source. It was discovered as a 15^{th} magnitude object, making it the faintest dwarf nova yet detected in the EUV. The discovery magnitude implies an EUV/optical ratio two orders of magnitude greater than that of SS Cyg, so it is likely that RX J0640–24 was in outburst during the WFC survey observation and in quiescence when identified optically.

3. Nova-like Variables

Pounds et al. (1993) identified IX Vel, the brightest UX UMa-type nova-like, in their initial WFC survey analysis. A search in the survey database for the next two brightest UX UMa-types revealed a detection of V8335 Sgr and a non-detection for RW Sex. No systematic search has been made for non-magnetic nova-like variables, which may be expected to have the same EUV properties as dwarf novae in outburst; Van Teeseling showed that they too are underluminous hard X-ray sources.

3.1. *Spectra*

IX Vel is an extremely soft WFC source. Its mean S1a and S2a count rates were 9 ± 3 and 29 ± 5 cts/ks respectively. This suggests a strong EUV emission component, capable of carrying the missing boundary layer luminosity. However, Beuermann & Thomas (1993) report a temperature of $kT \sim 1$ keV with the *ROSAT* PSPC during the survey. At these temperatures optically-thin emission in the WFC bandpass is dominated by line emission, and strong lines in the S2a band give the impression a soft spectrum. Folding a 1 keV "Mewe" spectrum through the responses of the WFC and PSPC demonstrates that this single component can account for the fluxes and colours in both instruments. It was also found that the detection of V3885 Sgr is consistent with an extrapolation of the PSPC spectrum presented by Van Teeseling & Verbunt (1994). The WFC-survey presents no evidence of distinct EUV emission in nova-like variables.

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