X-ray observations through the outburst cycle of the dwarf nova YZ Cnc

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Abstract. We have observed YZ Cnc at two day intervals from 6 to 24 April 1998, covering two full outburst cycles. The 0.1-2.4 keV flux is lower during optical outburst than in quiescence, and lowest at the end of the outburst. The decline of the X-ray flux in the quiescent interval appears to be in contrast to prediction of simple models for accretion-disk instabilities. Variability on \(\sim\)hour time scales is present, but appears not related to the orbital phase. YZ Cnc was less luminous in X-rays during our 1998 observations than in earlier ROSAT observations.

Key words: accretion disks – stars: individual: YZ Cnc – cataclysmic variables

1. Introduction

Dwarf novae are named after their outbursts, during which their luminosity at optical and ultraviolet wavelengths increases by factors \(\lesssim 100\) (for a review see the monography on Cataclysmic Variables by Warner 1995). The outbursts are thought to be due to increased accretion onto the white dwarf. Such an increase can be the consequence of increased transfer of matter from the donor star to the accretion disk that surrounds the white dwarf; alternatively an instability inside the accretion disk could trigger higher accretion onto the white dwarf. The latter model has been prominent in recent theoretical work, but is not without difficulties (see reviews by e.g. Cannizzo 1993, Verbunt 1991, Livio 1999).

X-rays of dwarf novae arise from close to the white dwarf and thus reflect the condition in the accretion disk close to the white dwarf (see, e.g., the review by Verbunt 1996). For a comparison between different models, it is necessary to consider the whole outburst cycle, including the quiescent interval (e.g. Pringle et al. 1986).

2. Observations and data reduction

All 1998 observations were obtained with the ROSAT X-ray telescope (Trümper et al. 1991) in combination with the high-resolution imager (HRI, David et al. 1995). The log of the observations is given in Table 1.

The data reduction was done with the Extended Scientific Analysis System (Zimmermann et al. 1996). YZ Cnc was detected in every pointing, the countrate was determined by applying a maximum-likelihood technique which disperses longer and brighter superoutbursts. Its orbital period is 0.0868(2) d (Shafter & Hessman 1988); a more accurate period of 0.086924(7) d is suggested by Van Paradijs et al. (1994). YZ Cnc is remarkable for the behaviour of its ultraviolet resonance lines during its dwarf nova outbursts: during each orbit the profiles of these lines change from almost pure emission to P Cygni profiles with deep absorption, and back again; these changes are not accompanied by changes in the continuum (Drew & Verbunt 1988, Woods et al. 1992). In X-rays YZ Cnc has been studied with the Einstein satellite (Córdova & Mason 1984, Eracleous et al. 1991), with EXOSAT (van der Woerd 1987), and with the ROSAT PSPC during the ROSAT All Sky Survey and in subsequent pointings (Verbunt et al. 1997, van Teeseling & Verbunt 1994). In this paper we report on a ROSAT campaign intended to determine the X-ray fluxes throughout the outburst cycle of YZ Cnc; and also to determine whether the orbital variation in the ultraviolet lines is accompanied by orbital variation in the X-ray flux. In Sect. 2 we describe the observations and data analysis, the results and their interpretation are given in Sect. 3; comparison with earlier X-ray observations is made in Sect. 4, and the implications for the models of dwarfs nova outbursts are discussed in Sect. 5.
Fig. 1. Optical and X-ray lightcurve of YZ Cnc in April 1998. The optical data (magnitude scale on the left) have been obtained by the American Association of Variable Star Observers: small dots indicate estimates made by eye; the large symbols indicate CCD measurements. The HRI countrates (logarithmic scale on the right) are shown as crosses, the horizontal and vertical lengths of which indicate the observation period and 1-σ error range, respectively.

Table 1. Log of the ROSAT HRI observations of YZ Cnc in April 1998, and one PSPC observation obtained on May 1, 1994. For each observation we give the UT at start and end of the exposures and the effective exposure time; as well as the observed countrate (with the 1-σ error in the last two decimals).

| date          | exposure start & end | $t_{\text{exp}}$ (s) | countrate (cts/s) |
|---------------|----------------------|-----------------------|-------------------|
| 1994 May 1    | 2449473.614-73.655   | 1369                  | 0.403(18)         |
| 1998 April 6  | 2450909.935-10.090   | 6708                  | 0.1121(41)        |
| 1998 April 8  | 2450911.921-12.152   | 10220                 | 0.0208(15)        |
| 1998 April 10 | 2450913.912-14.142   | 9417                  | 0.0124(12)        |
| 1998 April 12 | 2450915.905-16.132   | 9053                  | 0.0971(33)        |
| 1998 April 14 | 2450917.893-18.120   | 9425                  | 0.0842(30)        |
| 1998 April 16 | 2450919.813-20.041   | 9427                  | 0.0236(16)        |
| 1998 April 18 | 2450921.802-22.031   | 9925                  | 0.0156(13)        |
| 1998 April 20 | 2450923.790-24.020   | 9755                  | 0.0990(32)        |
| 1998 April 22 | 2450925.713-25.942   | 9245                  | 0.0866(31)        |
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In accordance with these findings, we interpret the change in HRI countrates during the outburst cycle as

3. Results and interpretation

We investigate the variation of the X-ray flux of YZ Cnc through the outburst cycle, and also on the orbital timescale.

3.1. Outburst cycle

In Figure 1 we show the optical lightcurve of YZ Cnc from April 5 to 26, 1998, as determined by the American Association of Variable Star Observers, together with the HRI countrates listed in Table 1. The optical lightcurve shows maxima of ordinary outbursts occurring on JD 2450912 and JD 2450921, and a superoutburst maximum near JD 2450930.

In comparing the X-ray countrates with the optical lightcurves we remark on three features of Fig. 1. First, the HRI countrates are lower during the optical outbursts than in the quiescent intervals. Second, in both quiescent intervals that we cover, the countrate is lower in the later observation. Third, in both outbursts that we cover, the countrate is lower in the later observation.

The distribution of the photons over the energy channels of the HRI is the same for the observations taking during outburst as for those taken during quiescence. Comparison of the distributions obtained for the first observations during outburst (i.e. those of April 8 and 16) with those obtained during the later outburst observations (of April 10 and 18) suggests that the decrease in X-rays is marginally less at the lower energies, i.e. that the spectrum becomes slightly softer as the optical outburst proceeds. The significance of this softening is marginal, but it suffices to show that the decrease of the X-ray flux cannot be due to the disappearance of an ultra-soft component.

countrate are therefore dominated by Poisson statistics on the detected number of source counts.
a change mainly in the amount of gas that emits keV photons. This amount drops gradually during quiescence, more dramatically in the beginning of an outburst, and gradually again as the outburst proceeds.

3.2. Short-term variability

We have searched for short-term variability by dividing the individual observations in smaller intervals. For the outburst data we determine the average countrate during each ROSAT orbit; for the higher countrate during quiescence we use bins of 256 s. Figure 2 show the resulting lightcurves. Significant variation is present both during outburst and during quiescence. During early ordinary outburst (April 8, 16) the variation appears dominated by a long-term decline. No orbital variation is apparent in any of the outburst data. During quiescence, the flux level at a given orbital phase varies as much as the overall variation. We have folded the variation on the orbital period of 0.086924 d, and find no significant variation on the orbital period, in quiescence or in outburst. Any orbital variation is less than the irregular variations seen in Fig. 2.

4. Comparison with previous X-ray observations

4.1. Previous observations of YZ Cnc

To compare our observations with previous ROSAT PSPC observations, we note that for a 2-3 keV thermal spectrum as found for YZ Cnc by Van Teeseling & Verbunt (1994) the ROSAT PSPC (channels 50-201) countrate is similar to the Einstein IPC countrate, and about twice the ROSAT HRI countrate. From the results listed in Table 1, we therefore expect countrates in the ROSAT PSPC (ch. 50-201) or Einstein IPC of 0.22-0.17 cts/s in quiescence and of 0.047-0.025 cts/s during outburst.

The All-Sky Survey observation was obtained from 10 to 12 October 1990, i.e. during the outburst which peaked on October 10 (Bortle 1990). The countrate (in PSPC channels 52-201) is about 0.1 cts/s (Verbunt et al. 1997), and does not vary significantly. The pointed observations with the ROSAT PSPC gave countrates (in channels 50-201) of 0.4 cts/s on 3 April 1991 immediately before an optical outburst maximum, and of 0.27 cts/s on 7-11 October 1993 in quiescence (van Teeseling & Verbunt 1994). We have analyzed a previously unpublished ROSAT PSPC observation, obtained on 1 May 1994. The countrate (ch. 50-201) is 0.249(14) cts/s, marginally lower than the 1993 countrate. All these countrates are significantly higher than the corresponding ones during outburst and in quiescence in April 1998, and indicate long-term variability in both quiescent and outburst X-ray fluxes of YZ Cnc of April 1998. Outbursts of YZ Cnc were observed by the AAVSO peaking on March 8, 18 and 28 and on April 15 and 23 in 1979 (Bortle 1979). AAVSO measurements of YZ Cnc in March and April 1979 are shown in Fig. 3. The quiescent interval separating the March 28 and April 15 outbursts was longer than the intervals preceding and following it. A single, uncertain measurement obtained close in time to the Einstein observation suggests that YZ Cnc was brighter than its quiescent level. We suggest that the Einstein observation was obtained during an outburst peaking close to 8 April 1979, which was missed by the optical observers.
and less luminous but constant during outburst, whereas a soft component is brighter during outburst than in quiescence, and decreases rapidly after reaching its maximum early in the outburst (Wheatley et al. 1996a,b, Ponman et al. 1995). The situation is different for the dwarf nova outbursts of U Gem, where both soft (0.15-0.5 keV) and hard (2-10 keV) X-ray fluxes are higher during outburst than in quiescence; and both components appear to decrease faster during the outburst than the optical flux (Mason et al. 1978, Swank et al. 1978). The EUVE observations of U Gem and SS Cyg show that the soft component is not altogether optically thick (Mauche et al. 1995, Long et al. 1996).

The soft component has a different temperature in each of the above dwarf novae, but in most cases the HRI band is dominated by the hard component. (The exception is SS Cyg, whose soft component has a relatively high characteristic temperature; Van Teeseling 1997.) This supports our conclusion in Sect. 3.1 that the hard component is responsible for the observed decrease during outburst of the X-ray flux in YZ Cnc.

As regards the quiescent interval between outbursts, we are aware of only one other system that has been observed throughout several full outburst cycles, viz. VW Hyi. EXOSAT observations of this system showed a decrease of the flux in the 0.05-1.5 keV energy range during each of three covered quiescent intervals (van der Woerd & Heise 1987, Pringle et al. 1987), in accordance with our findings for YZ Cnc.

5. Implications for outburst models
In Sect. 3.1 we concluded that the changes in X-ray flux of YZ Cnc that we observe through the outburst cycle are due mainly to changes in the amount of X-ray emitting gas. We will compare our results with the predictions of the two classes of models of dwarf nova outbursts, the mass transfer instability and the disk instability.

Both models can explain a lower X-ray flux during the outburst as a consequence of a transition of an optically thin, very hot boundary layer during quiescence into a rather less hot, optically thick gas during outburst when the accretion rate onto the white dwarf is high (Pringle & Savonije 1979). The observations of dwarf novae in outburst indicate that not all the X-ray emitting gas disappears during the outburst, but that some of it remains, at much the same temperature as during quiescence. It would be tempting to locate this remaining component away from the disk, e.g. in a white dwarf or disk corona, if it is to escape becoming optically thick with the increased accretion rate. However, it then has to be explained why this component has a spectrum very similar to the component remaining at much the same temperature as during quiescence.

4.3. Observations of other dwarf novae

In March 1979 the ROSAT HRI observations were repeated at the same time of year and reconfirmed that the X-ray flux of YZ Cnc is lower than that observed by the Einstein observatory. However, we have not seen any short term variability in the X-ray flux during the outburst cycle.

Fig. 3. Visual magnitude of YZ Cnc between March 16 and May 8 1979, as measured by the AAVSO. A magnitude estimate is shown as ●, an uncertain estimate as □, and an upper limit as ↓. The vertical dotted line indicates the time of the Einstein observation.

Fig. 2. Variation in X-ray flux of YZ Cnc through the outburst cycle, plotted as countrate vs. time. The countrate of the EXOSAT LE (3000 Lexan) in the time of the Einstein observation. The vertical dotted line indicates an upper limit in the column of $N_H \sim \leq 10^{20}$ cm$^{-2}$, an HRI countrate of 0.1 cts/s predicts an countrate for the EXOSAT LE (3000 Lexan) in the range 0.02 – 0.01 cts/s. Depending on the assumed column, the EXOSAT observations are thus compatible both with the higher X-ray luminosity as observed with the ROSAT PSPC observations, and with the somewhat lower luminosity of our ROSAT HRI observations.

4.2. Orbital variability

Our finding that the observed X-ray flux of YZ Cnc varies on short time scale unrelated to the orbital phase, is in accordance with similar findings by Van der Woerd (1987) in his analysis of the EXOSAT data. Any explanation of the marked change in the profiles of the ultraviolet resonance lines in YZ Cnc in terms of a variable absorption column between the ultraviolet continuum source and Earth, must be compatible with a much less marked variation in the X-ray flux. For a cold gas with cosmic abundances, an upper limit in X-ray variability on orbital time scales of $\lesssim 10\%$ (see the April 18 data in Fig. 2) corresponds to an upper limit in the column of $N_H \lesssim 10^{20}$ cm$^{-2}$. The upper limit to the column in the more realistic case of the complicated ionization structure in the wind of a dwarf nova can be determined only in a detailed model of this structure (see e.g. the review by Drew 1997 and references therein.).
compatibility with a large absorbing column required to explain the strong variations in the ultraviolet resonance lines.

The mass transfer instability model is not sufficiently developed to predict the mass transfer as a function of time, and thus to predict the evolution of the X-ray flux, during outburst. However, the model does predict a continued decrease of the accretion rate onto the white dwarf during quiescence, perhaps levelling off to a constant level in long quiescent intervals when the disk reaches equilibrium with the lower mass inflow rate at its outer edge. A continuing decrease of the X-ray flux in quiescence, as observed for YZ Cnc and various other dwarf novae, is thus in accordance with the transfer instability model (for model accretion rates onto the white dwarf during the outburst cycle, see e.g. Pringle et al. 1986).

The disk instability model in its simple form predicts a gradual increase of the accretion rate onto the white dwarf during quiescence, and there therefore a gradual increase in the optical and ultraviolet flux. An increased accretion rate through an optically thin disk also predicts an increase in the X-ray flux, contrary to our observations of YZ Cnc.

The rise of the ultraviolet flux in quiescence predicted by the disk instability model is contrary to observations of several dwarf novae, in particular the eclipsing system Z Cha, but also VW Hyi and WX Hyi (Van Amerongen et al. 1990, Verbunt et al. 1987, Hassall et al. 1985). Szkody et al. (1991) investigated the evolution of the ultraviolet flux of many dwarf novae in quiescence, and did not find a single case where the ultraviolet flux increases when measured in a single interoutburst interval. A white dwarf that dominates the ultraviolet flux in quiescence and cools after the outburst has been suggested as explanation for the observed ultraviolet flux decrease. This explanation is not compatible with the observations in the ultraviolet of Z Cha, in which the contribution by white dwarf and disk are determined separately. A cooling white dwarf doesn’t explain our X-ray observations of YZ Cnc.

A well-known problem of the disk instability model is its failure to describe the observation in short outbursts that the optical rise precedes the ultraviolet rise by several hours (Pringle et al. 1986). Various ad hoc suggestions have been made to explain this ultraviolet delay. These models suggest that the inner part of the disk continues to drain in quiescence. Such models, which include the effect of a magnetic field of the white dwarf (Livio & Pringle 1992), a wind from the accretion disk in quiescence (Meyer & Meyer-Hofmeister 1994), and irradiation of the disk by the (relatively) hot white dwarf (King 1997) possibly are compatible with the decrease of the ultraviolet and X-ray flux during quiescence.

Finally, we note that the X-ray flux at the end of an outburst is not constant, but decreases. For YZ Cnc, this decrease was observed during every measured outburst cycle. The decrease was also observed for various other dwarf novae (see Sect. 4.1). We do not find any clear correlation with the outburst pattern. Thus, the ROSAT PSPC measurements were made in relatively long quiescent intervals (11 days in Oct 1993, May 1994) and in a relatively short quiescent interval (5 days in April 1991). The ROSAT PSPC observations were obtained longer before the next superoutburst than our new HRI observations; but the Einstein observation was also made long before the next superoutburst. The high countrate observed with the ROSAT PSPC therefore is not due to a different length of the quiescent periods, nor to a different location in the interval between superoutbursts.

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