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Multi-frequency evolution of V2491 Cyg (nova Cyg 2008 number 2)

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Abstract. V2491 Cyg was the second nova detected in the constellation of Cygnus in 2008. It was monitored in detail by *Swift*, over both the X-ray and UV bands, from less than a day until almost 240 days after its discovery. The evolution of the light-curve and spectra are presented, and the possibility that V2491 Cyg is a recurrent nova is discussed.

Key words. stars: individual: V2491 Cyg – novae, cataclysmic variables

1. Introduction

V2491 Cyg was detected in outburst on 10th April 2008, with *Swift* observations starting very rapidly, less than a day after the announcement of the nova. Because of the brightness of the optical source, no useful UVOT (UV/Optical Telescope) were collected for the first three weeks. There were serendipitous pre-nova *Swift* observations of the field of V2491 Cyg (Ibarra et al. 2009) taken ∼ 100–300 days before the 2008 nova explosion, which revealed a persistent, but variable, X-ray source, as shown in the inset of Fig. 1. Suzaku observations obtained after the nova also detected V2491 Cyg out to 70 keV (Takei et al. 2009, 2011).

2. X-ray observations

Fig. 1 shows the full *Swift* XRT (X-ray Telescope) light-curve (over 0.3–10 keV), with the corresponding hardness ratio (1.5–10 keV/0.3–1.5 keV). Immediately after the outburst, the X-ray source was relatively faint. However, it started to brighten and soften steadily about 10 days later, followed by a rapid increase in count rate (and simultaneous softening) around day 36, reaching a peak count rate on day 42. Interestingly, the source only remained at the peak count rate for about a day, whereas other novae monitored by *Swift* have tended to stay at the peak for weeks, if not months (Osborne et al. 2011; Beardmore et al. 2010). Fig. 2 shows a brief, but dramatic, dip in the X-ray count rate, reminiscent of the high-amplitude flux variability seen at the start of the supersoft emission in novae such as RS Oph (Osborne et al. 2011), V458 Vul (Drake et al. 2008) and KT Eri (Beardmore et al. 2010), but on a much smaller scale.

The earliest spectra (both pre- and shortly after the nova) are relatively hard; soft emission became prominent around day 36 (Figs. 1 and 3), signifying the start of the supersoft source (SSS) phase. The soft emission showed strong absorption features, which were particularly obvious in the XMM-Newton data presented by Ness et al. (2011), though deviations

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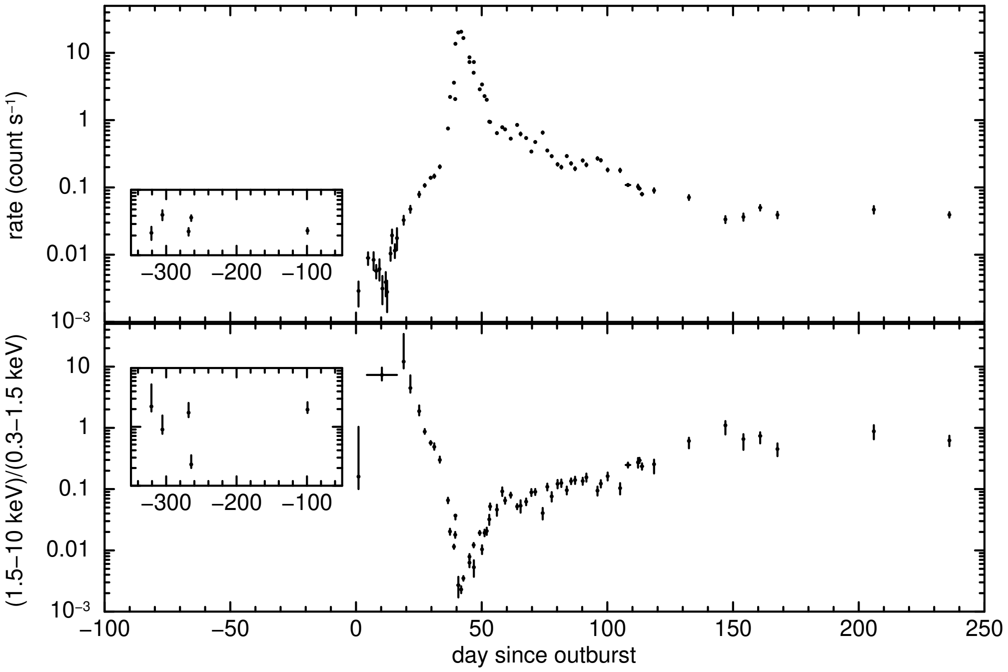

Fig. 1. The upper panel shows the *Swift*-XRT count rate light-curve, with the corresponding hardness ratio in the middle panel, with one bin per observation; the pre-nova data are plotted in the insets in each case.

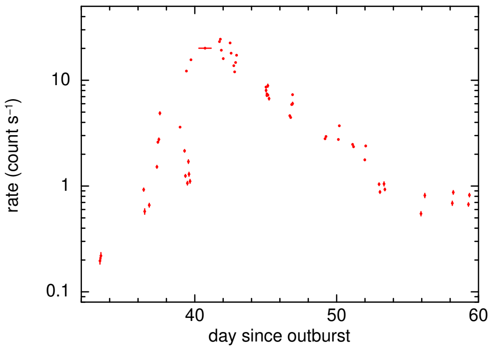

Fig. 2. This plot shows a zoom-in of the XRT light-curve, with a finer time-binning than in Fig. 1. A dramatic dip in the count rate is clearly visible just before day 40.

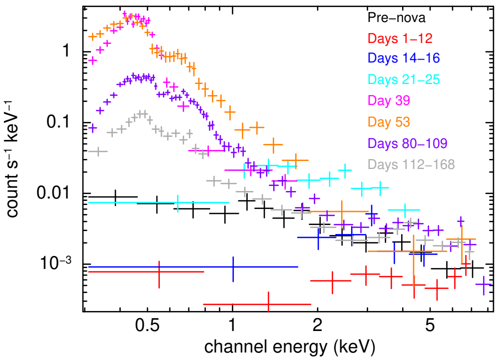

Fig. 3. A sample of *Swift*-XRT spectra, demonstrating the change from an early, relatively hard spectrum to the supersoft phase.

from a smooth continuum are clear in the XRT data too (Fig. 3).

The top panel of Fig. 4 demonstrates that the vast majority of the change in flux of V2491 Cyg occurs below 1.5 keV: the soft-band light-curve, plotted as black circles, first increases in brightness, followed by a rapid, and then more gradual, fading, while the hard-band (grey crosses) fades slowly throughout. Investigating the light-curve in higher time resolution, there is evidence of short-timescale flickering at least after day 57, which may be an indication of the resumption of accretion. Takei et al. (2011) come to a similar conclusion based on the presence of the quasi-neutral iron line in the Suzaku data. There is also some evidence for iron emission in the *Swift*-XRT data at these late times.

Spectra were extracted for each separate observation (approximately one every day or two, for the first ~ 100 days of the outburst) and fitted with a simple absorbed blackbody (BB) model, with a faint optically thin component to model the few higher energy counts. BBs are not the ideal model and this is discussed in more detail in Page et al. (2010); simple stellar atmosphere models reveal the same trends, however: the BB temperature increases slowly until day 57, with a 'hiccup' in the smooth rise at the time of the peak in the X-ray count rate (Fig. 4). During this time, the absorbing column decreases. After day 57, the temperature and N_H both flatten off, with the column then being consistent with the value obtained by Ibarra et al. (2009) for the pre-nova data. As the temperature increases, the radius of the emitting BB and the estimated bolometric luminosity decrease. These two parameters are plotted in terms of arbitrary units in Fig. 4, since BB models can overestimate the luminosity. See Page et al. (2010) for further information.

The UV data fade monotonically (Fig. 4), though with two points of inflexion: the decay slope steepens at the time of the peak X-ray count rate, and then flattens off again when the X-ray decay also slows, on day 57. Although the AAVSO data (bottom panel of Fig. 4) are sparse at later times, the rate of decay of the optical data decreases at this time as well.

3. A recurrent nova?

Although most novae are only seen to explode once (the 'classical' novae), others – the so-called 'recurrent' novae – are detected in outburst on more than one occasion. Classical novae are eventually expected to repeat, though on timescales of 10^{3-5} years, rather than over a matter of decades.

There are certain characteristics of V2491 Cyg which are similar to those of the known recurrent novae. For instance, V2491 Cyg is a fast nova, as evidenced by its high expansion velocities and rapid fading of the optical source (Tomov et al. 2008a). Fast novae are thought to host more massive WDs, which recurrent nova systems are expected to contain (Warner 2008). The detection of a pre-outburst X-ray source is also very suggestive, implying a high accretion rate, generally expected for recurrent systems. V2487 Oph is another source which was detected in X-rays before the nova explosion, thought initially to be a classical nova. However, this object has now been reclassified as a recurrent, since a previous optical eruption was identified on archival plates (Pagnotta, Schaefer & Shao 2008), revealing a recurrence timescale of around a century. The possibility of V2487 Oph being recurrent had been previously suggested by Hachisu et al. (2008). In addition, Tomov et al. (2008b) point out similarities between V2491 Cyg and the known recurrents U Sco and V394 CrA, in terms of line profiles, the lack of forbidden lines and the classification as a He/N nova.

We therefore computed the recurrence time expected for different WD masses, using the mass-radius relations of Nauenberg (1972) and Althaus et al. (2005), considering the range of inter-outburst luminosities derived by Ibarra et al. (2009) from fitting the pre-nova spectra (Fig. 5); details of the calculations are given in Page et al. (2010). If the higher luminosity is used, V2491 Cyg could actually recur over mere decades, although, since a previous eruption has not been detected, this seems unlikely. However, a timescale of a hundred years or so, similar to that found for V2487 Oph, could easily be accommodated.

4. Summary

V2491 Cyg went into nova outburst in 2008 and was closely monitored by *Swift*. Its X-ray emission shows at least three distinct phases, as is the case for most novae followed in detail by *Swift*. Shortly after the nova outburst, the X-ray emission was relatively faint and hard; this is interpreted as shocks caused by components within the ejecta having a range of ve-

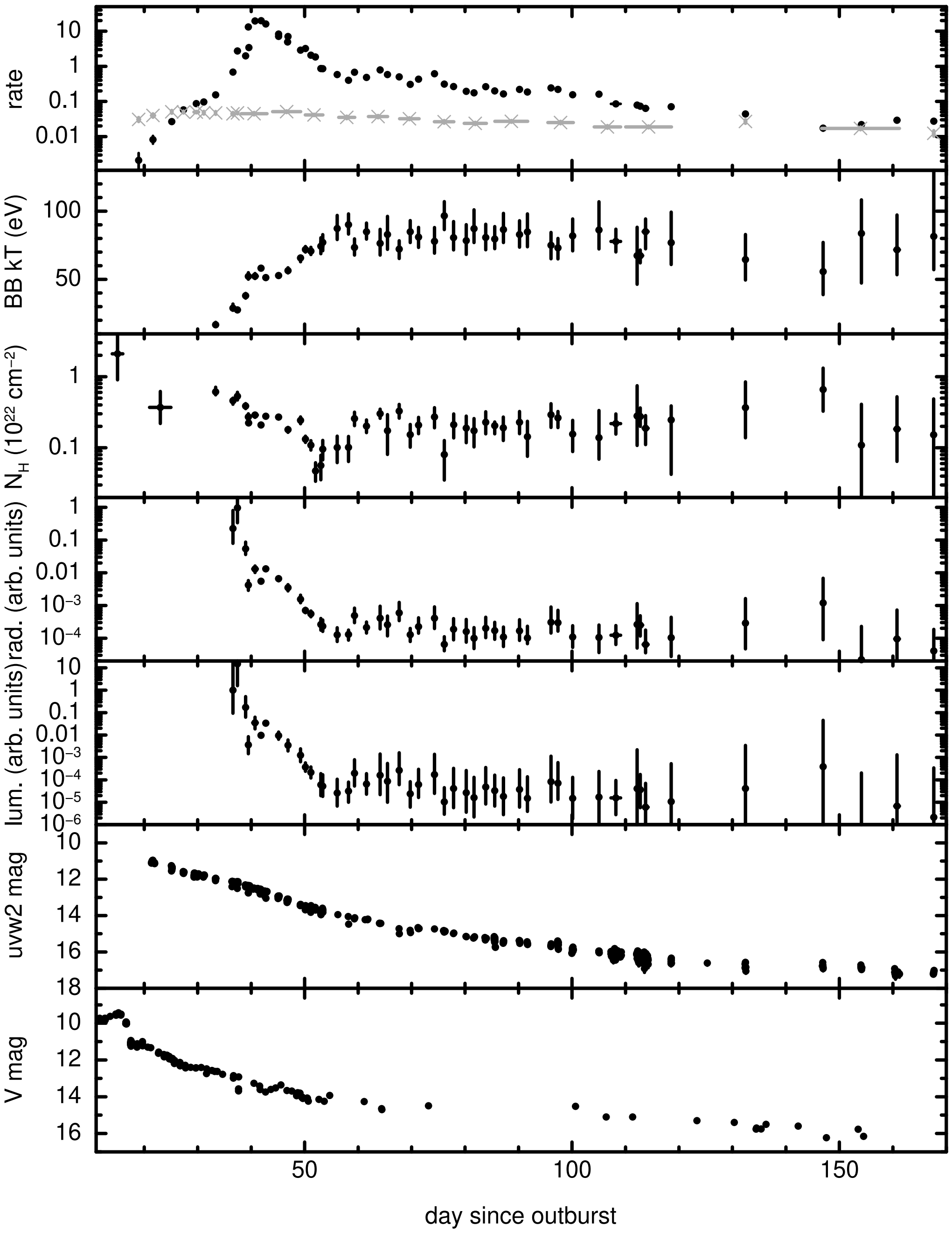

Fig. 4. The top panel shows the soft (0.3–1.5 keV) and hard (1.5–10 keV) light-curves of V2491 Cyg plotted as black circles and grey crosses respectively. The second panel shows the BB temperatures, while the third plots the absorbing column, both derived from fitting the *Swift* X-ray spectra. The radius of the emitting BB and the bolometric luminosity estimate are plotted in the fourth and fifth panels. The bottom two panels show the UVOT uvw2 and AAVSO V magnitudes respectively. The AAVSO data show that the optical source rebrightened just over two weeks after the initial explosion.

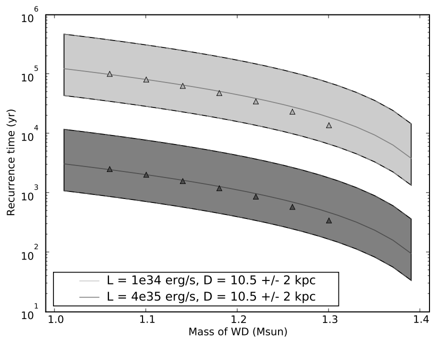

Fig. 5. Nova recurrence times as a function of WD mass. The solid lines represent calculations using the mass-radius relationship from Nauenberg (1972), while the triangles are from the more recent models of Althaus et al. (2005) for massive WDs. The outer, dashed lines, account for the uncertainties in the distance, while the different shades of grey are for the range of inter-outburst luminosities estimated from the pre-nova data by Ibarra et al. (2009).

locities. The faintness of the earliest detections may be (at least partly) due to absorption by the ejected nova shell. As this expands and the ejecta thin, the absorbing column drops and the X-rays brighten. The second stage of the emission occurs when nuclear burning on the surface of the WD becomes visible and we start to see the SSS X-ray emission. In the case of V2491 Cyg, it is interesting to note that there is only a very short interval of close-to-constant X-ray emission, before the count rate rapidly decreases again. This is in contrast to the typical results obtained by *Swift*. Finally, the SSS declines. Since the hard (>1.5 keV) emission fades less rapidly than the soft, it becomes more prominent once again. After ~ day 150, the decrease in X-rays has all but ceased, as the flux returns to the pre-outburst level. Curiously, there are at least two times where there appears to be some form of energy linkage across the X-ray and UV bands. On day 40 we see the X-ray emission peak, with a 'blip' in the otherwise smooth increase in temperature of the SSS emission (Fig. 4). At the same time, the UV decay steepens. Then, on day 57, the rates of decline in the X-ray, UV and optical emission slow, while the apparent X-ray temperature and absorbing column level off. The reasons for these correlated changes are unknown, however.

The high X-ray flux of the pre-nova X-ray source taken together with other characteristics suggest that V2491 Cyg could be another recurrent nova and therefore have a high WD mass.

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