Near Infrared Observations of the novae V2491 Cygni and V597 Puppis

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ABSTRACT
We present results obtained from near-infrared JHK spectroscopic observations of novae V2491 Cyg and V597 Pup in the early declining phases of their 2007 and 2008 outbursts respectively. In both objects, the spectra displayed emission lines of HI, OI, HeI and NI. In V597 Pup, the HeI lines were found to strengthen rapidly with time. Based on the observed spectral characteristics, both objects are classified as He/N novae. We have investigated the possibility of V2491 Cyg being a recurrent nova as has been suggested. By studying the temporal evolution of the line widths in V2491 Cyg it appears unlikely that the binary companion is a giant star with heavy wind as in recurrent novae of the RS Oph type. Significant deviations from that of recombination case B conditions are observed in the strengths of the HI lines. This indicates that the HI lines, in both novae, are optically thick during the span of our observations. The slope of the continuum spectra in both cases was found to have a $\lambda^{-3.5}$ dependence which deviates from a Rayleigh-Jeans spectral distribution. Both novae were detected in the post-outburst super-soft X-ray phase; V2491 Cyg being very bright in X-rays has been the target of several observations. We discuss and correlate our infrared observations with the observed X-ray properties of these novae.

Key words: infrared: stars – novae, cataclysmic variables – stars: individual (V597 Pup, V2491 Cyg)– techniques: spectroscopic

1 INTRODUCTION
We present here near-infrared studies of two classical novae V2491 Cygni and V597 Pup. The observations cover the early declining phase in both these novae. Both objects have been detected in X-rays but V2491 Cyg has specifically been the subject of considerable current interest. It is one of the rare novae to have been detected in X-rays even before its recorded optical outburst (Ibarra & Kuulkers, 2008). Apart from that, it has also shown very prominent and sustained super soft X-ray emission in recent times as described later. Our infrared observations, in conjunction with observations from other wavelength regimes like the X-ray and optical, should give a more comprehensive understanding of these interesting objects.

The characteristics of a nova outburst depend on three principal parameters viz. the white dwarf mass, the core temperature of the white dwarf and the rate of mass accretion from the binary companion. The accreted mass which eventually ignites the explosion is ejected back into space at high velocities of the order of a few hundreds to thousands of kilometers per second. A white dwarf accreting mass below the critical rate undergoes a thermonuclear runaway in the hydrogen burning shell at the bottom of the accreted layer and becomes a classical nova when sufficient amount of mass has been accumulated. The brightness of a classical nova begins to decline once mass ejection subsides after the ejection of most of the envelope. As the remnant of the envelope collapses back onto the white dwarf, residual hydrogen burning occurs in the shell radiating most of the energy in the UV to X-ray band. The photosphere of the white dwarf shrinks which increases the effective temperature and the nova appears as a hot blackbody-like object. The temperature of the blackbody-like object (post nova) is predicted to be about $3 \times 10^5$ K for classical novae for a few years after optical maximum (Prialnik 1986). The post-outburst nova with this high temperature photosphere is a source of super-soft X-rays which lasts for a duration depending on the leftover envelope mass, chemical composition of the envelope, mass of the white dwarf etc. (Kato 1997; Hachisu & Kato 2006). Seven such super-soft Galactic novae appear to have been observed with ROSAT and Swift till 2006 June 30 (Orio...
et al. 2001; Ness et al. 2007). Some of the novae also show hard X-ray emission, the origin of which is different from the emission from the white dwarf photosphere. X-ray emission from the white dwarf is not expected to be observed immediately after the nova outburst. X-ray detections in some of the novae during this phase is understood to originate from some other processes such as shocks within the expanding shell or from a collision of the expanding shell and the atmosphere of the companion as seen in RS Ophiuchi (Bode et al. 2006). Therefore, it is rather interesting to understand and relate the mechanism of classical nova outburst and the ensuing super-soft X-ray emission phase.

V2491 Cyg was discovered on 2008 April 10.728 UT at a visual magnitude of 7.7 (Nakano et al. 2008). Low resolution spectra of the source obtained on April 11.72 UT showed prominent broad Balmer emission lines indicating the object to be a nova in its early phase of outburst (Ayani & Matsumoto 2008). Subsequent infrared observations on April 12.56 UT confirmed the object as a nova with an unusual spectrum with extremely broad lines of complex profiles (Lynch et al. 2008). The presence of the helium line at 1.083 µm and strong emission features of NI and NII in the near-infrared spectrum suggested the object to be a helium-nitrogen (He/N) nova. Balmer lines from Hα to Hδ in emission were seen in the optical spectrum taken on April 11.99 UT and April 13.95 UT (Tomov et al. 2008). The FWHM of the Hα line decreased from ~1800 km s\(^{-1}\) to ~4600 km s\(^{-1}\) within about 2 days. Another near-IR observation on April 17.6 UT (Rudy et al. 2008) found that the brightness of the nova had already declined by a factor of three to photometric magnitudes of J=7.7, H=7.8 and K=7.4; this was accompanied by an increase in the strengths of three to photometric magnitudes of J=7.7, H=7.8 and K=7.4; this was accompanied by an increase in the strengths of three to K-shell N, O, and Ne lines in the spectrum (Osborne et al. 2008). Swift observations on May 16 showed a very strongly increasing count rate which touched ~5 counts s\(^{-1}\) on May 18. XMM-Newton observations of the nova showed the presence of strong low energy emission from K-shell N, O, and Ne lines in the spectrum (Osborne et al. 2008). Swift observations on May 16 showed a very strongly increasing count rate which touched ~5 counts s\(^{-1}\) on May 18. XMM-Newton observations of the nova, on 2008 May 20, detected several O and N absorption lines along with the broad Ne emission lines, suggesting the nova to be an ONe nova (Ness et al. 2008b).

2 OBSERVATIONS AND ANALYSIS

The optical light curves of V2491 Cyg and V597 Pup are shown in Figure 1. While V597 Pup showed a gradually declining light curve, V2491 Cyg showed an unusual second rebrightening with ~2 magnitude amplitude peaking after about 17 days of the main outburst. The nature of this second mini-outburst is rather similar to those observed in V1493 Aql and V2362 Cyg (Venturini et al. 2004; Kimeswenger et al. 2008). From the light curves we estimate \(t_2\) to be 2.5 and 5 days for V597 Pup and V2491 Cyg respectively which indicate they are fast novae. The \(t_2\) values yields distance estimates of 10.3 and 11.4 Kpc, for V597 Pup and V2491 Cyg respectively, from the MMRD relation of della Valle & Livio (1995). The near-infrared observations of the novae with the Mt Abu telescope are shown with arrow marks on the light curves in Figure 1. The log of the observations along with the signal-to-noise ratio (S/N) of the spectra of V597 Pup and V2491 Cyg, is given in Table 1.

Near-Infrared spectroscopic observations of V597 Pup and V2491 Cyg were carried out in JHK bands at the Mt Abu 1.2m telescope in the early declining phases of 2007 November and 2008 April outbursts respectively. The spectra were obtained at a resolution of ~1000 using a Near-Infrared Imager/Spectrometer with a 256\times256 HgCdTe NICMOS3 array. Spectral calibration was done using the OH
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Figure 1. The light curves of V597 Pup (left panel; V band data from AAVSO shown in filled circles while the V band data from AFOEV is shown in open circles) and V2491 Cyg (right panel; using V band data from the AAVSO). The arrow marks in both the panels show the days of our near-infrared observations.

sky lines that register with the stellar spectra. The spectra of the standard stars SAO 198195, SAO 174400 (for V597 Pup) and SAO 67663, SAO 68744, SAO 88071 (for V2491 Cyg) were taken at similar airmass as the corresponding targets to ensure the ratioing process (nova spectrum divided by the standard star spectrum) removes the telluric lines reliably. To eliminate artificially generated emission lines in the ratioed spectrum created due to the H I absorption lines in the spectrum of the standard star, the hydrogen absorption lines in the spectra of the latter were removed by interpolation before ratioing. The ratioed spectra were then multiplied by a blackbody curve corresponding to the standard star’s effective temperature to yield the final spectra.

Photometric observation of V2491 Cyg could only be done on one night viz. 2008 April 22 in photometric sky conditions using the NICMOS3 array in the imaging mode. Several frames in each of the three J, H and K bands were obtained in four dithered positions, offset by typically 30 arcsec from each other. The sky frames were generated by median combining the dithered frames and subtracted from the nova frames - aperture photometry was subsequently done using IRAF. A nearby star in the field, with known 2MASS magnitudes, was used as standard star for photometric calibration.

3 RESULT AND INTERPRETATION

3.1 General characteristics of the JHK spectra of V2491 Cyg and V597 Pup

The JHK band spectra of V597 Pup and V2491 Cyg at different epochs are presented in Figure 2 & 3 respectively. The prominent features detected in the spectra of both the novae are the He I 1.0830 μm, Paγ 1.0938 μm, O I 1.1287 μm, Paβ 1.2818 μm, He I 2.0581 μm and hydrogen Brackett series lines. A few relatively weaker NI lines are seen in the spectra of both objects. In V2491 Cyg, a line-like feature at ~1.36 μm is seen. Though it is susceptible to an error in identification since it is at the edge of the spectral window, we feel reasonably certain that this line is due to NI 1.3602-1.3624 μm. It may also be mentioned that in the JHK bands, there are certain regions with low atmospheric transmission e.g. the spectral region around the O I 1.1287 μm line and also that between 2 to 2.05 μm. In regions of such difficult atmospheric transmission, the process of ratioing the source spectrum with the standard star spectrum can produce some errors or artifacts in the final extracted spectrum. Thus the structures that are seen in the peak of the OI 1.1287 μm line should be treated with some caution. The reliability of these structures may be cross-checked by comparing them with the profiles of other O I line profiles (e.g. the 0.8446 μm line) in case optical spectra of the object are available on similar dates. The details of the line identification are given in Table 2. No significant evolution is seen in the lines in the case of V2491 Cyg during the 9 day span of the observations. However, in the case of V597 Pup, it is found that the He I line at 1.0830 μm strengthens dramatically (by a factor of about 7 within 17 days) by 2007 December 8 (Figure 2). On December 8, the HeI 1.7 μm line is also prominently seen along with weaker lines of HeI 2.1120-2.1132 μm. The rapid strengthening of the HeI lines, also noted by Rudy et al. (2008), indicates a quick evolution to higher excitation conditions in the ejected envelope. In both the novae, no coronal line features were detected till the last day of our campaign. This is consistent with the non-detection of both the novae in super-soft X-ray phases during the entirety of our observations.

Based on several optical and near-IR spectra taken after the outburst, V2491 Cyg has been classified as a He/N nova (Tomov et al. 2008; Lynch et al. 2008; Helton et al. 2008). From our spectra (Fig 3) we would agree with this classification based on the early appearance of prominent HeI lines and also the presence of NI lines. Based on the optical spectrum obtained on November 14.77, Naito and
Figure 2. The $JHK$ spectra of V597 Pup at different epochs are shown in the left, middle and right panels respectively. The $JHK$ spectra have been offset from each other for clarity. The $J$ band spectra have been plotted in different sub-panels to accommodate the strong changes in the HeI 1.0830 $\mu$m line strength between epochs.

Figure 3. The $JHK$ band spectra of V2491 Cyg at different epochs are shown in the left, middle and right panels respectively. The spectra have been offset from each other for clarity.

Tokimasa (2008) suggest V597 Pup to be of the FeII type. However we note that V597 Pup has a very similar near-IR spectrum compared to V2491 Cyg, which indicates it is also a He/N nova. In further support of this He/N classification, we note that neither V597 Pup nor V2491 Cyg show the typical IR spectrum expected of FeII novae (or equivalently CO novae) early after outburst. One of the principal IR signatures of such novae is the presence of prominent CI lines - especially in the J band but also in the K band (these CI lines are not seen here). Typical spectra of CO novae in the near-IR can be seen in the cases of V2274 Cygni &
3.1.1 V2491 Cyg: a possible recurrent nova?

There has been some discussion whether V2491 Cyg could be a recurrent nova (RN) based on the nature of its optical spectrum. Tomov et al. (2008) pointed out the similarities between the 15 April and 17 April 2008 optical spectra of V2491 Cyg with those of recurrent novae V394 CrA and U Sco recorded in earlier outbursts. Attention has also been drawn in VSNET (Japan) alerts to the similarity of the optical spectrum of V2491 Cyg on 20 April 2008 to that of the recurrent nova V394 CrA on 3 August 1987 (about 5 days after the outburst; Sekiguchi et al. 1989). The similarity is indeed striking though there are some differences: e.g., the peak of Hα line is a sharp peak in the case of V2491 Cyg whereas it is flat-topped in the case of V394 CrA. A thorough search in archival patrol plates should be able to give a more definitive answer to whether V2491 Cyg has had earlier outbursts - snapshot images of the object as in Palomar, Supercosmos plates etc. do not show any changes in the brightness of the progenitor. The recurrent nova hypothesis can be tested, to some extent, from the IR data present here. If it is indeed a recurrent nova of the RS Oph type, then considerable decrease in the width of the line profiles is expected with time. In RS Oph type systems the secondary is a high mass losing red giant and the ejected nova material is severely decelerated as it plows through the wind of the companion. This leads to rapid temporal changes in the expansion velocity of the ejecta - an effect that is well documented for the 2006 outburst of RS Oph in Das et al. (2006). In order to quantify the changes in the line profile widths, which effectively measure the expansion velocity, the evolution of the prominent emission lines in V2491 Cyg was investigated. Figure 4 shows the Paβ line profile for all six days of our observations of V2491 Cyg. The Paβ line is chosen because, among the HI lines, it is observed with a high S/N on all 6 days of observation. There appear to be some differences in the structure of the profile which is probably due to the inhomogeneities in the ejected envelope. Visual inspection shows that the overall width of the emission lines (Figure 4) does not change appreciably during the observations. The FWHM of the Paβ line (with one sigma uncertainty) is estimated to be 3950±65, 3975±48, 4085±34, 3971±87, 4053±110, 3920±112 km s⁻¹ on 2008 April 18, 20, 21, 22, 23, and 26 observations of V2491 Cyg respectively. This indicates very marginal change in the line width during the span of our observations. This is unlike the findings in the recurrent nova RS Oph in which the width of the emission lines started decreasing within only a few days of the nova outburst (Das et al. 2006). However, this is not the case in V2491 Cyg. Thus even if V2491 Cyg is a RN, it certainly is not of the RS Oph category and we can rule out the possibility of a red giant nature for the binary companion of V2491 Cyg. Further, the discovery of the variability in V and R spectral band of V2491 Cyg with a period of ~0.1 day (Baklanov et al. 2008) suggested the nova to be a binary system with orbital period of ~0.1 day. This value of binary period is extremely small compared to that of the recurrent novae binaries with giant binary companions.

3.2 The shape and evolution of the Continuum

The shape of the continuum of both novae was also studied for any significant changes with time. The flux calibrated JHK band spectra for V597 Pup and V2491 Cyg are plotted in Figure 5 & 6 respectively. As we did not have any photometric observations of V597 Pup, our spectra for 2007 November 21 & 2007 December 8 were flux calibrated by taking appropriate values of magnitudes from the nova light curve obtained from the KANATA telescope. Though, there is a possibility of some error in estimating the exact values of the continuum flux while using values taken from a

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1. http://ooruri.kusastro.kyoto-u.ac.jp/pipermail/vsnet-newvar/2008-April/000139.html
2. Spectra taken from Bisei Observatory: http://www1.harenet.ne.jp/~aikow/etc/v2491_cyg_20080412.gif
3. http://kanatatmp.blogspot.com

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Table 1. Log of the near-infrared spectroscopic observations of V597 Pup and V2491 Cyg. The date of outbursts have been assumed to be their discovery date viz. 2007 November 14.23 UT and 2008 April 10.728 UT, respectively.

| Date of Obs. | Days since outburst | Sp. band | Int. time (s) | S/N | Standard star |
|--------------|---------------------|---------|--------------|-----|---------------|
| Nov. 21      | 7                   | J       | 180          | 18  | SAO 198195    |
|              |                     | H       | 120          | 41  |               |
|              |                     | K       | 180          | 28  |               |
| Nov. 25      | 11                  | J       | 120          | 17  | SAO 174400    |
|              |                     | H       | 180          | 35  |               |
|              |                     | K       | 180          | 13  |               |
| Dec. 08      | 24                  | J       | 360          | 13  | SAO 174400    |
|              |                     | H       | 360          | 24  |               |
|              |                     | K       | 360          | 10  |               |

2008 April outburst of V2491 Cyg

| Date of Observation | Days since outburst | Sp. band | Int. time (s) | S/N | Standard star |
|---------------------|---------------------|---------|--------------|-----|---------------|
| April 18            | 8                   | J       | 120          | 28  | SAO 67663     |
|                     |                     | H       | 80           | 29  |               |
|                     |                     | K       | 120          | 26  |               |
| April 20            | 10                  | J       | 180          | 26  | SAO 68744     |
|                     |                     | H       | 180          | 42  |               |
|                     |                     | K       | 240          | 16  |               |
| April 21            | 11                  | J       | 180          | 29  | SAO 68744     |
|                     |                     | H       | 180          | 52  |               |
|                     |                     | K       | 240          | 21  |               |
| April 22¹           | 12                  | J       | 150          | 24  | SAO 88071     |
|                     |                     | H       | 80           | 44  |               |
|                     |                     | K       | 120          | 15  |               |
| April 23            | 13                  | J       | 150          | 27  | SAO 88071     |
|                     |                     | H       | 120          | 37  |               |
|                     |                     | K       | 120          | 15  |               |
| April 26            | 16                  | J       | 120          | 19  | SAO 88071     |
|                     |                     | H       | 120          | 31  |               |
|                     |                     | K       | 150          | 15  |               |

¹: Photometric observation of V2491 Cyg was also carried out on 22 April yielding J, H and K magnitudes of 8.22±0.03, 8.32±0.03 and 7.96±0.05 respectively.

V1419 Aql (Rudy et al. 2003) and V1280 Sco (Chesneau et al. 2008, Das et al. 2008).

V597 Pup (2008 April 10.728 UT, respectively).
Table 2. List of observed lines in the JHK spectra

| Wavelength (µm) | Species | Wavelength (µm) | Species |
|-----------------|---------|-----------------|---------|
| 1.0830          | He I*   | 1.0830          | He I*   |
| 1.0938          | Pa γ*   | 1.0938          | Pa γ*   |
| 1.1287          | O I     | 1.1287          | O I     |
| 1.1625, 1.1651  | N I     | 1.1625, 1.1651  | N I     |
| 1.1969          | He I    | 1.2074          | N I     |
| 1.2461, 1.2470  | N I     | 1.2461, 1.2470  | N I     |
| 1.2818          | Pa β    | 1.2818          | Pa β    |
| 1.3164          | O I     | 1.3164          | O I     |
| 1.3602, 1.3624  | N I     | 1.3602, 1.3624  | N I     |
| 1.6109          | Br 13   | 1.6109          | Br 13   |
| 1.6407          | Br 12   | 1.6407          | Br 12   |
| 1.6806          | Br 11   | 1.6806          | Br 11   |
| 1.7002          | He I    | 1.7002          | He I    |
| 1.7362          | Br 10   | 1.7362          | Br 10   |
| 1.9446          | Br 8    | 1.9446          | Br 8    |
| 2.0581          | He I    | 2.0581          | He I    |
| 2.1120, 2.1132  | He I    | 2.1120, 2.1132  | He I    |
| 2.1655          | Br γ    | 2.1655          | Br γ    |

* : He I 1.0830 µm & Pa γ lines are blended.

Figure 4. Evolution of Paβ line throughout the near-infrared observations of V2491 Cyg. There appear to be marginal differences in the line profiles during the observations probably due to the density inhomogeneities in the ejected envelope. The overall width of the line did not change appreciably.

The characteristics and evolution of a nova’s continuum spectrum are not too well understood. At the outburst maximum, during the fireball expansion phase, the pseudophotosphere is well reproduced by a black-body continuum of a A or F spectral type star. Subsequently the continuum deviates from a blackbody and can evolve into a free-free continuum. This is particularly well seen in the case of Nova Cygni 1975 in the 1-20 µm spectral region which showed a spectral change from a Rayleigh-Jeans spectrum to that of thermal bremsstrahlung emission within a short period of 2 to 3 days (Ennis et al. 1977). The near-infrared continua of V597 Pup and V2491 Cyg, however, do not show any significant changes in the shapes of the continua. The slopes of the continuum spectra in these novae were found to be ~ –3.0 and ~ –3.4. Though the deviation is not much from the Rayleigh-Jeans type spectrum with slope ~–4, it might be slowly changing towards the thermal bremsstrahlung emission. This slow change in the slope of the continuum spectrum is also evident in case of other novae e.g. V4643 Sagittarii where it changed from a slope of about –3 to –2 within about three months (Ashok et al. 2006). However in the case of another nova viz. V4633 Sagittarii (Lynch et al. 2001) the change in the slope of the continuum was found to be in the opposite direction i.e. the slope changed from –2 to –2.7 in observations taken 525 and 850 days after outburst. It is, therefore, necessary to follow the nova outburst more regularly to have a better spectral coverage to understand the behavior of the nova continua.

3.3 Recombination Case B Analysis

The presence of HI lines in the near-infrared spectra of V597 Pup and V2491 Cyg permit a recombination analysis to be done. In both the novae, Paγ at 1.0938 µm is strongly blended with the HeI 1.0830 µm line thereby making it difficult to assess the formers strength correctly. Hence in our analysis, among the HI lines, we consider only the intensities of Paβ at 1.2818 µm and the Br series lines. Among the Br series lines we restrict ourselves to Brγ, Br10, Br11, Br12, and Br13 lines. Higher Br series lines like Br14, Br15 etc. although present are too severely blended with each other to allow accurate extraction of their equivalent widths and hence intensities. We have done the recombination analysis for the April 22 and November 25 spectra of V2491 Cyg and V597 Pup respectively. In Figure 6 we have plotted the observed strength of the Brackett series lines along with the predicted values in two recombination case B conditions. The errors in the estimated values of the strength of the lines relative to that of the Br10 line are ~10% for all the lines other than the Br13, where it is about 20%. The errorbars in Figure 7 are smaller than the size of the symbols and hence not clearly visible. The case B line intensities are taken from Storey & Hummer (1995) for a representative temperature.
of $T = 10^4K$ and electron densities of $n_e = 10^{10} cm^{-3}$ and $n_e = 10^{12} cm^{-3}$. High electron densities are considered because the ejecta material is expected to be dense in the early stages after the outburst. Figure 5 shows that the observed line intensities clearly deviate from the optically thin case B values. In particular, Br$\gamma$, which is expected to be significantly stronger than Br10 or Br11, is instead observed to be of similar strength. We have not included Pa$\beta$ in Figure 7 but mention that the observed ratio of Pa$\beta$ to Br$\gamma$ is observed to be 9.4 and 9.2 in V2491 Cyg and V597 Pup respectively. Such observed ratios are again significantly different from the expected values of 5.2 and 6.5 for the above Case B conditions. The above analysis indicates that the ejecta of both the novae appear to be optically thick to the Brackett and Paschen lines during the span of our observations. Such optical depth effects during the early stages after outburst can be expected and have been observed in other novae too e.g. V4643 Sagittarii (Ashok et al. 2006) and V4633 Sagittarii (Lynch et al. 2001).

4 DISCUSSION

While our IR observations do not throw direct light on the interesting X-ray behavior of V2491 Cyg, there are some correlated aspects which could be discussed. But before proceeding to do so, it is appropriate to briefly discuss the super soft X-ray phase in novae.

The discovery of X-ray emission from nova GQ Mus, 463 days after the outburst (Ogelman et al. 1984), indicates that novae in post-outburst should go through an extended phase of residual hydrogen burning and appear as a super-soft X-ray source (SSS). The duration of the post-outburst super-soft X-ray phase depends on the nuclear burning of the residual mass on the surface of the white dwarf and also on the mass of the white dwarf. Massive white dwarfs
show super-soft X-ray phases for short duration. This is because the stronger gravity in massive white dwarfs finishes the hydrogen burning in the residual envelope faster compared to that of less massive white dwarfs. The theoretical estimation of the duration of the residual hydrogen burning (super-soft X-ray phase) ranges from 5.6 years to $2 \times 10^4$ years for white dwarf masses from 1.35 to 0.6 M$_\odot$ (Gehrz et al. 1998). However, observations showed a much shorter duration (a few hundred days) of the post-nova super-soft X-ray phase (Pietsch et al. 2005) implying that either the mass of the white dwarfs is much higher than the commonly assumed mass or the X-ray turn-off depends on some other parameters other than the white dwarf mass. Along with V597 Pup and V2491 Cyg, the super-soft X-ray emission has been detected, so it would appear, in fewer than a dozen novae (Orio et al. 2001; Drake et al. 2003; Ness et al. 2007 and references therein; Ness et al. 2008a, 2008b).

While the SSS phase is believed to arise from the hot photosphere of the white-dwarf, we investigate whether a fraction of the observed X-rays from V2491 Cyg could arise from an alternative mechanism viz. a shock in the ejecta. A plausible reason to expect a shock is the secondary outburst seen in V2491 Cyg. If this mini-outburst is due to a significant second mass-loss phase in which the ejected matter moves at a higher velocity than the primary ejecta, then this matter could catch up to and collide with the earlier expanding envelope leading to the formation of a shock. The hot shocked gas could then contribute to the observed X-rays. Hence it is necessary to check whether there is any significant increase in the velocity profiles during the second rebrightening. However, from Figure 4, we do not see any evidence for any enhancement in velocity for the matter ejected around the peak of the mini-outburst ($\sim$ 26 April). Therefore it is unlikely that a shock could have formed due to the mini-outburst. The optical light curve of V2491 Cyg resembles that of two other novae, V1493 Aql and V2362 Cyg, in terms of the presence of a secondary peak. The secondary peaks in V2491 Cyg and V1493 Aql (Venturini et al. 2004) were observed about 16 and 48 days after the primary outburst respectively, where as in case of V2362 Cyg it was after $\sim$240 days (Kimeswenger et al. 2008). Among these three novae, the SSS phase has been detected in V2491 Cyg (present work) and V2362 Cyg (Hernanz et al. 2007). Because of only three novae showing the secondary peak in the light curve, out of which only two are detected in X-ray, it is premature to say whether the secondary peak is linked to the detected X-ray emission from the novae.

The beginning of the SSS phase (X-ray turn-on) i.e. the residual nuclear burning in various novae is generally detected after more than a hundred days of outburst. Some of the examples are, 250 days after the outburst in V1974 Cyg (Krautter et al. 1996), 200 days in Nova LMC 1995 (Orio et al. 2003), 180 and 222 days in V382 Vel (Orio et al. 2002), about 250 days in V1494 Aql (Drake et al. 2003), about 180 days in V4743 Sgr (Ness et al. 2003) and about 175 days in V574 Pup (Ness et al. 2007). However, in case of V597 Pup and V2491 Cyg, the super-soft X-ray state was detected about 55 and 30 days after outburst respectively, which is rather early compared to the other novae discussed above. As per the model of Hachisu & Kato (2006) the relatively early onset of the SSS phase in these novae suggests the white dwarfs in these systems are very massive and close to the Chandrasekhar limit.

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