Mon. Not. R. Astron. Soc. **368,** 592–598 (2006) doi:10.1111/j.1365-2966.2006.10141.x

Near-infrared and optical studies of the fast nova V4643 Sgr (Nova Sagittarii 2001)

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Accepted 2006 January 30. Received 2006 January 27; in original form 2005 November 17

ABSTRACT

V4643 Sagittarii or Nova Sagittarii 2001 was discovered in outburst at 7.7 mag on 2001 February 24. Here, we present near-infrared results of this fast classical nova obtained in the early decline phase in 2001 March followed by optical observations about one month later. Subsequently, we also present near-infrared spectra taken later in the nova's evolution, about four months after the outburst, when V4643 Sgr had entered the coronal phase. The spectra in the early decline phase are dominated by emission lines of the H I Brackett series and also the Paschen β and γ lines. We study the cause of the excitation of the O I line at 1.128 μm and discuss the variation in its strength with time after outburst. We discuss the role of optical depth effects on the observed strengths of the hydrogen Brackett and Paschen lines and discuss possible reasons for the puzzling behaviour of the Brγ line strength and whether it is correlated with the O I 1.128-μm line behaviour. An optical spectrum is presented which shows that He II lines are the most prominent features – after H I – to be seen in early 2001 April. We present and also discuss spectra taken in 2001 June and August which prominently show coronal lines of [Si VI] and [Si VII] at 1.9641 and 2.4807 μm, respectively.

Key words: line: identification – techniques: spectroscopic – stars: individual: V4643 Sgr – novae, cataclysmic variables – infrared: stars.

1 INTRODUCTION

V4643 Sagittarii or Nova Sagittarii 2001 was discovered in outburst at 7.7 mag by Liller (2001) on 2001 February 24.369 UT. Nothing brighter than a limiting magnitude of 11.1 appeared at the position of the nova on photographs taken by Nakamura (2001) on 2001 February 20.852 UT. This indicates that the nova was detected close to maximum light. Samus (2001) has identified the possible progenitor with a star in the USNO-A2.0 catalogue (identification number 0600-29446361) which lies within 1 arcsec of the nova's position having blue and red magnitudes of 17.4 and 15.8, respectively. Initial optical spectra of the nova by Della Valle et al. (2001) on 2001 February 26.35 UT show it to be dominated by broad emission lines of the hydrogen Balmer series. Other lines due to Na I, He I, N II, He II and O I were also seen in the spectra. Della Valle et al. (2001) point out that the absence of Fe II lines and the large full width at zero intensity (FWZI) of the Hα profile, 10 000 km s^{-1}, imply that V4643 Sgr belongs to the He/N class – also referred to as the ONeMg class – of novae (Williams 1992). The detailed light curve of the object covering the initial 50 d is shown in Bruch (2001). Assuming that V4643 Sgr was detected very close to its outburst maximum, Bruch (2001) has estimated a t_2 and t_3 of 4.8 and 8.6 d, respectively (where t_2 and t_3 are the time taken to fall by 2 and 3 mag from maximum). This shows that V4643 Sgr belongs to the group of fast novae like V1500 Cyg, V838 Her and V2487 Oph.

In this work, we present near-infrared (near-IR) *JHK* spectra of V4643 Sgr at four different epochs. The spectra essentially cover two phases of the nova's evolution viz. (i) spectra obtained shortly after the outburst when it was dominated by hydrogen emission lines (Ashok, Tej & Banerjee 2001a) and (ii) spectra obtained when the nova had entered the coronal phase (Ashok, Banerjee & Varricatt 2001b). In addition, we also present an optical spectrum taken about a month after the outburst. Based on these observations, we discuss the properties and temporal evolution of V4643 Sgr.

2 OBSERVATIONS

Near-IR *JHK* spectra were obtained at the Mt Abu 1.2-m telescope in the early decline phase during 2001 March and later during 2001 June and August from the United Kingdom Infrared Telescope (UKIRT). The log of the observations is given in Table 1.

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Table 1. A log of the spectroscopic observations of V4643 Sgr. The date of outburst has been assumed to be its detection date viz. 2001 February 24.369 UT.

Date 2001 (UT)	Days since outburst	Telescope	Spectral band	Integration time (s)
Near-IR				
March 2.025	5	Mt Abu	J	240
		”	H	120
		”	K	120
March 3.021	6	”	J	240
		”	H	240
		”	K	240
March 14.031	17	Mt Abu	J	120
		”	H	120
		”	K	120
March 15.00	18	”	J	120
		”	H	120
		”	K	120
March 15.979	19	”	J	240
		”	H	240
		”	K	240
June 16.429	112	UKIRT	K	240
June 28.520	124	”	J	240
June 29.456	125	”	H	240
August 12.326	138	”	J	1200
August 12.349	”	”	H	960
August 12.299	”	”	K	960
Optical				
April 1	36	VBT	Visible	600

The Mt Abu spectra were obtained at a resolution of ~1000 using a Near-Infrared Imager/Spectrometer with a 256 × 256 HgCdTe NICMOS3 array. In each of the JHK bands a set of spectra were taken with the nova off-set to two different positions along the slit (slit width 1 arcsec). Spectral calibration was done using the OH sky lines that register with the stellar spectra. The spectra of the comparison star HR 6490 (for 2001 March 2 and 3) and HR 6486 (for 2001 March 14, 15 and 16) were taken at similar airmass as that of V4643 Sgr to ensure that the rationing process (nova spectrum divided by the standard star spectrum) removes the telluric lines reliably. To avoid artificially generated emission lines in the rationed spectrum – due to H I lines in the spectrum of the standard star – the hydrogen absorption lines in the spectra of the standard star were removed by interpolation before rationing. The rationed spectra were then multiplied by a blackbody curve corresponding to the standard star's effective temperature to yield the final spectra. The UKIRT spectra were obtained with the Cooled Grating Spectrograph (CGS4) using the 40 lines mm^{-1} grating with the J-band spectra being taken in the second order and the H-, K-band spectra taken in the first order. The UKIRT spectra were wavelength calibrated using arc spectra.

Photometry in the JHK bands was also done from Mt Abu on 2001 May 11 in photometric sky conditions using the NICMOS3 array in the imaging mode. Several frames, in four dithered positions, offset by 30 arcsec were obtained in all the filters with exposure times for the individual J, H, K frames being 60, 20 and 0.5 s respectively. The sky frames, which are subtracted from the nova frames, were generated by median combining the dithered frames. The standard star HD 161903 was used for photometric calibration on 2001 May 11. We also derived JHK magnitudes from the UKIRT spectroscopic observations of 2001 August 12 – the sky being photometric on this particular night. The results from the photometry are presented in Table 4 and discussed later.

An optical spectrum (4600–8200 Å, 2-pixel resolution of 11 Å) was obtained using an Opto Mechanics Research spectrograph at the Cassegrain focus of the 2.3-m Vainu Bappu Telescope, Kavalur, on 2001 April 1, 36 d after discovery. Feige 34 was used as the standard star. Wavelength calibration was established using FeAr spectrum. The data – both infrared and optical – were reduced and analysed using IRAF and Starlink packages.

3 RESULTS

Before presenting the results proper, we estimate some of the useful parameters of V4643 Sgr.

3.1 Light curve, outburst luminosity, reddening and distance

We present the light curve of the object in Fig. 1 using additional data beyond that presented in the light curve by Bruch (2001). The fast decline of the nova in the early stage may be noted. The absolute magnitude of V4643 Sgr has been estimated by Bruch (2001) using the different MMRD relations (maximum magnitude versus rate of decline) available in the literature. A consistent value of $M_V = -9.04 \pm 0.08$ is found from the different MMRD relations. We derive the reddening from the method of van den Bergh & Younger (1987) who show that at t_2, the $(B - V)$ colours of novae are $(B - V) = -0.02 \pm 0.04$. Taking the discovery epoch 2001 February 24.369 UT as the time of optical maximum and $t_2 = 4.8$ d (Bruch 2001), we have used data from Variable Stars Network (VSNET) to calculate $E(B - V)$ at t_2 (i.e. on 2001 March 1.169). The optical photometry reported in VSNET adjacent to 2001 March 1 is given in Table 2. Interpolating the $(B - V)$ colours given in Table 2, we get $(B - V) = 1.45$ at t_2, resulting in $E(B - V) = 1.47$ and $A_V = 4.56$ for $R = 3.1$. Such a large value for A_V is expected as the nova is located close to the Galactic plane with $b^{\rm II} = -0.34$. The distance to the nova is calculated using the standard relation $m_V - M_V = 5 \log d - 5 + A_V$. For $M_V = -9.04$, $m_V = 8.1$ and $A_V = 4.56$, the distance is estimated to be 3.3 kpc.

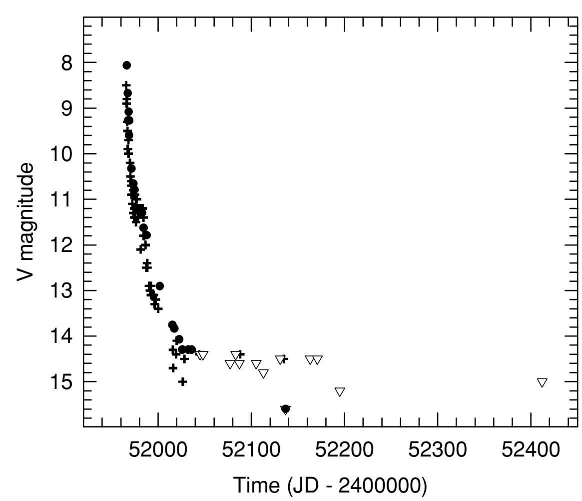

Figure 1. The visual light curve of V4643 Sgr. Crosses and open, inverted triangles are visual estimates from data from AFOEV – the majority of these observations coming from the Variable Star Section of the Royal Astronomical Society of New Zealand. The triangles represent limiting magnitudes. The filled circles are data from the VSNET, Japan.

Table 2. *BV* photometry data from VSNET.

Date 2001 (UT)	*B*	*V*	$(B-V)$
February 26.817	10.87	9.28	1.59
February 27.835	11.08	9.60	1.48
March 2.183	11.75	10.33	1.42

3.2 *JHK* spectroscopy

The *JHK* spectra at different epochs are presented in Figs 2–4. The prominent lines seen in the early decline phase are the hydrogen Brackett and Paschen series lines and the O I 1.128-μm line. Later in the evolution, during the coronal phase, the [Si VI] 1.9641-μm and [Si VII] 2.4807-μm lines are the most prominent emission features in the observed spectra. The details of the line identification are presented in Table 3 – some unidentified lines often seen in novae spectra are marked as u.i. Also given in Table 3 are equivalent widths (*W*) on selected days viz. 2005 March 2 & 14 and June 12. The *W* values on the first two of these days are representative for subsequent discussions in Sections 3.3 and 3.4 regarding the strength of the H I lines relative to themselves or to the O I lines. The *W* values of June 12 are specially relevant in context of the the Si coronal lines, seen most prominently at this epoch, and whose relative strengths are used subsequently in Section 3.7 to derive the coronal temperature. We discuss the spectral lines and their evolution in greater details in the coming subsections.

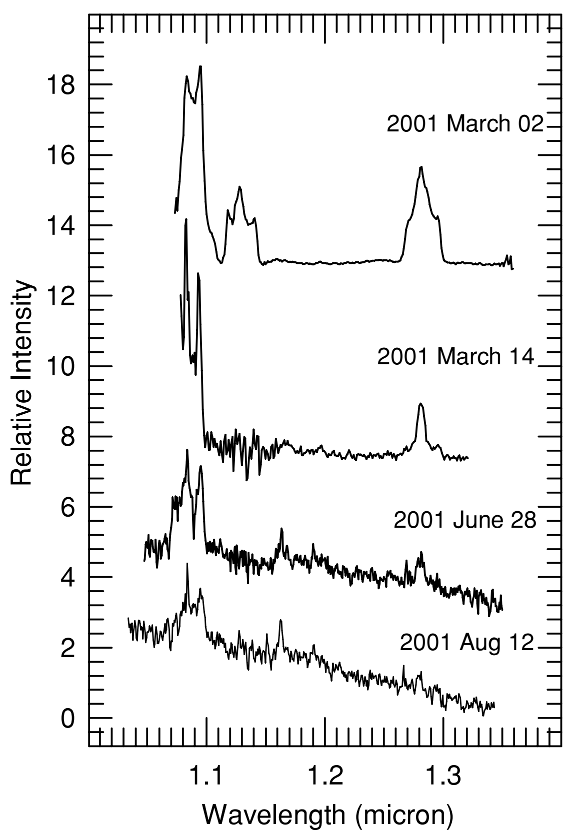

Figure 2. The *J*-band spectra of V4643 Sgr are shown at different epochs. The spectra have been offset from each other for clarity.

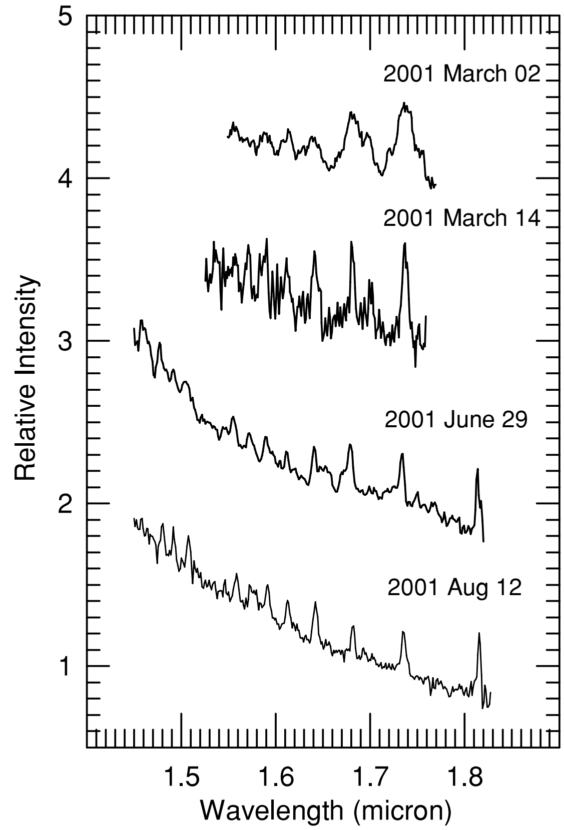

Figure 3. The *H*-band spectra of V4643 Sgr are shown at different epochs. The spectra have been offset from each other for clarity.

3.3 The behaviour of the O I 1.128-μm line

The O I 1.128-μm line is very prominently seen in the *J*-band spectra of 2001 March 2 whereas the O I 1.316-μm line is absent. This implies that continuum fluorescence cannot be the source of excitation of these O I lines because the predicted strength of the lines is $W(1.3164)/W(1.1287) \geqslant 1$ if continuum fluorescence is the significant excitation mechanism (Strittmatter et al. 1977 and references therein; Grandi 1980). The large strength of the O I 1.128-μm line indicates that Lyman (Ly) β fluorescence is the pumping mechanism. As is known, due to the close matching of energy levels, Lyβ photons can pump the O I ground state resonance line at 1025.77 Å. The generally accepted mechanism for Lyβ fluorescence to operate has been explained by Grandi (1980). This mechanism, used to explain the O I emission in Seyfert galaxies, is also applicable to nova shells (e.g. Strittmatter et al. 1977). In this scenario it is necessary to have a large population of neutral O I, a source of Lyβ photons and a large optical depth in Hα. Ionizing photons beyond the Ly continuum will not be able to penetrate into the deep, interior regions of the nova shell. At such sites hydrogen and oxygen can remain neutral as both species have similar ionization potentials of 13.6 and 13.62 eV, respectively. However, Lyα photons, formed at the ionized outer regions of the shell can migrate to the inner regions of the shell and get trapped. These Lyα photons can subsequently excite the neutral hydrogen to the $n = 2$ level, thereby creating the requirement of a large optical depth in Hα. Although, matter deep within the nova shell is shielded from Ly continuum photons from the central photoionizing source, Balmer continuum photons can penetrate to such sites and ionize the considerable population of hydrogen atoms in

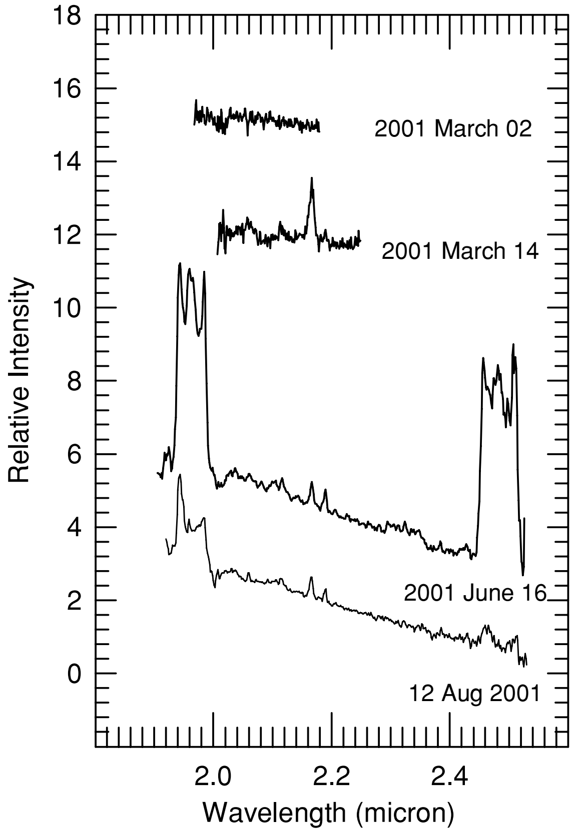

Figure 4. The K-band spectra of V4643 Sgr are shown at different epochs. The spectra have been offset from each other for clarity.

Table 3. List of observed lines in the *JHK* spectra.

Wavelength (μm)	Species	Eq. width (Å) March 2	Eq. width (Å) March 14	Eq. width (Å) June 16
1.0830	He I	He I 1.08		
1.0938	Pa γ	& Pa γ are blended		
1.1287	O I	435	Absent	
1.1626	He II			
1.1900	u.i			
1.2818	Pa β	568	72	
1.3164	O I			
1.4760	He II			
1.4882	He I			
1.5439	Br 17			
1.5557	Br 16	5	5.4	
1.5701	Br 15		12	
1.5881	Br 14	14	29	
1.6109	Br 13	16	12	
1.6407	Br 12	22	31	
1.6806	Br 11	94	17	
1.7002	He I			
1.7362	Br 10	128	43	
1.8174	Br 9			
1.9641	[Si VI]			426
2.100	u.i			
2.1120	He I			
2.1132	He I			
2.1655	Br γ	Absent	75.4	
2.1882	He II			
2.3205	[Ca VIII]			43
2.4807	[Si VII]			896

the $n = 2$ levels. Recombinations from such photoionizations, followed by downward cascading, can then produce the Lyβ photons needed to excite the O I line.

In the case of V4643 Sgr, it is necessary to see whether there is evidence for a large optical depth in Hα. We follow the analysis, done by Strittmatter et al. (1977) for Nova Cyg 1975 (V1500 Cygni), in predicting the relative strengths of the O I and Hα lines. They show that, if Lyβ fluorescence is the pumping mechanism, then the ratio $I(\mathrm{H}\alpha)/I(\mathrm{O\,I}\ 8446)$ should be very large ($\sim$7500), where $I(\mathrm{H}\alpha)$ and $I(\mathrm{O\,I}\ 8446)$ are the intensities of the Hα and the O I 8446 line. This assumes a normal abundance for oxygen, but as is known, the oxygen mass fraction in the ejecta of ONeMg novae like V4643 Sgr can be enhanced by a factor of 6–7 (e.g. Starrfield, Gehrz & Truran 1997). But even after taking this into account, a large value of the $I(\mathrm{H}\alpha)/I(\mathrm{O\,I}\ 8446)$ ratio is expected. It may be noted that other processes like recombination can add to the strength of the Hα line thereby increasing this ratio. On the other hand, the O I 8446 line, as can be seen from the energy level diagram for O I (e.g. fig. 3 in Grandi 1980), is fed only by the O I 1.128-μm line in the case of pure Lyβ fluorescence. Hence the number of photons in the 8446 Å and 1.128-μm lines are expected to be the same (Venturini et al. 2002). Thus the ratio of $I(\mathrm{H}\alpha)/I(\mathrm{O\,I}\ 1.128)$ is also predicted to be very large. The observed equivalent widths, that are available for the Hα line, are 450 Å on 2001 February 25.88 UT (Ayani & Kawabata 2001), 21.9 and 6.8 Å on 2001 March 16 and 2001 May 4, respectively (Bruch 2001). The first of these values can be compared with the equivalent width of the O I 1.128-μm line on March 2 (equivalent width = 435 Å), the observation epochs being quite close. As can be seen, the ratio of the equivalent widths is closer to 1 and departs radically from the predicted value of $I(\mathrm{H}\alpha)/I(\mathrm{O\,I}\ 1.128)$ thereby indicating a high optical depth in the Hα line. Thus the requirement of a large optical depth in Hα for effective Lyβ pumping of the O I line is satisfied. In fact, as discussed in the next subsection, there seems to be large optical depth effects not only in the Hα line but also in the hydrogen lines of the Paschen and Brackett series.

3.4 The near-infrared hydrogen lines

Only two of the Paschen series lines are covered in the spectra presented here viz. Paβ at 1.2818 μm and Paγ at 1.0938 μm. Both these Paschen lines are seen prominently soon after the outburst and then decline in intensity with time. Since Paγ is strongly blended with the He I at 1.0830 μm, it is difficult to estimate its equivalent width and compare its strength with Paβ. However, even a visual inspection suggests Paγ to be stronger than (or comparable to) Paβ at all epochs of our observations. This indicates that the Paschen series lines are optically thick since the expected ratio in recombination case B conditions is $I(\mathrm{Pa}\beta)/I(\mathrm{Pa}\gamma) \sim 1.6$ (for $T = 1 \times 10^4$ K, $n_e = 6 \times 10^{10}$ cm^{-3}). It is also pertinent to note that Paβ, Paγ and the O I 1.128-μm lines have broad wings with a relatively narrow peak at the centre – a profile similar to that seen in V2487 Oph (Nova Oph 1998; Lynch et al. 2000).

Optical depth effects are more clearly seen in the Brackett series lines in the H band. In the 2001 March spectra, while the higher Br series lines are clearly seen in the H band, Brγ which is expected to be much stronger in comparison is completely absent (Fig. 4). This is a puzzling result. By March 14, the Brγ line has begun to

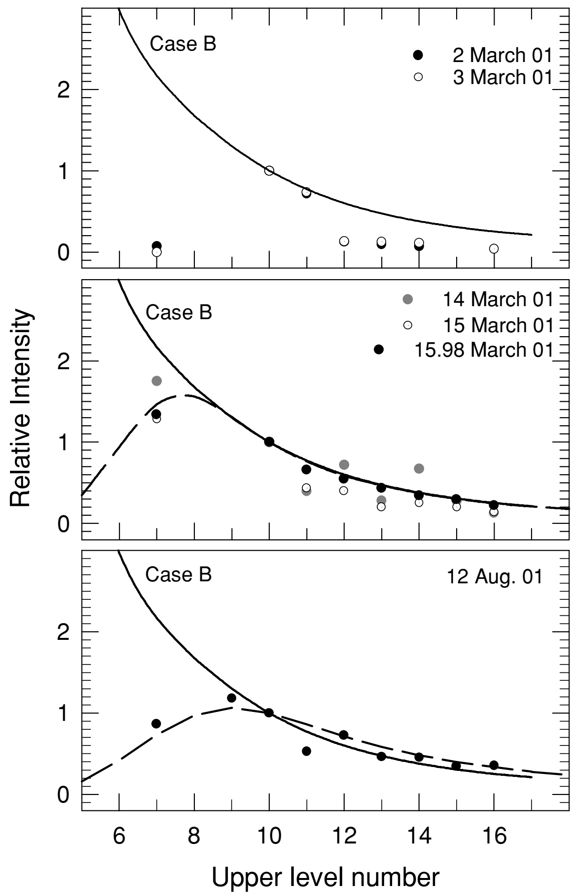

Figure 5. Optical depth effects seen in the hydrogen Brackett lines in V4643 Sgr. The abscissa gives the upper level number of the Brackett line transition. In all three panels, the Case B line strengths are shown by the continuous line and observed line strengths on different days are marked with black, grey or empty circles. The strength of Br10 line has been normalized to unity. Model fits to observed values, based on data from Lynch et al. 2001, are shown by the broken lines. The Brackett γ line is generally found to be weaker than expected (*vis-à-vis* the Case B predictions) than the higher lines in the series indicating that the H I lines are optically thick.

appear in the K-band spectra and strangely this coincides with the disappearance of the O I 1.128-μm line. We discuss the possible significance of this coincidence shortly. In Fig. 5, we present plots of the observed strength of the Brackett lines versus their predicted intensities in a recombination case B condition. The case B line intensities are from Storey & Hummer (1995) and assume a temperature $T = 1 \times 10^{4}$ K and electron density $n_{\rm e} = 6 \times 10^{10}\,{\rm cm}^{-3}$. For the data of 2001 March 2 and 3, since Brγ was not detected at all, we have assumed its equivalent width to be zero. At most it can be less than (or equal to) that associated with modulations in the continuum due to noise. We have also deblended the Br11 line at 1.6807 μm from the nearby He I line at 1.7002 μm in estimating the former's equivalent width. As can be seen from all three panels of Fig. 5, the observed line intensities deviate significantly from the optically thin case B values. This indicates that Brackett lines are optically thick both during the early decline phase and also at later stages.

Similar optical depth effects, in the near-IR hydrogen lines, were observed by Lynch et al. (2000) in the fast Nova Oph 1998 (V2487 Oph). These authors have developed a model to explain the observed line strengths and have shown that the relatively larger intensities of the higher members of the Paschen and Brackett series arise because of emission from high-density or optically thick emission-line gas. Increased strength in the higher lines occurs when the level populations become thermalized at high densities ($n_{\rm e} \geqslant 10 \times 10^{10}\,{\rm cm}^{-3}$) or at large optical depths. In such cases radiative decays become less important relative to electron collisions in determining level populations. We show a sample model fit to the data of 2001 August 12 (bottom panel, Fig. 5), using the tabulated results given in Lynch et al. (2000). The model values are the expected line strengths for a gas having $n_{\rm e} = 6 \times 10^{11}\,{\rm cm}^{-3}$, $T = 1.0 \times 10^{4}$ K and an optical depth $\tau = 100$ (τ has been given at the Paα line centre). We tried model fits for other combinations of the parameters $n_{\rm e}, T$ and τ since Lynch et al. (2000) give expected line strength data for combinations of $n_{\rm e} = 6 \times 10^{10}$ and $6 \times 10^{11}\,{\rm cm}^{-3}$; $T = 5 \times 10^{3}$, 1.0×10^{4}, 1.5×10^{4} K; and $\tau = 10$, 100 and 1000. However, we find that the excessive strength of the higher lines *vis-à-vis* the lower lines like Brγ (just the opposite of Case B predictions) can only be explained by invoking large optical depth values for the parameter τ. It may be pointed out that the data for 2001 March 14–16 (middle panel, Fig. 5) are also reasonably well fitted by Lynch et al. (2000) model fits (with $n_{\rm e} = 6 \times 10^{11}\,{\rm cm}^{-3}, T = 5 \times 10^{3}$ K, $\tau = 100$) but not the 2001 March 2 data where the optical depth in the Brγ line is most pronounced – in fact the line is absent. This could possibly be accounted for by extending the model calculations for even larger optical depths than listed in their work.

The lack of spectral data between 2001 March 2–13 does not permit us to conclude when exactly the O I 1.128-μm line disappeared and the Brγ line appeared. But the quasi-simultaneity of both phenomena indicate that they may be correlated and its implications therefore warrant at least a qualitative explanation. If it is accepted that O I is caused by Lyβ fluorescence then its fading would imply a lack of Lyβ photons for excitation. If this mechanism – described in detail earlier – is reviewed, such a possibility is unlikely. In this scenario the absence of Lyβ photons should also lead to the absence of Paschen and Brackett series photons, since all these quanta are produced by recombination and downward cascading. Since this is not what is observed, we conjecture that the disappearance of O I is due to its destruction by photoionization by a small fraction of Ly continuum photons from the central star. Such photons, which earlier could not penetrate into the core of the nova shell, due to large optical depth in the Ly continuum, are more likely to do so after the rapid expansion of the nova. We note that the absence of the O I 1.128-μm line in V4633 Sgr 525 d after the outburst was similarly interpreted by Lynch et al. (2001) to infer a considerable optical thinning of the ejecta. In the absence of frequent near-IR spectroscopic monitoring of novae in the early decline phase it is difficult to determine when the O I 1.128-μm line disappears but the present observations suggest that in a fast nova this could occur within a rather short period of ∼10 d. A general detailed study on the variation of the O I line strength with time, based on all novae spectra in which the line has been detected, is intended to be pursued as a part of a separate work.

3.5 The evolution of the infrared continuum

We used our photometric data, though not extensive, to study the shape of near-IR continuum. The JHK magnitudes of Table 4 were corrected for interstellar extinction using Koornneef's (1983) relations viz. $A_V = 3.1\,E(B-V)$, $A_J = 0.265\,A_V$, $A_H = 0.155\,A_V$ and $A_K = 0.090\,A_V$ and flux calibrated by using zero magnitude fluxes from Koornneef (1983). We have adopted a value of $A_V = 4.56$ (as discussed in Section 3.1) in our calculations. After plotting the

Table 4. *JHK* photometry of V4643 Sagittarii.

Obs. date (UT)	*J*	*H*	*K*
2001 May 11	11.3 ± 0.1	10.86 ± 0.1	10.80 ± 0.15
2001 Aug 12	13.57 ± 0.1	12.75 ± 0.1	12.40 ± 0.1

Table 5. Line identification in the optical spectrum and observed fluxes relative to Hβ.

λ	Identification	$F_{\lambda}/F_{\mathrm{H}\beta}$
4640	N III	0.65
4686	He II	0.97
5292	O VI	0.19
5412	He II	0.38
5805	C IV	0.51
6680	He I	0.12
7727	u.i	0.43

Note: $F_{\mathrm{H}\beta} = 1.07 \times 10^{-13}\,\mathrm{erg\,cm^{-2}\,s^{-1}}$.

spectral energy distribution using the *JHK* data, we do not see any evidence for IR excess indicating the absence of dust formation in this nova at these epochs. Among the fast novae, only V838 Her formed optically thin dust soon after its outburst (Chandrasekhar, Ashok & Ragland 1992). The typical time-scales for dust formation in novae, where it has been observed to form, are 50–70 d after outburst (Gehrz 1988). We also find from the data of Table 4 that the shape of the near-IR continuum (F_{λ} versus λ) shows a trend of becoming less steep with time. On 2001 May 11, the continuum shows a λ^{-3} dependence while on 2001 August 12 it is closer to λ^{-2}. In general, the evolution of the continuum of novae is not too clearly understood and shows considerable diversity in different novae (e.g. Ennis et al. 1977; Lynch et al. 2000, 2001).

3.6 Optical observations

We could obtain only one optical spectrum of the nova on 2001 April 1 which is shown in Fig. 6. The line identifications are presented in Table 5. The spectrum is typical of a He/N nova. The detailed Hα line profile, shown in Fig. 7, consists of a narrow component surrounded by broad shoulders. Some structures are seen in the broad component, particularly on the red side. The narrow component has a width of $\sim$3200 km s^{-1} (-2200 to $+1000$ km s^{-1}) and the broad component has an extent of $\sim$9000 km s^{-1} (-5000 to $+4000$ km s^{-1}). The Hβ profile is somewhat similar, but the broad components are not so pronounced. None of the other lines show a similar structure. He I is represented by the 6678-Å line; the 7065-Å line is weak and the 5876-Å line is absent. He II lines at 4686 and 5412 Å are strong though we note that the exact strength of the He II 4686-Å line is slightly difficult to ascertain as it blended with the N III 4640-Å line. The other prominent lines are O VI 5292 Å, C IV 5805 Å and the N III complex at 4640 Å, as just mentioned. In addition, a prominent line is seen at 7727 Å (denoted with a question mark in Fig. 6), which we are unable to identify with known lines from spectra of other novae. The interstellar Na D lines have a combined equivalent width of 2.13 Å, which translates to a distance of 3.55 kpc according to the empirical formula of Hobbs (1974). This distance estimate matches well the earlier estimate of 3.3 kpc derived in Section 3.1. Since the He II 4686-Å line is the strongest non-Balmer line in the spectrum, the nova was in the $\mathrm{P_{he^+}}$ phase according to the Tololo classification (Williams et al. 1991; Williams, Phillips & Hamuy 1994) during this time. Subsequent to this permitted line phase in early 2001 April, lack of data does not permit us to infer whether V4643 Sgr progressed through the auroral and nebular stages. But by 2001 mid-June the nova had progressed to a coronal phase as discussed in the next section.

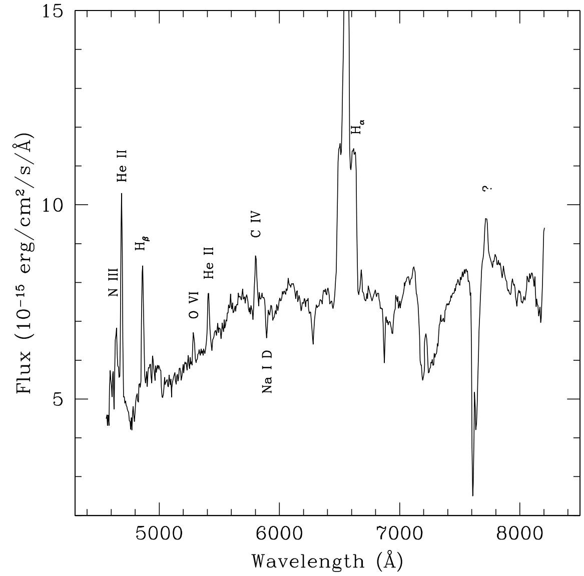

Figure 6. The optical spectrum of V4643 Sgr obtained on 2001 April 1 (36 d after outburst) from Vainu Bappu Observatory, India.

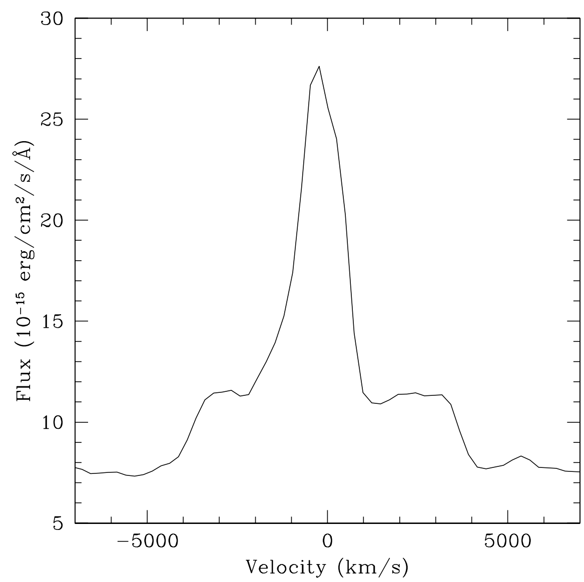

Figure 7. Hα emission profile of V4643 Sgr on a velocity scale showing the broad emission flanking the narrow component.

3.7 Coronal emission lines

Fig. 4 shows the UKIRT spectra taken on 2001 June 16 in the *K* band, 112 d after the discovery. The presence of strong [Si VI] 1.9641-μm and [Si VII] 2.4807-μm lines shows that the nova had entered the coronal phase by then. Though earlier observations of novae show that the coronal phase is observed only after a few hundreds of days, the appearance of strong [Si VI] and [Si VII] lines 112 d after discovery is not unexpected considering that V4643 Sgr is a very fast nova with $t_3 = 8.6$ d. Previous instances of fast novae exhibiting early occurrence of the coronal phase are V838 Her after 17 d and V1500 Cyg after 60 d. The t_3 values for these two fast novae are 5 and 3.6 d, respectively. Both the Si lines are broad – with FWZI of 11 700 and 9850 km s^{-1} for the [Si VI] and [Si VII] lines, respectively – and show considerable structure. Apart from the strong Si lines, we additionally detect weaker lines viz. [Ca VIII] at 2.3205 μm; a broad structure between 2.03 and 2.15 μm which we attribute to be a blend between He I 2.0581, 2.1120, 2.1132-μm lines; the 2.100-μm line which is common in novae but is unidentified (Lynch et al. 2001); and also the He II line at 2.1882 μm. These weak lines are more clearly seen on enlarging the 2001 June 16 spectrum of Fig. 4 but we do not present such a magnified figure here. The [Ca VIII] line is also broad like the Si lines and has a similar FWZI of 10 040 km s^{-1}. The *K*-band spectrum taken on 2001 August 12, 138 d since discovery, shows considerable weakening of the [Si VII] line *vis-à-vis* that seen in 2001 June. The [Si VI] line is still seen clearly but again with reduced strength *vis-à-vis* the June spectrum (the equivalent widths for the 1.96 and 2.48-μm Si lines are 122 and 70.5 Å, respectively on 2001 August 12). It is not firmly established, whether the 'coronal' lines in novae arise as a consequence of collisional ionization or alternatively from photoionization by radiation from the hot central remnant. Based on the compilation by Benjamin & Dinerstein (1990) of the observed time after outburst when novae have been detected in the coronal phase, Evans et al. (2003) show that it is likely that novae enter the coronal phase by a time $t_{\rm cor} \sim (3.34 \pm 1.50)\, t_3$. For a value of $t_3 = 8.6$ d for V4643 Sgr (Bruch 2001), $t_{\rm cor}$ is estimated to be ∼28.7 d. This would suggest that at 112 d after outburst i.e. at the time of our first detection of the Si coronal lines in V4643 Sgr, the nova was well into the coronal phase. An estimate for the temperature of the hot stellar remnant at such an epoch can be obtained from the relation $T_*(t) = T_0 \exp[0.921(t/t_3)]$, where $T_0 = 15\,280$ K (Bath & Harkness 1989; Evans et al. 2003). The use of this relation suggests that T_* was high enough at 112 d to generate the $\geqslant$100 eV photons that typically characterize the coronal phase (Greenhouse et al. 1990; Evans et al. 2003). Thus we are led to believe, while allowing for uncertainty in the calculations arising from the above approach, that the coronal lines in V4643 Sgr are due to photoionization. We however note that there are other novae where collisional ionization could play a significant role (Greenhouse et al. 1990; Evans et al. 2003).

To summarize, we have presented here spectroscopic and photometric observations of the fast nova V4643 Sgr which was discovered in outburst in late 2001 February. Our observations, spanning the period between early 2001 March and August, cover the nova's evolution from the early decline stage to the coronal phase. We discuss the behaviour and evolution of the prominent emission lines seen in the spectra during this time.

ACKNOWLEDGMENTS

The research work at Physical Research Laboratory is funded by the Department of Space, Government of India. We thank the UKIRT service programme for observation time in the service mode. UKIRT is operated by the Joint Astronomy Centre, Hawaii, on behalf of the UK Particle Physics and Astronomy Research Council. We express our thanks to A. Tej for helping with some of the observations and to the VSNET, Japan, and AFOEV, France, for the use of optical photometric data from their data bases. We thank the referee, Richard Rudy, for his valuable comments which helped to improve the manuscript.

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