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Nova V4444 Sagittarii 1999 in the early decline and quiescent phases

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Abstract. We present near-infrared and optical spectra of the fast nova V4444 Sagittarii at two single epochs in the early decline phase and unfiltered images obtained in quiescence. Based on this and other available data, we discuss about the nature of this nova, including the possibility of it being a recurrent nova.

Keywords : Stars: novae, cataclysmic variables – stars: individual: V4444 Sgr

1. Introduction

Nova V4444 Sagittarii 1999 was discovered by Minoru Yamamoto (Kushida & Kushida 1999) at a magnitude of 8.6 on 1999 April 25.731 UT. Optical spectra obtained in the next couple of days confirmed that the outbursting object was a nova at or near maximum light (Liller 1999; Garnavich 1999). The nova lightcurve showed a rapid, smooth decline. Visual observations by members of VSNET show that the nova took respectively ~ 3 and 10 days to decline by 2 and 3 magnitudes (Kiyota, Kato & Yamaoka 2004). Using visual observations by members of AAVSO, Venturini et al. (2002) have estimated t_3, the time for a 3 magnitude decline, as 23 days. The difference in estimated t_3 values could be the result of variations in the response of the human eye to strong emission lines in the nova. Since the maximum brightness reported for this nova is $V \sim 7.18$ (CCD V)[1] on 1999 April 27.364, we adopt this date as t = 0. Optical spectropolarimetry obtained during the first ten days after outburst showed that there existed an intrinsically

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[1]obtained by R. Zissel, communicated by E. O. Waagen of AAVSO in IAUC 7154

polarised component which could be explained by pre-existing dust cloud composed of small grains (Kawabata et al. 2000). A near-infrared spectrum obtained by Venturini et al. (2002) 125 days after outburst showed numerous emission lines and exhibited a large spread of excitation. A significantly rising continuum longward of 1.5 μm indicative of thermal emission from dust was also seen. However, the light curve showed no sudden dips in brightness as would be caused by an optically thick dust condensation episode. This suggested a relatively unobscured line of sight or that some or all of the circumstellar dust was pre-existing. The possibility of pre-existing circumstellar dust prompted them to indicate that V4444 Sgr could be a possible recurrent nova. Kato et al. (2004) explored this issue further using available outburst observations from the OGLE-II database and do not entirely rule out the recurrent nature.

In this paper, we present observations of V4444 Sgr in early decline and quiescent phases. Optical and near-infrared (JH band) spectra of V4444 Sgr obtained, respectively, three and fourteen days after maximum light. Unfiltered images of the nova field were taken 8 years after outburst with the aim of identifying the quiescent counterpart.

2. Observations and reduction

The optical spectrum of V4444 Sgr (two-pixel resolution 5.4 Å) was obtained on 1999 April 30 using the OMR spectrograph at the cassegrain focus of the 2.3m Vainu Bappu Telescope. An FeAr lamp spectrum was used for wavelength calibration. Kopff27 was used as the standard star for flux calibration. Integration times for the nova and standard star were 600s each. Standard procedures for bias-subtraction, flat-fielding and instrumental response correction were followed. All reductions were done using various tasks available within IRAF.

The near-infrared spectra were obtained on 11 May 1999 with PRLNIC, an imager-spectrometer based on a 256 $\times$ 256 HgCdTe NICMOS3 array detector, at the cassegrain focus of the 1.2m telescope of Mt. Abu Infrared Observatory. Spatially offset spectra were obtained by nodding the star along the slit, and at least two spectra were obtained in each spatial position. Subtracting spectra obtained at different spatial positions removes the dark current and sky emission lines. HR 6581 (o Ser) was used as the standard star and observed in the same manner as the nova. Individual integration times were 60s for the nova and 10s for the standard star. Wavelength calibration was done using the OH airglow lines registered along with the spectra. The nova spectrum was divided by the standard star spectrum. Known stellar absorption lines were removed from the HR 6581 spectrum before the division. The result was multiplied by a blackbody of temperature 8810 K, commensurate with the known spectral type (A2 V) of the star. This procedure removes the instrument response and the effects of atmospheric absorption. The mean airmass for the nova was 1.7105 and for HR 6581 it was 1.5241.

Ten unfiltered images, each of 10s integration time, of a $2' \times 2'$ region centered

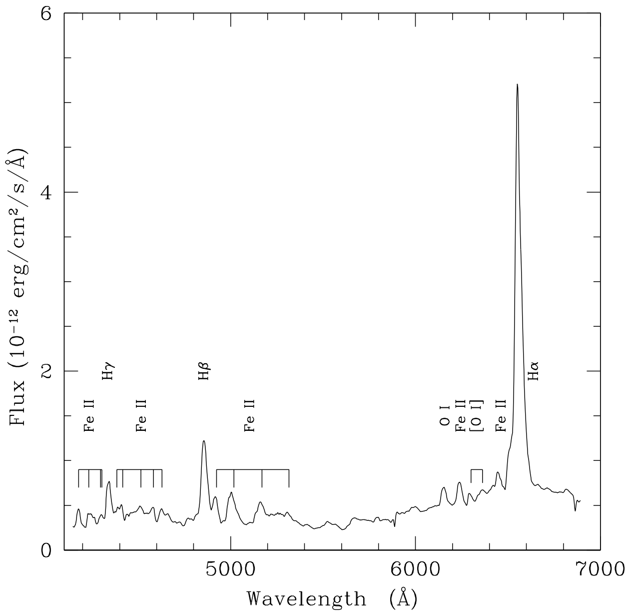

Figure 1. Optical spectrum of V4444 Sgr.

on V4444 Sgr were obtained with the HFOSC optical imager-spectrograph on the 2m Himalayan Chandra Telescope (HCT) on 21 May 2007. These were individually bias-subtracted, aligned and combined.

3. Results

The optical spectrum (Fig. 1) shows emission lines of the Hydrogen Balmer series, O I and [O I] and numerous emission lines of Fe II, typical of an "Fe II" nova. The emission lines show no evidence of P-Cygni profiles such as those seen in earlier spectra obtained by Howell & Soderberg (Garnavich 1999), indicating that the nova has evolved from the fireball phase to the permitted line phase. Since permitted lines of iron are the strongest non-Balmer lines seen in the spectrum, the nova is in the P_{fe} phase according to the Tololo Classification system (Williams et al. 1991 ; Williams et al. 1994). Observed fluxes of prominent lines are listed in Table 1.

The near-infrared spectra are shown in Figs 2 and 3. Brackett lines are prominently seen in the *H* band spectrum. The *J* band shows several lines arising from C I, N I and O I apart from the Hydrogen lines. The strong O I line at 1.128 μm shows that Lyman

Table 1. Optical line identification and observed fluxes relative to Hβ.

λ (Å)	ID	$F_\lambda/F_{H\beta}$
4173	Fe II	0.17
4340	Hγ	0.37
4861	Hβ	1.00
4924	Fe II	0.25
5018	Fe II	0.69
5169	Fe II	0.45
6157	O I	0.23
6243	Fe II	0.29
6300	[O I]	0.10
6363	[O I]	0.17
6456	Fe II	0.16
6563	Hα	6.27

$F_{H\beta} = 2.98 \times 10^{-11}$ erg/cm^2/s.

Table 2. *J* band line identification and observed fluxes relative to Paβ.

λ (μm)	ID	$F_\lambda/F_{Pa\beta}$
1.083	He I	2.8
1.093	Paγ	6.9
1.128	O I	0.56
1.165	C I	0.15
1.175	C I	0.37
1.188	C I	0.13
1.2471	N I	0.14
1.2583	He I	0.16
1.2823	Paβ	1.0
1.3168	O I	0.09

beta fluorescence is very strong. Helium lines have made their appearance at this stage. Line identifications and relative fluxes are listed in Tables 2 and 3.

The FWHMs of the optical and near-infrared lines lie in the range 1700–2000 km s^{-1}.

The unfiltered image of the nova field, showing possible quiescent counterparts is shown in Fig. 5.

Table 3. *H* band line identification and observed fluxes relative to Br 15.

λ (μm)	ID	F_{Br15}
1.5699	Br 15	1.0
1.5888	Br 14	1.03
1.6010	C I	0.39
1.6109	Br 13	1.00
1.6413	Br 12	1.31
1.6856	Br 11	3.53
1.7035	He I	0.3
1.7108	Mg I	0.16
1.7356	Br 10	3.75

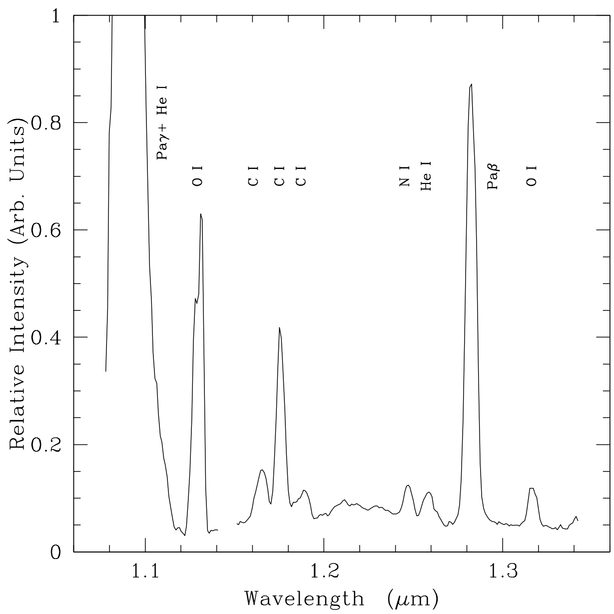

Figure 2. Near-Infrared *J* band spectrum of V4444 Sgr.

4. Discussion

4.1 Light curve, reddening and distance

As mentioned in section 1, the light curve of the nova shows a rapid, smooth decline. This is consistent with the appearance of near-infrared helium seen in our spectrum of day 14.

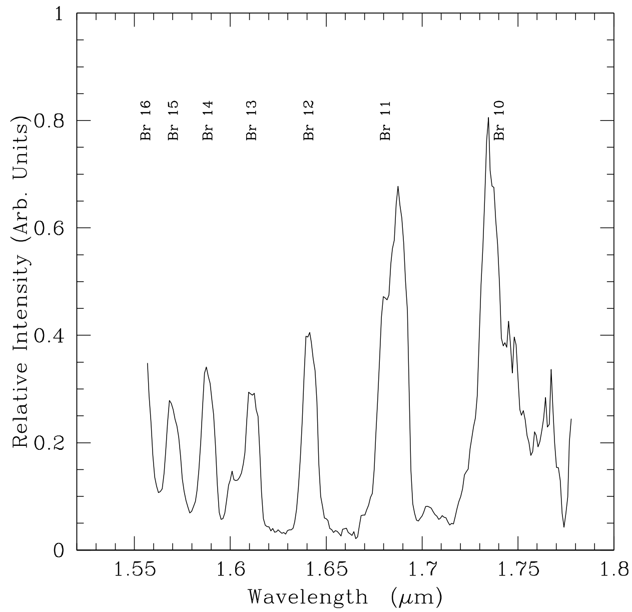

Figure 3. Near-Infrared *H* band spectrum of V4444 Sgr.

Kawabata et al. (2000) and Venturini et al. (2002) have derived very similar absolute magnitude values (around −9) from the light curve. Although the extinction estimates in these studies differ, the distance estimates agree with each other, placing the nova at around 4.5 kpc. Here, we try to determine extinction to the nova and its distance using different methods.

We looked for objects with known extinction lying close to V4444 Sgr. The WEBDA database shows two open clusters in this direction. No data is available for the open cluster, Collinder 468, which is angularly close to V4444 Sgr. The next closest, NGC 6520, is situated at a distance of 1577 pc and has $E_{B-V} = 0.431$.

V4444 Sgr is situated in the area covered by extinction map # 238 studied by Neckel & Klare (1980). This map shows large variations in A_V values upto 2 kpc. For example, at 1 kpc, the A_V value varies between 0.75 and 1.25. Beyond 2 kpc, however, A_V has a fairly constant value of about 1.5. We note that star C of Kawabata et al. (2000) which is closest to V4444 Sgr in terms of galactic latitude has $E_{B-V} = 0.49$.

The above estimates give an A_V value of around 1.5, thus placing the nova at 10.5 kpc. Since there exists a possibility of a circumstellar dust shell around V4444 Sgr, calculation of extinction using these methods will only give a lower limit. Indeed, Venturini et al.

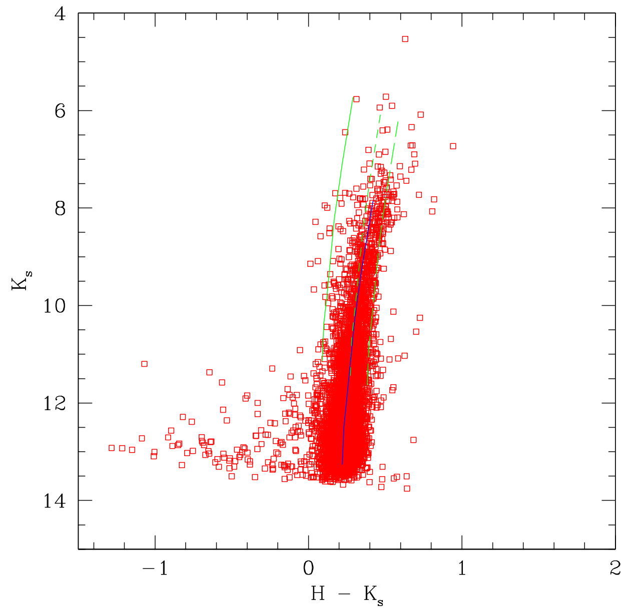

Figure 4. Using 2MASS data to find extinction and distance to V4444 Sgr. The green line represents a distance of 2.5 kpc with no extinction (solid line), with A_V = 2.8 (short dash) and A_V = 4.5 (long dash). The blue line is for a distance of 6 kpc and A_V = 2.

(2002) have derived an A_V of 3.32 from a late phase spectrum when a dust continumm could be seen in the near-infrared. The possibility of a local anomaly in the extinction further complicates matters (Kawabata et al. 2000).

A small, sharp absorption line attributable to interstellar sodium is seen in our optical spectrum. This line has a small emission component on the redward side, arising from the nova ejecta. The estimation of the correct continuum point is a bit difficult because of this. However, we have estimated the equivalent width of the line as 1.5 ± 1 Å . This gives a distance of 2.5–4.3 kpc based on the calibration of Hobbs (1974).

2MASS sources within a 5′ radius of V4444 Sgr were extracted from the Vizier database. When plotted on a K_s v/s (H - K_s) diagram, the stars seem to follow the giant star locus. We tried to superpose the giant locus on the data points using several combinations of A_V (from 0 to 4.5) and distances (2–6 kpc) and find that the combination of D = 6 kpc and A_V = 2 represents the data very well (see Fig. 4).

4.2 The 2MASS source and dust formation

Kawabata et al. (2000) studied the spectropolarimetric properties of V4444 Sgr from day 2 to 10. An intrinsic component to the polarisation was seen in their measurements. Based on dust production timescales, they argued that the observed dust must have been pre-existing when the outburst occurred. However, as pointed out by Venturini et al. (2002), an early dust formation episode, with very minor obscuration effects on the optical light, was seen in the very fast nova V838 Her.

A $2MASS$ source with $J = 8.732$, $H = 8.875$ and $K_s = 8.068$ is coincident with the position of V4444 Sgr [2]. At this early stage, free-free contribution to the near-infrared continuum is significant particularly in J and H bands; however the red (H - K_s) colour could be indicative of hot dust. The Venturini et al. (2002) observations 90 days later give a colour temperature of around 1000 K. Formation of hot dust early in the very early decline stage was observed in V838 Her (Chandrasekhar, Ashok & Ragland 1992 ; Harrison & Stringfellow 1994).

Both Kawabata et al. (2000) and Venturini et al. (2002) have raised the possibility that the dust in V4444 Sgr could be pre-existing. Could this cold dust have left some signature in the far-infrared ? We searched for MSX and $IRAS$ counterparts, but found no sources. Although a non-detection does not entirely rule out the existence of a minor amount of cold dust, it seems more likely from the $2MASS$ source that the dust continuum detected by Venturini et al. (2002) is from the present outburst.

4.3 Possibility of recurrent nova

Kato et al. (2004) have followed-up on the suggestion by Venturini et al. (2002) that V4444 Sgr could be a recurrent nova. They have compared the spectroscopic features, light curve and progenitor of V4444 Sgr with other recurrent novae. The outburst spectrum and preoutburst magnitude resemble classical novae more. The OGLE-II I band light curve of V4444 Sgr showed a distinct plateau phase between days 54 and 104 which is similar to the effect seen in light curves of other recurrent novae like U Sco and CI Aql. The accretion disc makes a significant contribution to the overall light in this phase. In the absence of conclusive evidence or detailed modelling the recurrent nature of the nova has remained a speculation. In any case, it would be interesting to study the quiescence phase of this nova. As mentioned in Sec. 2 we have obtained unfiltered images of the nova field. Upon visual comparison of the resultant image with Fig. 2 of Kato et al. (2004) two possible precursors, marked as A and B, can be identified. Source A is within their error circle and therefore the more likely candidate (see Fig 5). In order to get an estimate of the magnitudes of these candidates, we have compared our unfiltered images

[2] Source# 473107468 in scan 71 obtained on May 29, 1999 JD 2451327.6753

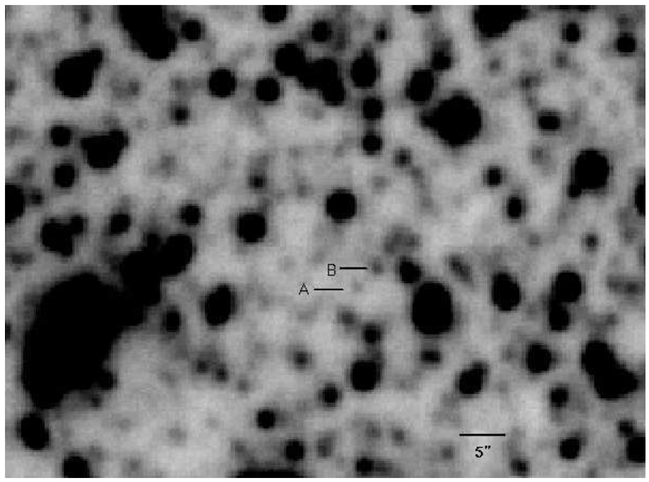

Figure 5. Unfiltered image of the V4444 Sgr field. Two possible quiescent counterparts, labelled A and B, are shown. A is the more likely counterpart based on positional coincidence. The image scale is denoted. North is up and East to the left.

with DSS2 *R*-band images. The *R* magnitude upper limits are 19 for candidate B and 20 for candidate A. Photometric observations are required for a more precise determination of the magnitudes.

5. Remarks

The near-infrared and optical spectra of V4444 Sgr 1999 in the early decline phase (the P_{fe} phase) show that it is an "Fe-II" nova with strong Lyman beta fluorescence. Estimates of extinction and distance to this nova lie in a broad range – the most likely values being in the range A_V = 2–3 and D = 4–6 kpc. V4444 Sgr shares with V838 Her some similarities such as fast evolution, possible early dust formation and signature of re-establishment of the accretion disc. The intriguing possibility, admittedly very slim, of V4444 Sgr being a recurrent nova makes it an interesting target of study.

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