Discovery of Multiple High-Velocity Narrow Circumstellar Na i D Lines in Nova V1280 Sco *

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Abstract

We discovered multiple high-velocity (ranging from -900 to -650 km s\(^{-1}\)) and narrow (FWHM ~ 15 km s\(^{-1}\)) absorption components corresponding to both the D2 and the D1 lines of Na i on a high dispersion spectrum of V1280 Sco observed on 2009 May 9 (UT), 814 d after the V band maximum. Subsequent observations carried out on 2009 June and July confirmed at least 11 distinct absorption components in both systems. Some components had deepened during the two months period while their HWHMs and wavelengths remained nearly constant. We suggest these high velocity components originate in cool clumpy gas clouds moving on the line of sight, produced in interactions between pre-existing cool circumstellar gas and high velocity gas ejected in the nova explosion. The optical region spectrum of V1280 Sco in 2009 is dominated by the continuum radiation and exhibits no forbidden line characterizing the nebular phase of typical novae. Permitted Fe ii lines show doubly peaked emission profiles and some strong Fe ii lines are accompanied by a blue shifted (~ -255 km s\(^{-1}\)) absorption component. However, no high-velocity and narrow components corresponding to those of Na i could be detected in Fe ii lines nor in the Balmer lines. The 255 km s\(^{-1}\) low velocity absorption component is most probably originating in the wind from the nova.

Key words: Stars: cataclysmic variables — Stars: classical novae — Stars: individual: V1280 Sco — Stars: spectroscopy

1. Introduction

The bright nova V1280 Sco (Nova Sco 2007 ♯1, 16°57′40″.91, −32°20′36″.74, equinox 2000.0) was discovered on 2007 February 4 by two Japanese observers (Y. Sakurai and Y. Nakamura) independently, as communicated by Yamaoka et al. (2007). Naito and Narusawa (2007) obtained a low dispersion spectrum of the object on Feb. 5.87 and found that it had a smooth continuum together with the Balmer and Fe ii lines showing P Cygni profiles. The nova had brightened greatly during the first 10 days and reached the maximum brightness on Feb. 16 (Munari et al. 2007a). The outburst amplitude (A) is 15 mag or larger because Das et al. (2008) noted that no star was visible down to B and R magnitudes of 20.3 and 19.3, respectively, on pre-discovery plates. Munari et al. (2007a) reported their photometric and spectroscopic monitoring of the nova and noted that on Feb. 20.24 the nova showed a typical classical nova spectrum of the Fe ii type characterized by a rich forest of strong permitted emission lines of Fe ii displaying deep P Cyg profiles.

Das et al. (2007) observed the nova in the near IR region on 2007 March 4.95 and found that the continuum in the 1.08 - 2.35 µ region had risen sharply indicating the dust formation in the nova ejecta. Puetter et al. (2007) reported spectroscopic observations in the visual - near IR regions carried out in 2007 May and found that the nova was in a very low excitation state showing strong C i lines and no discernible He i emission. They estimated the reddening, which is in part due to the dust shell, from the O i lines and derived E(B − V) = 1.7 mag. Photometric behaviors of the nova in the optical region until 2007 October 9 are summarized by Munari et al. (2007b). They pointed out a re-brightening in 2007 May and noticed an unexpected large re-brightening in 2007 September.

High spatial resolution interferometric observations in the near and mid IR regions were carried out using the Very Large Telescope Interferometer (VLTI). Chesneau et al. (2008) observed spectra and visibilities of the nova from 2007 February 28 to June 30 and determined an apparent linear expansion rate for the dust shell. They pointed out that the approximate time of the mass ejection during which the dust shell had formed was close to the date of the maximum brightness. They used the observed expansion velocity and the linear expansion rate to
derive an upper limit of the distance to be \(\sim 1.9\) kpc.

We have continued photometric observations in \(B,V,RC,IC\) and \(y\) bands at Osaka Kyoku University and in \(J,H\) and \(Ks\) bands at Higashi Hiroshima Observatory until 2009 September. Low resolution spectroscopic observations were conducted at Nish-Harima Astronomical Observatory. Part of our photometric and spectroscopic observations has been reported in Naito et al. (2009). A long-term (spanning three years) light curve of V1280 Sco reveals unique features among classical novae. Figure 1 shows long-term light curves in the \(V\) and \(y\) bands including the latest observations obtained in the summer of 2009. After the initial rapid decline in the \(V\) band, the nova showed a temporary re-brightening in 2007 May. Then it declined and reached a minimum (\(\sim 16\) mag in the \(V\) band) in 2007 August. After 2007 September, the nova recovered its brightness in all bands and a bright plateau (\(\sim 10\) mag in the \(V\) band) had continued throughout 2008. Although the nova showed a slight decline starting from 2009 May, it was still brighter than 11 mag in the \(V\) band in 2009 August, more than 900 d after the \(V\) band maximum. One of the notable feature of the optical light curve is a close resemblance between the \(y\), which is free from emission lines, and the \(V\) magnitudes. Even in the summer of 2009, its \(y\) magnitude is only slightly fainter than the \(V\) magnitude. This implies that the optical region spectrum is dominated by the continuum radiation even 900 d after the \(V\) band maximum. A detailed discussion of the light and color curves will be presented in a separate paper. A low resolution optical spectrum of V1280 Sco obtained at Higashi Hiroshima Observatory on 2009 February shows no hint of the \([\text{O II}]\) forbidden lines. Thus, the nova has not entered the Nebular phase yet. We have carried out high resolution optical region spectroscopic observations of the nova in 2009 in order to clarify the physical conditions in the continuum radiating source. Here we focus on a remarkable finding concerning the highly blue-shifted narrow absorption components associated with the Na\(^{I}\) yellow doublet lines.

![Fig. 1. Light curves in the \(V\) (dots) and the \(y\) (open triangles) bands obtained at Osaka Kyoku University. Data of photometric starndard stars given by Henden and Munari (2007) are used. Epochs of Subaru observations in 2009 are indicated by arrows.](image)

| Date  | UT after the \(V_{\text{max}}\) | Exposure sec |
|-------|------------------------------|--------------|
| May 9 | 12:30                        | 814          |
| June 15 | 12:30                        | 851          |
| June 16 | 11:55                        | 852          |
| July 4 | 11:00                        | 870          |
| July 6 | 9:30                         | 872          |

2. Observations

Spectroscopic observations of V1280 Sco were carried out at three epochs with the Subaru Telescope using the High Dispersion Spectrograph (HDS) on 2009 May 9, June 15 and 16 and July 4 and 6 (UT), as summarized in table 1. Our first observation was made 814 d after the optical maximum. On May 9, we obtained a sky observation using the same instrumental setup because the sky was hazy and the object was located close to the bright Moon. The sky condition on the subsequent nights in June and July was fairly clear and no sky subtraction had been applied for data obtained in June and July. Technical details and the performance of the spectrograph are described in Noguchi et al. (2002). We used a slit width of 0.6 (0.3 mm) and a 2x1 binning mode, which enabled us to achieve a nominal spectral resolving power of about \(R = 60000\) with a 3.5 pixel sampling. Our observations covered the wavelength region from 4050 \(\AA\) to 6760 \(\AA\). For flat-fielding of the CCD data, we obtained Halogen lamp exposures (flat images) with the same setup as that for the object frames.

The reduction of two-dimensional echelle spectra was performed using the IRAF software package in a standard manner. The wavelength calibration was performed using the Th-Ar comparison spectra obtained during the observations. Extracted one dimensional spectral data have been converted to the helio-centric scale and then continuum fitting was done using high order polynomials. The spectral data obtained on June 15 and 16 and July 4 and 6 were averaged to create data of June and July, respectively, in order to improve the signal-to-noise (SN) ratio. The measured FWHM of the weak Th lines was 0.11 \(\pm 0.05\) \(\AA\), and the resulting resolving power was around \(R = 55000\). Measured SN ratios at 5000 \(\AA\) were \(\sim 55\), 140, and 130 for data obtained on May, June, and July, respectively. The averaged FWHM of the atmospheric water vapor absorption lines near the Na\(^{I}\) D lines is 5.6 \(\pm 0.8\) km s\(^{-1}\), confirming the above resolution. Figure 2 displays a flux calibrated HDS spectrum of V1280 Sco obtained in June. We use the spectrum of an A0 III star HIP 83740 observed on June 15 and 16 with the same instrumental setup in the process of flux calibration.

3. Results

As a first step, we searched for signature of forbidden emission lines which are often observed in spectra of late-time novae. The most prominent features observed during classical novae nebular phase are the forbidden lines...
Fig. 2. Flux calibrated spectrum of V1280 Sco observed in 2009 June. The flux calibration might be somewhat uncertain because of the variable seeing and the atmospheric transparency. Major spectral features are indicated. Sharp emission lines below 5600 Å are identified as permitted lines of Fe II.

Fig. 3. Absence of the [O III] forbidden lines. Expected positions are indicated by upward arrows. Two prominent emission lines of Fe II are labeled.

Fig. 4. Normalized spectral data around the D2 and the D1 lines of Na I. Interstellar absorptions are labeled as D2 and D1. Arrows A and B indicate the blueward shifts of both the D2 and the D1 systems, respectively. Weak absorption lines labeled with asterisks are due to atmospheric water vapor.

Fig. 5. Blue shifted D2 (thick) and D1 (dashed) absorption lines observed on 2009 June plotted on the velocity scale. Eleven individual components are labeled from A to K.

of doubly ionized oxygen, [O III], at 4959.91 and 5006.84 Å. Figure 3 shows the region between 4955 Å and 5025 Å observed on June, where the [O III] lines are expected to be seen at positions indicated by upward arrows. The figure shows that the spectrum is dominated by the continuous radiation. We can find no trace of the emission lines on the high resolution and high SN data. Instead, we find emission lines of Fe II. The weak Fe II line at 4993.358 Å shows a double-peaked profile, while the stronger line at 5018.440 Å is single-peaked. Interestingly, the latter line is accompanied by a blue-shifted (∼ - 255 km s⁻¹) absorption component. The same is true for another strong Fe II line at 4923.927 Å.

Inspecting the spectral region near the Na I doublet lines, we noticed unfamiliar sharp absorption lines between 5870 and 5885 Å. These sharp features are superposed on a wide (FWHM ∼ 1300 km s⁻¹) emission line of He I at 5875.62 Å. We trace the profile of the emission line and use the result as a pseudo continuum in the present study. Resulting normalized spectrum is shown in figure 4. The two strong lines labeled as D2 and D1 are most probably interstellar (IS) absorptions. At least six IS components can be recognized on the data. The averaged FWHM of weak interstellar lines is 9.0 ± 1.0 km s⁻¹. We notice that the pattern of absorption features between 5872 and 5878 Å is just the same with the pattern observed between 5878 and 5884 Å. We measured the differences in wavelength between the former pattern and the strongest IS D2 line and those between the latter pattern and the strongest IS D1 line to find that the differences are exactly the same for all corresponding features. Thus, we conclude that the unfamiliar sharp lines are blue-shifted absorptions of both D2 and D1 lines.

We converted the wavelength scale to the velocity scale originating from the laboratory wavelengths of both D2 and D1 lines. Figure 5 displays blue-shifted absorption features observed on 2009 June plotted on the velocity scale. The two patterns which originate from the D2 and the D1 lines coincide exactly. We can recognize at least 11 pairs of absorption features and they are labeled as components A to K on the figure. The features in the D1 absorption system are systematically weaker than those
changes in the blue shifted absorptions in two months. Data observed on May, June, and July are displayed by dotted, thick and dashed lines, respectively. The D2 and the D1 systems are displayed in the upper and the lower panels, respectively.

We examine variations in strengths of the above 11 absorption features during the 2 months period (from May to July) in figure 6. Lines belonging to the D2 and the D1 systems are displayed separately on the figure. Measurements of the velocities and the depths for the 11 components belonging to the D2 system are given in table 2. Errors in measurements are estimated to be ±2.5 km s\(^{-1}\) in the velocity and ±0.03 in the depth. We find definite increase in line depth for six components (B, E, G, H, I, and K) in both the D2 and the D1 systems. Depths of the remaining five components stay nearly the same during the period. It is interesting to find that no component has weakened during the 2 months period. The strongest feature G had deepened between May and June, while its depth remained constant between June and July. The neighboring component H had significantly deepened from \(r = 0.24\) in May to 0.55 in July. The two neighboring components B and C clearly show different behaviors during the two months period. The former had deepened significantly (from \(r = 0.10\) to 0.24), while the depth of the latter remained nearly constant. The averaged FWHM of the three apparently unblended absorptions (A, E, and G) is 16.0 ± 2 km s\(^{-1}\), while that of the narrowest feature (component H) is 11.2 km s\(^{-1}\), nearly the same as that of the weak interstellar absorptions. It is interesting to examine whether the highly blue-shifted absorptions can be seen associated with other metal lines or the Balmer emission lines. A region near the strong Fe \(\text{II}\) line 5018.440 Å is displayed in figure 7 and the profile of H\(\beta\) is shown in figure 8. Expected positions for the two strong absorption features (E and G) are indicated by arrows. We can confirm no absorption feature in these lines and thus conclude that the highly blue-shifted absorptions are only associated with the resonant transitions of Na \(\text{I}\). A relatively broad (FWHM ∼ 60 km s\(^{-1}\)) absorption feature is seen in figures 7 and 8, which is blue-shifted by ∼ -255 km s\(^{-1}\) relative to the emission peak. We interpret this absorption originates in the expanding wind of the photosphere.

### Table 2. Measurements of the D2 system.

| Component | Velocity \(\text{km s}^{-1}\) | Depth |
|-----------|-----------------|-------|
|           | May  | June | July | May | June | July |
| A         | -649.4 | -650.4 | -650.4 | 0.35 | 0.32 | 0.31 |
| B         | -677.9 | -679.0 | -680.0 | 0.10 | 0.16 | 0.24 |
| C         | -692.2 | -692.2 | -692.0 | 0.13 | 0.14 | 0.12 |
| D         | -724.3 | -724.5 | -724.4 | 0.04 | 0.04 | 0.06 |
| E         | -751.8 | -753.8 | -754.8 | 0.62 | 0.76 | 0.86 |
| F         | -776.8 | -776.2 | -776.8 | 0.08 | 0.06 | 0.08 |
| G         | -806.3 | -806.3 | -806.8 | 0.80 | 0.87 | 0.88 |
| H         | -821.1 | -821.6 | -822.6 | 0.24 | 0.43 | 0.55 |
| I         | -845.5 | -847.5 | -848.1 | 0.14 | 0.21 | 0.23 |
| J         | -867.0 | -867.9 | -867.9 | 0.11 | 0.13 | 0.12 |
| K         | -885.8 | -884.7 | -885.8 | 0.08 | 0.17 | 0.17 |

4. Discussion

We have discovered multiple high-velocity absorption components corresponding to both the D2 and the D1 lines of Na \(\text{I}\) on high resolution spectra of V1280 Sco observed three years after the explosion. There are at least 11 sharp (FWHM ∼ 15 km s\(^{-1}\)) components and they are highly blue-shifted, ranging from -900 to -650 km s\(^{-1}\), on the helio-centric velocity scale. These absorptions are not associated with Fe \(\text{II}\) or the Balmer emission lines. This
implies that the high-velocity absorptions are produced in a cool environment where iron atoms are in neutral state and most hydrogen atoms stay in the ground state. This must be a very rare finding because we know no previous similar observation in the literature.

Williams et al. (2008) reported observations of short-lived blue-shifted metallic absorption systems, including the Na i D lines, near the maximum light of various novae. These absorption lines have expansion velocities from 400 to 1000 km s\(^{-1}\) and velocity dispersions between 35 and 350 km s\(^{-1}\). They are usually accelerated outward and progressively weaken and disappear over timescales of weeks (within 100 d). They proposed a spiral ring model to interpret their observations. They suggest that some material ejected by the secondary star before the nova outburst is spiraling around the binary system. After the nova outburst, a rapidly expanding luminous photosphere is produced and it collides with the pre-existing gas stream.

Our observations of narrow and high-velocity absorption components associated with the Na i D lines appear hard to be interpreted in this scheme. Our data were obtained more than 800 d after the explosion, while the transient absorptions reported in Williams et al. (2008) usually disappear over timescales of weeks. Their analysis of absorption line systems observed in LMC 2005 shows the excitation temperature to be around 10\(^4\) K, which is too high to explain the absence of high-velocity absorption components associated with Fe II lines. Furthermore, the observed line widths of the high-velocity absorption components in V1280 Sco are narrower than the widths noted in Williams et al. (2008). Finally, the large number (at least 11) of the absorption components looks difficult to be interpreted in this scenario.

We propose that the observed high velocity absorption components originate in many cool clumpy gas clouds moving toward the observer on the line of sight. These gas clouds are produced after the nova explosion in interactions between the pre-existing cool circumstellar gas and the high velocity gas (\(\sim 2000\) km s\(^{-1}\), Naito et al. 2009) ejected in the nova explosion. Naito et al. (2009) suggested that the 2000 km s\(^{-1}\) gas might be associated with the second mass ejection episode corresponding to the temporal re-brightening observed in 2009 May. In the case of V1280 Sco, the binary system had been embedded in a relatively dense circumstellar cloud, and the pre-existing circumstellar gas had not necessarily been supplied from the secondary star as suggested in Williams et al. (2008). The prompt formation of dust in this nova (Chesneau et al. 2008) is likely to be triggered by the interaction between the surrounding clouds and the expanding ejecta. Many small gas clouds might have been produced during the turbulent interaction in the shock and expelled outward with velocities ranging from -1000 to -500 km s\(^{-1}\). We suppose that some of the clouds are moving toward us on the line-of-sight and produce multiple absorption lines. The observed increase in line depths for several components may be the result of rapid cooling of these clouds, increasing the number density of neutral Na capable of absorbing the D line photons. This picture is hinted by a direct image of the old nova GK Per observed with the WIYN 3.5 m telescope (Slavin et al. 1995). Confirmation of this scenario could come from future high spatial resolution imaging observations.

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