

Detection of Diatomic Molecules in the Dust Forming Nova V2676 Oph

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Abstract

Novae are generally considered to be hot astronomical objects and show effective temperatures up to 10,000 K or higher at their visual maximum. But, it is theoretically predicted that the outer envelope of the nova outflow can become cool enough to form molecules that would be dissociated at high temperatures. We detected strong absorption bands of C₂ and CN radicals in the optical spectrum of Nova V2676 Oph, a very slow nova with dust formation. This is the first report of the detection of C₂ and the second one of CN in novae during outburst. Although such simple molecules are predicted to form in the envelope of the outflow based on previous studies, there are few reports of their detection. In the case of V2676 Oph, the presence of the molecular envelope is considered to be very transient, lasting several days only.

Keywords: cataclysmic variables - classical novae - optical - spectroscopy - IR - individual: V2676 Oph.

1 Introduction

Dust formation in the outflow of a nova had been proposed by McLaughlin (1935) to explain the rapid drop in the visual light-curve of DQ Her in 1934. Dust formation in FH Ser had also been confirmed by infrared observations by Geisel et al. (1970). DQ Her was the first nova in which molecular absorption bands of CN in optical wavelength had been identified. The formation of molecules as the precursor to dust grains in novae is considered important for understanding how dust grains form in the outflow of novae. In the case of DQ Her in 1934, strong CN absorption bands of both violet and red systems had been detected merely 2 days after the visual maximum, and these absorption bands were identified for only 1 week approximately (Wilson & Merrill, 1935; Sanford, 1935; Stoy & Wyse 1935; Antipova 1969; Sneden & Lambert, 1975). Since the formation of simple molecules such as CN is considered an intermediate process in the formation of dust grains from the hot atomic gas in the outflow of a nova, molecular formation in the early phase of DQ Her might be associated with dust formation its later phase.

Although CN is the first molecule observed in a nova during outburst (in the case of DQ Her), there are no further reports about CN in other novae. Whereas, carbon monoxide (CO) emission in the early phase of novae has been observed by both photometric and spec-

troscopic observations. In particular, the first overtone band of CO ($\Delta v = 2$) has been routinely detected in near-infrared spectra of several novae, as reviewed by Evans & Rawlings (2008). Based on previous observations, the correlation between detection of CO and dust formation is noticeable. However, hydrogen (H₂) or other molecules have not detected in novae during the early phase of their outburst.

Here we report the detection of C₂ and CN in optical spectra of the classical nova V2676 Oph during the early phase of its outburst. This nova could be classified as a slow nova, and it showed a rapid drop in its visual light curves about 90 days after its discovery. This is the first report of the detection of C₂ in novae during outburst and the second for CN. Furthermore, CO emission in the near-infrared had been detected in this nova (Rudy et al., 2012).

2 Observations

Nova V2676 Oph (PNV J17260708-2551454) was discovered at UT 2012 Mar 25.789 ($t = 0$ day) by H. Nishimura (reported in the Central Bureau Electronic Telegram (CBET) 3072). After the discovery of the nova, we carried out spectroscopic observations with the low-dispersion spectrograph LOSA/F2 (Shinnaka et al., 2013) mounted on the 1.3-m Araki telescope at Koyama Astronomical Observatory on UT 2012 Mar 27. On the

first night, we detected narrow Balmer emission lines (both $H\alpha$ and $H\beta$) and narrow Fe II emission lines on a highly reddened continuum that seemed to be due to interstellar extinction. The color excess $E(B - V)$ was estimated by using the Balmer decrement and the color of the nova ($B - V$); it was determined as 0.71 ± 0.02 and 0.72 ± 0.06 , respectively. Based on the P Cygni profile of

the $H\alpha$ emission, the expansion velocity was estimated to be ~ 800 km/s. We concluded that the object was a Fe II-type classical nova in the early phase (Arai & Isogai, 2012). After the first observation of V2676 Oph, we continued the observation of it routinely to assess its spectroscopic evolution (Nagahsima et al., 2014).

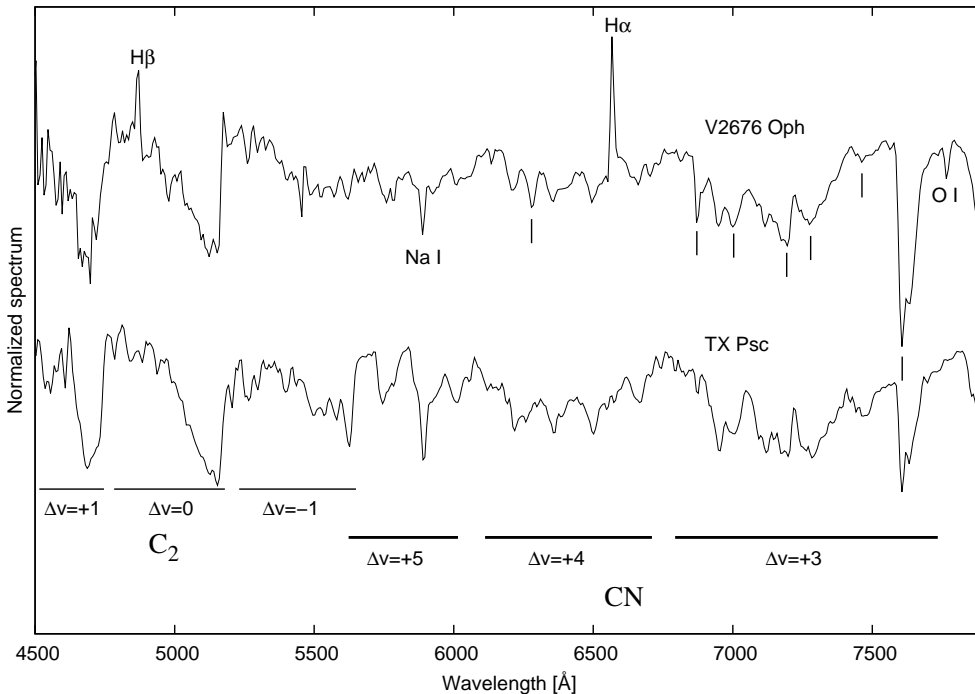


Figure 1: Comparison of the spectrum of V2676 Oph obtained on Apr 8 with that of a typical carbon star, TX Psc. Tick marks indicate telluric absorption lines.

After the first spectroscopic observations on UT 2012 Mar 27, the emission lines in the optical spectra became fainter relative to the continuum (on UT 2012 Mar 28, Apr 4 and 6), while the optical brightness was increasing slowly (the optical brightness changed gradually from 12 to 11 magnitudes in the V-band, see the American Association of Variable Star Observers (AAVSO) database, [http://http://www.aavso.org/lcg/](http://www.aavso.org/lcg/)). No emission lines could be observed (except $H\alpha$ emission with a P Cygni profile), but many absorption lines of Fe II and neutral atoms such as Na I (5890Å) and O I (7773Å) were detected clearly in the spectra obtained on Apr 6 ($t = 12$ days). Those absorption lines are indicative of lower ionization and the lower temperature conditions in the outflow of the nova.

Prominent C_2 (Swan) and CN (red system) absorp-

tion bands were detected on UT 2012 Apr 8 ($t = 14$ days), as shown in Figure 1. The obtained spectrum is similar to that of a carbon star. We also plotted the spectrum of TX Psc (a well-known carbon star of spectral type N0;C6,2, with $T_{\text{eff}} = 3030$ K; Lambert et al., 1986) for comparison. We also identified weak emission lines of $H\alpha$, $H\beta$, and Fe II. Based on the substructure of the C_2 Swan band ($\Delta v = -1$) absorption, we could derive the isotopic ratio of carbon. Figure 2 shows the spectrum of the nova, the modeled spectra of $^{12}C^{12}C$, $^{12}C^{13}C$, and $^{13}C^{13}C$ (with an excitation temperature of 4500K). The Doppler shift of the nova spectrum has been corrected by using the relative velocity of the nova to the observer, estimated as 341 ± 87 km/s (this is derived from the velocities for $H\alpha$ and $H\beta$ emission peaks). The wavelengths of sub-peaks in this band cannot be explained by $^{12}C^{12}C$ only. Clearly

$^{12}\text{C}^{13}\text{C}$ and $^{13}\text{C}^{13}\text{C}$ contribute to form the absorption.

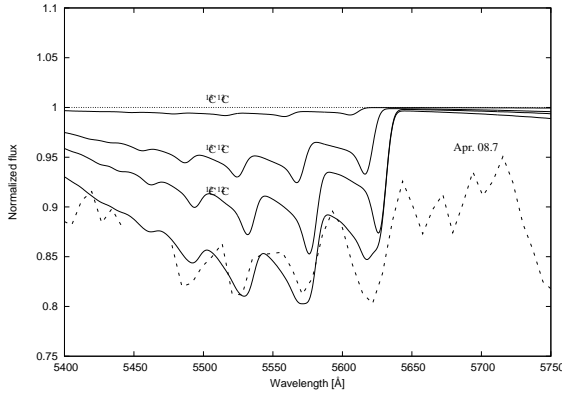


Figure 2: Comparison between observed and modeled spectra of the C_2 ($\Delta v = -1$) absorption band. The observed spectrum is shown by dashed line (the region influenced by the Hg emission from the city-light, at ~ 5460 Å, has been removed). The modeled spectra for $^{13}\text{C}^{13}\text{C}$, $^{12}\text{C}^{13}\text{C}$ and $^{12}\text{C}^{12}\text{C}$ are shown by the thin solid lines and the sum of those lines is shown by the thick solid line. For the modeled spectra, we assumed the rotational and vibrational temperatures of 4500 K and the isotopic ratio of $^{12}\text{C}/^{13}\text{C} = 4$.

The next observations were carried out on UT 2012 Apr 16 ($t = 22$ days). In these observations, the C_2 and CN absorption bands had already disappeared and strong Balmer emission lines and Fe II lines were again prominent. At that time, the spectra were typical of Fe II-type classical novae. The other difference from the previous observations was the expansion velocity derived from $\text{H}\alpha$, which had increased in comparison to that before molecular formation. This higher velocity is typical of the Fe II-type novae (Williams 1992). Thereafter, the spectra of this nova were not unusual for an Fe II-type nova, although we continued spectroscopic monitoring observations until UT 2012 May 26. The optical light curves showed a very slow decline after the visual maximum and a rapid drop (by about six magnitudes in the V-band) at around 90 days after the discovery (this nova can be classified as a “slow” nova). The drop in the light curves may be caused by dust formation in the outflow of the nova.

3 Results & Discussion

The equivalent widths of $\text{H}\alpha$ (and also of $\text{H}\beta$) measured in our spectra were almost constant before and after the appearance of molecular absorption bands. However, optical light curves showed a small drop of ~ 1 magnitude before and after molecular formation. Figure 3 shows the optical and near infrared light curves taken from the database of the AAVSO and Small and Mod-

erate Aperture Research Telescope System (SMARTS), the color indices of $(V - I)$ and the equivalent width of $\text{H}\alpha$ and $\text{H}\beta$. For example, the C_2 absorption could markedly affect B- and V-band magnitudes, while CN red absorption could also affect R- and I-bands. This implies that extinction of the molecules in the outflow affected both continuum and emission lines from the nova. The molecular formation zone could be in the outer region of the outflow compared with regions emitting the continuum and/or emission lines in the nova.

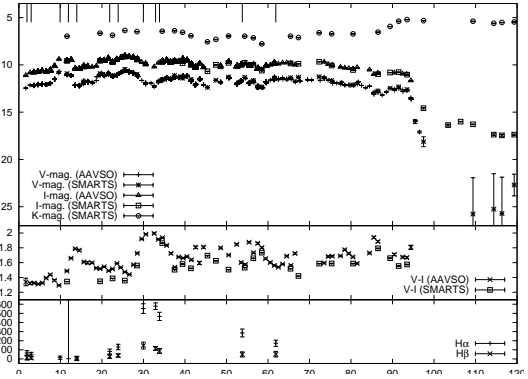


Figure 3: Multi band light curve of V2676 Oph (data from AAVSO and SMARTS), color indices $(V - I)$ based on the AAVSO and SMARTS database, and equivalent widths of $\text{H}\alpha$ and $\text{H}\beta$ measured in our spectra. Upper tick marks indicate days on which spectroscopic observations were performed.

Furthermore, molecular formation in V2676 Oph is considered very rapid (within 2 days or less) and the existence of the molecular envelope was transient (it was present at most 9 days) at around the brightness maximum in optical. Why was the appearance of both C_2 and CN absorption bands so transient that they could be detected on Apr 8 only? We considered that the outer region of the outflow became cool enough to form molecules, since the hard ultraviolet (UV) radiation from the pseudo-photosphere of the nova in the early phase was blanketed by an iron curtain, and the iron ions could have absorbed UV radiation strongly (Shore, 2008). This picture is consistent with the spectrum taken on Apr 6, which was dominated by a continuum with absorption lines indicative of lower ionization conditions. The measurements of the color indices $(V - I)$ obtained from the AAVSO and SMARTS database also showed a redder continuum for later periods after the discovery until the molecular bands appeared. This fact also supports the later lower color temperatures until molecular formation. However, as the envelope expanded and ejected materials rarefied (i.e., became more optically thin), hard UV radiation again increased in intensity. At this time, molecules would be destroyed

through photo-dissociation reactions caused by UV radiation. In support of this, the later spectra showed many emission lines from ionized species, such as Fe II. However, the molecular absorption bands may have disappeared due to some opacity effects.

Similar behavior in terms of CN formation was observed in DQ Her in 1934. The appearance of CN absorption bands immediately following the optical brightness maximum was transient, persisting for approximately 1 week only (Snedden & Lambert, 1975). The possible dust formation about 100 days after discovery was also similar to V2676 Oph. Theoretical studies of chemistry in the outflow of novae suggest that formation of even more complex molecules is possible (Pontefract & Rawlings, 2004; Evans & Rawlings, 2008). It has been demonstrated that a model atmosphere could reproduce both strong CN absorption bands in optical and the CO emission band in the near-infrared, as observed in some novae (Hauschildt et al., 1994). Although simple molecules might be destroyed by UV radiation, more complex molecules such as polycyclic aromatic hydrocarbons (PAHs) (if they formed during the transient cool phase of the outer envelope), could survive and might act as nuclei for dust formation. Indeed, PAH emission was detected in this nova. We performed mid-infrared spectroscopic observation using a Cooled Mid-Infrared Camera and Spectrometer (COMICS) mounted on the SUBARU telescope on UT 2013 June 20 ($t = 452$ days). The spectrum showed PAH emission at $11.4 \mu\text{m}$ (and a hint of the emission line at $7.7 \mu\text{m}$) on the smooth continuum that could be explained by amorphous carbon grains.

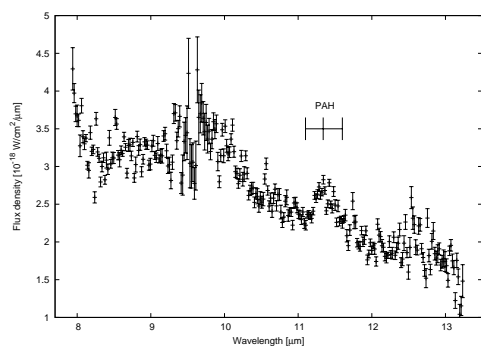


Figure 4: The mid-infrared spectrum of V2676 Oph.

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