A&A 516, A54 (2010)
DOI: 10.1051/0004-6361/200913287

Astronomy & Astrophysics

Spectral evolution of the extremely fast classical nova V838 Herculis

T. Iijima[1] and A. Cassatella[2,3]

[1] Astronomical Observatory of Padova, Asiago Section, Osservatorio Astrofisico, 36012 Asiago (Vi), Italy
e-mail: takashi.iijima@oapd.inaf.it
[2] INAF, Istituto di Fisica dello Spazio Interplanetario, via del Fosso del Cavaliere 100, 00133 Roma, Italy
[3] Departmento de Astrofisica, Facultad de Fisica, Universidad Complutense, 28040 Madrid, Spain

Received 12 September 2009 / Accepted 28 March 2010

ABSTRACT

Spectral evolution of nova V838 Her 1991 was monitored at Asiago Astrophysical Observatory from 1991 March 31 to July 2. The spectra in the early decline stage showed emission lines of H I, He I, He II, N II, N III, C II, C III, C IV, Si II, [S III], [Ne III], and Fe II, where some identifications are different from those reported in the previous works. The emission lines of [Ne III] and carbon ions were unusually intense. New emission peaks appeared at the blue-ward edges of the emission lines of H I and He I about one week after maximum luminosity. It seems that a new clump of gas was ejected at that time along the line of sight towards us. The helium abundance is estimated at N(He) = 0.11 ± 0.01.

Key words. stars: individual: V838 Her – novae, cataclysmic variables – ISM: general

1. Introduction

The nova (V838) Her 1991 was discovered independently by Sugano (1991) and Alcock (1991) on 1991 March 24 as a star of $m_{\rm vis.} \cong 5.4$. The outstanding property of this nova was the extremely fast decline rate: two mags in two days, which is one of the fastest novae on record (Vanlandingham et al. 1996, and references therein). It was suggested from infrared observations that a little of the dust had existed before the outburst and a condensation of new dust occurred in less than ten days from maximum luminosity (Chandrasekhar et al. 1992; Lynch et al. 1992; Woodward et al. 1992; Kidger & Martinez-Roger 1993; Harrison & Stringfellow 1994). This nova is classified as a neon nova, because strong emission lines of neon ions were detected since its early decline stage (Matheson et al. 1993; Williams et al. 1994). The central system is known as an eclipsing binary (Leibowitz et al. 1992; Ingram et al. 1992).

Chemical abundances of this object were estimated using optical and UV spectra (Vanlandingham et al. 1996, 1997; Schwarz et al. 2007), where overabundances of neon and carbon and a low abundance of oxygen were remarkable. Recently, Kato et al. (2009) analysed spectroscopic and photometric UV data and estimated the interstellar extinction and the distance to the nova as $E(B-V) = 0.53 \pm 0.05$ and $d = 2.7 \pm 0.5$ kpc. They proposed in the same article a model with a massive white dwarf, $1.35 \pm 0.02\ M_\odot$, for the outburst.

This paper presents the spectral evolution of V838 Her from 1991 March 31 to July 2.

2. Spectral evolution

Spectroscopic observations were carried out on 1991 March 31, April 2, and July 2 using a Boller & Chivens grating spectrograph mounted on the 182 cm telescope at the Mount Ekar station of the Astronomical Observatory of Padova. The spectra were reduced using the standard tasks of the NOAO IRAF[1] package at the Asiago Observatory of the University of Padova. The spectral resolution was $\lambda/\Delta\lambda \cong 800$ with a grating of 600 lines mm^{-1}, and the spectrophotometric calibrations were made using the spectra of the standard star Kopff 27 obtained in the same nights. The interstellar extinction was corrected assuming $E(B-V) = 0.53$ (Kato et al. 2009). A log of the observations is given in Table 1, where UT is the universal time at the start of exposure.

Table 1. Log of spectroscopic observations of V838 Her.

Date 1991	UT	JD	exp. s	Range Å
March 31	3:42	8 346.66	300	3870–5000
April 2	2:20	8 348.60	120	5980–7130
April 2	2:28	8 348.60	300	"
April 2	3:22	8 348.64	300	4920–6060
April 2	3:51	8 348.66	600	3900–5040
July 2	0:29	84 39.52	2400	3960–5100

Notes. JD: Julian date – 2 440 000. UT: Universal time at start of exposure.

2.1. 1991 March 31

Figure 1 shows a tracing of our first spectrum obtained on 1991 March 31. The emission lines of hydrogen Balmer series were prominent. Those of Hϵ and H$_8$ were blended with [Ne III] 3968 and [Ne III] 3869, respectively. The heliocentric radial velocity of the line centre of Hβ was -5 ± 20 km s^{-1}, and the *FWHM* was 4510 ± 20 km s^{-1}. The corresponding quantities of Hγ were

[1] IRAF is distributed by NOAO for Research in Astronomy, Inc. under cooperative agreement with the National Science Foundation.

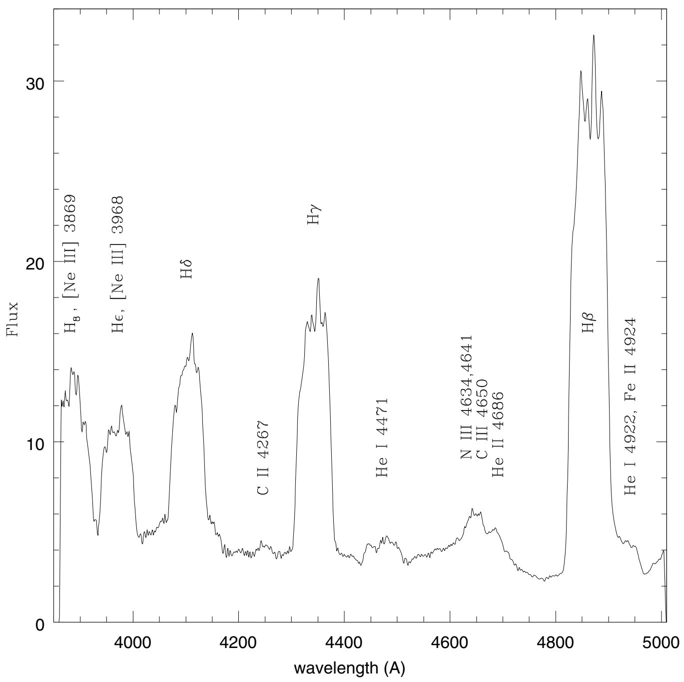

Fig. 1. A spectrum of V838 Her on 1991 March 31. The unit of the ordinate is 10^{-12} erg cm^{-2} s^{-1} Å^{-1}.

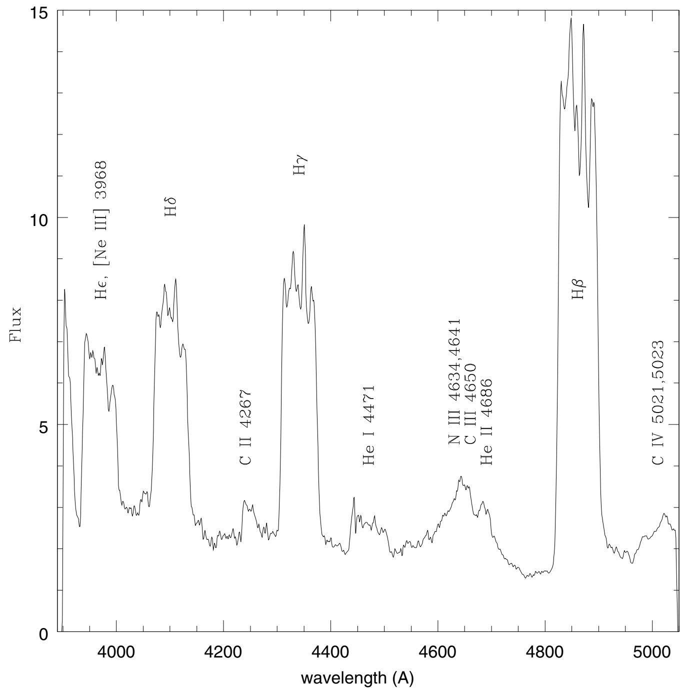

Fig. 2. A spectrum of V838 Her on 1991 April 2. The unit of the ordinate is 10^{-12} erg cm^{-2} s^{-1} Å^{-1}.

+40 ± 20 km s^{-1} and 4460 ± 20 km s^{-1}. The other prominent emission lines were of He I, He II, N III, and C III. The redward tail of Hβ was blended with the emissions of He I 4922 and Fe II 4924. A weak emission line found around 4248Å was identified as C II 6, 4267.0, 4267.3 (see Sect. 3.1).

2.2. 1991 April 2

Three spectra obtained on 1991 April 2 covered the spectral range 3900−7130 Å. Figure 2 shows a tracing of the blue spectrum. The heliocentric radial velocity of the line centre of Hβ and Hγ were −46 ± 20 km s^{-1} and −27 ± 20 km s^{-1}, respectively, and the line widths (*FWHM*) were 4670 ± 20 km s^{-1} and 4690 ± 20 km s^{-1}.

The emission lines of Hβ and Hγ showed four peaks on March 31 (Fig. 1), while a new peak was detected at the bluest side of the emissions on April 2 (Fig. 2). These variations suggest an ejection of a new clump of gas (see Sect. 4). The emission line at 4248 Å strengthened.

Figure 3 shows the spectral range 4950–6050 Å. The strongest emission line in this region was due to He I 5876. The second intense emission line at 5027 Å was identified as C IV 3, 5021 and 5023 (see Sect. 3.2). The emission lines of N II 3, 5680, Fe II 49, 5317, and C IV 1, 5801 and 5812 were also detected. A weak emission line at 5160 Å was identified as Fe II 42, 5169.

Figure 4 shows a tracing of the red spectrum. The dotted line demonstrates the peak profile of Hα emission with one tenth scale. The profile of Hα was nearly the same as that of Hβ (Fig. 2). The heliocentric radial velocity was −40 ± 20 km s^{-1}, and the width (*FWHM*) was 4650 ± 20 km s^{-1}. The heliocentric radial velocities of the five emission peaks were −1940, −930, −180, +630, and +1650 km s^{-1} with errors of ±20 km s^{-1}. These velocities were somewhat different from those observed by Matheson et al. (1993) on 1991 May 5, i.e., −1880, −946, −122, +746, and +1790 km s^{-1}. The peak at −930 km s^{-1} was the highest in our spectrum (Fig. 4), while the peak at +747 km s^{-1} was the highest on 1991 May 5 (Matheson et al. 1993). As seen later, the peak at −930 km s^{-1} became the highest again in Hβ on 1991 July 2 (Fig. 5). These variations of the individual peaks in radial velocity and in relative intensity suggest a very complicated structure of the ejecta.

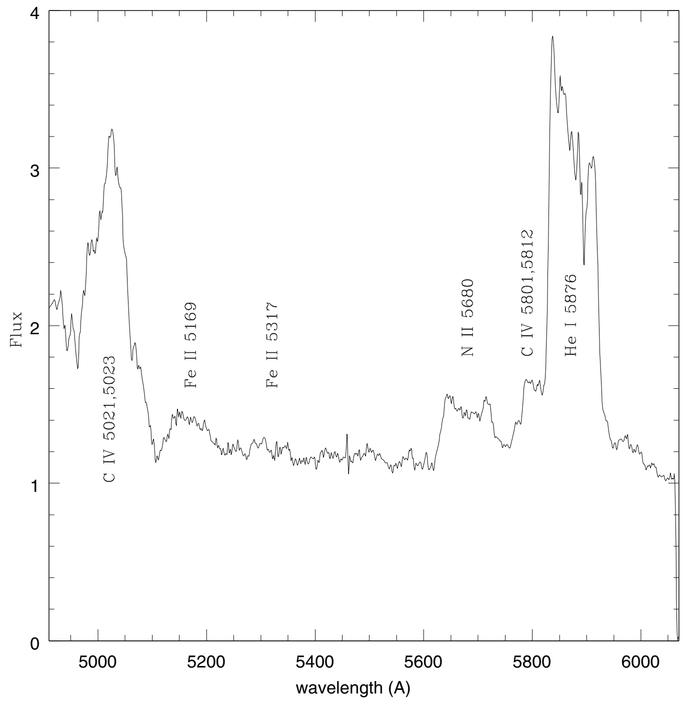

Fig. 3. A spectrum of V838 Her on 1991 April 2. The unit of the ordinate is 10^{-12} erg cm^{-2} s^{-1} Å^{-1}.

We identified the emission complex around 6353 Å as a blend of Si II 2, 6347, 6371, and [S III] 3F, 6310 (see Sect. 3.3). The last component became dominant in the nebular stage

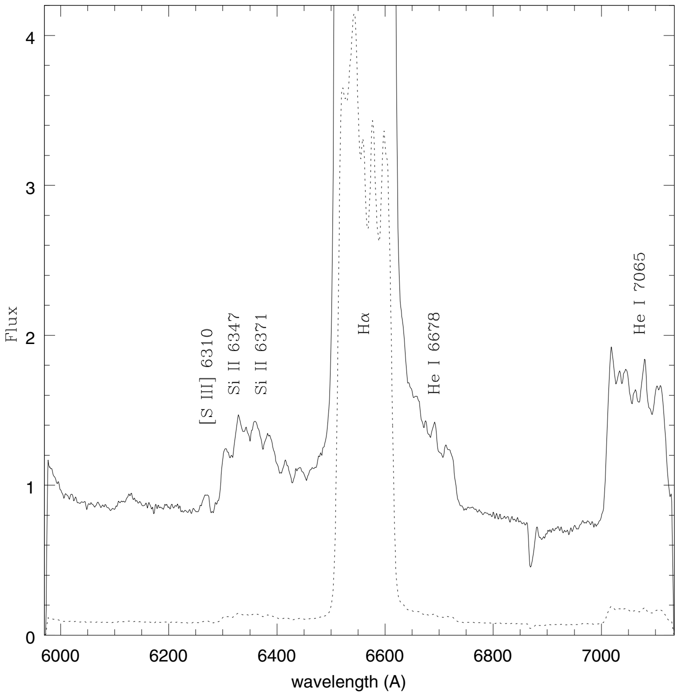

Fig. 4. A spectrum of V838 Her on 1991 April 2. The unit of the ordinate is 10^{-12} erg cm^{-2} s^{-1} $Å^{-1}$, and the profile of $H\alpha$ is shown by a dotted line with one tenth scale.

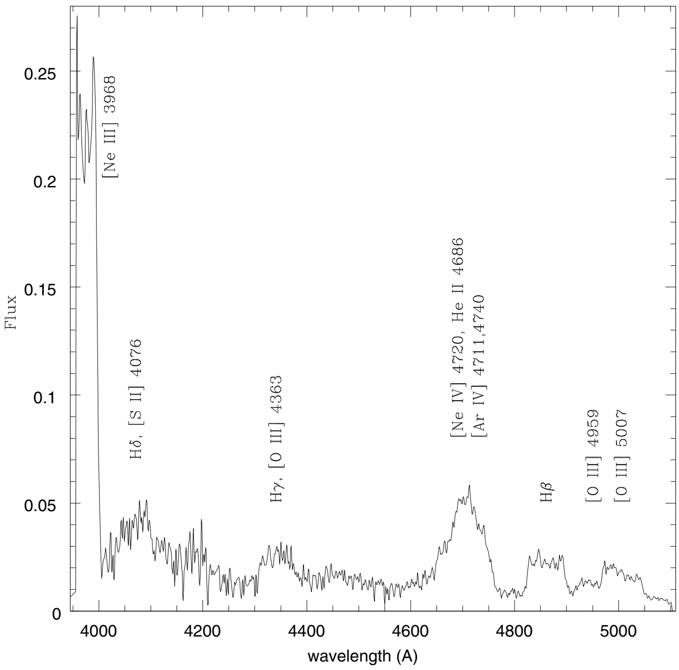

Fig. 5. A spectrum of V838 Her on 1991 July 2. The unit of the ordinate is 10^{-12} erg cm^{-2} s^{-1} $Å^{-1}$.

(Matheson et al. 1993; Williams et al. 1994; Vanlandingham et al. 1996), but it was still a minor component in this spectrum. The other prominent emission lines were of He I.

2.3. 1991 July 2

Our last spectrum, which covered the blue region 3950–5100 Å, was obtained on 1991 July 2 (Fig. 5). The strongest emission line in the spectrum was [Ne III] 3968. The broad emission complex at 4700 ± 50 Å was a blend of He II 4686, [Ne IV] 4720, and probably [Ar IV] 4711 and 4740. The castellated structure of $H\beta$ was virtually the same as that of April 2 (Fig. 2), which suggests that there was no further ejection of a clump of gas since the last observation. The other prominent emission lines were of [O III] 5007, 4959, $H\gamma$+[O III] 4363, and $H\delta$+[S II] 4076. These spectral features were nearly the same as those observed on 1991 June 12 by Williams et al. (1994). High intensities of the emission lines of neon ions and the weakness of [O III] lines were notable, which are consistent with the overabundance of neon and the low abundance of oxygen of this object (Schwarz et al. 2007).

3. Identifications of emission lines

Probably because of the overabundance of carbon (Schwarz et al. 2007), some emission lines unfamiliar in the spectra of usual classical novae were detected in our spectra. We discuss the identifications of these lines in this section.

3.1. Emission line at 4248 Å

A weak emission line was seen at 4248 Å in the spectrum on March 31 (Fig. 1). This emission line grew much in intensity on April 2 (Fig. 2). In our preliminary report (Iijima 1991), we tentatively identified it as N II 47, 4242. However, this identification is unlikely, because the line profile was different from that of N II 3, 5680 (Fig. 3). A prominent emission line with a nearby wavelength in the spectra of novae is [Fe II] 21F, 4244 (Meinel et al. 1968). The identification as [Fe II] 21F, 4244, however, is also unlikely, because emission lines of [Fe II] are usually observed in slow novae (McLaughlin 1960). CP Pup is the unique fast nova which showed [Fe II] lines (Sanford 1945). However, the other [Fe II] lines detected in the spectra of CP Pup, e.g., [Fe II] 21F, 4276.8 or [Fe II] 7F, 4287.4 (Sanford 1945), were not detected in this object.

As mentioned above, the emission line at 4248 Å grew much in intensity between 1991 March 31 and April 2. At the same time, the blue-ward parts of the emission lines of H I and He I also grew in intensity (Figs. 1, 2). Thus we assumed that the emission line at 4248 Å was due to a blue-ward part of an emission line, namely the peak at 4240 Å in the spectrum on April 2 was blue-shifted by -1920 km s^{-1} as for the bluest peaks of the H I and He I lines. Under this assumption, we estimated the laboratory wavelength of the emission line as 4267 ± 1 Å, which coincides with that of C II 6, 4267.0, 4267.3 (Moore 1959). These lines are prominent in the spectra of some novae (e.g., Sanford 1945; Iijima & Nakanishi 2008). Therefore we identified the emission line at 4248 Å as the blue-ward part of C II 6, 4267.0, 4267.3. The *FWHM* of the emission feature was about 2000 km s^{-1}, which was less than half that of H I lines (Sect. 2.2). This result seems to support our hypothesis, namely, only the blue-ward parts of the emission lines were seen. However, the reason why the red-ward parts were not seen is still an open question.

3.2. Emission line at 5027 Å

The second intense emission line in Fig. 3 is seen at 5027 Å. The blend of He I 5016 and Fe II 5018 is prominent around this wavelength in the spectra of usual classical novae in the early decline stage. Thus Williams et al. (1994) identified this emission as He I 5016. However, if this had been the case, the other emission line of He I 4922 should have been detected with nearly the same intensity, but such an emission was not seen in our spectrum (Fig. 2). In addition to this, the profile of the emission at 5027 Å was different from those of the other He I lines, but resembled that of the highly ionized emission line He II 4686 (Fig. 2). Because the emission lines of carbon ions were unusually intense in these spectra, we identified the emission at 5027 Å as C IV 3, 5021 and 5023 (Moore 1959). Probably there were also He I 5016, Fe II 42, 5018, and C II 35, 5047.2 as minor components in the emission.

3.3. Emission complex at 6353 Å

An emission complex with multiple peaks is seen around 6353 Å (Fig. 4). Williams et al. (1994) identified this emission complex as N II 46, 6346. This identification is problematic however, because there is no line with the wavelength of 6346 Å in the group of multiplet 46 of N II (Moore 1959). Probably they identified the emission complex as a blend of N II 46, 6340.7 and 6357.0 (Moore 1959), whose weighted mean wavelength is nearly 6346 Å. The resolution of our spectra was high enough to separate the two lines of N II multiplet 46. As seen in Fig. 3, the emission line of N II 3, 5680 showed prominent peaks at its blue and red edges. The heliocentric radial velocities of these peaks were -1830 ± 20 km s^{-1} and $+1890 \pm 20$ km s^{-1}, respectively. We assumed that the profiles of the other N II emission lines were similar to that of N II 3, 5680. Thus if the emission complex had been due to N II 46, 6340.7 and 6357.0, there should have been emission peaks at 6302, 6318, 6381, and 6397 Å. The corresponding emission peaks, however, were not detected. It seems that the emission complex were not due to the N II lines, but were more probably identified as a blend of Si II 2, 6347, 6371, and [S III] 3F, 6310.

4. Ejection of a clump of gas

As reported in Sect. 2.2, the profiles of the emission lines of H I and He I greatly changed between 1991 March 31 and April 2. The emission lines of Hβ and Hγ showed four peaks on March 31 (Fig. 1), which suggested that there were four major clumps of gas in the ejecta. Probably there was one more minor clump of gas in the ejecta, because a step was seen on the blueward wall of each emission, and weak emission peaks were seen on the blue-ward edges of the emissions of Hδ and Hϵ. The emissions of the last clump strengthened much and appeared as the bluest emission peaks of H I and He I lines by April 2 (Fig. 2). The blue-shifts of the new emission peaks with respect to the line centre were about -1920 km s^{-1}. Because the new peaks were found at the bluest part of the emissions, the clump of gas seems to have been ejected along the line of sight towards us.

Optical and infrared light curves showed that fading in V band and brightening in infrared *K* and *L* bands began about ten days after maximum luminosity (Woodward et al. 1992; Harrison & Stringfellow 1994). These phenomena suggest a dust condensation at that time in the circumstellar ambient. Woodward et al. (1992) suggested that a dust condensation occurred on 1991 March 31 or April 1 in an optically thick clump of gas that happened to lie along the line of sight. Our spectra suggest that a clump of gas was ejected along the line of sight towards us, probably several days earlier than March 31. At the present time we do not know whether the clump of gas proposed by Woodward et al. (1992) was identical with that suggested in our observations. If this was the case, the dust condensation should have occurred in a few days after the ejection of the clump of gas. Detailed studies, beyond the scope of this work, are required to understand whether such a rapid dust condensation is possible.

Table 2. Relative intensities of prominent emission lines of V838 Her on 1991 April 2.

λ_{obs} (Å)	Int.	ident.
3966	26.0:	Hϵ, [Ne III] 3967.5
4051	1.0	C III 24, 4056.1
4101	36.2	Hδ
4206	0.8	C IV 11, 4217
4248	2.8	C II 6, 4267.0, 4267.3
4341	47.5	Hγ
4467	5.9	He I 4471
4611	2.9	N II 5, 4607.2, 4613.9
4647	7.5	N III 2, 4640.6, 4641.9, C III 1, 4650.2
4688	4.3	He II 4686
4724	1.2:	He I 4713, [Ne IV] 4720
4861	100	Hβ
4934	1.9:	He 1 4922, Fe II 4924
5027	7.2	C IV 3, 5021,5023, He I 5016, Fe II 5018
5076	1.1:	Si II 5, 5056?
5167	2.1	Fe II 42, 5169.0
5314	0.7	Fe II 49, 5316.6
5468	0.8	N II 2, 5462.6
5675	3.5	N II 3, 5679.6, C III 2, 5696.0
5796	1.4:	C IV 1, 5801.5, 5812.1
5872	20.2	He I 5876, C III 20, 5871.6, 5894.1
6129	0.7	C III 13, 6154.4, 6156.6
6268	0.2	blue peak of [S III] 6310
6353	6.2	Si II 2, 6341, 6371 [S III] 6310
6559	435	Hα
6672	5.0:	He I 6678
7060	13.2:	He I 7065, C II 20, 7115

Notes. The effect of the interstellar extinction is corrected by $E(B-V) = 0.53$.

5. Helium abundance

Intensities of prominent emission lines relative to Hβ = 100 are measured in the spectra obtained on 1991 April 2, where the interstellar extinction is corrected by $E(B-V) = 0.53$ (Kato et al. 2009). The results are given in Table 2. The observational errors in the intensities are about 10%, and the values of larger errors are denoted by a colon.

Using the intensities of the emission lines of He I 4471, and He II 4686 relative to Hβ, the helium abundance in the ejecta were estimated. The other He I lines were not used, because He I 5876 was blended with C III 20, 5871.6 and 5894.1, He I 6678 was blended with Hα, and He I 7065 was blended with C II 20, 7115. The formula to derive the helium abundance is presented by Iijima (2006). The effect of the collisional excitation of the He I line was corrected using the formula of Peimbert and Torres-Peimbert (1987) at T_e = 10 000 K and $N_e = 10^8$ cm^{-3}. We estimated the abundances as $N(\mathrm{He}^0) = 0.107$ and $N(\mathrm{He}^+) = 0.004$, namely $N(\mathrm{He}) = 0.11 \pm 0.01$. Our result is slightly lower than those obtained by Schwarz et al. (2007), i.e., 0.14 ± 0.01.

The bluest peaks were higher than the others in the He I lines (Figs. 2–4), while they were not the highest peaks in the H I lines (Figs. 2, 4). These results, however, do not necessarily mean a higher helium abundance in the new ejecta. When the electron density in nebulosity is high, the collisional excitation plays an important role in He I lines (Clegg 1987; Peimbert & Torres-Peimbert 1987), and its efficiency depends on the electron temperature. If the electron temperature in the new ejecta were higher than those in the other parts of the ejecta by 1000 degrees, the high emission peaks of the He I lines would be possible even with the same helium abundance. At the present time, we are not able to estimate the electron temperatures of the individual clump of gas precisely. Thus we can not decide whether the high emission peaks in the He I lines were due to a higher helium abundance or a higher electron temperature.

6. Concluding remarks

Because of the very fast fading, we observed only three nights of this nova. However, even with these scarce data, we noticed some interesting phenomena which were not reported in the previous works.

The variations of the profiles of the emission lines of H I and He I between 1991 March 31 and April 2 suggest that a clump of gas was ejected along the line of sight towards us. The dust condensation started at nearly the same time in a clump of gas, which happened to lie along the line of sight (Woodward et al. 1992). If these two clumps of gas were identical, the dust should have condensed in a few days after the ejection of the clump.

New identifications are proposed for some emission lines (Sect. 3). The emission lines of carbon ions, which were unfamiliar in the spectra of usual classical novae, were detected in this object. It will be necessary to take into account the unusually intense emission lines of carbon ions in the analyses of the chemical abundance of this object, because for example some He I lines were probably blended with those of carbon ions.

Acknowledgements. We are grateful to Profs. M. Kato and I. Hachisu for the useful discussions. Thanks are also due to Prof. R. Barbon for the careful reading of the manuscript and useful suggestions.

References

Alcock, G. 1991, IAU Circ., 5222
Chandrasekhar, T., Ashok, N. M., & Ragland, S. 1992, MNRAS, 255, 412
Clegg, R. E. S. 1987, MNRAS, 229, 31p
Harrison, T. E., & Stringfellow, G. S. 1994, ApJ, 437, 827
Iijima, T. 1991, IAU Circ., 5236
Iijima, T. 2006, A&A, 451, 563
Iijima, T., & Nakanishi, H. 2008, A&A, 482, 865
Ingram, D., Garnavich, P., Green, P., & Szkody, P. 1992, PASP, 104, 402
Kato, M., Hachisu, I., & Cassatella, A. 2009, ApJ, 704, 1676
Kidger, M. R., & Martinez-Roger, C. 1993, A&A, 267, 111
Leibowitz, E. M., Mendelson, H., Mashal, E., Prialnik, D., & Seitter, W. C. 1992, ApJ, 385, L49
Lynch, D. K., Hackwell, J. A., & Russell, R. W. 1992, ApJ, 398, 632
McLaughlin, D. B. 1960, in Stellar Atmospheres, ed. J. L. Greenstein (The University of Chicago Press), 585
Matheson, T., Filippenko, A. V., & Ho, L. C. 1993, ApJ, 418, L29
Meinel, A. B., Aveni, A. F., & Stockton, M. W. 1968, Catalog of Emission Lines in Astrophysical Objects, Optical Sciences Center and Steward Obs. (Tucson: The University of Arizona)
Moore, C. E. 1959, A Multiplet Table of Astrophysical Interest, US Dept. of Commerce, Office of Technical Services, Washington DC.
Peimbert, M., & Torres-Peimbert, S. 1987, Rev. Mex. Astron. Astrofis., 14, 540
Sanford, R. F. 1945, ApJ, 102, 357
Schwarz, G. J., Shore, S. N., Starrfield, S., & Vanlandingham, K. M. 2007, ApJ, 657, 453
Sugano, M. 1991, IAU Circ., 5222
Vanlandingham, K. M., Starrfield, S., Wagner, R. M., Shore, S. N., & Sonneborn, G. 1996, MNRAS, 282, 563
Vanlandingham, K. M., Starrfield, S., & Shore, S. N. 1997, MNRAS, 290, 87
Williams, R. E., Phillips, M. M., & Hamuy, M. 1994, ApJS, 90, 297
Woodward, C. E., Gehrz, R. D., Jones, T. J., & Lawrence, G. F. 1992, ApJ, 384, L41