Contrib. Astron. Obs. Skalnaté Pleso **43**, 330 – 337, (2014)

Photometry and spectroscopy of the classical nova V339 Del (Nova Del 2013) in the first month after outburst

D. Chochol[1], **S. Shugarov**[1,2], **T. Pribulla**[1] **and I. Volkov**[2]

[1] *Astronomical Institute of the Slovak Academy of Sciences 059 60 Tatranská Lomnica, The Slovak Republic, (E-mail: chochol@ta3.sk)*

[2] *Sternberg State Astronomical Institute, Universitetskij Prosp. 13, Moscow 119992, Russia*

Received: November 7, 2013; Accepted: January 3, 2014

Abstract. The V and B light curves of the classical nova V339 Del, discovered on August 14, 2013, are presented. The V light curve of the nova was used to estimate the times of decline from brightness maximum $V = 4.4$ mag, reached on August 16.47, 2013, as $t_{2,V} = 10$ days, $t_{3,V} = 18$ days, so it can be classified as a fast nova. We determined the basic parameters of the nova: absolute magnitude at maximum $M_{V,max} = -8.70 \pm 0.03$, interstellar extinction $E(B-V) = 0.184 \pm 0.035$ and distance $d = 3.2 \pm 0.3$ kpc. The echelle spectroscopy of the nova obtained on August 15 and 17, 2013 with the 0.6-m Cassegrain telescope at the Stará Lesná Observatory is discussed.

Key words: novae – photometry – spectroscopy

1. Introduction

Classical novae are cataclysmic variables with 6 to 19 mag brightness increase, caused by a thermonuclear runaway event on the surface of a white dwarf. They arise in close binaries with orbital periods of a few hours, consisting of a red dwarf filling up its Roche-lobe and a mass-accreting white dwarf. After the outburst, the photosphere of the white dwarf component of the nova expands to supergiant dimensions and engulfs the binary. Due to a strong wind, a large part of the envelope is ejected and the photospheric radius shrinks.

Classical novae can be divided according to their photometric and spectroscopic appearance to fast and slow. Classification is usually based on a time interval in which a nova fades by 2 or 3 magnitudes (t_2, t_3) from its maximum brightness. The fast super-Eddington novae ($t_2 < 13$, $t_3 < 30$ days) have smooth light curves with well-defined maxima. They may be He/N, "hybrid" Fe II or Fe II novae in the case of a slower evolution. The slow Eddington novae ($t_2 > 13$, $t_3 > 30$ days) have structured light curves and many of them have standstills at maximum and dust formation at later stages. They belong to the Fe II spectroscopic type (Downes, Duerbeck 2000).

2. Discovery and first spectroscopy

Classical nova V339 Del (Nova Delphini 2013) was discovered by Koichi Itagaki (2013) on 2013 August 14.584 at mag 6.8 at the coordinates $\alpha_{2000} = 20^h23^m30\overset{s}{.}73$, $\delta_{2000} = 20°46'04\overset{''}{.}1$. The variable, preliminary designated as PNV J20233073+2046041, was named V339 Del by Samus (2013). The nova reached the brightness maximum $V_{max} = 4.4$ and $B_{max} = 4.76$ on 2013 August 16.47 (this paper). Denisenko (2013) found a nova precursor as the blue star USNO-B1 1107-0509795 (B = 17.2 - 17.4 mag) at position $\alpha_{2000} = 20^h23^m30\overset{s}{.}713$, $\delta_{2000} = 20°46'03\overset{''}{.}97$, so the total outburst amplitude was $\sim$ 12.6 mag in B.

The first optical spectrum of V339 Del, taken by Darnley *et al.* (2013) by the 2m robotic Liverpool Telescope on La Palma at August 14.909, contained strong Balmer series emission, exhibiting P Cygni profiles, suggesting an eruption of the classical nova. Shore *et al.* (2013 a) reported high dispersion spectroscopy obtained on Aug. 14.87 with the 2m Ondřejov telescope. The P Cyg H_α profile extended from -2300 $\mathrm{km\,s^{-1}}$ to 2400 $\mathrm{km\,s^{-1}}$. Tomov *et al.* (2013) reported echelle spectroscopy taken by a 60/90 cm Schmidt-Cassegrain telescope in Torun and coude spectroscopy with the 2m RCC telescope at the Rozhen Observatory between Aug. 14.88 and Aug. 15.08. They measured radial velocity at the minima of the P Cyg absorptions of Balmer lines to be about -1600 $\mathrm{km\,s^{-1}}$. The H_α emission shows a flat top. Weaker lines of Fe II, He I, Si II and Mg II were present, some of them with P Cygni profiles. Radial velocities of metallic absorptions were about -850 $\mathrm{km\,s^{-1}}$. Equivalent width of the interstellar Na I line suggests $E(B-V) \sim 0.17$. Low resolution spectra obtained by Tarasova (2013) on Aug. 15.8 exhibited two emission components of the H_α line with the radial velocity -310 and 340 $\mathrm{km\,s^{-1}}$. The high resolution spectra of the nova, taken between Aug. 14.84 - 16.86 by Munari *et al.* (2013) with Varese 61cm and Asiago 1.82m telescopes, allowed to determine the heliocentric RV of interstellar Ca II and Na I lines to be -2.6(2) $\mathrm{km\,s^{-1}}$ and to measure the equivalent width of Na I line as 0.3945(30) Å, which corresponds to a reddening $E(B-V) = 0.182$, following the calibration by Munari, Zwitter (1997). The spectra of the nova exhibited: i) rapid and profound changes of the line profiles on a time scale of hours, ii) the flat topped H_α emission on Aug. 15.83, iii) weakening of the He I lines and steady decline of the Balmer emissions during the rise to maximum.

Shore *et al.* (2013 b, c) described continuing optical spectroscopy of V339 Del with the 2.6m Nordic Optical Telescope Fibre-fed Echelle Spectrograph (R $\sim$ 67000), the Ondřejov Observatory 2m Perek telescope coude spectrograph (R = 18000) and a variety of grating and echelle spectrographs of the ARAS group with resolution between 580 - 11000. The spectra are presented at the ARAS consortium web-site. On Sept. 23, 2013 altogether 734 spectra of V339 Del were available. Spectral changes of the nova were faster during the first two weeks than afterwards. All emission lines have shown the same multiple-peaked line profile. A bipolar ejection was suggested.

Rudy *et al.* (2013) reported 0.45 - 2.5-micron spectroscopy by the 3m Shane reflector at Lick Observatory. The object is an "Fe II" type nova. The strong emission lines of C I, N I, O I and Ca II are present. The interstellar reddening derived from O I lines is E(B-V) = 0.33(10).

3. Our observations

3.1. Photometry

Our CCD V, B observations of the nova in August and September 2013 were taken with the SBIG ST10-XME camera mounted in the focus of a 180 mm telephoto lens. The observations in September were taken also by the CCD camera mounted in the Cassegrain focus of the 0.6m telescope at the Stará Lesná Observatory and by a one-channel UBV-photometer of Volkov's construction, equipped by an EMI-9789 photomultiplier, mounted in the Cassegrain focus of the the Zeiss-600 telescope of the Crimean Astrophysical Observatory at Mt. Koshka. In Fig. 1 we present our individual V CCD observations (black symbols) together with the mean AAVSO V CCD data (gray symbols). During Aug. 14-19, 2013 we used 6 hours means and after August 20, 2013 daily means. In Fig. 2, showing the V, B light curves and $B - V$ colour index evolution, our individual V, B observations were also included into the 6 hours and daily means. The increase of $B - V$ colour index (reddening of the object) after the brightness maximum on Aug. 16, caused by an expansion of the nova envelope, is well visible.

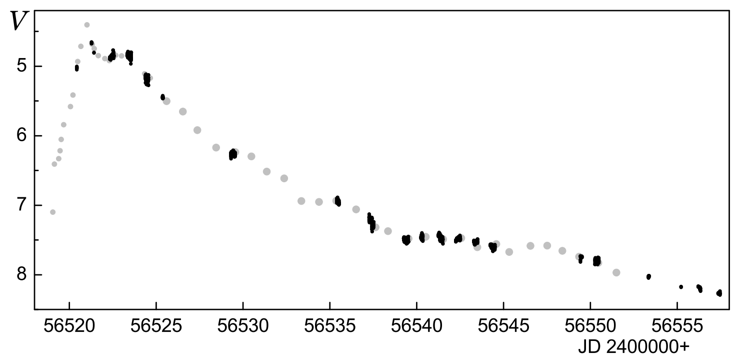

Figure 1. A V light curve of the nova.

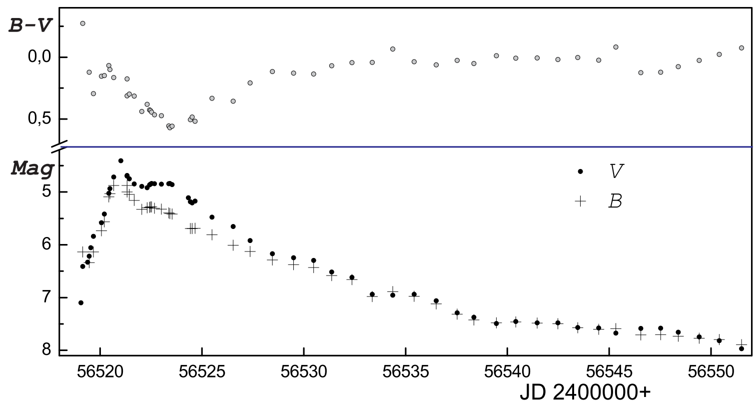

Figure 2. V and B light curves and $B-V$ colours of the nova.

3.2. Spectroscopy

Our spectra of V339 Del were obtained on August 15.98 and 17.83, 2013 by the eShel optical fiber fed echelle spectrograph (R = 11000) attached to the 0.6-m Cassegrain telescope at the Stará Lesná Observatory. The first spectrum corresponds to an early type supergiant atmosphere of the burning white dwarf, expanding with the velocity of $650\,\mathrm{km\,s^{-1}}$, which we derived from the RV shift of the He I absorptions (6678 Å, and 5875 Å). The second spectrum obtained on Aug. 17 reflects the expanding envelope of the nova.

As seen in Fig. 3, the main changes in the spectra can be described as follows:
1) Disappearance of He I 4922, 5016, 5875 and 6678 Å absorption lines.
2) H_α emission on Aug. 15.98 exhibited two peaks as reported by Tarasova (2013), while on Aug. 17 it had a flat top.

4. Basic parameters of the nova

The basic parameters of the nova V339 Del were determined using the photometry, presented in Fig. 1. The nova reached maximum on August 16.47 at V_{max} = 4.40(5) mag, found by the 5th order polynomial fit of the individual AAVSO, Burlak et al. (2013) and our data. Waagen (2013) also noticed that the nova brightened to visual magnitude 4.4. A similar fit to the B data, from the same sources, provided $B_{max} \sim 4.76(15)$ mag. The V light curve was used to find the rate of decline $t_{2,V}$ = 10 days, $t_{3,V}$ = 18 days, which allowed to classify the nova as a fast one. We estimated the absolute magnitude of the nova at maximum MV_{max} using the MMRD (Magnitude at Maximum – Rate of Decline) relations:

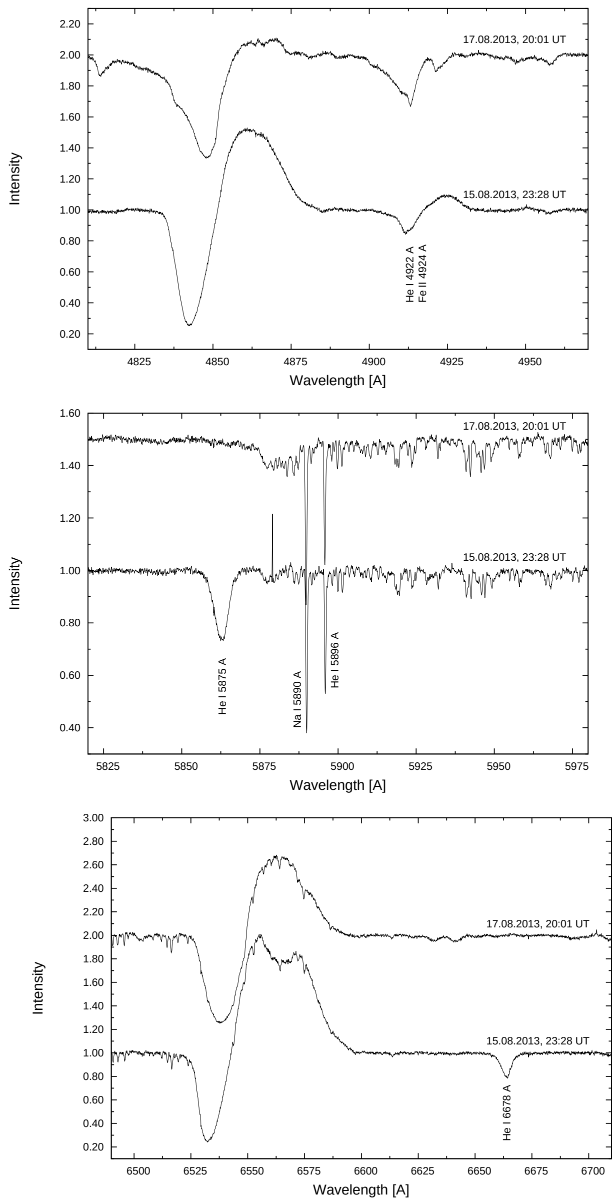

Figure 3. The spectra of the nova taken on August 15 and 17, 2013.

a) absolutely calibrated MV_{max} - t_2 relation of Della Valle, Livio (1995)

$$MV_{max} = -7.92 - 0.81 \arctan \frac{1.32 - \log t_2}{0.23}, \quad (1)$$

b) MV_{max} - t_2 relation of Downes, Duerbeck (2000),

$$MV_{max} = (-11.32 \pm 0.44) + (2.55 \pm 0.32) \log t_2, \quad (2)$$

c) MV_{max} - t_3 relations of Schmidt (1975) and Downes, Duerbeck (2000)

$$MV_{max} = -11.75 + 2.5 \log t_3, \quad (3)$$

$$MV_{max} = (-11.99 \pm 0.56) + (2.54 \pm 0.35) \log t_3, \quad (4)$$

d) MV_{15} empirical relation of Cohen (1985) revised by Downes, Duerbeck (2000). They found that novae 15 days after maximum have a similar absolute magnitude

$$MV_{15} = -6.05 \pm 0.44. \quad (5)$$

The V magnitude of V339 Del declined by 2.59 mag 15 days after maximum.

We have calculated the following values of MV_{max} using these relations: MV^1_{max} = –8.69, MV^2_{max} = –8.77, MV^3_{max} = –8.61 MV^4_{max} = –8.80, MV^5_{max} = –8.64 with the unweighted mean: MV_{max} = -8.70 ±0.03.

Downes, Duerbeck (2000) found that novae at maximum have an intrinsic colour index $(B-V)^{in}_{max}$ = 0.25±0.05, so MB_{max} = -8.45 ±0.08. Using this value and the formula given by Livio (1992)

$$MB_{max} = -8.3 - 10.0 \log(M_{wd}/M_\odot), \quad (6)$$

we can estimate the mass of the white dwarf component of the nova as M_{wd} = 1.04±0.02 $M_\odot$.

The interstellar extinction can be found:

1) From the comparison of the observed colour index at maximum $(B-V)_{max} = 0.36$, affected by extinction, with the intrinsic colour index $(B-V)^{in}_{max}$ = 0.25. We thus find the colour excess $E(B-V) = 0.11$.

2) From the relation of van den Bergh, Younger (1987), who found that novae two magnitudes below maximum have an unreddened colour index of

$$B - V = -0.02 \pm 0.04. \quad (7)$$

The observed colour of V339 Del two magnitudes below maximum is $B-V$ = 0.11, which thus yields $E(B-V) = 0.13$.

3) From equivalent width of the interstellar Na I 5890 Å line Tomov *et al.* (2013) and Munari *et al.* (2013) found $E(B-V) = 0.17$ and $E(B-V) = 0.182$, respectively.

4) From the flux ratios of O I (8446 Å and 11287 Å) lines Rudy *et al.* (2013) found $E(B-V) = 0.33 \pm 0.1$.

The mean value of the reddening found from the data mentioned above is $E(B-V) = 0.184 \pm 0.035$. Corresponding absorption in V is $A_V = 0.57 \pm 0.11$. The distance modulus of the nova is $V_{max} - MV_{max} = 13.10 \pm 0.08$, which yields a corresponding distance to the nova of 3.2±0.3 kpc.

Using the classification scheme of nova light curves (Downes, Duerbeck 2000), we can classify V339 Del as a fast super-Eddington nova of Fe II type.

5. Rapid variablity and possible orbital period

In September 2013 we monitored the nova in the V, B passbands using the photoelectric and CCD photometry with one minute time resolution. Total time of observations of the nova was 56.7 hours in 13 nights between JD 2456537.265 and JD 2456557.474. We obtained 2380 individual observations. The longest night run lasted 6.65 hours. During the night runs the light curves show rapid variability combined with possible orbital period variations. We removed the declining trend of the nova and tried to find the periodicity in residuals using the Fourier period analysis. We found the best period 6.43 hours as well as its one day alias. The phase diagram for the combined V and B data, presented in Fig. 4, was constructed using the ephemeris HJD(Max) = 2456539.20 + 0.26792 ×E. The brightness variations could reflect the orbital motion in the binary system V339 Del.

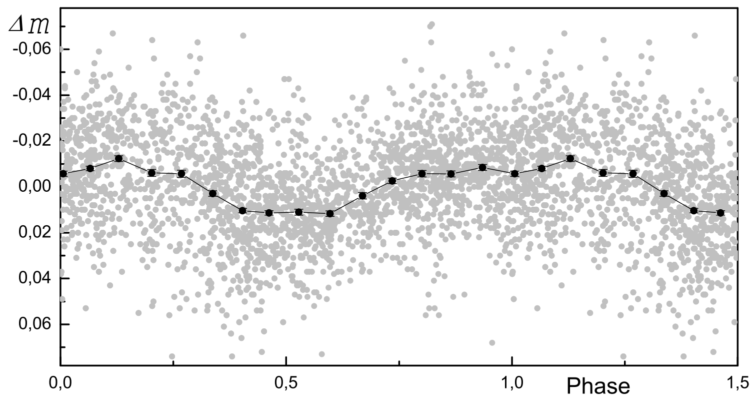

Figure 4. The phase diagram of brightness variations for the combined V and B data, after the removal of the declining trend of the nova.

Acknowledgements. We acknowledge with thanks the variable star observations from the AAVSO International Database contributed by observers worldwide and used in this research. This study was supported by the VEGA grants 2/0094/11, 2/0002/13 and RFBR research projects No. 11-02-01213a and 14-02-00825. This article was supported by the realization of the Project ITMS No. 26220120029, based on the supporting operational Research and development program financed from the European Regional Development Fund.

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