SPECTRAL EVOLUTION OF NOVA DEL 2013

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Abstract. We investigate the spectral evolution of the cataclysmic stellar object V339 Delphini (Nova Del 2013), using observations made at "Amiral Vasile Urseanu" Astronomical Observatory (A92) in *Bucharest*, and Stardreams Observatory (L16) in *Vă lenii de Munte*, Romania, between August 2013 and October 2014. Starting with the official announcement on 14 August 2013, we obtained spectroscopic and photometric data using 0.3 m Schmidt-Cassegrain and respectively 0.2 m Ritchey- Chretien telescopes equipped with Alpy 600 spectrograph. We determined that V339 Del is a Fe II type nova with strong Fe II and P Cygni lines in the aftermath of the cataclysmic event, variable Balmer and Fe II lines intensities and a continuous but slow spectral evolution.

Key words: stars – novae – cataclismic variables – spectroscopy.

1. INTRODUCTION

Nova Delphini 2013 was discovered by Koichi Itagaki on 14.584 August 2013 (where the UT time is expressed in fraction of the day), at 6.8 optical magnitude. The discovery was announced by Central Bureau Electronic Telegrams (CBET) No. 3628. Its progenitor was identified by Denisenko *et al.* (2013) as the blue star USNO-B1.0 1107-0509795, and the first spectra were reported by the observers of Astronomical Ring for Access to Spectroscopy (ARAS)* on 14.909 August 2013.

The first spectra were dominated by strong Balmer and Fe II lines, most of them with a pronounced absorption / emission components (P Cyg type profiles) typical for a nova in the optically thick fireball phase while later spectra revealed the transition to the nebular phase. The P Cyg profile is a typical example of a mixed absorption and emission lines spectrum which is observed in most nova explosions. Like in P Cyg case, we can observe in our spectra the presence of absorption and

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*`http://www.astrosurf.com/aras/`

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emission lines during the first days of explosion which reveals the ejecta evolution after the cataclysmic moment. This effect is a real marker for expanding star material (Walker, 2013).

In this article we present the spectral and photometric data acquired between 15 August 2013 and 31 October 2014. Section 2 describes the observation circumstances and the data reduction procedures. The spectral evolution is analyzed in section 3.

2. OBSERVING TECHNIQUES AND DATA PROCESSING

Our spectroscopic and photometric observations began on 15 August 2013 (one day after the discovery of the nova) and continued until 31 October 2014. The observations were made using a 0.3 m Meade Schmidt-Cassegrain telescope, with a focal length of 1900 mm (using a focal reducer) and a 0.2 m Ritchey-Chretien telescope, with a focal length of 1625 mm. We used the QHY6 and Atik 314L+ mono CCD cameras for spectral images acquisition together with an Alpy 600 spectrograph and silt widths of 25 μm and 23 μm, respectively. The wavelength interval covered was 400 to 690 nm, with an average dispersion of 0.40 nm/ pixel. A total of 14 spectra were acquired. The details of the observational equipment are presented in Table 1 and the observing log is shown in Table 2.

Our observational sequence consisted first in Nova Del 2013 spectrum acquisition followed by a nearby reference star spectrum. As a reference star we always used Altair (HIP 97649), having an A7V spectral type (Gray *et al.*, 2003), useful for Balmer lines identification and spectrum calibration. The exposure times varied according to the brightness of the object. The Nova Del 2013 spectrum was acquired with 1-30 seconds exposure time and the reference star spectrum with 1-5 seconds exposure time. The spectrum taken in October 2014 required 1 hour exposure time due to the low brightness of the object (V = 12.6). At the end of each session dark and flat frames were acquired for image calibration.

The data reduction and the analysis of the spectral lines were made using MaximDL and Octave software. The preprocessing of the data involved dark-frames subtraction, flat field normalization and bad pixel corrections. These steps were performed using the standard procedures of MaximDL. A selection of the images was

Table 1

Description of the telescopes and cameras used.

Telescope Type	Aperture [m]	Focal Ratio	Camera	Array [pixels]	Pixel Size [μm]
Schmidt-Cassegrain	0.3	6.3	QHY6	795 x 596	6.25 x 6.25
Ritchey- Chretien	0.2	8	Atik314L+	1391x1024	6.45 x 6.45

Table 2

The observing log: the date, the Julian Day, the slit width of the Alpy 600 spectrograph, the telescope and the camera used, the exposure time, the altitude and the air mass of the target are shown.

Date	Julian Date	Slit [μm]	Instrument	Itime [sec]	Altitude [°]	Air mass
08-15-2013	2456520.315	25	SC	10	60	1.2
08-16-2013	2456521.438	25	SC	10	59	1.2
08-17-2013	2456522.364	25	SC	20	66	1.1
08-18-2013	2456523.364	25	SC	20	66	1.1
08-19-2013	2456524.382	25	SC	10	65	1.1
08-20-2013	2456525.373	25	SC	10	66	1.1
08-23-2013	2456528.438	25	SC	10	56	1.2
08-26-2013	2456531.351	25	SC	10	66	1.1
09-04-2013	2456540.400	25	SC	20	57	1.2
09-21-2013	2456557.329	25	SC	20	61	1.1
09-25-2013	2456561.342	25	SC	20	57	1.2
10-04-2013	2456570.326	25	SC	30	55	1.2
10-08-2013	2456574.322	25	SC	30	54	1.2
10-30-2014	2456962.290	23	RC	3600	46	1.4

made based on visual inspection. The images with poor SNR (signal to noise ratio) or those affected by tracking errors were removed. For further computation a dedicated pipeline was designed in Octave. The choice of the software was made based on the fact that it has dedicated routines to handle arrays and matrices, and for numerical processing. This pipeline involves the following steps (*e.g.* Popescu *et al.* (2012)): 1) the extraction of the raw spectrum from the ".fits" images; 2) the wavelength calibration; 3) the removing of the optical system wavelength dependence sensibility. These steps are described below. For the first step, the following tasks were executed: a) identification of the spectrum in the spectral images based on the trace with the pixels with the highest counts. In this way an oblique spectra (referred to CCD orientation) can be also correctly extracted and processed. b) the spread of the spectrum (characterized by the FWHM), the signal to noise ratio and the bias level are computed; c) the spectrum is extracted by taking the width equal with 2.5 x FWHM (full width at half maximum) of the spectrum; d) the sky level is considered by taking a pixel trace parallel to the spectrum trace at 25 pixels (≈5xFWHM of the spectrum) distance of it. The sky level is subtracted from the spectrum. The wavelength calibration was made relative to the hydrogen lines - H_α, H_β, H_γ, considering the absorption lines for the calibration star and the emission lines for the Nova. The wavelength calibration was made for each spectrum, to avoid mismatches caused by the "ad-hoc" equipment setup. The optical system (including the CCD) has a sensitivity that varies significantly with the wavelength. In order to correct this effect, we acquired spectra of a standard star (α Aql Altair). The optical system sensitivity variation over the wavelength was obtained by dividing the raw spectrum of Altair with a black body radiation curve corresponding to T = 7483 K (the effective temperature of Altair) and fitting the result with a fifth order polynomial curve. The spectrum of the nova was divided by this resulting curve. The spectra were calibrated and normalized in order to characterize the flux intensity and spectral lines identification.

3. RESULTS

The first spectra showed prominent Balmer and Fe II lines, together with strong P Cygni profiles. This allowed us to determine from the beginning that Nova Del 2013 is an iron type nova. The novae belonging to the Fe II class are generally the moderately fast to the slow novae, with their spectra evolving over timescales of weeks.

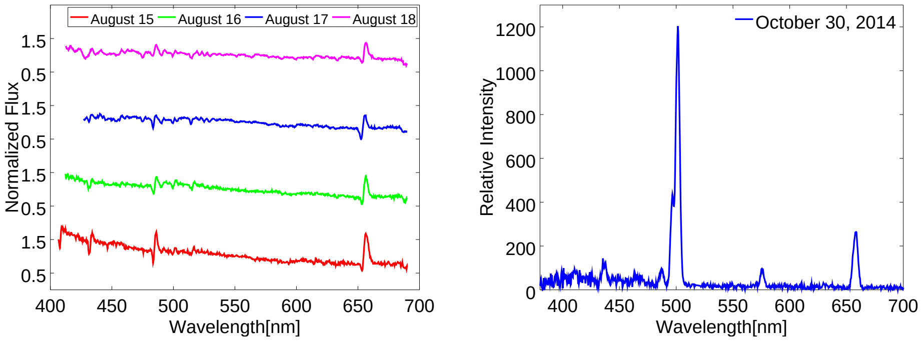

Fig. 1 – Nova Del 2013 spectra: left – Spectra obtained in August 2013, showing the fireball stage; right – spectrum obtained in October 2014.

In Fig. 1 and 2 the evolution of the spectra between August 15^{th} and September 25^{th}, 2013 shows major modifications. During the first few days of the outburst, the most prominent features are the Balmer series (H_α, H_β, H_γ), Fe II emission lines at 462.9 nm, 492.4 nm, 516.9 nm and a strong blue continuum. A common feature of Fe II type novae is the presence of emission-absorption lines, called P Cygni type lines right after the explosion. These are caused by the Doppler effect due to the expansion of the fireball. We observed these features between August 15^{th} and August 18^{th}, 2013.

After 18 August 2013 the absorption components of P Cygni profiles are no longer apparent and we can observe a progressive increase in intensity of Balmer lines relative to the continuum, especially the Hydrogen alpha line.

Starting with September 2013, as the nova progressed further into the nebular phase with a more optically transparent envelope, we can notice the appearance of several emission lines: N III at 464 nm, N II at 575.5 nm, He I at 587.56 nm, O I

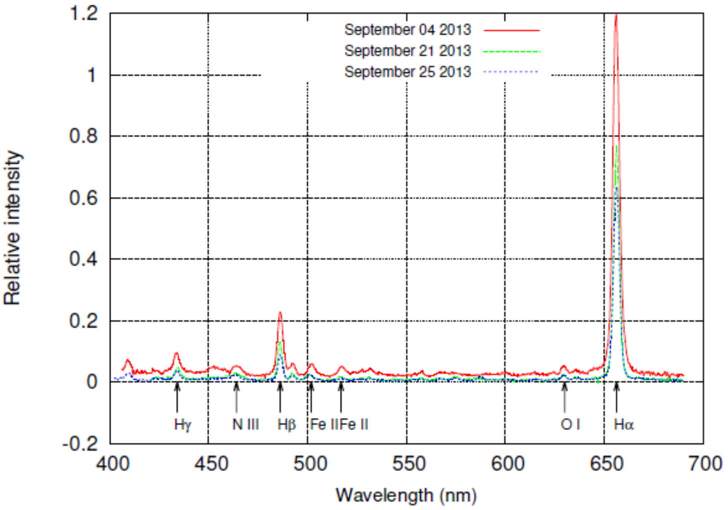

Fig. 2 – Nova Del 2013 spectrum evolution in September 2013. The continuum was removed using a fit with a polynomial function as explained into the text of this article.

at 557.7 nm and 630 nm (Fig. 2). During October 2013 the OIII line at 500.7 nm becomes noticeable. This line will remain prominent until the end of our observation series, in October 2014 (Fig. 1). Overall, the identified emission lines and date of first detection in our spectra are presented in Table 3. The evolution of Fe II line is shown in Fig. 3.

The spectrum recorded in October 2014 (Fig. 1), more than one year after the outburst shows significant changes, as it matches a planetary nebula spectrum in early stages. On this spectrum we can clearly identify the O III lines at 436.3 nm and 500.7 nm, the N II line at 575.5 nm and a broadened H_α line (due to high expansion velocity).

3.1. MEASURING THE EJECTA VELOCITY

We determined the radial velocity of the ejecta at different depths based on H_α and H_β absorption lines in spectra taken between 15 August and 18 August 2013 and the Doppler formula (Eq. 1).

$$v_r = \frac{\Delta_\lambda}{\lambda_0} c \tag{1}$$

The calculated radial velocity based on the H_α absorption line span the interval [-1400; -1750] km s^{-1}, while the radial velocity measurement based on the H_β absorption line span the interval [-1000;-1200] km s^{-1}, as depicted in Fig. 3. As

Table 3

Identified emission lines.

Wavelength [nm]	Emission line	Date of first detection in our spectra
434.047	$H\gamma$	15-Aug-2013
462.9	Fe II	16-Aug-2013
464	N III	20-Sep-2013
486.133	H_β	15-Aug-2013
492.4	Fe II	15-Aug-2013
500.7	O III	08-Oct-2013
501.8	Fe II	15-Aug-2013
516.9	Fe II	15-Aug-2013
557.7	O I	04-Sep-2013
575.5	N II	21-Sep-2013
587.56	He I	21-Sep-2013
630	O I	04-sep-2013
656.285	H_α	15-Aug-2013

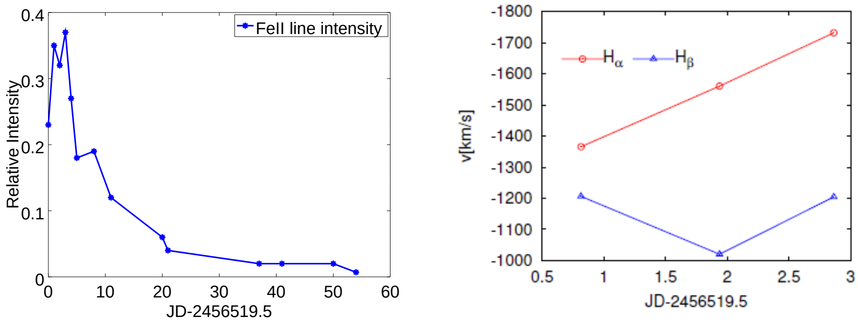

Fig. 3 – Left - the 501.8 nm Fe II line intensity evolution over time. Right - the radial velocity based on H_α and H_β profiles.

the H_β line is weighted toward the inner ejecta, we have thus obtained information about the structure and dynamics of the ejecta, the outer layers being less dense and expanding faster compared to the inner layers.

We also calculated an expansion velocity between 1300 km s^{-1} and 1800 km s^{-1} from the FWHM value (corrected for the instrumental broadening) of the emission component of H_α line:

$$v_r = FWHM_{korr}\frac{c}{\lambda} \tag{2}$$

$$FWHM_{korr} = \sqrt{FWHM^2_{measured} - FWHM^2_{instrument}} \tag{3}$$

3.2. PHOTOMETRIC AND SPECTROPHOTOMETRIC EVOLUTION

We performed photometric measurements using the QHY6 CCD camera and a Johnson V standard photometric filter starting with 15 August2013 up to 18 May 2014. Starting with 15 August there is a sharp increase in brightness, with the observed peak at 4.99 magnitude on 17 August 2013 at 21:14 UT (compared to V = 4.3 magnitude on 16.45 August according to Munari *et al.* (2013)). After this date the nova rapidly decreased in brightness continuously, as seen in Fig. 4. Thus, we can conclude that Nova Del 2013 is a type ”NA” fast nova. V-band spectrophotometric data was calculated from the spectra by integrating the spectral intensity data corresponding to Johnson V profile wavelengths. As can be seen Fig. 4, the computed spectrophotometric data matches the V-Band photometric data directly acquired, which further confirms the accuracy of the spectral data.

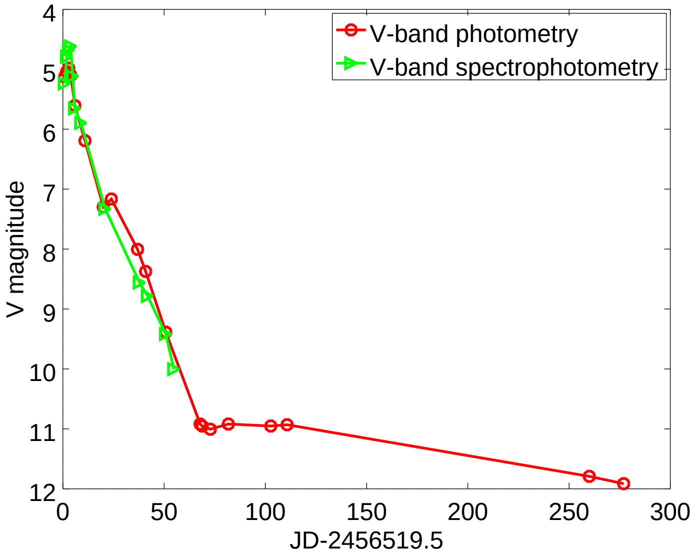

Fig. 4 – V-band photometric and spectrophotometric data.

4. CONCLUSIONS

We used spectroscopy as a powerful observation tool in order to reveal the physical characteristics of Nova Del 2013, and to explore its evolution from the initial phase immediately after the explosion, to the nebular phase one year later.

From the initial observations we determined that Nova Del 2013 has a ”Fe II” spectrum, which indicates its origin in a circumbinary envelope of gas from the white dwarf's companion star.

We were also able to map the velocity structure of the outer ejecta, and document the spectral evolution and transition from the fireball stage to the nebular stage, with no significant dust formation (421.6 nm CN absorption line is not detectable). Our photometry and spectrophotometry measurements show that after the luminosity peak at V=4.99 magnitude on 17 August, the nova declined rapidly and monotonically in visual brightness by 6 magnitudes in less than 100 days, with no secondary peaks, followed by a slowly declining plateau stage. Therefore, we found that Nova Del 2013 is a very fast type "NA" nova.

REFERENCES

Denisenko, D., Jacques, C., Pimentel, E., Guido, E., Ruocco, N., Howes, N., Masi, G., Schmeer, P., Nocentini, F.: 2013, *IAU Circ.*, **9258**, 2.

Gray, R. O., Corbally, C. J., Garrison, R. F., McFadden, M. T., Robinson, P. E.: 2003, *Astrophys. J.* , **126**, 2048.

Munari, U., Henden, A., Dallaporta, S., Cherini, G.: 2013, *Information Bulletin on Variable Stars*, **6080**, 1.

Popescu, M. and Birlan, M., Gherase, R. M., Sonka, A. B., Naiman, M., Cristescu, C. P.: 2012, *UPB Scientific Bulletin, Series A: Applied Mathematics and Physics*, **3**, 107.

Walker, R.: 2013, *Analysis and Interpretation of Astronomical Spectra*, `http://www.ursusmajor.ch/downloads/analysis-and-interpretation-of-astronomical-sp.pdf` .

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