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Multicolour Photometry and Spectroscopy of the Slow Nova V475 Sct (Nova Scuti 2003)

D. Chochol[1] ⋆, N.A. Katysheva[2], T. Pribulla[1], L. Schmidtobreick[3], S.Yu. Shugarov[2], P. Škoda[4], M. Šlechta[4], A.A. Vittone[5] and I.M. Volkov[2]

[1] Astronomical Institute of the Slovak Academy of Sciences, 059 60 Tatranská Lomnica, Slovakia,
[2] Sternberg State Astronomical Institute, Universitetskij Prosp. 13, Moscow 119992, Russia
[3] European Southern Observatory, Casilla 19001, Santiago 19, Chile
[4] Astronomical Institute of the Academy of Sciences, 251 65 Ondřejov, The Czech Republic
[5] Osservatorio Astronomico di Capodimonte, Via Moiariello 16, 80131 Napoli, Italy

Abstract The $UBVRI$ photometry and 460–900 nm spectroscopy of a classical nova V475 Sct obtained after its outburst in August 2003 is discussed. The nova was classified as a Fe II slow nova with the $t_{2,V}$ = 48 d, $t_{3,V}$ = 53 d. The absolute magnitudes of the nova at maximum $M_V^{\rm max} = -7.16\pm0.15$, $M_B^{\rm max} = -6.96\pm0.39$, the color excess $E(B-V) = 0.69\pm0.05$ and the distance to the nova $d = 4.8\pm0.9$ kpc was determined. Observed 13.4-day periodicity of flares can be explained either by pulsation of the nova envelope or by the mass transfer bursts from the red to the white dwarf probably caused by a periastron passage of the third body. The rapid fade of the brightness, which started 57 days after the maximum, is related to a dust formation in the ejecta of the nova. The early optical spectra display the forest of low ionization emission lines, primarily Fe II and Balmer H, accompanied by two P Cygni absorptions, arising in the inner and outer envelope of the expanding nova shell ejected at brightness maximum and accelerated by continuous stellar wind. The spectrum taken in the nebular stage of the nova, which started in March 2004, shows very strong emission [O III] 495.9 nm and 500.7 nm lines, responsible for discrepancy of the B and V magnitudes determined from observations taken by different instruments. The nebular emission line profiles suggest a non-spherical ejection of the shell.

Key words: stars: novae, cataclysmic variables, circumstellar matter, individual: V475 Sct

1 INTRODUCTION

Outbursts of classical novae are caused by a thermonuclear runaway of a hydrogen–rich material on the surface of a white dwarf accreting matter from a Roche lobe filling red dwarf companion. Classical nova V475 Sct (Nova Scuti 2003) was discovered by Nishimura (see Nakano & Sato (2003)) on August 28.58, 2003, at mag 8.5 at the coordinates $\alpha_{2000} = 18^{\rm h}49^{\rm m}37^{\rm s}.6$, $\delta_{2000} = -9^\circ33'50''.85$ (Yamaoka, 2003). Optical spectra taken by Boeche & Munari (2003) on August 31.97 UT showed a well-developed F2 Ia absorption spectrum with weak emissions of Balmer lines. The nova reached the brightness maximum $V_{\rm max}$ = 8.43 on September 1, 2003. We did not identify the nova precursor on the POSS prints. This sets the outburst amplitude > 12 mag.

⋆ E-mail: chochol@ta3.sk

2 PHOTOMETRIC AND SPECTROSCOPIC OBSERVATIONS

Our photometry consist of *UBV* photoelectric observations obtained by 0.6 m reflector at the Crimean station of the Sternberg Astronomical Institute at Nauchnyj (CN) and 1 m reflector at the Simeiz station of the Crimean Astrophysical Observatory (CS), $UBV(RI)_C$ CCD observations taken with the SBIG ST10-XME camera mounted in the 2.5 m Newton focus of the new 0.5 m reflector at the Stará Lesná Observatory, $UBVRI$ CCD observations taken with portable SBIG ST7, Apogee Ap7p, Pictor–416, VersArray–1300 CCD cameras mounted in the Cassegrain focus of the 1.25 m, 0.6 m, 0.5 m and 0.38 m reflectors at the CN and by Ap47p and Ap7 (with R_C) CCD cameras mounted in the Cassegrain focus of the 0.7 m reflector in Moscow (M). The reduction of the photoelectric and CCD observations was done using the standard procedure. The coefficients for transformation of photoelectric and CCD observations to the international Johnson system were found using the stars in open cluster M67 (Mendoza, 1967).

Our CCD images revealed that V475 Sct is a member of an optical pair. We determined the brightness of its southern component located in an angular distance of $3\overset{''}{.}3$ from V475 Sct from our CCD observations as: U = 17.80(20), B = 17.35(8), V = 16.334(30), R = 15.444(10), I = 14.856(10), R_C = 15.718, I_C = 15.187. In cases when this nearby component and V475 Sct was not resolved (all photoelectric observations and most of the CCD observations), we corrected our data for the light of this component. Due to the different spectral sensitivity of the CCD cameras and different sets of filters used, our observations of V475 Sct were transformed and corrected to the international Johnson $UBVRI$ system using our UBV photoelectric photometry and RI CCD photometry with the Ap7p CCD camera of the 0.6m telescope in CN (reference data). The observations from other instruments were suitably shifted for a constant value (up to a few tenth of magnitude) to be compatible with the reference data. The shifts during the nebular stage of the nova (after JD 2453050) differ from those during the earlier evolutionary stages. For details see Chochol et al. (2005). The $UBVRI$ magnitudes and corresponding color indices of V475 Sct based on our photometric observations taken in 127 nights between August 30, 2003 and November 11, 2004 are shown in Figure 1.

Altogether 11 CCD spectra of V475 Sct were obtained at the Ondřejov observatory between September 15 and 25, 2003, using the 2 m reflector equipped with Coudé spectrograph with the dispersions 0.85 nm/mm (region 475.4–500.6 nm) and 1.7 nm/mm (regions: 547–598.3 nm, 625.7–677 nm, 750.3–801.3 nm and 814.8–865.7 nm). The CCD camera with the chip SITe 2000×800 pixels of the size of 15 micrometers was used. On August 27, 2004, the 480–670 nm spectroscopy of V475 Sct was performed at the 3.6 m telescope at La Silla, Chile, using EFOSC2 with grating 18 and a $0\overset{''}{.}7$ slit. Total observation time was 1h, split in three exposures of 1200 s. A final resolution of 0.39 nm/FWHM was reached. The reduction of our spectra was done with IRAF and SPEFO software (Škoda, 1996).

The 460–900 nm spectroscopy of V475 Sct was obtained between September 2 and October 10, 2003 by the amateur astronomer Christian Buil at Castanet Tolosan (France), using the Takahashi FS-128 5-inch refractor equipped with MERIS spectrograph (sampling of 0.287 nm/pixel) + Audine KAF–0401E CCD camera. The spectra were corrected for the instrumental spectral response. Free data are available on the internet page *http://www.astrosurf.com/buil/us/nscuti*.

3 RESULTS AND DISCUSSION

The basic parameters of the nova V475 Sct were determined using our B and V light curves (Fig. 1). The maximum of the first flare was identified as the principal maximum of the nova and according to our photometric observations it was reached at JD 2452884.25 ($V = 8.43$ mag, $B = 9.33$ mag). The F2 supergiant spectrum taken one day before the maximum suggests that in the principal maximum the expanding atmosphere of the outbursted white dwarf was ejected. The V and B light curves were used to find the rates of decline $t_{2,V} = 48$ days, $t_{3,V} = 53$ days, $t_{2,B} = 50$ days, $t_{3,B} = 58$ days and to estimate the absolute magnitudes of the nova at maximum $M_V^{\max} = -7.16{\pm}0.15$, $M_B^{\max} = -6.96{\pm}0.39$ using the various MMRD relations (Della Valle & Livio, 1995; Downes & Duerbeck, 2000; Livio, 1992; Pfau, 1976). Using the derived $M_B^{\max}$ and the formula given by Livio (1992), we can estimate the mass of the white dwarf in V475 Sct as $M_{\rm wd} = 0.73 \pm 0.07\,M_{\odot}$. The interstellar extinction was derived by different methods:

1) from the comparison of the observed color index at maximum $(B-V)_{\max} = 0.91$, affected by extinction, with the calculated intrinsic color index at maximum $(B-V)^{\rm in}_{\max} = 0.2$. We thus find the color excess $E(B-V) = 0.71$.

2) from the relation of van den Bergh & Younger (1987) who found that novae two magnitudes below maximum have an unreddened color index of $B - V = -0.02{\pm}0.04$. The observed color of V475 Sct two magnitudes below maximum is $B - V = 0.45$, which thus yields $E(B - V) = 0.47$.
3) from the relation of Miroshnichenko (1988) who developed the photometric method to determine the interstellar extinction towards novae. He found that during "stability stage", which occurs not very long after maximum when both $U - B$ and $B - V$ indices do not change systematically, the color excess is given by $E(B - V) = (B - V)_{\rm SS} + 0.11(\pm 0.02)$, where $(B - V)_{\rm SS}$ is the mean color index during the stability stage. In V475 Sct the stability stage lasted from September 15 to September 21, 2003. For $(B - V)_{\rm SS} = 0.61$ we find a corresponding $E(B - V) = 0.72$.
4) from the comparison of the intrinsic color index $B - V = 0.23$ of F2 supergiant (Cox, 2000), as found spectroscopically on August 31.97, with our observed index for the nova of $B - V = 1.08$. This results in $E(B - V) = 0.85$.
5) from the interstellar K I (769.8979 nm) line. Munari & Zwitter (1997) derived a useful relation to estimate extinction from the equivalent width of the interstellar K I line. Our measurement of the EW of the single sharp interstellar component of this line from the Ondřejov spectrum of V475 Sct taken on September 16, provides the value of 0.179, which corresponds to the value of $E(B - V) = 0.70$.

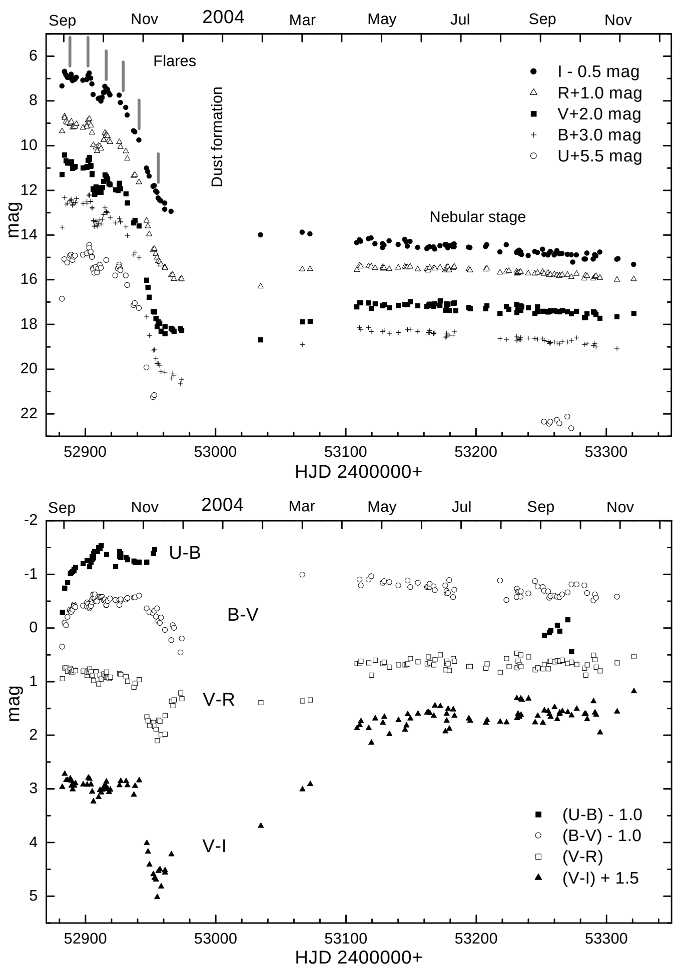

Fig. 1 $UBVRI$ magnitudes (top) and $U - B$, $B - V$, $V - R$, $V - I$ indices (bottom) of V475 Sct.

The mean value of the reddening found from the data mentioned above is $E(B-V) = 0.69{\pm}0.05$. Corresponding absorptions in V and B are $A_V = 2.15{\pm}0.15$ and $A_B = 2.88{\pm}0.21$. The resulting distance moduli of the nova are $V^{\max} - M_V^{\max} = 15.57{\pm}0.15$ and $B^{\max} - M_B^{\max} = 16.28{\pm}0.39$, which yields a corresponding distance to the nova of 4.8±0.9 kpc. Using the classification scheme of nova light curves (Downes & Duerbeck, 2000), we can classify V475 Sct as a slow Eddington nova of Ca type with standstill at maximum and dust formation at later stages.

The periodic maxima of activity (flares) are present on the light curve during the standstill and on the decline. Their existence is independently confirmed by the visual AAVSO light curve (see *www.aavso.org*). In our light curves, the brightness maxima were detected at JD 2452000+ (888.3; 902.2; 916.2; 929.2; 941.3; 956.2), clearly indicated in the $V-I$ index. The following ephemeris, found by linear regression, is valid for the brightness maxima: $JD_{\max} = 2\,452\,875.3\,(\pm 0.7) + 13.4\,(\pm 0.2) {\times} E$.

The detected maxima of activity can be caused either by pulsation of the nova envelope as discussed by Schenker (1999) or by mass transfer bursts from the red to the white dwarf caused by the periastron passage of a third body in the system, which could also have triggered the outburst of the nova around JD 2452875. The behavior of V475 Sct is similar to the nova V723 Cas, where the flares repeated with a 180-day period (Chochol & Pribulla, 1998). Chochol et al. (2000) explained the flares by non-degenerate flashes on the hot white dwarf induced by mass transfer bursts from the red to the white dwarf due to the periastron passage of the third body on its 180-day orbit.

The rapid decline of optical brightness which started 57 days after the principal maximum and simultaneous increase of the $V-R$ and $V-I$ indices could be related to a dust formation in the ejecta of the nova. The maximum of the indices was reached 71 days after the principal maximum.

Our V and B observations obtained since April 2004 by different instruments started to differ by up to 0.7 mag. Such a phenomenon is associated with the nebular stage of the nova and differences in the width of the V and B filter. According to Stringfellow & Walter (2004), at the beginning of March 2004, very strong [O III] 495.89 nm and 500.69 nm emission lines, which characterize the nebular stage of the nova, had developed. These lines, located on the edge of the transmission curves of the B and V filters, are responsible for the observed difference. Chochol et al. (1993) found the same phenomenon in nova V1974 Cyg. In our spectrum of V475 Sct, taken on August 27, 2004 (see Fig. 2), we have found that fluxes of the 495.89 nm and 500.69 nm lines were 8.4 and 25.7 times larger than the flux of Hβ line.

As seen in Figure 3, the nova can be classified as an Fe II class object (Williams, 1992) with an emission spectrum including also O I, Na I, Ca II, Mg II and Balmer H lines accompanied by P Cygni absorptions. The spectrum was formed in an expanding shell ejected during the maximum on September 1, 2003. The

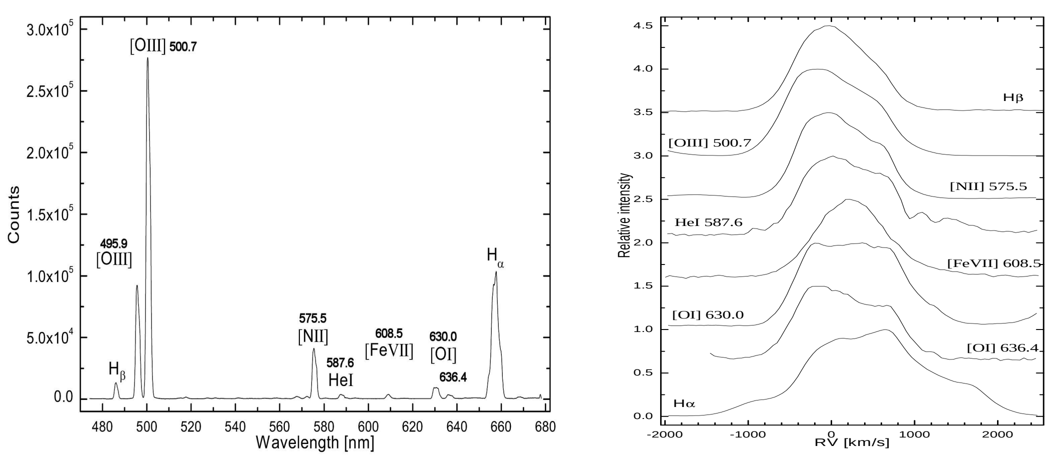

Fig. 2 Nebular spectrum of V475 Sct taken at ESO on August 27, 2004 (top) and emission line profi les of selected lines (bottom).

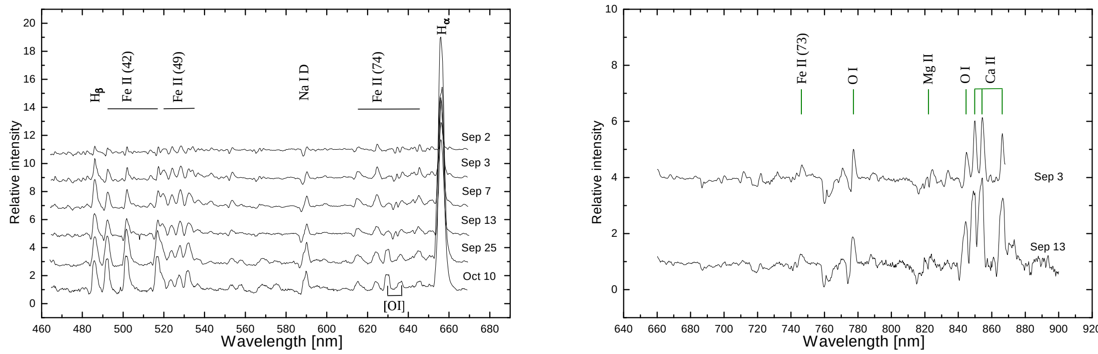

Fig. 3 The low-dispersion spectra of V475 Sct.

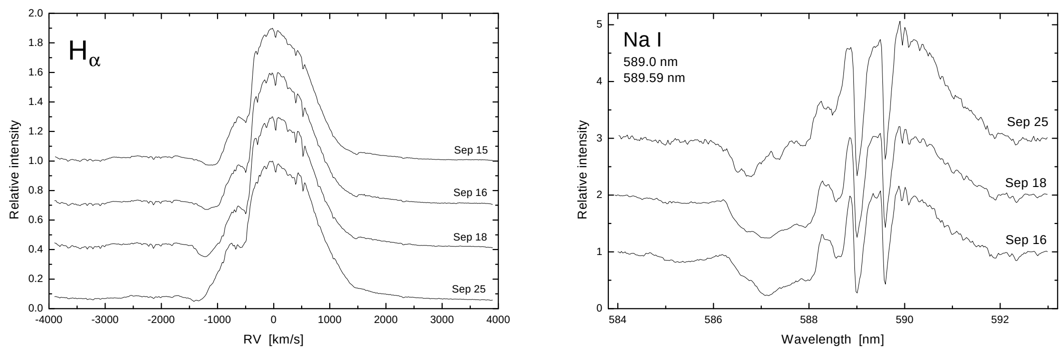

Fig. 4 The evolution of the H_α (left) and Na I doublet (right) profiles at Ondřejov spectra.

first forbidden line [O I] developed between September 13 and 25, 2003. As seen in Figure 4, two sets of absorptions were present in the P Cygni H_α line profile. Their radial velocities were measured with respect to the laboratory wavelength of H_α centered at 0 km s^{-1}. Between September 15 and 25, 2003, they increased their RVs from –480 to –640 km s^{-1} and from –1140 to –1370 km s^{-1}, suggesting the acceleration of the inner and outer envelope of the nova shell, where the absorptions arise, by continuous wind. The radial velocities of absorptions in the Na I doublet 589.0 nm and 589.59 nm were –530 km s^{-1} and –940 km s^{-1} on September 16 and –560 km s^{-1} and –1120 km s^{-1} on September 25. Moreover, the spectrum from September 16 shows also the presence of a very broad absorption formed in the continuous wind with the RV centered at –1900 km s^{-1} and terminal velocity of the wind 2250 km s^{-1}.

The medium-dispersion spectrum obtained at La Silla (see Fig. 2) during the nebular stage of the nova shows the presence of prominent emission lines of H, He I, [O I], [N II], [O III] and [Fe VII]. Their shapes suggest a non-spherical ejection of the main envelope of the nova. The [O I] 630 nm profile is almost symmetric with peaks indicating the presence of an equatorial ring and polar blobs in the expanding main envelope of the nova. High-resolution spectra are necessary to study detailed structures.

The expansion velocity of the main inner envelope of V475 Sct as calculated from the empirical relation $\log v = 3.22 - 0.22 \log t_3$ found by Chochol et al. (1997) from nebular spectra of 13 novae, is $v = 693$ km s^{-1}. This value is in agreement with the expansion velocity of V475 Sct found from our spectroscopic observations taken on August 27, 2004. We have measured the full width at half maximum of the prominent emission lines presented in Figure 2, which is a suitable measure of twice the expansion velocity of the shell (Cohen & Rosenthal, 1983). We obtained the expansion velocities in the range 550–780 km s^{-1} and the mean value of the expansion of the main envelope 655±25 km s^{-1}. We did not included into the mean the expansion velocity 490 km s^{-1} of the [Fe VII] line, because it is formed in the vicinity of the hot object and not in the main expanding envelope of the nova.

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DISCUSSION

J. DANZIGER: Were there any mid - IR observations that might reveal heated dust in the envelope?

D. CHOCHOL: Our spectra of V475 Sct cover the first 44 days after the outburst of the nova. The dust formation stage started $\sim$ 60 days after the outburst.

J. DANZIGER: Did you look for signs of dust in shapes of the emission-line profiles?

D. CHOCHOL: Our nebular spectrum of V475 Sct was obtained one year after the outburst, when the dust has already dissipated.