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Post-outburst photometry of the classical nova V2468 Cygni

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Abstract. We present $UBVR_CI_C$ CCD photometry of a "Fe II" type classical fast nova V2468 Cyg, which underwent an outburst in March 2008. Our H_α spectra of the nova, taken 10 and 16 days after the outburst, show the presence of an outer envelope accelerated by wind. The *B* and *V* photometric light curves of the nova were used to determine its basic parameters: absolute magnitude at maximum $M_{V,max} = -8.70\pm 0.07$, interstellar extinction $E(B-V) = 0.79\pm0.01$ and distance $d = 5.4\pm0.6$ kpc. During the first 100 days after the outburst, the light curve of the nova exhibited small flares with the cycle of 2.36 days, later replaced by larger flares with the cycle of 64 days. *V* observations in 2011 allowed to find quasi-periodic oscillations with the periods in the range of 21 to 50 minutes and a possible orbital period of the nova of 0.1699 days.

Key words. novae, cataclysmic variables – stars: individual (Nova Cygni 2008, V2468 Cygni)

1. Introduction

Classical novae are semidetached binaries with orbital periods of a few hours, consisting of a mass losing red dwarf and an accreting white dwarf. Classification to the fast and slow novae is based on a time interval, during which nova declines by 2 or 3 magnitudes from its maximum brightness (so called t_2 or t_3 time). The fast novae ($t_2 < 13$ days, $t_3 < 30$ days) have smooth light curves with well defined maxima and some of them may show quasi-periodic light oscillations in their later evolution. The slow novae ($t_2 > 13$ days, $t_3 > 30$ days) have structured light curves and many of them have standstills at maximum and signatures of a dust formation at later stages (Downes & Duerbeck 2000). The fast novae have higher ejection velocities of the envelope than the slow novae.

Classical nova V2468 Cyg (Nova Cygni 2008) was discovered by H. Kaneda on March 7.801 UT at mag 8.2 at the coordinates $\alpha_{2000} = 19^h58^m33\overset{s}{.}39$, $\delta_{2000} = +29^\circ52'06\overset{''}{.}5$ measured by K.Kadota on the CCD image taken on March 8.716 UT (Nakano 2008). Henden & Munari (2008) found a faint star USNO-B1 1198-0459968 ($R = 18$ mag) at position end figures $33\overset{s}{.}16$ and $06\overset{''}{.}4$ visible only on POSS-II red plates, not the blue ones. The amplitude of the outburst was larger than 12 mag in the *B* band.

On March 8.794 UT, Nogami et al. (2008) obtained the low-resolution spectrum

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(400–800 nm) of the nova at the Okayama Astrophysical Observatory and found a blue continuum with strong Balmer and Fe II lines with prominent P-Cyg profile (the shift of H_α absorption from emission peak was about -880 kms^{-1}). On March 11.46 UT, Beaky (2008) obtained the spectra at Truman Observatory and classified the object as Fe II class nova (Williams 1992). The infrared spectra of the nova obtained with Infrared Telescope Facility by Rudy et al. (2008) show emission lines of C I, N I, O I, Fe II and Ca II on March 13. On April 12, the Ca II emission lines faded and prominent He I lines appeared.

The spectral evolution of the nova from March 2008 till the end of 2009 was described by Iijima & Naito (2011), based on the spectra taken at Asiago (Italy) and Nishi-Harima (Japan) observatories. On March 11, the blue shifts of H_β absorptions were -1750 kms^{-1}and -1070 kms^{-1}. On March 18, the mean blueshift of H I and Fe II absorptions were -2120 kms^{-1}and -1270 kms^{-1}. The nova entered to nebular stage 122 days after its outburst. The H_α, H_β, [O III], He II and [Fe VII] line profiles showed 4 peaks with the radial velocities -640, -260, 255, 620 kms^{-1}, suggesting the equatorial rings and polar caps structures in an expanding inner main envelope. The spectra showed asymmetric and variable profiles of emission lines, difficult to explain by any known model of nova shells. During the small brightening in November 2008 the emission lines of He II, [Ca V], [Fe VII] faded or disappeared. The authors estimated the mass of the ejecta to be $1.7 \pm 1 \times 10^{-5}$ $M_\odot$.

V2468 Cyg was detected by Swift with both XRT and UVOT instruments on June 9,14,15,16, 2009 and August 2009 (Schwarz et al. 2009). The average X-ray (0.3-10 keV) count rate was $\sim$ 0.02 count s^{-1}. The X-ray light curve was variable on time scales of 500 seconds. The UVOT ligh curve showed large amplitude variations of order 0.3 mag, uncorrelated with the X-ray light curve. The ROTSE IIId photometry, obtained in June and July, 2009 in Tubitak Observatory (Turkey), implied possible 0.242 day orbital period. The Balmer decrement at optical spectrum obtained on July 12, 2009 with the B&C spectrograph of the 2.3m telescope at Steward Observatory provided a reddening $E(B-V) = 0.8$.

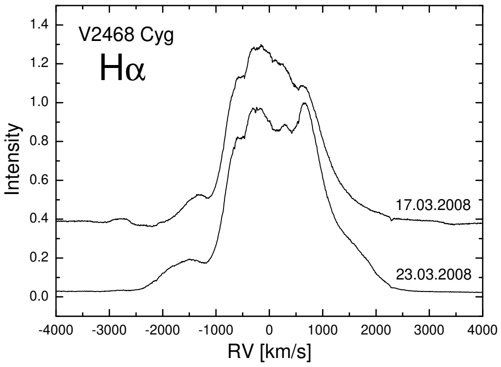

Fig. 1. The H_α line profiles of the nova.

2. Our photometry and spectroscopy of the nova

Our CCD $UBVR_CI_C$ observations of the nova were taken with the SBIG ST10-XME camera mounted in the 2.5 m Newton focus of the 0.5 m reflector at the Stará Lesná Observatory. In Fig. 1 we present our V and B CCD observations (important for the determination of the rate of decline of the novae) plotted together with other available CCD data from the databases of the nova: AAVSO, VSNET and MEDÚZA. We used also AAVSO visual estimates.

Our V observations in May 2011 were taken by the 1.25m telescope at the Crimean Laboratory of the Sternberg Institute in Nauchnyj and in June, July and September 2011 by the Zeiss-600 and Zeiss-1000 telescopes at Crimean Astrophysical Observatory at Mt. Koshka. In May-July 2011 the same portable VersArray 512UV CCD chip was used. In September 2011 VersArray 1340x1300 CCD chip was used.

Our spectroscopy of the nova in March 2008 was performed at the David Dunlop Observatory, University of Toronto (DDO), using the long-slit spectrograph, equipped with a Jobin Yovon Horiba CCD detector, mounted at the Cassegrain focus of the 1.88-m telescope. The resolution power was R = 12 000 in the H_α region.

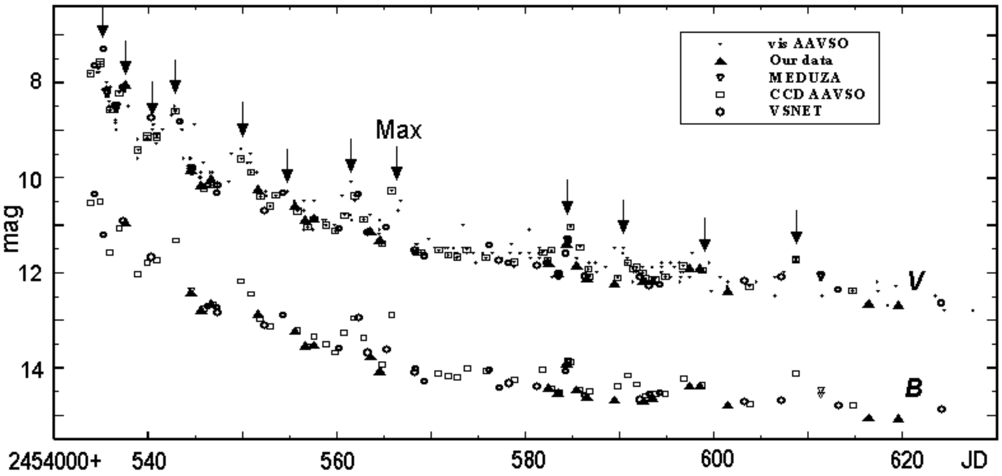

Fig. 2. The V and B light curves of V2468 Cyg. The B data are shifted by + 2 mag. The maxima of brightness (flares) follow the ephemeris: HJD(Max) = 2454535.6(2) + 2.36(1) ×E.

We obtained two H_α spectra of the nova. On March 17, 2008 the P Cygni type absorptions with RV = -1140 kms^{-1}and -2300 kms^{-1}were present, as signatures of the expanding outer envelope and wind with the terminal velocity of 2600 kms^{-1}. On March 23, 2008 the RV of the P Cygni absorption increased to -1210 kms^{-1}, caused by the acceleration of the outer envelope by the wind (Fig. 1). The nova shell consists of an outer fast tenuous envelope and an inner slow main envelope similarly as in the nova V1974 Cygni (Chochol et al. 1997).

3. Basic parameters of the nova

The basic parameters of the nova V2468 Cyg were determined using the photometry, presented in Fig. 2. The nova reached maximum on March 9.474 UT at V_{max} = 7.57 mag, B_{max} = 8.50 mag (AAVSO). The V, B light curves were used to find the rate of decline $t_{2,V}$ = 9, $t_{2,B}$ = 10, $t_{3,V}$ = 20 and $t_{3,B}$ = 22 days, which allowed to classify the nova as a fast one. Using the MMRD (Magnitude at Maximum – Rate of Decline) relations: (Schmidt 1957); (Pfau 1976); (Livio 1992); (Della Valle & Livio 1995); (Downes & Duerbeck 2000), we estimated the magnitudes of the nova at its maximum to $MV_{max} = -8.70 \pm 0.07$ and $MB_{max} = -8.27 \pm 0.02$.

The formula, given by Livio (1992): $MB_{max} = -8.3 - 10.0 \log(M_{wd}/M_\odot)$, was used to estimate the mass of the white dwarf in V2468 Cyg as $M_{wd} = 0.99 \pm 0.01$ $M_\odot$.

The interstellar extinction was derived

1) from the relation of van den Bergh & Younger (1987). The observed colour of V2468 Cyg two magnitudes below maximum was $B - V = 0.76$, which thus yielded $E(B - V)$ = 0.78.

2) from the flux ratios of O I (844.6 nm and 1128.7 nm) lines. The intrinsic flux ratios of the Lyβ-fluoresced O I lines are precisely known and therefore any departure from them is a good indicator of interstellar reddening. Rudy et al. (2008) derived from IRTF spectra interstellar reddening $E(B - V) = 0.77$.

3) from the Balmer decrement. Schwarz et al. (2009) derived $E(B - V) = 0.80$.

4) from the column density of hydrogen atoms. Iijima & Naito (2011) derived $E(B-V)$ = 0.80.

The mean value of the reddening, found from the data mentioned above, is $E(B - V)$ = 0.79±0.01. Corresponding absorptions in V and B are $A_V = 2.45 \pm 0.02$ and $A_B = 3.24 \pm 0.04$. The distance moduli of the nova are $V_{max} - MV_{max} = 16.27 \pm 0.07$ and $B_{max} - MB_{max}$ =

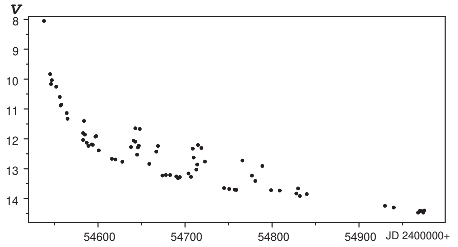

Fig. 3. *V* light curve of the nova.

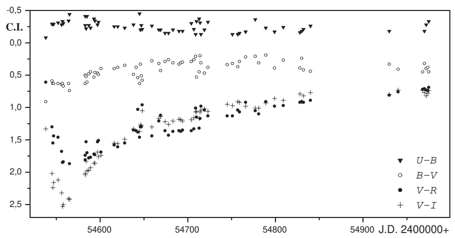

Fig. 4. Colour indices of the nova.

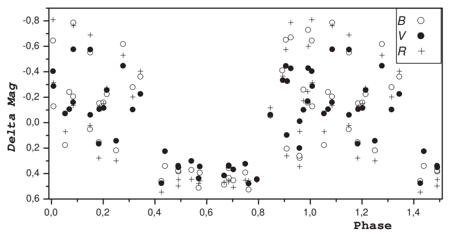

Fig. 5. The phase diagram of activity folded with the ephemeris: HJD(Max) = 2454650(2) + 64 ×E.

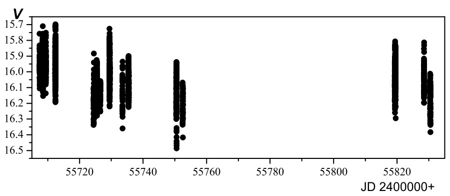

Fig. 6. *V* light curve of the nova in 2011.

16.77±0.02, which yields a corresponding distance to the nova d = 5.4±0.6 kpc. This value is in close agreement with the distance of the nova estimated by Iijima & Naito (2011) d = 5.5±0.8 kpc.

4. Multicolour brightness variations

The mean night values of our $UBVR_CI_C$ observations in 2008 were used to show the brightness increases (flare-like events) on the declining branch of the light curve (Figs. 3 and 4). The most interesting result is a decline of the $B-V$ index during these events. The phase diagram of B, V, R data after the trend removal was constructed using the ephemeris HJD(Max) = 2454650(2) + 64 ×E. As seen from Fig. 5, the activity stage lasted the half of the 64 day cycle of variations. The activity stages were caused by the pulsations of the nova envelope (Schenker 2002). Fading or disappear-

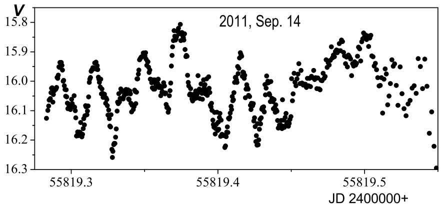

Fig. 7. QPOs at JD 2455819.

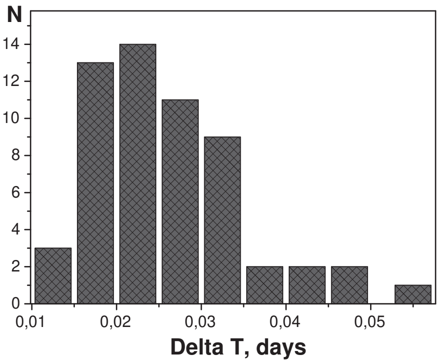

Fig. 8. Histogram of QPOs periods in *V* data.

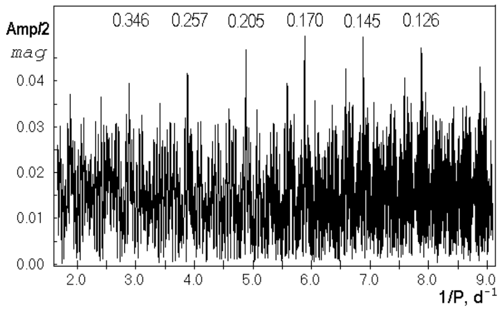

Fig. 9. Fourier period analysis of the *V* data.

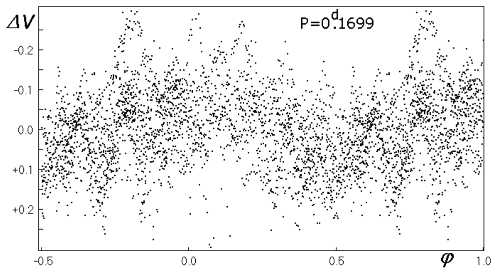

Fig. 10. The phase diagram for the best possible orbital period.

ance of highly ionized spectral lines during the brightness increase in November 2008 (Iijima & Naito 2011), supports this view.

5. Quasi-periodic oscillations in 2011 and possible orbital period

In 2011, we monitored the nova in the *V* passband using one minute time resolution. The light curve, presented in Fig. 6 was highly variable due to the presence of quasi periodic oscillations (QPOs) combined with the orbital period variations. We observed the object in 15 nights. The longest night run is presented in Fig. 7. The histogram of QPO periods found from their brightness maxima is presented in Fig. 8. The most of the detected periods are in the range 0.015 - 0.035 days (21 - 50 minutes). The QPOs arise in an accretion disk of the white dwarf.

Our *V* observations in 2011 were used to find the orbital period of the nova using the Fourier period analysis. Fig. 9 presents the possible orbital periods. The determination of the true orbital period of the nova is influenced by the presence of one day aliases. The phase diagram for the best period was constructed using the ephemeris HJD(Max) = 2455729.477 + 0.169915 ×E (Fig. 10).

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