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STELLA NOVAE: PAST AND FUTURE DECADES

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Photometric and Spectroscopic Behavior of V407 Cygni during 2010–2012

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Abstract. We present the results of new *UBVRIJHKLM* photometric and spectroscopic observations of the recurrent symbiotic Nova V407 Cyg obtained during its nebular stage. Different types of the brightness variability are analyzed.

1. Introduction

V407 Cyg is a unique symbiotic binary. For a long time it had been known as a Mira variable (suspected symbiotic nature). Although it was discovered by Hoffmeister (1949) during its nova-like outburst in 1936–1939, the first symbiotic spectrum of V407 Cyg was published only in 1994 (Munari et al. 1994).

V407 Cyg underwent a small outburst in 1998 (Kolotilov et al., 2003). Its photometrical evolution was nearly the same as during previous outburst in 1936. Both spectral and photometric evolution are similar to Z And-type outburst of a classical symbiotic star.

A very fast and bright nova eruption of V407 Cyg was discovered on 2010 March 10 by Nishiyama et al. (2010). Its photometrical and spectroscopic behavior according to Munari et al. (2011) was much similar to outbursts observed in the recurrent symbiotic novae (T CrB and RS Oph). It is the first Mira symbiotic system in the small group of recurrent symbiotic novae (and the first system with unknown orbital period). Also it is the first symbiotic star which was detected as a γ-ray source (Abdo et al. 2010).

2. Observations

The photometric *UBVJHKLM* observations of V407 Cyg have been carried out with the 0.6-m and 1.25-m telescopes at the Crimean Station of the SAI. Some $UBVR_CI_C$ observations were taken with the CCD camera, mounted on the Newton focus of the 0.5 m telescope of the Slovak Academy of Sciences (Observatory Stara Lesna). Spectroscopic observations were acquired with the 2.6-m G.A. Shain reflector of the Crimean Astrophysical Observatory and 1.25-m telescope using slit spectrographs.

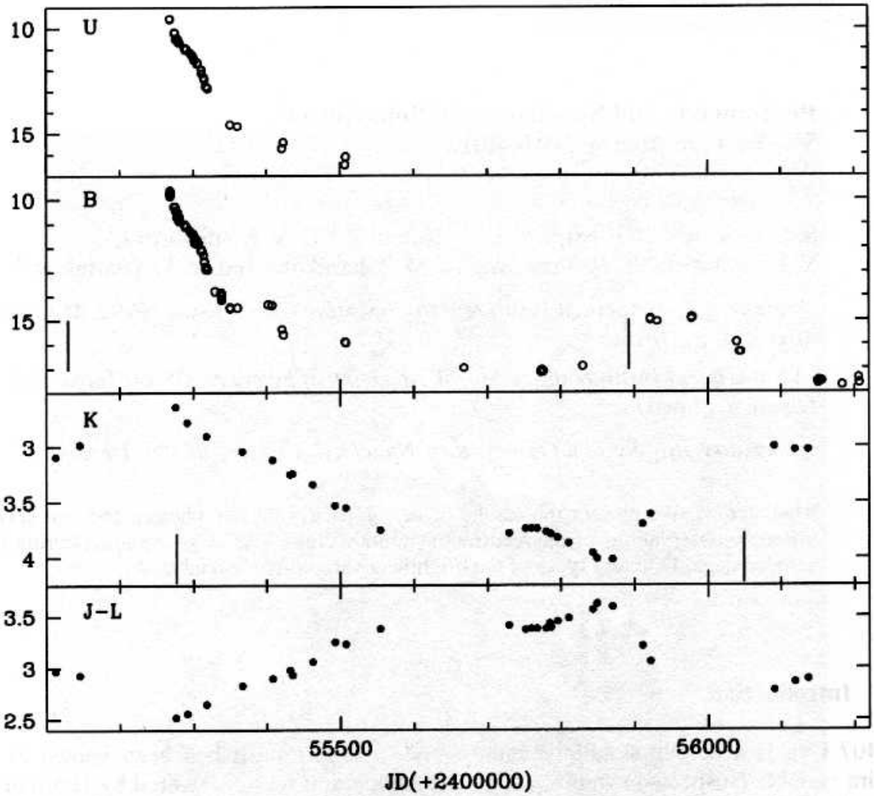

Figure 1. *U, B, K* light curves and $J - L$ color curve of the V407 Cyg. Dates of maxima in *B* and *K* bands are marked by vertical lines.

We carried out some sets of *B*-photometric observations with the CCD camera on the 0.6-m telescope of the Crimean Laboratory of SAI to look for rapid brightness variability in spring, summer and autumn of 2010, in summer of 2011 and 2012. Rapid brightness variability has not yet been detected.

3. Photometry

Figure 1 shows *U, B, K* light curves and $J - L$ color curve of the star. We obtained new ephemeris for Mira component by means of Fourier analyzes of the entire IR light curve (we also included the results of our photometry from Kolotilov et al. 2003, and references therein): Max (IR)=JD 2449873 + 772×E.

These dates are marked by vertical dashes on the *K* light curve. Ephemeris for *B* light curve differs from IR ephemeris (it is typical for Miras). From the period-luminosity relation for Miras (Whitelock, Feast, & van Leeuwen 2008) we estimated a distance to the system of 2.4 kpc. We used the color excess $E(B-V) = 0.6$ and distance $d = 2.4$ kpc in all our calculations.

On the early phase of the outburst $B-V$ and $U-B$ colors were nearly constant. Their dereddened values are consistent with the spectral class F5 I (for $B-V$) and A0 I-B9 I ($U-B$). We estimated the luminosity of F5 I supergiant on the JD=2455268 (the first date of our photometrical set) as $L \approx 10000\ L_{\odot}$. There are two theoretical models which describe continuum emission of V407 Cyg in the visual range for this stage. Hachisu & Kato (2012) and Shore at al. (2011) analyzed X-ray observations of V407 Cyg and demonstrated that free-free emission of the shocked gas is the main contributor to the total flux on the optical wavelengths. But Martin & Dubus (2012) on the base of the same X-ray observations concluded that contribution of the free-free emission was negligible and A-supergiant photosphere is the main source of continuum emission in the optical region during the early stage of the outburst. According to Martin & Dubus (2012) the temperature of the supergiant must grow with time, but $U-B$ color was constant during at least 48 days after the beginning of the outburst.

4. Spectral evolution

Our first spectrum was obtained on 2010 April 19 (Figure 2a). At that time the system was in the nebular stage (lines [O III] 5007, 4959, [N II] 5755, [O I] 6300 are clearly visible on the spectrum) but some coronal lines had been sufficiently prominent yet. An emission feature on the 6370Å was a blend of [O I] 6363, Si II 6372 and [Fe x] 6375. The main contribution to the total flux of this blend is given by [Fe x] 6375 line. Red giant's molecular bands were veiled by emission of the active hot component or free-free emission of the shocked gas (or both).

According to Martin & Dubus (2012) the envelope of the active hot component shrinks while maintaining a nearly constant bolometric luminosity during the initial 50 days. Therefore, the temperature of the hot component must grow. If the temperature near maximum light was 10000 K (Martin & Dubus 2012) it must be about 25000 K on day 40. Figure 2a shows the model of SED which consists of fluxes from B1 I and M6 III components. The approximation is not very good in the blue range, but U magnitude of the B1 I component is equal to our photometric U magnitude, obtained in the same date. In 2010 SED and emission lines fluxes demonstrated fast evolution.

But during our observations in 2011 continuum fluxes and emission lines fluxes had not demonstrated significant variations. The red giant's emission dominated in the SED of all these spectra. A small contribution from the hot component or gas may be detected only near the Balmer jump. Bad signal/noise ratio in this range prevents us to estimate this contribution. Figure 2b shows two spectra obtained on 2006 July 19 (passive state, Esipov et al., 2012) and 2011 July 24. Their SEDs are similar (the main contributor is M7-8 red giant) but on the latter date we can see rich emission lines spectrum (with the brightest nebular lines). We measured the dereddened nebular-line ratios R_1 = [O III](λ4959 + λ5007)/[O III](λ4363)=4.0, R_2 = [O III](λ4959 + λ5007)/[Ne III](λ3869)=4.1 and estimated the temperature and electron density in the nebula ($T_e \approx 13000\ K$ and $n_e \approx 5 \times 10^6\ cm^{-3}$, if the oxygen-to-neon abundance ratio was equal to the mean cosmic value). R_2 ratio in 2011 was equal to R_2 ratio obtained before outburst (2009 September 25). All continuum flux variations observed in 2012 were connected with Mira's pulsations. Fluxes in the emission lines were nearly the same as in 2011.

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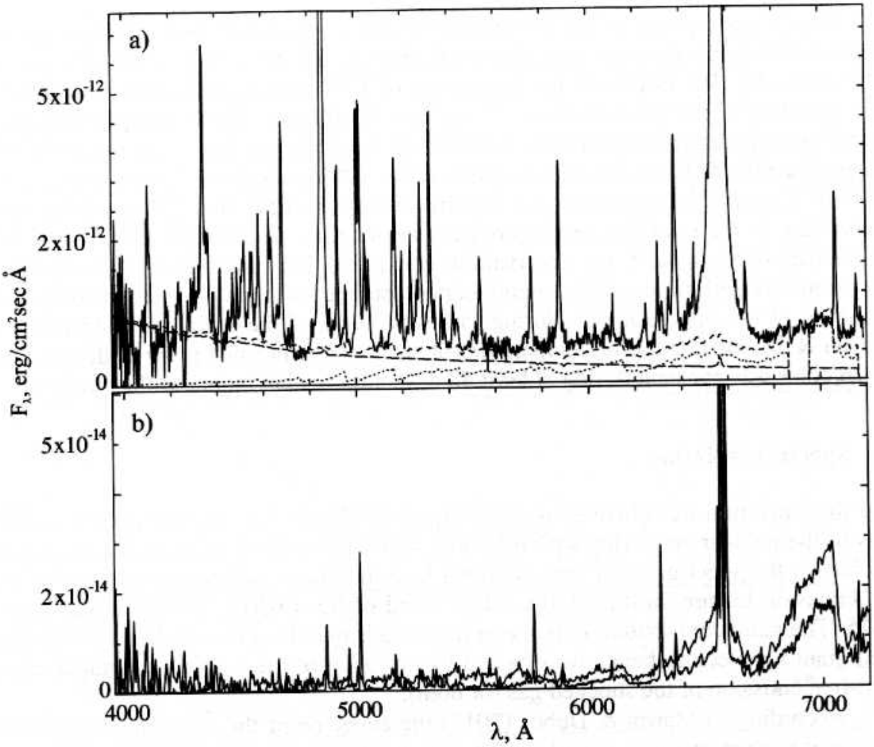

Figure 2. a) Dereddened spectrum of V407 Cyg obtained 2010 April 19. Dashed line - model fitting, consists of M6 III (dotted line) and B1 I (line with long dashes) contributions. b) Two spectra of V407 Cyg obtained during passive state on 2006 July 19 (upper curve) and during nebular stage on 2011 July 24

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