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Unveiling the nature of red novae cool explosions using archive plate photometry

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Abstract

Based on archive photographic photometry and recent CCD photometric data for red novae V4332 Sgr and V838 Mon, we established their stellar composition, exploded components, and the nature of explosions. Low temperature in the outburst maximum is due to quasi-adiabatic expansion of a massive stellar envelope after the central energy surge preceded the outburst.

Keywords: binary systems, mergers, red novae stars; individual: V4332 Sgr, V838 Mon

Red novae are the stars erupting into cool supergiants [1]. There are images of progenitors for red novae V4332 Sgr and V838 Mon in Moscow and Sonneberg plate collections. The first star is an age-old object seen at the latitude of –9.4° and located in the Galactic bulge or in the thick disk, the second one is a young object associated with the cluster of B type stars and the dust environment located at the distance of 6.1±0.6 kpc.

Three pairs of deep one-hour exposures in *B* and *V* bands of V4332 Sgr were taken with the meniscus 50 cm Maksutov telescope AZT-5 of the SAI Crimean Station between 1977 June and 1986 June. For V838 Mon we have 148 *B*-band plates suitable for eye estimates, dated between 1928 and 1994 and taken with identical 40 cm astrographs in Sonneberg and Crimea. 57 of them are good for digitization and accurate measurements. In addition, there are 50 *V*-band plates obtained with AZT-5, all are good for measurements. Emulsions of AGFA and ORWO ZU-21 (Germany) were used to reproduce the *B* band with the 40-cm astrographs, the ORWO ZU-21 was used with the BS-8 filter at AZT-5 to cut the ultraviolet part of a spectrum. The Kodak 103aD emulsion (USA) with the GS-17 filter was used to fit *V* band at the AZT-5. So, the observations were performed in the standard bands of Johnson *UBV* system.

To digitize plates, the Eastman Kodak CREO scanner of the Sternberg Institute was used. Scanner output images in TIFF format were transformed to BITMAP by MaxIm DL software with changing cuts. Additionally we used the FinePix F10 FujiFilm camera in gray mode with an ordinary convex lens, and transformed its JPEG images to BITMAP with MS Paint. The last method of digitization can't be used for wide fields due to lens distortion, but it is as good for a single star with outskirts as CREO scanner. Self-focusing and very short exposures of the FinePix

F10 camera allow shooting without support stands. So, this method may be widely used by students and amateurs. Digital BITMAP images were reduced with Goranskij's software WinPG, the characteristic curves were plotted with 17 to 23 comparison stars and approximated with the 1st or 2nd order polynomial. The mean squire residuals are in average of $0^m.08 – 0^m.12$, but vary in the range of $0^m.04 – 0^m.23$ depending on the size of emulsion grains that is typical for photography.

The historical light curve of V4332 Sgr in the *B* band based on DSS and AZT-5 plates, and modern CCD data is shown in Fig. 1. The outburst is not plotted. The progenitor was a binary of a blue and a red star. The *B*-band data along with other filters shows pre-outburst brightening similar to that one detected in V1309 Sco by OGLE [2]. After the outburst, the brightness level fell down due to disappearance of an exploded blue companion. The second brightness decay happened between 2006 and 2008, and accompanied by the temperature drop of a red M-type star by 1000 K.

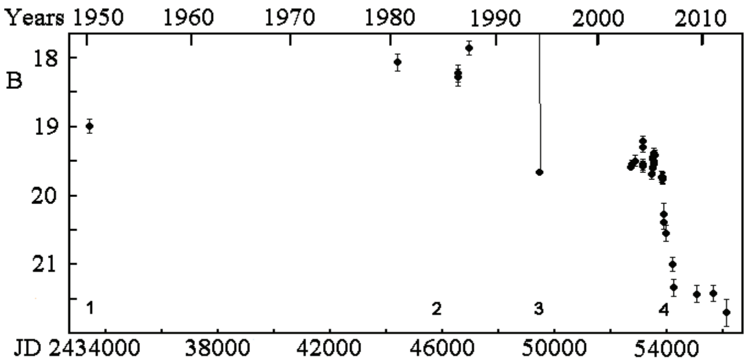

Figure 1. Historical light curve of V4332 Sgr in the *B* band. The main points of the evolution are marked. 1 – POSS I. 2 – AZT-5 + POSS II; brightening before the outburst. 3 – The outburst. 4 – The light and temperature decay of an M-type star after the outburst.

The historical light curve of V838 Mon in the *B* band based on archival plates, and on modern CCD data is given in Fig. 2. The outburst is not presented in this Figure, too. Our photometry does not show any significant variability of the progenitor but reveals that it was a binary of B-type stars. It weakened by $0^m.461$ *R* in 1998, 4 years before the outburst [3]. In October 2002 the explosion remnant became so cool (1200 K) that its radiation was not visible in *UBV* bands, where the light of the B3V star, survivor of the explosion was dominating. Having known magnitudes of the companion and the progenitor, we determined magnitudes of the exploded star. It was a B3V star, too, and it was brighter than its companion by 36 per cent. In December 2006 the explosion remnant evolved to M-type giant, and in its approach, the B3V companion disappeared totally for 70 days in all the photometric bands, what allowed us to measure its *UBVRI* magnitudes. In 2007 we observed a submergence of the companion into the remnant. During 200 days the hot companion moved in the void under an exterior shell of the remnant, and the radiation of the companion was absorbed by a factor of five. Then in 2008 it disappeared, and was not visible up to present time.

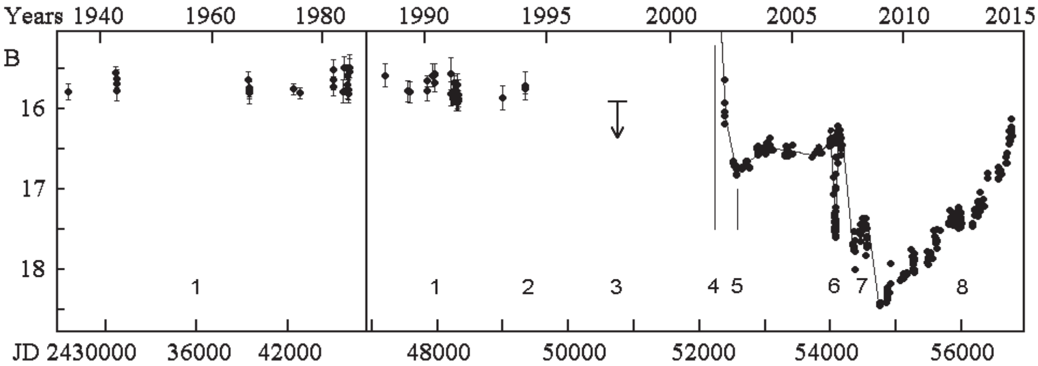

Figure 2. Historical light curve of V838 Mon in the *B* band. Main phases of the evolution are noted. 1– Progenitor, the pair of B3V stars. 2 – Stop the astro-plate production. 3 – Kimeswenger & Eires found a decay in the *R* band. 4 – Outburst of the brighter B3V star in the binary. 5 – B3V companion is only visible in the *B* band. 6 – The eclipse. The B3V companion vanished for 70 days. 7 – The B3V companion moving in the void is visible through the shell. 8 – The B3V companion plunged into the M-type remnant.

Finally, we were able to determine the spectral energy distributions (SED) of progenitors and remnants of both red novae (Fig. 3). We found that in V4332 Sgr SEDs (Fig. 3, left), the continuum of the M giant was visible both before and after the outburst, and it was stronger and hotter when it was closer to the outburst in time. We inclined to treat the explosion in V4332 Sgr as a merger event in a blue straggler which might be a contact binary in a system with the M giant. We think that brightening of M star is connected with the accretion of matter onto its surface in the stages of forming common envelope of the binary and of a dynamical destruction of the merger remnant.

To extract SEDs of V838 Mon components from the common light of the binary, we measured the light of each component lost in the eclipse or after the explosion. The SED of the exploded star (central one of the three in Fig. 3, right) was determined as a difference of the progenitor's SED and the survived B3V companion's SED. The SED of exploded star is compared with the SED of HD 29763 (B3V). With the known distance, it is found to be located in the zero-age main sequence of the Temperature – Luminosity diagram. The exploded component of the system was a young star with $R = 2.9\ R_{\odot}$, $L = 1020\ L_{\odot}$, $\log T_e = 4.29$. Its companion is a lower luminosity star having $R = 2.5\ R_{\odot}$, $L = 740\ L_{\odot}$ and the same temperature. There is no evidence of binary nature or merger for the exploded star in V838 Mon. In addition, we established that the radius of the remnant at the first appearance in the outburst with K0 I spectrum was equal to 327 $R_{\odot}$, and that the exploded star's envelope had undergone pre-outburst expansion in the conditions close to adiabatic which continued at least four years. The central energy surge causing a slow shock to massive star envelope is a reason of cool explosions of red novae [4].

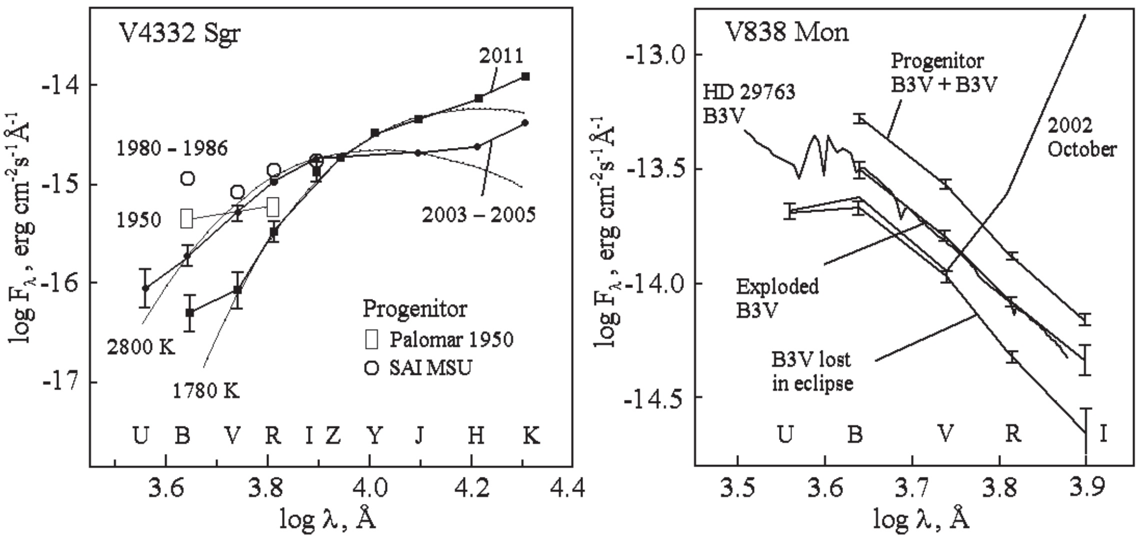

Figure 3. Spectral energy distributions (SED) of V4332 Sgr (left) and V838 Mon (right). All SEDs are corrected for interstellar reddening. Empty signs in V4332 Sgr SED are photographic observations of the progenitor, black signs and lines mark M-type star continuum without emission-line contribution. Blackbody fitting is also shown. SEDs extracted from the common light of V838 Mon (right). The following SEDs are given: the progenitor binary (top), the exploded component before its explosion compared with the SED of HD 29763 (B3V) (middle), and the B3V companion (bottom). The two-component SED of the binary with the cool remnant in 2002 October is also shown.

In a massive star experienced such an energy surge, the radiation transfer time exceeds its dynamic expansion time by many orders of value, so the explosion energy is concentrated in the bottom of the expanding envelope. The surface area of the envelope becomes very large when the radiation reaches it, and the explosion energy is insufficient to heat the star surface to a high temperature. Reasons of such energy surges may be both the merger of stellar nuclei after forming a massive common envelope in a contact binary, and the instability in the nucleus of a massive young star. So, the red nova phenomenon is representative of both old and young stellar populations.

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