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V838 Mon BEFORE AND AFTER ITS OUTBURST

GORANSKIJ, V. P.[1]; SHUGAROV, S. Yu.[1]; BARSUKOVA, E. A.[2]; KROLL, P.[3]

[1] Sternberg Astronomical Institute, Moscow University, 119992 Russia; e-mail:goray@sai.msu.ru

[2] Special Astrophysical Observatory, Russian Academy of Sciences, Nizhny Arkhys, Karachai-Cherkesia, 369167 Russia; e-mail:bars@sao.ru

[3] Sternwarte Sonneberg, Sternwartestrasse 32, D-96515, Germany

V838 Mon is a member of a new class of novae which show late K-M type spectra in outburst and do not experience the nebular stage. Two more objects of this class are known: V4332 Sgr (Martini *et al.*, 1999) and V1006/7 in M31 (Rich *et al.*, 1989). The outburst of V838 Mon in 2002 was studied by Barsukova *et al.* (2002), Bond *et al.* (2003), Crause *et al.* (2003), Kimeswenger *et al.* (2002), Munari *et al.* (2002b). Crause *et al.* (2003) report that the star underwent a deep decline and faded to $16^{\rm m}$ V in June 2002, reaching its pre-outburst magnitude, and developed a strong IR excess. The spectral energy distribution of the progenitor (at $V = 15\overset{\rm m}{.}6$) resembles an under-luminous main-sequence F star (Munari *et al.*, 2002c) or an F0III-II star (Munari *et al.*, 2002a). On the other hand, it could have been a blue star, with $B = 15\overset{\rm m}{.}85$ and $(B-V)_0 = -0\overset{\rm m}{.}03 \pm 0\overset{\rm m}{.}1$ (Barsukova *et al.*, 2002). Quite different values ($B = 15\overset{\rm m}{.}87$, $R = 14\overset{\rm m}{.}56$) were given for the progenitor by Kimeswenger *et al.* (2002). The progenitor was associated with IRAS 07015-0346, a point source detected only at $\lambda \geq 60$ μm. A B3V star is seen in the spectra of the remnant (Munari *et al.*, 2002a), along with evidence for the presence of the first known extremely cool "L supergiant" in the system (Evans *et al.*, 2003). On the base of their spectroscopy, Mikolajewski *et al.* (2003), whose direct-imaging, but not spectroscopic, results were disclaimed, speculate that the B3V star may be a blending object lying about 1000 pc behind V838 Mon, and the cool supergiant is evidently the remnant of V838 Mon outburst.

To establish the nature of the progenitor and the remnant of V838 Mon, we estimated the star's brightness using the photographic plate archives of Sonneberg Observatory and Sternberg Astronomical Institute, re-measured the B, R and I images in the DSS survey, and specially carried out $UBVRI$ CCD observations of the star during its faint state in 2002–2004. All our calibrations were based on the photometric $UBVR_CI_C$ sequence from Munari *et al.* (2002c). We used these local standard stars to calibrate a total of 41 stars lying close to V838 Mon. For flux calibrations and taking into account the interstellar reddening effect in the $UBVR_CI_C$ bands, we followed Moro & Munari (2000).

Kimeswenger *et al.* (2002) applied published color corrections to reduce DSS plate measurements to standard B and R_C bands. We used a different way to improve the DSS photometry: we selected reference stars having colors close to those of the V838 Mon progenitor, in the narrow $B-V$ range between $0\overset{\rm m}{.}45$ and $0\overset{\rm m}{.}75$. Our measurements show that about a half of surrounding stars have $B-V$ colors in this range.

The image of V838 Mon has faint close or partially merged companions. With our measuring software, we removed the distorted pixels from the star's image profile and replaced them by averaged profile values calculated assuming radial symmetry of the profile. As a result, we obtained the following mean pre-outburst values: $B = 15\overset{\text{m}}{.}81 \pm 0\overset{\text{m}}{.}06$, $R_C = 14\overset{\text{m}}{.}84 \pm 0\overset{\text{m}}{.}06$, and $I_C = 14\overset{\text{m}}{.}27 \pm 0\overset{\text{m}}{.}03$ ($B - V \approx 0.^{\text{m}}60$ can be deduced).

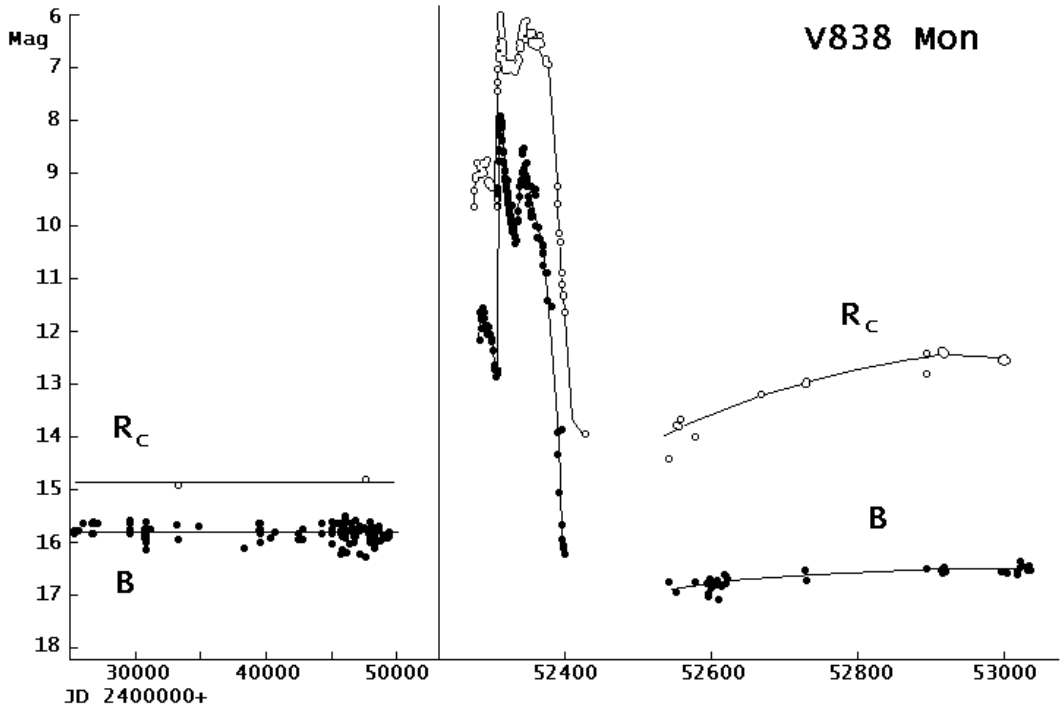

Figure 1. Archival light curves of V838 Mon and recent photometry in the B and R_C bands.

The plate archive observations of the progenitor consist of 118 eye estimates on Sonneberg plates taken between JD 2425322 and 2448329 and 26 eye estimates on Moscow plates taken between JD 2433184 and 2449394. All these estimates were done by S.Yu. Shugarov. The Moscow observations were published by Goranskij *et al.* (2002). Thus, we have followed V838 Mon during 66 years, between 1928 and 1994. All the observations are in the B band. The typical error of eye estimates is $0\overset{\text{m}}{.}2$. Our photometry of the remnant includes $UBVR_CI_C$ observations using the Electron K-585 and EEV42-40 CCDs with the 100 cm Zeiss reflector of the Special Astrophysical Observatory and BVR_JI_J observations using the SBIG ST-7 and Apogee-7p CCDs with the 60 cm Zeiss reflector of the Sternberg Institute's Crimean Station. The total time range is JD 2452552–2453036. The exposure times were 10 min or shorter. Our SBIG ST-7 frames have insufficient S/N ratios in B and V bands due to poor sensitivity of this CCD at short wavelengths. Therefore, all the frames in these bands were co-added each night, giving accumulated exposure times within 40–200 min. We also consider the data from Munari *et al.* (2002a), Crause (2003), Wagner *et al.* (2003). All available observations in the B and R bands, including the outburst data (see references in Bond *et al.*, 2002), are displayed in Fig. 1.

The energy distributions of the progenitor of V838 Mon and of the remnant (October, 2003) are compared in Fig. 2 with the energy distribution for the B3V type star HD 29763 (Glushneva *et al.*, 1992) measured in the λ3325-7675Å range. HD 29763 has a low interstellar reddening, $E(B - V) = 0\overset{\text{m}}{.}07$, as it can be inferred from its UBV photometry

(Mermilliod *et al.*, 2003). The JHK values for the progenitor were taken from the 2MASS IR survey, and the far IR magnitudes of the remnant are from Lynch *et al.* (2003) and Tapia & Persi (2003). Our measurements in the UV, optical, and near IR bands are also included. In Fig. 2, the $E(B-V)$ value for V838 Mon was used as a free parameter to fit its pre-outburst energy distribution with the spectrum of HD 29763, and the best fit is achieved for $0\overset{\mathrm{m}}{.}70$. The color excess of V838 Mon is the sum of this value and the color excess of HD 29763, giving $E(B-V) = 0\overset{\mathrm{m}}{.}77$. With this reddening, the U and B magnitudes of the remnant also fit the spectrum of HD 29763 well, but with a downward shift. Goranskii *et al.* (2002) give a smaller value, $E(B-V) = 0\overset{\mathrm{m}}{.}63$, for V838 Mon, based on its location in the $(U-B)-(B-V)$ diagram during the outburst, when the star was red. Note that the photometric color excess, $E(B-V)$, depends on the $(B-V)_0$ color of the measured star, being larger for blue stars. This effect was studied by Straizys (1992).

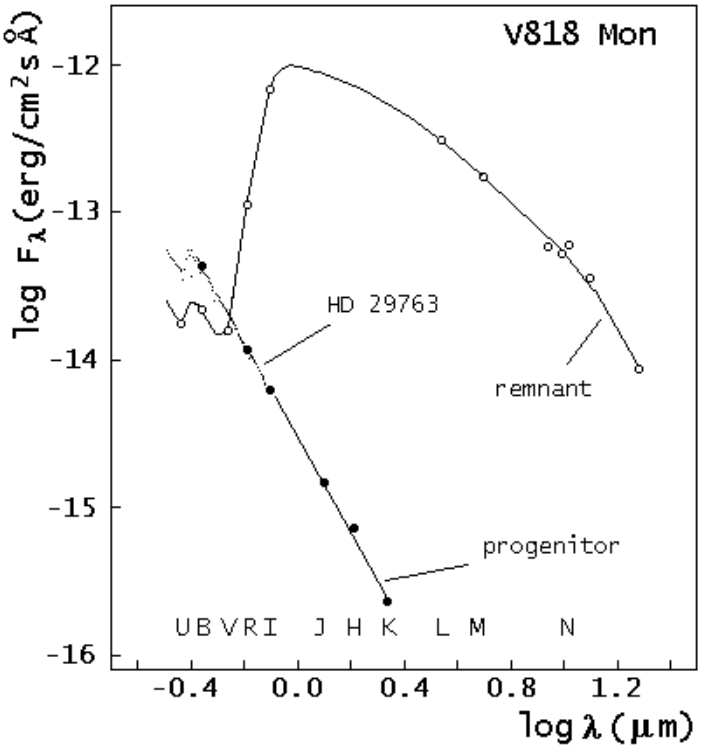

Figure 2. Comparison of the energy distributions of the progenitor and the remnant (filled and open circles) with the energy distribution of the B3V star HD 29763 (small dots).

The results of our photometric investigation are the following.

(1) The progenitor of V838 Mon is definitely a blue star, with $(B-V)_0 = -0\overset{\mathrm{m}}{.}17 \pm 0\overset{\mathrm{m}}{.}10$ for $E(B-V) = 0\overset{\mathrm{m}}{.}77$. The progenitor's energy distribution consists of a single stellar blue B3 component, without any notable excess in the JHK bands, and there is no evidence for an F-type star. During the 66 years preceding the 2002 outburst, it did not show considerable variability.

(2) In October 2002, four months after the end of the optical outburst, the remnant was fainter than the progenitor by $1\overset{\mathrm{m}}{.}1$ in the B band, but brighter in the R band (Fig. 1), in agreement with the observations by Munari *et al.* (2002a). During about 500 days after the end of the optical outburst, the remnant brightened gradually in all the bands

with the rates dependent on wavelength. The amplitudes of these brightness changes are the following: $0\overset{m}{.}1$:, $0\overset{m}{.}3$, $0\overset{m}{.}6$, $1\overset{m}{.}55$, $0\overset{m}{.}47$ respectively in U, B, V, R_C, and I_C. This brightening was noted also by Wagner *et al.* (2003) and Crause (2003).

(3) The energy distribution of the remnant is two-component, containing a stellar blue B3 component with a Balmer jump and a strong IR component of the L-type supergiant. The contribution of the cool supergiant's light to the V band can be estimated as $0\overset{m}{.}4$ in October 2003, it increases to longer wavelengths, but is small and negligible in the U and B bands.

These results contradict the conclusion by Mikolajewski *et al.* (2003) that the blue companion is a blending object, lying behind V838 Mon. Its strong brightness decay, by $1\overset{m}{.}1$ in the B filter, apparently coincided with the outburst event. V838 Mon is a binary system which consists of a blue companion and a cool supergiant. The companion that became a supergiant is invisible in the progenitor's spectrum or mimics a B-type star.

Availability of the data. Our observations are available through the IBVS web site as 5511-t1.txt . The file includes the Sonneberg archive data in Table 1A, the measurements of the DSS plates in Table 2A, the UBV photometry in Table 3A, the Cousins RJ photometry in Table 4A, the Johnson RJ photometry in Table 5A, and the $UBVR_CI_C$ photometry of surrounding stars in Table 6A.

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