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V838 Monocerotis — a Newly Discovered, Very Peculiar, Slow Nova-Like Object

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Abstract. The eruptive variable V838 Mon was discovered on Jan 6, 2002. Due to a subsequent phase of almost constant brightness and a spectral appearance which is unlike classical novae, speculations have been made about its nature. Either it was a very peculiar, slow nova defining a new class, an eruptive event in an evolved star as in the case of Sakurai's Object but in a much earlier phase, or something completely different.

1. Introduction

V838 Mon ($\alpha_{2000} = 07^{\rm h}04^{\rm m}04\overset{\rm s}{.}85, \delta_{2000} = -03°50'51\overset{''}{.}1$) was discovered on Jan 6, 2002 when its optical brightness rose to about 10$^{\rm th}$ magnitude (Brown & Rocks 2002). A first low-resolution spectrum (Wagner, Halpern, & Jackson 2002, 3930 – 8560 Å) showed numerous absorption lines and prominent emission lines (Ba II $\lambda\lambda$ 5855, 6142, 6497 Å, Na I λ 5897 Å, Hα, Fe II 5000–5600 Å, O I λ 7774 Å, Ca II $\lambda\lambda$ 8498, 8542 Å) which are not normally found in Fe- or He/N-type classical novae spectra. Some of the lines showed pronounced P-Cygni profiles. Measurements of these profiles indicated a systemic velocity of 53 km s^{-1} (Zwitter 2002) and terminal velocities of 380 to 500 km s^{-1} for a wind or expanding shell (Della Valle & Iijima 2002). Many of the observed lines are from heavy metals, indicating that the object may be in a highly advanced stage of stellar evolution. Otherwise the spectrum seemed to be similar to that of a K-type star of about 4500 K temperature. Infrared spectroscopy revealed a continuum peaking near one micron which is equivalent to a photospheric temperature of roughly 3000 K (Lynch et al. 2002).

Only little change was seen for the next three weeks (pre-maximum plateau phase): V838 Mon was slightly decreasing in brightness (down to 11$^{\rm th}$ magnitude) leading to speculations that it was either a very slow peculiar nova or an eruptive event on an evolved star (Della Valle & Iijima 2002), like for instance the final helium flash in V4334 Sgr (Sakurai's Object), a so-called "born-again post-AGB star". Such stars give invaluable constraints to evolutionary theory. It is worthwhile to note that Sakurai's Object was initially misidentified as a nova (Nakano et al. 1996) and has been identified later as a born-again star (Duerbeck & Benetti 1996). Since only a very few born-again post-AGB stars are known, namely V605 Aql , FG Sge , and V4334 Sgr, V838 Mon has been of great interest and we initiated an observational campaign to establish a baseline for its monitoring.

Unfortunately, at that time little was known about the object before its first brightening. There is a rather bluish object on the Palomar Survey plates but it seemed to be a blend of two stars.

2. Establishing an observational baseline

Soon after the discovery of V838 Mon we were awarded DDT at several observatories (HST: STIS medium-resolution UV spectrum; ESO, La Silla, Chile: high-resolution optical spectra with FEROS@1.5m, 3500 – 8000 Å; low-resolution infrared spectra with TIMMI2@3.6m, 8 - 13.2 μ). Additional high-resolution optical spectra were obtained at the Calar Alto observatory in Spain with the fiber-fed echelle spectrograph FOCES@2.2m, 4015 – 10456 Å). The first optical spectra were taken at Calar Alto on Jan 26, 30, Feb 4, 9, and 20 – starting already some days before the brightness maximum. Other optical spectra were supplied e.g. by the Ondrejov Observatory, Czech Republic (Petr Skoda, private communication). Photometry has continuously been performed by several groups and amateurs, such as AAVSO (http://www.aavso.org/var_mon_02.stm) or VSNET (http://vsnet.kusastro.kyoto-u.ac.jp/vsnet/Novae/gsc4822.39.html) display observational data etc.

3. The UV spectrum of V838 Mon on Feb 9, 2002

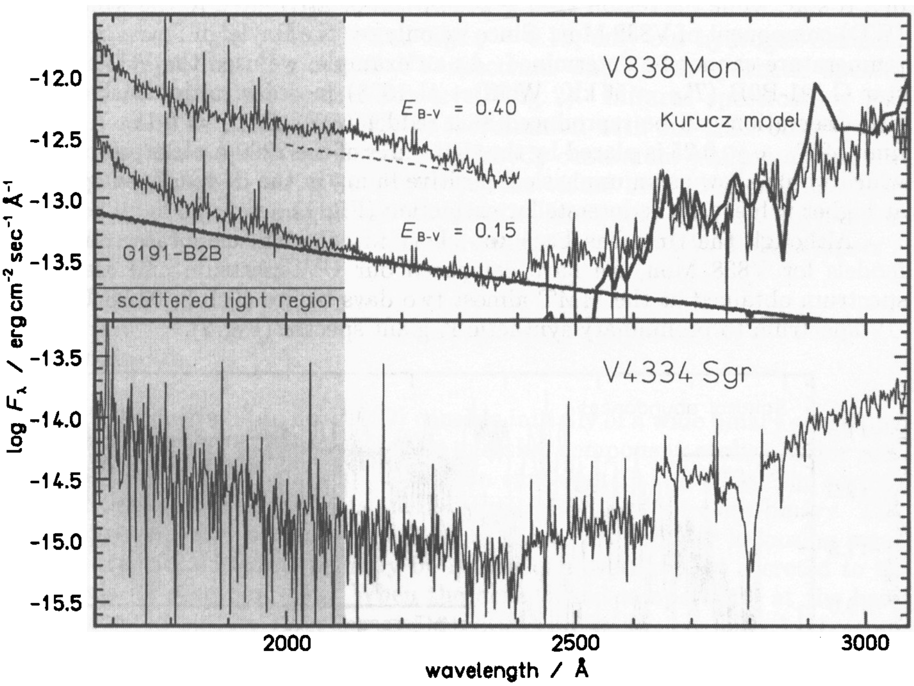

Figure 1. Top: The de-reddened ($E_{B-V} = 0.15$ and 0.40) UV spectrum of V838 Mon taken on Feb 9, 2002 with STIS. Overplotted is the flux of a K-type Kurucz model ($T_{\rm eff}$ = 4500 K, $\log g = 4$, solar abundances, scaled to fit the observed flux at 2700 Å) which fits the observation. In addition, the flux of the WD G 191-B2B is plotted, scaled to fit the observation at 2200 Å. At wavelengths shorter than 2100 Å, the impact of scattered light is obvious. A de-reddening of $E_{B-V} = 0.40$ is too high and yields already a strong positive bump. Bottom: The de-reddened ($E_{B-V} = 0.15$) NUV spectrum of Sakurai's Object (taken on Jul 10, 1997 with the same STIS setup). Note that V838 Mon and Sakurai's Object both exhibit cool-giant spectra of almost the same spectral type at their brightness maximum. However, these objects appear to have a completely different nature.

Our HST observation, one orbit DDT, had been scheduled for Feb 9, 2002, 23:16 UT. We proposed to perform FUV + NUV echelle spectroscopy with gratings E140M (1100 – 1700 Å) and E230M (1650 – 3000 Å), respectively, with MAMA detectors. The whole setup had to be changed only three days before the planned execution due the outburst of V838 Mon on Feb 4 and the maximum brightness of 6.7 magnitudes which appeared to be too close to the MAMA brightness maximum. We then used grating G230LB + CCD which covers the NUV range of 1669 – 3074 Å only. Unfortunately, spectra taken with

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this grating are dominated by scattered light at wavelengths shorter than 2100 Å (Fig. 1). However, at longer wavelengths ($\gtrsim$ 2400 Å) there is a spectrum typical of a K star, while the region 2100 – 2400Å can be attributed to the white dwarf (WD) component of V838 Mon. Since we only see the Rayleigh-Jeans regime, its temperature cannot be determined. As an example, we used the WD standard star G 191-B2B ($T_{\rm eff}$ = 56 kK, Wolff et al. 1998) in order to demonstrate that the observation can be reproduced at a reddening of $E_{\rm B-V} = 0.15$. An upper limit of $E_{\rm B-V} \lesssim 0.25$ is placed by the signatures of the 2200 Å absorption feature which would show as an unphysical positive bump in the de-reddened spectrum at higher values for the interstellar extinction (Fig. 1).

Although the time has been too short to calculate elaborate, fine-tuned models for V838 Mon, we have compared our UV spectrum and an optical spectrum obtained at the MMT almost two days before (Feb 8, 03:28 UT) our UV spectrum to preliminary synthetic K-giant spectra (Fig. 2).

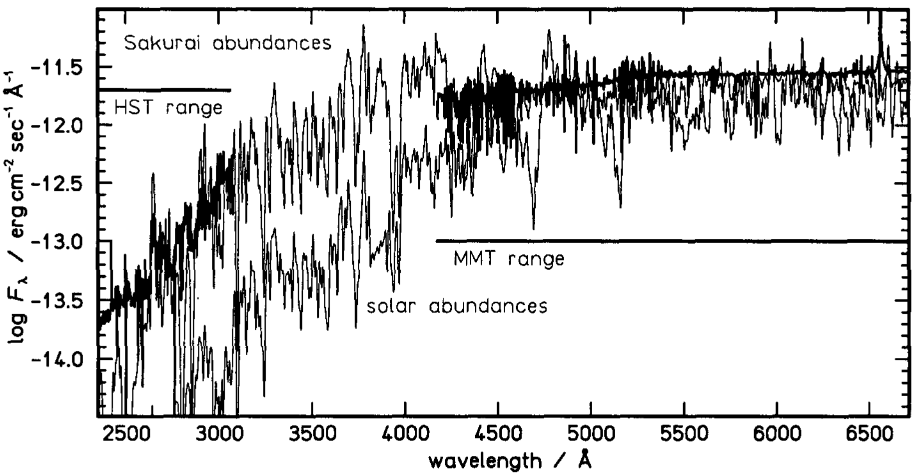

Figure 2. Comparison of our de-reddened ($E_{\rm B-V} = 0.15$) UV (HST) and optical (MMT) spectra (thick lines) with two synthetic spectra (for clarity smoothed with a Gaussian of 10 Å FWHM) of K-type giants ($T_{\rm eff}$ = 4500 K) calculated with different elemental compositions. The synthetic spectra are normalized to fit the optical spectra around 4400 Å. Note that in contrast to the model calculated with Sakurai's Object's abundance ratios, the model with solar composition has a flux level in the NUV which is too low by an order of magnitude.

The models were calculated using an approach similar to that of Allard, Hauschildt, & Schweitzer (2000). They use spherical symmetry for an assumed mass of the object of 0.7 $M_\odot$ and a gravity of $\log g = 0.0$. The models presented here use updated equations of state and molecular line lists (Allard et al., in prep.). The Sakurai-abundance models are H deficient with the following values for some important elements (normalized to $\epsilon_{\rm He} = 11.6$ by logarithmic number): $\epsilon_{\rm H} = 9.0$, $\epsilon_{\rm C} = 9.7$, $\epsilon_{\rm N} = 9.0$, $\epsilon_{\rm O} = 9.3$, $\epsilon_{\rm Ne} = 9.5$, $\epsilon_{\rm Ti} = 5.02$, and $\epsilon_{\rm Fe} = 6.6$. Most other elements have their solar ratios relative to helium. For simplicity, the models presented here are *static*, which is clearly a poor assumption, but more complex wind-type models are being constructed to more accurately describe the formation of the observed spectrum.

If we assume $T_{\rm eff} = 4500\,$K and $E_{\rm B-V} = 0.15$, only our hydrogen-deficient model can reproduce the overall UV spectrum when both synthetic spectra are scaled to match the optical flux level (Fig. 2). Infrared spectroscopy had been performed at ESO (TIMMI2) in coordination with our HST observation: The low-resolution spectrum shows a blackbody continuum which corroborates $T \approx 4500\,$K (Käufl et al. 2002). However, the visual brightness of V838 Mon decreased by about one magnitude between the MMT and the HST observation and nothing is known about the spectral evolution in the UV. This hampers a precise abundance analysis.

4. Discussion

A classical nova (e.g. Starrfield 1989) consists initially of a wide binary consisting of two main sequence stars. The more massive component evolves faster and becomes a red giant building up a common envelope. In this phase the system looses orbital energy and angular momentum, resulting in a close binary. The evolved primary star becomes a WD while the cool secondary is loosing mass which is transferred to the primary by Roche-lobe overflow and accreted to its surface via an accretion disk. When the density and temperature at the base of the accreted surface layer surpass a critical limit, electrons at the bottom become partially degenerate. At $2 \times 10^7\,$K hydrogen burning is ignited. Since the matter is degenerate, temperature increases in a thermonuclear runaway. At about $2 \times 10^8\,$K the gas becomes ideal. Within one hour, the envelope has expanded to several solar radii and engulfs both stars. The temperature reaches several $10^8\,$K before it decreases, then β^+ decay yields a great amount of energy. H burning on the WD surface continues at thermal equilibrium until all H is either burned or lost in a wind. Then the system returns to the pre-outburst appearance. During eruption, a nova generally shows a characteristic lightcurve. Its brightness maximum is generally reached within a very few days. Due to the time scale of the decrease of their brightness after maximum, fast (3 magnitudes in 100 days) and slow novae are defined.

A born-again post-AGB star (Iben et al. 1983) experiences a late He-shell flash after its first departure from the AGB. The star then returns to the AGB. Due to mixing processes during the final flash, the entire H shell is burnt and the star becomes H deficient. After its second departure from the AGB it evolves in a He-burning post-AGB phase. In contrast to novae, final-flash objects, e.g. Sakurai's Object (Duerbeck et al. 2000), reach the maximum brightness on a time scale of years.

Regarding the lightcurve of V838 Mon, a born-again scenario can definitely be ruled out: After a steep rise to the pre-maximum plateau, the main outburst followed after three weeks. Several slightly fainter maxima followed within two months until V838 Mon began to fade (6 magnitudes in one month) towards its pre-outburst brightness. The similarity of the spectra of V838 Mon and Sakurai's Object on Feb 9, 2002, as well as their similar surface abundances, may just be a short cross-over of their evolutionary tracks in the HRD.

A more likely scenario for the mysterious eruption of V838 Mon has been given in the meantime by Munari et al. (2002) and Bond et al. (2002): Since the progenitor of V838 Mon has been a main-sequence star and V838 Mon has been extremely luminous during its prolonged outburst, they concluded that the eruption of V838 Mon has the closest similarity with one (M31-RedVar) discovered in M31 by Rich et al. (1989) which might have been the consequence of the explosion of hydrogen in a relatively massive envelope accreted by a low-mass degenerate dwarf in a short-period cataclysmic binary (Iben & Tutukov 1992). Thus, it appears possible that V838 Mon belongs to a new class of eruptive variables, together with M31-RedVar and V4332 Sgr.

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