V838 Mon and the new class of stars erupting into cool supergiants (SECS)

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Abstract. V838 Mon has undergone one of the most mysterious stellar outbursts on record. The spectrum at maximum closely resembled a cool AGB star, evolving toward cooler temperatures with time, never reaching optically thin conditions or showing increasing ionization and a nebular stage. The latest spectral type recorded is M8-9. The amplitude peaked at ΔV=9 mag, with the outburst evolution being characterized by a fast rise, three maxima over four months, and a fast decay (possibly driven by dust condensation). BaII, LiI and s−element lines were prominent in the outburst spectra. Strong and wide (500 km/sec) P-Cyg profiles affected low ionization species, while Balmer lines emerged to modest emission only during the central phase of the outburst. A light-echo discovered expanding around the object constrains its distance to 790 ± 30 pc, providing $M_V = +4.45$ in quiescence and $M_V = −4.35$ at optical maximum (dependent on the still uncertain $E_B−V = 0.5$ reddening). The visible progenitor resembles a somewhat under-luminous F0 main sequence star, that did not show detectable variability over the last half century.

V838 Mon together with M31-RedVar and V4332 Sgr seems to define a new class of astronomical objects, Stars that Erupt into Cool Supergiants (SECS). They do not develop optically thin or nebular phases, and deep P-Cyg profiles denounce large mass loss at least in the early outburst phases. Their progenitors are photometrically located close to the Main Sequence, away from the post-AGB region. After the outburst, the remnants still closely resemble the precursors (same brightness, same spectral type). Many more similar objects could be buried among poorly studied variable stars that have been classified as Miras or SemiRegulars on the base of a single spectrum at maximum brightness.

THE OUTBURST OF V838 MON

A detailed description of the outburst of V838 Mon is given by [1], to which the reader is referred. In this note only the main features are summarized with some updates on the late photometric and spectroscopic evolution of the outburst.

An updated lightcurve of the eruption of V838 Mon is presented in Figure 1. A first maximum was reached by $+10^d$ (see abscissae scale on Figure 1) when the continuum energy distribution was characterized by a temperature of 4150 K. A second maximum at $+37^d$ peaked around 5200 K and a third one at $+68^d$ reached 4600 K. Each decline from maxima was accompanied by a monotonic cooling, with the last one taking V838 Mon to 3500 K by $+90^d$. From $+90^d$ to $+120^d$ the color temperature in the region of the $V, R, I_c$ bands decreased to that of an M8-9 supergiant, or 2600 K. The retracing of the $U−B$ and $B−V$ color indexes when the spectrum developed the coolest temperatures is a real effect (cf. absolute spectrophotometry in Figure 2 at $+119^d$), and it is normally seen
FIGURE 1. $V, B - V$ and $V - I_c$ lightcurves of the outburst of V838 Mon. Dots mark NOFS data, open circles Tsukuba data. Crosses and open triangles are values from various IAUC and VSNET circulars (mainly from SAAO, D.West, P.Sobotka, L.Smelcer, F.Lomoz and J.Bedient). The solid line indicates the quiescence brightness.

in M-type stars of the corresponding spectral types due to progressive disappearance of TiO absorptions at the shortest wavelengths. The spectral evolution well followed the $V - I$ color temperature evolution. During the first three months the spectrum closely resembled a K giant, slowing progressing toward later spectral types and reaching K5 by $+90^d$. In the following month the spectrum rapidly entered the M-type realm and reached M8-9 by $+119^d$. The spectrum of V838 Mon for this date is shown in Figure 2. The spectral evolution of V838 Mon has been
FIGURE 2. The spectrum of V838 Mon for April 29, 2002 obtained with WHT 4.2m in La Palma.

FIGURE 3. Small sections of sample of Asiago Echelle spectra to document the evolution around the far-red Calcium triplet and Hα of the V838 Mon outburst.

exciting also on a much finer scale, as Figure 3 indicates, where Echelle spectra around the CaII far-red triplet and Hα are presented for +25^d, +56^d, +86^d and +112^d. P Cyg line profiles for low-excitation species have a terminal velocity which monotonically decreased with time from the initial value of $-500$ km/sec, with Balmer lines appearing in emission with their own P-Cyg profiles only after the second maximum. BaII, LiI and s—elements are present in the V838 Mon spectra.

In mid-February, [2] discovered the formation of a light-echo around V838 Mon, when the light from the second maximum began illuminating pre-existing circumstel-
lar material responsible for the IRAS detection of the precursor. This light-echo was followed as it expanded to a maximum diameter of 35 arcsec, a size that has remained essentially constant during the following months, as Figure 4 shows. The light-echo expansion rate of $0.44 \pm 0.017 \text{ arcsec day}^{-1}$ sets the distance of V838 Mon to $790 \pm 30$ pc for a spherical distribution of the scattering material. The outburst light sweeping through the circumstellar material allows us to read the recent mass loss history of the progenitor: assuming 15 km sec$^{-1}$ velocity for its wind (typical for an AGB), the light-echo has reached by April 1 material lost $\sim$4900 years ago. High resolution imaging with HST by [3] confirms the spherical symmetric dust distribution around V838 Mon and reveals multiple circularly-symmetric rings, along with a central void. This void was also visible on ground-based images after V838 Mon faded. The void is the likely reason why the light-echo was not seen until some time after the rise to second maximum. The angular separation of the concentric rings in the HST images indicate a $\sim$500 year recurrence time in the enhanced mass loss events.

Using the 790pc distance estimate and the peak brightness, we can derive $M_V = +4.45$ for V838 Mon in quiescence and $M_V = -4.35$ at peak outburst. The precise values depend on the exact amount of reddening, here estimated to be $E_{B-V}=0.5$. At galactic coordinates $l = 217.80 \ b = +1.05$, the height over the Galactic plane is just $z = 13$ pc. It is relevant to note that the progenitor of V838 Mon was not detected by H$\alpha$ emission-line surveys in the region (these surveys discovered several faint emission line stars close to V838 Mon), and inspection of Palomar and SERC plates as well as results from many archival plates presented at this conference by [4] reveal absence of photometric variability in quiescence. Both H$\alpha$ emission and variability would have supported an interactive binary nature of the precursor.
V838 MON AND THE STARS ERUPTING INTO COOL SUPERGIANTS (SECS)

In 1989 an erupting star in the Andromeda Galaxy (M31) developed a M-type cool supergiant spectrum at maximum, with pronounced P-Cyg profiles and Balmer lines in emission ([5], [6]). The progenitor was too faint to be identified and the event has been modeled by [7] in terms of a cool WD accreting at a very low rate from a companion and under such circumstances the entire WD could experience a thermonuclear runaway. The similarities with V838 Mon are the cool supergiant spectrum at maximum, the emission in the Balmer lines, the variable P-Cyg profiles and the faintness of the progenitor. However, the event in M31 peaked to $M_V = -9.95$, much brighter than the $M_V = -4.45$ reached by V838 Mon. Nevertheless, the light curve presented by [8] is quite similar to V838 Mon.

Another close match is Nova Sgr 1994 V4332 Sgr (Nova Sgr 1994 #1). As described in [9], V4332 Sgr displayed a flat outburst, dramatic increase in $(V - I)$ during its fade from maximum, an M-type spectrum at maximum and P-Cyg profiles. The progenitor was a K star close to the Main Sequence. The outburst duration was only 20 days, however, and perhaps this variable was not discovered until some time after the beginning of the outburst. Imagery during outburst as well as more recently does not show any signs of a light-echo surrounding V4332 Sgr.

There have been several possible novae reported over the past century that have been ascribed to Mira variability on the base of the spectrum in outburst. Perhaps some of these are similar objects to M31 RedVar, V4332 Sgr and V838 Mon. The latter may represent a new class of astronomical objects: stars erupting into cool supergiants but that never develop an optically thin phase (increasing excitation temperature and development of a nebular spectrum) like in classical novae. Their progenitors lies away from the post-AGB stars and appear close to the cool main sequence on the HR diagram. These stars, characterized by heavy mass loss at least in the early outburst phases, could be binaries even if no evidence of this has been found (in V838 Mon the circumstellar dust envelope could be the relic of an AGB phase of an hypothetical companion to the F0 V star seen in quiescence). We suggest for this new class of astronomical objects the name of stars erupting into cool supergiants (SECS).

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