Modelling the Spectrum and SED of V838 Mon

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Abstract. We model the spectra and spectral energy distribution of V838 Mon which were observed in February, March, and November, 2002. Theoretical spectra are calculated using the classical model atmospheres taking into account absorption of atomic and molecular lines. By fitting the observed spectra we determine the physical parameters of the atmosphere of V838 Mon. These parameters are determined to be $T_{\text{eff}} = 5330 \pm 300$ K, $5540 \pm 270$ K, $4960 \pm 190$ K, and $2000 \pm 200$ K for February 25, March 2, March 26, and November 6, respectively.

1. Introduction

The cause of the eruption of V838 Mon and the nature of its progenitor are unclear. Desidera and Munari (2002) reported a faint hot continuum at short wavelengths, recently confirmed by Munari et al. (2005) and identified as a B3V companion.

1.1. Observational data

Some spectra obtained on February – March, 2002 are analysed here. The first spectrum of V838 Mon taken on Feb. 4 is shown in Fig. 1. It was obtained by V.Klochkova at the 6 m telescope (SAO, Russia). Details of the data reduction can be found in Kipper et al. (2004).

On February 25 and March 26, 2002, high resolution spectra ($R \sim 20000$) of V838 Mon were obtained by U. Munari with the Echelle+CCD spectrograph on the 1.82m telescope operated by Osservatorio Astronomico di Padova on Mount Ekar (Asiago), and made available to us (see Munari et al. 2002 for details).

Spectra on March 2 were obtained with the echelle fibre-fed spectrograph on the 1.9-m SAAO telescope, and kindly provided to us by Lisa Crause (see Crause et al. 2003 for details).

The November 6, 2002 spectrum was obtained with the Kast spectograph on the Cassegrain focus of the Shane 3-m telescope at Lick Observatory. Full details of the observing and data-reduction processes are given in Rushton et al. (2005).

1.2. Computation of theoretical spectra

Through February to March 2002, the spectrum of V838 Mon looks like a normal spectrum of a supergiant of spectral class K – G. The optical spectra of V838Mon over these dates are governed by absorption by the neutral atoms. A comparison
Figure 1. Left: a comparison of observed spectra of V838 Mon for different dates in February – March, 2002. Right: comparison of the spectrum of V838 Mon and that of Arcturus (Hinkle et al. 2000), convolved with macroturbulent profile $V_{\text{macro}} = 50 \text{ km s}^{-1}$. See Kaminsky & Pavlenko (2005) for more details.
with a synthetic spectrum of Acturus, with lines broadened by macroturbulent velocities of 50 km/s, shows good agreement (Fig. 1).

To model these spectra we used classical model atmospheres from the Kurucz (1993) grid. Computations of the synthetic spectra were carried out using the program WITA6 Pavlenko (2000) assuming LTE and hydrostatic equilibrium for a one-dimensional model atmosphere without sources and sinks of energy. The equations of ionization-dissociation equilibrium were solved for media consisting of atoms, ions and molecules. Computations were carried out for the VALD (Kupka et al. 1999) line list.

Up until November 2002 both effective temperature and luminosity of V838 Mon drop significantly with time (see also Tylenda 2005). The spectrum of V838 Mon contains strong molecular features. To compute theoretical spectral energy distributions (SEDs) we used a number of model atmospheres, with $T_{\text{eff}} = 2000 \sim 2200$ K, $\log g = 0, 0.5$ from the NextGen grid of Hauschildt et al. (1999).

In addition atomic line data from VALD, molecular line data were taken from a variety of sources:

- CN lines from CDROM 18 (Kurucz 1993);
- CrH and FeH lines from Burrows (2002) and Dulick et al. (2003), respectively
- lines of $\text{H}_2\text{O}$ from the BT2 database (Barber et al. 2006)
- absorption by VO, and by a few molecules of (in the case of V838 Mon) lesser importance, was computed in the JOLA approximation (see Pavlenko 2000).

The relative importance of the different opacities contributing to our synthetic spectra is shown in Fig. 1.

2. Results

2.1. V838 Mon in February – March, 2002

It is worth noting a few results (see Kaminsky & Pavlenko 2005 for more details of our procedure and results):

For February 25 we obtained $T_{\text{eff}} = 5330 \pm 300$ K, $\log N(\text{Fe}) = -4.7 \pm 0.14$ dex and $V_t = 13. \pm 2.8$ km s$^{-1}$.

For March 2 $T_{\text{eff}} = 5540 \pm 190$ K, $\log N(\text{Fe}) = -4.75 \pm 0.14$ dex, $V_t = 13.3 \pm 3.2$ km s$^{-1}$.

For March 26 $T_{\text{eff}} = 4960 \pm 270$ K, $\log N(\text{Fe}) = -4.68 \pm 0.11$ dex, $V_t = 12.5 \pm 1.7$ km s$^{-1}$.

To account for processes of broadening of spectral lines in spectrum of V838 Mon we used parameter $V_g$. In our case $V_g$ represents the macroturbulent velocity. We obtained $V_g = 54 \pm 3, 47 \pm 3$ and $42 \pm 5$ km s$^{-1}$ for February 25, March 2 and March 26, respectively.

Finally, we obtained changes of the radial velocity $V_{\text{radial}} = -76 \pm 3, -70 \pm 3$ and $-65 \pm 3$ km s$^{-1}$ for February 25, March 2 and March 26, respectively, it appears possible that there is a reduction in the expansion velocity of the envelope.

2.2. V838 Mon in November, 2002

On November, 2002 V838 Mon was classified by Evans et al. (2002) as an L-supergiant. The infrared spectrum of V838 Mon shows deep absorption bands of
Figure 2. Left: the contribution of different molecules to the formation of the spectrum of V838 Mon. Right: our fit to the observed V838 Mon spectrum on November 6, 2002 (Pavlenko et al. 2006).
H$_2$O. In the optical spectra there are strong TiO bands as well as bands of a few diatomic molecules (Fig. 2).

A numerical analysis of V838 Mon spectrum was carried out by Pavlenko et al. (2006). We showed that the slope of the spectrum on 0.6 – 1 micron depends on T$_{\text{eff}}$. The best fit was obtained for T$_{\text{eff}} = 2000$ K (Fig. 2).

It is worth noting that the Balmer hydrogen lines, from H$_\beta$ to the Balmer jump, are clearly seen in the observed B3V spectrum. Using the Kurucz (1993) model atmospheres we computed theoretical spectra using WITA6 for different T$_{\text{eff}}$ and log g. The best fit to the observed spectrum provides T$_{\text{eff}} = 18000 - 23000$ K and log g = 4.0 - 4.5.

Our fits of the combined (supergiant+dwarf) synthetic spectrum to the observed spectrum provide the unique possibility for the determination of the radius of the V838 Mon photosphere. This is only possible if V838 Mon and the B3V dwarf form a physically bound system.

Indeed, the radius and effective temperature of the “normal” B3V star should be $\sim 6$ R$_\odot$ and $\sim 20 000$ K, respectively. Then, the ratio of the theoretical fluxes around 7000Å computed by WITA6 for the model atmospheres of different effective temperatures is $\sim 100$. Using one simple suggestion that this ratio can be applied to integrated fluxes from both stars, we get for November 2002

$$(R_{V838\text{Mon}}/R_{B3V})^2 = 100 \times (T_{\text{eff}}^{B3V}/T_{\text{eff}}^{V838\text{Mon}})^4$$

and

$$R_{V838\text{Mon}} = 6000 R_\odot.$$ 

Again, we note that this estimation is only correct if V838 Mon and the B3V dwarf are located at the same distance from the Sun.

### 3. Conclusion

From February until November 2002, we do not see any chemical peculiarities in the spectrum of V838 Mon. The observed spectrum resembles the spectrum of the photosphere of a normal supergiant of slightly reduced metallicity [Fe/H] = $-0.4$ or $-0.2$ (see Kipper et al. 2004, Kaminsky & Pavlenko, 2005). It therefore provides indirect observation of the evolution of a massive star or binary system with a massive component.

Then, V838 Mon represents a case of very slow evolution. The spectral sequence of V838 Mon can be fitted by the sets of computations for model atmospheres with hydrostatic equilibrium. The observed absorption lines form in the atmospheres with decreasing temperature outwards. Only the strongest lines in February-March 2002 show P Cyg profiles. The relaxation time after the stellar flash(es) does not exceed 10 days. All these factors should be accounted for in future theoretical models.

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References

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Discussion

Hirschi: With Teff=2000K, a radius of the order of 1000 R seems reasonable at least for Red Super Giants

Pavlenko: OK, we get the radius 6000 R⊙.

Goranskij: In the spectra shown in web page of Conference, we see that details of L supergiant expand more and more in the blue region. This means that the star becomes hotter and hotter. And this tendency is confirmed by photometry. But your calculations show cooling of the star. Why?

Pavlenko: IR region is better to find temperature of so cool star, because there is the maximum of flux located. Note, by definition the blue part of the spectra should show stronger dependence on shock waves or any other processes of stellar activity. Fortunately, there is only small part of the total/integrated flux of our cool supergiant is located.