The absorption spectrum of V838 Mon in 2002 February - March. I. Atmospheric parameters and iron abundance.*

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ABSTRACT

We present a determination of the effective temperatures, iron abundances, and microturbulent velocities for the pseudophotosphere of V838 Mon on 2002 February 25, and March 2 and 26. Physical parameters of the line forming region were obtained in the framework of a self-consistent approach, using fits of synthetic spectra to observed spectra in the wavelength range 5500-6700 Å. We obtained $T_{\text{eff}} = 5330 \pm 300$ K, $5540 \pm 270$ K and $4960 \pm 190$ K, for February 25, March 2, and March 26, respectively. The iron abundance $\log N(\text{Fe}) = -4.7$ does not appear to change in the atmosphere of V838 Mon from February 25 to March 26, 2002.

Key words: stars: atmospheres – stars: abundances – stars: individual: V838 Mon

1 INTRODUCTION

The peculiar variable star V838 Mon was discovered during an outburst in the beginning of 2002 January (Brown 2002). Two further outbursts were then observed in 2002 February (Munari et al. 2002a; Kimeswenger et al. 2002; Crause et al. 2003) and in general the optical brightness in V-band of the star increased by 9 mag. Since 2002 March, a gradual fall in V-magnitude began which, by 2003 January, was reduced by 8 mag. The suspected progenitor of V838 Mon was identified by Munari et al. (2002a) as a 15 mag F-star on the main sequence. Possibly V838 Mon might have a B3V companion (Desidera & Munari 2002), but it could be a background star. The discovery of a light echo (Henden et al. 2002) allowed an estimate of the distance to V838 Mon and, according to recent works based on HST data (Bond et al. 2003; Tylenda 2004) its distance is 5-6 kpc. If these estimations are correct, at the time of maximum brightmess V838 Mon was the most luminous star in our Galaxy.

Details of the spectral evolution of the star are described in Kolev et al. 2002; Wisniewski et al. 2003; Osiwala et al. 2002). During outbursts (except for the last) the spectrum displayed numerous emission lines with P Cyg profiles, formed in the expanding shell and around an F- or A-star (Kolev et al. 2002). On the other hand, absorption spectra appropriate to a red giant or supergiant were observed in quiescent periods. Strong lines of hydrogen, D lines of sodium, triplets of calcium and other elements show P Cyg profiles. They have similar profiles and velocities varying from $-500$ km s$^{-1}$ in late January to $-280$ km s$^{-1}$ in late March (Munari et al. 2002a). Since the middle of 2002 March, the emissions are considerably weakened and the spectrum of V838 Mon evolved to later spectral classes. In middle of 2002 April, there were present some lines of TiO; in May the spectrum evolved to the “very cold” M-giant (Banerjee & Ashok 2002). In October Evans et al. (2003) characterized it as a L-supergiant.

Recently Kipper et al.(2004) found for iron group elements [m/H] = −0.4, while abundances of lithium and some s-process elements are clearly enhanced. This results was obtain using the static LTE model.

These results are very dependent on the model atmosphere and spectrum synthesis assumptions.

The nature of the outbursts remains a mystery. Possible explanations include various thermonuclear processes (very slow nova, flare post-AGB), and the collision of two stars (Soker & Tylenda 2003). Munari et al. (2002a) suggested that V838 Mon is a new type of a variable star, because comparison with the closely analogous V4334 Sgr and M31 RV has shown significant enough differences in the observed parameters.

In this paper we discuss the results of the determination of iron abundance and atmospheric parameters of V838 Mon. These we obtained from an analysis of absorption spectra of V838 Mon on 2002 February 25 and March 2 and 26. The complexity and uniqueness of the observed characteristics of V838 Mon practically excluded a definition of the parameters of the atmosphere using conventional methods, based on calibration on photometric indices, ionization balance, profiles of hydrogen lines. Indeed, the presence around the star of a dust shell, and the uncertain determination of
interstellar reddening (from $E_{B-V} = -0.25$ to $E_{B-V} = -0.8$ Munari et al. 2002a), affects the $U - B$ and $B - V$ colours. Emission in the hydrogen lines provides severe problems for their application in the estimation of effective temperature. Moreover, both the macroturbulent motions and expansion of the pseudophotosphere merges the numerous lines in wide blends. As a result, a single unblended line in the spectrum of V838 Mon cannot be found at all, and any analysis based on measurements of equivalent widths is completely excluded.

The observational data used in this paper are described in section 2. Section 3 explains some background to our work and some details of the procedure used. We attempt to determine $T_{eff}$, the microturbulent velocity $V_t$ and the iron abundance $\log N(Fe)$ in the atmosphere of V838 Mon in the framework of the self-consistent approach in section 4. Some results are discussed in section 5.

2 OBSERVATIONS

Spectra of V838 Mon were obtained on 2002 February 25 and March 26 with the Echelle+CCD spectrograph on the 1.82m telescope operated by Osservatorio Astronomico di Padova on Mount Ekar (Asiago), and freely available to the community from [http://ulisse.pd.astro.it/V838Mon/](http://ulisse.pd.astro.it/V838Mon/). A 2 arcsec slit was used with fixed E-W orientation, producing a PSF with a FWHM of 1.75 pixels, corresponding to a resolving power close to 20000. The detector was a UV coated Thompson CCD 1024 $\times$ 1024 pixel, 19 micron square size, covering in one exposure the wavelength range 4500 to 9480Å (echelle orders #49 to #24). The short wavelength limit is set by a 2 mm OG 455 long-pass filter, inserted in the optical train to cut the second order from the cross-disperser. The wavelength range is covered without gaps between adjacent echelle orders up to 7300Å. The spectra have been extracted and calibrated using IRAF software running under Linux operating system. The spectra are sky-subtracted and flat-fielded. The wavelength solution was derived simultaneously for all 26 echelle orders, with an average r.m.s of 0.0025 Å. The 8480-8750 Å wavelength range of these Asiago spectra has been described in Munari et al. (2002a,b).

Another set of spectra (R $\sim$ 32000) for March 2 was obtained with the echelle fibre-fed spectrograph on the 1.9-m SAAO telescope kindly provided for us by Dr. Lisa Crause (see Crause et al. 2003 for details).

3 PROCEDURE

To carry out our analysis of V838 Mon we used the spectral synthesis techniques. Our synthetic spectra were computed in the framework of the classical approach: LTE, plane-parallel media, no sinks and sources of energy inside the atmosphere, and transfer of energy provided by the radiation field and by convection.

Strictly speaking, none of these assumptions is 100% valid in atmosphere of V838 Mon. Clearly we have non-static atmosphere which may well have shock waves moving trough it. Still we assumed that in any moment the structure of model atmosphere of V838 Mon is similar to model atmospheres of supergiants. Indeed, temporal changes of the absorption spectra on the days were rather marginal. Most probably, for this object, we see only a pseudophotosphere, which is the outermost part of an expanding envelope. Therefore, our first goal was to determine whether it is possible to fit our synthetic spectra to the observed V838 Mon spectra.

At the time of the observations the spectral class of V838 Mon was determined as K-type (Kolev et al. 2002). Absorption lines in spectrum of V838 Mon form comparatively broad blends.

Generally speaking, there may be a number of broadening mechanisms:

- Microturbulence, which is formed by small scale (i.e $\tau \ll 1$) motions in the atmosphere. In the case of a supergiant, $V_t$ usually does not exceed 10 km s$^{-1}$. In our analysis we determined $V_t$ from a comparison of observed and computed spectra.
- Stellar rotation. Our analysis shows that, in the case of V838, we should adopt $V \ast \sin i = 80$ km s$^{-1}$ to fit the observed spectra. This value is too high for the later stages of stellar evolution, for obvious reasons. In reality rotation cannot contribute much to the broadening of lines observed in spectra of most supergiants.
- Expansion of the pseudophotosphere of the star. Asymmetrical profiles of expansion broadening can be described, to a first approximation, by the formula

$$G(v, \lambda, \Delta \lambda) = \text{const} \ast \Delta \lambda \sqrt{1 - (\Delta \lambda / \lambda_{\exp})^2}, \quad (1)$$

where $V_{\exp}$ is the expansion velocity. The observed spectra can be fitted with $V_{\exp} = 160$ km s$^{-1}$ (see Fig. 1).

From February 25 to March 2 the brightness of the star was approximately constant, but at the time of the observation on March 26 there was a small drop in visual brightness (see Kolev et al. 2002). In Fig. 2 we show a comparison of the observed spectra of V838 Mon at the times of the increase in luminosity (February 3; Kipper & Klochkova, private communication) and at approximately constant luminosity (February 25, March 2 and March 26). They differ drastically – the spectrum of February 3 is severely veiled by
emission: many lines are observed in emission. This demonstrates that effects of the radial expansion of the line-forming layers were not significant for the dates of our data and formally obtained value \( V_{\text{exp}} = 160 \) km s\(^{-1}\) is not real.

- Macroturbulence. After the large increase of luminosity in 2002 January-February, large scale (i.e. of magnitude \( \tau > 1 \)) macroturbulent motions should be very common in the disturbed atmosphere of V838 Mon. Our numerical experiments showed that, to get appropriate fits to the observed spectra taking into account only macroturbulent velocities, we should adopt \( V_{\text{macro}} \sim 50 \) km s\(^{-1}\).

In any case, for the times of our observations the spectra of V838 Mon resemble the spectra of “conventional” supergiants. Our V838 Mon spectra for February 25, March 2 and March 26 agree, at least qualitatively, with the spectrum of a normal late (super)giant, broadened by strong macroturbulence motions and/or expansion of its pseudophotosphere. Unfortunately we cannot, from the observed spectra, distinguish between broadening due to the macroturbulence and expansion (see next section).

It is worth noting that the observed spectra of V838 Mon are formed in a medium with decreasing temperature to the outside, i.e. in the local co-moving system of co-ordinates the atmosphere, to a first approximation, can be described by a “normal” model, at least in the region of formation of weak or intermediate strength atomic lines.

3.1 Fits to observed spectra

We computed a sample of LTE synthetic spectra for a grid of Kurucz (1993) model atmospheres with \( T_{\text{eff}} = 4000 - 6000 \) K using the WHTA612 program (Pavlenko 1997). Synthetic spectra were computed with wavelength step 0.02 Å, macroturbulent velocities 2 – 18 km s\(^{-1}\) with a step 1 km s\(^{-1}\), iron abundances \( \log N(\mathrm{Fe}) = -5.6 \rightarrow -3.6 \) dex\(^{-1}\), with a step 0.1 dex. Then, due to the high luminosity of the star, we formally adopt \( \log g = 0 \). Synthetic spectra were computed using the VALD (Kupka et al. 1999) line list. For atomic lines the line broadening constants were taken from VALD or computed following Unsold (1955).

For the dates of our observations lines of neutral iron dominate in the spectra. Fortunately, they show rather weak gravity/pressure dependence, therefore the uncertainty in the choice of \( \log g \) will not be important in determining our main results; the dependence of the computed spectra on \( T_{\text{eff}} \) is more significant (see Fig. 4). The computed synthetic spectra were convolved with different profiles, and then fitted to the observed spectra following the numerical scheme described in Jones et al. (2002) and Pavlenko & Jones (2002).

In order to determine the best fit parameters, we compared the observed residual fluxes \( r_{\lambda}^{\text{obs}} \) with computed values \( H_{\lambda}^{\text{theor}} \). We let \( H_{\lambda}^{\text{obs}} = \int F_{\lambda}^{\text{theor}} \ast G(y) \ast dy \), where \( F_{\lambda}^{\text{theor}} \) is the theoretical flux and \( G(y) \) is the broadening profile. In our case \( G(y) \) may be wavelength dependent. To get the best fit we find the minima per point of the 2D function

\[
S(f_\lambda, f_k) = \Sigma[1 - H_{\lambda}^{\text{theor}}/H_{\lambda}^{\text{obs}}]^2
\]

We calculated these minimization parameters for our grid of synthetic spectra to determine a set of parameters \( f_\lambda \) (wavelength shift parameter) and \( f_k \) (convolution parameter).

The theoretical spectra were convolved with a gaussian profile. Our convolution profile is formed by both expansion and macroturbulent motions. We cannot distinguish between them in our spectra. To get a numerical estimate

\[\sum N_i = 1\]
of the broadening processes in the pseudophotosphere, we use a formal parameter $f_{g}$, which describes the cumulative effect of broadening/expansion motions. The parameters $f_{g}$ and $f_{b}$ were determined by the minimization procedure; the procedure was carried out for different spectral regions. We selected for analysis 6 spectral orders in the interval 5600-6700 Å. In the red, spectral lines are blended by telluric spectra, and are of lower S/N. In the blue the blending of the spectra are rather high. Our main intention was to obtain a self-consistent solution separately for different echelle orders, and then compare them. If we could obtain similar parameters from different spectral regions it can be evidence of the reality of the obtained solution.

4 RESULTS

4.1 The Sun

To be confident in our procedure, we carried out a similar analysis for the Sun. For this case we know the solar abundances and other basic parameters, therefore our analysis provides an independent estimation of the quality of our procedure:

- From the solar atlas of Kurucz et al (1984) we extract spectral regions corresponding to our observed orders of V838 Mon;
- we convolve the solar spectra with a gaussian of $V_{\text{macro}} = 50$ km s$^{-1}$;
- we carried out a spectral analysis of the spectral regions with our procedure; again, model atmospheres from Kurucz (1993) with a grid of different log g, $T_{\text{eff}}$, log N(Fe) were used.

The results of our “re-determination” of parameters of the solar atmosphere are given in Table 1. The best fit to one spectral region is shown in Fig. 4. From our analysis of the solar spectrum we obtained $T_{\text{eff}} = 5625 \pm 125$ K, log N(Fe) = $-4.48 \pm 0.15$ dex, $V_{l} = 1.2 \pm 0.4$ km s$^{-1}$. Here and below we used the standard deviation for error estimates. All these parameters are in good agreement with the known parameters of the Sun (Allen 1973) as well as $V_{l} = V_{\text{macro}} = 44.3 \pm 1.3$ km s$^{-1}$ with initial parameter of convolution.

4.2 V838 Mon

The obtained best fits of the synthetic spectra to the observed spectrum of V838 Mon for February 25 are shown in Figs. 5 and 6. Spectral regions containing emission lines were removed before we conducted our analysis. Each plot shows the fits for a) “the best” $T_{\text{eff}}$, and b) a case in which the effective temperature has been reduced by 1000 K. The latter value corresponds more with the $T_{\text{eff}}$ obtained from photometric measurements (c.f. Munari et al. 2002a). Our procedure allows us to choose the best fit from the grid of theoretical spectra computed for model atmospheres with different log N(Fe), $V_{l}$, $T_{\text{eff}}$. As we see in Figs. 5 and 6, some differences between observed spectra and synthetic best fits still remain. In this work we taken into account only the iron abundance, abundances of the other elements suggested to be solar. Furthermore, lines of ions can not be described properly due to too high gravity of used model atmospheres.

Our main goal was to determine $T_{\text{eff}}$ and log N(Fe) for the dates of our observations. Results of the determination of the parameters of the pseudophotosphere of V838 Mon in 2002 February and March are given in Table 1.

| Order | Wavelength range (Å) | $T_{\text{eff}}$ (K) | $V_{l}$ (km s$^{-1}$) | log N(Fe) | $V_{\text{macro}}$ (km s$^{-1}$) |
|-------|----------------------|----------------------|----------------------|-----------|----------------------|
| 11    | 6480 – 6685          | 5500                 | 1                    | -4.5      | 45.8                 |
| 12    | 6300 – 6490          | 5750                 | 2                    | -4.6      | 46.4                 |
| 13    | 6125 – 6315          | 5750                 | 1                    | -4.4      | 42.9                 |
| 14    | 5960 – 6145          | 5750                 | 1                    | -4.2      | 44.1                 |
| 15    | 5660 – 5810          | 5500                 | 1                    | -4.6      | 43.9                 |
| 16    | 5520 – 5670          | 5500                 | 1                    | -4.6      | 42.9                 |
| Averaged | 5625               | 1.2                  | -4.48                | 44.3     |

Figure 4. Dependence of computed spectra on $T_{\text{eff}}$ and log g of the broadening processes in the pseudophotosphere, we use a formal parameter $V_{g}$, which describes the cumulative effect of broadening/expansion motions.

Figure 5. The best fit to the solar spectra.
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 the March 26 data the mean values are $T_{\text{eff}} = 4960 \pm 270$ K, $\log N(\text{Fe}) = -4.68 \pm 0.11$ dex, $V_t = 12.5 \pm 1.7$ km s$^{-1}$.

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

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.

The $f_g$ parameter provides the heliocentric velocity of V838 Mon. We obtained $V_{\text{radial}} = -76 \pm 3, -70 \pm 3$ and $-65 \pm 3$ km s$^{-1}$ for February 25, March 2 and March 26, respectively. Most probably, we see some reduction in the expansion velocity of the envelope.

5 DISCUSSION

From a comparison of our results for all three dates we see that:

- The effective temperature for March 26 is somewhat lower than for the previous dates. This is an expected result, in view of the gradual cooling of envelope. However, for March 2 we found a slightly higher value of temperature than for February 25. A possible explanation is the heating of the pseudophotosphere as a result of the third outburst.

- The microturbulent velocities are very similar and extremely high for all three dates.

- Our analysis shows a lower value of $V_g$ for the later dates: the effects of expansion and macroturbulence were weakened at the later stages of evolution of the pseudophotosphere of V838 Mon.

- The iron abundances $\log N(\text{Fe}) = -4.7 \pm 0.14$ are similar for all dates.

Our estimates of effective temperature are in a good agreement with Kipper et al. (2004), although we used different procedures of analysis. The iron abundance ([Fe/H] = $-0.4$) and microturbulent velocity ($V_t = 12$ km s$^{-1}$) found by Kipper et al. (2004) for March 18 are in agreement with our results.

Our deduced “effective temperatures” as well as those in Kipper et al (2004) do not correspond with values obtained from photometry ($T_{\text{eff}} \sim 4200$ K). We assume that in our analysis we deal with temperatures in the line forming region, rather than with the temperatures at photospheric levels which determine the spectral energy distribution of V838 Mon and the photometric indices. Indeed, the formally determined microturbulent velocity $V_t = 13$ km s$^{-1}$ exceeds the sound velocity in the atmosphere (4-5 km s$^{-1}$). This means that the region of formation of atomic lines should be heated by dissipation of supersonic motions: the temperature there should be higher than that given in a plane-parallel atmosphere of $T_{\text{eff}} \sim 4200$ K.

Certainly the effect cannot be explained by sphericity effects: the temperature gradients in the extended atmospheres should be steeper (see Mihalas 1978), therefore temperatures in the line forming regions should be even lower, in contradiction with our results.

Strong deviations from LTE are known to occur during the photospheric stages of the evolution of novae and super-

![Figure 6](image-url) The best fits of synthetic spectra to 11-13 orders of the observed spectrum of V838 Mon on February 25, found by the minimization procedure.

novae. The main effect there should be caused by deviations from LTE in the ionization balance. However, in our case we used lines of the neutral iron, which dominate by number. We cannot expect a reduction in the density of Fe I atoms in the comparatively cool atmosphere of the star. Furthermore, we exclude from our analysis strong lines with P Cyg profiles. Lines of interest in our study have normal profiles.
In our work we used model atmospheres computed by Kurucz (1993) for the comparative low value of $V_t = 2 \text{ km s}^{-1}$. Our estimates of $V_t$ in the atmosphere of V838 Mon are much higher. In general, the temperature structures of the model atmospheres of late spectral classes respond to changes in $V_t$. Nonetheless, in our case, the results depend mainly on temperatures in the line-forming region. We can use “standard model atmospheres” only in the first approach computations. The dependence of our results on $V_t$ should be of second order of importance.

To check this we computed the grid of models with $V_t = 2$ and 15 km s$^{-1}$ for $T_{\text{eff}} = 4750-5750 \text{ K}$ with step 250 K and log g = 1. Unfortunately we were not able to compute models with log g = 0 in case $V_t = 15 \text{ km s}^{-1}$. A program SAM12 (Pavlenko 2003) was used. Line opacity treatment was used to account absorption of atomic and ion lines. Then we carry out our fitting procedure for this grid of models for February 25 data. We found that differences in results less then 0.1 dex in iron abundance and 1 km s$^{-1}$ in $V_t$. Still this “$V_t$ factor” must be considered in detail in future work based on the more sophisticated models.

In the present work we determined only the iron abundance. The effects of other element abundances should be taken into account as well. However, the obtained effective temperatures of V838 Mon are rather low and lines of neutral iron are of prime importance. Changes in the abundances of other free electrons donors – sodium, potassium, etc. – cannot affect the ionization equilibrium of iron. However, we suggest continued attempts to determine their abundances. In addition to their direct importance to the determination of the evolutionary status of V838 Mon, they are also of importance for the determination of the opacities in the stellar atmosphere. Generally, to determine the abundances of a few elements from modelling of complex blends we need to know a) the number and b) relative intensities of contributing lines, i.e the abundances of all elements.

6 CONCLUSIONS

We have carried out our study in the framework of a comparatively simple model. The static LTE model for the star with expanding pseudophotosphere is the rough enough approximation. Most of our results are rather qualitative, and they should be confirmed and/or refined in the future. However, in general we are confident enough in our results, in particular:

- we obtain some evidence of cooling of the line-forming region;

| Order | Wavelength range (A) | $T_{\text{eff}}$ (K) | $V_t$ (km s$^{-1}$) | log N(Fe) | $V_g$ (km s$^{-1}$) | $V_r$ (km s$^{-1}$) |
|-------|----------------------|----------------------|----------------------|-----------|----------------------|----------------------|
|       | Asiago spectra       |                      |                      |           |                      |                      |
|       | February 25          |                      |                      |           |                      |                      |
| 11    | 6480 – 6685          | 5250                 | 15                   | -4.7      | 53.2                 | -79.6                |
| 12    | 6300 – 6490          | 5000                 | 14                   | -4.9      | 54.5                 | -76.3                |
| 13    | 6125 – 6315          | 5250                 | 10                   | -4.7      | 56.0                 | -82.7                |
| 14    | 5960 – 6145          | 5750                 | 17                   | -4.5      | 52.5                 | -79.5                |
| 16    | 5660 – 5810          | 5000                 | 9                    | -4.9      | 60.7                 | -67.1                |
| 17    | 5520 – 5670          | 5750                 | 14                   | -4.7      | 51.1                 | -73.6                |
|       | Averaged             | 5330                 | 13.2                 | -4.73     | 54.7                 | -76.5                |
|       | March 26             |                      |                      |           |                      |                      |
| 11    | 6480 – 6685          | 4750                 | 12                   | -4.8      | 43.7                 | -67.3                |
| 12    | 6300 – 6490          | 4750                 | 14                   | -4.8      | 44.7                 | -68.3                |
| 13    | 6125 – 6315          | 4750                 | 10                   | -4.5      | 46.0                 | -74.3                |
| 14    | 5960 – 6145          | 5000                 | 15                   | -4.8      | 42.1                 | -65.8                |
| 16    | 5660 – 5810          | 5000                 | 11                   | -4.7      | 38.8                 | -52.2                |
| 17    | 5520 – 5670          | 5500                 | 13                   | -4.5      | 39.7                 | -63.6                |
|       | Average              | 4960                 | 12.5                 | -4.68     | 42.5                 | -65.2                |
|       | SAAO spectra         |                      |                      |           |                      |                      |
|       | March 2              |                      |                      |           |                      |                      |
| 11    | 6480 – 6685          | 5500                 | 12                   | -4.6      | 55.8                 | -77.3                |
| 12    | 6300 – 6490          | 5250                 | 16                   | -4.9      | 52.8                 | -78.9                |
| 13    | 6125 – 6315          | 5250                 | 7                    | -4.6      | 49.0                 | -80.6                |
| 14    | 5960 – 6145          | 5750                 | 14                   | -4.8      | 49.0                 | -80.6                |
| 16    | 5660 – 5810          | 5500                 | 15                   | -4.9      | 51.7                 | -68.1                |
| 17    | 5520 – 5670          | 6000                 | 16                   | -4.7      | 42.1                 | -80.0                |
|       | Average              | 5540                 | 13.3                 | -4.75     | 47.8                 | -77.6                |
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REFERENCES

Allen C.W., 1973, Astrophysical quantities, 3rd edition, The Athlone Press, London
Banerjee D.P.K., Ashok N.M., 2002, A&A, 395, 161
Bond H.E., et al., 2003, Natur, 422, 405
Brown N.J., 2002, IAU Circ, 7785, 1
Crause L.A., Lawson W.A., Kilkenny D., van Wyk F., Marang F., Jones A.F., 2003, MNRAS, 341, 785
Desidera, S., Munari, U., 2002, IAU Circ, 7982, 1
Evans A., Geballe T.R., Rushton M.T., Smalley B., vanloon J.Th., Eyres S.P.S., Tyne V.H., 2003, MNRAS, 343, 1054
Henden A., Munari U., Schwartz M.B., 2002, IAU Circ, 7859
Jones H.R.A., Pavlenko Ya., Viti S., Tennyson J., 2002, MNRAS, 330, 675J
Kimeswenger S., Lederer C., Schmeja S., Arnsdorfer B., 2002, MNRAS, 336, L43
Kipper T., et al., 2004, A&A, 416, 1107
Kolev D., Mikolajewski M., Tomow T., Bliev I., Osiwala J., Nirske J., Galan C., 2002, Collected Papers, Physics (Shumen,Bulgaria: Shumen University Press), 147
Kupka F., Piskunov N., Ryabchikova T.A., Stempels H.C., Weiss W.W., 1999, A&AS, 138, 119
Kurucz R.L., Furenlid I., Brautl J., Testerman L., 1984, National solar obs. - Sunspot, New Mexico
Kurucz R.L., 1993, CD-ROM 13
Mihalas D., 1978, Stellar atmospheres, Freeman & Co.
Munari U., et al., 2002a, A&A, 389, L51
Munari U., Henden A., Corradi R.M.L., Zwitter T., 2002b, in "Classical Nova Explosions", M.Hernanz and J.Jose eds., AIP Conf. Ser. 637, 52
Osiwala J.P., Mikolajewski M., Tomow T., Galan C., Nirske J., 2003, ASP Conf. Ser., 303, in press
Pavlenko Ya.V., 1997, Astron. Reps, 41, 537
Pavlenko Ya.V., Jones H.R.A., 2002, A&A, 397, 967
Pavlenko Ya.V., 2003, Astron. Reps, 47, 59
Soker N., Tylenda R., 2003, ApJ, 582, L105
Tylenda R., 2004, A&A, 414, 223
Unsold A., 1955 Physik der Sternatmospheren, 2nd ed. Springer.
Wünsiedel J.P., Morrison N.D., Bjorkman K.S., Miroshnichenko A.S., Gault A.C., Hoffman J.L., Nett J.M., 2003, ApJ, 588, 486

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