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On the progenitor of V838 Monocerotis

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ABSTRACT

We summarize and analyze the available observational data on the progenitor and the environment of V838 Mon. From the available photometric data for the progenitor of V838 Mon we exclude the possibility that the object before eruption was an evolved red giant star (AGB or RGB star). We find that most likely it was a main sequence or pre-main sequence star of $\sim 5-10\ M_{\odot}$. From the light echo structure and evolution we conclude that the reflecting dust is of interstellar nature rather than blown by V838 Mon in the past. We discuss the IRAS and CO data for interstellar medium observed near the position of V838 Mon. Several interstellar molecular regions have radial velocities similar to that of V838 Mon, so dust seen in the light echo might be related to one of them.

Key words. stars: early-type – stars: binaries: close – stars: circumstellar matter – stars: individual: V838 Mon – ISM: reflection nebulae – ISM: structure

1. Introduction

V838 Mon is a star caught in eruption at the beginning of January 2002 (Brown 2002). The eruption, as observed in optical wavelengths, lasted about three months, and was composed of two or three major peaks. After developing an A-F supergiant spectrum at the optical maximum at the beginning of February, the object showed a general tendency to evolve to lower effective temperatures. In April 2002 it almost disappeared from the optical but remained very bright in infrared becoming one of the coolest M-type supergiants yet observed. Detailed descriptions of the spectral and photometric evolution of V838 Mon can be found in a number of papers including Munari et al. (2002b), Kimeswenger et al. (2002), Kolev et al. (2002), Osiwała et al. (2003), Wisniewski et al. (2003), Crause et al. (2003) and Kipper et al. (2004).

The nature of the V838 Mon eruption is enigmatic. As discussed by Soker & Tylenda (2003), thermonuclear models (classical nova, He-shell flash) seem to be unable to explain this type of eruption. Therefore other mechanisms such as a stellar merger model (Soker & Tylenda 2003) or a giant swallowing planets scenario (Retter & Marom 2003) have been proposed.

The global fading of V838 Mon in optical after outburst has enabled us to discover a faint hot continuum in short wavelengths (Desidera & Munari 2002; Wagner & Starrfield 2002) later classified as coming from a normal B3 V star (Munari et al. 2002a). This strongly suggests that V838 Mon is a binary system which can be an important fact for identifying the outburst mechanism.

V838 Mon has received significant publicity due to its light echo, which was discovered shortly after the main eruption in February 2002 (Henden et al. 2002), and was seen in images by the HST (Bond et al. 2003). The light echo was used, e.g. in Bond et al. (2003, 2004), to claim that the echoing matter was ejected by V838 Mon in previous eruptions. This conclusion was disputed by Tylenda (2004), who examined the evolution of the light echo and concluded that the dust illuminated by the light echo was of interstellar origin rather than produced by mass loss from V838 Mon in the past.

van Loon et al. (2004) argue that there are multiple shells around V838 Mon, which were ejected by V838 Mon in previous eruptions. Hence they reason that prior to eruption V838 Mon was an asymptotic giant branch (AGB) star. These authors have also analyzed the light echo with more recent observations than in Tylenda (2004), and argue that the echoing dust was ejected by V838 Mon in past eruptions.

In the present paper we collect and discuss the data available on the progenitor of V838 Mon. This includes the archival photometric measurements done in the optical and infrared before 2002, results of analysis of the evolution of the light echo after the eruption, as well as available data on regions of interstellar matter (ISM) near the position of V838 Mon. In the case of erupting stars, conclusions drawn from the progenitor usually are very important for constraining the mechanism of the

Table 1. Photometry of the V838 Mon progenitor.

Band	$\lambda_{\rm eff}(\mu$m)	Magnitude	Reference
B	0.44	15.87 ± 0.10	Kimeswenger et al. (2002)
B	0.44	15.81 ± 0.06	Goranskij et al. (2004)
R_c	0.65	14.84 ± 0.06	Goranskij et al. (2004)
R	0.71	14.56 ± 0.10	Kimeswenger et al. (2002)
I_c	0.80	14.27 ± 0.03	Goranskij et al. (2004)
$I_{\rm Gunn}$	0.82	14.51 ± 0.03	DENIS
J	1.25	13.86 ± 0.11	DENIS
J	1.25	13.87 ± 0.05	2MASS
H	1.65	13.51 ± 0.06	2MASS
$K_{\rm s}$	2.15	13.14 ± 0.16	DENIS
$K_{\rm s}$	2.17	13.33 ± 0.06	2MASS

eruption. An analysis of the observational data for V838 Mon during and after its eruption is done in another paper (Tylenda 2005).

2. The analysis of the photometric data

Table 1 lists the photometric results for V838 Mon prior to its outburst. Columns 1 and 2 give the names and the effective wavelengths of the photometric bands. The magnitudes and the error estimates in Col. 3 are from the references given in the last column. Optical magnitudes have been taken from Kimeswenger et al. (2002) and Goranskij et al. (2004). Munari et al. (2002b, 2005) have also estimated magnitudes of the V838 Mon progenitor. However, the results given in these two references differ by ~1 mag. We do not take them into account as it is not clear what caused such large differences (Munari et al. 2005 do not comment on this). However, if one takes mean values from Munari et al. (2002b, 2005) they do not significantly differ from those quoted in Table 1. The object has also been observed in infrared surveys. *JHK* magnitudes can be found in the 2MASS data while the DENIS experiment measured the *IJK* bands.

Note that different measurements have been based on observations taken at different epochs. However, the fairly constant B magnitude obtained in Goranskij et al. (2004) between 1928–1994 shows that the progenitor of V838 Mon was not significantly variable.

As can be seen from Table 1, for four photometric bands we have two independent measurements. In the case of the B and J magnitudes the agreement is good. The values in the I and K bands are discrepant by ~0.2 mag. As it is difficult to judge which result is more reliable, for futher analysis we have adopted mean values in the bands for which two measurements have been available.

An analysis of the progenitor has to take into account the B-type companion discovered by Munari et al. (2002a). It accounts for about half the brightness of the progenitor. It seems most reasonable to assume that V838 Mon and its B-type companion form a binary system. The main argument obviously comes from the observed positions. From the instrumental crosses of stars seen on the HST images taken in September–December 2002 (`http://hubblesite.org/newscenter/archive/2003/10/`, see also Bond et al. 2003) one can deduce that the central object in the B images (dominated by the B-type companion) very well coincides with the central object in the I image (dominated by V838 Mon itself) and that both stars cannot be separated by more than $\sim 0\farcs1$. In the HST field ($83'' \times 83''$) there are ~10 field stars of similar brightness as V838 Mon before outburst and the B-type companion. In this case the probability that due to a random coincidence one of these stars is separated by $\lesssim 0\farcs1$ from V838 Mon is $\lesssim 10^{-4}$. Next, as discussed below, the binary hypothesis leads to a consistent interpretation of the observational data of the progenitor. Observational determination of the distance and reddening to V838 Mon itself and its B-type companion, summarized and discussed in Tylenda (2005), give consistent results, in the sense that there is no significant difference in the results for both objects. Therefore in most of our discussion we assume that V838 Mon and its B-type companion are at the same distance and suffer from the same interstellar extinction. In some cases, however, we relax this assumption and discuss the consequences of that.

As mentioned above, from spectroscopy Munari et al. (2002a) have identified the hot companion of V838 Mon as a typical B3 V star. Indeed their photometric results obtained in September and October 2002, i.e. $V = 16.05$, $B - V = 0.68$ and $U - B = -0.06$ (Munari et al. 2005), can be well reconciled with the standard B3 V colours (see Schmidt-Kaler 1982) provided that the object is reddened with $E_{B-V} = 0.90$ (see open symbols and crosses in Fig. 1a).

The brightness of the B-type companion can also be deduced from the photometric results of Crause et al. (2005). Between September 2002 and January 2003 (AJD 529−668 in Table 2 of Crause et al.) V838 Mon was practically constant in *UBV* while steadily brightening in R and I. This behaviour of the object was also noted by Munari et al. (2002a, 2005) and indicates, in accord with their spectroscopic results, that the *UBV* magnitudes were dominated by the B-type companion during this time period. From the most reliable results of Crause et al., i.e. those for dates not marked with an asterisk in their Table 2, obtained between AJD 529–668 one derives (mean value ± standard deviation) $V = 16.26 \pm 0.02$, $B - V = 0.51 \pm 0.02$, and $U - B \simeq -0.1$. Thus the object is by ~0.2 mag. fainter in V than in Munari et al., while the $B - V$ value if interpreted with the B3 V standard gives $E_{B-V} = 0.72$. In this case however the object seems to be not blue enough in $U - B$. A better agreement with the above results derived from Crause et al. is obtained for a B4 V standard and $E_{B-V} = 0.71$ (see open symbols and crosses in Fig. 1b).

From the beginning of October 2002 V838 Mon has also been measured by Goranskij et al. (2004). From their results obtained in October–December 2002 one derives $V = 16.17 \pm 0.05$ and $B - V = 0.64 \pm 0.13$ (no U measurements have been done during this time period). Thus the V magnitude is in between the values of Munari et al. and Crause et al., while the $B - V$ value is closer to that of Munari et al. and implies $E_{B-V} = 0.84 \pm 0.14$. A large scatter in the B measurements of Goranskij et al. should however be noted.

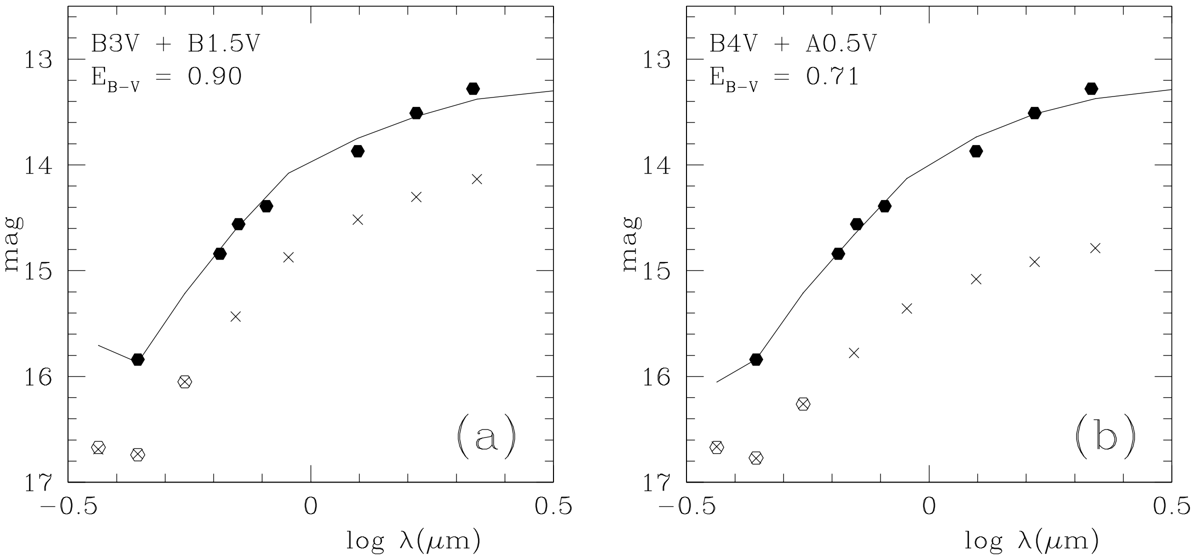

Fig. 1. Spectrophotometry of the progenitor of V838 Mon. Full symbols – observed magnitudes from Table 1. Part **a)** (*left panel*): *UBV* magnitudes of the B-type companion (open symbols) and E_{B-V} = 0.90 adopted from Munari et al. (2002a). Crosses – standard B3 V star, full curve – standard B3 V and B1.5 V stars co-added. Part **b)** (*right panel*): *UBV* magnitudes of the B-type companion (open symbols) and E_{B-V} = 0.71 derived from Crause et al. (2005) (see text). Crosses – standard B4 V star, full curve – standard B4 V and A0.5 V stars co-added. General note: all the model spectra (crosses and full curves) have been reddened with the respective values of E_{B-V}.

Later on in this section we consider two cases depending on whether the photometric data for the B-type companion are adopted from Munari et al. (2005) or from Crause et al. (2005). The differences in the magnitudes between these two references are extreme (the data from Goranskij et al. 2004 are in between them) so these two cases allow us to see how the results of our analysis depend on uncertainties in the photometry of the B-type companion.

Figure 1 presents our interpretation of the available photometric data done assuming that both V838 Mon and the B-type companion have the same reddening. In the discussion we also assume that both components are at the same distance, namely that they form a binary system. In both parts of the figure full symbols display the observed magnitudes from Table 1. The best fits, shown with full curves, have been made using the least square method and the intrinsic photometric colours for the main sequence stars taken from Schmidt-Kaler (1982), Johnson (1966), Koornneef (1983) and Bessell & Brett (1988) (for more details on the fitting procedure see Tylenda 2005).

In part (a) open symbols show the *UBV* photometry of the B-type companion taken from Munari et al. (2005) fitted with a standard B3 V star shown with crosses. The full curve presents the best fit to the full points obtained with a standard B1.5 V star added to the B3 V companion. Both spectral components have been reddened with E_{B-V} = 0.9. The ratio of the luminosity of the B1.5 component to that of B3 is 1.9. This ratio is somewhat too low for the B1.5 V and B3 V stars but given the uncertainties in the observational data we can conclude from Fig. 1a as follows. The progenitor of V838 Mon was a binary system consisting of two early B main sequence stars. V838 Mon itself was probably somewhat brighter, hotter and more massive than its companion. The system is young, i.e. $\lesssim 2 \times 10^7$ yr (main sequence lifetime of a 9 $M_\odot$ star, typical for B2 V). Note that it is excluded that V838 Mon was an evolved B1.5 star as then it would have been significantly more luminous than the B3 main sequence companion.

Figure 1b adopts the parameters of the B-type companion derived from the photometry of Crause et al. (2005), i.e. a B4 V star reddened with E_{B-V} = 0.71. In this case in order to reproduce the observational data for the progenitor an A0.5 V standard star has been added to the B4 V companion. The luminosity ratio of the A component to the B one is 0.43. This is much larger than the ratio for the main sequence of the same types which, according to Schmidt-Kaler (1982), is ~0.02[1]. Also the possibility that the A component was an evolved star, e.g. a giant evolving towards the red giant branch (RGB), the AGB, or a post-AGB star, can be ruled out. In this case it would be expected to have been initially (while being on the main sequence) more massive and thus, at present, significantly more luminous than the B4 main sequence companion. Therefore the only possibility within the binary hypothesis is that the A0.5 star is in the pre-main-sequence phase. The system would thus be very young. Judging from the luminosity of the A-type component, ~550 $L_\odot$ if 1300 $L_\odot$ is assumed for the B4 V component, its mass would be ~5 $M_\odot$ and the age of the system would be of ~3×10^5 yr (Iben 1965).

In summary, although the uncertainties in the observational data for the progenitor and for the B-type companion do not allow us to unambiguously identify the nature of V838 Mon the above discussion allows us to put rather narrow constrains if the most probable hypothesis of binarity is adopted. In this case V838 Mon is a system consisting of two intermediate mass

[1] From this result one may consider that V838 Mon was an A-type main sequence star prior to eruption, thus rejecting the binarity hypothesis. However in the case of the A0.5 main sequence star it would be at a distance of 3.0 kpc which is too low given the distance estimates from the light echo.

stars. V838 Mon itself certainly was not an evolved star, e.g. RGB, AGB, post-AGB. It is either slightly more massive than its B-type companion, i.e. 8–10 $M_{\odot}$, and was on the main sequence prior to eruption, or is somewhat less massive, ∼5 $M_{\odot}$, being in the pre-main-sequence phase. The system is young, with the age estimated between 3×10^5 and 2×10^7 yr. The abundances in V838 Mon obtained by Kipper et al. (2004) are reminiscent of those in the so-called HAEBE stars (e.g. Acke & Waelkens 2004) which are believed to be more massive analogues of the T Tauri stars. Therefore it is likely that the V838 Mon system is still partly embedded in the interstellar complex from which it has been formed. Indeed, as discussed in Sect. 3.3, near the position of V838 Mon there are several star-forming regions with radial velocities close to that of V838 Mon and its B-type companion. This also fits well the conclusion of Tylenda (2004) and Sect. 3.1 that the circumstellar dust producing the light echo of V838 Mon is most probably of interstellar origin.

Munari et al. (2005) have made an analysis of the photometric data for the V838 Mon progenitor similar to ours. Their conclusion is qualitatively similar to ours in the sense that the progenitor was an early-type star. However, contrary to our main-sequence or pre-main-sequence hypothesis, Munari et al. conclude that the V838 Mon outburst was that of an evolved star of initial mass of ∼65 $M_{\odot}$, at present in a region occupied by Wolf-Rayet stars in the HR diagram and having $T_{\rm eff} \simeq 50\,000$ K. However, in a case like this we should see a bright HII region surrounding V838 Mon. The observed light echo (discussed in Sect. 3.1) shows that there is a lot of diffuse matter extending from ∼0.1 pc up to at least ∼4 pc. The 50 000 K star of Munari et al. (2005), assuming $E_{B-V} = 0.9$ and a distance of 8 kpc, would have a luminosity of $\sim 3 \times 10^4\ L_{\odot}$. Using model results of Stasińska (1990), for abundances depleted by a factor of 2 relative to standard values (V838 Mon lies at the outskirts of the Galactic disc), we can estimate that a star like this would be able to ionize the surrounding matter up to $R_{\rm s} \simeq 8$ pc if its density is $n_{\rm H} = 10$ H atoms cm^{-3} ($R_{\rm s}$ scales as $n_{\rm H}^{-2/3}$). The emission line spectrum would be dominated by [OIII] and Balmer lines ([OIII]λ5007 Å/H$\beta \simeq 8$), while the Hβ luminosity would be ∼230 $L_{\odot}$. For an observer (at 8 kpc and $E_{B-V} = 0.9$) it would look like a nebula with a diameter of ∼7′ and an Hβ flux of $\sim 6 \times 10^{-12}$ erg s^{-1} cm^{-2}. The resultant Hβ surface brightness of $\sim 4.5 \times 10^{-17}$ erg s^{-1} cm^{-2} arcsec^{-2} is typical for many extended planetary nebulae, e.g. those in the Abell (1966) catalogue (observed Hβ fluxes and nebular diameters can be found in Acker et al. 1992). Thus the nebula would be rather easy to discern observationally, especially that in Hα and [OIII]λ5007 Å it would ∼8 times brighter than in Hβ. Yet no emission-line nebula have been discovered around the position of V838 Mon (Orio et al. 2002; Munari et al. 2002b). Thus the idea of Munari et al. (2005) that V838 Mon prior outburst could have been as hot as 50 000 K is not consistent with the observations. From the observed lack of any significant emission nebula around V838 Mon we can conclude that before the outburst the star was cooler than ∼30 000 K, i.e. of a spectral type not earlier than B0. Munari et al. (2005) also consider that the progenitor could have had $T_{\rm eff} \simeq 25\,000$ K (although they argue that this is not likely). This solution is practically the same as our case of a B1.5 star in Fig. 1a which we interpret as an early B-type main sequence star.

As discussed above it is evident that V838 Mon was not a typical red giant nor an AGB star prior to eruption if V838 Mon and its B-type companion form a binary system. The only way to reconcile the RGB or AGB hypothesis is to assume that the B-type companion has nothing to do with V838 Mon and that the coincidence of the two objects in the sky is purely accidental. Then one may assume that V838 Mon is less reddened than the B-type companion and a cooler star can be fitted to the observations. Let us consider that the B-type companion has the parameters derived from the observations of Crause et al. (2005), i.e. B4 V reddened with $E_{B-V} = 0.71$, as then the fits give later spectral types for V838 Mon than if the results of Munari et al. (2002a) were adopted. Let us also use the standard supergiant spectra (intrinsic colours taken from the same references as the main sequence ones) to model the contribution from V838 Mon. This is more relevant with the RGB/AGB hypothesis and also results in later spectral types from the fits than the main sequence spectra. $E_{B-V} = 0.5$ seems to be a lower limit for the extinction towards V838 Mon (see discussion of different observational determination in Tylenda 2005). Assuming this value, the best fit to the observations is obtained for the spectral type F1 (effective temperature ∼7500 K). If, in spite of observational determination, the extinction is pushed to its limit, i.e. $E_{B-V} = 0.0$ is assumed, the fit gives G7 (effective temperature ∼4700 K). Thus there is no way to reconcile an M-type star with the observational data. This conclusion is obvious if one realises that the $B - R$ colour for an unreddened M-type star is ≥2.7 while that of the V838 Mon progenitor was ≃1.3.

From the above results we can firmly conclude that V838 Mon was not an AGB star. If one still does not want to leave the AGB hypothesis and argues that it best explains the existence of the circumstellar matter seen in the echo and infrared images, then the only way to reconcile it with the photometric data is to say that V838 Mon had quite recently left the AGB and prior to eruption was in the post-AGB phase. However in this case its luminosity would be close to $5 \times 10^3\ L_{\odot}$ and its distance would have to be ∼55 kpc in the case of the F1 type and $E_{B-V} = 0.5$ or even ∼90 kpc if one prefers G7 and $E_{B-V} = 0.0$. Thus a typical spectral types of the post-AGB stars (F−G) would require rather unacceptable conditions, i.e. a very low reddening and a very large distance putting V838 Mon in the extreme outskirts of the Galaxy. For the observationally acceptable range of the extinction, i.e. E_{B-V} between 0.7 and 1.0 (Tylenda 2005), V838 Mon would have been of the B9−B0 type and, assuming the typical post-AGB luminosity as above, its distance would be between 7 and 30 kpc. Thus the only possibility within the AGB – post-AGB hypothesis, which is not excluded by the photometric data, is that V838 Mon was a B-type post-AGB star. However, as discussed above, the binarity with the B-type main sequence component is, in this case, excluded in spite of similar estimated distance ranges (7.5−12.5 kpc for the B-type companion, see Tylenda 2005), close values of interstellar extinction and the same positions in the sky of both objects. If one adds that the duration of the phase when the post-AGB star can be classified as B-type is typically 10^3 years it is clear that this solution is extremely improbable.

Finally let us discuss the giant hypothesis. As discussed above it is certain that V838 Mon was not a typical RGB star, i.e. of K–M spectral type, prior to eruption. The latest acceptable spectral type, obtained assuming the lower limit of $E_{B-V} = 0.5$, is F0–A5. At the lower limit of the distance of 5 kpc (Tylenda 2005) the star would have a luminosity of 40−50 $L_\odot$ which is more or less consistent with the standard giant luminosities for these spectral types (Schmidt-Kaler 1982). For the more probable reddening, i.e. $E_{B-V} = 0.7-1.0$, we have to move to the B types and correspondingly larger luminosities and distances. Thus the hypothesis that V838 Mon was a giant before its eruption is not excluded provided that it was an early (A−B) type giant. The binarity with the B-type companion is excluded in this case (as discussed above). The star would be quite massive, $\gtrsim 2.5\ M_\odot$, not far evolved from the main sequence and thus be in a fast evolutionary phase (time scale $\lesssim 5 \times 10^6$ years). The object would be quite rare in the stellar population although not as rare as the B-type post-AGB case considered above. The discussed case would however have difficulties in explaining the origin of the circumstellar matter seen in the light echo. The wind from an early type giant would not be enough. On the other hand, the giant, being significantly older (most probably at least as old as 10^8 years) than the B-type binary system considered above, would have little chance to still reside in a dense interstellar cloud.

3. Circumstellar and interstellar environment

3.1. The light echo

The phenomenon of light echo observed in V838 Mon during and after the outburst suggests that there is much dusty matter in the vicinity of the object. Since the light echo works as a sort of scanner, an analysis of the light echo images in different epochs should provide detailed information on the dust distribution near the object which would be important for constraining the nature of the object. Unfortunately, in spite of numerous images obtained at different observatories (including HST) no elaborate study of the light echo has been done as yet. So far the most detailed, but still very simple, analysis has been done by Tylenda (2004) on five echo images obtained with HST between 30 April and 17 December 2002. His conclusion is that the dust distribution does not show any signs of spherical symmetry and that dust is likely to be of interstellar origin rather than due to past mass loss from V838 Mon.

We have extended the analysis of Tylenda (2004) using two recent echo images obtained on 21 Oct. 2003 at the USNO (`http://www.ghg.net/akelly/v838lar3.jpg`) and on 8 Feb. 2004 with the HST (`http://hubblesite.org/newscenter/newsdesk/archive/releases/2004/10/`). On these images we have measured the outer rim of the light echo. Then a least square fit of a circle to the measurements has been done in the same way as in Tylenda (2004). The results of the fits are given in the last two lines of Table 2. The first five lines in the table repeat the results from Table 1 of Tylenda (2004) as the uncertainties there have been slightly overestimated. The first column of Table 2 shows the time of observations, t_{obs}, given in days since 1 January 2002. The radius of the echo, θ, and its uncertainty are given in the second column. The next two columns show the (x, y) position of the centre of the fitted circle relative to the central star. Note that x points to west while y is to north. The last column gives the angular distance of the echo centre from the central star. All the results are in arcsec. Following Tylenda (2004) we adopt in our analysis that the zero age of the echo is $t_0 = 34$ days (since 1 Jan. 2002).

Table 2. Results of fitting a circle to the outer edge of the light echo of V838 Mon. Time of observations, t_{obs}, is in days since 1 January 2002. Results are in arcsec.

t_{obs}	θ	x_c	y_c	θ_c
120.0	18.55 ± 0.62	−0.83 ± 0.90	0.46 ± 0.86	0.95 ± 0.88
140.0	20.89 ± 0.61	−1.12 ± 0.88	0.50 ± 0.84	1.23 ± 0.86
245.0	30.32 ± 0.83	−2.27 ± 1.21	0.37 ± 1.15	2.30 ± 1.18
301.0	33.68 ± 0.84	−2.36 ± 1.23	1.11 ± 1.17	2.60 ± 1.20
351.0	36.66 ± 0.90	−2.61 ± 1.31	1.58 ± 1.23	3.05 ± 1.27
659.0	52.10 ± 1.15	−6.05 ± 1.65	3.12 ± 1.61	6.80 ± 1.63
769.0	56.67 ± 1.19	−5.91 ± 1.66	5.37 ± 1.71	7.99 ± 1.69

Filled symbols in the left panel of Fig. 2 display the evolution of the echo radius, θ, with time. The full curve shows the best fit to the data of a plane slab model, i.e. of Eq. (17) in Tylenda (2004), obtained for $d \simeq 11.1$ kpc and $z_0 \simeq 7.1$ pc, where d is the distance between the light source and the observer while z_0 is the distance of the dust slab from the source. However, similarly to Tylenda (2004), the χ^2 minimum of the fit is quite shallow and extended along $z_0 \sim d^2$. The right panel of Fig. 2 shows the 95% confidence region of the fit. From this figure one can conclude that the distance to V838 Mon is $\gtrsim$5 kpc. Recently, Crause et al. (2005) have analysed the light echo evolution from their observations done at the SAAO. Their results obtained for the sheet model are well within the hatched region in the right panel of Fig. 2.

As can be seen from Table 2, the centre of the light echo has been migrating from the central object. This migration, displayed in Fig. 3, has kept the same pattern for ~2 years. The following two conclusions can be drawn from Fig. 3. First, since the appearance of the light echo its center has been moving away from the central object in roughly the same (north-east) direction, as can be seen from the left panel of Fig. 3. Second, the distance of the echo centre from the central star has been increasing linearly with time, as shown in the right panel of Fig. 3.

As discussed in Tylenda (2004), the fact that the light echo has an outer edge means that the dusty medium producing the echo has a boundary in front of the central star. However, the fact that the echo edge is *not* centered on the star and that the distance of the echo centre from the star *does* increase with time shows that this dust boundary is *not* spherically symmetric with respect to the central object.

Following the theory of the light echo, as e.g. summarized in Tylenda (2004), the only reasonable interpretation of the observed evolution of the outer edge of the light echo is that the

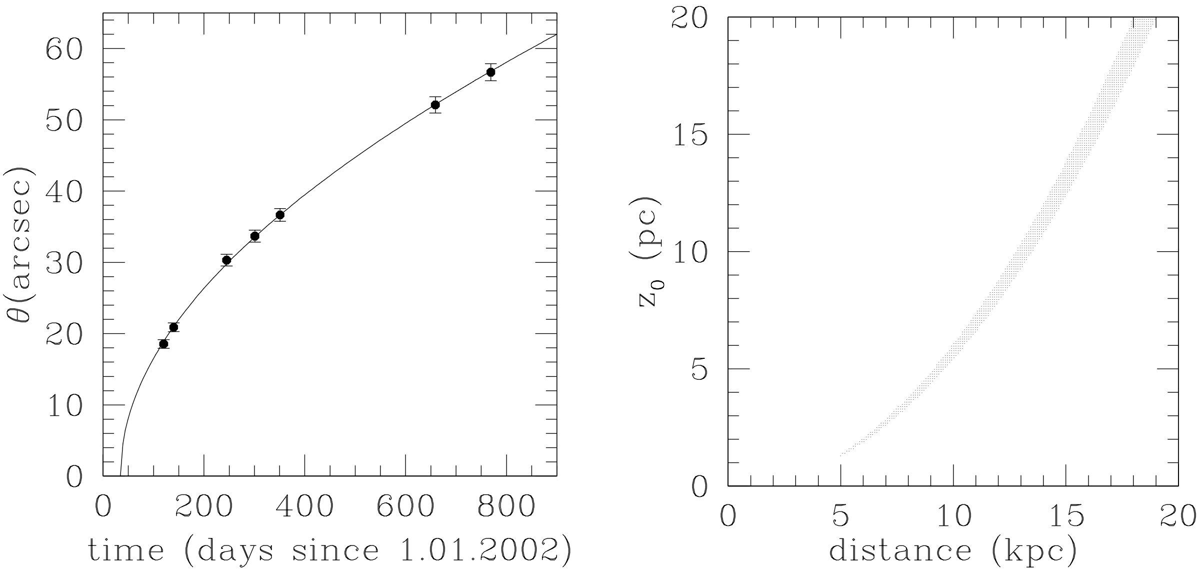

Fig. 2. *Left panel*: the best fit of a plane model to the observed evolution of the light echo radius. Symbols with error bars – the values and uncertainties of θ from Col. 2 of Table 2. Full curve – model predictions for $d = 11.1$ kpc and $z_0 = 7.1$ pc (see text). *Right panel*: the 95% confidence region (hatched) of the plane model fitted to the observed light echo expansion (symbols in the left panel).

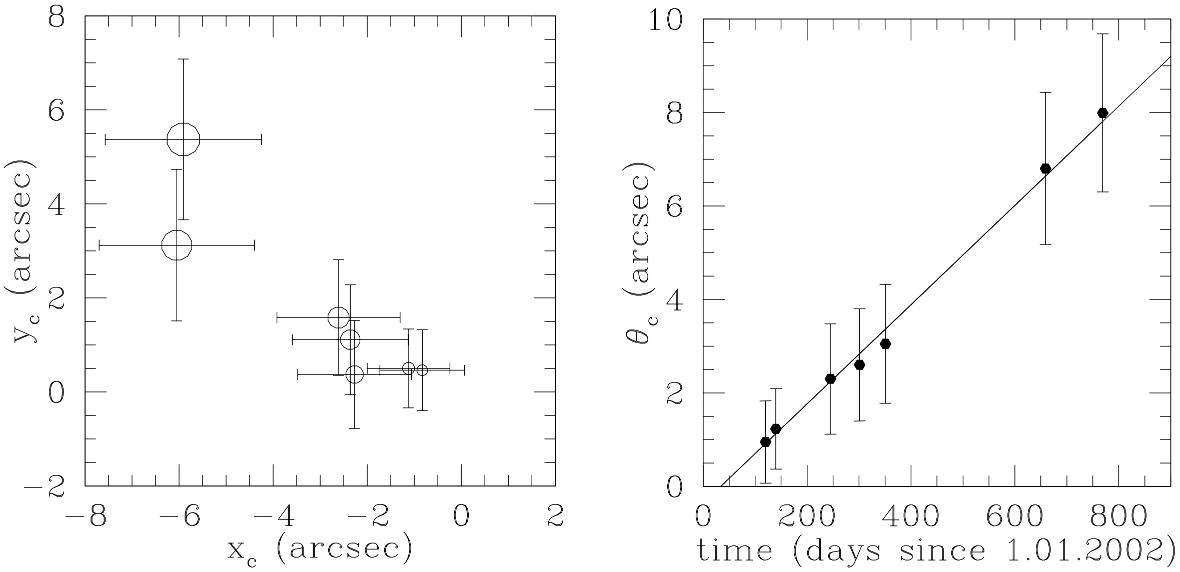

Fig. 3. Migration of the echo centre from the central star. *Left panel*: (x, y) positions of the echo centre from Cols. 3 and 4 of Table 2. The size of the symbols is proportional to the echo radius given in Col. 2 of Table 2. Note that the x and y axes point to west and north, respectively. The central star is at $(x = 0, y = 0)$. *Right panel*: evolution of the distance of the echo centre from the central star, θ_c, with time. Symbols – the data from Col. 5 in Table 2. Full line – a linear fit to the data as given in Eq. (1).

dust boundary in front of V838 Mon is more or less in the form of a plane inclined to the line of sight. A linear fit to the observed evolution of the distance of the echo centre from the central object, i.e. last column in Table 2 or symbols in the right panel of Fig. 3, gives the relation

$$\theta_c = (0.''0106 \pm 0.''0030) \left(\frac{t}{1\ \mathrm{day}}\right) \quad (1)$$

where $t = t_{\rm obs} - t_0$ is the time since the zero age of the echo. This relation is shown by a full line in the right panel of Fig. 3. Assuming a distance of 8 kpc Eq. (1), together with Eq. (7) of Tylenda (2004), implies that the normal to the dust surface is inclined to the line of sight at an angle of ~26°. This surface is at a distance of ~3.5 pc from V838 Mon (along the line of sight) and its portion so far (i.e. till Feb. 2004) illuminated by the light echo has dimensions of ~4.4 × 4.9 pc. It is difficult to imagine that such a large flat surface of the dusty medium could have been produced by mass loss from V838 Mon itself. Instead, it suggests that the dusty medium in the vicinity of V838 Mon is much more extended than the illuminated part, thus most probably being of interstellar origin.

In April 2002, when V838 Mon faded in the optical, the light echo started developing an asymmetric hole in the centre. As analyzed in Tylenda (2004) this clearly shows that there is a dust-free region around V838 Mon and that this empty region is strongly asymmetric. The inner edge of the dusty region in the southern directions is at 0.10−0.15 pc from the central object whereas in the opposite directions it is at least 10 times further away. It can be noted that the IRAS PSC source 07015−0346 coincides with the position of V838 Mon within a position elipse of 48″ × 10″ (see also Kimeswenger et al. 2002). The measured fluxes at 100 μm and 60 μm are 4.6 Jy and 1.4 Jy, respectively, while at 25 μm and 12 μm the catalogue gives only an upper limit of 0.25 Jy. When fitted with a simple dust emission model, i.e. emissivity proportional to $\lambda^{-1}B_\lambda(T_\mathrm{d})$, the IRAS fluxes give a dust temperature, T_d, of ~30 K. For a central source of 10^4 $L_\odot$ (two B3 V stars, see Sect. 2) this value of dust temperature is reached at ~0.2 pc (see e.g. Eq. (7.56) in Olofsson 2004). Thus the IRAS fluxes can be consistently interpreted as due to inner parts of the dusty region inferred from the light echo analysis. In particular, they give evidence that there is no significant amount of dust at distances ≲0.1 pc, thus confirming the existence of the central dust-free region.

The strongly asymmetric central dust-free region would be very difficult to understand if the echoing dust were produced by a past mass loss from V838 Mon. The hole would imply that mass loss stopped a certain time ago, e.g. 10^4 yr for the 0.10−0.15 pc inner dust rim if a wind velocity of 10 km s^{-1} is assumed. However the hole asymmetry would imply that in the opposite direction either mass loss stopped 10 times earlier or the wind velocity was 10 times higher. Neither of these two possibilities seems to be likely.

Instead, as discussed in Tylenda (2004), the asymmetric hole is easy to understand if the echoing dust is of interstellar origin. Then it is natural to suppose that V838 Mon is moving against the ISM. If possessing a fast wind it would create a hole largely asymmetric along the direction of the movement. Indeed, the structure of the inner edge of dust in Fig. 5 of Tylenda (2004) well resembles stellar wind bow shocks investigated in e.g. Van Buren & McCray (1988) and Wilkin (1996). The nearest rim in the southern directions, being at 0.10−0.15 pc from the central star, would correspond to a region where the stellar wind collides head-on with the ambient medium.

Let us assume that a star losing mass at a rate, $\dot{M}_\mathrm{w}$, and a velocity, v_w, is moving in the ISM of number density, n_0, with a relative velocity of v_*. A swept-up shell is created in the form of a bow shock and in the up-stream direction this takes place where the wind ram pressure is comparable to that of the ambient medium (see e.g. Van Buren & McCray 1988, Wilkin 1996), i.e.

$$v_*^2\, n_0 \simeq v_\mathrm{w}^2\, n_\mathrm{w} \tag{2}$$

where n_w is the number density in the wind and is related to the mass loss rate in a standard way

$$\dot{M}_\mathrm{w} = 4\pi r^2\, v_\mathrm{w}\, \mu m_\mathrm{H}\, n_\mathrm{w} \tag{3}$$

where m_H is the H atom mass while μ is the mean molecular weight in units of m_H. Then Eq. (2) yields a standoff distance, r_0, from the star, i.e.

$$r_0 \simeq 0.15\left(\frac{\dot{M}_\mathrm{w}}{10^{-9}\ M_\odot\ \mathrm{yr}^{-1}}\right)^{1/2}\left(\frac{v_\mathrm{w}}{1000\ \mathrm{km\ s}^{-1}}\right)^{1/2} \times\left(\frac{v_*}{10\ \mathrm{km\ s}^{-1}}\right)^{-1}\left(\frac{n_0}{1\ \mathrm{cm}^{-3}}\right)^{-1/2}\ \mathrm{pc} \tag{4}$$

where $\mu = 1.4$ has been assumed.

A B3 main sequence star has a luminosity of 5.0×10^3 $L_\odot$ (Schmidt-Kaler 1982). Thus, according to the relation of Howard & Prinja (1989), the expected mass loss rate would be 7×10^{-10} $M_\odot$ yr^{-1}. If V838 Mon is a young binary system, as discussed in Sect. 2, its velocity relative to the ISM should be rather low. Assuming v_* between 3−10 km s^{-1} and the above mass loss rate, Eq. (4) yields $n_0 \simeq 1$−10 cm^{-3} if $r_0 = 0.10$−0.15 pc. This result is uncertain but it indicates that V838 Mon is imbedded in a relatively dense ISM. In principle, the density could be estimated from the echo brightness. Unfortunately there is no such estimate available, although the presence of the bright echo suggests that the density of the ambient medium must be significant.

A fast stellar wind colliding with a circumstellar medium should produce X-rays. V838 Mon was observed with Chandra a year after the outburst by Orio et al. (2003). The object was not detected and the upper limit to the X-ray luminosity is ~0.13 $L_\odot$ (for a distance of 8 kpc). The kinetic power of a wind with parameters as above (7×10^{-10} $M_\odot$ yr^{-1} expanding at 1000 km s^{-1}) is ~0.06 $L_\odot$, thus it is below the X-ray limit, although only by a factor of 2. However, the X-ray luminosity from a colliding wind is usually much below the wind kinetic power (e.g. Soker & Kastner 2003). A hot bubble is usually formed and, if the radiative cooling time is long, the shocked gas cools adiabatically by expansion of the bubble. In our case the cooling time is estimated to be above 10^8 years, i.e. much longer that the life time of a B3 main sequence star. In the case of a bow-like inner edge of the circimstellar matter, as discussed above, a hot bubble need not be formed. Instead the shocked gas may flow along the edge and escape through the open side, thus expanding, cooling adiabatically and radiating very little X-rays.

van Loon et al. (2004) have also analyzed the expansion of the light echo. Their analysis has been based on their measurements of the echo diameter on images from different sources. However, as also noted in Crause et al. (2005), their diameters are systematically smaller by factor of 2.5–2.7 than any other measurements available in the literature (Munari et al. 2002b; Tylenda 2004; Crause et al. 2005, see also numerous individual measurements in IAU Circ. in 2002), including our present results in Table 2. It is curious that these authors do not note this discrepancy and do not comment on it. In any case it can be concluded that the whole analysis of the light echo made by van Loon et al. is questionable as it has been based on wrong data. In particular, their rather speculative interpretation of the outer edge of the echo in October 2003–February 2004 as being produced by scattering under right angles does not hold. With the correct values of the echo diameter in these dates this interpretation would imply a distance of ~2 kpc (and not 5.5 kpc as written in van Loon et al.). which is much too low compared with any other distance estimates from the light echo evolution (Bond et al. 2003; Tylenda 2004; Crause et al. 2005).

3.2. Infrared and CO shells of van Loon et al.

van Loon et al. (2004, hereafter vLERS) from their analysis of the IRAS and MSX images and the CO maps claim that V838 Mon is surrounded by three shells. The innermost, seen from the MSX, is highly irregular and has dimensions of $\sim 1\overset{\prime}{.}5$. The second one would be the elliptical one referred from the IRAS with dimensions of 15–20′. The largest one, having a diameter of $\sim 1°$, is suggested from the CO maps. On this basis vLERS conclude that V838 Mon is a low mass AGB star experiencing thermal pulses. As we have shown in Sect. 2, the photometric data on the V838 Mon progenitor exclude the AGB hypothesis. However, even if the latter is not taken into account, we find severe problems with the results of vLERS and their interpretation.

First questions arise when analyzing the innermost structure seen in the band A (8.3 μm) of MSX. Unlike the two outer shells (IRAS and CO) showing an elliptical or circular symmetry this structure is very distorted and does not show any kind of symmetry with respect to V838 Mon. It does not resemble objects involving AGB, like planetary nebulae, envelopes of AGB and post-AGB stars. Usually, as in planetary nebulae for example, the ISM affects external regions so one would expect to see more distortion in the IRAS and CO shells than in the MSX structure.

The dimensions of the IRAS and CO shells seem to be too large to be compatible with the hypothesis that they have been produced by an AGB mass loss. Adopting a distance to V838 Mon of 8 kpc (Tylenda 2004) the radius of the IRAS shell is ~20 pc while that of the CO shell is ~70 pc. (Munari et al. 2005 argue for 10 kpc as the most probable distance, which would make radii even larger thus strengthening our conclusions below.) The largest observed AGB dust shells have radii of 2–3 pc (Speck et al. 2000) while the CO shells are usually well below 1 pc (Olofsson 2004). We can thus conclude that the IRAS and CO shells, if real, are not typical AGB shells.

Below we show that it is unlikely that AGB shells could survive and be observed as fairly symmetric structures at distances of 20–70 pc from the central star. As a mass-losing star moves relative to the ISM, the shell's segment in the up-stream direction (the side facing the ISM) is slowed down, until it is stopped at a time $t_{\rm stop}$, when the leading edge is at a distance $r_{\rm stop}$ from the star. Next the up-stream segment of the shell is pushed by the ISM toward the central star. At the same time the shell's segment in the down-stream direction is expanding at a constant, undisturbed rate. Soker et al. (1991) have derived simple analytical expressions for these parameters which can be used here.

Let a shell of mass, M_s, expand with a velocity $v_{\rm exp}$, and let v_* be the relative velocity of the mass-losing star and the ISM. Also let ρ_0 be the mass density of the ISM, and n_0 the total number density of the ISM. For a distance of ~150 pc from the galactic plane, we can scale the ISM density with $\rho_0 = 10^{-25}\,{\rm g\,cm^{-3}}$, which corresponds to $n_0 = 0.1$ cm^{-3}. Following Soker et al. (1991) we define the radius of a sphere which contains an ISM mass equal to the shell mass

$$R_0 \equiv \left(\frac{3\,M_s}{4\pi\rho_0}\right)^{1/3} = 3\left(\frac{M_s}{0.2\,M_\odot}\right)^{1/3}\left(\frac{n_0}{0.1\ {\rm cm^{-3}}}\right)^{-1/3}\ {\rm pc}. \quad (5)$$

The stopping distance of the up-stream shell's segment is given by (Eq. (5) of Soker et al. 1991)

$$r_{\rm stop} = R_0\,[2\alpha\,(1+\alpha)]^{-1/3}, \quad (6)$$

where $\alpha \equiv v_*/v_{\rm exp}$. The time the up-stream segment reaches this maximum distance is

$$t_{\rm stop} = \frac{R_0}{v_{\rm exp}}\alpha^{-2/3}. \quad (7)$$

As the down-stream segment expands undisturbed the diameter of the shell along the stream at $t_{\rm stop}$ is

$$d_{\rm stop} = R_0\,\left[(2\alpha\,(1+\alpha))^{-1/3} + \alpha^{-2/3}\right]. \quad (8)$$

After reaching its maximum distance from the central star at $r_{\rm stop}$, the up-stream segment of the shell is pushed by the ISM toward the central star.

For an AGB star $v_{\rm exp} \simeq 10$ km s^{-1}. The typical star-ISM velocity at ~150 pc from the galactic plane is $v_* > 10$ km s^{-1}. For $\alpha = 1$ and assuming $M_s = 0.1\,M_\odot$, we get from Eqs. (5), (6) and (8) $r_{\rm stop} = 1.6$ pc and $d_{\rm stop} = 4$ pc. Even for an extreme case of $n_0 = 0.01$ cm^{-1}, $M_s = 1\,M_\odot$ (which is a generous upper limit for an AGB shell, especially if it were ejected in a thermal pulse from a low mass star, as suggested in vLERS) and $\alpha = 0.25$ (say, expansion velocity of 20 km s^{-1} and $v_* = 5$ km s^{-1}), we find $r_{\rm stop} = 13.5$ pc and $d_{\rm stop} = 43$ pc. Given the observed diameter of the CO shell of ~140 pc we can conclude that an AGB shell would have been seriously disturbed by the ISM before reaching these dimensions, its up-stream part would have to be significantly brighter (because of significant accretion of the matter from the ISM) than the opposite part and the central star would very likely be now observed outside the up-stream rim. All this is not observed.

The above estimates are supported by observations of planetary nebulae. From Eq. (5) we see that when a typical planetary nebula shell of 0.2 $M_\odot$ reaches a radius of ~3 pc, it is expected to be highly distorted by the ISM. Indeed, examining the list of planetary nebulae interacting with the ISM compiled by Tweedy & Kwitter (1996, their Table 3), we find that all the planetary nebulae in this list have radii <5 pc. Most of the large planetary nebulae are highly distorted; not is only the central star not at the center, but the shells are neither circular nor elliptical. Some planetary nebulae, like NGC 6826 NGC 2899 and A 58 (surrounding the final helium shell flash star V605 Aql), have very large, diameters ~10−40 pc, IRAS structures around them (Weinberger & Aryal 2004; Clayton & De Marco 1997). They are all severely distorted. Clayton & De Marco (1997) argue that structures of this size are swept-up ISM dust, rather than AGB mass-loss shells.

The above analysis rises a question: are the shells claimed in vLERS indeed real and related to V838 Mon?

Table 3. Interstellar regions within ∼1$^\circ\!\!.$5 from the position of V838 Mon.

No.	l (°)	b (°)	Name	T_A^* (K)	$V_{\rm LSR}$ (km s^{-1})	Notes	References
1	216.5	+0.5			47.	MC	MAB
2	216.5	+1.2			48.	MC	MAB
3	217.0	+0.9	FT 84		51.	MC	Av, DHT
4	217.2	+0.5		2.6	52.	MC	Av, WB, MAB
5	217.3	+0.0			27.	MC	MAB
6	217.4	–0.1	FT 87, BFS 57	18.9	26.	MC	Av, WB
7	217.4	+0.3	FT 88, BFS 58	3.7	50.	MC	Av, WB, MAB
8	217.6	–0.2	FT 89, BFS 59	10.4	26.	MC	Av, WB
9	217.6	+2.4		6.3	55.	MC	Av, WB
10	217.9	+0.9				RN	Ma
11	218.0	+0.2			23.	MC	MAB
12	218.1	–0.3	S 287, FT 91	18.2	26.–30.	HII, MC	Av, WB, MAB
13	218.7	+1.8	IC 466, S 288	6.3	57.	HII, MC	Av, WB

Notes: HII – HII region, MC – molecular cloud, RN – reflection nebula.
References: Av – Avedisova (2002), DHT – $V_{\rm LSR}$ estimated from original data of Dame et al. (2001), Ma – Magakian (2003), MAB – May et al. (1997), WB – Wouterloot & Brand (1989).

It is difficult to discuss the nature of the emission seen in the MSX image as it has been recorded only in the *A* band (8.3 μm) image. No emission is seen in the bands *C* (12.1 μm), *D* (14.6 μm) and *E* (21.4 μm). This is perhaps due to the highest sensitivity of band A.

The elliptical structure around V838 Mon in the IRAS image shown in Fig. 1 of vLERS at first sight looks convincing. However, in the whole field of this figure it is easy to fit several ellipses of similar sizes and similar orientations as the one drawn by vLERS. One possible explanation is that the image pattern seen in Fig. 1 of vLERS might be spurious, i.e. of instrumental and/or image processing origin. Another likely interpretation is that this is a general pattern of the interstellar diffuse emission in this region and thus it has nothing to do with V838 Mon. The discussed region is a part of an extended infrared emission related to several molecular clouds and HII regions near the direction to V838 Mon (see Sect. 3.3). Whether or not a part of this emission is physically related to V838 Mon is an important question but it cannot be decided just from the image.

Figure 3 of vLERS has been derived from a compilation of surveys in the CO 1-0 line made by Dame et al. (2001). However, if one takes the composite map from Fig. 2 of Dame et al. and expands near the position of V838 Mon the resultant image is not the same as that in vLERS. In particular, there is no emission to the left and upper-left of the position of V838 Mon [i.e. $l \gtrsim l$(V838 Mon) and $b \gtrsim b$(V838 Mon)], so no bubble-like structure is seen. Apparently Dame et al. (2001) considered this emission as statistically insignificant. Indeed, the data for this region come from a low resolution (0$^\circ\!\!.$5) and low sensitivity survey of Dame et al. (1987). Thus the emissions seen in Fig. 3 of vLERS and coming from this last survey is uncertain and might be spurious. This is supported by the fact that two large, faint patches seen to the left and upper-left of the V838 Mon bubble in Fig. 3 of vLERS (not seen in Fig. 2 of Dame et al. 2001) cannot be identified with any known CO cloud while two known CO regions, namely regions (9) and (13) in Table 3 (see Sect. 3.3), are not seen in the image of vLERS.

3.3. Interstellar medium

The presence of the light echo proves that there is dusty matter around V838 Mon. As argued in Tylenda (2004) and in Sect. 3.1 of the present paper this matter is likely to be of interstellar character. This notion is supported by the conclusion of Sect. 2 that V838 Mon is likely to be a young binary system, as well as by the fact that having the Galactic coordinates, $l = 217^\circ\!\!.80, b = +1^\circ\!\!.05$, the object is located near the Galactic plane. Therefore it is important to investigate observational data on the ISM in the vicinity of V838 Mon. In this section we discuss the available data from the IRAS and CO surveys.

Figure 4 shows the IRAS image at 100 μm centered at the position of V838 Mon. At this wavelength practically all emission seen comes from dust (interstellar or circumstellar). As can be seen from the figure V838 Mon is located in a faint diffuse emission probably related to bright regions near the Galactic plane. The numbers in the figure show the positions of molecular and HII regions listed in Table 3, which are within ∼1$^\circ\!\!.$5 of the position of V838 Mon. The table gives the galactic coordinates of the regions, their usual names, values of T_A^* taken from Wouterloot & Brand (1989), $V_{\rm LSR}$ resulting from CO line observations, and types of the regions. The references to the data are given in the last column of the table.

As can be seen from Table 3 the regions marked in Fig. 4 can be divided into two groups from the point of view of their positions, brightness and $V_{\rm LSR}$. The brightest regions near and slightly below the Galactic plane (regions 5, 6, 8, 12) have $V_{\rm LSR}$ in the range of 20–30 km s^{-1}. The heliocentric radial velocity of V838 Mon is not well known as it has been estimated

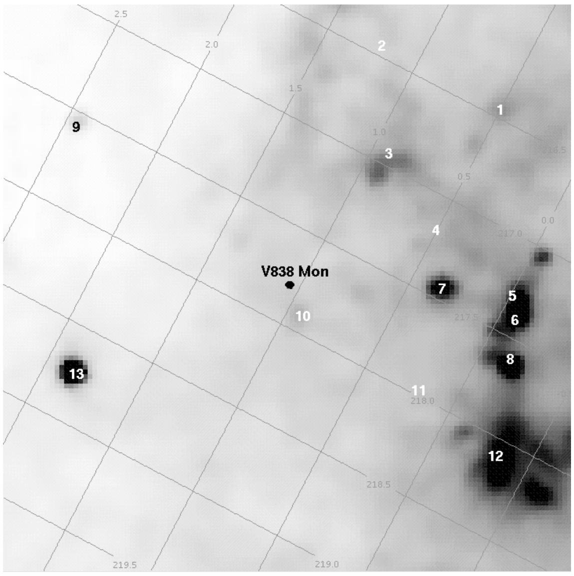

Fig. 4. The 100 μm IRAS image centered on the position of V838 Mon (north is up, east to the left). The grid shows the galactic (l, b) coordinates. Numbers show the positions of the ISM regions from Table 3.

from outburst spectra. The results are within 55–65 km s^{-1} (Kolev et al. 2002; Kipper at al. 2004; M. Mikołajewski – private communication). That of the B-type companion is ~64 km s^{-1} (T. Tomov – private communication). Using the results of Dehnen & Binney (1998) this can be transformed to $V_{\rm LSR}$ = 44−54 km s^{-1}. Thus the above regions are most probably at much smaller distances (2–3 kpc if interpreted with the Galactic rotation curve of Brand & Blitz 1993) than V838 Mon and they are simply seen in front of the object.

However the regions lying above the Galactic plane (regions 1, 2, 3, 4, 7, 9, 13) have $V_{\rm LSR}$ between 47–57 km s^{-1}. When interpreted with the rotation curve of Brand & Blitz (1993) their distances are in the range of 6–8 kpc. Thus these regions are located much closer to V838 Mon and a physical relation between one of them and the matter seen in the light echo is quite possible.

Region (10), whose apparent position is closest to that of V838 Mon, has been listed in Magakian (2003) as a reflection nebula related to a 9 magnitude B9 star HD 53135 (LS −03 15) estimated to be at a distance of ~2 kpc (Vogt 1976, Kaltcheva & Hilditch 2000). Thus this region is probably located well in front of V838 Mon.

Interstellar Na I lines in the spectrum of V838 Mon during eruption showed two components at heliocentric velocities of ~37 and ~64 km s^{-1} (Zwitter & Munari 2002; Kolev et al. 2002; Kipper et al. 2004). When transformed to $V_{\rm LSR}$ the figures become ~26 and ~53 km s^{-1}. Thus both line components can be interpreted as due to ISM related to the above two groups of the ISM regions. Detailed observations of the vicinity of V838 Mon in molecular lines might be important for discussing the nature of V838 Mon.

4. Discussion and summary

The goal of this paper is to use available observational data on the progenitor and environment of V838 Mon to better constraint the nature of its eruption. Below we summarize and discuss our main findings and conclusions.

(1) *The nature of the progenitor.* In Sect. 2 we have analyzed the photometric data available for the progenitor. Most likely the progenitor was a young binary system consisting of two intermediate mass (5−10 $M_{\odot}$) stars. V838 Mon itself was either a main sequence star of similar mass as its B-type companion or a slightly less massive pre-main-sequence star. The system is very wide as the B-type companion observed today does not seem to be affected by the eruption. From the maximum photospheric radius of V838 Mon during eruption (Tylenda 2005) we can estimate that the separation of the components is $>3 \times 10^3\ R_{\odot}$ so the orbital period is >12 years. The B-type companion was probably not involved in the eruption of V838 Mon, at least directly. The hypothesis of a young binary system is also supported by the position of the object near the Galactic plane and the conclusion of Sect. 3 that V838 Mon is probably embedded in the ISM.

A less likely hypothesis is that the presently observed B-type companion does not form a binary system with V838 Mon. In this case, other than a B-type main sequence star, the progenitor could have been an A−B spectral type giant evolving from the main sequence or a B-type post-AGB star. These two possibilities however involve a short (giant in the Hertzsprung gap) or very short (post-AGB) evolutionary phase. As it is an old object in these cases it would not be expected to reside inside or close to dense ISM regions.

We can safely excluded the possibility that before eruption V838 Mon was of spectral type K–M, so it could not have been a typical RGB or AGB star.

(2) *The light echo and the Galactic environment of V838 Mon.* In several studies the light echo was used to argue that the light-reflecting dust was expelled by V838 Mon in previous eruptions (e.g. Bond et al. 2003, vLERS). As argued by Tylenda (2004), and discussed here in Sect. 3.1, the data strongly suggests that dust is of ISM origin. The dust structure derived from the echo analysis does not show any hint of spherical symmetry. On the contrary, the outer boundary of the echoing dust in front of the object can be approximated by a plane at a distance of ~3.5 pc from V838 Mon and inclined at an angle of ~26° to the line of sight. The strongly asymmetric dust-free region in the near vicinity of V838 Mon, inferred from the central hole in the echo, is interpreted as produced by the V838 Mon progenitor (and possibly its B-type companion) moving relative to the local ISM and sweeping out the medium by its fast wind. As discussed in Sect. 3.3, there are several interstellar molecular regions seen in the IRAS image and CO surveys probably located near V838 Mon. The local ISM seen in the light echo is therefore likely to be related to one or some of them.

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Note added in proof. Thomas Dame (private communication) has recently confirmed our discussion in the last paragraph of Sect. 3.2. The emission that van Loon et al. (2004) plotted as the upper-left section of their CO loop comes from the survey of Dame et al. (1987) and is way down in the noise of this survey.

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