Infrared observations of V838 Mon

M. T. Rushton
Astrophysics Group, Keele University, Keele, Staffordshire, ST5 5BG, UK

T. R. Geballe
Gemini Observatory, 670 N. A’ohoku Place, Hilo, HI 96720, USA

A. Evans, J. Th. van Loon, B. Smalley
Astrophysics Group, Keele University, Keele, Staffordshire, ST5 5BG, UK

S. P. S. Eyres
Centre for Astrophysics, University of Central Lancashire, Preston, PR1 2HE, UK

Abstract. We describe the results of fitting simple spherically symmetric models to the first overtone CO and AlO A–X (2–0) bands in V838 Mon. We find that the temperature and column of both CO and AlO systematically decline over the period 2002 October – 2005 February and that an additional, hotter and denser, component is present from 2005 January. We also describe the results of an observation of the star and its light echo at 850 µm. We do not detect the ‘infrared’ echo at these wavelength, and place an upper limit of $3 \times 10^7$ cm$^{-2}$ on the column of grains.

1. Introduction

We began a programme of regular infrared (1–5 µm) spectroscopic monitoring of V838 Mon soon after the 2002 eruption was reported by [4]; the results are described in [5]; [6]; [7]; [8]. All of the data reported here cover the first overtone CO bands (bandhead at 2.29 µm) and the A–X (2–0) AlO bands at 1.67 µm. In this contribution we discuss our attempts to model the complex evolution of these bands, as revealed by our low resolution observations of CO and AlO.

Details of the infrared data we obtained at high resolution, and what the data tell us about the complex velocity systems in the environment of V838 Mon, is discussed by Geballe elsewhere in these proceedings.

We also describe here the results of an observation at 850 µm with the James Clerk Maxwell Telescope (JCMT).
2. Modelling CO and AlO

We consider the star to be at the centre of one or two spherically symmetric, expanding shell(s). As noted by Geballe (this volume) it is more likely that three, or even four, shells are present; however at the low resolution of the spectra one or two shells gives a good representation of the data. We have taken the first overtone CO linelist (in excess of 40000 lines) from (10) and AlO data from various sources (see (15) for details).

We fit the models to the data using an AMOEBA algorithm, based on downhill simplex (12). We optimized for the excitation temperature and column of CO, and similarly for AlO, and for the temperature of the background (blackbody) continuum. For the present we assume LTE. We found that the temperature of the background varied between $\sim$ 4000 K and $\sim$ 2000 K. Initially we also optimized for the $^{12}$C/$^{13}$C ratio but this was not well constrained, with a lower limit of 16; this is consistent with the apparent absence of $^{13}$CO bands described by Geballe (this volume).

Optimization (particularly for AlO) is not helped by the presence of many other species, particularly H$_2$O, which are not included in our analysis at this stage.

Figure 1. Model spectra around the first overtone $^{12}$CO bands. CO column $= 10^{21}$ cm$^{-2}$ and excitation temperature $T_{\text{CO}}$ as shown (15; 10).
3. Results

3.1. Models

Examples of model spectra around the first overtone CO bands are shown in Fig. 1. The model spectra qualitatively cover the range of first overtone CO profiles observed in V838 Mon by our programme and by (1). At 2800 K the CO spectra are qualitatively similar to those seen in late giants. At low enough CO excitation temperature ($T_{\text{CO}}$) the optical depth in the CO lines is $\sim$ constant across the band and the bands lose their characteristic asymmetric shape. At $T_{\text{CO}} = 2000$ K the model bands resemble data obtained in our programme, those at 1800 K resemble data reported by (1). At high excitation temperatures the CO begins to appear in emission. In particular the 1800 K model is strikingly similar to the CO profiles for 2002 October and, while the models with $T_{\text{CO}} > 3000$ K produce emission, the profiles are not flat as they are in the 2002 March data.

3.2. Fits

The fits to the first overtone CO bands in V838 Mon are shown in Fig. 2; the fits to the AlO bands are shown in Fig. 3. We find that the excitation temperature and column of CO decline with time, as shown in Fig. 4, presumably the result of the detachment, followed by cooling and dispersal, of material ejected in the 2002 event. The run of CO excitation temperature and column is broadly in line with that found by (11); furthermore the decline in the excitation temperature, for both CO and AlO, is consistent with that found by (2) for H$_2$O.

We note that there is clear evidence at the band head for an additional, hotter component in the later data; this may be the photosphere reappearing through the ejected material.

![Figure 2. Model fits to the CO data for 2002 October – 2005 February.](image)

While our simple model provides a good qualitative account of the behaviour of the CO and AlO we consider that a more complete description will likely
require more shells than we have considered here (cf. Geballe, this volume) and non-LTE treatment.
4. Observation at 850µm

There are benefits in observing the infrared equivalent of light echoes, for example the fact that detailed knowledge of the grain scattering phase function is not required for interpretation. In this case we see the ‘infrared echo’, commonly observed (as indeed are light echoes) when supernovae erupt (5). In the infrared case we see the results of grain heating and re-radiation as the paraboloid of constant light travel time (see Sugerman, this volume) passes through the dust. The thermal inertia of grains is such that they react essentially instantaneously to changes in the ambient radiation field.

(1) has presented Spitzer MIPS observation of the V838 Mon infrared echo; see also Ashok (this volume). They find that the emission at 24, 70 and 160µm is spatially correlated with the HST light echo; they also find emission associated with the dust located close to the star itself. They estimate that the mass of dust in the light echo material is ~ a few solar masses, and they conclude that a significant fraction of the emitting dust is likely interstellar in origin.

We have used the Sub-millimetre Common User Bolometer Array (SCUBA) on the JCMT to make a 2' × 2' 850µm jiggle map of the light echo over the period 2003 October – 2004 January (most of the observations being in 2004 January), when the radius of the light echo was ~ 53" (5). We get a 3σ upper limit of 160mJy from the star itself; the SED for late 2003 is shown in Fig. 5.

We find a 3σ upper limit at 850µm of 2 × 10^4 Jy sr^{-1} from the region containing the light echo material. In order to interpret this result we have estimated the likely intensity of the 850µm emission from the light echo dust by making an analytic fit to the time-dependence of the bolometric luminosity L_*(t) and T_ex(t) from (15) and integrating through a plane thin dusty inclined slab (6). We take optical constants for silicates from (7).

We find an upper limit on the dust column in the echo material 3 × 10^7 cm^{-2}. This column gives an upper limit of < 0.1 M_⊙, within 50", for 0.1µm silicate grains and for 5–9 kpc distance; this is clearly significantly below the mass deduced by (3).

5. Conclusions

We have fitted a spherically symmetric, expanding shell of CO and AlO to the near-infrared spectra of V838 Mon. We find a declining column of CO and AlO, and a declining T_ex for both species. However there is an additional hot CO component from 2005 Jan.

We find an upper limit of 3 × 10^7 cm^{-2}, and corresponding upper mass limit of 0.1 M_⊙, for the dust in light echo material; this is significantly lower than that implied by the Spitzer observations.

Further details of this work will be published elsewhere.

Acknowledgments. MTR was supported by the UK Particle Physics & Astronomy Research Council (PPARC) and is now supported by the University of Central Lancashire. TRG is supported by the Gemini Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., on behalf of the international Gemini partnership of Argentina, Australia, Brazil, Canada, Chile, the United Kingdom, and the United States of America.
Figure 5. The spectral energy distribution of V838 Mon from late 2003. Filled circles, data from [6, 21, 11, 17]. The $UBVRI$ data are from 2003 September, while the remainder are from 2003 October. Triangle: our upper limit at 850$\mu$m. The dotted line is a B3V star, reddened by $E(B-V) = 0.85$ and scaled to match the $U$ and $B$ bands.

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