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MID-INFRARED OBSERVATIONS OF V838 MON

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RESUMEN

Presentamos observaciones fotométricas de la estrella peculiar V838 Mon, entre 8 y 13 μm en bandas angostas, efectuadas en septiembre de 2002. El espectro es consistente con una ley de potencias, aunque un espectro con exceso de emisión entre 9 y 12 μm produce un mejor ajuste a los datos.

ABSTRACT

We present 8–13 μm narrow-band photometry of the peculiar star V838 Mon in 2002 September. Our spectrum is consistent with a simple power-law spectrum, although a spectrum with excess emission between 9 and 12 μm provides a better fit.

Key Words: **INFRARED: STARS — STARS: INDIVIDUAL (V838 MONOCEROTIS)**

1. INTRODUCTION

The variable star V838 Mon is one of the most peculiar objects discovered in recent years. It erupted in early 2002 January (Brown 2002) and initially appeared to be a nova. However, it soon departed from the behavior expected for novae, and appears to have formed a very cool supergiant with a moderate wind.

The visible light curve shows brightenings in 2002 January, February, and March followed by a deep fading of 6 magnitudes in V during 2002 April. While the stellar photosphere showed evolution to increasingly lower temperatures during this period (Henden et al. 2002; Rushton et al. 2005), it appears that the formation of circumstellar dust was at least partly responsible for this fading (Crause et al. 2003). There is evidence for previous ejections of circumstellar dust (van Loon et al. 2004).

Circumstellar dust is best studied in the mid-infrared. In this context, the 1–13 μm spectroscopy of Lynch et al. (2004) is very interesting. Their 2002 January spectrum, taken shortly after the first outburst, shows emission from a relatively featureless 2700 K continuum. However, one year later, in 2003 January, the spectrum had brightened by 4 magnitudes at 10 μm and showed strong emission and absorption features. In particular, it showed a peculiar double-peaked emission at 9.2 and 11.3 μm, which Lynch et al. suggest might be the result of broad silicate emission and narrow silicate absorption at 10.3 μm. They comment that absorption at this wavelength may arise from hydrated silicates. A spectrum obtained in 2003 October by Lynch, Russel, & Polomski (2003b) showed narrow absorption at 10.3 μm but no excess emission.

In this work we present broad-band and narrow-band photometry of V838 Mon in 2002 September, shortly after it emerged from behind the Sun.

2. OBSERVATIONS

We observed V838 Mon on the nights of 2002 September 16 and 19 with the CID mid-infrared camera (Salas et al. 2003) on the 2.1 m telescope of the Observatorio Astronómico Nacional on Sierra San Pedro Mártir. On the first night, we observed in N and $Q2$ filters and on the second in N and "OCLI silicate" filters that sample the broad silicate dust feature around 10 μm (see Table 1 for central wavelengths and widths). Total integration times were about 226 seconds in N and 14 seconds in $Q2$ on the first night and 56 seconds in N and 115 seconds in each of the silicate filters on the second night. The airmass of the observations ranged from 1.60 to 1.77.

We used a standard chopping and nodding technique. However, we arranged the chops and nods so that the star always appeared on the detector. Thus, at each chop position we obtained both a positive and negative image of the star.

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TABLE 1

OBSERVATIONS

Filter	$\bar{\lambda}$ (μm)	$\Delta\lambda$ (μm)	Mag	Flux Density (W cm^{-2} μm^{-1})
			2002 September 16	
N	10.88	5.62	1.44 ± 0.08	
Q2	18.75	0.85		$< 2.3 \times 10^{-18}$ (1σ)
			2002 September 19	
N	10.88	5.62	1.33 ± 0.06	
SiN	7.73	0.70		$6.62 \times 10^{-17} \pm 10\%$
SiO	8.74	0.78		$4.57 \times 10^{-17} \pm 5\%$
SiP	9.69	0.93		$3.90 \times 10^{-17} \pm 6\%$
SiQ	10.29	1.01		$3.01 \times 10^{-17} \pm 5\%$
SiR	11.66	1.11		$1.92 \times 10^{-17} \pm 6\%$
SiS	12.50	1.19		$1.25 \times 10^{-17} \pm 7\%$

We reduced each chop-nod sequence by simply subtracting chopped images and adding nodded images. Each sequence yielded an image with four images of the star, two positive and two negative. We detected V838 Mon in these images in all filters except $Q2$. We co-added the positive and negative detections. In the case of $Q2$, we were unable to co-add the images reliably and so determined the upper limit from a single image.

We did not apply a flat field correction; a grid of standard stars showed that the variation across the field was only about 2.5% RMS, and this is negligible in comparison to other sources of error.

We calibrated the data using observations of α Tau and γ Dra between 1 and 2 airmasses. We fitted for zero-point and extinction terms. We adopted standard flux densities in all filters except N from Cohen et al. (1999) and Cohen et al. (1996). We adopted a standard magnitude of $N = -3.02$ for α Tau from Cohen, Walker, & Witteborn (1992). Since α Tau and γ Dra are both classified as K5III, we obtained a standard magnitude of $N = -1.55$ for γ Dra by scaling the magnitude for α Tau by the ratio of the flux densities at 10.88 μm from the previous references.

3. RESULTS

In all of the images in which it was detected, V838 Mon appeared to be point-like. Our final magnitudes, flux densities, and 1σ errors are shown in Table 1. The errors are dominated by a combination of sky noise and uncertainties in the calibration. Our 1σ upper limit on the flux density in $Q2$ is 2.3×10^{-18} W m^{-2} μm^{-1}.

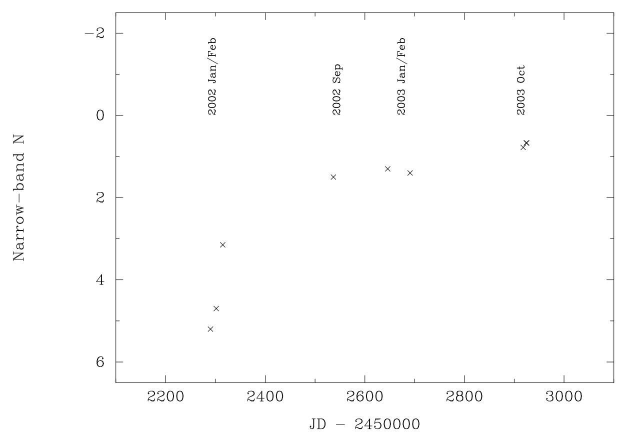

Fig. 1. The light curve for V838 Mon in narrow-band N magnitudes.

4. DISCUSSION

Figure 1 shows the light curve for V838 Mon in narrow-band N magnitudes (Käufl et al. 2002; Lynch et al. 2003a; Sitko et al. 2003; Lynch et al. 2003b; Tapia & Persi 2003, and this work). The curve shows an abrupt rise in the infrared in spring 2002 followed by a more gentle increase between fall 2002 and fall 2003. Our observations show that the star was well into its infrared-bright phase by 2002 September. This is consistent with evidence that the fading and reddening of V838 Mon prior to the June-August solar conjunction was caused at least in part by the formation of dust (Crause et al. 2003).

Figure 2 shows the 8–13 μm spectrum of V838 Mon on 2002 September 19. The vertical bars show the 1σ uncertainties in the flux density measure-

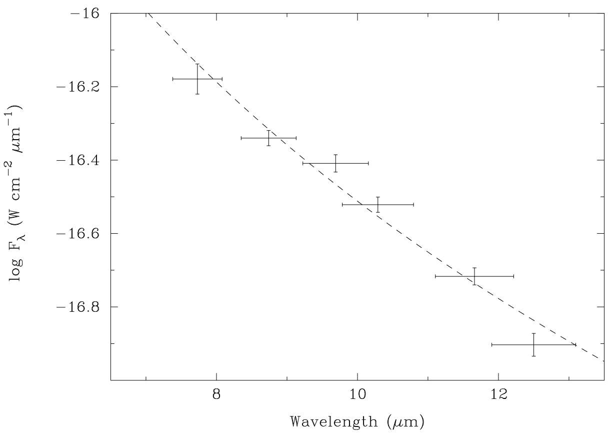

Fig. 2. The 8–13 μm spectrum of V838 Mon on 2002 September 19. The dashed line is a power-law fit to all measurements.

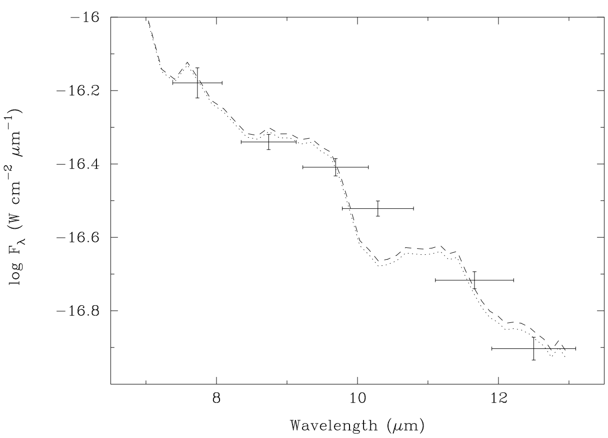

Fig. 3. The 8–13 μm spectrum of V838 Mon on 2002 September 19. The dashed line is a fit of the 2003 January spectrum, faded, and steepened, to all measurements. The dotted line is a fit of the same model to the all measurements except the one at 10.29 μm.

ments and the horizontal bars the FWHM of the filters.

The 2002 September spectrum is slightly fainter than the 2003 January spectrum of Lynch et al. (2004). Furthermore, the 2002 September spectrum drops more steeply between 7.7 and 12.5 μm than the 2003 January spectrum. The decline in the 2002 September spectrum corresponds to a color temperature of about 1530 K, whereas Lynch et al. fitted the continuum of the 2003 January spectrum with a color temperature of 650 K.

The 2003 January spectrum shows excess emission at 9.2 and 11.3 μm and absorption at 10.3 μm. Lynch et al. (2004) suggest this may be the superposition of broad silicate emission and narrow silicate absorption. While the spectral resolution $\lambda/\Delta\lambda \approx 10$ of our 2002 September spectrum is relatively poor, we can investigate whether there is evidence for silicate emission or absorption.

A fit of a power-law spectrum $\lambda F_\lambda \propto \lambda^{-\alpha}$ to all six measurements (integrating over the approximate filter band passes) has $\alpha \approx 2.35$ and is shown as a dashed line in Fig. 2. This fit has a reduced χ^2 of 3.72, which corresponds to a probability of 14%. Thus, a simple power-law is an adequate albeit not especially convincing representation of the 2002 September spectrum.

The residuals to the power-law fit suggest that there might be excess emission at 10 μm. We can investigate this by fitting the spectrum of Lynch et al. (2004) scaled by a factor $f(\lambda/10\mu\mathrm{m})^\beta$. A fit to all six measurements (integrating over the approximate filter band passes) has $f = 0.65$ and $\beta = -0.85$ and is shown as a dashed line in Figure 3. This fit has a reduced χ^2 of 4.29, which corresponds to a probability of 12%. Thus, again, this model is an adequate but not especially convincing representation of the 2002 September spectrum.

On inspection of Fig. 3, it is clear that the single point at 10.29 μm dominates the contribution to χ^2, being discrepant by 3.3σ. A fit to all of the filters except the 10.29 μm filter has $f = 0.63$ and $\alpha = -0.90$ and is shown as a dotted line in Fig. 3. This fit has a reduced χ^2 of 1.07, which corresponds to a probability of 43%.

We conclude that the best representation of the 2002 September spectrum is the 2003 January spectrum, faded, steepened, and *without* the apparent absorption seen near 10.3 μm. Unfortunately, we are unable to convincingly eliminate simpler alternatives such as a power-law or the 2003 January spectrum, faded, steepened, and *with* the apparent absorption seen near 10.3 μm.

5. SUMMARY

We present a 8–13 μm narrow-band photometry of the variable star V838 Mon in 2002 September. Our spectrum shows similar levels of emission to the higher-resolution 2003 January spectrum of Lynch et al. (2004). Our spectrum is consistent with a simple power-law spectrum, although a spectrum showing excess emission between 9 and 12 μm, presumably from silicate dust, is a better fit.

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