HIGH SPATIAL RESOLUTION MID-IR IMAGING OF V838 MONOCEROTIS: EVIDENCE OF NEW CIRCUMSTELLAR DUST CREATION

JOHN P. WISNIEWSKI, MARK CLAMPIN, KAREN S. BJORKMAN, AND RICHARD K. BARRY

ABSTRACT

We report high spatial resolution 11.2 and 18.1 μm imaging of V838 Monocerotis obtained with Gemini Observatory’s Michelle instrument in 2007 March. Strong emission is observed from the unresolved stellar core of V838 Mon in our Gemini imagery and is confirmed by Spitzer MIPS 24 μm imaging obtained in 2007 April. The 2007 flux density of the unresolved mid-infrared emission component is ~2 times brighter than that observed in 2004. No clear change in the net amount of 24 μm extended emission is observed between the 2004 and 2007 epoch Spitzer imagery. We interpret these data as evidence that V838 Mon has experienced a new circumstellar dust creation event. We suggest that this newly created dust has condensed from the expanding ejecta produced from V838 Mon’s 2002 outburst events and is most likely dusty. We speculate that one (or more) of these clumps might have passed through the line of sight in late 2006, producing the brief multiwavelength photometric event reported by H. Bond in 2006 and U. Munari et al. in 2007b. We detect no evidence of extended emission above a level of ~1 mJy at 11.2 μm and ~7 mJy at 18.1 μm over radial distances of 1800–93,000 AU (0.3″–15.0″) from the central source. Using the simple assumption that ejecta material expands at a constant velocity of 300–500 km s⁻¹, this gap of thermal emission suggests that no significant prior circumstellar dust production events have occurred within the past ~900–1500 yr.

Subject headings: circumstellar matter — stars: individual (V838 Monocerotis)

1. INTRODUCTION

V838 Monocerotis experienced three photometric outbursts in early 2002, beginning with an initial event on 2002 January 6.6 (Brown et al. 2002) and continuing with events in 2002 February and 2002 March (Kimeswenger et al. 2002; Munari et al. 2005). The star’s spectrum cooled through the F, G, and K spectral types throughout February (Munari et al. 2007a), transitioned to a late M-type giant by 2002 April 16 (Rauch et al. 2002), and had cooled to a L-type supergiant appearance by 2002 October (Evans et al. 2003). The circumstellar ejecta from the outburst events was not spherically symmetric, as revealed by the intrinsic polarization detected until 2002 February 13 (Wisniewski et al. 2003a; Desidera et al. 2004); Wisniewski (2007) estimated that ejecta located interior to the region producing Hα and Ca ii emission was flattened by a minimum of 10% from a spheroidal shell. A renewed intrinsic polarization component observed on 2002 October 22 might be attributable to a new source of asymmetrical scatterers in V838 Mon’s circumstellar envelope or to a change in the opacity of the existing envelope (Wisniewski et al. 2003b).

V838 Mon produced a spectacular light echo first detected on 2002 February 17 by Henden et al. (2002) which evolved dramatically over time (Bond et al. 2003). Banerjee et al. (2006) imaged V838 Mon with the Spitzer Space Telescope at 24, 70, and 160 μm and attributed the observed excess of thermal infrared (IR) emission from the unresolved central source as evidence of the formation of circumstellar dust produced by the 2002 outbursts. An IR excess was also observed from the spatially resolved light echo, and Banerjee et al. (2006) concluded that the source of this emitting dust could have both interstellar and circumstellar components.

V838 Mon resides in a young open cluster (Afsar & Bond 2007) at a distance of 6.2 ± 1.2 kpc (Sparks et al. 2008). It has a known, albeit unresolved, B3 V binary companion (Munari et al. 2005). The nature of V838 Mon prior to outburst is a subject of active debate (cf. Munari et al. 2005; Tylenda et al. 2005); a wide variety of mechanisms have been proposed to explain the eruptive events in V838 Mon, including a shell thermoneutral event (Munari et al. 2005), a born-again star which experienced an accretion event (Lawlor 2005), a stellar merger (Tylenda & Soker 2006), and a star which engulfed several planets (Ritter et al. 2006). Determining the amount and spatial distribution of dust within the V838 Mon line of sight, and quantifying how much is circumstellar versus interstellar in nature, would help constrain whether its outburst mechanism was a variant of a repeatable phenomenon, such as a thermonuclear runaway or nova-like explosion, or more likely a singular event, such as a stellar merger.

2. OBSERVATIONS

We obtained N’ (11.2 μm) and Q2 (18.1 μm) imaging of V838 Mon on 2007 March 21–22 using Gemini Observatory’s Michelle imager. Michelle is a 320 × 240 pixel array which has a 32.0″ × 24.0″ field of view (0.1″ per pixel). All observations were obtained using a standard chop-nod mode with the same instrument configuration: a detector position angle of 110° east of north, a chop angle of 130° east of north, and the maximum chop throw of 15.0″. The weather and seeing conditions during our observing runs were stable, with FWHM values of individual chop-nod pairs deviating from the average values quoted in Table 1 by less than 0.02″ on 2007 March 21, 0.05″ on 2007 March 22, 0.04″ on 2007 August 6, and 0.01″ on 2007 August 9.

The data, summarized in Table 1, were reduced with procedures similar to those prescribed in Gemini’s MIDIR package. Following combination of individual chop-nod pairs,
known image artifacts such as vertical and horizontal “staircases” were characterized by sampling 15 pixel wide regions along column and row borders and removed via custom IDL routines. Cleaned images were registered to a common position and examined for evidence of anomalous elongation along the chop direction, which is known to characterize a fraction of all Michelle data since early 2007. Our final combined images were flux calibrated using observations of Cohen standards all Michelle data since early 2007. Our final combined images were flux calibrated using observations of Cohen standards all Michelle data since early 2007. The displayed panels include (a) 24 μm MIPS data, we simply scaled and registered the 2004 and 2007 V838 Mon data to match our Gemini data were obtained. The 24 μm MIPS data. These authors fitted a scaled PSF-star to match the brightness of V838 Mon’s first airy ring and replaced the saturated V838 Mon core by the core of this scaled PSF-star to recover a flux density measurement of the unresolved V838 Mon central source (Table 1). To extract similar measurements for the 2007 24 μm MIPS data, we simply scaled and registered the 2004 and 2007 V838 Mon data to match their unsaturated PSF wing regions. The optimal scaling factor yielded a 24 μm flux density of 29.67 ± 1.95 Jy at 18.1 μm, are cited in Table 1. The quoted errors are the standard deviations from our different apertures and provide an estimate of the internal uncertainty in our measurements (~1%). Additional uncertainties in the absolute flux calibration, owing to the internal accuracy of the Cohen flux standards and changes in the atmospheric conditions between our observations, are expected to be of order several percent for bright sources observed in stable conditions (K. Volk 2008, private communication).

3. ANALYSIS

3.1. Photometry of the Unresolved Point Source

We used simple aperture photometry to extract flux densities for the unresolved V838 Mon point source in our Gemini data. We explored the use of five circular apertures having radii ranging in size from 0.6′′ to 3.0′′ for our N′ data and from 0.7″ to 3.0″ for our Q′ data and found consistent results from each. The mean flux density values from these apertures, 29.54 ± 0.14 Jy at 11.2 μm and 36.43 ± 0.82 Jy at 18.1 μm, are cited in Table 1. The quoted errors are the standard deviations from our different apertures and provide an estimate of the internal uncertainty in our measurements (~1%). Additional uncertainties in the absolute flux calibration, owing to the internal accuracy of the Cohen flux standards and changes in the atmospheric conditions between our observations, are expected to be of order several percent for bright sources observed in stable conditions (K. Volk 2008, private communication).

Spitzer’s MIPS observed V838 Mon in 2007, ~2 weeks after our Gemini data were obtained. The 24 μm imagery was heavily saturated at the core. Banerjee et al. (2006) reported similar saturation effects in their 2004 24 μm MIPS data. These authors fitted a scaled PSF-star to match the brightness of V838 Mon’s first airy ring and replaced the saturated V838 Mon core by the core of this scaled PSF-star to recover a flux density measurement of the unresolved V838 Mon central source (Table 1). To extract similar measurements for the 2007 24 μm MIPS data, we simply scaled and registered the 2004 and 2007 V838 Mon data to match their unsaturated PSF wing regions. The optimal scaling factor yielded a 24 μm flux density of 29.67 ± 1.95 Jy (Table 1). Note that the quoted error represents the uncertainty we estimated for our image scaling (~1.5%) along with the 5% absolute flux uncertainty of the 2004 Spitzer flux densities reported by Banerjee et al. (2006). Using simple aperture photometry, we also extracted a flux density for the 2007 April Spitzer MIPS 70 μm observation of 7.34 ± 0.73 Jy (Table 1).

The 2007 March Gemini 18.1 μm flux density is consistent with the 2007 April Spitzer 24 μm flux density at the 3 σ level; these flux densities are a factor of 2 stronger than that observed...
in 2004 October observations. Similarly, the 2007 April Spitzer 70 μm flux density is ~2 times stronger than that observed in 2005 April. The amount of excess IR emission associated with the unresolved central source of V838 Mon has clearly increased between 2004/2005 and 2007 (see Fig. 2).

3.2. Extended Emission

Gemini’s Michelle provides a 10-fold improvement in spatial resolution compared to Spitzer’s MIPS; hence, our data provide us the unique opportunity to search for mid-IR extended emission interior to that probed by Banerjee et al. (2006). Comparison of median azimuthally averaged radial profiles of our 11.2 μm and 18.1 μm imagery of V838 Mon with a similar color PSF-star observation (HD 52666; M2 III), obtained immediately before our V838 Mon data, reveals no convincing evidence of extended emission nearby the stellar core. Measured median FWHM values of V838 Mon and our PSF-star are the same at 11.2 and 18.1 μm (Table 1) to within the maximum observed deviation among chop-nod pairs (<0.02" at 11.2 μm and <0.05" at 18.1 μm), which quantitatively supports this conclusion.

To search for extended emission outside of the immediate vicinity of the stellar core, we used both contemporaneously observed PSF-star observations (HD 52666; Table 1) and longer integrations of a PSF-star obtained several months after our V838 Mon observations (HD 168723; Table 1) to model and subtract the PSF from our V838 Mon imagery. The deeper PSF-star observations exhibit marginally different FWHM values as compared to V838 Mon, likely attributable to minor differences in atmospheric conditions, but provide a lower average detector noise background which is better suited to identifying faint extended emission far from the V838 Mon stellar core. Figure 3 illustrates our V838 Mon imagery following subtraction of optimally scaled and registered PSF-star observations, plotted on a linear stretch in units of mJy, and smoothed by a second-order Gaussian function. We have masked the region inside a radial distance of 0.8" (8 pixels) which exhibited a commonly observed detector artifact which arises when Michelle images bright sources.

We detect no convincing evidence of extended emission above a level of ~1 mJy at 11.2 μm and above a level of ~7 mJy at 18.1 μm. Applying additional binning or alternative smoothing functions to the data presented in Figure 3 yielded no evidence of extended emission above the observed residual detector noise background.

As described in § 3.1, we shifted and scaled the archival 2004 Spitzer MIPS 24 μm data to extract point-source photometry for the 2007 Spitzer 24 μm data. The scaling factor we applied to the 2004 data (1.97) led to an optimal cancellation of the PSF wings of the 2007 data in the subtraction process but produced a large region of oversubtracted flux exterior to the stellar core, whose morphology corresponded to the extended emission reported by Banerjee et al. (2006). Using a circular aperture of radius 80.0" and masking the central PSF-core region, we determined that the net 24 μm flux density of this oversubtraction region was ~0.88 Jy. This is exactly the flux density one would expect to see if the extended emission component did not vary between 2004 and 2007, given the
reported 2004 extended emission flux of 0.91 Jy (Banerjee et al. 2006) and our use of a scaling factor of 1.97, i.e.,

$$24 \mu m_{2007} - (1.97 \times 24 \mu m_{2004}) = 24 \mu m_{\text{net}},$$

$$0.91 \text{ Jy} - (1.97 \times 0.91 \text{ Jy}) = -0.88 \text{ Jy}.$$ 

While a comprehensive comparative analysis of the 2004 and 2007 Spitzer MIPS data is outside of the scope of this Letter, our simple analysis suggests that (a) the amount of 24 \mu m and 70 \mu m emission in the unresolved V838 Mon stellar core has increased by a factor of \sim 2 from 2004 to 2007 and (b) the net amount of 24 \mu m extended emission appears unchanged from 2004 to 2007.

4. DISCUSSION

We detect no evidence of extended 18.1 \mu m emission above a level of \sim 7 mJy from radial distances of 1860 AU (0.3") to 93,000 AU (15.0"), assuming a distance of 6.2 kpc (Sparks et al. 2008). Making the simple assumption that V838 Mon’s circumstellar ejecta expands at a constant velocity, this gap of thermal IR emission suggests no circumstellar dust producing events have occurred within the past \sim 900 (if \nu_{\text{ejecta}} \sim 300 \text{ km s}^{-1}; Wisniewski et al. 2003a) to \sim 1500 yr (if \nu_{\text{ejecta}} \sim 500 \text{ km s}^{-1}; Munari et al. 2002). Our analysis of 2007 imagery of V838 Mon from both Gemini’s Michelle and Spitzer’s MIPS indicates the presence of significantly enhanced 10–70 \mu m emission in the unresolved central stellar core in 2007 as compared to 2004. We interpret our 2007 data as evidence that a new circumstellar dust production event has occurred since 2004.

Spectroscopic evidence of V838 Mon’s binary companion disappeared and Hα returned to emission in late 2006, corresponding with a temporary multicolor photometric fading (Bond 2006; Munari et al. 2007b). Munari et al. (2007b) attributed these events to either (a) an eclipse between the primary and secondary or (b) a dust cloud characterized by \nu_{\text{E}-\nu} = 0.55 \nu \text{ and } R_{\text{d}} = 3.1, gravitationally bound to the binary system, which eclipsed the B3 V secondary. We suggest that alternative interpretations are possible if these photometric and spectroscopic events are correlated to the new mid-IR behavior we have found in data from early 2007. A gravitationally bound dust cloud would radiate a constant amount of thermal IR emission throughout its orbit except during the brief time that it is occulted by the secondary; thus, unless it was only recently formed, such a cloud could not be singularly responsible for producing the observed enhanced mid-IR emission. A simple eclipse between the primary and secondary also would not lead to enhanced thermal IR emission.

Bond (2006) suggested that the photometric and spectroscopic events of late 2006 were indicative of the 2002 ejecta interacting with and overtaking the B3 V binary. More recent observations indicate that V838 Mon is experiencing a prolonged period of reduced photometric brightness (H. Bond 2008, private communication), further supporting this interpretation. While the temporal resolution of our data does not allow us to quantitatively determine whether this proposed encounter is related to the new circumstellar dust creation event we report, we suggest that such a correlation is plausible.

We suggest that the expanding ejecta from the 2002 outburst has condensed to form new circumstellar dust, producing the enhanced IR excess observed inside a radial distance of 1860 AU. The dust condensation radius of \sim 3.5 AU for the B3 V companion, which assumes \nu_{\text{cond}} \sim 1000 \text{ K}, \nu_{\text{cond}} \sim (\nu_{\text{star}}/2)(\nu_{\text{star}}/\nu_{\text{cond}})^2 (Ireland et al. 2005), and the estimated primary-secondary separation of \sim 34 AU derived from interferometry (Lane et al. 2005), indicates that dust can survive within the radial distance constraint of <1860 AU implied by our observations. This type of event is not altogether unexpected, as Lynch et al. (2004) previously reported the detection of an expanding region of molecular gas which they noted was likely dust precursor material. The enhanced flux at 18.1, 24, and 70 \mu m we observed in 2007 suggests that the equally strong (2007 epoch) 1.2 \mu m flux might not represent an additional enhancement of gas-phase molecular emission above that suggested by Lynch et al. (2004) but rather represents a warm thermal dust emission component.

Early postoutburst polarimetric observations (Wisniewski et al. 2003a; Desidera et al. 2004) indicated this ejecta was asymmetric; hence, we suggest that it is likely that dust which condenses from this ejecta will be spatially nonuniform and/or clumpy. We speculate that it is possible that one or more of these clumps eclipsed the line of sight in late 2006, producing the attenuation event reported by Bond (2006) and Munari et al. (2007b). Unlike the dust cloud eclipse event invoked by Munari et al. (2007b), we believe that any eclipsing dust blob is more likely to located in the expanding ejecta which is condensing to form new dust. Follow-up interferometric observations might reveal differences in the angular size of the system from that found in 2004 epoch observations by Lane et al. (2005) if this ejecta has indeed recently reached the location of the B3 V secondary star.

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