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IR Spectroscopy of Nova-like Sources

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Abstract. Near - IR spectroscopic and photometric observations of the eruptive variables V838 Mon and V445 Puppis in the *JHK* bands are reported. These objects erupted in nova-like explosions but evolved into rather unique and enigmatic objects. One of unusual features of the V838 Mon spectra is the detection of several strong TiI lines in emission in the *K* band. These spectra also show the strong presence of the ^{12}CO bands. Deep water bands at 1.4 μm and 1.9 μm are also seen later in the object's evolution. Blackbody fits to the *JHK* photometric data show that V838 Mon evolves to low temperatures between 2400-2600 K after its outburst. The spectra of V445 Puppis are found to be hydrogen deficient and unusually rich in CI lines leading to the possibility that it is a rare Helium nova. The nature of both the objects is discussed and it is shown that they do not fit into known categories of eruptive variables.

Keywords : V838 Mon, V445 Puppis, novae, Infra-red spectroscopy

1. Introduction

We discuss two strange, nova-like variables here viz. V838 Mon and V445 Puppis which may be opening out new vistas in astronomy. The eruptive variable V838 Mon was first reported to be in outburst on 6 January 2002 (Brown, 2002). The object had multiple outbursts with a first maximum of $V \sim 9.8$ being reached around 11 January followed by a slow decline. A second strong outburst followed on 2 February which changed the brightness by 4.3 magnitudes to a peak value of $V = 6.7$. A smaller, third brightening was also observed in early March. The initial spectra of the object in the optical have shown several emission lines, in general having P Cygni profiles, of BaII, LiI and those of several *s* process elements (Munari et al. 2002a). However, the distinguishing feature of V838 Mon was the detection of an expanding light echo around

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the object. (Munari et al. 2002a; Bond et al., 2003). Being a rare phenomenon, this generated considerable interest in this puzzling object. The object is being actively studied at present.

The outburst of V445 Puppis was first reported on 30 December 2000 by Kanatsu (Kato and Kanatsu, 2000). The exact date of the outburst is not known but is estimated to lie between 26 September 2000 to 23 November 2000. Several spectra in the visible region - taken shortly after outburst - showed many permitted lines of FeII, CaI, CaII, OI and NaI (Fuji 2001; Liller 2001; Wagner et al. 2001a). What was peculiar about V445 Puppis was the absence of Hydrogen lines in the optical spectra. We also confirm the absence of Hydrogen lines in the *JHK* bands. The deficiency of Hydrogen in V445 Puppis is rather unusual and indicates that V445 Puppis is not an usual nova. In this work, we present results on V838 Mon and V445 Puppis from *JHK* observations. These results should help in understanding the nature and evolution of these puzzling objects and how they fit into the known categories of eruptive variables. Greater elaborations on all aspects of V838 Mon and V445 Puppis which are described here can be found in Banerjee and Ashok (2002) and Ashok and Banerjee (2003) respectively.

2. Observations

Near-IR *JHK* spectra of V838 Mon and V445 Puppis at a resolution of $\sim$ 1000 were obtained at the Mt. Abu 1.2m telescope using a Near Infrared Imager/Spectrometer with a 256×256 HgCdTe NICMOS3 array. V838 Mon and V445 Puppis were observed at 5 epochs each between February - May 2002 and January - March 2001 respectively. Photometric observations of both objects were also done - some of these results are presented here.

3. Results

3.1 *JHK* spectroscopy of V838 Mon and V445 Puppis

We have reproduced here only a few sample spectra of the two objects. The *JHK* spectra of V838 Mon on 2 May 2002 are shown in Fig. 1. Line identification was done on the basis of available *JHK* spectral catalogs - for e.g. those compiled by Meyer et al. (1998), Wallace & Hinkle (1997) and Lancon & Roca-Volmerange (1992). The *J* and *H* bands do not show any prominent features. In the *J* Band, only Paschen beta at 1.2818 μm is seen weakly. The *H* band spectra show the second overtone ^{12}CO ($\Delta\nu = 3$) bands - although weakly. The spectra in the *H* band, in general, resemble those of later M type giant stars, but not completely. The *K* band spectrum of V838 Mon is interesting - one of the most prominent features being the the strong first overtone ^{12}CO bands. The ^{12}CO bands, in general, showed a complex evolution with time. The shape and strength changed considerably at different epochs and an emission component was also seen in the March spectra. The CO bands need to be modeled carefully since such an analysis can determine factors such as the excitation temperature of the different CO components, the isotopic ratio of ^{13}C/^{12}C in V838 Mon and also the kinematics of the ejected matter.

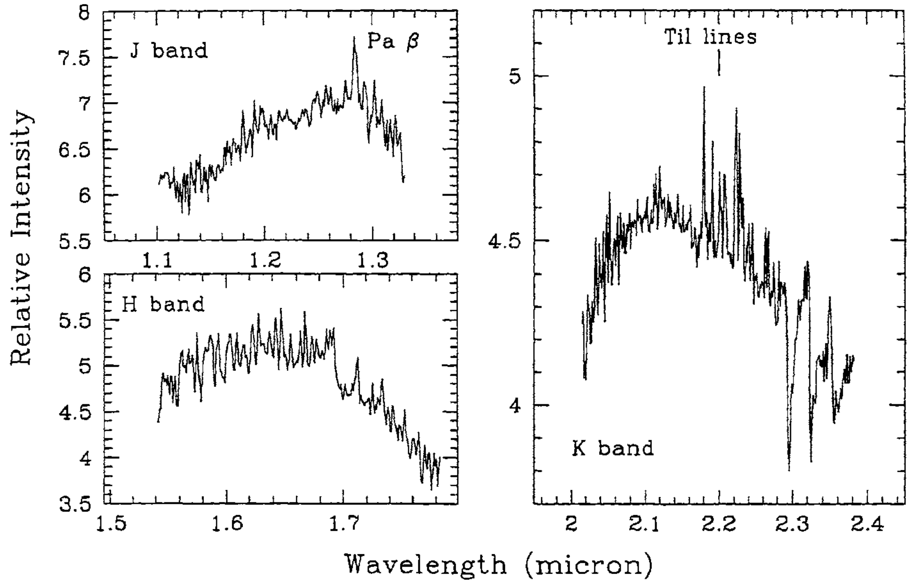

Figure 1. The *JHK* band spectra of V838 Mon on 2 May 2002 are shown. The *K* band spectrum is shown enlarged to clearly show the first overtone ^{12}CO bands and also the several TiI lines that are present.

The interesting features in the spectra of V445 Puppis lie in the *J* and *H* bands. We show in Fig. 2 (right panel) the observed *J* band spectrum for 1 January 2001. Several emission lines are present which appear to be due to neutral Carbon. The identification of the CI lines is done on the basis of laboratory IR spectra of CI as given by Johansson & Litzen (1965) and Johansson (1966). Further we have computed a simple model spectrum that should arise from CI emission from the shell. For this spectrum we have selected the known CI lines, with their transition probabilities, from available atomic line lists. The relative line strengths were computed by assuming thermal equilibrium i.e. a Boltzmann distribution for the level populations. A model computation, for an assumed gas temperature of 8000K, is also shown in Fig 2. The good match between the observed lines and the model spectrum makes the identification of the CI lines fairly reliable. It may be pointed out, that no Hydrogen lines (from the Brackett and Paschen series) were detected in the *JHK* spectra of V445 Puppis as is usually seen in the spectra of classical novae. However Helium lines were seen in the optical spectra (Wagner et al., 2001b).

3.2 TiI lines in V838 Mon

The second striking feature of the *K* band spectrum of V838 Mon is the presence of several emission lines around 2.2 μm. These lines were first visible in early April 2002 and peaked in

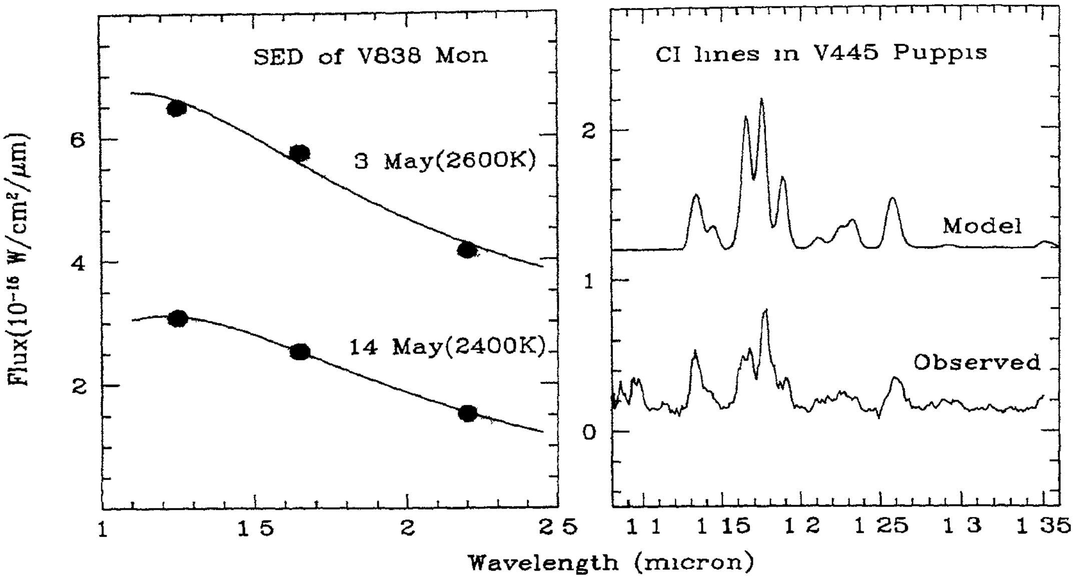

Figure 2 The left panel shows the computed fluxes from V838 Mon on 3 and 14 May 2002 from *JHK* photometry (shown by filled circles) fitted by blackbody curves (bold lines) at temperatures of 2600 and 2400 K The flux for the 14 May data can be read off directly from the graph whereas the 2 May data has been off-set by 2 5 flux units for clarity The *JHK* spectra, represented by the grey lines, are also superposed in the figure The right panel (bottom) shows the observed *J* band spectrum of V445 Puppis on 1 Jan 01 On top is shown a model spectrum simulating the several observed CI lines The Y axis for the right panel is in relative intensity units

strength on May 2002 (Fig 1) These lines have been identified with neutral Titanium (TiI) based on the laboratory spectrum of TiI (Forsberg, 1991) Based on the strength of these lines the mass of the shell has been estimated to be in the range 10^{-7} to 10^{-5} $M_{\odot}$ The shell mass has been computed based on an assumption that the distance to the object is 790pc but recent reports (Bond et al 2003) indicate that the distance may be significantly more The shell mass will accordingly increase as the square of the distance

3.3 Near Infrared photometry of V838 Mon

We use our photometry results to discuss the evolution of V838 Mon as seen from the shape of its near-IR continuum. The observed *JHK* magnitudes on 3 614 May and 14 604 May 2002 (UT) were 5 15 ± 0.14, 4 16 ± 0 15, 3 63 ± 0 14 and 5 43 ± 0 04, 4 43 ± 0 07, 3 72 ± 0 03 respectively A value of $E(B-V) = 0\ 5$ was used to correct the observed fluxes for extinction (Munari et al , 2002a) The broad band *JHK* fluxes from V838 Mon are shown in Fig 2 (left panel) as filled circles These broad band fluxes were fitted by black body curves of 2600 and 2400 K which are seen to fit the data reasonably well for the 3 and 14 May data respectively The overall temporal evolution of V838 Mon since outburst has been towards cooler temperatures. This is confirmed by a large body of photometric data as given by Munari et al. (2002a, b) and also from other reports. We have superposed the *JHK* spectra of 2 and 14 May 2002 in Fig. 2 to bring out the strong dips seen in the spectra between the *J* & *H* and the *H* & *K* bands. The strong absorption bands between the near-IR bands is attributed to water vapor in V838 Mon and such bands are generally seen in the spectra of cool M giants/supergiants.

4. Discussion: The Nature of V838 Mon and V445 Puppis

The nature of V838 Mon is puzzling. Available results show that its post-outburst evolution is to a cool M giant/supergiant. This is not expected in a classical nova where a high temperature is associated with the post-outburst nebular and coronal phase. Munari et al. (2002a) have summarized the other difficulties in classifying it within the existing categories of eruptive variables like classical novae or born-again AGB stars. The closest resemblance of V838 Mon is to a red variable star (M31 RV) that erupted in M31 (Rich et al. 1989) and also the eruptive variable V4332 Sgr (Martini et al. 1999). All three of these objects showed an evolution to a very cool giant/supergiant. Thus V838 Mon, M31 RV and V4332 Sgr may belong to a new genre of astronomical objects. A new mechanism, invoking the merger of 2 stars, has been proposed to explain the outburst of such objects (Soker and Tylenda, 2003). But the several rings seen in the light-echo of V838 Mon show that several mass loss episodes (or eruptions) have taken place earlier and that a single catastrophic event may not explain its outburst (Bond et al., 2003).

The nature of V445 Puppis is also enigmatic. It differs from novae (classical, recurrent or symbiotic) on one or more of the following grounds viz. the low amplitude of the outburst (6.5 mag), the hygrogen deficiency of the spectra, rate of decline of the light curve and lack of previous outbursts. It differs from born-again AGB stars like V605 Aql, FG Sge or Sakurai's object by showing a lack of nebulosity around it. It also differs from V838 Mon type of objects. It doesn't appear to be a RCB or Hydrogen deficient Carbon star. RCB stars show episodic dimming, typically have a F type absortion spectrum and are generally IRAS sources - V445 Pup differs on these counts. It is possible that V445 Pup is a Helium nova. It has been shown that a thermo-nuclear runaway can occur on the surface of a white dwarf accreting helium from its helium rich companion (Kato et al. 1989, Iben and Tutukov 1994). The ejecta of such an outburst, in the Kato et al. (1989) model, is expected to be He/C rich and highly hydrogen-deficient based on the assumed, pre-ignition, chemical composition of the envelope by mass viz $X = 0$, $Y = 0.97$ and $Z = 0.03$. Further, Carbon in the ejecta is expected to be additionally enhanced because Helium burning should create Carbon. The above mechanism, if applicable to V445 Pup, may explain the hydrogen-deficiency and He/C enrichment of its optical and IR spectra. To summarize - the outburst mechanisms of both V838 Mon and V445 Puppis are puzzling and not too well understood. Further observations of these objects should give a better insight into their nature and evolution. However, V445 Puppis is at present enshrouded in a deep dust shell (Ashok and Banerjee, 2003) but V838 Mon is still bright and observable in the infrared.

Acknowledgments

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