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Infrared study of the first identified helium nova V445 Puppis

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Abstract. The eruptive variable V445 Puppis has been proposed by us as the first observed Helium nova. The absence of hydrogen lines in the early optical spectra showed the peculiar nature of this object. We have observed V445 Pup for three months following its discovery at near infrared wavelengths. Our observations confirm the absence of hydrogen lines in V445 Pup and exhibit several prominent emission features. Based on the identification of several CI lines in J and H bands we suggested that V445 Pup is a prospective candidate for theoretically hypothesized Helium nova. Subsequently Kato and Hachisu (2003) have done modeling of its low amplitude light curve in the context of helium nova outburst and show that the observed low amplitude light curve of V445 Pup is reproduced by thermonuclear runaway in helium rich material on a massive white dwarf in a close binary system.

Keywords : stars : individual : V445 Puppis - infrared : stars - stars : novae, cataclysmic variables

1. Introduction

The nova like outburst V445 Puppis was discovered by Kanatsu towards the end of 2000 (Kato and Kanatsu 2000). The early optical spectra brought out the unusual nature of this object as it was extremely deficient in hydrogen (Wagner et al., 2001 a,b). The optical spectra showed that though FeII, CaI, CaII, OI and NaI lines are present the hydrogen lines are conspicuously missing (Fuji 2001; Liller 2001 a,b; Shemmer et.al, 2001). Near-infrared spectra presented here show that Paschen and Brackett series lines from hydrogen are indeed absent. In addition our spectra show that V445 Pup is unusually rich in CI

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emission lines. The deficiency of hydrogen in V445 Pup shows that it is not a conventional nova. Wagner et al., (2001a) have also pointed out on the basis of optical spectra that V445 Pup does not resemble classical FeII type novae, recurrent novae or symbiotic novae. The 3 to 14 μm spectroscopy by Lynch et al., (2001) showed a featureless continuum that deviated considerably from a blackbody flux distribution. A multiple shell model with a range of temperature is able to explain the observed flux distribution.

In the present work the near-infrared spectroscopic results are given that bring out the unique properties of V445 Pup. Based on these unique properties Ashok and Banerjee (2003) suggested that V445 Pup is the first case of observationally identified helium nova. This suggestion has been subsequently supported by Kato and Hachisu (2003) who modeled the slowly decaying optical light curve. Subsequently, recent near-IR observations by Lynch et al., (2004) who report the appearance of HeI lines in emission and optical spectroscopy by Woudt and Steeghs (2004) that show HeI, [OI], [OII] and [OIII] emission lines are in conformity with expected behaviour of increasing ionization level of nova ejecta and further strengthen the case of V445 Pup as the first example of helium nova. These spectra also confirm the extreme hydrogen deficiency of V445 Pup.

2. Observations

Spectra in JHK bands were obtained at the Mt.Abu 1.2m telescope using near-infrared imager/spectrometer with 256 X 256 HgCdTe NICMOS 3 array. The spectral resolution is 1000 and the observations spanned the period January to March 2001. The J and H band spectra display several prominent emission features. The details of the identification of these spectral features with CI lines are described later. A representative set of J and H spectra is shown in Figure 1. The K band spectra are featureless. There is a red ward rise in the continuum of H band spectra starting from 1.65 μm. Photometry was done once during January 2001 and again in November 2001 when the source became accessible after its conjunction with the sun.

3. Results and discussion

The J and H band spectra taken on 2001 January 1 are shown in Figure 1 and 2. The large number of emission lines that are seen have been identified with CI lines. The details of the line identification like wavelength and equivalent widths are described in Ashok and Banerjee (2003). Briefly, the identification of the CI lines was done by comparing the strengths and positions of the observed lines with the laboratory IR spectra of CI as given by Johansson and Litzen (1965) and Johansson (1966). There was a good match between the observed and laboratory spectra. To further confirm that the observed emission lines are due to CI we computed a simple model spectrum arising from CI emission from a shell. The strongest 170 transitions of CI between 1.08 and 2.5 μm with their transition probabilities were taken from the list of Kurucz. Assuming that the number density of CI lines in the excited state is same for all the transitions the line intensities were calculated

using the transition probabilities. The model spectrum was calculated by representing the shapes of individual lines by a Gaussian profile with 1500 km s^{-1} a typical value for the observed individual isolated lines. All the Gaussian profiles were co-added to give a model spectrum. The model spectrum along with the observed spectrum of 2001 Jan. 1 shown in Figure 1 brings out the good matching between the two and thus makes the line identifications more secure. Similar calculations of model spectra for H and K bands have shown good match with the observed spectra. The model reproduces the strong line at 1.69 μm and does not show any line with significant strength in K band consistent with our observations.

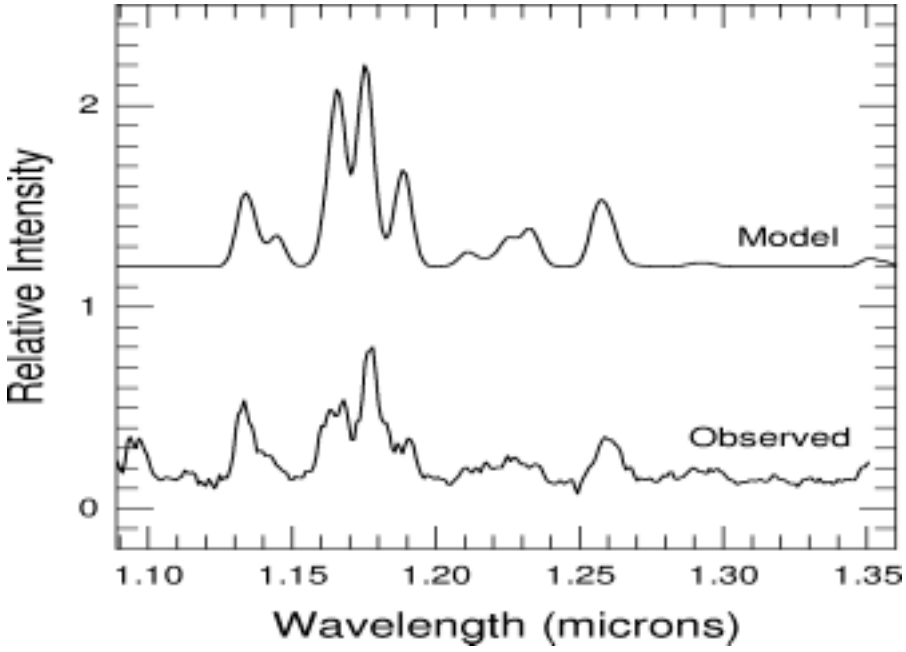

Figure 1. The observed J band spectrum of 1 January 2001 compared with the model spectrum.

The unusual properties of V445 Pup rule out its identification with classical nova, recurrent nova and symbiotic nova. We also rule out the possibility of V445 Pup being a born again asymptotic joint branch (AGB) star as it does not display Hα nebulosity seen in the case of 3 known examples of born-again AGB stars in our galaxy and its faster time scale of brightening.

As our J and H band spectra of V445 Pup showed large number of CI spectral features we considered whether it belongs to R Corona Borealis (RCB) or hydrogen deficient carbon (HdC) stars. The irregular fading followed by slow recovery to original brightness over next few months is characteristic property of RCB stars apart from being over abundant in carbon. They are typically F supergiants with IR excess characterized

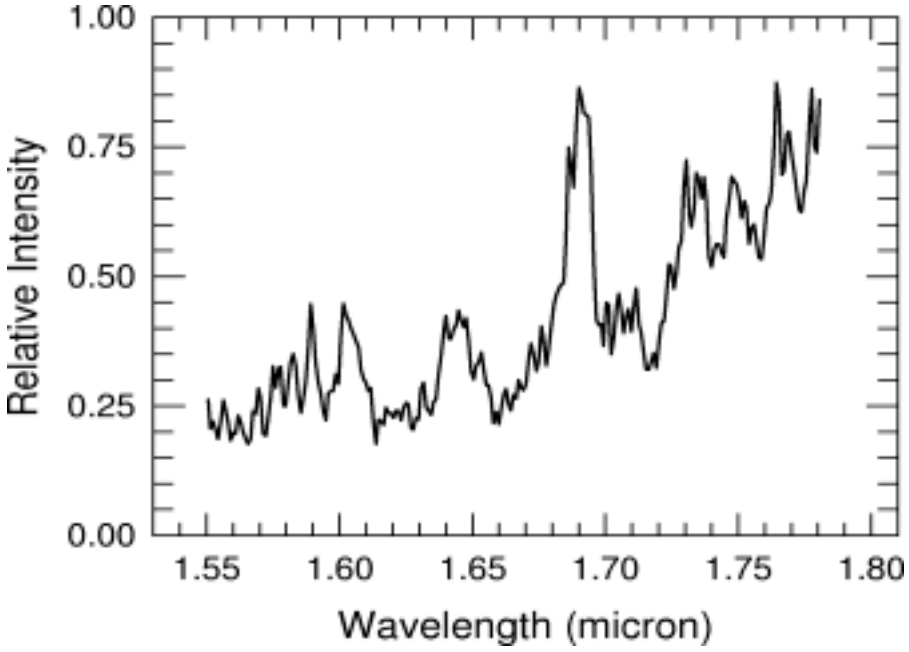

Figure 2. The H band spectrum of 1 January 2001 showing CI emission features.

by IRAS detections. HdC stars are similar to RCB stars but do not show irregular episodic fadings. As V445 Pup was not detected by IRAS and is also under luminous with $M_V \sim 0$ to be a supergiant, it does not belong to this group of carbon rich stars.

The above discussion brings out the difficulty of classifying V445 Pup in known categories of eruptive variables or carbon rich stars. The case of Helium novae has been discussed in the literature for last 15 years or so (e.g., Kato et al., 1989 and Iben and Tutukov 1994). Kato et.al., (1989) have shown that for appropriate mass accretion rate of helium rich material on white dwarf in a close binary system, runaway thermonuclear reactions can get initiated leading to a Helium nova outburst. Such an outburst results in nova ejecta rich in helium and carbon and highly deficient in hydrogen. The near-IR spectra of V445 presented here show the deficiency of hydrogen presence of large number of strong CI emission lines. The carbon lines are also seen with significant strength in optical spectra as well (Kamath and Anupama 2002). Although the HeI lines are not present in our near-IR spectra they are seen in optical spectra taken soon after the outburst. On the basis of these observational facts we suggested that Helium nova scenario is applicable to V445 Puppis (Ashok and Banerjee 2003)

Subsequently Kato and Hachisu (2003) have calculated the theoretical light curves of helium novae for a range of white dwarf masses and mass accretion rates, and are able to reproduce the observed slowly evolving low amplitude outburst light curve of

V445 Puppis. These calculations indicate that our suggestion of being the first identified Helium nova is well supported by theoretical considerations.

The near spectra of V445 Pup taken in early 2004 by Lynch et.al (2004) show presence of only HeI lines, the 1.08 μm line being exceptionally strong. The optical spectra by Woudt and Steeghs (2004) show presence of HeI, [OI], [OII] and [OIII] lines indicating the increased ionization conditions expected in the expanding nova ejecta. The continued monitoring of V445 Pup at infrared and optical wavelengths in the coming years will provide important clues to understand the temporal evolution helium nova.

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