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How peculiar is the 'peculiar variable' DZ Crucis (Nova Cru 2003)?

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ABSTRACT

The variable star DZ Cru was thought to be a nova when it was discovered in eruption in 2003 August. This explanation was later challenged, however, when the first spectra of the object were reported. We present near-infrared spectroscopy of DZ Cru obtained at the New Technology Telescope on three occasions, starting ~1.5 yr after outburst, with the aim of establishing the nature of the object. The spectra display H I, O I, [N I] emission lines, together with He I P Cygni lines superposed on a dust continuum. These observations suggest the 'peculiar variable in Crux' is a classical nova.

Key words: circumstellar matter – novae, cataclysmic variables.

1 INTRODUCTION

The 'peculiar variable' DZ Cru (Della Valle et al. 2003) was discovered in outburst in 2003 August (Tabur & Monard 2003). The object was assumed to be a nova at that time, but a spectroscopic observation reported shortly after suggested other possible interpretations (Della Valle et al. 2003). Perhaps the most intriguing is the suggestion that DZ Cru is similar to the eruptive variable V838 Mon (Corradi & Munari 2007). No further observations of DZ Cru have been reported, despite this possibility, and the nature of the object has remained uncertain.

V838 Mon showed an extraordinary outburst in early 2002 and has confounded all explanation and classification. It too was assumed to be a nova when it was discovered (Brown et al. 2002), but its light curve showed more than one peak and its spectra lacked many of the lines observed in novae near maximum light (Munari et al. 2002; Crause et al. 2003). Instead V838 Mon showed lines of neutral and singly ionized metals forming in a moderate velocity stellar wind (Kipper et al. 2004; Rushton et al. 2005).

In the post-outburst phase, V838 Mon developed strong molecular absorption bands before stabilizing as an 'L supergiant' (Evans et al. 2003a). In contrast, novae show increasing levels of excitation, developing nebular, auroral and sometimes even coronal lines (Warner 2008). Thus, an object like V838 Mon is unlikely to be mistaken for a nova during and after decline. In this paper, we present near-infrared (near-IR) spectroscopy of DZ Cru obtained ~1.5–1.9 yr post-eruption, in order to establish the nature of the object.

2 DZ CRU

On 2003 August 20 UT, JD 245 2872, Tabur announced the discovery of a possible nova in Crux (hereafter DZ Cru RA = $12^{\mathrm{h}}23^{\mathrm{m}}16\overset{\mathrm{s}}{.}2$, Dec. = $-60°22'34''$ J2000; Tabur & Monard 2003). The visual light curve of DZ Cru, compiled by magnitude estimates posted on the Variable Star Network (VSNET)[1] and published in International Astronomical Union circulars, is shown in Fig. 1. We assume maximum light (t_0) occurred on 2003 August 20 UT, JD 245 2872, the date the outburst was first detected. The object was at least 2 mag fainter only two days previous (Tabur & Monard 2003).

Prediscovery images taken by Tabur, which date back to 2000 January, do not show an object at the position of DZ Cru, although the outbursting star may be close to the limiting magnitude of the CCD ($V = 11.9$) on 2003 August 18 UT, JD 245 2870 (shown as an upper limit in the figure). Palomar Sky Survey plates also show no object at this position (Tabur & Monard 2003). Thus, the amplitude of the outburst is $\Delta V > 10$, as expected for a fast, or a moderate speed, classical nova (Warner 2008).

At the time of its discovery, DZ Cru had a visual magnitude of $V = 10.2$. CCD observations taken in poor conditions a day later showed the 'possible nova' at its peak observed brightness: $V = 9.2$. By the following day it had become a magnitude fainter, and a further drop in brightness of $\Delta V > 2$ mag began a week later, at a rate expected for a fast nova: 0.3 mag d^{-1} (Warner 2008). On 2003 September 18 UT, JD 245 2901 ($t = 29$ d), the visual magnitude of the object was $V > 12.1$. A final, unsuccessful attempt to detect DZ Cru was made on 2003 September 22 UT, JD 245 2904 ($t = 32$ d), when the object was fainter than $V = 11.9$.

Optical spectroscopy of DZ Cru was obtained by Bond (2003) on 2003 August 21 UT, JD 245 2873 and Della Valle et al. (2003) on 2003 August 22 UT, JD 245 2874. No other spectra of DZ Cru have been reported hitherto. Bond (2003) and Della Valle et al. (2003) reported Hα and Hβ P Cygni lines, with weak emission components. According to Della Valle et al. (2003), however, the spectrum showed few other signatures of a classical nova. The expansion

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[1] http://www.kusastro.kyoto-u.ac.jp/vsnet/

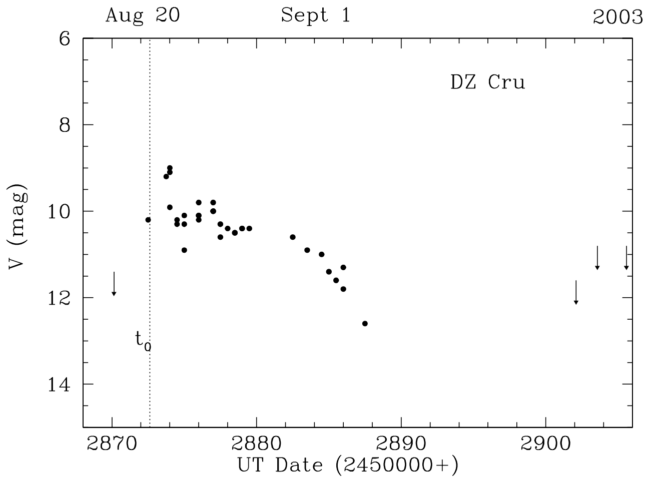

Figure 1. Visual light curve of DZ Cru based on estimates compiled by VSNET, Tabur & Monard (2003), Souza, Aguiar & Pearce (2003) and Liller et al. (2003). *Arrows* denote upper limits. We assume 2003 August 20 UT (JD 245 1872) to be the date of maximum light (t_0). The spectra reported here were obtained ∼1.5–1.9 yr after outburst, and well outside the time-interval shown.

velocity was found to be ∼500 km s^{-1} from the P Cygni lines, a value not expected for a fast nova (∼800–2500 km s^{-1}; Warner 2008). DZ Cru also appeared too red to be a nova. The *B*-band magnitude on 2002 August 22 UT, JD 245 2874, is $B = 11.16 \pm 0.05$ (Liller et al. 2003), giving a $B - V$ index of $+1.25 \pm 0.05$; if DZ Cru is a nova one would expect $(B - V) = +0.23 \pm 0.05$ at t_0 (van den Bergh & Younger 1987). These peculiarities led to speculation the 'peculiar variable in Crux' may be a 'V838 Mon type object', or may be experiencing a very late thermal pulse (VLTP) (Della Valle et al. 2003).

3 OBSERVATIONS

Near-IR spectroscopy of DZ Cru was obtained on three occasions at European Southern Observatory's (ESO's) New Technology Telescope (NTT), La Silla, in a five month period starting ∼ 1.5 yr after outburst. An observing log is shown in Table 1. The observations employed the Son OF Isaac (SOFI) IR spectrograph and imaging camera (Lidman & Cuby 2002), with the blue and red low-resolution grisms, and a 0.6 arcsec slit. The wavelength coverage on each occasion is 0.95–2.52 μm. The resolving power is $R \sim 1000$.

The data were obtained in nod-on-slit mode, and sky emission lines were removed by subtracting off-source spectra from on-source spectra. Atmospheric absorption was eliminated to a large extent by dividing the sky-subtracted spectra by spectra of the standard stars listed in Table 1. In order to maximize cancellation of telluric lines, atmospheric absorption features in the calibration stars were used to realign the wavelength axis of the target spectra prior to division. The hydrogen absorption lines in the standards were manually snipped out of the data to avoid spurious emission in the ratioed spectra. Flux calibration was accomplished by multiplying the ratioed spectra by the spectrum of a blackbody with appropriate effective temperature for the calibration star. The uncertainties in the fluxes are ∼10–20 per cent. Wavelength calibration was achieved from Xenon arc spectra, and is accurate to ±0.003 μm (1σ). In spectral regions with good transmission, the signal-to-noise ratio of the data is ∼200 in the first two observations and ∼50 in the final observation.

4 RESULTS

Fig. 2 shows the evolution of the near-IR spectrum of DZ Cru between 2005 February 16 UT, JD 245 3417, and 2005 July 22 UT, JD 245 3574 ($t \sim 544$ to 701 d). Data are not shown in the ∼1.34–1.50 and ∼1.80–1.95 μm ranges, owing to poor telluric cancellation in those regions. Fig. 3 displays the same spectra expanded in the blue (∼0.95–1.33 μ m) and red (∼1.56–2.40 μ m) regions to show spectral lines clearly. Approximate *JHK* magnitudes of DZ Cru, derived by convolving the spectra with the relevant band profile, are given in Table 1.

The near-IR spectrum of DZ Cru shows an emission-line spectrum superposed on a dust continuum on all dates of observation. Table 2 lists observed wavelengths, proposed identifications, full width at half-maximum (FWHM) and integrated fluxes of most spectral lines in the data. The spectra contain resolved Paβ, γ, δ, ϵ and weak Brγ emissions, along with higher order ($n \gtrsim 12$) hydrogen Brackett lines. Blends of He I ^{3}S–^{3}P^0 lines at 1.08321, 1.08332 and 1.08333 μm (van Hoof 2006) give rise to the most prominent spectral line, which clearly displays a P Cygni type profile. The identification with helium is secured by the presence (on 2005 February 16 at least) of the ^{1}S–^{1}P^0 He I singlet at 2.058 μm, the only other spectral line with a P Cygni profile. The forbidden [N I]^{2}D^0 − ^{2}P^0 doublet at 1.040 μm and the allowed O I ^{3}P—^{3}S^0 triplet at 1.316 μm are likely identifications of the remaining features.

The mean expansion velocities deduced from deconvolved FWHM of the H I lines are constant over the course of observation; they are 527 ± 109 km s^{-1} (2005 February 15), 496 ± 50 km s^{-1}

Table 1. Observing log.

UT Date	JD[a]	Age[b] (d)	Exposure (s)	Flux std	Airmass[c] (Target)	Airmass[c] (Standard)	*J*[d]	*H*[d]	*K*[d]
2005 February 16	3417	544	151	HIP037732 (G1 V)	1.23	1.19	13.8	11.5	9.7
2005 June 16	3538	665	480	HIP062871 (G0 V)	1.17	1.18	14.1	12.2	10.4
2005 July 22	3574	701	480	HIP92233 (F8 V)	1.59	1.56	14.2	12.5	11.0

All observations were conducted at the NTT using SOFI and a 0.6 arcsec slit.
Resolving power is $R \sim 1000$ on each occasion.
[a] JD – 245 0000.
[b] 2003 August 20 UT, JD 245 2872 is taken as t_0.
[c] Airmass near mid-point of each set of observations.
[d] Approximate magnitude. Deduced by convolving the spectra with the relevant band profile.

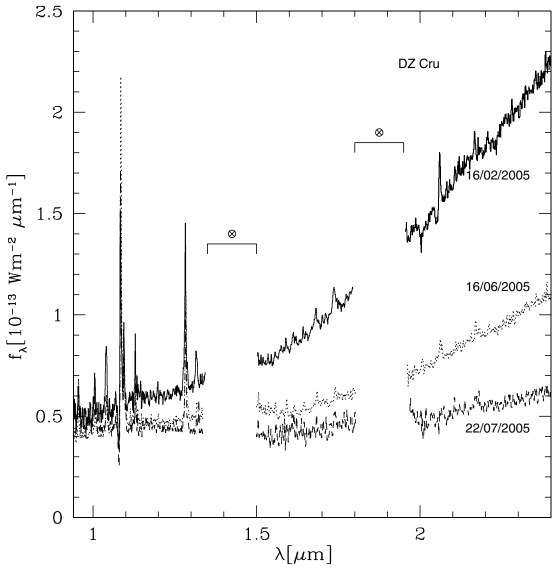

Figure 2. NTT time-series spectra of DZ Cru in the *JHK* bands (0.95–2.52 μm), spanning from 2005 February 16 to 2005 July 22 UT (∼1.5–2 yr from maximum brightness). Gaps in the data in the ∼1.34–1.50 and ∼1.80–1.95 μm regions are owing to strong absorption from terrestrial H_2O. Identifications of the spectral lines are given in Fig. 3. Date format is DD/MM/YY.

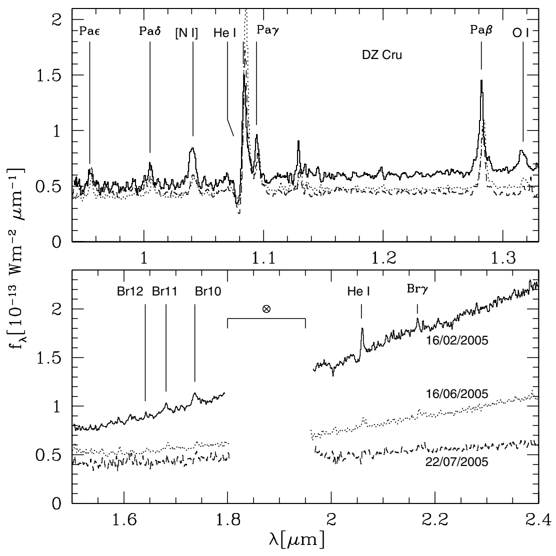

Figure 3. Enlargement of the near-IR spectra of DZ Cru shown in Fig. 2, with the individual spectral features identified. Br10, Br11 and Br12 are hydrogen Brackett lines labelled with their upper level quantum numbers. Date format is DD/MM/YY.

(2005 June 16) and 462 ± 35 km s^{-1} (2005 July 22), in agreement with outflow velocities reported by Della Valle et al. (2003) near t_0. The expansion velocity determined from Brγ is lower on all dates (Table 2). This line is swapped by the thermal continuum, and was not used in calculating the mean. The He I P Cygni lines indicate mean expansion velocities of ∼1500 km s^{-1}; weak emission components are seen in H I at this velocity (see Fig. 4) – similar line profiles were observed in the nova V2487 Oph (Lynch et al. 2000).

The most notable changes that occurred over the course of our observations are an increase in the strength of the He I 1.083 μm emission component, and a sharp decrease in the *K*-band flux. The evolution of the He I 1.083 μm line is similar to its development in nova PW Vul (Williams, Longmore & Geballe 1996). Williams et al. (1996) attributed the behaviour to the hardening radiation field from the central source and its effect on the He I 2^3S–2^3P collisional cross-section. For electron temperatures in the range of $T_e = 5000$–20 000 K, the cross-section varies as $T_e^{1.26}$.

The decline in the *K*-band flux is presumably owing to dispersal and cooling of the dust over the ∼157-d interval of observation. We find the dust temperatures T_d by fitting the dust continuum with $B(\lambda, T_d)\lambda^{-\beta}$, where B is the Planck function at temperature T_d and β is the emissivity index, which depends on the nature of the dust; for amorphous carbon $\beta \simeq 1$ (Mennella et al. 1998). We find dust temperatures of $T_d = 690 \pm 40$ K (February) and $T_d = 620 \pm 50$ K (June), where the uncertainty is owing to the limited wavelength range of the data.

5 THE NATURE OF DZ CRU

There are a number of possible explanations for the outburst of DZ Cru. We address each in turn.

5.1 A V838 Mon type event?

This is referring to the eruption of V838 Mon in early 2002. The object is perhaps best known for a spectacular light echo that developed around the star shortly after its discovery (Bond et al. 2003). It is thought V838 Mon belongs to a new class of eruptive variable, along with M31 RV (Rich et al. 1989), V4332 Sgr (Martini et al. 1999) and M85 OT2006-1 (Rau et al. 2007), although the latter has been interpreted as a low-luminosity Type II plateau supernova (Pastorello et al. 2007).

Our near-IR spectra of DZ Cru bear no resemblance whatsoever to those of V838 Mon ∼1.5–2 yr after its outburst, nor to those observed at any stage in the evolution of the object. By that time V838 Mon had stabilized somewhat as a very cool supergiant, with a near-IR spectrum dominated by strong molecular bands of H_2O, CO and metal oxides (Evans et al. 2003a). V838 Mon did not show high excitation He I lines, nor did it display outflow velocities greater than ∼500 km s^{-1} (Kipper et al. 2004). Thus, we conclude that the outburst of DZ Cru is unlikely to have been a V838 Mon type event.

5.2 A born-again asymptotic giant branch?

The central stars of planetary nebulae may experience a VLTP, resulting in a dramatic brightening of the star. They are known as ‘born-again giants’ because they retrace their evolution towards the region of the Hertzsprung–Russell (HR) diagram occupied by the asymptotic giant branch (AGB) stars and repeat their post-AGB evolution. The eruptions of V605 Aql in 1919 (Lechner & Kimeswenger 2004) and Sakurai’s Object in 1996 (Evans & Smalley 2002) have been attributed to VLTPs.

The photometric behaviour of DZ Cru is unlike that of Sakurai’s Object, the best-studied born-again giant: the amplitude of the outburst of DZ Cru is at least $\Delta V \simeq 5$ mag larger, and the time it took to attain maximum light is much shorter: $\lesssim 2$ d as opposed to ∼1 yr. The light curve of Sakurai’s Object has been interpreted in terms of a slowly expanding photosphere (Duerbeck 2002). Its spectral evolution suggested a rapidly cooling star, and deep molecular absorption bands developed shortly after maximum light (Eyres et al. 1999). Unlike DZ Cru, no emission lines, or P Cygni profiles were observed after more than 2 yr since outburst.

Table 2. DZ Cru linelist. Date format is DD/MM/YY.

Observed λ^a	Identification	FWHM^{b,c}			Flux^b		
(μm)		(km s^{-1})			(10^{-16} W m^{-2})		
2005 February 16		2005 February 16	2005 June 16	2005 July 22	2005 February 16	2005 June 16	2005 July 22
0.9554	H I Paϵ 0.9549	990	1048	1011	0.49 ± 0.04	0.60 ± 0.03	0.46 ± 0.02
1.0054	H I Paδ 1.0052	872	1095	831	0.53 ± 0.04	0.38 ± 0.02	0.92 ± 0.06
1.0405	[N I] 1.0401	1568	1738	–	1.72 ± 0.09	0.92 ± 0.03	–
–^{d}	He I 1.0833	–	–	–	–	–	–
1.0944	H I Paγ 1.0941	885	1048	889	1.43 ± 0.04	1.51 ± 0.03	1.56 ± 0.05
1.2824	H I Paβ 1.2822	1008	1055	961	2.45 ± 0.21	2.29 ± 0.33	2.13 ± 0.24
1.3163	O I 1.3168	1437	1042	–	0.90 ± 0.05	0.40 ± 0.02	–
1.6811	H I Br11 1.6811	1047	836	–	0.51 ± 0.04	0.40 ± 0.02	–
1.7369	H I Br10 1.7367	1519	869	–	0.98 ± 0.03	0.33 ± 0.02	–
–^{d}	He I 2.0587	–	–	–	–	–	–
2.1667	H I Brγ 2.1661	477	554	–	0.47 ± 0.04	0.46 ± 0.02	–

[a] For the spectrum obtained on 2005 February 16. No significant shift had occurred by the later dates.
[b] Deconvolved for instrumental profile and deduced from gaussian fitting.
[c] Uncertainty $\sim\pm150$ km s^{-1}.
[d] P Cygni type profile.

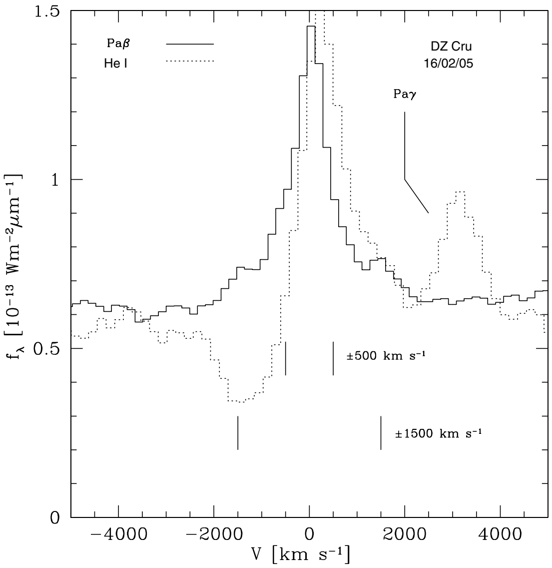

Figure 4. Close up of the Paβ line in DZ Cru on 2005 February 16 (*solid*), showing the line structure, which is similar on all dates of observation. The helium line at 1.083 μm from the same spectrum is shown for comparison (*dotted*). The emission feature redward of the He I line is Paγ.

During a VLTP convection in the region surrounding the helium, shell leads to mixing and changes in the chemical abundances. This process renders born-again giants hydrogen-deficient and C-rich (Herwig 2005). Consequently, they display weaker H I lines than stars with similar effective temperature. Thus, strong hydrogen lines, such as those present in the spectrum of DZ Cru, are not expected in a born-again giant. We conclude this explanation is unlikely.

5.3 A nova type object?

The spectra presented here leave us in no doubt DZ Cru is a nova, for H I, He I, [N I] and O I lines appear in their near-IR spectra (e.g. Evans et al. 2003b; Rudy et al. 2003; Lynch et al. 2004; Venturini et al. 2004; Lynch et al. 2006), and extensive dust shells are known to have formed around some novae (Evans & Rawlings 2008). Furthermore, the outflow velocities in DZ Cru are within the range shown by novae (Warner 2008).

Principal ejection velocities in novae range from $\sim$500 to $\sim$2500 km s^{-1} depending on speed class. For DZ Cru, this velocity is $\sim$500 km s^{-1} (Della Valle et al. 2003). As we noted above, the outburst amplitude and decline rate suggest a fast nova, and the principal velocities of such objects are $\sim$800–2500 km s^{-1} (Warner 2008). This discrepancy suggests that the object is deviating from the expansion velocity-rate of decline relationship of classical novae. However, DZ Cru is not alone in showing this behaviour: QU Vul (Rosino et al. 1992), V838 Her (Harrison & Stringfellow 1994) and V2487 Oph (Lynch et al. 2000) are just three other examples.

DZ Cru shows two outflows in our data: one at the principal velocity and a second at $\sim$1500 km s^{-1}. The fast outflow – unreported near t_0 – is likely to have emerged in the decline phase, when multiple velocity components appear in the spectral lines of novae (Warner 2008). A similar situation was observed in V723 Cas several hundred days after t_0, when this slow nova showed hydrogen emission lines indicating an outflow velocity of $\sim$300 km s^{-1} and He I P Cygni lines indicating an outflow velocity of $\sim$1500 km s^{-1} (Evans et al. 2003b). There are some major differences between DZ Cru and V723 Cas, however: whereas DZ Cru was dusty and non-coronal, V723 Cas was dust-free and strongly coronal. The absence of dust in V723 Cas could be related to its coronal behaviour. Novae that show a coronal phase are generally poor dust producers (Evans & Rawlings 2008).

The only unresolved problem is the colour of DZ Cru on $t = 2$ d [$(B - V) = +1.25 \pm 0.05$], which is 1.02 ± 0.08 mag redder than intrinsic colours of classical novae at t_0 (van den Bergh & Younger 1987). The colour of DZ Cru is affected by an unknown amount of interstellar reddening, however, and we need to account for this before making a comparison with the intrinsic colours of novae. According to the relevant extinction curve in Marshall et al. (2006), the reddening rises rapidly with distance along the line of sight towards DZ Cru (see Section 6). It is probably the unusual colour near t_0 is owing to heavy interstellar reddening in this direction; if so, the distance to DZ Cru is $d \gtrsim 7$ kpc.

6 DISTANCE

Absolute magnitudes of classical novae can be found from the magnitude at maximum ($M_V^{\max}$) rate of decline (MMRD) relationship which states $M_V^{\max}$ is linearly proportional to the logarithm of the time taken t_2 to decline by $\Delta V = 2$ mag from t_0 (Warner 2008). From the light curve (Fig. 1), we find $t_2 = 15$ d. We note that there is a spike in the light curve on $t = 1$ d; this could be owing to a flare, which is thought to arise from wind interactions, or variations in the mass loss, and is a common phenomenon in slow novae, e.g. HR Del (Drechsel et al. 1977), V1548 Aql (Kato & Takamizawa 2001) and V723 Cas (Munari et al. 1996). The most recent calibration of the $M_V^{\max}$–t_2 relation is: $M_{\rm V}^{\max} = (-11.32 \pm 0.44) + (2.55 \pm 0.32)$ log (t_2) (Downes & Duerbeck 2000), where t_2 is in days. We obtain $M_V^{\max} = -8.3 \pm 0.5$ mag, which is bright for a nova with a principal velocity of $\sim$500 km s^{-1}, as this velocity implies a longer decline time.

In order to determine the distance to the nova from this result, we need the interstellar extinction along the line of sight in the visual. The Galactic coordinates of DZ Cru are $l = 299^{\circ}\!.45$, $b = +2^{\circ}\!.31$. According to dust maps in Schlegel, Finkbeiner & Davis (1998), the total extinction along this line of sight is $A_V = 3.6$, which agrees with results in Marshall et al. (2006), showing that A_V rises linearly beyond $d = 3$ kpc, reaching $A_V = 3.4 \pm 0.3$ at $d = 8.02 \pm 1.33$ kpc. Assuming this value for the extinction, we obtain a distance to DZ Cru of $d = 10.5 \pm 2.8$ kpc with $M_V^{\max} = -8.3 \pm 0.5$ mag. A similarly large distance is found from the relation which states all novae have similar absolute magnitudes (-6.05 ± 0.44 mag) near $t \sim 15$ d (Downes & Duerbeck 2000): $d = 11.1 \pm 2.8$ kpc.

In view of the discrepancy between t_2 and the principal velocity, the distance may be poorly determined from the light curve. As an alternative, we estimate the distance to DZ Cru from the t_2 implied by its principal velocity, while being mindful of the lower extinction for distances of $d < 8$ kpc in the direction of the object. Fitting the Marshall et al. (2006) extinction curve towards DZ Cru with a straight line using the FITEXY routine (Press et al. 1992), we find A_V increases by 0.40 ± 0.03 mag kpc^{-1}. From the expansion velocity-rate of decline relationship of classical novae (Warner 2008), we find $t_2 = 55$ d for a principal velocity of 500 km s^{-1}. This result leads to $M_V^{\max} = -6.9 \pm 0.5$ mag from the MMRD. Assuming the extinction gradient above, the distance is then $d = 7.3$ kpc. This nearer estimate is still consistent with the lower limit implied by the reddening. Thus, we have possible distances of $d \sim 7$–12 kpc. As a compromise, we adopt $d = 9$ kpc, and assume this distance throughout the remainder of this paper.

7 DISCUSSION

Now the nature and distance are determined, we are in a position to estimate the dust mass $M_{\rm d}$. If we assume the dust shell is optically thin in the IR, and dominated by amorphous carbon (Mennella et al. 1998), then $M_{\rm d}$ (in M$_\odot$) can be found from

$$M_{\rm d} \simeq 6.8 \times 10^{11} f_\lambda d_{\rm kpc}^2 \lambda / B(\lambda, T_{\rm d}),$$

where f_λ is the flux density in Wm^{-2} μm^{-1}, λ is wavelength in μm and $d_{\rm kpc}$ is the distance in kpc. We use the K-band magnitude to deduce f_λ (Table 1), as the dust emission is more important at longer wavelengths. We find $M_{\rm d} = 3 \times 10^{-8}$ M$_\odot$ (February) and 5×10^{-8} M$_\odot$ (June). For a canonical gas-to-dust ratio of 100, the total mass ejected is $M_{\rm g} \sim 10^{-6}$ M$_\odot$, although this mass is uncertain, owing to uncertainty in the gas-to-dust ratio. In novae, ratios from 10^1 to 10^4 have been reported (Gehrz et al. 1998).

If we know the electron temperature $T_{\rm e}$ and density $N_{\rm e}$ of the gas, we can calculate its mass from the H I line fluxes. Since the luminosity of Paβ is $L_{{\rm Pa}\beta} = h\nu\alpha_{{\rm Pa}\beta}(N_{\rm e}, T_{\rm e})N_{\rm e}^2 V$, $N_{\rm e}$, in cm^{-3}, can be found from

$$N_{\rm e} \simeq 2.0 \times 10^{21} d_{\rm kpc} \left[\frac{F_{{\rm Pa}\beta} T_{\rm e}}{f(vt)^3}\right]^{\frac{1}{2}},$$

where $F_{{\rm Pa}\beta}$ is the line flux in Wm^{-2}, $T_{\rm e}$ is in 10^4 k, f is the filling factor, v is the velocity of the ejecta in km s^{-1}, t is the time since outburst in days and V is the volume of the emitting region $[= f \frac{4}{3}\pi(vt)^3]$. For the recombination coefficient $\alpha(N_{\rm e}, T_{\rm e})$, we have used the expression

$$\alpha_{{\rm Pa}\beta}(N_{\rm e}, T_{\rm e}) \simeq \frac{1.2 \times 10^{-14}}{T_{\rm e}} \ {\rm cm^3\ s^{-1}},$$

which is an analytical fit to data for case B in Hummer & Storey (1987). Their data cover $T_{\rm e} = 3 \times 10^3$– 3×10^4 K and $N_{\rm e} = 10^2$–10^{10} cm^{-3}. This expression gives a reasonable approximation of all $\alpha_{{\rm Pa}\beta}(N_{\rm e}, T_{\rm e})$ in Hummer & Storey (1987). For $T_{\rm e} = 10^4$ K, $N_{\rm e} = 2 \times 10^6 f^{-1/2}$ cm^{-3}.

Since $M_{\rm g} = N_{\rm e}\mu m_{\rm H}\, V$, the mass of the ejected shell, in M$_\odot$, can be found from

$$M_{\rm g} \simeq 8.1 \times 10^{15} \frac{\mu d_{\rm kpc}^2 F_{{\rm Pa}\beta} T_{\rm e}}{N_{\rm e}},$$

where μ is the mean molecular weight and $m_{\rm H}$ is the mass of a hydrogen atom. Assuming $\mu = 1.5$, we deduce a gas mass of $M_{\rm g} = 1 \times 10^{-4} f^{1/2}$ M$_\odot$. In novae filling factors as low as $f \sim 10^{-4}$ have been calculated (Gehrz et al. 1998). Thus, we derive $M_{\rm g} = 10^{-6}$–10^{-4} M$_\odot$. This result is consistent with the masses ejected by novae, and further supports our interpretation of DZ Cru.

8 CONCLUSIONS

In this paper, we presented near-IR spectra of DZ Cru obtained $\sim$1.5–1.9 yr post-eruption. This star was thought to be a nova when it was discovered in outburst in 2003 August, but optical spectroscopy reported a few days later suggested otherwise. Since then the 'peculiar variable' has been thought to be a V838 Mon type object, or a born-again giant. Our spectra however, show beyond all doubt, DZ Cru is a classical nova. They display many of the usual signatures of classical novae (H I, O I and [N I] emission lines) and He I P Cygni lines, indicating outflow speeds of $\sim$1500 km s^{-1}. Further, the level of the continuum increases with increasing wavelength, owing to emission by dust. As expected for a classical nova, the total mass ejected in the eruption is $\sim 10^{-6}$–10^{-4} M$_\odot$.

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