DT Serpentis: neither a symbiotic star nor a planetary nebula associate

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ABSTRACT
We present an alternative interpretation for the putative symbiotic star DT Serpentis, and its proposed planetary nebula (PN), recently announced by Munari et al. Our analysis is based on their data combined with additional archival data trawled from Virtual Observatory databases. We show that the star known as DT Ser is not a symbiotic star, and is merely superposed on the newly discovered but unrelated background PN. There is no evidence for any periodic variability for DT Ser as expected for a symbiotic star. We further establish that there is no physical association between DT Ser and the PN, which has a considerably higher extinction, befitting the larger distance we estimate. The significantly different radial velocities of the star and nebula also likely preclude any association. Finally, we show that the mid-infrared source detected by the IRAS and WISE surveys is actually coincident with the PN so there is no evidence for DT Ser being a dusty post-AGB star.

Key words: planetary nebulae. general – planetary nebulae. individual – symbiotic stars – surveys

1 INTRODUCTION
In this paper we suggest an alternative interpretation for the proposed association between a newly discovered planetary nebula (PN) and the “known” symbiotic star DT Serpentis recently announced by Munari et al. (2013, hereafter MC13). As discussed in their paper, the apparent connection of a symbiotic star in around planetary nebula, closely associated with a potential post-AGB star, would be a unique occurrence, and this led us to more closely investigate this very interesting association. Our new interpretation is based solely on the data presented by MC13, combined with multi-wavelength data trawled from Virtual Observatory databases. As the new PN does not appear to have a common name, we designate it as MCS 1, after the first three authors of MC13. This paper is arranged as follows: in \S2 we describe the archival data used, and in \S3 we assess the nature of DT Ser and the evidence for its variability. We provide a discussion of the PN, its distance and properties in \S4 and present our conclusions in \S5.

2 ARCHIVAL DATA
To supplement the spectroscopic and photometric data presented by MC13, we searched for archival multi-wavelength data for DT Ser and MCS 1 using a range of online tools (e.g. Frew et al. 2011). We interrogated the Aladin Sky Atlas, the SIMBAD database, the Vizier service\textsuperscript{1}, the SkyView Virtual Observatory\textsuperscript{2}, the NASA/IPAC Infrared Science Archive\textsuperscript{3} and SkyDOT\textsuperscript{4} (Sky Database for Objects in Time-Domain). Aperture photometry of the low resolution narrowband H\alpha (+ [N II]) image from the Southern H-Alpha Sky Survey Atlas (SHASSA) (Gaustad et al. 2001) provided the integrated H\alpha flux of the nebula. Multi-wavelength broadband images and data were also obtained from the Galaxy Evolution Explorer (GALEX) survey (Morrissey et al. 2007), the SuperCOSMOS Sky Survey (SSS; Hambly et al. 2001), the Two Micron All Sky Survey (2MASS; Skrutskie et al. 2006), and the Wide-Field Infrared Survey Explorer (WISE; Wright et al. 2010) Survey. Additional photometry for DT Ser were retrieved from the VizieR service, or the literature where noted.

3 IS DT SER A SYMBIOTIC STAR?
Symbiotic stars are interacting binary systems, in which an evolved star (usually a red giant) transfers matter onto a hotter, more compact companion star, most typically a white dwarf (Kenyon 1986).
Depending on the relative contributions of the cool star and any dust enveloping the system, they are subdivided into S-type (stellar) and D-type (dusty) systems. A small group of systems containing hotter companion stars (spectral types of F, G and K) are the so-called yellow symbiotic stars; a subset of these showing thermal emission from hot dust are designated D'-type systems (Allen 1982; Belczyński et al. 2000).

Symbiotic stars can show a complex range of photometric variations, depending on the exact orbital parameters and the nature, luminosity, and mass-loss rate of the secondary star. Symbiotic stars are known to show eclipses, ellipsoidal variability or a reflection effect due to orbital motion (mostly S-type and D-type), pulsational variability of the cool component (D-type and S-type), dust obscuration events (D-type), short-period flickering associated with the accretion disk, high- and low-activity states, and rare nova-like outbursts originating from the white dwarf in the system (Mikołajewska 2001; Gromadzki et al. 2009; Gromadzki, Mikołajewska & Soszyński 2013; Angeloni et al. 2014).

### 3.1 Historical Background

DT Ser was originally discovered by Hoffmeister (1949) from photographic plates taken at Sonneberg Observatory, later appearing on the MVS charts (Hoffmeister 1957). The latest edition of the General Catalogue of Variable Stars (GCVS; Samus et al. 2007-2012) gives a photographic (blue) range of 13.2-13.9 mag, based on the analyses of Götz (1957) and Meuninger (1980).

Nebular emission around this star was first noted by Bond (1978) who wrote: “Superposed on an absorption spectrum of about type G0 are [O III] emission lines at 4959–5007 Å. The object appears stellar on the Palomar Sky Survey and at the telescope, with a slightly fainter companion ~5′′ away.” The PN was not noticed in any broad-band imagery, and on this basis Bond suggested the star was probably a symbiotic variable. We follow the nomenclature of MC13 in referring to DT Ser as star A and the fainter companion 5′′ away as star B, which is the ionizing star of MCS 1.

Cieslinski et al. (1997) however, suggested that the symbiotic star is the companion noticed by Bond (1978), in effect transferring the designation DT Ser to the central star, and categorising star A as a field star. Henden & Munari (2001) concurred, further commenting that the old GCVS data refer to the combined light of the two stars. Cieslinski et al. (1997) further suggested DT Ser was a yellow symbiotic star (Schmid & Nüssbauer 1993; Jorissen et al. 2005), some of which are known to have resolved nebulae associated with them (e.g. Schwarz 1991; Van Winckel et al. 1995; Miszalski et al. 2012), so this interpretation seemed feasible. Based on this information, DT Ser was included as a suspected symbiotic star in the catalogue of Belczyński et al. (2000), who commented that the cool component might not be physically associated with the emission-line source. In addition, Carballo, Wesselsus & Whitet (1992) and Kinnunen & Skill (2000) noted the coincidence of an IRAS mid-infrared source with DT Ser. We will assess the nature of DT Ser and the likelihood of a physical association with MCS 1 in the following sections.

### 3.2 Spectral Classification

MC13 determined the spectral type of DT Ser to be F8, with an indeterminate luminosity class. The spectral type is consistent with the older determination of G0e by Bond (1978), however Cieslinski, Steiner & Jablonski (1998) obtained a later spectral type of G2-K0 III–I, noting Balmer, [O III], and He II lines in emission (this classification was adopted by Mürset & Schmid 1999). We carefully examined enlarged reproductions of DT Ser’s spectrum from Figure 3 of MC13 and find the weakness of the G-band and the strength of the Balmer lines to be inconsistent with a type later than mid-G, and take at face value the F8 spectral type. From the complete absence of the luminosity sensitive Sr II λ4077 line adjacent to Hδ, and the λ4172–79 Å blend of CN, we can clearly exclude a supergiant or bright-giant luminosity (Gray & Corbally 2009) though we cannot differentiate between the luminosity classes III, IV or V. Furthermore, a luminosity class of III–V is also a better fit to the overall strength of the many neutral metal lines in the blue.

Indeed, using high-resolution Echelle spectra, MC13 note only a late-F continuum with no emission lines, and find the centroid of the Balmer, [O III], and He II nebular emission lines to be offset from DT Ser. Thus, the emission lines recorded by Bond (1978) and Cieslinski et al. (1997, 1998) are undoubtedly due to the small PN partly superposed on the image of DT Ser, especially at small plate scales. On the basis of all available spectroscopic data, we assert that neither star A or star B is a bona fide symbiotic star, and that the observed nebular lines seen by earlier workers solely originate in the extended PN.

### 3.3 Photometry

We compiled all reliable survey photometry for DT Ser from the references given in Table I, including several reddening-corrected colour indices. The \( U - B \) colour index is the most useful luminosity diagnostic for F-type stars, as it measures the depth of the Balmer discontinuity which is sensitive to surface gravity (e.g. Bond 1997); supergiants have large Balmer jumps and redder \( U - B \) colours. DT Ser plots close to the main-sequence locus (and well away from the supergiant locus) in the \( B - V \) versus \( U - B \) colour-colour diagram (Johnson & Morgan 1953), providing additional support for a luminosity class of III–V.

To detect any variability from DT Ser, and to further assess its classification as a putative symbiotic star, we combined the \( V \)-band photometric data in MC13 with \( V \)-band magnitudes from the All Sky Automated Survey (ASAS; Pojmanski 1997), and data from the SuperWASP survey (Pollacco et al. 2006), which cover an 11 year period in total. The largest data set of 403 points comes from ASAS, which gives a mean \( V \)-band magnitude of 12.785 ± 0.069 (1-sigma dispersion). We have normalised all three data sets to the ASAS mean magnitude, and the resulting light-curve is presented in Figure 1. Due to the non-uniform data sampling we have adopted a Lomb-Scargle periodicity analysis, and tested for periods as low as one hour. The resulting periodogram, shown in Figure 2, exhibits peaks at one cycle per day and every multiple of one hour periods. This is a consequence of the sampling frequency of the ASAS data and the one day cycle of long-baseline observations and is a natural artefact of the Lomb-Scargle method. The analysis is therefore consistent with no periodic variations for DT Ser. All tested periods over one day (less than one cycle per day) are highlighted in Figure 3. An increase in significance is observed for long periods, which is potentially indicative of some residual systematic noise in the light curves, but entirely consistent with no detected periods of astrophysical nature.

\[ \text{http://www.astrouw.edu.pl/asas/?page=aasc} \]

\[ ^5 \text{A simple guess } a \text{ priori is that the star is a main-sequence object, as F8 giants are located in the Hertzsprung Gap on the HR diagram and are relatively uncommon stars.} \]
DT Serpentis

We also downloaded the ASAS data for all 615 stars detected within 30′ of DT Ser, investigating the root-mean-square (RMS) scatter as a function of V magnitude for each individual star (each has between 50 and 420 independent points). Based on this analysis, DT Ser would be considered constant in brightness down to an amplitude of 0.07 mag, which happens to be the average RMS variation at this magnitude level. This conclusion is consistent with examination of the less precise photometry from The Amateur Sky Survey (TASS-IV; Droge et al. 2006; Richmond 2007), and the AAVSO Photometric All-Sky Survey (APASS; Henden et al. 2012). In addition, J and Ks magnitudes are available from two different surveys, DENIS and 2MASS (Epchtein et al. 1997; Skrutskie et al. 2006), and the magnitudes agree within the uncertainties. The low-precision photographic measurements compiled by Jurdana-Sepic & Munari (2010) also imply constancy within the uncertainties. In summary, we conservatively estimate that any intrinsic variability is less than 0.1 mag, much lower than the photographic range given in the GCVS, which we consider is spurious.

In summary we are unable to detect any periodic behaviour on a time scale of several months to years symptomatic of a symbiotic star. Our optical light-curve also shows no evidence for either eclipses or eruptive events. While the light-curve cannot definitively exclude a symbiotic interpretation as the system could be at an unfavourable inclination, this interpretation is highly unlikely once all of the other observational evidence is taken into account.

With a spectral type of F8, an inferred surface temperature of \(\sim 6100 \text{ K} \) (Cox 2000), and the assumption that the star is on, or near, the main sequence, DT Ser is located in a part of the Hertzsprung-Russell Diagram where intrinsic variability is uncommon (e.g. Eyer & Mowlavi 2008). DT Ser is noticeably cooler than the classical instability strip at this luminosity, so pulsational variability is not expected. A perusal of the literature confirms this, with the \(\delta\) Scuti and \(\gamma\) Doradus stars (e.g. Uytterhoeven et al. 2011) being considerably hotter than DT Ser. However, if DT Ser is shown in the future to have low-level variability, it may either be due to chromospheric activity, or the star is possibly part of a grazing eclipsing binary system. However, further investigations are needed to definitively show if DT Ser should be reclassified as a constant star.

But how do we explain the large magnitude range detected on the Sonneberg plates? Without having access to the original plates we can hypothesise that variations in sky brightness, atmospheric transparency, exposure time and the technique used to measure the plates would cause the PN image to vary in its detectability. Thus its variable contribution to the blended image with DT Ser on the old

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Figure 1. Light-curve for DT Ser, based on photometric data from MC13 and the ASAS and SuperWASP surveys (refer to the text). All three data sets were normalised to the weighted average magnitude of the ASAS V-band data.

Figure 2. Lomb-Scargle periodogram for DT Ser, showing peaks located at one cycle per day and every multiple of one hour periods.

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7 http://stupendous.rit.edu/tass/tass.shtml
8 http://www.aavso.org/apass/
9 Many named variable stars in the latest edition of the GCVS are denoted as CST (constant). Two brighter examples are Z Gem (Parkhurst 1905) and X Tau (Gaposchkin 1952); see Schmidt (1996) for some other cases.
Table 1. Summary of photometric measurements for DT Ser. The dereddened colours were calculated assuming $E(B-V) = 0.25$.

| Waveband | mag     | Source   |
|----------|---------|----------|
| $U$      | 13.66 ± 0.01 | HM01, HM08 |
| $B$      | 13.56 ± 0.10  | CS97     |
| $V$      | 13.55 ± 0.00  | HM01, HM08 |
| $g'$     | 13.57 ± 0.04  | APASS    |
| $V$      | 12.8 ± 0.1    | CS97     |
| $V$      | 12.77 ± 0.01  | HM01, HM08 |
| $V$      | 12.65 ± 0.19  | APASS    |
| $V$      | 12.81 ± 0.11  | CMC      |
| $V$      | 12.79 ± 0.07  | ASAS     |
| $V$      | 12.79 ± 0.13  | TASS IV  |
| $V/R$    | 12.82 ± 0.12  | NSVS     |
| $r'$     | 12.44 ± 0.18a | APASS    |
| $r'$     | 12.58 ± 0.01a | CMC15    |
| $R_F$    | 12.38 ± 0.01  | ACR99    |
| $R_C$    | 12.31 ± 0.03  | HM01, HM08 |
| $i'$     | 12.20 ± 0.11a | APASS    |
| $I_C$    | 12.02 ± 0.07  | TASS IV  |
| $I_C$    | 11.84 ± 0.05  | HM01, HM08 |
| $I_s$    | 11.86 ± 0.02  | DENIS    |
| $(U - B)_0$ | −0.07   | This work |
| $(B - V)_0$ | +0.52  | This work |
| $(V - I_C)_0$ | +0.62  | This work |
| $(V - J)_0$ | +1.06  | This work |
| $(V - K_s)_0$ | +1.34  | This work |

This work

4 THE PLANETARY NEBULA

4.1 Nebular Morphology

MC13 presented high-resolution Hα and [O III] images of MCS 1 taken in good seeing with the 2.6-m Nordic Optical Telescope (NOT). The images show a double-shelled nebula with a faint round outer shell and an elliptical inner rim. The overall angular diameter is $11''4$. In Figure 4, we present a montage showing GALEX ultraviolet, SSS optical, and WISE infrared images of DT Ser and its superposed PN. While MC13 noted that the apparently distorted inner rim of the PN shell suggested an association with Star A, we find this argument non-compelling.

It is true that their [O III] image in particular appears to show that the inner ring is elongated towards star A. However, this could simply reflect the ellipticity of the inner PN shell with a major axis position angle aligned coincidentally with star A. The slightly off-centred central star is not an issue, as many CSPNe are not located at the exact geometric centres of their nebulae (e.g. Sahai et al. 1999; Bobrowsky et al. 2004; Pereira et al. 2008). Such an effect is possibly due to the central star being part of a wide binary system.
4.2 Integrated Fluxes

MC13 give a Hα flux of \(1.55 \times 10^{-13}\) erg cm\(^{-2}\) s\(^{-1}\) derived from their long-slit spectrum. This is a lower limit to the true flux, as (i) the slit width did not include all of the PN, and (ii) the Hα absorption feature in the spectrum of the F8 star may have affected the nebular flux. By scaling up the measured flux to the full area of the PN, we obtain a crude estimate of the total flux as \(9 \pm 3 \times 10^{-13}\) erg cm\(^{-2}\) s\(^{-1}\). Fortunately, the nebula is visible on SHASSA Hα images (Gaustad et al. 2001), so we can determine an independent integrated Hα flux following the recipe of Frew, Bojičić & Parker (2013). Our determination, \(F(H\alpha) = 7.1 \pm 1.0 \times 10^{-13}\) erg cm\(^{-2}\) s\(^{-1}\), is consistent with the scaled-up estimate. There is also a radio detection of the PN in the 1.4 GHz NRAO VLA Sky Survey (NVSS; Condon et al. 1998), designated NVSS 180152−303836.5, with a total flux of \(\sim 4.3\) mJy. The NVSS position is \(8^\circ\) SE of Star A, and \(4^\circ\) SSE of Star B, which corresponds to the planetary nebula, given the typical NVSS astrometric uncertainty of \(\sim 3^\prime\) for a source with this flux (see Fig. 30 of Condon et al. 1998).

We can also estimate an approximate integrated [O III] flux from the available literature data. While Cieslinski et al. (1997) caution against using the fluxes they measured owing to continuum contamination, the graphical plot in their Fig. 1 can be used to estimate a rough \(\lambda 4959/\lambda 4861\) intensity ratio of \(\sim 4.5\) for the PN, with an error of about 50 per cent (note the Hα flux cannot be estimated directly from their plot). Since at the adopted reddening (see below) the \(\lambda 5007/\lambda 4959\) and Hα/Hβ line ratios are predicted to be 3.0 and 4.9 respectively, we can infer that the raw \(5007/\lambda 4959\) ratio must be \(\sim 3.1\), quite typical for a high-excitation PN (Ciardullo 2010). From the measured Hα flux, an approximate integrated [O III] flux, \(F(5007) = 2.2 \pm 1.0 \times 10^{-12}\) erg cm\(^{-2}\) s\(^{-1}\) is determined. Using the formula of Jacoby (1989), this flux corresponds to an apparent V-band equivalent magnitude for the PN of +15.4, with an uncertainty of perhaps half a magnitude.

4.3 The Central Star

The central star is clearly visible in the 2.6-m NOT images reproduced in MC13. Photoelectric \(UBVRI\) photometry of this star was presented by Cieslinski et al. (1997), and more recent CCD PSF-fitting photometry was given by Henden & Munari (2008). The CCD data, taken at three epochs, show the CSPN to be constant within the uncertainties, with a mean magnitude of \(V = 16.21\). We also locate photometry from GALEX on the AB system (Bianchi et al. 2011). Table 2 summarises all literature photometry which unambiguously refers to the central star.

In their paper, MC13 suggested the 0.8 mag difference between the photoelectric photometry of Cieslinski et al. (1997) and the CCD photometry of Henden & Munari (2008) provided evidence for intrinsic variability. Given how close the stars are together and how star B is about 3.4 mag fainter than star A, we believe that photometric contamination from the nebula, and potentially the brighter star as well, has affected the earlier results. Recall that the PN’s apparent magnitude, \(V = 15.4\) (from Table 2), is brighter than the central star itself, and some flux from the PN would probably have been included in the photoelectric measurement. In summary, there is currently no observational evidence for variability of the CSPN, though dedicated time-series photometry is needed to make a definitive statement.

4.4 Reddening

We estimate the reddening to MCS 1 using three separate methods. As noted by MC13, the reddening estimated from the photometry of the F8 star cannot reproduce the colours of the central star B for any spectral type. Using the photometry from Table 2 assuming the F8 star cannot reproduce the colours of the central star B for any spectral type. Using the photometry from Table 2 assuming the F8 star cannot reproduce the colours of the central star B for any spectral type. Using the photometry from Table 2 assuming the F8 star cannot reproduce the colours of the central star B for any spectral type.

Table 2. Summary of photometric measurements for the PN central star. The dereddened colour indices were calculated assuming \(E(B − V) = 0.50\).

| Waveband | Source | mag | \(E(B − V)\) |
|----------|--------|-----|--------------|
| FUV      | GALEX  | 16.58 ± 0.03 99 | −2.3 |
| NUV      | GALEX  | 17.06 ± 0.03 100 | −1.8 |
| U        | CS97   | 15.32 ± 0.07     | −0.3 |
| B        | CS97   | 15.76 ± 0.03     | −0.3 |
| V        | HM08   | 15.91 ± 0.07     | −0.3 |
| I        | CS97   | 15.82 ± 0.07     | −0.3 |

\(\lambda 5007/\lambda 4959\) ratio must be \(\sim 3.1\), quite typical for a high-excitation PN (Ciardullo 2010). From the measured Hα flux, an approximate integrated [O III] flux, \(F(5007) = 2.2 \pm 1.0 \times 10^{-12}\) erg cm\(^{-2}\) s\(^{-1}\) is determined. Using the formula of Jacoby (1989), this flux corresponds to an apparent V-band equivalent magnitude for the PN of +15.4, with an uncertainty of perhaps half a magnitude.

Other objects in the vicinity lend support to a higher value for the total reddening in this direction than assumed by MC13. For the extreme-He star BD −1° 34384 (NO Ser), 40° north-east of DT Ser, Heber & Schönberner (1981) estimate a visual absorption of 1.76 mag, or \(E(B − V) = 0.57\), for a distance of 4.7 kpc. This agrees within the uncertainties with the SF11 value, \(E(B − V) = 0.51\), and shows the value adopted by MC13 was too low.
4.5 Distance and Derived Properties

Simple algebra shows a PN as small and as faint as this one must be well beyond the 1.0 kpc volume-limited sample of Frew (2008). We can use our integrated Hα flux, the nebular reddening and the angular diameter of 11.4′′ from MC13 to determine the distance to the PN using the Hα surface brightness – radius (S−r) relation of Frew (2008) and Frew et al. (2014). The observed and reddening-corrected logarithmic Hα surface brightnesses are \( \log S(H\alpha) = -3.52 \) and \( \log S(H\alpha) = -3.02 \) erg cm\(^{-2}\) s\(^{-1}\) sr\(^{-1}\) respectively. Since the PN is moderately evolved and of high excitation (i.e. −3 \( \lambda r \) size the distance is readily calculated to be 6.4 ± 2.0 kpc. This distance places MCS 1 behind the F8 III–V star DT Ser. The absolute \([O\text{III}]\) λ5007 magnitude is −0.4, after correcting for extinction. This is ~4.1 magnitudes down from the tip of the \([O\text{III}]\) PN luminosity function (PNLF; Ciardullo 2010), consistent with the relatively evolved nature of this optically thin PN.

At a Galactic latitude of +10.3°, the PN is located more than 1.1 kpc from the plane, suggesting it is an old thin-disk or thick-disk object. We note that if the optically-thick S−r relation from Frew (2008) is applied, then the distance is >8 kpc, but we consider the shorter distance the more likely, based on the spectroscopic characteristics of the PN. Round PNe are known to be at relatively evolved nature of this optically thin PN.

From the nebular flux and our preferred distance of 6.4 kpc, we calculate a root-mean-square electron density, \( n_e = 320 \text{ cm}^{-3} \), and an ionized mass of 0.16 \( M_\odot \) (for a filling factor of unity), typical values for a middle-aged PN of relatively low mass. Using the expansion velocity of 37 km s\(^{-1}\) from the \([O\text{III}]\) line splitting (MC13), we estimate an approximate dynamical age of 4700 years for the PN shell. In Table 3 we give a comparison of the properties of the PN at our adopted distance, and at the distance we have estimated for DT Ser. A comparison of these properties with other PNe (see Frew & Parker 2010), in particular the ionized mass and \([O\text{III}]\) absolute magnitude, show that the shorter distance estimates can be definitively ruled out.

![Figure 4](image.png)

Figure 4. Montage of images showing DT Ser and the unrelated planetary nebula MCS 1, all at the same scale. In order, we show a SuperCOSMOS B_J/R_p/I_N composite, a GALEX FUV/NUV false colour composite, and a WISE 3.4/4.5/12 μm composite. The bluish PN is just visible in the optical image, close southwest of DT Ser, which has diffraction spikes. Two slightly offset components are seen in the combined GALEX image, with the hotter (bluish) component at lower left representing the CSPN. The WISE image clearly shows DT Ser as a white compact component offset from the centroid of the longer wavelength 12μm feature which represents the PN. Each panel is 90′′ on a side with NE at top-left. A colour version of this figure is available in the online journal.

| Distance (pc) | 400  | 1400 | 6400 |
|-------------|-----|-----|------|
| \( M_\odot \) | +4.0 | +1.3 | -2.0 |
| \( z \) (pc) | 72  | 250 | 1150 |
| \( m_{\text{ion}}(M_\odot) \) | \( 1.2 \times 10^{-4} \) | \( 2.7 \times 10^{-3} \) | 0.16 |
| \( r_{\text{shell}} \) (pc) | 0.011 | 0.039 | 0.18 |
| \( T_{\text{kin}} \) (yr) | 290 | 1000 | 4700 |
| \( M_{5007} \) | +6.5 | +3.8 | -0.4 |

Table 3. A comparison of the physical properties of Star A and the PN, at near, intermediate, and far distance estimates (refer to the text).

4.6 The Mid-infrared Source

DT Ser is ostensibly an IRAS mid-infrared (MIR) source, designated IRAS 17592-0126, with 25 and 60 μm fluxes of 299 mJy and 608 mJy respectively. However, the coarse resolution of the IRAS survey means it is impossible to tell if the MIR source is coincident with the brighter star, the PN, or both. In addition, the WISE survey has a detection in all four bands, with the astrometry showing that the WISE band-1 (W1) and W2 magnitudes unambiguously refer to star A. However MC13 assumed that the WISE W3 and W4 detections (and by extension the IRAS fluxes) also apply to this star. Thus MC13 claimed that DT Ser had a large MIR excess and was possibly a post-AGB star, using this interpretation to potentially explain the observed velocity shift between star A and MCS 1. Recall that we showed in §4.2 that DT Ser cannot be a low-gravity post-AGB star on the basis of its spectrum and \((U - B)_{0}\) colour.

We carefully examined the WISE images and found that the centroid of the WISE W3 and W4 point-spread function (PSF) is clearly offset from the W1 and W2 PSFs by about 5″ and is within 1″ of the nominal PN position (see Figure 4). Our analysis shows that the W1 and W2 magnitudes clearly refer to star A, while the W3, W4, and IRAS fluxes refer to MCS 1. The MIR colours are similar to other PNe (Anderson et al. 2012; Parker et al. 2012), but since the PN is optically thin, with moderately strong He II emission, we would expect that much of the W4 flux is due to the \([O\text{IV}]\)
fine-structure line at 25.9\(\mu m\) (e.g. Chu et al. 2009; Fesen & Milisavljevic 2010), with only a small contribution from warm dust.

4.7 Is the nebula variable?

The conflicting information in the literature about MCS 1 and its lack of detection by earlier authors led MC13 to speculate that the PN has varied with time. This would be an almost unique occurrence for an evolved PN, with the only roughly comparable examples known to the authors being the flash-ionized PN around the classical nova V458 Vul (Wesson et al. 2008) and the slow secular variation seen in the old PN Hen 1-5 (Henize 1969; Arkhipova, Espov & Ikonnikova 2009) around the born-again star FG Sge. However there is no evidence to suggest an eruptive event in either star A or B has ever been seen on archival plates, even though Henden & Munari (2001) and MC13 speculated that star B may be strongly variable, perhaps based in part on the mis-classification by Cieslinski et al. (1997) that star B is a symbiotic star.

The surface brightness of MCS 1 is modest, and it may have been simply missed by Bond (1978), though it is unclear if his observation “at the telescope” was through the eyepiece or noted from an acquisition screen of some sort. We also examined all available blue and red Schmidt plate scans from the MAST DSS and SSS websites. The PN clearly contributes to the image blend on all three plates. We have offered an alternative interpretation for the putative symbiotic reddening on this sightline from Schlafly & Finkbeiner (2011). MCS 1 is more heavily reddened than DT Ser, as expected for a dusty post-AGB star, nor any evidence to suggest that the PN itself evolved

4.8 A short comparison with symbiotic outflows

Frew & Parker (2010) and MC13 reviewed a number of resolved bipolar nebulae surrounding some symbiotic stars, like BI Cru (Schwarz & Corradi 1992; Corradi & Schwarz 1993), Hen 2-104 (Santander-García et al. 2008), and probably OH 231.8+4.2 (Bu-jarrabal et al. 2002; Meakin et al. 2003; Vickers et al. 2014). Closely related nebulae include Mz 3 (e.g. Santander-García et al. 2004; Cohen et al. 2011), Hen 2-25 and Th 2-B (Corradi 1995), and M 2-9 (Corradi et al. 2011, and references therein), which also overlap in their observational properties with some strongly bipolar PNe (see Corradi & Schwarz 1995). The very high expansion velocities seen in many of these objects suggest they were expelled in a transient event, possibly associated with the binary nature of their nuclei (e.g. Soker & Kashi 2012). However all of these objects are morphologically and kinematically distinct from the nebula MCS 1.

Based on the results of this study, the number of classical symbiotic stars (Kenyon 1986) in elliptical or round PNe is zero.

5 SUMMARY

We have offered an alternative interpretation for the putative symbiotic star DT Serpentis, and its supposed planetary nebula MCS 1, recently announced by MC13. Our new scenario is based on clarifying the past confusion as to which of the two stars is actually DT Ser, pointing to the true nature of the WISE detections of DT Ser and MCS 1. We used the data presented in their paper supplemented with publicly available data obtained from Virtual Observatory databases. After applying Ockham’s Razor, we make the following conclusions:

(i) The designation DT Ser applies to the brighter 12.7-mag star superposed on the periphery of MCS 1 (star A of MC13), and should not be applied to the PN’s central star (star B).

(ii) DT Ser is a foreground F8III-V star 400 – 1400 pc away. The nearer distance is more likely.

(iii) We find no evidence for any periodic variability of DT Ser. While MC13 find evidence of secular variability, an analysis of more than a decade of ASAS and SuperWASP data did not confirm this, down to a limit of ±0.07 magnitude. While the possibility remains the star is a low-level variable, it is not a symbiotic star.

(iv) There is currently no observational evidence for any variability of the CSPN, though dedicated time-series photometry is needed to make a definitive statement.

(v) The substantially different (~60 km s\(^{-1}\)) radial velocities of DT Ser and MCS 1 appear to preclude any association, though we note the stellar velocity was only a single epoch measurement.

(vi) The reddening of MCS 1 determined from the colours of star B, and from a comparison of the H\(_o\) and NVSS 1.4 GHz radio flux measurements are consistent, and agree with the asymptotic reddening on this sightline from Schlafly & Finkbeiner (2011). MCS 1 is more heavily reddened than DT Ser, as expected for a greater distance.

(vii) Based on the H\(_o\) \(S-r\) relation we estimate a distance of 6.4 ± 2.0 kpc to the PN, placing it in the far background of DT Ser.

(viii) The longer wavelength mid-infrared WISE (and IRAS) detections are unambiguously associated with the high excitation PN, and not DT Ser. There is therefore no evidence that star A is a dusty post-AGB star, nor any evidence to suggest that the PN itself has varied markedly with time.

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