CSIRO PUBLISHING
www.publish.csiro.au/journals/pasa *Publications of the Astronomical Society of Australia*, 2010, **27**, 203–209

PHL 932: When Is a Planetary Nebula Not a Planetary Nebula?

David J. Frew[A,B,E], *Greg J. Madsen*[C], *Simon J. O'Toole*[D], *and Quentin A. Parker*[A,D]

[A] Department of Physics, Macquarie University, NSW 2109
[B] Perth Observatory, Bickley, WA 6076
[C] Sydney Institute for Astronomy, School of Physics, University of Sydney, NSW 2006
[D] Anglo–Australian Observatory, PO Box 296, Epping, NSW 1710
[E] Corresponding author. Email: dfrew@physics.mq.edu.au

Received 2009 July 20, accepted 2009 October 7

Abstract: The emission nebula around the subdwarf B (sdB) star PHL 932 is currently classified as a planetary nebula (PN) in the literature. Based on a large body of multi-wavelength data, both new and previously published, we show here that this low-excitation nebula is in fact a small Strömgren sphere (HII region) in the interstellar medium around this star. We summarise the properties of the nebula and its ionizing star, and discuss its evolutionary status. We find no compelling evidence for close binarity, arguing that PHL 932 is an ordinary sdB star. We also find that the emission nebulae around the hot DO stars PG 0108 + 101 and PG 0109 + 111 are also Strömgren spheres in the ISM, and along with PHL 932, are probably associated with the same extensive region of high-latitude molecular gas in Pisces–Pegasus.

Keywords: HII regions — ISM: clouds — planetary nebulae: general — stars: horizontal-branch — stars: individual (PHL 932) — subdwarfs

1 Introduction

PHL 932 was first noted as a 12th-magnitude blue star during a survey by Haro & Luyten (1962). It was studied in more detail by Arp & Scargle (1967), who discovered a faint emission nebula surrounding the star which they assumed to be a planetary nebula (PN). The nebula is asymmetrically placed around the ionizing star (Figure 1), which has a position of $\alpha, \delta = 00^{\mathrm{h}}\ 59^{\mathrm{m}}\ 56.67^{\mathrm{s}}$, $+15^{\circ}\ 44^{\mathrm{m}}\ 13.7^{\mathrm{s}}$ (J2000). A spectrum of the nebula was obtained by Arp & Scargle (1967), who noted strong [OII] λ3727 and weak Hα emission. The almost complete absence of [OIII] emission (see Section 4 below) suggests the nebula has a very low ionization parameter, assuming it is photoionized. An investigation of the stellar spectrum by Méndez et al. (1988) placed the central star squarely on the extreme horizontal branch (EHB) and allowed the classification of PHL 932 as a hot subdwarf B (sdB) star.[1]

Subdwarf B stars are unlike the typical central stars of PN. They do not evolve to the asymptotic giant branch (AGB), but rather move directly on to the white dwarf cooling curve. Their progenitors are solar-like stars that have somehow shed nearly all of their hydrogen envelopes prior to the onset of core helium fusion (e.g. Heber 1986). Exactly how this occurs is uncertain, although it is possible that some kind of binary interaction is involved (Han et al. 2003). Indeed, De Marco et al. (2004) and Afşar & Bond (2005) have claimed the radial velocity of PHL 932 is variable, which may indicate binarity (however, see Section 3.2). More recently, De Marco (2009) has strongly argued for the general importance of binary interactions for the formation and shaping of PN.

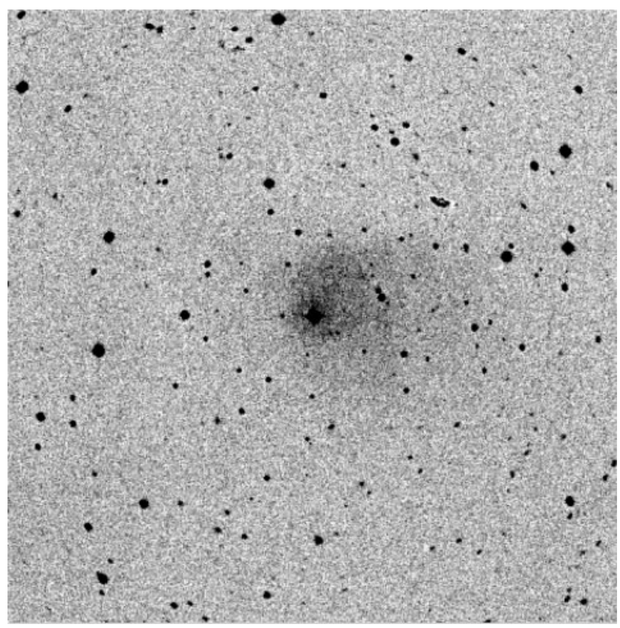


Figure 1 The asymmetric emission nebula around PHL 932. The star is at the centre of this combined SuperCOSMOS broadband red and blue image, which is 10′ across.

Despite the unusual nature of this system, the nebula around PHL 932 has not been studied in much detail since

[1] Méndez et al. (1988) classified the star as 'late sdO' (or sdOB) based on their detection of HeII λ4686 in absorption.

10.1071/AS09043 1323-3580/10/02203

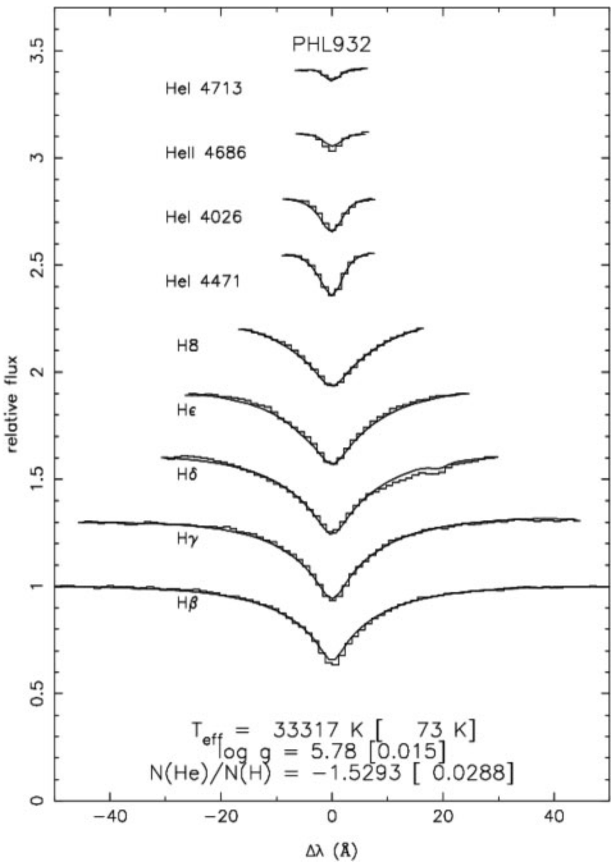


Figure 2 Model fit to the individual lines in the VLT FORS1 spectrum of PHL 932. The spectrum is represented by a histogram, while the best-fit model is given as an overlaid solid line.

its discovery. In this paper, we present an in-depth analysis of the nebula and the ionizing star based on new and archival multi-wavelength observations. We use the results of this investigation to examine the evolutionary status of the star and to reclassify the nebula.

2 Observations

This study makes use of new and previously unpublished data, as well as already published observations. Details of the new data are given here, while other archival observations used will be cited as they are discussed.

2.1 The Ionizing Star

We use an archival ESO VLT/FORS1 spectrum of the star (Figure 2), observed as part of an investigation of magnetic fields in hot subdwarfs (Program ID: 075.D-0352A). This spectrum was observed using the 600B grating in spectropolarimetric mode with a slit width of 0.5″, which gives a resolution of about 2.8 Å. The starlight passed through a Wollaston prism and a rotatable retarder plate rotated to two different angles, giving extraodinary (*e*) and ordinary (*o*) beams. Bias frames, flat fields and He + HgCd arc spectra were taken at the end of the night of observation. For the purposes of this study, the resulting *e*- and *o*-spectra were combined, creating a Stokes *I* spectrum with very high signal-to-noise ratio. The data reduction was done using standard routines in the IRAF package and the two spectra were reduced separately and combined only after wavelength calibration.

2.2 The Emission Nebula

The large angular size and low surface brightness of the nebula requires special instrumentation to measure accurately the emission line properties. New observations of the nebula were obtained in 2005 with the Wisconsin H-Alpha Mapper (WHAM) at the Kitt Peak National Observatory. WHAM is a remotely operated Fabry-Peròt spectrograph designed to detect very low-surface brightness optical emission lines at high spectral resolution of R = 25 000 (Reynolds et al. 1998).

WHAM records the spatially averaged spectrum over a 60′ circular diameter beam. Figure 3 shows WHAM spectra of the Hα, [NII] λ6584 and [OIII] λ5007 lines toward PHL 932. Contamination from atmospheric lines were removed, and the spectra were calibrated using synoptic observations of NGC 7000 (tied to results from the WHAM Northern Sky Survey of Haffner et al. 2003) as well as a range of PN calibrators. The spectra are displayed in units of milli-Rayleigh per km s^{-1}; the secondary peak at $v_{\rm LSR} = -30$ km s^{-1} in the Hα spectrum is an artefact of imperfect subtraction of the bright geocoronal Hα line.

In Sep 2008 we observed the nebula with the SPIRAL integral field unit (Sharp 2006) on the 3.9-m AAT, located at Siding Spring Observatory, NSW. The SPIRAL IFU is a 22.4″ × 11.2″ 512-element lenslet array linked by fibre feed to the AAOmega spectrograph. It is placed at the Cassegrain focus, uses the f/8 secondary and provides a spatial resolution of 0.7″. Standard 685V and 385R medium- and low-resolution gratings were employed in the blue and red arms of the AAOmega spectrograph.

3 Evolutionary Status of PHL 932

3.1 Spectral Analysis and Distance

We have used the archival, high signal-to-noise FORS1 spectrum to derive the stellar parameters of PHL 932 using the same method and model grid ([Fe/H] = 0.0) as Lisker et al. (2005). We find $T_{\rm eff} = 33\,490 \pm 73$ K, $\log g = 5.81 \pm 0.02$ and $\log(\mathrm{He/H}) = -1.58 \pm 0.03$, or in other words, consistent with being a typical hot sdB star. The model fit to selected absorption lines is shown in Figure 2. We note that the line profiles of both the HeI 4471 Å and HeII 4686 Å lines are well matched by the synthetic spectrum. In several sdB stars with similar parameters, there is a mismatch between the two ionization species (Heber et al. 2000). O'Toole & Heber (2006) investigated this further after discovering large overabundances of iron-group elements using high-resolution UV echelle observations and found that models with enhanced metals ([Fe/H] = +1.0) could remove or reduce the discrepancy. They also found that there was no discrepancy for the one star they studied with reduced iron abundance (Feige 66). It is likely that PHL 932 has a similarly depleted iron abundance; indeed, this is suggested

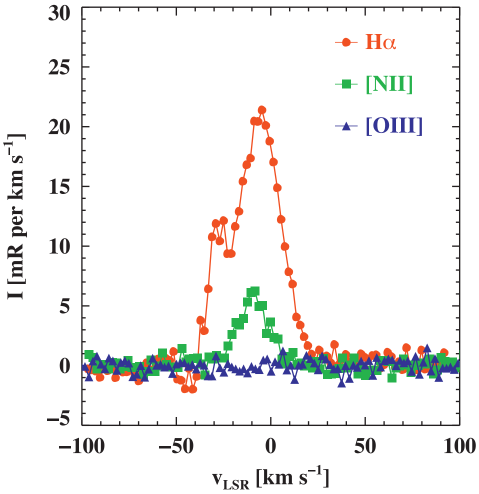


Figure 3 WHAM spectra through a 60′ beam centred on PHL 932.

in the work of Edelmann (2003). Alternatively, there may be a resolution effect clouding the issue. Further high-resolution optical studies are needed to clarify the situation.

Inferring the evolutionary status of the ionizing star depends critically on its distance. It is only recently that the distance has been determined accurately. Méndez et al. (1988) derived a spectroscopic parallax (a distance derived using surface gravity, but assuming a stellar mass) of $\sim$390 pc after assuming $M \simeq 0.3\,M_\odot$, while Napiwotzki (1999) found a distance of 235 pc using the same method.

PHL 932 was observed by the *Hipparcos* satellite. The revised *Hipparcos* catalog gives a distance of 113(+114, −38) pc (van Leeuwen 2007), however this value, as with the original *Hipparcos* parallax leads to an non-physical stellar mass for PHL 932 of $<$0.1 $M_\odot$. An improved parallax of 3.36 ± 0.62 mas (Harris et al. 2007) has shown that the Hipparcos value is in error. We adopt the new parallax distance of 298(+67, −47) pc hereafter. Combining this distance with our new gravity determination above leads to a possible mass range of 0.3–0.6 $M_\odot$, which is consistent with the expected properties of a hot sdB star. This distance does not constrain the evolutionary history of PHL 932 however.

O'Toole (2008) discussed the possible evolution channels that can produce a spectroscopically identified hot subdwarf and ways to distinguish them. In brief, a star that suffers extreme mass-loss on the red giant branch may either ignite helium or not, depending on the amount of mass lost. In the former case, the star will become an EHB star and eventually become a C/O white dwarf with a mass of $\sim$0.48 $M_\odot$, while in the latter case, the star will become a He-core white dwarf with mass $<$0.46 $M_\odot$. See also Brown et al. (2001) and Han et al. (2002, 2003) for further discussion of potential evolutionary channels for hot subdwarf stars. Currently, with a mass range for PHL 932 which covers several possibilities, it is not possible to determine the correct channel. Only a more precise distance determination will allow this.

3.2 *Non-Binary Status of PHL 932*

In a spectroscopic study investigating the binary status of PN central stars, De Marco et al. (2004) claimed a 98% probability that PHL 932 is a radial velocity variable, based on one discrepant radial velocity measurement out of nine. However, when we look at other radial velocity measurements in the literature, we find that radial velocity variability is unlikely. Arp & Scargle (1967) give $V_{\rm hel} = +15 \pm 20$ km s^{-1} based on a low-dispersion blue spectrum. Using high-resolution echelle spectroscopy, Edelmann (2003) found $V_{\rm hel} = +18 \pm 2$ km s^{-1} ($V_{\rm LSR} = +16.4 \pm 2$ km s^{-1}) with no evidence for radial velocity variability.[2] Méndez (1989) also used echelle spectroscopy and found an identical value of $V_{\rm hel} = +18 \pm 2$ km s^{-1} based on two spectra. Wade (2001) used spectra obtained with the Hobby–Eberly Telescope to also show that no large radial velocity amplitude exists.

Furthermore, Bond & Grauer (1987) photometrically observed the central star but found no evidence for any variation due to irradiation effects, making it unlikely to be a close binary. In addition, the spectral energy distribution derived from available optical and 2MASS data (Arp & Scargle 1967; Wesemael et al. 1992; Allard et al. 1994; Cutri et al. 2003; Harris et al. 2007) is consistent with no near-IR excess from a cool companion.

Given the constancy of the high resolution RV data of Edelmann (2003), supported by Méndez (1989), Wade (2001) and Saffer, Green & Bowers (quoted by Wade 2001), we believe it is unlikely that PHL 932 is a *close* binary system.

3.3 *Kinematics*

While the Hipparcos parallax is in error, the catalogued proper motion (van Leeuwen 2007) for PHL 932 agrees well with the value in the UCAC2 catalogue (Zacharias et al. 2004), and the new determination by Harris et al. (2007). We adopt the UCAC2 value of 36.6 mas yr^{-1} in PA 83°. The tangential velocity at the adopted distance of 298 pc is then 52 ± 10 km s^{-1}.

Using the mean heliocentric radial velocity of $+18 \pm 2$ km s^{-1} (Méndez 1989; Edelmann 2003) and following the precepts of Johnson & Soderblom (1987), the space motion vectors are determined to be $U = -52$ km s^{-1}, $V = -15$ km s^{-1}, $W = -7$ km s^{-1}. These vectors are typical for the kinematics of old-disk stars. The total space motion is $\sim$55 km s^{-1} with respect to the Sun, or $\sim$42 km s^{-1} with respect to the local standard of rest. The space motion is consistent with the kinematics of sdB stars, most of which belong to the old disk (Thejll et al. 1997), though some halo objects are known.

4 Nebular Properties

We use the WHAM spectra (Figure 3) to calculate the total Hα and [N II] fluxes of the emission nebula, finding $\log F_{\rm H\alpha} = -10.67 \pm 0.05$ (in units of erg cm^{-2} s^{-1}),

[2] In the direction of PHL 932, $v_{\rm LSR} = v_{\rm helio} - 1.6$ km s^{-1}.

$\log F_{[\mathrm{N\,II}]} = -11.32 \pm 0.05\,\mathrm{erg\,cm^{-2}\,s^{-1}}$, and [O III] emission too faint to be detected over the 60′ WHAM beam. Note that the large WHAM aperture includes the extended ionized wake (see below). The Hα nebula was also reported by Reynolds et al. (2005), using lower signal-to-noise WHAM data, and cataloged as WPS 37. They found an integrated Hα flux of $\log F_{\mathrm{H}\alpha} = -10.75 \pm 0.10\,\mathrm{erg\,cm^{-2}\,s^{-1}}$, but this beam was not centred on PHL 932.

To confirm the accuracy of the WHAM Hα flux, we performed aperture photometry on images from the Southern H-Alpha Sky Survey Atlas (SHASSA; Gaustad et al. 2001), following the precepts of Frew, Parker & Russeil (2006). The estimated flux is $\log F_{\mathrm{H}\alpha} = -10.73 \pm 0.06\,\mathrm{erg\,cm^{-2}\,s^{-1}}$ through a 12′ aperture (mean of two SHASSA fields, #235 & 236), after adopting [N II]/H$\alpha = 0.3 \pm 0.1$ from our WHAM data. The measured Hα flux through a larger 60′ aperture is $\log F_{\mathrm{H}\alpha} = -10.63 \pm 0.06\,\mathrm{erg\,cm^{-2}\,s^{-1}}$ (mean of two fields), in excellent agreement with the measured integrated flux from our new WHAM data.

There is a simple linear relationship between Hα surface brightness, an observational property, and emission measure $\left(\int n_e^2 \mathrm{d}l\right)$, a physical property, provided a nebula is photoionized and has a temperature near $T_e = 10^4$ K (see Madsen, Reynolds & Haffner 2006). The surface brightness of the emission nebula around PHL 932 is non-uniform; we use the higher angular resolution SHASSA data to measure the peak surface brightness. Using both SHASSA fields, we find concordant results with a peak Hα surface brightness of 36 Rayleighs, or $2.1 \times 10^{-16}\,\mathrm{erg\,cm^{-2}\,s^{-1}\,arcsec^{-2}}$ (corrected for background and [N II] contribution). This implies an emission measure of 80–100 cm^{-6} pc, accounting for the uncertainties in surface brightness and nebular temperature. The SHASSA data also reveal an extended 5 Rayleigh tail of emission that subtends ∼18′ southwest from the ionizing star; this is opposite to the direction of the proper motion vector and implies the tail may be some form of a wake.

We also comment on our SPIRAL data. We decided to forego any spatially resolved information from the IFU and binned up all the spaxels to get maximum S/N in the spectrum of this faint nebula. The binned, wavelength calibrated spectrum from the blue arm is shown in Figure 4. The data are not flux calibrated, but we can extract useful line ratio data for emission lines close together in wavelength. We measured a λ5007/Hβ ratio of only ∼0.1, which is much lower than is typical for bona fide evolved PN of comparable surface brightness (Frew 2008). This could be explained by the low temperature of the CS of only 33 000 K. While we note this very low level of excitation is sometimes seen in bona fide PN, these are all very young, highly compact nebulae that have cool central stars evolving to the left in the HR diagram. None has a radius as large as the emission nebula surrounding PHL 932.

Preliminary inspection of the spatially resolved data shows that the [O III] emission is confined to an area closest to the ionizing star. We also note a [N II]/Hα ratio of

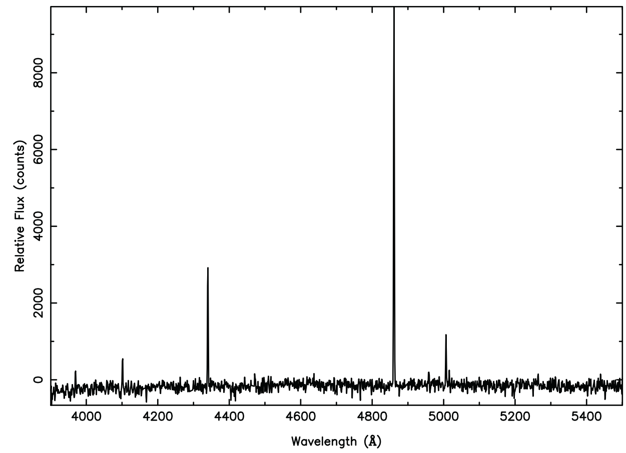


Figure 4 Blue-arm, wavelength-calibrated AAT SPIRAL spectrum of the brightest part of the nebula, 20″ NW of PHL 932. Note the very low nebular excitation, with an λ5007/Hβ ratio of ∼0.1.

0.7 from the SPIRAL red-arm data, which is higher than the value determined from WHAM for the whole nebula (integrated over a 1° beam). This suggests the electron temperature of the gas is higher closer to the star.

The mass of the ionized nebula may be estimated from its distance, measured angular size, and the integrated Hα flux (following the recipe of Hua & Kwok 1999). Using the appropriate values for PHL 932, we find the ionized mass is $0.04\epsilon^{1/2}\,\mathrm{M}_\odot$, where ϵ is the (unknown) volume filling factor. This is an order of magnitude less than the median PN mass of $0.5\epsilon^{1/2}\,\mathrm{M}_\odot$ (Frew & Parker 2010).

The radial velocity of the ionized gas is provided by the high spectral resolution WHAM data. A Gaussian fit to the line profiles in Figure 3 yields velocity centroids of $v_{\mathrm{LSR}} = -5 \pm 3\,\mathrm{km\,s^{-1}}$ for Hα and $v_{\mathrm{LSR}} = -13 \pm 3\,\mathrm{km\,s^{-1}}$ for [N II]; we adopt the mean value of $v_{\mathrm{LSR}} = -9 \pm 4\,\mathrm{km\,s^{-1}}$ as the velocity of the nebula. The IRAF *emsao* package was used to determine an emission-line velocity for the nebula from our SPIRAL data. Using the higher-resolution blue data (excluding two weak lines), we derive $v_{\mathrm{LSR}} = -3 \pm 5\,\mathrm{km\,s^{-1}}$, in excellent agreement with our WHAM results.

The velocity from WHAM can be compared to the stellar radial velocity of PHL 932 (Méndez 1989; Edelmann 2003) of $v_{\mathrm{LSR}} = +16.4 \pm 2\,\mathrm{km\,s^{-1}}$ (see Section 3.2). The radial velocity of the nebula differs from the radial velocity of the ionizing star by ∼6σ. This is very strong evidence that the two are not associated, especially since the star does not exhibit radial velocity variability.

Lastly we use a Gaussian fit to the WHAM data to measure the line widths of the gas. We find an Hα full-width half-maximum line width of $2v_{\exp} = 22 \pm 4\,\mathrm{km\,s^{-1}}$. This line width is typical of diffuse interstellar ionized gas and significantly lower than the average width seen in evolved PN, ∼50 km s^{-1} (Reynolds et al. 2005).

5 Identity of the Nebula

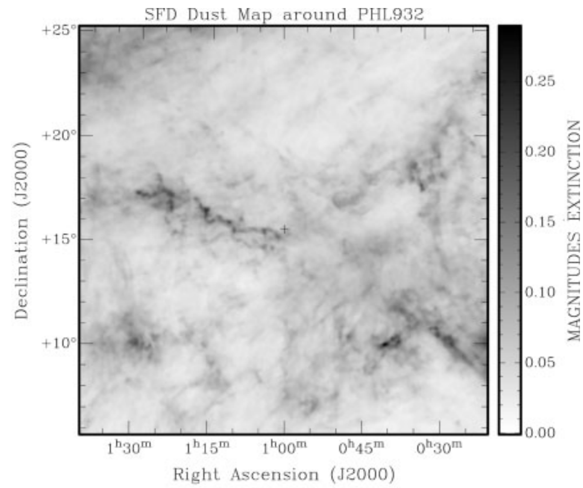
The nebula surrounding PHL 932 has long been categorized as a PN (e.g. Acker et al. 1992). Méndez et al. (1988)

assessed the identity of the nebula and argue that their estimate of its emission measure ($\sim$60 cm^{-6} pc) is too large to be attributed to the ambient interstellar medium. They conclude it must have been ejected from the star and affirm its status as a 'planetary nebula', albeit a peculiar one with an sdB central star (see Frew & Parker 2010, for a review of PN taxonomy).

We have presented new data that strongly suggest that the nebula is, in fact, an HII region unrelated to the star. Firstly, independent measures of the radial velocity of the gas are significantly different from the radial velocity of the star. Second, the nebular line width is typical of the ionized ISM and is lower than is seen in most evolved PN. Third, the ionized mass is significantly lower than is expected for an evolved PN. Fourth, the [OIII]/Hβ ratio shows the level of excitation is very low, much less than for any evolved PN. Lastly, the detailed nebular morphology is not consistent with the emission nebula being ejected from PHL 932. Indeed, the morphology is irregular and the surface brightness essentially drops off away from the ionizing star in all directions.[3] From section 3.3, the total velocity with respect to the local standard of rest is $\sim$43 km s^{-1}. Despite the moderately fast space motion, there is no sign of an enhanced rim or bowshock on the leading side of the nebula (see Figure 1) as expected from theoretical modelling (e.g. Wareing, Zijlstra & O'Brien 2007) of PN/ISM interactions. In the light of this, we find that the nebula is not moving through the ISM and we interpret the observed wake as a recombining fossil 'contrail'.

In summary, we conclude that the star is in an over-dense region of the ISM and has ionized a small volume around it. To further assess this scenario, we consider the interstellar environment of PHL 932. There are at least three high-latitude molecular clouds in the broad vicinity, part of a large arc of CO emission (Magnani et al. 2000) which may link a south-extending spur from the Taurus–Auriga dark cloud complex with the eastward extension of the Pegasus molecular cloud association (note that a recent detailed study in CO of the extended Pegasus region has been undertaken by Chastain et al. 2006). The molecular cloud MBM 3 (Magnani, Blitz & Mundy 1985) is found 4° northeast of PHL 932 and has a similar systemic radial velocity to the emission nebula around PHL 932. This cloud seems to be associated with the diffuse nebula LBN 639 (Lynds 1965), listed in SIMBAD as a HII region, but is more likely to be a reflection nebulosity, or galactic cirrus, as an enhancement is not present in the WHAM-NSS data (Haffner et al. 2003). Other molecular clouds are nearby; MBM 4 (associated with LBN 644) is 2° east of MBM 3 and linked to it, while MBM 2 is 7.5° southwest of PHL 932.

[3] Deep Hα and [NII] images taken by C.-T. Hua with the OHP 1.2-metre reflector show a non-limb brightened, irregular nebulosity with apparent dust lanes. The morphology is consistent with the nebula being a small HII region. See `http://www.oamp.fr/people/trung/phl932.html`.



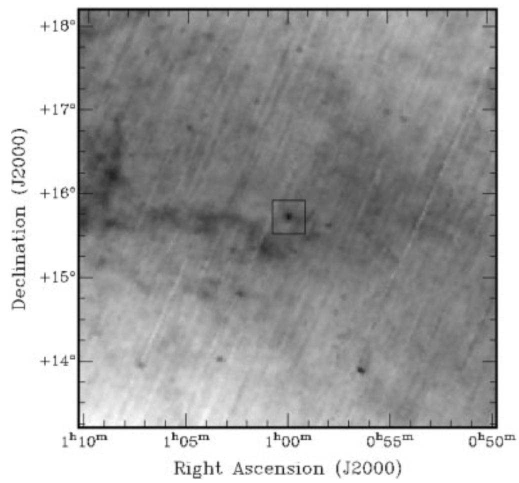


Figure 5 Top panel: Region (20° × 20°) surrounding PHL 932 from the dust map of Schlegel et al. (1998). The position of PHL 932 is marked with a cross and is found at the end of a filament of molecular emission associated with MBM 3 and MBM 4. Lower panel: IRAS 60 micron dust map centred on the position of PHL 932. The image is 5° on a side.

It seems there is good evidence for widespread high-latitude gas and molecular material in this general direction, as shown on IRAS images (see Figure 5). In Table 1, we summarise the radial velocities of the various molecular clouds and emission nebulae within a 10° radius of PHL 932. The velocities for the molecular clouds are taken from Magnani et al. (1985). In addition, Magnani et al. (2000) detected CO at l, $b = 127.4$, -47.0 on a sightline 1.5° from the position of PHL 932. They measured $V_{\mathrm{LSR}} = -10.5$ km s^{-1} and associated the emission with the MBM 3 cloud. The OH data for MBM 2 from Magnani & Siskind (1990) are also consistent in velocity.

As seen in Table 1, all features have a mean velocity near $V_{\mathrm{LSR}} = -8$ km s^{-1}, suggesting that the widespread molecular and ionized gas in this direction is at a common distance, $\sim$300 pc. Crucially, the systemic velocity of the ionized gas around PHL 932 is identical within the errors with the mean velocity of the molecular gas in this direction. We note, however, that Penprase (1992)

Table 1. Summary of radial velocity determinations

Object	Type	l	b	V_{LSR} (km s^{-1})	Line	Ref.
MBM 2	MC	117.4	−52.3	−7.3	CO	1
–	...	...	...	−7.4	OH	2
PHL 932	EN	125.9	−47.1	−9.0	Hα, [NII]	3
PG 0108 + 101	EN	130.8	−52.2	−8.6	Hα, [NII], [OIII]	3
–	...	...	...	−11.0	Hα	4
PG 0109 + 111	EN	131.1	−51.2	−10.1	Hα	3
MBM 3	MC	131.3	−45.7	−7.6	CO	1
MBM 4	MC	133.5	−45.3	−8.7	CO	1

Notes. LSR velocities are quoted for all emission nebulae (EN) and molecular clouds (MC) within 10° of PHL 932, ordered by Galactic longitude. MBM 3 and MBM 4 are associated with LBN bright nebulae (Lynds 1965). References: 1. Magnani et al. (1985); 2. Magnani & Siskind (1990); 3. This work; 4. Reynolds (1987).

has estimated an approximate distance to the MBM 3/4 complex of 90 pc ≤ D ≤ 190 pc, so it is possible there is a considerable depth to the gas along this sightline.

However, we ask if it is reasonable to expect interstellar gas with the observed emission measure at this location, ~220 pc from the Galactic midplane? It is widely known that there are large electron density variations in the ISM on all scales (e.g. Elmegreen 1998; Stinebring 2006) as seen in Figure 5. We also note that dense molecular gas is known to exist at remarkably large $|z|$ distances from the plane, as seen in the case of the Draco cloud which has $z \gtrsim 500$ pc (Mebold et al. 1985; Penprase, Rhodes & Harris 2000). Hence, we conclude that molecular gas and dust exists at moderate z distances in the direction of PHL 932.

Finally, we comment on the emission nebulae associated with the hot DO white dwarfs PG 0108 + 101 (Reynolds 1987; Frew, Parker & Madsen 2006; Madsen & Frew, in prep.) and PG 0109 + 111 (Reynolds 1987; Werner et al. 1997) that are only ~6° southeast of PHL 932. The fairly similar apparent magnitudes, temperatures, and surface gravities of these two stars (e.g. Wesemael, Green & Liebert 1985) suggest they are at quite similar distances; gravity distances range between 200 and 400 pc (Pottasch 1996; Dreizler & Werner 1996). Considering the error bars on the published log g values, their distances are consistent both with each other, and with the distance to PHL 932. The systemic velocities of the gas are taken from unpublished WHAM data (Madsen & Frew 2009, in prep.). The consistency of these velocities with the mean velocity of the molecular gas in the area, as well as the narrow emission line widths from WHAM show that these nebulae are also Strömgren spheres in the ISM. Their very low emission measures are consistent with the lack of obvious extinction in the SFD dust map (Figure 5).

6 Conclusions

We have used a combination of new and archival multi-wavelength observations to show that (a) PHL 932 is unlikely to be in a close binary system as previously suggested, and (b) the emission nebulosity surrounding PHL 932 is *not* a PN as has been commonly assumed, nor is it physically associated with the star. We conclude instead that PHL 932 is ionizing a 'clumpy' region of the ISM as it travels through it; in other words, the emission nebula is simply a Strömgren zone (or HII region), rather than a PN.

We note that another putative PN, EGB 5 (Ellis, Grayson & Bond 1984) is also associated with an sdB star. An unpublished MSSSO 2.3-m long-slit spectrum of the nebula taken by one of us (D.J.F.) shows a nebula of low excitation, similar to that around PHL 932. Like PHL 932, the morphology of EGB 5 on DSS images militates against it being a bona fide PN, though deep narrowband Hα images are required for a definitive conclusion. We likewise consider the nebula around EGB 5 to be another candidate Strömgren zone in the ISM. Such nebulae are seen around hot subdwarfs and white dwarfs when the ISM is sufficiently dense to give an emission measure that facilitates optical detection (cf. Tat & Terzian 1999). In future papers in this series, we will show that several other nearby emission nebulae currently assumed to be PN are also Strömgren zones in the ISM; see Frew & Parker (2006), Parker et al. (2006) and Madsen et al. (2006) for preliminary results.

Acknowledgments

D.J.F. gratefully acknowledges Macquarie University for a research scholarship, and also the Government of Western Australia for additional financial support. This study used data from the Wisconsin H-Alpha Mapper (WHAM), which was produced with support from the National Science Foundation through grant AST-0607512, and data from the Southern Hα Sky Survey Atlas (SHASSA), which was also produced with support from the National Science Foundation. This research has made use of the SIMBAD database, operated at the CDS, Strasbourg, France. Data products from the Two Micron All Sky Survey (2MASS) were also utilised, which is a joint project of the University of Massachusetts and the Infrared Processing and Analysis Center/California Institute of Technology, funded by the National Aeronautics and Space Administration and the National Science Foundation. We also thank the support staff at the Anglo-Australian Observatory for assistance in observing with SPIRAL, and the anonymous referee for a careful reading of the manuscript.

References

Acker, A., Ochsenbein, F., Stenholm, B., Tylenda, R., Marcout, J. & Schohn, C., 1992, Strasbourg-ESO Catalogue of Galactic Planetary Nebulae (Garching: ESO)
Afşar, M. & Bond, H. E., 2005, MmSAI, 76, 608
Allard, F., Wesemael, F., Fontaine, G., Bergeron, P. & Lamontagne, R., 1994, AJ, 107, 1565
Arp, H. & Scargle, J. D., 1967, ApJ, 150, 707
Bond, H. E. & Grauer, A. D., 1987, in IAUC, 95, The Second Conference on Faint Blue Stars, Eds. Philip, A. G. D., Hayes, D. S. & Liebert, J. W. (Schenectady: L. Davis Press), 221
Brown, T. M., Sweigart, A. V., Lanz, T., Landsman, W. B. & Hubeny, I., 2001, ApJ, 562, 368
Chastain, R. J., Shelton, R. L., Raley, E. A. & Magnani, L., 2006, AJ, 132, 1964
Cutri, R. M. et al., 2003, VizieR On-line Data Catalog: II/246
De Marco, O., Bond, H. E., Harmer, D. & Fleming, A. J., 2004, ApJ, 602, L93
De Marco, O., 2009, PASP, 121, 316
Dreizler, S., Werner, K., 1996, A&A, 314, 217
Edelmann, H., 2003, PhD thesis, Friedrich-Alexander-Universität, Erlangen-Nürnberg
Ellis, G. L., Grayson, E. T. & Bond, H. E., 1984, PASP, 96, 283
Elmegreen, B. G., 1998, PASA, 15, 74
Frew, D. J., 2008, PhD thesis, Macquarie University, Sydney
Frew, D. J. & Parker, Q. A., 2006, in IAUS, 234, Planetary Nebulae in our Galaxy and Beyond, Eds. Barlow, M. J. & Méndez, R. H. (Cambridge: CUP), 49
Frew, D. J. & Parker, Q. A., 2010, PASA, 27, 129
Frew, D. J., Parker, Q. A. & Russeil, D., 2006, MNRAS, 372, 1081
Gaustad, J. E., McCullough, P. R., Rosing, W. & Van Buren, D. J., 2001, PASP, 113, 1326
Haffner, L. M., Reynolds, R. J., Tufte, S. L., Madsen, G. J., Jaehnig, K. P. & Percival, J. W., 2003, ApJS, 149, 405
Han, Z., Podsiadlowski, Ph., Maxted, P. F. L., Marsh, T. R. & Ivanova, N., 2002, MNRAS, 336, 449
Han, Z., Podsiadlowski, Ph., Maxted, P. F. L. & Marsh, T. R., 2003, MNRAS, 341, 669
Haro, G. & Luyten, W. J., 1962, Bol. Obs. Tonantzintla y Tacubaya, 3, 37
Harris, H. C. et al., 2007, AJ, 133, 631
Heber, U., 1986, A&A, 155, 33
Heber, U., Reid, I. N. & Werner, K., 2000, A&A, 363, 198
Hua, C. T. & Kwok, S., 1999, A&AS, 138, 275
Johnson, D. R. H. & Soderblom, D. R., 1987, AJ, 93, 864
Lisker, T., Heber, U., Napiwotzki, R., Christlieb, N., Han, Z., Homeier, D. & Reimers, D., 2005, A&A, 430, 223
Lynds, B. T., 1965, ApJS, 12, 163
Madsen, G. J., Frew, D. J., Parker, Q. A., Reynolds, R. J. & Haffner, L. M., 2006, in IAUS, 234, Planetary Nebulae in our Galaxy and Beyond, Eds. Barlow, M. J. & Méndez, R. H. (Cambridge: CUP), 455
Madsen, G. J., Reynolds, R. J. & Haffner, L. M., 2006, ApJ, 652, 401
Magnani, L. & Siskind, L., 1990, ApJ, 359, 355
Magnani, L., Blitz, L. & Mundy, L., 1985, ApJ, 295, 402
Magnani, L., Hartmann, D., Holcomb, S. L., Smith, L. E. & Thaddeus, P., 2000, ApJ, 535, 167
Mebold, U., Cernicharo, J., Velden, L., Reif, K., Crezelius, C. & Goerigk, W., 1985, A&A, 151, 427
Méndez, R. H., Groth, H. G., Husfield, D., Kudritzki, R. P. & Herrero, A., 1988, A&A, 197, L25
Méndez, R. H., 1989, in IAUS, 131, Planetary Nebulae, Ed. Torres-Peimbert, S. (Dordrecht: Kluwer), 261
Moehler, S., Richtler, T., de Boer, K. S., Dettmar, R. J. & Heber, U., 1990, A&AS, 86, 53
Napiwotzki, R., 1999, A&A, 350, 101
O'Toole, S. J., 2008, in ASPC, 392, Hot subdwarf stars and related objects, Eds. Heber, E., Jeffery, C. S. & Napiwotzki, R. (San Francisco: ASP), 67
O'Toole, S. J. & Heber, U., 2006, A&A, 452, 579
Parker, Q. A. et al., 2006, MNRAS, 373, 79
Penprase, B. E., 1992, ApJS, 83, 273
Penprase, B. E., Rhodes, J. D. & Harris, E. L., 2000, A&A, 364, 712
Perryman, M. A. C. et al., 1997, A&A, 323, L49
Pottasch, S. R., 1996, A&A, 307, 561
Reynolds, R. J., 1987, ApJ, 315, 234
Reynolds, R. J., Tufte, S. L., Haffner, L. M., Jaehnig, K. & Percival, J. W., 1998, PASA, 15, 14
Reynolds, R. J., Chaudhary, V., Madsen, G. J. & Haffner, L. M., 2005, AJ, 129, 927
Schlegel, D. J., Finkbeiner, D. P. & Davis, M., 1998, ApJ, 500, 525
Sharp, R., 2006, AAO Newsletter, 110, 24
Stinebring, D. R., 2006, ChJAS, 6, 233
Tat, H. H. & Terzian, Y., 1999, PASP, 111, 1258
Thejll, P., Flynn, C., Williamson, R. & Saffer, R., 1997, A&A, 317, 689
van Leeuwen, F., 2007, Hipparcos, the New Reduction of the Raw Data, ASSL, 350 (Cambridge: CUP)
Wade, R., 2001, in ASPC, 226, 12th European Workshop on White Dwarfs, Eds. Provencal, L., Shipman, H. L., MacDonald, J. & Goodchild, S. (San Francisco: ASP), 199
Wareing, C. J., Zijlstra, A. A. & O'Brien, T. J., 2007, MNRAS, 382, 1233
Werner, K., Bagschik, K., Rauch, T. & Napiwotzki, R., 1997, A&A, 327, 721
Wesemael, F., Green, R. F. & Liebert, J., 1985, ApJS, 58, 379
Wesemael, F., Fontaine, G., Bergeron, P., Lamontagne, R. & Green, R. F., 1992, AJ, 104, 203
Zacharias, N., Urban, S. E., Zacharias, M. I., Wycoff, G. L., Hall, D. M., Monet, D. G. & Rafferty, T. J., 2004, AJ, 127, 3043