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Letter to the Editor

The distance to the WN8 star We 21

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Abstract. A high-resolution spectrum of the interstellar Na D lines towards We 21 shows a total velocity extent of about 95 km s^{-1} , extending from -65 to $+30 \text{ km s}^{-1}$ in the LSR velocity frame. In this line-of-sight the positive velocities can only arise from beyond the solar circle, and this suggests that We 21 lies in the far part of the Carina spiral arm, at a distance of about 11.5 kpc. Contrary to the conclusions of Duerbeck & Reipurth (1990), We 21 appears to be a massive Population I WN8 star surrounded by a stellar ejecta bubble, and not a PN central star.

Key words: interstellar medium: spectroscopy – planetary nebulae: general – stars: Wolf-Rayet

1. Introduction

Duerbeck & Reipurth (1990) have recently discovered that star number 21 in Weaver's (1974) list of $H\alpha$ emission-line objects towards the Southern Coalsack (We 21) is in fact a background WN 8 star. The star is surrounded by a ring-like nebula and appears to illuminate the edge of a dark cloud some 24 arcseconds to the east (cf. their Figures 2 and 3). Duerbeck & Reipurth observed the CO $J = 1 \rightarrow 0$ line towards this cloud and found components with LSR velocities of -34 and -40 km s^{-1} (in addition to the foreground Coalsack emission at -4 km s^{-1}). Velocities in this range are characteristic of the near intersection of the line-of-sight with the Carina spiral arm (i.e. that part of the arm lying within the solar circle; Grabelsky et al. 1987) and, based on the apparent interaction of We 21 with a cloud at this velocity, Duerbeck & Reipurth concluded that the star also lies in this part of the Carina arm, at a distance of about 1 kpc.

Based on this distance estimate, Duerbeck & Reipurth (1990) concluded that We 21 is a subluminescent WN-type central star of a low excitation planetary nebula. In support of this conclusion, they drew attention to spectral similarities between We 21 and 209 BAC (=WR 124) which van der Hucht et al. (1985) had argued to be another example of a subluminescent WN star in a planetary nebula. We have recently presented a high-resolution study of interstellar sodium absorption towards

209 BAC (Crawford & Barlow 1991), in which we showed that the LSR velocity range occupied by foreground interstellar clouds indicates that 209 BAC lies at a distance of 4–5 kpc, rather than the 0.5 kpc estimated by van der Hucht et al. This result confirmed that 209 BAC is actually a massive Population I WN8 star surrounded by an ejection nebula, and not a PN central star. Esteban et al. (1991) also reached this conclusion based on properties of the nebula, M 1-67, which surrounds 209 BAC. We suggested that We 21 was also likely to be a luminous, distant, Population I WN8 star, and that high-resolution observations of the interstellar Na D lines towards this object could help resolve its status. Such observations have now been obtained.

2. Observations

The spectra of We 21 ($V = 15.3$; Duerbeck & Reipurth 1990) were obtained as a service observation with the Anglo-Australian Telescope on 1991 May 31 U.T., using the UCL Echelle Spectrograph. The 79 grooves mm^{-1} échelle grating was used, giving a dispersion at the Na D lines (order 38) of 2.6 \AA mm^{-1} . The seeing was recorded as 2.0 arcsec FWHM and the spectrograph slit projected to a width of 1.0 arcsec and a length of 14.0 arcsec on the sky. The resolution, based on the FWHM of the Th-Ar comparison lines, was 7.6 km s^{-1} ($R = 39,500$). The detector was a 1024×1024 ($19 \mu\text{m}$ square) pixel Thomson CCD, and several additional échelle orders were recorded, including order 34 which covers the $H\alpha$ emission line.

Three consecutive exposures of the Na D region were obtained, each of 1800 sec duration, together with a Th-Ar comparison spectrum and several flat-field exposures. The spectra were extracted and calibrated using the FIGARO package (Shortridge 1988) on the STARLINK node at University College London. The raw spectra were found to have strong, but unresolved, Na D emission lines (presumably due to air-glow) in the cores of the much broader interstellar absorption lines. These were removed by subtracting the sky spectrum, taken from adjacent rows, from the spectrum of We 21. The spectra were wavelength calibrated by fitting a third-order polynomial to 11 Th-Ar comparison lines (giving an rms residual

of 0.003\AA). Finally, the three spectra were merged (using the DIPSO program; Howarth & Murray 1988) and converted to the LSR velocity frame.

Figure 1 shows the extracted regions of order 38 (He I $\lambda 5876$ and interstellar Na D) and order 34 ($H\alpha$). Figure 2 shows the LSR velocity profiles of the interstellar Na D₂ (5889.950 \AA) and D₁ (5895.924 \AA) lines. The equivalent widths of these lines were measured to be $1.7 \pm 0.2 \text{\AA}$ and $1.4 \pm 0.2 \text{\AA}$ for D₂ and D₁ respectively.

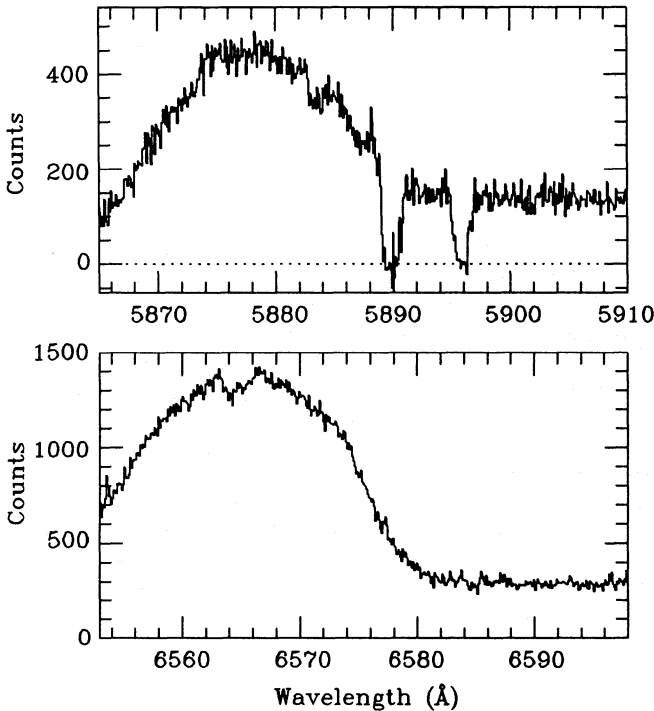


Fig. 1. *Upper:* the region of the Wolf-Rayet He I 5876\AA emission feature and the interstellar Na I D₁ and D₂ absorption lines in the spectrum of We 21. *Lower:* the region of the Wolf-Rayet $H\alpha$ /He II 6-4 emission feature.

3. The stellar spectrum of We 21

As high resolution observations of the spectrum of We 21 have not previously been published, it seems worth reporting a few of the details discernible on our spectrum. Figures 1a and b show the profiles of the emission features due to He I $\lambda 5875.57$ and the blend of $H\alpha$ $\lambda 6562.79$ and He II $\lambda 6560.11$. Duerbeck & Reipurth (1990) reported a mean stellar emission line LSR radial velocity of $+130 \text{ km s}^{-1}$ from their low resolution spectrum. Fits to the emission peaks in Fig. 1 yield $v_{\text{LSR}} = +87 \text{ km s}^{-1}$ for He I $\lambda 5876$ and $v_{\text{LSR}} = +117 \text{ km s}^{-1}$ for $H\alpha$ (if the latter feature was mainly due to He II $\lambda 6560$, its peak radial velocity would be $+239 \text{ km s}^{-1}$, so $H\alpha$ seems to dominate). Our observing set-up did not fully cover the P Cygni absorption profile of He I $\lambda 5876$ nor the blue emission wing of the $H\alpha$ profile. The half-width at zero intensity on the redward side of both lines is 850 km s^{-1} , which may be taken as an indication of the wind expansion velocity. The higher S/N $H\alpha$ spectrum appears to show an absorption feature cutting into

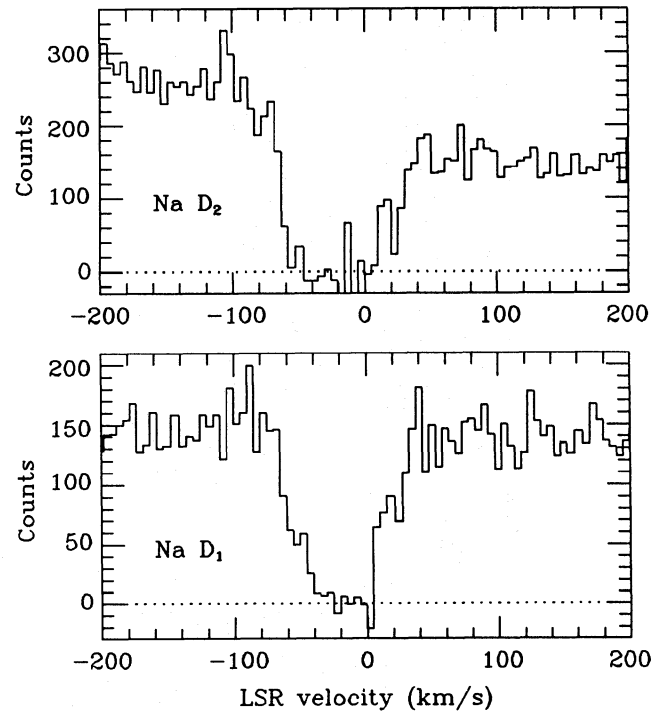


Fig. 2. *Upper:* the Na I D₂ interstellar absorption line observed towards We 21, in the LSR velocity frame. *Lower:* the same for the Na I D₁ absorption line.

its emission peak (Fig. 1b). The absorption might be intrinsic to the WN8 atmosphere (e.g. Moffat & Robert 1991) or it could be a superposed photospheric absorption line due to an O-star companion. However, Moffat & Robert noted that no WN8 star had so far been found to have a spectroscopic companion. The equivalent width of the He I $\lambda 5876$ emission feature in We 21 is 35\AA , compared to the mean of $(34 \pm 17) \text{\AA}$ found for ten galactic WN8 stars by Conti & Massey (1989). We estimate the equivalent width of We 21's $H\alpha$ emission line to be 75\AA , by doubling the equivalent width measured for the redward half of the feature. This compares with a mean (photographic) $H\alpha$ equivalent width of $(47 \pm 8) \text{\AA}$ measured for seven galactic WN8 stars by Conti et al. (1983). There is therefore no evidence for dilution of We 21's emission line equivalent widths by the continuum of an additional star.

4. The interstellar spectrum and distance of We 21

It is immediately apparent from Figure 2 that the interstellar Na absorption towards We 21 occupies a very large velocity range; at the continuum the absorption extends from -65 km s^{-1} to $+30 \text{ km s}^{-1}$ for both lines of the doublet. Moreover, the lines are fully saturated (i.e. there is zero residual intensity) between about -45 to $+10 \text{ km s}^{-1}$ (in D₂) and -40 to $+5 \text{ km s}^{-1}$ (in D₁). The observation that D₁ is somewhat narrower than D₂ in the core indicates that the column densities of the clouds responsible for the extreme positive and negative velocities are insufficient to cause total saturation in the intrinsically weaker D₁ line.

The LSR radial velocities predicted for this line-of-sight by the galactic rotation model of Fich, Blitz & Stark (1989; adopting the IAU standard solar galactocentric distance of 8.5 kpc) are shown in Figure 3. The velocity reaches a maximum negative value of -33 km s^{-1} at a distance of about 4.5 kpc, and then becomes positive as the solar circle is crossed at a distance of 9 kpc; in order to account for the maximum observed positive velocity ($+30 \text{ km s}^{-1}$) a kinematic distance of 11.5 kpc is implied.

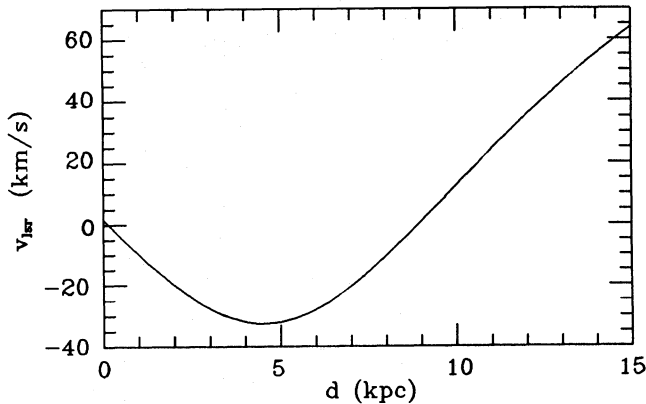


Fig. 3. The LSR radial velocities as a function of distance predicted for the line-of-sight to We 21 ($l = 302^\circ.2$, $b = -1^\circ.3$) by the galactic rotation model of Fich et al. (1989).

As noted by Duerbeck & Reipurth (1990), the line-of-sight to We 21 passes first through the Southern Coalsack (distance about 170 pc; Rodgers 1960, Franco 1989), the near part of the Carina spiral arm (distance about 1 kpc) and the far part of the Carina arm which lies outside the solar circle at a distance of at least 10 kpc (cf. Fig. 3 of Cohen et al. 1985 for a diagram showing the entire extent of the Carina arm). Cohen et al. (1985, Fig. 1; see also Grabelsky et al. 1987) measured a velocity of $+30 \pm 10 \text{ km s}^{-1}$ for CO-emitting clouds in the far part of the Carina Arm, which is consistent with the maximum Na D absorption velocity observed towards We 21.

Cohen et al. obtained a kinematic distance for the far part of the Carina arm in this direction of about 13.5 kpc, but this was based on a solar galactocentric distance of 10 kpc; as can be seen from Fig. 3, the new IAU standard implies the closer distance of 11.5 kpc. The interstellar spectra therefore suggest that We 21 is located at the far intersection of the line of sight with the Carina arm, at a distance of about 11.5 kpc.

Independent confirmation of the expectation that positive velocity gas is not found towards objects in the near Carina arm may be obtained by studying the interstellar spectra of stars known to be located within it. One such star is HD 111904 which is a member of the Cen OB1 association, located in the Carina arm at a distance of 2.5 kpc (Humphreys 1978). This line-of-sight has been discussed in detail elsewhere (Crawford 1991), but as HD 111904 lies within four degrees of We 21, its interstellar spectrum is relevant to this discussion. The spectrum of interstellar Na D towards this star is shown in Figure 4. It can be seen that although this line-of-sight exhibits quite high negative velocities (up to about -40 km s^{-1} , which may be attributed to material in the Carina arm and, possibly, outflow from the Cen OB1 association), there is no absorption

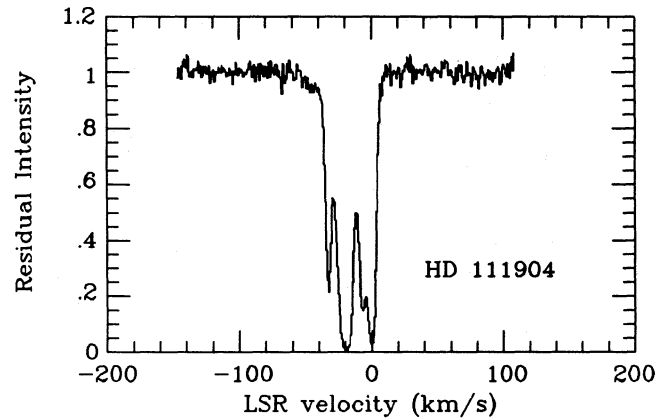


Fig. 4. The interstellar Na I D₂ line observed towards HD 111904, which lies at a distance of 2.5 kpc in the near part of the Carina arm (see Crawford 1991 for details). Note the absence of absorption at positive LSR velocities.

at positive velocities. This provides an independent lower limit of 2.5 kpc for the distance of We 21.

In order to check whether a distance of 11.5 kpc to We 21 implies an absolute magnitude consistent with that of other WN8 stars, we need to estimate the reddening to the star. The reddening to WR stars is normally derived from narrow-band line-free photometry, which has so far not been published for We 21. However, Duerbeck & Reipurth (1990) found $V = 15.30$ and $(B-V) = 1.95$ for We 21 and noted that its spectrum was almost identical to that of 209 BAC (WR 124), for which Schmutz & Vacca (1991) have derived $E(B-V) = 1.10$. Since the observed $(B-V)$ for 209 BAC is 1.07 (Cohen & Barlow 1975), we can estimate $E(B-V) = 1.98$ and $A_V = 6.1$ to We 21. The distance of 11.5 kpc which we have estimated to We 21 then implies an absolute visual magnitude of -6.1 , which is within the range found for galactic and LMC WN8 stars by Torres-Dodgen & Massey (1988).

To summarise, we conclude that We 21 is a massive Population I WN8 star located in the outer part of the Carina arm at a distance of approximately 11.5 kpc. The object may be listed as WR 47a in the numbering system of van der Hucht et al. (1981).

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