Astron. Astrophys. 249, 518–520 (1991)

ASTRONOMY AND ASTROPHYSICS

Research Note

On the distance to M 1–67

I. A. Crawford and M. J. Barlow

Department of Physics and Astronomy, University College London, Gower Street, London WC1E 6BT, UK

Received February 1, accepted February 28, 1991

Abstract. The interstellar Na I D_2 absorption spectrum of 209 BAC, the WN 8 central star of M 1–67, shows a total velocity extent of 60 km s^{-1}. This is consistent with the spread of gas velocities expected from galactic rotation, provided 209 BAC is at a distance of 4–5 kpc, implying that it is a massive Population I WN 8 star surrounded by a stellar ejecta nebula. If M 1–67 was a planetary nebula at a distance of only 0.5–1 kpc, the velocity extent of the Na I absorption line should be 5–6 times smaller than that observed. We suggest that similar observations should be obtained of We 21, recently discovered by Duerbeck & Reipurth to be a WN 8 star in a ring-like nebula.

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

1. Introduction

The Wolf-Rayet nature of the star 209 BAC (= WR 124; van der Hucht et al. 1981) was discovered by Merrill (1938). A 1$'$.5 diameter nebula (M 1–67) around 209 BAC was discovered by Minkowski (1946) during a Hα objective prism survey. Bertola (1964) classified the central star as WN 8, a classification which subsequent investigations have not changed. Bertola noted that WR 124 had a very high radial velocity ($\sim$200 km s^{-1}; as does the nebula: Cohen & Barlow 1975) and proposed that the object was a planetary nebula (PN), as such representing the first example known of a PN with a WN Wolf-Rayet central star (other WR nuclei in PN all being of WC type). Bertola adopted a distance of 0.9 kpc for the system, from Perek (1963), who assumed that it was an ordinary PN.

Cohen & Barlow (1975) argued that M 1–67 was a ring nebula around a Population I WN 8 star, similar to objects such as NGC 6888 and NGC 2359. Based on the WN 8 absolute magnitude calibration of Smith (1973), they estimated a distance to the system of 4.3 kpc and noted that such a distance was far more consistent with the observed interstellar extinction to 209 BAC of $A_V = 4.1$ mag than was the distance of $\sim$0.9 kpc that would be implied if the object were a PN. Chu & Treffers (1981) refined the classification of the M 1–67 nebula from an interstellar wind-blown bubble to a nebula consisting mainly of stellar ejecta slowed down by interaction with the interstellar medium.

Van der Hucht et al. (1985) found strong infrared emission from M 1–67 in the IRAS wavebands and estimated a dust emission colour temperature of $\sim$100 K. They noted that this was close to the colour temperatures found in PN but warmer than found in Population I Wolf-Rayet nebulae. They therefore argued that M 1–67 was a PN and estimated a distance of $\sim$0.5 kpc from the optical angular radius and a statistical relation between dust colour temperature and absolute PN radius.

A possible way to distinguish between the PN and Population I Wolf-Rayet nebula hypotheses for M 1–67 is to measure the velocity extent of interstellar absorption lines in the spectrum of 209 BAC. In the direction of M 1–67 ($l = 50^\circ.2$, $b = +3^\circ.3$), galactic rotation will cause interstellar gas to show a strong radial velocity gradient as a function of distance, such that the widths of absorption lines towards objects less than 1 kpc distant will be much narrower than towards objects which are several kpc distant. We have therefore obtained a spectrum of 209 BAC at the wavelength of the Na I D_2 line (5889.950 Å).

2. Observations

The observation of 209 BAC was obtained on 1990 June 14 with the coudé échelle spectrograph of the Mt. Stromlo 74-inch telescope. The 130-inch focal length camera was used, giving a dispersion of 0.53 Å mm^{-1}, and the slit width was 900 μm, resulting in a velocity resolution of 10.8 km s^{-1} (FWHM). The detector was a two-dimensional PCA (Photon Counting Array; Rodgers et al. 1988) and, with an integration time of 1.5 h, approximately 100 counts were obtained for the continuum in each spectral channel. The PCA image was divided by a flatfield, and the spectrum extracted using the FIGARO package (Shortridge 1988) on the UCL STARLINK node. The background, obtained from the inter-order region, was subtracted, and the spectrum calibrated in wavelength by means of a Th-Ar lamp. Finally the wavelength scale was converted to the LSR velocity frame (assuming a solar motion of 20 km s^{-1} towards $l = 57^\circ$, $b = +22^\circ$; Allen 1973).

Figure 1 shows the observed interstellar Na I D_2 line. It can be seen that the fully saturated core of the line extends from zero to about +60 km s^{-1} relative to the LSR. The "emission" feature in the centre of the absorption line is due to Na I emission by

Send offprint requests to: M.J. Barlow

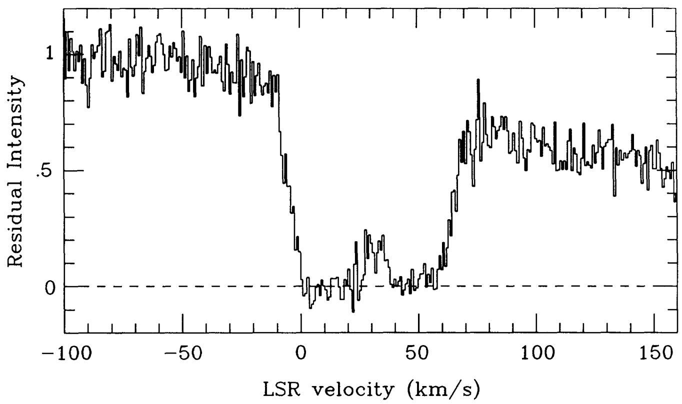

Fig. 1. The spectrum of interstellar Na I $D_2(\lambda5889.95)$ obtained towards 209 BAC. The weak emission feature in the core of the line is due to light pollution from Canberra street lights. The sloping continuum is due to the Na I D_2 line being located in the red wing of the strong, broad, He I 5876 Å emission feature of this $V = 11.1$ WN8 star

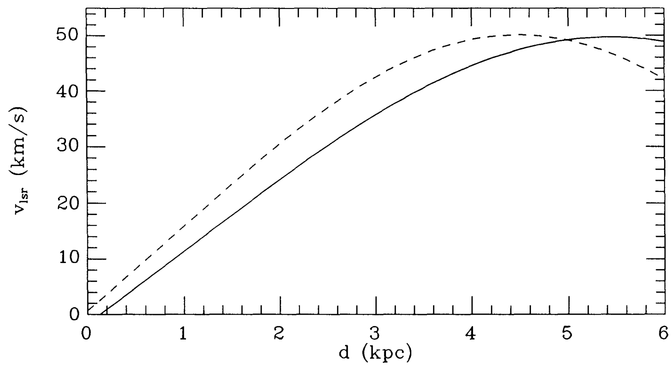

Fig. 2. Solid line: the LSR radial velocity predicted to arise from galactic rotation as a function of distance towards 209 BAC ($l = 50\overset{\circ}{.}2$, $b = +3\overset{\circ}{.}3$), assuming a solar galactocentric distance of 8.5 kpc (Fich et al. 1989). Dashed line: the radial velocity predicted for a solar galactocentric distance of 7 kpc

Canberra street lights. (This feature has zero velocity in the terrestrial reference frame and, in any case, could be traced across the whole length of the slit in the PCA image. The emission was much stronger in the raw data, but has been mostly removed by the background subtraction.)

3. The velocity expected from Galactic rotation, and the distance of 209 BAC

The very large velocity range occupied by interstellar Na I towards 209 BAC immediately indicates that the star lies at a considerable distance from the Sun. Figure 2 shows the LSR radial velocity expected to result from galactic rotation at different distances towards 209 BAC (Fich et al. 1989). The solid line shows the velocities predicted by Fich et al.'s model assuming a solar galactocentric distance of 8.5 kpc. This model indicates a maximum radial velocity of about $+50\,\mathrm{km\,s^{-1}}$ at a heliocentric distance of 5.5 kpc (at larger distances the predicted radial velocity decreases as the tangent point is passed). If M1–67 was at a distance of 0.5–1 kpc, then Galactic rotation would only produce interstellar absorption component velocity spreads of the order of 5–10 $\mathrm{km\,s^{-1}}$ (Fig. 2). Our observations strongly suggest that 209 BAC lies close to or beyond the tangent point along this line-of-sight, and therefore at a distance of approximately 5 kpc. If the Sun's galactocentric distance is assumed to be as low as 7 kpc (e.g. Frenk & White 1982), rather than the IAU standard of 8.5 kpc, then the rotation model of Fich et al. (1989) indicates that the maximum radial velocity occurs at the somewhat closer distance of 4.4 kpc (dashed line in Fig. 2).

The fact that the Na I D_2 line remains saturated out to $+60\,\mathrm{km\,s^{-1}}$ does not conflict with the interpretation that the Na I absorption arises in material corotating with the Galaxy, since interstellar clouds often have peculiar velocities of the order of $10\,\mathrm{km\,s^{-1}}$. Since our spectral resolution is very much narrower than the line profile, the latter has not suffered significant instrumental broadening; a fact that has been verified by convolving the instrumental response function with theoretical line profiles.

We note that absorption in the expanding shell of M1–67 will not contribute to the deep profile shown in Fig. 1, since the LSR radial velocity of the centre of expansion of the nebula lies at $+177\,\mathrm{km\,s^{-1}}$, while the nebular expansion velocity is $42\,\mathrm{km\,s^{-1}}$ (Solf & Carsenty 1982).

4. Discussion

Our results rule out a planetary nebula status for M1–67, and confirm the distance of ~4 kpc implied if 209 BAC is a massive WR star. Esteban et al. (1991) have provided independent evidence for this conclusion. They find N-enhancement and O-depletion in the nebula, consistent with ejection from a massive star. They show that the reddening versus distance relation for stars in the field around M1–67 implies a distance larger than 1.5–2.5 kpc for the nebula and exciting star. Finally, they show that the argument put forward by van der Hucht et al. (1985) for the reclassification of M1–67 as a PN, namely that its infrared flux distribution resembles those of PN and not those of other WN-nebulae, is not supported when the integrated IRAS Sky Flux data for the larger WR nebulae are considered.

Duerbeck & Reipurth (1990) have recently discovered a WN8 star (We 21) immersed in a ring-like nebula resembling M1–67. By analogy with the conclusions of van der Hucht et al. (1985), they argue that nebula around We 21 is a PN, in which case a distance of 1 kpc would be implied. In support of this interpretation, they show that the nebula abuts, and appears to illuminate the edge of, a region of CO molecular emission in the Southern Coalsack zone and that the observed CO emission radial velocities from this region are consistent with is being no further than the 1 kpc distance of the inner Carina spiral arm. Clearly, our present results on M1–67 would lead us to interpret the nebula around We 21 as a ring nebula around a massive WN8 star. The photometry of Duerbeck & Reipurth (1990) and the calibration of Torres-Dodgen & Massey (1988) would then imply a distance of 7–8 kpc to the system. Figure 3 shows the LSR radial velocity dependence on distance that is predicted by the galactic rotation model of Fich et al. (1989) in the direction of We 21 ($l = 302\overset{\circ}{.}3$, $b = -1\overset{\circ}{.}3$). Figure 3 shows that absorption components from interstellar gas out to 1 kpc should only have a velocity extent of $\sim 10\,\mathrm{km\,s^{-1}}$, while absorption components in front of a star at 7–8 kpc should show a total velocity extent of $\sim 35\,\mathrm{km\,s^{-1}}$. The stellar radial velocity of $v_{\mathrm{LSR}} = +130\,\mathrm{km\,s^{-1}}$ found for We 21 by Duerbeck & Reipurth (1990) should again ensure that any absorption arising

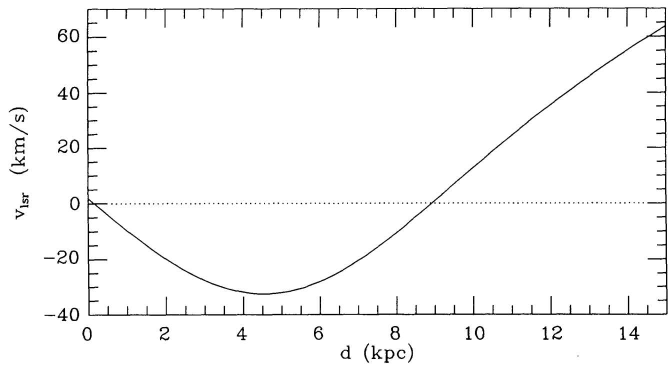

Fig. 3. The LSR radial velocity predicted as a function of distance for the line-of-sight towards We 21 ($l = 302\overset{\circ}{.}3$, $b = -1\overset{\circ}{.}3$) for an assumed solar galactocentric distance of 8.5 kpc (Fich et al. 1989). Here the calculation has been performed out to a distance of 15 kpc; in this direction the radial velocity is initially negative, but changes sign when the line of sight crosses the solar circle

in the nebular shell around We 21 will be well separated in velocity from interstellar absorption components. An interstellar absorption line spectrum of We 21 is therefore desirable. With $V = 15.30$ and $B - V = 1.95$ (Duerbeck & Reipurth 1990), We 21 is quite faint for high resolution absorption line spectroscopy. However, as was the case with 209 BAC, absorption in the Na I *D*-lines will occur in the red wing of the broad He I 5876 Å WN8 emission feature, significantly elevating the local "continuum" in the vicinity of the *D*-lines.

Acknowledgements. We thank C. Esteban, J.M. Vilchez, L.J. Smith, and A. Manchado for a preprint of their paper on M1-67. We thank the Mt Stromlo and Siding Spring Observatories for the award of time on the 74-inch telescope, and the UK Panel for the Allocation of Telescope Time (PATT) for the provision of travel money.

References

Allen C.W., 1973, Astrophysical Quantities, Athlone Press, London
Bertola F., 1964, PASP 76, 241
Chu Y-H., Treffers R.R., 1981, ApJ 249, 586
Cohen M., Barlow M.J., 1975, Astrophys. Lett. 16, 165
Duerbeck H.W., Reipurth B., 1990, A&A 231, L11
Esteban C., Vilchez J.M., Smith L.J., Manchado A., 1991, A&A 244, 205
Fich M., Blitz L., Stark A.A., 1989, ApJ 342, 272
Frenk C.S., White S.D.M., 1982, MNRAS 198, 173
Merrill P.W., 1938, PASP 50, 350
Minkowski R., 1946, PASP 58, 305
Perek L., 1963, Bull. Astron. Inst. Czech. 14, 201
Rodgers A.W., van Harmelen J., King D., Conroy P., Harding P., 1988, PASP 100, 841
Shortridge K., 1988, Starlink User Note, No. 86
Smith L.F., 1973, IAU Symp. No. 49, eds. M.K.V., Bappu, J. Sahade, Reidel, Dordrecht, p. 15
Solf J., Carsenty U., 1982, A&A 116, 54
Torres-Dodgen A.V., Massey P., 1988, AJ 96, 1076
van der Hucht K.A., Conti P.S., Lundstrom I., Stenholm B., 1981, Space Sci. Rev. 28, 227
van der Hucht K.A., Jurriens T.A., Olnon F.N., The P.S., Wesselius P.R., Williams P.M., 1985, A&A 145, L16