Mon. Not. R. Astron. Soc. **283,** L69–L71 (1996)

The expansion of the outer circumstellar shell of P Cygni

J. Meaburn,[1] J. A. López,[2] M. J. Barlow[3] and J. E. Drew[4]

[1]*Department of Physics and Astronomy, University of Manchester, Oxford Road, Manchester M13 9PL*
[2]*Instituto de Astronomía, UNAM, Apdo Postal 877, Ensenada, BC 22800, México*
[3]*Department of Physics and Astronomy, University College London, Gower Street, London WC1E 6BT*
[4]*Department of Physics, Imperial College of Science, Technology & Medicine, Prince Consort Road, London SW7 2BZ*

Accepted 1996 August 29. Received 1996 August 28; in original form 1996 July 23

ABSTRACT

The expansion of a faint, outer irregular shell to the circumstellar nebulosity of the luminous blue variable P Cygni has been measured with the Manchester Echelle Spectrometer combined with the high-altitude San Pedro Mártir 2.1-m UNAM telescope. This is the first ever measurement of the expansion velocity of such a historic remnant of a luminous blue variable star eruption. The faintness of the outer shell and the high brightness and close proximity of the star make it a particularly difficult observation. The high optical luminosity of the spectrometer and the clarity of the sky have combined to permit a successful measurement.

A radial expansion velocity of 185 ± 10 km s^{-1} is implied, which suggests an age of 2100 ± 200 yr for this 1.6 arcmin diameter outer shell, if we assume a distance of 1.8 kpc to P Cygni.

Key words: line: profiles – circumstellar matter – stars: individual: P Cygni – stars: mass-loss – ISM: bubbles.

1 INTRODUCTION

The nebulosities surrounding luminous blue variables (LBVs) are of considerable interest, for they are the relics of the most recent eruptions of these stars. Expanding shells of circumstellar gas have now been found around six galactic LBVs [see Barlow et al. (1994) and Nota et al. (1995) for a summary of these observations]. In particular, two distinctly different shells were found (Barlow et al. 1994) with occulting-mask imagery around P Cygni ($V=4.8$). A bright inner shell, of $\approx$22-arcsec diameter, has a radial expansion velocity of 140 km s^{-1} in the [N II] λ6584-Å line, but only 110 km s^{-1} in the exceptionally bright [Ni II] $\lambda\lambda$7378- and 7412-Å lines. Lucy (1995) has explained convincingly the dominance of the [Ni II] $\lambda\lambda$7378- and 7412-Å emission, showing that the [Ni II] emission in ejected globules is being fluorescently excited by the intense near-UV flux of P Cygni. Bow-shocks around these globules, generated by the subsequent 206 km s^{-1} (Lamers, Korevaar & Cassatella 1985) wind from P Cygni, can then be invoked to explain the difference between the [N II] λ6584-Å and [Ni II] $\lambda\lambda$7378- and 7412-Å expansion velocities (Barlow et al. 1994).

The second circumstellar shell, with a diameter of $\approx$1.6 arcmin, is both far larger and fainter than the inner shell. Consequently, measurements of its kinematics were hampered in the previous long-slit observations with the Manchester Echelle Spectrometer (MES) (Meaburn et al. 1984) by the scattered continuous and line emission from P Cygni. The centres of all of these previous east–west orientated slit positions were within $\pm$10 arcsec, in a north–south direction, of the star.

A successful observation has now been made of the expansion velocity of this outer shell, in the [N II] λ6584-Å line with the MES on the San Pedro Mártir 2.1-m UNAM telescope.

2 OBSERVATIONS AND RESULTS

The long-slit observations were obtained with the Manchester Echelle Spectrometer (MES) (Meaburn et al. 1984), combined with the *f*/7.9 focus of the 2.1-m San Pedro Mártir UNAM telescope, on 1996 April 18. This spectrometer has no cross-dispersion. For the present observations, filters of

90-Å bandwidth were used to isolate the 87th order containing the Hα and [N II] λ6584-Å nebular emission lines.

A Textronix CCD with 1024 × 1024, 24 μm square pixels was the detector. Two-times binning was employed in both the spatial and spectral dimensions. Consequently, 512 increments, each 0.60 arcsec long, gave a total projected slit length of 5.12-arcmin on the sky. 'Seeing' varied between 1 and 2 arcsec during these observations. The slit was 150 μm wide ($\equiv$10 km s^{-1} and 1.9 arcsec) and the integration time was 1000 s. The spectrum was calibrated to $\pm$1 km s^{-1} accuracy against that of a Th–Ar arc lamp.

The east–west slit position, 24 arcsec north of P Cygni, where profiles of the Hα and [N II] λ6584-Å lines were obtained, is shown against an [N II] λ6584-Å image of the outer circumstellar shell of P Cygni in Fig. 1 (opposite) [fig. 3(b) in Barlow et al. (1994)]. This image was obtained with a north–south occulting slit intersecting the central star.

The resultant position–velocity (PV) array of Hα and [N II] λ6584-Å line profiles was still heavily contaminated with the scattered Hα and continuum emission of P Cygni. (Note that a PV array contains all the spatially resolved line profiles along the long slit of the spectrometer.) Attempts to extract the Hα profiles from the outer shell were foiled by the intensity of this contamination. However, [N II] λ6584-Å emission from the outer shell could be seen in the raw PV data array. Consequently, two subtractions were made to minimize the impact of this scattering in both spatial and spectral dimensions on these [N II] λ6584-Å profiles. First, the mean spectrum along broad spectral strips just above and below the diameter of the outer shell was subtracted from the whole array. Then the mean brightness variations along the slit on either side of the [N II] λ6584-Å profiles from the outer shell were similarlysubtracted.

A grey-scale representation of the resultant PV array of [N II] λ6584-Å profiles is shown in Fig. 2 (opposite p. 71). The dark vertical band is the residual of the scattered P Cygni emission after this process. However, split [N II] λ6584-Å line profiles can be seen to form a 'velocity ellipse' 320 ± 20 km s^{-1} in extent, the outer edges of which coincide with those of the outer shell in Fig. 1. This 'velocity ellipse' is nearly symmetric around the systemic radial velocity of P Cygni ($V_{\rm HEL} = -25$ km s^{-1}). The dark horizontal features along $V_{\rm HEL} = -150$ km s^{-1} in Fig. 2 are most likely artefacts. However, the faint features that stretch from -100 arcsec east to 130 arcsec west at $V_{\rm HEL} \approx 80$ km s^{-1} are possibly real and worthy of further observation.

3 DISCUSSION

The maximum splitting of the [N II] λ6584-Å profiles 24 arcsec north of P Cygni implies an expansion velocity for the outer 1.6 arcmin diameter shell of 160/cos 30°, i.e. of 185 ± 10 km s^{-1}. Here, 30° is the angle between the sight-line and the line connecting the position of maximum splitting and the star. In this case the 1.6 arcmin diameter shell is approximated as a sphere. For a distance of 1.8 kpc [based on membership of the open cluster IC 4996 (van Schewick 1968)] and at constant expansion velocity, to reach a diameter of 0.84 pc ($\equiv$1.6 arcmin) the outer shell must be 2100 ± 200 yr old. Skinner et al. (1996) have mapped the free–free emission from the outer nebulosity around P Cygni by combining VLA data from various epochs and array baselines. They comment that the approximate age (although with no velocity mesurement) for the outer 1.6 arcmin diameter nebulosity, of about 2000 yr, puts its origin interestingly close to an event appearing in certain biblical records. The more certain age derived here lends support to this conjecture (P Cygni is low in the west in evening twilight during the winter solstice).

The origin of the ionization of the outer 1.6-arcmin nebulosity is not clear at present. Barlow et al. (1994) found that the [N II] λ6584-Å emission from the inner 22-arcsec nebulosity originated from stellar wind-generated bow-shocks around embedded neutral globules, the latter being revealed by their strong [Ni II] λλ7378- and 7412-Å emission. Spectra in the [NiII] λλ7378- and 7412-Å lines would be required to determine whether or not this mechanism also applies to the outer 1.6 arcmin diameter nebula. If it does, then, by analogy with the inner nebulosity, the expansion velocity of the embedded globules could be expected to be somewhat smaller than that derived from the [N II] λ6584-Å line. On the other hand, it is not clear that neutral globules could have survived the buffeting from P Cygni's massive wind for 2000 years. Given that the current velocity of the outer shell is only 20 ± 10 km s^{-1} smaller than the current terminal velocity of P Cygni's wind, the outer shell might represent material that originally had an expansion velocity similar to that of the inner neutral globules (110 km s^{-1}), but which has now been disrupted and swept up to higher velocities by the wind; or it might just represent an episode of enhanced mass loss by P Cygni which has always had its current velocity.

Although P Cygni is currently too cool to produce enough Lyman continuum photons to ionize the outer nebula, it may have experienced an LBV excursion to higher $T_{\rm eff}$ since the time of the outburst $\approx$2100 yr ago, producing a large enough flux of Lyman continuum photons to photoionize the ejecta. This flux has since switched off. However, since the recombination time-scale for ionized gas is $1.2 \times 10^5/N_{\rm e}$ yr and the electron density $N_{\rm e}$ estimated by Skinner et al. (1996) for the 1.6-arcmin shell is about 20 cm^{-3}, the material would not yet have recombined.

The previous (Barlow et al. 1994) and present observations have identified shells from outbursts from P Cygni $\approx$900 and $\approx$2000 yr ago respectively. It would now be interesting to search for even larger shells to map out the eruptive history of this star.

ACKNOWLEDGMENTS

We acknowledge the excellent assistance of staff at the San Pedro Mártir telescope where these observations were made. JM is grateful to PPARC for funding the conversion of the Manchester Echelle Spectrometer for use on the San Pedro Mártir telescope. JAL acknowledges support from CONACYT and DGAPA-UNAM.

REFERENCES

Barlow M J., Drew J. E., Meaburn J., Massey R. M., 1994, MNRAS, 268, L29

Opposite p. L70, MNRAS, **283**

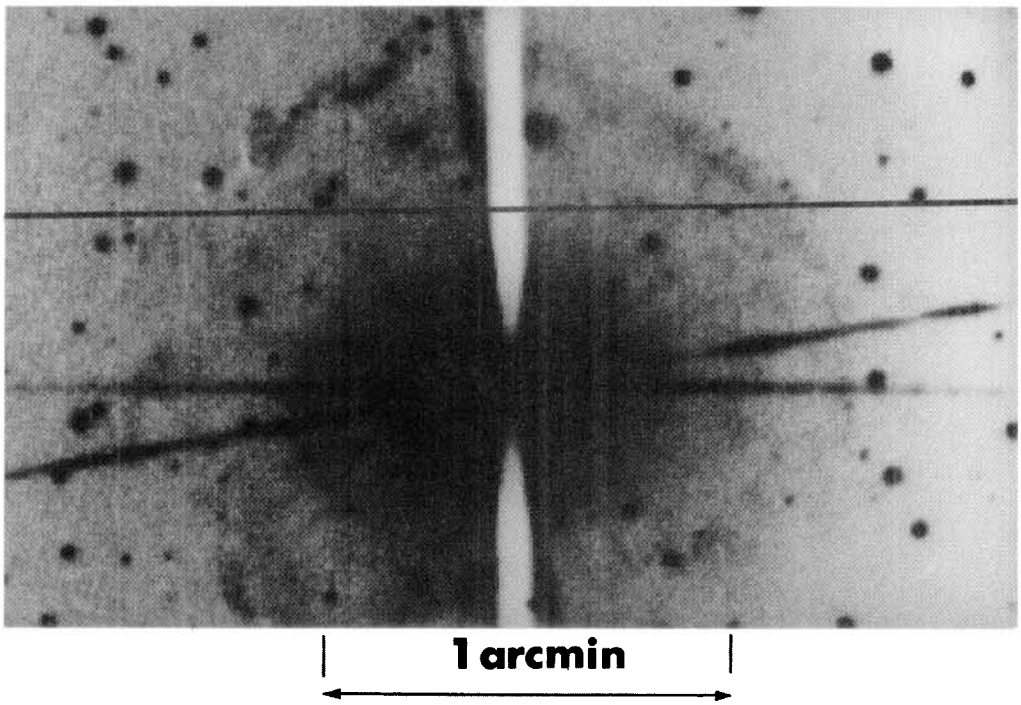

Figure 1. The east–west slit position is shown against a negative [N II] λ6584-Å image of the outer circumstellar shell of P Cygni. The vertical white band is caused by the occulting strip which intersects the star.

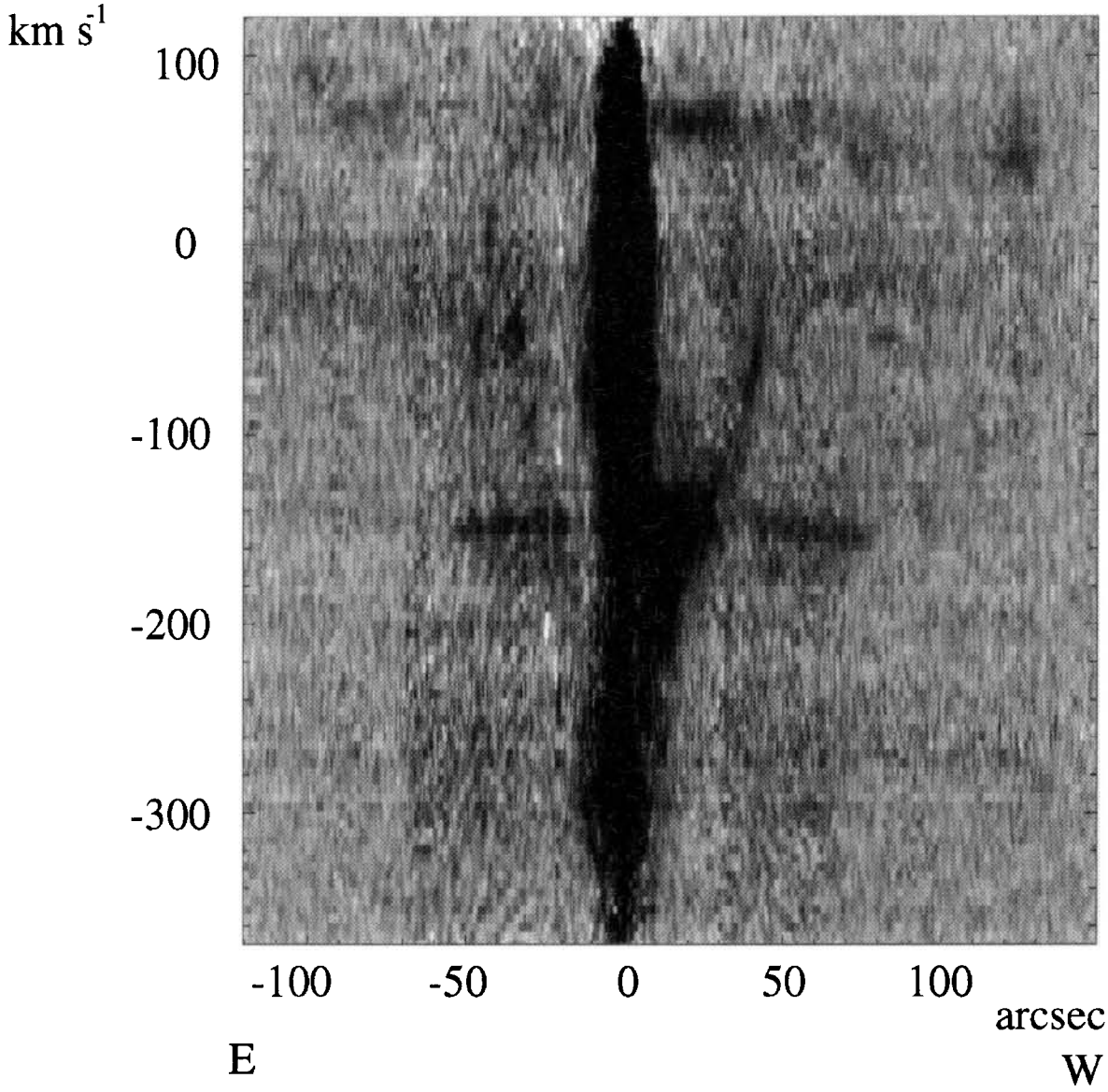

Figure 2. A negative grey-scale representation of the position–velocity array of [N II] λ6584-Å profiles along the east–west slit shown in Fig. 1. The vertical dark band is a residual spectrum of the scattered light from P Cygni and the inner shell after subtraction. The horizontal band at $V_{\rm HEL} \approx -150$ km s^{-1} is similarly an artefact, whereas the horizontal band at $\approx +80$ km s^{-1} could be real. The [N II] λ6584-Å profiles from the outer shell can be seen to form a 'velocity ellipse', 320 km s^{-1} in extent. The radial velocity scale is heliocentric.

Lamers H. J. G. L. M., Korevaar P., Cassatella A., 1985, A&A, 149, 29
Lucy L. B., 1995, A&A, 294, 555
Meaburn J., Blundell B., Carling R., Gregory D. F., Keir D., Wynne C., 1984, MNRAS, 210, 463
Nota A., Livio M., Clampin M., Schulte-Ladbeck R., 1995, ApJ, 448, 788
Skinner C. J., Becker R. H., White R. L., Exter K. M., Barlow M. J., Davis R. J., 1996, ApJ, submitted
van Schewick H., 1968, Z. Astrphys., 68, 229