STUDIES OF THE LARGE MAGELLANIC CLOUD USING OPTICAL INTERSTELLAR EMISSION LINES

J. MEABURN
Department of Astronomy
The University
Manchester M13 9PL
England

ABSTRACT. Optical observations have been made of the halo of 30 Doradus, in the vicinity of SN 1987A and of giant shells in the LMC.

1. Introduction

Spatially resolved observations of profiles of optical emission lines combined with deep Hα photographs have revealed a complex array of kinematical and morphological phenomena along many sight-lines through the Large Magellanic Cloud (LMC). Localised motions of several origins, invariably associated with bursts of star formation in the vicinity of giant interstellar shells, are superimposed on the pre-existing motions of the giant molecular clouds which constitute the spiral features of the young LMC (McGee and Milton 1966, Feitzinger and Weiss 1979). The kinematics and morphology of some particularly significant regions will be illustrated by comparing positional - velocity (p-v) arrays of emission line profiles with deep images. These profiles were obtained principally with the Manchester echelle spectrometer (Meaburn *et al.* 1984).

2. Halo of 30 Doradus

The only truly massive HII complex in the LMC, 30 Dor, occupies a unique position as the nucleus of the spiral features of the youngest phenomena (Schmidt-Kaler and Feitzinger 1976). Its dense ionized core is energised by the OB association around R136. Filamentary ionized shells whose diameters (30-100 pc) increase with distance from the core surround separate OB associations distributed throughout the halo. These giant shells culminate in the two supergiant shells that can be seen in Figure 1 (Meaburn 1979 and 1980). The lines along which spatially resolved profiles of Hα and [OIII] emission lines were obtained (Meaburn 1981, 1984 and 1988) are shown against a sketch of the ionized filaments and star clusters of 30 Dor in Figure 2.

It is important to realise that the application of different analytical techniques to the same long-slit spectrum reveals distinctly separate types of kinematical behaviour. For example, Gaussian fitting of complex profiles is most useful for tracing separate velocity components along a p-v array. Contouring is poor for this purpose but permits the display of high-velocity spikes etc. where Gaussian fitting has no application.

The positions of components with separate radial velocities, after simulation of the line profiles by multiple Gaussians, are depicted in Figure 3a for the NS line in Figure 2 (Meaburn 1981) and in Figure 3b for one of the EW lines in Figure 2 (Meaburn 1984). Only components which appear as

R. Haynes and D. Milne (eds.), The Magellanic Clouds, 421–427.

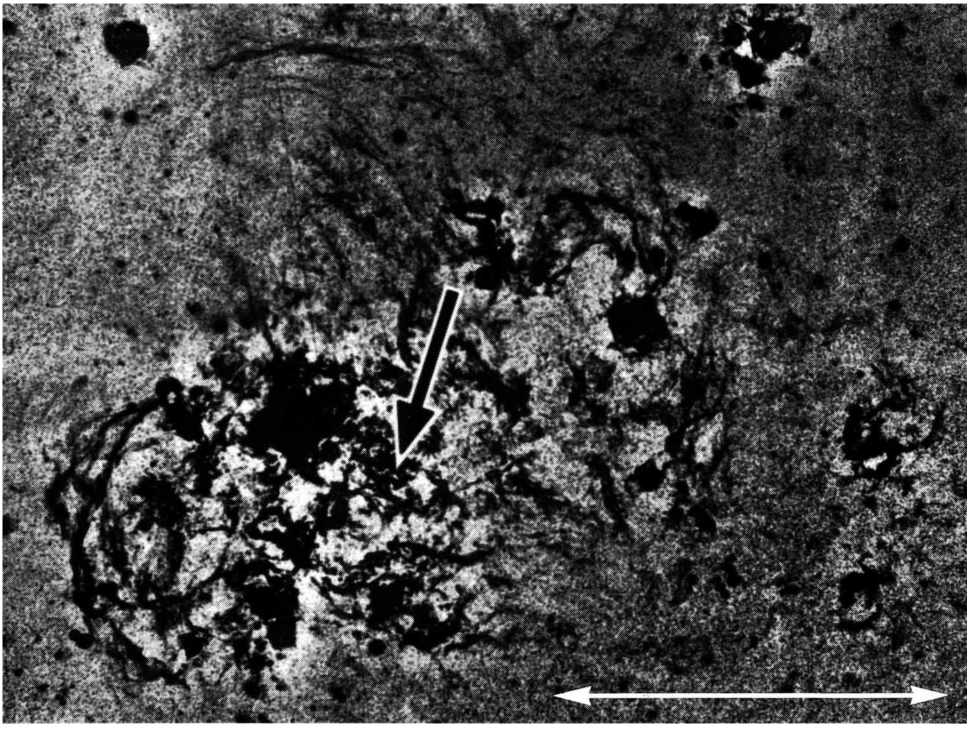

Figure 1. A deep Hα photograph of the vicinity of 30 Dor. SN 1987A is arrowed. The white line is 1 Kpc long.

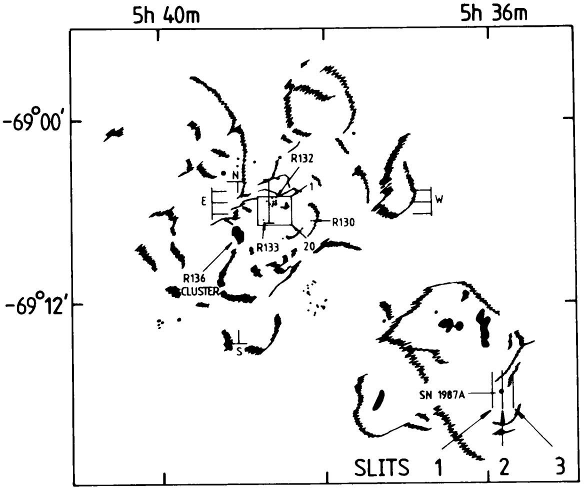

Figure 2. Paths along which optical line profiles have been obtained over 30 Dor and near SN 1987A.

https://doi.org/10.1017/S0074180900201058 Published online by Cambridge University Press

distinct maxima in the profiles are included to eliminate any possibility of over-interpretation. The extents of non-Gaussian wings to profiles are shown as arrowed lines in Figure 3b. High velocity ridges are contained within dashed lines. The nature of one of these is better displayed in the contour map in Figure 4a for the p-v array over the cluster containing R132 (Figure 2).

The existence of a sheet of ionized gas in the halo of 30 Dor with a high radial velocity (≈ -200 km/s) with respect to the systemic (Figure 3b) is also illustrated in Figure 4b, where an extensive feature with V_{HEL} = 90 - 130 km/s is present along the southern slit lengths of the box of slit positions around R132 in Figure 2 (also see Chu and Kennicutt, 1990).

Some sense can be made out of this confusion of features in the p-v arrays. Firstly, bright, extensive velocity components are present which are coincident with those at V_{HEL} ≈ 246, 265, 277 and 296 km/s in the HI 21 cm profiles over this region. These must then have been produced as the primeval molecular clouds became photoionized by the Lyman flux from the newly formed stars.

Continuous features abound in the p-v arrays which systematically diverge in radial velocity by 30 - 50 km/s over distances of 25 - 50 pc (for diameters of 50 - 100 pc). Radial expansions of the approximately spherical, giant shells in the halo of 30 Dor are implied. If the extreme sheet with V_{HEL} ≈ 100 km/s (Figures 3b and 4b) has this origin then an expansion velocity for this giant shell would be 200 km/s. Alternatively, this extensive, high-speed feature may represent a centrally-driven outflow from the vicinity of R136 (Meaburn 1981).

Every sight-line through the halo of 30 Dor then intersects several giant shells each with a different expansion velocity. Any explanation of these halo giant shells must also apply to those giant shells in the LMC which surround isolated OB associations (see the discussion in Section 4). The supergiant shells near 30 Dor (Figure 1) may be spherical but those well away are most likely toroidal. In all cases, stochastic star formation in their expanding perimeters is their most likely origin.

The most dramatic features in the p-v arrays over the halo of 30 Dor are the ≈ 15 pc diameter regions emitting complex profiles which extend out to ± 250 km/s (eg. Figures 3a and 4a). That around the R132 cluster (Figures 2 and 4a) has all the characteristics of a high-speed expanding shell. Bursts of stellar wind from enclosed O-type or WR stars could produce energy-conserving bubbles such as these in ≤ 10^4 yrs (Dyson and de Vries 1972). However, these features are more likely manifestations of the remnants of Type II supernova explosions of similar ages. In the limited area of 30 Dor sampled here (say 10% - see Figure 2) there are ≈ 4 of these 15 pc diameter high-speed regions, in which case ≈ 40 could be expected, in the whole halo of 30 Dor, to give an average time between explosions $\tau \leq 250$ yr if the supernova explanation applies. The halo of 30 Dor may then be a region of exceptionally high supernova activity. (Mathewson *et al.* 1983 give $\tau \approx 275$ yr for the rest of the LMC.)

3. SN 1987A

Extensive (≥ 30 pc across) clouds of ionized gas with distinctly separate radial velocities of V_{HEL} = 255, 280, 300 and 318 km/s are revealed (Meaburn 1990) in the p-v arrays of [OIII] profiles in the vicinity of SN 1987A (slits 1-3 in Figure 2 and see Figure 5). Those at 255 and 280 km/s closely match velocity components in the interstellar absorption line profiles found in the light of SN 1987A (see Pettini 1988 and Savage *et al.* 1989 for a summary of many authors' work), and must consequently be from sheets of neutral and ionized interstellar gas on the nearside of the explosion (i.e. the nearsides of giant shells). The 300 and 318 km/s clouds are likely to be on the far side.

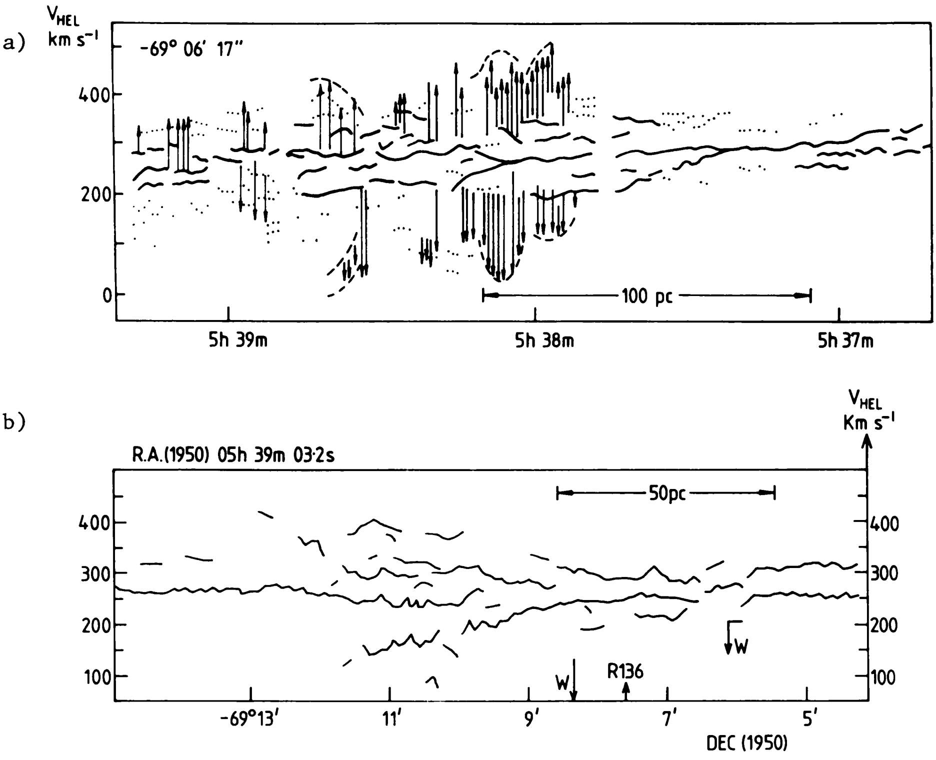

Figure 3. Separate velocity components along the a) EW and b) NS lines marked in Fig. 2 are traced by heavy solid lines for major features. Arrowed lines imply wings. High speed shells are contained within the dashed lines.

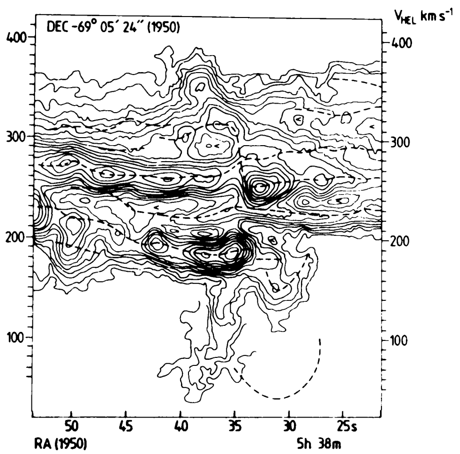

Figure 4a. Contours of the p-v array of [OIII] profiles from the EW line over R132 in Fig. 2.

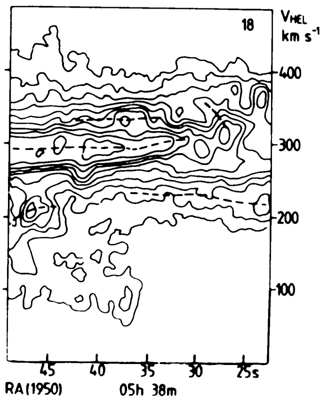

Figure 4b. As for a) but from the southern part of the box around R132 also shown in Fig. 2.

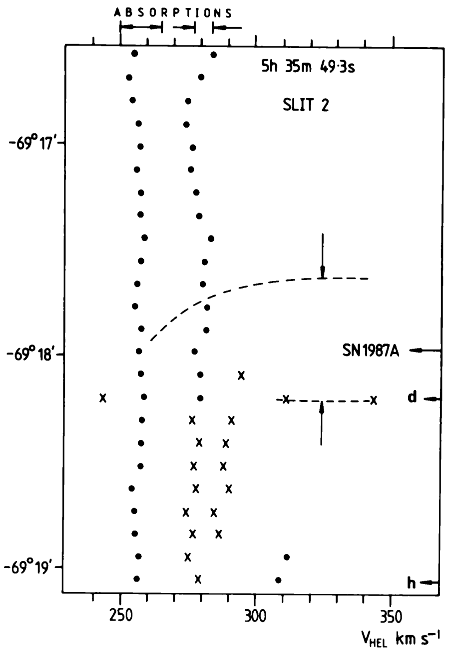

Figure 5. Velocity components in [OIII] profiles along slit (2) in Fig. 2 over SN 1987A. The dashed lines mark ridges.

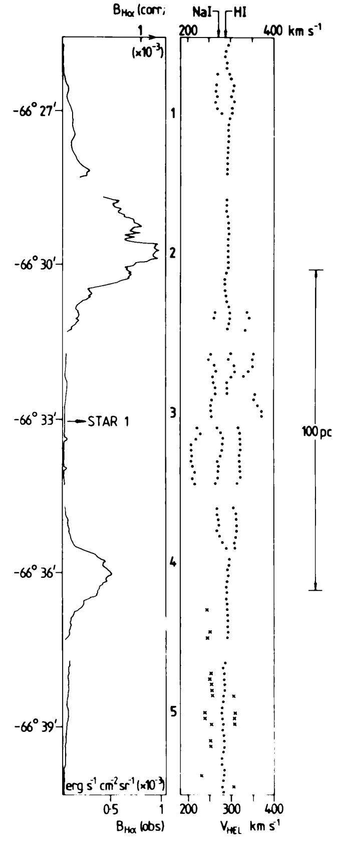

Figure 6. Velocity components along a line through the giant shell N11 (DEM 34).

https://doi.org/10.1017/S0074180900201058 Published online by Cambridge University Press

In the p-v array for slit 2 in Figure 2, which is the closest to SN 1987A, two ridges project ≈ 100 km/s towards positive radial velocities on either side of the supernova (shown as dashed curves in Figure 5). Although higher signal-to-noise ratios are required to map these features completely, an elongated cavity ≈ 8 pc across could be present, with outflowing walls, similar to one lobe of many galactic bi-polar nebulae.

It is proposed that the precursor star, in its red giant phase, emitted a slow, dense wind which formed a disc. The later hypersonic, supergiant wind could then have driven elongated cavities perpendicular to the plane of the disc. The remnant is now expanding into this most likely bi-polar structure.

4. Giant shells

There are three sub-groups in the classification of giant (20 - 350 pc diameter) LMC shells (see Meaburn *et al.* 1989 and see refs. therein for many authors' optical and other observations). Evolved supernova remnants appear as isolated, fine filamentary shells. Filamentary shells also surround OB associations, and shells with more amorphous filaments surround old associations with younger associations in their perimeters.

Stellar winds from OB and WR stars could combine with a modest number of successive supernova explosions in the central OB associations to pressurise the expansions of the latter two types of giant shell. Alternatively, supernova explosions could dominate all other sources if these events are sufficiently frequent.

An attempt has been made (Meaburn *et al* 1989) in recent observations of the amorphous, 350 pc diameter LMC giant shell, N11 (DEM 34) to investigate these possibilities quantitatively. Complex radial expansion of ≈ 80 km/s (see Figure 6) is occurring in the tenuous ionized gas over the central and oldest OB association, LH9, which emits Lyman photons at the same rate as would 7 ± 4 supergiant 05 type stars. The expanding ionized gas has an observed kinetic energy KE (Obs) ≈ 2.3 x 10^{50} erg and momentum P (Obs) ≈ 10^{44} g cm/s. If the energy conversion efficiency is defined as ε_E = KE (Obs)/KE (In) and momentum efficiency as ε_P = P (Obs)/P (In) then for energy conserving, pressure driven bubbles $\varepsilon_E = 0.2$ and $\varepsilon_P >> 1$, and for momentum conserving shells (snowploughs) $\varepsilon_P << 1$ and $\varepsilon_P \approx 1$.

If Type II LMC explosions occur predominantly in OB associations and if their probability of occurence is naively taken to be proportional to the total Lyman flux from each association, then around 160 ± 80 explosions are expected in the lifetime (< 10^7 yr) of LH 9 to drive the expansion of N11.

With this number, then $\varepsilon_E \approx 0.001$and $\varepsilon_P \approx 0.3$, which suggests that the motions are those of momentum conserving shells with winds playing little part in their generation. However, a better method of estimating the rate of supernova explosions in OB associations is needed before any certain conclusions are drawn. This may arise from X-ray observations similar to those of Chu and Low (1990). They show remnants in collision with the inner surfaces of giant LMC shells.

5. References

Chu, Y. and Kennicutt, R.C. (1990), this volume.
Chu, Y. and Low, M.M. (1990), *Astrophys. J.* in press.
Dyson, J.E. and de Vries, J. (1972), *Astron. Astrophys.* **20**, 223.

Feitzinger, J.V. and Weiss, G. (1979), *Astron. Astrophys. Suppl.* **37**, 575.

Mathewson, D.S., Ford, V.L., Dopita, M.A., Tuohy, I.R., Long, K.S. and Helfand, D.J. (1983), *Astrophys. J. Suppl.* **51**, 345.

McGee, R.X. and Milton, J.A. (1966), *Australian J. Phys.* **19**, 343.

Meaburn, J. (1979), *Astron. Astrophys.* **75**, 127.

Meaburn, J. (1980), *Mon. Not. R. Astron. Soc.* **192**, 365.

Meaburn, J. (1981), *Mon. Not. R. Astron. Soc.* **196**, 19P.

Meaburn, J. (1984), *Mon. Not. R. Astron. Soc.* **211**, 521.

Meaburn, J. (1988), *Mon. Not. R. Astron. Soc.* **235**, 375.

Meaburn, J. (1990), *Mon. Not. R. Astron. Soc.* **244**, 551.

Meaburn, J., Blundell, B., Carling, R., Gregory, D.F., Keir, D. and Wynne C.G. (1984), *Mon. Not. R. Astron. Soc.* **210**, 463.

Meaburn, J., Solomos, N., Laspias, V. and Goudis, C.D. (1989), *Astron. Astrophys.* **225**, 497.

Pettini, M. (1988), *Proc. Astr. Soc. Australia* **7**, 527.

Savage, B.D., Jenkins, E.B., Joseph, C.L. and de Boer, K.S. (1989), *Astrophys. J.* **345**, 393.

Schmidt-Kaler, Th. and Feitzinger, J.V. (1976), *Astrophys. Space Sci.* **41**, 357.