OPTICAL GIANT AND SUPERGIANT INTERSTELLAR SHELLS

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ABSTRACT

Giant (20 - 260 pc) and supergiant (600 - 1400 pc) filamentary ionized shells are found in several galaxies. Some giant shells are collisionally ionized supernova remnants but many surround ≃ 5 - 50 OB stars and, if approximately spherical, could be formed by the combined effects of successive, 10^{50} erg, supernova explosions, pressure of the Lyman photons and stellar winds. Other mechanisms are required for their supergiant counterparts for perhaps they are toroidal rings rather than radially expanding spherical shells.

INTRODUCTION

High contrast, unsharp masked,prints of deep photographs of the LMC, through narrow-band interference filters (Meaburn, 1978) centred on Hα + [N II] , with the 1.2-m SERC Schmidt camera, have revealed the presence of 85 giant (20 - 260 pc diam.) filamentary shells and possibly as many as 9 supergiant (600 - 1400 pc diam.) ones.

Photographs of these have been published by Meaburn, (1979, 1980 and 1981a) and references cited therein, and a sketch of the supergiant shells SGS LMC 1 - 9 is shown in Figure 1 compared with the young ($\lesssim 10^7$ yr old) spiral arms of the LMC (Schmidt-Kaler, 1977).

The shells SGS LMC 1-6 are very clear filamentary rings on these prints and 7 and 8 are large irregular regions of filaments. SGS LMC 9 is less certainly detected but here a very faint ionized ridge connects a group of interlocking giant shells and partially completes the circumference of a circle.

In the LMC a typical giant shell has filaments of Hα + [N II] emission on the inside edge of a corresponding HI shell all of which surround an OB association containing anywhere between 5 - 50 hot blue stars. In some cases (Chu and Lasker, 1981) Wolf-Rayet stars are also present in these clusters.

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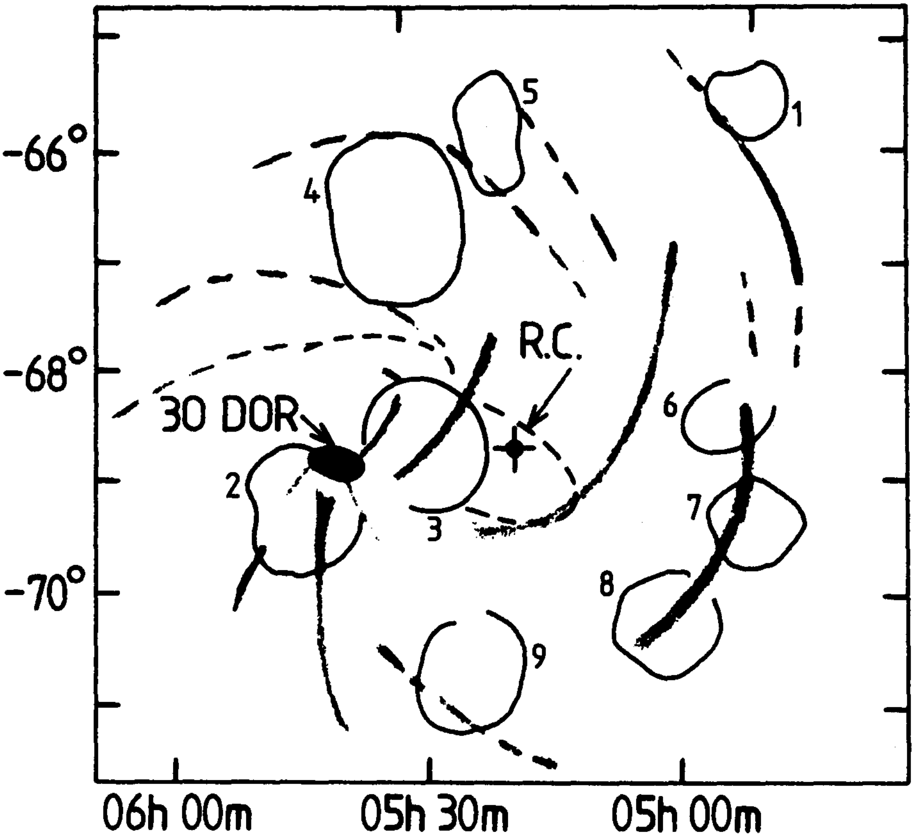

Figure 1. The supergiant shells SGS LMC 1-9 are sketched against the young spiral arms (Schmidt-Kaler, 1977) of the LMC.

Some giant shells are coincident with non-thermal radio sources and collisionally ionized nebulosity which indicates that supernova activity has occurred whereas most are thermal radio sources in which cases radiative ionization, of the inside edges of their HI shells by the hard ionizing photons from the enclosed stars, is dominant.

The dynamics of many of these giant shells are often complicated though, for instance, some form of simple spherical expansion at ≃ 30 km s^{-1} is suggested for N51 (Meaburn and Terrett, 1980; Lasker, 1980; de Boer and Nash, 1982). This is 176 x 113 pc and surrounds the OB association LH54 which contains 12 blue stars (Lucke and Hodge, 1970; Lucke, 1974). Its relationship to the ridges of HI emission (McGee and Milton, 1966) is shown in Figure 2 and it is coincident with the thermal radio source MC46.

Similar simple expansion, but of 70 km s^{-1}, is suggested by Rosado et al. (1982) for the filamentary shell N185 but they think that the high [S II] /Hα intensity ratio favours a supernova origin. More complex motions are found in N59 (Meaburn, Terrett and Blades, 1981), N70 (Blades et al., 1980) and N57 (Meaburn and Blades, 1980) than can be accounted for by simple radial expansion of a spherical shell. For example, over the centre of the 160 x 105 pc shell, N57, five velocity components at V_{HEL} = 277, 294, 310, 339 and 342 km s^{-1} are present and three at 300, 310 and 320 km s^{-1} on one edge (see Figure 3). This shell is a thermal radio source (MC57) and surrounds 13 blue stars in LH76.

The supergiant shells sketched in Figure 1, the one of 600 pc diameter, SGS SMC1, in the Small Magellanic Cloud (Meaburn, 1980) and that of 700 pc diameter found by Graham and Lawrie (1982) in NGC 55 seem to be a distinctly different phenomenum to their smaller counterparts. This is illustrated in the histograms for those in the LMC shown in Figure 4 (Meaburn, 1980). It is apparent that the supergiant shells (SGS) occur within a range of much larger diameters than do the giant shells.

The supergiant shells are surrounded by HI ridges and enclose up to hundreds of young blue stars. Many giant shells exist in their perimeters (see Goudis and Meaburn, 1978; Meaburn, 1979, 1980 and 1981a). This is particularly clear for SGS LMC 4 (Goudis and Meaburn, 1978) and SGS LMC 2 and 3 (Meaburn, 1979 and 1981a) on either side of the massive HII/HI mol complex of 30 Doradus. The dynamics of these supergiant shells are not yet well understood simply because the observations are limited to SGS LMC 2. However, as for the giant shells, these are likely to be complicated. For instance, the several outer optical ridges of SGS LMC 2 have separate radial velocities (White, 1981) each characteristic of the overlapping ≳ 3 kpc HI sheets discovered by McGee and Milton (1966) in this vicinity. However, Caulet et al. (1982) present some evidence that a 480 pc diameter region of the 900 pc diameter SGS LMC 2 is the far side of a radially expanding shell (though other interpretations of this data, not involving radial expansion, seem possible). They suggest that an approaching part of this shell is not present. It is perhaps relevant that systematic changes in radial velocity of individual velocity com-

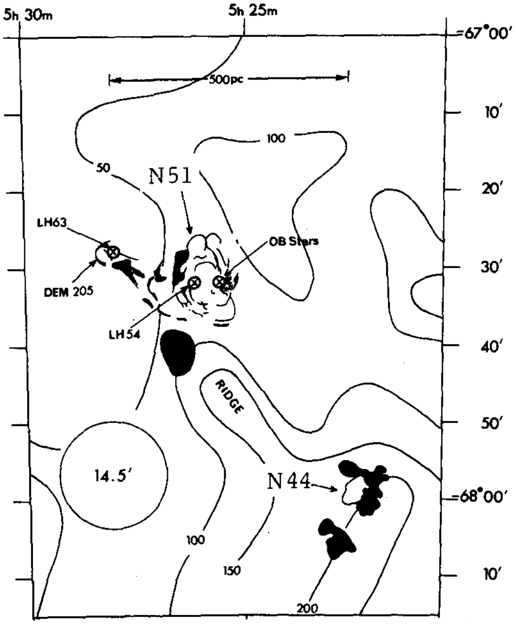

Figure 2. The relationship of the giant shells, N51 and N44, to the distribution of neutral hydrogen (McGee and Milton, 1966) and hot blue stars.

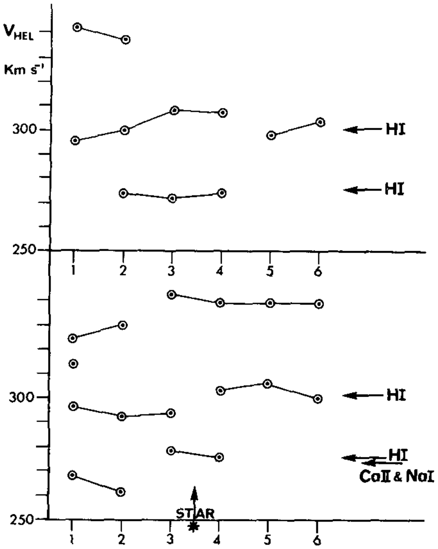

Figure 3. The radial velocities of separate components in the [O II] lines from the centre of the giant shell N57.

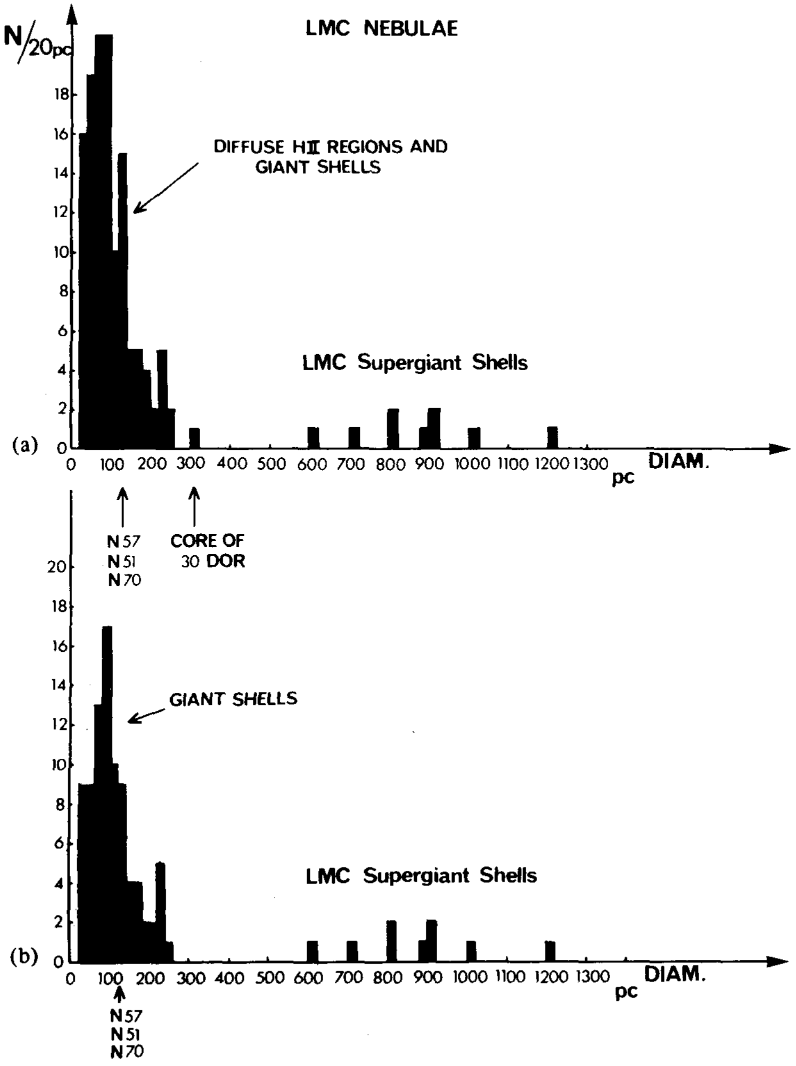

Figure 4. The statistics of giant and supergiant shells in the LMC.

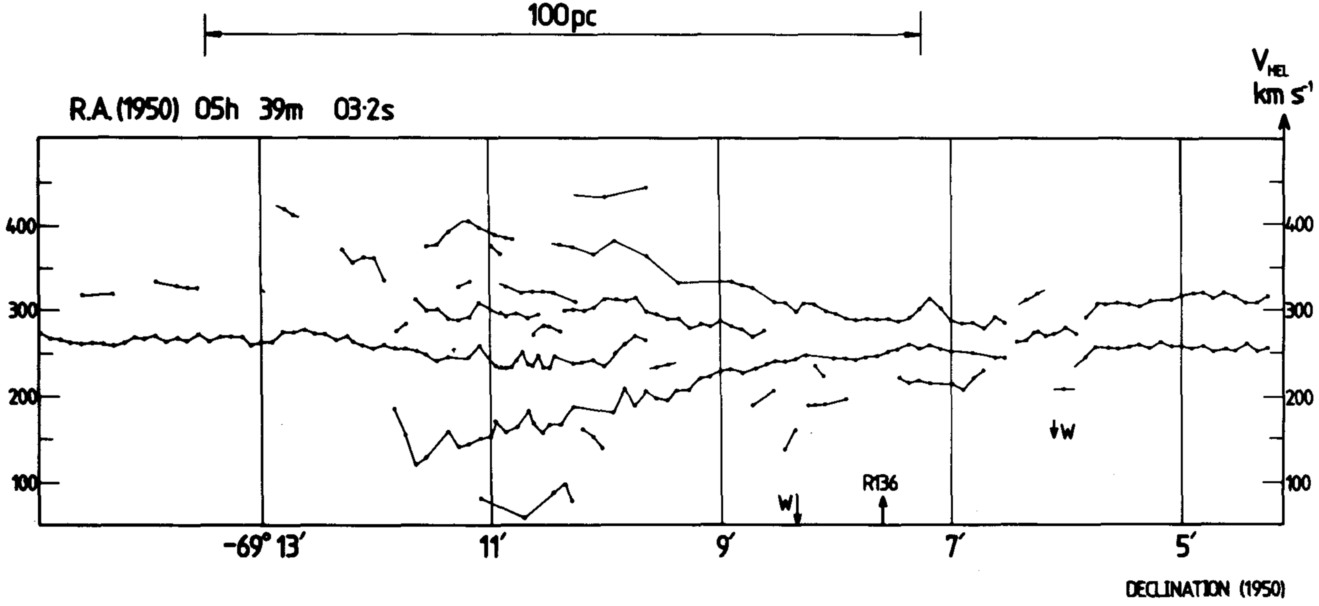

Figure 5. The radial velocities in separate components within Hα profiles over the 30 Doradus nebula are shown. This is on one edge of SGS LMC 2.

ponents, within complex and broad Hα profiles, have been found over a region, $\lesssim$ 100 pc long, away from R136, the central stellar-like object in the 30 Doradus nebula (Meaburn, 1981b and see Figure 5). This is on the inside edge of SGS LMC 2 (see Figure 1).

MECHANISMS

Many of the giant shells included in the histogram in Figure 4 are distinct non-thermal sources surrounded by collisionally ionized filaments (Mathewson and Clarke, 1973; Lasker, 1976) and must be supernova remnants of single stars similar to the Cygnus Loop etc. in the Galaxy. However, the majority have a much more complex structure and origin and most likely resemble the radiatively ionized Banard's Arc.

For instance, a single supernova explosion of 3×10^{51} erg, 8×10^{5} yr old (or successive 10^{50} erg explosions) could produce N51 if this is a 144 pc diam spherical shell expanding radially at 30 km s^{-1} in a uniform medium of 0.75 atom cm^{-3}. Alternatively a total stellar wind with a rate of emission of mechanical energy of 3.5×10^{37} erg s^{-1} blowing from the enclosed 8 supergiant OB stars could have the same effect. This amount is easily conceivable particularly if a Wolf-Rayet star is also present. Radiation pressure of Lyman photons from these OB stars on the radiatively ionized gas in the filaments of the shell could also contribute to the expansion (see Meaburn, 1980 and 1981a for a summary of the relevent theory and the references cited therein). It then seems likely that all three effects could combine to produce radially expanding giant shells which are approximately spherical though the unusual motions in N57 (and others) - see Figure 3, still remain very difficult to explain.

Single supernova explosions of $\simeq 10^{53}$ erg over $\simeq 5 \times 10^{7}$ yr ago are required to produce (Meaburn, 1980) the supergiant shells, shown in Figure 1, and included in Figure 4, if these are spherical and in a uniform medium of between 0.8 and 3 atom cm^{-3}. Alternatively, sustained stellar winds of 2×10^{41} erg s^{-1} for 3×10^{6} yr would be necessary in the absence of supernova explosions.

Before dismissing the possibility of such energetic explosions it is worth considering the implications of R136 if this is indeed a single star of $\simeq 2500\ M_{\odot}$ as proposed by Feitzinger et al. (1980) as a consequence of their optical photometry, Cassinelli et al. (1981) from ultra-violet spectroscopy and recently Meaburn et al. (1982) from optical speckle observations with the 3.9-m Anglo Australian Telescope. The integrated, two dimensional, autocorrelation of 2.6×10^{4} speckle images of R136 is shown in Figure 6. It can be seen here that the total amount of visible light ($10^{8}\ L_{\odot}$) from R136 is concentrated around the 00 pixel and is emitted from a volume $\lesssim$ 0.02 arcsec ($\lesssim 5 \times 10^{-3}$ pc) in diameter. It is then most likely a single object and not a compact cluster of hot stars. Cassinelli, Mathis and Savage (1981) predict that a single star of mass of $2500\ M_{\odot}$, and surface temperature of 60,000 K will have a diameter of 5×10^{-6} pc and a lifetime of only 10^{5} yr. Perhaps such massive stars can end their lives as super-supernova explosions and be sufficiently frequent to cause

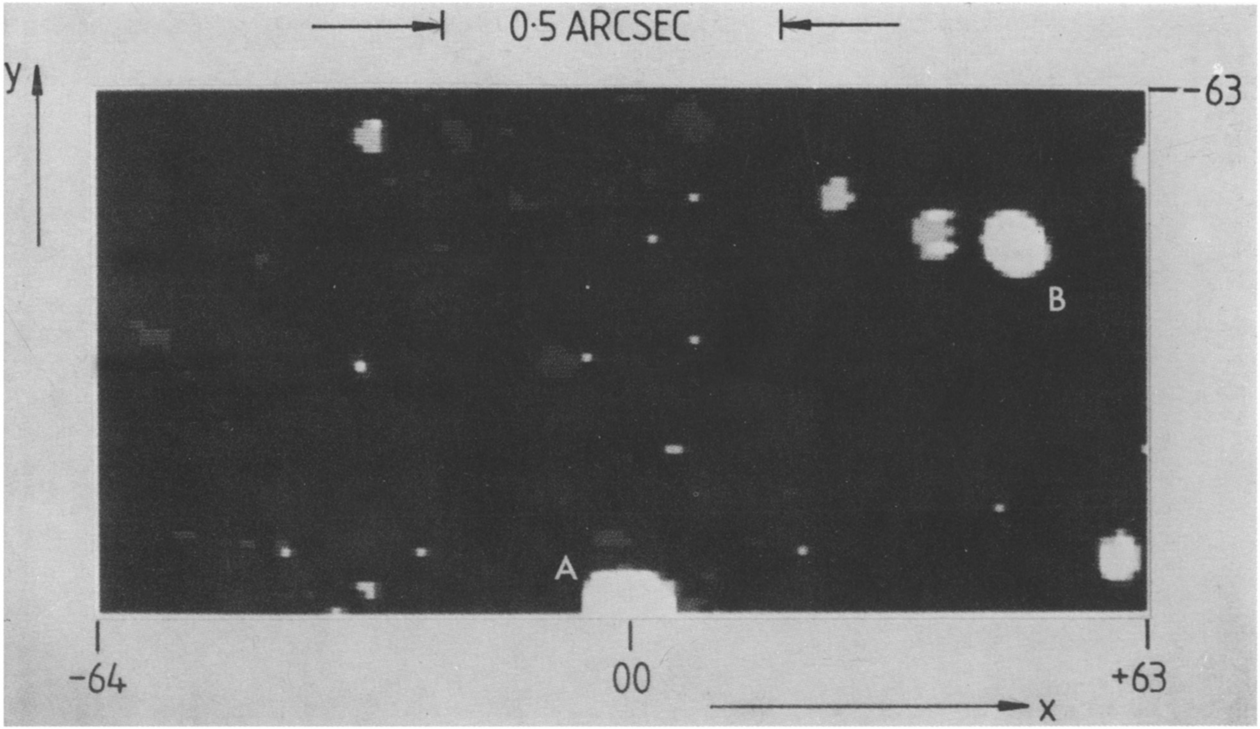

Figure 6. A two-dimensional autocorrelation of the speckle images of R136 obtained with the 3.9-m Anglo Australian Telescope. All the light from R136 is concentrated in a volume of < 0.02 arcsec diameter around the 00 pixel.

several supergiant shells in any galaxy which is rich in neutral interstellar material.

However, it seems most unlikely that the large ($\gtrsim$ 3 kpc across) overlapping sheets of neutral interstellar material in the LMC each with their separate radial velocities (McGee and Milton, 1966) could be of uniform density over thicknesses as large as 1.5 kpc as is required for SGC LMC 4 to be a spherical expanding super-supernova remnant. More likely these supergiant shells are toroidal rings $\gtrsim$ 1 kpc diameter but only $\simeq$ 200 pc thick. In which case their formation by a process of chiselling can be envisaged. In this the supernova explosions, stellar winds and radiation from a newly created OB association form a giant spherical shell $\simeq$ 200 pc diameter in $\lesssim 10^6$ yr. New star formation is then triggered in the perimeter of this shell and eventually a supergiant shell $\simeq$ 1 kpc diameter is chiselled out of neutral sheets only $\simeq$ 200 pc thick as this process proceeds for $> 10^7$ yr. The many giant shells in the perimeter of SGS LMC 4 and the population of hot stars in its centre lend credence to this mechanism. Also the separate velocity components in the outer filaments of SGC LMC 2 can be accounted for as the separate toroidal rings expand in the separate overlapping HI sheets. Incidentally, computer simulations of the mechanism involving stochastic star formation by Gerola and Seiden (1978) and Seiden (1981 - private communication) predict very convincingly the creation of both giant and supergiant shells in the LMC.

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