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OPTICAL EMISSION FROM RING-SHAPED NEBULAE IN THE LMC

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RESUMEN

Por medio de un estudio fotográfico con filtros de interferencia de banda angosta centrados en Hα y [S II] podemos estimar los cocientes [S II]/Hα de algunas nebulosas con forma de anillo en la Nube Mayor de Magallanes. Con la información adicional derivada de la dispersión de velocidades observadas en los anillos de interferogramas de Fabry-Pérot y el conocimiento del contenido estelar de esas nebulosas, se puede tener una vista de conjunto de estas regiones y de su origen probable. Se discuten algunas de estas nebulosas.

ABSTRACT

A photographic survey of ring-shaped nebulae in the LMC, performed with narrow band interference filters in Hα and [S II], permits us to determine their mean [S II]/Hα line-ratios. This information, together with the velocity dispersion obtained from FP interferograms and the knowledge of their stellar content allow us to have an overall view of these regions and of their probable origin. Some specific nebulae are discussed.

Key words: **GALAXIES-MAGELLANIC CLOUDS – NEBULAE-GENERAL**

I. INTRODUCTION

The ring-shaped nebulae appearing in the photographs of the LMC by Davies, Elliot and Meaburn (1976; hereafter DEM) are a subject of controversy when one tries to explain their origin. Some of them have been identified as supernova remnants, SNRs, on the basis of their non-thermal radio spectrum and their high [S II]/Hα line-ratio as revealed in the survey of Mathewson and Clarke (1973). However, for some of these nebulae the radio observations are meagre because of the weakness of their emission. Based on their spherical shape consisting of filaments, DEM proposed some nebulae as SNR candidates. However, other authors (Lasker 1977, 1980; Meaburn 1978) suggested that these nebulae could be interpreted also as supersonic stellar wind-driven nebulae, SSSW nebulae. Until radio observations are improved, the only way of determining their origin is by means of a better knowledge of their [S II]/Hα line-ratios, their expansion velocities, a careful analysis of their stellar content, and their X-ray emission.

Under these conditions we have undertaken a study of these ring-shaped nebulae by means of narrow-band interference filter photographs and Fabry-Pérot interferometry in order to determine their approximate [S II]/Hα line-ratios and their radial velocity field. Here we will discuss three of these nebulae. The common features among them are that: they are all ring-shaped and they contain a Wolf-Rayet star embedded in them.

Figure 1 shows the Hα and [S II] photographs of these selected nebulae: DEM 137, N198 and N200 where N refers to the catalogue of Henize (1956). These photographs were obtained by means of a focal reducer attached to the Cassegrain focus of the 1.52-m telescope of the European Southern Observatory at La Silla, Chile. The interference filters centered on Hα and on [S II] λ6717A have widths of 20 and 16 A respectively. Their peak transmissions are of about 60%. The exposure times for the [S II] photographs were 4 times longer than those for the Hα-photographs.

Figure 2 reproduces the fields of Hodge and Wright (1967) covered by these nebulae. In these fields, the WR star is marked.

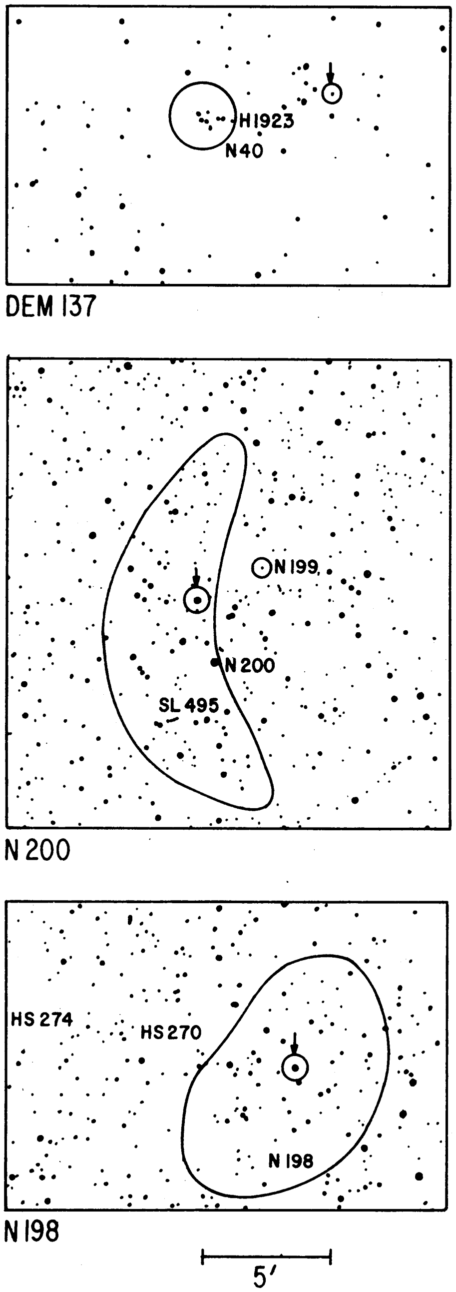

Fig. 2. Hodge and Wright's (1967) fields of the ring-shaped nebulae discussed in the text. The position of the WR star is indicated by a circle and an arrow.

II. THE SELECTED NEBULAE

a) *DEM 137*

Only the eastern knot of the nebula has been catalogued by Henize (1956) and not the whole structure.

The dimensions of this knot are of about 1 arcmin, while the dimensions of the entire nebula are of about 13.5 arcmin. Inside this knot there is the stellar association LH 43 from the catalogue of Lucke and Hodge, (1970); it contains nine blue stars, according to Lucke (1974). In the Hodge and Wright map shown in Figure 2 only the bright knot, N40, is marked. The overall shape of this nebula is better seen in the photographs of DEM where the WR star (NS45-65, from the catalogue of Sanduleak 1969) appears to be located near the center of this nebula.

Our photographs reveal a rather difusse shell in Hα with quite low emission in [S II]. There is no radio information on this nebula.

b) *N198*

This interesting nebula of elliptical shape, catalogued by Henize (1956) and by DEM, has major and minor axes of 8 and 6 arcmin respectively. It resembles, in shape, the galactic nebula NGC 6888 but not on linear dimensions. The dimensions are 7.6 X 5.0 pc for NGC 6888 and 128 X 96 pc for N198. Our photographs show that this nebula exhibits sharp filaments, some of them with some [S II] emission. Lasker (1977) has studied spectroscopically this nebula and he found a [S II]/Hα ratio of 0.19 and a sulphur I(6717)/I(6731) line-ratio of 1.61 suggesting that the electron density of the filaments falls within the low density limit. Available radio information on this region exists only in the 21 cm line survey of McGee and Milton (1966) which reported an H I complex at the position of this region with a mean density of about 0.5 cm^{-3}.

The WR star (NS21-71 from Sanduleak 1969) appears located at the center of this nebula as seen in Figure 2. There are also three OB stars catalogued by Philip and Sanduleak (1979).

Fabry-Pérot interferometry of this region, performed with an etalon of interference order p = 1365 has also been obtained by us revealing no splitting of the rings and a ring width smaller than 20 km s^{-1}.

c) *N200*

This nebula catalogued by Henize (1956) and by DEM has an angular diameter of 14.4 arcmin. At first sight it appears similar in shape and dimensions to DEM 137. However, our photographs reveal a filamentary structure with slightly higher [S II]/Hα line-ratios as compared to DEM 137. The 21-cm line survey of McGee and Milton (1966) reveals that N200 is located in an H I complex, with H density of 0.5 cm^{-3}. No other radio information is available.

The position of the WR star (NS26-71) is shown in Figure 1. There is also the stellar association LH50 (Lucke and Hodge 1970) containing 14 blue stars.

III. DISCUSSION

Table 1 shows the general characteristics of some of he ring-shaped nebulae in the LMC having WR stars at heir interiors, preferentially of the type WN. Among hese we include the three nebulae already discussed. We ıave marked those nebula observed by us. In the third :olumn we present their dimensions as measured from ›ur photographs and DEM photographs. In column 4 we ›resent the widths of the broader rings, (where $\Delta V \leqslant N$:m s^{-1}). In column 5 we give line ratios estimated from ›ur photographs or by Lasker (1979). In column 6 we ›resent the average density of the large complex of H I ıssociated with the nebulae (McGee and Milton 1966). n column 7 we list the spectral types and in column 8 he *V* magnitude taken from Breysacher (1980). And, in :olumn 9 we list the number of stars belonging to the nterior stellar association, brighter than $V = 15$ mag and ›luer than $B-V = 0.25$ (Lucke 1974).

From this table the following remarks can be made:

1) WR stars of subclass WN3 are found associated vith ring-shaped nebulae.

2) The nebulae shown in Table 1 appear to have low S II]/Hα line-ratios; lower than those of the SNRs of he same dimensions.

3) Those nebulae containing a WN star, with avail- ble radial-velocity information, do not show violent notions or high expansion velocities as it can be :oncluded from the widths of the FP rings and by the act that these do not show a splitting. This is in greement with the low values of the [S II]/Hα line- atios and with the fact that they are (by a selection ffect) greater in diameter than the galactic nebulae ssociated to WR stars, indicating that LMC nebulae must be older and must have smaller expansion velocities than the galactic ones. The special case of N51D could be due to the relative youth of this nebula (although associated with a binary WC) and to the fact that these motions do not represent a simple expansion (Lasker 1980).

4) If we assume that these nebulae are blown by SSSWs, we can estimate the required mass-loss rate of the stars producing the SSSWs, and the ages of the nebulae. Then, we can compare the agreement of the results with the assumptions. From the relations derived by the application of the theoretical models of Castor *et al.* (1975) and by assuming that *a)* the stellar wind velocity is of 2000 km s^{-1}, *b)* the velocity of the shock driving the nebulae ranges from 20 to 30 km s^{-1} and *c)* the pre-shock density is similar to the density of the H I complexes presented in Table 1 (we have assumed $n_0 = 0.5$ cm^{-3} unless a value for the density is reported). From these assumptions, we obtain the required mass-loss rates estimates of about $10^{-6} - 10^{-5}$ $M_\odot$ yr^{-1} and ages of a few 10^6 yr. Since these estimated values can be fulfilled with only the presence of the WR star, then, these ring-shaped nebulae could be explained as blown out by SSSWs, being the WR stars the major contributors to these winds. The other stars can also contribute, complicating the scenario and making it quite hard to estimate the ages of the WR stars by means of their associated nebulae. A careful analysis of the stellar content of these nebulae and further spectroscopic and kinematical studies must be done in order to have a better knowledge of these nebulae and their associated stars.

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TABLE 1

PROPERTIES OF SOME RING-SHAPED NEBULAE CONTAINING A WR STAR

Nebula (1)	DEM (2)	Diameter (pc) (3)	Maximum width (km s^{-1}) (4)	[S II]/Hα[b] (5)	$\bar{n}_H$ (cm^{-3}) (6)	Spectral type (7)	*V* (8)	No. of blue stars (9)
N204[a]	208	200	20	VL	–	WN3+OB	14.1	3
–	137	216	–	L	–	WN3	14.4	9
N16A	45	131	–	VL	0.5	WN3	14.6	–
N62[a]	239	123	30	L	0.9	WN3	14.8	–
N105A	86	108	–	VL,L	0.9	WN3-4p+OB	13.6	2
N30A[a]	105	154	25	–	1.3	WN4+OB	13.04	6
N74	315	123	–	L	0.4	WN4	14.7	–
N198[a]	165	108	20	L	0.5	WN7	12.9	3[d]
N200	164	231	–	L	0.5	WC5-6+OB	12.92	14
N51D[a]	192	105	30 (Splitting p=3000)	0.16[c]	$n_0 \cong 0.7$[c]	WC5+O9	11.3	19

a. FP interferometry has been performed by us.
b. VL and L mean very low and low, equivalent to 0 and 0.2, respectively.
c. Line-ratio and pre-shock density of N51D derived by Lasker (1980).
d. Three blue stars located inside the nebula, appearing in the catalogue of Philip and Sanduleak (1979).

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DISCUSSION

Calvet: ¿Se han determinado las abundancias químicas en estas nebulosas?
Rosado: Nosotros no lo hemos hecho y no tenemos información sobre las observaciones de otros grupos.

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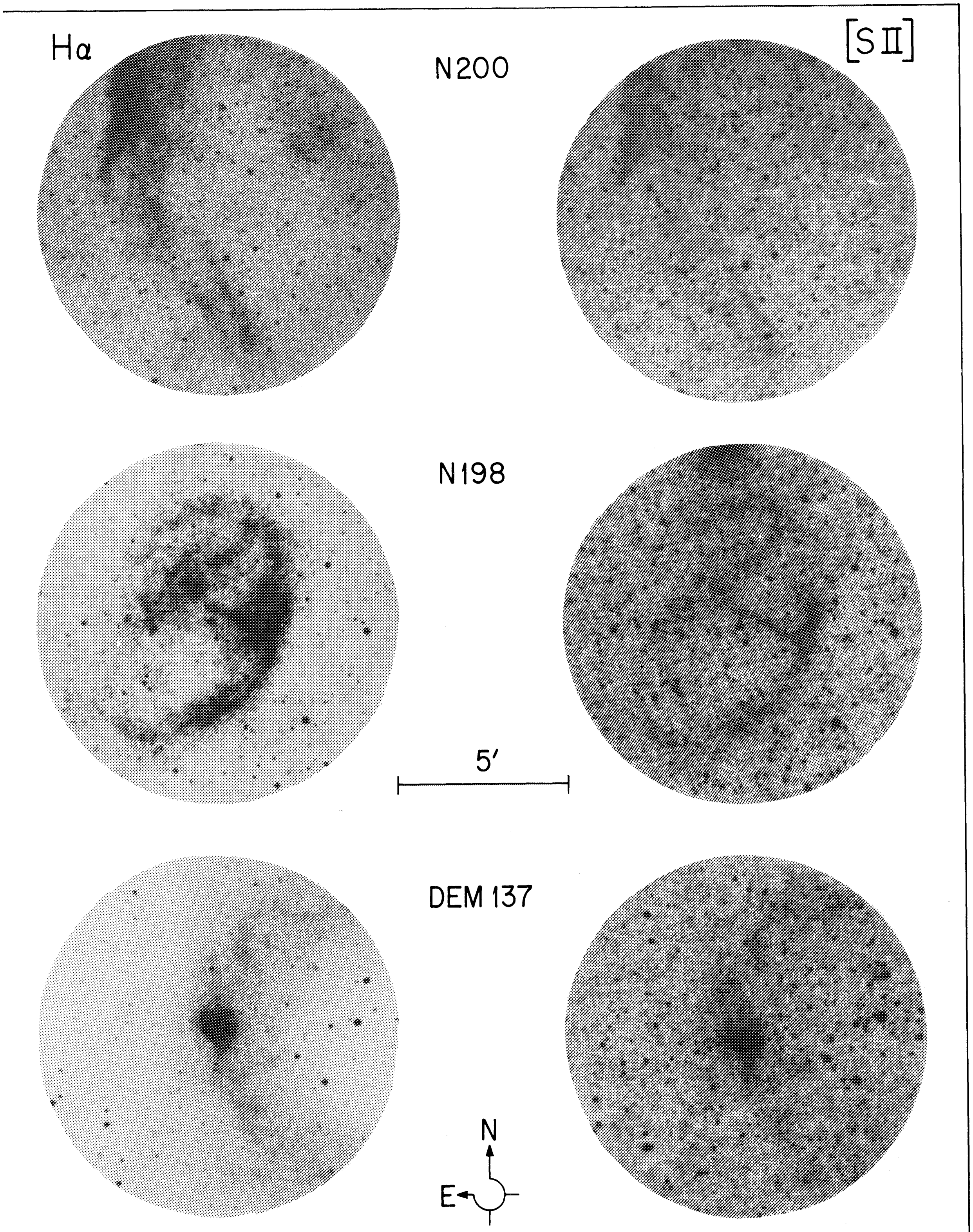

Fig. 1. Hα and [S II] photographs of the ring-shaped nebulae discussed in the text.

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