RevMexAA (Serie de Conferencias), **3**, 237–240 (1995)

TWO SMALL BUBBLES AROUND LMC BLUE SUPERGIANTS

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RESUMEN

Los vientos estelares rápidos de las estrellas masivas barren el medio ambiente formando burbujas. Las burbujas alrededor de estrellas no evolucionadas consisten en material del medio interestelar, mientras que las burbujas alrededor de estrellas evolucionadas pueden contener material procesado por la estrella. En el campo de la cáscara supergigante LMC 2 de la Nube Mayor de Magallanes, encontramos unas pequeñas burbujas alrededor de Sk-69 271 y Sk-69 279, dos estrellas supergigantes azules. Sk-69 271 es una supergigante B2 y su burbuja puede estar externamente ionizada por el flujo UV del complejo N160, ya que solo la mitad de la cáscara en dirección de N160 está ionizada. Estas dos estrellas están entre las estrellas azules más brillantes del campo examinado. Se necesitan estudios de abundancia para determinar si estas burbujas son de origen circunestelar o interestelar.

ABSTRACT

Fast stellar winds of massive stars sweep up ambient medium to form bubbles. Bubbles around unevolved massive stars consist of interstellar material, while bubbles around evolved massive stars may contain processed stellar material. In the field of the Supergiant Shell LMC 2 in the Large Magellanic Cloud (LMC), we found two small bubbles around the blue supergiants Sk-69 271 and Sk-69 279. Sk-69 271 is a B2 supergiant and its bubble could be externally ionized by UV flux from the H II complex N160, as only the half shell facing N160 is ionized. These two stars are among the brightest blue stars within the field we examined. Follow-up abundance observations are needed to determine whether the bubbles are circumstellar or interstellar in origin.

Key words: **H II REGIONS — ISM: BUBBLES — STARS: EARLY TYPE — STARS: MASS-LOSS**

1. INTRODUCTION

Ring nebulae around massive stars are formed by fast stellar winds sweeping up the ambient medium. For main-sequence massive stars, the ambient medium is interstellar, and the ring nebulae are called "interstellar bubbles" (Weaver et al. 1977). For evolved stars, the ambient medium could be stellar material lost via slow winds during the red supergiant phase or outbursts during the luminous blue variable phase, and the ring nebulae would be "circumstellar bubbles".

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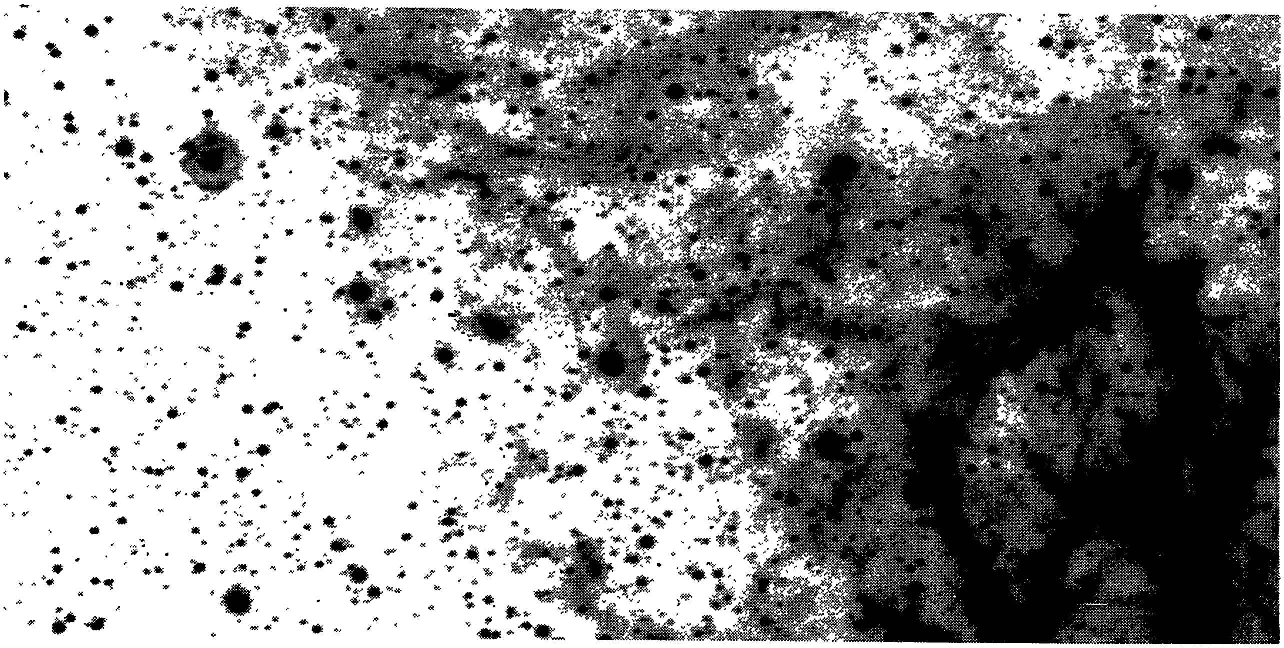

Fig. 1. Large-field Hα image showing the locations of the two bubbles around Sk-69 279 (closed shell) and Sk-69 271 (half shell). North is up and east is to the left. The bright H II region to the west is N160.

Studies of ring nebulae around massive stars are useful for deriving stellar properties that often cannot be extracted directly from studies of the stars themselves. More importantly, circumstellar bubbles contain stellar material, hence their spectroscopically derived metal abundances can be used to probe stellar nucleosynthesis and the mixing processes that bring the processed material to the surface of a massive star (Dufour 1989).

Tremendous efforts have been devoted to studies of ring nebulae around Wolf-Rayet stars in the Galaxy and the Magellanic Clouds (MCs). The recent CCD survey of LMC Wolf-Rayet nebulae (Dopita et al. 1994) has detected 2–3 times as many ring nebulae as the previous photographic survey (Chu & Lasker 1980). However, very little has been done for ring nebulae around single O or B stars (Chu 1991). Few ring nebulae around OB stars are known in our Galaxy (Lozinskaya 1981), and none has been reported in the Magellanic Clouds. No imaging surveys, photographic or CCD, for ring nebulae around OB stars have been carried out in the MCs.

Circumstellar bubbles around OB stars should be common, especially the blue supergiants that have looped around the red supergiant region of the H-R diagram. This is testified to by the rings around SN1987A, whose progenitor was a B3 supergiant. Recently, we discovered serendipitously two possibly circumstellar shells around blue supergiants within the supergiant shell LMC 2. This paper reports the discovery of these bubbles and discusses their nature. In the future, we intend to survey the LMC for more circumstellar bubbles, so that we may determine the relationship between the abundances in the nebulae and the spectral types of the central stars and use the relationship to constrain stellar evolutionary models.

2. OBSERVATIONS AND RESULTS

The data used for the discovery were taken with a CCD camera on the 0.9-m telescope at Cerro Tololo Inter-American Observatory in January 1995. A Tek 2K CCD was used to give a $13'.5\times13'.5$ field of view and a $0''.4$ pixel size. We investigated three fields in the southern part of the supergiant shell LMC 2. The location of this area is illustrated in Bomans et al. (1995). For each field we have at least two exposures for each of the Hα, B, V, and I filters. The exposure time ranges from 1 to 10 min.

The data were reduced with IRAF and displayed with SAOIMAGE. Upon visual inspection, it is obvious that two stars are surrounded by shell structures. One is complete, with a diameter of $18''$, and the other incomplete with a diameter of $21''$. Both shells are confirmed in the lower-resolution Hα CCD images taken with the Curtis Schmidt telescope as part of the Emission Line Survey of the Magellanic Clouds (PI: R. C. Smith). Some other stars are surrounded by faint filamentary nebulosities, but none show shell structures as well-defined as the two shown in Figure 2.

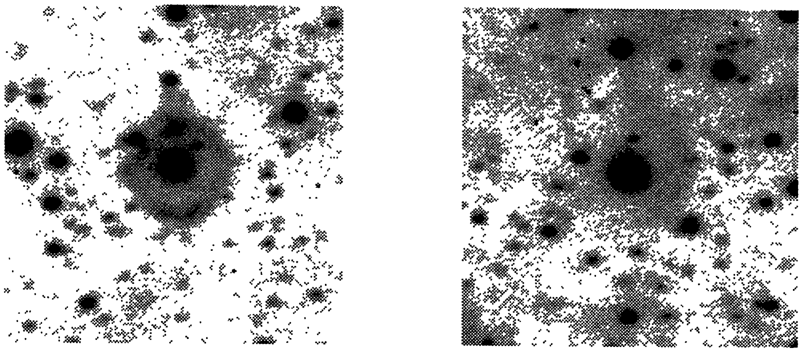

Fig. 2. Images of the bubbles. Sk-69 279 is on the left and Sk-69 271 is on the right. The box is 60″ × 60″.

To identify the two stars surrounded by bubbles, we compared our Hα images with the maps of Sanduleak's (1971) Survey of LMC members. The central stars are identified as Sk-69 271 and Sk-69 279. We used the DAOPHOT task in IRAF to carry out photometry with the B and V images, and made the color-magnitude diagram (CMD) shown in Figure 3. The positions of Sk-69 271 and Sk-69 279 are marked with starlets. The V magnitudes and $(B-V)$ colors of these two stars are listed in Table 1.

TABLE 1

DATA OF THE STARS

Star	V	$B-V$	Spectral Type
Sk-69 279	12.79	0.05	O9f
Sk-69 271	12.01	0.00	B2

3. BUBBLES AND THEIR CENTRAL STARS

To investigate the origin of the bubbles we first need to take a closer look at the central stars. The spectral type of Sk-69 271 is B2, according to the compilation by Rousseau et al. (1976), and that of Sk-69 279 is O9f, according to Conti et al. (1986). The classification of Sk-69 271 may be somewhat uncertain, because it was based on an objective prism spectrum.

The CMD in Figure 3 shows that both Sk-69 271 and Sk-69 279 are among the brightest blue stars, in agreement with the spectral classification. For the observed visual magnitudes and a distance modulus of 18.5 for the LMC, these two stars must be supergiants. No Galactic OB stars of such late spectral types are known to be in small bubbles. Therefore, these two bubbles are the first ones discovered around late-O or early B-supergiants!

4. PHYSICAL NATURE OF THE BUBBLES

The shell around Sk-69 279 has a diameter of 18″ and the half shell around Sk-69 271 is 21″. These sizes correspond to 4.5 and 5.3 pc, respectively. Such sizes for ring nebulae around Wolf-Rayet stars are usually indicative of a circumstellar nature. However, the stars' spectral types being late-O or early-B means that their stellar winds are not as powerful as those of Wolf-Rayet stars, hence the associated bubbles would be smaller. Furthermore, the evolutionary stage of the stars, whether they have journeyed through the red supergiant phase or not, are unknown. It is therefore premature to conclude that these bubbles are circumstellar in origin. We intend to carry out follow-up spectroscopic observations to measure the abundances in these bubbles in order to determine the nature of the bubbles and the evolutionary status of the central stars.

The ionization of the bubble around Sk-69 271, a B2 star, presents a puzzle. Stars with such a late spectral type are not capable of emitting much ionizing flux. Why is the bubble ionized? A clue to the ionization source

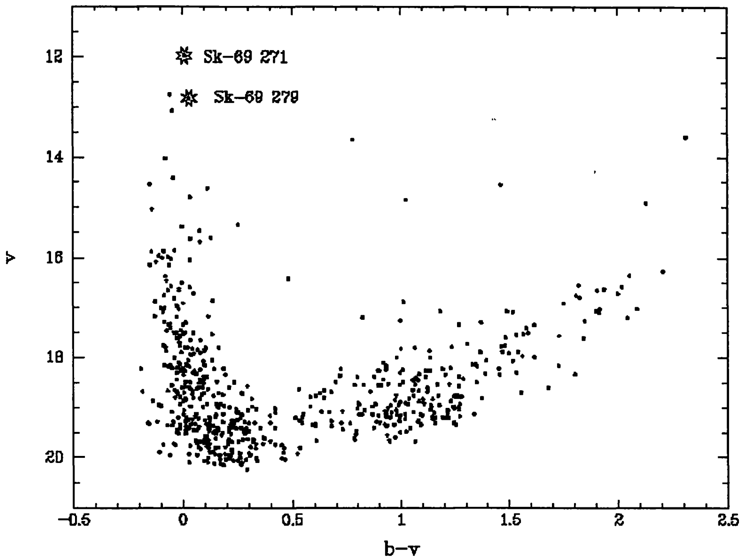

Fig. 3. Color-Magnitude Diagram of the stars within the field where Sk-69 271 and Sk-69 279 are located.

resides in the nebular morphology. Only half of the shell is visible — the half that is facing the active star formation region N160 (Henize 1956). It is most likely that the ionizing flux is provided by the massive stars in this luminous H II region. The bubble around Sk-69 271 may be the first known case of externally-ionized shell around a B supergiant!

The dynamic age of a bubble is $\eta(R/V_{exp})$, where R is the radius and V_{exp} is the expansion velocity of the bubble. η is 1 for a bubble formed by a steady fast wind sweeping up a circumstellar red supergiant wind (García-Segura & Mac Low 1995), 0.6 for an energy-conserving bubble (Weaver et al. 1977), or 0.5 for a momentum-conserving bubble (Steigman, Strittmatter, & Williams 1975). If we assume that the expansion velocity is 20 km s^{-1}, the dynamic ages of these two bubbles will be within the range of 6×10^4 to 1.3×10^5 yr.

Considering that only two small OB bubbles are known in the Galaxy — NGC 7635 (the Bubble Nebula) and NGC 6164-5 (Rosado 1986) — it is surprising that we discovered two of them in such a small volume within the LMC. We have requested CCD imaging time on the CTIO 0.9-m telescope in the coming LMC season to search for more OB bubbles in the LMC. A systematic survey is long overdue!

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