New Views of the Magellanic Clouds
IAU Symposium, Vol. 190, 1999
Y.-H. Chu, N.B. Suntzeff, J.E. Hesser, and D.A. Bohlender, eds.

Formation of Ring Nebulae around Massive Stars in LMC H II regions

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Abstract. Massive stars have strong stellar winds and consequently a high mass loss during their lifetimes. Therefore they can form ring nebulae by stellar winds sweeping up the ambient medium in the main sequence phase or through wind-wind interaction or eruptions in the evolved state. We present preliminary results of a search for single bubbles and ring-nebulae around massive stars in the Large Magellanic Cloud (LMC).

1. Introduction

Massive stars with ZAMS masses above $\sim 25\,M_\odot$ during most of their lifetimes lose mass through stellar winds of at least 10^{-6} $M_\odot$ yr^{-1}. Main-sequence O stars, for instance, exhibit wind velocities of 1500-3000 kms^{-1} and shed half of their mass into the interstellar medium within less than 10^7 yrs. The exact value strongly depends on the ZAMS mass and the stars' metallicities ($Z \downarrow \Rightarrow \dot{M} \downarrow$). Evolving further, massive stars pass the red supergiant phase or, if they are more massive than $M_{ZAMS} > 50\,M_\odot$, enter an unstable phase as *Luminous Blue Variables* (LBVs). If massive main-sequence stars form ring nebulae these are called *interstellar bubbles* since most of the bubbles' material is swept up ISM, while for evolved stars part of the ring nebula's material could be stellar material lost via slow winds during the red supergiant phase or via outbursts during the LBV phase. The ring nebulae around evolved stars are therefore called *circumstellar bubbles* or *Luminous Blue Variable nebula* (LBVN), depending on their origin.

The Large Magellanic Cloud reveals different large-scale bubbles formed by the combined actions of stellar winds and supernovae in OB associations, like superbubbles and supergiant shells. Surprisingly only a small number of bubbles around *single* OB stars is known. The same paucity of OB star bubbles is observed in the Milky Way. To differentiate whether this is a real physical

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effect or an observational bias we intend to improve the statistics by performing a comprehensive search for small single star bubbles in the LMC.

2. The Survey in the Magellanic Clouds

To search for bubbles and ring nebulae we used the CTIO 0.9 m telescope and took images in H_α as well as in the broad band B and R filters. The analysis was concentrated on fields which are expected to include a large number of massive stars (like OB stars in H II regions). The core of 30 Dor was avoided as were the supergiant shells since in these environments we expect that bubbles may be confused with effects from groups of neighboring stars or could be undetectable due to a low-density, hot-gas environment. The identifications of ring nebulae was performed by visually inspecting our H_α images. The 28 fields used cover a total of $1.2° \times 1.2°$ ($\approx$ 1 kpc $\times$ 1 kpc using a distance modulus of $18^{\mathrm{m}}.5$). The seeing was better than $1''.4$ in all our images, therefore we can safely detect structures around stars down to 0.5 pc. Our images reach down to a limiting surface brightness of about 1×10^{-17} ergs cm^{-2} sec^{-1} arcsec^{-2}.

3. Discussions and First Results

In the data set described above we identified 36 ring-nebulae/bubble candidates around single stars. All of them show a spherical geometry. As selection criterion we used a maximum diameter of the bubbles of 15 pc. This allowed us to differentiate between bubbles created by a single star and larger structures, which are probably created collectively from a number of massive stars. Nevertheless kinematics for all candidates is needed to differentiate classical Strömgren spheres from expanding bubbles.

A statistical analysis shows an increased number of bubbles with diameters of 2-3 pc clearly indicating bubbles intrinsic to single stars. Typical dynamical ages are of the order of 10^5 yrs if they are interstellar bubbles. If the ring nebulae are circumstellar, ages cannot be estimated, since we cannot decide from the current data whether wind-wind interaction or a single eruption in the LBV phase created the nebulae. With sizes as small as a few pc these bubbles are comparable to typical LBVNs in the LMC like R 127 or S 119. A second accumulation of diameters around 6-7 pc indicates bubbles around more evolved stars with nebulae formed through wind-wind interactions or older interstellar bubbles.

We conclude that with our survey we are able to identify bubbles around reasonably isolated massive stars in the LMC. The sizes for the bubbles we find range from 1-15 pc with the upper limit given by our selection criterion. If they are interstellar bubbles, we pick up interactions between very young stars and the surrounding ISM. In case of the stars being very massive, their ring nebulae could be circumstellar. They then are candidates for new LBVN or wind-wind interaction nebulae in the evolved states of the stars. To differentiate between these possibilities, chemical abundances and kinematic analyses are needed.