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SMALL BUBBLES AROUND BIG STARS

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RESUMEN

La vida de las estrellas masivas es corta y está dominada por fuertes vientos estelares. Este viento puede acumular material en nebulosas circunestelares alrededor de estrellas masivas. Algunas estrellas masivas pueden pasar la fase de variable luminosa azul (LBV), una fase de transición entre la fase de secuencia principal de la estrella y su estado final como RSG, BSG o la estrella Wolf-Rayet. Las LBVs son, como su nombre indica, estrellas variables y tienen una tasa de pérdida de masa muy alta. Muchas, por lo tanto, tienen pequeñas nebulosas. Cómo se ven estas nebulosas, cómo se formaron y qué implican para la fase LBV y lo que causa la inestabilidad que además del viento es responsable de la formación de las nebulosas son los temas que se abordan aquí.

ABSTRACT

The life of massive stars is short and dominated by strong stellar winds. This wind can accumulate material in circumstellar nebulae around massive stars. Some massive stars may pass the Luminous Blue Variable (LBV) phase, a transitional phase between the stars main-sequence phase and its final state as either RSG, BSG or Wolf-Rayet star. LBVs are as the name indicates variable stars, have a very large mass-loss rate. Many therefore have small nebulae. How these nebulae look like, how they formed and what they imply for the LBV phase and what causes the instability that beside the wind is responsible for the formation of the nebulae are topics adresses here.

Key Words: stars: massive — stars: mass loss — stars: winds, outflows

1. INTRODUCTION

Circumstellar nebulae or bubbles around stars are not unusual. During the rather short life massive star lose a signficant part of their mass via stellar winds. In the main-sequence phase this wind sweeps up the surrouning interstellar medium and forms a wind blown bubble a theoretical description is given by Weaver et al. (1977). Only later, after several evolutionary phases with faster and slower winds circumstellar bubble form around stars. Examples are Planetary Nebulae, Wolf-Rayet Nebulae and Luminous Blue Variable Nebulae.

2. LUMINOUS BLUE VARIABLES (LBVS)

LBVs are evolved massive stars. Observations and theoretical stellar evolution models that include rotation (Meynet & Maeder 2005) find LBVs with initial mass as low as 22 $M_{\odot}$. The original term Luminous blue Variables was introduced by Peter Conti during a conference talk he said: I shall refer to the non WR or other hot stars as Luminous blue Variables. This spontaneous introduction of the name was not intended as and is far from any good definition. By now several characteristics are known to clearly distinct an LBV from normal blue supergiant. It is the variability! LBVs change their spectra from a hot OB stars to a cool AF stars and back by changing their radius. This S Dor varibility or S Dor cycle can be as short as a few years or up to several decades and is intrinsic to LBVs. More violent variations are the giant eruptions, here the brightness rises spontaneously by several magnitudes. These LBVs are designated *giant eruption LBVs*, the best known examples are η Car, P Cygni, NGC2403-V12, and SN1961V, the latter indicating LBV giant eruptions have been mistaken for supernovae. In wake of the large SN search programms now ongoing, transient events that look like a supenova at first, but for the one or the other reason turn out to be nonterminal explosions, are dubbed 'SN imposters'. One view is indeed to claim that they are LBV giant eruptions. Indeed giant eruptions will look like SN imposters **but not** all SN imposter are giant eruptions. For a detailed review of LBVs see Weis & Bomans (2020)

3. LBV NEBULAE

The change in spectral type during a S Dor cycle leads to changes in the stellar wind velocity and wind wind interaction of the fast hot star wind with slower and denser cool star wind. During a giant eruption

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larger amounts of mass can be ejected in less than a few years. Both scenarios are formation mechanism for circumstellar nebula, the LBV nebulae. LBV nebulae are rather small, with a typical diameters of a few parsec A large fraction ($\sim$ 70%) shows a bipolar morphology only a few are really spherical. So far only one R 143 is irregular (Weis 2003), given its position in a rather turbulent environement–near the center of 30 Dor giant HII region–this is not really surprising.

The expansion velocities are often complex patterns with a range from a few km/s to well above 1000 km/s. LBV nebulae have strong [N II] emission. Nebulae of LMC LBVs are on average larger, at the same time their expansion velocities are slower as the galactic. (Weis 2011)

3.1. *The petite LBV nebulae*

A few LBVs nebulae have physical size below 1 parsec, for now I call them the petite LBV nebulae. This subsample contains the nebulae of the giant eruption LBVs η Car and P Cygni, the classic galactic LBVs HD 168625, the largest petite is WRA 751 and finally S 61 the smallest of all LMC LBV nebulae.

HD 169625: Is with a size of 0.13×0.17 pc the smallest galactic LBV nebula. The size indicate an already not spherical shape, the kinematics I derived from longslit echelle spectra indicate an asymertic or even bipolar structure expanding with 30 km/s. Supportingly Mahy et al. (2016) mentioned biploar components, looking at the enlargment of the HST image in Fig.1 one is tempted to identify two shells nearly on top of each other.

WRA 751: The nebulae appear very diffuse, its inner body is spherical with a radiuds of 0.38pc but to the north and south triangular shaped extension are detected, they are 0.05 and 0.1 pc long and the kinematics reveal a clearely bipolar nature. For a detailed discussion Weis (2000)

P Cygni: Is one of the few LBVs in the northern hemisphere. It has two distinct nebulae a larger outer structure with a size of larger with a diameter of 0.8 to 0.9 pc (not shown here) And the inner nebulae with a diameter of 0.2 pc (Fig. 1 shows our new LBT AO image) and an expansion velocity of 100-250 km/s that matches an ejection during the 1600AD giant eruption (Weis et al. in Prep)

η **Carinae**: Has at least three nebula structures, the Homunculus,first observed and discribed as little manikin or Homunculus by Gaviola (1950), the Little Homunculus (Ishibashi et al. 2003) nestled inside the Homunculus (maximum size of about 0.04 pc).

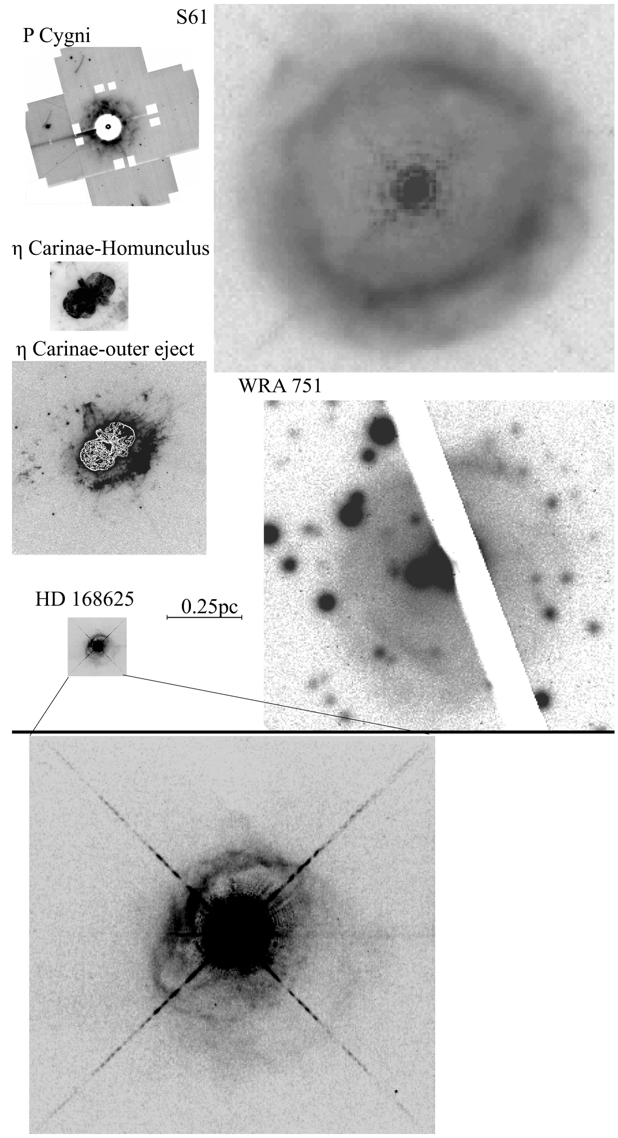

Fig. 1. Top:petite nebulae on scale. Bottom: enlargment of the HD 168625 nebula (HST F656N image).

Further out is the filamentary but bipolar outer ejecta (Weis 2012) it covers a radius of about 0.67 pc and has expansion velocities ranging from several 100km/s to several 1000km/s.

S 61: With a diameter of about 0.85 pc S 61 is the smallest LBV nebula in Large Magellanic Cloud (LMC). While the nebulae appears spherical at first an accurate measurment reaveals a slight elongation with a a larger axis of 0.89 pc and a smaller of 0.82 pc. Noteworthy is also that the brightest part of the nebulae is not as expected for a bubble the outer radius. But diffuse emission surpasses the brighter ring at all sides. The kinematics fits well to a spherical expansion of 27 km/s (Weis 2003).

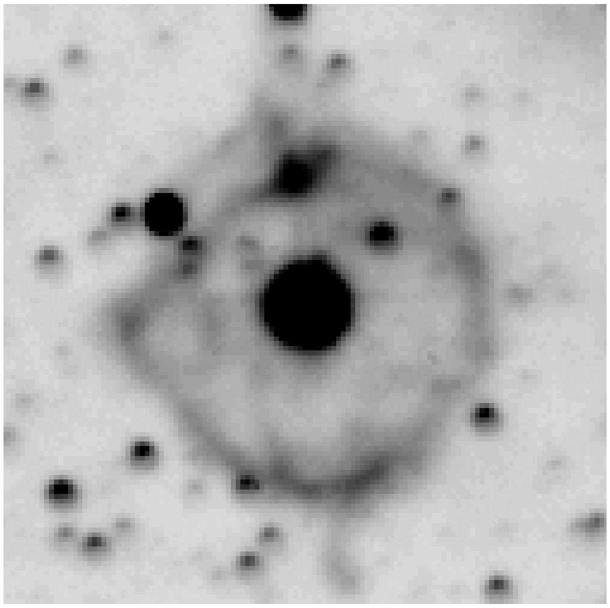

Fig. 2. the Sk -69 279 nebula

4. THE PERSONAL SIDE

Since this conference is also Happy Birthday event I like to add a small personal touch to this text. I met You-Hua being a visiting grad student from the University Heidelberg, Germany. On the long run she became an additional supervisor for my Diploma and PhD theses. For more than 3 years I spent several month per year with her in Illinois and very much enoyed the time working with her, as well as watching the squirrels.

4.1. *Sk-69 279 - my first astronomical image*

At my starting visit You-Hua gave me an imaging dataset from the LMC. The first data I ever analysed. I opened my first completely reduced image and was surprised by a nice ring nebulae that appeared near the center of the image. I was excited and expected You-Hua to tell me a lot about this object. But she looked astonished at the image and said simply: I have never seen this nebula before. The image of this surprise nebulae is given in Fig. 2 It turned out the centralstars is Sk-69 279, an O9f supergiant. That started my astronomical career and long term connection to You-Hua as well as a life long affection for bubbles and circumstellar nebulae. The star was the topic of my Diploma thesis (german analog for Master at that time). Today it is a good LBV candidate (Weis & Bomans 2020) and like the other LBVs its nebulae shows strong [N II] emission.

4.2. *Sk-69 279 - my first astronomical conference and publication*

The story continuued with You-Hua dragging me to a conference and present this discovery in a poster. Furthermore the confernce proceedings became my first paper Weis et al. (1995) and was published in RMxAC!

4.3. *Sk-69 279 - scientific results*

My detailed analysis (Weis et al. 1997) of the nebulae shows a sphere with a radius of 4.5 pc. In an echelle long-slit spectrum of the nebulae an expansion ellipse was detected with an expansion velocity of 14 km/s, it further supported the spherical shape. Further observations, in particular additional spectra, revealed more details and deviations from a perfect sphere. We also detected a faint faster outflow to the north (Weis & Duschl 2002).

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