Clumping in Hot Star Winds
W.-R. Hamann, A. Feldmeier & L.M. Oskinova, eds.
Potsdam: Univ.-Verl., 2008
URN: http://nbn-resolving.de/urn:nbn:de:kobv:517-opus-13981

Wind relics: clumps, inhomogeneities and outflows in LBV nebulae

K. Weis
Astronomisches Institut, Ruhr-Universität Bochum, Germany
Lise-Meitner fellow

The most massive stars are those with the shortest but most active life. One group of massive stars, the *Luminous Blue Variables (LBVs)*, of which only a few objects are known, are in particular of interest concerning the stability of stars. They have a high mass loss rate and are close to being instable. This is even more likely as rotation becomes an important factor in stellar evolution of these stars. Through massive stellar winds and sometimes giant eruptions, LBV nebulae are formed. Various aspects in the evolution in the LBV phase lead, beside the large scale morphological and kinematical differences, to a diversity of small structures like clumps, rims, and outflows in these nebulae.

1 A primer to LBVs and LBV nebulae

All massive evolved stars do have a certain potential to enter the LBV phase. Initial mass, metalicity, strength and structure of the stellar wind, and in particular stellar rotation seem to impact the star's evolution and therefore its passage through an LBV phase see, cf. Meynet & Maeder (2005) and Meynet et al. (2007). Models with rotation of 300 km/s show that stars with masses even as low as about 20 $M_\odot$ (for Z=0.02) may encounter the LBV phase (40 $M_\odot$ without rotation). In contrast, these models also show that rotating star with very high mass will totally skip the LBV phase and directly enter the Wolf-Rayet phase. LBVs—as the name indicates—are characterized being luminous (blue) stars, and posses photometric as well as spectral variabilities with various amplitudes (both in time and brightness). A variability intrinsic to LBVs, is the S Dor variability. Depending on the direction of its evolution the star gradually brightens in the V band by up to 3^{mag} in roughly 10 years, as the spectrum changes from a hot O-B to a cooler A-F star. It dims on its return to the hot phase. The Balmer lines are seen in emission (P Cygni profiles), during the hot phase He I and He II lines pop up too. LBVs do have a high mass loss rate and may undergo giant eruptions, likely due to their closeness to the Eddington/break-up limit. This predestinates the formation of LBV nebulae.

LBV nebulae formed through the continuous stellar winds (mixed with swept-up ISM) and eruption in which larger amounts of mass are carried away in a more instant event. LBV nebulae can be identified through the presence of CNO processed material, e.g. more nitrogen. The abundances are enhanced even more, if the star rotates and material from deeper layers is mixed up and peeled off. Expansion velocities and morphologies are manifold. For a more comprehensive description the reader is refereed to e.g. van Genderen (2001), Weis (2001, 2003) and references therein. Here only a short description and summary of the basic parameters of LBV nebula, e.g. their morphology and kinematics is given. Fig. 1 already visualizes the manifold of morphologies and sizes of the majority of known and resolved LBV nebulae. The images are either taken with Hα and/or [N II] filters and F656N or F658N filters for the HST images (S119, R127, S61, R143, η Car, AG Car, HD 168625). The Pistol star was observed with the NICMOS F187N filter (Brγ). All images are drawn to scale. There is a small tendency that the LMC LBVs are larger in size compared to their Galactic mates, see also Weis (2003). From pure morphological aspects 5 (38%) of the LBVs show indications for a bipolar structure. The expansion velocities for LBV nebulae, excluding η Car, generally range between 20-100 km/s, a few are as high as 150-170 km/s (P Cygni, HR Car). η Car is an exceptional case with an expansion velocity of roughly 600 km/s for the Homunculus and the outer ejecta escaping with up to 2500 km/s, giving rise to X-ray emission, see Weis et al. (2004). Kinematic analyses add R127 and WRA 751 to the list of nebulae which posses bipolar structures (the caps) to some degree. The current, obviously poor statistics yields about 50% of the nebulae having indications for bipolar structures, about 40% are roughly spherical and 10% (1 object=R143) is irregular. On smaller scales the nebulae are highly complex, and their characteristics depend even more on the history of stellar winds, the interstellar surrounding, stellar rotation and instabilities.

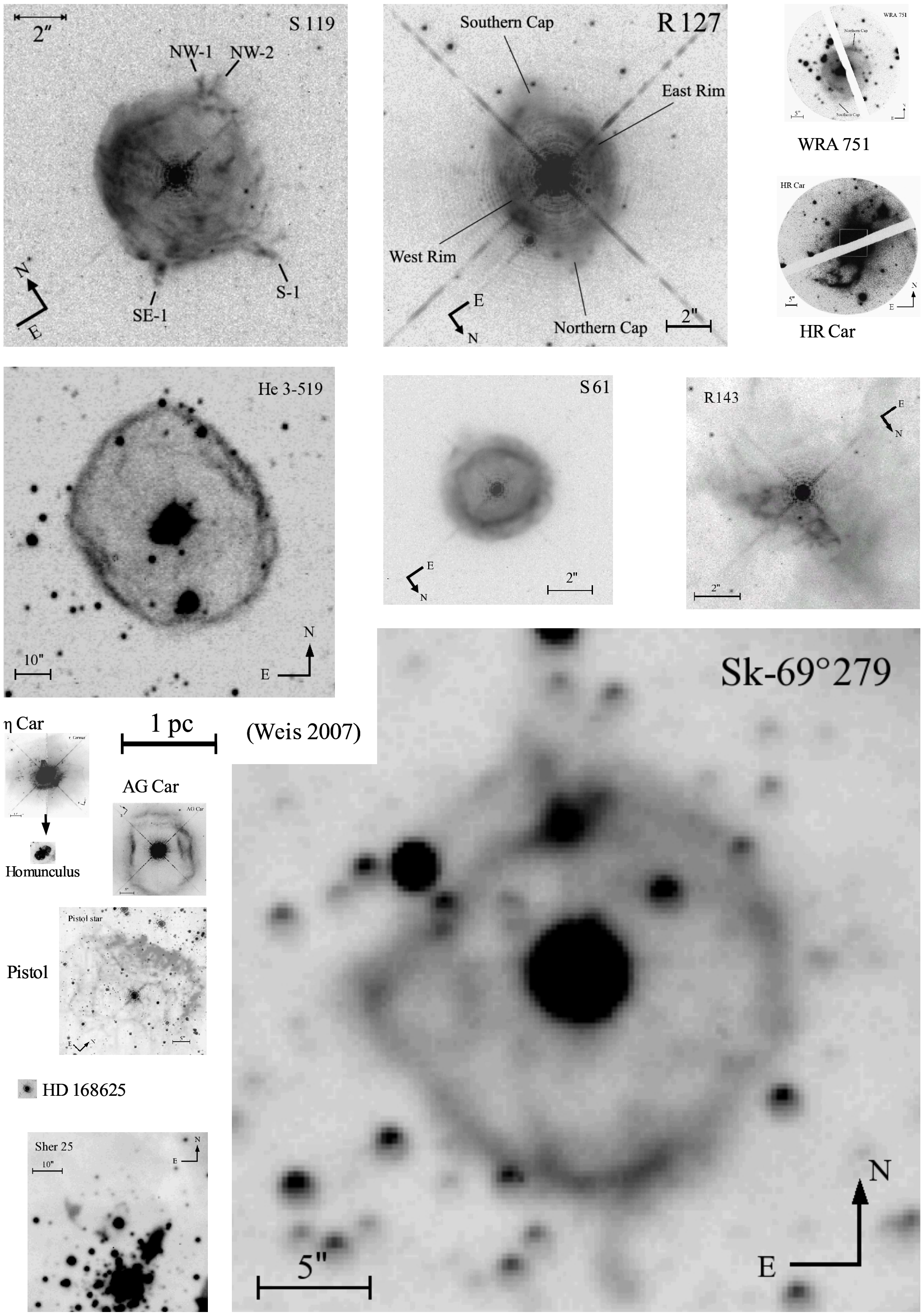

Figure 1: LBV nebulae drawn to scale. Sk-69 279: Weis et al. (1997); Pistol: Figer et al. (1999); WRA 751: Weis (2000); S119: Weis et al. (2003); S61, R127, R143: 2003; η Car, HR Car, HD 1682625, AG Car, Sher 25: Weis(2001); He 3-519: (Weis 2007, in prep)

2 Nebulae as imprints of stellar and interstellar parameters

During the LBV phase several parameters will influence the final—the currently observed—structure and properties of the nebula. The most obvious are discussed here.

WIND. Being formed by stellar winds the properties of the winds are among the most important that determine the shape and kinematics of LBV nebulae. The wind during the star's main sequence phase already pre-structures the environment and can lead to the formation of bubbles with lower density. This bubble expands and already sweeps up ISM around the star. Several such bubbles might merge and even enclose whole OB associations. In the evolved phase the characteristics of the stellar wind changes back and forth between fast and slow wind velocities, high and low mass loss rates, and last but not least higher and lower fractions of clumpiness. By compression, material from the different wind phases (and eruptions) forms the LBV nebula, uniform or already fragmented. Different wind phases could be for instance be the explanation for the shape of the nebula around S61 (see Fig.1). Diffuse less dense material possibly from an earlier faster wind phase is found outside the brighter ring.

ISM. Staring right from the formation, a massive star's stellar wind will impact the ISM. The ISM is different in e.g. density for each birth cloud. In this way the surrounding of a star evolving into an LBV is individual. The combination of the initial structure of the ISM and influence of stellar wind forms bubble of different sizes, different densities, density gradients, clumps etc. During the formation process, therefore the ISM surrounding the LBV, shapes the nebula. The image of S119 is an example of a density gradient, with denser material detected in the (north-)east, leading to a more compressed rim of the LBV nebula on this side.

ROTATION. In recent years the in-cooperation of rotation in stellar models has changed our picture of the stellar evolution, in particular concerning instabilities, mass loss and the lifetime spend in different phases. The most massive stars are therefore even more likely to reach break up, and according to the models may not enter the LBV phase at all. More importantly rotation also influences the 3D topology of the wind and consequently the nebula. It seems natural to connect the presence of bipolar LBV nebulae η Car, HR Car, or Sher 25 with the fact that rotation does play an important role for the evolution and winds of massive stars.

INSTABILITIES/OUTFLOWS. Nebulae are very likely to encounter instabilities. This will sometimes lead to the disintegration of the confining shell structure and can even give rise to outflow of material. From a hydrodynamic perspective the nebulae are subject to Rayleigh-Taylor and Vishniac instabilities. In the first case due to an external density gradient fragments of the nebula shell are left behind as the less dense interior expands out. Spike like structure form and material is torn outwards by the wind. An example for such an instability seem the filamentary structures of the Pistol nebula. In Vishniac instabilities, an expanding shell with an already intrinsic density contrast expanding into an uniform medium, enhances the density contrast (clumpiness) as ram pressure and thermal pressure are not perpendicular to each other. Sheer forces therefore lead the clumps grow even further. Small subclumps in the nebula around S119 (towards the north and south) are an example for such a process.

3 Summary: What's wind got to do with it?

Analyzing various aspects of LBV nebulae provides an additional tool to obtain information about stellar parameters. The nebulae manifest relics of the star's wind (former envelope) and are therefore sensitive to wind properties like density, abundances, velocity, clumpiness and asymmetry.

References

Figer, D.F., Morris, M., Geballe, T.R., Rich, R.M., Serabyn, E., McLean, I.S., Puetter, R.C., & Yahil, A. 1999, ApJ, 525, 759

van Genderen, A.M. 2001 A&A 366, 508

Meynet, G., & Maeder, A. 2005, A&A 429, 581

Meynet, G., Eggenberger, P., & Maeder, A. 2007, IAU Sym 241, (astro-ph/0702515v1)

Weis, K. 2000, A&A, 357, 938

Weis, K. 2001, Reviews in Modern Astronomy 14, 261, (astro-ph/0104214)

Weis K. 2003, A&A, 408, 205

Weis, K., Chu, Y.-H., Duschl, W.J., Bomans, D.J. 1997 A&A 325, 1157

Weis, K., Duschl, W.J., & Bomans, D.J. 2003, A&A, 398, 1041

Weis, K., Corcoran, M. F., Bomans, D. J., & Davidson, K. 2004, A&A, 415, 595

Cassinelli: Some of the LBV nebulae appear like shocked shells, like one would get from fast with slow wind interactions. Do you have X-ray information?

Weis: Only for a few LBVs X-ray measurements have been made. From the low expansion velocities ($20-90\,\mathrm{km/s}$) except in η Car a shock in X-rays is not expected.

Cassinelli: X-rays from wind/ISM?

Gull: The Homunculus interacts with the residual wind. Indeed weak shocks are seen in Hα, [N II], [S II], but too weak that X-rays are detected.

Owocki: I really like your comparison to LBV nebulae at fixed spatial scale, which makes η Car look small and insignificant. But of course the reason is that we are lucky to see η Car at a relatively young phase, when the nebula from outburst has not expanded much. This implies, if ever we want to find other η Car analogs, we need to think of what η Car would look like thousand years from now.