LMC LBV Nebulae as Stepping Stones to Stellar Evolution and Feedback at Low Z

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Stellar Evolution and a Guide to LBVs

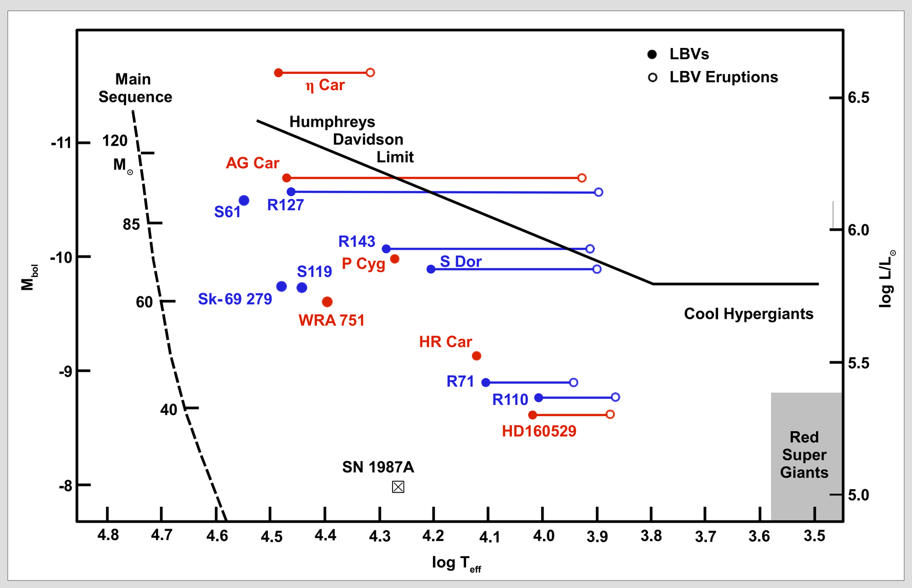


Fig.1: HRD with positions of LBVs, for some in both their hot and cool phase within an S Dor cycle (LBV Eruption). LMC LBVs are indicated in blue, Galactic objects in red. Figure adapted from Weis & Duschl (2002).

During their evolution massive stars – depending on their initial mass, metalicity and rotation rate – may enter after the main-sequence (MS) phase an instable state turning into **Luminous Blue Variables (LBVs)**. Models of rotating massive stars (by e.g. Maeder et al. 2005) show that LBV stars can have an initial mass as low as 22 $M_\odot$ for Galactic and 25 $M_\odot$ for stars in the LMC. **LBVs** are characterized by being **luminous** stars with **photometric** and **spectral variabilities** on various timescales and magnitudes. A variability intrinsic to LBVs, is the **S Dor variability**, also known as S Dor cycle (e.g. van Genderen 2001) where changes in **temperature** (hot O-B to cooler A-F) and **radius** occur with a **few years**. Even stronger variation occur if an LBVs has a **giant eruption**. Here the stars brightness increases spontaneously by several magnitudes and larger amounts of mass are ejected within a short (few years) timescale. Some of these **LBV giant eruptions** have been **mistaken** for **supernovae** (e.g. SN1961V). In context with current SN monitoring and search programs, more and more candidates are found and dubbed as **SN impostors**. Characteristics of LBVs are their variablility, high mass loss rate and or eruptions. However, at last for some time LBVs appear also 'as well behaved' normal supergiant ! **Note**: No unique classification scheme exists to pinpoint an LBV !

So: ***To be or not to be an LBV ?***

What causes the variability and eruptions is not fully understood, but metalicity dependent mechanisms are likely, making a study of LBVs at lower and very low Z extremly valuable.

LBV Nebulae

The large mass loss of LBVs can lead to the **creation** of **LBV nebulae** by either **wind-wind interaction** of faster and slower winds (LBV+MS wind or cool+hot LBV phase) or by the **ejection of stellar material during a giant eruption.** Typical for all nebulae is a strong **[NII] emission** (↔ CNO processed material). Well known examples of galactic LBV nebulae are the nebulae around η Car or AG Car (see Fig. 2). General properties are (see Tab. 1)

- **morphologies** range from **spherical** (S61) and **elliptical** (He 3-519), to **irregular** (R143).
- **a statistics** shows a distribution of **40% spherical/elliptical and only 10% irregular nebulae, but a significant** number (**50%**) **of bipolar, hourglass type** (e.g. η Car) or with **bipolar components (caps)** (e.g. R 127)
- the maximum **sizes** of LBV nebulae roughly range from **0.1 to 5 pc** with an **average** around **1.3 pc**
- expansion velocities are between **20-150 km/s**.
- **η Car** is **exceptional**, velocities are ~ **600 km/s** for the **Homunculus** and **3200 km/s** in the **outer ejecta**

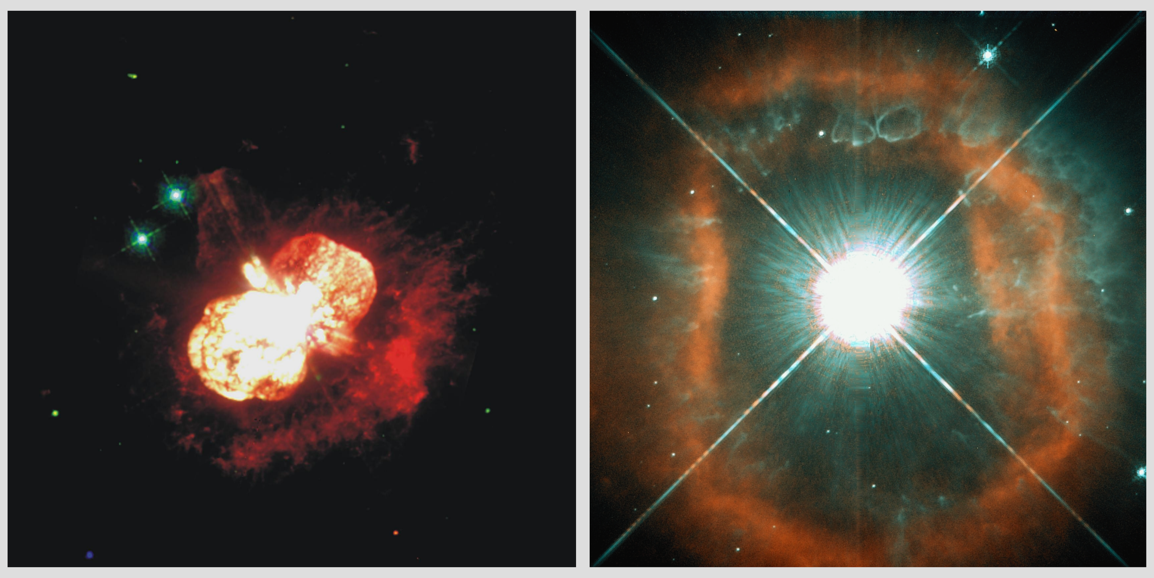
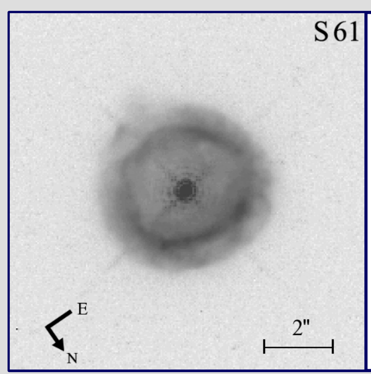


Fig.2: HST color images of bipolar galactic LBV nebulae. On the left η Carinae (Weis 1999) and on the right AG Carinae (Weis 2011).

LBV Nebulae – the LMC Gang

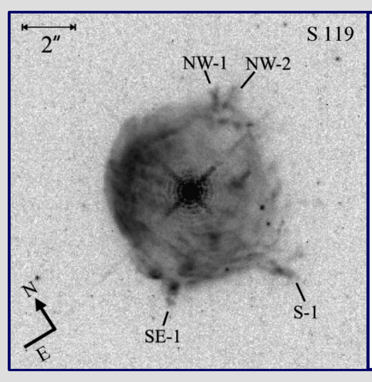


S61

spherical

size = 0.82 pc

v_{exp} = 27 km/s

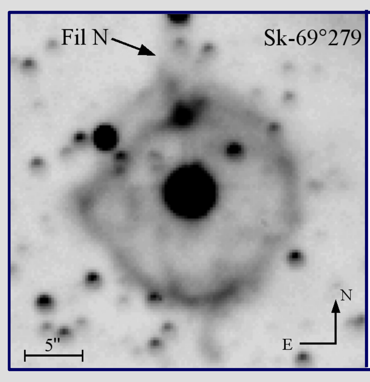


S119

spherical + outflow

size = 1.8 pc

v_{exp} = 26 km/s

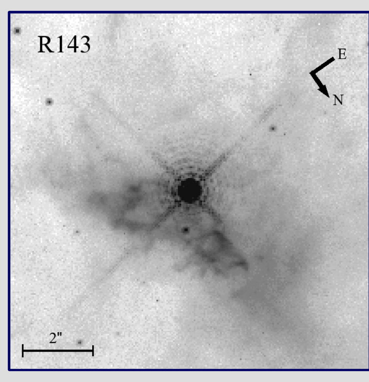


Sk –69° 279

spherical + outflow

size = 4.5 pc

v_{exp} = 14 km/s



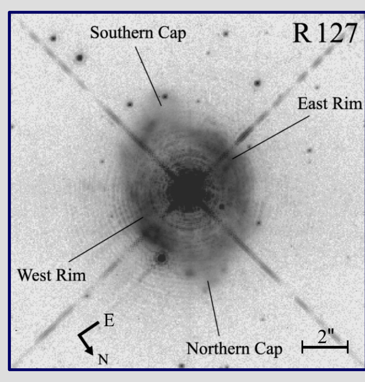
R143

irregular

size = 1.2 pc

v_{exp} = 24 km/s*

*line-split



R127

bipolar

size = 1.3 pc

v_{exp} = 32 km/s

Galactic and LMC LBV Nebulae in Comparison

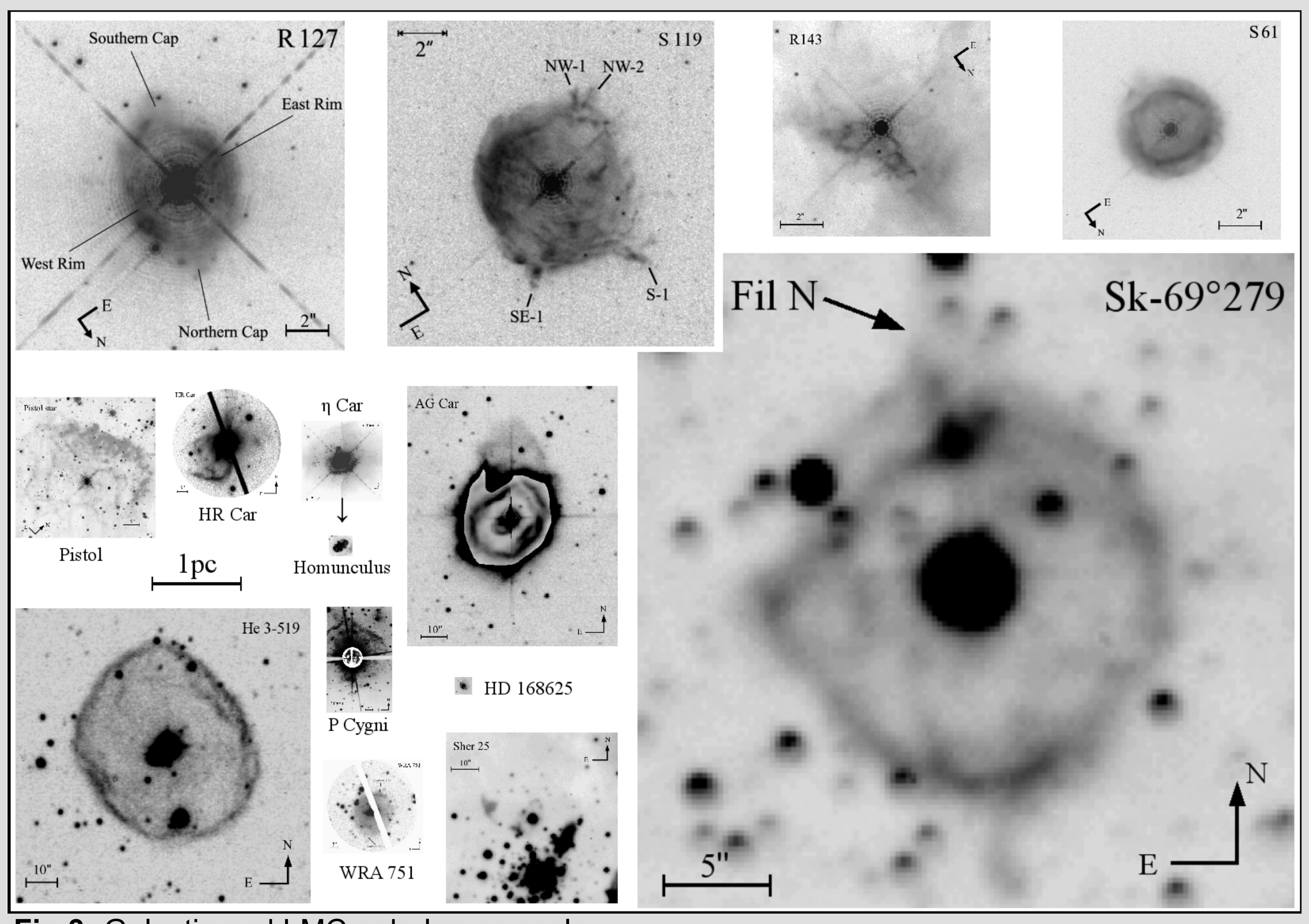


Fig.3: Galactic and LMC nebulae on scale

Significant differences between the parameters like their size, morphology and expansion velocity of the LBV nebulae in our Galaxy and those in the LMC can be noticed (see Tab. 1, for details on each object):

- **LMC nebulae** are generally **larger** compared to those in the Milky Way, **average size** for nebulae is in the **LMC ~ 2 pc**, the **MW** only **1 pc***
- the **expansion velocities** of **LMC nebulae** is **smaller**, on average is $\mathbf{v_{exp}}$ **~ 22 km/s** for **LMC** and **64 km/s** for **MW nebulae***
- the **fraction** for **bipolar nebula** is **higher for galactic LBV nebulae,** currently **75% galactic** but only **20% LMC** nebulae are bipolar

* statistics excludes the nebulae around η Car, that has the most extreme values of all.

LBV	host galaxy	maximum size [pc]	radius [pc]	v_{exp} [km/s]	kinematic age [10^3 yrs]	morphology
η Carinae	Milky Way	0.2/0.67	0.05/0.335	300*/10 – 3200		bipolar
AG Carinae	Milky Way	1.4 × 2	0.4	~ 25*	~ 30	bipolar
HD 168625	Milky Way	0.13 × 0.17	0.075	30	1.8	bipolar ?
He 3-519	Milky Way	2.1	1.05	61	16.8	spherical/elliptical
HR Carinae	Milky Way	0.65 × 1.3	0.325	75*	4.2	bipolar
P Cygni	Milky Way	0.2/0.84	0.1/0.42	110 – 140/185	0.7/2.1	spherical
Pistol Star	Milky Way	0.8 × 1.2	0.5	60	8.2	spherical
Sher 25	Milky Way	0.4×1	0.2×0.5	30 – 70	6.5 – 6.9	bipolar
WRA 751	Milky Way	0.5	0.25	26	9.4	bipolar
R 71	LMC	< 0.1?	< 0.05?	20	2.5 ?	?
R 84	LMC	< 0.3 ?	< 0.15?	24 (split)	6 ?	?
R 127	LMC	1.3	0.77	32	23.5	bipolar
R 143	LMC	1.2	0.6	24 (split)	49	irregular
S Dor	LMC	< 0.25?	<0.13?	< 40 (FWHM)	3.2 ?	?
S 61	LMC	0.82	0.41	27	15	spherical
S 119	LMC	1.8	0.9	26	33.9	spherical/outflow
Sk –69° 279	LMC	4.5 × 6.2	2.25	14	157	spherical/outflow

Table Parameters of Galactic and LMC LBV nebulae. For nebulae with a distinct inner and outer section both values are given and are separated with a slash. The maximum size given is either the largest diameter measured if spherical or the major and minor axes. For hourglass shaped bipolar nebulae, the radius and expansion velocities (marked with *) referes to just one lobe.

Tab.1: Parameters of galactic and LMC LBV nebulae

LBV Nebulae – Near and Far

Results for the LMC & Milky Way sample → differences from the **lower metalicity** in the **LMC**

- **size & expansion velocities**
  - line driven winds ↔ lower wind velocities → lower expansion velocities
  - underlying instabilities for giant eruption ↔ e.g if κ-mechanism
- **morphologies**
  - analysis for AG Car and HR Car (both bipolar) show that high stellar rotation that can be the cause for bipolarity → LMC B supergiants are show to have on avarage a lower rotation rate (Hunter et al. 2008) ↔ fewer bipolar LBV nebulae in LMC

Digging even deeper and further → what would that **imply** for other **galaxies**

- **Local Group**
  → indications for LBV nebulae are seen in images or spectra of M31, M33 (Weis et al. in prep) and IC 10 (Bomans & Weis in prep).
- **beyond the Local Group**
  → extended emission was detected for the LBV V37 (=SN2002kg , Weis & Bomans 2005), and the supernova impostor in NGC 3109 (Bomans et al. 2012, in print)

Predictions for low metalicity LBV nebulae → what we can extrapolate from the LMC sample

- **low metalicity LBV nebulae may be even larger as LMC objects**
  → if the trend from the LMC nebulae holds towards even lower metalicities, the prediction for even lower Z galaxies in the Local Volume (D < 11Mpc) (Bomans & Weis 2012) is that their LBV nebulae should be well detectable with AO supported IFU spectrographs and imagers, having a large size and a high [N II] emission.