Radio Nebulae around Luminous Blue Variable Stars

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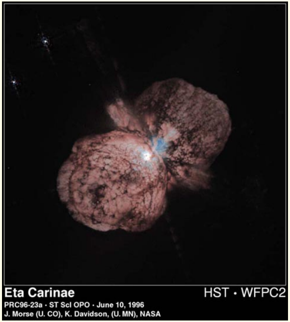
Outline

Luminous Blue Variable Stars

- $L \sim 10^6 L_\odot$
- $T < 30,000K$ (Early type)
- Variable
- $M \sim 20 - 120 M_\odot$
- $\dot{M} \sim 10^{-6} - 10^{-4} M_\odot yr^{-1}$ (stellar wind and/or eruption)
- post-MS toward Wolf-Rayet star



LBV stars are named after their peculiar luminosity, the P-Cygni profile of some spectroscopic lines and their spectroscopic and photometric variability

Humphreys & Davidson 1994, Pub. Astron. Soc. Pac. **106**, 1025

Known LBVs

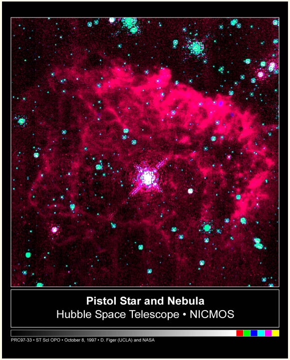
LBVs are quite rare objects in our **Galaxy**.
A recent census reports:

- 12 confirmed LBV
- 23 candidates LBV

A few reported in nearby galaxies.

E.g., in the **Large Magellanic Cloud**:

- 22 LBVs between effective members and candidates



Lifetime of the LBV phase is very short, about $\sim 10^4$ *ys.*

Census reported by van Genderen 2001, A&A,366,508; Clark et al. 2005, A&A,434,949.

Open questions

- Most interesting aspects of LBVs
  - major contributors to the interstellar UV radiation
  - provide enrichment of processed material and mechanical energy
  - might be direct SN progenitors
- Aspects not completely understood
  - the total mass lost during the LBV phase
  - the origin and shaping of the LBV nebulae
  - the mass-loss behavior

The total mass lost is a fundamental parameter to test evolutionary models.

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A multiwavelength approach

Full characterization of mass-loss properties to understand their role in massive star evolution.

Multi-wavelength observations that trace different emitting components coexisting in the ejecta. In particular

- radio observations reveal the ionized gas and the stellar wind
- IR observations show the dust emission

A galactic LBV candidate: G79.29+0.46. State of Art

Three-color image of G79.29+0.46 in the IRAC bands. Red: 8 μm; Green: 5.4μm; Blue 3.6 μm.

- Observed in the Cygnus-X star forming region ($D \sim 1.7 kpc$ (Jimenez-Esteban et al 2010, ApJ, 713, 429)
- First detection of a symmetric ringlike structure in the radio (by Higgs et al. 1994, TL, 291, 291)

→ *Thermal gas shell*

- IR observations (with IRAS and Spitzer) revealed a detached shell due to an epoch of high mass loss ($\sim 5 \times 10^{-4} M_\odot yr^{-1}$)

→ *Dust shell*

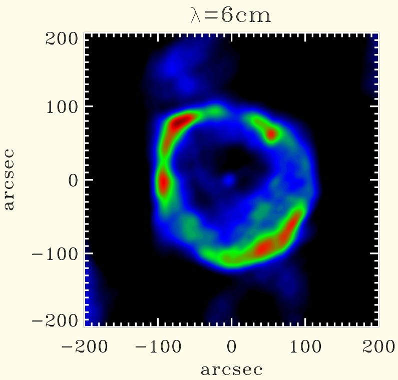
The radio observations: our analysis

For a point-by-point comparison with the dusty components, we performed high sensitivity, high dynamic range observations at EVLA.

Observing dates	EVLA Conf.	Frequency GHz	Integration time (min)
2010 June 1	D	1.4	90
2010 June 11	D	4.9	90
2010 Dec. 1	C	1.4	90
2010 Dec. 5	C	4.9	90

The radio observations: our analysis

- For each frequency and each configuration, datasets were indipendently calibrated
- then combined into a single *uv* dataset to improve *uv*-covarage
- Imaging process using Briggs-type weighting (robust 0) and a multi-scale CLEANing algorithm
- Final image noise 0.07 *mJy beam*$^{-1}$, peak 1.76 *mJy beam*$^{-1}$ and synthetic beam 4.6" $\times$ 3.1" at 6cm



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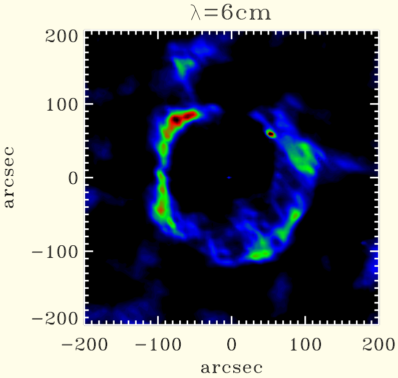

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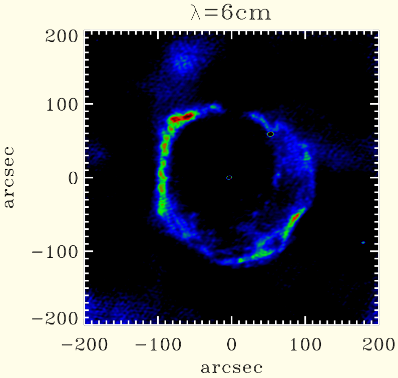


The radio observations: our analysis

Derived parameters (central object)

Central object $F_{5GHz} = 1.51 \pm 0.08 mJy$, consistent with Higgs et al. 1994.
Assuming a stellar wind object:

Current-day mass-loss
(Panagia&Felli 1975, A&A, 39, 1)

$$\dot{M} = 6.7 \times 10^{-4} v_{\infty} F_{\nu}^{3/4} D_{kpc}^{3/2} (\nu \times g_{ff})^{-0.5} M_{\odot} yr^{-1}$$
$$= 5 \times 10^{-7} M_{\odot} yr^{-1}$$

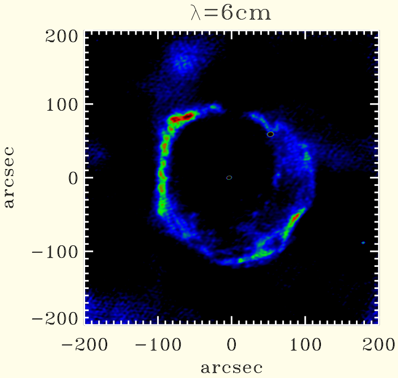
where

$v_{\infty} \sim 110 kms^{-1}$ (Voors et al. 2000)

$D = 1.7 kpc$ (Jimenez-Esteban et al. 2010)

$g_{ff} = 9.77(1 + 0.13 log \frac{T^{3/2}}{\nu})$
(Leitherer&Robert 1991)

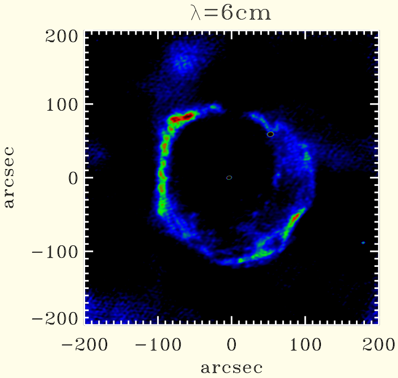
$T = 10^4 K$



The radio observations: our analysis

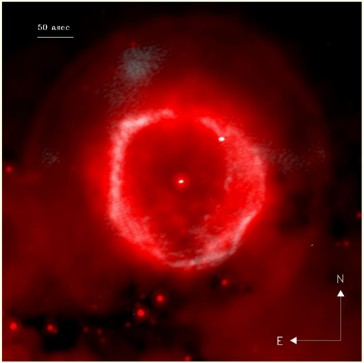
Other parameters (nebular gas)

- Ionized mass not estimated yet, because the interferometer does not provide for the zero-baseline
- Single dish observation just made (at Green Bank Telescope (GBT), June 2011)
- **Work in progress** on data reduction

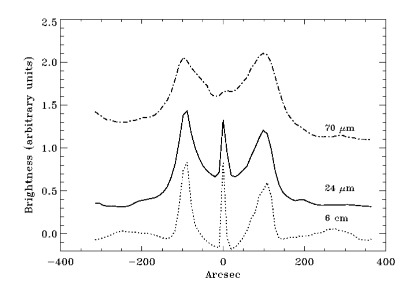


Ionized component versus dust components

Comparison of the spatial distribution of the ionized gas component with the morphology of the dust component, superimposing the 6*cm* and 24μm maps (angular resolution comparable, respectively $\sim$ 5'' and $\sim$ 6'')



Our 6cm EVLA map (grey) superimposed to the Spitzer/MIPS 24μm map (red, Kraemer et al. 2010, ApJ, 139, 2329).



Averaged profiles through the nebula at three wavelengths. Each profile was obtained from 18 individual cuts in the corresponding map and was shifted vertically by and arbitrary quantity for easier comparison.

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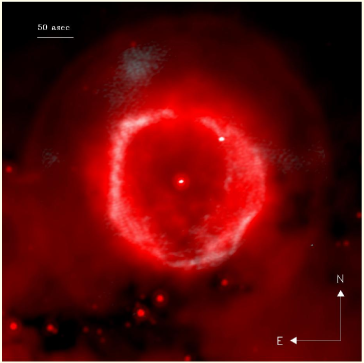

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Time scale for the mass-loss episodes

The inner shell peaks at 100" and the second one at 200" from the central object. Assuming a distance of 1.7 kpc $\Rightarrow$
0.82 pc and 1.64 pc respectively.

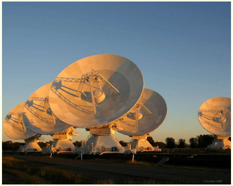
- $\rightarrow$ We estimate mass-loss episodes occured 2.7×10^4 and 5.4×10^4 years ago (assuming a shell expansion velocity of $\sim$ 30 km s^{-1})
- $\rightarrow$ Constraints for stellar evolutionary models

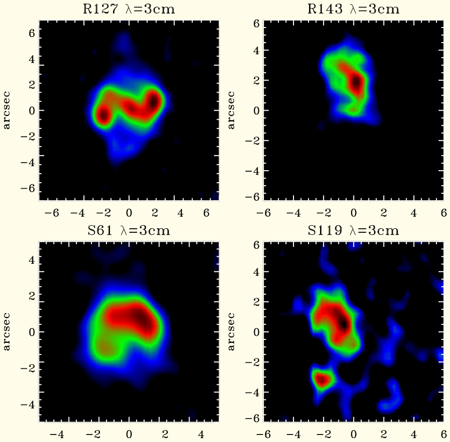
LBVs nebulae in the Large Magellanic Cloud
State of Art

- LMC is an ideal laboratory to test if LBV is a metallicity independent phenomenon (as its metallicity is half the solar one)
- 22 stars are either effective or candidates LBV (classification based only on ultraviolet, optical and near-IR photometry and spectroscopic)
- Four of them show a nebula emitting in the H_α band (HST observations, Weis et al 2003)

Based on this, we have observed them at 3+6cm at ATCA (in April 2011)

ATCA observations

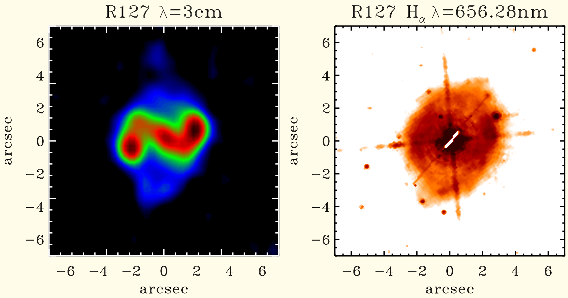




Obs Date	ATCA Conf.	Freq GHz	Integration time (min)
April 2011	6km	5+8	240

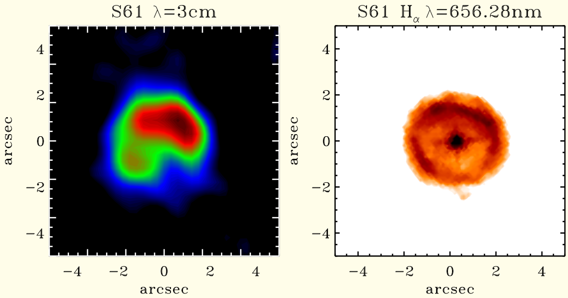
First radio detection

Tipically: image noise $\sim$ 0.02 $mJy\ beam^{-1}$, peak $\sim$ 0.02 — 0.9 $mJy\ beam^{-1}$, synthetic beam 2.5"×2.0".



First results:

- Radio free free emission resembles the H_α one
- Radio flux densities are similar to the values estimated from the H_α but R143 (3 times brighter at the cm wavelengths than the expected value). *As it is near the Tarantula star forming region, might the H_α nebula be affected by extinction?*
- Integrating over to whole nebulae, spectral index ranging from 0.1 to 0.3, indicating a contribution from the central stellar wind to the nebular emission (usually optically thin free-free)
- Higher resolutions images are needed to fully resolve the central objects



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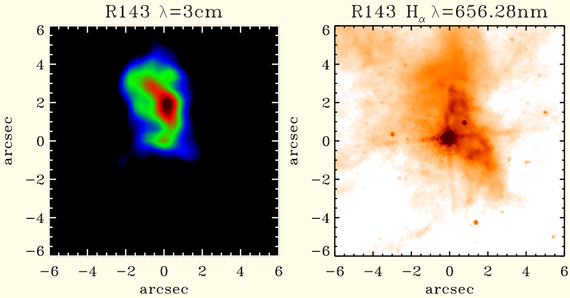

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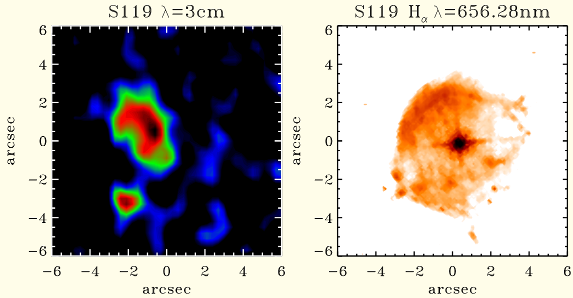

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Summary

- G79 shows that mass-loss can occur in different episodes
- Dust and gas can spatially coexist
- LBVs in the LMC show mass ejecta, but without dusty nebular components.

- Outlook / Future prospects
  - Recover the total mass content of the LBV nebulae in our sample
  - Extend the study of the LBV in the LMC in the IR when Herschel(*Heritage*) data will be available in the data archive
  - Compare Galactic templates to extragalactic objects (different metallicity environments), to assess how metallicity influences the LBV phase