Exploring the mass-loss history and the mass content in circumstellar nebulae around three magellanic luminous blue variable stars

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LMC as seen by Herschel (red 250 μm, green 100 μm) and Spitzer (blue 70 μm)

Image credit: ESA/NASA/JPL-Caltech/STScI

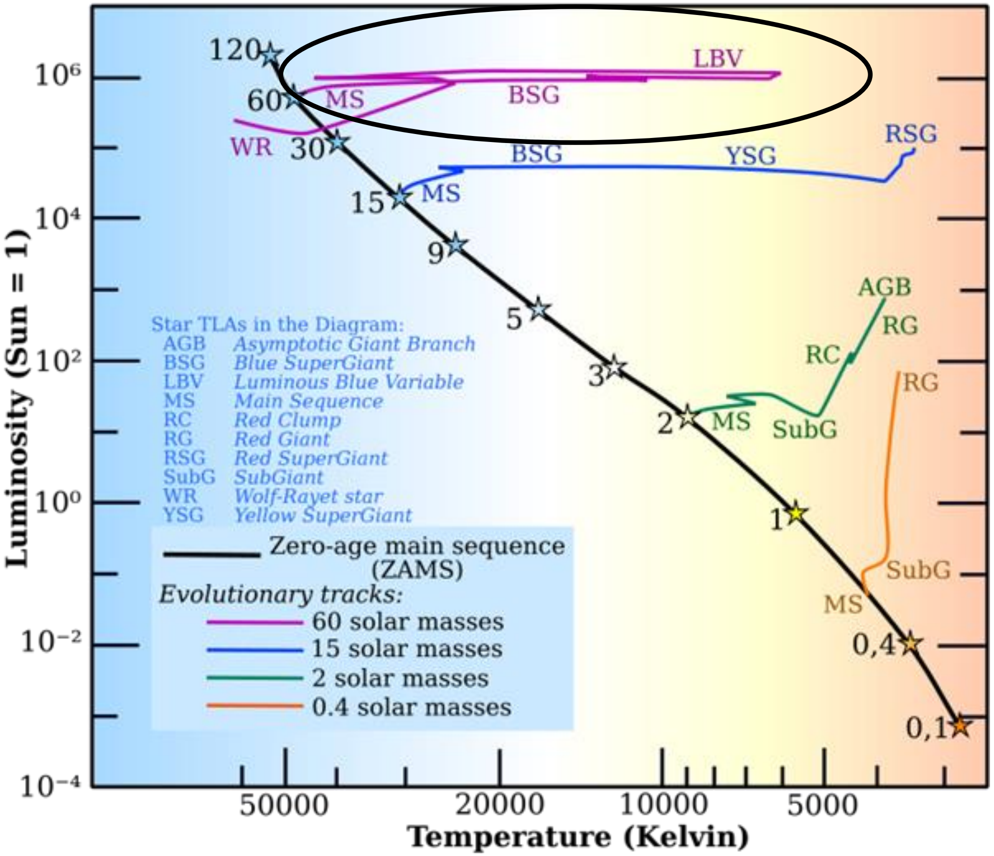
OUTLINE

- LBVs: open issues
- G79.29+0.46: a Galactic example
- LBVs at different metallicity: the Magellanic sample
- ALMA project and future work

Luminous Blue Variable Stars

PROPERTIES

- **Post-MS**
- $M_{MS} > 22\ M_{\odot}$
- $L \sim 10^{5}\text{-}10^{6.3}\ L_{\odot}$
- **spectral type: O-B**
- **Visual spectroscopic and photometric variability**
- $\dot{M} > 10^{-6} - 10^{-5} M_{\odot} yr^{-1}$ **(stellar wind or outburst)**
- **Formation of nebula ~ some** $M_{\odot}$



Final Destiny

Wolf-Rayet star

$M \sim 20\ M_{\odot}$

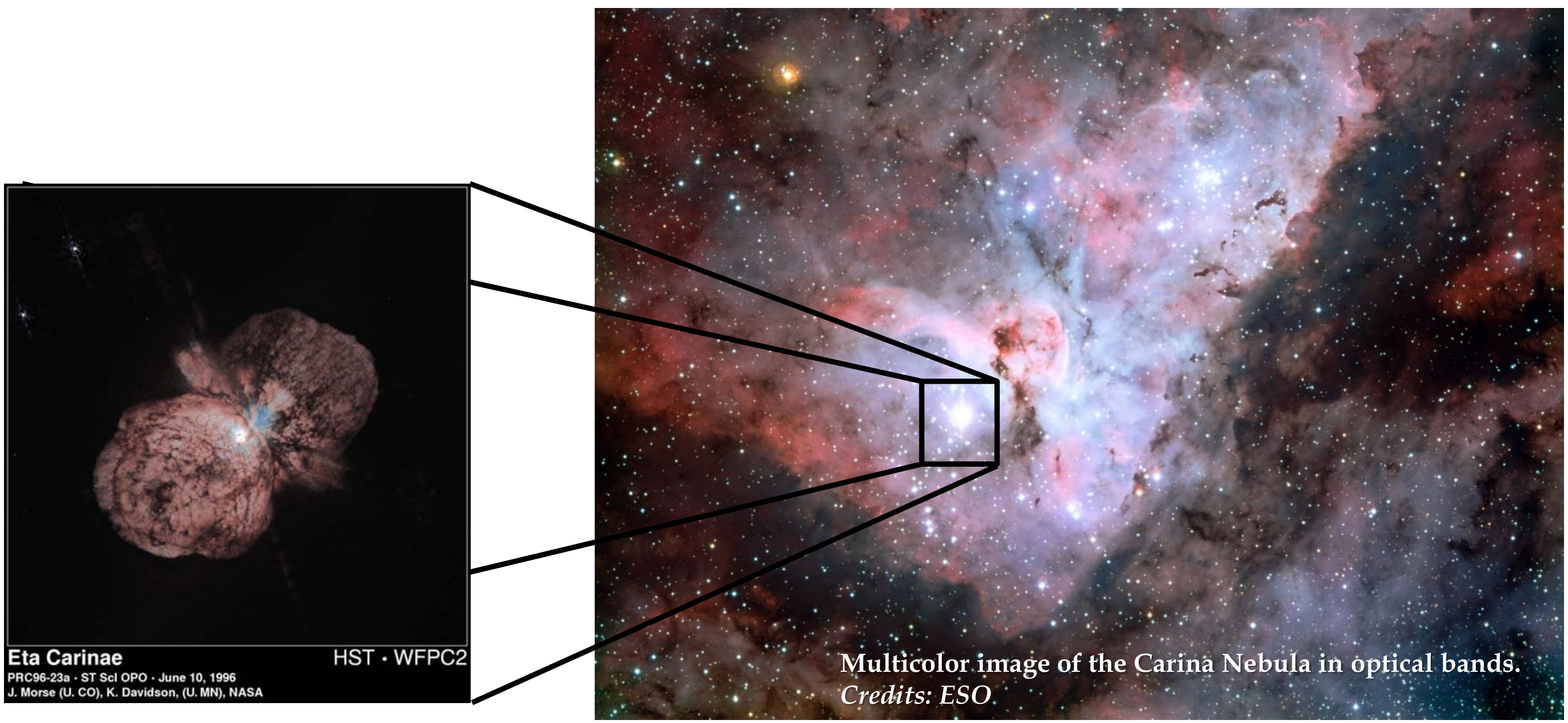
Core Collapse-Sne

Type IIn Sne?

Open issues

- **Mass-loss mechanism indipendent of metallicity?**

- **Dust producers in high-redshift galaxies?**



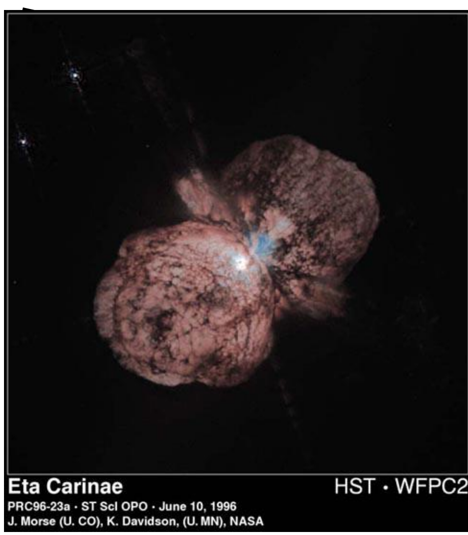
Multicolor image of the Carina Nebula in optical bands.
Credits: ESO

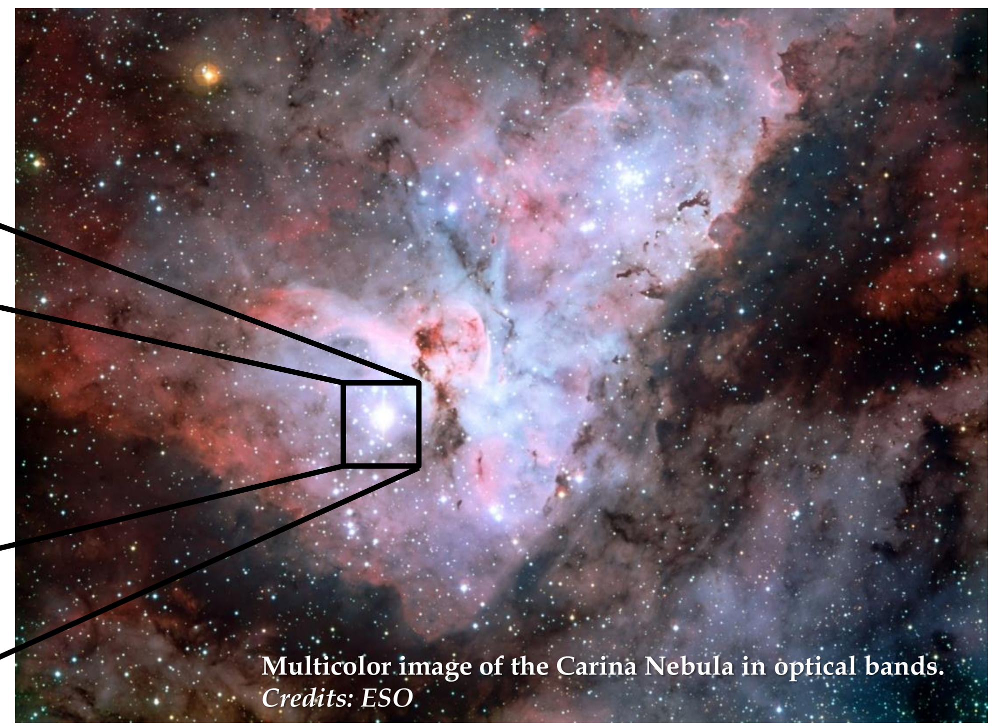
Strategy

- **Mass-loss mechanism indipendent of metallicity?**

➡ **Study of the mass-loss history of LBVs in different environments**

➡ **Mass-loss history by means of multiwavelength and high-resolution observations (Umana et al. 2011a)**





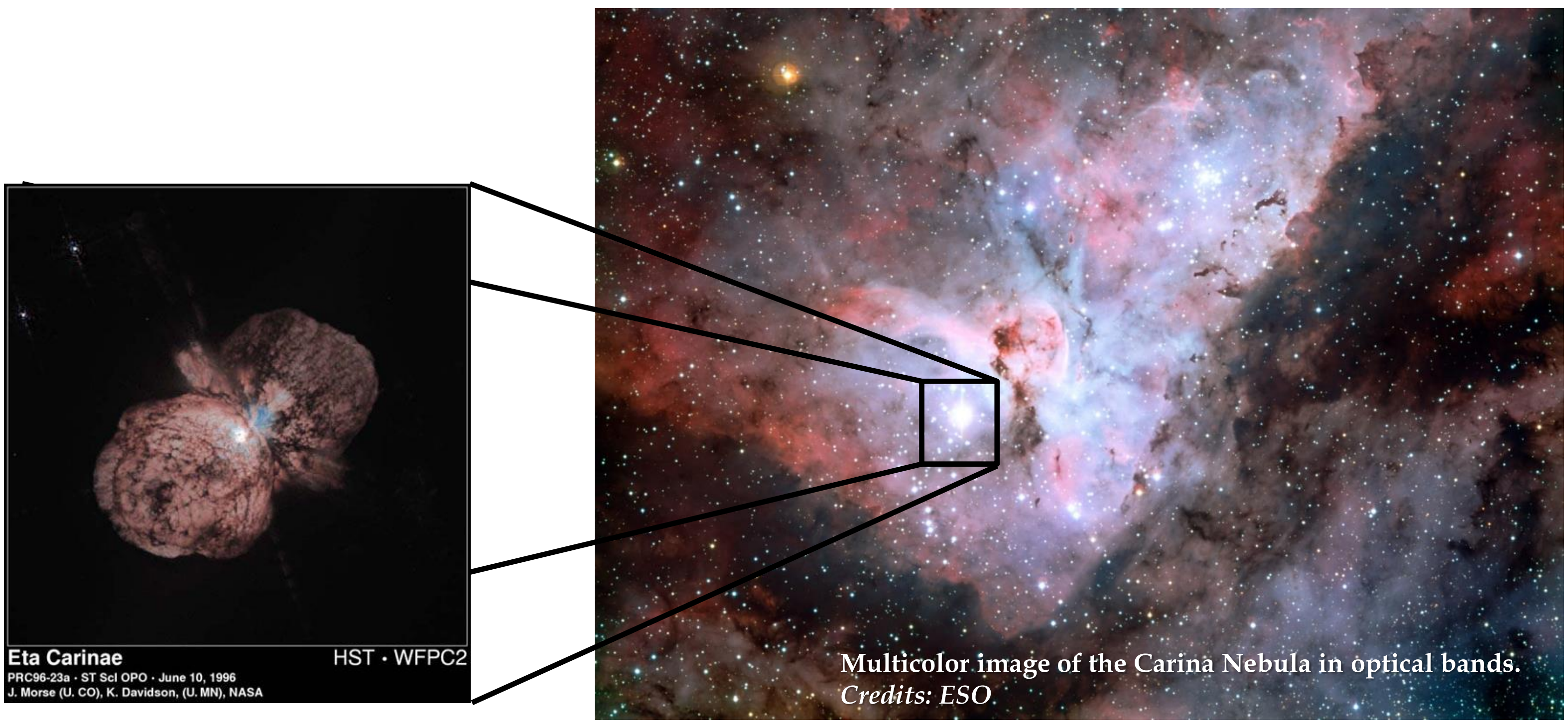
Multicolor image of the Carina Nebula in optical bands.
Credits: ESO

Strategy

- **Dust producers in high-redshift galaxies?**

➡ **Determine the dust content and the rate of dust formation**

➡ **IR and sub-mm observations**



Multicolor image of the Carina Nebula in optical bands.
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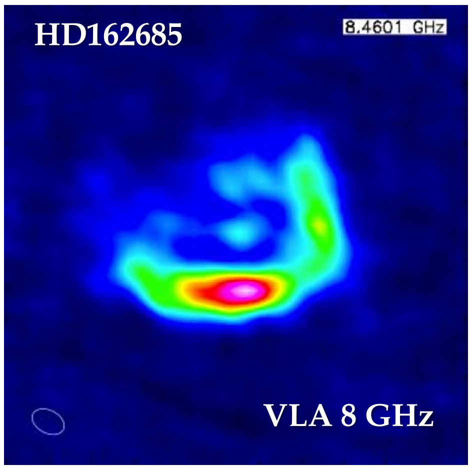
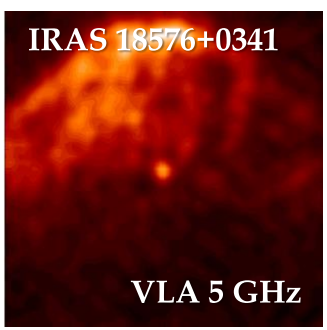
Studying the mass-loss

Radio observations of Galactic LBVs provided:

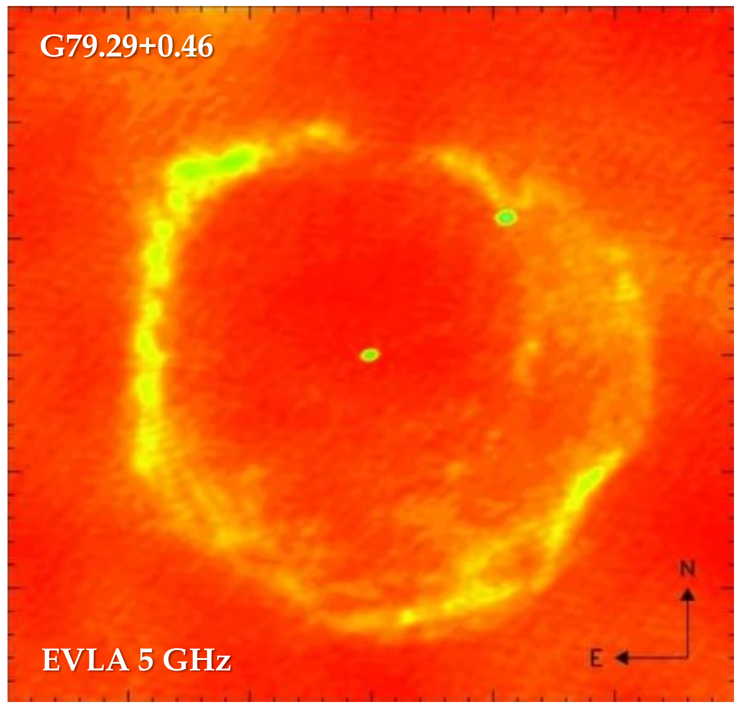
- **ionized component of the nebula (bulk of the nebula mass)**
- **current mass-loss (central object, high-resolution)**



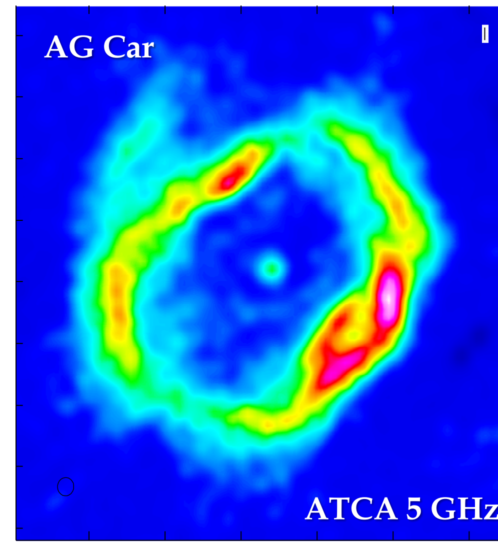
Umana et al. 2011, a

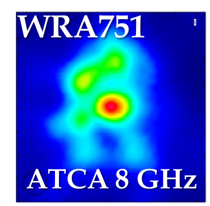


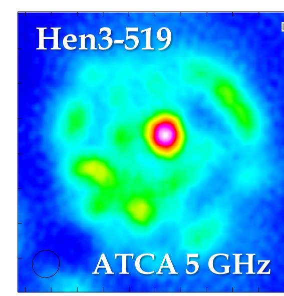
Buemi et al. 2010



Umana et al. 2011, b







Buemi et al. in preparation
Duncan & White 2000

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- **ionized component of the nebula (bulk of the nebula mass)**
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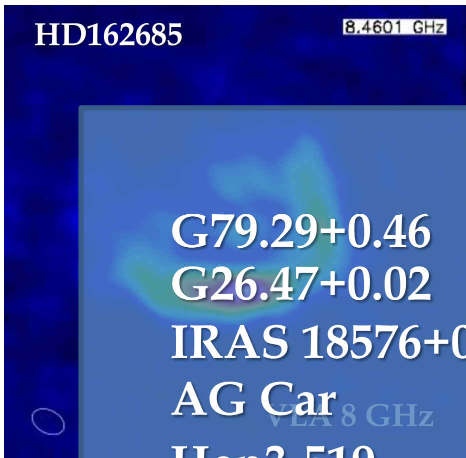
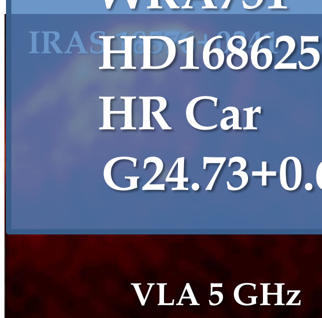
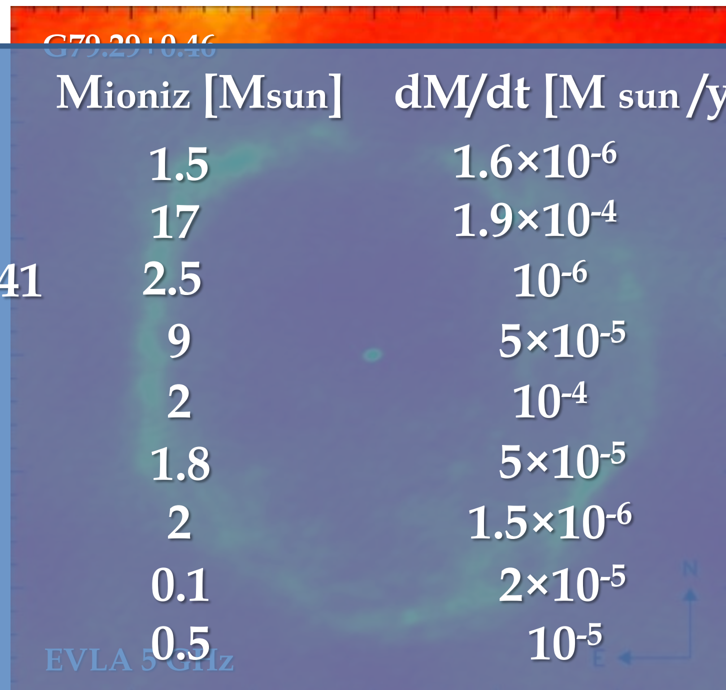


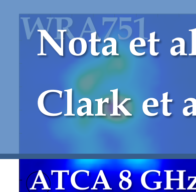
Umana et al. 2011, a

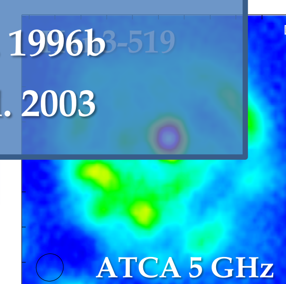


Buemi et al. 2010



Umana et al. 2011, b





Buemi et al. in preparation
Duncan & White 2000

	Mioniz [Msun]	dM/dt [M sun /yr]	Ref
G79.29+0.46	1.5	1.6×10^{-6}	Agliozzo et al. 2014
G26.47+0.02	17	1.9×10^{-4}	Umana et al. 2012
IRAS 18576+0341	2.5	10^{-6}	Buemi et al. 2010
AG Car	9	5×10^{-5}	Voors et al. 2000; Duncan & White 2002; Buemi et al. in prep.
Hen3-519	2	10^{-4}	
WRA751	1.8	5×10^{-5}	
HD168625	2	1.5×10^{-6}	Umana et al. 2010
HR Car	0.1	2×10^{-5}	Nota et al. 1996b
G24.73+0.69	0.5	10^{-5}	Clark et al. 2003

Exploring the mass-loss history

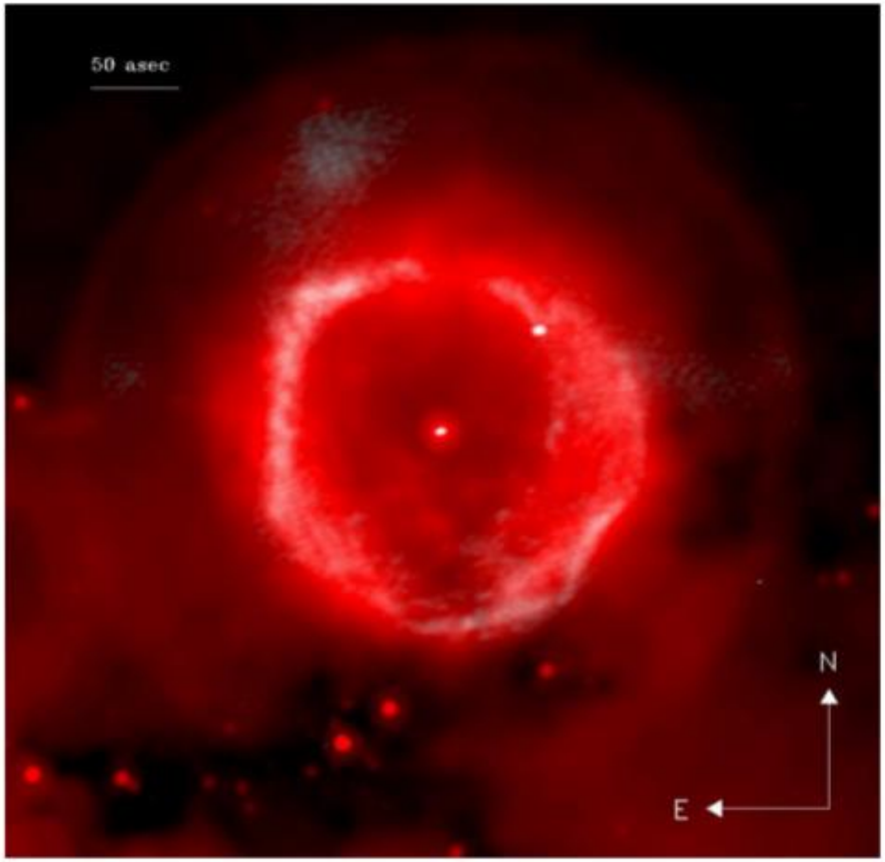


Figure 3. 6 cm EVLA map of G79.29+0.46 (gray) superimposed to the MIPS 24 μm map (red). The field of view is 3.′5 × 3.′5 centered on the LBV position.

Umana et al. 2011, b

G79.29 + 0.46 is a candidate luminous blue variable located in the *Cygnus-X star forming region* at a distance of D ~ 1.7 kpc
Nebula size 2′×2′

MIPS image at 24 μm (red)

\+

EVLA map at 5 GHz (grey)

⇩

Nebula is ionization bounded

Umana et al. 2011, b

Exploring the mass-loss history

Umana et al. 2012

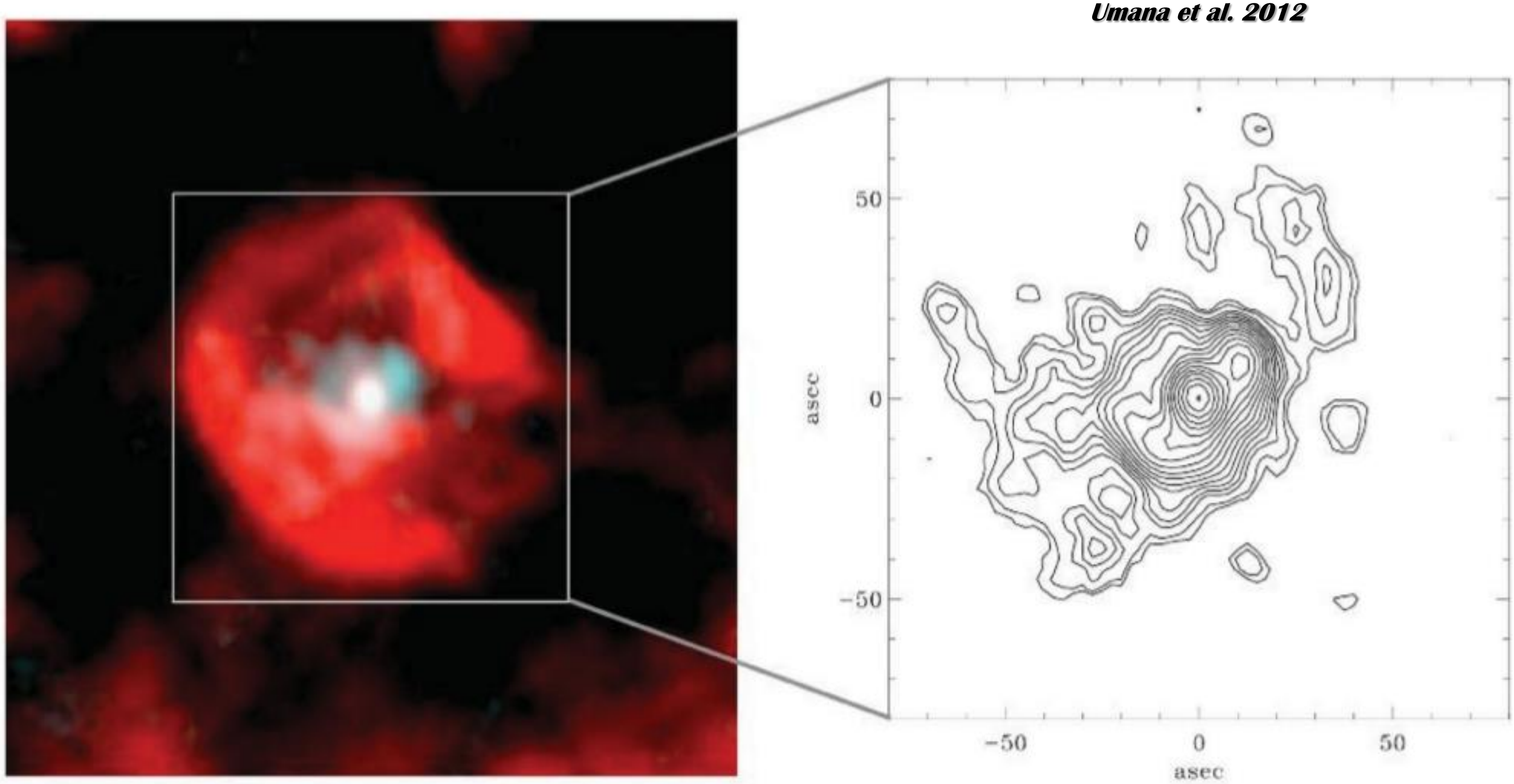


Figure 2. Left: the map of Gal 026.47+0.02 at 5 GHz superimposed on to the 70-µm image (FOV ~250 arcsec). In the zoom of the radio image (right), the contour levels are 0.18 × (4, 6, 8, 10, 13, 16, 20, 25, 30, 40, 50, 60, 80, 100, 130, 160, 200) mJy beam^{-1}.

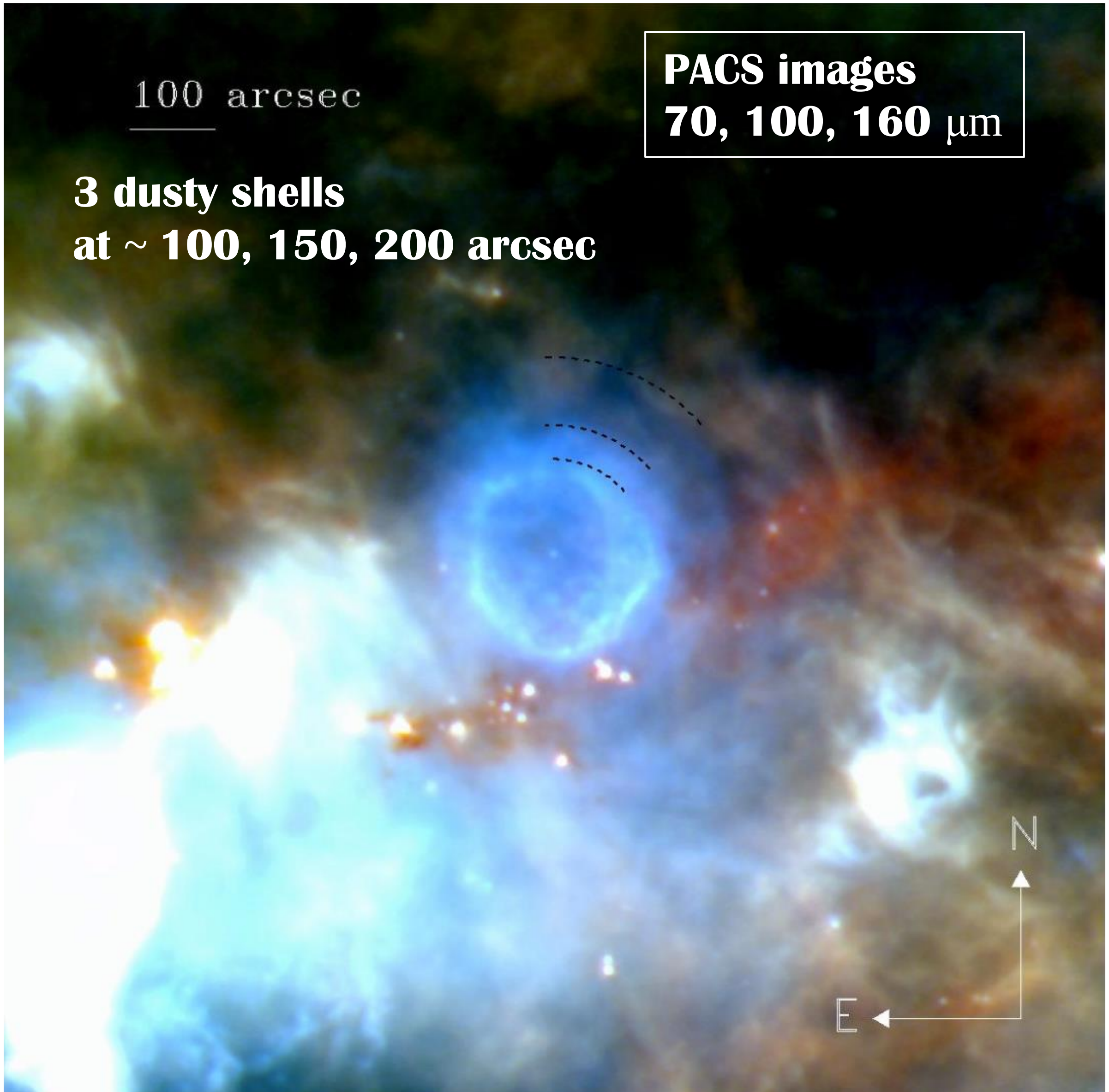
PACS image at 70 µm (red)

+

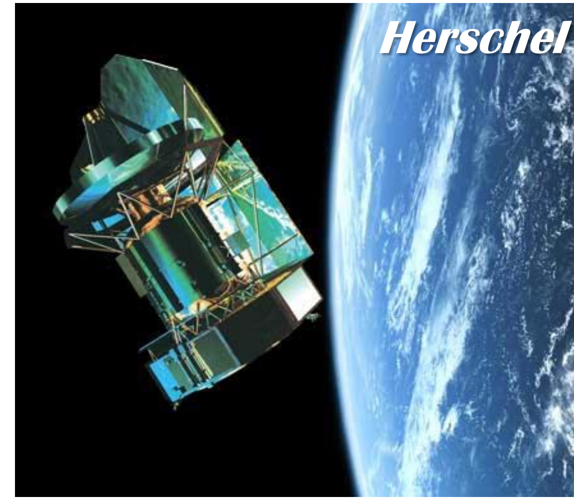
VLA map at 5 GHz (grey)

G26.47 + 0.02 is a candidate luminous blue variable at a distance of D ~ 4.8 kpc

Exploring the mass-loss history of G79.29+0.46



Agliozzo et al. 2014



v_{exp} = 30 km s^{-1} *Waters et al. 1996*

Kinematical ages

t_1 = 5.4x10^4 yr

t_2 = 4.0x10^4 yr

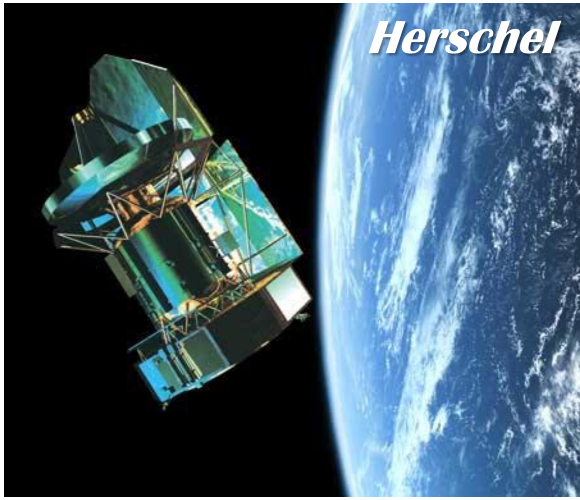
t_3 = 2.7x10^4 yr

The derived mass-loss rate

$$\dot{M} = 1.4\times10^{-6}\ [M_{\odot} yr^{-1}]$$

can not explain the nebula mass (~1.53 $M_{\odot}$) in a timescale ~ 10^4 yr

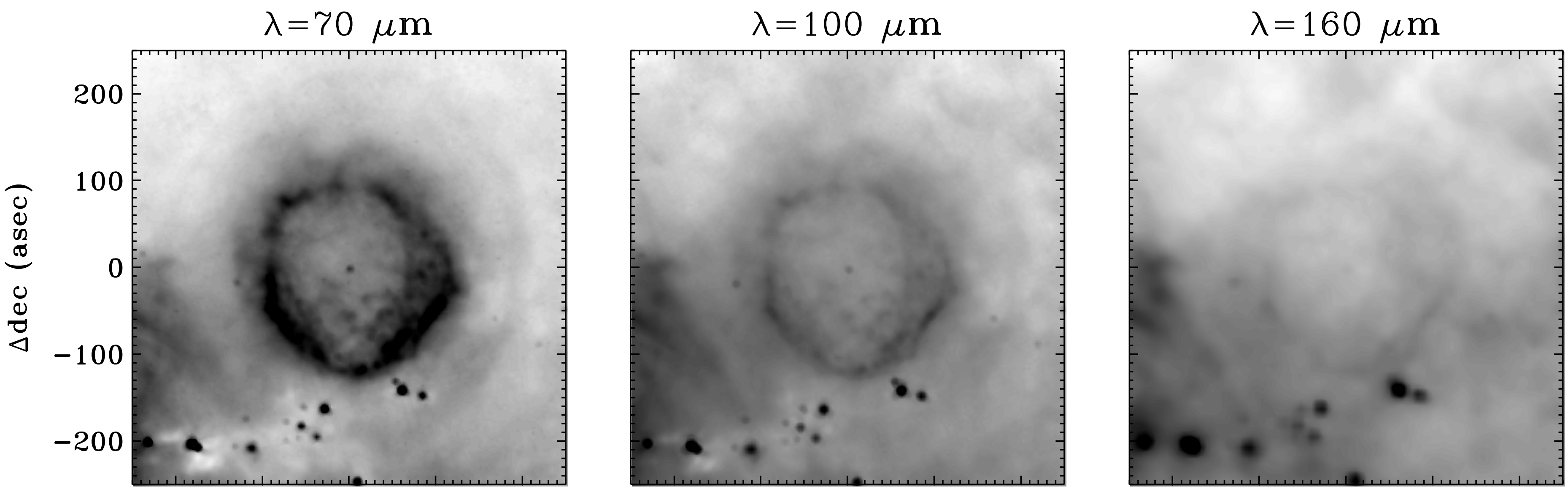
Exploring the dust content in G79.29+0.46



Hot stars do not emit down to 160 μm

Nature of the central object?

PACS images



Agliozzo et al. 2014

Exploring the dust content in G79.29+0.46

Point source catalogues

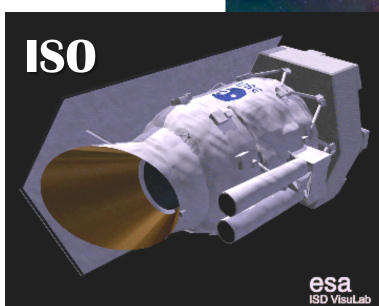
2MASS J, H, K
WISE (3-12 μm)

Archival data

Spitzer

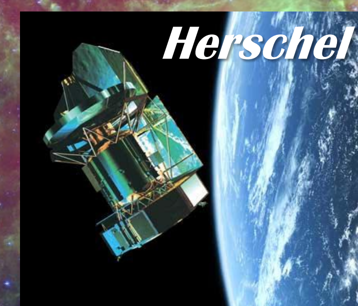
IRAC (8 μm)
MIPS (24, 70 μm)
IRS (5-37μm)

ISOCAM (8-16 μm)
ISOPHOT (25, 60, 105 μm)

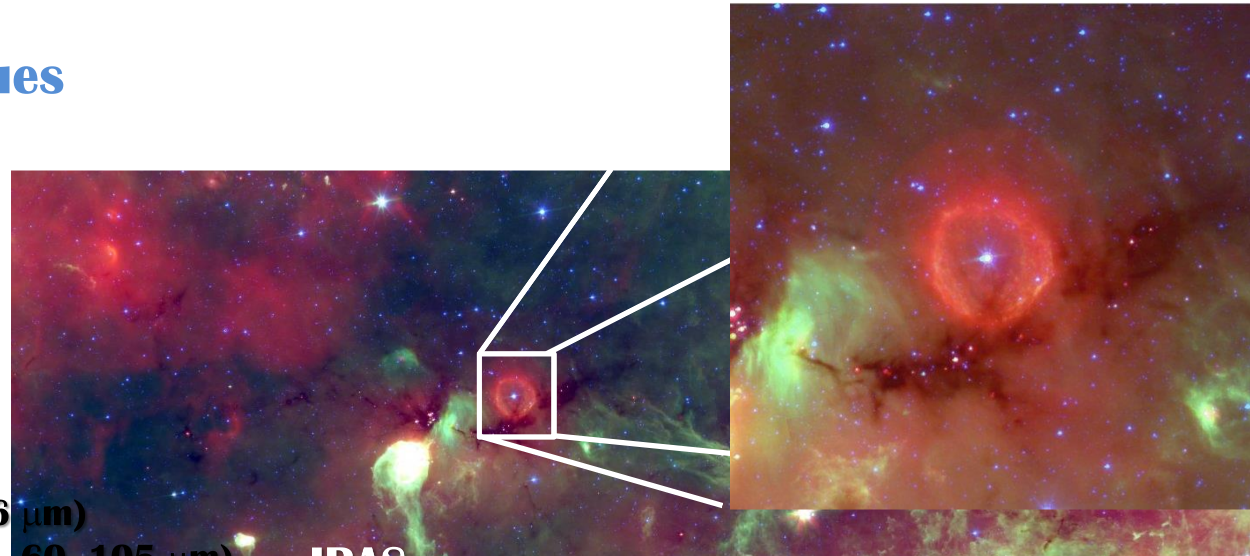


SWS (12-13, 17-26, 30-35 μm)
LWS (50-170 μm)

(60 μm)

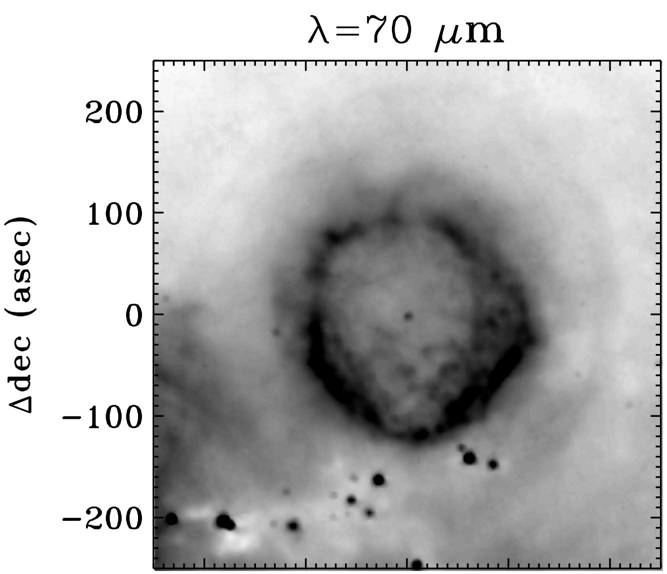


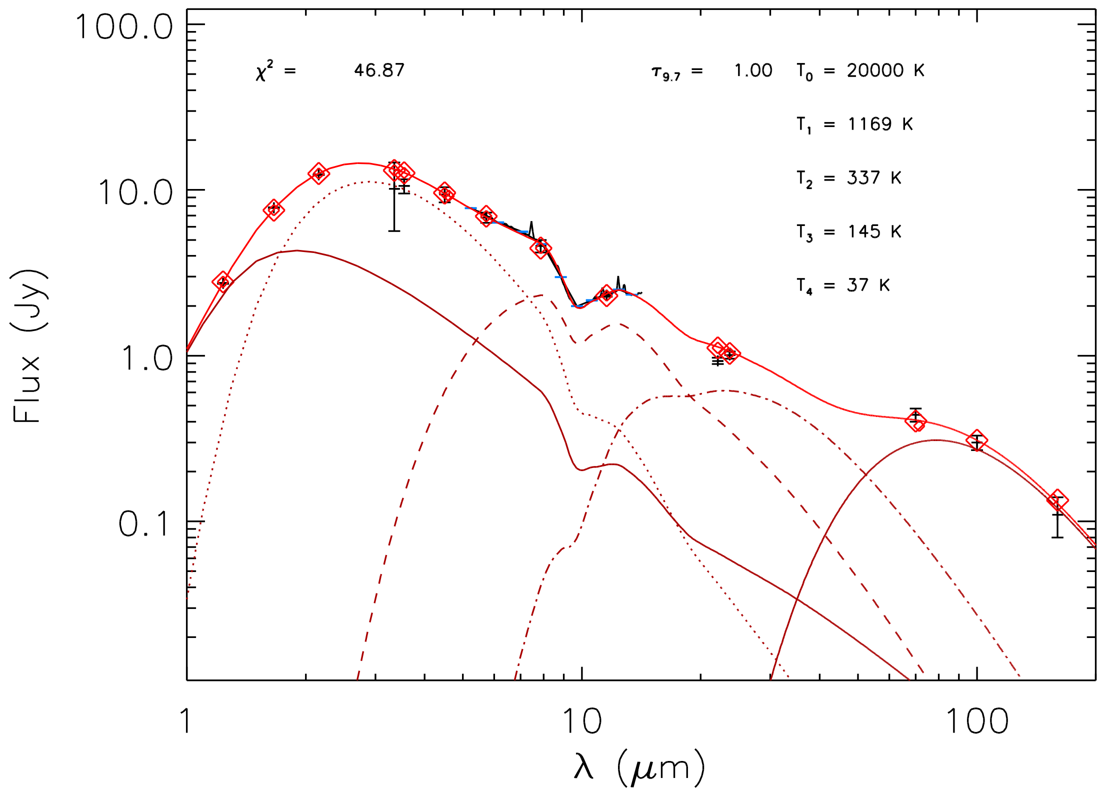
PACS
(70, 100, 160 μm)



Three color image of G79.29+0.46 and the Cygnus-X (red 24 μm, green 8 μm, blue 3.6 μm). *Cygnus-X Spitzer Legacy Survey*

The nature of the central object in the IR





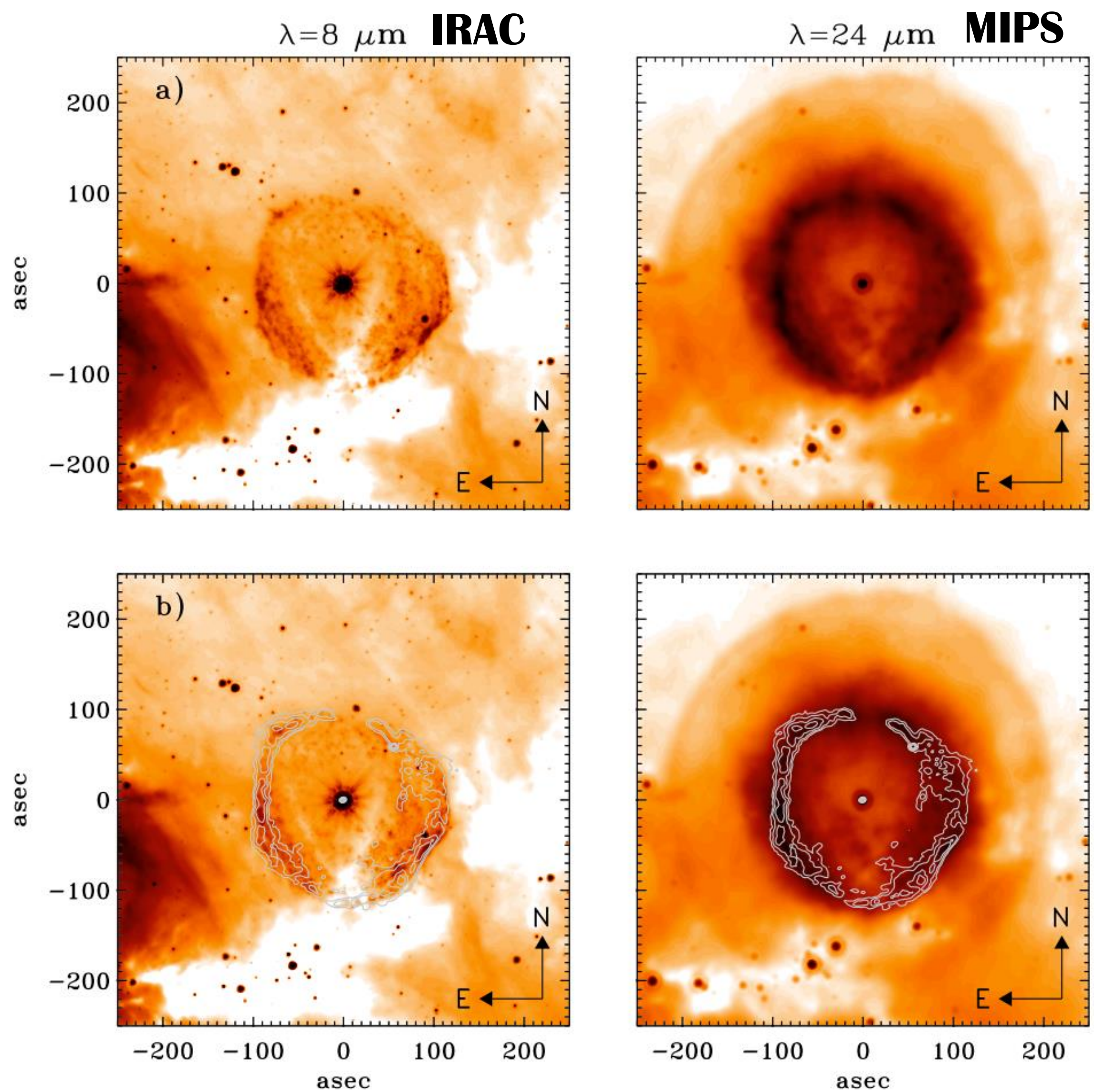
1 black body (input: T_{eff}) + 4 grey bodies (T_N: free parameters)
BESTFIT (following Flagey et al. 2011)

We suggest a range of temperatures explored by T1 to T4, in a circumstellar envelope close to the central star.

Agliozzo et al. 2014, MNRAS, 440, 1391A

The IR nebula of G79.29+0.46: populations of dust

Resolution:
2″ × 2″ (IRAC)
6″ × 6″ (MIPS)



Nebula ionization bounded

8 μm well-contained within the ionized nebula

24 μm emission more extended than the ionized gas

Umana et al. 2011, ApJL, 739, L11

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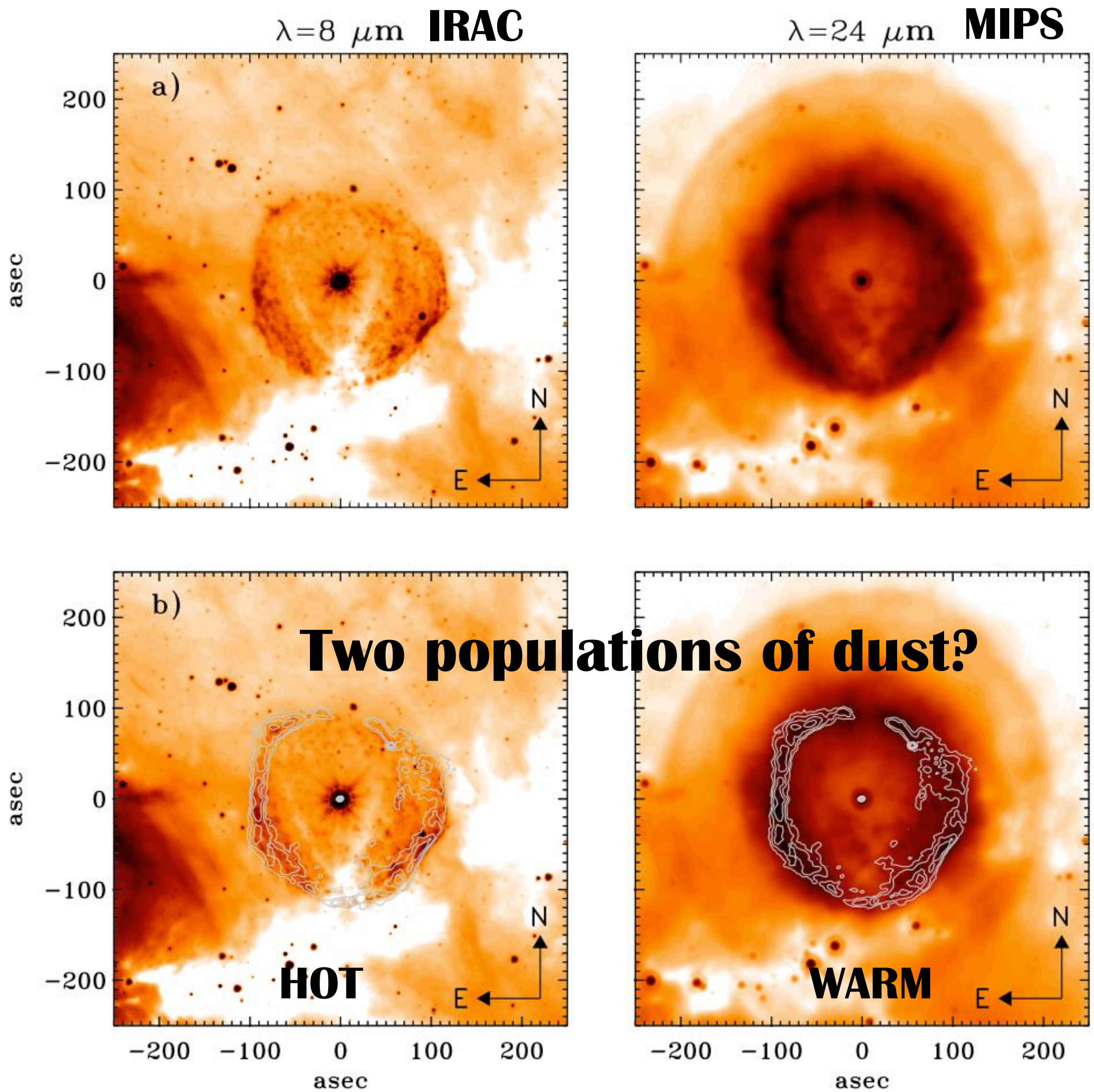


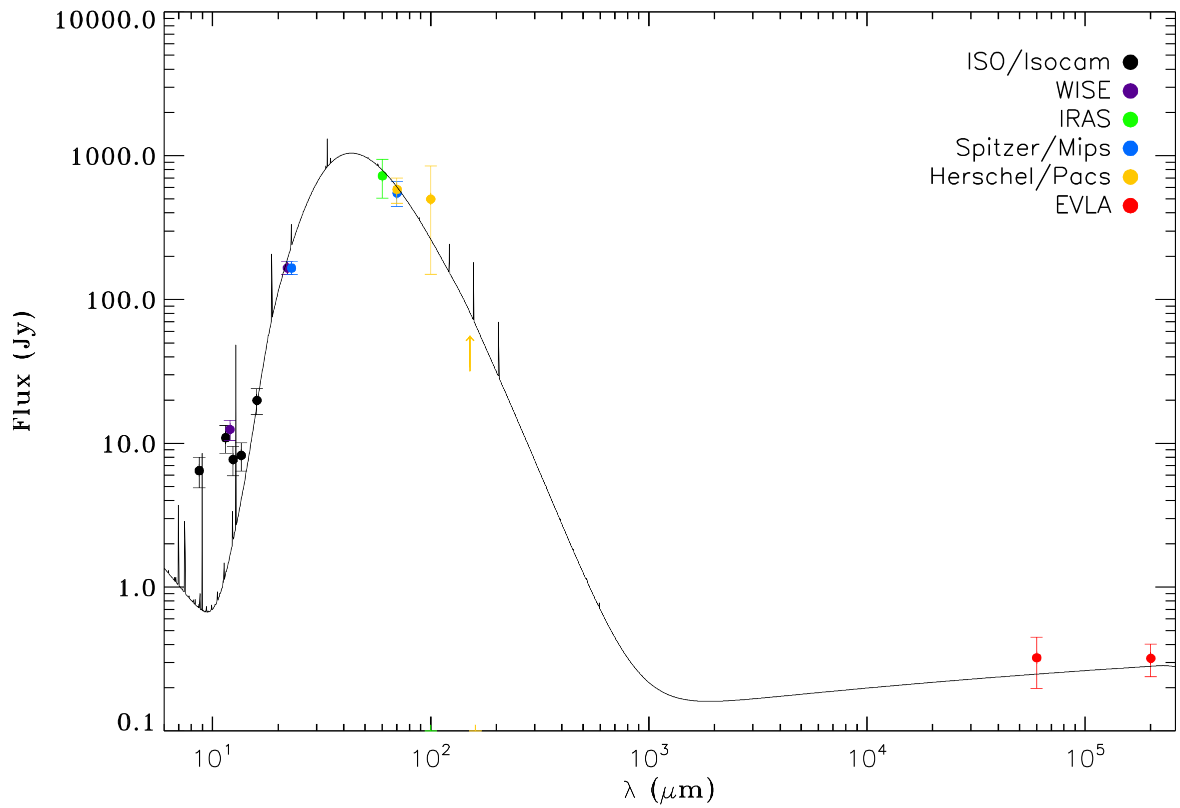
Umana et al. 2011, ApJL, 739, L11

Modelling the nebula of G79.29+0.46

Photo-ionization code CLOUDY

Input:
parameters derived from radio and infrared analysis

Parameter	Value
T_{eff} (K)	20400
D (pc)	1700
$\log(r_{in})$ (cm)	18.3085
$\log(r_{in})$ (pc)	0.66
M ($M_{\odot}$)	1.53
$\log(L/(L_{\odot}))$	5.4
$\log(n_H)$ (cm^{-3})	2.13
T_e (K)	5800
gas/dust	99



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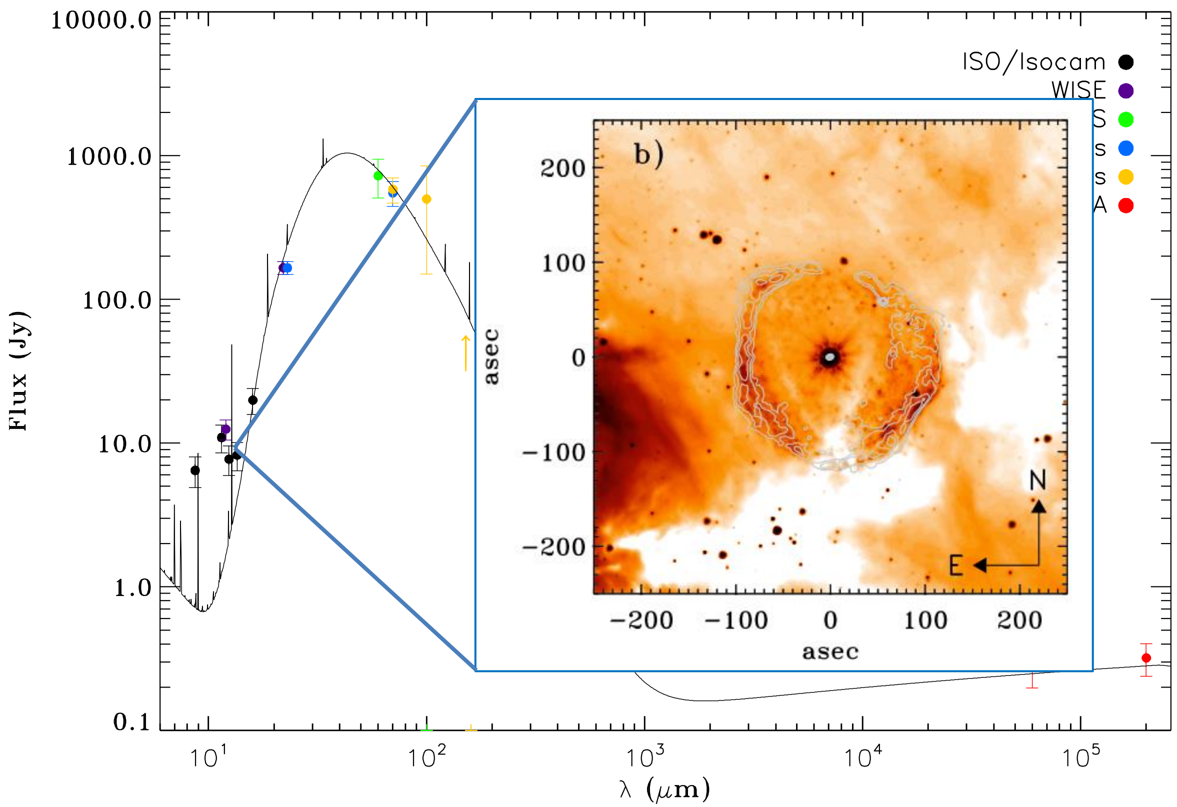

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Agliozzo et al. 2014, MNRAS, 440, 1391A

Luminous and variable stars in M31 and M33

(Humphreys et al. 2014)

no evidence hot dust.

The dust may be cold and needed to be observed from the mid-IR to the sub-mm

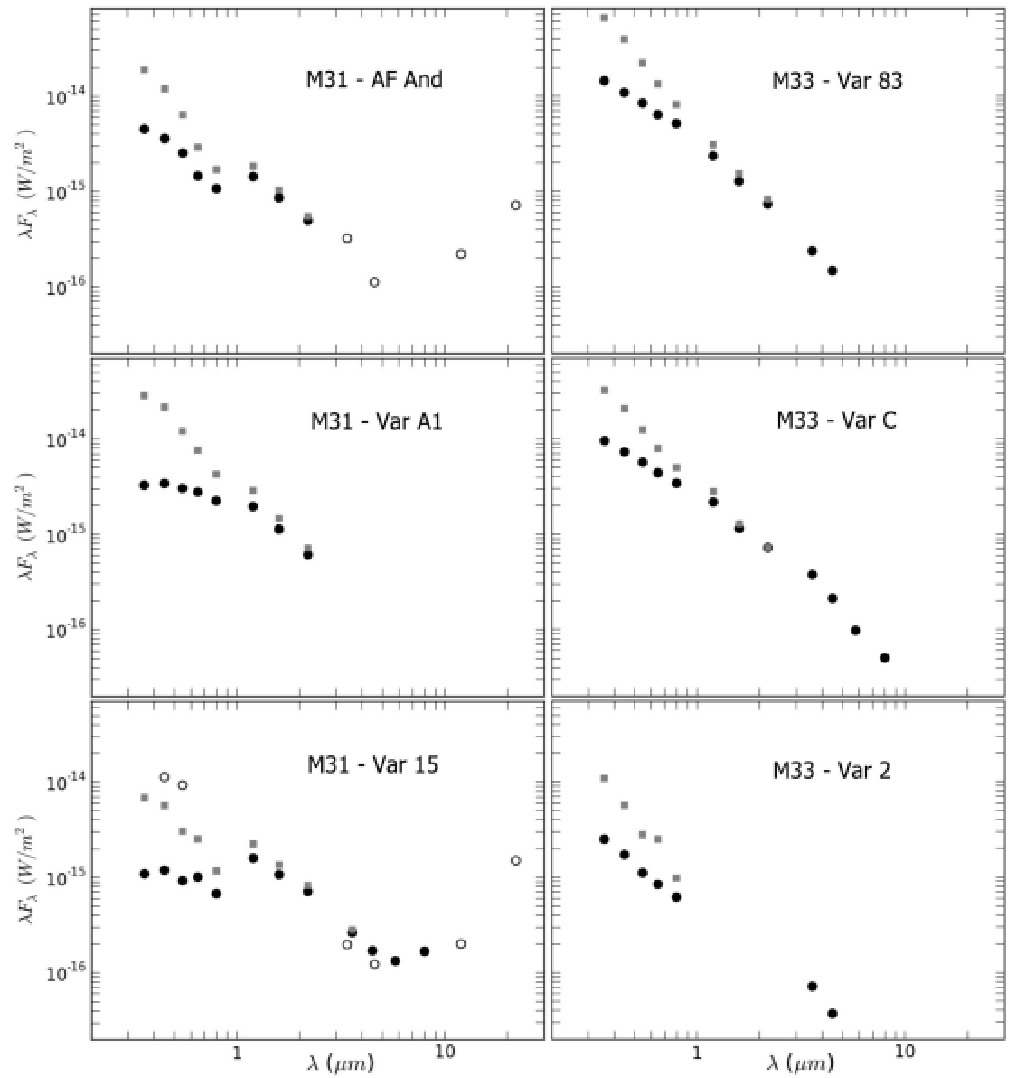

Fig. 9.— The SEDs for the confirmed LBVs. The symbols are the same as in Figure 7, e xcept for Var. 15. We also use open circles for the earlier B and V photometry when it was brighter. As no ted in the text we've used visual and near-infrared photometry for Szeifert et al. (1996) for Var C. Note that AF And and Var. 15 show PAH emission.

Properties of the dust in the nebula

Hp: **thermal dust, opically thin**

Table 7. Assumed chemical composition, grain size and absorption coefficient. We also show the derived optical depth, temperature and mass of the dust, where λ_1 and λ_2 are 8.69 and 13.5 μm, respectively (for hot dust) and 24 and 70 μm (for warm dust).

Composition and size (μm)	κ_{λ_1} (cm^2 g^{-1})	κ_{λ_2} (cm^2 g^{-1})	τ_{λ_1}	τ_{λ_2}	T (K)	M_{λ_1} (M$_\odot$)	M_{λ_2} (M$_\odot$)
Warm dust							
Silic. (0.01, 0.1, 1)	647.7	69	$(4.0 \pm 0.4) \times 10^{-4}$	$(4.2 \pm 0.8) \times 10^{-5}$	59 ± 18	0.032 ± 0.006	0.032 ± 0.006
Graph. (0.01)	300	107	$(6.1 \pm 0.6) \times 10^{-5}$	$(2.2 \pm 0.4) \times 10^{-5}$	72 ± 22	0.011 ± 0.002	0.011 ± 0.002
Graph. (0.1)	309	109	$(6.2 \pm 0.6) \times 10^{-5}$	$(2.2 \pm 0.4) \times 10^{-6}$	72 ± 22	0.010 ± 0.002	0.010 ± 0.002
Graph. (1)	600	300	$(3.6 \pm 0.4) \times 10^{-5}$	$(1.8 \pm 0.4) \times 10^{-5}$	77 ± 23	0.0031 ± 0.006	0.0031 ± 0.006

$$I_\nu \approx B_\nu(T)\tau_\nu$$

$$\tau_\nu = \kappa_\nu \rho l$$

$$M = \rho l \Omega D^2$$

Average dust temperature ~ 60-80 K

Average dust mass ~ 0.02 M_{sun}

Agliozzo et al. 2014, MNRAS, 440, 1391A

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Graph. (1)	[illegible]	[illegible]	$(3.6 \pm 0.4) \times 10^{-5}$	[illegible]	[illegible]	[illegible]	[illegible]

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$$\tau_\nu = \kappa_\nu \rho l$$

$$M = \rho l \Omega D^2$$

	Mdust [Msun]	Tdust [K]	Ref
G79.29+0.46	0.02	60-80	Agliozzo et al. 2014
G26.47+0.02	0.01-0.03	71-92	Umana et al. 2012
IRAS 18576+0341	0.01	130-150	Buemi et al. 2010
AG Car	0.2		Voors et al. 2000; Smith et al. 1994; Vamvatira-Nakou et al. 2013; Buemi et al. in prep.
Hen3-519	0.007		
WRA751	0.04	81	
HD168625	0.001	110-210	Umana et al. 2010
G24.73+0.69	0.004	60	Clark et al. 2003

Average dust temperature ~ 60-80 K

Average dust mass ~ 0.02 M_{sun}

Agliozzo et al. 2014, MNRAS, 440, 1391A

LBVs in the Magellanic Clouds

PROBLEM

LBV phenomenon indipendent of metallicity?

Smith & Owocki 2006, ApJ, 645, L45

METHOD

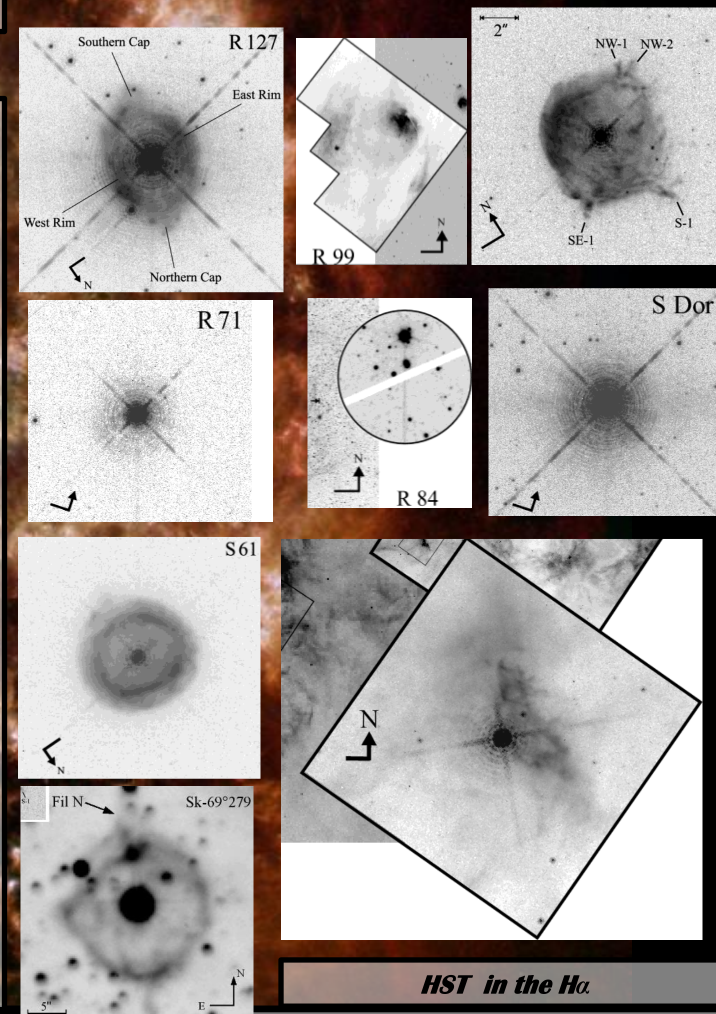
LMC: laboratory to test if LBV is a metallicity independent phenomenon (D ~ 48.5 kpc, $Z_{LMC} \sim {}^{1}/_{2}\, Z_{\odot}$).

TARGET

LBVNe in the LMC (poorly observed).

No observations in the radio so far. IR observations not suitable for exploring the dust content in the LMC.

HST optical images available in the data archive.



HST in the Hα

Weis 2003, A&A, 408, 205

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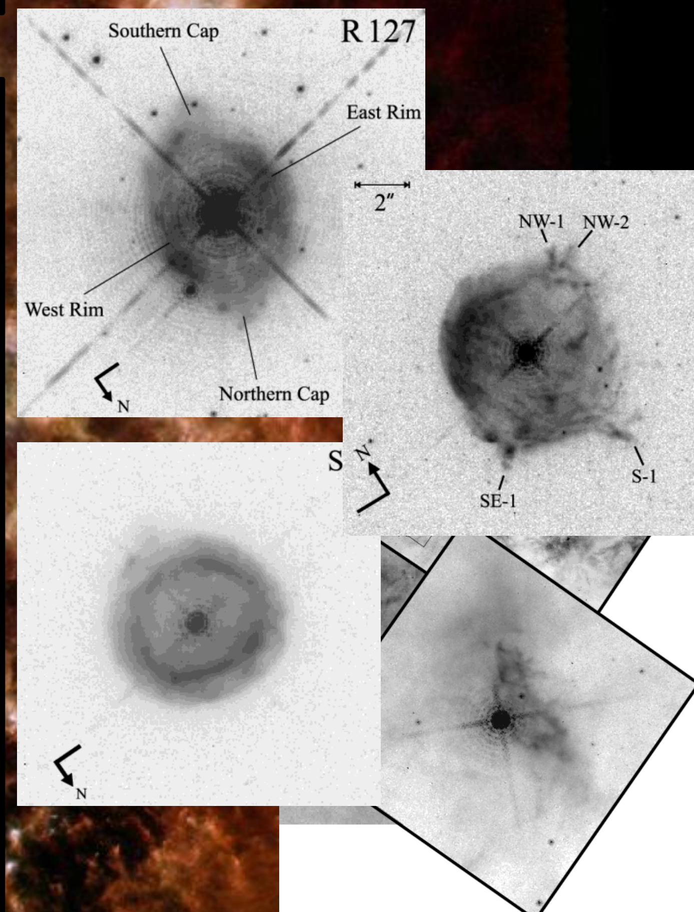
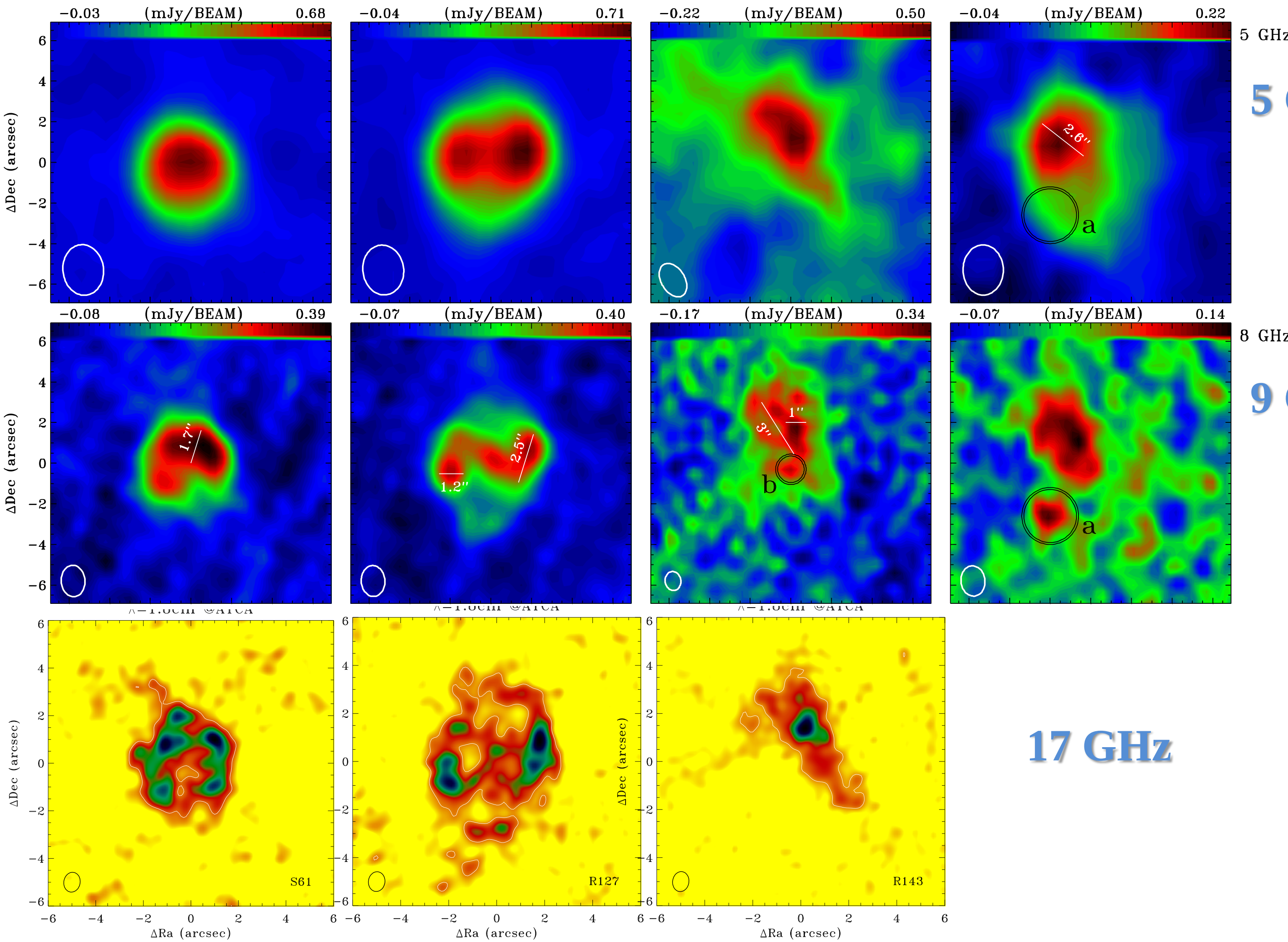


HST in the Hα

Weis 2003, A&A, 408, 205

Radio detection at ATCA



5 GHz

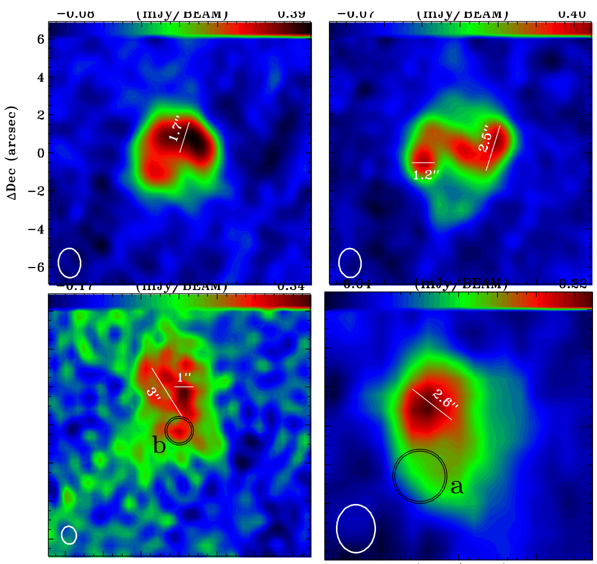
9 GHz

17 GHz

Agliozzo et al. 2012
Agliozzo et al. 2015, in preparation

Mass-loss of the magellanic LBVs

MASS OF THE IONIZED NEBULA



Source	s (pc)	Ω_s $(\mathrm{arcsec})^2$	$< n_e >$ (cm^{-3})	$M_{ionized}$ $(\mathrm{M}_\odot)$
S61	0.40	24.5	58	0.78
R127	0.28-0.59	38.1	69-48	1.01-1.46
R143	0.24-0.71	19	85-49	0.52-0.90
S119	0.61	71	19	1.13

CURRENT MASS-LOSS

Source	v_∞ $(\mathrm{km\,s}^{-1})$	$\dot{M}$ $(\mathrm{M}_\odot\,\mathrm{yr}^{-1})$
S61	250^a	$< 1.4 \times 10^{-5}$
R127	110^b	$< 2 \times 10^{-5}$
R143	130^c	$< 7 \times 10^{-6}$
S119		$1.34 \times 10^{-5}\ a$

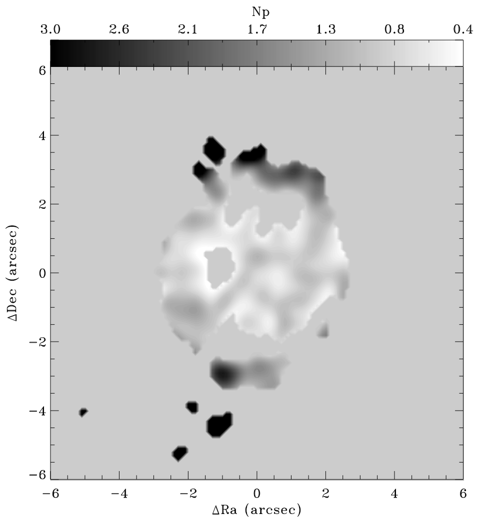
KINEMATICAL AGE

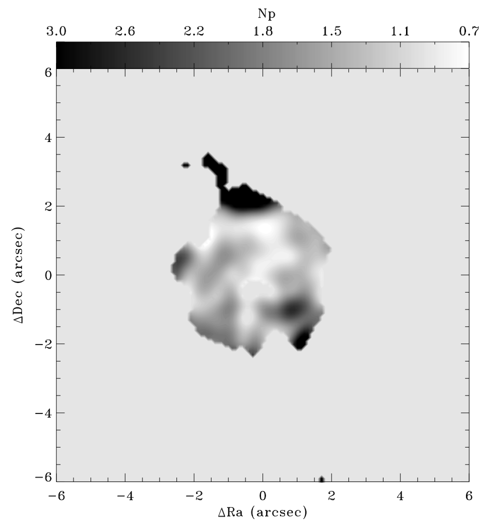
Source	size (pc)	v_{exp} $(\mathrm{km\,s}^{-1})$	t_{nebula} $(\times 10^4\,\mathrm{yr})$
S61	1.17	27^a	4.2
R127	1.65	30^b	5.4
R143	0.59	24^c	2.4
S119	1.90	25.5^d	7.2

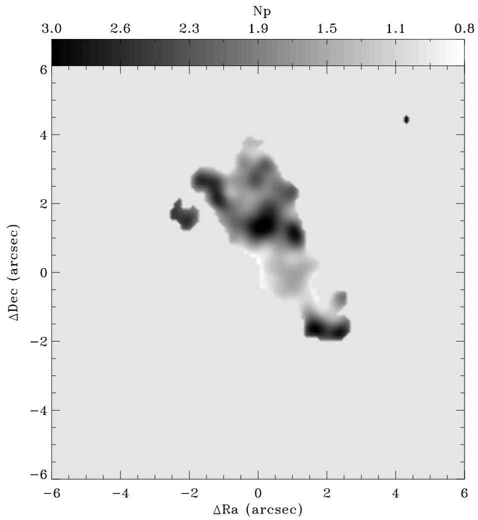
Agliozzo et al. 2012
Agliozzo et al. 2015, in preparation

Extinction maps: evidence of dust?

Extinction maps: evidence of dust?

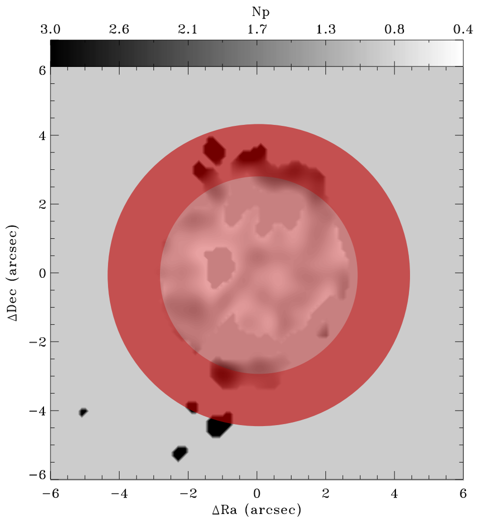


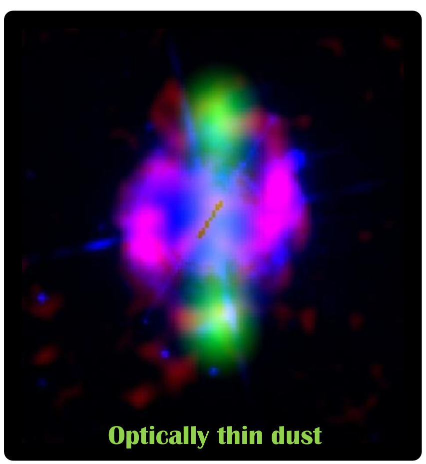


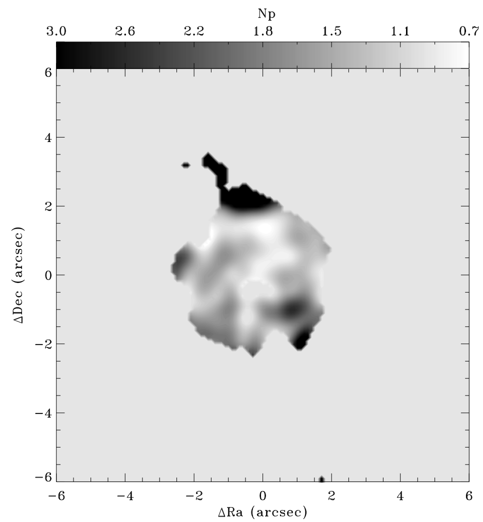


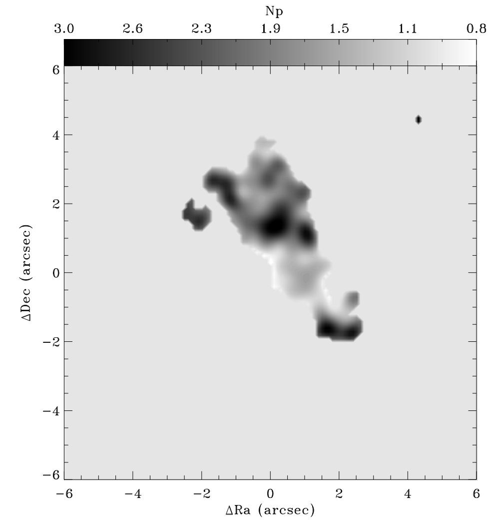
Agliozzo et al. 2014, in preparation

Extinction maps: evidence of dust?





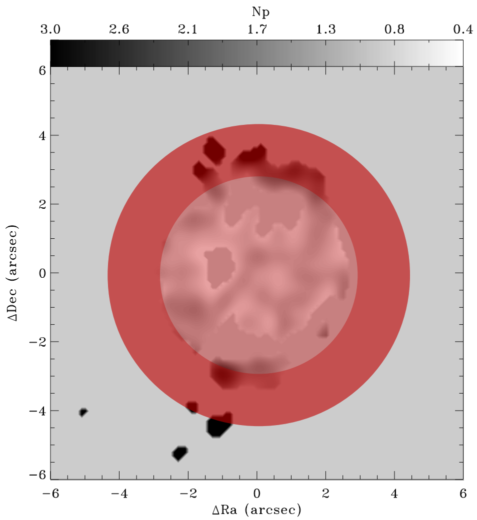


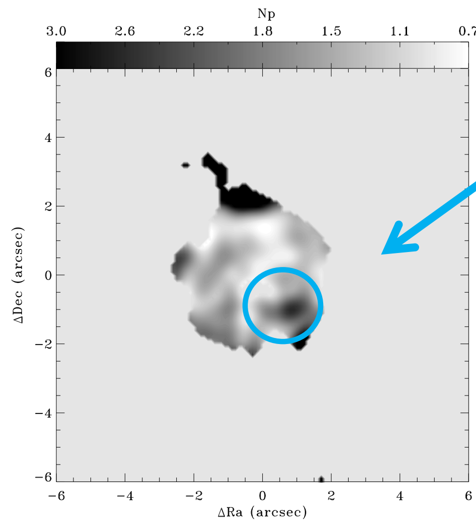


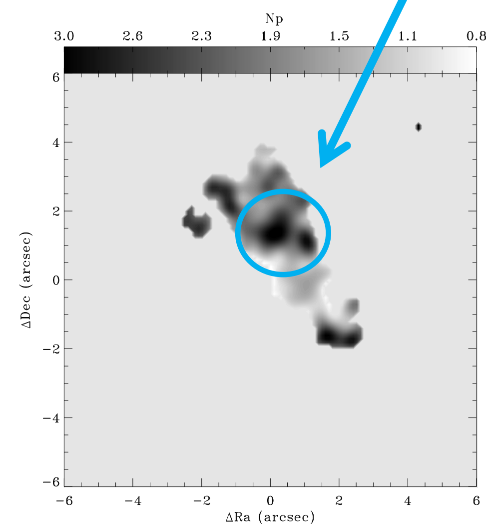
Agliozzo et al. 2014, in preparation

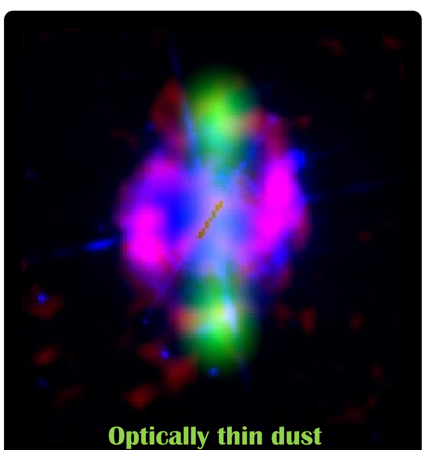
Extinction maps: evidence of dust?

Density clumps



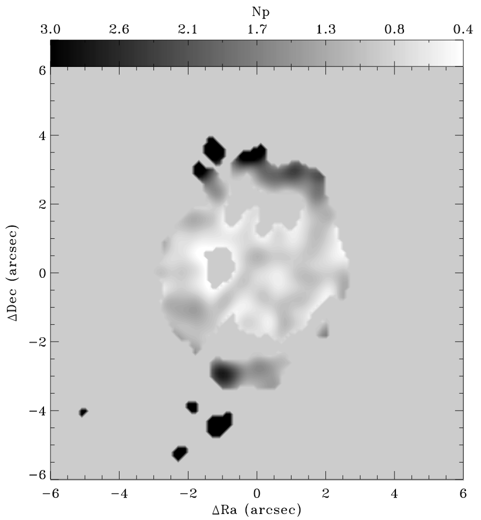






Agliozzo et al. 2014, in preparation

ALMA project



Dust properties for the simulation

1) **T=100 K**
2) **chemical composition: graphite (worst case for absorption)**
3) **extinction map: R127**

$$\tau_{336GHz}=(\kappa_{336GHz}/\kappa_{H\alpha})\tau_{H\alpha}$$
$$I_{336GHz}=B(100K)\tau_{H\alpha}$$

Average flux density and continuum sensitivity required at 336.5 GHz

Source	Average Flux Density (mJy beam^{-1})	Sensitivity (mJy beam^{-1})
R127	0.15	0.04

Model for the simulation with SIMOBSERVE

ALMA project

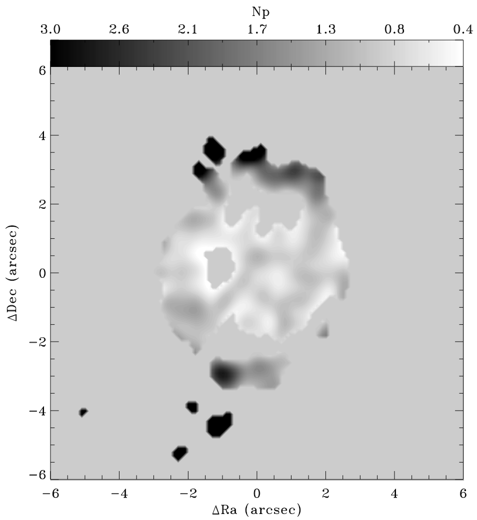
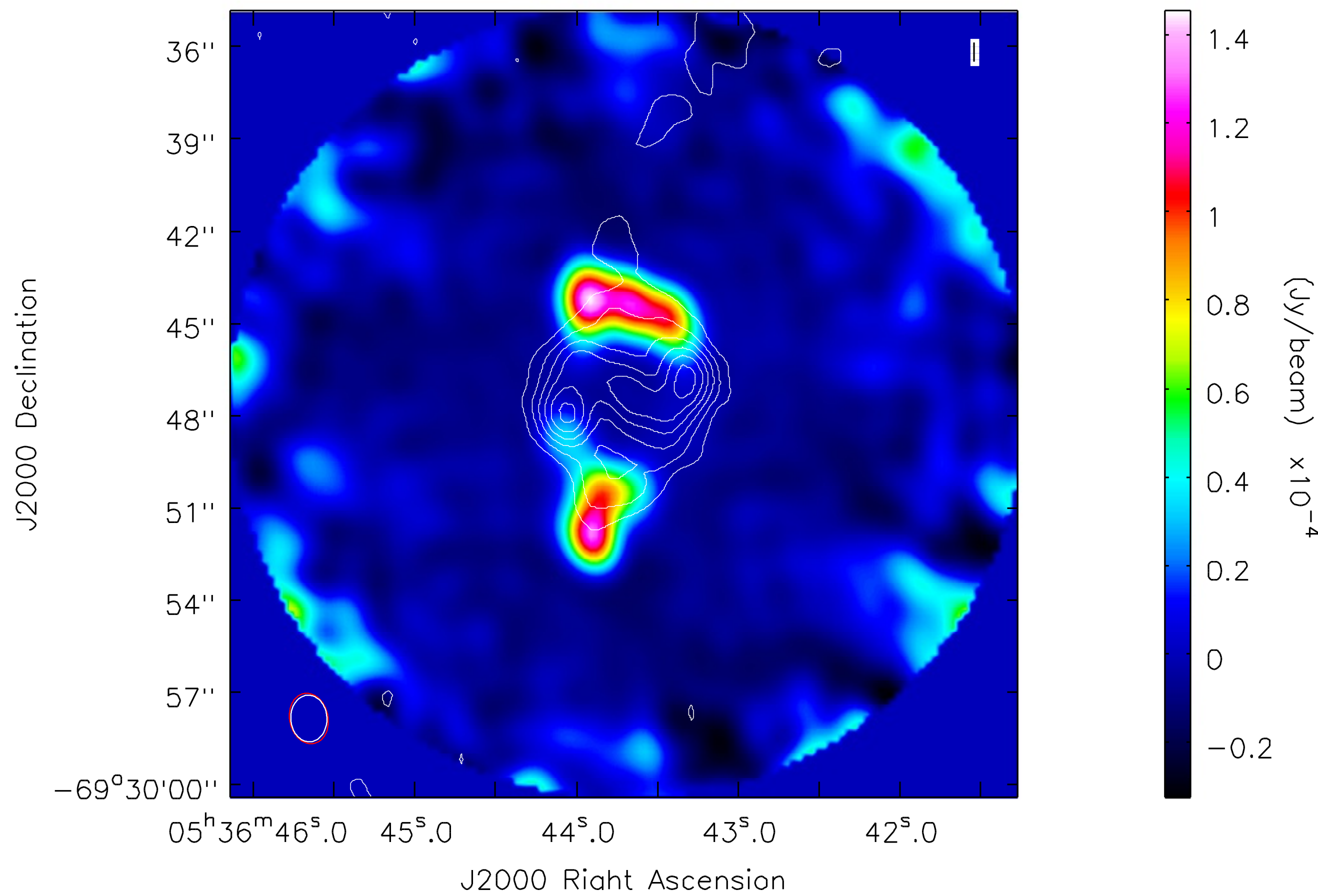
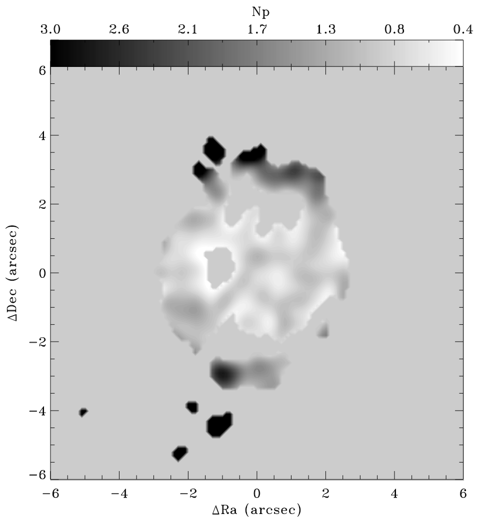


Image: Simulation of ALMA observations, Band 7
Beam 1.1 arcsec
Contours: ATCA observations, 9 GHz
Beam 1.1 arcsec



ALMA project



Proposed array setup

1) only main array (12m)

2) Band 7, Time Division Mode (continuum observations)

3) resolution: 1.1 arcsec (comparable with ATCA resolution) – compact configuration

4) bandwidth: 7.5 GHz for high sensitivity

5) Single pointing (sources smaller than the maximum recoverable scale)

ALMA observations: in progress

2013.1.00450.S - Exploring the mass-loss history and the dust content in circumstellar nebul

Entity	Status
2013.1.00450.S	InProgress
Proposal	
ObsUnitSet	PartiallyObserved
SG OUS (B7 continuum: r127 - r143 -	PartiallyObserved
Group OUS	PartiallyObserved
Member OUS (rmc_127)	PartiallyObserved
rmc_127_a_07_TE	PartiallyObserved

Requested Array

Science Goal: B7

Notes

Mapping the dus

Performance P

Desired noise l

Targets	Line
rmc_127	
rmc_143	
al_418	

QA0 Report

Project Code	2013.1.00450.S
Session	uid://A001/X144/X60
SchedBlock	uid://A001/X144/X5c (rmc_127_a_07_TE)
ExecBlocks	uid://A002/X97db9c/X1b60 ✓ Pass
Sources	J0519-454, J0538-4405, J0635-7516
# Antennas	40
Baselines	15m -- 348m
Band	ALMA_RB_07
Frequency	336.5000000001 [GHz]

Atmosphere Summary

Receiver Temperatures

J0519-454@ALMA_RB_07

Antenna	Mean [°K]		RMS [°K]	
	XX	YY	XX	YY
DA41	120.4	112.0	0.0	0.0
DA42	86.2	100.0	0.0	0.0
DA43	97.0	93.5	0.0	0.0

J0519-454@ALMA_RB_07

Antenna	Mean [°K]		RMS [°K]	
	XX	YY	XX	YY
DA41	98.0	103.5	0.0	0.0
DA42	90.2	91.8	0.0	0.0
DA43	80.9	72.5	0.0	0.0

2013.1.00450.S
Executive: CL

Exploring the mass-loss history and the dust content in circumstellar nebulae around three magellanic luminous

Claudia Agliozzo
<c.agliozzo@gmail.com>

Timeline

Friday, 26 Dec 2014

UTC

02:54:24 - 04:16:33 ***SchedBlock: rmc_127_a_07_TE***

Correlator	BL	**SB UID**	uid://A001/X144/X5c
Band	ALMA_RB_07	**ExecBlock**	uid://A002/X97db9c/X1b60
Frequency	336.5 [GHz]	**QA0 Status**	Pass
Antennas	DA02, DA49, DA55, DV09, DV18, DA50, DA43, DA52, DA45, DA00, DV10, DV12, DA41, DV05, DV10, DV07, DV14, DA64, DV22, DV20, DA54, DA48, DA63, DA46, DA56, DA42, DV02, DA51, DV17, DA58, DA61, DV11, DA53, DV13, DV15, DV06, DV04, DV25, DV08, DV21		

Weather Report

Friday, 26 Dec 2014

UTC	Station	Pressure (hPa)	Temperature (°C)	Humidity (%)	Dew Point (°C)	Wind direction (°)	Wind speed (m/s)
02:42	WSTB1	557.44	-5.00	29.59	-20.07	245.00	5.30
	WSTB2	557.46	-4.97	34.91	-18.10	309.00	2.60
							PWV: 1.402
02:57	WSTB1	557.47	-5.53	29.81	-20.45	250.00	3.20
	WSTB2	557.49	-5.50	35.07	-18.52	316.00	2.90
							PWV: 1.368
03:12	WSTB1	557.48	-5.35	30.39	-20.07	281.00	2.80
	WSTB2	557.50	-5.44	35.76	-18.24	332.00	4.40
							PWV: 1.425
03:27	WSTB1	557.47	-4.87	29.07	-20.16	292.00	3.70
	WSTB2	557.49	-4.82	34.15	-18.24	335.00	4.90
							PWV: 1.458
03:42	WSTB1	557.34	-4.55	28.48	-20.12	291.00	5.50
	WSTB2	557.34	-4.51	33.70	-18.11	324.00	4.40
							PWV: 1.381
03:57	WSTB1	557.40	-4.71	29.36	-19.88	278.00	4.30
	WSTB2	557.37	-4.66	34.60	-17.94	320.00	5.00
							PWV: 1.404
04:12	WSTB1	557.28	-5.93	31.41	-20.20	298.00	4.20
	WSTB2	557.29	-5.94	36.75	-18.37	332.00	4.80
							PWV: 1.371
04:27	WSTB1	557.09	-5.50	31.96	-19.61	303.00	4.40
	WSTB2	557.10	-5.57	37.50	-17.80	341.00	6.30
							PWV: 1.245

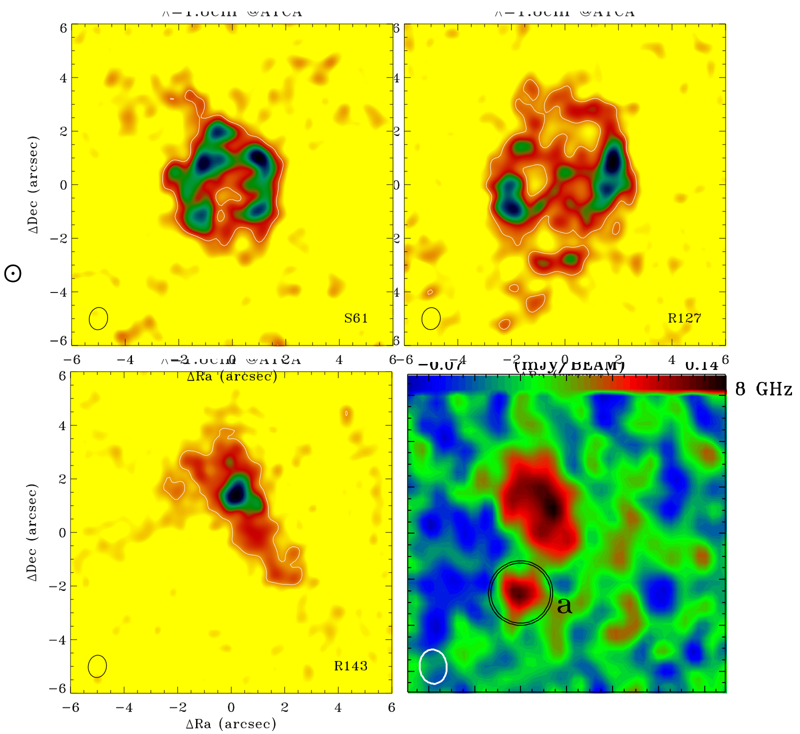
Conclusions

Is the LBV phenomenon indipendent of metallicity?

PRELIMINARY

LBVs in the LMC have

- **nebular properties similar to those galactic (size 0.87-2.1 pc, ionized gas mass 0.8-1.5 $M_{\odot}$ morphology, kinematical age)**
- **average mass-loss rates**
- **possibly presence of dust in density clumps**



Implications

LBV phenomenon important in the evolution of galaxies and of the Early Universe

WORK IN PROGRESS

- **ATCA observations of 10 LBVs in the MCs**
- **During P95 VISIR observations to complent the ALMA dataset and to derive physical properties of the dust content**
- **Further: local metallicity studies to correlate the mass-loss properties with the environment**

THANK YOU