The Herschel view of nebulae around evolved massive stars

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Outline

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  - Circumstellar environment of evolved massive stars (Luminous Blue Variables (LBVs) and Wolf-Rayet (WR) nebulae characteristics)
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MESS – Mass-loss of Evolved StarS

"The circumstellar environment in post-main-sequence objects"

A Herschel Guaranteed Time key programme => http://www.univie.ac.at/space/MESS/

Groenewegen, et al. 2011, A&A, 526, 162

Main aims:

To study the time dependence of the mass loss process, via a search for shells and multiple shells around a wide range of evolved objects, in order to quantify the total amount of mass lost at the various evolutionary stages of low to high-mass stars

To study the dust and gas chemistry as a function of progenitor mass

To study the properties of the envelopes of a representative sample of low and intermediate mass stars (AGB, post-AGB, PN), high mass stars (RSG, WR, LBV) and Supernovae (SNe)

Circumstellar environment of evolved massive stars

Standard evolutionary model for a single massive star:
The outer envelopes are removed through the stellar wind revealing chemically enriched material and the star becomes a WR

early type O star → WR star

must lose a big fraction of its initial mass

Episodes of extreme mass loss during a Red Supergiant or an LBV phase

- The outer layers are removed and the bare core becomes a WR star

- Extended regions of stellar ejecta are produced ==> circumstellar nebulae (sources of IR emission)

Circumstellar environment of evolved massive stars

Luminous Blue Variables (S Doradus variables)

Evolved, massive, very luminous, unstable hot supergiants in the upper left of the HR diagram, suffer irregular eruptions, precursors of Wolf-Rayet stars

Luminosity: ~10^6 $L_\odot$ (close to the 'Eddington limit')

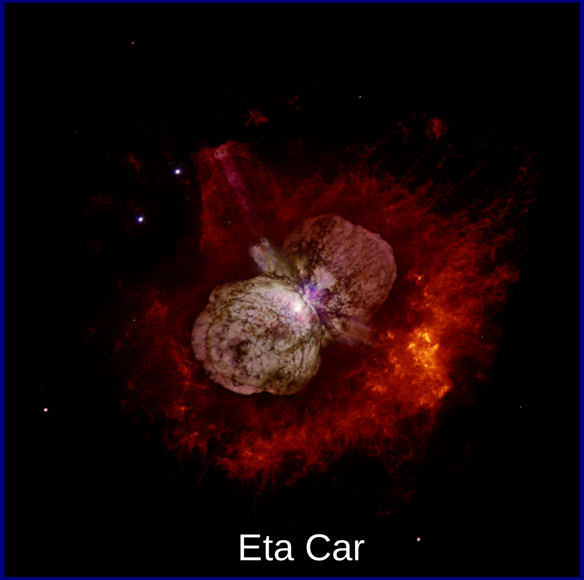
Photometric variability:
- giant eruptions of ≥2 mag, uncertain time scale 10^2 -10^3 yr (Eta Car, P Cyg)
- eruptions of 1-2 mag, time scale of 10-40 yr (AG Car, S Dor & R 127 in LMC)
- oscillations of ~0.5 mag, time scale of months-years (on top of normal eruptions)
- microvariations of ≤0.1 mag (R 71, AG Car, HR Car)

Spectra: variable (visual min: hot supergiant, visual max: cooler supergiant A or F)

Temperatures: 12,000-30,000 K at visual min, ~7000-8000 K at visual max

Mass loss rates: 10^{-5} – 10^{-4} $M_\odot yr^{-1}$ at the active-shell ejection phase

Circumstellar environment of evolved massive stars



Luminous Blue Variables

Ejected nebulae:

- *Diameter* of 0.5 - 2 pc

- *Expansion velocity* between 25 and 140 km s^{-1}

- *Dynamical age* of 5×10^3 to 5×10^4 yr

- *Morphology*: axisymmetric-mildly to extremely bipolar or elliptical

- *Spectra*: typical nebular emission lines (Hα, [N II], λλ6548, 6583,5755, [O II] λλ3726, 3729, [S II])

- Contain significant amounts of CO and dust (e.g. McGregor et al. 1988, Hutsemékers 1997), mainly in the form of amorphous silicates, minor contribution from crystalline silicates (Voors et al. 2000)

Circumstellar environment of evolved massive stars

Wolf-Rayet Stars

Hot, luminous objects (‘bare cores’) with strong broad emission lines due to stellar winds.

Mass: 5 – 50 $M_\odot$

Luminosity: $10^{4.5}$ - 10^{6} $L_\odot$

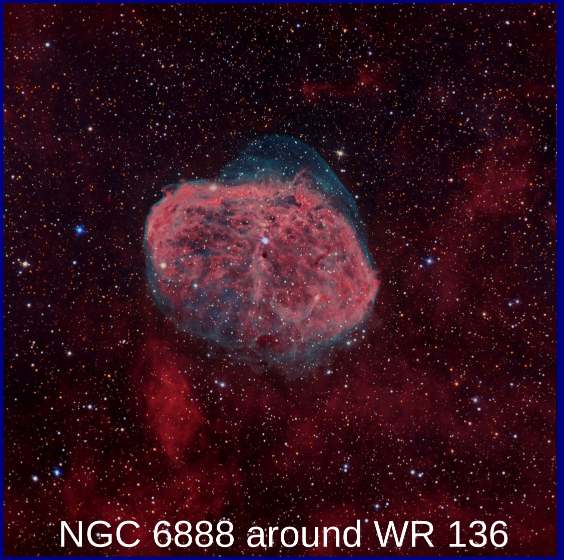
Temperature: 30,000-90,000 K

Mass loss rate: 10^{-5} – 10^{-4} $M_\odot yr^{-1}$ (average 4×10^{-5} $M_\odot yr^{-1}$)

Spectra: strong broad emission lines

- strong lines of He and N (WN subtype show the products of CNO, H-burning, cycle)
- strong lines of He, C and O (WC and WO subtypes show the products of triple-α, He-burning)

Circumstellar environment of evolved massive stars



NGC 6888 around WR 136

Wolf-Rayet Stars

Circumstellar bubbles:

Bigger than LBVs nebulae

Nebulae around one third of the Galactic WR stars
in the optical (Marston 1997)

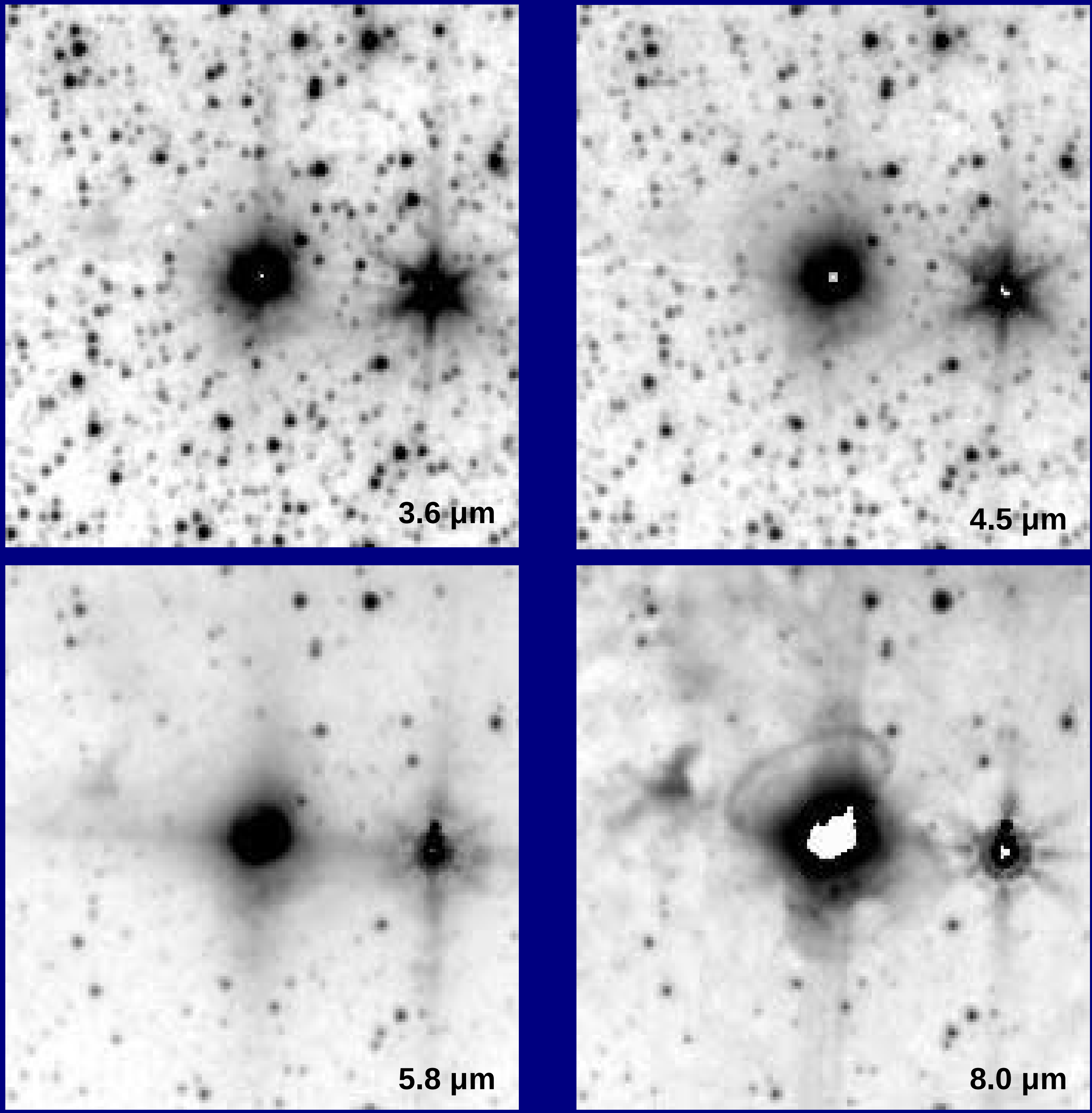
WR Ring nebulae believed to represent material ejected during the RSG or LBV phase that is photo-ionized by the WR star and interacts with the ISM

Scientific aims of our project

Study of the dust and the gas in the circumstellar environment of evolved massive stars (LBVs and WR Stars)

- Information on the dust shells (size, structure)
- Determination of dust properties (temperature, mass, composition, dust grain size)
- Determination of gas chemical abundances and photodissociation region (PDR) properties
- Estimation of dust location with respect to the gas
- Study of the mass-loss history

HD 168625 - Spitzer IRAC imaging

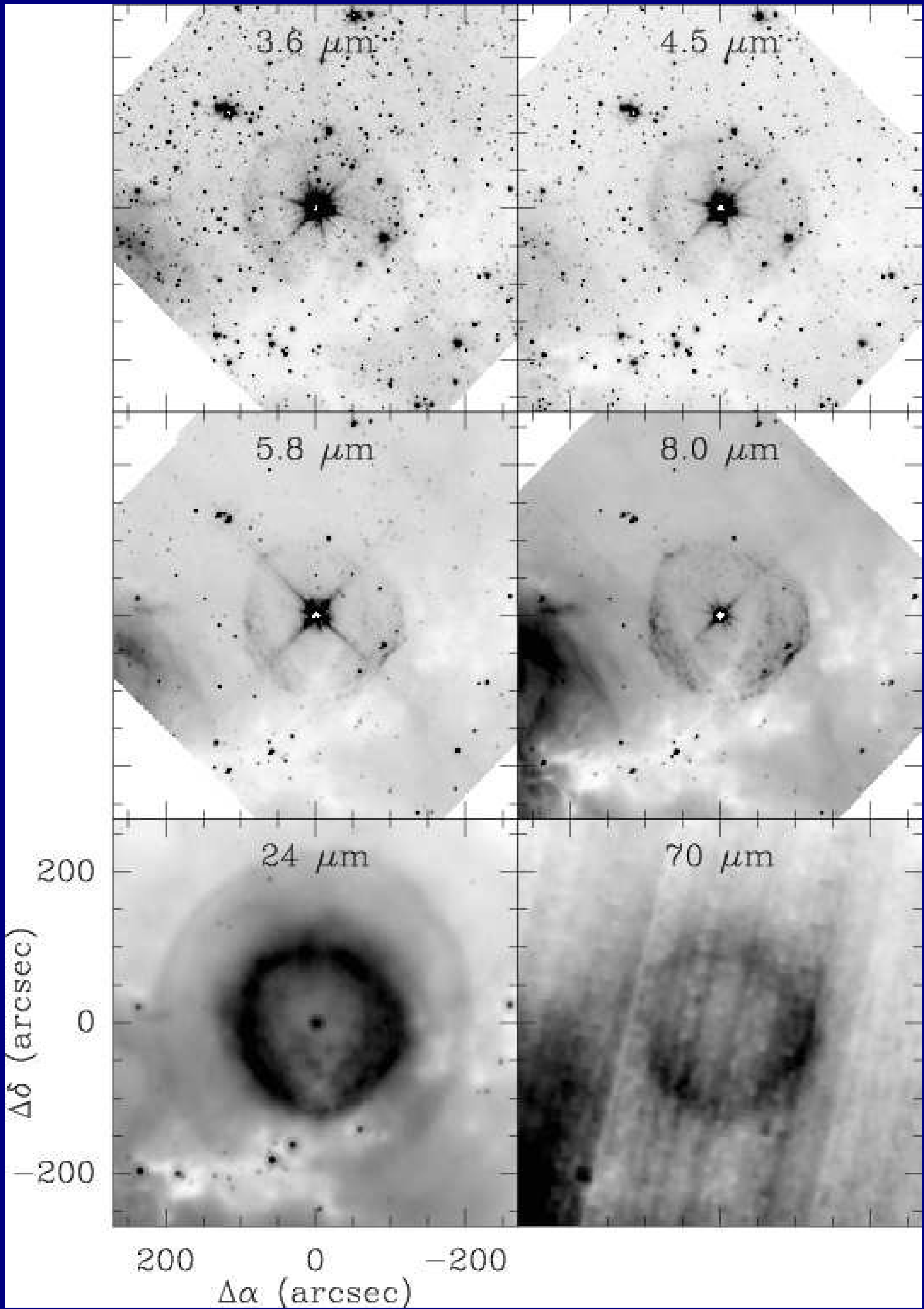


Ring nebula
Size: 12×16 arcsec

Extended bipolar nebula
~40 arcsec

N. Smith 2007

G79.29+0.46



Spitzer IRAC & MIPS imaging

F. M. Jiménez-Esteban, J. R. Rizzo & A. Palau 2010

Observations with Herschel

List of targets

		PACS (imag.)	PACS (spec.)	SPIRE (imag.)	SPIRE(spec.)
AG Car	LBV	X	X		X
HR Car	LBV	X	X		
WRAY 15-751	LBV	X	X		
G79.29+0.46	LBV	X	X		
He 3-519	LBV cand.	X			
HD 168625	LBV cand.	X	X		
M 1-67	WR	X	X	X	X
NGC 6888	WR	X			
NGC 6164/5	Of?p	X	X		

Observations with Herschel

Imaging

<u>PACS</u>

2 bands simultaneously:
60-85 μm or 85-130 μm and 130-210 μm

Two filled bolometer arrays:
32 × 16 pix. (red channel) and
64 × 32 pix. (blue channel)

Same field of view: 1.75 x 3.5 arcmin

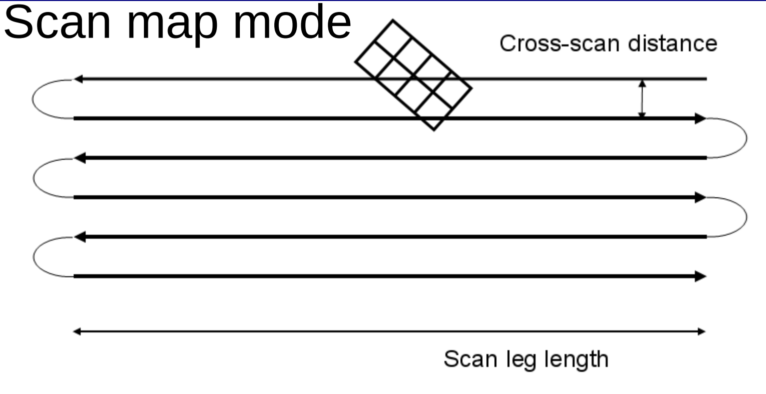
<u>SPIRE</u>

3 bands simultaneously:
250 μm, 350 μm and 500 μm

Three arrays:
139, 88 and 43 pix. (respectively)

Field of view: 4 x 8 arcmin

Scan map mode



Observations with Herschel

Spectroscopy

PACS

Integral field spectrometer

Range: 55-210 μm

Field of view: 47 × 47 arcsec (5 × 5 pix)

Resolution: 1000-5000

SPIRE

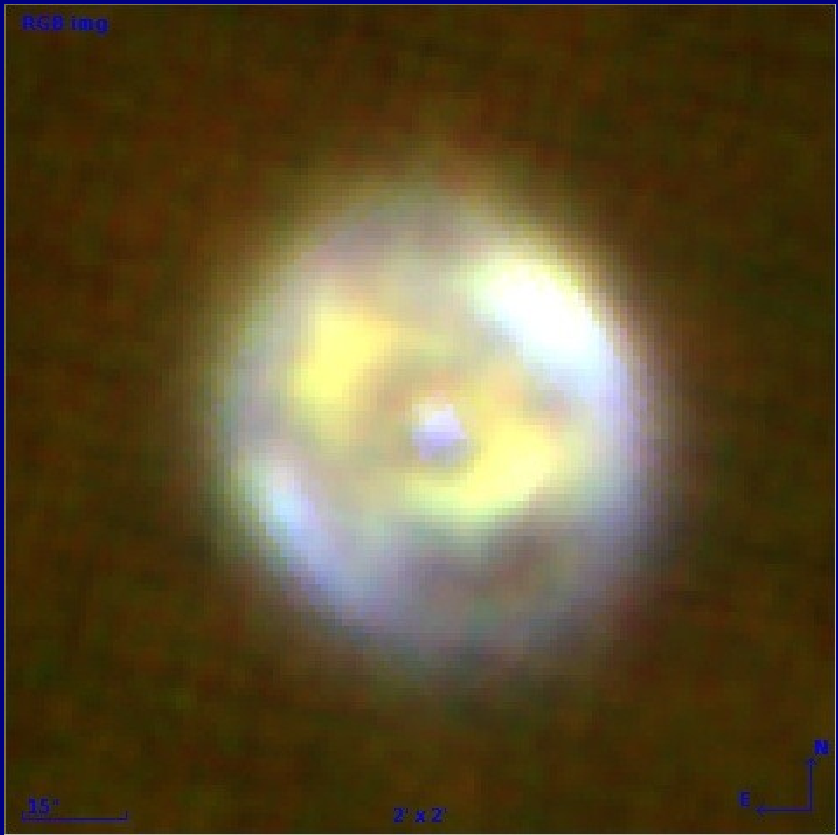
Imaging Fourier transform spectrometer

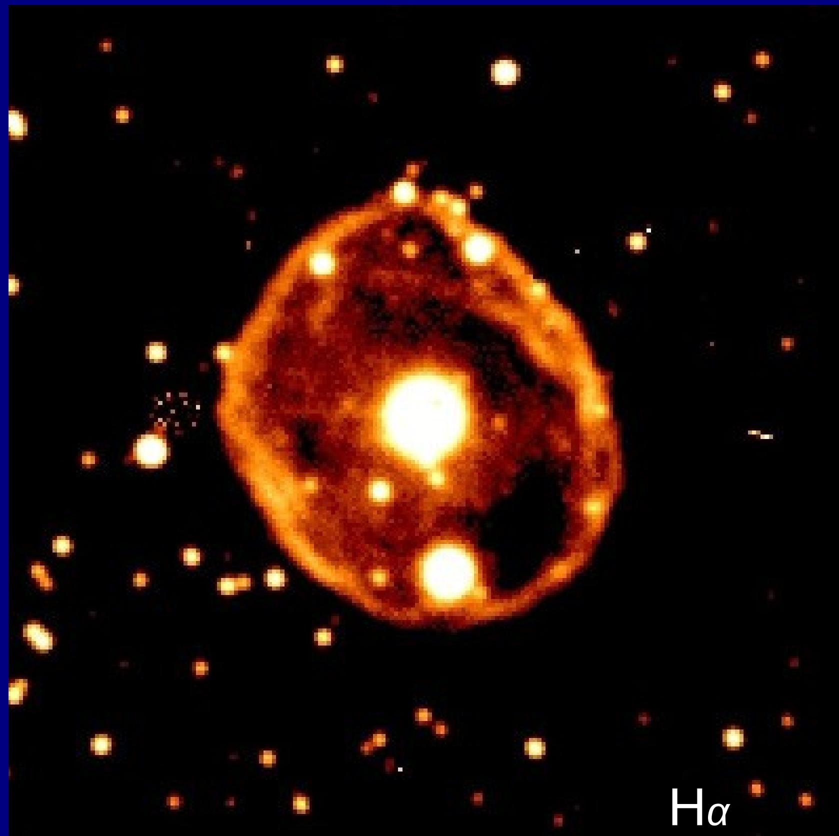
Range: 194-672 μm

Field of view: 2.6 arcmin (diameter)

Resolution: 1000 at 250 μm

The nebula around He 3-519



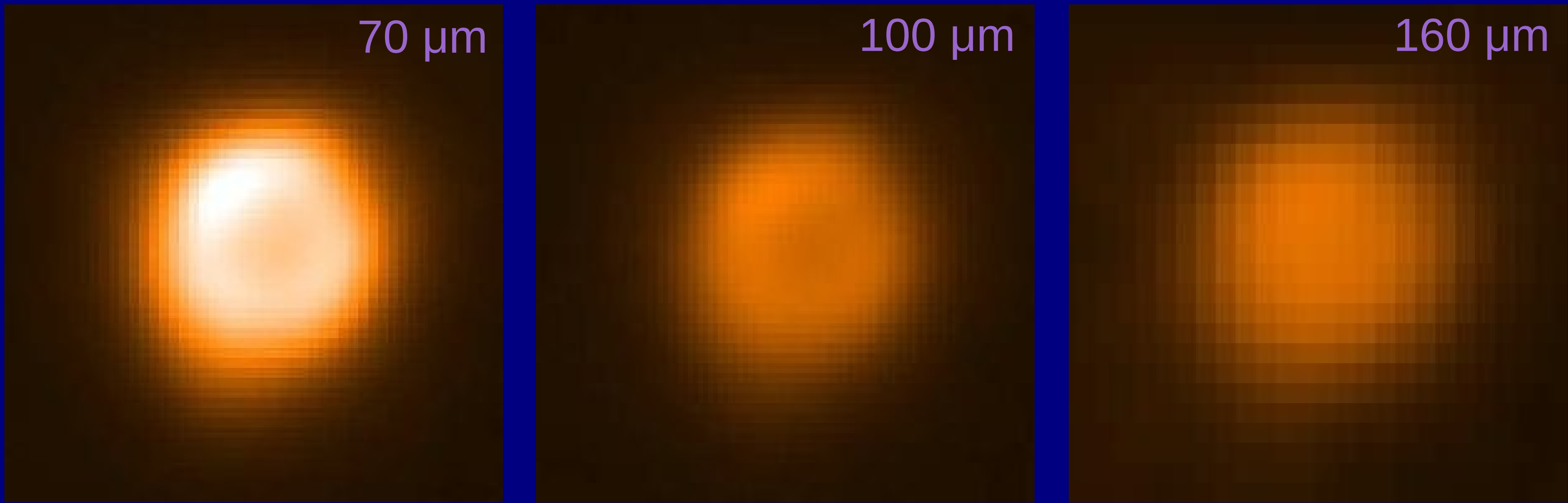


B:24 μm (Spitzer)
G:70 μm, R:100 μm (Herschel)

Diameter=75 arcsec

The nebula around WRAY 15-751

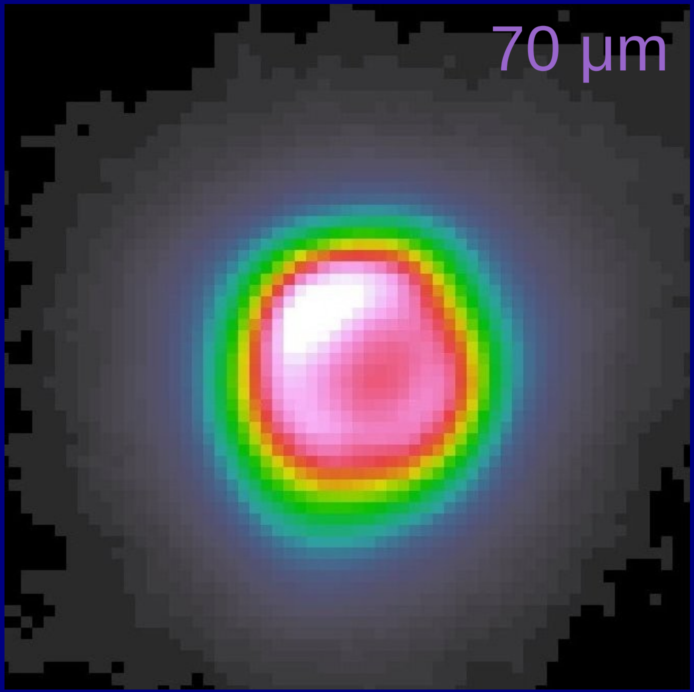
PACS photometric maps

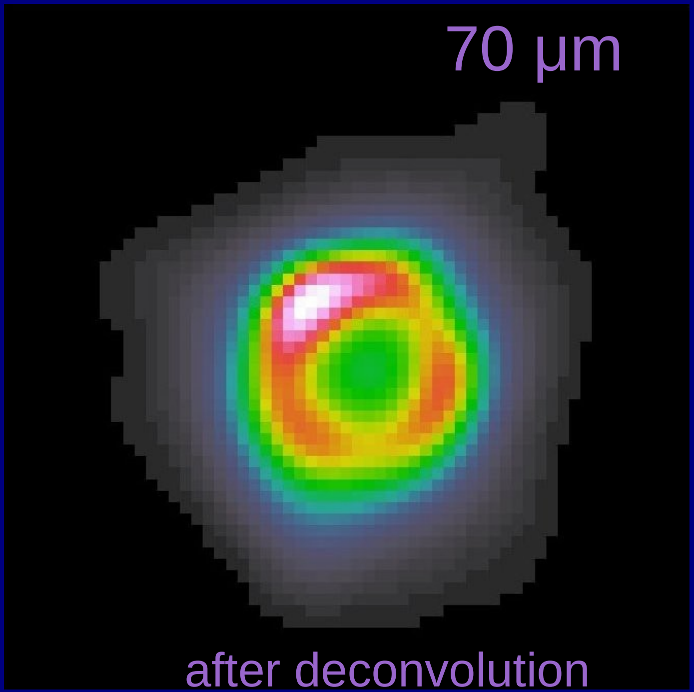


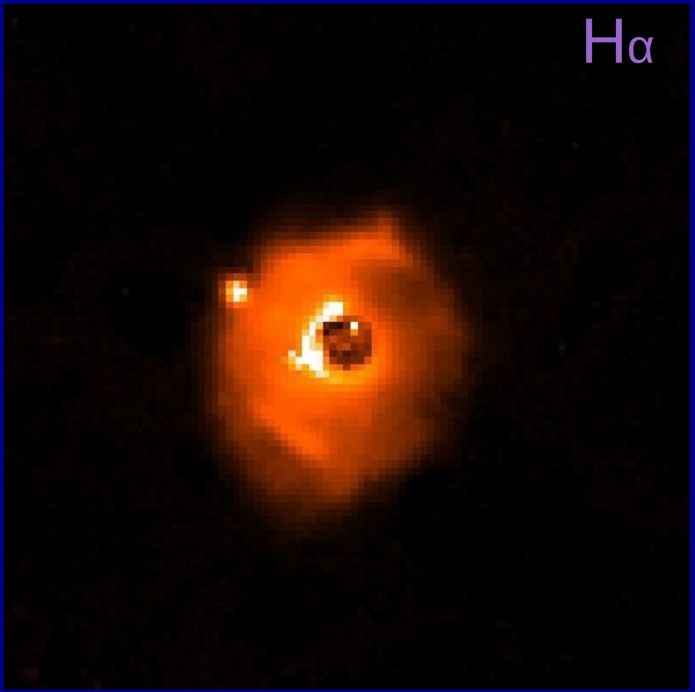
Vamvatira-Nakou et al., A&A, in prep.

The nebula around WRAY 15-751

Deconvolution – IRAF



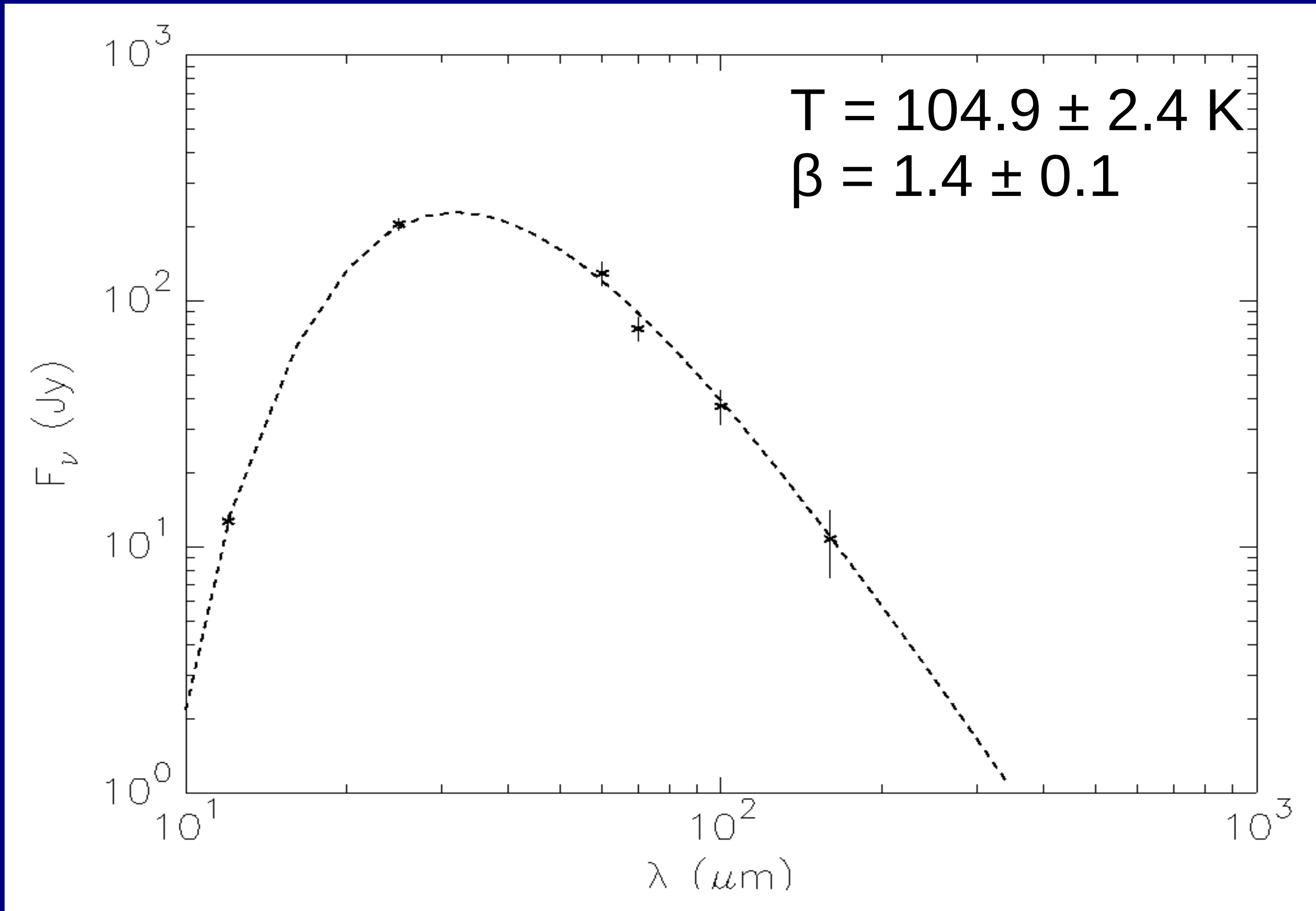




Ring nebula
Diameter: ~ 27 arcsec

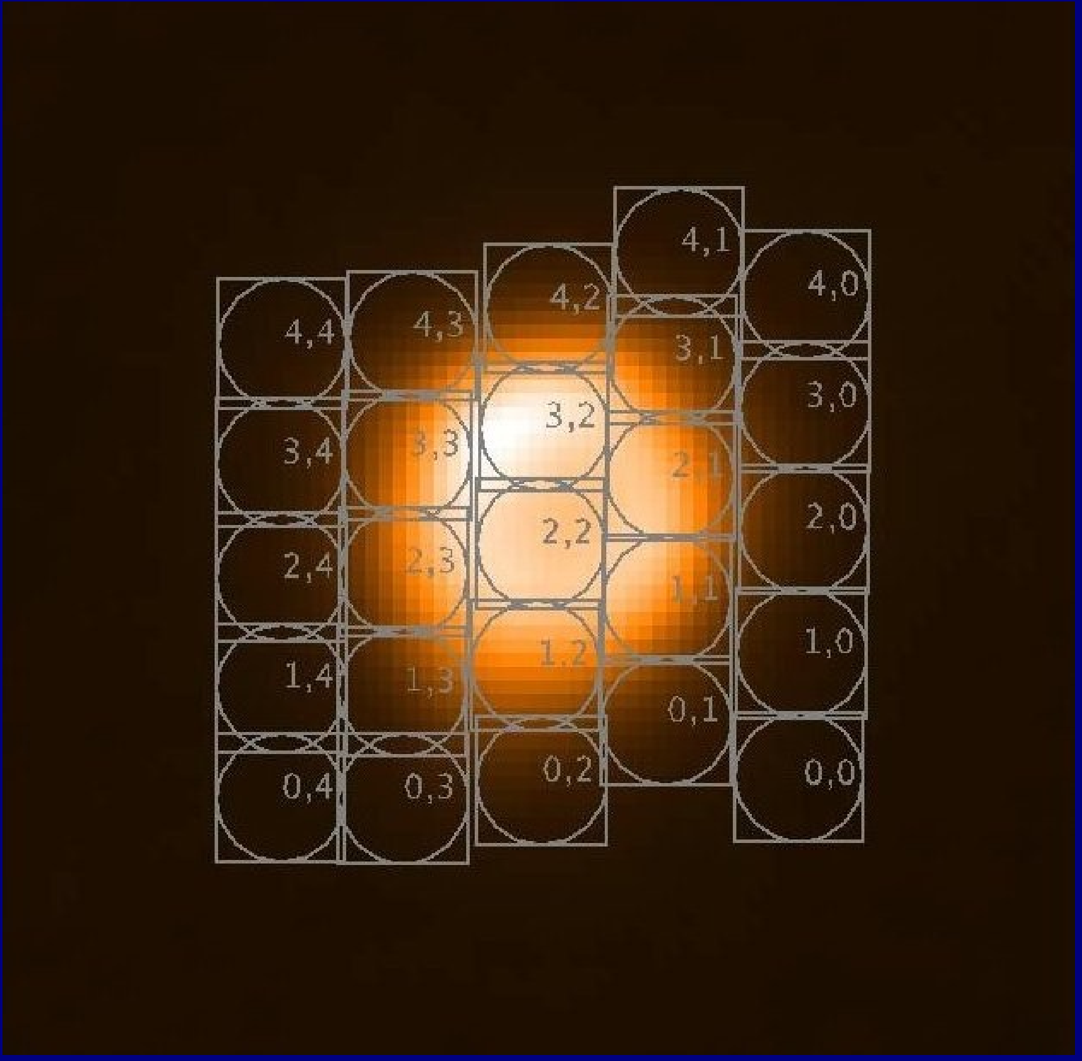
The nebula around WRAY 15-751

Modified Black Body fit ($B_\nu \cdot \lambda^{-\beta}$)



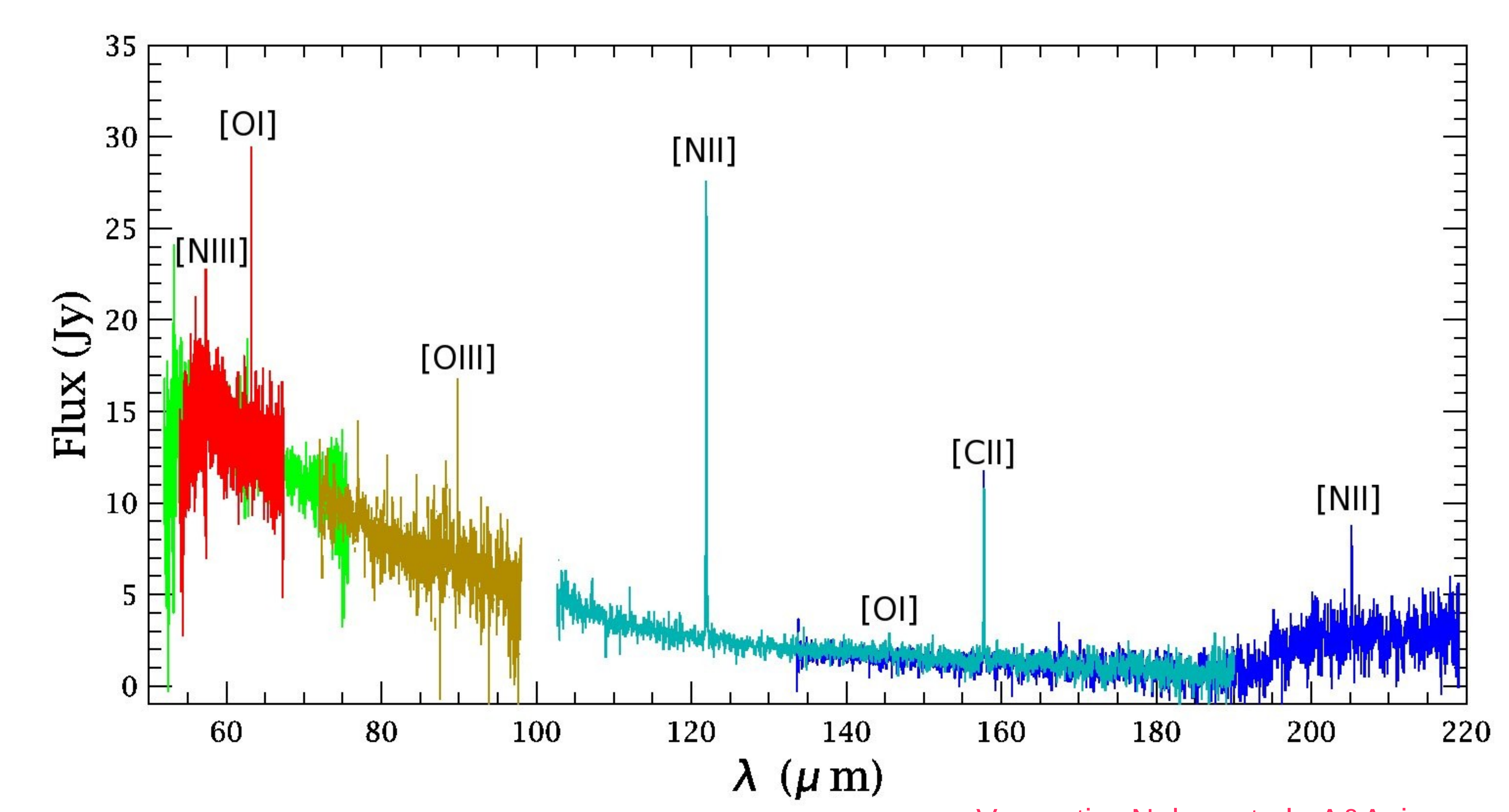
The nebula around WRAY 15-751

Spectral Footprint on image



The nebula around WRAY 15-751

PACS spectrum (SED mode)



Vamvatira-Nakou et al., A&A, in prep

The nebula around WRAY 15-751

Photo-ionisation region properties

===> emission lines [NII] 122 & 205 μm, [NIII] 58 μm, [OIII] 88 μm

-> density from [SII] I(6716)/I(6731) (Hutsemekers & Van Drom, 1991):

$N_e = 443.62$ /cm^3 , assuming constant $T_e = 10{,}000$ K

-> abundance N/O from [NIII]/[OIII] :

N/O = N++/O++ = 0.90 ± 0.21 (solar value = 0.12)

-> T_{eff} from [NIII]/[NII] (Rubin et al, 1994):

N++/N+ = 0.035 => $T_{eff} < 33000$ K

The nebula around WRAY 15-751

Photo-dissociation region (PDR)

===> emission lines [OI] 63 & 145 μm, [CII] 158 μm

- atomic mass estimation:

$M(M_\odot) = 7\times10^{6}\, F(\mathrm{CII})\, d^{2} / X_c$ (Fong et al. 2001, Castro-Carrizo et al. 2001)

D = 7 kpc (Hu et al. 1990, Hutsemekers Van Drom 1991, Pasquali et al. 2006)

$X_c = 4.86 \times 10^{-3}$ (solar)

=> $M_{atomic} = 0.063\ M_\odot$

$M_{ionised} \sim 3.2\ M_\odot$ (Hutsemekers & Van Drom 1991)

- models of PDR (Kaufman et al. 1999)

Conclusions

- Images and spectra in these wavelenghts for the first time
- Morphology of the nebulae
- Dust emission modelling (temperature, composition)
- Abundances estimations
- PDR characteristics
- Estimation of the dust and gas mass
- Study the mass-loss history

T h a n k   y o u