Kandinsky-Squares with concentric Circles

ALMA post-MS studies: the journey from AGB to PN

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-AGB, post-AGB and PN

-mm observations of CSE in AGB→PN:

continuum and line

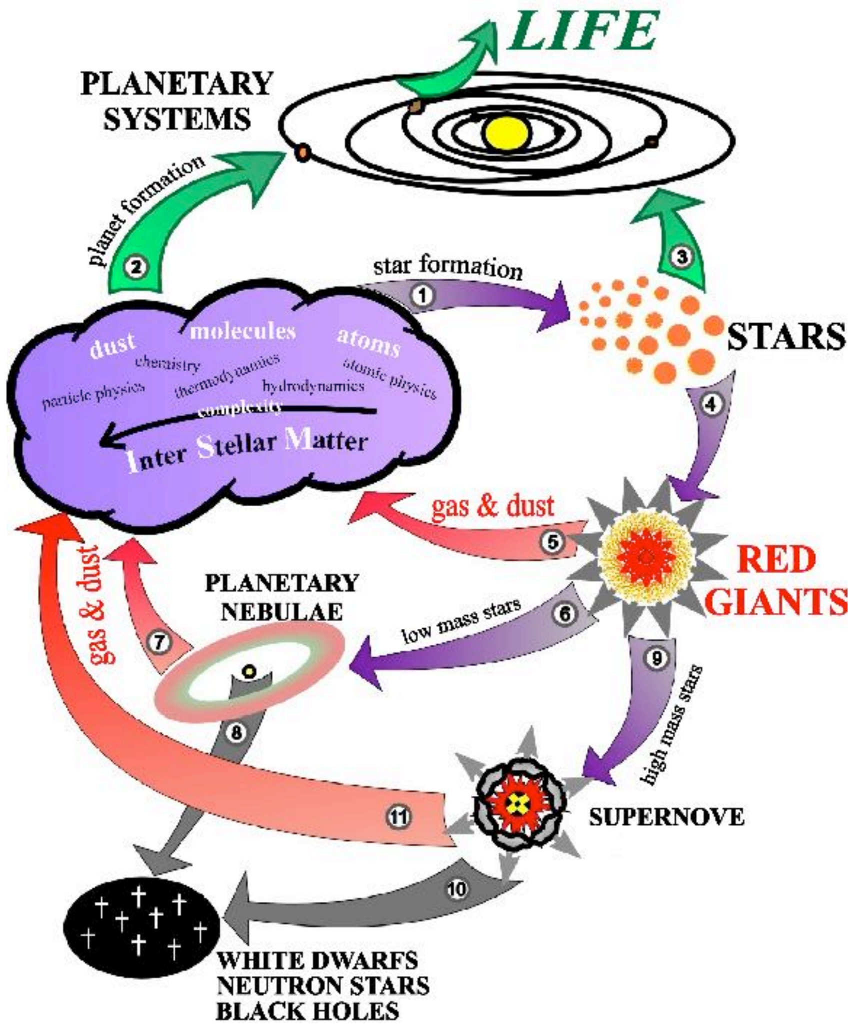
-problems still unresolved

-ALMA contribution

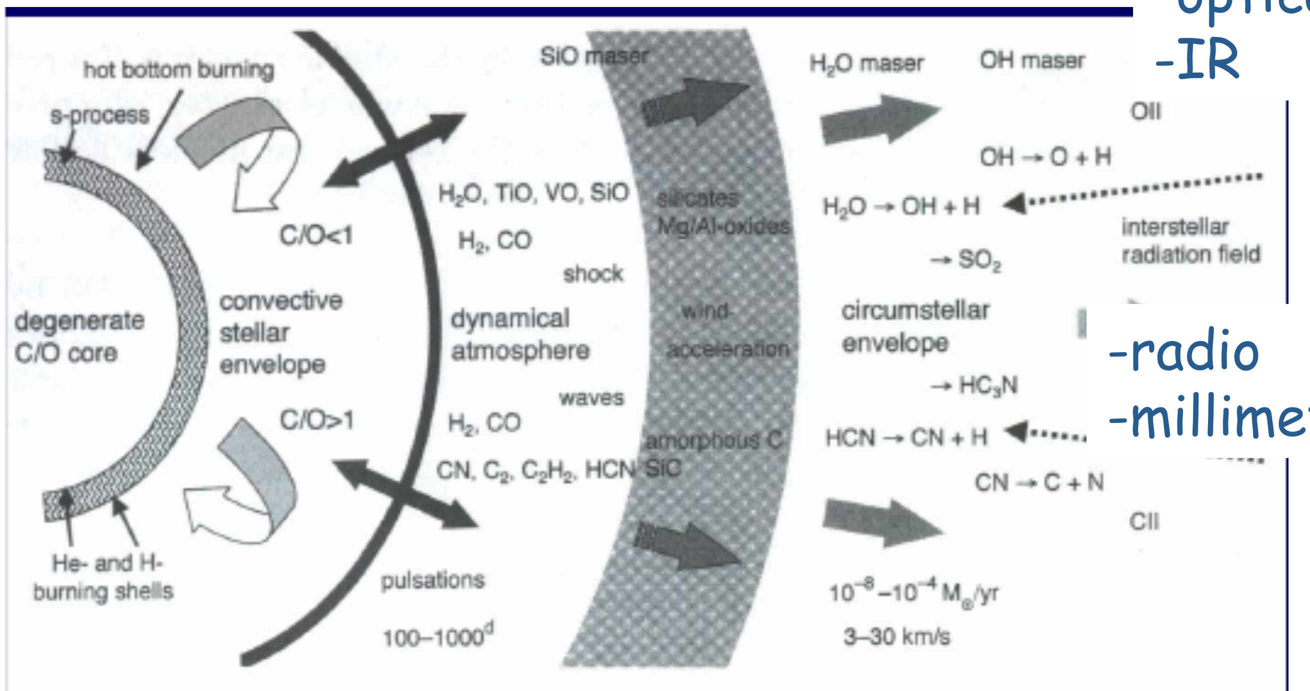
Final phase of low-mass stars
(M_{MS} ~ 0.8 -8.0 M_{Sun})
Destiny of majority of stars in the Galaxy

Among the best ISM polluters important quantities of processed material to the ISM
(Implications on Galaxy evolution)

CSE: a ideal laboratory to study interaction between winds (collimated) and ISM



Central star:



Habing and Olofsson, 2004

-optical
-IR

continuum, lines

-radio
-millimeter

continuum (phot)

CSE:

-IR (continuum (dust), lines (molecular))
-radio (maser lines)
-mm (continuum (dust), lines (molecular))

Molecular lines , very good tracer of CSE

Single-dish (overall properties, Mass-loss,…)
Interferometers (density distribution (maps) , kinematic)

Aims:

- ✓ Mass-loss: (multi events?)
- ✓ Quantify and qualify (chemical composition) of processed gas returned to ISM

Implication on "dust cycle" of ISM

Circumstellar Molecules

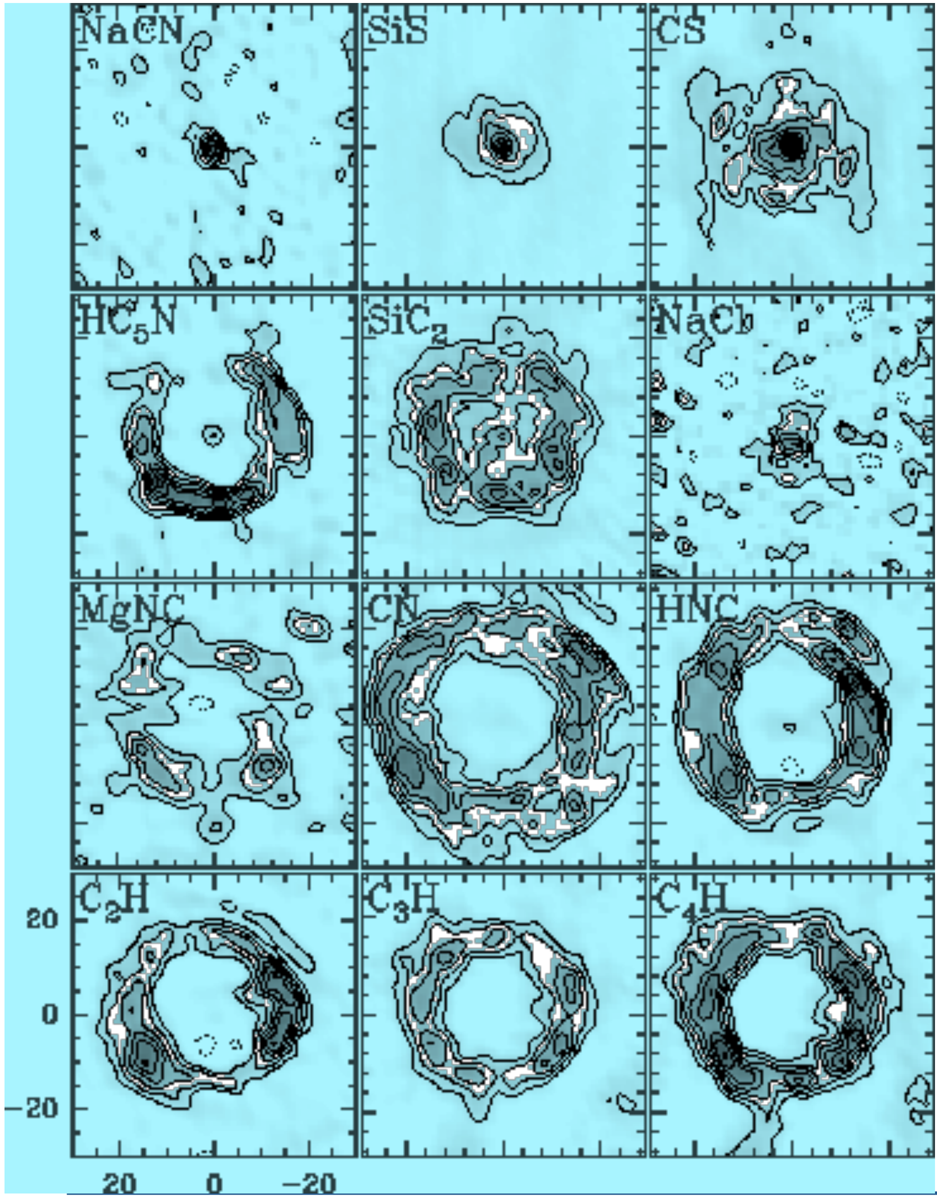
Number of objects

	Molecule	Σ	Chem. O	Chem. C	Molecule	Σ	Chem. O	Chem. C
2-atoms	AlCl	1		1(−7)	NaCl	1		1(−9)
	AlF	1		4(−8)	OH	2000	2(−4)	4(−8)
	C_2	1		2(−6)	PN	1		?
	CO	600	5(−4)	1(−3)	SiC	2		4(−8)
	CN	40	2(−7)	5(−6)	SiN	1		2(−8)
	CP	1		2(−8)	SiO	500	5(−6)	1(−7)
	CS	35	1(−7)	1(−6)	SiS	20	7(−7)	2(−6)
	KCl	1		2(−9)	SO	20	2(−6)	
3-atoms	AlNC	1		1(−9)	HNC	15	1(−7)	1(−7)
	C_3	1		1(−6)	MgCN	1		1(−9)
	C_2H	20		4(−6)	MgNC	1		2(−8)
	C_2S	5		1(−6)	NaCN	1		2(−8)
	CO_2	15	3(−7)		SiC_2	5		3(−7)
	HCN	120	4(−6)	2(−5)	SiCN	1		4(−9)
	H_2O	300	3(−4)	1(−6)	SiNC	1		4(−9)
	H_2S	20	1(−5)		SO_2	15	2(−6)	
4-atoms	l-C_3H	2		4(−8)	HC_2N	1		8(−9)
	C_3N	5		3(−7)	H_2CO	1		1(−8)
	C_3S	1		3(−8)	NH_3	5	4(−6)	1(−7)
	C_2H_2	7		5(−5)	SiC_3	1		3(−9)
5-atoms	C_5	1		1(−7)	HC_3N	10		1(−6)
	C_4H	5		3(−6)	HC_2NC	1		2(−9)
	C_4Si	1		3(−9)	H_2C_3	1		2(−9)
	c-C_3H_2	5		3(−8)	SiH_4	1		2(−7)
	CH_4	1		4(−6)				
6-atoms	C_5H	1		6(−8)	CH_3CN	5		3(−9)
	C_5N	1		9(−9)	HC_4N	1		1(−9)
	C_2H_4	1		1(−8)	H_2C_4	1		5(−9)
≥7-atoms	C_6H	1		8(−8)	HC_7N	2		4(−8)
	C_7H	1		3(−9)	HC_9N	1		1(−8)
	C_8H	1		1(−8)	H_2C_6	1		?
	HC_5N	5		2(−7)				
Ions:	HCO^+	2		1(−9)				

Presently 69 molecular species detected in CSE

55% detected in IRC +10216
Bias :
-strong mass-loss
-D=120 pc

CO e masers lines more common



IRAM PdB, 3″

Lucas & Guielin 1996

Stellar origin

Shell
(photodissociation + ongoing chemistry)

Perfect tool to study physical conditions within CSE
- Check for chemistry modeling.

Unfortunately only in IRC+10216!!!!!

Best tool to study CSEs
→ CO (rotational transitions , mm)

J=1→0	ν= 115.271 GHz
J=2→1	230.537
J=3→2	345.796
J=4→3	461.041
J=6→5	691.472

E(J=1) 5.5 K
E(J=2) 16.6 K

↓

Easily excited in CSE

-sub-mm: Very few telescopes,
Difficult (technically) observations

Large abundance f_{CO} →

Most intense CSE molecular lines :
detected in more than 500 objects

CO envelope extension:

R_{CO} ➔ Photodissociation

-UV radiation of local Interstellar Medium (ISRF)

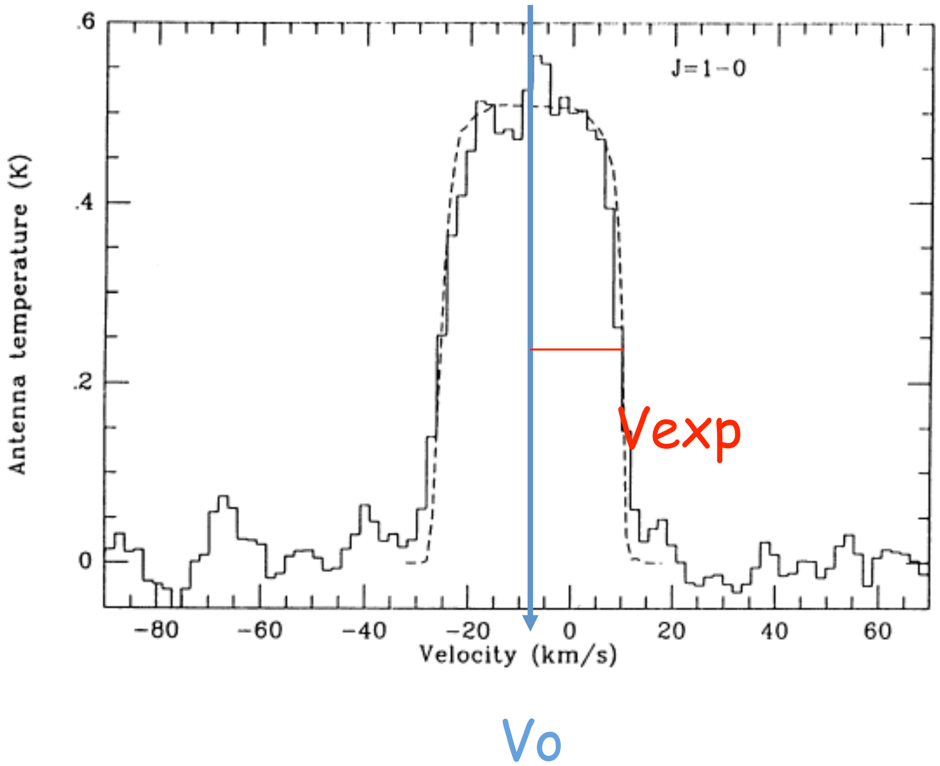
R_{CO} function of mass-loss (Mamon et al., 1988)

-self-shielding CO, dust shielding , H_2

Low mass-loss rates	*(10^{-6} Msol/yr)*	*R_{CO} ~10^{16} cm*
High mass-loss rates	*(10^{-4} Msol/yr)*	*R_{CO} ~few 10^{17} cm*

(Bujarrabal & Alcolea, 1991)

$$R_{CO} \propto \sqrt{\dot{M} f_{CO}}$$



From CO line profile:

Systemic velocity Vo
Expansion velocity Vexp

Mass-loss (Model dependent)
as function of some observables

$$\dot{M} = F(D, T_A, R_{CO}, f_{CO}, v_{\exp})$$

Knapp & Morris, 1985
Olofsson, et al., 1993
Schöier & Olofsson, 2001
Ramstedt et al., 2008

$10^{-7} \le \dot{M} \le 5\times10^{-5}$ MSun/yr O-rich

$3\times10^{-7} \le \dot{M} \le 5\times10^{-5}$ MSun/yr C-rich

Ramstedt et al., 2008

$$F_{CO(2\text{-}1)} \approx 6\left(\frac{\dot{M}}{10^{-6}}\right)^{1.2}\left(\frac{15km/\sec}{v_{exp}}\right)^{1.6}\left(\frac{f_{CO}}{10^{-3}}\right)^{0.7}\left(\frac{1kpc}{D}\right)^{2} \quad \text{Jy}$$

$v \cong 15$ km/s, $f_{CO} \sim 10^{-3}$

$$F_{CO(2\text{-}1)} \approx 6\left(\frac{\dot{M}}{10^{-6}}\right)^{1.2}\left(\frac{1kpc}{D}\right)^{2} \quad \text{Jy}$$

ALMA Fmin~5σ (σ=sensitivity for velocity pixel 1 km/s)

1 hour Fmin~5 mJy
dM/dt=10^{-6} D ~34 kpc dM/dt=10^{-7} D~ 8.5 kpc GC

4 hours Fmin~2.5 mJy
dM/dt=10^{-6} D~50 kpc dM/dt=10^{-7} D~15 kpc

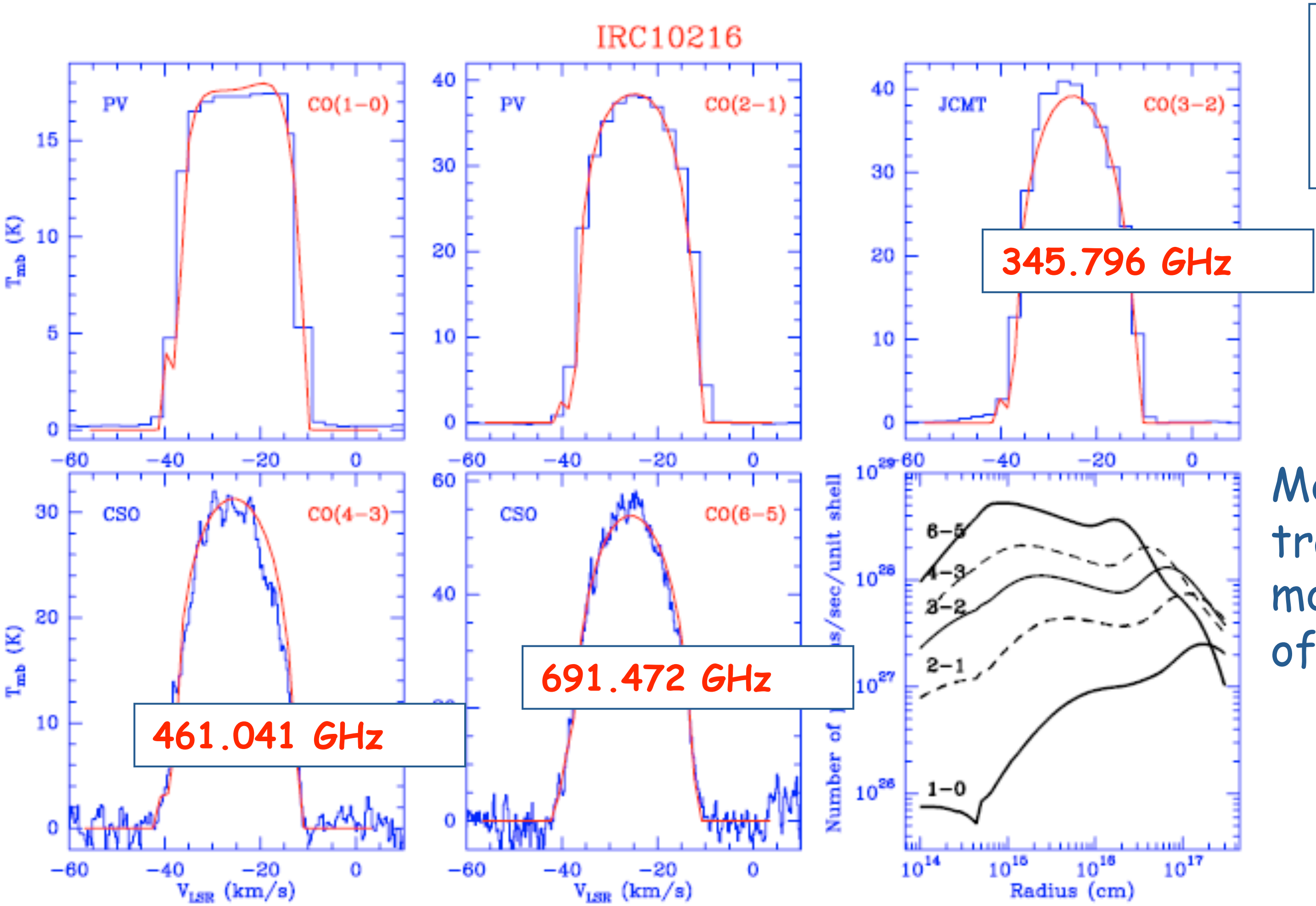
We are getting close to LMC

Mass-loss studies in environments with different metallicity

Teyssier et al., 2006

AGB: CO

N_{phot} from a transition as function of R_{CSE}



More energetic transitions trace more internal regions of CSE

Only done for IRC+10216

ALMA would provide *frequency coverage* and *sensitivity* for multi-transition observations in large samples: *physical conditions inside CSEs*

Mass-loss from single-dish: averaged over 300-10000 yrs
(characteristic timescale for CSE to form)

Open questions: CSE geometry still unclear
Asymmetry already present in AGB?
Multi mass-loss events?

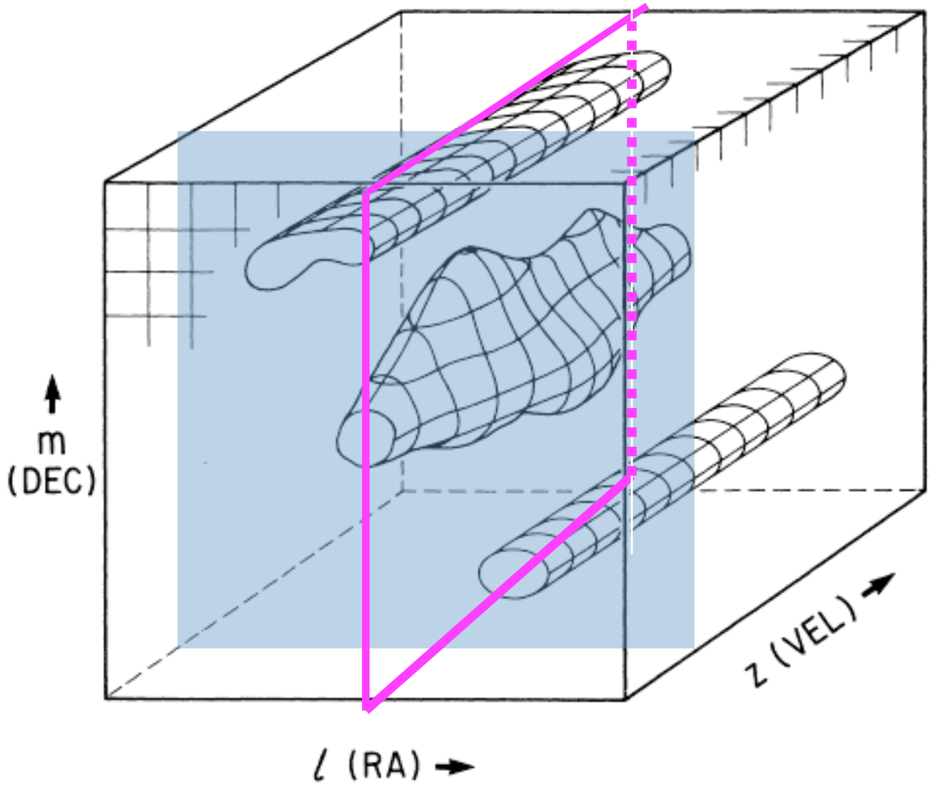
Millimeter Interferometric observations :

Morphological and kinematic infos on molecular CSEs
- Overall structure
- Mass distribution
- dynamic

Mostly CO, but also other molecules.....

Rolfselma (1989)

Data Cube



✓A cut (1D) along z at fixed m,l
Line profile

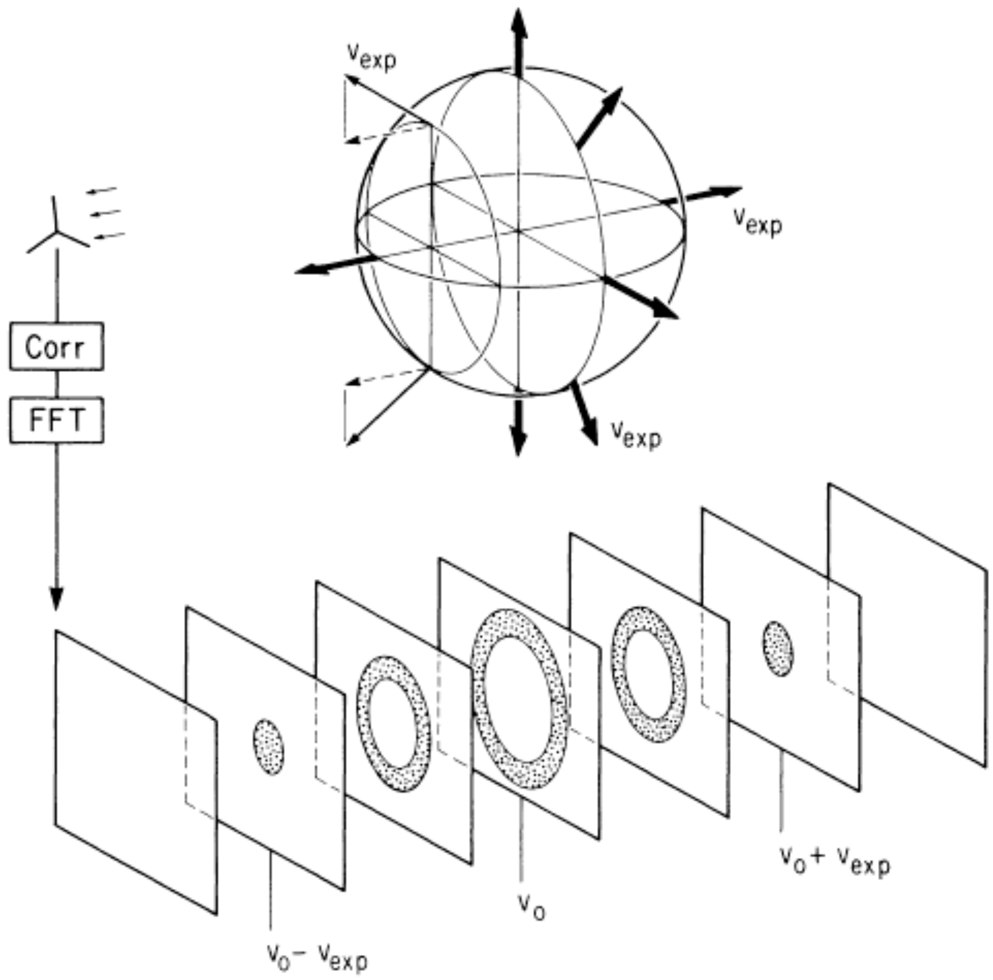
✓A series of "line profiles" along m (N-S) or l (E-W)
P-V plot

✓A 2D map at fixed velocity
Channel map

✓Integrating all the"channel maps" over v.

Global structure

Rolfselma (1989)



For an envelope expanding with a constant velocity vexp the iso-velocity curves are circles

(Rmax at the sys velocity)

IRAM PdB project

CO J=2→1 (230 GHz), CO J=1→0 (115 GHz),

-Neri et al., 1998
-Castro-Carrizo et al , 2004; 2007

More than 60 objects in AGB and PPN

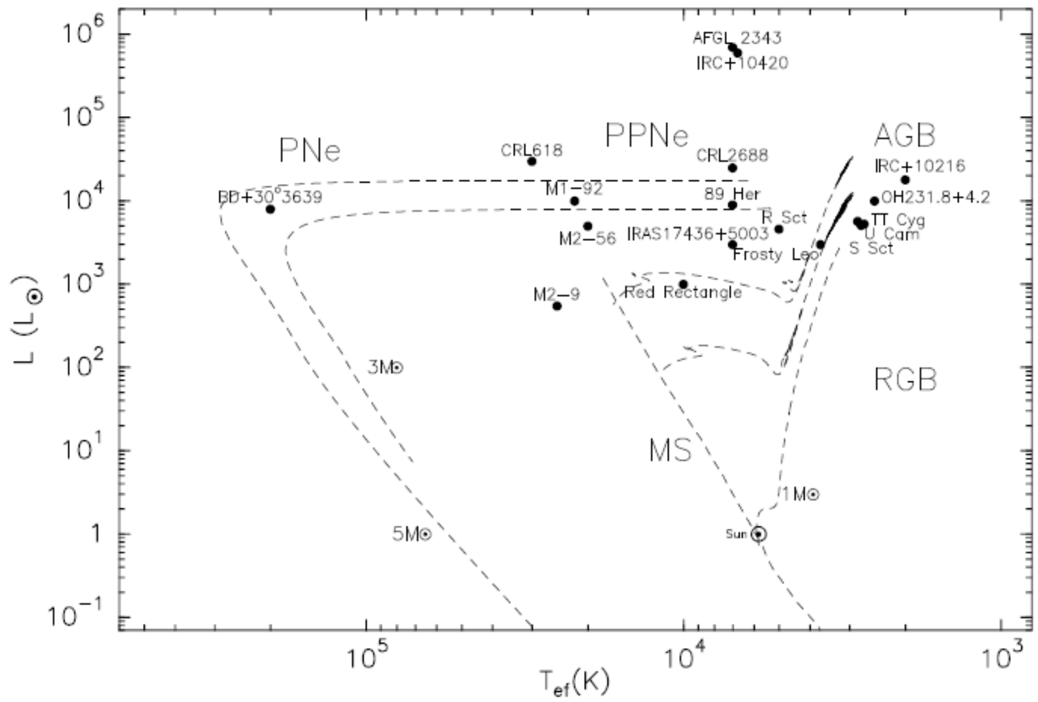
-sample covers large variety of stellar parameters (variability, chemistry…)

- bias vs mass-loss, distance,….

Results:

-AGB, CSE generally with circular symmetry and isotropic expansion

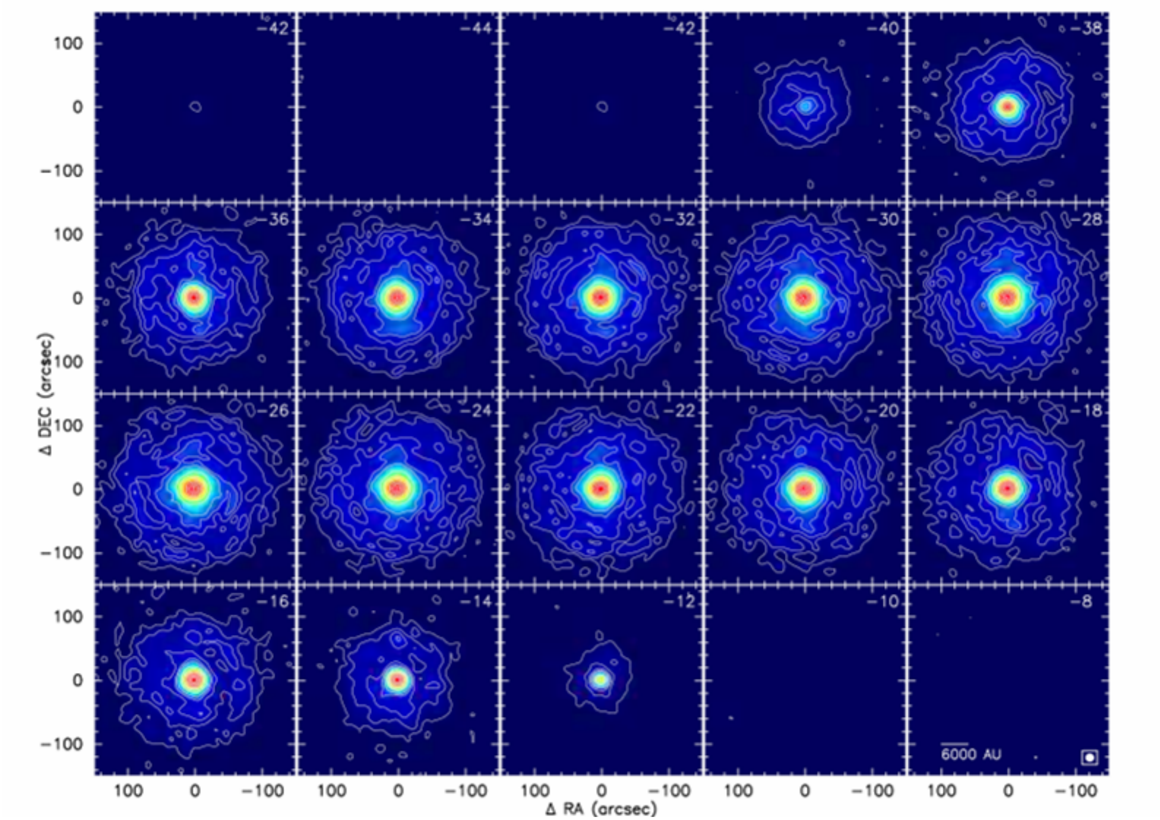
-Growing evidences (new PdB) for departure from isotropy and mass-loss variability

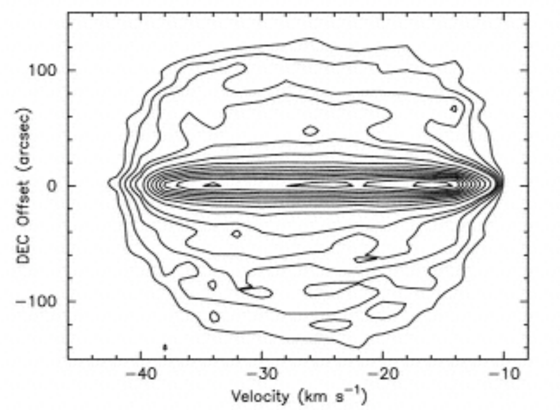


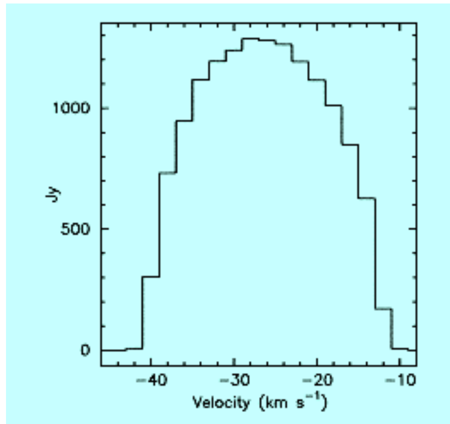
But also BIMA and SMA

BIMA: CO J=1→0 115.271 GHz, θ≅13″, spe_res=2 km/sec
+ 12m (to recover extended emission)

← 200″ → IRC+10216



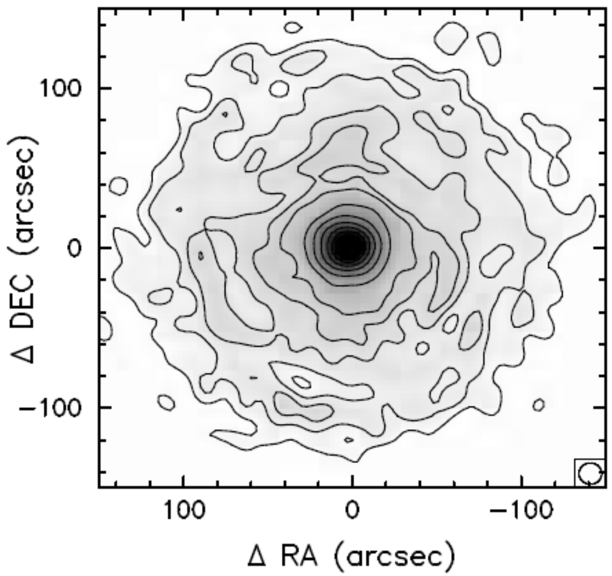


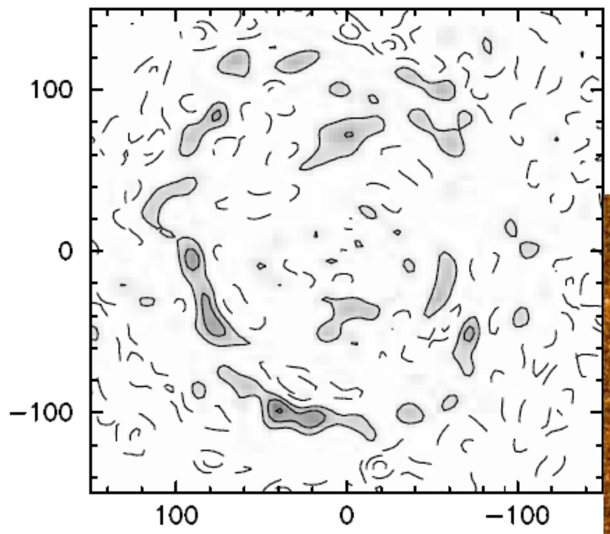


Spherically symmetric CSE , vexp constant

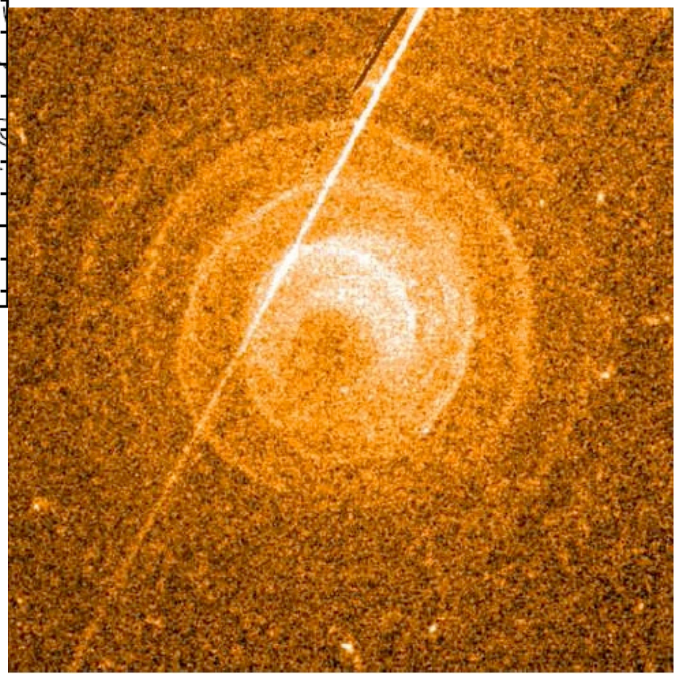
BIMA: CO J=1➔0 115.271 GHz, $\theta \cong 13''$, spe_res=2 km/sec
+ 12m NRAO (to recover extended emission)

-Channel map "residual"





Mauron & Huggins, 2006



HST V

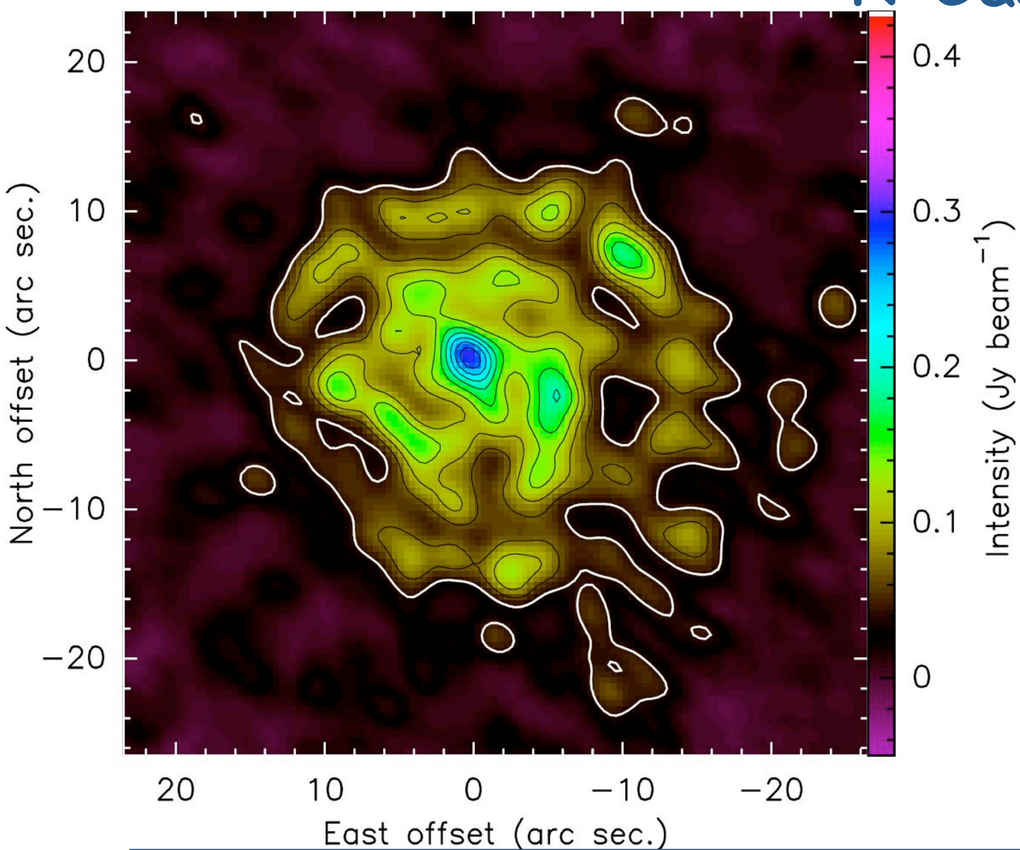
-Channel map sys velocity

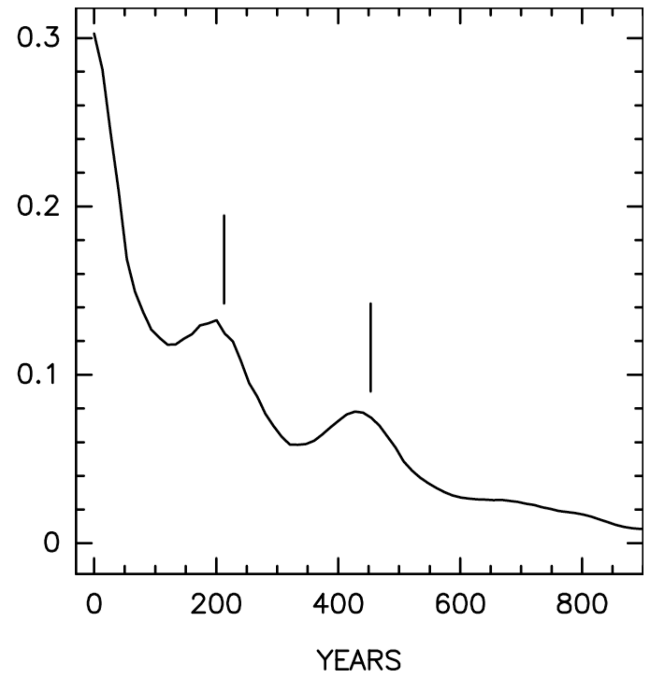
✓ Episodic mass-loss

PdB: CO 115 GHz and 230 GHz
PV (to recover extended emission)

spa_res= 1″ (230)
spa_res=3″ (115)

R-Cas



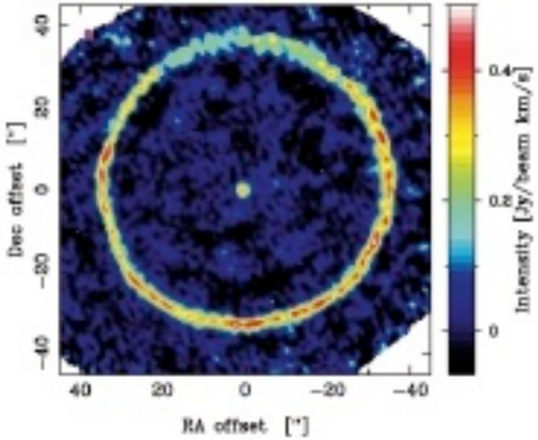


Radial brightness increases ↔ Mass loss fluctuations

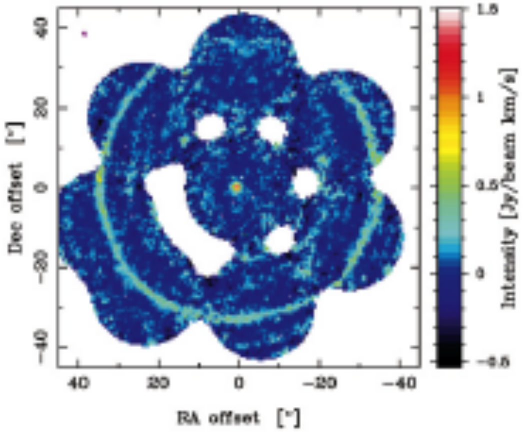
Olofsson et al., 2000

TT Cyg

CSE morphology

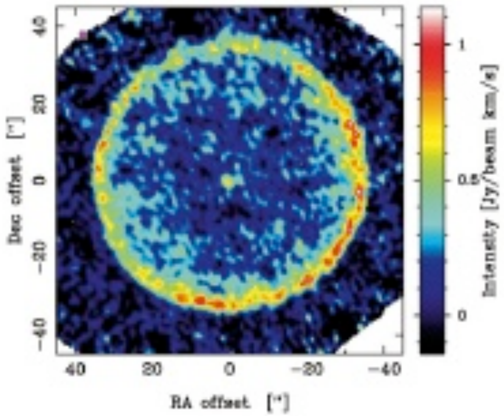


PdB 115 (230 GHz)
θ~ 2.5″ (1″)
Spe_res 1km/sec

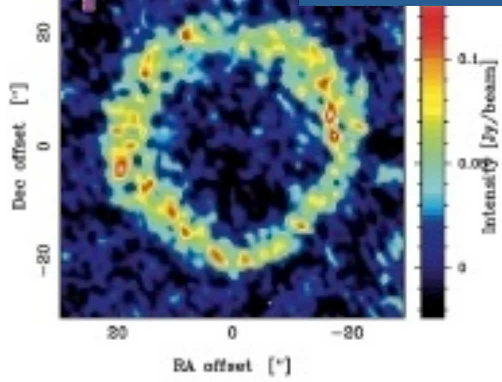


CO (J=1➔0) 4 km/sec, centered on systemic velocity (-27.5 km/sec)

CO (J=2➔1)



V=-38 km/sec

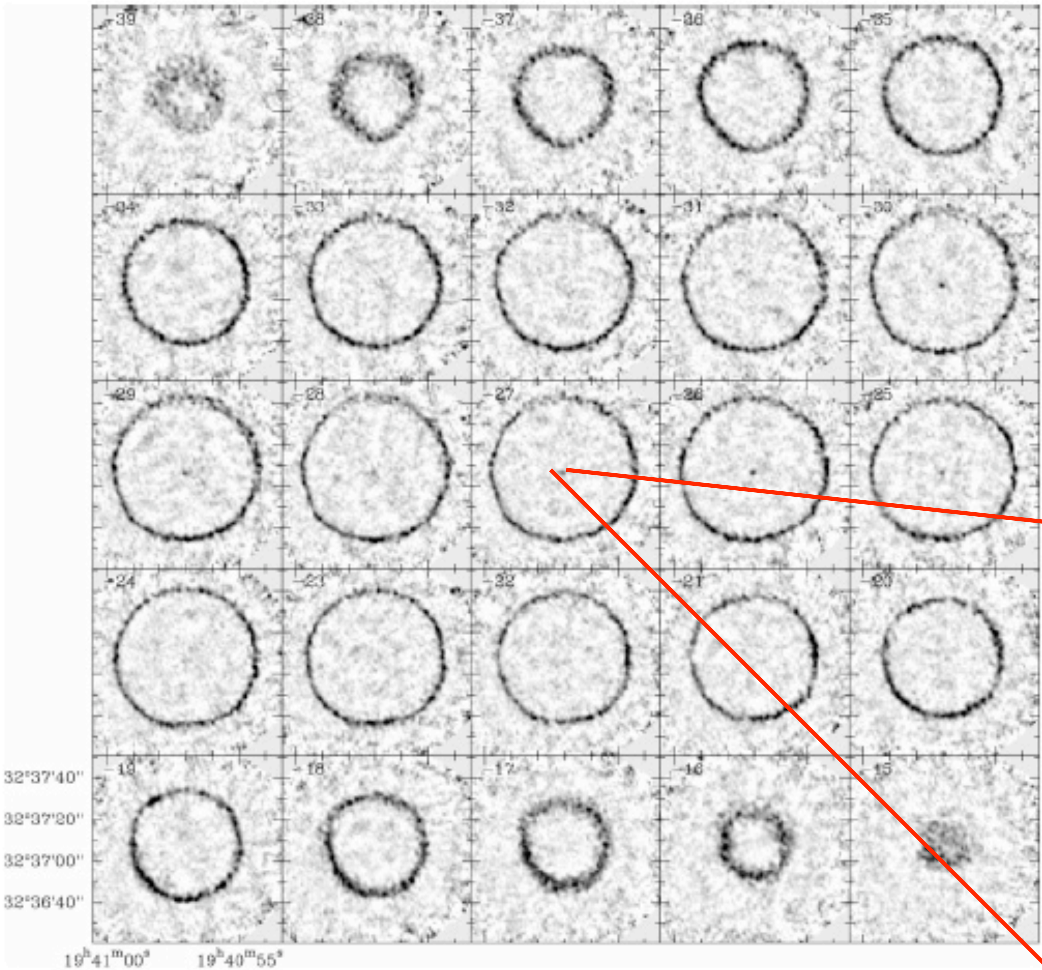


CO (J=1➔0) integrated

single velocity pixel (1 km/sec)

CO (J=2➔1) ,   channel maps (1 km/sec)

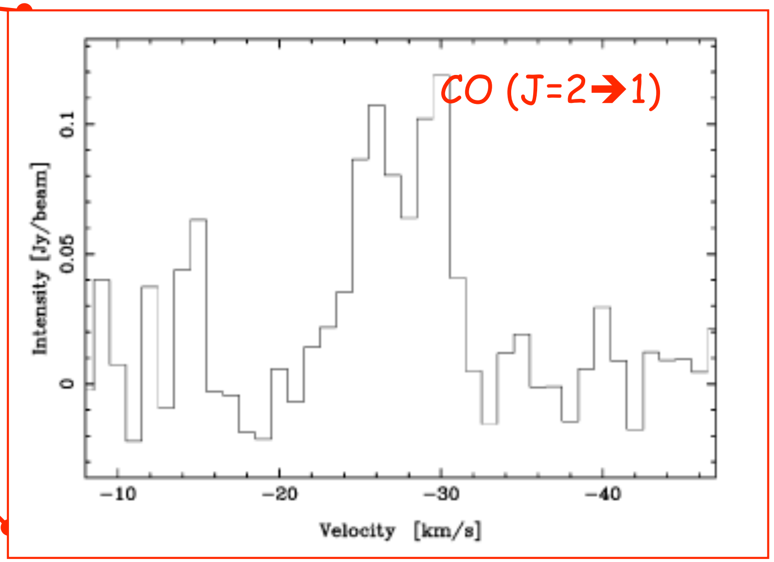
IRAM PdB



From line profile + modeling
dM/dt

Parameters: D, T, v_{exp}, R_{CO},f_{CO}

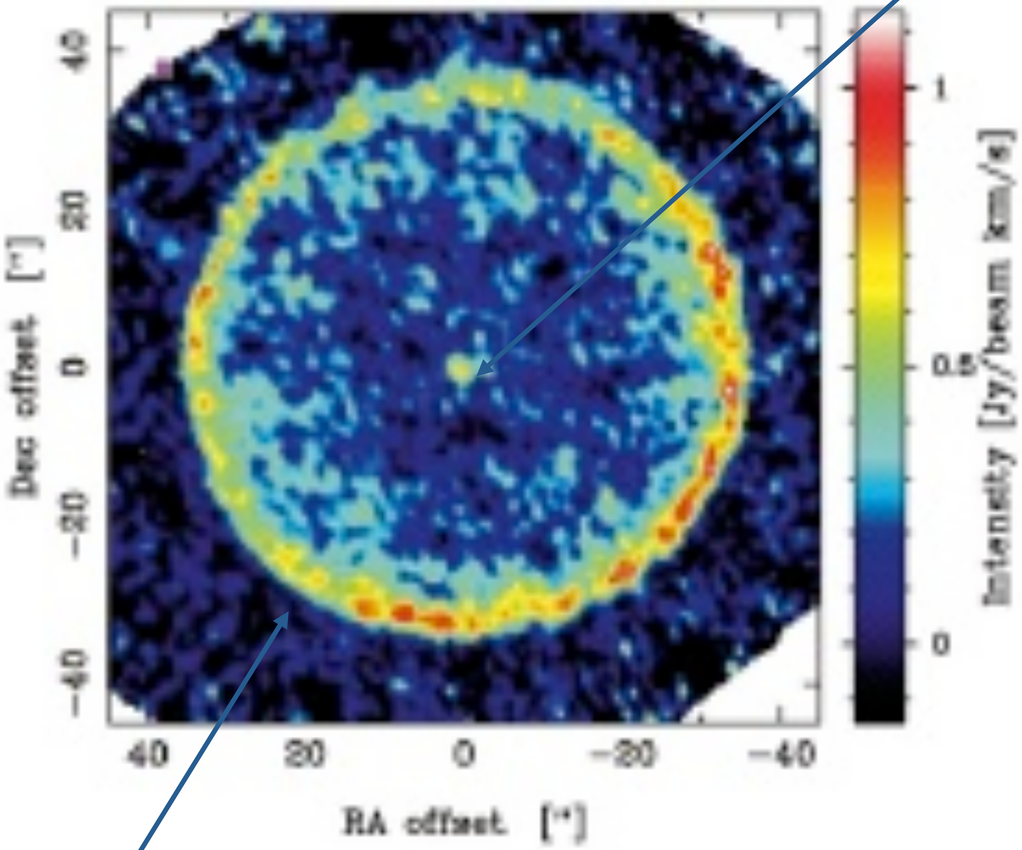
$$\dot{M} \approx 3\,10^{-8} \;\; M_O/yr$$



Current mass-loss

Shell 2

$$\dot{M} \approx 3\ 10^{-8}\ \ M_O/yr$$



- Evidence for varying mass-loss

35″ ➔ 7000 yr
(D=510 pc)

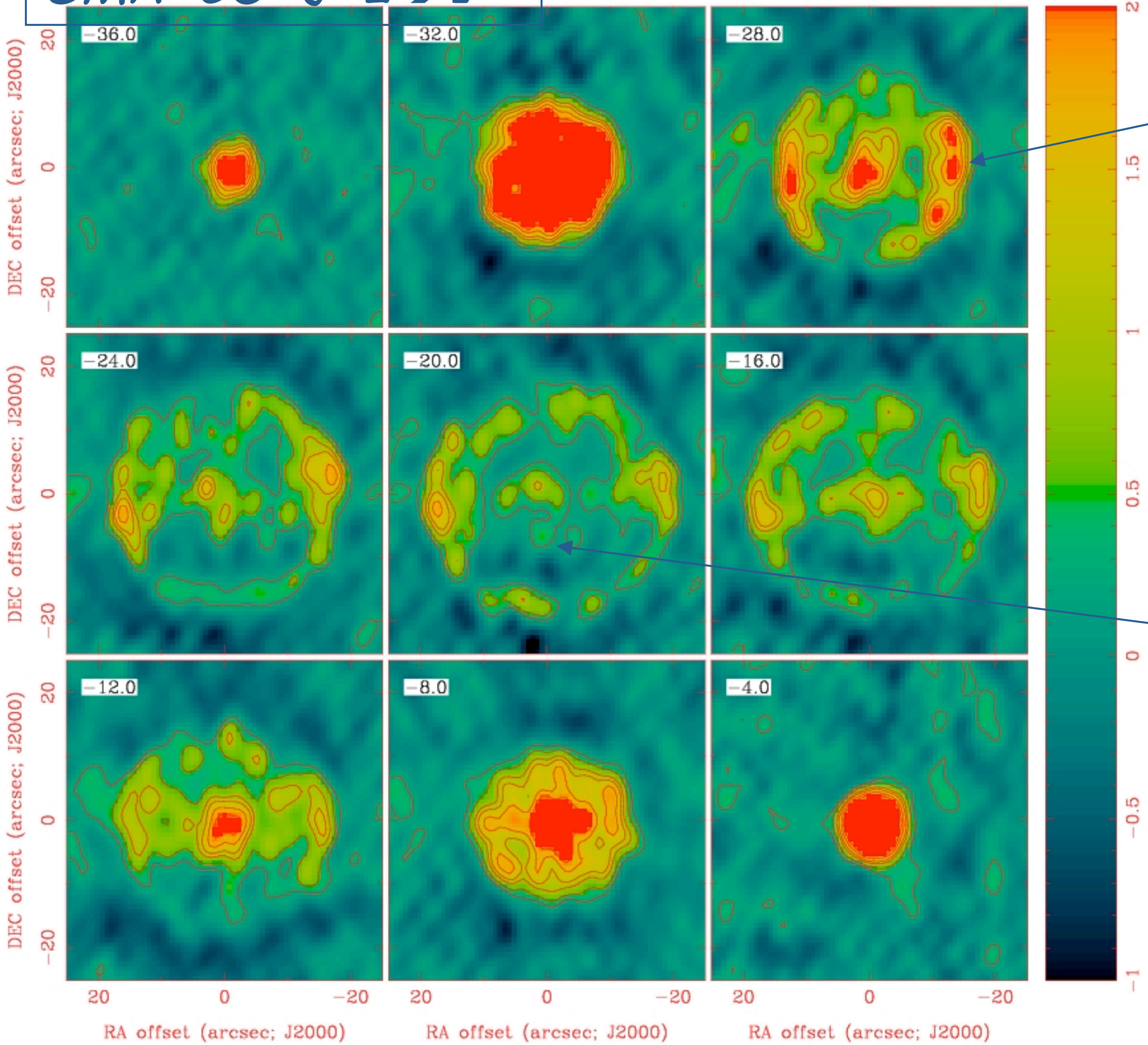
- Strong mass-loss event followed by much slower wind

Shell 1

$$\dot{M} \approx 10^{-5}\ \ M_O/yr$$

SMA CO J=2➔1

Morphology: R Scl



Shell 1

Detached
v~15 km/sec
20″ ➔ 1700 yr

Shell 2

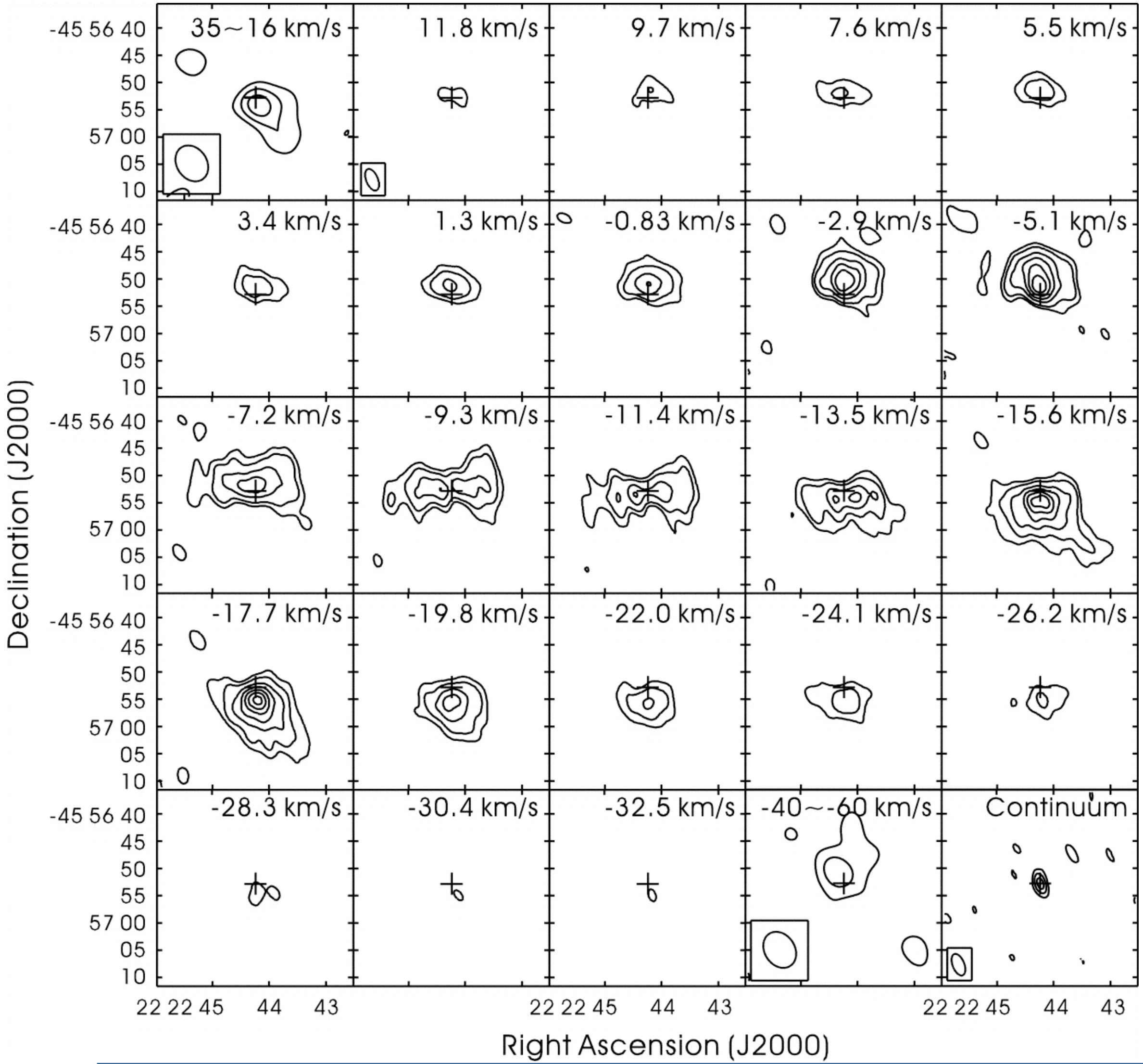
Hints for
"current mass-loss"

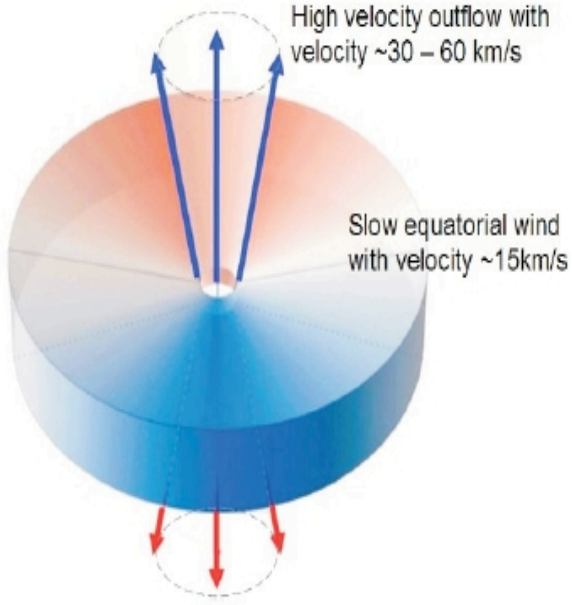
Episodic mass-loss: how common in AGB?

A disk around π Gru

SMA CO J=2→1
Res_spa 2.2 x 4.2 ″
Res_spe =1 km/sec

Chiu et al., 2006





Modeled as an equatorial expanding wind (disk) + Bi-polar outflow

- ✓ Episodic mass-loss?
- ✓ Presence of outflows, disk?

How common are those (*unexpected*) phenomena?

The angular dimension of CO radius can be expressed as function of the mass-loss (Mamon et al., 1988), $f_{CO}=10^{-3}$, $v_{exp}=15$ km/sec

$$\theta_{\mathrm{CO}} \approx 6\left(\frac{\dot{M}}{10^{-6}}\right)^{0.6}\left(\frac{1kpc}{D}\right) \quad \mathrm{arcsec}$$

$\theta_{CO}(8\text{Kpc}, 10^{-6}\ M_{Sun}/\text{yr}) \sim 0.75''$

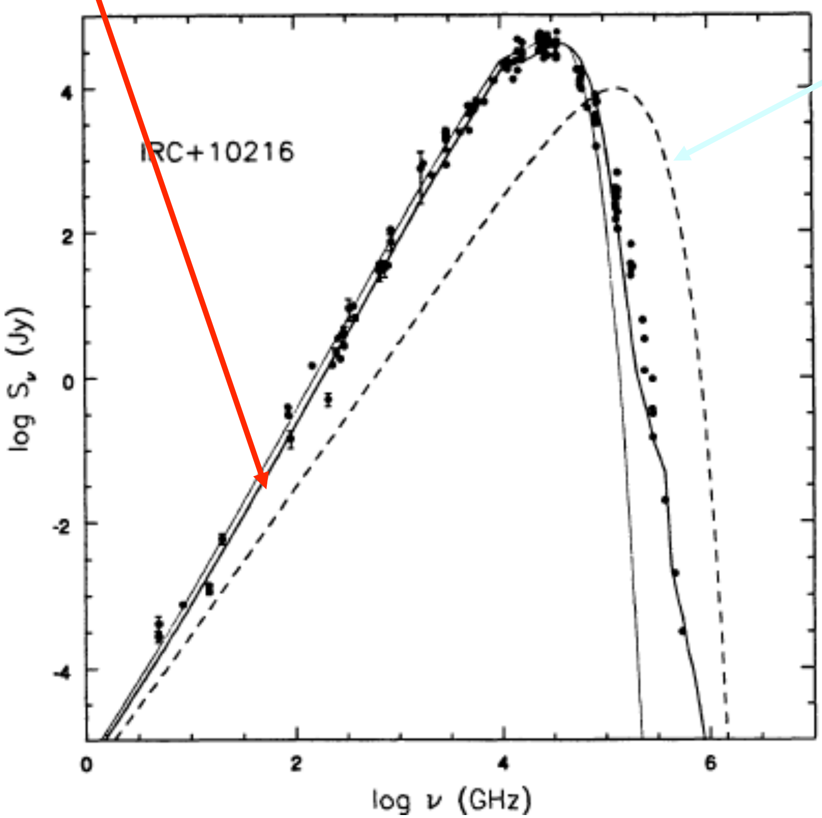
Sensitivity ok: 1hr, S/N ~90 (1 km/s)

$\theta_{CO}(50\text{ Kpc}, 10^{-5}\ M_{Sun}/\text{yr}) \sim 0.5''$

The high resolution and sensitivity of ALMA would allow to maps (in details) the molecular CSEs in large sample of stars:

Dust grains (T_{dust}) produce an IR-(sub)mm excess

$$S_\nu \propto \nu^{(2+\beta)}$$



$$S_\nu \propto \nu^2$$

$Q\nu = Q_0(\nu/\nu_0)^\beta$

β depends on grains composition and dimension

mm measurements: characterization of CSE mineralogy

The flux density emitted from thermal dust in an expanding CSE (Knapp et al., 1993):

$$S_\nu(mJy) = 1.6\,\mathrm{x}10^{-4}\,\frac{\dot{\mathrm{M}}_{\mathrm{dust}}}{D^2 v_{\mathrm{exp}}}\,\mathrm{L}^{0.2}\,\mathrm{R}^{0.6}\,\nu^{(2+\beta)}$$

For $L=10^4$ L_{Sun}
$R=10^{18}$ cm
Vexp=15 km/sec
$\beta \sim 1$

$$S_\nu(mJy) \approx 15\left(\frac{\dot{\mathrm{M}}_{\mathrm{dust}}}{10^{-6}}\right)\left(\frac{1\,\mathrm{kpc}}{\mathrm{D}}\right)^2\left(\frac{\nu}{230}\right)^3$$

Fmin~5σ (σ=in mJy @ 230 GHz)
ALMA (full array)
In 1 hr= Fmin~85 μJy

$$D \approx 13\left(\frac{\dot{\mathrm{M}}_{\mathrm{dust}}}{10^{-6}}\right)^{0.5}\quad \mathrm{kpc}$$

$dM/dt = 10^{-5}$ D=40 kpc (D_{LMC} in 2 hrs)
$dM/dt=10^{-7}$ D=8 kpc (GC in 4 hrs)

$S_{350\ GHz} \sim 4\ S_{230\ GHz}$

The photospheric flux at frequency ν from a star of radius R, temperature T, at distance D can be express as:

$$S_\nu = \frac{\pi R^2}{D^2} 2\,\mathrm{k}\,\mathrm{T} \frac{\nu^2}{\mathrm{c}^2}$$

R-J forBB

@ 230 GHz (1.2mm)

$$S_{250} = 1.42 \times 10^{-4}\,\mathrm{T}\,\vartheta^2$$

with S in mJy
T in K
θ in mas

Important photospheric contribution at mm (Rstar ≥ 300 R_{Sun})

Surveys IRAM 30m, SEST 15m @230GHz :

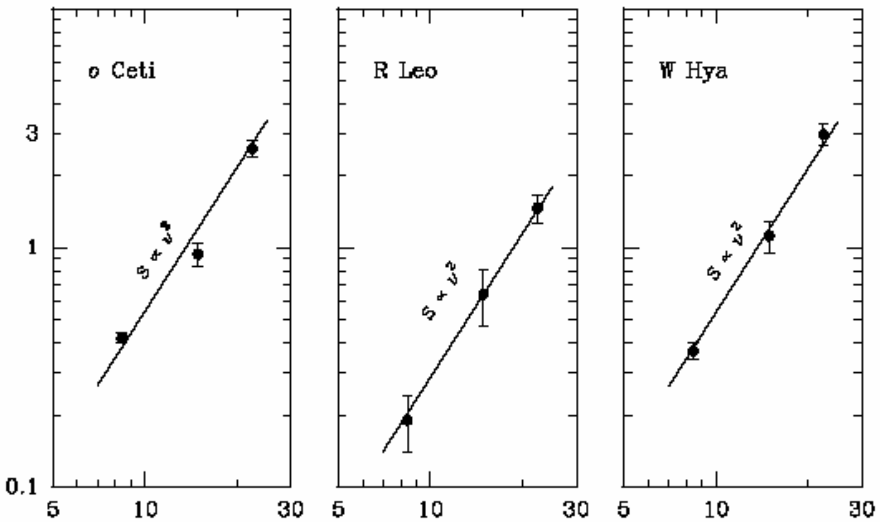
Altenhoff et al., 1994; Wamsley et al., 1991,…, Dehaes et al., 2007

AGB stars:

-bright mm objects (10-200mJy)

- Observed fluxes consistent (more or less) with photospheric contribution (in some cases possible dust contribution)

Existence of a RADIOSPHERE (Reid and Menten, 1997; 2007)!



- Radio spectral index (α=2)
- Observed fluxes higher than Phot. values
- Modeled with:

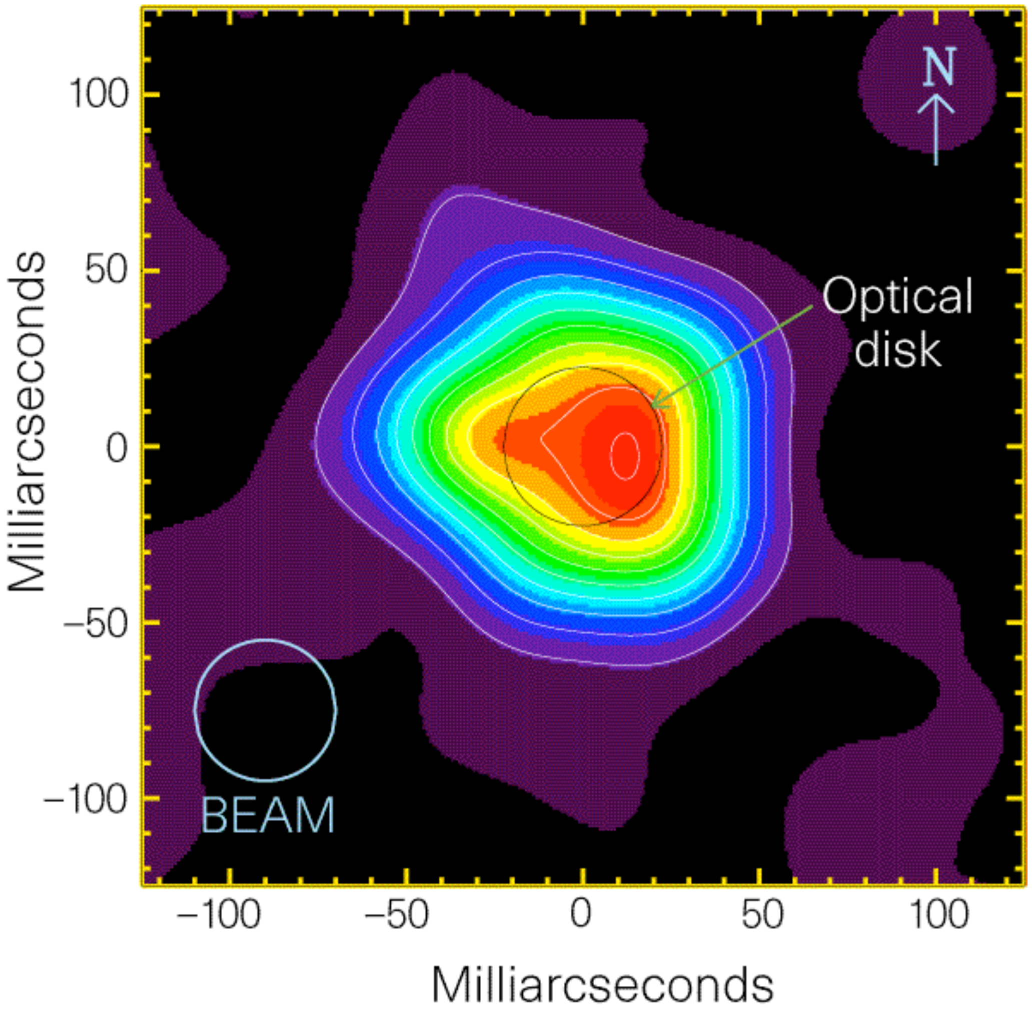
R~2 Rphot

T~1500 (T_{phot} 2000-2005 K)

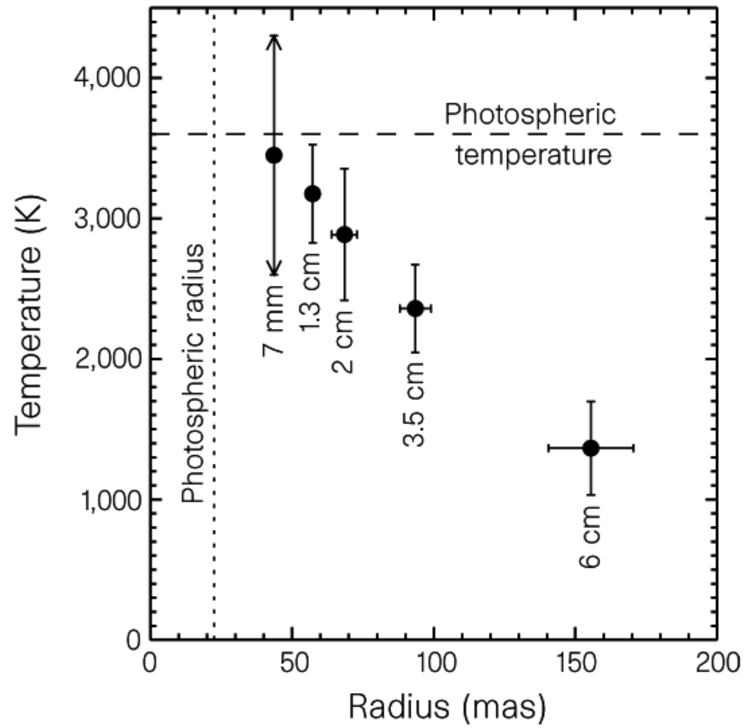
-Radio flux constant (on timescale of yrs)

Lim et al., 1998

The central star: mm continuum



VLA-A, 7mm, θ~40 mas



Structured morphology: big convective cells?

Evidence for an extended atmosphere (~ 7 RStar)

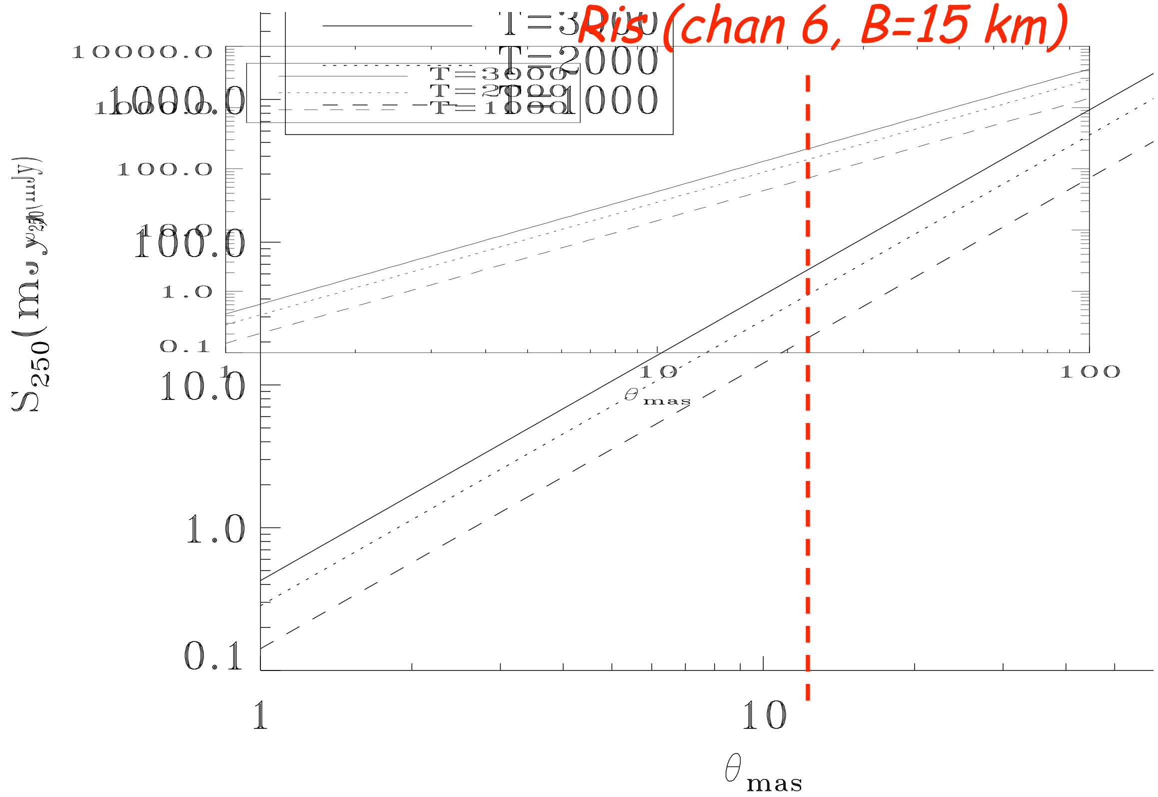
$$S_{250} = 1.42 \text{ x}10^{-4}\,\text{T}\,\vartheta^2$$

Assuming Rstar~5 10^{13}cm

$$\theta_{Star} \approx 3\left(\frac{1Kpc}{D}\right)\text{mas}$$

For D≤ 100 pc

θstar ≥ 30 mas
(resolved by ALMA)



Fluxes 20-100 mJy
10 min , 50 antennas, 1 σ= 0.03 mJy

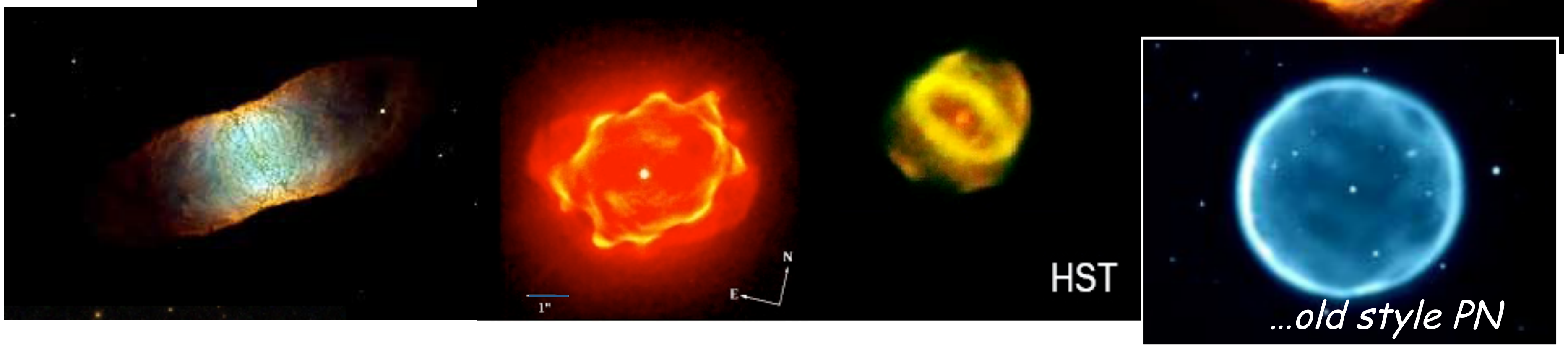
Observations as those of αOri will be a "piece of cake" for ALMA!

HST images:

PN show a rich variety of morphology:

-small scale structures
-not consistent with
Interacting winds model

Which ***shaping mechanism*** transform the (almost) spherical CSE in AGB into the CSE observed in PN?



Several models have been proposed:

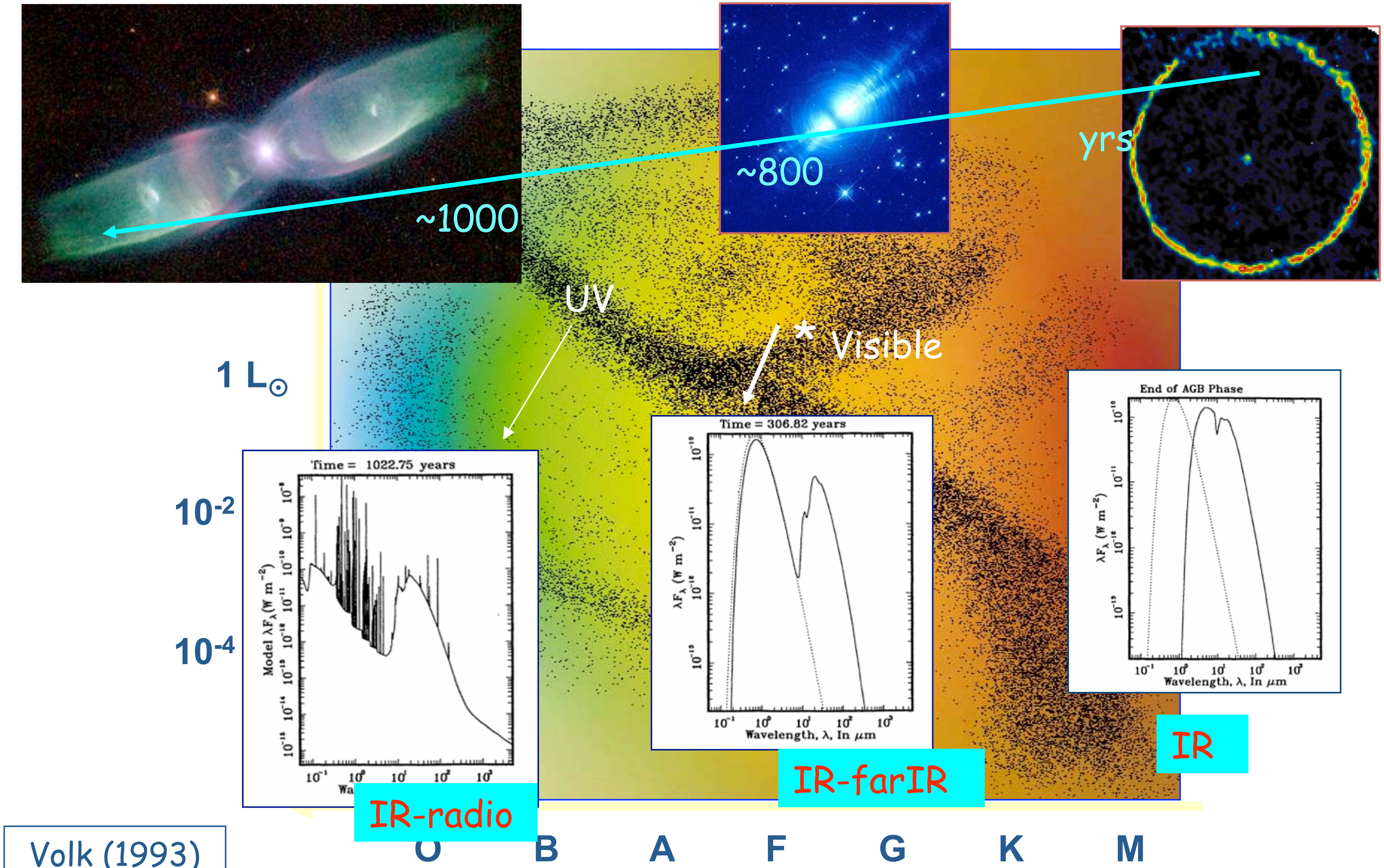
Principal ingredient

-interaction between the fast but tenous wind (begin of PPNs) with the massive, slow AGB wind.

...cooked in different sauces..

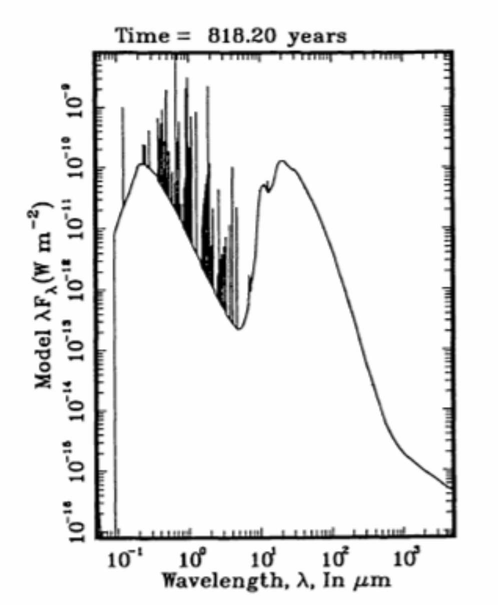
- ✓ Interaction collimated, fast winds (jets?)/CSE ?
- ✓ Interaction fast wind /asymmetric CSE (binarity ?, asymmetric mass-loss in AGB?)

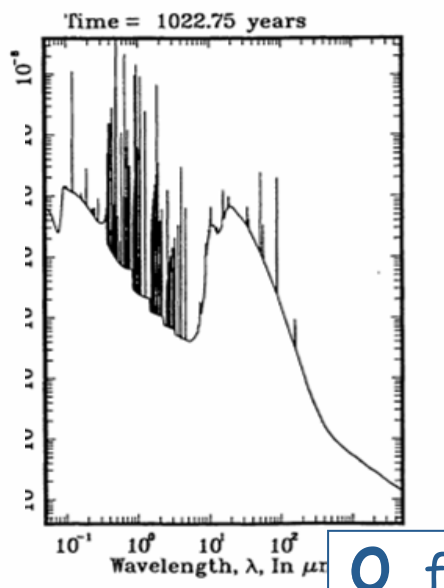
\+ a possible magnetic field contribution (collimator?)


~1000
~800
yrs
UV
* Visible
1 L⊙
10-2
10-4
Time = 1022.75 years
Model λFλ (W m-2)
Time = 306.82 years
λFλ (W m-2)
Wavelength, λ, In μm
End of AGB Phase
λFλ (W m-2)
Wavelength, λ, In μm
IR-radio
IR-farIR
IR
O B A F G K M

Volk (1993)

Late post-AGB





More diagnostics available

In the band

(30 GHz $\leq \nu \leq$ 300 GHz)

- free-free contribution (bremhstralung)
- RRLs

Tracers of (ionized) gas

In AGB and early post-AGB : Only molecular gas and dust tracers

In late post-AGB (YPNe) is possible to study ALL the stellar ejecta components: gas (both ionized and molecular) and dust

Mass-loss history imprinted in the CSE

CO the best means to study CSE

(detected in AGB, postAGB and PNe)

Interferometric CO observations allow:

- Map the distribution of molecular gas within the CSE
- Track its kinematic

Interferometric observations of molecular CSE in objects in different evolutionary phases

→ to follow as its characteristics evolve as AGB→ PNe

Clues on shaping (possibly!)

Molecular CSE (CO) ➔ function of ISM radiation field (as in AGB), but in PPN and PNe also of central object UV

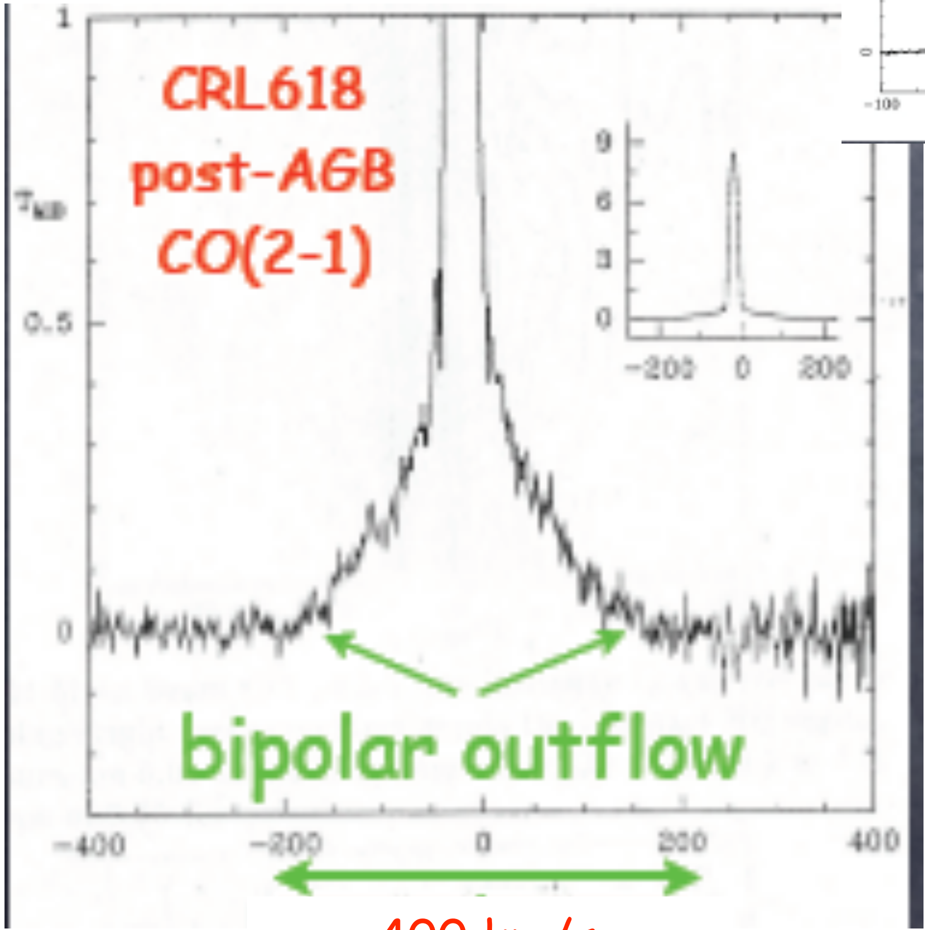
There is a increasing "erosion" of molecular CSE as the central object evolves $UV \sim 10^5 \;\; 10^7 \;\; UV_{ISM}$

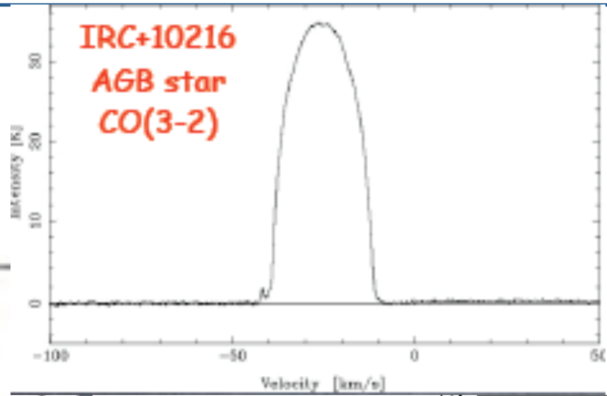
✓ Survey single dish: (detection rate)

PPNe ~AGB= 80%

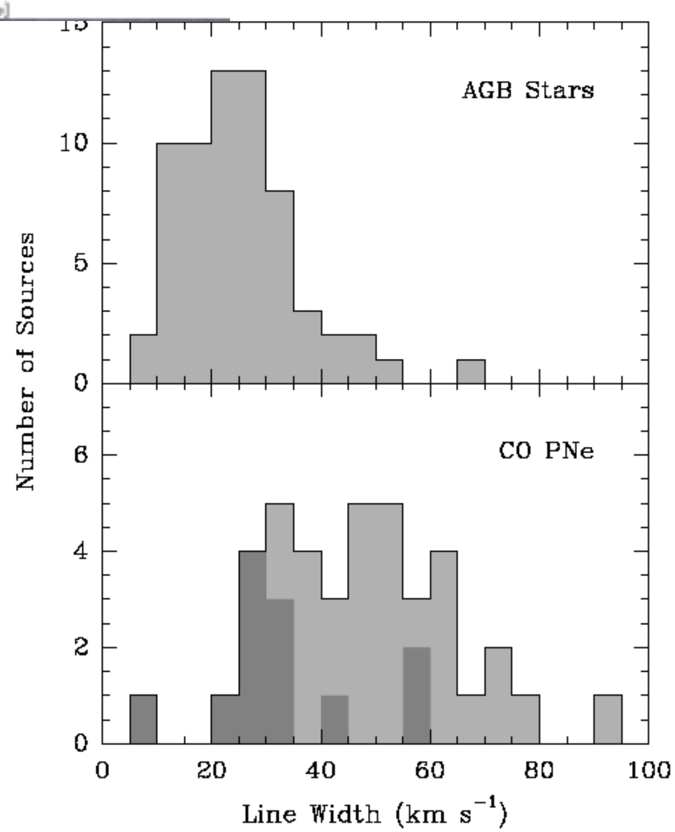
PNe ~35%

CO profiles in post-AGB (fast winds components)





Huggins et al., 2006



Molecular CSE (CO) ➔ function of ISM radiation field (as in AGB), but in PPN and PNe also of central object UV

There is a increasing "erosion" of molecular CSE as the central object evolves $UV \sim 10^5 \quad 10^7 \quad UV_{ISM}$

- ✓ Survey single dish: (detection rate)
  PPNe ~AGB= 80%
  PNe ~35%

- ✓ Interferometric observations (PdB, BIMA, SMA):
  R_{CO} in post-AGB « R_{CO} in AGB (~ 2 orders of magnitude)

The observed sample has a bias towards:

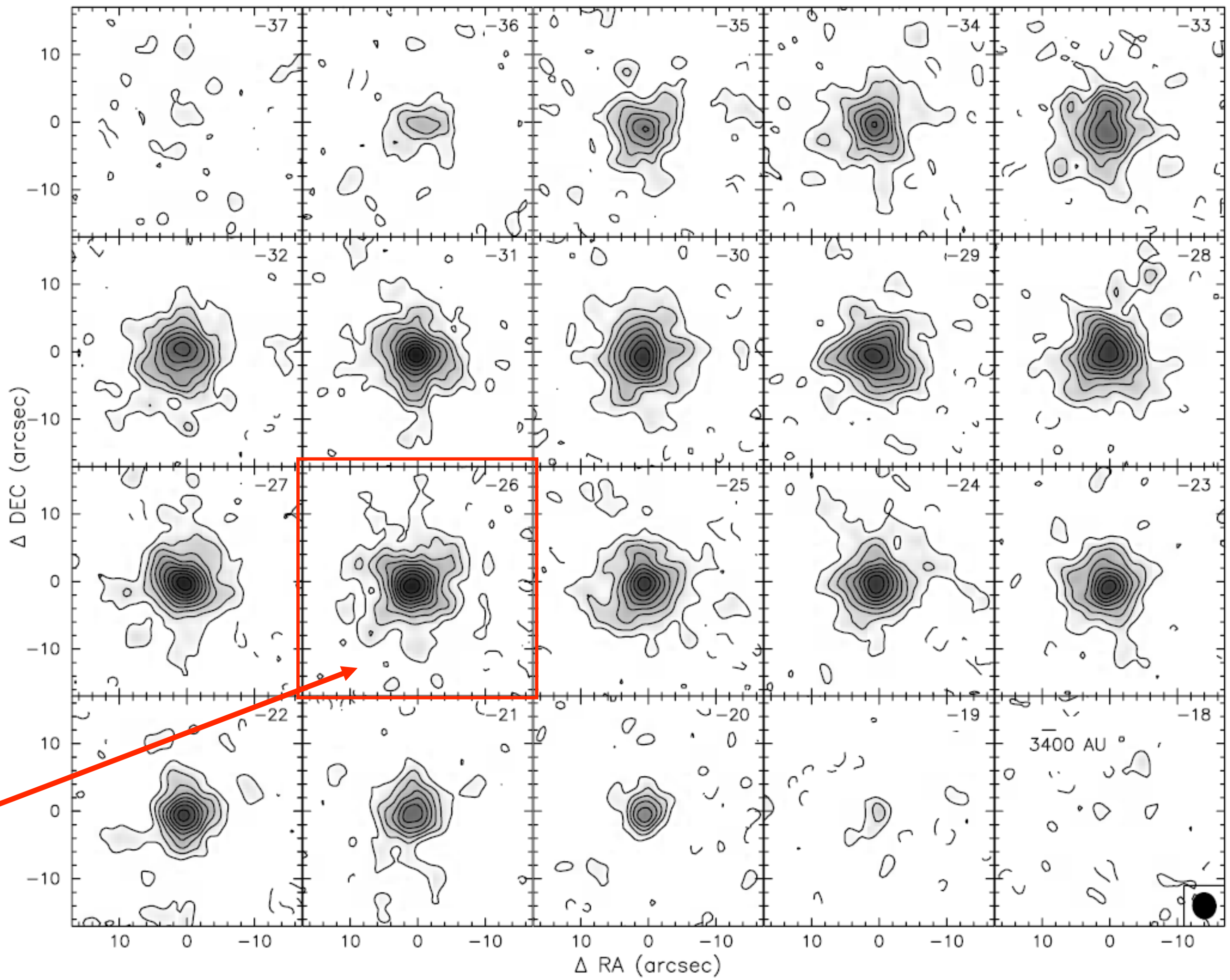
- ✓ CO brightest objects (to be detectable with actual sensitivities)
- ✓ Closeby objects (to map structures with actual angular resolution)
- ✓ "Interesting" structures at other wavelengths

Few examples: IRAS 22272+5435

BIMA +12m NRAO res_spa ~2", res_spe=1 km/sec

CO J=1→0 (115.27 GHz)

Cube:
Channel map=1 km/sec
Δv=-37 -18 km/sec
σ=0.21 Jy/beam

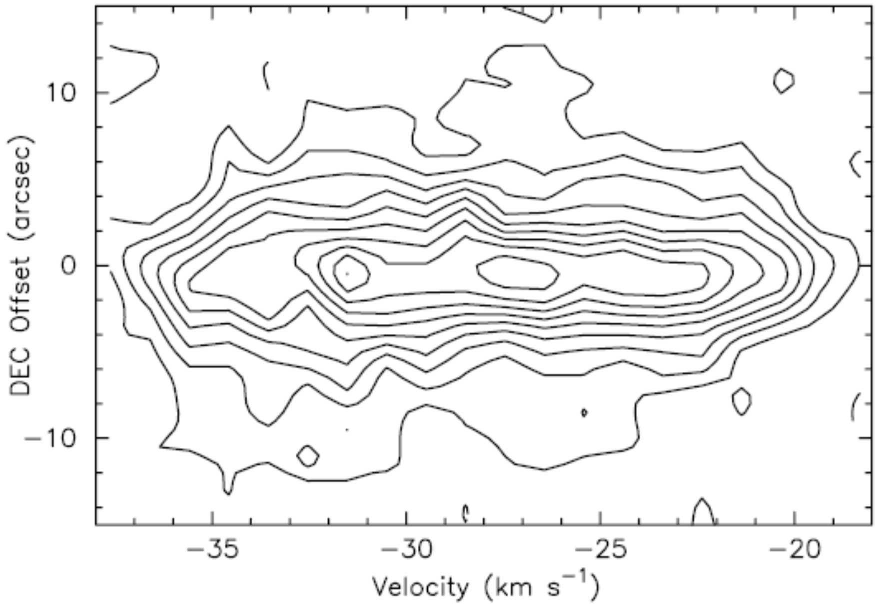


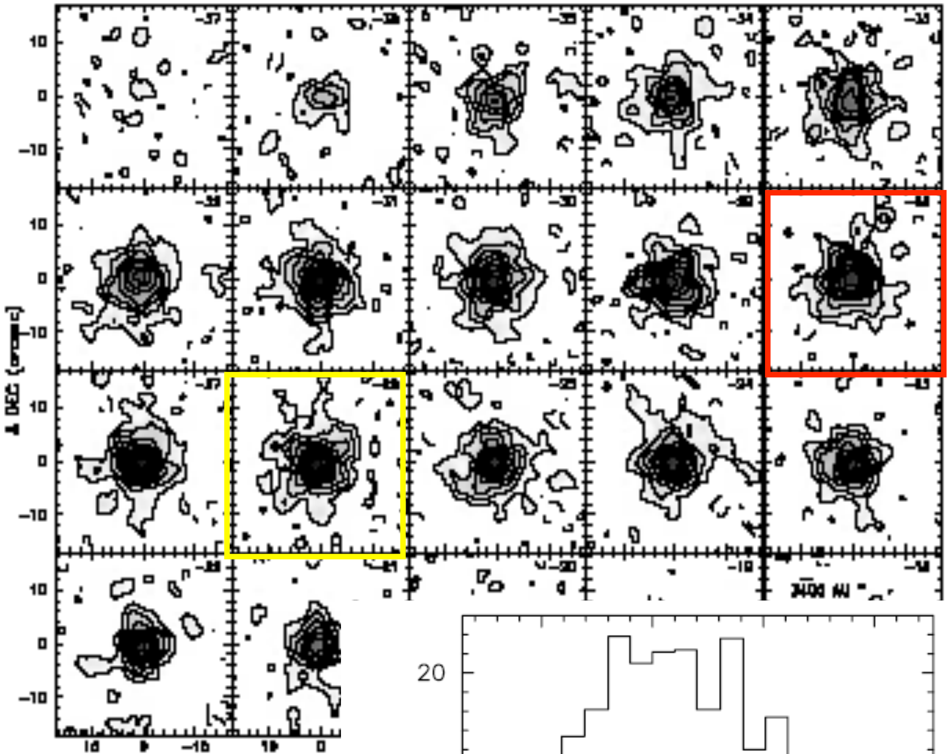
Channel map consistent with a spherically expanding envelope but

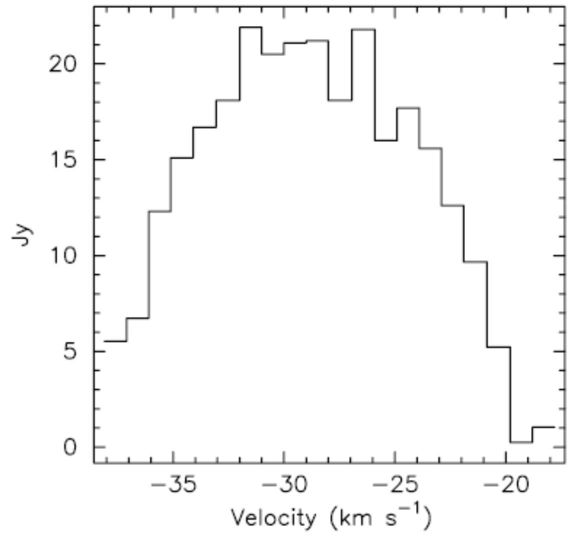
...deviating from spherical symmetry on smaller scale!

Fong et al., 2006

Cube:
Channel map=1 km/sec
Δv=-37 -18 km/sec
σ=0.21 Jy/beam

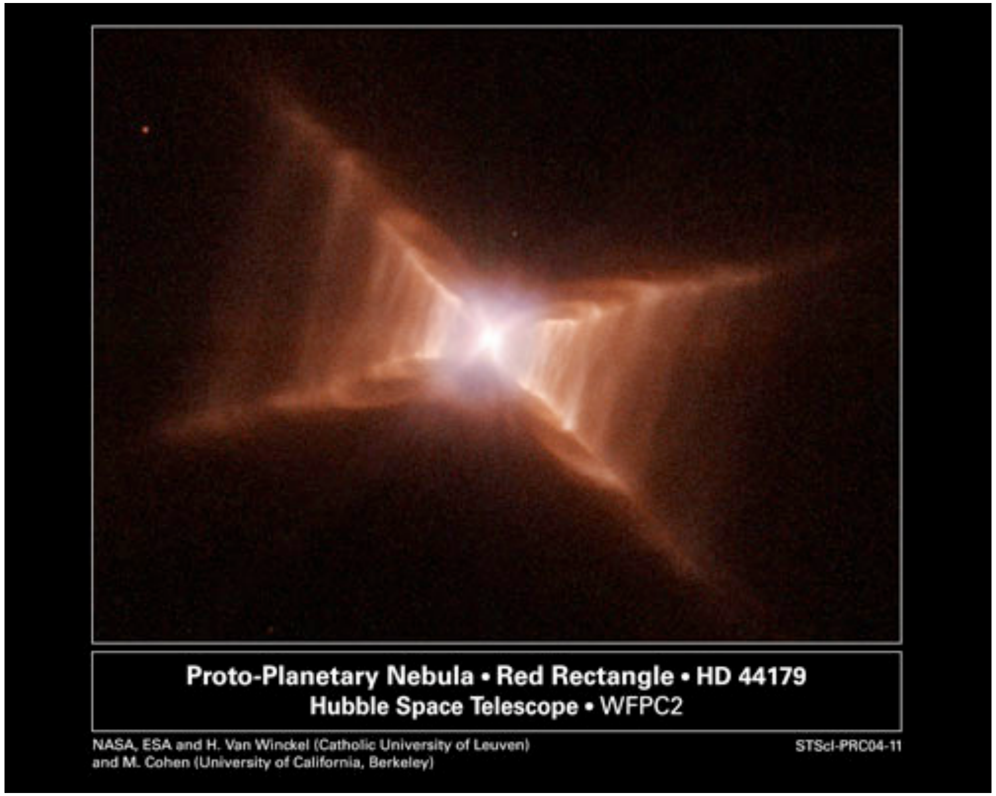


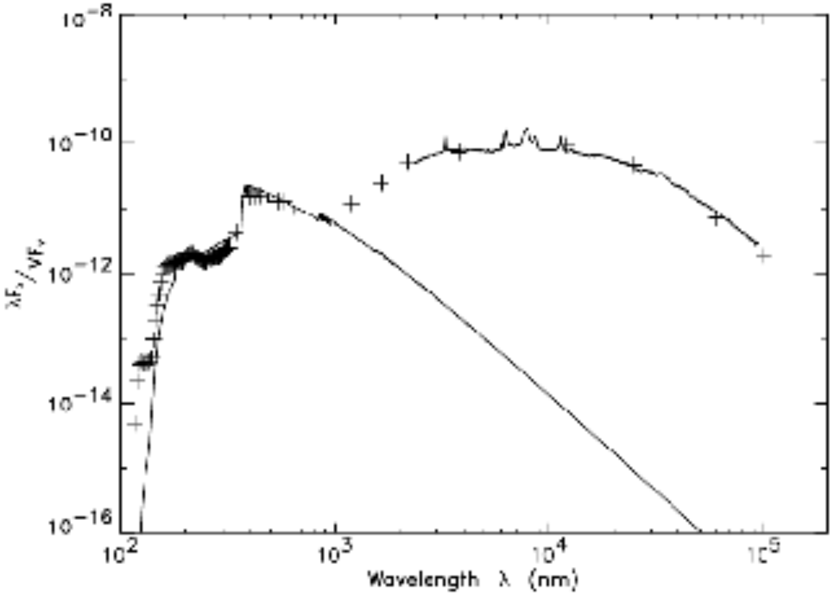




P-V in RA: consistent with a spherically symmetric expanding envelope
-no evidence for outflow structures

Well known PPN (binary central object)
Extended optical nebula ~1´, whose shape is the origin for the name
Presence of orbiting material proposed (Jura et al 1995, 1997,…) to justify
- presence of big grains (sub-mm)
- mixed chemistry in the CSE



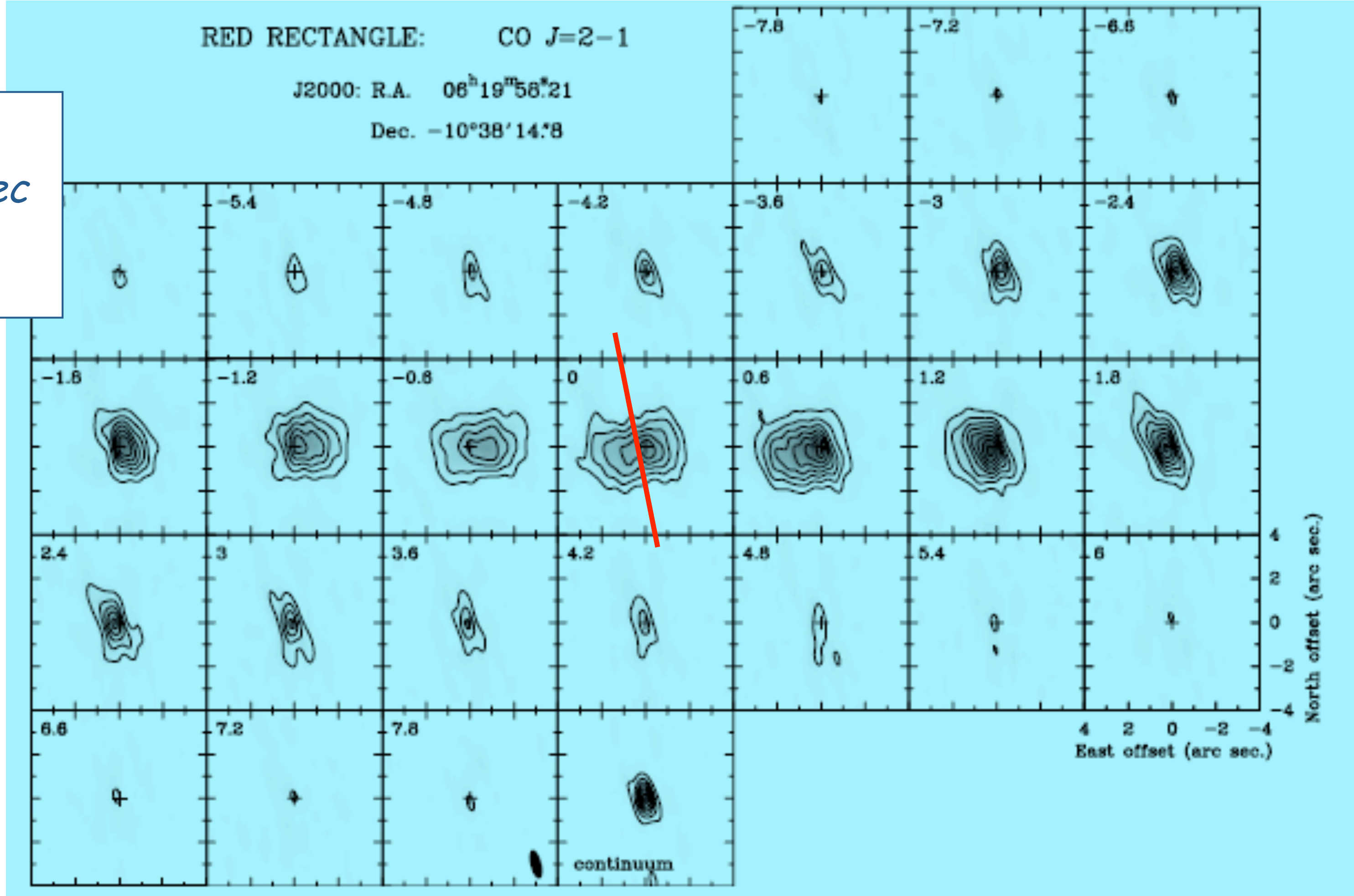


PdB CO J=2→1, 230.538 GHz
(CO J=1→0 115.271 GHz)

Bujarrabal et al., 2005

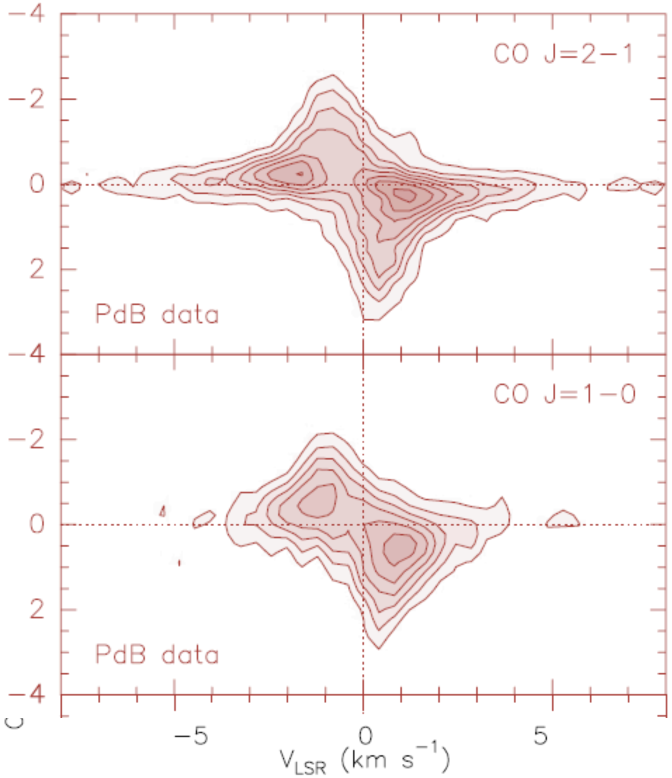
res_spa =1.3″ x0.5 ″ (2.6 x 1.0) res_spe=0.6 km/sec

Cube:
Channel map=0.6 km/sec
Δv=-7.8-7.8 km/sec
σ=0.21 Jy/beam

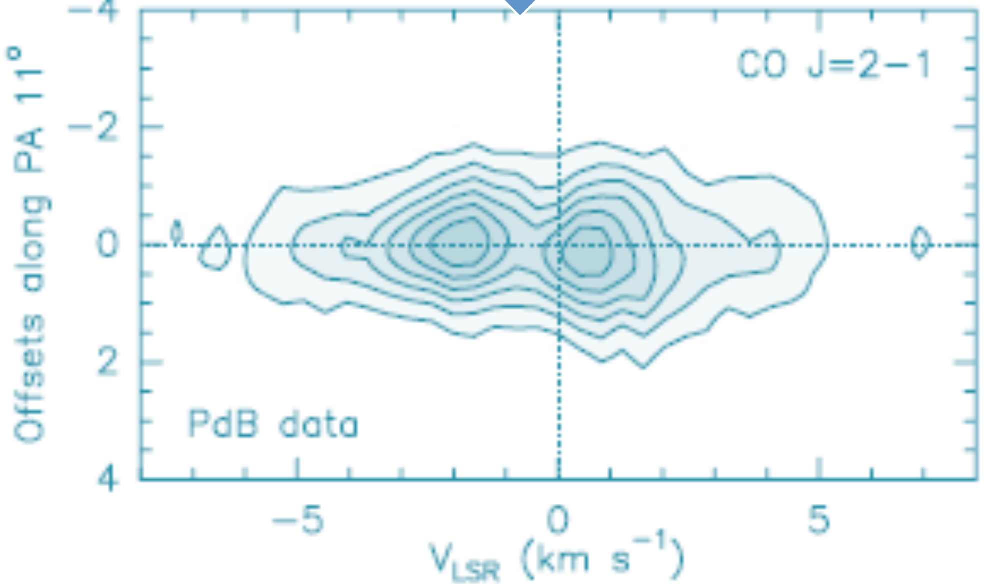


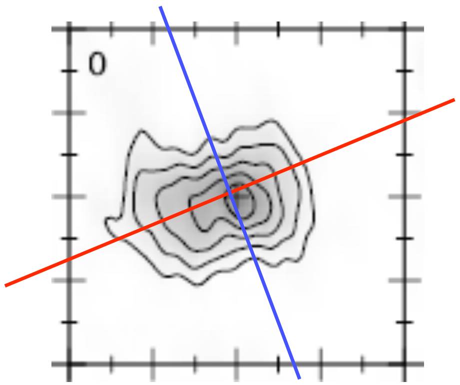
CO emission from extended region, perpendicular to the optical axis (red line)

A disk orbiting the Red Rectangle



A velocity gradient along the disk direction…
But none in the perpendicular direction

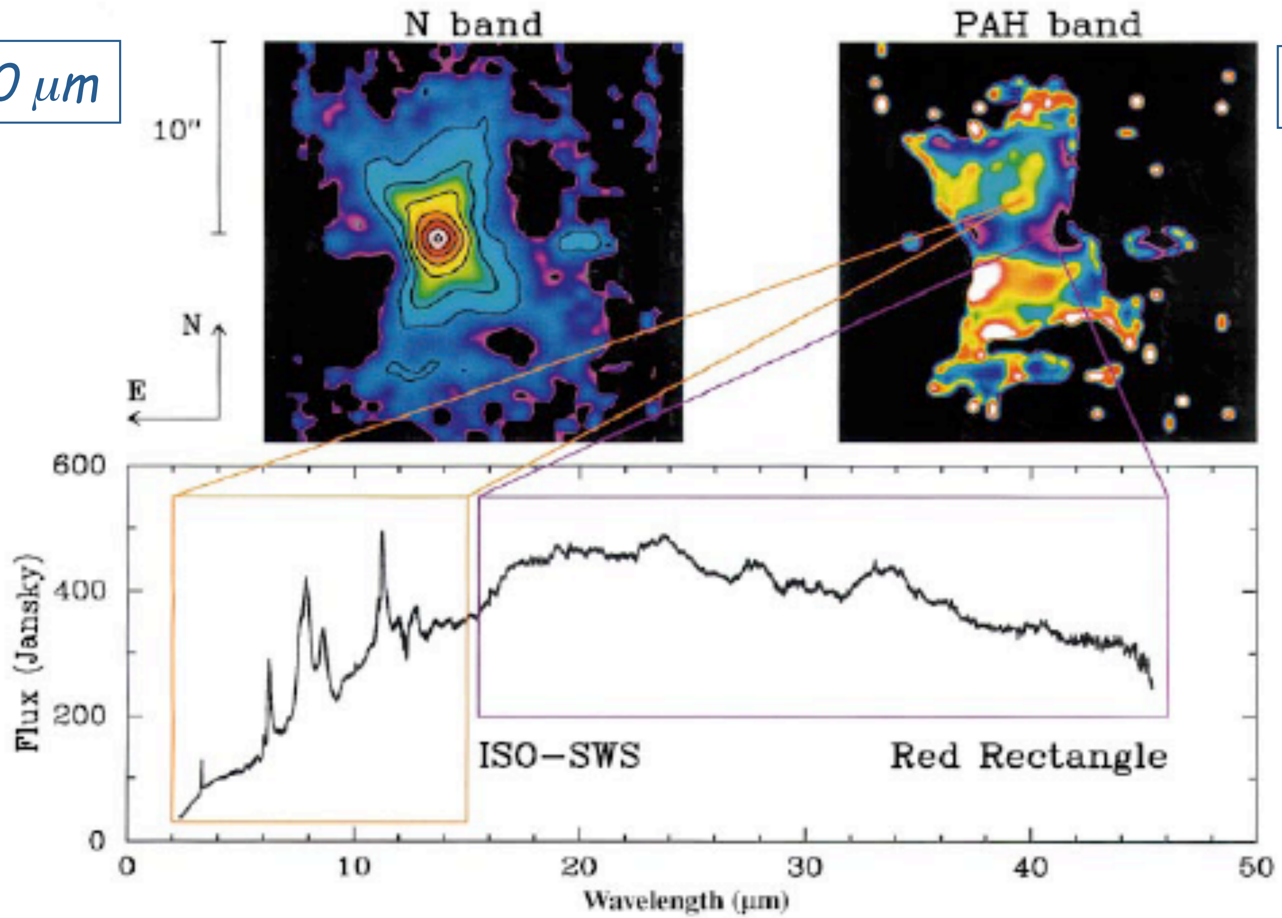




Consistent with a disk in the central part of Red Rectangle in Keplerian-like stable rotation

10.0 μm

11.3 μm



UIR bands: PAH

Waters et al., 1998

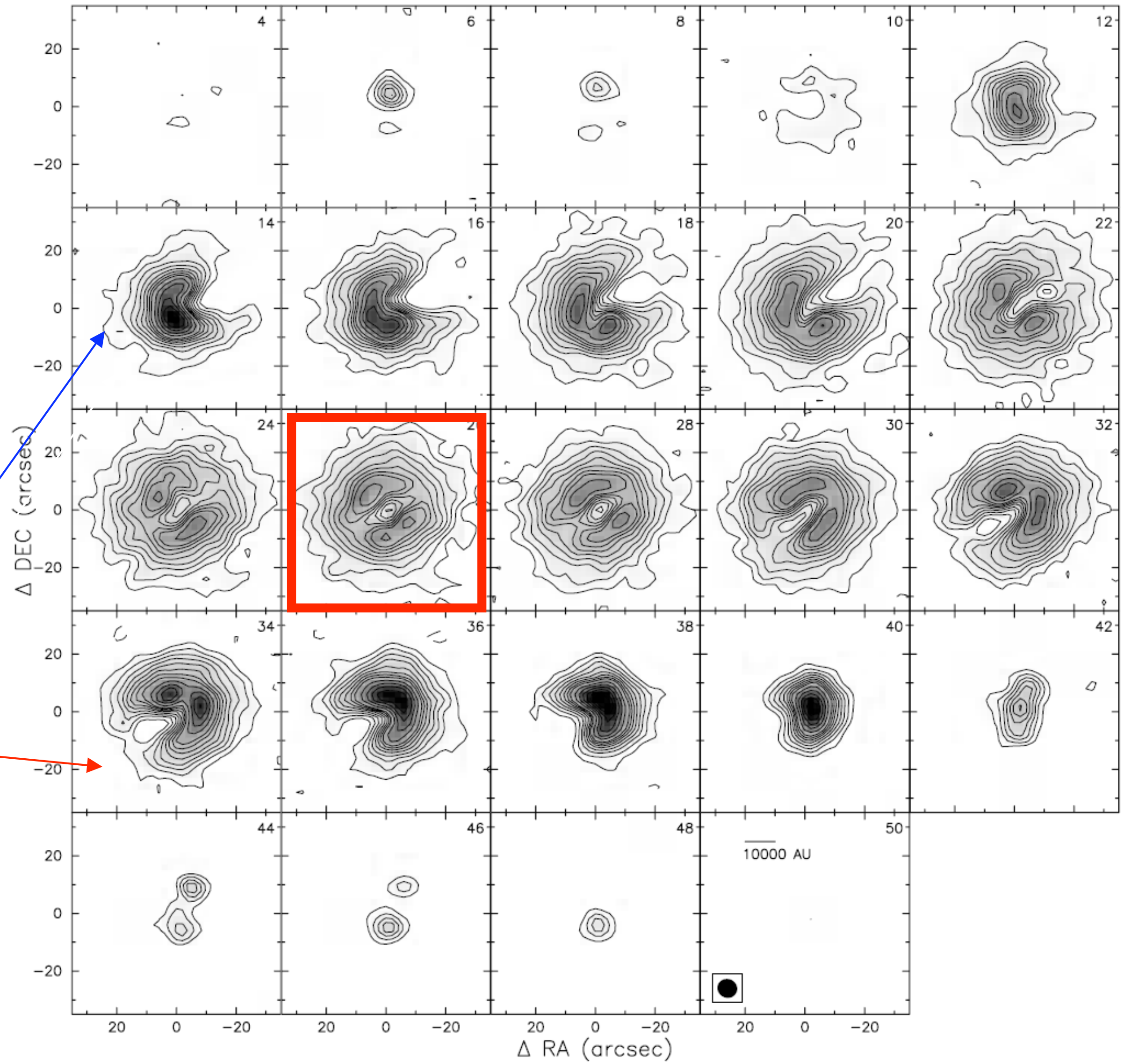
Silicates

Few examples: NGC 7027 (YPN)

BIMA +12m NRAO res_spa ~6″, res_spe=2 km/sec

Cube:
Channel map=2 km/sec
Δv=-37 -18 km/sec
3σ=0.50 Jy/beam

CO J=1➔0 (115.27 GHz)



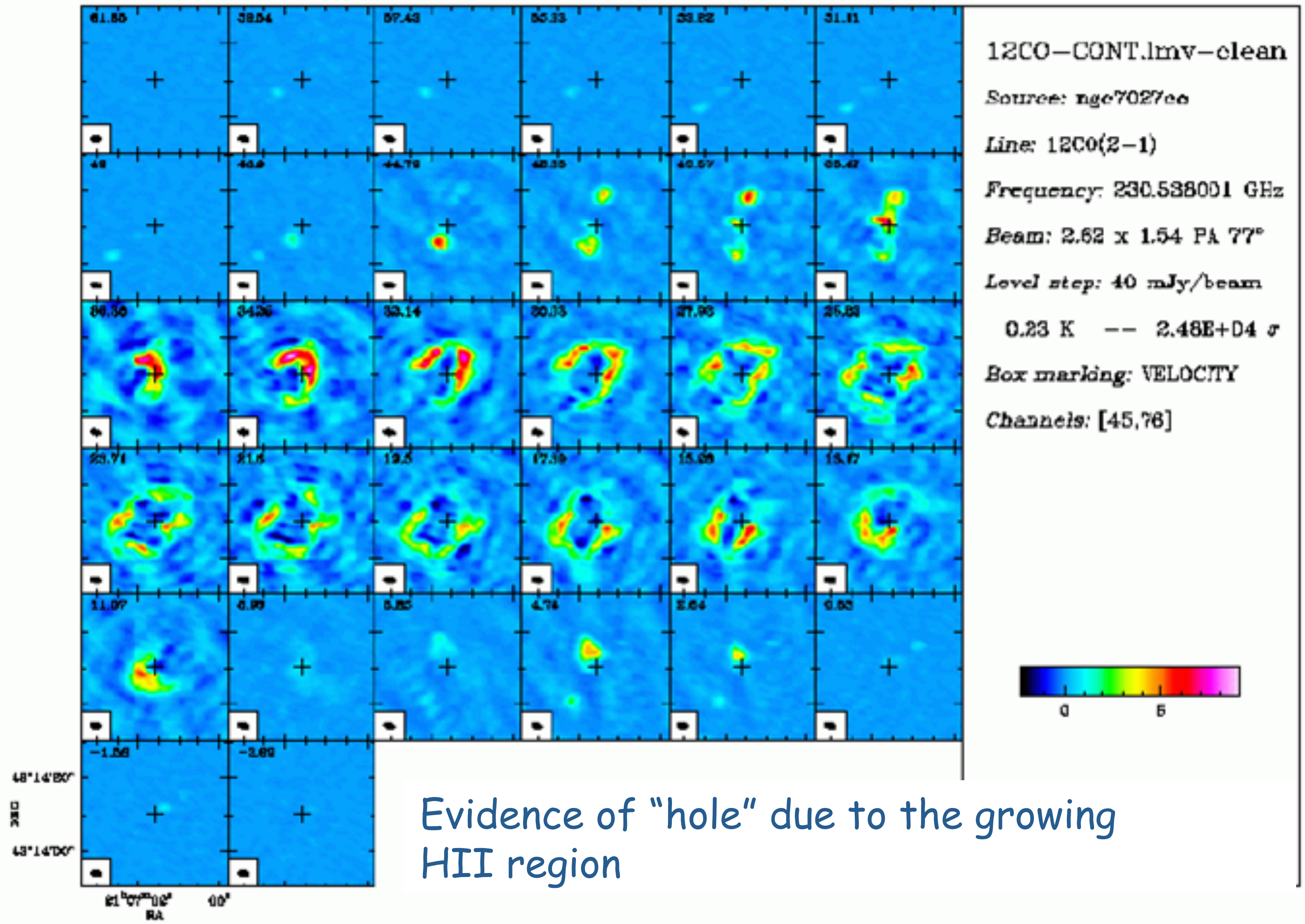
Consistent with a expanding envelope

Uncomplete shell ….
N-W (blu-shifted)
S-E (red-shifted)

..we see the effects of an agent that is progressively piercing the molecular envelope…

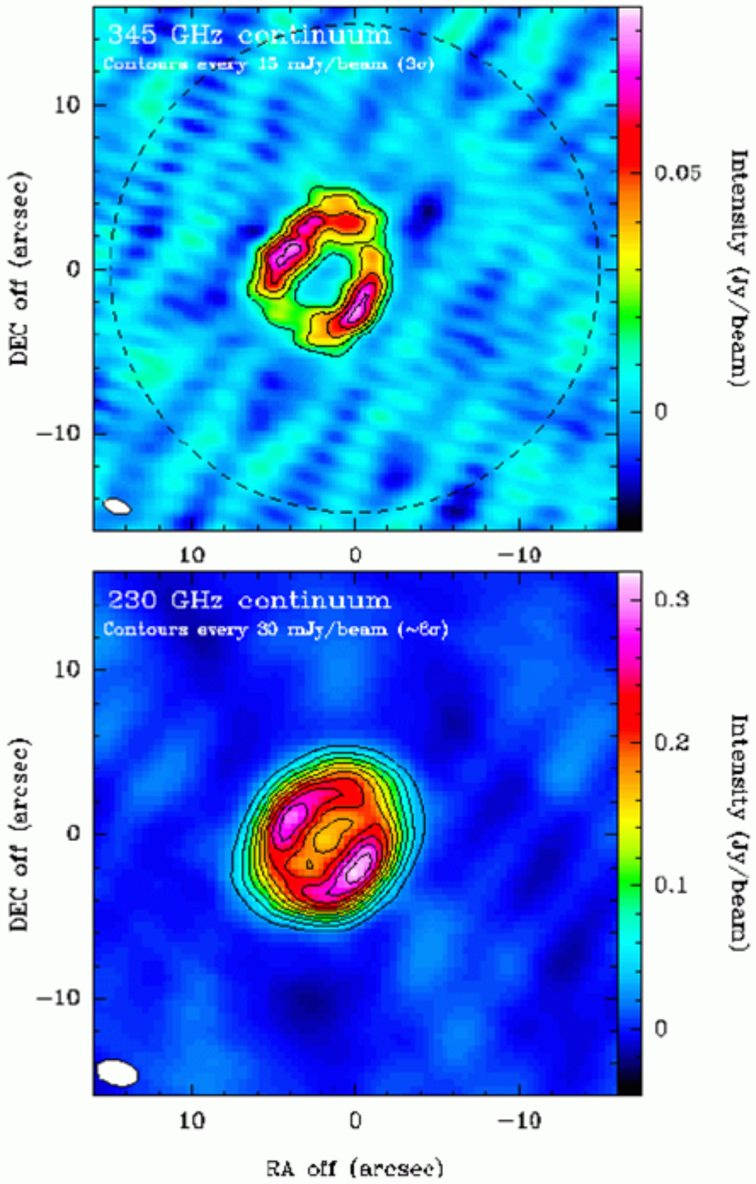
Dinh-V-Trung et al., 2006

SMA



Evidence of “hole” due to the growing HII region

Dinh-V-Trung et al., 2006



Few examples: NGC 7027 (YPN)

CONTINUUM

345 GHz
Beam : 1.71″ x 0.85″ (73°)
Total flux : ~ 1.45 Jy

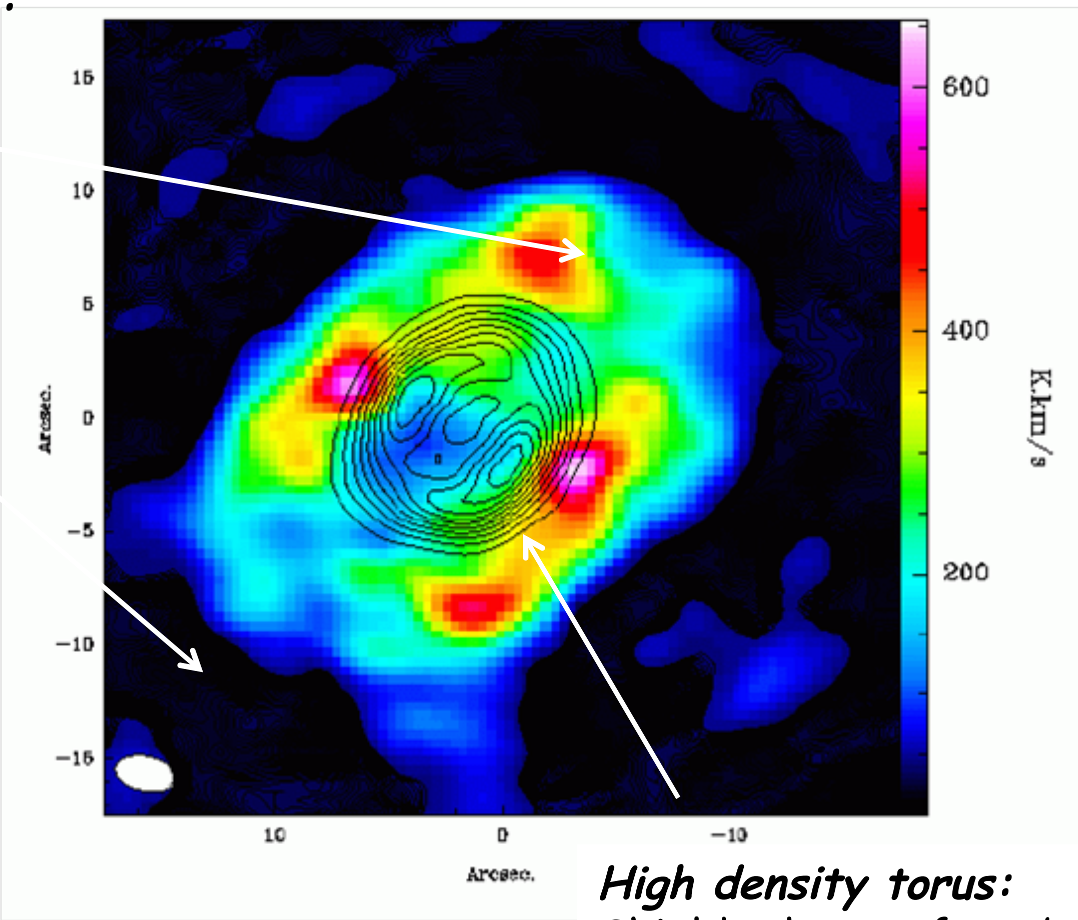
230 GHz
Beam : 2.65″ x 1.52″ (77°)
Total flux : ~ 3.6 Jy

JCMT : 3.8 ± 0.2 Jy
(Knapp et al. 1993)

Integrated intensity $^{12}CO(2-1)$ and 1.3 mm continuum

Dinh-V-Trung et al., 2006

Low density polar regions:
Where high-velocity winds (outflows) are channeled

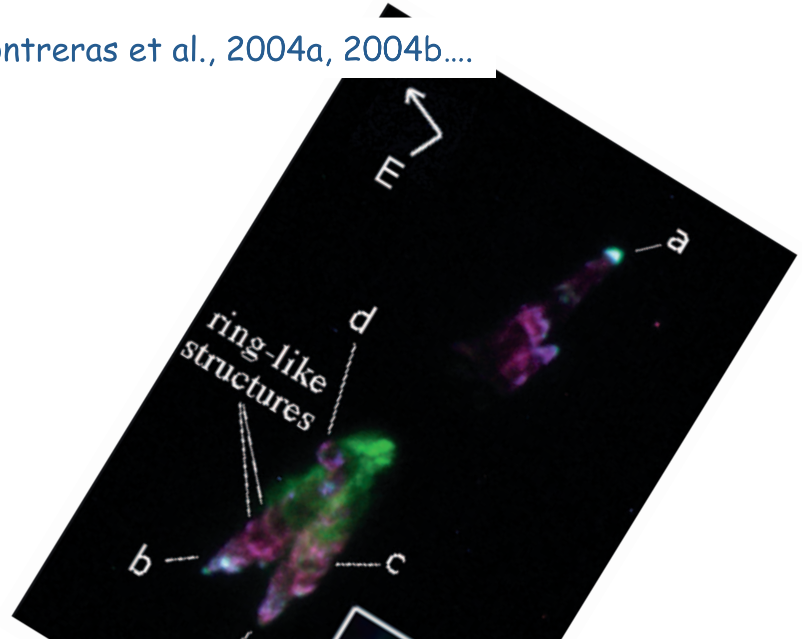


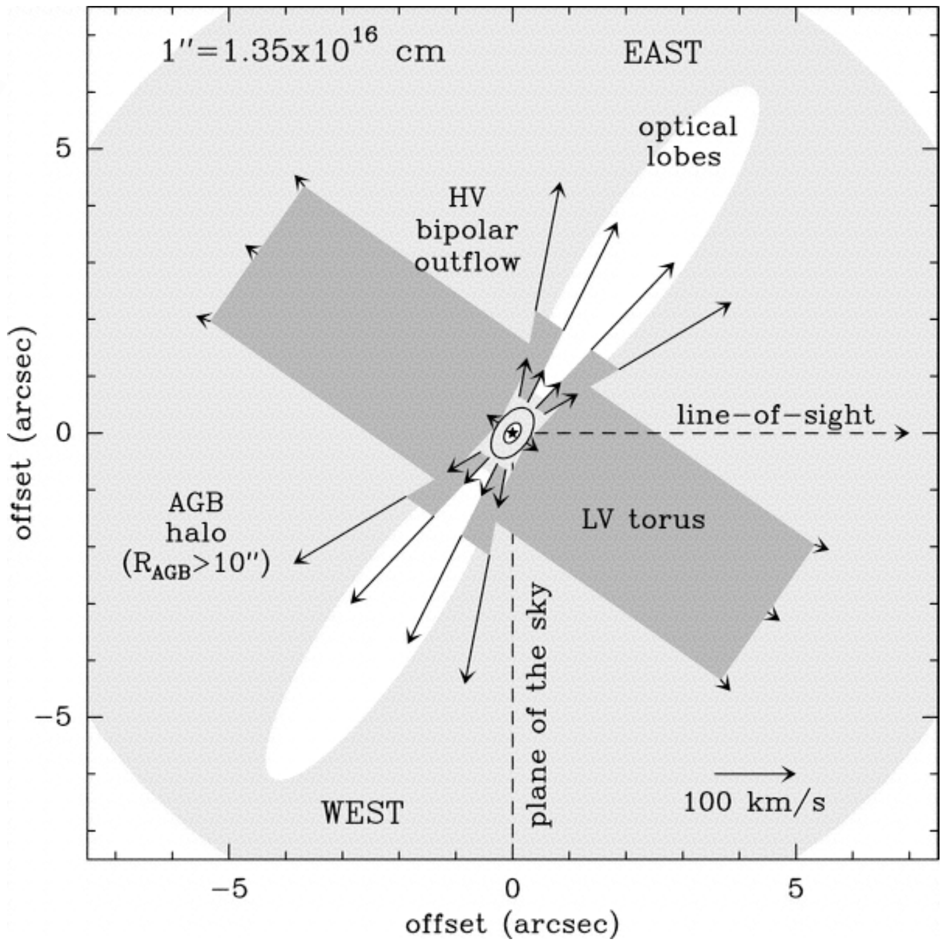
High density torus:
Shields the gas from being quickly photodissociated along the equator

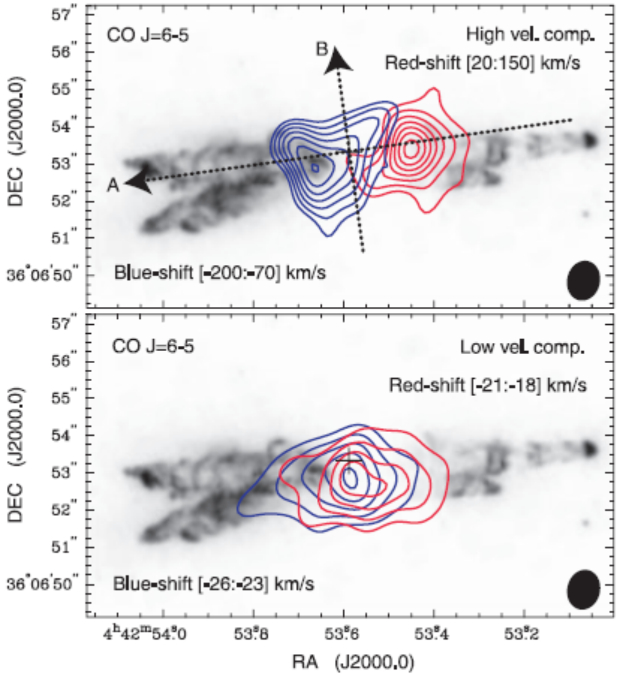
To understand "the shaping":
-need to observe *different stages*
-need to *combine different components* of the ejecta

Sanchez Contreras et al., 2004a, 2004b....

CRL 618: a PN in the making





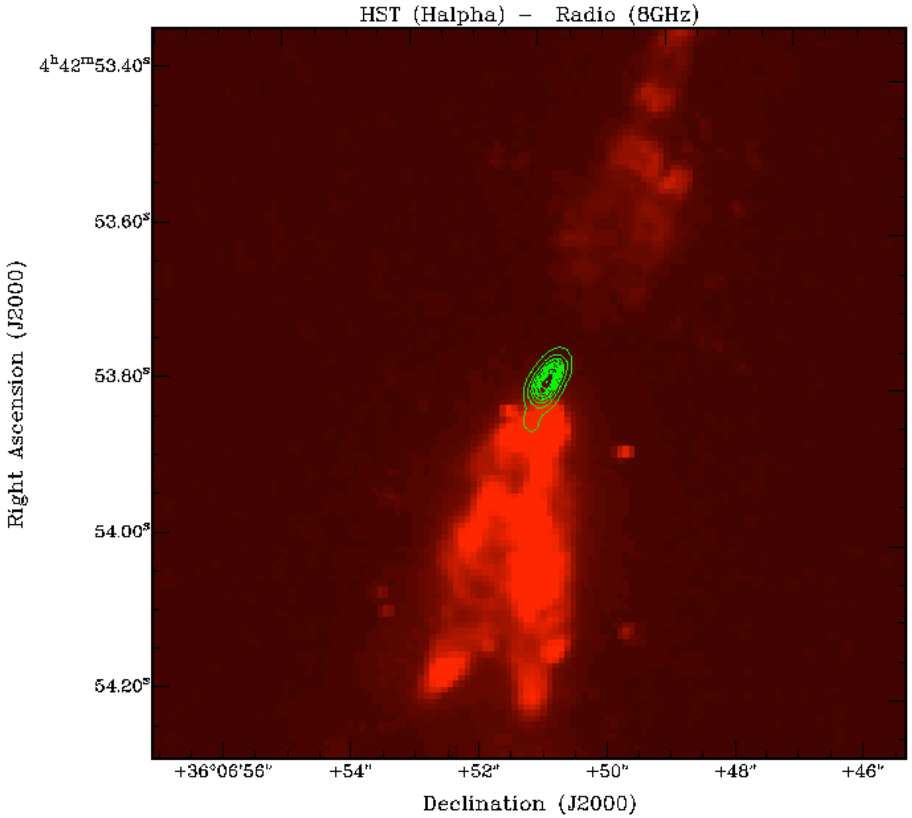


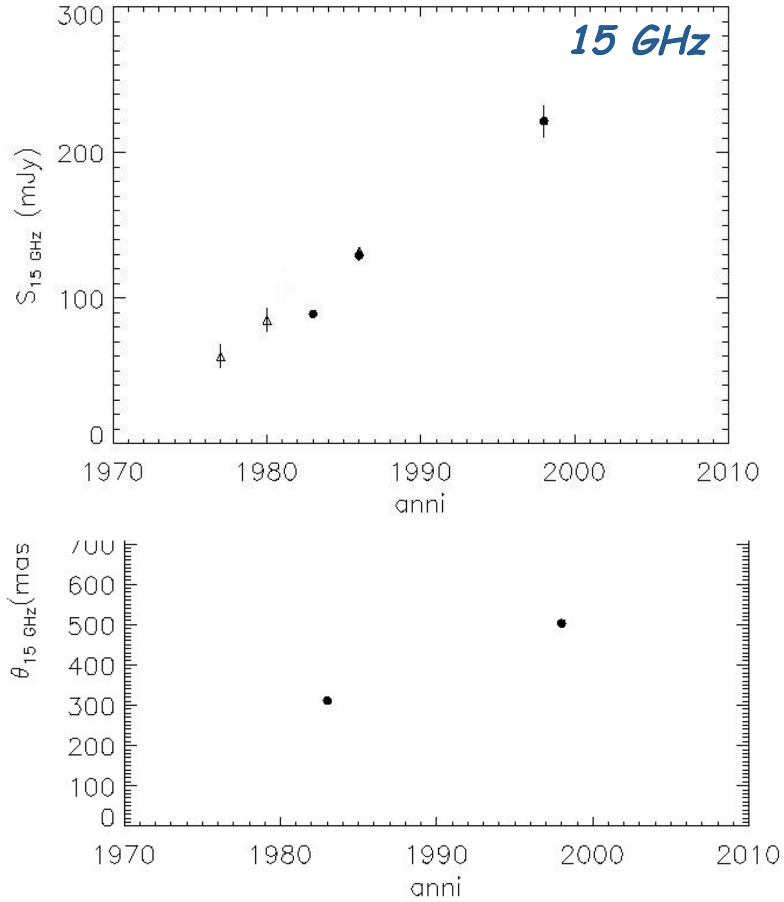
Nakashima et al., 2007

The History of the inner HII….
over 15 years

CRL 618: a PN in the making

Umana, Trigilio and Agliozzo , 2010





- Variation of density flux, expansion of the HII –perpendicular to the torus- consistent with evolution of central HII ..*in human time scale*
- Very interesting to follow this together "on going chemistry" of CSE

(Sub)-mm of transition objects allow to study the dust component in their CSEs.

In some cases (YPNe) the ionized fraction of CSE can give also a contribution.

As for molecular CSE, continuum observatios have a bias toward:

- ✓ Bright objects (to be detectable with actual capabilities)
- ✓ Closeby objects (to be mapped with actual resolving power)
- ✓ "Interesting objects" in other wavelengths.

(sub)-mm observations $30 \leq \nu \leq 900$ GHz

-Strong constraints on the SEDs

(thermal dust contribution extends to near and far-IR)

- Critical frequency range:

To disentagle between ionized (free-free) and dust components

Up to now, most of the mm continuum observations have been conducted in "spectral line" projects (ch 0).

-In most of the cases the mm source is very compact and it is NOT possible to localize the mm source within the molecular CSE.

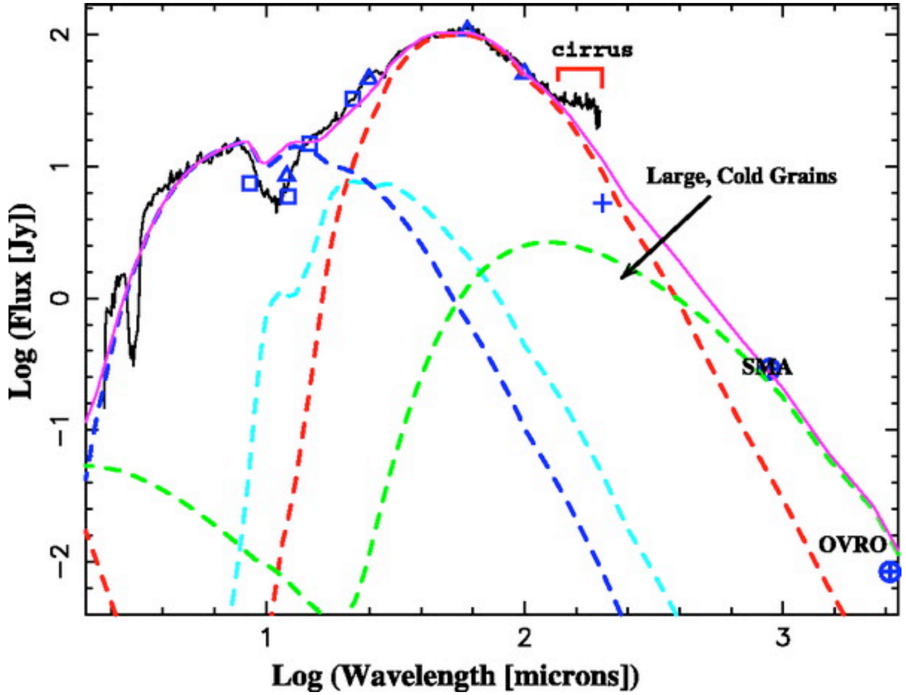
-It is possible to get clues on grains emissivity

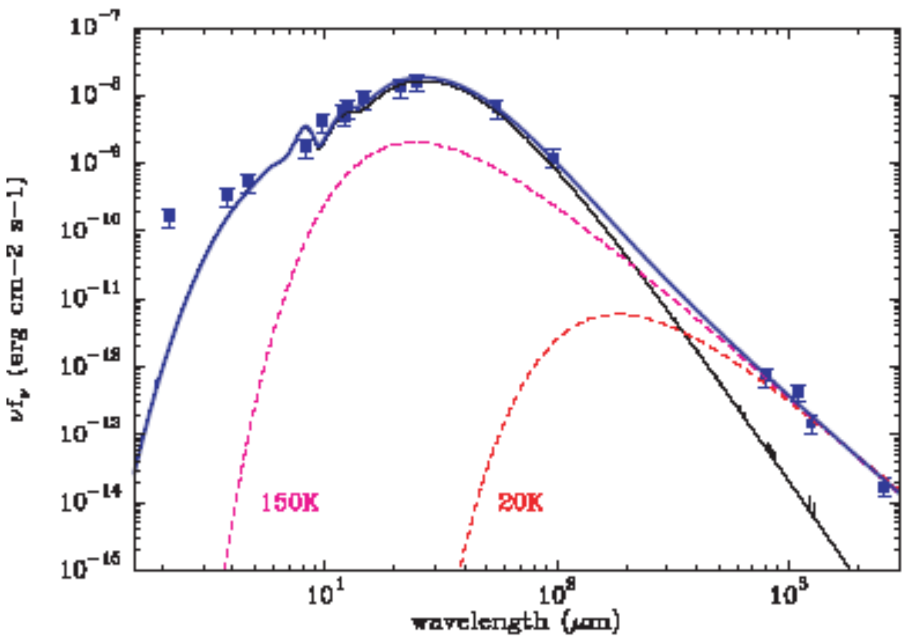
➔ Related (also) to the grains size (Knapp et al., 1993)

$$S_\nu \propto \nu^{(2+\beta)}$$

β is function of both the grains composition and of their size.

Sahai et al., 2006
Sanchez-Contreras et al., 2007
Jura et al., 2000





Recent mm and sub-mm observations of 3 PPNs pointed out The existence of cold, big grains (from SED fitting)

β 0.6-1.2

Morphological and kinematic properties of molecular CSE (as traced by CO) point to the interaction of fast post-AGB winds with the ABG remnant as *origin of shaping* .

Only for very few (and peculiar) objects!

In some cases such wind are collimated (outflows).

we see the *imprinting* of such outflows as *cavities* in the molecular CSE

The collimating "agent" is, at the moment, unknown

In other cases (binaries) the presence of a circum-binary, rotating disk appears to indicate that post-AGB winds propagate in a non-uniform AGB remnant

There are different shaping model for single star or binary system?

It is essential to map and get kinematic for all the emitting components of the ejecta

ionized gas Synergy: **EVLA**

continuum (chs 1,2,3,...,6, 7, 8, 9..) morphology and kinematic

RRL

molecular gas

CO (+....) (chs 3,6,7, 8,9...) morphology and kinematic

dust

continuum (chs 3,4,5,6,..) Synergy: **JWST**

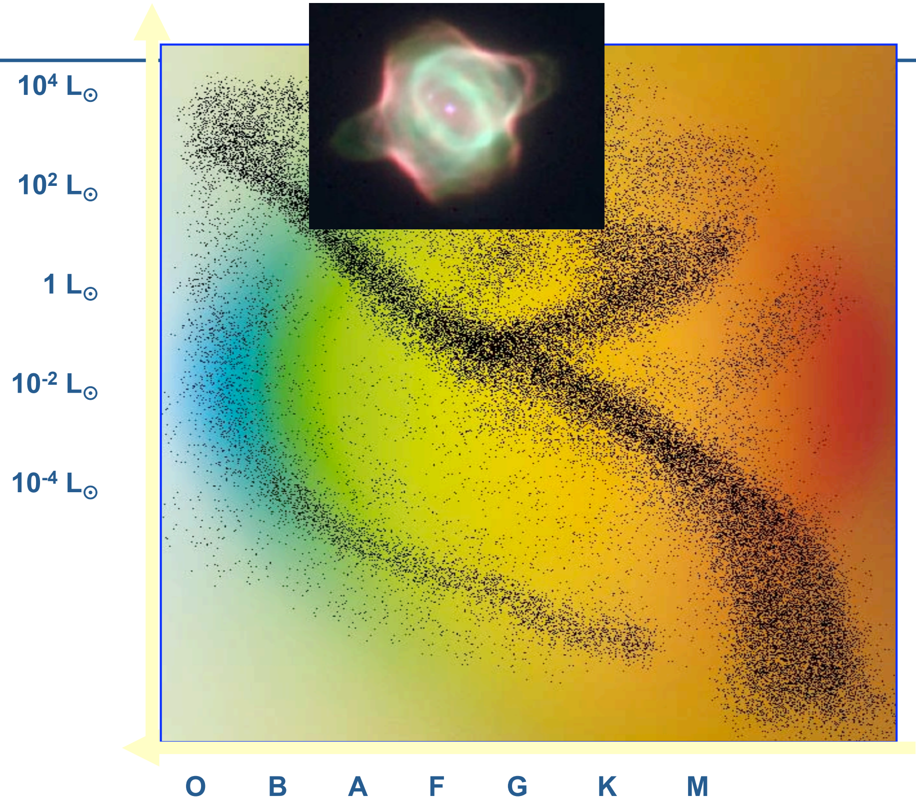
morphology

High sensitivity, high angular and spectral resolution morphological and kinematical studies of different components of CSEs

In large samples of PPN and PNe!!!

Shaping:ALMA

Best "study case" : YPNe



✓ The central object is evolving toward higher temperatures ➔ 10^4 K

onset of ionization in the CSE (…we can use more diagnostics)

mapping/deriving kinematics of fast winds in the radio-mm

✓ In YPNe the mechanism responsible for shaping is still "at work"

(….or its effects are still "fresh"!…)

Start with a suitable sample: *hot post-AGB*

-Observed mid-far IR excess

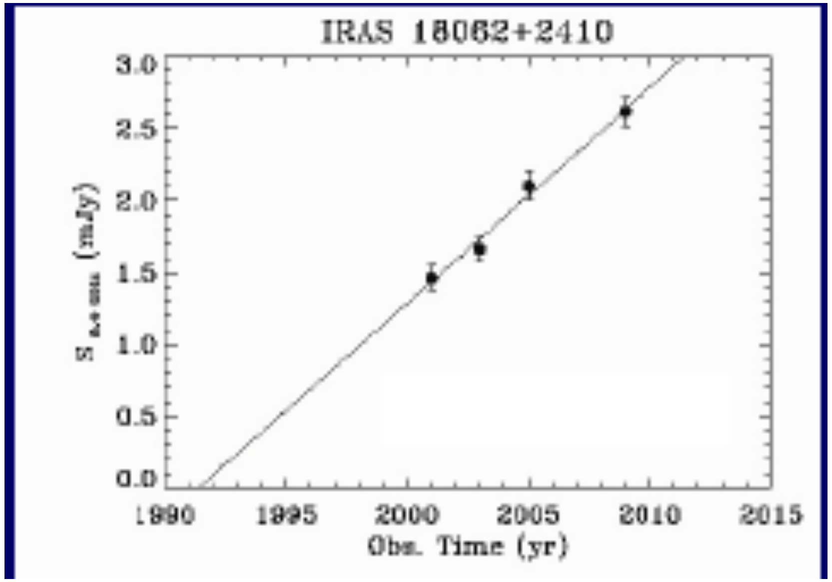
-Spectral Classification: B

- Observed variability: both spectral and photometric

Onset of ionization➔ radio free-free

Original sample of 42 hot-post AGB observed at VLA and ATCA

(Umana et al., 2004; Cerrigone et al., 2007; Umana et al., 2009)



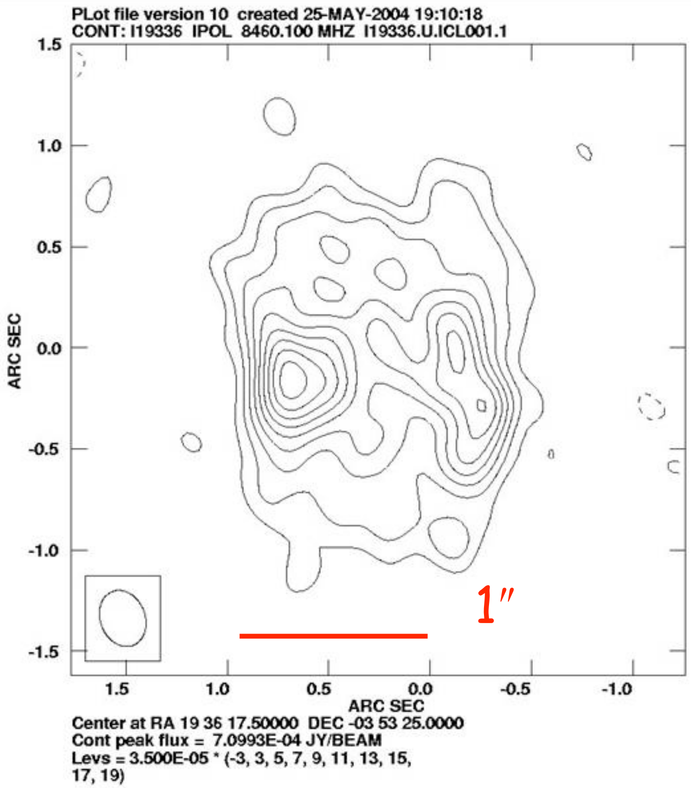
- Detected 17 sources; established their evolutionary status (YPNe). Other 25 objects are genuine hot post-AGB stars.

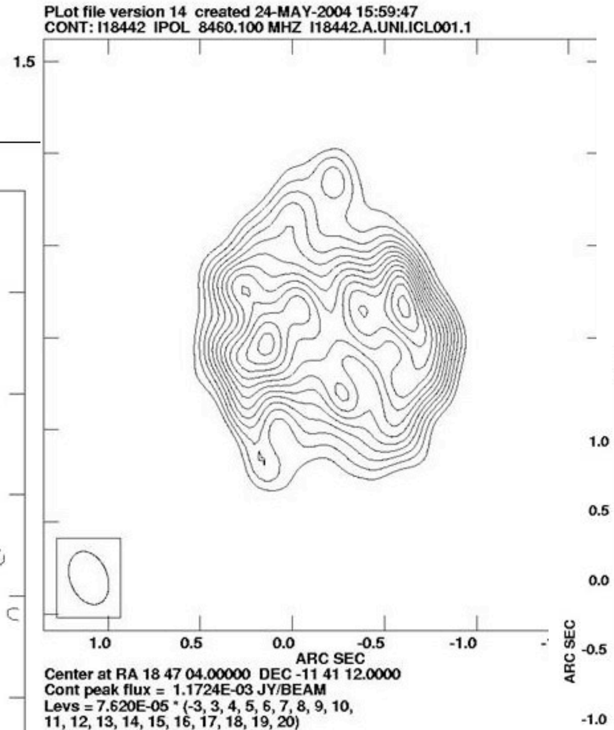
- Radio spectra consistent with a PN in the early stage of its evolution -

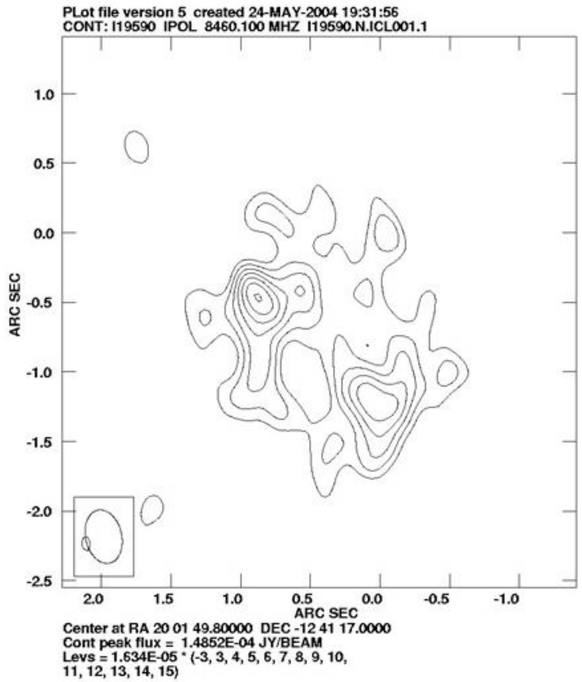
Observed some degree of variability!!

VLA-A, 3.6cm

Radio morphology: bi-polar shaping is already active!

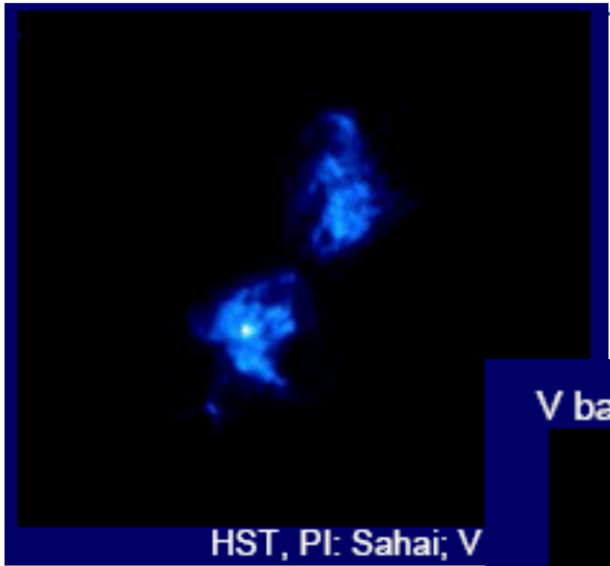


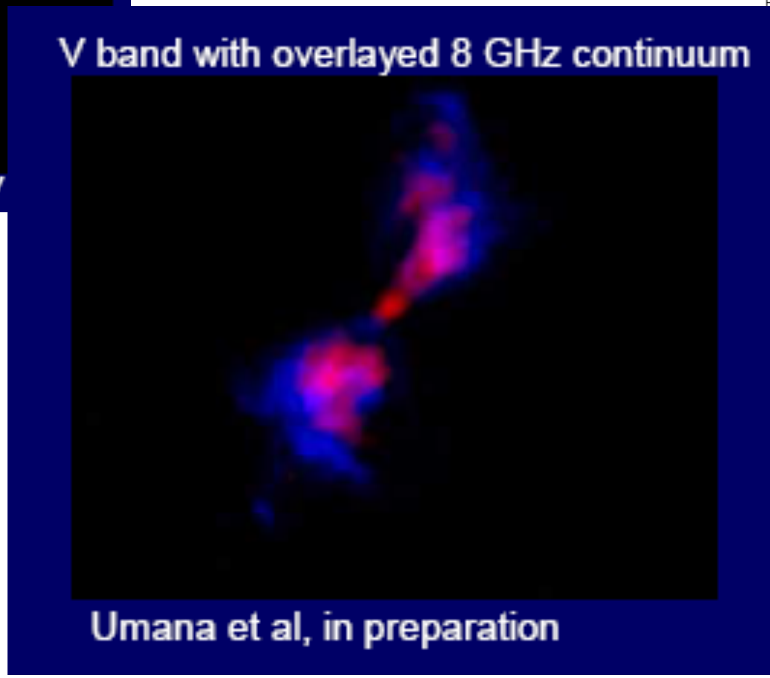


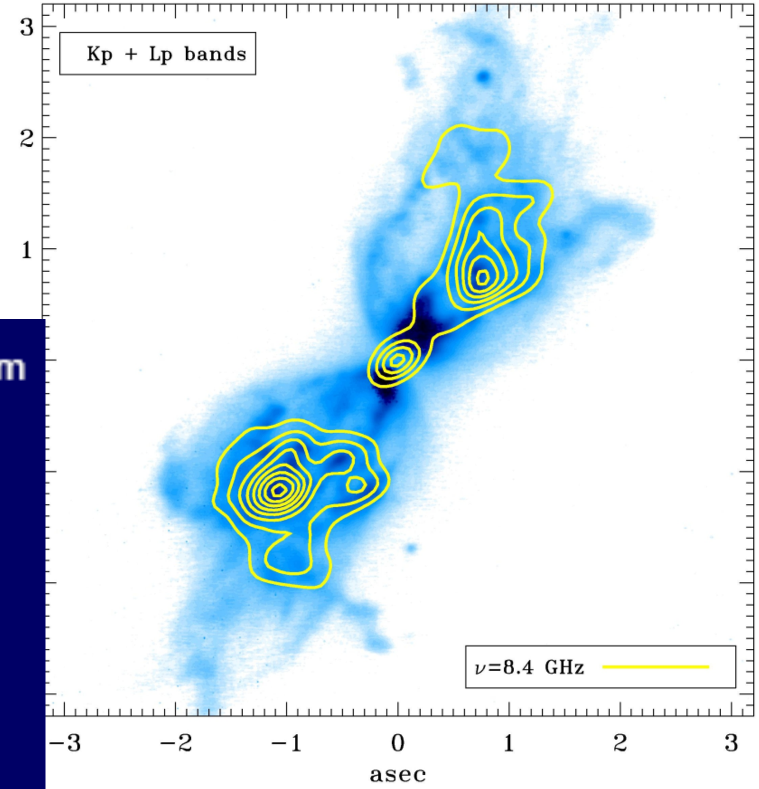


Cerrigone,L., Umana, G., trigilio, C., Buemi, C., Leto, P. ., 2008

IRAS 22568+6141: when we put together the CSE components...







KeckII N-ir, Kp + Lp

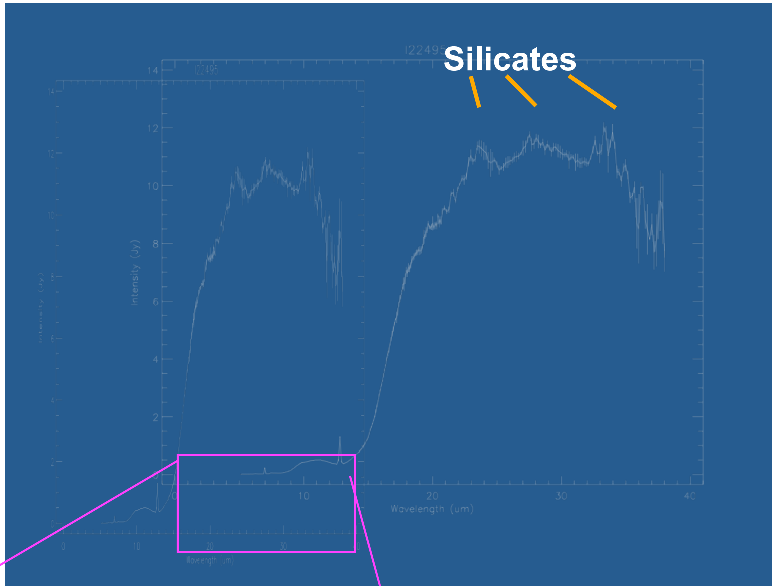
Preliminary results:

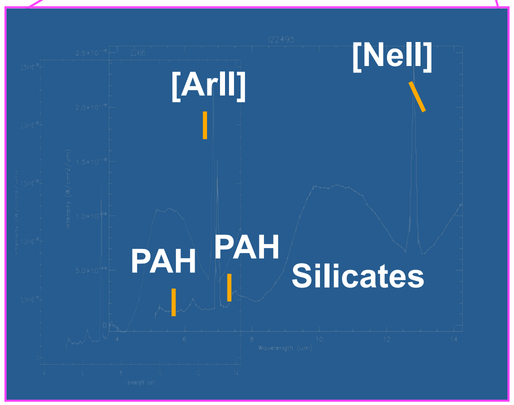
The central radio component is not observable up to n-IR

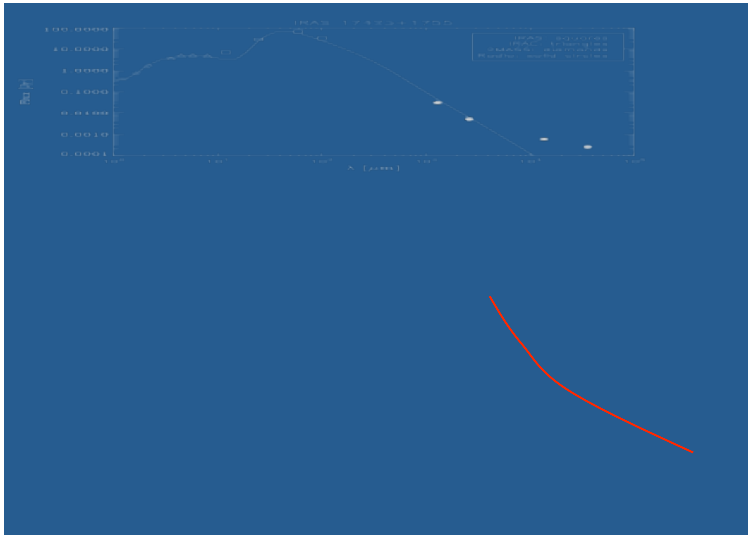
Strong intrinsic absorption => equatorial structure (disk?) with cold (T~ 50 K) big (a~0.02 cm) grains?????

CSE around YPN generally very compact (not resolvd by IRAC)

Cerrigone et al., 2009







When SED (up to mm) are modeled:
- necessity to consider multi-component CSE
- big grains (0.05-100 μm)

- IRS spectra dominated by thermal dust emission plus spectral structures due to crystalline silicates
- part of the sample shows mixed chemistry

- Consistent with a reservoir of O-rich material, probably an equatorial disk (PPNe Red Rectangle)
  ➔ strong clue for stellar ejecta being collimated by such structures!

A typical YPN : IRAS 17423-1755

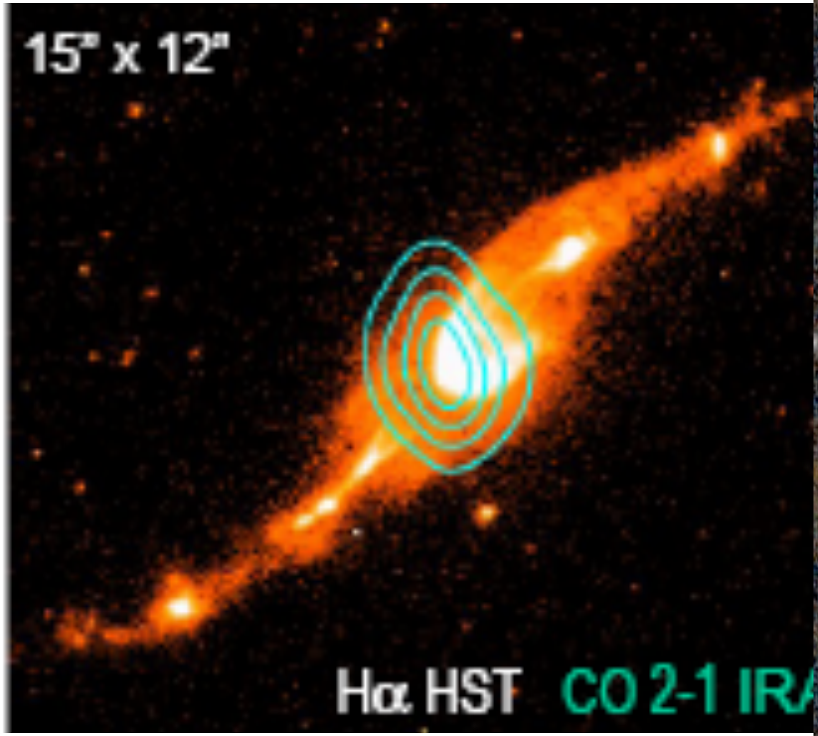
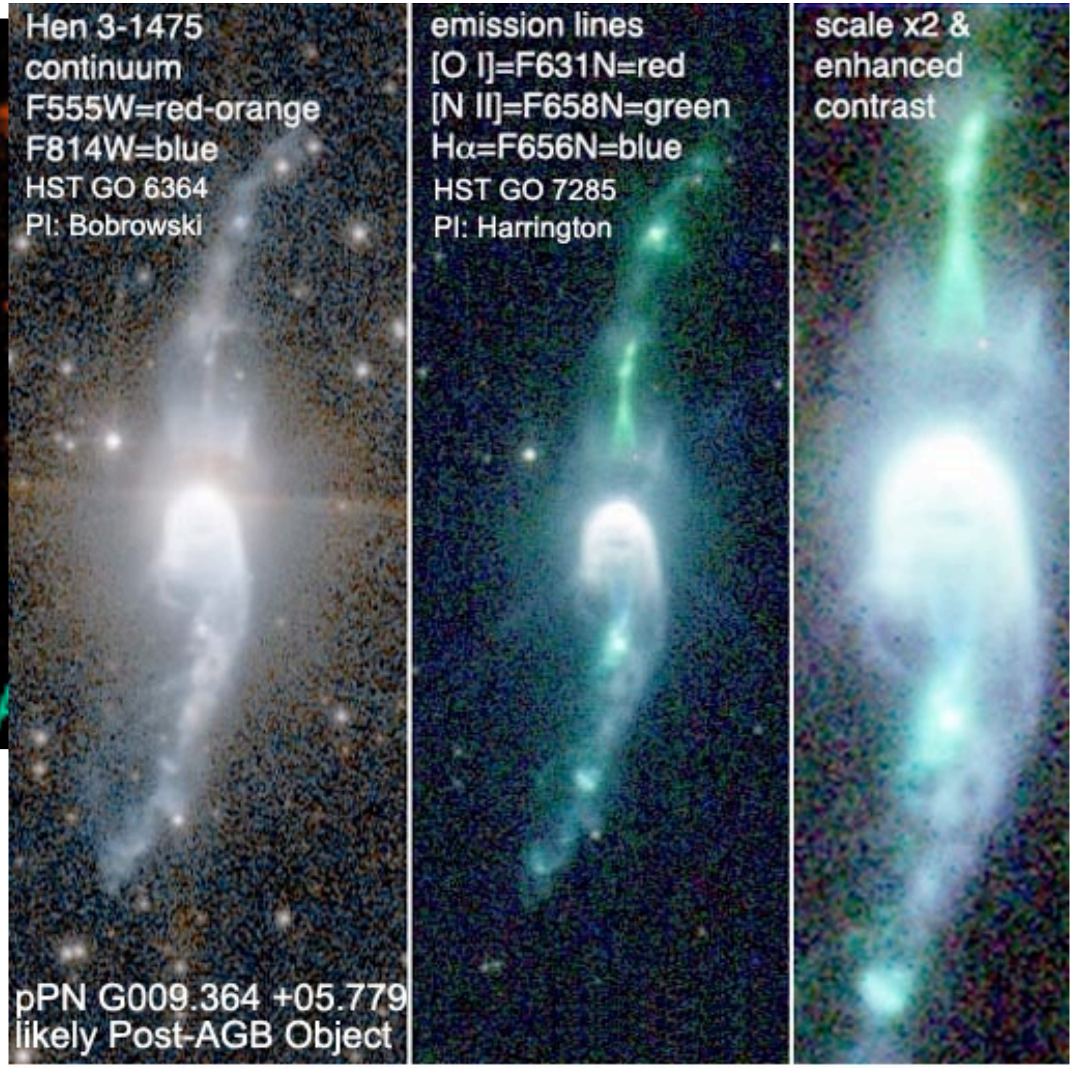


Immagine HST, Hα
CO 2-1 IRAM PdB
Huggins et al., 2004



IRAS 17423-1755 [GLMP632, Hen 3-1475, 2MASS J17451419-1756469]
266.309139 -17.94636 (2000), FOV=23.3", R:G:B = (as indicated)
WFPC2/PC, credit PI: GO6364 & GO7285, NASA/ESA/STScI, Hubble Archives

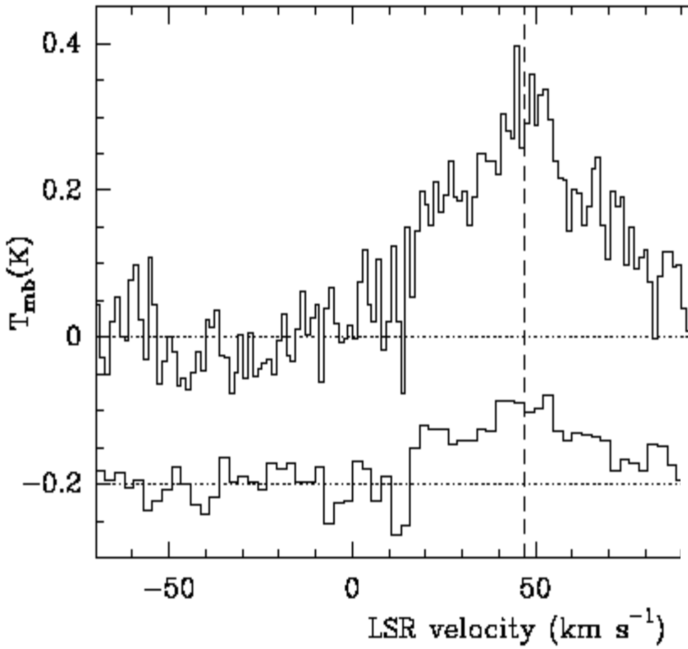
Radio (VLA), very weak, very compact
Umana et al., 2004

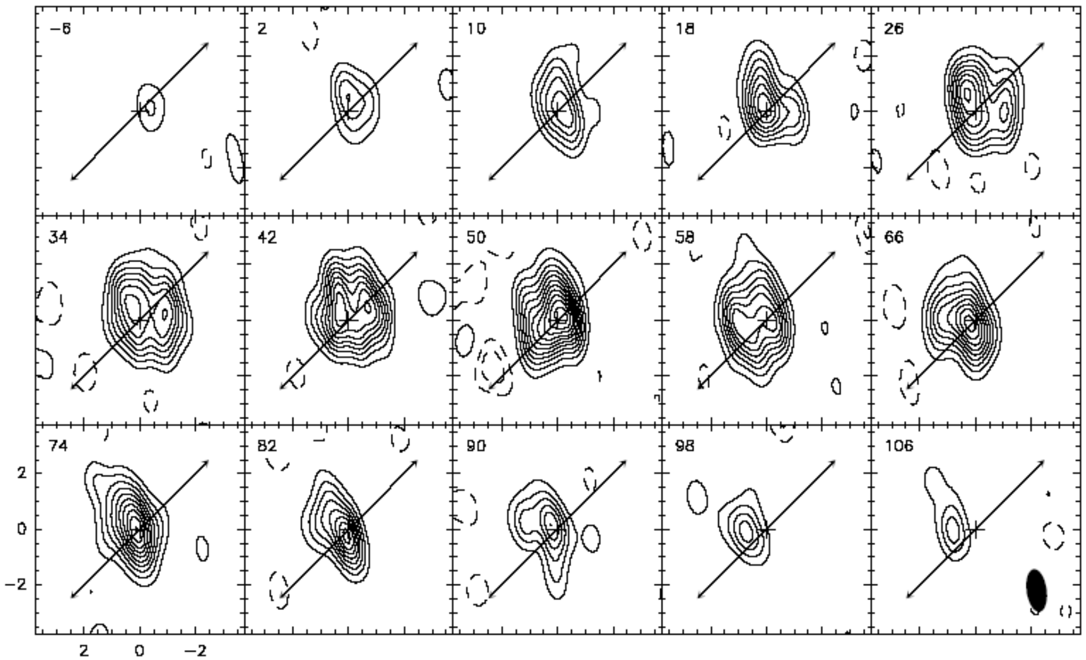
Huggins et al., 2004

A typical YPN

PdB, res_spa =1.6″,
res_spe=8 km/sec
1σ=50 mJy 7 hrs

Actual resolution do not allow to determine the details of CSE morphology





ALMA (full array, B=1 km),
res_spa =0.25″, res_spe=1 km/sec
1σ=10 mJy in 1min!

or σ~30 mJy in 1min
(early ALMA 16 antennas)

Angular resolution do not allow to localize the mm component

A typical YPN

Cerrigone et al., 2009

Huggins et al., 2004

5.3 mJy Point

PdB
115.3 GHz
Res_spa =3.4″,
1σ=1.2 mJy, 7 hrs

31 mJy Point

231.5 GHz
Res_spa=1.6″
1σ=4 mJy, 7 hrs

ALMA (full array, 1km baseline)
chan 3 (110 GHz) res_spa =0.5″, 1σ=0.05 mJy in 1 min
chan 6 (230 GHz) res_spa =0.25″, 1σ=0.1 mJy in 1 min

High resolution and sensitivity maps
➔ *DUST component distribution*

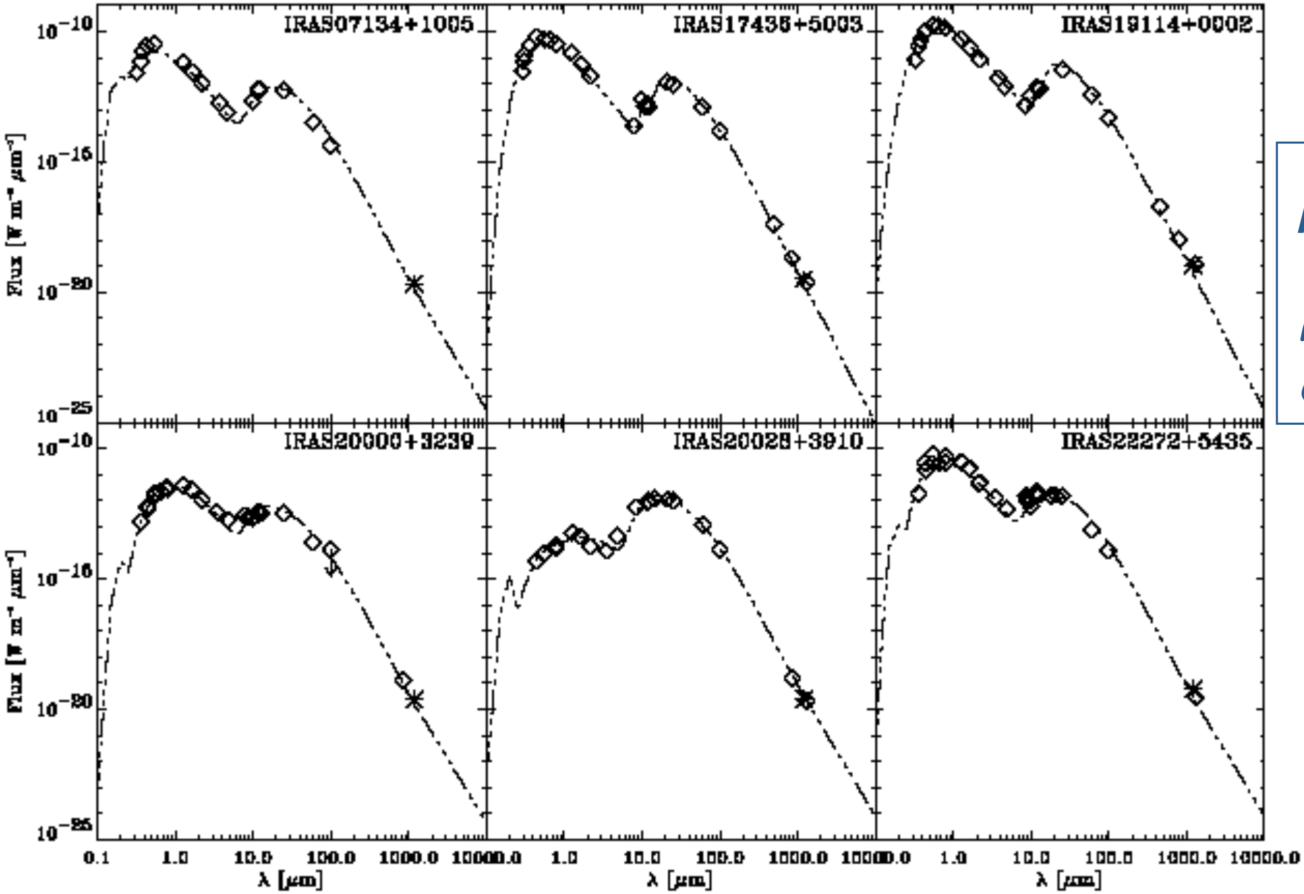
Early **ALMA**

1σ=0.16 (0.4) mJy in 1 min
at 110 (230) GHz 16 antennas

Buemi et al., 2007

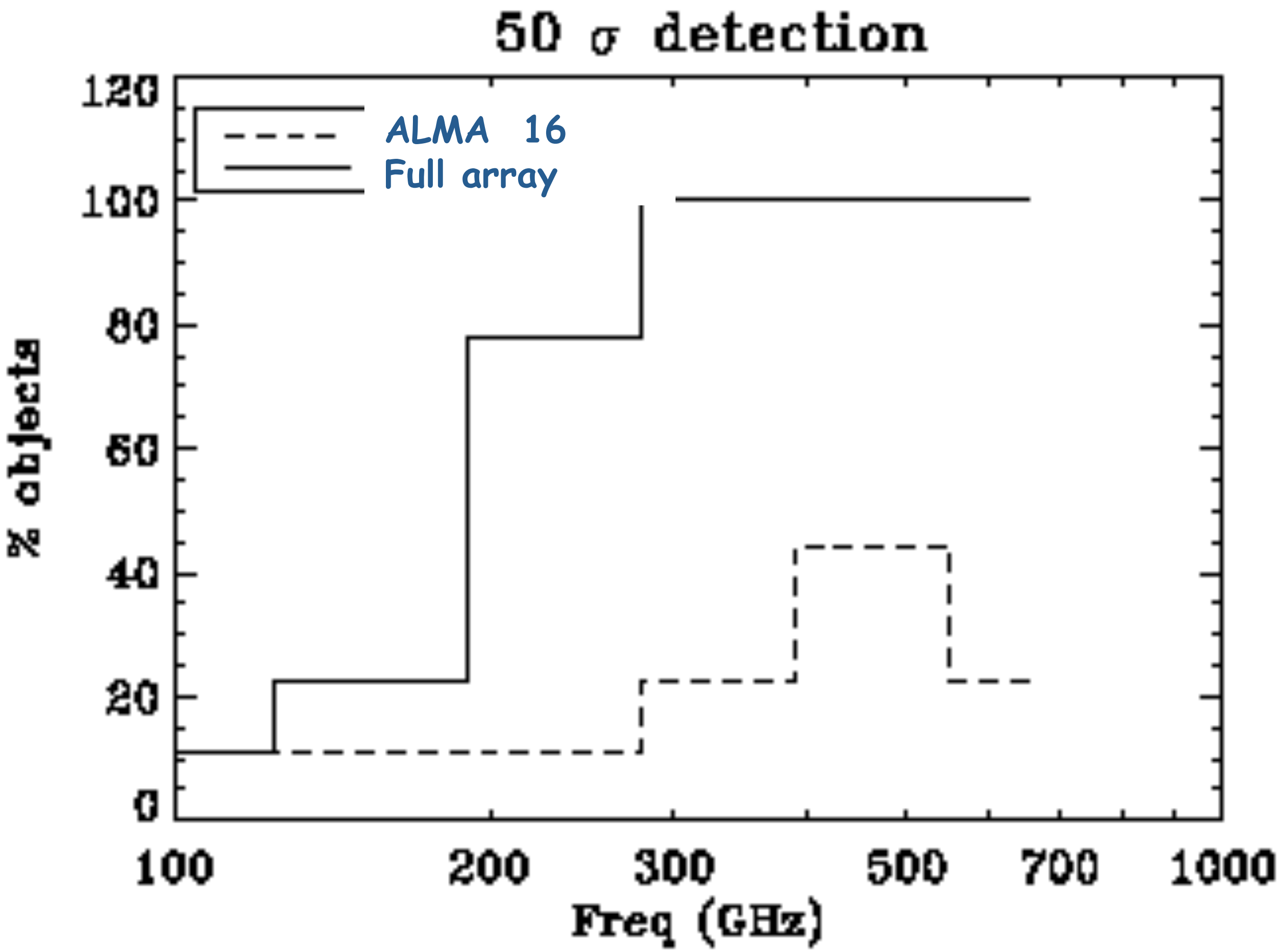
Mm observations pose strong constraint on SEDs

MAMBO@Iram 30m   survey of PPNe



β 0.9-1.6

R_{dust} 10^{16} 10^{17} cm
$dM/dt\sim 10^{-6}$-10^{-5} Ms_{ol}/yr

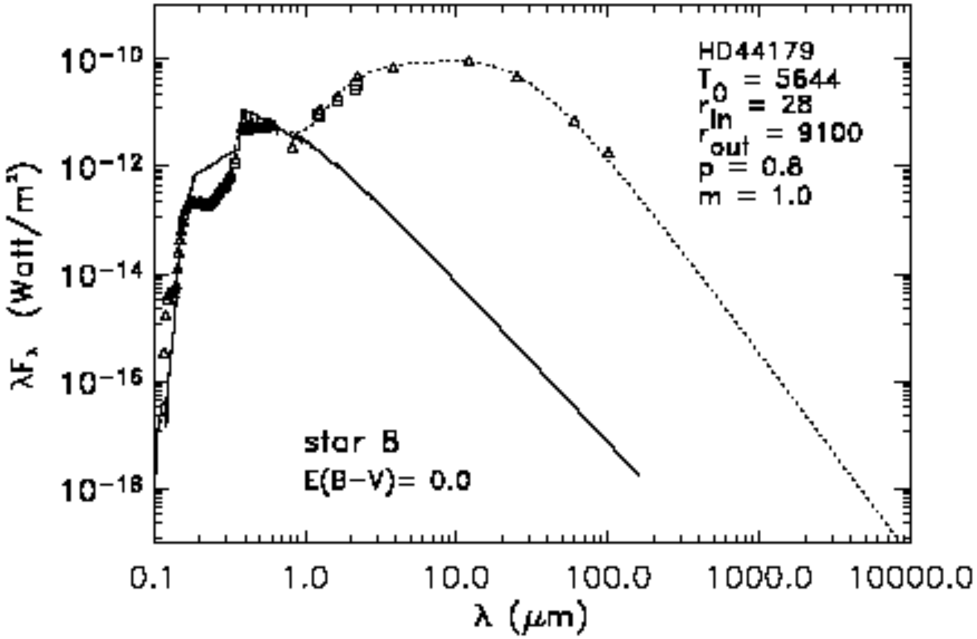


ALMA: High resolution and sensitivity mapping
➔ dimensions, dust distributions….

How common are Red Rectangle-type disk?

De Ruyter et al., 2006

No	Name	F_{850} (mJy)
1	TW Cam	11.0 ± 2.3
2	RV Tau	50.3 ± 3.6
6	SU Gem	7.5 ± 2.5
7	UY CMa	2.4 ± 2.1
11	HD 52961	2.8 ± 1.9
13	U Mon	181.6 ± 2.6
21	HR 4049	8.7 ± 2.8
		10.4 ± 2.2
38	89 Her	40.9 ± 2.4
42	AC Her	99.4 ± 3.8
47	IRAS 20056	21.8 ± 1.8



ALMA (Full array, 1 km Baseline)
chan 7
1σ=0.15 mJy in 1 min !!

High resolution, high sensitivity mapping
➔ DUST DISTRIBUTION

High resolution and sensitive mapping of Molecular (CO but not only) CSE in large sample of AGB, post-AGB stars and PN
(very easily within 2-4 Kpc, up to LMC with some integration time)

-asymmetries in AGB?
-mass-loss variation
- Interaction central star UV with molecular CSE→clues on shaping.

High resolution and sensitive mapping of dust component in CSE in large sample of AGB, post-AGB stars and PN
(very easily within 2-4 Kpc, up to LMC with some integration time)

-Mineralogy in CSE
-Dust distribution: Disk in PPN?
- Interaction central star UV with dust in CSE→clues on shaping.
- Relation with evolving HII inside YPN with the dust→clues on shaping