AGB mass-loss and recycling

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MCCT-SKA, Paris, 26 Aug. 2009

outline :

- stellar evolution in one slide
- AGB stars and their outflows
- circumstellar HI (21 cm)
- circumstellar shells with the SKA

Hony (2002)

M_{in} ~ 1-6 M_{sol}

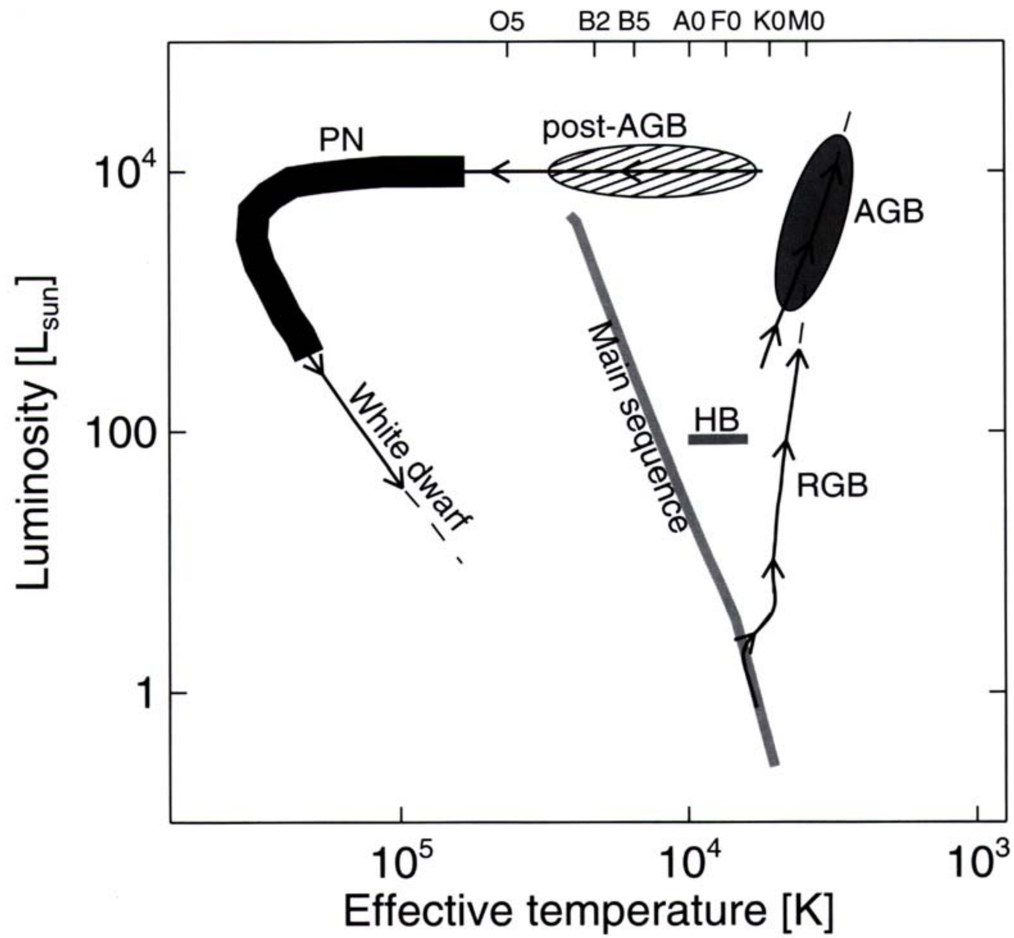
M_{end} ~ 0.6-1 M_{sol}

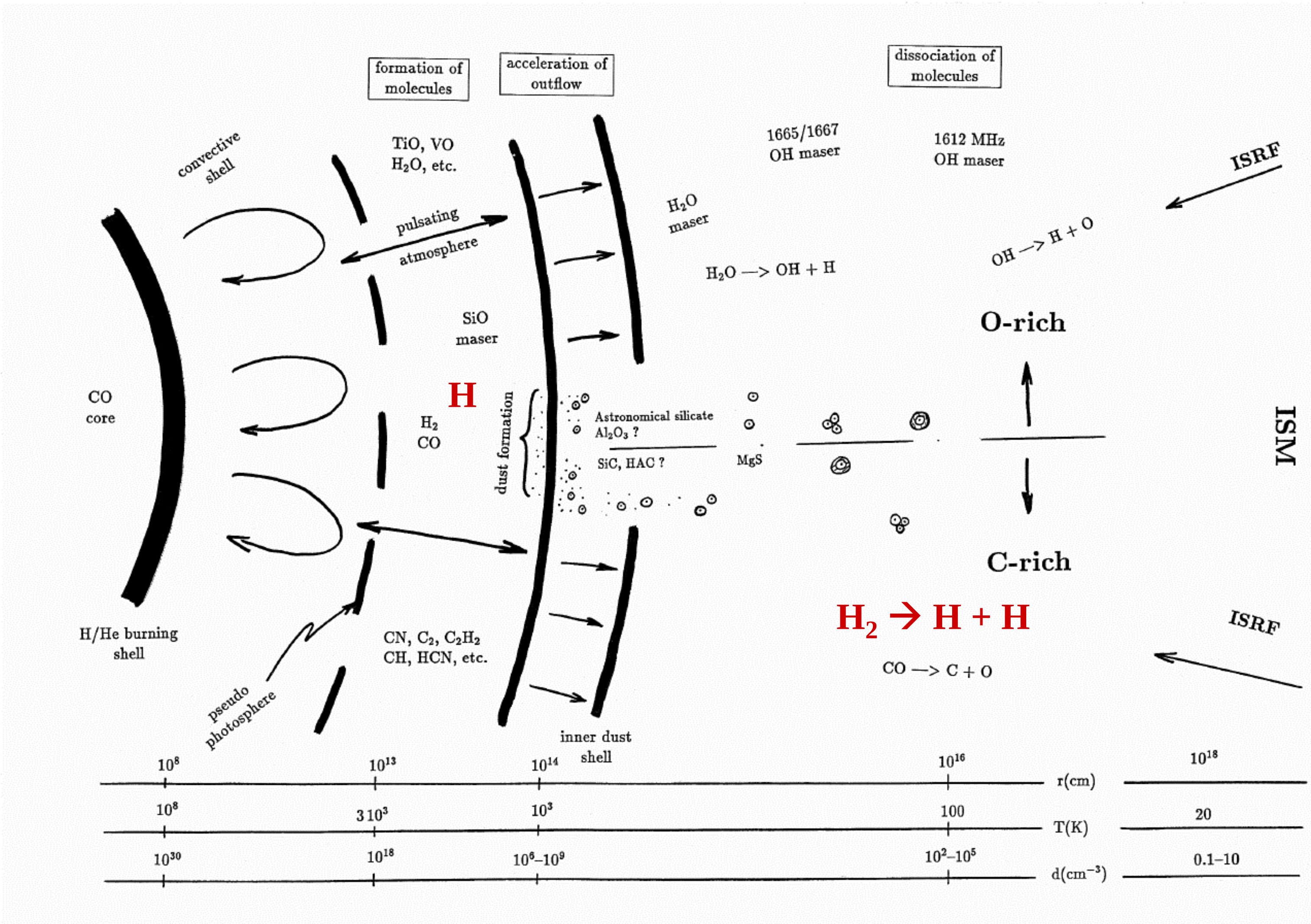
Σ(mass loss) ~ 0.4-5 M_{sol}

mass loss (RGB) ~ 0.1-0.2 M_{sol}

history of mass loss ?

→ integrated mass loss
(at different stages/over the complete life)



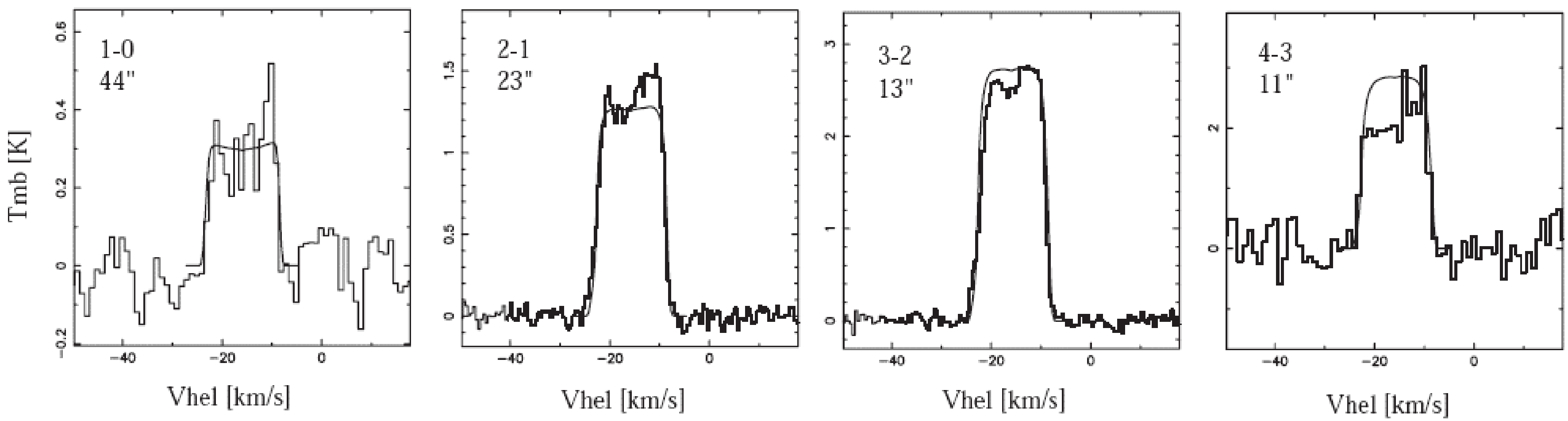


Le Bertre T., 1997, Lecture Notes in Physics 497, 133

SW Vir, 7.5 km/s, 4 10^{-7} Msol/yr at 120 pc

CO: SEST + JCMT

Olofsson et al. 2002, A&A **391**, 1053



115 GHz **2.6 mm** | **230 GHz** **1.3 mm** | **345 GHz** **870 µm** | **460 GHz** **650 µm**

CO → expansion velocity + mass loss rate

AGB outflows

Slow winds :

V_{exp} ~ few to 20 km s^{-1}

Massive winds :

M_{dot} ~ 10^{-8} to a few 10^{-4} M_{sol} yr^{-1}

AGB stars are therefore surrounded by expanding circumstellar shells that can be traced through their emission from dust and gas in the IR and radio domains.

For comparison, the solar wind :

V(Earth) ~ 400 km s^{-1}, M_{dot} ~ 3 10^{-14} M_{sol} yr^{-1}

- **through mass loss they contribute to the replenishment of the ISM**

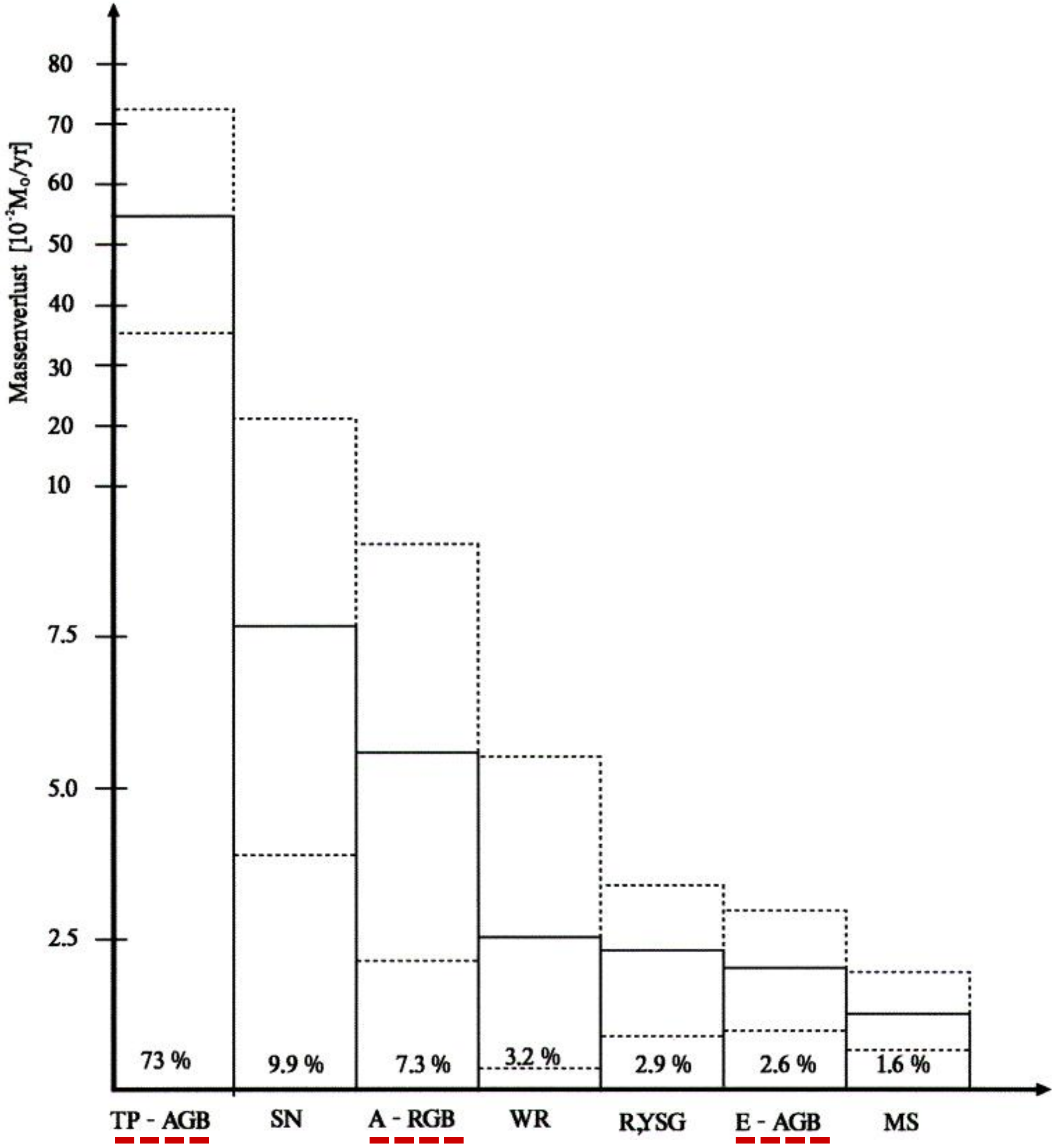
- **they also contribute to the chemical evolution of the ISM, in particular to its enrichment in carbon**

  → role of stellar mass loss in galactic evolution

  (in particular as compared to infall)

+ Mass loss affects the star evolution

(luminosity, nucleosynthesis)



Sedlmayr (1994, IAU coll. 146, 163)

but dependence with galactic location and with time
+ galactic infall

The outflows on the AGB are variable on timescales that may be short compared to stellar evolution.

206 N. Mauron & P.J. Huggins: Multiple shells in the circumstellar envelope of IRC+10216

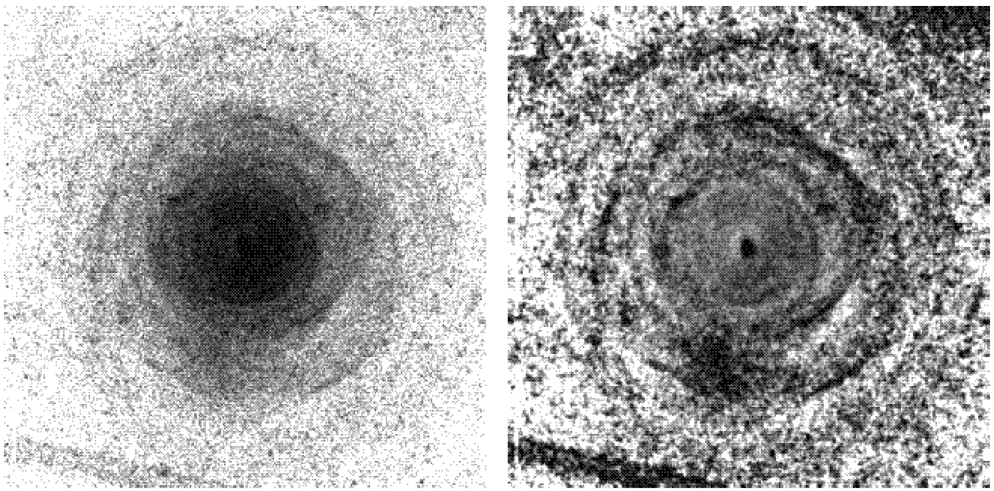
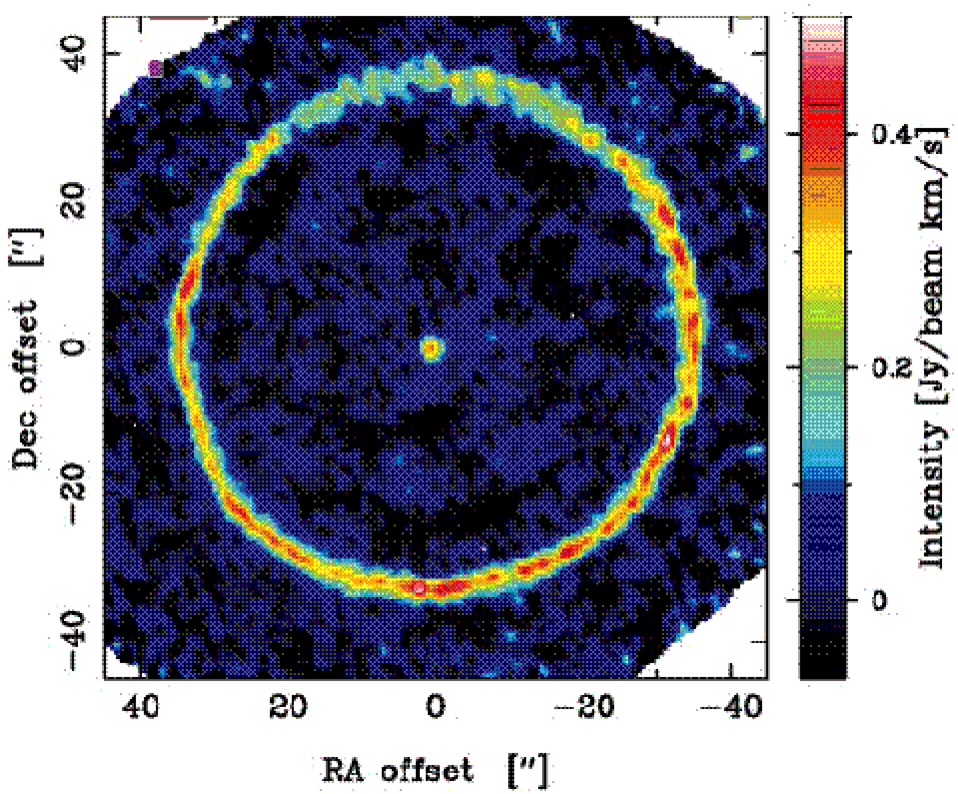


Fig. 3. Composite $B + V$ image of IRC+10216, shown with a regular transfer function (left) and with an average radial profile subtracted (right) to enhance the contrast. The field is $131'' \times 131''$. North is at the top, East to the left.

IRC +10216 (Mauron & Huggins 2000, A&A 359, 707)

- **CO rotational transitions from J=2-1 to J=7-6 indicate mass loss variations on the same timescales (Kemper et al. 2003, A&A 407, 609).**
- **Mass loss variations may be so large that one observes a "detached shell" (e.g. Olofsson et al. 2000, A&A 353, 583).**

TT Cyg
(Olofsson et al. 2000, A&A 353, 583)
CO 1-0
V_{lsr} +/- 2 km/s



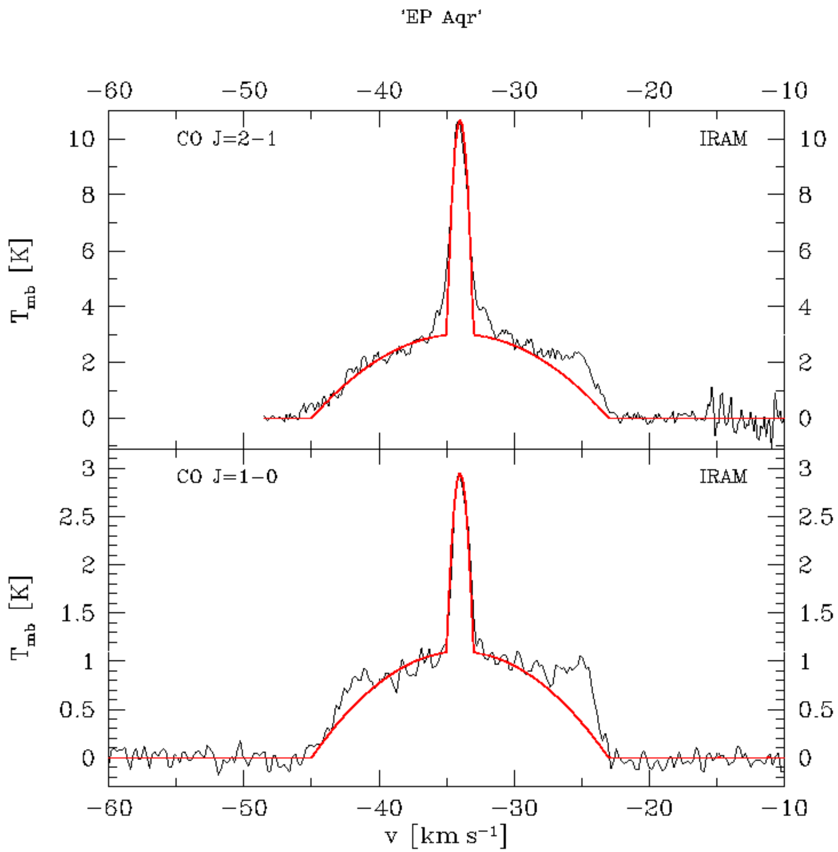
M_{dot} (in.) ~ $3\ 10^{-8}\ M_{sol}\ yr^{-1}$

M_{dot} (out.) ~ a few $10^{-5}\ M_{sol}\ yr^{-1}$

→ meaning of M_{dot} ?

We may have large differences on the estimates of M_{dot} when we use different tracers sensitive to different zones of the circumstellar shells (in addition to the abundance problem).

Winters et al. 2003, A&A 409, 715



EP Aqr

M_{dot} = 5 10^{-8} M_{sol}/yr
V = 1 km/s

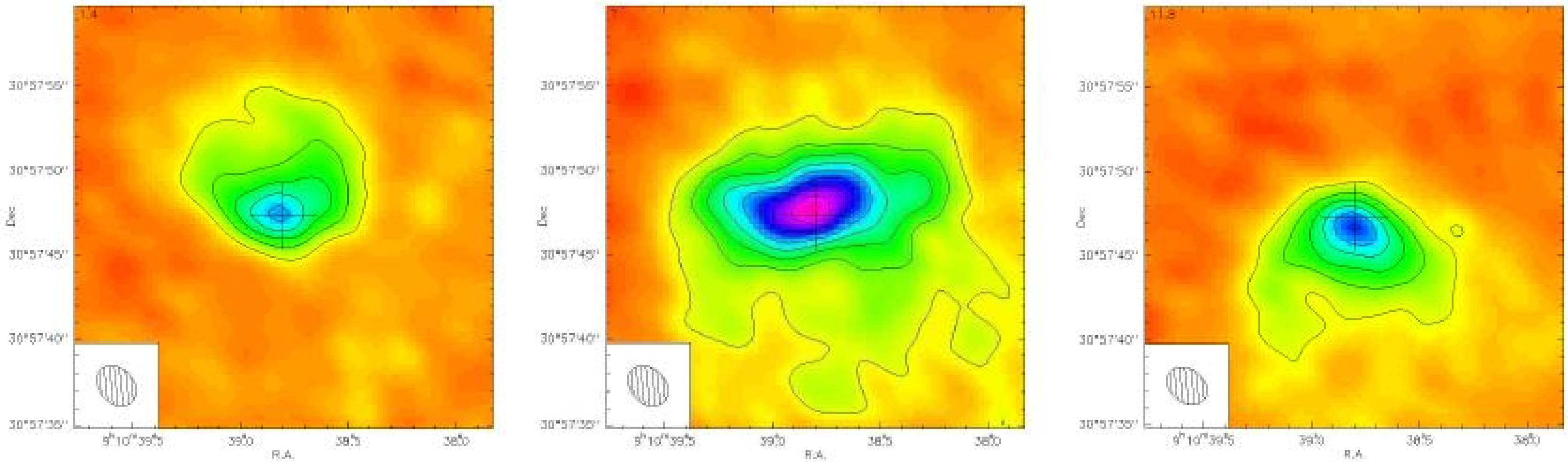
M_{dot} = 10^{-6} M_{sol}/yr
V = 11 km/s

Composite profiles in CO :

→ **evidence for multiple successive winds of different nature ?**

→ **or deviation from sphericity ? (e.g. bipolarity, …)**

CO(1-0), IRAM-PdB

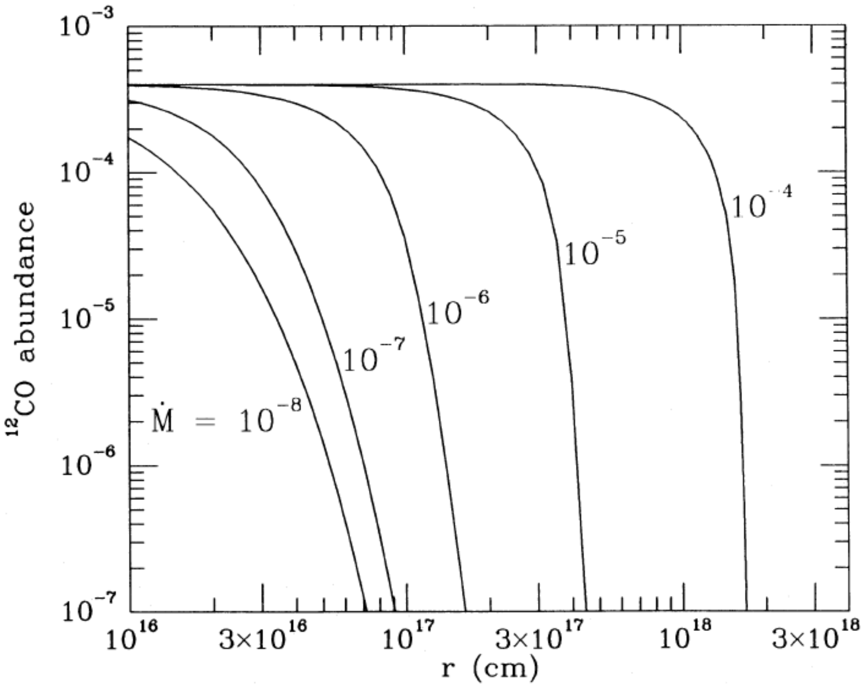


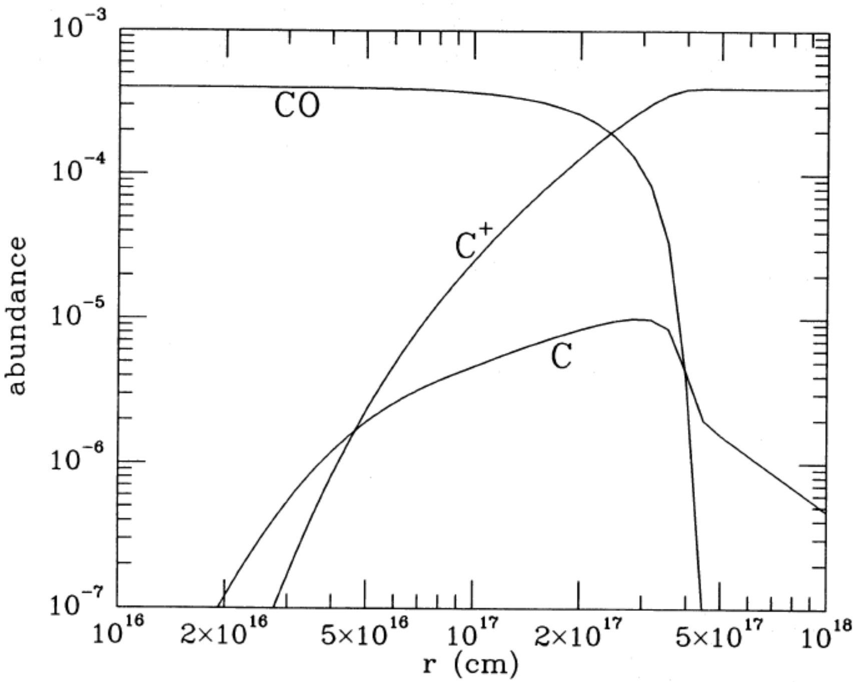
V_r~2 km/s ~7 km/s ~12 km/s

Libert et al. 2009, submitted to A&A

Mamon, Glassgold & Huggins, 1988, ApJ **328**, 797

→ photodissociation of CO by the ISRF





typical size ~ 0.01 – 0.2 pc

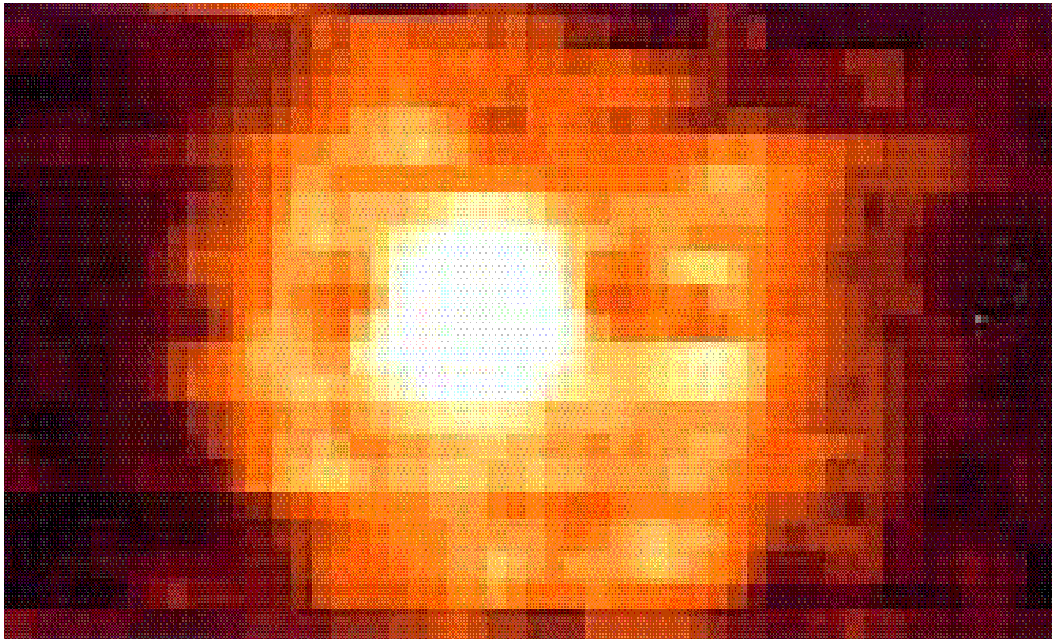
(10 arcsec. to a few arcmin. for a source at 100 pc)

- **Need to understand better the mass loss process and its history**
- **Molecular lines are useful in particular because of the high spectral resolution available with heterodyne techniques, but they probe a limited extent of the circumstellar shells.**
- **The dust emission at long wavelengths may help to trace the circumstellar shells on large distances, but cannot provide velocity information.**

→ mass loss history

Izumiura et al. 1996,
A&A 315, L221
ISOPHOT 90 µm

Ø ~ 8 arcmin. ~ 0.5 pc



→ necessity to combine these different tracers

A special mention may be done to the atomic line of hydrogen at 21 cm that up to now has not been much used.

→ circumstellar HI should be protected by the surrounding ISM

- hyperfine-structure line of hydrogen in the ground state

  $\lambda = 21$ cm, $\nu = 1400$ MHz, $A_{10} \sim 3\ 10^{-15}\ s^{-1}$
- optically thin in most situations
- $\nu = 1.4$ GHz ==> $h\nu/kT << 1$

  ==> 1. $\kappa_\nu\ \alpha\ g_1/g_0\ A_{10}\ N_0(1 - e^{-h\nu/kT})\ \alpha\ N_H/T$

  2. $B_\nu\ \alpha\ T$

  ==> $\kappa_\nu x B_\nu\ \alpha\ N_H$ (i.e.: **measured flux** α N_H)

  (HI is a good tracer of morphology)
- **<u>If the distance is known, we get the mass in atomic hydrogen</u>**
- ~70 % of mass in hydrogen : **HI → mass**

Hydrogen in HI or H_2 ?

Glassgold & Huggins (1983, MNRAS 203, 517):

if $T_{eff} > 2500$ K, all hydrogen should be atomic

if $T_{eff} < 2500$ K, H_2 should be photodissociated at ~ 10^{17} cm

(lines at 28 μm….)

H_2 is expected to be photodissociated by the ISRF at r > 10^{16} -10^{17} cm (depending on mass loss rate, …)
[unless self-shielding preserves it within clumps]

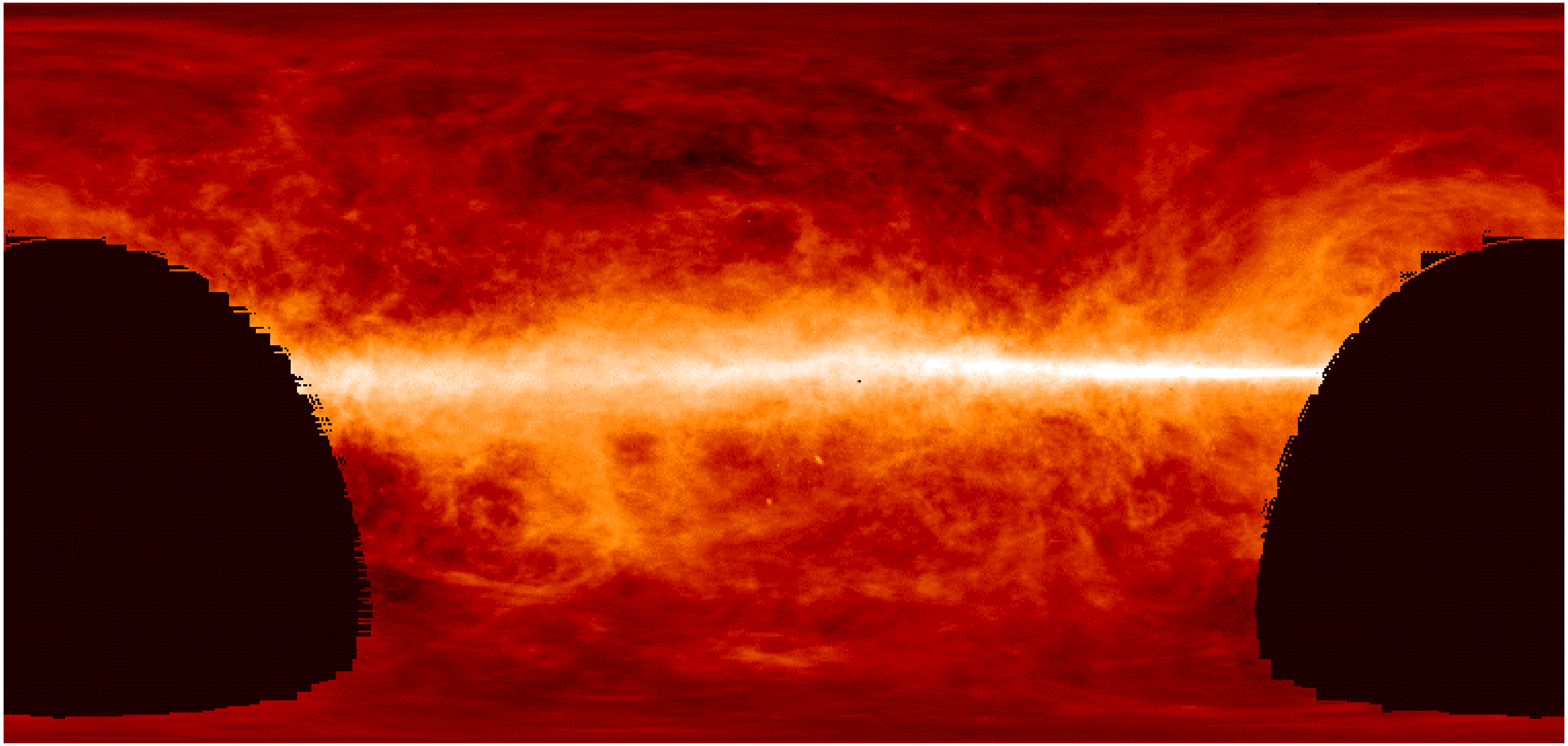
Nançay Radio-Telescope (NRT)

spherical mirror

effective dimensions:
160m x 30 m
→ at 21 cm :
<u>beam of 4'x22'</u>

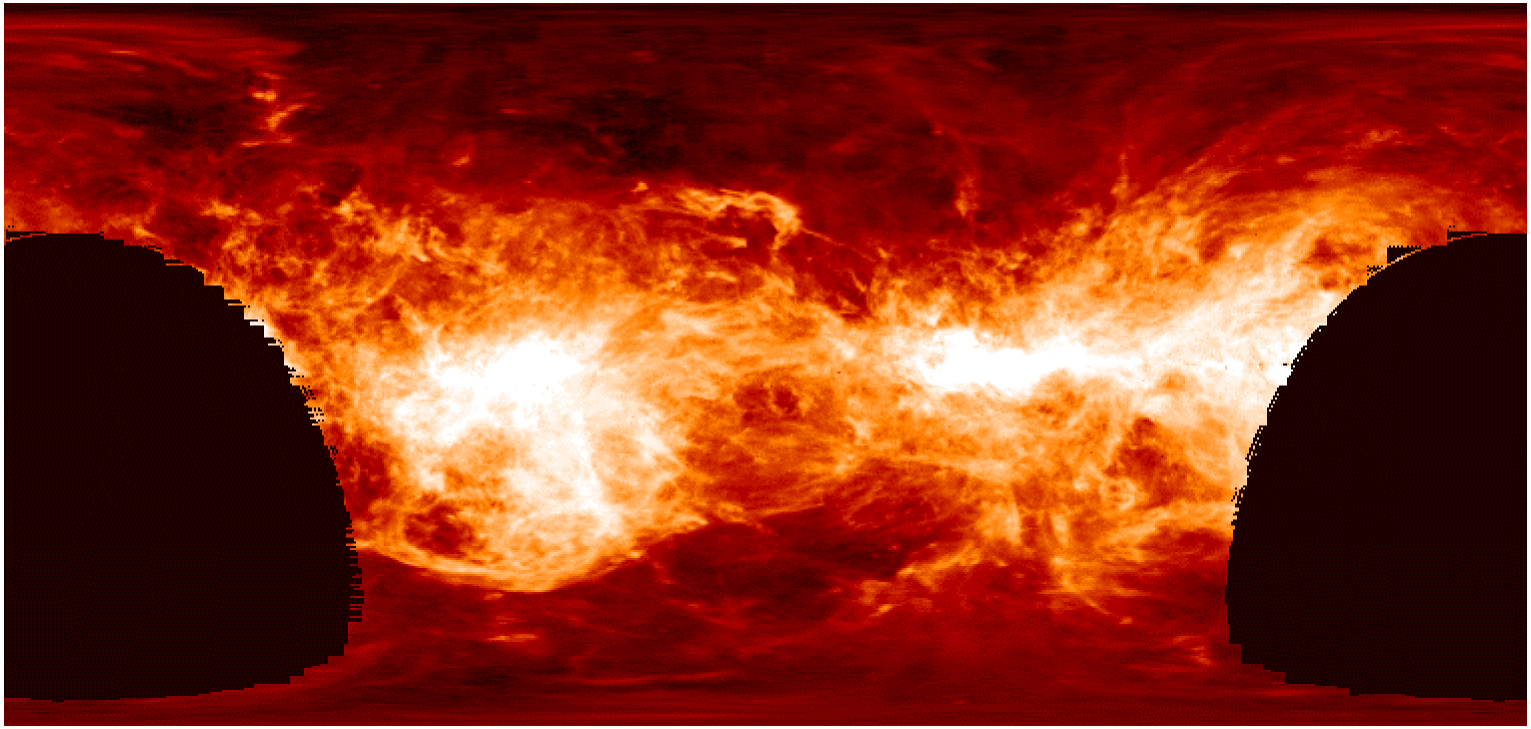
plane
mirror

But HI is ubiquitous !!



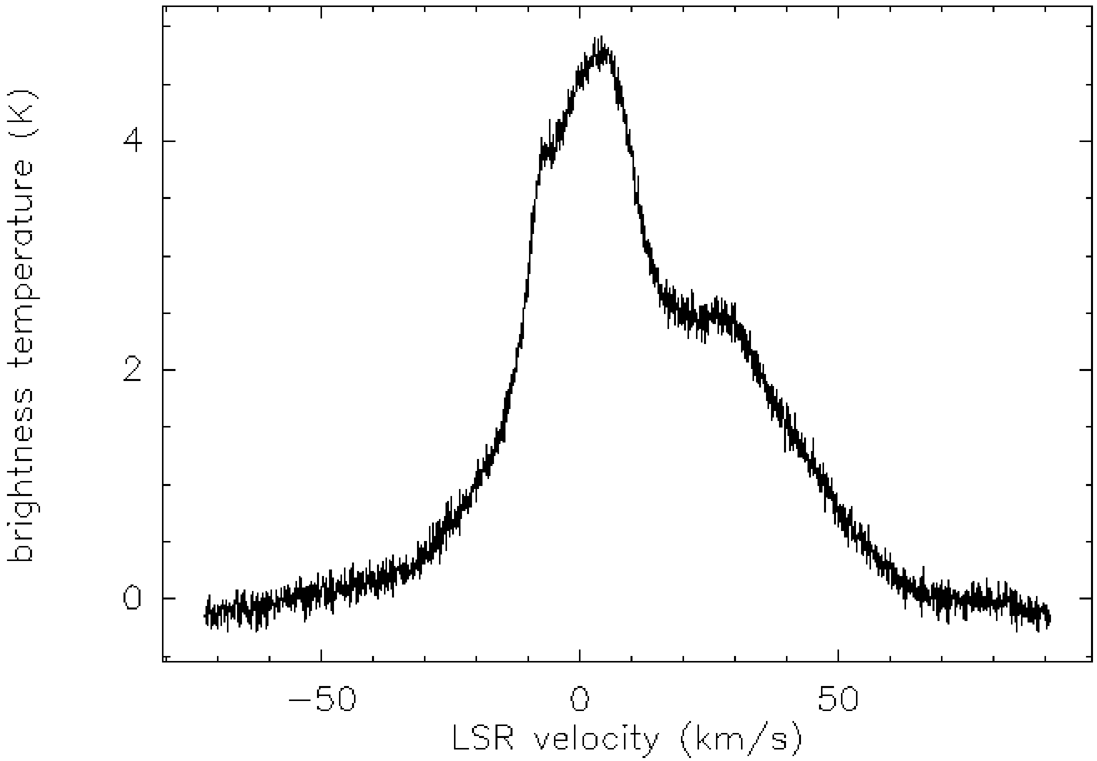
Hartmann & Burton 1997; total galactic HI

Ubiquity of HI emission (2)



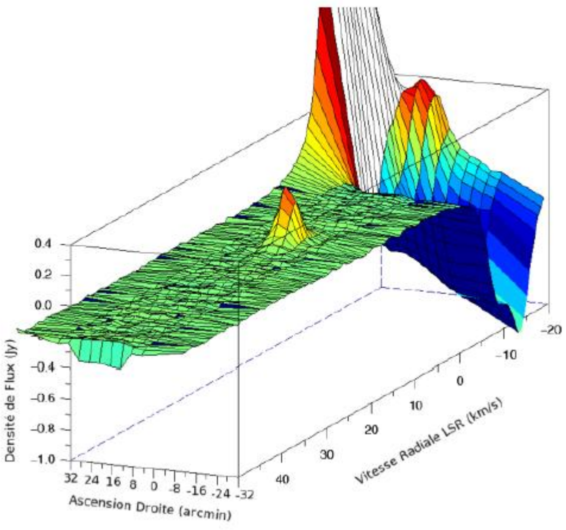
Hartmann & Burton 1997; + 6 < V_{lsr} < +8 km s^{-1}

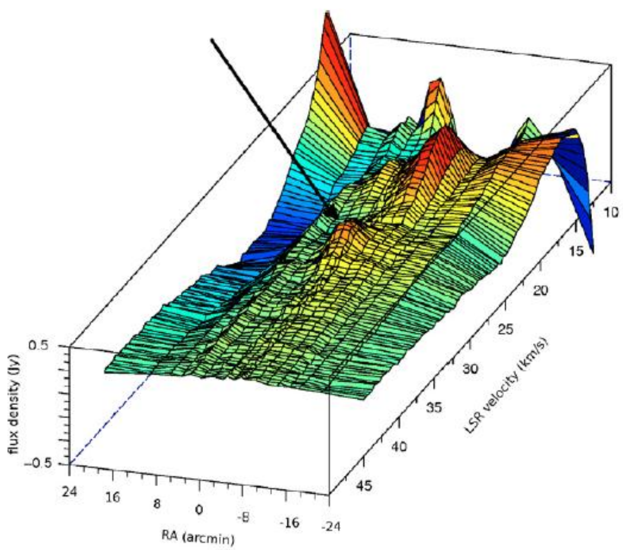
In the direction of RS Cnc ($l^{II} \sim 195^o$, $b \sim +42^o$)

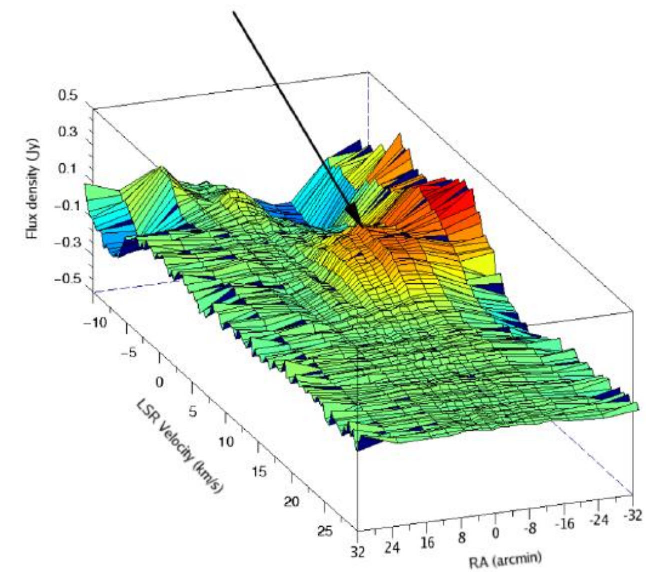


($V_{lsr} = 7.5$ km s^{-1})

Need to understand the competing galactic emission (confusion)





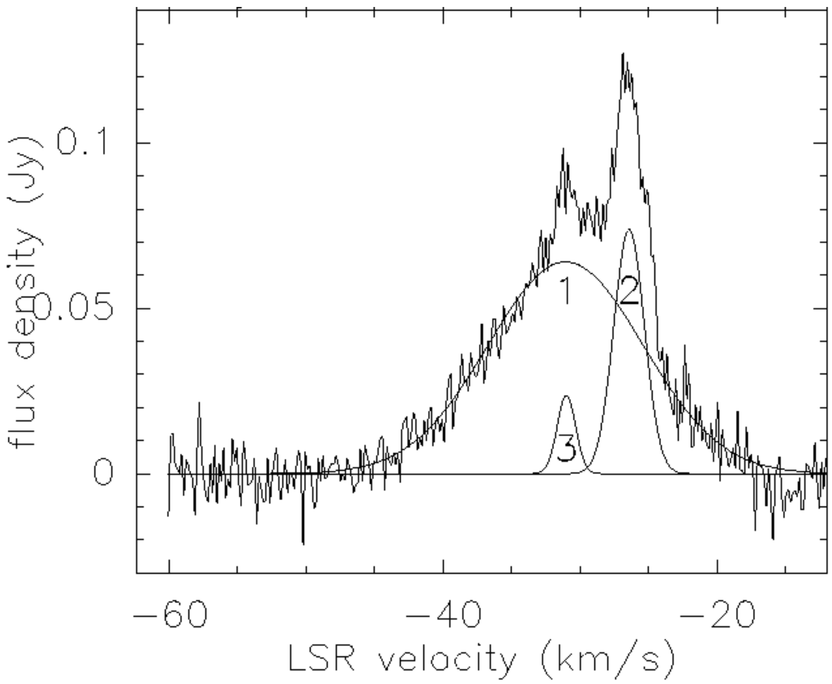


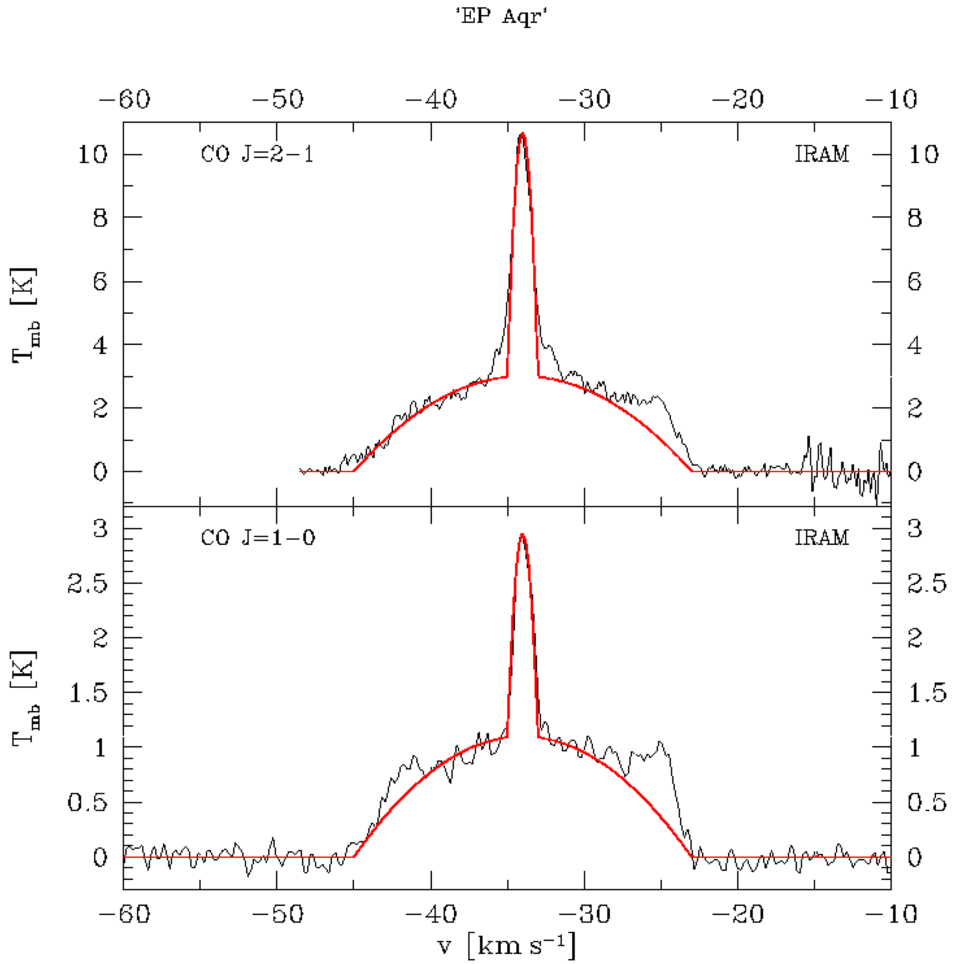
(b ~ +72º) **(b ~ -28º)** **(b ~ +42º)**

Libert, 2009, PhD, University of Paris 6

EP Aqr

(Winters et al. 2003, A&A 409, 715)





Le Bertre & Gérard 2004, A&A 419, 549

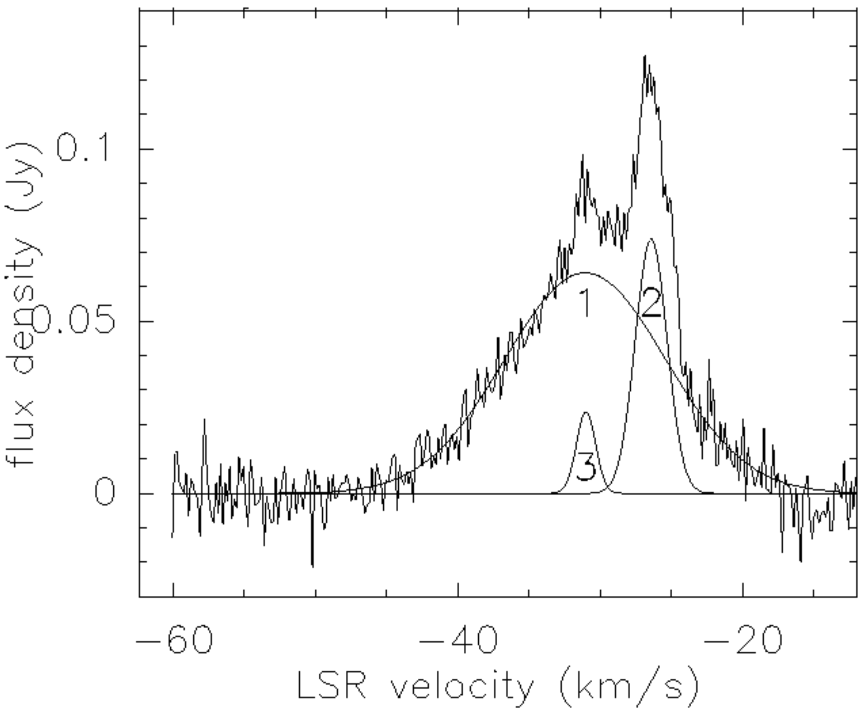
Complementarity between HI and CO :

(the zones which are probed are distinct)

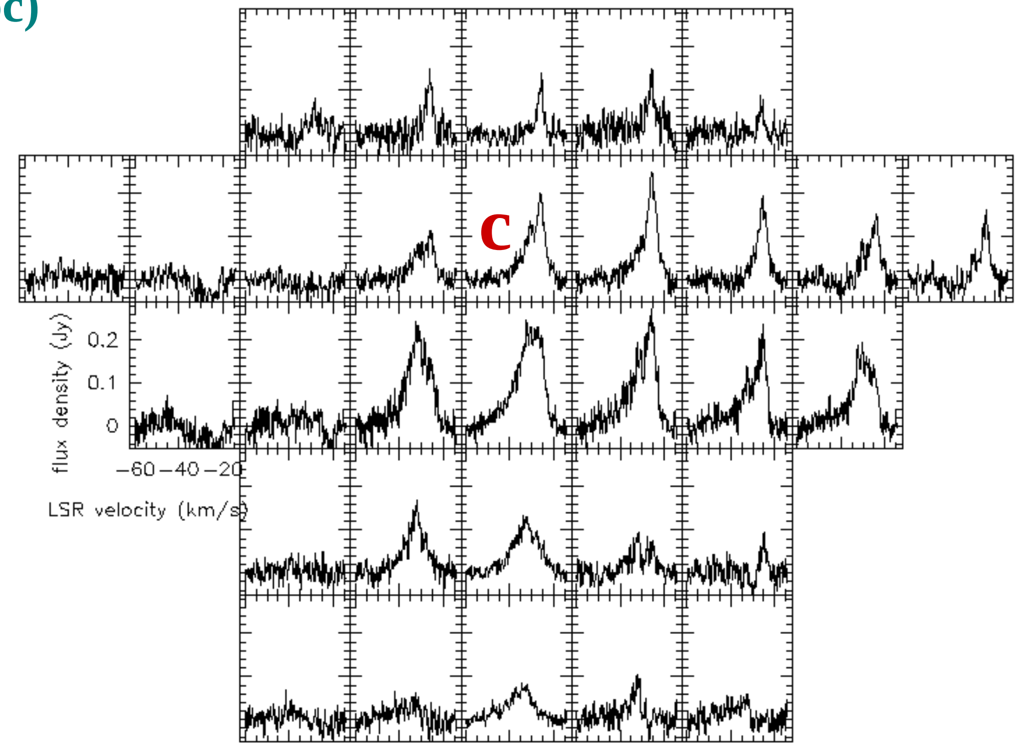
EP Aqr

(Le Bertre & Gérard 2004, A&A 419, 549)

4’ x 22’ or 0.16pc x 0.86pc (at 135 pc)



steps 4’ in RA and Dec 11’ in Dec



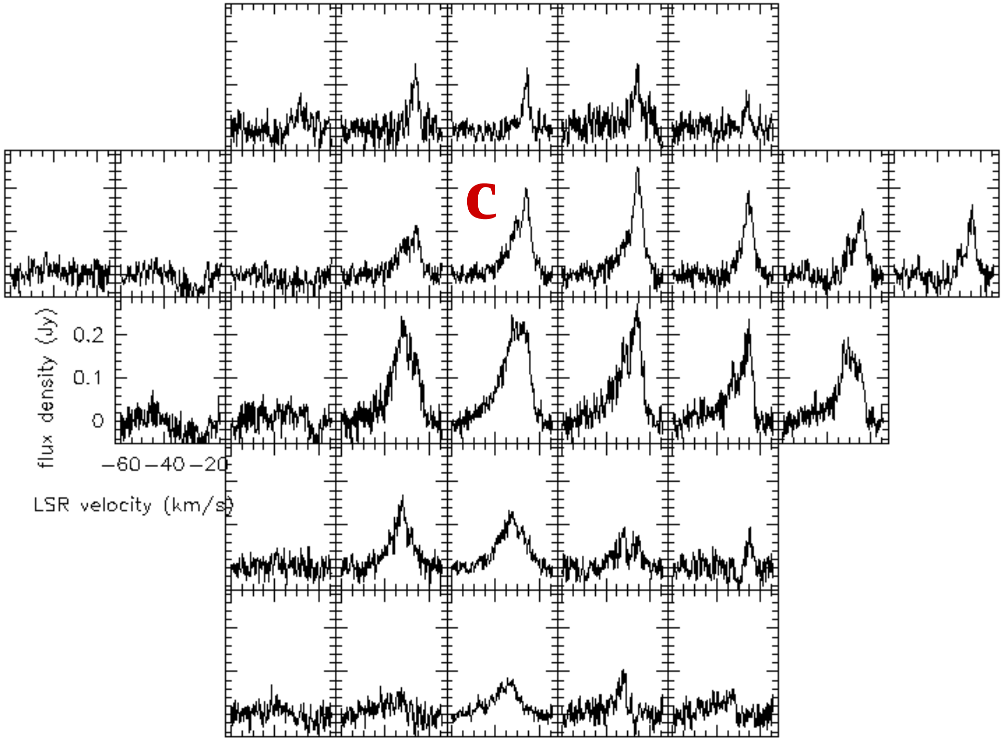
proper motion: -1 mas in RA and 26 mas in Dec.

Complex spatial and dynamic structures

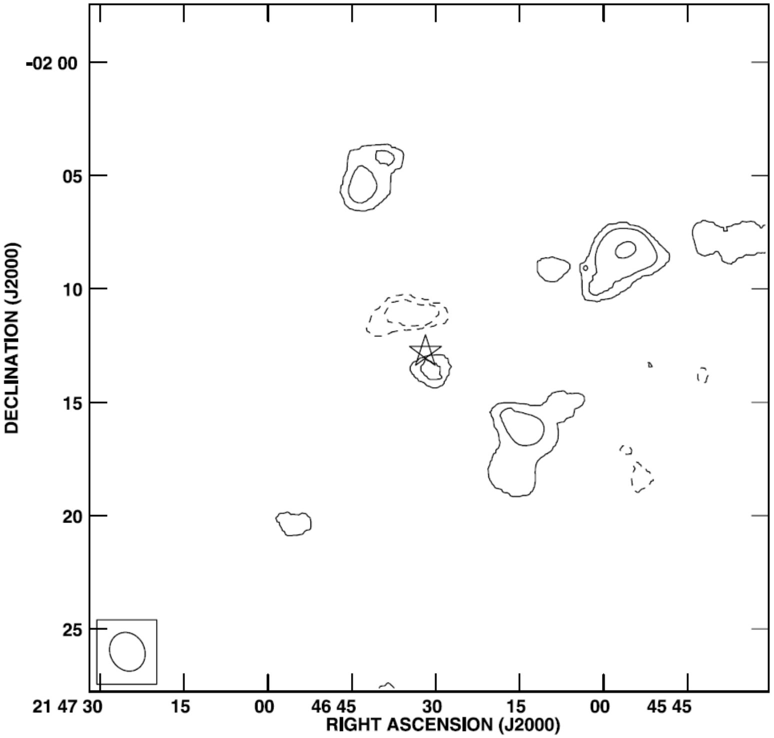
The HI emission is very extended (~ 1 pc)

M_{tot} ~ 0.07 M_{sol}

EP Aqr at the **NRT** and at the **VLA**



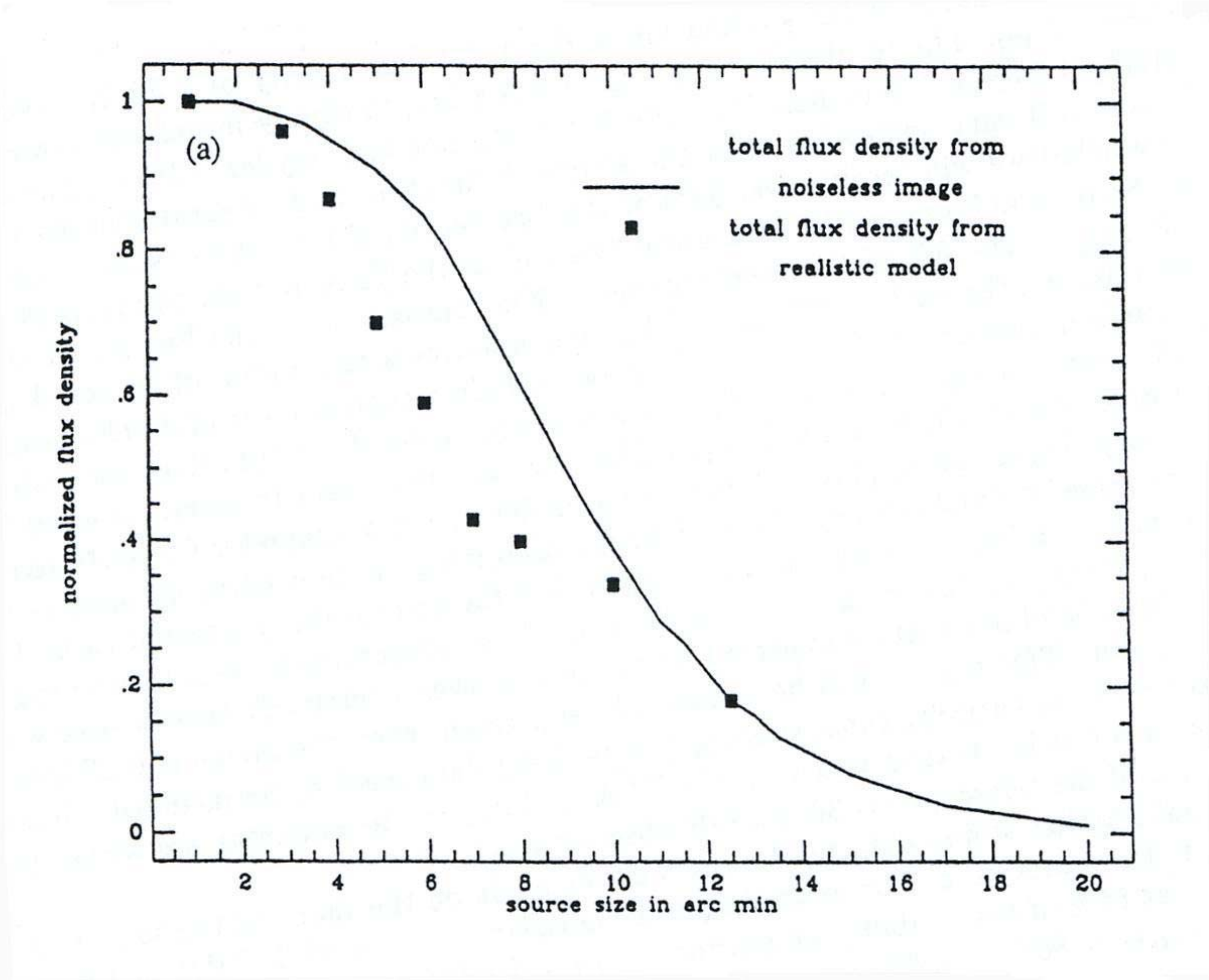
Le Bertre & Gérard, 2004



Matthews & Reid, 2007

fov (VLA antenna @ 21 cm) ~ 30 arcmin.

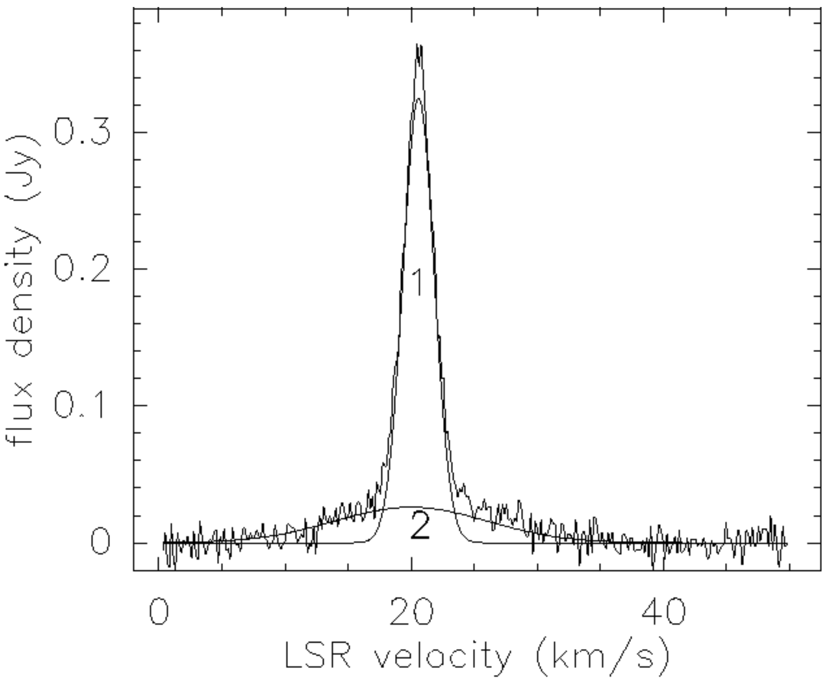
interferometer in the D configuration

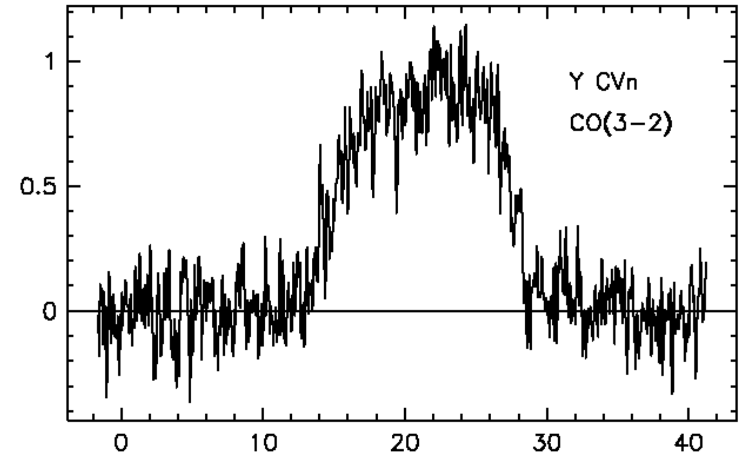


de Pater, Palmer, Snyder, 1991, Ap&SS Lib. 167, 175

Y CVn

(Le Bertre & Gérard 2004, A&A 419, 549)





Knapp et al. 1998, ApJS 117, 209

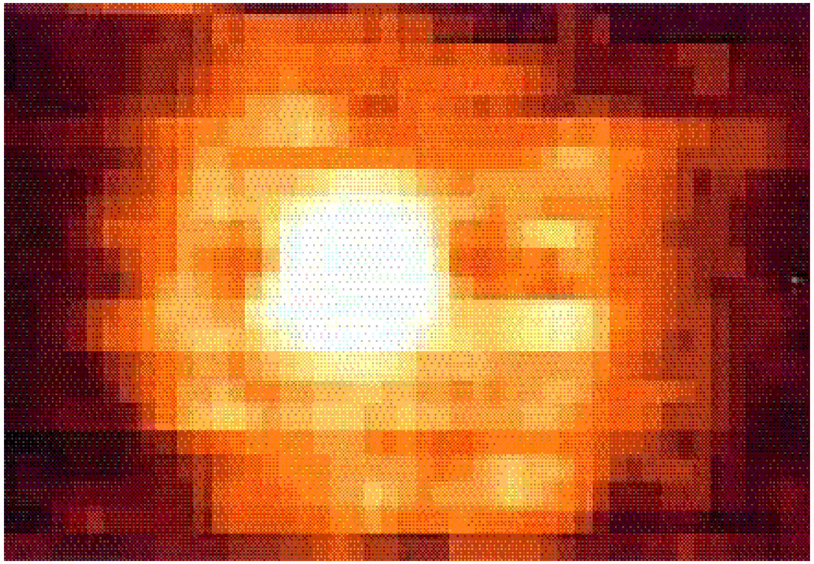
HI can be traced out

to the ISM

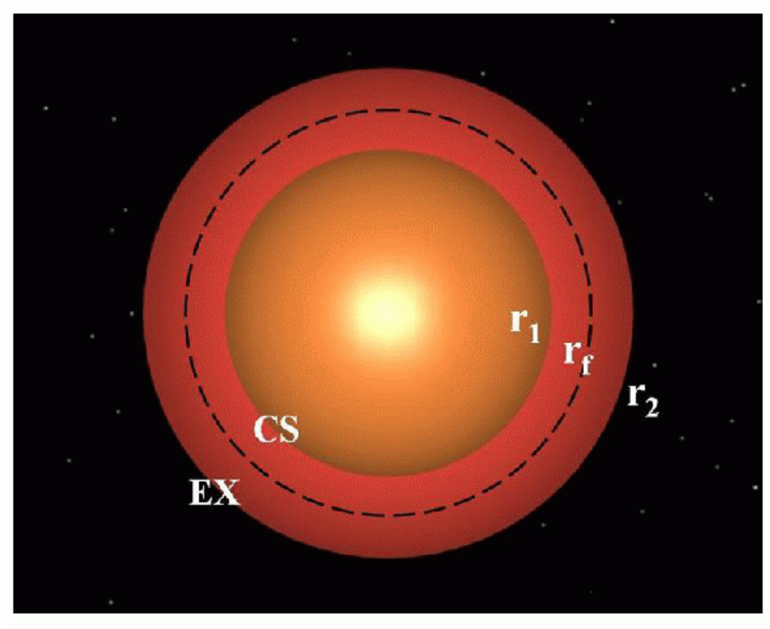
(Mtot ~ 0.06 Msol)

Izumiura et al. 1996, A&A 315, L221 →

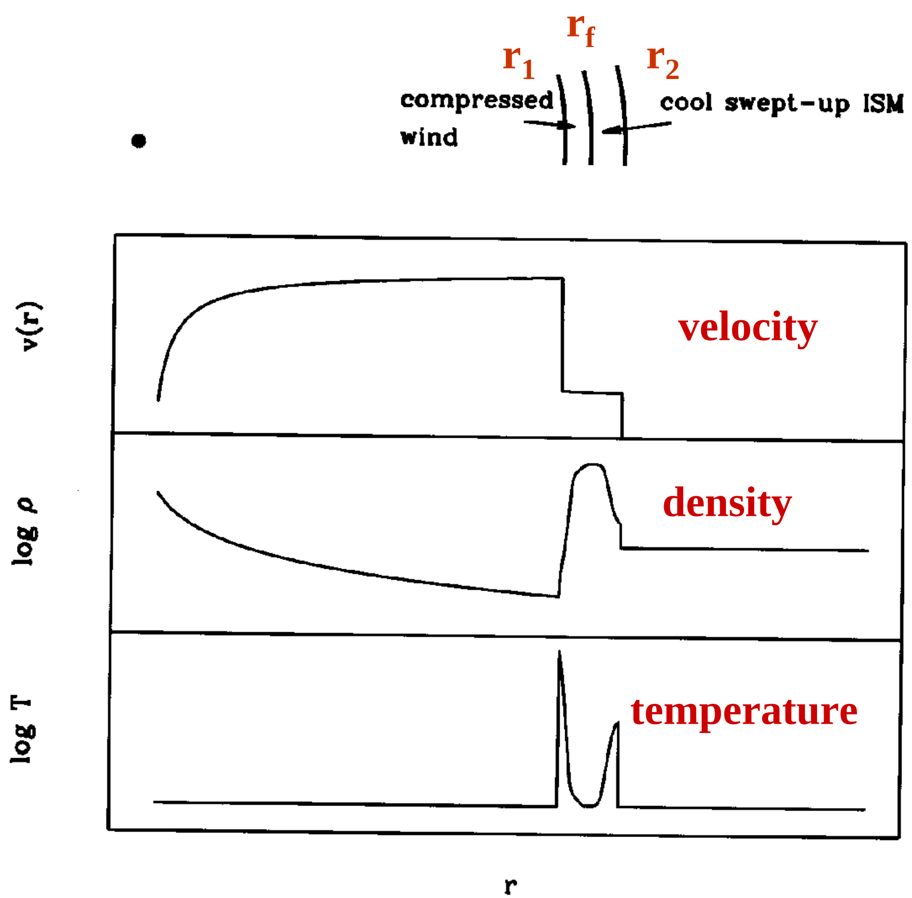
(ISOPHOT 90 µm : 12 x 8 arcmin^2)



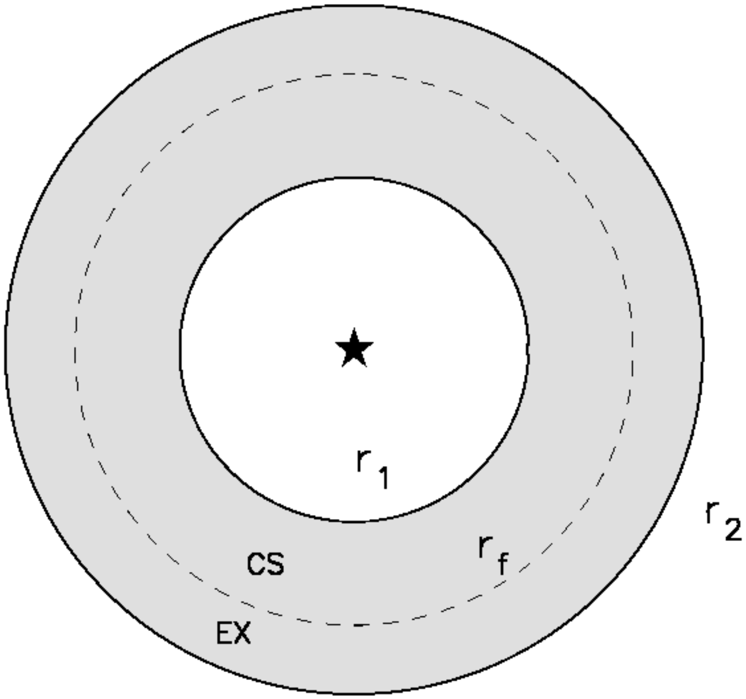
The matter in the shell is the sum of slowed down circumstellar material and accelerated external (ISM ?) material



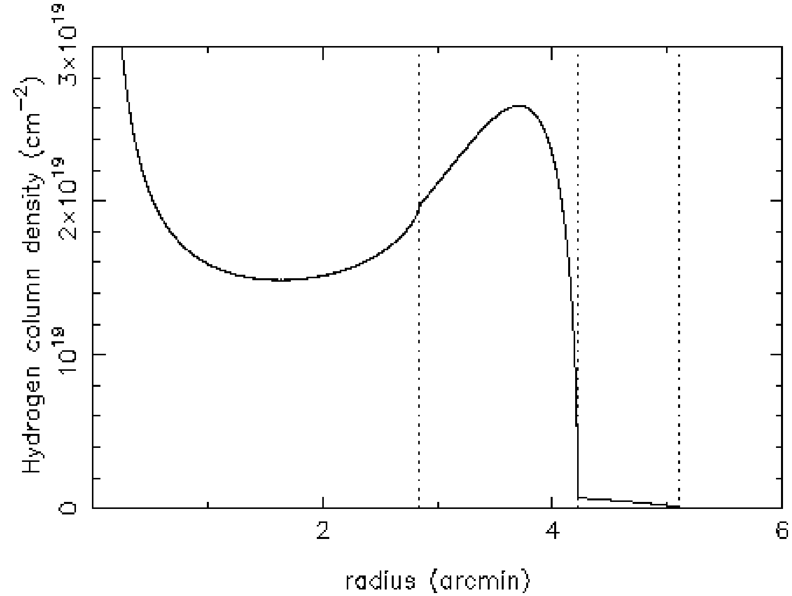
from Libert (2009)



Lamers & Cassinelli (2004)
"Introduction to Stellar Winds"

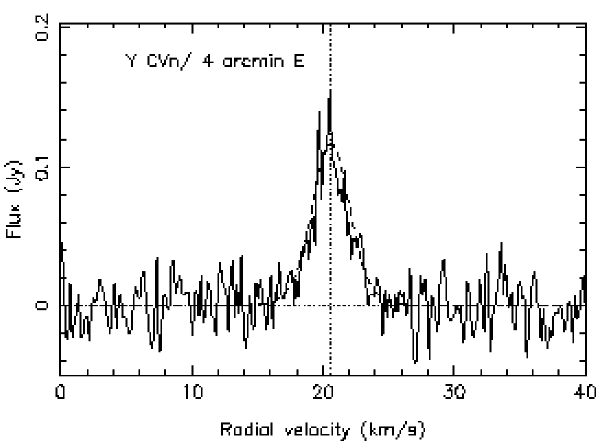


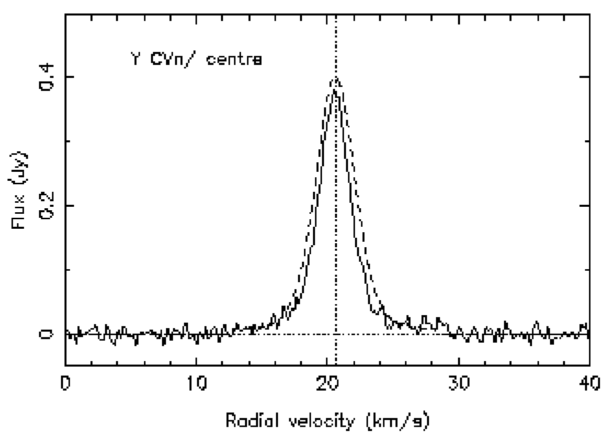
(Libert et al. 2007, MNRAS, 380, 1161)

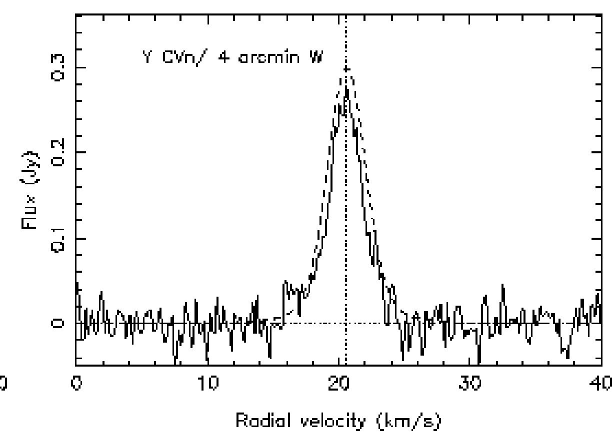


~0.8 10^{-7} M_{sol} yr^{-1} (H) during 4.5 10^{5} years

$T_{detached\ shell}$ ~ 100-2000 K







HI : first conclusions

- <u>extended emission</u> (~1 pc; 30-60 arcmin. for nearby sources)

→ history of the mass loss over <u>10^5-10^6 years</u>

- complex spatial and kinematic structures

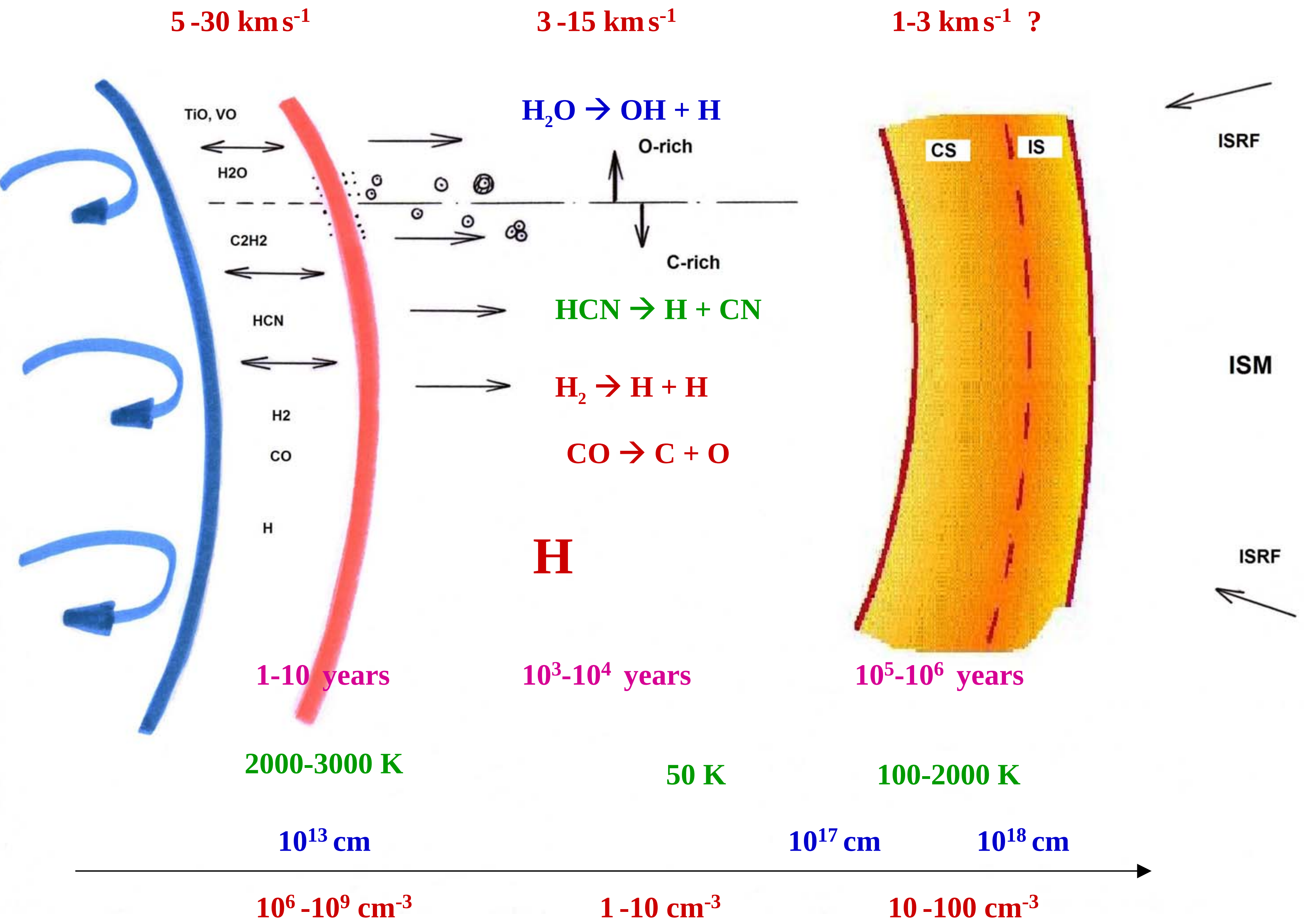
- masses ~ 0.01 to 0.8 solar masses (product : <u>mass-loss-rate x duration</u>)

→ HI is an indicator of circumstellar mass

- line-profiles generally narrower than CO line-profiles

→ the regions of the outflows that are probed in CO and HI are not the same

- <u>interaction with the ISM</u> : → ‘‘circumstellar buffer’’

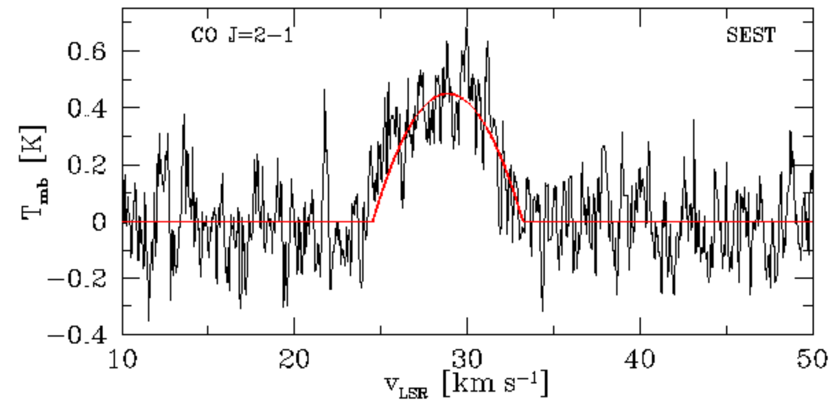


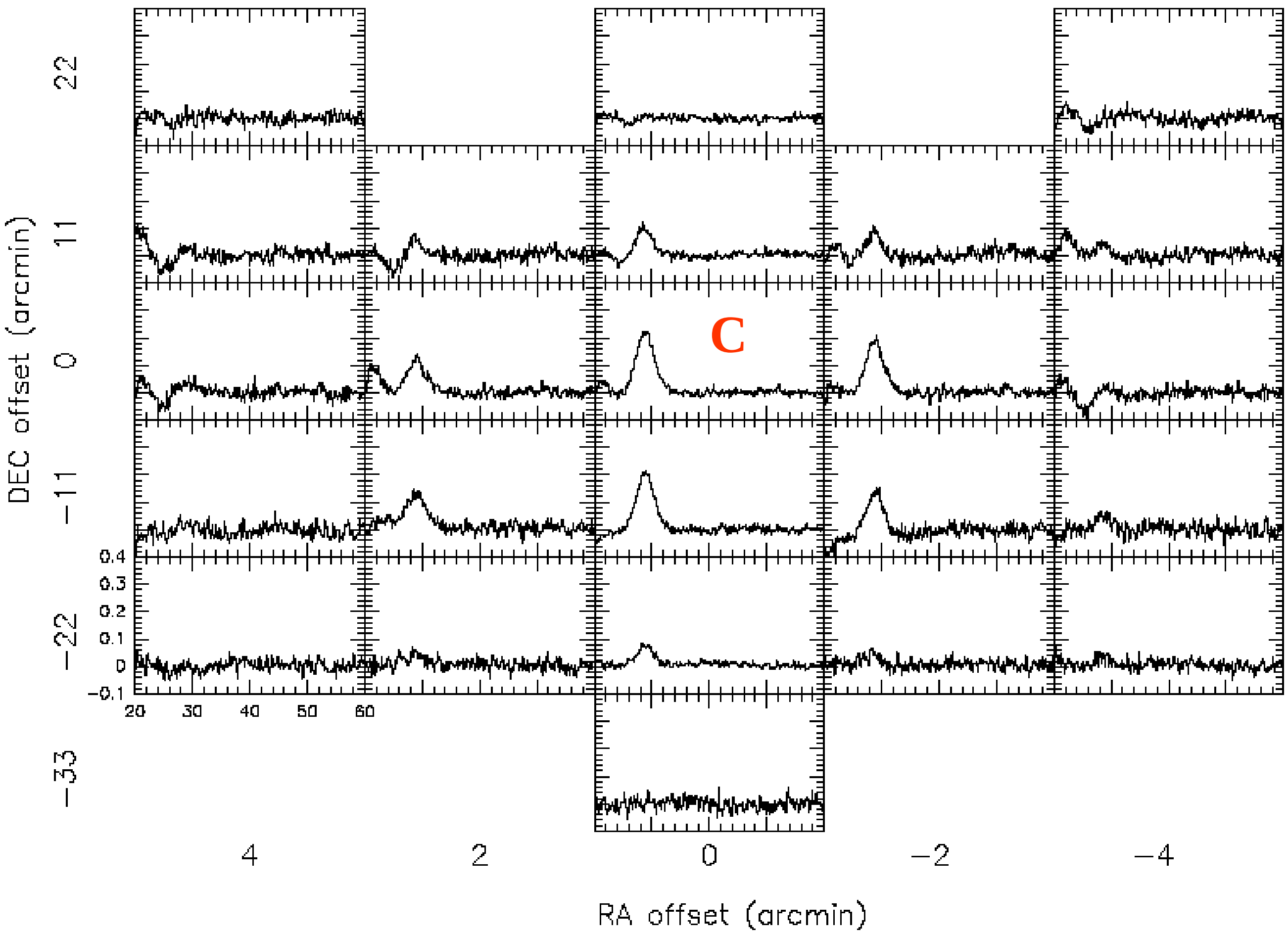
5 -30 km s-1
3 -15 km s-1
1-3 km s-1 ?
TiO, VO
H2O
C2H2
HCN
H2
CO
H
H2O → OH + H
O-rich
C-rich
HCN → H + CN
H2 → H + H
CO → C + O
H
CS
IS
ISRF
ISM
ISRF
1-10 years
10³-10⁴ years
10⁵-10⁶ years
2000-3000 K
50 K
100-2000 K
10¹³ cm
10¹⁷ cm
10¹⁸ cm
10⁶ -10⁹ cm-3
1 -10 cm-3
10 -100 cm-3

RX Lep :
a star on the early-AGB

Vexp (CO) = 4.2 km s^{-1}

3-D space velocity : 53 km s^{-1} (d= 137 pc)



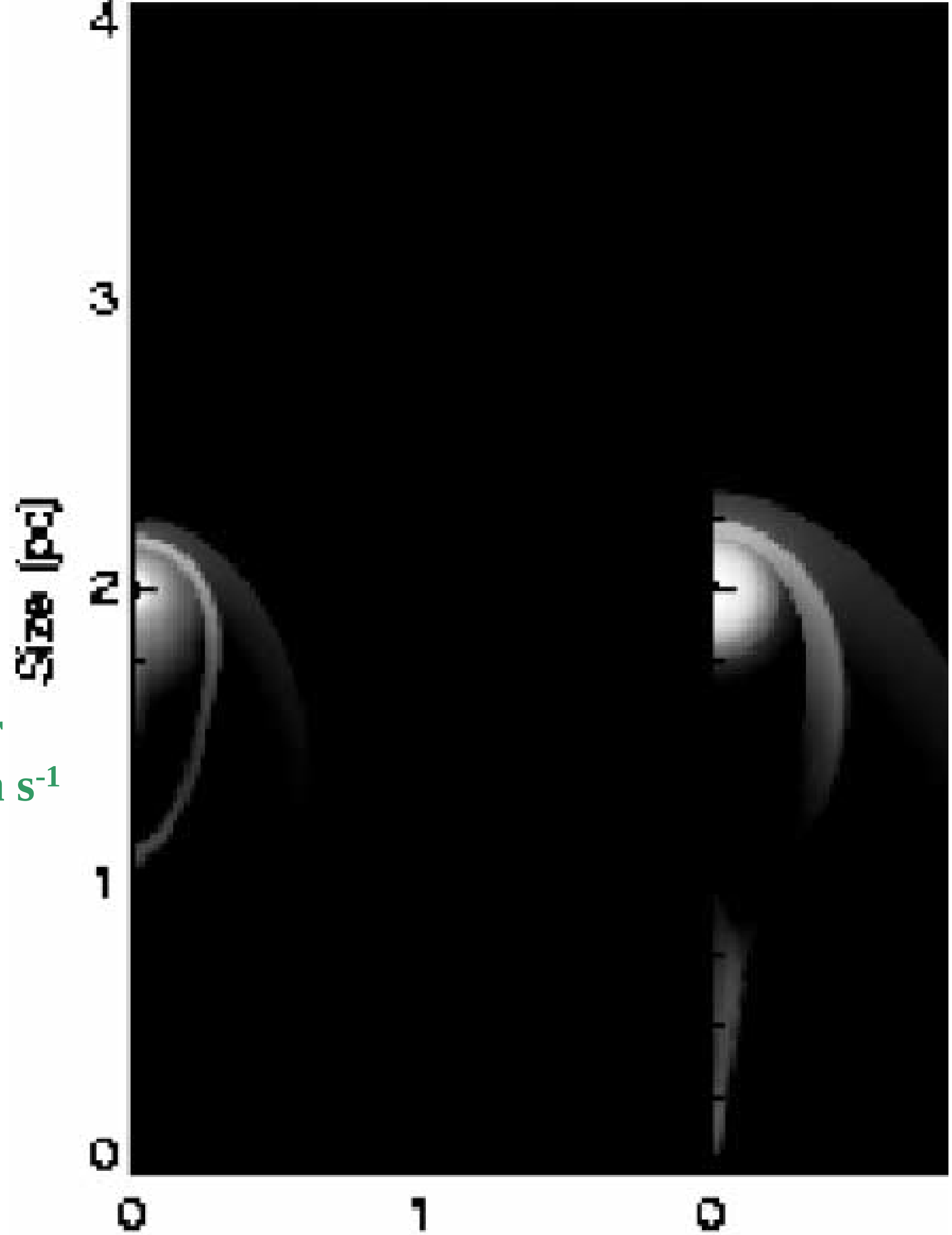


Libert et al. 2008,

A&A 491, 789

~ 0.1 x 0.6 pc in HI

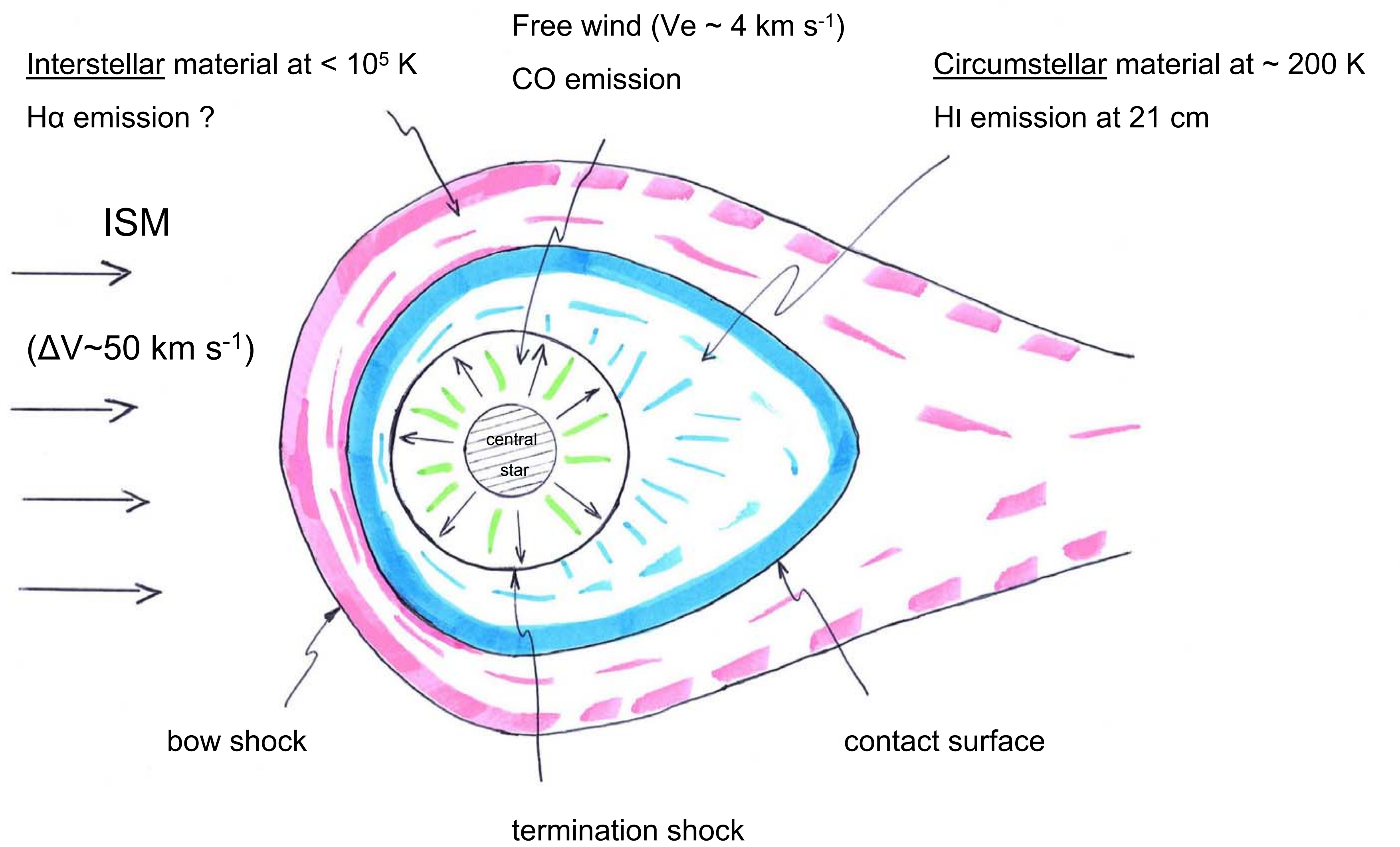
Villaver et al. 2003, ApJ 585, L49



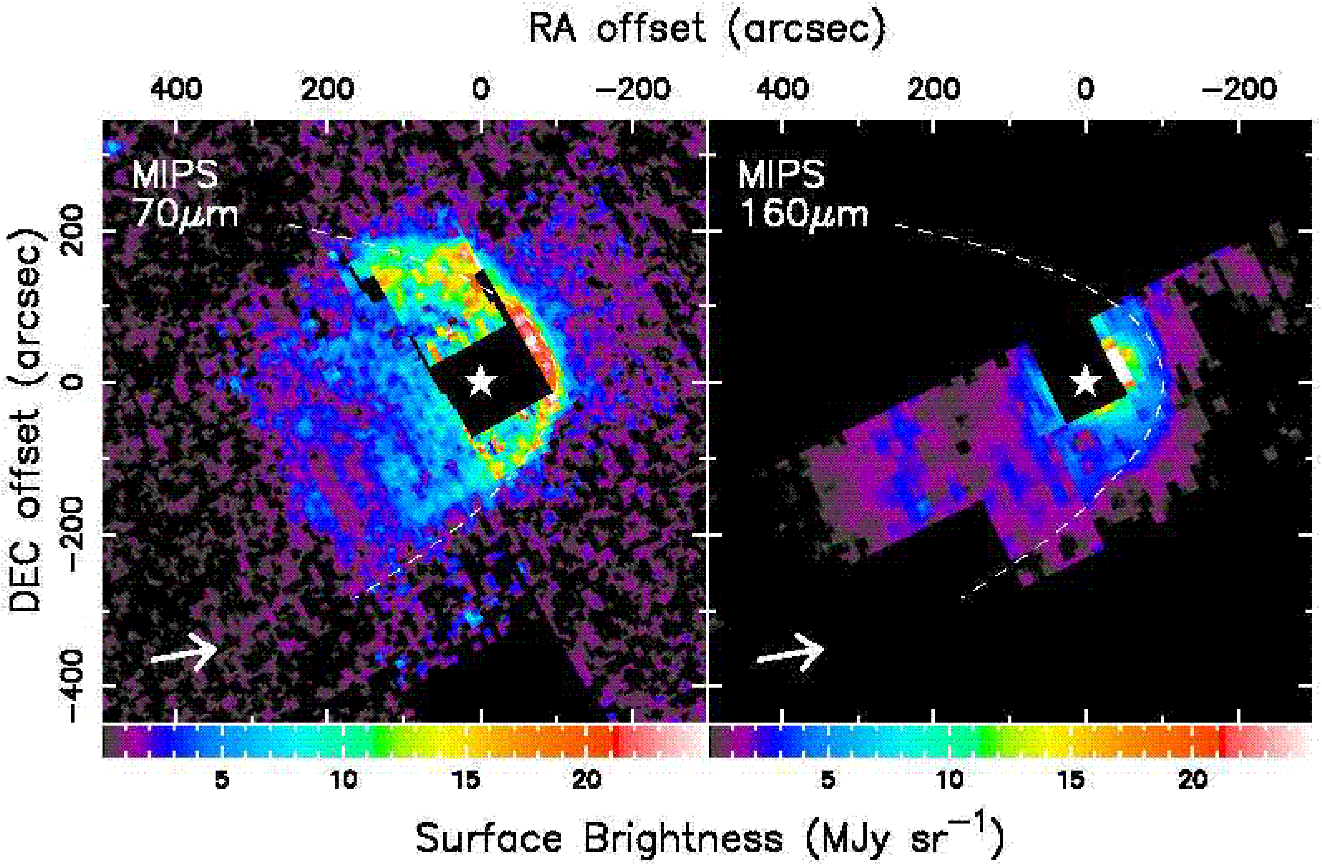
Evolution of a low-mass AGB star moving through the ISM at 20 km s^{-1}

t_1 = 85 10^3 years
t_2 = 206 10^3 years

A cartoon of the RX Lep circumstellar environment
(not to scale: 0.1x0.6 pc in HI)



a general phenomenon



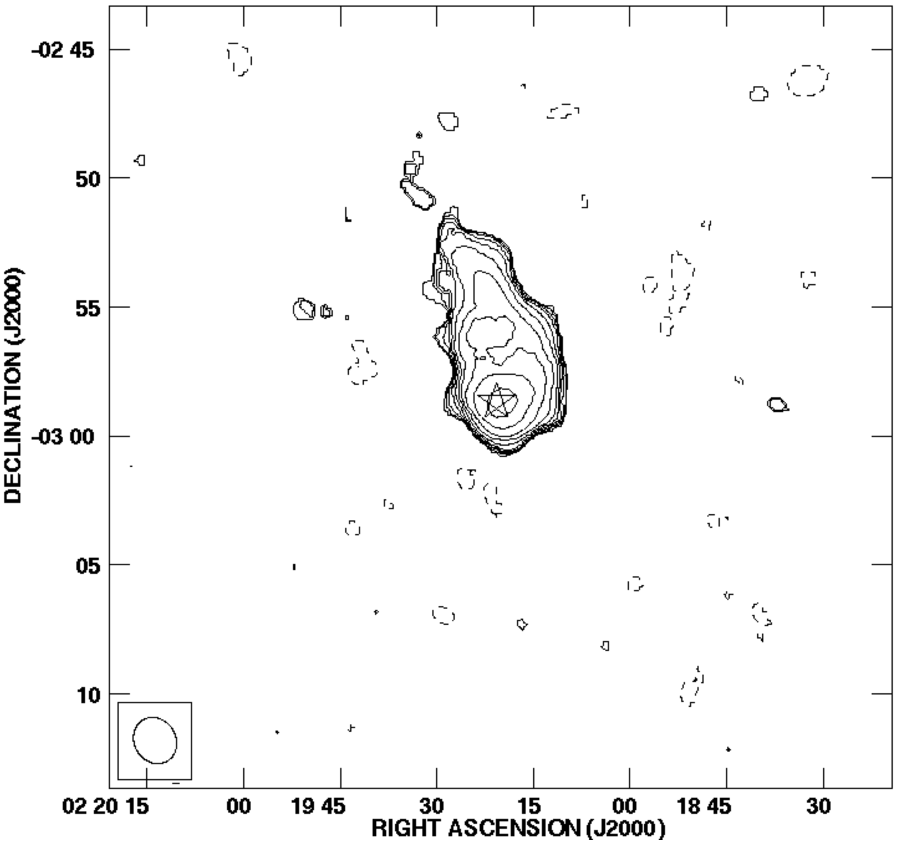
R Hya

Spitzer

[OI] at 63 μm ?

Ueta et al. 2006, ApJ **648**, L39

Mira in HI with the VLA (D; 2007)

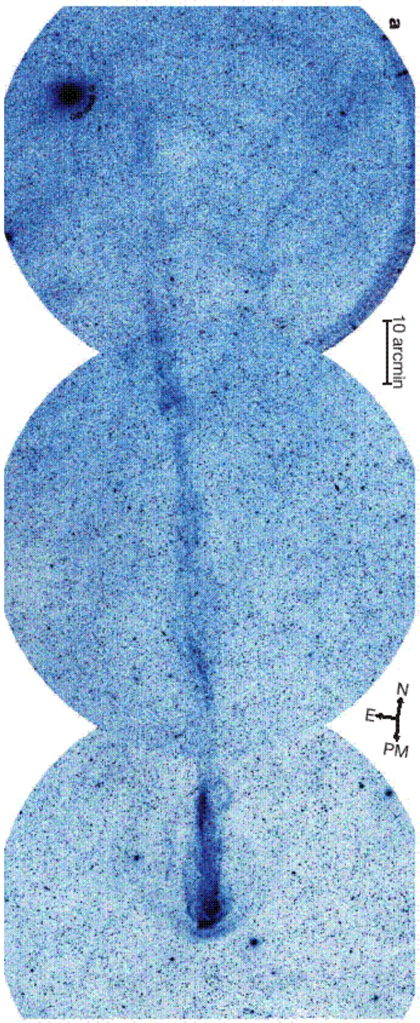


Proper motion :
(-12 , -235 mas an^{-1})

V_{tot} ~ 128 km s^{-1}

(d=107 pc)

GALEX
FUV (~1500 Å)
narrow & long trail
fluorescence H_2 ?

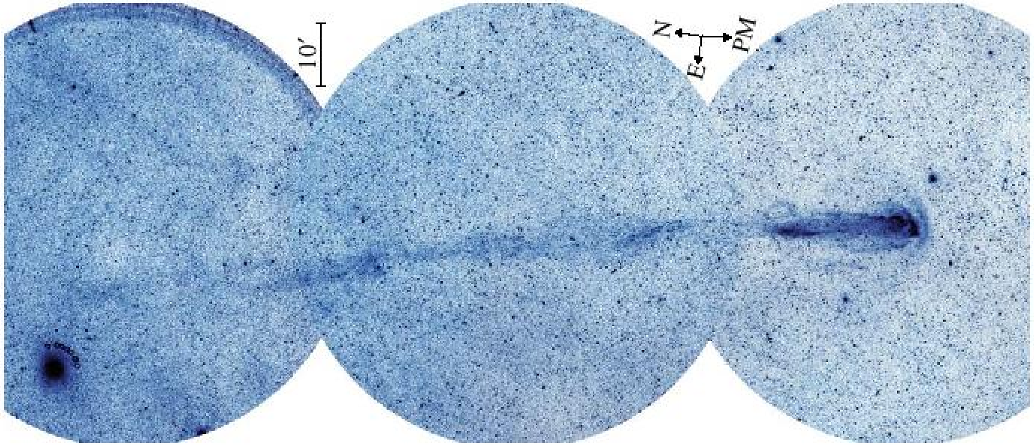


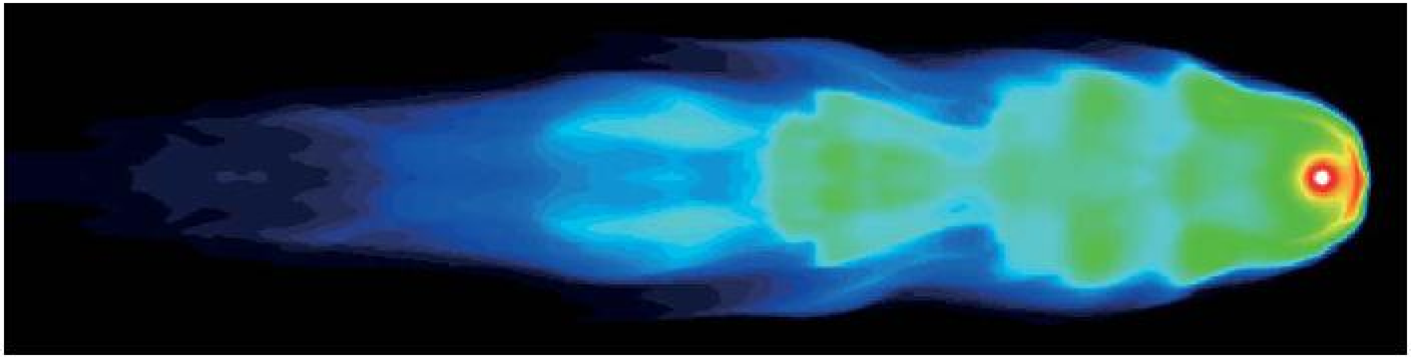
Matthews et al. 2008, ApJ 684, 603

Martin et al. 2007, Nature 448, 780

Wareing et al. (2007, ApJ <u>670</u> , L125)

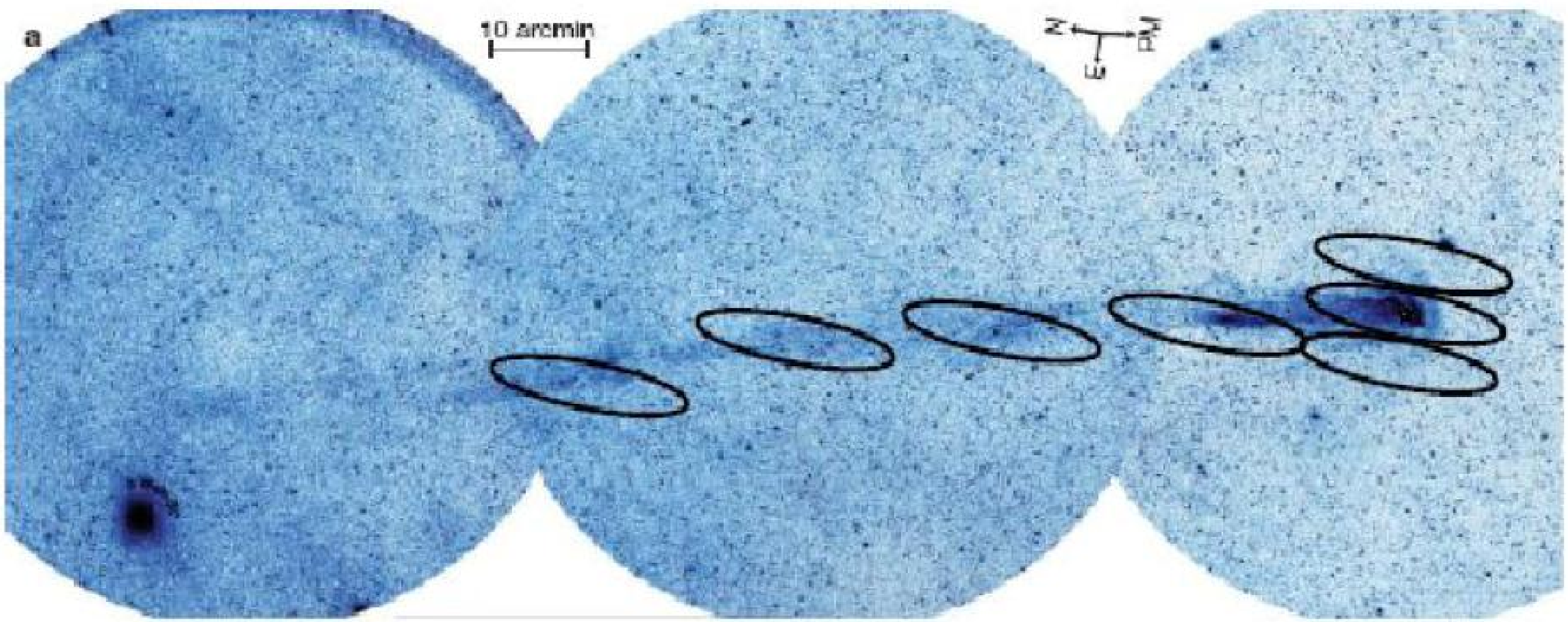
2.7° x 1.1°



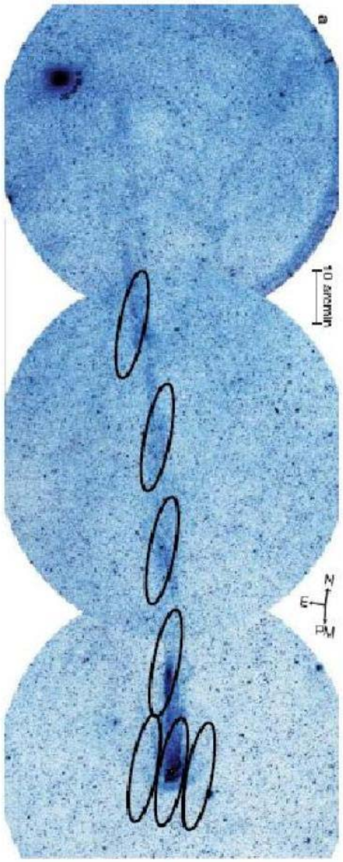


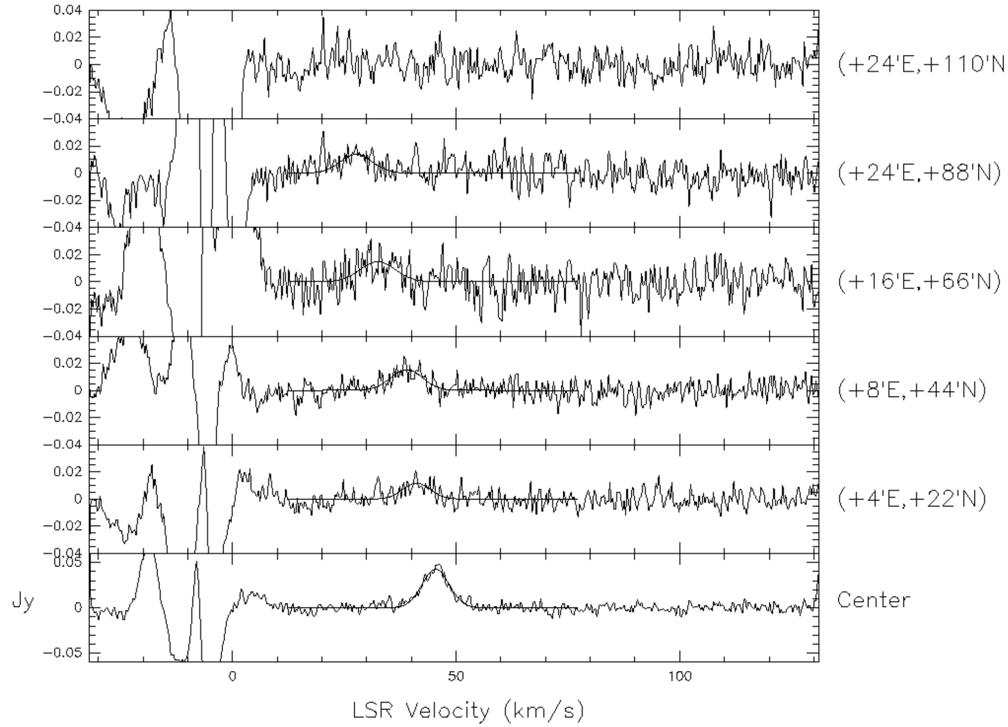
age ~ 450 000 years ?

field of view (NRT @ 21 cm) : 4 x 22 arcmin.



VLA + GALEX + NRT





Matthews et al. 2008, ApJ 684, 603

Radial velocity measurement in the trail → age estimate (~ 1.2 10^5 years)

New results

- **Shaping by the interaction with ISM:**

  → Slowing down + <u>stripping</u>

- **Injection of circumstellar matter in the ISM**

Rapid variations of the physical properties

(on scales of ~1/10 arcmin for a source at 200 pc)

[or 1 arcsec at 1 kpc]

The need for the SKA

- Improved **angular resolution** : 10 arcsec
  morphology of outer CS
  interface with ISM
  (with a goal of 1 arcsec for sub-structures)

➔ need for **high brightness sensitivity** (~0.1 mJy)

- **Fidelity** (HI provides an image of the column density directly comparable to the images obtained with models)

- **Wide field** :
  1. the sources that we prefer are close and large on the sky (up to 2 degrees)
  2. we need to correct for galactic emission

- High **spectral resolution** (~ 0.3 km/s; goal ~ 0.1 km/s)

Complementarity of CO and HI

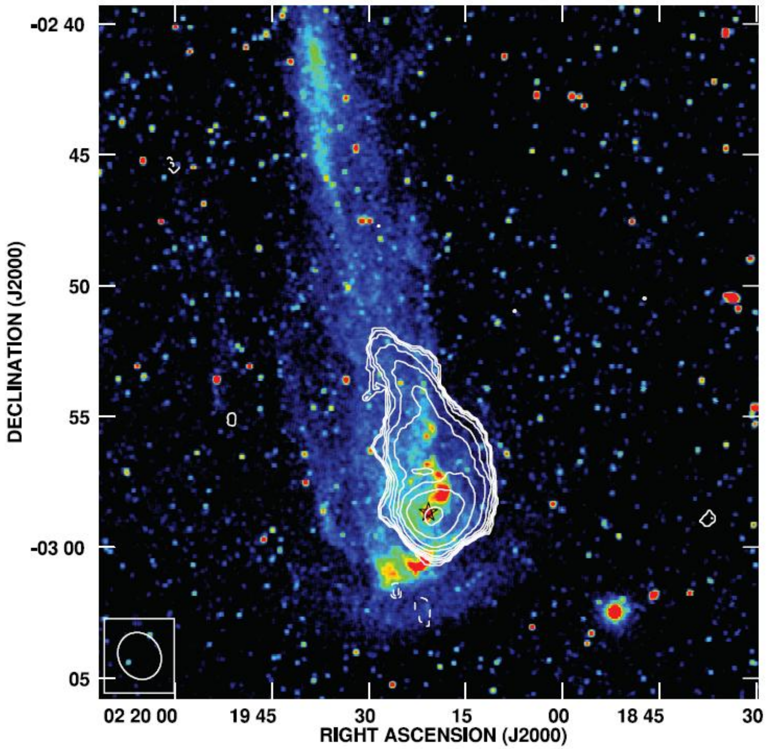
inner shell (few 10^{-2} pc)	**outer shell (~1 pc)**
10^4 years	**10^6 years**
Mass loss rate	**Mass**
Mass loss process	**Interaction with ISM**
→ ALMA	**→ SKA**

The combination of the 2 tracers gives access to the history of mass loss.

Summary

CO, HI, H_2, SiO, …, **emission lines and dust emission** are complementary probes of the expanding circumstellar shells and of the zones where they interact with the ISM.

GALEX
+
VLA



Thank you and good luck with the SKA !