HI emission from red giants with the VLA and FAST

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l'Observatoire de Paris

Blowing in the Wind, Quy Nhon,
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pcmi

Red giants outflows

Slow winds :

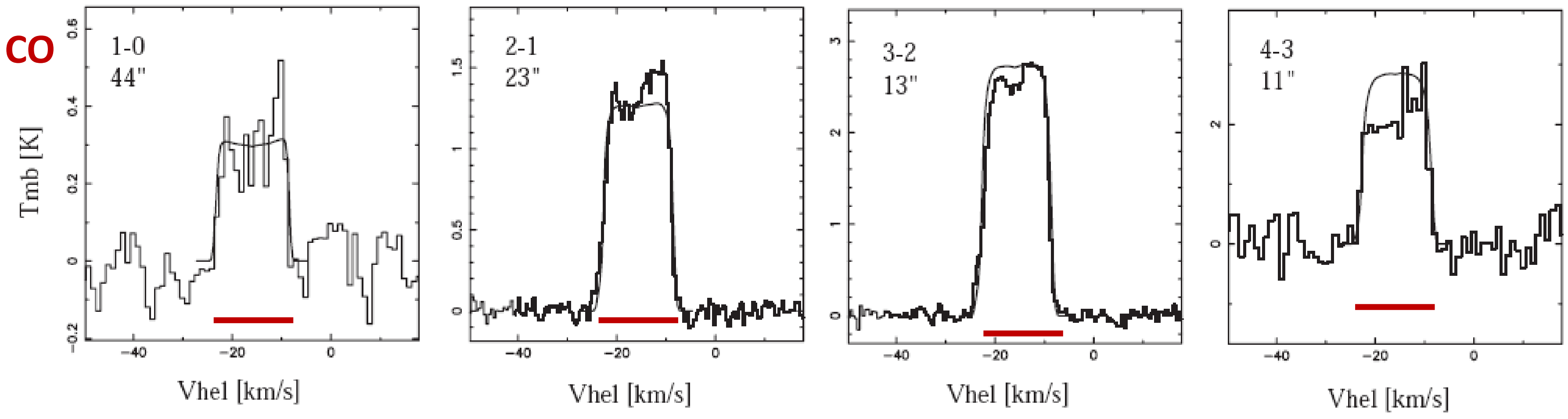
V_{exp} ~ few to 20 km s^{-1}

Massive winds :

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

Extended shells :

R_{shell} ~ 0.01 to 1 pc



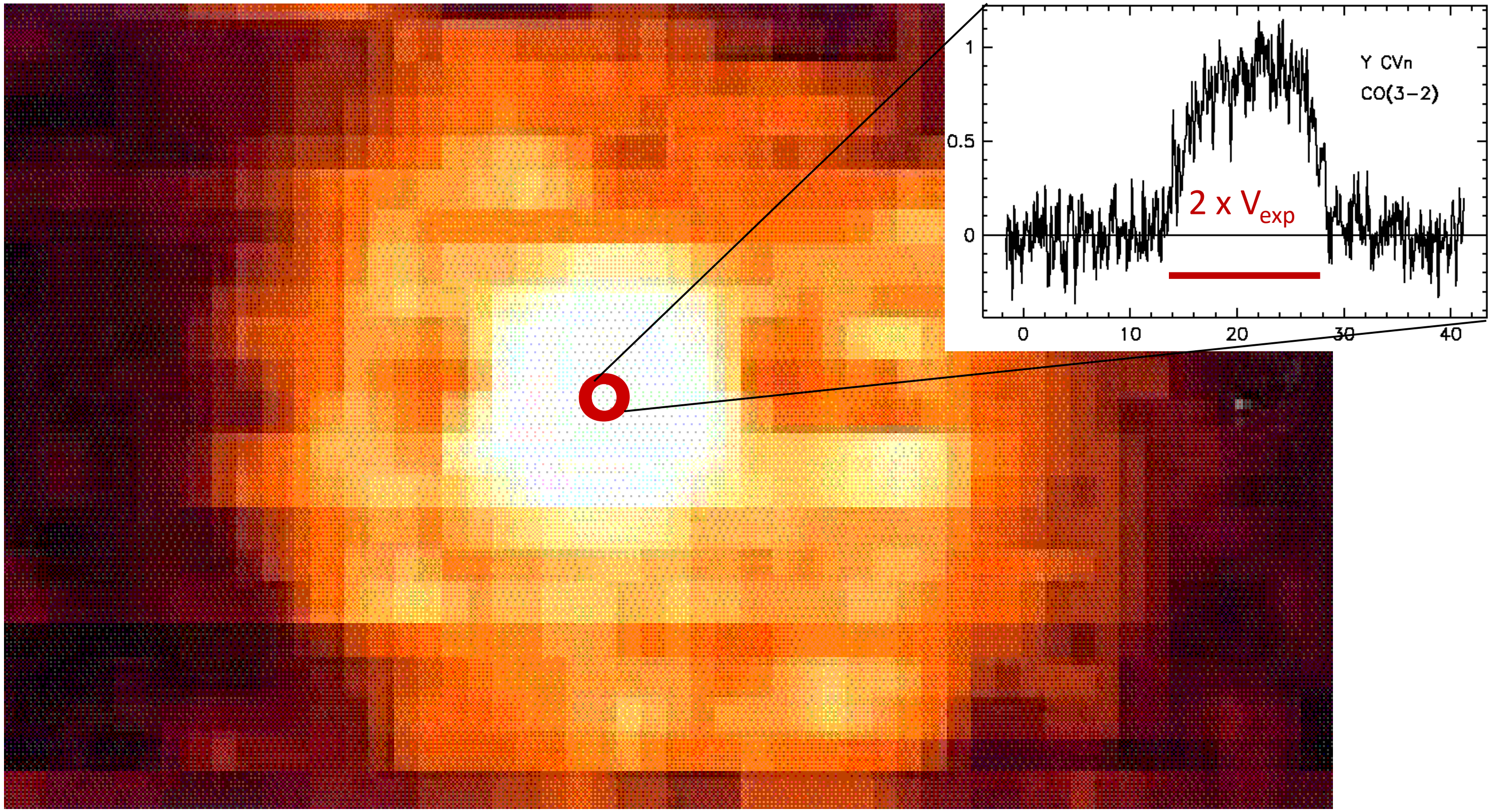
Olofsson et al. 2002, A&A 391, 1053 [SW Vir] dust, at low temperature, is emitting in the far-infrared

→ IRAS, ISO, Spitzer, Akari, and Herschel

Y CVn

8 km s^{-1}

~1 x10^{-7} M_{sol} yr^{-1}



ISOPHOT 90 µm; dust detached shell of ~ 8 arcmin. diameter (~0.5 pc)

(Izumiura et al. 1996, A&A, 315, L221)

φ(CO) ~13 arcsec. (0.02 pc; Neri et al. 1998, A&AS, 130, 1)

HI at 21 cm

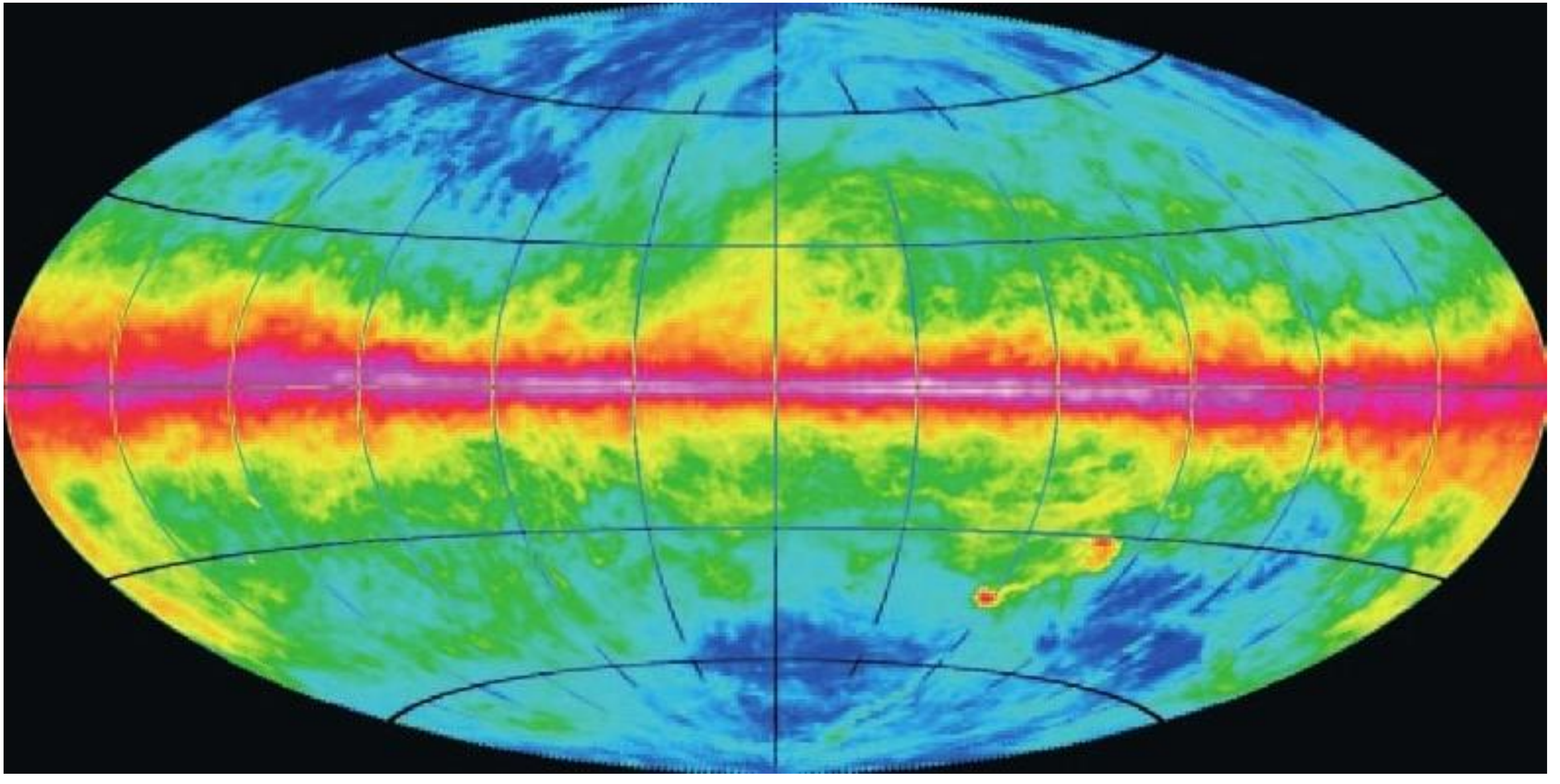
- HI in CS is expected to be protected by surrounding HI in the ISM
- hyperfine-structure line of hydrogen in the ground state

  λ = 21 cm, ν = 1400 MHz, A_{10} ~3 10^{-15} s^{-1}
- 1. optically thin in most situations
- 2. ν = 1.4 GHz → **$h\nu/kT << 1$**

  measured flux α N_H

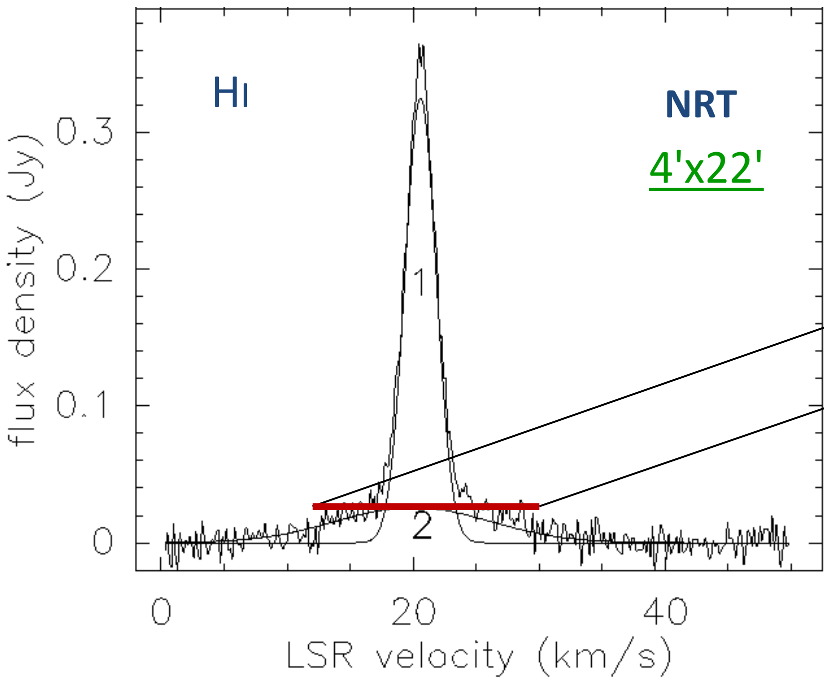
  (the emission in HI line is a good tracer of morphology)
- If the distance is known, we can estimate the mass in atomic hydrogen
- ~70 % of mass in hydrogen : HI → mass (≠ mass loss rate)
- Caveat: ionized hydrogen and molecular hydrogen are not seen.

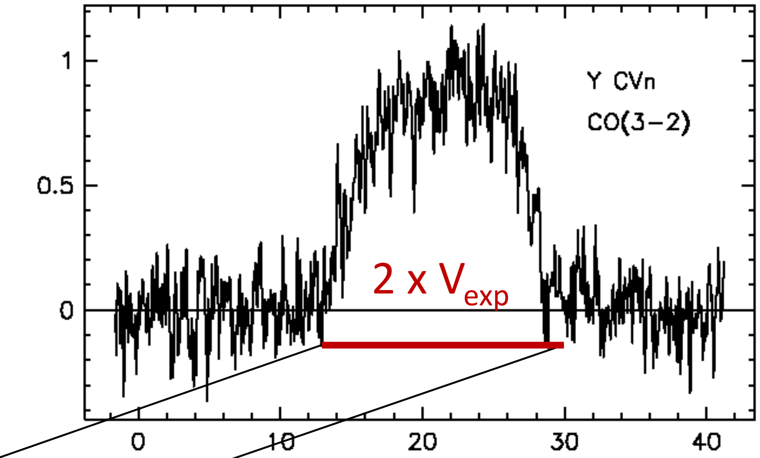
- Large beams at 21 cm: **Nançay : 4'x22'; GBT : 8.7'; VLA (D) : ~ 1'**
- **Competing emission by the interstellar medium on the same line of sight**



Kalberla et al. 2005, A&A, 440, 775; total galactic HI

Y CVn (b^{II} = +72°)
(Le Bertre & Gérard 2004)





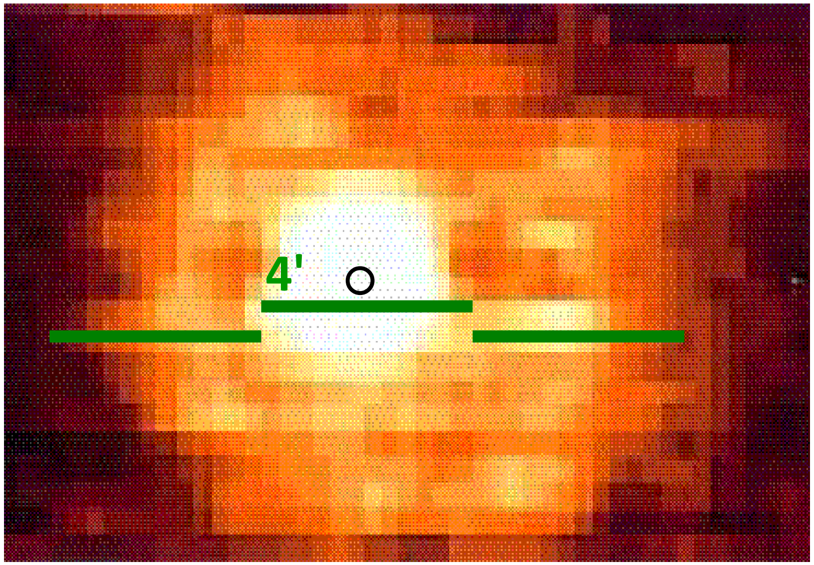
Knapp et al. 1998

Ø~ 13'' ~ 0.01 pc

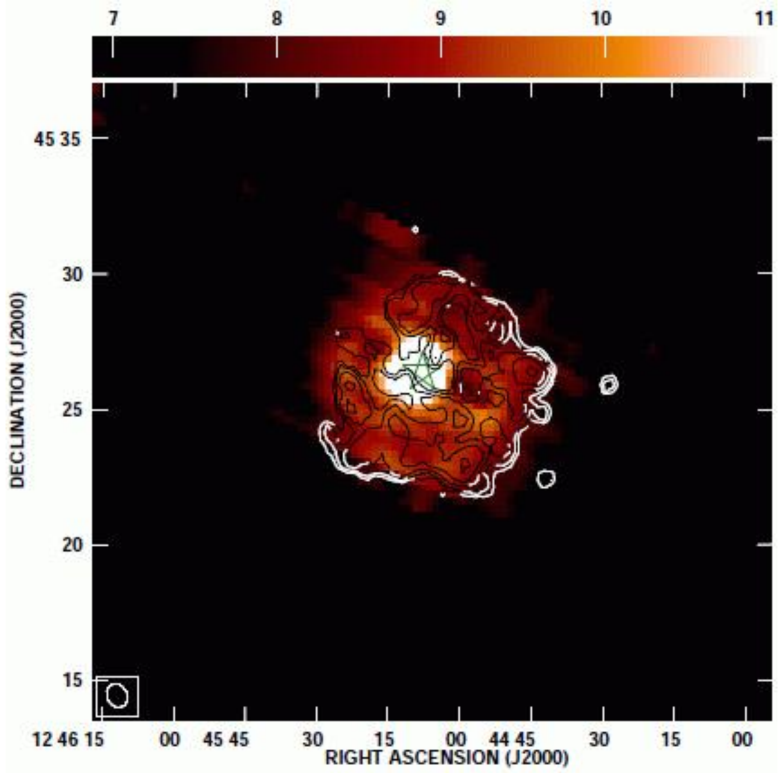
Izumiura et al. 1996 →

(ISOPHOT 90 µm : 12 x 8 arcmin^2; Ø~8', or 0.5 pc)

[dust emission]



Matthews et al. 2013, AJ, 328, 797
(~ 50'' spatial resolution)



FWHM (HI) << 2 x V_{exp} (CO)

1. HI probes a region where the stellar outflow has been slowed down.

V_{cent} (HI) ~ V_{star}

2. This region shares the same space velocity as the central star.

→ HI reveals a quasi-stationary shell around the central star

Before being injected into the ISM the stellar matter is slowed down

a digression:
line broadening by the Doppler effect

1. Thermal Doppler effect

For a maxwellian distribution, the line profile is gaussian:

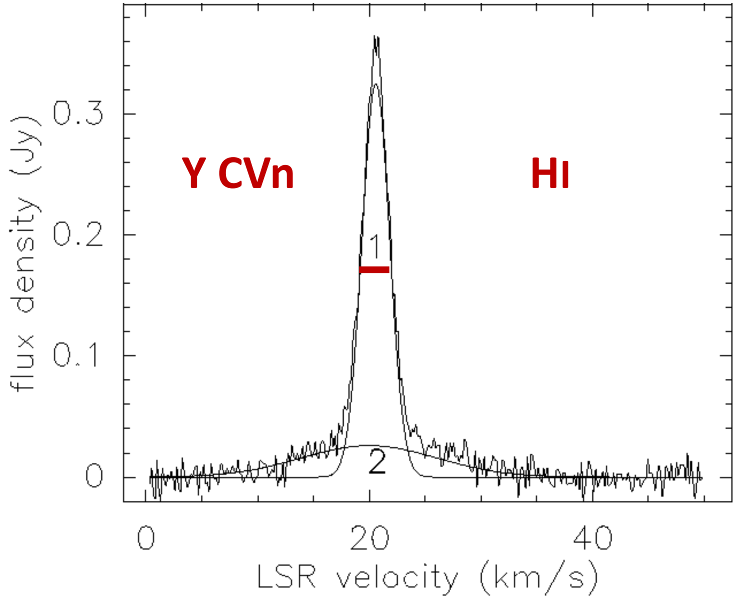
$FWHM(km\ s^{-1}) = 0.214\ [T(K)/M(at.\ unit)]^{1/2}$

e.g. for a gas at 1000 K : FWHM(HI line) ~ 6.8 km s^{-1}

FWHM(CO line) ~ 1.3 km s^{-1}

2. Kinematic Doppler effect

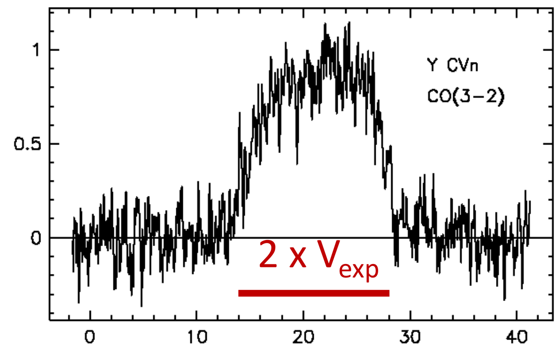
has a direct and identical effect on the line profiles. For instance, for a gas in spherical and uniform expansion, the width of the line is ~ $2xV_{exp}$.



3. For Y CVn, the main component has a gaussian line profile with FWHM ~ 3.1 km s^{-1}

→ **1. the bulk of the material is at a temperature ≤ 210 K.**

→ **2. the bulk of the material is expanding at ≤ 1.6 km s^{-1}.**



From CO observations, we see evidence of a freely expanding wind at V_0~8 kms^{-1} , c ~$(kT/\mu m_H)^{1/2}$ ~ 0.4 kms^{-1} (isothermal sound speed, T =20 K).

<u>The freely flowing wind must be stopped by a shock</u>.

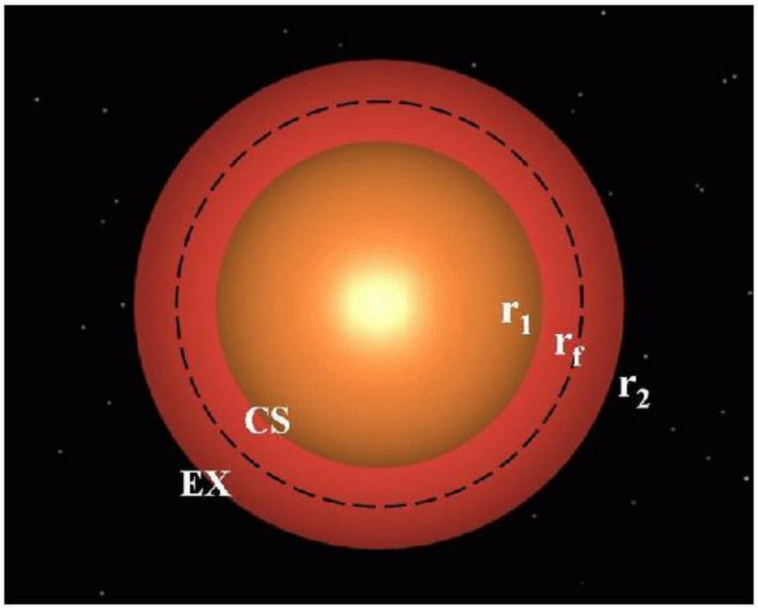
For a mono-atomic adiabatic gas:

v_1/v_0 ~1/4 ➔ v_1 ~ 2 kms^{-1} (but ≤ 1.6 km s^{-1} !)

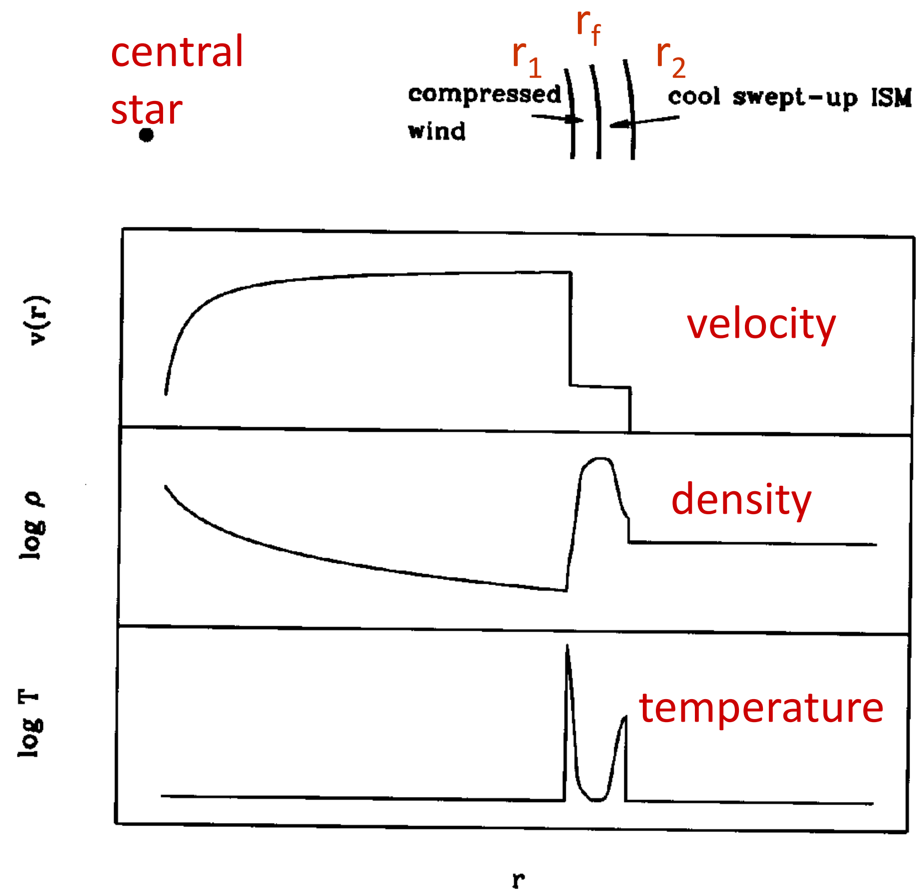
T_1 ~ $(3\mu m_H/16k)\, v_0^2$ ➔ T_1 ~ 1800 K (but ≤ 210 K !)

The gas should slow down, and it should cool down, further out <u>within the shell revealed by HI observations</u> (Libert et al. 2007).

We interpret these results with a simple model of a wind interacting with its surrounding medium
(Lamers & Cassinelli 1999).



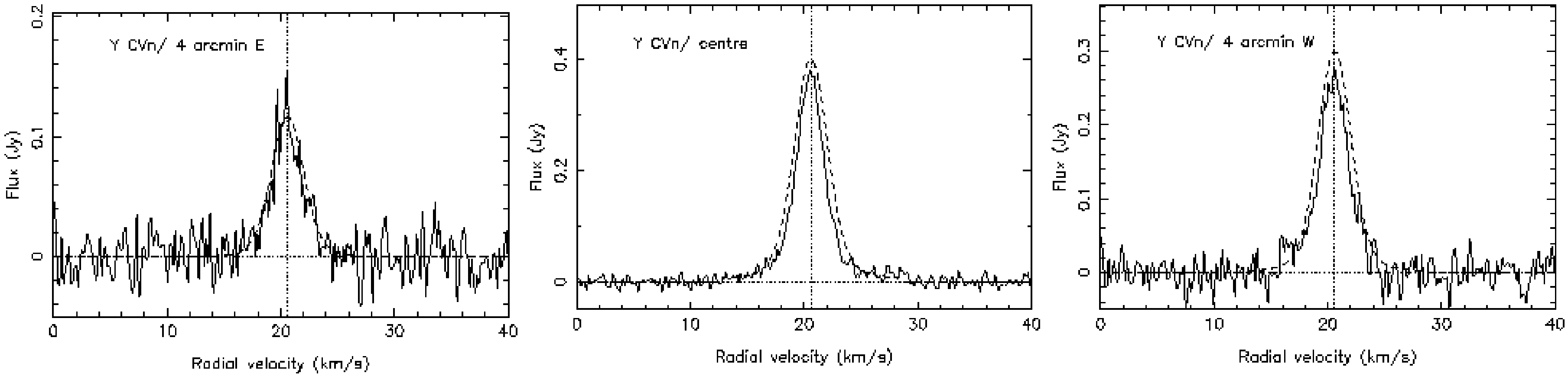
Libert's PhD thesis (2009)



Lamers & Cassinelli (1999)
"Introduction to Stellar Winds"

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

$T_{detached\ shell} \sim 100\text{-}2000$ K

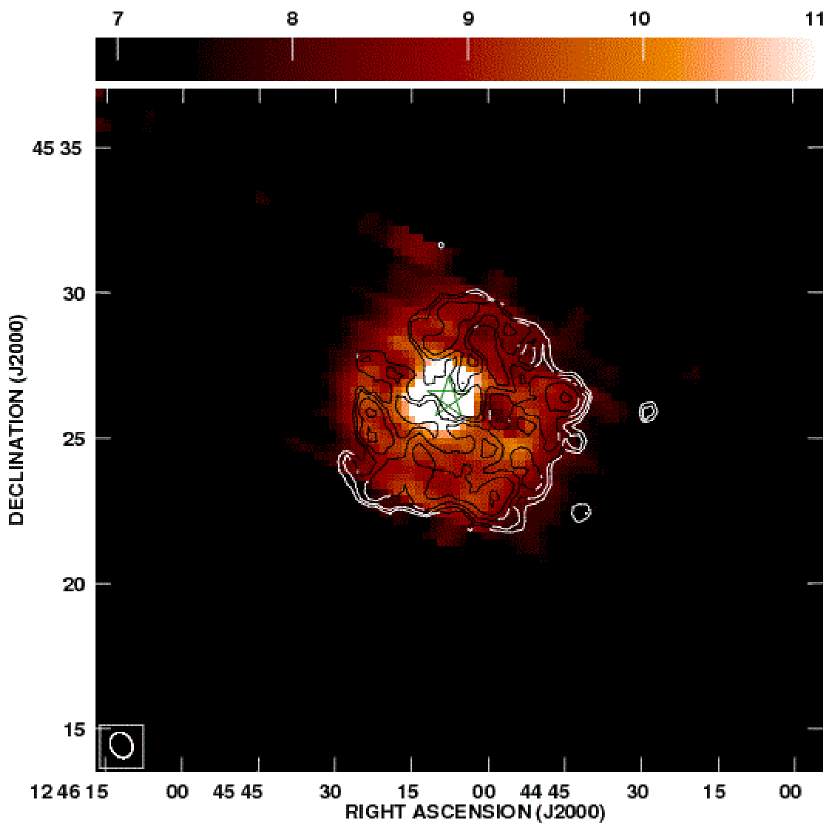


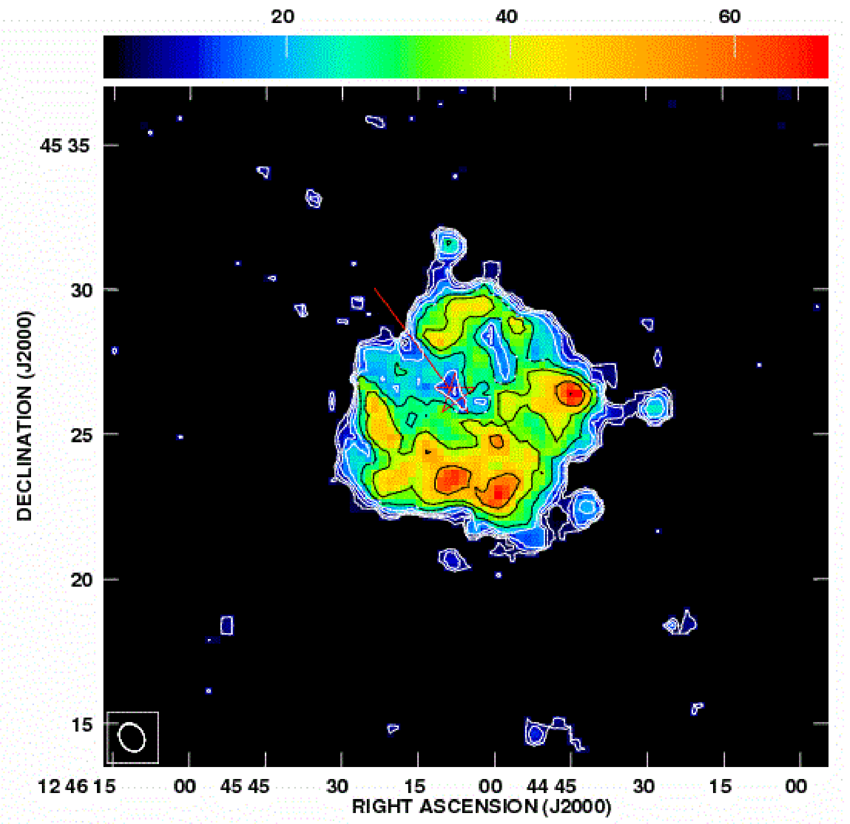
(Libert et al. 2007, MNRAS, 380, 1161)

•A constant mass loss rate can account for the spectroscopic observations obtained with the Nançay radiotelescope. The value of the mass loss rate used in the model is the same as that determined from CO observations.

•There is no need to invoke an intense episode of mass loss followed by a drastic reduction of the production rate.

This model works well for reproducing the observed HI line profiles, but it is less satisfactory when compared in detail to the spatially resolved data obtained at the VLA by Matthews et al. (2013), in particular for lines of sight close to the central star.

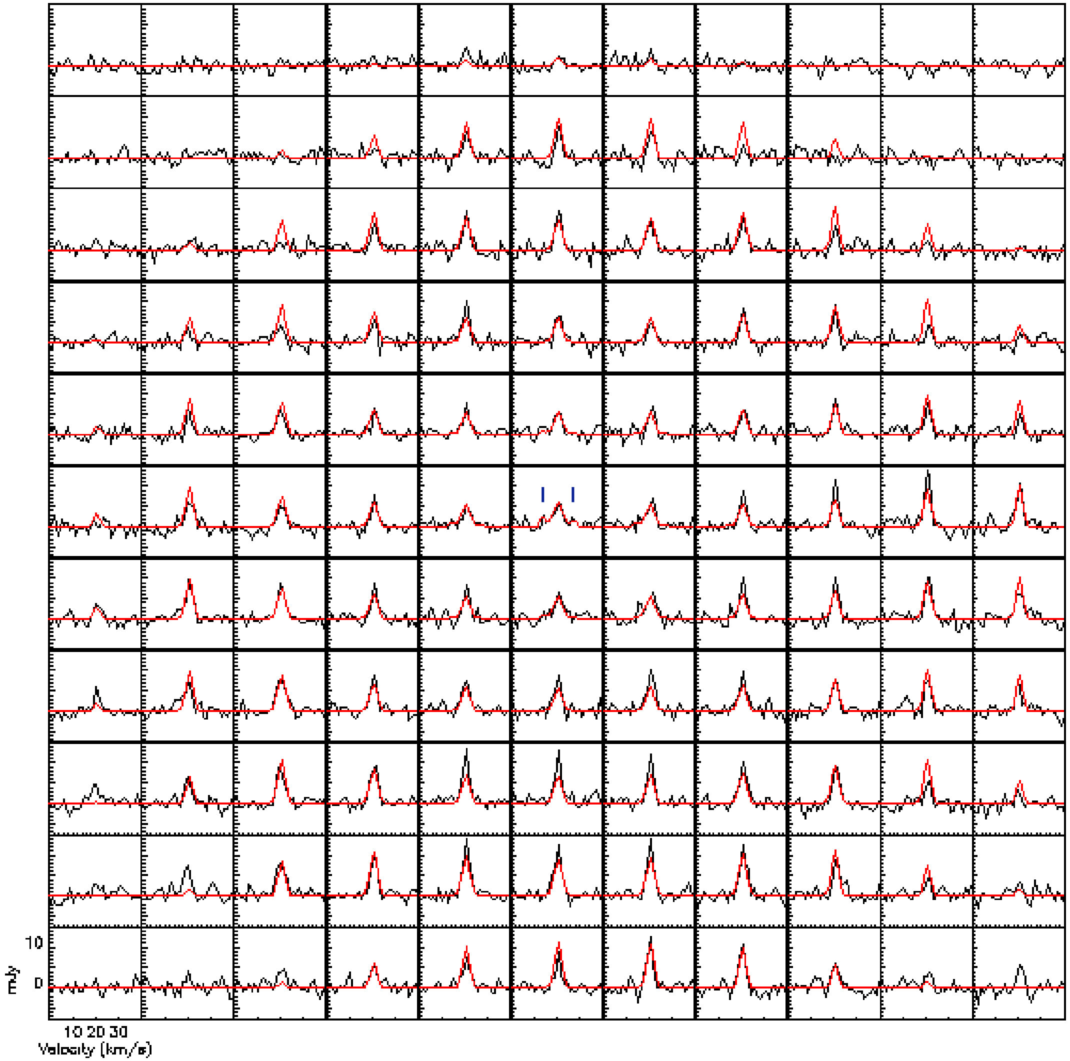




HI total intensity map (with ISO 90µm image at left)

V_{3D}(*)= 35 kms^{-1}

VLA spectral map
with step = 50'' and
channel width = 1.3 km s^{-1}



Detached shell model
+
distortion along
proper motion direction
(Hoai et al., in prep.)

Also, the average mass loss rate has to be decreased wrt the value determined from CO modeling, and conversely the duration has to be increased.

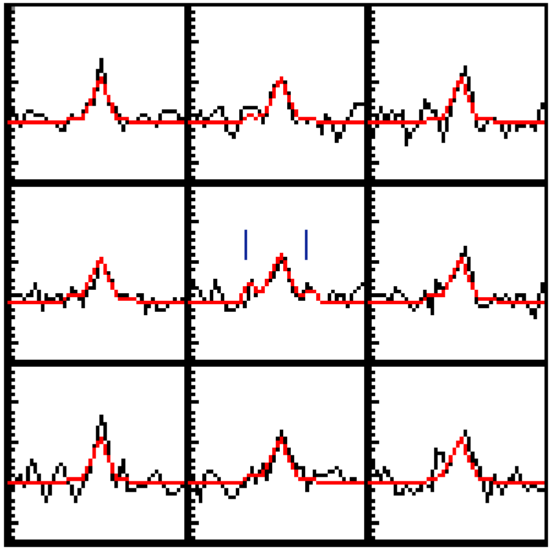
→ The mass loss rate cannot be anymore assumed to be constant over such a long period of time (~5 10^5 years).

Y CVn is almost a "textbook" case (~spherical symmetry).

→ the HI shell looks as a persistent structure where stellar matter is accumulating with time.

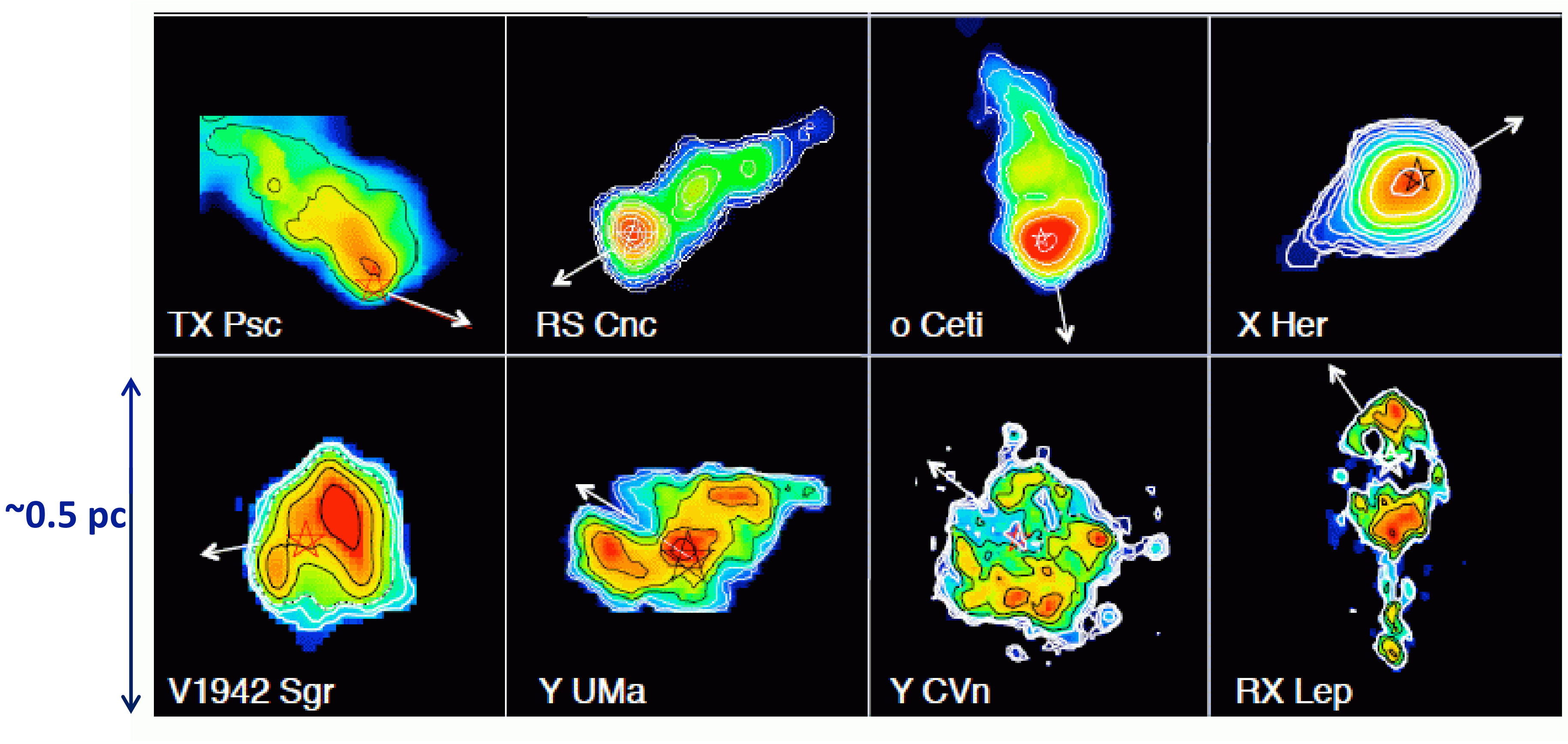
→ a proper modeling for the interaction with the surrounding medium, incorporating stellar evolution, is necessary.

There is clearly a need for spatially resolved spectra with a high spectral resolution and excellent signal to noise ratio, in order to study the distortion due to the motion of the star relative to the local ISM, and to reveal the extension of the central free flowing wind.



VLA observations show a wide variety of different situations

(Matthews & Reid 2007; Matthews et al. 2008, 2011, 2013)

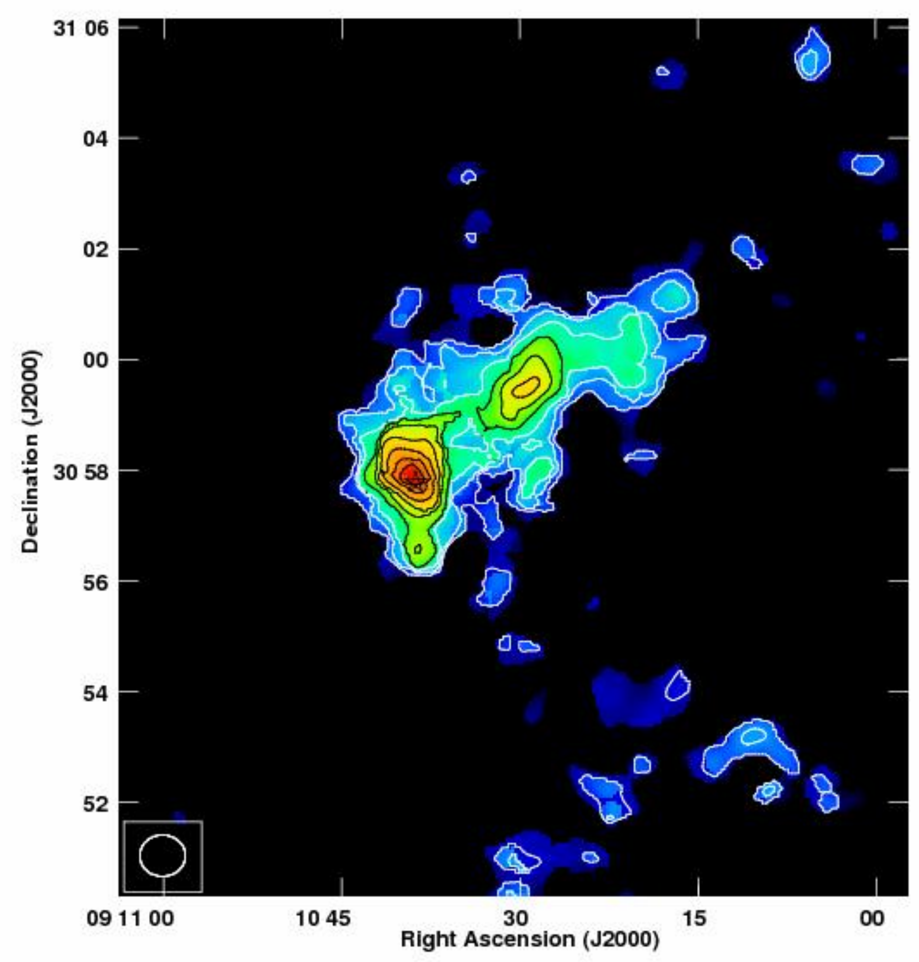


However, always a narrow spectral line (3-5 kms^{-1}), with sometimes a gradient in the centroid velocity (extreme case of Mira ~ 15 kms^{-1} /degree)

RS Cnc (Hoai et al. 2014, A&A, 565, A54)

$V_{lsr}(*)$= 7 kms^{-1}
d = 143 pc

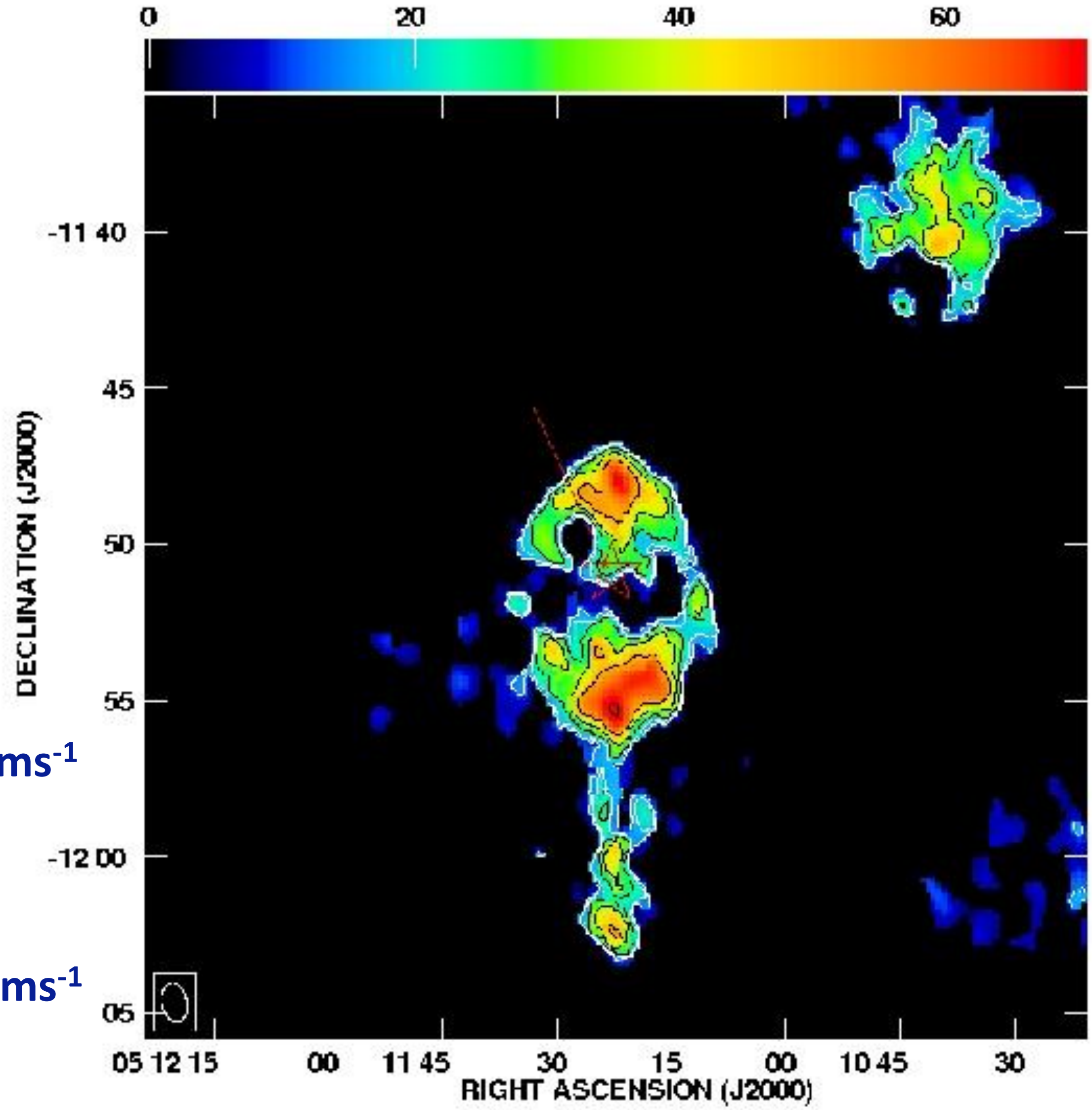
$V_{3D}(*)$= 15 kms^{-1}



length~6' (0.25 pc)

Head-tail morphology with indices of vortices
Injection of stellar matter into the ISM ?
→ need for high spectral resolution

RX Lep (Matthews et al. 2013, AJ, 145, 97)



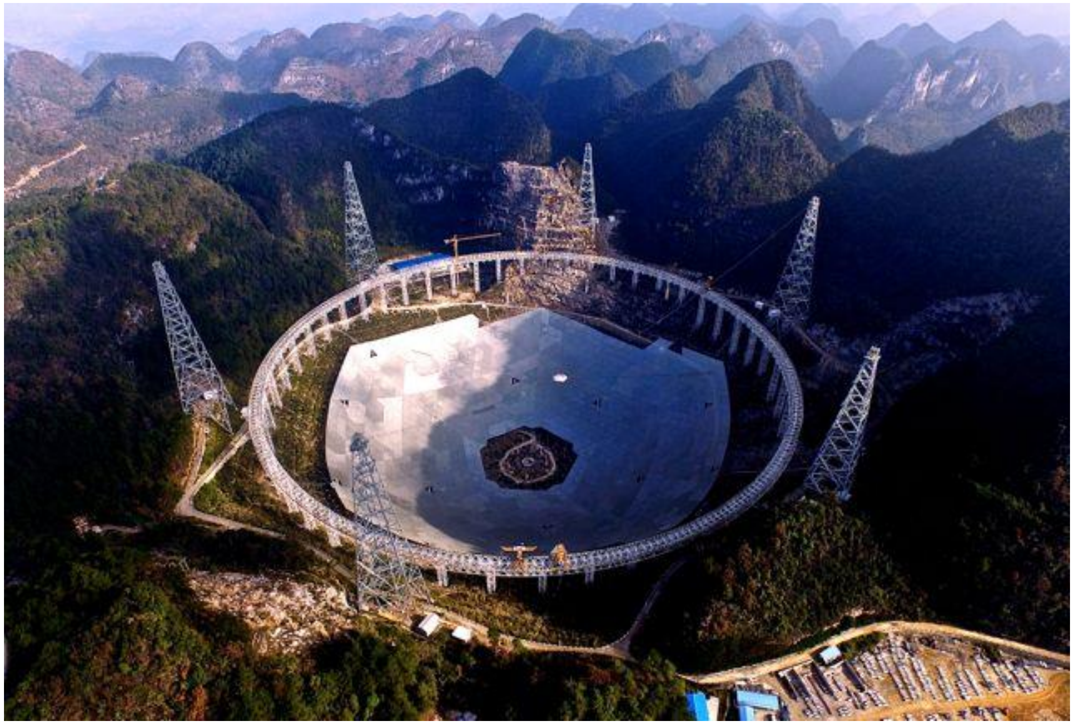
broken ring + tail
length~18' (0.75 pc)

$V_{lsr}(*)$= 29 kms^{-1}
d = 149 pc

$V_{3D}(*)$= 57 kms^{-1}

Suspicion of a bipolar outflow at center
that may shape the extended static shell (<u>Hoai et al. in prep.</u>)

New radiotelescopes



FAST (Jan. 2016)

beam of 2.9 arcminutes at 21 cm
Tsys ~ 30 K, gain ~ 16K/Jy
focal cabin with 19 beams !

→huge collecting area (7x10^4 m^2) + multiplexing (19)
→ unique potential for mapping large areas with high sensitivity

Concluding remarks

- **HI data can provide unique information on the kinematics and physical properties of the gas in extended shells around red giants.**
- **However, the emission is weak, and the confusion by galactic HI emission can be extremely challenging. Present observations are scarce.**
- **The advent of a new generation of powerful radiotelescopes, such as FAST, with collecting area ≥ 5 10^4 m^2, will open fascinating new possibilities for studying the intriguing HI structures revealed by the NRT and the VLA around AGB stars.**
- **Three different cases (Y CVn, RS Cnc, RX Lep) illustrating the need for 3D hydrodynamic modeling, incorporating the motion w.r.t. ISM and the axi-symmetry of the central source.**

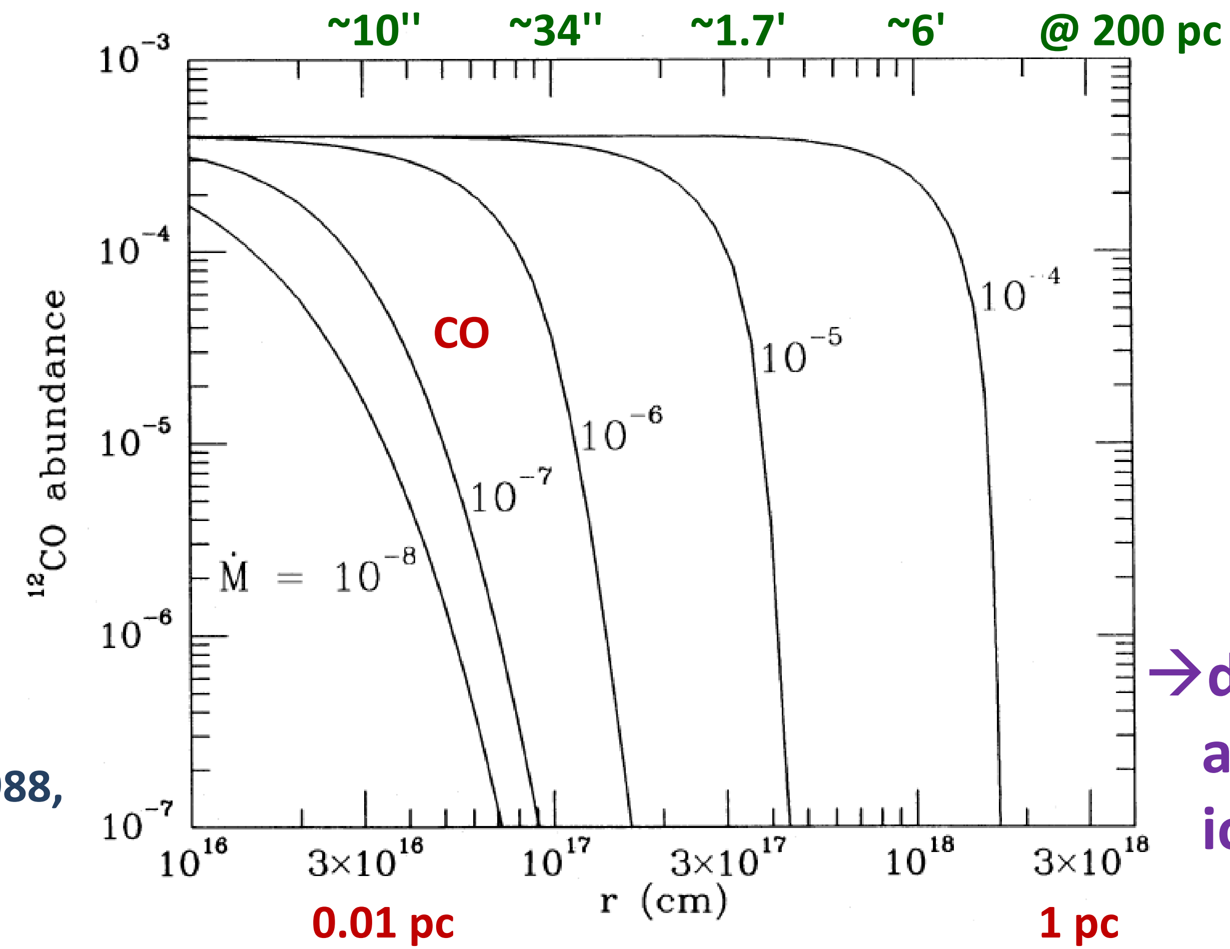
Assuming a gain of 16 K/Jy and a system temperature of 30 K, a sensitivity corresponding to 1σ=10mJy in a channel of 0.1 kms^{-1} should be reached in ~5 minutes (one beam).

A 12'x 12' field (eg. Y CVn) could be covered in 5-6 hours with a 1.5' step at this level of sensitivity allowing us to investigate kinematic effects presently not accessible in the VLA data.

In addition, at this level of sensitivity, the free flowing wind should be detectable and mapped, allowing for a complete description of the wind.

With 19 beams → enormous potential for detecting and mapping red giant extended circumstellar shells, and tails such as that of Mira (larger than the VLA field-of-view).

However, molecules are photo-dissociated by the interstellar radiation field (ISRF).

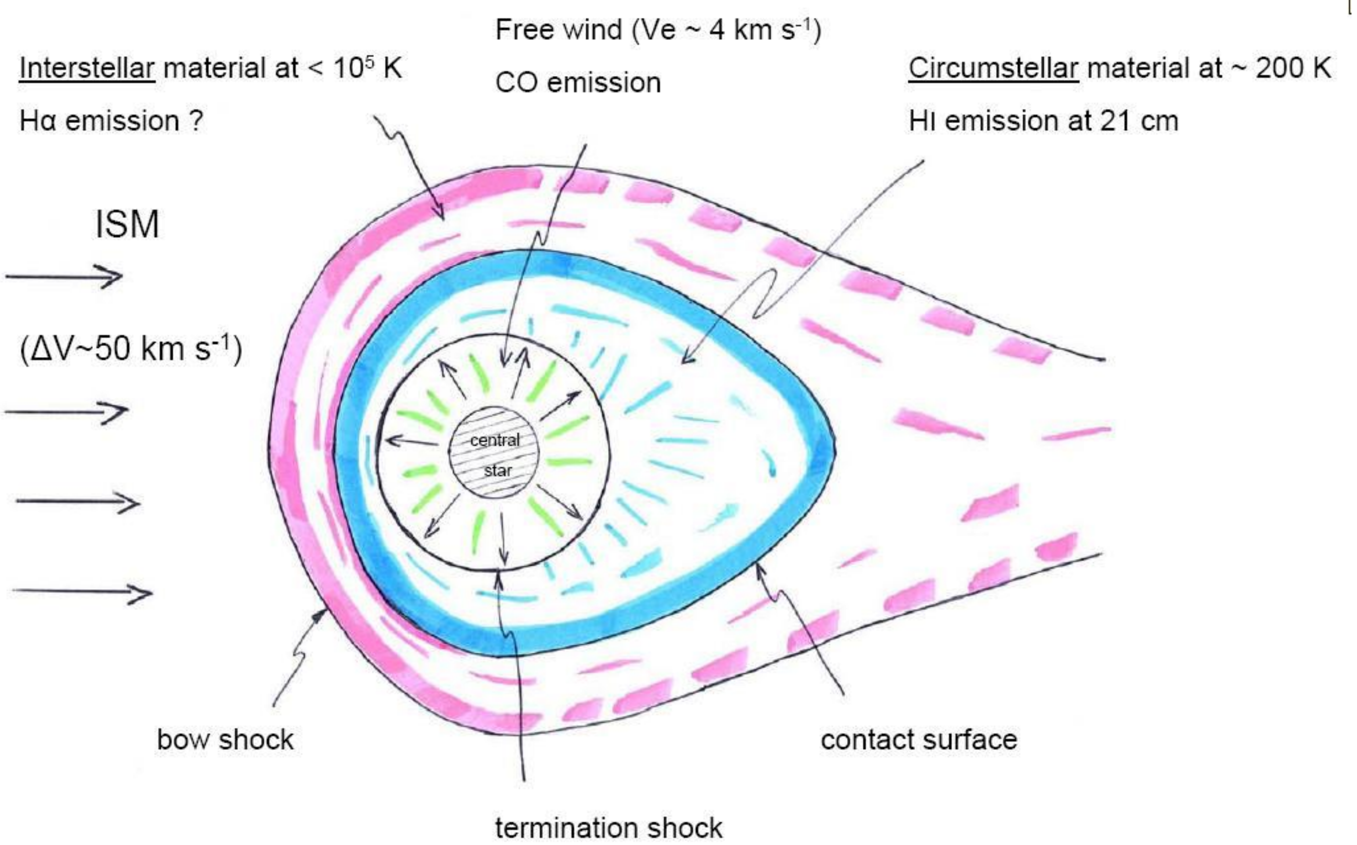


→dust
atoms (HI)
ions

Mamon et al. 1988, ApJ, 328, 707

RX Lep cartoon

- **Due to the relative motion between the stars and their ambient medium, the shells get distorted and elongated in a direction opposite to the space motion (Libert et al. 2008, A&A, 491, 789).**



drawing inspired from Figure 1 in Villaver et al. (2003)

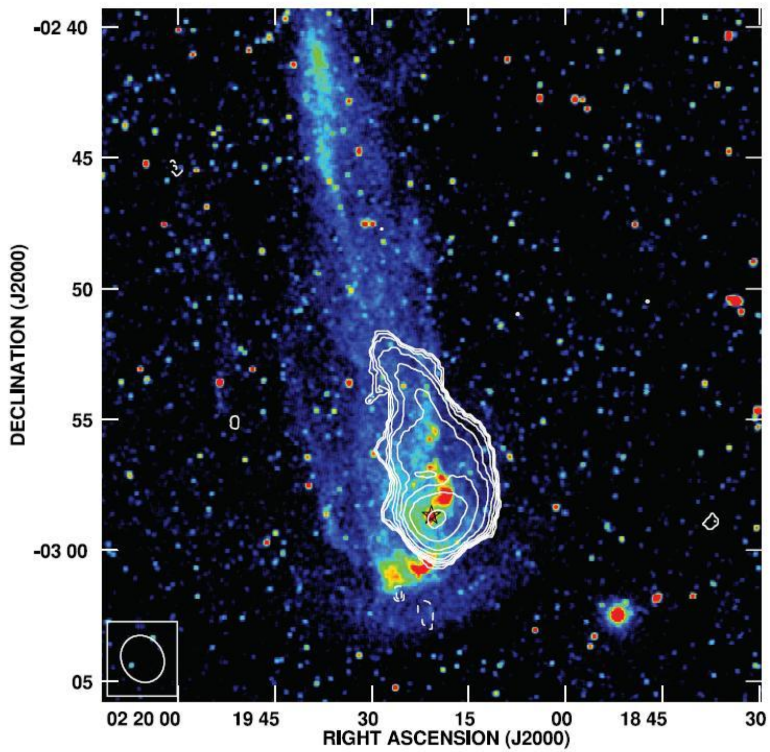
Mira Ceti

The material is progressively stripped away in the star's wake, and forms a tail that may reach a length of a few parsecs (Martin et al. 2007, Nature, 448, 781; Matthews et al. 2008, ApJ, 684, 603).

GALEX

&

VLA

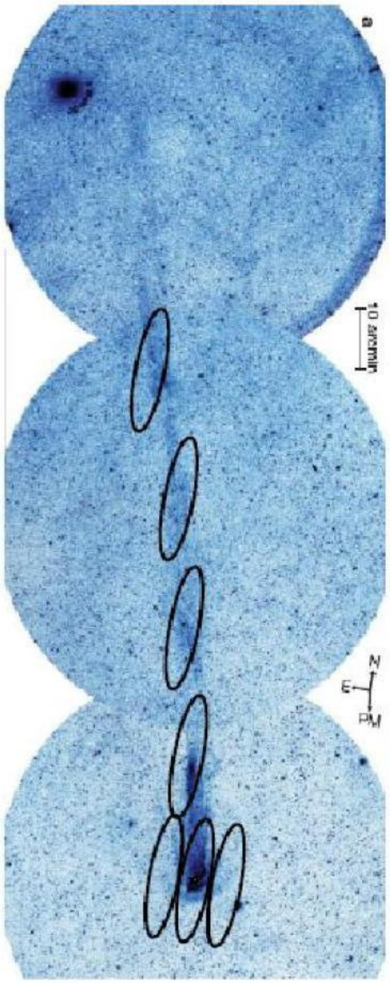


GALEX

&

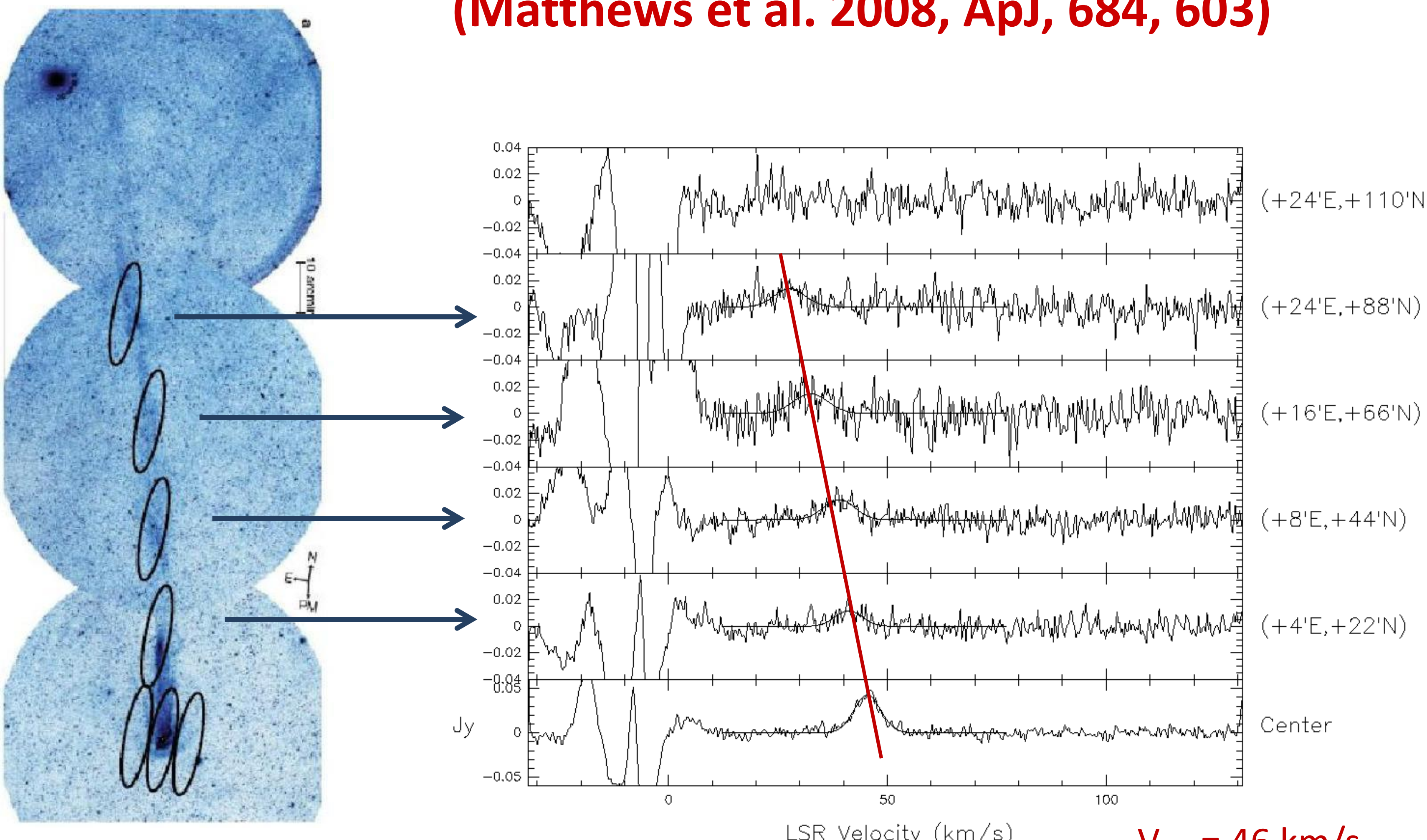
NRT

(4'x22')



« head-tail » morphology

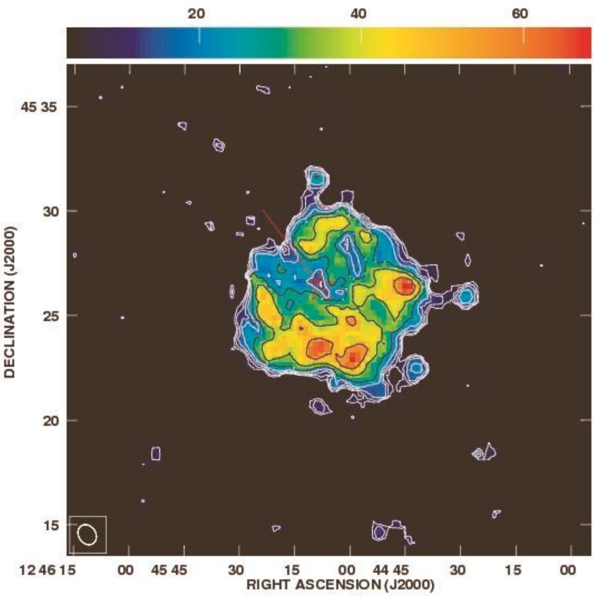
Mira Ceti
(Matthews et al. 2008, ApJ, 684, 603)

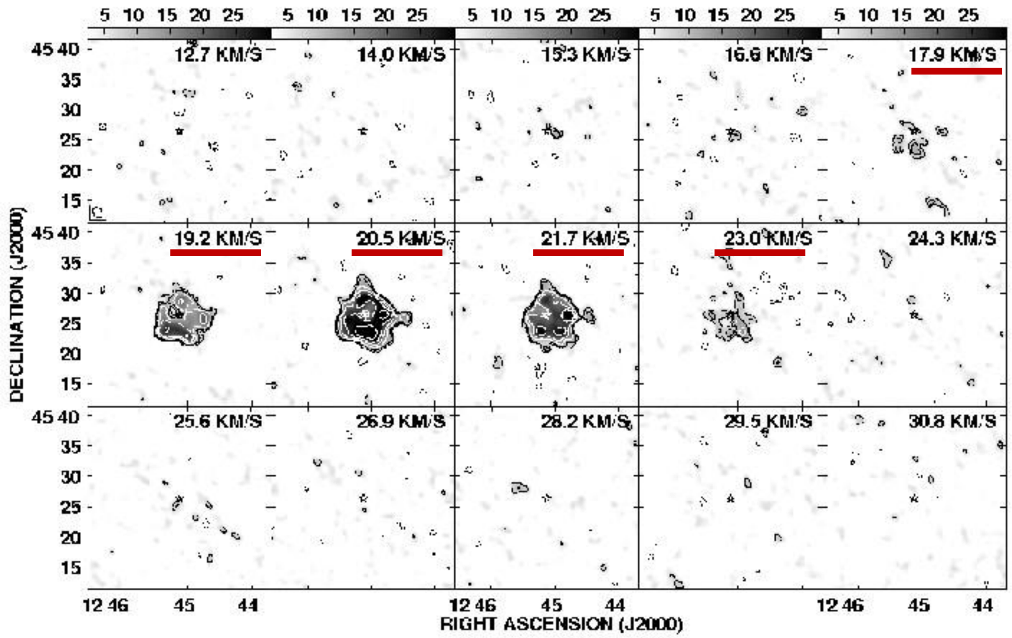


V_{CO} = 46 km/s

The peak of HI emission is drifting from 45 to 25 km/s.

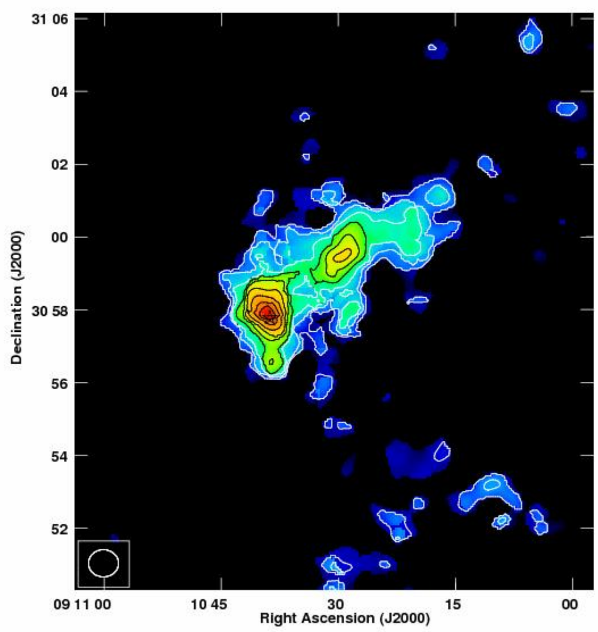
Matthews et al. 2013, AJ, 145, 97

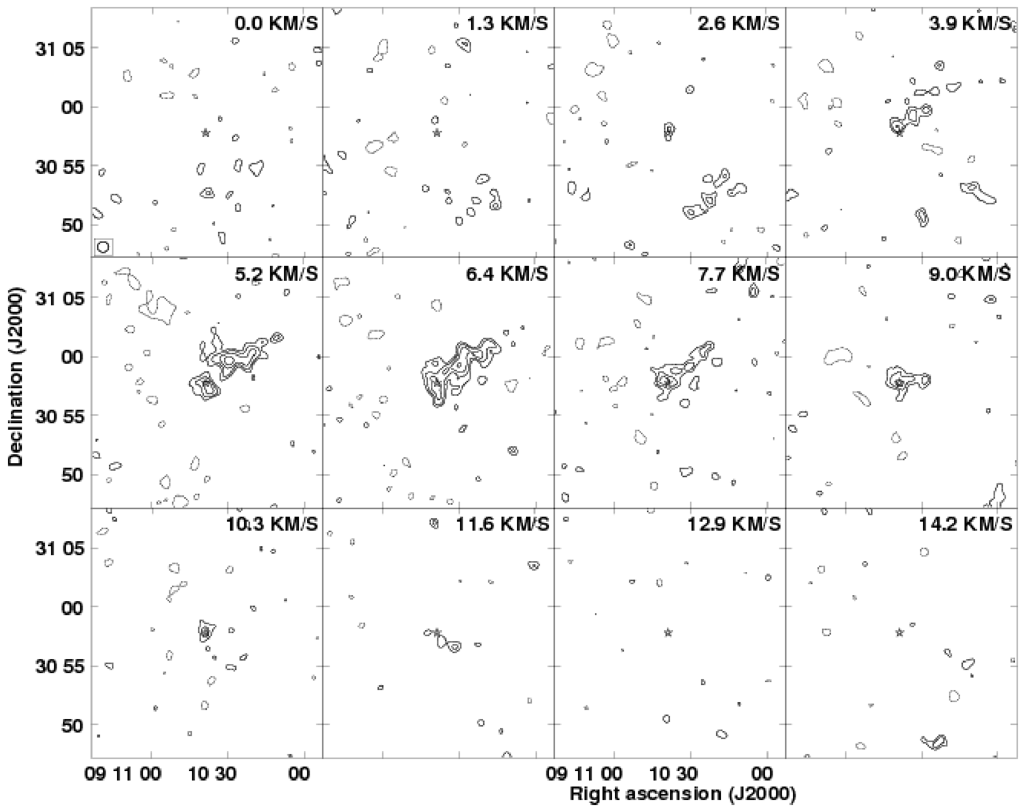




Y CVn, VLA

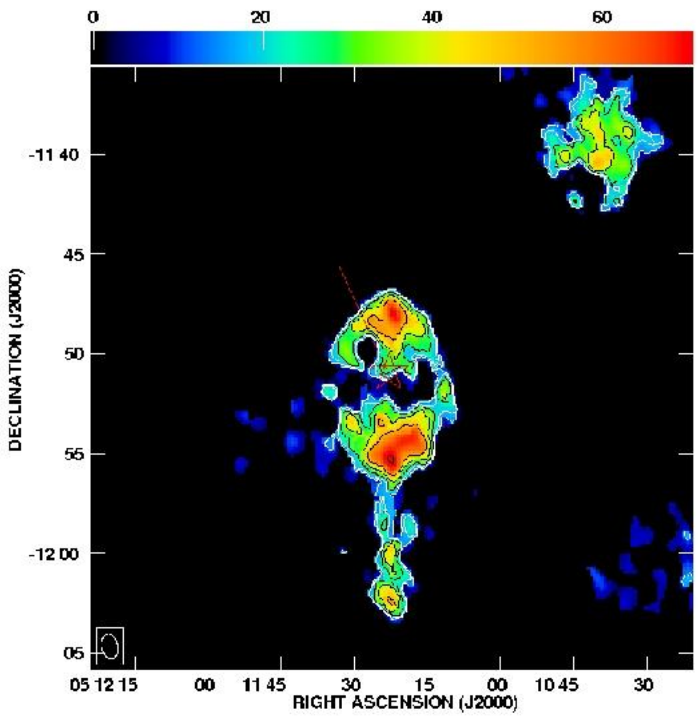
RS Cnc (Hoai et al. 2014, A&A, 565, A54)

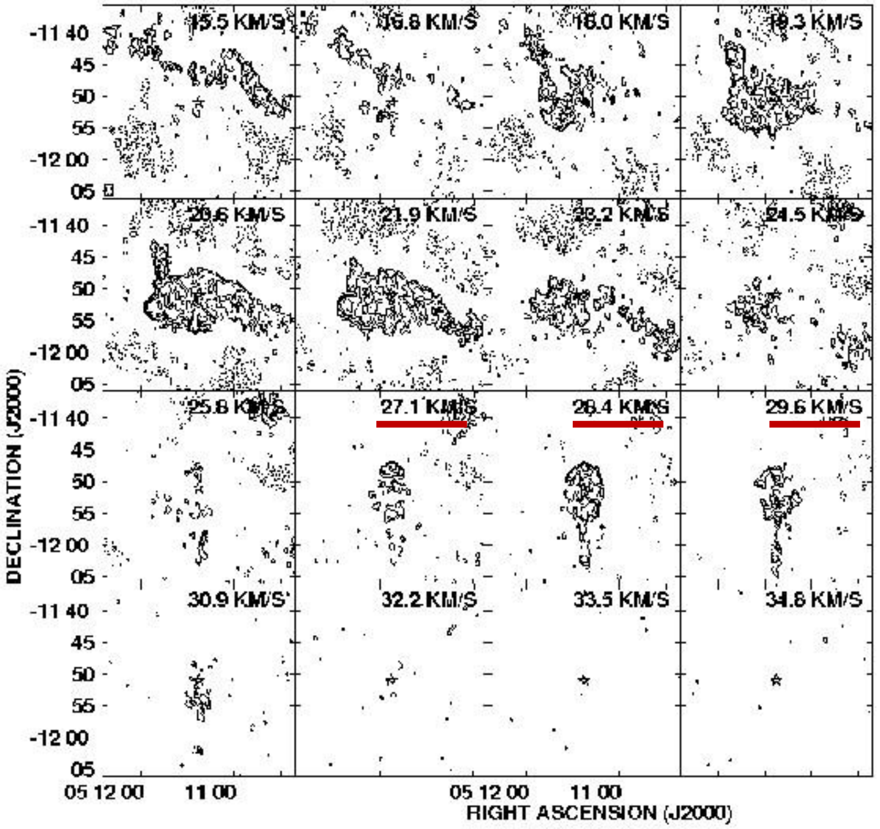




RS Cnc, VLA (C+D)

Matthews et al. 2013, AJ, 145, 97





RX Lep, VLA