The kinematics in the large-scale environment of Betelgeuse from radio HI-line observations

T. Le Bertre, E. Gérard

Observatoire de Paris

& L.D. Matthews

MIT Haystack Observatory

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HI at 21 cm

- hyperfine-structure line of hydrogen in the ground state

$$\lambda = 21 \text{ cm}, \nu = 1400 \text{ MHz}, \ A_{10} \sim 3\ 10^{-15}\ s^{-1}$$

- generally optically thin
- $\nu = 1.4$ 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**
- **circumstellar HI should be protected by the surrounding ISM**

Hydrogen in HI or H_2 ?

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

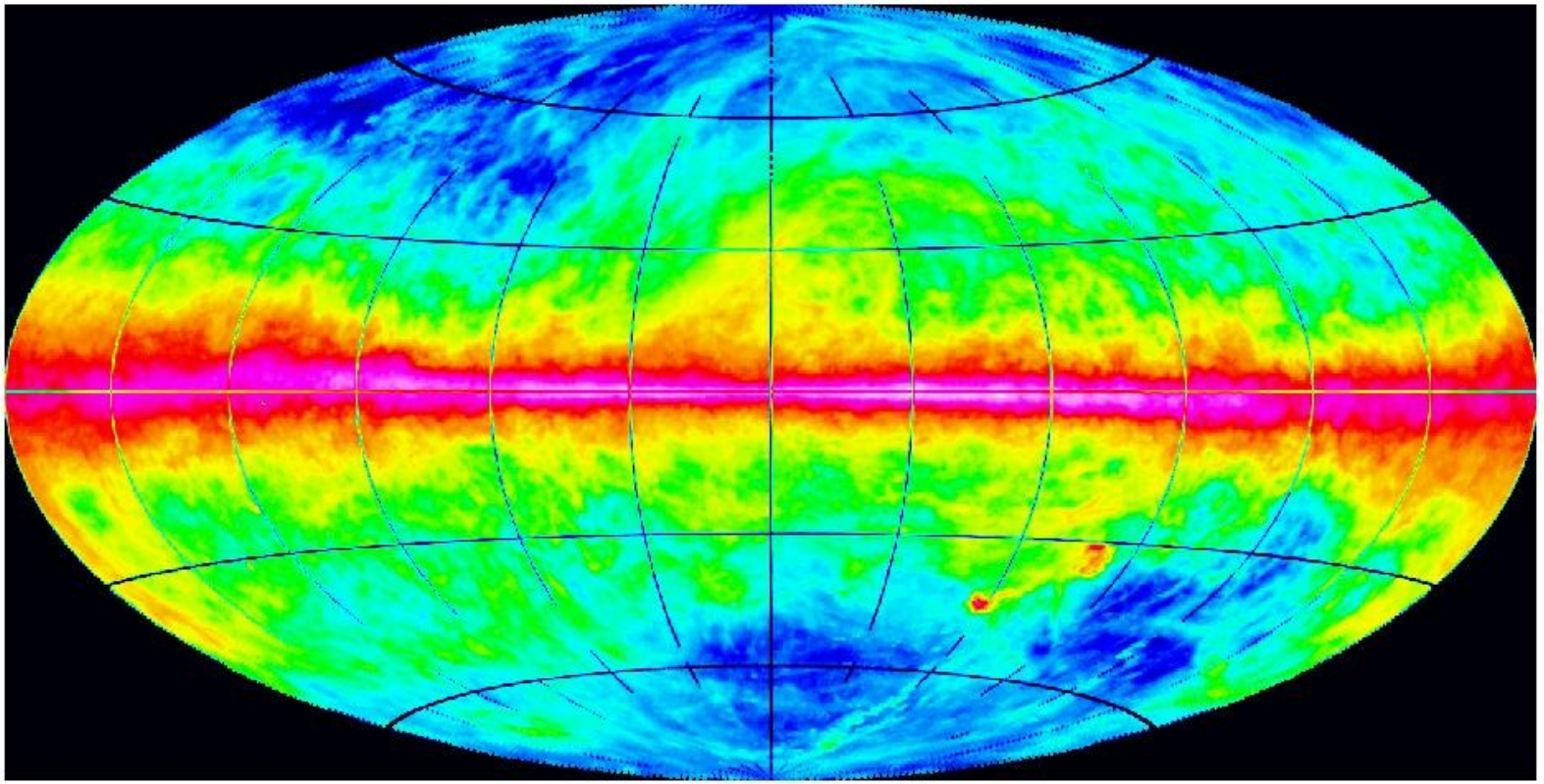
- **if T_{eff} > 2500 K, all hydrogen in the atmosphere should be atomic;**

- **if T_{eff} < 2500 K, all hydrogen should be molecular,**

  but H_2 should be photodissociated at r ~ few 10^{17} cm

Betelgeuse : T_{eff} ~ 3641 +/- 53 K (Perrin et al., 2004, A&A, 418, 675)

main difficulty : HI is ubiquitous



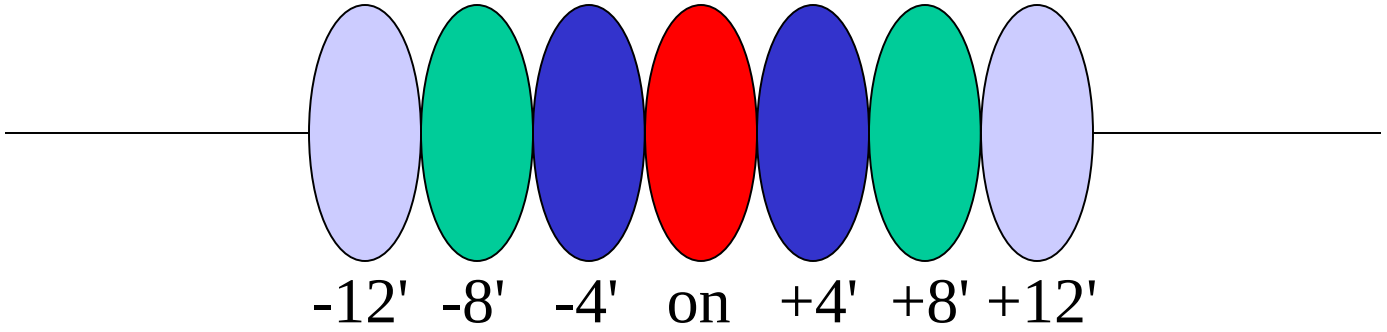
Kalberla et al., 2005, A&A, 440, 775; total galactic HI

-400 km s^{-1} < v < + 400 km s^{-1}

- **In 2000, we started a programme of observations of evolved stars with the Nançay Radiotelescope**

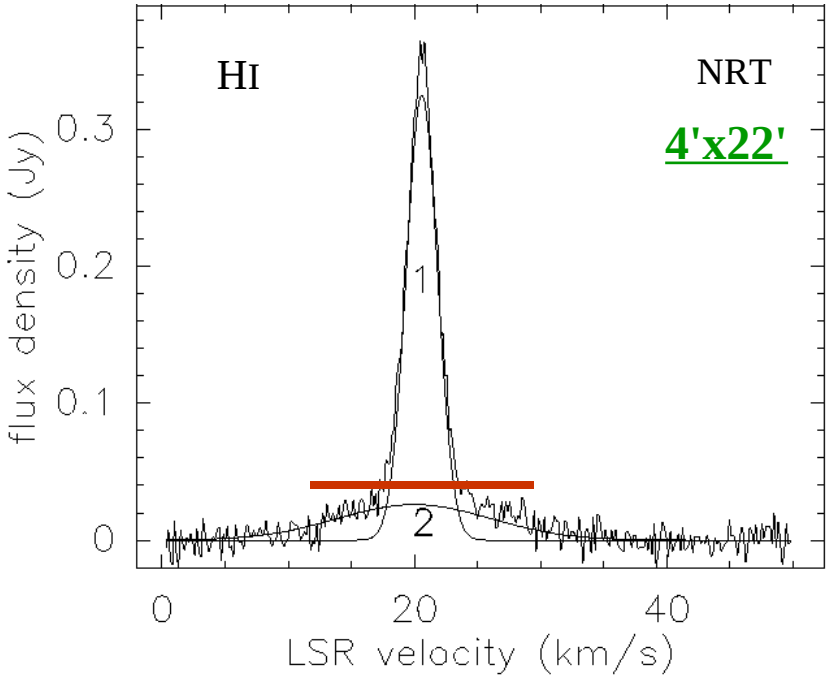
  (160m by 30m → 4'x22' at λ=21 cm)

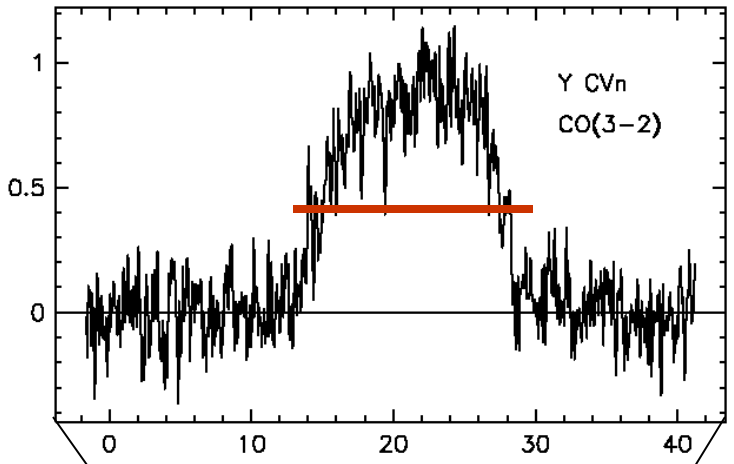
- **The spectra are obtained in the position-switched mode of observation (+/- 2' in RA, +/- 4' in RA, +/- 6', etc.).**



- **several detections that showed emission lines with line profiles narrower than in CO**

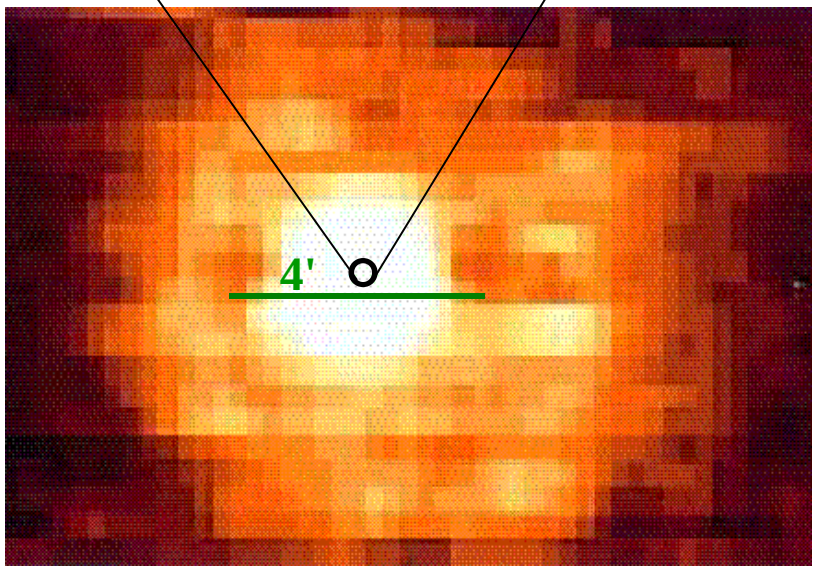
Y CVn: b^{II} = 72° (Le Bertre & Gérard 2004, A&A 419, 549)





Knapp et al. 1998, ApJS 117, 209

Φ ~ 10'' ~ 0.01 pc



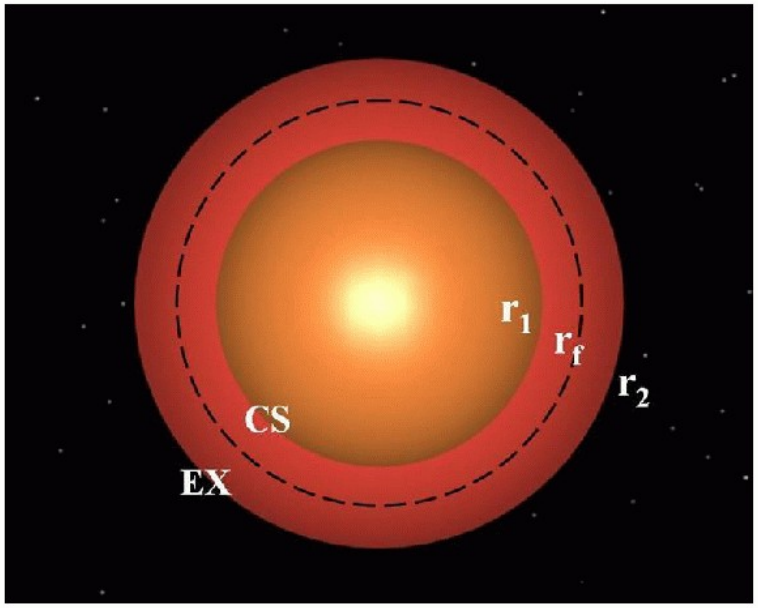
Slowing down of the circumstellar outflow

Izumiura et al. 1996, A&A, **315**, L221 →

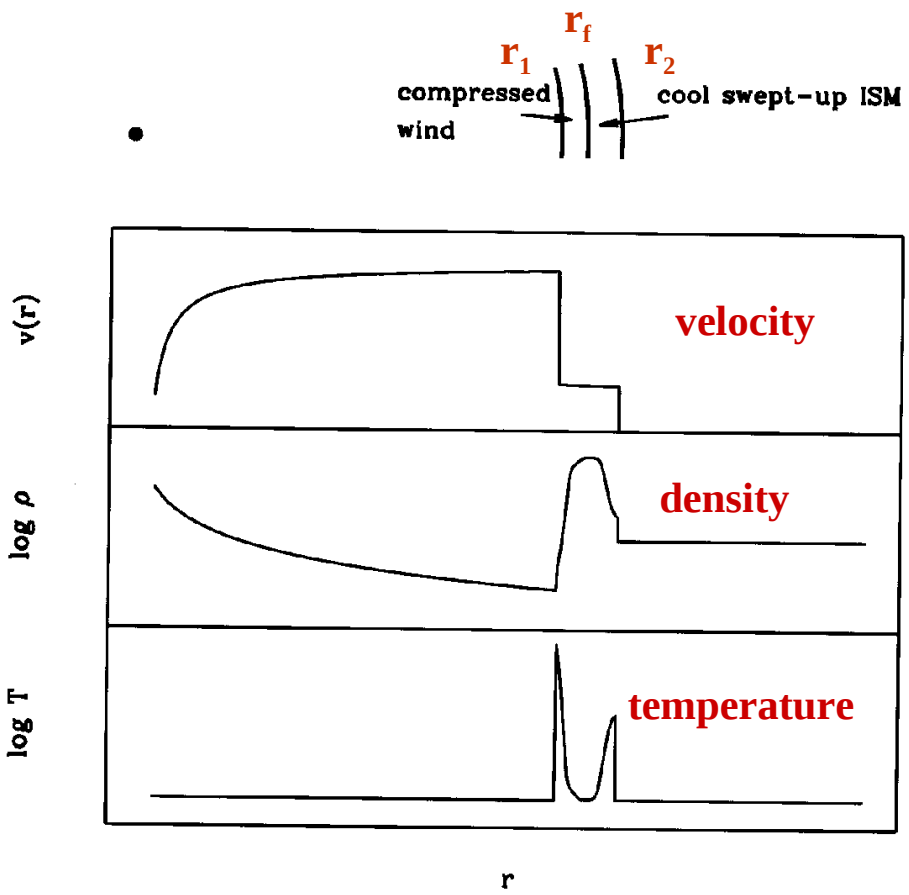
(ISOPHOT 90 μm : 12 x 8 arcmin²; Φ ~8', or 0.5 pc)

[dust emission]

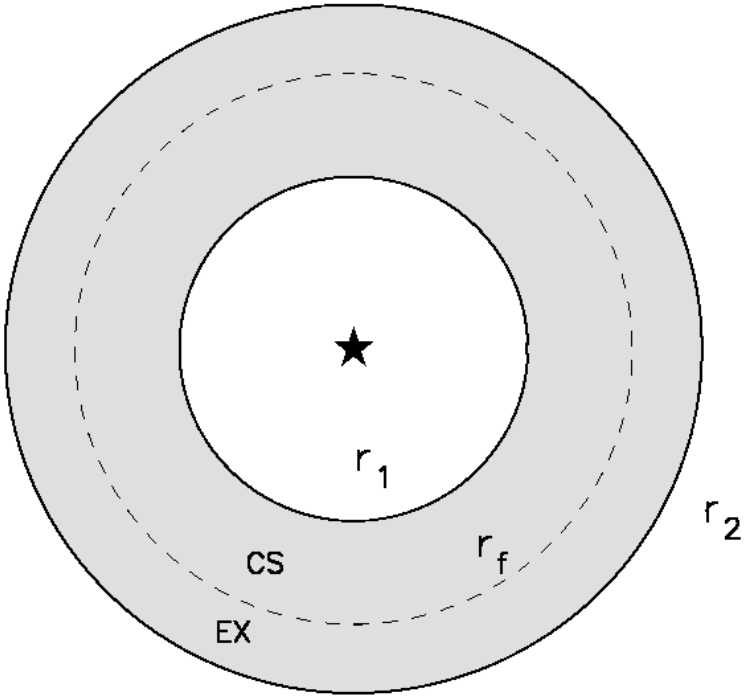
A new view on the “detached shells” (Young et al. 1993): the matter in the shell is the sum of slowed down circumstellar material and accelerated external (ISM ?) material



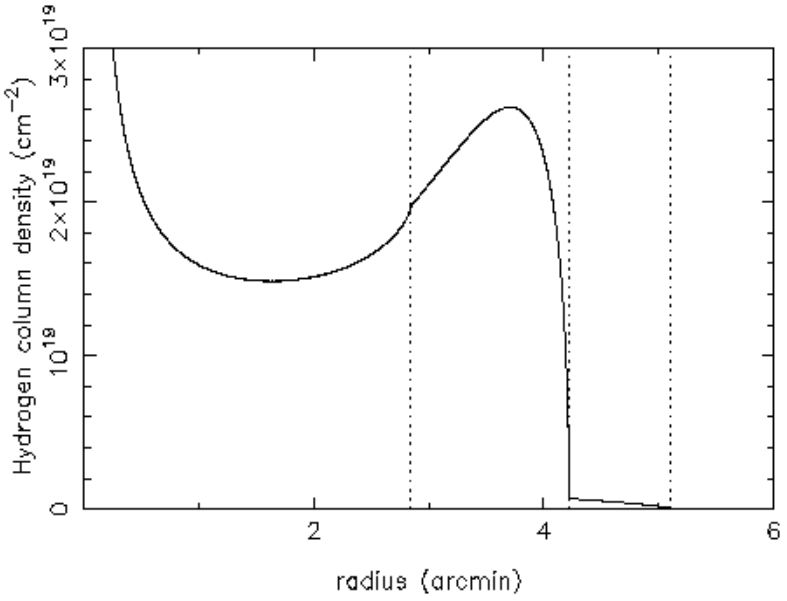
Libert’s PhD thesis (2009)



Lamers & Cassinelli (2004)
“Introduction to Stellar Winds”

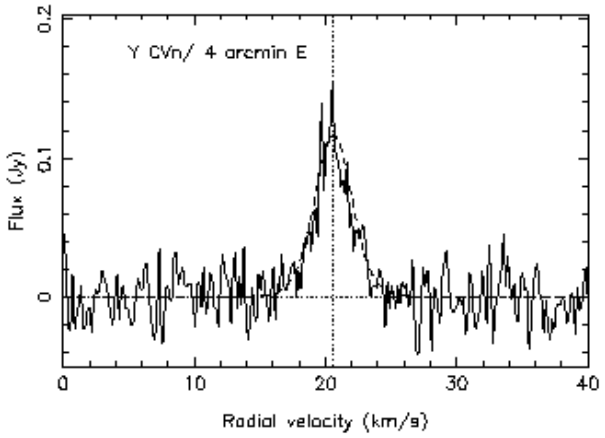


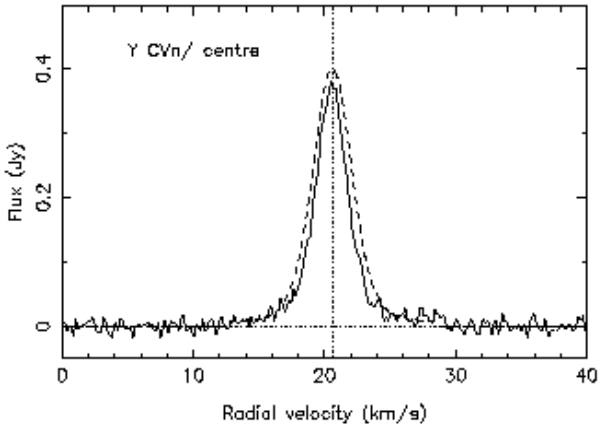
(Libert et al. 2007, MNRAS, 380, 1161)

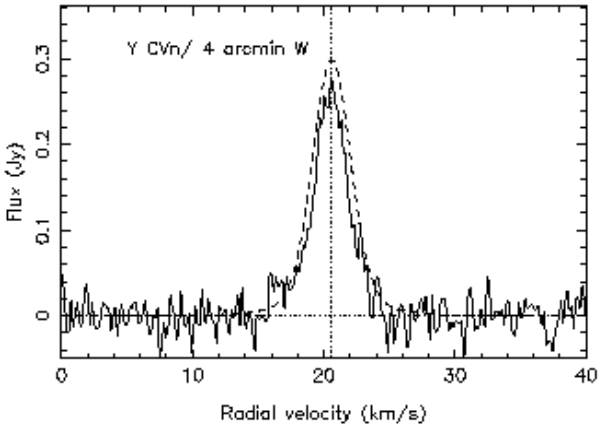


~0.8 10^{-7} M_{sol} yr^{-1} (H) during 4.5 10^5 years

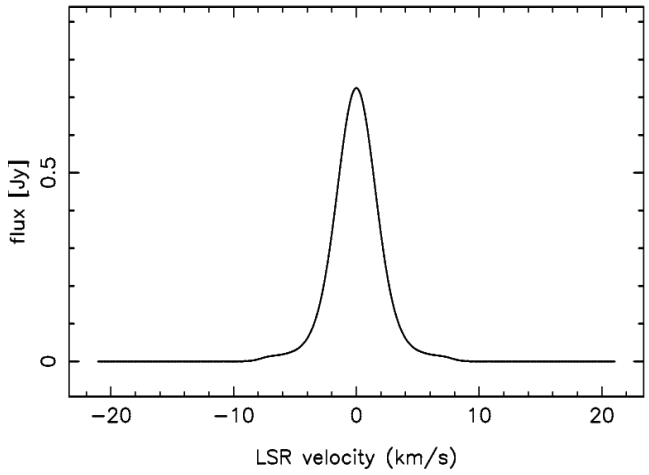
$T_{detached\ shell}$ ~ 100-2000 K



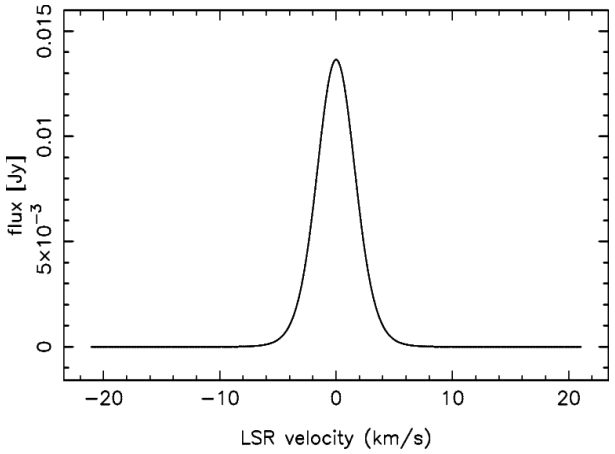


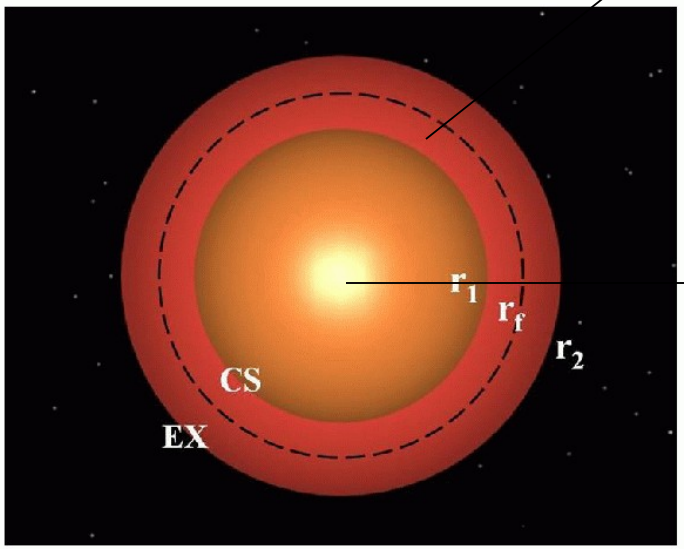


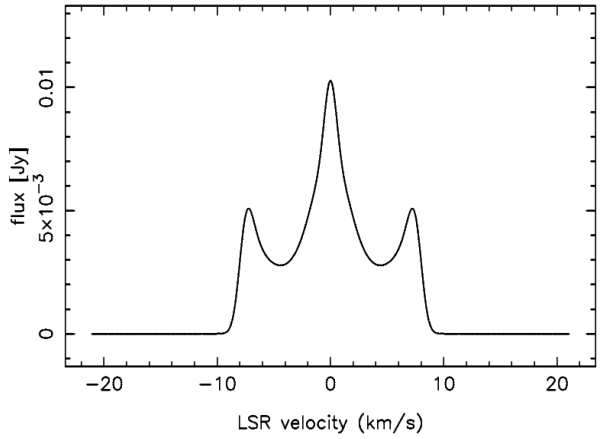
unresolved shell (all)



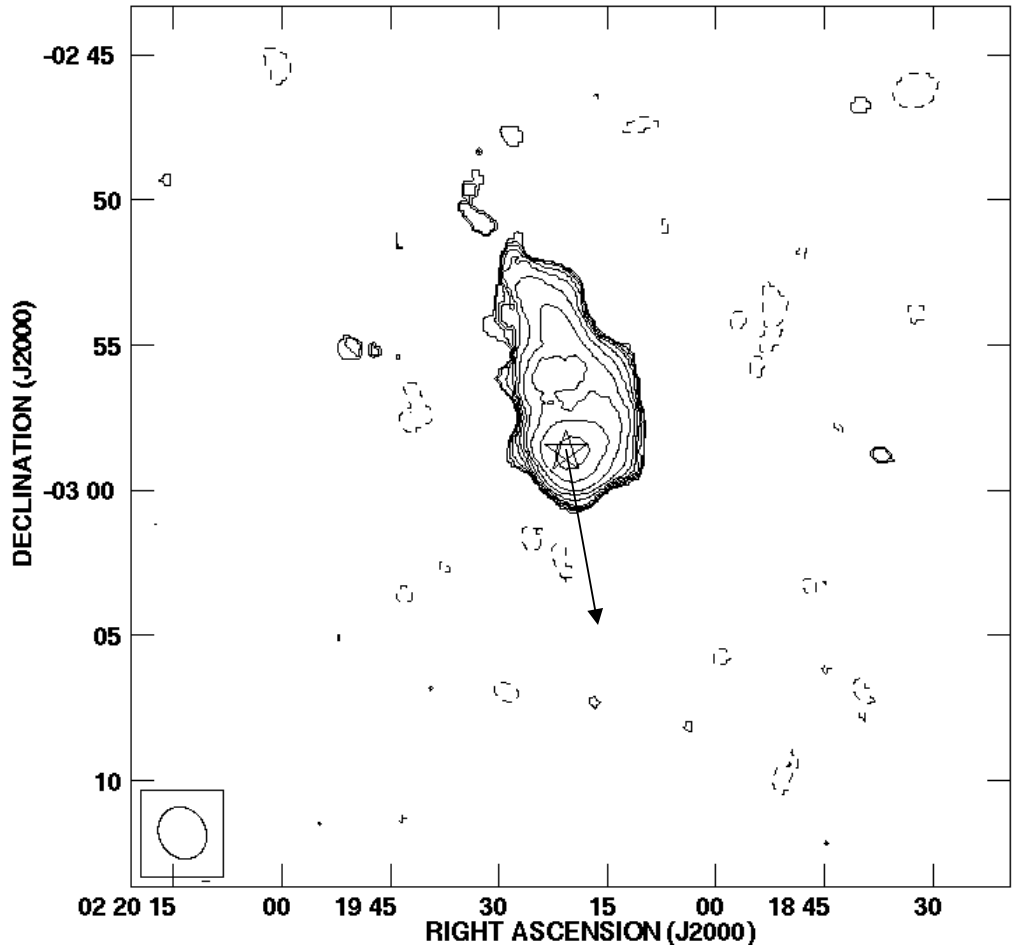
spatially resolved shell







HI map of Mira obtained at the VLA by Matthews et al. (2008, ApJ, 684, 603)



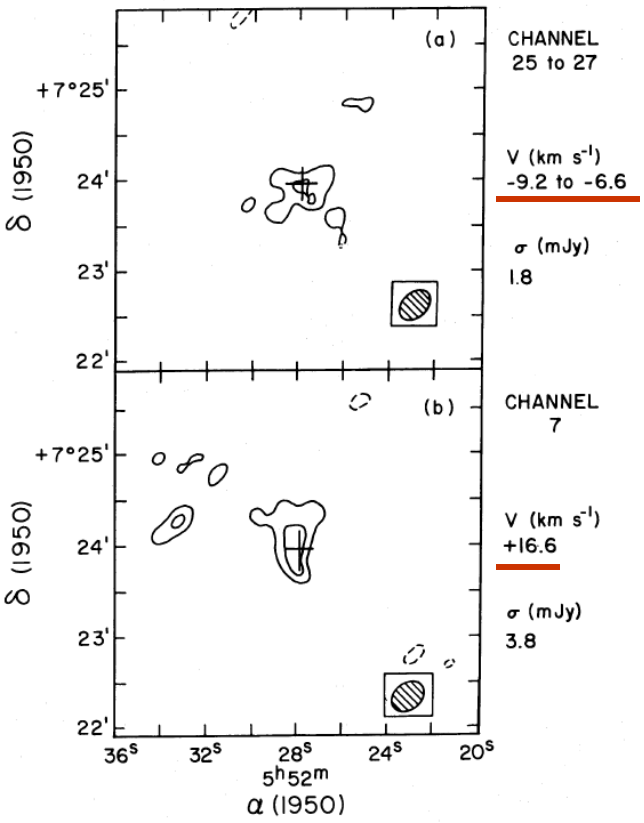
HI observations of Betelgeuse

- **VLA data obtained in the C-configuration (0.08 – 3.2 km) by Bowers & Knapp (1987, ApJ, 315, 305).**

  → emission peaks at ~ -9 and +16 km s^{-1}

  Φ ~ 2 arcmin

  dM/dt = 2.2 10^{-6} Msol yr^{-1} (200 pc)



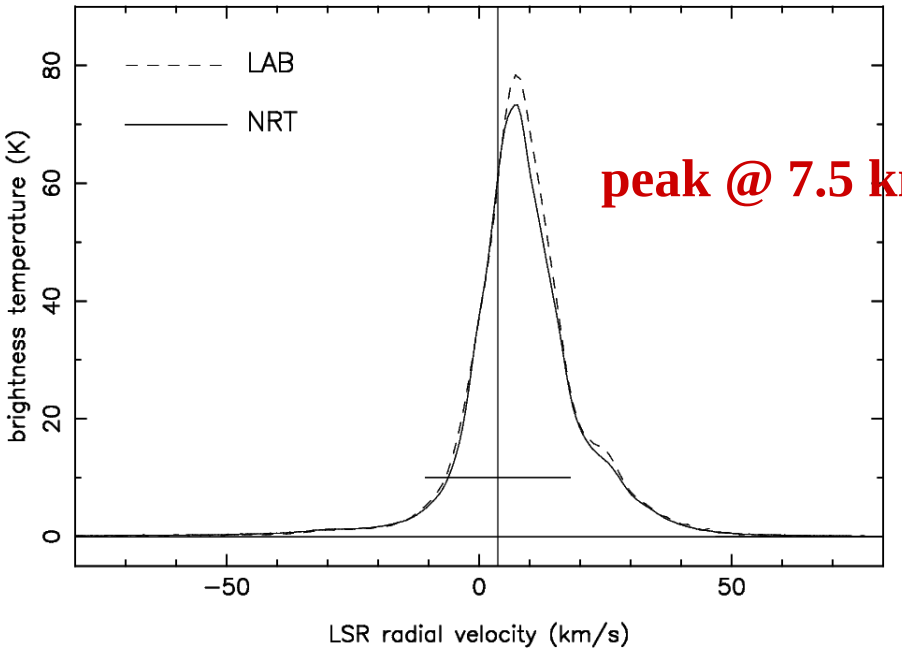
- **VLA data in the D-configuration (0.035 – 1.0 km; 2010)**

+ NRT data obtained in the position-switched mode of observation.

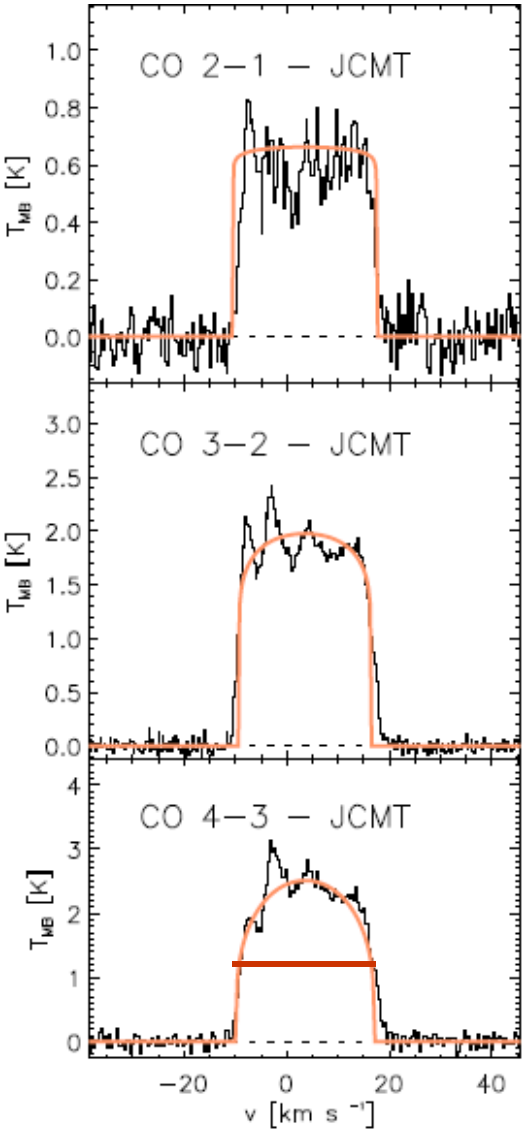
→ Le Bertre et al. (2012, MNRAS, 422, 3433)

Betelgeuse

- **Galactic latitude : b^{II} = -9°**
- **V_* = 3.7 +/- 0.4 km s^{-1}**
- **V_{exp}= 14.3 km s^{-1} (radio CO observations)**



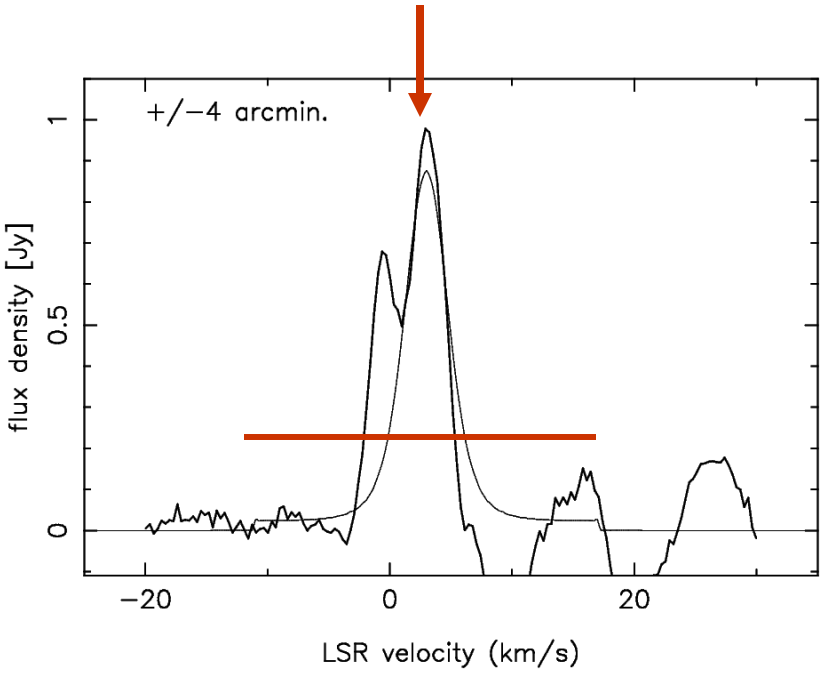
peak @ 7.5 km s^{-1}

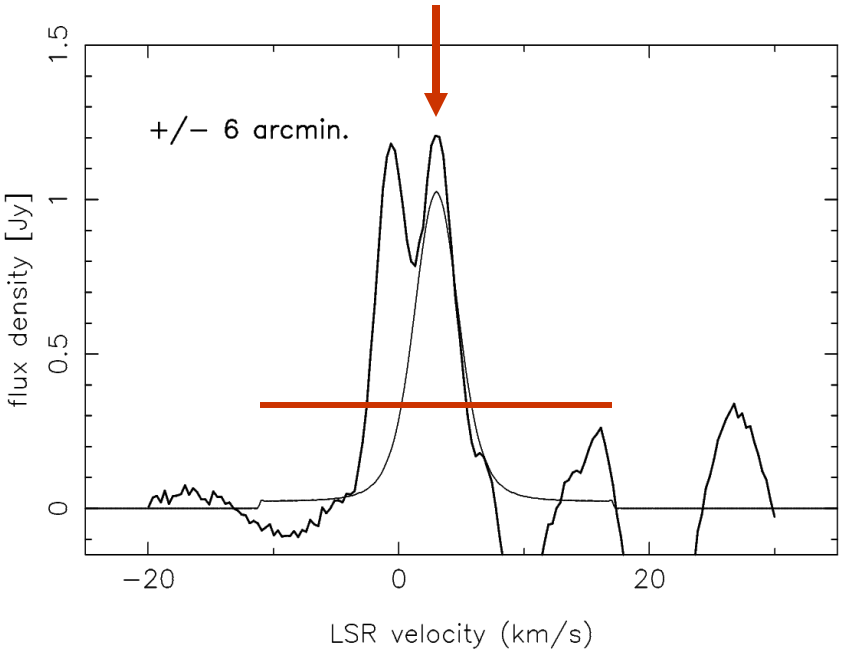


ISM on the line of sight

De Beck et al. (2010, A&A, 523, A18)

NRT position-switched spectra + model



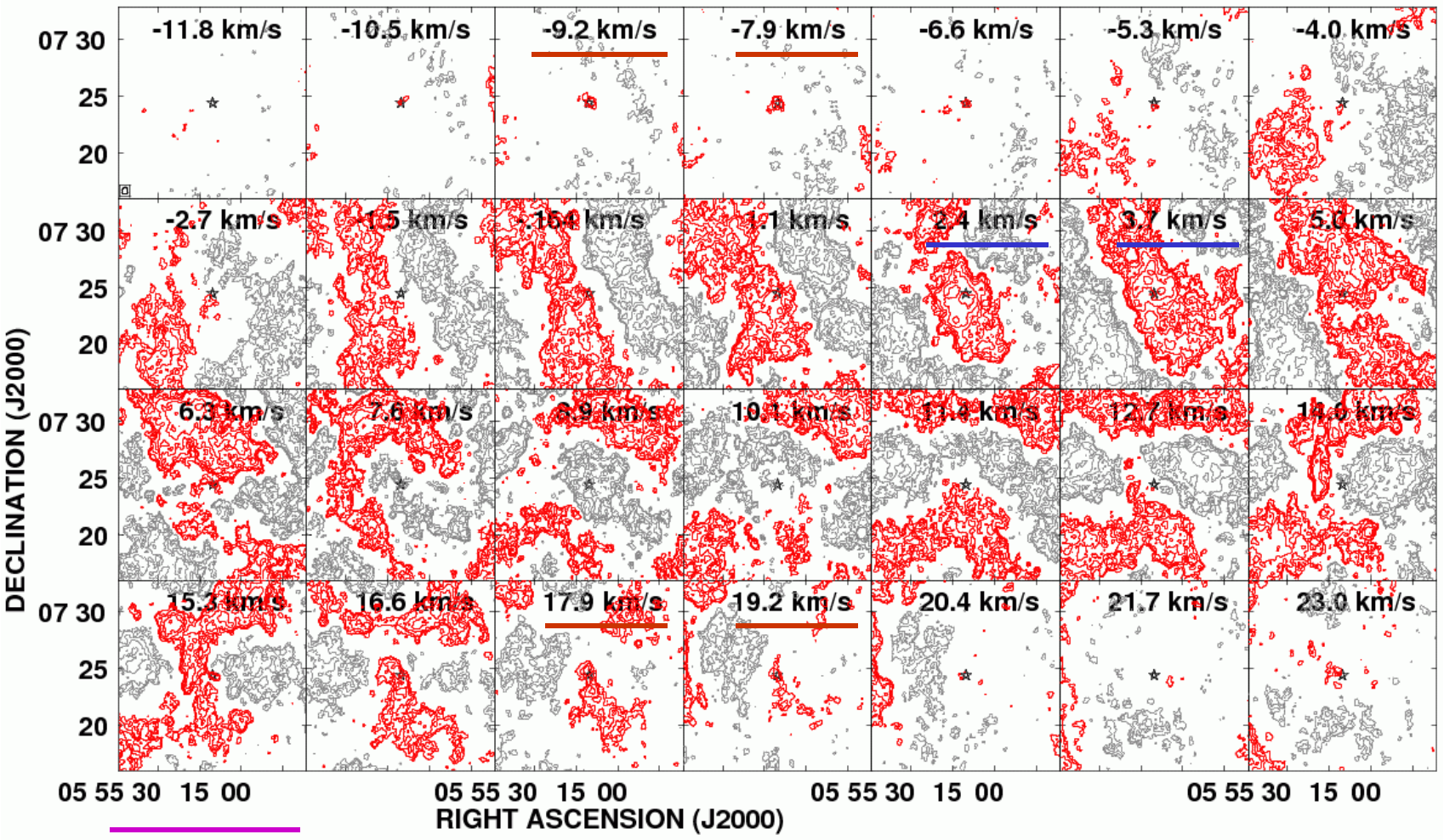


- V_{lsr} (HI) = 3 km s^{-1}
- Φ ~ 4 arcmin
- FWHM ~3 km s^{-1}

- integrated intensity ~ 5 Jy km s^{-1}
  → 0.05 Msol in HI (@200 pc)

α Ori, VLA C+D, all baselines

channel maps from –11.8 to + 23 km s^{-1}

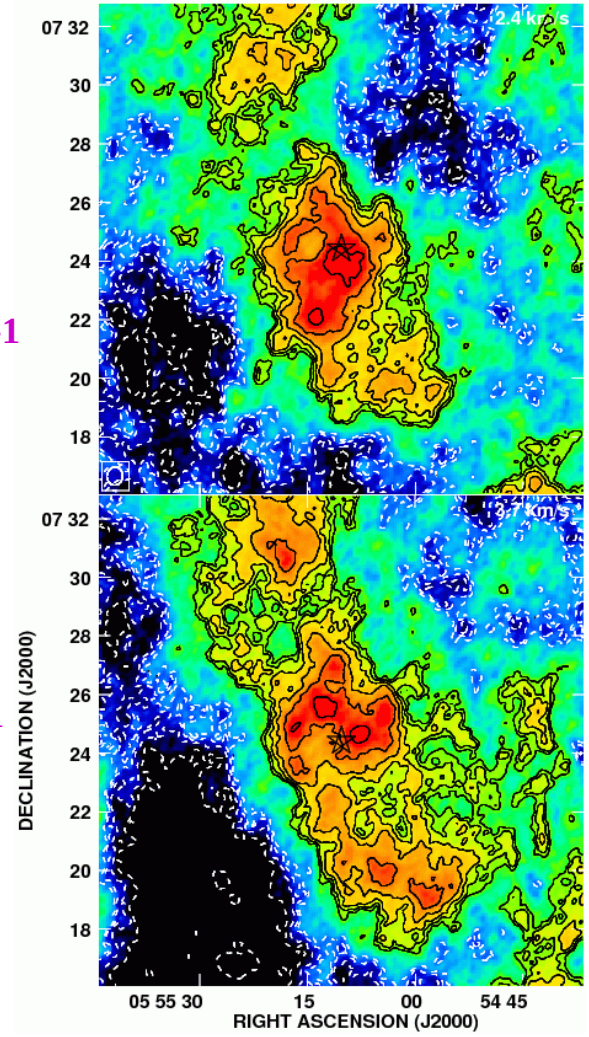


channel spacing = 1.29 km s^{-1}

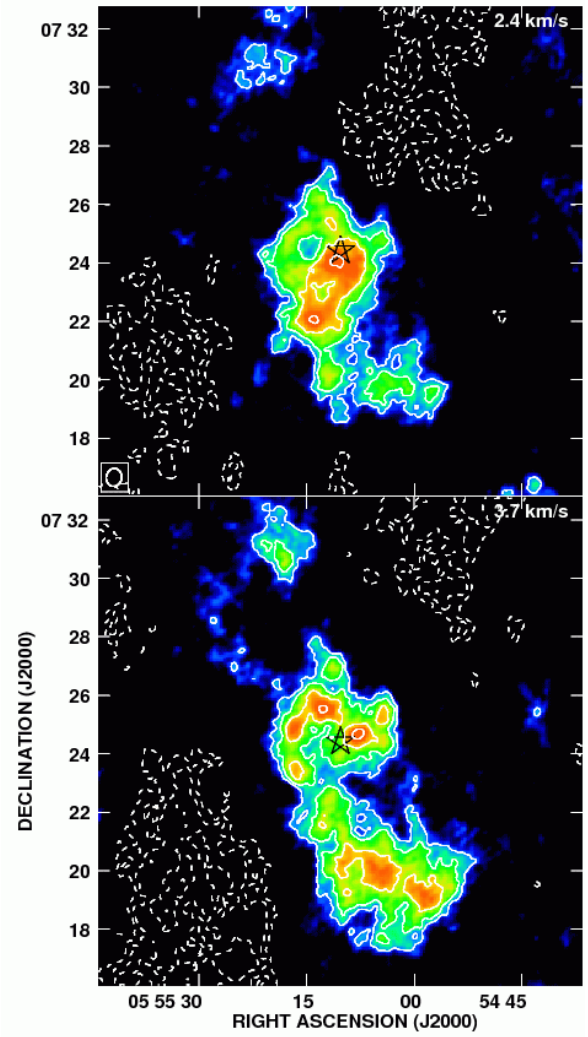
17'

2.4 km s^{-1}

3.7 km s^{-1}

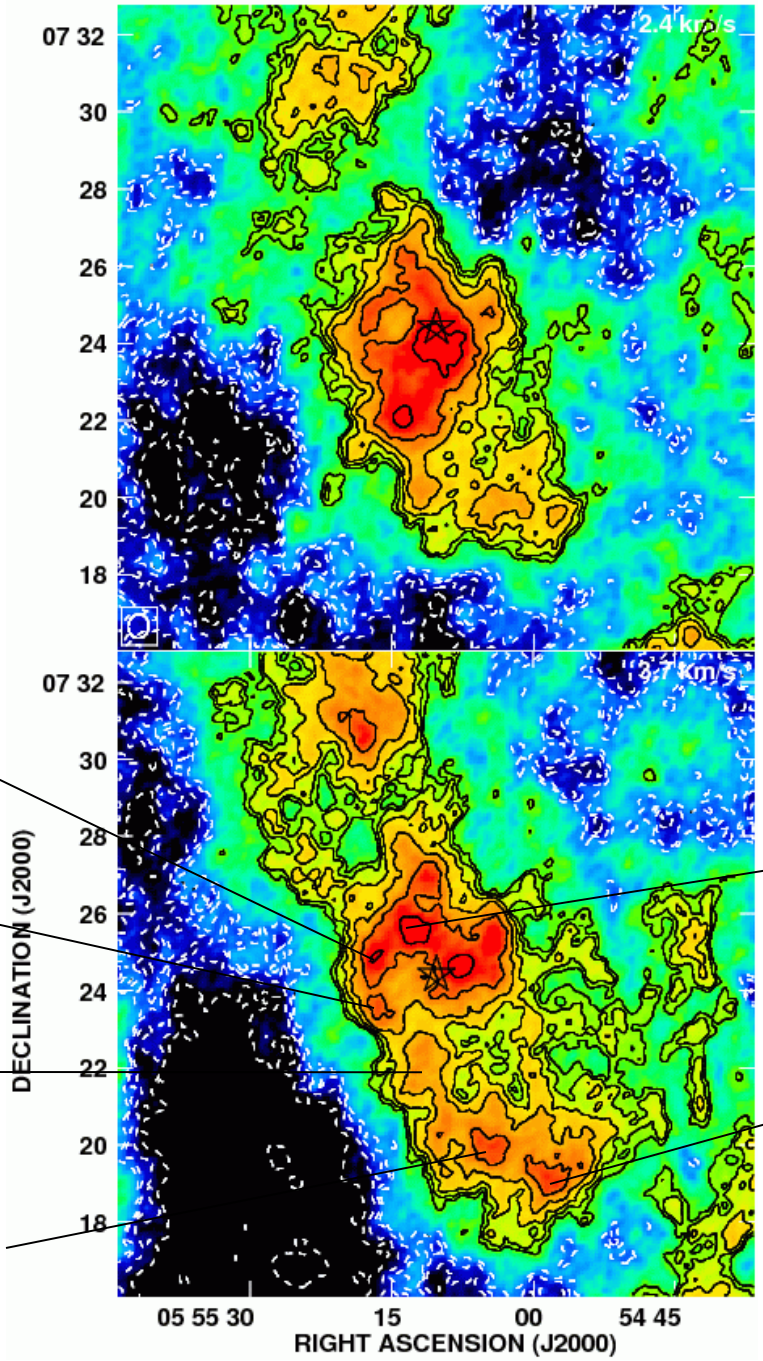


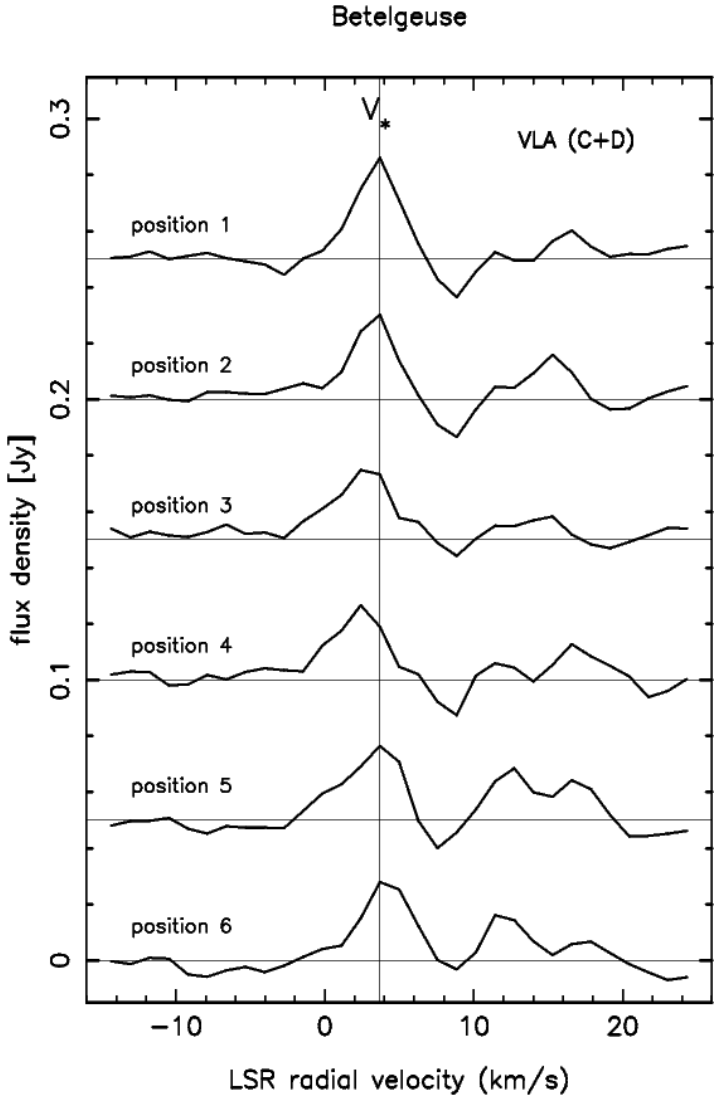
all baselines



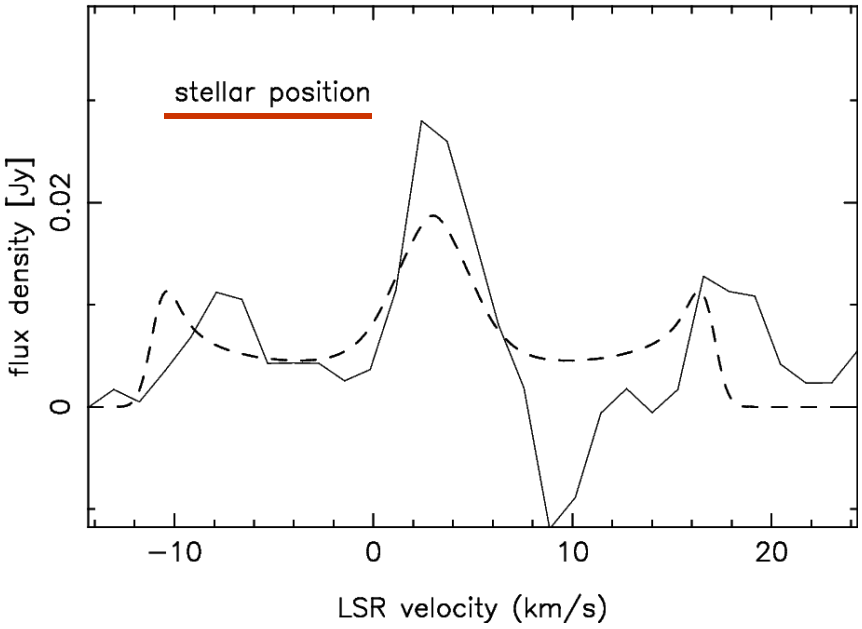
baselines > 0.2 kλ (0.042 km)

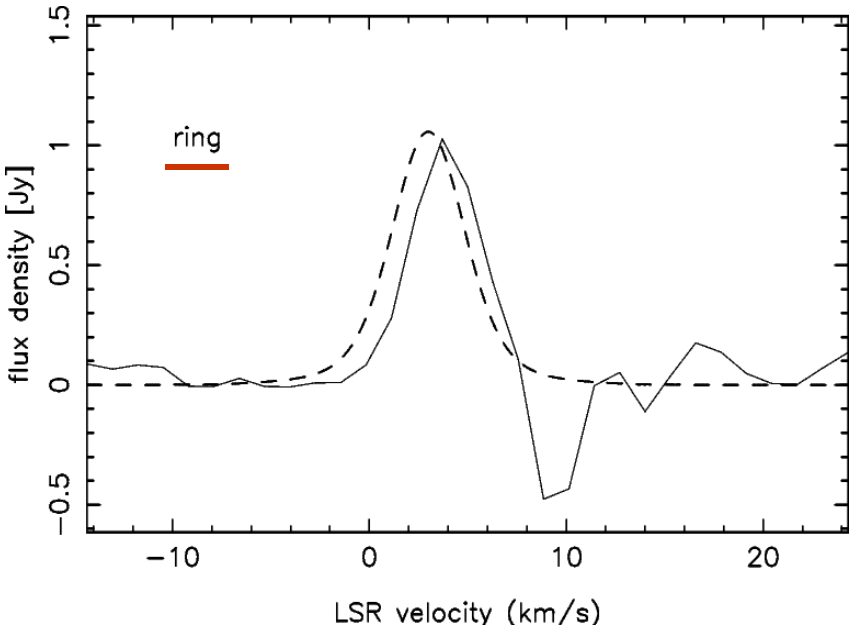
Φ = 34 arcsec


2.4 km/s
07 32
30
28
26
24
22
20
18
07 32
30
28
26
24
22
20
18
DECLINATION (J2000)
05 55 30
15
00
54 45
RIGHT ASCENSION (J2000)
1
2
3
4
5
6


Betelgeuse
V*
VLA (C+D)
position 1
position 2
position 3
position 4
position 5
position 6
flux density [Jy]
0.3
0.2
0.1
0
−10
0
10
20
LSR radial velocity (km/s)

α Ori, VLA C+D





diameter = 34 arcsec

inner radius = 80 arcsec
external radius = 160 arcsec

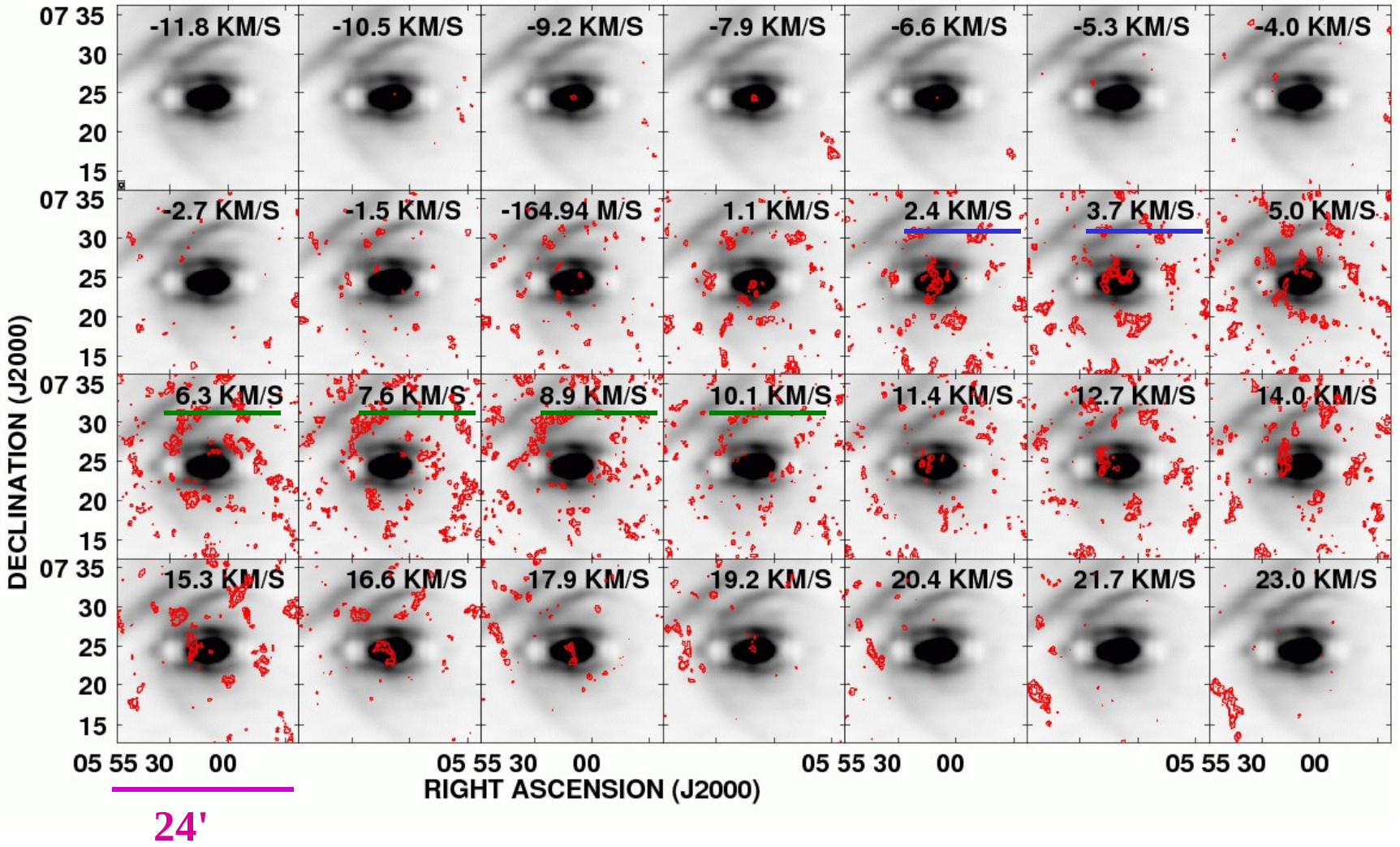
Implication : detection of an HI compact source

- diameter ~4 arcmin (~ 0.24 pc)
- coincident with Betelgeuse
- with same radial velocity
- emission in a narrow spectral line (FWHM~3 km s^{-1})

HI detached shell model

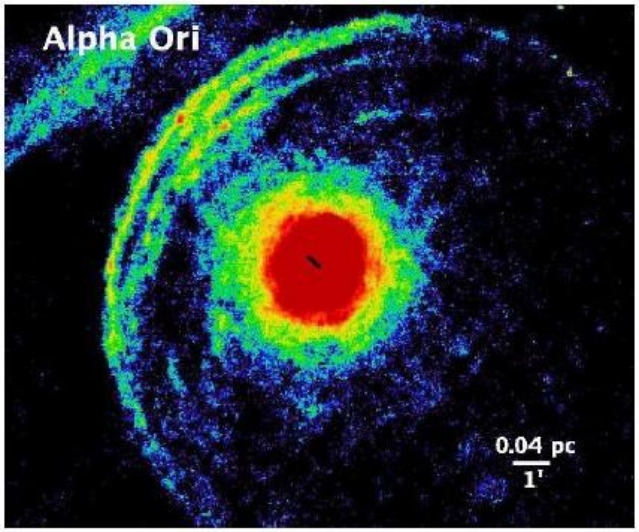
- d = 200 pc
- dM/dt = 1.2 10^{-6} M_{sol} yr^{-1}
- duration = 8 10^{4} yr
- V_{exp} = 14 km s^{-1}
- r_{in} = 0.12 pc (2.0 arcmin)
- r_{out} = 0.18 pc (3.0 arcmin)
- T ~ 6000 - 200 K

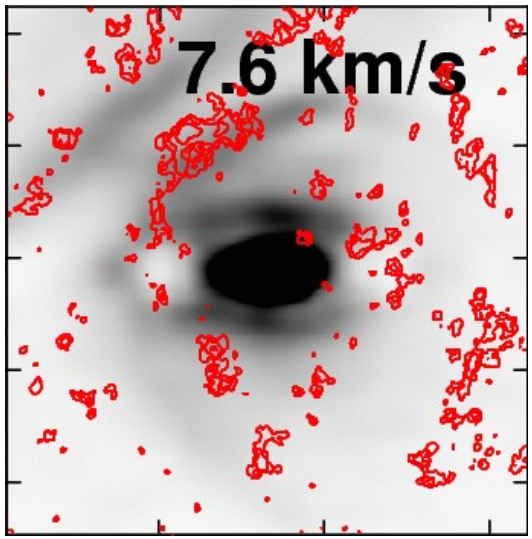
α Ori, VLA C+D, baselines > 0.4 kλ (0.084 km)



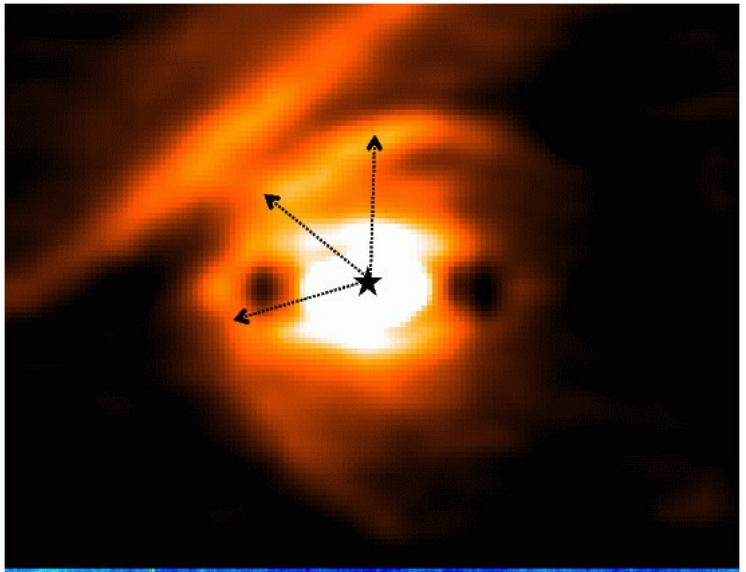
background : IRAS image at 60 μm

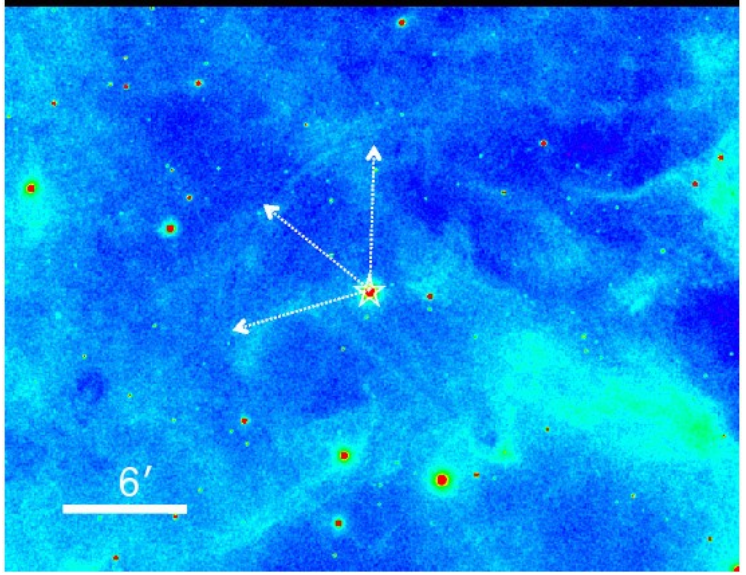
Herschel (70 μm)





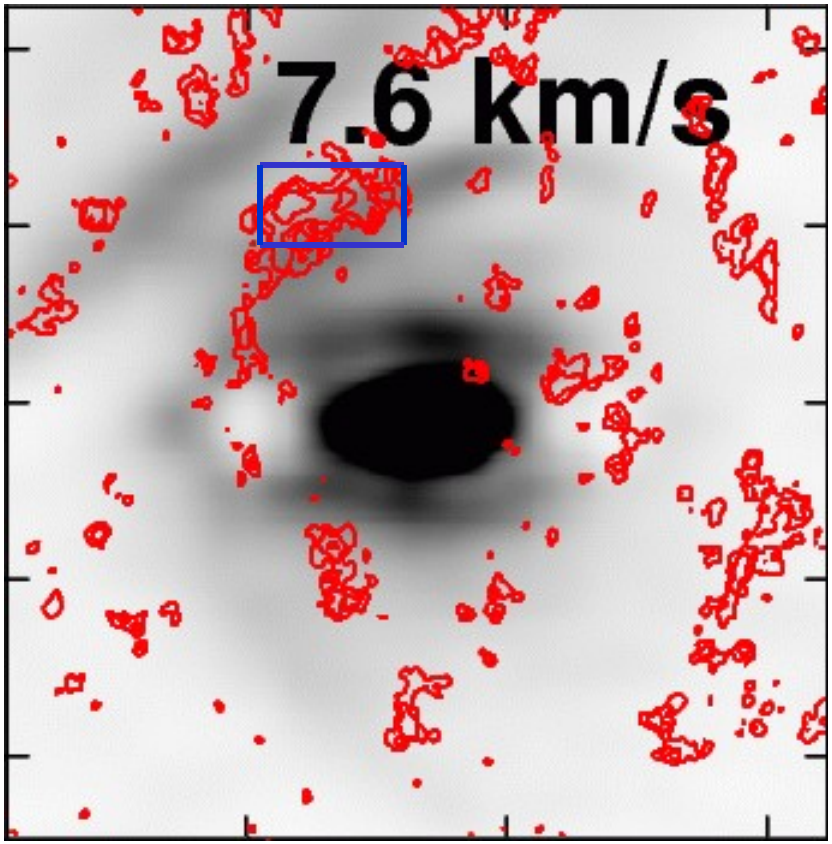
IRAS (60 μm)



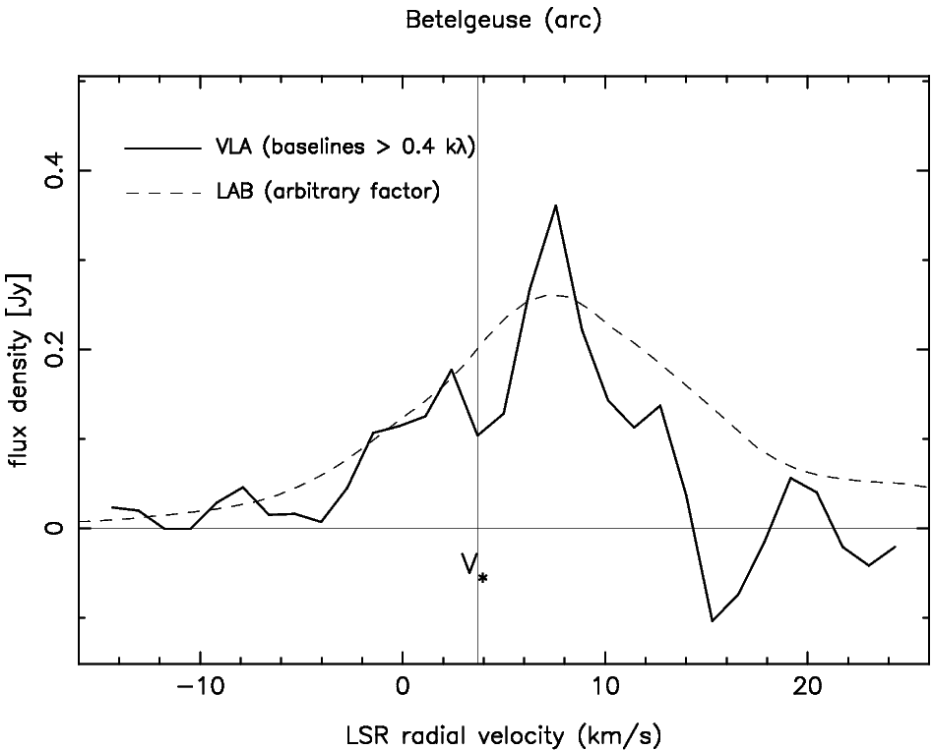


GALEX (FUV)

HI spectrum of the arc



24'



implication : HI arc

- **emission seems associated with the far-IR/UV arc**

- **V_{lsr} ~ +6.3 – 10.1 km s^{-1} different from star velocity**
  (and from HI compact source velocity),
  but corresponding to the ISM peak of emission (7.5 km s^{-1})

- **integrated intensity ~ 4.9 Jy km s^{-1}**
  → 0.05 Msol in atomic hydrogen (at 200 pc)

Summary

We have detected atomic hydrogen from the environnement of Betelgeuse, and found three components:

- **two peaks at ~ V_* +/- V_{exp} (-9 and +16 km s^{-1}) coincident with the central star and arising from the free-flowing wind;**
- **a quasi-stationary detached shell of ~ 0.24 pc diameter at 3 km s^{-1} (~ V_*) that can be accounted for by a mass loss rate of ~ 1.2 10^{-6} M_{sol} yr^{-1} for a duration of ~ 8 10^4 yr;**
- **an emission coincident with the far-IR ring at ~ 6 – 10 km s^{-1}.**