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The search for massive protostars

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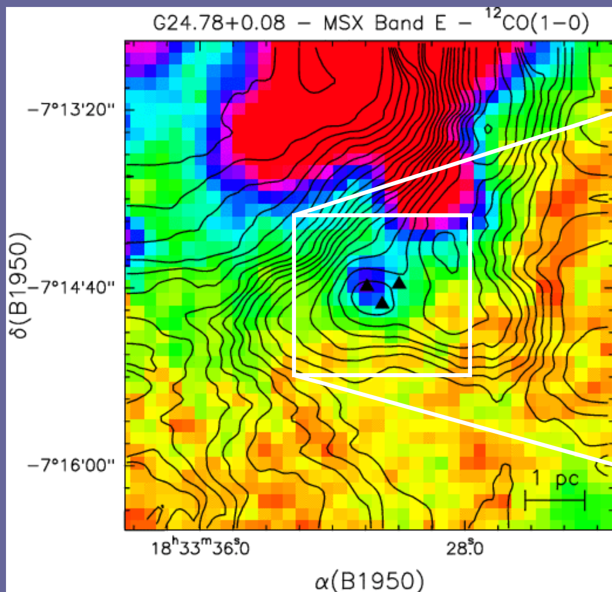
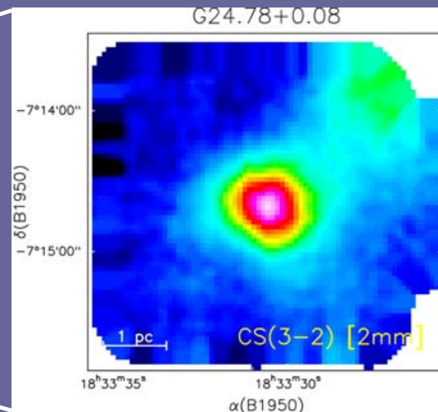
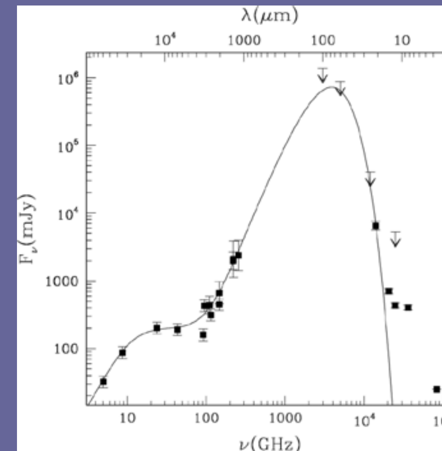
G24.78+0.08: the clump



IRAM 30-m

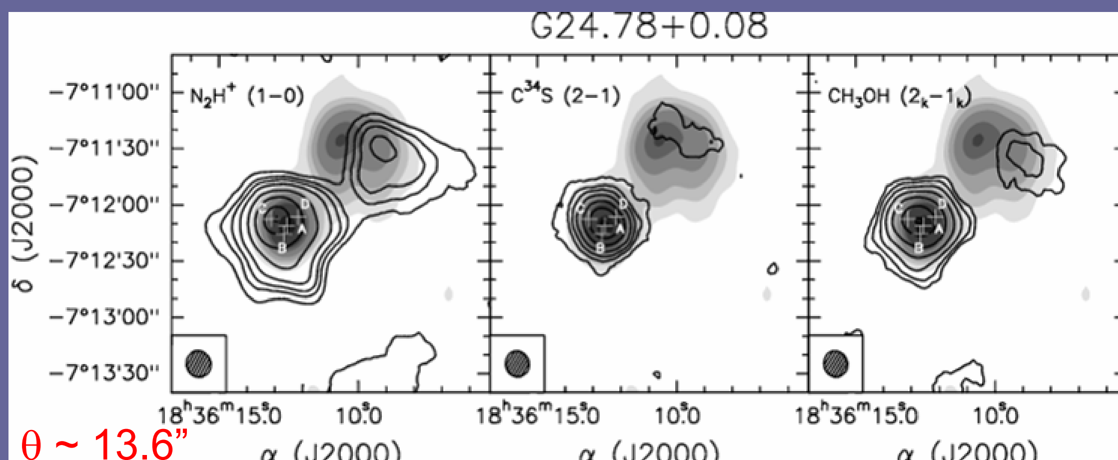


Cesaroni et al. (2003, A&A)



- G24.78 is located at a distance of 7.7 kpc
- L_{IRAS} = 7x10^5 $L_\odot$

BIMA interf.

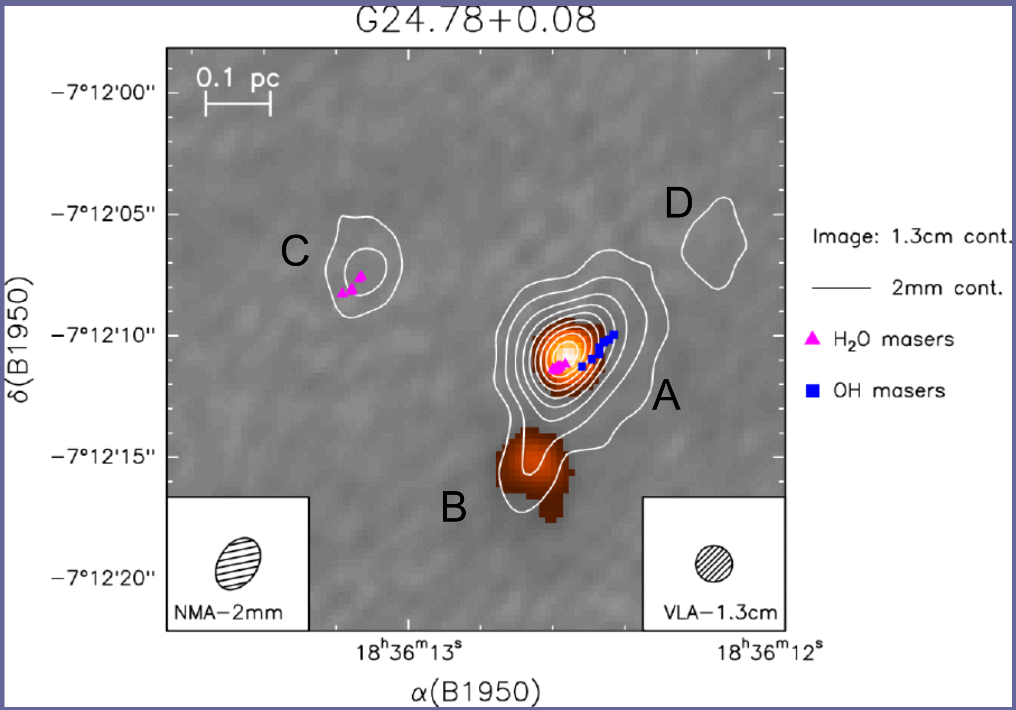


θ ~ 13.6"

Beltrán et al. (2005, A&A)

G24.78+0.08: the hot core

- The clump is hosting a cluster of massive YSOs in different evolutionary stage:



Codella et al. (1997, A&A)
Furuya et al. (2002, A&A)

- All cores associated with mm continuum emission
- two of them (A and C) associated with maser emission
- two of them (A and B) associated with UC HII regions

G24.78+0.08: the hot core

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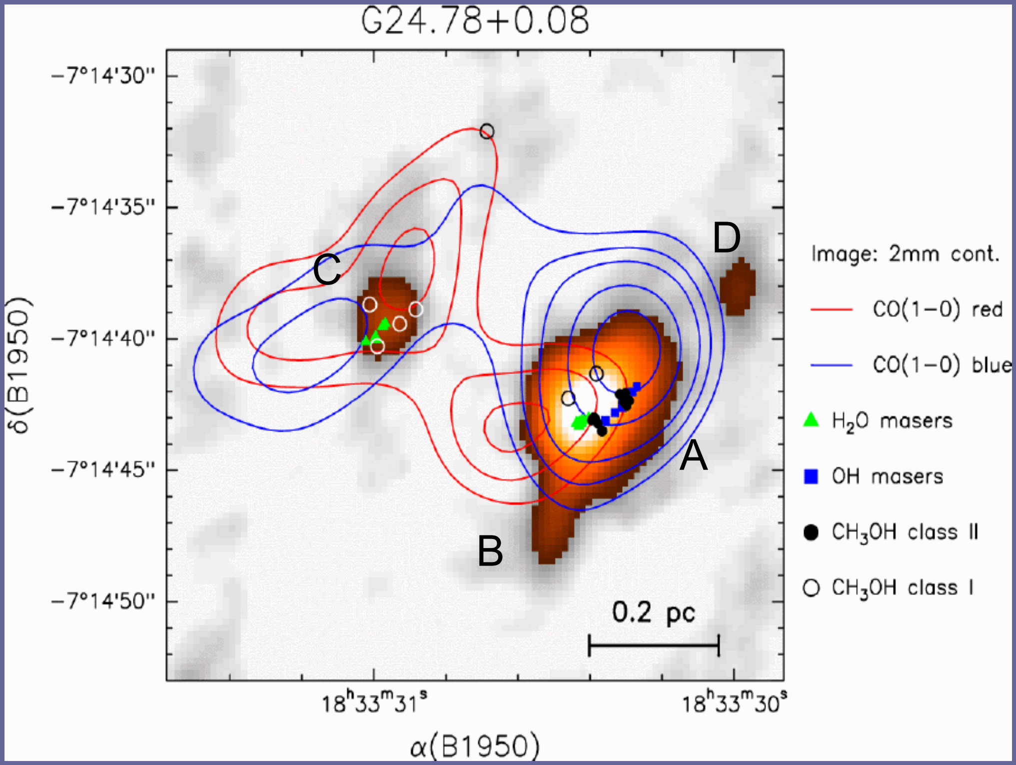


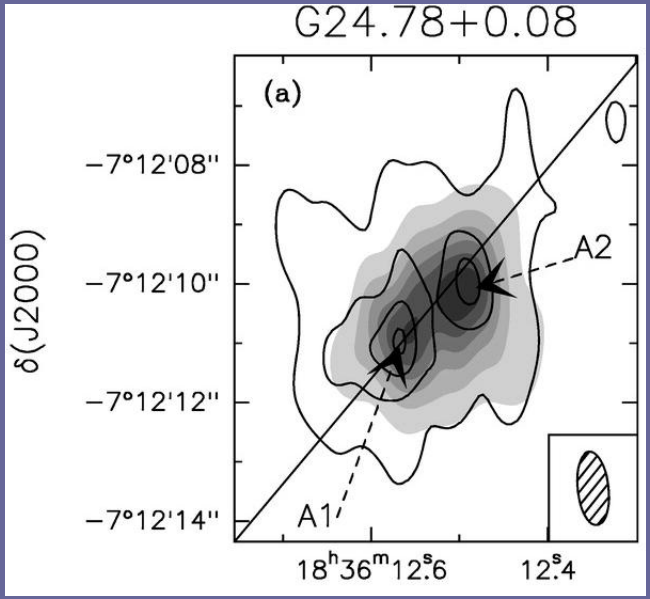
Furuya et al. (2002, A&A)

- All cores associated with mm continuum emission
- two of them (A and C) associated with maser emission
- two of them (A and B) associated with UC HII regions
- two of them (A and C) powering molecular outflows

G24.78+0.08: the cores A1 and A2

- High-angular resolution mm continuum and CH_3CN PdBI observations have resolved the core A into two separate cores, named A1 and A2, probably in different evolutionary stage.

1.4 mm + CH_3CN (12-11)



Beltrán et al. (2004)

G24.78+0.08: the cores A1 and A2

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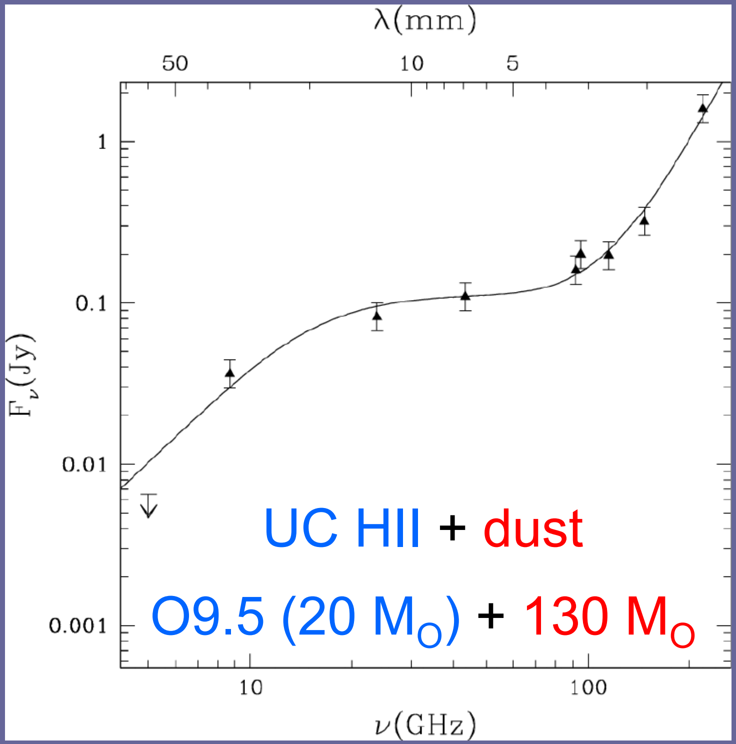
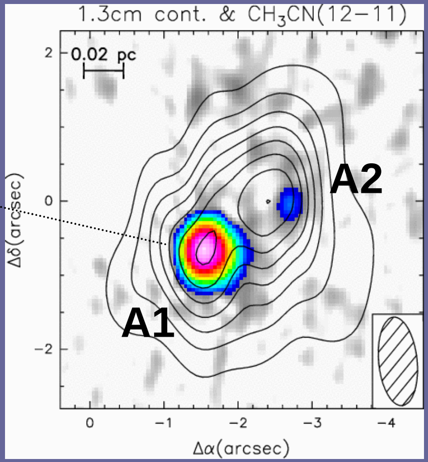
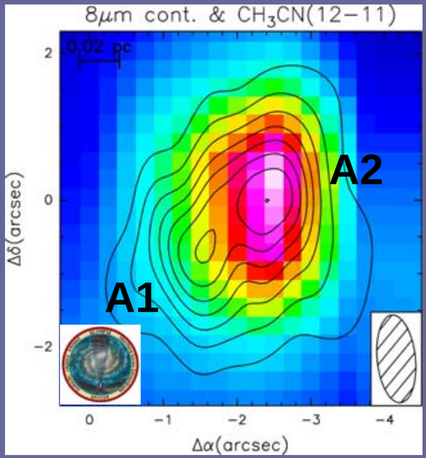




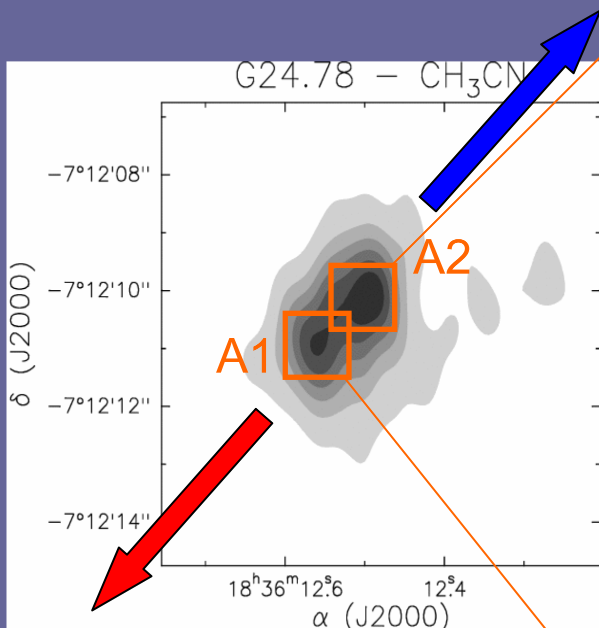
PdBI + VLA



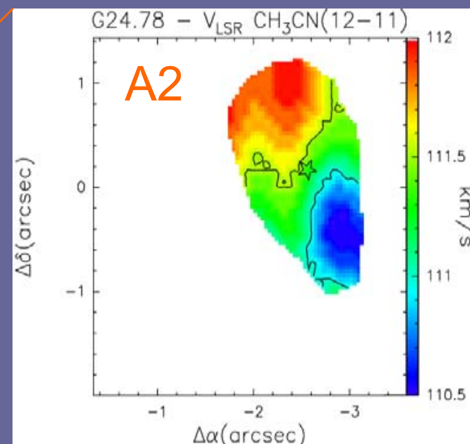
PdBI + Spitzer

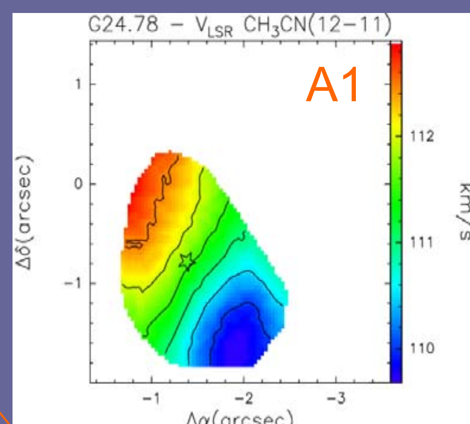
G24.78+0.08 A1 and A2: rotation

- To search for velocity gradients in the cores, we have fitted simultaneously the multiple K-components of the different rotational transitions of $CH_3CN(12\text{-}11)$



Beltrán et al. (2004, ApJ)





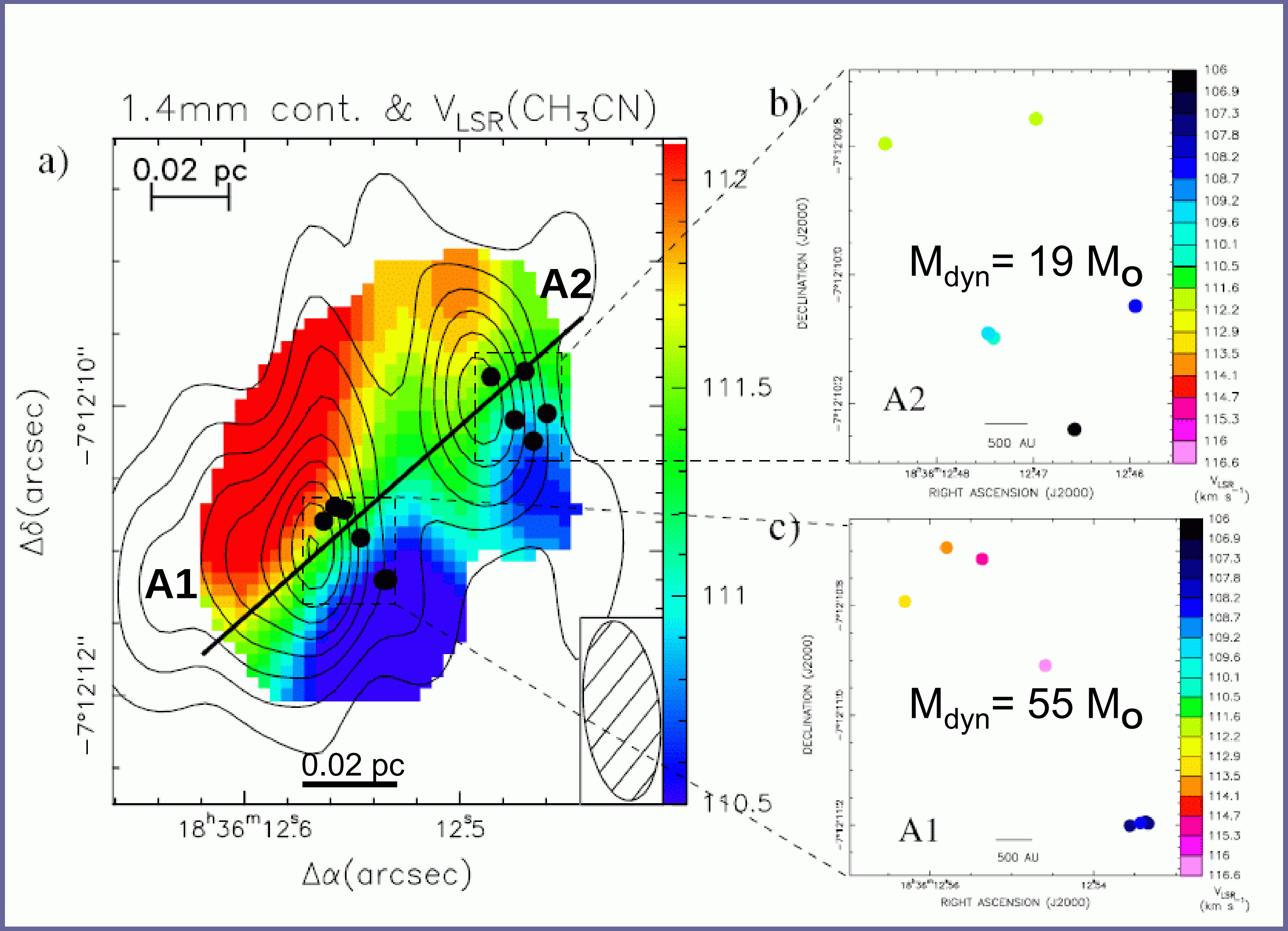
- Parameters of the toroids

R = 4000 AU
M_{gas} = 80 $M_\odot$
M_{dyn} = 4 $M_\odot$
V_{rot} = 0.75 km/s
$\dot{M}_{accr}$ = 8 x 10^{-3} $M_\odot$/yr
t_{accr} = 1 x 10^4 yr

R = 4000 AU
M_{gas} = 130 $M_\odot$
M_{dyn} = 23 $M_\odot$
V_{rot} = 1.50 km/s
$\dot{M}_{accr}$ = 2x 10^{-2} $M_\odot$/yr
$\dot{M}_{out}$ = 5 x 10^{-4} $M_\odot$/yr
t_{accr} = 7 x 10^3 yr
t_{out} = 2 x 10^4 yr

G24.78+0.08 A1 and A2: rotation

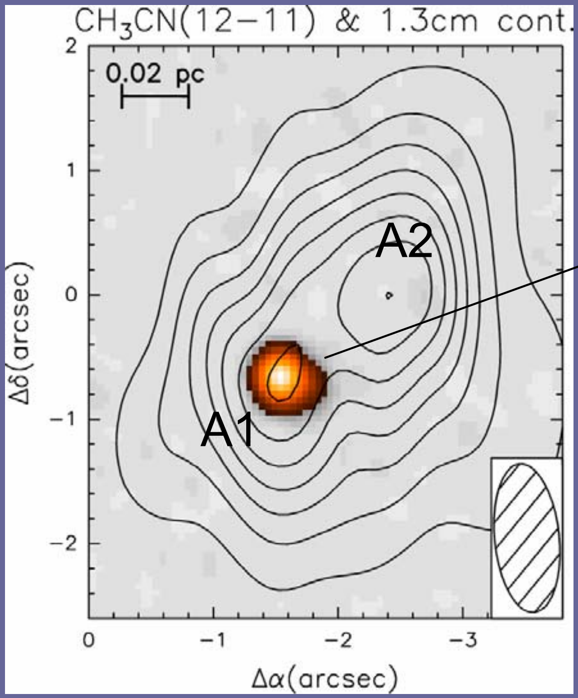
- EVN methanol maser emission observations have revealed two groups of masers associated with cores A1 and A2, aligned perpendicular to the direction of the bipolar outflow and with a velocity gradient consistent with the CH_3CN one.



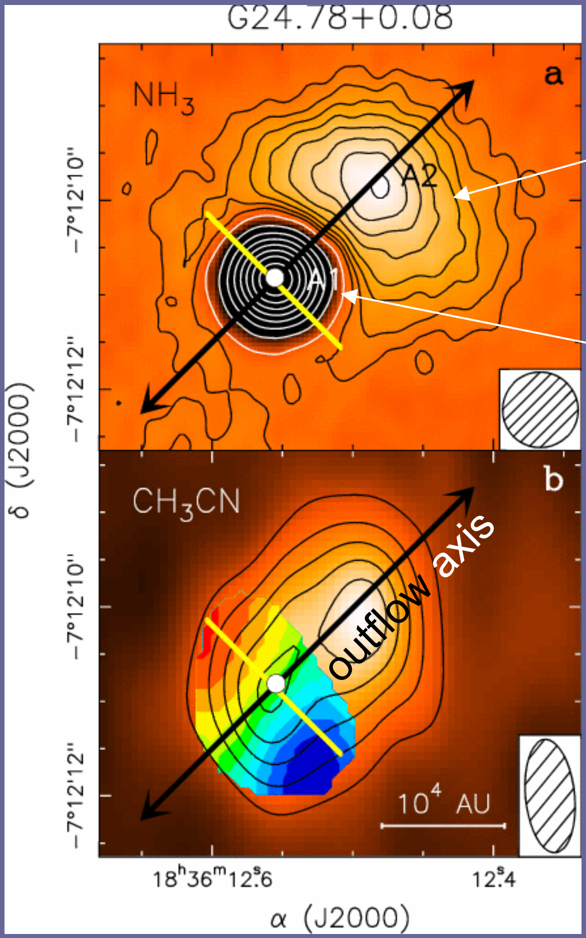
Moscadelli et al (2007, A&A)

G24.78+0.08 A1: infall

- The HC HII associated with G24 A1 is very bright at cm λ's (>2000 K), it is easy to observe the colder molecular gas (~100 K) in absorption against it.



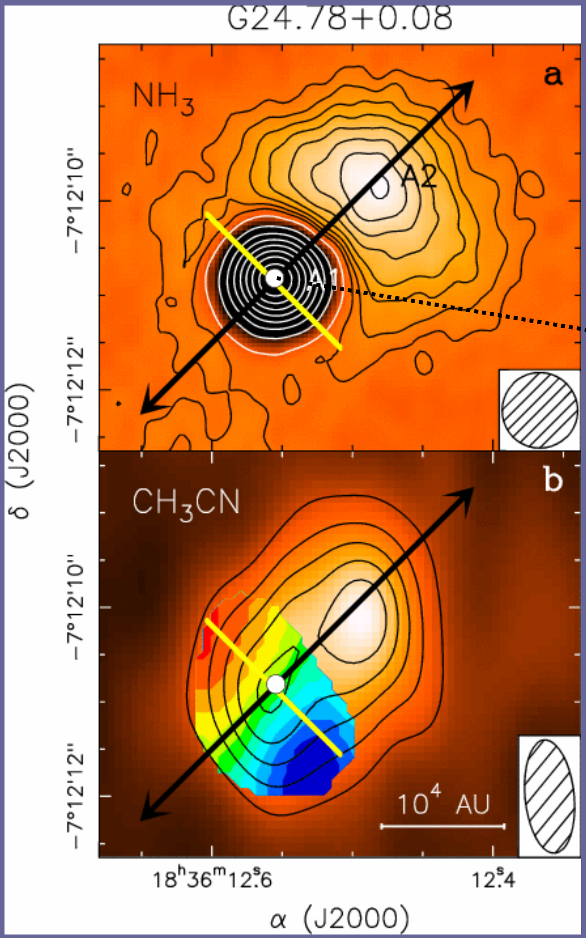
NH_3(2,2) VLA B

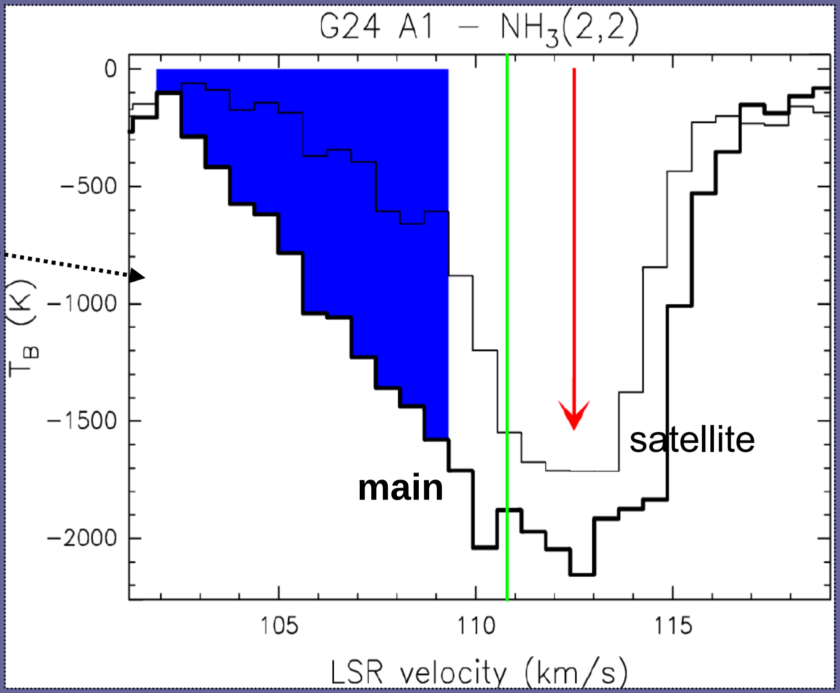


Beltrán et al. (2006, Nature)

G24.78+0.08 A1: infall

- Towards the HC HII, the satellite absorption is strongly biased towards positive velocities; the peak of the satellite absorption is red-shifted ~2 km/s.





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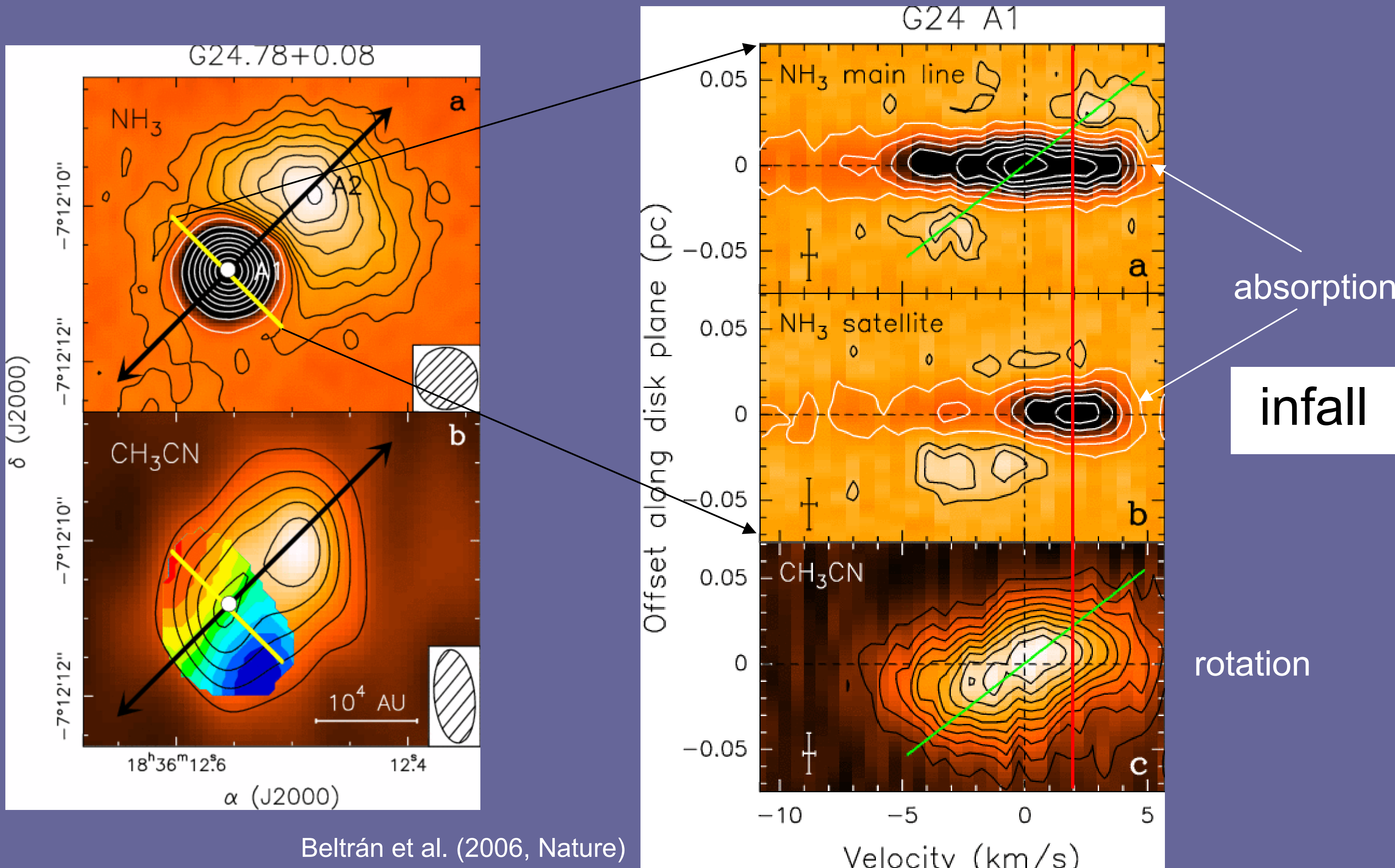


Beltrán et al. (2006, Nature)

G24.78+0.08 A1: infall

- Towards the HC HII, the satellite absorption is strongly biased towards positive velocities; the peak of the satellite absorption is red-shifted ~2 km/s.

- This indicates that the toroid is not only rotating but also accreting onto the central object.

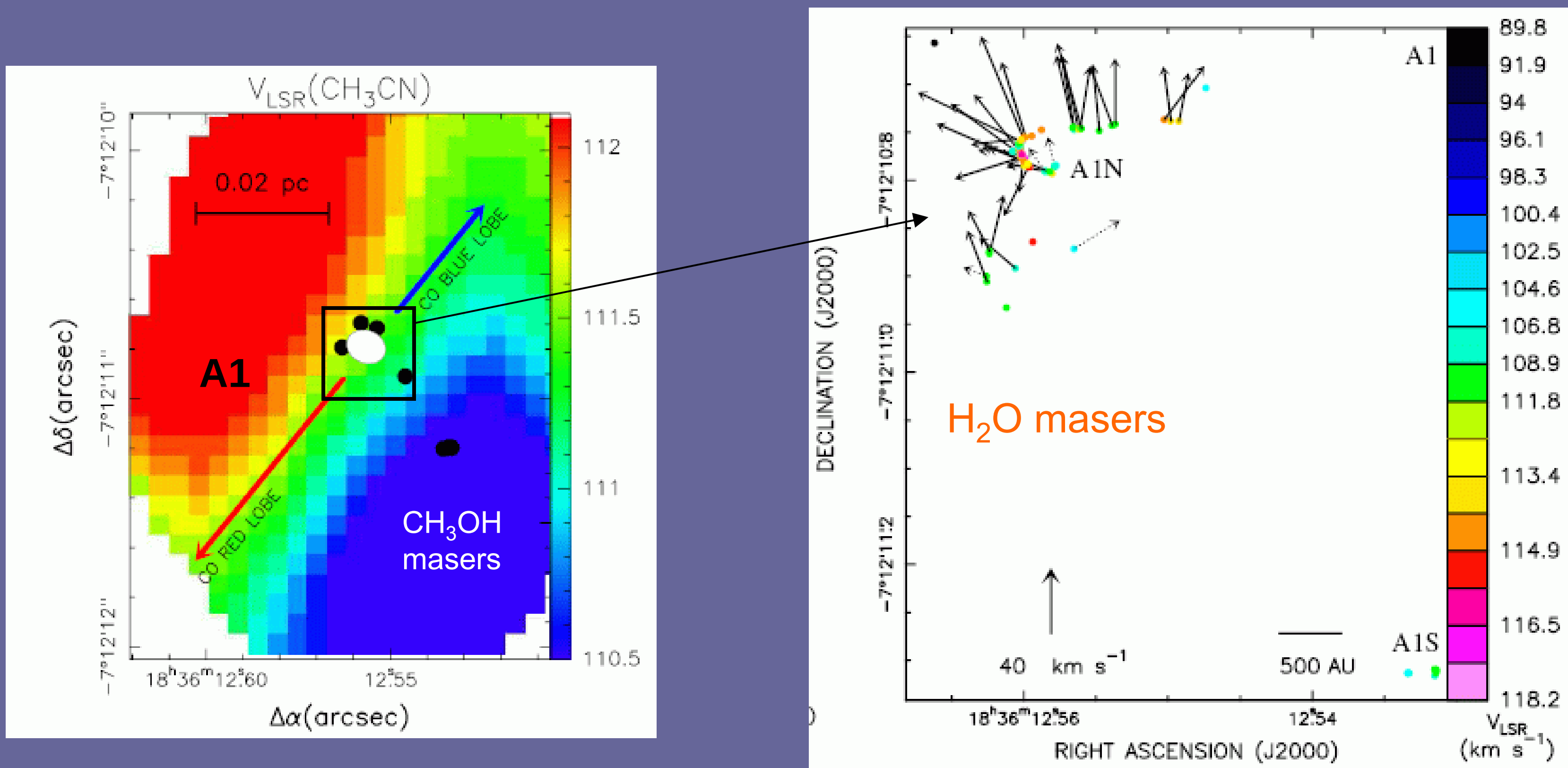
- From N_{H2} = 6x10^{23} – 6x10^{24} cm^{-2}, and the infall velocity v_{inf}= 2 km/s, assuming free-fall, one obtains the mass accretion rate onto a solid angle Ω: $\dot{M}_{accr} = \frac{\Omega}{4\pi}\left[(4\times10^{-4})-10^{-2}\right]M_{\Theta}yr^{-1}$

- The radius at which is measured is estimated to be 0.1" < R < 1" (0.0037 < R < 0.037 pc)

- (dM/dt)$_{infall}$ is much larger than the critical rate above which formation of an HII region is inhibited if the accretion is spherical (Ω=4π), (dM/dt)$_{inh}$ ≈ 8x10^{-6} $M_{\odot}$ yr^{-1}. The fact that the HII exists can be explained only if the accretion is not spherically symmetric (Ω<4π)

G24.78+0.08 A1: expansion?

- Recent multi-epoch 22 GHz water maser VLBA observations have clearly shown evidences for expanding motions perpendicular to the outflow main axis (along the plane of the rotating and infalling toroid).

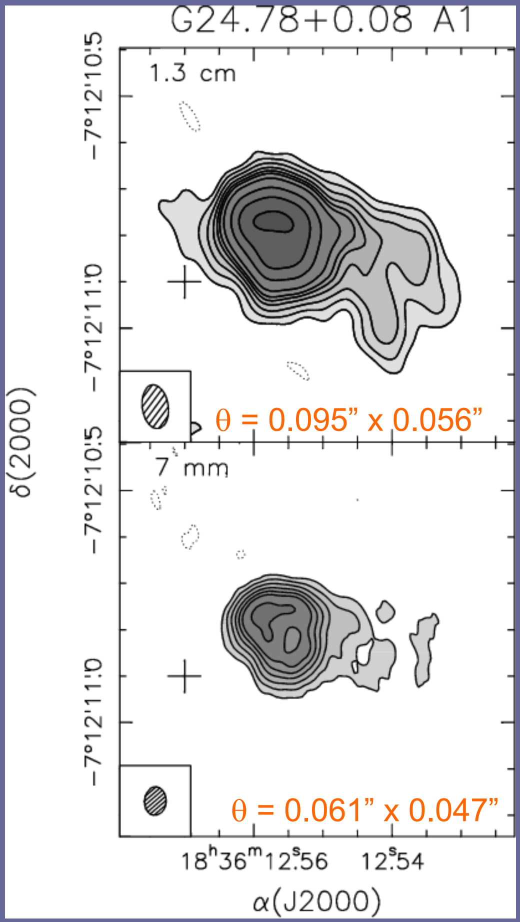


Moscadelli et al. (2007, A&A)

G24.78+0.08 A1: expansion?

- The HC HII region has a ring-shaped structure with an outer radius of ~550-580 AU with the H_2O maser features distributed along the border of the ionized gas.

VLA A + Pie Town



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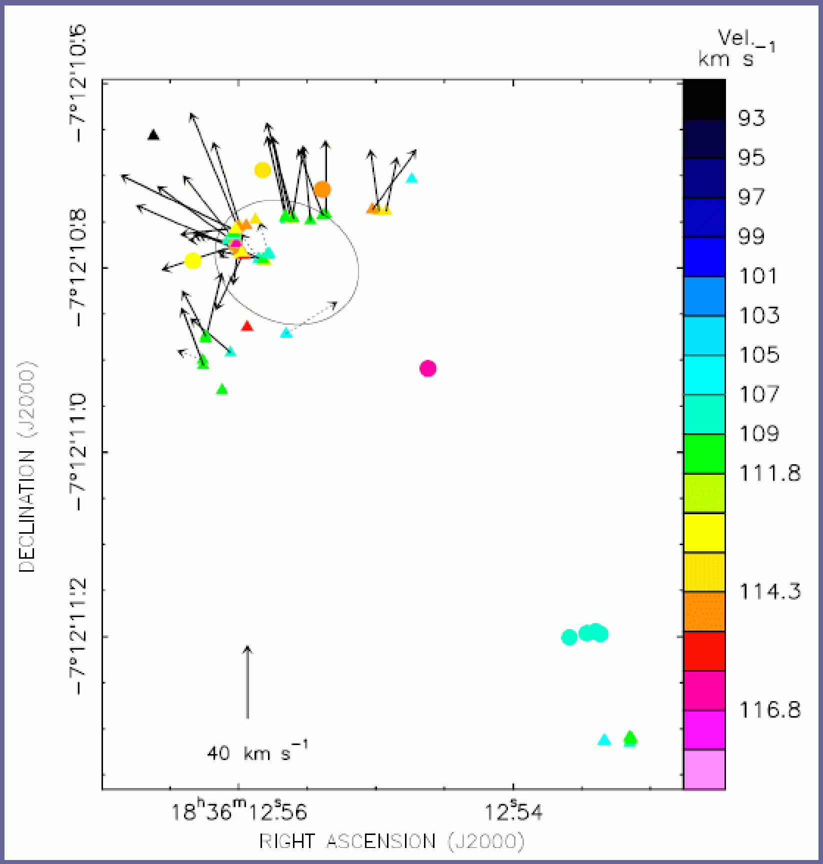

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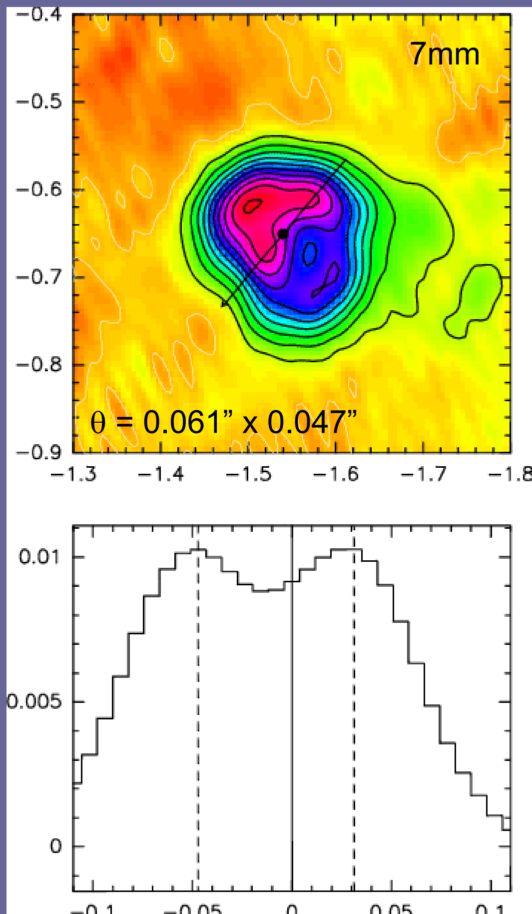
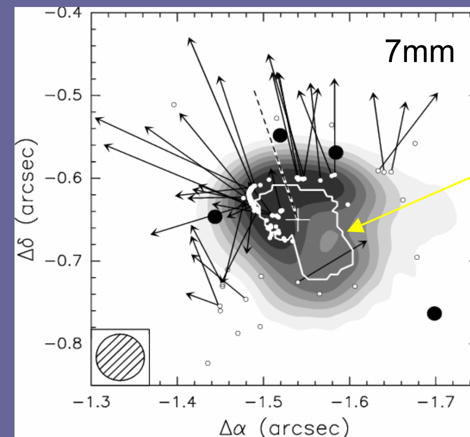
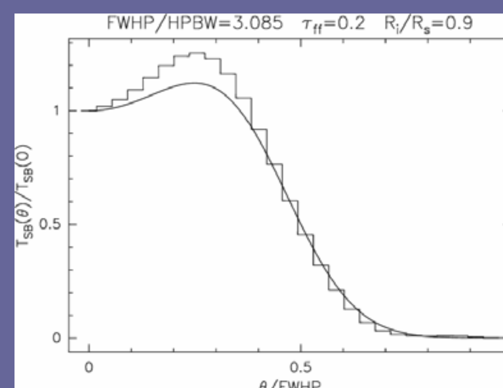




white line connects the peaks of the profiles

- For an optical depth of 0.2 and T_e =10^4 K, the best fit to the normalized temperature profile along a cut passing through the barycenter at 7mm and the peak of emission is when R_i/R_o ~0.9 → very thin shell → radius of the shell ~590 AU



Beltrán et al. (2007, A&A)

- The profiles of the emission at different angles by taking slices passing through the barycenter of the HC HII show two peaks.

G24.78+0.08 A1: expansion

- The water masers appear to be tracing expansion, which suggests that the HC HII is expanding. Because of the high velocities (~40 km/s), the expansion cannot be led by the thermal pressure of the ionized gas (e.g. Depree et al. 1995, v~10 km/s). It must be an additional mechanism driving the expansion.

- Following the model by Shull (1980, ApJ), the HII region expansion may be driven by a powerful stellar wind.

  I. Initial phase of free expansion at the wind velocity, when the wind sweeps up its own mass in interstellar matter

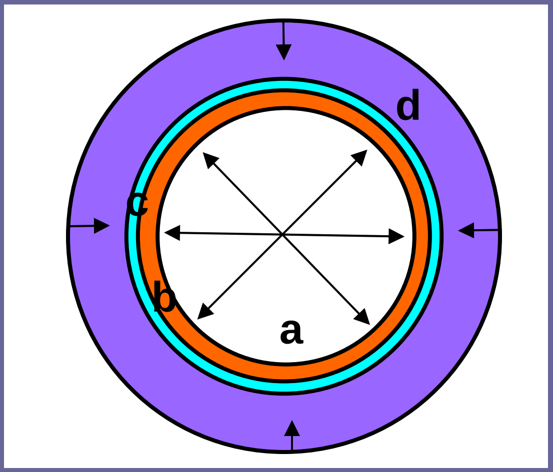
  II. Four-zone structure, in which a thin, dense ionized shell containing most of the swept up material is created:

  a) free-flowing wind

  b) thin region of hot shocked wind material

  c) thin, dense shell of swept-up of HMC material

  d) accreting HMC

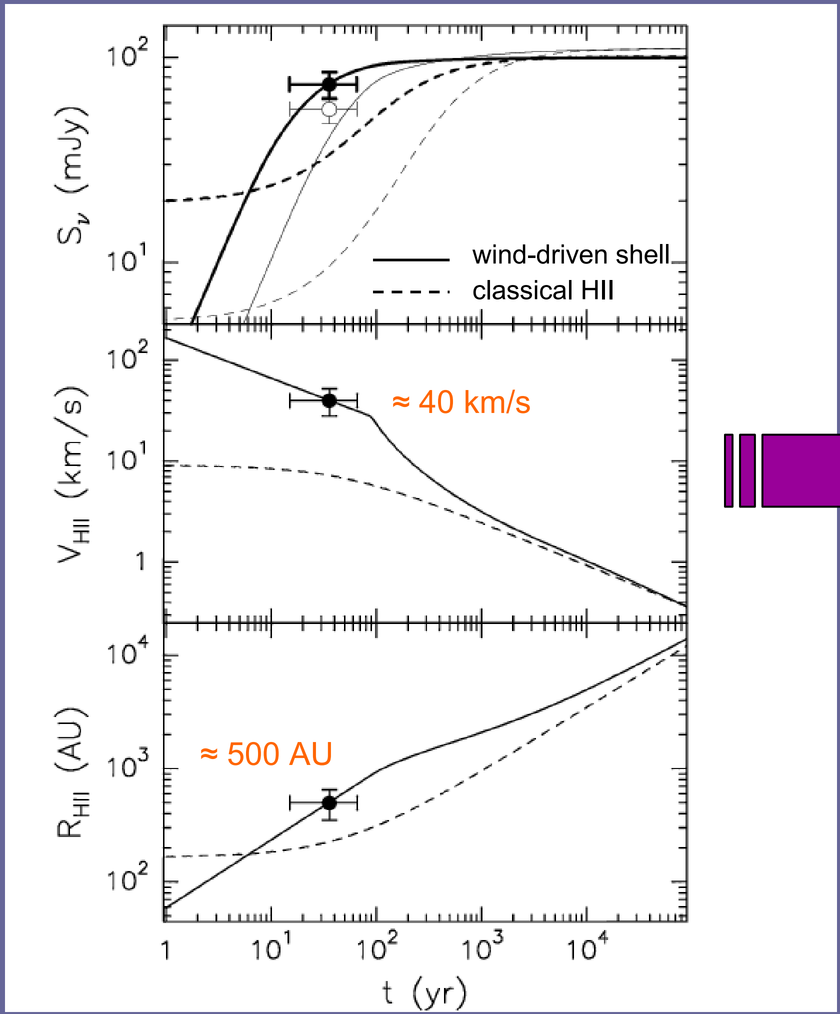


(see e.g. González-Avilés et al. 2005, ApJ)

- Two phases can be identified: a pressure-driven expansion followed by a momentum-driven expansion (after a critical time that depends on the wind mechanical luminosity and density of the surrounding environment).

G24.78+0.08 A1: expansion

- For a wind mechanical luminosity (10^{36} ergs) and density (10^7 cm^{-3}), R_{HII} and V_{HII} of the expanding shell can be expressed as a function of time (Shull 1980). V_{wind}=2000 km/s for O9.5



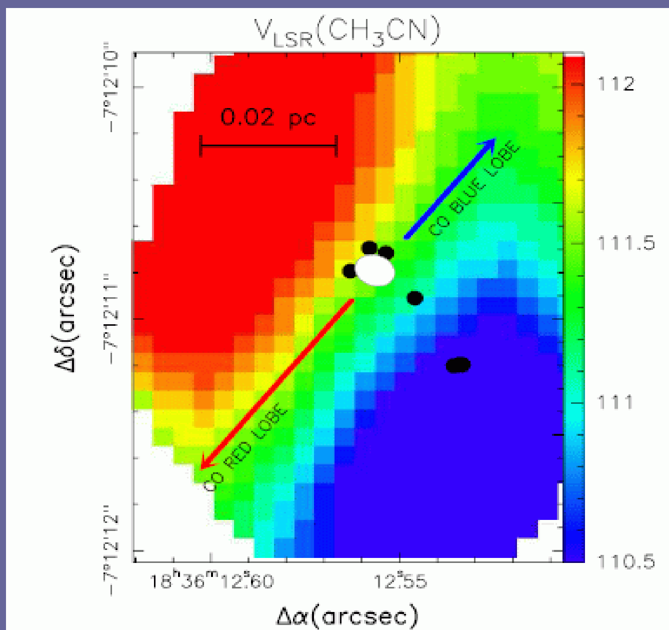
Beltrán et al. (2007, A&A)

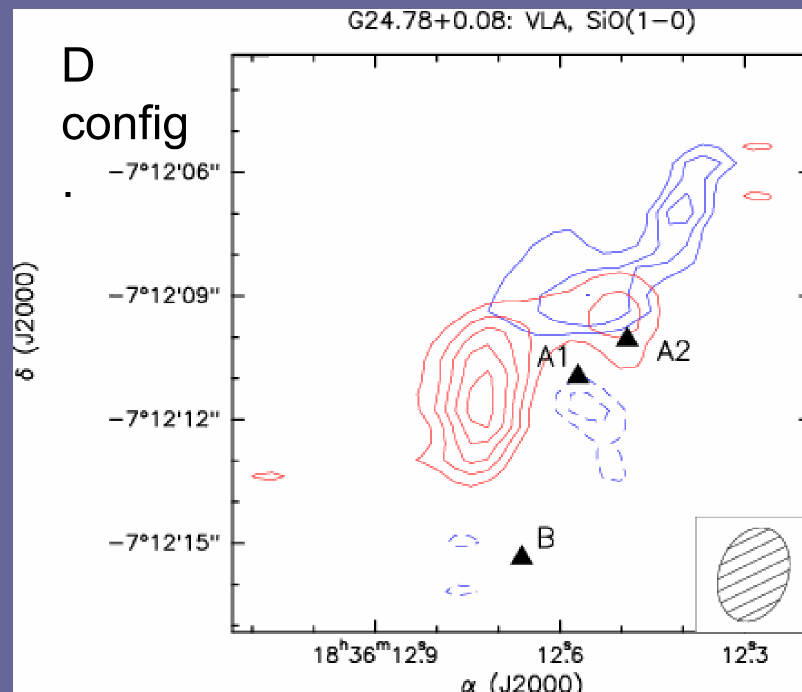
The solution of the wind-driven expansion that reproduces the observed shell parameters predicts a shell age of 21-66 yr !

- The detected shell expansion is probably an episodic event

G24.78+0.08 A1: rotation or expansion?

- Is the velocity gradient observed in the thermal CH_3CN (12-11) line as well in the CH_3OH maser emission due to expansion rather than rotation? Is there a collimated, compact bipolar outflow, perpendicular to the outflow seen on a larger scale in the CO(1-0) line?





G24.78+0.08 A1: the global view

- G24.78+0.08 A1 is a 20 $M_{\odot}$ where the simultaneous presence of rotation, outflow and infall has been detected. The large accretion rate and the existence of an HC HII region at the center of the rotating toroid confirm that the accretion cannot be spherically symmetric and must occur in a circumstellar disk.

- High-angular resolution radio continuum images and water maser emission indicate that the HC HII region is expanding on a very short time scale. The infalling gas is no longer accreting onto the star, but is stopped at the surface of the HC HII region, right at the shock front traced by the H_2O maser spots.

- CH_3OH masers appear to lie further from the HC HII region, may be located in the pre-shock material, and might still be participating in the infall (proper motions should be directed towards the HC HII).

- Even if the accretion phase were finished, the presence of a rotating toroid infalling on a HC HII located at the base of a powerful bipolar outflow is broadly in agreement with the expectations of the non-spherical accretion scenario for the formation of massive stars.

- The detected shell expansion is probably an episodic process. Then, has the star reached its final mass?