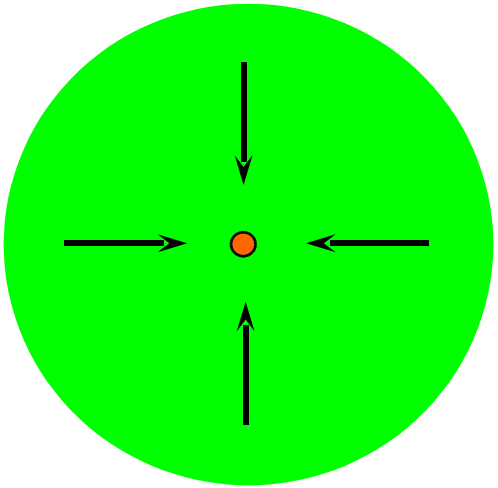
Il ruolo dei dischi nella formazione delle stelle O-B

Riccardo Cesaroni
INAF – Osservatorio Astrofisico di Arcetri

1) Il problema della formazione delle stelle OB
2) Il (possibile) ruolo dei dischi di accrescimento
3) Risultati attuali: dischi (stelle B) e toroidi (stelle O)
4) Il **progetto ALMA**: proposta Ciclo 0 e scopo finale

Come si formano le stelle?

Nucleo (protostella) con inviluppo:

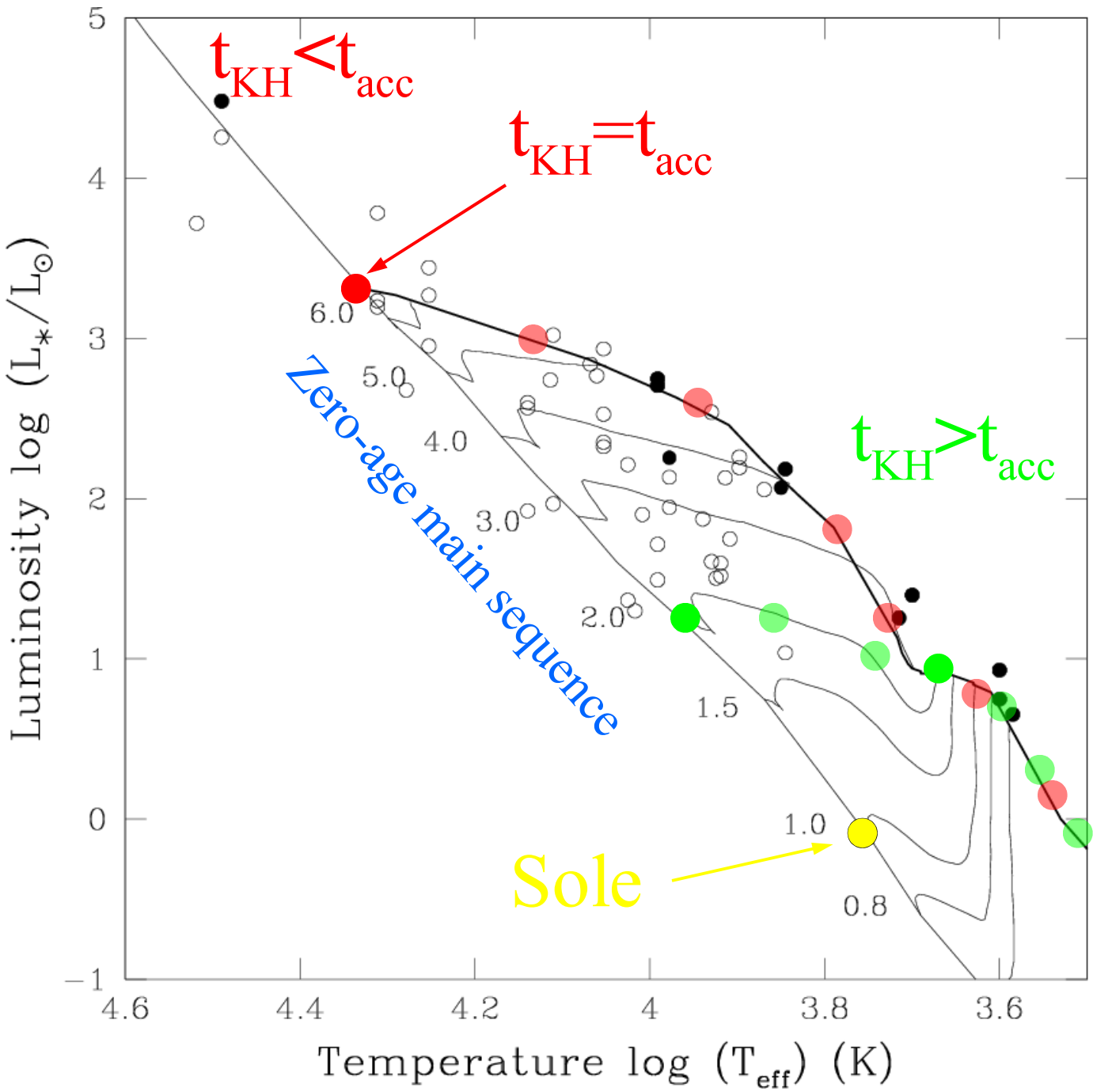


- Contrazione protostella → $\mathbf{t_{KH}}$
- Accrescimento da inviluppo su protostella → $\mathbf{t_{acc}}$

t_{acc} cresce con M_* mentre t_{KH} diminuisce con M_*

Palla & Stahler (1990, 1993)

accrescimento con
$dM/dt=10^{-5}\ M_o/yr$



PROBLEMA

- Le stelle massicce arrivano sulla ZAMS ancora in fase di accrescimento
- In simmetria sferica, la pressione di radiazione blocca l'accrescimento (Kahn 1976)
- stelle > 8 M_O non possono esistere!?

SOLUZIONE

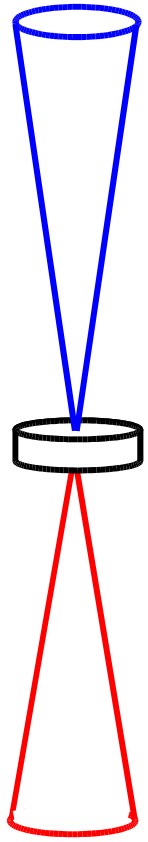
Accrescimento mediante disco (+outflow) (Yorke & Sonnhalter, Krumholz et al.):

Outflow → incanala i fotoni →

→ riduce la pressione di radiazione

Disco → concentra l'accrescimento →

→ aumenta la ram pressure

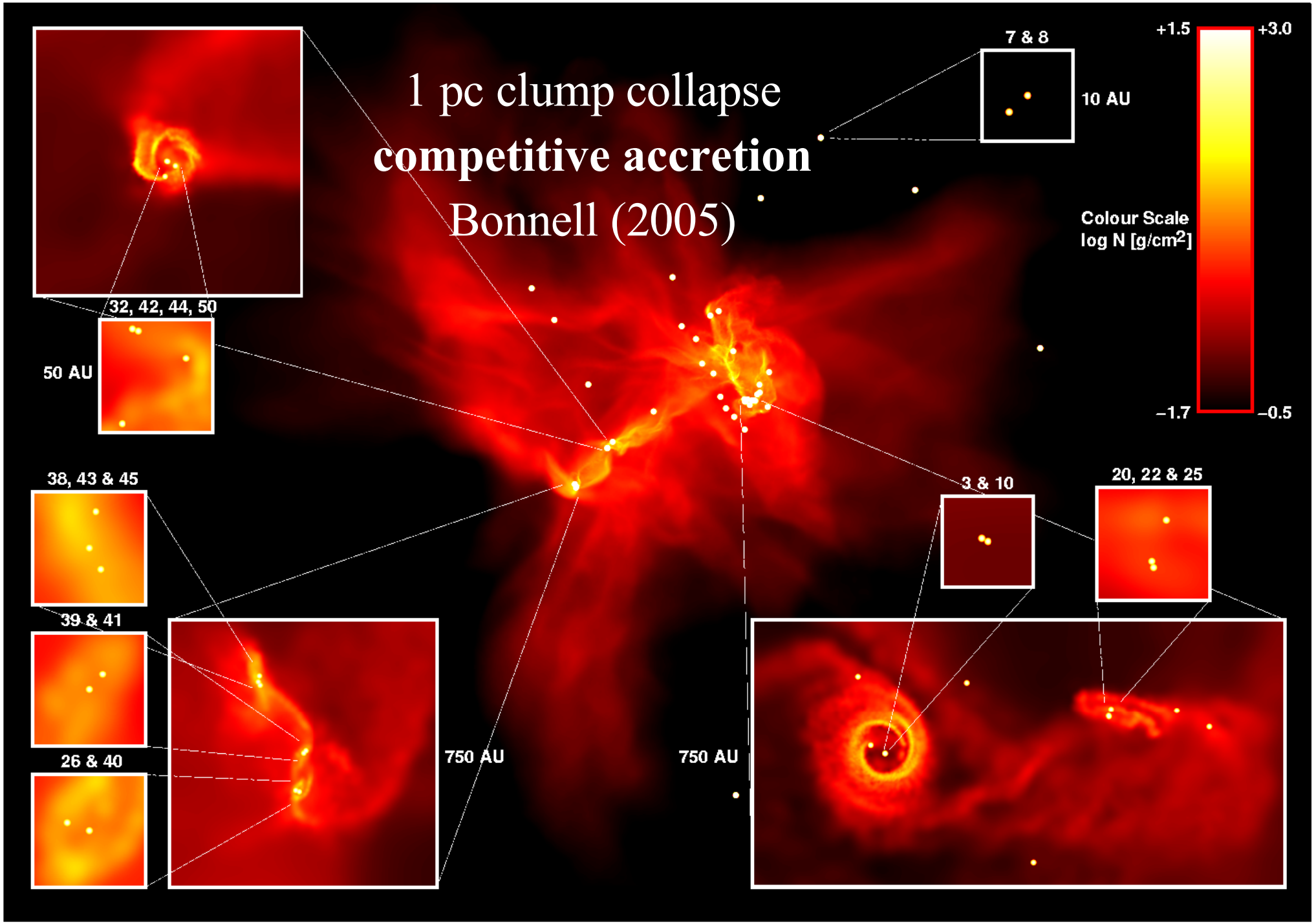


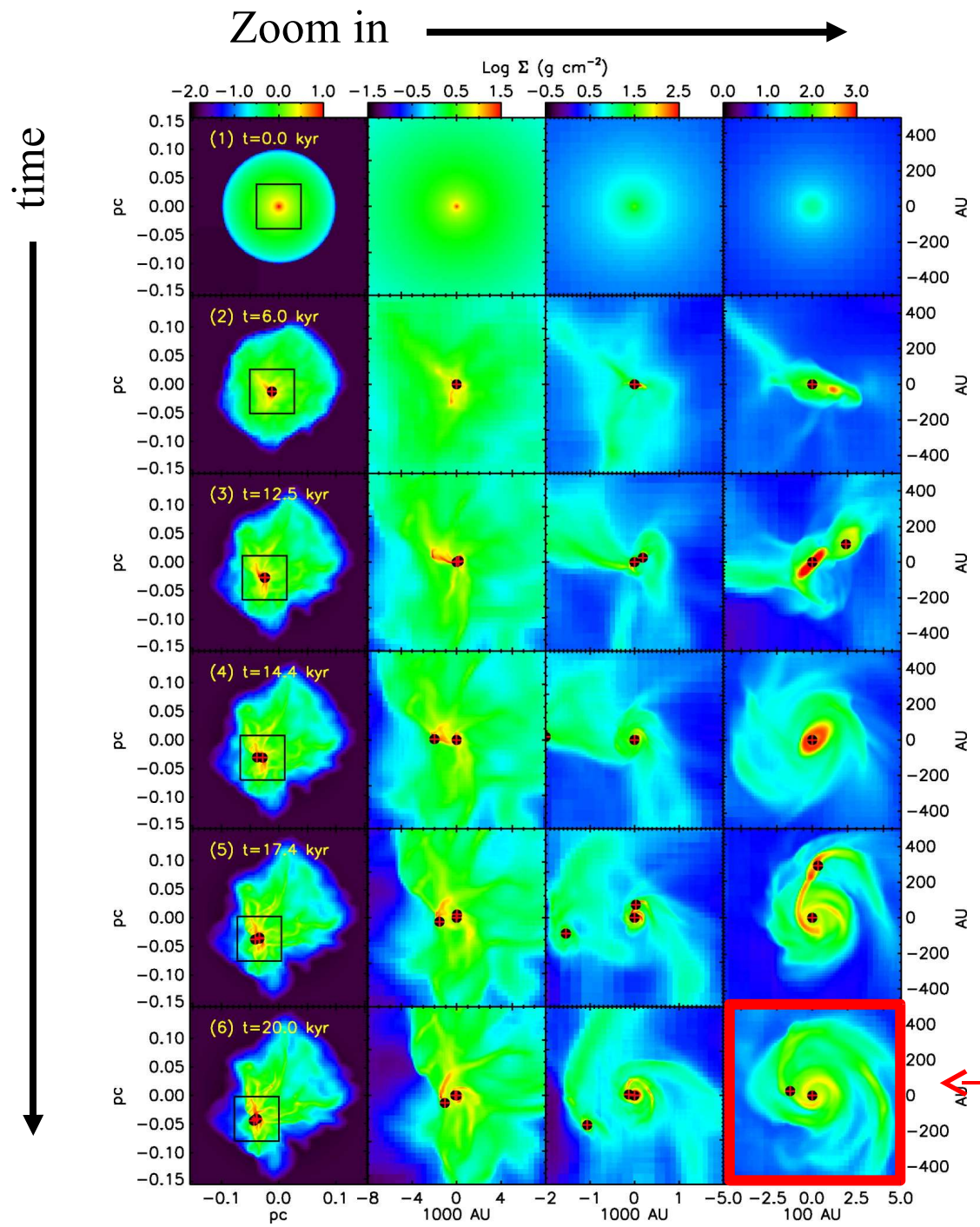
→ L'esistenza dei dischi in stelle OB indicherebbe una continuità nel modo di formazione, dalla piccola all'alta massa

Buone notizie: teoria

→ Tutte le teorie di formazione stellare predicono dischi attorno a stelle OB (dimensioni ~100-1000 AU) - e.g. Bonnell 2005, Krumholz et al. 2007, Keto 2007,

→ Le teorie spiegano la formazione di stelle fino a **140 M_o** mediante disco di accrescimento → soluzione problema pressione di radiazione (Kuiper et al. 2010, 2011)


1 pc clump collapse
competitive accretion
Bonnell (2005)
7 & 8
10 AU
+1.5
+3.0
Colour Scale
log N [g/cm2]
−1.7
−0.5
32, 42, 44, 50
50 AU
38, 43 & 45
39 & 41
26 & 40
750 AU
3 & 10
20, 22 & 25
750 AU



core accretion
in 0.2 pc clump
Krumholz et al. (2007)

disk

Cattive notizie: osservazioni

→ Dischi attorno a stelle OB molto difficili da osservare: **lontani** ed **embedded**

- → dist. OB > 1 kpc, disco ~100 AU ➡ **HPBW < 0.1”**
- → A_V=1000 ➡ **λ > mid-IR** necessaria

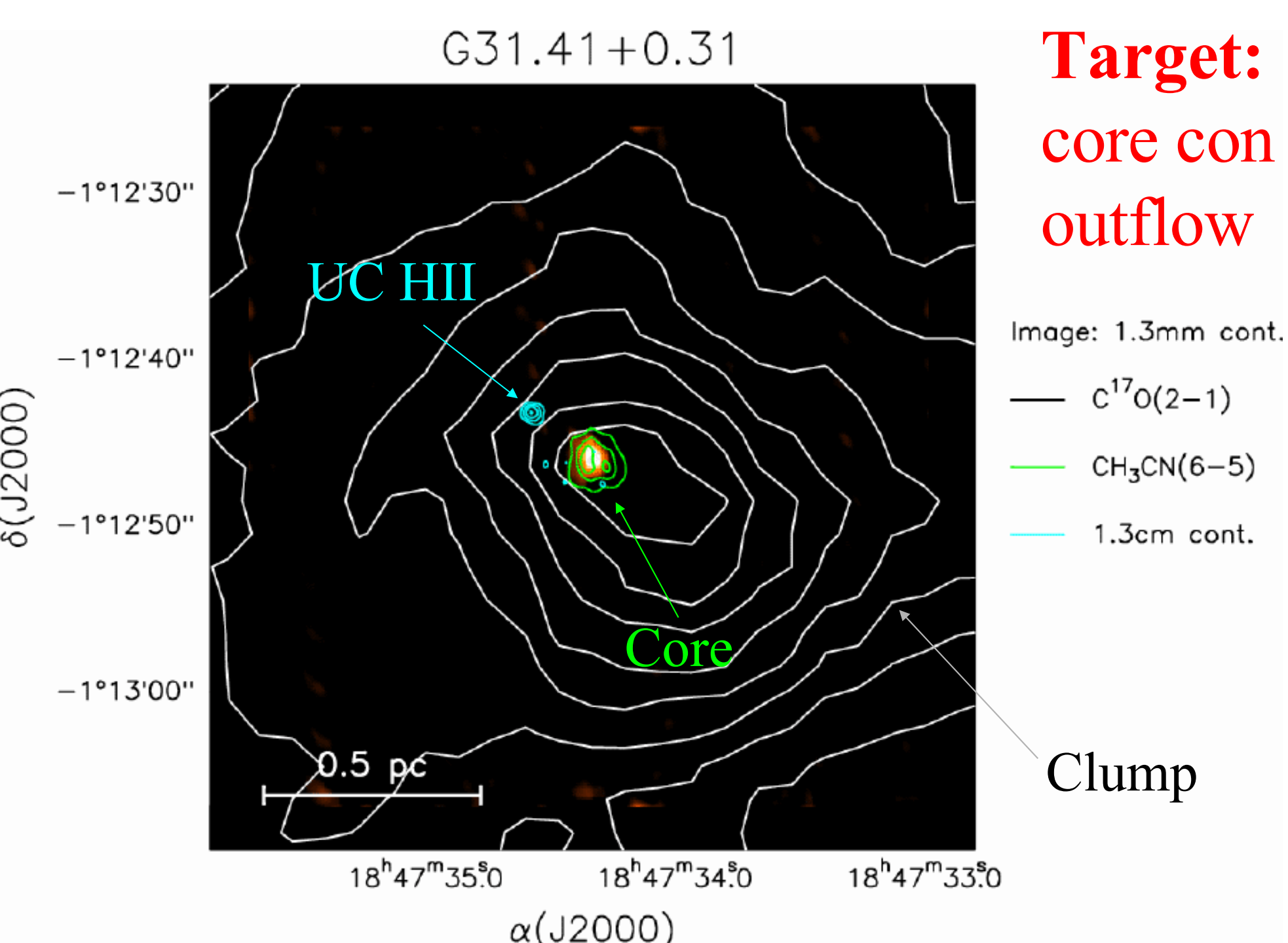
Finora risoluzione angolare radio-submm > 0.5”

Adesso fattibile con **ALMA**!

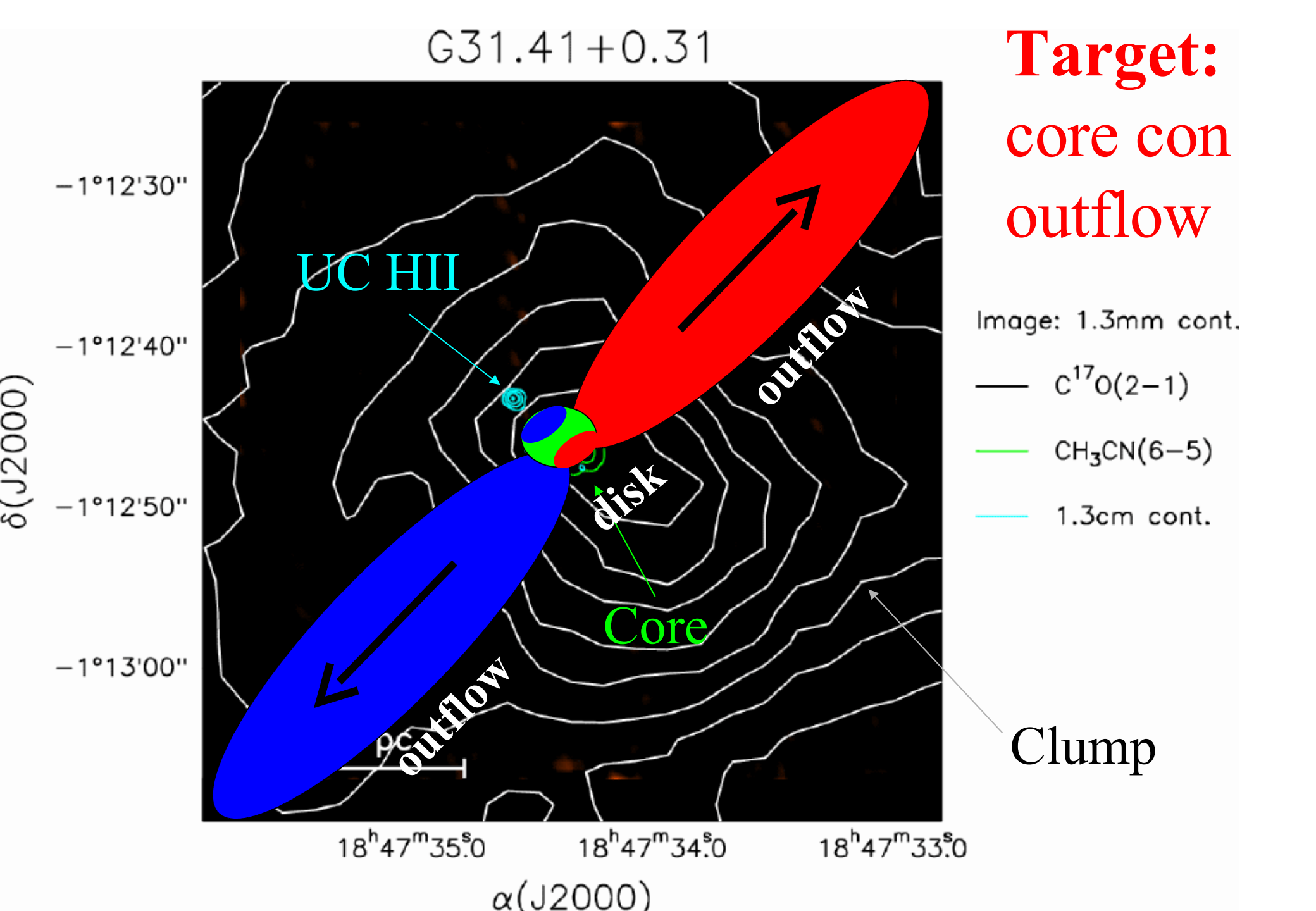
Ricerca dei dischi

Dove cercarli? → scelta **target**

Cosa osservare? → scelta **tracciante**



Target:
core con
outflow

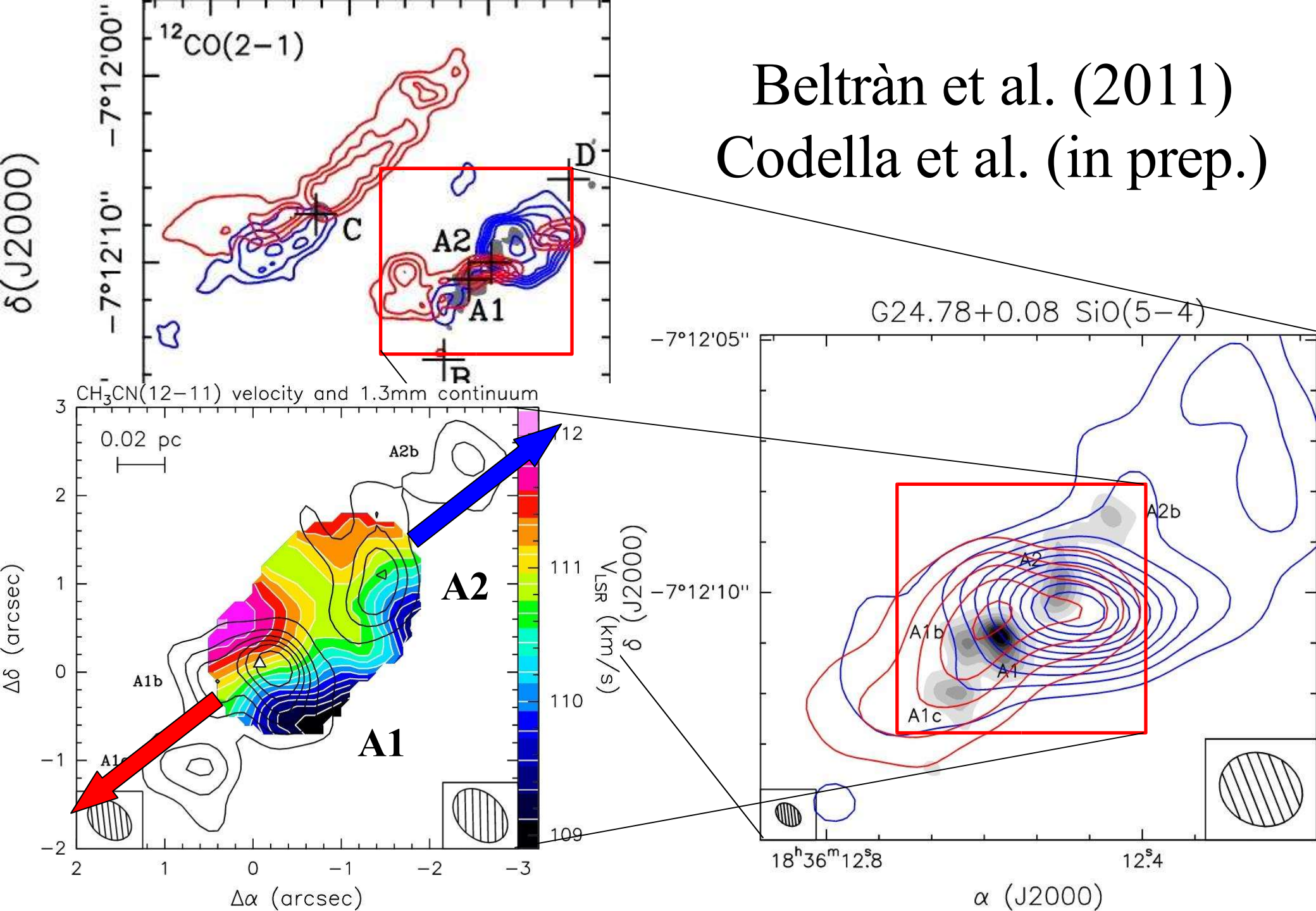

G31.41+0.31
Target:
core con
outflow
UC HII
outflow
disk
Core
outflow
Clump
pc
Image: 1.3mm cont.
C17O(2–1)
CH3CN(6–5)
1.3cm cont.
−1°12'30"
−1°12'40"
−1°12'50"
−1°13'00"
δ(J2000)
18h47m35s.0
18h47m34s.0
18h47m33s.0
α(J2000)

Traccianti possibili:

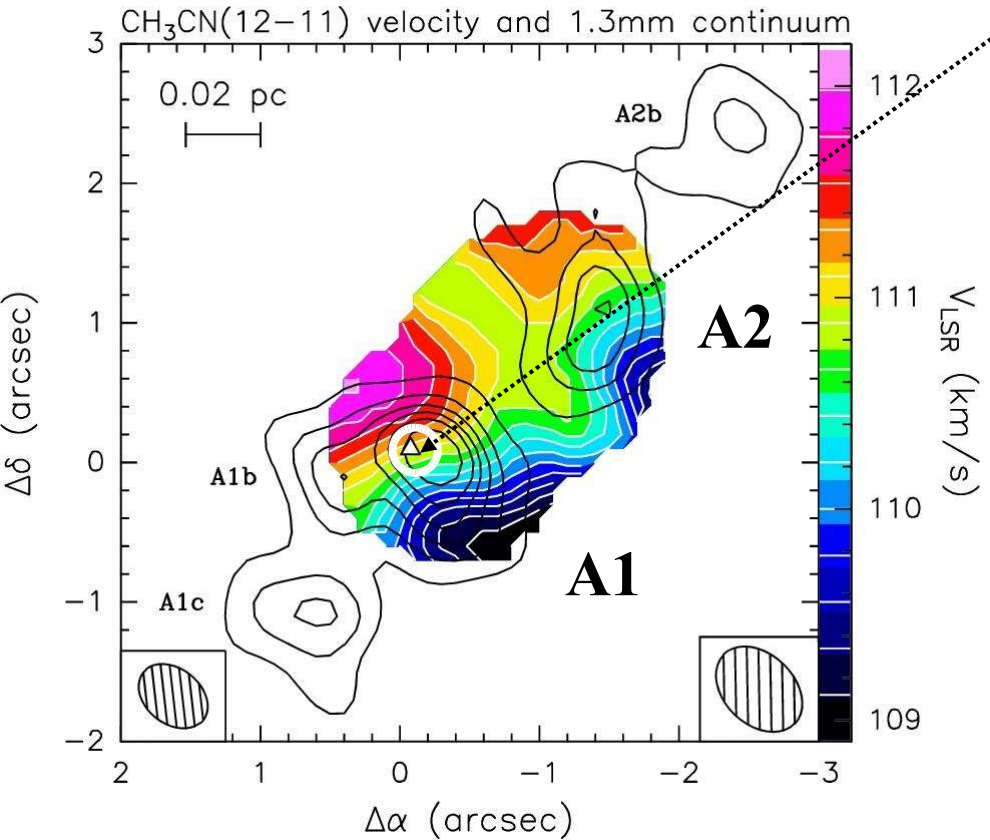
A_v~1000 mag → radio-submm

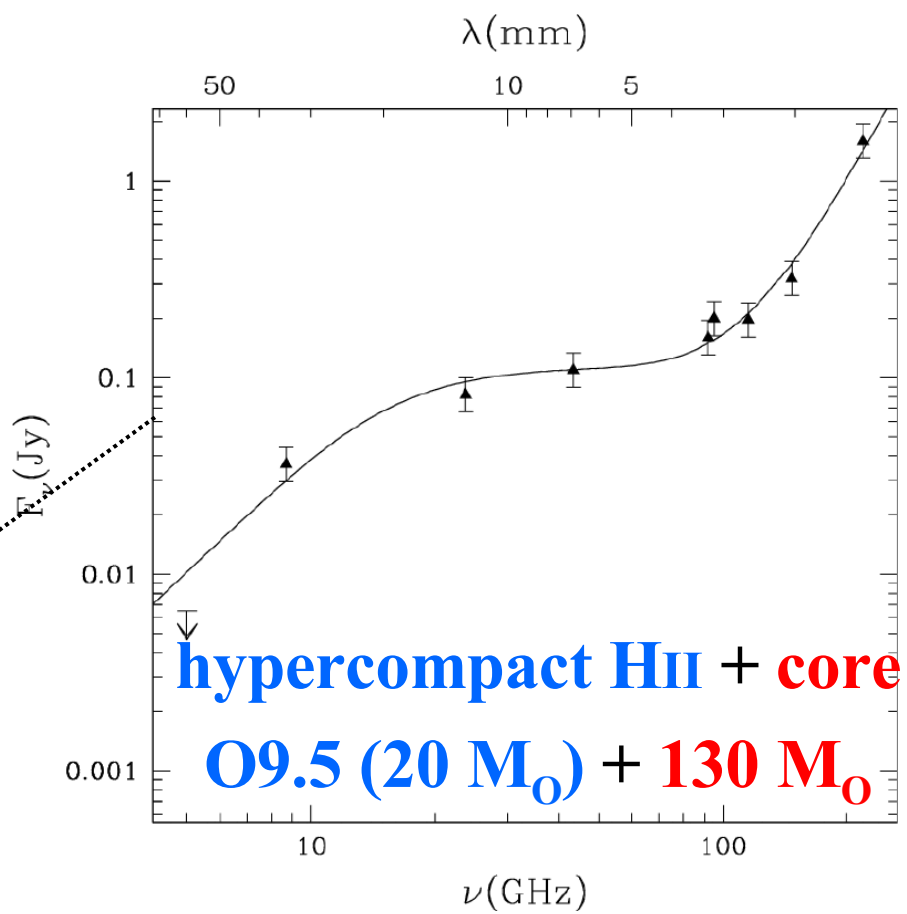
TRACCIANTE	PRO	CONTRA
Righe maser	Alta risol. angolare; moti propri → vel. 3D	Informazione "patchy"
Continuo (sub) mm	Banda larga → Alta sensibilità	No info velocità Confusione con free-free e/o inviluppo
Righe molecolari termiche	**Cinematica e geometria di outflow e disco**	**Risoluzione e sensibilità → ALMA!**

Esempio: stella O

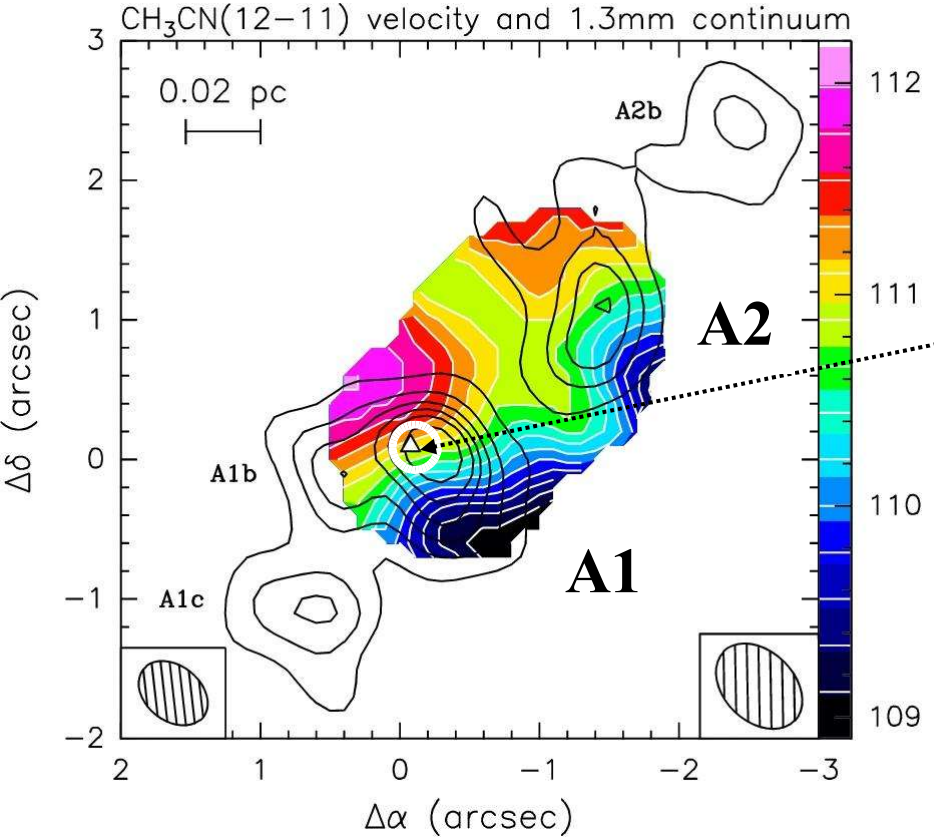

Beltràn et al. (2011)
Codella et al. (in prep.)
^{12}CO(2−1)
−7°12'00"
−7°12'10"
δ(J2000)
C
D
A2
A1
B
CH$_3$CN(12−11) velocity and 1.3mm continuum
0.02 pc
A2b
A2
A1b
A1
A1c
Δδ (arcsec)
Δα (arcsec)
V$_{LSR}$ (km/s)
δ (J2000)
G24.78+0.08 SiO(5−4)
−7°12'05"
−7°12'10"
A2b
A2
A1b
A1
A1c
18^{h}36^{m}12^s.8
12^s.4
α (J2000)

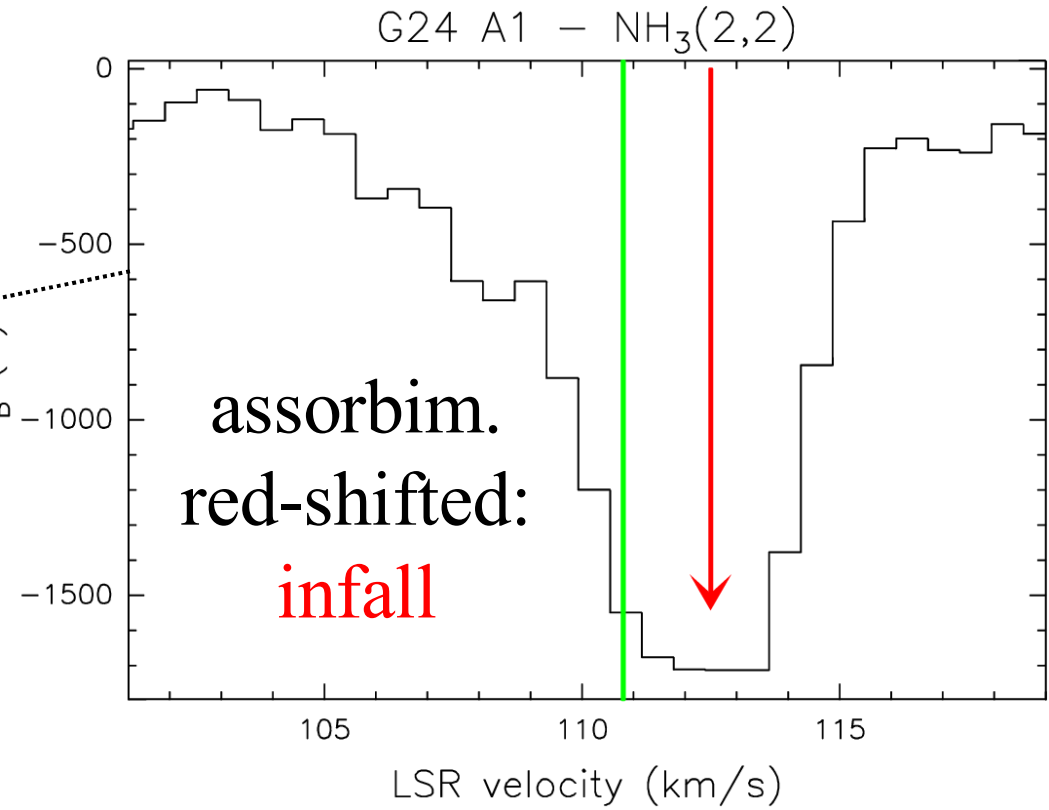
Beltran et al. (2006)
Beltran et al. (2011)





Beltran et al. (2006)
Beltran et al. (2011)





Risultati:

- $M_{star} = 20\ M_o$ dentro core con $M_{gas} = 130\ M_o$
- Gradiente di velocità perpendicolare ad asse outflow ➔ core rotante ➔ **toroide (≠ disco)**
- Assorbimento red-shifted in riga molecolare contro regione HII ➔ infall *verso* stella O ($10^{-3}\ M_o\ yr^{-1}$)

  ➔ accrescimento *sulla* stella?

Esempio: stella B

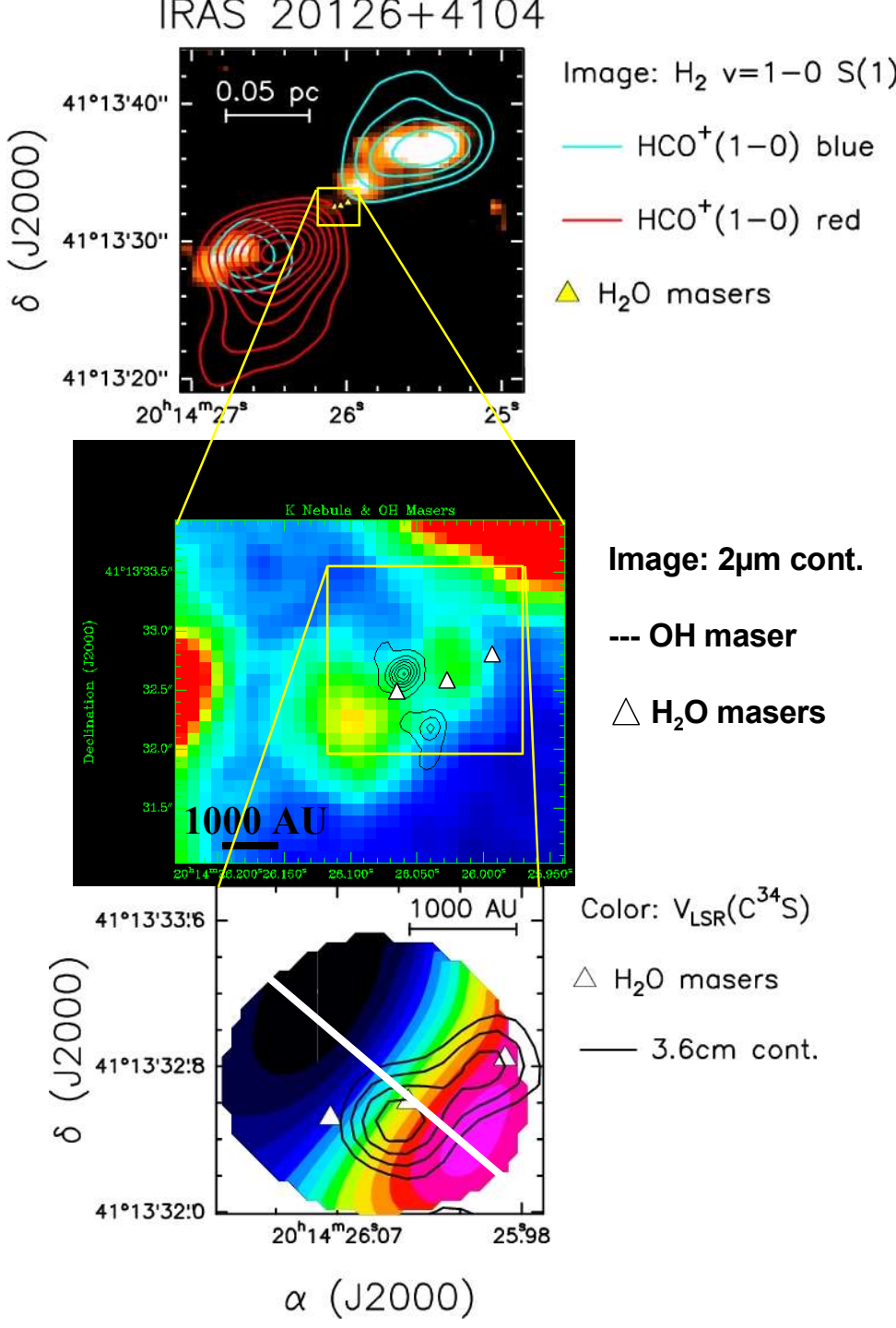
IRAS 20126+4104

Cesaroni et al.

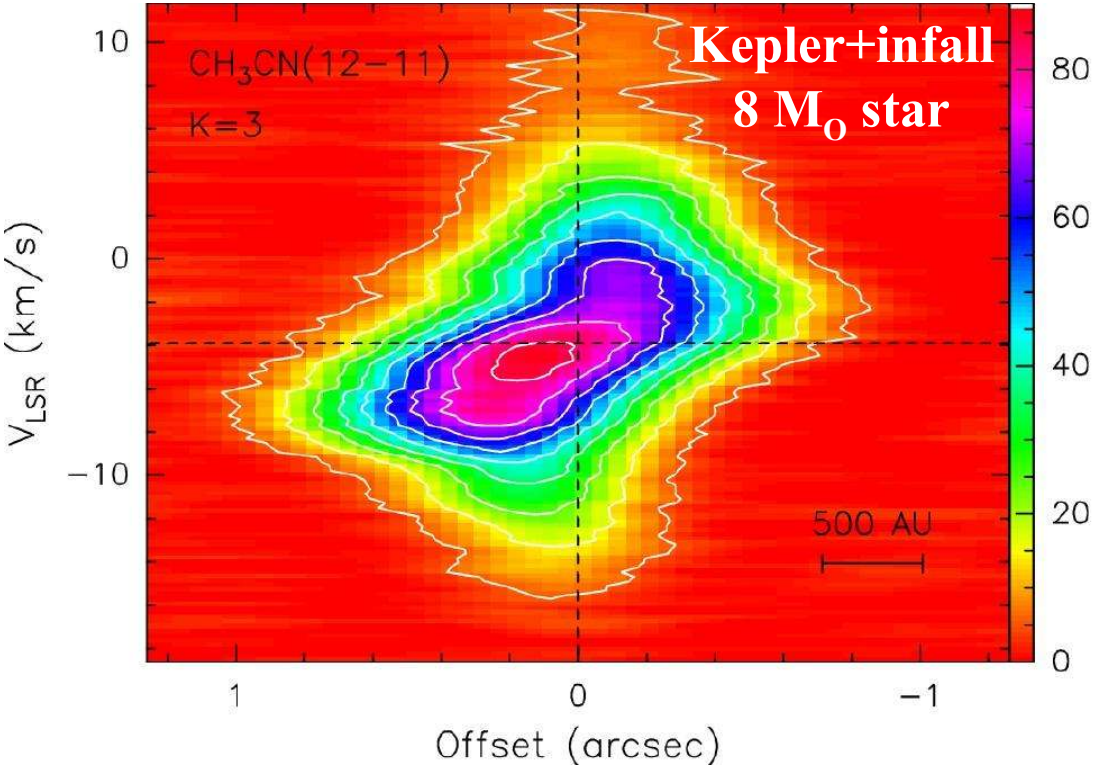
Hofner et al.

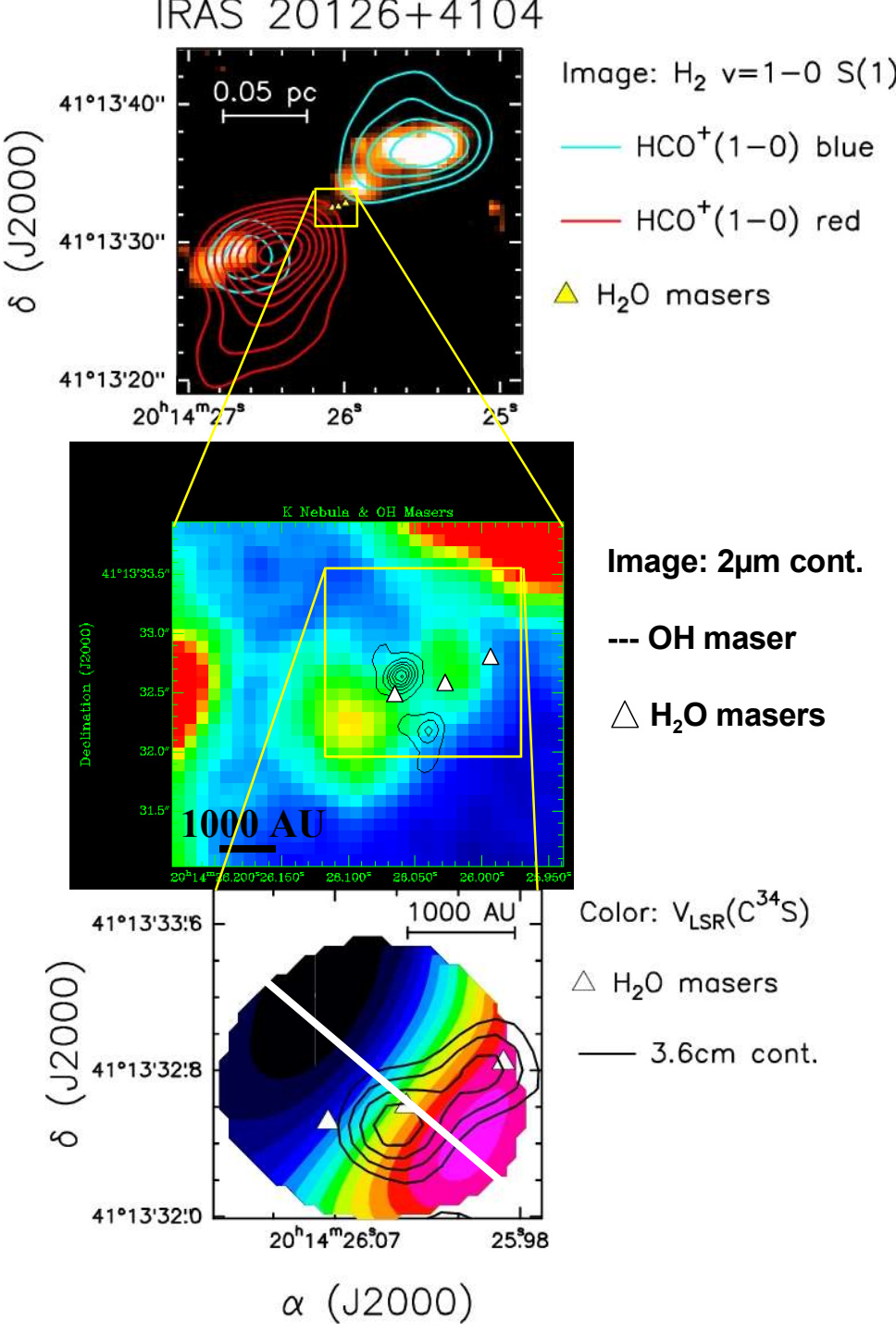
Sridharan et al.

Moscadelli et al.

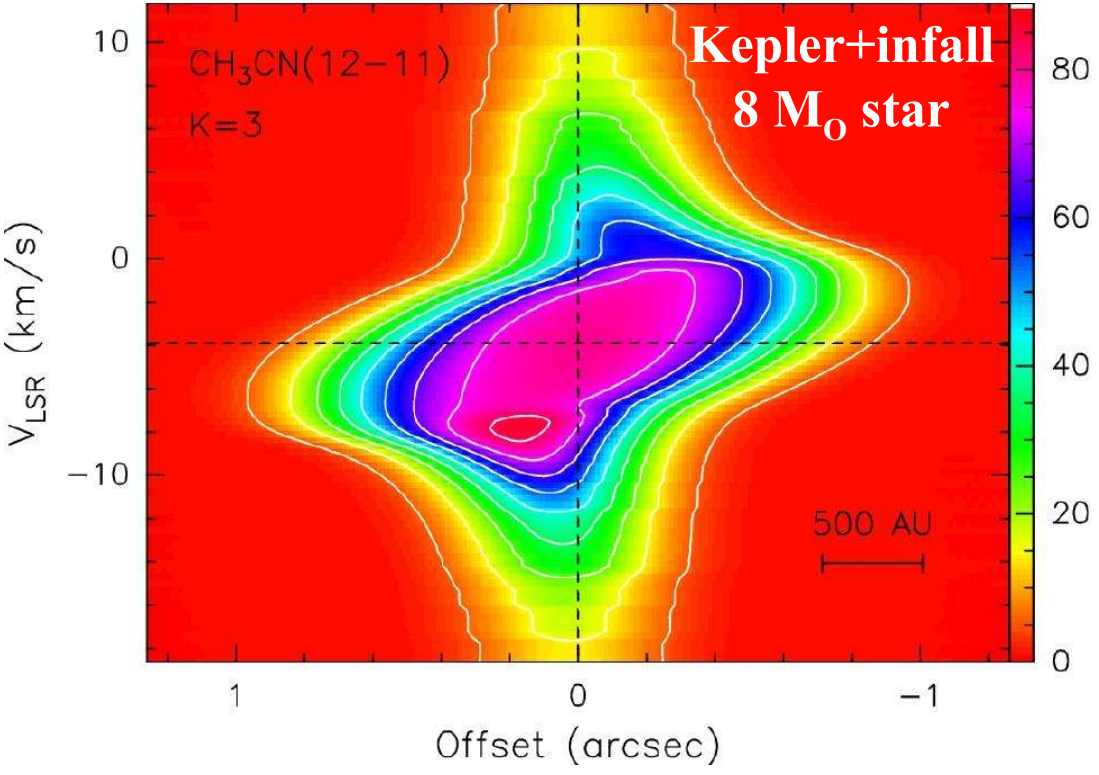


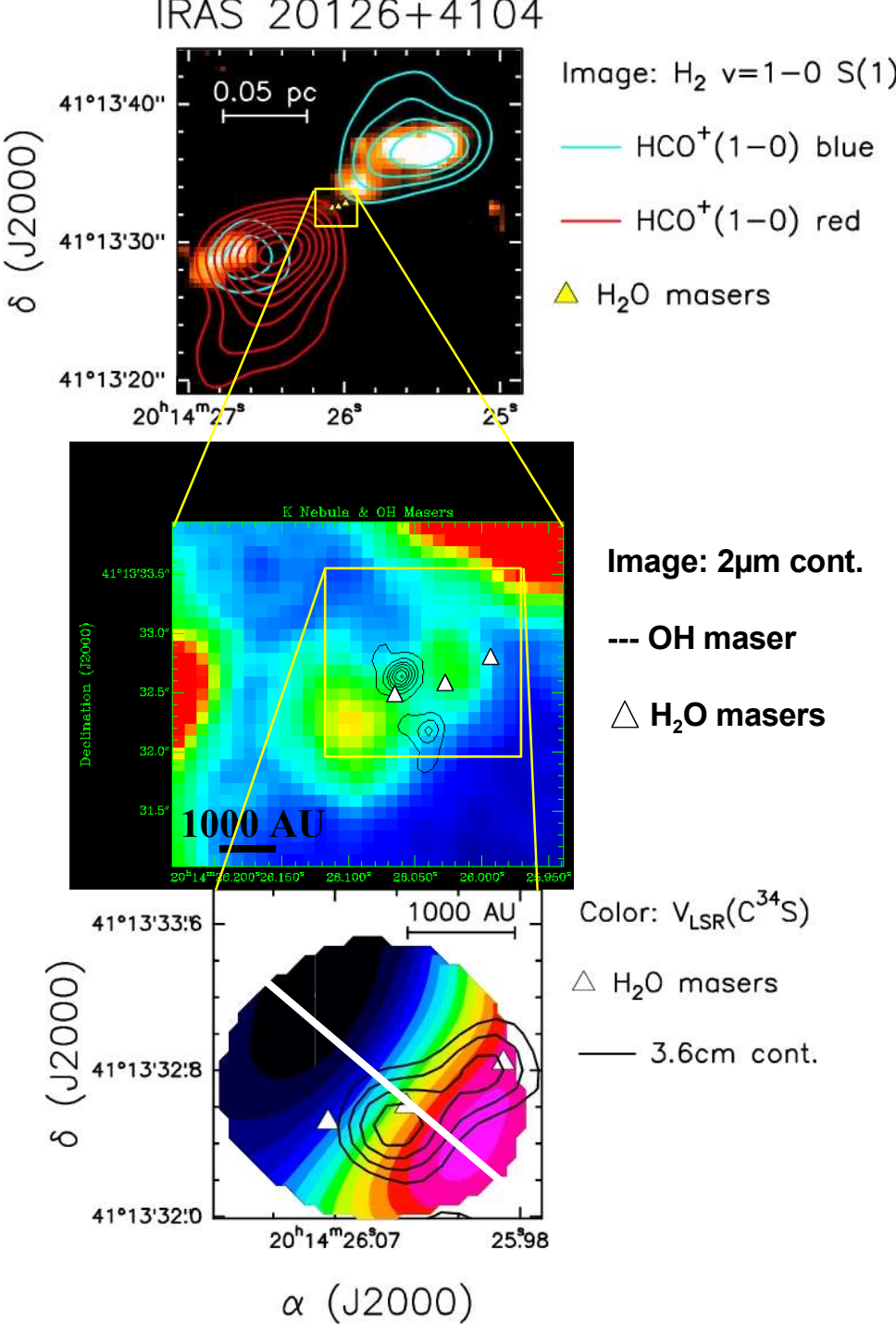
IRAS 20126+4104



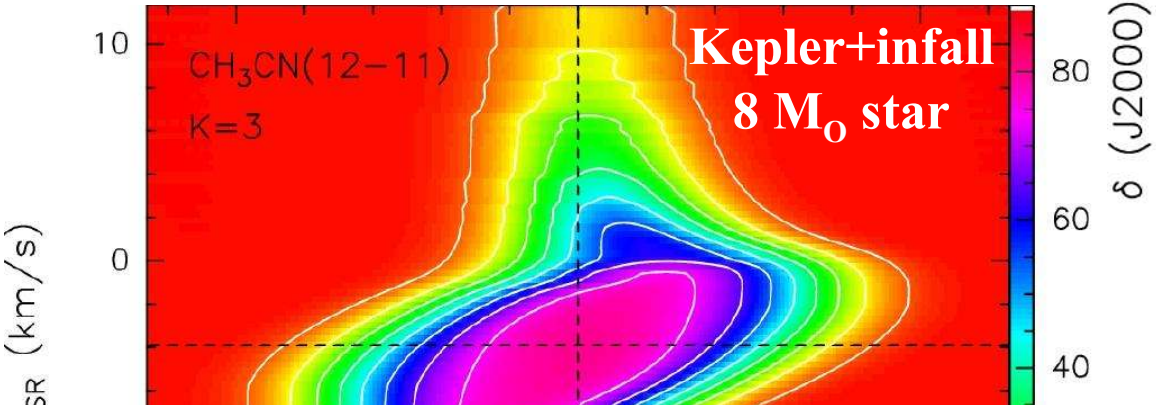


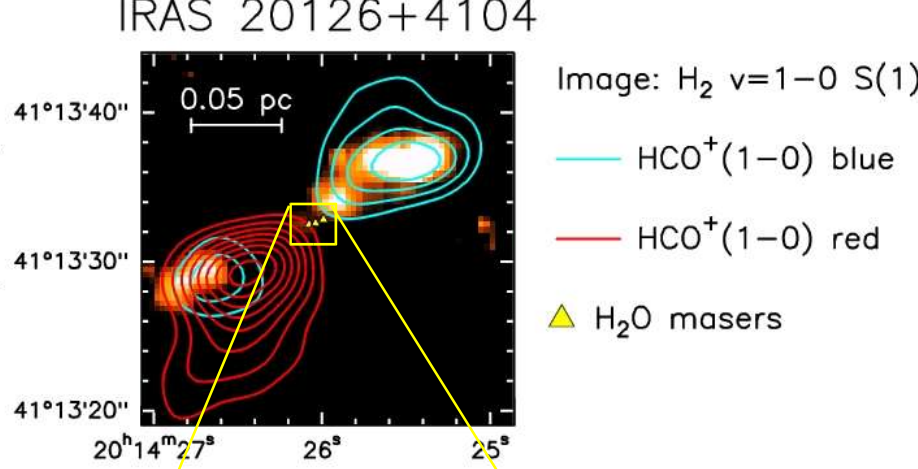
IRAS 20126+4104

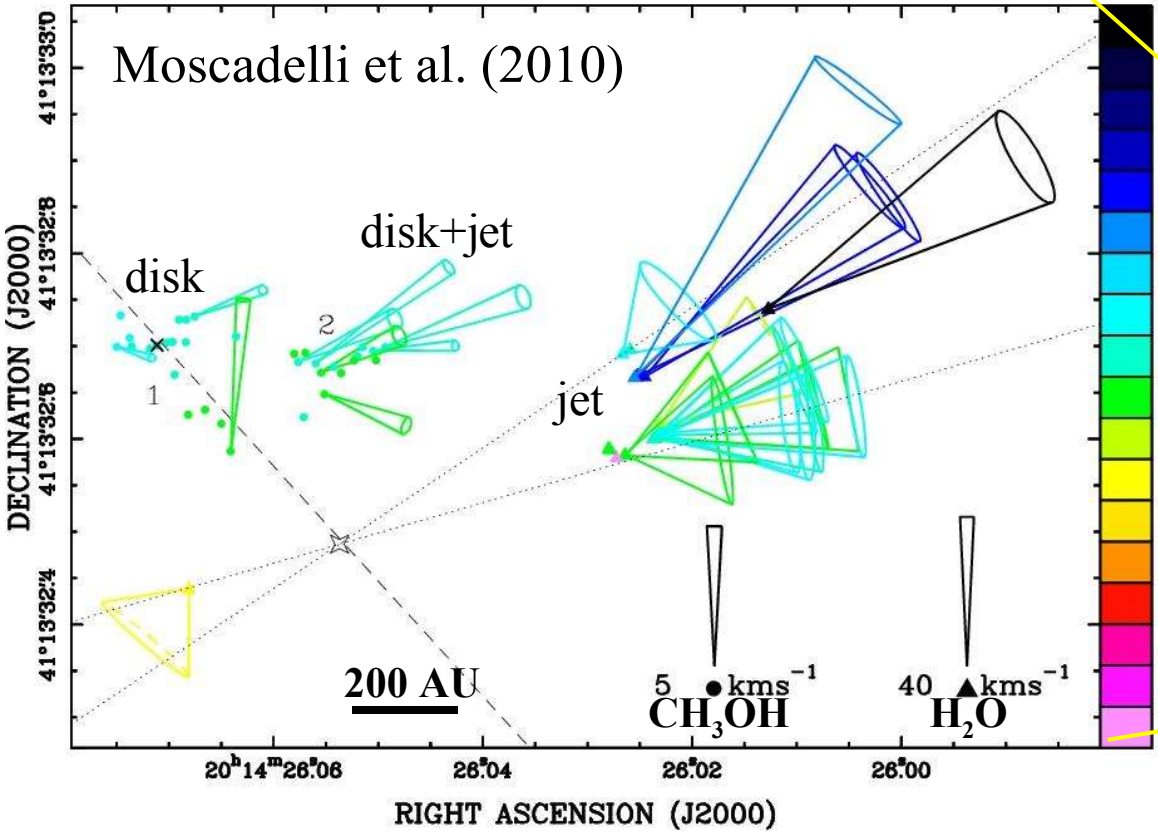




IRAS 20126+4104







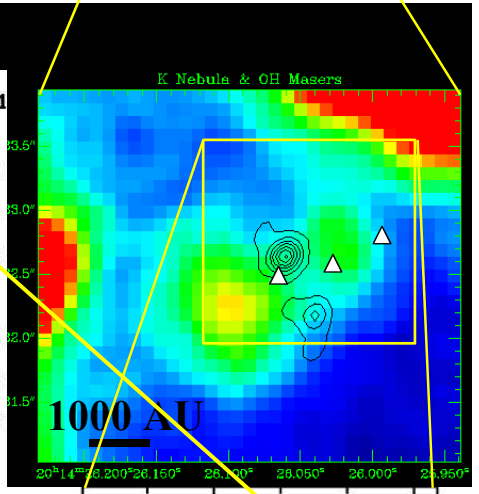
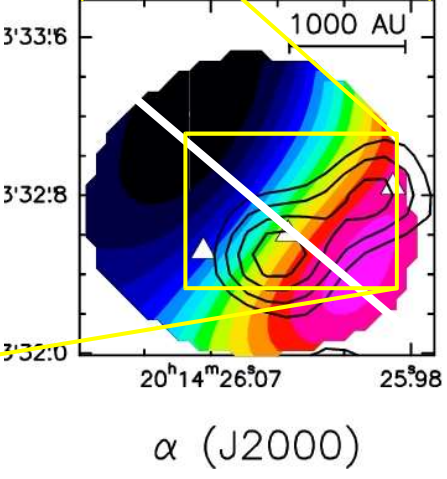


Image: 2μm cont.

--- OH maser

△ H_2O masers



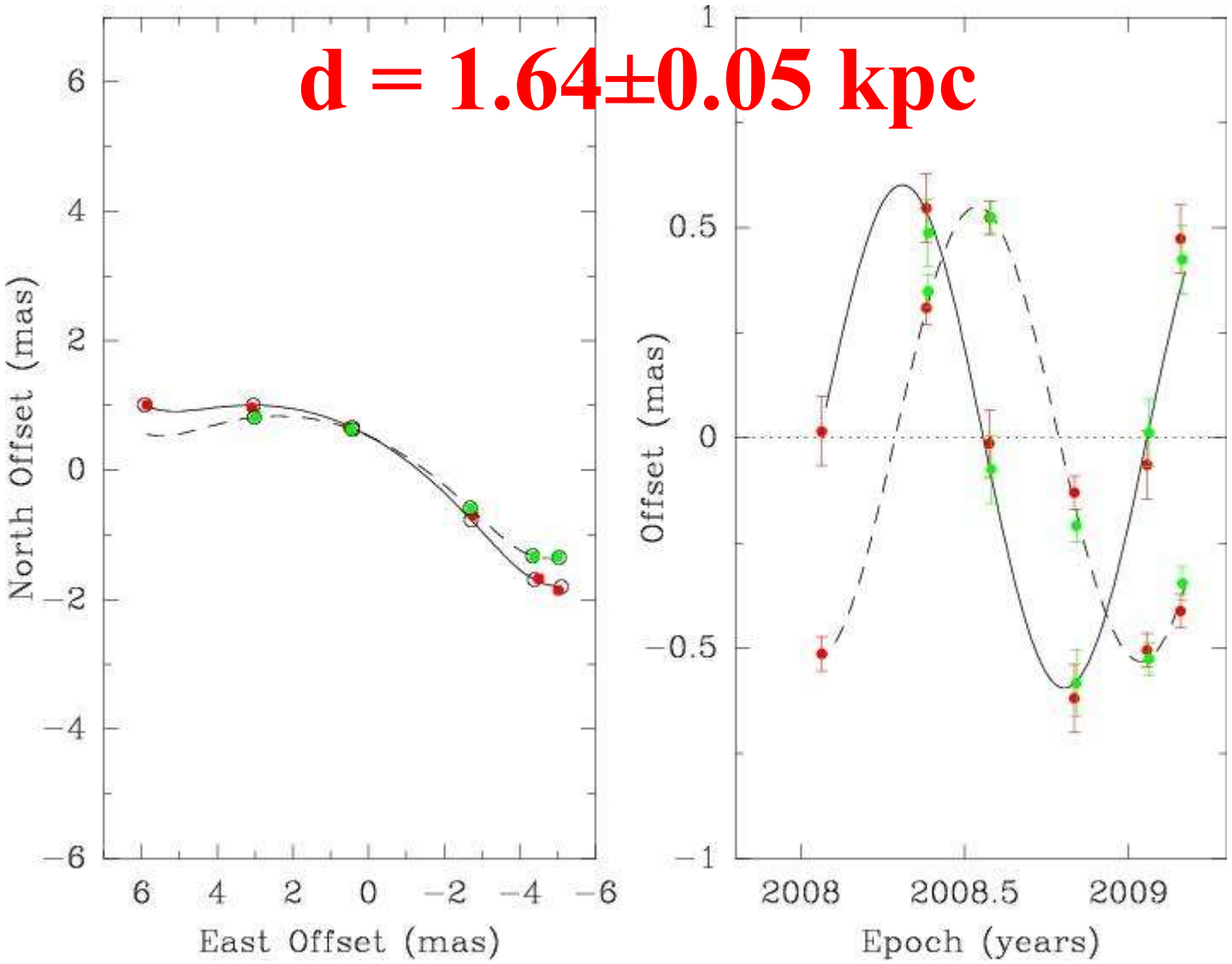
Color: $V_{LSR}(C^{34}S)$

△ H_2O masers

—— 3.6cm cont.

Distance measurement to **IRAS 20126+4104** with H_2O maser parallax (Moscadelli et al. 2010)

d = 1.64±0.05 kpc



Risultati

- Stelle **B** (~ 10^4 L_o): evidenza di **dischi** di accrescimento circumstellari (Kepleriani)

- Stelle **O** (> 10^5 L_o): nessuna evidenza di dischi; solo **toroidi** rotanti (molto massicci)

Dischi

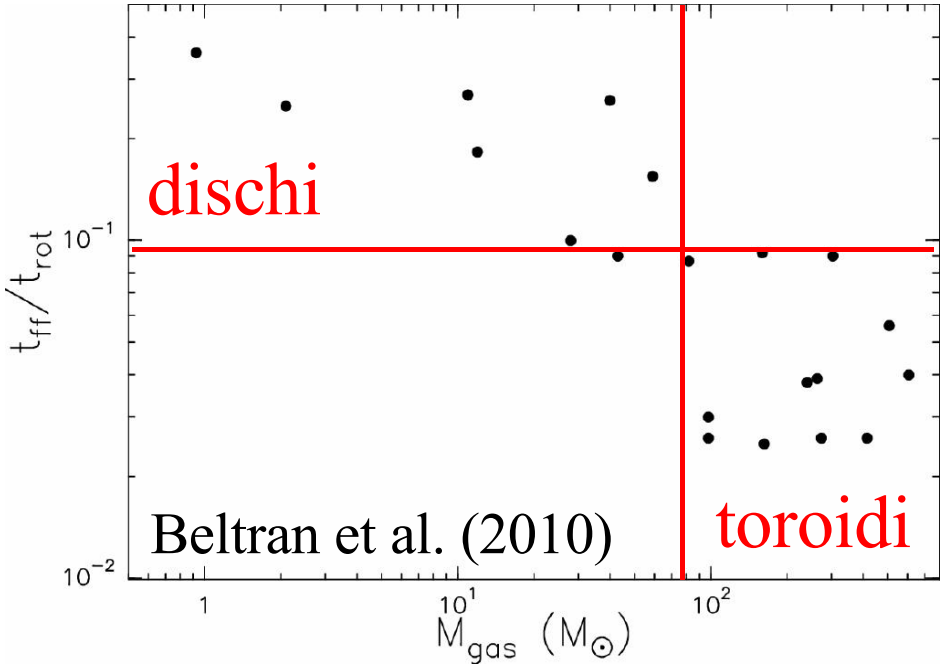
- M < alcune 10 M_o
- R ~ 1000 AU
- **L ~ 10^4 L_o** ➔ (proto)stelle **B**
- **t_{acc}/t_{rot}** grande

➔ Strutture circum*stellari* in equilibrio

Toroidi

- M > 100 M_o
- R ~ 10000 AU
- **L > 10^5 L_o** ➔ (proto)stelle **O**
- **t_{acc}/t_{rot}** piccolo

➔ Strutture transienti, contenenti *cluster*



Interrogativo

Perché **non** si osservano **dischi** attorno a (proto)stelle di **tipo O** ?

Possibile causa: **bias** osservativo per scarse sensibilità e risoluzione

Ipotesi:

$HPBW = R_{disk}/4$

$FWHM_{line} = V_{rot}(R_{disk})$

$M_{disk} \propto M_{star}$

$\langle N_{col} \rangle$ = cost.

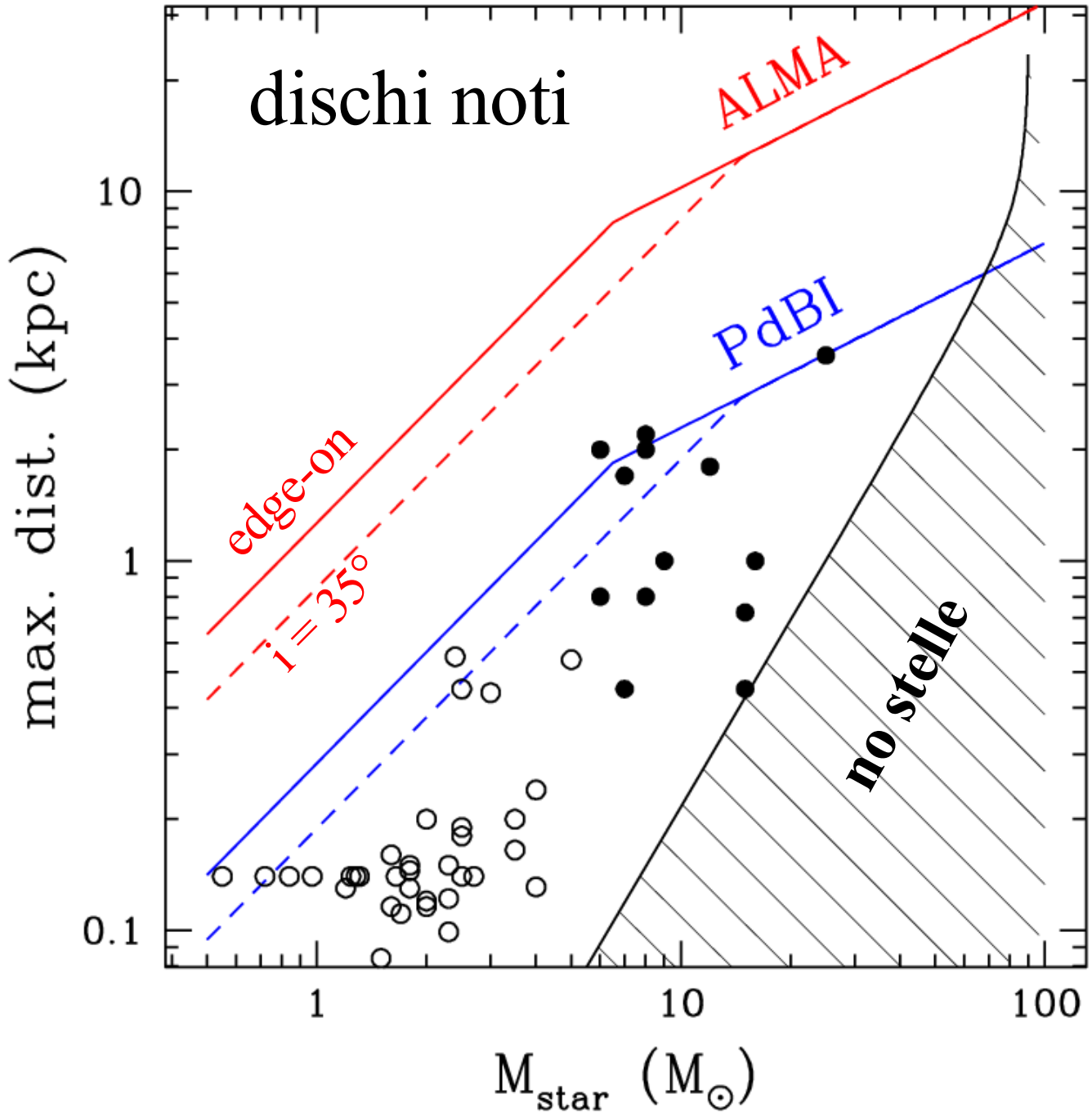
$T_B > 20$ K

$\nu = 230$ GHz

5 ore ON-source

risol. spettr. = 0.2 km/s

S/N = 20

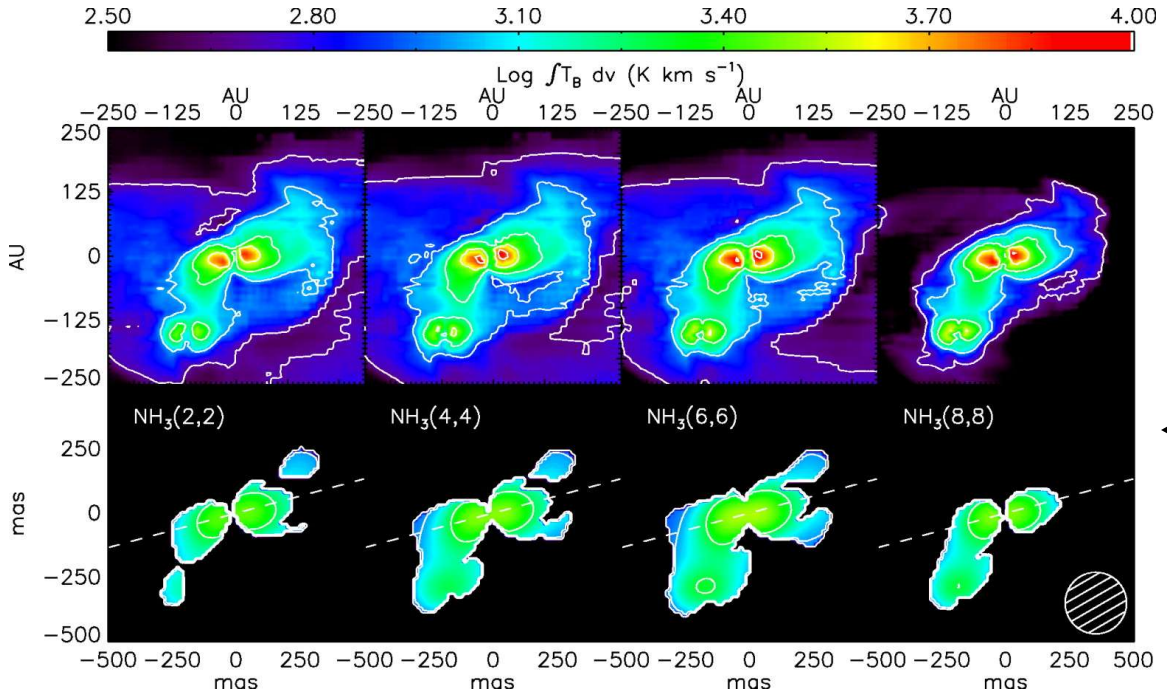


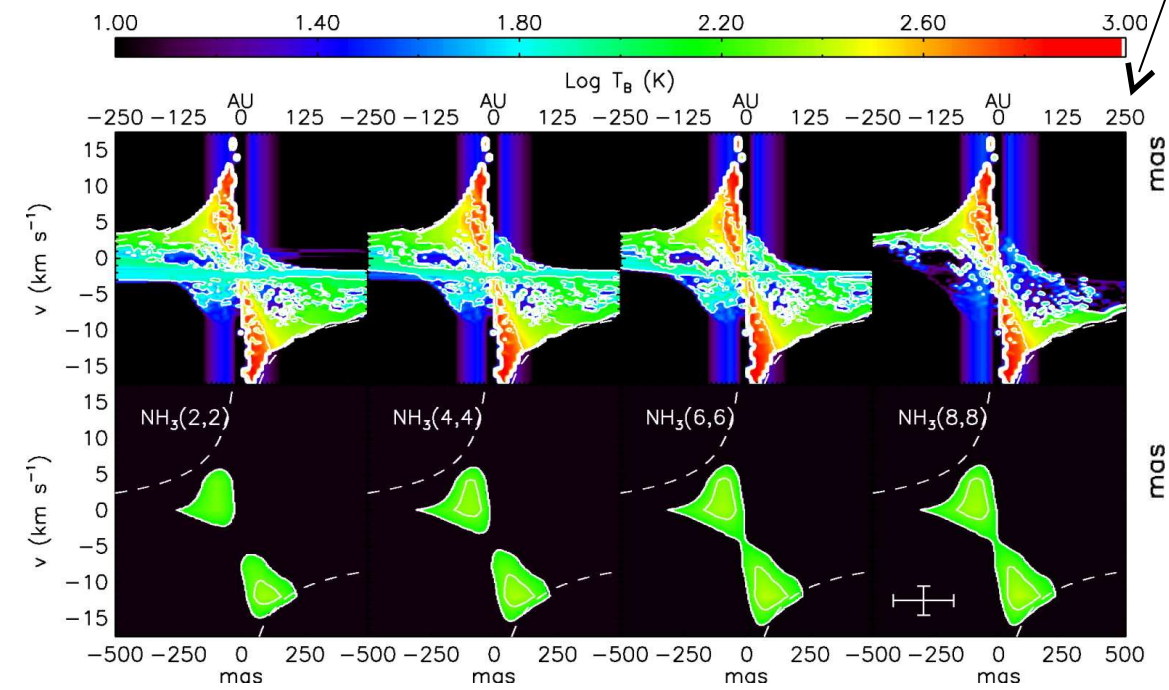
Simulazioni di dischi attorno a stella 8 M_o

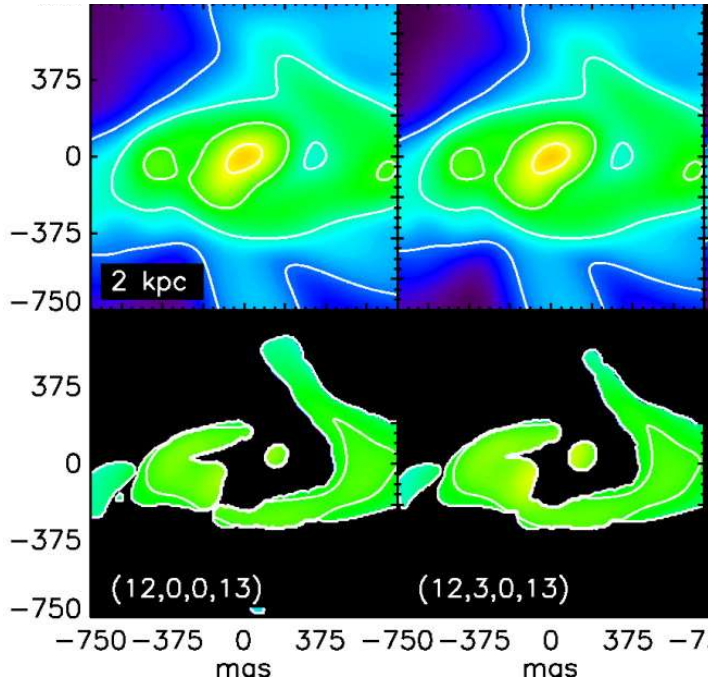
Krumholz et al. (2007)

NH_3 con EVLA

$CH_3CN(12\text{-}11)$ con **ALMA**







cont. + riga

riga

Progetto ALMA

R. Cesaroni, H. Zinnecker, M.T. Beltran, S. Etoka, D. Galli, C. Hummel, N. Kumar, L. Moscadelli, T. Preibisch, A. Sanchez-Monge, T. Stanke, F. Van der Tak, S. Vig, C.M. Walmsley, K.S. Wang

Osservare dischi attorno a (proto)stelle di tipo O per stabilire processo di formazione stelle massicce

Tuttavia…

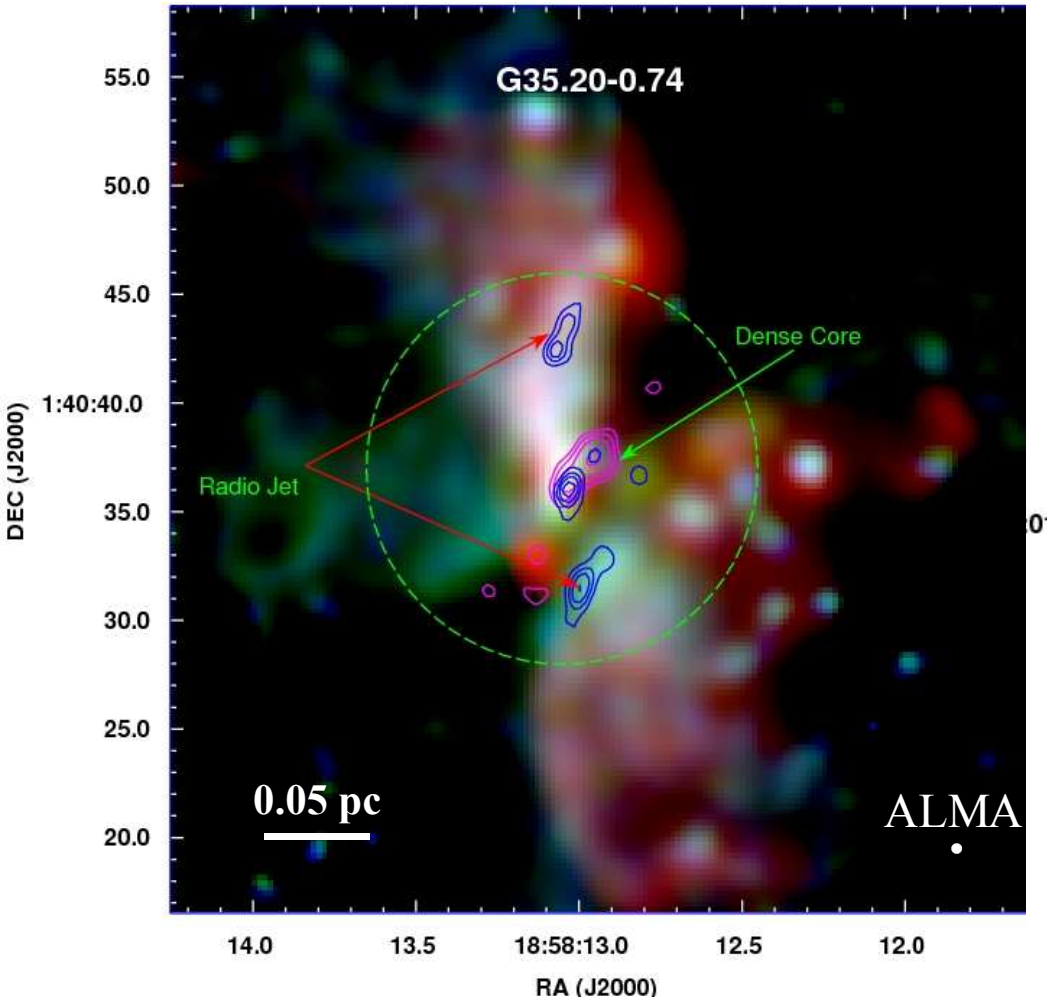
- Ciclo 0 insufficiente per distanze > 2-3 kpc
- Rivelabili solo dischi in (proto)stelle B

➔ Scopo Ciclo 0: trovare altri dischi **Kepleriani** come IRAS 20126+4104 in **(proto)stelle B**

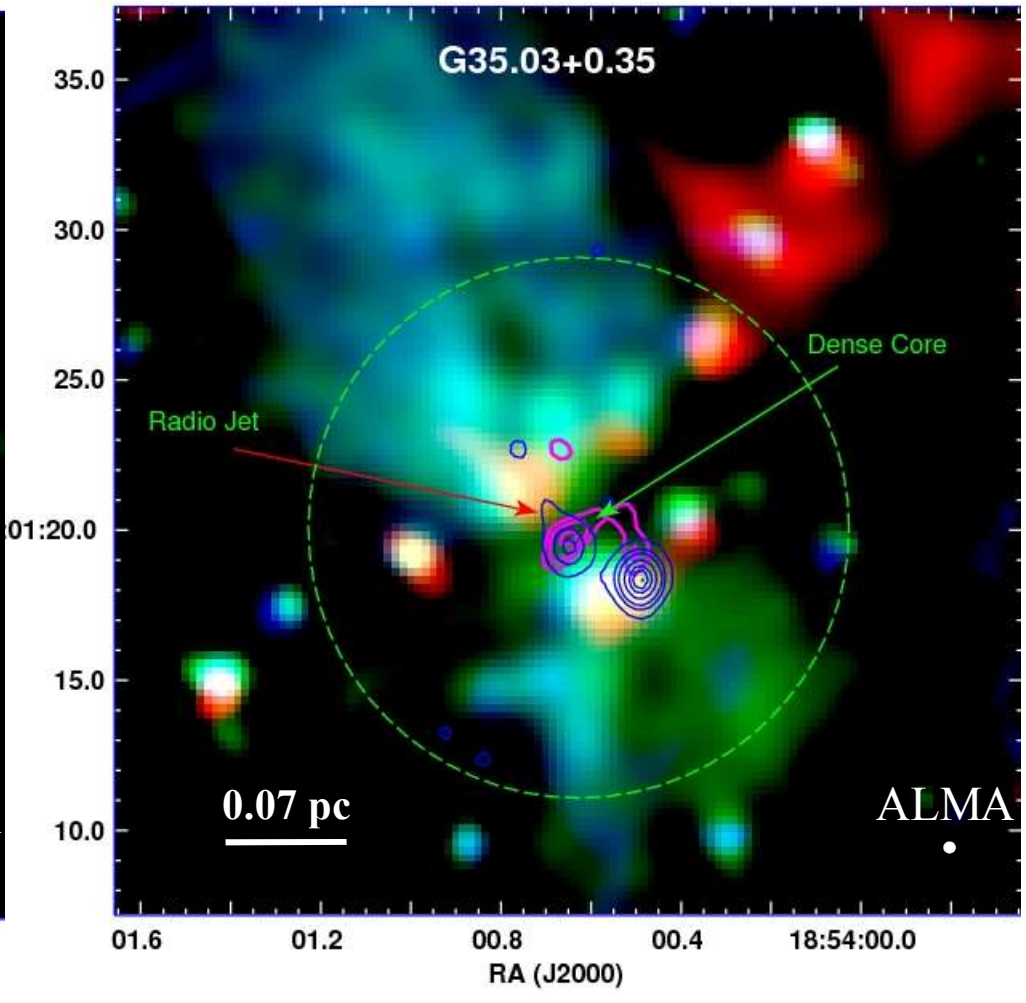
Target: nebulosa bipolare + radio jet + core denso

Spitzer/IRAC VLA 1.3cm VLA NH_3

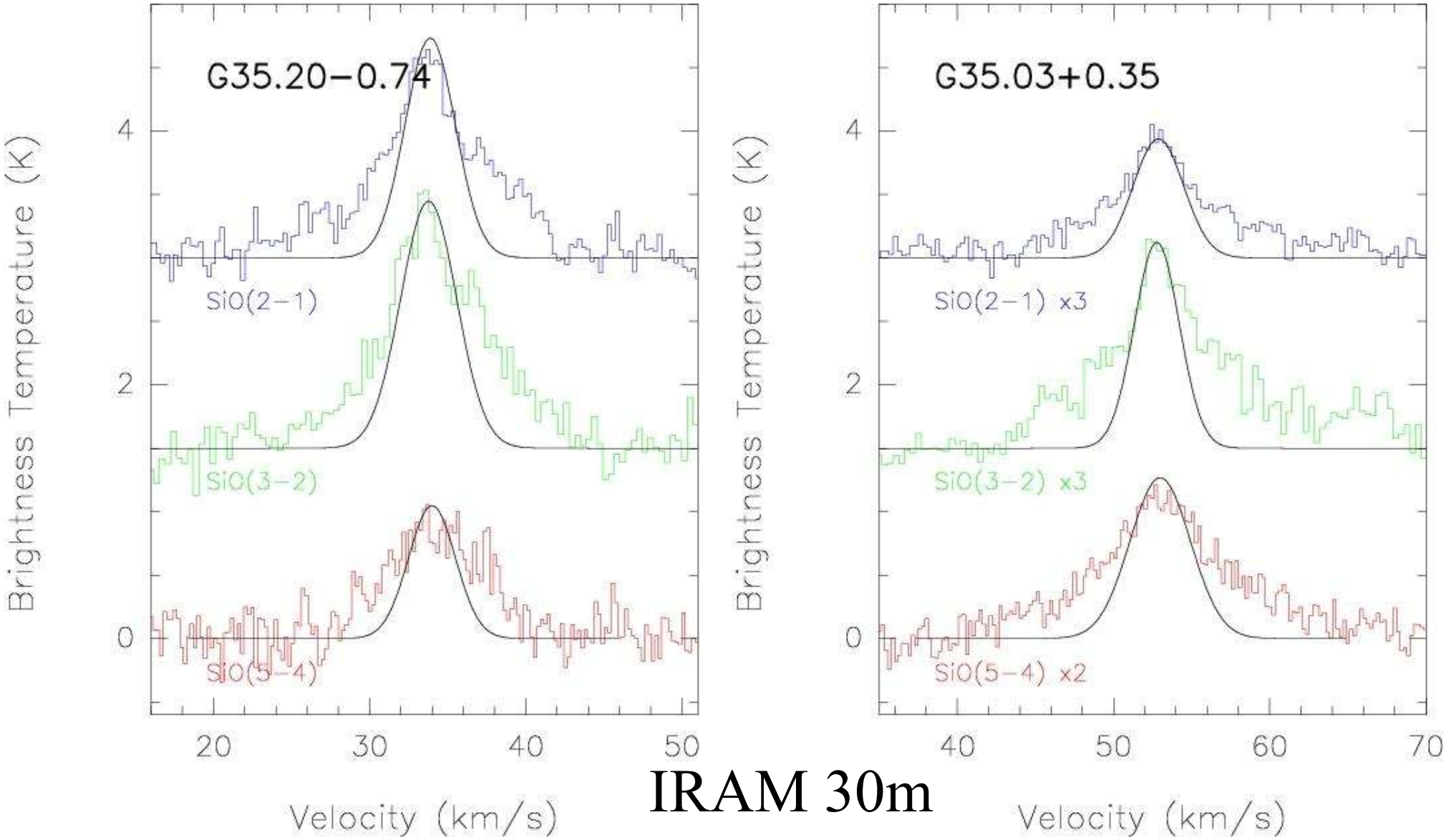
10^4 L_o, 2.2 kpc



10^4 L_o, 3.6 kpc



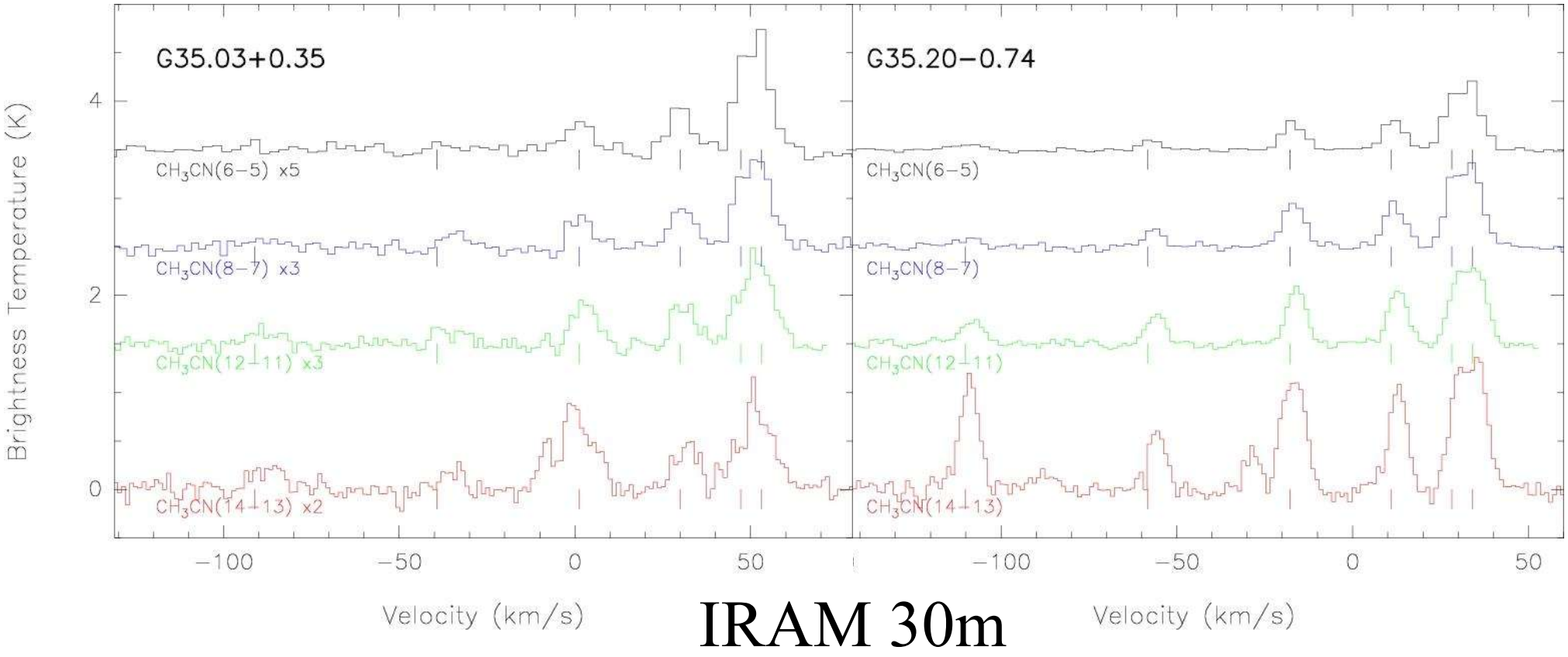
Tracciante outflow: ali prominenti in SiO



IRAM 30m

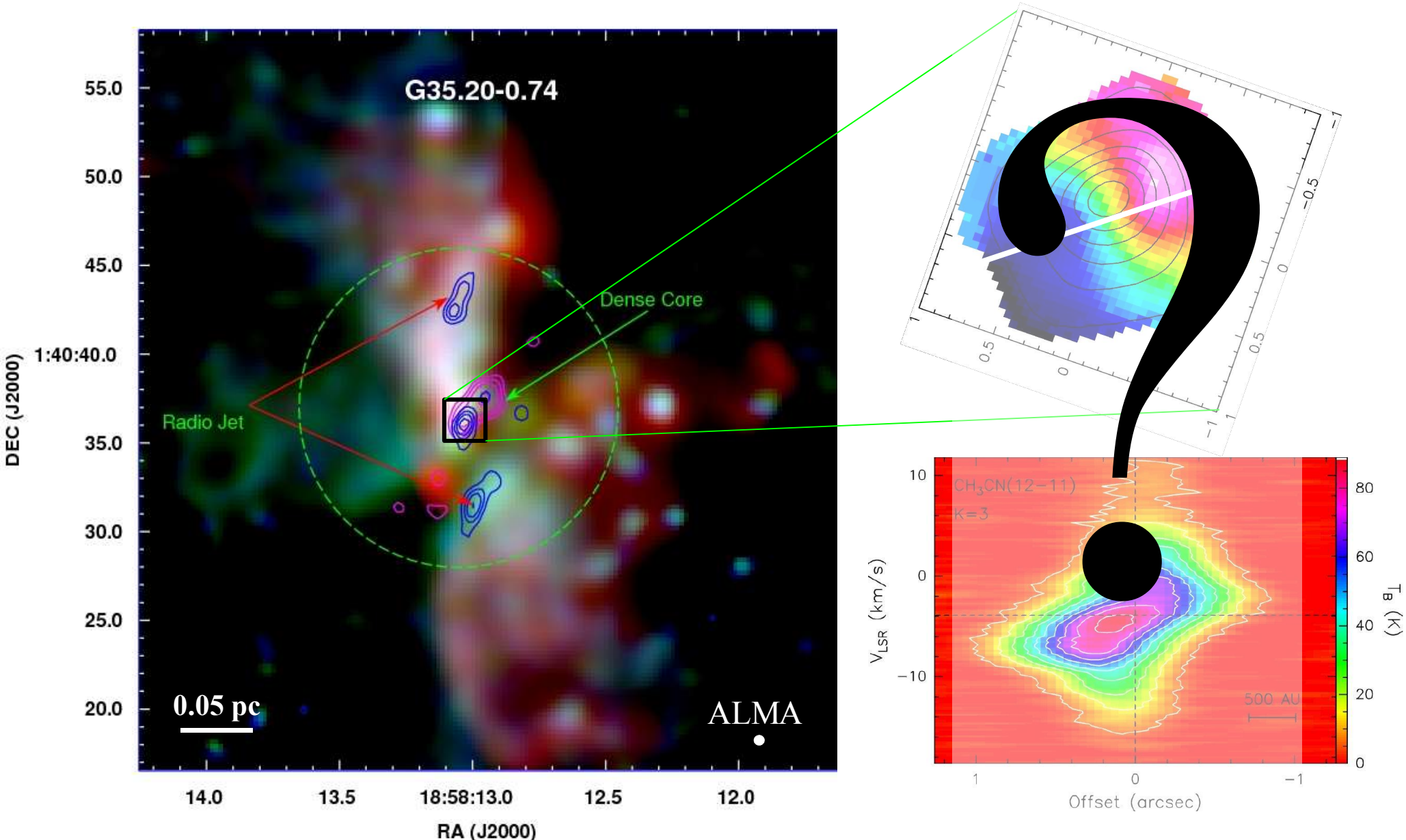
Tracciante disco: CH_3CN intenso

➔ gas denso e caldo



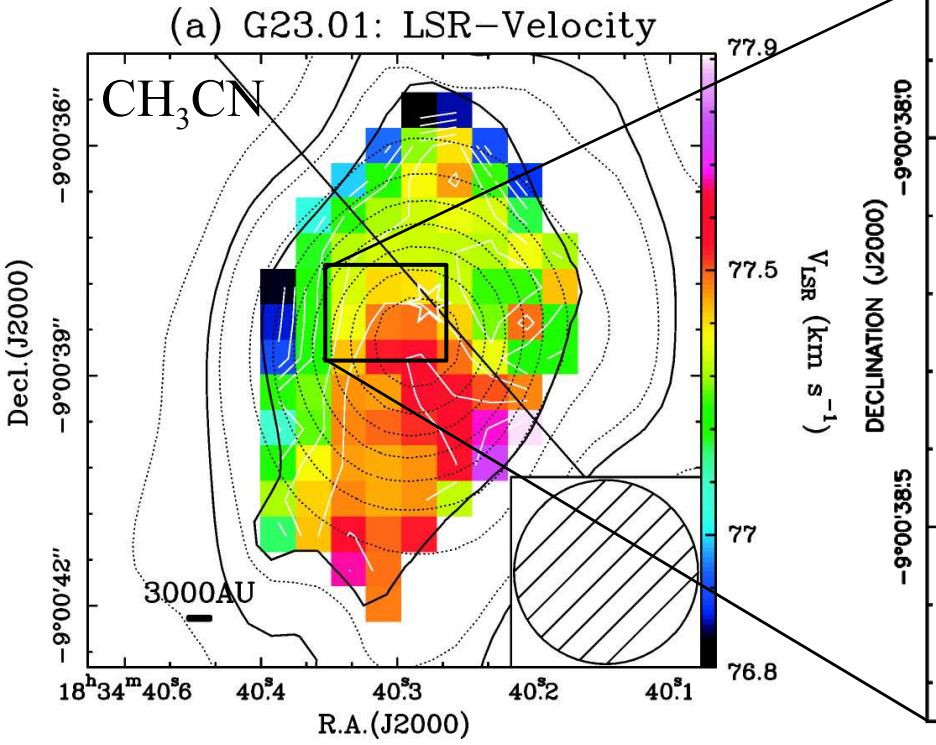
IRAM 30m

Cosa ci aspettiamo dal Ciclo 0…?



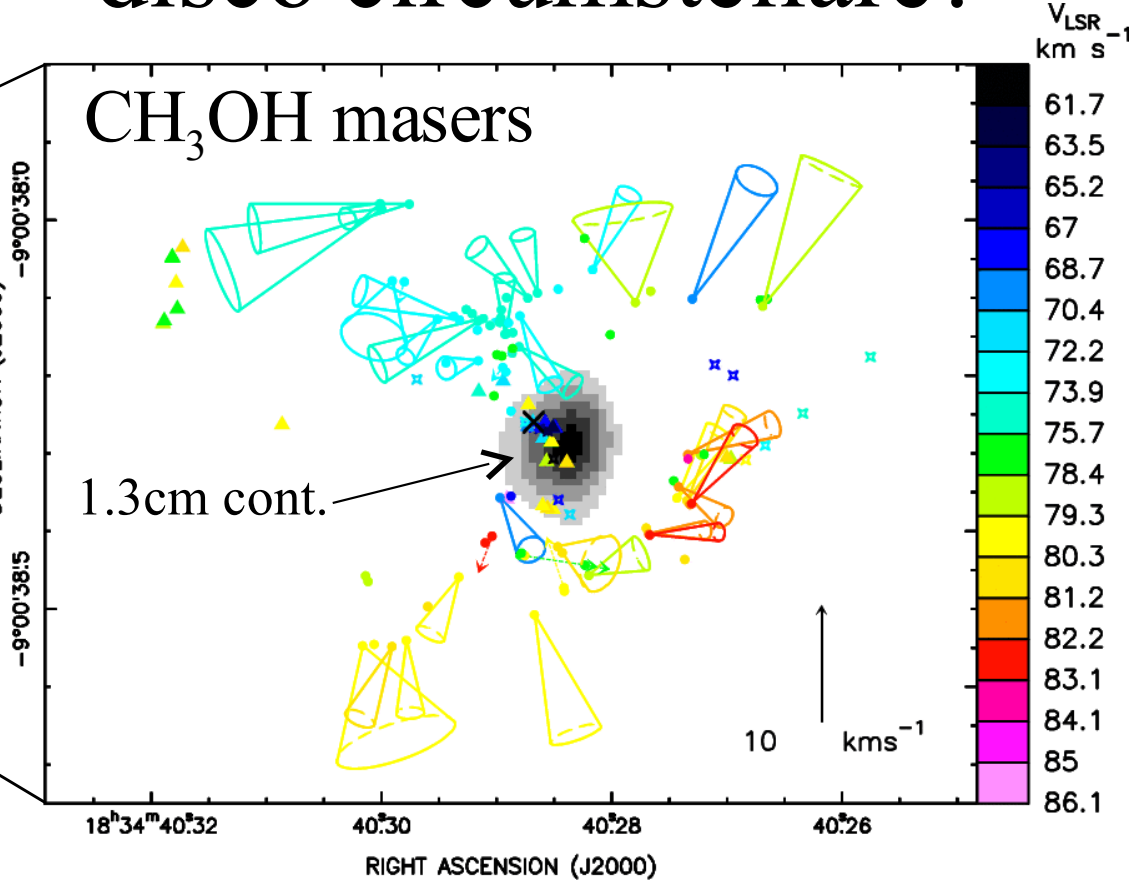
Il futuro: con ALMA completo dischi dentro toroidi in stelle O

toroide rotante?



Furuya et al. (2008)

disco circumstellare?



Sanna et al. (2010)