High-mass star formation explored with maser VLBI & thermal (ALMA/JVLA) observations

Luca Moscadelli

INAF – Osservatorio di Arcetri

EUROPEAN VLBI NETWORK
Consortium for Very Long Baseline Interferometry in Europe

closest collaborators:

Riccardo Cesaroni

Ciriaco Goddi

Alberto Sanna

HM SF Open Problems and Talk Outline

Low-mass (~1 $M_\odot$) SF: disk-jets well characterized by observations.

In high-mass (> 8 $M_\odot$), from (mainly ALMA / JVLA) Observations:

B-type YSOs with disks. Few (claims of) disks towards O-type YSOs

A few thermal jets towards high-mass YSOs (VLA, rms ~ 0.3 mJy)

G16.59-0.05: one of the few observed disk-jet systems in HMYSO.

HM SF Open Problems and Talk Outline

Low-mass (~1 $M_\odot$) SF: disk-jets well characterized by observations.

In high-mass (> 8 $M_\odot$), from (mainly ALMA / JVLA) Observations:

B-type YSOs with disks. Few (claims of) disks towards O-type YSOs

A few thermal jets towards high-mass YSOs (VLA, rms ~ 0.3 mJy)

G16.59-0.05: one of the few observed disk-jet systems in HMYSO.

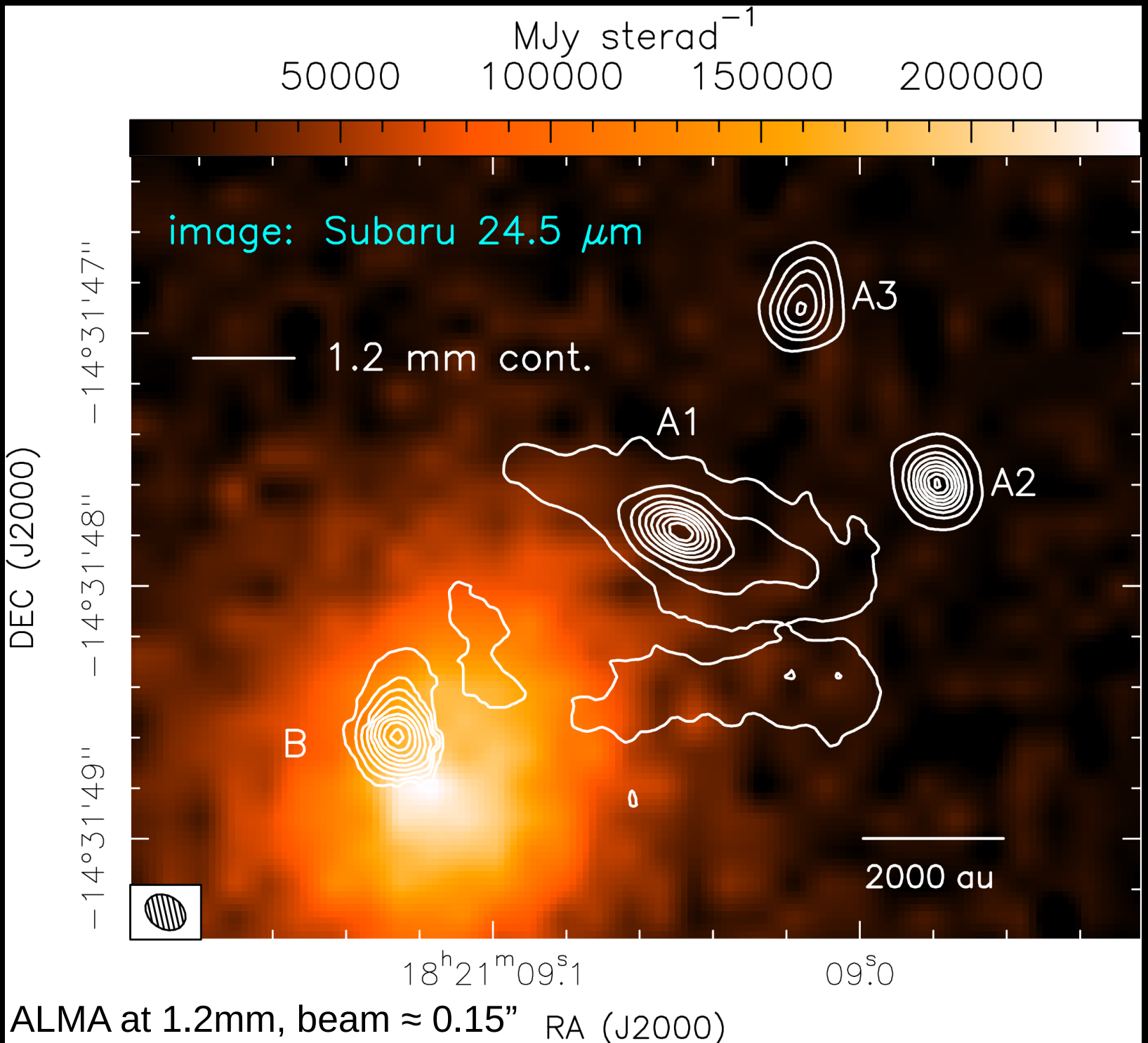
Peculiar for high-mass SF:

Impact of radiation pressure and photoionization (thermal pressure from ionized gas) on the accretion/ejection.

The onset of the ionization: hyper-compact (HC) HII region.

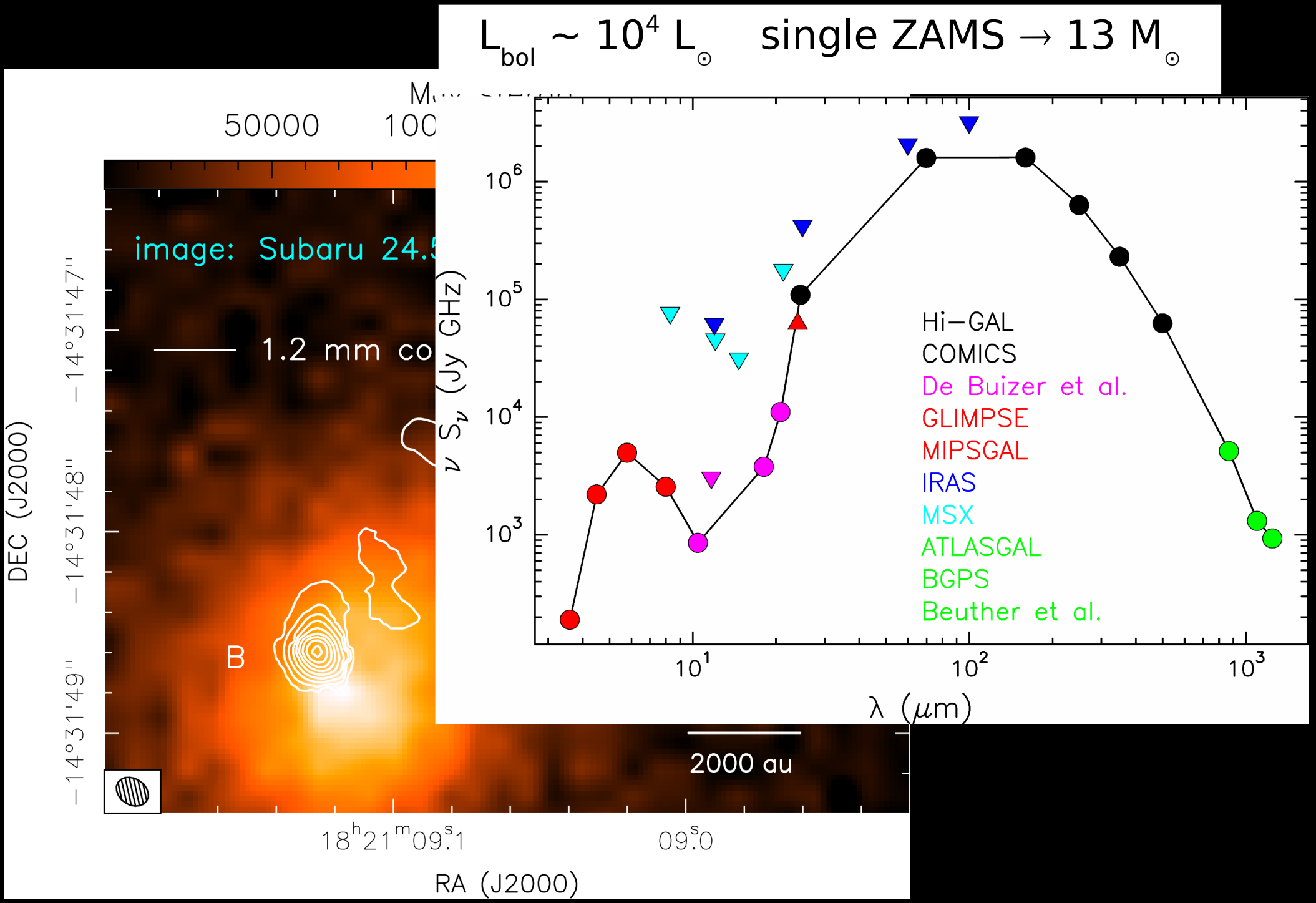
The HC HII region inside core A1 in the SFR G24.78+0.08.

The disk-jet around the high-mass YSO G16.59-0.05



ALMA at 1.2mm, beam ≈ 0.15”

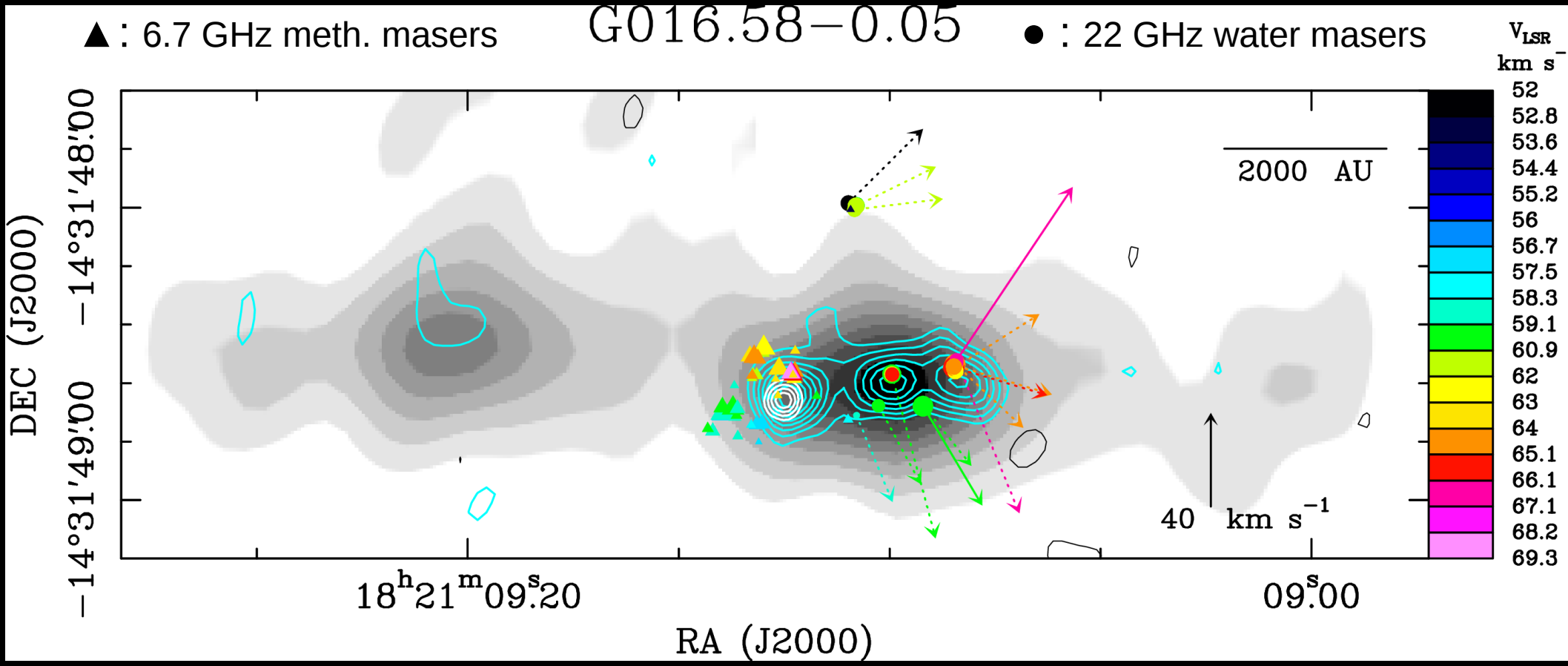
The disk-jet around the high-mass YSO G16.59-0.05



The disk-jet around the high-mass YSO G16.59-0.05

continuum (JVLA, A-Array)

gray scale: 6 GHz 13 GHz 22 GHz



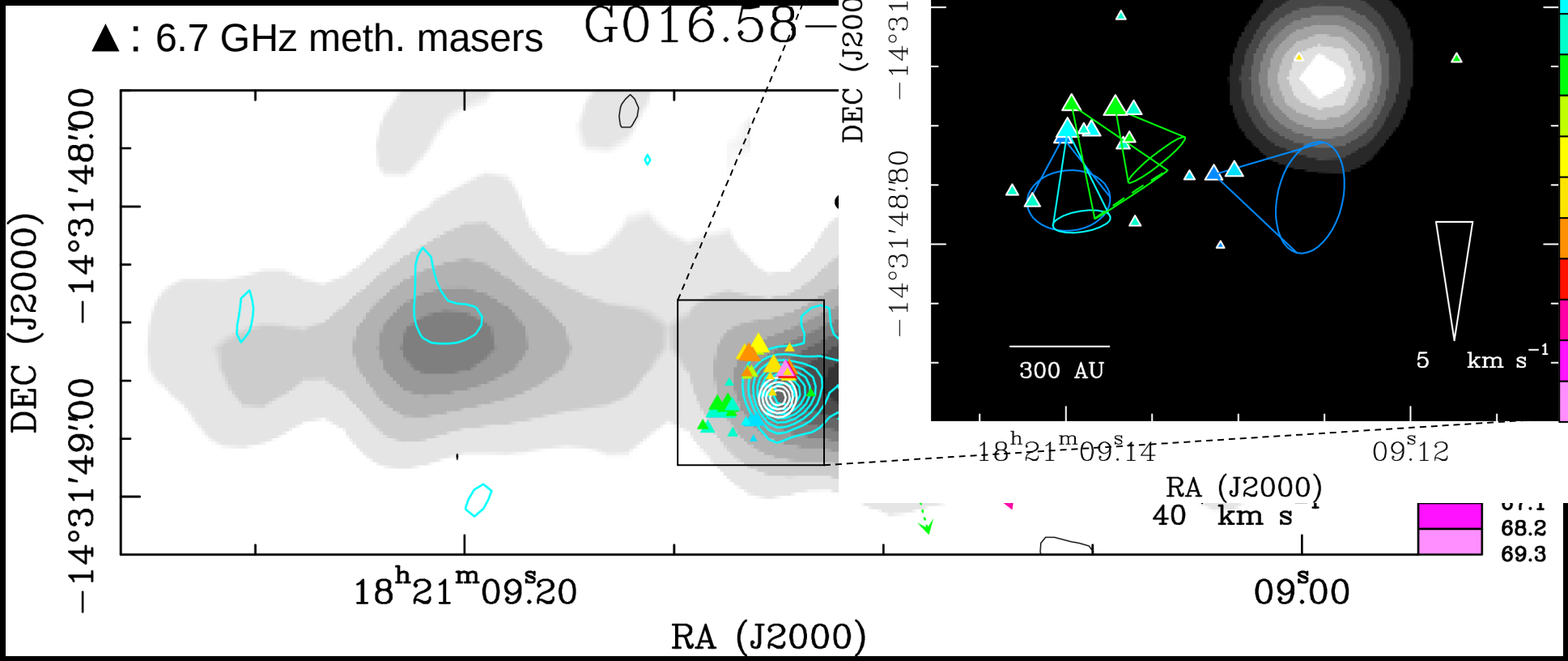
Sanna et al. (2010)

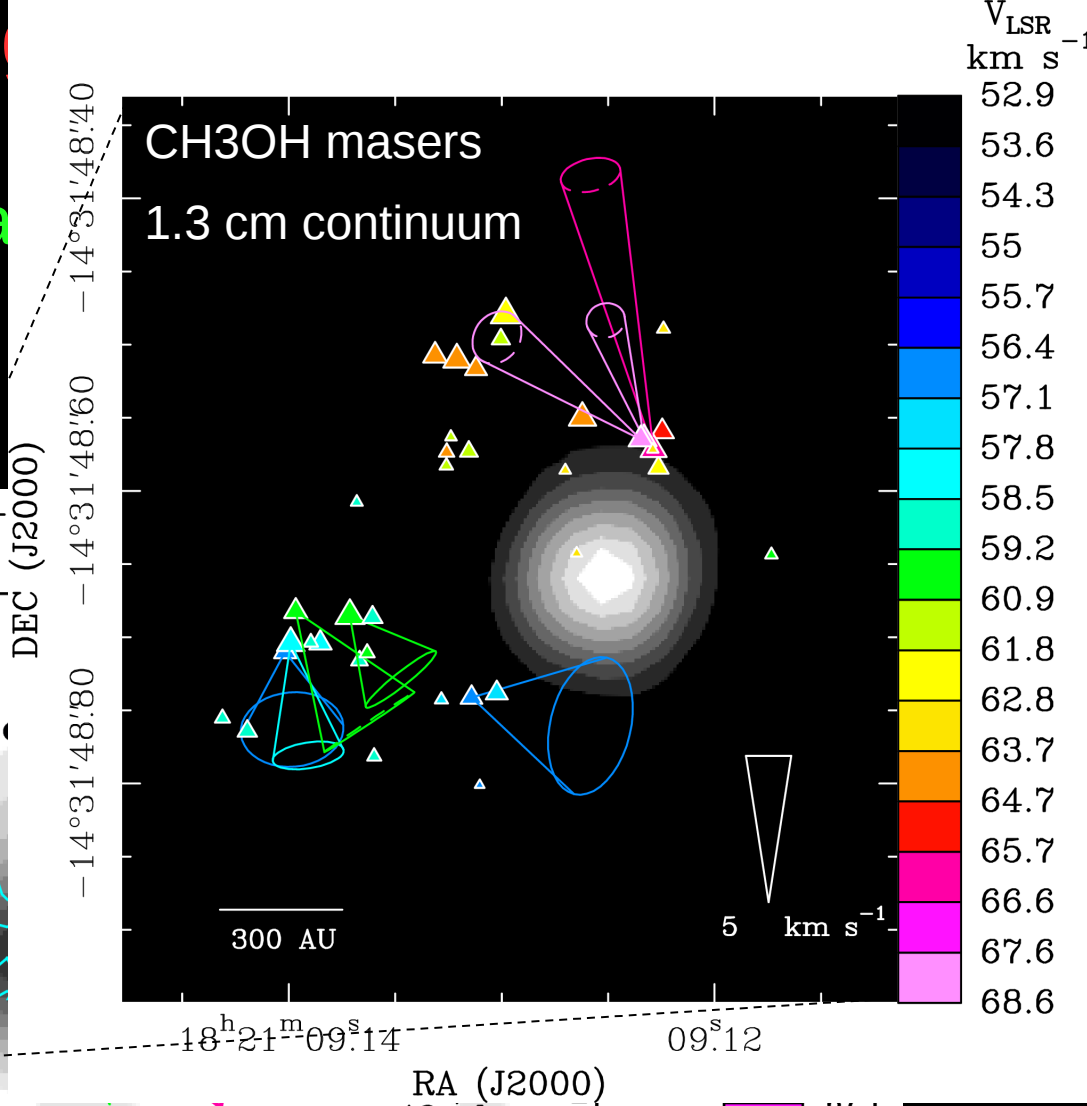
Moscadelli et al. (2016)

The disk-jet around the hi

continuum (JVLA, A-Arra

gray scale: 6 GHz 13 GHz





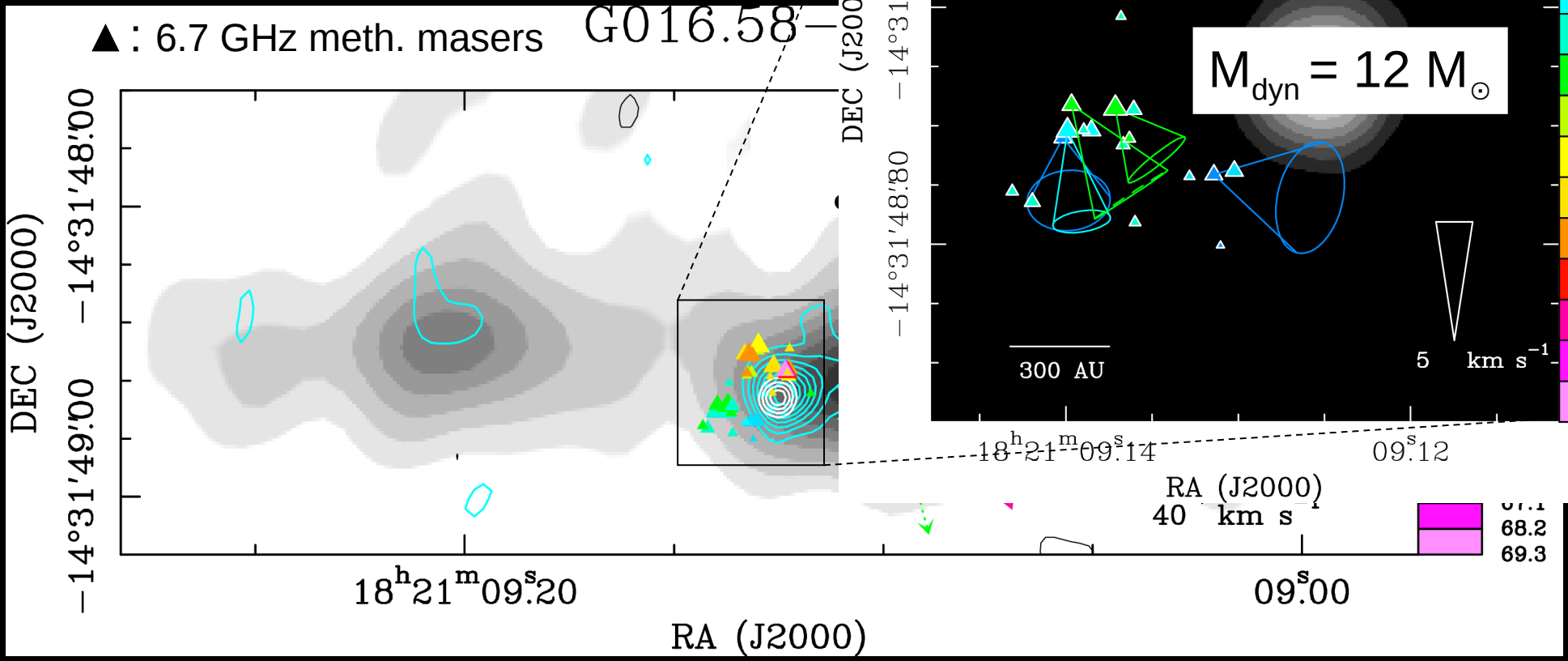
Sanna et al. (2010)

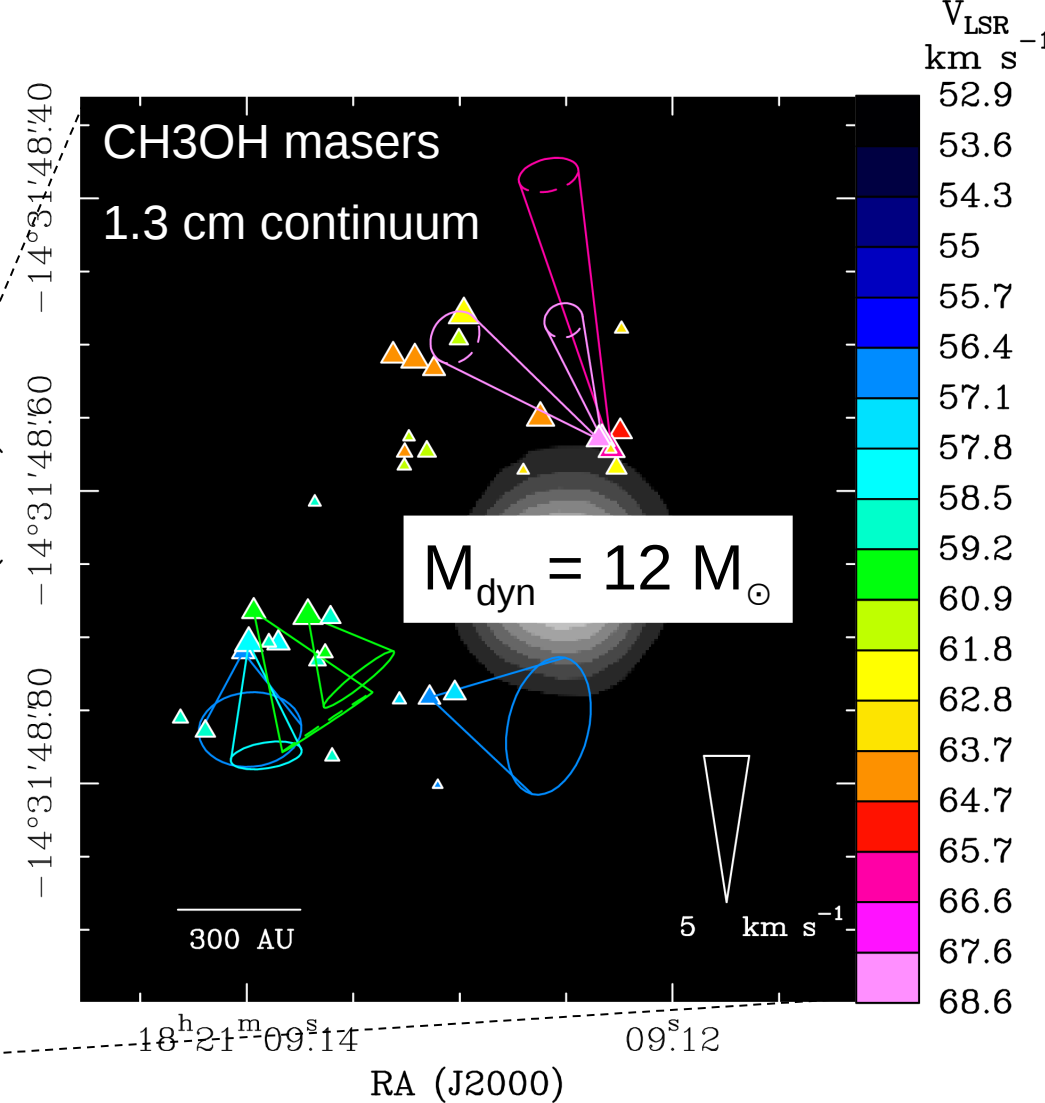
Moscadelli et al. (2016)

The disk-jet around the hi

continuum (JVLA, A-Arra

gray scale: 6 GHz 13 GHz



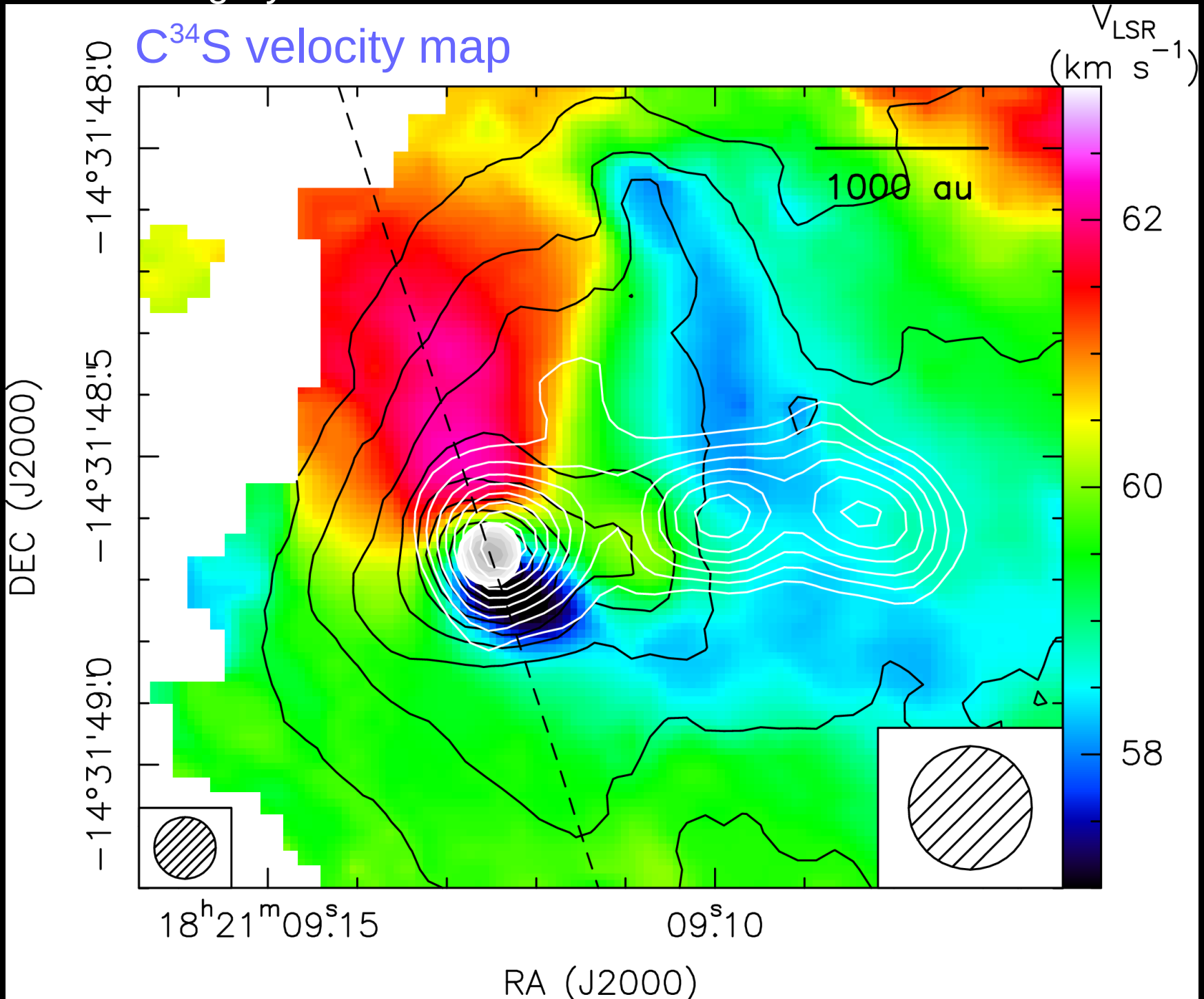


Sanna et al. (2010)

Moscadelli et al. (2016)

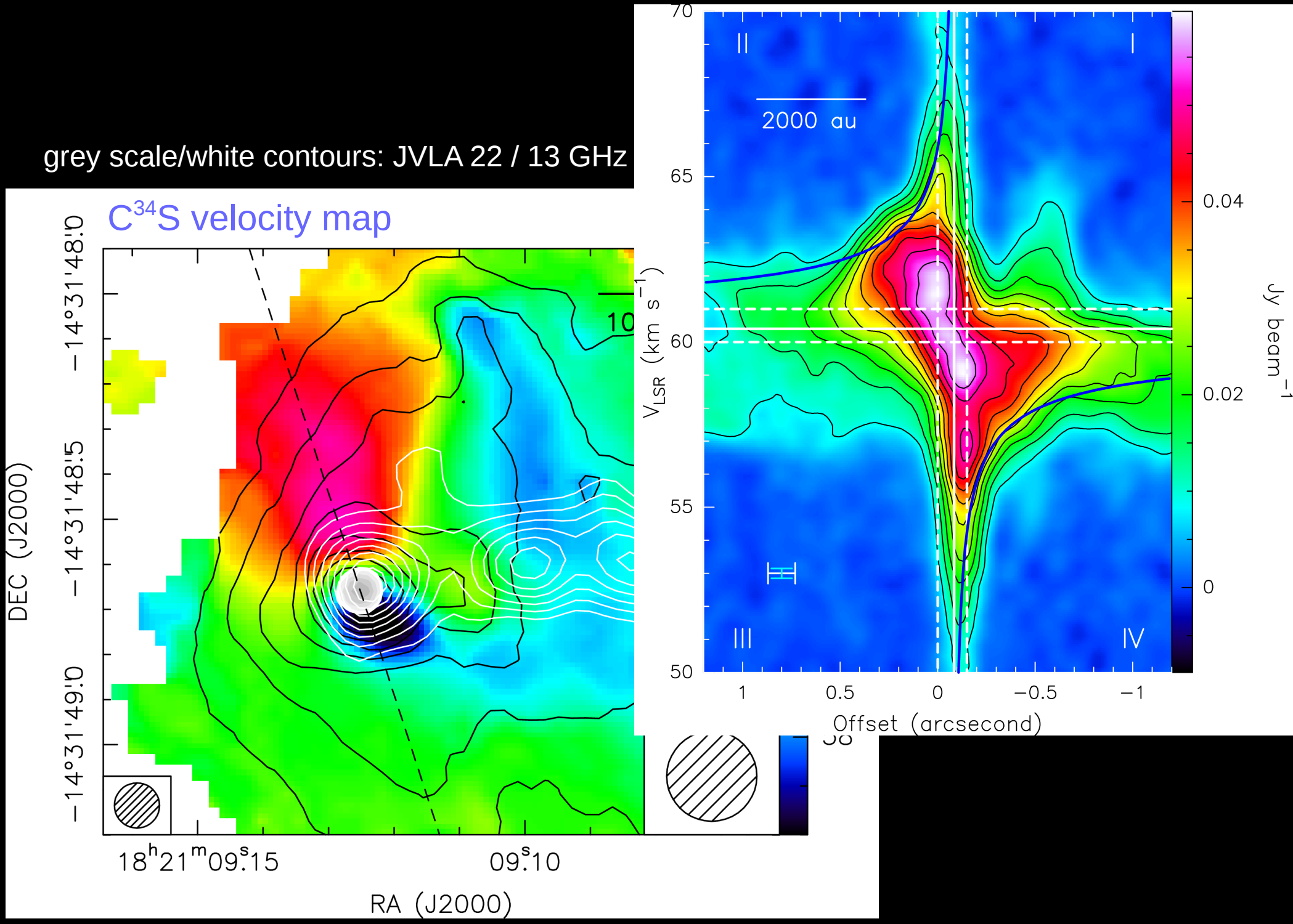
The disk-jet around the high-mass YSO G16.59-0.05

grey scale/white contours: JVLA 22 / 13 GHz continuum



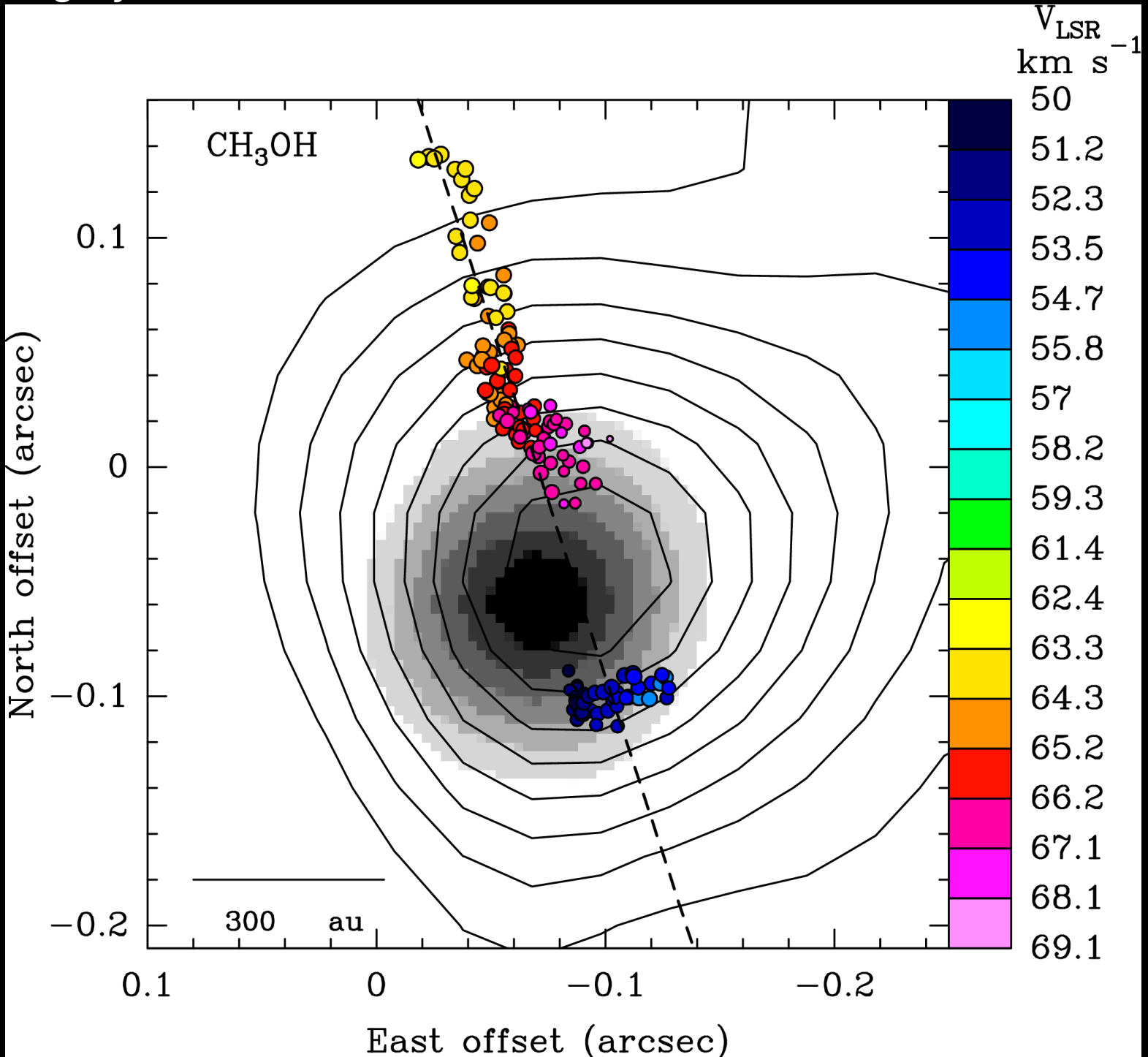
The disk-jet around the high-mass YSO G16.59-0.05

grey scale/white contours: JVLA 22 / 13 GHz



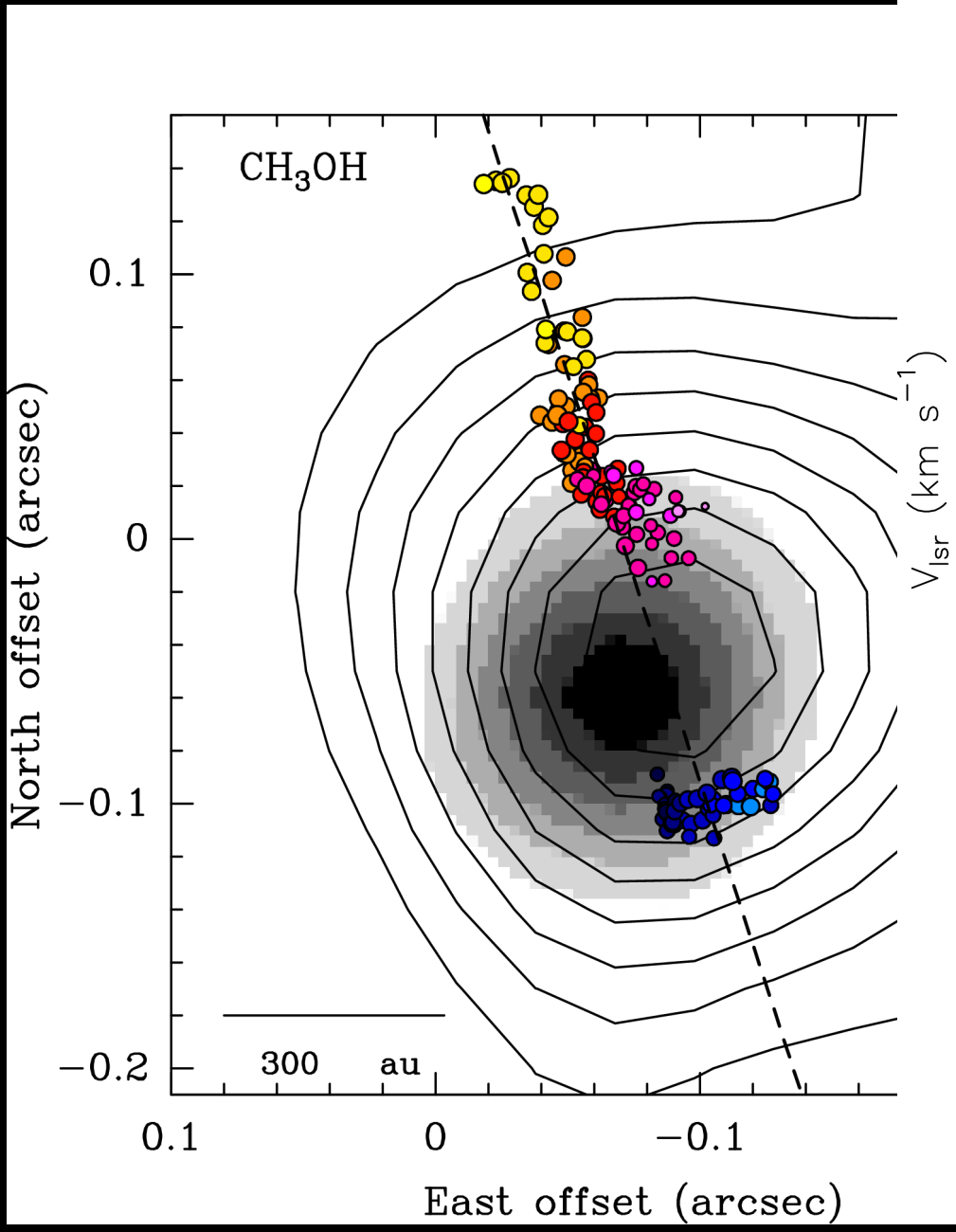
The disk-jet around the high-mass YSO G16.59-0.05

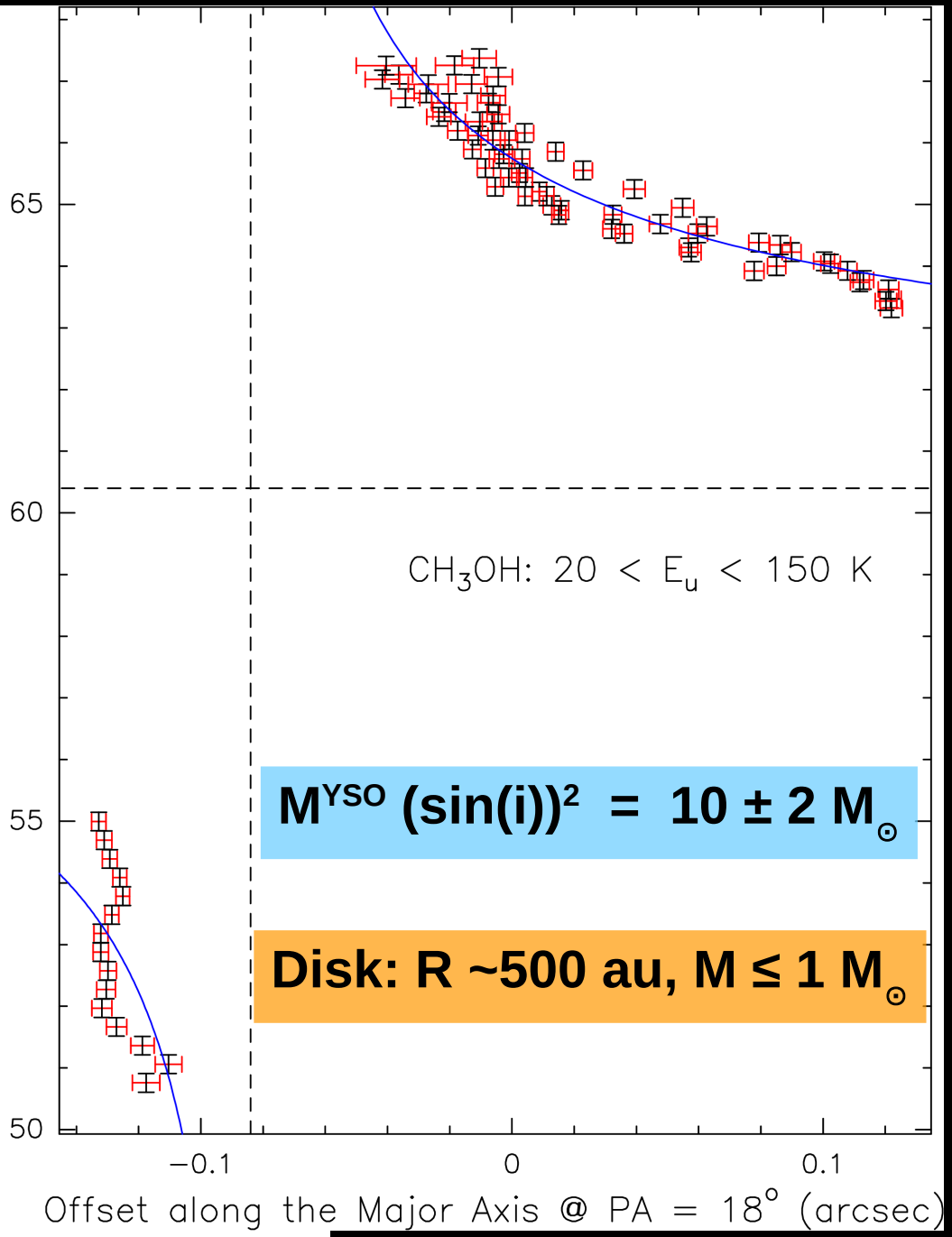
grey scale/black contours: JVLA 22 / 13 GHz continuum



The disk-jet around the high-mass YSO G16.59-0.05

grey scale/black contours: JVLA 22 /

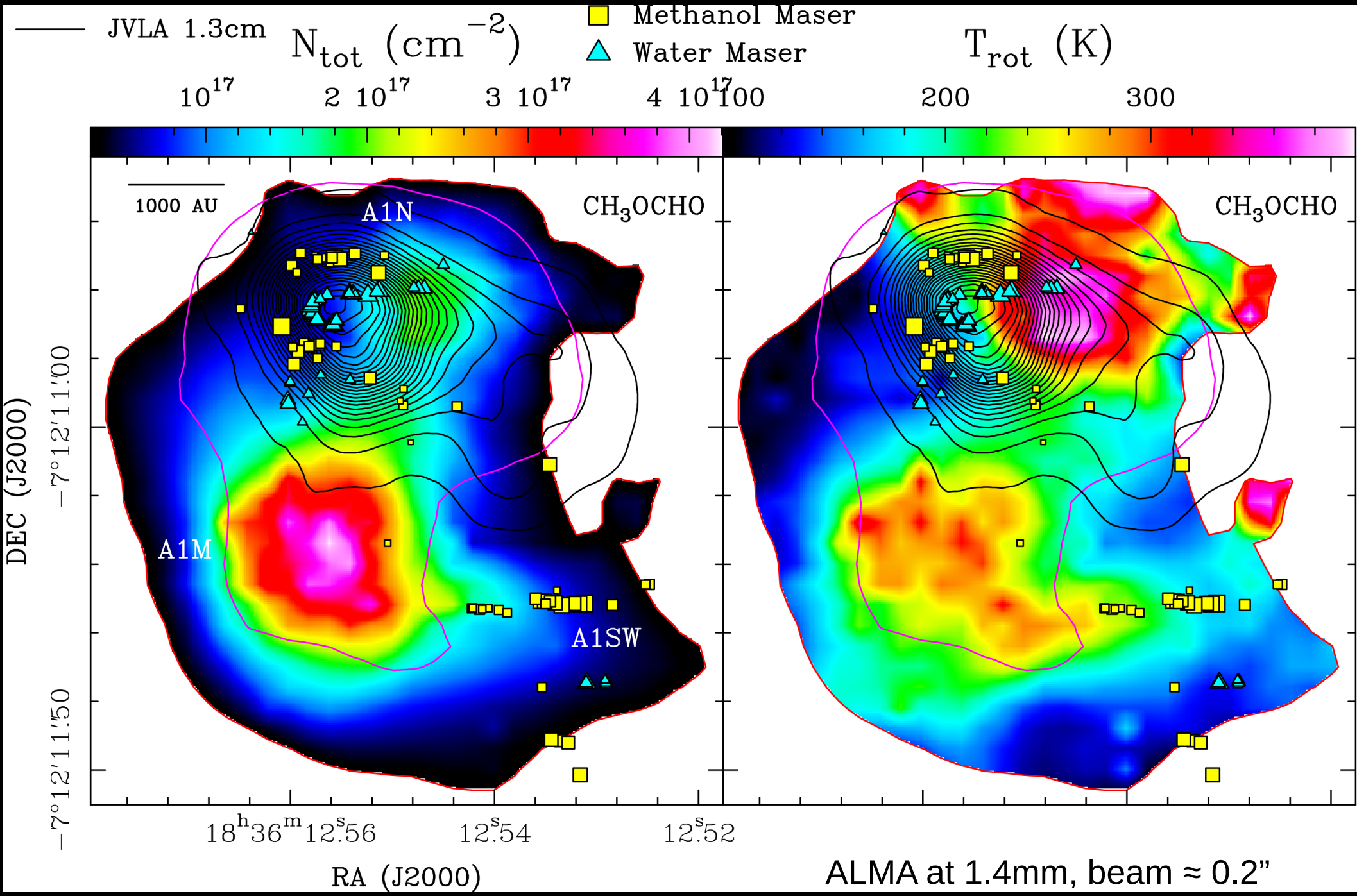




M^{YSO} $(\sin(i))^2$ = 10 ± 2 $M_\odot$

Disk: R ~500 au, M ≤ 1 $M_\odot$

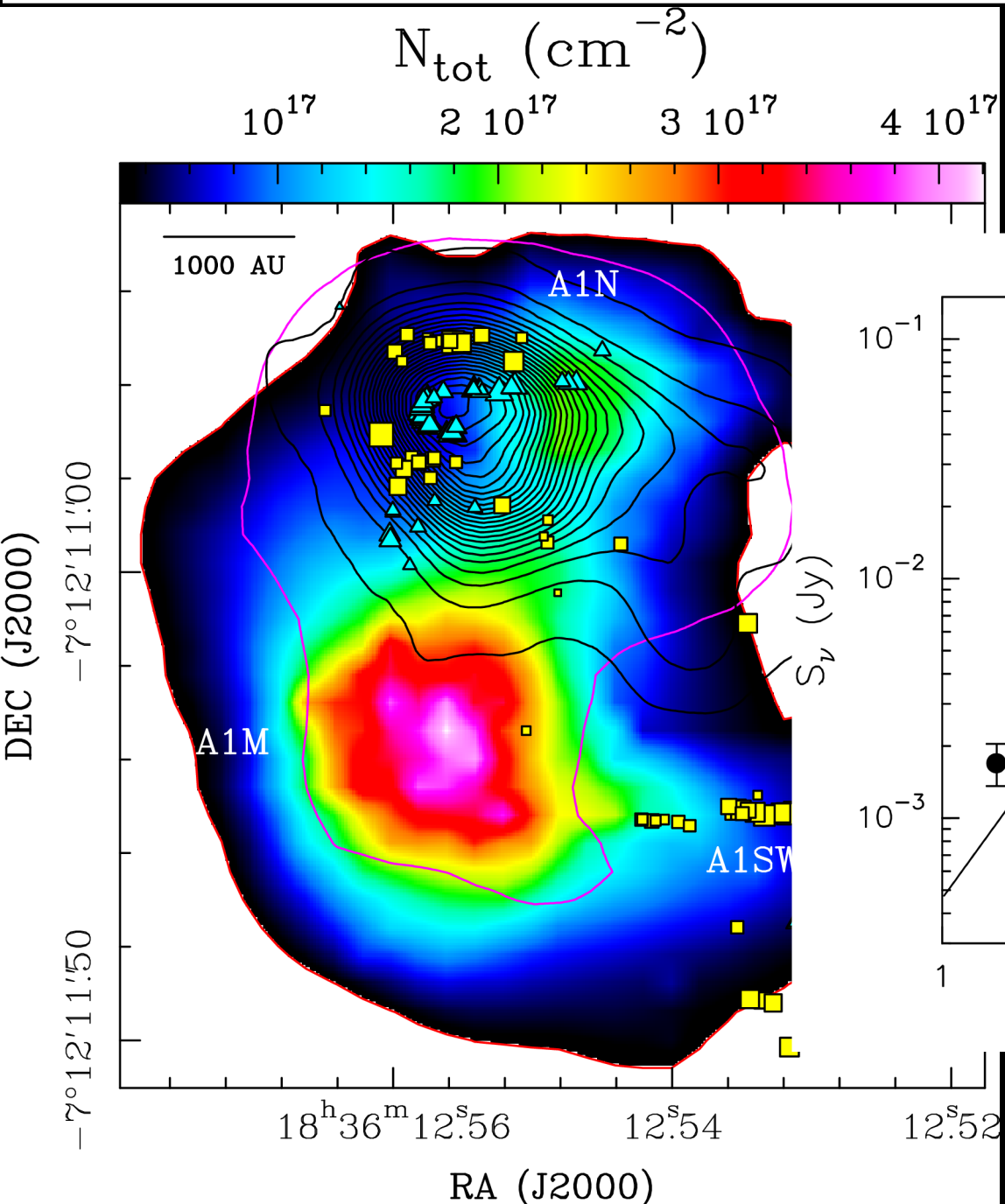
Core A1 in the high-mass SFR G24.78+0.08



(Moscadelli et al. 2018)

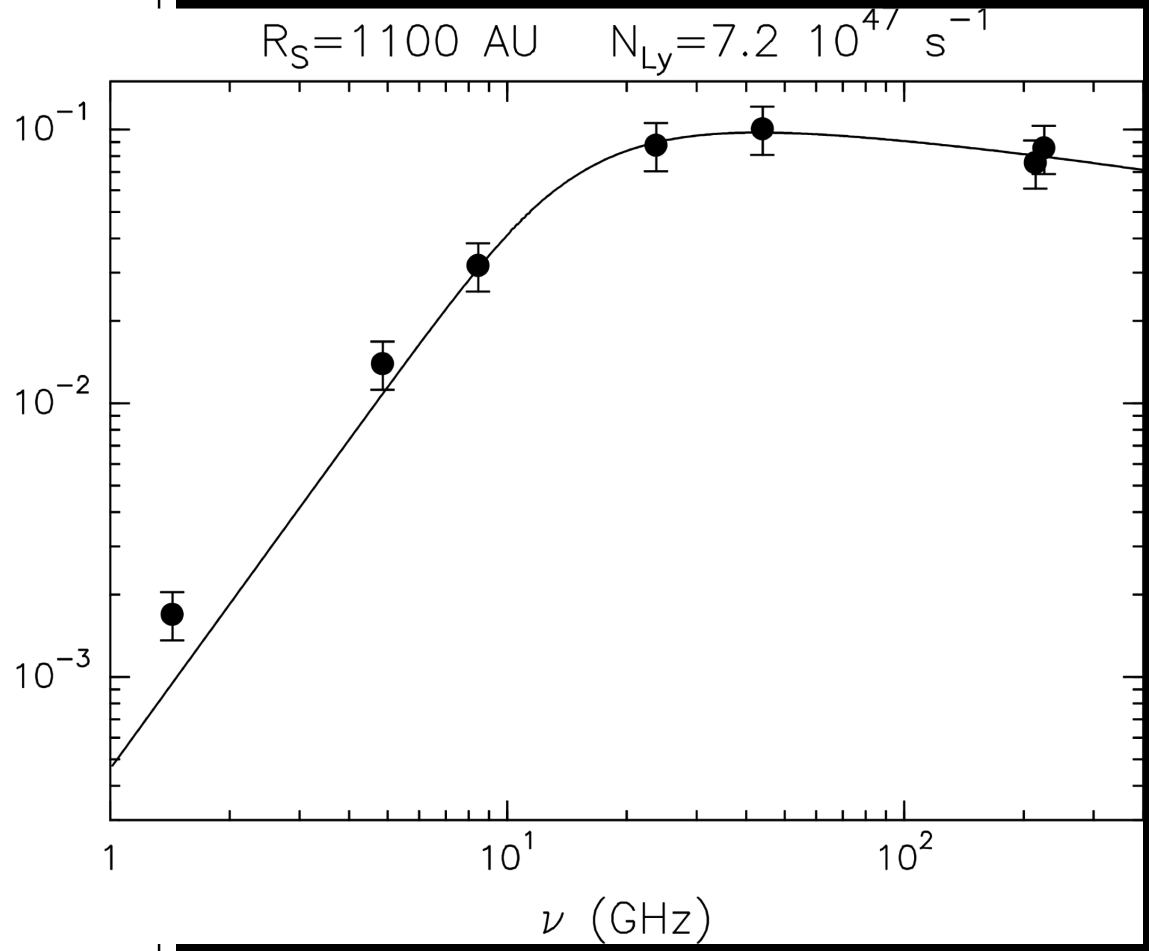
Core A1 in the high-mass SFR G24.78+0.08

—— : JVLA 1.3 cm ; ■ : meth. maser ; ▲ : water maser



FREE-FREE EMISSION:

ZAMS TYPE O9.5, M ≈ 20$M_\odot$



ALMA at 1.4mm, beam ≈ 0.2”

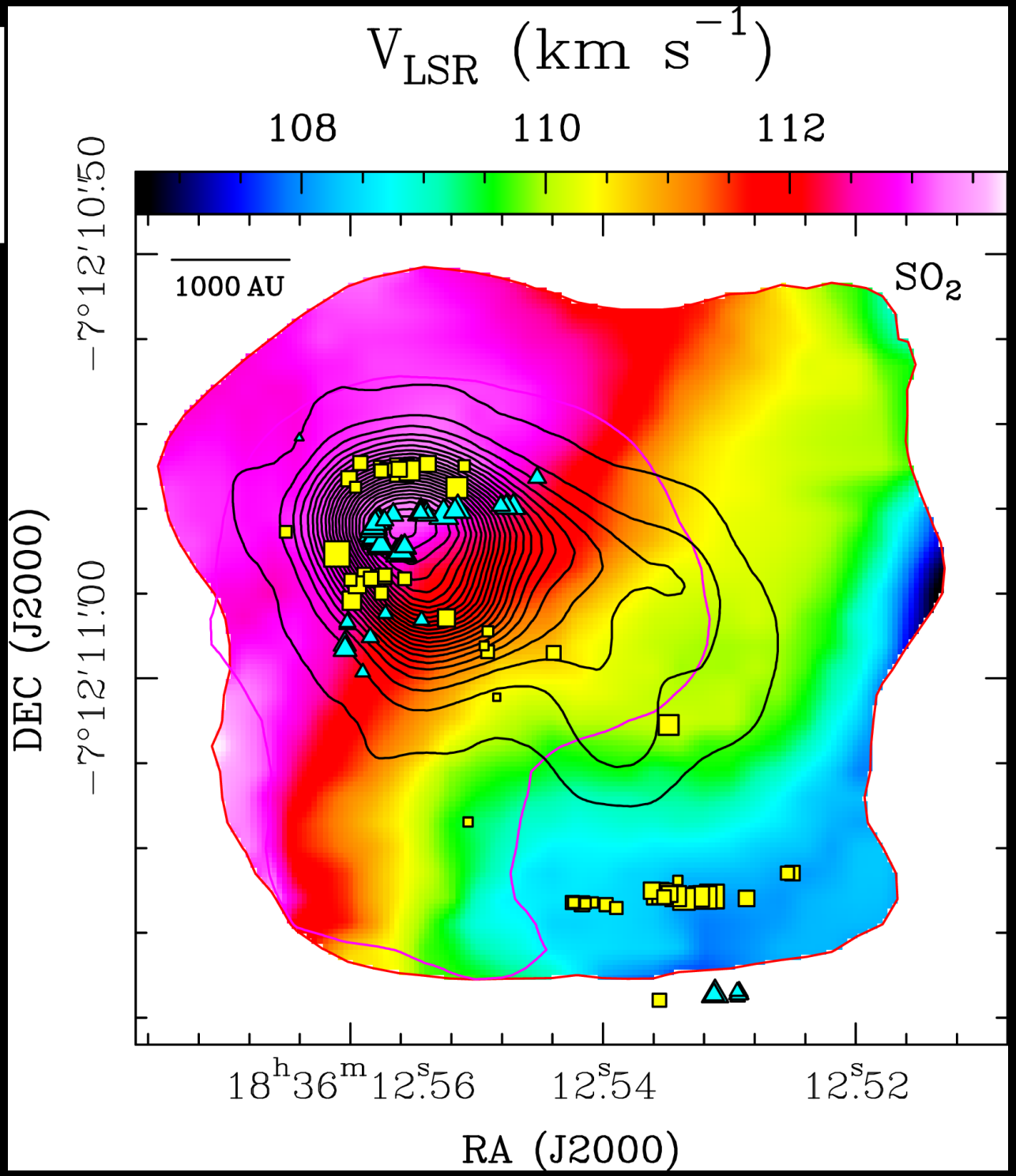
(Moscadelli et al. 2018)

Core A1 in the high-mass SFR G24.78+0.08

— : JVLA 1.3 cm ;

■ : meth. maser ;

▲ : water maser

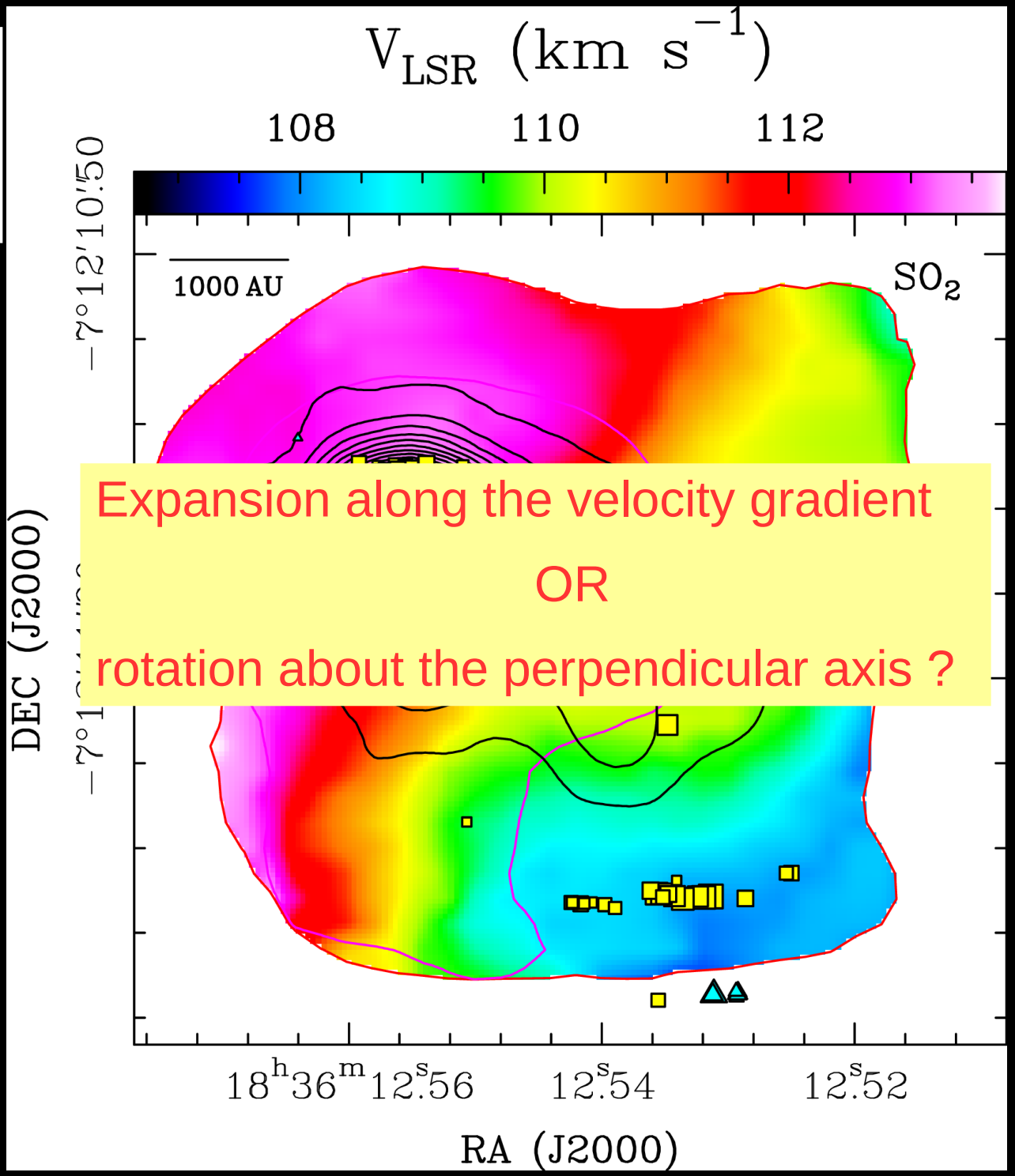


Core A1 in the high-mass SFR G24.78+0.08

— : JVLA 1.3 cm ;

■ : meth. maser ;

▲ : water maser

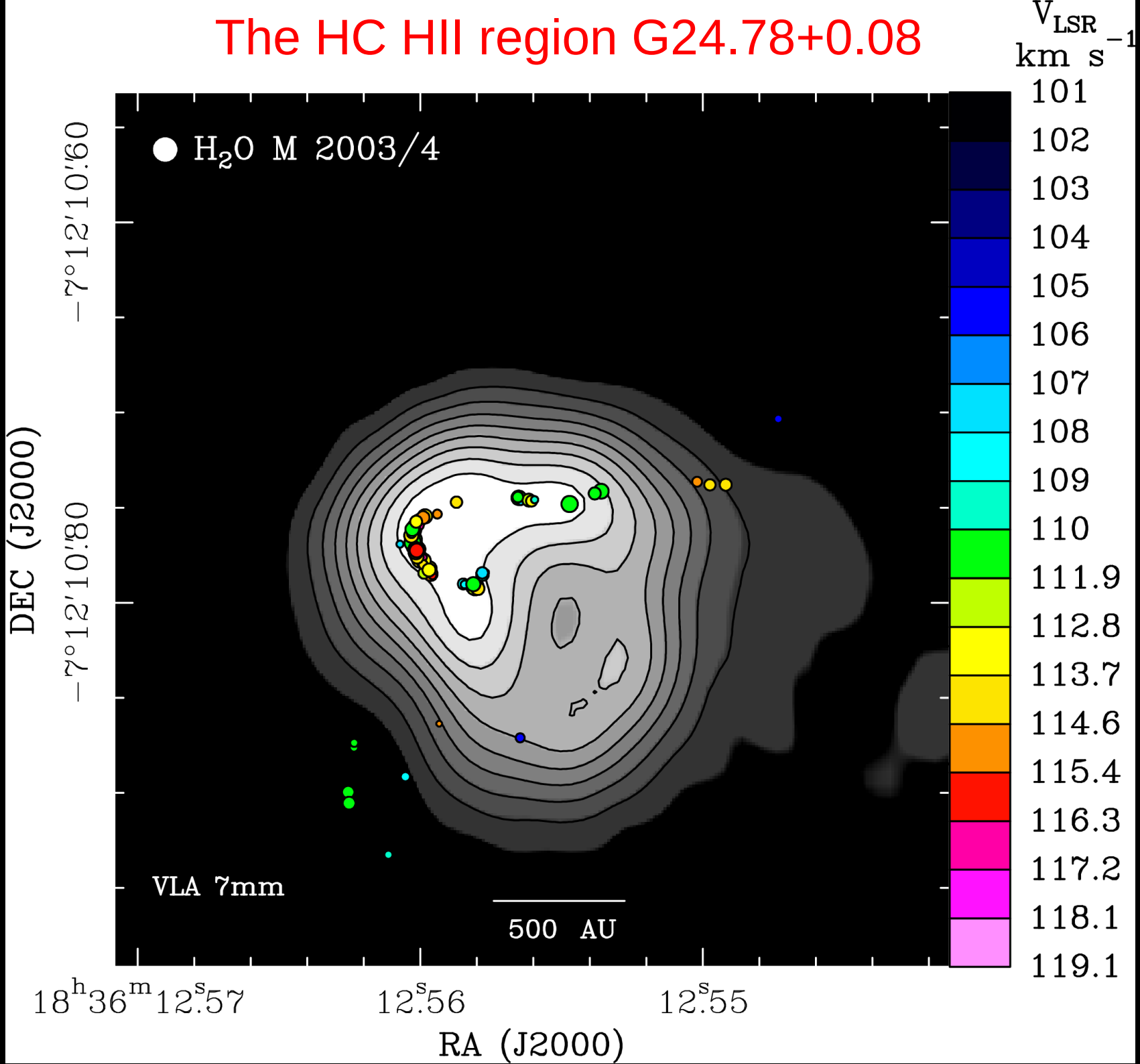


Expansion along the velocity gradient

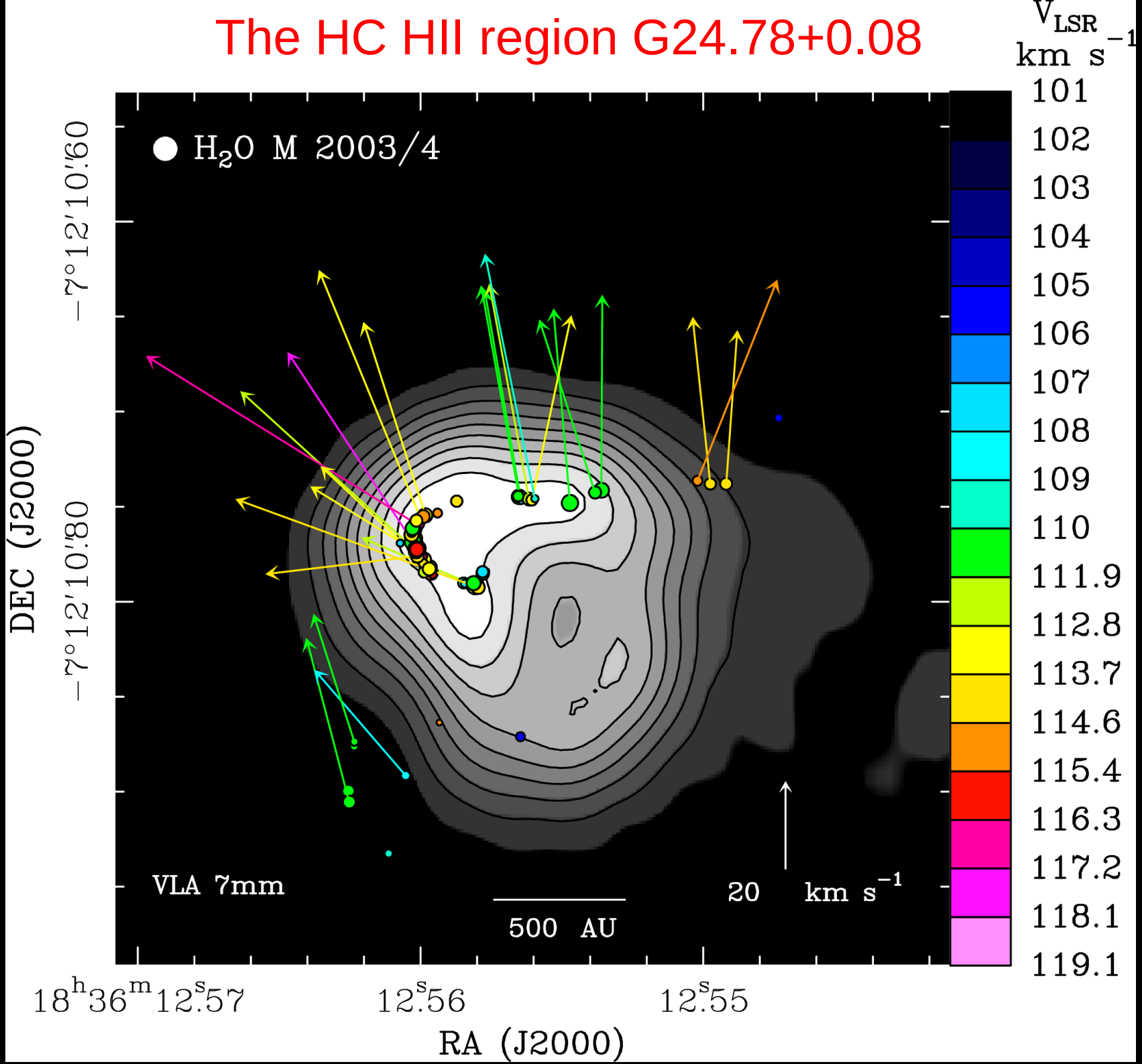
OR

rotation about the perpendicular axis ?

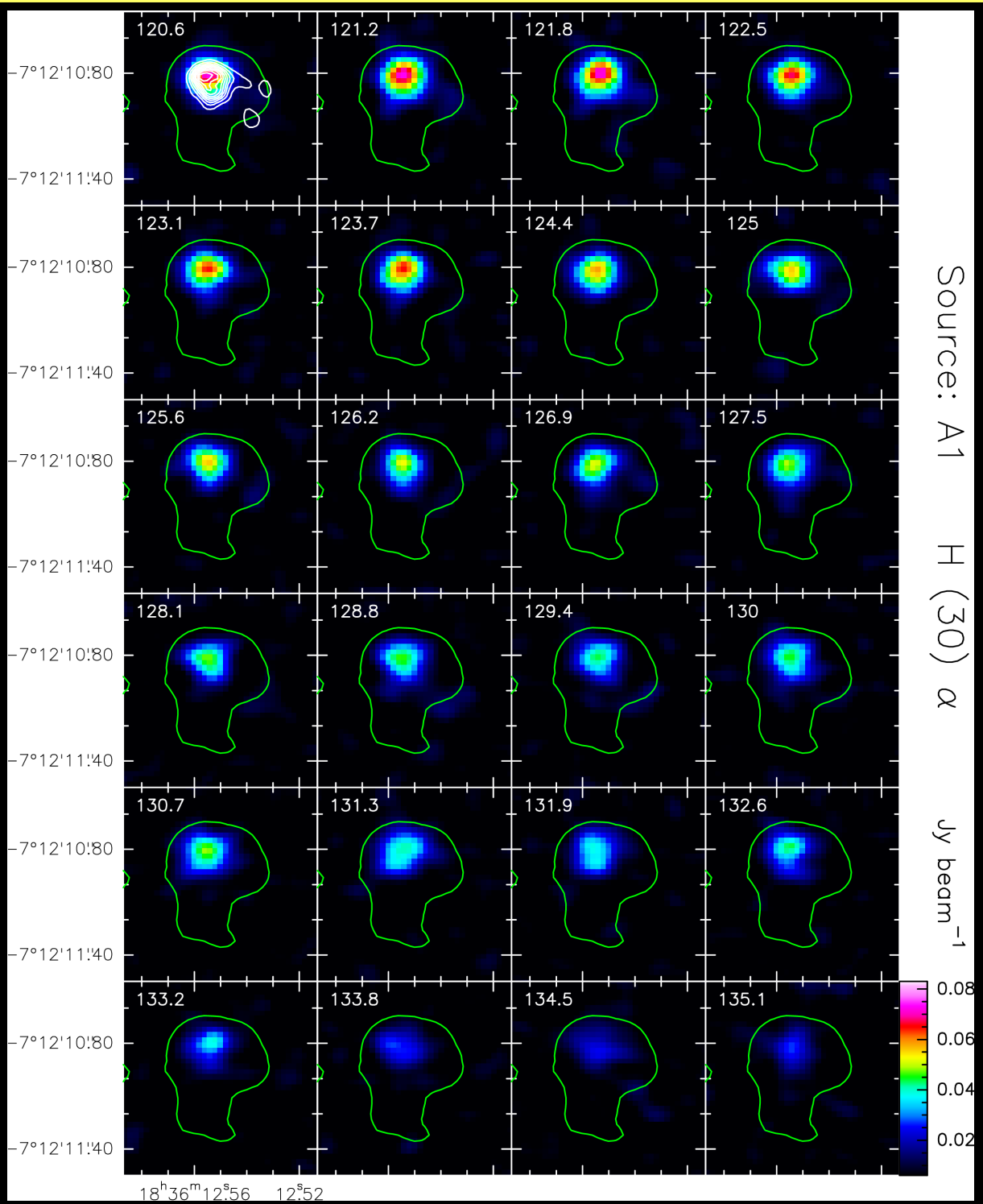
The HC HII region G24.78+0.08



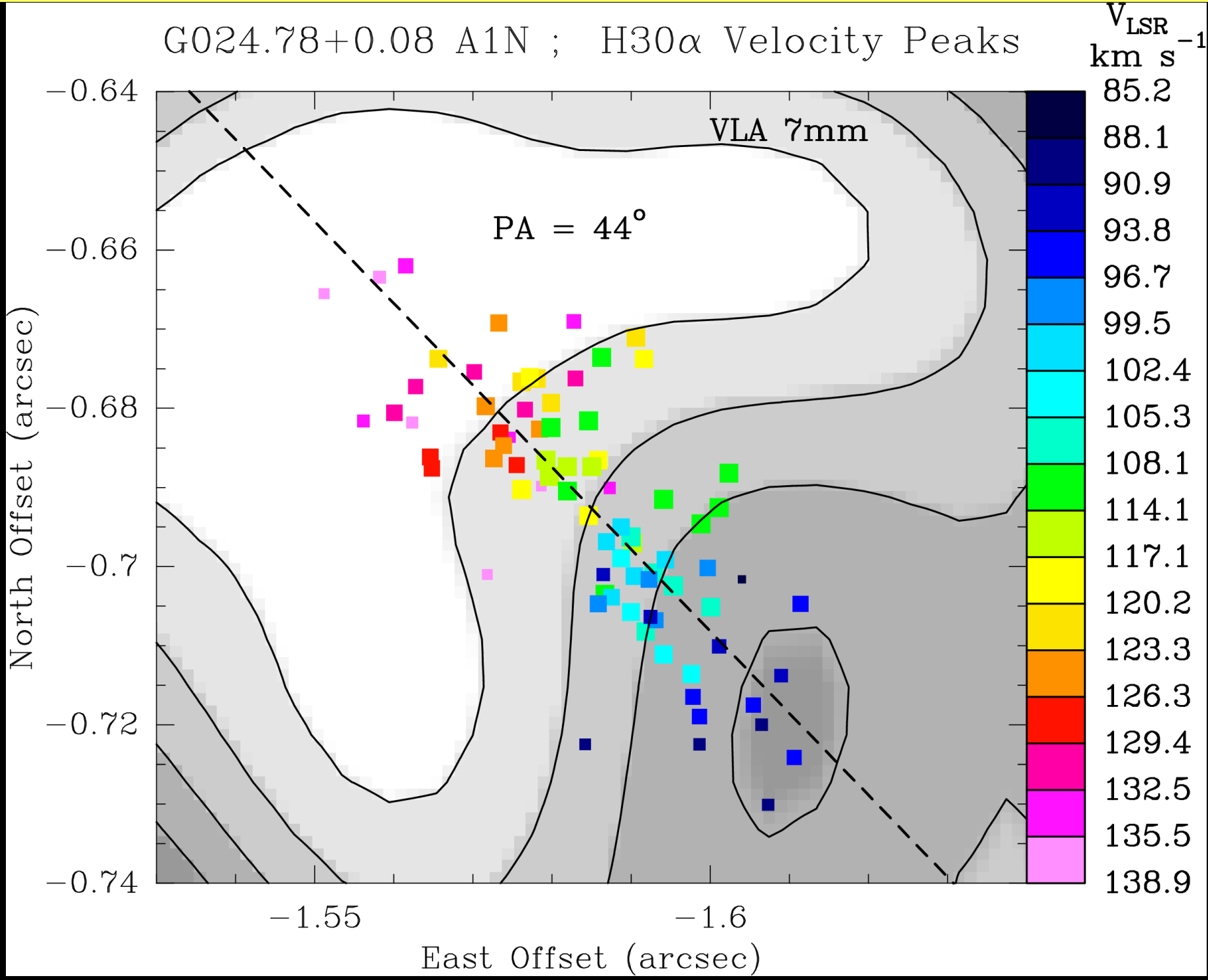
The HC HII region G24.78+0.08

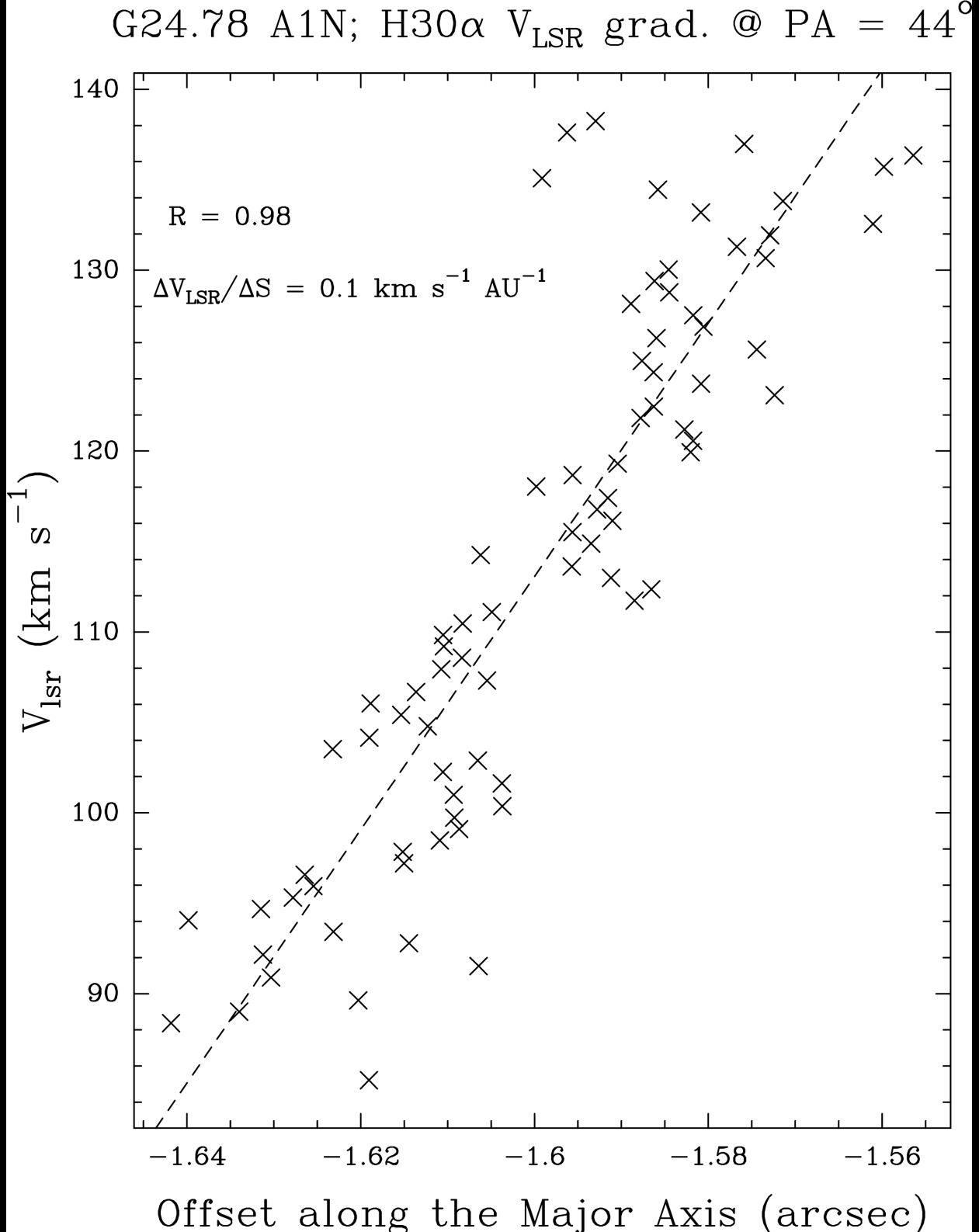


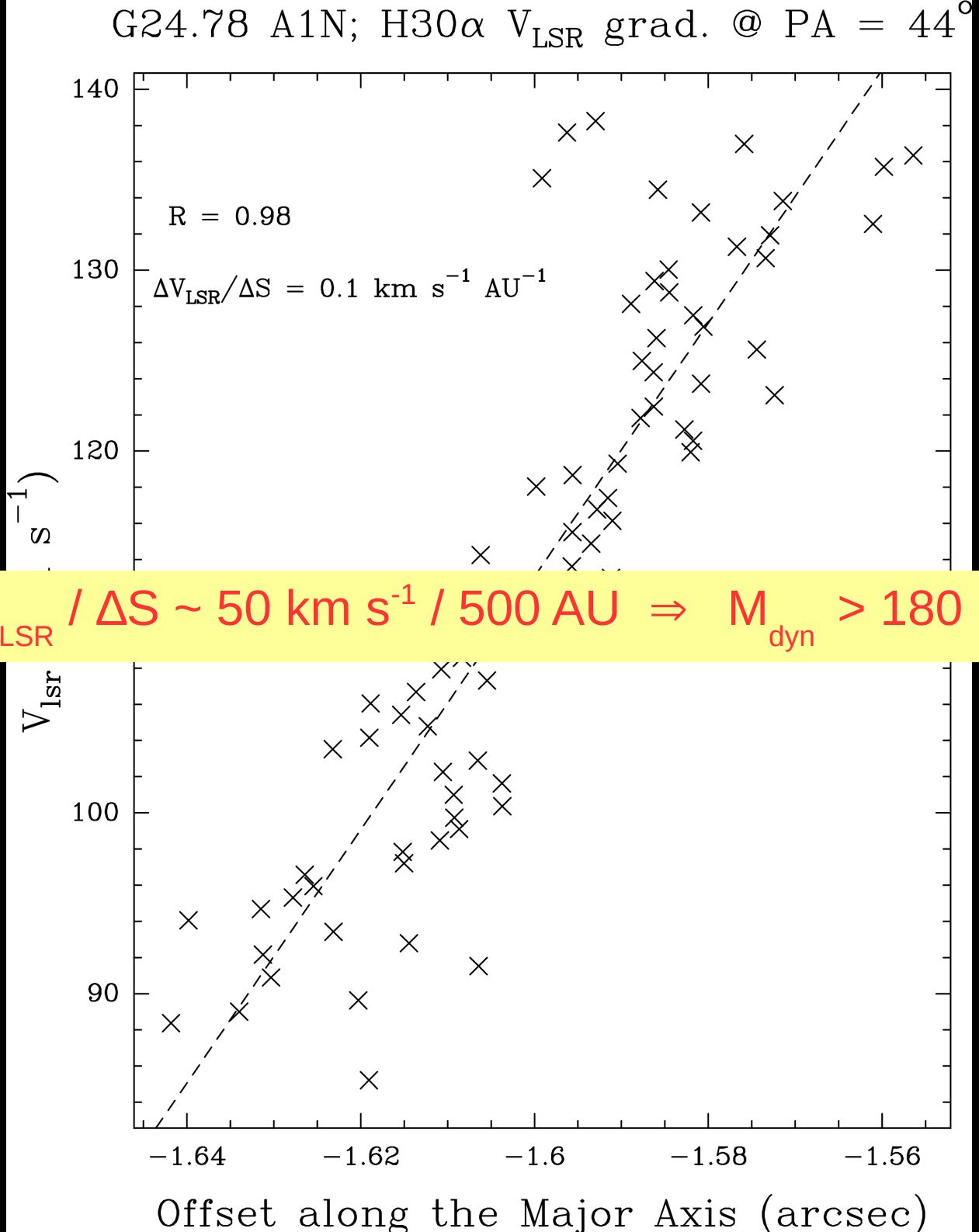
ALMA @ 1.3mm: H30α channel maps towards core A1



ALMA @ 1.3mm: H30 α Vel. Grad. towards A1N HCHII

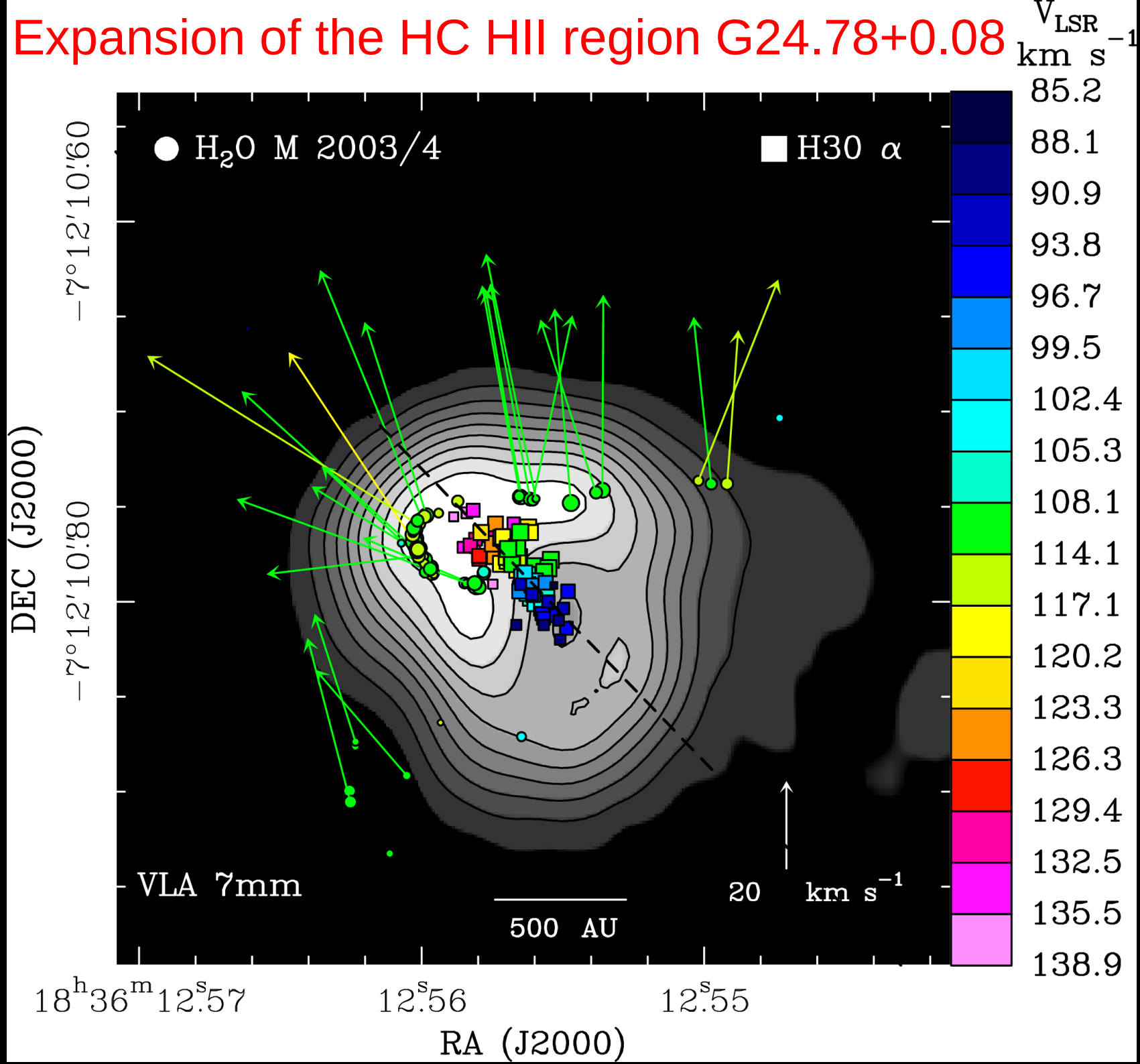



G24.78 A1N; H30α V_LSR grad. @ PA = 44°
R = 0.98
ΔV_LSR/ΔS = 0.1 km s^-1 AU^-1
V_lsr (km s^-1)
140
130
120
110
100
90
−1.64
−1.62
−1.6
−1.58
−1.56
Offset along the Major Axis (arcsec)



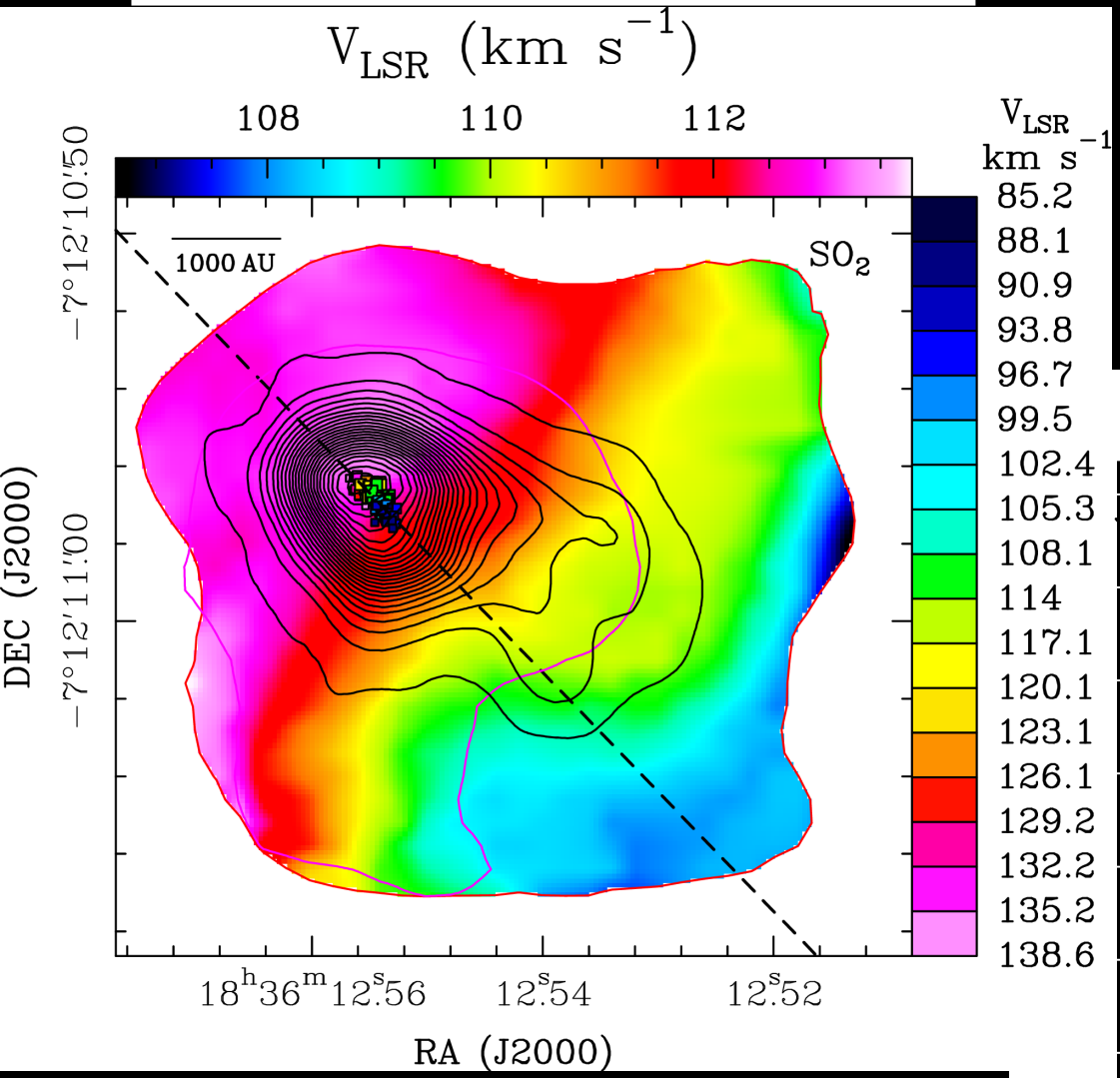
$\Delta V_{LSR} / \Delta S \sim 50$ km s^{-1} / 500 AU $\Rightarrow$ $M_{dyn} > 180\ M_{\odot}$

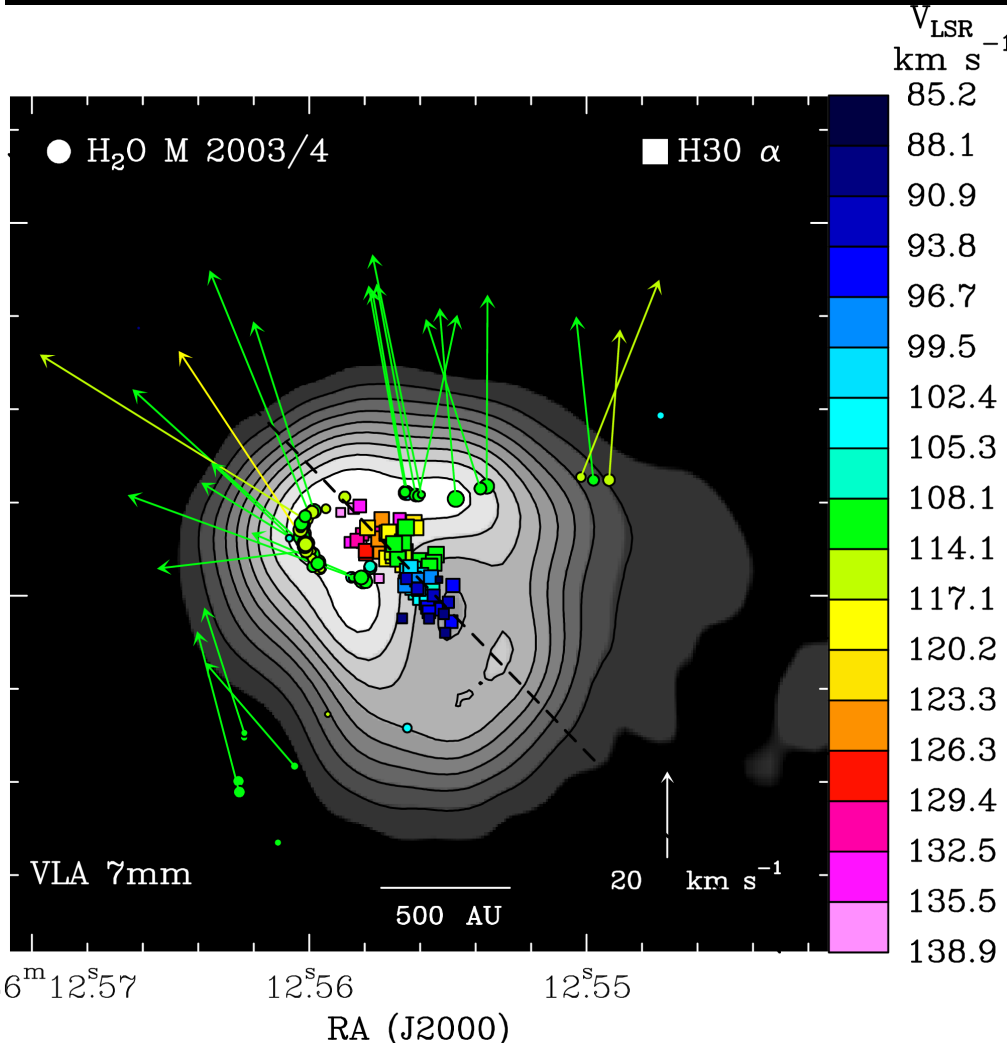
Expansion of the HC HII region G24.78+0.08



Expansion of the HC HII region G24.78+0.08

—— : JVLA 1.3 cm ; ■ : H30α





ALMA at 1.4mm, beam ≈ 0.2”

CONCLUSIONS

1) Presently, the most detailed view of a high-mass (embedded) YSO can be obtained combining JVLA + ALMA (continuum / line, 0.05”-10”) thermal data with multi-epoch VLBI (milli-arcsec) maser observations.

CONCLUSIONS

1) Presently, the most detailed view of a high-mass (embedded) YSO can be obtained combining JVLA + ALMA (continuum / line, 0.05”-10”) thermal data with multi-epoch VLBI (milli-arcsec) maser observations.

2) The sub-arcsecond angular resolution and high sensitivity of the new-generation cm & mm interferometers provide us with kinematics and physical conditions of the maser environment on larger scales.

CONCLUSIONS

1) Presently, the most detailed view of a high-mass (embedded) YSO can be obtained combining JVLA + ALMA (continuum / line, 0.05”-10”) thermal data with multi-epoch VLBI (milli-arcsec) maser observations.

2) The sub-arcsecond angular resolution and high sensitivity of the new-generation cm & mm interferometers provide us with kinematics and physical conditions of the maser environment on larger scales.

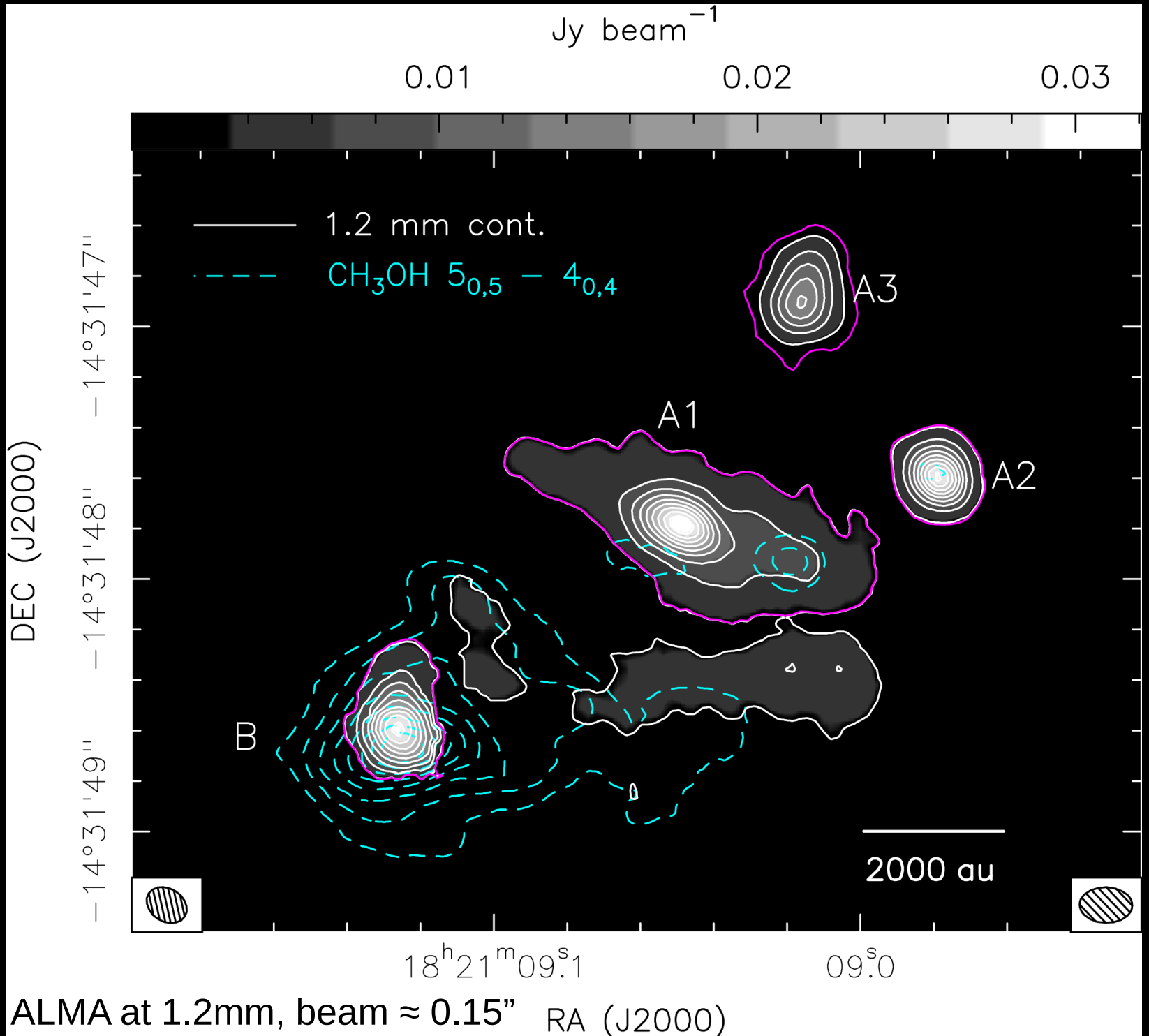
3) Masers are unique tools for 3-D velocities at ~100 au from the YSO:

a) resolving ambiguities in the interpretation of the l.o.s. velocity pattern.

b) proper comparison with (ad-hoc) models of massive (proto)stars.

Thanks for your attention !

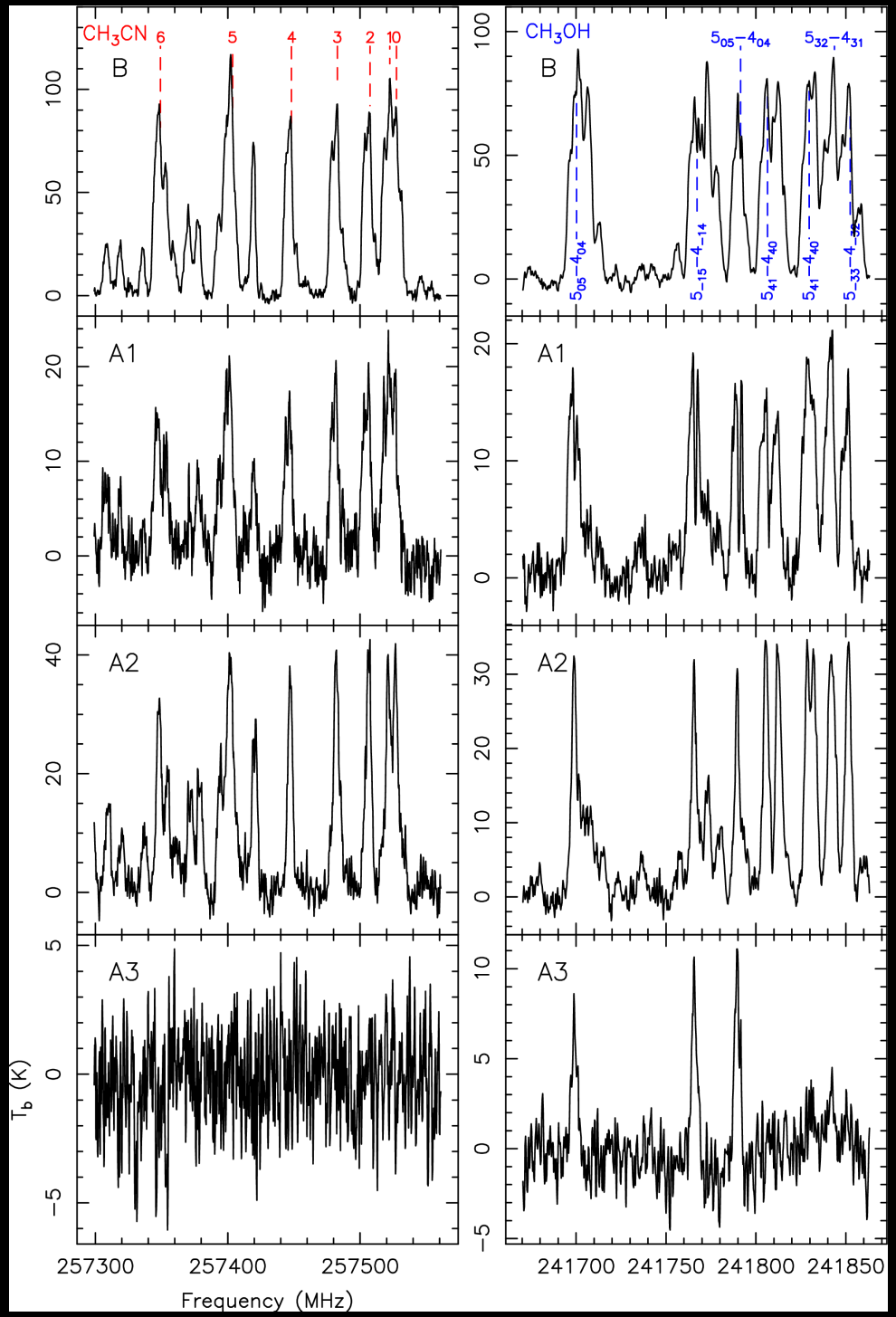
The disk-jet around the high-mass YSO G16.59-0.05

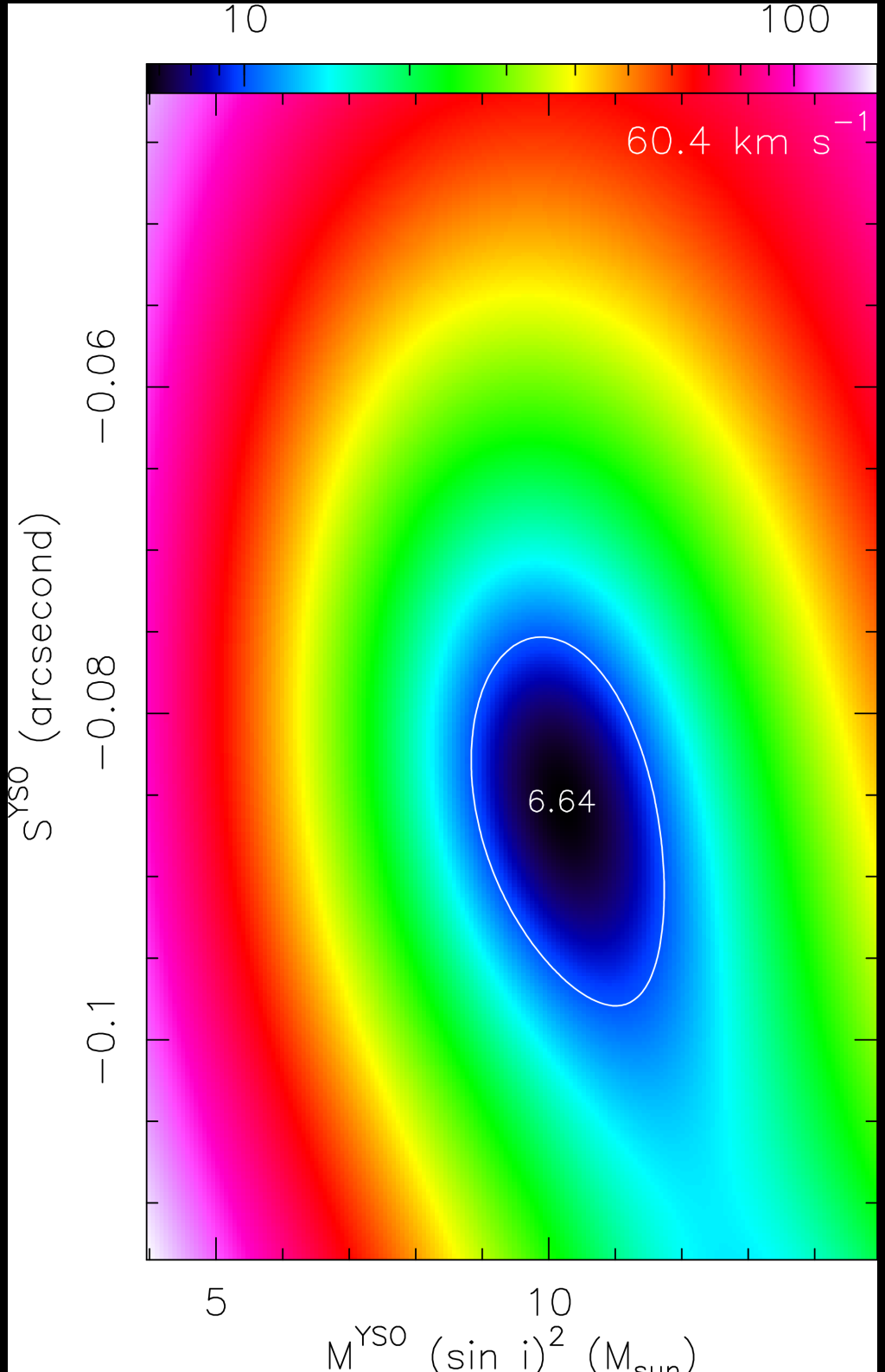


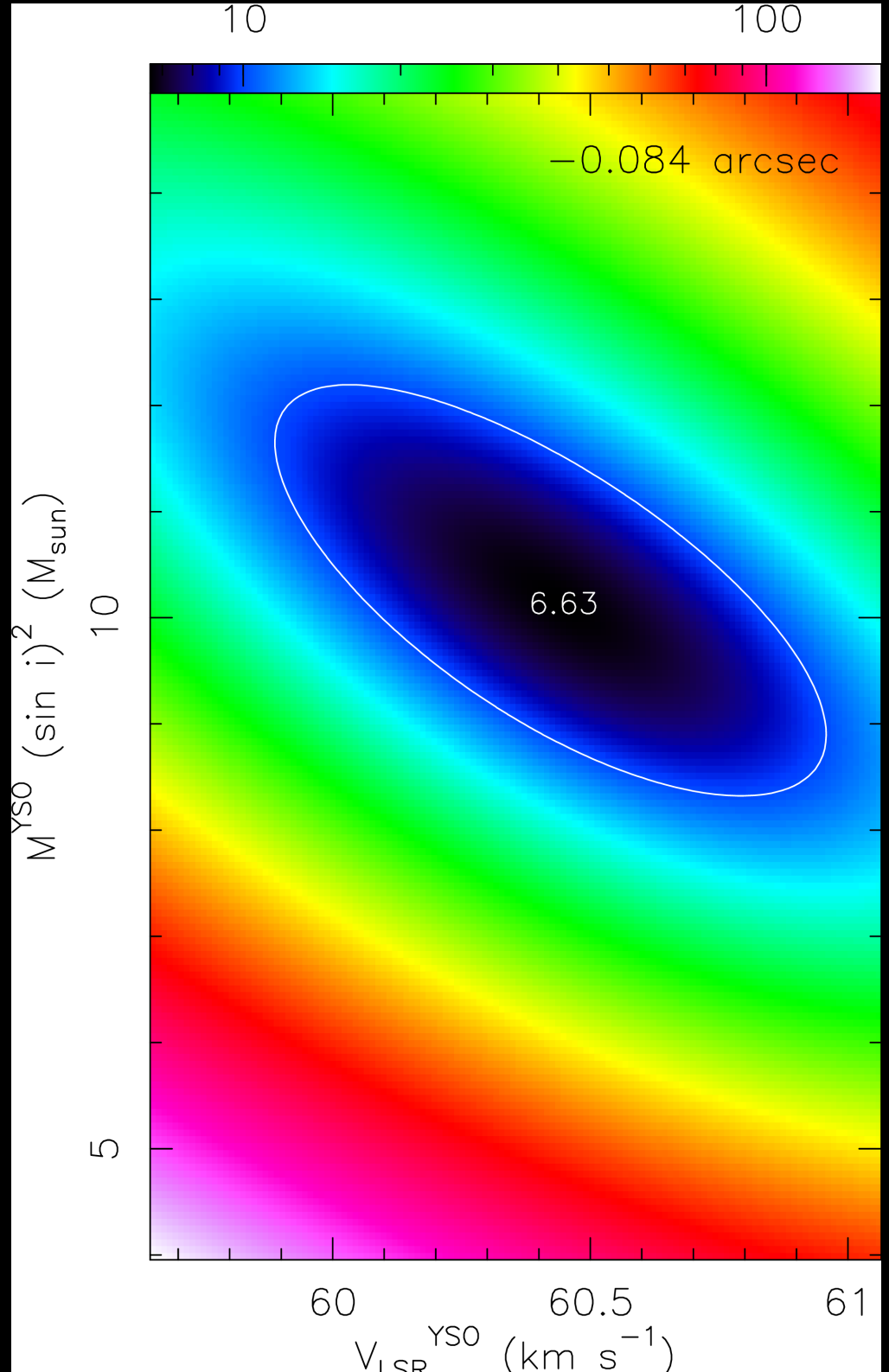
ALMA at 1.2mm, beam ≈ 0.15”

The disk-jet around the high-mass YSO G16.59-0.05

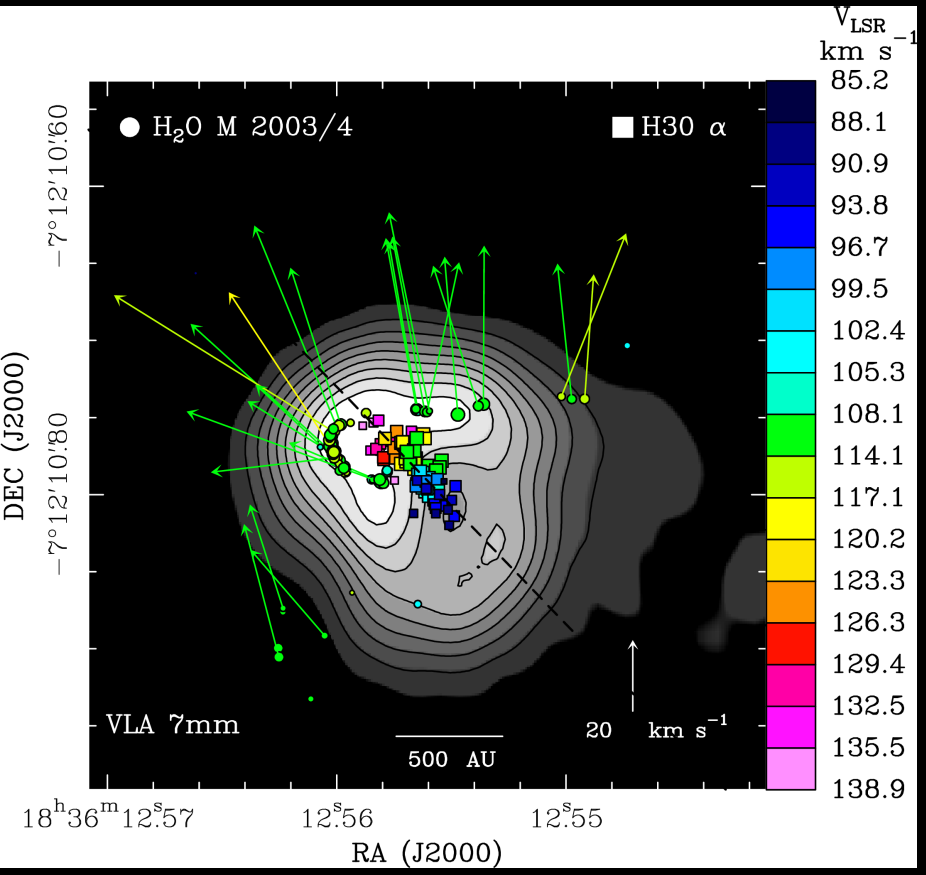
Source	T(K)	M ($M_\odot$)
B	131 ± 11	1.6 ± 0.3
A1	111 ± 18	4.4 ± 1.3
A2	106 ± 16	1.2 ± 0.4
A3	42 ± 7	3.2 ± 1.1




10
100
60.4 km s^{-1}
6.64
−0.06
−0.08
−0.1
S^{YSO} (arcsecond)
5
10
M^{YSO} (sin i)^2 (M_{sun})


10
100
−0.084 arcsec
6.63
10
5
M^{YSO} (sin i)^2 (M_{sun})
60
60.5
61
V_{LSR}^{YSO} (km s^{-1})

Expansion of the HC HII region G24.78+0.08



Momentum-driven: $\rho_{mol} V^2_{sh} \approx \rho_{ion} V^2_{ion}$

$V_{sh} \approx V_{wat.mas.} \approx 40$ km s^{-1}

$n_{ion} \sim 3\ 10^5$ cm^{-3} $n_{mol} > 10^7$ cm^{-3}

→ sky-plane $V_{ion} > 200$ km s^{-1}

maximum $V_{los} \approx 30$ km s^{-1} → $i_{sky} \leq 10^o$

proper motion PA: 0^o — 90^o → $\theta \approx 45^o$

Water Maser Shell

Kinematic Status: $R_0 \approx 500$ AU , $V_0 \approx 40$ km s^{-1}

Maser Action → pre-shock $n_H > 10^6$ cm^{-3}

Wind-driven shell

For a ZAMS O9.5 type:

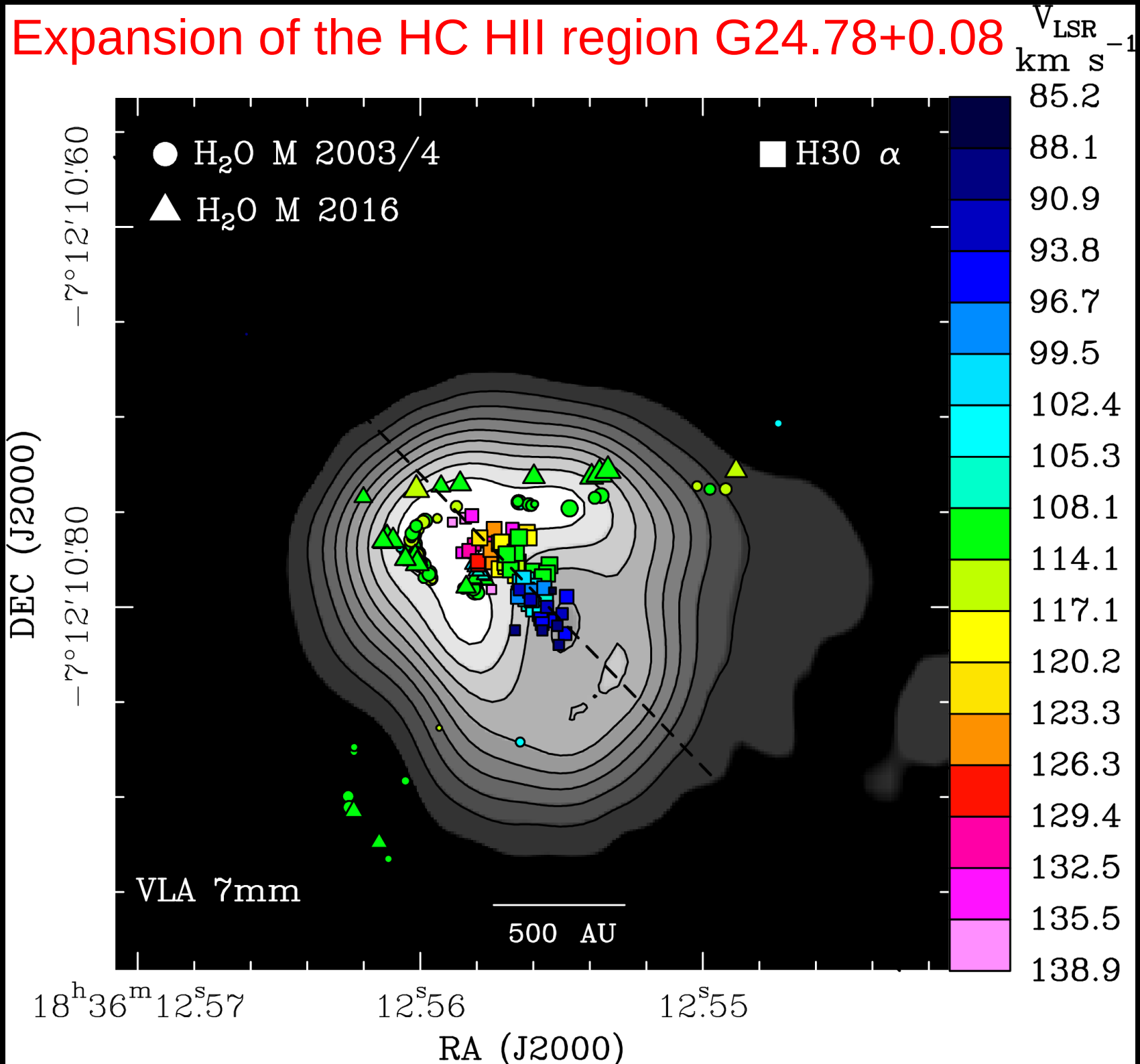
$M_w \sim 10^{-6}$ $M_\odot$ yr^{-1}, $V_w \sim 2000$ km s^{-1} , $L_w \sim 1\text{-}5$ 10^{36} erg s^{-1}

pressure and momentum-driven solutions require:

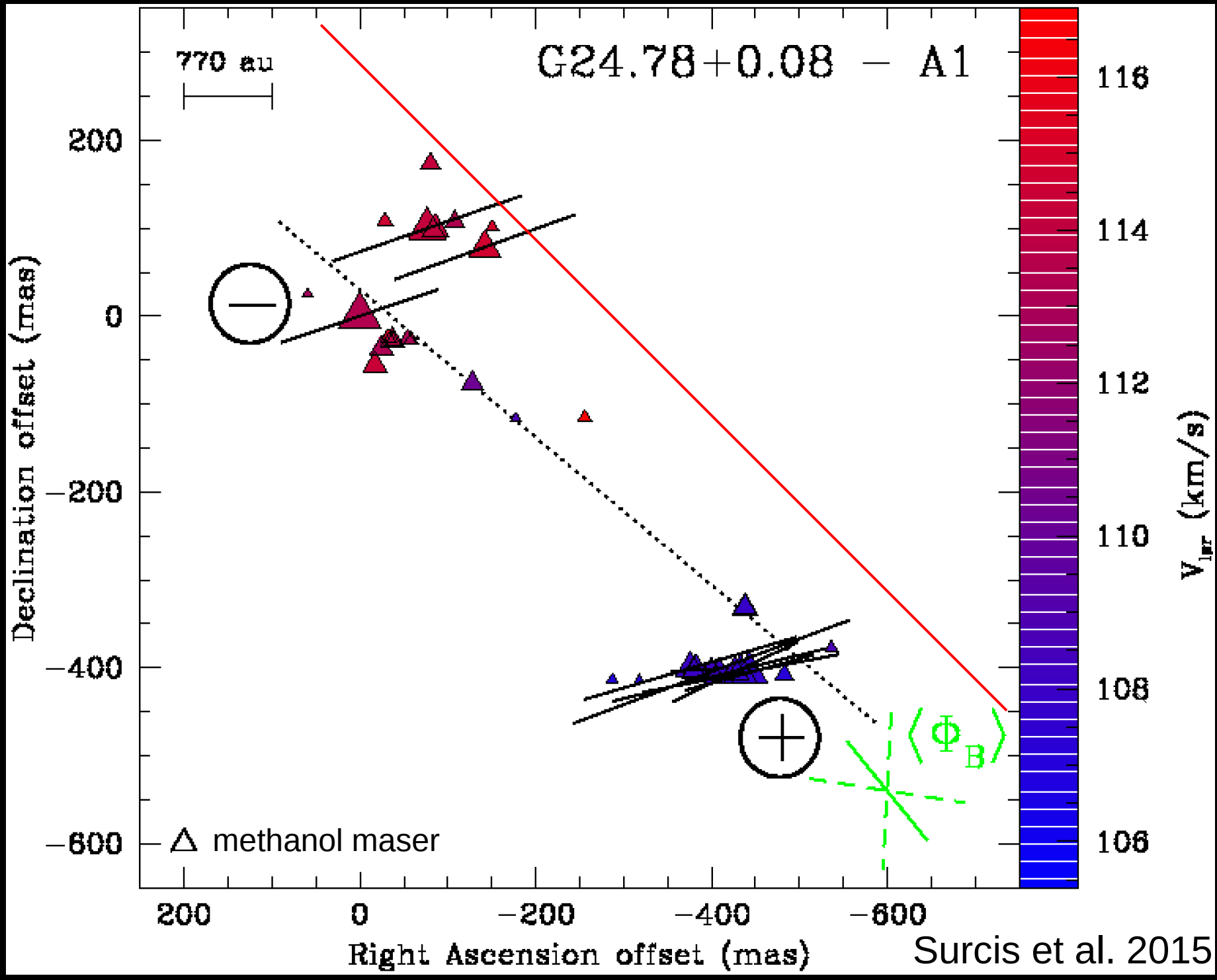
$t_0 \approx 40$ yr , $n_H \sim 10^7$ cm^{-3}

radio appearance similar to an UCHII region

Expansion of the HC HII region G24.78+0.08



Expansion of the HC HII region G24.78+0.08



Surcis et al. 2015

Fit of the radio continuum towards core A1

FREE-FREE EMISSION: ZAMS SPECTRAL TYPE O9.5, M ≈ 20M$_\odot$