Kinematics of high-mass star formation: The case of G31.41+0.31

Riccardo Cesaroni

with: ***M. Beltran, Q. Zhang, C. Codella, J.M. Girart, P. Hofner, etc…***

1) Disks and high-mass star formation: existence and implications
2) The case of G31.41+0.31: characteristics
3) Velocity field in G31.41: rotation or expansion? → toroid **vs** outflow
4) Possible solution: measurement of 3D velocity field

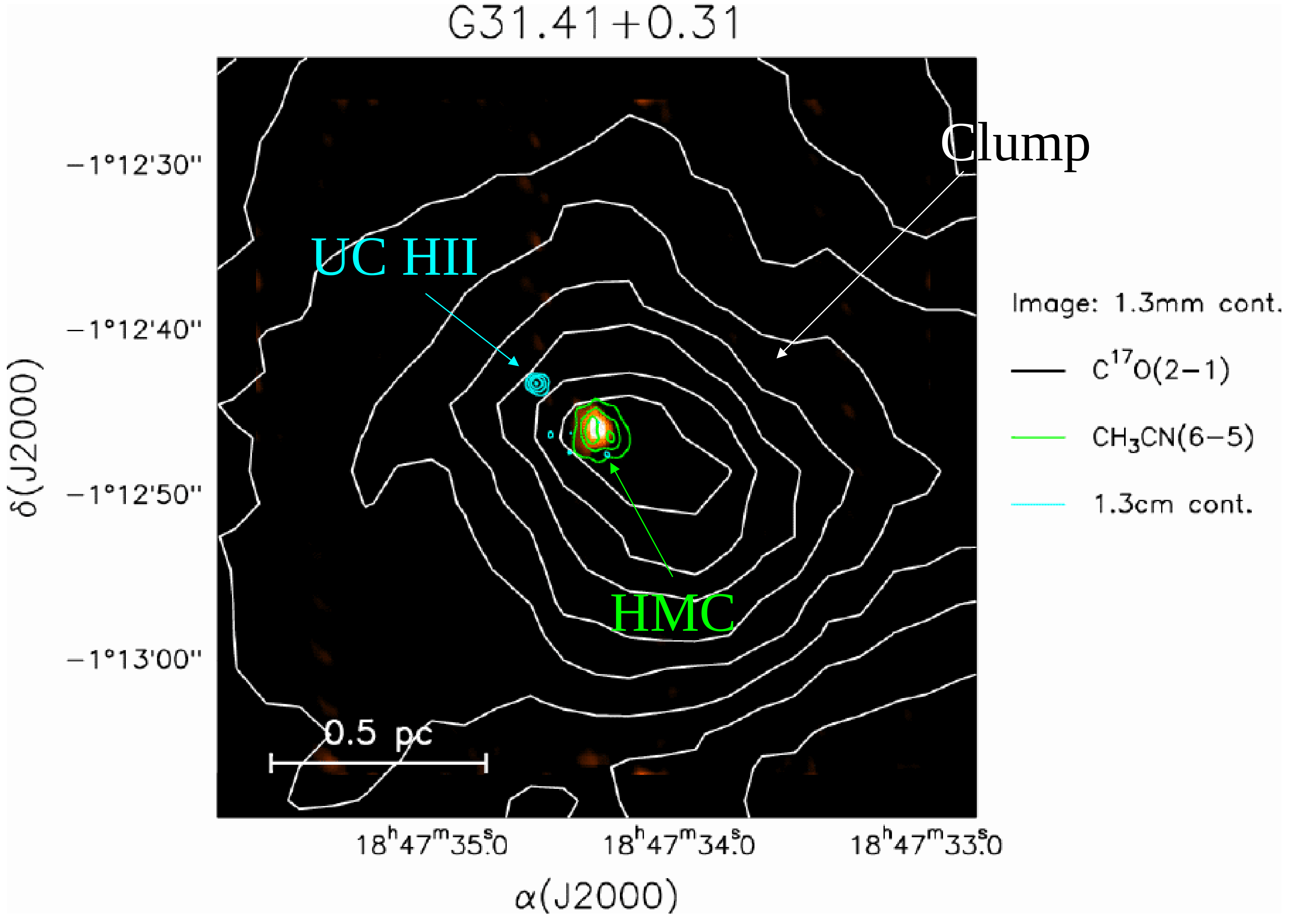
Disks in high-mass (proto)stars

- So far only disks in B-type (proto)stars
- No detection of disks in early O-type (proto)stars → implications on high-mass star formation models
- Absence of evidence: may be observational bias
- Evidence for rotating toroids ($M >> M_{star}$) → could be envelopes of circumstellar disks?
- Hot molecular core **G31.41+0.31** excellent toroid candidate (Beltran et al. 2005), but Araya et al. (2008) propose bipolar outflow interpretation

→ **important to establish true nature of G31.41**

G31.41+0.31: characteristics

- HMC with nearby UC HII region inside pc-scale clump
- HMC detected in lots of molecular lines: first detection of glycolaldheide outside Galactic center (Beltran et al. 2009)
- High-excitation lines and mm continuum peak at geometrical center → temperature increasing outside-in → embedded heating star(s) inside HMC



G31.41+0.31
Clump
UC HII
HMC
0.5 pc
−1°12'30''
−1°12'40''
−1°12'50''
−1°13'00''
δ(J2000)
18h47m35.s0
18h47m34.s0
18h47m33.s0
α(J2000)
Image: 1.3mm cont.
C17O(2−1)
CH3CN(6−5)
1.3cm cont.

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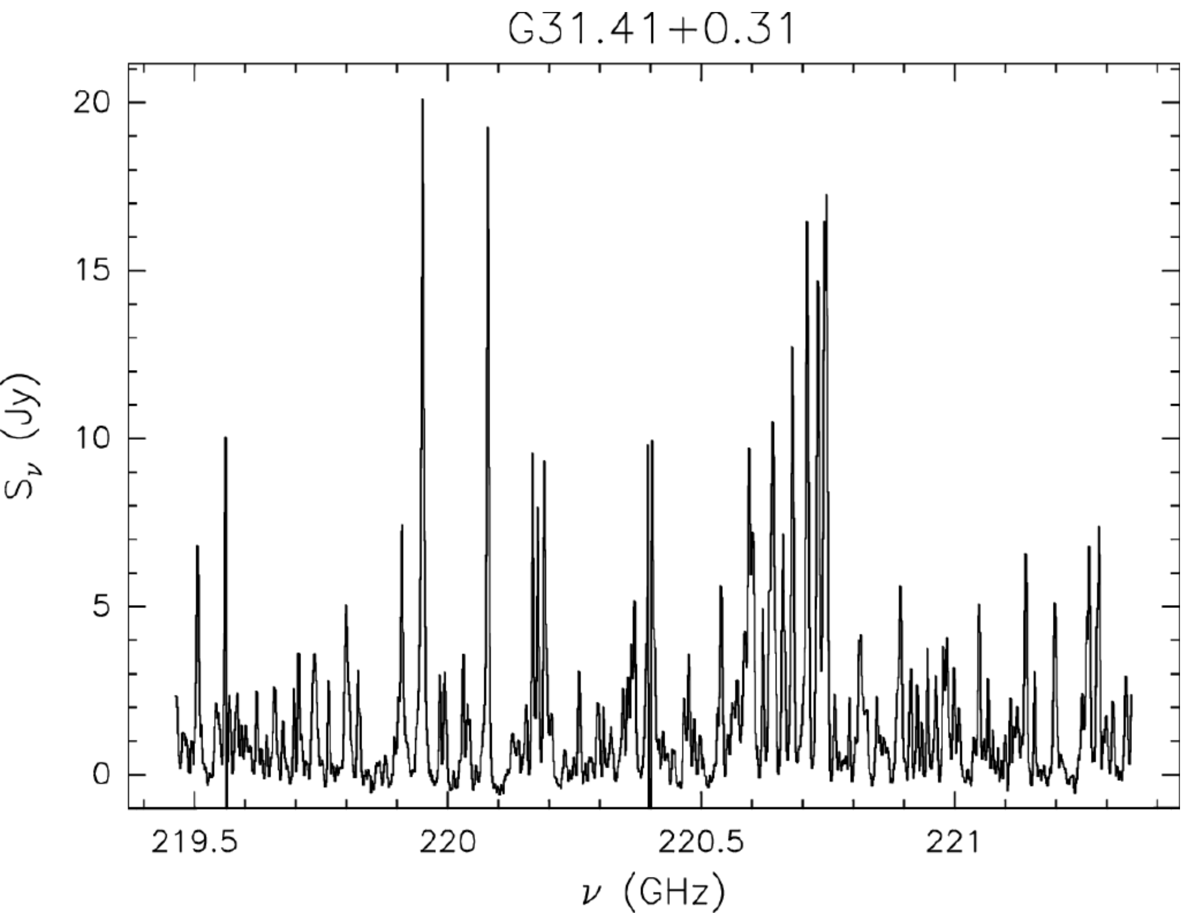
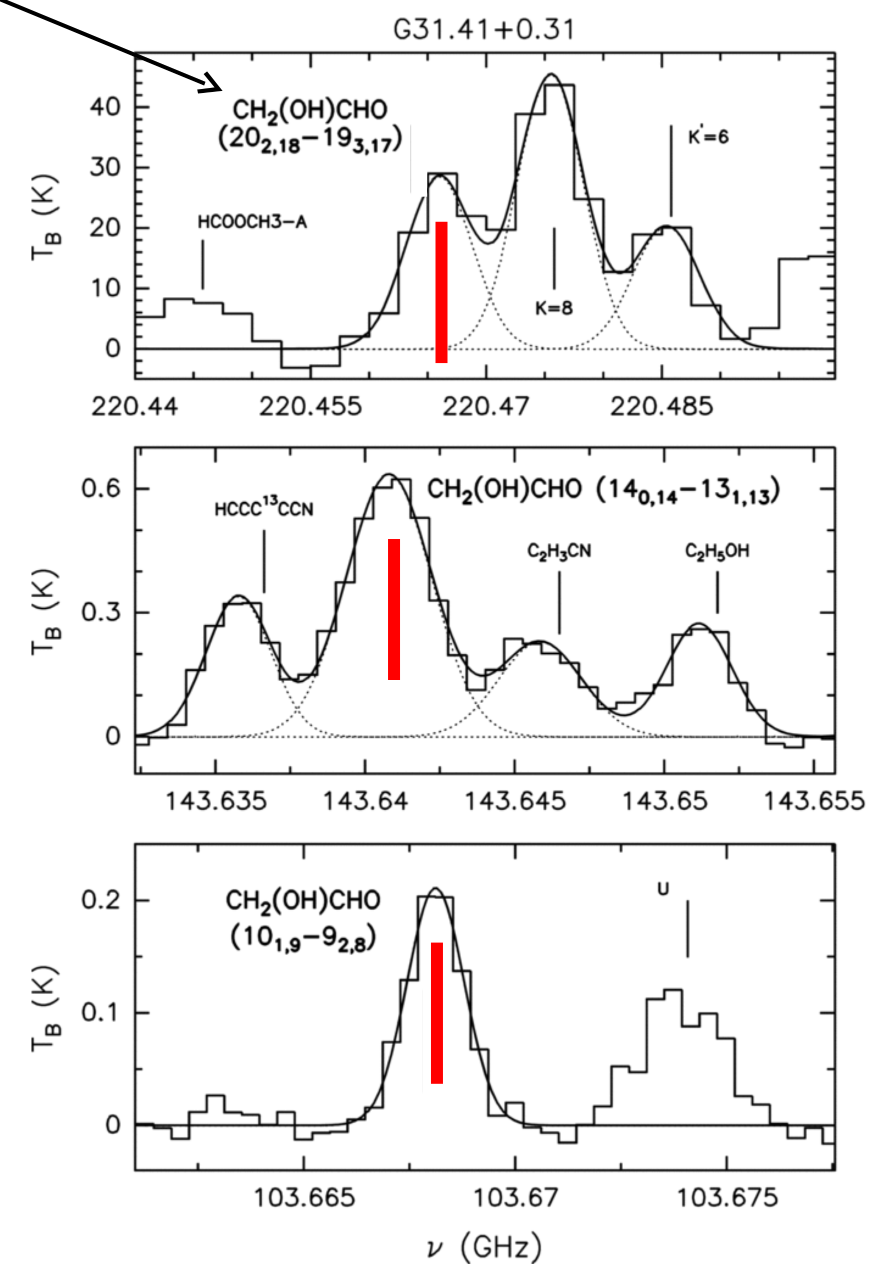
First detection of glycolaldehyde outside Galactic center (Beltran et al. 2009)

SMA spectrum of CH_3CN, etc…





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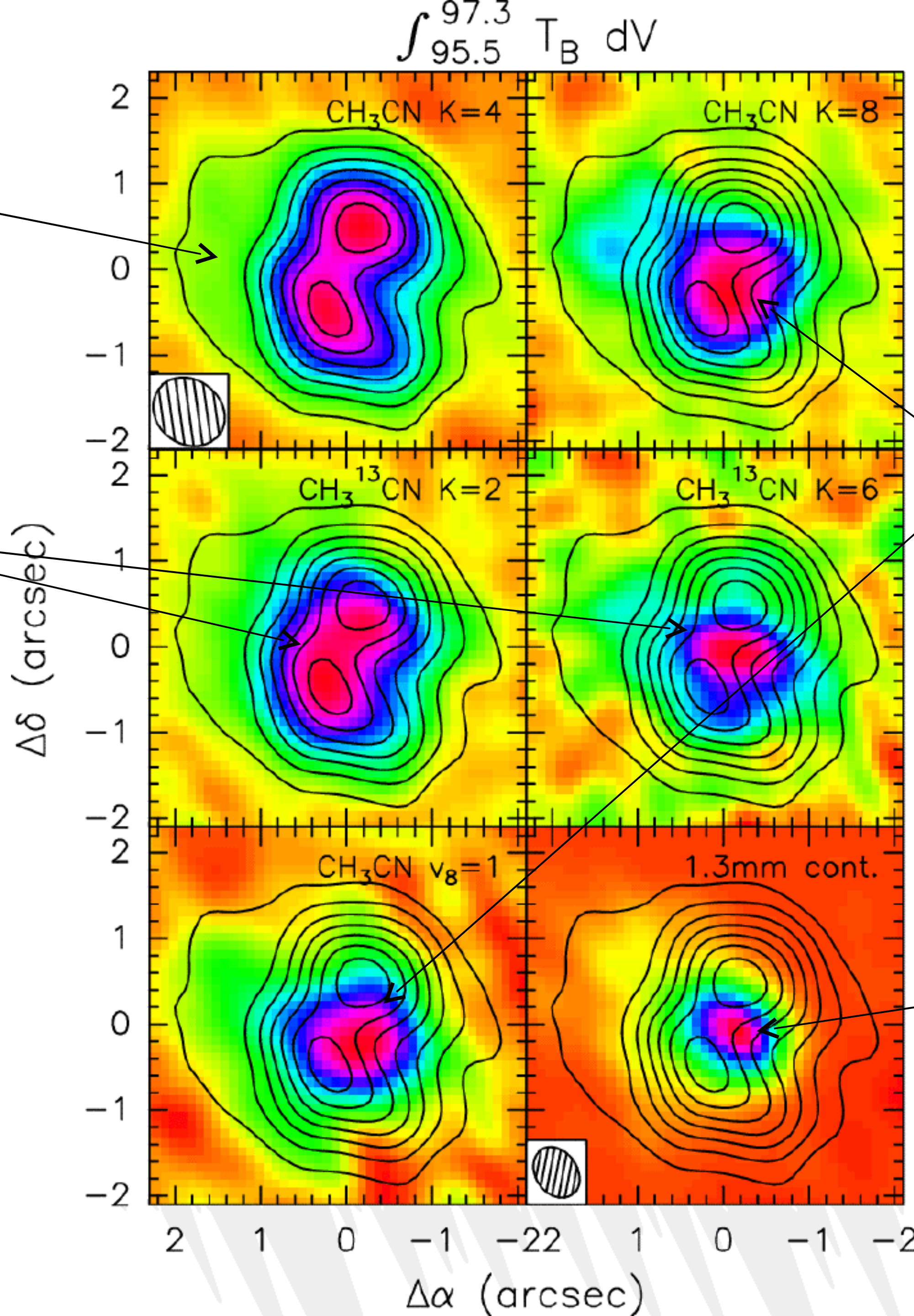
SMA
(Zhang et al. in prep.)



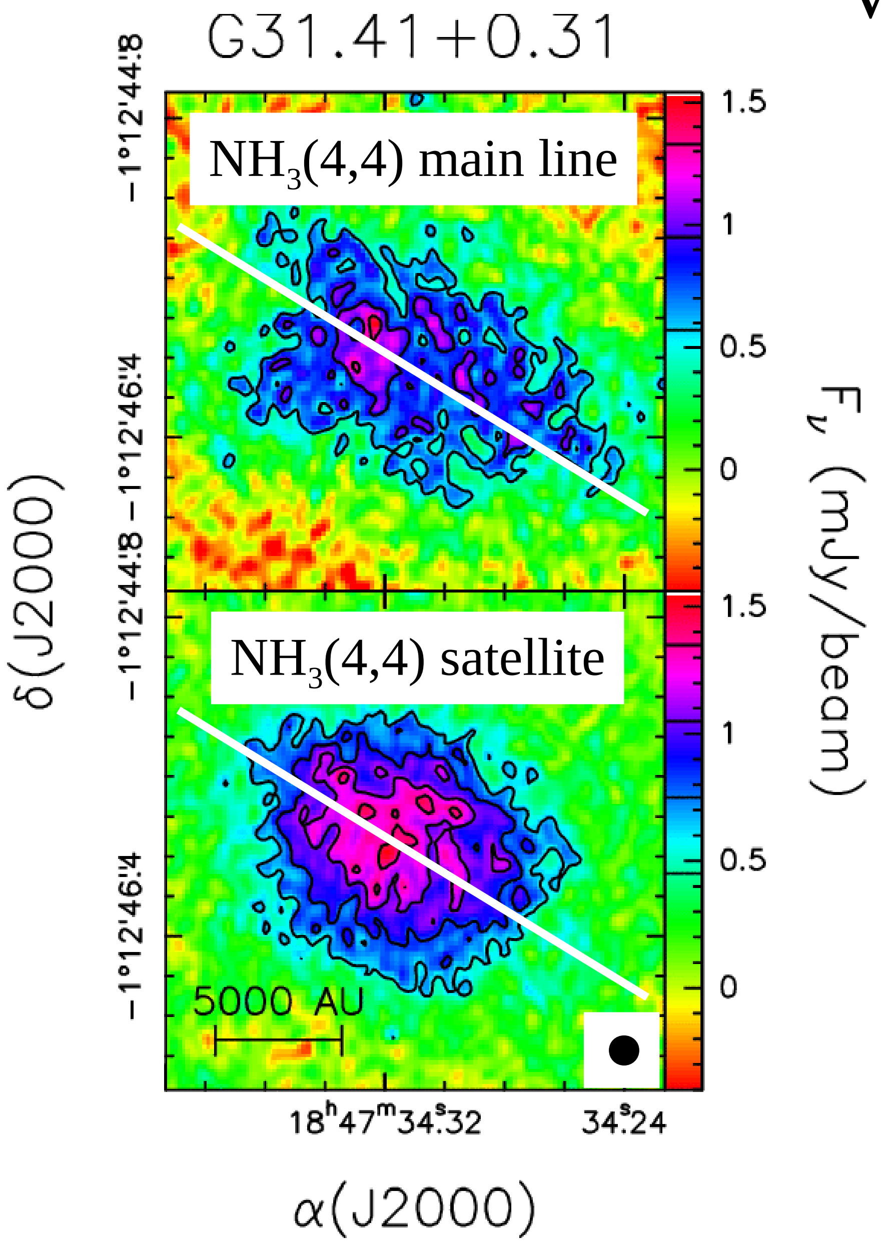
low energy

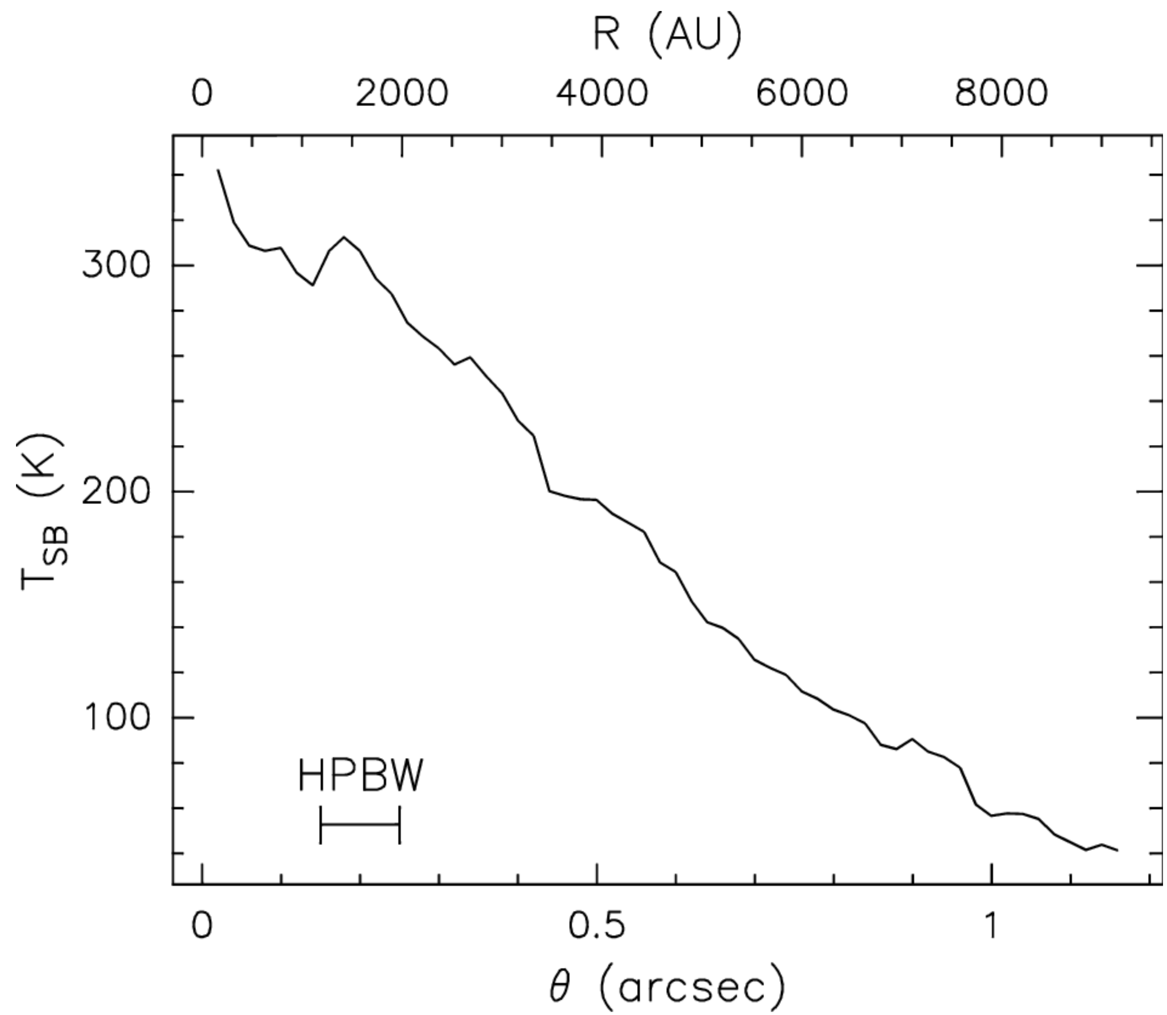
optically thin

high energy

continuum

VLA A-array (Cesaroni et al. subm.)

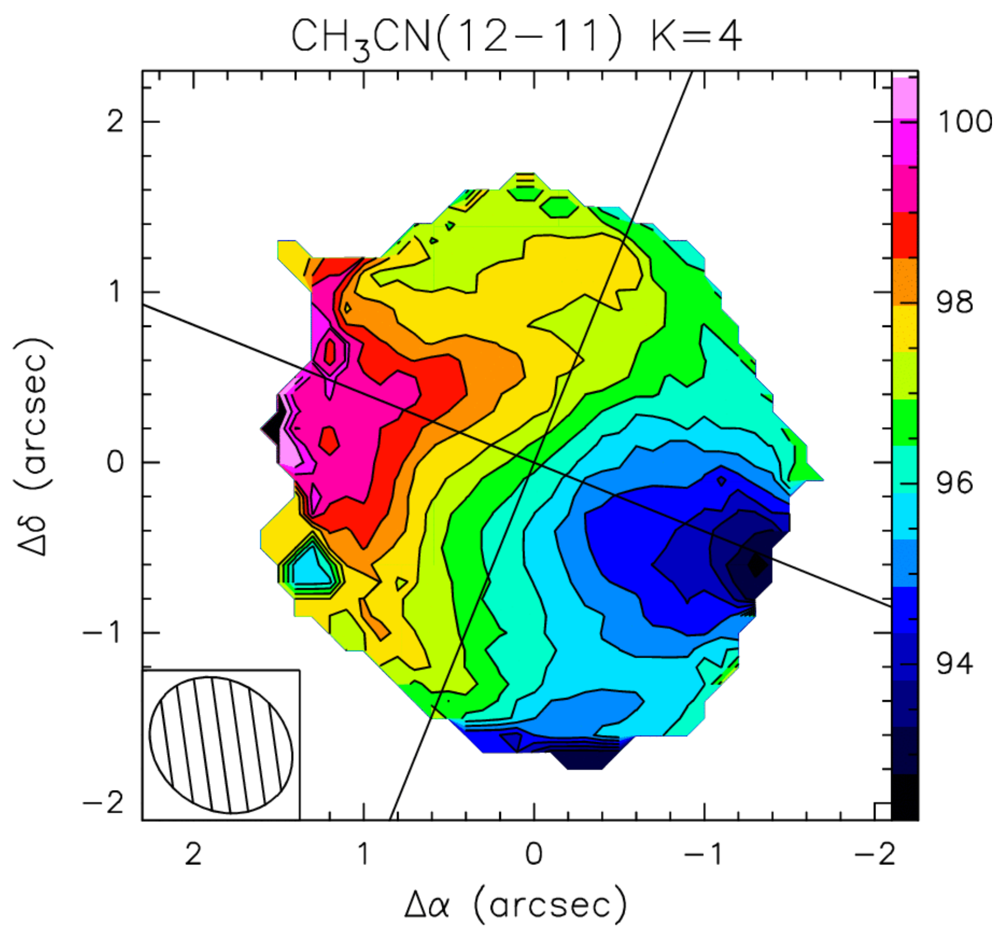


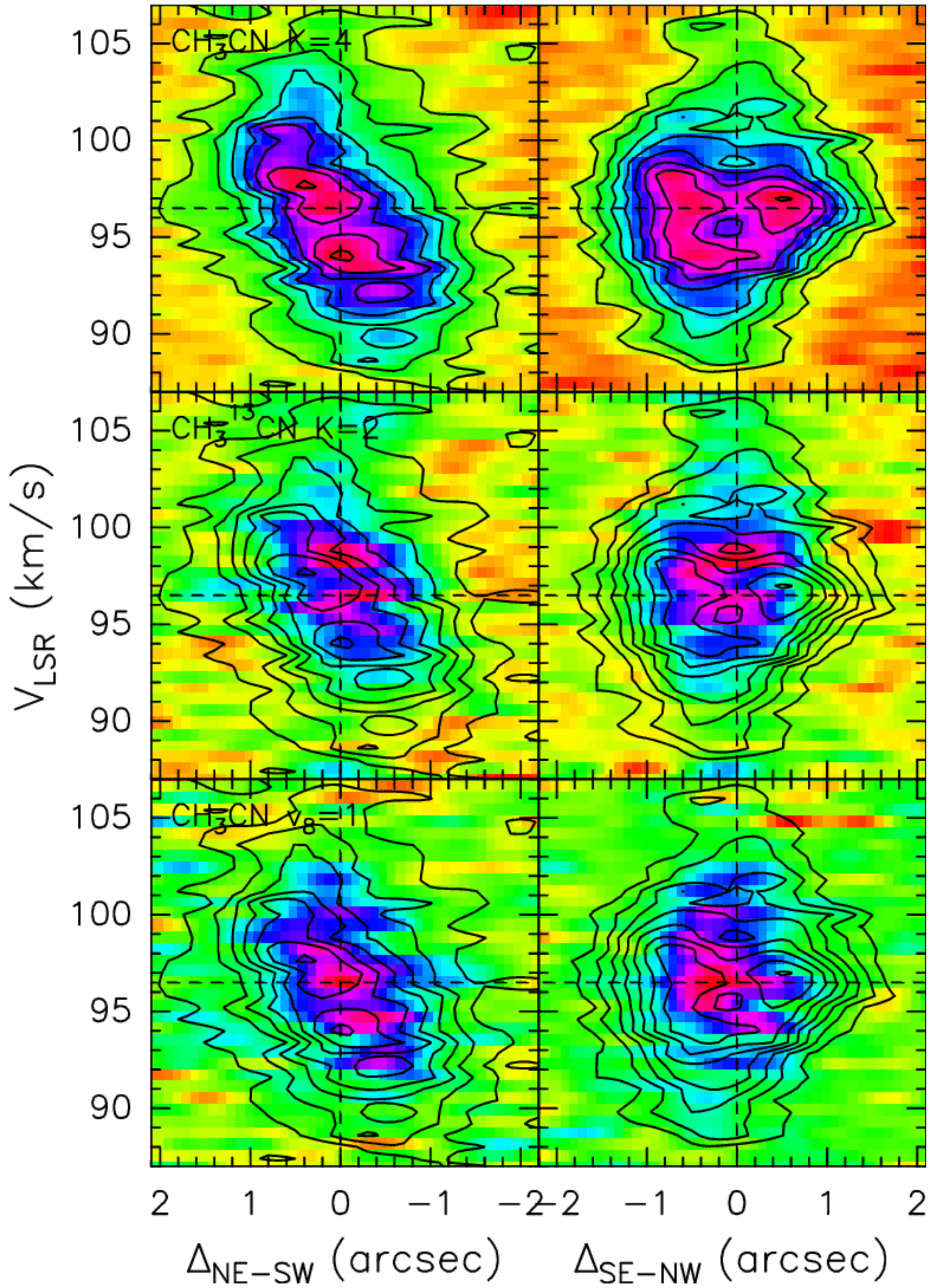


G31.41+0.31: the velocity field

- Clear NE-SW velocity gradient seen in HMC (Beltran et al. 2004, 2005)
- Same velocity gradient in all molecular lines
- Possible interpretations: rotation or expansion → **toroid** or **outflow**?
  - Toroid: M_{dyn} = 175 M_0 < M_{HMC} = 490 M_0 from mm cont. → dynamically unstable
  - Outflow: dM/dt = 0.04 M_0 yr^{-1} and dP/dt = 0.23 M_0 km s^{-1} yr^{-1} very large (but still acceptable)

SMA (Zhang et al. in prep.)





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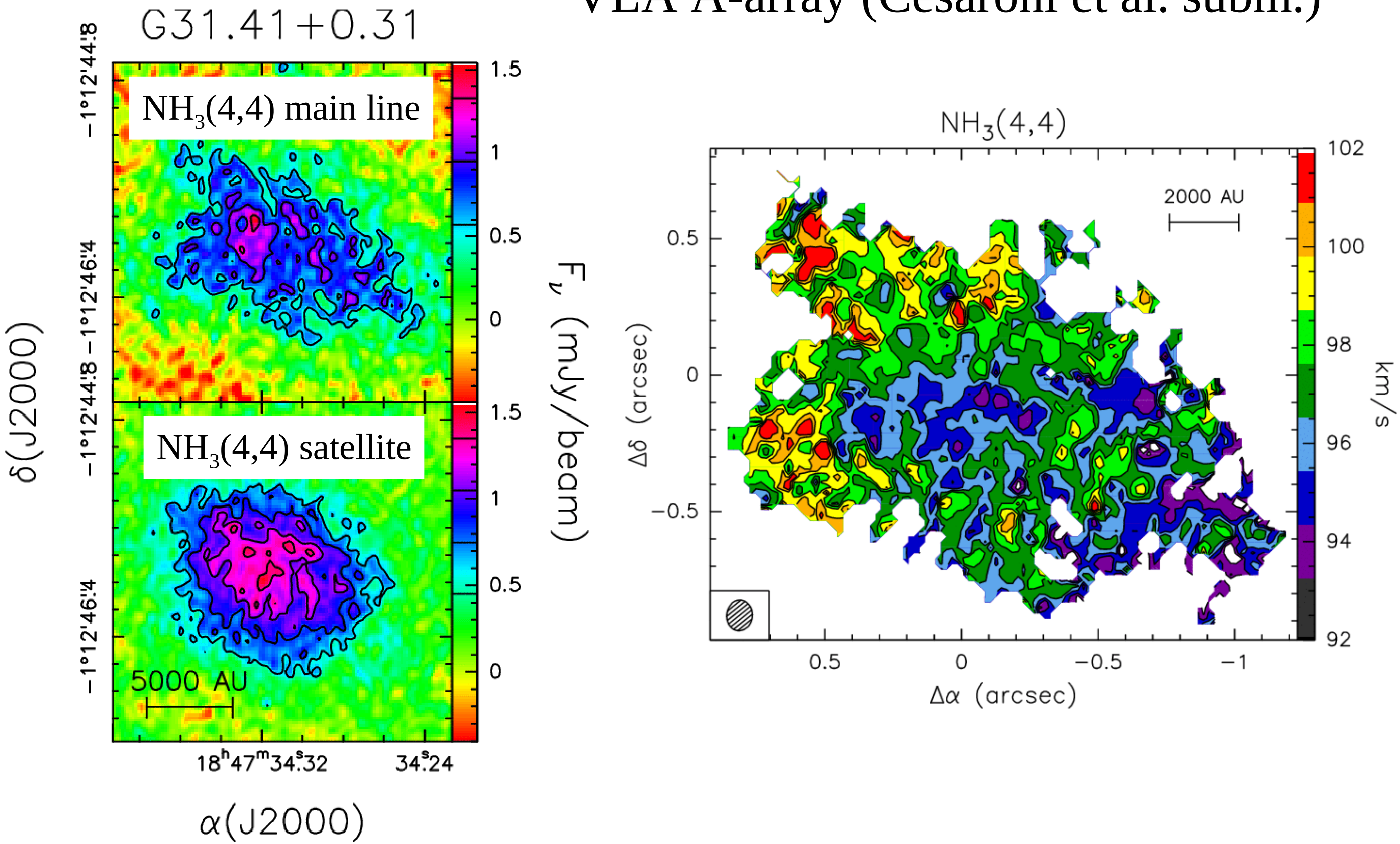

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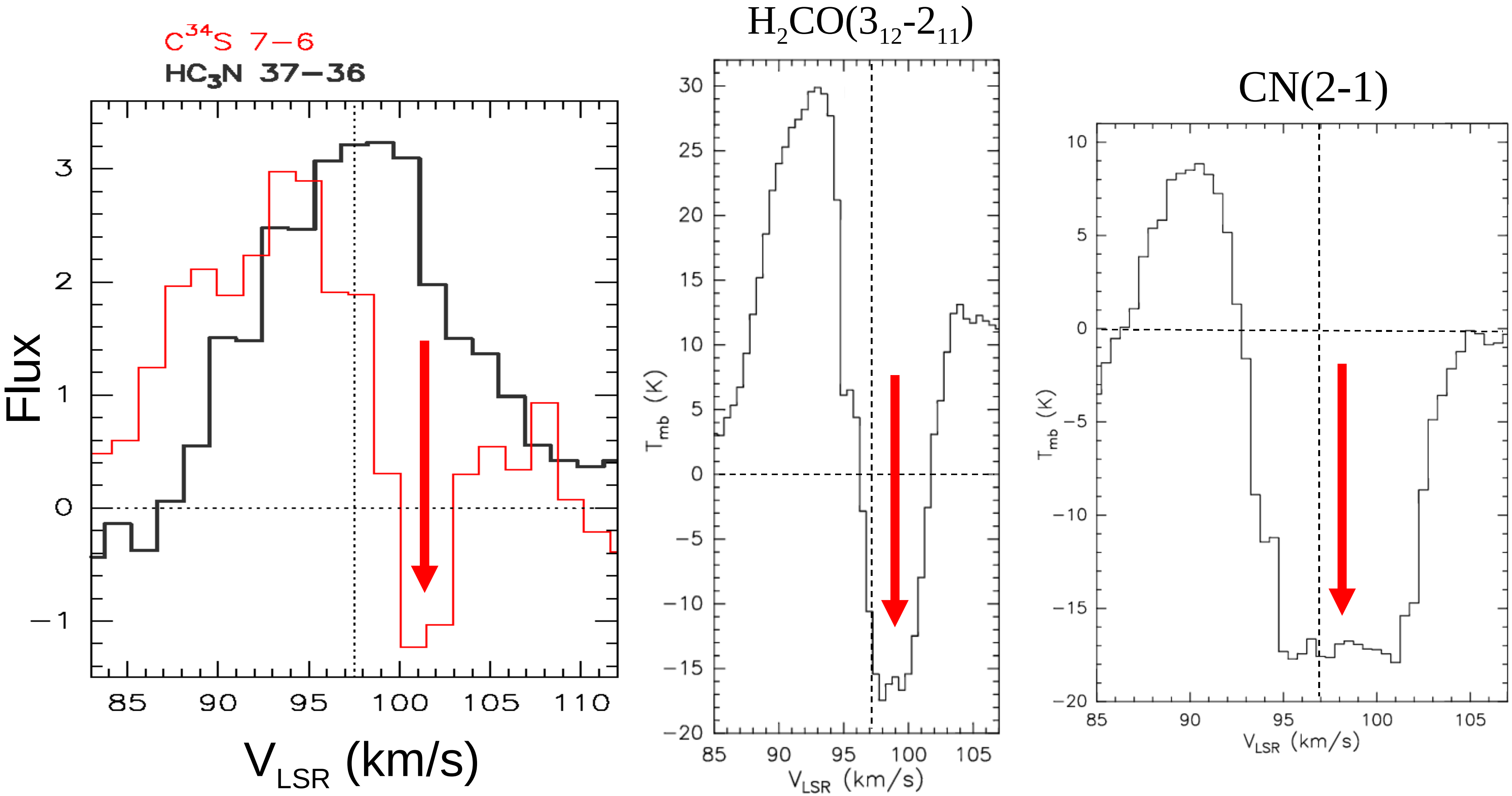
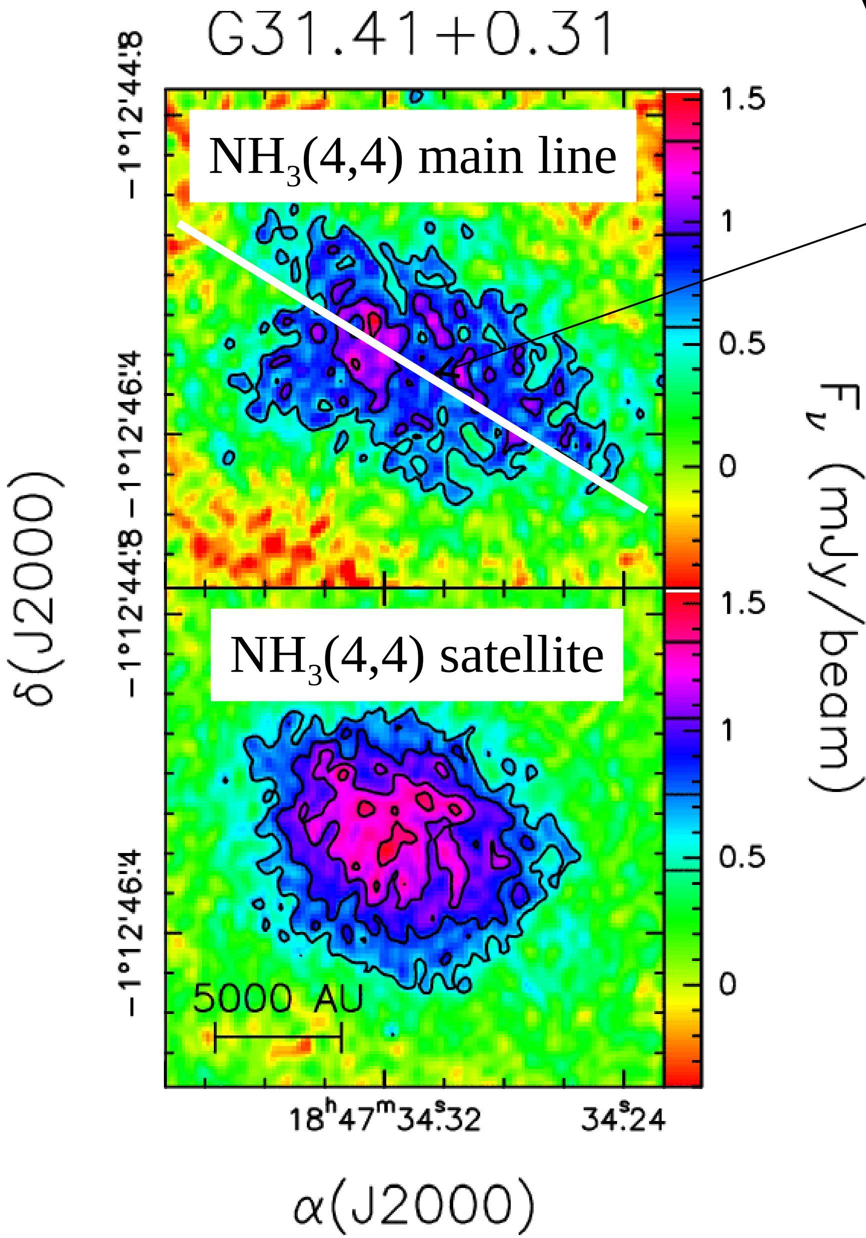
Toroid VS Outflow

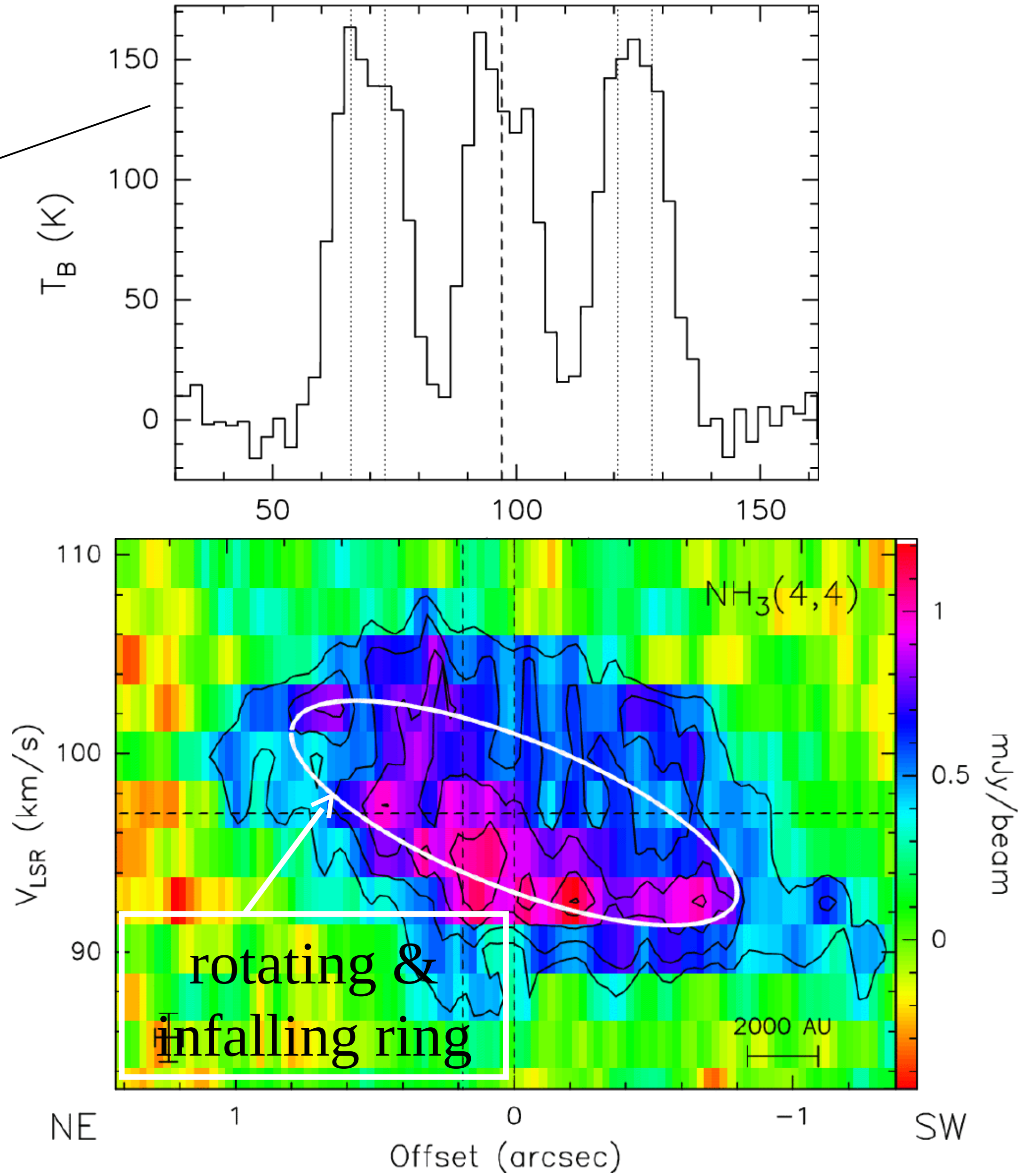
- Red-shifted (self) absorption → infall → **toroid**
- Two unresolved continuum sources oriented parallel to velocity gradient and with power-law spectra →
  - Loose binary system → **toroid**
  - Bipolar jet → **outflow**
- Mid-IR emission brighter towards red-shifted gas → HMC heated by nearby O star → **toroid**
- Hour-glass shaped magnetic field perpendicular to velocity gradient → **toroid**

Inverse P Cyg profiles (Girart et al. 2009) ➔ infall



VLA A-array (Cesaroni et al. subm.)





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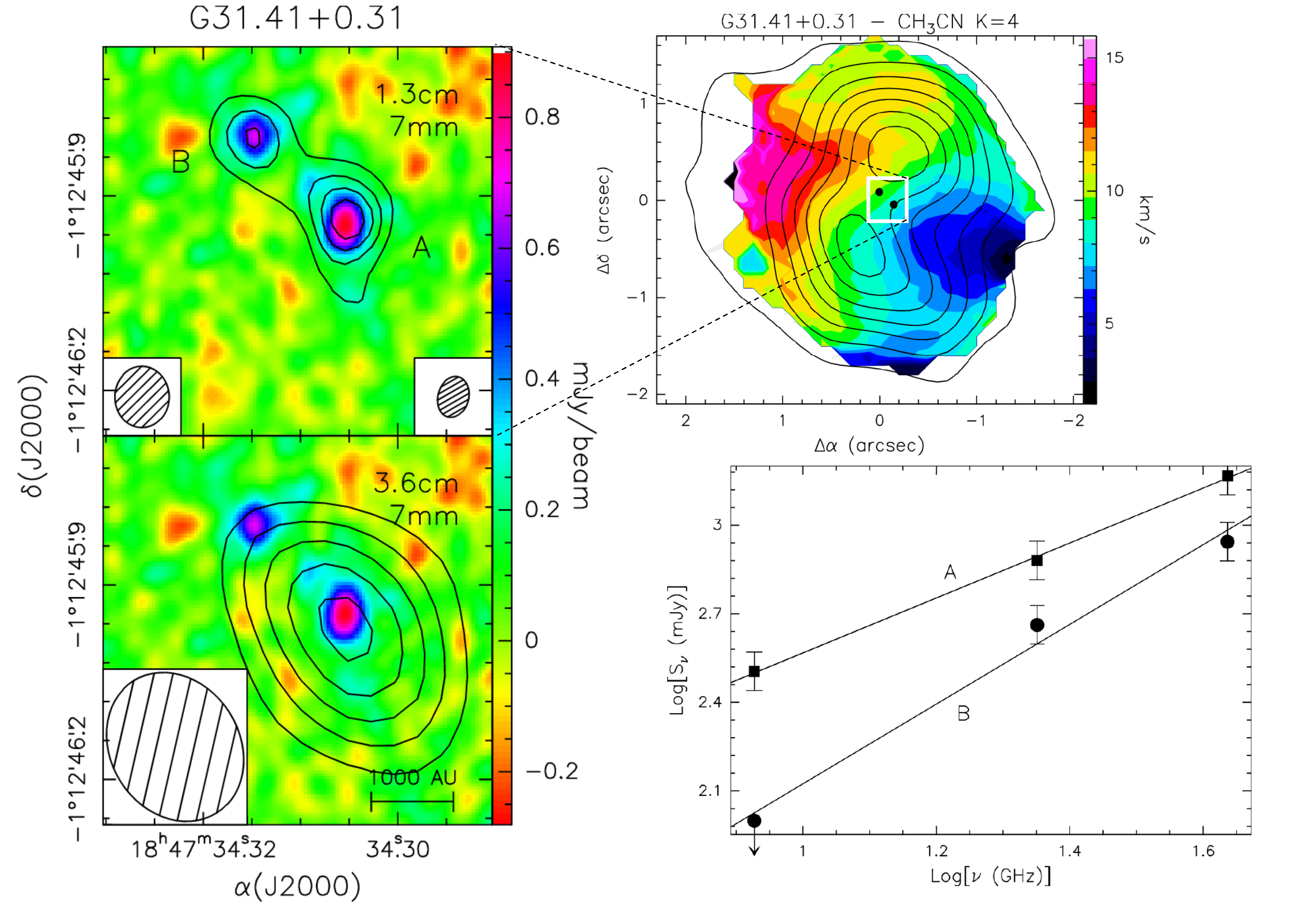

G31.41+0.31
1.3cm
7mm
B
A
3.6cm
7mm
1000 AU
mJy/beam
δ(J2000)
α(J2000)
G31.41+0.31 – CH3CN K=4
Δδ (arcsec)
Δα (arcsec)
km/s
Log[Sν (mJy)]
Log[ν (GHz)]
A
B

Toroid VS Outflow

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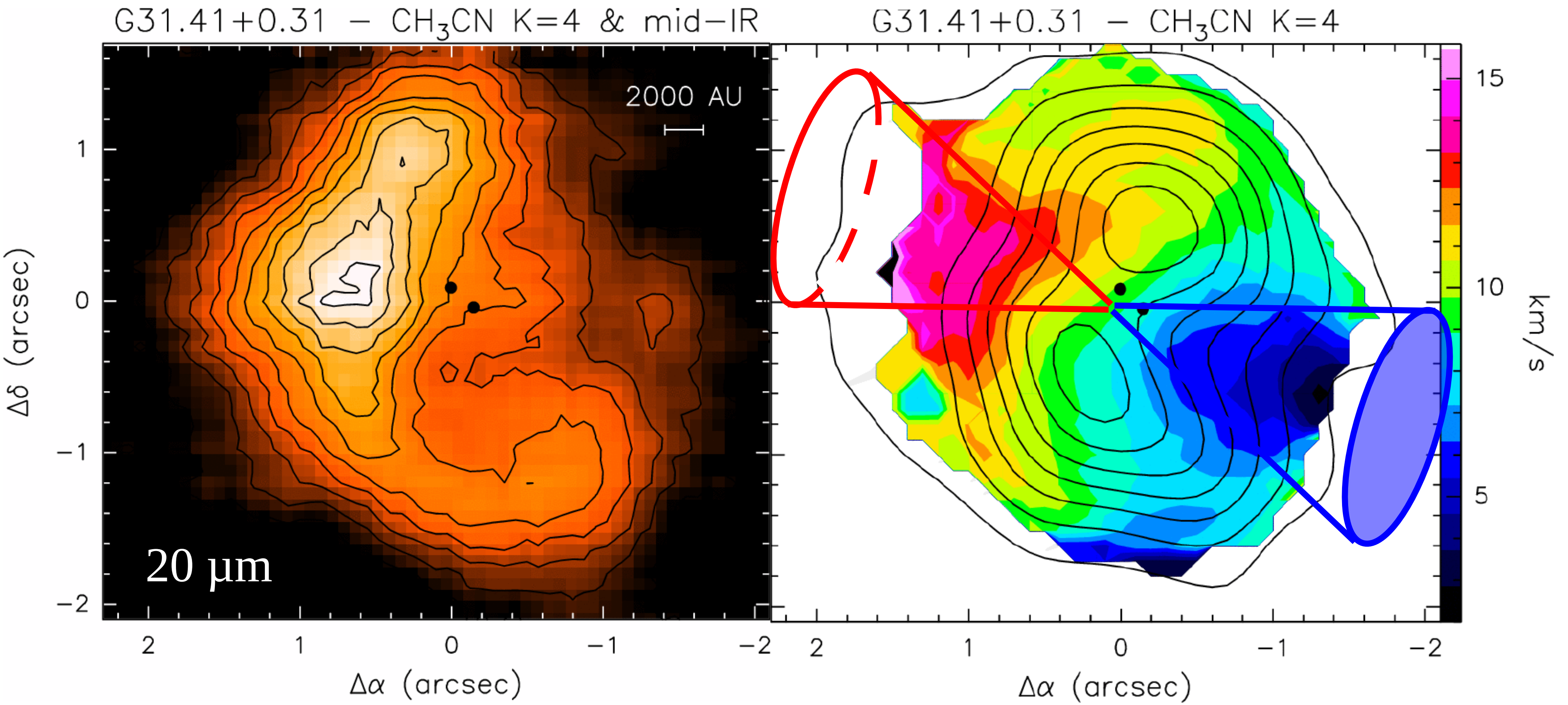
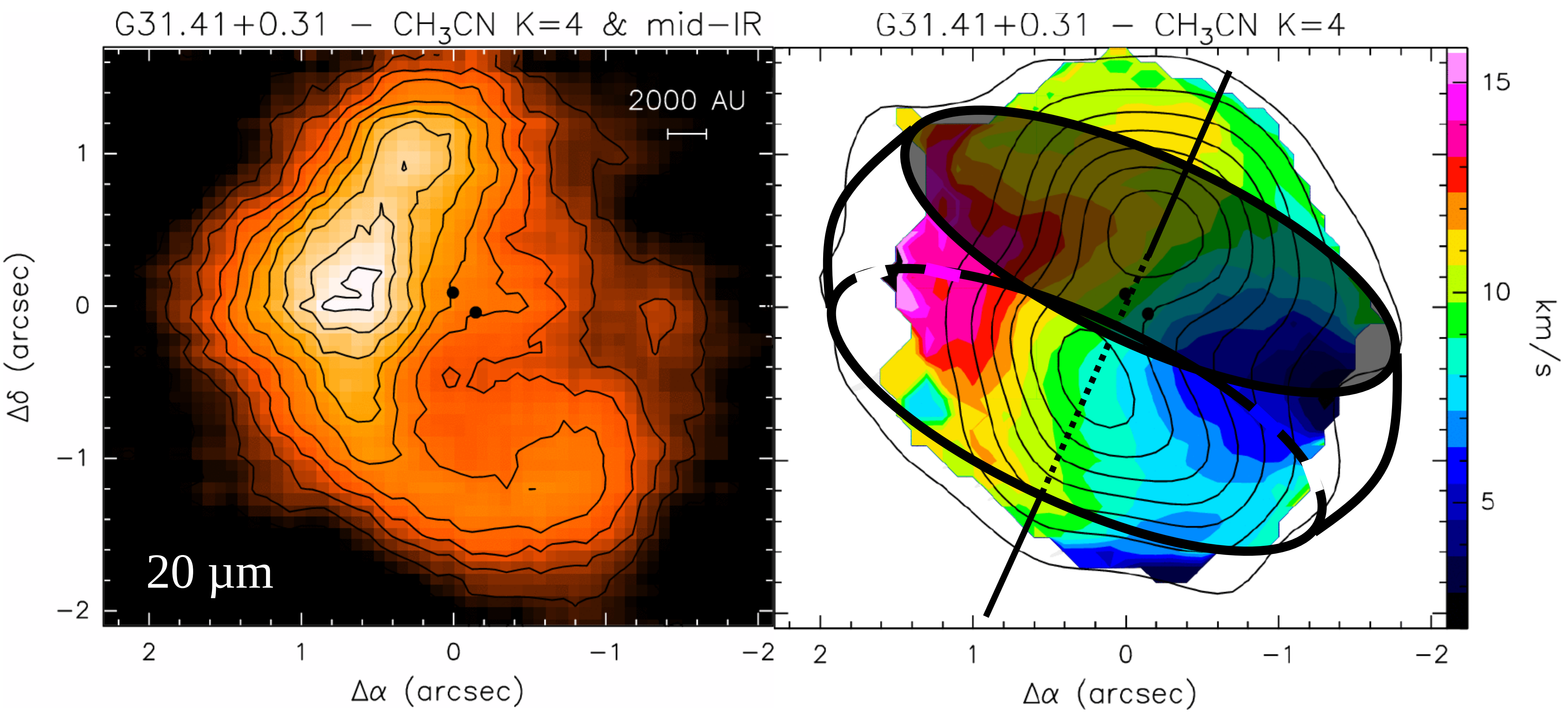
Outflow?

mid-IR should brighter towards blue lobe…

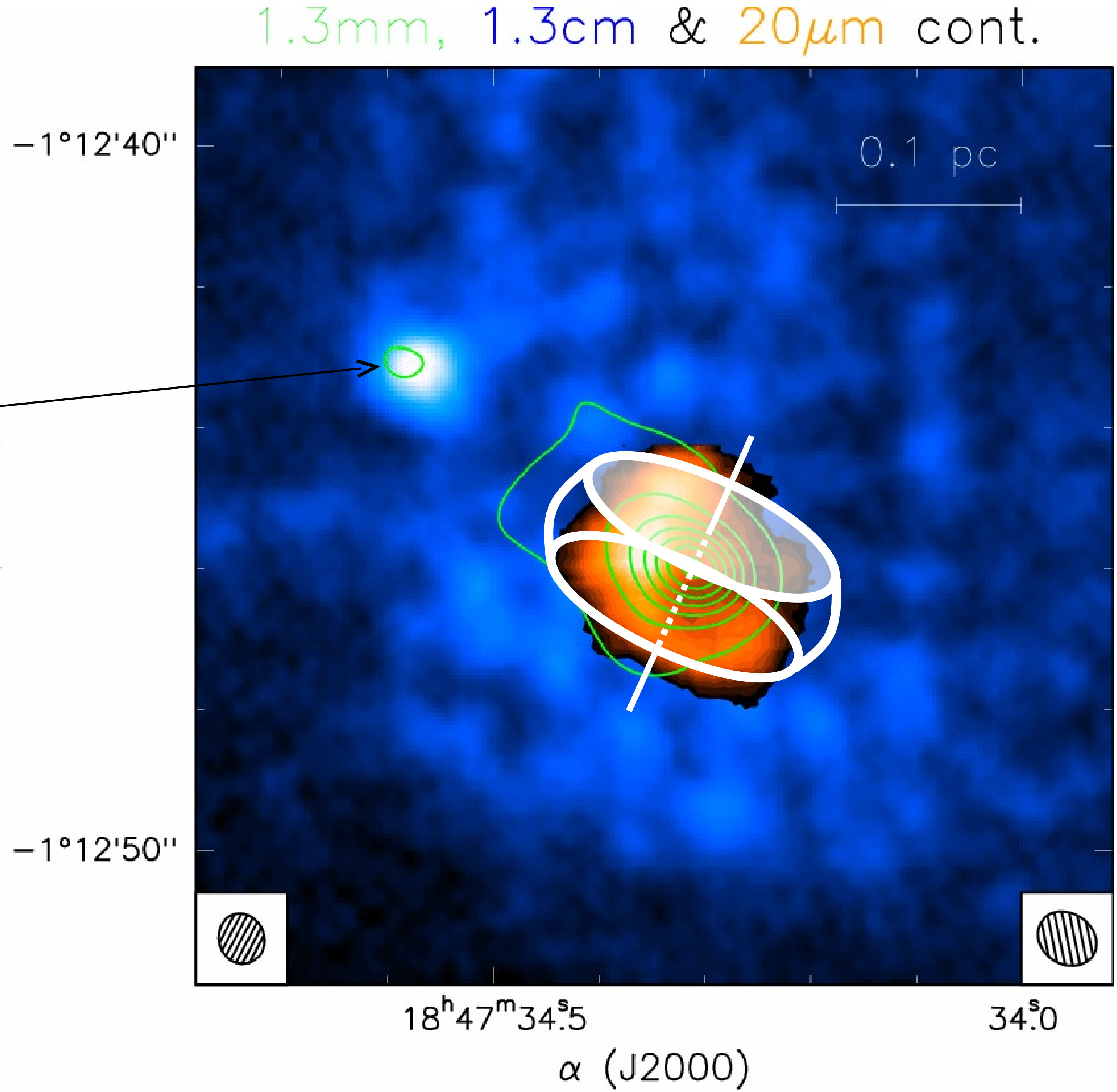


Toroid?

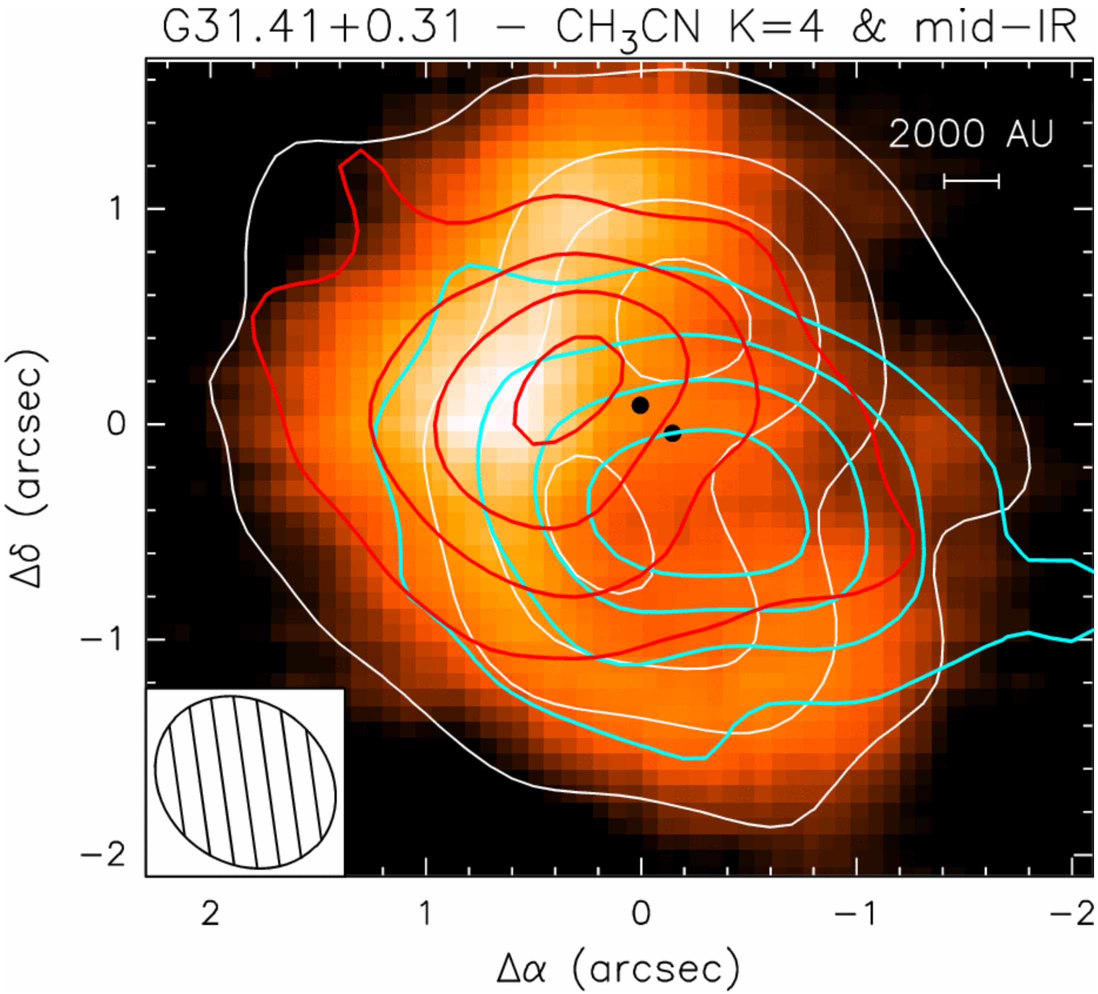
mid-IR should brighter along axis…

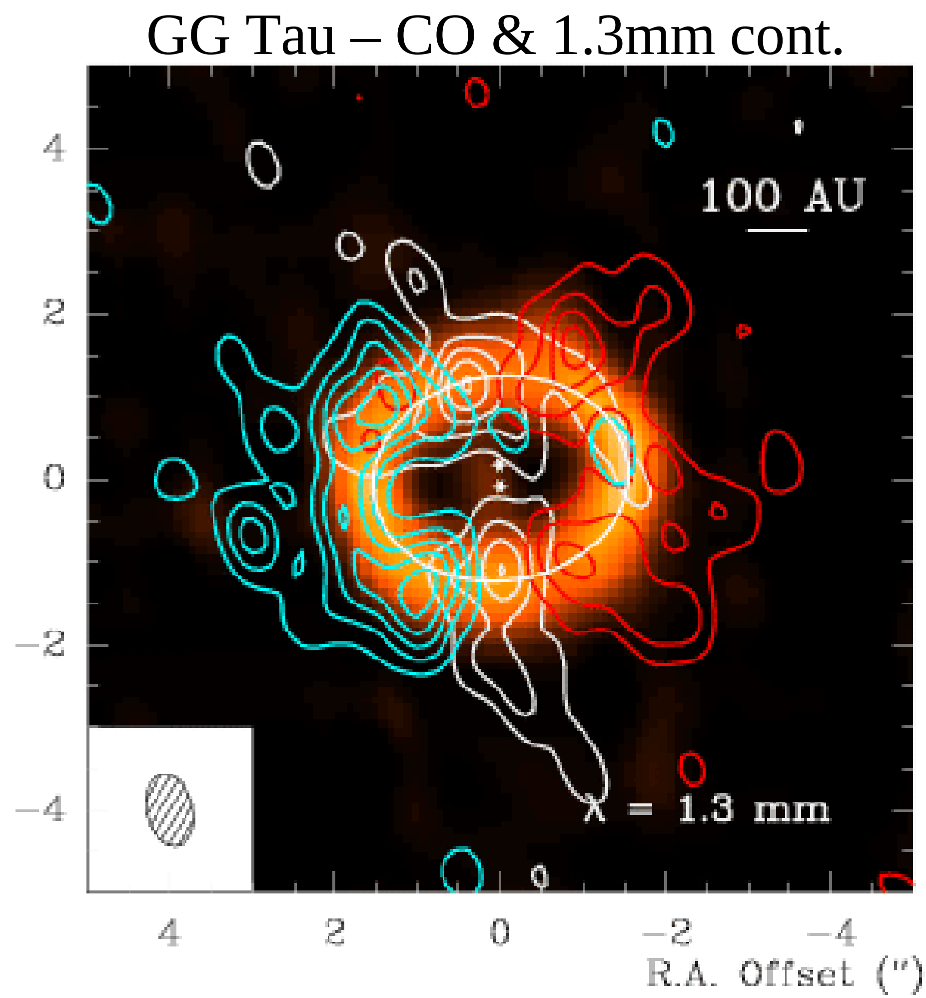


But… **toroid** could be heated from outside by nearby O star



analogy with low-mass case…





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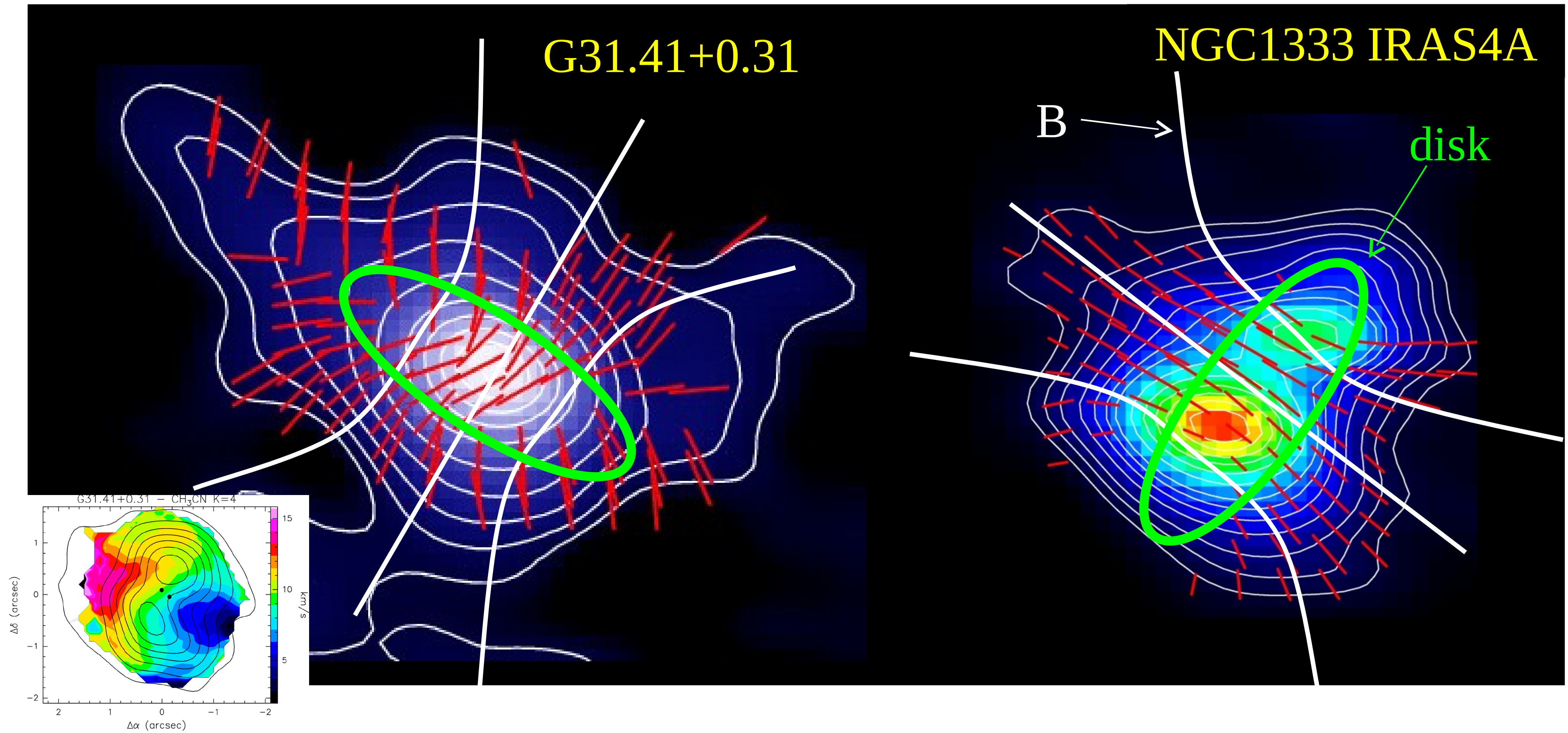
Hour-glass shaped magnetic field (Girart et al. 2009)

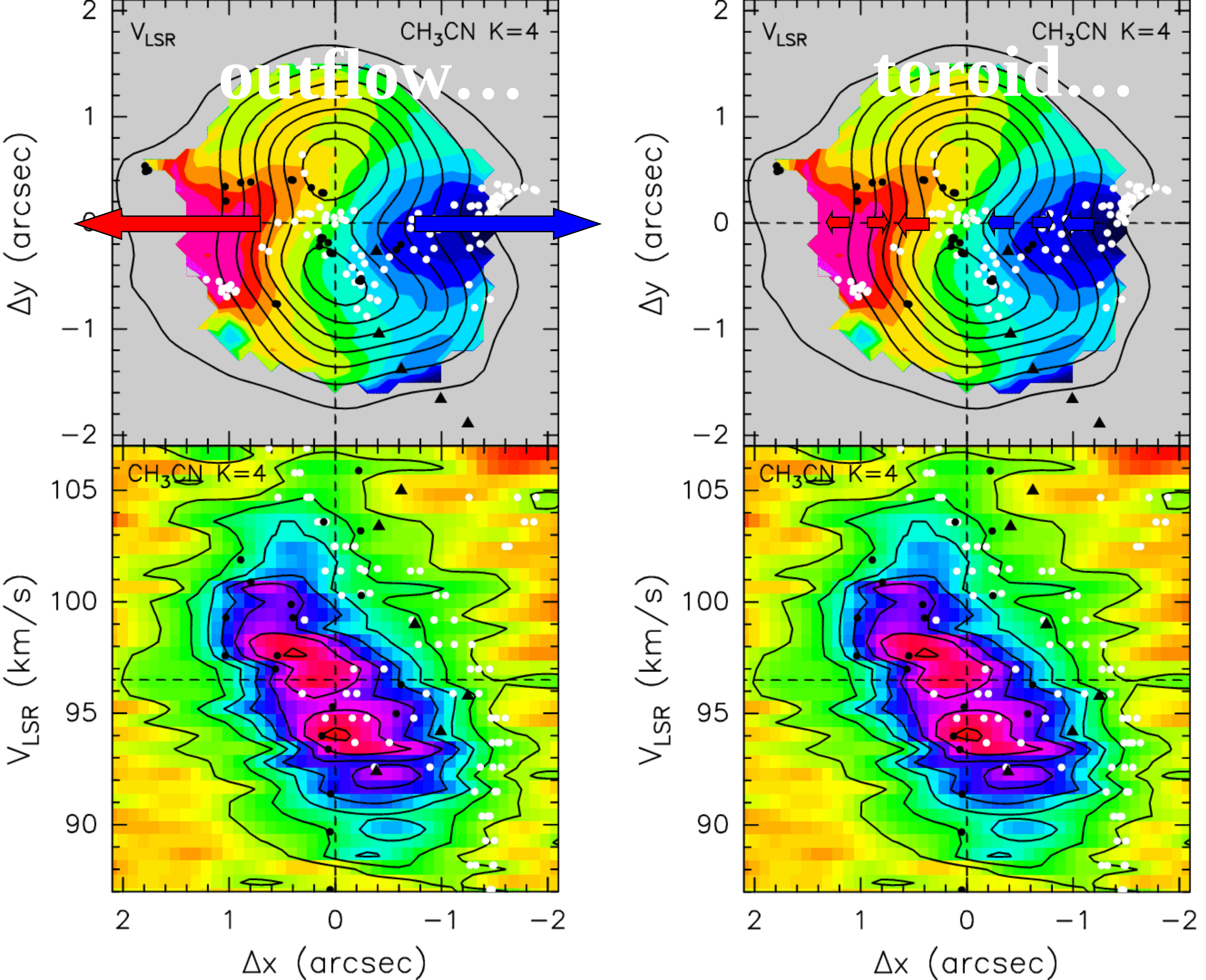
high-mass

low-mass



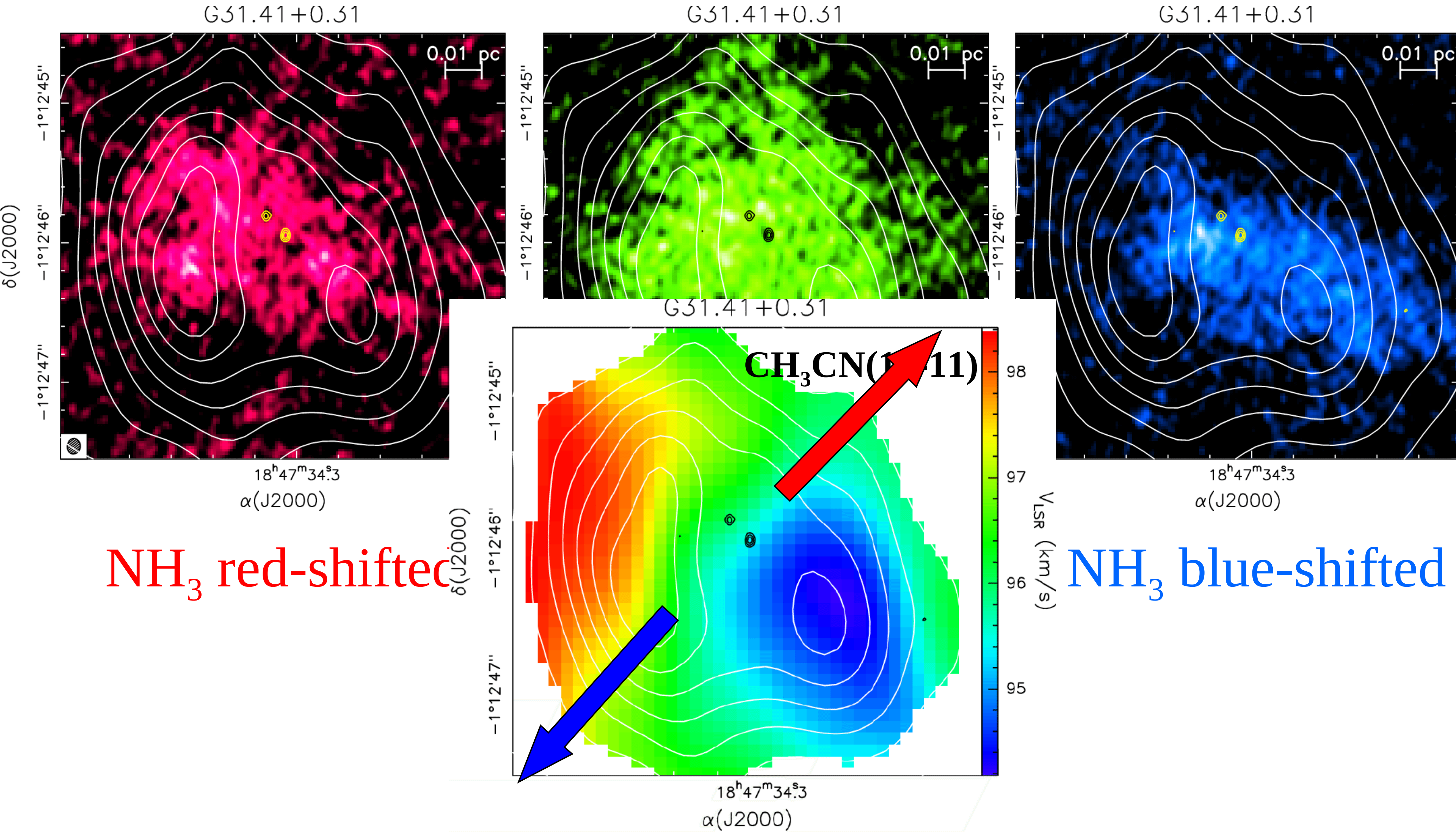
Conclusion

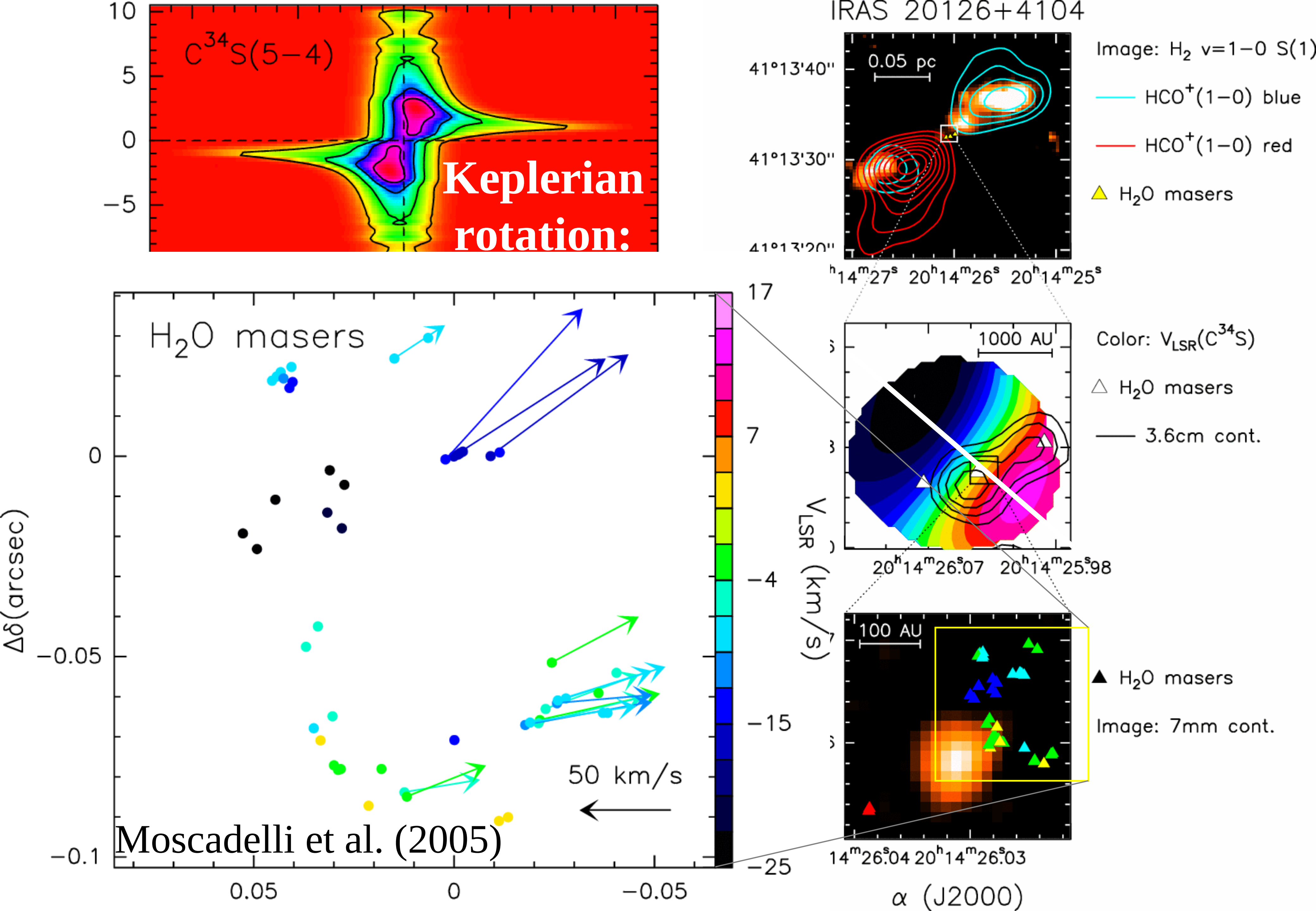
- Observational evidence seems to favour **rotating + infalling toroid**, but controversy is still open…
- Only 3D velocity field will discriminate → maser spot proper motions VLBI measurements undergoing



outflow…
toroid…
V_LSR
CH3CN K=4
Δy (arcsec)
V_LSR (km/s)
Δx (arcsec)

Beltran et al. (2005); Hofner et al. (in prep.)





C^{34}S(5−4)
Keplerian rotation:
IRAS 20126+4104
Image: H_2 v=1−0 S(1)
HCO$^+$(1−0) blue
HCO$^+$(1−0) red
H_2O masers
0.05 pc
41°13'40"
41°13'30"
41°13'20"
20^{h}14^{m}26^s
20^{h}14^{m}25^s
1000 AU
Color: V_{LSR}(C^{34}S)
H_2O masers
3.6cm cont.
20^{h}14^{m}26^s.07
20^{h}14^{m}25^s.98
100 AU
H_2O masers
Image: 7mm cont.
14^{m}26^s.04
20^{h}14^{m}26^s.03
α (J2000)
H_2O masers
Δδ(arcsec)
V_{LSR} (km/s)
50 km/s
Moscadelli et al. (2005)

Disks in high-mass (proto)stars

- So far only disks in B-type (proto)stars
- No detection of disks in O-type (proto)stars → implications on high-mass star formation models
- Absence of evidence: could be observational bias

Assumptions:

HPBW = $R_{disk}/4$

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

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

same $\langle N_{col} \rangle$ in all disks

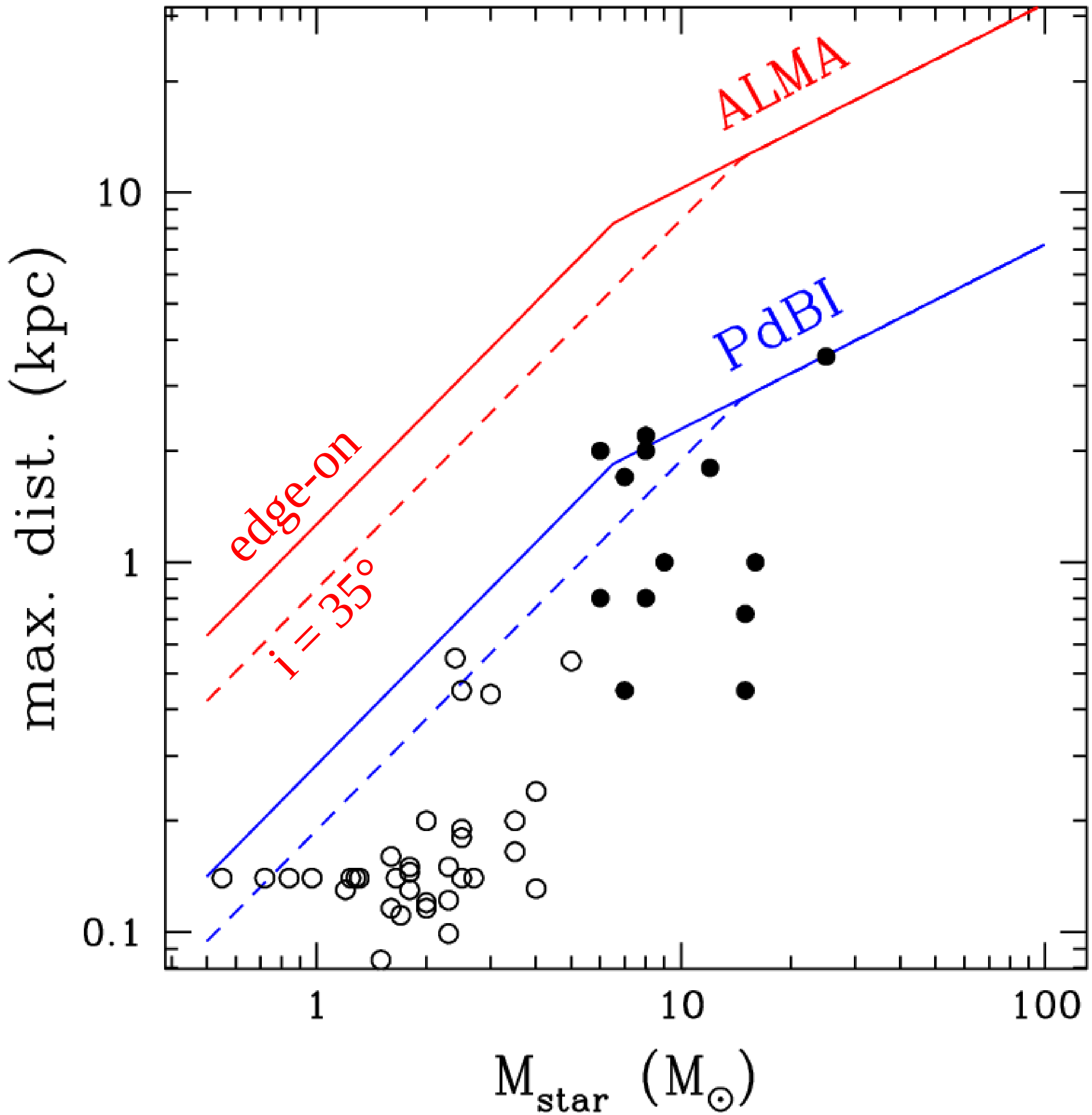
$T_B > 20$ K

obs. freq. = 230 GHz

5 hours ON-source

spec. res. = 0.2 km/s

S/N = 20



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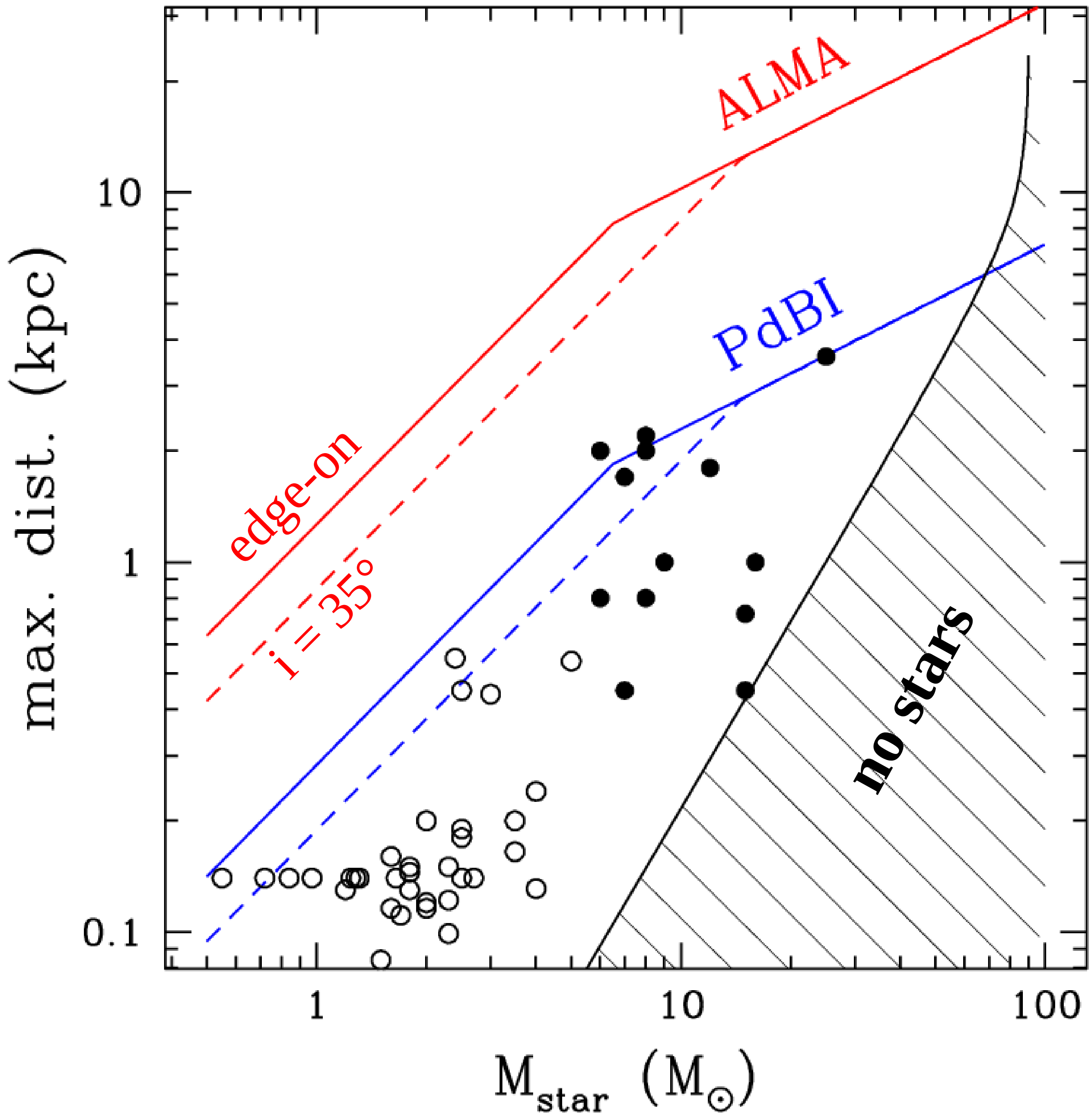
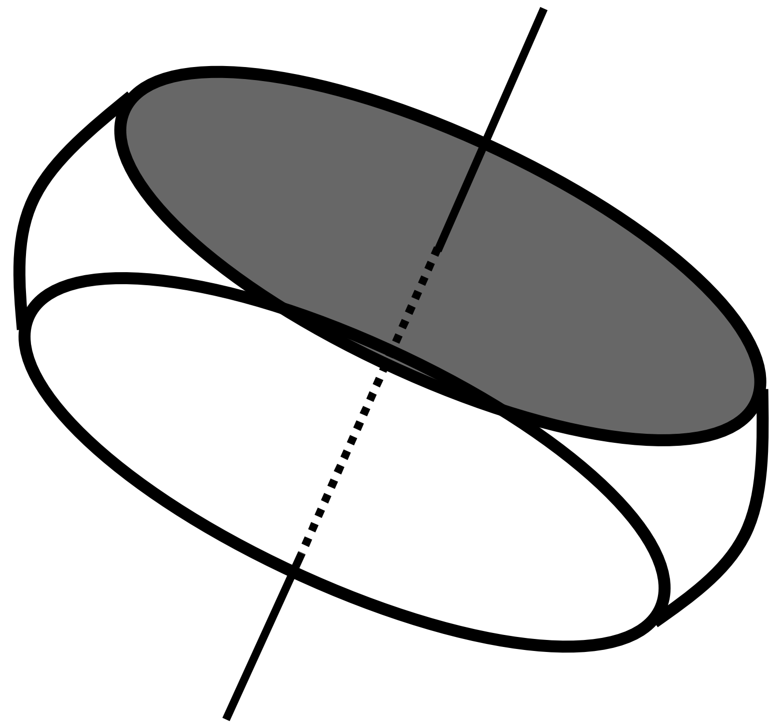
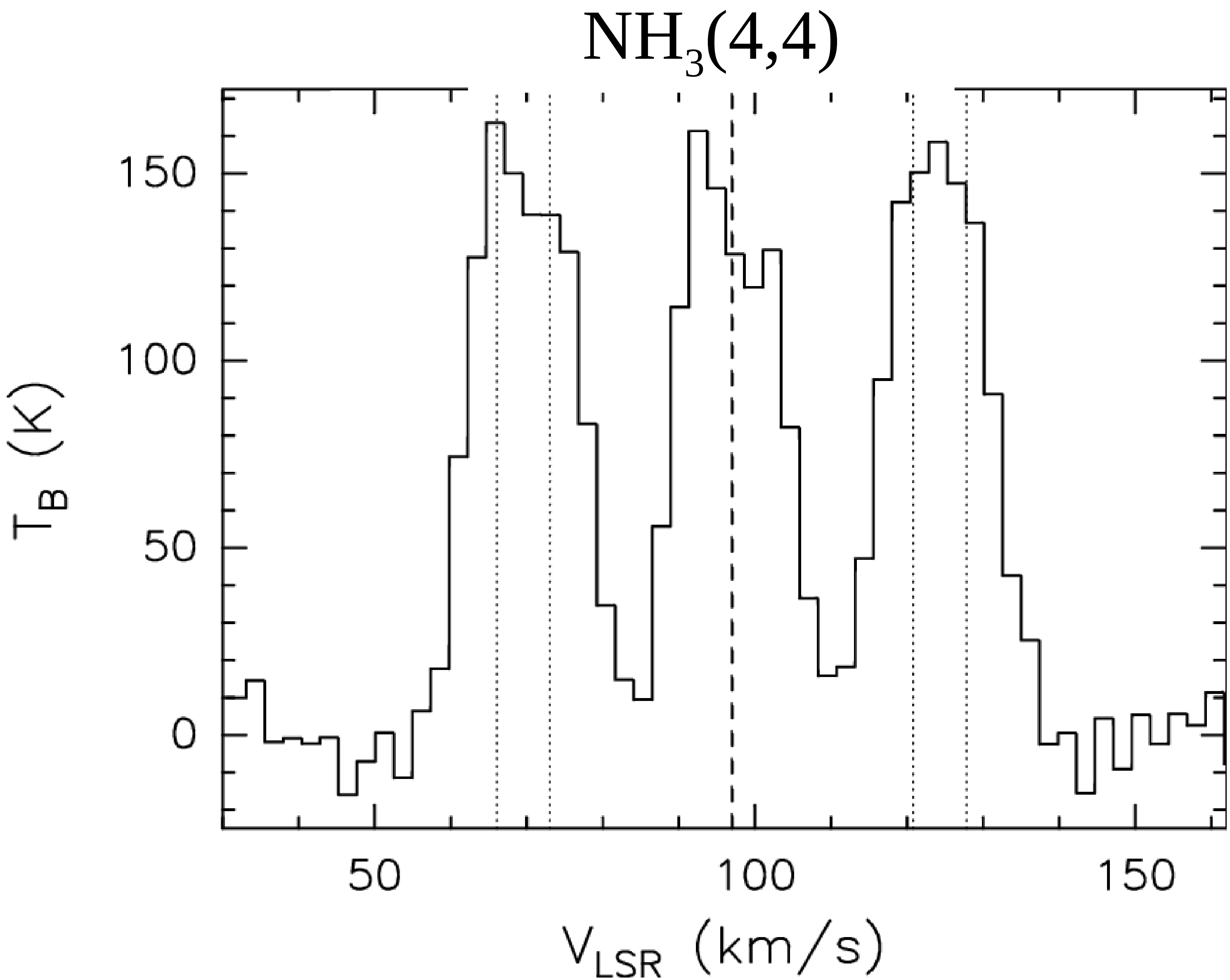


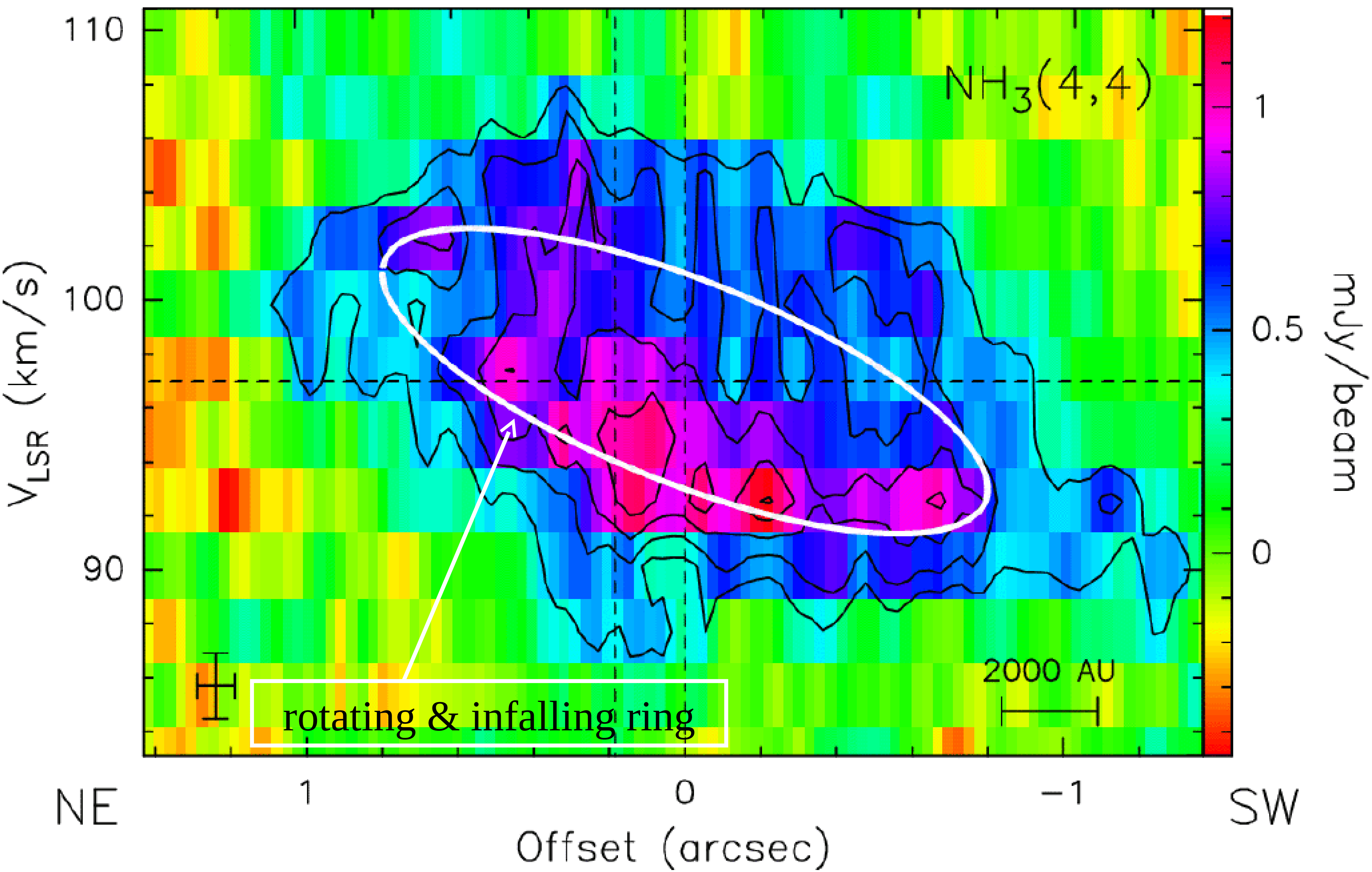
- Disks in O stars might exist, but not detectable at O-star distances
- Evidence for rotating toroids ($M >> M_{star}$) → could be envelopes of circumstellar disks?
- Hot molecular core **G31.41+0.31** excellent toroid candidate, but Araya et al. (2008) propose bipolar outflow interpretation

→ **important to establish true nature of G31.41**



Red-shifted self-absorption (Cesaroni et al. subm.)




NH3(4,4)
110
100
90
V_{LSR} (km/s)
1
0.5
0
mJy/beam
rotating & infalling ring
2000 AU
NE
1
0
−1
SW
Offset (arcsec)