Disks in High-Mass YSOs

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1) High-mass vs low-mass: the dividing line
2) The formation of high-mass stars: accretion vs coalescence
3) The importance of disks in massive YSOs
4) The search for disks: results & implications

Low-mass vs High-mass

Theory (Shu et al. 1987): star formation from inside-out collapse onto protostar

Two relevant timescales:

accretion → $t_{acc} = M_*/(dM/dt)$

contraction → $t_{KH} = GM_*/R_*L_*$

- Low–mass (< 8 M_O): $t_{acc} < t_{KH}$
- High–mass (> 8 M_O): $t_{acc} > t_{KH}$ → accretion on ZAMS (Palla & Stahler 1993)

PROBLEM:

High-mass stars "switch on" still accreting ➔

➔ radiation pressure stops accretion ➔

➔ stars > 8 M_{O} cannot form**!?**

SOLUTIONS

Yorke (2003): $\boldsymbol{\kappa_{dust} < \kappa_{crit} \propto M_*/L_*}$

1) "Increase'' M_*/L_*: non-spherical accretion

2) Reduce κ_{dust}: large grains (or coalescence of lower mass stars)

Possible models

- (Non-spherical) accretion: Behrend & Maeder (2001); Yorke & Sonnhalter (2002); Tan & McKee (2003)

  ram pressure > radiation pressure

- Coalescence: Bonnell et al. (1998, 2004) many low-mass stars merge into one massive star

Infall + angular momentum conservation ➔

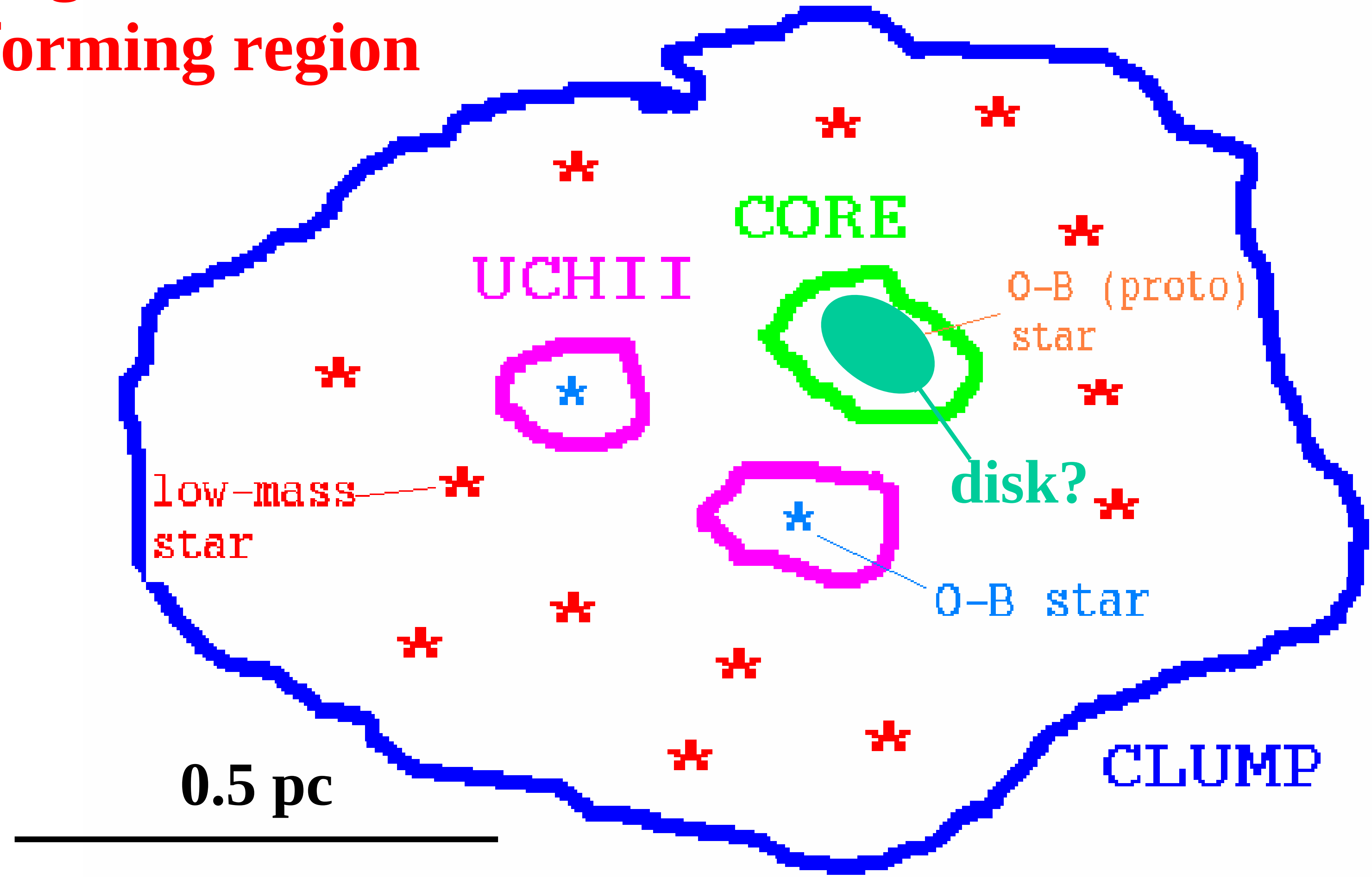
➔ rotating disks: “only’’ in accretion model

➔ discriminant between models: rotation of molecular cores

High-mass star forming regions: Observations

- Observational problems:
  - IMF → high-mass stars are rare
  - large distance: >300 pc, typically a few kpc
  - formation in clusters → confusion
  - rapid evolution: $t_{acc}=20\ M_O/10^{-3} M_O yr^{-1} = 2\ 10^4 yr$
  - parental environment profoundly altered
- Advantage:
  - very luminous (cont. & line) and rich (molecules)!

High-mass star forming region



The evidence for disks in massive YSOs

- Large scale (1 pc)

  rotating clumps seen e.g. in NH_3 (G35.2-0.74; Little et al. 1985), CO (IRAS07427; Kumar et al. 2003)

- Small scale (<0.1 pc)

  many claims of rotating "disks''…

The evidence for disks in massive YSOs

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  many claims of rotating “disks’’…

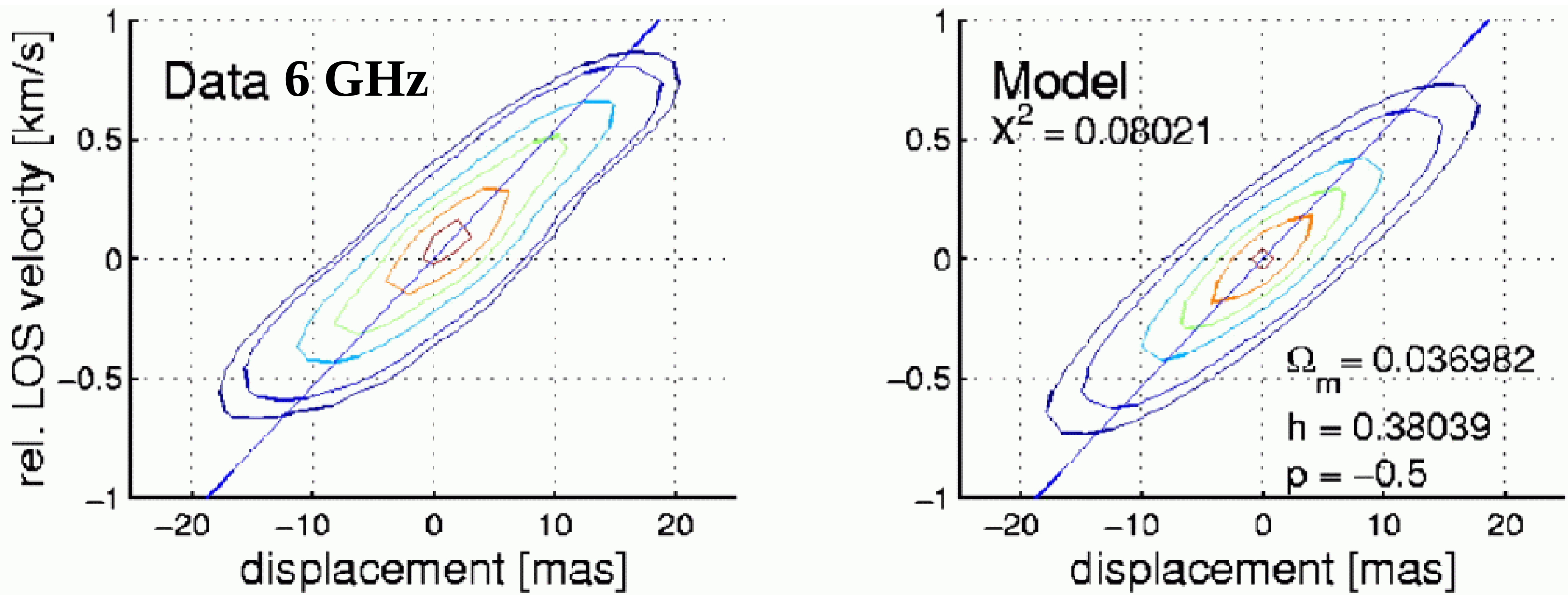
CH_3OH masers	ATCA, EVN	Ellingsen et al., Walsh et al. Minier et al., Edris et al., Pestalozzi et al.
OH masers	Merlin	outflow sources: Cohen et al., Edris et al.
SiO & H_2O masers	VLA, VLBA	e.g. Orion source I Greenhill, Torrelles et al.
NIR, mm & cm continuum	BIMA, VLA	jets/outflows in massive stars Hoare et al., Gibb et al.
NH_3, $C^{18}O$, CS, $C^{34}S$, CH_3CN,…	PdBI, OVRO, BIMA, NMA	UC HIIs, Hot Cores Keto et al., Cesaroni et al., Zhang et al., etc. etc….

- CH_3OH masers: stellar mass too low; H_2 jets parallel to CH_3OH spots (De Buizer 2003)
- OH masers: very few examples
- SiO & H_2O masers: outflow and/or disk
- NIR-cm cont.: confusion between disk and wind emission
- Molecular lines: kinematical signature of disk & outflow

CH_3OH masers
NGC7538

Pestalozzi et al. (2004)

M_*=30 M_O ???



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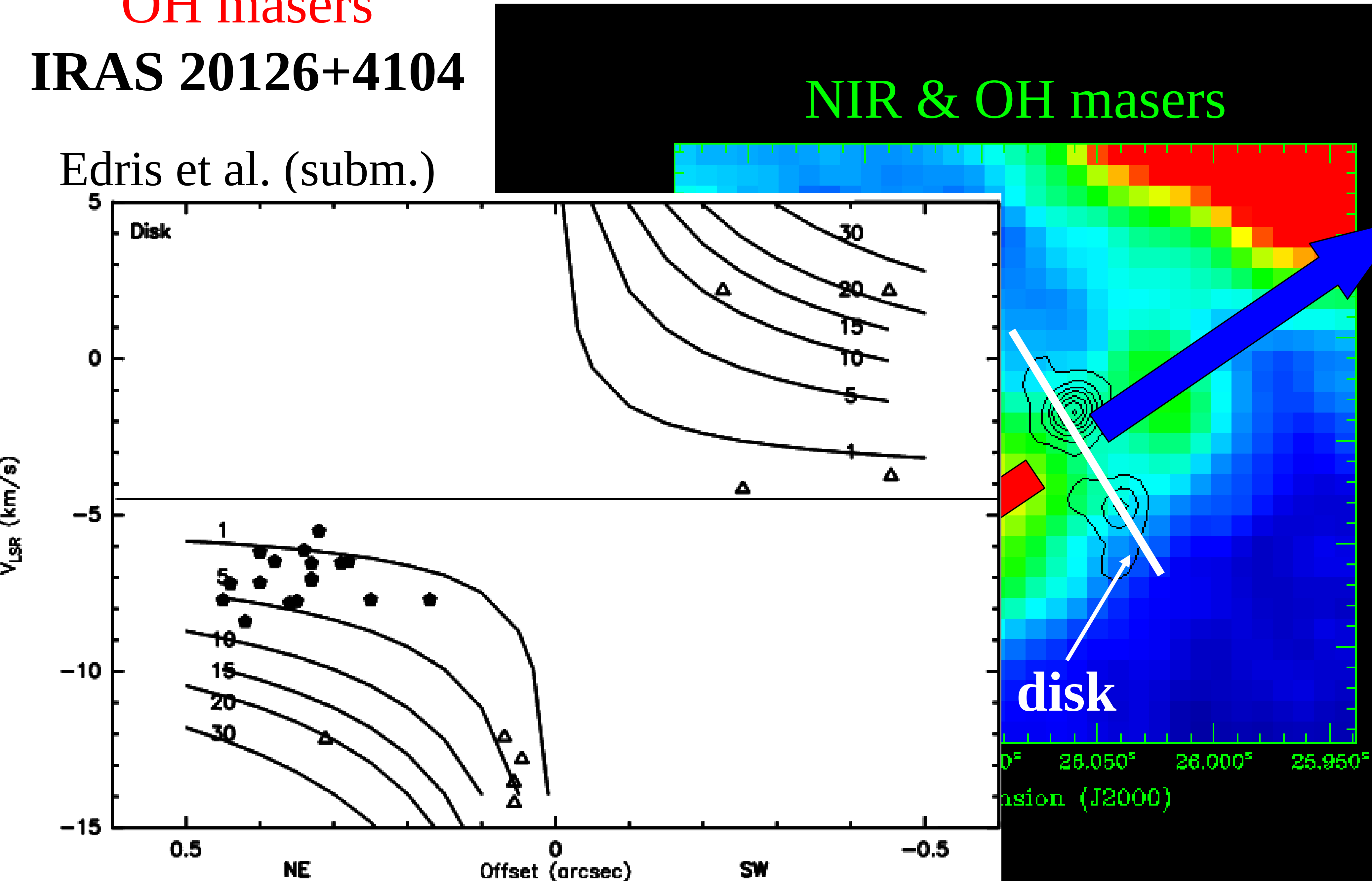
OH masers
IRAS 20126+4104

Edris et al. (subm.)

NIR & OH masers



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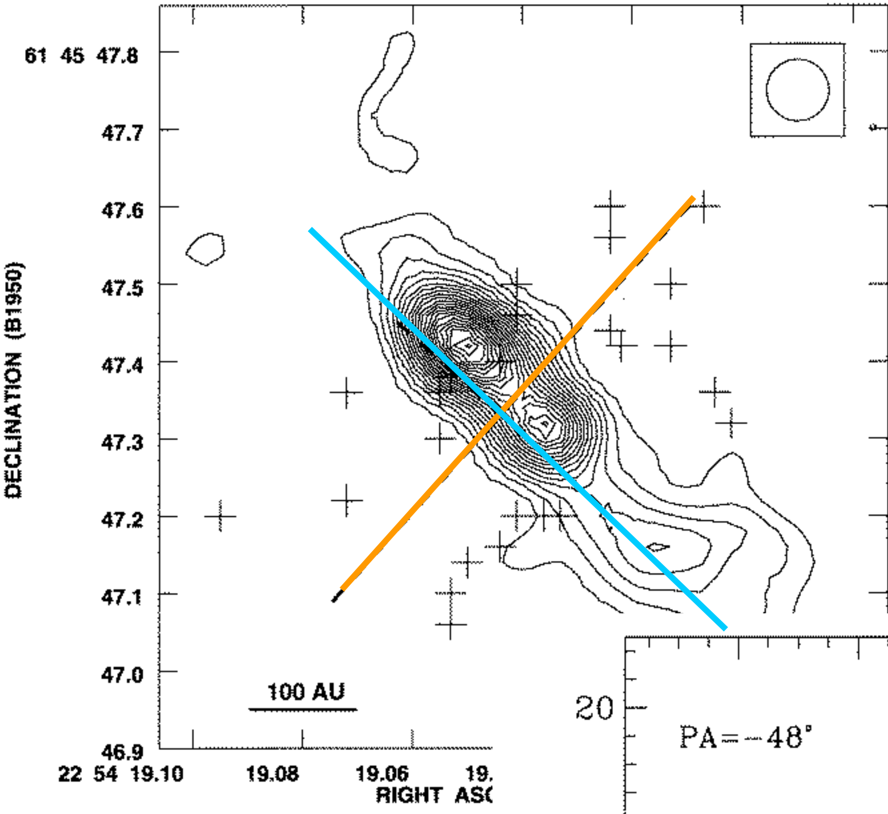
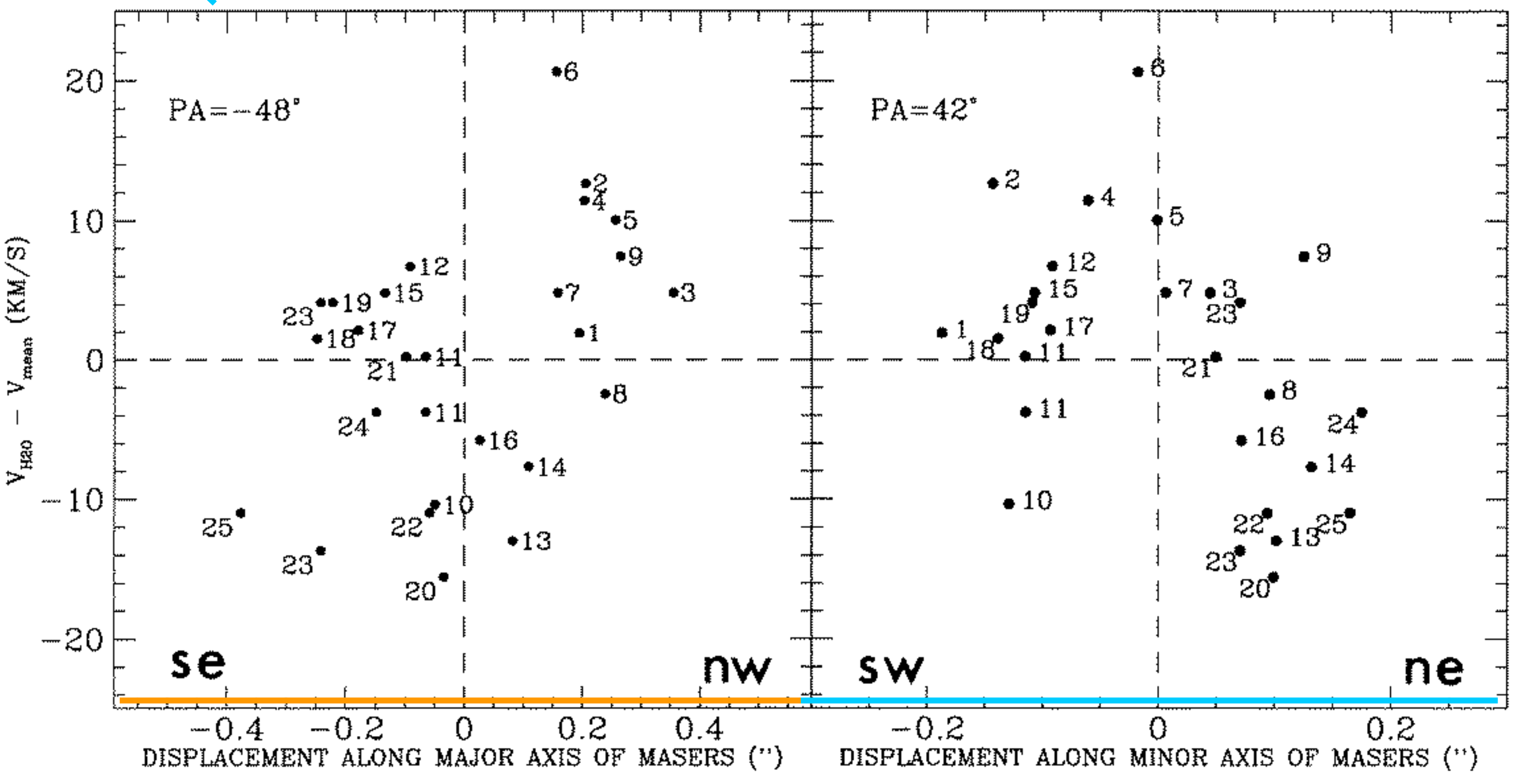
H_2O masers

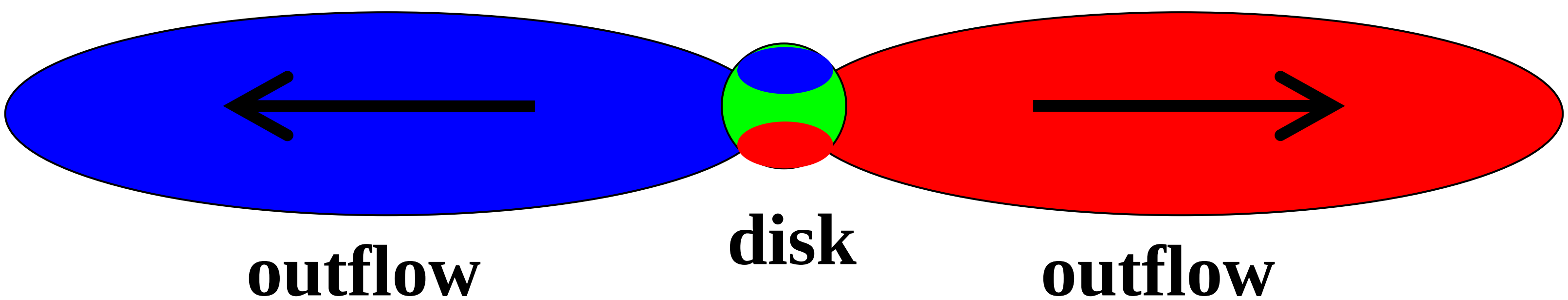
Cep A HW2

Torrelles et al. (1996)



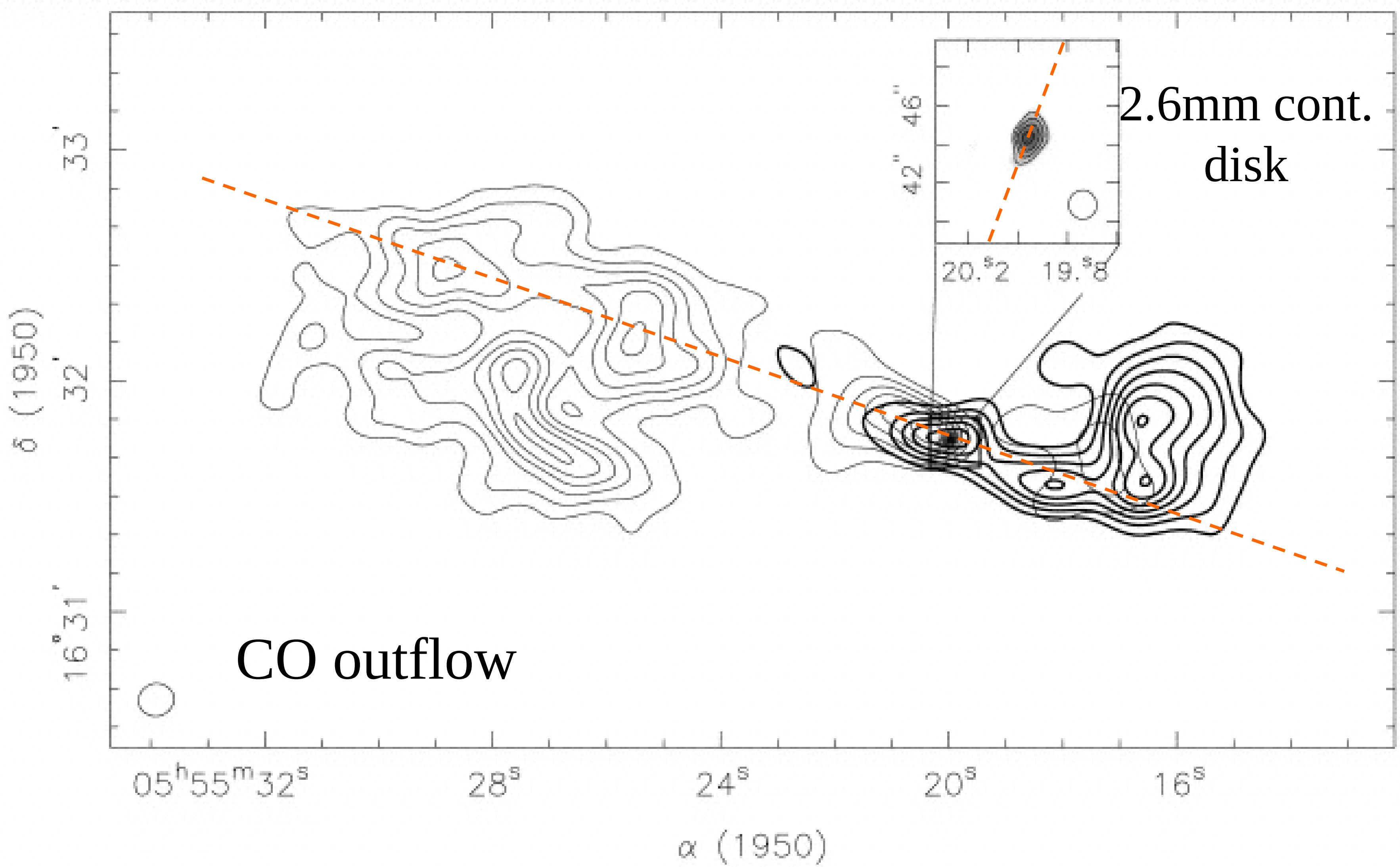


- CH_3OH masers: stellar mass too low; H_2 jets parallel to CH_3OH spots (De Buizer 2003)
- SiO & H_2O masers: outflow or disk?
- NIR-cm cont.: confusion between disk and wind emission?
- Molecular lines: kinematical signature of rotation & outflow



G192.16-3.82

Shepherd & Kurtz (1999)



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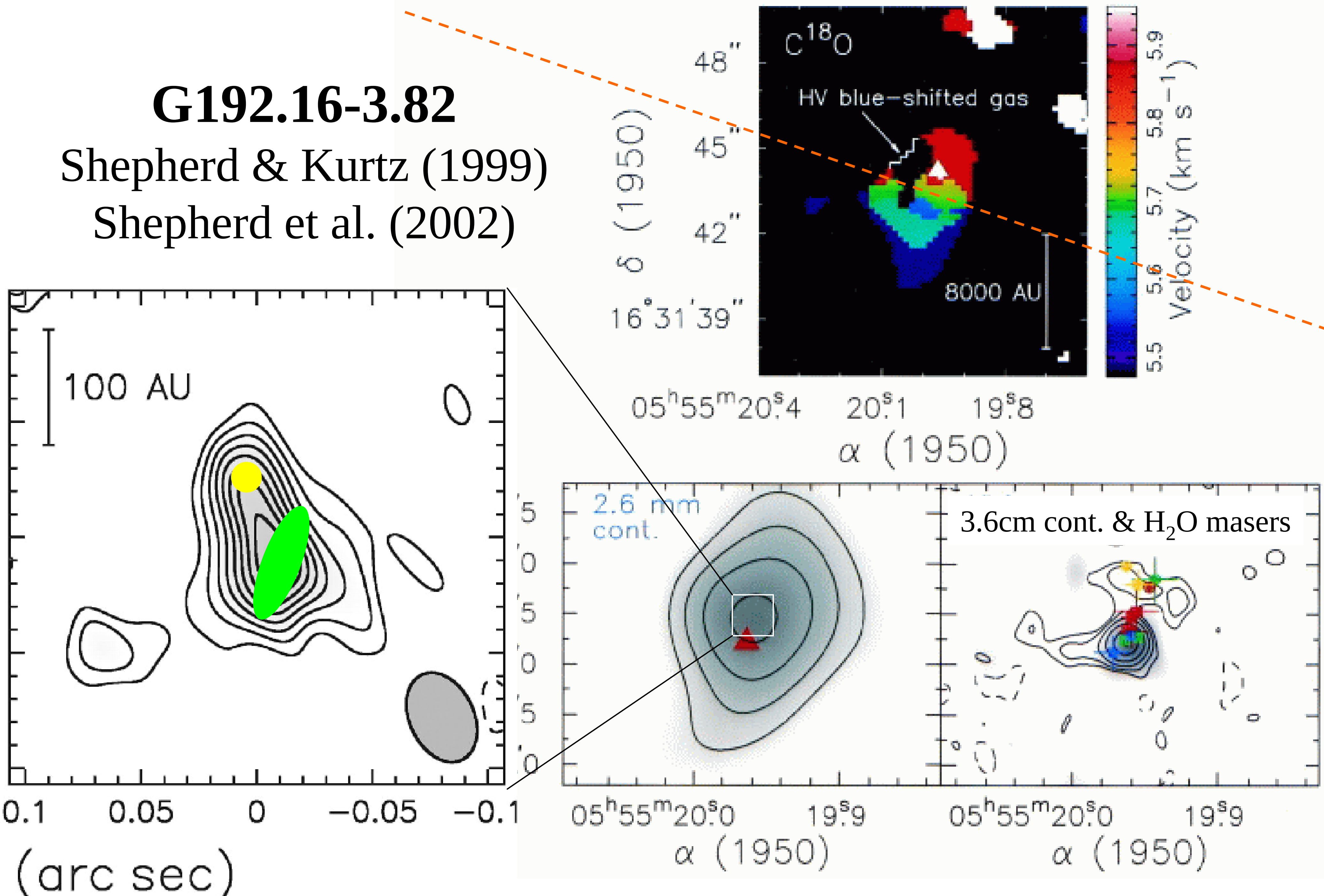
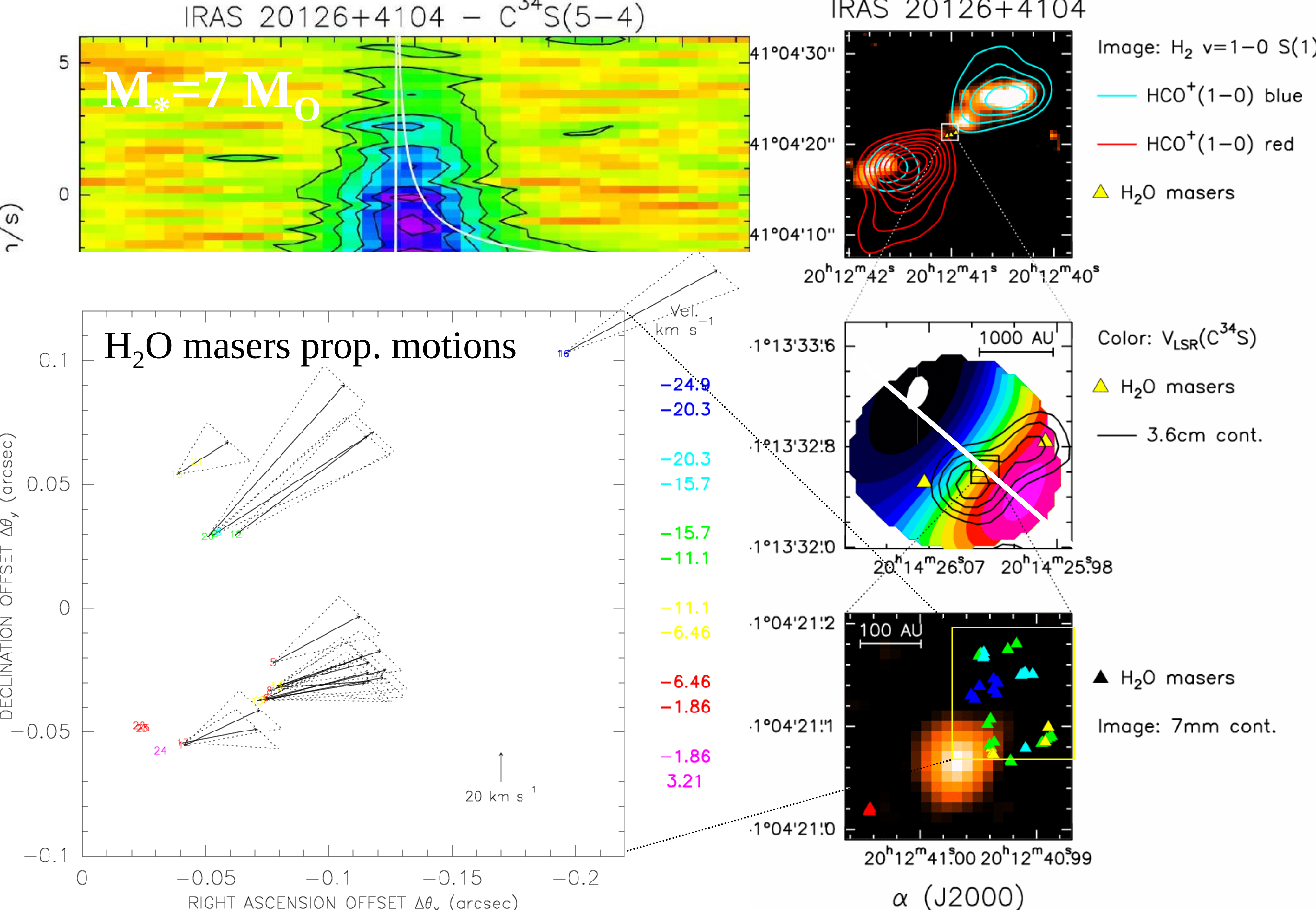
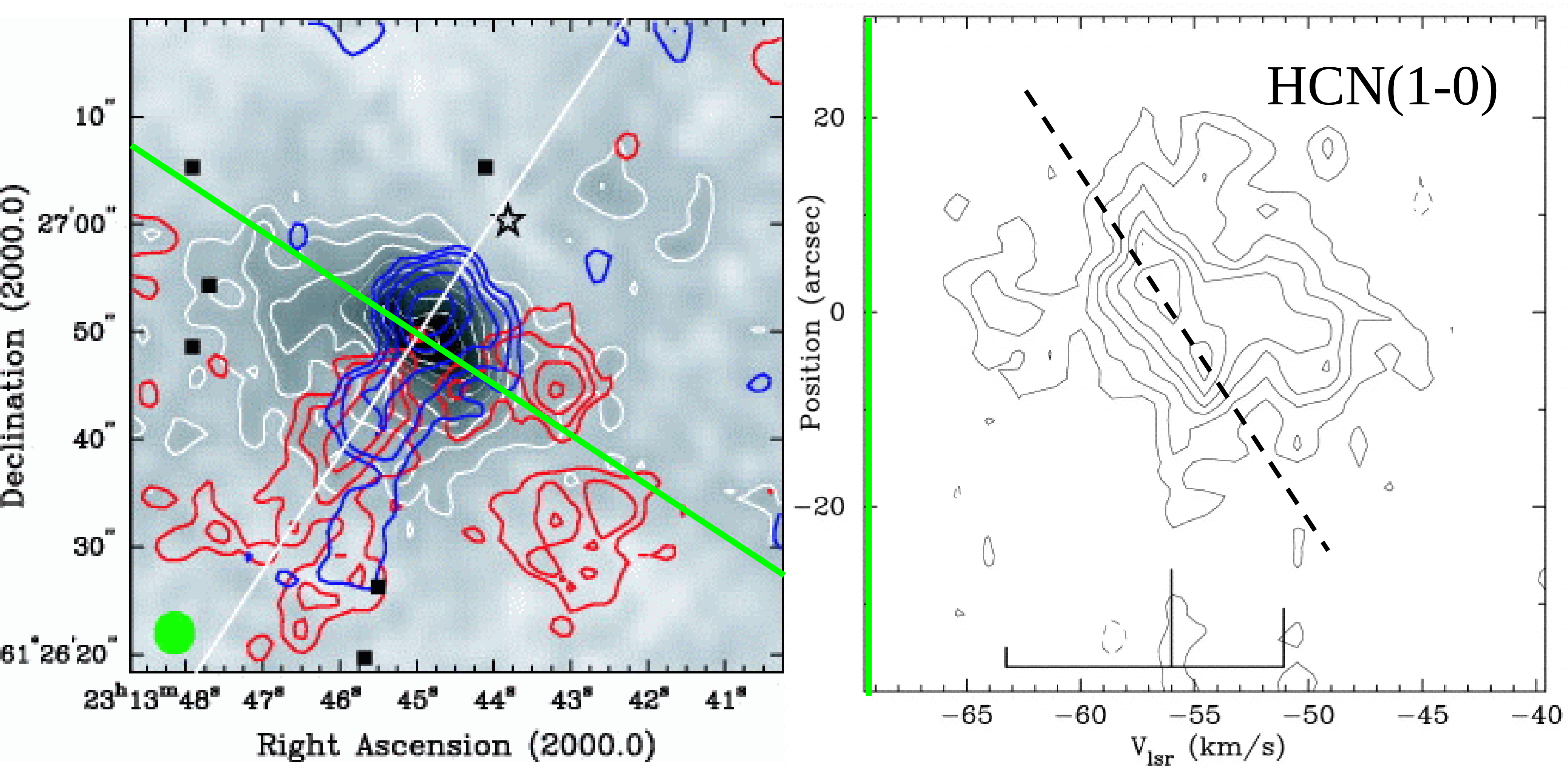
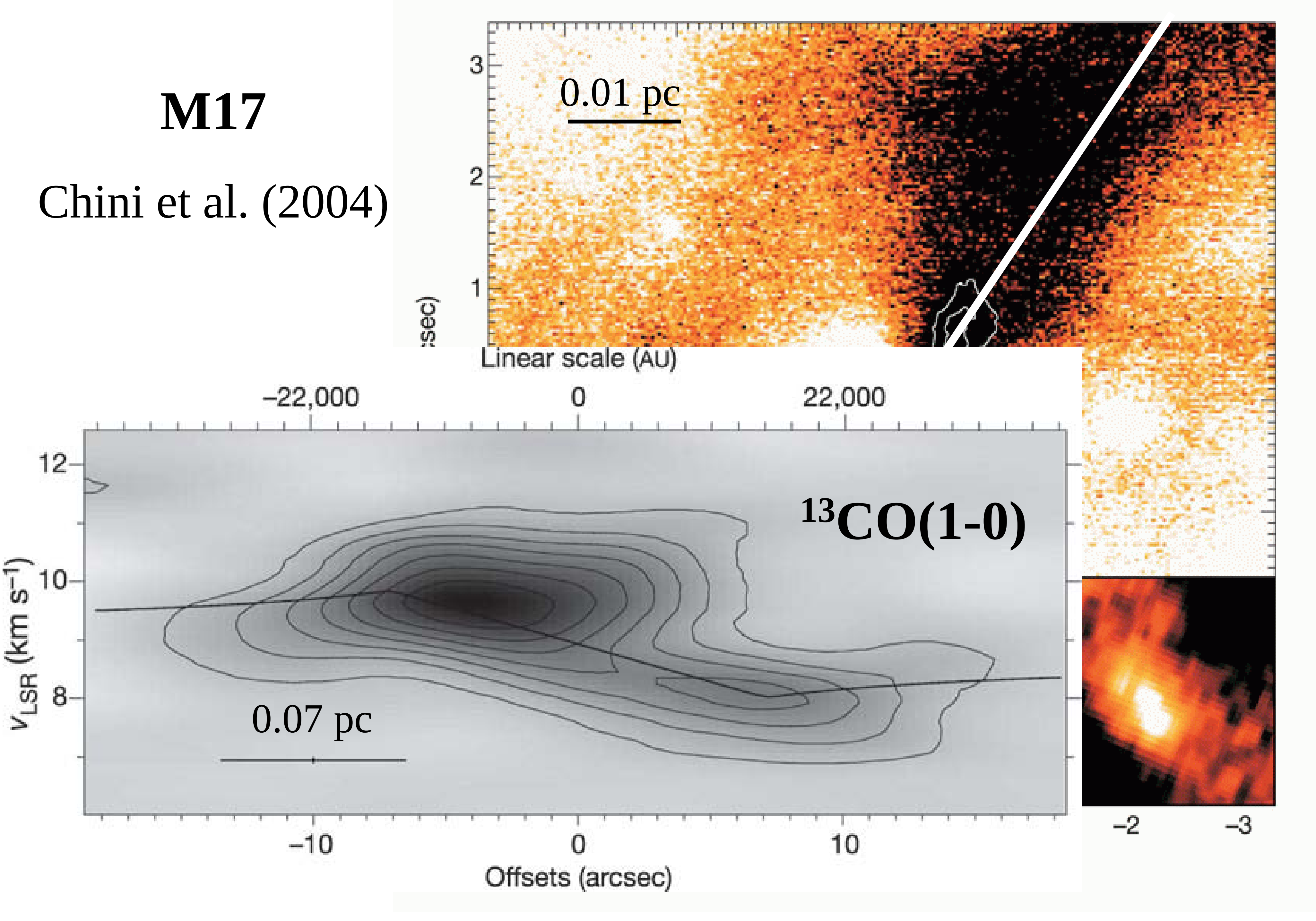



IRAS 20126+4104 – C34S(5–4)
M*=7 MO
H2O masers prop. motions
DECLINATION OFFSET Δθy (arcsec)
RIGHT ASCENSION OFFSET Δθx (arcsec)
20 km s−1
Vel. km s−1
−24.9
−20.3
−20.3
−15.7
−15.7
−11.1
−11.1
−6.46
−6.46
−1.86
−1.86
3.21
IRAS 20126+4104
Image: H2 v=1–0 S(1)
HCO+(1–0) blue
HCO+(1–0) red
H2O masers
Color: VLSR(C34S)
H2O masers
3.6cm cont.
1000 AU
100 AU
H2O masers
Image: 7mm cont.
α (J2000)

NGC7538S Sandell et al. (2003)





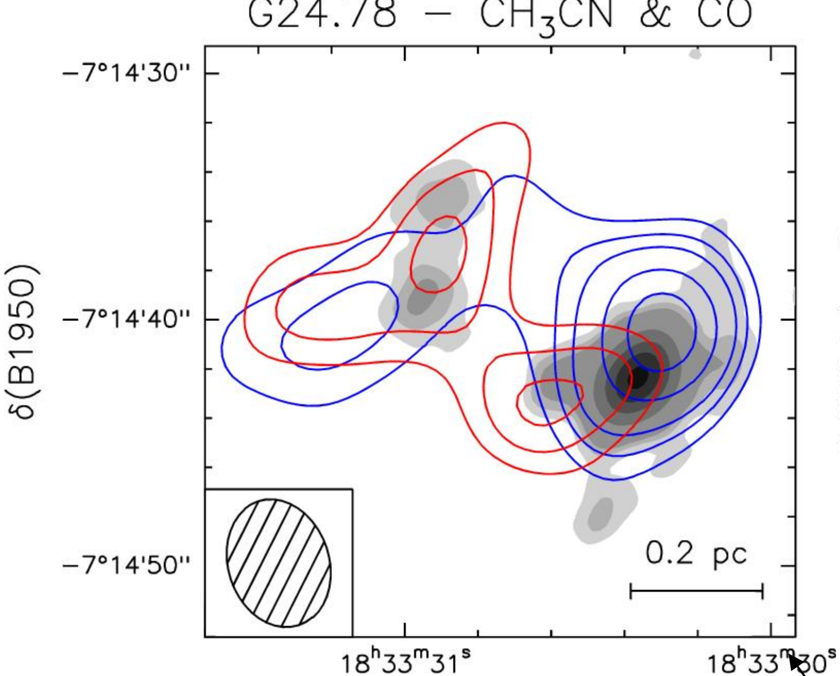
M17
Chini et al. (2004)
0.01 pc
3
2
1
Linear scale (AU)
−22,000
0
22,000
12
10
8
v_{LSR} (km s^{-1})
^{13}CO(1-0)
0.07 pc
−10
0
10
Offsets (arcsec)
−2
−3

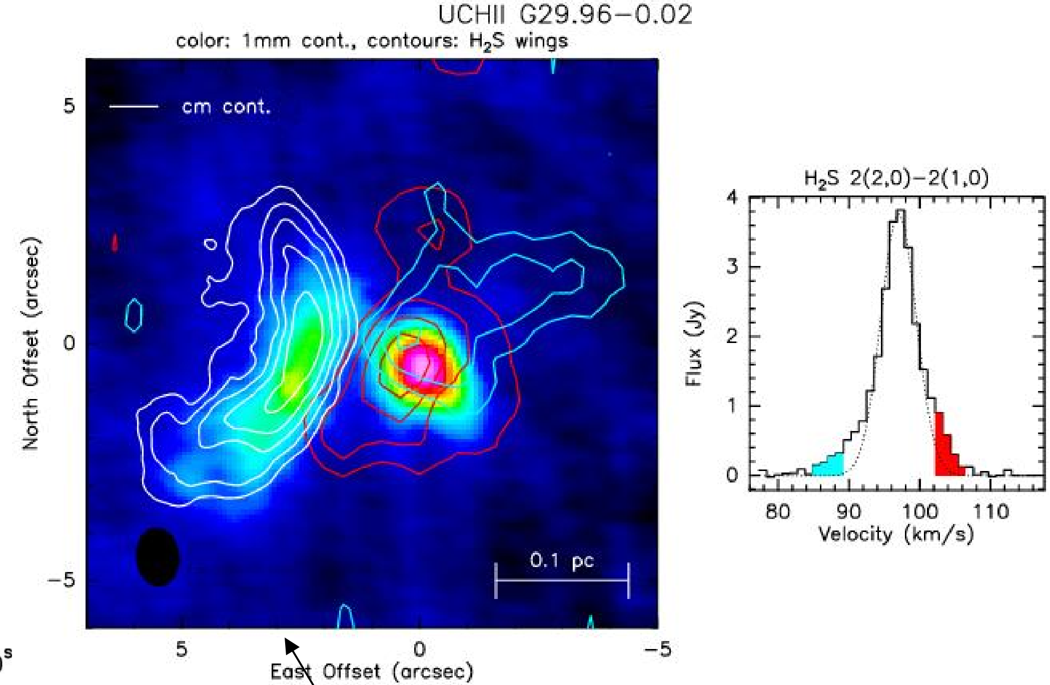
Disks & Toroids

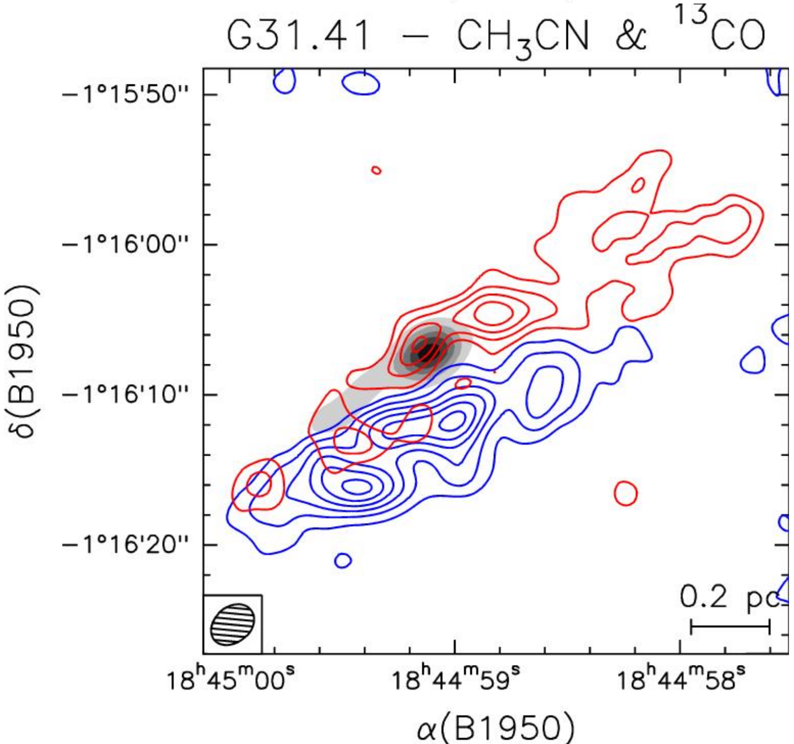
	L (L_O)	M_{disk} (M_O)	D_{disk} (AU)	M_* (M_O)
IRAS20126	10^4	4	1600	7
G192.16	$3\ 10^3$	15	1000	6-10
M17	?	>110	20000	15-20
NGC7538S	10^4	100-400	30000	40?
G24.78 (3)	$7\ 10^5$	80-250	4000-8000	20…
G29.96	$9\ 10^4$	300	14000	-
G31.41	$3\ 10^5$	490	16000	-

B stars

O stars







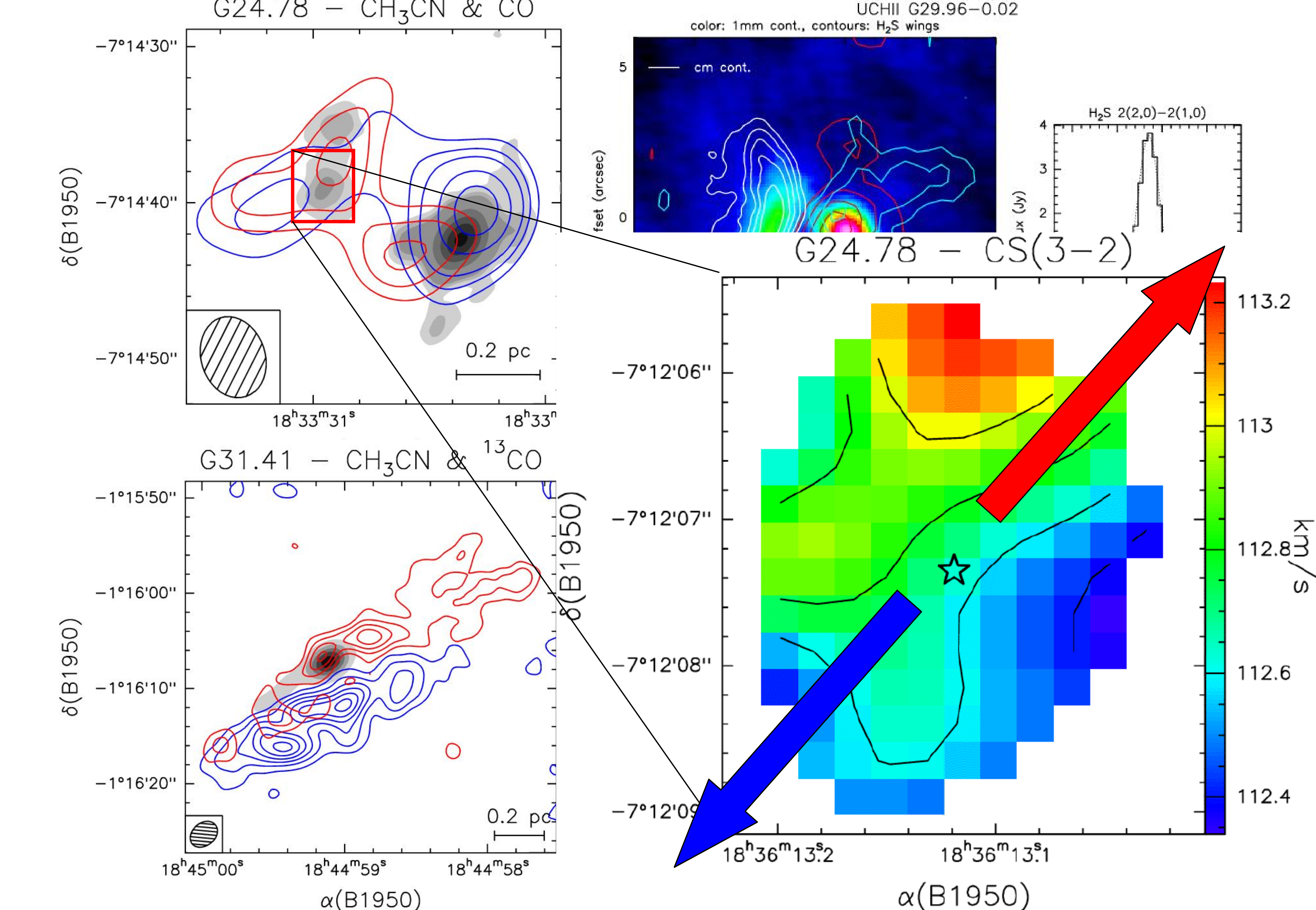
Gibb et al. (2002)

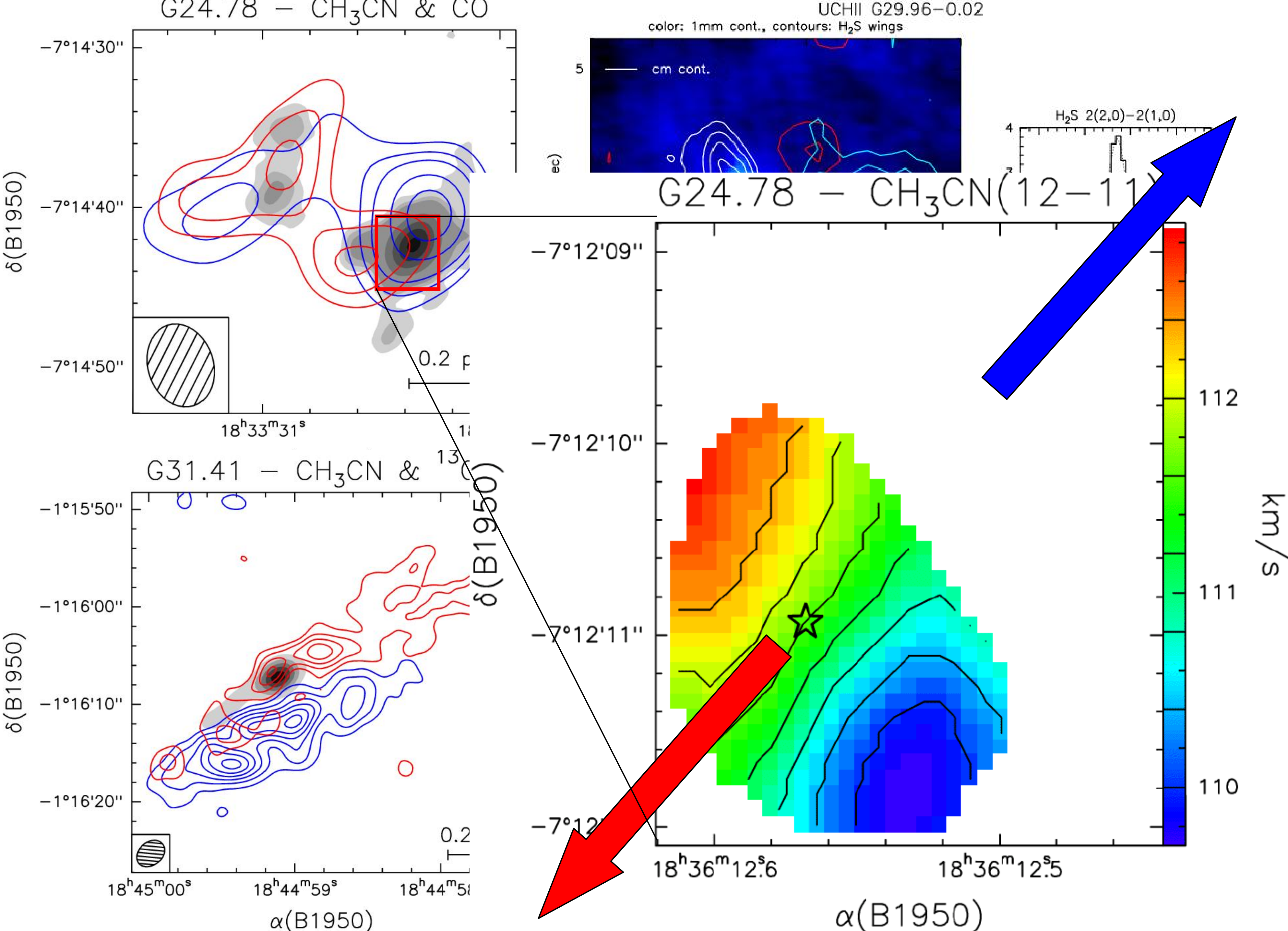
Olmi et al. (2003)

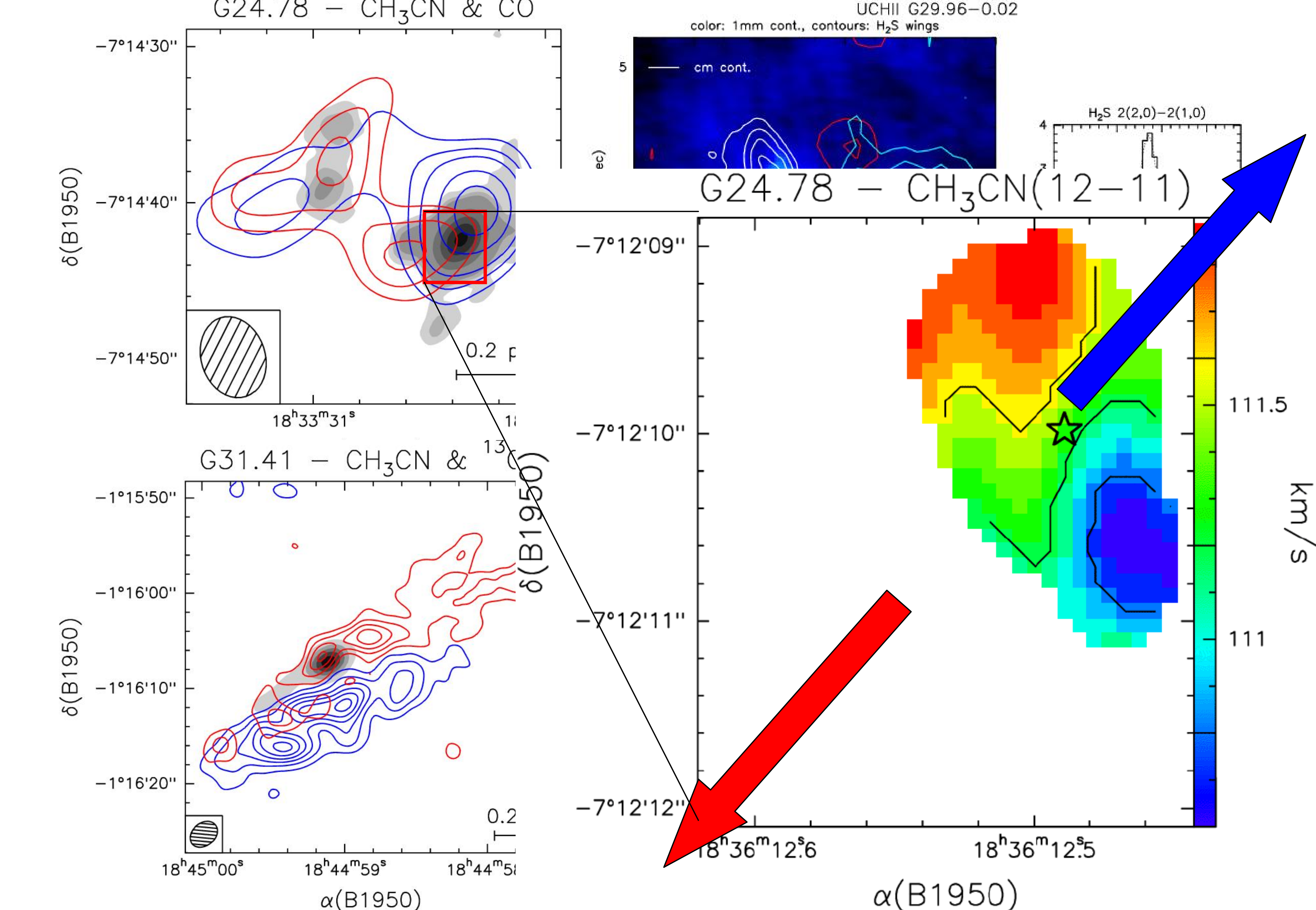
Olmi et al. (1996)

Furuya et al. (2002)

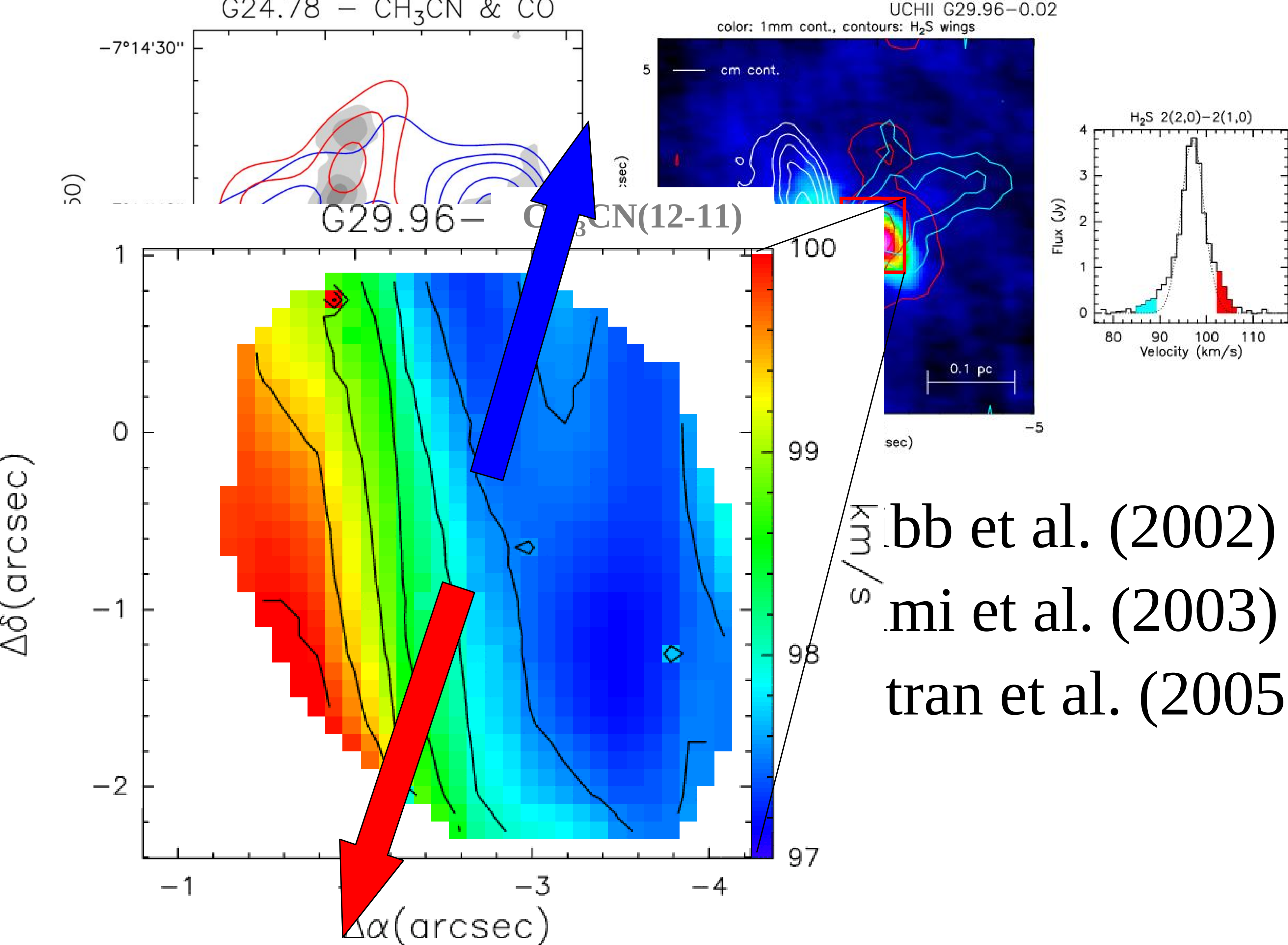
Beltran et al. (2004)


G24.78 – CH$_3$CN & CO
−7°14'30''
−7°14'40''
−7°14'50''
δ(B1950)
0.2 pc
18^{h}33^{m}31^s
18^{h}33^m
G31.41 – CH$_3$CN & ^{13}CO
−1°15'50''
−1°16'00''
−1°16'10''
−1°16'20''
δ(B1950)
0.2 pc
18^{h}45^{m}00^s
18^{h}44^{m}59^s
18^{h}44^{m}58^s
α(B1950)
UCHII G29.96−0.02
color: 1mm cont., contours: H$_2$S wings
cm cont.
H$_2$S 2(2,0)−2(1,0)
G24.78 – CS(3−2)
−7°12'06''
−7°12'07''
−7°12'08''
δ(B1950)
113.2
113
112.8
112.6
112.4
km/s
18^{h}36^{m}13.^{s}2
18^{h}36^{m}13.^{s}1
α(B1950)


G24.78 – CH3CN & CO
−7°14'30''
−7°14'40''
−7°14'50''
δ(B1950)
18h33m31s
0.2
UCHII G29.96−0.02
color: 1mm cont., contours: H2S wings
cm cont.
H2S 2(2,0)−2(1,0)
G24.78 – CH3CN(12−11)
−7°12'09''
−7°12'10''
−7°12'11''
18h36m12.6s
18h36m12.5s
α(B1950)
112
111
110
km/s
G31.41 – CH3CN & 13C
−1°15'50''
−1°16'00''
−1°16'10''
−1°16'20''
18h45m00s
18h44m59s
α(B1950)



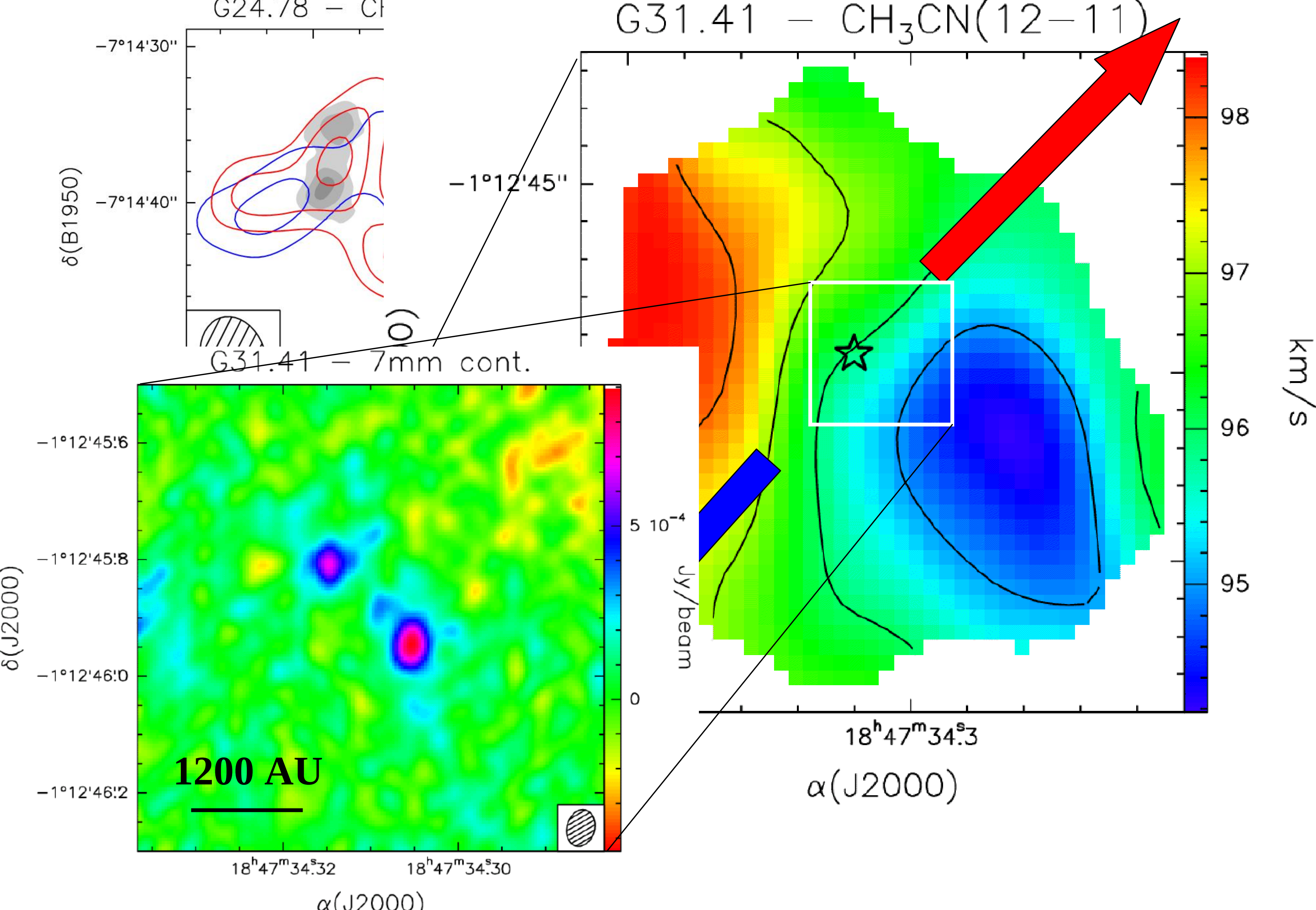
G24.78 – CH3CN & CO
−7°14'30"
−7°14'40"
−7°14'50"
δ(B1950)
0.2
18h33m31s
G31.41 – CH3CN & 13C
−1°15'50"
−1°16'00"
−1°16'10"
−1°16'20"
δ(B1950)
0.2
18h45m00s
18h44m59s
18h44m58
α(B1950)
UCHII G29.96−0.02
color: 1mm cont., contours: H2S wings
5
cm cont.
H2S 2(2,0)−2(1,0)
4
G24.78 – CH3CN(12–11)
−7°12'09"
−7°12'10"
−7°12'11"
−7°12'12"
δ(B1950)
18h36m12.6s
18h36m12.5s
α(B1950)
111.5
111
km/s



…ibb et al. (2002)

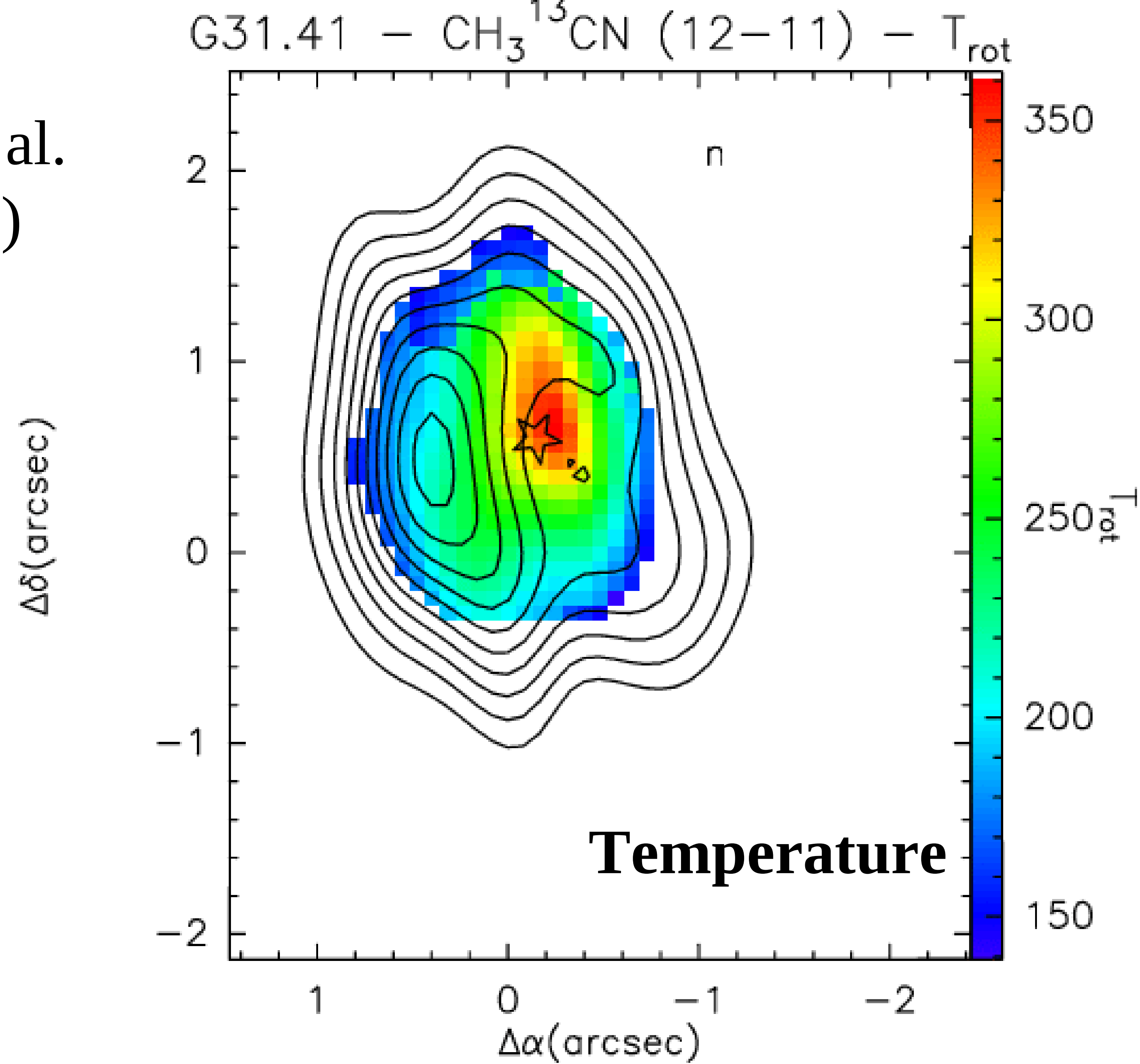
…mi et al. (2003)

…tran et al. (2005)



G24.78 − CH
−7°14'30"
−7°14'40"
δ(B1950)
G31.41 − CH$_3$CN(12−11)
−1°12'45"
98
97
96
95
km/s
18^{h}47^{m}34^s.3
α(J2000)
G31.41 − 7mm cont.
−1°12'45".6
−1°12'45".8
−1°12'46".0
−1°12'46".2
δ(J2000)
5 10^{-4}
0
Jy/beam
1200 AU
18^{h}47^{m}34^s.32
18^{h}47^{m}34^s.30
α(J2000)

Beltran et al.
(in prep.)



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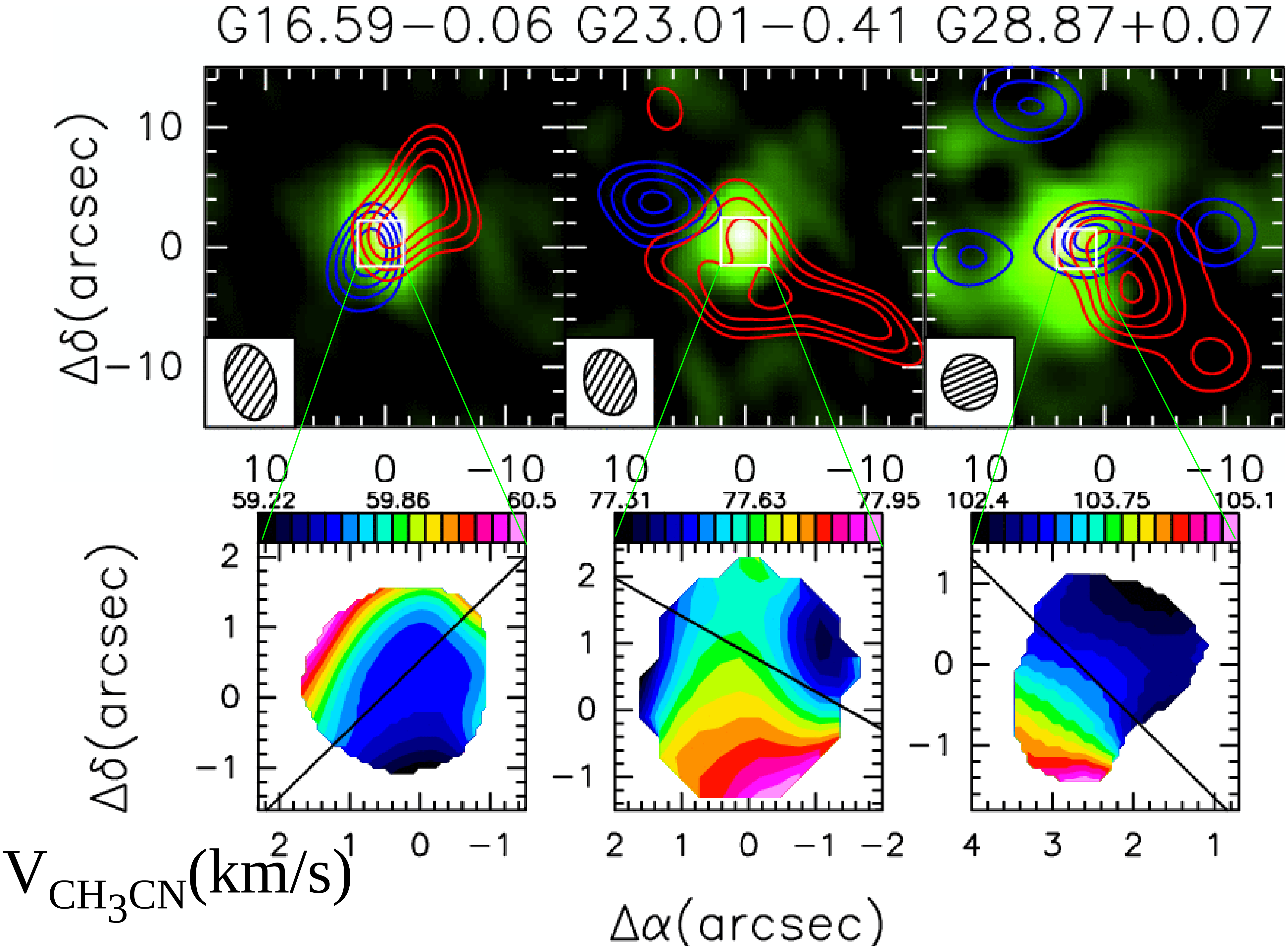


G16.59−0.06
G23.01−0.41
G28.87+0.07
Δδ(arcsec)
10
0
−10
10
0
−10
59.22
59.86
60.5
77.31
77.63
77.95
102.4
103.75
105.1
2
1
0
−1
−2
3
4
V$_{CH_3CN}$(km/s)
Δα(arcsec)

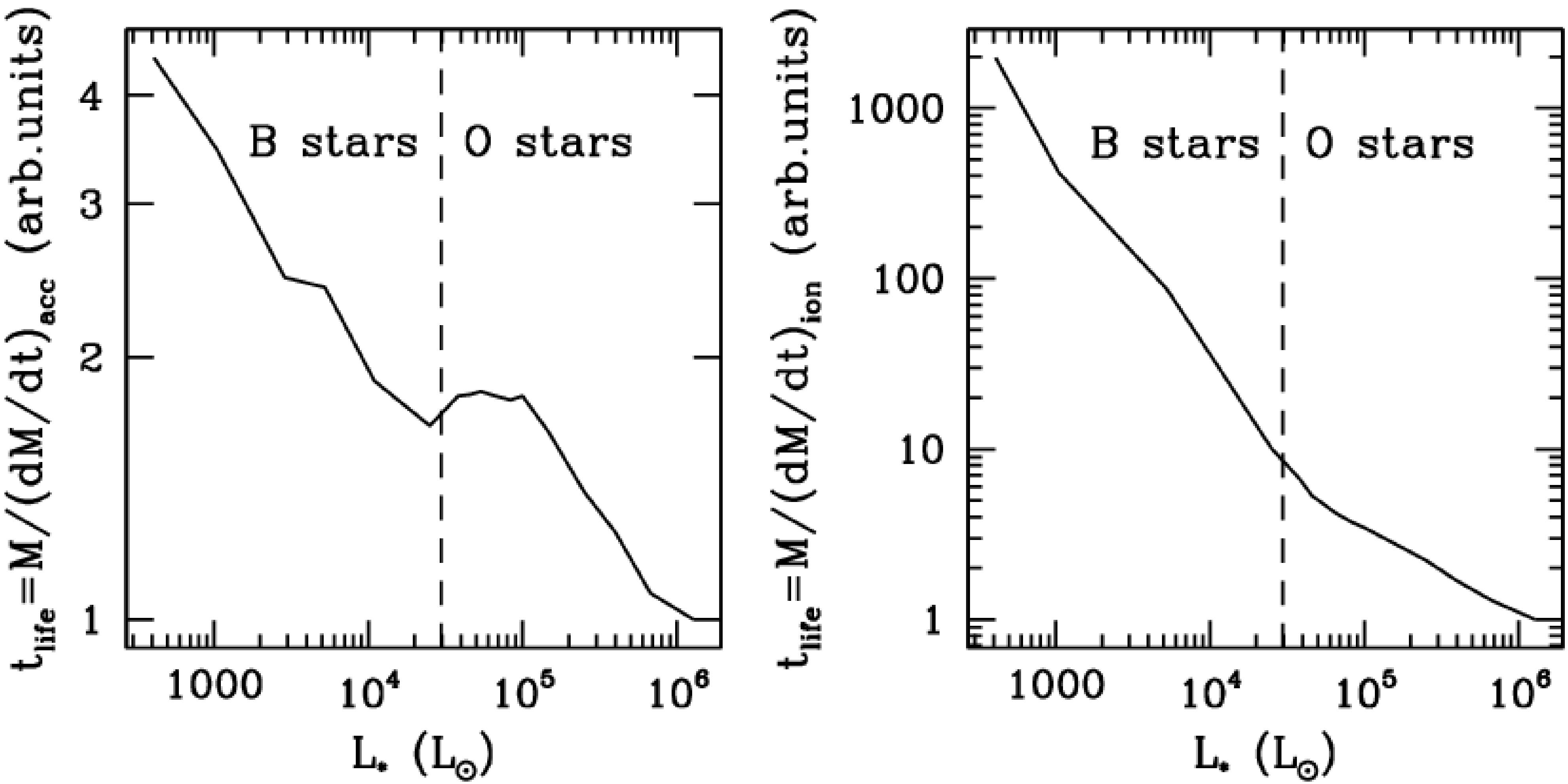
Results

- "Circumcluster'' (massive) **toroids** in **O** (proto)stars
- Circumstellar (Keplerian) **disks** in early-**B** (proto)stars

➔ **Are *disks* in O (proto)stars short lived?**

Disk life time

Assuming $(dM/dt)_{acc} \propto (dM/dt)_{outflow}$ and $M_{disk} \propto M_*$



Conclusions

- Circum**stellar** (Keplerian) disks in early-B (proto)stars → disk accretion likely
- Circum**cluster** (unstable) toroids in O (proto)stars → large accretion rates make them long-lived

↓

ACCRETION SCENARIO MORE LIKELY