Studying circumstellar environment of intermediate –mass stars

Yufang Wu1,

Collaborators: Jing-Hua Yuan2, Tie Liu1

1. Astronomy Department, Peking University
2. National Astronomical Observatories, Chinese Academy of Sciences

Outline

1. Introduction

- How do Herbig Ae/Be stars link low- and high-mass stars

  Formation

  Feedback

  - Our investigation:

    A search for their surrounding gas with 2-1, 3-2 lines of CO and 13CO

    Mapping with J=1-0 of CO, 13CO and C18O

3. General conditions of surrounding molecular gas:

- Observation
- SED for envelopes and stars
- Gas properties: Parameters from CO lines

  Parameter changes

5. Structures of surrounding gas – Effects of central stars

6. Summary

1. Introduction

- How do Herbig Ae/Be stars link low- and

  High-mass star formation

  Two basic processes in surrounding gas:

  Formation:

  low-mass stars: accretion-disk-outflow

  High – mass stars: Problem:

  when forming stars with 10 M☉ radiation

  pressure can halt spherical infall

  (Wolfire & Cassinelli 1987)

  Two opposing views:

  Still via infall –outflow-accretion

  Collision- coalescence   of less massive stellar objects

  These years observational evidences found mostly

  support the accretion model,   but to detect high-mass

  young stellar system is difficult.

  Herbig Ae/Be: Mass < 10 M☉

  Their formation --   same with low-mass stars

  Great superiority to investigate high –mass star

  forming –a bridge of the two kind star f0rmation

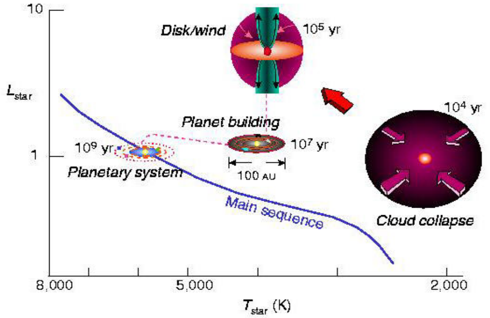
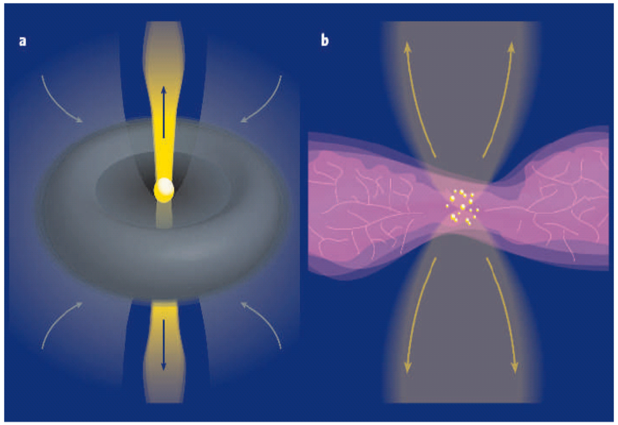


Fig. 2, Beckwith & Sargent, *Nature*, **383**, 139-144.

Shu, Adams & Lizano 1987;
Backwith & Sargent 1996

Whitney 2005



Do HAe/Be stars link low- and high-mass star feed back?

Feed back is different for the two kinds of stars:

Surrounding regions:	Structure	molecular outflow	HH object*	Water masers*	Triggered SF
Low-mass stars	simple	common	90%	rare	no evidence
high-mass stars	clusters	common	rare	61%	found

* compare with molecular outflows

- ## Our investigation:

A search for their surrounding molecular gas

Mapping gas regions – so far 12 sources were mapped

2. Statius of surrounding molecular gas

- A survey for 54 H Ae/Be stars
- KOSMA 2-1, 3-2 lines of CO (41)

  2-1, 3-2 lines of 13CO (28)

- Sample: Chosen from Thé et al (1994)

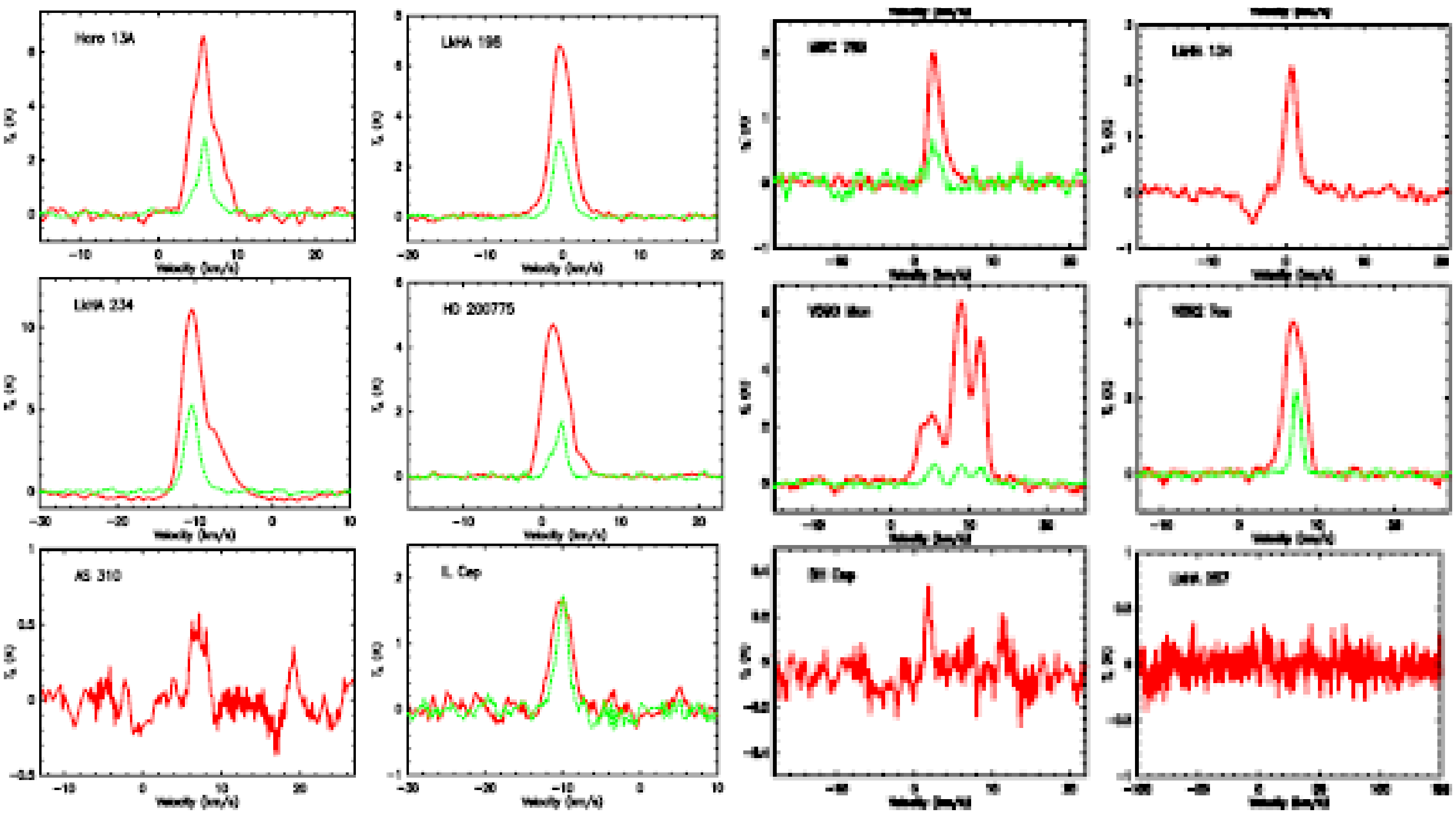
  Dec > -20o

  Age: 104 to 107 yr

  24 Be, 27 Ae, 3 Fe

- Results:_ Physical parameters were derived _

  Systematic velocity., line widths, NH2 _



Haro 13A
LkHA 198
LkHA 234
HD 200775
AS 310
IL Cep
Velocity (km/s)

Derived Parameters of the Lines

Name	V_{LSR} (km s^{-1})	$\frac{^{12}CO(2-1)}{^{13}CO(2-1)}$	$\tau_{^{13}CO(2-1)}$	$\tau_{^{12}CO(2-1)}$	T_{ex} (K)	Θ_s ($''$)	$\frac{^{12}CO(3-2)}{^{12}CO(2-1)}$	N_{H_2} (10^{21} cm^{-2})
MacC H12	−4.7	3.6	0.33	28.96	20.93	179	0.95	5.49
LkHA 198	−0.2	3.1	0.39	34.66	15.76	530	0.68	5.89
RNO 6	−36.0	2.8	0.44	39.32	10.20	230	0.77	3.06
XY Per	−4.2	7.4	0.15	12.92	11.24	133	0.64	1.55
V892 Tau	7.2	4.2	0.27	24.20	12.05	310	0.64	2.76
AB Aur	6.1			26.60	15.29	188	0.72	1.40
T Ori	7.5	4.4	0.26	22.95	86.79	74	0.87	39.81
	11.0	6.4	0.17	15.12	44.65	141	0.87	13.47
	13.2	8.9	0.12	10.61	32.99	162	0.92	6.16
V380 Ori	7.0			26.60				
	9.0	2.2	0.61	53.95	16.36	800	0.69	12.83
V586 Ori	6.5			26.60	8.36	300	0.72	1.23
	8.7			26.60	24.12	153	0.82	3.68
BF Ori	6.2	4.1	0.28	24.88	17.12	285	0.72	4.42
	9.2	3.4	0.35	31.00	14.57	164	1.00	3.59
	10.9	2.6	0.49	43.21	7.55	300	0.54	1.66
Haro 13A	5.6	4.3	0.26	23.56	14.25	600	0.68	4.11
V599 Ori	5.0	5.2	0.21	19.01	11.43		0.70	2.66
	7.2			26.60				
RR Tau	−5.4	4.5	0.25	22.37	21.09	126	0.90	3.43
V350 Ori	4.4	6.3	0.17	15.38	6.84		0.60	1.20
MWC 789	2.6	3.8	0.31	27.18	7.06		0.50	1.33
LkHA 208	−0.1	2.9	0.42	37.63	10.05	290	0.45	2.28
LkHA 339	11.3	3.8	0.31	27.18	>12.7			>7.53
LkHA 215	2.5	5.1	0.22	19.42	20.66	170	0.86	4.08
R Mon	9.6	10.1	0.10	9.28	12.58	250	0.61	0.91
V590 Mon	5.2	6.2	0.18	15.65	10.16			1.08
	8.9	11.8	0.09	7.88	18.24	207	0.83	1.09
	11.4	7.9	0.14	12.05	17.88	152	0.82	1.26
VV Ser	5.4			26.60	6.23	270	0.44	0.98

- SED of 53 sources were obtained

Except MWC 614 for un-complete data

Archive data : UBV, JHK,

IRAC and MIPS

MSX, AKARI

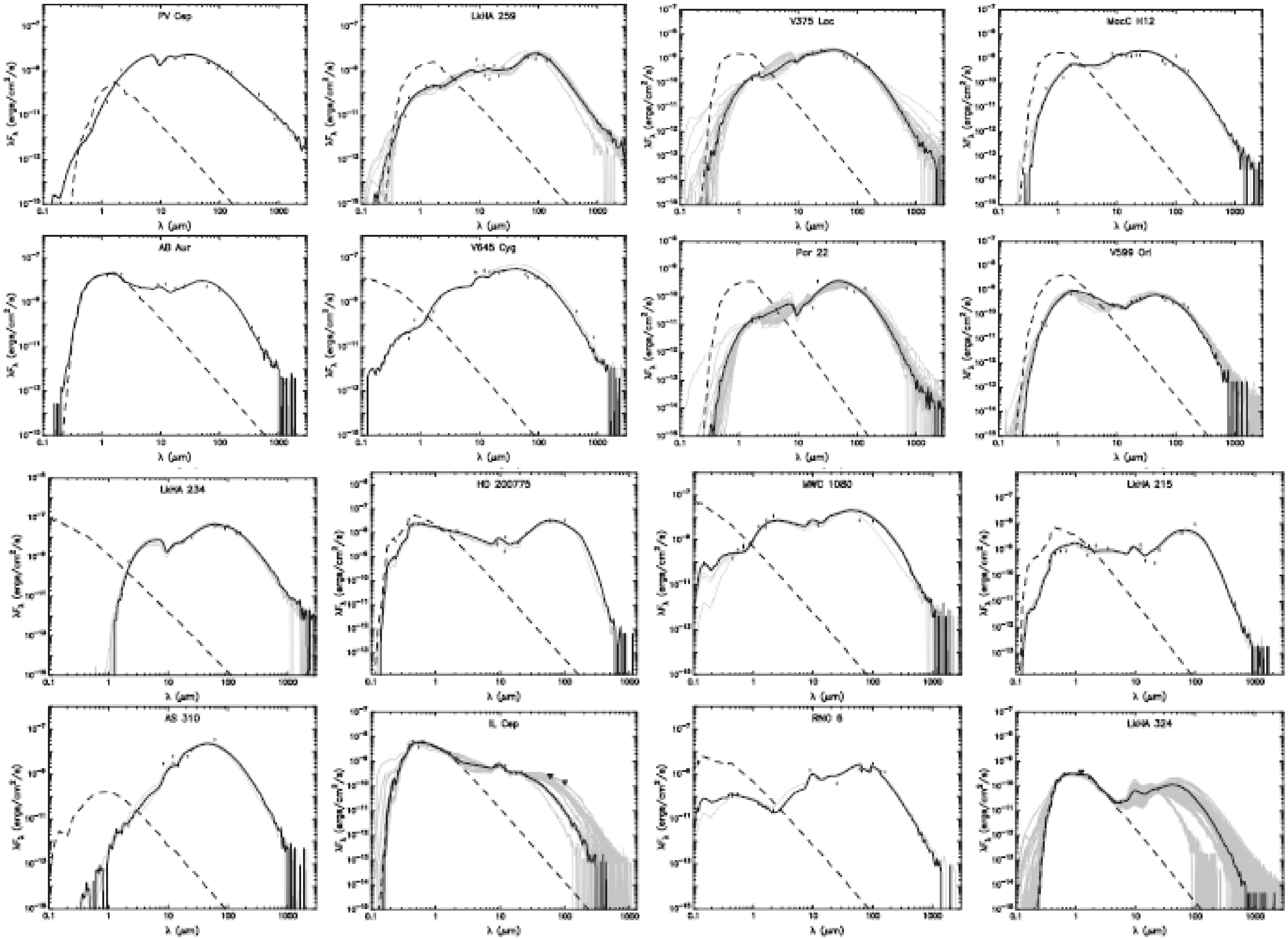
SCUBA 450 and 850 μm

1.3 mm wavelength

(Liu et al. 2012 and the references therein)

2D radiation transfer Robitaille et al. (2006, 2007)

 Parameters of envelopes, disks, stars


PV Cep
LkHA 259
V375 Lac
MacC H12
AB Aur
V645 Cyg
Par 22
V599 Ori
LkHA 234
HD 200775
MWC 1080
LkHA 215
AS 310
IL Cep
RNO 6
LkHA 324

Ae

B
e

SED Fitting Results

	A_v (mag)	log(Age) (log(yr))	M_* ($M_\odot$)	R_* ($R_\odot$)	$\log(L_*)$ ($\log(L_\odot)$)	$\log(T_*)$ (log(K))	$\log(M_{\rm env})$ ($\log(M_\odot)$)	$\log(\dot{M}_{\rm env})$ ($\log(M_\odot\ {\rm yr}^{-1})$)	$\log(M_{\rm disk})$ ($\log(M_\odot)$)	Incl (°)	$\log(R_{\rm out})$ (log(AU))	$\log(\dot{M}_{\rm disk})$ ($\log(M_\odot\ {\rm yr}^{-1})$)
H12	0.61 ± 0.57	3.73 ± 0.32	1.84 ± 0.16	14.96 ± 2.44	1.79 ± 0.13	3.62	0.32 ± 0.16	−4.88 ± 0.07	−1.74 ± 0.10	18.19	1.21 ± 0.32	−6.55 ± 0.35
198	0.00	3.07 ± 0.06	3.84 ± 0.38	29.95 ± 5.60	2.42 ± 0.14	3.62	0.06 ± 0.35	−4.56 ± 0.13	−2.12 ± 0.63	57.17 ± 24.78	0.54 ± 0.16	−5.33 ± 0.12
s	1.48 ± 0.30	6.66 ± 0.25	3.62 ± 0.24	2.22 ± 0.08	2.17 ± 0.11	4.13 ± 0.02	−4.30 ± 0.54		−2.55 ± 0.13	41.80 ± 19.87	3.00 ± 0.32	−7.89 ± 0.46
5	0.71 ± 0.65	6.03 ± 0.07	5.10 ± 0.42	2.76 ± 0.08	2.75 ± 0.12	4.23 ± 0.02	1.08 ± 0.10	−8.47 ± 0.31	−1.78 ± 0.23	78.59 ± 2.92	2.40 ± 0.21	−6.79 ± 0.94
	0.00 ± 0.01	5.71 ± 0.09	2.17 ± 0.47	5.03 ± 0.50	1.09 ± 0.09	3.67 ± 0.01	−1.64 ± 0.44	−5.62 ± 0.41	−1.49 ± 0.35	28.66 ± 9.47	2.45 ± 0.25	−6.85 ± 0.78
Tau	6.44 ± 1.95	6.50 ± 0.37	2.50 ± 0.88	4.04 ± 2.84	1.81 ± 0.24	3.98 ± 0.18	−0.88 ± 0.38	−5.62 ± 0.38	−1.29 ± 0.30	30.50 ± 9.53	2.69 ± 0.35	−7.14 ± 0.15
r	3.06 ± 0.09	6.99	2.81	1.93	1.75	4.06	−5.71		−2.02	78.61 ± 2.92	2.77	−8.81
ır	1.04	5.14	1.10	6.73	1.10	3.62	−1.33	−5.65	−2.12	31.79	2.15	−7.34
480	0.33 ± 0.35	6.33 ± 0.16	3.04 ± 0.33	4.47 ± 1.10	1.78 ± 0.92	3.86 ± 0.19	−6.13 ± 0.35		−1.29 ± 0.25	54.75 ± 19.35	2.38 ± 0.25	−6.36 ± 0.67
5929	0.24 ± 0.16	6.36 ± 0.19	3.10 ± 0.47	5.19 ± 0.95	1.81 ± 0.23	3.85 ± 0.03	−2.87 ± 0.36		−4.87 ± 0.63	56.30 ± 19.64	3.61 ± 0.72	−10.66 ± 0.71
5112	0.60 ± 0.04	6.96 ± 0.05	1.95 ± 0.05	1.83 ± 0.05	1.11 ± 0.02	3.91	−5.86 ± 0.44		−1.78 ± 0.49	35.05 ± 11.45	2.58 ± 0.33	−8.23 ± 0.14
5185	0.00	6.13	3.74	5.68	2.17	3.93	−6.84		−1.41	81.37	2.29	−7.19
	1.47 ± 0.16	6.69 ± 0.28	3.72 ± 0.51	2.33 ± 0.31	2.27 ± 0.18	4.13 ± 0.04	−5.42 ± 0.46		−1.26 ± 0.51	53.80 ± 15.54	2.60 ± 0.71	−6.54 ± 0.43
u	2.31 ± 0.13	6.85 ± 0.15	2.82 ± 0.27	2.07 ± 0.03	1.78 ± 0.16	4.04 ± 0.04	−4.50 ± 0.32		−2.03 ± 0.47	47.41 ± 31.50	2.67 ± 0.23	−7.47 ± 0.54
Ori	2.87 ± 1.42	5.87 ± 0.11	4.68 ± 0.05	6.62 ± 2.95	2.62 ± 0.21	4.03 ± 0.13	0.88 ± 0.21	−5.66 ± 0.43	−3.51 ± 0.29	45.12 ± 18.54	2.88 ± 0.39	−8.52 ± 0.48
Ori	1.00	6.01	3.86	7.62	1.93	3.80	−0.06	−7.56	−1.60	81.37	2.24	−6.86
i	1.81 ± 0.31	6.72 ± 0.17	3.09 ± 0.31	2.19 ± 0.29	1.94 ± 0.16	4.07 ± 0.04	−4.60 ± 0.98		−2.94 ± 0.57	49.03 ± 21.24	2.58 ± 0.53	−8.08 ± 0.59
411	11.65	6.63	0.35	1.04	−0.15	3.55	−8.77		−2.33	63.26	2.09	−7.18
3A	0.00	3.02	3.47	24.48	1.34 ± 0.32	3.63	−0.25 ± 0.65	−4.71	−1.84	64.16 ± 21.08	0.67	−5.62 ± 0.36
Ori	2.94 ± 1.62	5.64 ± 0.30	1.83 ± 1.19	5.29 ± 1.59	1.20 ± 0.31	3.65 ± 0.06	−1.36 ± 0.52	−5.76 ± 0.35	−1.24 ± 0.27	42.47 ± 24.22	2.59 ± 0.46	−6.71 ± 0.37
u	1.82 ± 0.27	6.53 ± 0.28	3.68 ± 0.42	2.60 ± 0.49	2.30 ± 0.17	4.12 ± 0.03	−5.71 ± 0.46		−1.12 ± 0.24	43.72 ± 19.52	2.60 ± 0.32	−6.41 ± 0.32
Ori	1.69 ± 0.47	6.73 ± 0.16	2.73 ± 0.39	2.05 ± 0.31	1.75 ± 0.19	4.03 ± 0.06	−3.48 ± 0.39		−2.52 ± 0.50	43.21 ± 19.30	3.39 ± 0.32	−7.29 ± 0.73
789	2.42 ± 0.77	6.24 ± 0.17	3.90 ± 0.37	2.81 ± 0.29	2.36 ± 0.10	4.12 ± 0.02	−6.47 ± 0.18		−1.02 ± 0.13	22.65 ± 6.39	2.43 ± 0.05	−6.49 ± 0.37
208	5.39 ± 0.09	5.97	4.23	6.69	2.32	3.93	−0.93	−7.33	−1.00	55.80 ± 14.37	3.06	−7.71
339	2.96 ± 0.12	6.60 ± 0.31	3.42 ± 0.60	2.25 ± 0.25	2.17 ± 0.28	4.11 ± 0.05	−2.38 ± 0.76		−1.78 ± 0.36	40.20 ± 21.08	3.73 ± 0.52	−8.67 ± 0.38
215	1.34 ± 0.35	5.74	5.13	8.46	2.59	3.95	1.05	−5.01	−2.15	46.40 ± 21.09	3.65	−9.19

- Column density:

  4.9x1021 cm-2   Age<106 yr

  2.5x1021 cm-2 Age>106 yr

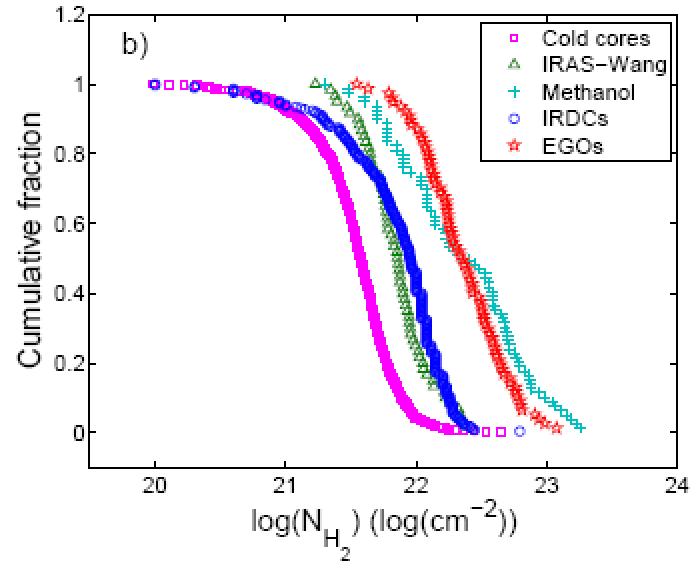
- Low-mass cores:

  ~ 1022 cm-2 (Myers et al. 1983)

- High-mass cores: --

  Except Planck Clumps in the right Figure.

  > 1022 cm-2



less dense than low- and high –mass cores

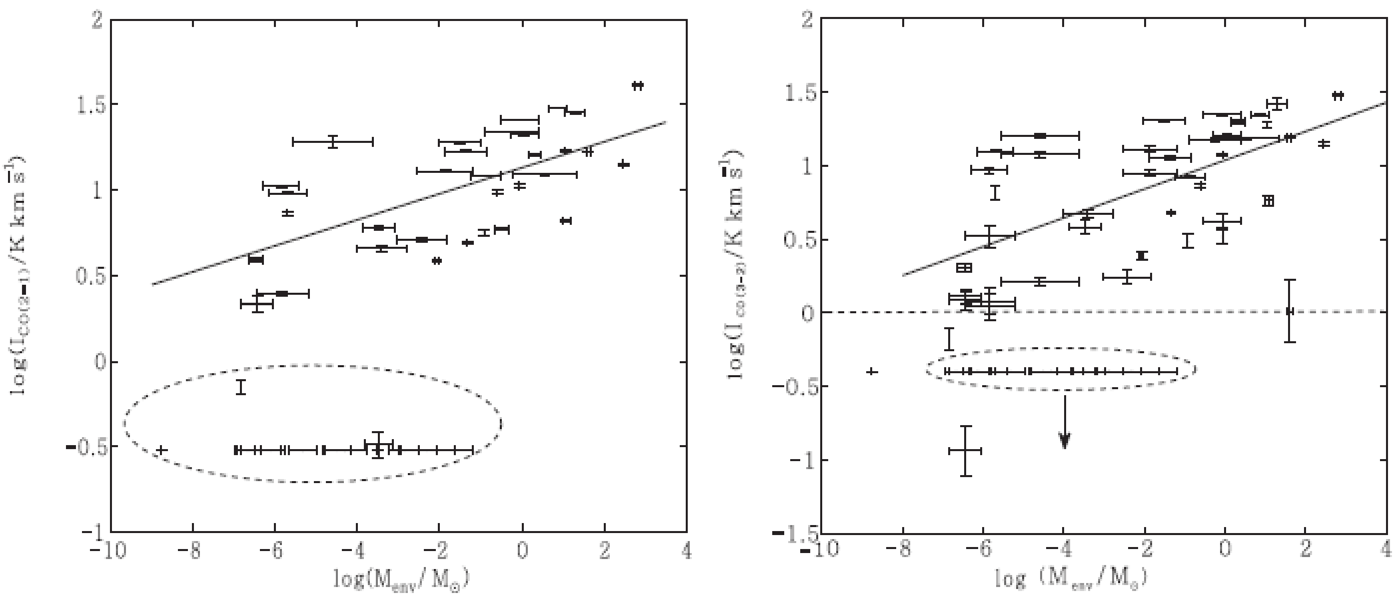
Line width: 1.87 km/s

 between those of low- and high mass cores (1.3 and 3.5 km/s, Myers et al 1983, Wu et al. 2001)

- CO gas seems to be correlated with envelope ma ss:
- Log (I_CO(2-1)/K km s-1) = (1.129±0.052)+(0.076±0.017)log(Men v/M⊙)

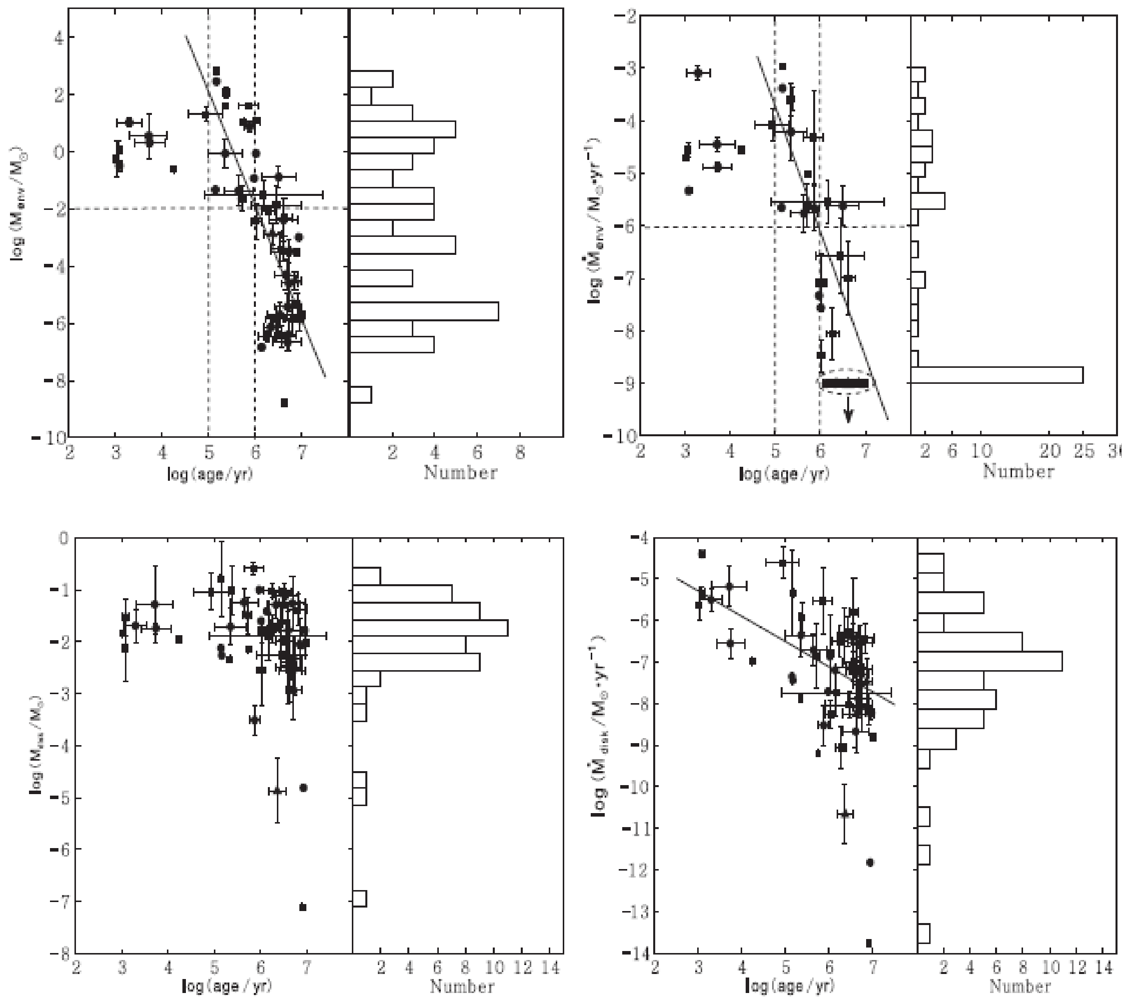
R=0.64

- log(Menv/



- Envelope: masses, accretion rates decrease with age after 105 yr

- Disk accretion rates decrease with age, but more slow than that of envelopes



3. Structures of surrounding gas – Effects of central stars

Observations:

- Mapping with J=1-0 lines of CO, 13CO and C18O
- 13.7 m telescope

  Purple Mountain Observatory

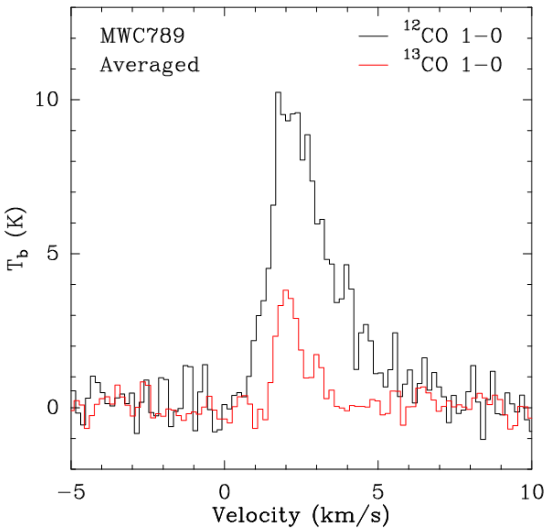
  HD200775 observed with CO 3-2 and 13CO 2-1 at KOSMA
- Mapped sources: 12
- One of them observed with Hα emission

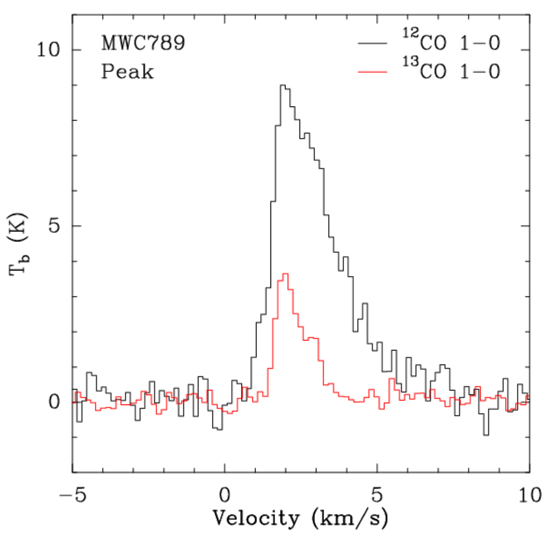
  2.16 m telescope

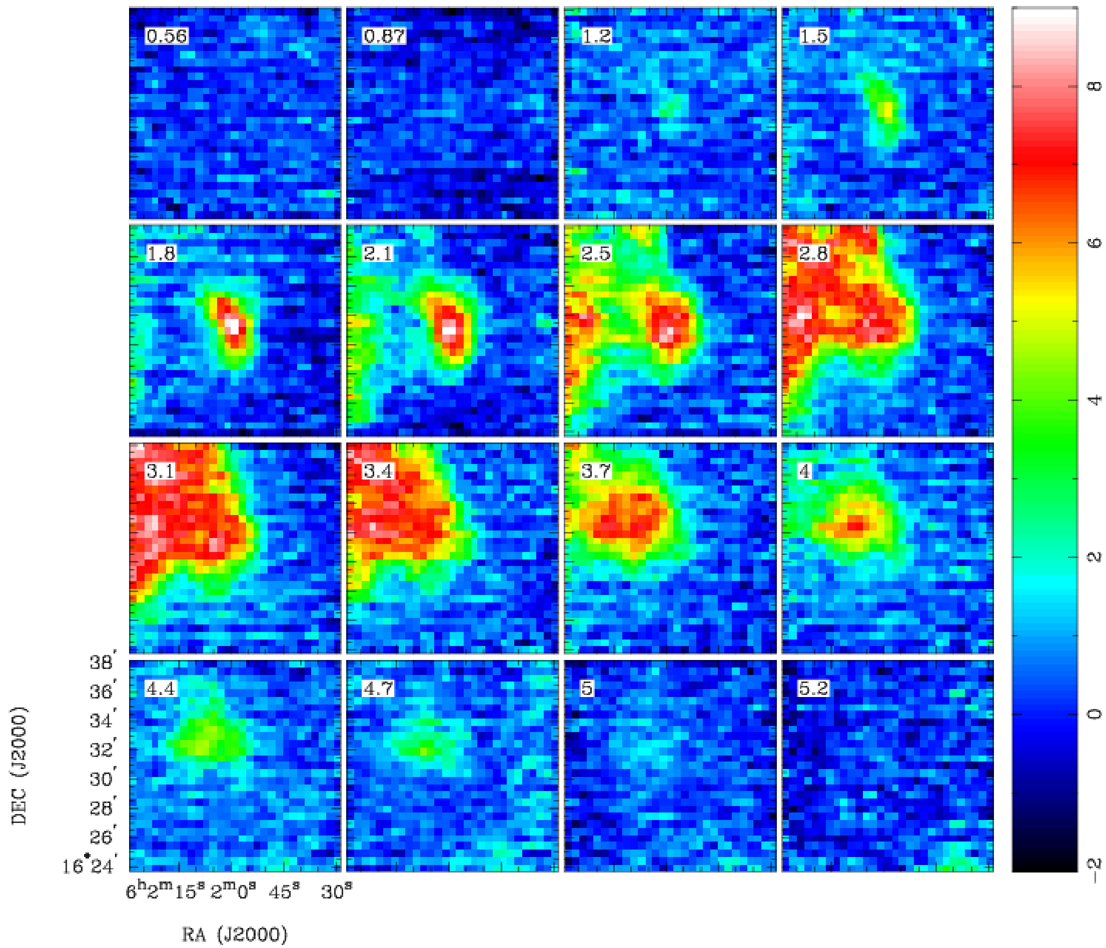
  National Astronomical Observatories

Results: divided into 6 groups:

Group I: 3 sources: core+ star(s)
MWC 789

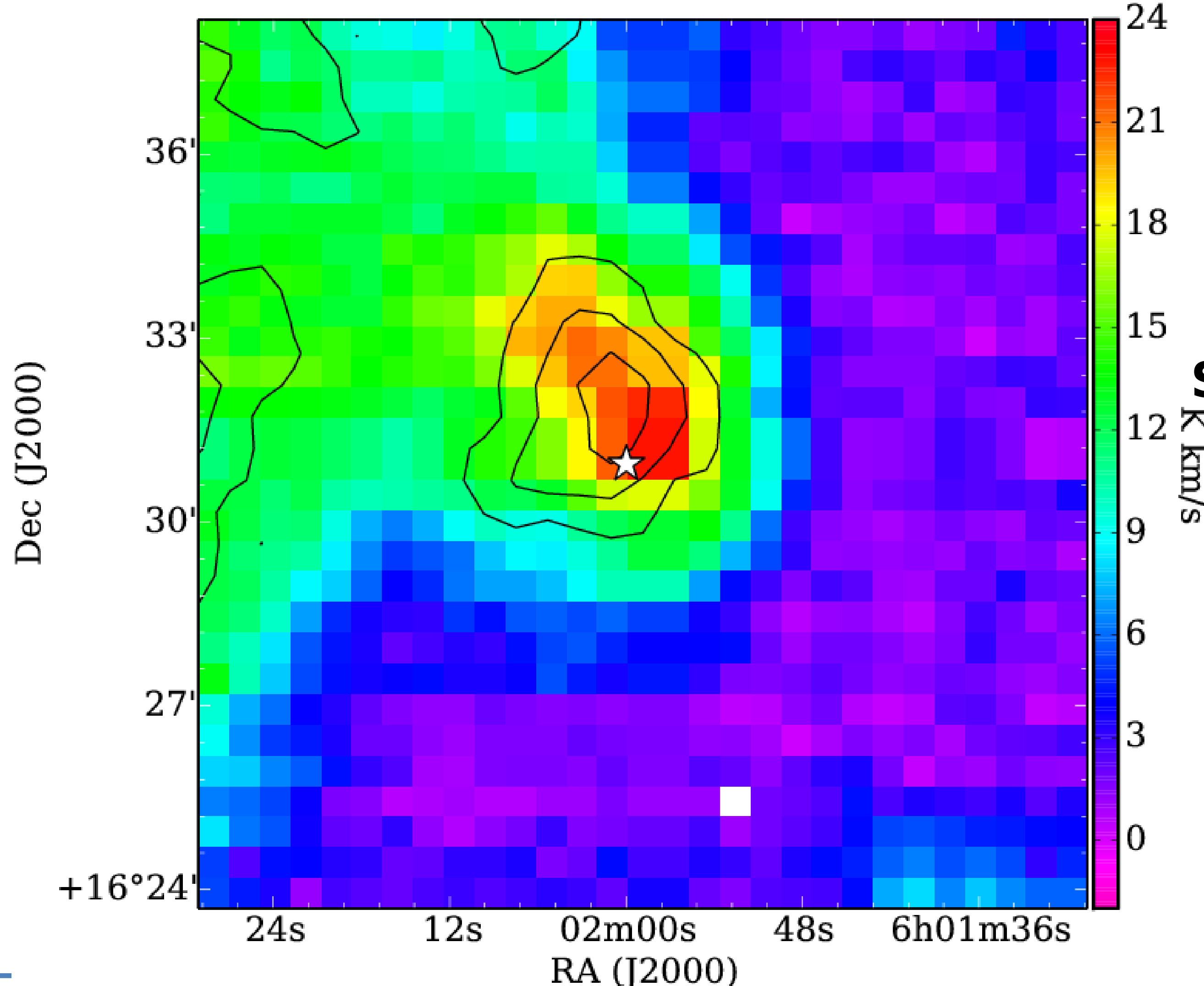






- Channel maps of 12CO 1-0

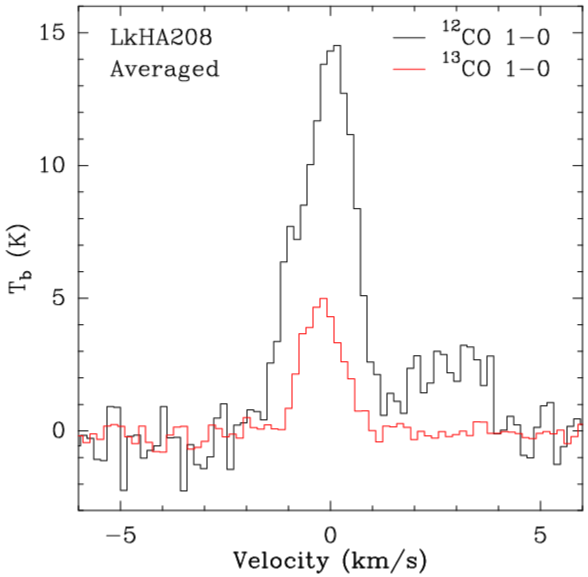
MWC 789

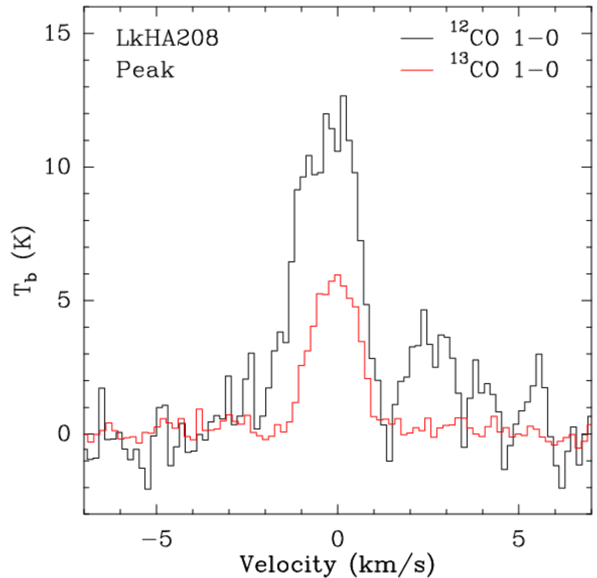


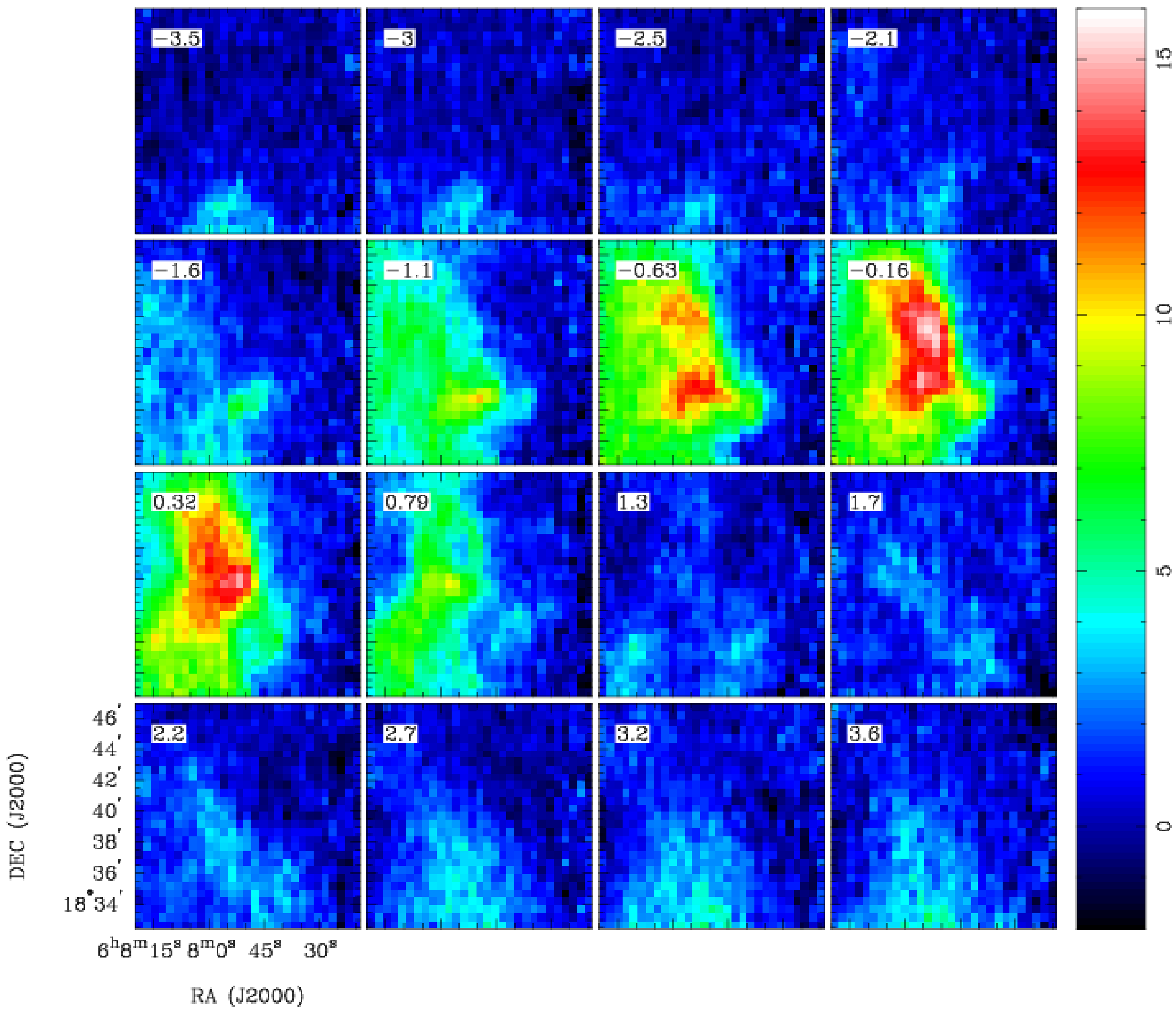
Star: MWC 789

- **Velocity integrated intensity map of 13CO 1-0 overlaid on that of 12CO 1-0.**

LkHα 208

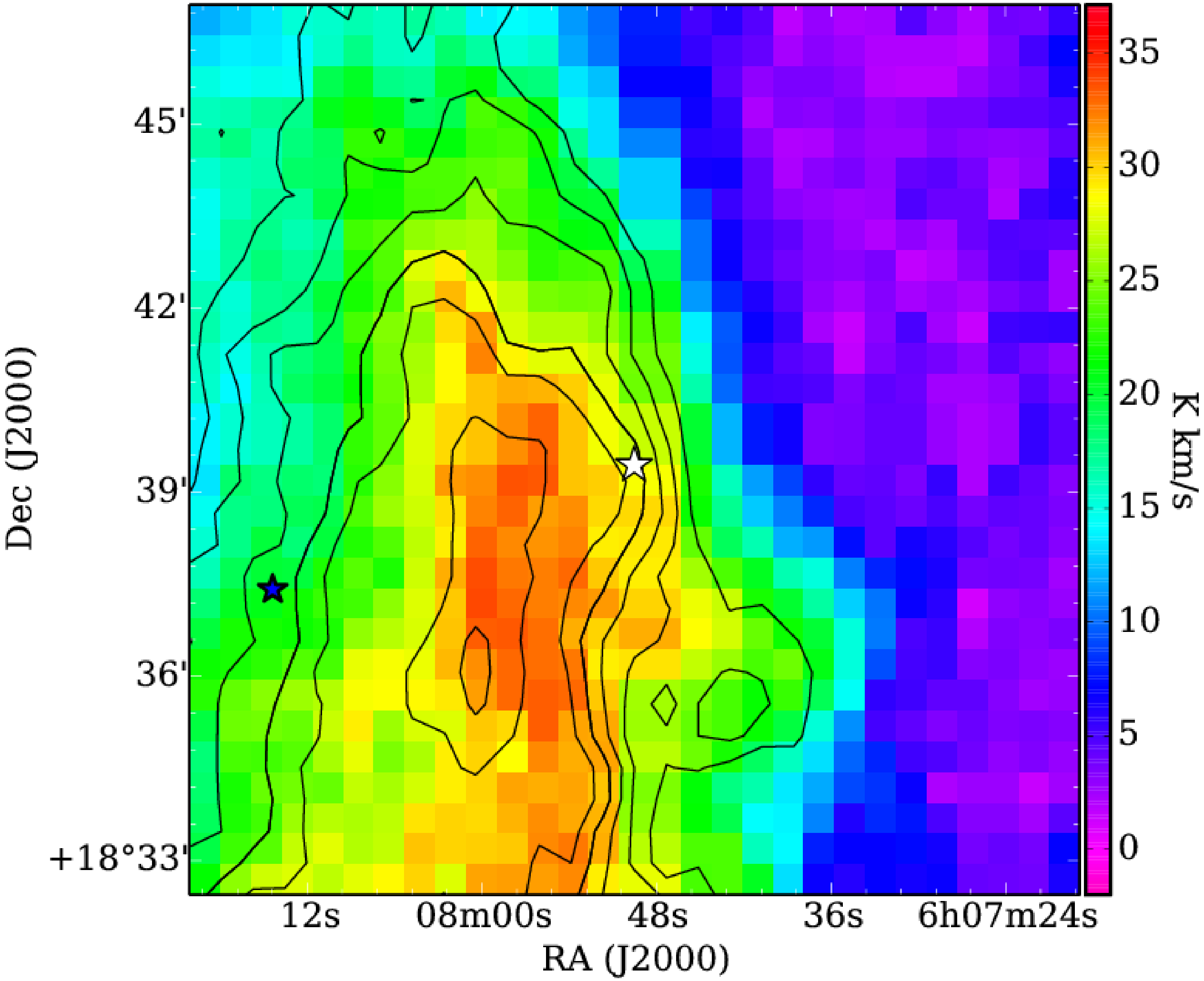






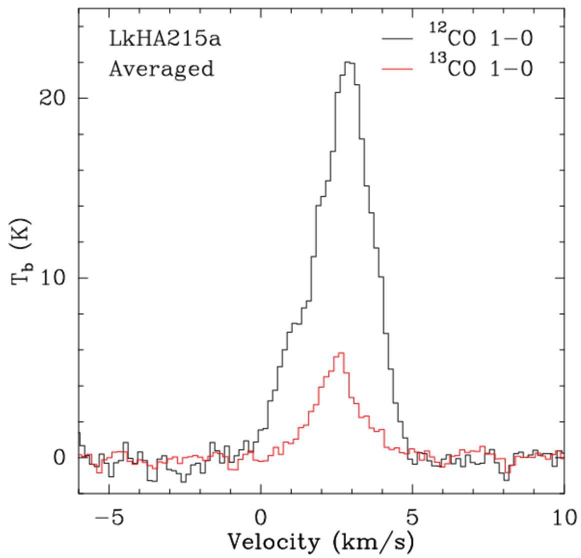
- Channel maps of 12CO 1-0

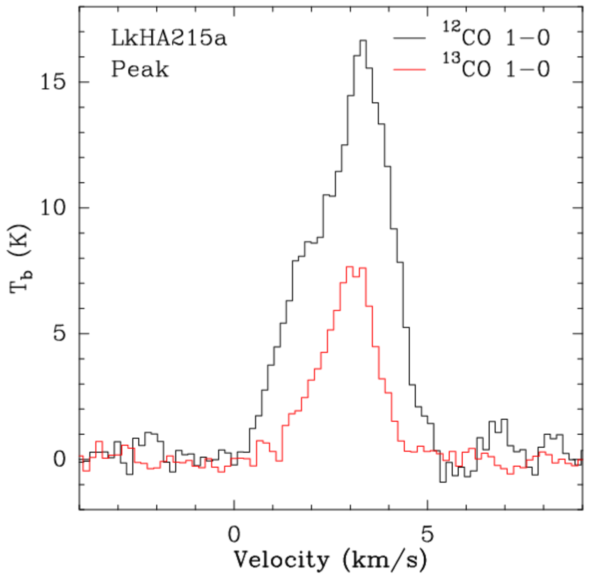
LkHα 208

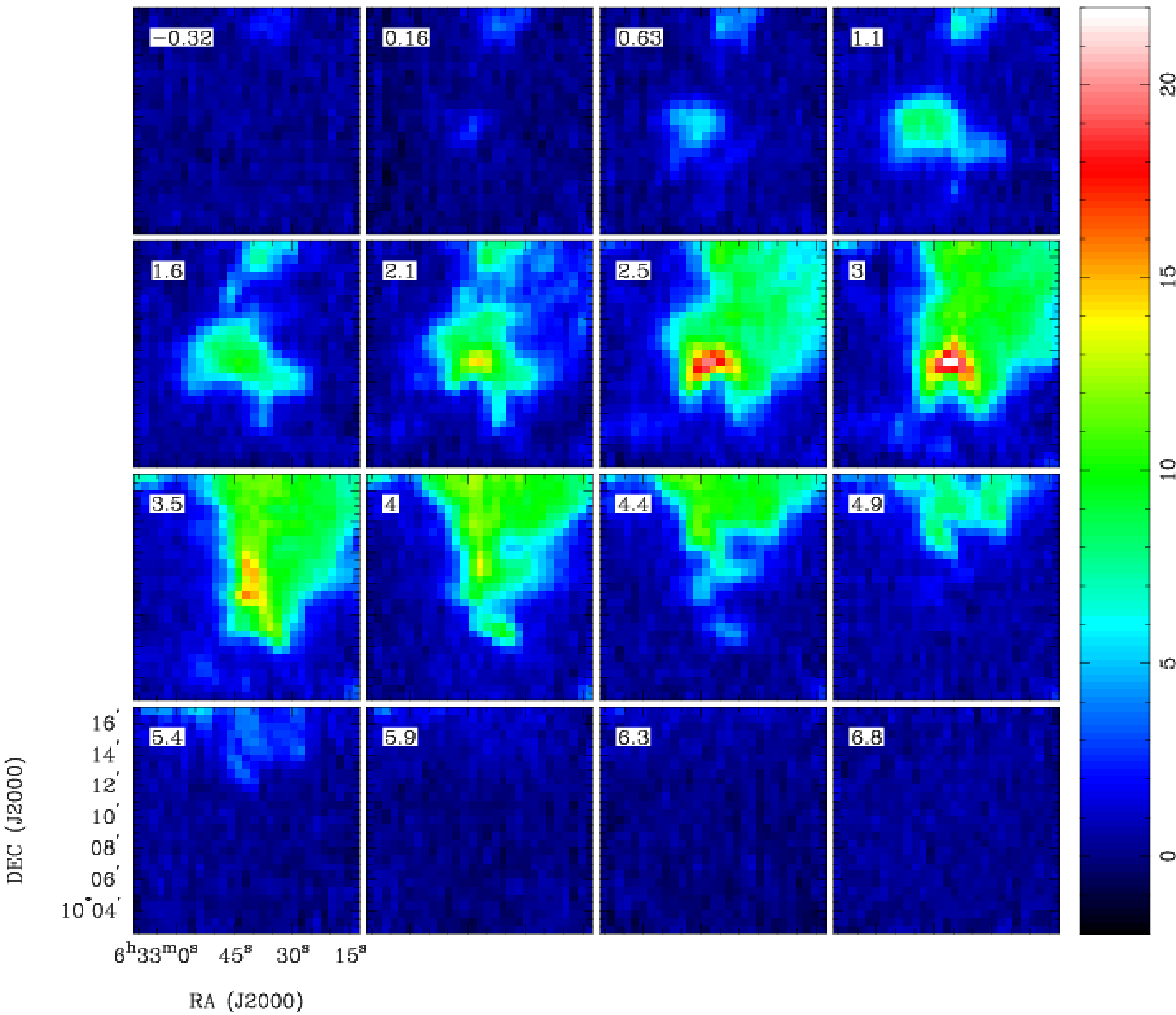


- **Velocity integrated intensity map of 13CO 1-0 overlaid on that of 12CO 1-0.**

LkHα 215

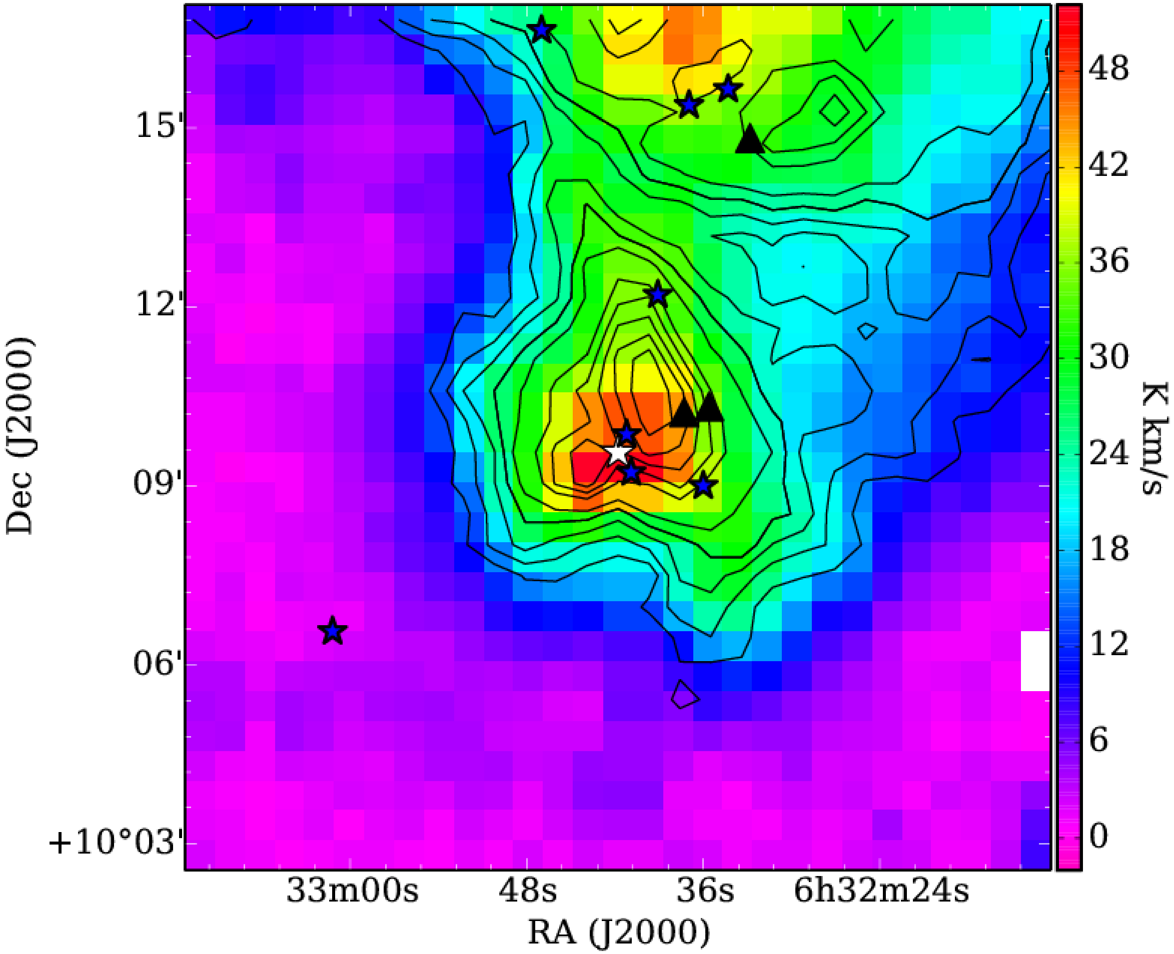






- Channel maps of 12CO 1-0

LkHα 215

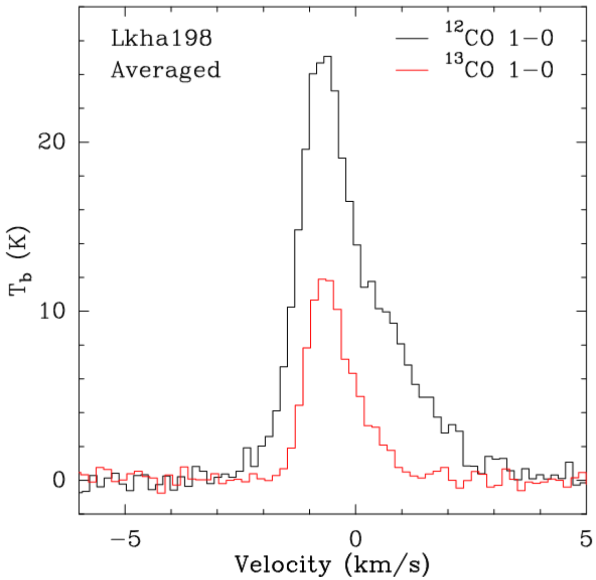


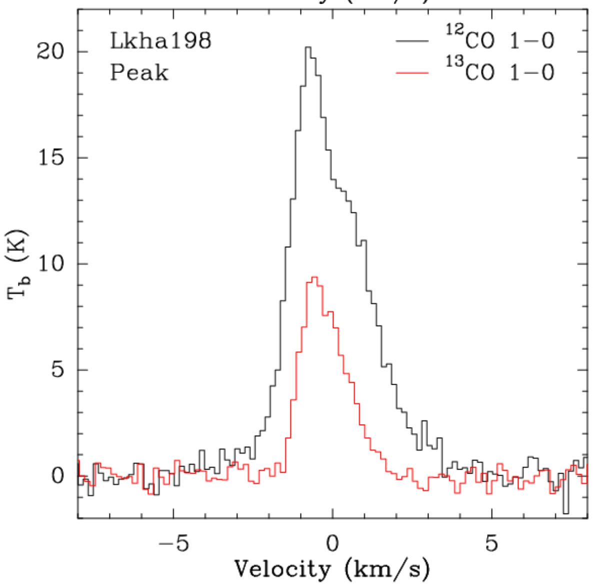
- White star: Lkha 215a
- Blue stars: emission-line stars, Variable Stars of Orion Type, Be Stars, or Ae Stars.

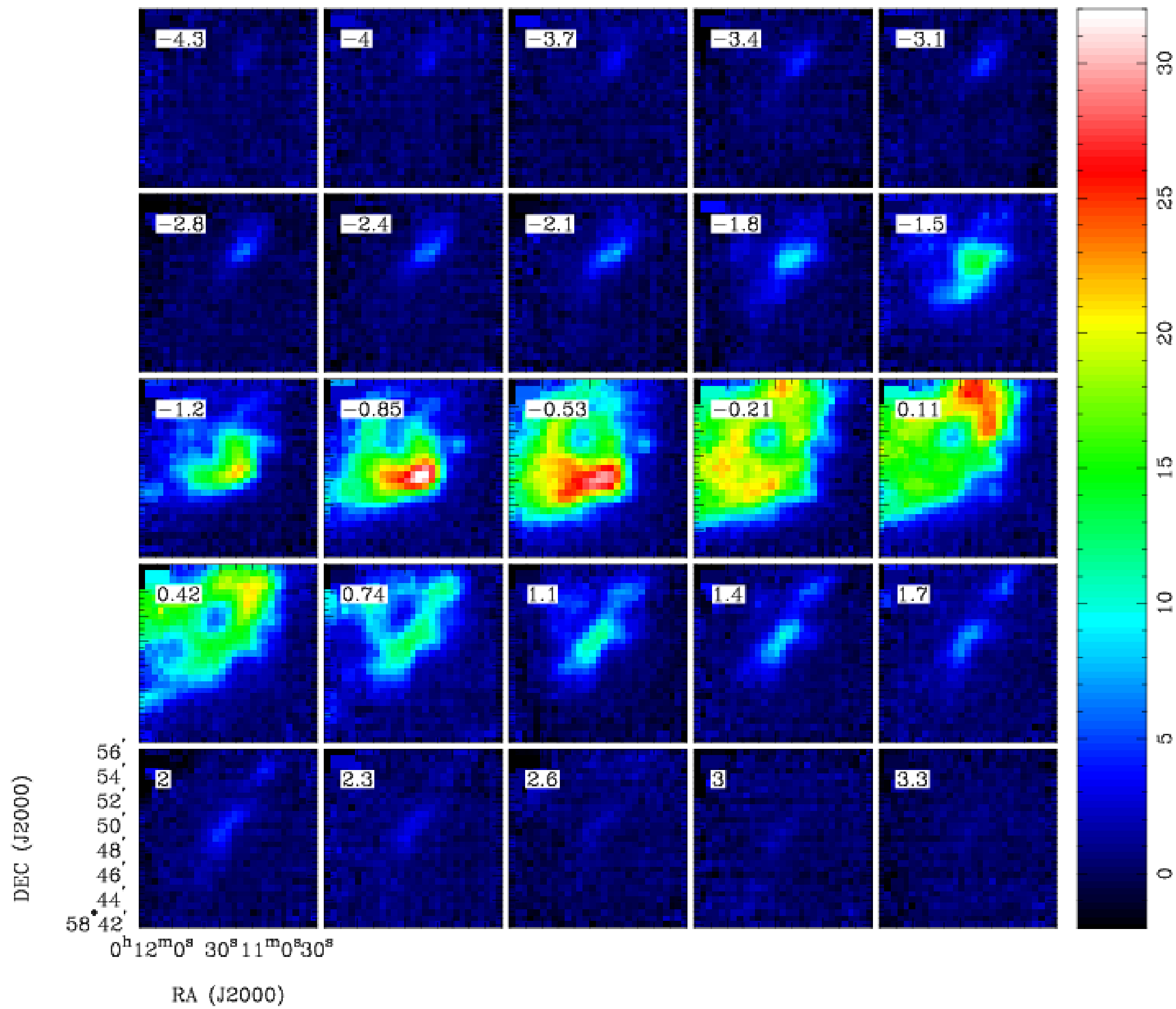
Triangles: (sub) mm sources

- Velocity integrated intensity map of 13CO 1-0 overlaid on that of 12CO 1-0.

Group II: 2 sources Core+outflow, jet + star(s)
LkHα 198



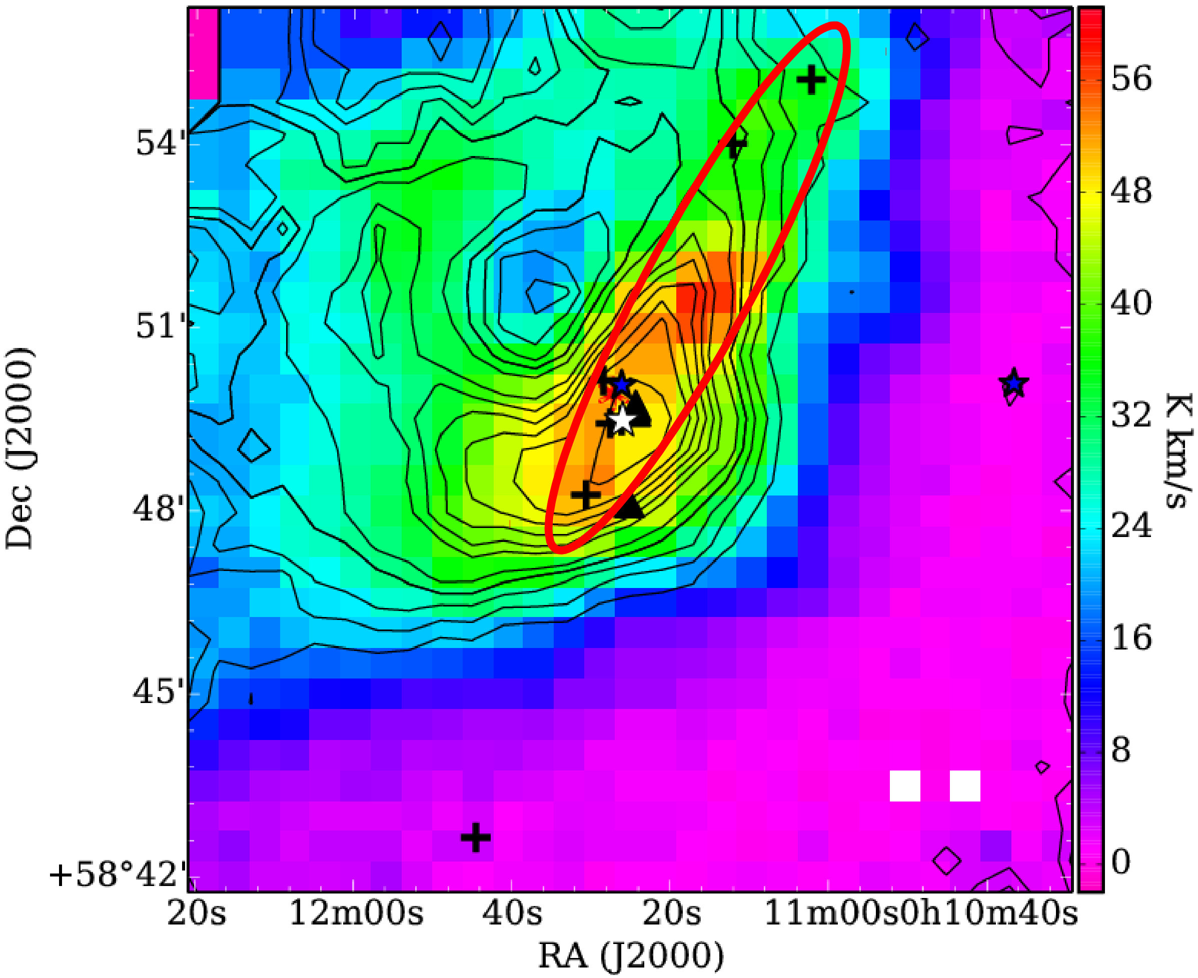


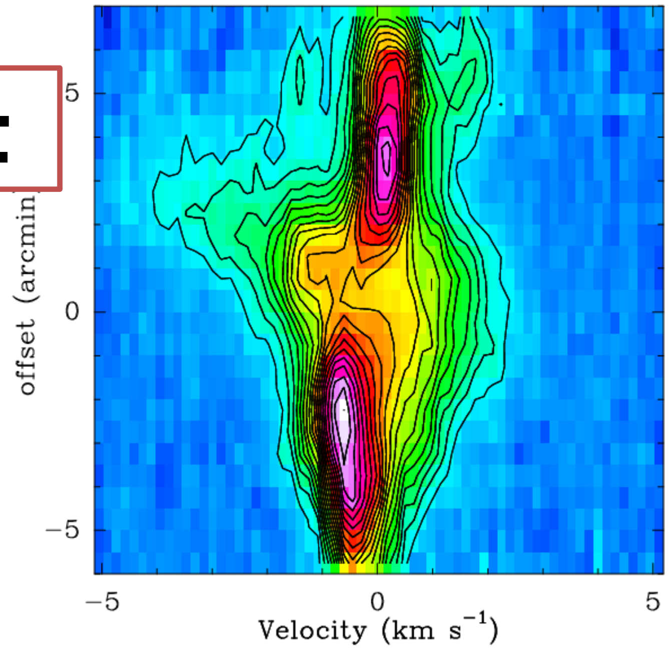


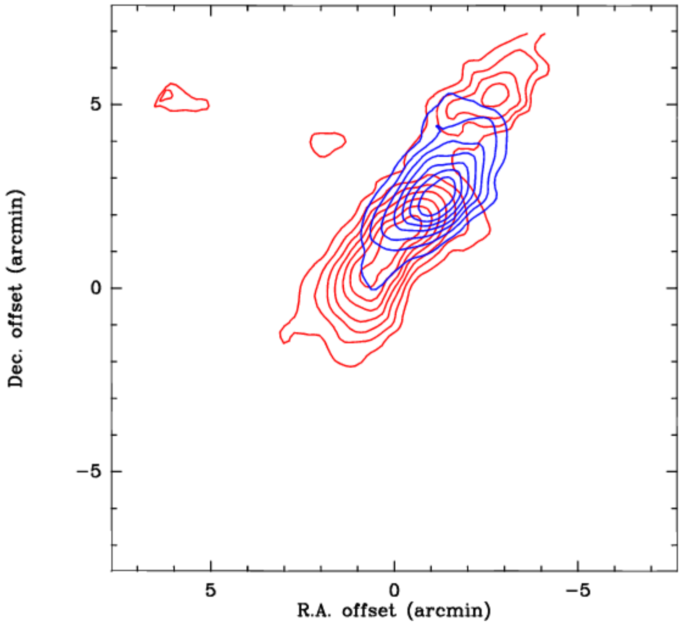
- Channel maps of 12CO 1-0

LkHα 198

NW-SE Jet

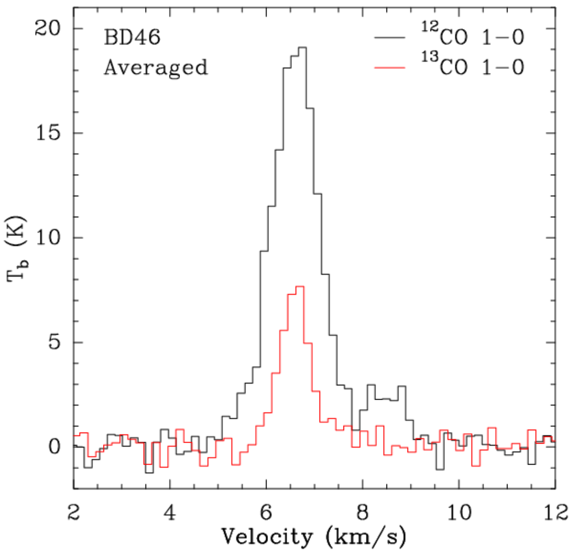


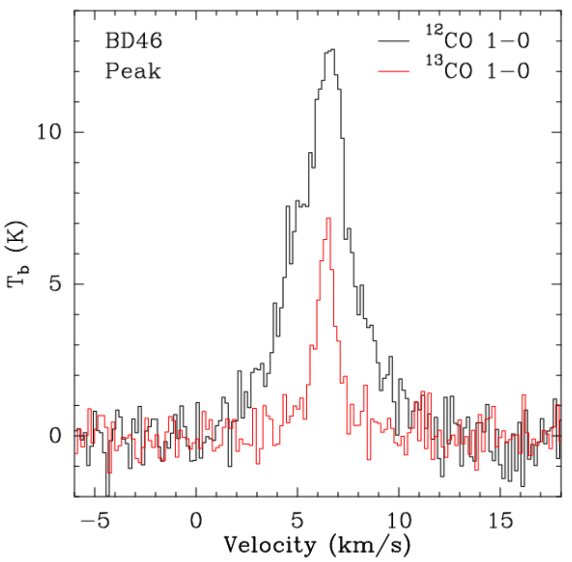


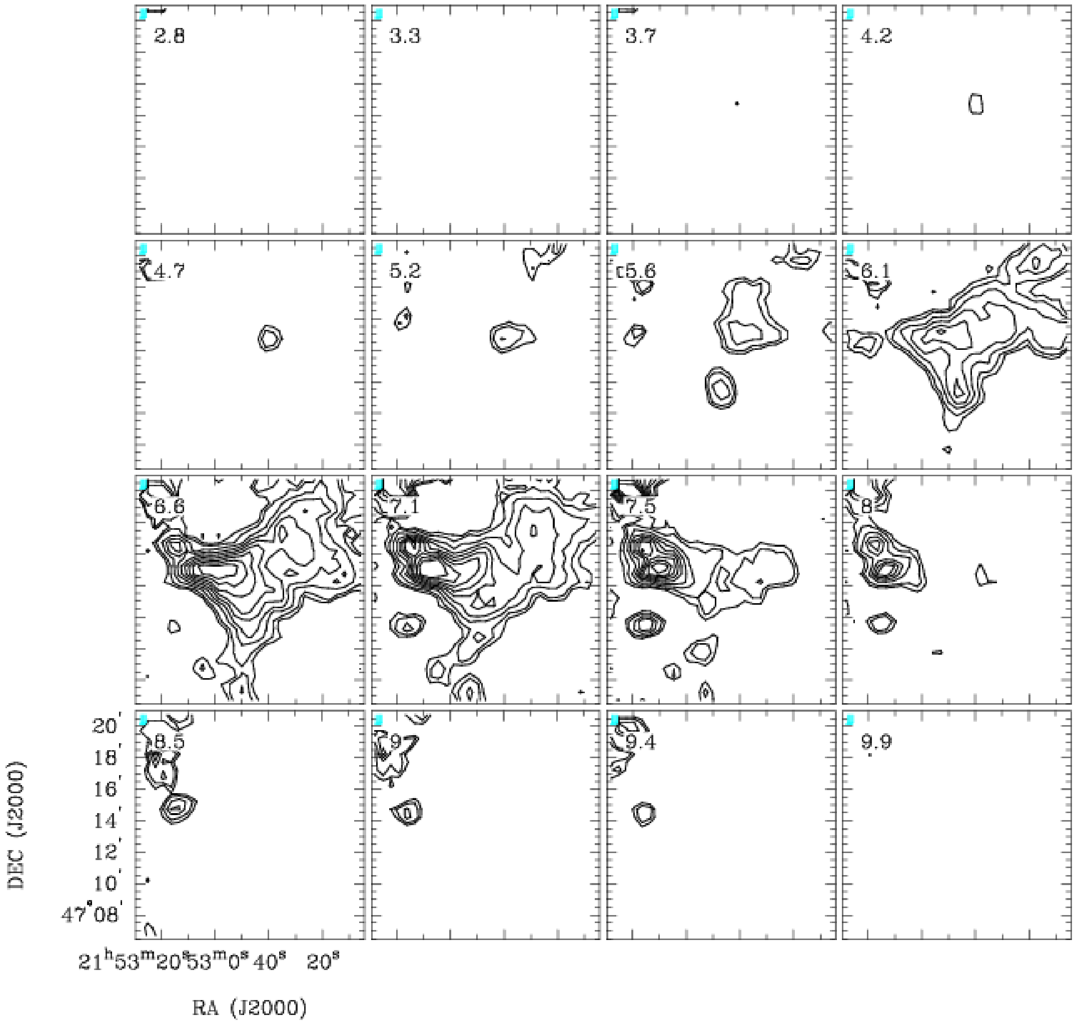


- **Velocity integrated intensity map of 13CO 1-0 overlaid on that of 12CO 1-0.**

BD 46

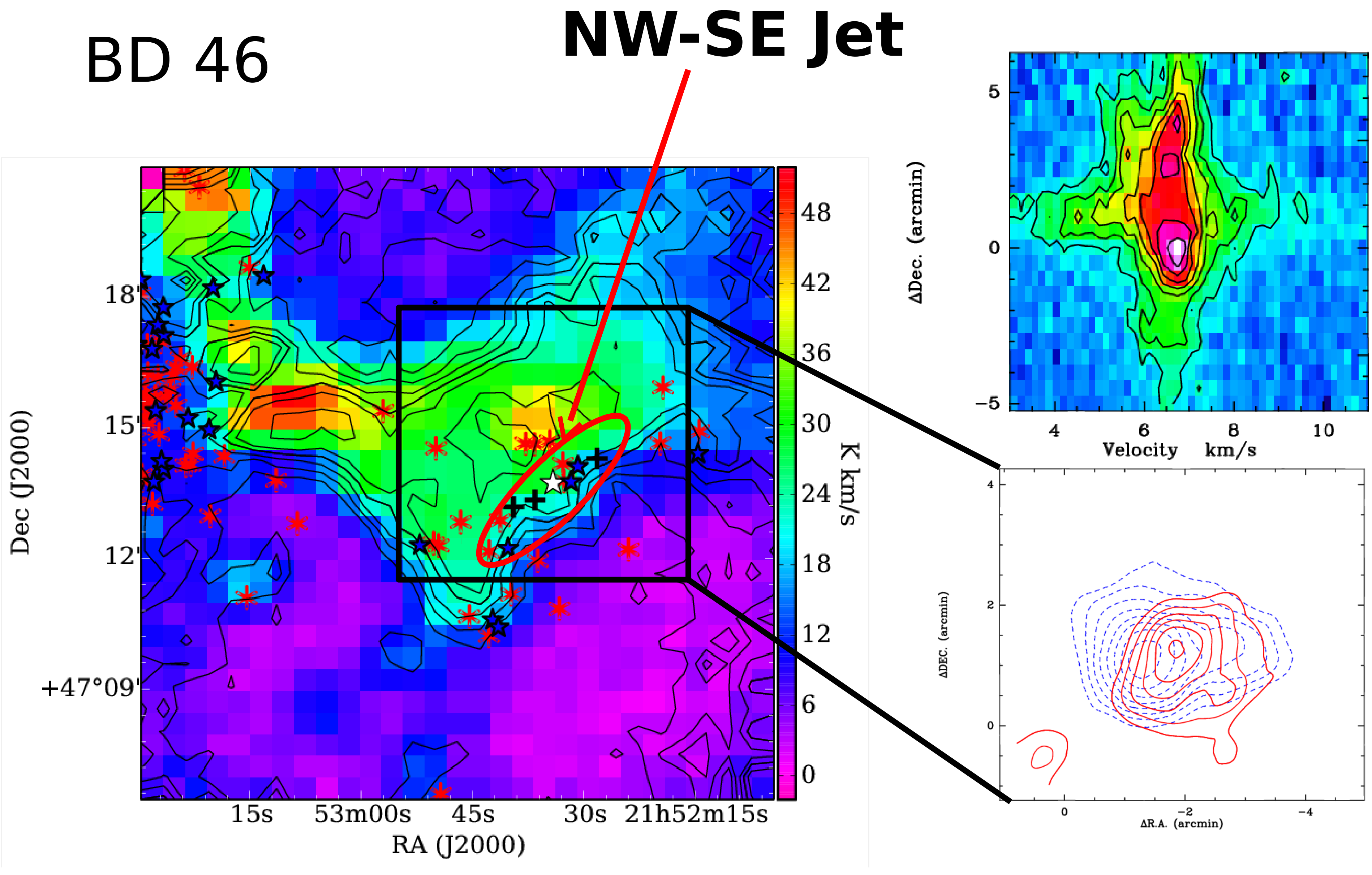






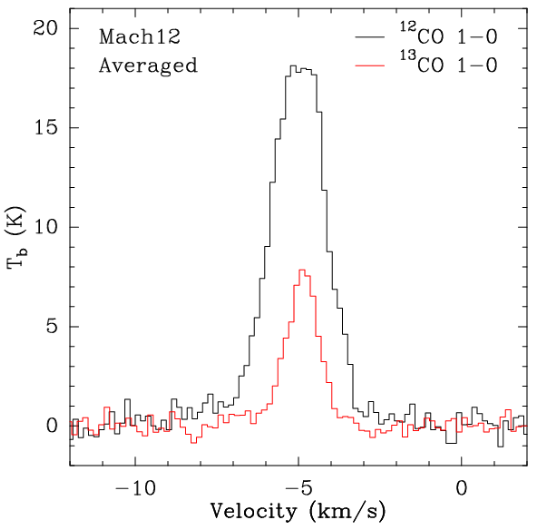
- Channel maps of 12CO 1-0

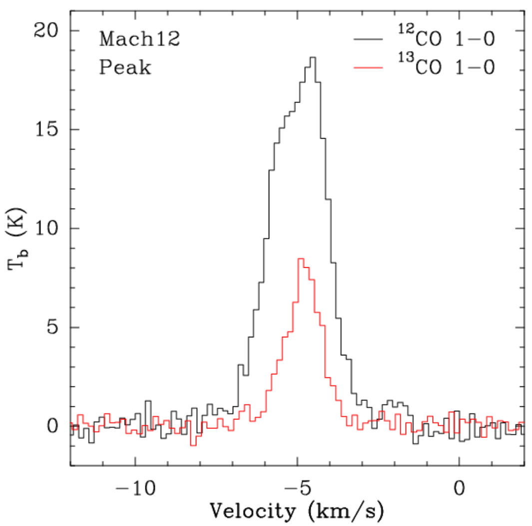
BD 46

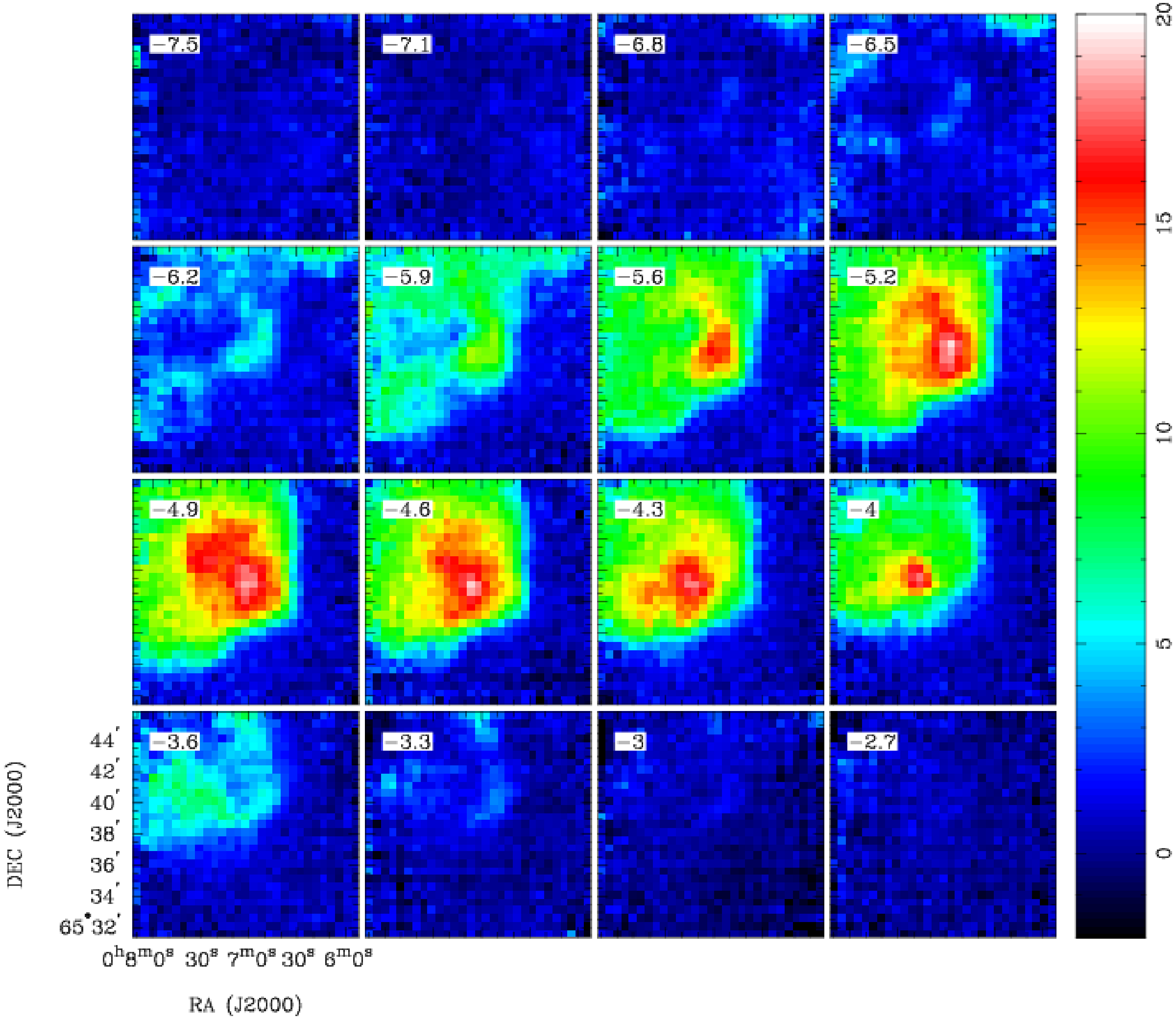


- **Velocity integrated intensity map of 13CO 1-0 overlaid on that of 12CO 1-0.**

Group III: 3 sources, Core + jets +star(s)
MacC H12

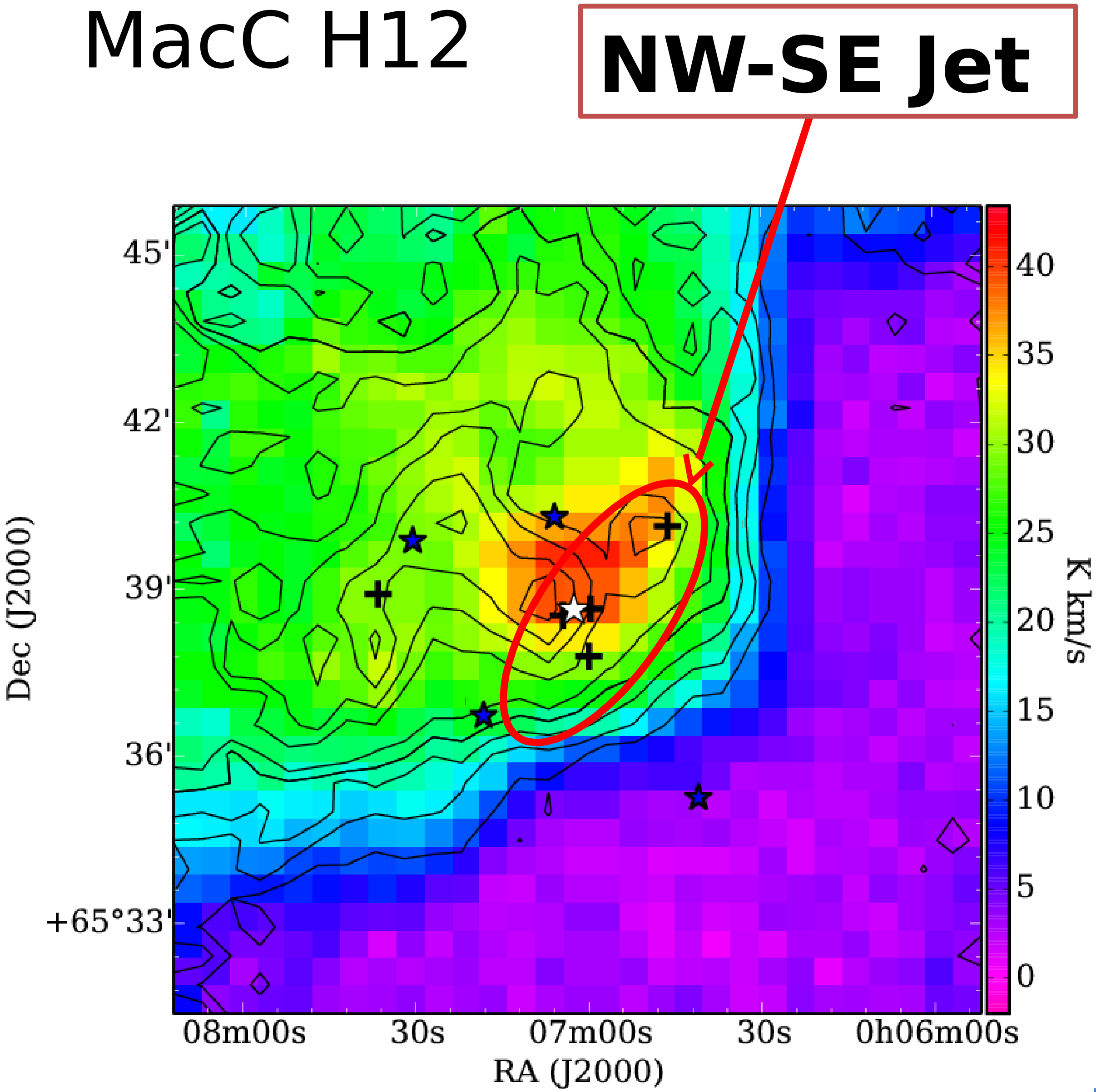






- Channel maps of 12CO 1-0

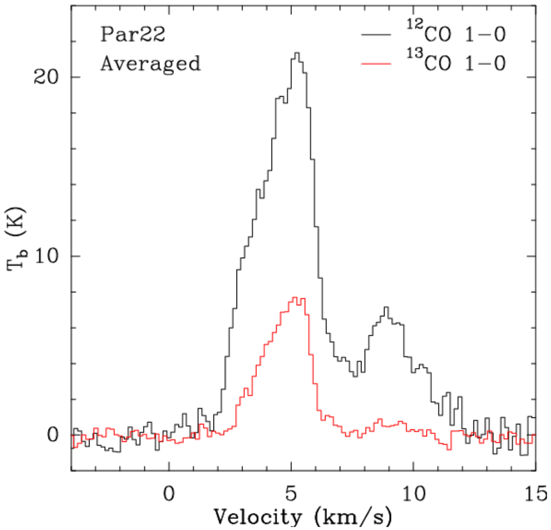
MacC H12

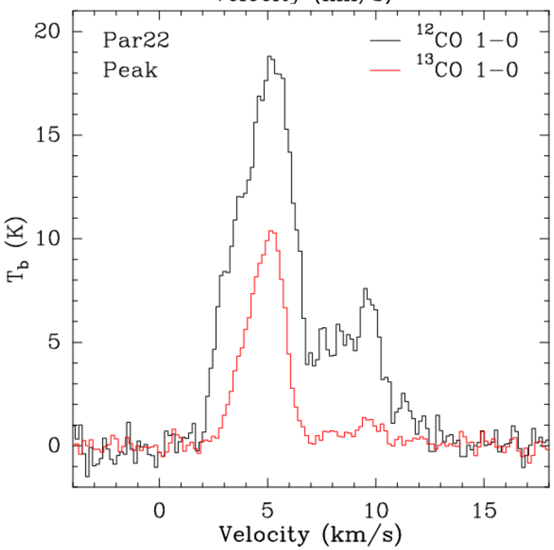


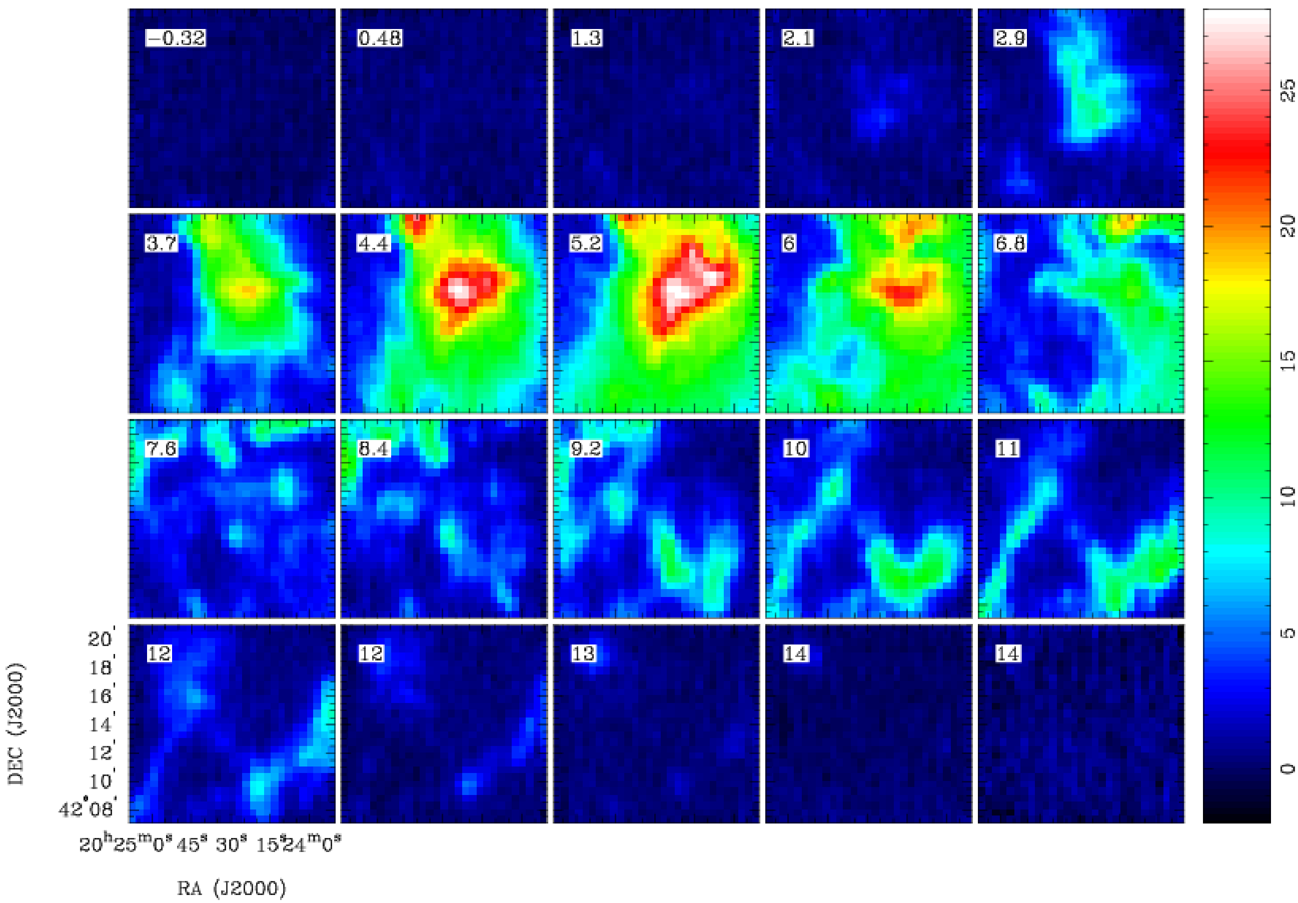
- White star: MaccCH12
- Blue stars: emission-line stars, Variable Stars of Orion Type, Be Stars, or Ae Stars.
- "+" symbols: HH objects

- **Velocity integrated intensity map of 13CO 1-0 overlaid on that of 12CO 1-0.**

Par 22

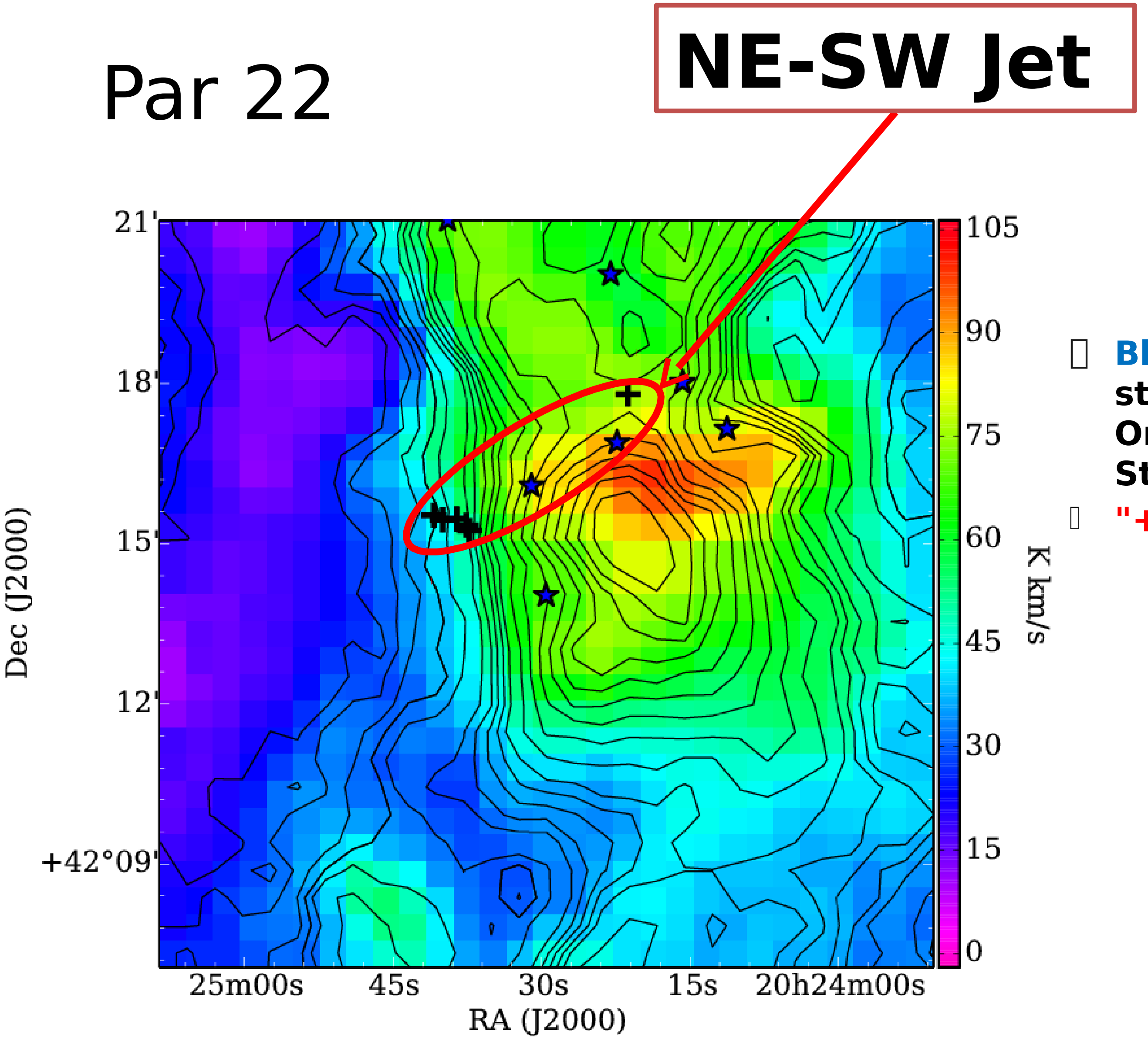






- Channel maps of 12CO 1-0

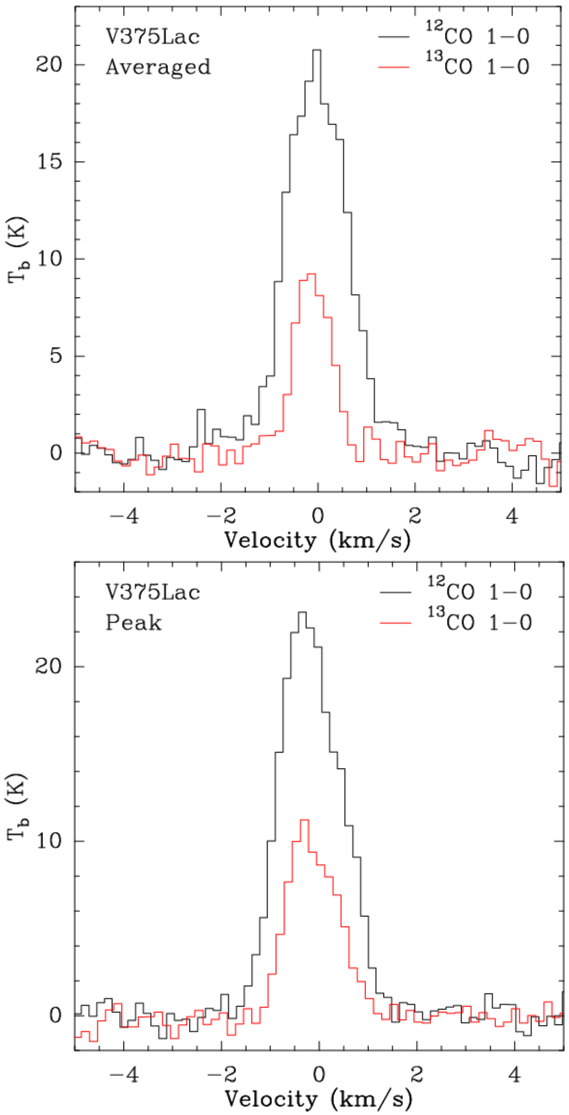
Par 22

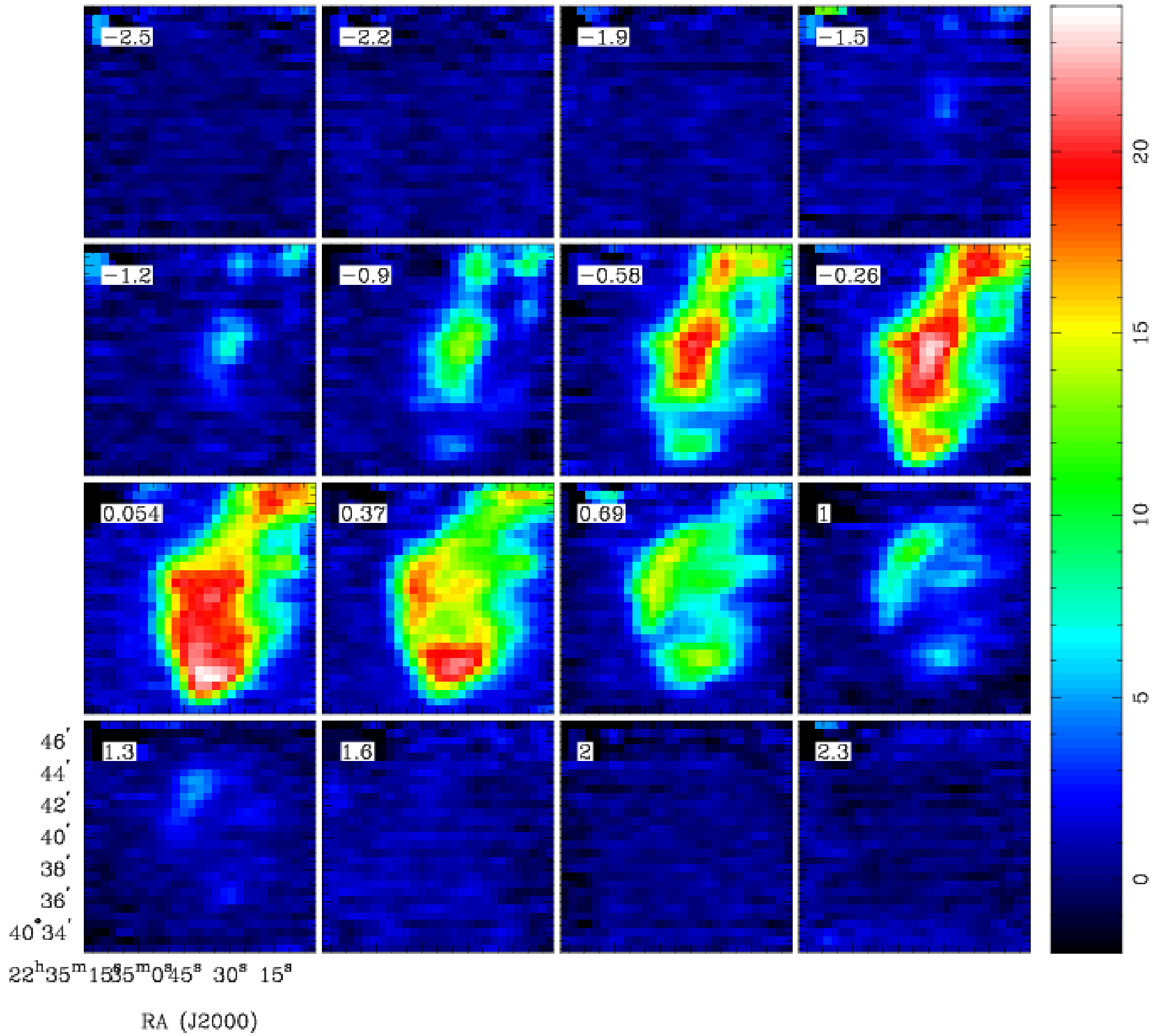


- **Blue stars:** **emission-line stars, Variable Stars of Orion Type, Be Stars, or Ae Stars.**
- **"+" symbols: HH objects**

- **Velocity integrated intensity map of 13CO 1-0 overlaid on that of 12CO 1-0.**

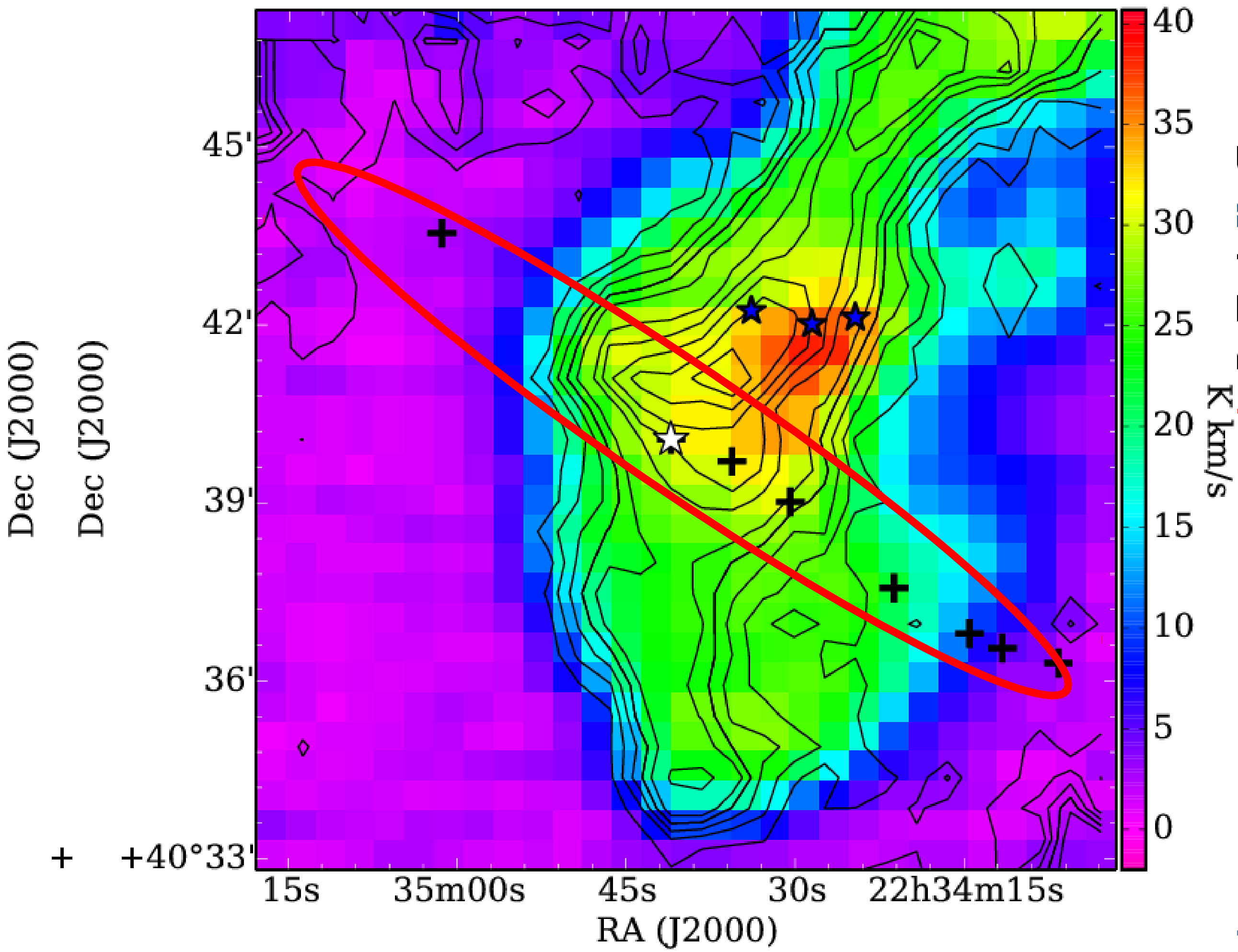
V375Lac





Channel maps of 12CO 1-0

V375Lac



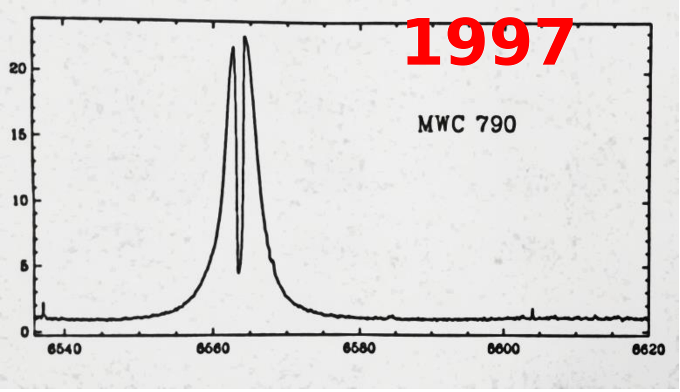
Vhite star: V375Lac

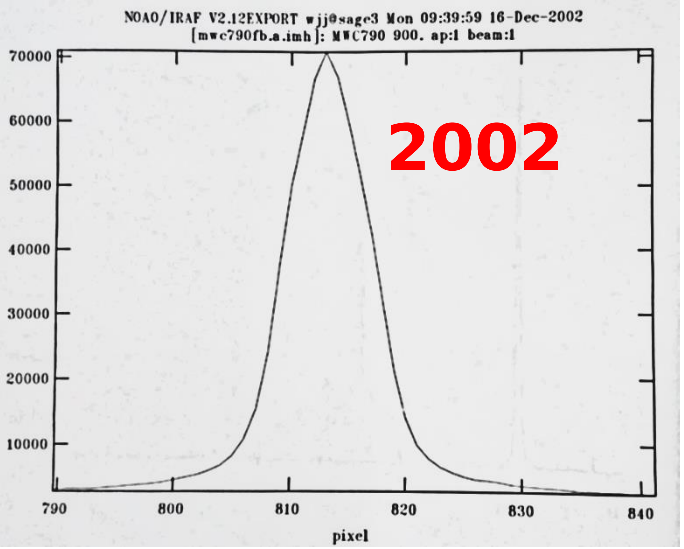
lue stars: emission-line tars, Variable Stars of)rion Type, Be Stars, or e Stars.

+" symbols: HH objects

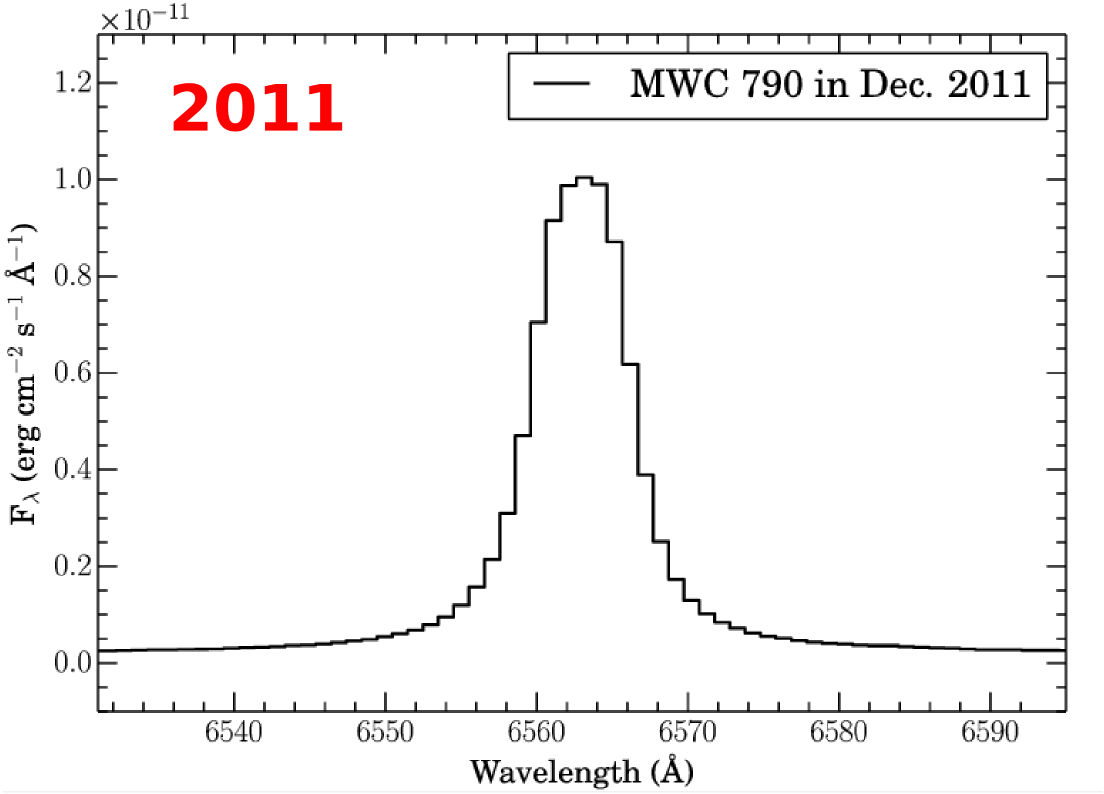
- Velocity integrated intensity map of 13CO 1-0 overlaid on that of 12CO 1-0.

Group IV: 1 source VI: diffuse core+ optical line chang
e
MWC 790

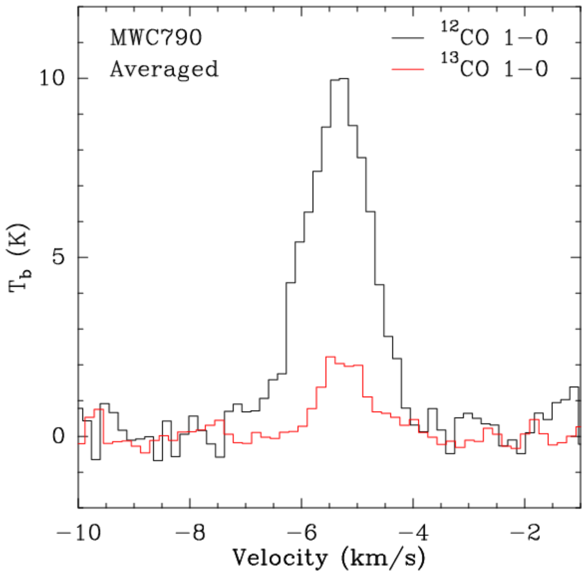


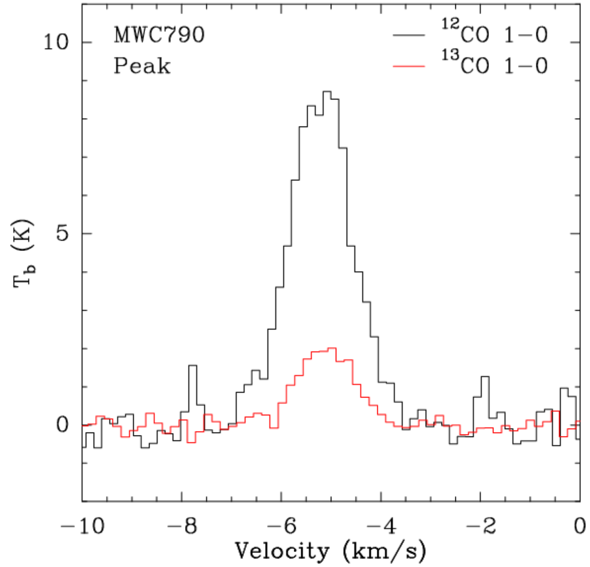


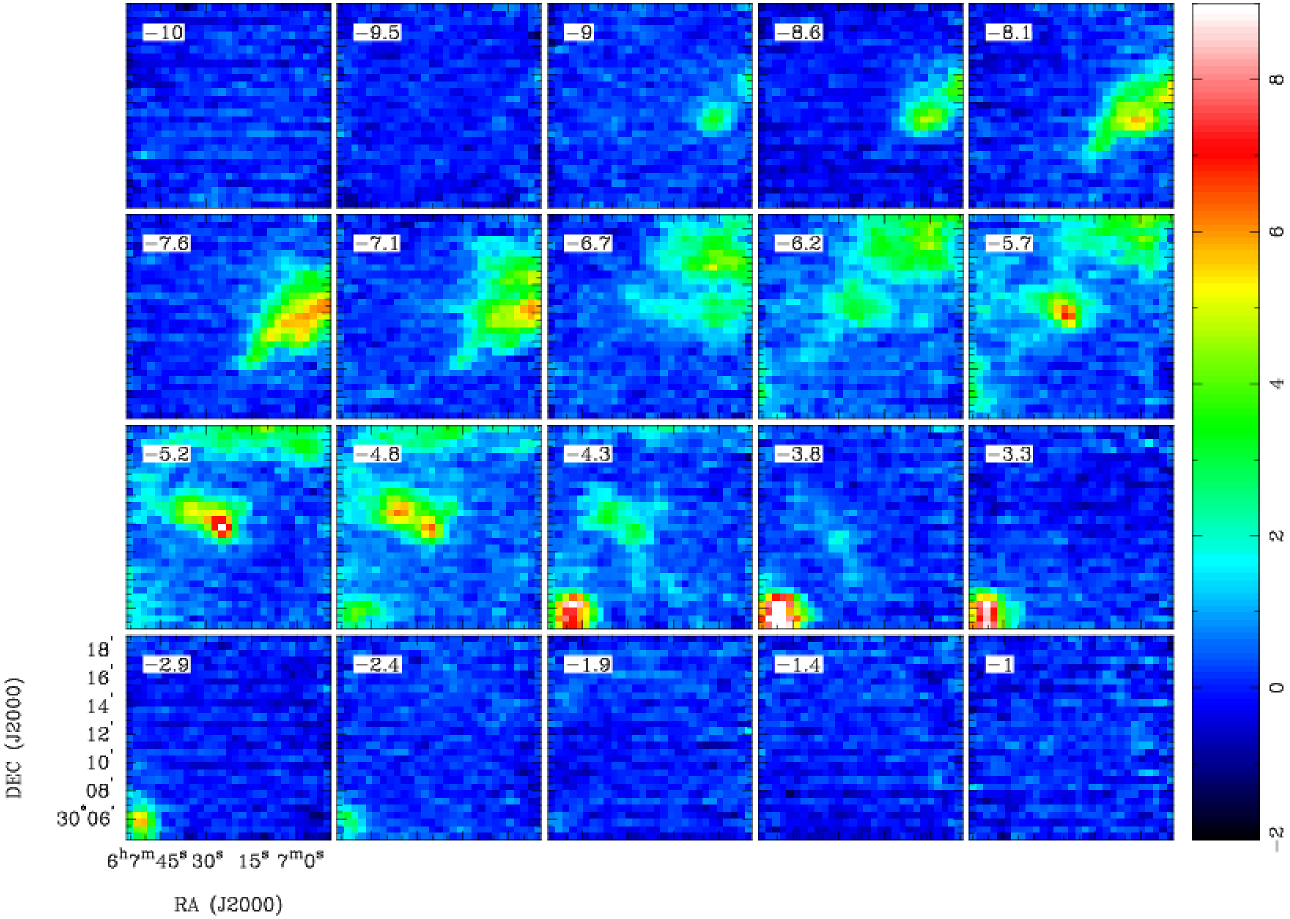
- **Hα in three epochs**



MWC 790

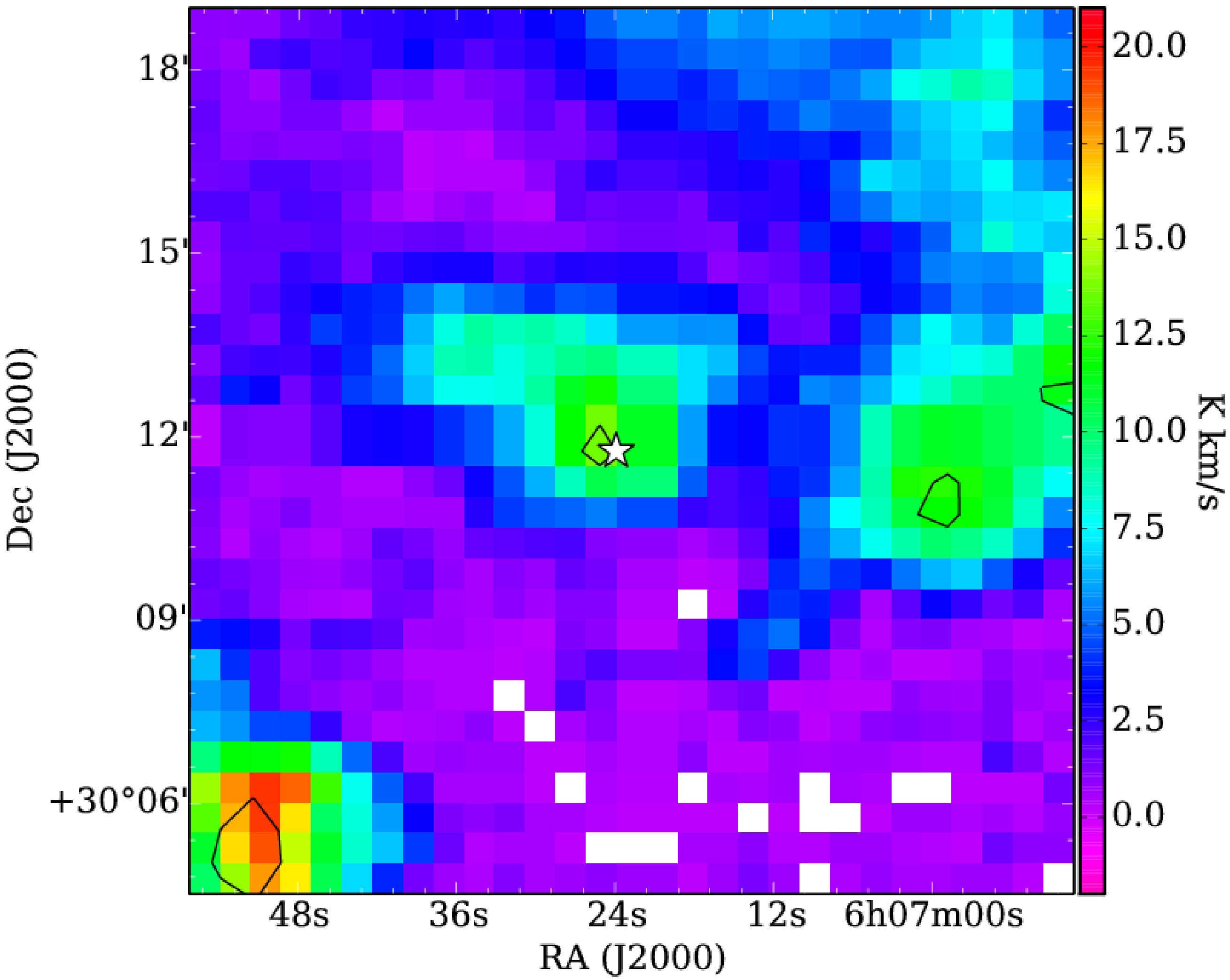






- Channel maps of 12CO 1-0

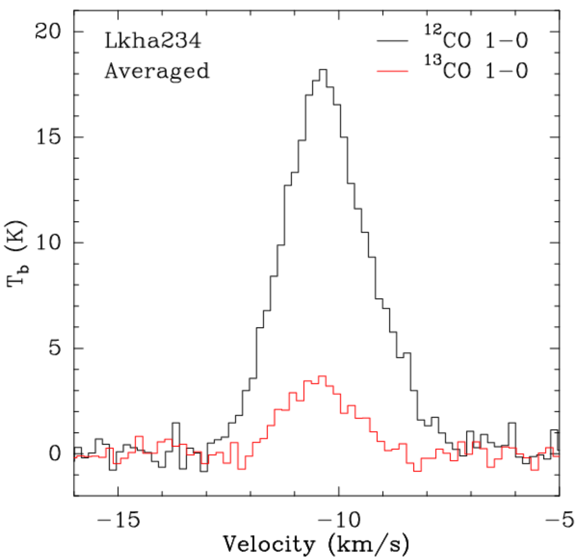
MWC 790

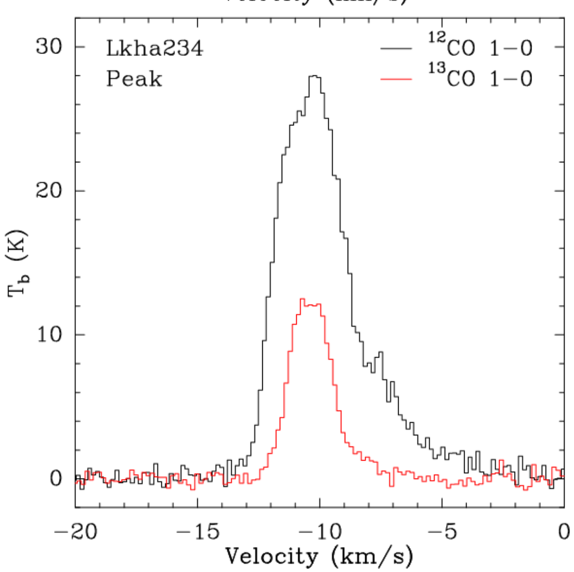


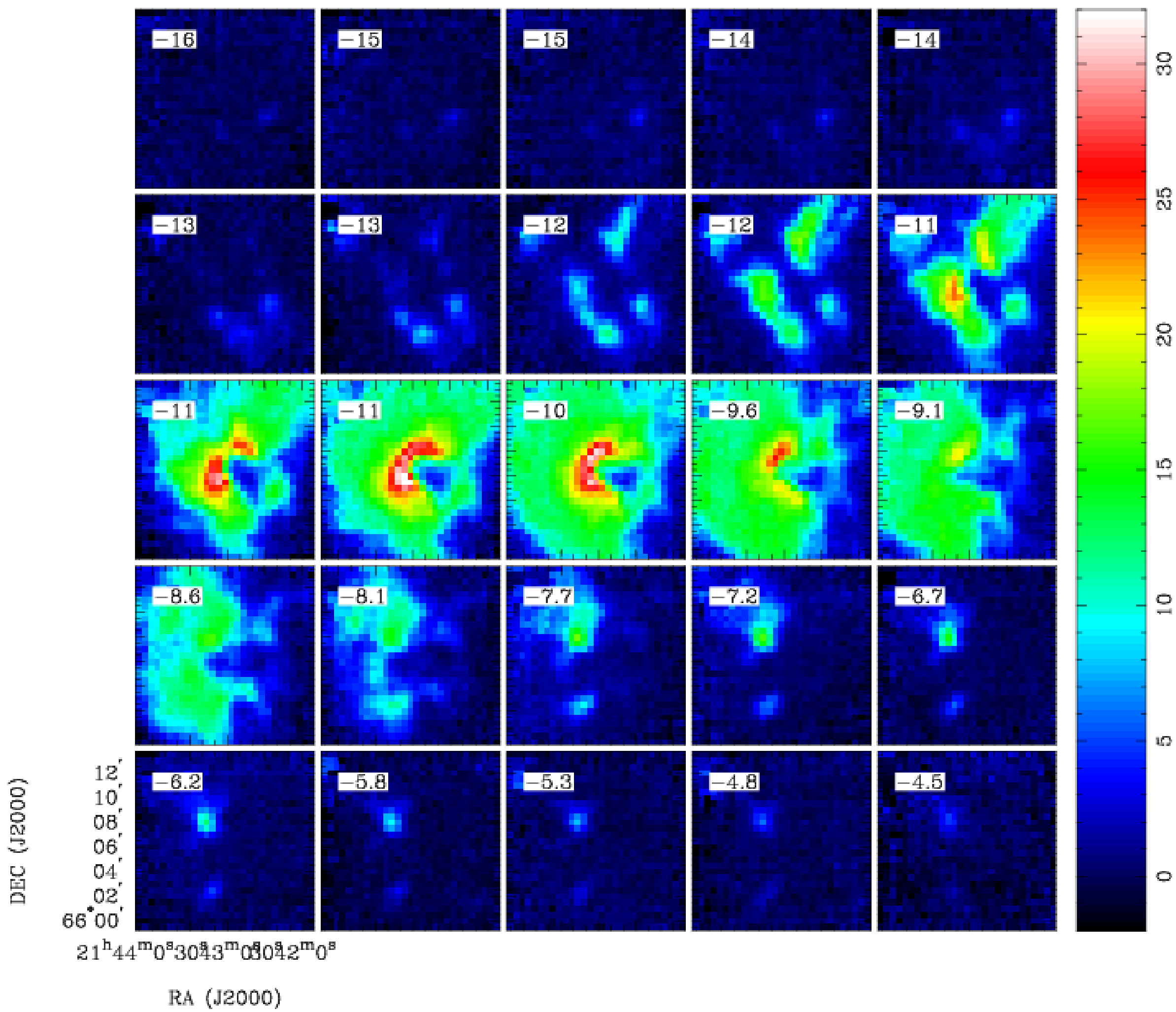
- **Velocity integrated intensity map of 13CO 1-0 overlaid on that of 12CO 1-0.**

Group V: 3 sources, core+semi-cavity or cavity+stars

LkHα234—also +HH jet

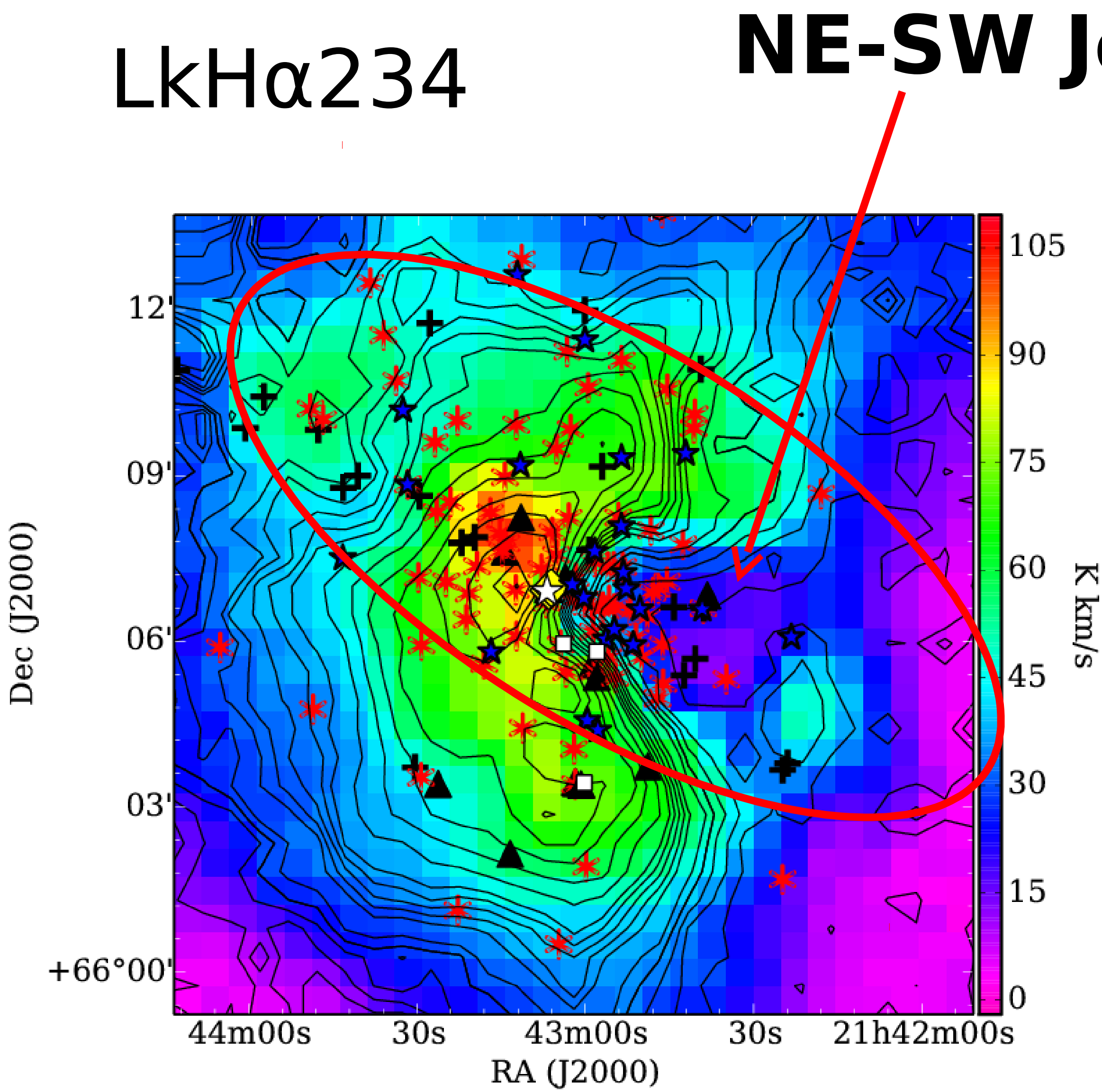






- Channel maps of 12CO 1-0

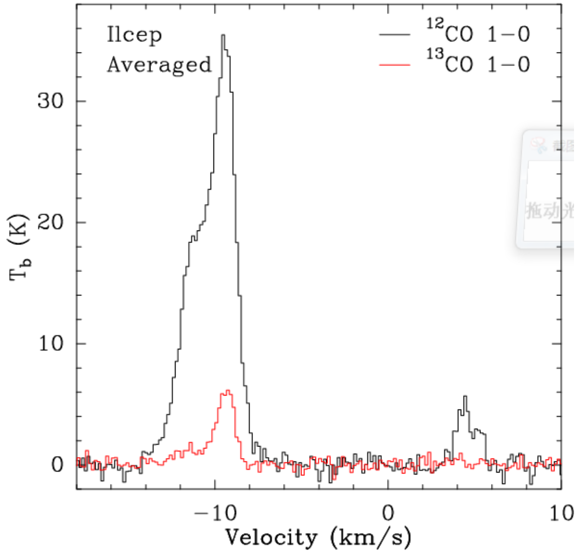
LkHα234

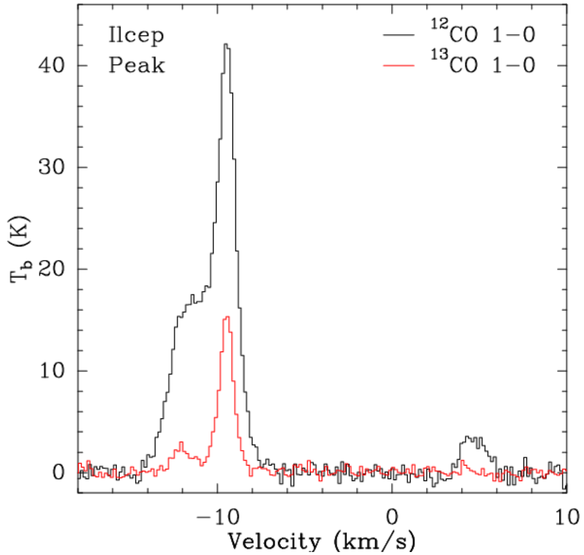


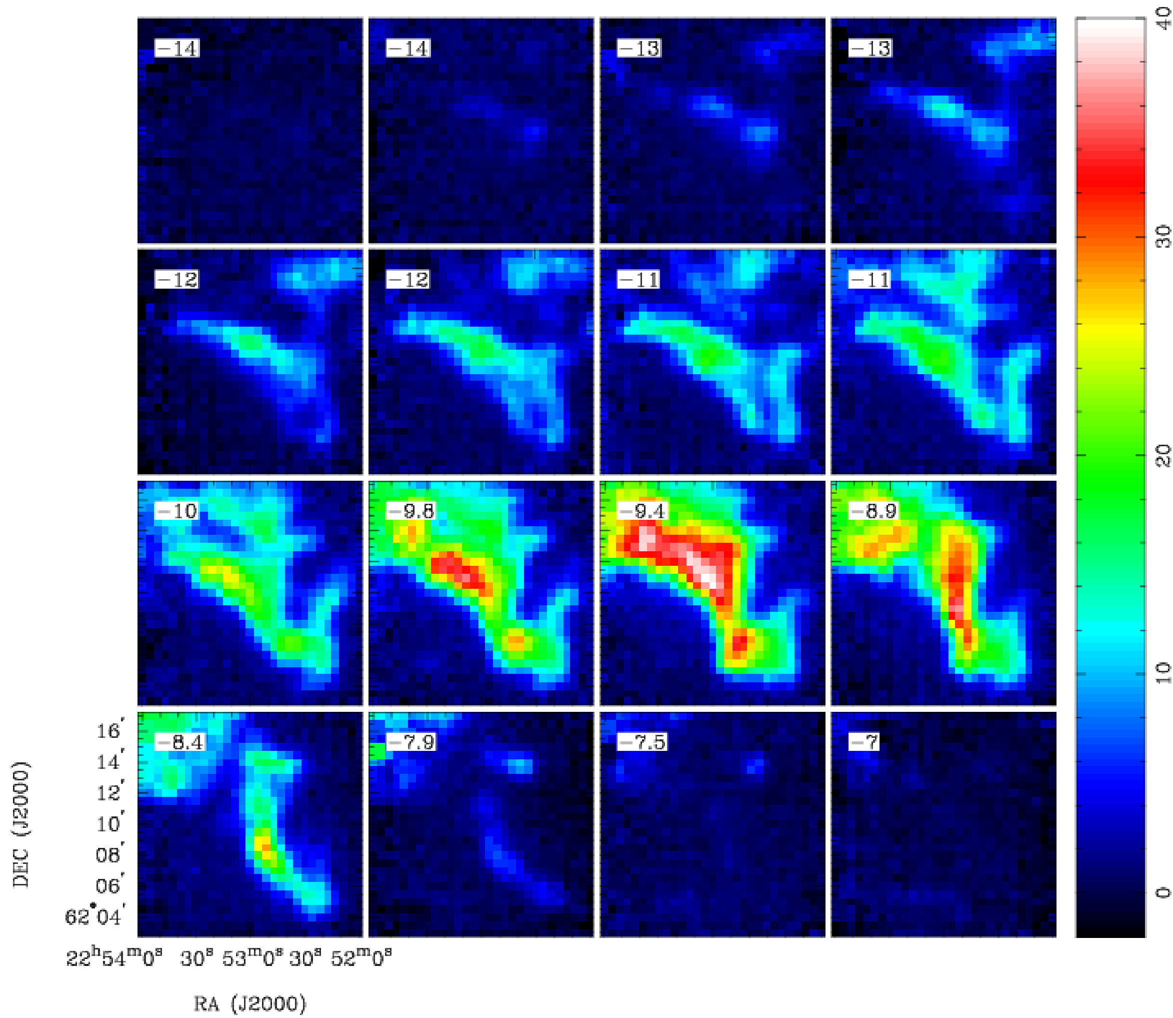
- White star: Lkha 234
- **Blue stars:** emission-line stars, Variable Stars of Orion Type, Be Stars, or Ae Stars.
- Asterisks: YSOs
- Triangles: (sub) mm sources
- Diamonds: cm sources
- "+" symbols: HH objects
- Squares: masers

- **Velocity integrated intensity map of 13CO 1-0 overlaid on that of 12CO 1-0.**

ILcep

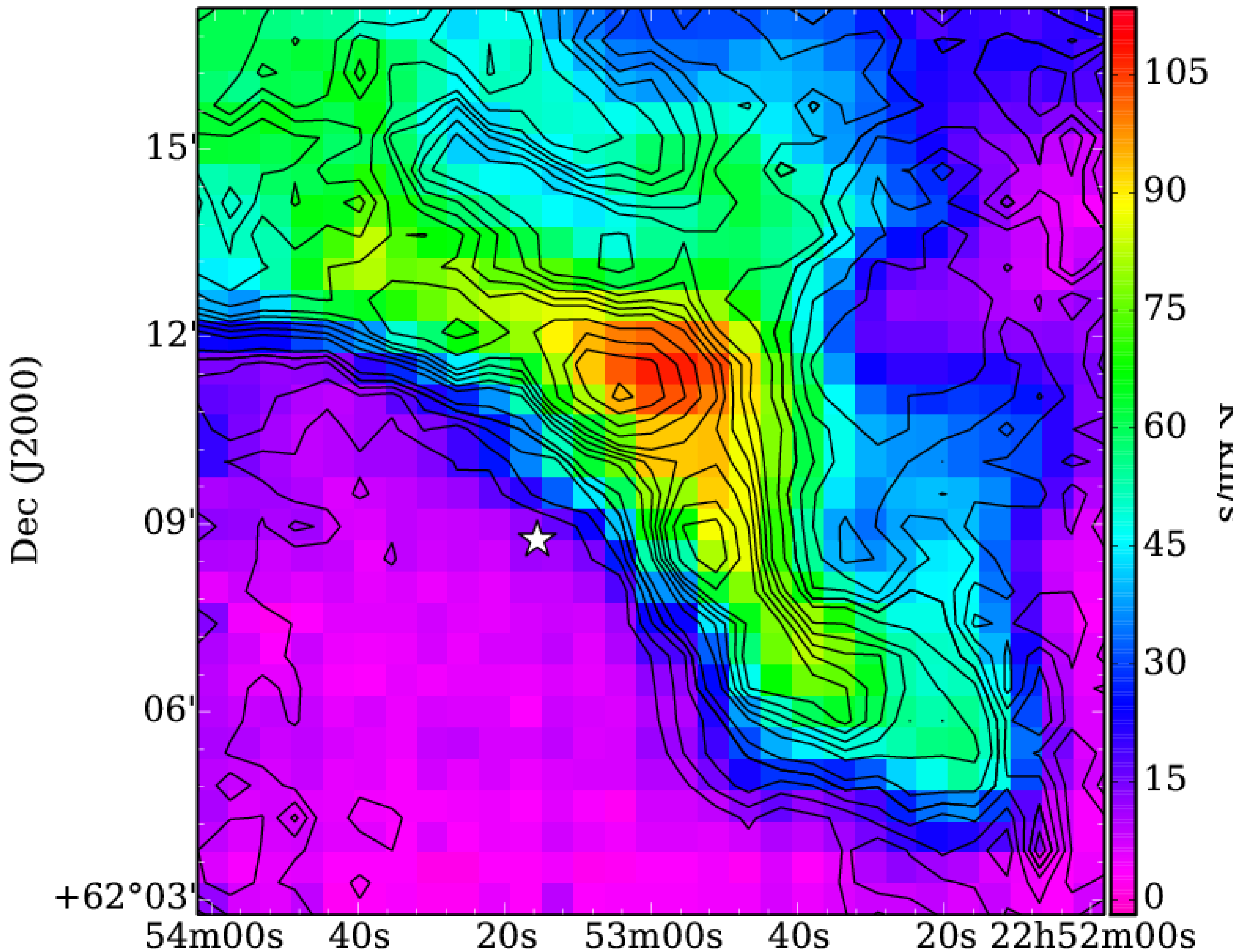






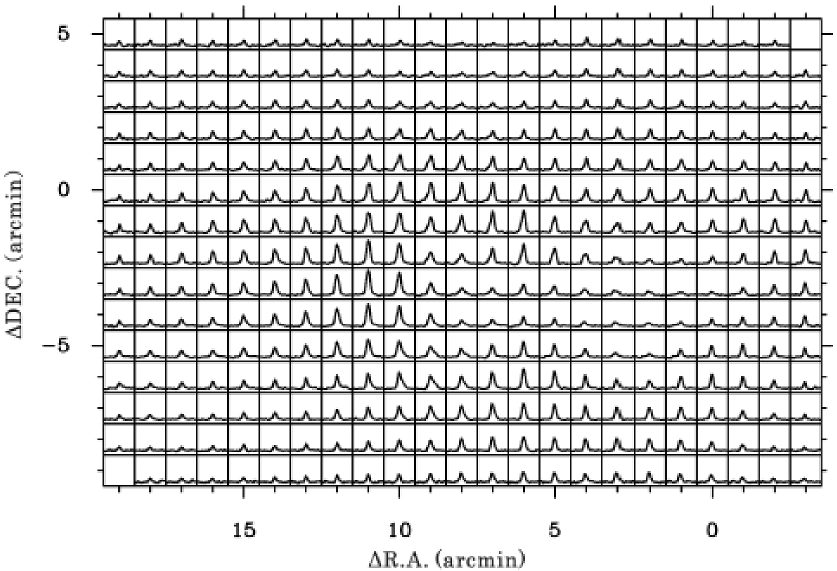
- Channel maps of 12CO 1-0

ILcep

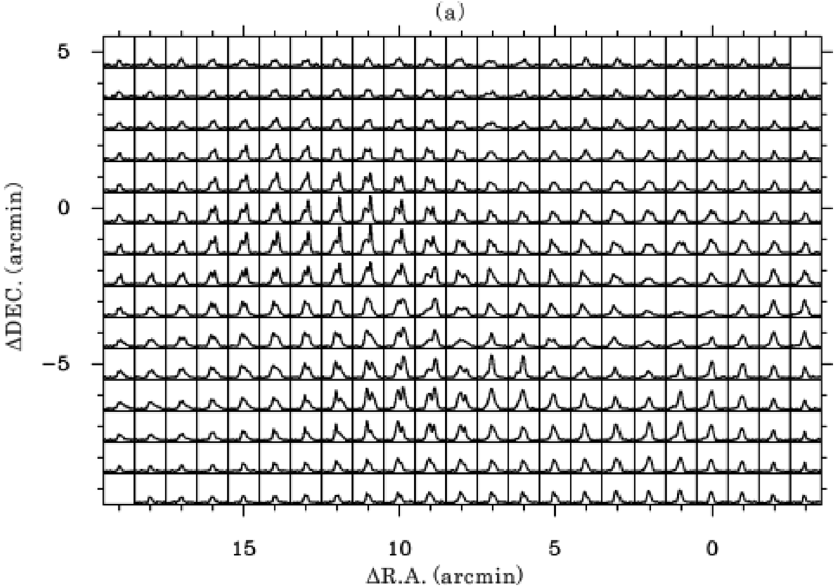


- **Velocity integrated intensity map of 13CO 1-0 overlaid on that of 12CO 1-0.**

HD200775



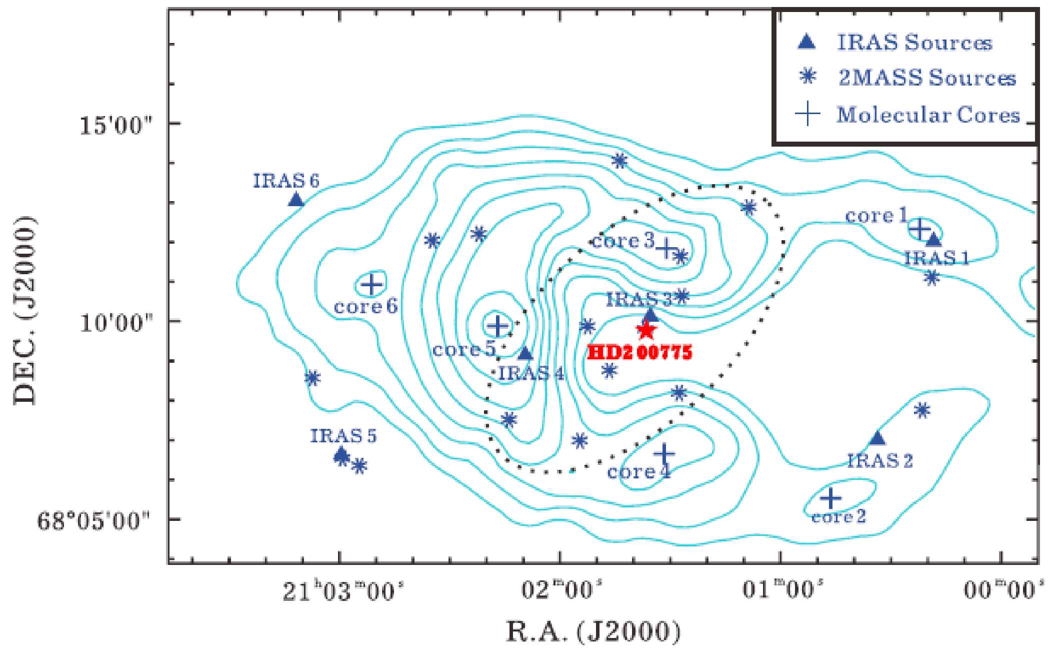
(a)



(b)

- KOSMA
- 13CO 2-1
- 12CO 3-2

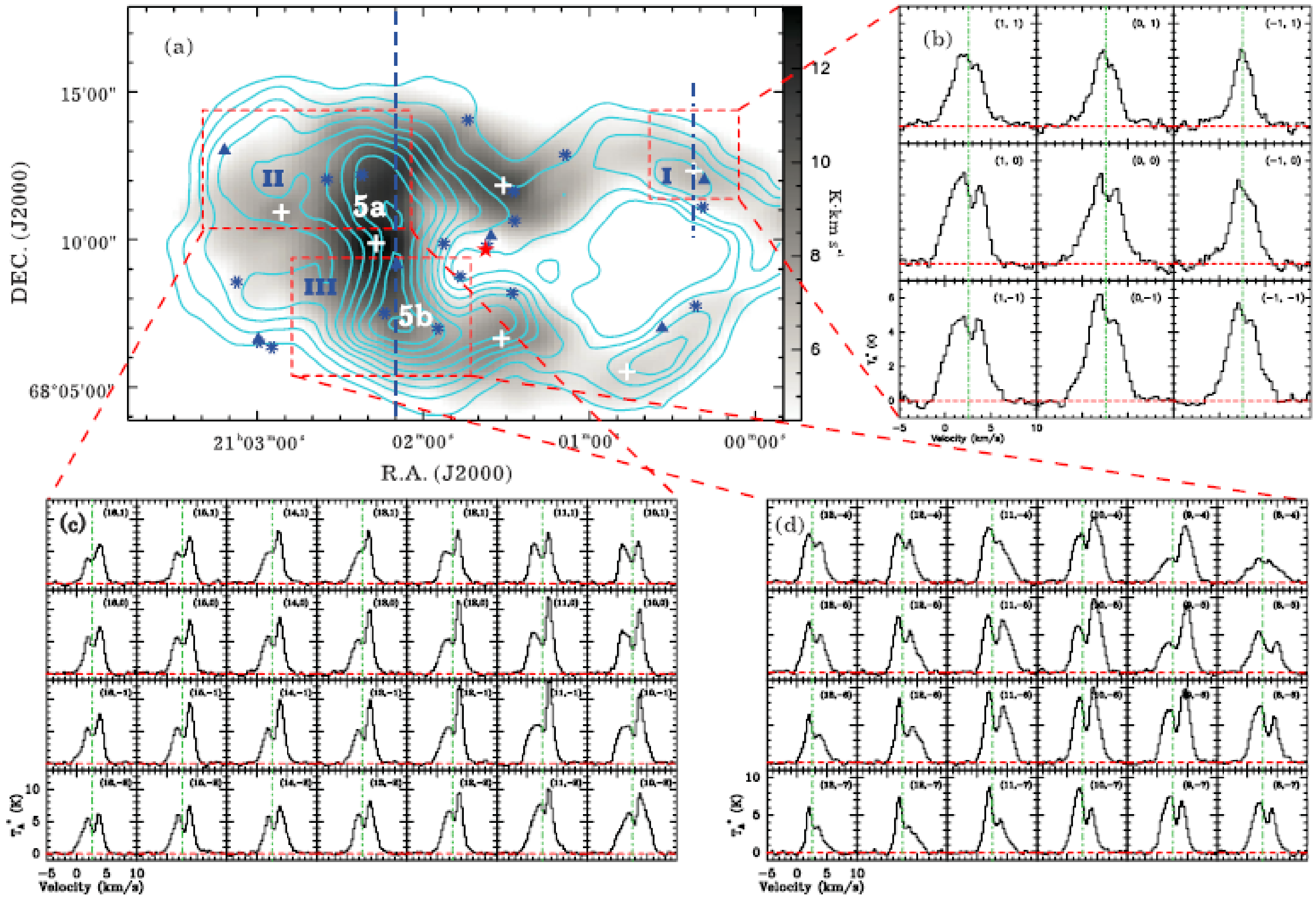
L1174
21 00 00.03
68 12 57.6



Velocity integrated intensity of 13CO 2-1

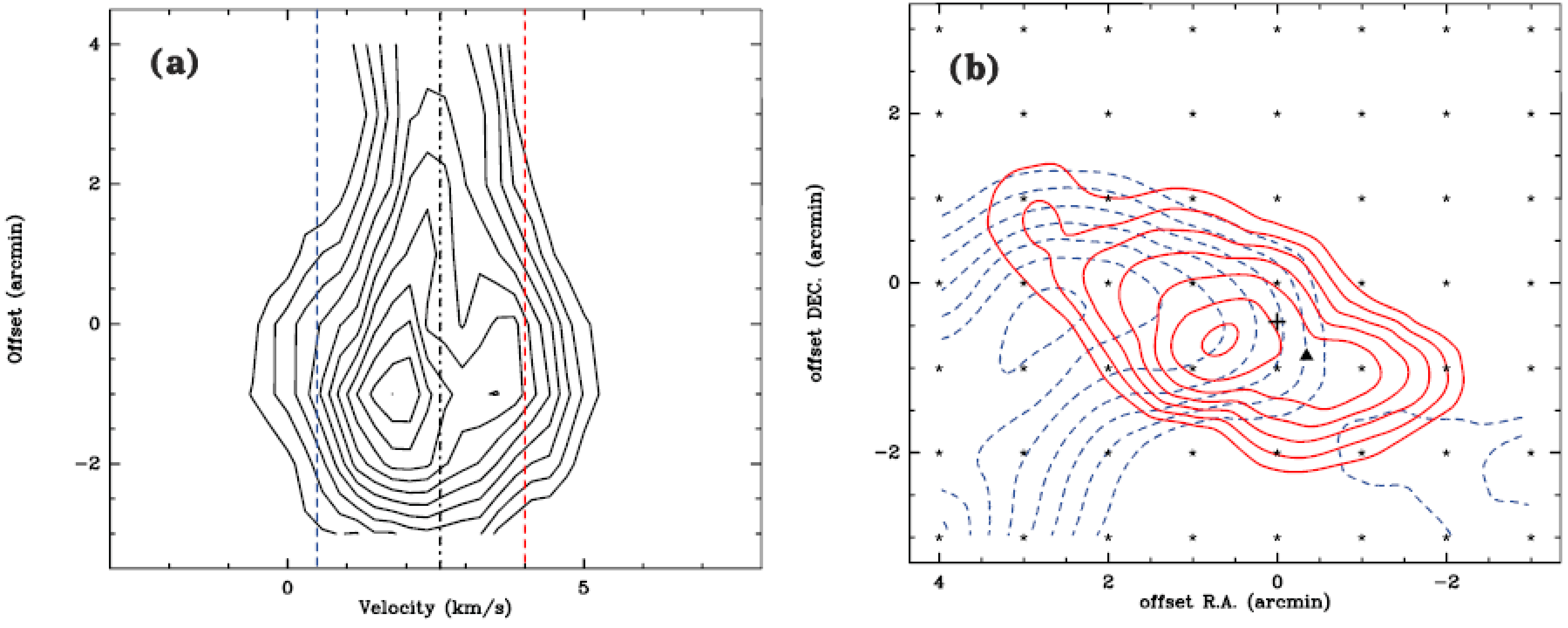
6 Dense cores

HD200775



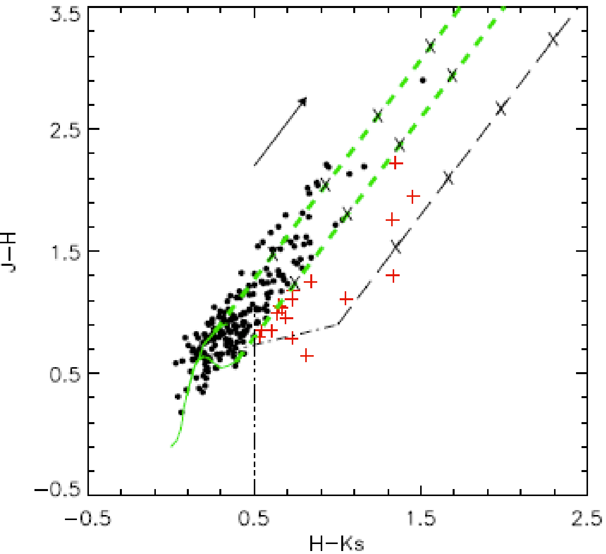
12CO 3-2 (contour)+13CO 2-1 (grayscale)

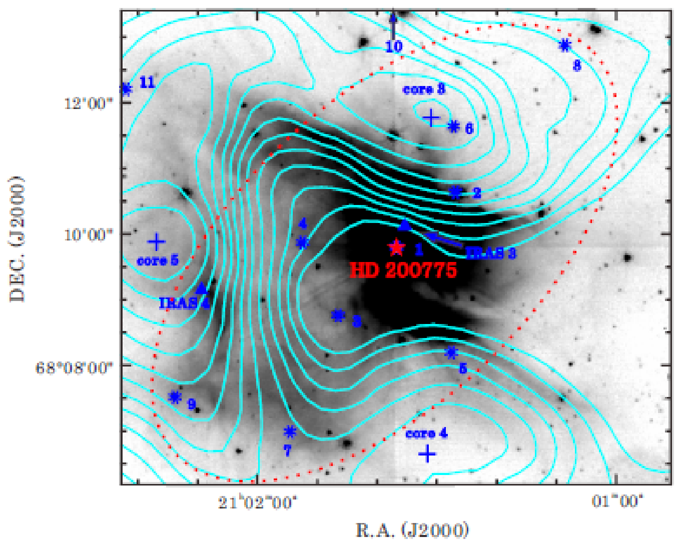
HD200775

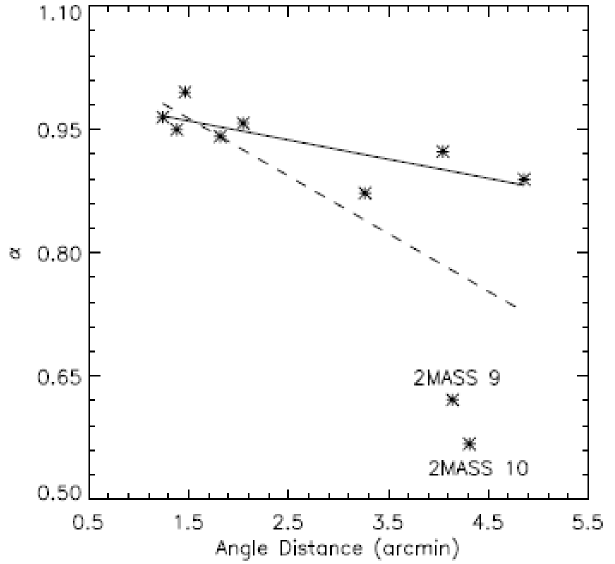


- Outflow of Core 1

HD200775







- 17 YSOs identified based on 2MASS colors

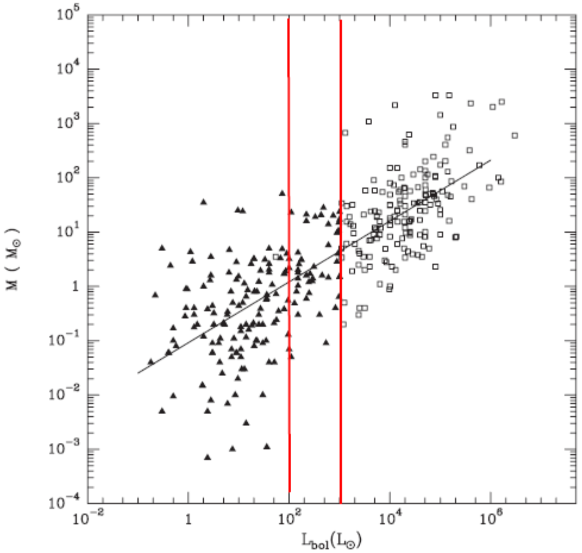
- $\alpha = \frac{[J-H]}{1.8[H-Ks]-0.1035}$
- Black Dashed Line:
  - $\boldsymbol{\alpha = (-0.049 \pm 0.024) + (1.034 \pm 0.072)d, \quad R^2 = 0.38}$
- Blue Solid line:
  - $\boldsymbol{\alpha = (-0.023 \pm 0.007) + (0.995 \pm 0.021)d, \quad R^2 = 0.62}$

MacC H12	00 07 02.6 65 38 38.2	Core+ HH jet	star group
LkHα 198	00 11 26.0 58 49 29.1	Core + Outflow + HH jet	two stars
MWC 789	06 01 60.0 16 30 56.7	Core	single star
LkHα 208	06 07 49.5 18 39 26.5	Core	two stars
MWC 790	06 07 23.9 30 11 46	Diffuse + optical variety	single star
LkHα 215	06 32 41.8 10 09 33.6	Core + Sub mm cores	group stars
Par 22	20 24 29.5 42 14 03.7	Core + HH jet	group stars
LkHα 234	21 03 54.2 50 15 10.2	$H2O$ masers HH Jet + Half Cavity	group s. YSOs
HD 200775	21 01 36.9 68 09 47.8	cores, outflow, infall, Cavity	group s. YSOs, IRAS,
BD 46	21 52 34.1 47 13 43.6	core, Outflow + HH jet, group stars, YSOs	
V375 Lac	22 34 41 40 40 04.5	Core + HH Jet ,	star group
IIL Cep	22 53 15.6 62 08 45	core, Half Cavity,	single star

Cores 3
Core +outflow + HH jets 2
Core + HH jets 3
diffuse core, single star, optical change 1
core, half cavity 2 , one with HH Jet
cores, outflow, infall, cavity 1

Single star 3
Two stars 2
Groups stars 7

4. Summary



- Gas: less dense comparing with low- and high mass cores
- Line width: between that of low – and high mass cores
- CO represents surrounding gas and related envelope gas

  Envelope and disk accretion rates change with age
- Gas cores dense or diffuse , isolate or a number coexist
- Outflow: mm outflow: detection rate: low, consistent with a

  statistics using large sample (Wu et al. 2004)

  Optical jet: with high detection rate- similar to low-mass

  regions but usually appear as a string
- Group stars > 50% , including isolated and clustered
- Cavity exists- similar to high-mass stars, possible triggered star formation was found

  but without strong HII region

  For feed back HAe/Be stars also link low- and high-mass stars
- Further: Map more samples

  Probe typical sources such as disk in MWC 789 with high resolution observation

Thank You for

Your Attention!