Dense cores and outflows in the S255 area of high mass star formation

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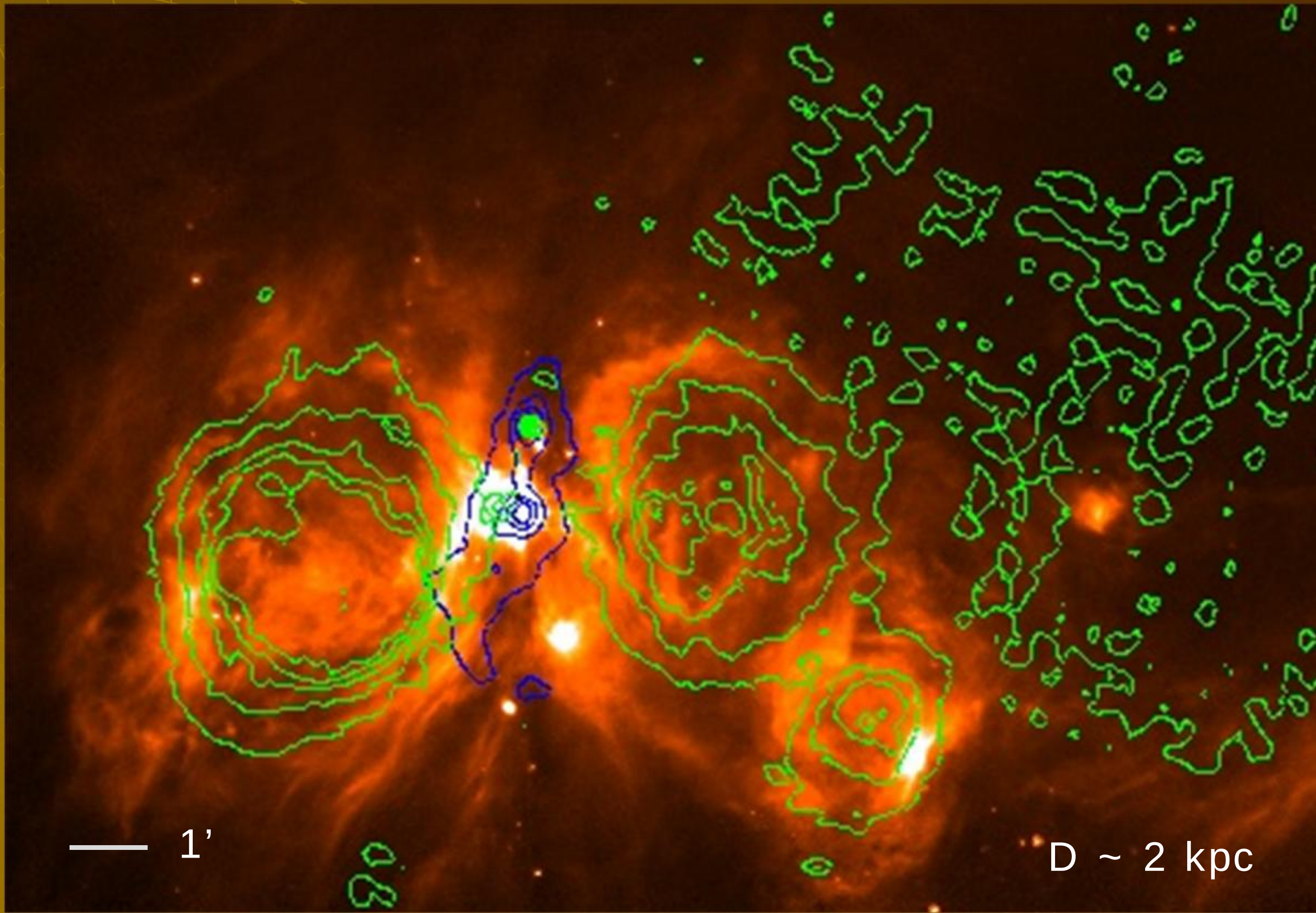
Motivation

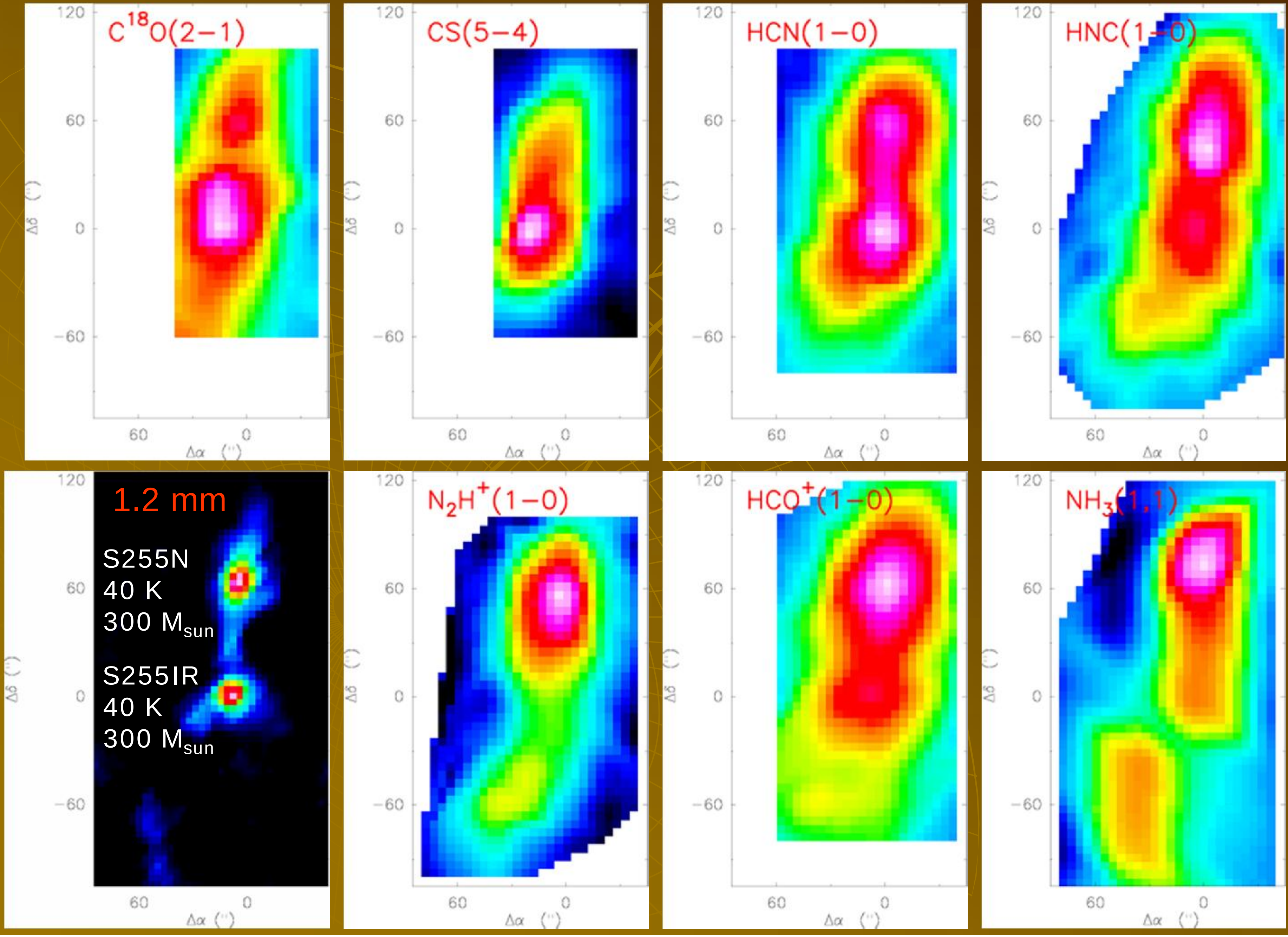
- Detailed study of high mass star forming cores at various stages of evolution.
- S255 is one of the most promising candidates.

S255 star forming region



GMRT 610 MHz (green) and IRAM 30m 1.2 mm (blue) contours overlaid on the Spitzer 8 µm image

Single-dish multi-line observations of S255



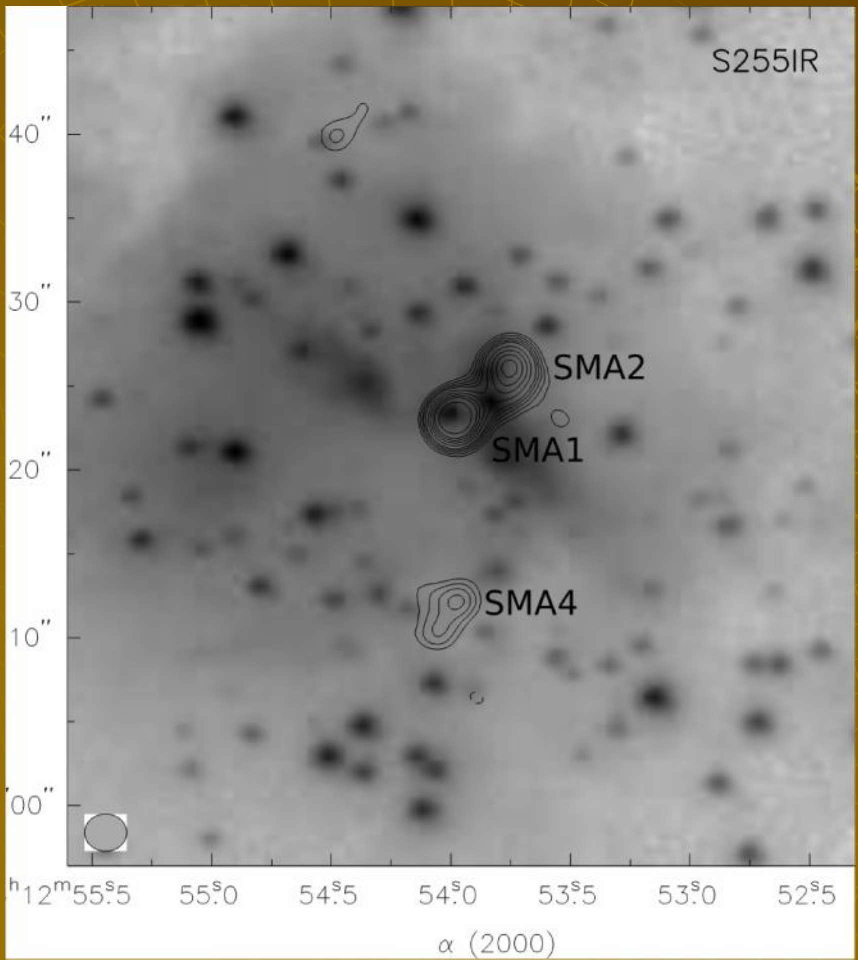
Multi-frequency interferometric observations: SMA, VLA and GMRT

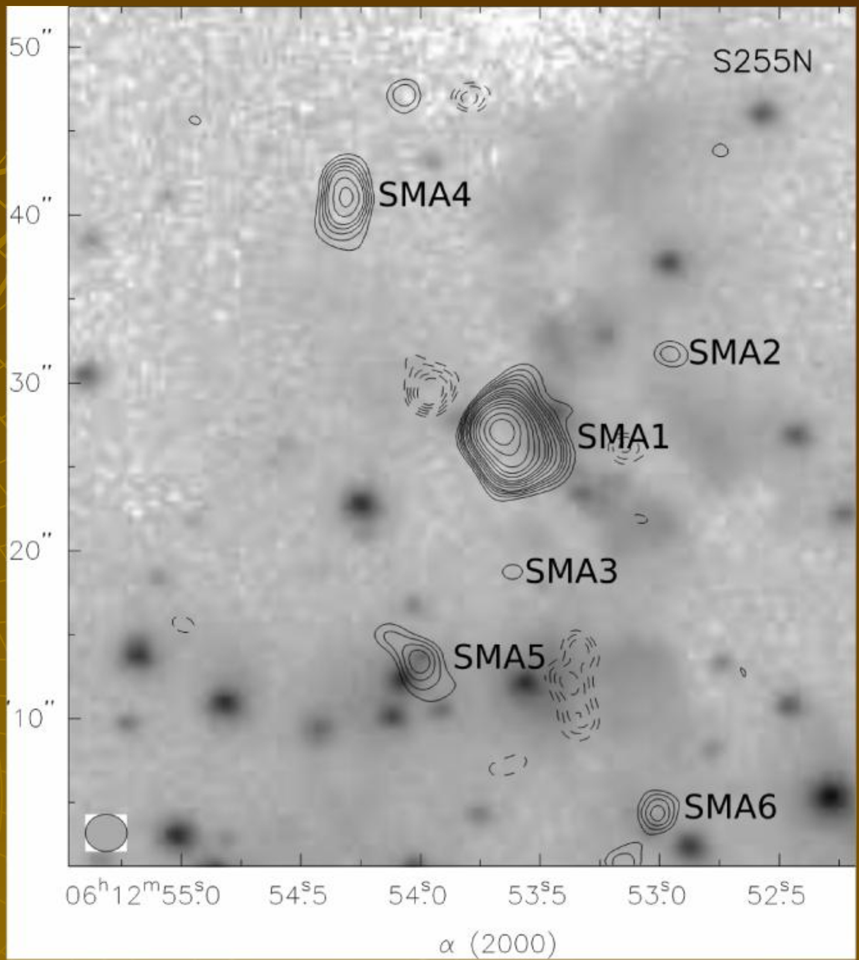
216.8-220.8 GHz $\theta \sim 2.5''$,
228.8-232.8 GHz $0.4''$
277.9-279.9 GHz
287.9-289.9 GHz
342.0-346.0 GHz $\theta \sim 2''$
354.0-358.0 GHz
Continuum and multiple (several tens) spectral lines

NH_3 (1,1) & NH_3 (2,2) at 1.3 cm
$\theta \sim 2.5''$

Continuum at 23 and 50 cm
$\theta \sim 4''$

New continuum clumps





Clump parameters

Table 4

Velocities and Physical Parameters (Line Width, Linear Size, Kinetic Temperature Derived from Ammonia Observations, *Assumed* Dust Temperature, Mass, Virial Mass, and Mean Density) of the Millimeter Wave Continuum Sources

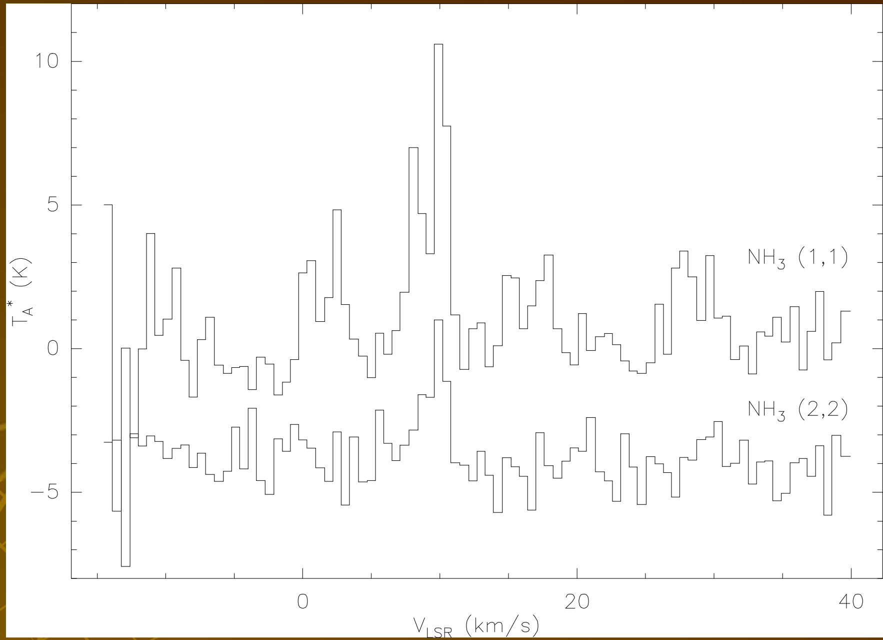
Name	V_{LSR} (km s^{-1})	ΔV (km s^{-1})	L (pc)	$T_{kin}(NH_3)$ (K)	T_d[a] (K)	M ($M_\odot$)	M_{vir} ($M_\odot$)	$\bar{n}$ (cm^{-3})
S255IR-SMA1	4.4	3.3	0.012	240, (80 ?)	40	10	14	2×10^8
S255IR-SMA2	9.2	2.0	0.031	44	40	10	13	10^7
S255IR-SMA4	7.9	2.6	0.048	$\lesssim$20	20	14	34	4×10^6
S255N-SMA1	8.0	3.5	0.030	29, (>200 ?)	30	23	39	3×10^7
S255N-SMA2	8.7	3.0	0.028		20	2	26	4×10^6
S255N-SMA3	9.0	<2	0.037	29	30	2	<10	10^6
S255N-SMA4	7.0	4.2	0.020		20	8	40	2×10^7
S255N-SMA5	9.5	3.9	0.048	24	25	7	80	2×10^6
S255N-SMA6	8.9	4.5	0.039		20	6	80	4×10^6

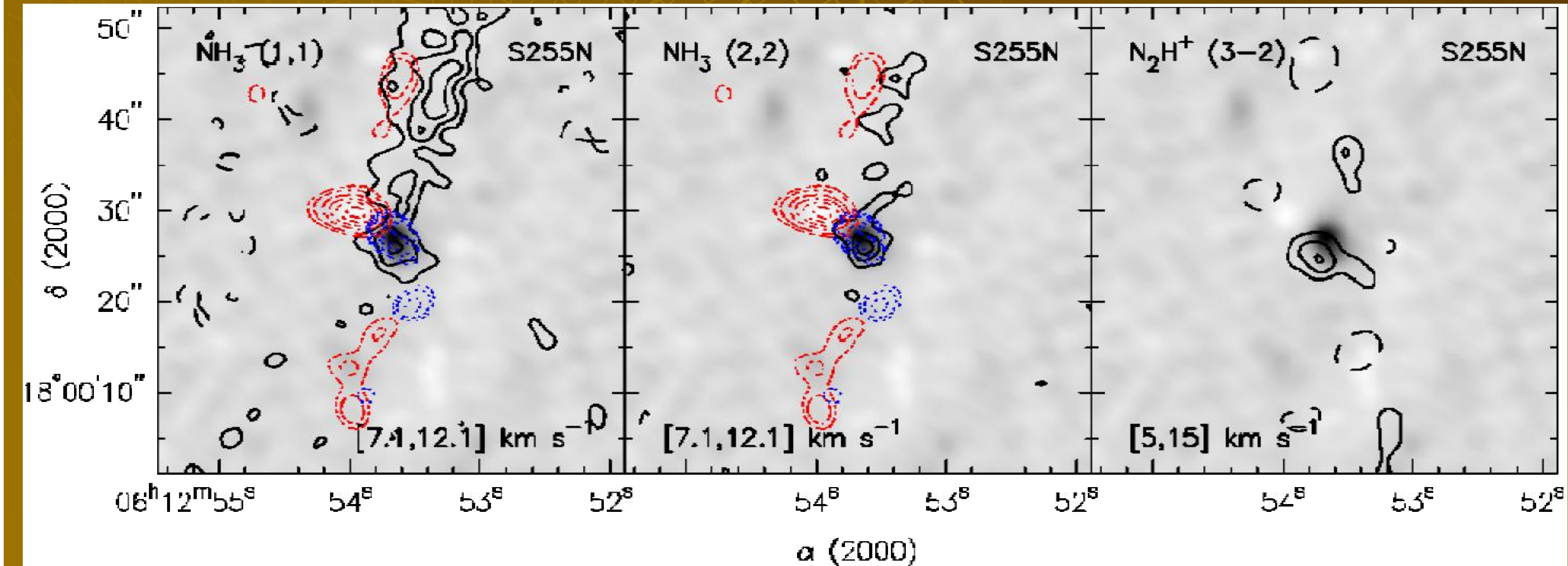
Note. [a] Assumed.

Zinchenko et al. ApJ 755, id.177 (2012)

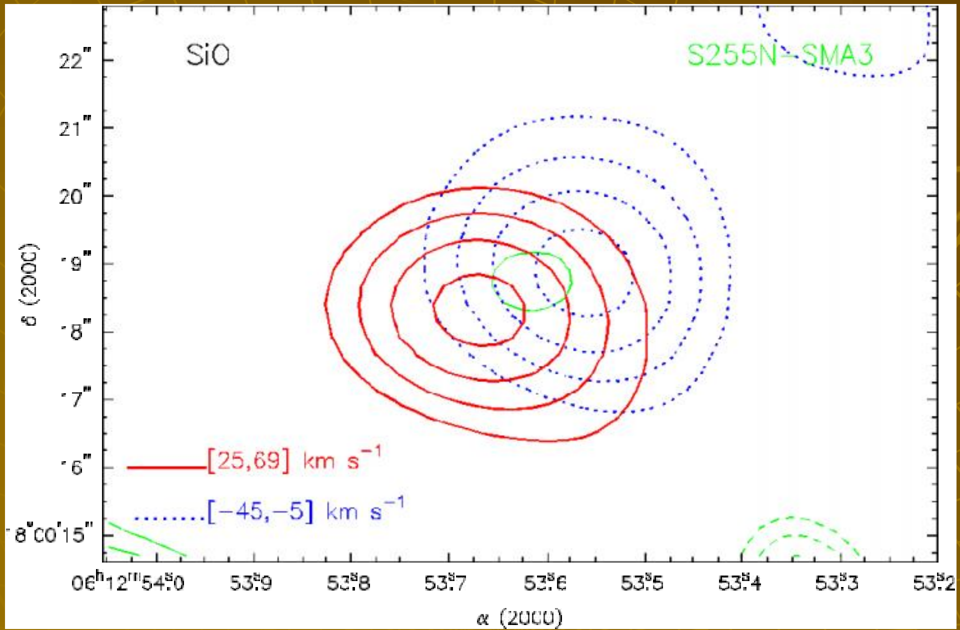
An ammonia source in S255N

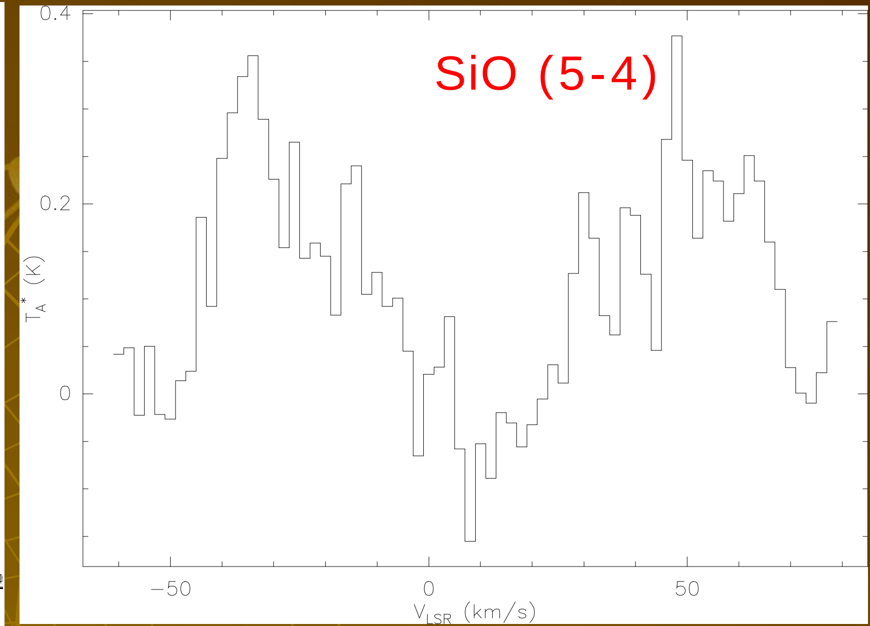
Two velocity components:
8 km/s (T ≈ 13 K)
10 km/s (T ≈ 23 K)
The source is associated with the high velocity CO emission.





Very young outflows in the S255N area

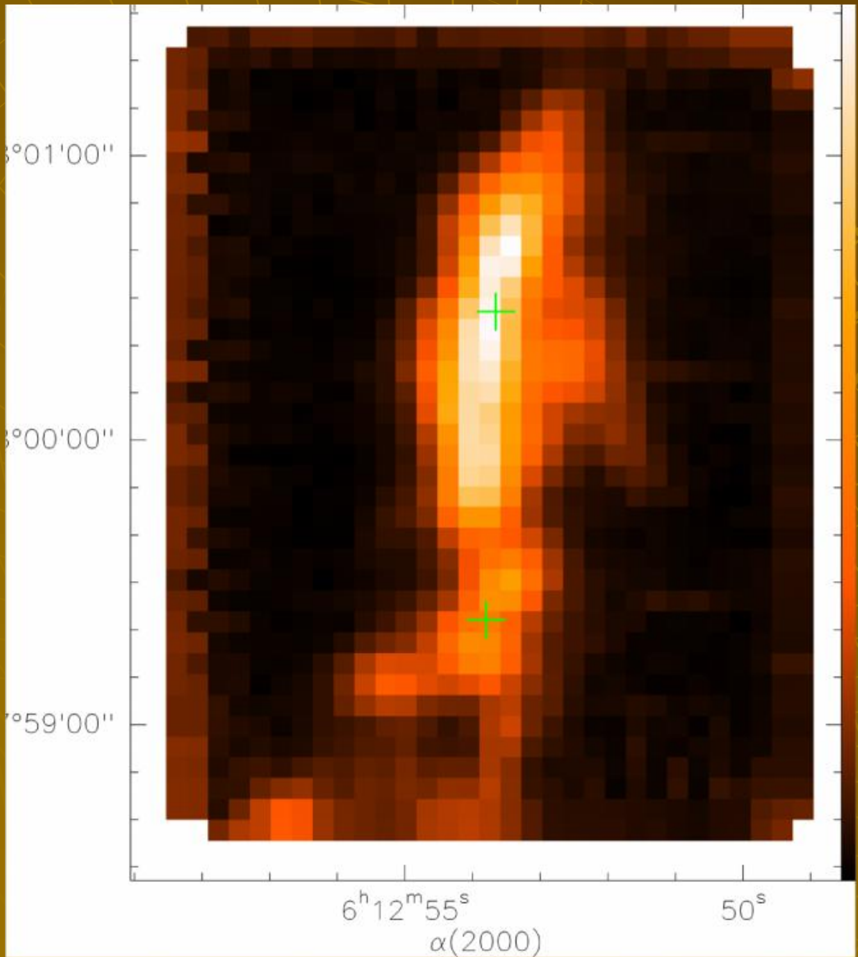




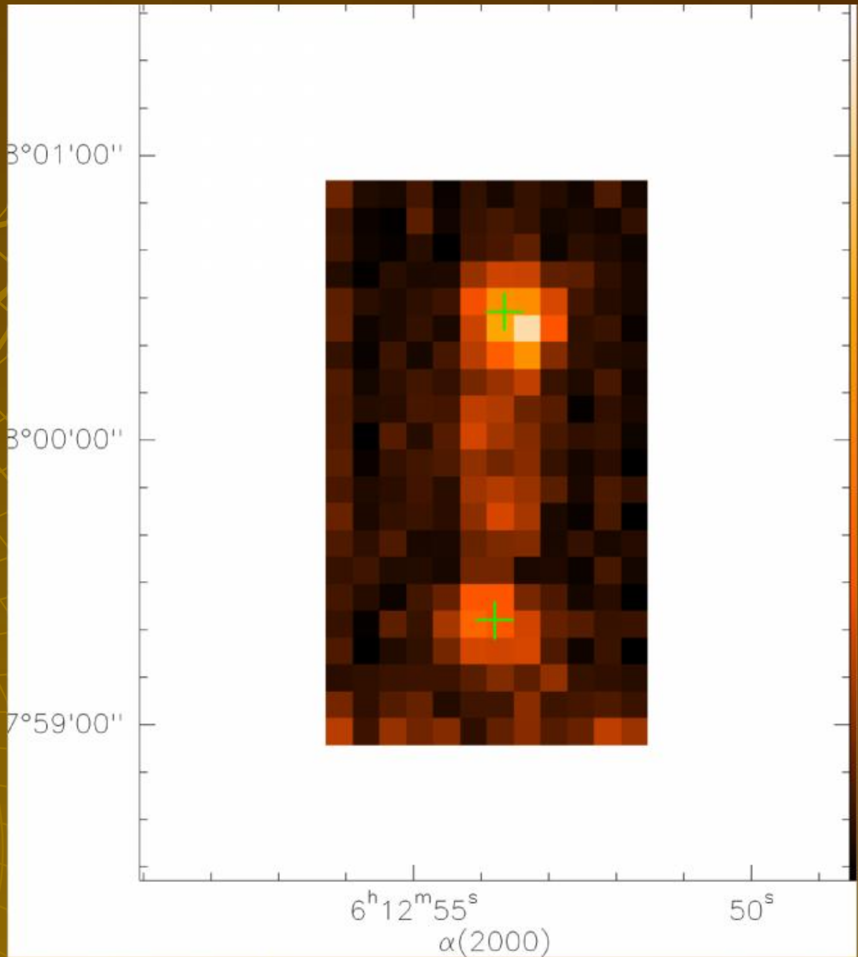
Parameters of the Outflows in S255N-SMA3 and S255N-SMA5 (Mass, Momentum, Energy, Size, Age, Mass Loss Rate, and Mechanical Force)

Name	M ($M_\odot$)	P ($M_\odot$ km s^{-1})	E (erg)	Size (pc)	t (yr)	$\dot{M}$ ($M_\odot$ yr^{-1})	F ($M_\odot$ km s^{-1} yr^{-1})
S255N-SMA3	0.003	0.15	8×10^{43}	0.009	200	2×10^{-5}	8×10^{-4}
S255N-SMA5	0.012	0.36	10^{44}	0.012	400	3×10^{-5}	9×10^{-4}

IRAM-30m observations



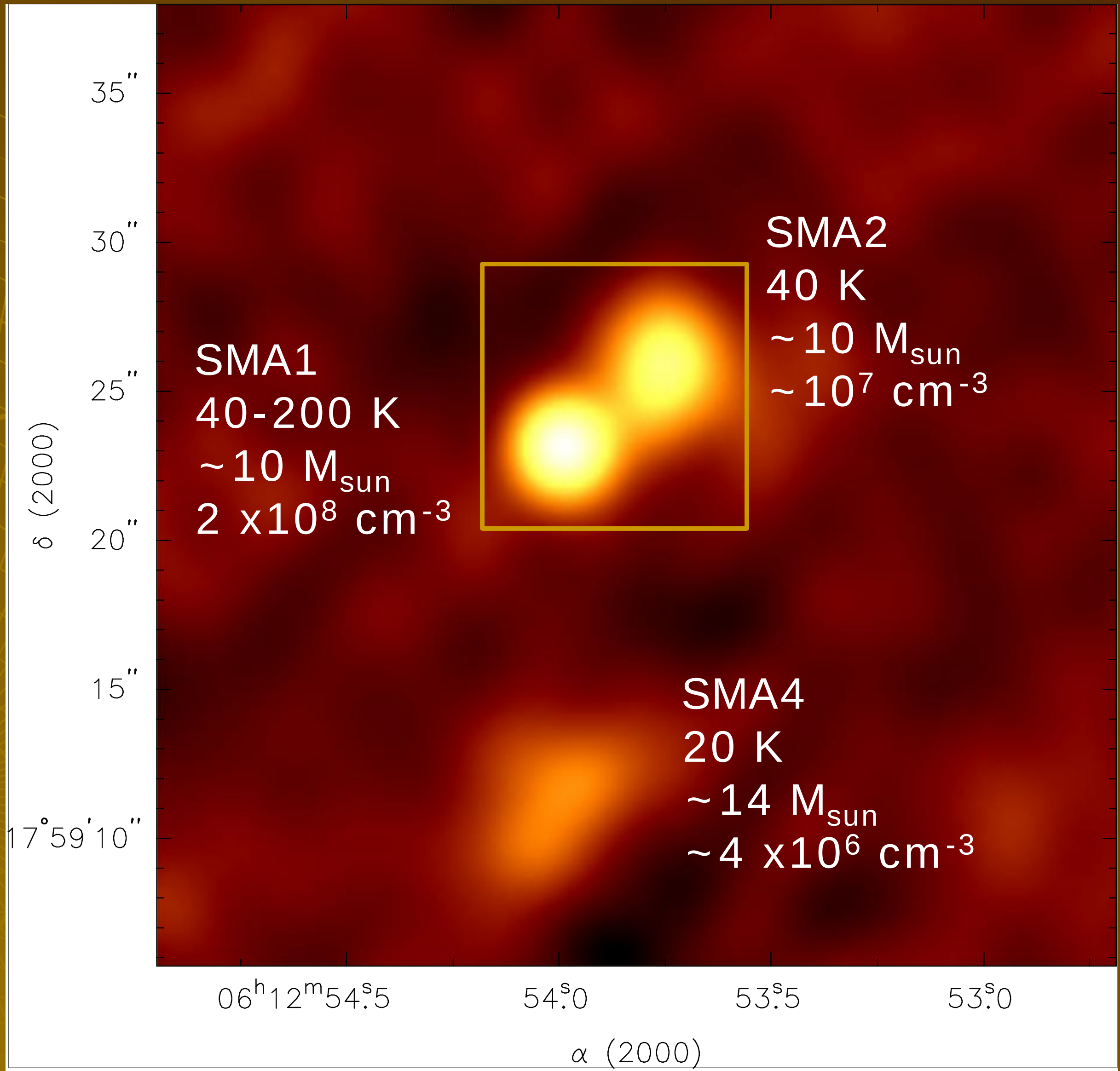
N_2H^+ (3-2)



SiO (5-4)

Masses and densities

Masses and beam averaged volume densities estimated from dust continuum emission at 1.1 mm. Temperatures are derived from ammonia observations.

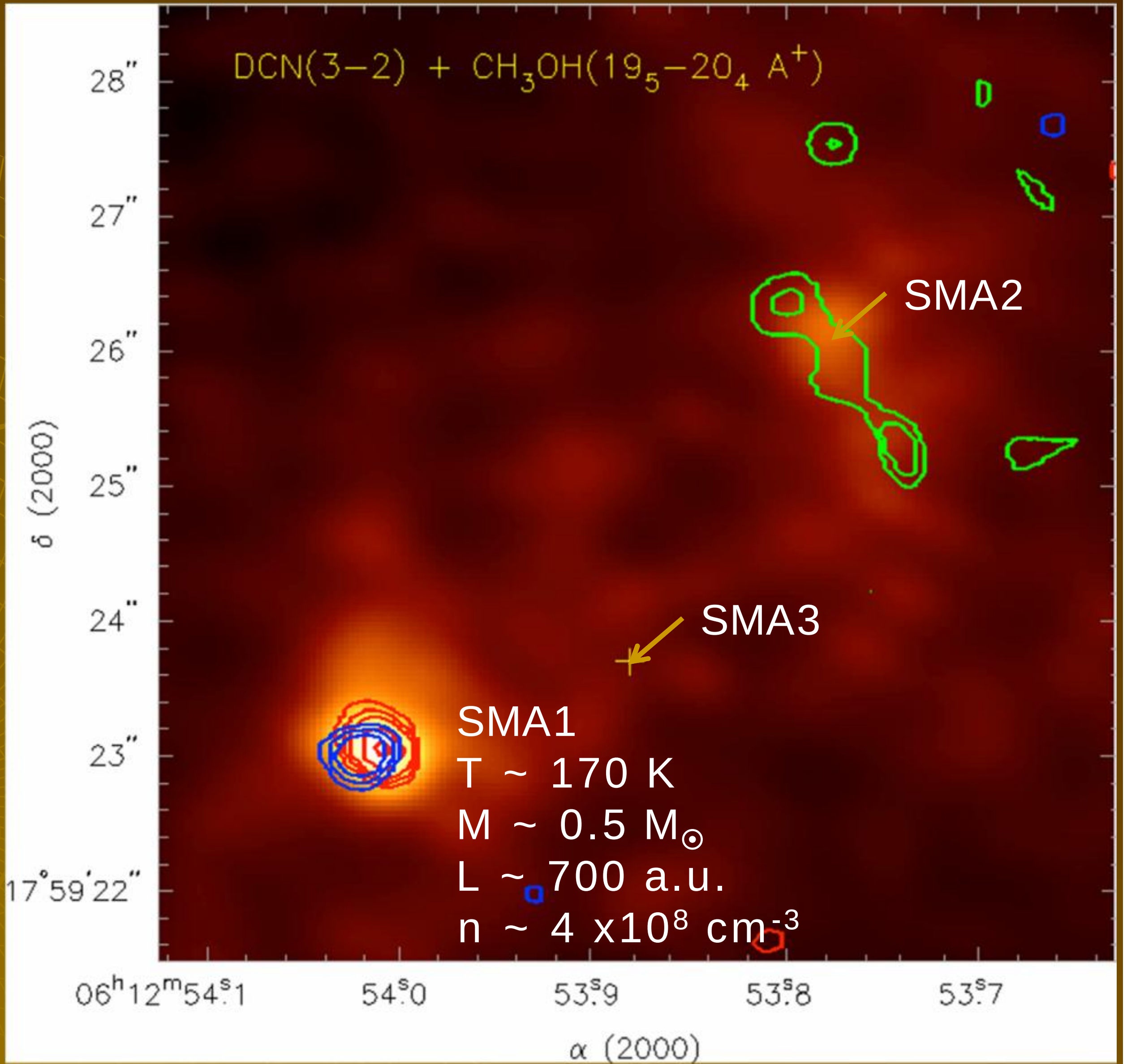


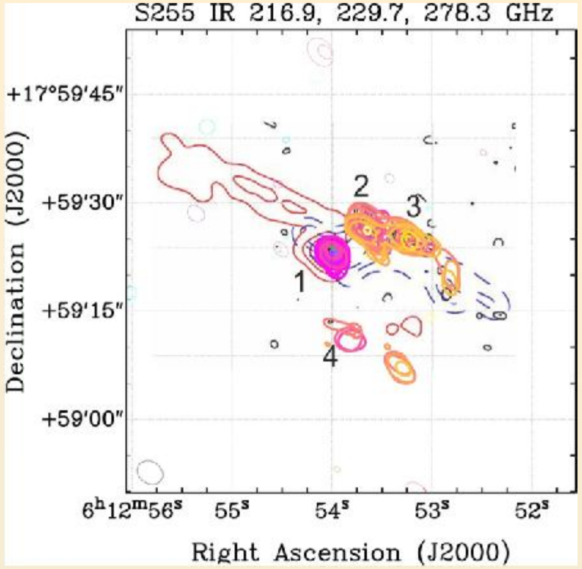
S255IR at sub-arcsecond resolution

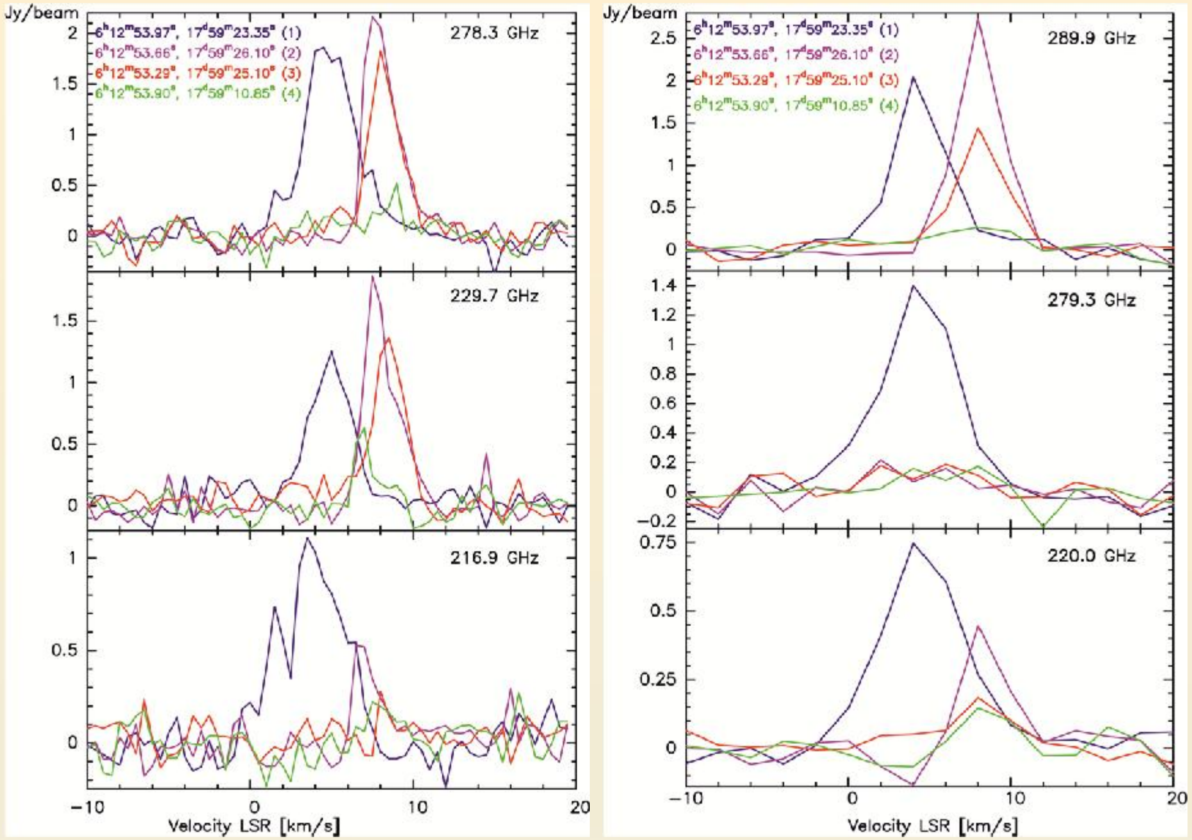
The dynamical mass of the hot core derived from the line widths is ~ 20 $M_\odot$, which is consistent with the estimated mass of the central B1 star.

The surface filling factor for the hot gas is about 0.2.

A rather strong DCN emission is observed towards the hot core at the same velocity as the hot gas. This implies a presence of a cold material here.



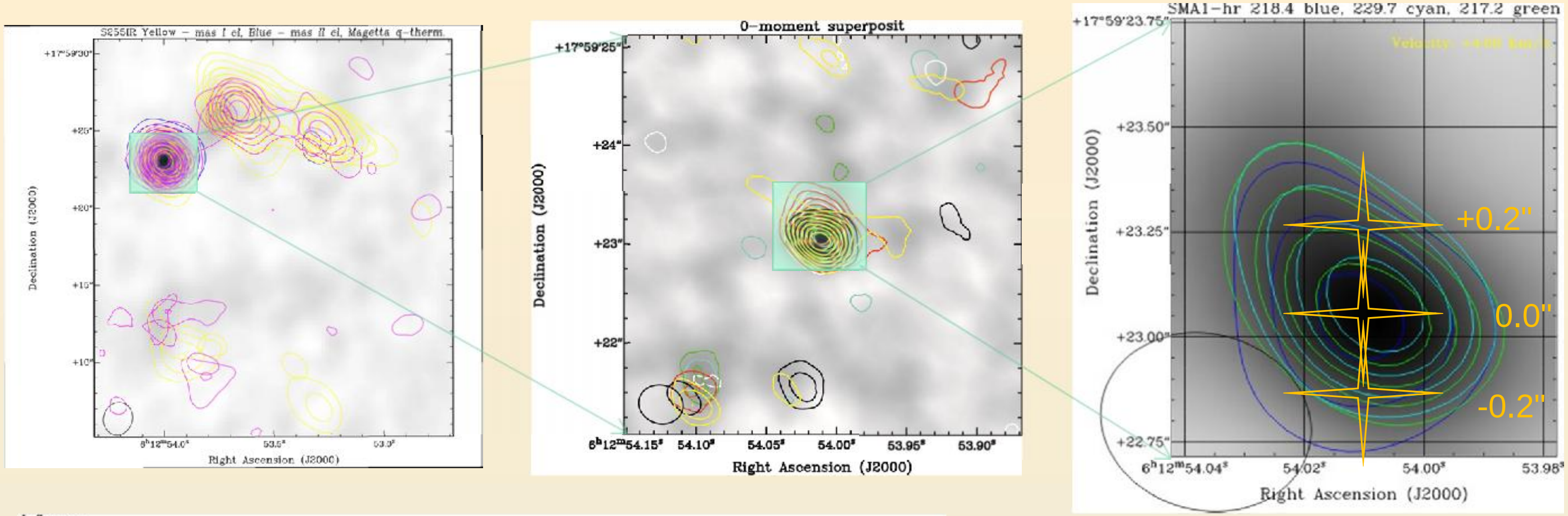


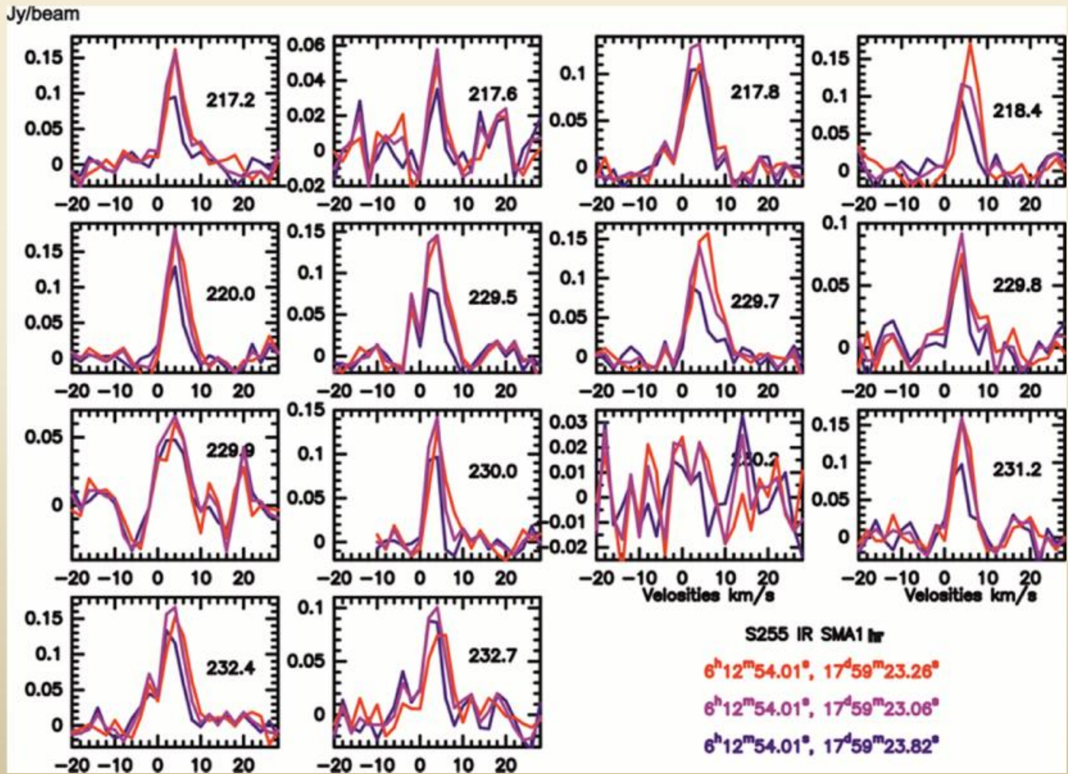


№	Freq. (MHz)	E_{up} (K)
1	216945.60	48.0
2	218440.05	37.6
3	220078.49	88.7
4	229589.07	366.5
5	229758.81	81.2
6	230027.00	31.9
7	278304.57	102.1
8	278599.08	331.8
9	289939.39	54.0
10	343601.49	616.1
11	344109.13	411.5
12	217299.20	373.9
13	231281.15	165.3
14	232418.57	165.4
15	279351.91	190.9
16	342729.78	227.5
17	344443.90	451.2
18	345903.97	332.7
19	355603.11	211.0

Name	α(2000)	δ(2000)
S255IR-SMA1	6:12:53.98	17:59:23.1
S255IR-SMA2	6:12:53.75	17:59:25.7
S255IR-SMA4	6:12:54.03	17:59:11.5
S255IR-3	6:12:53.30	17:59:24.8

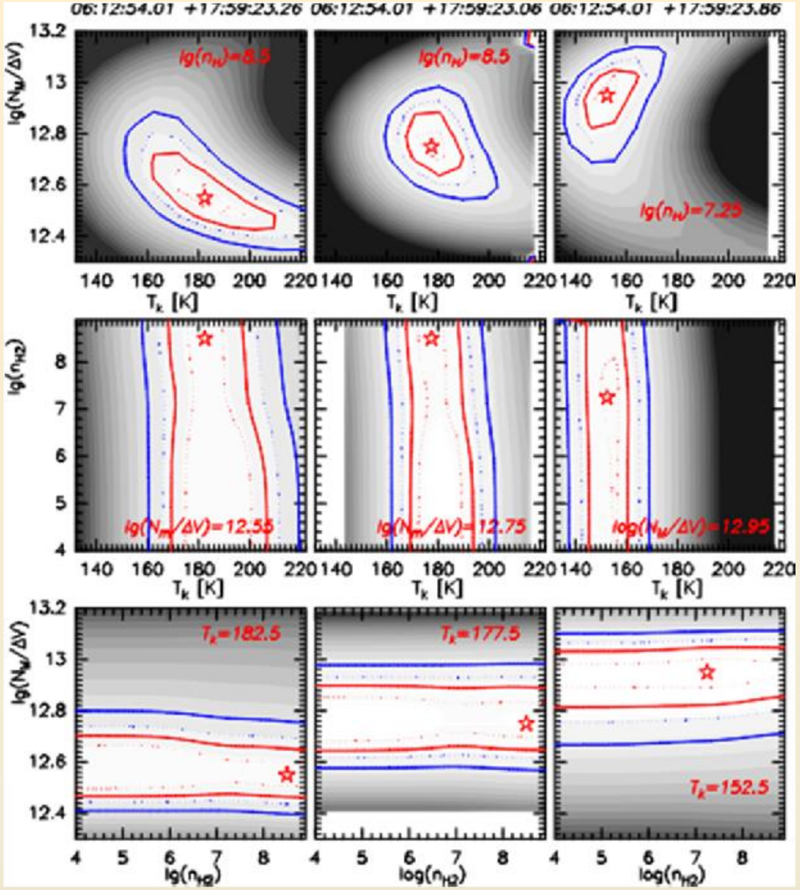
npos	T_k (K)	$\lg(N_{CH3OH}/\Delta V)$	$\lg(n_{H2})$	fil. fac. (% from 4”)
S255IR 1	220	12.00	9.0	0.39
S255IR 2	50	9.50	6.5	2.36
S255IR 3	155	8.75	5.5	2.21
S255IR 4	105	10.25	5.5	0.73

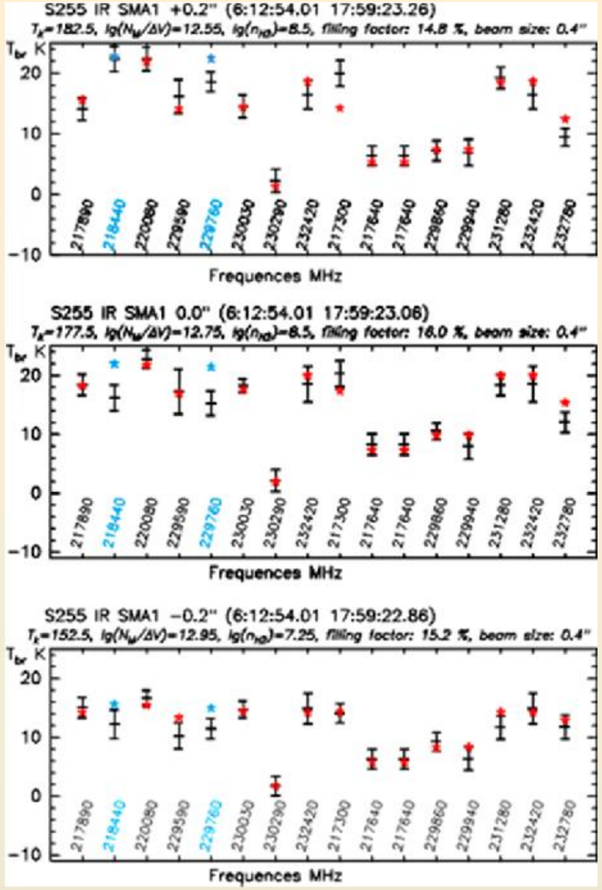




npos	α (2000)	δ (2000)
+0.2''	6:12:54.01	17:59:23.26
0.0''	6:12:54.01	17:59:23.06
-0.2''	6:12:54.01	17:59:22.82

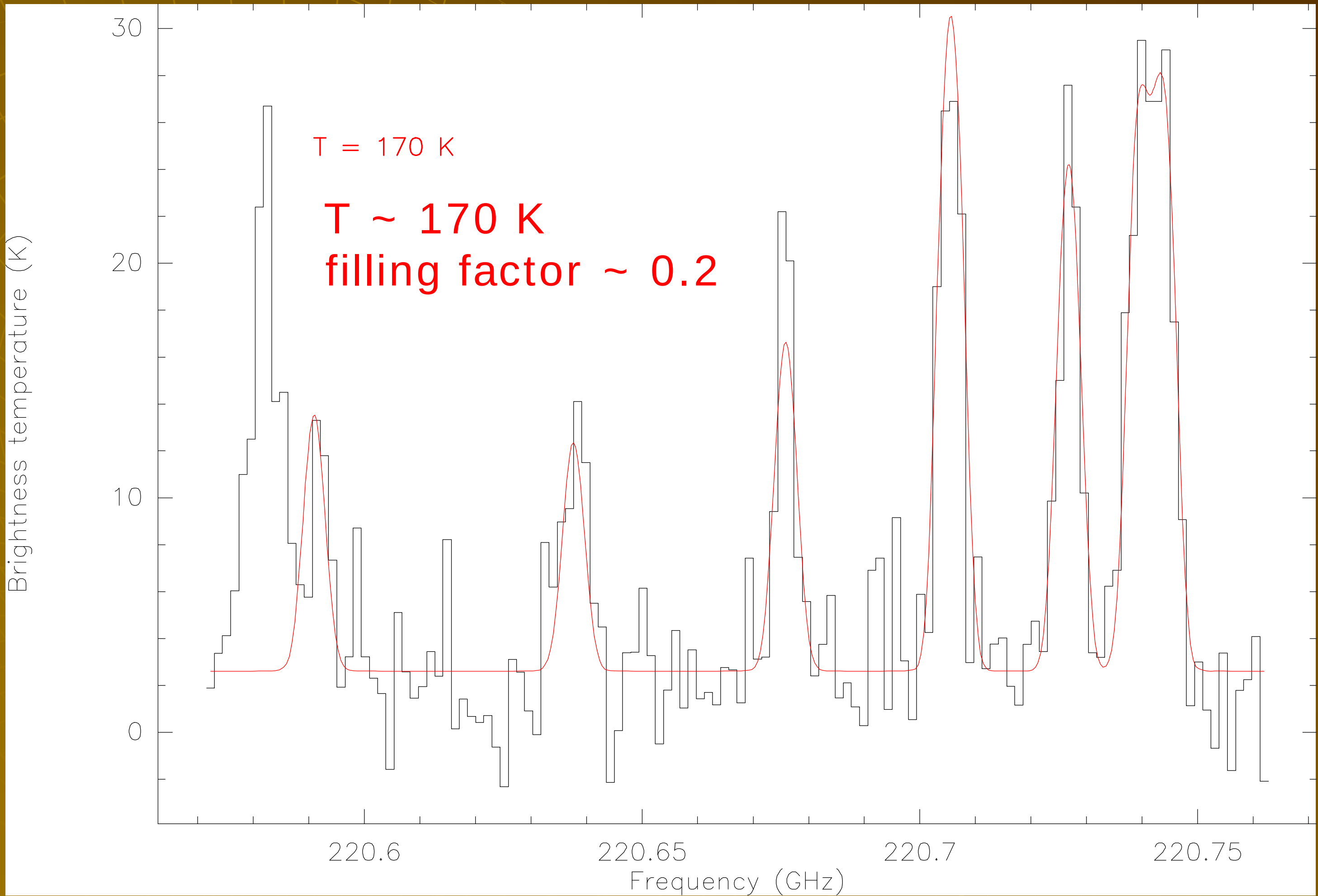
№	Freq. (MHz)	E $_{up}$ (K)
1	217886.39	500.5
2	218440.05	37.6
3	220078.49	88.7
4	229589.07	366.5
5	229758.81	81.2
6	230027.00	31.9
7	230292.73	601.7
8	232419.50	649.2
9	217299.20	373.9
10	217642.86	745.6
11	229864.22	578.6
12	229939.18	578.6
13	231281.15	165.3
14	232418.57	165.4
15	232783.59	446.5





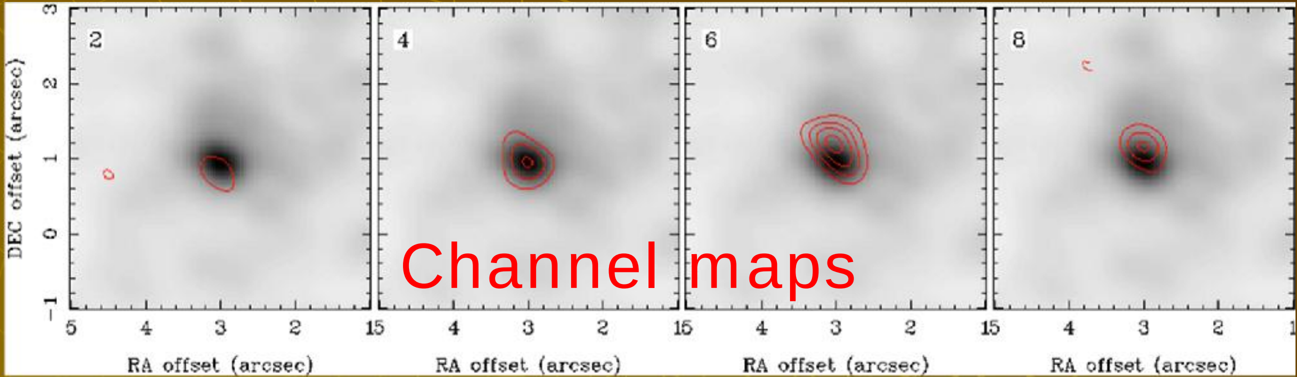
npos	T_k (K)	lg(N_{CH3OH}/ΔV)	lg(n_{H2})	fil. fac. (%)
+0.2''	182.5 (170-200)	12.55 (12.45-12.70)	(3.5-9.0)	14.8
0.0''	177.5 (165-195)	12.75 (12.60-12.98)	(3.5-9.0)	16.0
-0.2''	152.5 (140-165)	12.95 (12.70-13.10)	7.25 (3.5-9.0)	15.2

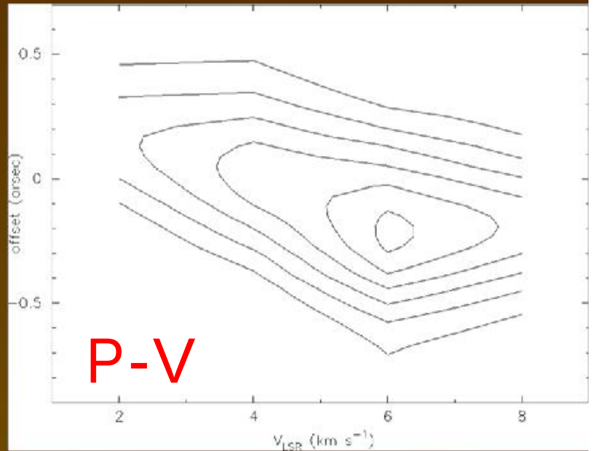
Hot core temperature from CH_3CN

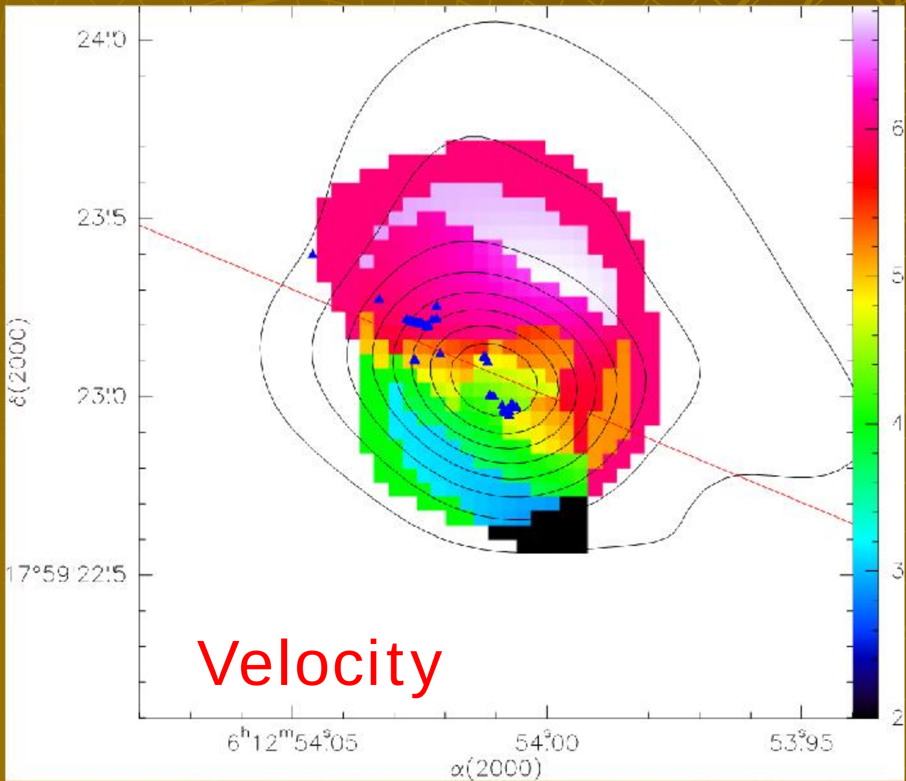


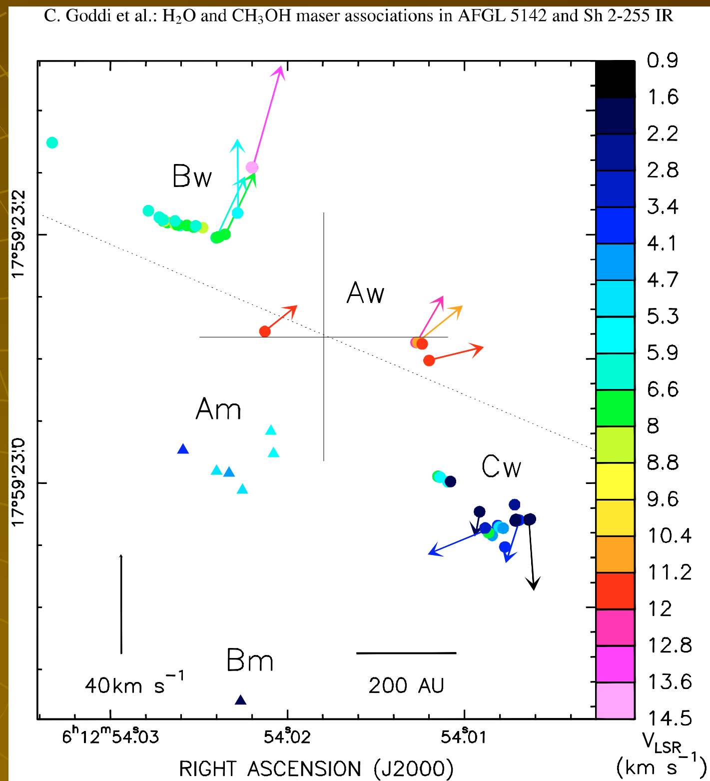
Core rotation

CH_3OH 4_2-3_1 E maps

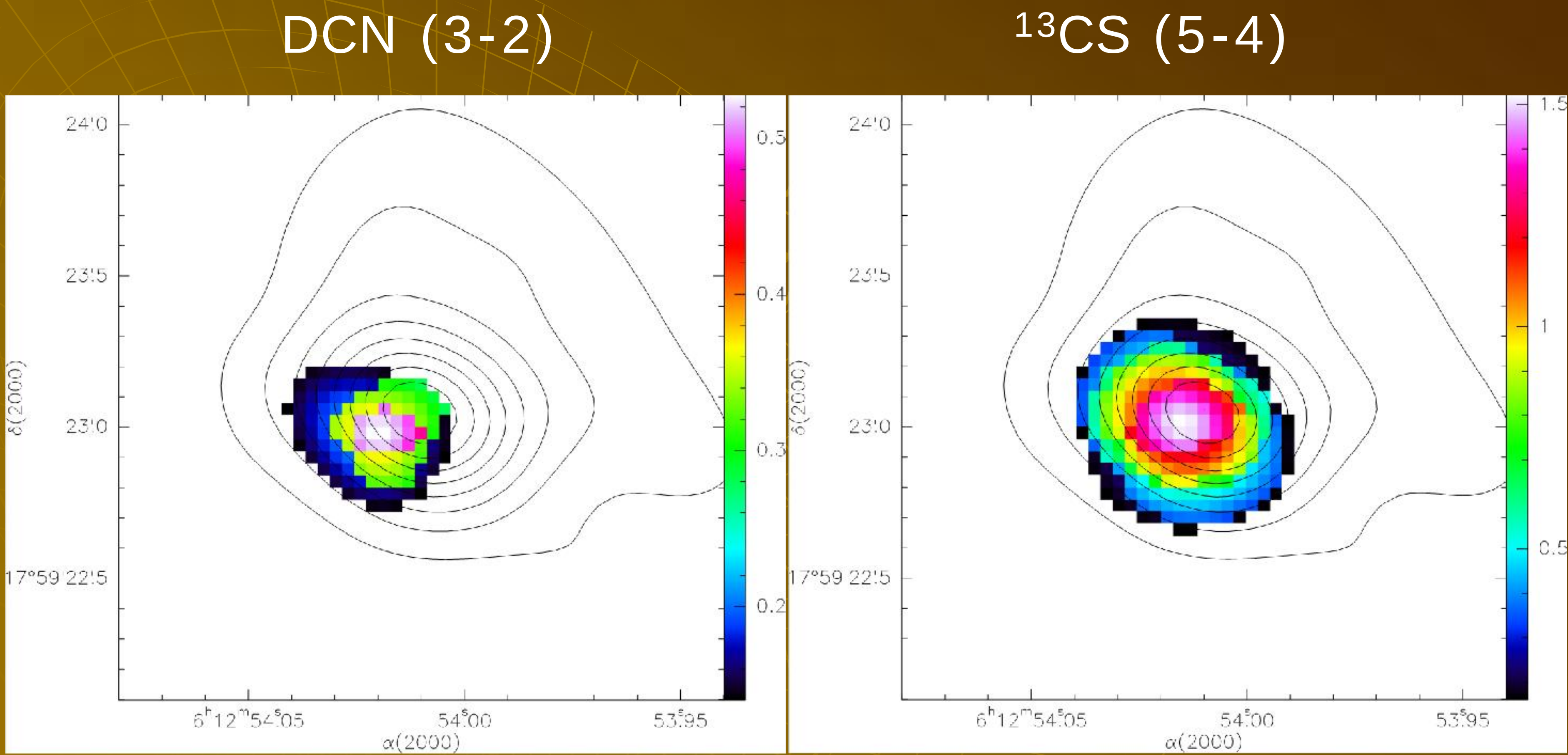






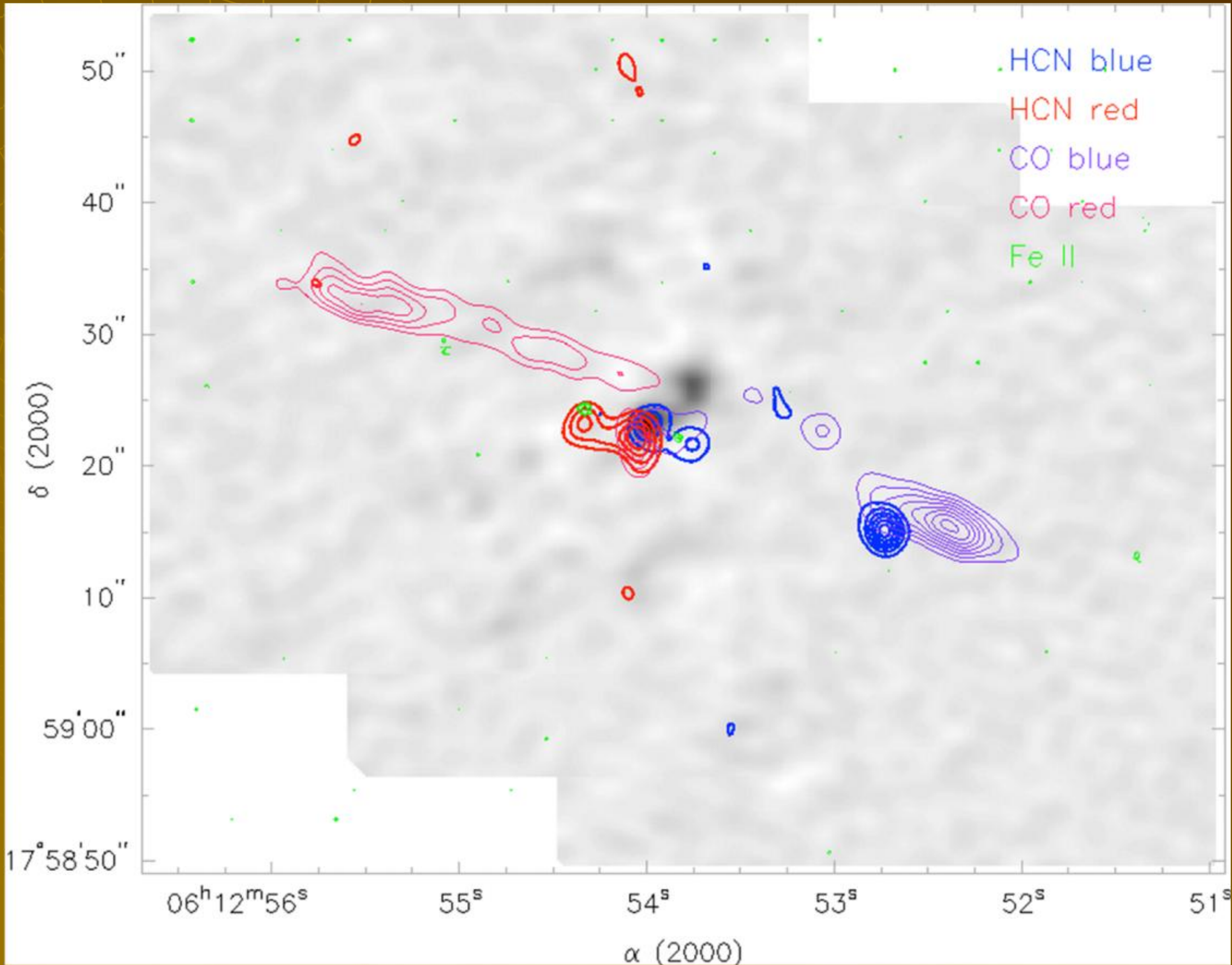


DCN in the hot core

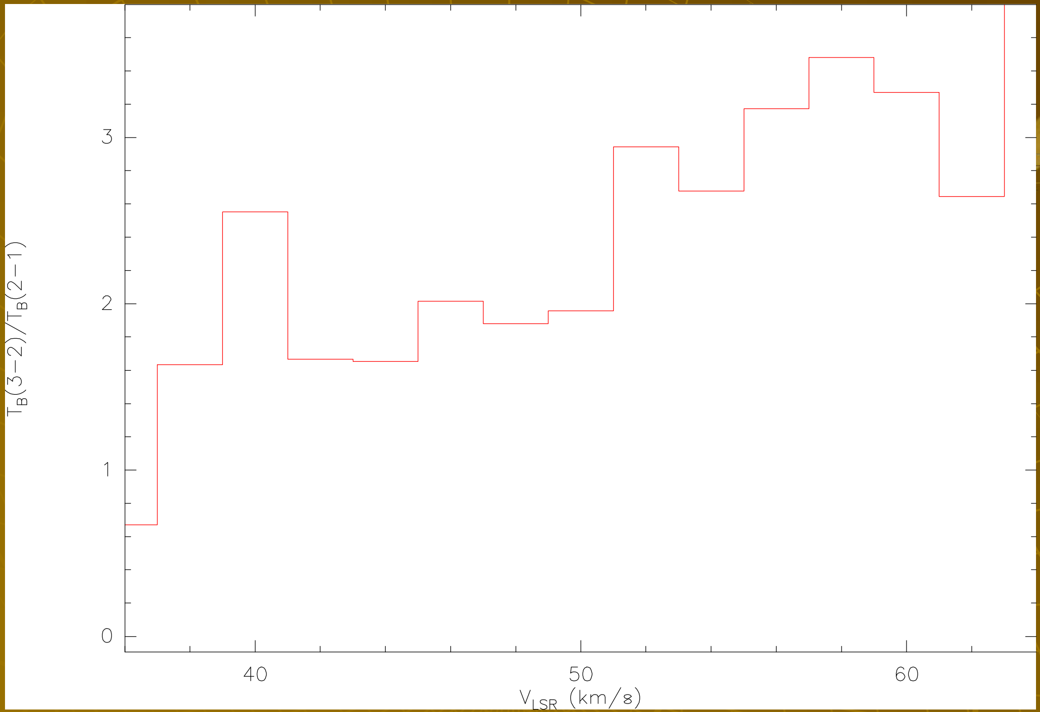


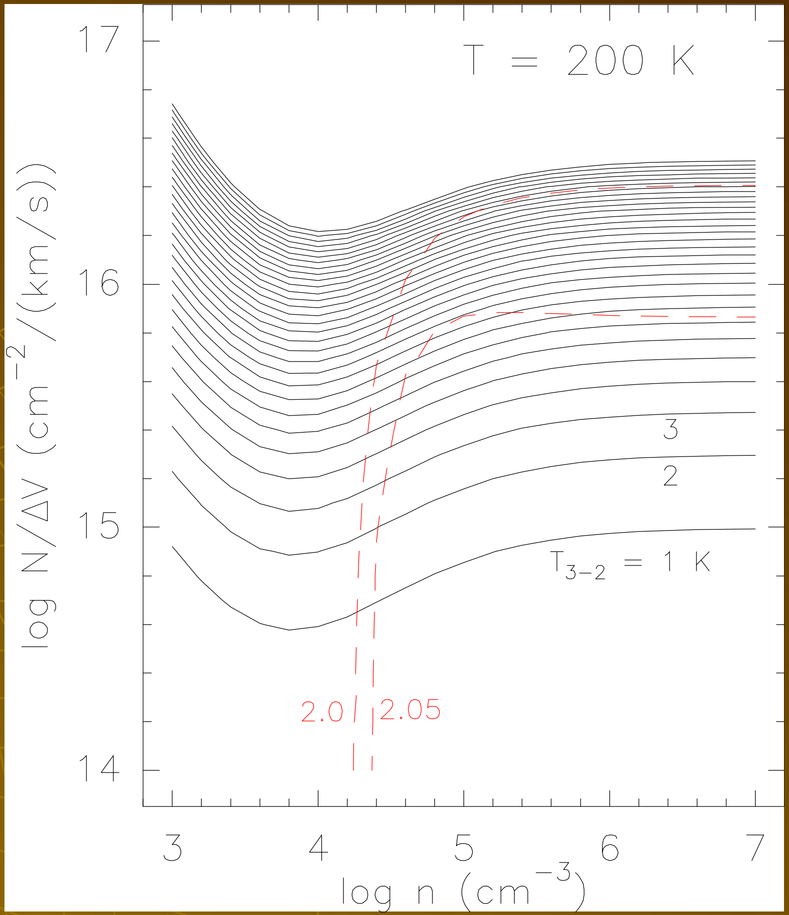
DCN abundance is ~ 3 10^{-11}.
A low temperature or a very young age are implied.

Molecular outflows in S255IR: CO (3-2) and HCN (4-3)



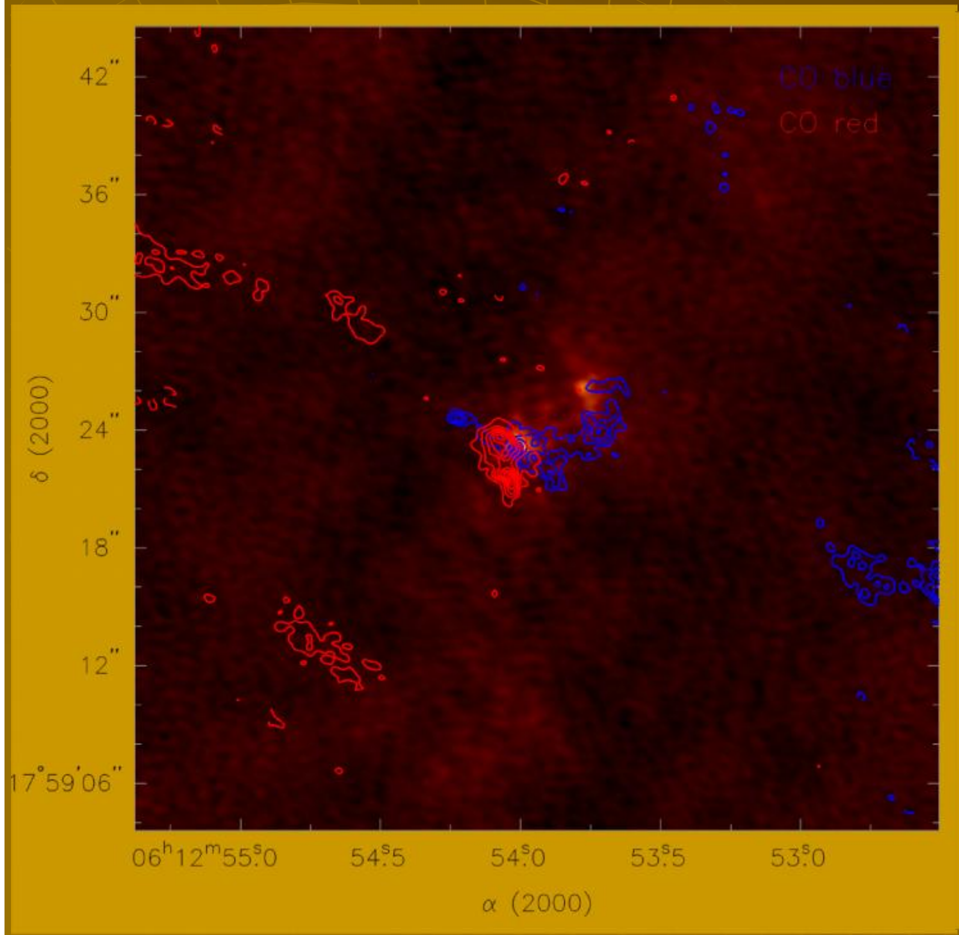
Outflow parameters from the CO(3-2)/CO(2-1) intensity ratio

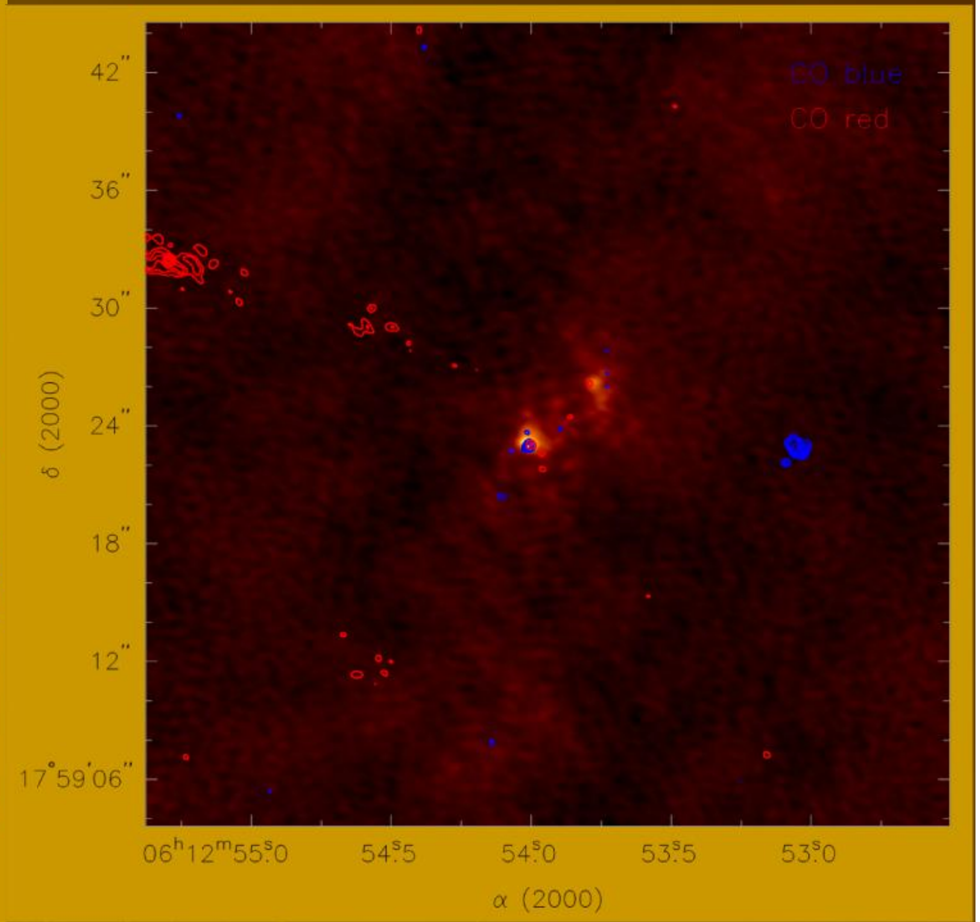




The CO emission is apparently optically thin. High temperature and density are implied. The excitation increases with velocity.

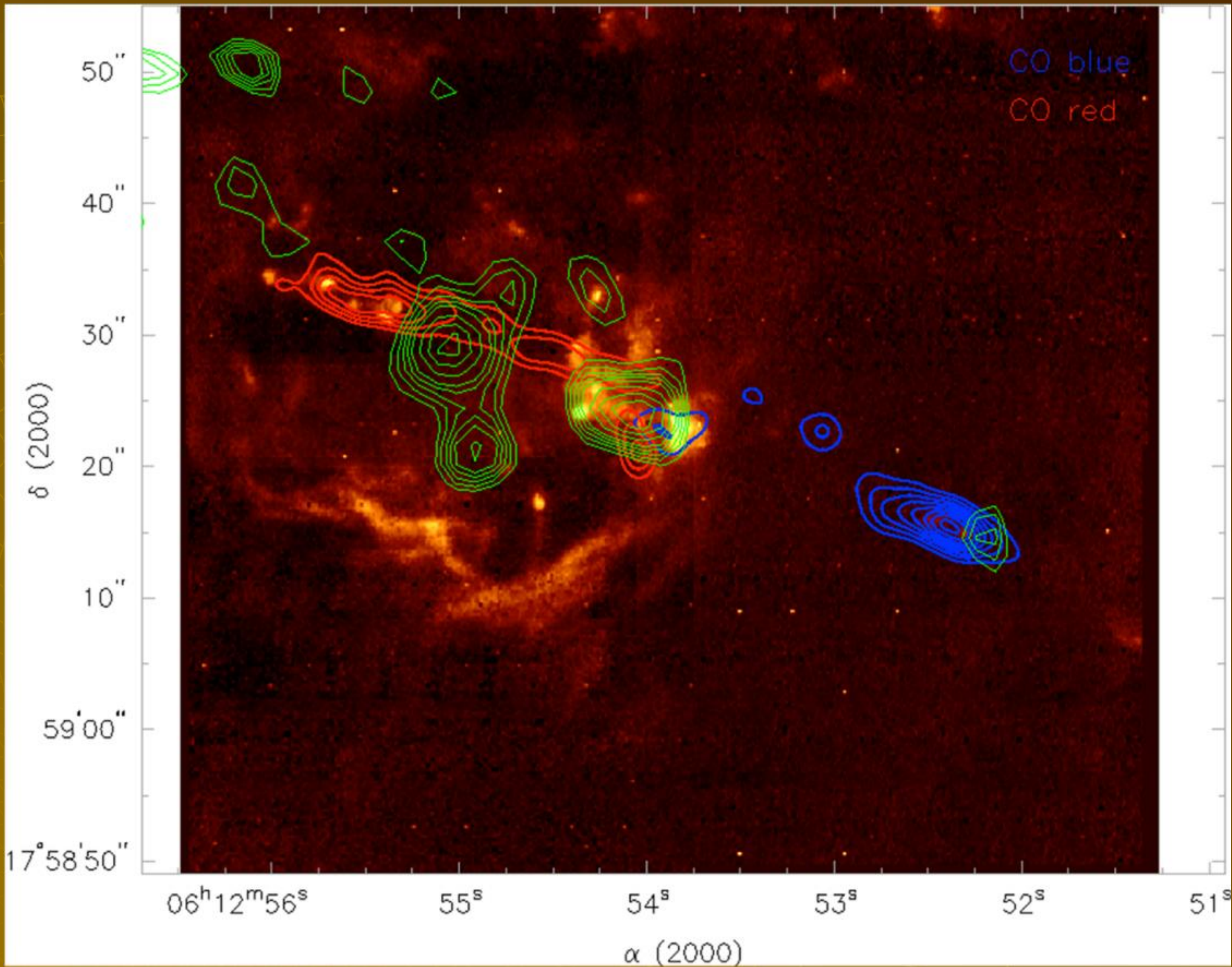
Molecular outflows in S255IR: CO (2-1) at high resolution



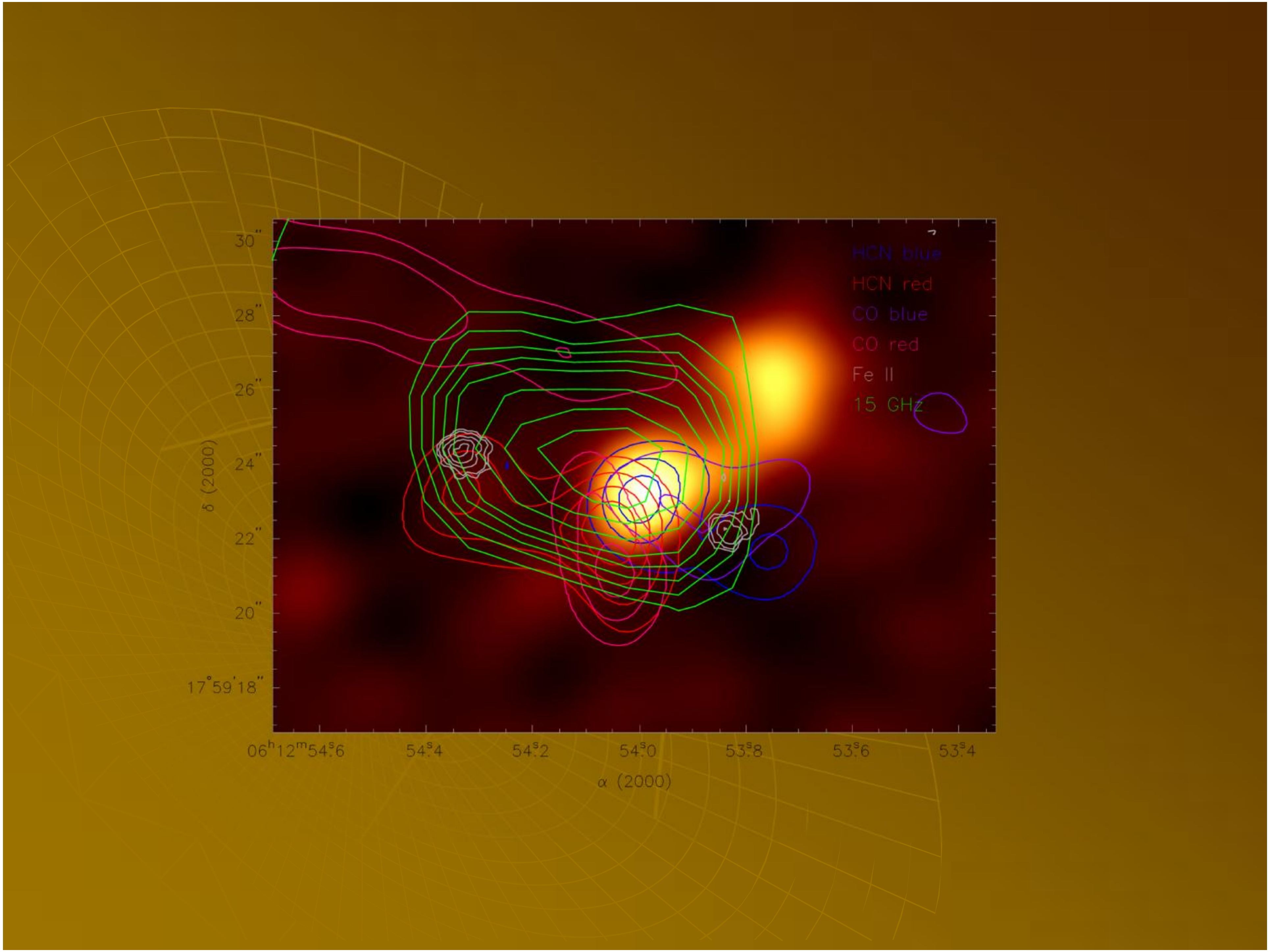


[-51, -7] km/s
[19, 71] km/s

[-51, -39] km/s
[51, 71] km/s

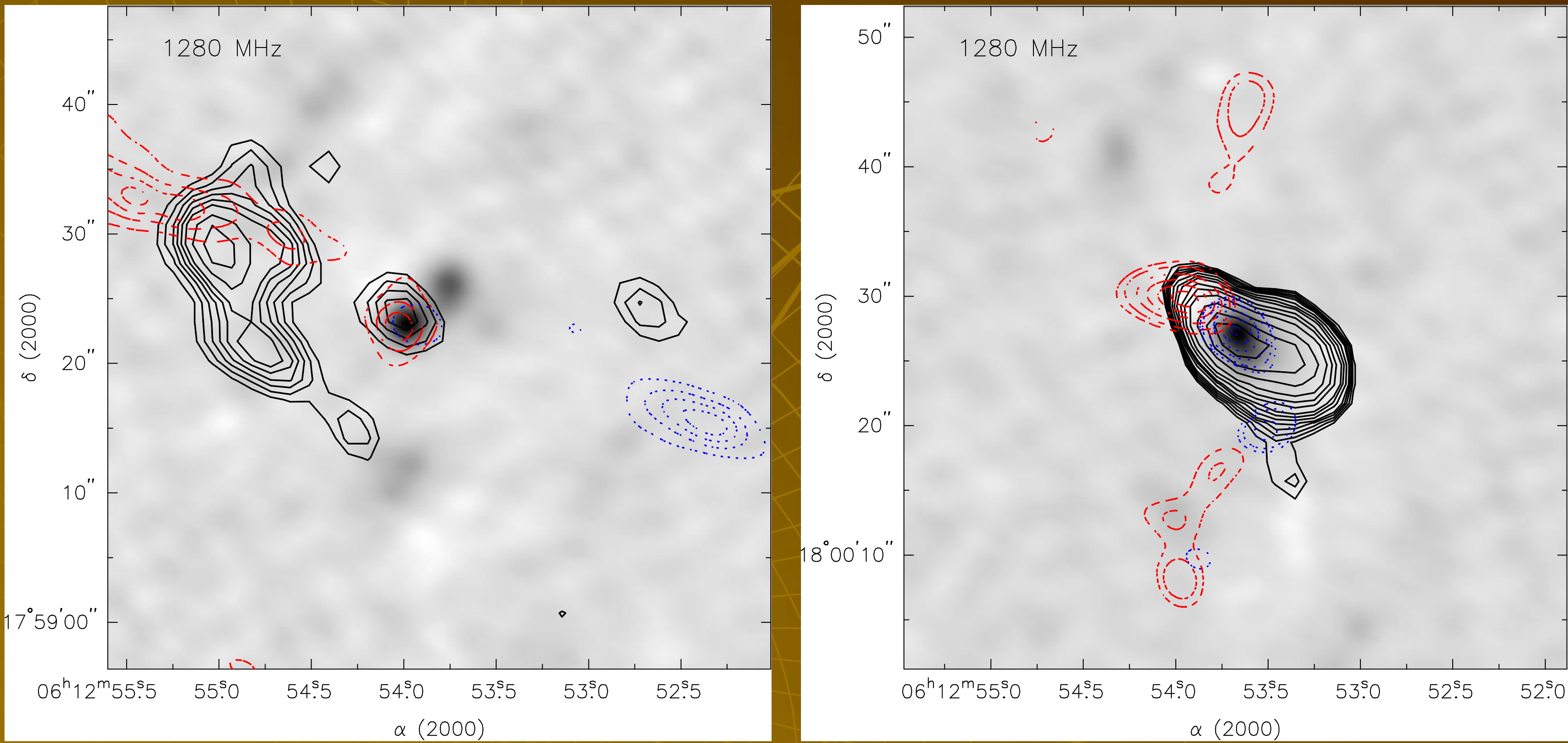


The color image shows the H_2 emission. The green contours indicate the 15 GHz radio continuum (from VLA). The blue and red contours show the CO(3-2) high velocity emission.

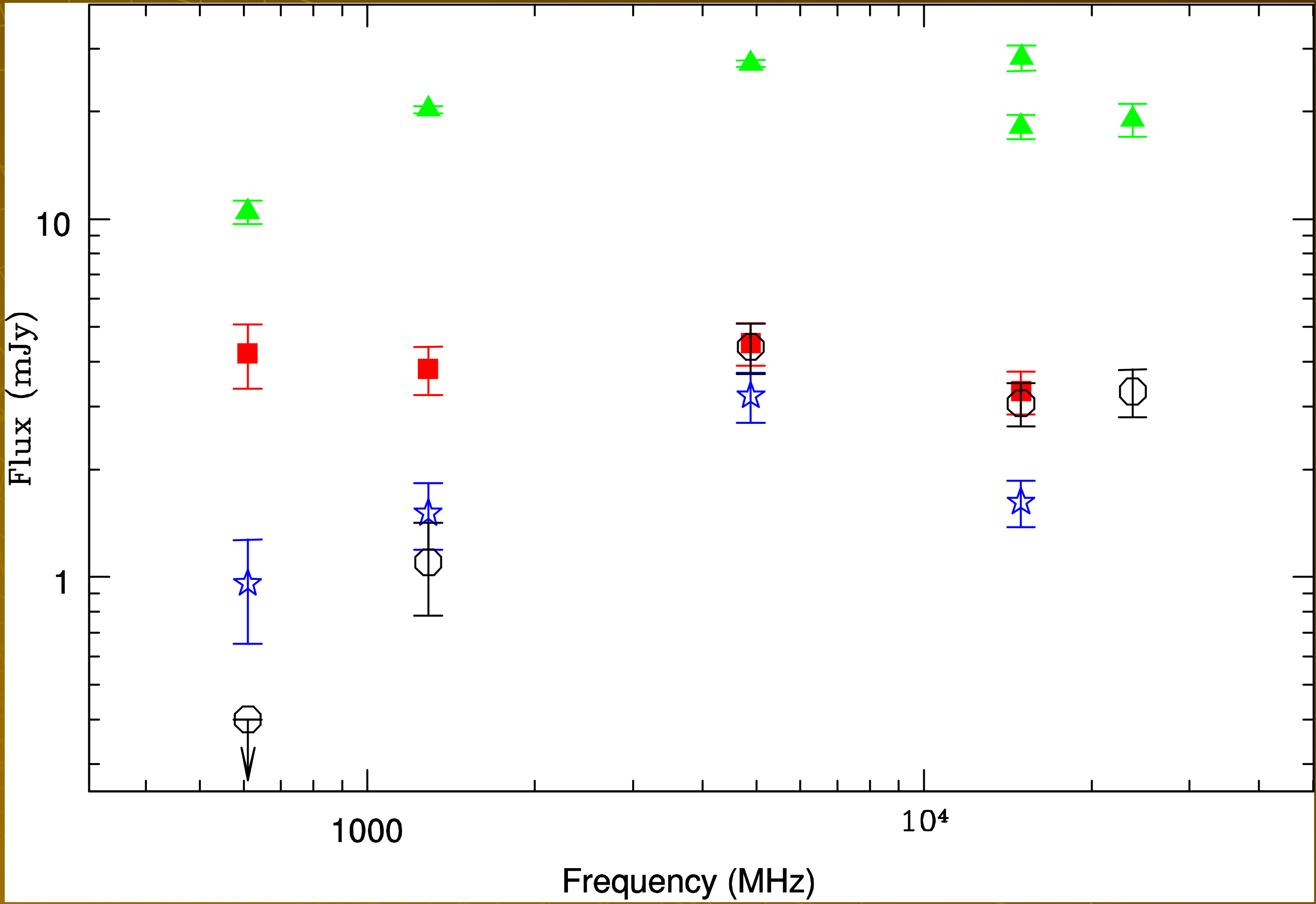


HCN blue
HCN red
CO blue
CO red
Fe II
15 GHz
30"
28"
26"
24"
22"
20"
17°59'18"
δ (2000)
06h12m54s.6
54s.4
54s.2
54s.0
53s.8
53s.6
53s.4
α (2000)

Maps of the radio continuum sources



Spectra of the radio continuum sources



EM from ~ 10^6 pc cm^{-6} to ~ 3×10^7 pc cm^{-6}

Summary

- The cores are fragmentary on all observed scales. Several new clumps are detected in both S255IR and S255N with sizes ~ 0.01-0.05 pc. Their masses are estimated at a few solar masses. The properties and, apparently, evolution stages of the clumps are very different.
- New very young high velocity outflows from faint clumps without any other sign of star formation are detected.
- High velocity emission in various molecular lines is observed in the S255IR area. It looks like highly collimated outflows originating at different points. However, this can be a single powerful wide-angle outflow with the SMA1 as a driving source.
- The SMA1 hot core is rotating and probably represents a protostellar disk with a size of several AU. The beam filling factor for the 0.4” beam is ~ 0.2.
- There is a significant deuteration in all cores. In the S255IR-SMA1 a strong DCN enhancement is observed very close to the center of the hot core, implying either a presence of a cold material here or a very young age.

THANK YOU!