2021 ALMA Summer school

group 1

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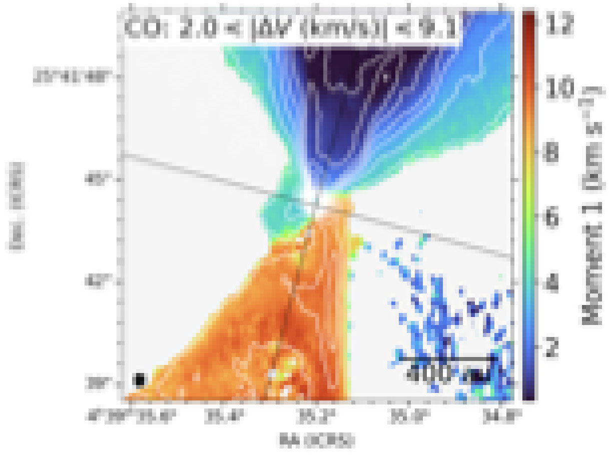
0. Introduction: ALMA obs. ↔ physics

- Observable intensity depends on temperature, density, opacity, velocity, etc.
- We attempted to untangle them by using multi-band data.

- The target is a late-phase (Class I) protostar, TMC-1A, in the Taurus molecular cloud.

Distance	V_{sys}	Inclination	L_{bol}	T_{bol}
140 pc	6.4 km s^{-1}	50°-60°	2.7 $L_{\odot}$	118 K

Galli+18; Aso+15, 21; Kristensen+12

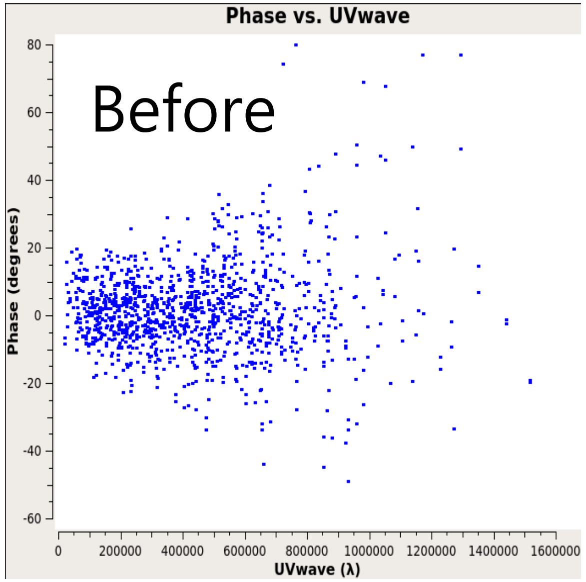


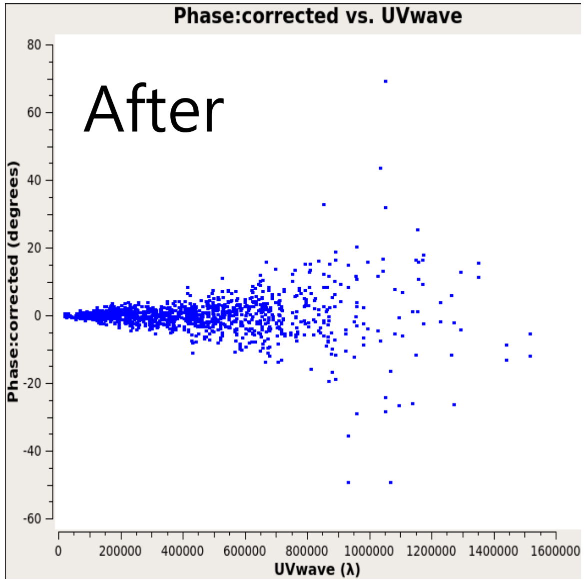
(f)

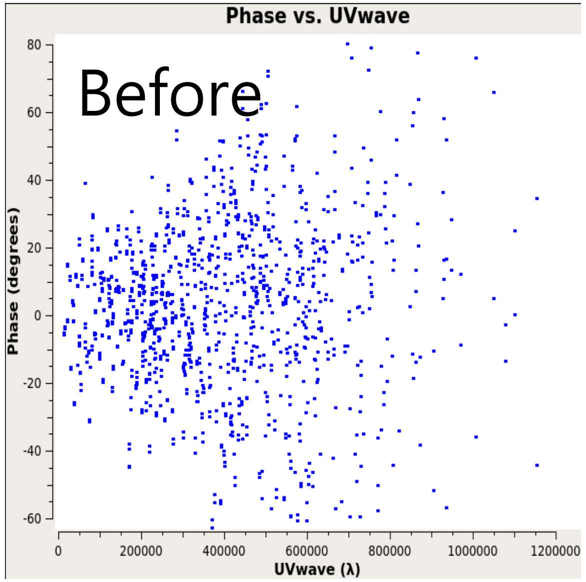
CO J=2–1 outflow in TMC-1A

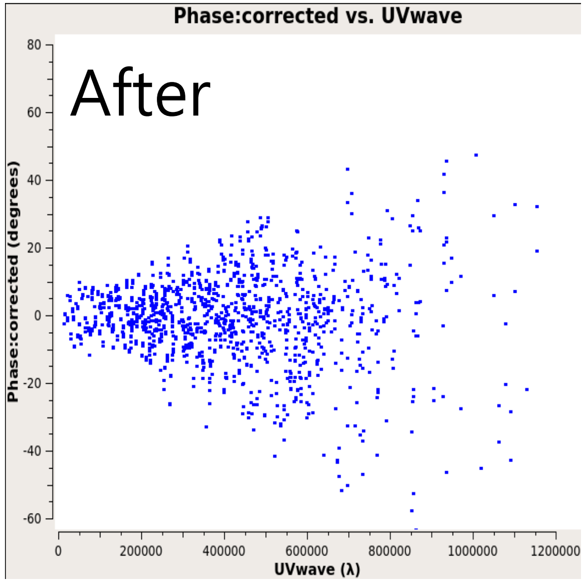
1. Continuum: Self-calibration

Band 6 (1.3 mm) Band 7 (0.9 mm)







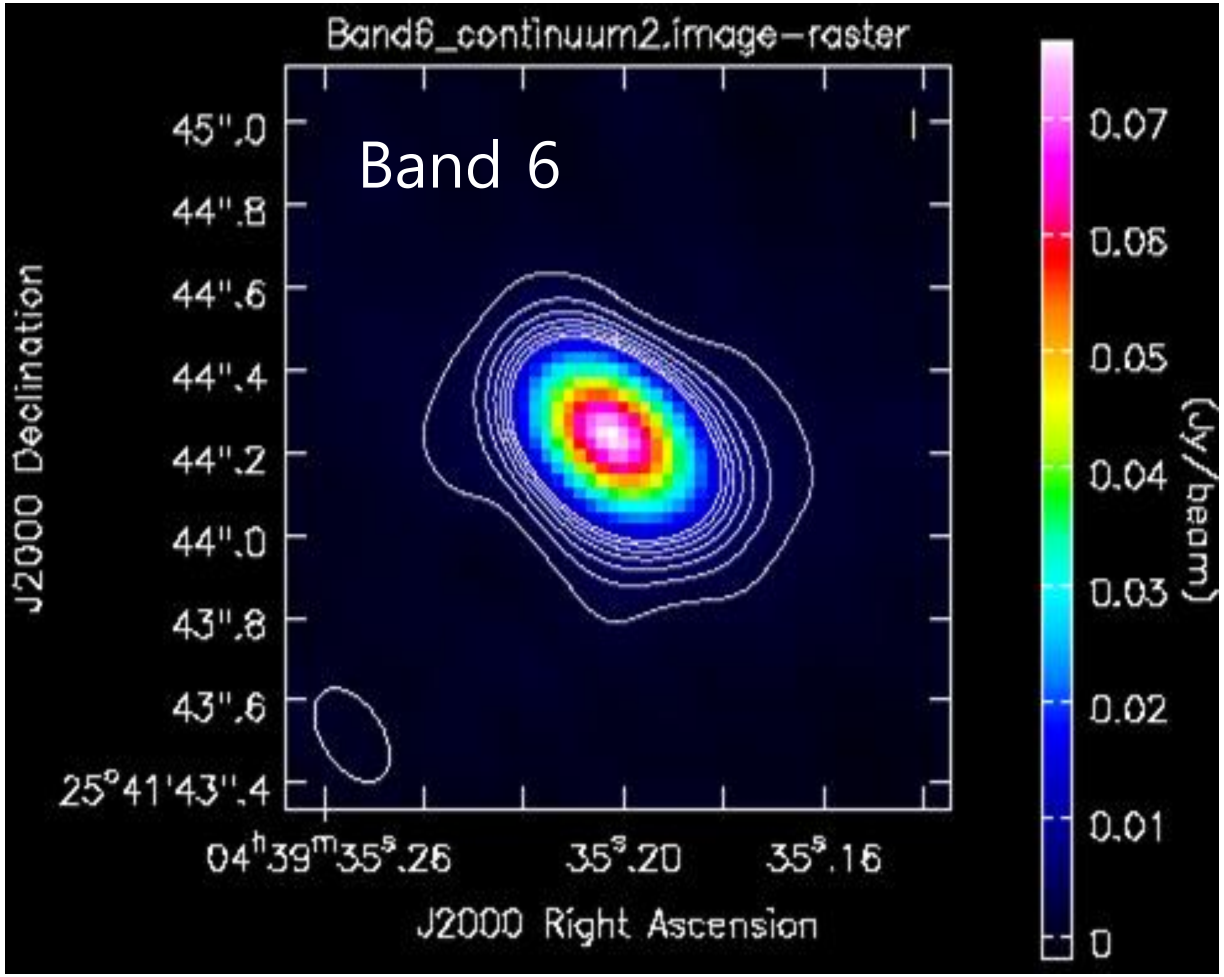


UVwave vs Phase

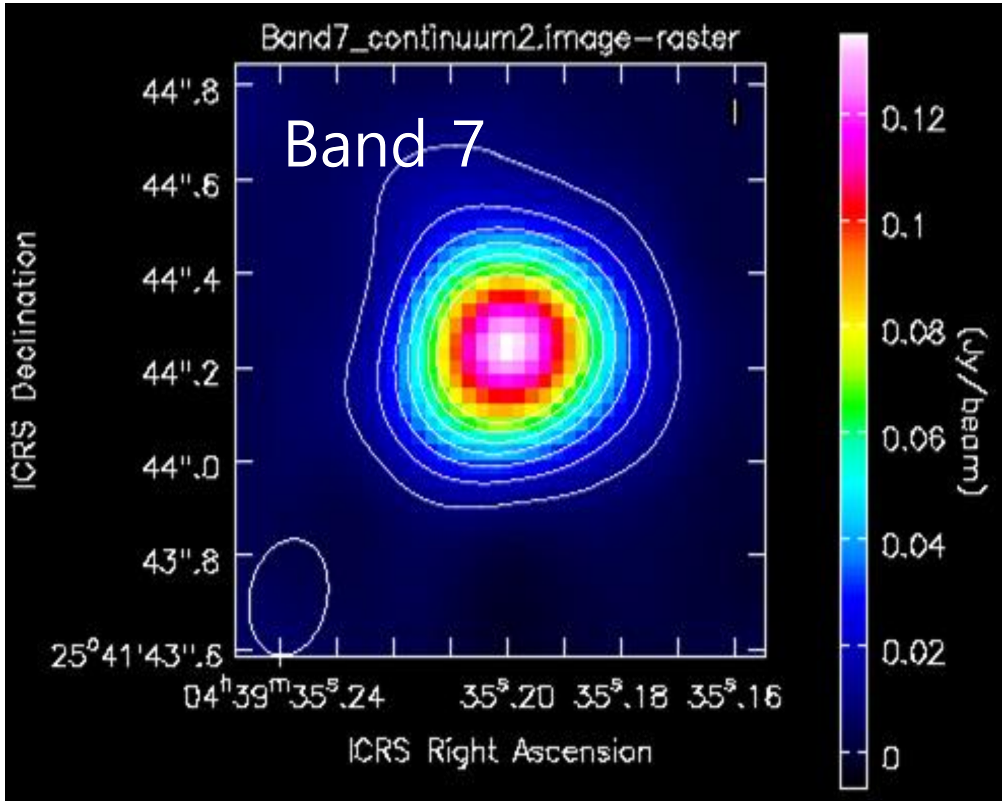
Band 6 S/N = **152.44**
Band 7 S/N = **64.04**

Band 6 Rms **4.08e-4** → **1.67e-4**
Band 7 Rms **1.46e-3** → **1.43e-3**

1. Continuum: CLEANed Images



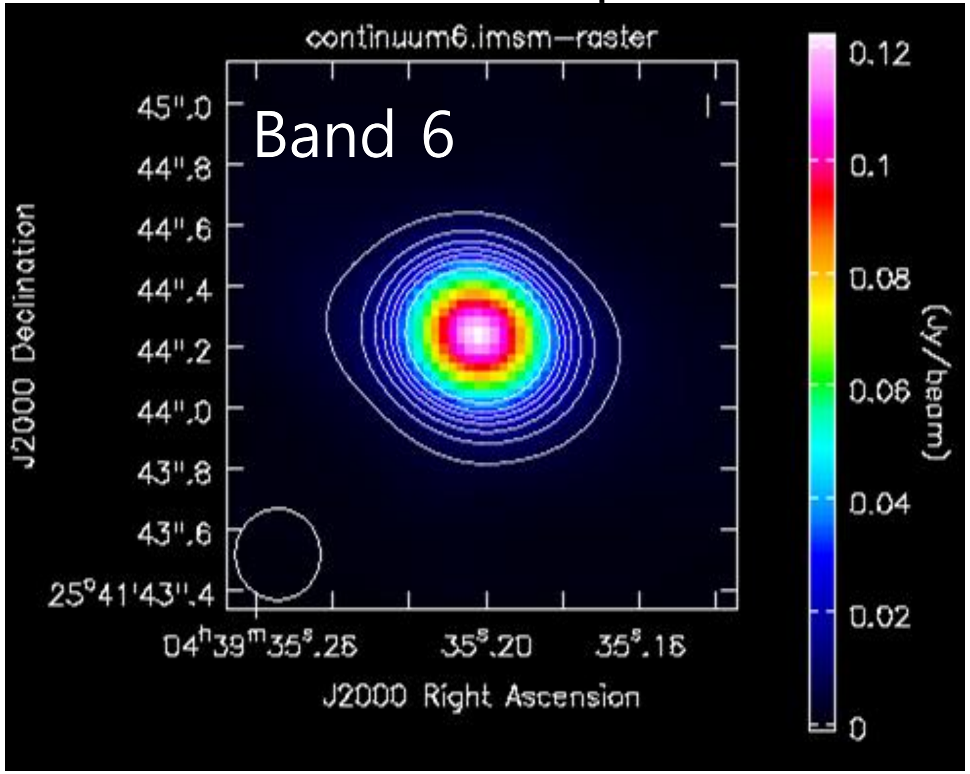
Rms=4.92e-4, Peak=0.075, S/N=152.44



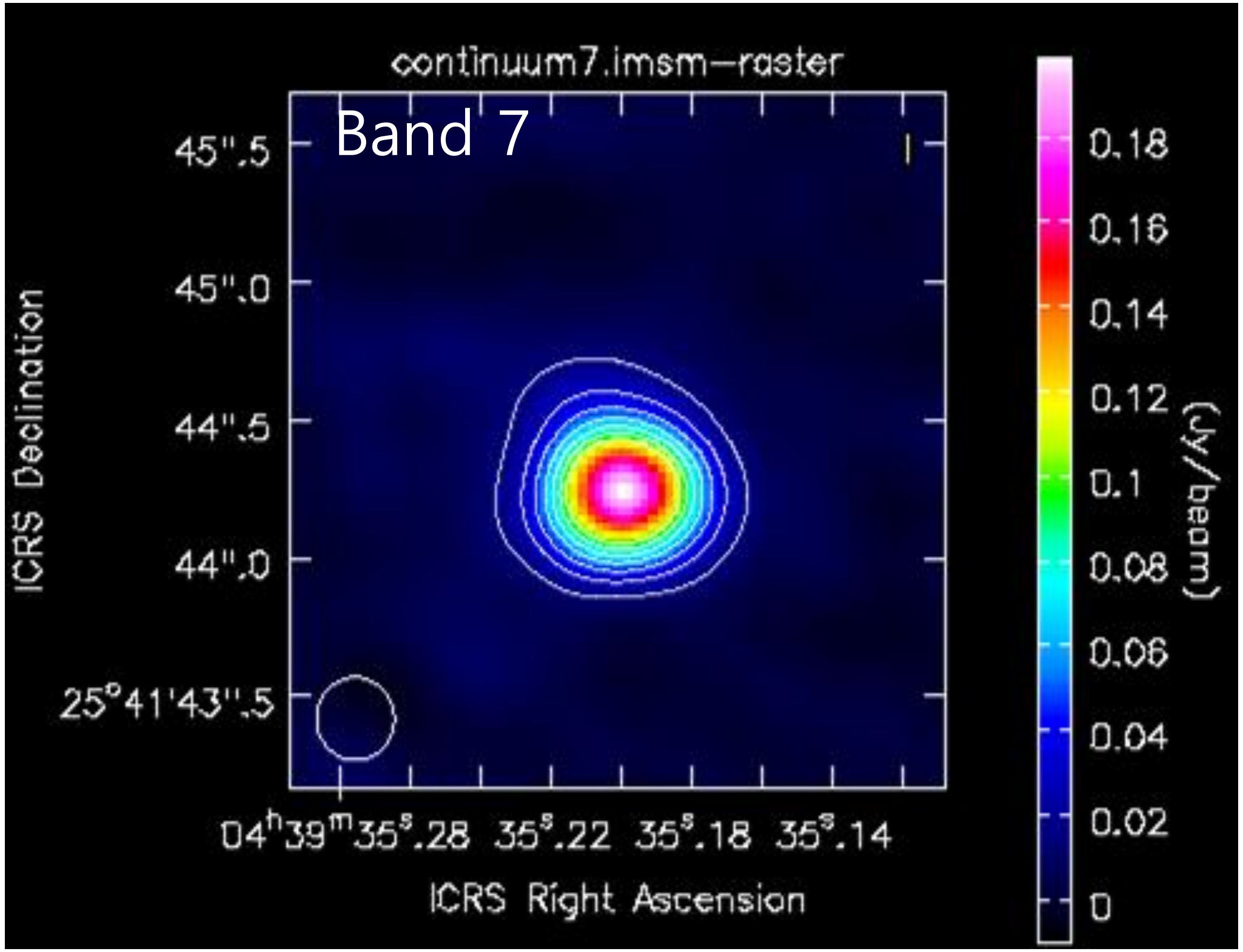
Rms=2.03e-3, Peak=0.13, S/N=64.04

1. Continuum: Smoothed Images

- Smoothed to the same beam size for fair comparison.



Rms=5.45e-4, Peak=0.12, S/N=220



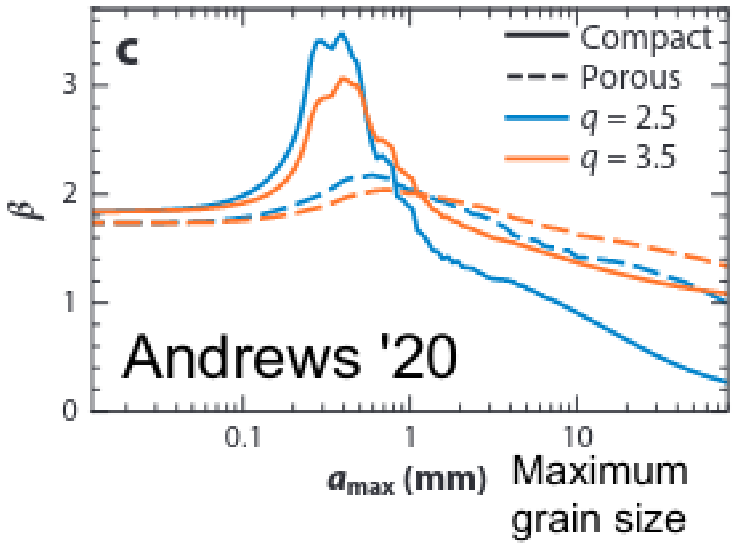
Rms=2.88e-3, Peak=0.195, S/N=67.71

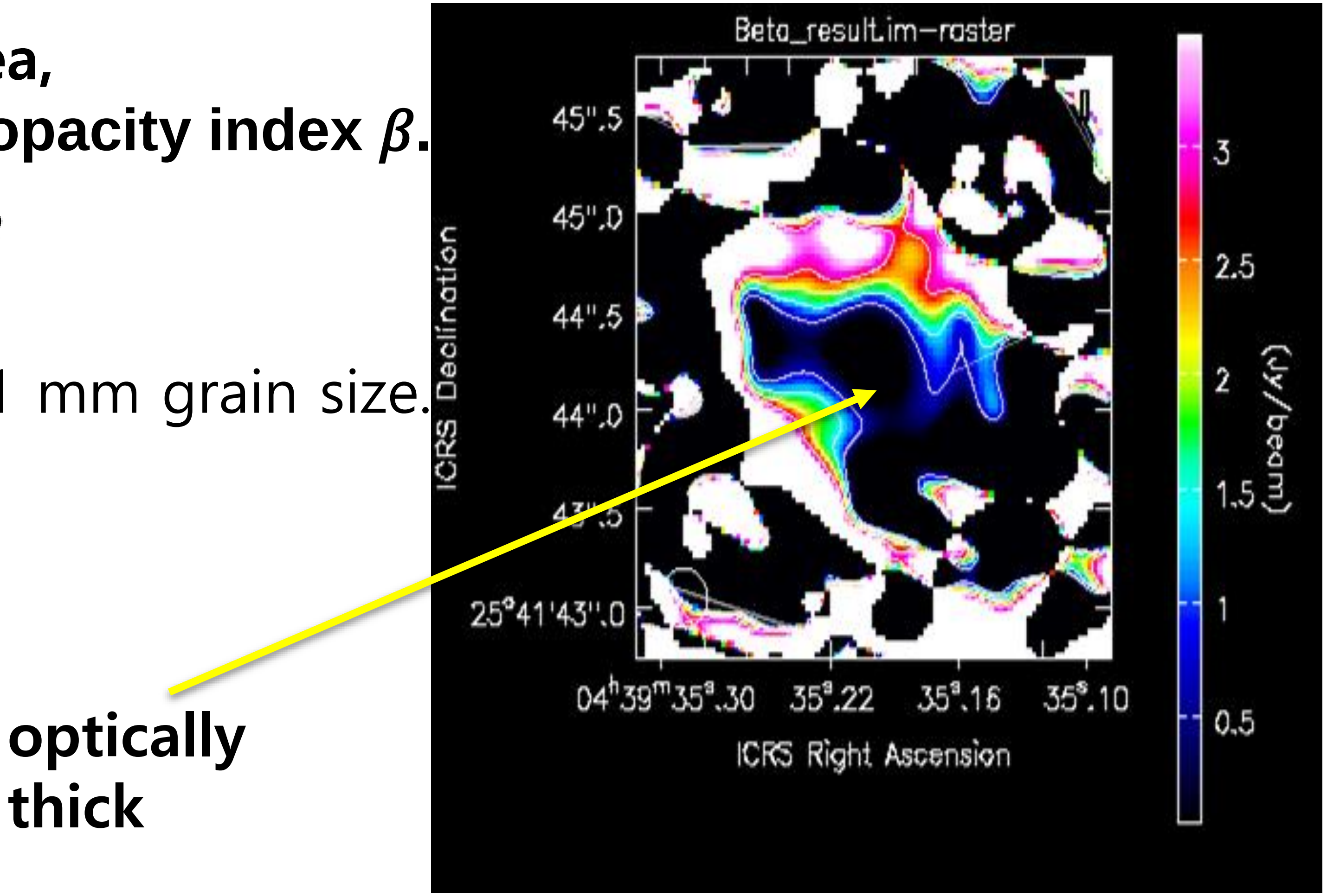
1. Continuum: Beta map

- **From the Statics of this area,**
  We can calculate the dust opacity index β.

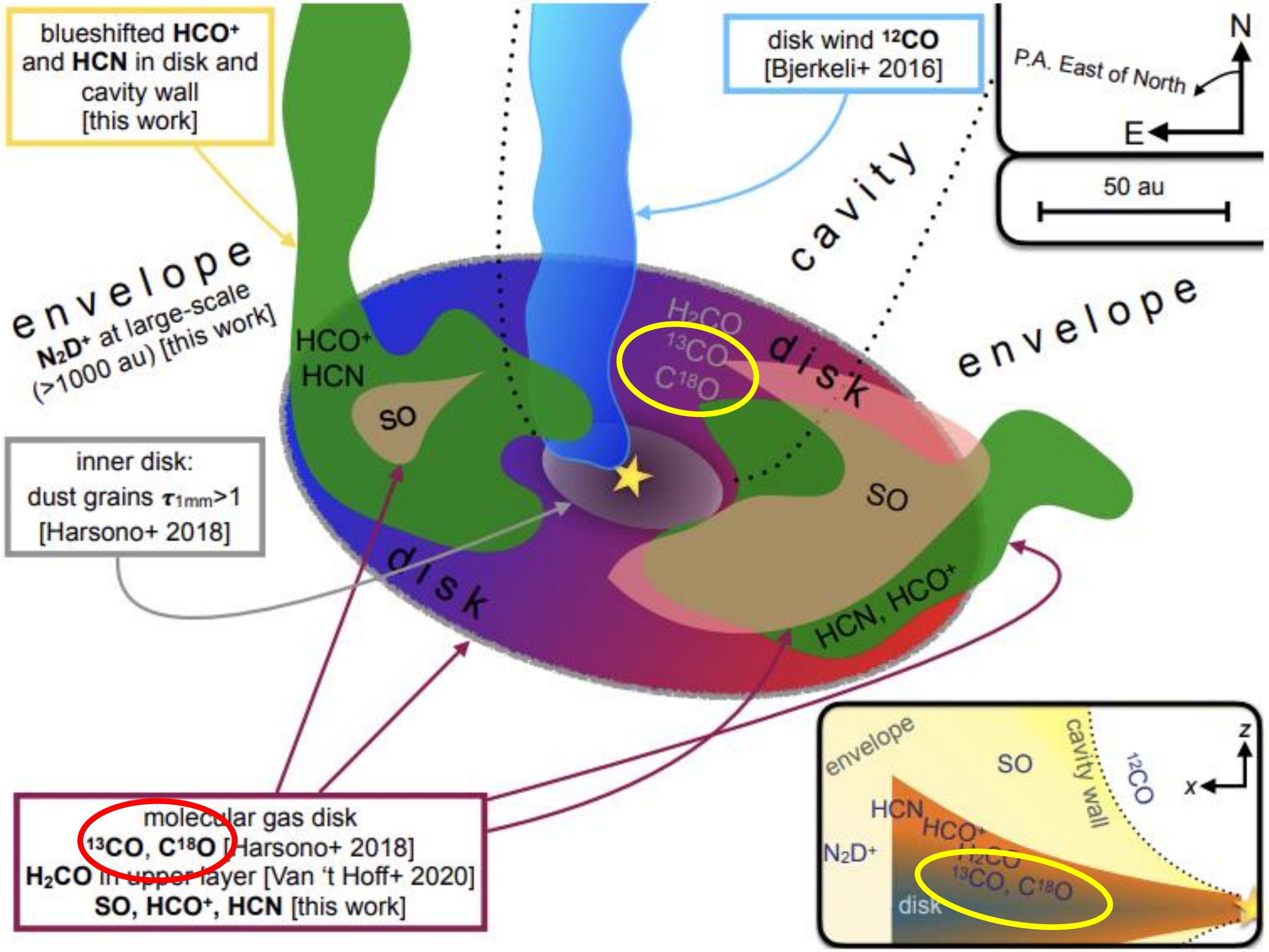
$$\frac{F_7}{F_6} \sim \frac{\nu_7^2 \tau_7}{\nu_6^2 \tau_6} = \frac{\nu_7^2 \kappa_7}{\nu_6^2 \kappa_6} = \left(\frac{\nu_7}{\nu_6}\right)^{2+\beta}$$

- Green to pink suggests 0.1-1 mm grain size.





2. Band 7 lines



Molecular gas disk component

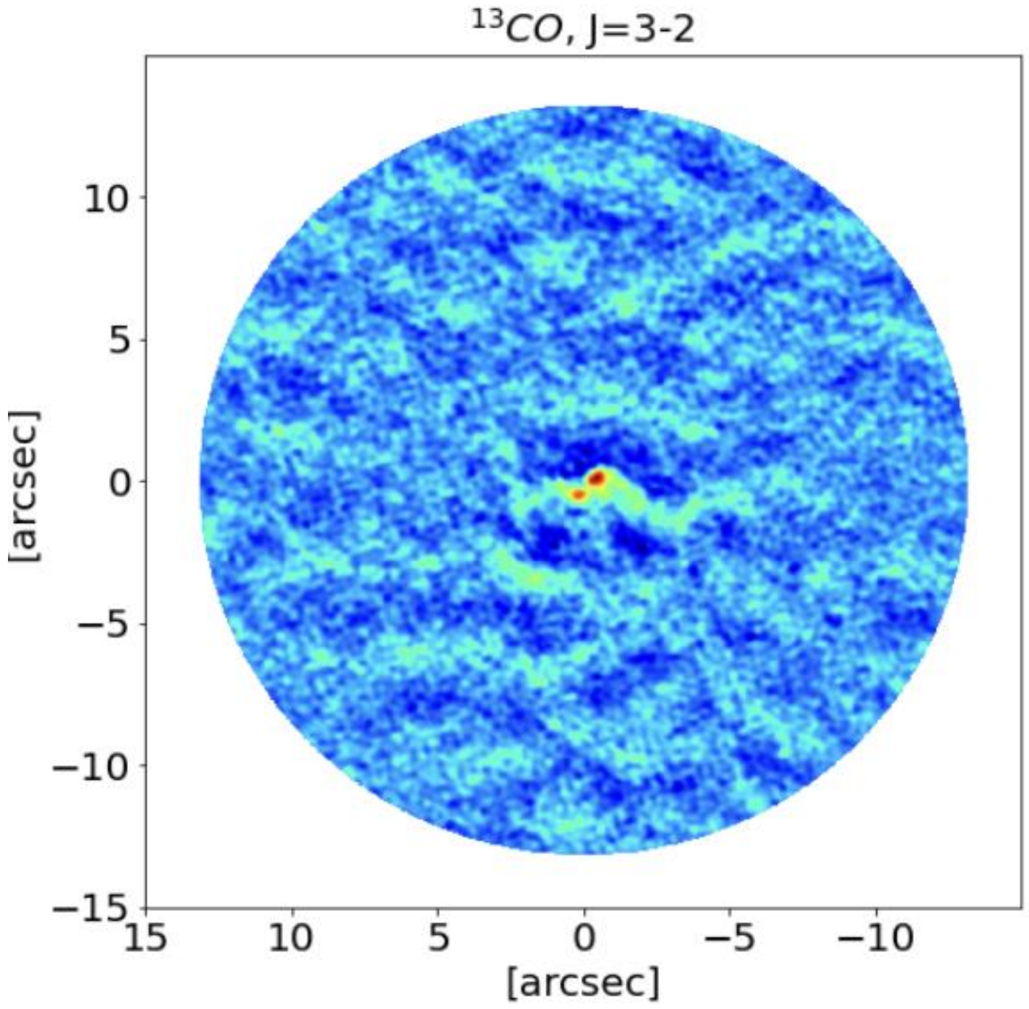
- ^{13}CO
- $C^{18}O$
- H_2CO

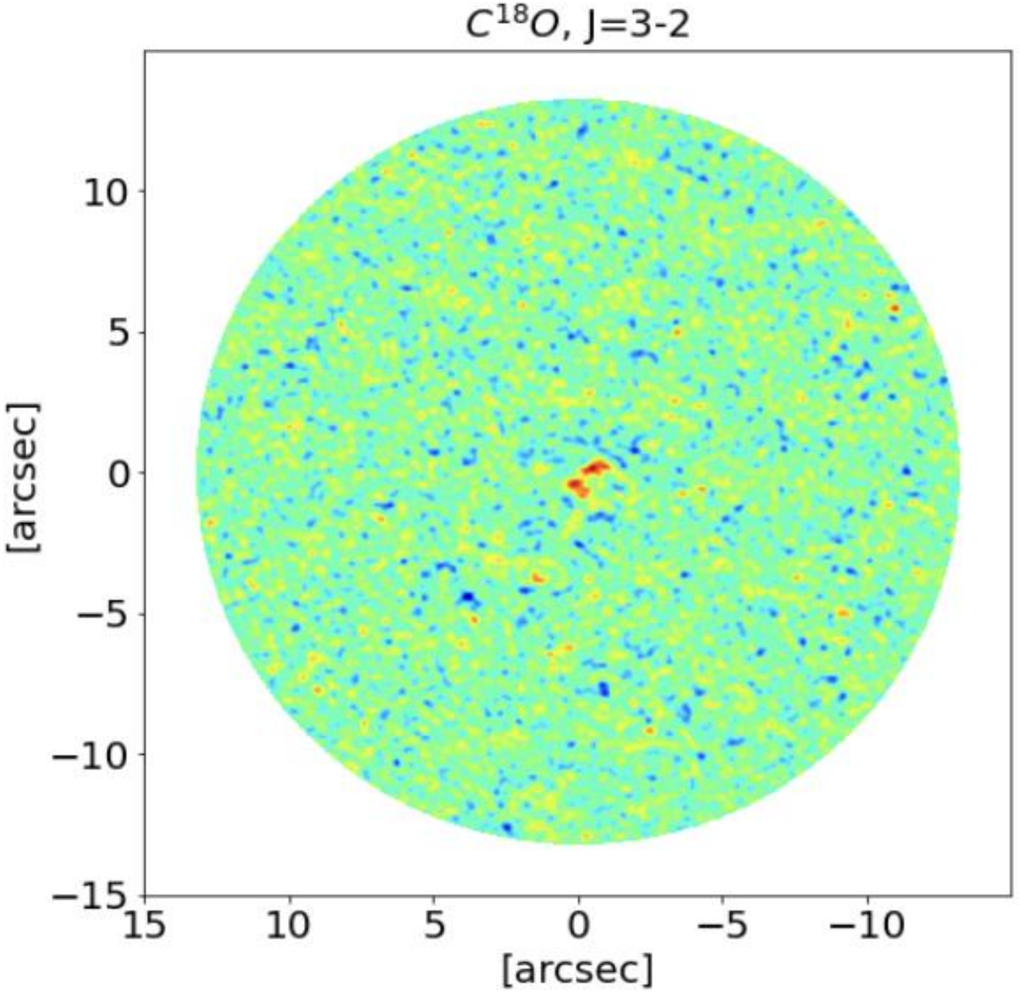
Observe molecular (Band 7)

- ^{13}CO
- $C^{18}O$

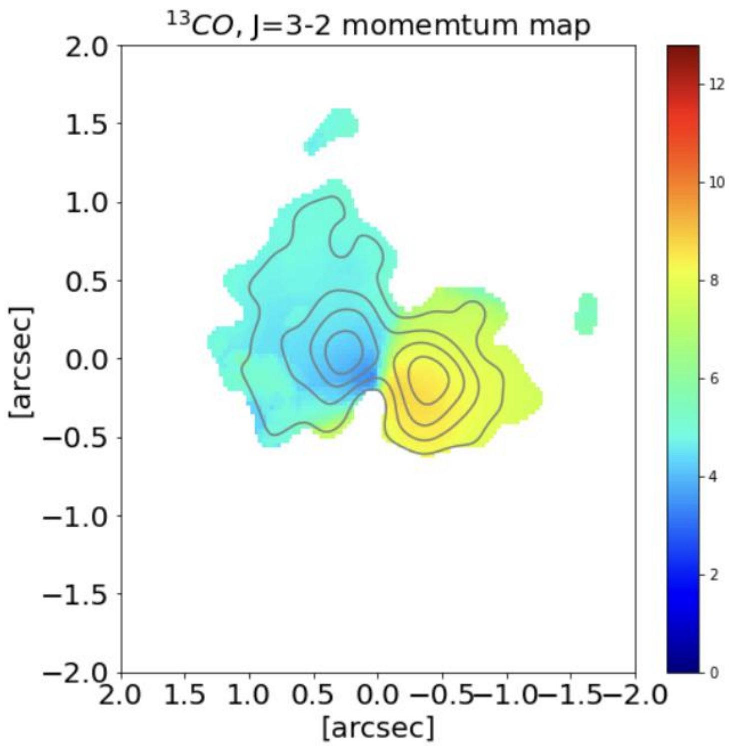
Daniel Harsono et al, (2021), Astronomy & Astrophysics 646, A72

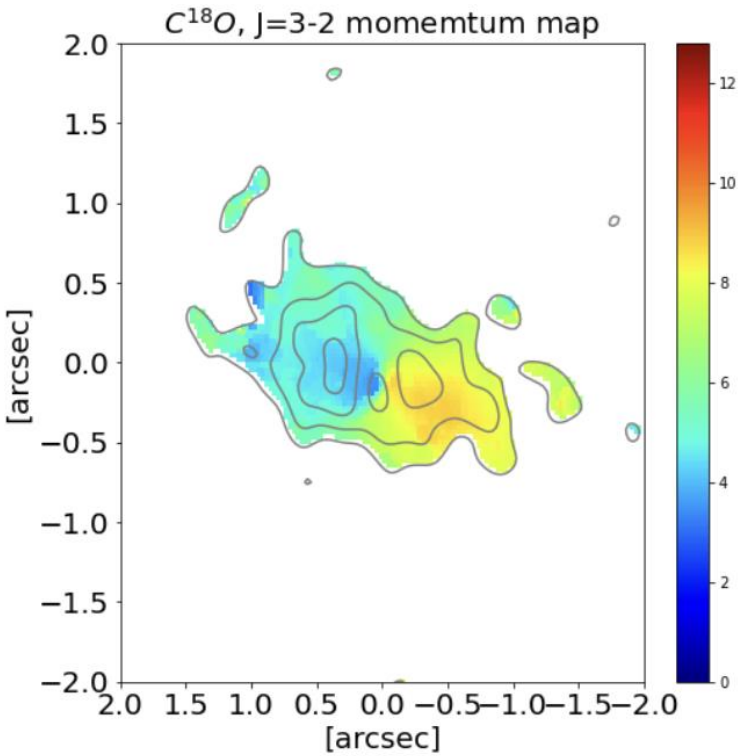
2. Band 7 lines: Data cube

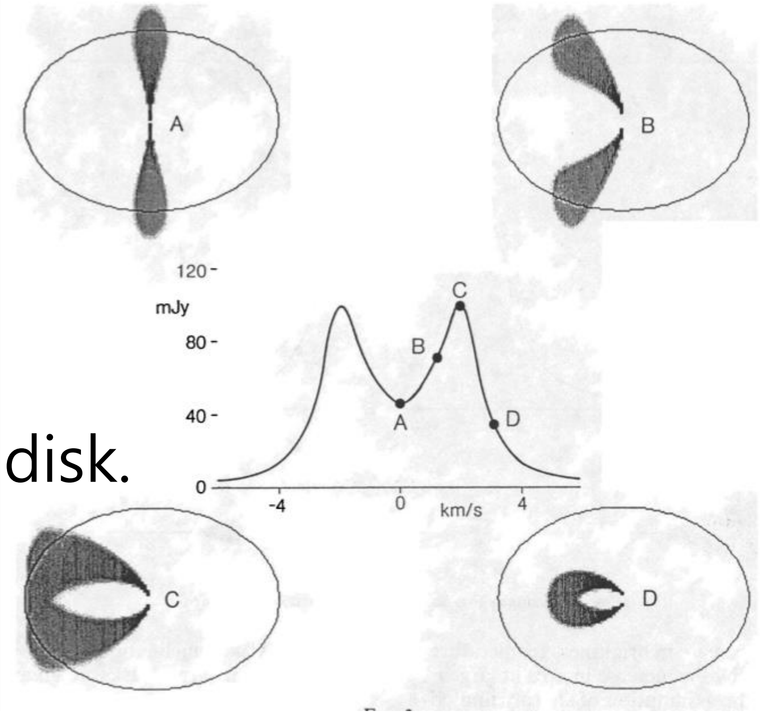




2. Band 7 lines: Momentum maps







- The velocity gradient is consistent with the rotating disk.
- The double peak is because “A” is resolved out.

2. Band 7 lines: T and N_{H2}

Assume ^{13}CO is optically thick

Moment0_mean_value_^{13}CO = $B_\nu(T)\Omega\Delta V \sim \frac{\nu_{\rm rest}^2}{c^2}(2kT - h\nu_{\rm rest})\Omega\Delta V$

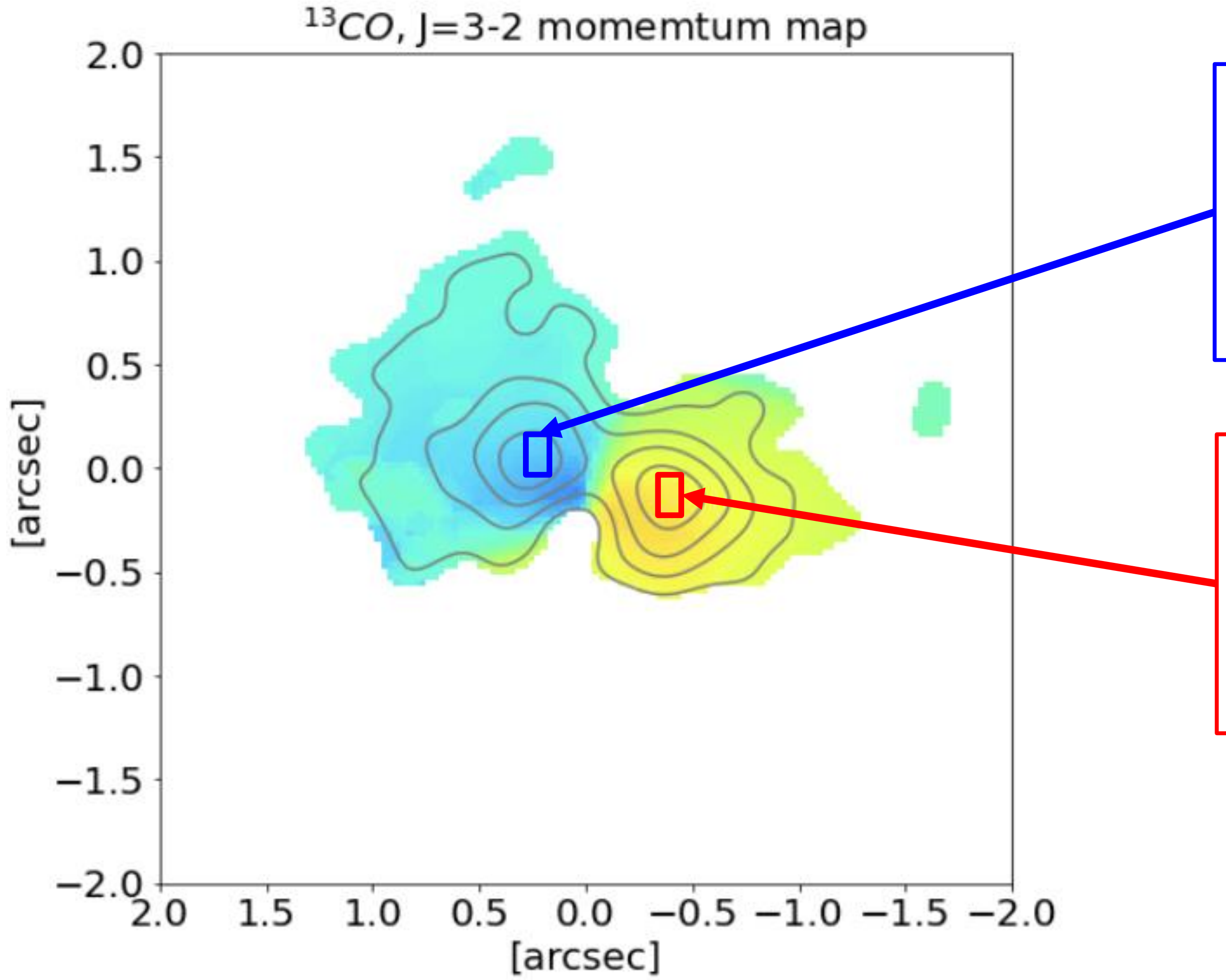
Assume $C^{18}O$ is optically thin

Moment0_mean_value_$C^{18}O$ = $\int B_\nu(T)\tau_\nu dv\,\Omega = \int \frac{hc}{4\pi}A_{\rm ul}\frac{g_{\rm u}e^{-\frac{E_{\rm u}}{kT}}}{Z(T)}XN_{\rm H_2}\phi(v)\,dv\Omega$

$$\sim \frac{hc}{4\pi}A_{\rm ul}\frac{g_{\rm u}e^{-\frac{E_{\rm u}}{kT}}}{Z(T)}XN_{\rm H_2}\int \phi(v)dv\,\Omega$$

$$= \frac{hc}{4\pi}A_{\rm ul}\frac{g_{\rm u}e^{-\frac{E_{\rm u}}{kT}}}{Z(T)}XN_{\rm H_2}\Omega.$$

2. Band 7 line: temperature



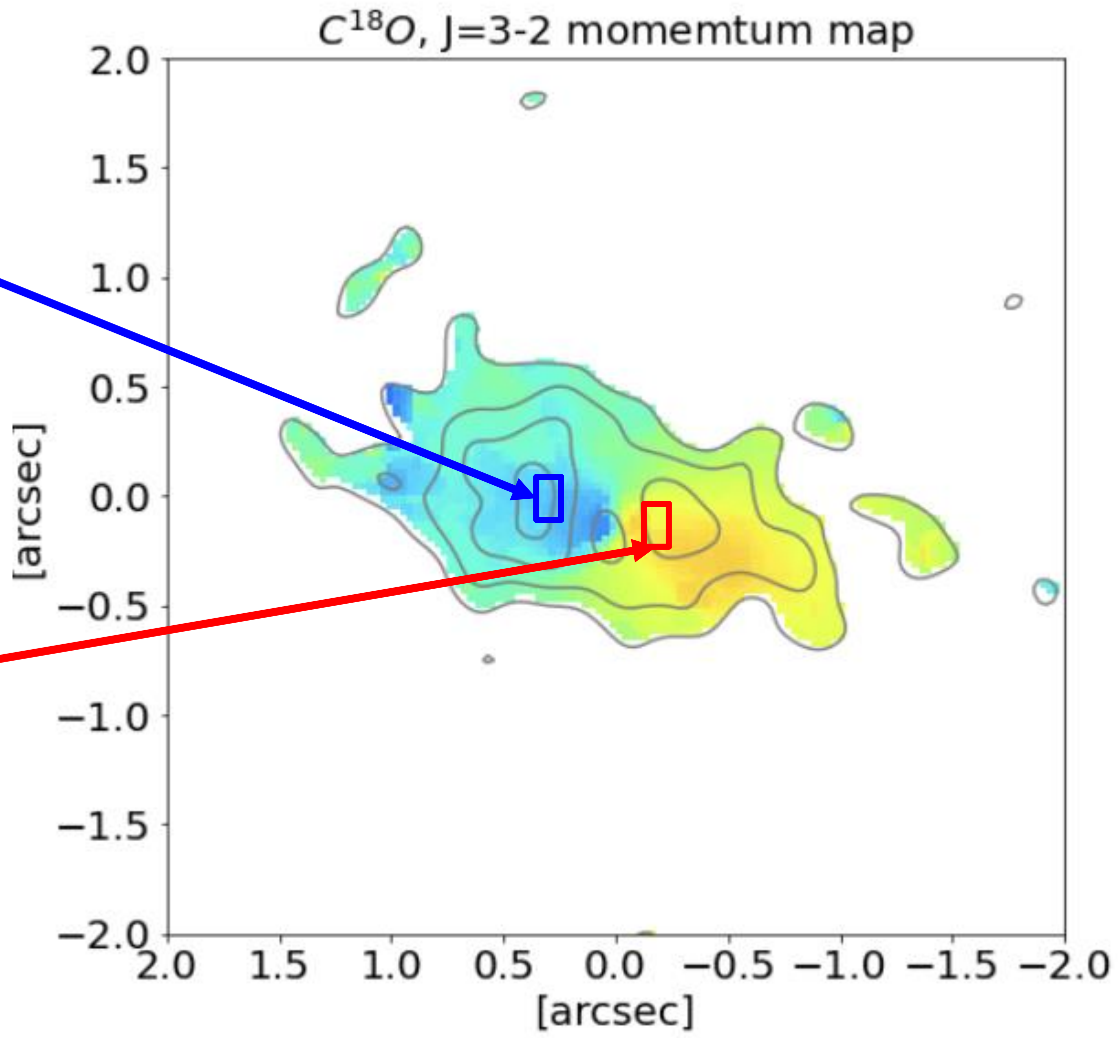
Moment 0 value: 0.424 [Jy/beam km/s]
^{13}CO : optically thick
ν_{rest} = 330.5879652218 GHz
T ~ 11.98 K

Moment 0 value: 0.462 [Jy/beam km/s]
^{13}CO : optically thick
ν_{rest} = 330.5879652218 GHz
T ~ 12.35 K

2. Band 7 line: Column density

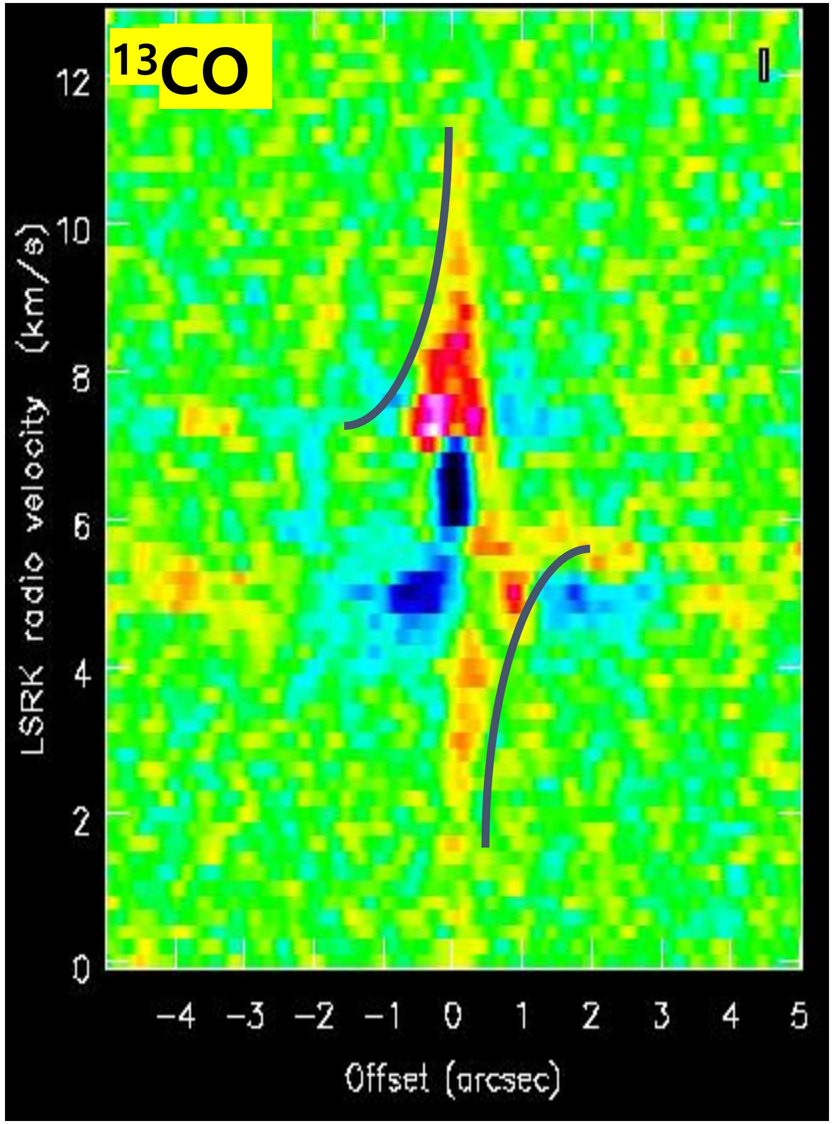
Moment 0 value : 0.233 [Jy/beam km/s]
$C^{18}O$: optically thin
v_{rest} = 329.3305525 GHz
T ~ 11.98 K
-> N_{H2} = 8.337e+26m^{-2}

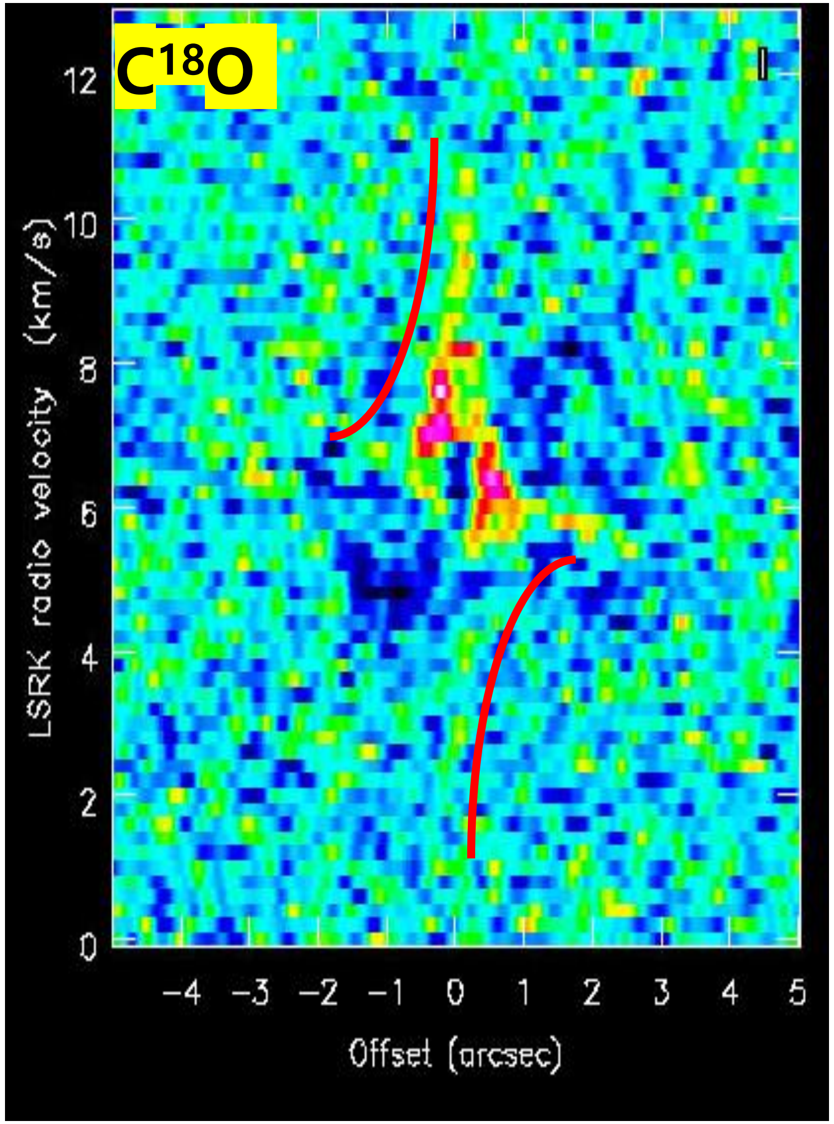
Moment 0 value : 0.170 [Jy/beam km/s]
$C^{18}O$: optically thin
v_{rest} = 329.3305525 GHz
T ~ 9.56 K
-> N_{H2} = 3.722e+26 m^{-2}



2. Band 7 lines: PV diagram

- ^{13}CO J=3-2 shows emission closer to the center at higher velocities (spin-up).
- $C^{18}O$ J=3-2 is fainter than ^{13}CO at the higher velocities.





3. Band 6 lines:

Band	Wavelength (mm)	Frequency (GHz)
1	8.57 – 6.00	035 – 050
2	4.48 – 3.33	067 – 090
3	3.57 – 2.59	084 – 116
4	2.40 – 1.84	125 – 163
5	1.84 – 1.42	163 – 211
6	1.42 – 1.09	211 – 275
7	1.09 – 0.80	275 – 373
8	0.78 – 0.60	385 – 500
9	0.50 – 0.42	602 – 720
10	0.38 – 0.32	787 – 950

^{13}CO, J=2-1

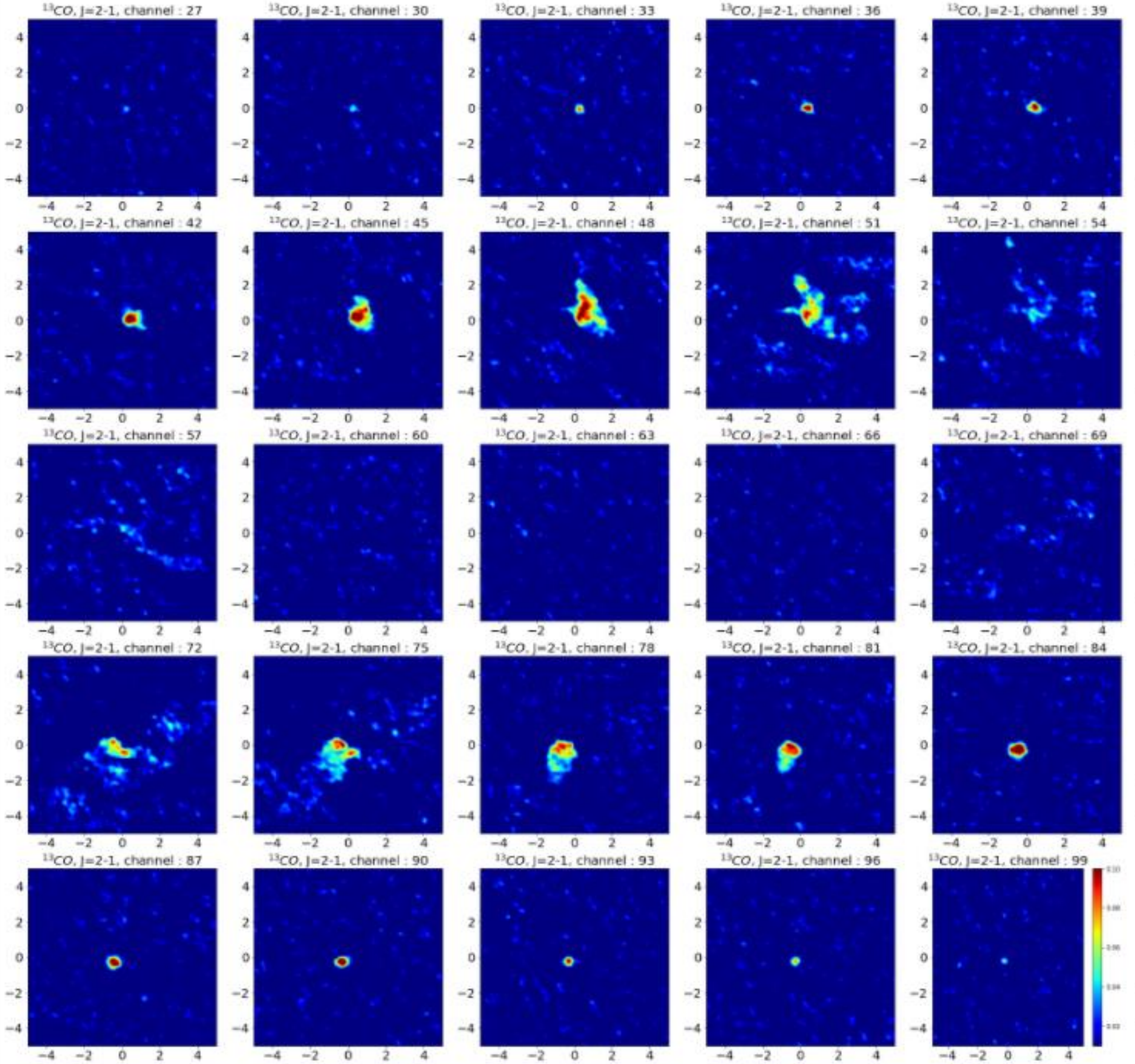
(rest frequency = 220.399GHz)

$C^{18}O$, J=2-1

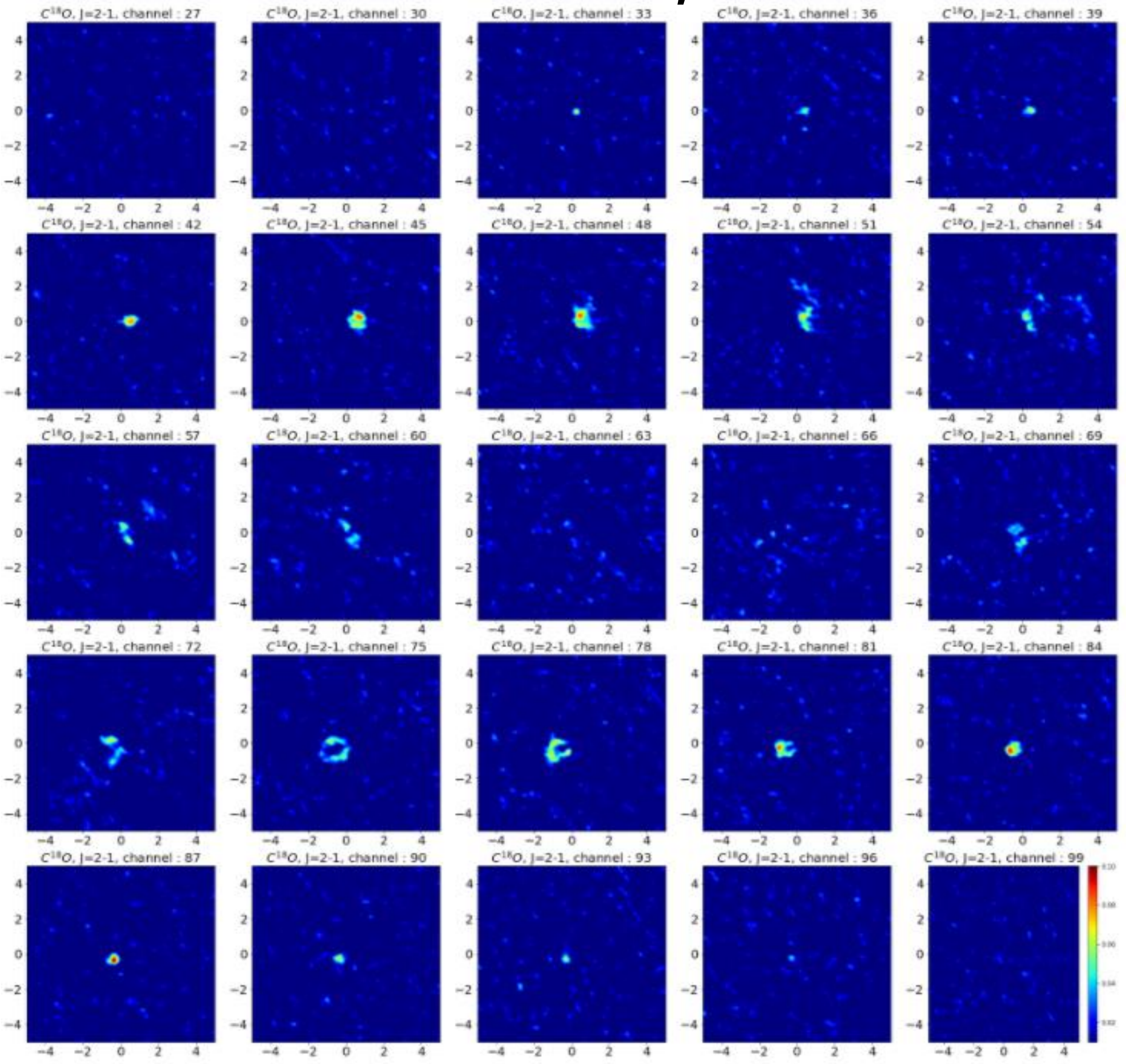
(rest frequency = 219.560GHz)

3. Band 6 lines: Channel map

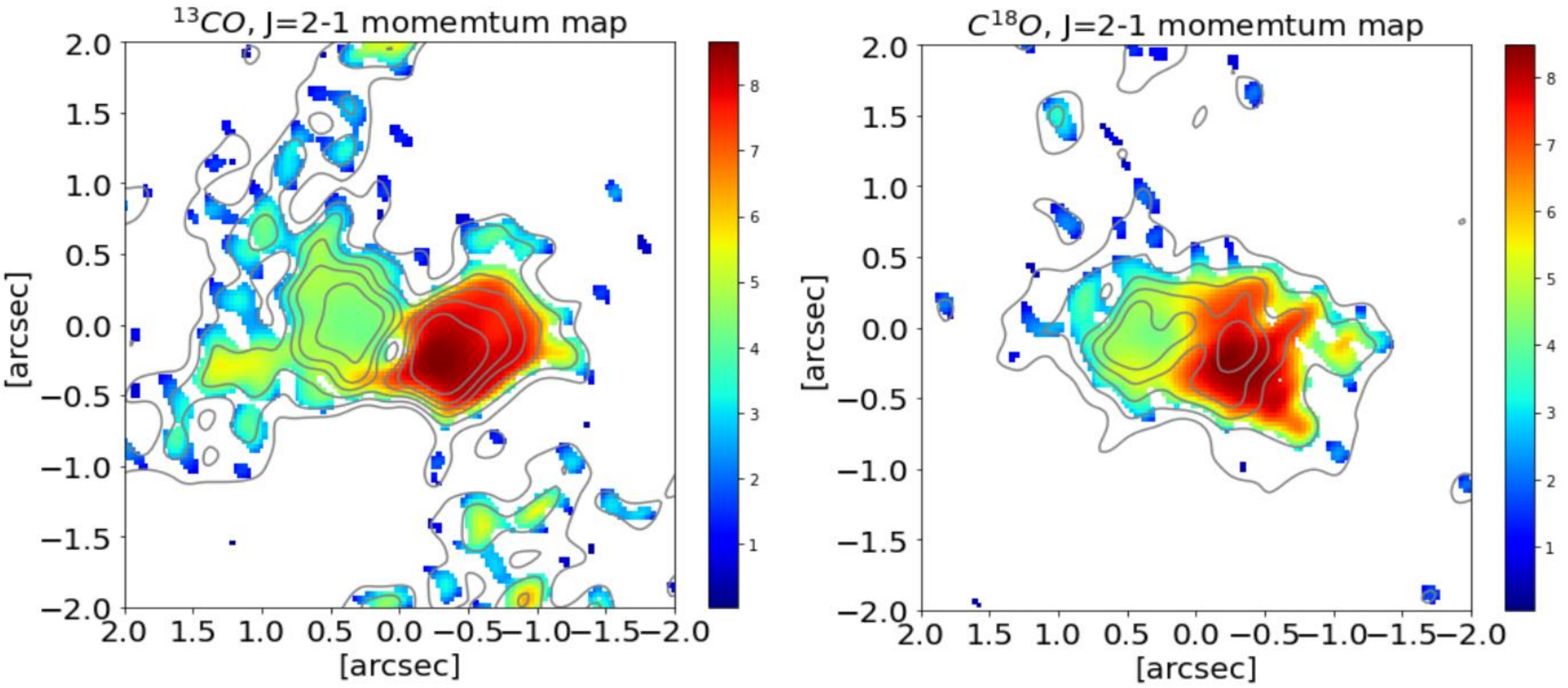
^{13}CO, J=2-1



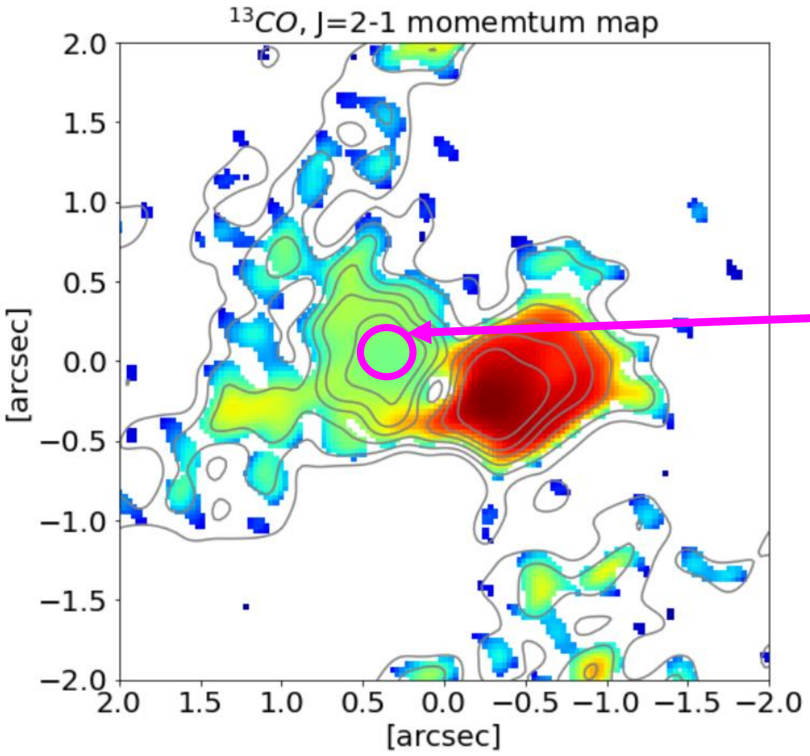
$C^{18}O$, J=2-1



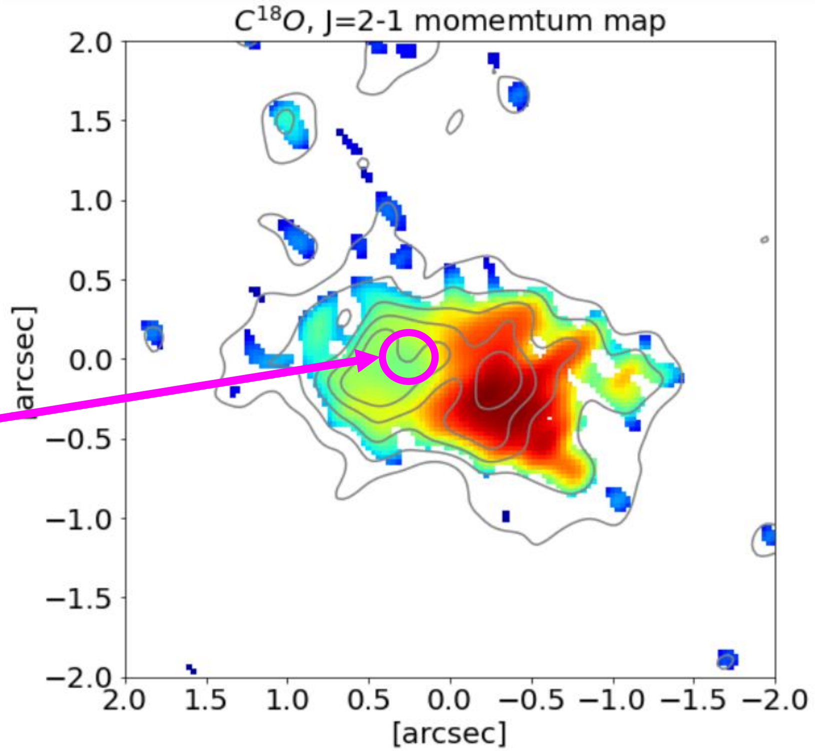
3. Band 6 lines: Momentum maps



3. Band 6 lines: T and N_{H2}



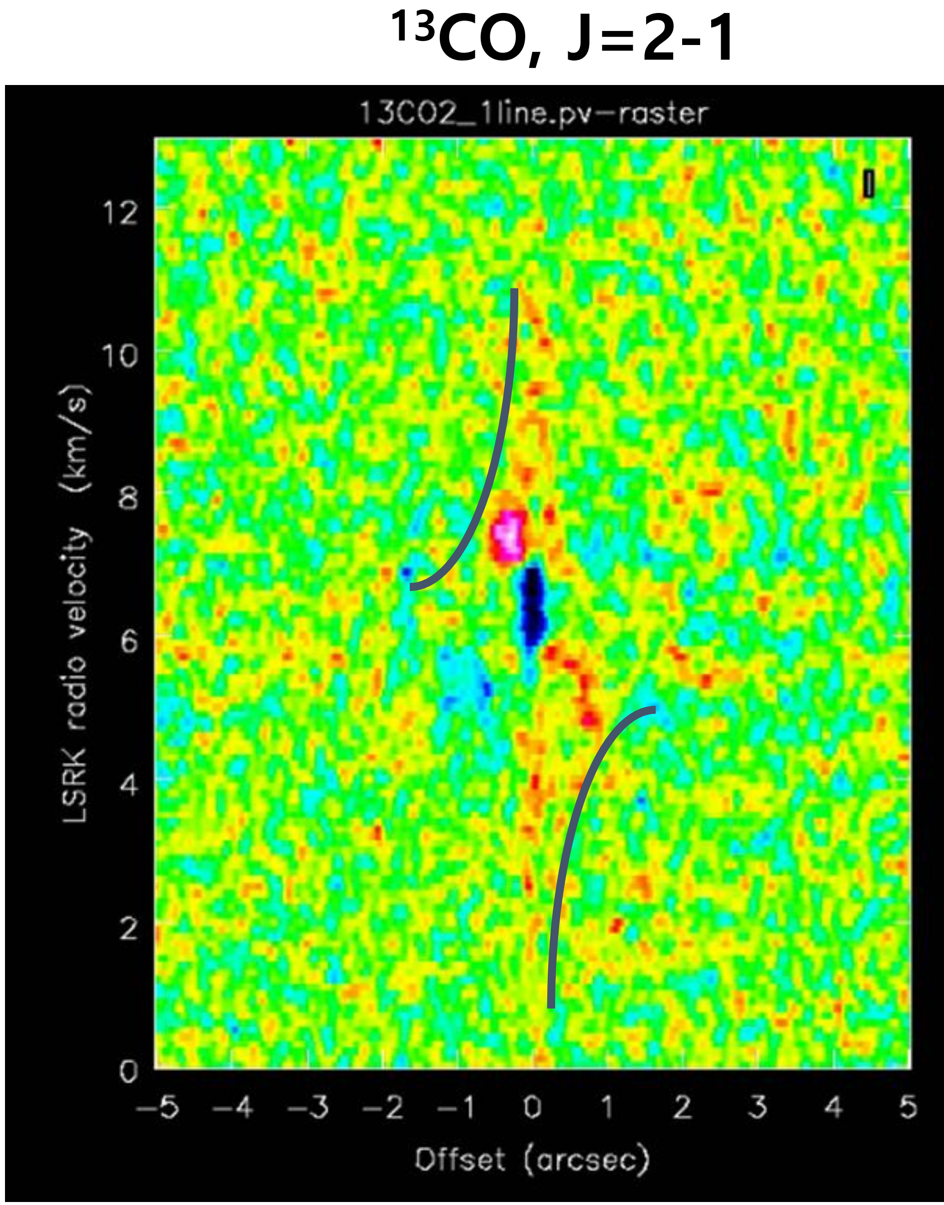
mom0_^{13}CO = 0.2072814 Jy/beam km/s
v_{rest} = 220.398641281 GHz
-> T ~ 9.75 K ~11.98 K (Band 7)

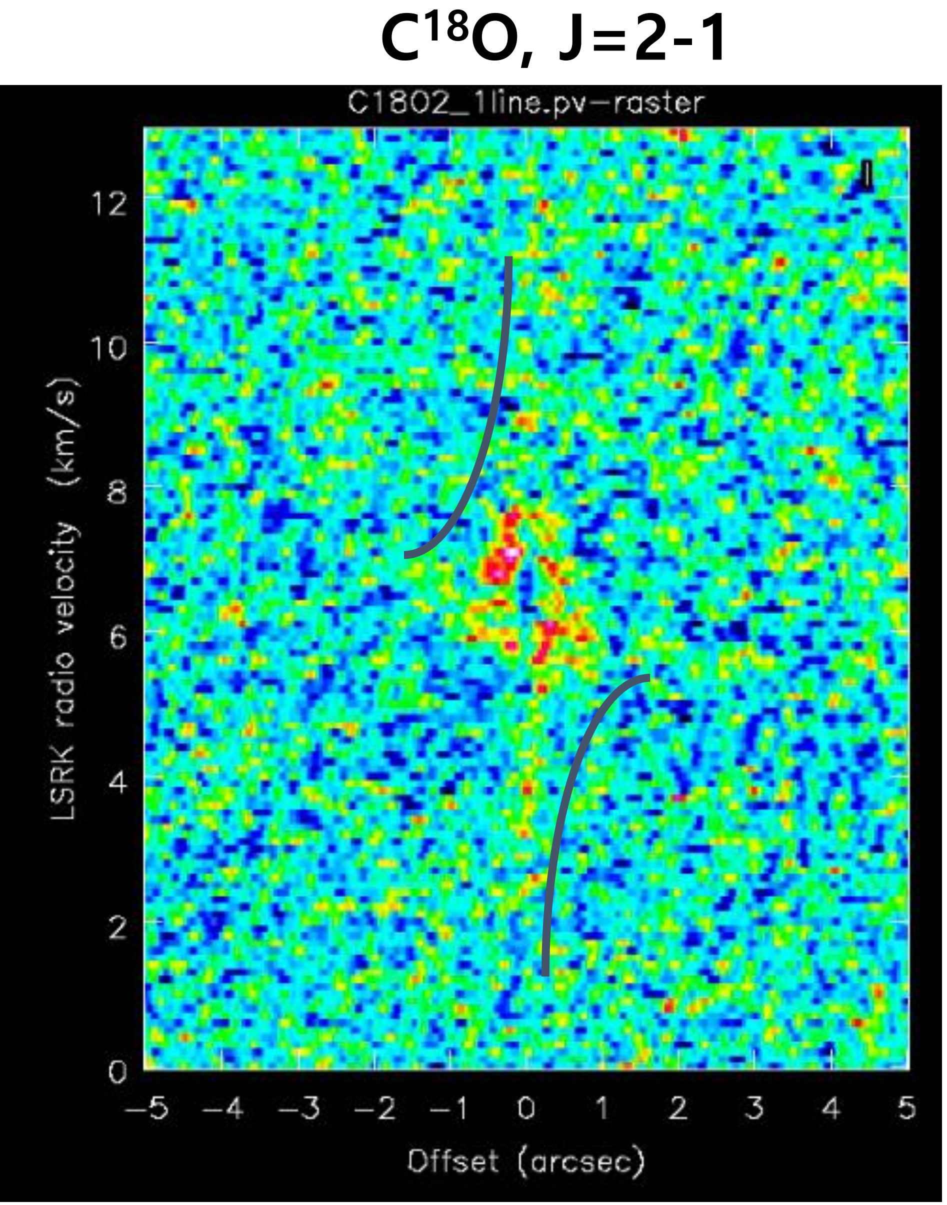


mom0_C^{18}O = 0.06287736 Jy/beam km/s
v_{rest} = 219.5603541 GHz
T ~ 9.75 K
-> N_{H2} ~ 2.14e+26 m^{-2} ~8.337e+26 m^{-2} (Band 7)

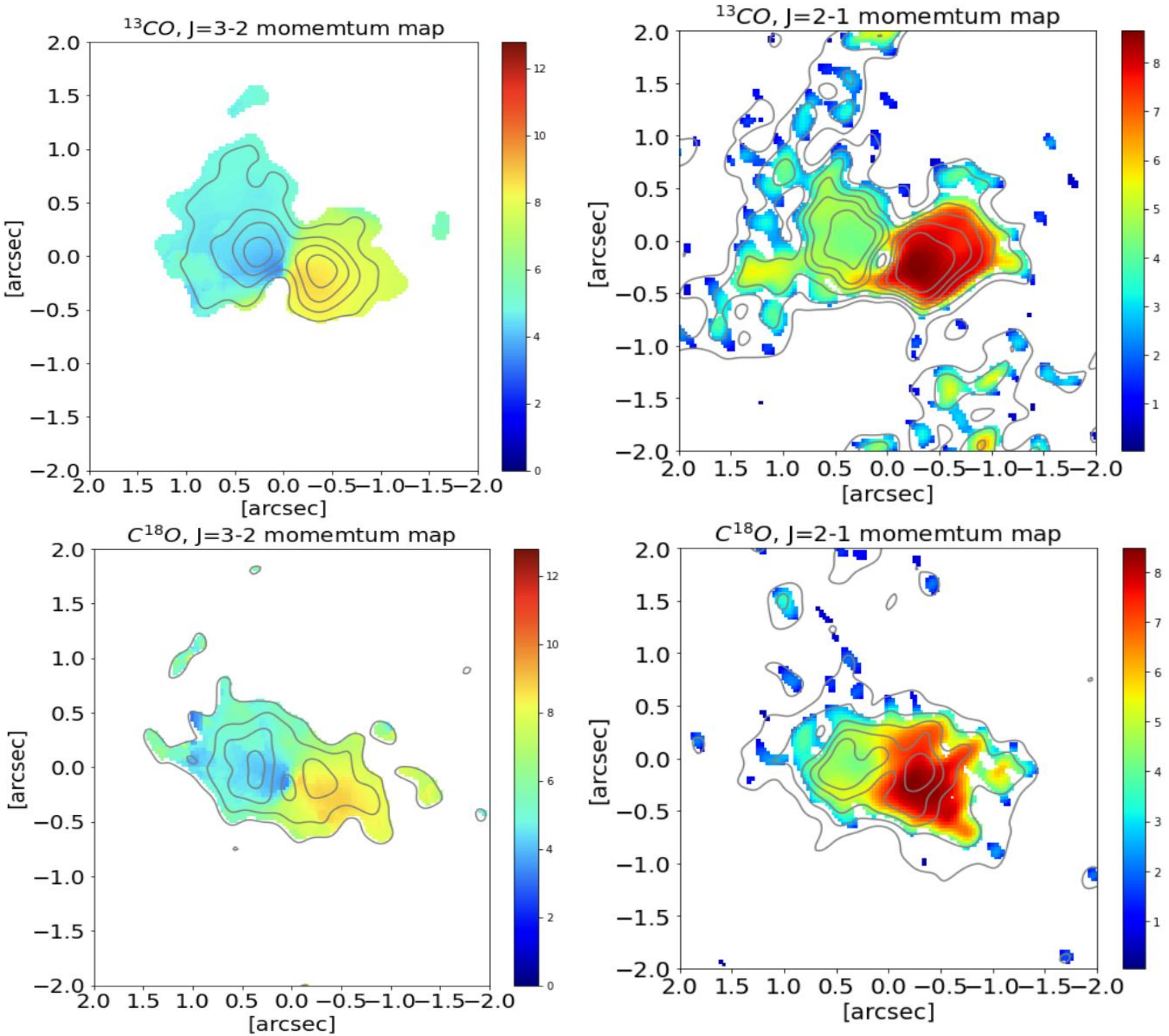
3. Band 6 lines: PV diagrams

- The J=2-1 lines also traces the spinning-up velocity pattern same as the J=3-2 lines.
- Again, ^{13}CO shows the high velocity emission more clearly.





3. Band 6 lines: Compare with Band 7



^{13}CO

C^{18}O

velocity range
J=3-2 : 3 - 9
J=2-1 : 4 - 9

J=3-2 (Band 7) and J=2-1 (Band 6) shows…
similar **shapes** and **velocity ranges**
similar calculated **physical values** (T, N_{H2})

Hence, the two transitions trace the **same region**.
=>We can use the "four" together
for more realistic calculation in **this** region.

4. Summary

- Self-calibration indeed let the visibility phase concentrate near 0.
- We measured the dust opacity index to investigate the maximum grain size.

- The ^{13}CO J=2-1 and 3-2 moment 0 maps show a double peak structure because of the resolving out effect.
- The ^{13}CO and $C^{18}O$ lines trace spinning-up rotation around TMC-1A.
- We attempted to estimate T and N_{H2} from the moment 0 maps.

- We conclude the combination of $^{13}CO/C^{18}O$ J=2-1 / 3-2 can be used together for calculating physical quantities because they show very similar results.