Large variety of the velocity profile of C^+, C, and CO in N159

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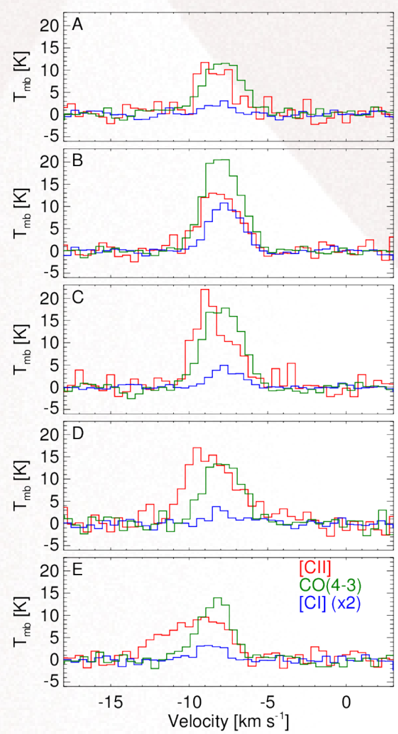
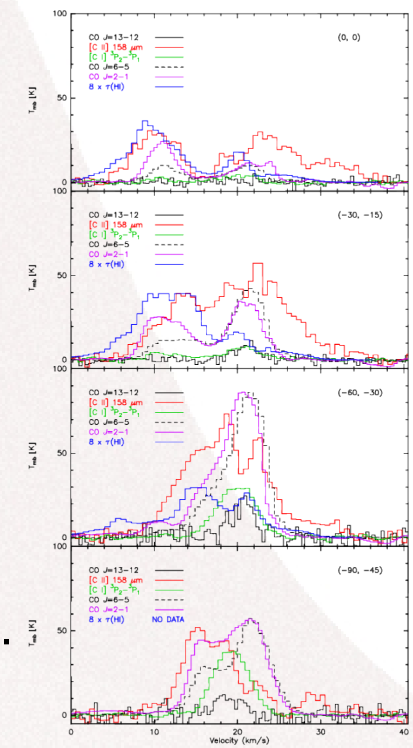
1. Introduction ([CII] 158µm)

- Dominant line in PDRs (photodissociation regions)
- Tracer of star-formation activity (estimate of the star formation rate)
- Different velocity profiles are observed in Galactic PDRs



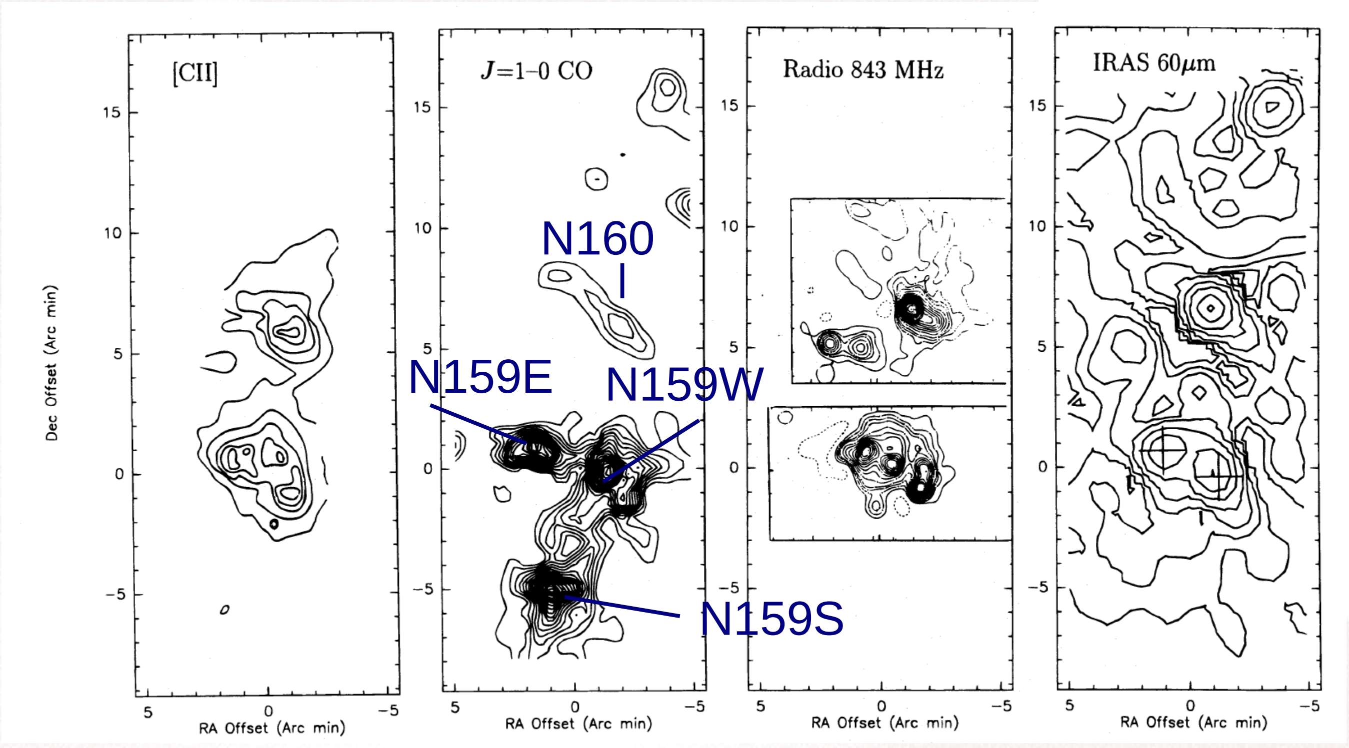
← IC1396A
Okada et al. (2012)

M17 →
Perez-Beaupuits et al. 2012



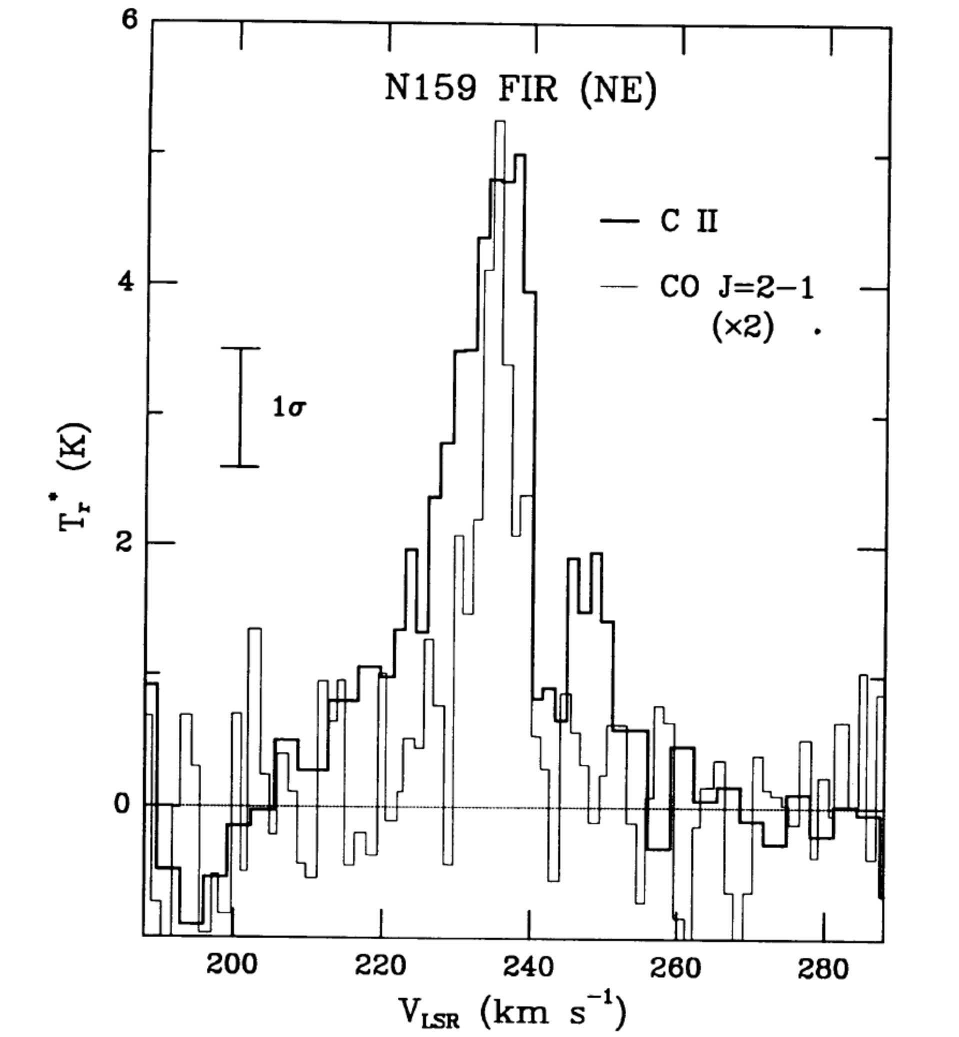
The Large Magellanic Cloud (LMC)

- Low metallicity environment (~1/3 solar)
- Close (~50kpc)
- Giant star-forming regions can be studied by spatially resolved mapping observations



Israel et al. (1996)

Velocity-resolved [CII] in LMC



Boreiko & Betz (1991)

Observed 17 locations in LMC including the N159 region with far-infrared heterodyne receiver onboard KAO

[CII] emission is ~50% wider than the CO(2-1) line

Velocity-resolved, good S/N mapping observations are needed!

2. Observations

- OTF mapping with 6” step size, 4'x(3'-4') area covering N159W and E
- SOFIA/GREAT + APEX/FLASH$^+$ & CHAMP$^+$

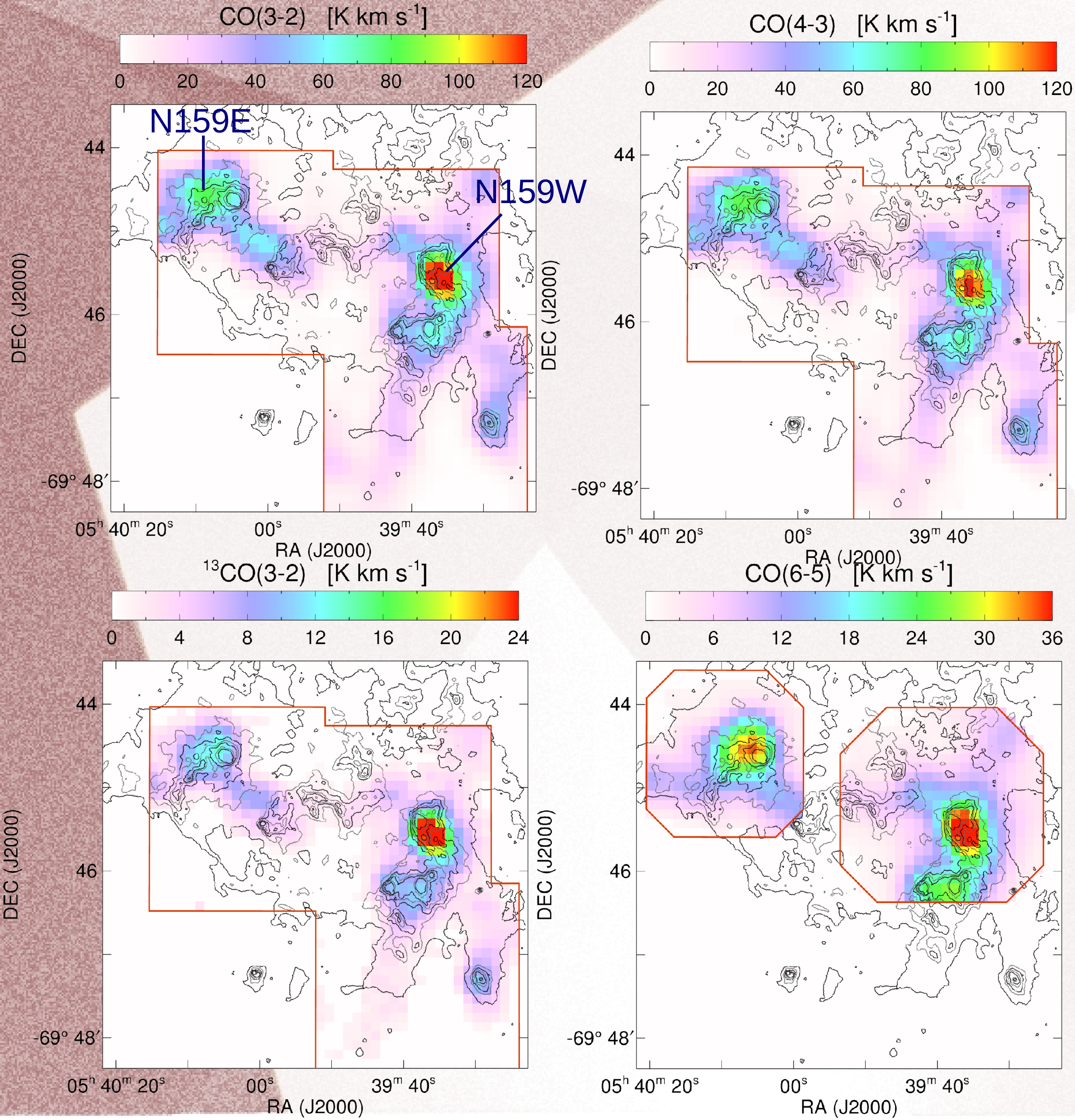
Line	Frequency [GHz]	Instrument	η_f^a	η_{mb}^b	HPBW^c [″]
^{13}CO(3-2)	330.5879653	FLASH$^+$	0.95	0.6	19.0
CO(3-2)	345.7959899	FLASH$^+$	0.95	0.6	18.2
CO(4-3)	461.0407682	FLASH$^+$	0.95	0.43	13.6
[C I] $^3P_1$-$^3P_0$	492.1606510	FLASH$^+$	0.95	0.43	12.8
CO(6-5)	691.4730763	CHAMP$^+$ LFA	0.95	0.56	8.8
[C I] $^3P_2$-$^3P_1$	809.3419700	CHAMP$^+$ HFA	0.95	0.43	7.7
[N II]	1461.1338000	GREAT L1	0.95	0.67	19.9
[C II]	1900.5369000	GREAT L2	0.95	0.67	15.3

GREAT observations

- New Zealand deployment (2013)
- [CII] : 4 flights (1.5h+2h+0.3h+0.2h)
- [NII] : first 2 flights
- XFFTS (2.5GHz bandwidth, 44kHz resolution)

3. Results

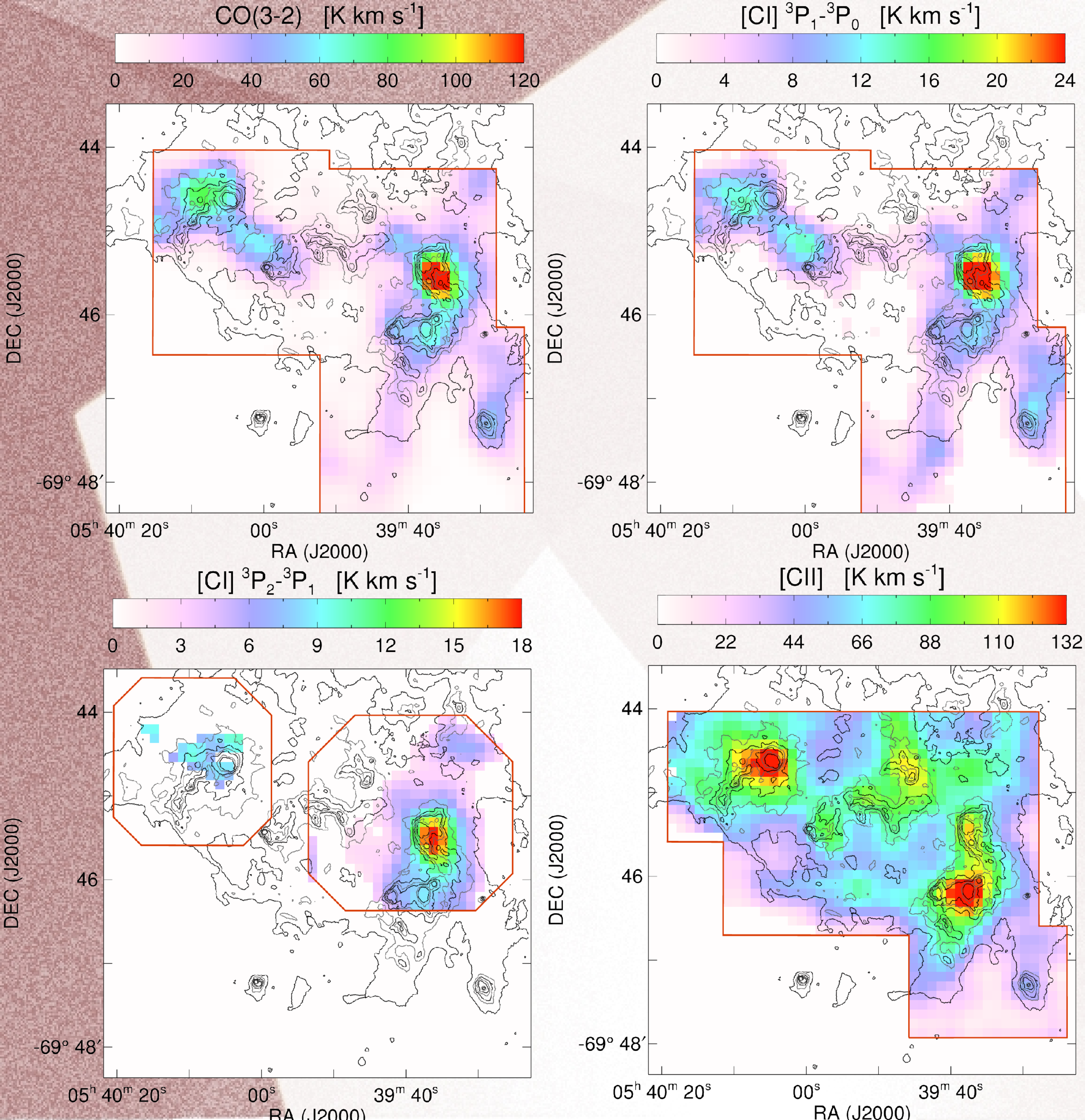
- All data are spectrally resampled to 1km/s resolution and spatially resampled to 20” resolution



Color = Integrated intensity
Contour = IRAC 8μm

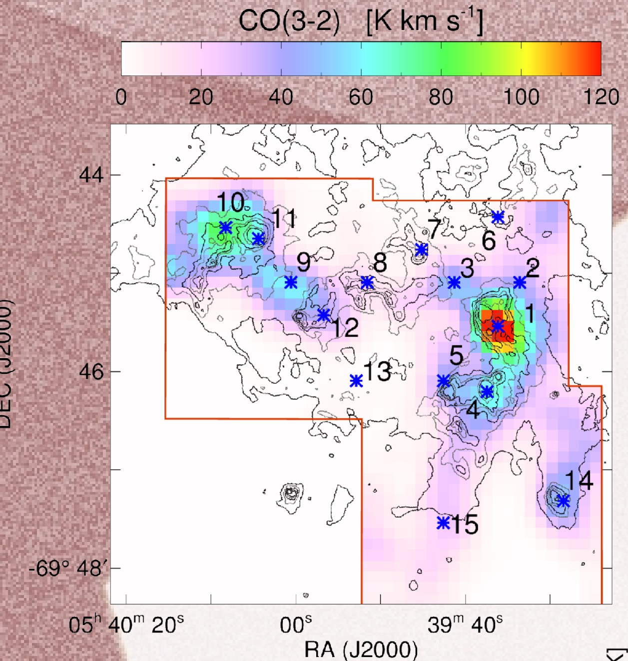
Red lines indicate the observed area

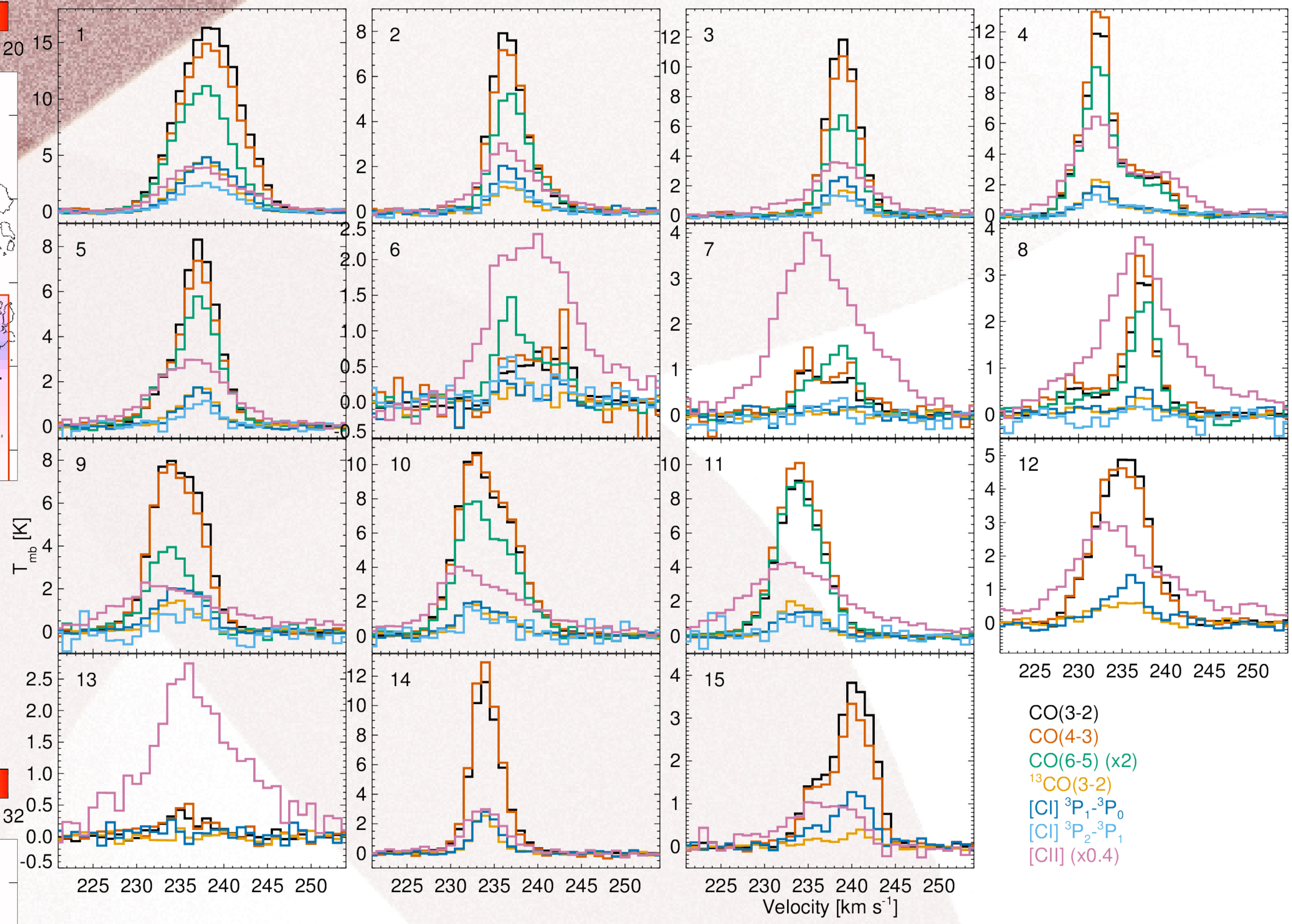
Spatial distribution of the integrated intensity looks similar among CO and ^{13}CO(3-2), but relative strength between cores are different

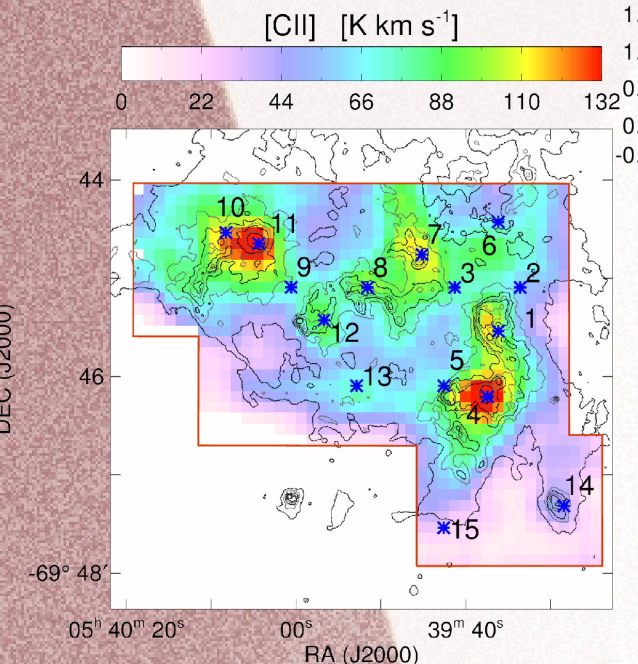


[CII] emission matches well the IRAC 8μm

The velocity information tells much more!

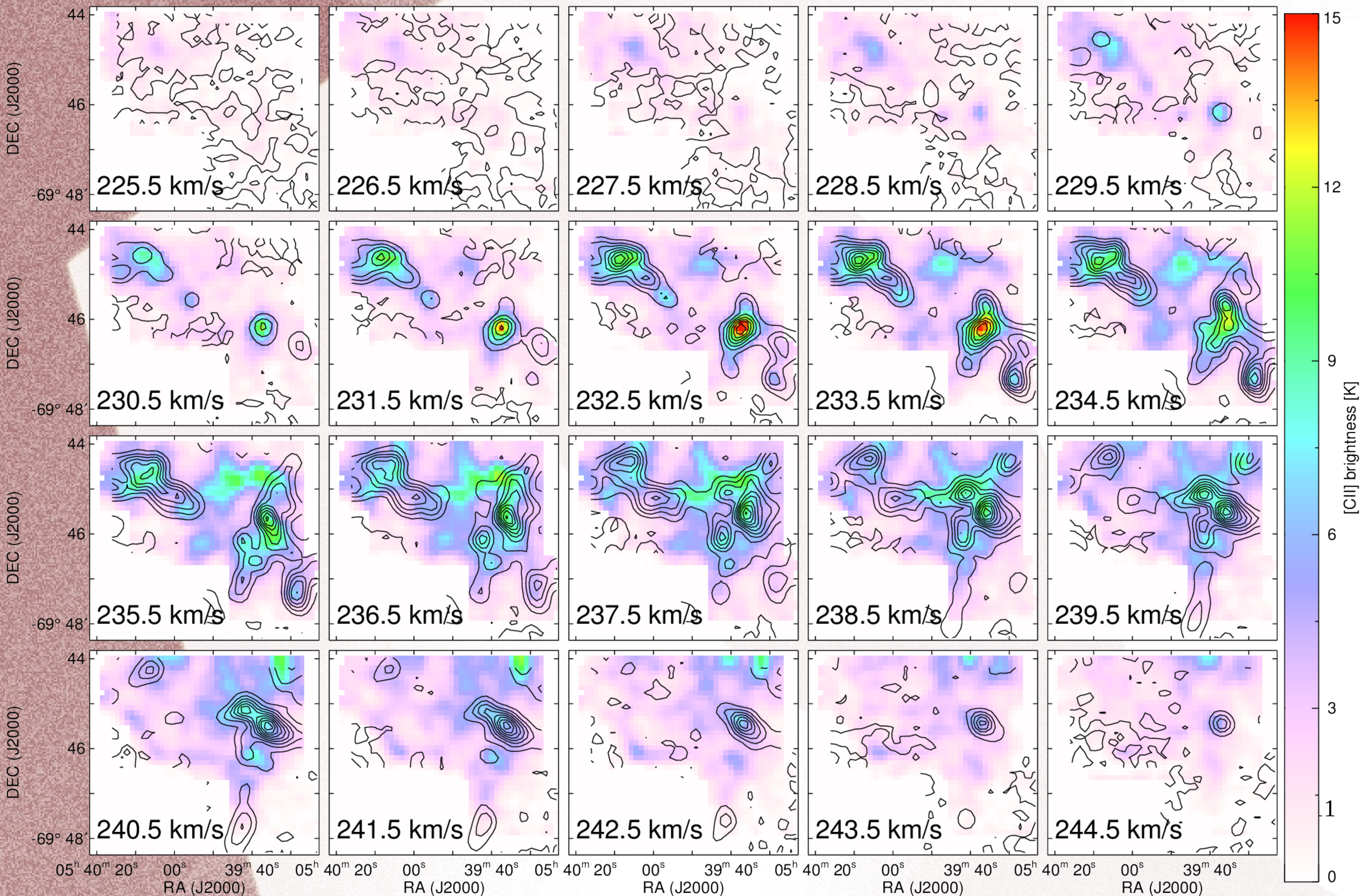




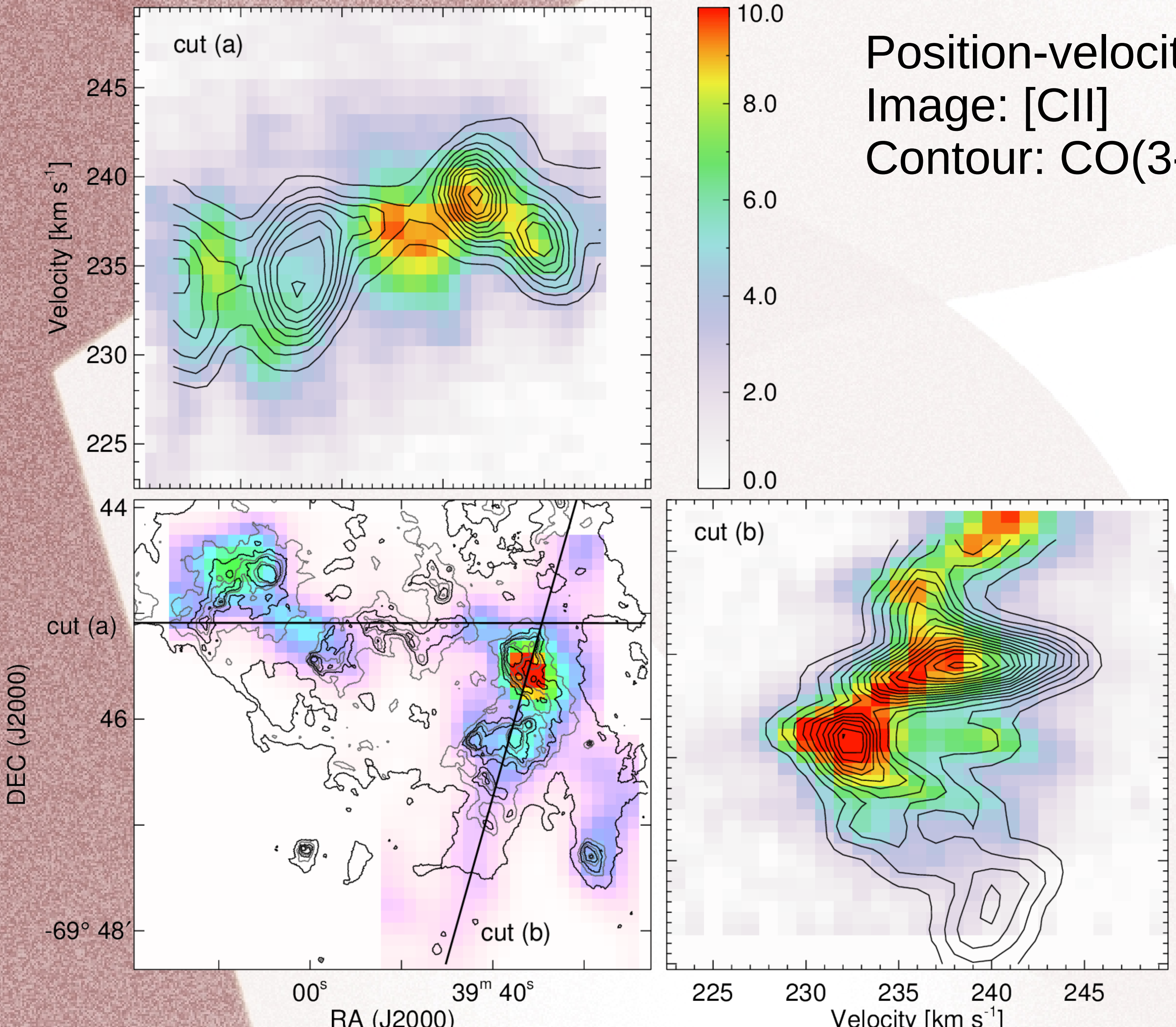


- Large variations over the area
- [CII] has a very different velocity profile compared to other emission lines

Channel map Image: [CII] Contour: CO(3-2)



Position-velocity map
Image: [CII]
Contour: CO(3-2)



Gaussian fit to CO(3-2)

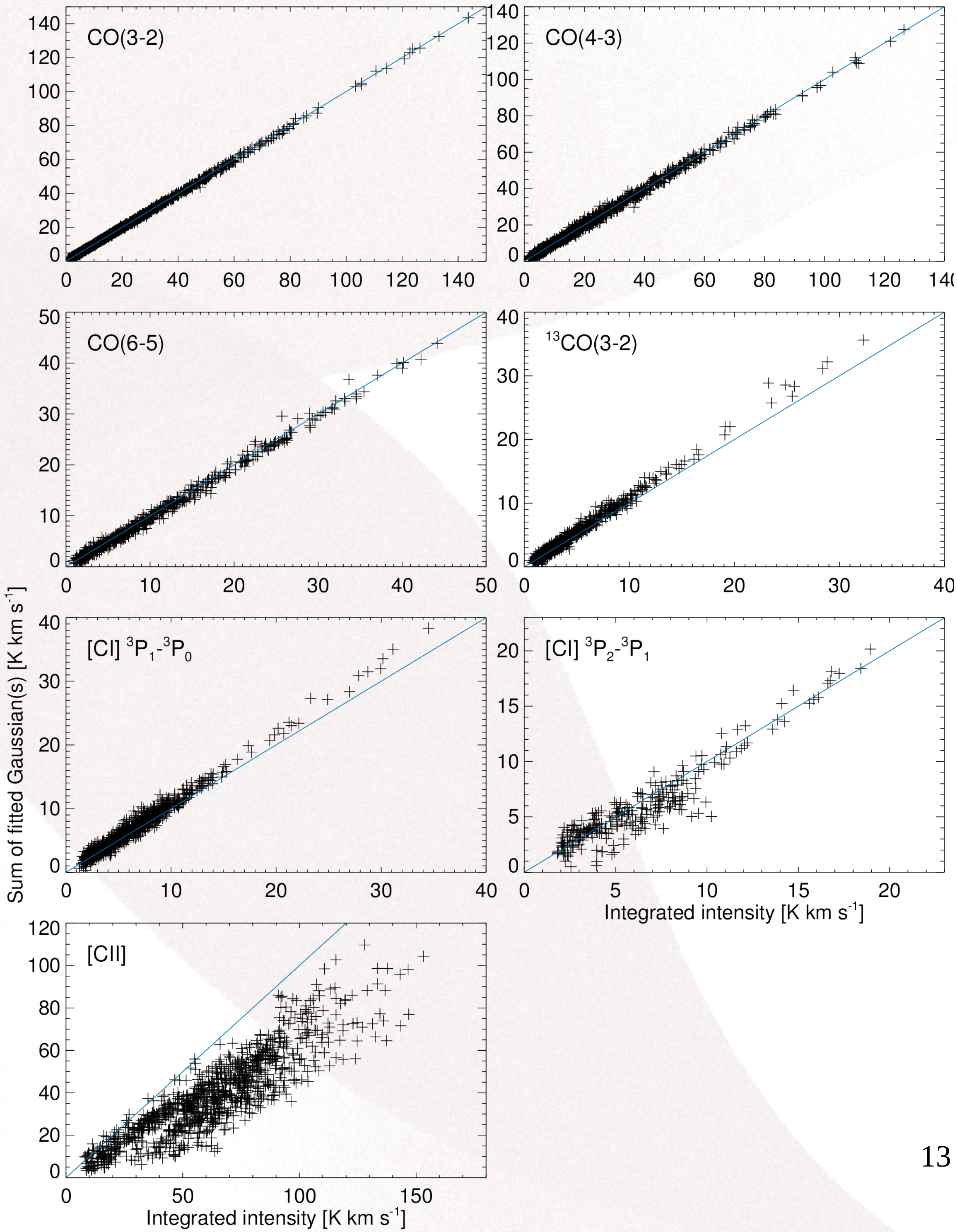
- 1 or 2 Gaussian(s)

→ use the center and width to fit the other emission lines

- All CO and [CI] lines have the same velocity components
  ** the relative amplitude can be different

- The deviation at the brightest part of ^{13}CO and [CI] is likely because of the opacity effect

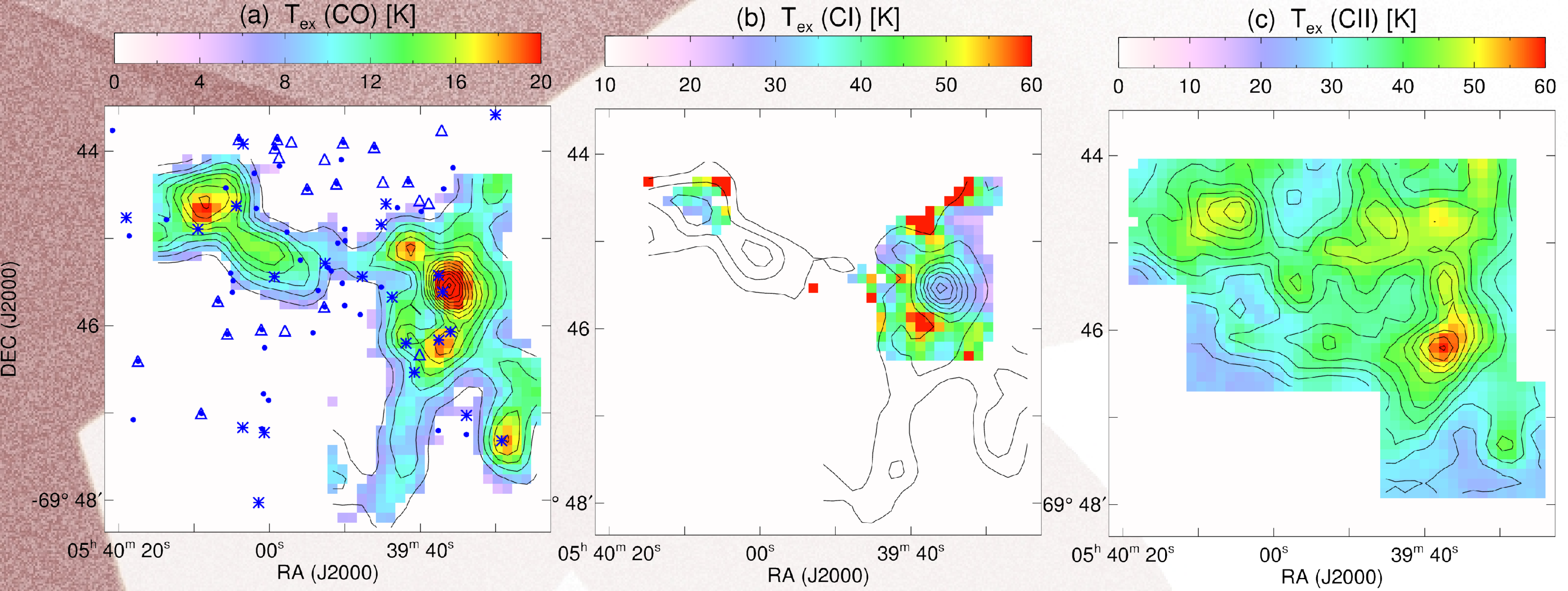
- [CII] cannot be reproduced by the CO-constrained Gaussians



Abundance ratio of C^+/C/CO at each velocity bin

← Column density $N(C^+)/(N(C^+)+N(C)+N(CO))$

← excitation temperature (T_{ex})



CO

$^{12}CO(3\text{-}2)/^{13}CO(3\text{-}2)$ → τ_{13} (= 0.06 to 0.4 across the map)

Brightness and τ → T_{ex} (assumption of the filling factor η is needed)

[CI]

$[CI]^3P_2\text{-}^3P_1/^3P_1\text{-}^3P_0$ → T_{ex} (optically thin)

T_{ex}(CI) is higher than Tex(CO) with η=1

[CII]

We need to assum τ

τ>>1 : lower limit of T_{ex}, τ=1 : Figure above

Total column density

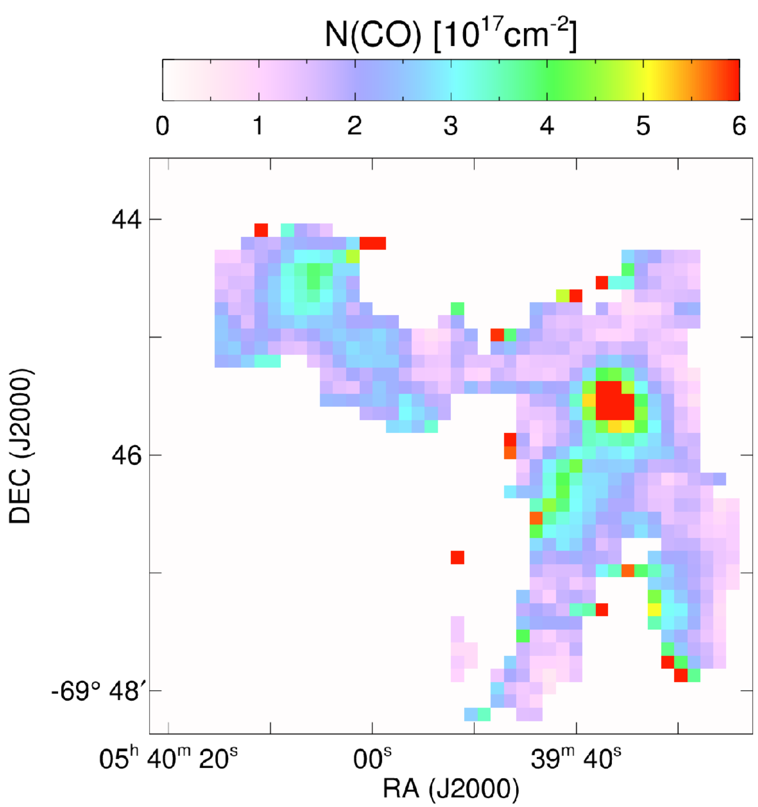
CO

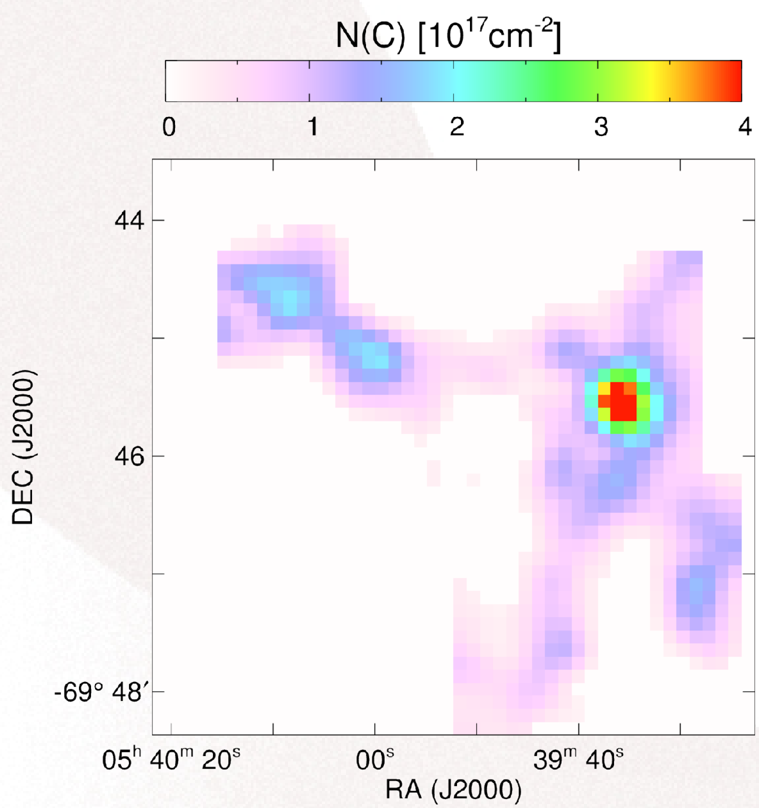
Consistency check with CO(4-3) and (6-5) need to be done/interpreted, maybe some indication for η

C

T_{ex} from the line ratio: limited spatial range, large error

Column density here is calculated with T_{ex}=40K



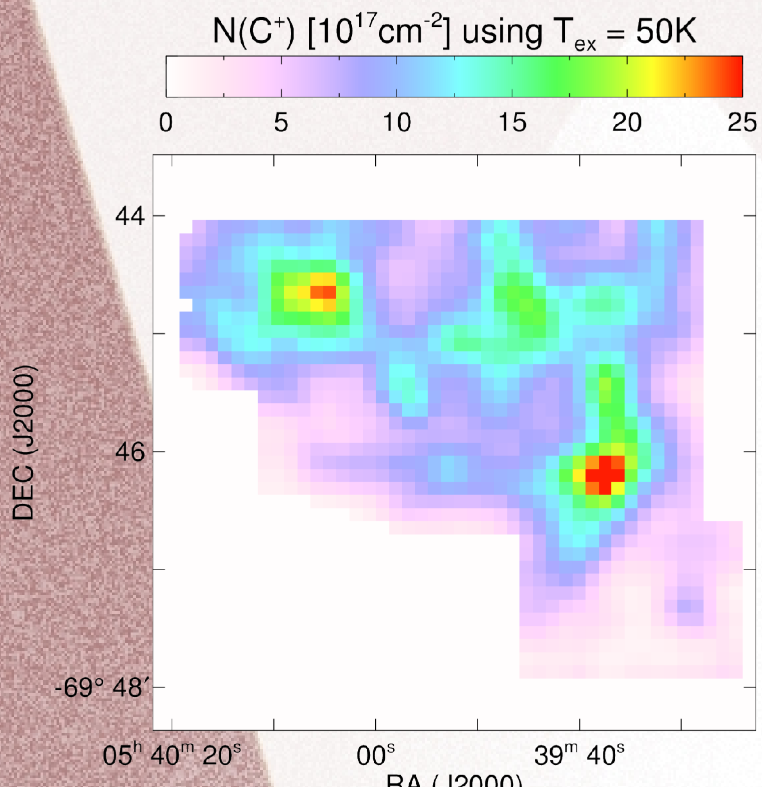


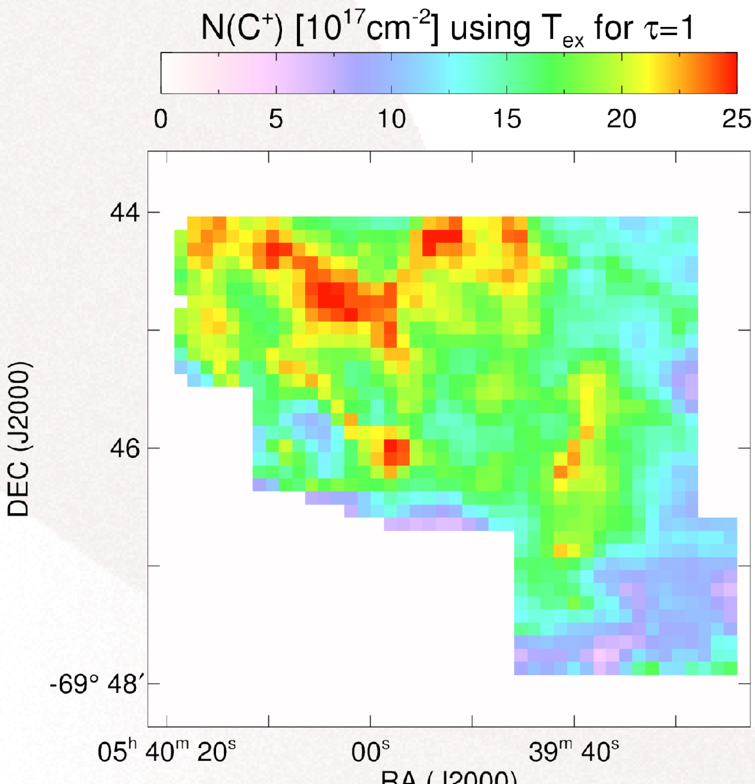
Total column density

C^+

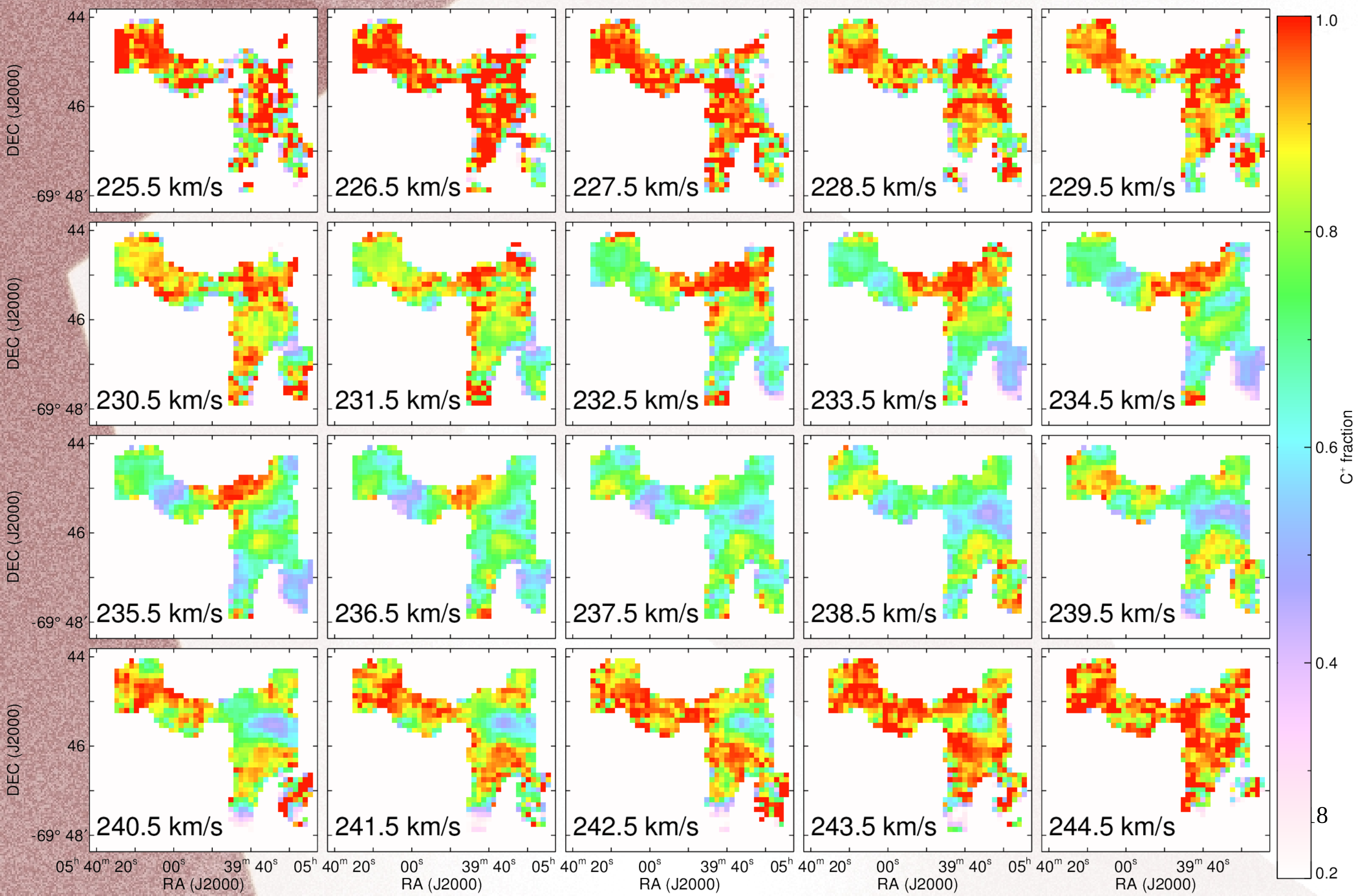
Case 1: T_{ex}=50K

Case 2: τ=1



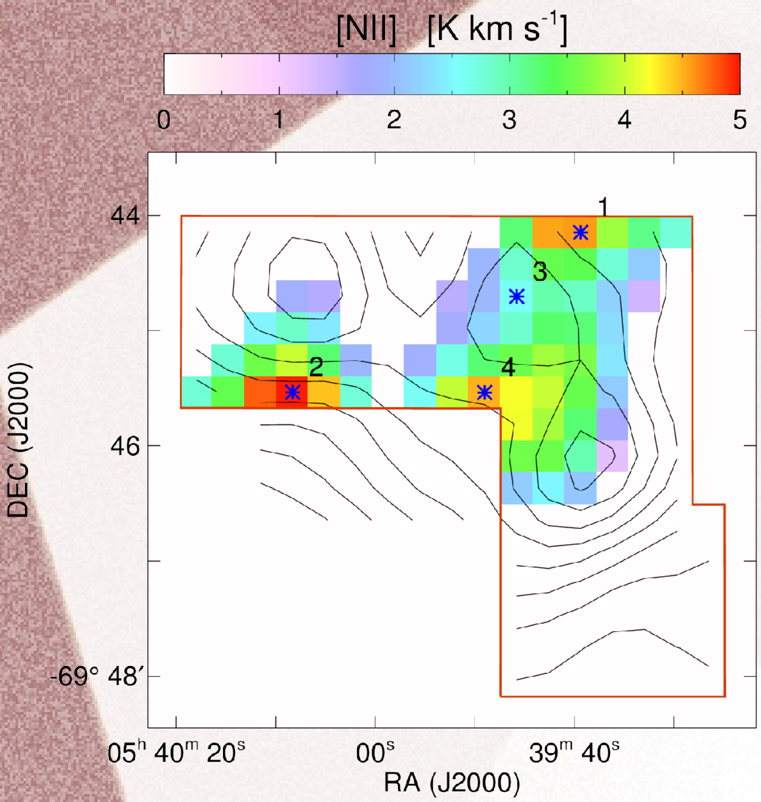


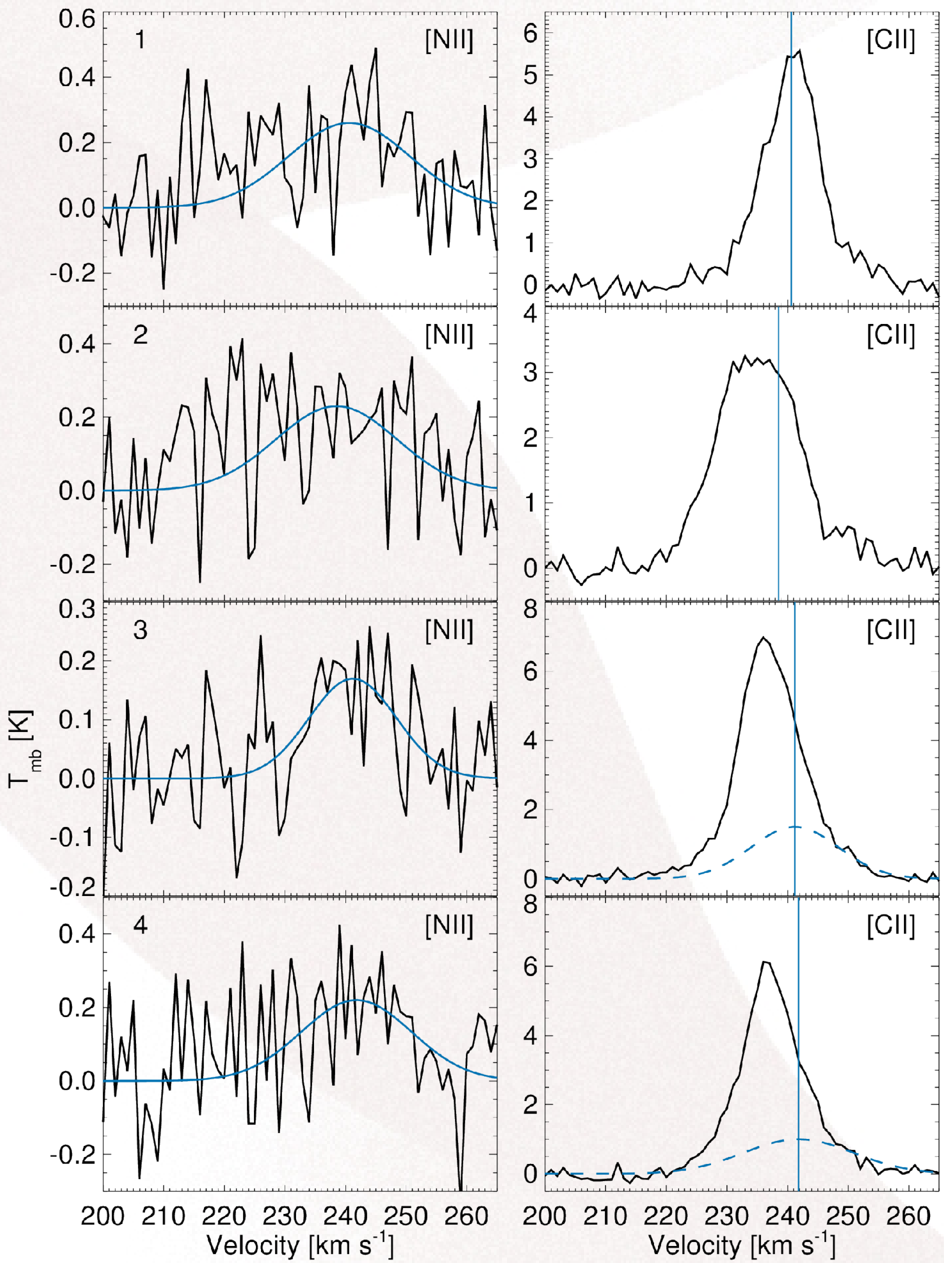
Channel map of $N(C^+)/(N(C^+)+N(C)+N(CO))$ at each velocity bin



- Over the whole velocity range, C+ is the most dominant (> 50%) species at most positions
- At the center of N159W core, at 240 km/s C^+:C:CO=50:20:30
- In the region between N159W and E, almost all carbon atoms are in C^+
- Current masked area is due to the non-detection of $^{13}CO(3-2)$ or [CI] $^3P_1$-$^3P_0$, naively indicating a dominant contribution of C^+

The estimate of the [CII] emission coming from ionized gas using [NII]/[CII]





- Max. ionized gas fraction is 26% at position 2, 8% of position 3 ([CII] blob)
- At position 3 and 4, high velocity wing of [CII] may come from the ionized gas

4. Summary

- The first arcmin scale mapping observations of the velocity resolved [CII] with SOFIA/GREAT
- The fraction (20-50%) of the [CII] emission cannot be fitted by the CO velocity components
- The fraction of the C^+, C, and CO column density against the sum of them was derived at each spatial position and each spectral bin. Overall C^+ is dominant, and its contribution increases at the velocity far from the line center, and the area between the CO cores.
- The velocity-resolved spectra are essential to get a picture of different clump components and further model the emission lines in detail.