Velocity profiles of [CII], [CI], CO and [OI] and physical conditions in four star-forming regions in the Large Magellanic Cloud

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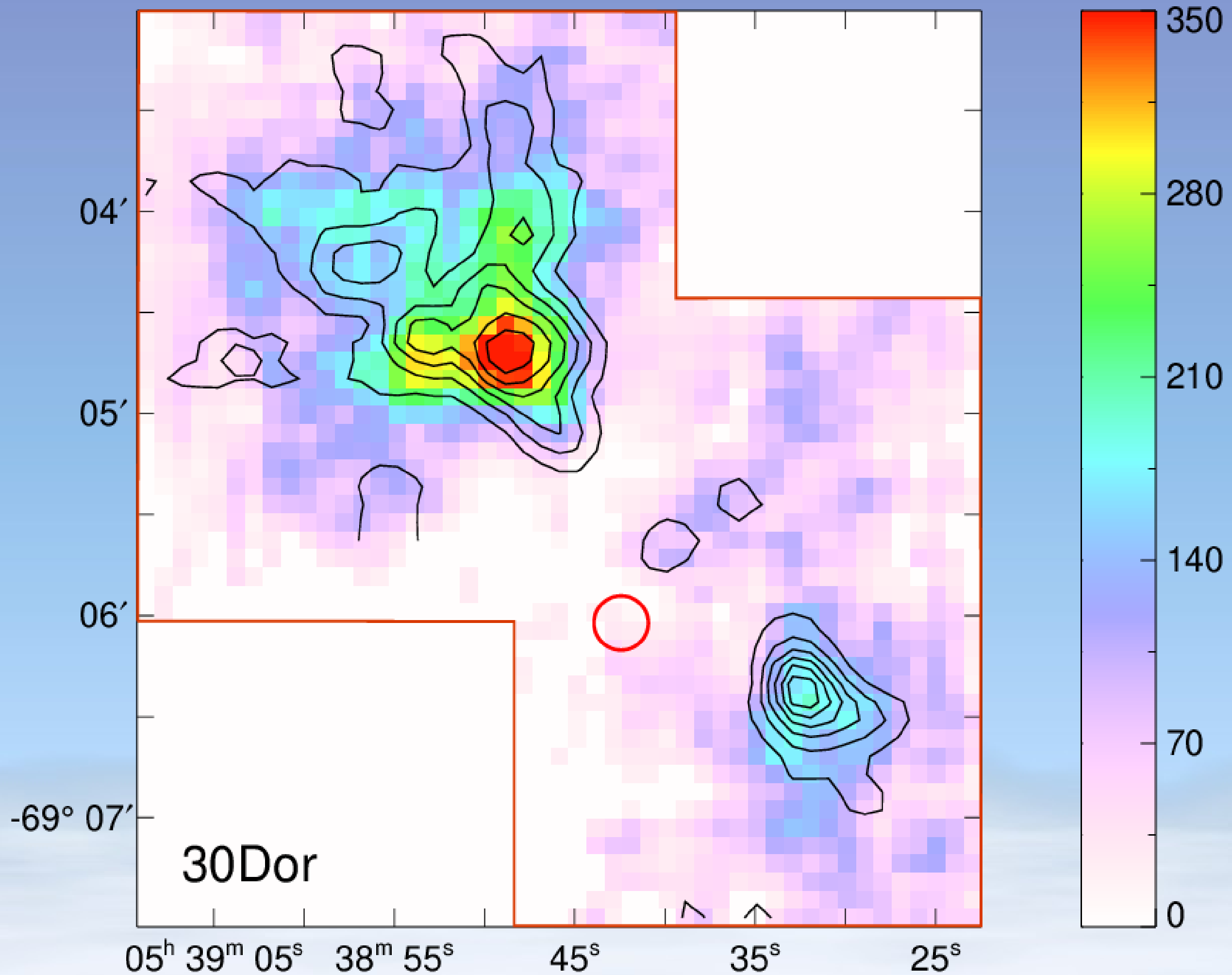
Reference: Okada et al. A&A 621, 62 (2019)

- Velocity profiles of [CII], [CI], CO, and [OI]
- Column densities of C^{+}/C/CO
- PDR modeling in four star-forming regions

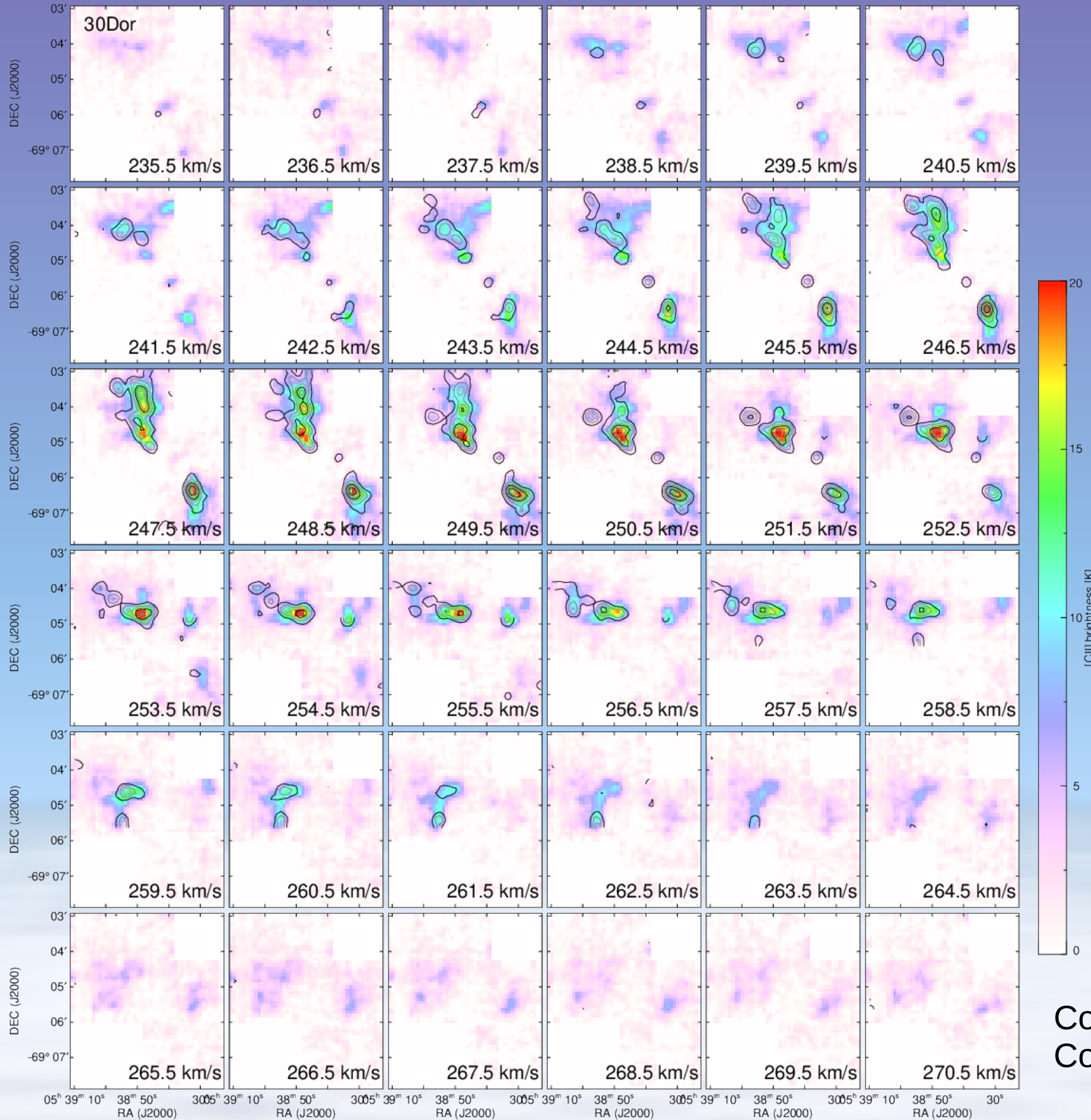
Velocity profiles of [CII], [CI], CO and [OI]

Velocity structure in 30Dor



Color = [CII]
Contour = CO(4-3)

16” resolution
= 4 pc in the LMC



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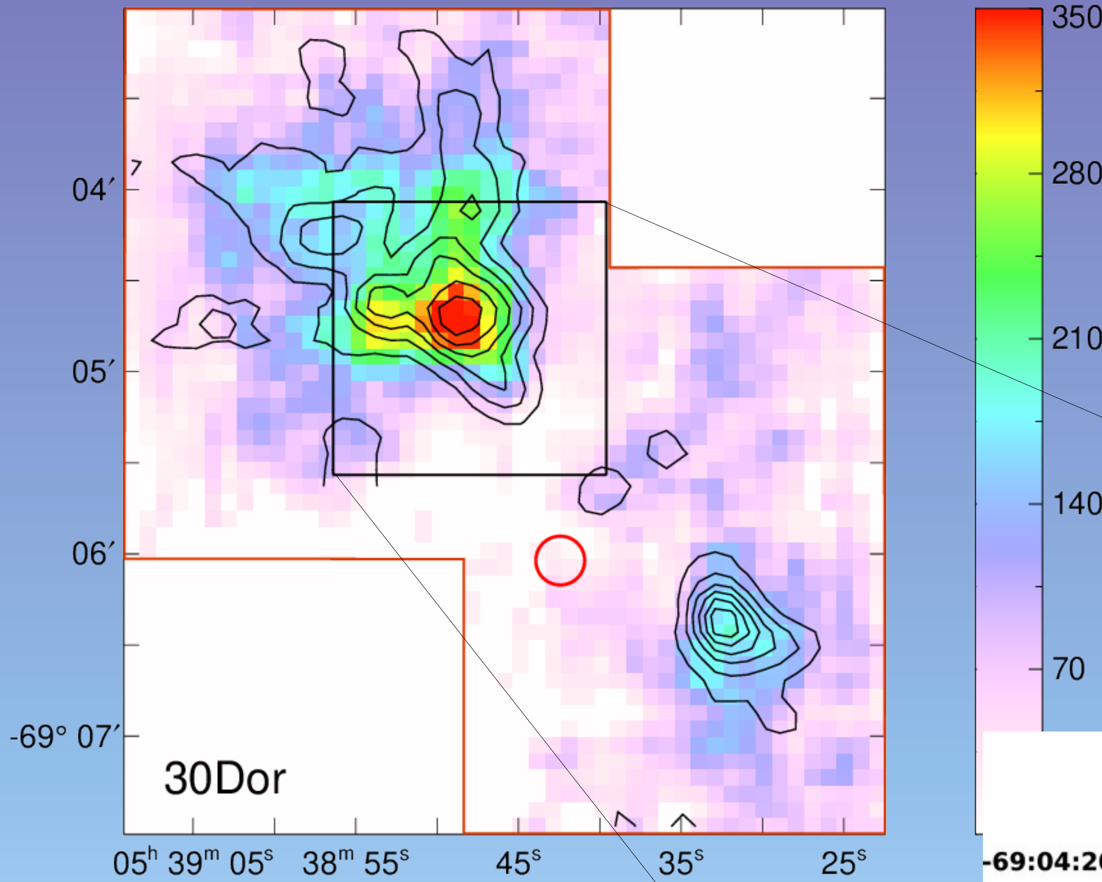
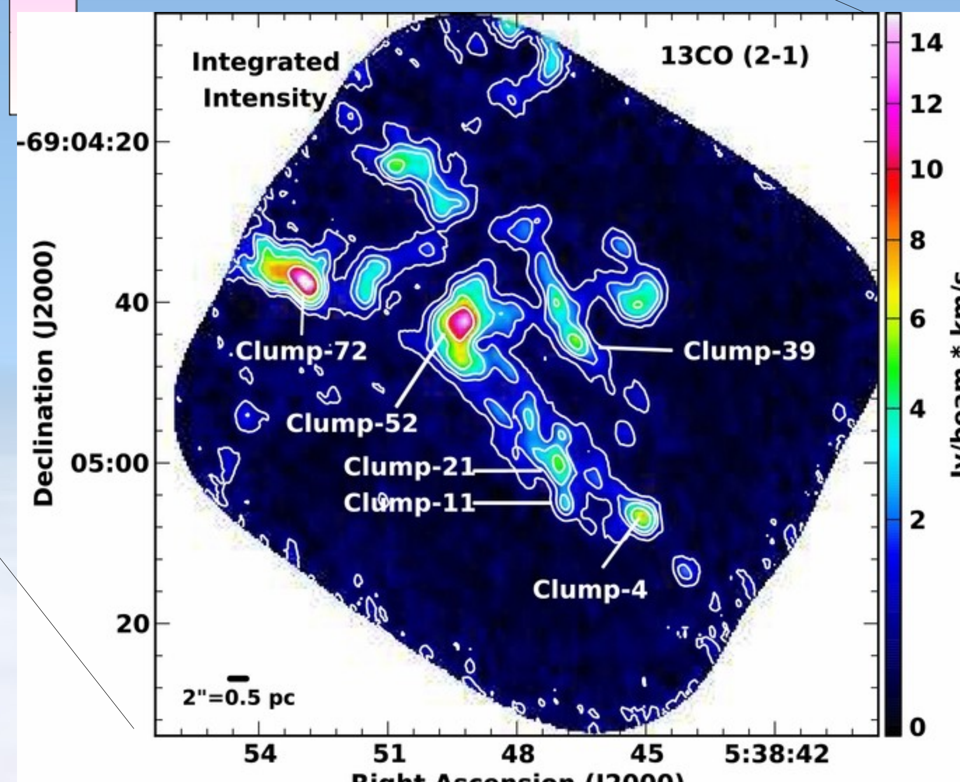
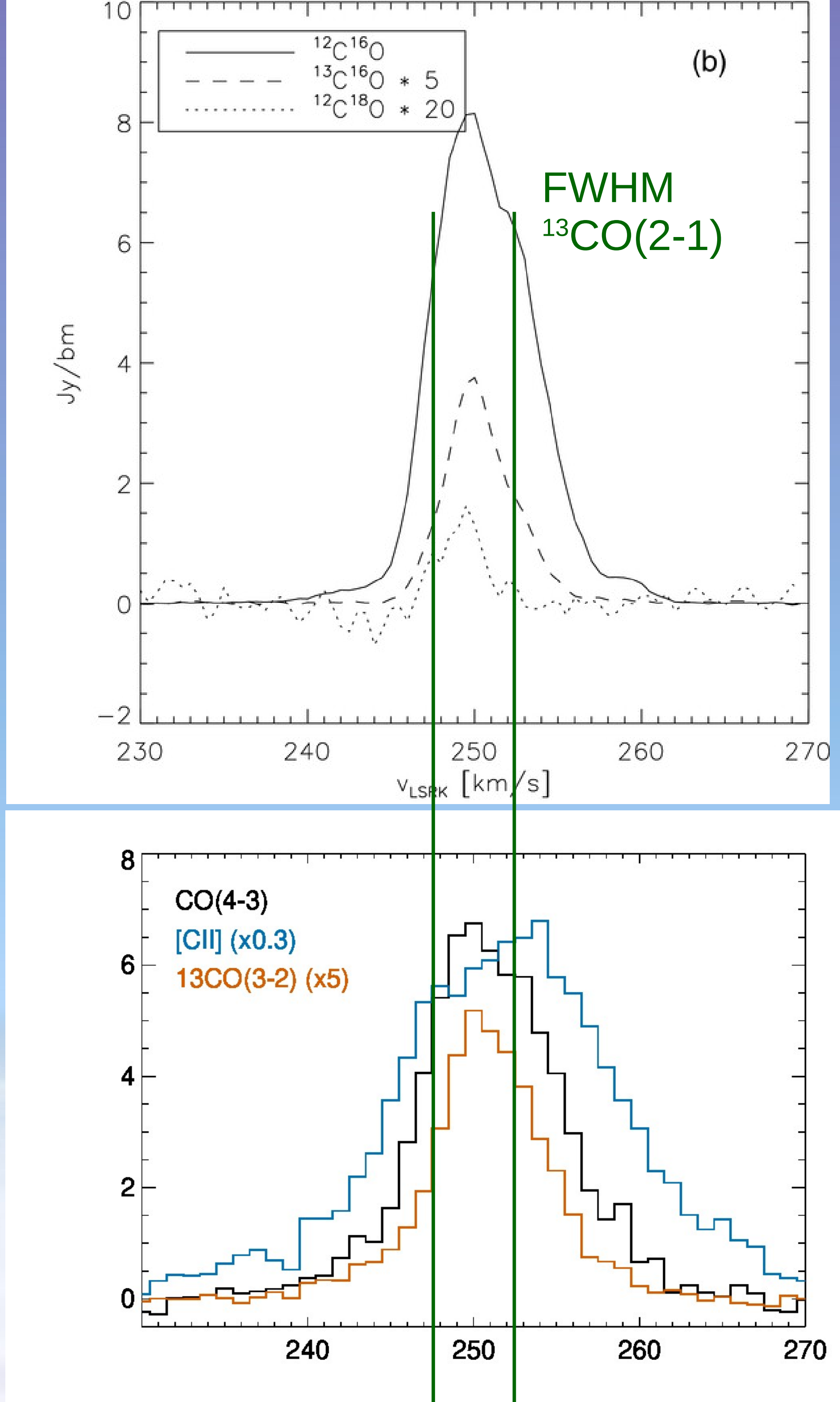
Contour = CO(4-3)



Indebetouw+ (2013)





Clump 52
Indebetouw+ (2013)

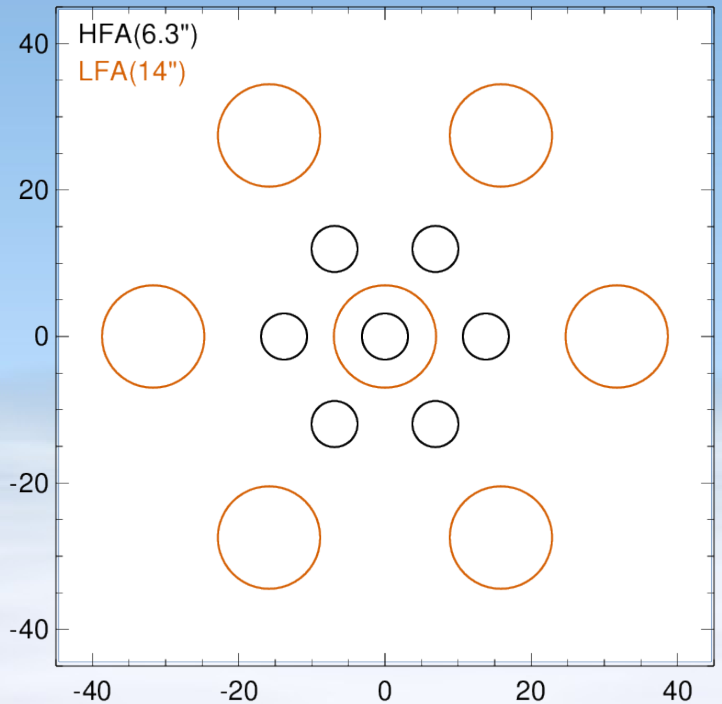
CO peak,
30” resolution for ^{13}CO(3-2)
16” resolution for others
Okada+ (2019)

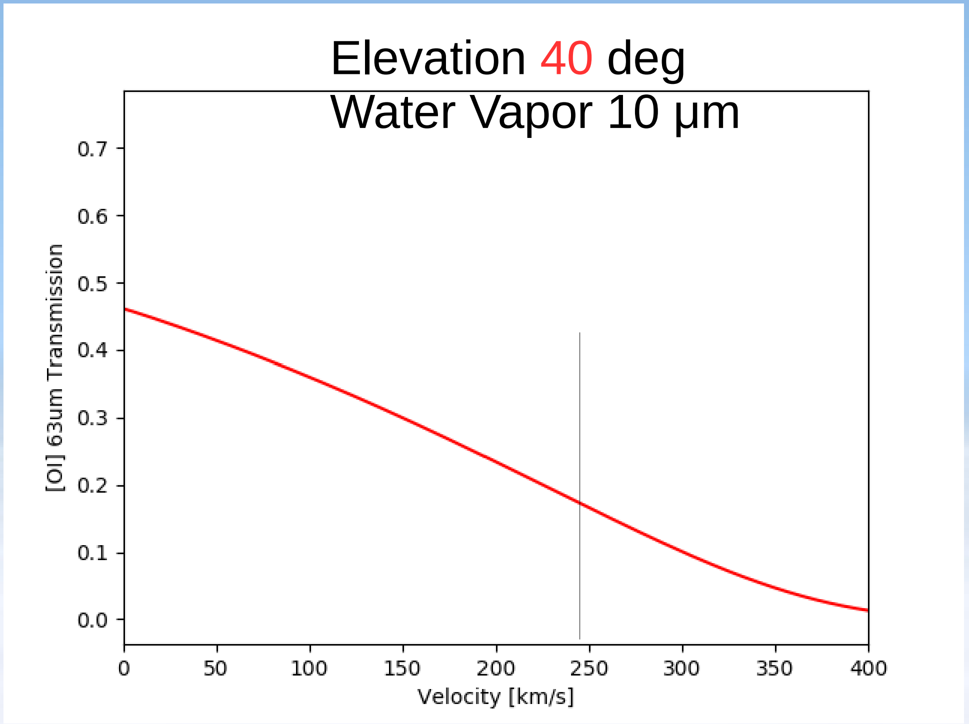
Different velocity components :

- Different cloud components
- Velocity-resolved [OI] and [CII] spectra are useful to distinguish different cloud components and model them individually

[OI] 145μm and 63μm observations with upGREAT

- N159 : 2 pointings, 145μm is detected by 3 pixels in total
- 30Dor : 1 pointing, 4” step 4 point raster observations so that the 63μm beam (6.3”) can fill the 145μm beam (13”).





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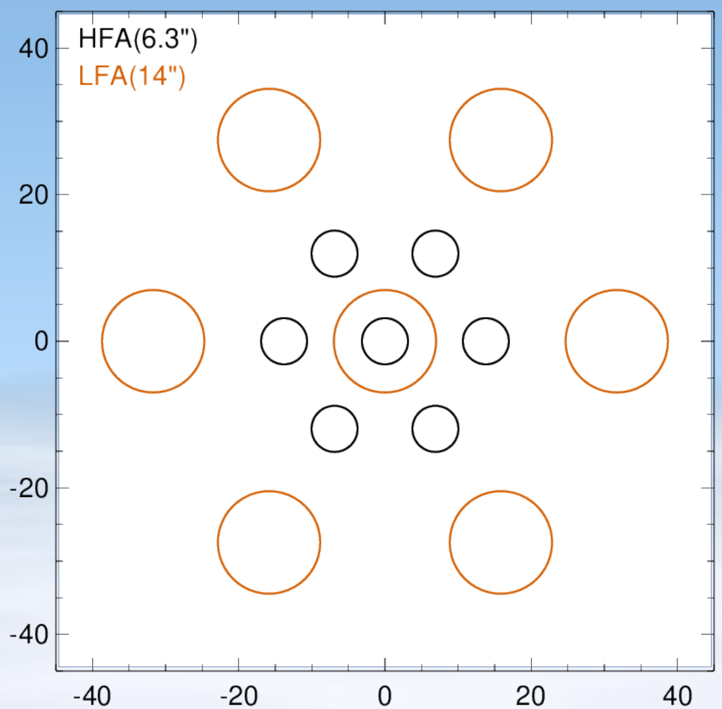

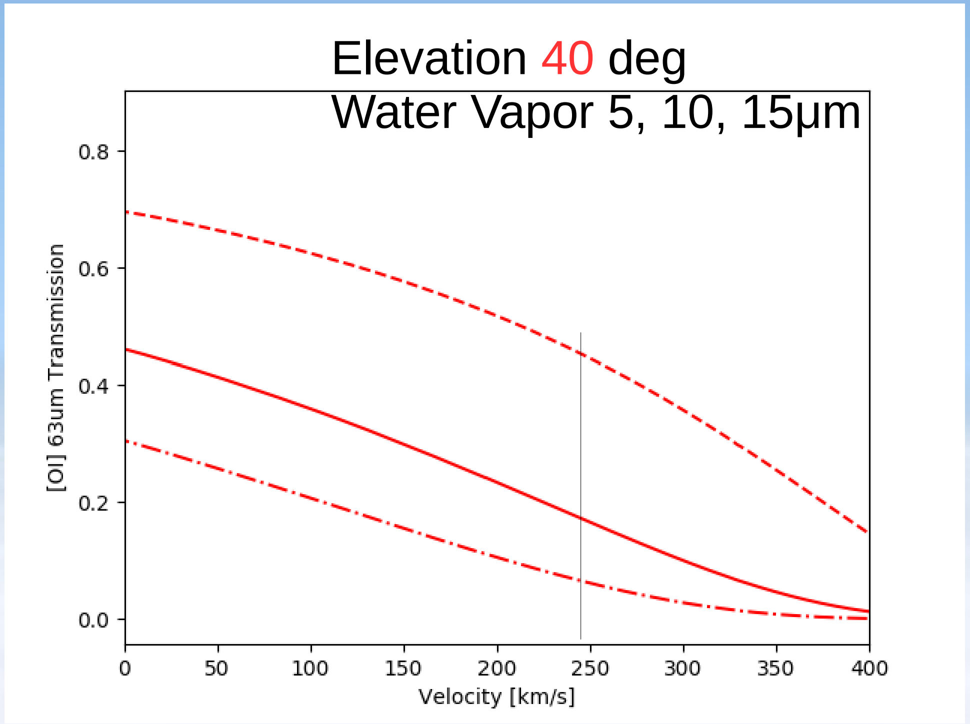

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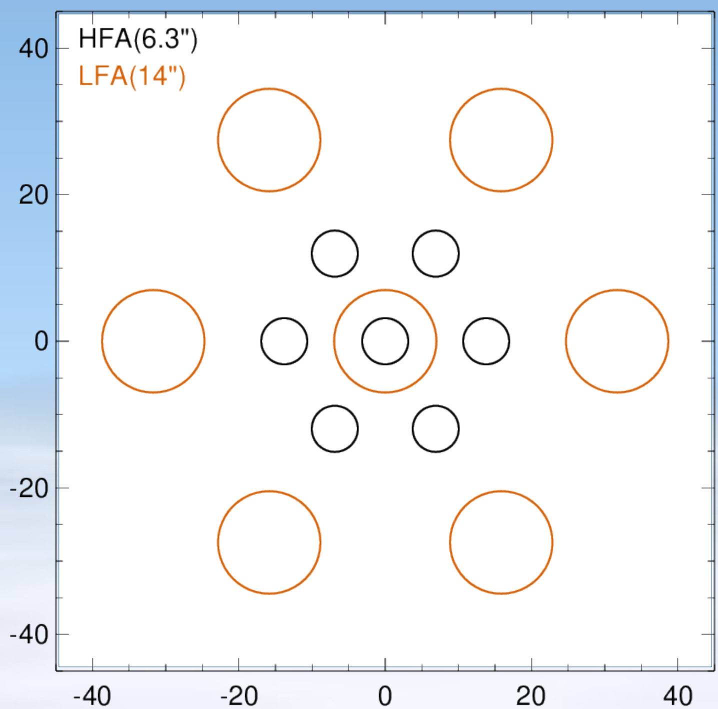
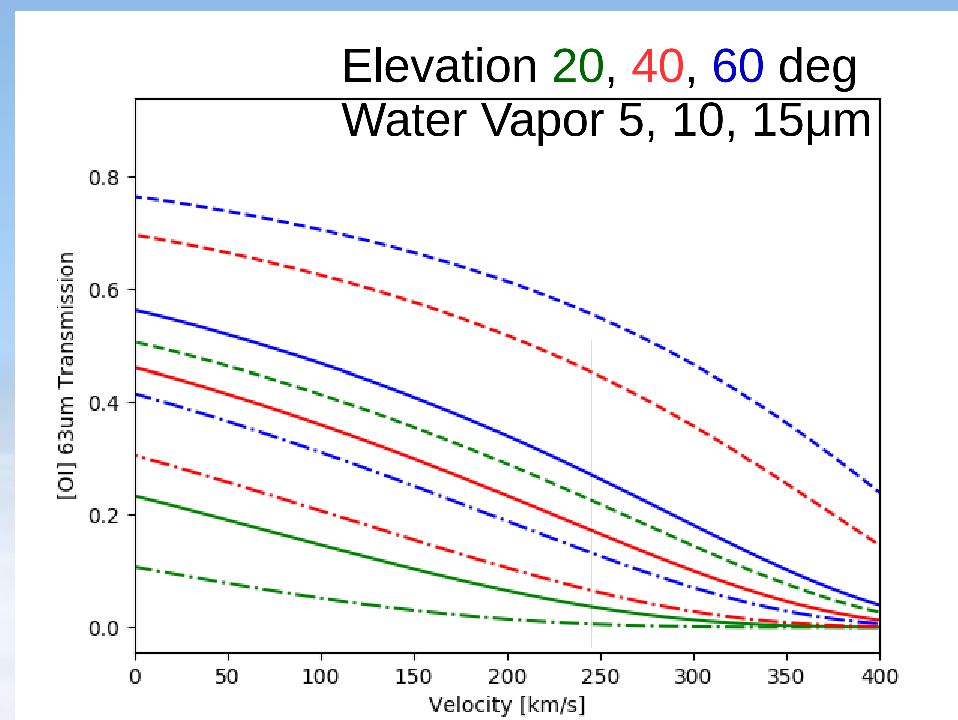
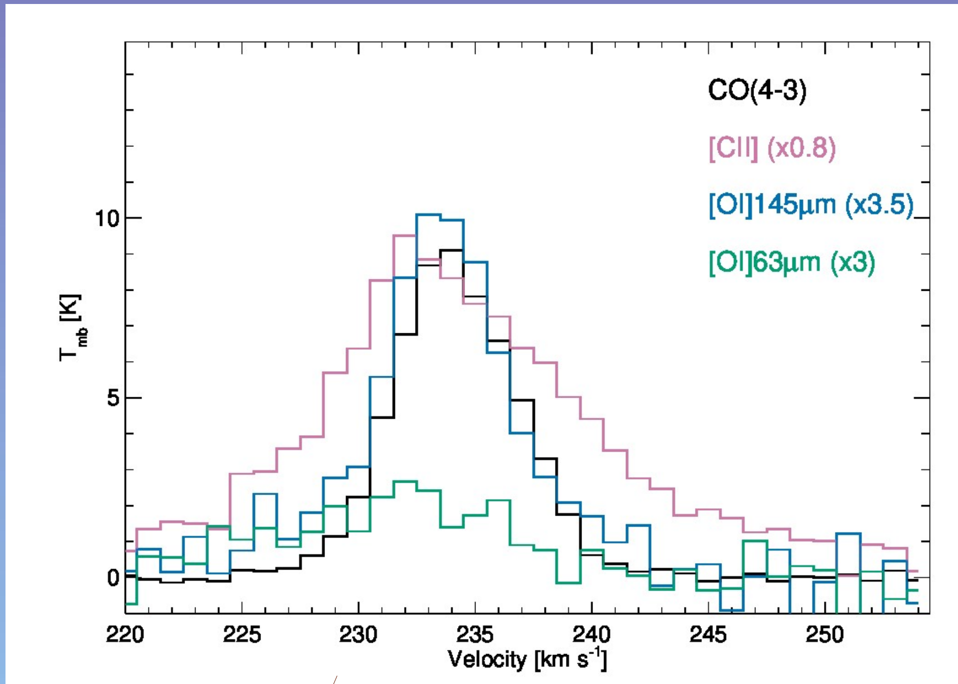
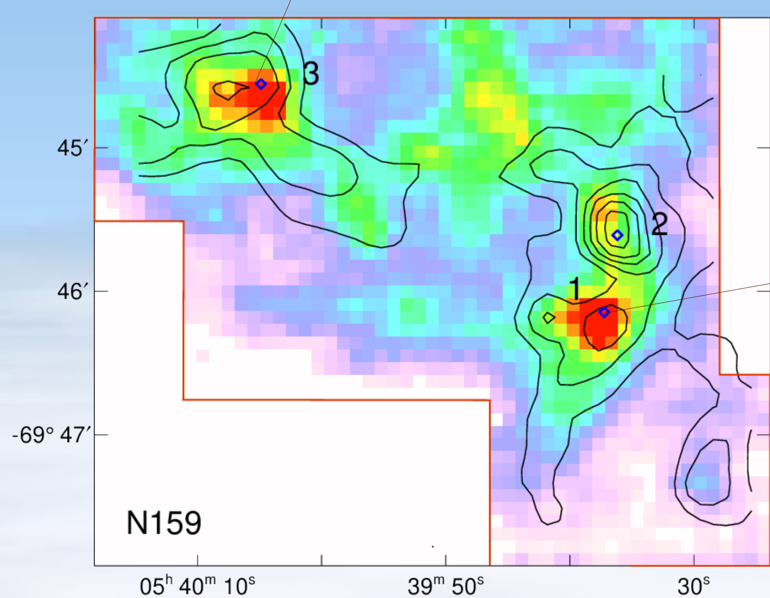
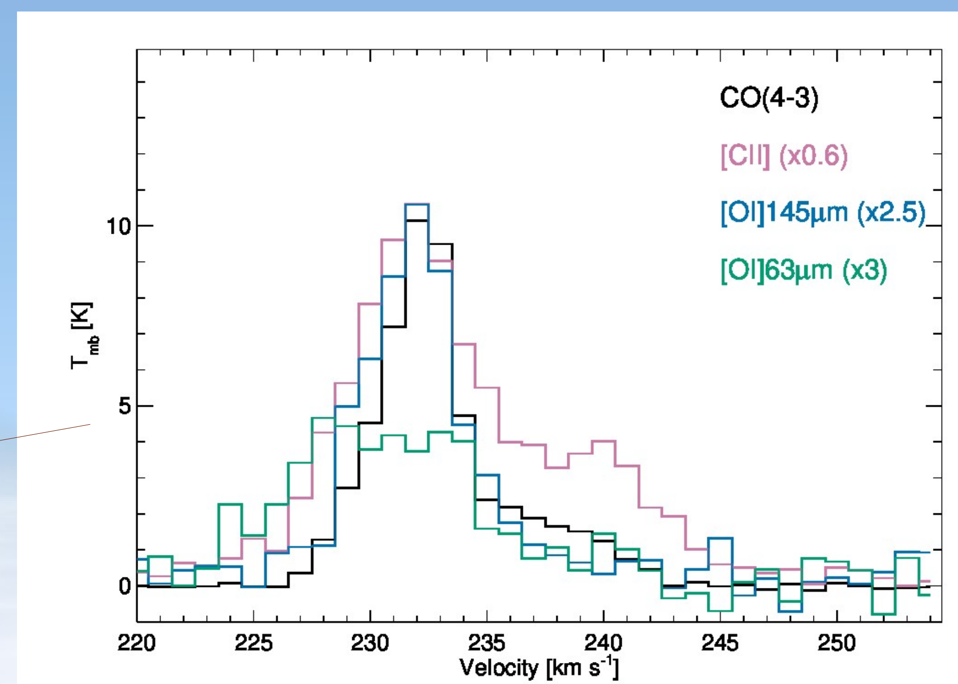


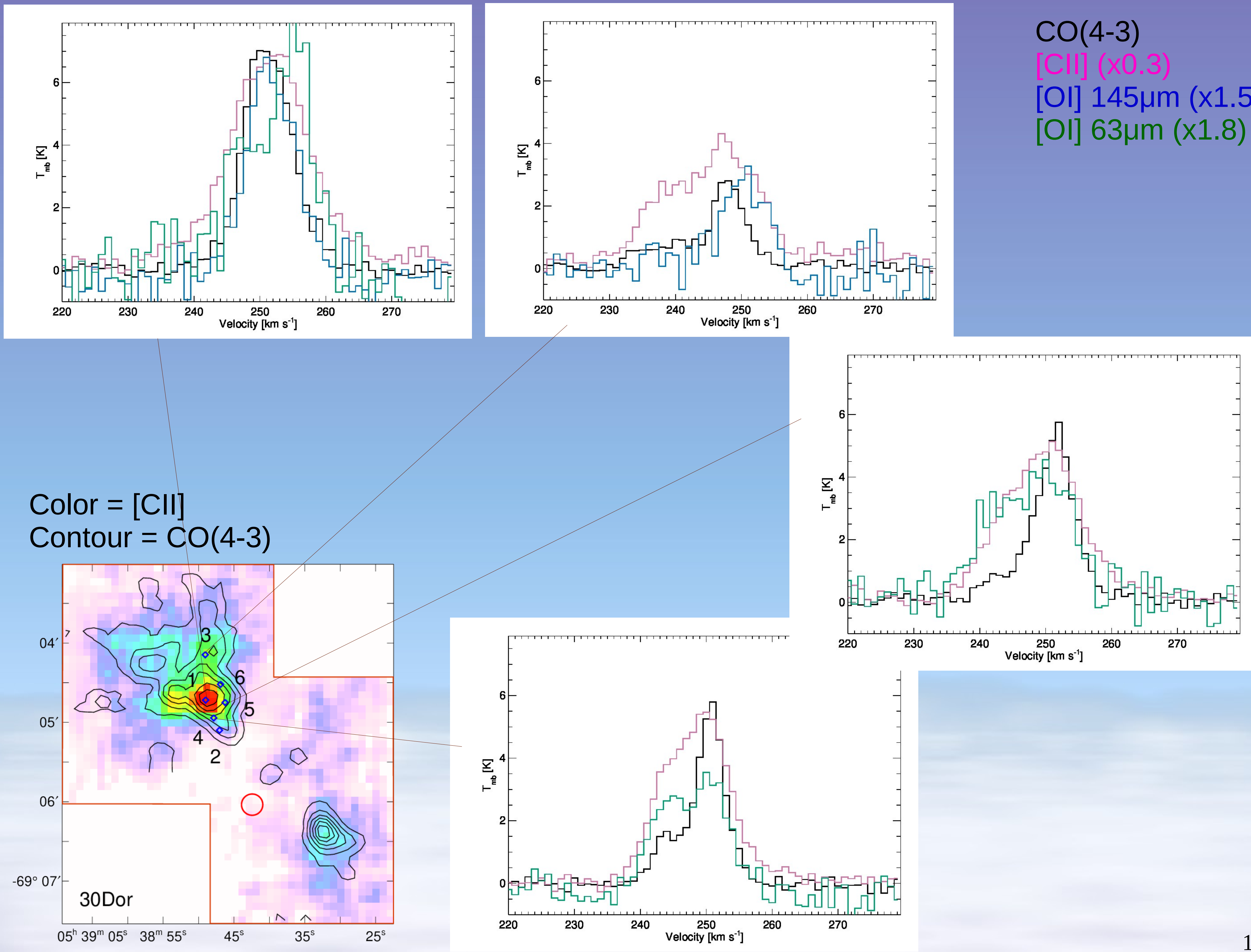








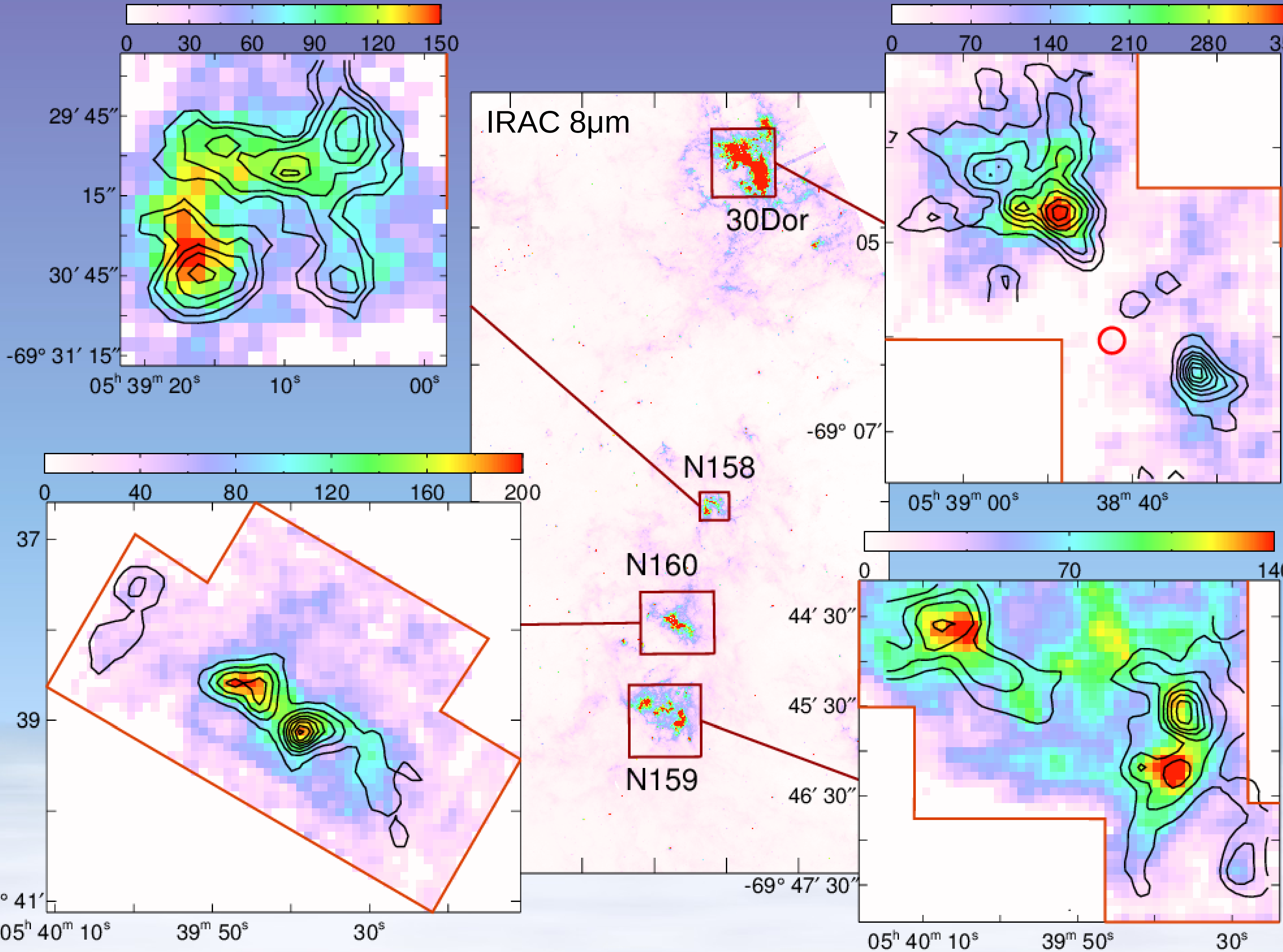
Color = [CII]
Contour = CO(4-3)


CO(4-3)
[CII] (x0.3)
[OI] 145μm (x1.5)
[OI] 63μm (x1.8)
Color = [CII]
Contour = CO(4-3)
30Dor
04′
05′
06′
-69° 07′
05h 39m 05s
38m 55s
45s
35s
25s
1
2
3
4
5
6
T_mb [K]
Velocity [km s^-1]

The line profiles of the [OI] 63μm and 145μm

- Match those of the CO at some positions, but are more similar to the [CII] profiles at other positions.
- The Gaussian fit result confirms that the [OI] emission has a profile between CO(4-3) and [CII]
- Different physical properties in different cloud components
- We cannot simply assume that the velocity components of the [OI] emission are the same as either CO or [CII]

Column densities of C^+/C/CO



Color = [CII], Contours = CO(4-3)

Deriving column density at each position in a map

- CO

  $CO(3\text{-}2)/^{13}CO(3\text{-}2)$ → optical depth τ (with assuming $^{13}C/C = 49$, Wang et al. 2009)

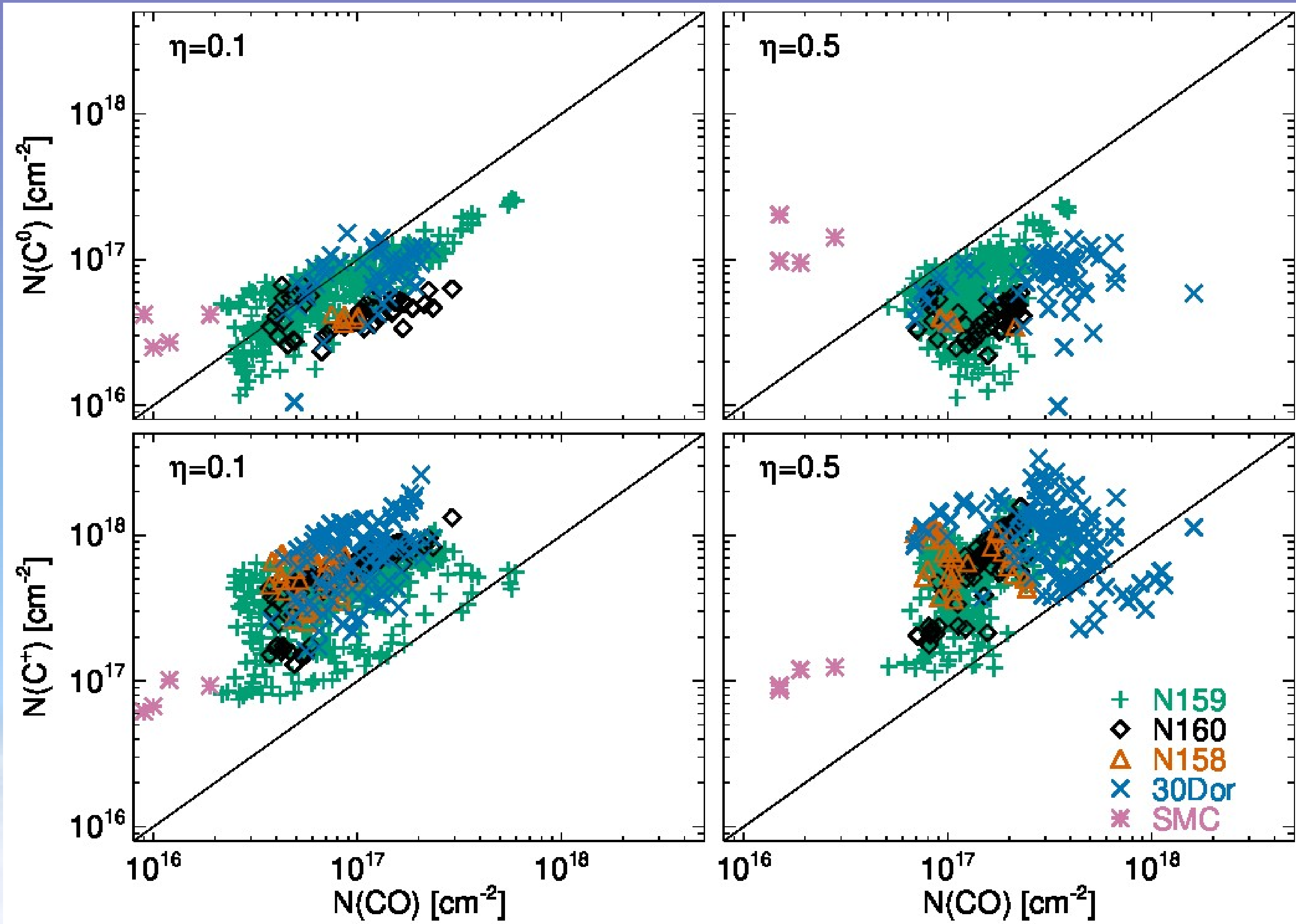
  Absolute intensity of $^{13}CO(3\text{-}2)$ and τ → Tex (with assuming a beam filling factor η)

- C^0

  [CI]492GHz/809GHz → Tex (small area in N159 and 30Dor) → constant Tex over a map

- C^+

  constant Tex over a map (with assuming τ>>1 at the brightest pixel in a map)


η=0.1
η=0.5
η=0.1
η=0.5
N(C⁰) [cm⁻²]
N(C⁺) [cm⁻²]
N(CO) [cm⁻²]
N(CO) [cm⁻²]
N159
N160
N158
30Dor
SMC

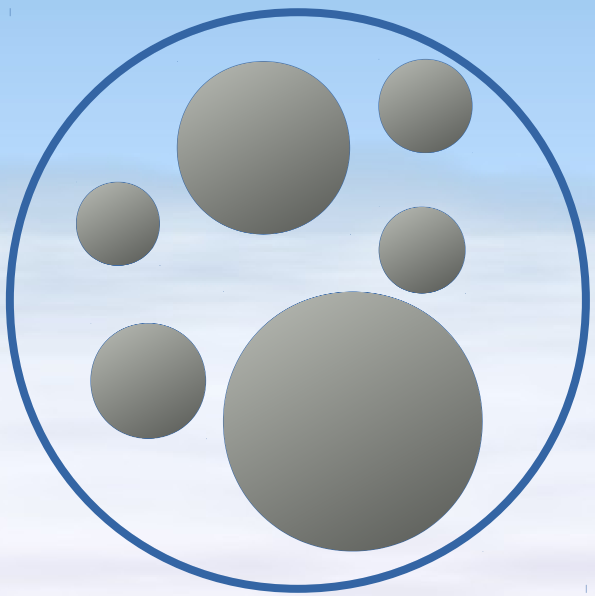
C^+/C/CO column densities in the LMC and SMC

- In a low metallicity environment, a thicker C^+ layer is expected because of lower dust extinction.
- How C/CO depends on the metallicity is not well understood.
- No clear metallicity effect in the C^+/CO column density ratio among the observed LMC and SMC regions, while the C/CO ratio in the SMC regions looks larger.

PDR modeling in four star-forming regions

KOSMA-τ PDR model fit

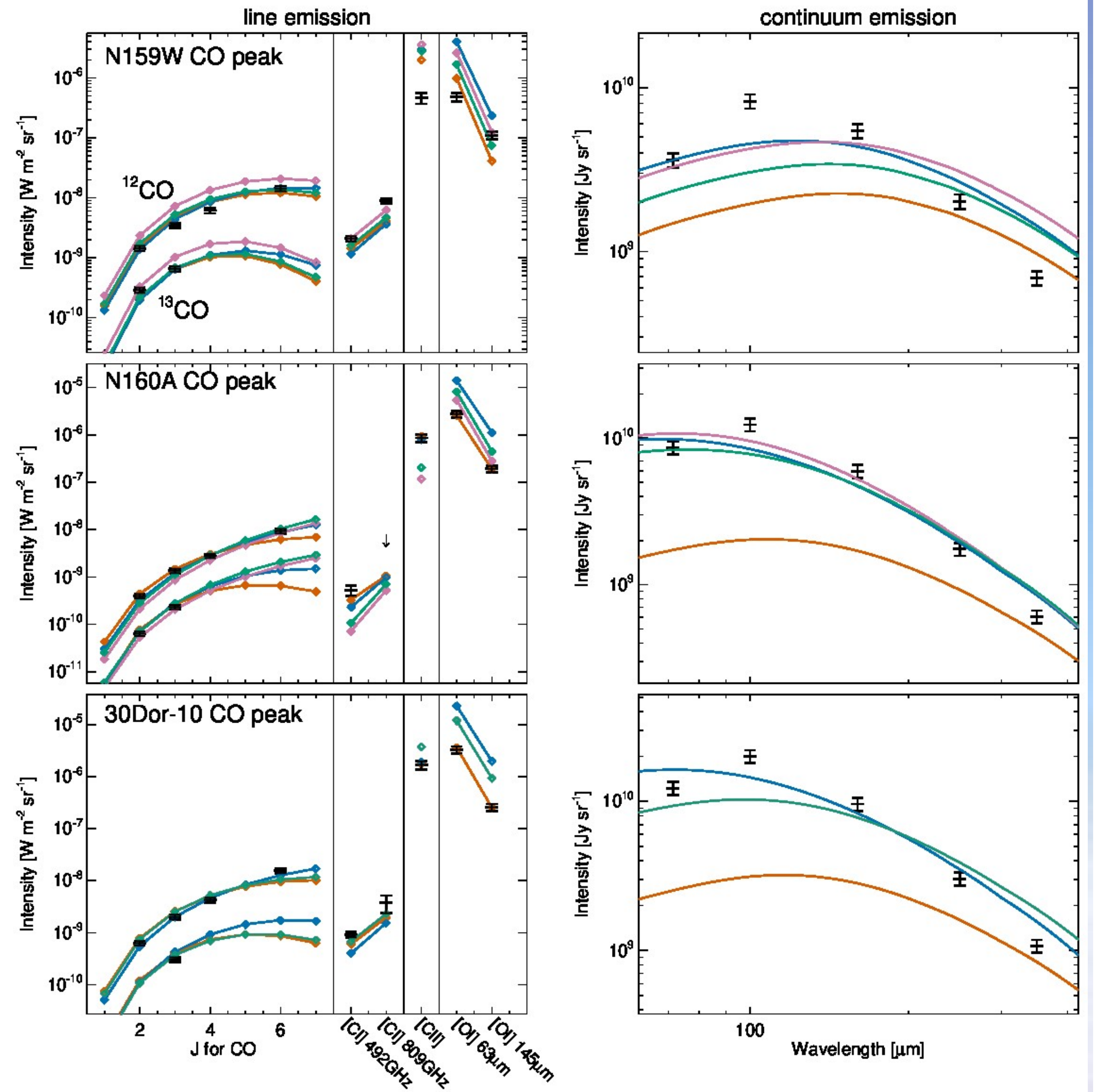
- Consistent treatment of the dust-related physics (Röllig+ 2013)
- Simultaneous fit of the line intensities and the continuum SED
- One clump ensemble with free parameters of mean density, UV field strength, and total mass
- Observations : a few arcmin^2 maps of [CII], [CI], CO, ^{13}CO, and [OI] in N158, N159, N160 and 30Dor
- Line intensities are the sum of CO-defined Gaussian profiles (except for [OI], where integrated intensities of the PACS is used)



KOSMA-τ PDR model fit

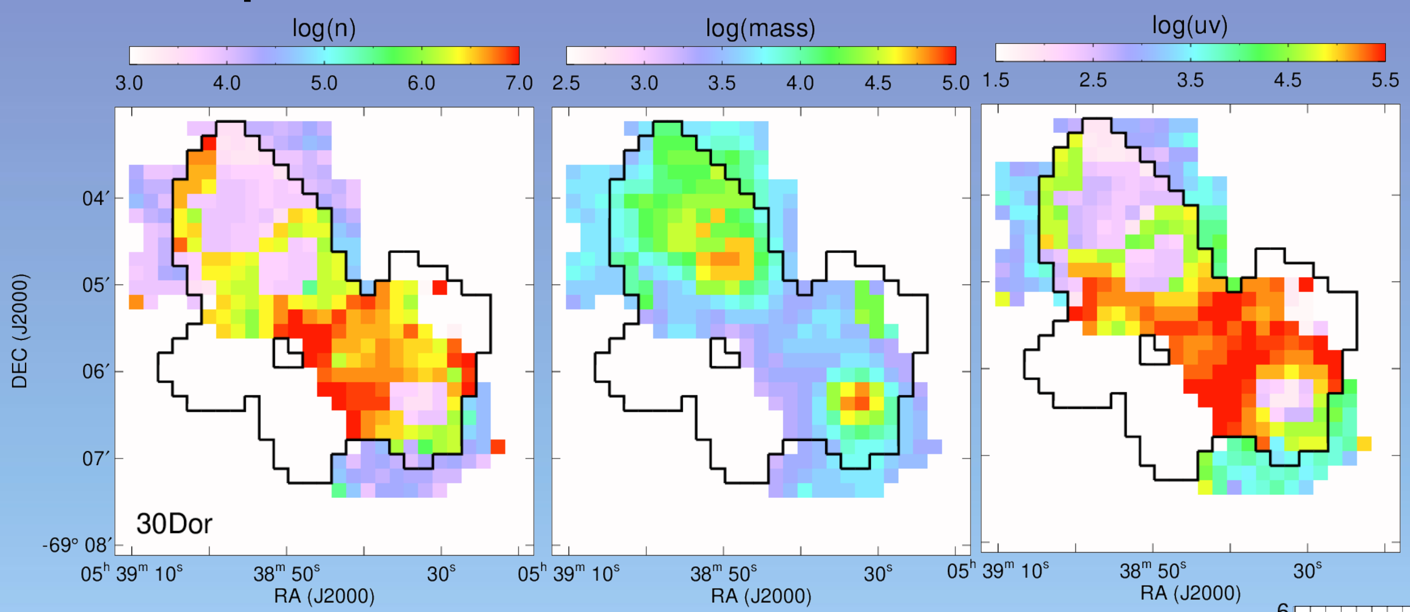
- For N159W CO peak, the fit results from optically thin lines is qualitatively reasonable
- For other regions, one clumpy ensemble model cannot fit all the line and continuum emissions.

Position	Model in Fig. 13	log(n)	log(m)	log(UV)
N159 W	Red (without continuum)	3.5	4.9	1.3
	Blue (without [O I])	3.7	4.9	1.8
	Purple (thin)	3.6	5.1	1.5
	Green (all)	3.5	5.0	1.4
N160 A	Red (without continuum)	3.9	4.3	2.2
	Blue (without [O I])	4.7	4.2	3.7
	Purple (thin)	6.2	4.1	4.8
	Green (all)	5.9	4.2	4.4
30Dor-10	Red (without continuum)	3.8	4.6	2.0
	Blue (without [O I])	4.4	4.5	3.4
	Redpurple (thin)	3.8	4.8	2.4
	Bluegreen (all)	3.8	4.8	2.4

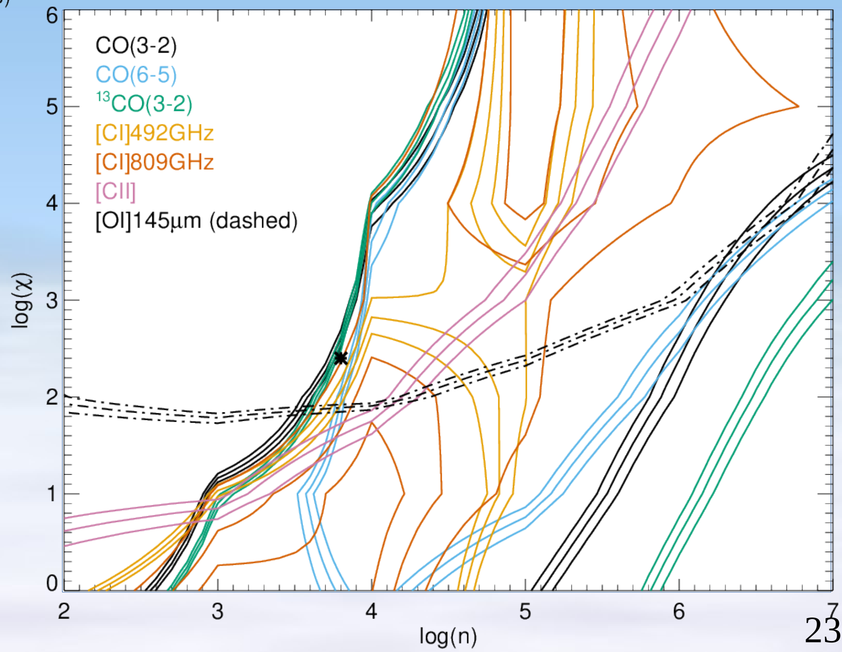


Consistent picture of the regions

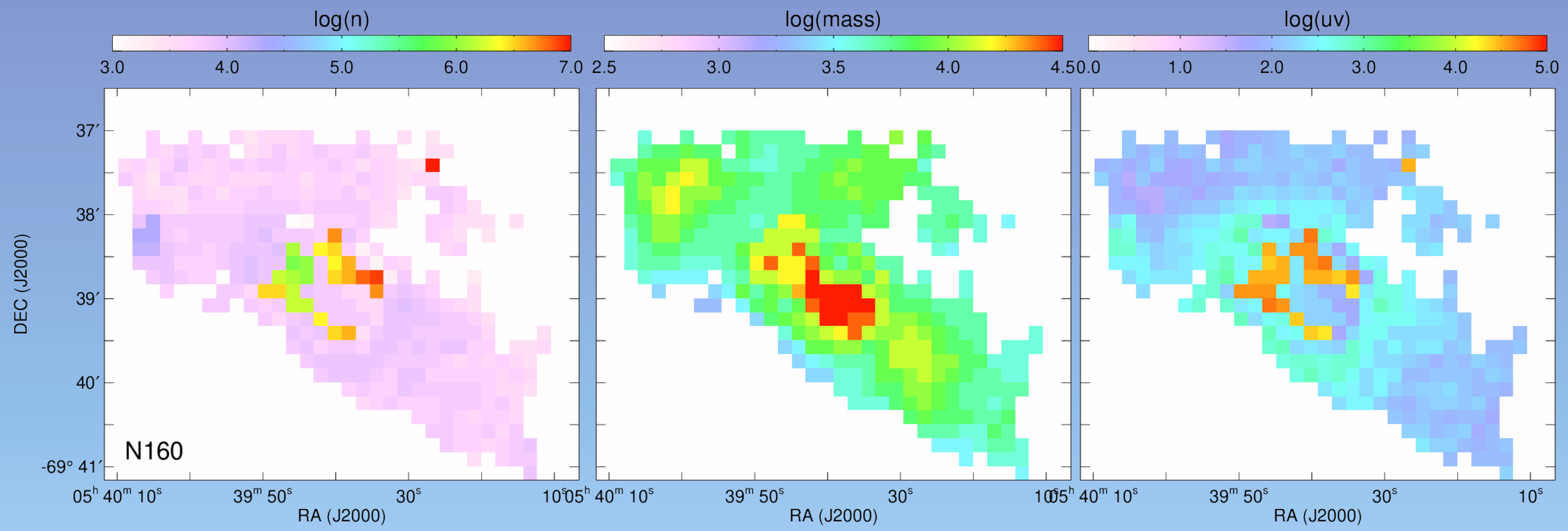
- Spatial distribution of the derived density and UV field



- Clear boundary with and without [OI]
- Lower density toward the CO peak



- Patchy density (3 orders of magnitude)



Consistent picture of the regions

- Area filling factor (e.g. compare with ALMA)

Position	Model in Fig. 13	log(n)	log(m)	log(UV)	Area filling factor
N159 W	Red (without continuum)	3.5	4.9	1.3	42.5
	Blue (without [O I])	3.7	4.9	1.8	31.3
	Purple (thin)	3.6	5.1	1.5	57.8
	Green (all)	3.5	5.0	1.4	53.6
N160 A	Red (without continuum)	3.9	4.3	2.2	5.8
	Blue (without [O I])	4.7	4.2	3.7	1.3
	Purple (thin)	6.2	4.1	4.8	0.1
	Green (all)	5.9	4.2	4.4	0.2
30Dor-10	Red (without continuum)	3.8	4.6	2.0	13.5
	Blue (without [O I])	4.4	4.5	3.4	4.3
	Redpurple (thin)	3.8	4.8	2.4	21.3
	Bluegreen (all)	3.8	4.8	2.4	21.3

Conclusions (PDR modeling)

- Line and continuum emissions are not well reproduced by a single clump ensemble
- PDR modeling in a map gives more possibilities of consistency check. Establishing a dependent fit among pixels in a map may be required.
- More lines would help. Better velocity resolved.