First detection of [^{13}CII] in the Large Magellanic Cloud

A&A 631, L12

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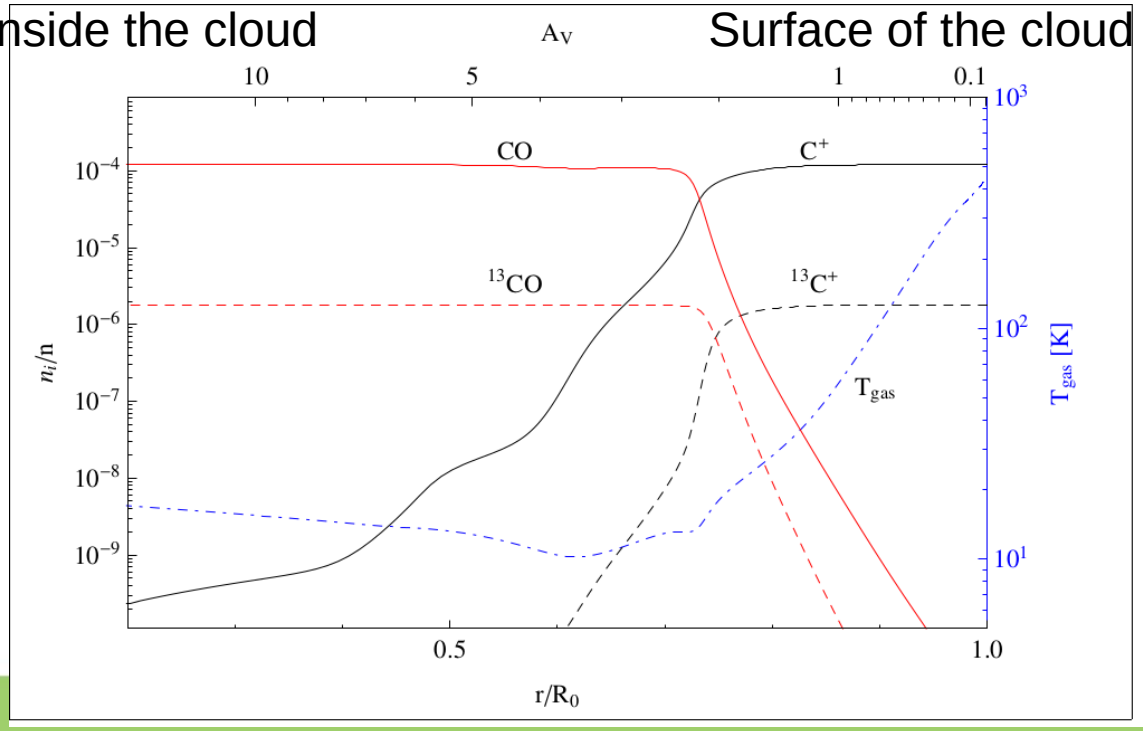
[CII] in photon-dominated regions (PDRs)

- One of the dominant cooling lines
- UV radiation from massive stars

  → star formation tracer

[CII] emission comes from Av ~ 1
↔ τ ~ 1



Ossenkopf+(2013)

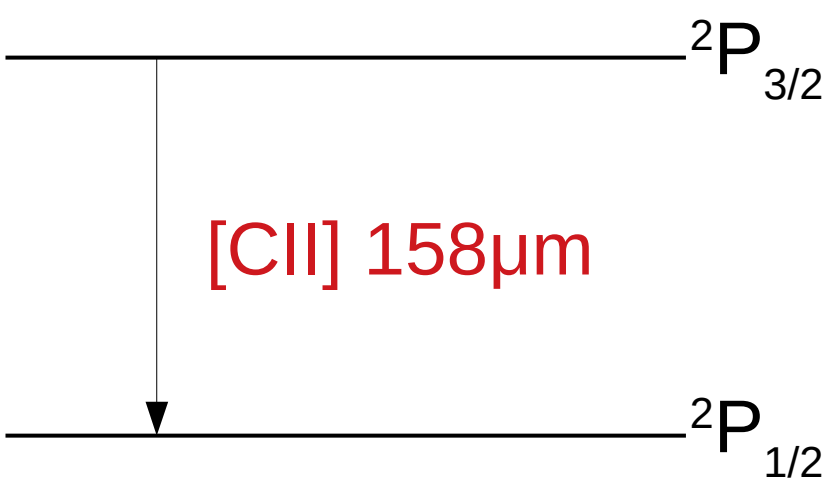
$C^+ = 1s^2 2s^2 2p^1$

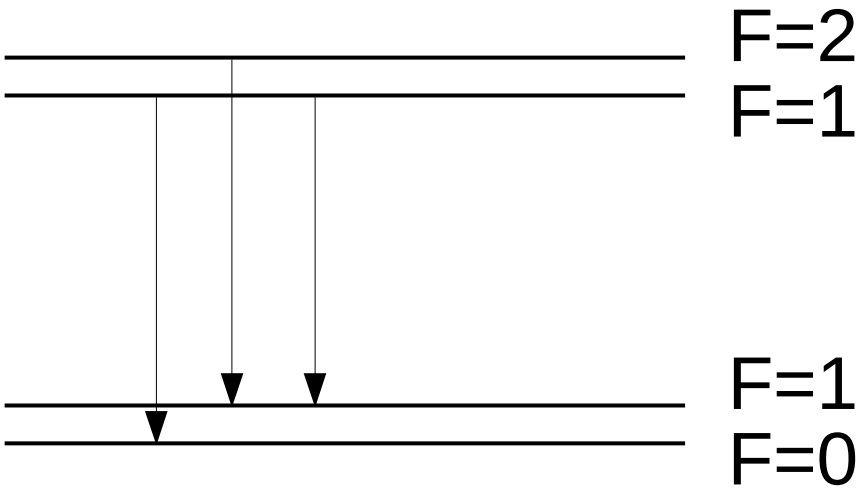
S = 1/2, L = 1

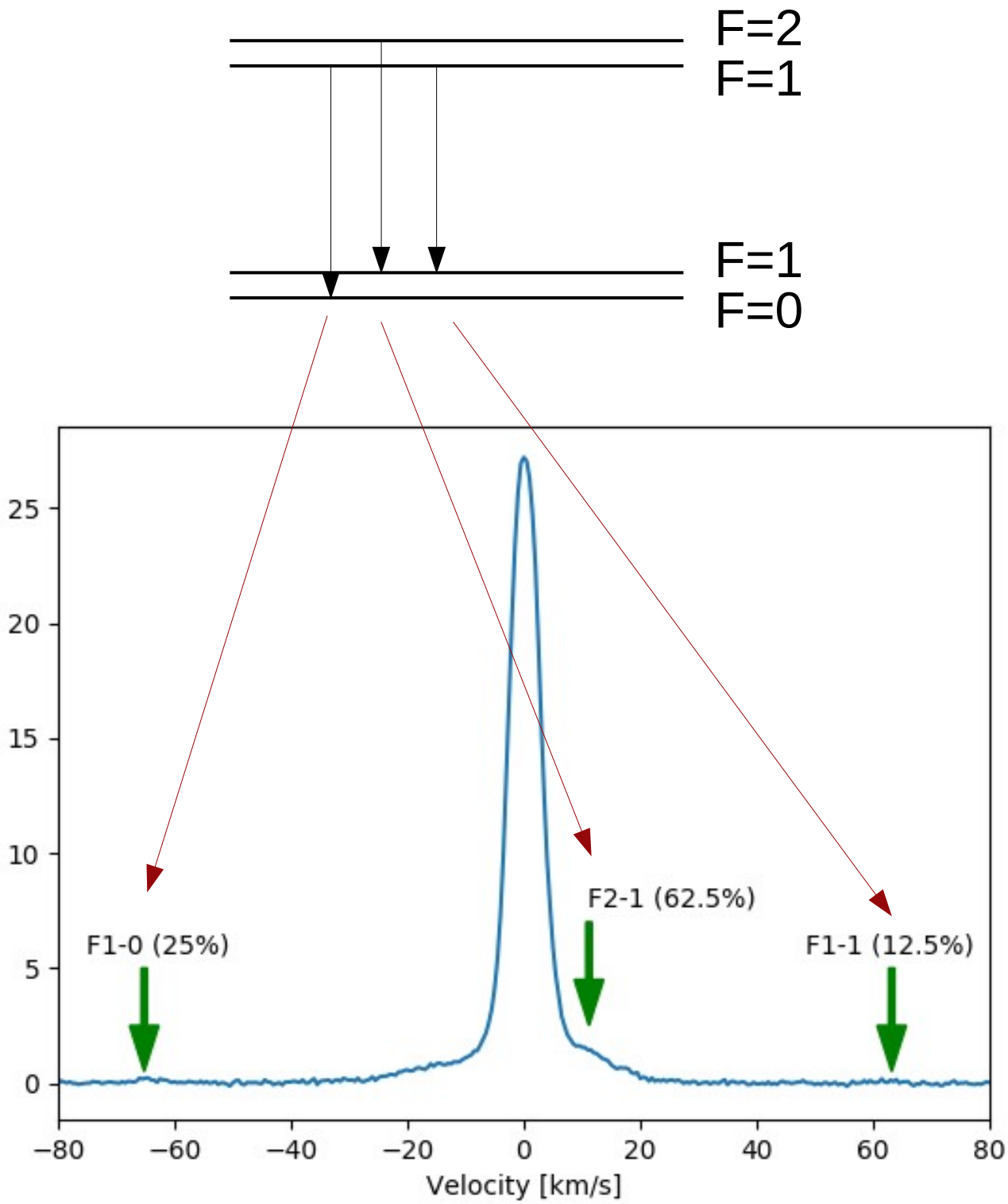
→ J = 1/2, 3/2

$^{13}C^+$

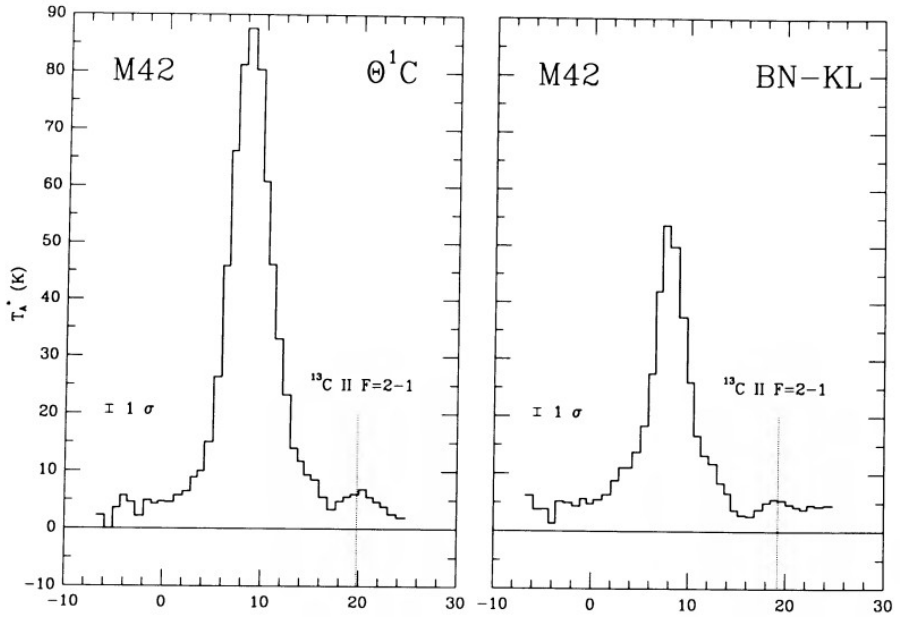
Nuclear spin does not sum up to 0



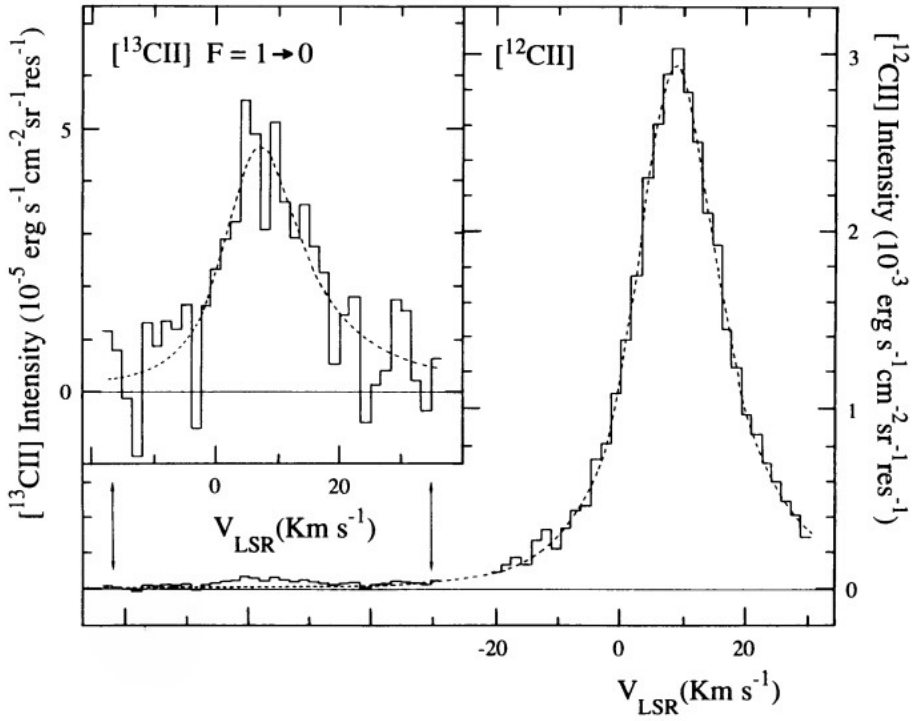



F=2
F=1
F=1
F=0
F1-0 (25%)
F2-1 (62.5%)
F1-1 (12.5%)
25
20
15
10
5
0
−80
−60
−40
−20
0
20
40
60
80
Velocity [km/s]

Early detection in Orion

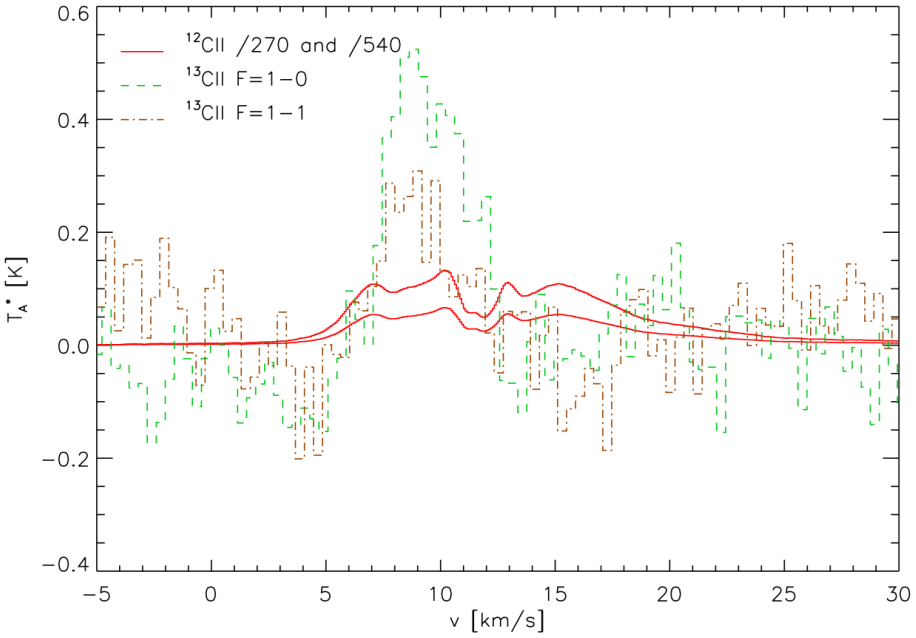


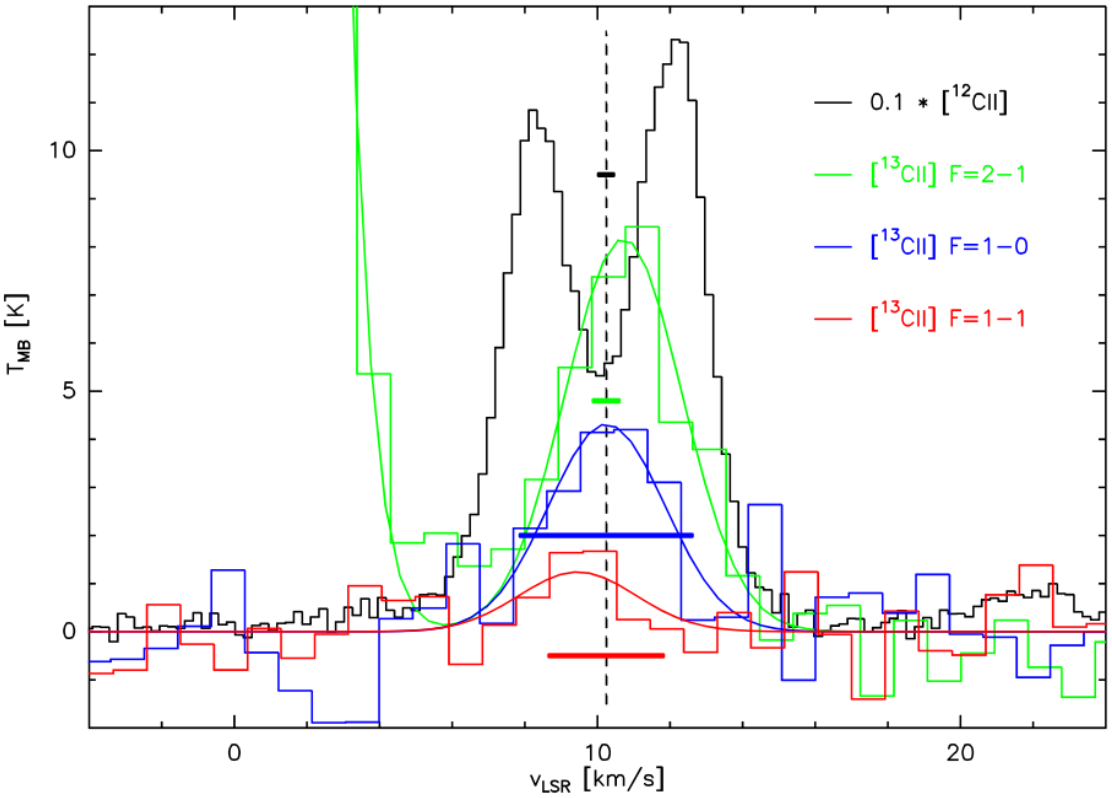
Boreiko+ (1988)



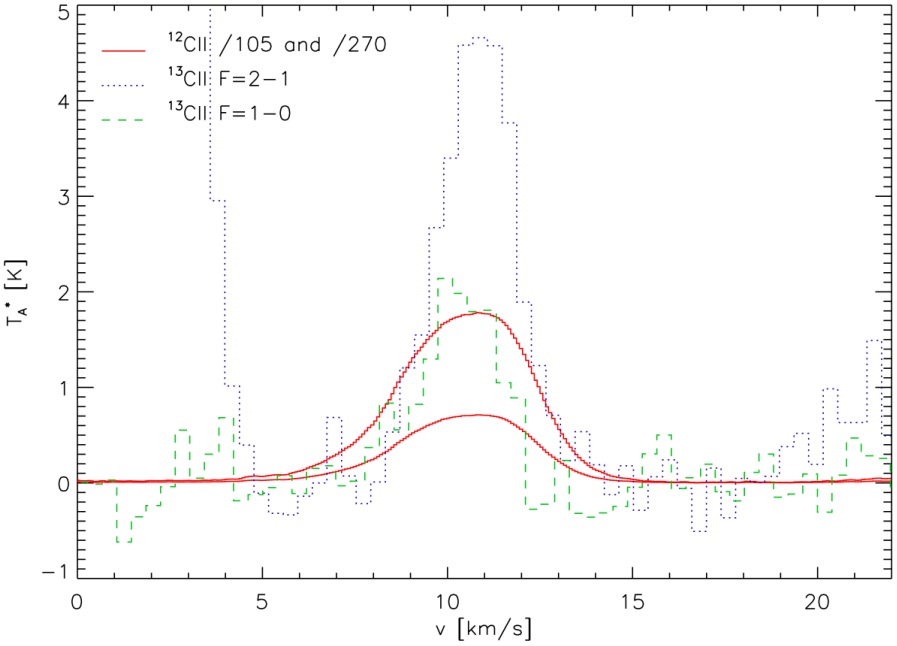
Stacey+ (1991)

MonR2, HIFI
Ossenkopf+ (2013)





NGC2024, GREAT
Graf+ (2012)



Orion Bar, HIFI
Ossenkopf+ (2013)

Detailed analysis in four Galactic star-forming regions (Guevara+ 2020)

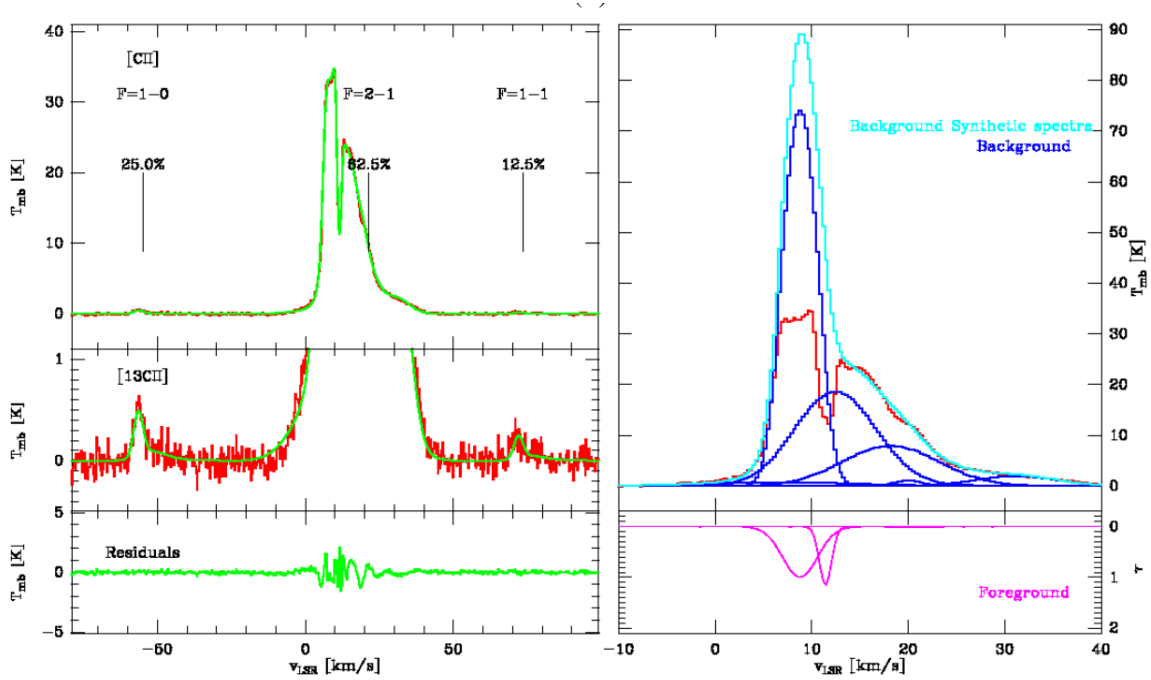
- Single layer analysis

  → τ ([CII]) = 2-7

- Some sources show an absorption in [CII]

  → two layers model

- Warm background: column density as high as Av ~ 40 mag

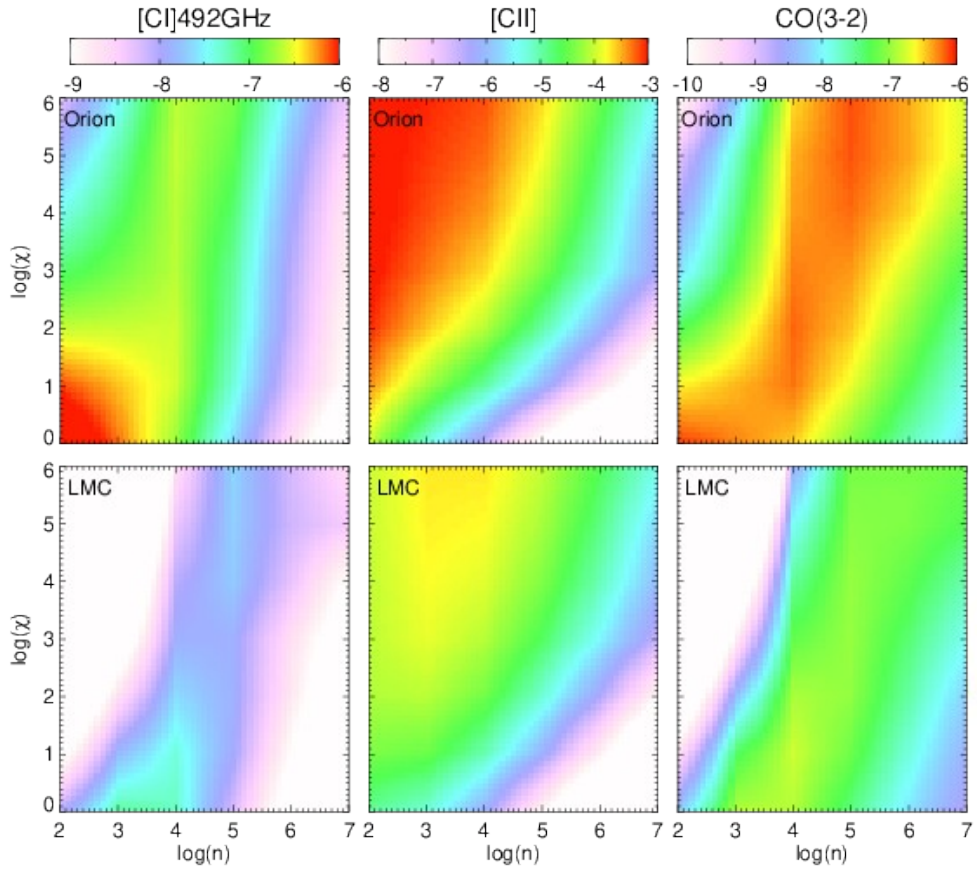


MonR2

- Foreground: Tex=20-40 K gas with Av ~ 1-10

Impact on the extragalactic [CII] observations

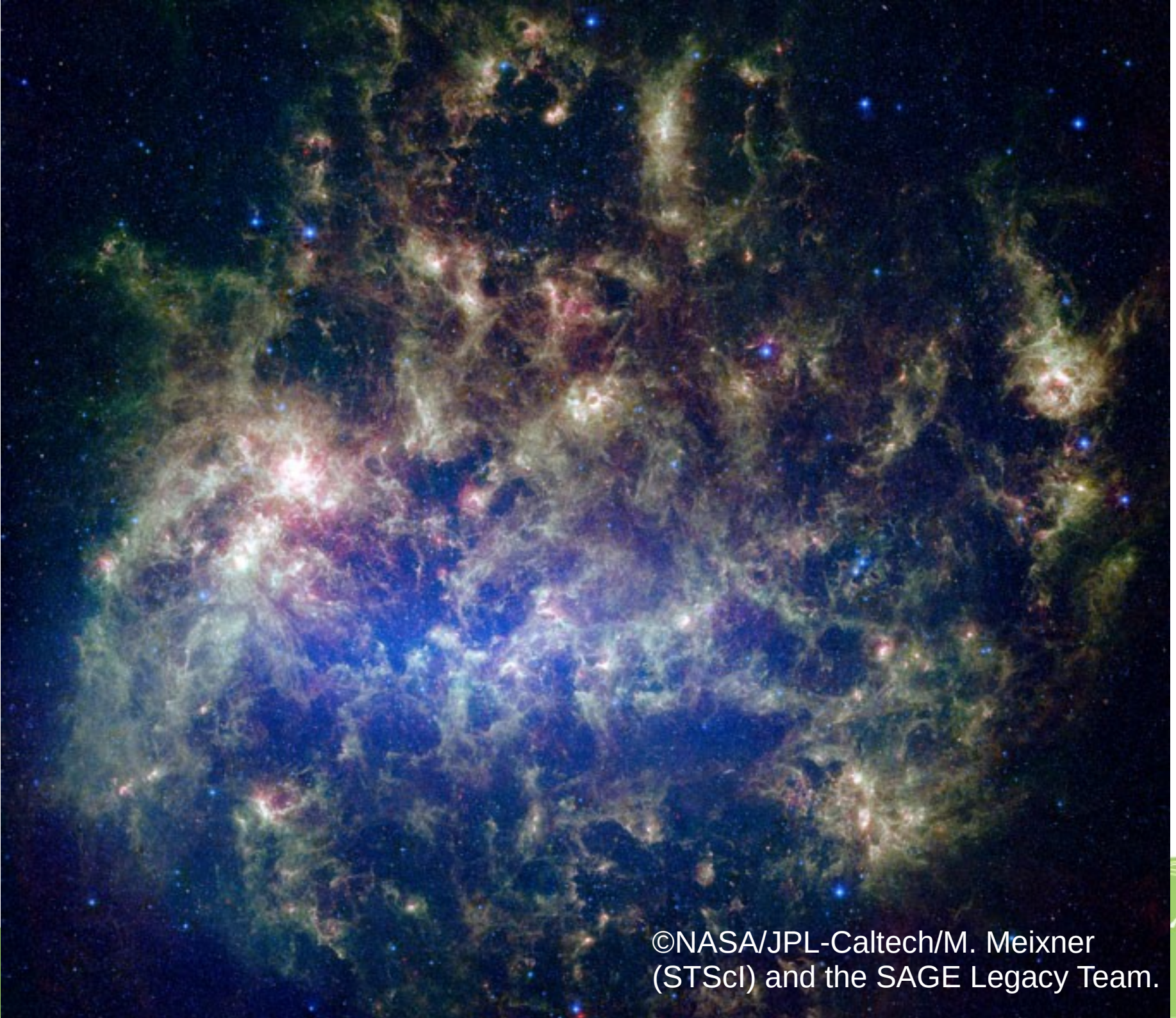
- Diluted within a larger beam
- Metallicity

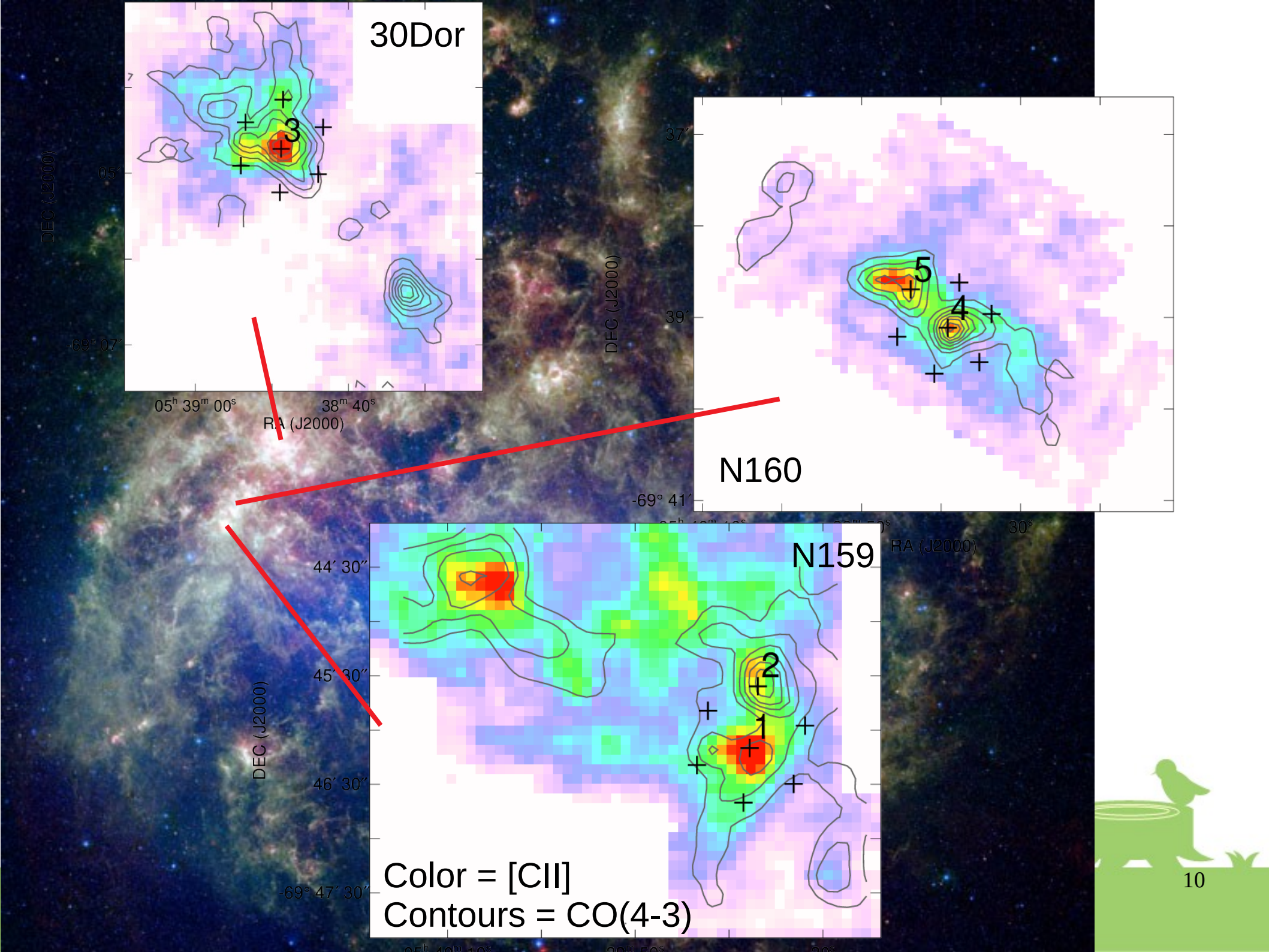


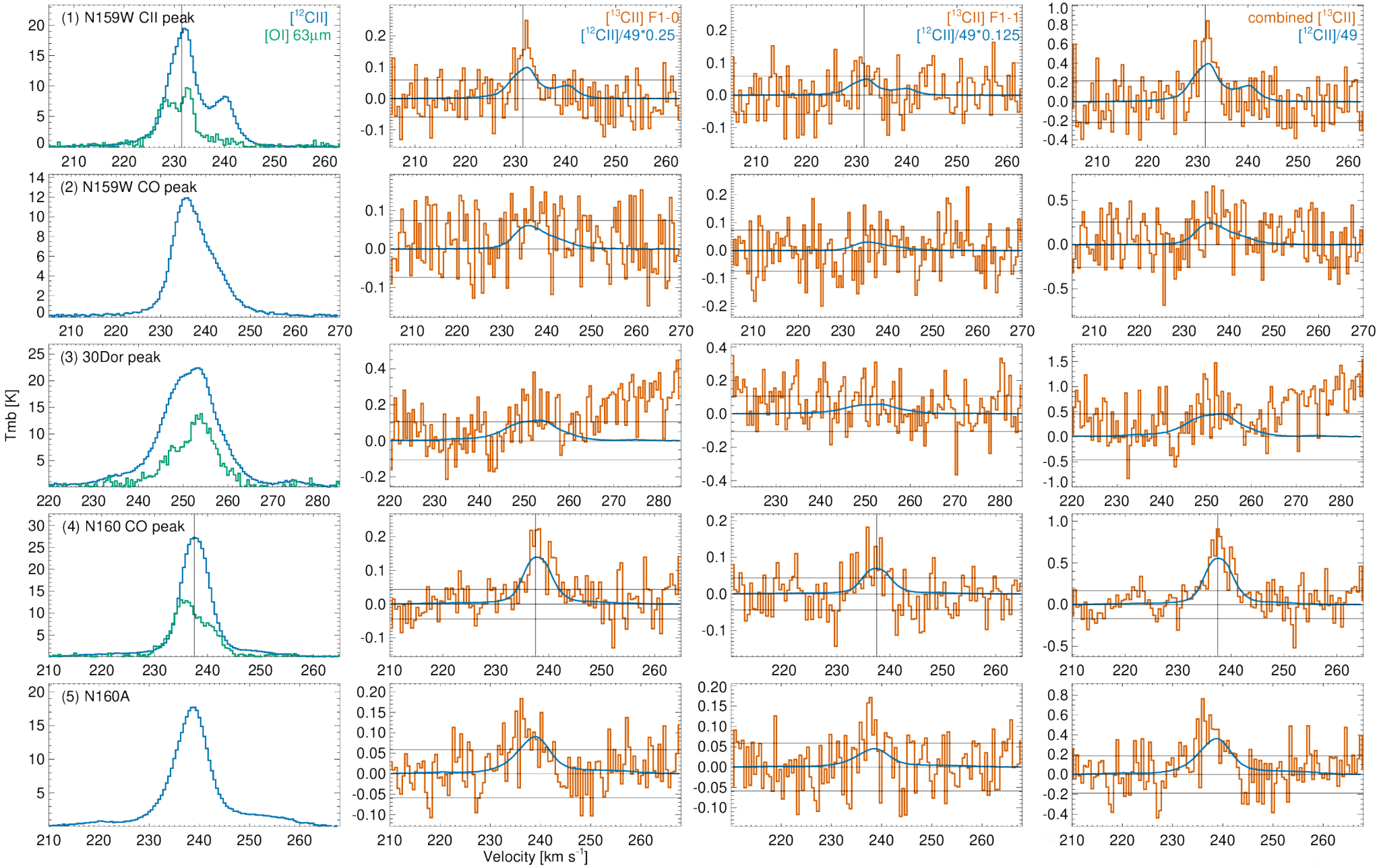
KOSMA-τ
PDR model

UV field

density




30Dor
3
05′
-69° 07′
05h 39m 00s
38m 40s
RA (J2000)
DEC (J2000)
N160
5
4
37′
39′
-69° 41′
30s
RA (J2000)
DEC (J2000)
N159
2
1
44′ 30″
45′ 30″
46′ 30″
-69° 47′ 30″
DEC (J2000)
Color = [CII]
Contours = CO(4-3)

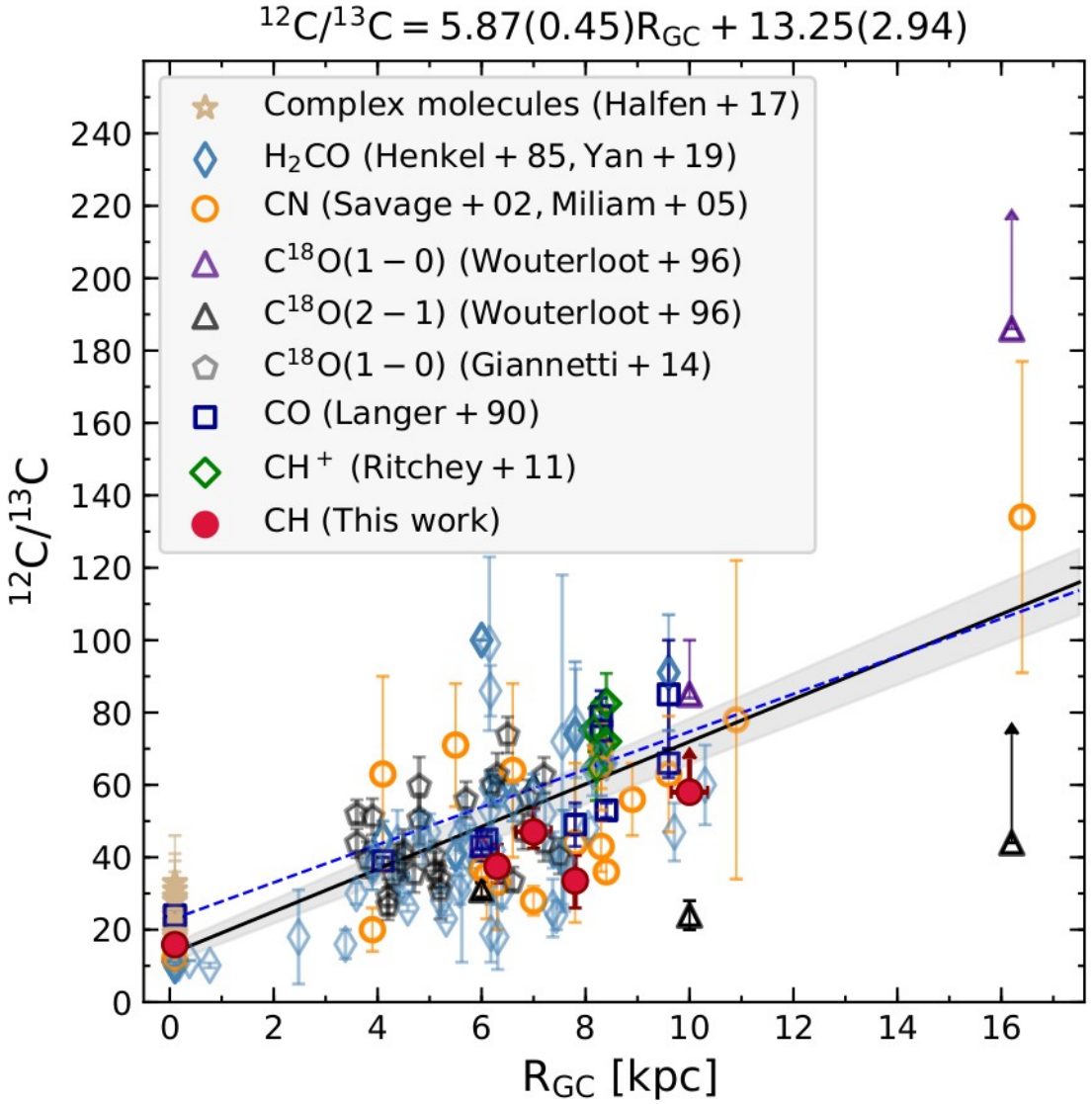

(1) N159W CII peak
[12CII]
[OI] 63μm
[13CII] F1-0
[12CII]/49*0.25
[13CII] F1-1
[12CII]/49*0.125
combined [13CII]
[12CII]/49
(2) N159W CO peak
(3) 30Dor peak
(4) N160 CO peak
(5) N160A
Tmb [K]
Velocity [km s-1]

[^{13}CII] enhancement

[^{12}CII] is optically thick or $^{12}C^+/^{13}C^+ < 49$

$$\frac{T_{\rm mb,12}(v)}{T_{\rm mb,13}(v)} = \frac{1-\exp(-\tau_{12}(v))}{1-\exp(-\tau_{13}(v))}$$

$$\tau_{13}(v) = \tau_{12}(v)/\alpha^+, \quad \alpha^+ = \frac{^{12}{\rm C}^+}{^{13}{\rm C}^+}$$



Jacob+ (2020)

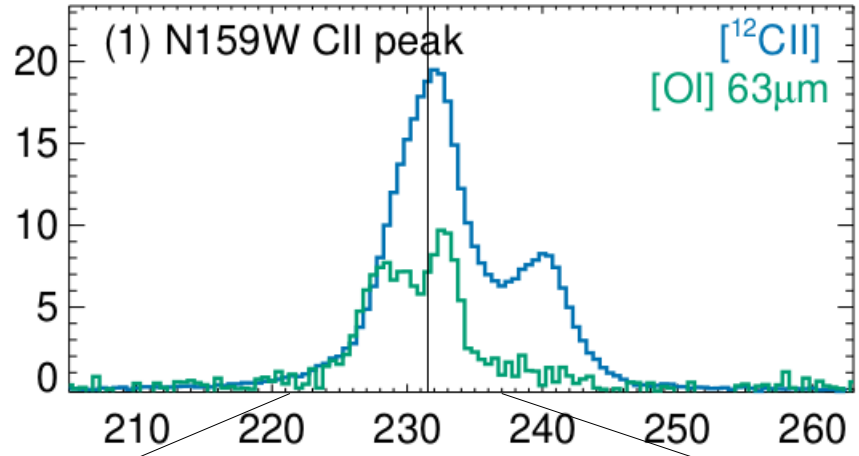
Not a pure function of metallicity

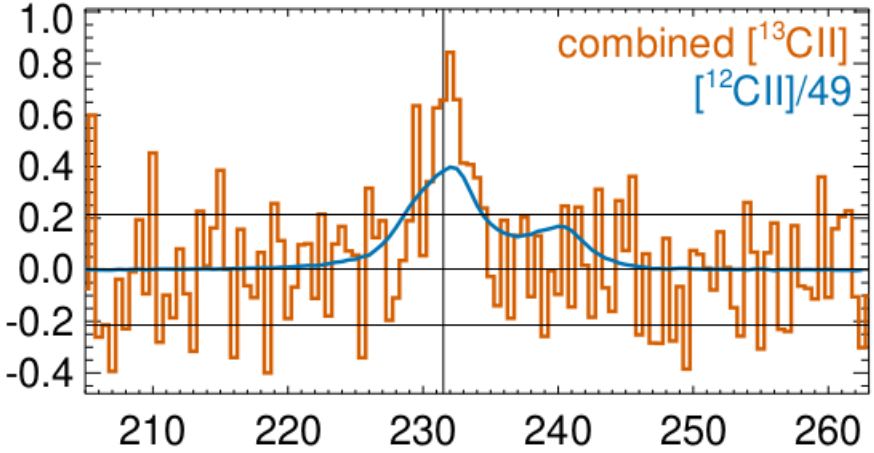
Old population in the LMC (Wang 2009)

LMC SMC

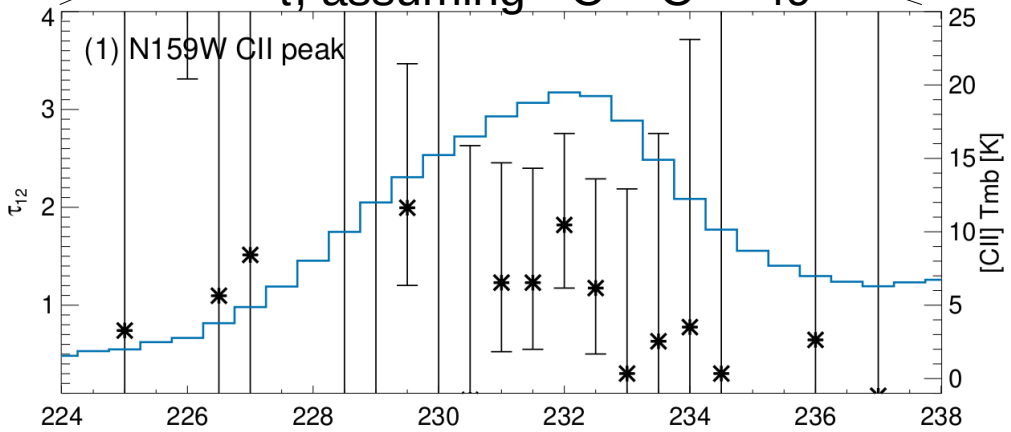
40-90 in N27/SMC
HCO^+
Heikkilä+ (1999)

49 +/- 5 in N113/LMC
$H^{13}CN$ / HCN hpf
(Wang+2009)

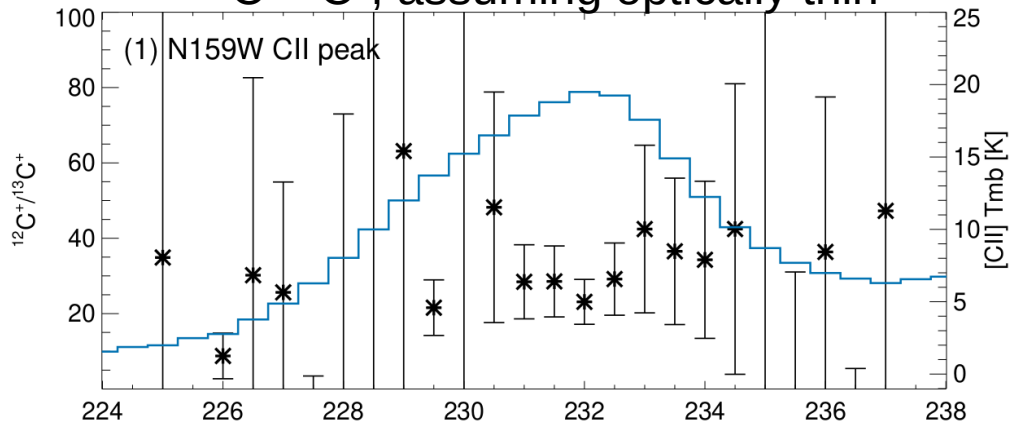




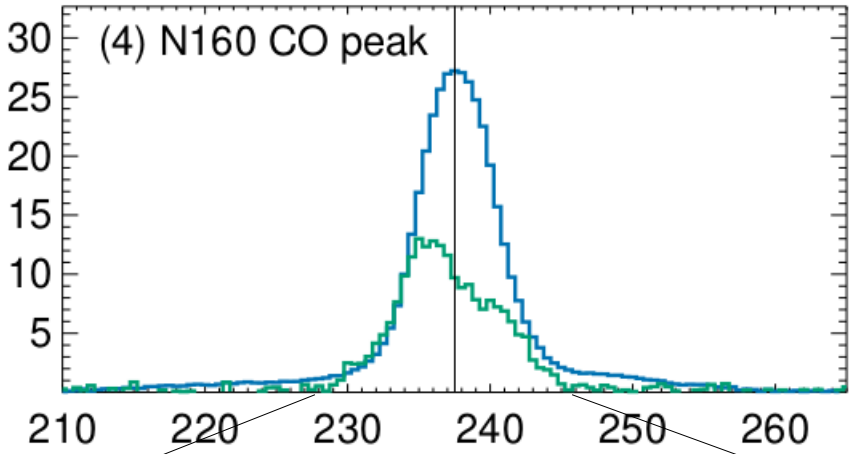
τ, assuming $^{12}C^{+}/^{13}C^{+}$ = 49

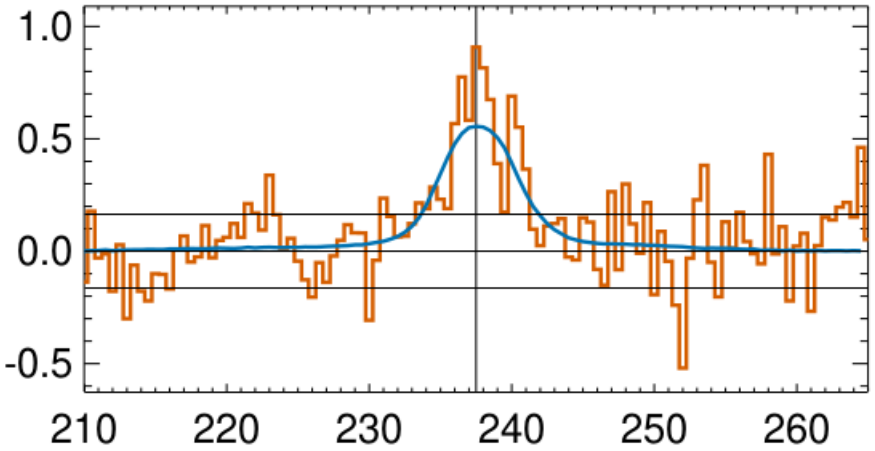


$^{12}C^{+}/^{13}C^{+}$, assuming optically thin

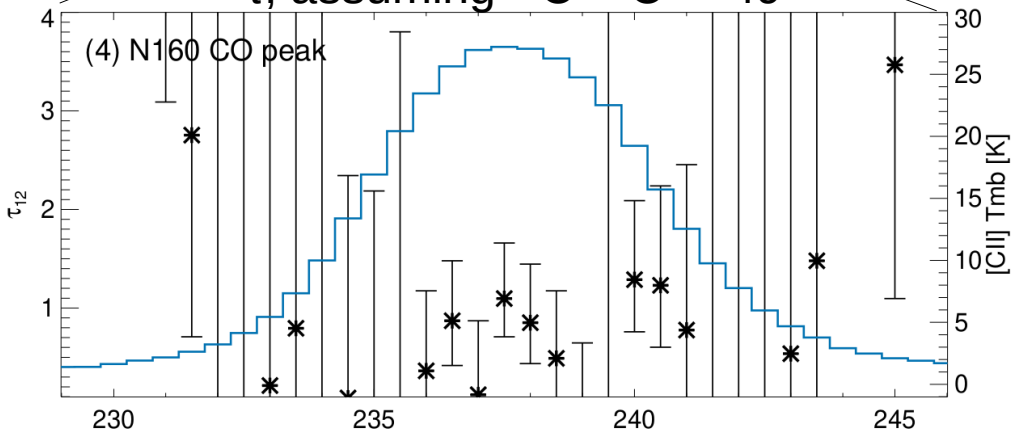


- [^{12}CII]/[^{13}CII] is different among two velocity components
  → difference in τ is more likely than in $^{12}C^{+}/^{13}C^{+}$ within a beam (a few pc)
- The line width of [^{12}CII] = 6.8 km/s, [^{13}CII] = 3.4 km/s
- [OI] 63μm absorption

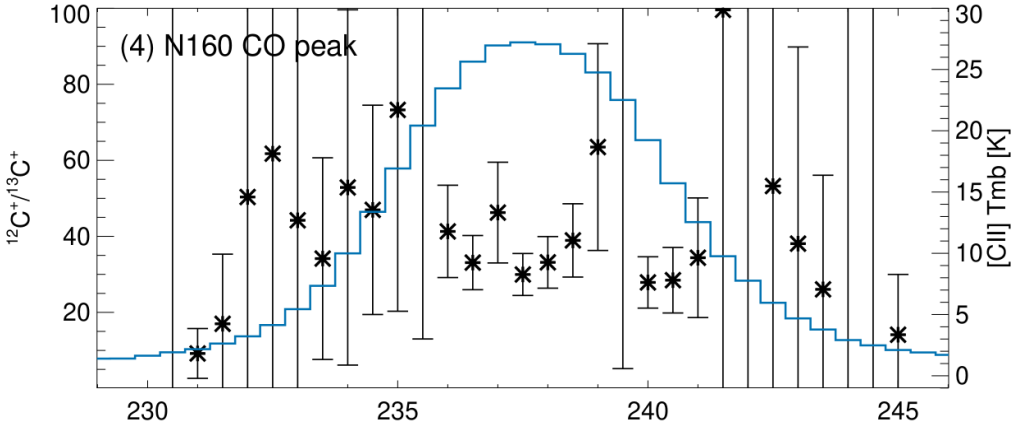




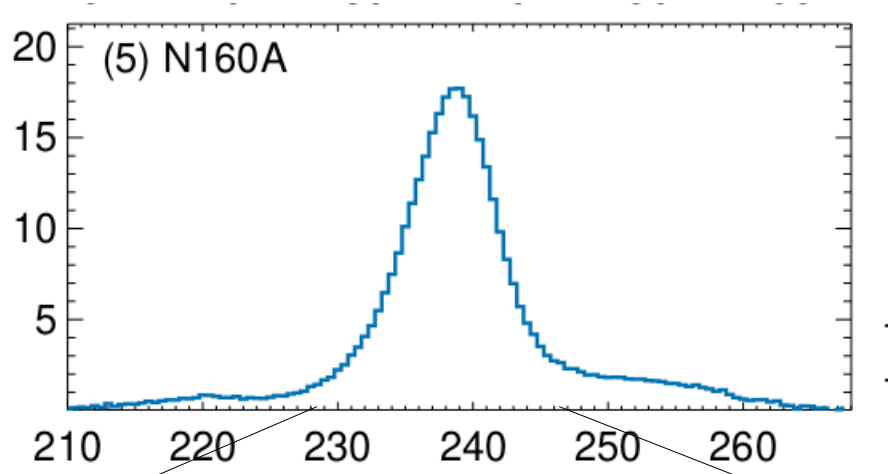
τ, assuming $^{12}C^{+/13}C^{+}$ = 49

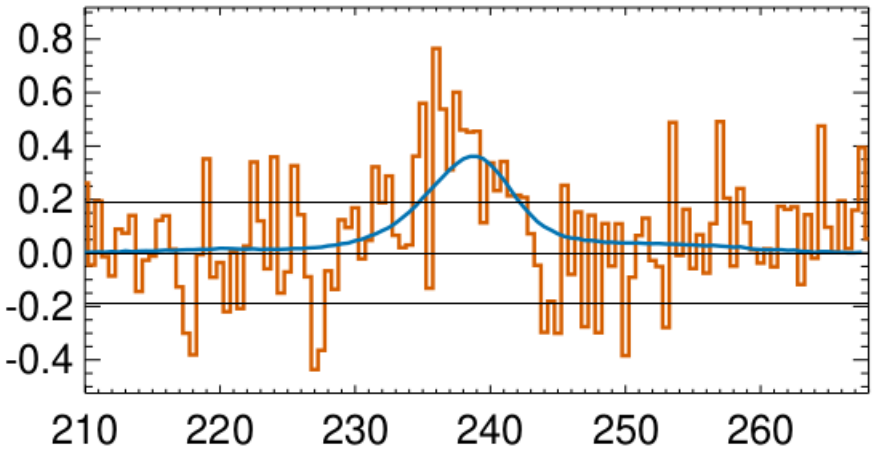


$^{12}C^{+/13}C^{+}$, assuming optically thin

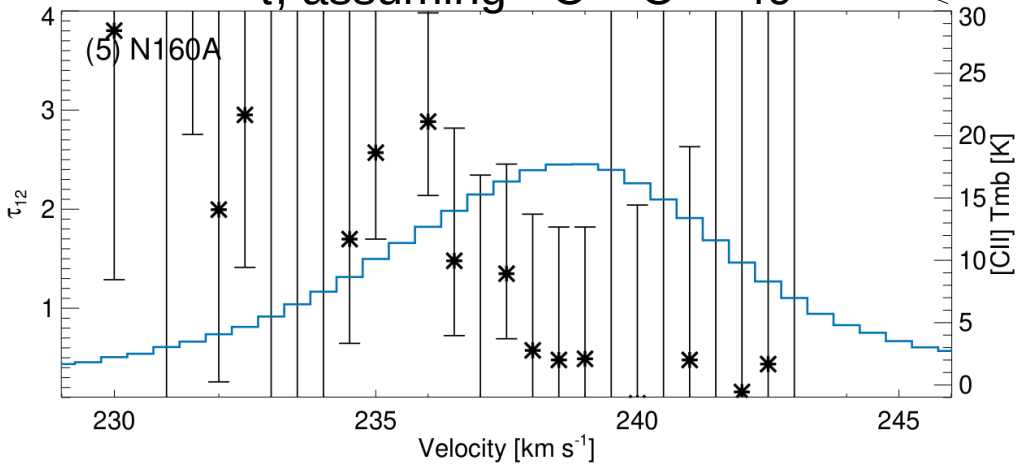


- Less enhancement, corresponding to τ ~ 1
- [OI] 63μm profile

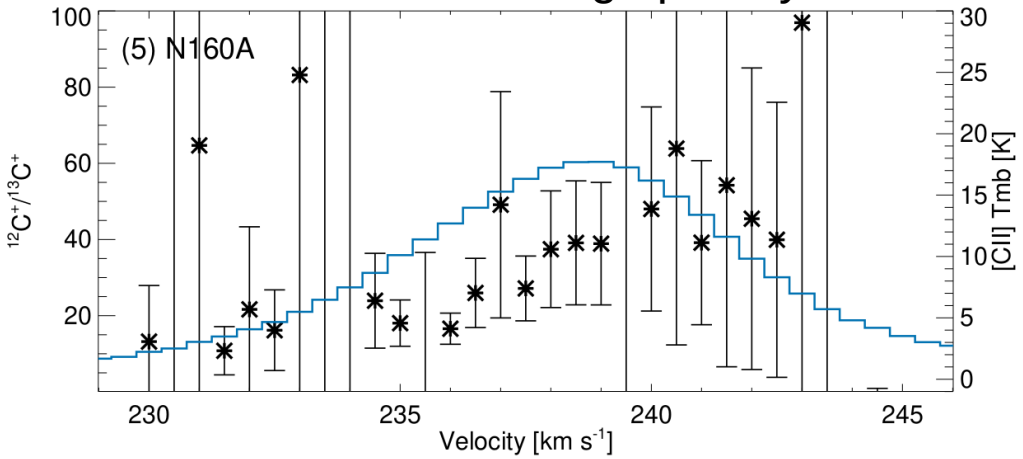




τ, assuming $^{12}C^{+}/^{13}C^{+}$ = 49

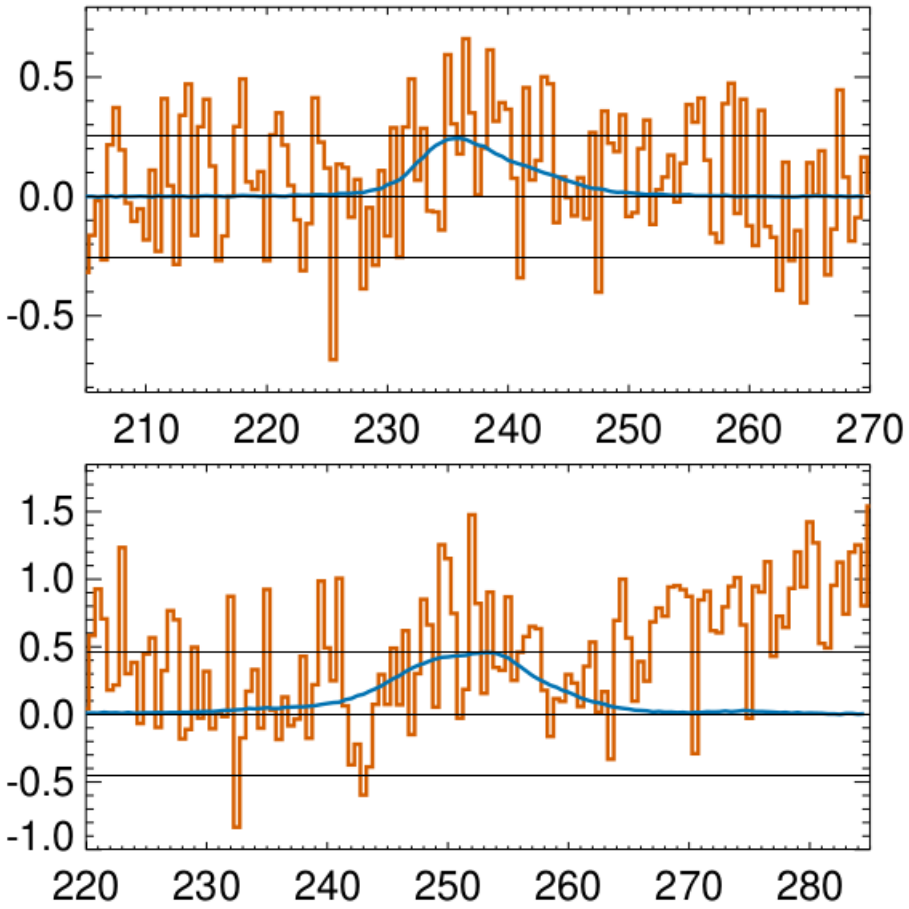


$^{12}C^{+}/^{13}C^{+}$, assuming optically thin



- [CII] peak (238.5 km/s)
  → optically thin
- Enhancement at 235-237 km/s maybe real

  [CI]492GHz peak = 237.5 km/s
  ^{13}CO(3-2) peak = 237.9 km/s
- Velocity gradient in τ is more likely than velocity gradient in $^{12}C^{+}/^{13}C^{+}$

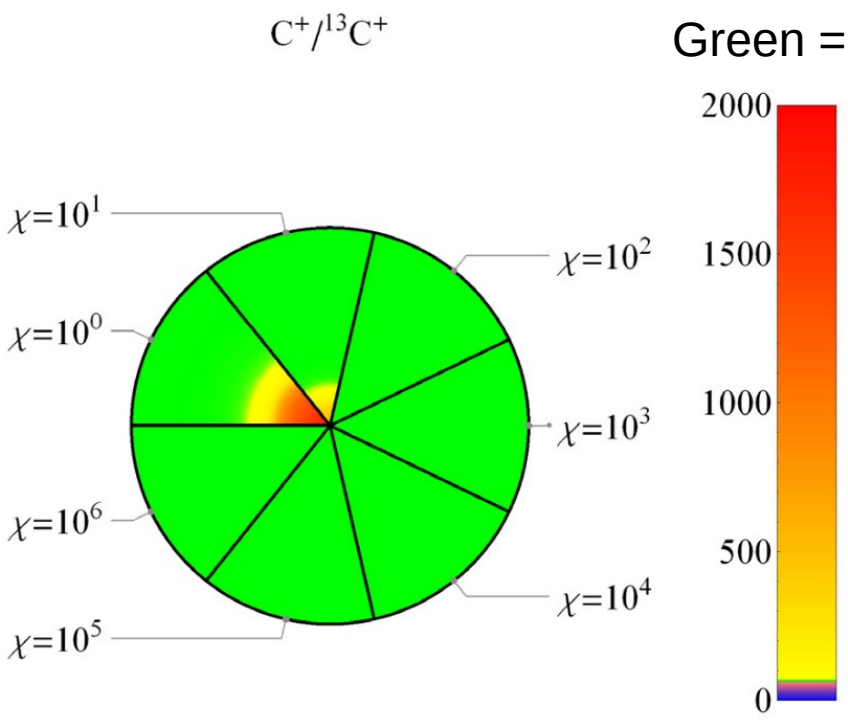


Consistent with optically thin [CII] within the noise level

Fractionation

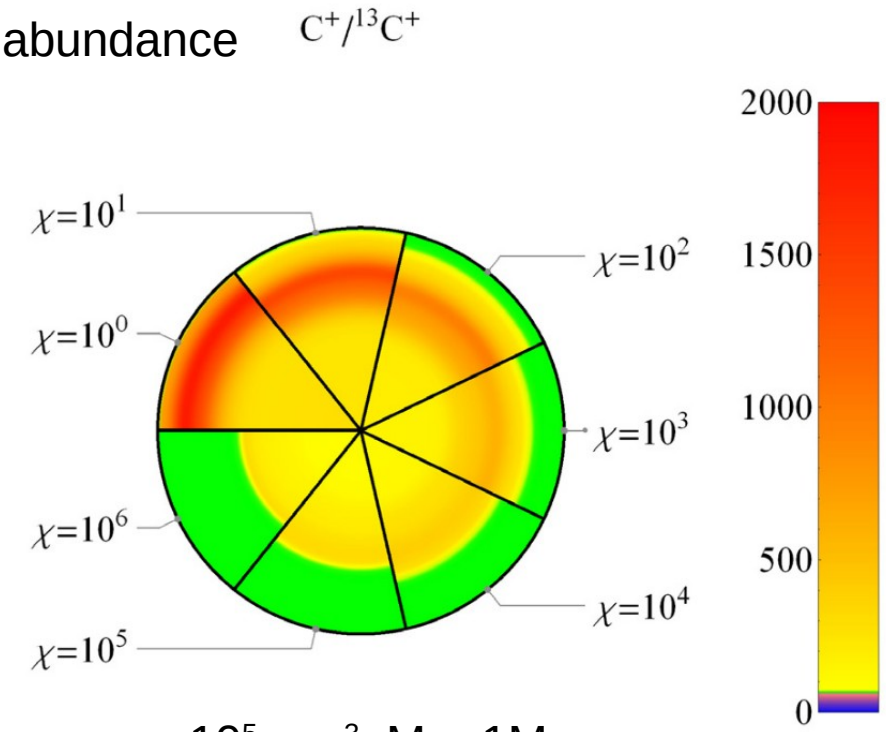
$$^{13}C^+ + CO \rightleftharpoons C^+ + {}^{13}CO + \Delta E = 35\ K$$ (exothermal)

⟶ At low temperature ↔ high Av



n = 10^3 cm^{-3}, M = $1M_{solar}$

Green = elemental abundance



n = 10^5 cm^{-3}, M = $1M_{solar}$

Only significant in $\chi \leq 100$ and $n \geq 10^5\ cm^{-3}$

Röllig & Ossenkopf (2013)

Implication for the interpretation of the [CII] intensity

- For a face-on plane parallel or a spherical, isotropically illuminated clump, PDR models take the optical depth into account correctly.
- Significant effect if, for example, many clumps overlap along the line-of-sight.
- The results in LMC (14” beam = 3.4 pc): $\tau([^{12}CII]) = 1\text{-}3$
- Averaged over Galactic large area maps

  Orion (1 deg map → 30” at LMC distance): $\tau([^{12}CII]) \sim 1$

  M17 (2.5’ map → 6” at LMC distance): $\tau([^{12}CII]) \sim 3$
- Moderately optically thick, leading to an underestimate of the [CII] intensity by a factor of two.

Summary

- We detected [^{13}CII] F = 1−0 and F = 1−1 emissions in N159 and N160 in the LMC for the first time.
- Assuming $^{12}C^+/^{13}C^+$=49, τ([^{12}CII]) is estimated as 1-3 at peak velocities.
- Variations of [^{12}CII]/[^{13}CII] over velocities and the [OI] 63μm self-absorption favor an interpretation with optically thick [^{12}CII] emission over variation in $^{12}C^+/^{13}C^+$
- If this applies to distant galaxies, the [CII] intensity would be underestimated by a factor 2.