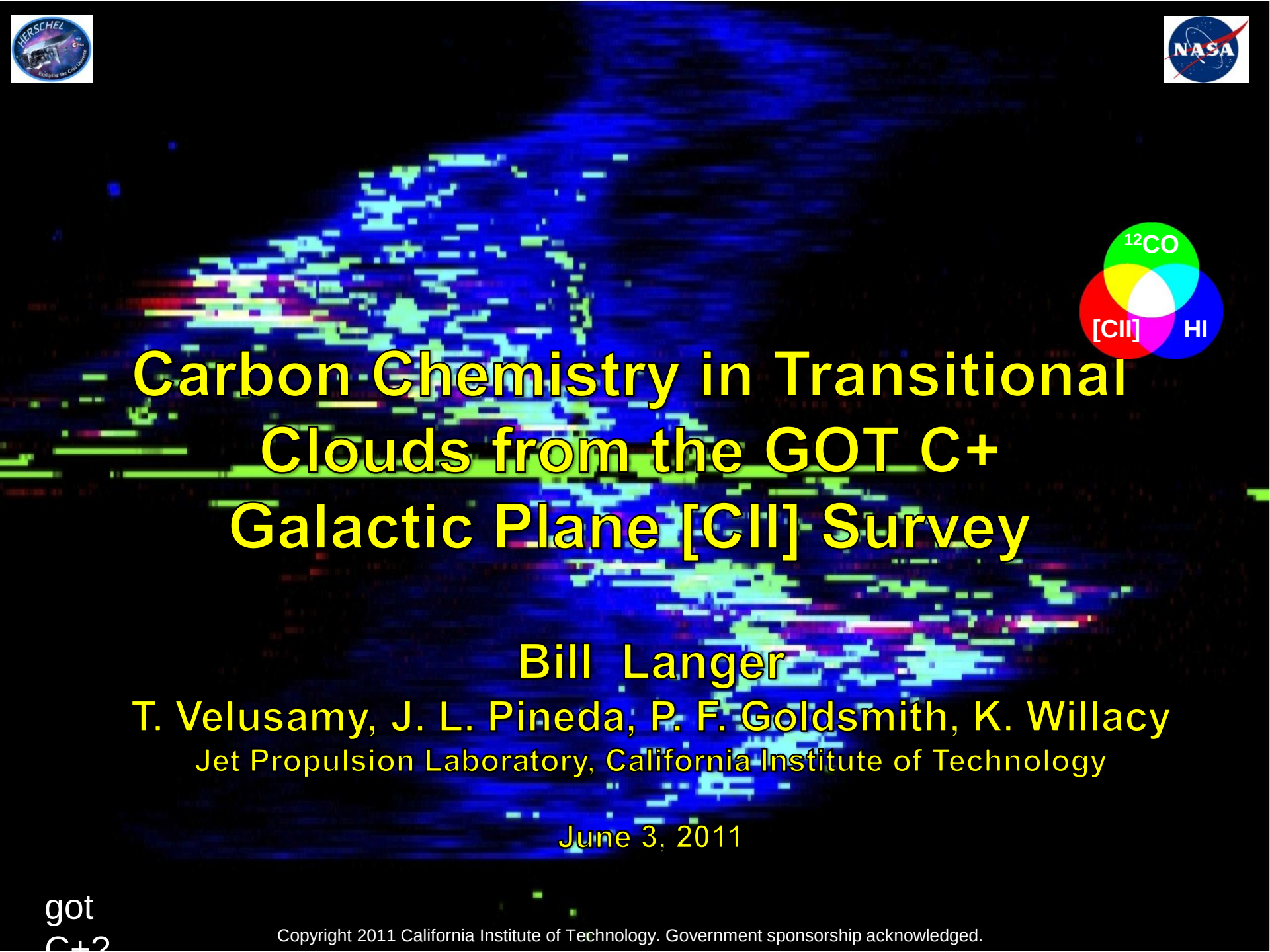

Carbon Chemistry in Transitional Clouds from the GOT C+ Galactic Plane [CII] Survey

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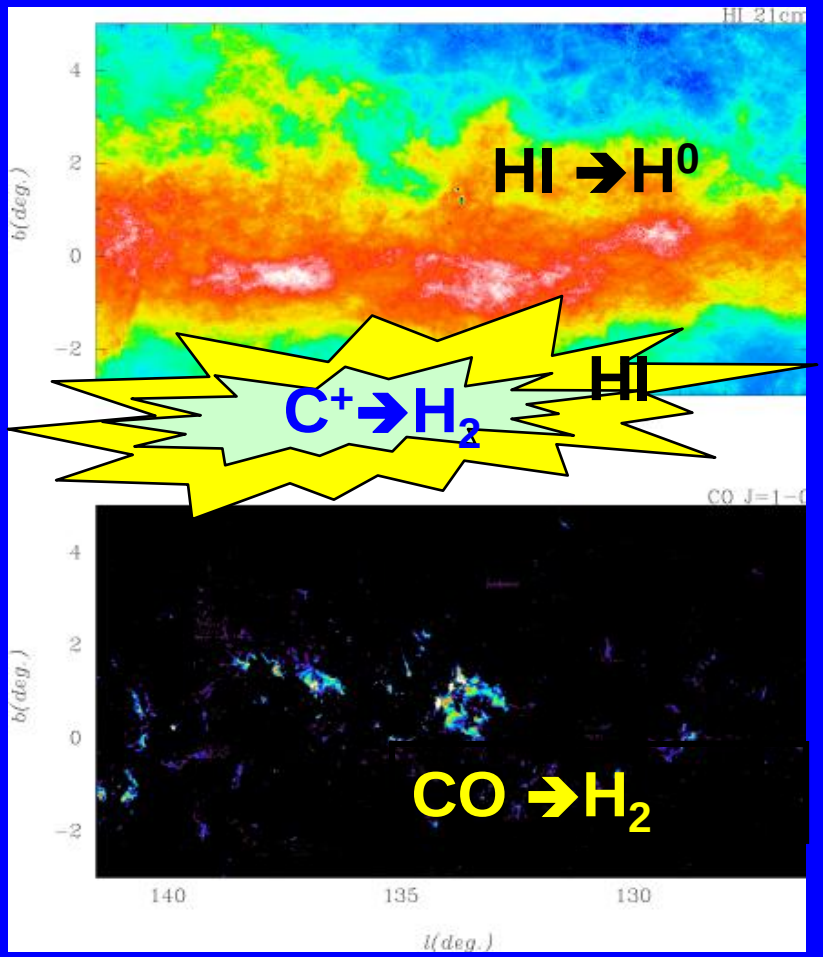
[CII] Tracks Interstellar Cloud Evolution

- Diffuse Atomic Clouds
  - HI traces N(H)
  - [CII] traces warm, dense H
- Diffuse Molecular Clouds
  - [CII] traces warm HI & H_2
  - No CO
- Transition Clouds
  - H_2 & C^+,
  - C^0 & CO
  - [CII] -> warm, dense H_2
- Dense Molecular Clouds
  - ^{12}CO & ^{13}CO



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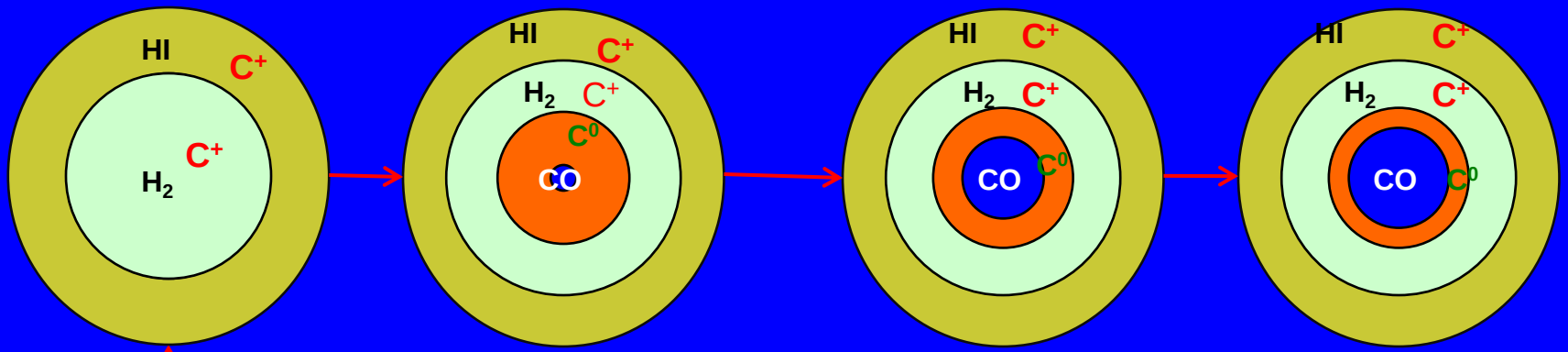
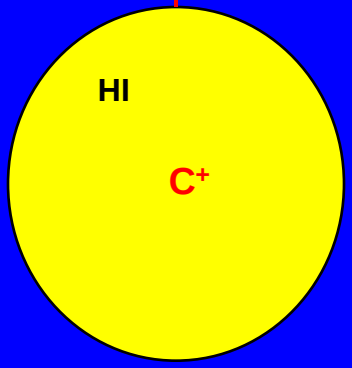
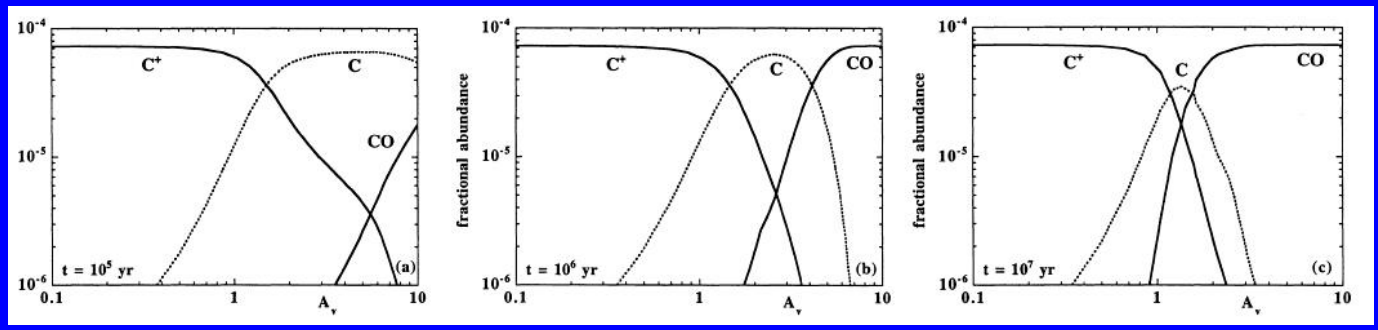
Evolution of Hydrogen and Carbon







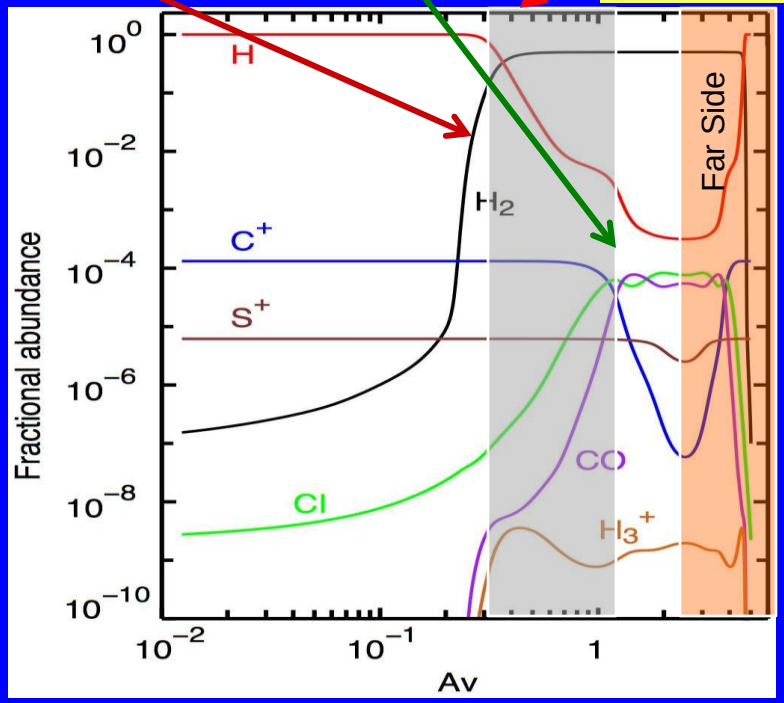
(Lee et al. 1996)

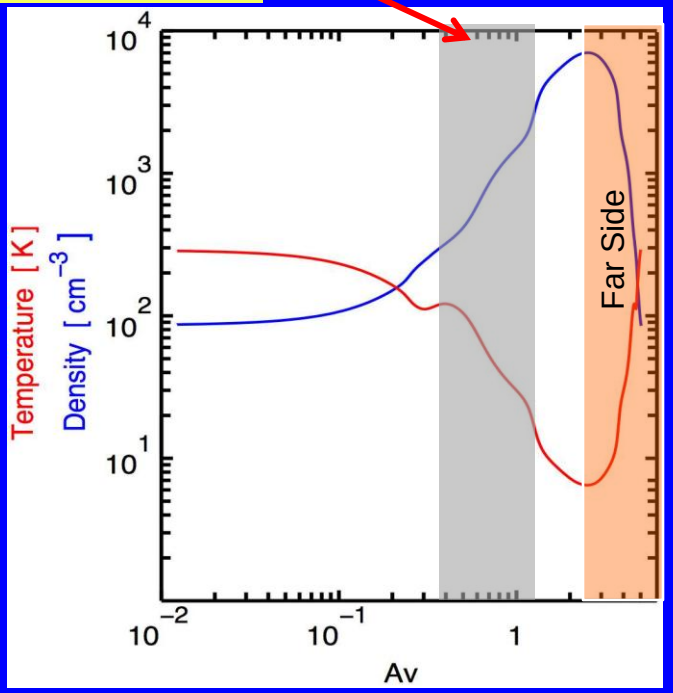
Transition Cloud Model of HI and [CII]

H → H_2

C^+ to C^o/CO

H_2 "Dark Gas" not traced by HI or CO





Willacy et al. (2011) based on Meudon Code

- ζ_0 ~ 50 (finite slab - both sides illuminated) & P ~2 x10^4 K cm^{-3}
  - n(HI) ~ 50 - 100 cm^{-3} , T_{kin} ~ 100 to 200K
  - n (H_2,CII) ~ 2-8 x10^2 cm^{-3} & T_{kin} ~ 50 – 100K

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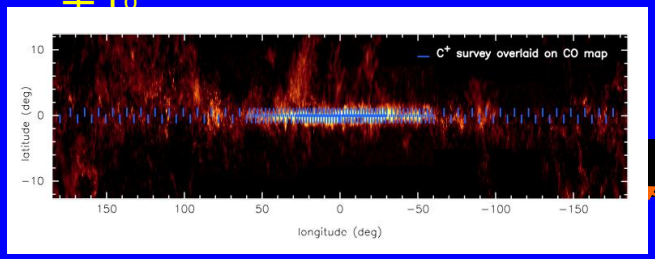
GOT C+ - [CII] Galactic Plane "Statistical" Survey

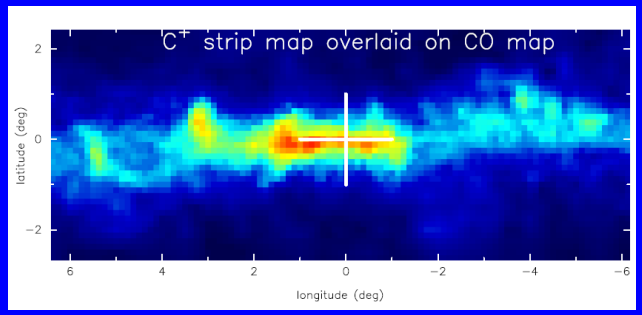
Galactic Plane Survey - volume weighted

~ 500 l.o.s. in the disk

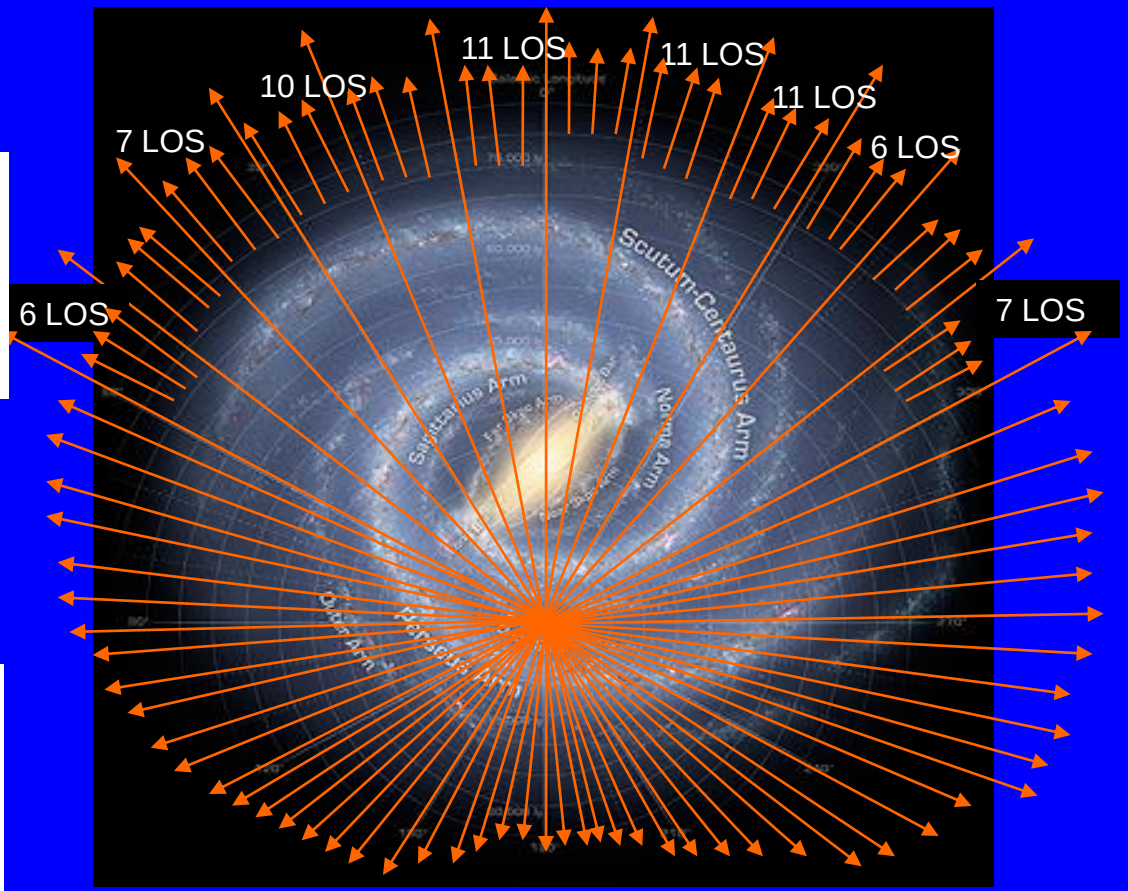
– *l* (0°–360°) at *b* = 0°, ± 0.5° & ± 1°



Inner Galaxy: [CII] strip maps - 360 positions in on the fly (OTF) mapping



Almost all 900 los observed to date.



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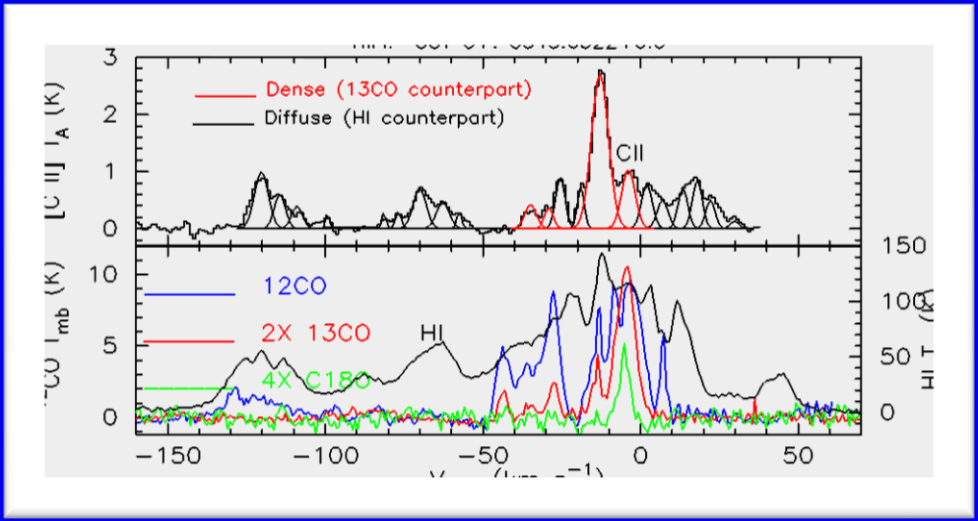
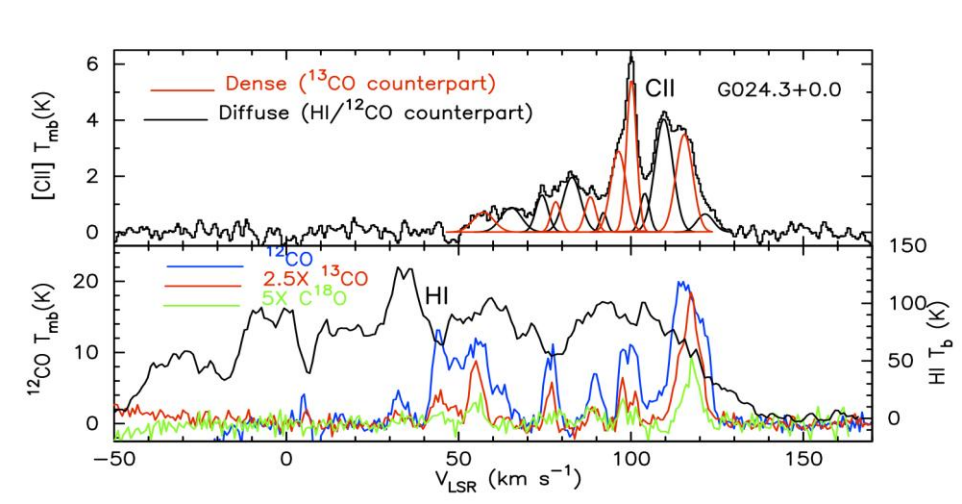
Representative (Really!) [CII], HI, CO Data





l =345°,b=0°

l =24°,b=0°

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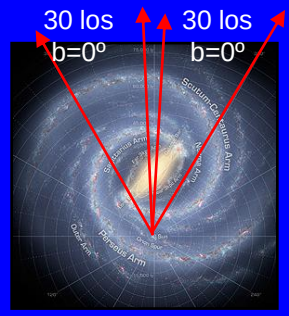
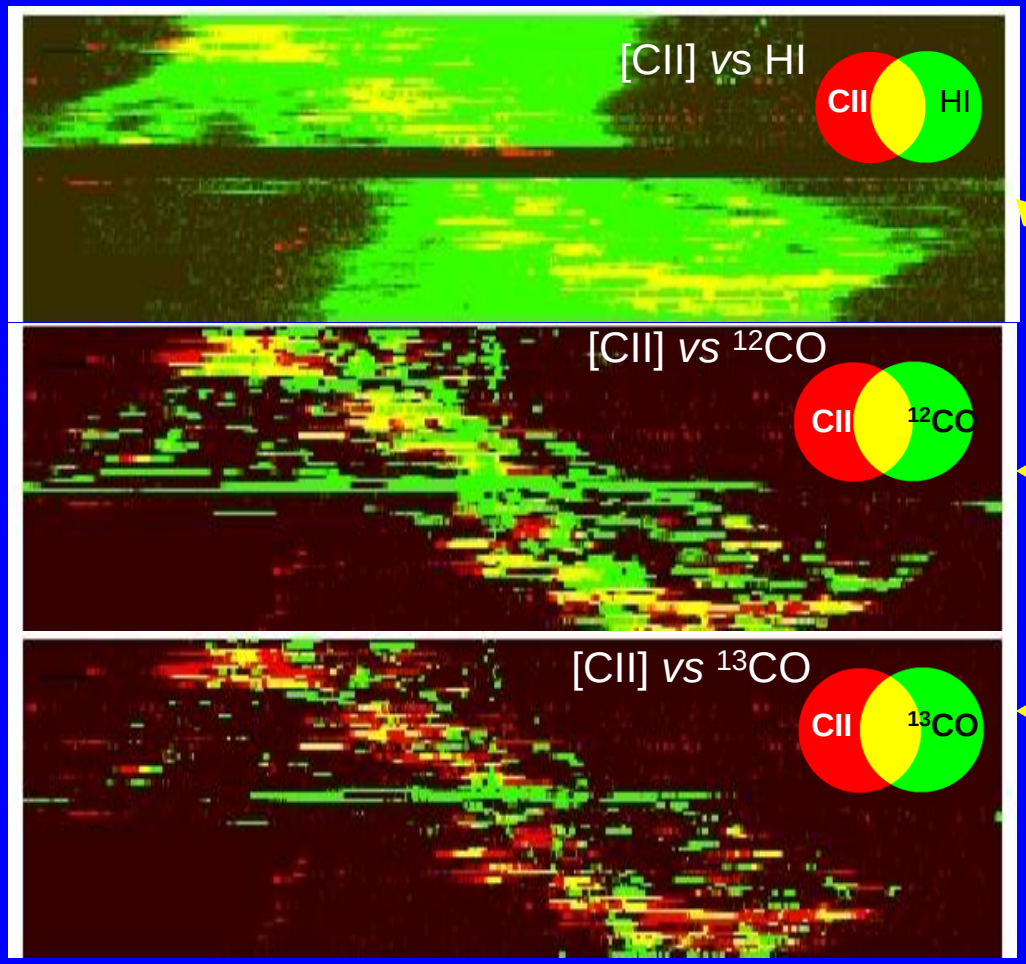
PV Maps l = ±30°





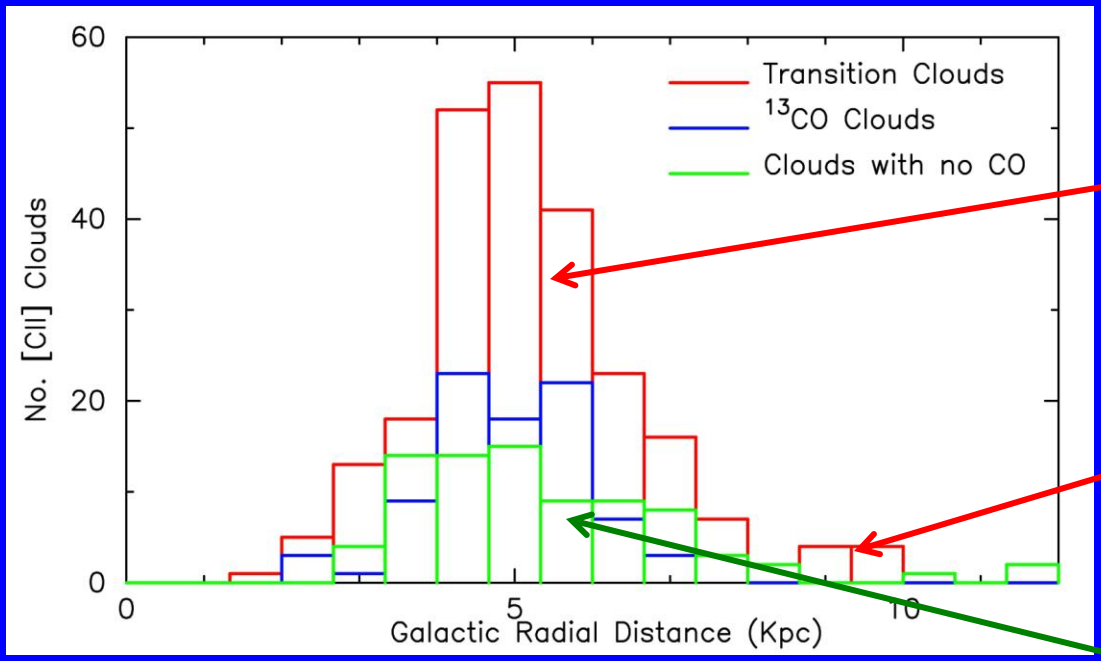
Warm "diffuse" atomic and molecular gas?

Warm, dense transition clouds?

Dense cold clouds, with warm transition zone?

For more details see Velusamy et al.(2011) – Poster Session 2

Distribution of [CII] Clouds with R_{Gal}



~ 60% of Transition Clouds are located at R = 4 kpc

Few clouds detected in local ISM (R~8 kpc)

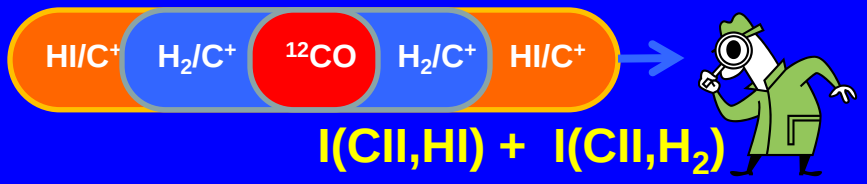
[CII] clouds with no CO have a flatter radial distribution

- 429 [CII] narrow components
- HI associated with all CII Clouds
- 88 have no CO emission
- 247 with ^{12}CO, but no ^{13}CO
- 94 with ^{13}CO(1-0) emission

One explanation lies with the properties of the ISM environment and its influence on cloud-chemical models

Transitional Cloud Analysis - Simplified

I(CII) => N(HI) + N(H_2) layers along line of sight up to C^+/C^o/CO transition.



$N(HI) \alpha I(HI)$

$I(CII)_{HI} = f(n_{HI}, T_K)\, N(HI)\, x(C^+)$ (f = excitation of C^+)

[CII] sensitive to (n,T)

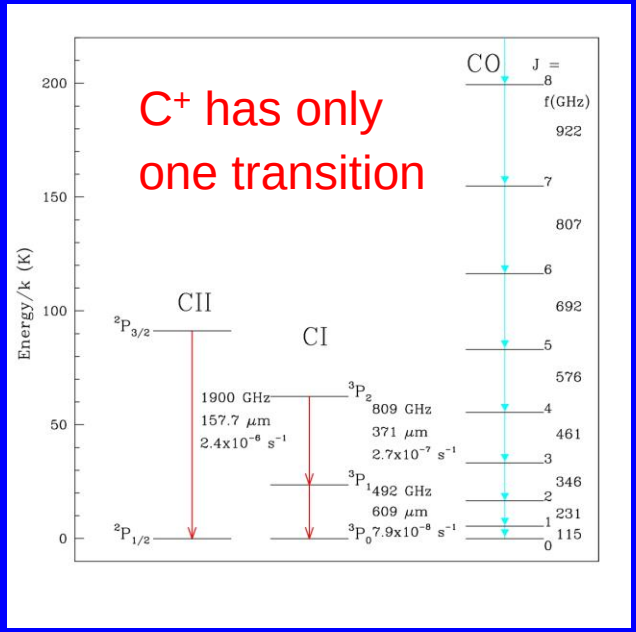
C^+ excitation - high densities & temperatures

$n_{cr}(H) \sim 3x10^3$ & $n_{cr}(H_2) \sim 6x10^3$ cm^{-3}

$I(CII)_{H2} = I(CII) - I(CII)_{HI}$

$N(C^+)_{H2} = f(n_{H2}, T_K)^{-1}\, I(CII, H_2)$

$N(H_2)_{C+} = N(C^+)_{H2} / x(C^+)_{H2}$



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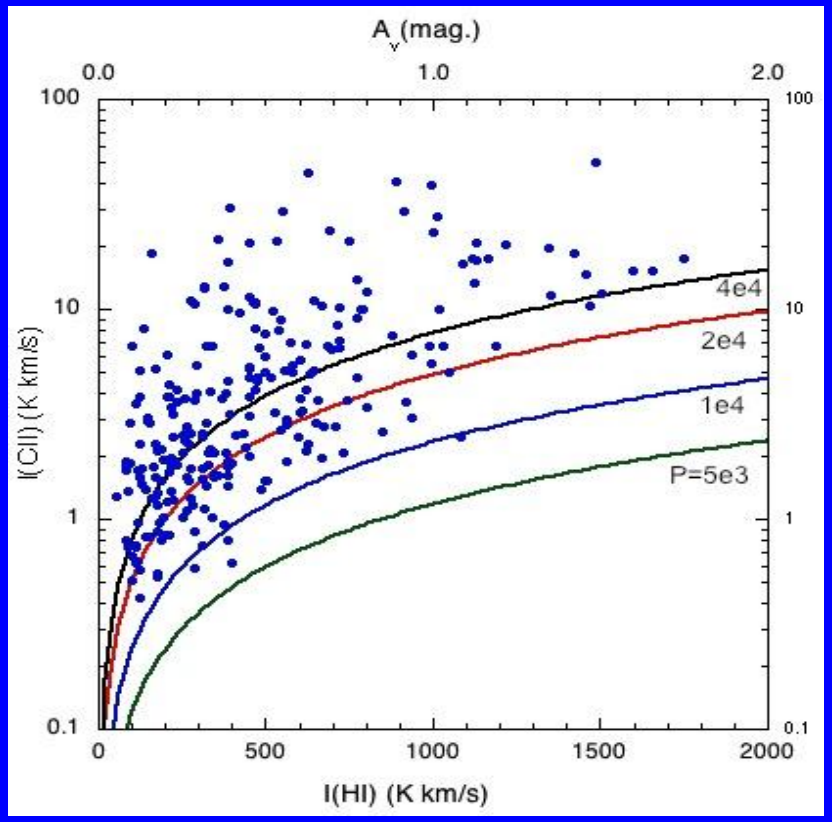
Statistical Study: [CII] Excess in Transition Clouds (^{12}CO – no ^{13}CO)



- Dots (•) – I([CII]) vs. I(HI)
- Solid curves – Model of I(CII) for various HI cloud pressures (P=nT) -> assumes [CII] arises ONLY from an HI cloud.
- Cannot explain I(CII) as arising from HI cloud

- I_{data} – $I(P_{HI})$ is excess [CII] emission tracing warm "Dark H_2 Gas"
- P must be higher than local ISM to explain [CII] emission
- Higher P from high FUV and/or dynamical pressure

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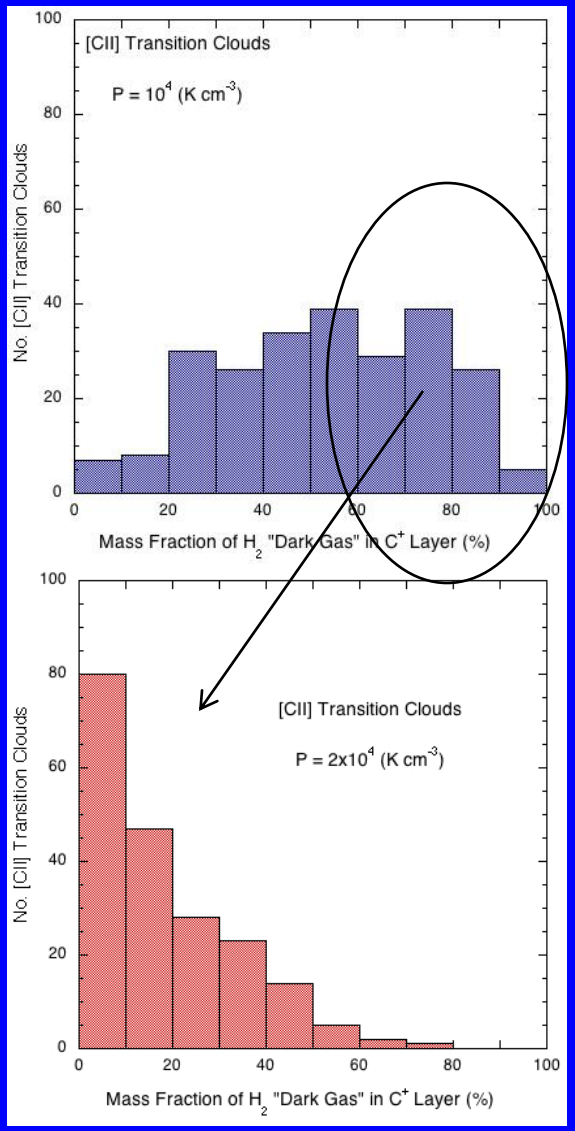
"Dark H_2 Gas" Mass Fraction



- Use excess I(CII) to estimate $N(H_2)_{CII}$
  - $I_{H2}(CII) = I_{tot}(CII) - I_{HI}(CII)$
- Fractional H_2 mass in the C^+/H_2 layer of transition clouds

$$f = \frac{M(H_2)_{CII}}{M(HI) + M(H_2)_{CII} + M(H_2)_{CO}}$$

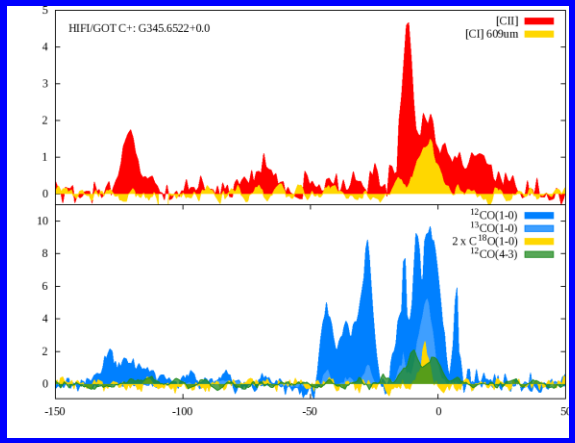
- Distribution for two pressures
  - Lower Pressure has a broad distribution of "Dark H_2 Gas"
  - Higher Pressure corresponds to a narrower distribution
- Results are qualitative - need more information about the C^o/CO transition zone from [CI] and high-J CO

Summary

- Detected several hundred [CII] features over $l = \pm 30^o$, $b=0^o$
- [CII] diffuse and transition clouds have warm dense HI and significant amounts of warm dense H_2
- [CII] clouds are at R_{Gal} = 4-6 kpc and require high P – e.g. FUV radiation $\chi_0 \sim 5$ to 200, or dynamical force to explain [CII] emission
- The full **GOT C+** Galactic Disk survey will:
  - Constrain Chemical Models of the diffuse and transition clouds, PDRs
  - Trace the evolution of clouds
  - Characterize PDRs in star forming environments.
  - Provide a quantitative measure of the fraction of warm "Dark H_2 Gas"
  - Determine the fraction of [CII] tracing star formation.

Beyond **GOT C+**

- We used a statistical interpretation assuming a single model for all clouds.
- Need additional density-temperature probes to model structure & chemistry in the transition zone; good probes would be:
  - CI ($^3P_2$-$^3P_1$, and $^3P_1$-$^3P_0$)
  - High-J CO



- Mapping can discriminate between observing a diffuse cloud and edge of a larger CO cloud
- Large scale [CII] maps needed to explore the structure & dynamics of the [CII] clouds