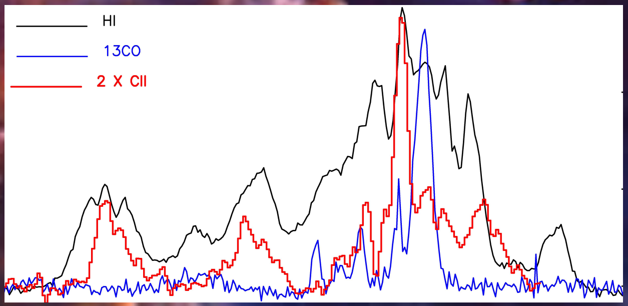

Galactic Observations of Terahertz C^+ (GOT C^+): CII Detection of "Hidden" H_2 in the ISM

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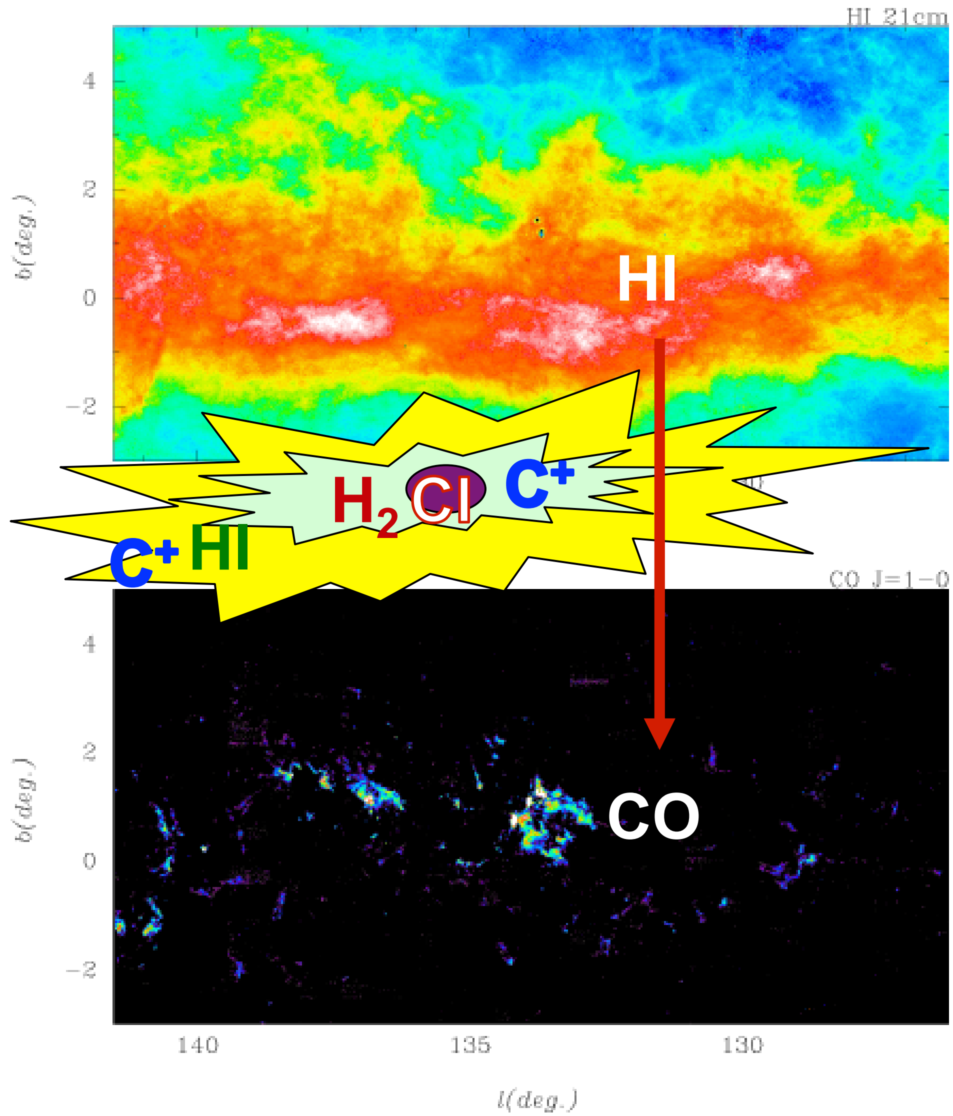
Atomic to Molecular Gas Clouds

HI, CII, CI, and CO, track the evolution of clouds from the diffuse to dense state

- Diffuse Atomic Clouds
  - Warm, low density HI & CII
- Transition Clouds – a phase with H_2 and CII, but little or no CI & CO.
- Dense Molecular Clouds - H_2 is traced by CO

We are missing a critical stage of cloud evolution without CII



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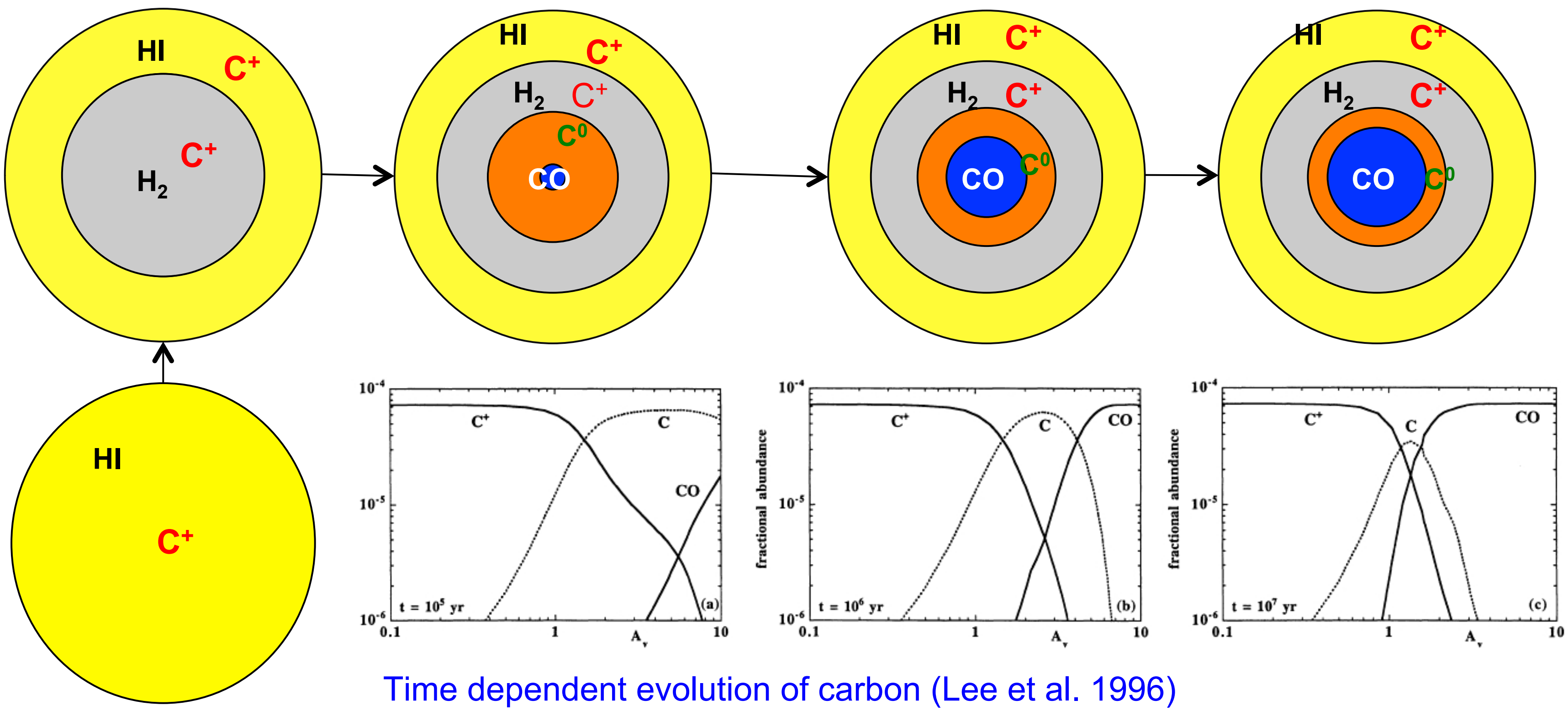
Evolution of HI and CII

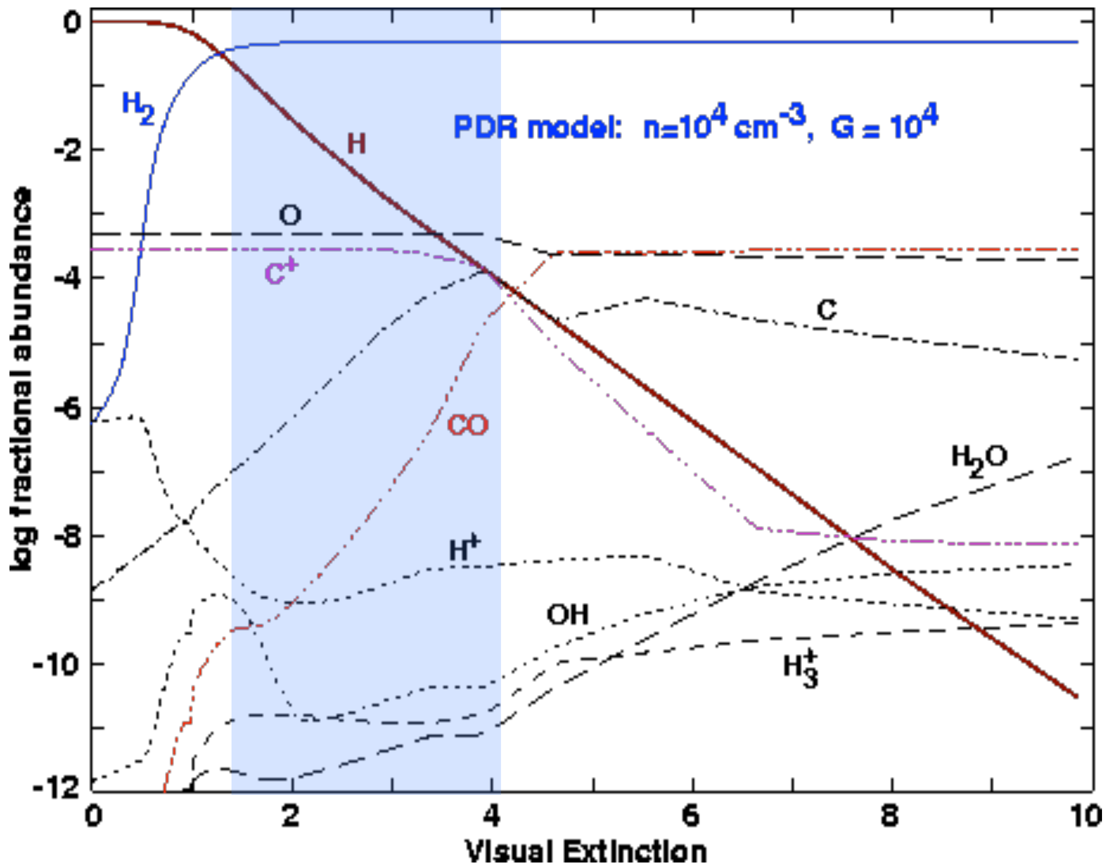


Time dependent evolution of carbon (Lee et al. 1996)

PDR Model

“hidden gas”
~ 30% of H_2

FUV
irradiation



Wolfire et al. 2010

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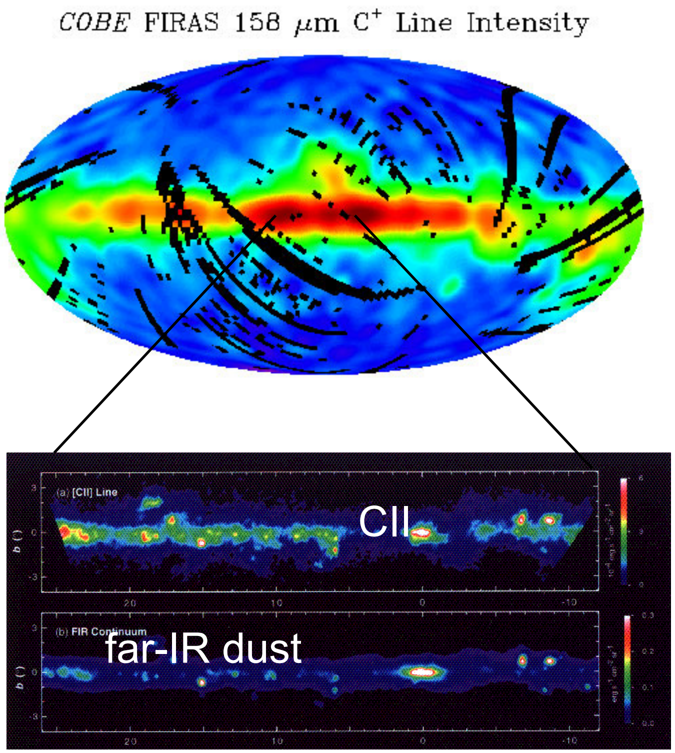
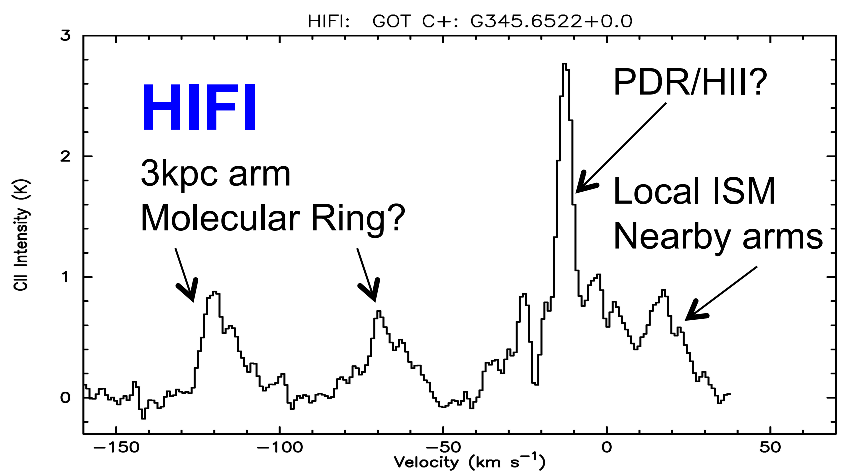
From COBE & BICE to Herschel HIFI



$350^o < l < 30^o$ & $|b| < 3^o$

BICE and IRAS

- CII - strongest Galactic far-IR line
- COBE 7º beam & ΔV ~ 10^3 km/s
- BICE 15’ beam & ΔV ~ 175 km/s
- *COBE - widespread distribution of CII in the Galactic plane*
- *BICE - inner Galaxy distribution.*



Herschel HIFI has the spectral (<0.5 km/s) and spatial resolution (12”) to study individual clouds.

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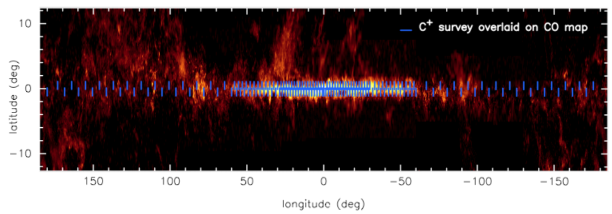
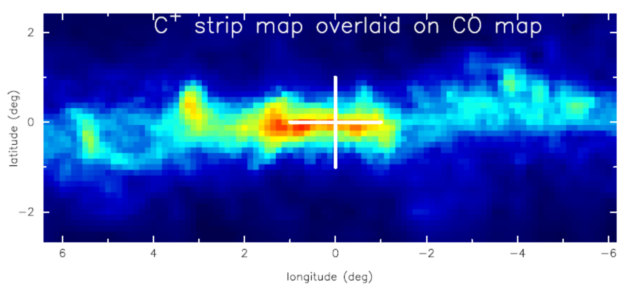
GOT C+ Samples CII throughout the Galactic Plane

Galactic Plane Survey - systematic volume weighted sample of 500 l.o.s. in the disk

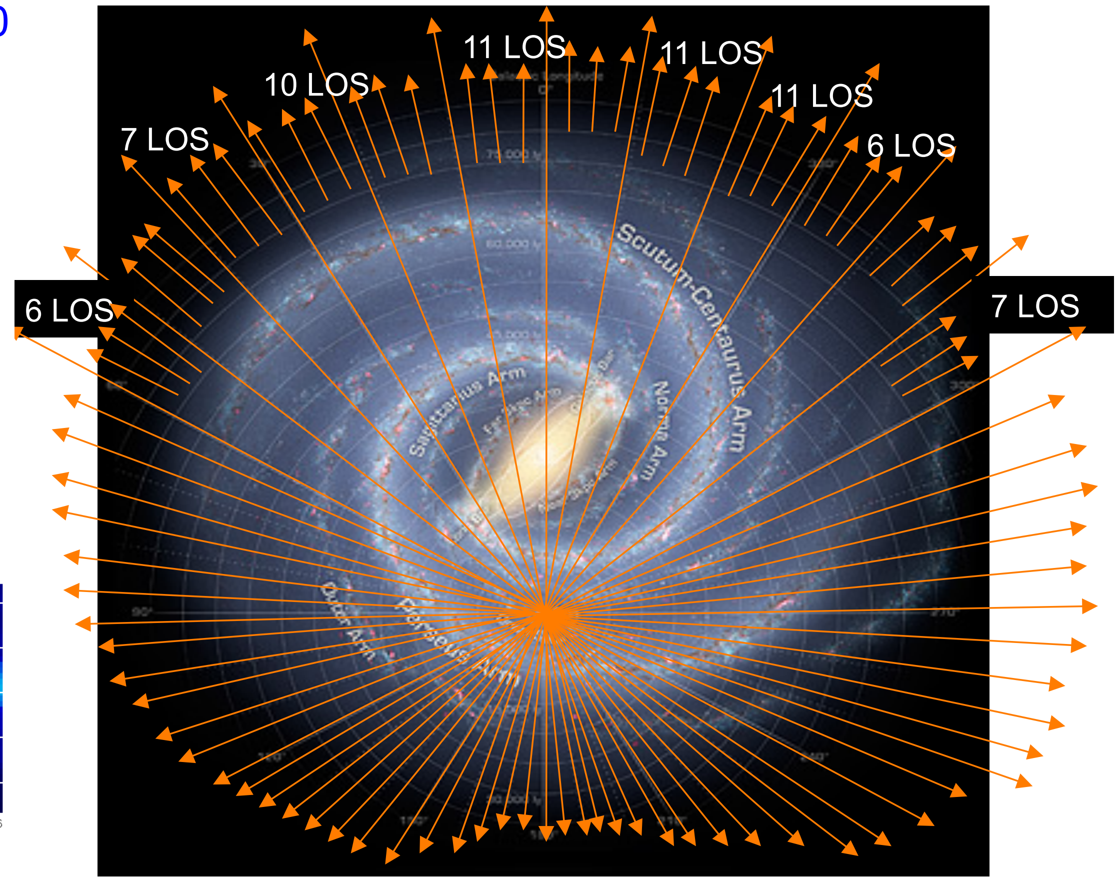
– l (0º – 360º) at b = 0º, +/- 0.5º & 1º



Galactic Central Region: CII strip maps at 360 positions in on the fly (OTF) mapping mode.

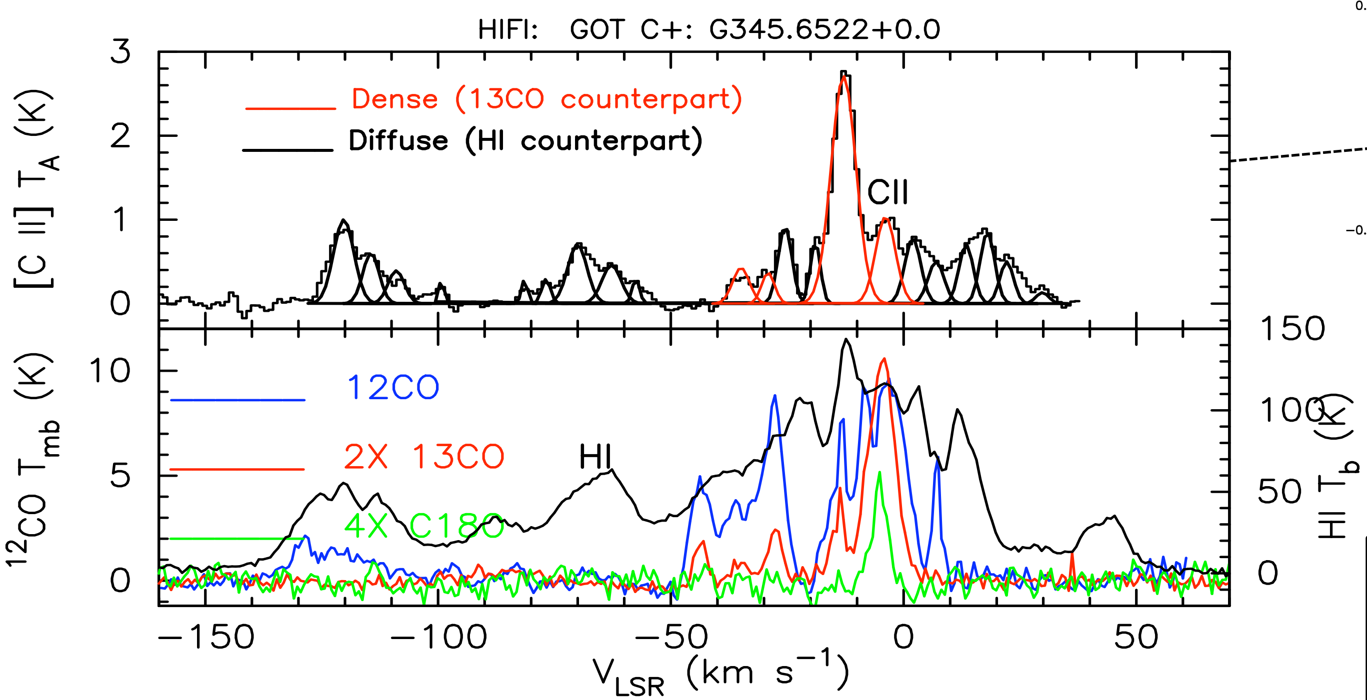


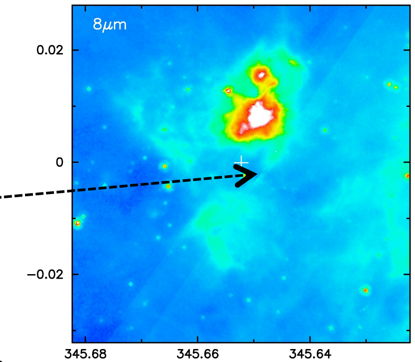
Over 360 los observed to date.

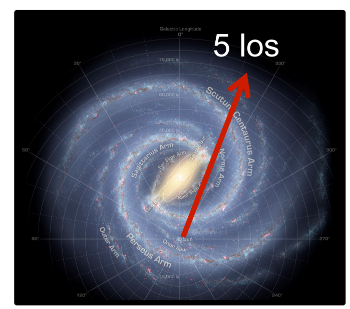


GOT C+ First Results

One of 16 LOS taken in the PSP &
PVP phase located along *l* =345°







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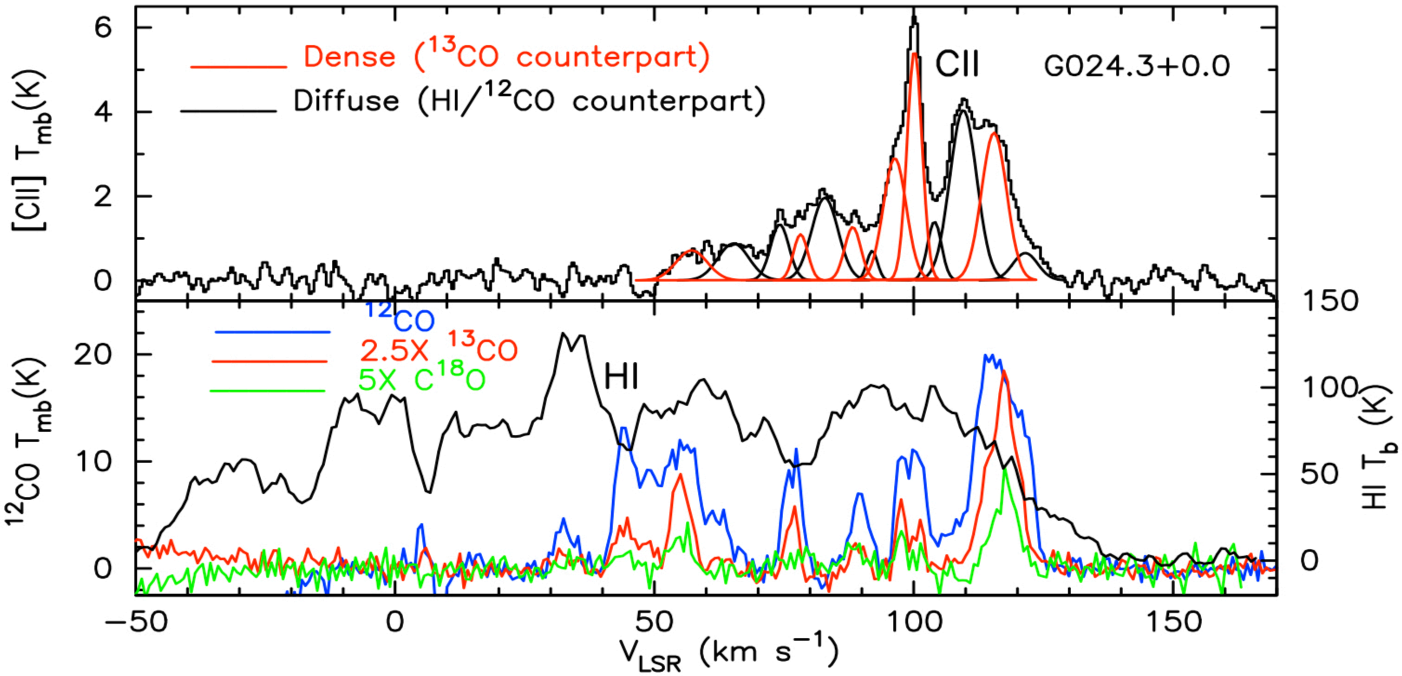
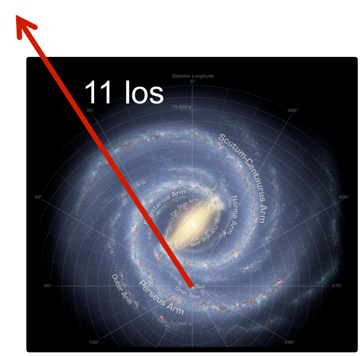
GOT C+ First Results





One of 16 LOS taken in the PSP & PVP phase located along *l* =24^{o}

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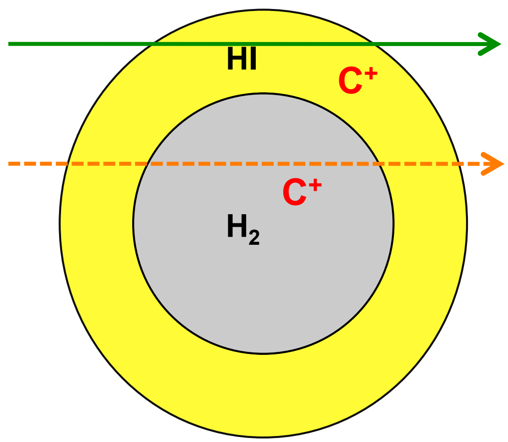
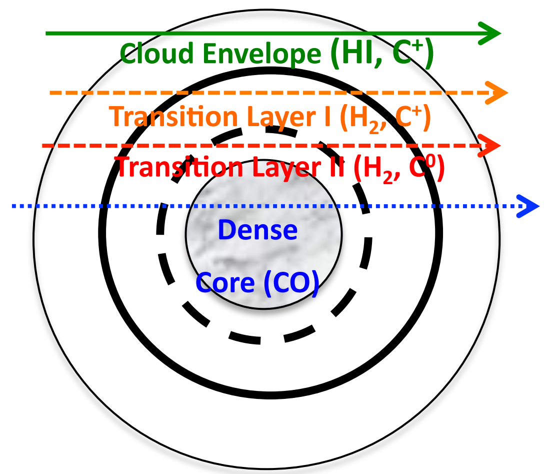
GOT C+ First Results: Statistics

- **Detected 146 CII features in first 16 LOS**
  - 35 no ^{12}CO – Diffuse atomic & molecular clouds (Langer et al. 2010)
  - 53 with ^{12}CO, but no ^{13}CO – Transition clouds (Velusamy et al. 2010)
  - 58 with ^{12}CO & ^{13}CO – Dense Molecular Clouds (Pineda et al. 2010)
    - 12 of these with $C^{18}O$ – Dense Cores



or



Are we looking through a cloud or an edge – is it a diffuse cloud or a PDR?

Complete GOT C+ survey will intersect thousands of clouds and allow a statistical study of ISM conditions in various Galactic environments.

H_2 in Diffuse Clouds

$I(CII) = I(CII,HI) + I(CII,H_2)$ (K km/s)

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

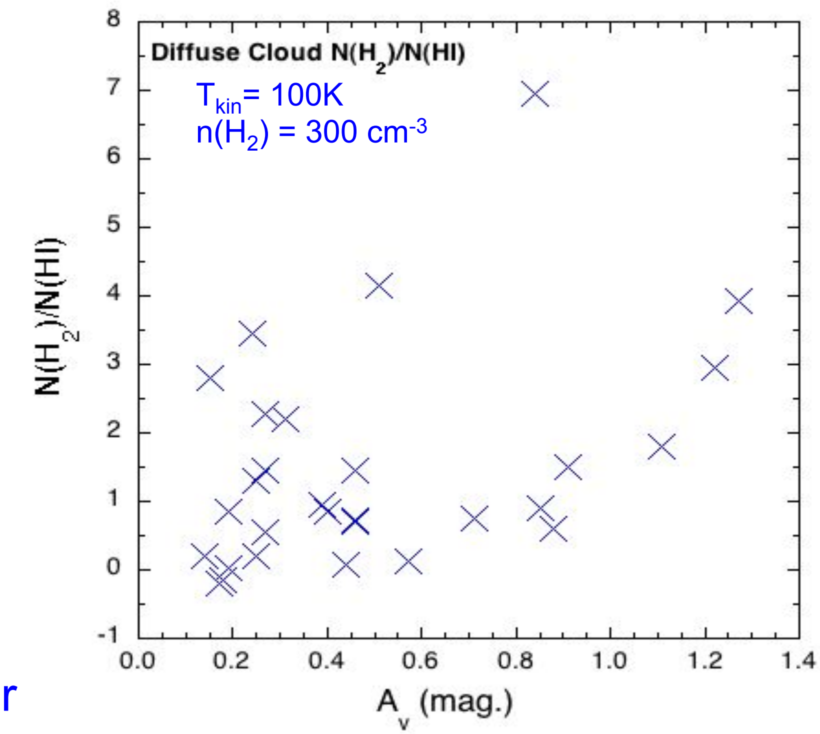
f = CII excitation

Use HI to estimate I(CII,HI)

Calculate $N(H_2)$ as f(n,T)

Details in Langer et al. 2010

- Many clouds have excess C^+ not readily explained as coming from an HI layer
- Need very warm, dense gas to explain I(CII) as coming just from HI cloud or layer
- CII traces warm (T_{kin} > 30K) "hidden" H_2.
- Diffuse clouds or edges of dense clouds?



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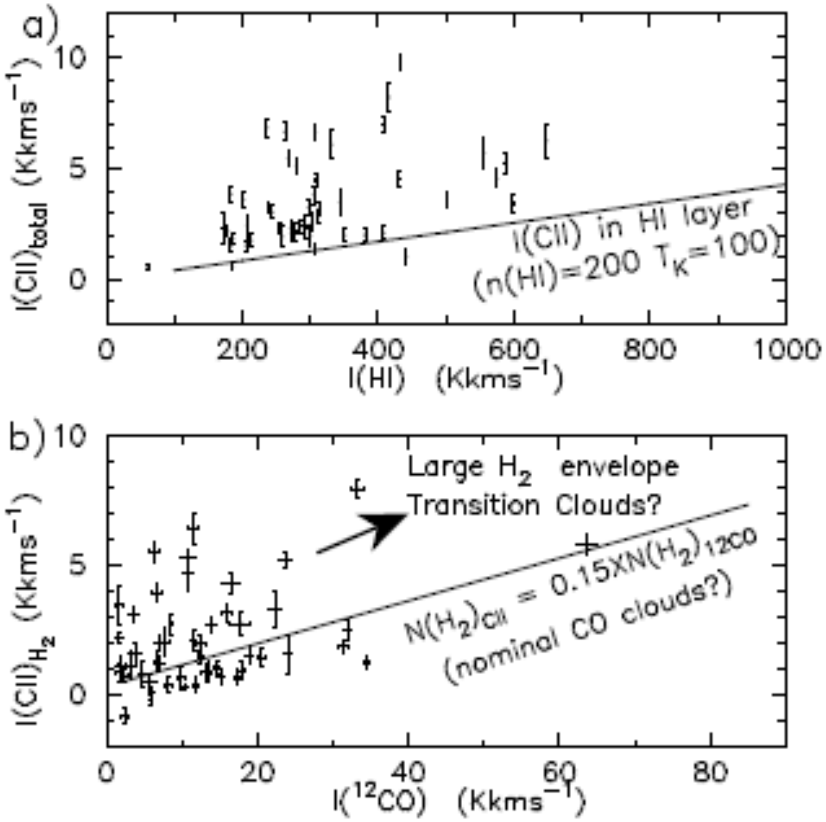
Transitional Molecular Clouds: CII + ^{12}CO

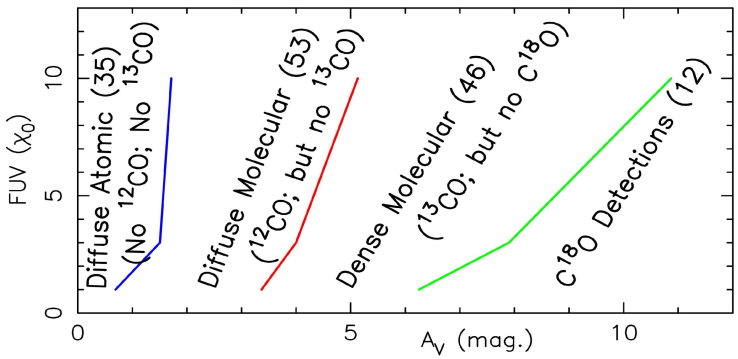


- Analysis of CII versus HI and ^{12}CO reveals excess C^+ that traces a warm "hidden" H_2 cloud layer.
- Comparing mass traced by CII and CO, on average, ~25% of the mass is in the C^+ layer in agreement with models (e.g. Wolfire et al. 2010).
- Velusamy et al. (2010) for details.

(a) The line is a fit for I(CII) vs. I(HI) in "nominal" HI clouds. I(CII) above this line arises from C^+ in the H_2 layer surrounding a ^{12}CO core.

(b) Excess I(CII) plotted against I(^{12}CO). The line is a fit to I(CII) from "nominal" clouds containing about 15% of the total H_2 in the H_2/C^+ layer. Clouds with larger H_2 envelopes lie above this line.

Constraining n, T, and G_{FUV}

- Constrain [n, T,G_{FUV}] (G_{FUV} the intensity of the FUV field), with cloud models including: chemistry, thermal properties, radiative transfer of UV in and sub-mm and far-IR out
- ^{12}CO provides an important constraint: C^+ has converted to CO and we can calculate extinction to the C^+-C^o-CO transition
- 

  Detection thresholds for ^{12}CO, ^{13}CO, $C^{18}O$ based on chemical-cloud models (Visser et al. 2009).
- Additional observations of CI and CO(J>3) in transition zone, can provides tight constraints (n,T,G_{FUV})
- Otherwise, use thermal models to estimate (n,T) in the HI and H_2 layers and get indirect, but looser, constraints.

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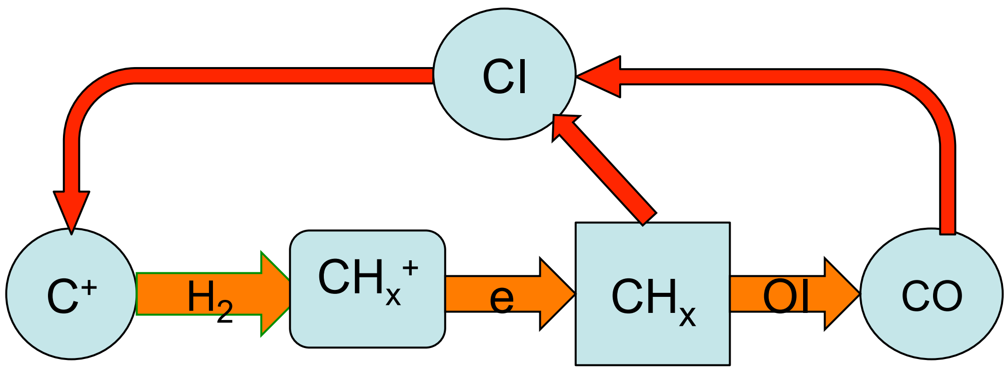
Cloud Models

- Several time dependent codes available & under development
  - Smooth density models – e.g. Meudon code, Visser and Glover models, PDR models of Tielens, Hollenbach, Kaufman, & Wolfire
  - Clumpy models – e.g. KOSMA-TAU code (Cologne group and Sternberg)
- In all cases one needs to develop a grid of models as a function of parameters to search for the best solution for each cloud.
- We have used a simple model to estimate the cloud conditions



- Simple chemical model for C^+ to CO
- Heating: UV + grain & PAHs; C.R. ionization
- Cooling: CII emission
- Iterate on G_0(FUV) until match I(CII) and I(CO)

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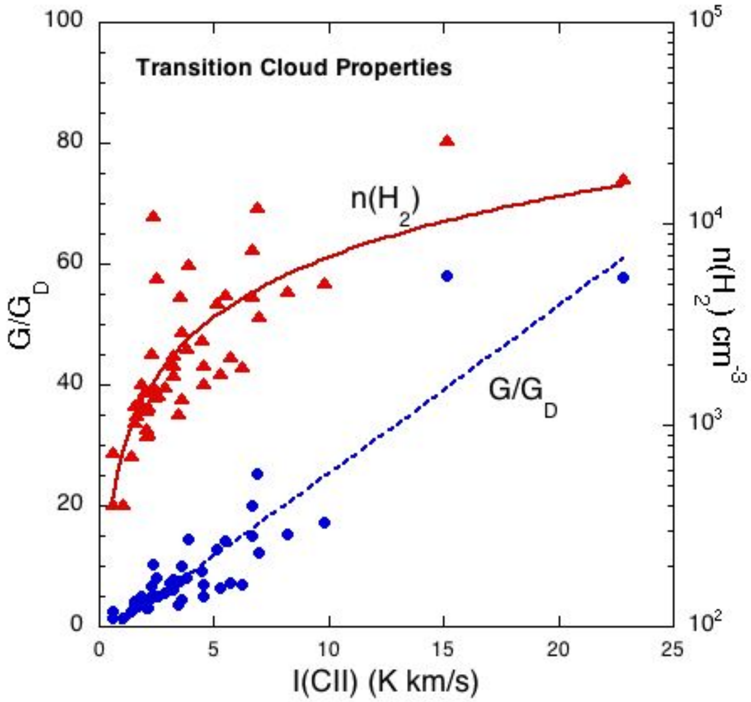
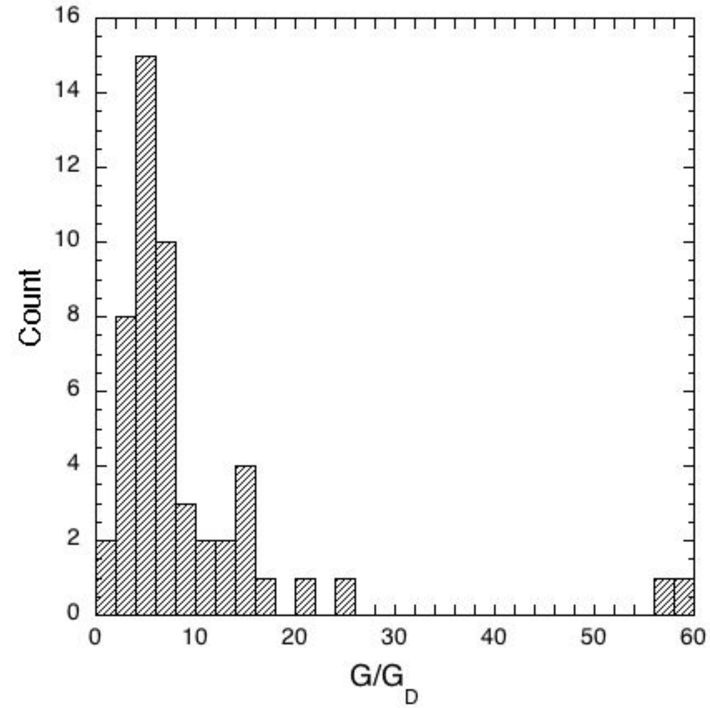
Transition Cloud Solutions (Illustrative)





- Set of solutions using simple thermal and chemical models
- More exact modeling with cloud-chemical models is underway using the Meudon and KOSMA-TAU codes.

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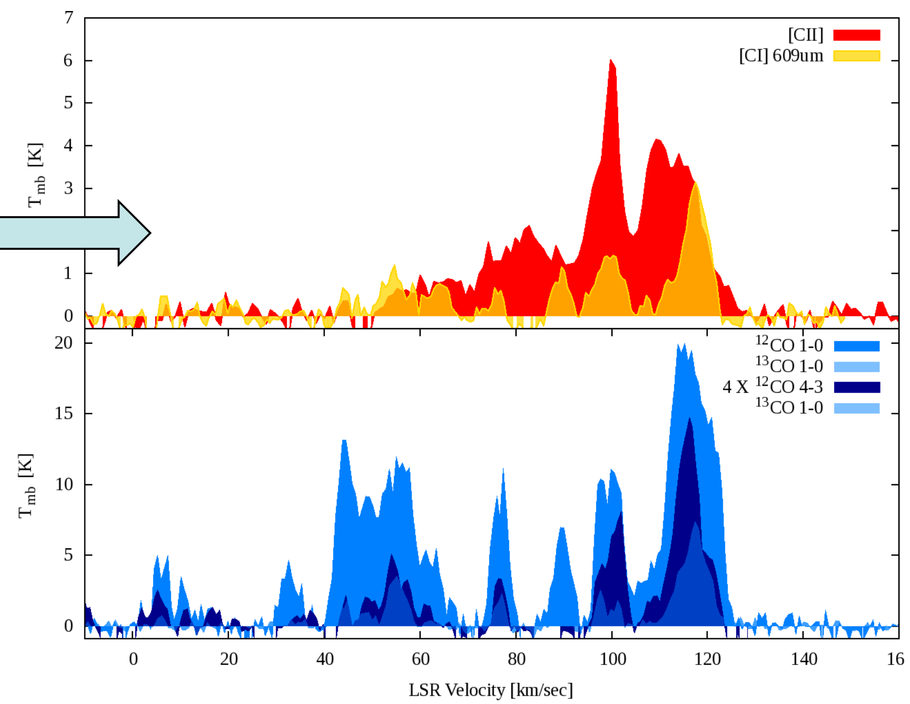
PDRs in Dense Molecular Clouds

- Adding CI & CO(J≥3) better constrains n, T, G_{FUV}, in PDRs
- 4 LOS observed in CI (609 μm) and CO(4-3) at NANTEN2
- 21 CII components have associated CI and CO emission

- Combined CII, CI, and CO (1-0) to determine PDR conditions using a grid of KOSMA-TAU PDR models– see Poster by Pineda et al.
- Most of the sources have high density, ~10^4 cm^{-3}, and G_{FUV} < 100 G_D.
- Comparisons with Meudon code are underway.



Summary

- Detected 146 CII features in 16 LOS (335° - 25°), out of 900 planned LOS; 350 LOS observed to date
  - 35 HI and no ^{12}CO – Diffuse atomic & molecular clouds
  - 53 HI, ^{12}CO, but no ^{13}CO – Transition clouds
  - 58 ^{12}CO and ^{13}CO PDRs, a few of which have $C^{18}O$ on the line of sight
- Results
  - Significant amount of warm H_2 in diffuse and transition clouds
  - Fraction of H_2 in dense clouds observable only in CII – warm “hidden” H_2 ~ 25%
  - 44% of I(CII) comes from warm, dense PDRs, rest diffuse and transition clouds
  - PDRs observed in CII, CI, CO show high n (>10^4 cm^{-3}) and G_{FUV} <$100G_D$
  - Three papers published in the A&A HIFI Special Issue
- These early results show great promise for using CII 158 μm line to study the H_2 gas in the UV radiated portion of clouds.
- A larger cloud sample on completion of the GOT C+ Disk survey will:
  - Trace the evolutionary status of transition clouds and their role in the ISM
  - Characterize PDRs in star forming environments.
  - Provide an estimation of the fraction of [CII] emission tracing star formation