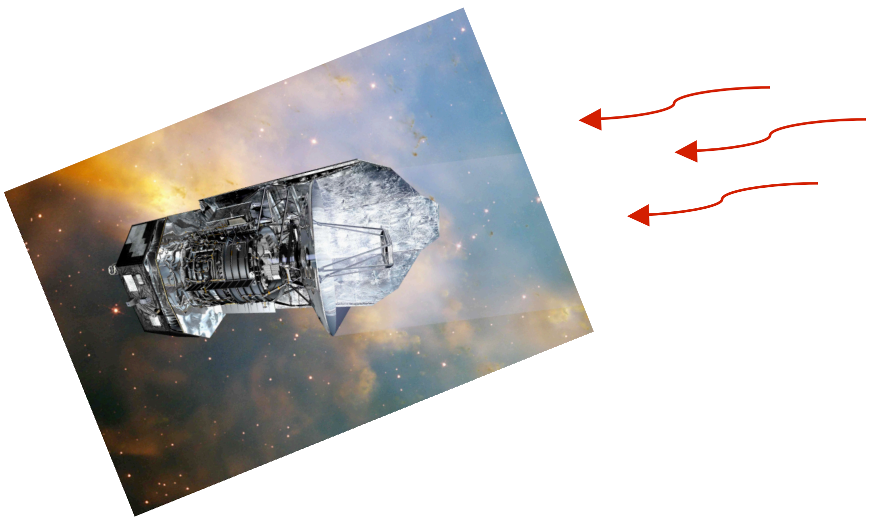
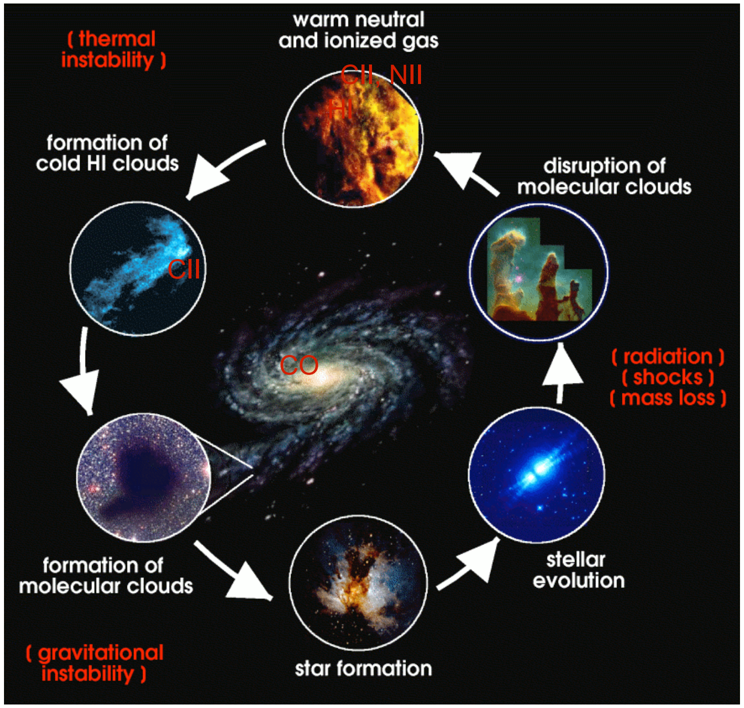
The State of the Diffuse ISM:
Galactic Observations of the Terahertz CII Line

GOT C^+





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GOT C^+ Goal

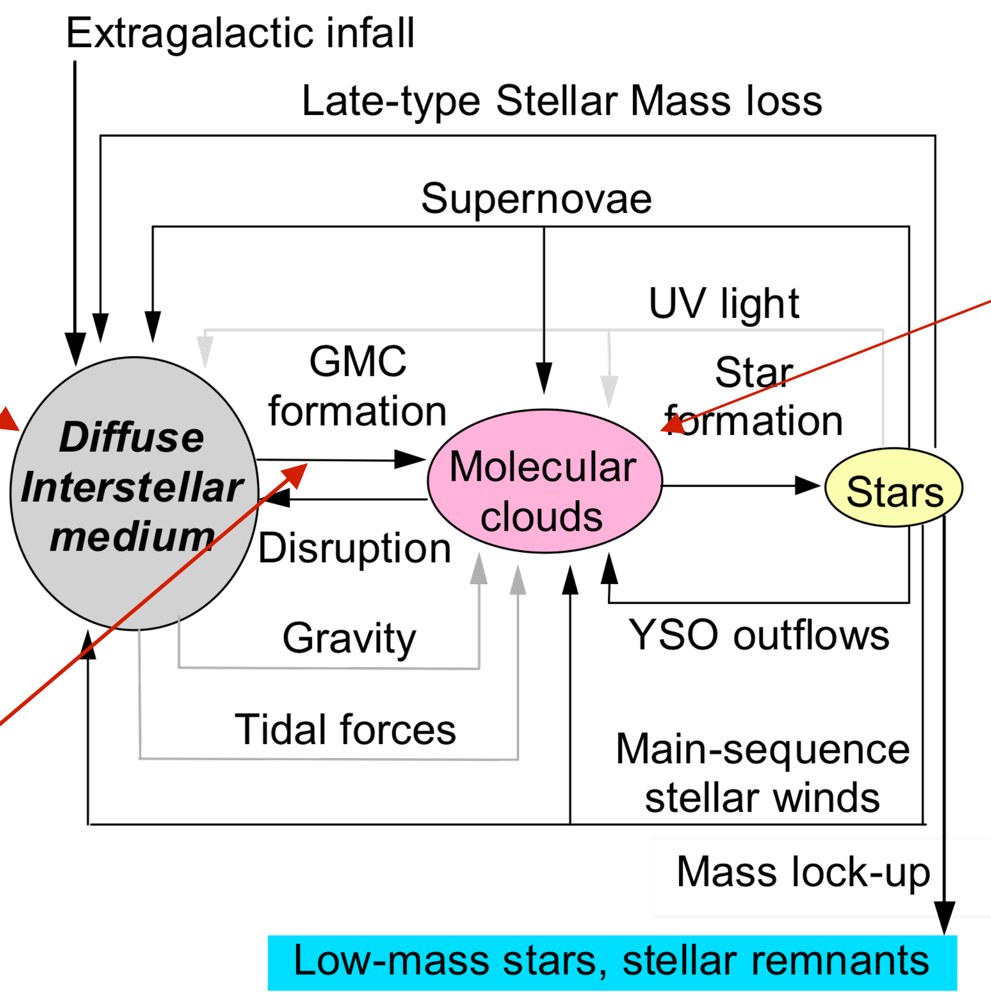
Obtain a reasonable sample of C^+ (CII) fine-structure emission lines, in representative Galactic environments, to enable a statistical characterization of the diffuse Interstellar Medium in the entire Galaxy, for purposes of understanding the life cycle of interstellar clouds.

GOT C^+ Science Themes

Interstellar Medium (ISM) Lifecycle

Formation of Diffuse Clouds

Atomic to Molecular Cloud Transition



Cloud Boundary (PDR) Properties

Diffuse Clouds: Gas-to-Stars

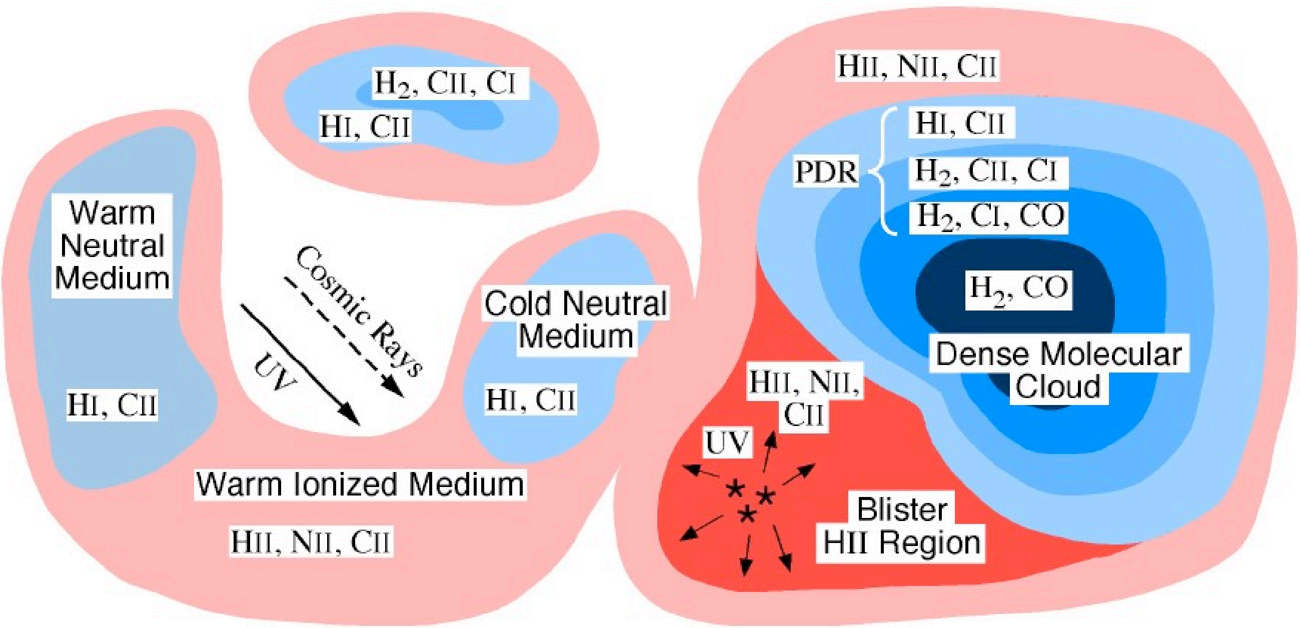
- Galactic Star formation occurs in interstellar clouds
  - Spatially coherent and density enhanced regions
    - Spiral arms
    - Galactic Nuclei
- The formation of these large scale gas clouds is related to the thermal and dynamical state of the diffuse interstellar gas, which is linked to
  - Heating and cooling of the gas
  - Gravitational potential
  - Turbulent Pressures
  - Magnetic forces
  - Radiation, wind, and shock pressures
- Limited knowledge
  - Thermal pressure throughout ISM
  - Transition from diffuse atomic to diffuse molecular clouds
  - Properties of Photon Dominated Regions (PDRs)

Carbon in the ISM

- Carbon in its various gaseous forms is both a tracer of different states of the ISM, and an important coolant in most stages of cloud evolution
- Three species make up the bulk of gaseous carbon
  - C^+ (often designated CII) diffuse gas coolant, warm gas tracer via one far-IR line
  - CO molecular cloud coolant, moderately dense gas tracer via several rotational lines
  - C^0 (neutral carbon - designated CI) is a PDR gas tracer with two fine-structure lines at sub-mm wavelengths

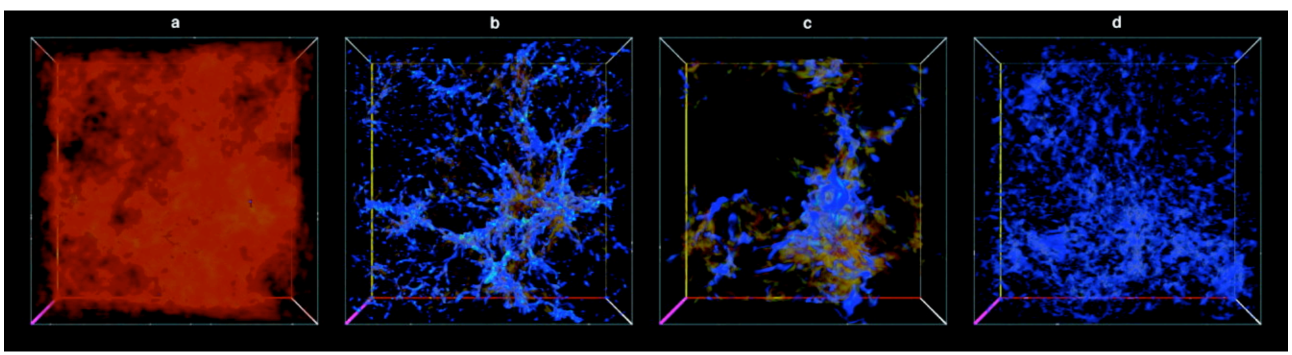
Reservoirs of Carbon and ISM Gas

- Warm Ionized Medium
- Warm Neutral Medium
- Cold Neutral Medium
- PDRs
- Diffuse Atomic Clouds
- Diffuse Molecular Clouds
- Translucent Clouds
- Dense Molecular Clouds



ISM Lifecycle Challenges

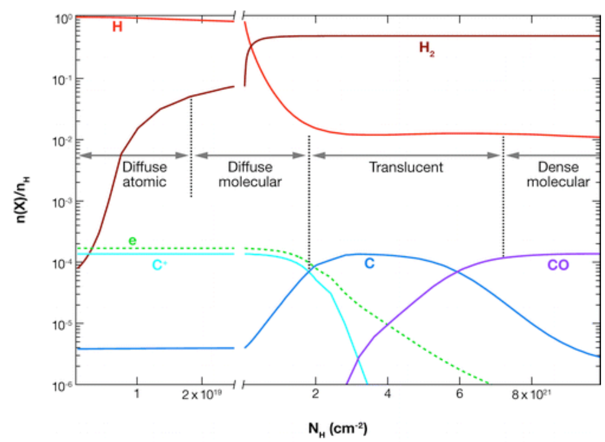
- We do not know enough about the physical and dynamical state of the diffuse galactic gas to develop and test models of how this gas is transformed into star forming clouds, nor about the mechanisms that trigger these transformations
- This stage of the lifecycle of the ISM sets the distribution and evolution of the star forming clouds,and may determine the time scale (and rate) of star formation



Thermal instability induced interstellar turbulence - dynamics of phase transitions in the ISM using realistic cooling and heating (Kritsuk & Norman 2002). At t = 0, n = 1 cm^{-3}, T = 7000K.

ISM Lifecycle Challenges

- Diffuse **molecular** clouds are difficult to study using standard tracers
  - HI < H_2 and CO << CI < C^+ (CII)
  - these clouds can be studied in CII emission
- Determine the nature (n, T_{kin}, and I_{rad}) of the cloud boundary, the PDRs, for molecular clouds to determine their role in energy transfer and cloud evolution



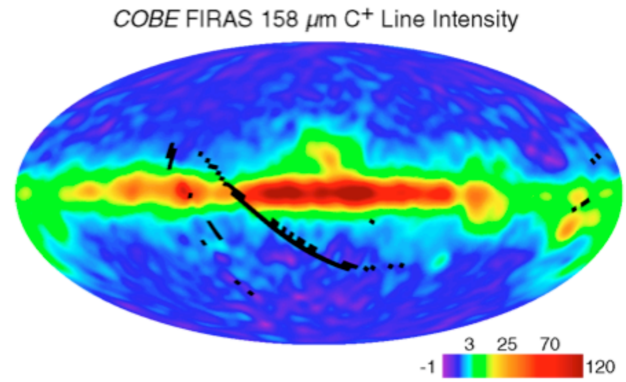
Snow TP, McCall BJ. 2006.
Annu. Rev. Astron. Astrophys. 44:367–414

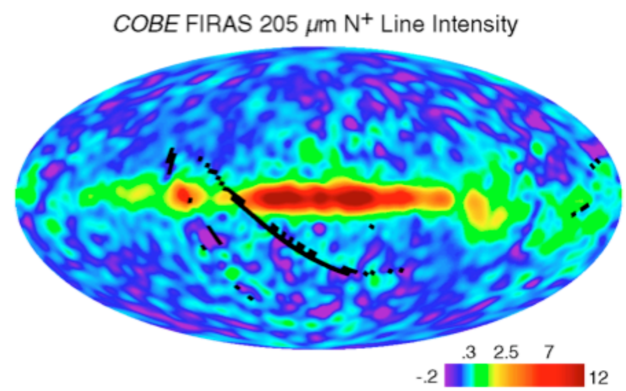
Why C^+?

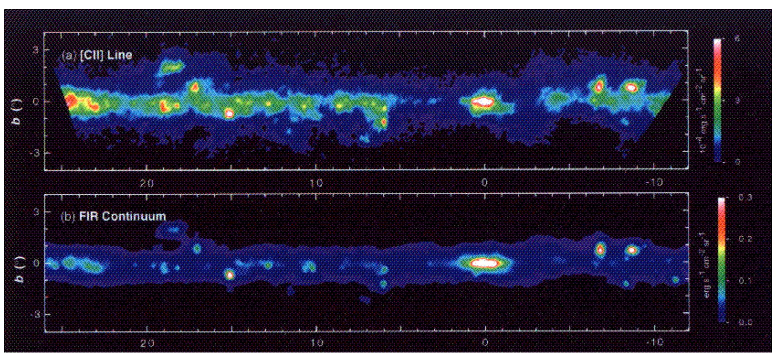
CII Galaxy wide Probe

C158_N205_line_maps.png (PNG Image, 1024x1344 pixels) - Scaled (72%) http://lambda.gsfc.nasa.gov/product/cobe/cobe_images/C158_N205_line_maps.png

- COBE and BICE: CII fine-structure emission is widespread throughout Galactic plane
- CII is the strongest Galactic far-IR line about 5 x 10^7 L_{solar}, ~10^3 x CO(1-0)
- CII is strongest in PDRs







BICE CII intensity (top) at 15' resolution & far-IR Continuum from IRAS (bottom). CII/far-IR is largest for diffuse regions and lowest in Galactic Center.

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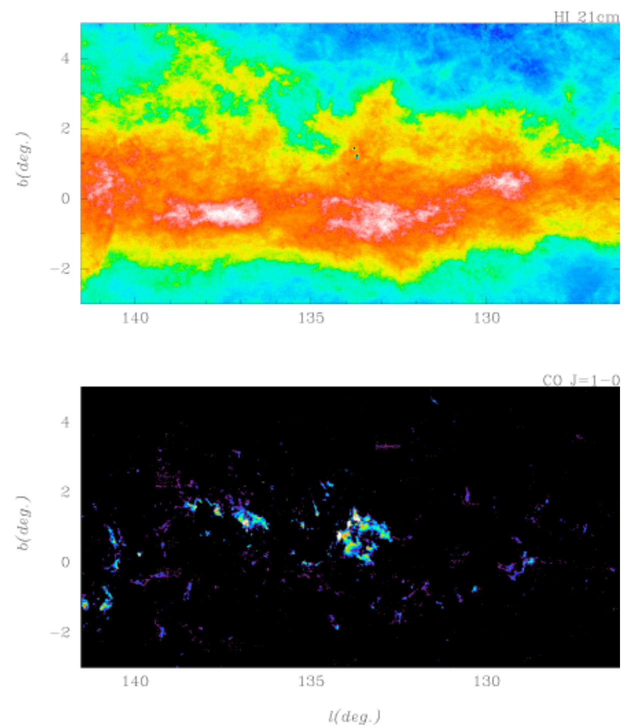
Diffuse versus Dense Gas Distribution

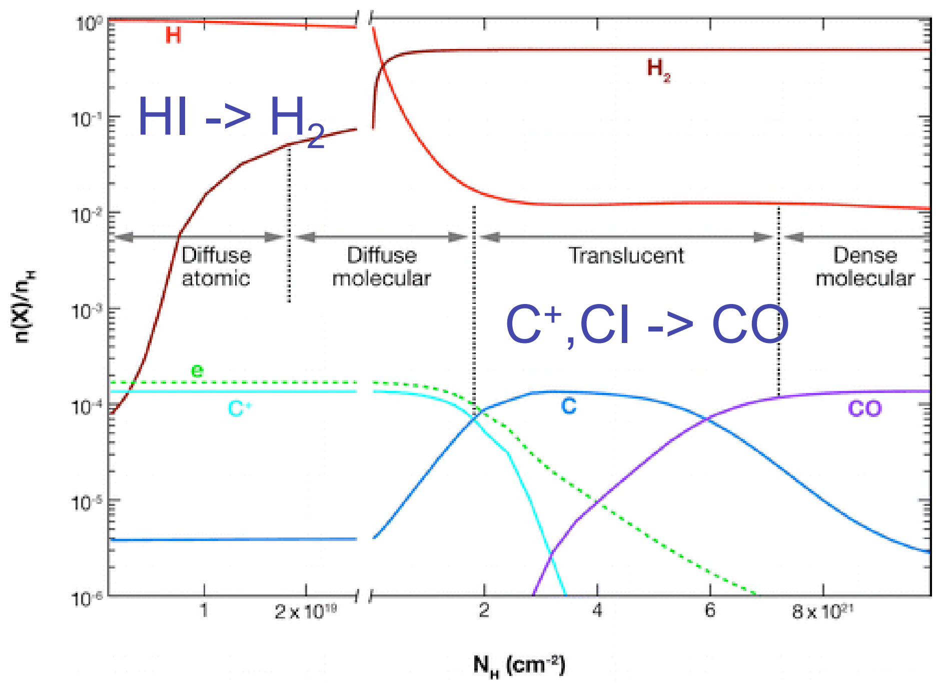
- Diffuse and dense gas distributions are different
  - Integrated HI 21cm line from Canadian Galactic Plane Survey (top)
  - FCRAO CO(1-0) survey (bottom)
- C^+ maps would allow more direct comparison of diffuse gas with associated molecular and/or atomic material
  - C^+ is more sensitive to T_{kin} and density than HI
  - HI and C^+ ➔ Thermal Pressure in atomic diffuse clouds
- The chemical transformation of the key reservoirs of carbon, C^+, C, and CO, track the evolution of clouds from the diffuse to dense state



Perseus Spiral Arm

PDRs: Atomic to Molecular Transition

- Photon-dominated regions (PDRs) properties depend on the strength of the impinging visual and UV radiation field
- PDRs are the energy transfer interface between the clouds and inter-cloud medium
- Transition of carbon from ionized to neutral and hydrogen from atomic to molecular occur in PDRs



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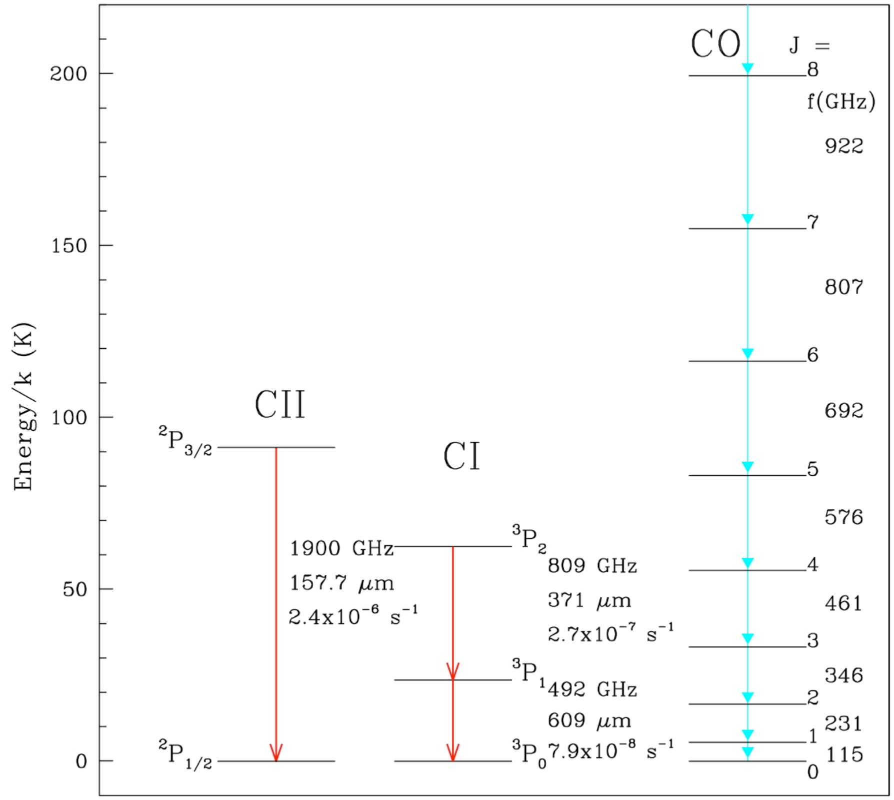
Properties of CII Fine Structure

- CII has Spin-orbit splitting: $^2P_{1/2}$ & $^2P_{3/2}$
- ν = 1900.5369 GHz
- $\Delta T_{equivalent}$ = 91.25K
- $A_{3/2-1/2} = 2.4 \times 10^{-6}\ s^{-1}$
- Critical density (T_k~20-100K)
  - HI ~ $3 \times 10^3\ cm^{-3}$
  - H_2 ~ $7 \times 10^3\ cm^{-3}$
  - e^- ~ $9\ cm^{-3}$
    - Dominates for $x(e) > 3x10^{-3}$
- CII excitation is more sensitive to T_{kin} and density than is HI
- CII emission is important to the energy balance in the ISM

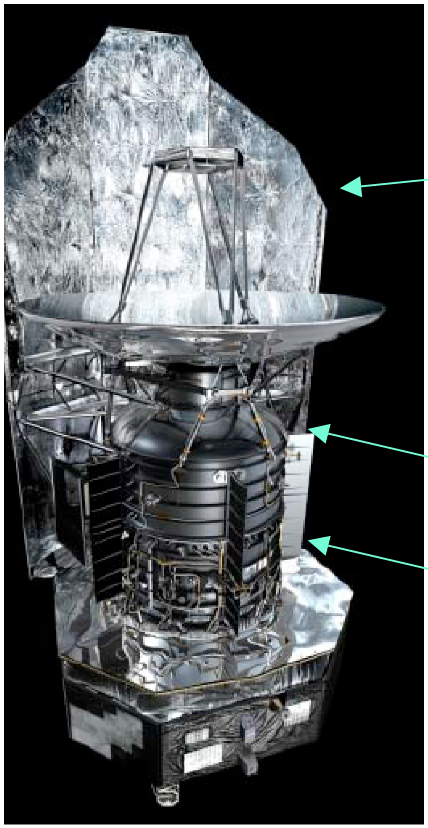


HSO HIFI Instrument

Herschel - 2nd Generation Submm/far-IR mission

- 3.5m diameter SiC Cassegrain telescope
- 3 L-He cooled instruments
- 670 µm → 60 µm range
- Wavefront error < 6µm rms
- $\Delta\theta = 50'' \rightarrow 9''$
- L2 orbit
- Minimum 3.5 yr mission lifetime
- Ariane 5 Dual launch with Planck CMB satellite

Herschel - Planck



Sunshield and Solar Array

Focal Plane Instruments

Cryostat

Herschel Orbit

Herschel Instruments

Two are imaging photometers and spectrometers

- Photodetector Array Camera and Spectrometer (PACS)
  - 60 µm – 210 µm PI = Albrech Poglitsch, MPE, Garching [Germany]]
  - 2 bolometer arrays w/ 32x16 and 64x32 pixels
  - R up to 4000 at shortest wavelength with grating w/ 25 spatial x 16 spectral pixels

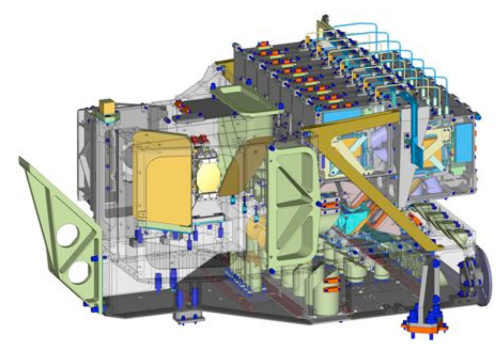
- Spectral and Photometric Imaging Receiver (SPIRE)
  - 200 µm – 670 µm PI = Matt Griffin, Cardiff Univ. [UK]
  - R up to 1200 using FTS with 19/37 detectors; 43/88/139 pixel photometer arrays (long → short wavelengths)

The third is a high resolution heterodyne spectrometer

- Heterodyne Instrument for the Far Infrared (HIFI)
  - 157 µm – 212 µm & 240 µm – 625 µm
  - PI: Thijs de Graauw (now Frank Helmich SRON [Netherlands]); US PI: Tom Phillips, CIT
  - R up to 10^6; 1 pixel x 2 polarizations at each frequency

CII Observed with HSO HIFI Band 7 Receiver

- Heterodyne Instrument for the Far-Infrared (HIFI)
- Band 7 - dual polarization HEB receiver will operate up to 1.95 THz
- IF Bandwidth 4 GHz
  - velocity resolution up to 0.1 km/s
  - velocity coverage up to 350 km/s (at 0.22 km/s velocity resolution)
- Observe in OTF mapping mode (Galactic Center)
- Observe in pointed staring load chop mode



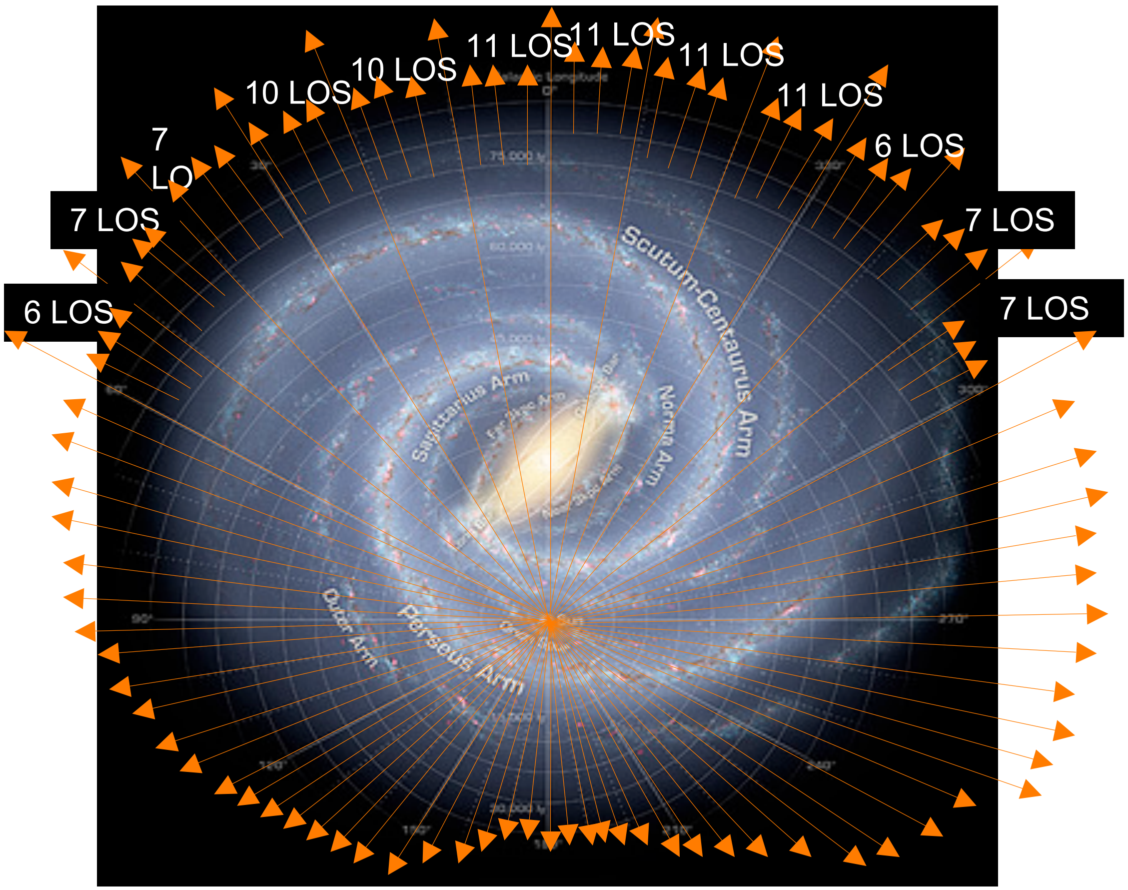
GOT C^+ Observing Strategy

Two Approaches to Studying ISM with CII

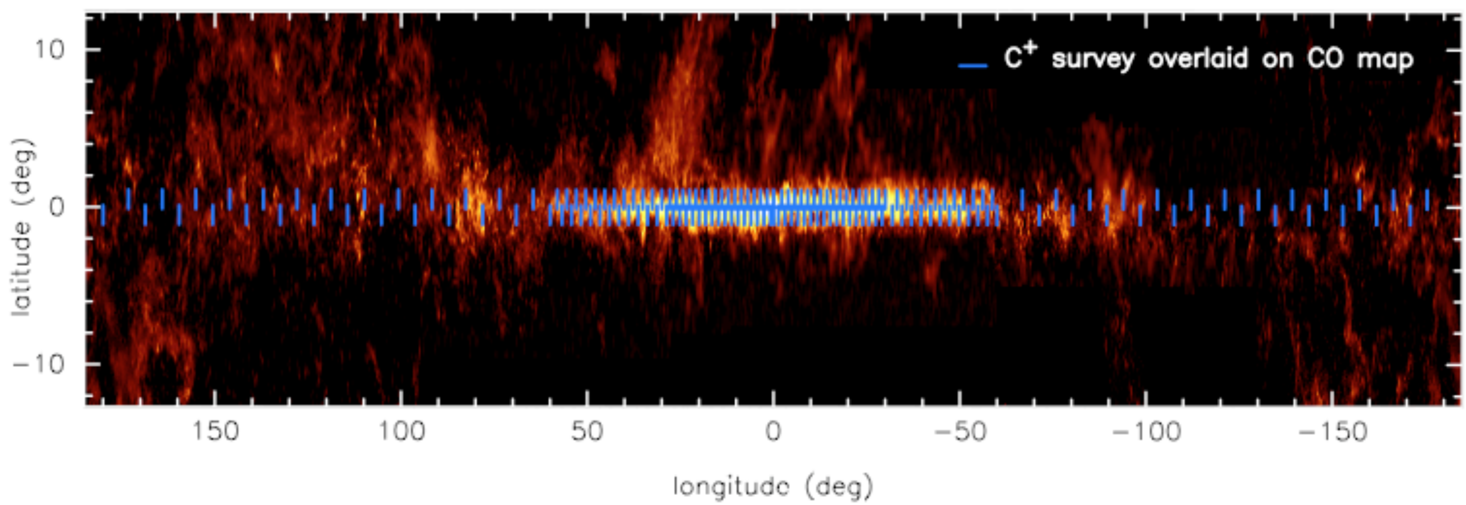
- Large scale, full coverage, maps using a small telescope with a large beam,
  - dedicated satellite mission with angular beam ~ 1-2 arcmin
  - Such surveys are limited in sensitivity due to short integration times per position but provide maps of clouds and PDRs
- Uniform, but sparse, volume sample using a large telescope with a small beam
  - "pencil-beam" and high-spectral resolution observations along many lines-of-sight and with deep integrations
  - Generates a statistical sample of the ISM and PDRs

Galactic Plane: Uniform Volume Sample (1/2)

- 500 lines of sight in the plane
  - Concentration of lines of sight is larger towards inner Galaxy
  - Every degree in latitude at b = 0º
  - Every other degree at b= +/- 0.5º & +/- 1º



Galactic Plane: Uniform Volume Sample (2/2)



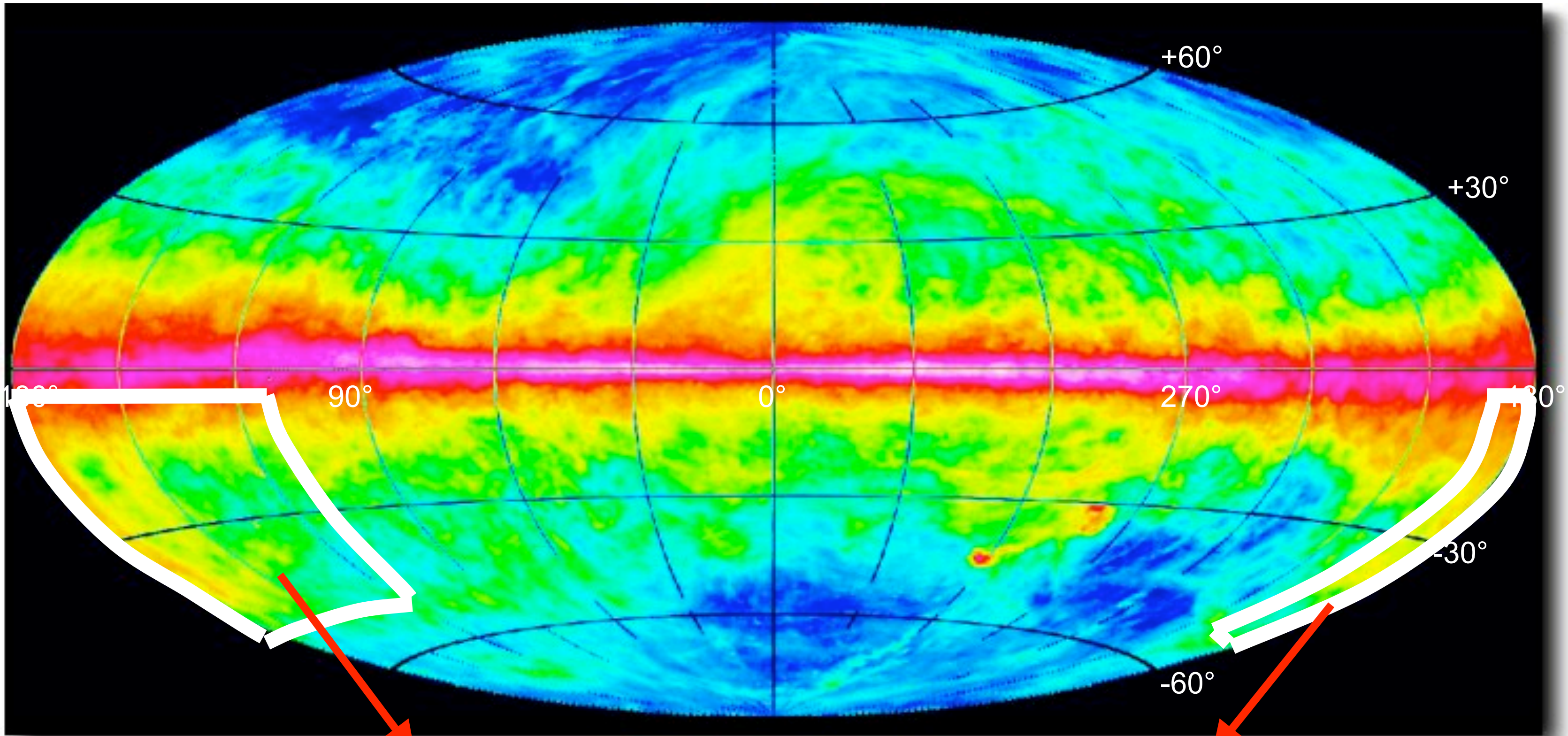
Observation along 166 longitudes in the Galactic plane. At each observed longitude three pointings will be observed in and above the plane at:

b = 0°

b = - 0.5° , -1 °, or

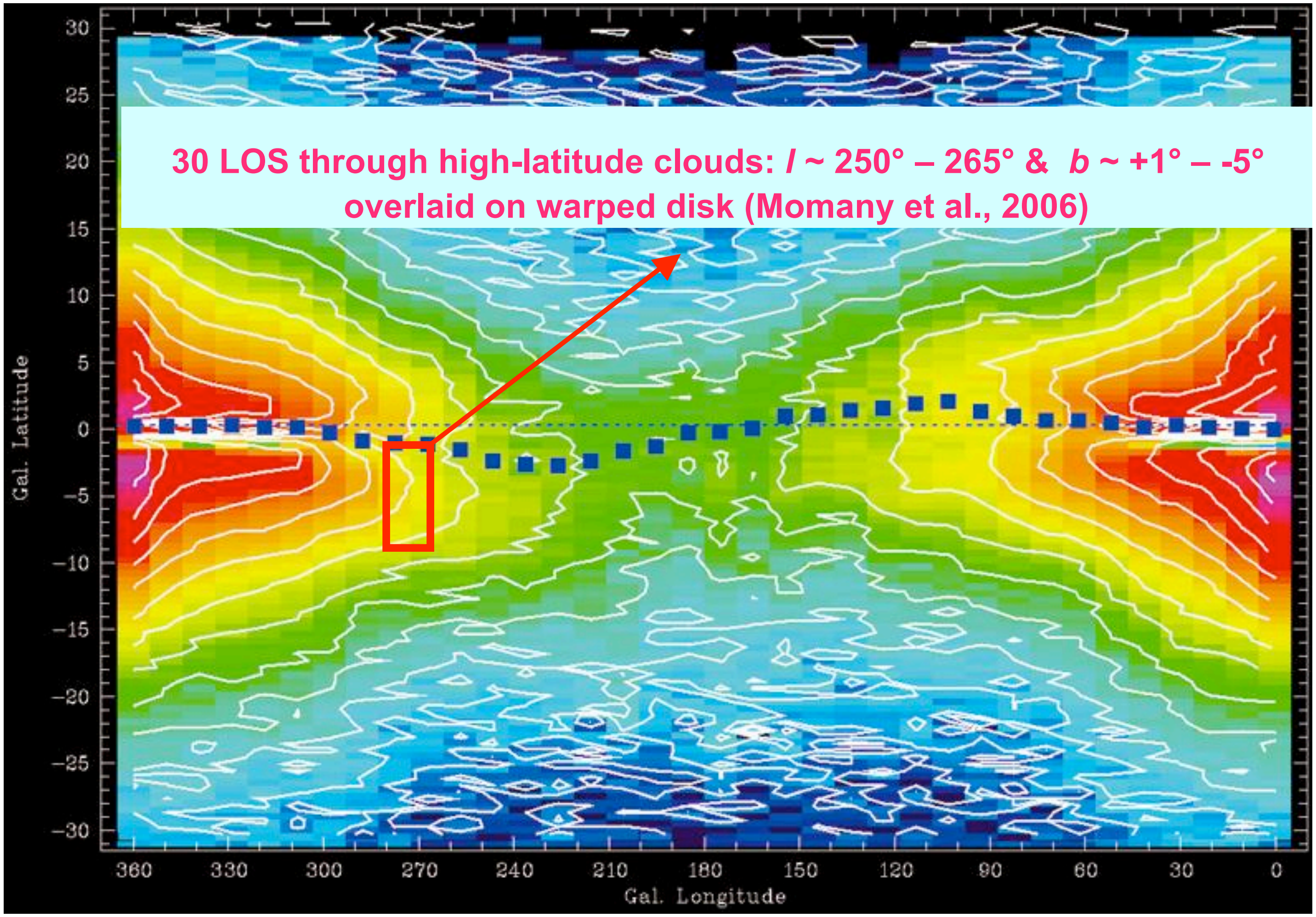
b = + 0.5 ° , +1 °

GOT C^+ Survey: High Altitude Galactic HI absorption sources

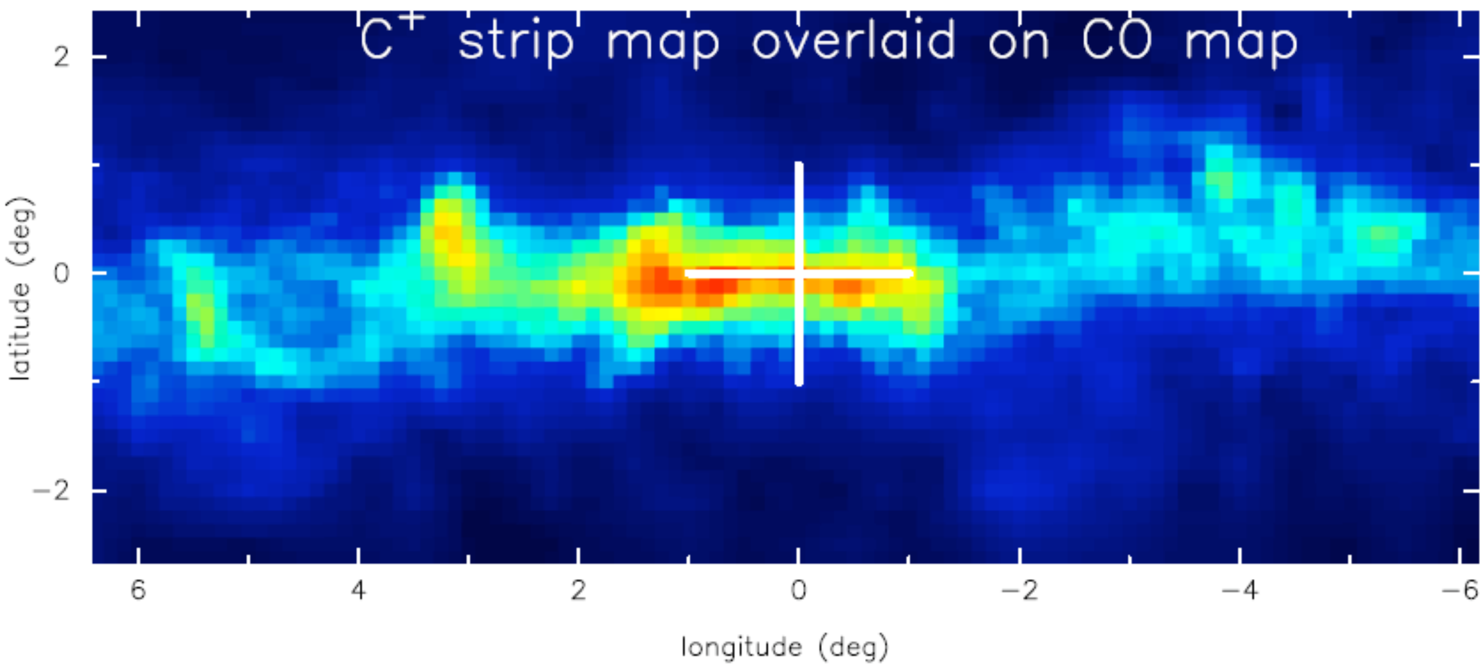


27 LOS through Heiles & Troland HI absorption clouds towards extragalactic objects in
l = 118° to 190° & *b* = -9° to -52°
shown on HI map of the Galaxy, will provide information about a sample of high-latitude clouds

GOT C$^+$ Survey: Outer Galactic Warp Region



Strip maps of Central 300pc of Galaxy



- Region of strongest CII emission
  - –Observe about 360 LOS in strip maps (using OTF mapping mode)
  - –Bright CII emission from the GC itself may also be observed
  - –in absorption by foreground cooler CII clouds

Data Product

Science and Data Outputs (1/2)

- GOT C^+ will provide the community with a 3-D data cube sampling of CII 158 micron emission
  - ~900 spectral scans, each with 4080 channels
- Extracted C^+ spectra in 1000 - 3000 representative clouds throughout the Galaxy
  - Enabled by the high spectral (e.g. velocity) resolution of HIFI to separate components along each LOS
- Catalog of diffuse and transition clouds
  - Position and V_{lsr}
  - Distance using Galactic rotation curve
  - CII emission Peak antenna temperature
  - ΔV (km/s)
  - Integrated intensity
- Statistically significant representation of ISM conditions throughout the Galactic disk and at selected high latitude positions.

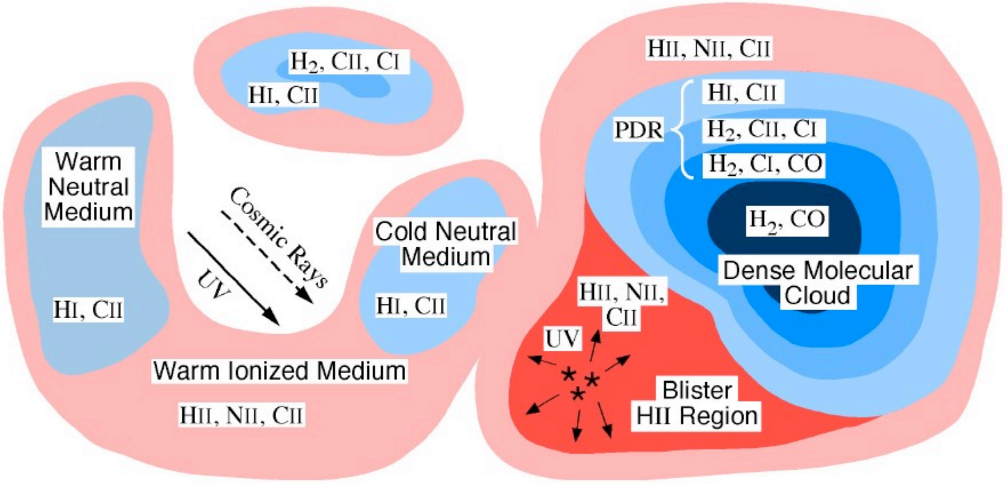
Science and Data Outputs (2/2)

- Characterize ISM in the disk
  - Combine CII with other data (e.g. HI, CI, CO, H_2, and, where it is meaningful far-IR continuum)
  - Use excitation and cloud models to derive physical parameters (density, temperature, fractional abundance, radiation field) characterize clouds and PDRs
- These products will help assess the variation of ISM properties as a function of local energy and dynamical conditions

Supporting Observations

Supporting Observations

- Diffuse Atomic Clouds
  – HI 21 cm
  – CI fine structure lines at 492 and 809 GHz
- Diffuse Molecular Clouds
  – HI 21cm
  – CI (492 and 809 GHz)
  – CO J=1-0
- PDRs
  – CI
  – CO (and ^{13}CO) J=1-0, 2-1, and high J transitions
  – Dust emission
- Intercloud medium (warm ISM)
  – NII fine structure line 1.45 THz
  – OI fine structure line 2.06 THz



Observatory and Archive Data

- HI
  - DRAO Survey/ VLA?/ AT?
  - Heiles & Troland (2003) Arecibo absorption line survey
  - Blitz Studies
- CI
  - APEX or NANTEN2
  - ASTRO
  - SOFIA
  - HSO
- CO low J
  - FCRAO survey, U of A ARO
  - MOPRA 20m (Australia) - Survey of southern hemisphere
- CO high J
  - NANTEN2
  - HSO
  - SOFIA
- NII
  - HSO
  - SOFIA ??
- OI
  - SOFIA ??

Comparison to Models

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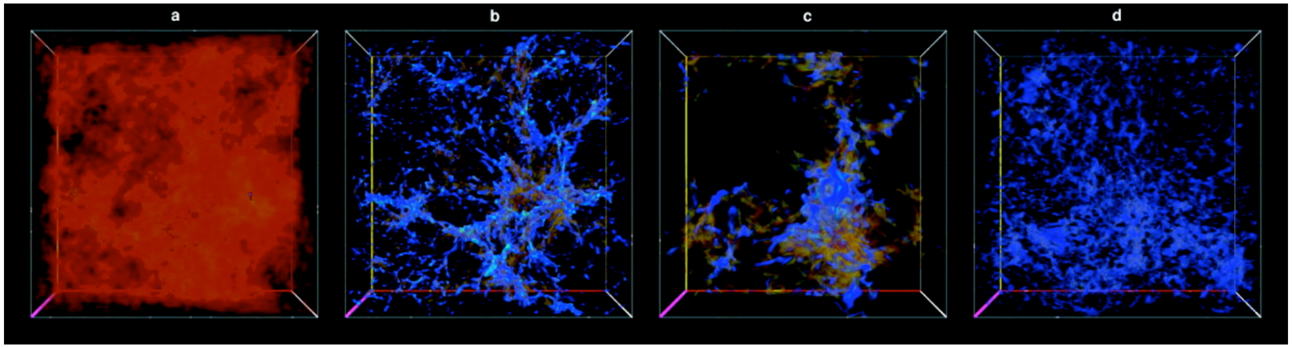

Thermal instability induced interstellar turbulence - dynamics of phase transitions in the ISM using realistic cooling and heating (Kritsuk & Norman 2002). At t = 0, n = 1 cm^{-3}, T = 7000K.

- Diffuse cloud conditions as a function of local environment
- PDR properties
- Thermal pressure of atomic gas (in conjunction with HI)
- Turbulent pressure of H_2 diffuse clouds from ΔV
- Large scale distribution of diffuse gas and PDRs in the ISM
- Dynamics of cloud formation

Summary

Summary

- GOT C^+ is a sparse sampling of Galactic C^+ fine-structure line emission at 158 microns covering the Galactic disk, central region, and various HI clouds of interest
- It will provide the astronomical community with a statistical data base with which to characterize the diffuse ISM and PDRs on a uniform volume sample
- This data will be important to understand the state of the atomic diffuse ISM clouds and their transition to the diffuse molecular, and ultimately, dense molecular clouds