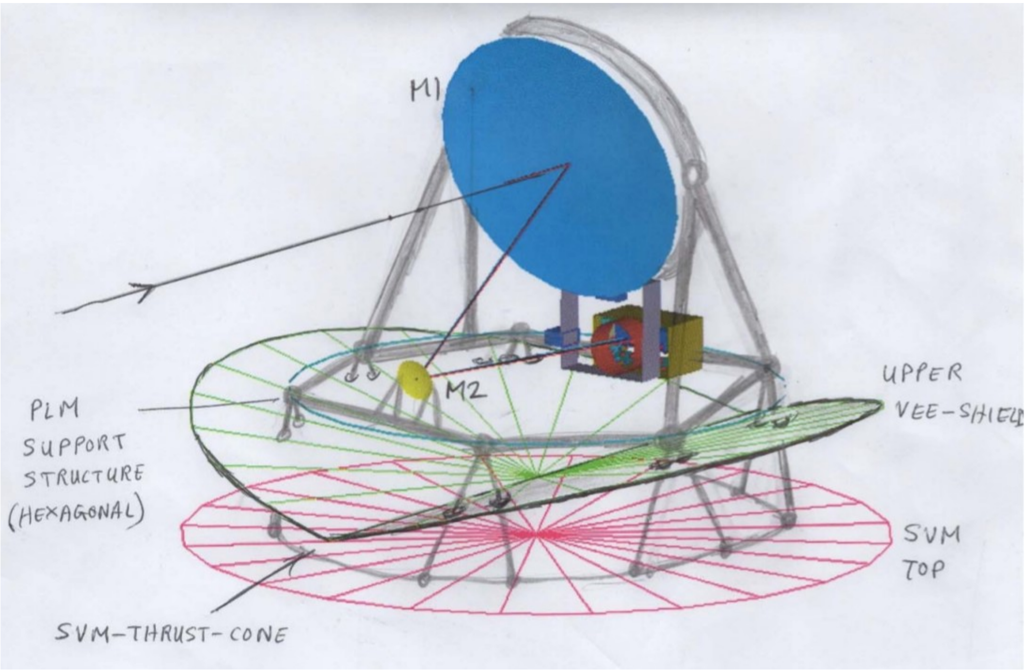
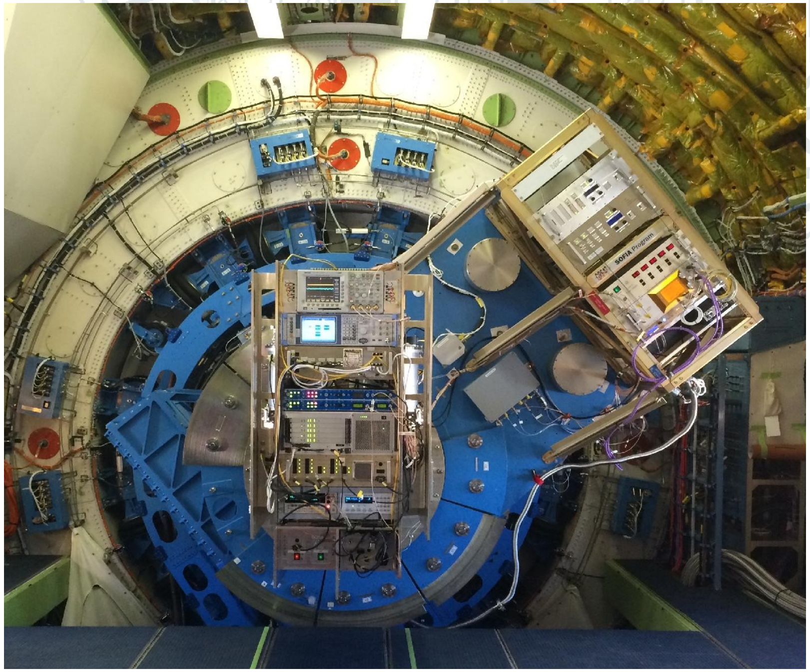
FIRSPEX and GREAT
The perfect couple





Volker Ossenkopf-Okada

FIRSPEX - Mission profile

Large-scale 3-D mapping of the Milky Way and Nearby Galaxies

Extend the HiGal survey into the third dimension (Molinari et al. 2016)

Channels: **[CII]** 158 µm, **[NII]** 205µm, **[OI]** 63µm, **[CI]** 370µm
Spectral resolution: ~10^6, spatial resolution: 0.8-2.4'

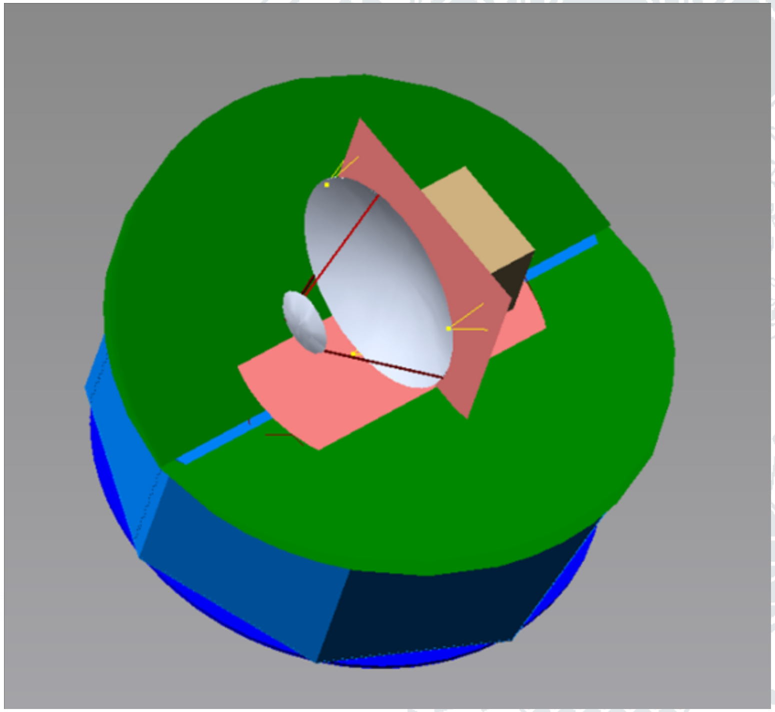
Science goals: "Decompose Galaxies" - tracing the phases of the ISM

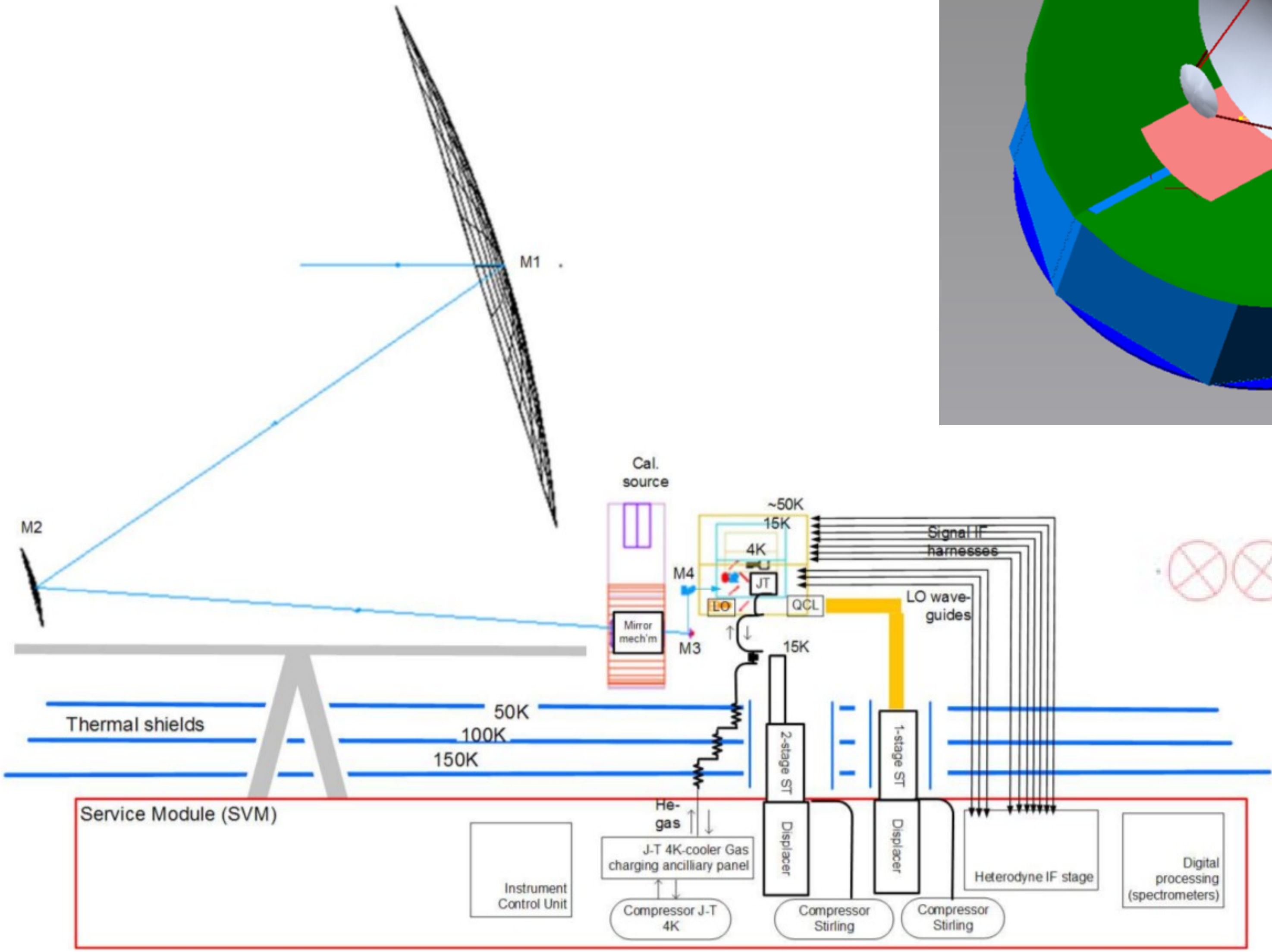
- Global census of atomic, ionic, and molecular material
- Feeding the MW ISM by material above the Galactic plane
- Follow assembly of clouds in the Milky Way
- Delineate the transition of atomic to molecular clouds
- Distribution of fundamental elements: C, N, O
- Characterize environment of nearby galaxies

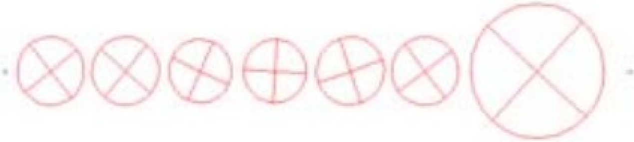
Mission design

Scan large field by scanning satellite

- 7 pixels simultaneously



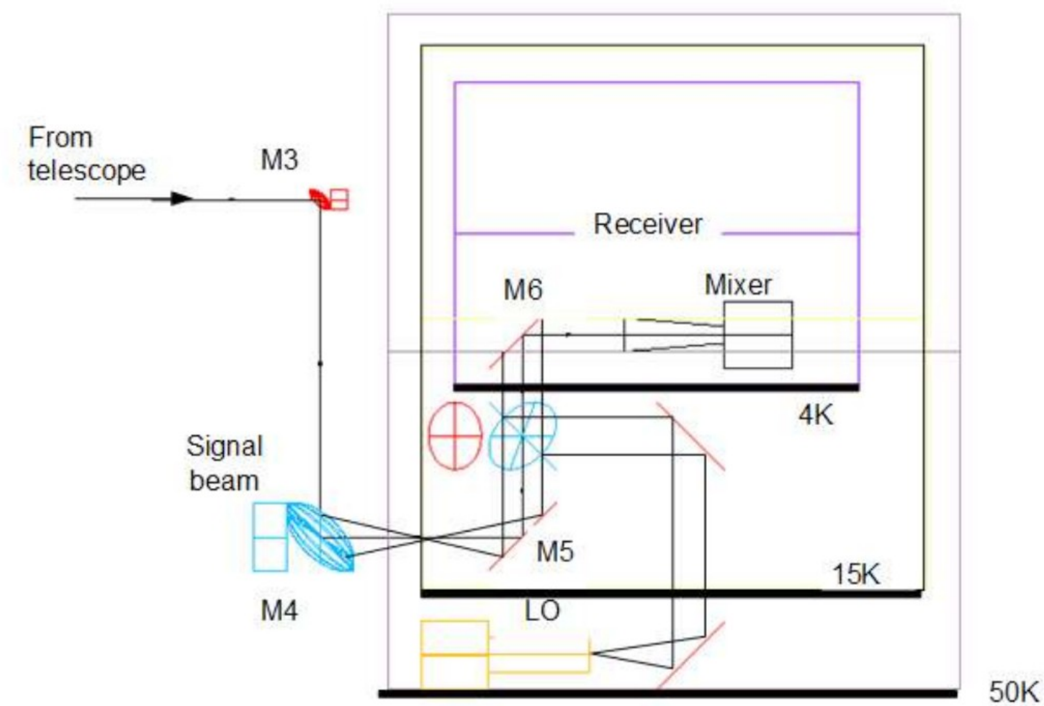




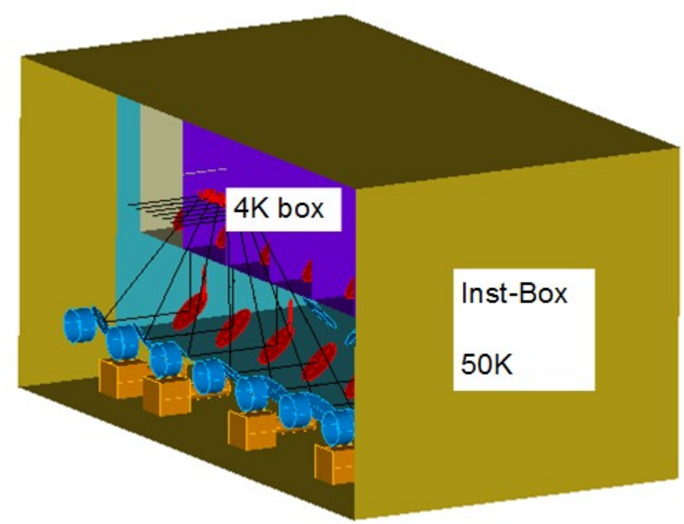
Focal-plane geometry (3σ waists)

Technical design

- 120cm telescope
  - passively cooled (Airbus)
- J-T and Stirling coolers to 4K for receivers
- HEBs (SIS for 809GHz)
- FFT backends

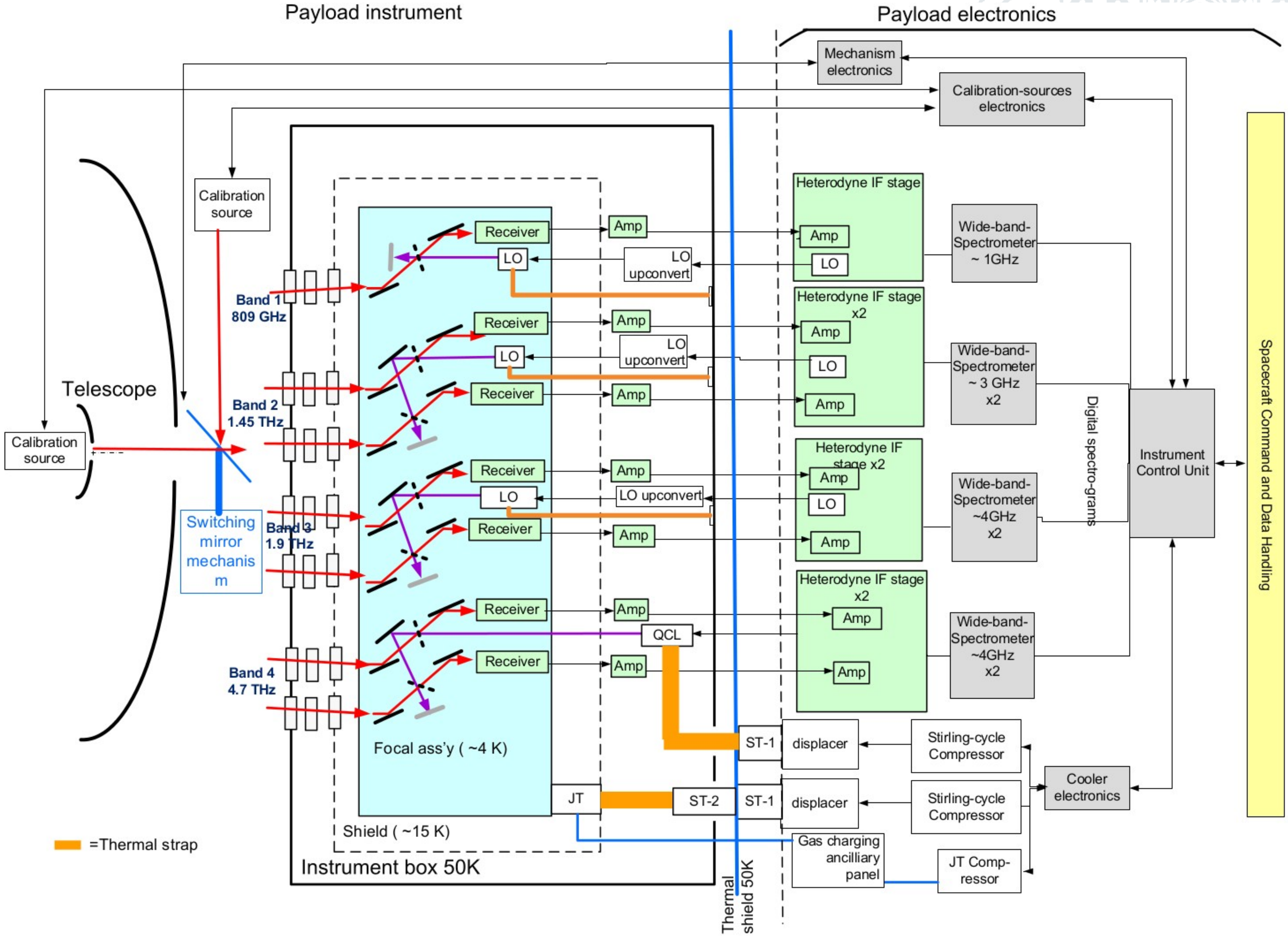


Mixer optics design



Follows HIFI FPU, but simultaneous operation of all pixels

Technical design

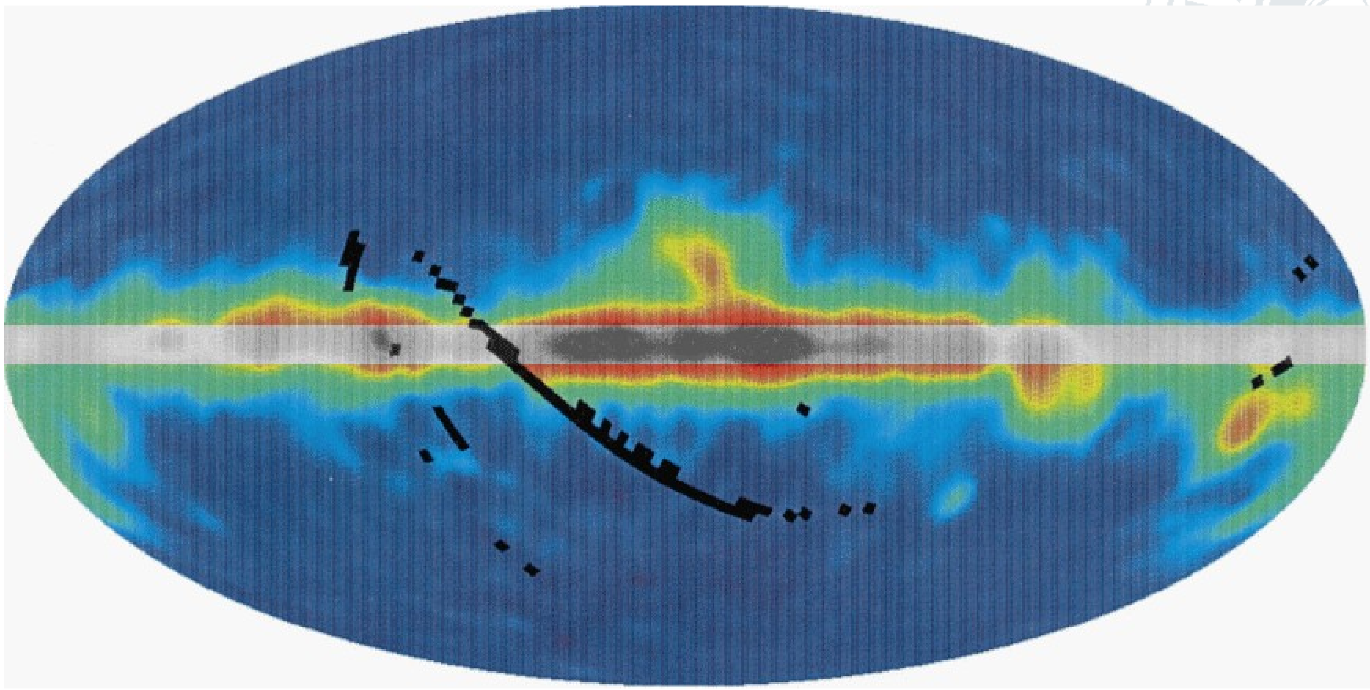


Major heritage from Herschel/HIFI and SOFIA/GREAT

Three Main Science projects

1) Galactic plane survey

Spectroscopic equivalent to Herschel continuum survey of Galactic Plane



Comparison with the all-sky [CII] intensity from COBE on a 5' resolution (Fixsen et al. 1999)

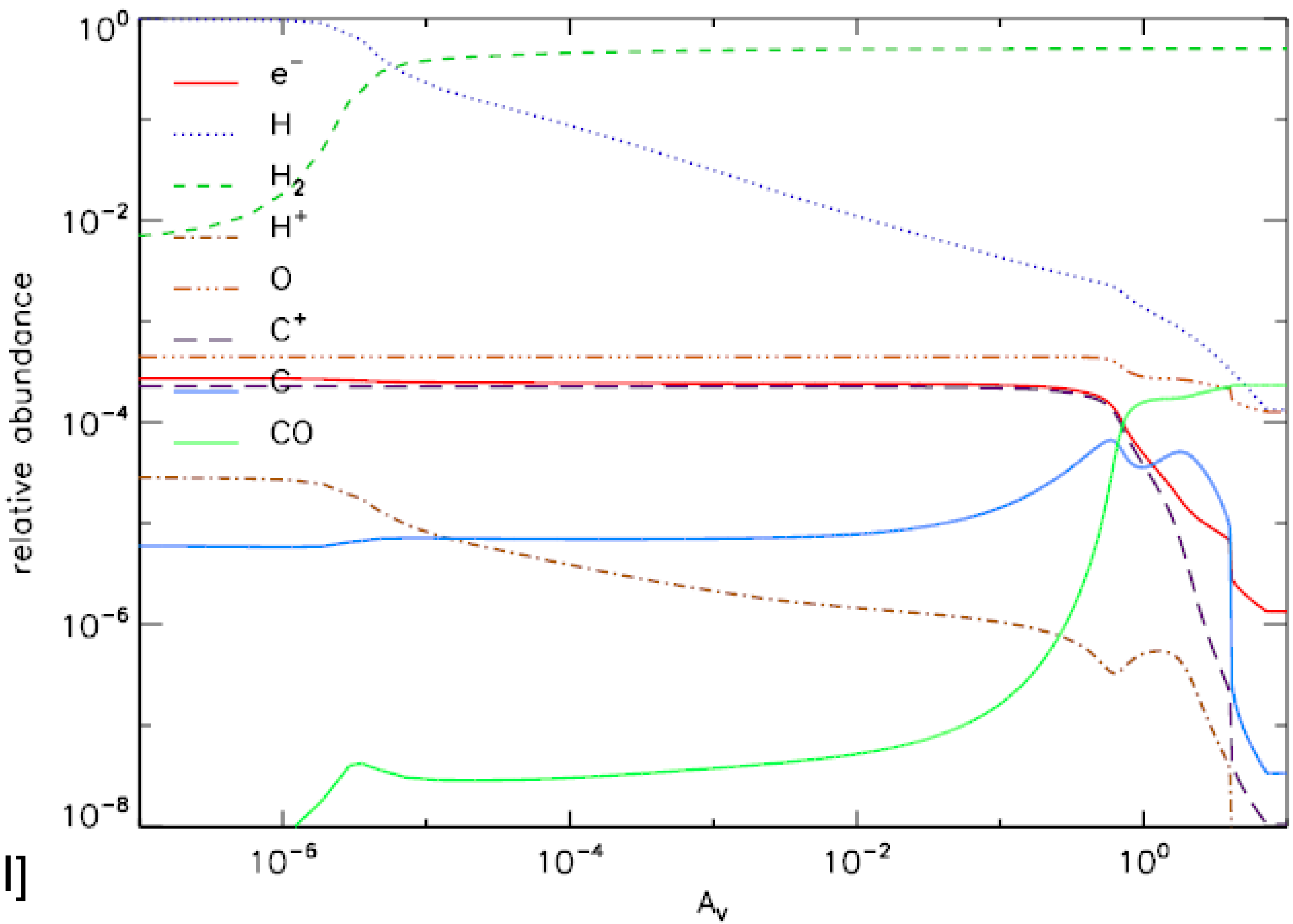
- 360° x 10° = 9% of the sky
  - $3600°^2/0.86'^2 = 1.752\ 10^7$ points on the sky
  - 2 years: 2(4 for 2 pixel channels) coverages of 1.6s per 0.86' beam
  - Periodic reference to large angle beam
  - Data rate: 123kbit/s

FIRSPEX target

- Widely distributed gas
  - Not (yet) forming molecular clouds
  - Feeding
    - Molecular clouds
    - Galactic disk
    - Turbulence in the ISM
  - Follow assembly of clouds in the Milky Way
    - Delineate the transition of atomic to molecular clouds
- Heated gas around young (massive) stars
  - Global star formation tracer
- Distribution of elements in Milky Way ISM

CO dark gas:

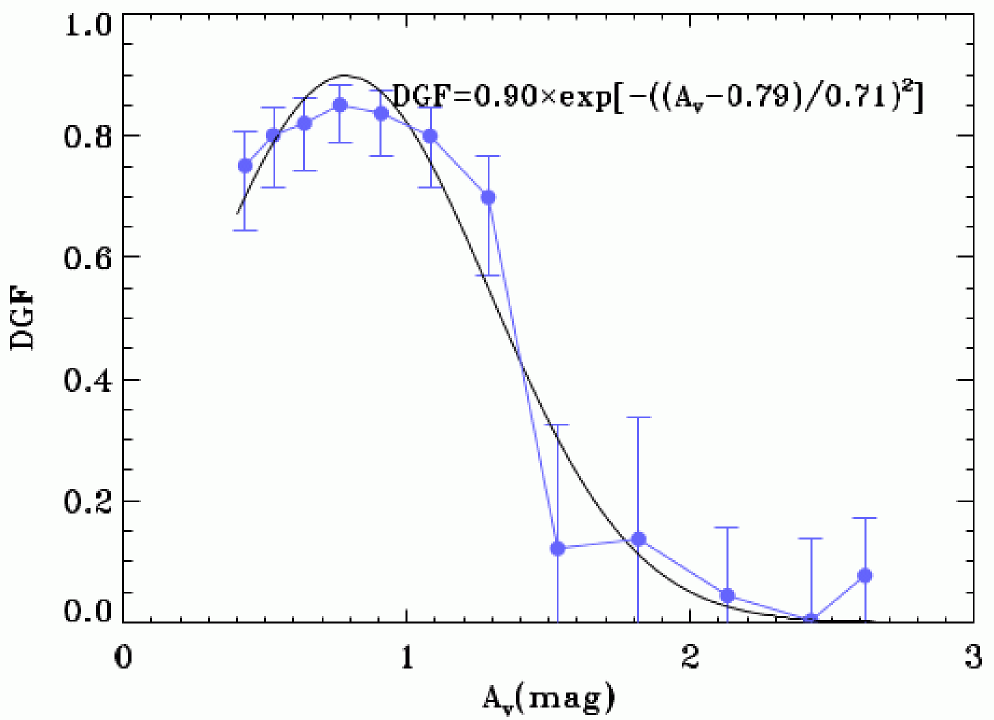
- PDR model for $\chi=1$, $n=10^3$ cm^{-3}:

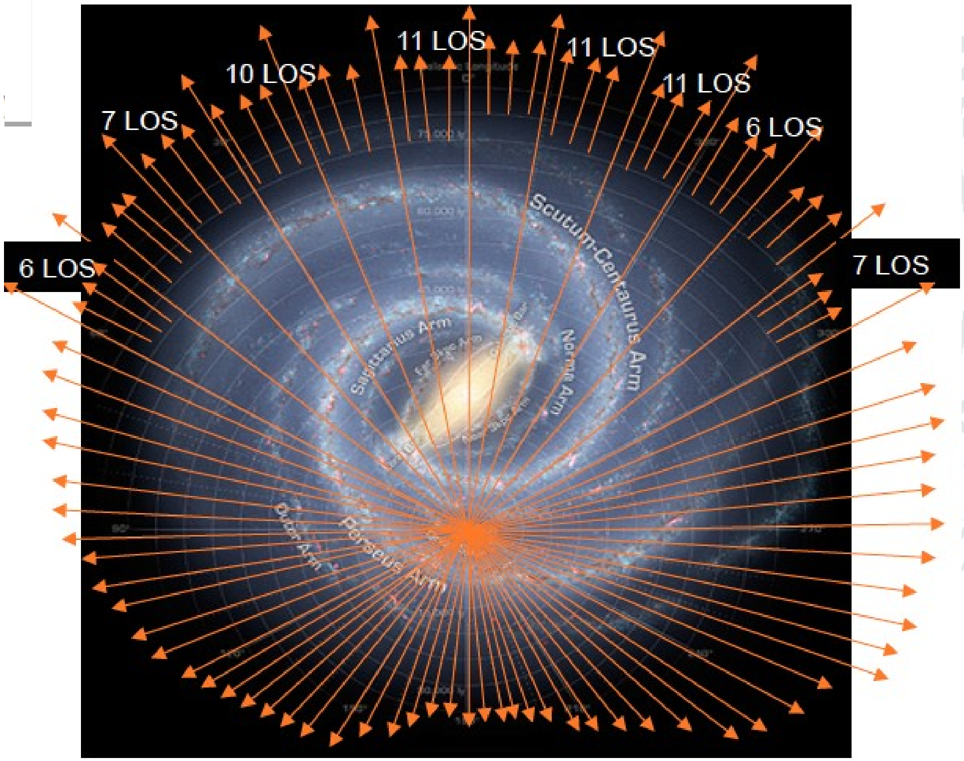


- Large fraction of H_2 not traced by CO
- Visible in [CII] and [CI]
- No other abundant tracer
- [OI] throughout the whole cloud → temperature and density tracer

Fraction of material

- In Galactic Plane (GOTC+, Pineda, Langer et al. 2010, 2013, 2014)
  - 20-75%
  - Highest fraction in diffuse clouds
- Across molecular cloud boundaries:
  - Up to 80% (Xu 2016)

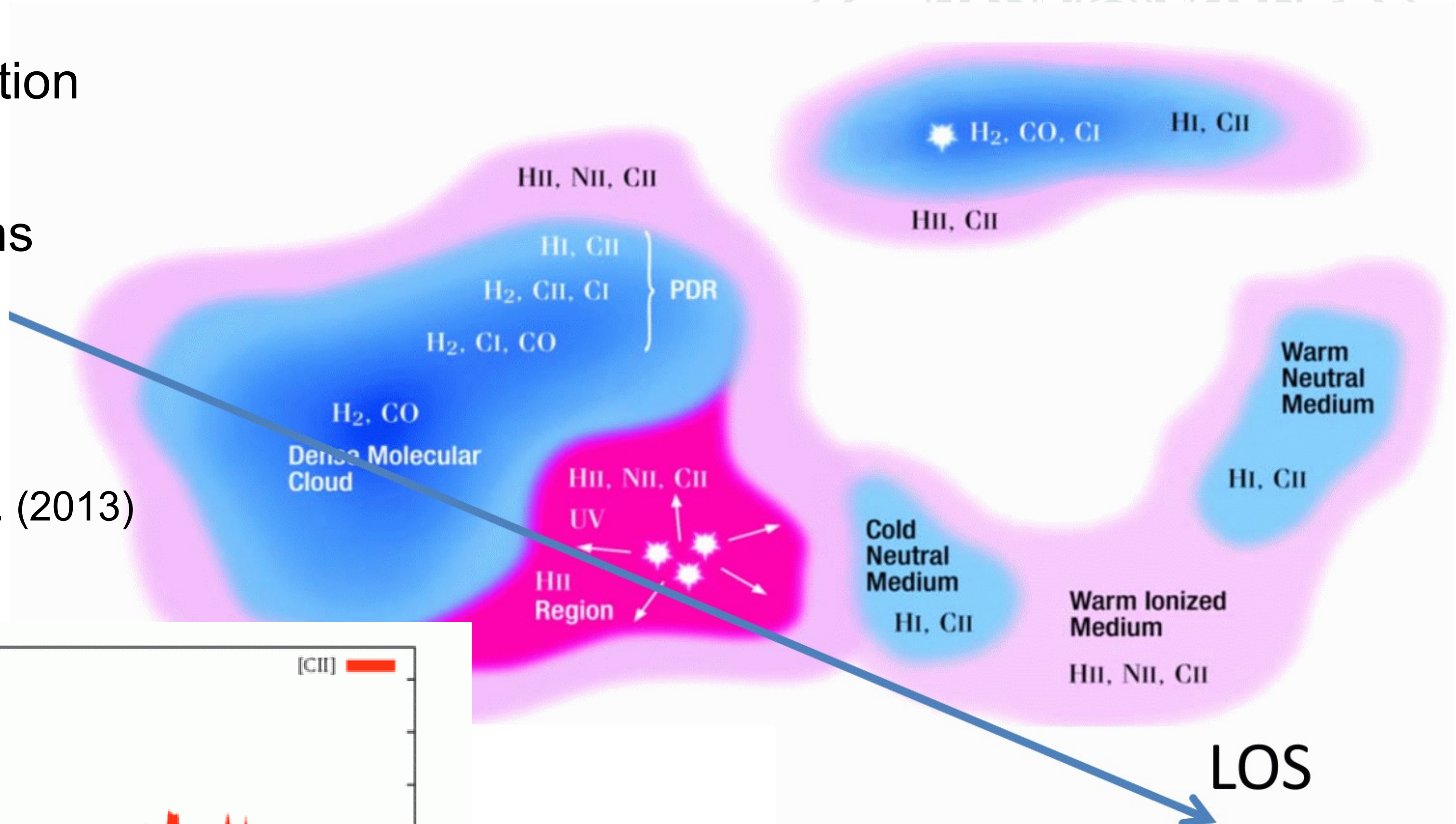




- Not much information yet for $b\neq0$
- Fraction certainly higher
- We may still miss the majority of the interstellar gas today!

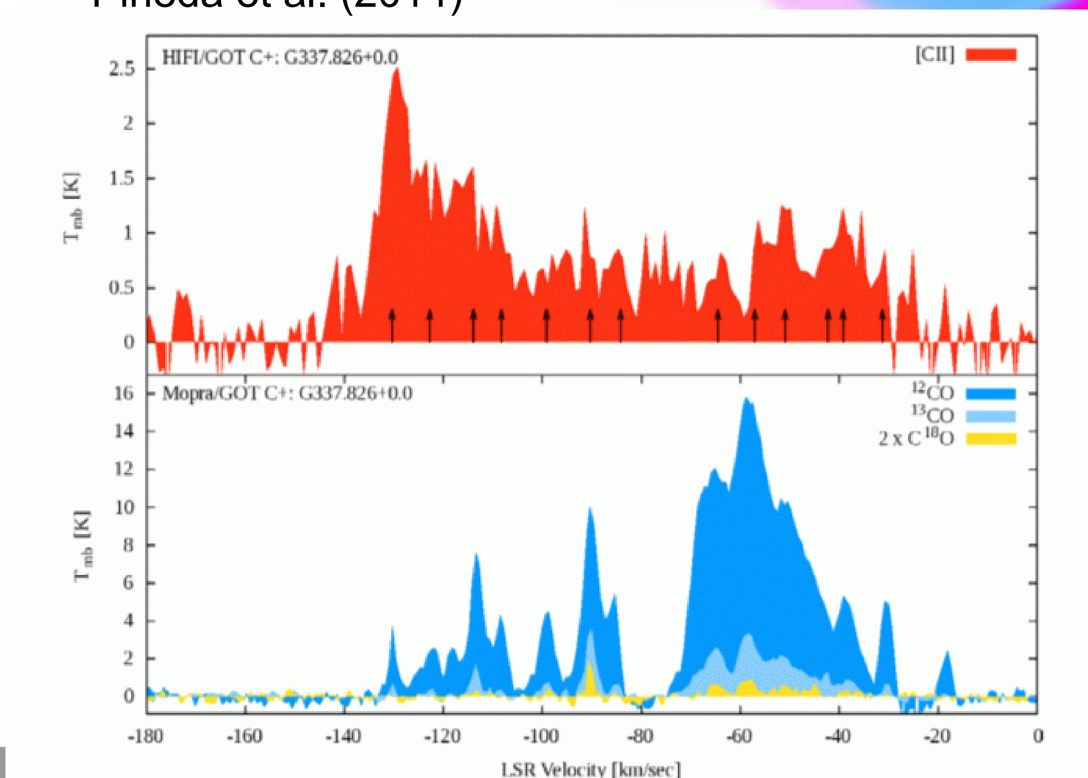
Probing the different phases

- Complex configuration
- Mixture of phases including HII regions
- Separated in velocity space



Velusamy et al. (2013)

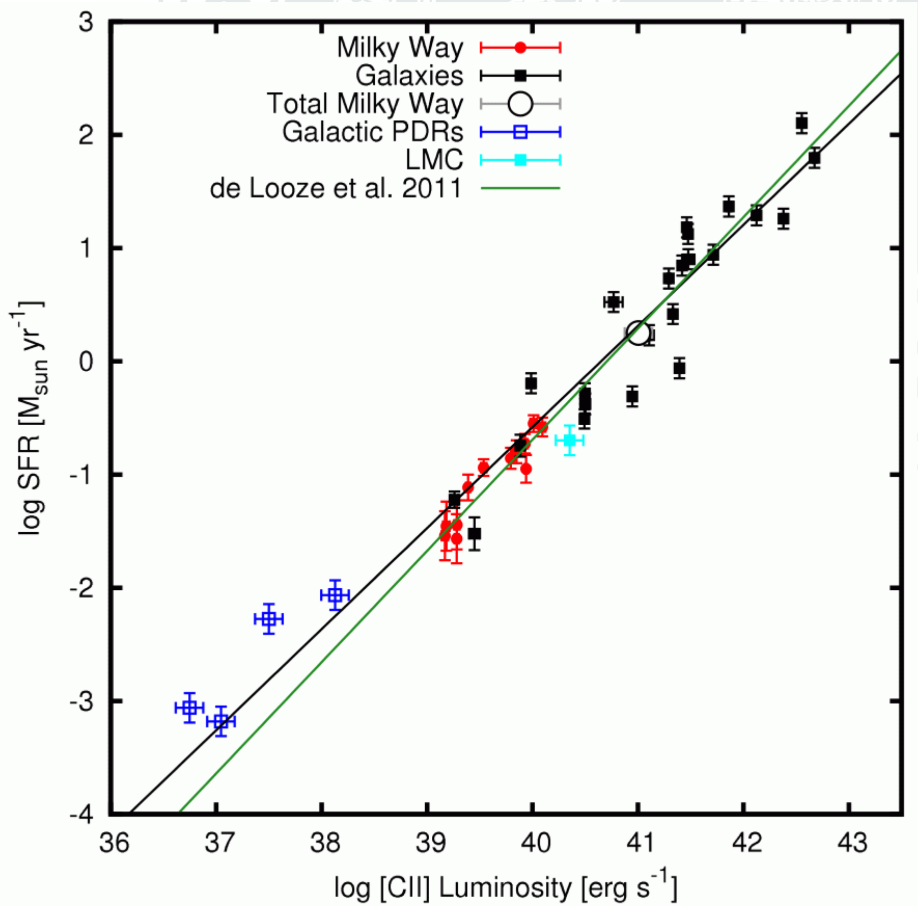
Pineda et al. (2014)



- [CII] from HII regions, CNM, PDRs
- [NII] from HII regions, little from WIM
- [OI] for hot dense gas
- [CI] for part of CO-dark gas
- Complementary HI and CO surveys
  - needs data at same vel. resolution

[CII] as a star-formation tracer

- C^+ in dense medium mainly produced and excited from FUV radiation
  - Highest efficiency: B stars
  - Therefore SF tracer for last 10Mio a
- But: Efficiency varying by factor > 100
  - FIR line deficit
- Many lines self-absorbed:
  - Spectral resolution is the key!
    - Explanation of FIR line deficit needs resolved lines



Pineda et al. (2014)

Science questions

- Mass assembly of molecular clouds
  - Accretion of high-latitude material onto the Milky Way, feeding the clouds
  - Galactic scale statistics on the CO-dark molecular gas
  - Verification of transition time scales by direct observation of velocity structures
- Main driver of turbulent flows in the ISM
  - Mass accretion as a feed of turbulent motions
  - Deconvolution of the effect of Galactic shear
  - Quantify SN driving
- Role of stellar feedback on the Galactic scale
  - Calibrate [CII] as a star-formation tracer
  - Contributions of different phases to Galactic emission of [OI], [NII], [CII]
  - Role of PDRs in the total line cooling of a galaxy
- Large scale structure of the Galaxy
  - Metallicity gradient
  - 3-D distribution of the different phases

Performance from 2 years Milky Way survey:

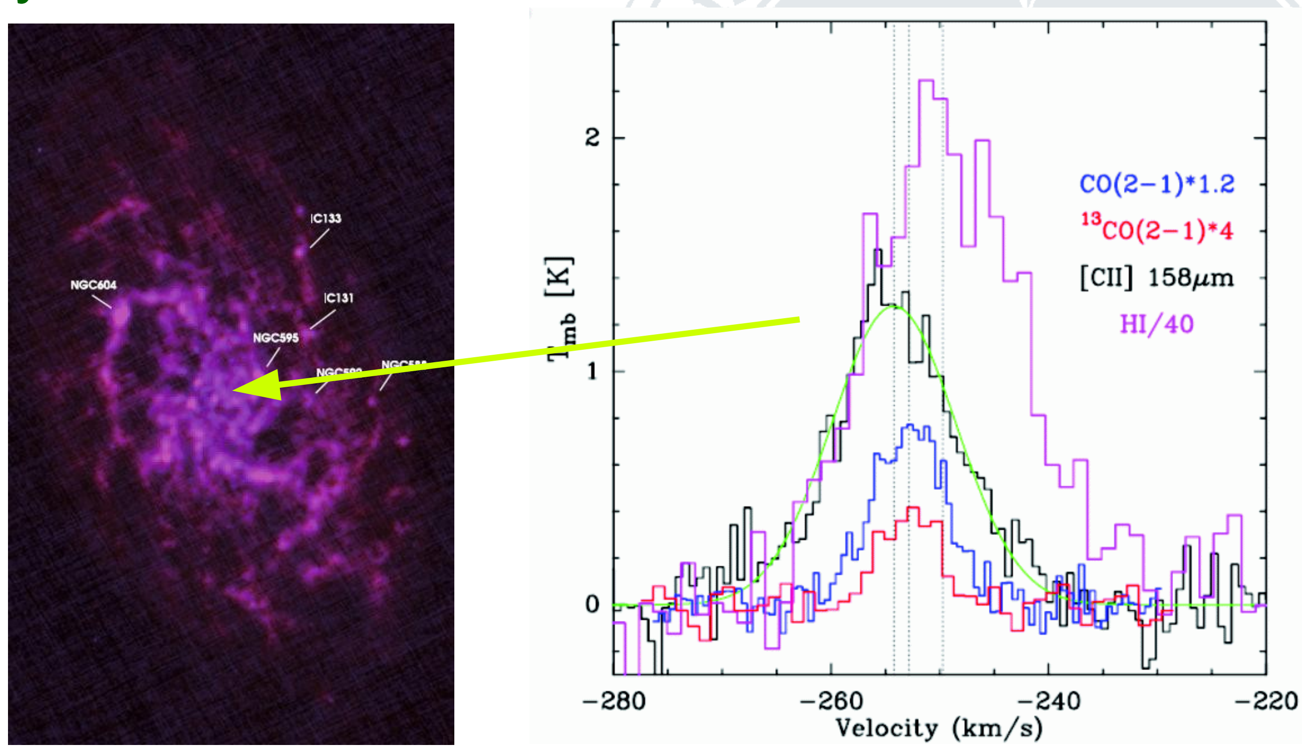
	CI	NII	CII	OI
Line frequency [GHz]	809.3	1461.3	1900.5	4745.8
System temperature (DSB) [K]	180	350	400	500
Bandwidth for 0.3km/s [MHz]	0.8	1.4	1.9	4.7
Beam width [arcmin]	1.71	0.86	0.86	0.8
Noise T_{mb} (for long ref., η=0.79) [K]				
$\Delta v = 0.3$ km/s, $t_{int} = 3.2$s, $\theta = \theta_{native}$	0.14	0.29	0.29	0.23
$\Delta v = 0.8$ km/s, $t_{int} = 3.2$s, $\theta = 2.4'$	0.061	0.064	0.064	0.047

Averaging over larger area needed for [^{13}CII]

2) Nearby Galaxy Survey

S. Viti & C. Kramer

M33 (Kramer et al. 2010, Mookerjea et al. 2013)

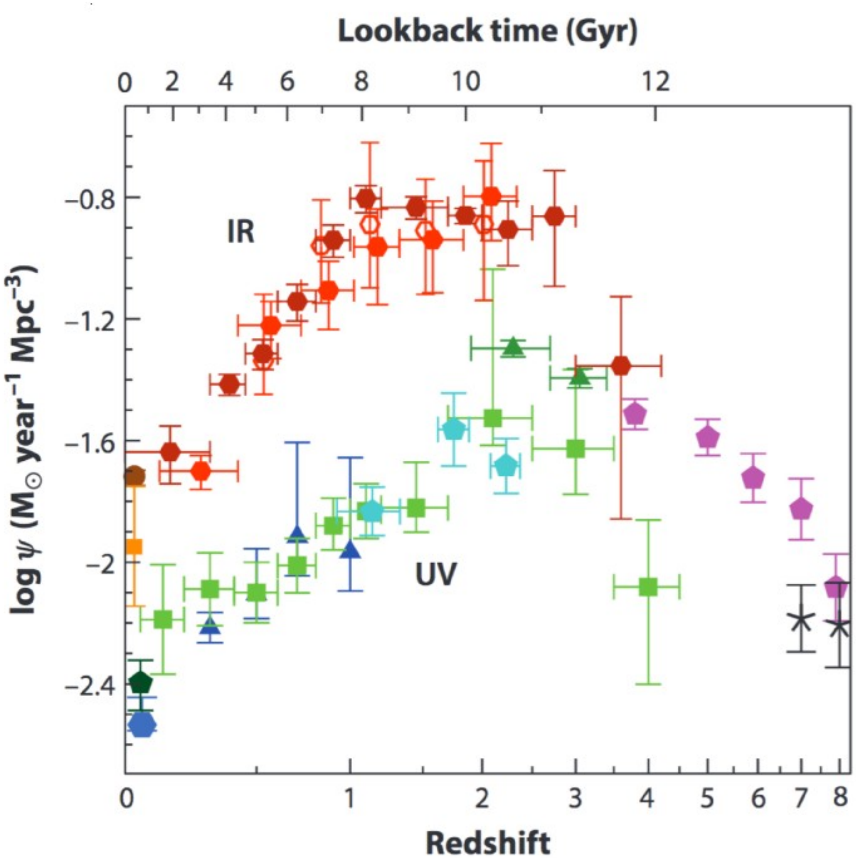


- Quantify the amount of each phase of the ISM in a range of galaxies.
- Obtain the mass and characteristics of the gas contained within each component for different type of galaxies.
- Determine how the contributions of each ISM phase differs across types and as function of environment.
- Deduce how these properties affect Star Formation Rates.

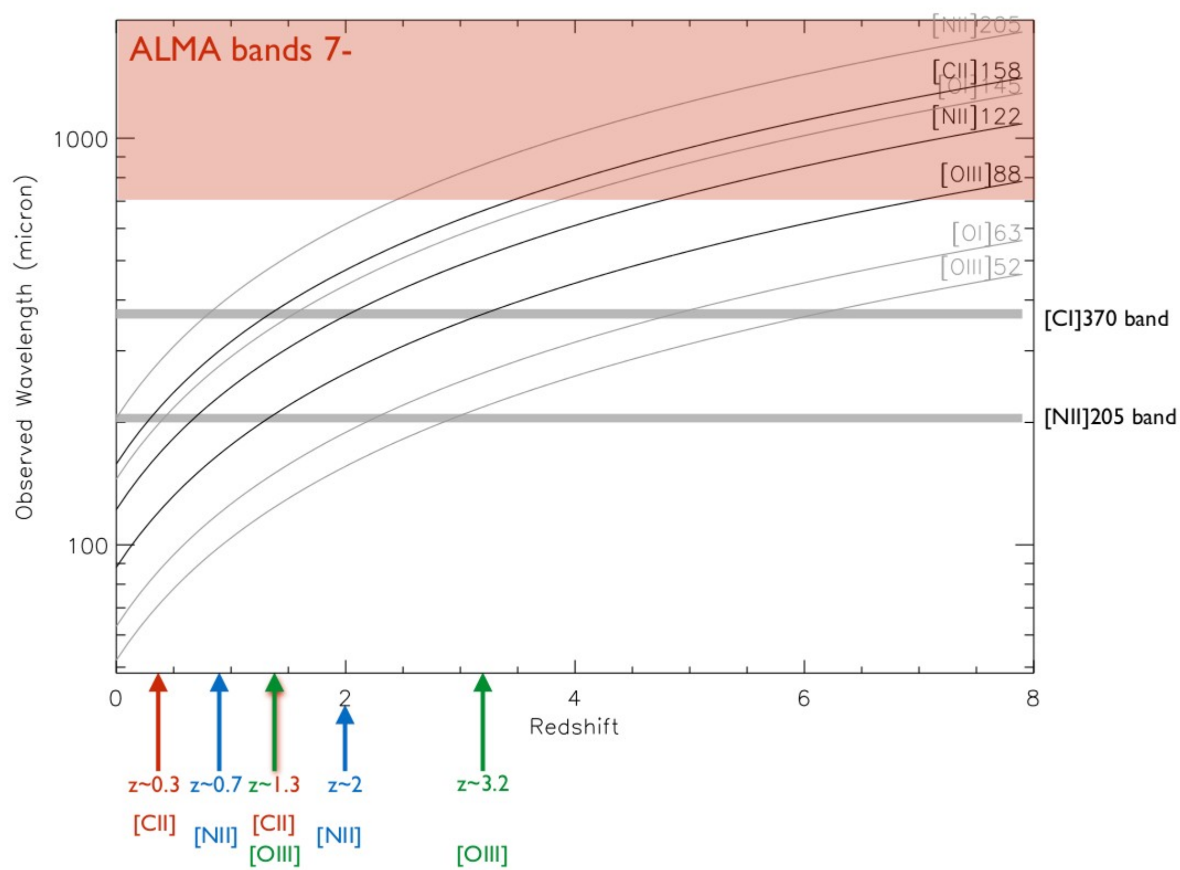
Three Main Science projects

3) The SF peak

Asanta Cooray, Julie Wardlow, & Carlotta Gruppioni

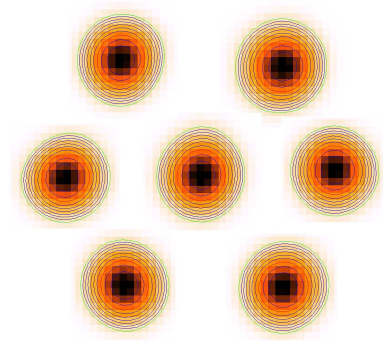


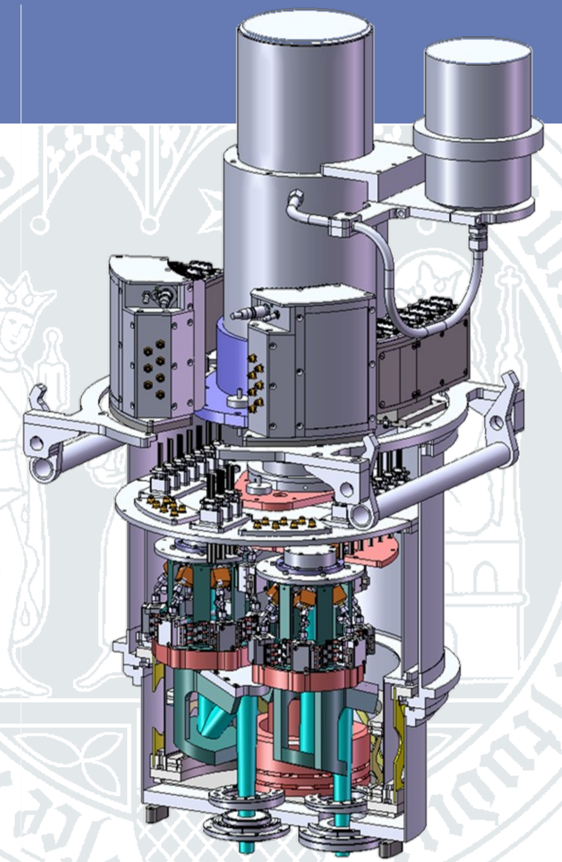
Madau & Dickinson (2014)



- 6 month survey
- Cover 32 GHz by multiple tunings
- 20-2000 detections expected - depending on line deficit at z = 2-3

Synergies with upGREAT





- FIRSPEX will identify all FSL sources in the Galaxy and nearby galaxies.
- Follow-up with upGREAT at 3x higher spatial resolution required to understand individual sources.
- FIRSPEX will identify ≈ 10^8 [CII] clouds
- Perfect data set for calibration and time estimates
- Same [CII] survey possible with upGREAT when blocking SOFIA for 8 years, all channels 35 years.

Supporters needed:

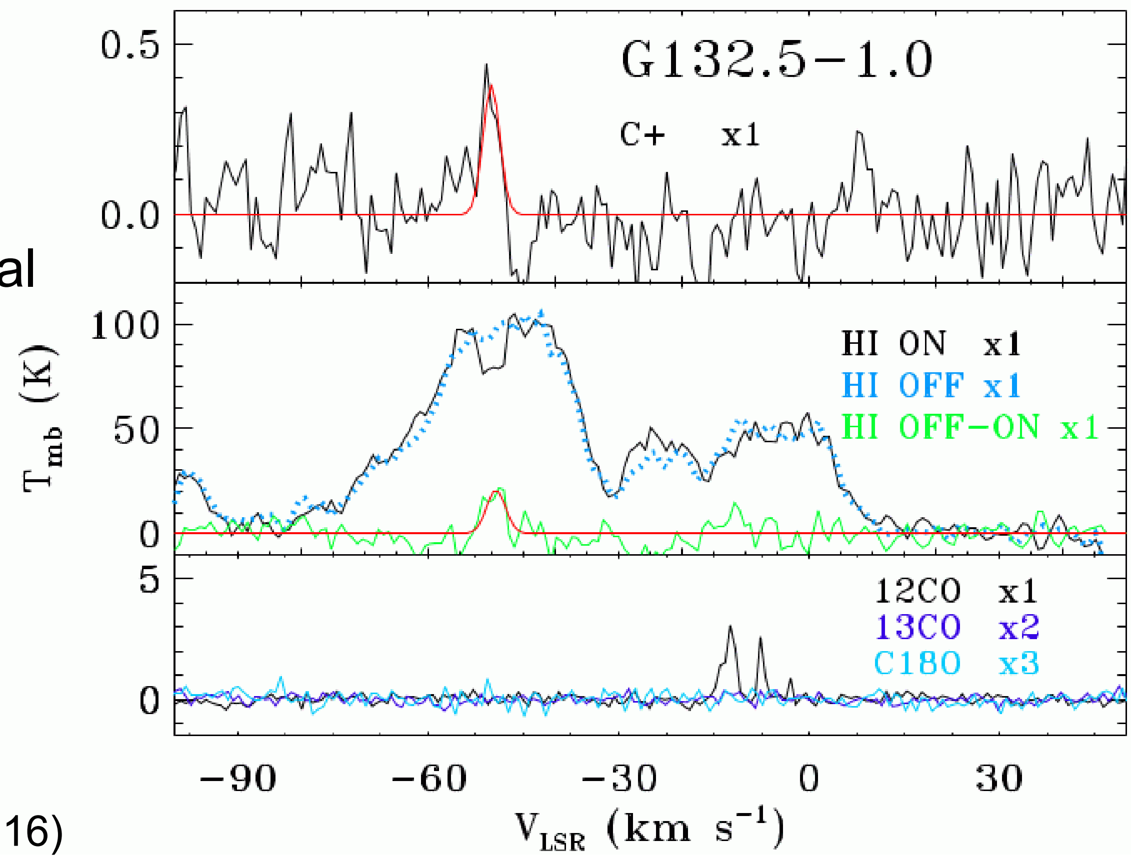
- Support the project at:

  http://futuremission.wixsite.com/firspex/support

- Deadline for M5 proposal: October 5, 2016
- Planned launch: 2029

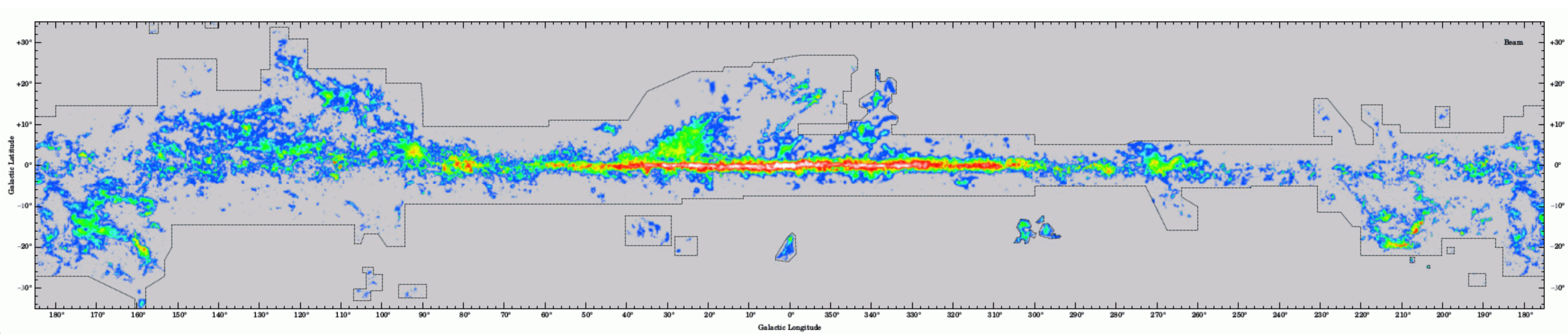
Probing the different phases

- Complementary data:
  - HI traces CNM and WNM
    - Only available at lower spatial resolution (11-16')
  - CO for molecular gas
    - Well covered
  - Dust for total column
    - Limited value



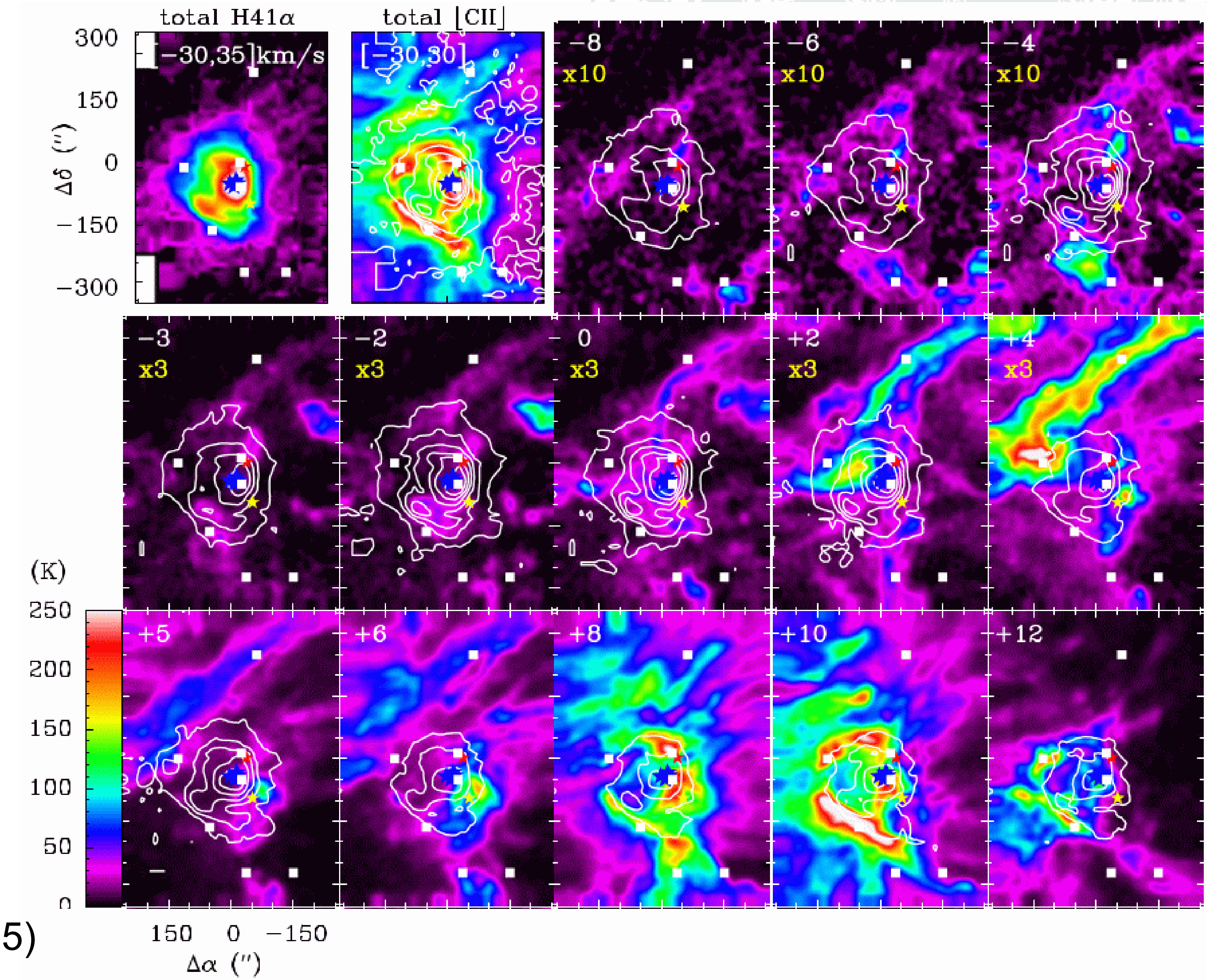
Tang et al. (2016)

Dame (2001)



How are molecular clouds assembled?

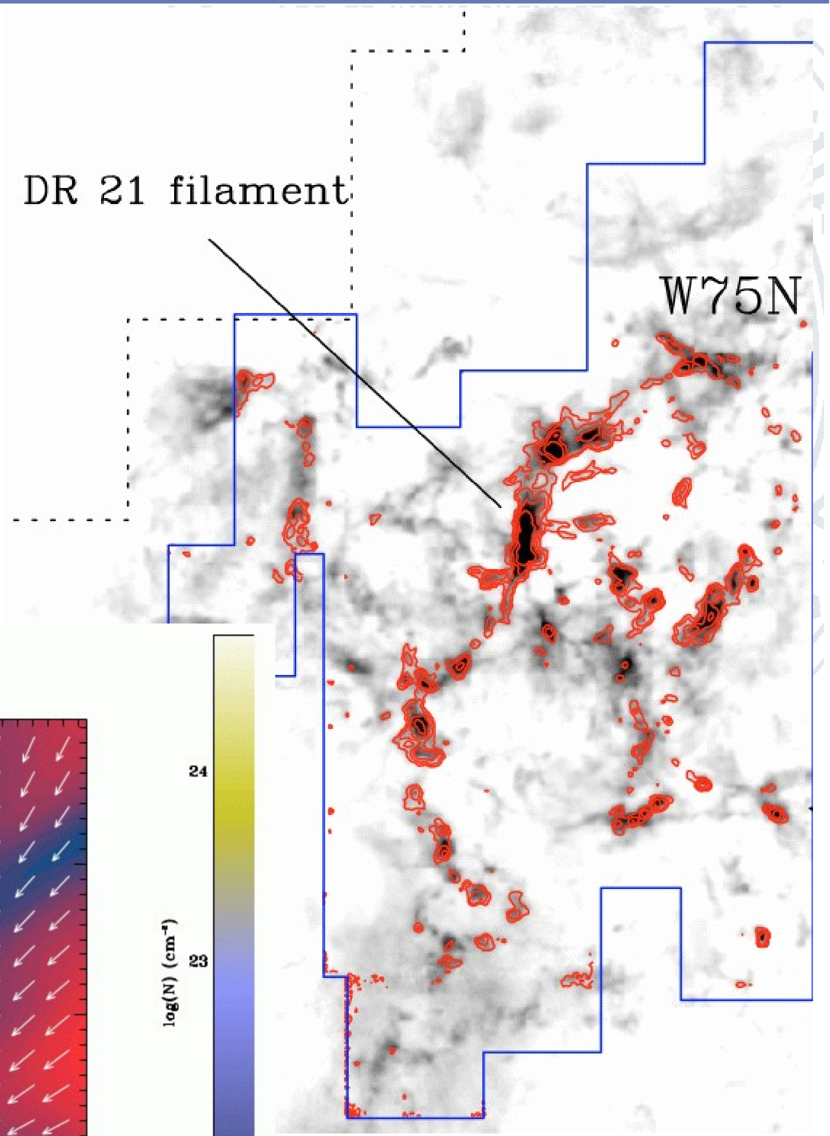
- Inflow as [CII] observed:
  - Orion A

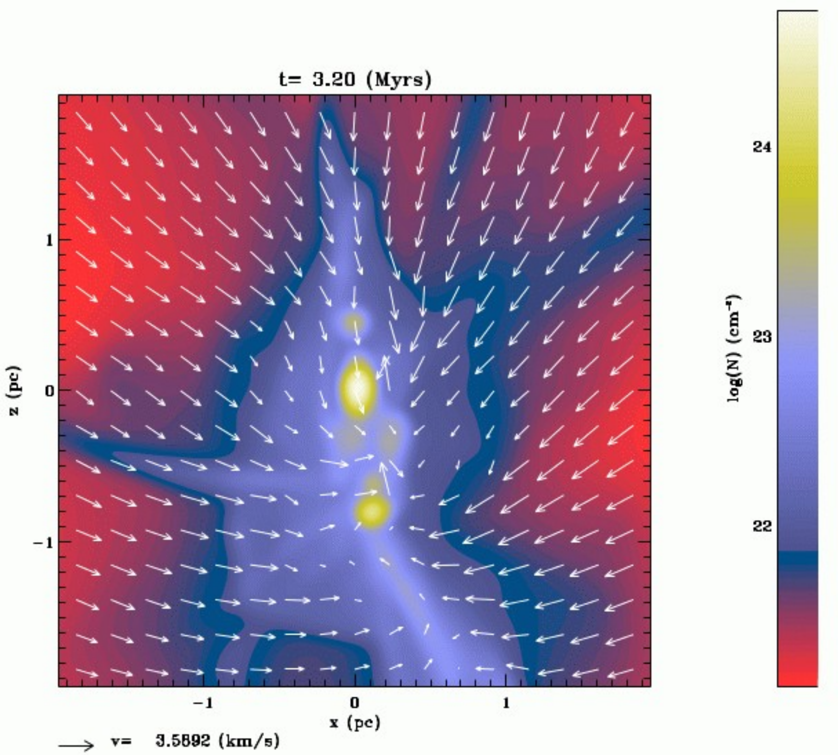


Goicoechea et al. (2015)

How are molecular clouds assembled?

- Inflow of material along filaments and spurs
  - Does the magnetic field direct the gas or does the gas assemble the magnetic field?
  - At which column density does the material turn molecular?
  - What is the infall velocity?
  - Does the infall create shocks?

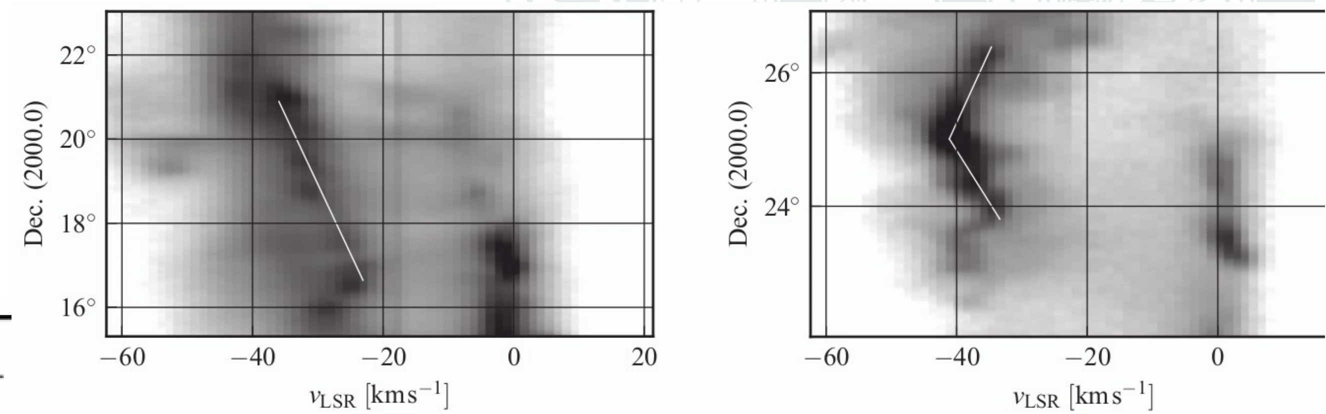


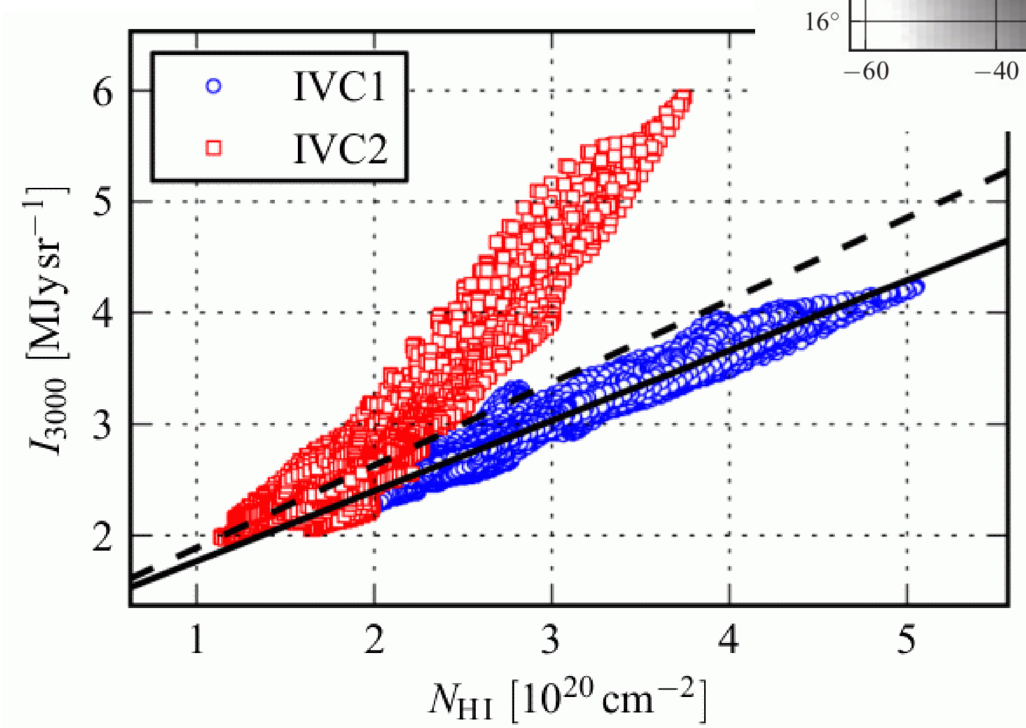


Schneider et al. (2010)

How are is the Milky Way ISM assembled?

- Disk ISM fed by infall of high- and intermediate velocity clouds
  - Ejected material?
  - Intergalactic material?
  - Dwarfs?



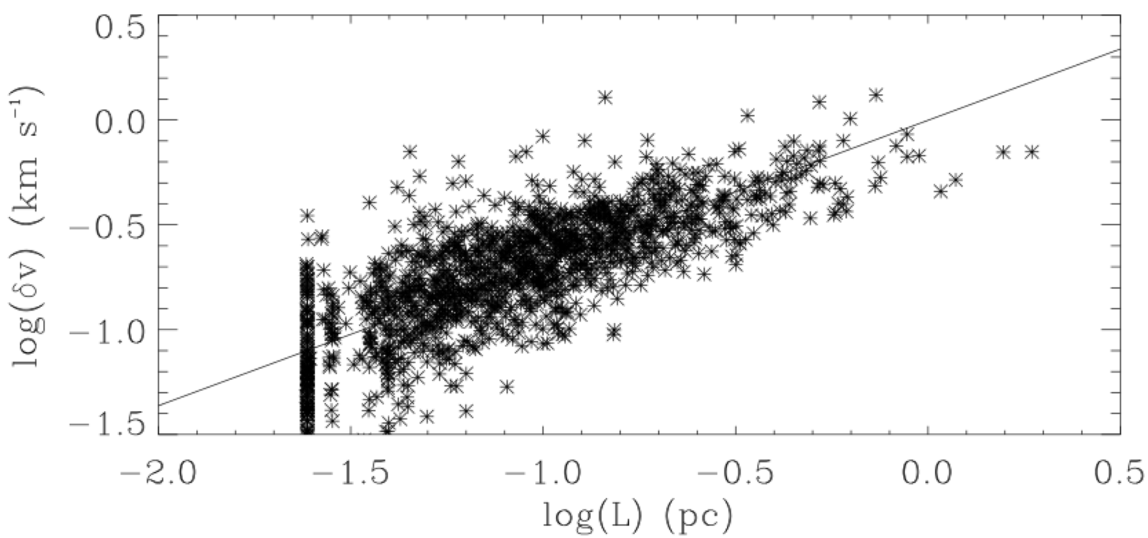


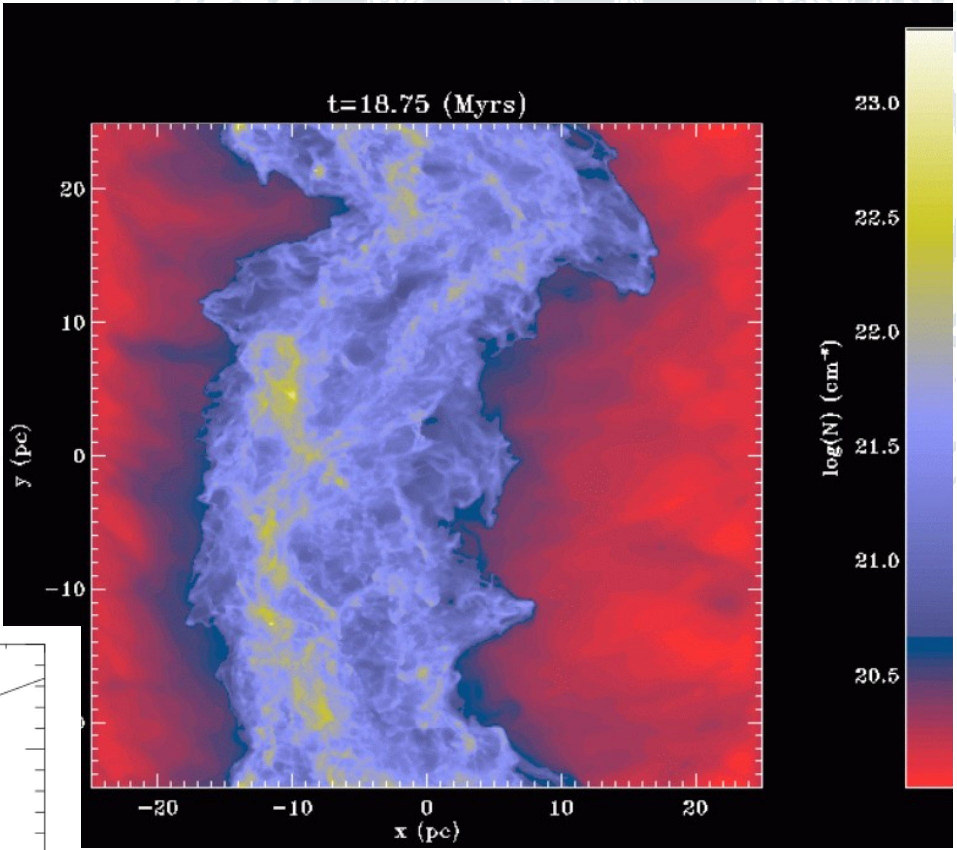
- 2 Intermediate-velocity clouds mapped by Röhser et al. (2014)
  - p-v-diagrams
  - Dust column vs. HI column (both clouds invisible in CO)
  - Material largely dark gas

How does the feeding drive interstellar turbulence?

- Colliding flows unavoidably create turbulence
  - Mach-number of infall?
  - Impact relative to Galactic shear?

Size-linewidth relation of clumps identified in colliding flow



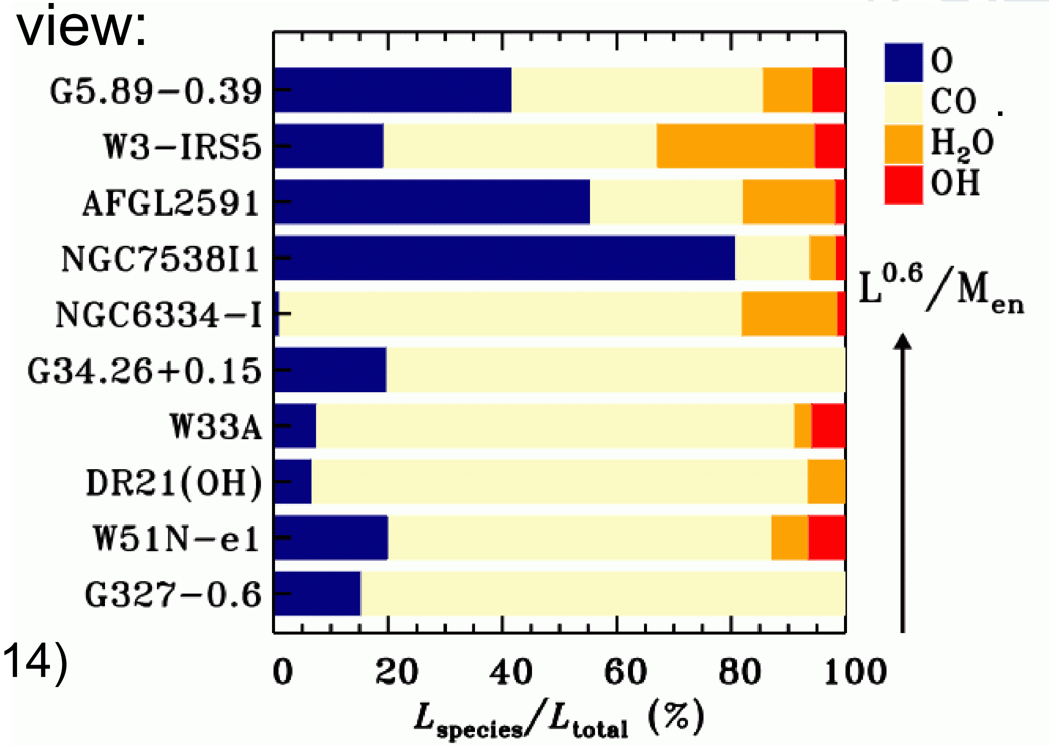


Colliding-flow simulation (column density map)

Klessen & Hennebelle (2010)

YSO line cooling dominated by [OI]:

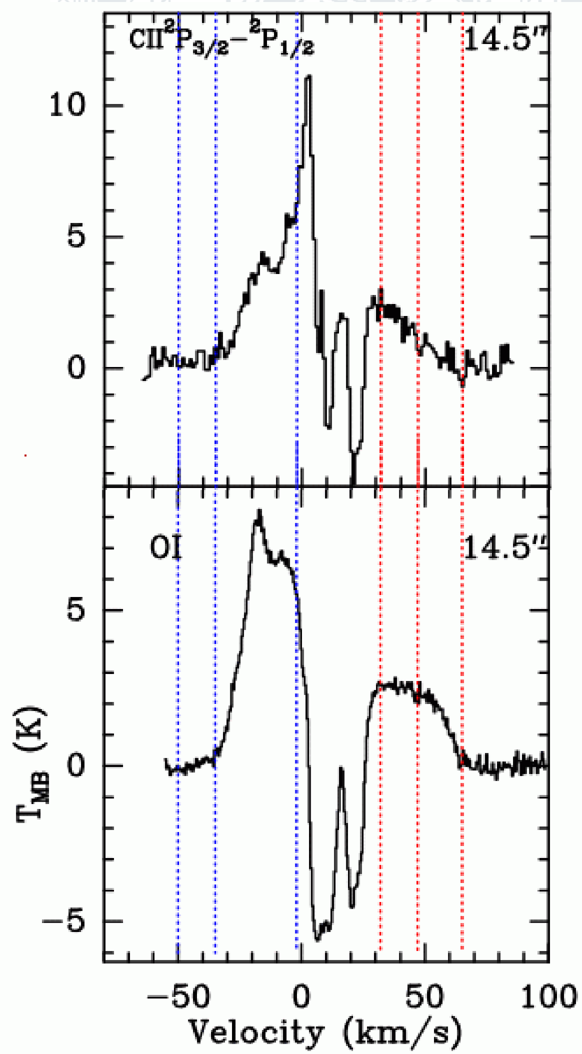
- The Herschel view:



Karska et al. (2014)

G5.89-0.39:

(Leurini et al. 2015)

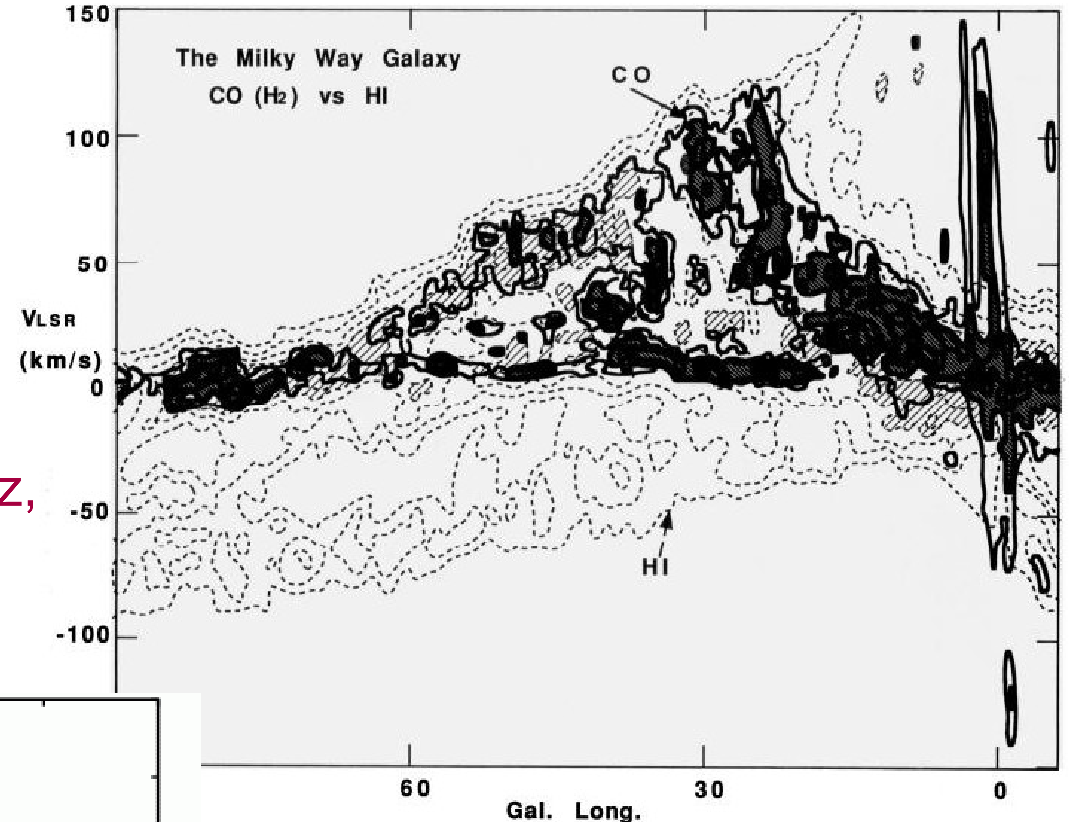


- News from SOFIA:
  - Complex [OI] profile with broad wings
- Spectral resolution is the key!
- Explanation of FIR line deficit needs resolved lines

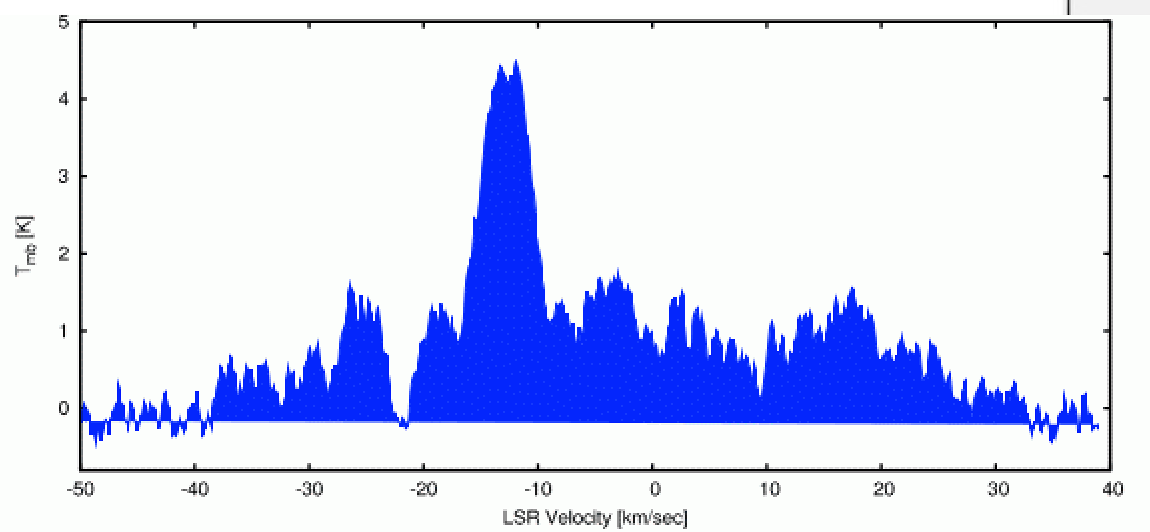
Requirements

Velocity structure

- Cover at least Galactic rotation, i.e. > 400km/s
- [CII] probably also at higher velocities
- Required min. bandwidth: [CI] 1.4GHz, [NII] 2GHz, [CII] 3GHz, [OI] 7GHz



Velocity distribution of HI and CO 1-0 at *b*=0 (Sofue et al. 1995)

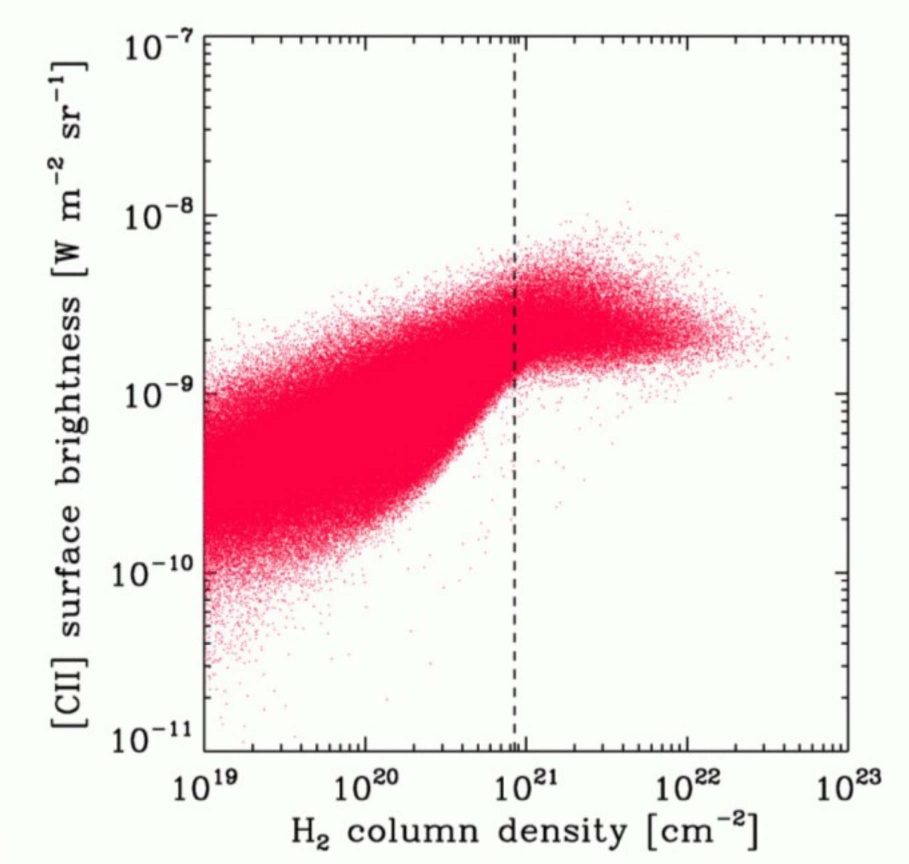


[CII] Spectrum towards massive SF region G345.65+0.0 (Pineda et al. 2010)

- Many components as narrow as 2-3km/s
- Needs velocity resolution of 0.3km/s to resolve details of line structure

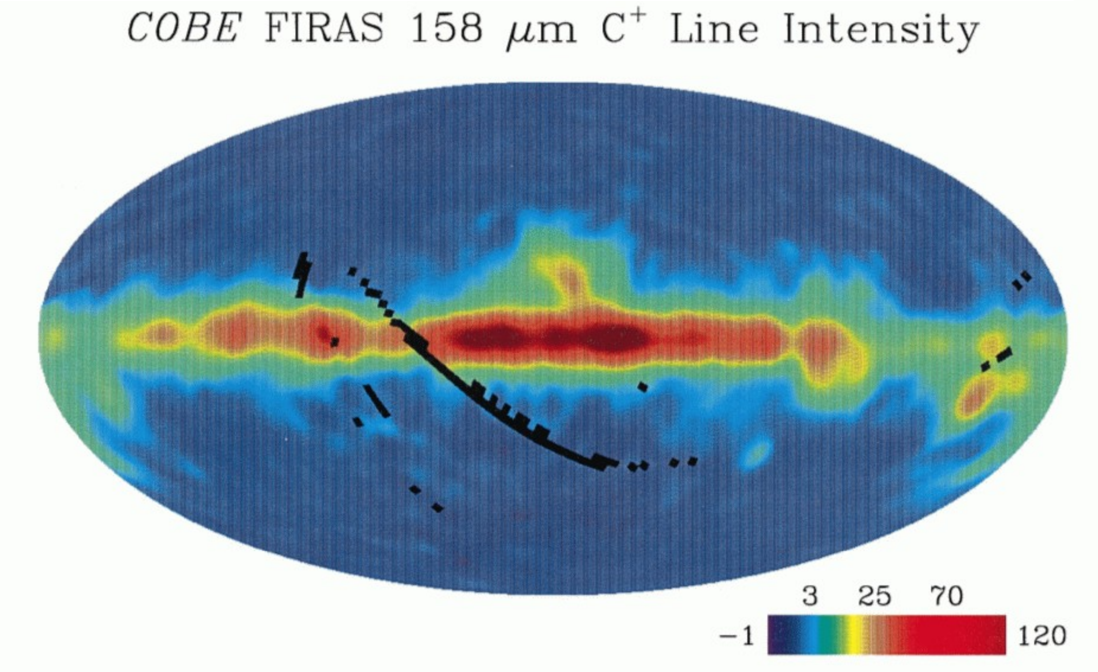
Milky Way simulations by Glover et al. (2015,16):

- Narrow lines
  - 1nW m^{-2} sr^{-1} ≈ 0.15 K (CII)



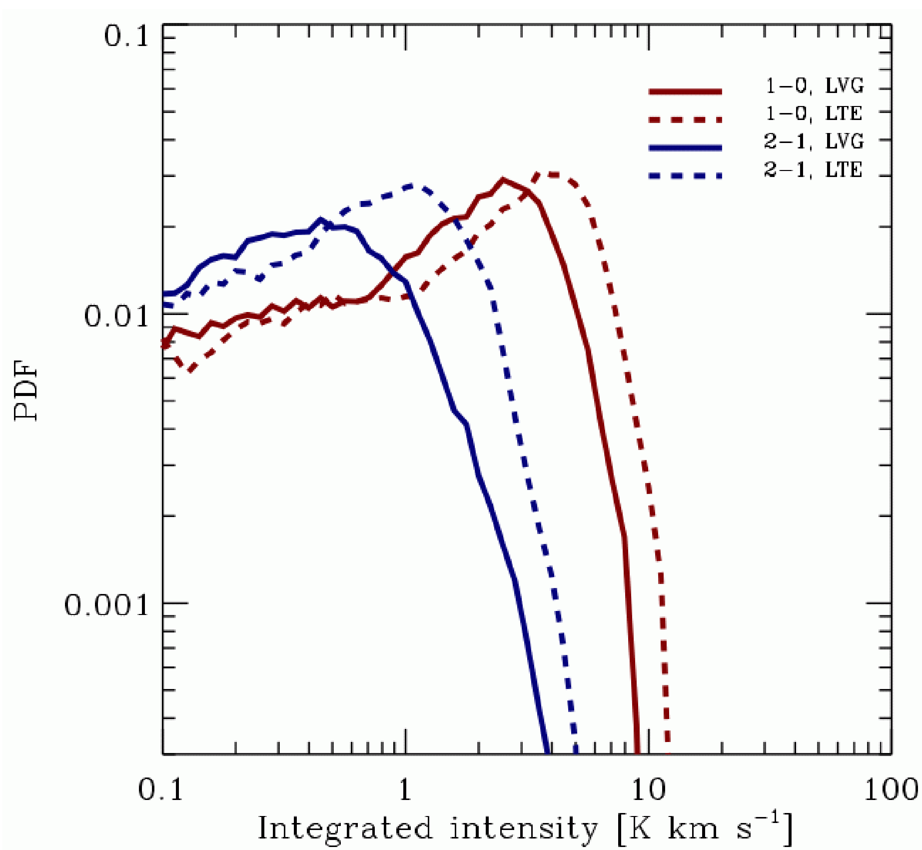
COBE (Fixsen et al. 1999)

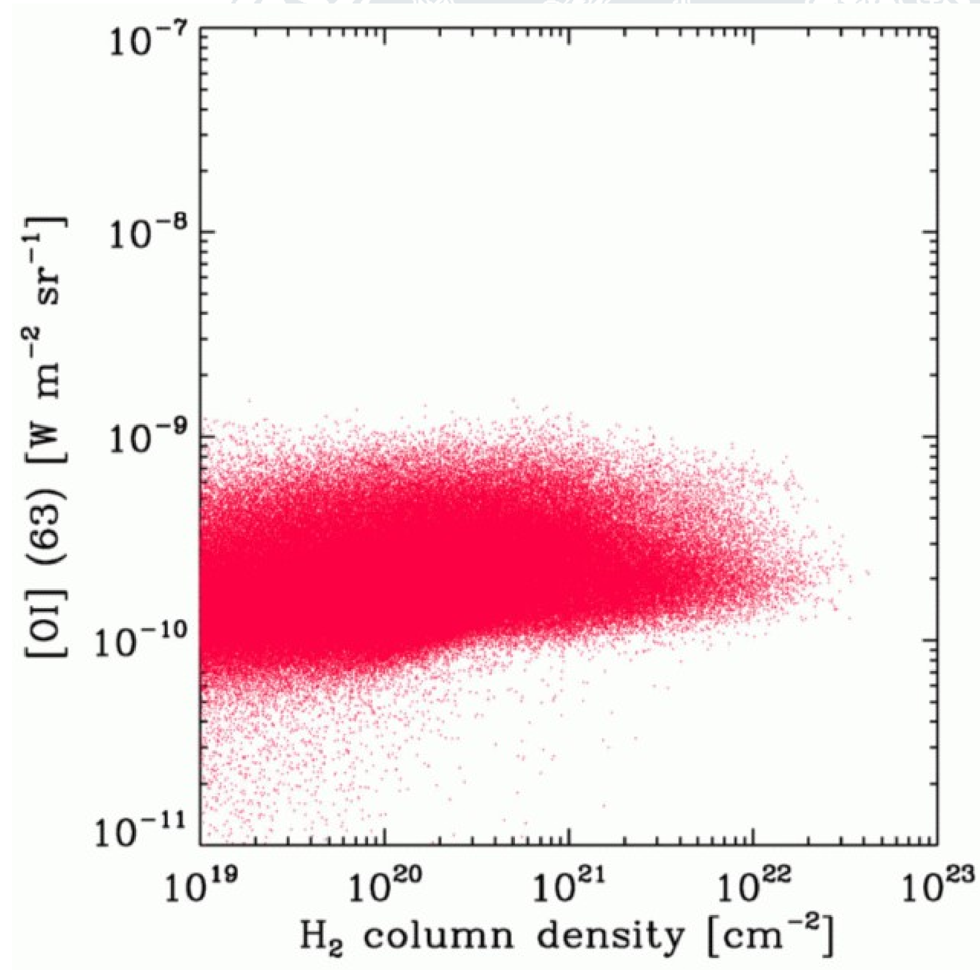
- Broad lines with many components
  - Full plane above 3nW m^{-2} sr^{-1}



Milky Way simulations by Glover et al. (2015,16):

- Narrow lines
  - 1nW m^{-2} sr^{-1} ≈ 0.03 K (OI)
  - CI peaks at 0.25 K





COBE (Fixsen et al. 1999):

- Broad lines with many components
  - Large fraction of the plane above 1nW m^{-2} sr^{-1}
  - Narrow-line translation: 1nW m^{-2} sr^{-1} ≈ 0.15 K (NII) (favourable)