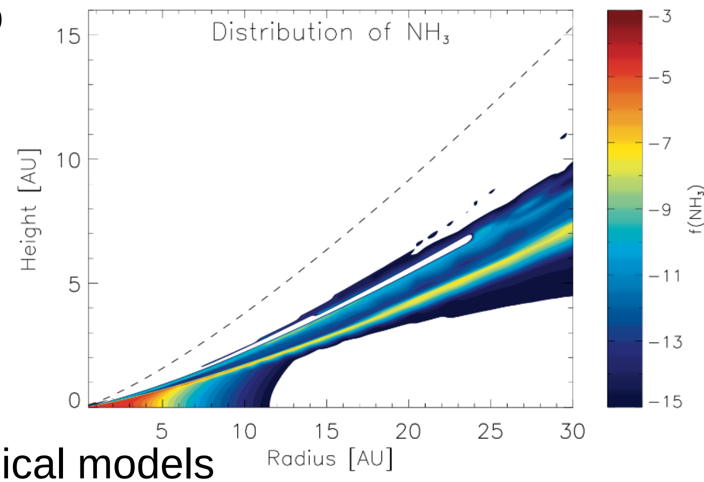
Unraveling the distribution of ionized gas in the Galactic plane with radio recombination lines.

Jorge Pineda

Jet Propulsion Laboratory

Willacy & Woods 2009



Science with ngVLA at JPL

Geoff Bryden, Karen Willacy, Tom Kuiper, Jorge L. Pineda

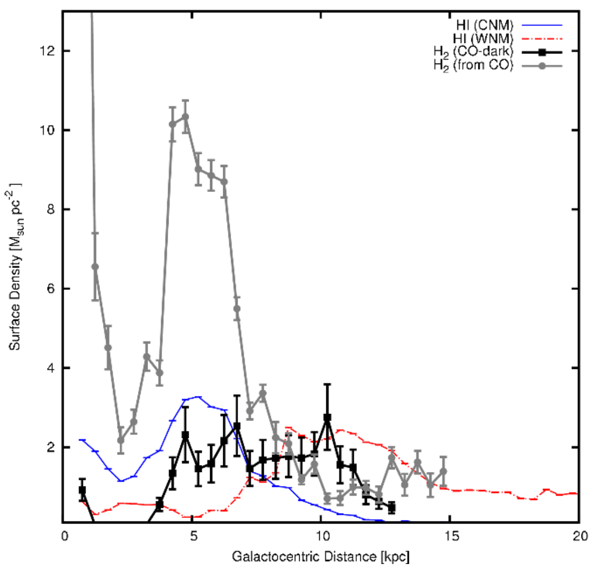
Science topic 1: Protostellar disks

- Explore disks using combination of observations and chemical models
- Different molecules probe different conditions and regions within the disk.
- Key species at radio wavelengths include:
  - **ammonia** - probes disk temperature
  - **complex organics** - probe grain surface chemistry, high temperature chemistry, desorption processes, and potentially disk turbulence

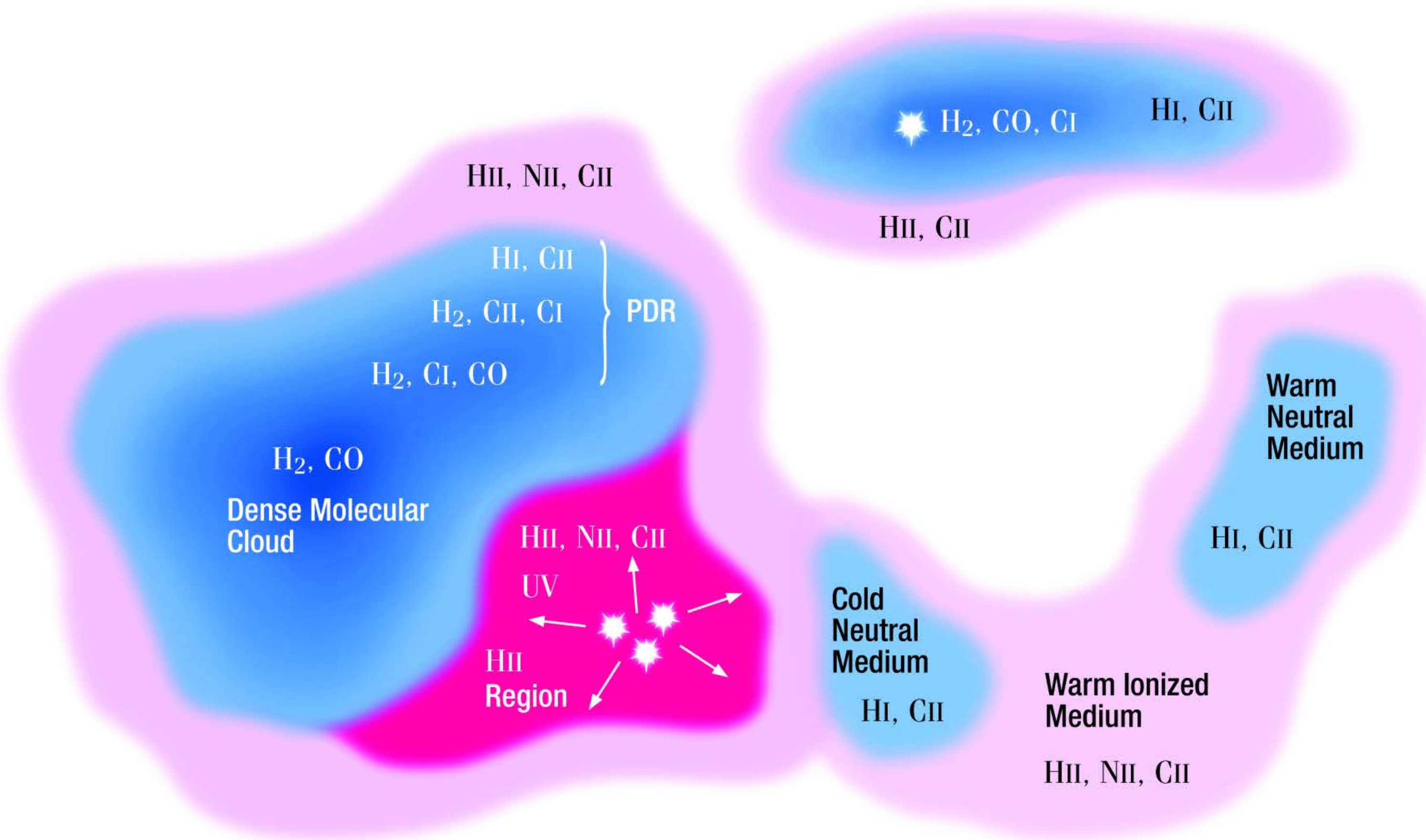
Science topic 2: Interstellar Medium

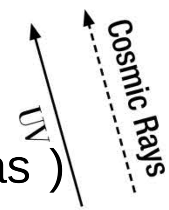
- What is distribution of the various phases of ISM gas in our Galaxy and beyond?
- Radio recombination lines probe *ionized gas - a key unconstrained component of ISM*
- ngVLA radio observations will complement our *Herschel* far-IR surveys of neutral gas

Pineda et al. (2013)



Goal: Understand the lifecycle of the interstellar medium





Far-IR tracers:

[CII] 158um (Traces H_2, HI, and ionized gas)
[NII] 205 and 122um (Ionized gas)
[OI] 145 and 63um (Dense and warm H_2 gas)
Etc.

ngVLA tracers:

High density molecular tracers.
Radio Recombination Lines
Radio Continuum

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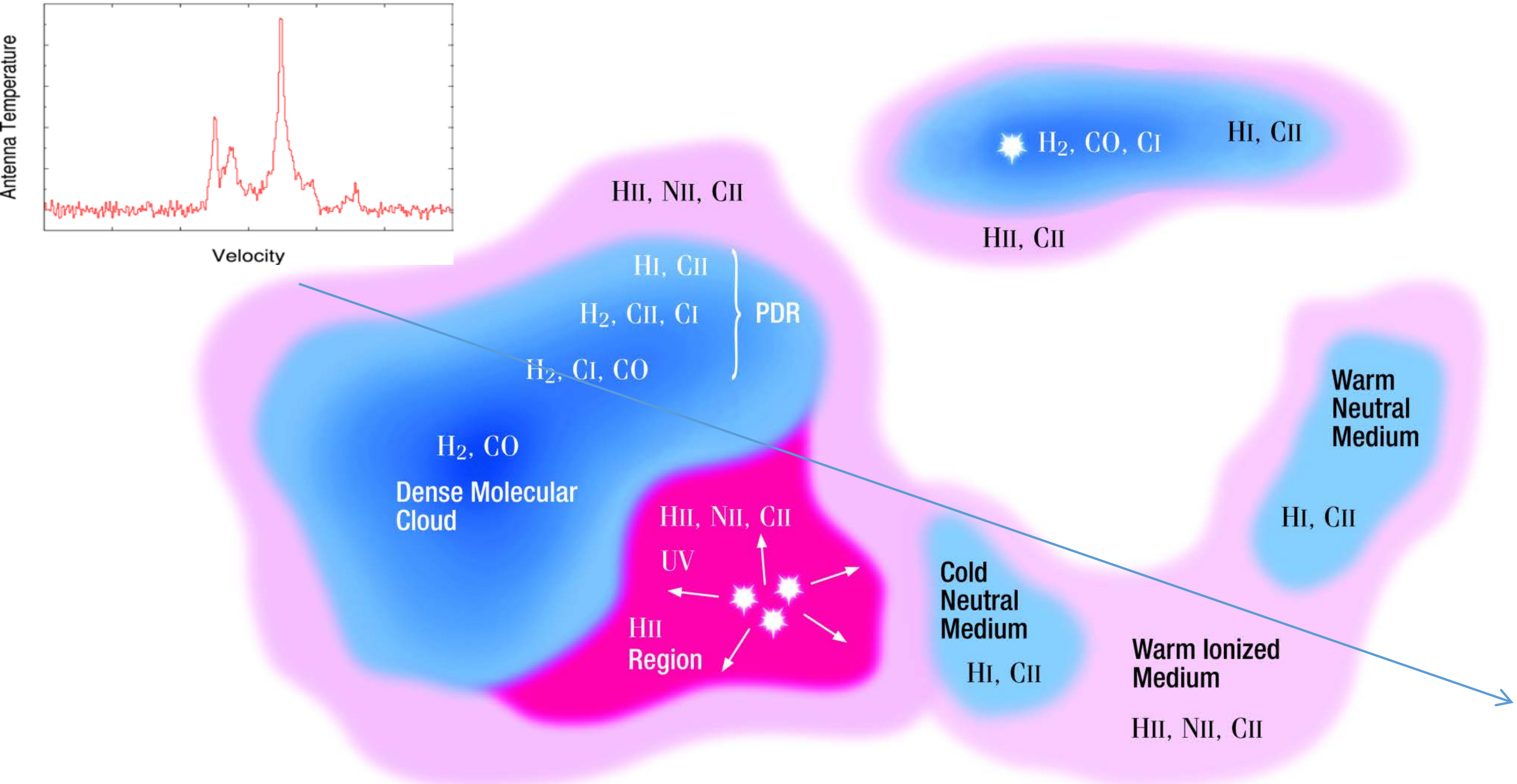

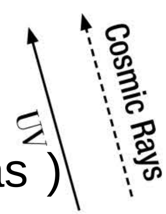

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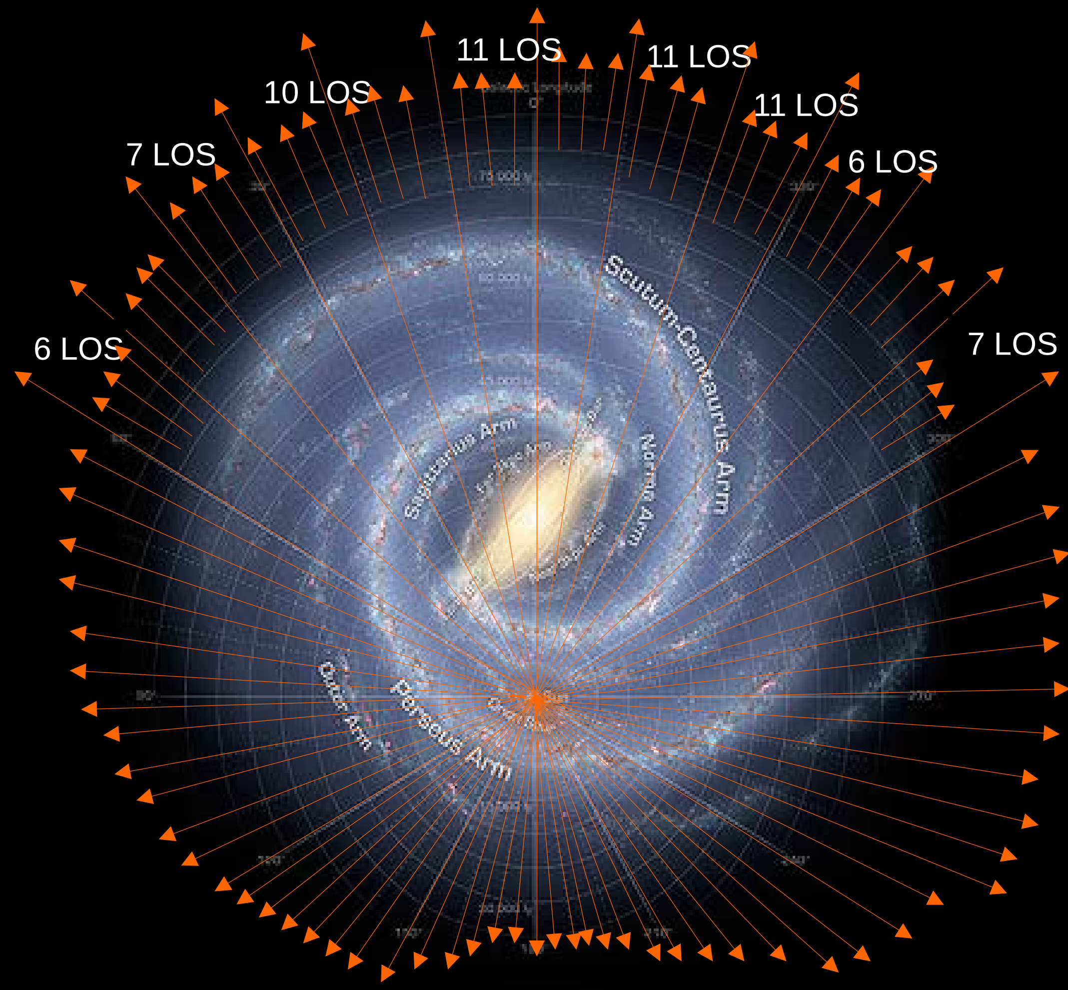
GOT C+ [CII] 1.9 THz Survey

GOT C+ is a volume weighted sample of ≈500 LOSs in the disk of the Milky Way.

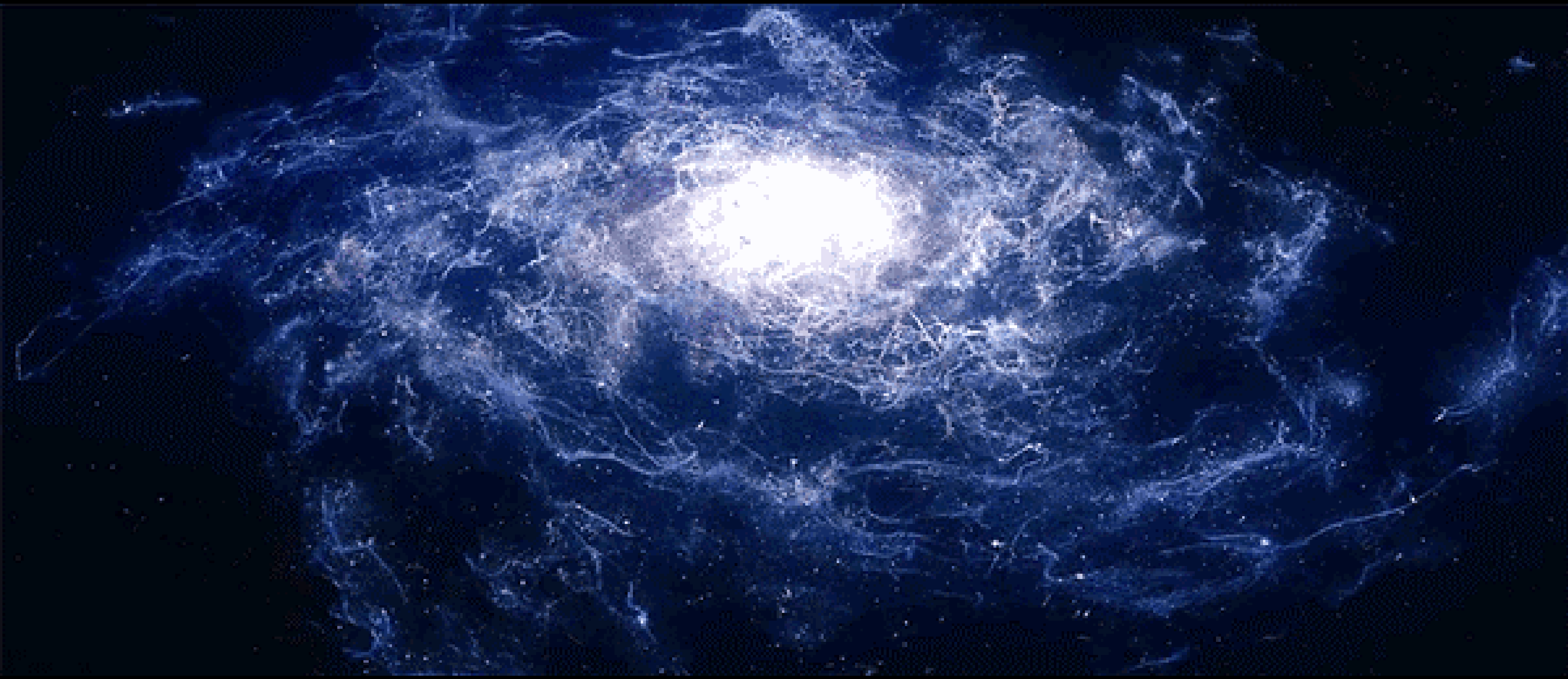
We sample the Galactic plane every one degree in the inner galaxy and every two in the outer galaxy.

GOAL: Sample as many different clouds as possible over a wide range of physical conditions.

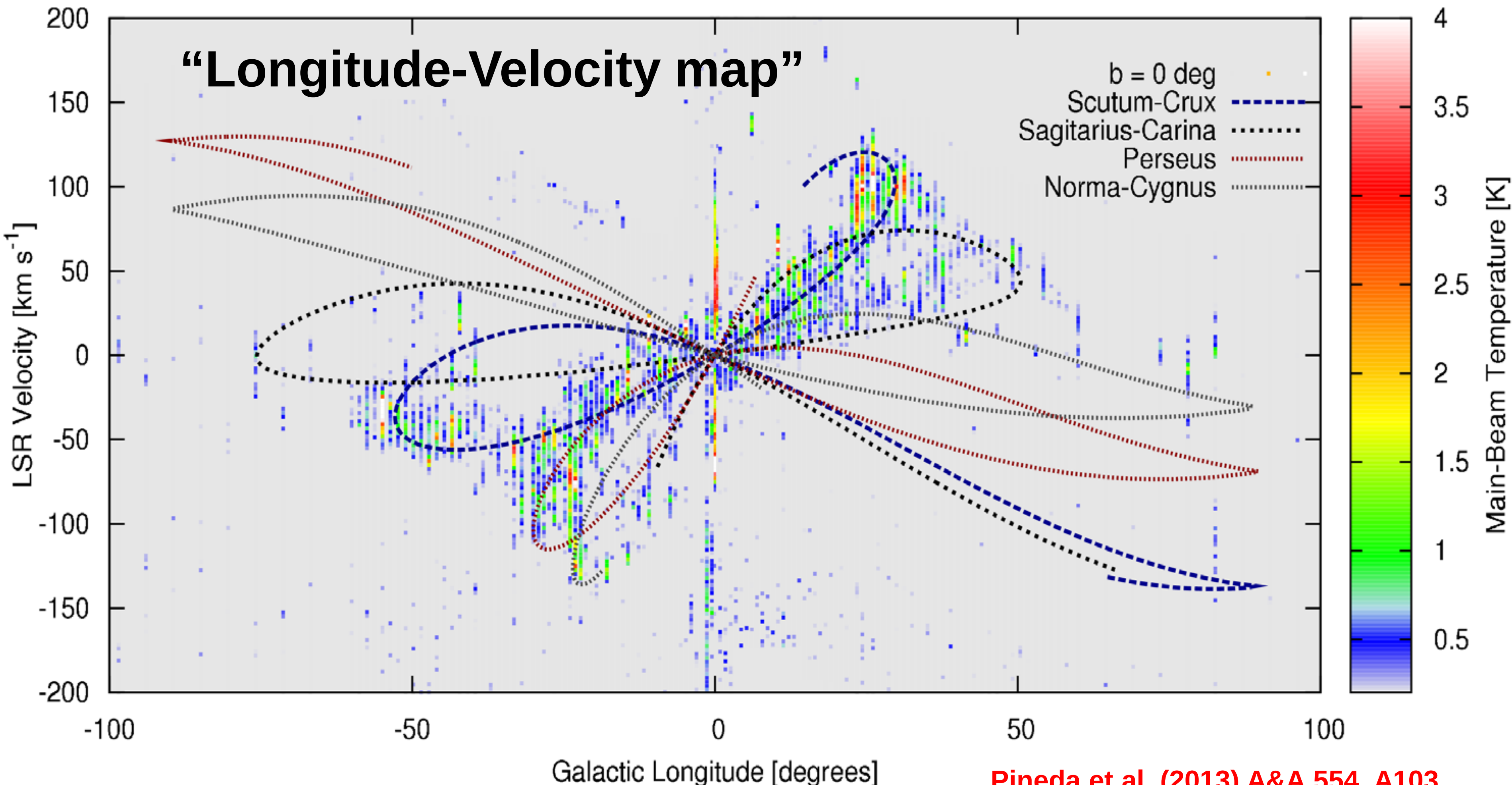
This allow us to obtain statistical information about the clouds in the Milky Way.



The rotation of the Milky Way



The [CII] distribution of the Milky Way:

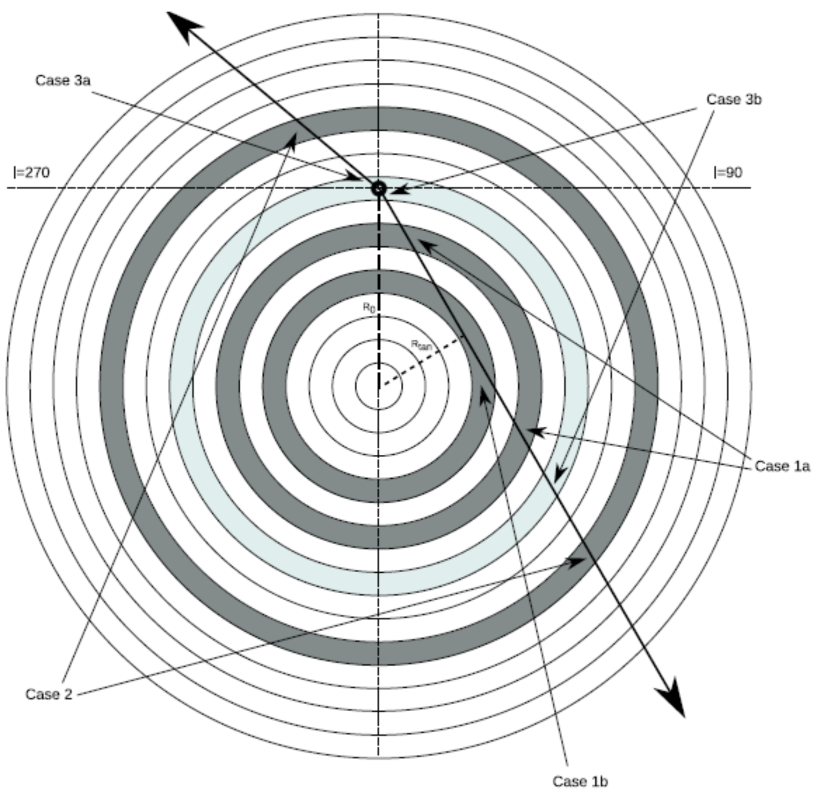


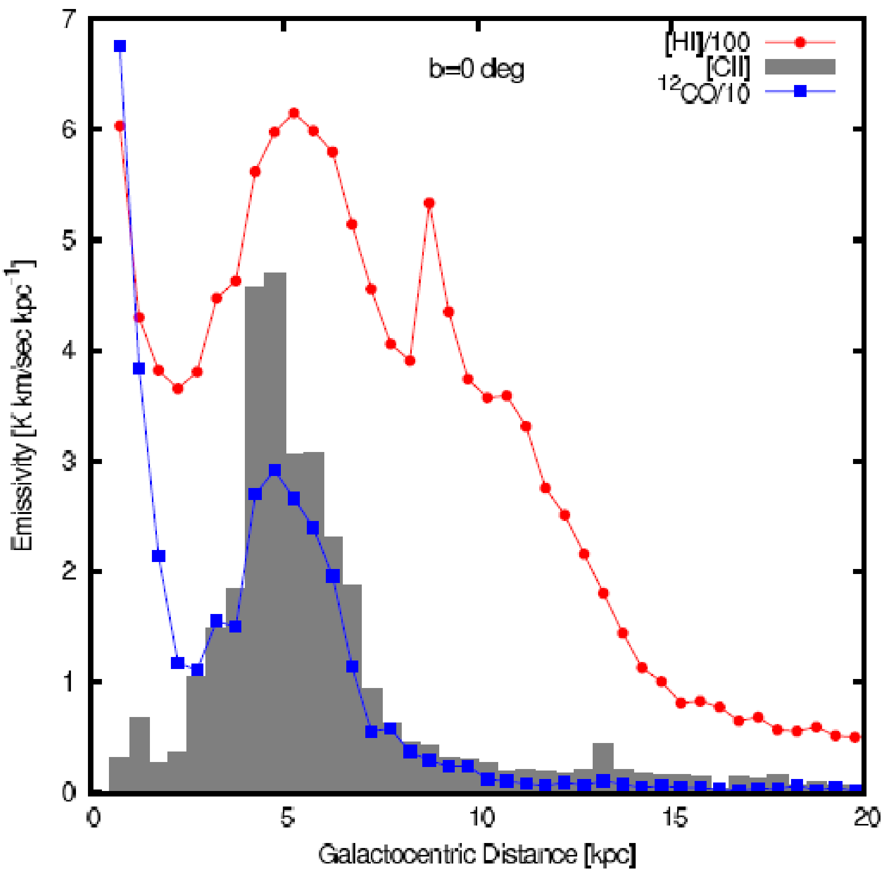
Pineda et al. (2013) A&A 554, A103

The lines are projection of the Milky Way's spiral arms into the Longitude-Velocity map.

Galactocentric Distribution

To derive global properties of population of clouds in the Milky Way we divide it into a set of rings and calculate the radially average distribution of different tracers.





Most of the [CII] emission in the galaxy comes from the inner galaxy (3-10 kpc).
(We are 8.5 kpc away from the galactic center)

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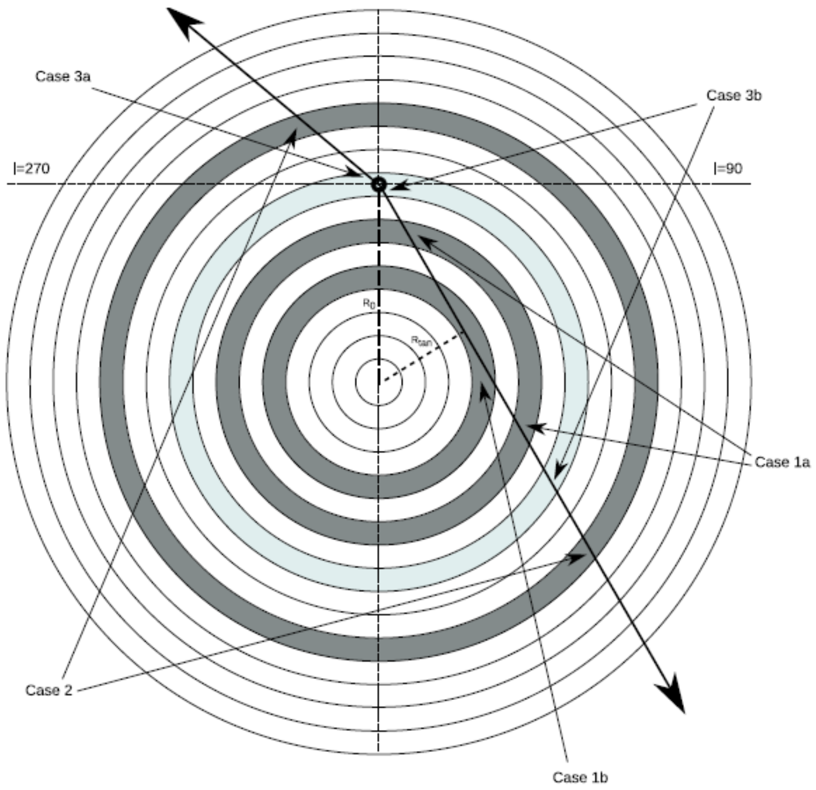

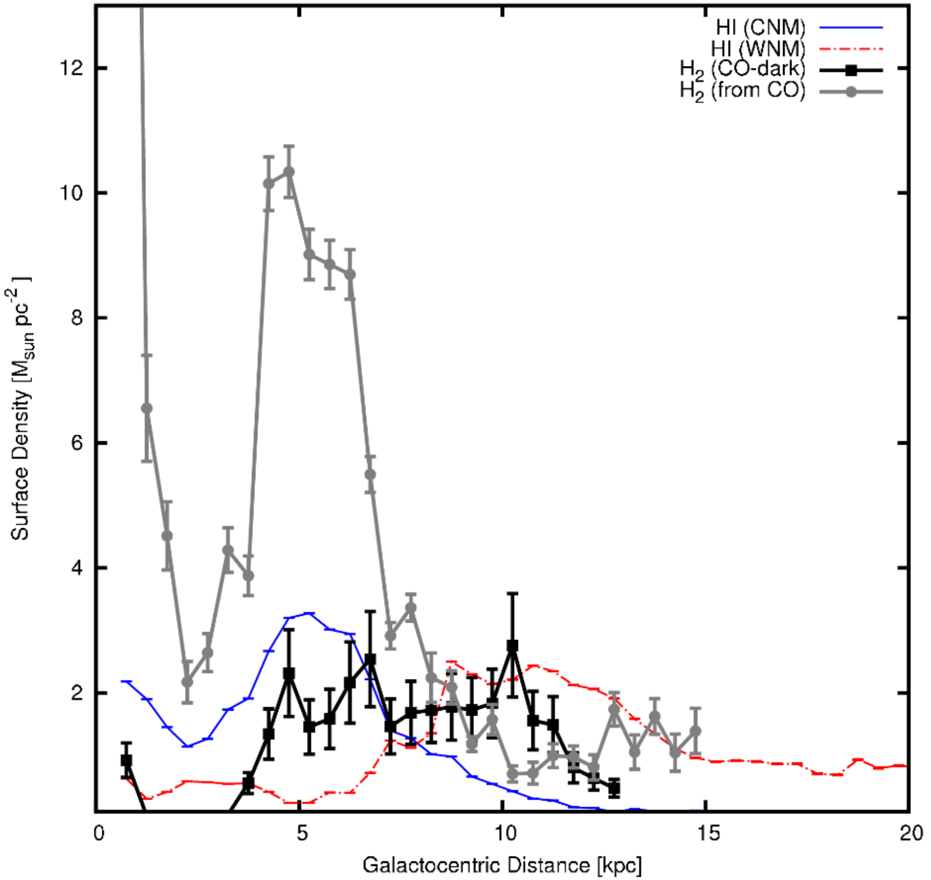

Knowing the distribution of the ionized gas in the Galaxy is fundamental for the interpretation of [CII] observations.

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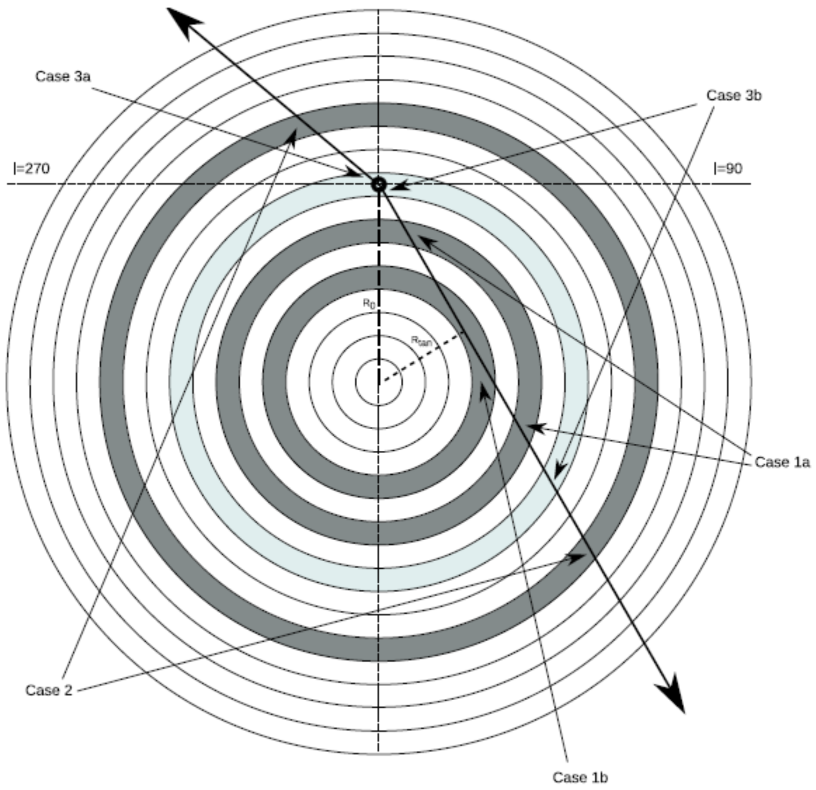

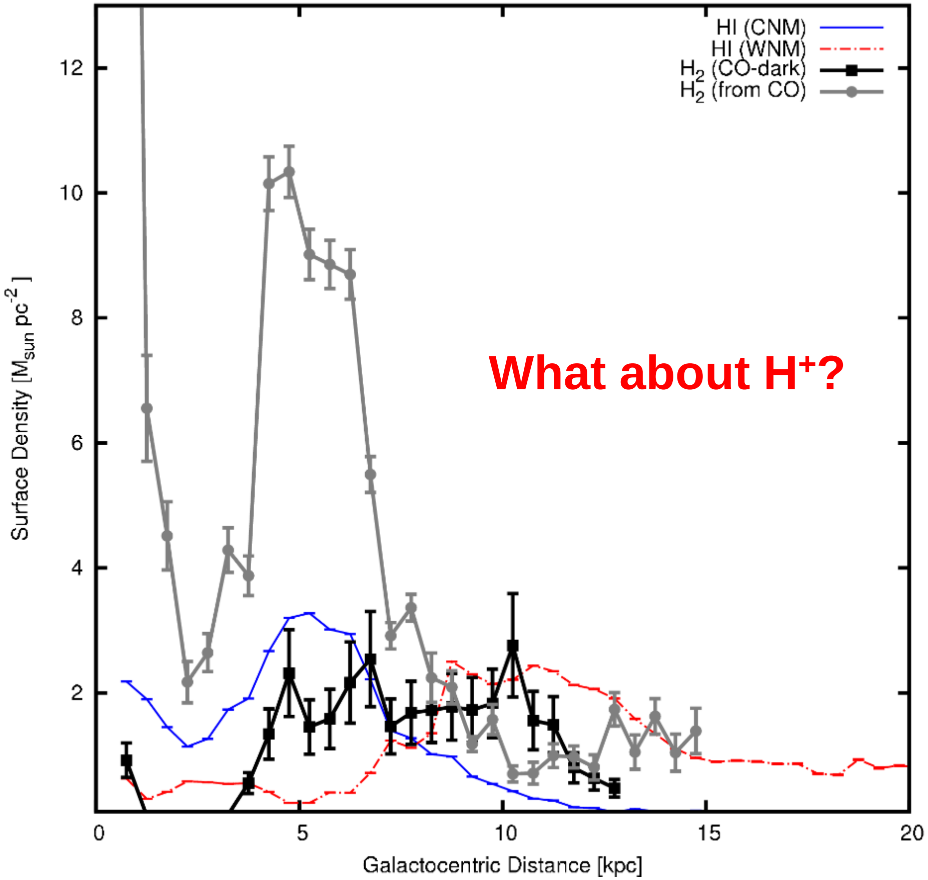

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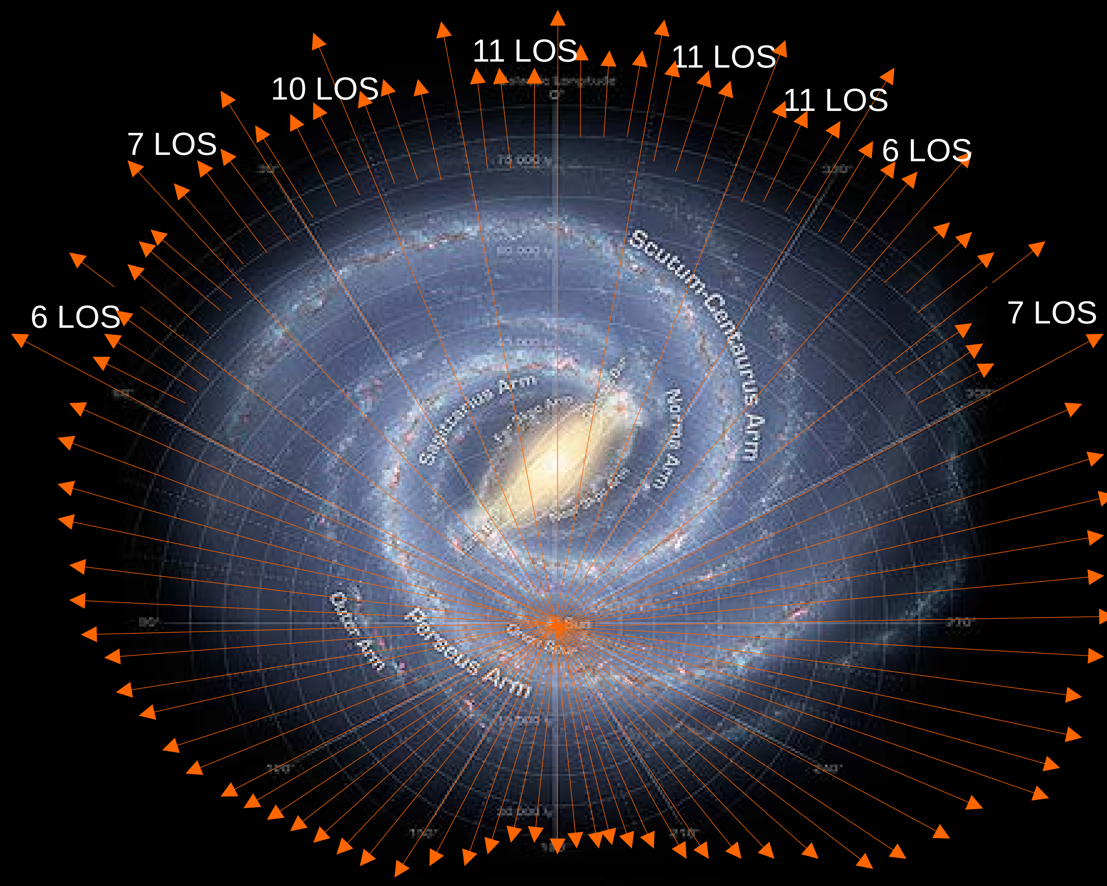
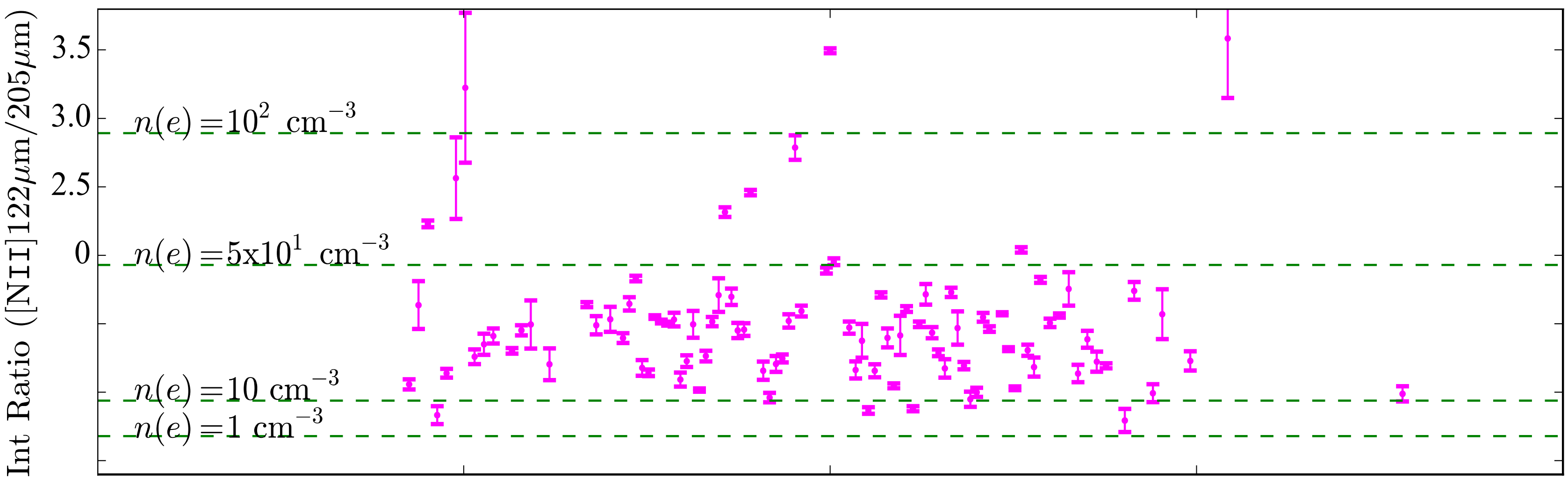
The Herschel [NII] Galactic Plane Survey

- Nitrogen IP is 14.5 eV so found only in regions where H completely ionized. Electron collisions dominate.
- Herschel OT2 Project. PI: Paul Goldsmith
- 140 GOT C^+ lines of sight at b=0º observed in [NII] 205 um and 122um with PACS (897 s per observation)
- 10 selected lines of sight in [NII] 205um with HIFI (7041 s per observation)



Electron density distribution as a function of Galactic longitude (from [NII] 122um/205um)



- The [NII] 122um/205um gives the electron density.
- Typical n_e =10 – 50 cm^{-3}. Much larger than WIM (~0.1 cm^{-3}).
- Is the density the average along the line of sight? Or is dominated by a single source? **We need a velocity resolved, unobscured tracer of ionized gas.**

Goldsmith, Yildiz, Langer and Pineda (2015) ApJ

Radio Recombination Line Survey of the Galactic Plane

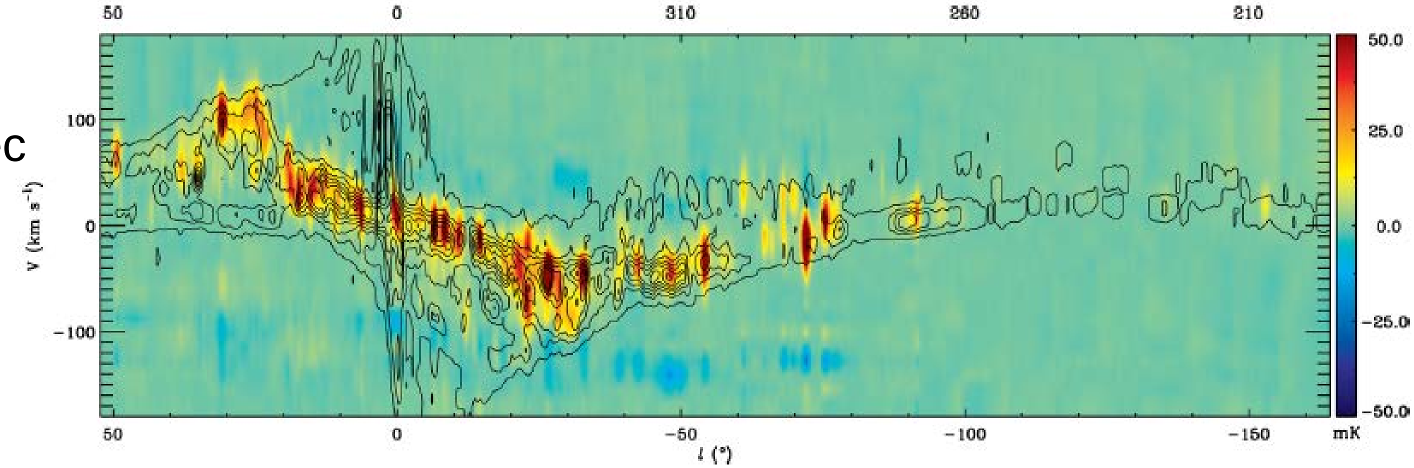
- RRLs are spectrally resolved, unobscured tracers of ionized gas.
- Provide unambiguous determination of the emission measure EM=neN(H^+)=ne^{2}L. It allows us to study the electron density distribution. (Continuum has to be separated between thermal and non-thermal emission).
- Hydrogen RRLs are the brightest, but Helium and Carbon RRLs can be detected in bright sources.
- Line to continuum ratio gives the electron temperature (e.g. Quireza et al. 2006)
- They trace the number of Lyman continuum photons and thus they trace the Star Formation Rate.
- There are 1 Hydrogen RRL per GHz. Observations with a **broad instantaneous bandwidth** can allow us to observe many RRLs simultaneously, thus significantly increasing the sensitivity (**Balser 2006**).

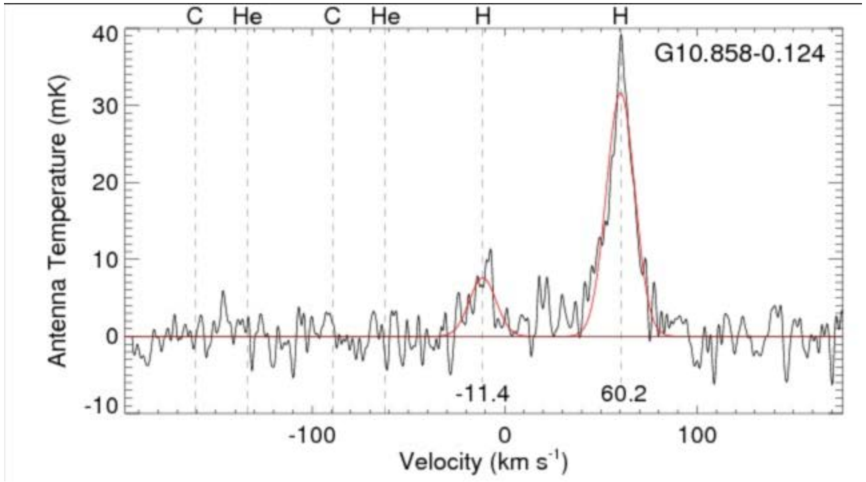
Radio Recombination Line Survey of the Galactic Plane

Alves et al. 2015 MNRAS 450 2025-2042

Parks survey
14' angular, 20 km/sec velocity resolution.

Herschel GOT C$^+$ survey: 15" angular, <1 km/sec resolution.





HRDS GBT Survey: Bania et al.2010 Anderson et al. 2011.

80" angular, 2 km/sec velocity resolution.

Focus on 603 individual HII regions.

Radio Recombination Line Survey of the Galactic Plane

- We will observe 112 GOT C+ lines-of-sight in RRL with the NASA DSS-43 70m telescope (40” angular, <1 km/sec velocity resolution)
- Upcoming capabilities of the DSS 43 will allow simultaneous observations of RRL between 18 and 24 GHz (2 pol x 8 RRLs)
- Test observations are underway.

NASA DSS-43 Deep Space Network 70m antenna. Canberra, Australia.

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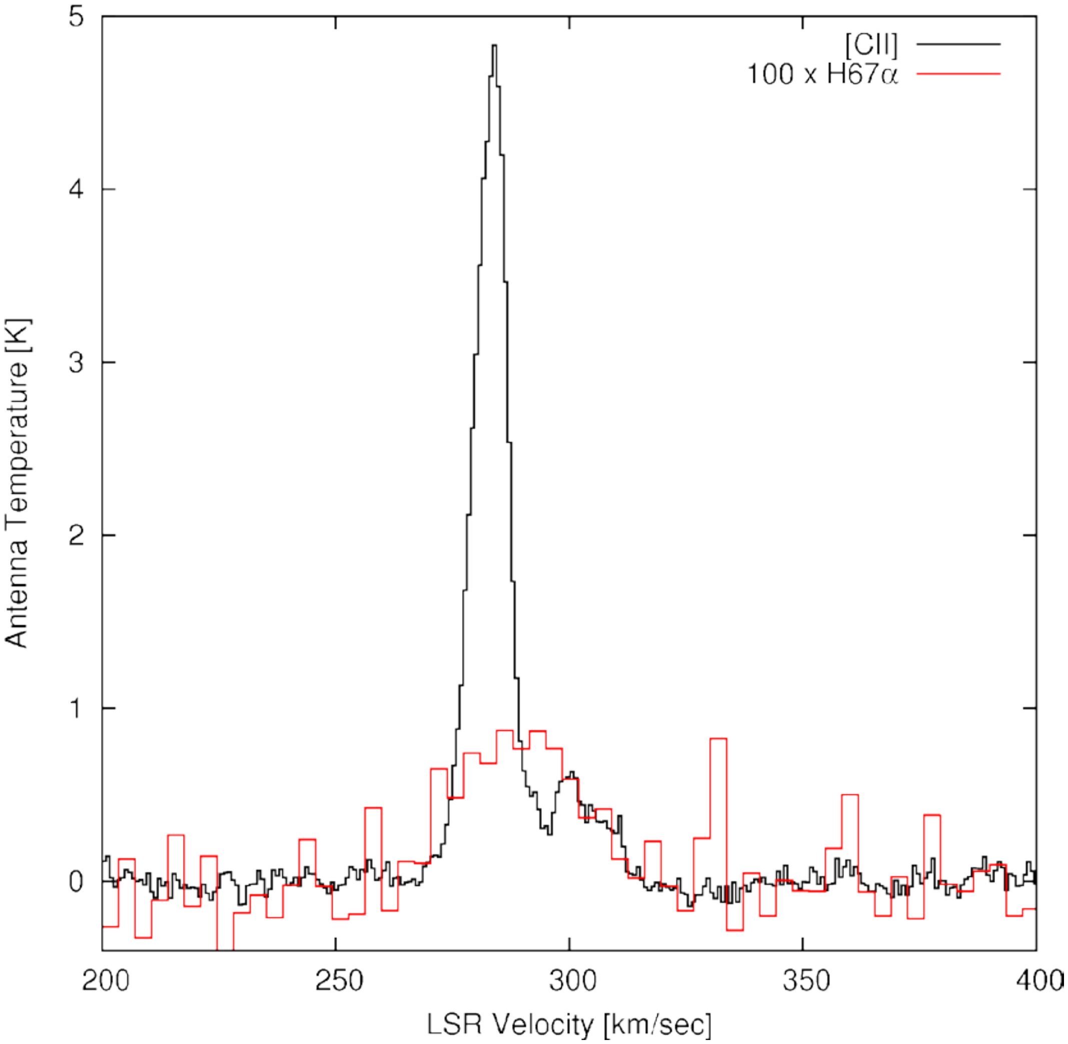
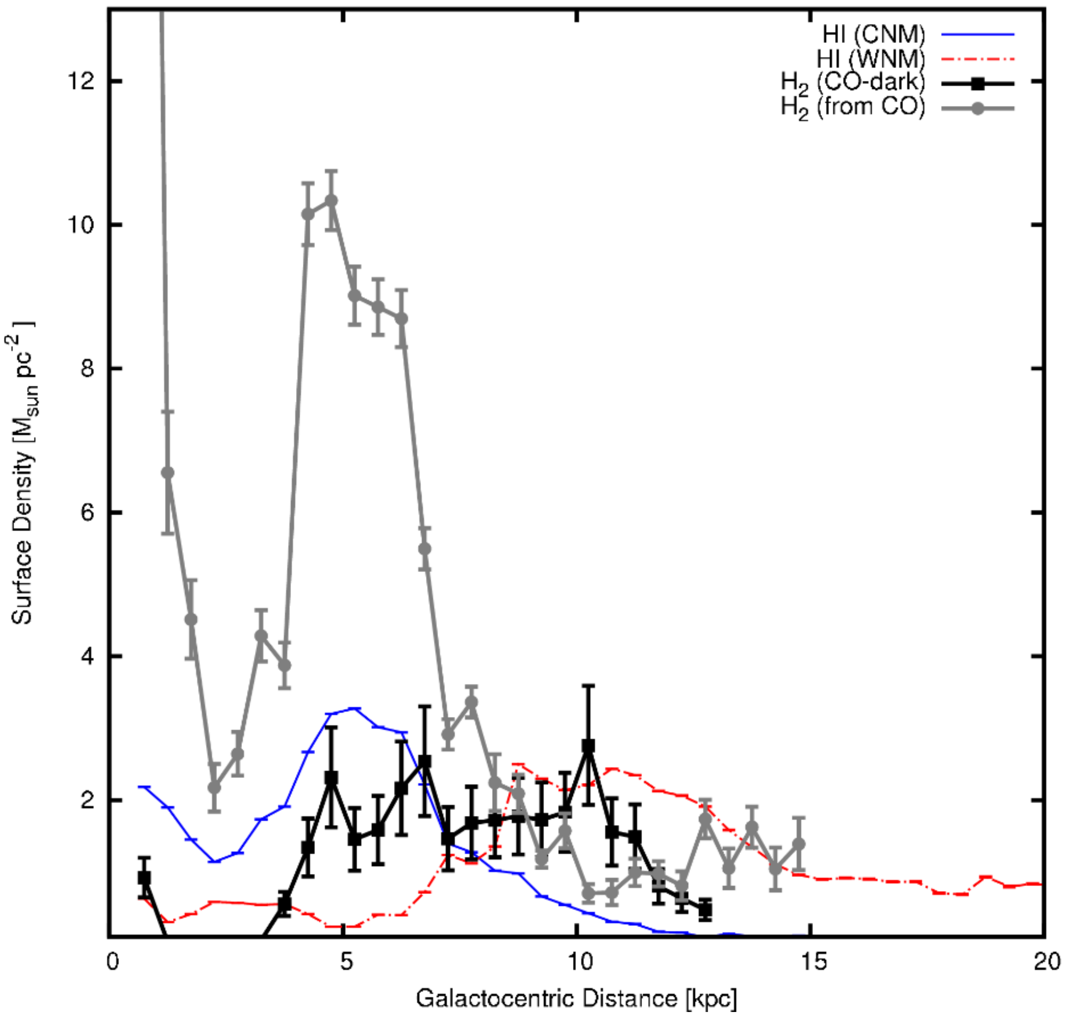


Radio Recombination Line Survey of the Galactic Plane

Science Objective #1:

Follow techniques used in the GOT C+ survey to determine the distribution of ionized gas in the plane of the Milky Way.

Determine the contribution from ionized gas to the observed [CII] emission.

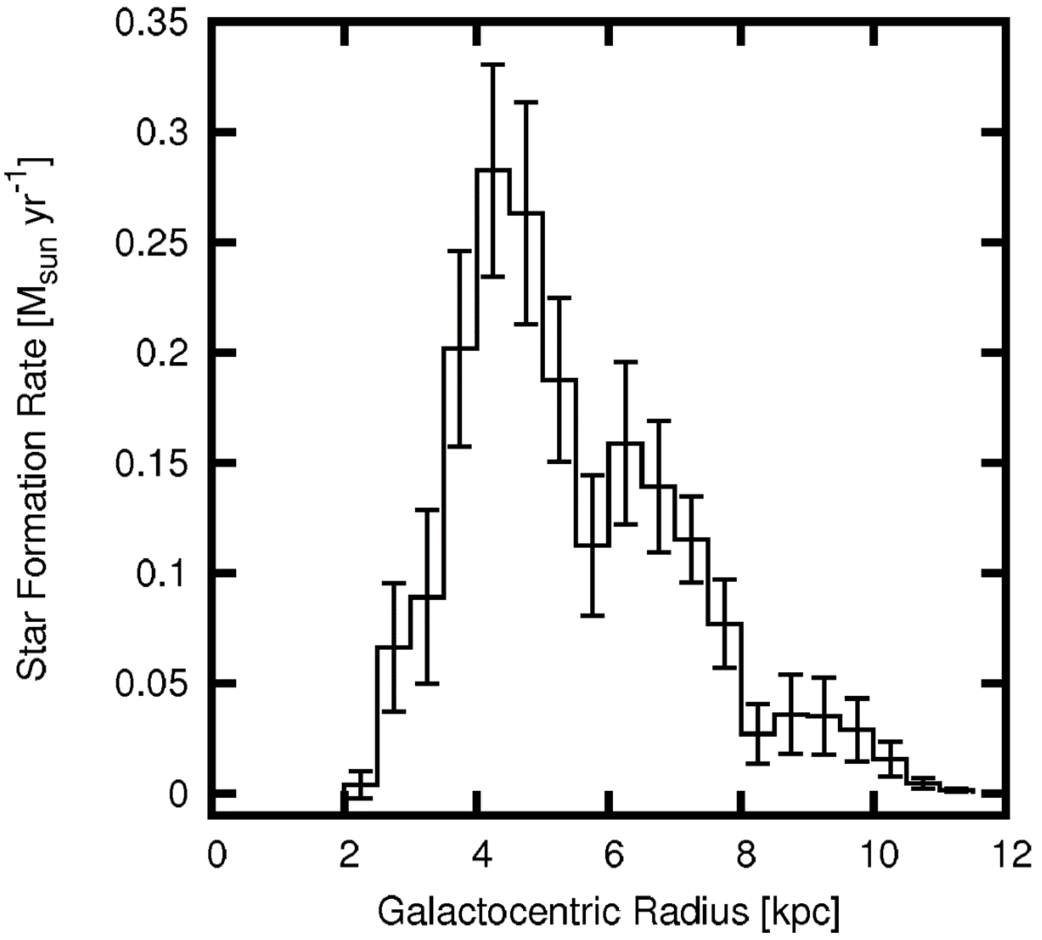


Radio Recombination Line Survey of the Galactic Plane

Science Objective #2:

Derive the distribution of the Star Formation Rate in the plane of the Milky Way

Compare the RRL derived SFR with other tracers such as [CII].



Pineda et al. 2014 A&A 570, A121

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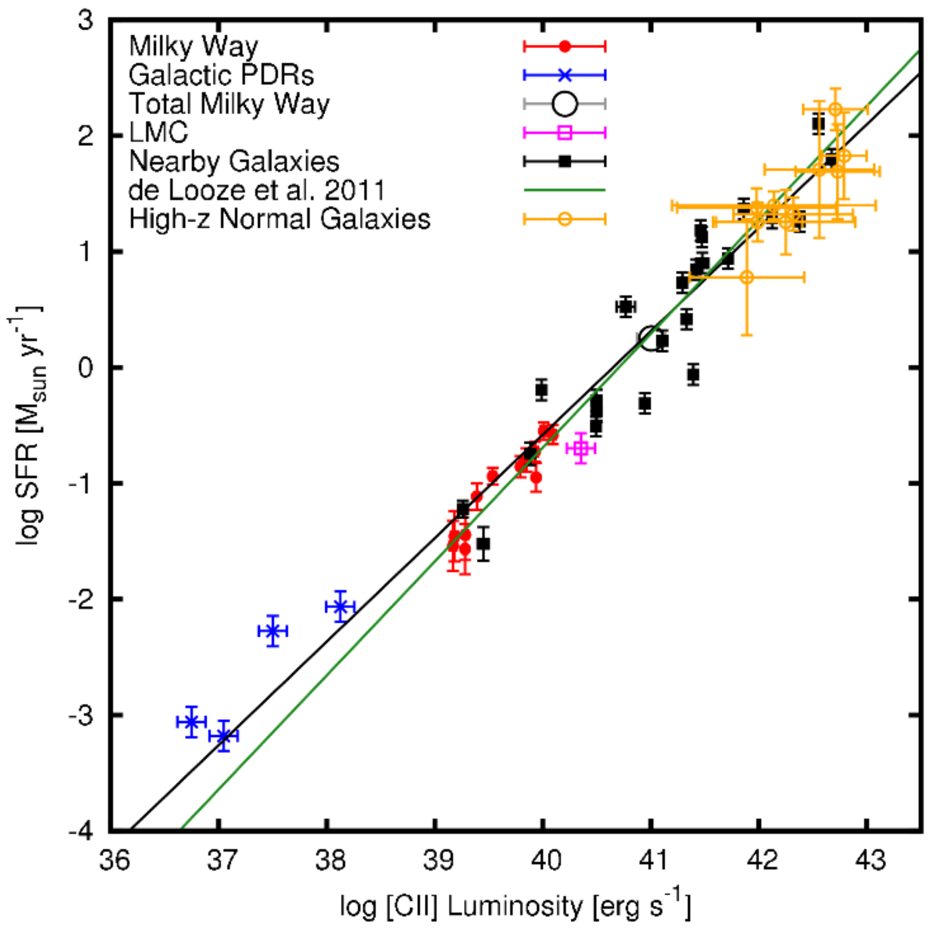

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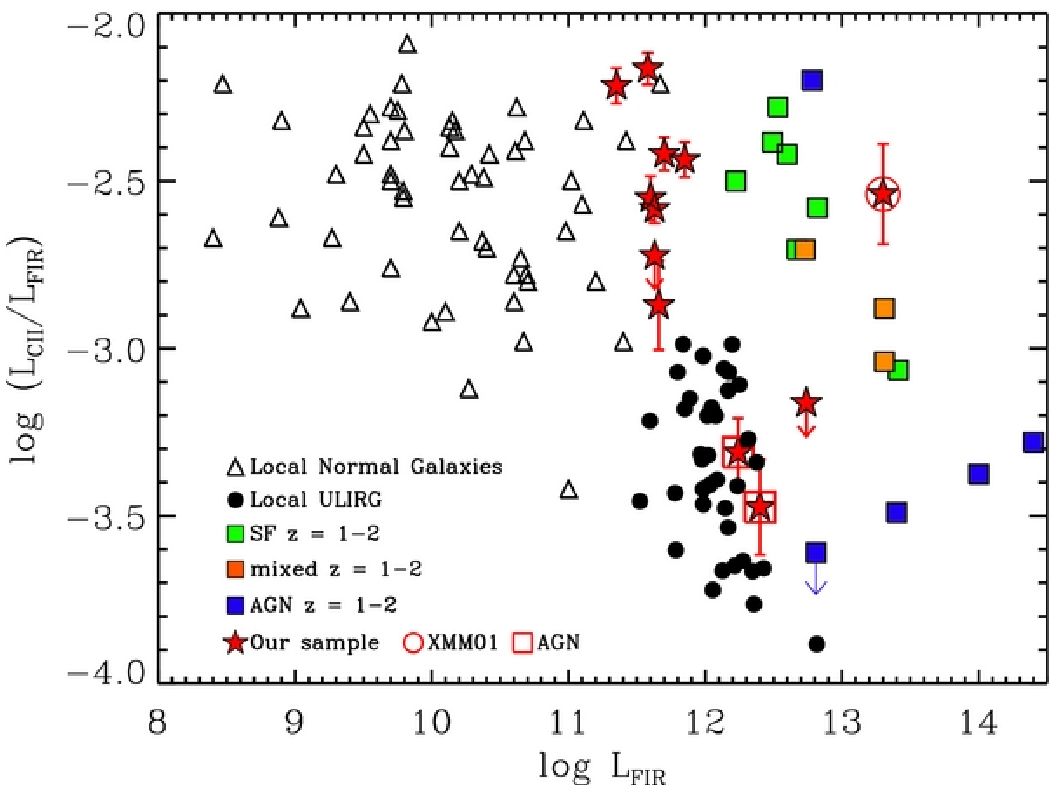

Rigopoulou et al. 2015

Luhman et al (1998) – ULIRGs (see also Malhotra et al. 1997)

Radio recombination line observations with the ngVLA

- The large collecting area of the ngVLA combined with large instantaneous bandwidths can provide extreme sensitive observations of RRLs.

- Our work in the Milky Way will pave the way for similar studies in external galaxies.

- We can learn about the properties of the ISM over different environmental conditions in galaxies as well as determine the star formation history of the universe.

- These data will have synergies with surveys of [CII] emission of high-Z galaxies with ALMA and future Far-IR observatories.