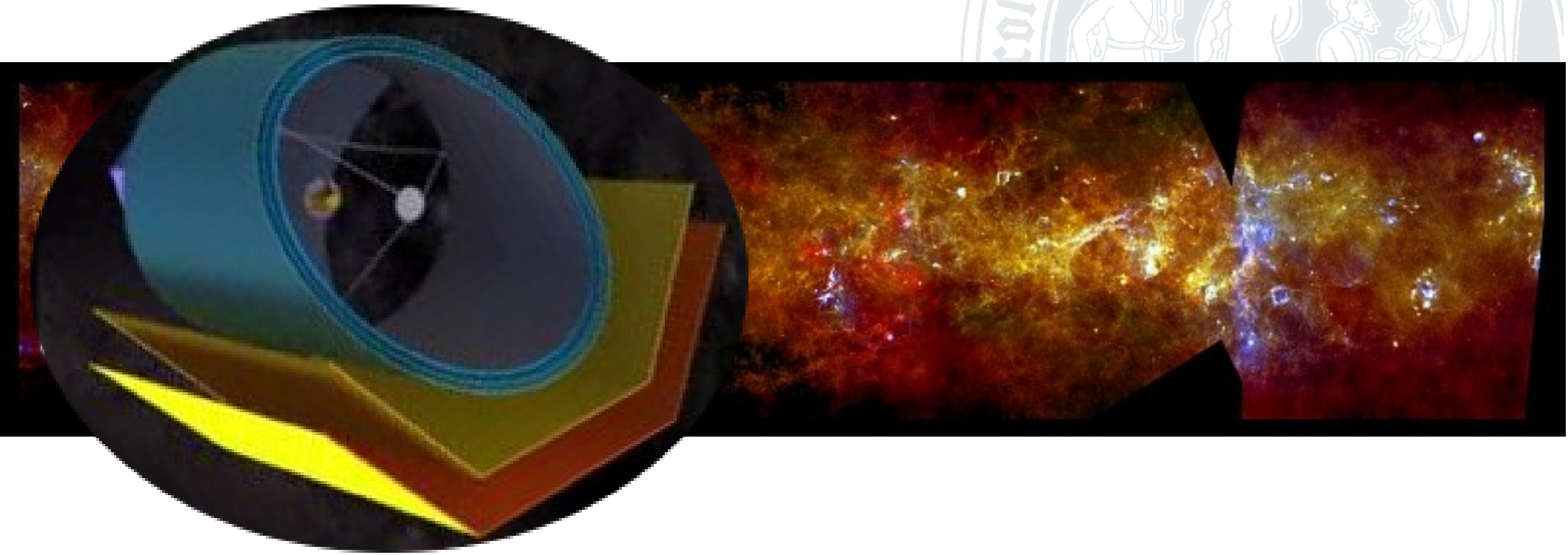
Galactic ecology with OST heterodyne observations



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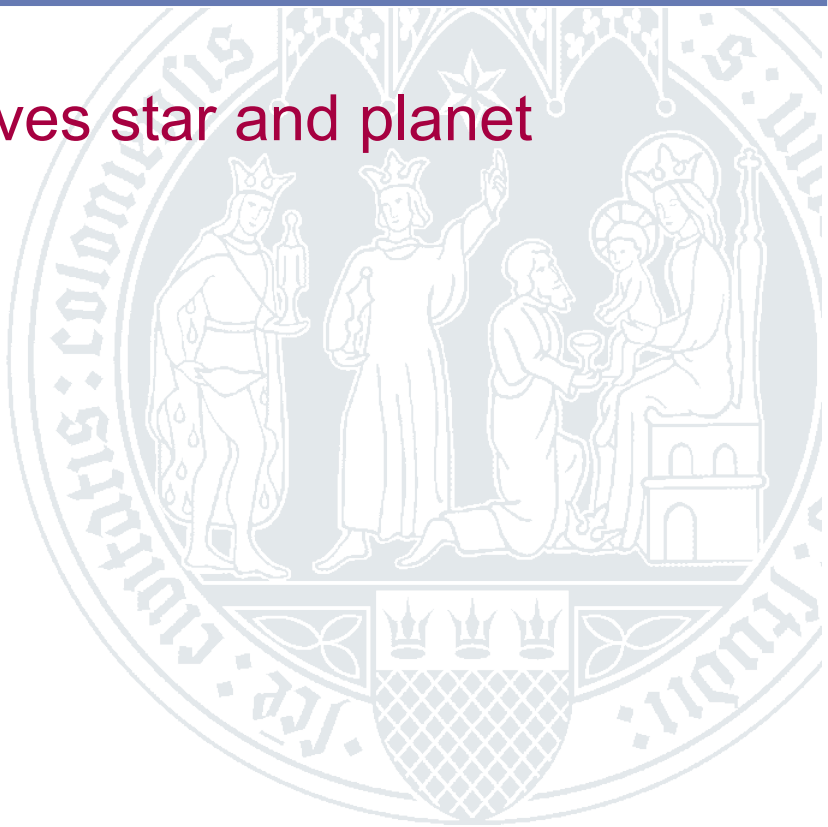
Galactic Ecology



What determines the ISM structure that drives star and planet formation in galaxies?

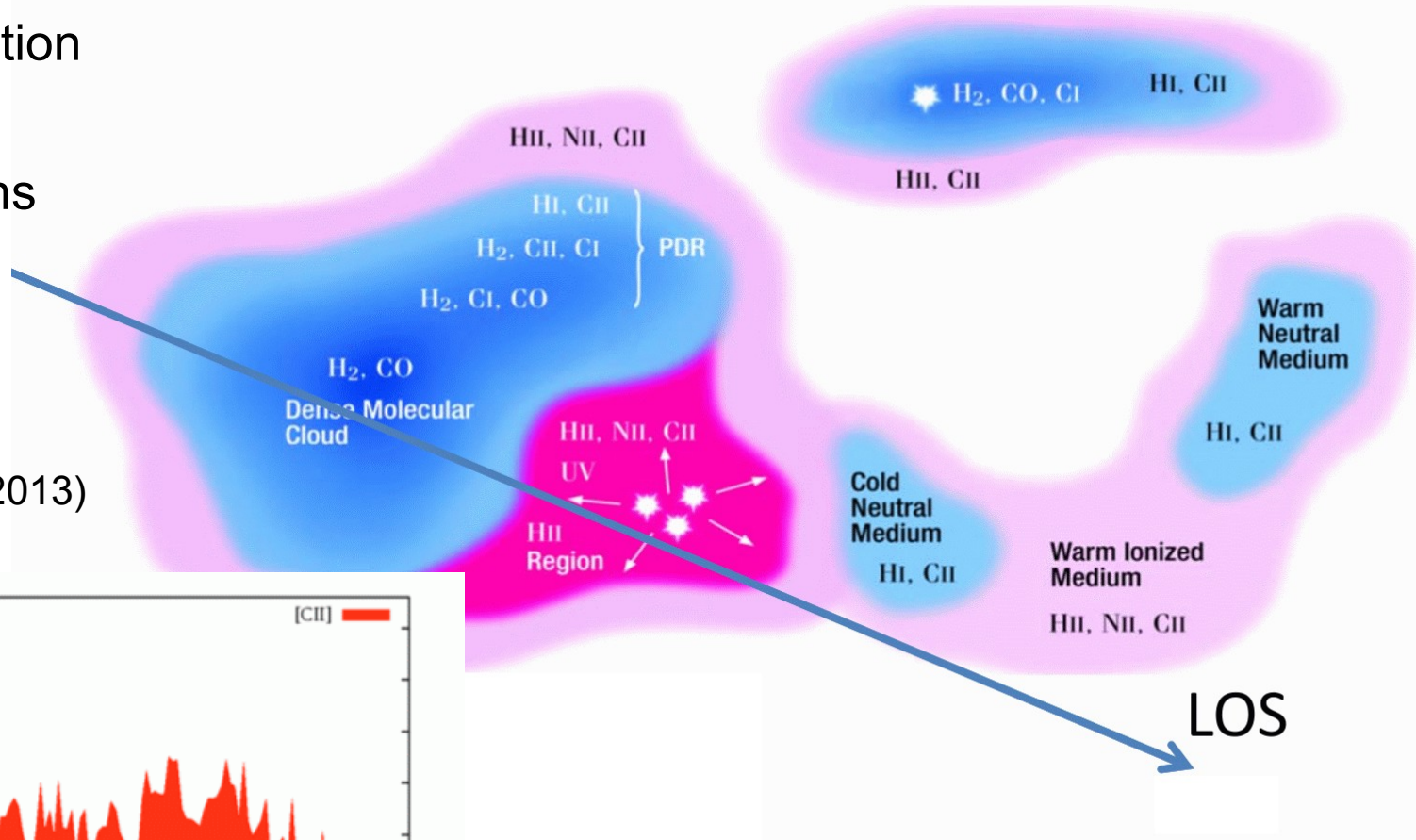
- Gas flow over large scales: Mpc → AU
  - Accretion onto galactic disks
  - Formation of neutral and molecular clouds
  - Formation of clouds and clumps
- Governed by
  - Heating and cooling
  - Turbulence
- Feedback
  - Winds, radiation, SNe

Approach:

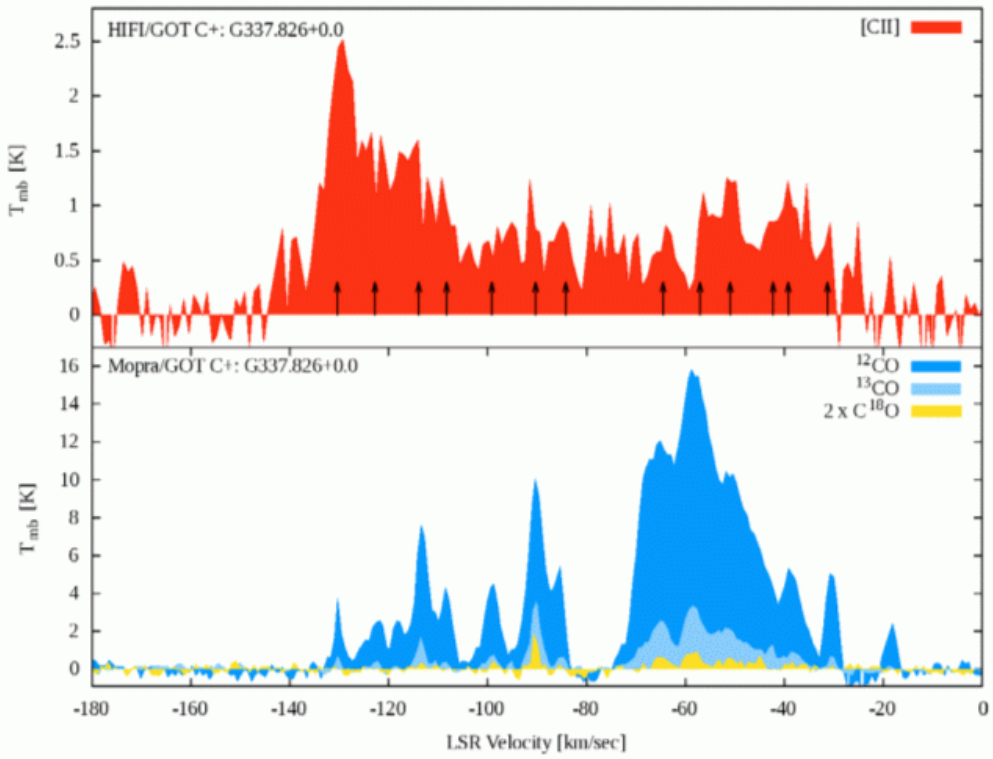
Observe the dynamics of the different phases of the ISM in the Milky Way and nearby galaxies

How to probe the different ISM phases

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



Velusamy et al. (2013)



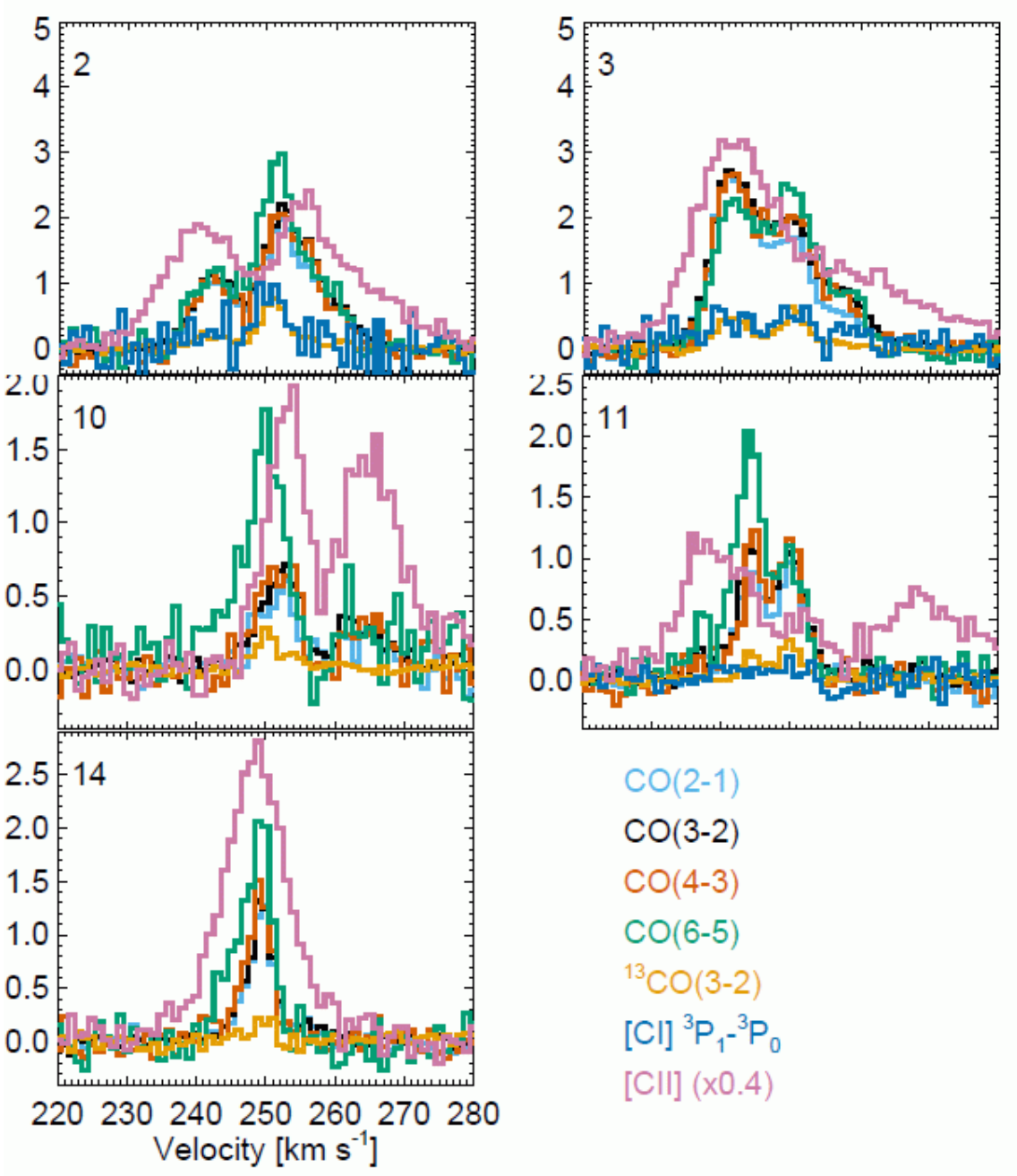
- [CII] from HII regions, CNM, PDRs
- [NII] from HII regions, little from WIM
- [OI] for hot dense gas
- [CI] for part of CO-dark gas

Pineda et al. (2014)

How to probe the different ISM phases

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

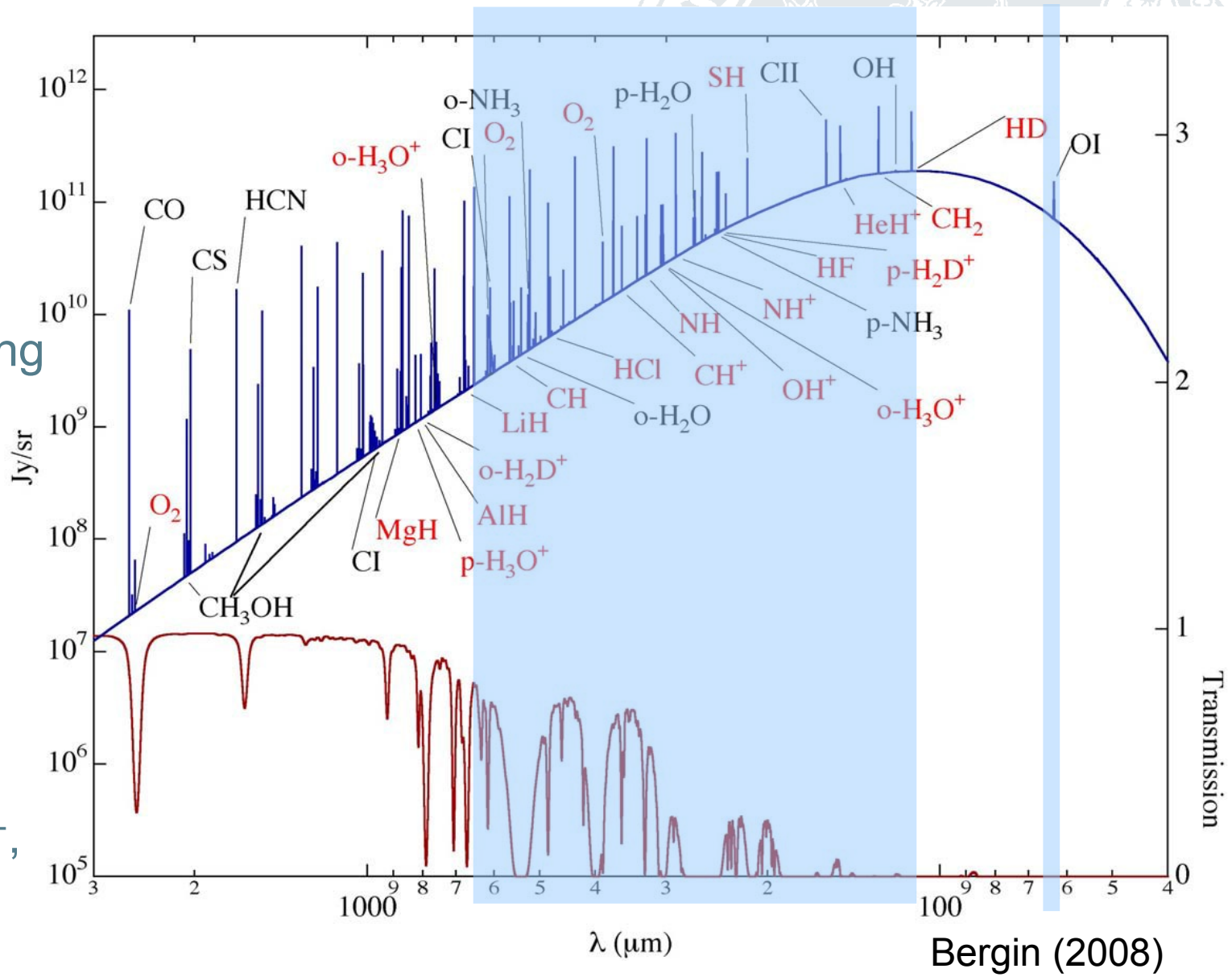
Ignoring the LOS confusion in other face-on galaxies does not solve the problem!



Typical spectra across 30 Dor (Okada et al. 2018)

OST-HERO science

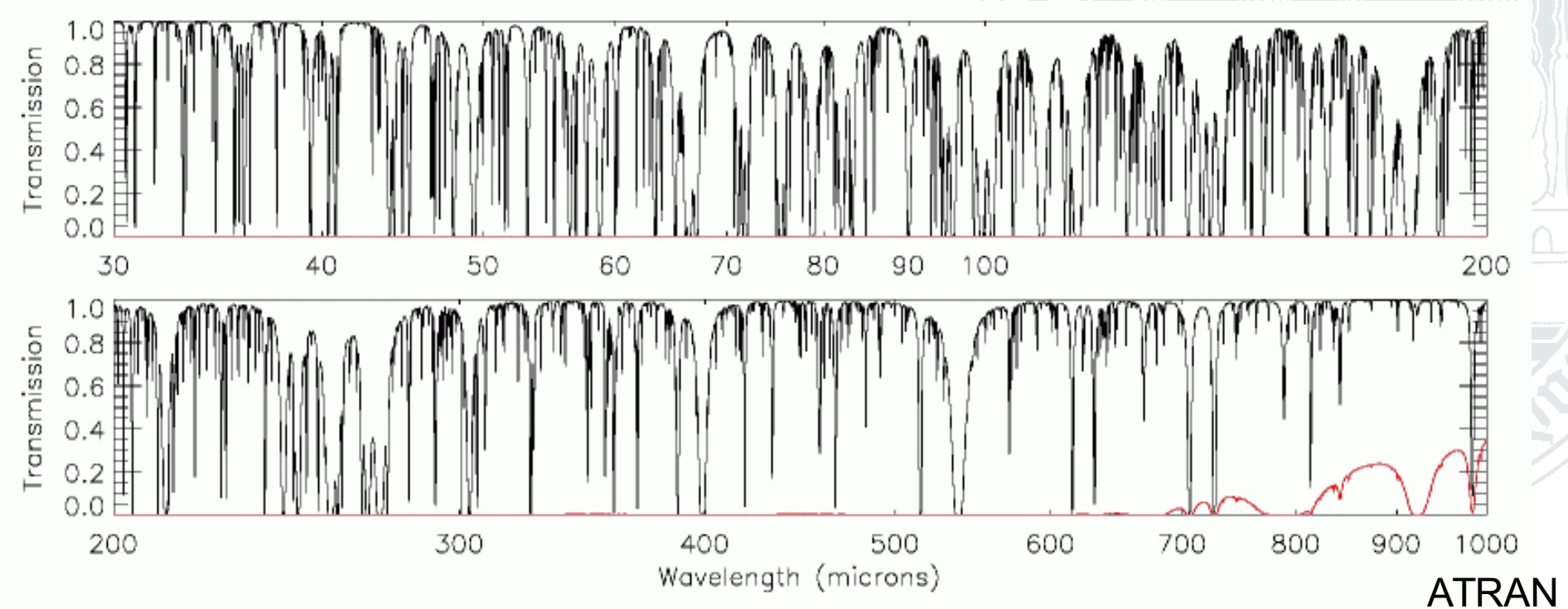
- Main cooling lines:
  - [OI], [CII]
- Embedded HII:
  - [NII], [OIII]
- Chemistry building blocks:
  - C, OH, HD
- High-J CO
- Hydrides
  - H_2O, HF, ArH^+, OH^+, H_2O^+



Bergin (2008)

Comparison with upGREAT onboard SOFIA

- Main problem – atmosphere:



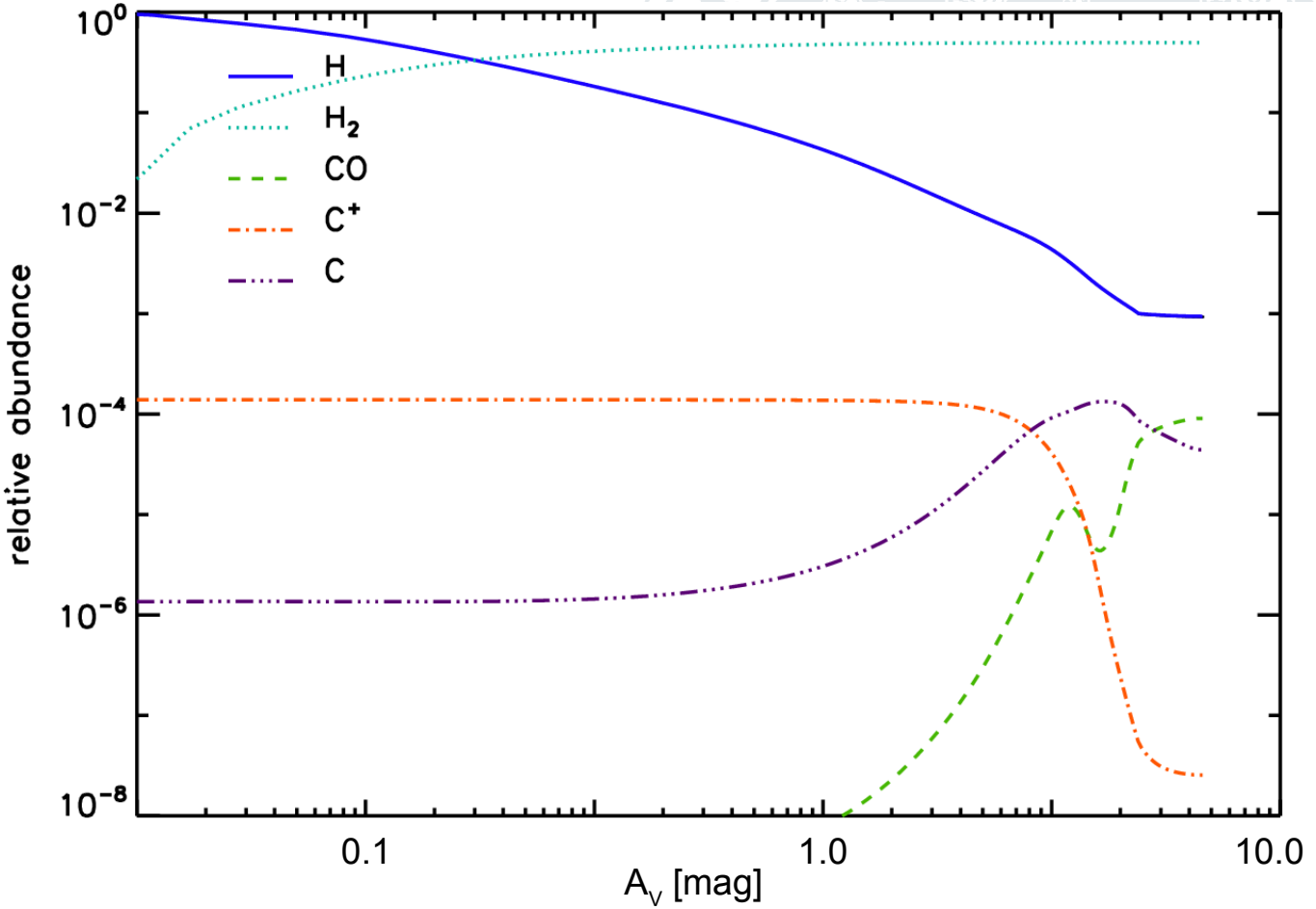
ATRAN

  - [OI] 145μm often impossible for Galactic sources, both [OI] lines impossible for nearby galaxies
  - Sparse redshift coverage of [CII] below z=3
  - Basic hydrides impossible from SOFIA: CH, CH^+, H_2O, HF, (HD)

- And of course we would profit from a factor 2 higher spatial resolution!

Critical component - CO dark gas:

- PDR model for χ=1, n=10^3 cm^{-3}:

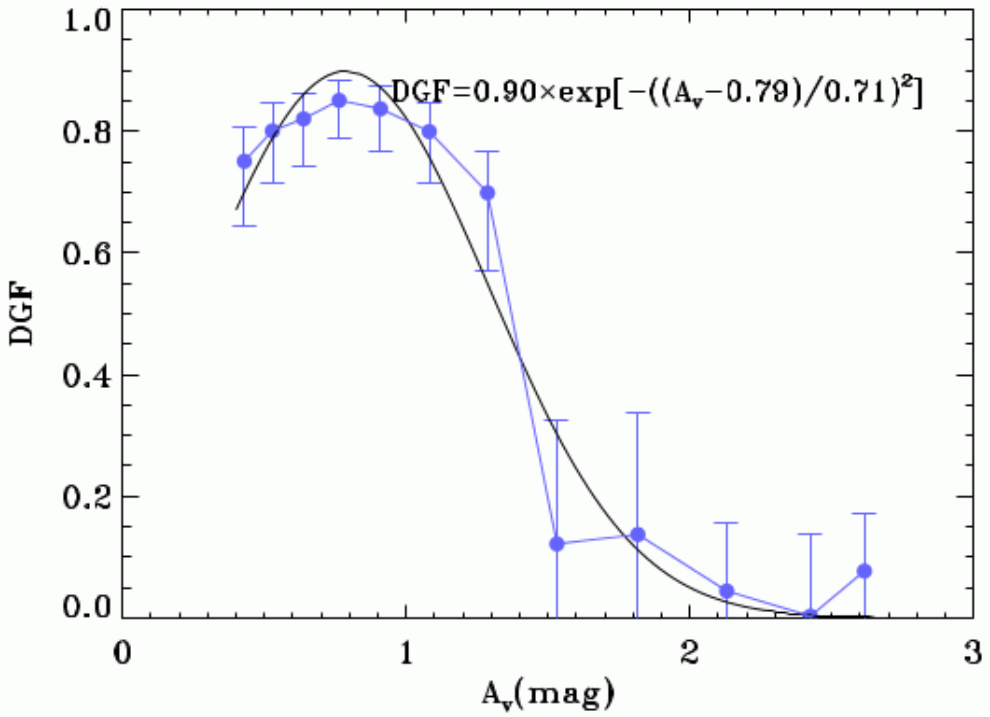


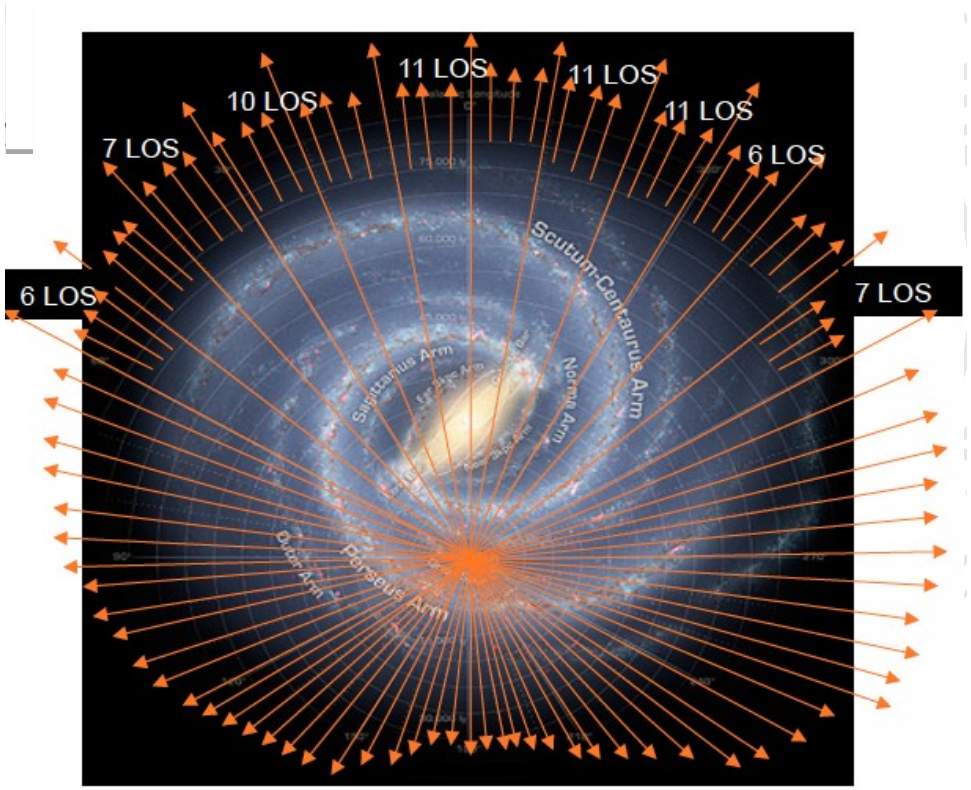
- Large fraction of H_2 not traced by CO
- Visible in [CII], HF, CH, CH^+

CO dark gas

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)

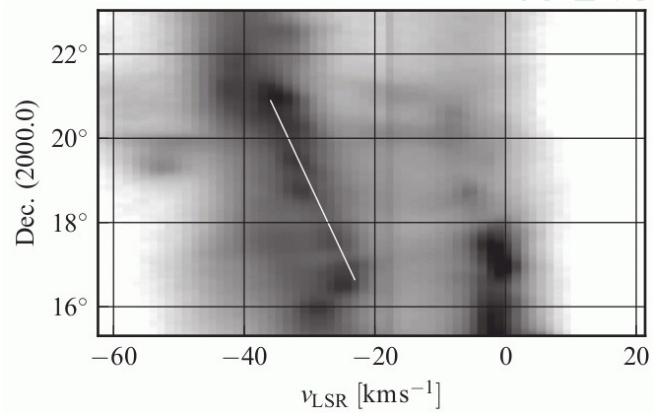


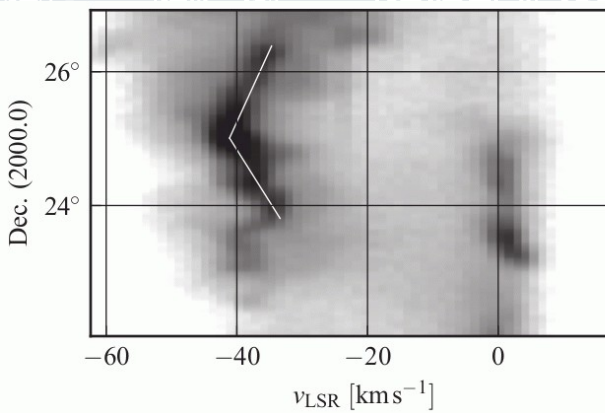


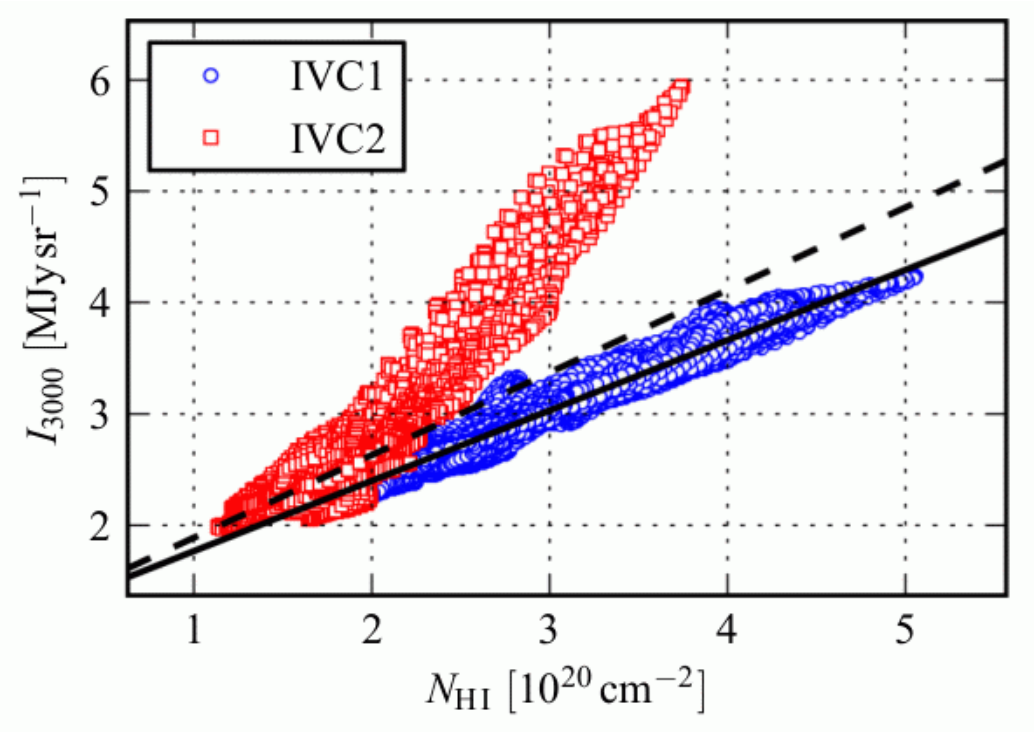
- Not much information yet for $b \neq 0$
- Fraction certainly higher
- We may still miss the majority of the interstellar gas today!

Mass assembly of the Milky Way disk

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





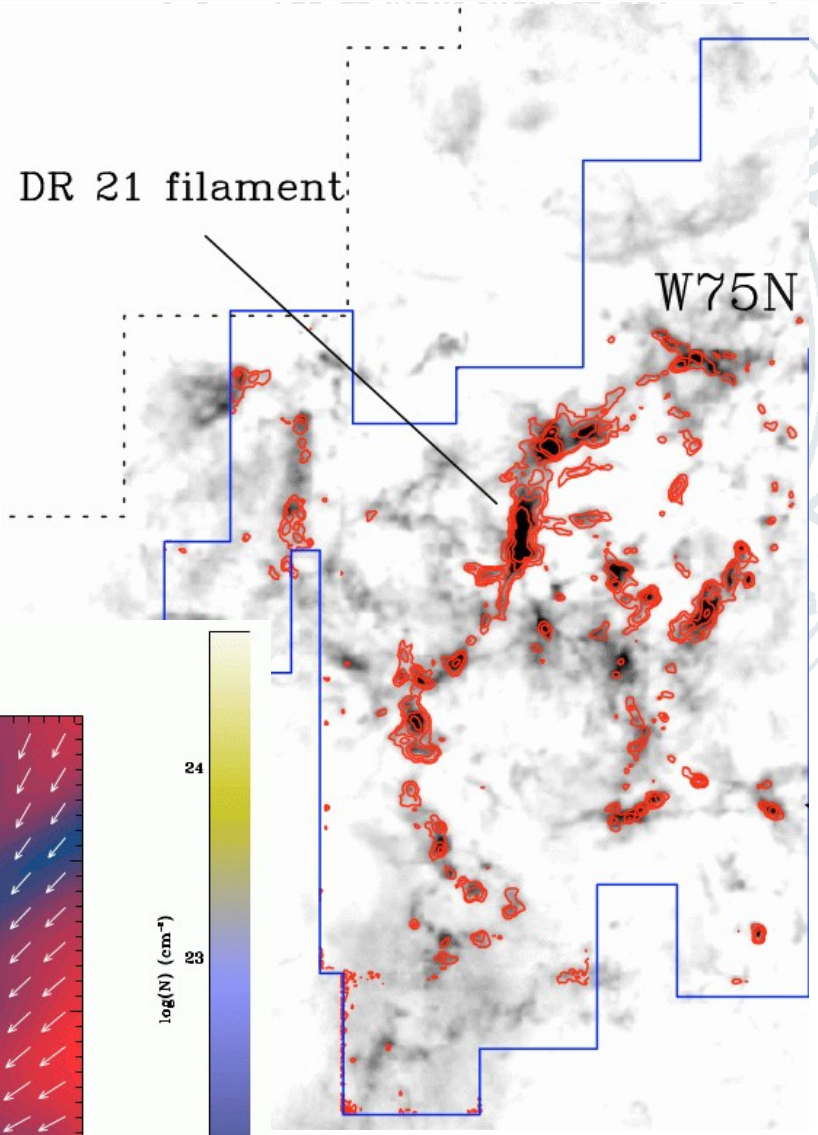


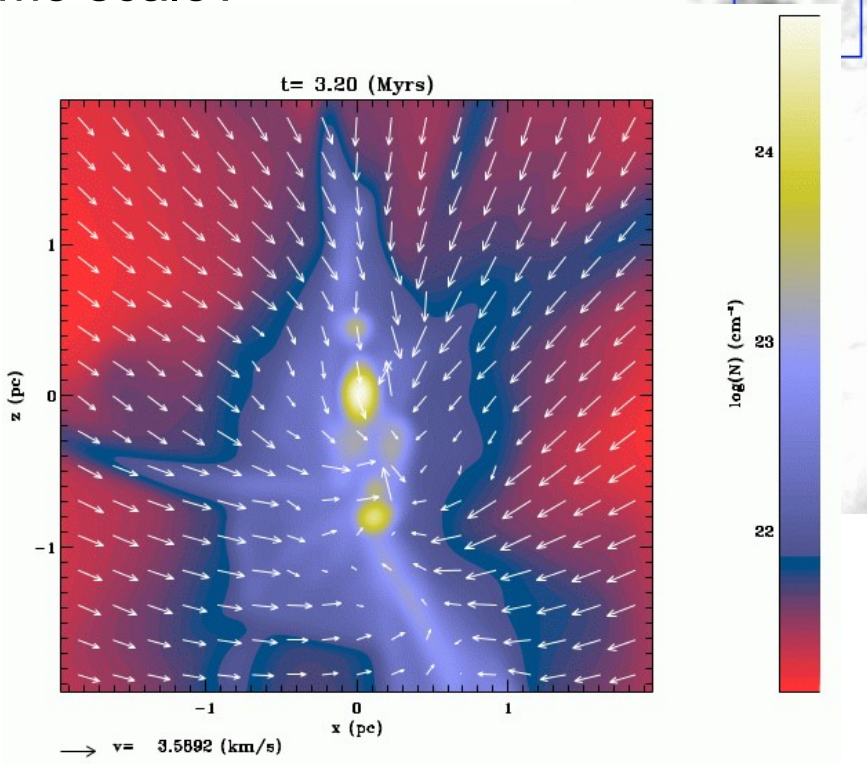
• 2 Intermediate-velocity clouds mapped by Röhser et al. (2014)

- p-v-diagrams show interaction with disk material at Δv ~ few km/s
- Dust column vs. HI column shows very different dust content
- Clouds dense but invisible in CO

Open questions

- 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?
  - Relation between chemical transition time scales and infall time scale?
  - What is the infall velocity?
  - Does the infall create shocks?



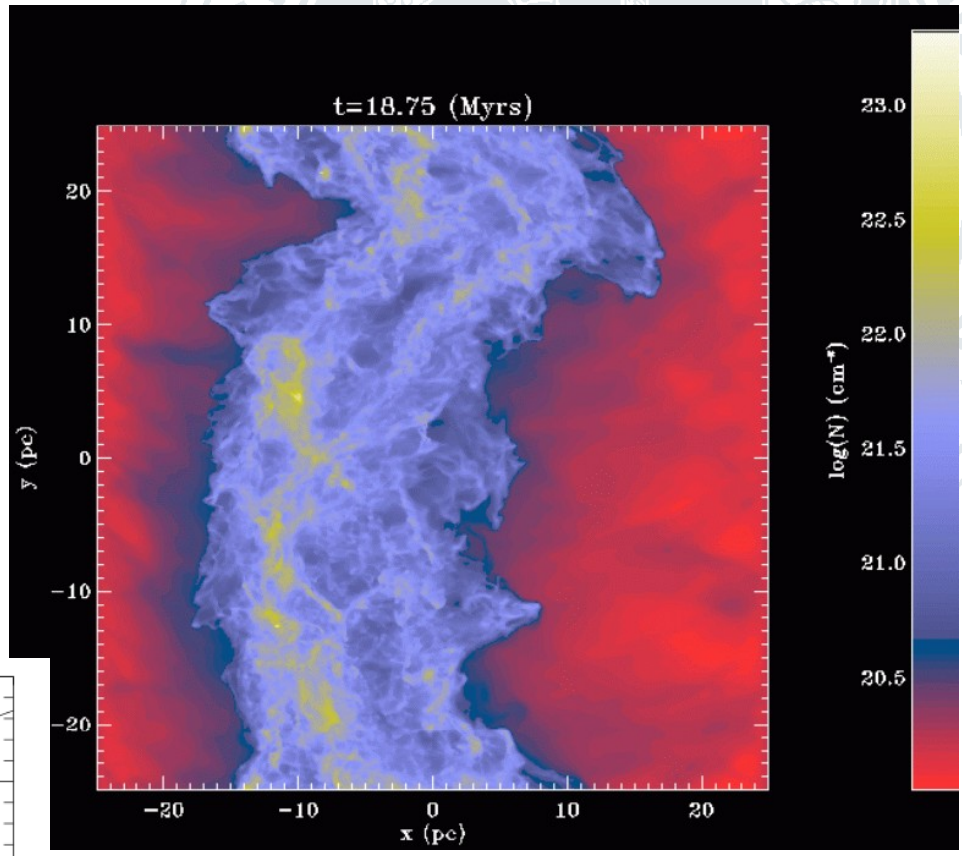


Schneider et al. (2010)

Science example II: Driver of interstellar turbulence

ISM feeding as main driver of interstellar turbulence?

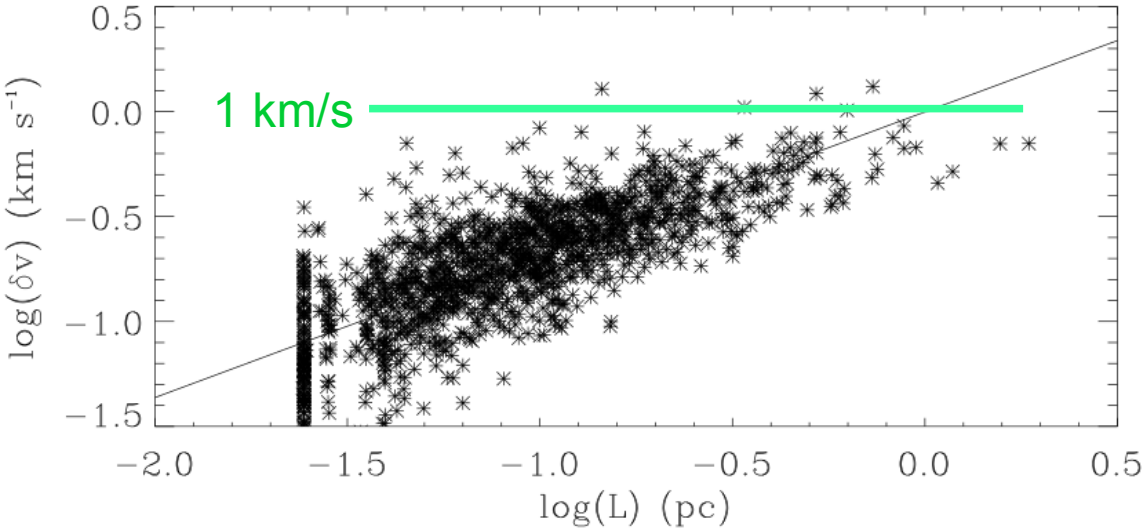
- Colliding flows unavoidably create turbulence
  - Mach-number of infall?
  - Impact relative to Galactic shear?
- Flows always chemically unstable
  - CO-dark material tracers



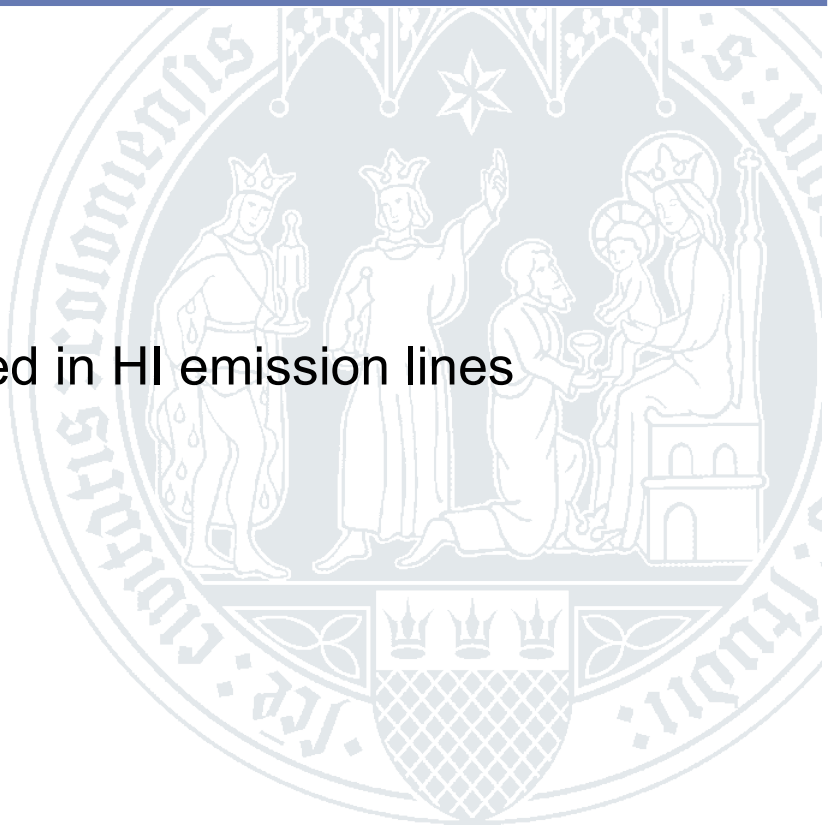
Colliding-flow simulation (column density map)

Klessen & Hennebelle (2010)

Size-linewidth relation of clumps in colliding flow



Open questions



Driver of large-scale turbulence in the ISM

- Mass accretion as a feed of turbulent motions
  - Primarily diffuse atomic gas, but too confused in HI emission lines
  - Low density molecular hydrogen:
    - *CO-dark* molecular gas
- Deconvolve the effect of Galactic shear
- Quantify SN driving

Hierarchy of intermittent scales of turbulence dissipation

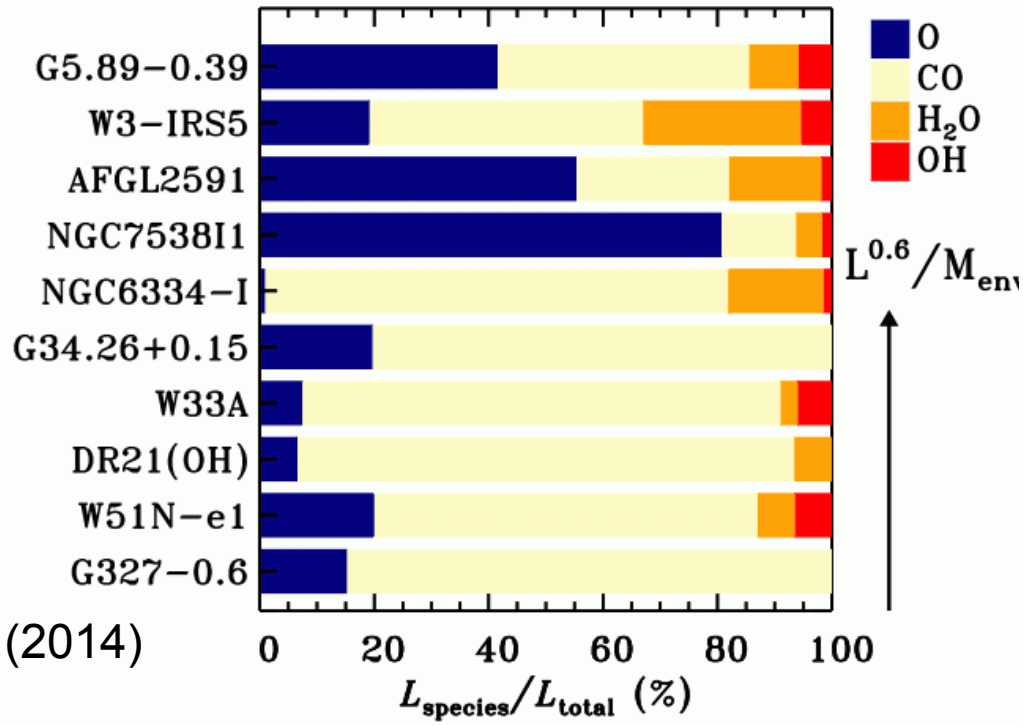
- Low velocity shocks as tracers of intermittency
- Line cooling of shocks
- Localized and direct measure of energy losses due to turbulent dissipation observed in post-shock gas

Science example III: Role of stellar feedback on galactic scales

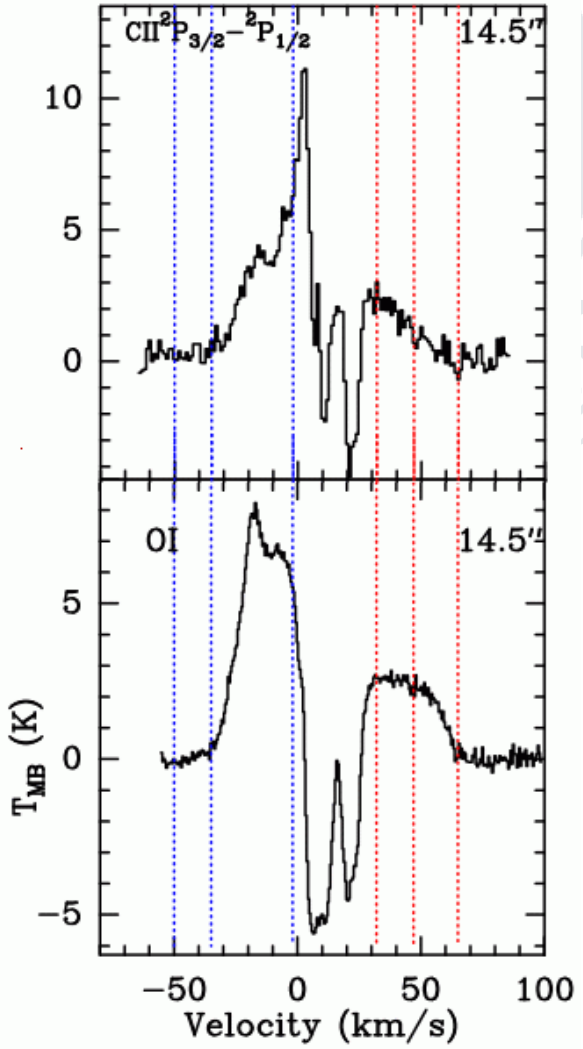
[CII] and [OI] as cooling lines and star-formation tracers:

- The Herschel view:
  - [OI] main cooling line
  - [CII] SF tracer
    - But line deficits

Karska et al. (2014)



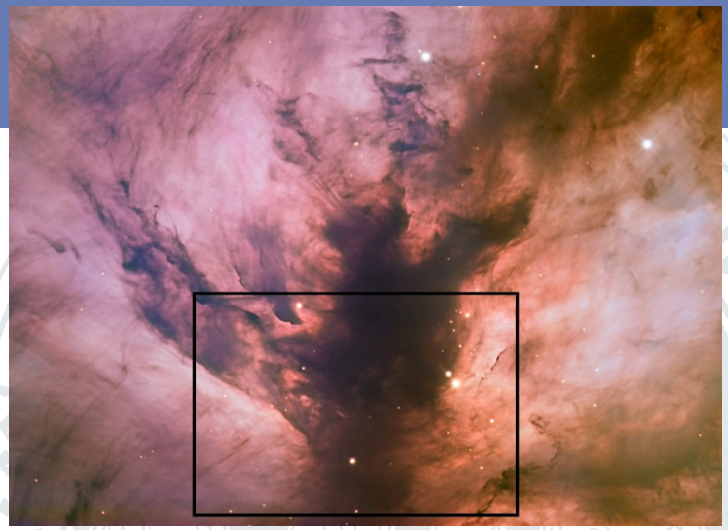
G5.89-0.39:



- News from SOFIA:
  - Complex [CII] and [OI] profiles
- Spectral resolution is the key!
- Explanation of FIR line deficit needs resolved lines

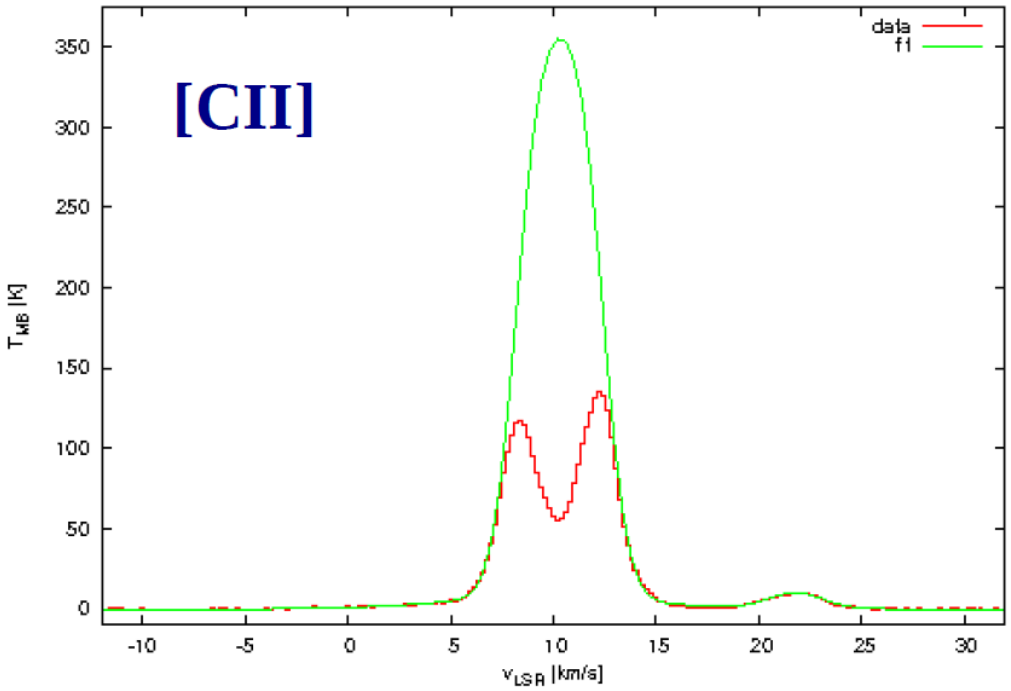
(Leurini et al. 2015)

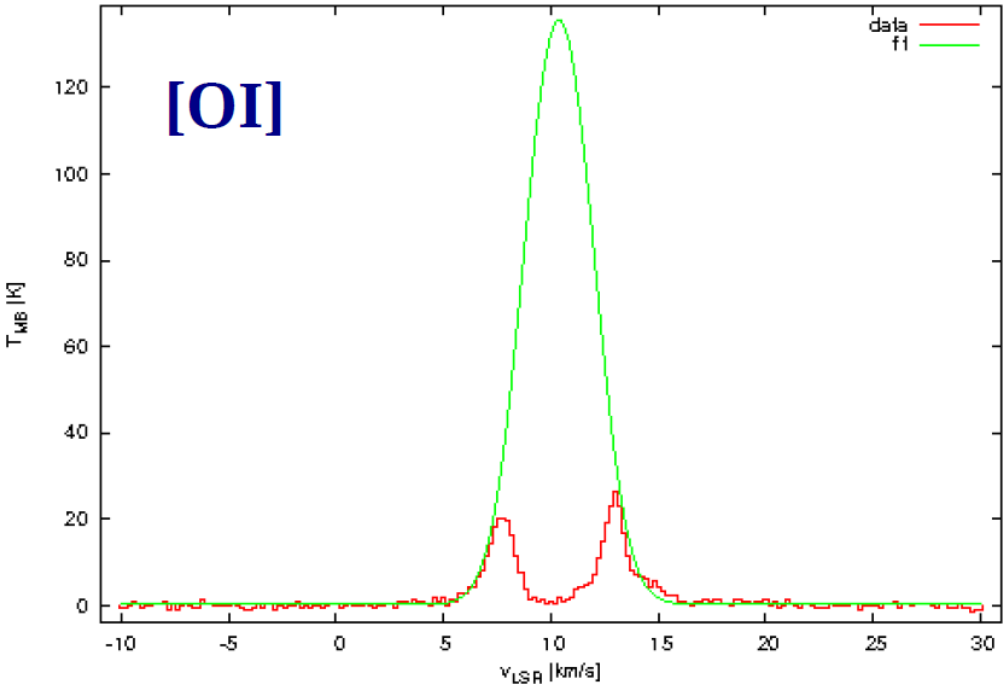
Extreme example: NGC2024



SOFIA/upGREAT observations:

Graf et al. 2012, Graf et al. in prep.





- 85% of [OI] emission obscured by foreground
- Consistent with foreground hydrogen column density 10^{22} cm^{-2}

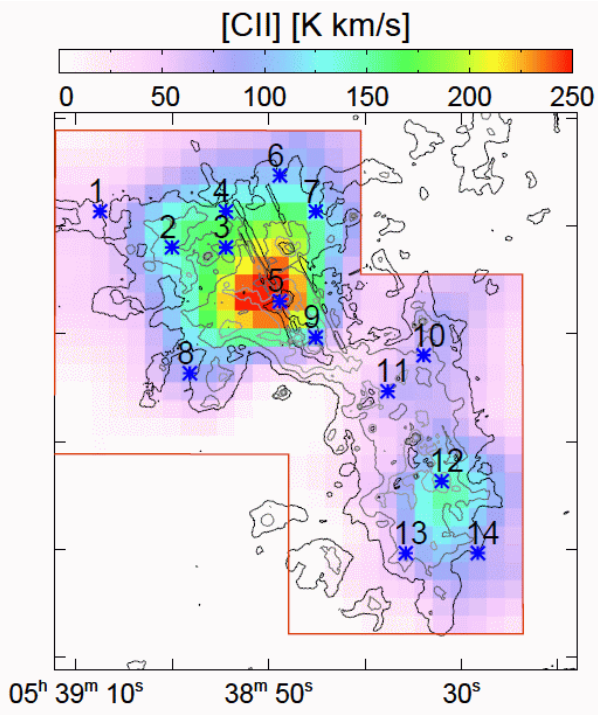
Open questions:

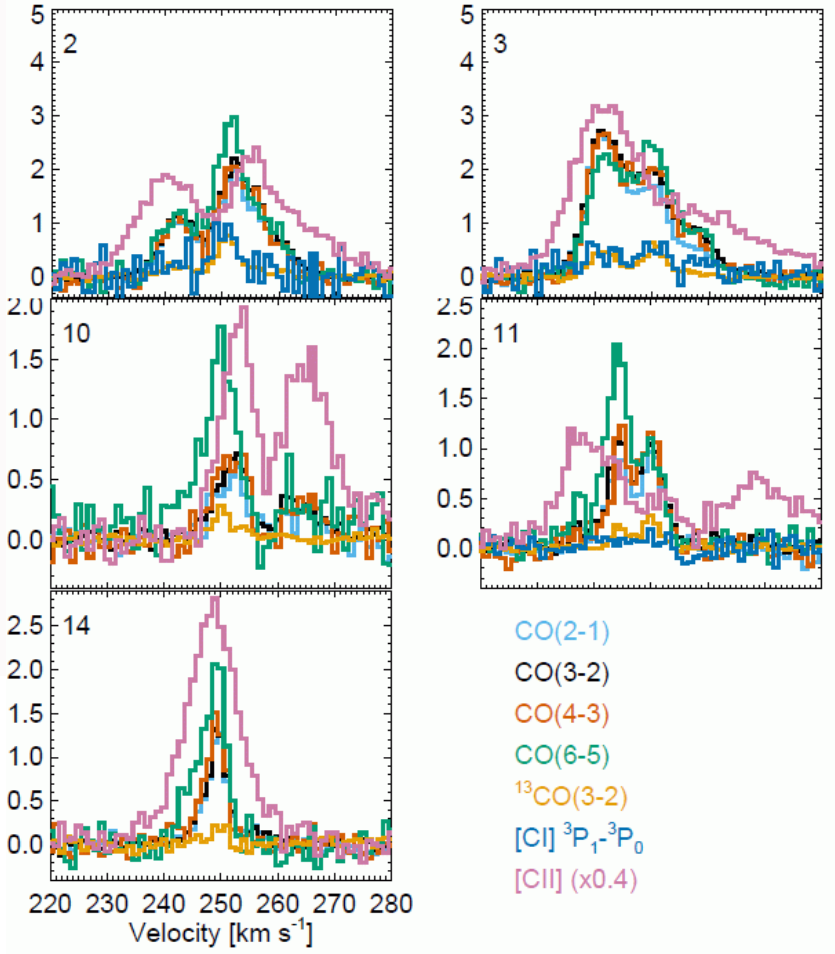
- Role of stellar feedback on the Galactic scale
  - What are good star-formation tracers ?
  - Contributions of different phases to Galactic emission of [OI], [NII], [CII]
  - Role of PDRs in the total line cooling of a galaxy

Science example IV: Nearby Galaxies

Same questions also for resolved galaxies

30Dor (Okada et al. 2018)





- Quantify the amount of each ISM phase
- Determine how the phase distribution varies
  - for different type of galaxies.
  - as function of environment
- Deduce how these properties affect star formation rates

But: For most nearby galaxies both OI lines not observable from SOFIA

Summary of the science case

What determines the ISM structure that drives star and planet formation in galaxies?

- Formation, growth, evolution, and dispersal of ISM clouds
  - Accretion of high-latitude material onto the Milky Way
  - Mass assembly of molecular clouds
  - Galactic scale statistics on the CO-dark molecular gas
  - 3-D distribution of the different phases
- Main driver of turbulent flows in the ISM
  - Mass accretion as a feed of turbulent motions
- Role of stellar feedback on the ISM dynamics on Galactic scale
  - [CII] as a star-formation tracer ?
- Large scale chemical and metallicity structure of the Galaxy
  - Including isotopes

All requires spectral resolution **better than 1 km/s**.