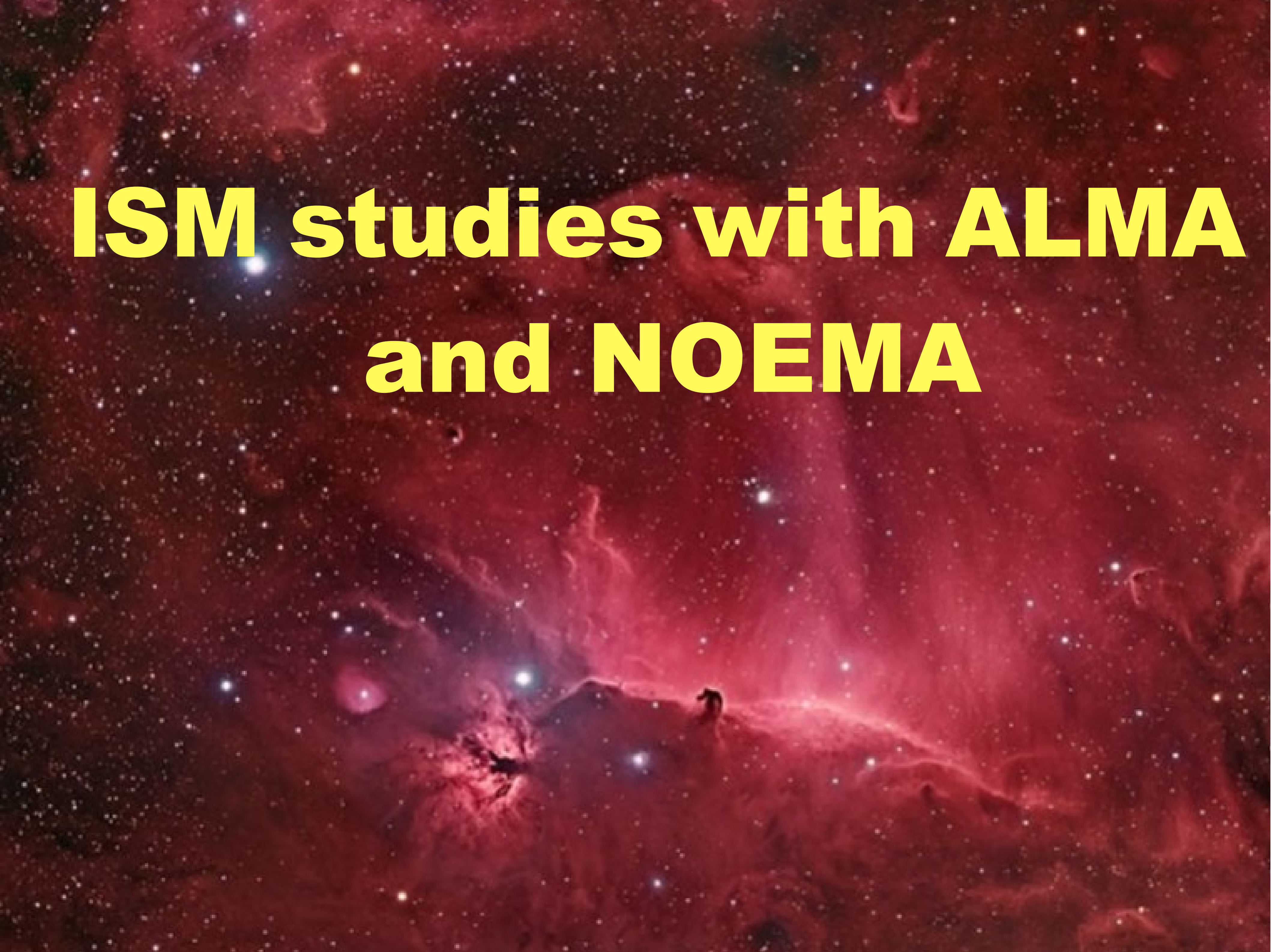
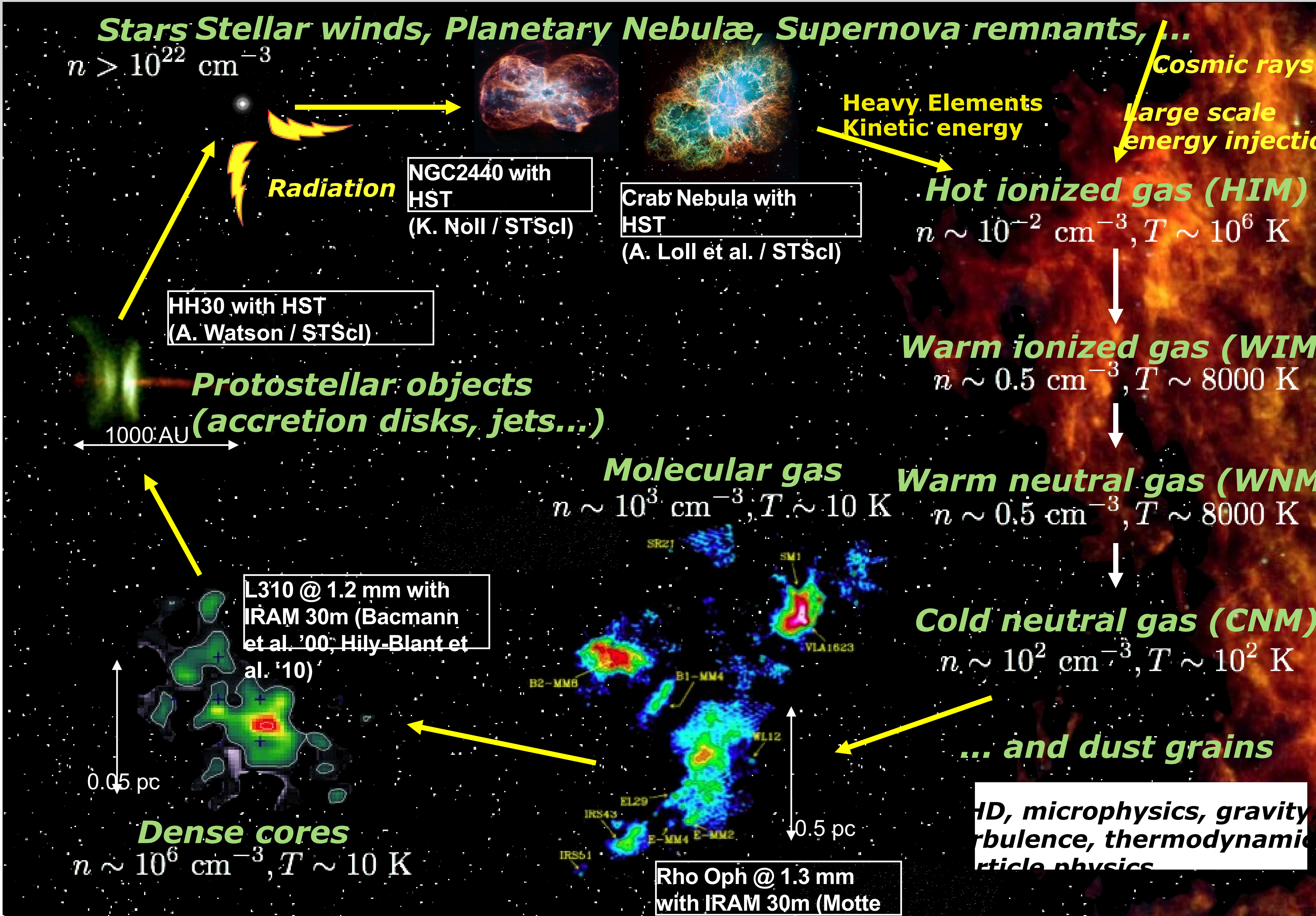
ISM studies with ALMA and NOEMA



The interstellar matter life cycle



Why ISM ?

- ISM : fuel & birth place for star formation → structure & physical conditions (n, T, B, v field)
- Enriched by stellar ejecta :

  - AGB stars , planetary nebulae, SNR

  - high energy radiation and particles
- Witness of star formation :

  - Energy balance → ISM thermal properties : heating / cooling processes

  - feedback processes : radiative, mechanical,

  - star formation diagnostics
- Fuel for planet formation : Astrochemistry & molecular complexity.

  - Evolution of the matter (gas, dust, ices), connection with solar system
- In galaxy nuclei : Fuel for high energy phenomena (massive BH, AGN)

Why ALMA & NOEMA

Complex medium :

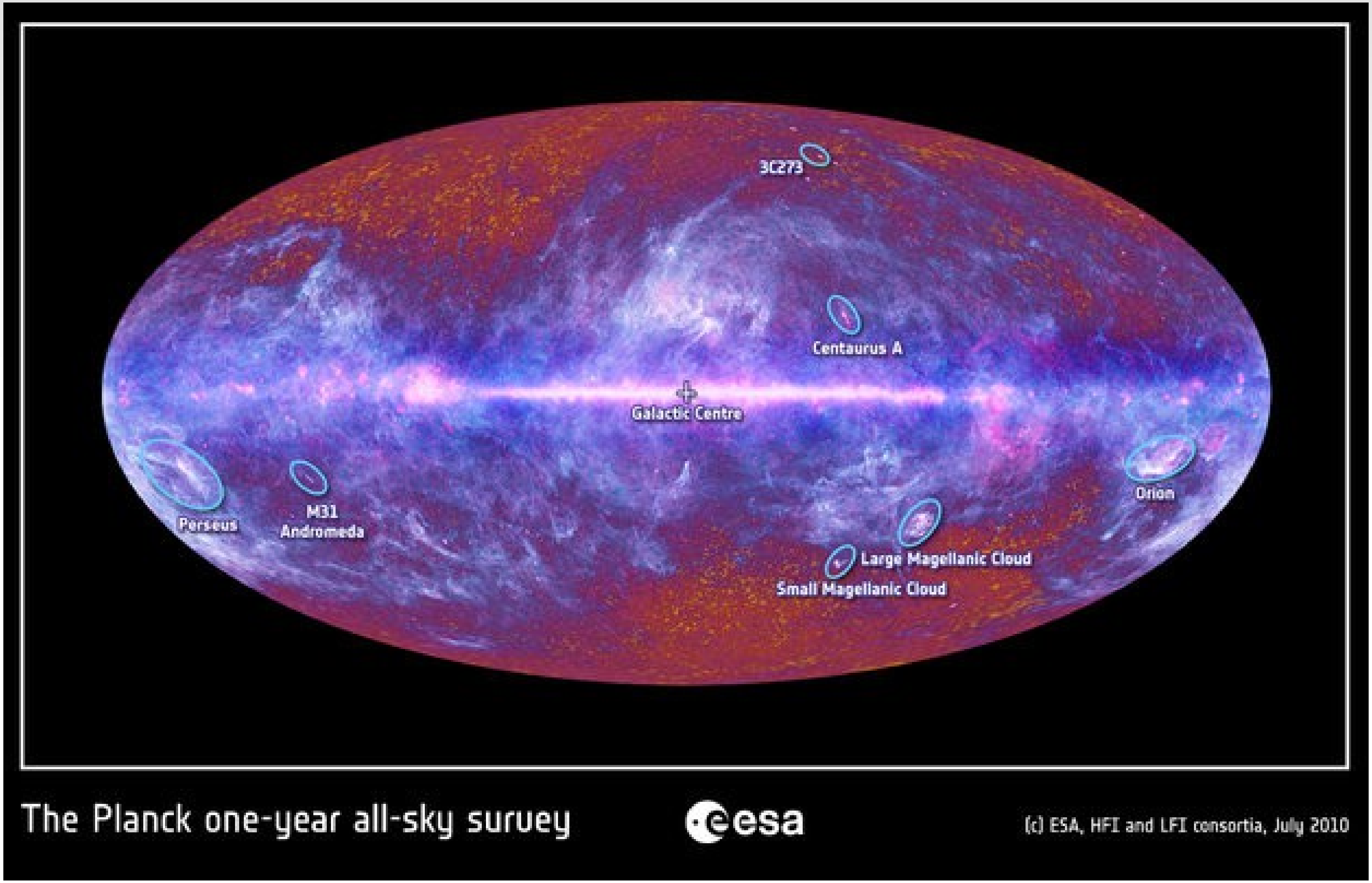
- Multiphase medium : Neutral (CNM/WNM), ionised
- self-similar structure from mpc structures up to GMCs (50pc) and GMC associations (500pc)
- multi-phase medium with broad range of physical conditions & complex geometry

A new dimension : Time variation : proper motions, source variation

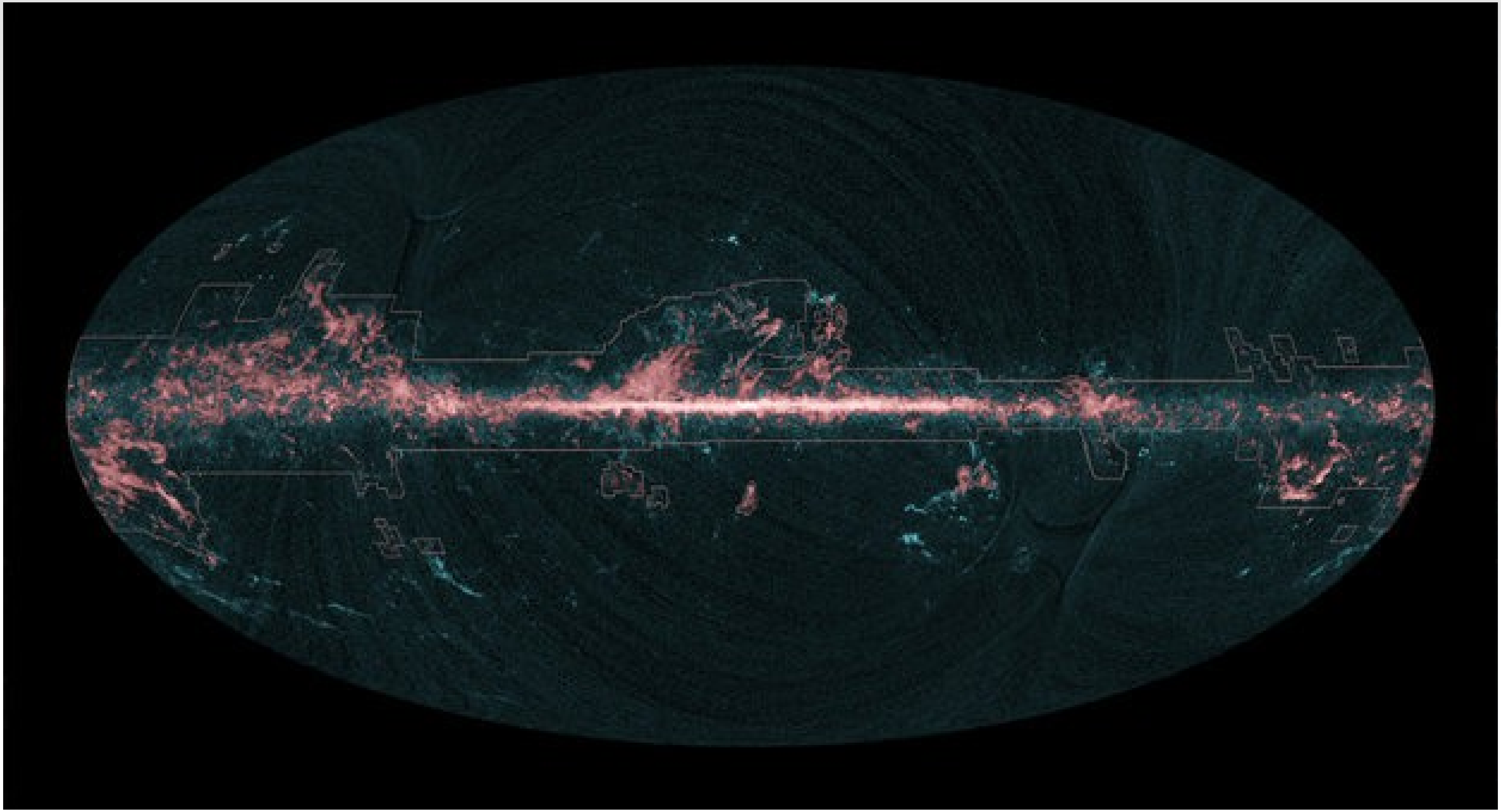
Some examples

- Feeding the ISM with stellar ejecta
  - IRC+10216, Mira …-> P. Kervella
- Diffuse ISM
- Filaments → P. André
- From prestellar to protostellar cores → P. André
- Radiative feedback : PDRs
- Dynamical feedbacks : Shocks
- The Galactic center as a template for external galaxies
- Global view in nearby galaxies : GMC and star formation
- ULIRGs : Massive black holes and feedback

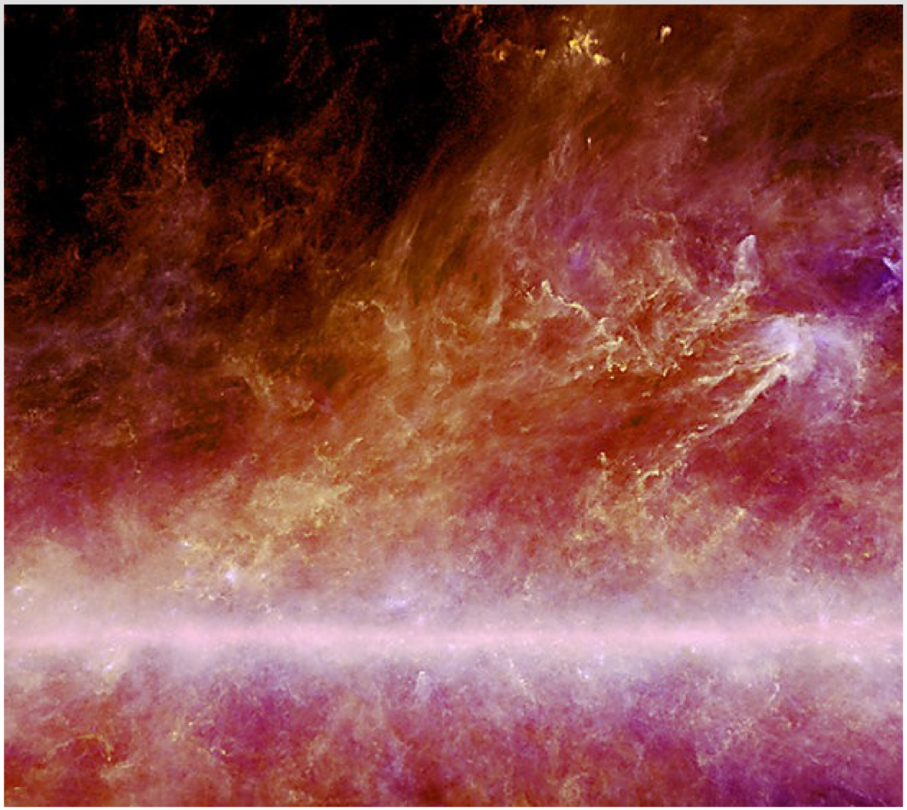
Planck view of the microwave sky

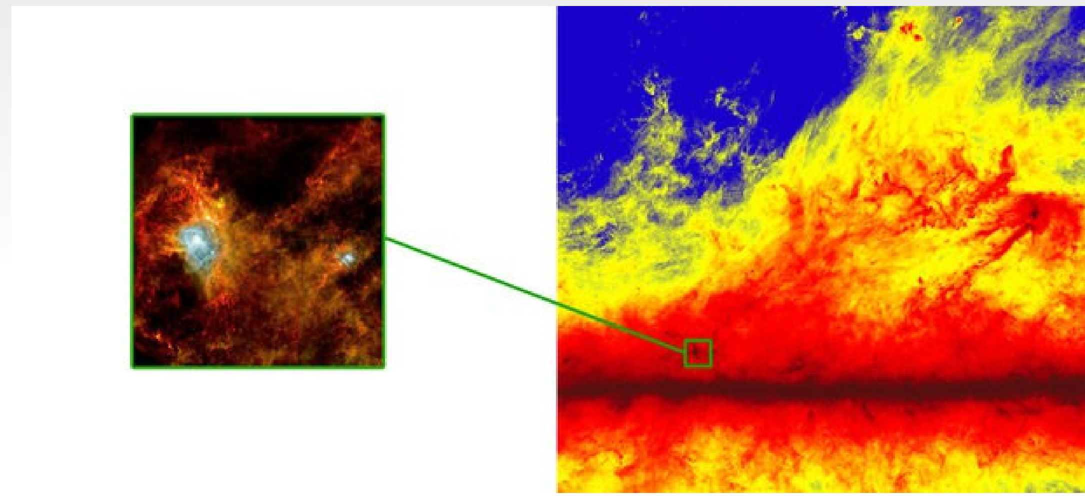


And a CO map



Large scale view from Planck & Herschel



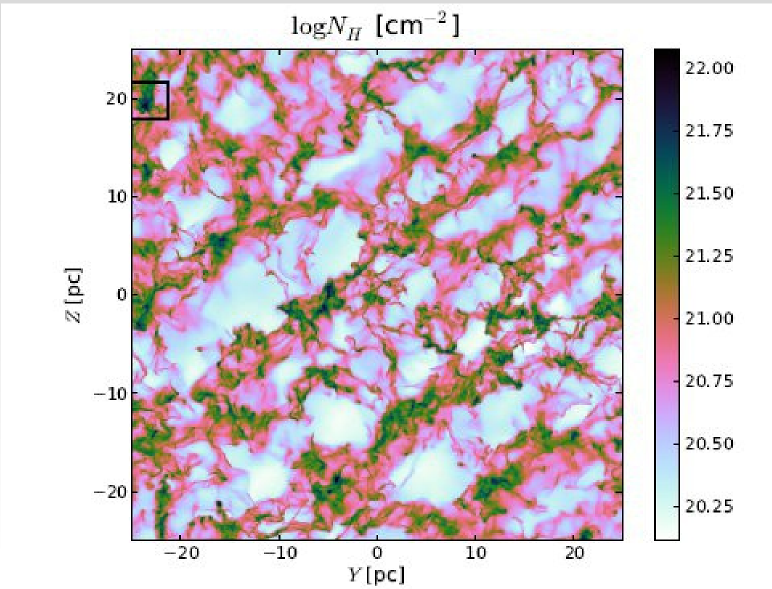


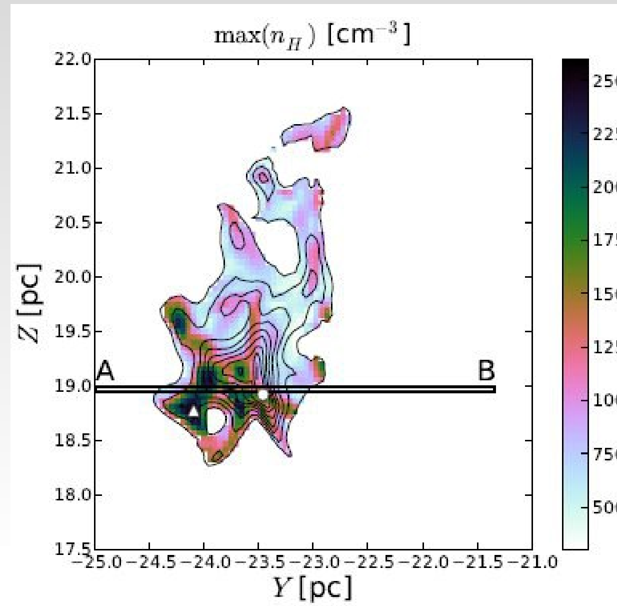
Planck : All sky + Herschel HI-GAL : MW plane

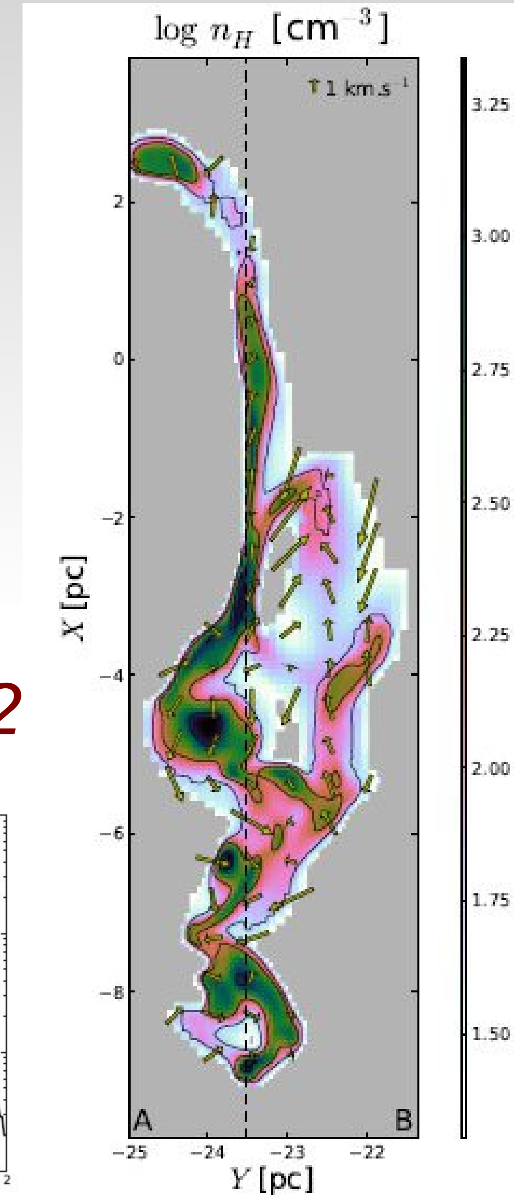
Ubiquitous filamentary structure

Tight connection between diffuse and dense ga

ISM models : coupling chemistry & MHD

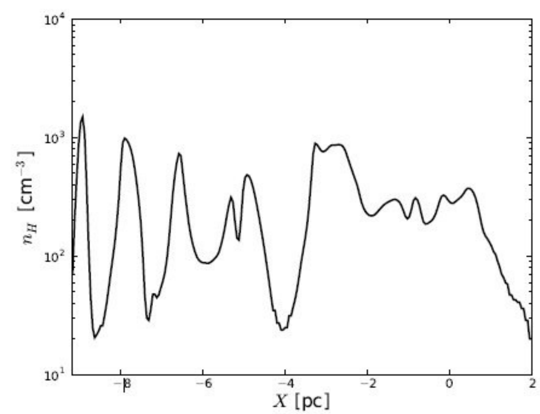




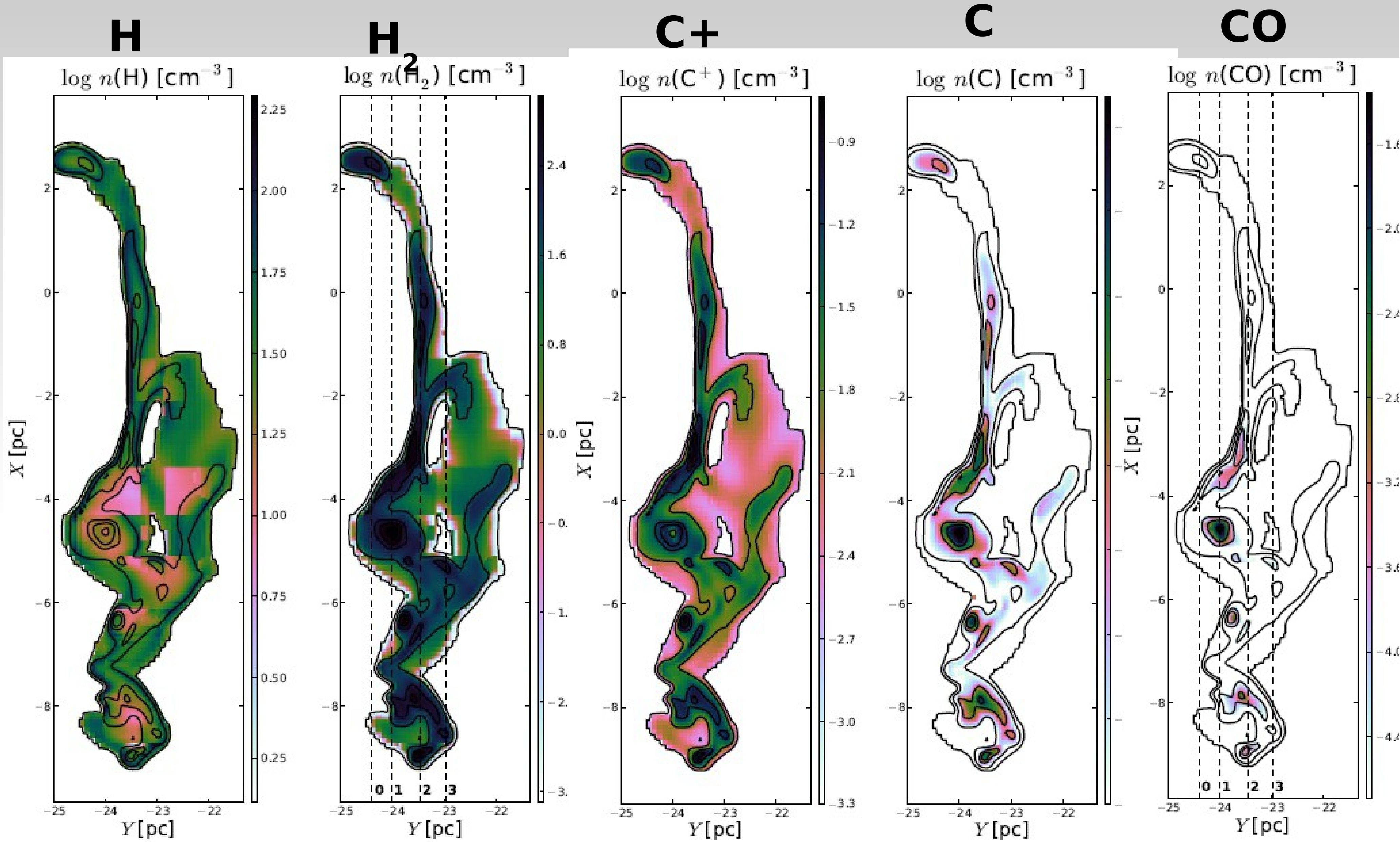


Levrier et al. 2012

MHD simulations + Meudo
PDR model
Color : density ~ 20 to 20(
cm^{-3}
Contours : T (20, 30, 50K)
Velocity field : arrows



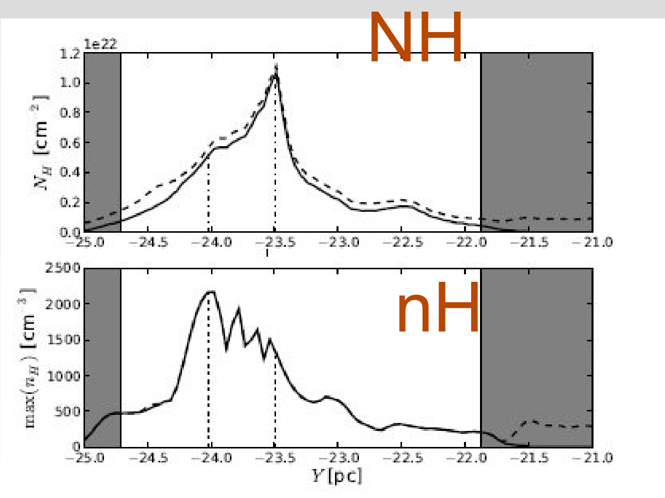
Density structure along the dashed line

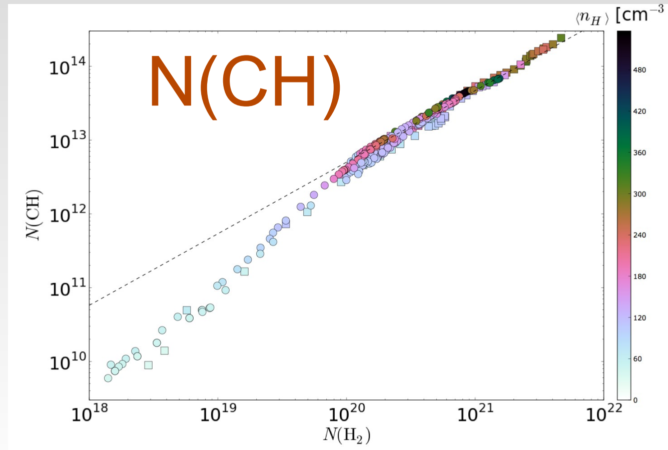


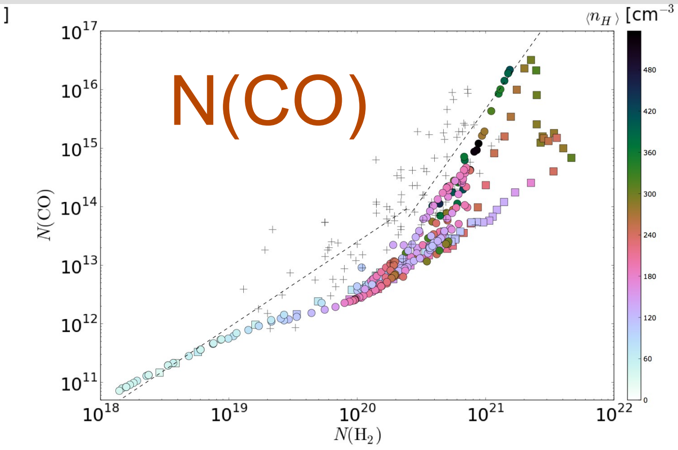
CO confined in density peaks

C^+ & C trace H_2 better. C^+ is the main reservoir of carbon in most of the domain.

Computing column densities

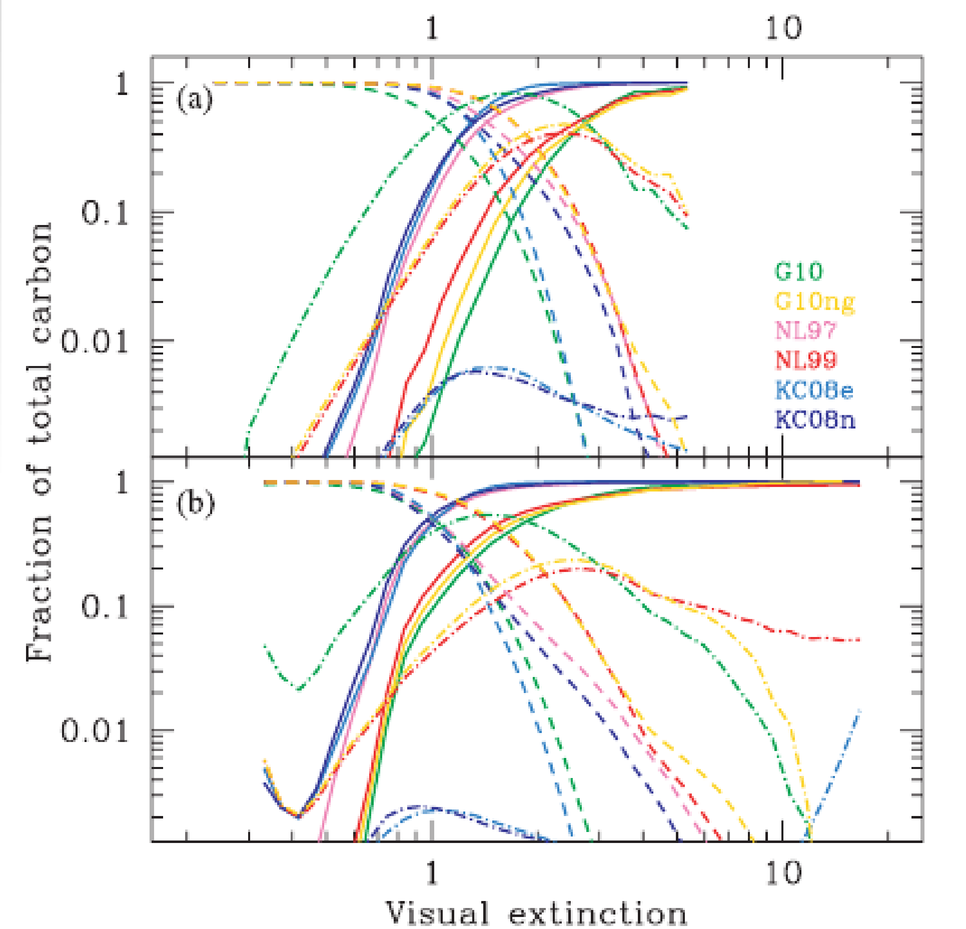


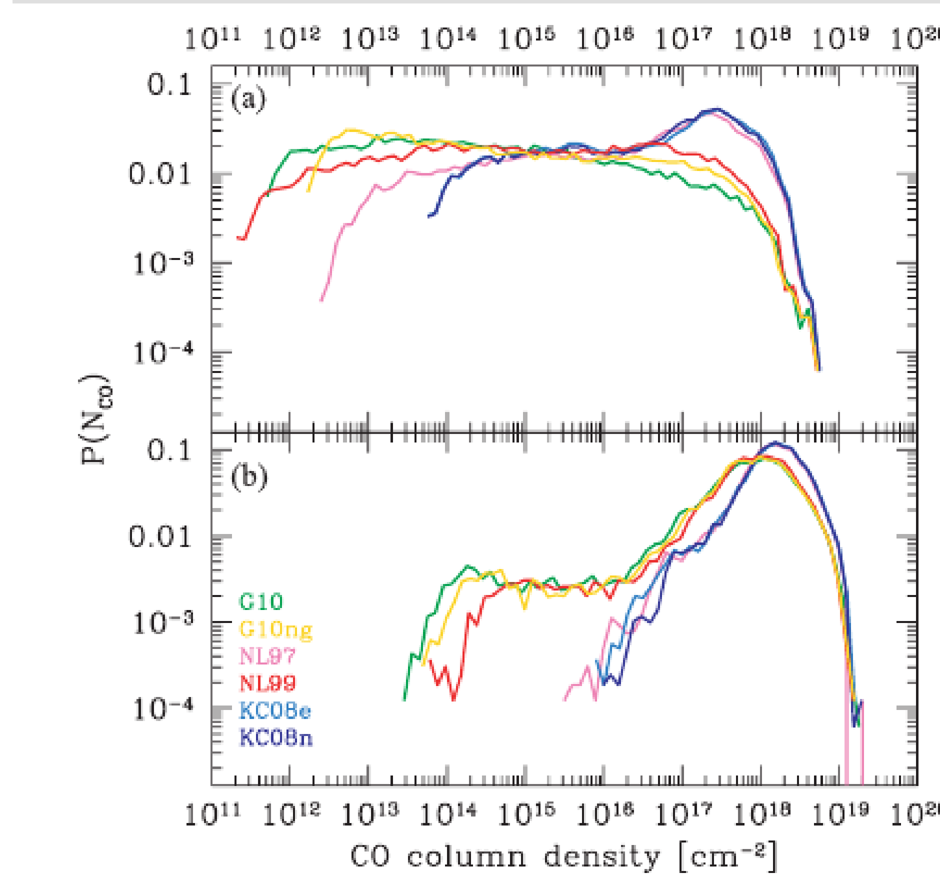




- The maximum NH does not go through the density peak
- CH follows H_2 closely, with the same mean abundance as observed in local diffuse clouds ($3.5\ 10^{-8}$; Sheffer et al 2008)
- CO is not reproduced at Av ~ 1mag → formation connected to the turbulence dissipation regions

Chemistry + MHD ; Network comparison



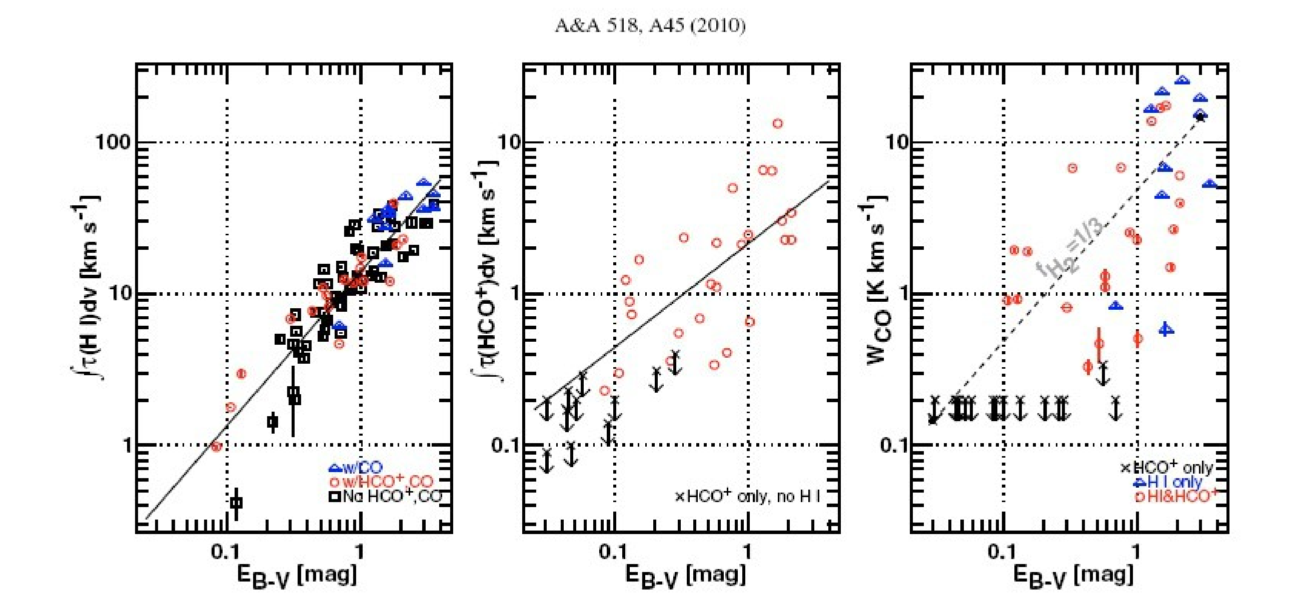


Set 1 low density (100 cm-3), set 2 medium density (300 cm-3). CO OK in the high density regions and for global X_{CO} but deficiency in the low column density regions

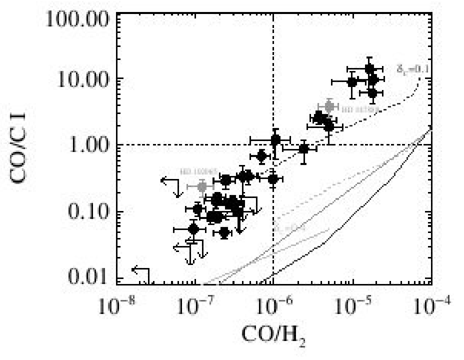
Glover & Clark 2012

CO formation and structure of the diffuse gas

- CO ~ Carbon reservoir fo
  Av > 1~ mag → GMC
- C+ carbon reservoir , CO ~
  optically thin. Diffuse gas
- Different 12CO/13CO line
  ratio



- Sharp spatial variation of CO brightness in diffuse gas
- Strong abundance variation in a small range of AV



Liszt et al 2010 + Sheffer et al 2008, Burgh et al 2009)

Diffuse gas at PdBI

CO in diffuse clouds

Falgarone et al 2009

Sharp structures in extended emission

Association with velocity shears

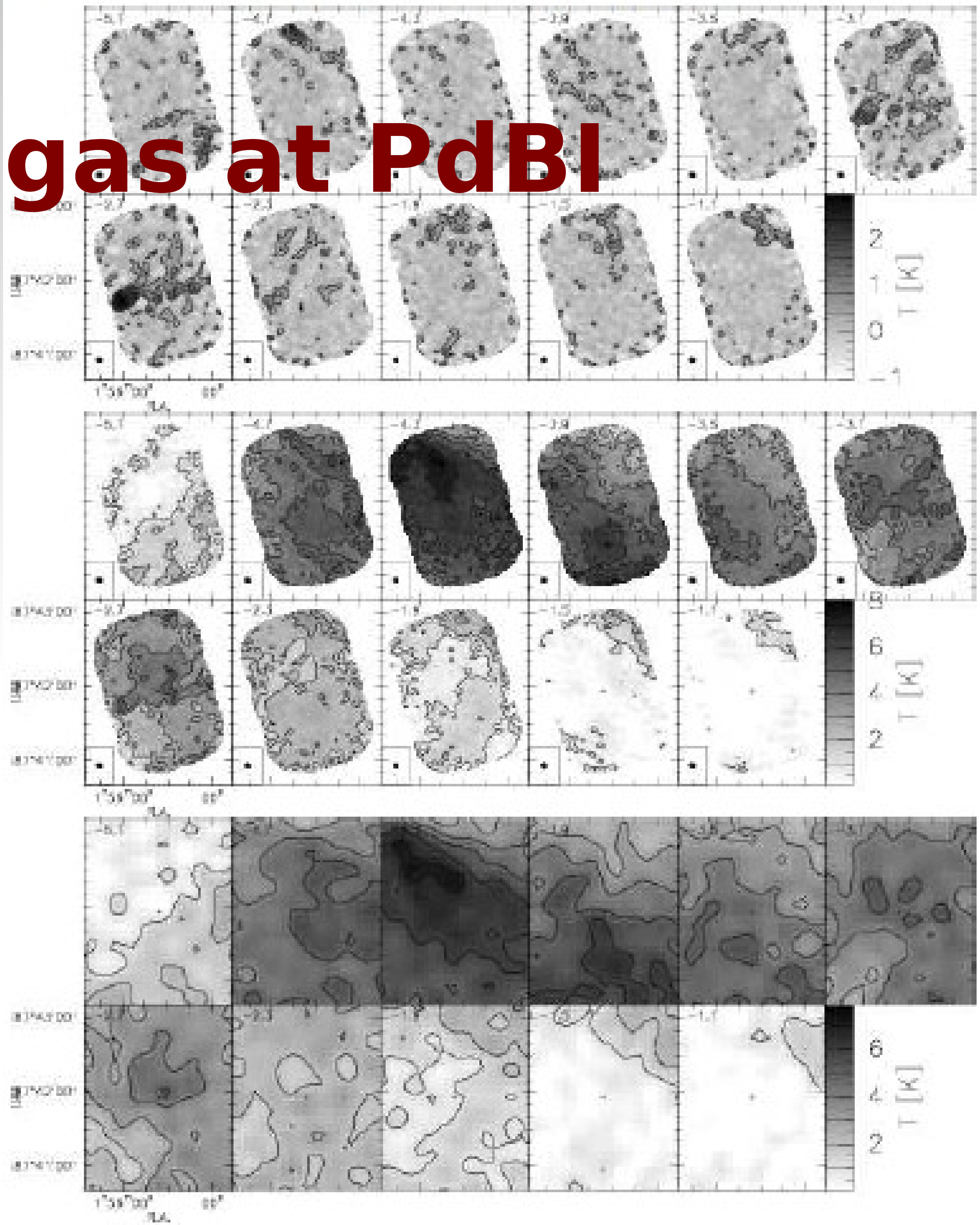
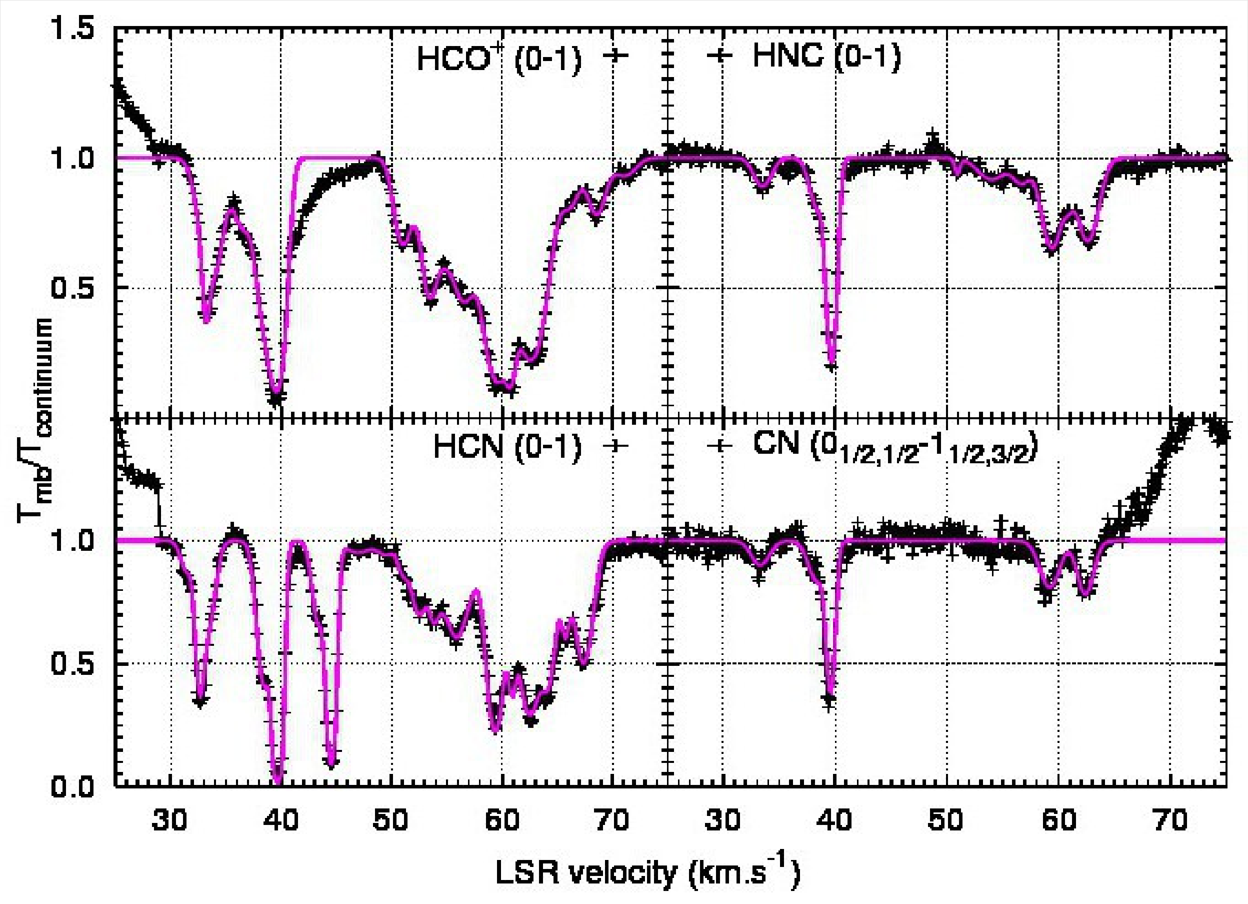
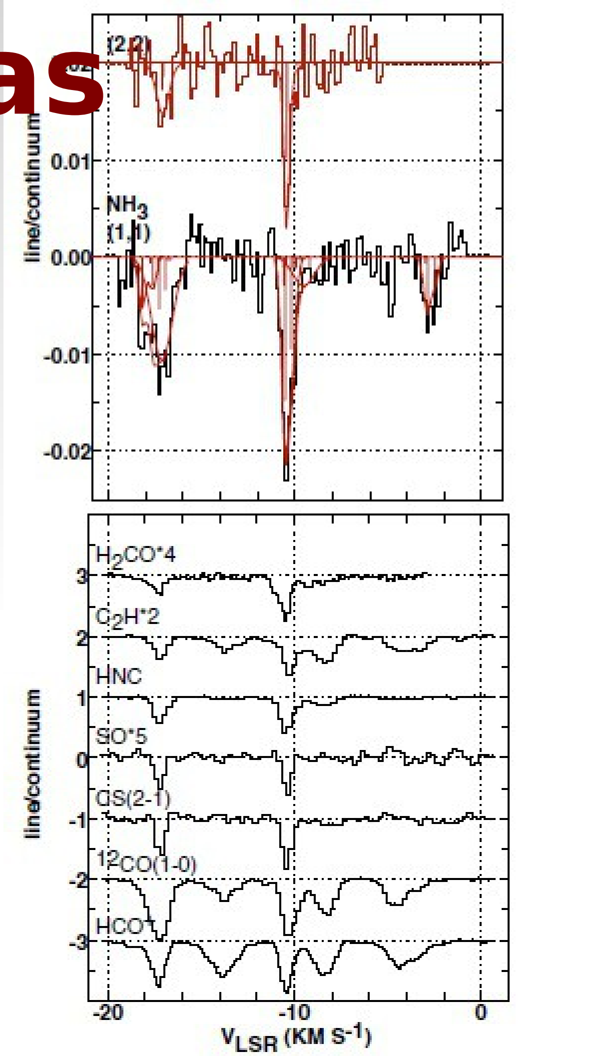


Fig. 3. From top to bottom, maps of the PdBI, PdBI+30m and 30m of $^{12}CO(1-0)$ emission integrated over the same velocity slices of 0.3 km s^{-1} centered as indicated.

Absorption : characterization of the diffuse gas

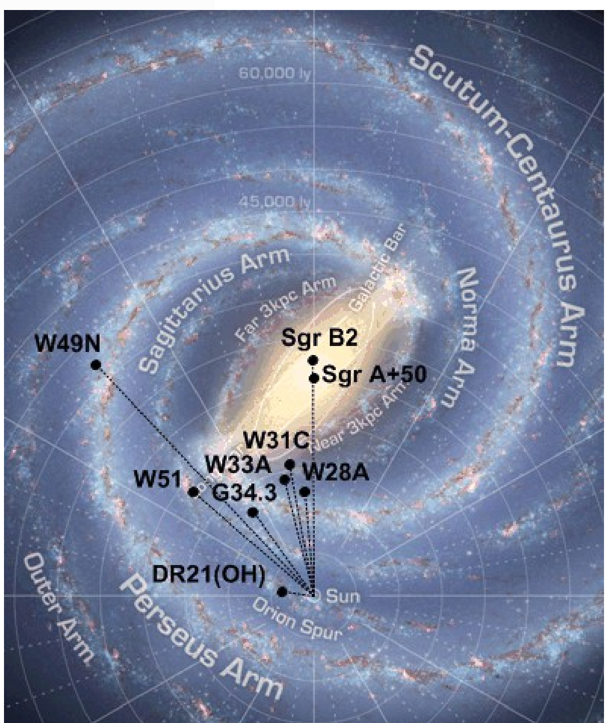


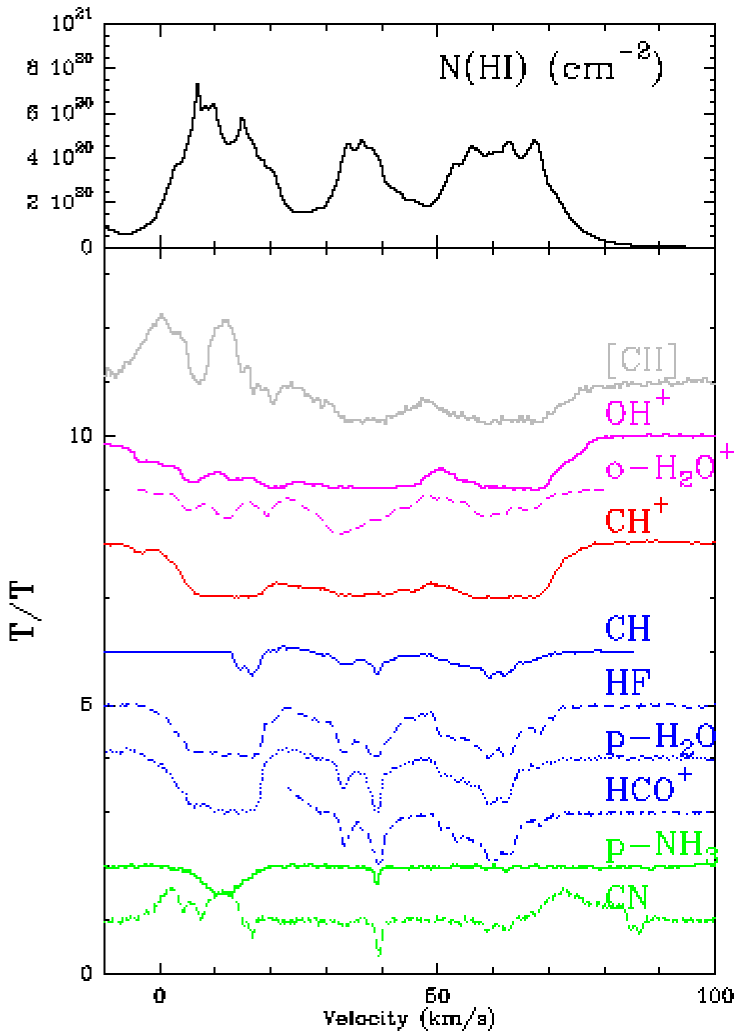


- Background sources = Distant HII regions or bright radio sources (QSOs) (Liszt et al, Godard et al 10 …) well suited to Inteferometers
- H2 tracers (CH like),--> Gas kinematics ;
- Turbulence (CH+, SH+), Cosmic rays (OH+, H3+, etc.)

Herschel hydride : the example of the line of sight towards W49N

The line of sight crosses two spirals arms.
V → position in the MW
Similar line ratios → Similar properties of the diffuse ISM across the Galactic plane





New Diagnostics

OH^+, H_2O^+, H_3O^+ : CR ionization rate

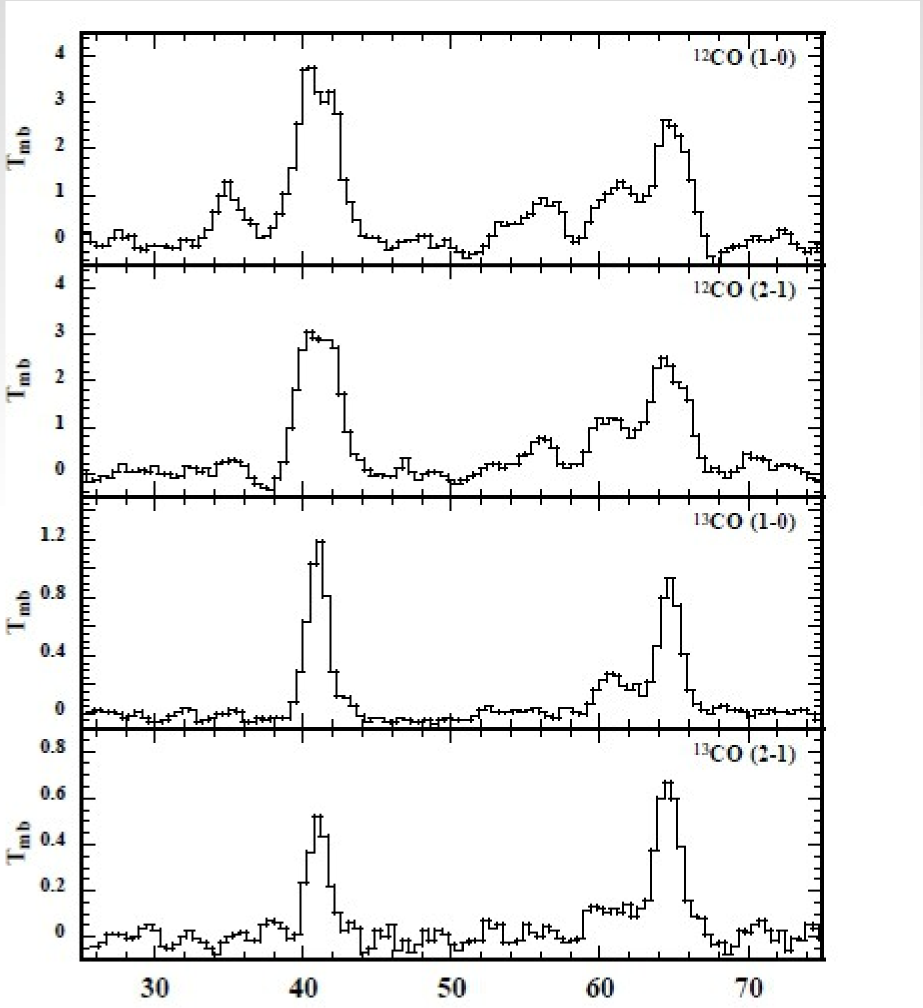
CH^+, SH^+ : Dissipation of turbulence

CH, HF (H_2O, HCO^+) → H_2

C^+ , C & HI → n,T

NH_3 (NH_2, NH, CN) → higher density

H_2 tracers vs CO along the W49N line of sight

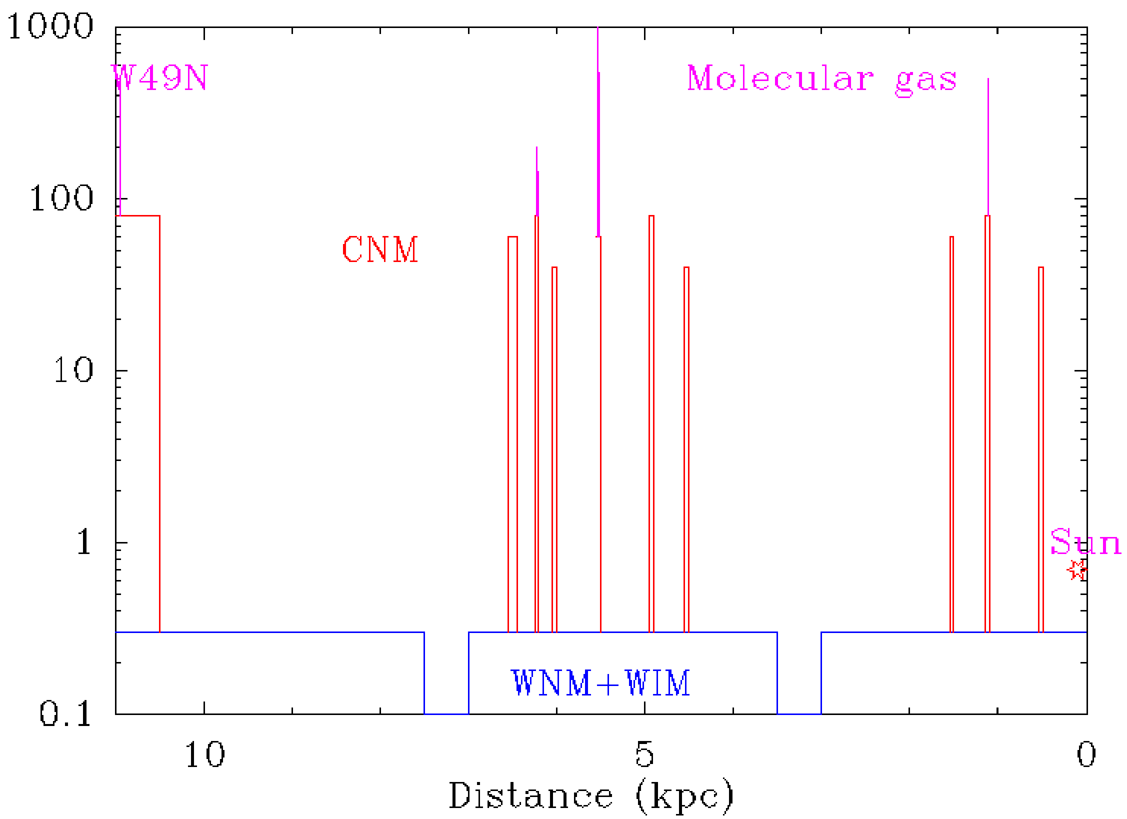


CH, HF (Herschel) CO (Vastel 2000)

Broader velocity distribution of CH & HF opacity than CO emission

Tomography along the line of sight to W49N

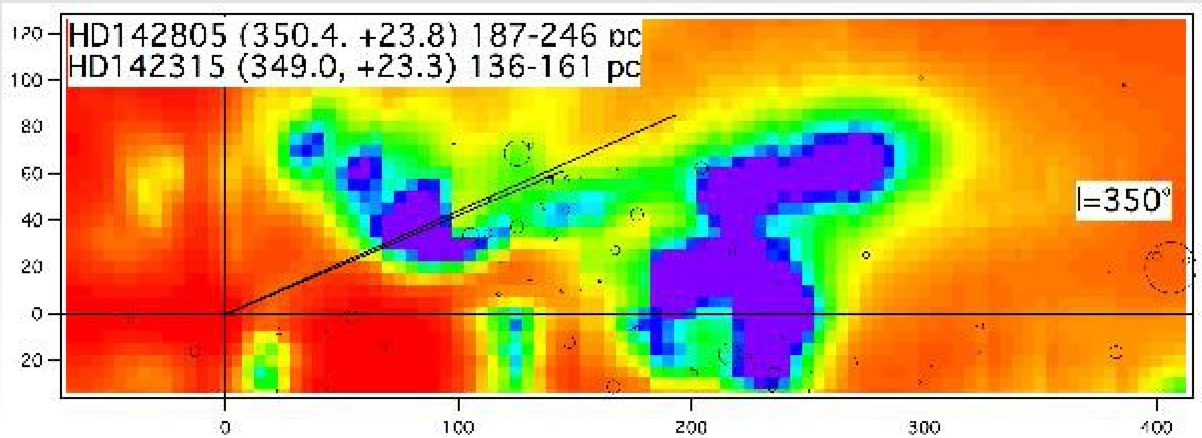
Thanks to Herschel, we have good tracers of the total gas column density :
HI abs → CNM; CH & HF → H_2, CII → H_tot
We can determine the fraction of H in H_2 the gas density & pressure (using T from HI) & connect CNM and molecular gas.

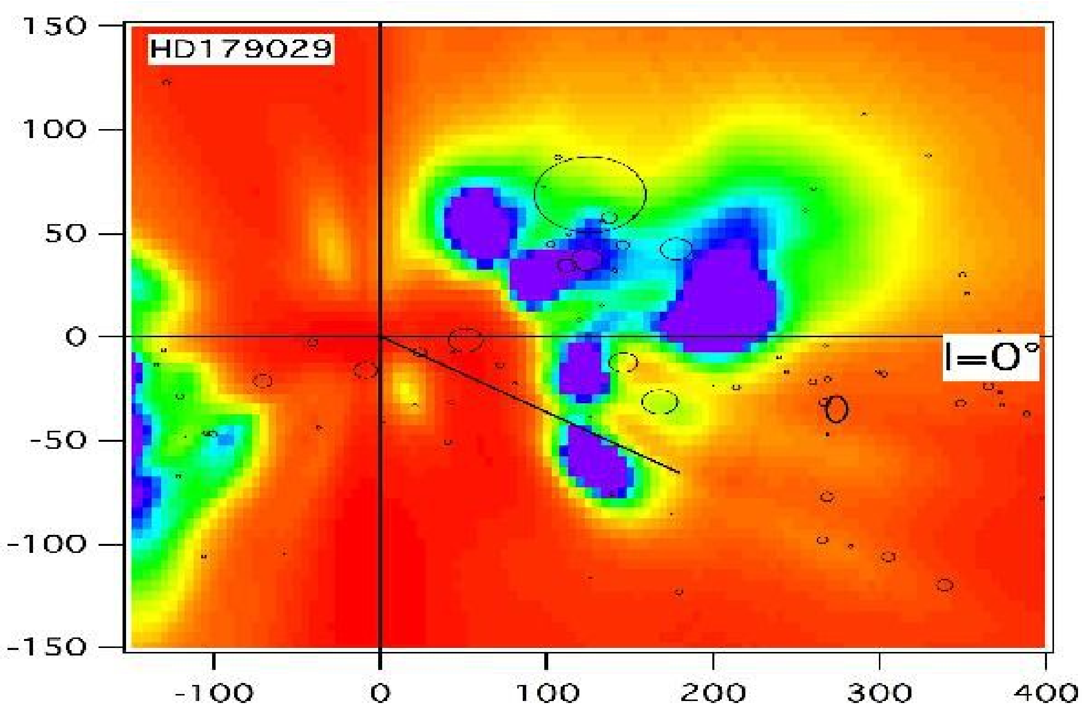


- CNM contribution to the column density > 85%
- CNM pressure ~ 6500 Kcm^{-3}
- CNM Filling factor along the line of sight ~ 10%
- Higher density regions from NH_3 , CN , (300 – 1000cm^{-3})
- OH^+ trace the CNM interfaces with low H_2 fraction

- Most of the volume is filled by the warm phases (> 50%)

3D structure of the local ISM before GAIA

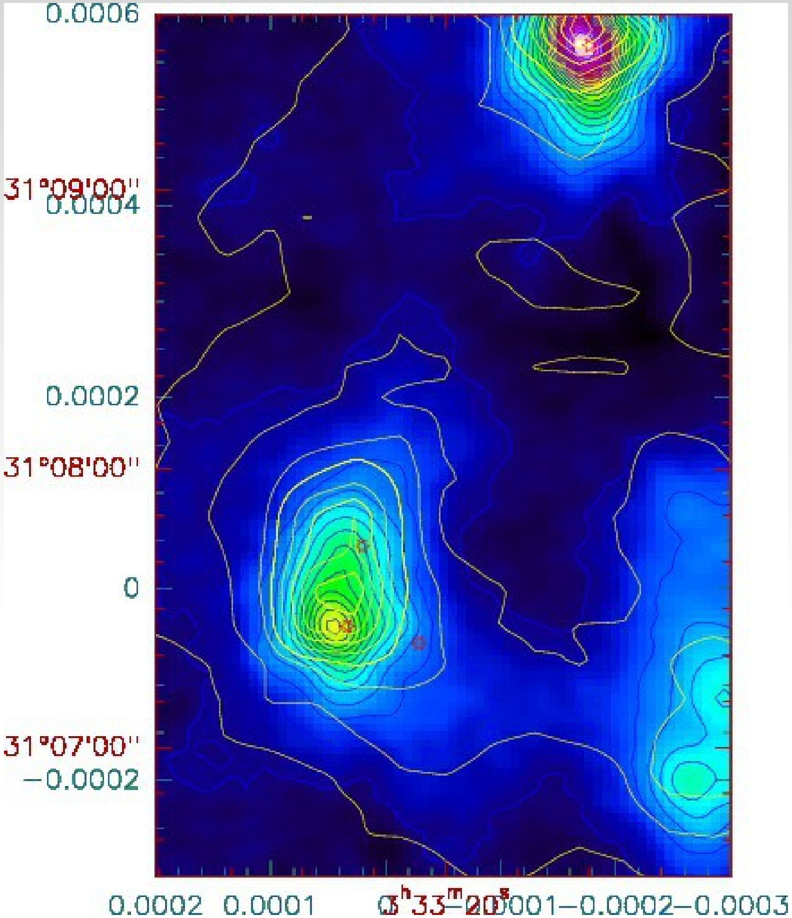


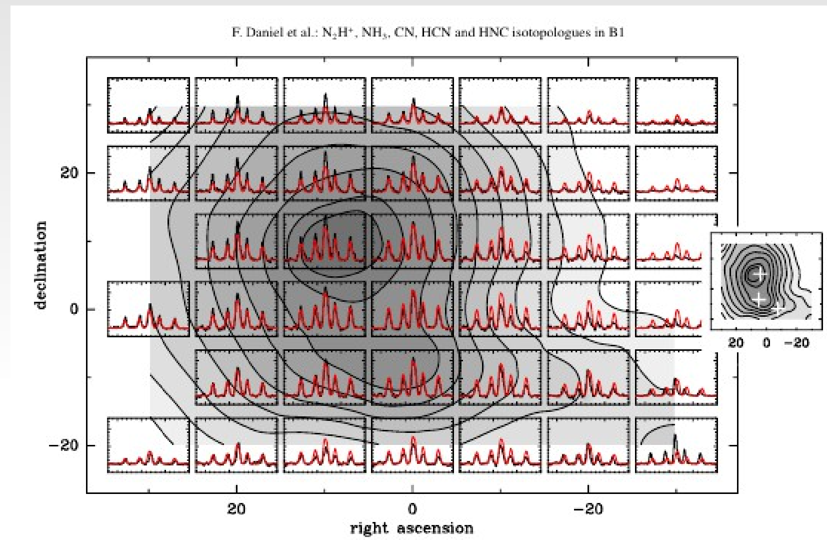


Inversion of extinction data and line absorption towards thousands of stars → correlation with QSO data ?

(*Raimond , Lallement et al 2012*

Dense cores ; IRDCs

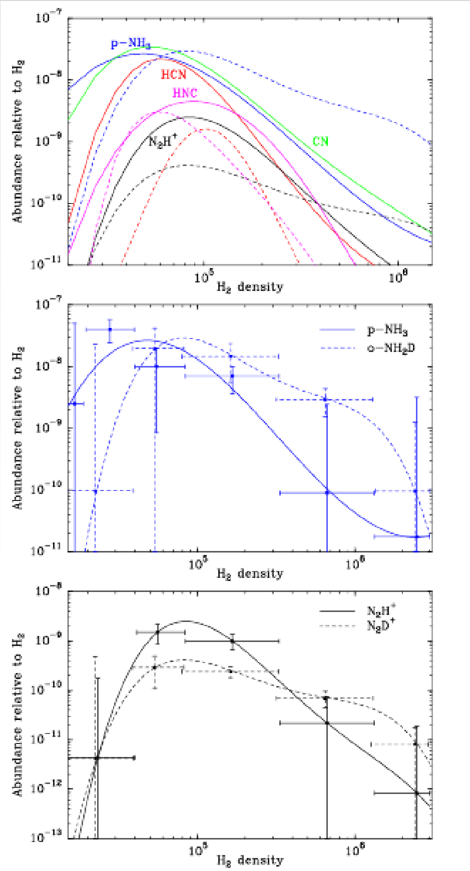


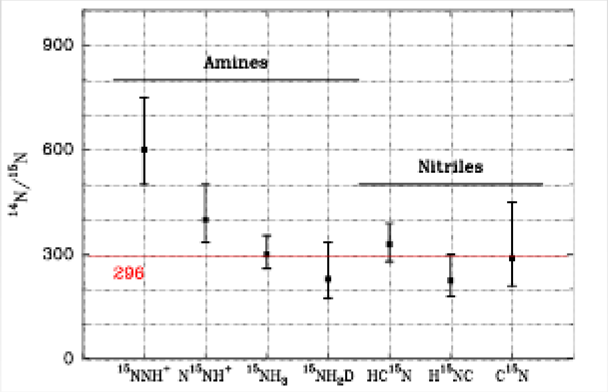


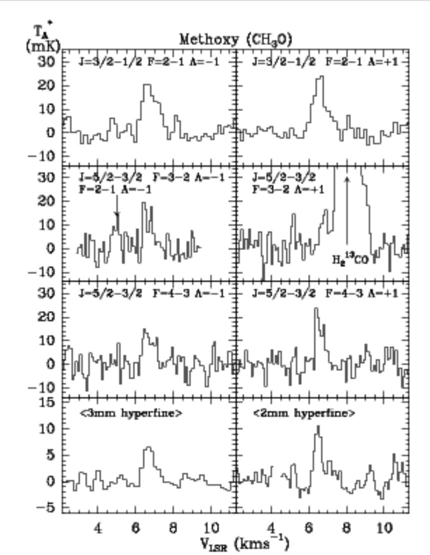
Barnard 1 : Daniel et al., Cernicharo et al)

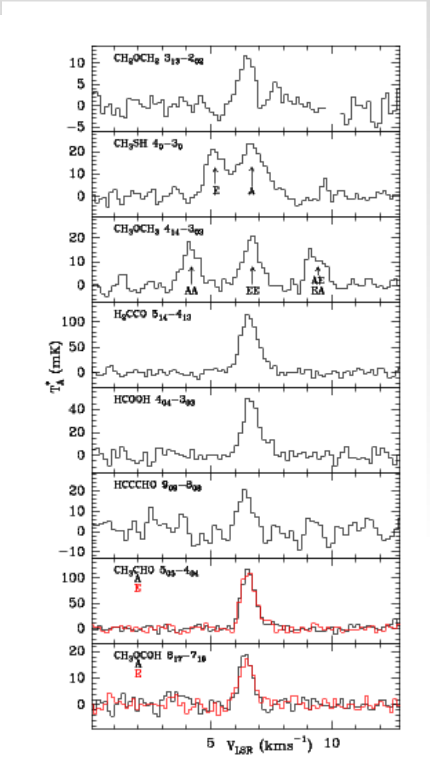
- Birth place for protostars → infall ; accretion
- "Cold chemistry" , low ionisation fraction, fractionation effects (D/H, 13C/12C, 15N/14N ...)
- Depletion on grain → ice formation & surface chemistry

Dense cores ; IRDCs









B1b Daniel et al., Cernicharo et al)

- Birth place for protostars → infall ; accretion
- “Cold chemistry” , low ionisation fraction, fractionation effects (D/H up to triply deuterated species (ND3), 13C/12C, 15N/14N 15NH2D...)

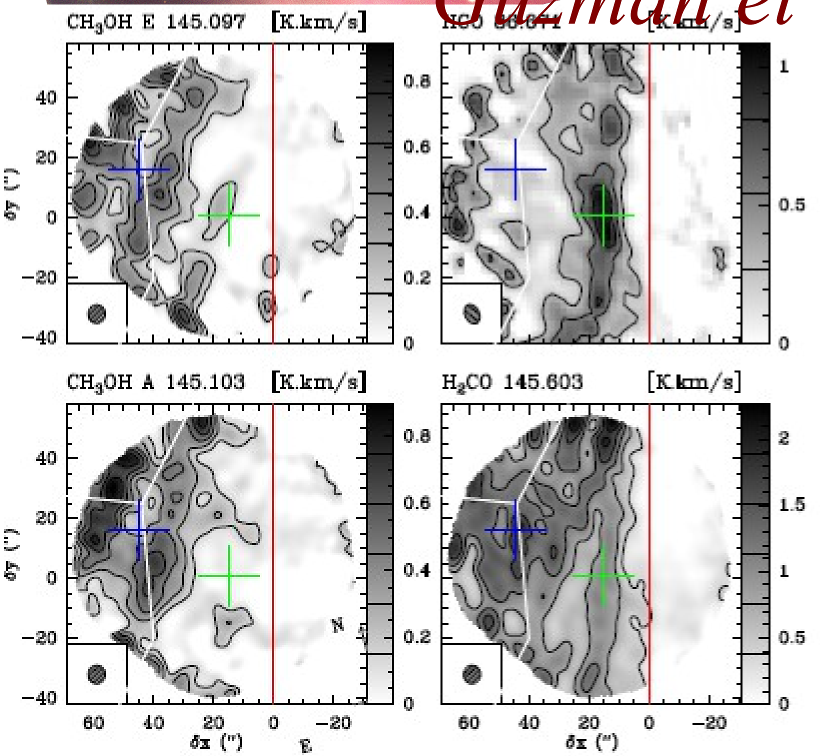
  → Radial variation of D/H
- Depletions on grain ; desorption → ice formation & surface chemistry

Radiative feedback : PDRs

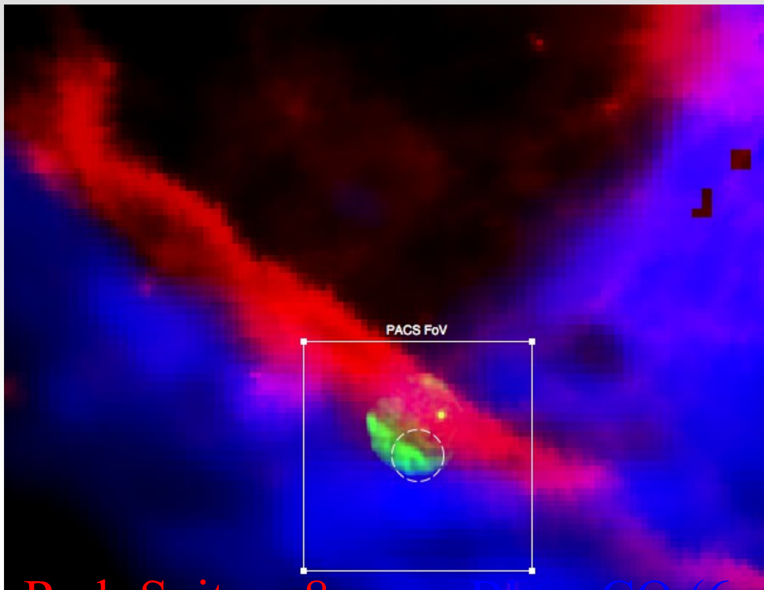
- Template sources for understanding the heating/cooling processes and gas phase/solid phase chemistry including ionization balance
- Elemental abundances / Depletions
- Sharp variations of the physical conditions due to dimming of FUV flux
- Identification of specific diagnostic (eg reactive ions CO+, HOC+; ions CF+, radicals HCO)
- Templates for disks / Starburts galaxies

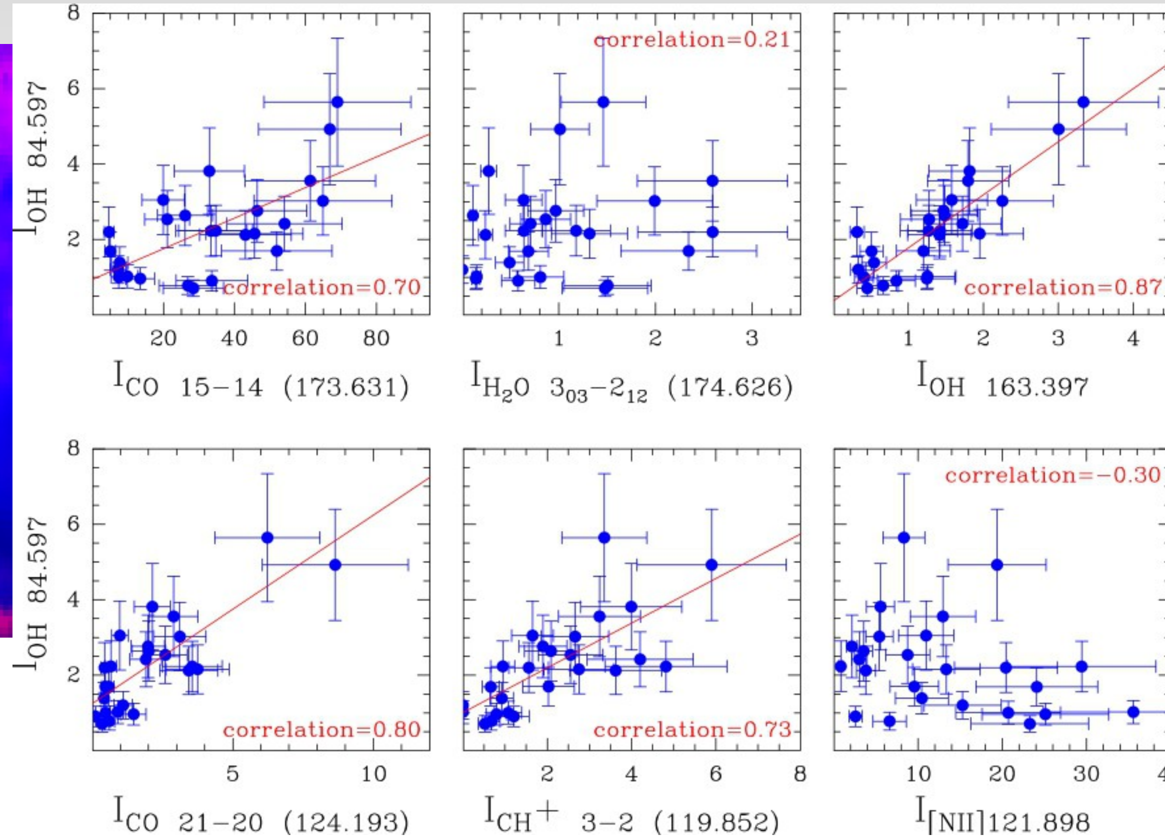
- Extended sources with small scale structure : needs combination Interferometer & short spacings

Guzman et al



Radiative feedback

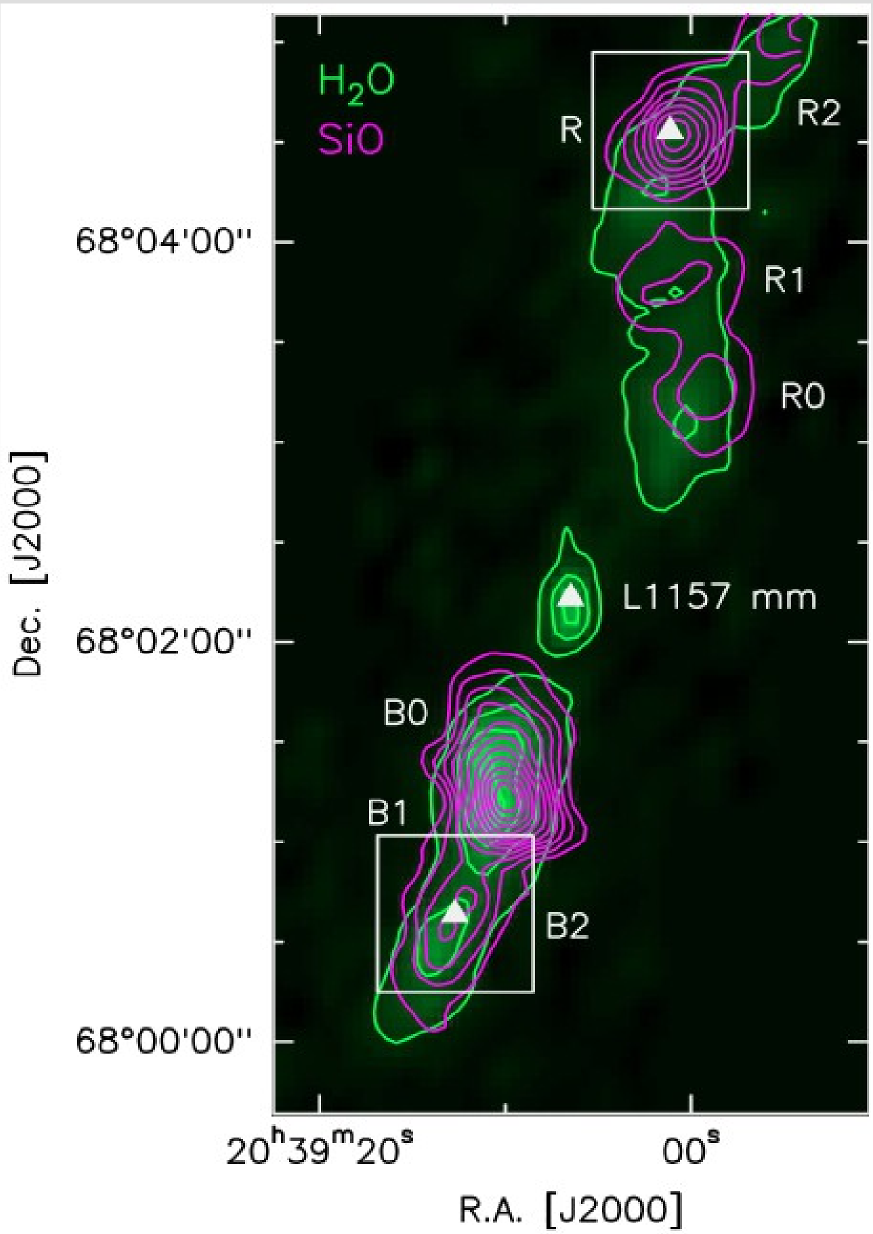


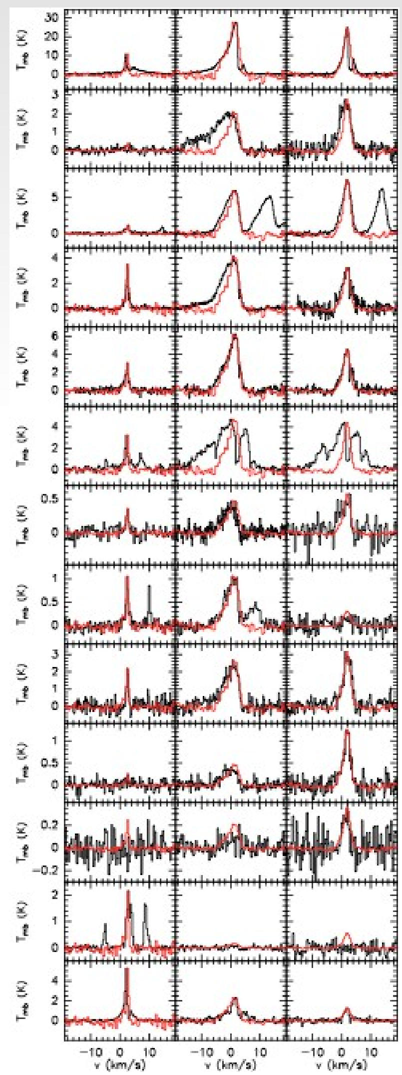


Red=Spitzer 8 µm – Blue=CO (6-5) *(Lis & Schilke 2003)*
Green = H_2 v=1-0S(1) 2.12 µm
(Joblin & Maillard, unpublished)

- 2 key parameters : FUV Intensity G0 & gas density n
- Sampling a wide range of parameters → significant source sample
- Herschel : Orion Bar OH emission from a warm (160 -220K) very dense (106 – 107 cm-3) gas with a small filling factor (0.1) everywhere at the interface.
- Evidences for small scale structure → high angular resolution

Mechanical feedback : Shocks and outflows





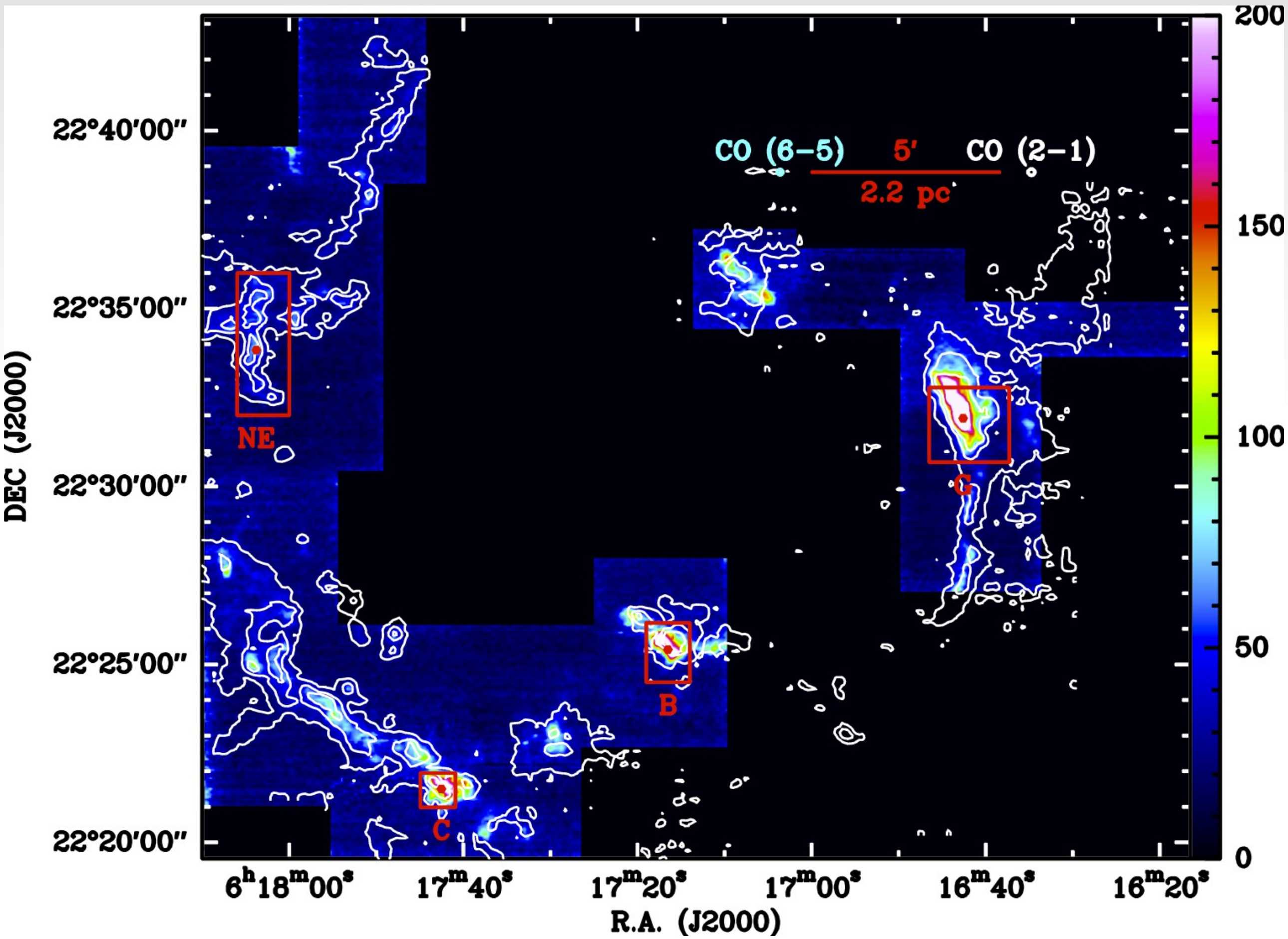
Molecular outflows

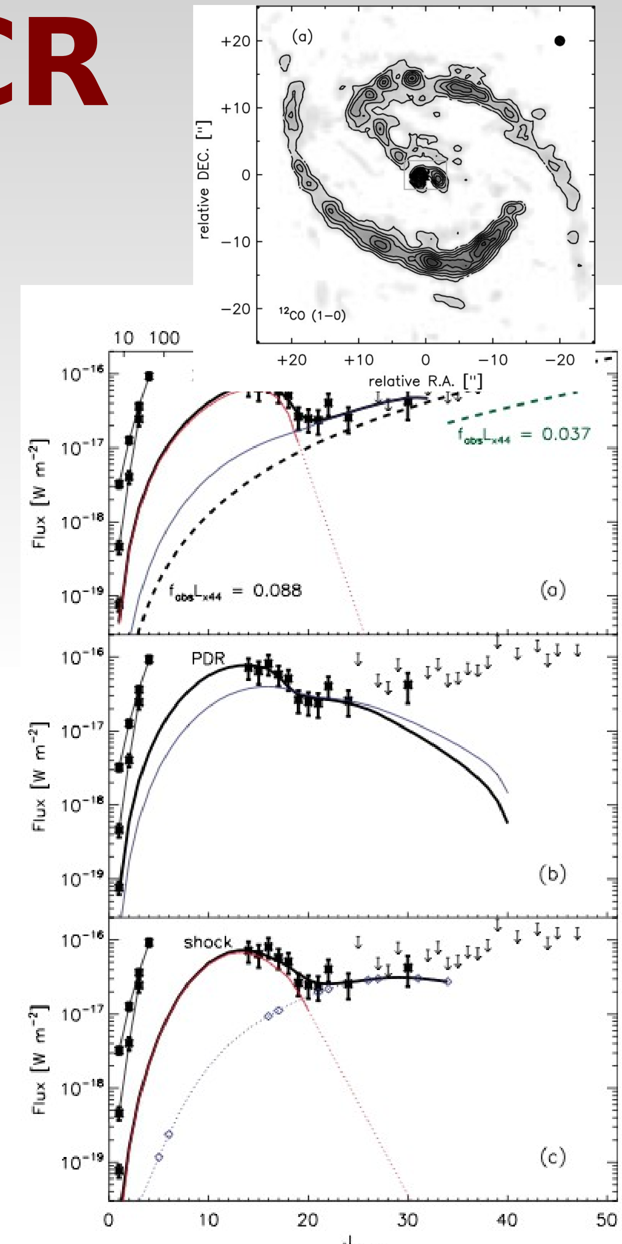
shock physics

accretion & ejection processes and magnetic field

L1157

Supernovae remnants : Shock physics and CR acceleration



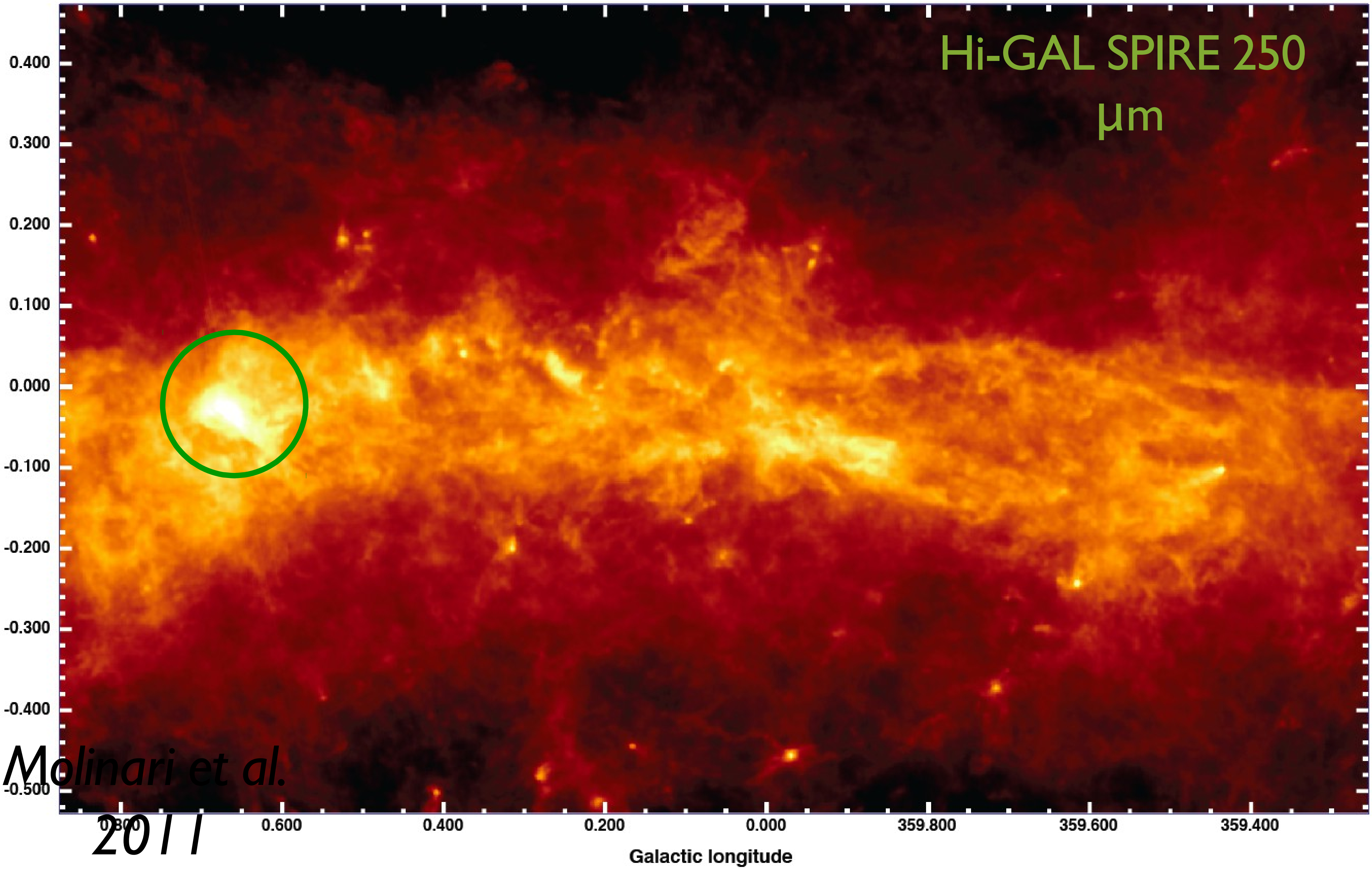


IC443, with APEX.

Güsten Gusdorf

Origin of the NGC1068, CO lines ?

Herschel View of the Galactic Center



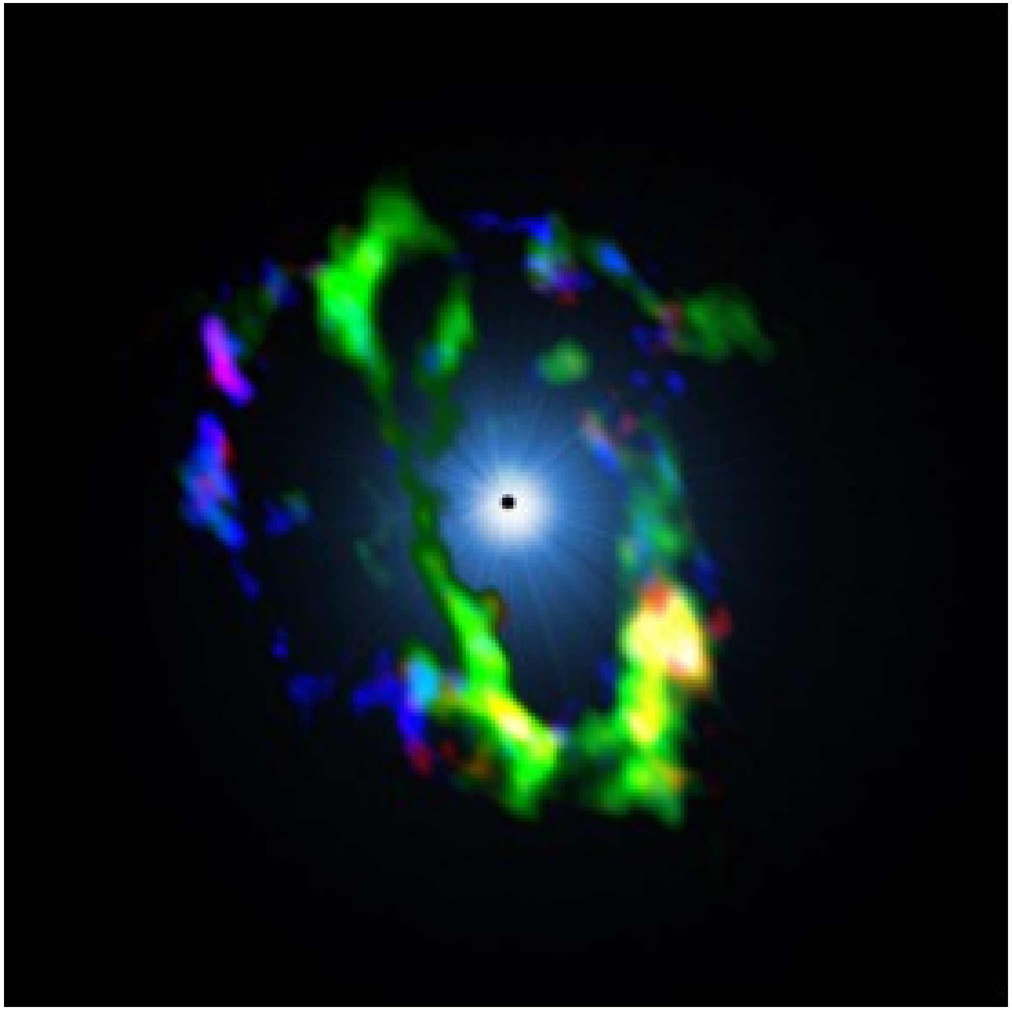
Molinari et al. 2011

The circum nuclear disk and SgrA*

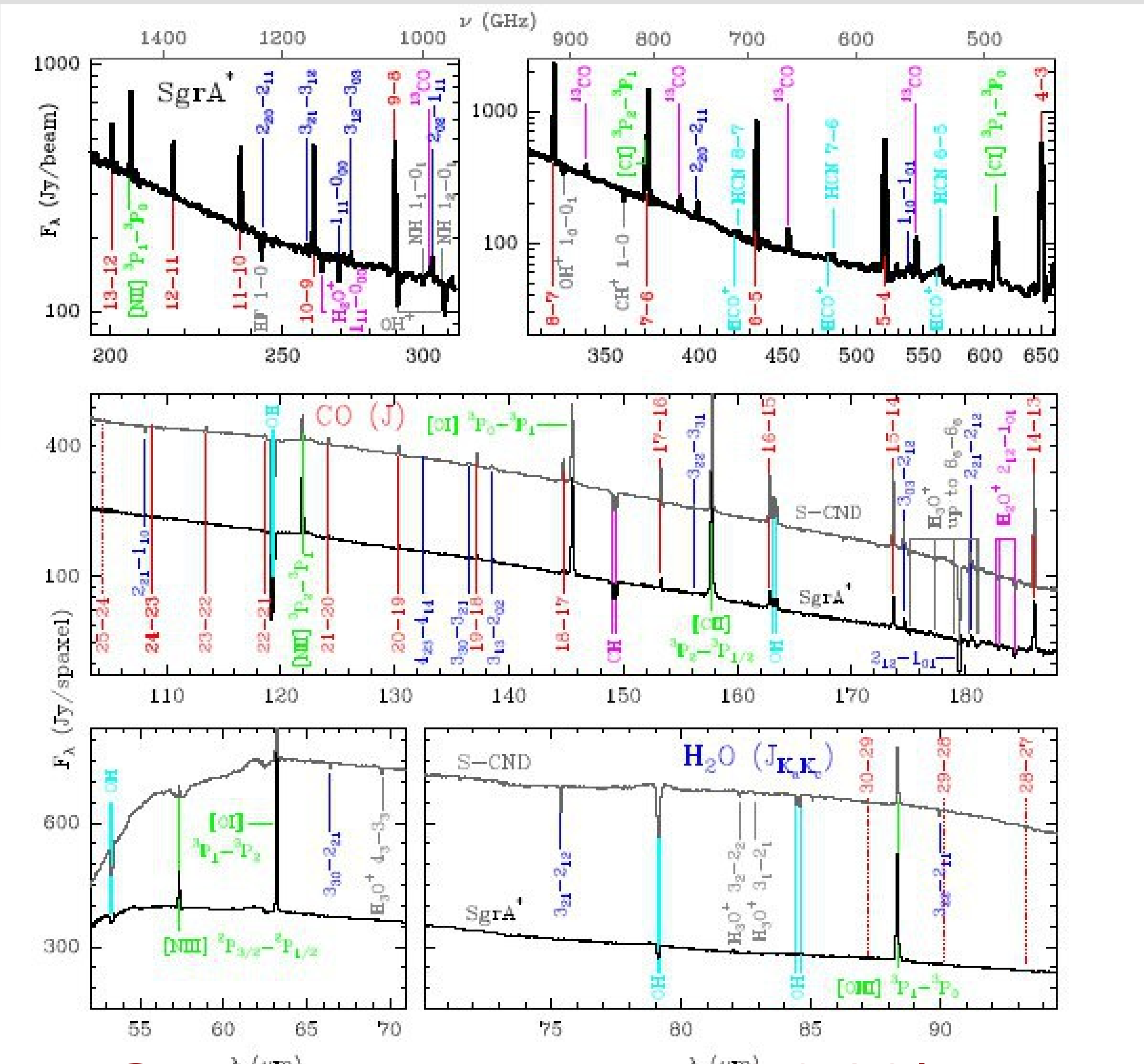
Studying the environment of a supermassive black hole

Template for external galaxies

Red : SiO
Green CN
Blue H2CO
Martin et al



The CND with Herschel



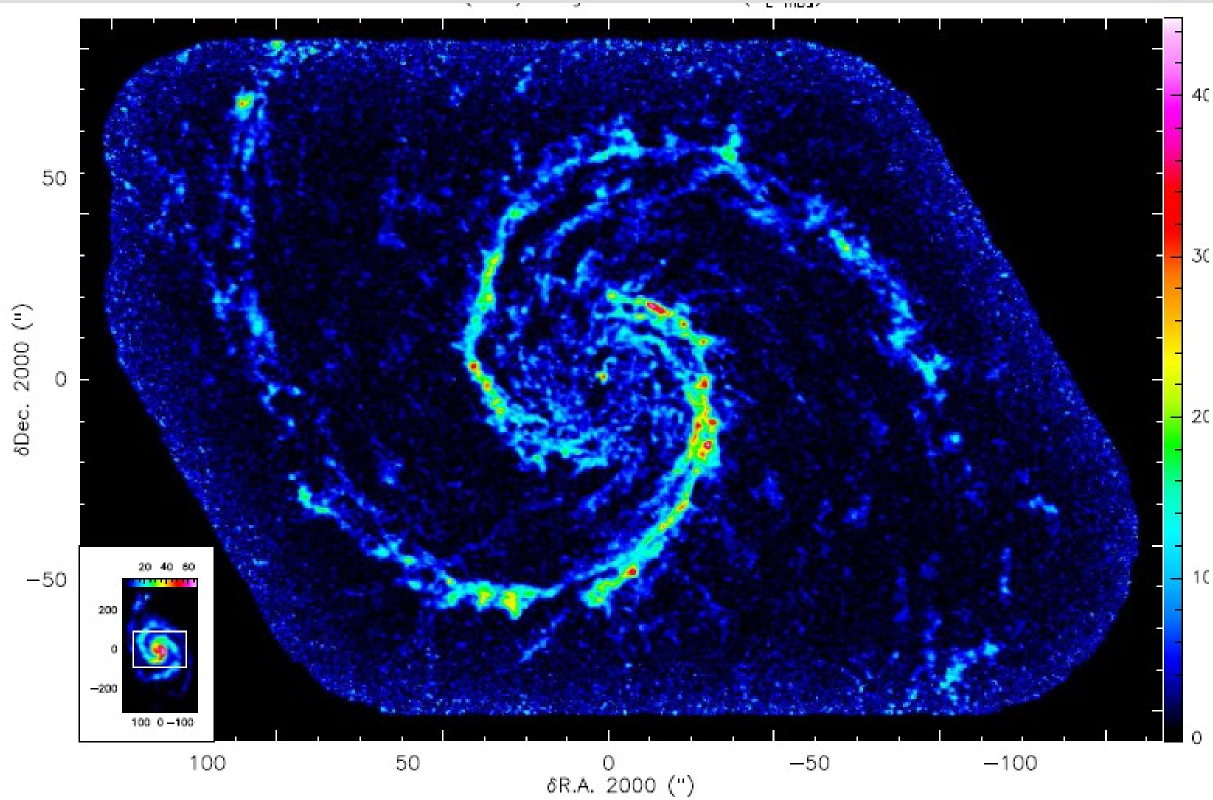
Goicoechea et al 2013)

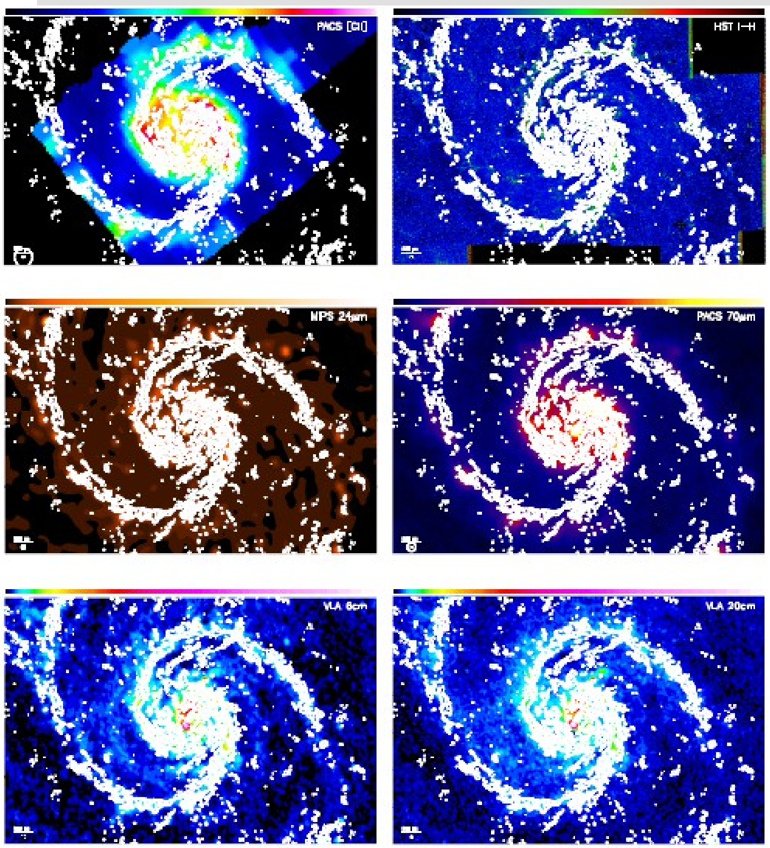
Fine structure lines
Hot CO
Hydrides.

Other GC issues :

- Star formation : superclusters like The arches
- Very massive & Turbulent GMCs (eg SgrB2, G0.25)
- High energy radiation & Cormic rays, Flares ...

Large scale view, M51

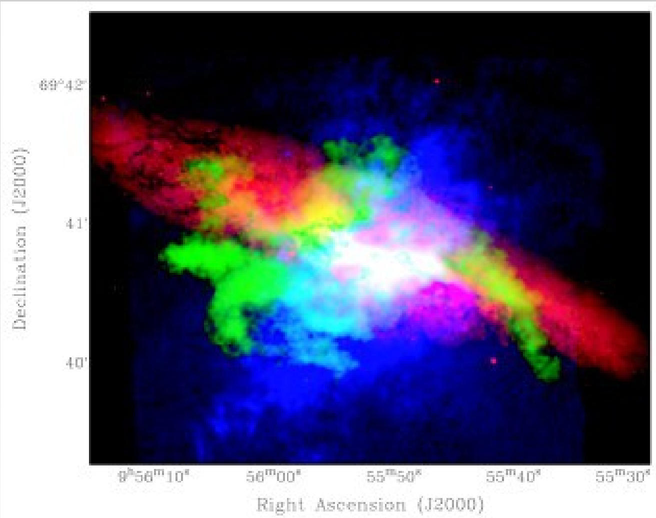




Schinnerer et al., Pety et al

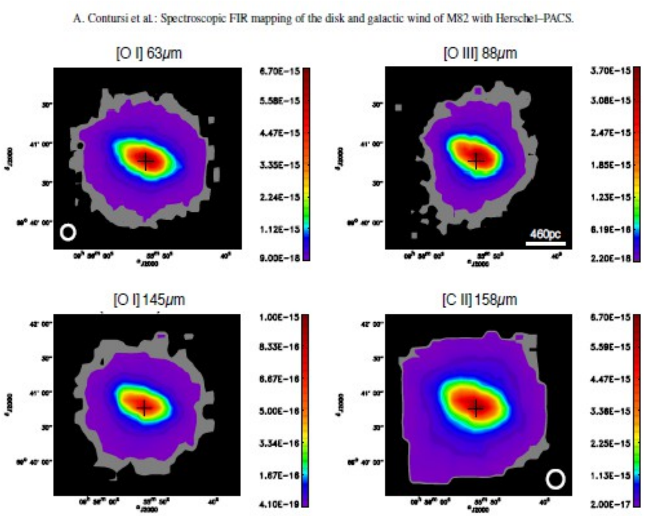
Wide mosaic with PdBI. Reach the GMC size → connecting GMC formation & galaxy dynamics. Relation with star formation, with dust Detection of extended emission → “thick” molecular disk ; diffuse gas

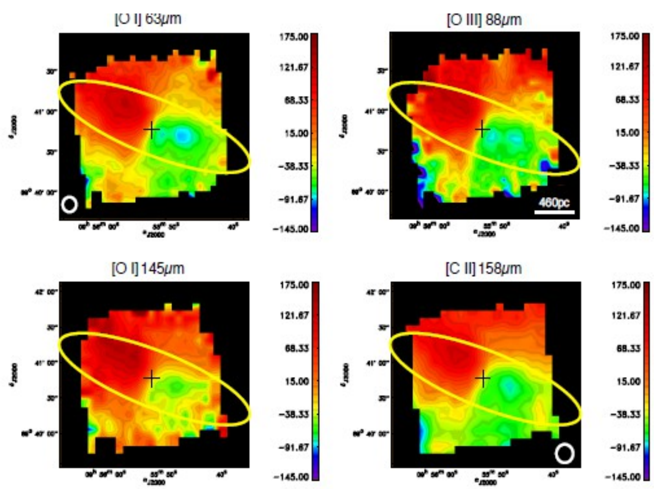
Feedback effects : M82

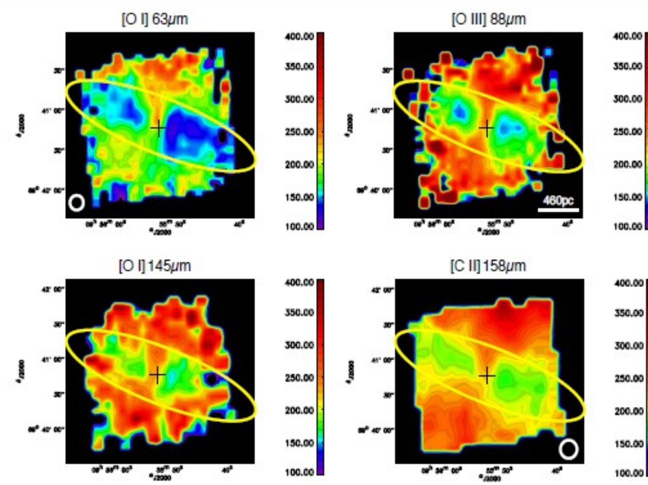


Weiss et al

Starburst + strong wind/outflow

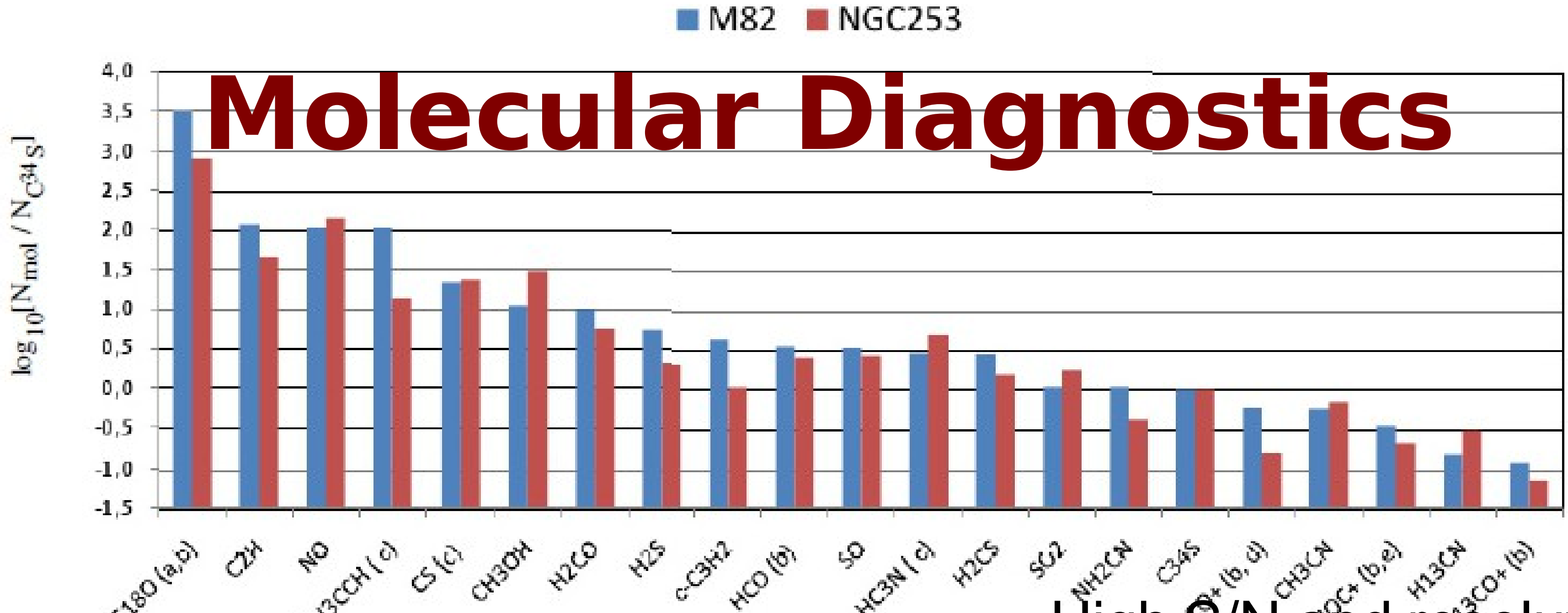


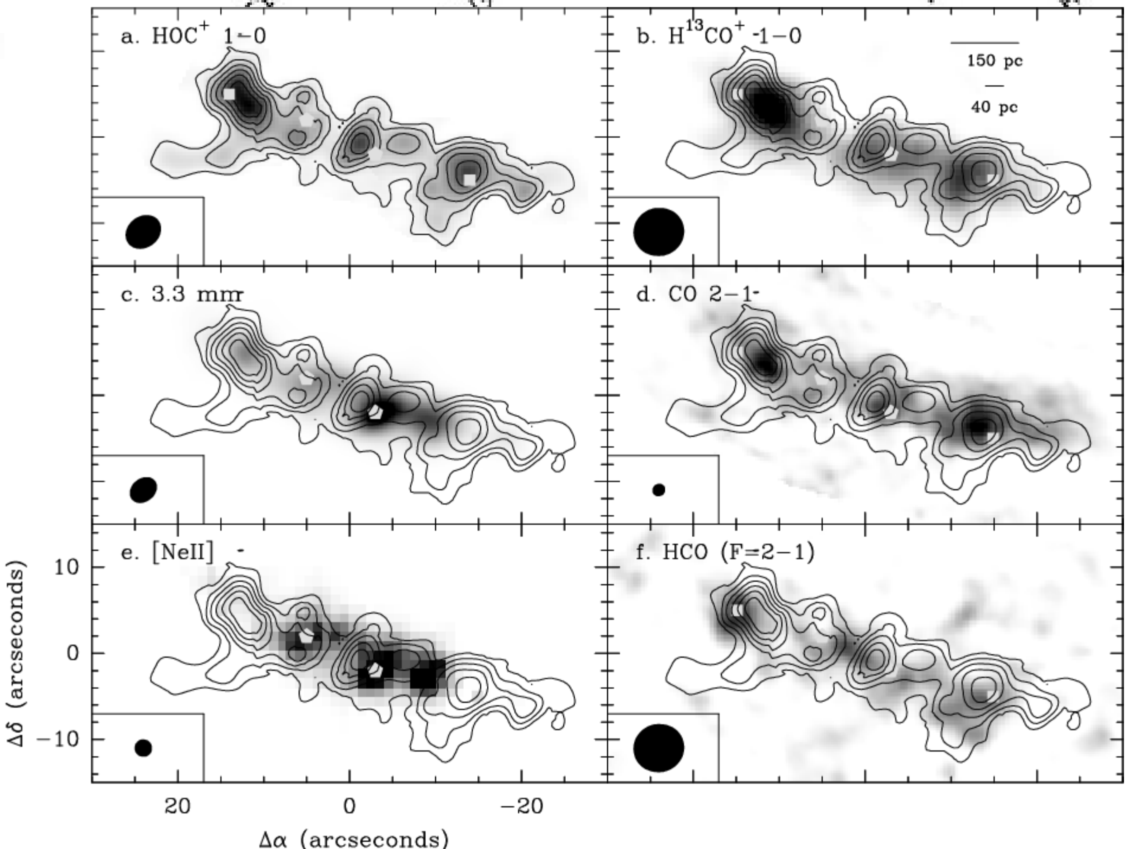




Contursi et al 2013

Molecular Diagnostics



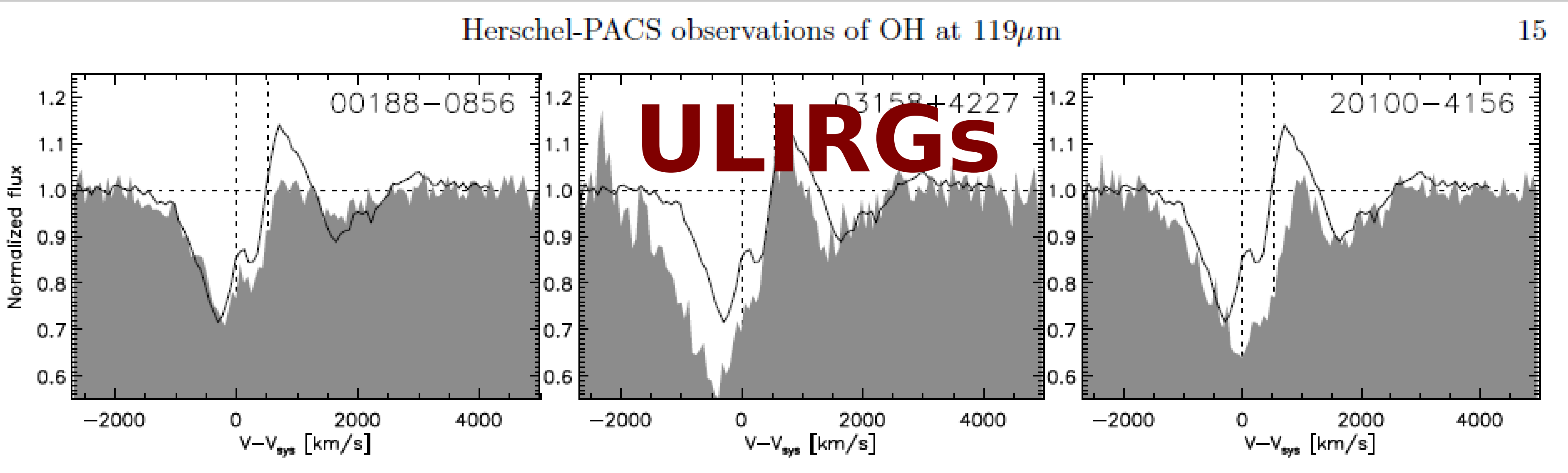


High S/N and resolution maps → isolate specific regions with key spectral features

+

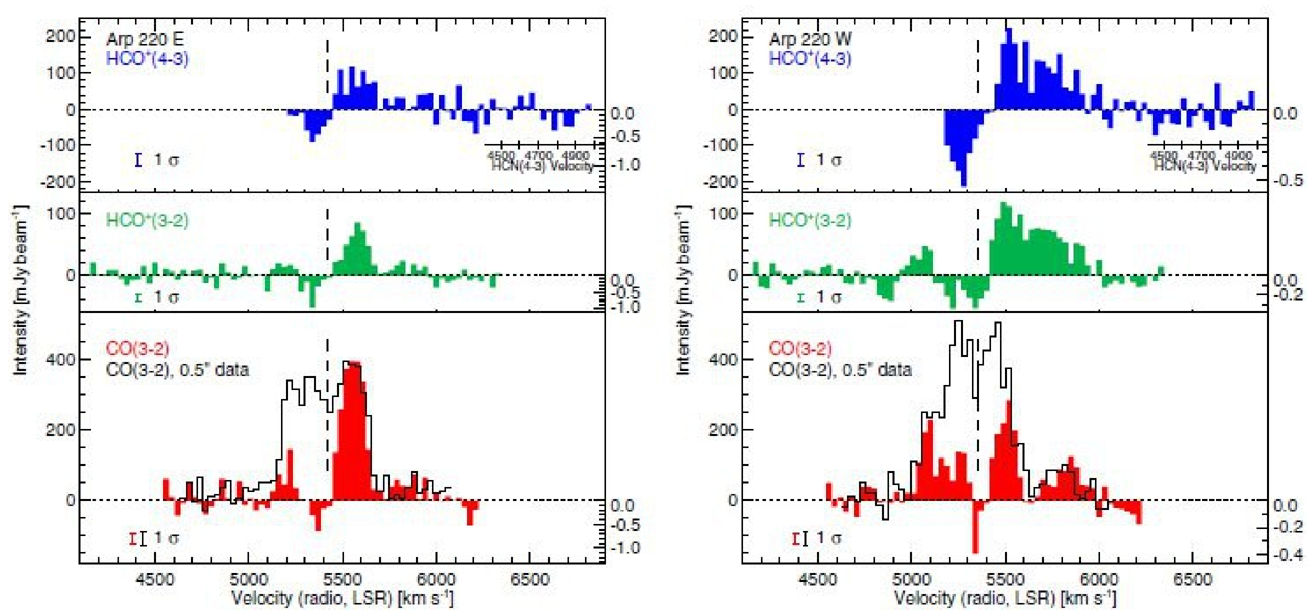
Global characterization of the molecular composition

Based on local (galactic) templates



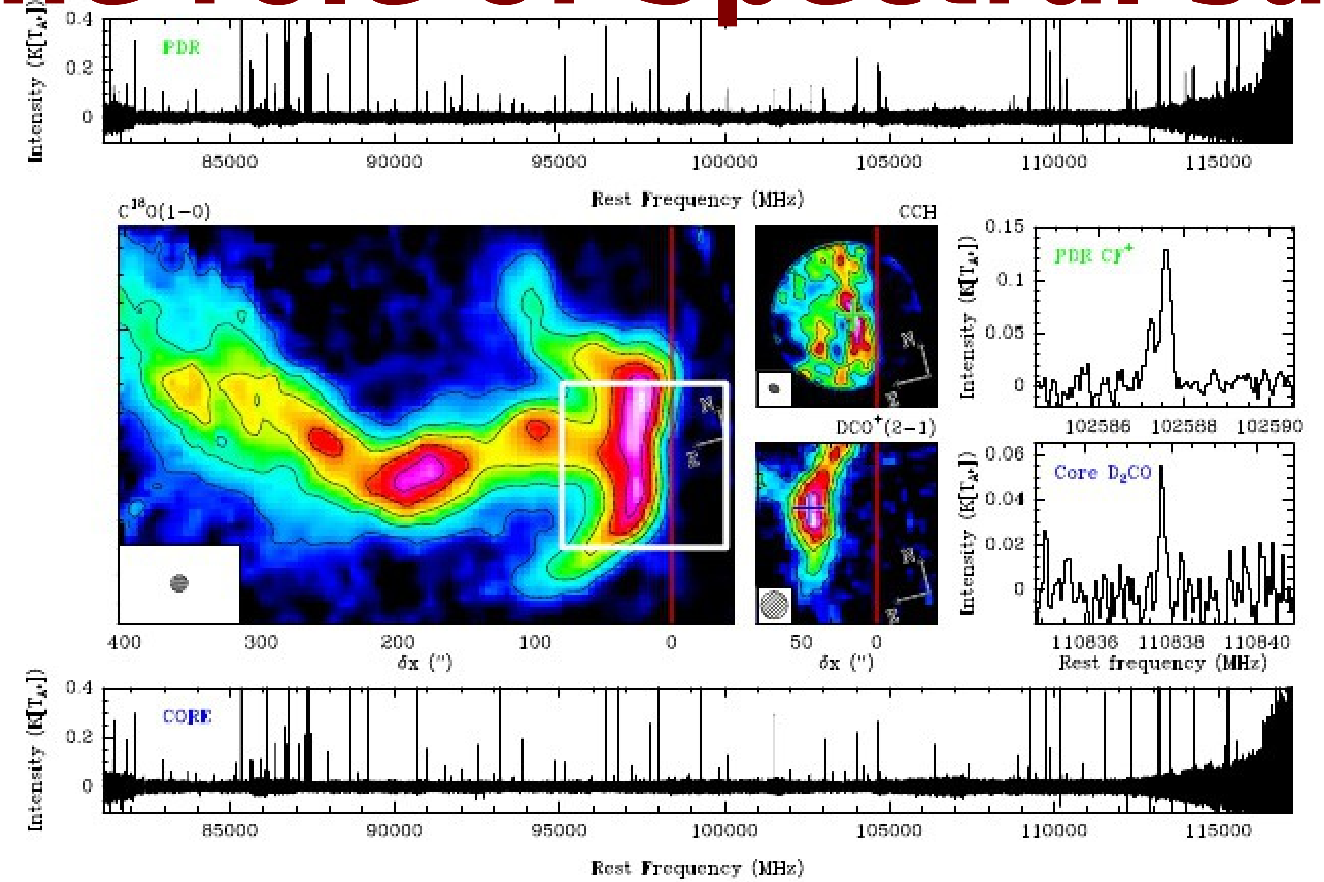
ULIRGs

- Feedback → FIR OH lines
- Complex spectral line profiles at high resolution
- Rich spectra → diagnostic of the main physical processes (Starburst, AGN, shocks ...)



Spoon et al , Sakamoto et al

The role of Spectral surveys



Pety et al

- For astrochemistry : full characterization of the gas composition
- For star formation : multiple tracers of physical conditions → separation of the physical components

Broad band receivers (EMIR, Herschel/HIFI, ALMA, NOEMA) → fast coverage of tens of GHz

Need dedicated analysis tools for spectral line analysis.

Interferometry : combining maps and spectral surveys

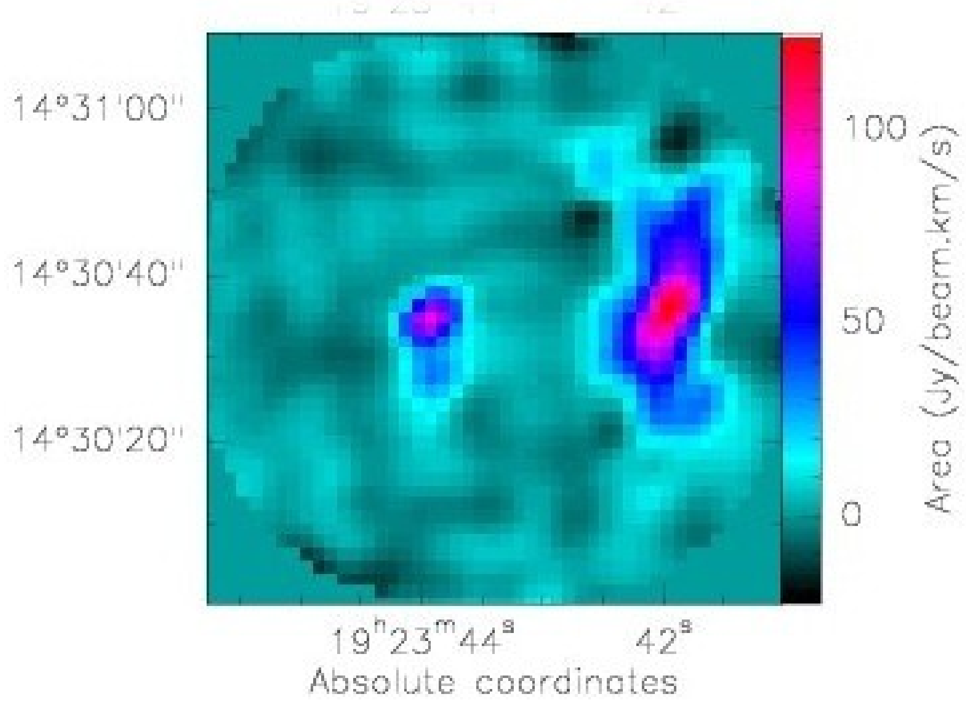
- Molecular diagnostics : enhanced abundance in specific regions due to chemistry + enhanced spectral line intensity due to most favorable excitation conditions

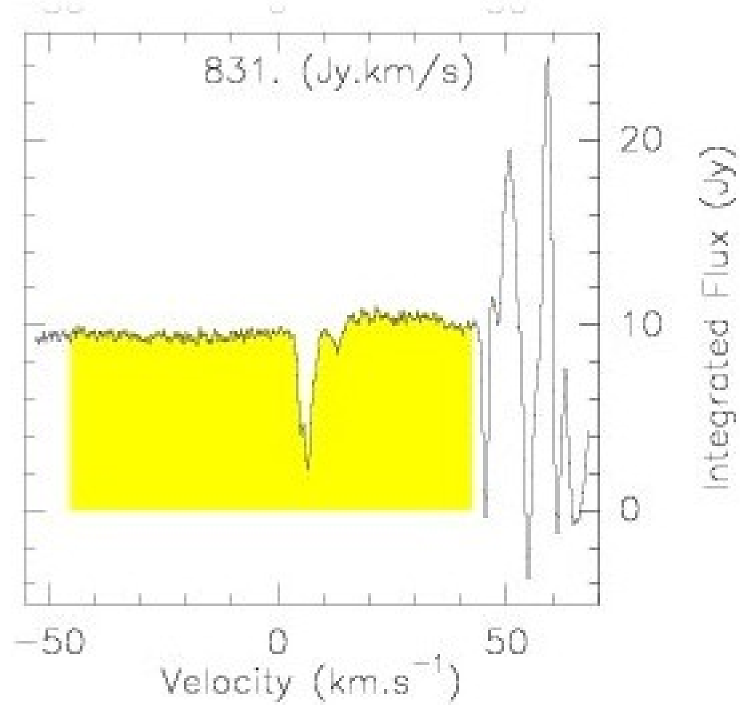
  → probe a specific region along the line of sight.

- High spatial resolution → identify and separate the regions

→ better understanding of the source physical structure and kinematics

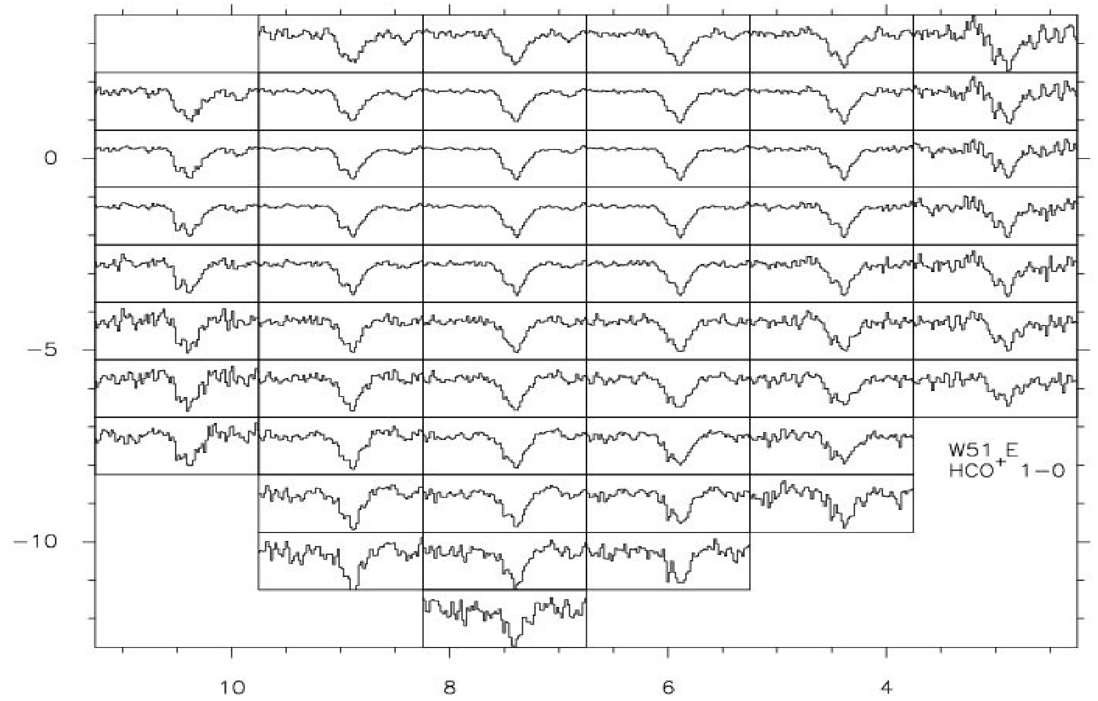
IRAM-PdBI observations





- Set-up with HCO+, H13CO+, CCH, HCN, SiO & HCO, 40 kHz
-
- W49N : conf CD 3.5” beam
- W51, conf D, 2 field mosaic : ~ 5” beam

Velocity structure (W51)



3 velocity components at 5, 6 & 13 km/s

Similar profiles over the mapped area