New perspectives on the interstellar medium : *Herschel* and *Planck* highlights

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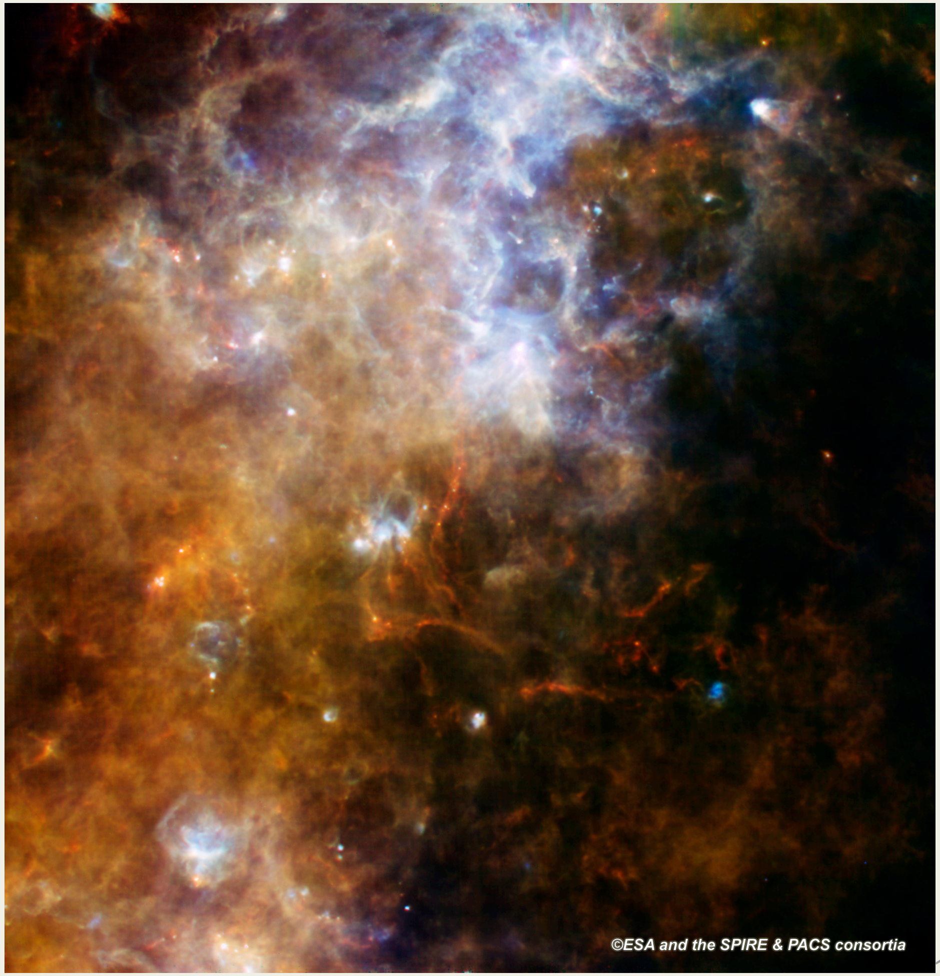
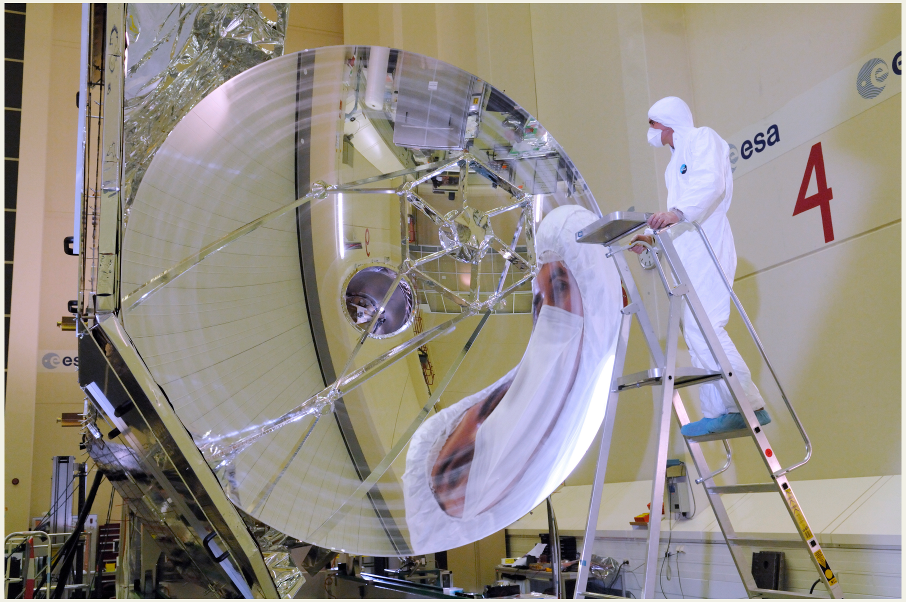


« Colloque National PCMI»,
Paris, 19 – 21 November 2012



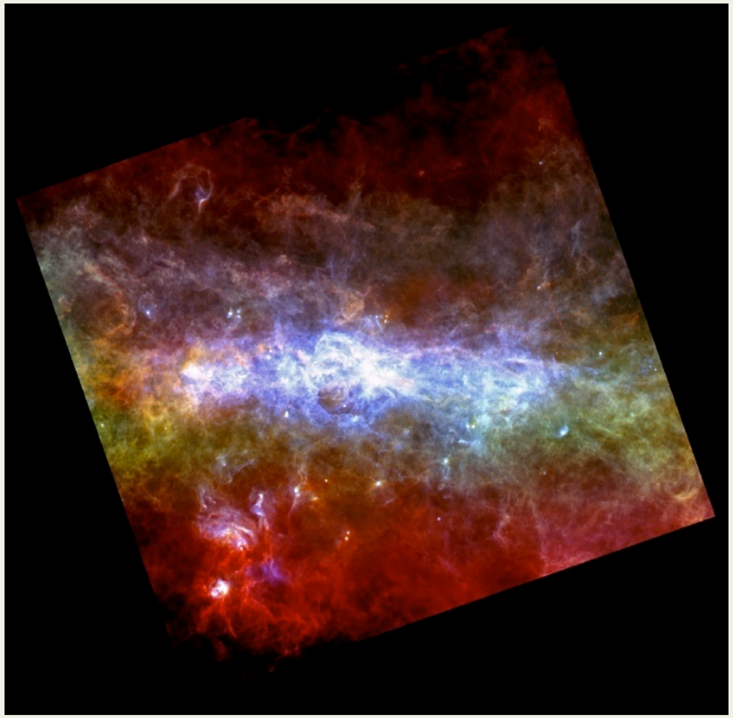
Herschel

- 3.5 m mirror, passively cooled,
  2400 liters liquid Helium

- HIFI
  500 GHz to 2THz
  Heterodyne spectroscopy (R~10^7)

- SPIRE
  200 to 650 μm
  Imager + FTS (R ~ 300)

- PACS
  60 to 200 μm
  Bolometer camera



Galactic Center SPIRE

Planck surveyor

- LFI - 30 to 100 GHz, HFI - 100 GHz to 857 GHz
- HFI : 54 bolometers, 6 bands, Resolution = 0.3

Cooled down to 0.1 K

Polarization capabilities

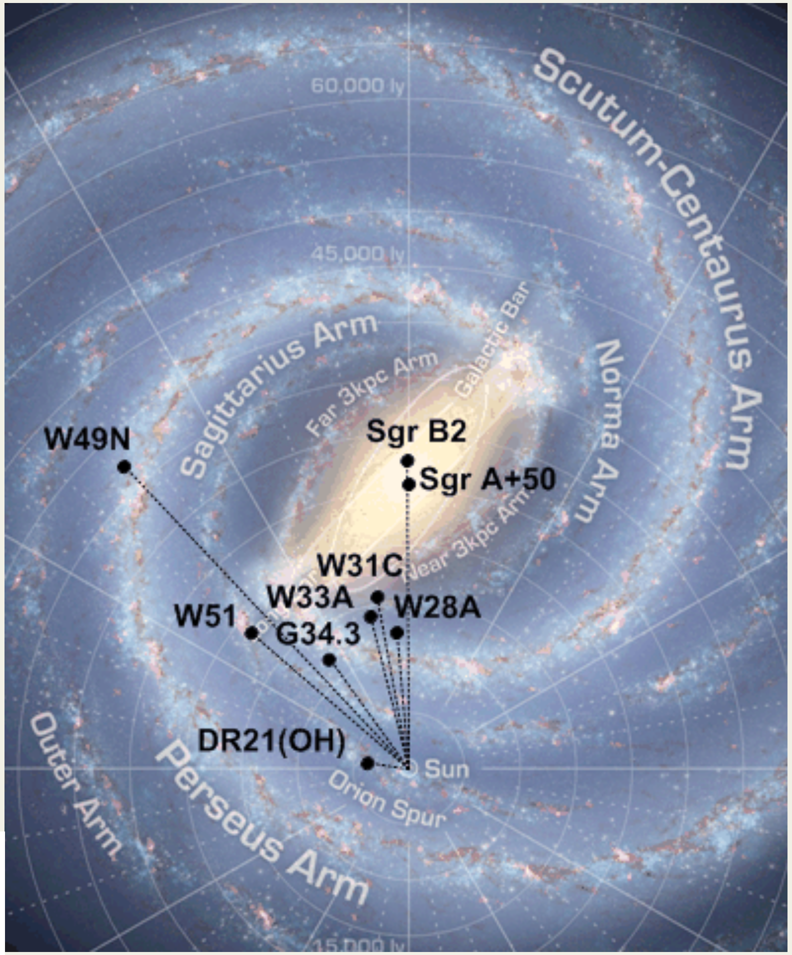
- 600 times more sensitive than COBE
- HFI mission last twice longer than foreseen
- All-sky survey made 5 times

Outline and opened questions

- **Hydride absorption spectroscopy :** unexpected molecular richness of gas with low H_2 fraction. Origin?
- **[CII] emission and absorption:** what does [CII] trace? Missing heating mechanism? Excitation?
- **Power-law spectra of cold dust :** comparison with CO, probes of the dynamic origin of density structure?
- **CO at high galactic latitude:** dynamic origin?
- **High polarization degree of dust emission** in diffuse ISM : B topology ? Alignment process?

(see Jean-Philippe Bernard's talk)

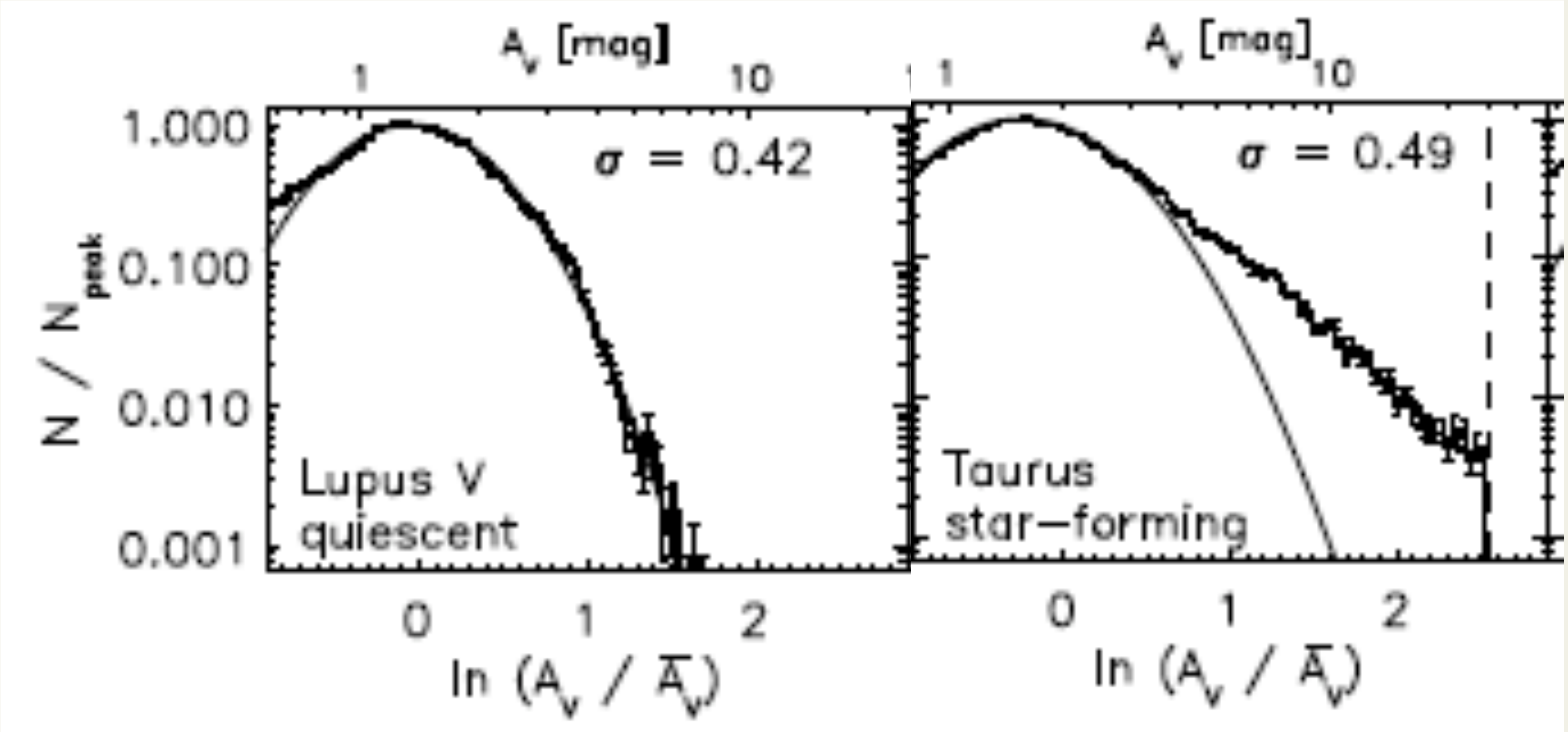
I - Herschel/HIFI absorption spectroscopy



Background sources:
dust continuum emission of massive star forming regions

Lines of sight:
sample kpc's of galactic ISM

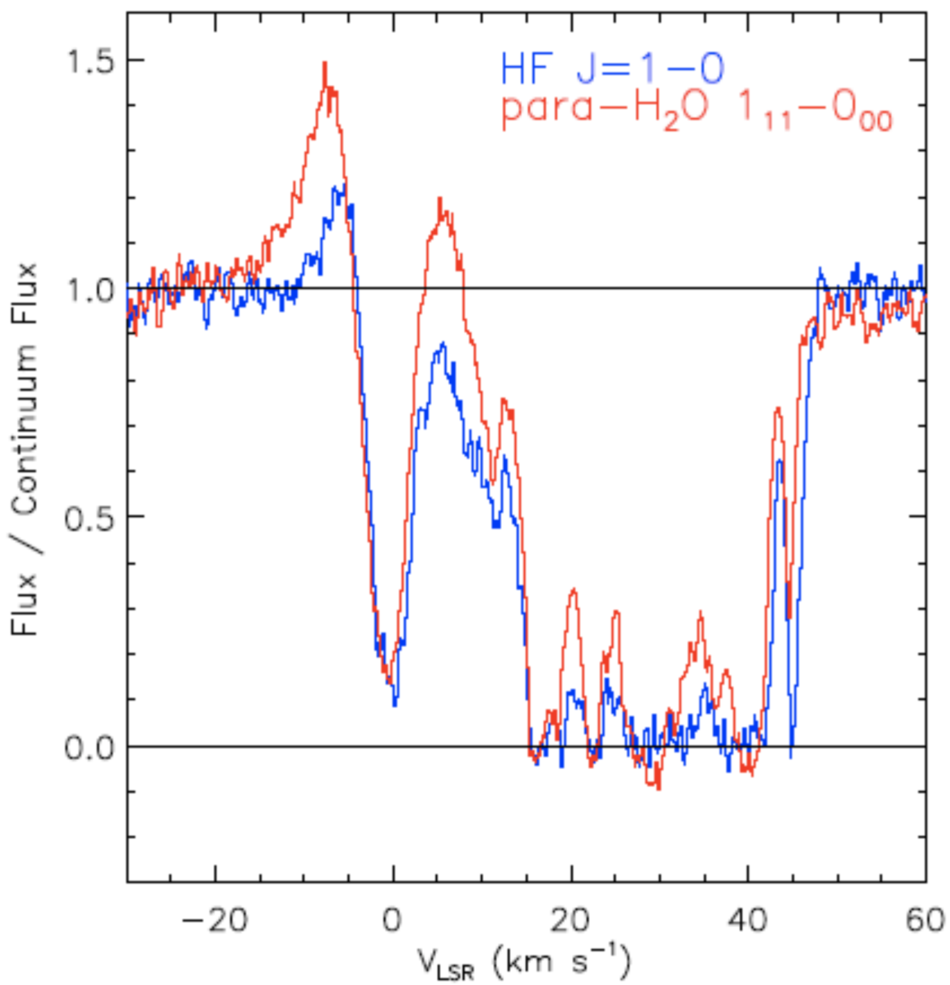
Cloud mass in diffuse component



Distribution of column density: K-extinction, 2MASS, Kainulainen et al 09

- A_V < 3 - 5 mag : log-normal distribution ➪ **Turbulence**
- A_V > 3 - 5 mag : power-law tail ➪ **Self-gravity**

HF (J=1-0) 1.23GHz



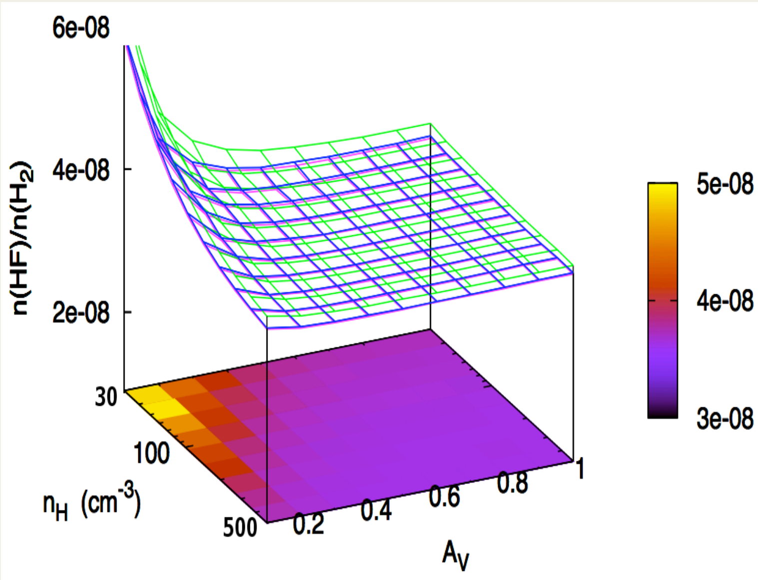
HF unique = larger binding energy than H_2

H_2 + F = exothermic reaction with activation energy barrier ~ 500 K

Saturated absorption
Large optical depths

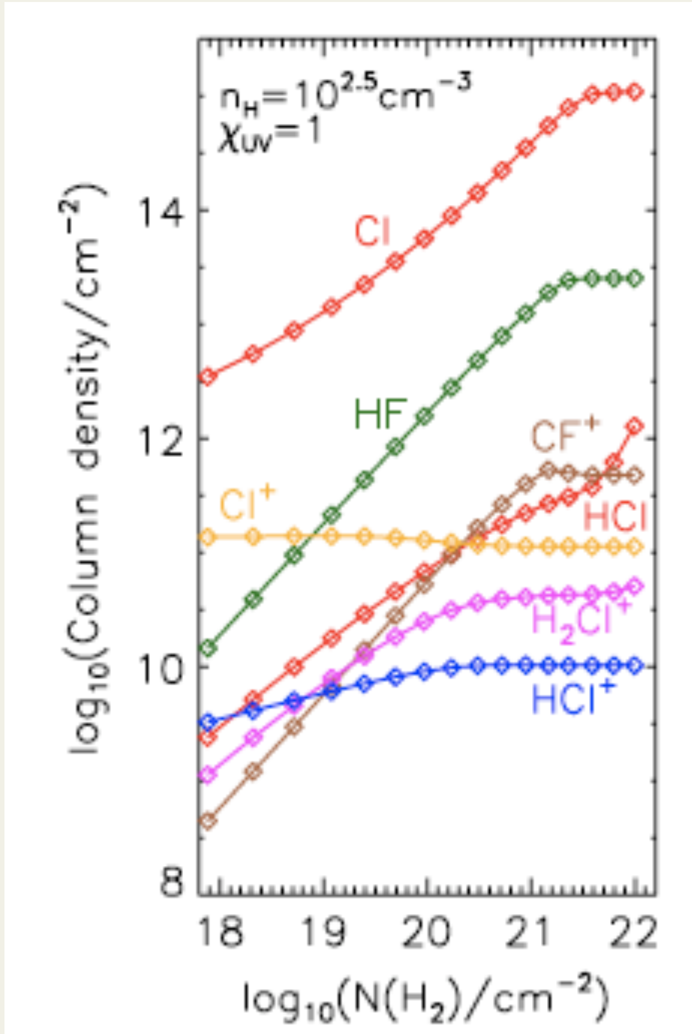
HF (1-0) thicker than para-water

HF : a new tracer of H_2



$$
\begin{array}{lllll}
F & + H_2 & \rightarrow HF & + H & (k_1), \\
HF & + \gamma & \rightarrow F & + H & (\zeta_{HF}), \\
HF & + C^+ & \rightarrow CF^+ & + H & (k_2),\ \text{and} \\
CF^+ & + e^- & \rightarrow F & + C & (k_3),
\end{array}
$$

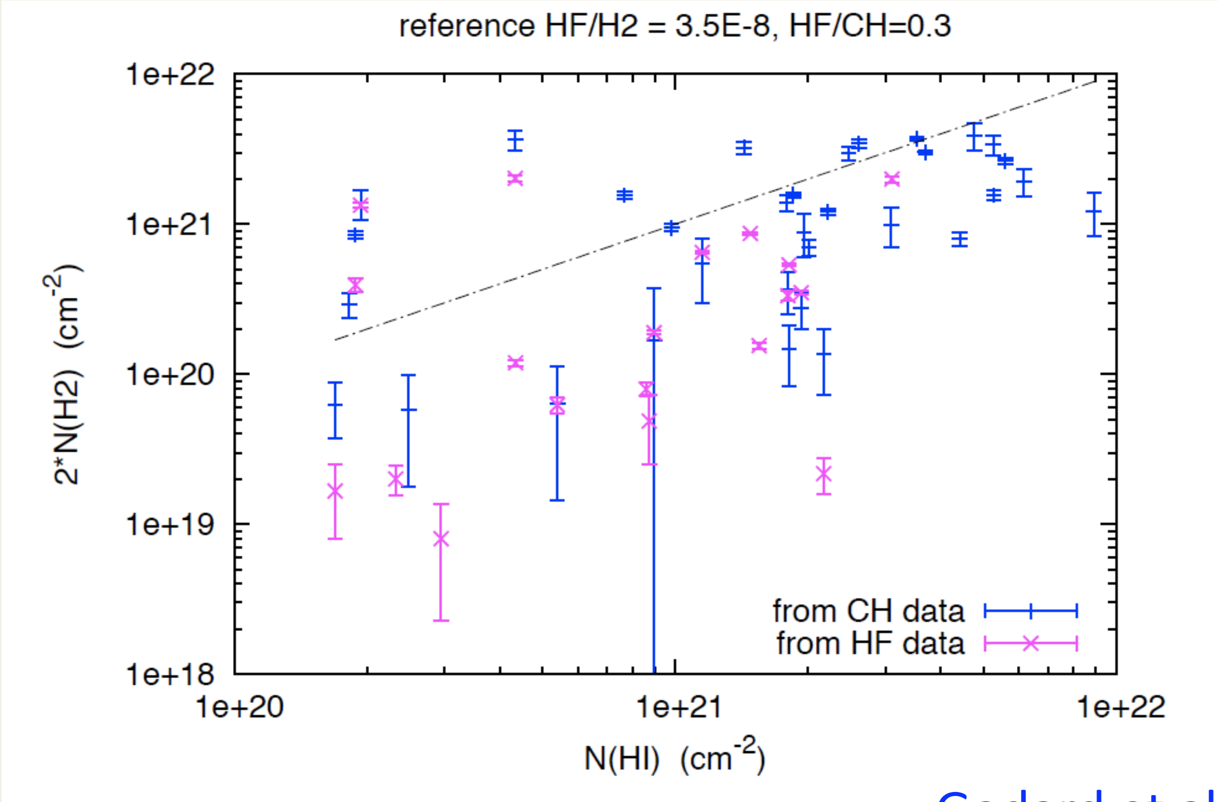
$$\frac{n(HF)}{n(H_2)} = \frac{[F]}{([C]\,k_2 + \zeta_{HF}/n_H)/k_1 + 1/2 f_{H_2}(1 + k_2/k_3)}$$



Godard et al. 2012

Neufeld et al 2009

H_2 fraction



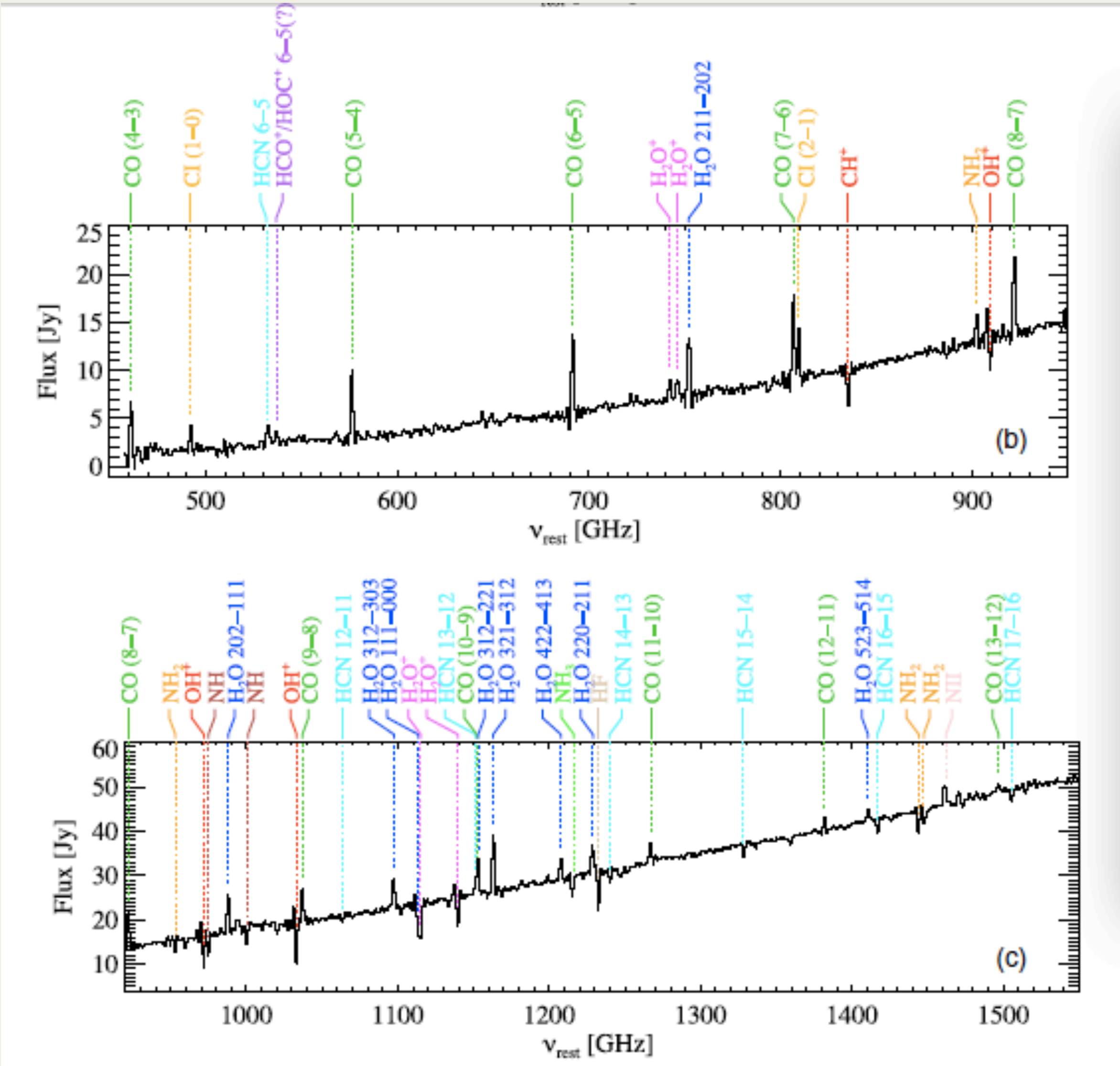
Godard et al., in prep.

$$0.04 < f_{H2} < 1$$

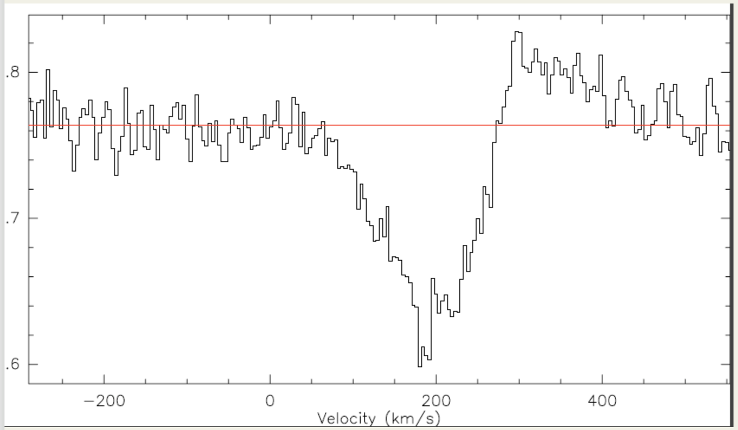
N_H range : 0.1 to 5 mag = turbulent dominated phase

N_{H2} range : 10^{19} cm^{-2} to 2 x 10^{21} cm^{-2} = CO over-rich

Extragalactic HF



Arp220, SPIRE FTS Rangwala et al. 2011

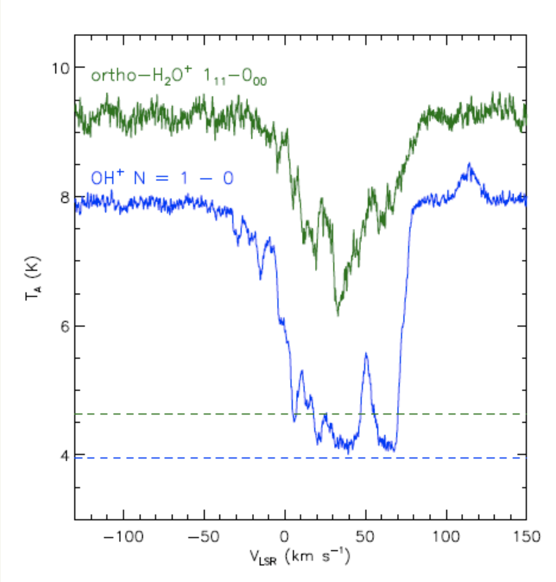


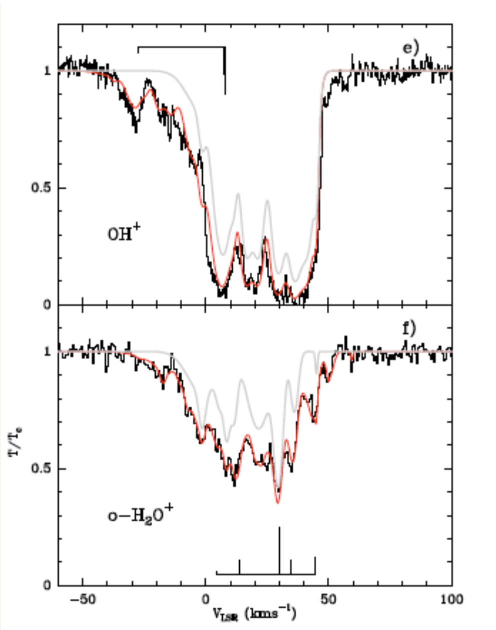
NGC253

HIFI

Monje et al. in prep

OH^+, H_2O^+ and H_3O^+ absorption





$$n(OH^+)/n(H_2O^+) = (k_2/k_1) + (k_3/k_1)[n(e^-)/n(H_2)]$$

$N(OH^+)/N(H_2O^+) > 4$

➪ OH^+ mostly in atomic gas with a small fraction of H_2 (< 10%)

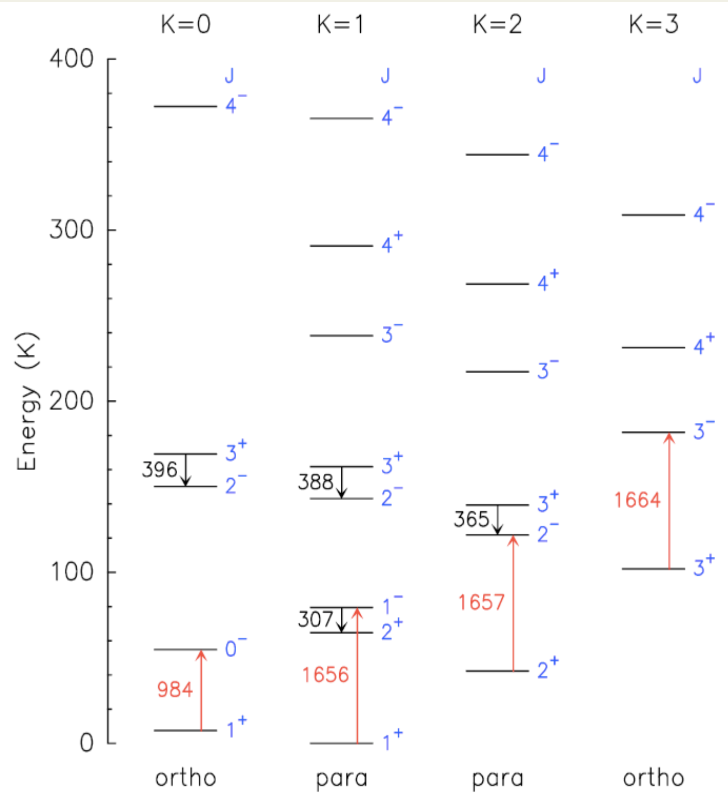
➪ H cosmic ray ionization rate $\zeta_H = 0.6 – 2.4 \times 10^{-16}\ s^{-1}$

Gerin et al. 2010, Neufeld et al. 2010

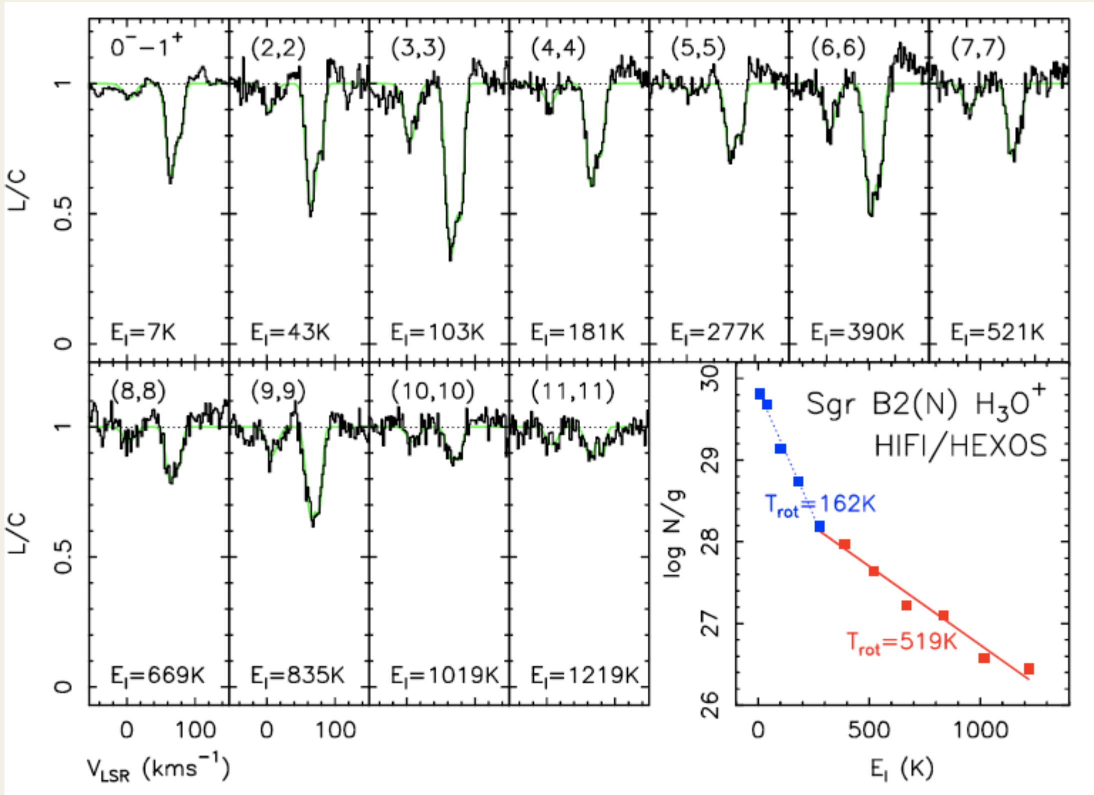
➪ H_3^+ in W51 : loss of H^+ with PAH^-?

Indriolo et al. 2012

H_3O^+ : metastable rotational transitions



Absorption lines against SgrB2(N)



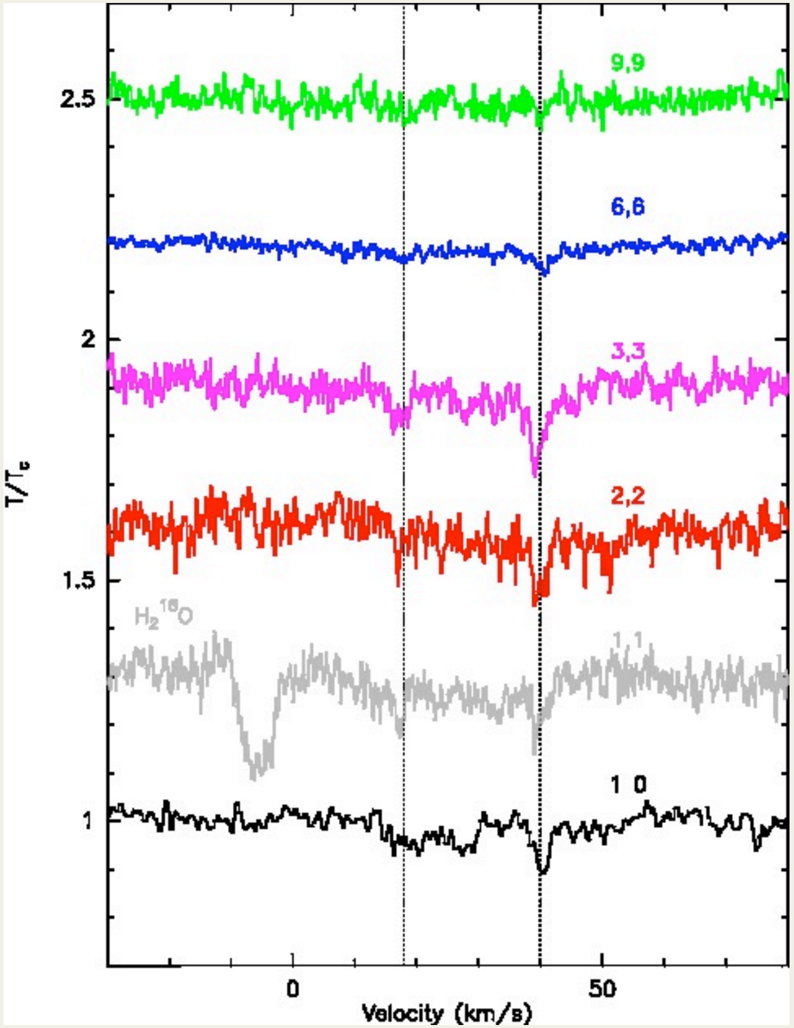
Hot H_3O^+

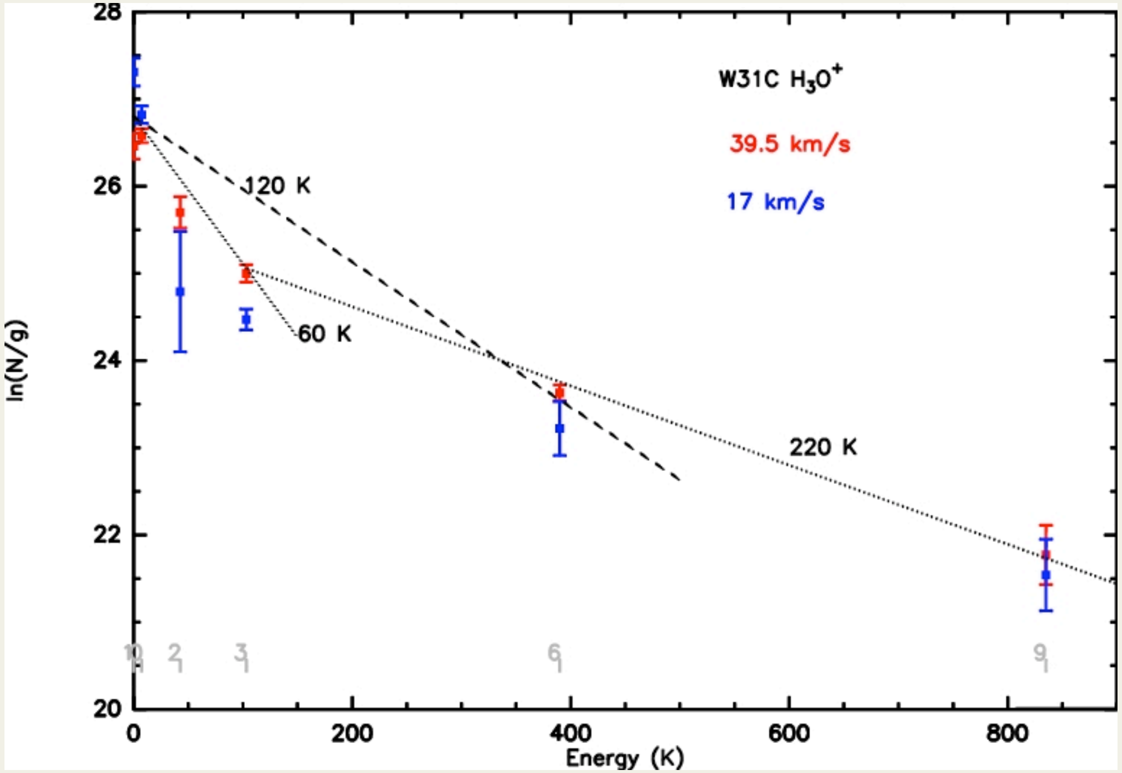
➪ Formation pumping in X-ray irradiated gas in the CMZ

Lis et al 2012

Benz et al 2010

H_3O^+ : metastable rotational transitions G10.6-0.34

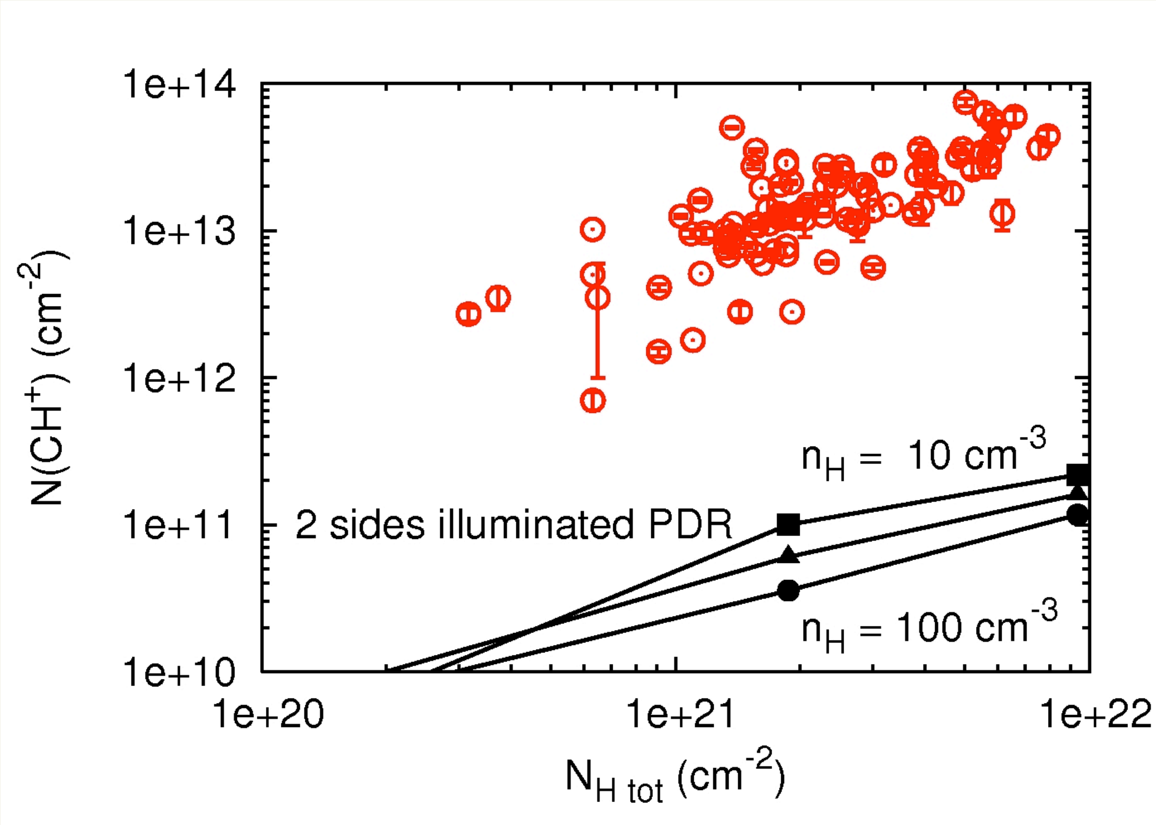




Hot H_3O^+

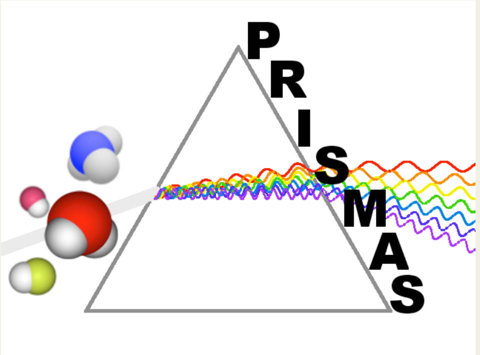
➪ Formation pumping?

High CH^+ abundances



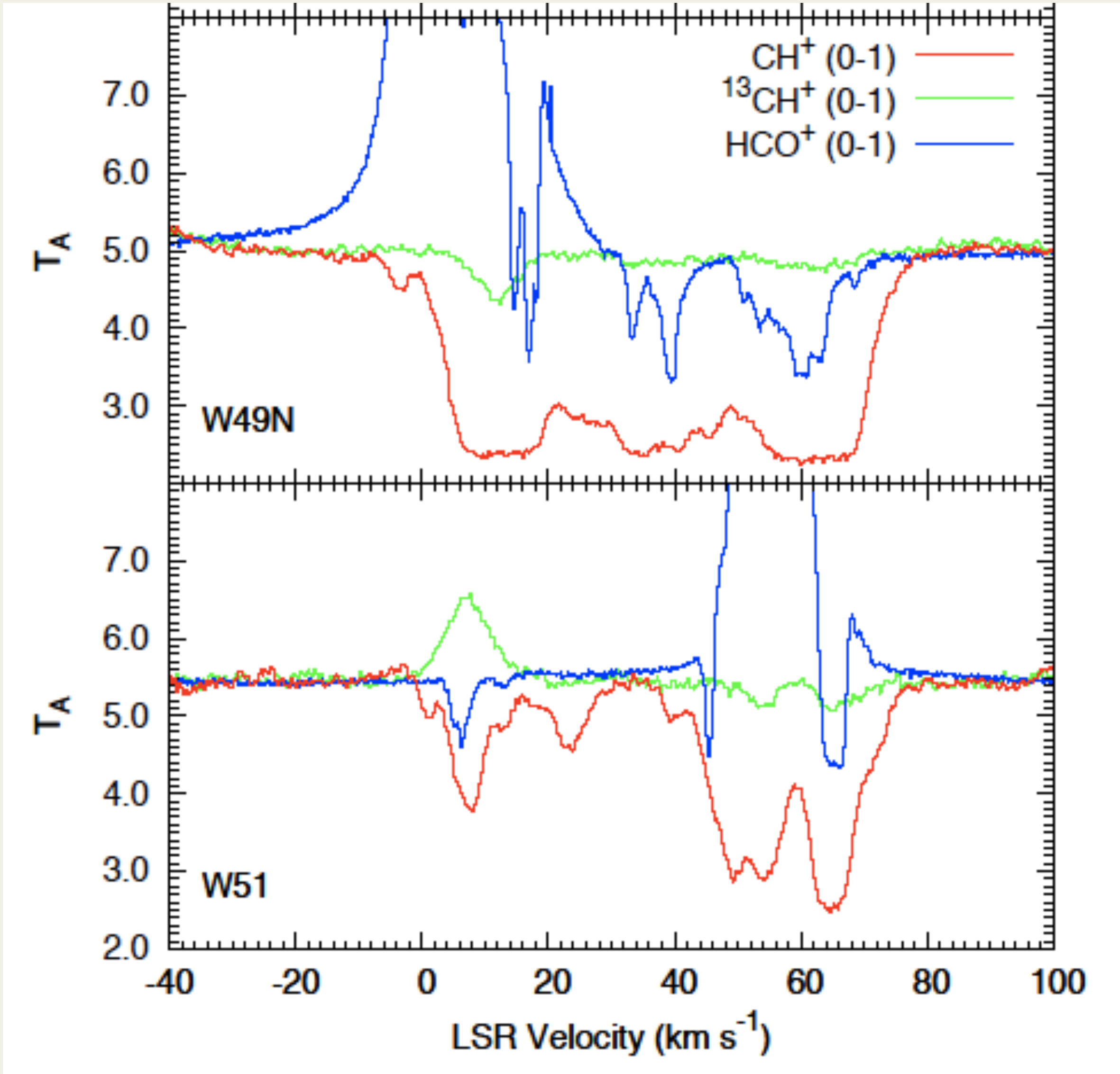
Visible lines : Crane et al. 1995, Gredel 1997, Weselak et al. 2008

- High endothermicity
  $C^+ + H_2 \rightarrow CH^+ + H$
  $\Delta E/k = 4640$ K
- Fast destruction
  by collisions with H_2



Herschel/HIFI absorption lines

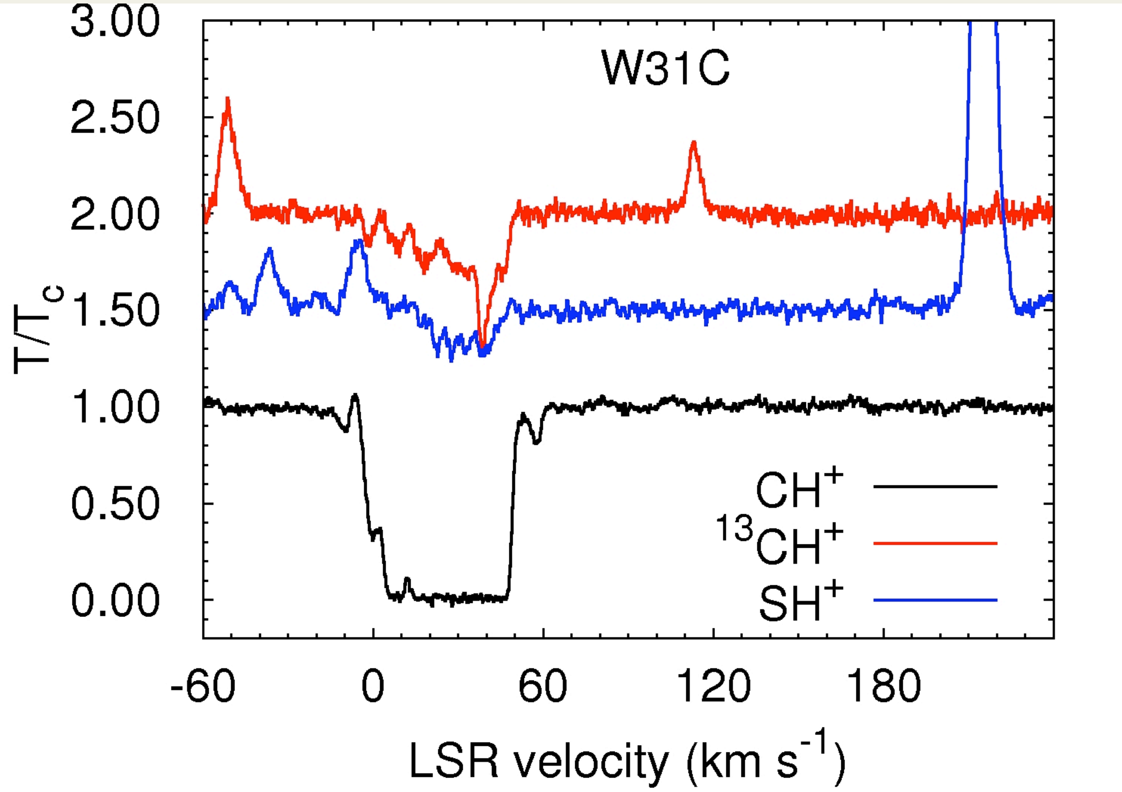
- Saturated CH^+(1-0) lines

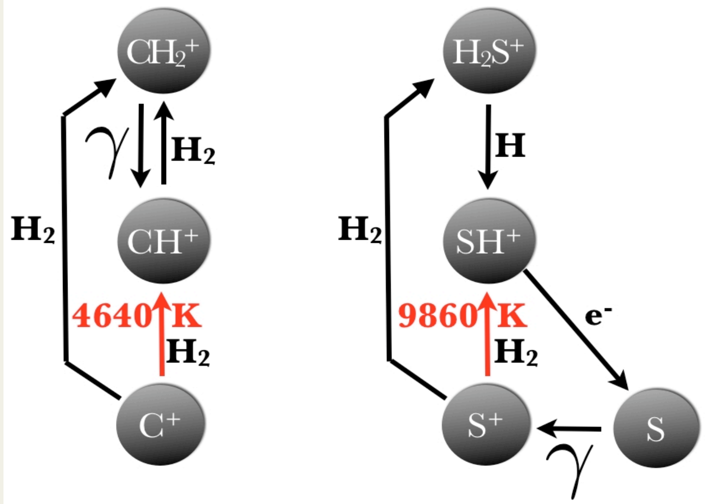


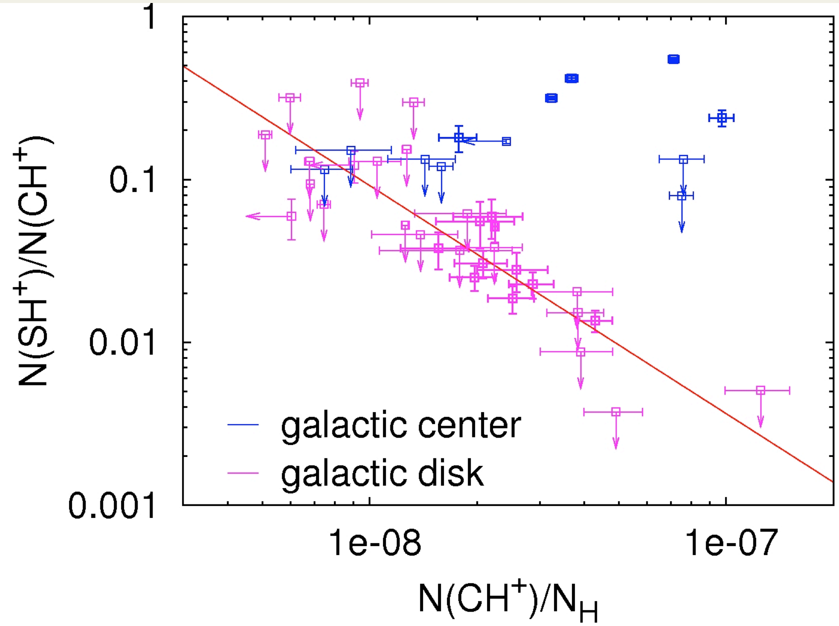
Falgarone et al. 2010, Godard et al. 2012

HCO^+(1-0) IRAM-30m
Godard et al. 2010

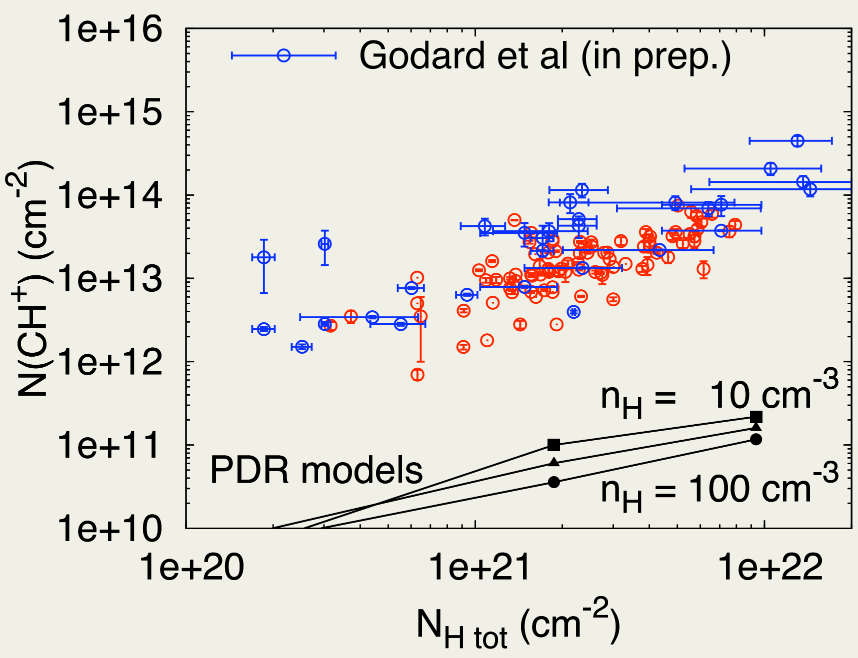
SH^+ (1-0) detections

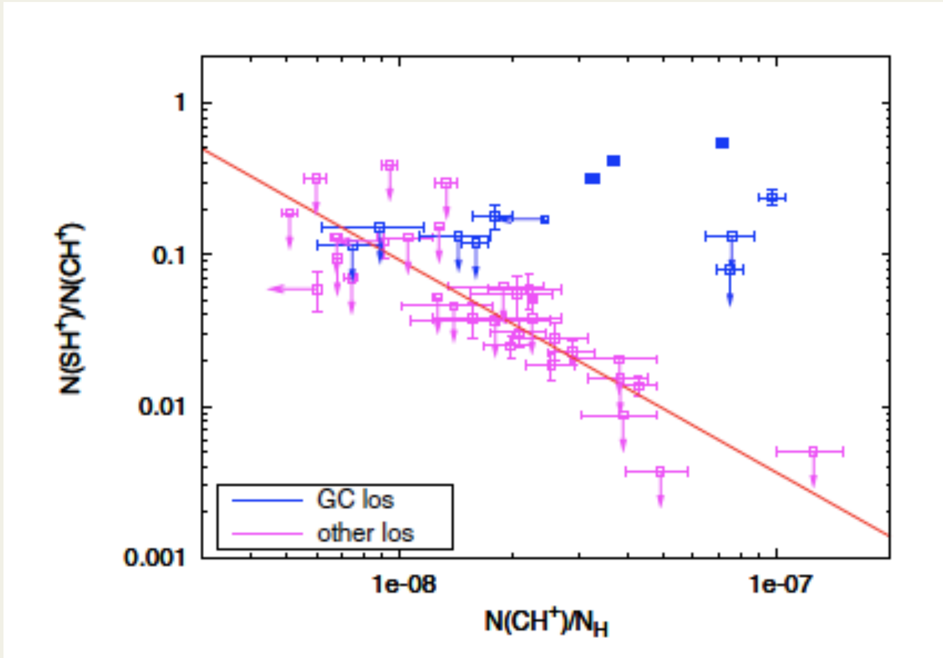


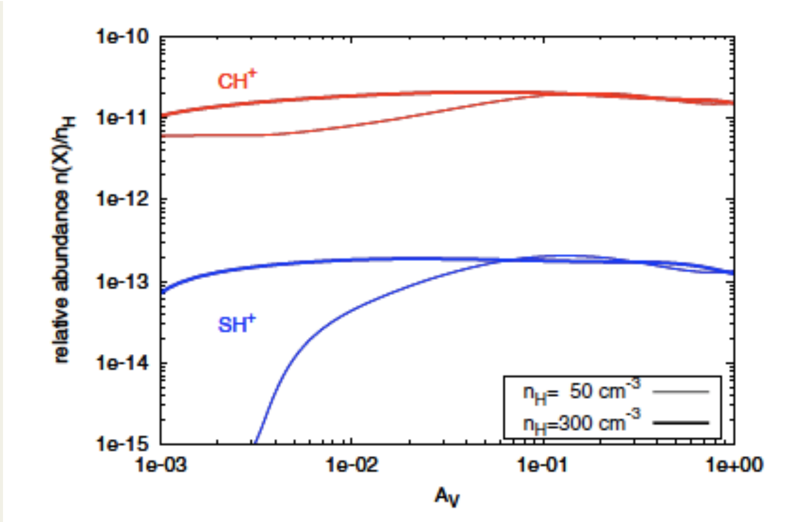




CH^+ and SH^+ : failures of PDR models







➮ both abundances and abundance ratios cannot be reproduced

Warm chemistry as an alternative

- **PDR models : C^+**

C^+ + OH and H_2O → CO

- **Alternative: CH_3^+**

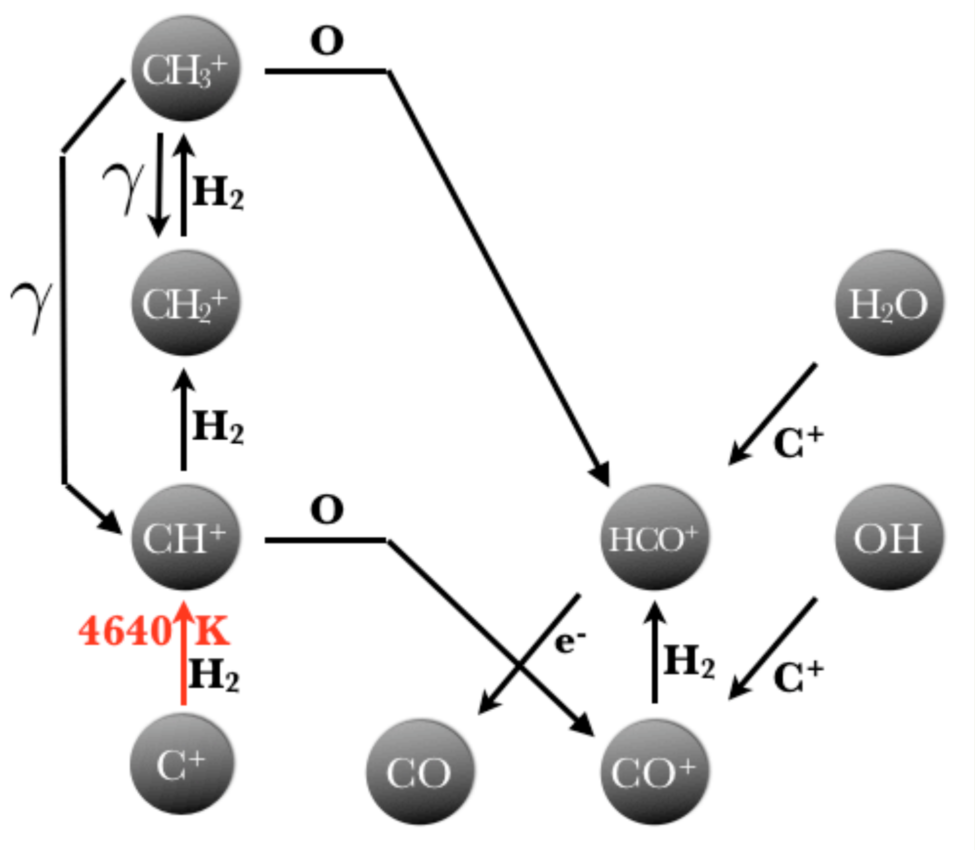
$C^+ + H_2$ → CH^+ highly endothermic

$CH^+ + H_2$ → CH_2^+ → CH_3^+

➪ **Warm non-equilibrium chemistry**

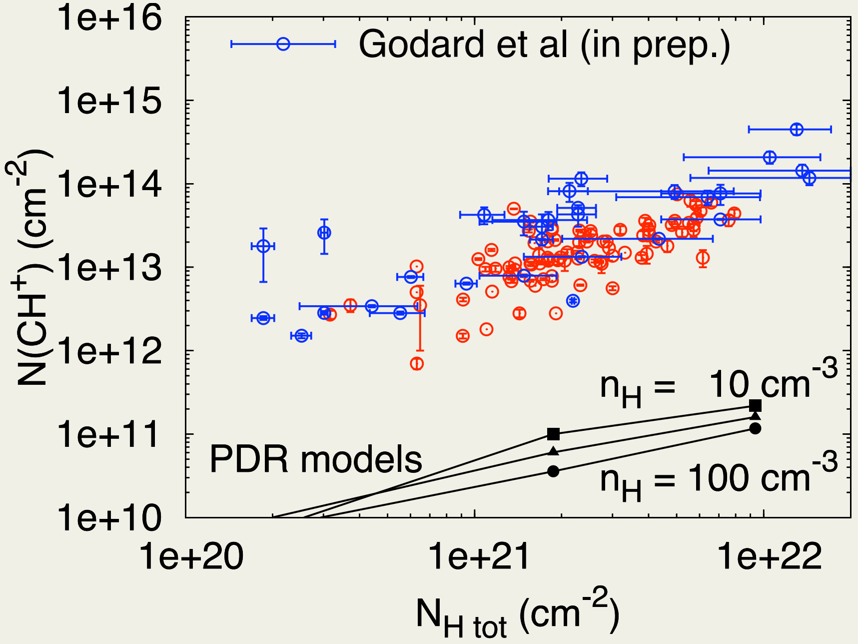
➪ **Energy source:**

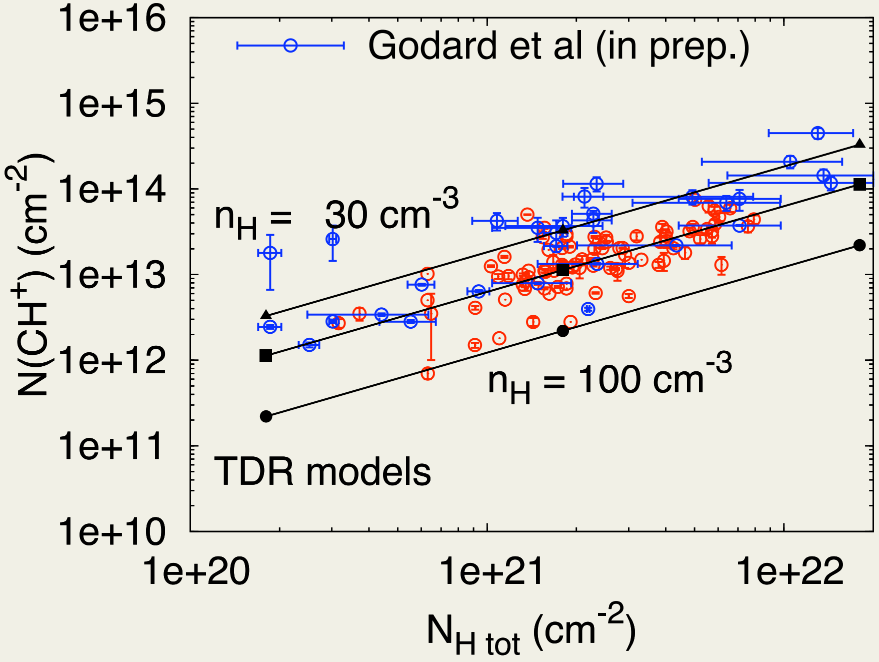
Intermittent turbulent dissipation



Godard et al. 2009

Models of Turbulent dissipation regions: CH^+





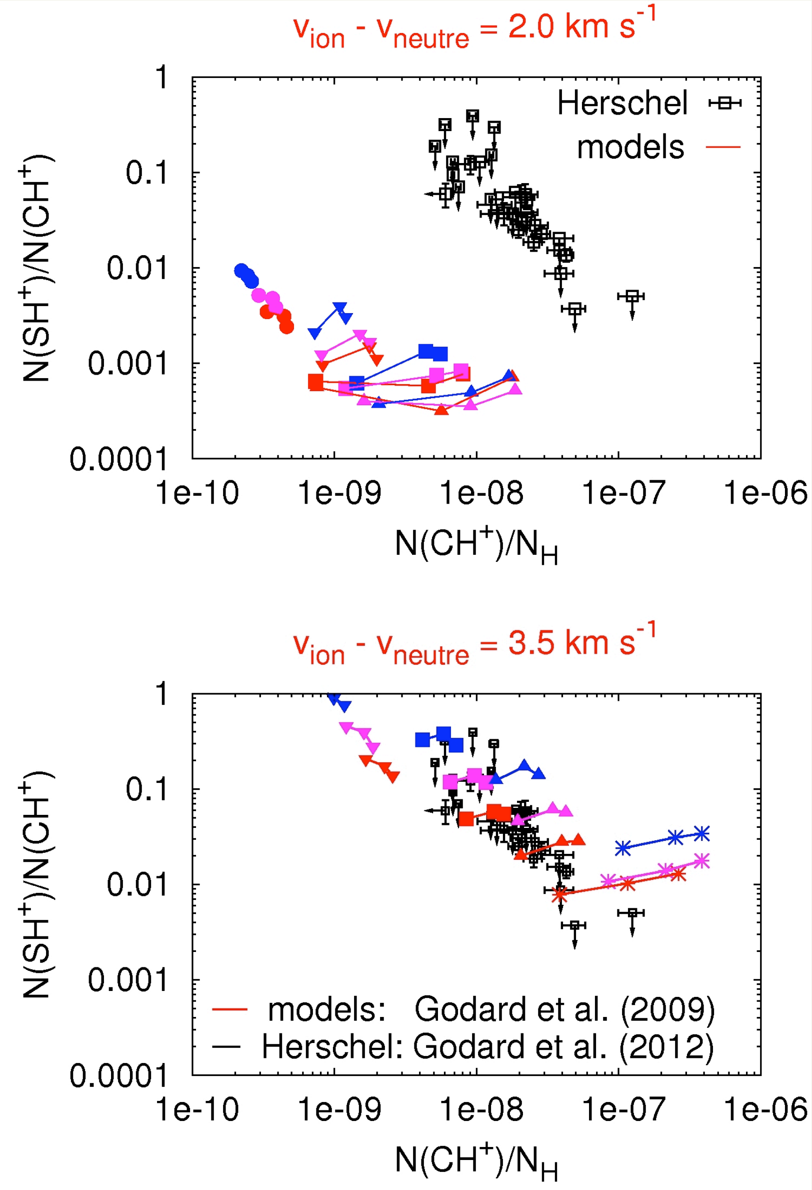
$$N(CH^+)/N_H \sim 2 \times 10^{-8}\ \varepsilon_{24}\ (n_H/50\ cm^{-3})^{-2.3}\ (A_V/0.2)^{-1}$$

⇨ $N(CH^+)$ increases with UV-field

$\propto$ turbulent dissipation rate

$\varepsilon_{24} = 10^{-24}$ erg cm^{-3} s^{-1}

CH^+ and SH^+

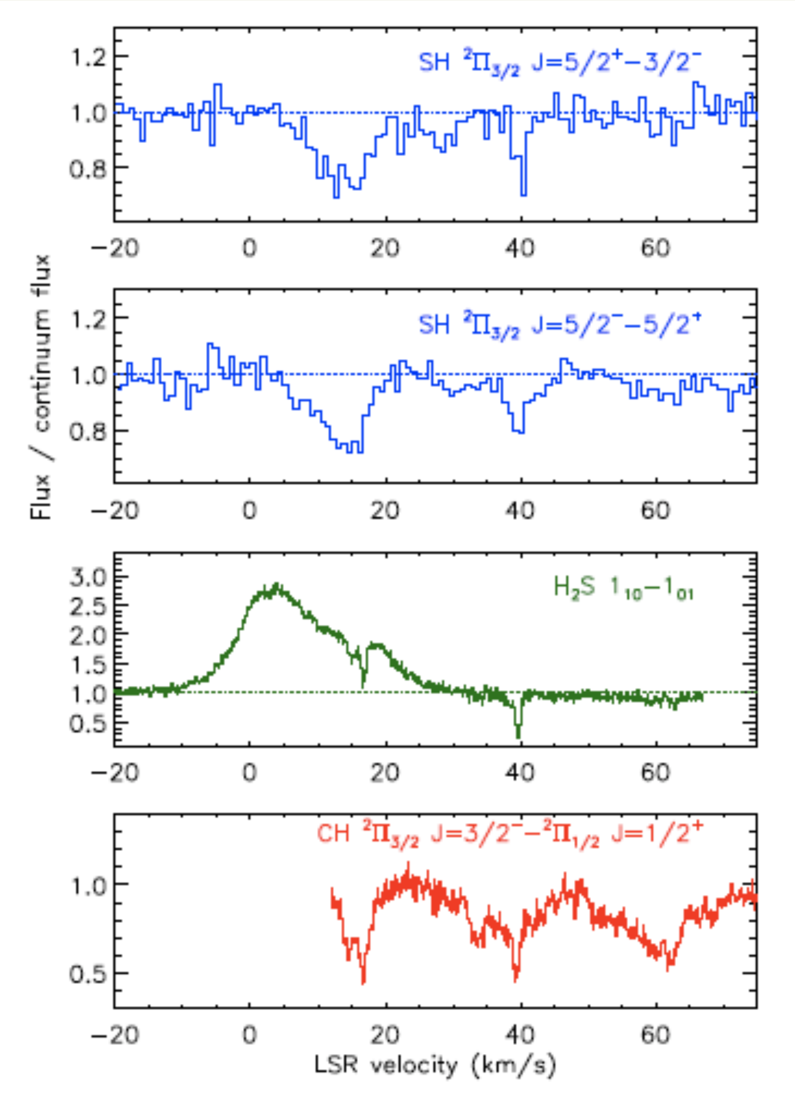


Turbulent Dissipation Regions model :

➪ Heating via ion-neutral drift favored over viscous heating

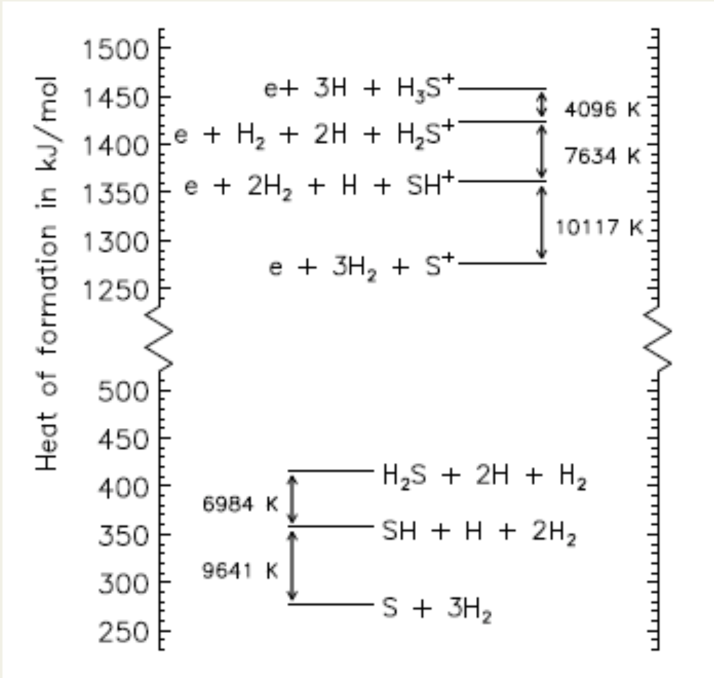
Godard et al. in prep.

SH, SH^+ and H_2S



SH from SOFIA, Neufeld et al 2012

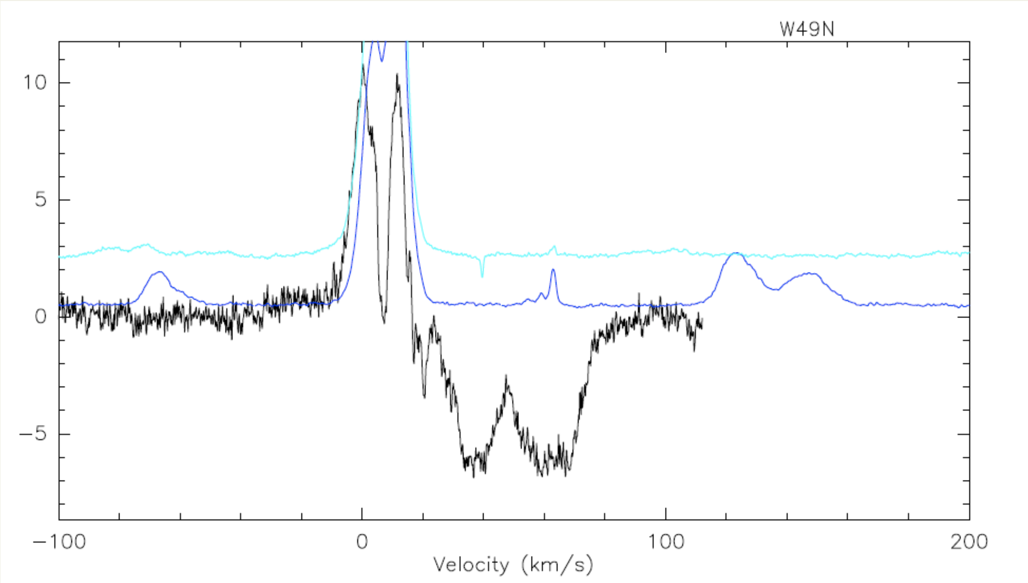
All H abstraction reactions are endothermic

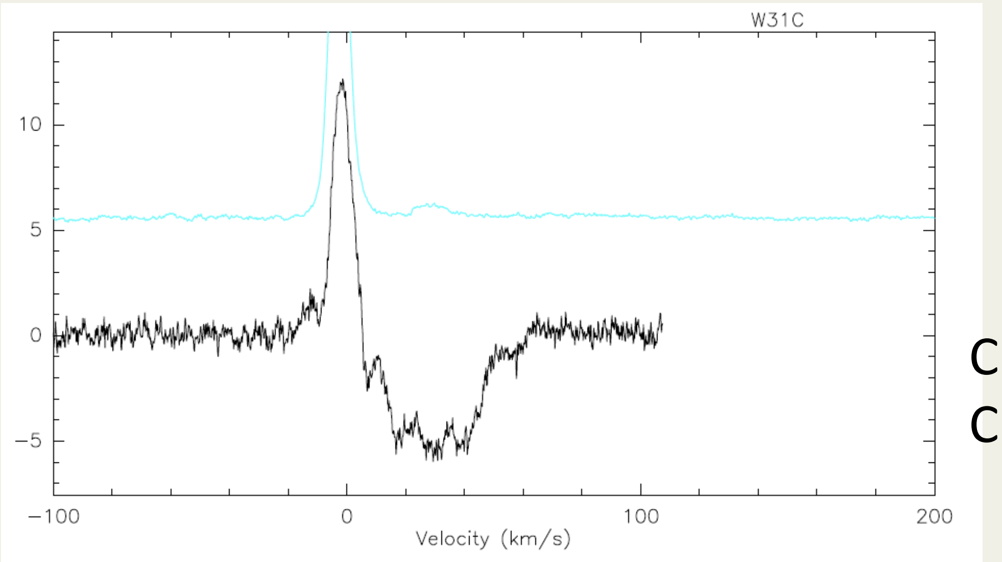


$SH/H_2S = 0.13 >> PDR$ predictions

➪ Enhanced neutral-neutral rate for H_2S formation

[CII] line absorption and CI lines





[CII] absorption

➪ same velocity coverage as CH^+ absorption

Excitation conditions

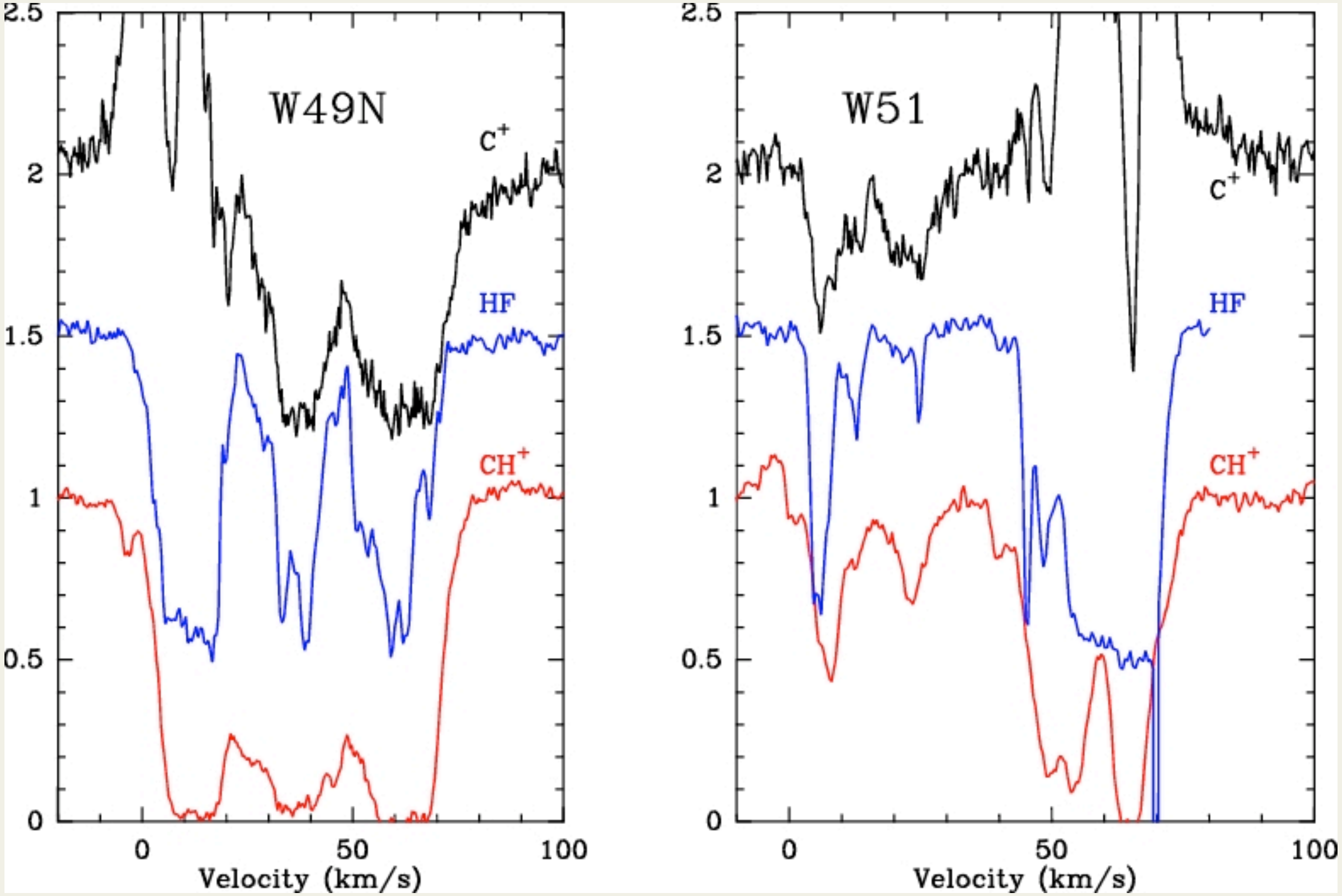
➪ absorption occurs in CNM

CII (158 µm black)

CI (dark blue $^3P_1$-$^3P_0$, turquoise $^3P_2$-$^3P_1$)

Gerin et al. in prep

Comparison of line profiles

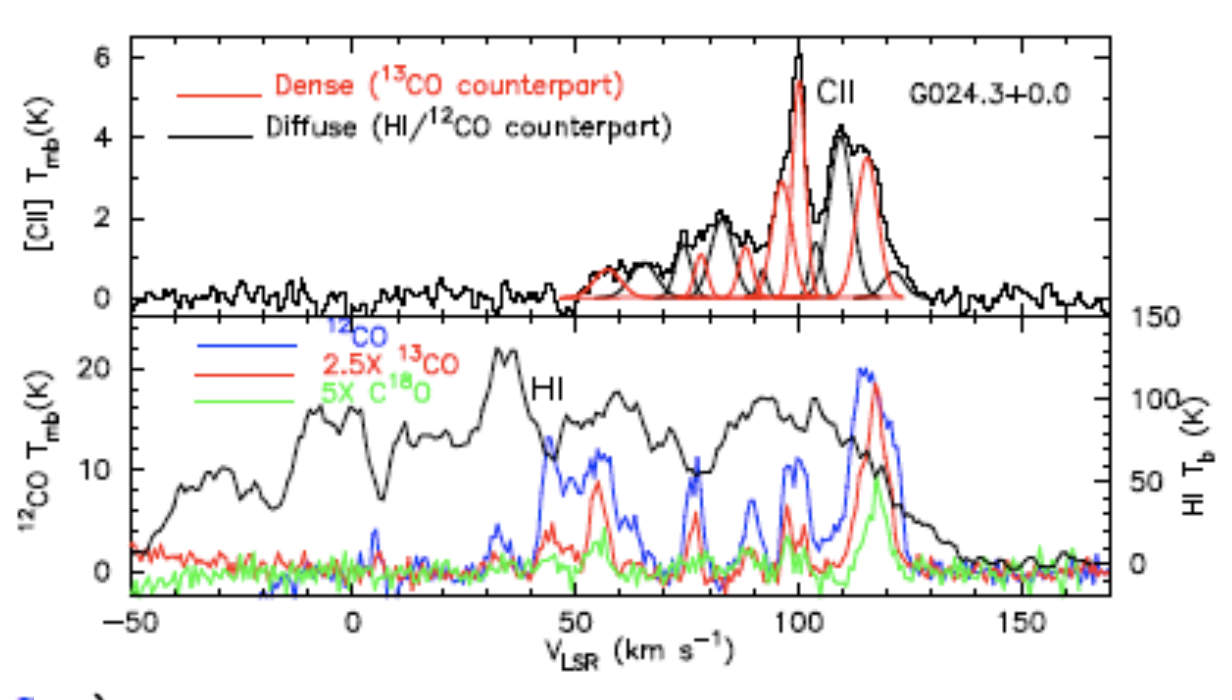


CII absorption

➯ same velocity coverage as CH^+ absorption

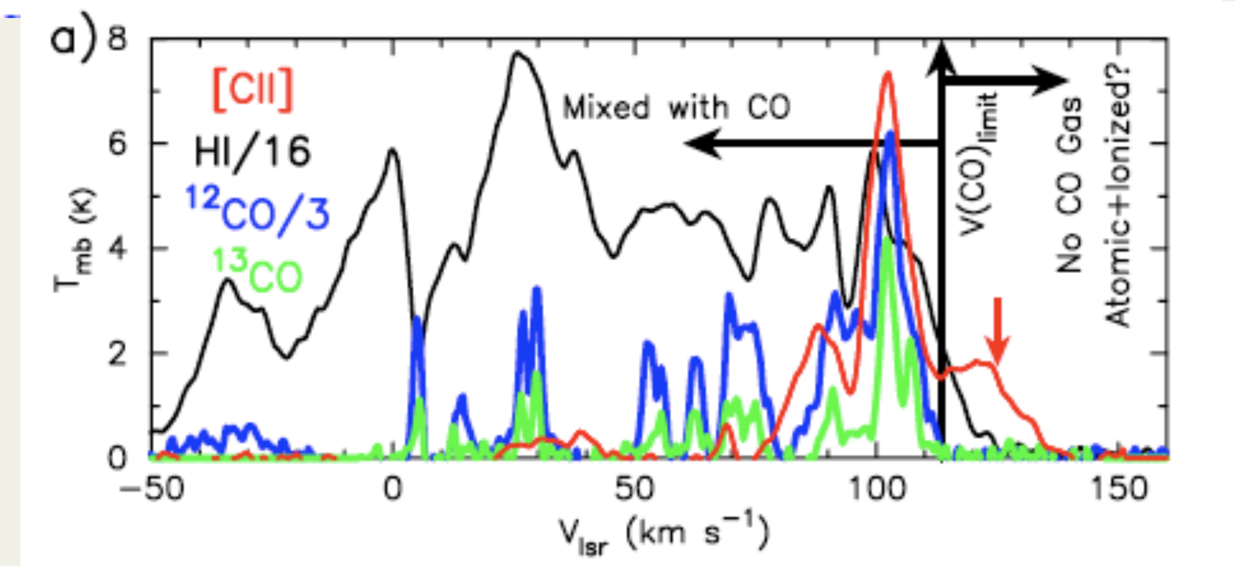
➯ confirms that CH^+ is formed in CNM

II - Galactic plane [CII] line survey



➪ Detection of warm H_2
CO-dark gas
$T_k > 30$ K

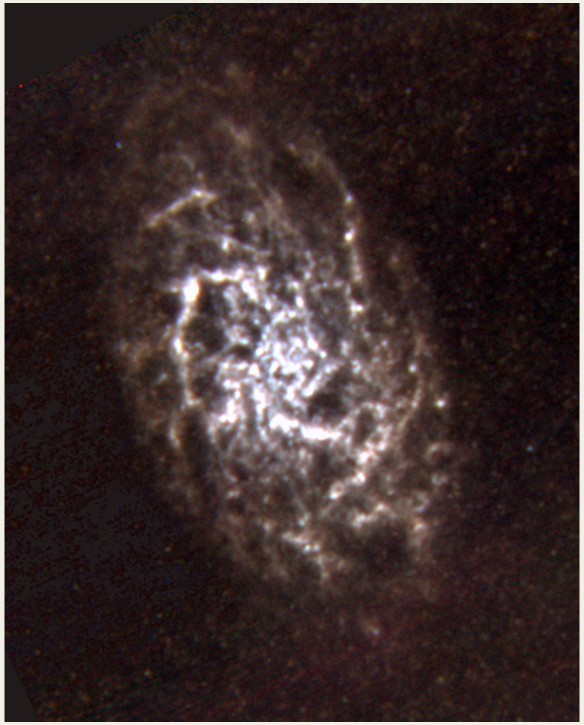
Langer et al. 2010

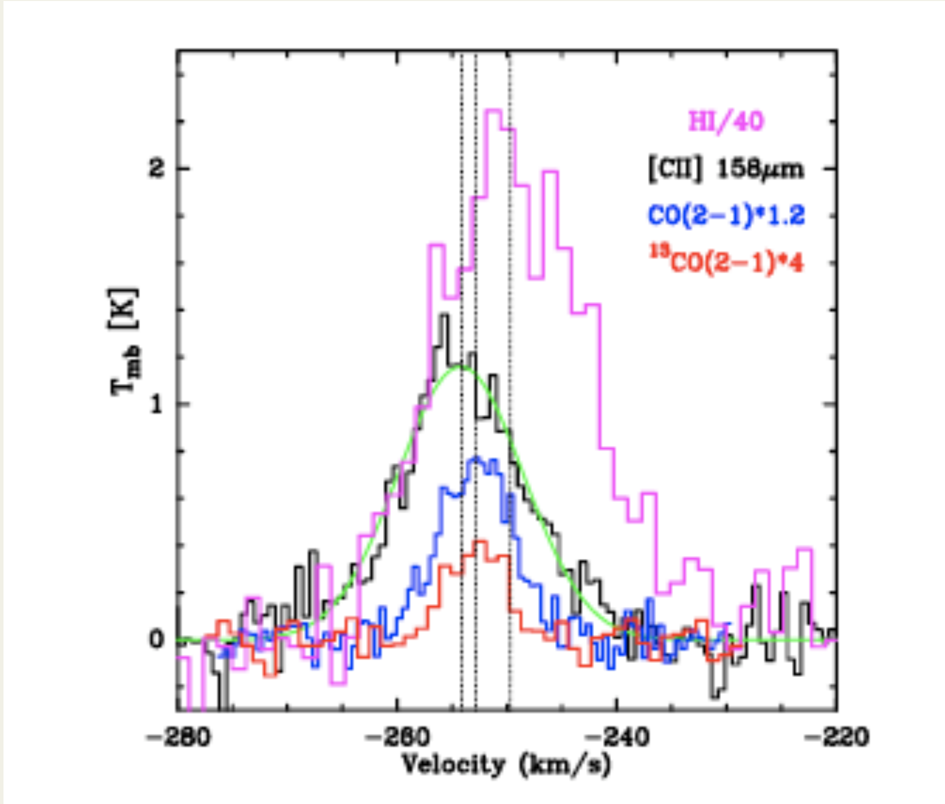


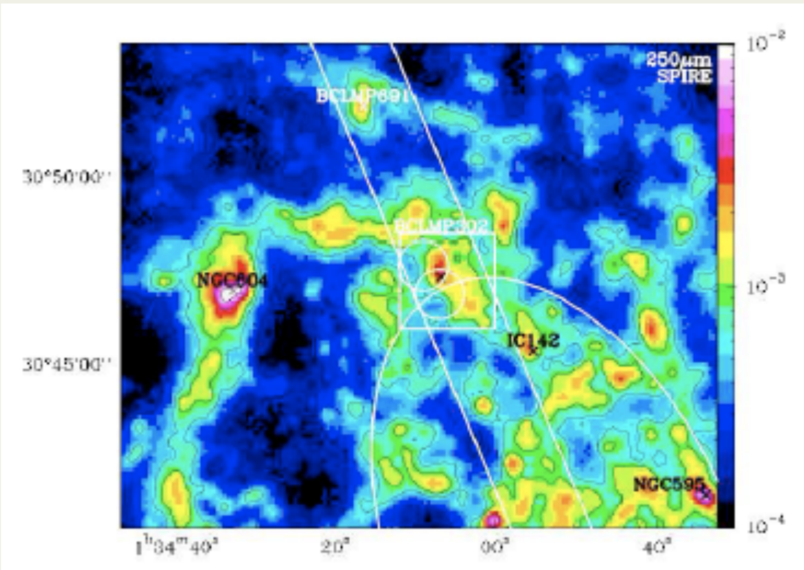
➪ Detection of WIM

Velusamy et al. 2012

[CII] 158 µm in M33

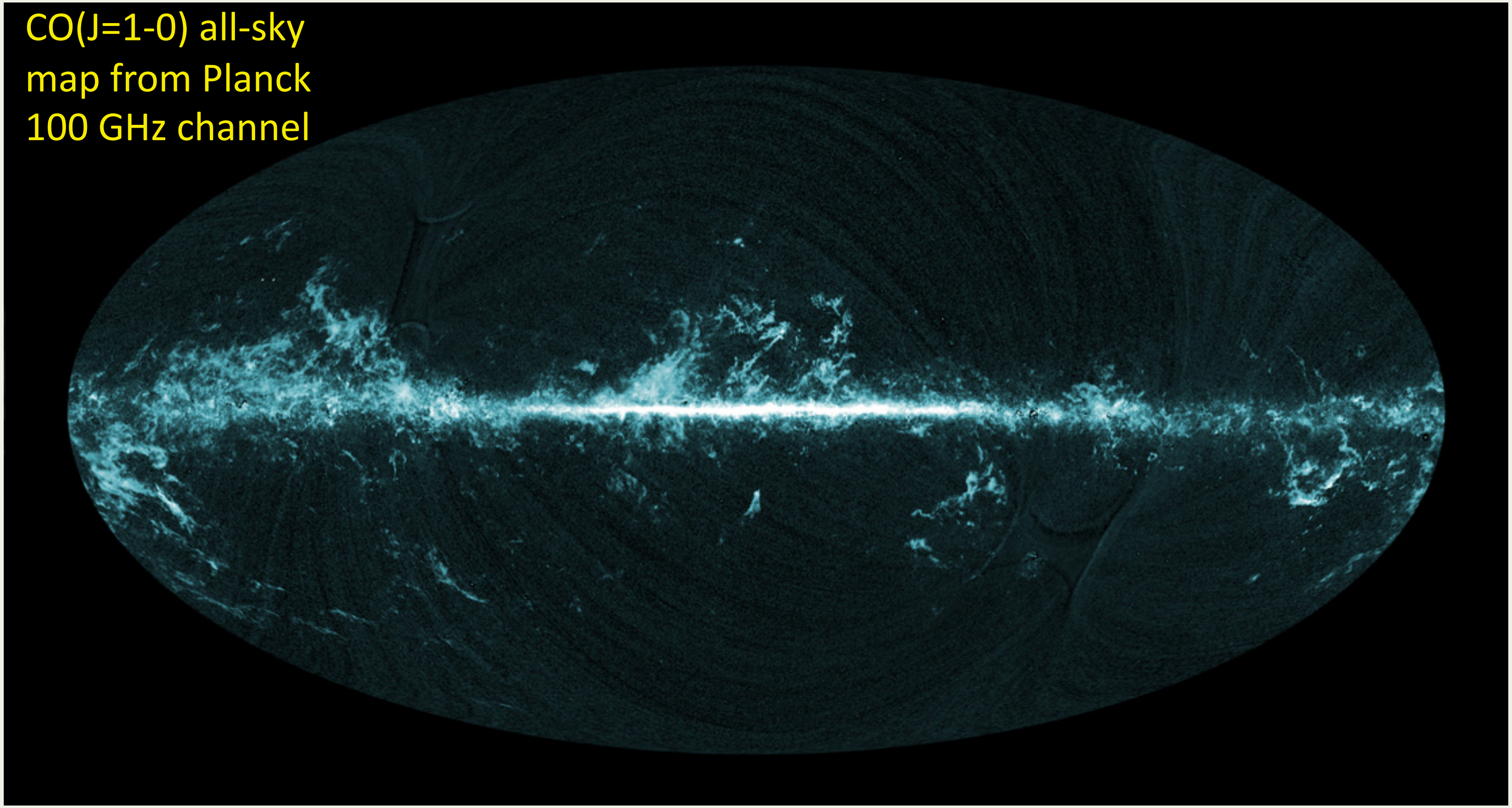






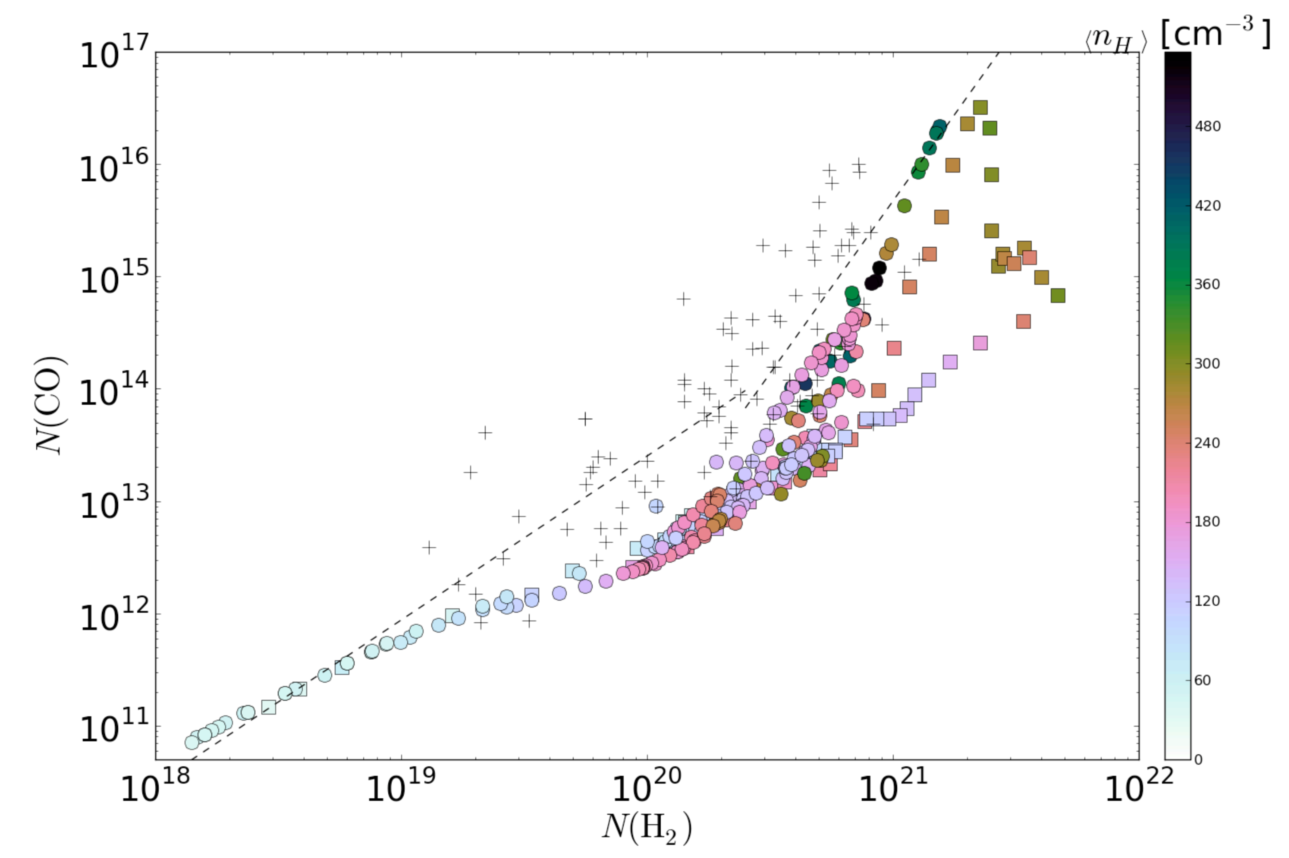
Mookerjea et al. 2011

III - Planck CO detections at high latitude



The 100 GHz channel of Planck includes the $^{12}CO(J=1\text{-}0)$ line (and ^{13}CO, $C^{18}O$).
Provides an all-sky map with sensitivity comparable to that of the Dame & NANTEN surveys
Planck also sees $^{12}CO(J=2\text{-}1)$ and $^{12}CO(J=3\text{-}2)$. CO at high latitude raises the problem of CO formation in gas poorly shielded from the UV-field.

CO richness of diffuse gas

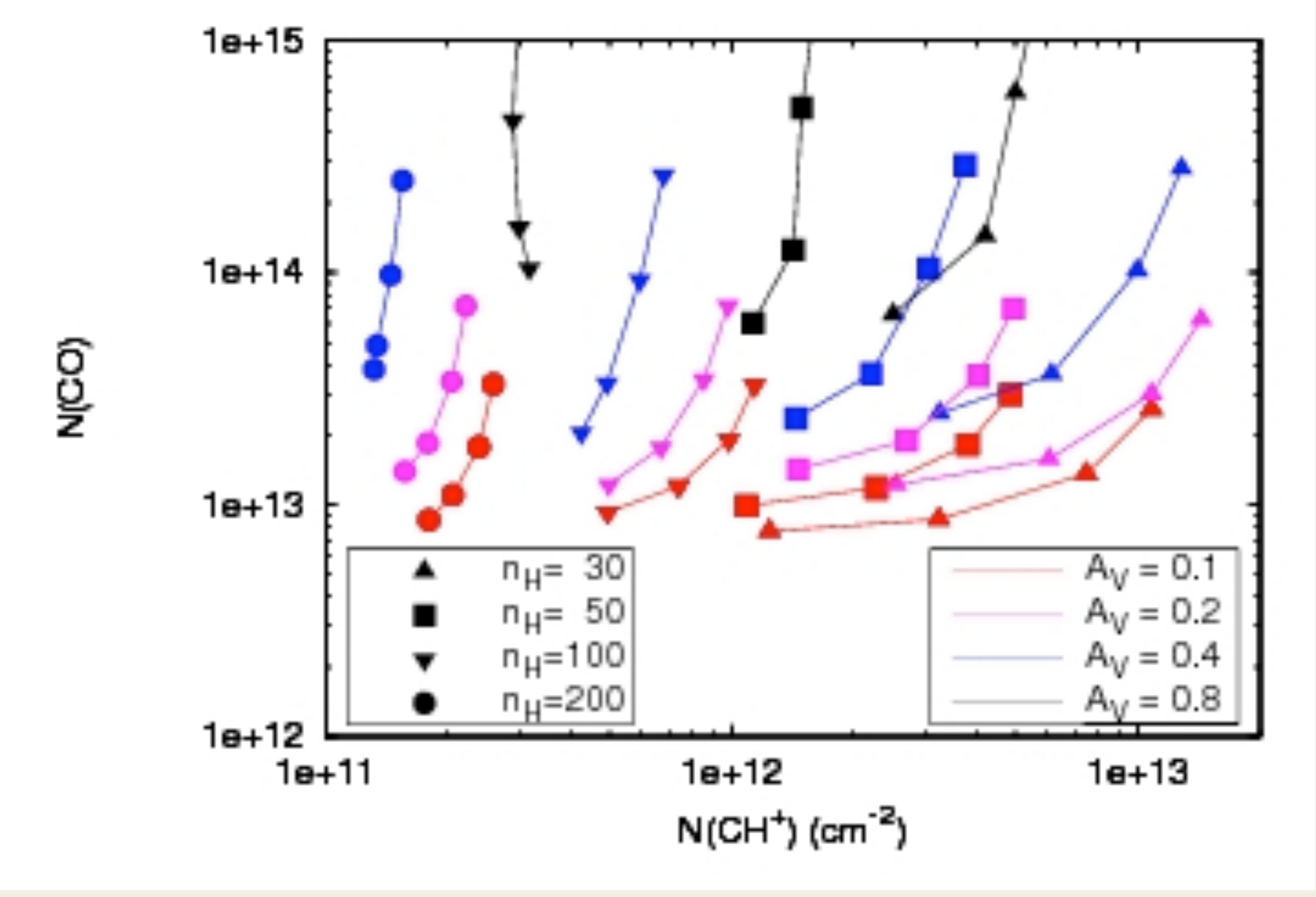


MHD simulations Hennebelle et al. 2008

Chemistry post-treatment Levrier et al. 2012

CO data (crosses) : Sheffer + 08, Pan+05, Crenny+04, Lacour+05, Rachford+02,09, Snow+ 08

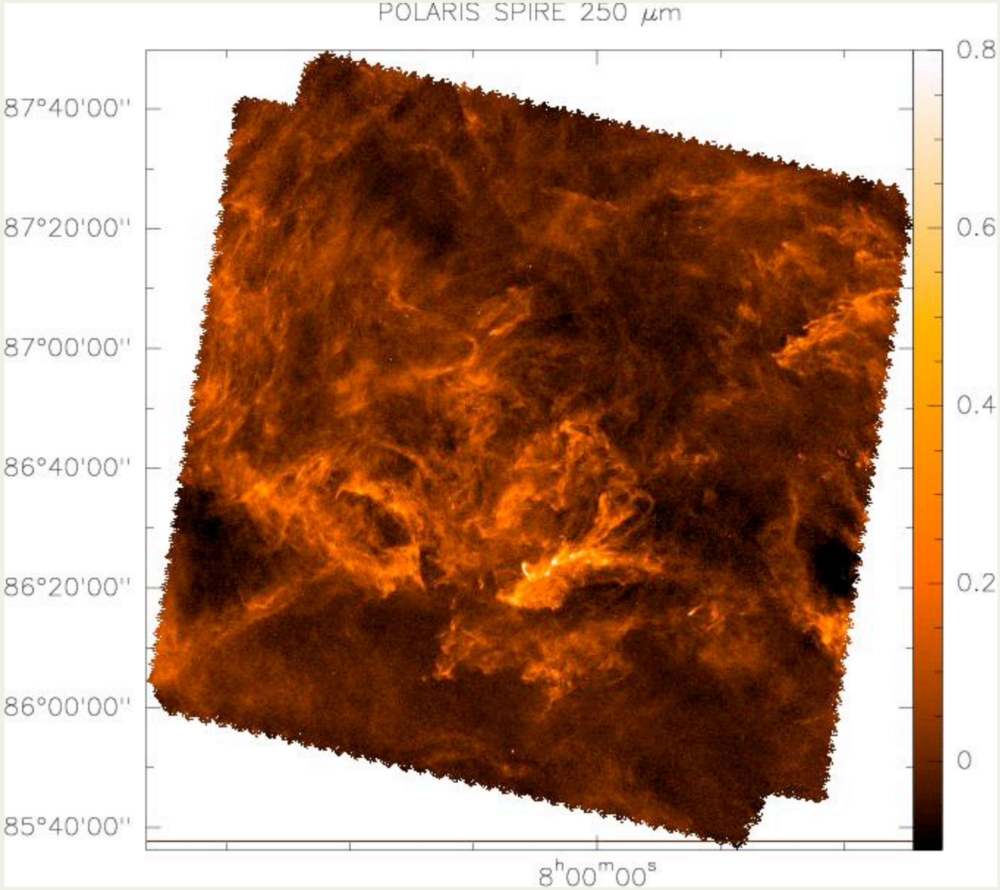
TDR models : CO and CH^+



Godard et al.
In prep.

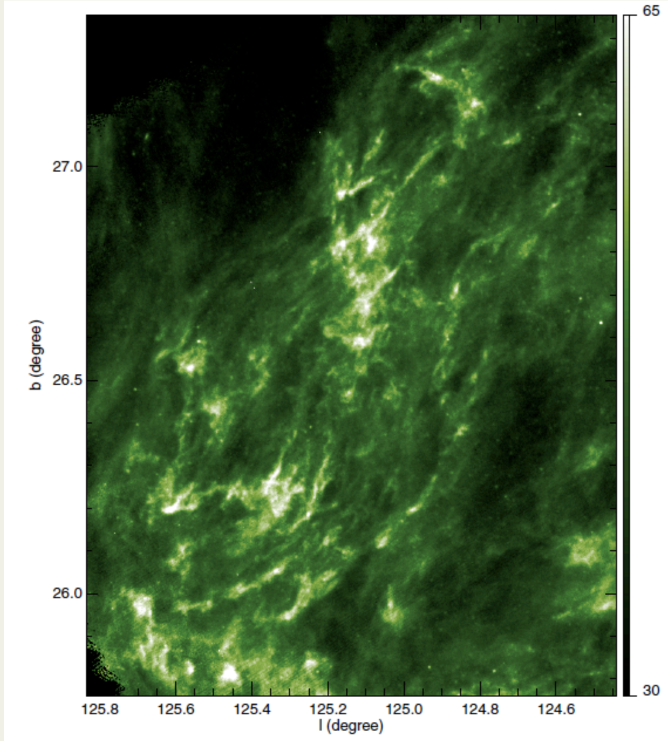
Observed range in diffuse gas

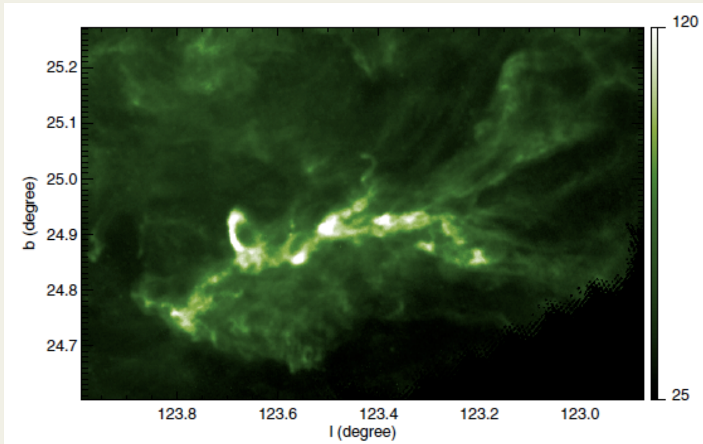
IV - Small-scale filamentary dust emission



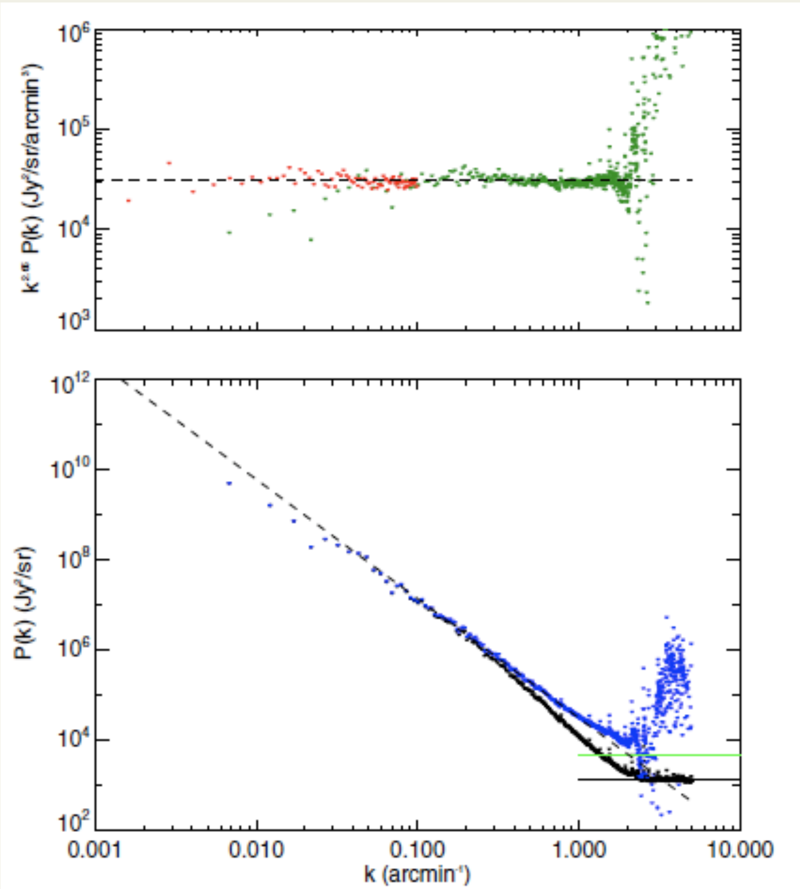
Polaris Flare : SPIRE 250μm emission

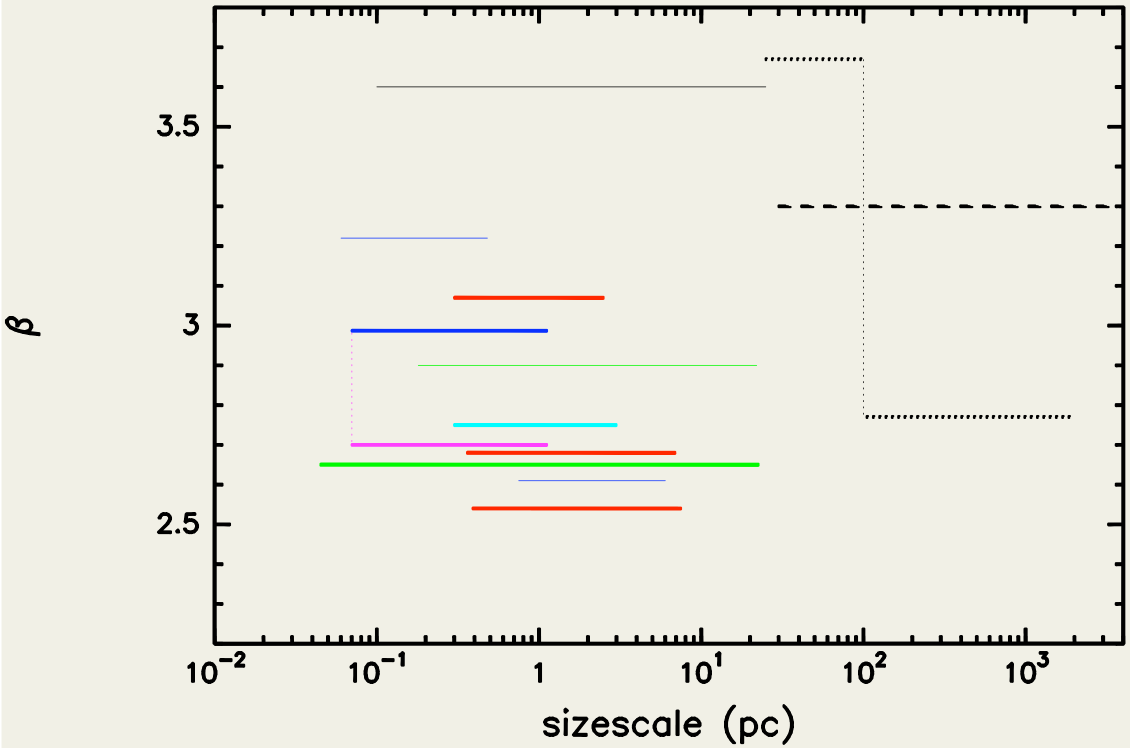
Miville-Deschênes et al. 2010





Dust, HI and CO power spectra





Polaris Flare, SPIRE 250 µm (green)
IRAS 100 µm (red) dust emission

Polaris Flare :
CO Hily-Blant et al. in prep
HI Miville-Deschênes et al. 03

The future

- Coupling of dynamics and chemistry, non-equilibrium chemistry
- Formation pumping, state-to-state chemistry
- Additional heating sources
- Cosmic rays:propagation, role in chemistry
- Charged PAHs
- Magnetic fields: a new world is just opening