Warm chemistry in the diffuse ISM : a tracer of turbulent dissipation

Edith Falgarone
ENS & Paris Observatory, France

Benjamin Godard, CAB/CSIC Madrid, Spain
Guillaume Pineau des Forêts, IAS, France
Maryvonne Gerin, ENS & Paris Observatory, France
& PRISMAS Herschel/HIFI KP team

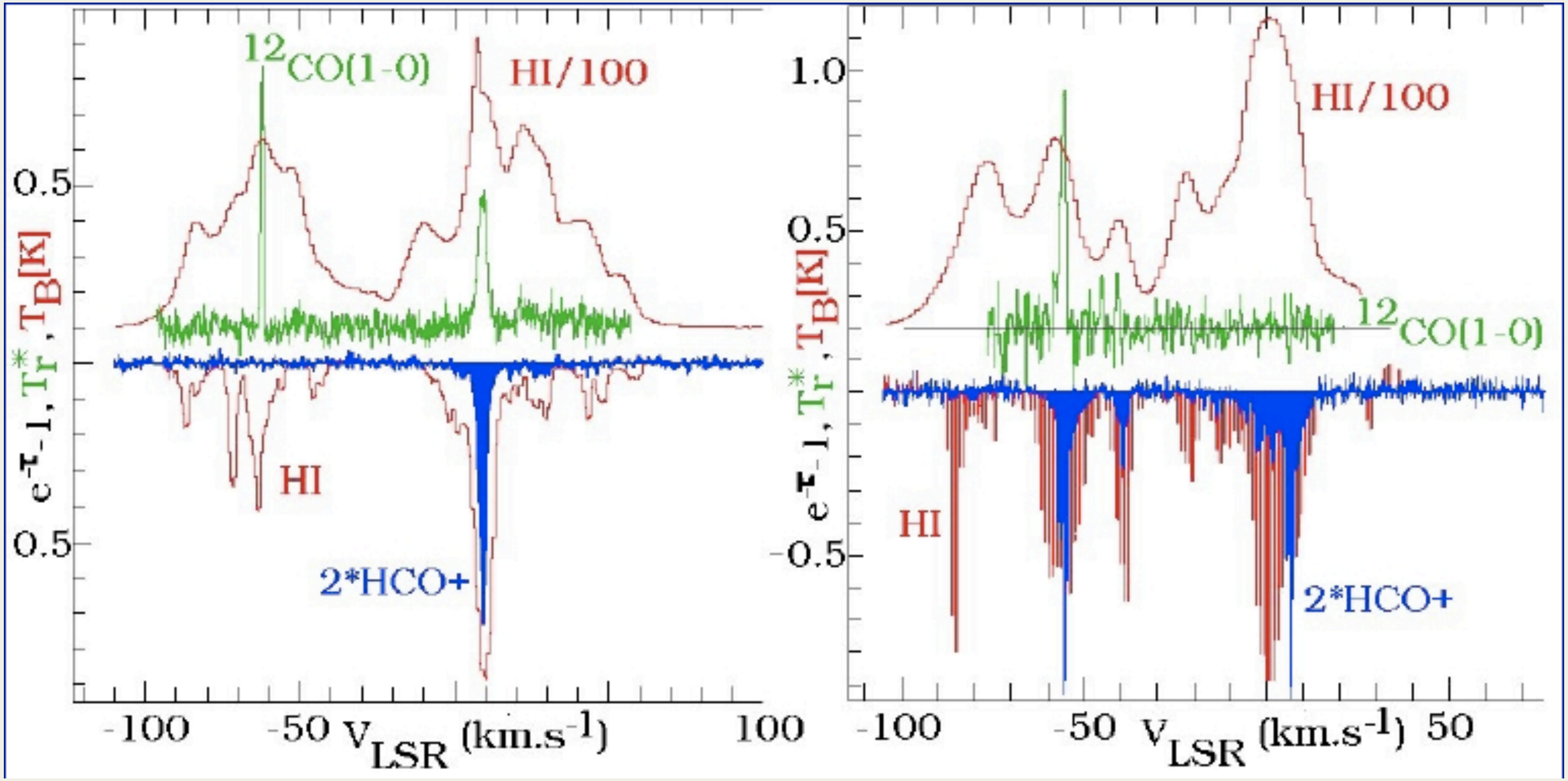
SOFIA tele-talk,
Pasadena, 30 March 2011

Outline

- Diffuse ISM : observations and puzzles
- Physical framework of the turbulent dissipation models
- Results
- A niche for SOFIA/GREAT?

1 - Diffuse ISM : observations and puzzles

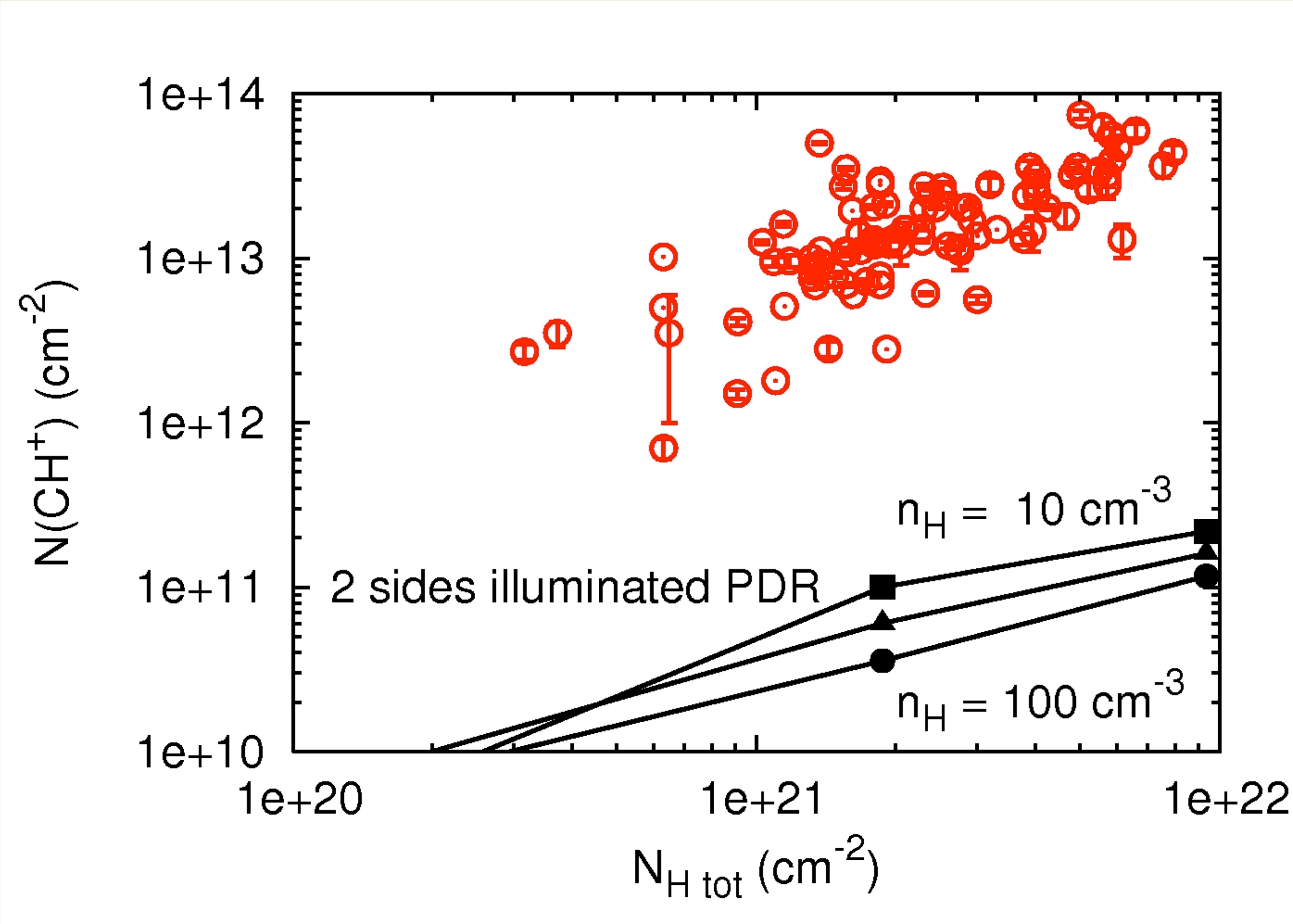
Chemical richness and complexity of diffuse ISM



Lines of sight toward extragalactic radiosources and QSOs

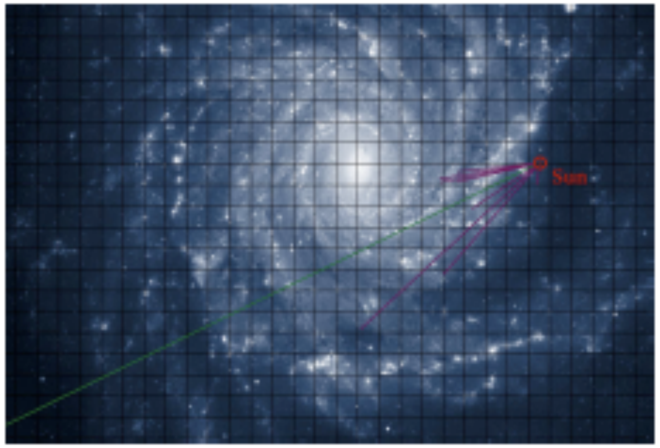
Liszt (priv. comm.)

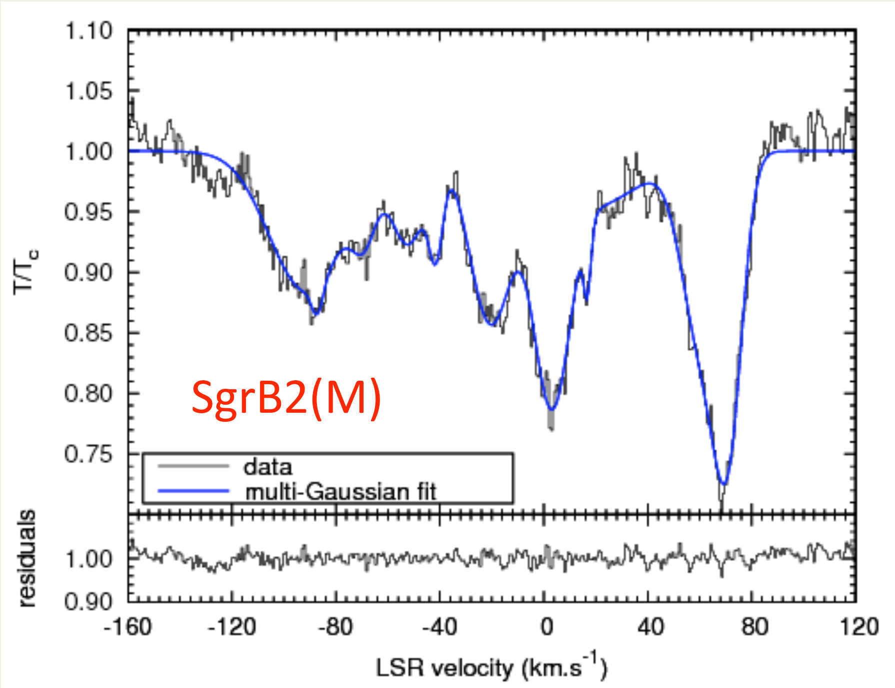
The CH^+ puzzle in the diffuse ISM

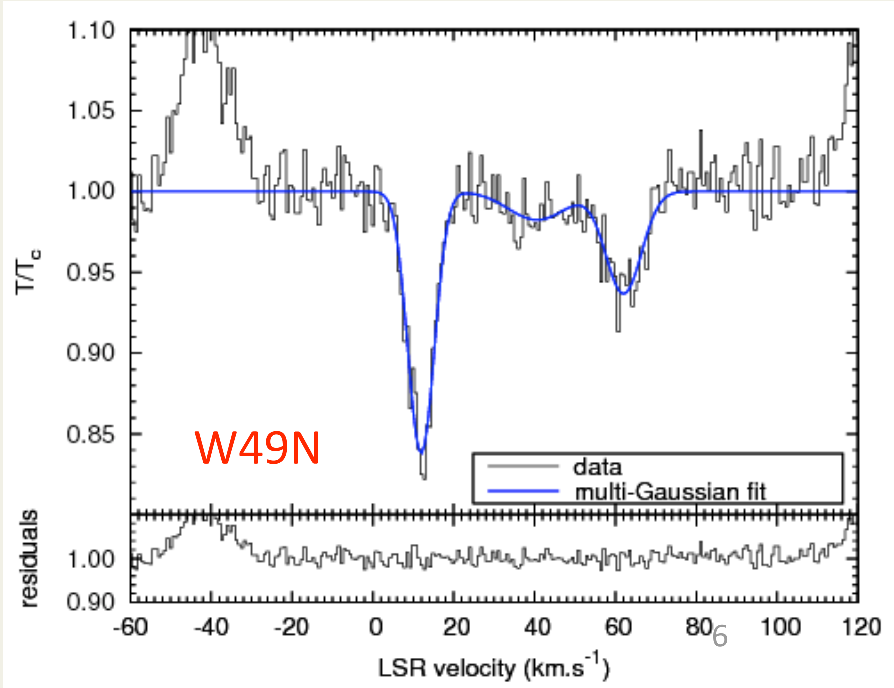


Visible lines : Crane et al. 1995, Gredel 1997, Weselak et al. 2008

$^{13}CH^{+}$(1-0) absorption at 830 GHz : opacities τ ~ a few 0.1







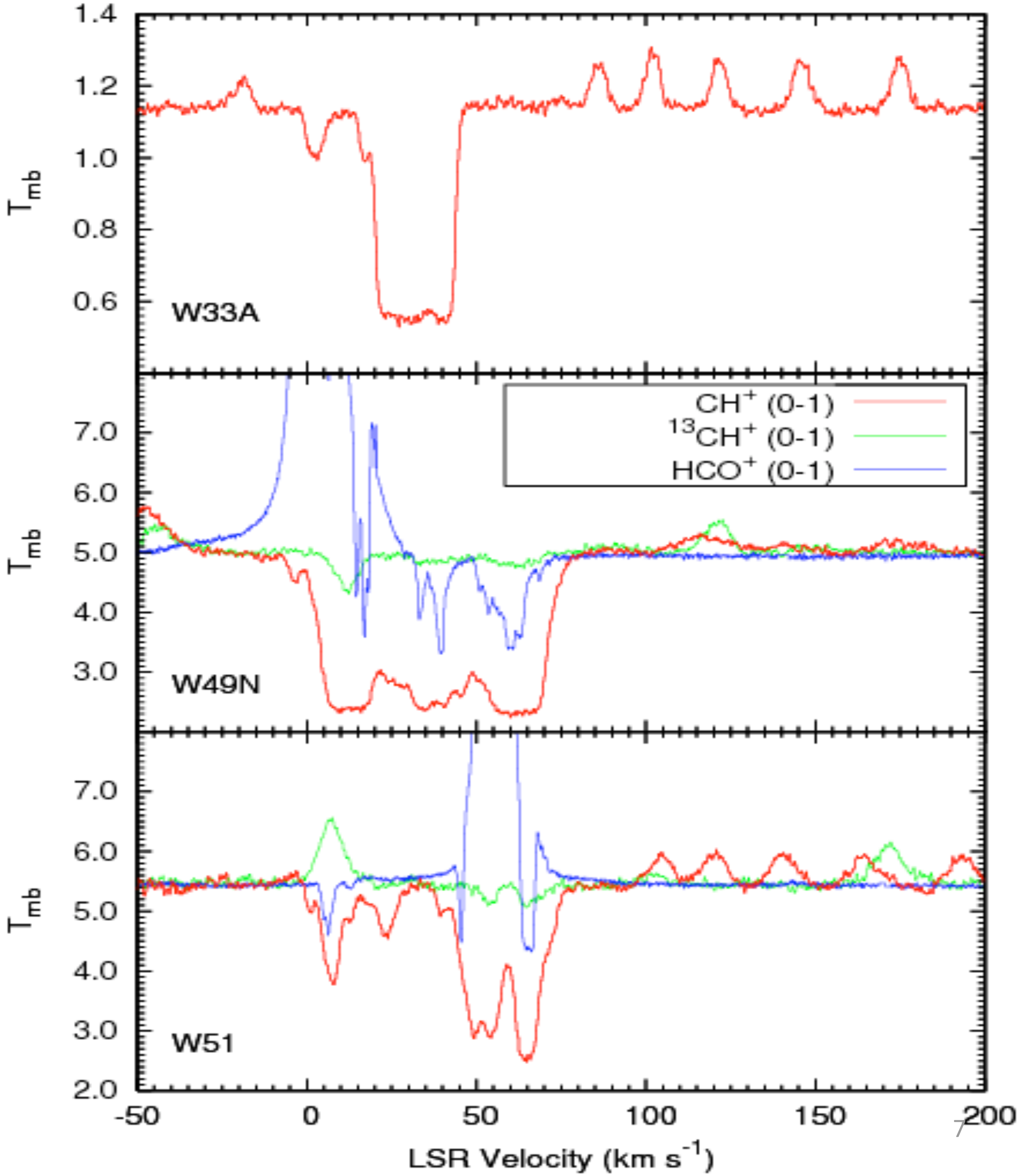
Ground-based observations 830 GHz,
Caltech Submillimeter Observatory

Falgarone et al. 2005, Lis et al. 2009; Falgarone et al. 2011, Menten et al. (APEX)

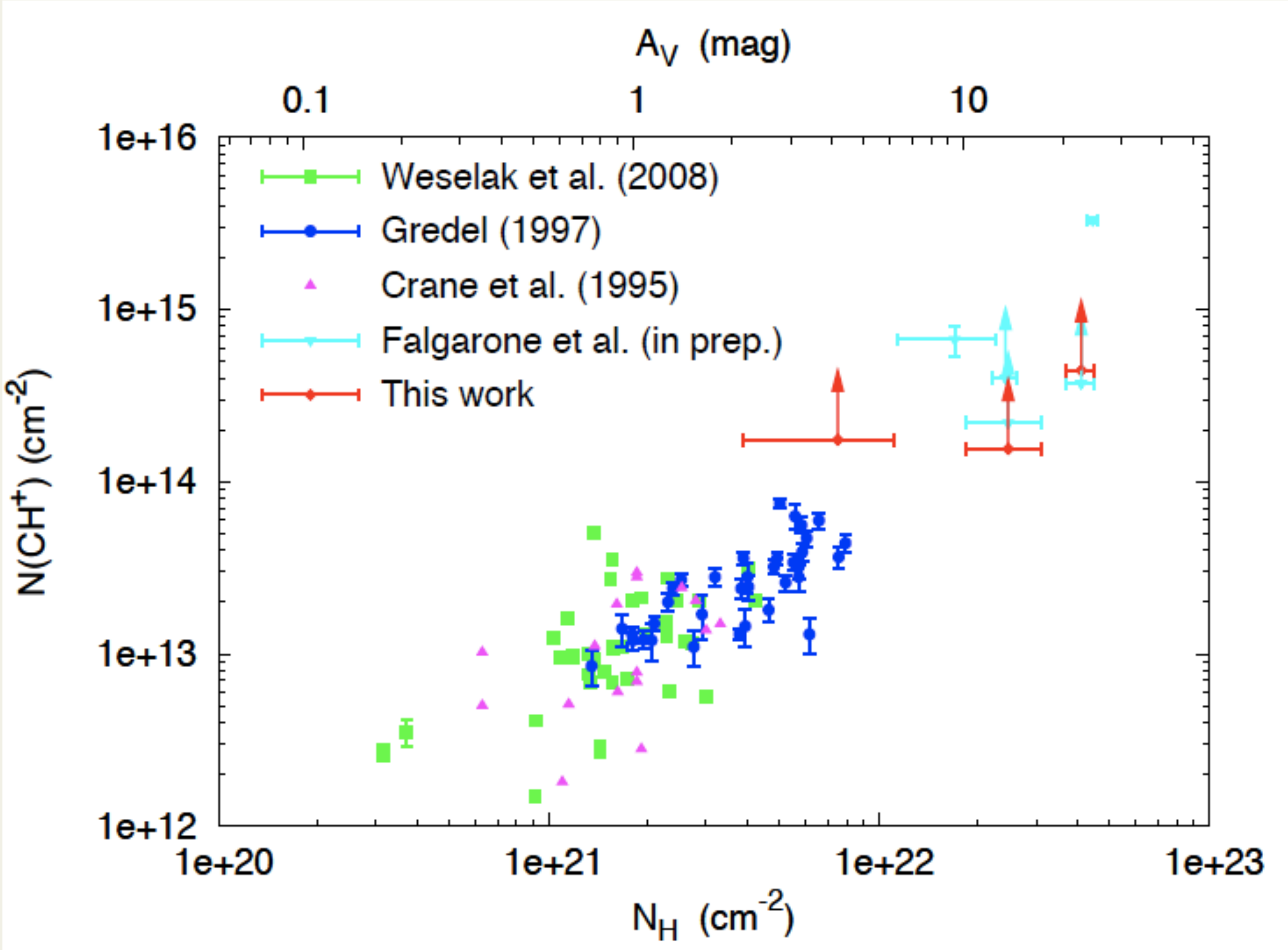
Herschel/ HIFI PRISMAS GT-KP (PI : M. Gerin)

CH^+(1-0) and $^{13}CH^+$ (1-0)
Falgarone et al. 2010

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



CH^+ in galactic diffuse ISM: $[CH^+]/[H] = 10^{-9}$ to 5×10^{-8}



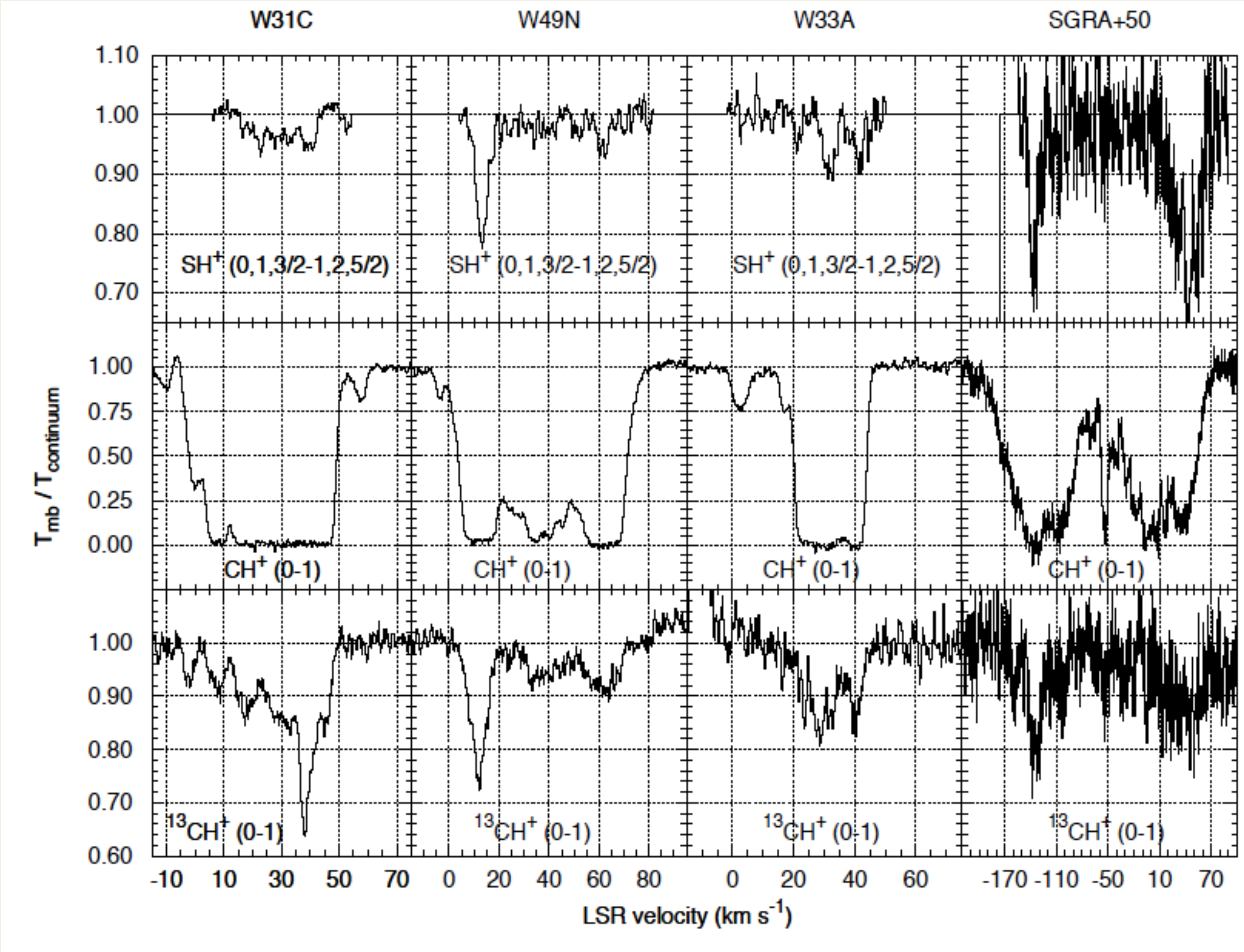
$^{13}CH^+(1\text{-}0)$ from CSO observations, $CH^+(1\text{-}0)$ from Herschel/HIFI (Falgarone et al. 2010)

SH^+ detections thicken the puzzle

SH^+

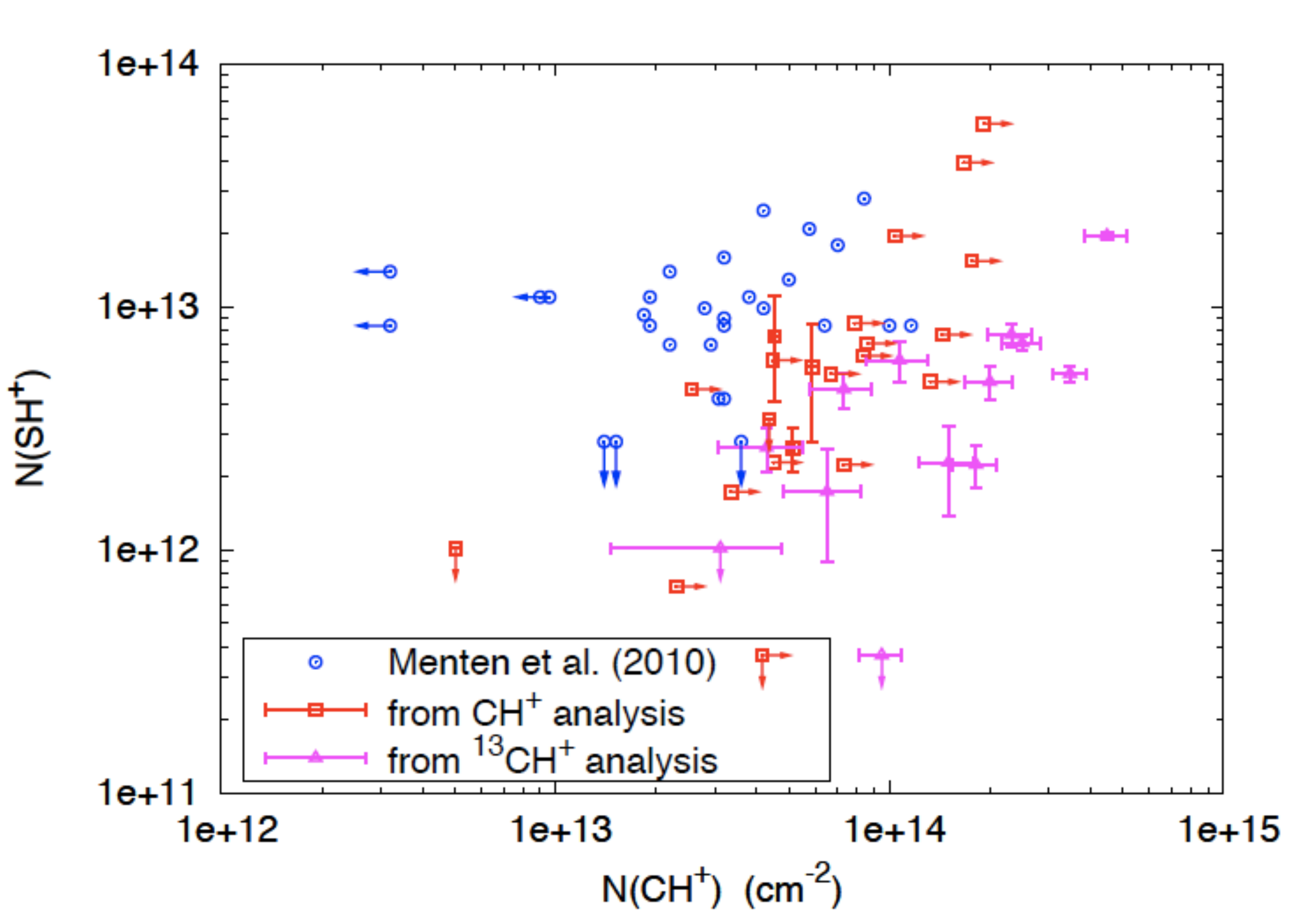
$^{13}CH^+$

CH^+



Godard et al. 2011, PRISMAS collaboration

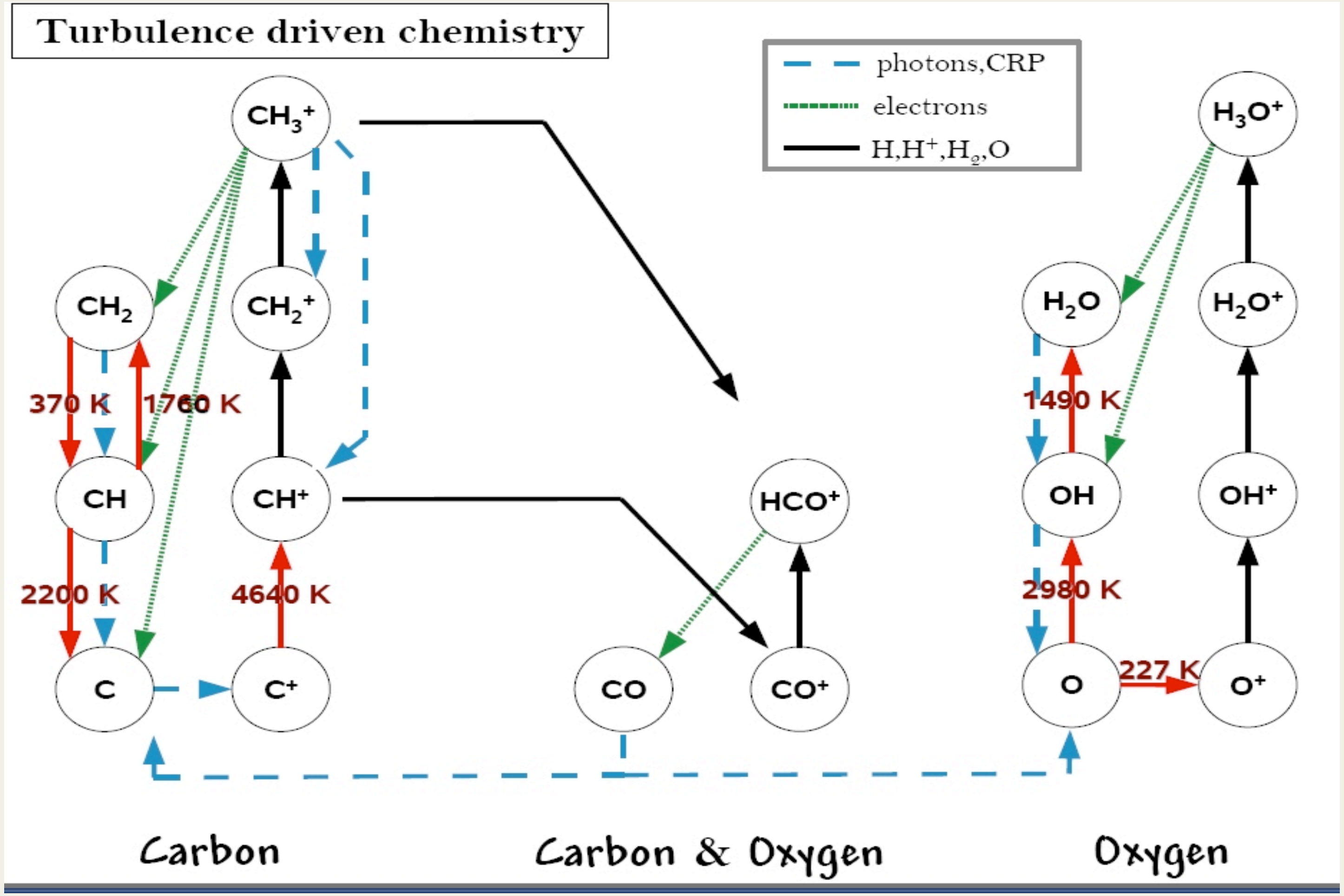
CH^+ and SH^+ column densities



Determinations over velocity ranges varying from 3 to 37 km s^{-1}

Galactic $^{12}C/^{13}C$ gradient used (Milam et al. 2005)

Endo-energic barriers

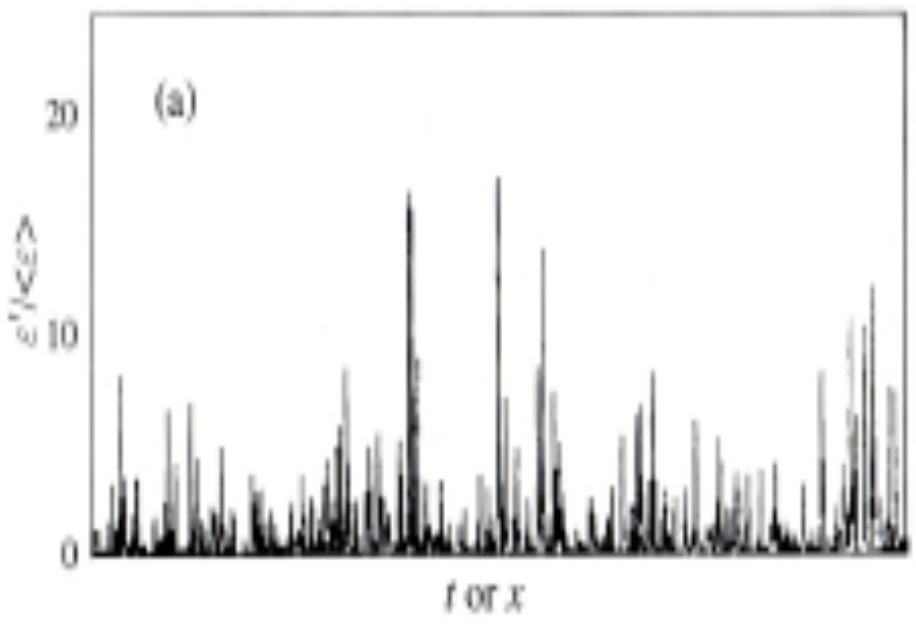


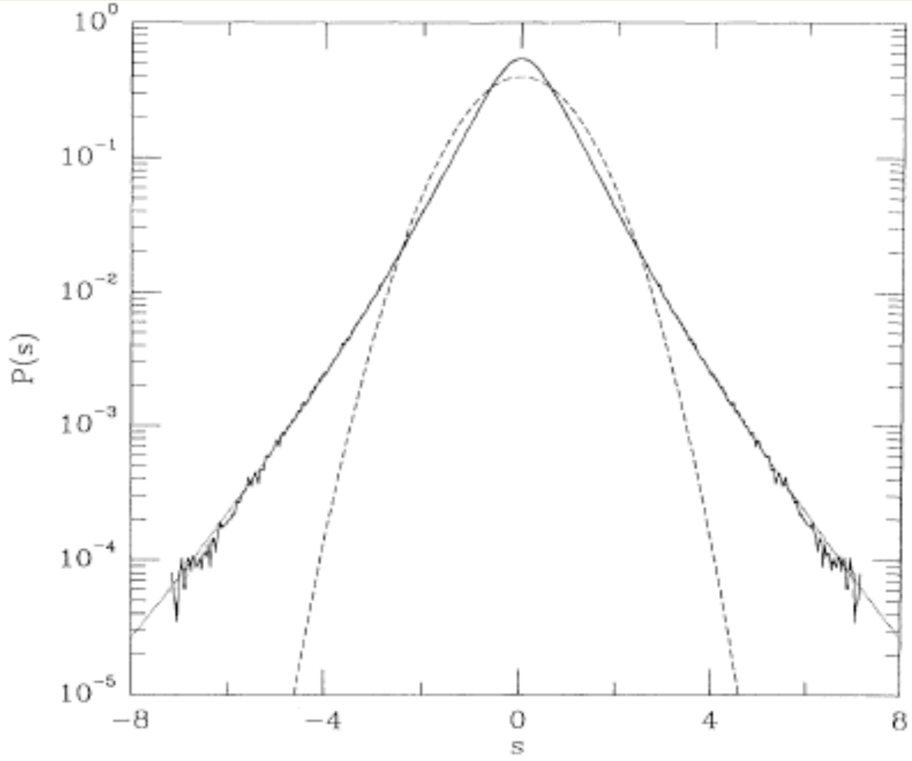
Godard et al 2009,2010

$S^+ + H_2 \rightarrow SH^+ + H \quad \Delta E/k = 9860\ K$

2 – The physical framework of the turbulent dissipation model

Intermittency of turbulent dissipation





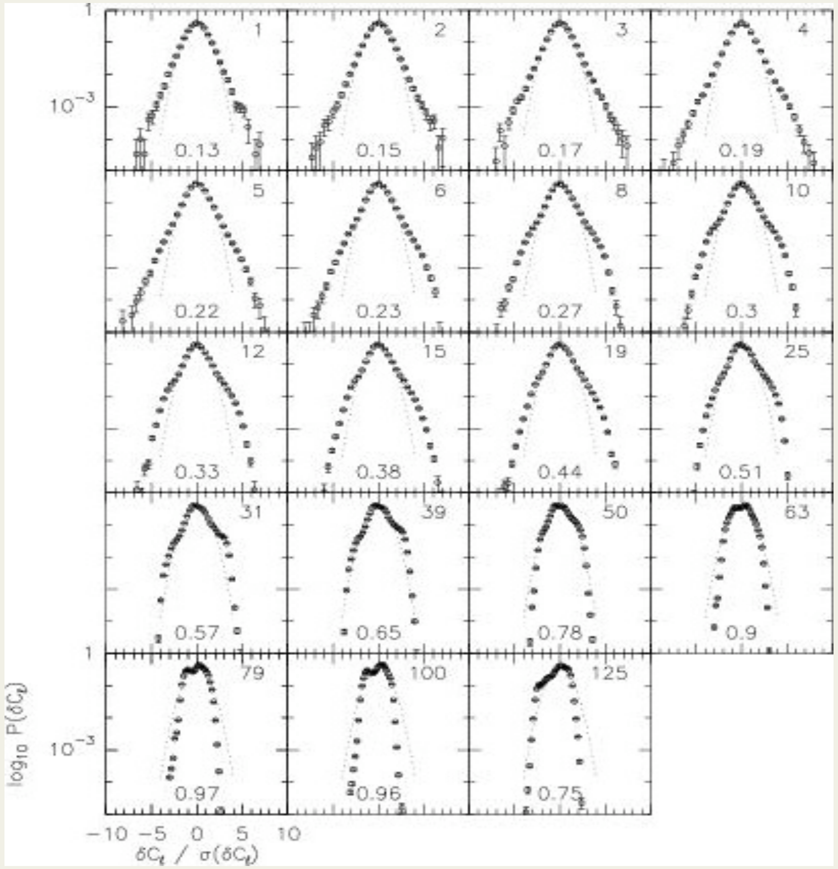
Velocity time/space derivative
Méneveau & Sreenivasan (1991)

Non-Gaussian PDF of transverse velocity gradients
She 1991

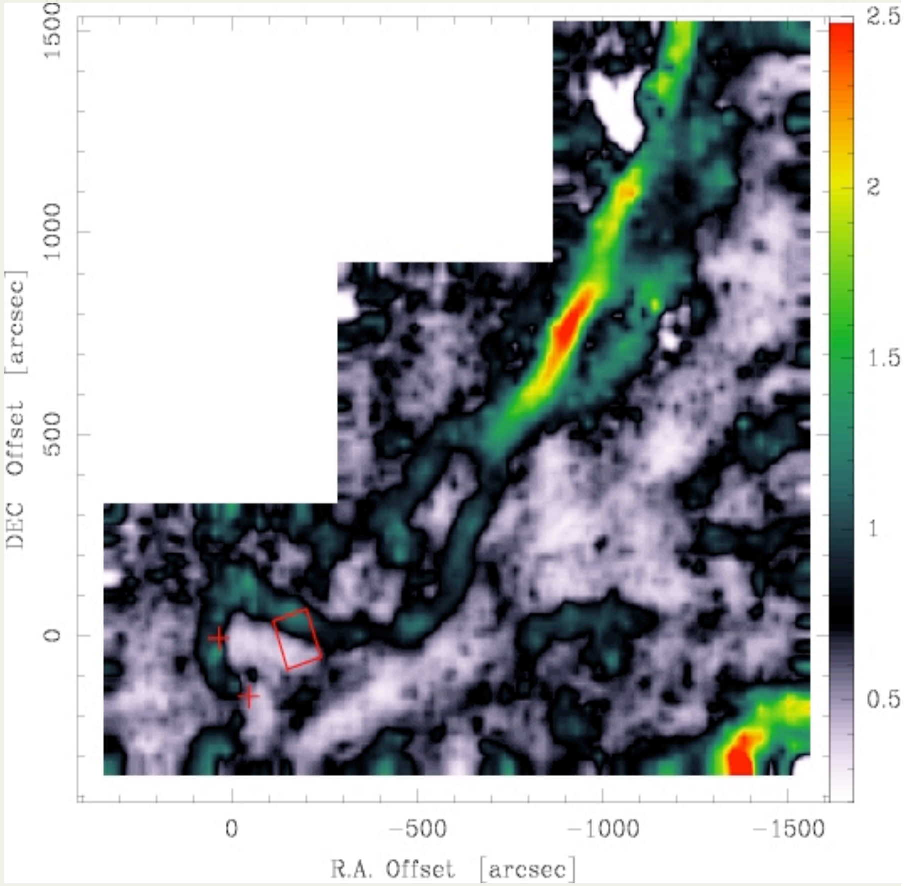
Dissipation rate : $\varepsilon \propto (\nabla \times u)^2$ and $(\nabla . u)^2$

Case of ISM turbulence: Hily-Blant et al. 2008, 2009; Falgarone et al. 2009

Locus of extrema of velocity increments

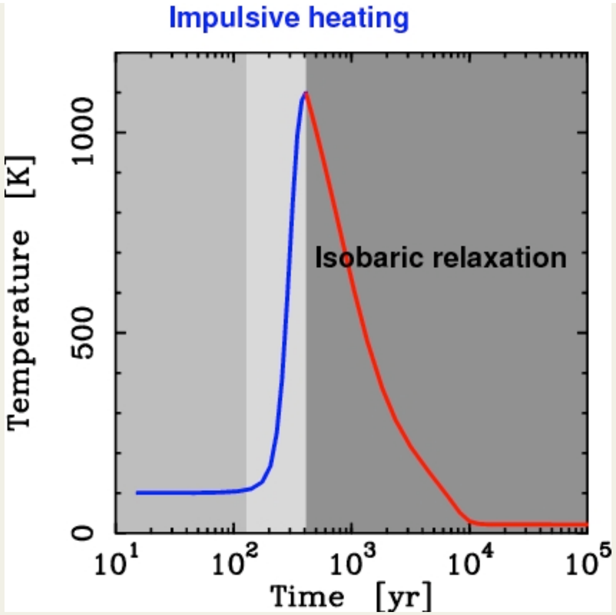


Non-Gaussian PDF of centroid velocity increments from IRAM-30m $^{12}CO(2\text{-}1)$ OTF-maps
10^5 independent spectra
Hily-Blant, Falgarone, Pety 2008



Parsec-scale structures,
0.02 pc thick
Substructures down to 1mpc (IRAM-PdBI)
Falgarone et al 2009

Models of Turbulent Dissipation Regions (TDR)

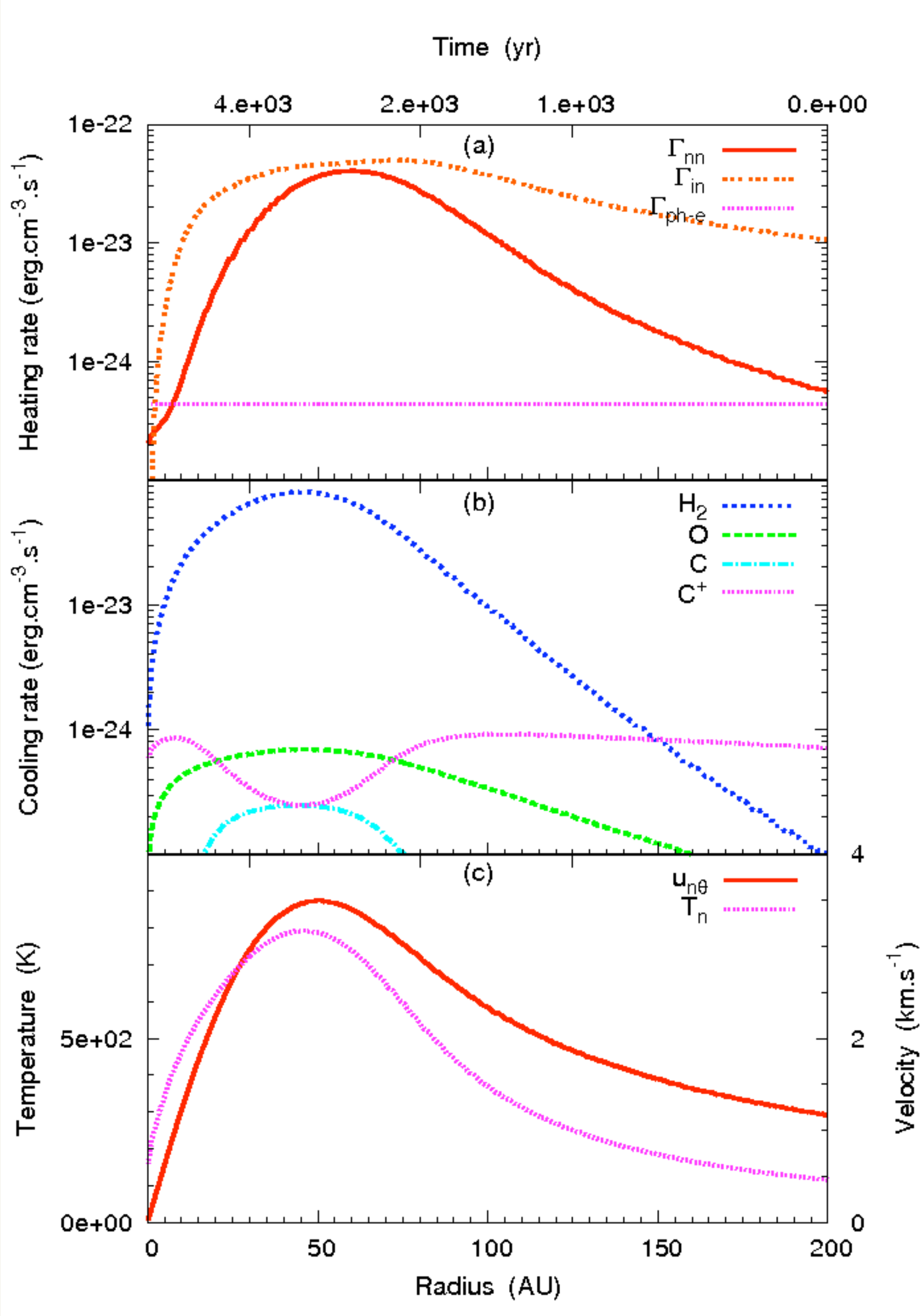


- Magnetized coherent vortices : a few 10 AU, short-lived (a few 100 yr) = bursts
- Turbulent dissipation : viscous + ion-neutral friction → warm chemistry
- Thermal and chemical relaxation :

  τ_{relax} = 40 yr to 4 x10^4 yr
- Vortex characteristics set by ambient turbulence : coupling between scales
- Few free parameters : rate of strain a, n_H, A_v
- Random line of sight : Coexistence of active and relaxation phases (a few %) + ambient medium
- Turbulent energy transfer rate : ε

Joulain et al. 1998;

Godard, Falgarone, Pineau des Forêts 2009

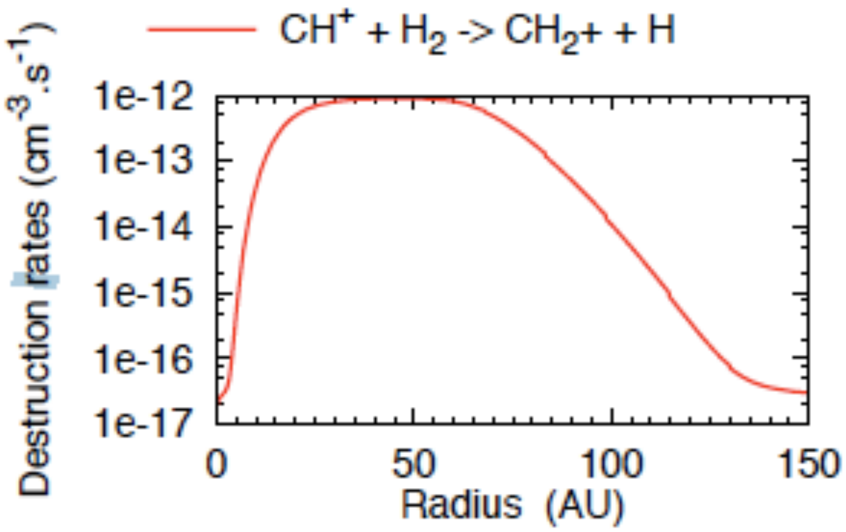


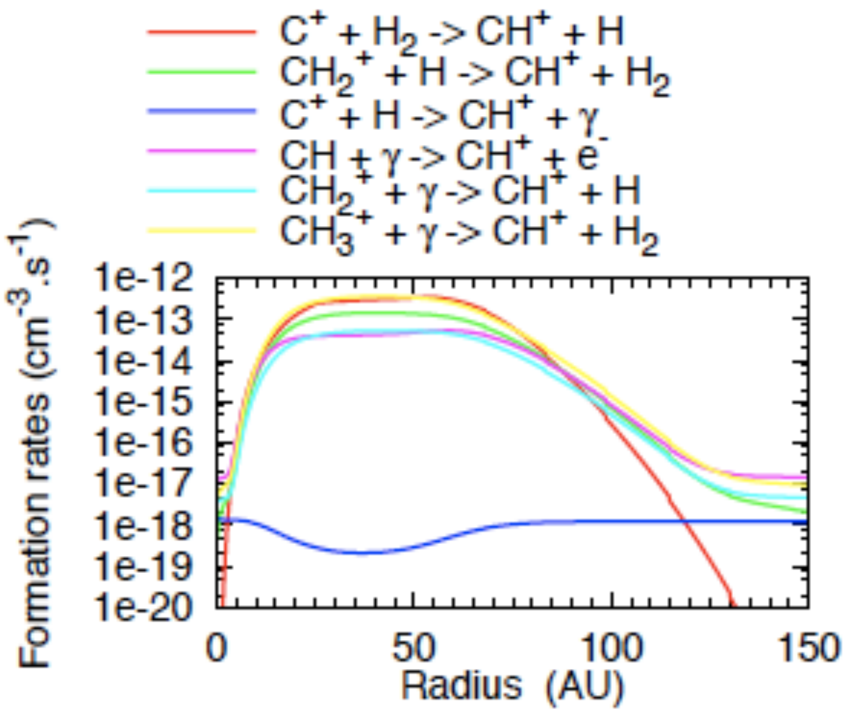
Active phase:

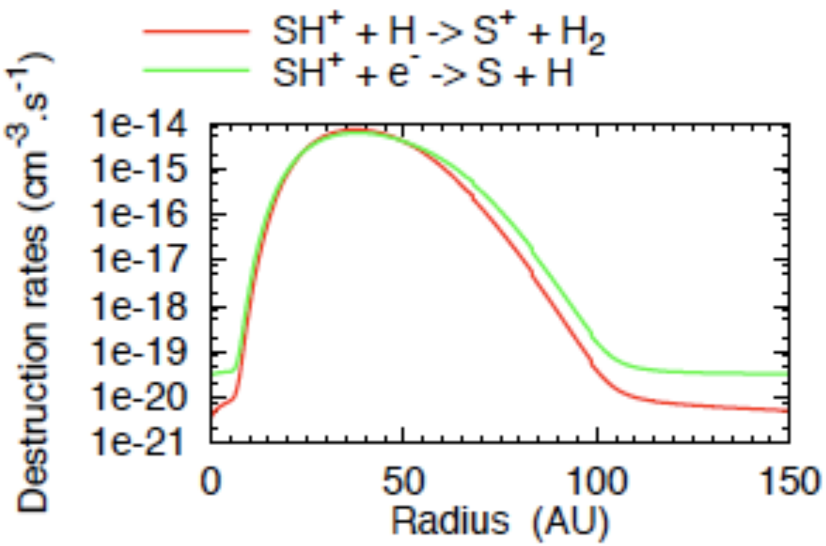
Heating & cooling rates and temperature across a magnetized Burgers vortex

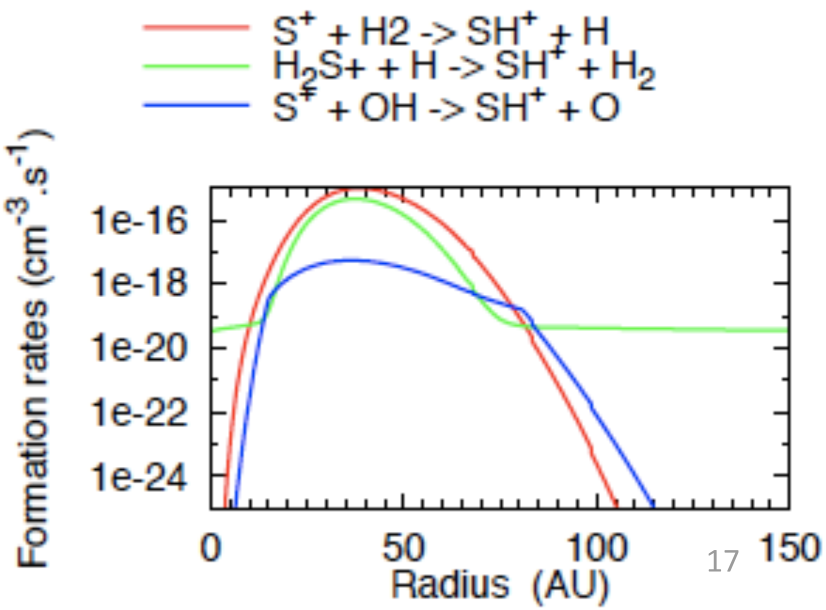
Godard et al. 2009

Active phase : warm chemistry CH⁺ and SH⁺

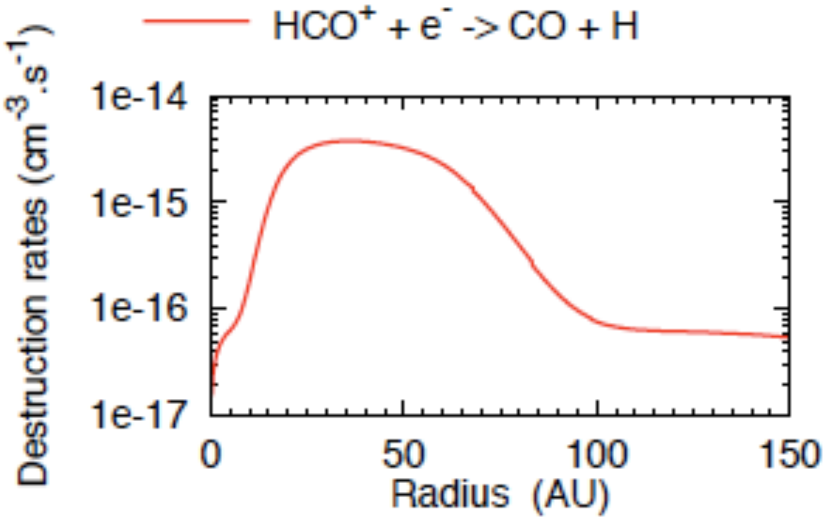


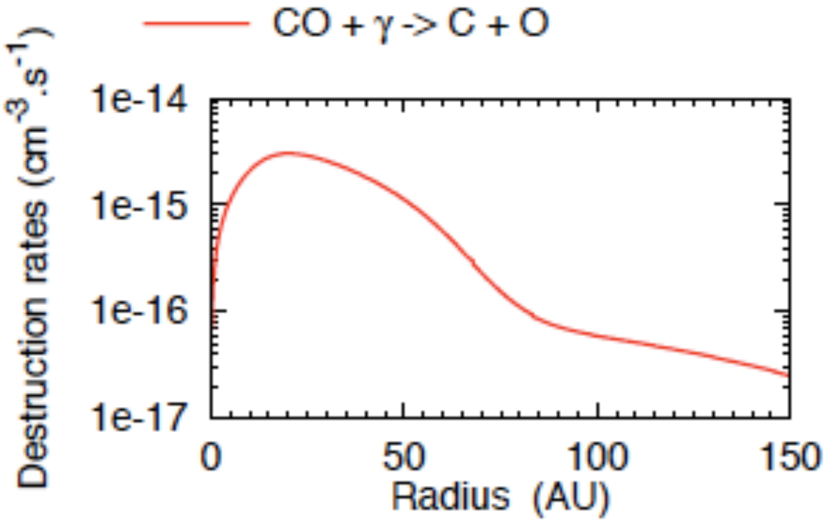


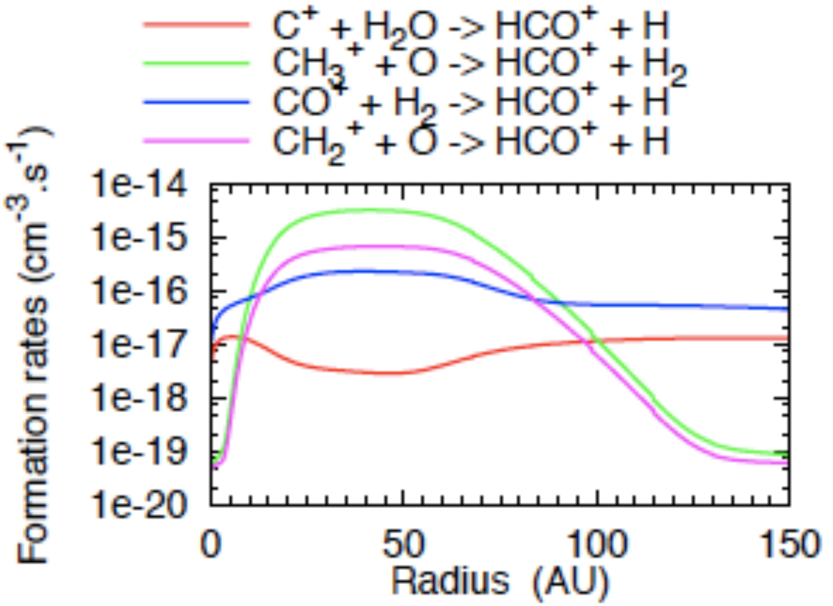


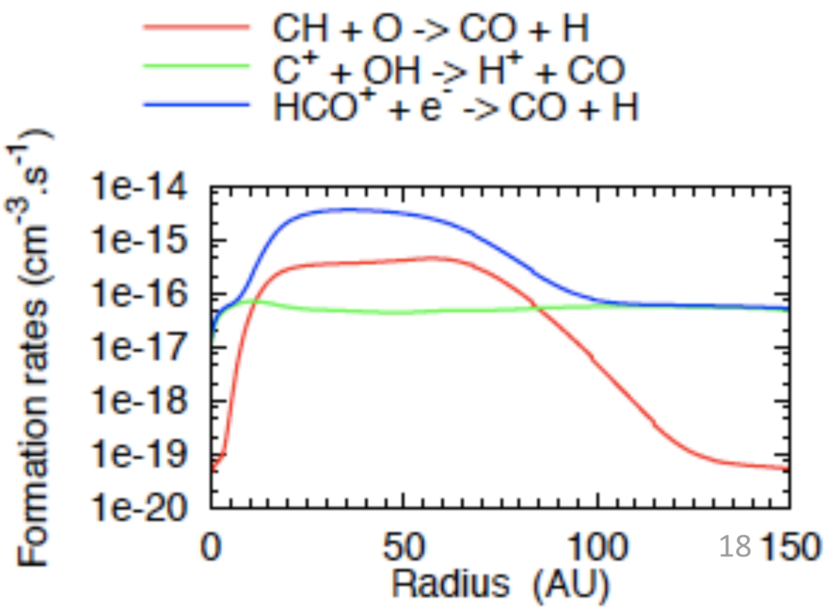


Active phase : warm chemistry HCO^+ and CO

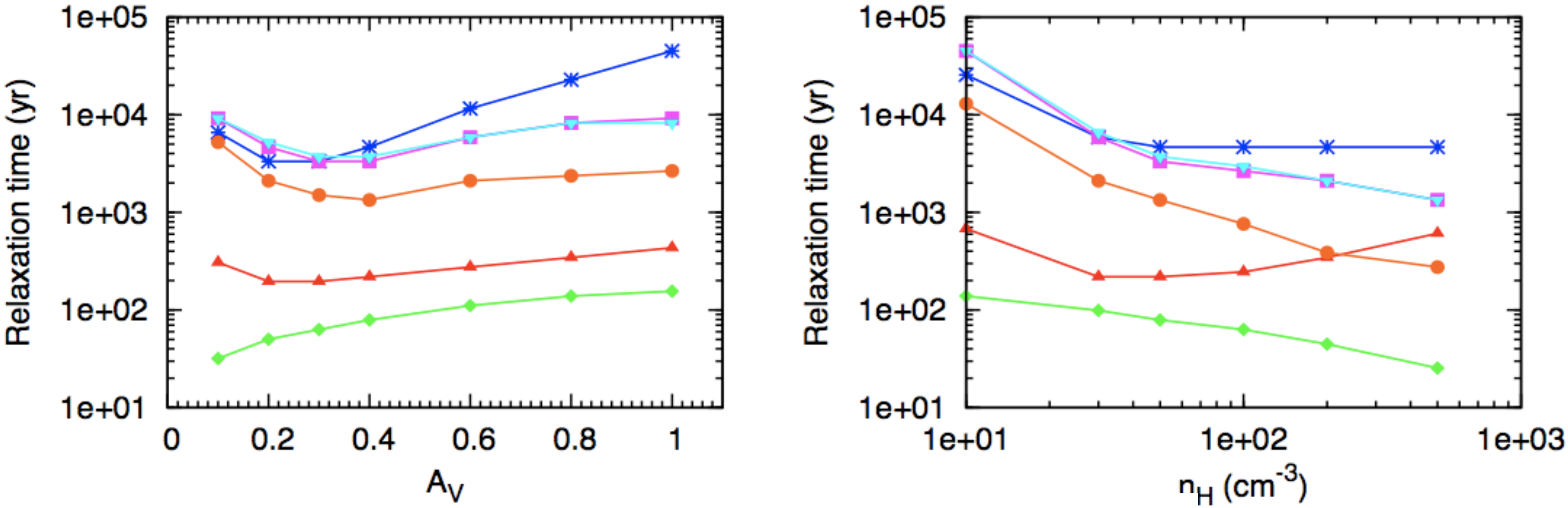






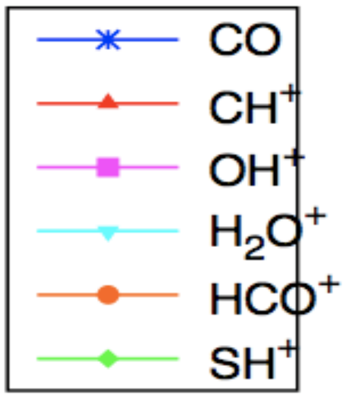


Relaxation phase : chemical relaxation times

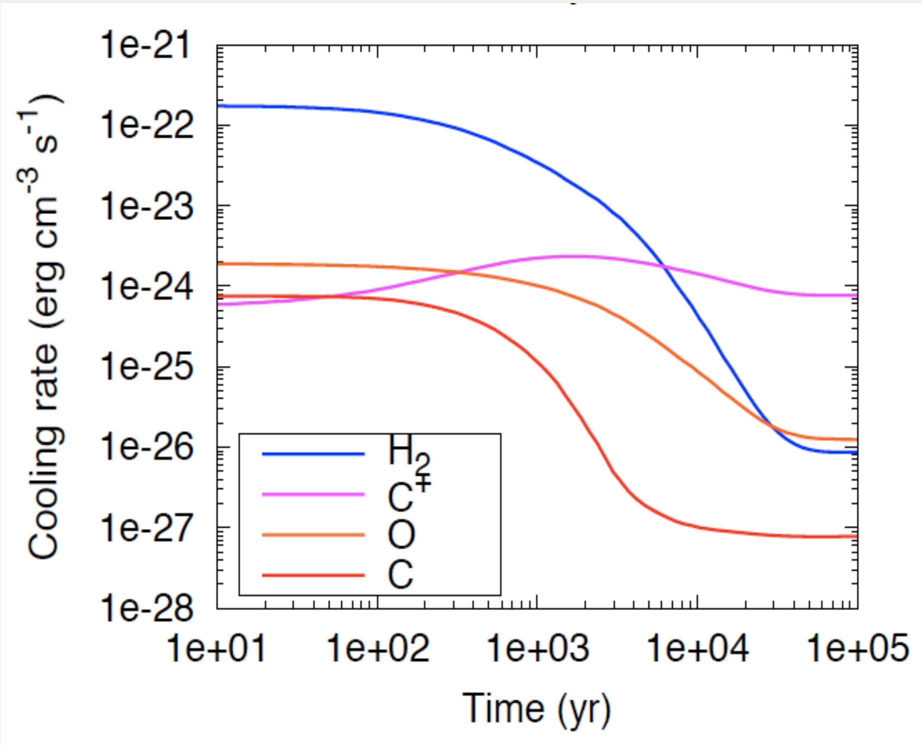


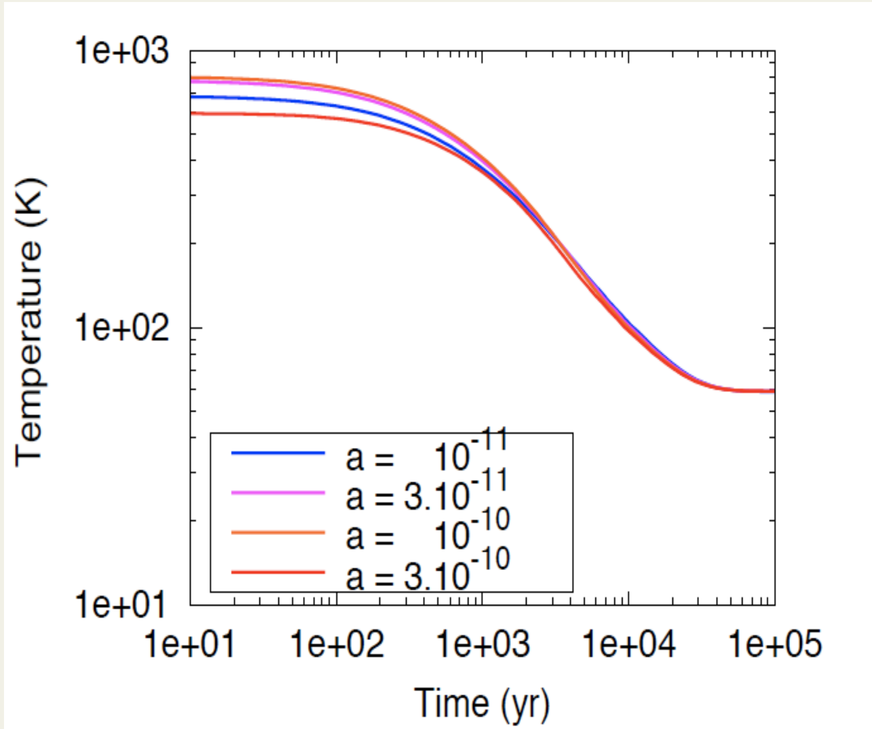
SH$^+$ as short as 40 yr

CO as long as 4 x 10^4 yr



Relaxation phase : cooling rates





A_v=0.4, n=50 cm^{-3}, a=3 10^{-11} s^{-1}

Godard et al. in prep

3 - Results

Modelling a random line of sight

Three phases :

- Active vortices,
- Dead vortex & relaxation,
- Ambient medium

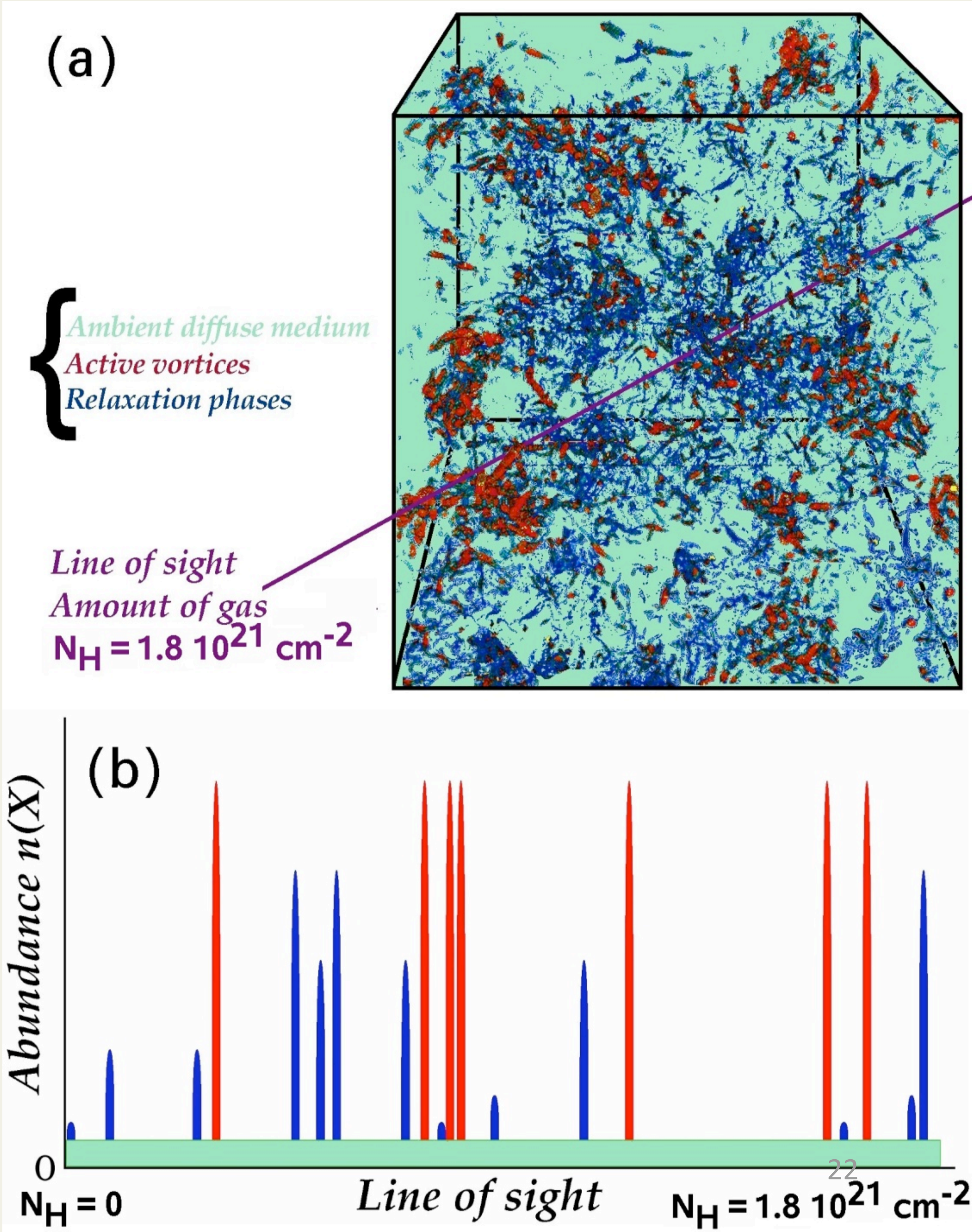
-**Vortex number ∝** energy turbulent transfer rate

$N_V \sim 500(n_H / 50cm^{-3})^{-2.1}$

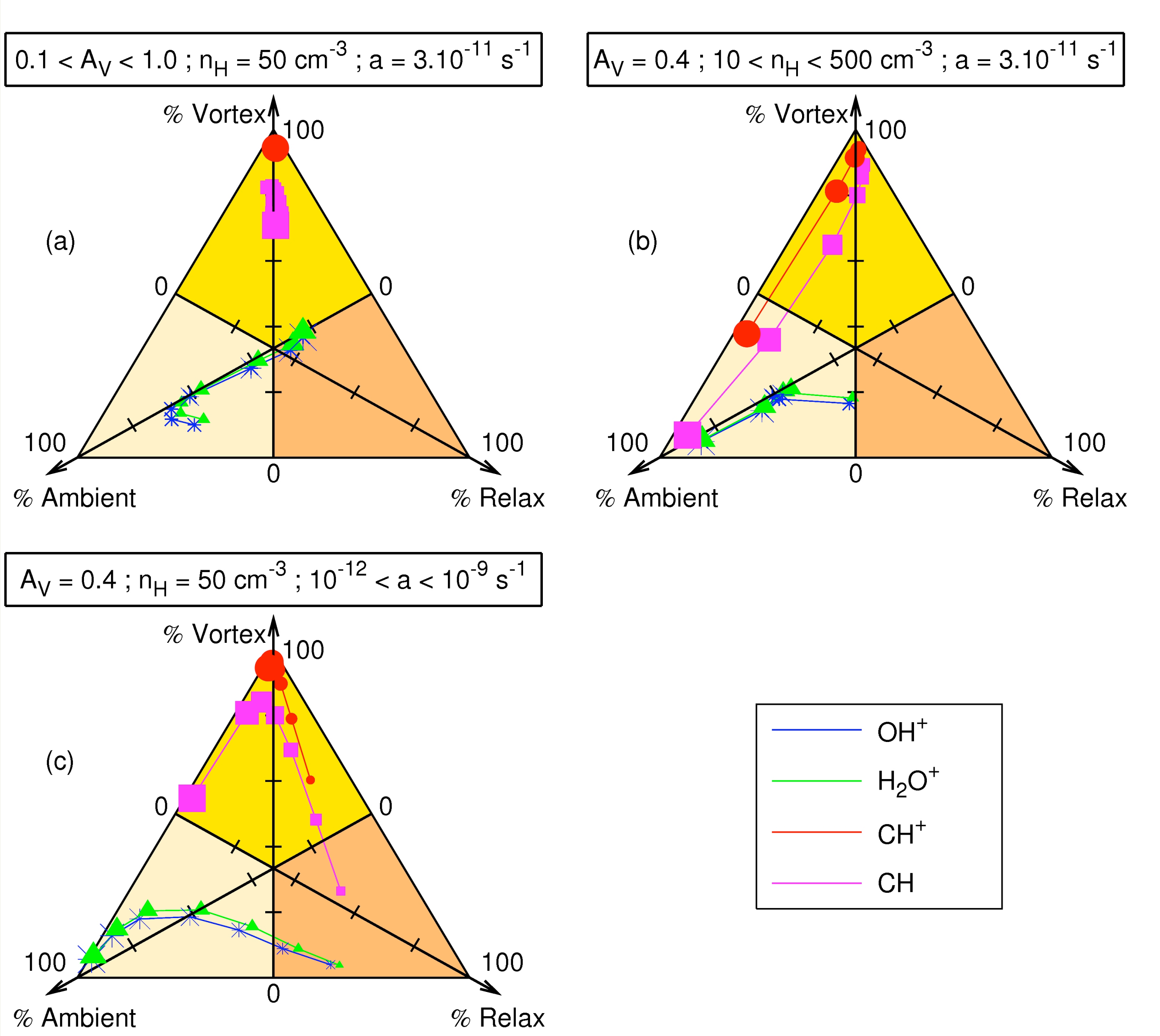
in 1 mag of gas sampled

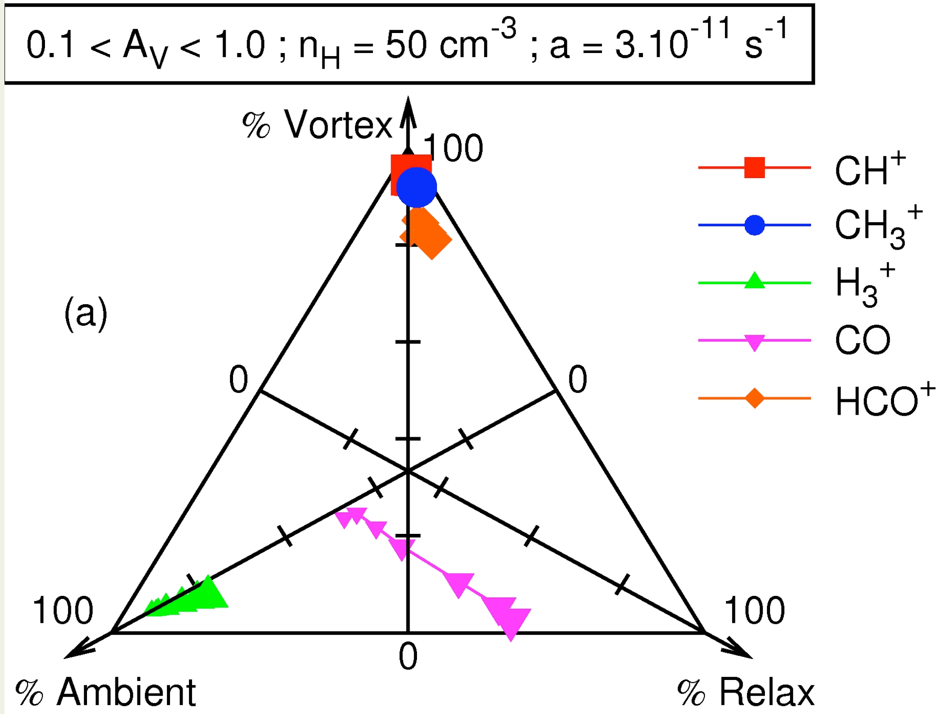
for $\varepsilon = 2x10^{-24}$ erg cm^{-3} s^{-1}

≈ a few % of gas on LOS

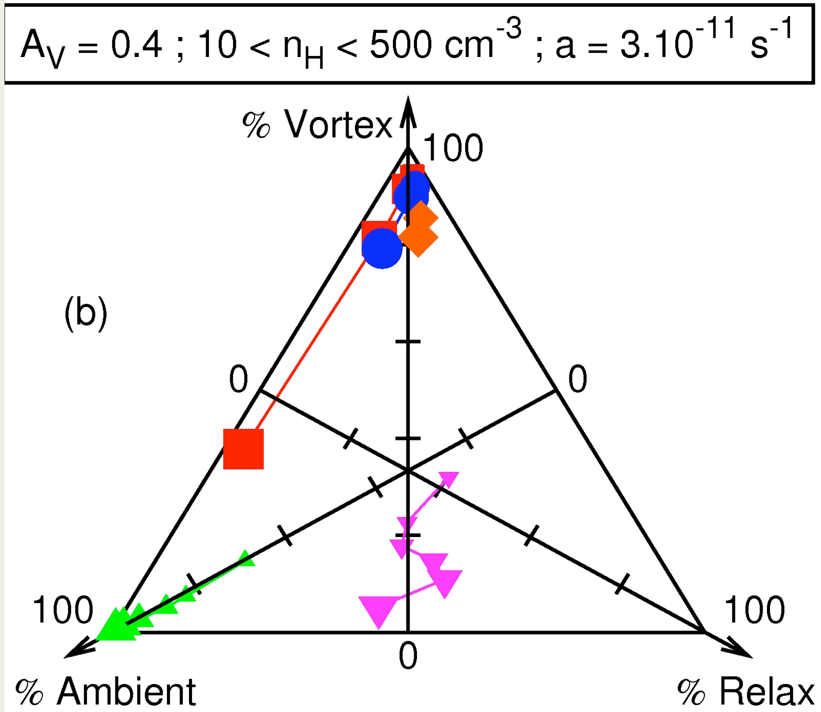


Relative contributions of active, relaxation and ambient phases





← Increase of UV-shielding

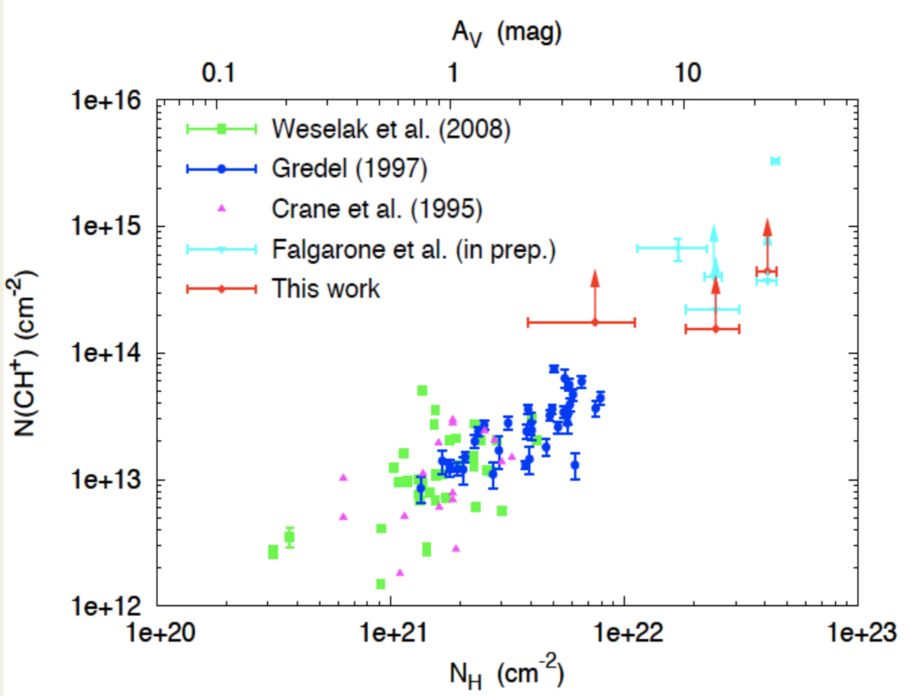


← Increase of density

CH^+ : Observations and TDR model

Large scatter of observed abundances :

$[CH+]/[H] = 10^{-9} - 5 \times 10^{-8}$



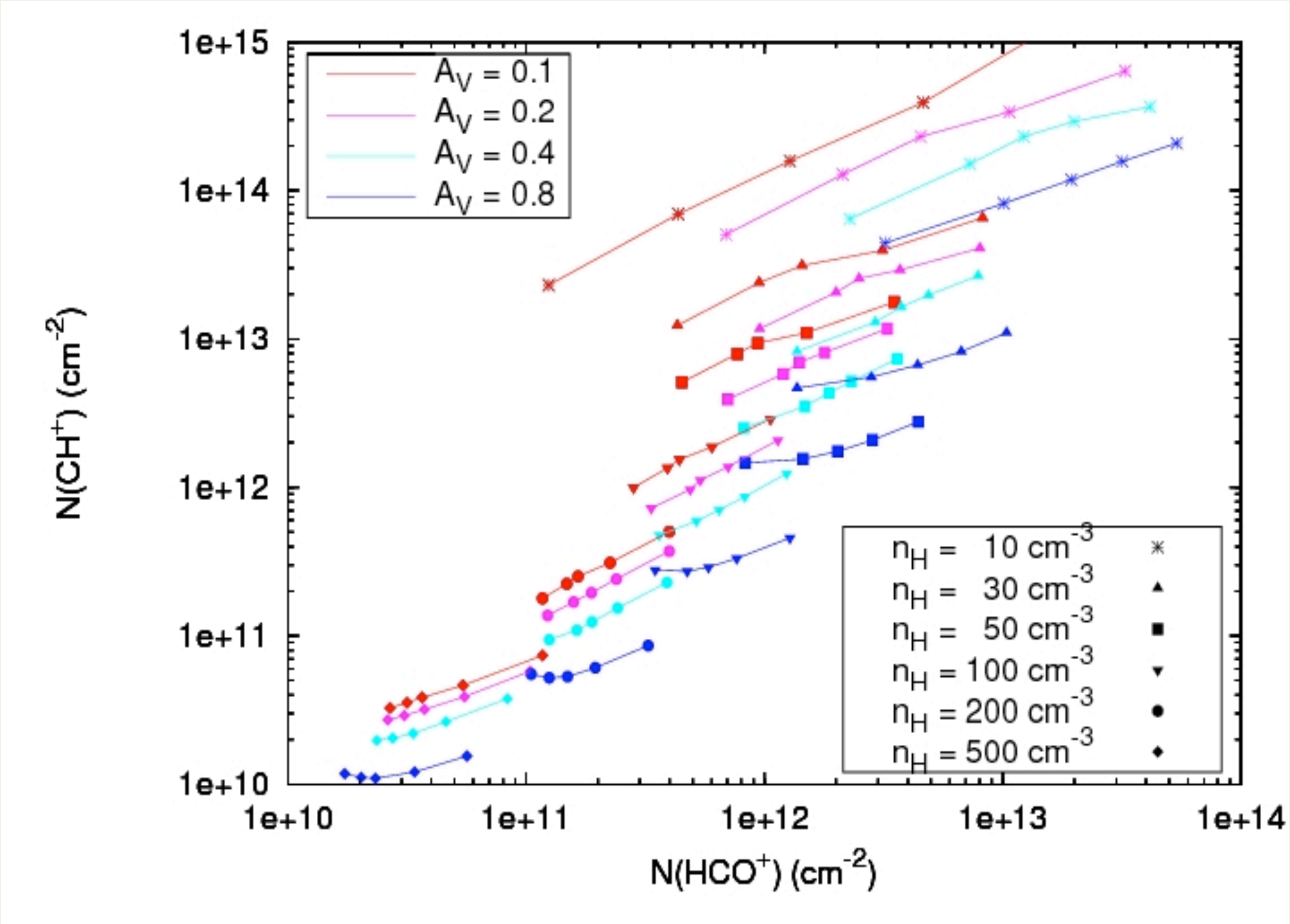
TDR model predictions:

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

for $50\ cm^{-3} < n_H < 10^3\ cm^{-3}$

N(CH+) increases as UV-field increases and is proportional to ε

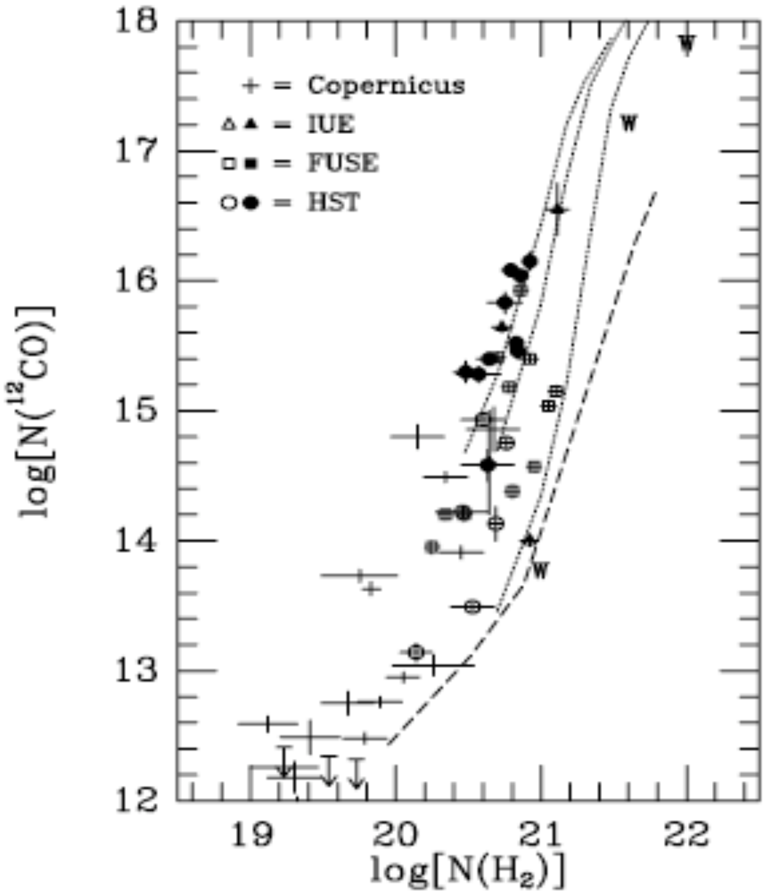
CH^+ and HCO^+

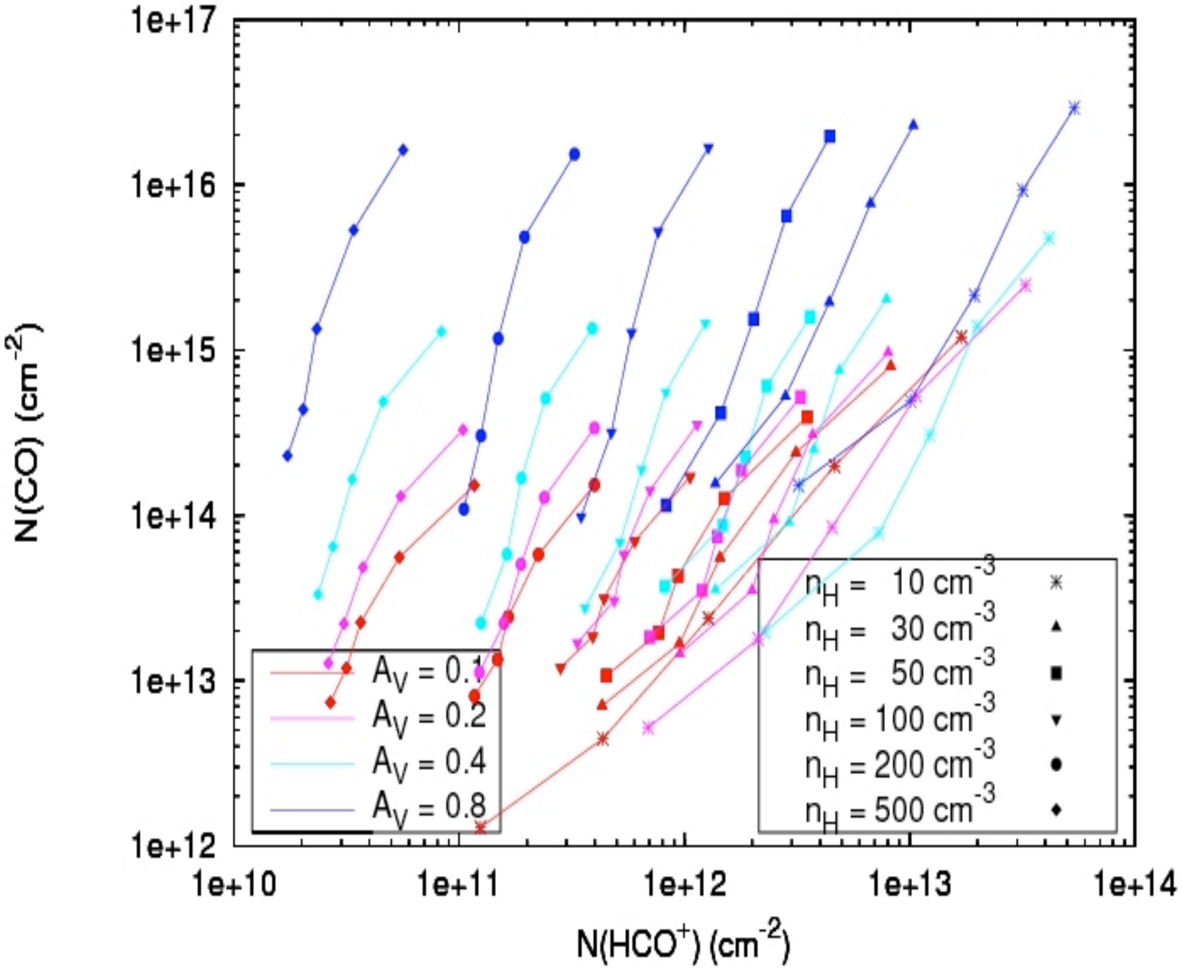


Observed ranges per magnitude

Free parameter along each curve : a

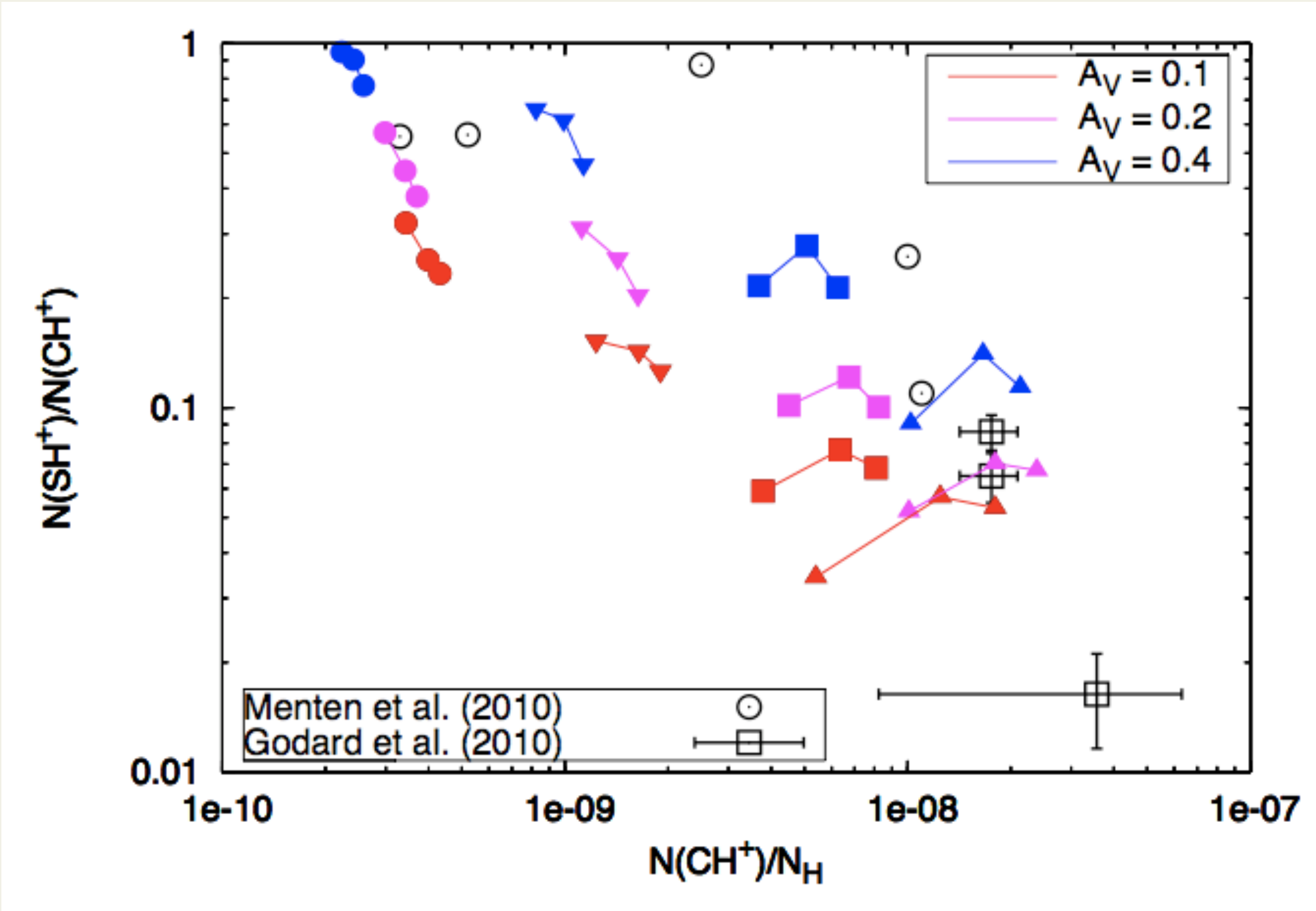
CO and HCO⁺





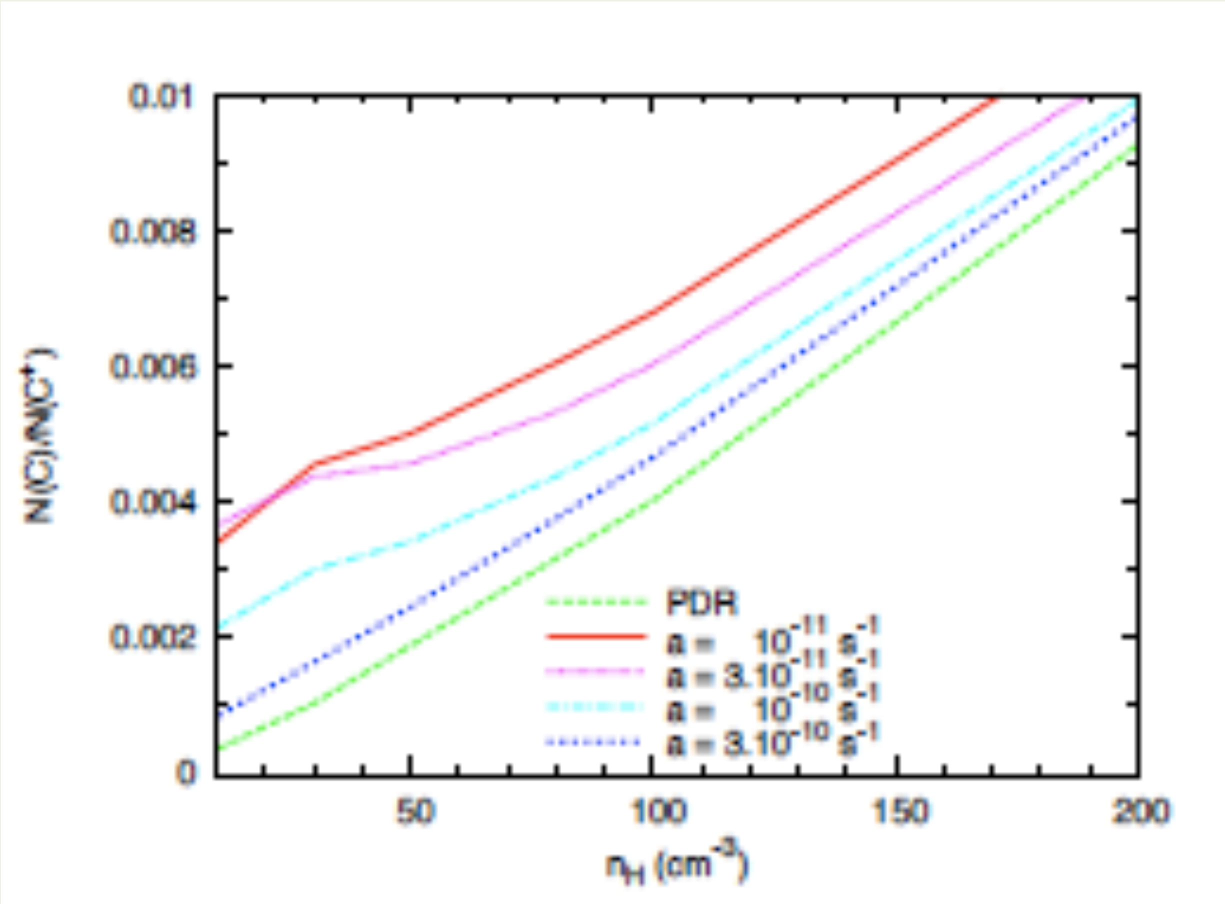
Sonnentrucker et al 07

SH^+ and CH^+

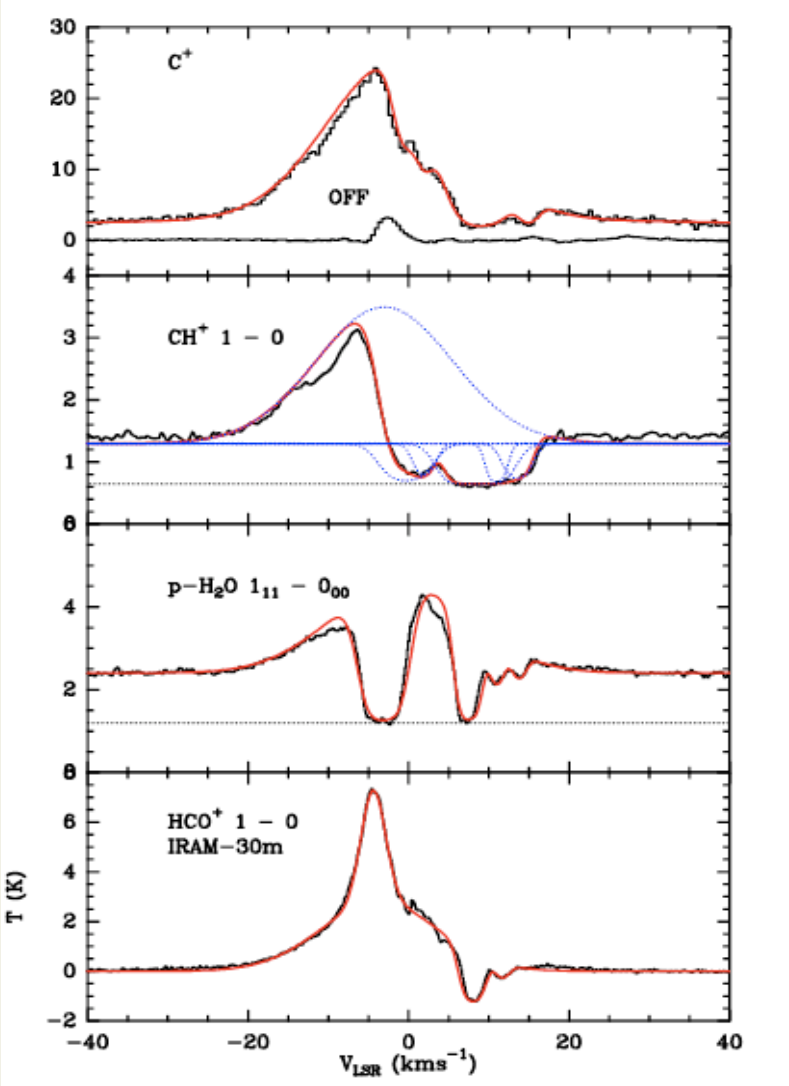


Godard et al. in prep.

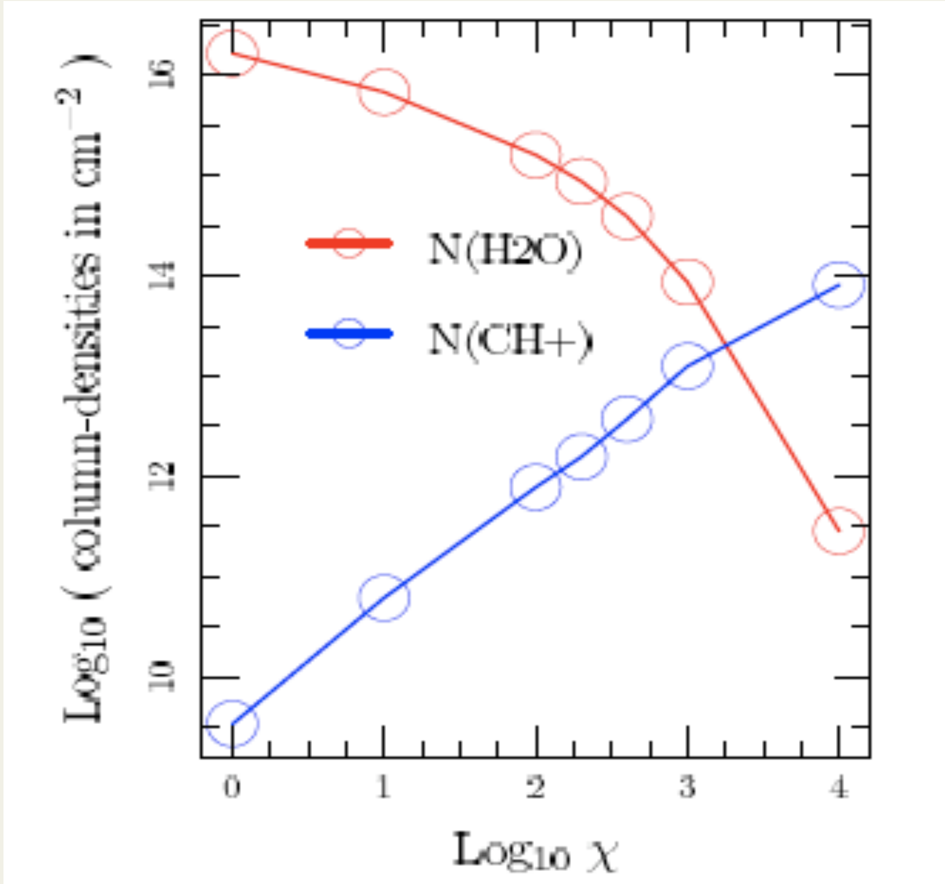
Carbon is not at ionisation equilibrium



DR21 : a massive star forming region



Emission $N(CH^+) > 2 \times 10^{13}$ cm $^{-2}$



C-shock model : V_S=20 km/s

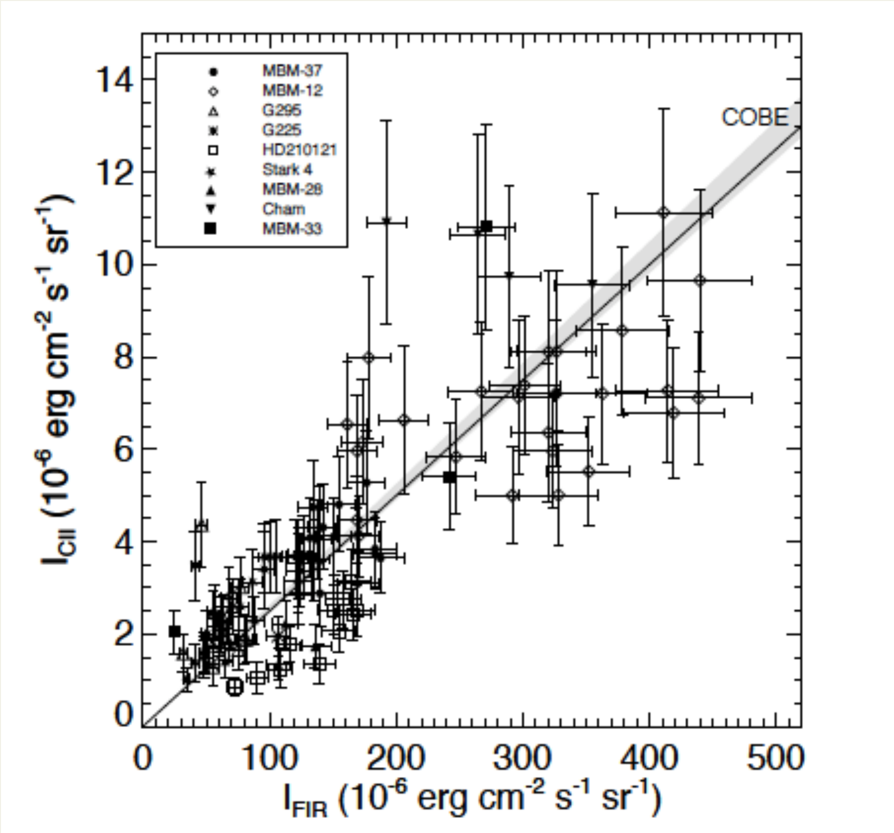
Dependence on UV radiation field χ

WADI collaboration

Falgarone et al. 2010

4 – A niche for SOFIA/GREAT

[CII] 158 μm emission of diffuse ISM: SOFIA-GREAT perspective



- Diffuse ISM :

I_{CII} ~ 1 – 10 x10 $^{-6}$ erg cm^{-2} s^{-1}sr^{-1}

- Local excesses above COBE correlation with FIR

- Search for [CII] small-scale structure associated with turbulent dissipation

High latitude clouds (ISO-LWS)

Ingalls et al. 2002

Summary and perspectives

- Only a few % of warm gas heated by turbulent dissipation reproduce observed CH^+, SH^+ ,HCO^+ as well as CO in diffuse gas
- Abundances consistent with known energy in turbulent cascade and intermittency properties
- [CII] and pure H_2 rotational lines : main coolants. Line emission = direct measurement of the turbulent dissipation rate
- Search for [CII] small-scale structure in diffuse ISM associated with non-Gaussianities of velocity field