CH^+ in the diffuse ISM : a tracer of turbulent dissipation

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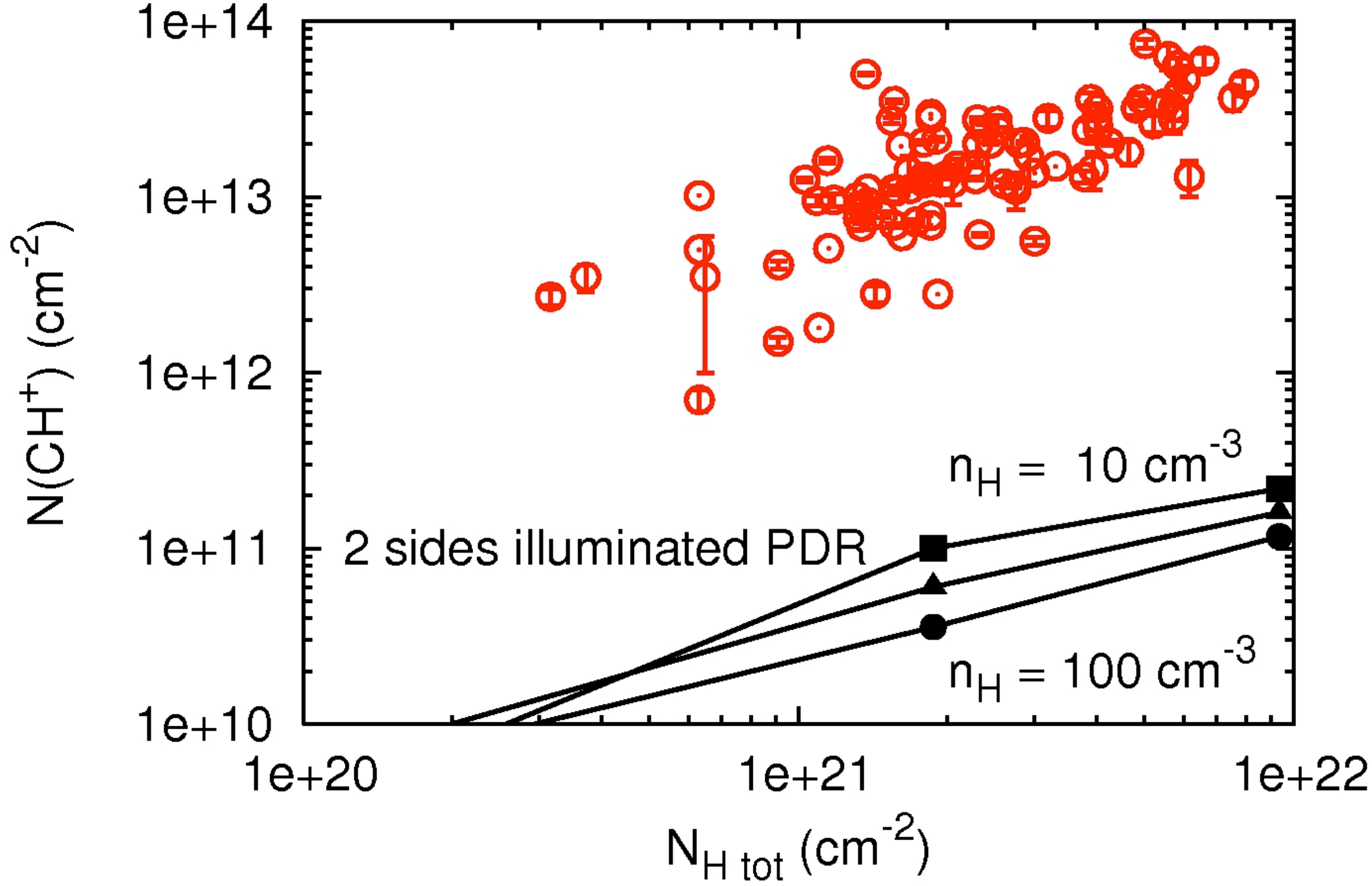
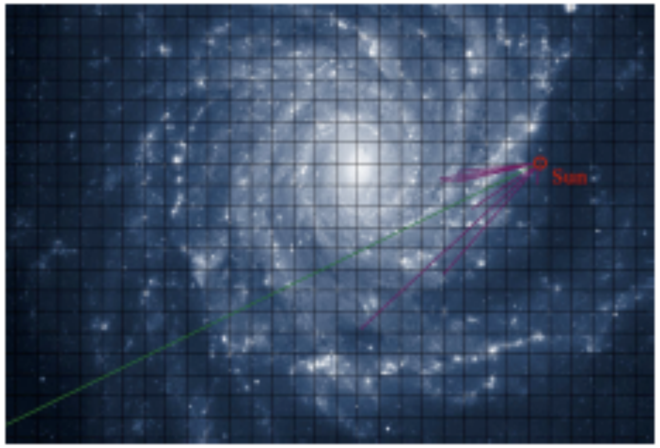
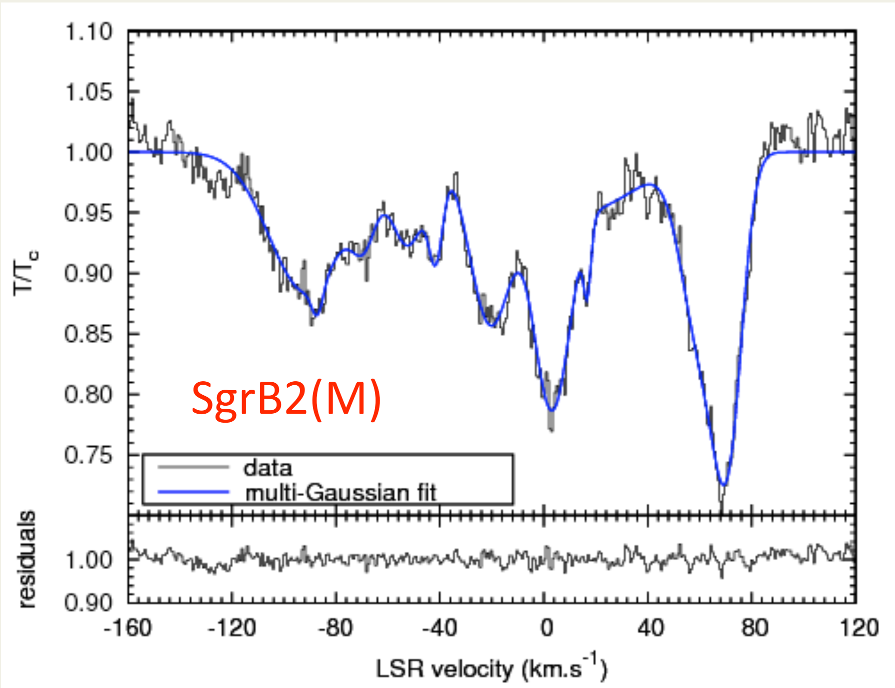
The CH+ puzzle in the diffuse ISM

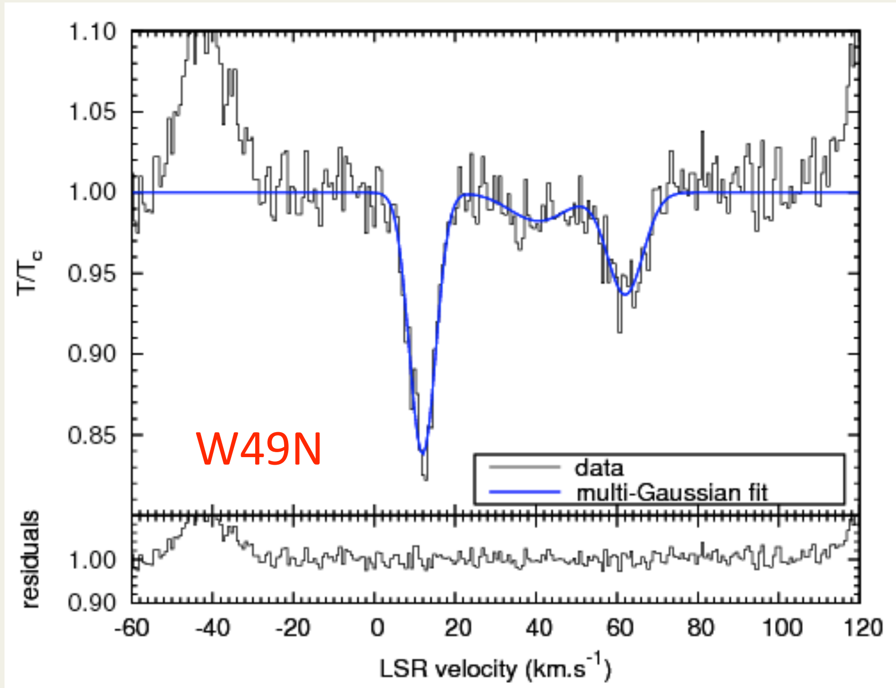


Visible lines : Crane et al. 1995, Gredel 1997, Weselak et al. 2008

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







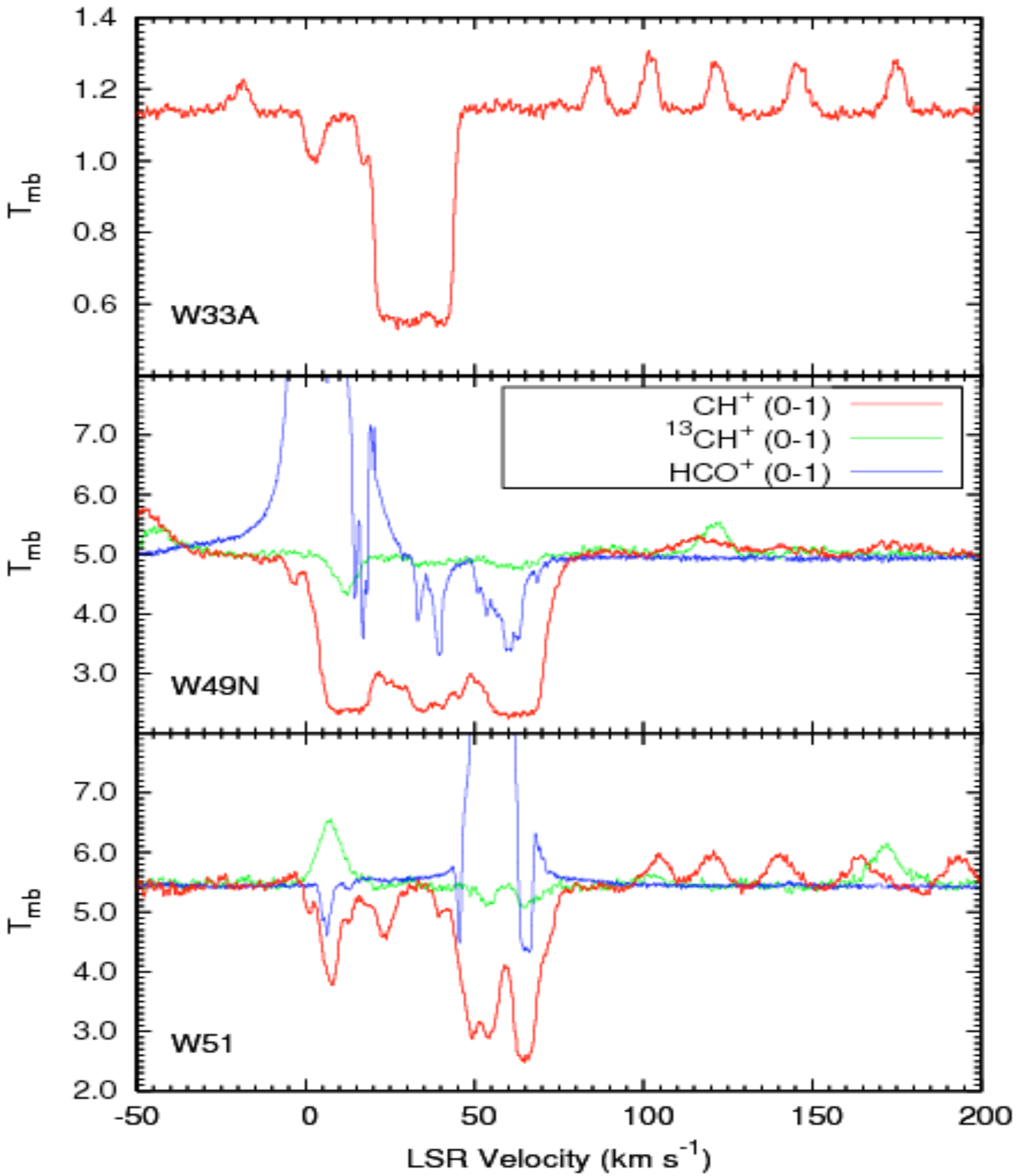
Ground-based observations 830 GHz,
Caltech Submillimeter Observatory
Falgarone et al. 2005, Lis et al. 2009; Falgarone et al. in prep.

APEX
Menten et al. 2010

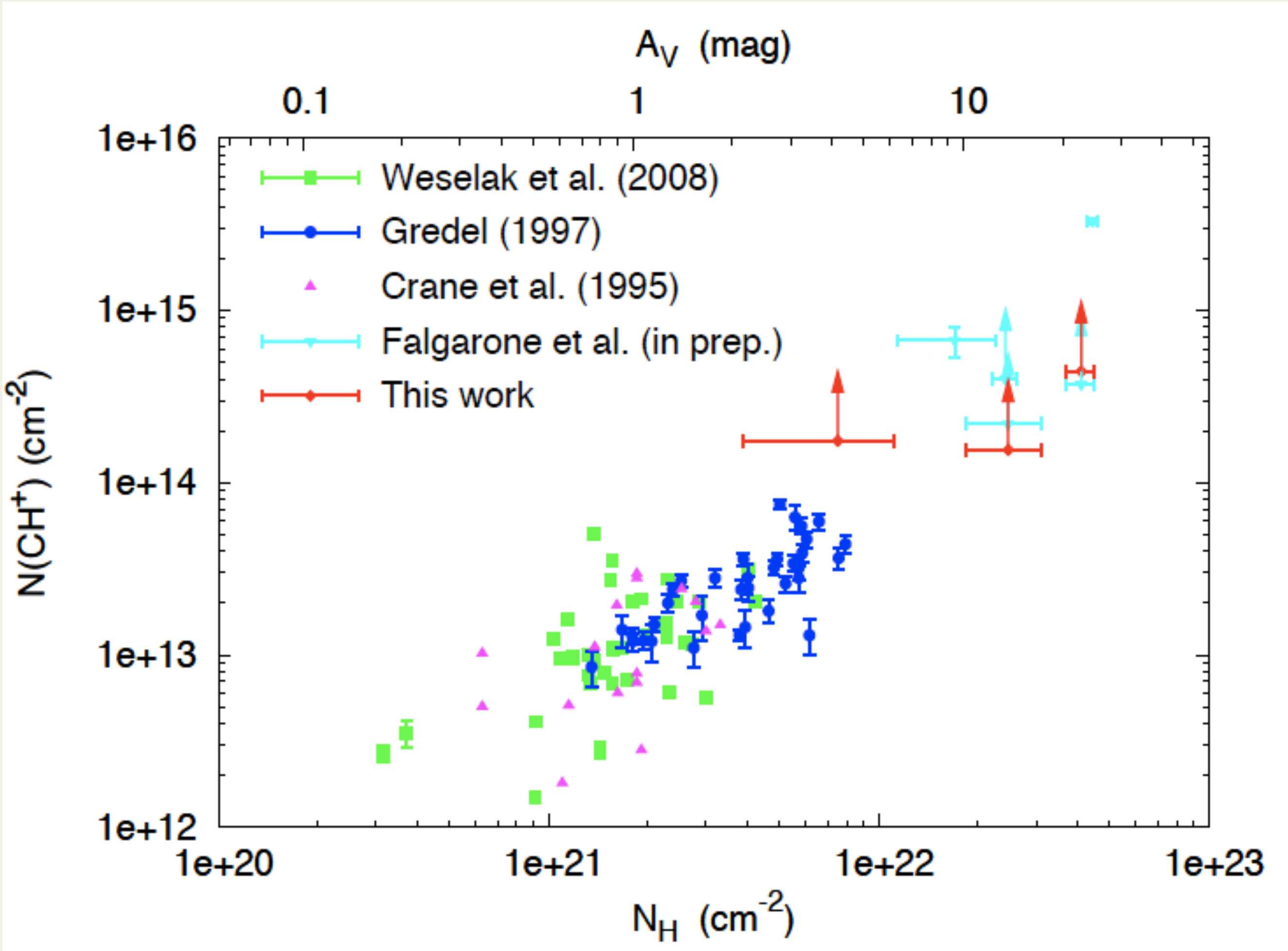
Herschel/ HIFI
PRISMAS GT-KP
(PI M. Gerin)

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

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

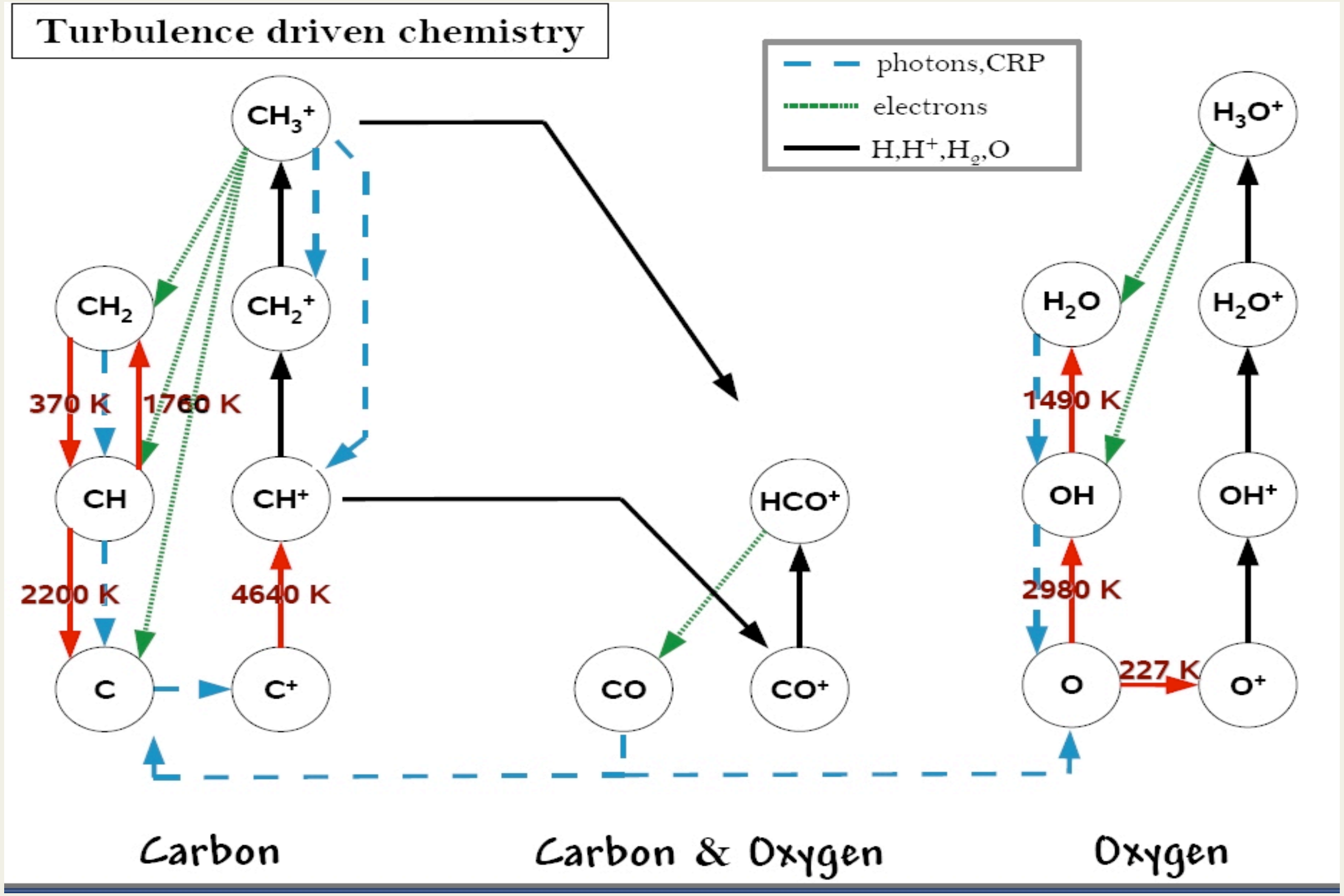


CH^+ in galactic diffuse ISM: $[CH^+]/[H] = 10^{-9}$ to 5×10^{-8}



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

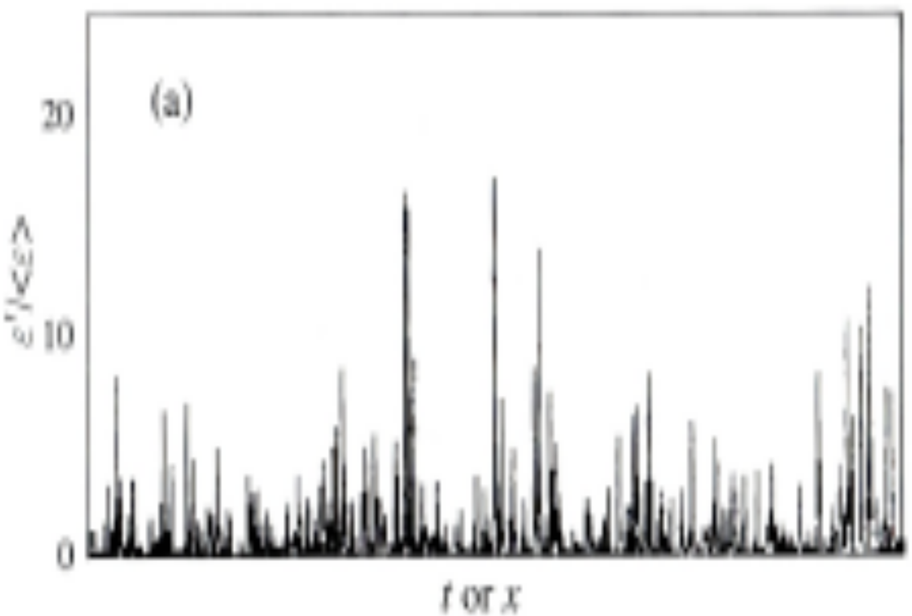
Endo-energic barriers

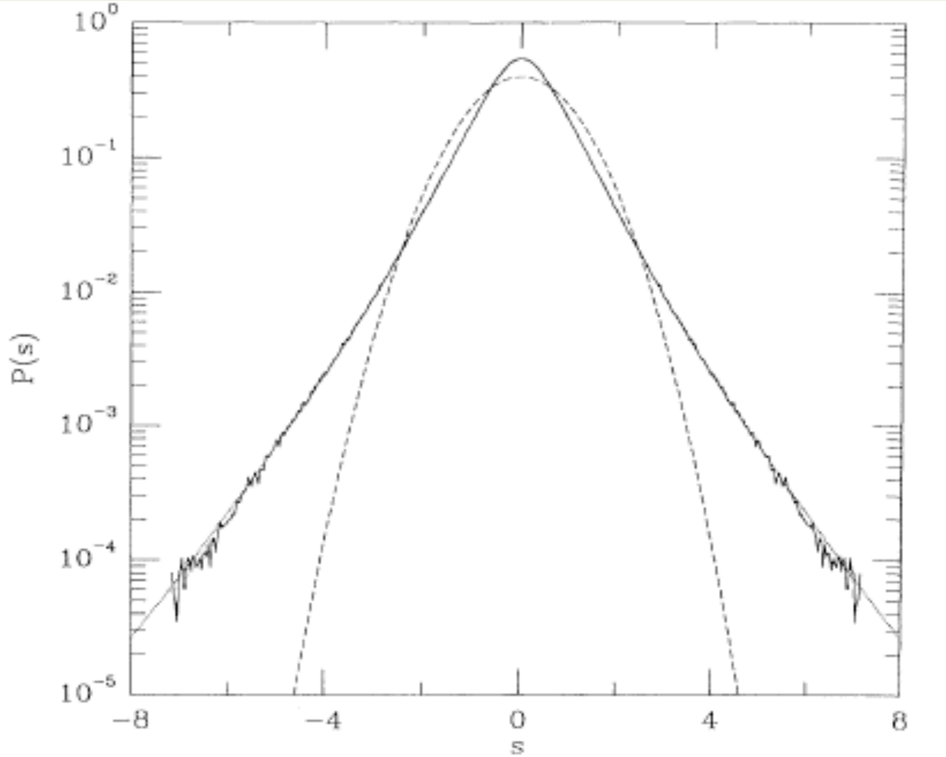


Godard et al 2009,2010

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

Intermittency of turbulent dissipation





Velocity time/space derivative

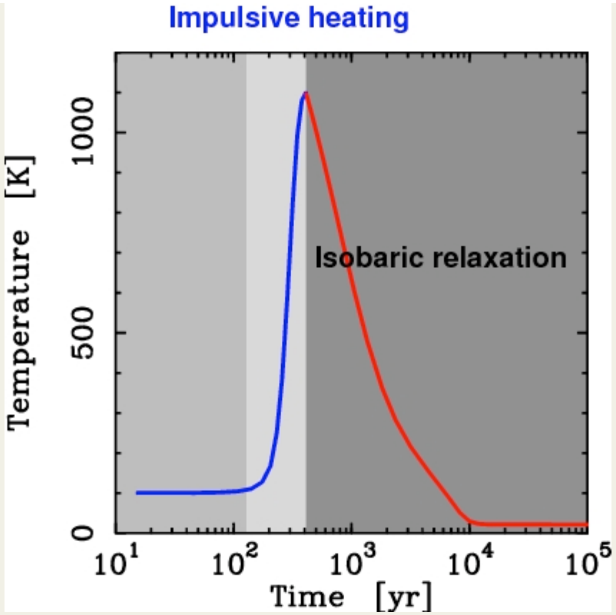
Méneveau & Sreenivasan (1991)

Non-Gaussian PDF 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

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 :

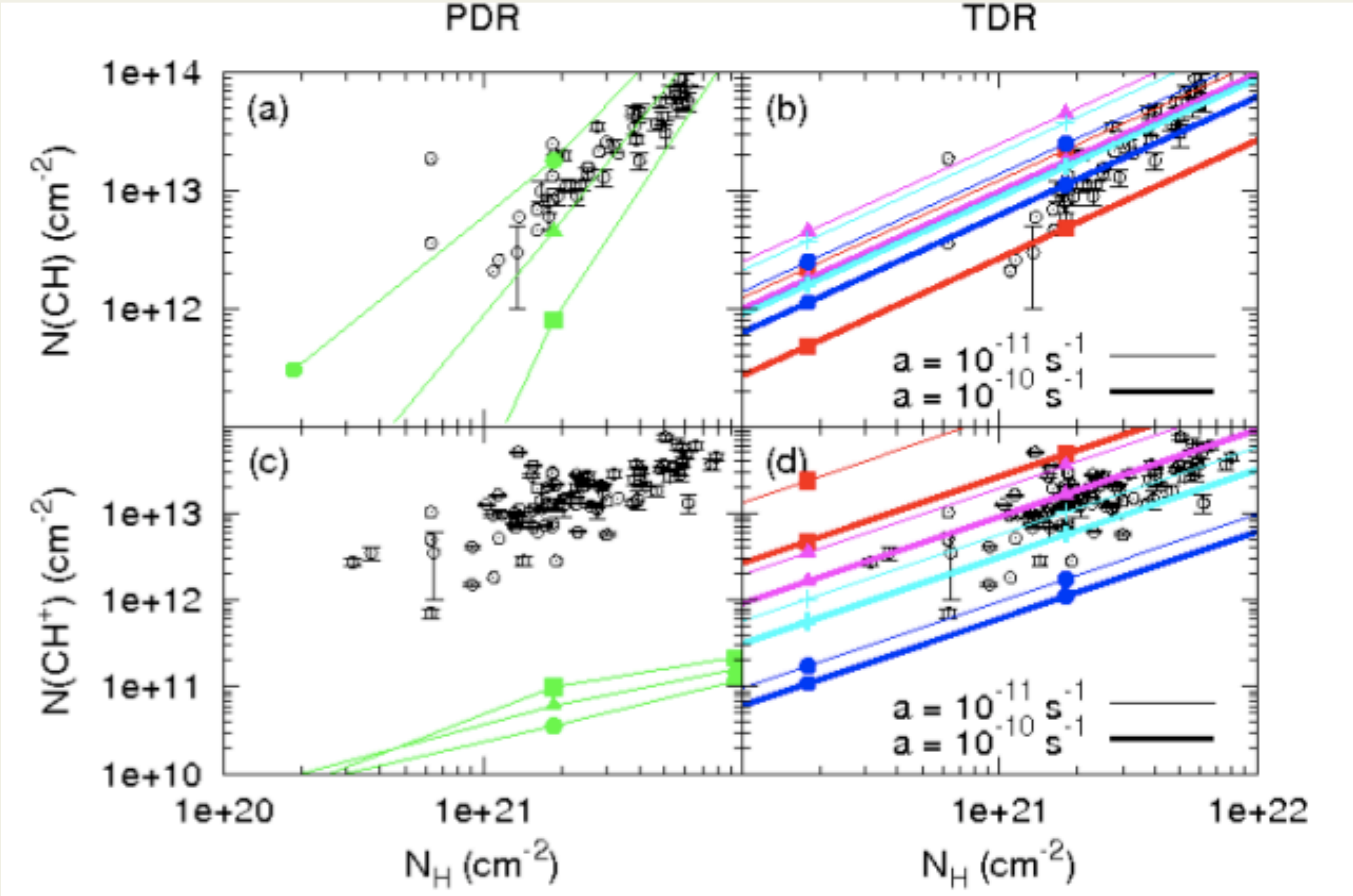
  τ_{relax} = 40 yr to 4 x10^4 yr
- Vortex characteristics set by ambient turbulence : coupling between scales
- Few free parameters : rate of strain a, n_H, A_v
- Random line of sight : Coexistence of active and relaxation phases (a few %) + ambient medium
- Turbulent energy transfer rate : ε

Joulain et al. 1998;

Godard, Falgarone, Pineau des Forêts 2009

Results of TDR models :

(1) - CH^+ reproduced without CH excess



(2) - Scalings of CH^+ abundance

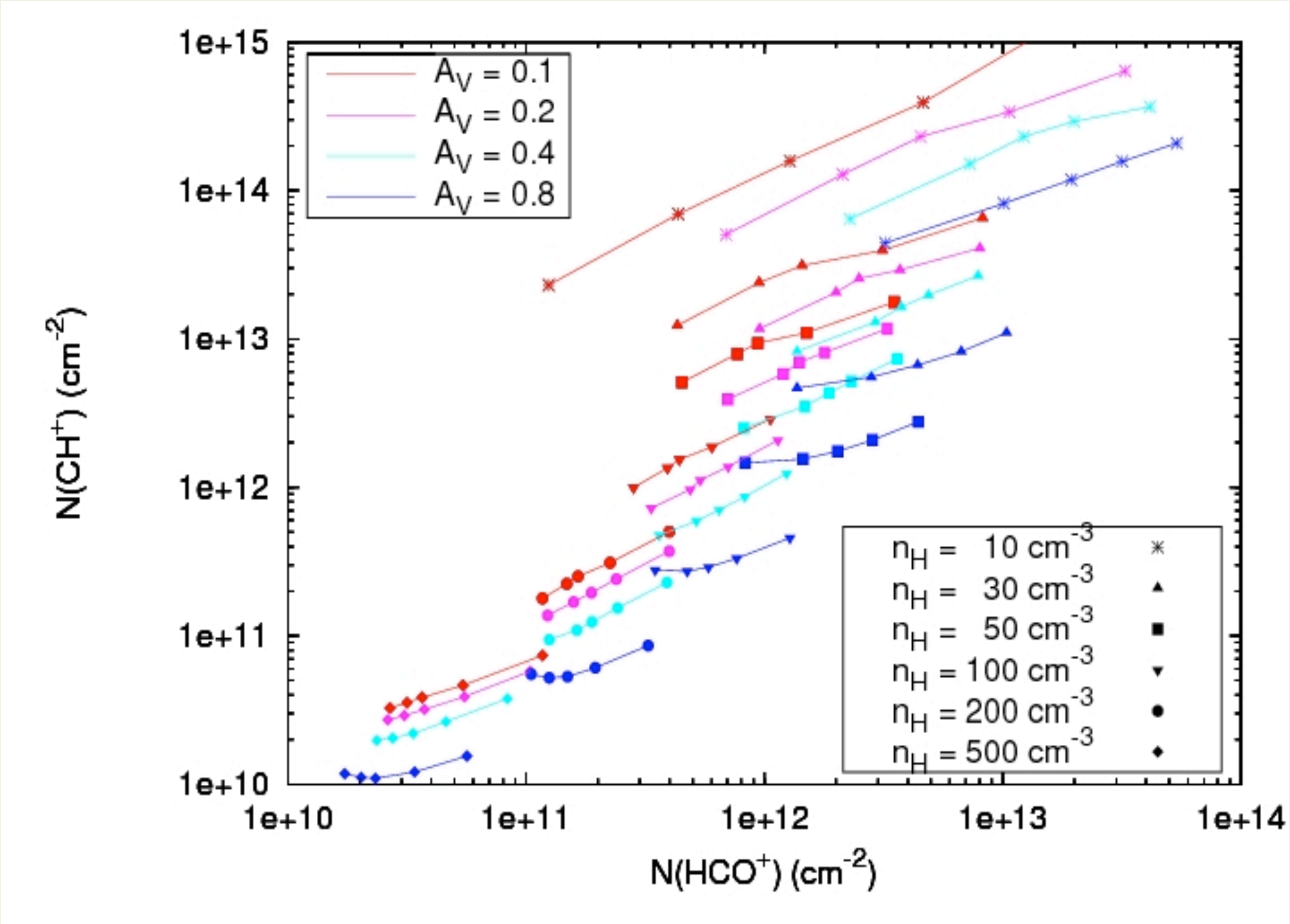
$$N(CH^+)/N_H \sim 2 \times 10^{-8}\ \varepsilon_{24}\ (n_H/50\ cm^{-3})^{-2.3}\ (A_v/0.2)^{-1}$$

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

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

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

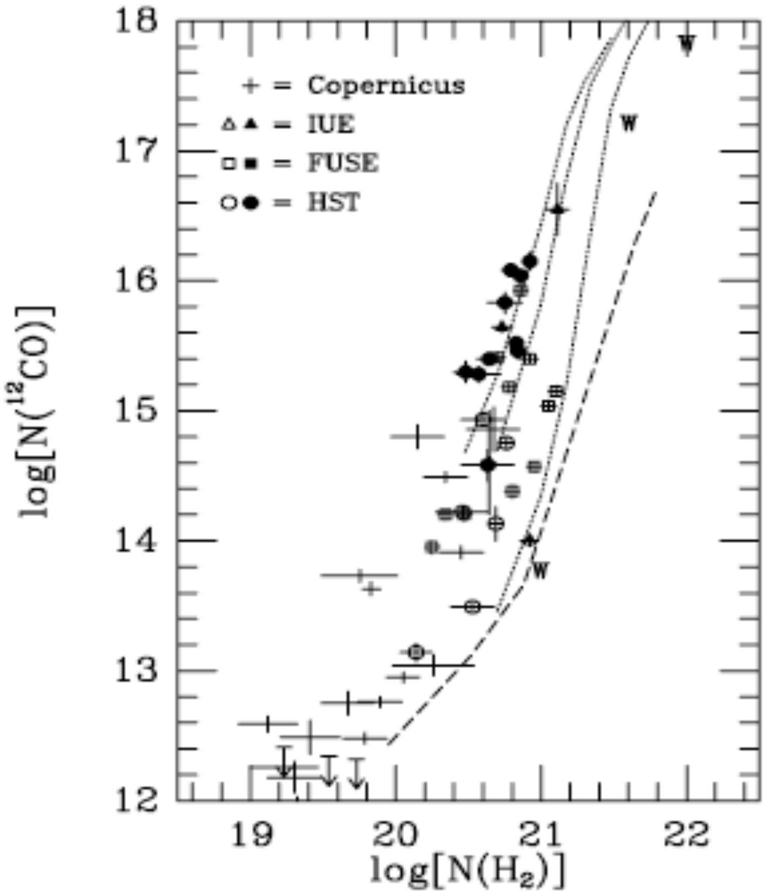
(3) - CH^+ and HCO^+

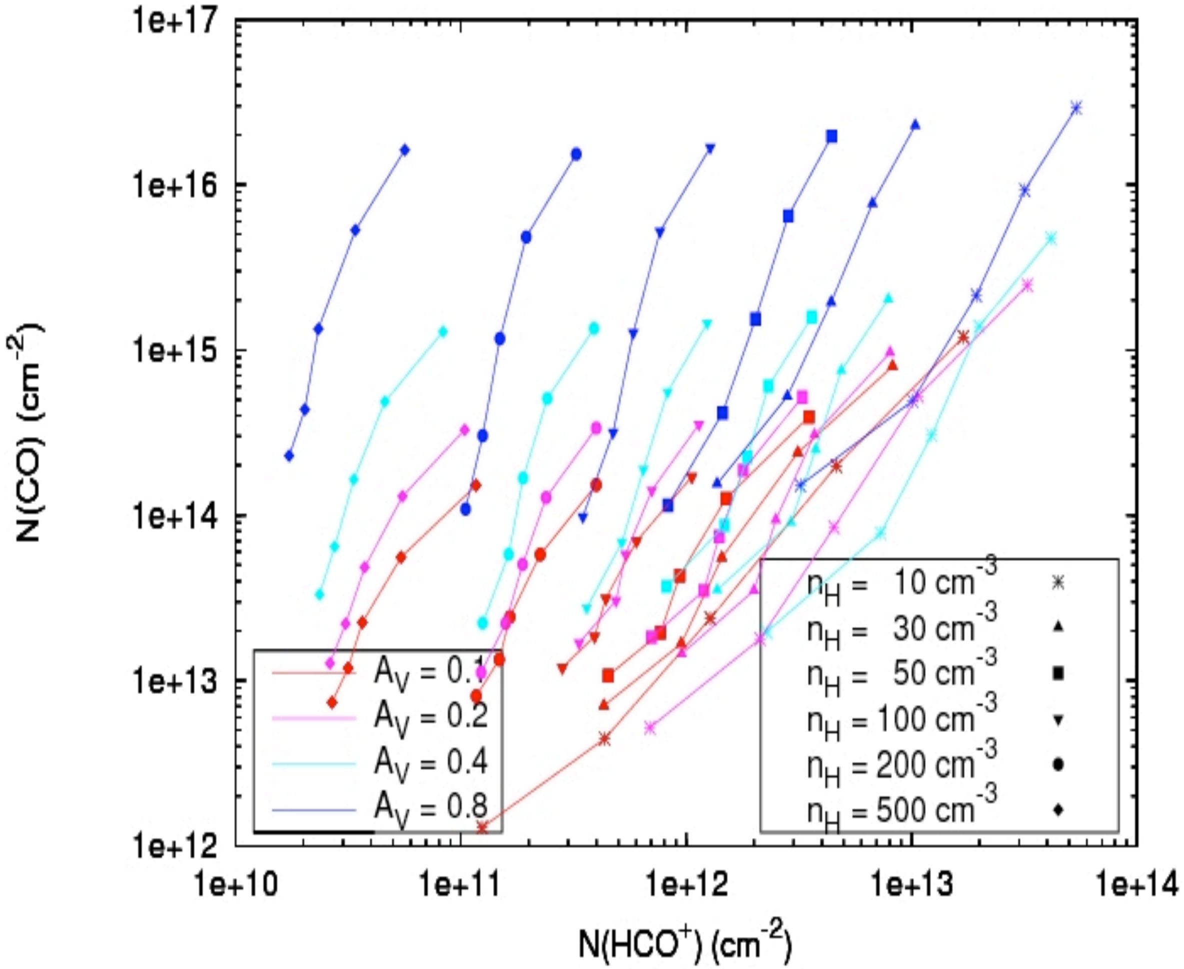


Observed ranges per magnitude

Free parameter along each curve : a

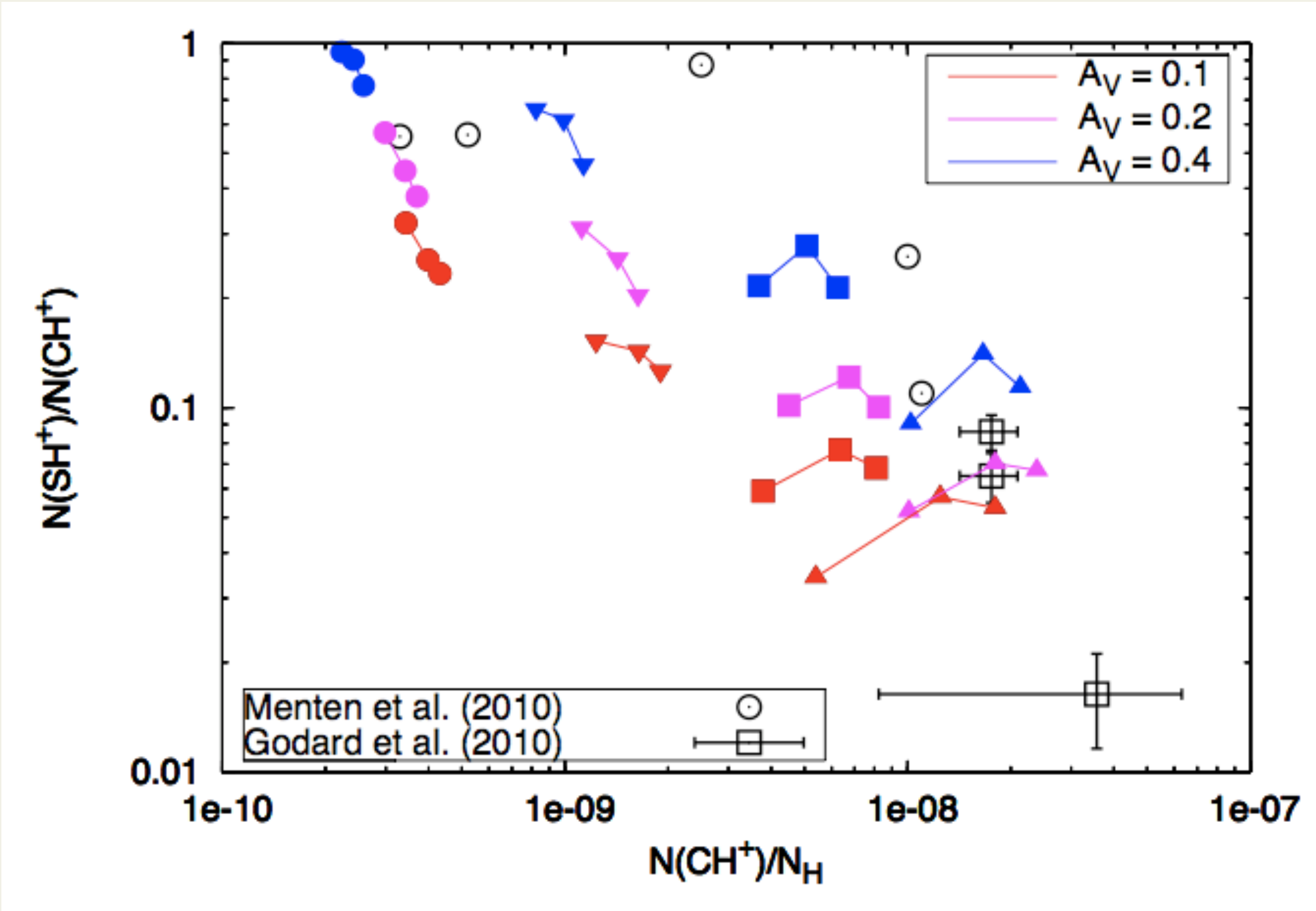
(4) - CO and HCO^+



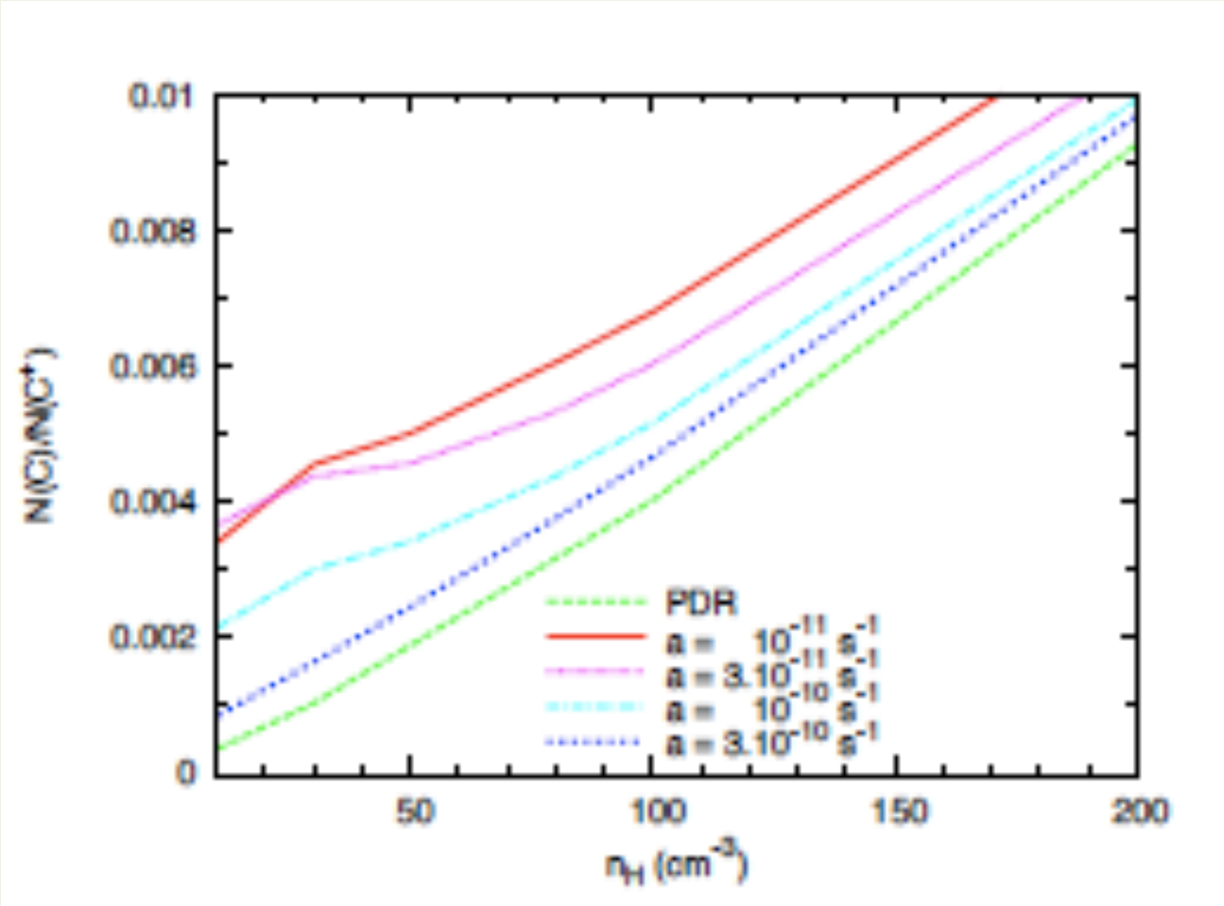


Sonnentrucker et al 07

(5) – SH^+ and CH^+



Godard et al. in prep.



(6) - Carbon is not at ionisation equilibrium

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
- CH^+ (and SH^+) is unique : tracer of gas components with a low fraction of H_2 and direct tracer of turbulent dissipation
- Absorption spectroscopy in high-z galaxies (IRAM-PdBI, ALMA) : access to turbulent dissipation in massive reservoirs of diffuse gas