

# Non equilibrium chemistry driven by turbulence dissipation

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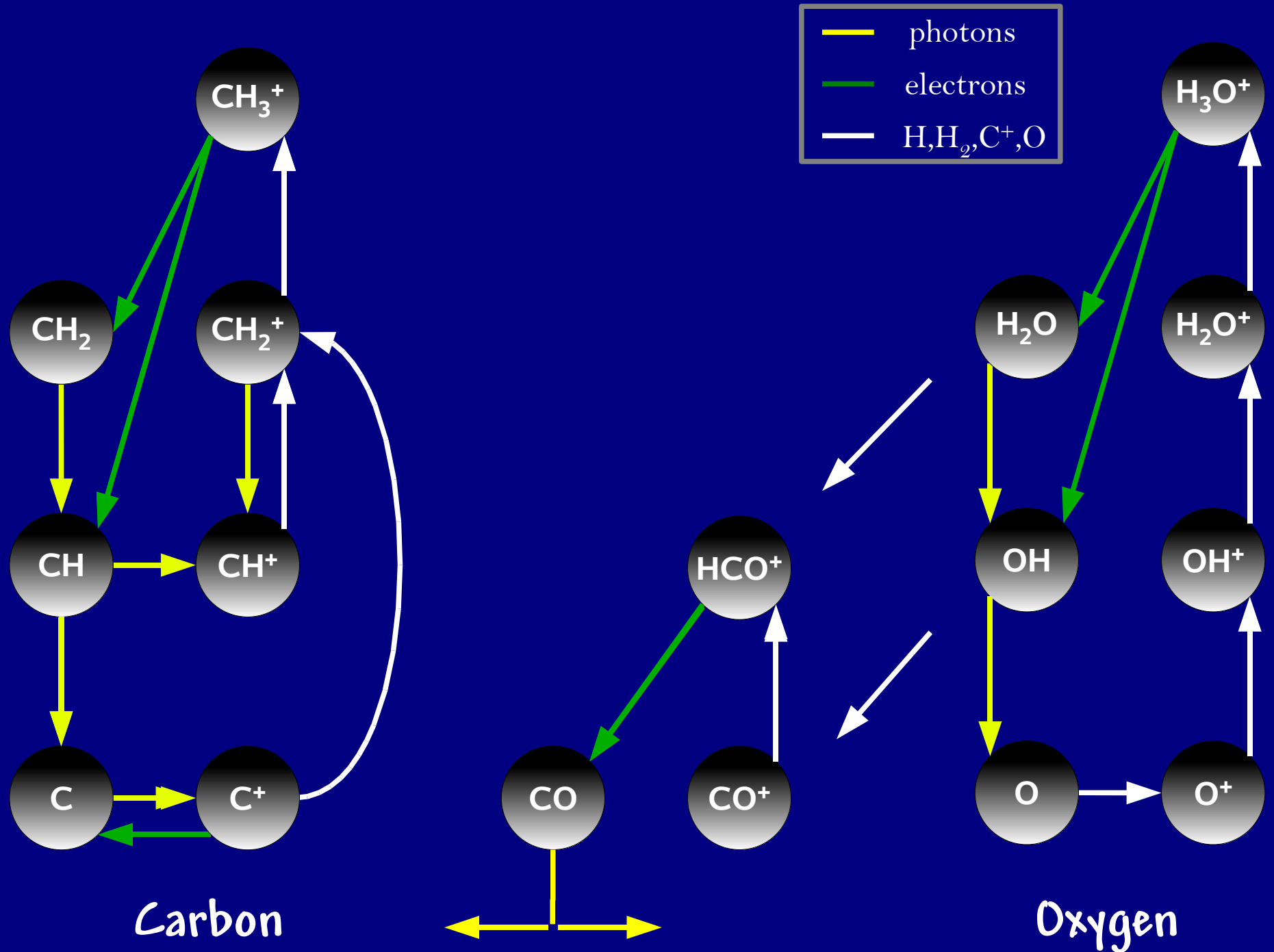
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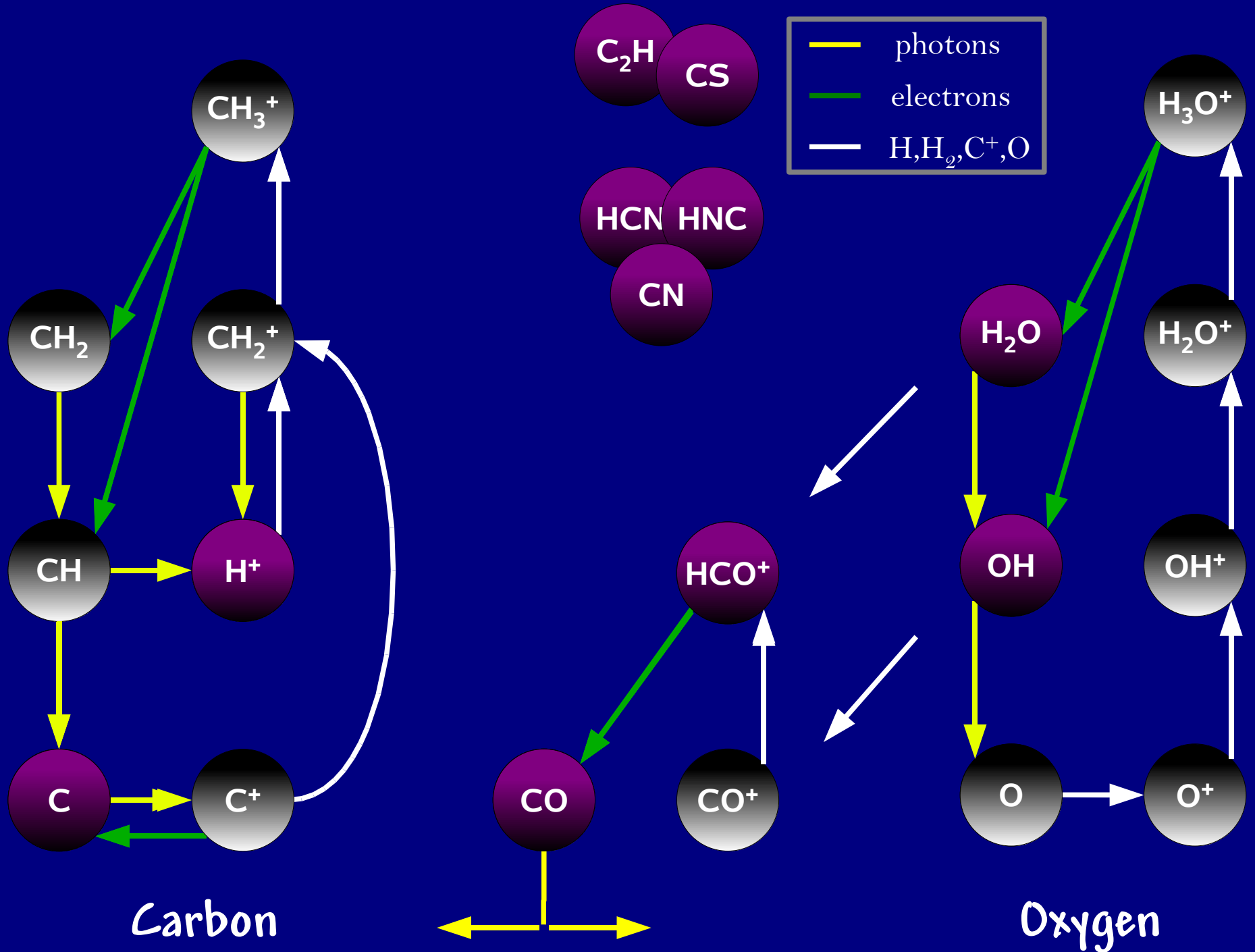
<sup>3</sup>Observatoire de Grenoble

- *Observed abundances in diffuse medium can't be entirely explained by a chemistry only driven by the photons*
- *Turbulence and its space-time intermittency*
- *Modeling dissipative structures*
- *Confrontation with observations & open problems*

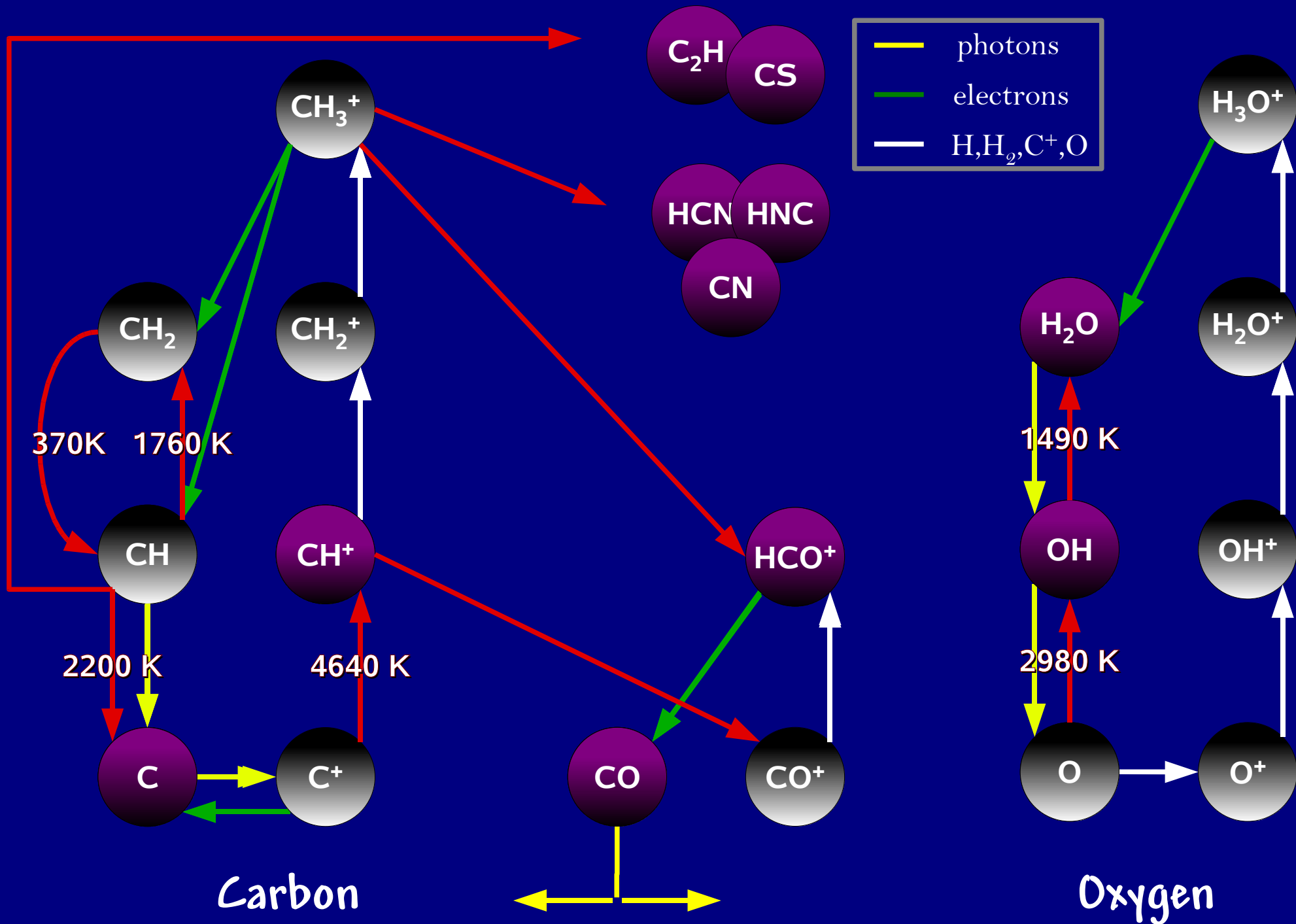
# Chemistry driven by UV photons in the diffuse medium



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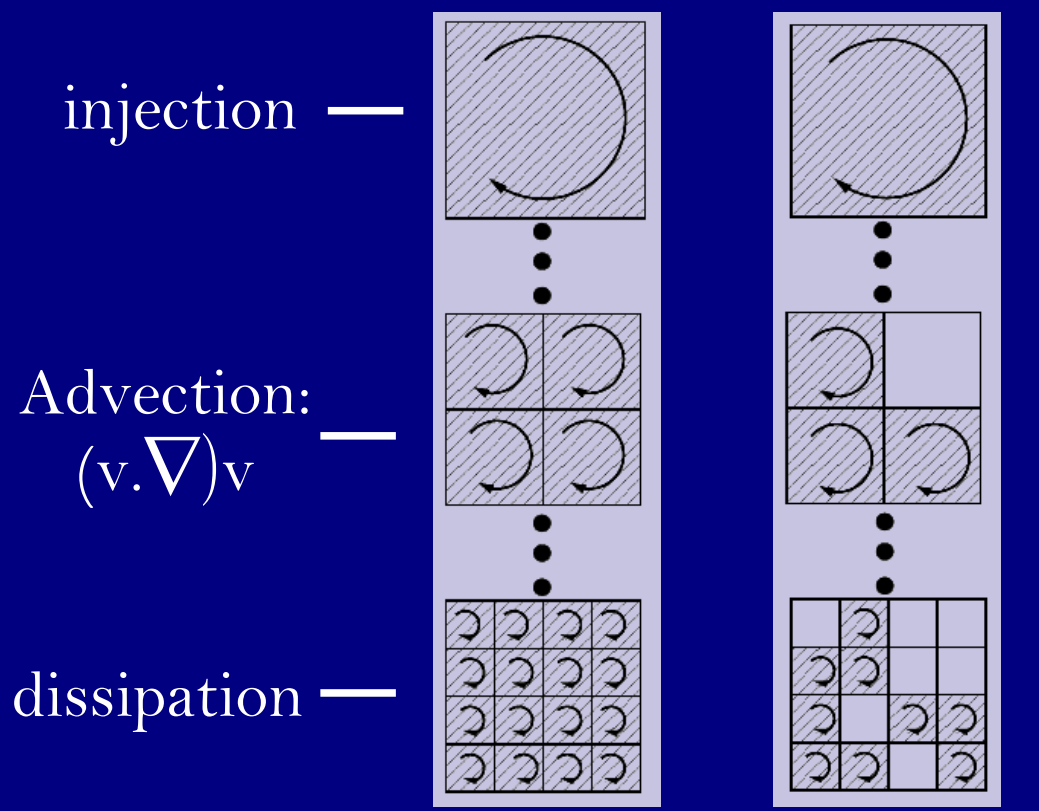


# Chemistry driven by UV photons in the diffuse medium



• Turbulence: main properties

Turbulent cascade



Small scales & Large scales are coupled

**Via coherent structures**

Rotational velocity  $\sim$  rms velocity of ambient turbulence

Mininni et al. (2006)

**Intermittency:**

→ in space

→ in time

$$\epsilon_{\text{local}} = 1/f_v \bar{\epsilon}$$

• Model of a dissipative structure: a magnetized vortex

✓ Solution of Navier-Stokes equation  
(Incompressible fluid, axisymmetric flow)

Nolan & Farrell (1998)

Vorticity:

$$\omega_z(r) = \omega_0 e^{-ar^2/4U}$$

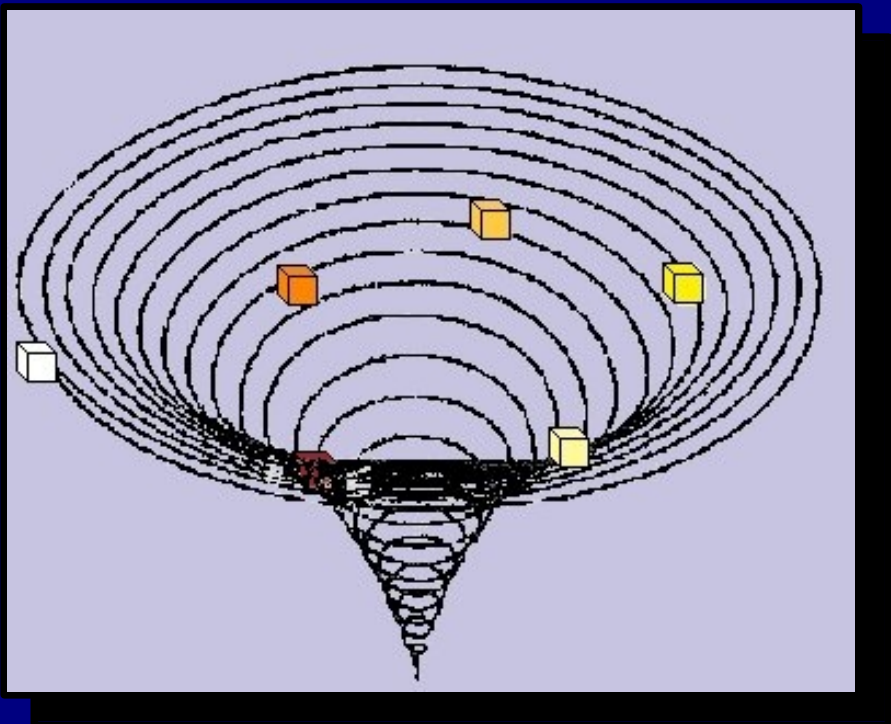
rate of strain : controlled by  
large scale turbulence

axial vorticity constrained by:  
the rms velocity of HI turbulence = 3.5 km.s<sup>-1</sup>

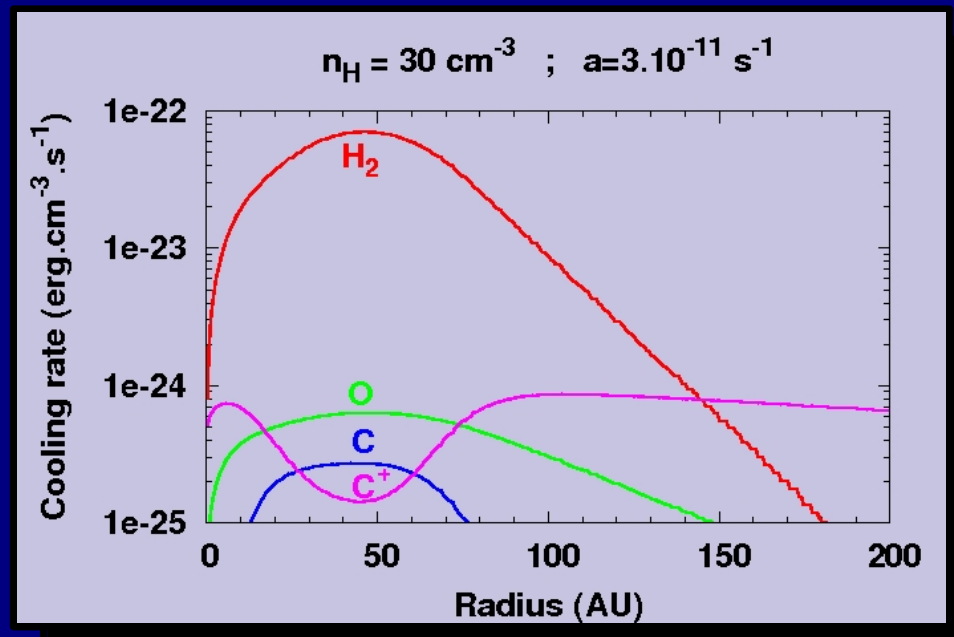
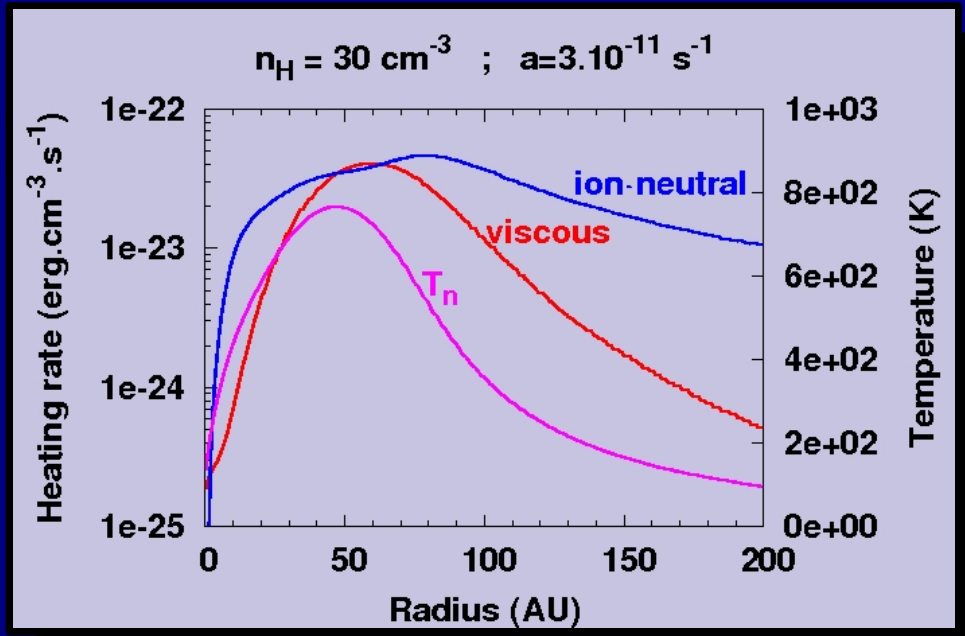
Crovisier (1981)

✓ Coupling with the magnetic field → computed with a 2D code

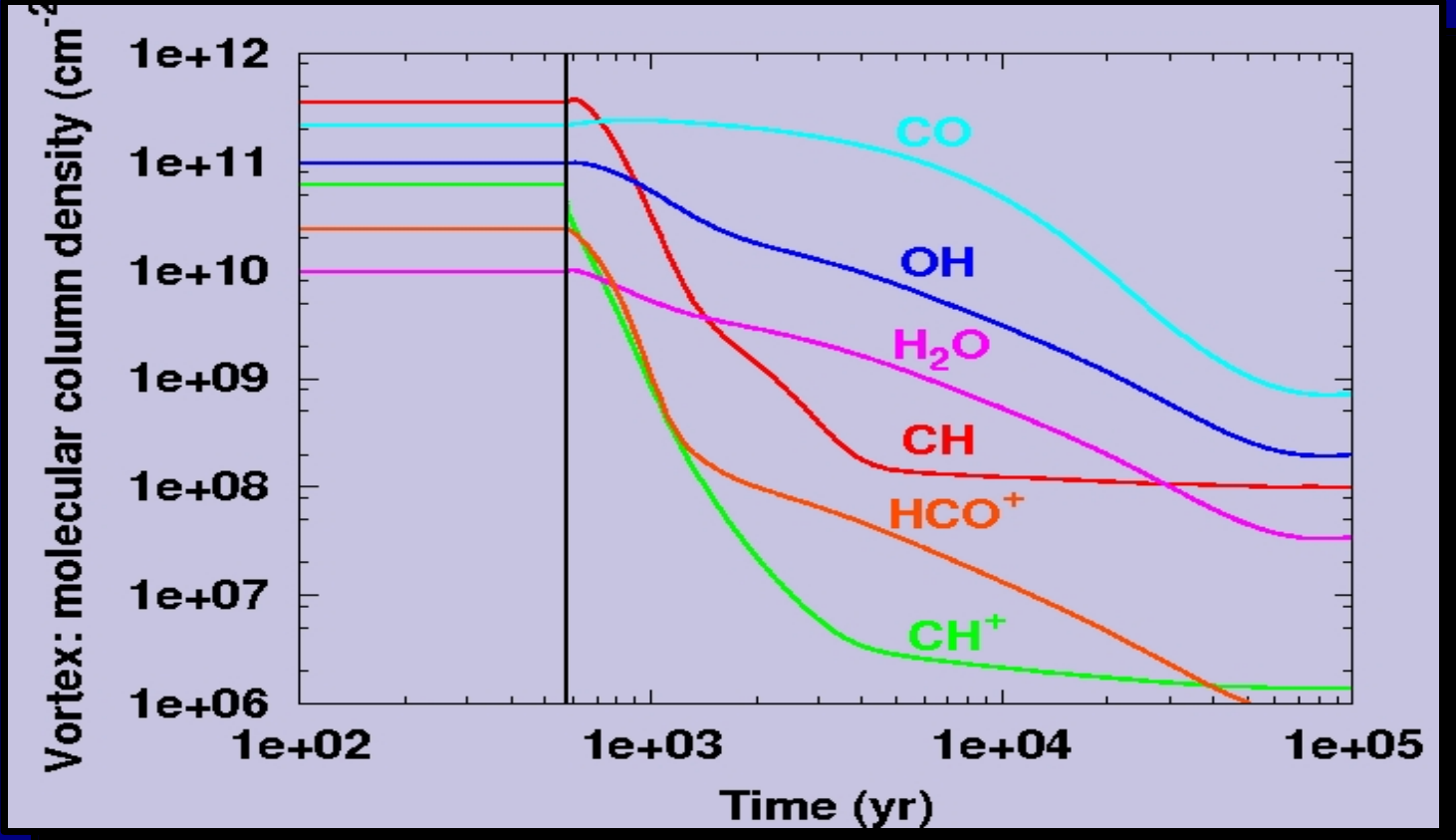
• Model of a dissipative structure: a magnetized vortex



Joulain et al. (1998)



• Model of a dissipative structure: a magnetized vortex



**Active vortex**

- Life time  $\tau_V$
- Controlled by the turbulent cascade

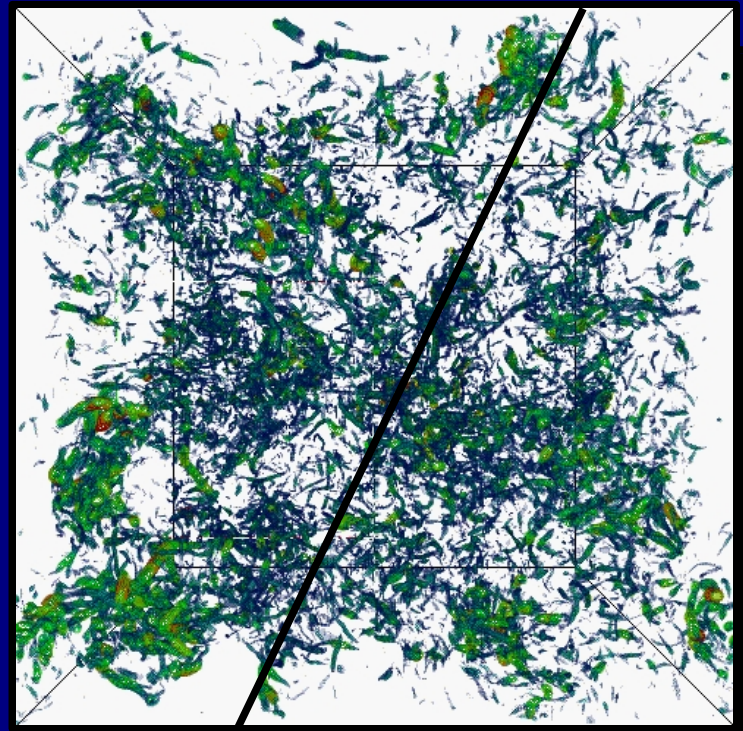
**Relaxation phase**

- Timescale  $\tau_R$
- Depends on the molecule

$$\tau_R(\text{CO}) \sim 5\tau_R(\text{OH}) \sim 10\tau_R(\text{CH}^+)$$

• Building of a line of sight

Fernandez et al. (2000)



Line of sight  
normalized to:

$$N_H = 1.8 \cdot 10^{21} \text{ cm}^{-2}$$

3 phases

✓ Ambient medium

✓ Actives vortices

✓ Relaxation phases

characteristics

pdr-type  
chemistry

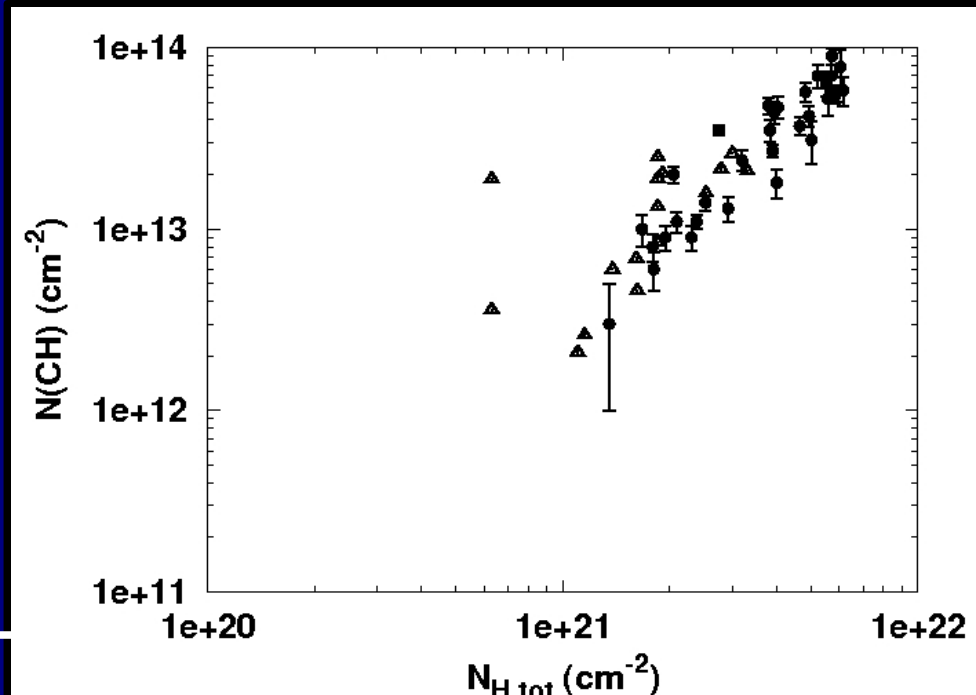
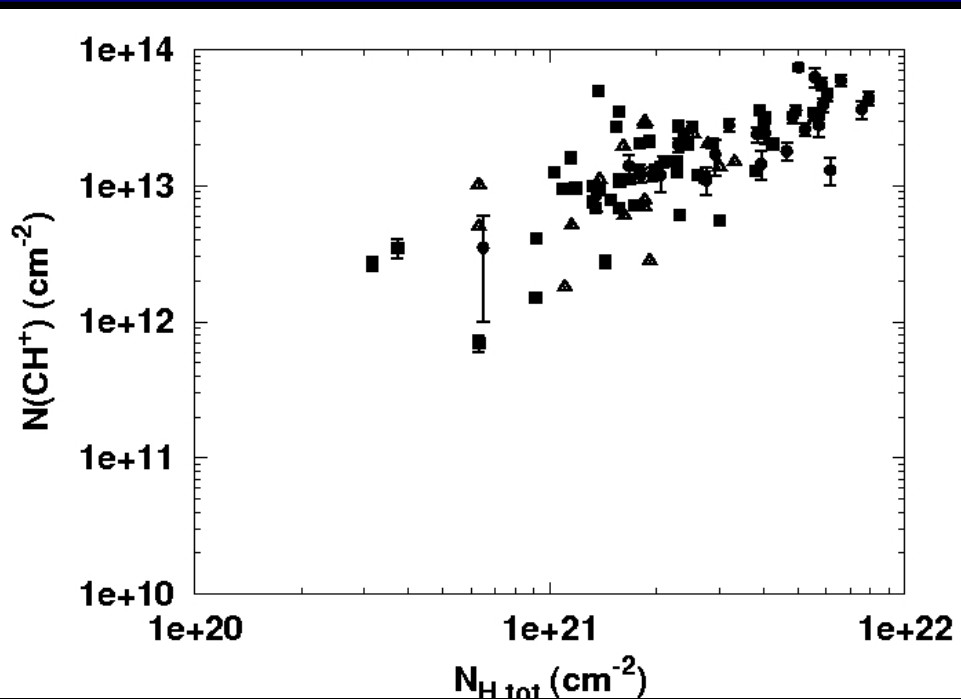
$N_V \leftrightarrow$  Available  
turbulent  
energy

$$\bar{\epsilon} = 10^{-3} \text{ erg.g}^{-1}.\text{s}^{-1}$$

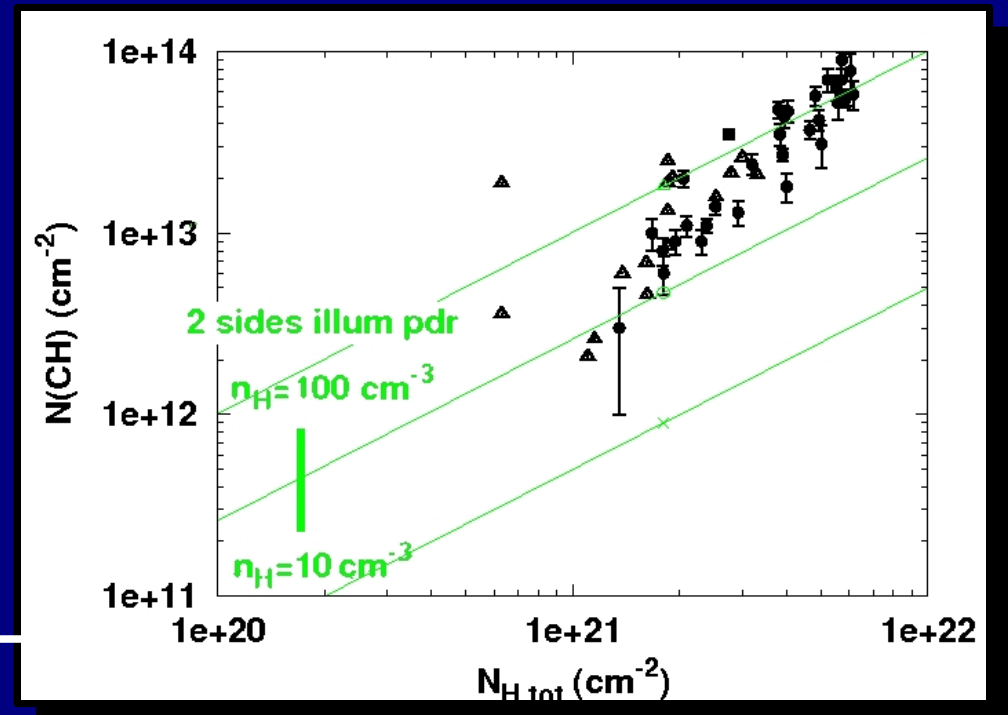
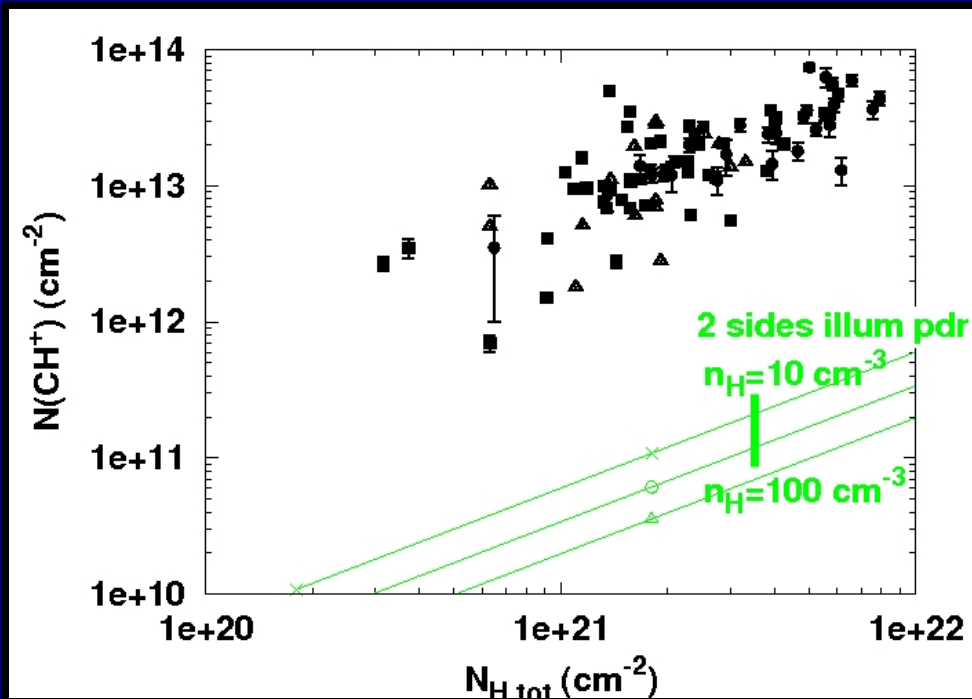
$$N_V \sim 10 - 1000$$

$$N_R/N_V = \tau_R/\tau_V$$

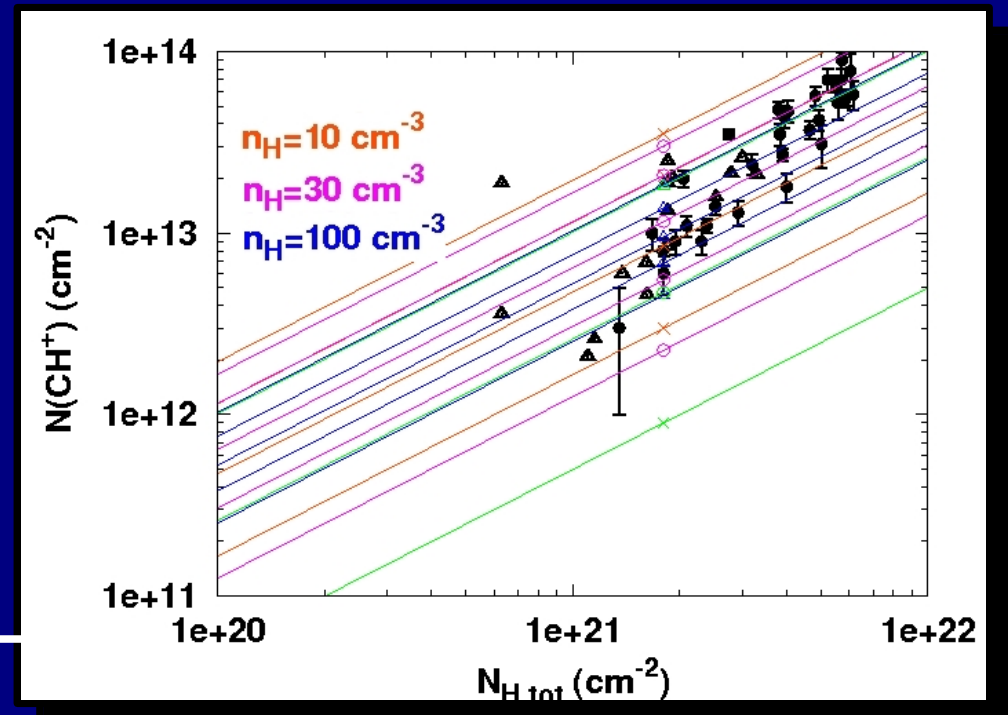
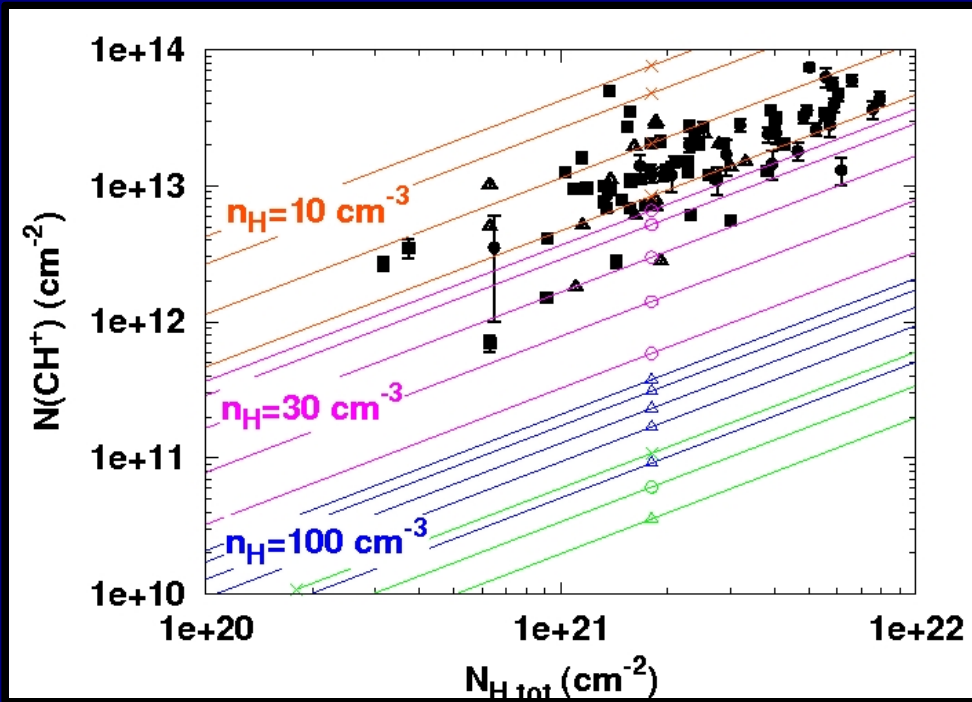
• Building of a line of sight: chemical signatures

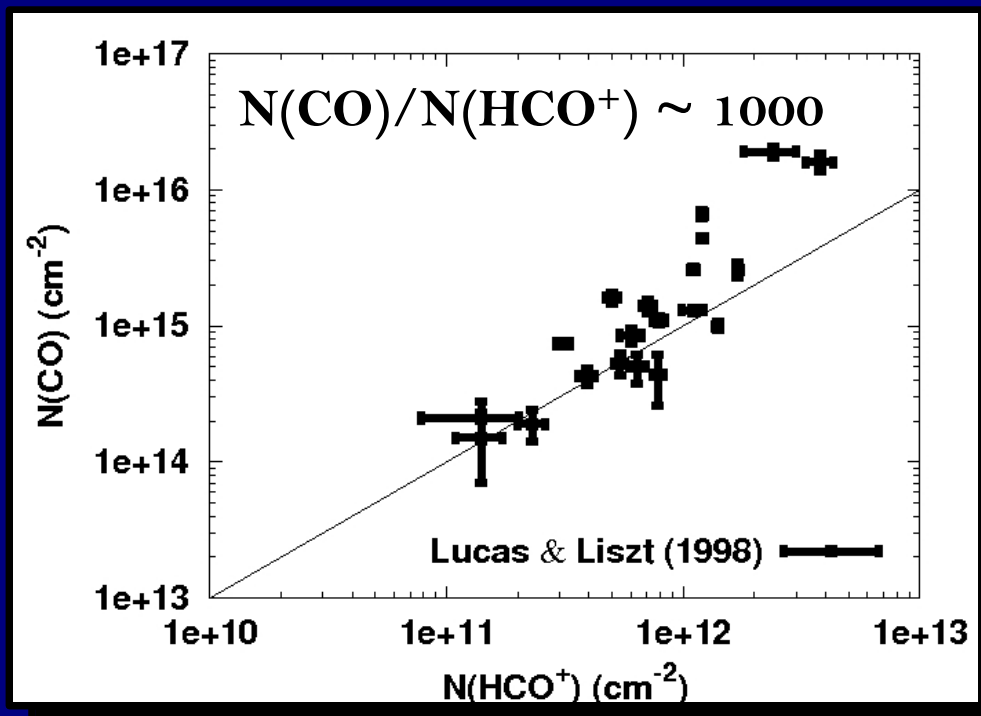
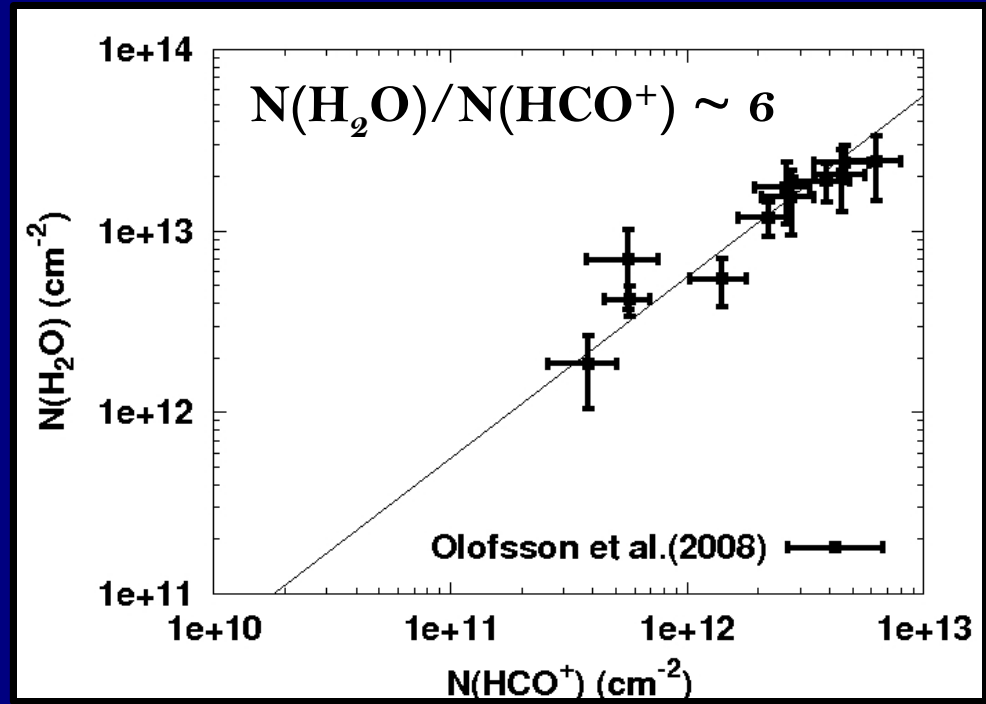
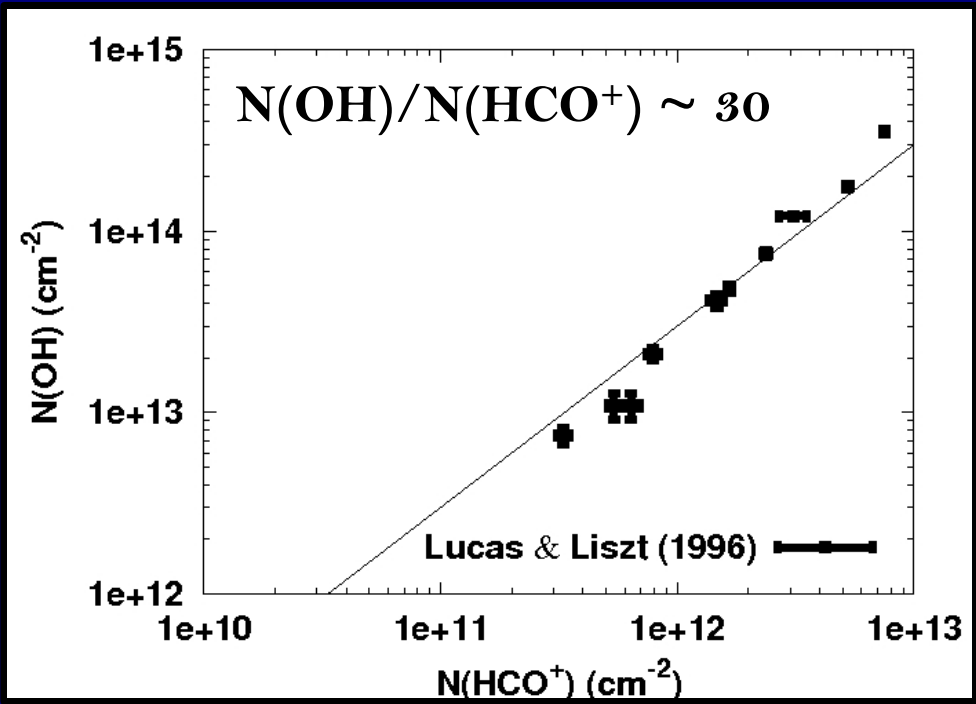


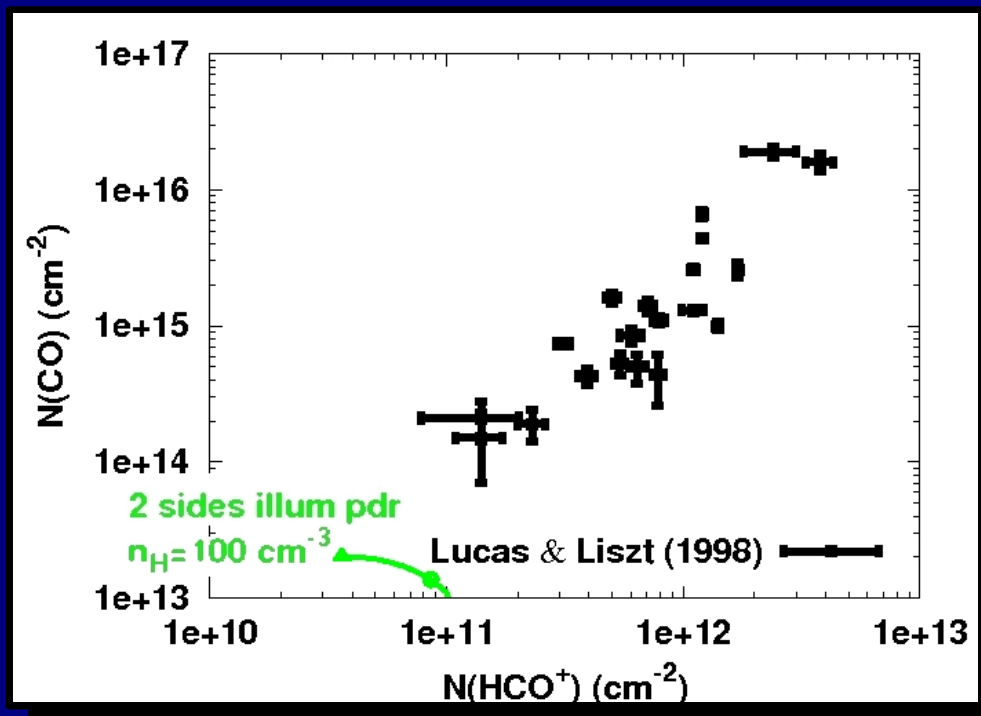
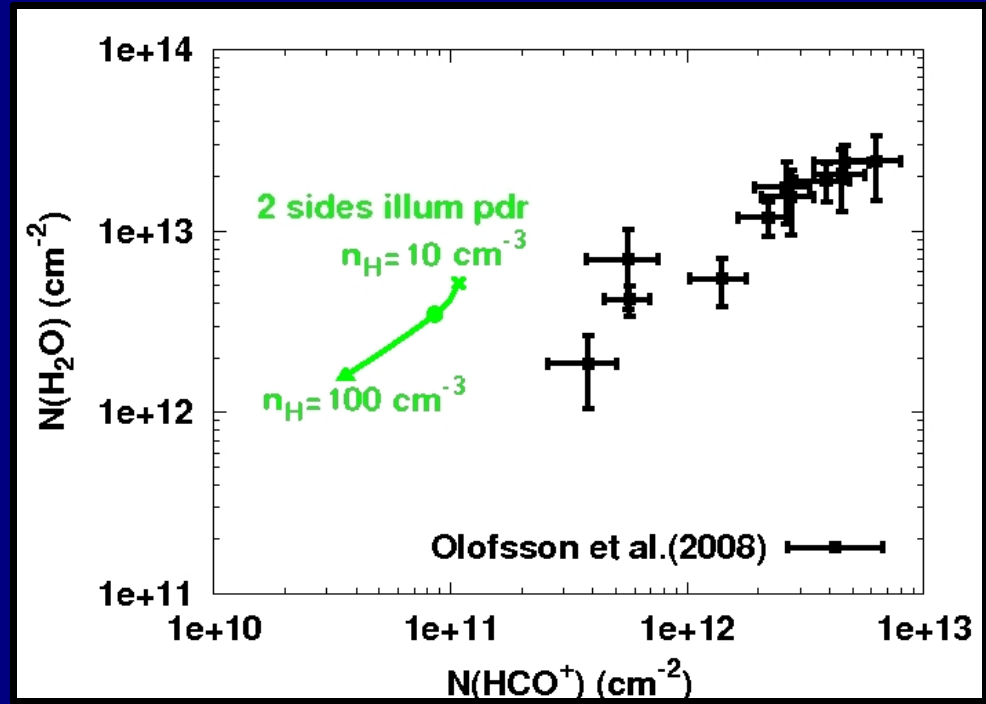
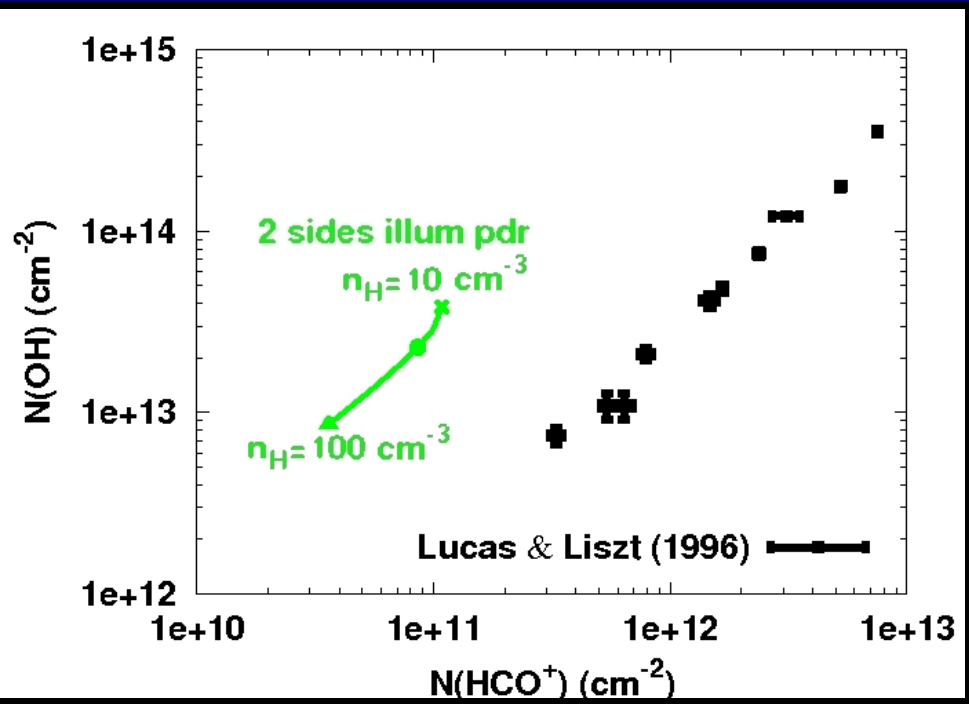
# Building of a line of sight: chemical signatures



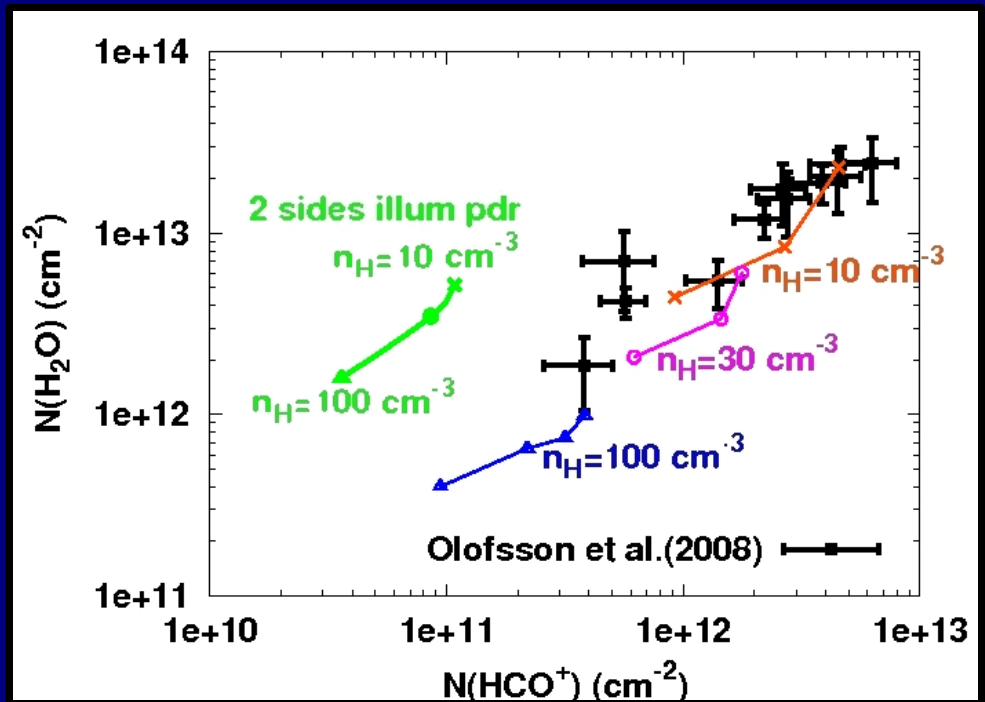
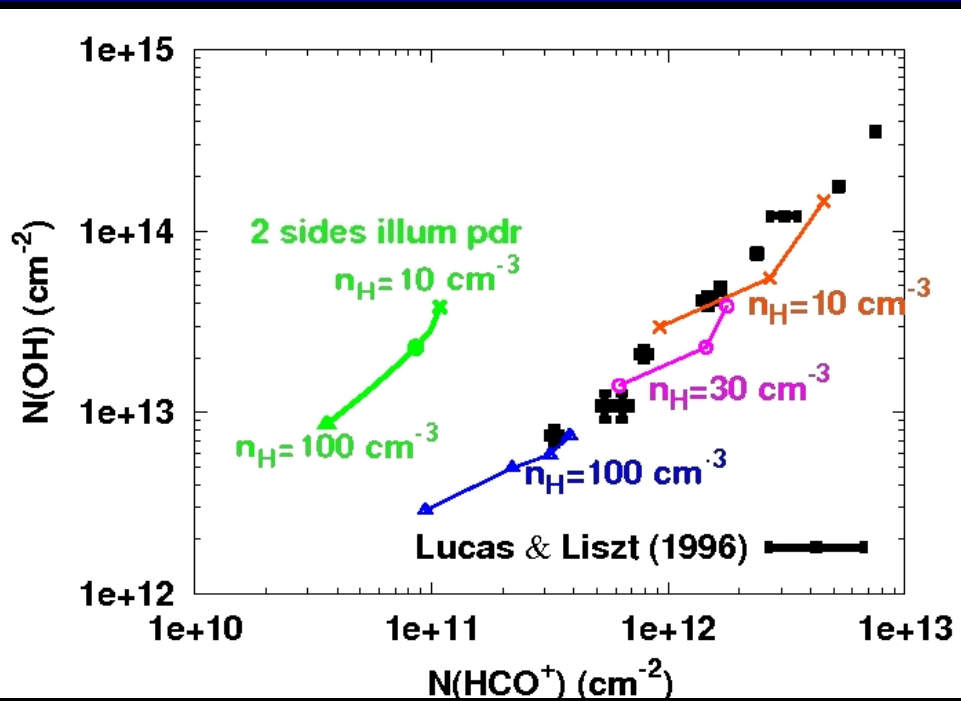
• Building of a line of sight: chemical signatures



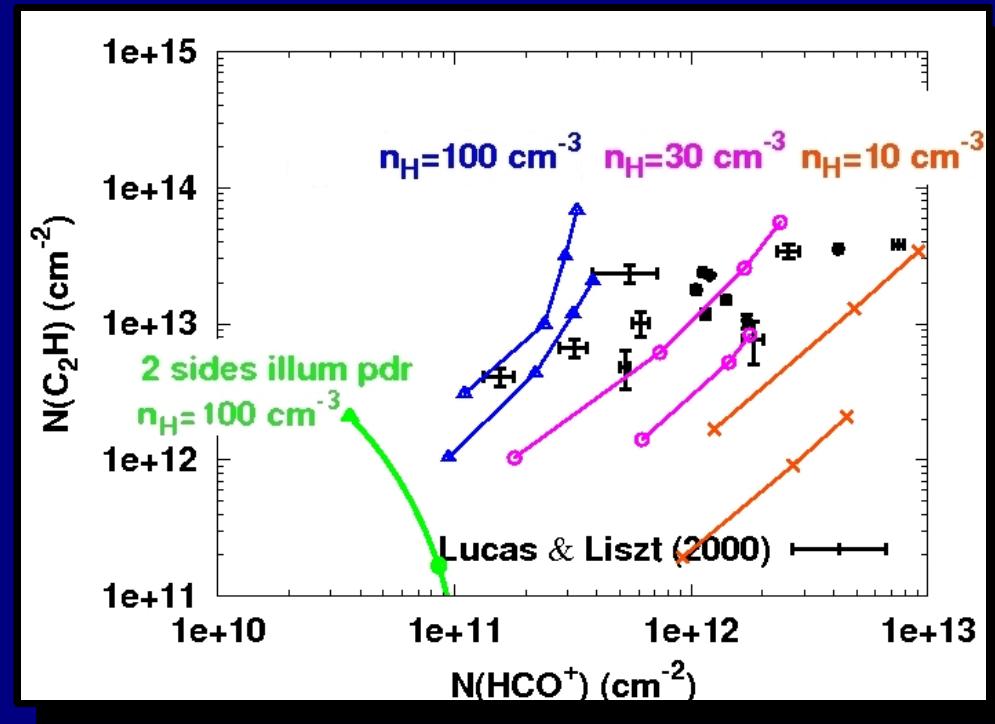
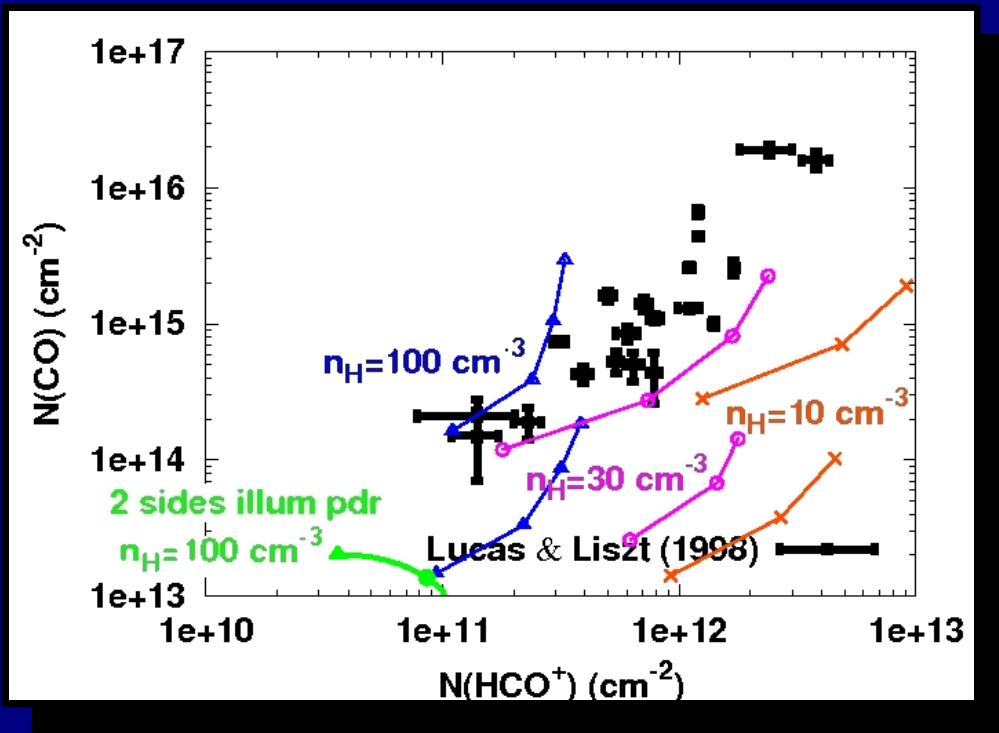




# Building of a line of sight: chemical signatures



• Building of a line of sight: chemical signatures



## Summary

- Essential properties of turbulence taken into account
  - ✓ Average available energy in the diffuse medium –  $\bar{\epsilon} - N_V$
  - ✓ Its intermittent nature –  $\epsilon_{\text{local}} - f_V$
  - ✓ Decoupling of ion and neutral at small scale –  $V_{\text{Drift}}$
  - ✓ The coupling of large and small scales –  $a - V_\theta$
- Would require numerical simulations of 3D magnetized bi-fluid compressible turbulence over a dynamical range  $> 10^3$
- Naturally reproduce the observed column densities but also the tight correlations between molecules

## Limitations

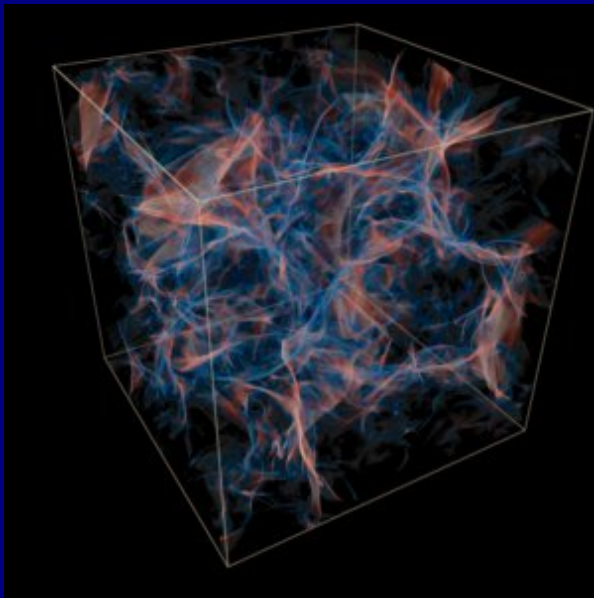
- Idealized vortex: analytical solution for the neutrals
- No feedback of chemistry
- Dynamical inertia not treated
- Identical vortices along the line of sight ( $A_V$  fixed)
- Isochoric relaxation

- *Turbulence: main properties*

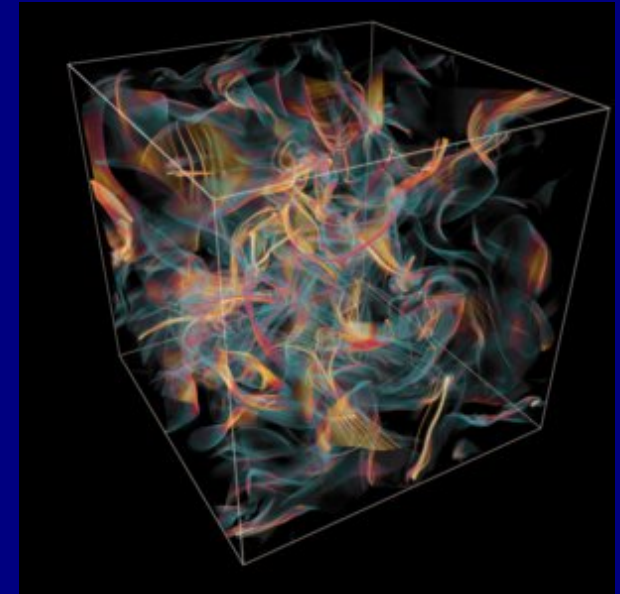
Average available energy

Compressible modes  
Shocks

Incompressible modes  
Vorticity



Porter, Woodward  
& Anderson (1997)

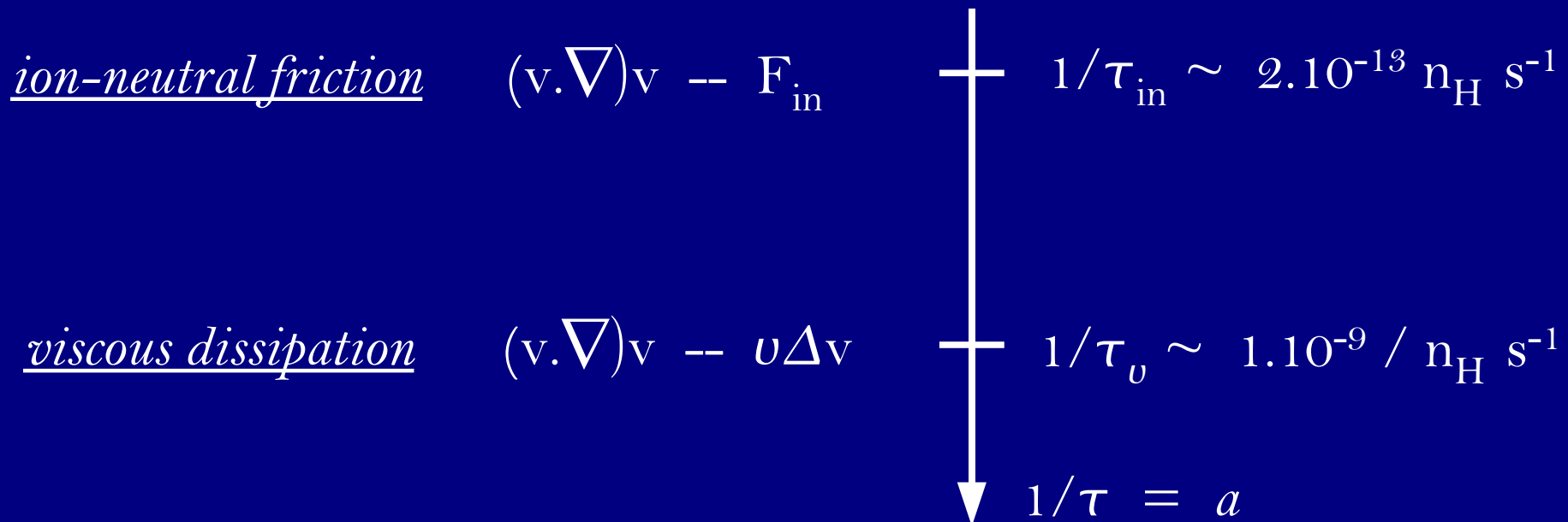


In time a large fraction of the energy lies in  
solenoidal modes

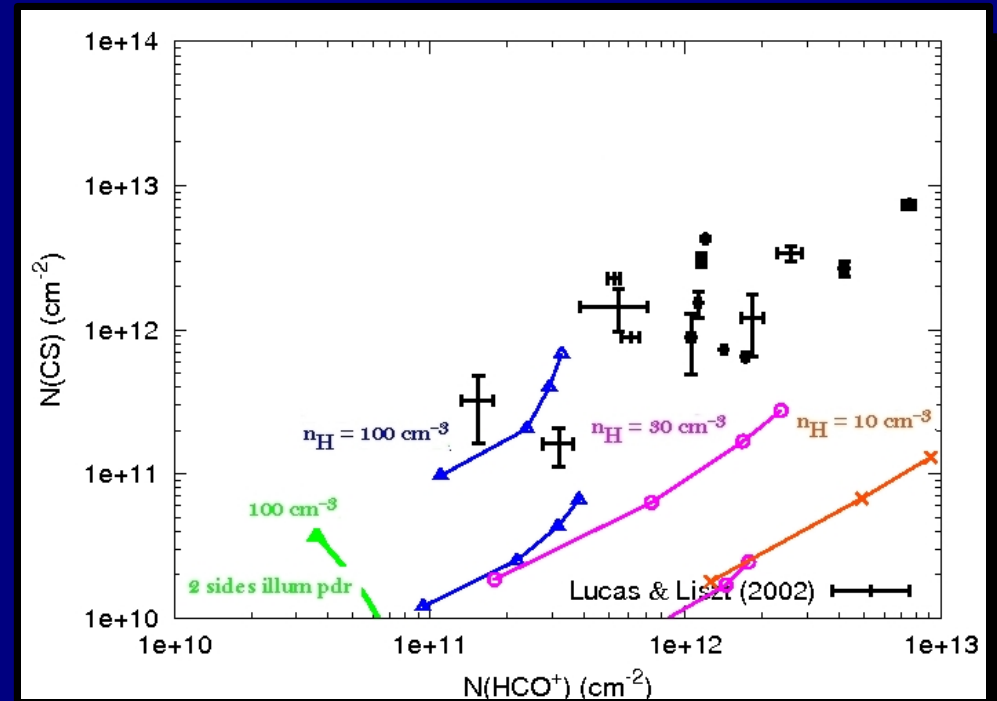
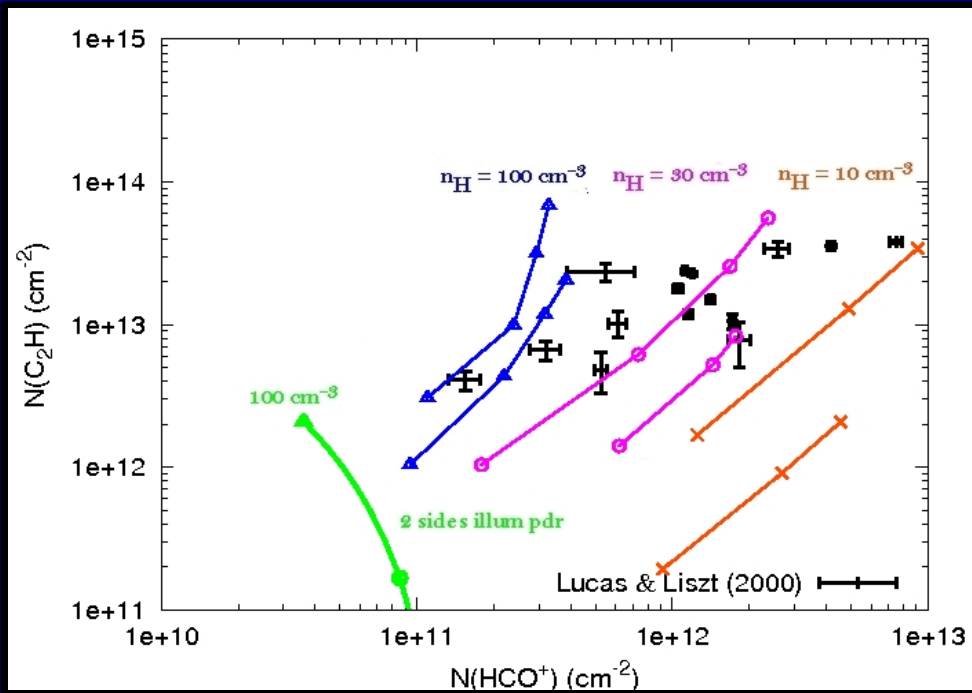
# • Turbulence in the diffuse medium

How and where (which scale) the energy could be dissipated ?

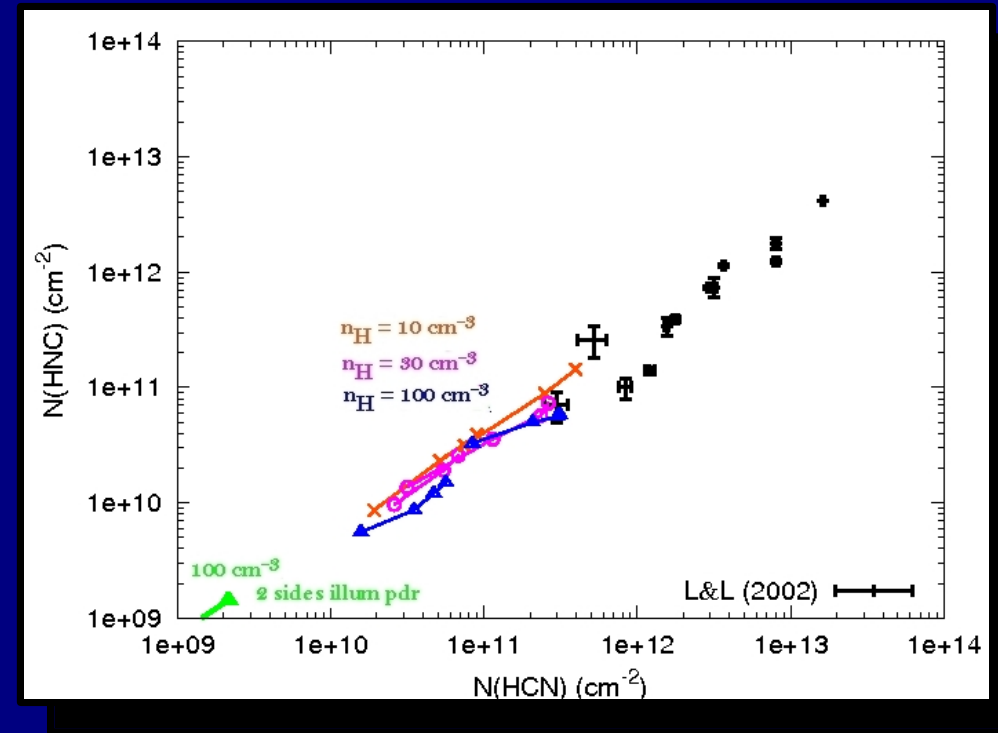
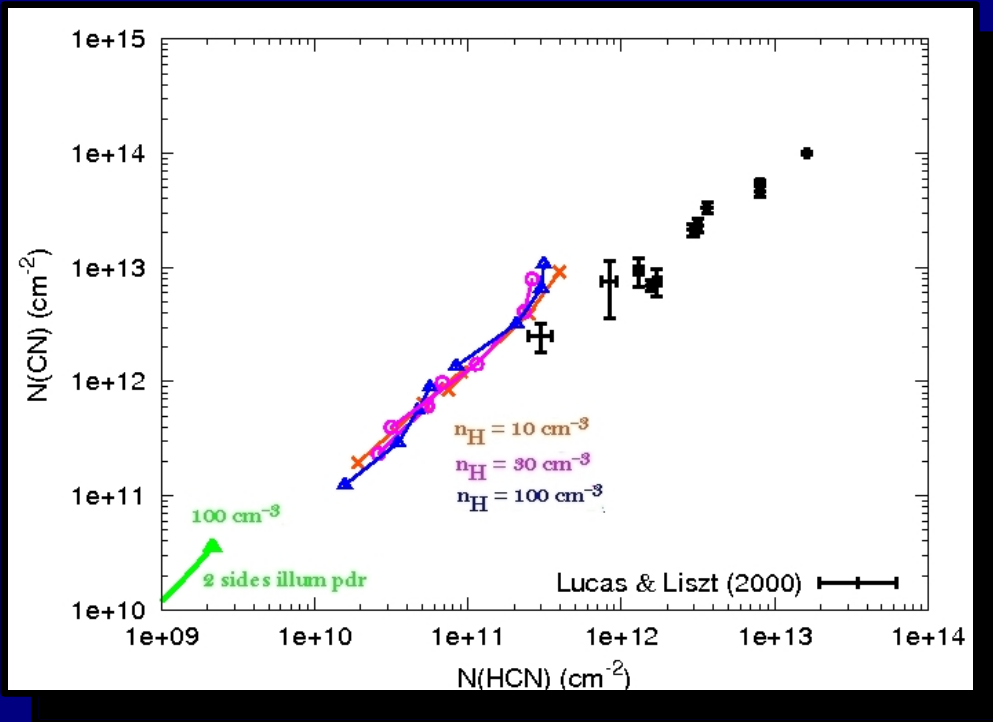
Density	$n_H \sim 10 - 100 \text{ cm}^{-3}$
Ionisation degree	$x \sim 10^{-4}$
Turbulent energy	$\epsilon \sim 10^{-3} \text{ erg.g}^{-1}.\text{s}^{-1}$
Dissipative scale	$l_d \sim \text{few AU}$



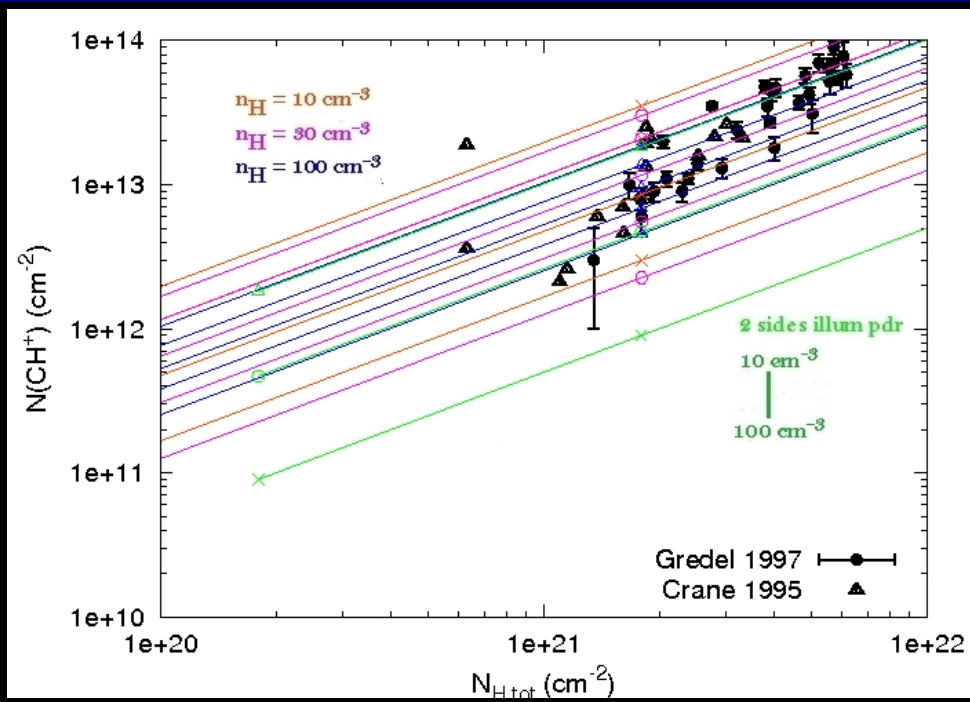
# Building of a line of sight: chemical signatures



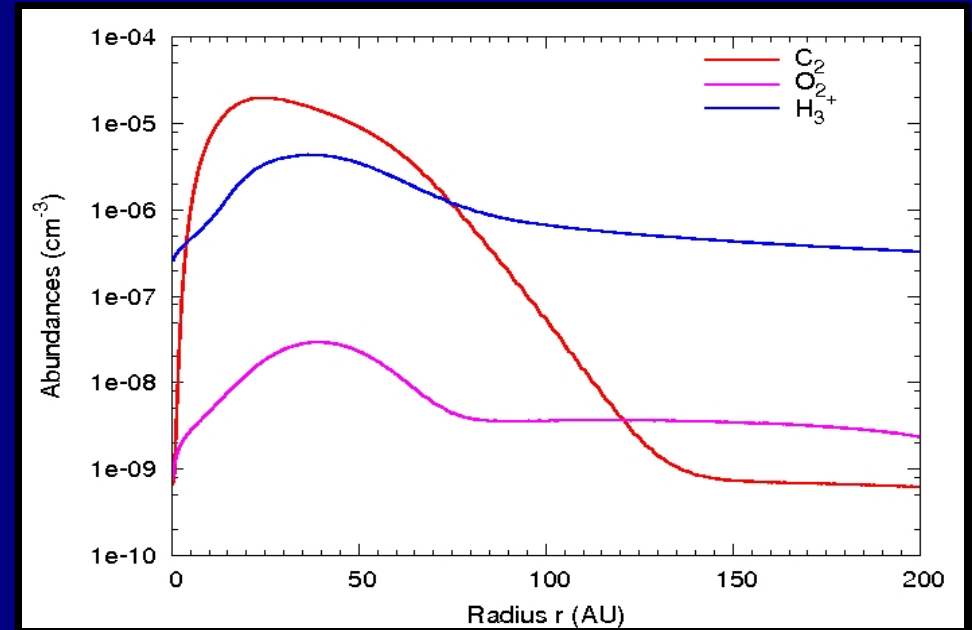
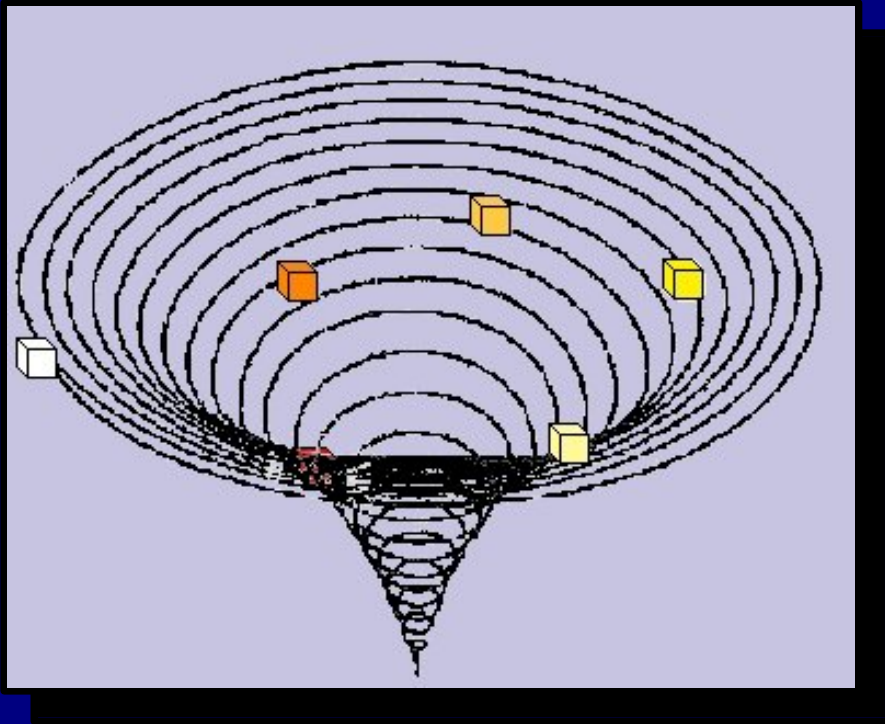
# Building of a line of sight: chemical signatures



# Building of a line of sight: chemical signatures



• Model of a dissipative structure: a magnetized vortex



# Prediction of dynamical signatures

## Classement of the molecules

