The HI-to-H_2 Photodissociation Transition

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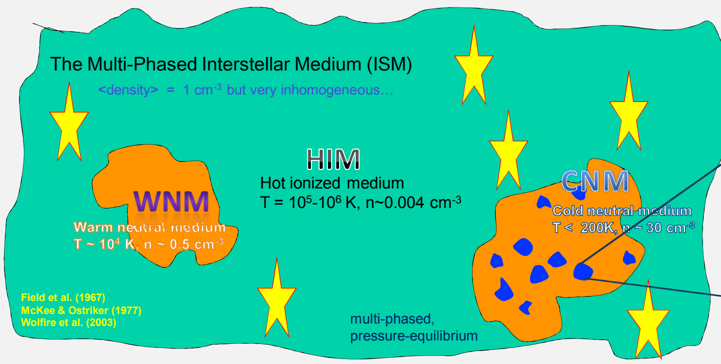
Bialy & Sternberg (2016, ApJ in press)
arXiv: 1601.02608

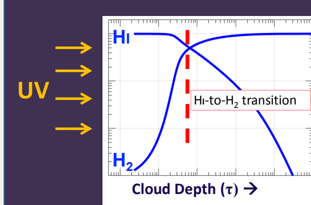
Sternberg et al. (2014, ApJ 790 10)
arXiv: 1404.5042

Motivation

The atomic (HI) to molecular transition (H_2) is fundamental for star-formation, and also initiates molecular chemistry, and the production of molecules such as CO, OH and H_2O.



- H_2 is formed on dust-grains
- H_2 is destroyed by photodissociation (11.2-13.6) ev
- UV radiation is absorbed by dust and H_2
- With increasing column→ HI-to-H_2 conversion
→ Star-formation! + molecule-formation!



We present HI/H_2 density profiles and an analytic formula for the HI-to-H_2 transition point

Physics

coupled radiative transfer + H_2 formation-destruction

H_2 formation — H_2 photodissociation

$$Rn\,n_1 \;=\; \frac{1}{2} D_0\, f_{shield}(N_2)\, \mathrm{e}^{-\tau_g}\, n_2$$

R - H_2 formation coefficient
n- volume density
n_1 - HI volume density

D_0 - H_2 free-space photo-dissociation rate
f_{shield} - H_2 self-shielding factor ≤ 1, depend on the H_2 column
$\tau = \sigma_g N$ - dust opacity
n_2 - H_2 volume density

Controlling Dimensionless parameter

αG

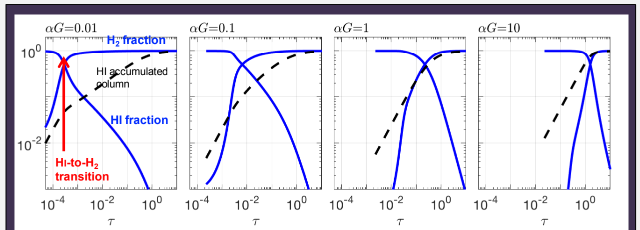
***α** ≡ $D_0/(Rn)$* – H_2 photodissociation to H_2 formation rate ratio
***G** ≡ $\sigma \int dN_2 f_{shield} e^{-2\sigma N}$* – average shielding factor.

For various astrophysically relevant conditions αG may be small (<<1) or large (>>1).
In terms of volume density (n), UV field intensity (I_{UV}) and dust absorption croiss section (σ_g):

$$\alpha G \;=\; 0.59\, I_{\rm UV} \left(\frac{100\ {\rm cm^{-3}}}{n}\right) \left(\frac{9.9}{1+8.9\tilde{\sigma}_g}\right)^{0.37}$$

The HI-to-H_2 density profiles

*Solving the H_2 formation-destruction equation we obtain the HI-to-H_2 density profiles. These are the HI and H_2 fractions **n_1/n** and **$2n_2/n$** as function of the the optical depth **τ** (or visual extinction A_V).*



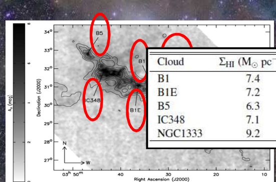
→ With increasing τ, the UV radiation is absorbed by dust and H_2 lines
→ HI-to-H2 transition occurs.

The profile shapes and the HI-to-H_2 transition points are determined by αG

αG<<1 "weak field limit"	***αG>>1 "strong field limit"***
Transition occurs at smaller columns.	Transition occurs at large gas columns.
Transition induced by H_2 self-shielding	Transition induced by dust absorption
HI column is built up after the transition	HI column is built up before the transition

Observational example - *The Perseus molecular cloud*

We used observations of HI (21 cm) and H_2 (IR) column densities, for several 100s of sight lines toward Perseus to constrain the αG parameter and the average volume density n. ***(Bialy et al. 2015; ApJ 809, 122)***

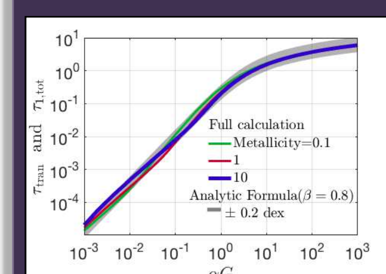


Cloud	Σ_{HI} ($M_\odot$ pc^{-2})
B1	7.4
B1E	7.2
B5	6.3
IC348	7.1
NGC1333	9.2

Source	αG	n (cm^{-3})
B1	6.5 – 26.1	9.1 – 1.8
B1E	6.1 – 23.8	9.6 – 2.0
B5	5.0 – 17.7	11.8 – 2.6
IC345	6.0 – 23.2	9.8 – 2.0
NGC1333	9.5 – 47.0	6.2 – 1.0

Large αG → *HI-to-H2 transition dominated by dust absorption.*
$n_{WNM} < n < n_{CNM}$ → the volume density falls within the unstable-neutral medium (UNM)

The HI-to-H_2 Transition point



Analytic formula for the HI-to-H_2 transition point

$$\tau_{\rm tran} \;=\; \beta\, \ln\left[\left(\frac{\alpha G}{2}\right)^{1/\beta} + 1\right]$$

The formula is useful for interpreting observations and as a sub-grid model in hdrodynamics simulations

- For αG>>1: τ_{tran}~ln(αG/2) and the dust opacity is regulated to~1 (transition is induced by dust absorption)
- For αG<<1: τ_{tran}~$(\alpha G)^{1/\beta}$<<1 and dust absorption is negligible (transition is induced by H_2 self-shielding)
- The required gas column to convert HI-to-H_2 is $N_{tran} = \tau/\sigma_g = 4\times10^{20}\ \ln[(\alpha G/2)^{1/\beta}+1]\ /\ Z'$ cm^{-2}