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David Wilner

Molecular Clouds H_2

most impt tracer = CO
- high abundance $\sim 5\times10^{-5}$ CO/H_2 molecules
- (next highest abund = dust)
- favorable excitation $\sim 5.5K$ $(J=1\to0)$
- chemically robust

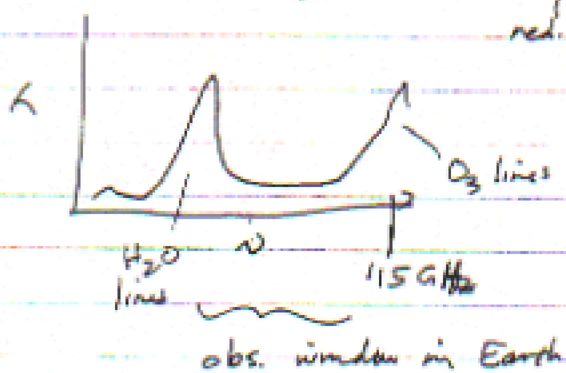
$$h\nu = hB\,2(j+1)$$

rotational constant $= \dfrac{h}{8\pi^2 I}$ (units of freq.)

$I \sim MR^2$

M: red. mass of C+O, $R \sim 1^\circ$ ⇒ radio freq.

$$\nu_{1-0} = 115.27\ GHz$$



Use CO to measure N, T

$$\Delta I^{12} = \left(B(T_{ex}^{12}) - B(T_{bg})\right)\left(1-e^{-\tau_{12}}\right) \qquad (^{12}CO)$$

T_{bg} = 2.7 K

$$\frac{n_2}{n_1} = \frac{g_1}{g_2}\, e^{-h\nu/kT_{ex}}$$

LTE ⇒ $T_{ex} = T$

$$B = \frac{2kT\nu^2}{c^2}$$

$$\Delta I^{13} = \left(B(T_{ex}^{13}) - B(T_{bg})\right)\left(1-e^{-\tau_{13}}\right) \qquad (^{13}CO)$$

if $\tau_{12}, \tau_{13} \ll 1$ and $T_{ex}^{12} = T_{ex}^{13}$

$$\Rightarrow \frac{\Delta I^{12}}{\Delta I^{13}} = \frac{\tau^{12}}{\tau^{13}} = \frac{N^{12}}{N^{13}} = 89 \Rightarrow \text{solar neighborhood, Sun}$$

"solar abundance"

measure w/ telescope:

$$\frac{\Delta I^{12}}{\Delta I^{13}} \sim 3\text{-}5$$

$\Rightarrow$ ^{12}CO optically thick

$\Rightarrow \tau_{12} \gg 1$

$$\Rightarrow \frac{\Delta I^{12}}{\Delta I^{13}} \approx \frac{1}{\tau_{13}} \quad {}^{13}CO \text{ opt. thin.}$$

$$\Delta I^{12} = [B(T_{ex}) - B(T_{bg})](1) \quad \text{for } \tau_{12} \gg 1$$

$$\tau_\nu = \frac{(h\nu)^2}{4\pi k} B_{lu} \phi_\nu \frac{N_l}{T_{ex}} \quad (HI)$$

ϕ_ν → line profile

apply to ^{13}CO

$$N_{tot}(^{13}CO) = (\text{const})\, \tau\, T_{ex}$$

const ← physics; τ ← ^{13}CO spectrum; T_{ex} ← ^{12}CO

$$N_{tot}(H_2) = X\, N_{tot}(^{13}CO)$$

(digression)

^{12}CO opt thick, yet measured ^{12}CO still related to mass size of cloud

$\Rightarrow$ filling factor, clumpiness