Ay 20 # 20 - Components of the ISM

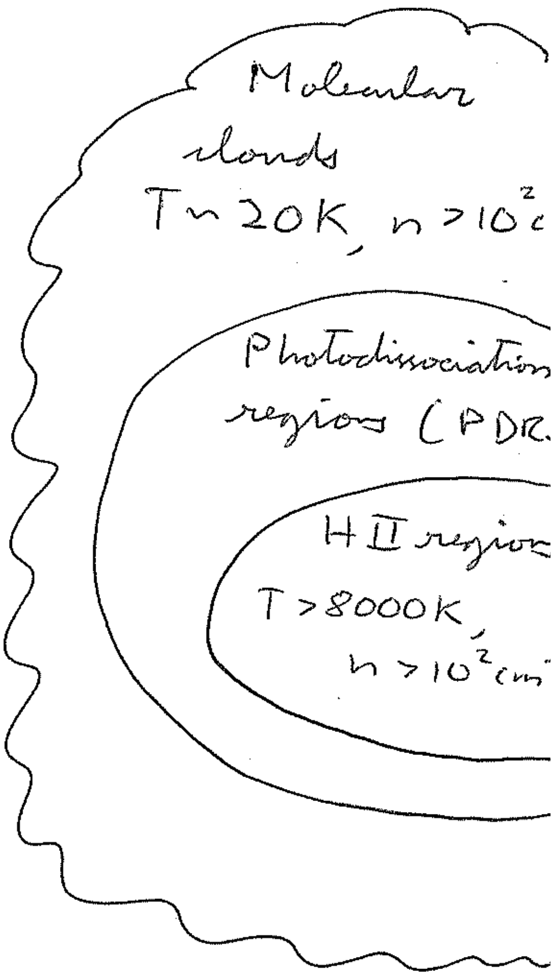
We have looked at dust and H II regions in the dense parts of the ISM. These are $<\sim 1\%$ of the ISM volume.

* Cold Neutral Medium (CNM)
  $T < 100K$, $n \sim 10\,cm^{-3}$.

* Warm Neutral Medium (WNM)
  $T \sim few \times 10^3 K$, $n \sim 0.5\,cm^{-3}$

* Warm Ionized Medium (WIM)
  $T \sim 8000K$, $n \sim 0.5\,cm^{-3}$

* Hot Coronal Gas
  $T \sim 10^6 - 10^8 K$, $n \sim 10^{-3}\,cm^{-3}$



Diffuse ISM - relative volume abundances and thermodynamics are not well understood.

Heating mechanisms? Cooling mechanisms?

* Diagnostics - CNM, WNM.

<u>Resonance transitions</u> of HI and metals involve allowed e-dipole transitions from ground states with electrons singly occupying s-orbitals.

e.g., HI [1s] 1216 Å

NaI [{$1s^2 2s^2 2p^6$} 3s] 5890, 5896 Å

(also Mg II)

Ca II [{$1s^2 2s^2 2p^6 3s^2 3p^6$} 4s] 3934, 3968

These lines are complicated to interpret!

The <u>HI 21cm line</u> is physically easier to understand.

Magnetic interaction between spins of e^- & p^+ in H-atom flip from aligned to misaligned emits photons at

$$\nu_{10} = 1420.405751 \text{ MHz}.$$

The spontaneous emission coefficient $A_{10} = \tau_{1/2}^{-1} \sim 3\times10^{-15}$ s^{-1}

half-life

Recall the definition of the critical density

$$n_{cr} = \frac{A}{q_{\downarrow}} \simeq \frac{A}{\sigma v}.$$

collision

2)

Taking $\sigma \sim (2r_B)^2 \sim 10^{-16}\ \mathrm{cm}^2$, and

$$v \sim \sqrt{\frac{kT}{m_H}} \sim \begin{array}{ll} 10^5\ \mathrm{cm\,s^{-1}}, & T \sim 100\,\mathrm{K} \\ 10^6\ \mathrm{cm\,s^{-1}}, & T \sim 10^4\,\mathrm{K}, \end{array}$$

we have $n_{cr} \sim 3\times10^{-4} - 3\times10^{-5}\ \mathrm{cm}^{-3}$.

This is low! Therefore, as $n > n_{cr}$, collisions dominate over line cooling in most Galactic regions, and LTE is maintained.

Define a spin (or excitation) temperature, T_S, as

$$\frac{n_1}{n_0} \equiv 3 \exp\left(-\frac{h\nu_{10}}{kT_S}\right).$$

The opacity on the line is $\rho\kappa \propto \frac{n_H}{T_S}$ (for $\frac{h\nu_{10}}{kT_S} \ll 1$), and so the column density

$$\eta_H = \int_0^d n_H(s)\, ds \propto \tau_H T_S.$$

Now, as $T_B = T(1-e^{-\tau}) \sim T\tau$, $\tau \ll 1$, $T_B \propto \eta_H$. In fact,

$$\frac{\eta_H}{\mathrm{cm}^{-2}} = 1.8\times10^{18} \int_0 T_B(\nu)\, d\nu.$$

But what about absorption?

$$\tau = \int_{LOS} \kappa \rho \, ds \propto \int_{LOS} ds \int_T \frac{d\rho}{dT} \frac{1}{T} dT .$$

is weighted in favor of colder gas. → CNM in absorption, WNM in emission.

* Diagnostics of WIM

We have already discussed $H\alpha$ emission from recombination

$$I_\nu (H\alpha) = \frac{h\nu}{4\pi} \int n_e n_{H+} \alpha \, ds .$$

Actually, α is slightly less than even Case B – empirical

Defining an Emission Measure (EM) as

$$EM = \int ds \, n_e^2 \quad (\text{units of pc cm}^{-6}),$$

$$I_\nu (H\alpha) = \frac{h\nu}{4\pi} \bar{\alpha} \, EM, \quad \alpha \sim 7.9 \times 10^{-14} T_4^{-1} \text{ cm}^3 \text{ s}^{-1},$$

$$T_4 = T / 10^4 \text{ K}.$$

Additionally, an EM wave traveling through a plasma has a velocity (group)

$$v = n c,$$ where n is the refraction ...

$$n = \sqrt{1 - \frac{\omega_{pe}^2}{\omega^2}}$$, where the plasma frequency

(cgs) $$\omega_{pe} = \sqrt{\frac{4\pi n_e e^2}{m_e}} = 9\sqrt{n_e} \text{ kHz}.$$

To first order in $\left(\frac{\omega_{pe}}{\omega}\right)^2$, the time delay at a given frequency is given by

$$\tau(\omega) = \frac{4\pi e^2}{2 m_e c \omega^2} \underbrace{\int_0^d n_e \, ds}_{\text{Dispersion Measure (DM)}}$$

Radio pulses from pulsars can be used to measure this!

$$\tau(\nu) = 4.15 \, DM \left(\frac{\nu}{GHz}\right)^{-2} \text{ ms},$$

DM in pc, cm^{-3}

How can DM be related to distance?