(LF)

Meeting 3

Velocities ← see also handout from Mtg #2

Galactic scale – spiral density wave pattern speed
e.g. Andromeda $\Omega_p = 18$ km/s/kpc (e.g. 180 km/s @ 10 kpc)

w/in ISM — 1 km/s = 1 pc in 10^6 yr

"thermal" (sound, isothermal) speed $= \sqrt{\frac{kT}{\mu}}$ — speed of sonic disturbances

	T = 10	100	1000	10,000 K
for $\mu = m_H$, c_s =	0.3	1 (remember)	3	10 km/s
$\mu = m_{avg}$ (molec cld), c_s =	0.2	0.7	2	7

Alfvén speed — speed of magnetic disturbances

$$V_A = \frac{B}{\sqrt{4\pi\rho}}$$

note if $B \propto \rho^{1/2}$ then V_A = constant

	atomic	molecular	molecular
	$B = 1\mu G$, $n = 1\ cm^{-3}$	$30\mu G$, $10^4\ cm^{-3}$	$1 mG$, $10^7\ cm^{-3}$
V_A =	2 km/s	0.4 km/s	0.5 km/s

(0.4 km/s: at least twice as big as c_s for 10 K)

General Notes on Ionization / Dissociation (T, n, $F(\nu)$)

- generally easier (req lower E $h\nu$) to dissociate a molecule than to ionize something
- the lower the electronic state you're trying to ionize, the more E (shorter λ) you need
- $E_{\text{Ionization of H from ground state}} = 13.6\,eV = \frac{hc}{912 Å}$ = "Lyman Limit"
- how is (ave) ionization state (and density & temperature) measured?

(More Next week — Intro for now —)

- Q. Mech tells us what ratios of certain lines should be for certain n, T, $F(\nu)$ conditions

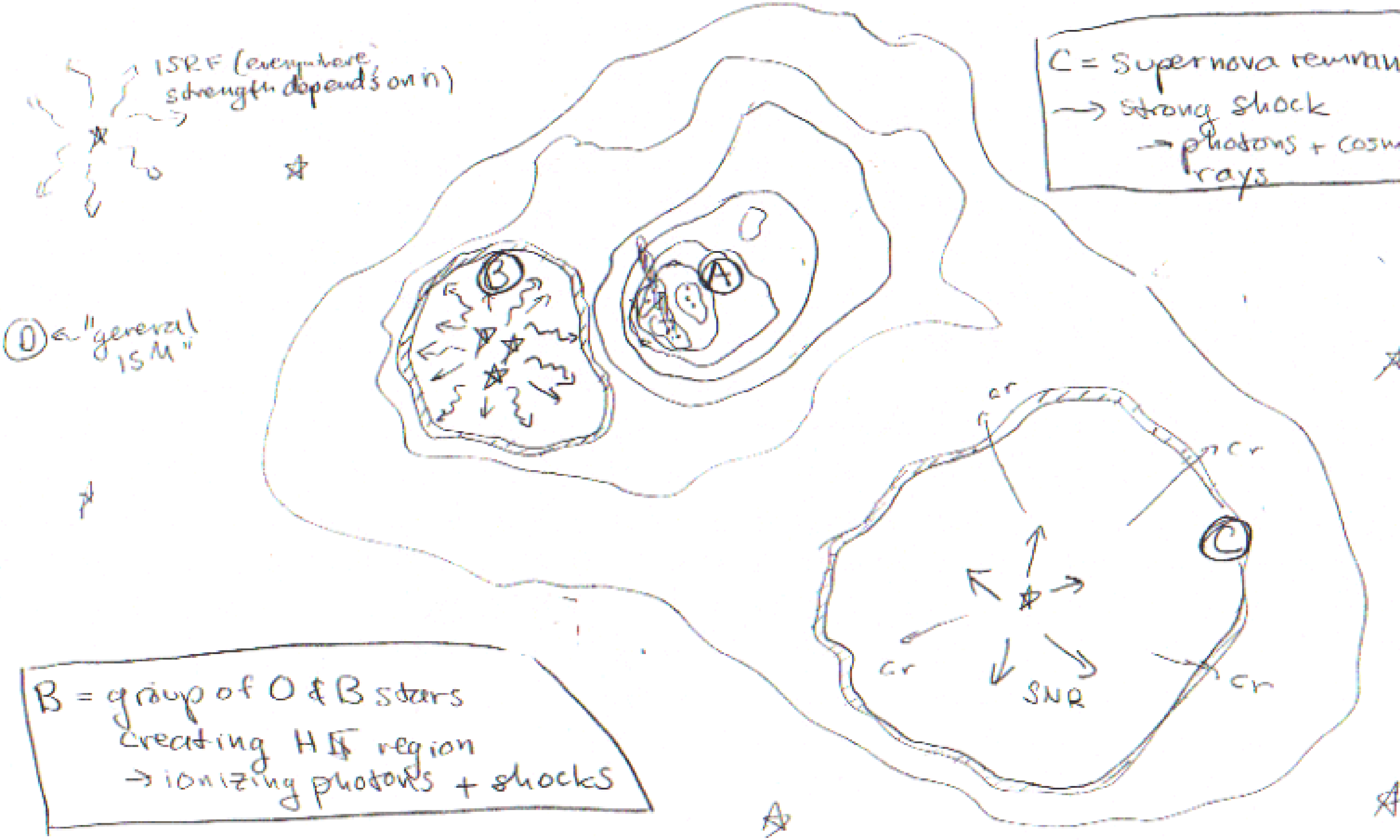
line ratios → n, T, n_i & sometimes $F(\nu)$

- continuum "SED" (spectral energy distribution) depends on n, T

($1'^2_c/d$) **Temperature & Ionization** (from last time)

A = very dense gas, possible site of ★-formation
possible outflows from young stars (shocks, heating)

C = Supernova remnant
→ strong shock
→ photons + cosmic rays



B = group of O & B stars
creating HII region
→ ionizing photons + shocks

In (A) Very Dense Region

$T \sim 10 - 50\,K$ {line ratios, etc}

- gas mostly molecular (T low, n high, no dissoc $h\nu$ or shocks)
- not much photoionization due to high extinction (but what if extinction "patchy")
- cosmic rays can get in and

$n_i \propto n_H^{1/2}$
so $x_i = \frac{n_i}{n_H + n_i} \propto n_H^{-1/2}$
↑ but n_i very small

$X_e \sim 10^{-6}$ to 10^{-7} (presumed $= X_i$)

other considerations:

- shocks due to impinging H II region (raise T, x_i?, n, chemistry)
- shocks due to embedded young stars w/outflows (localized changes in T, n, x_i, chemistry)
- time-evolution (what happens to chemistry?)

(See "Molecular Clouds" chart)

Note Idea of Photoionization-Regulated Star-Formation (McKee)

How long does a molecular cloud last?
(see 2h)

"Photon Dominated Region" (also "Photodissociation")

In (B) **H II Region** $7{,}000 \lesssim T_K \lesssim 10{,}000\,K$ } line ratios, etc.

- gas primarily ionized (but some neutral left), due to photons shortward of Lyman Limit $13.6\,eV = h\left(\frac{c}{912Å}\right)$ produced by O ★'s (& some B ★'s)

notes ① elements other than H have different ionization energy so will ionize more or less easily, (depending also on how ionized they already were... these elements have $>1\ e^-$!!)

② evidence that H II regions are clumpy (in many cases)
rms value of n_e (* note) from continuum radiation ← (avg'd over vol) is only ~ 1/6 of what's derived from line ratios ⟶ radiation is not produced in a filled volume... note: what is "filling factor" of ___ (in this case, ionized gas)

VERY IMPORTANT CONCEPT → $\text{filling factor} = \frac{\text{filled volume}}{\text{total volume}}$

③ dust present in H II regions (evidence scattered ★ light)
Smaller grains may be destroyed... study thermal emission SED

④ much free-free (e^- → ion, bremsstrahlung) radio emission, synchrotron, & recomb-line (e.g. H76α)

⑤ chemistry **very** dependent on time, n, T, flux

*For ref
n_e $1.6\times10^4\,cm^{-3}$ near Trapezium 2.6×10^2 3pc away

In (C) SNR

- gas can be ionized in shocks by collisions (high v required, to produce high-energy collisions, T)

e.g. if $v > 1000$ km s^{-1} $T > 10^6$ K

atom–electron collisions will
- ionize H & He,
- produce X-rays ← observed ✓
- produce highly ionized atoms of elements heavier than H, He ← observed in abs lines.

$\sqrt{\frac{kT}{\mu}} = \sqrt{\frac{1.38\times10^{-16}}{1.67\times10^{-24}}} \sim \sqrt{10^{8}} \sim 10^{4}$ → 100 km/s thermally

- gas is also excited (e.g. "shocked H_2" (vibrational) emission) and dissociated by shocks

In (D) UV photons from ISRF produce the "mean ionization"

best measure is n_e from Pulsar DM

Role of B-fields depends critically on x_i, n (B has no effect on neutrals, they need to collide w/ ions ∴ need to know $|B|$, n, x_i)