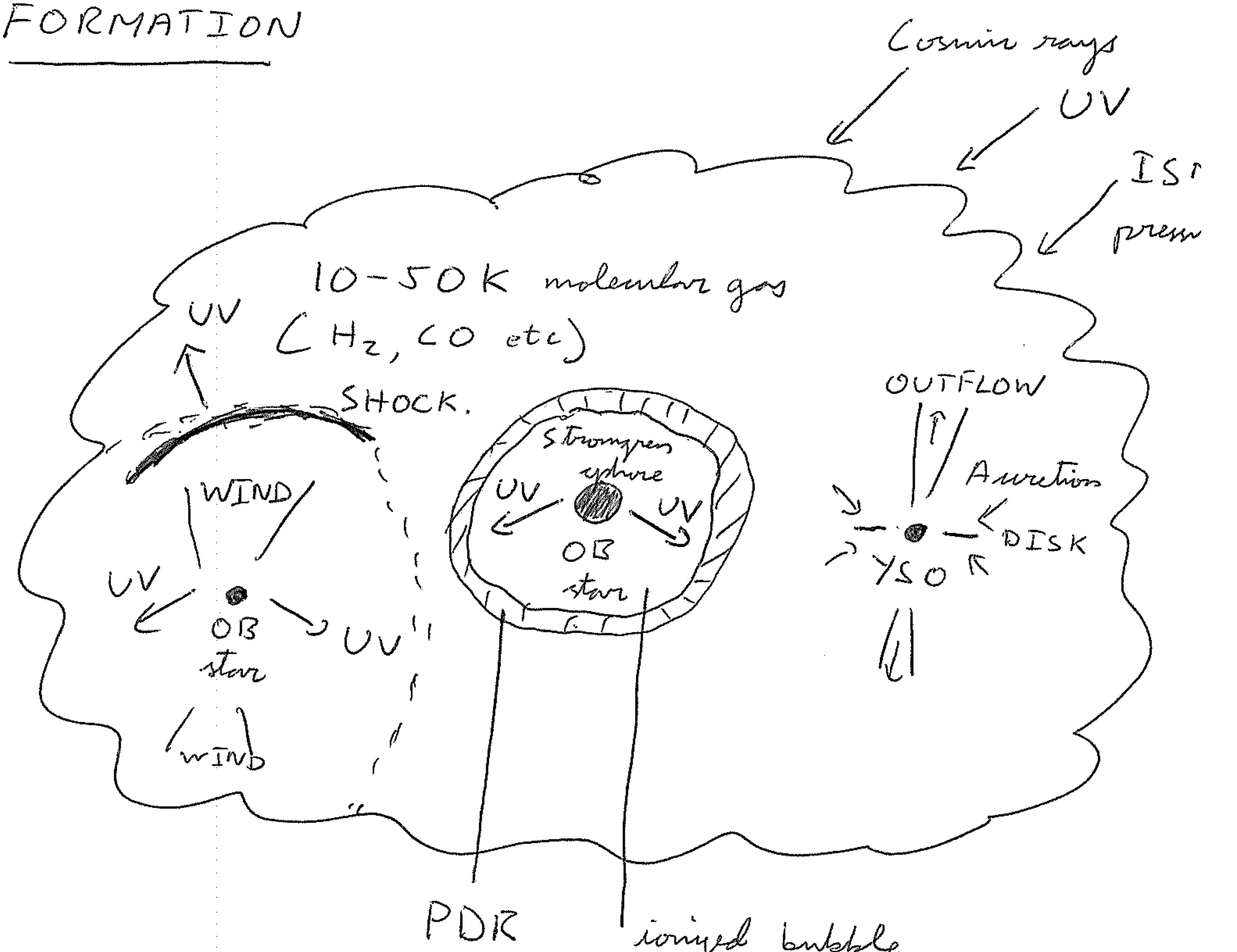
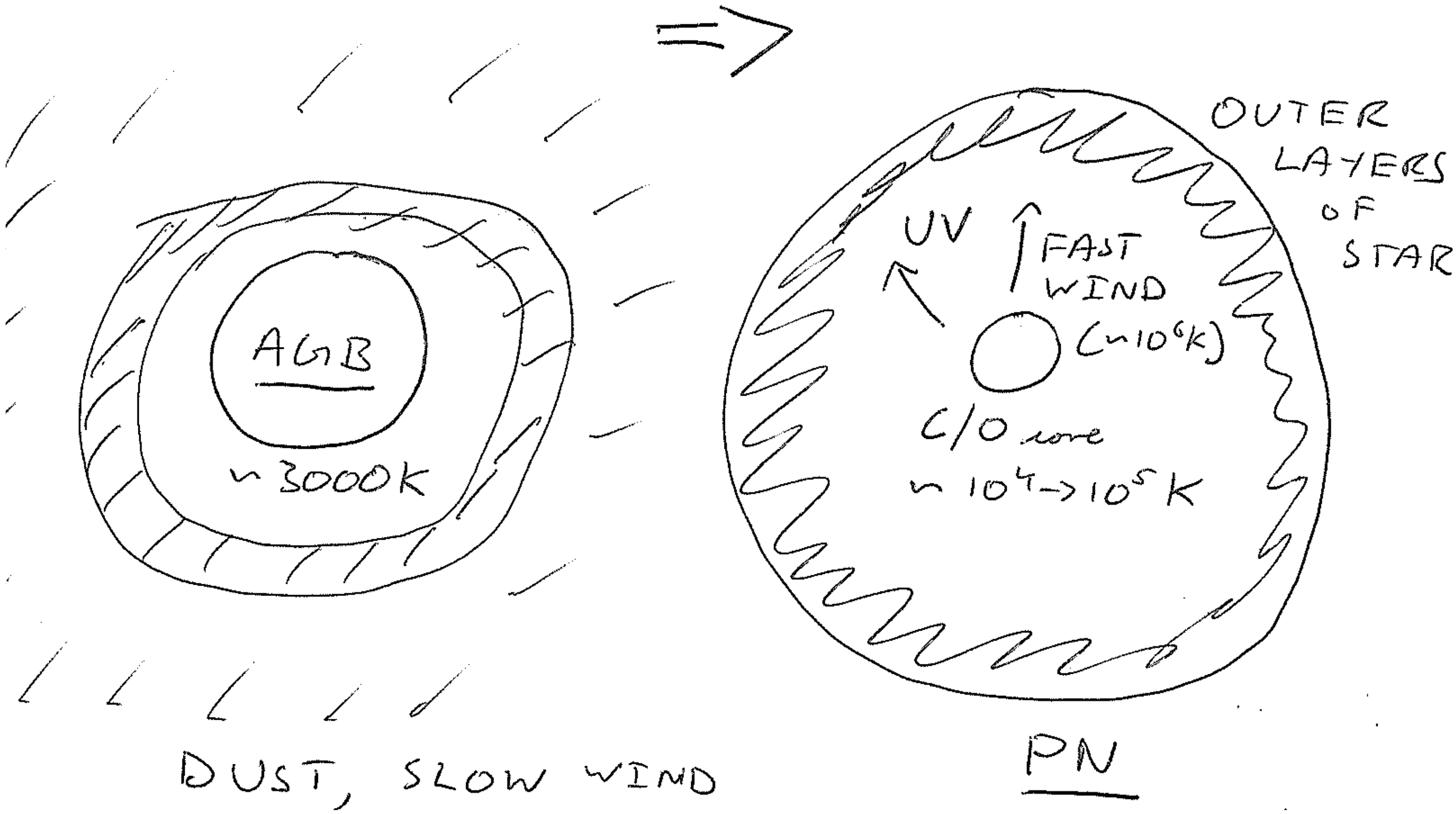
Ay 20 #19 - Revealing the ISM

The big picture: star formation out of (giant) molecular clouds → UV radiation, outflows (shocks) regulate star-formation → stellar evolution to giant (AGB, RSG, PNe) stages → winds & dust pollute ISM → supernovae → metal formation, dust formation, cosmic rays.

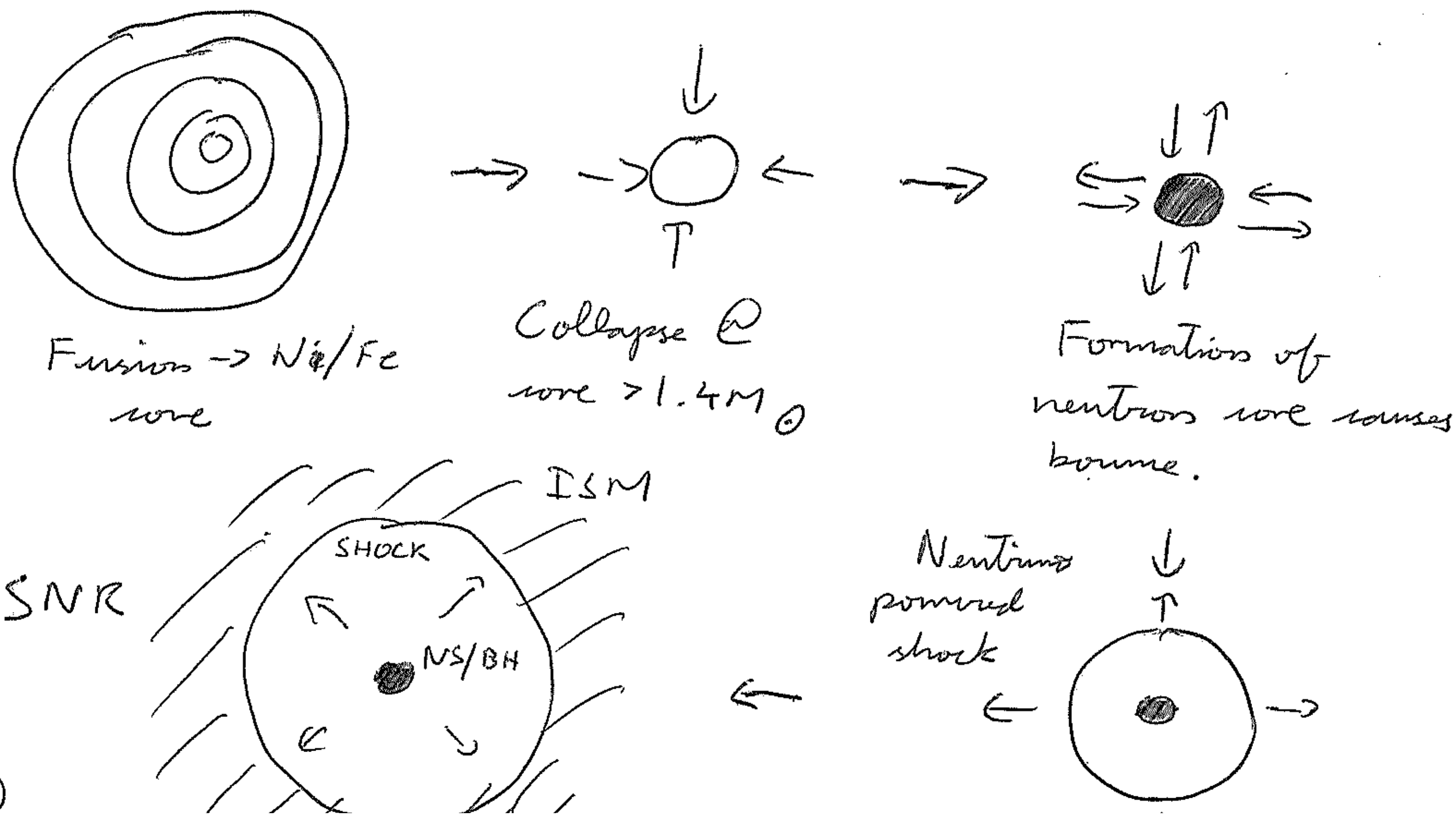
FORMATION



EVOLVED STARS



SUPERNOVAE



Questions

* How can the properties (structure, composition, radiation field) of star-forming regions be mapped to the formation of stars?

* How does radiation and winds from stars regulate the physical conditions in the ISM?

* How is the ISM chemically enriched by evolved stars and supernovae?

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* Dust and extinction.

Dust was first revealed through attenuation of light - extinction.

$A(V)$: V-band extinction in magnitudes

$A(\lambda)$: @ other band.

$E(B-V)$: $A(B) - A(V)$

$E(\lambda - V)$: $A(\lambda) - A(V)$

$$R_V = \frac{A(V)}{E(B-V)} = 3.1 \text{ (diffuse ISM)}$$

$= 4-6$ (GMCs)

How is $A(\lambda)$ related to $\tau(\lambda)$?

$$(A_\lambda = 1.086\, \tau_\lambda).$$

The dust density is commonly normalized to the (H - or H_2 -) gas density, with a dust to gas ratio of ~ 100.

$$\frac{A(\lambda)}{N_H} = 1.086 \int \frac{1}{n_H} \frac{d n_{gr}}{da} (\sigma_{abs} + \sigma_{sc})\, da$$

where a is the grain size.

Dust also emits !

- surface B-B radiation
- rotational & vibrational modes.
- spinning charged dust in magnetic fields.

* H II regions. (and other photo-ionized regions)

Consider a star radiating ionizing ($E > 13.6\,eV$) photons at a rate Q. The ionization fraction at a radius r is given by

$$\dot{\xi}(r) = \underbrace{-\alpha n_H \xi^2(r)}_{\text{recombinations}} + \underbrace{\frac{Q a(1-\xi(r))}{4\pi r^2} e^{-\tau(r)}}_{\text{ionizations}},$$

$$\tau(r) = \int_0^r n_H (1-\xi(r')) a \, dr' \quad , \quad a \text{ is ionization cross-section.}$$

α is recombination rate ($H^+ + e^- \rightarrow H + \gamma$).

- Case A: all states of H are counted ($\alpha_A = 4.2 \times 10^{-13} \, cm^3 s^{-1}$) @ 10^4 K
- Case B: if the final H is in the ground state, the γ can ionize another H-atom - don't count. ($\alpha_B = 2.6 \times 10^{-13} \, cm^3 s^{-1}$) @ 10^4

Define a radius r_s such that

$$\underbrace{\frac{4}{3}\pi r_s^3 \alpha_B n_H^2}_{\text{recomb rate @ full ionization}} = \underbrace{Q}_{\text{production of ionizing photons}}.$$

$$r_S = \left(\frac{3Q}{4\pi\alpha_B n_H^2}\right)^{1/3}$$ is the Stromgren radius of an H II region.

Consider $n_H \sim 10\ \mathrm{cm}^{-3}$, $Q \sim 10^{49}\ \mathrm{s}^{-1}$ for OB star, $r_S \sim 15$ pc.

Finally, after much pain,

$$\xi(u) = 1 - \frac{3u^2}{n_H r_S a (1-u^3)}, \quad u = \frac{r}{r_S}.$$

How is a derived?

Heating and cooling:

$$G_{pi} - L_{rec} = L_{ff} + L_{line}$$

$\alpha_B n_H^2 k T_\star$ heating rate.

recomb cooling

$\propto T^{1/2}$ (free-free)

i)

Line emission is affected by the balance between

radiative decay : $S_1 \rightarrow S_0 + \gamma$

collisions : $e^- + S_1 \leftrightarrow e^- + S_0$

If A is the radiative rate and $q_\downarrow$ is the downward collisional rate, we have a critical density

$$n_{cr} = \frac{A}{q_\downarrow} . \quad \begin{array}{l} n < n_{cr} : \text{radiation} \\ n > n_{cr} : \text{collisions.} \end{array}$$

The lines dominate cooling @ low (ish) densities and temperatures.