One zone model

$$E = E_0 \frac{R_0}{R} \phi(t)$$

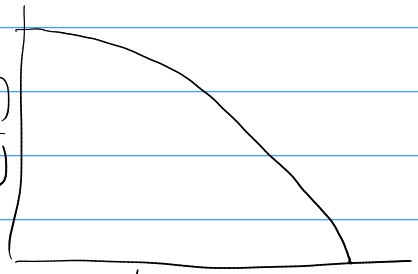
ad. exp → heating & cooling

Homology → internal structure stays the same

$$T^4(x,t) = T_0^4 \frac{R(0)}{R(t)} \phi(t) \psi(x)$$

$x = r/R$

$\frac{T(r/R)}{T_0(r/R)}$



for supernovae $\rho(r) \approx$ Const

$\kappa(r) \approx$ const (e.s.)

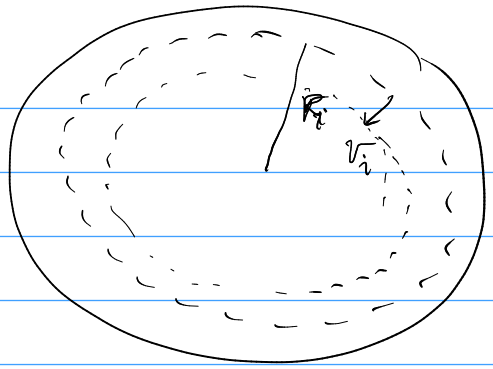
$l_{mfp} \ll R$

$$\psi(x) = \frac{\sin(\pi x)}{\pi x} \Big| x = r/R$$

$$E(t) = \int_0^R a (T(r,t))^4 4\pi r^2 dr = 4\pi R^3 a T_0^4(x) \underbrace{\int_0^1 \psi(x) x^2 dx}_{= \frac{1}{\pi^2}}$$

$$= E_0 \frac{R_0}{R} \phi(t)$$

Recombination



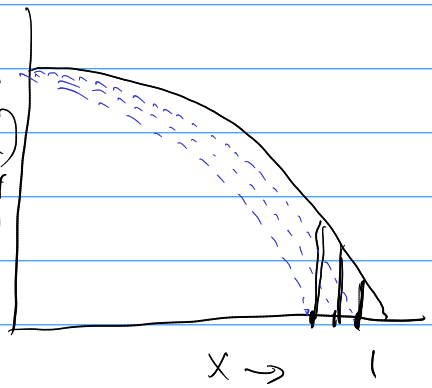
- photosphere at R_i
- release Rec. en.
- free radiation (advection)

$$L_{rec} = -4\pi R_{ion}^2 v_{ion} \rho Q_{ion} = -4\pi x_i^2 \dot{x}_i R^3 \rho Q \quad [\text{erg/g}]$$
$$= -3 x_i^2 \dot{x}_i M Q$$

FAST $\quad L_{adv} = -\dot{x}_i \frac{\partial E}{\partial x_i}$

$$E(x_i) = E_0 \frac{R_0}{R}\phi(t) \frac{\int_0^{x_i} \psi(x) x^2 dx}{\int_0^1 \psi(x) x^2 dx} \qquad x_i^2 \psi(x_i)$$
$$\approx \frac{1}{\pi^2}$$

$$L_{adv} = -x_i^2 \dot{x}_i \pi^2 \psi(x_i) E_0 \frac{R_0}{R}\phi(t) \left(\frac{T(x)}{T_{c0}}\right)^4$$



SLOW $\quad E(x_i) = E_0 \frac{R_0}{R}\phi(t) x_i^3$

$$L_{adv} = -\dot{x}_i 3 x_i^2 E_0 \frac{R_0}{R}\phi(t)$$

Diffusion

FAST: $\quad L = L_0 \phi(t) \frac{[-x^2 \partial\psi/\partial x]_{x=x_i}}{[-x^2 \partial\psi/\partial x]_{x=1}}$

SLOW $\quad L = \frac{E}{\tau_d} = \frac{E_0 \frac{R_0}{R}\phi(t) x_i^3}{\tau_{d0} \frac{R_0}{R} x_i^2} = L_0 \phi(t) x_i$ $\quad \leftarrow \tau_d \propto \frac{M}{R} \propto \frac{x_i^3}{x_i}$

Know $\quad L = 4\pi R_{ion}^2 \sigma T_{eff}^4 = 4\pi R^2 x_{ion}^2 \, 2\sigma T_{ion}^4$
$$\approx 2 T_{ion}^4 \quad (\tau = 2/3)$$

$$L = L_{diff} + \underbrace{L_{adv} + L_{rec}}_{\propto \dot{x}_i}$$

two coupled equations for $\dot{\phi}$ & $\dot{x}_i \Rightarrow \phi(t)$ & $x_i(t)$