RADIATION IN THERMODYNAMIC EQUILIBRIUM:

RAD. FIELD IS γ-ENSEMBLE

- DETERMINES SOURCE Fn, S_ν:

"STRICT" THERMODYNAMIC Eq. (TE):

- REQUIRES PERFECT HOMOGEITY, ISOTROPY & STASIS:

$$f(\vec{r}, \vec{l}, t) = f$$

- TE A GOOD APPROXIMATION IN STELLAR INTERIOR:

  - $dP/dr < 0$

  $\rightarrow$ ρ LARGE

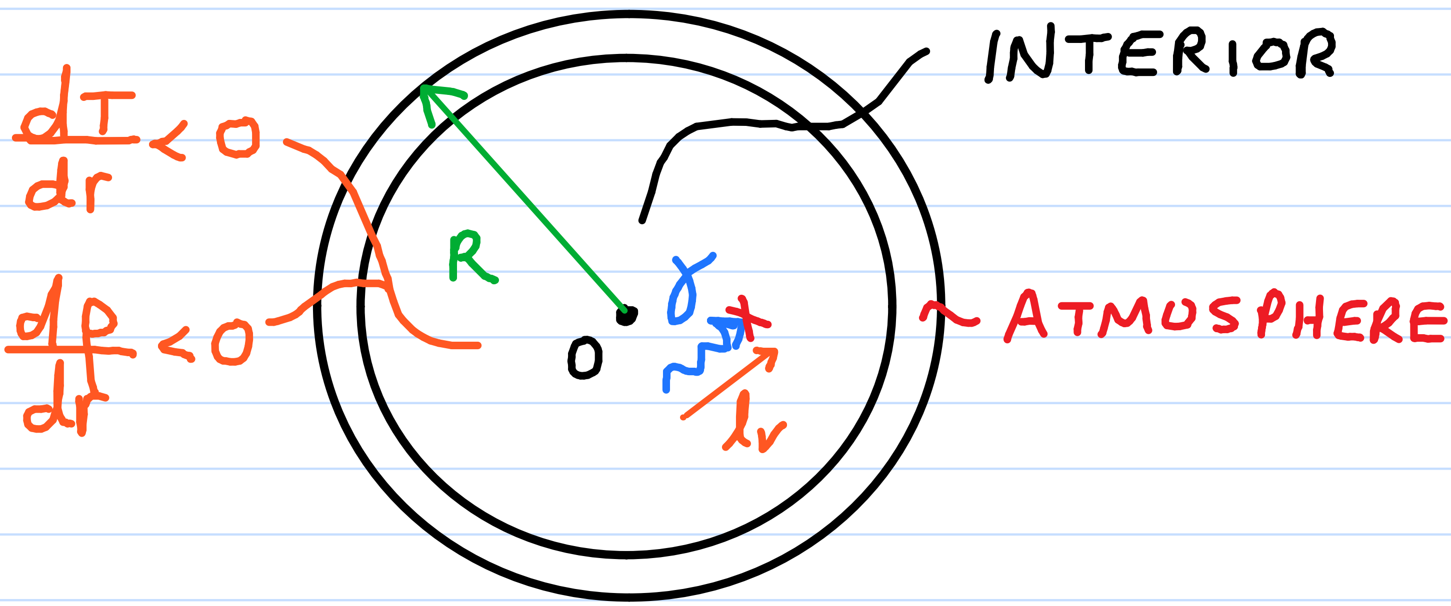
  $\rightarrow$ $K_\nu = \rho\,\alpha_\nu$ LARGE

  $\rightarrow$ $l_\nu \approx 1/\alpha_\nu \lll R$

  $\rightarrow$ FOR MEAN PHOTON (γ) FLIGHT:

$$\frac{\Delta T}{T} \approx \frac{l_\nu}{T}\frac{dT}{dr} \ll 1$$

$\therefore$ TE IS LOWER BOUNDARY CONDITION OF ATMOSPHERE



IN TE:

$$I_\nu(\tau_\nu, \mu) = B_\nu(\nu, T_{KIN}(\tau_\nu)) = \text{"} B_\nu(\tau_\nu) \text{"}$$

- $B_\nu(\nu, T_{RAD})$ = PLANCK fn
  - BLACKBODY (BB) SPECTRUM
  - T_{RAD} = RADIATION TEMPERATURE (K)
  - IN TE: $T_{RAD}(\tau_\nu) = T_{KIN}(\tau_\nu)$

ISOTROPY IN TE:

$$I_\nu(\tau_\nu, \mu) = J_\nu(\tau_\nu) = B_\nu(\tau_\nu)$$

AND:

$$S_\nu(\tau_\nu) = B_\nu(\tau_\nu)$$

$$\therefore \; I_\nu(\tau_\nu, \mu) = S_\nu(\tau_\nu), \text{ ALL } \mu$$

BUT S_ν NOT NEEDED! $\left(I_\nu(\tau_\nu, \mu) = B_\nu(\tau_\nu)\right)$

LOWER BOUNDARY CONDITION:

$\tau_\nu \to \infty$:

$$I_\nu(\tau_\nu, \mu) \to J_\nu(\tau_\nu)$$

$$J_\nu(\tau_\nu) \to B_\nu(\tau_\nu)$$

$$\left(S_\nu(\tau_\nu) \to B_\nu(\tau_\nu)\right)$$

PLANCK fn:

$$B_\nu(\nu, T_{RAD}) = \frac{2h\nu^3}{c^2}\frac{1}{e^{h\nu/kT_{RAD}} - 1}$$

(erg/s/cm^2/STER/Hz)

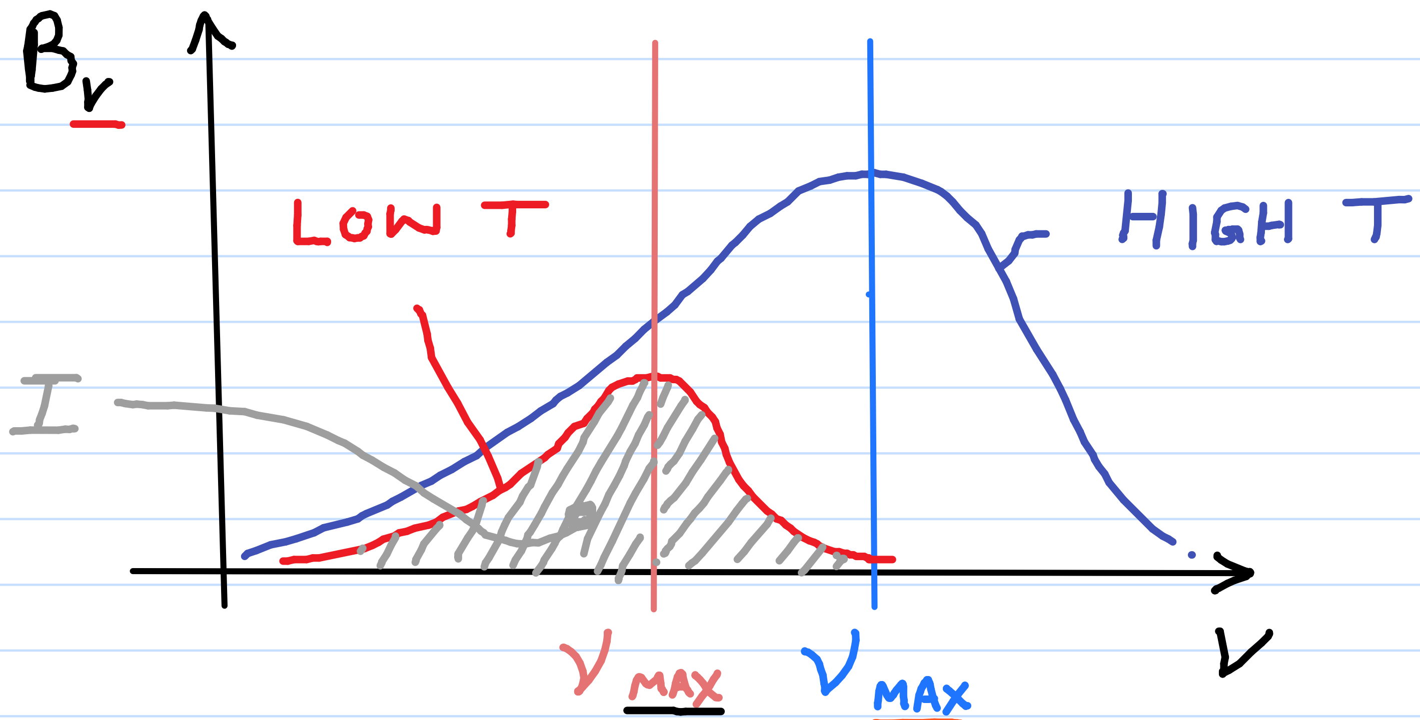
- RECALL: IN TE: $T_{RAD}(\vec{r}) = T_{KIN}(\vec{r})$

- BOLTZMANN FACTOR: $e^{-h\nu/kT}$

  → $h\nu$ = γ-ENERGY

  kT_{KIN} = THERMAL E

$$B_\nu(\nu, T_{RAD}) = \frac{2h\nu^3}{c^2} \frac{1}{e^{h\nu/kT_{RAD}} - 1} \quad :$$



IN TE:

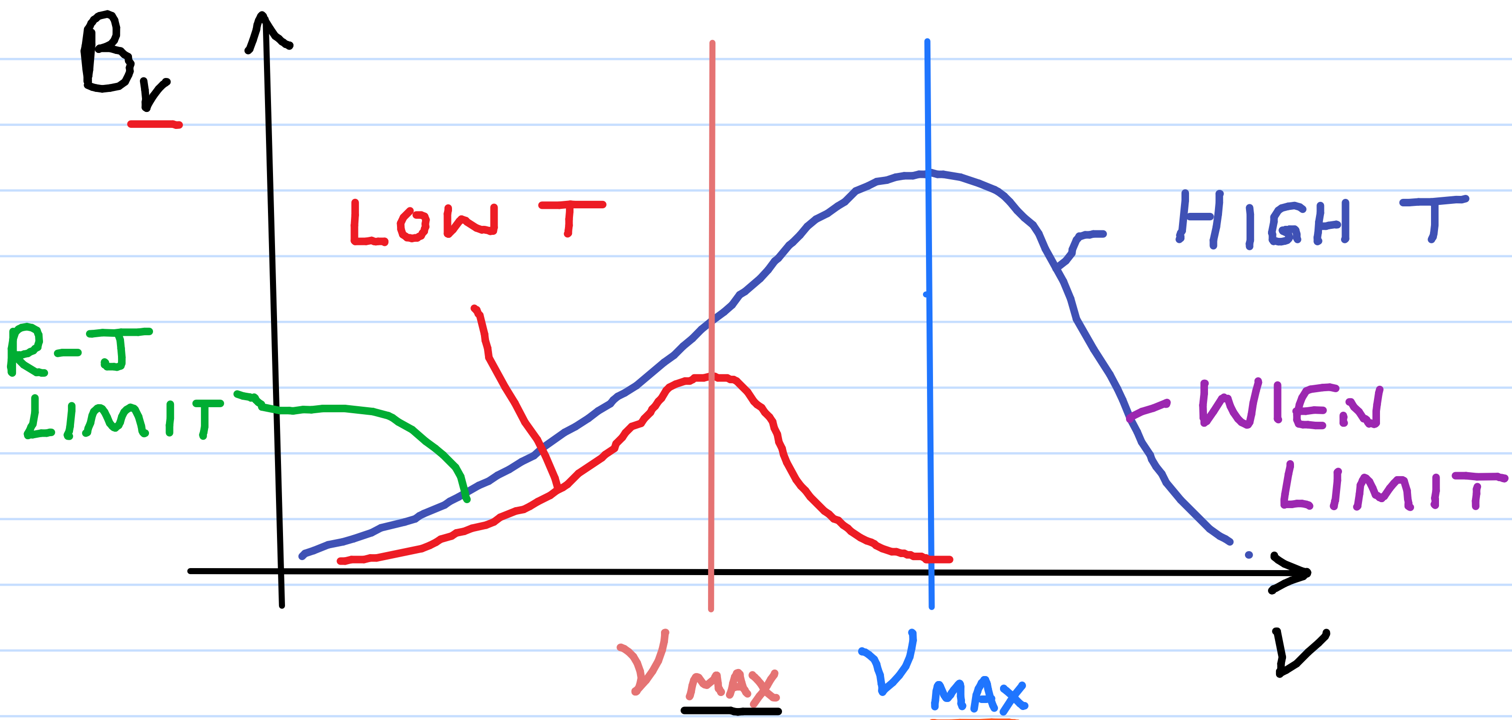
$$I = J = \int_{\nu=0}^{\infty} B_\nu \, d\nu = \frac{\sigma}{\pi} T_{RAD}^4$$

– STEFAN – BOLTZMANN LAW

WIEN LAW FOR B_ν:

$$\lambda_{MAX} = \frac{c}{\nu_{MAX}} = \frac{0.50995 \text{ cm} \cdot \text{K}}{T_{RAD}}$$

$$B_\nu(\nu, T_{RAD}) = \frac{2h\nu^3}{c^2} \frac{1}{e^{h\nu/kT_{RAD}} - 1} \quad :$$



RAYLEIGH-JEANS (R-J) LIMIT: $h\nu/kT \ll 1$:

$$B_\nu \approx \frac{2kT\nu^2}{c^2}$$

WIEN LIMIT: $h\nu/kT \gg 1$:

$$B_\nu \approx \frac{2h\nu^3}{c^2} e^{-h\nu/kT}$$

PLANCK fn, B_{λ}

(erg/s/cm²/STER/nm)

$$B_{\lambda}(\nu, T) = \frac{2hc^2}{\lambda^5} \frac{1}{e^{hc/\lambda kT} - 1}$$

WIEN LAW FOR B_{λ}:

$$\lambda_{MAX} = \frac{0.28978 \text{ cm} \cdot \text{K}}{T_{RAD}}$$

Eg. SUN:

ADOPT $T_{RAD} = T_{eff} \approx 5800$ K

B_{λ} $\lambda_{MAX} = 550$ nm

B_{ν} $\lambda_{MAX} = 880$ nm (IR)

LOCAL THERMODYNAMIC EQUILIBRIUM (LTE):

- BETTER APPROXIMATION IN ATMOSPHERE:

  - $dP/dr < 0$

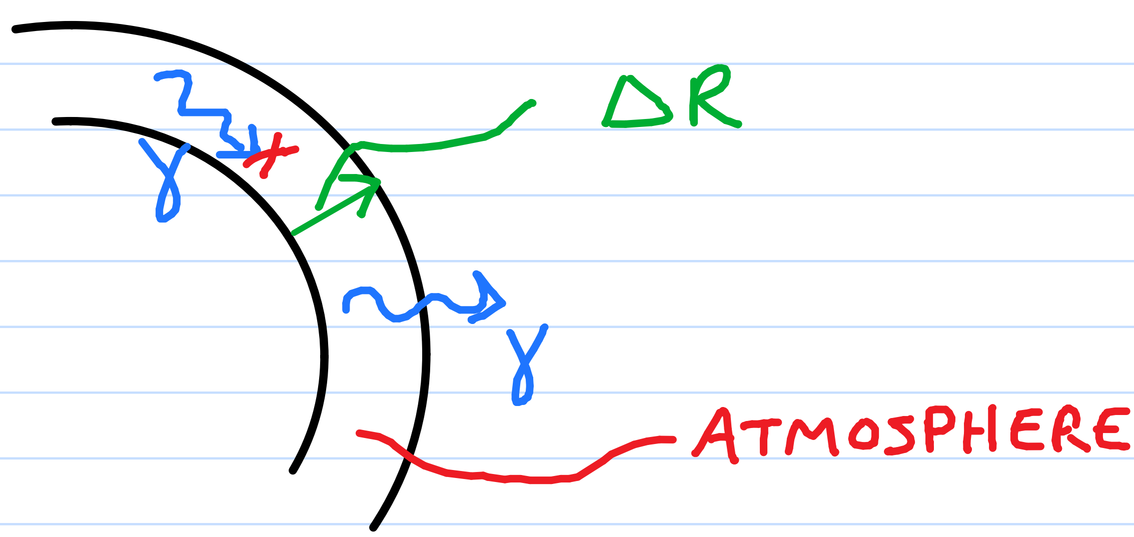
$\rightarrow \rho$ SMALL

$\rightarrow K_\nu = \rho \alpha_\nu$ SMALL

$\rightarrow l_\nu \approx 1/\alpha_\nu \lesssim \Delta R$

$\rightarrow$ FOR MEAN PHOTON (γ) FLIGHT:

$$\frac{\Delta T}{T} \approx \frac{l_\nu}{T}\frac{dT}{dr} \approx \mathcal{O}(1)$$



IN LTE:

ASSUME:

$$S_\nu(\tau_\nu) = B_\nu\left(T_{KIN}(\tau_\nu)\right) = \text{“}B_\nu(\tau_\nu)\text{”}$$

- ONLY EXACT AT $\tau_\nu \to \infty$

$\therefore$ NEED RAD. TRANS. Eq. TO FIND I_ν

Eq. IN LTE:

$$J_\nu(\tau_\nu) = \Lambda_\tau\left[S_\nu(\tau_\nu)\right] = \Lambda_\tau\left[B_\nu(\tau_\nu)\right]$$

TEMPERATURE OUT OF TE:

$$I_\nu(\tau_\nu, \mu) \neq B_\nu\left(T_{KIN}(\tau_\nu)\right)$$

BUT, ALWAYS:

$$I_\nu(\tau_\nu, \mu, \nu) \equiv B_\nu\left(\nu, T_{RAD}(\tau_\nu, \nu)\right)$$

- FOR SOME T_{RAD} VALUE

GENERALLY: $T_{RAD}(\tau_\nu, \nu) \neq T_{KIN}(\tau_\nu)$

DEPARTURE FROM T.E., ΔT:

$$\Delta T(\tau_\nu, \nu) = T_{RAD}(\tau_\nu, \nu) - T_{KIN}(\tau_\nu)$$