EMISSIVITY & EXTINCTION COEFFICIENTS: α_ν & j_ν:

2) b-f & f-f TRANSITIONS

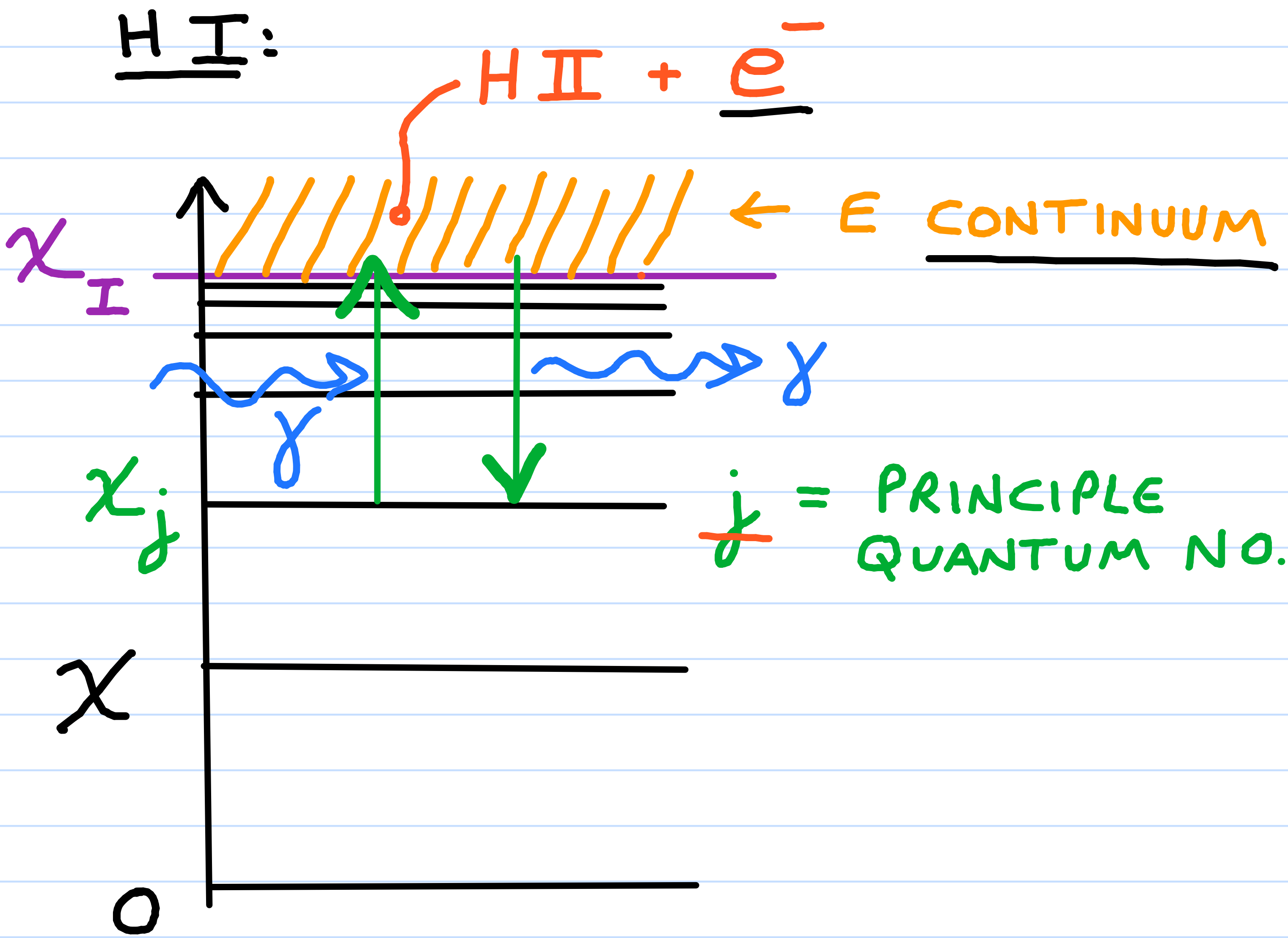
MONOCHROMATIC VOLUME EXTINCTION COEFFICIENT, α_ν^c (cm^{-1})

- DOMINATED BY H IN EXTENDED VISIBLE BAND IN MOST STARS

- Ref: D. F. GRAY

RADIATIVE b-f TRANSITIONS:

- PHOTO-IONIZATION
- PHOTO-RECOMBINATION



E - CONSERVATION:

$$\frac{1}{2} m_e v_e^2 = h\nu - (\chi_I - \chi_j)$$

THRESHOLD (b-f EDGE, JUMP)

FOR LEVEL j, $\nu_{0,j}$:

$\nu_e = 0$

$\therefore h\nu_{0,j} = (\chi_I - \chi_j)$

FROM LEVEL j:

$\alpha^c_{\nu,b\text{-}f}(\nu) > 0$ FOR $\nu \geq \nu_{0,j}$

FOR HYDROGENIC SPECIES:

- RYDBERG-LIKE E-LEVELS
- PRINCIPLE QUANTUM NO., j

eg. HI, Na I, Mg II, KI, Ca II, ...

FOR TRANS. $j \rightarrow$ CONTINUUM:

$$\sigma_{\nu, b\text{-}f}(\nu) \approx \begin{cases} G \dfrac{Z^4}{j^5 \nu^3} g_{b\text{-}f}, & \nu \geq \nu_{0,j} \\ 0, & \nu < \nu_{0,j} \end{cases} \quad (\text{cm}^2)$$

$G = 2.815 \times 10^{29}$

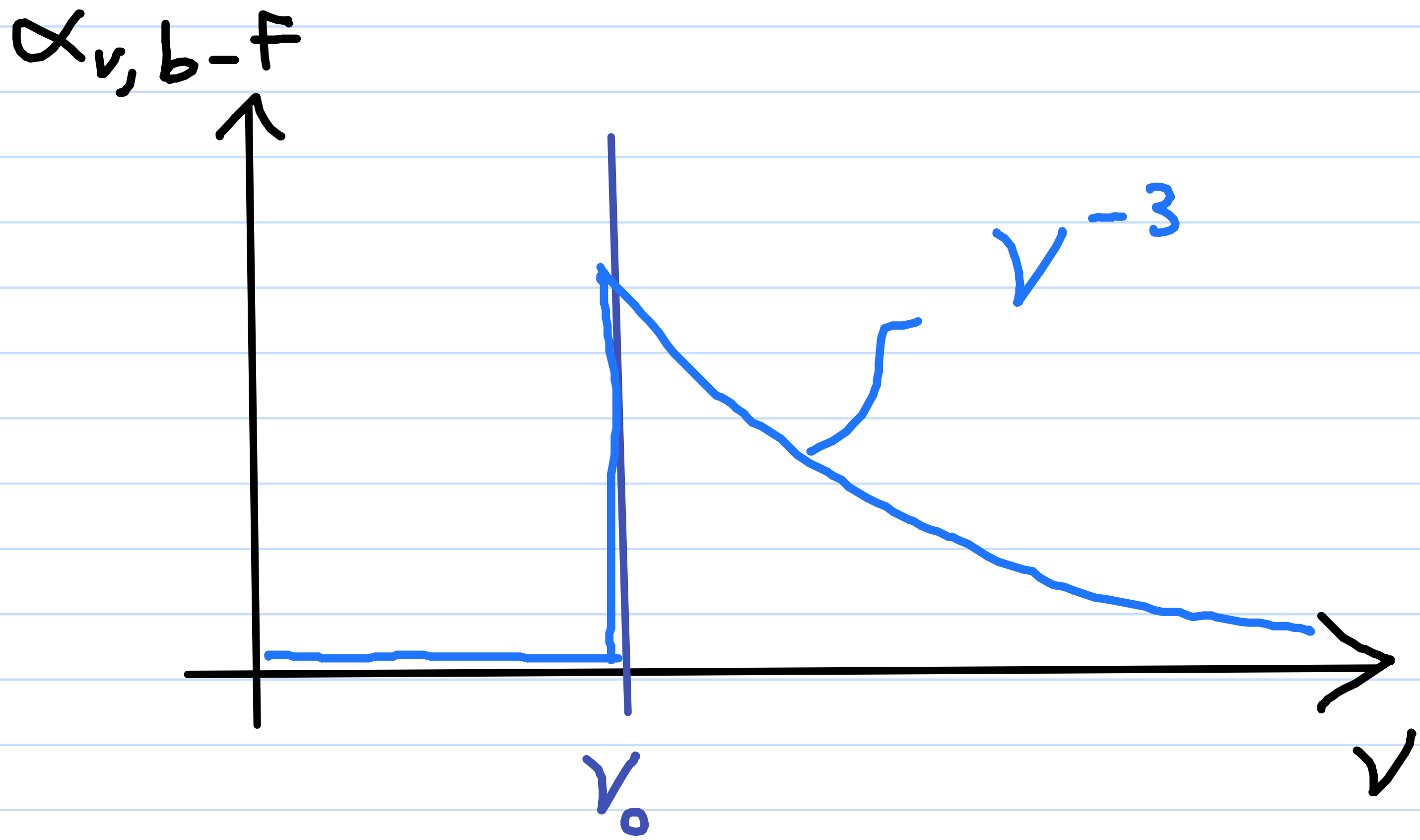
Z = CHARGE AFTER IONIZATION (CHARGE UNITS)

$g_{b\text{-}f}$ = b-f GAUNT FACTOR $(\mathcal{O}(1))$

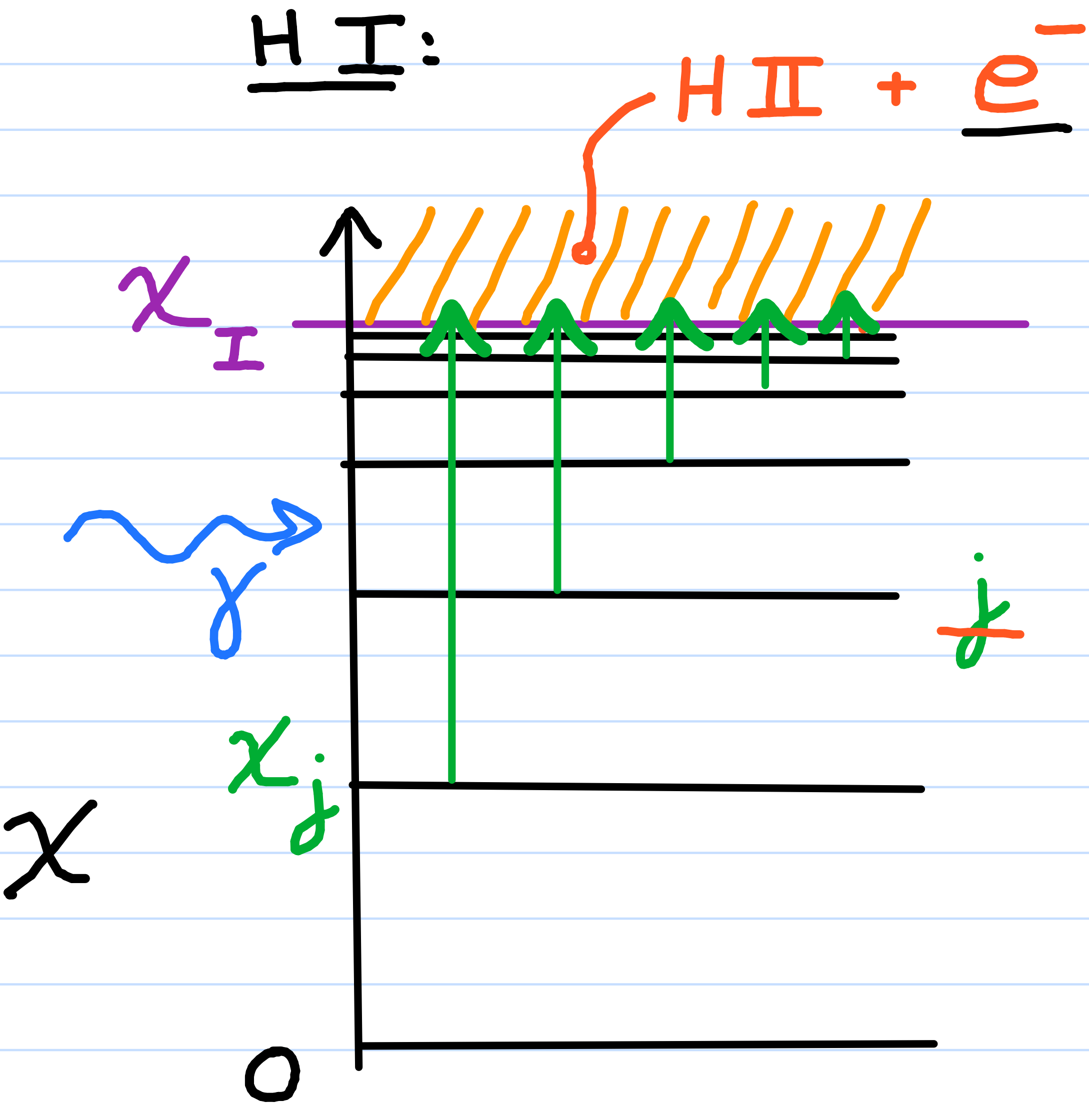
FOR TRANS. $j \rightarrow$ CONTINUUM:

$$\alpha^{c}_{\nu,b\text{-}f}(\nu) \approx n_j \, \sigma_{\nu,b\text{-}f}(\nu)\left(1 - e^{-h\nu/kT_{KIN}}\right), \quad \nu \geq \nu_{0,j} \quad (\text{cm}^{-1})$$

$\rightarrow \left(1 - e^{-h\nu/kT_{KIN}}\right)$ = LTE STIM. EM. CORRECTION



TOTAL $\alpha_{\nu, b\text{-}f}$ FROM HI AT $\nu \gtrsim \nu_{0,j}$:



$$\alpha_{\nu, b\text{-}f} = \sum_{i \geq j}^{L} n_i \, \sigma_{\nu, b\text{-}f}(i) \left(1 - e^{-h\nu/kT}\right)$$

MAJOR HI b-f FEATURES :

1) PASCHEN JUMP : $j = 3 \to$ CONT.

$\chi_3 = 12.1$ eV

$\therefore h\nu_{0,3} = (\chi_I - \chi_3) = (13.6 - 12.1)$ eV

$\therefore \lambda_{0,3} = c/\nu_0 = 820$ nm

2) BALMER JUMP : $j = 2 \to$ CONT.

$\chi_2 = 10.2$ eV

$\therefore h\nu_{0,2} = (13.6 - 10.2)$ eV

$\therefore \lambda_{0,2} = 364$ nm

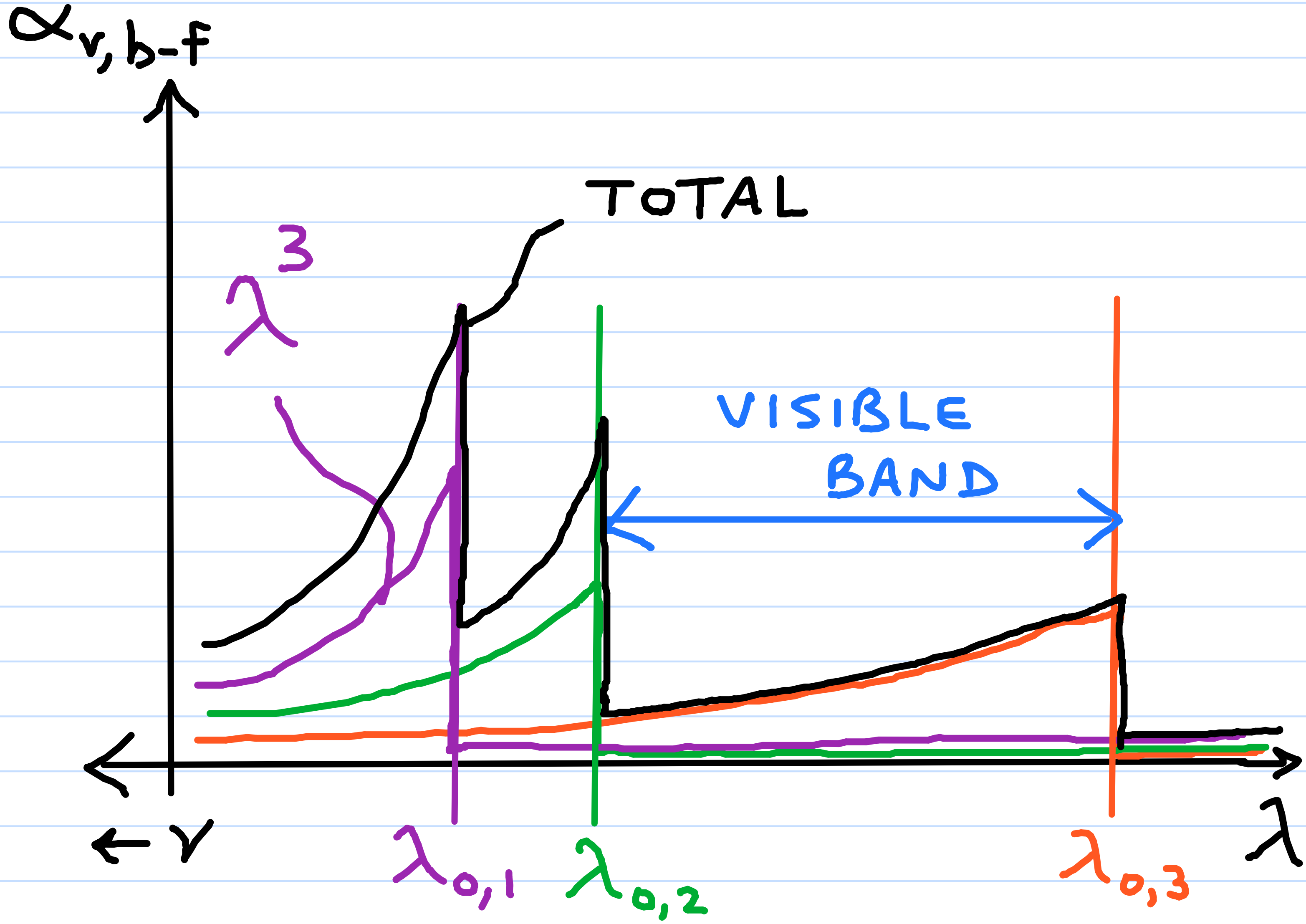
3) LYMAN JUMP : $j = 1 \to$ CONT.

$\chi_1 = 0.0$ eV

$\therefore h\nu_{0,1} = (13.6 - 0.0)$ eV

$\therefore \lambda_{0,1} = 91.1$ nm

MAJOR HI b-f FEATURES :



MAJOR HI b-f FEATURES:

RECALL:

LTE E-B RELATION:

$$I_\nu(\tau_\nu=0,\nu) \approx B_\nu(T_{KIN}(\tau_\nu(\nu)=1))$$

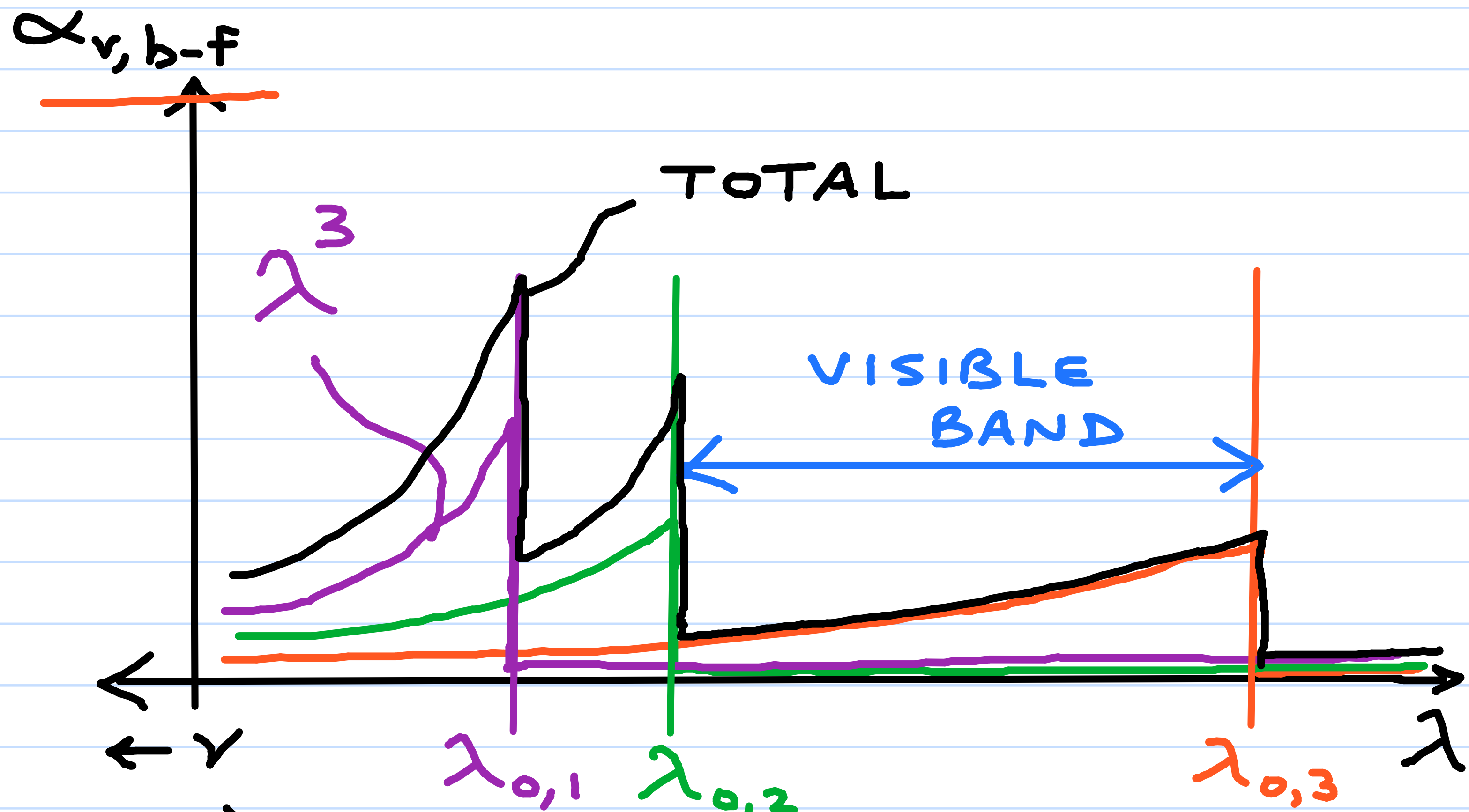
ACROSS A B-F EDGE (JUMP), ν_0:

$$\alpha_\nu(\nu \gtrsim \nu_0) > \alpha_\nu(\nu \lesssim \nu_0)$$

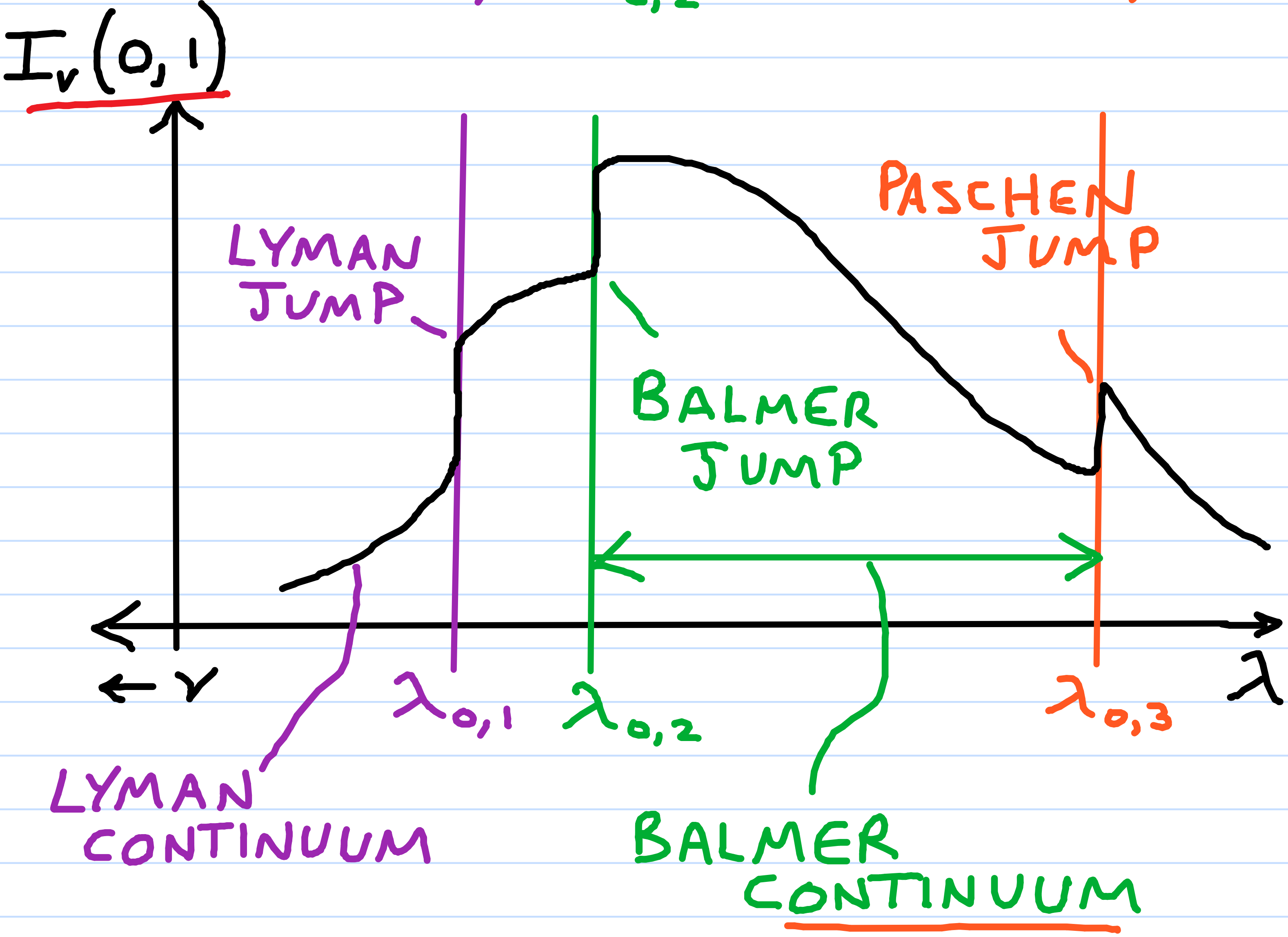
$$\therefore\ z(\tau_\nu(\nu \gtrsim \nu_0)=1) < z(\tau_\nu(\nu \lesssim \nu_0)=1)$$

$$\therefore\ T_{KIN}(\tau_\nu(\nu \gtrsim \nu_0)=1) < T_{KIN}(\nu \lesssim \nu_0)=1)$$

$$\therefore\ I_\nu(0,\nu \gtrsim \nu_0) < I_\nu(0,\nu \lesssim \nu_0)$$



α ν, b-f
TOTAL
λ3
VISIBLE BAND
← ν
λ0,1
λ0,2
λ0,3
λ



Iν(0,1)
PASCHEN JUMP
LYMAN JUMP
BALMER JUMP
← ν
λ0,1
λ0,2
λ0,3
λ
LYMAN CONTINUUM
BALMER CONTINUUM

SIGNIFICANCE:

H I b-f DOMINANT EXTINCTION SOURCE IN EXTENDED VISIBLE BAND OF B, A STARS:

BALMER CONT.: $j=2 \rightarrow$ CONT.

HI: $\chi_I = 13.6$ eV ; $\chi_2 = 10.2$ eV

FOR $8000 < T_{KIN} < 20{,}000$ K:

→ SAHA DIST.:

$$\frac{N_{HII}}{N_{HI}} \approx C\, T^{3/2} e^{-\chi_I/kT} \approx \mathcal{O}(1)$$

→ BOLTZMANN DIST.:

$$\frac{n_{j=2}}{n_{j=1}} = C\, e^{-\chi_2/kT} > 0$$

"H-MINUS" (H^-) b-f:

H^- : $\chi_I = 0.77$ eV

FOR $T_{KIN} < 8000$ K :

$$H^- + \gamma \rightleftarrows HI + e^-$$

- FREE e^-s FROM e^- DONORS

$\therefore$ $[H^-]$ DEPENDS ON $\left[\frac{A_Z}{H}\right]$

$$\lambda_o = \frac{hc}{\chi_I} = 1644 \text{ nm} = 1.64 \ \mu m$$ - NIR

SAHA:

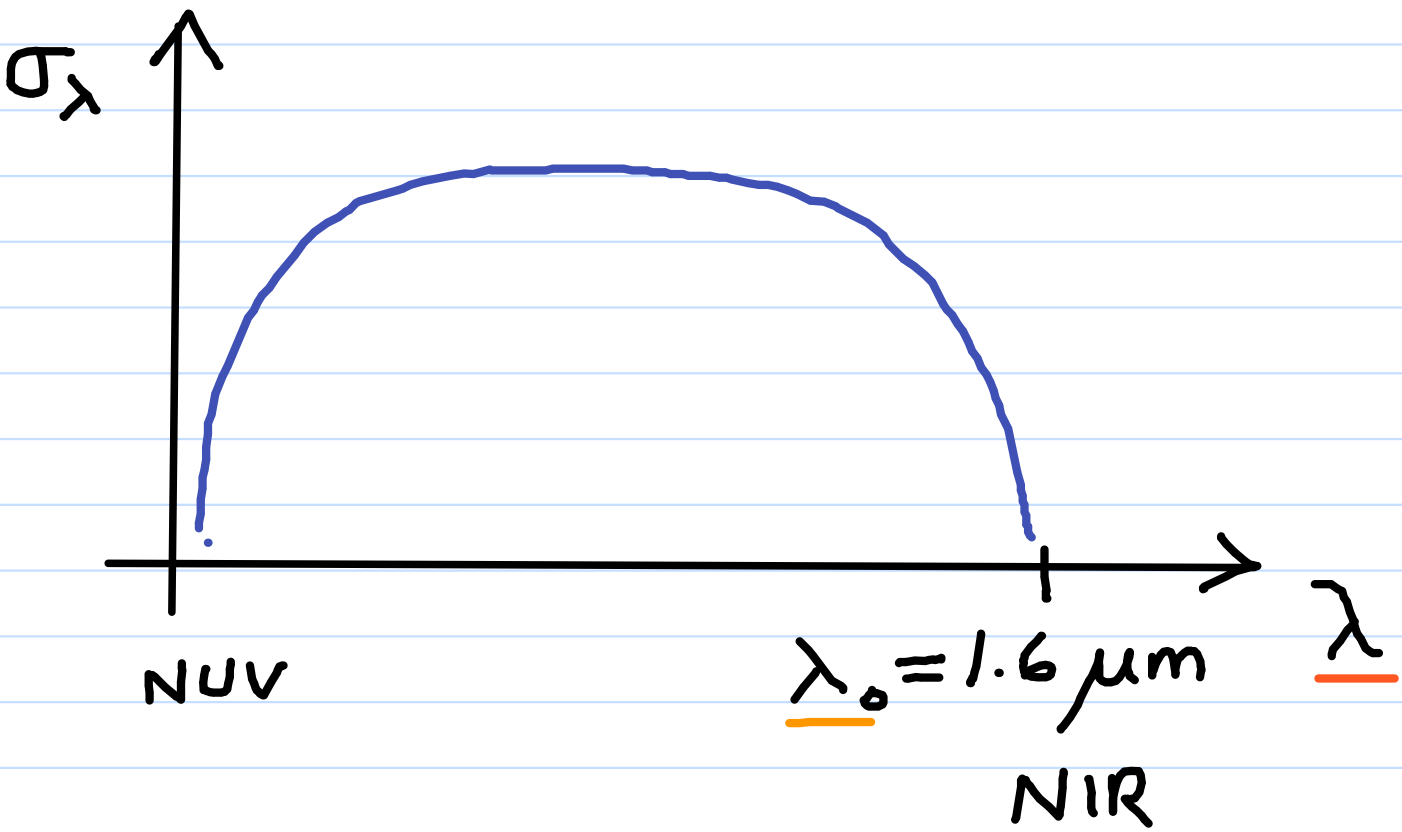
$$\frac{N_{HI}}{N_{H^-}} = \frac{2}{N_e} \frac{U_{HI}}{U_{H^-}} G T^{3/2} e^{-\chi_{I,H^-}/kT}$$

NON- HYDROGENIC:

PARAMETERIZED EMPIRICAL FIT:

$$H^- \text{ b-f}: \quad \sigma_\lambda(\lambda) \approx \sum_{k=0}^{6} a_k \lambda^k \qquad (\text{cm}^2)$$

$$\therefore \quad \alpha_\lambda \approx n_{H^-} \sigma_\lambda \left(1 - e^{-h\nu/kT}\right) \qquad (\text{cm}^{-1})$$



H^- b-f IS DOMINANT EXTINCTION SOURCE IN EXTENDED VISIBLE BAND IN GK STARS

$\therefore$ $z(\tau_\nu^c = 1)$ SMALLEST IN SOLAR ATMOSPHERE AT $\sim 1.6\ \mu m$

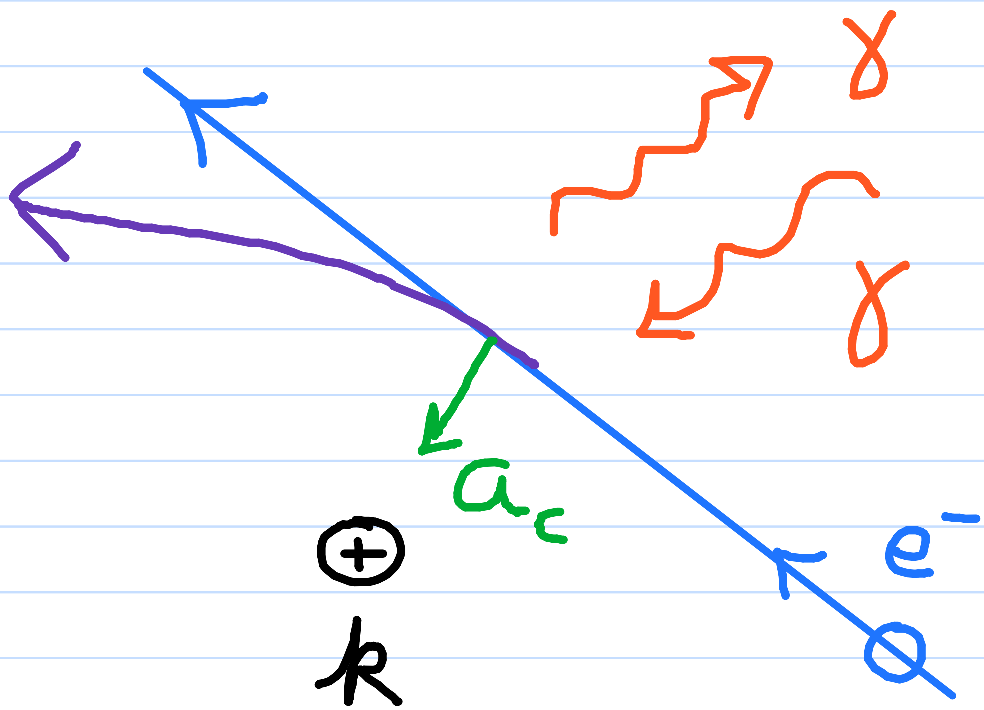
- He I & He^- b-f OF MINOR IMPORTANCE IN OB STARS

FREE-FREE (f-f) TRANSITIONS

BREMSTRAHLUNG
BRAKING RADIATION

k^- f-f:

$$k + e^- \rightleftharpoons e^- + k$$



α_ν^c IF $\Delta KE > 0$

j_ν^c IF $\Delta KE < 0$

Eg. HI f-f EXTINCTION:

$$HII + e^- + \gamma \longrightarrow e^- + HII + KE$$

- B, A, F STARS

Eg. H^- f-f EXTINCTION

$$HI + e^- + \gamma \longrightarrow e^- + HI + KE$$

- G, K STARS

HeI & He^- f-f OF MINOR IMPORTANCE IN OB STARS

FOR HYDROGENIC SPECIES:

$$\text{f-f}: \sigma_\nu \approx G \frac{N_e Z^2}{T_{KIN}^{1/2} \nu^3} g_{f\text{-}f} \quad (cm^2)$$

- $G = 3.7 \times 10^8$
- Z = CHARGE OF k
- $g_{f\text{-}f}$ = f-f GAUNT FACTOR

$$\therefore \alpha_\nu = N_k \sigma_\nu \left(1 - e^{-h\nu/kT}\right) \quad (cm^{-1})$$

SCATTERING PROCESSES:

THOMSON SCATTERING:

$$\gamma + e^- \rightarrow e^- + \gamma$$

NON-RELATIVISTIC LIMIT:

THOMSON CROSS-SECTION:

$$\sigma_\nu = \frac{8\pi}{3} r_e^2 \neq f(\nu) \quad (\text{cm}^2)$$

- GRAY OPACITY SOURCE

$$\alpha_\nu = N_e \sigma_\nu \quad (\text{cm}^{-1})$$

MOST IMPORTANT IN O STARS

- LARGE N_e

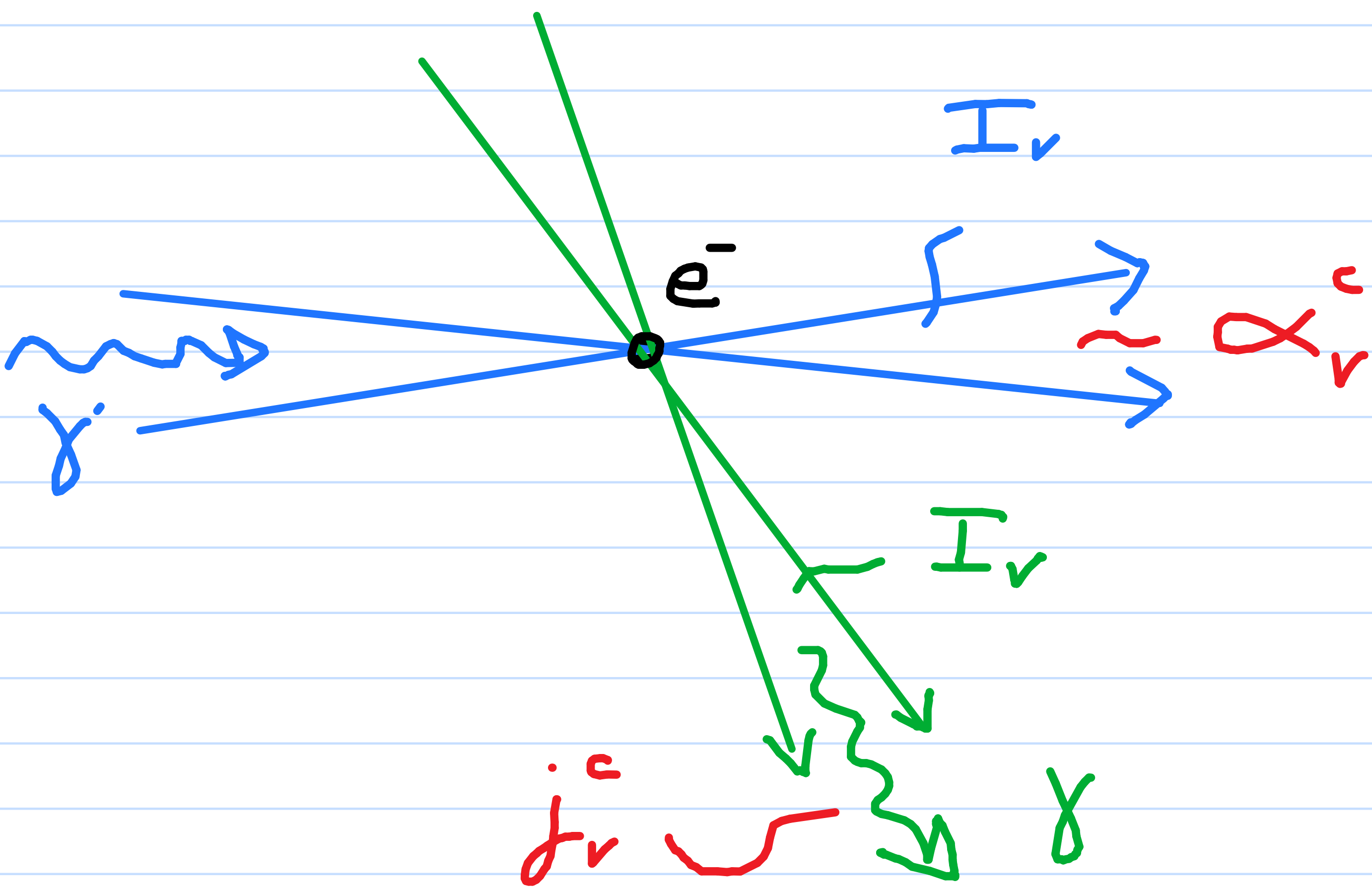
RAYLEIGH SCATTERING:

$$\gamma + k \rightarrow k + \gamma$$

k = HI, He I

-MINOR IMPORTANCE

SCATTERING GENERALLY:



TOTAL α_ν AT FREQ. ν IN VISIBLE BAND:

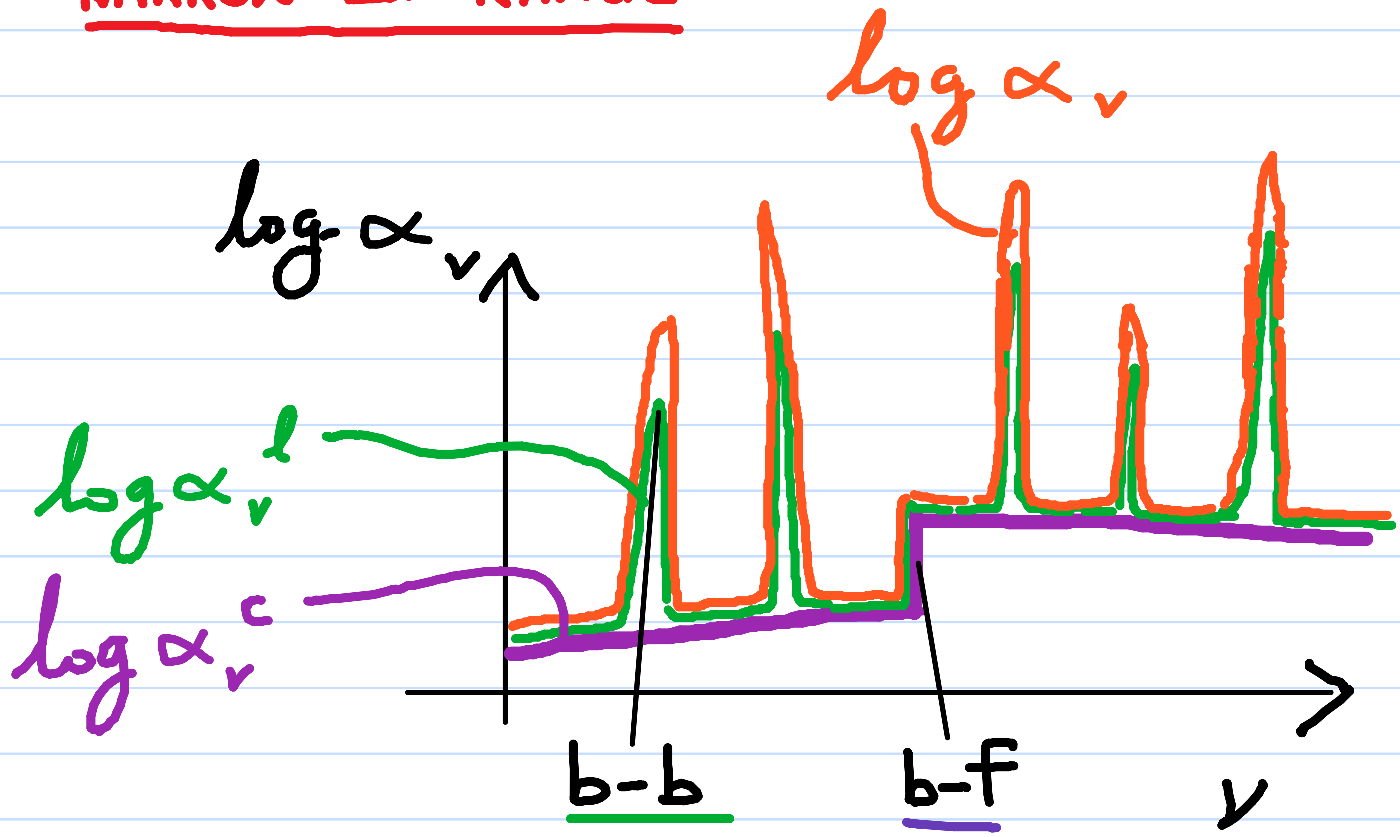
$$\alpha_\nu = \alpha_\nu^{l} + \alpha_\nu^{c}$$

$$= \sum_{k}^{\text{SPECIES}} \alpha_{\nu,k}^{l} + \sum_{k}^{\text{H I, H}^-\text{, He I} \ldots} \alpha_{\nu,\,\underline{b\text{-}f}}^{c}$$

$$+ \sum_{k}^{\text{H I, H}^-\text{, He I} \ldots} \alpha_{\nu,\,\underline{f\text{-}f}}^{c} + \alpha_{\nu,\,\underline{\text{THOM.}}}$$

$$+ \sum_{k}^{\text{H I, He I} \ldots} \alpha_{\nu,\,\underline{\text{RAYL}}} + \ldots$$

NARROW $\Delta\nu$ RANGE:



TOTAL CONTINUUM EMISSIVITY, j_ν^c :

$$S_\nu = \frac{j_\nu}{\alpha_\nu} = \frac{j_\nu^c + j_\nu^l}{\alpha_\nu}$$

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

$$\therefore \; j_\nu^c(\tau_\nu) = \alpha_\nu(\tau_\nu)\, B_\nu(\tau_\nu) - \alpha_\nu^l(\tau_\nu)$$