

CONTINUUM EMISSIVITY &

EXTINCTION COEFFICIENTS:

$$\underline{\alpha}_\nu^c \text{ \& \ } \underline{j}_\nu^c:$$

2) THERMAL γ -DESTRUCTION
EXTINCTION

MONOCHROMATIC VOLUME

EXTINCTION COEFFICIENT, $\underline{\alpha}_\nu^c$ (cm^{-1})

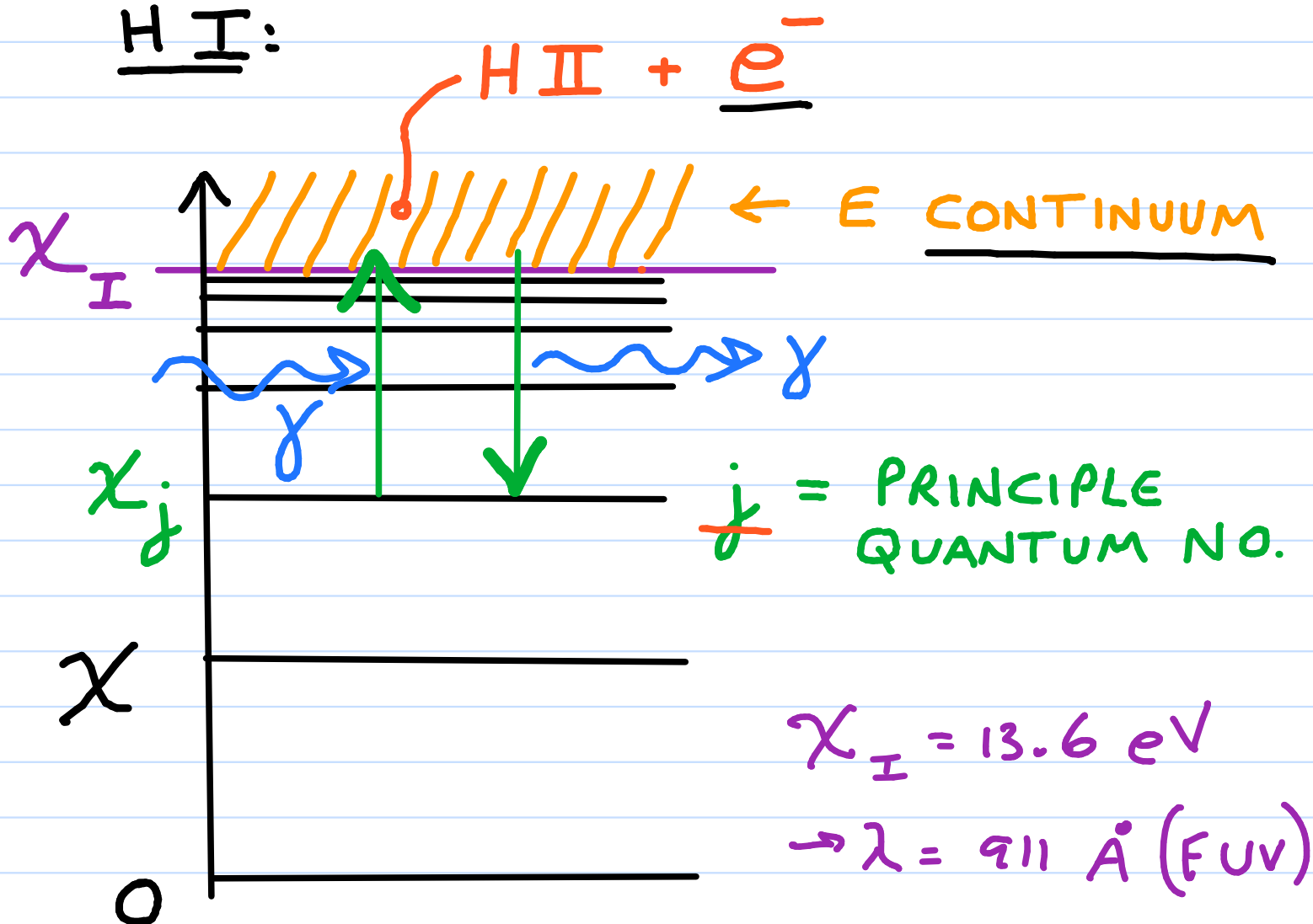
- DOMINATED BY H IN
EXTENDED VISIBLE BAND
IN MOST STARS

- Ref.: D. F. GRAY

RADIATIVE b-f TRANSITIONS:

- PHOTO-IONIZATION
- PHOTO-RECOMBINATION

HI:



E-CONSERVATION:

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

THRESHOLD (b-f EDGE, JUMP)

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

$$V_e = 0$$

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

FROM LEVEL j:

$$\alpha_{r,b-f}^c(\nu) > 0 \text{ FOR } \nu \geq \nu_{0,j}$$

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:

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

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

Z = CHARGE AFTER IONIZATION
(CHARGE UNITS)

g_{b-f} = b-f GAUNT FACTOR ($\Theta(1)$)
- SPECIES-SPECIFIC

FOR TRANS. $\underline{j} \rightarrow$ CONTINUUM:

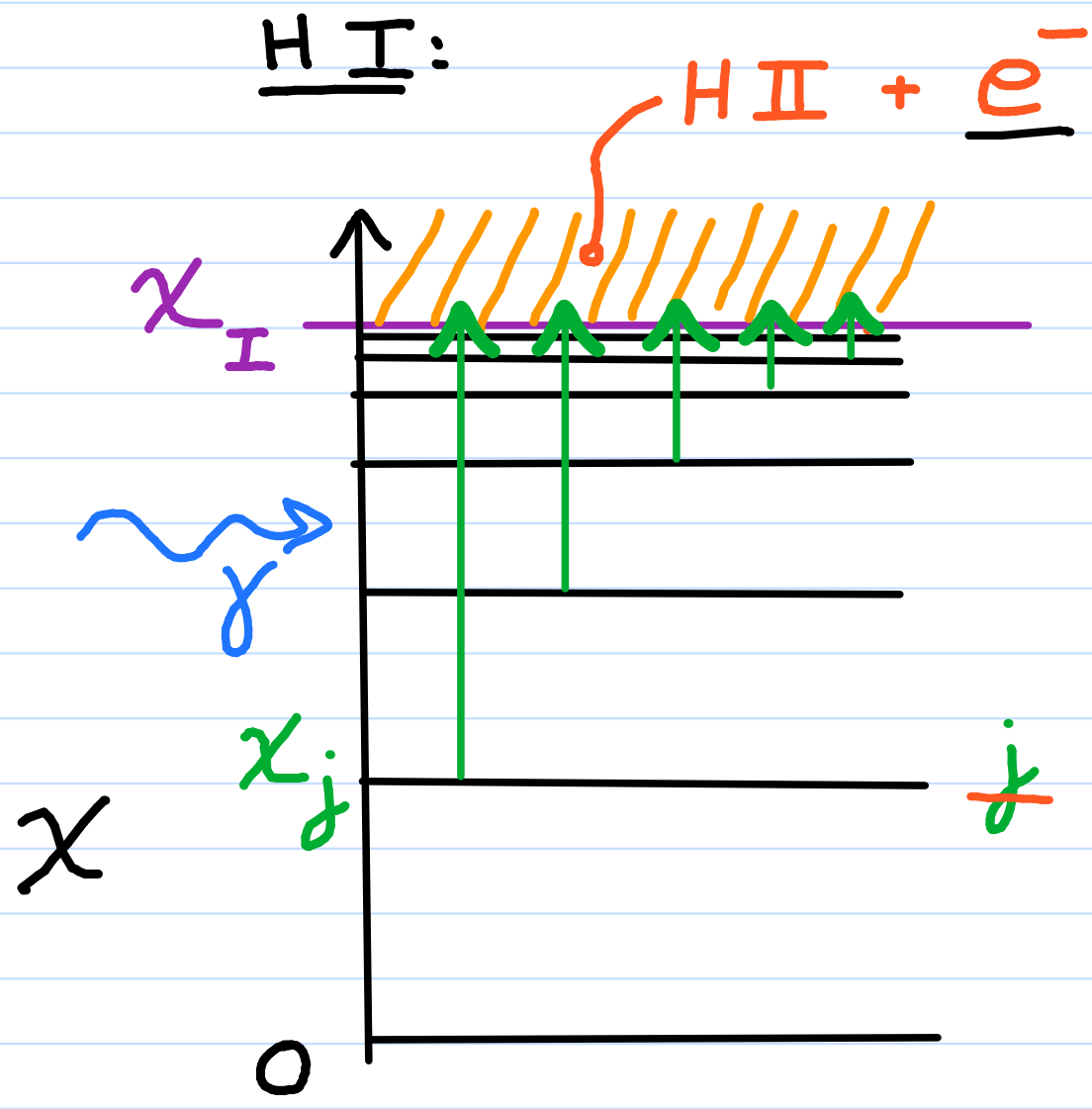
$$\alpha_{\nu, b-f}^c(\nu) \approx \eta_{\underline{j}} \sigma_{\nu, b-f}(\nu) (1 - e^{-h\nu/kT_{\text{kin}}}),$$

$$\nu \geq \nu_{0, \underline{j}} \quad (\text{cm}^{-1})$$

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



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



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

MAJOR HI b-f FEATURES :

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

$$\chi_3 = 12.1 \text{ eV}$$

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

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

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

$$\chi_2 = 10.2 \text{ eV}$$

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

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

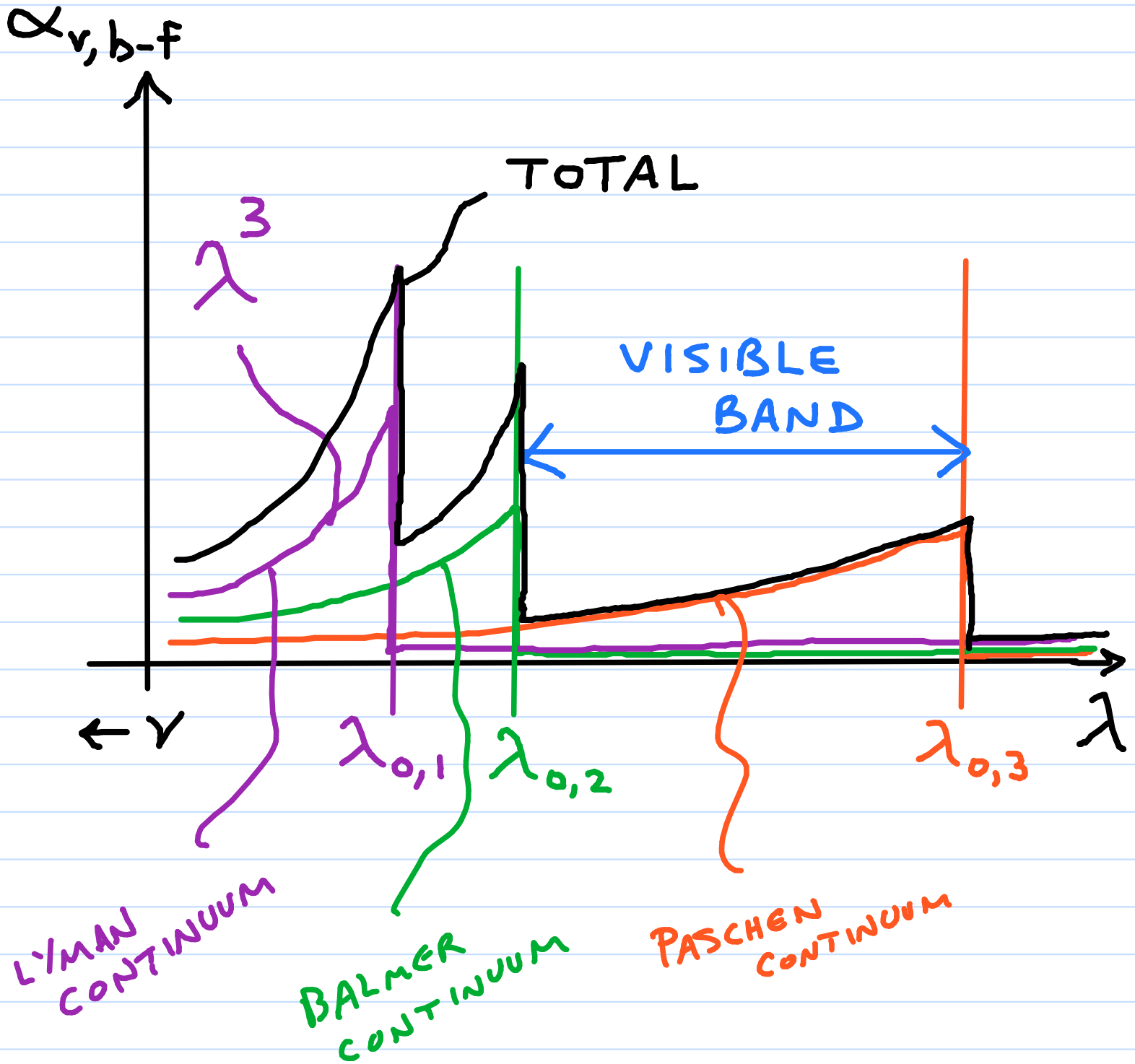
3) LYMAN JUMP : $j=1 \rightarrow$ CONT.

$$\chi_1 = 0.0 \text{ eV}$$

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

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

MAJOR HI b-f FEATURES :



MAJOR HI b-f FEATURES :

RECALL:

LTE E-B RELATION:

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

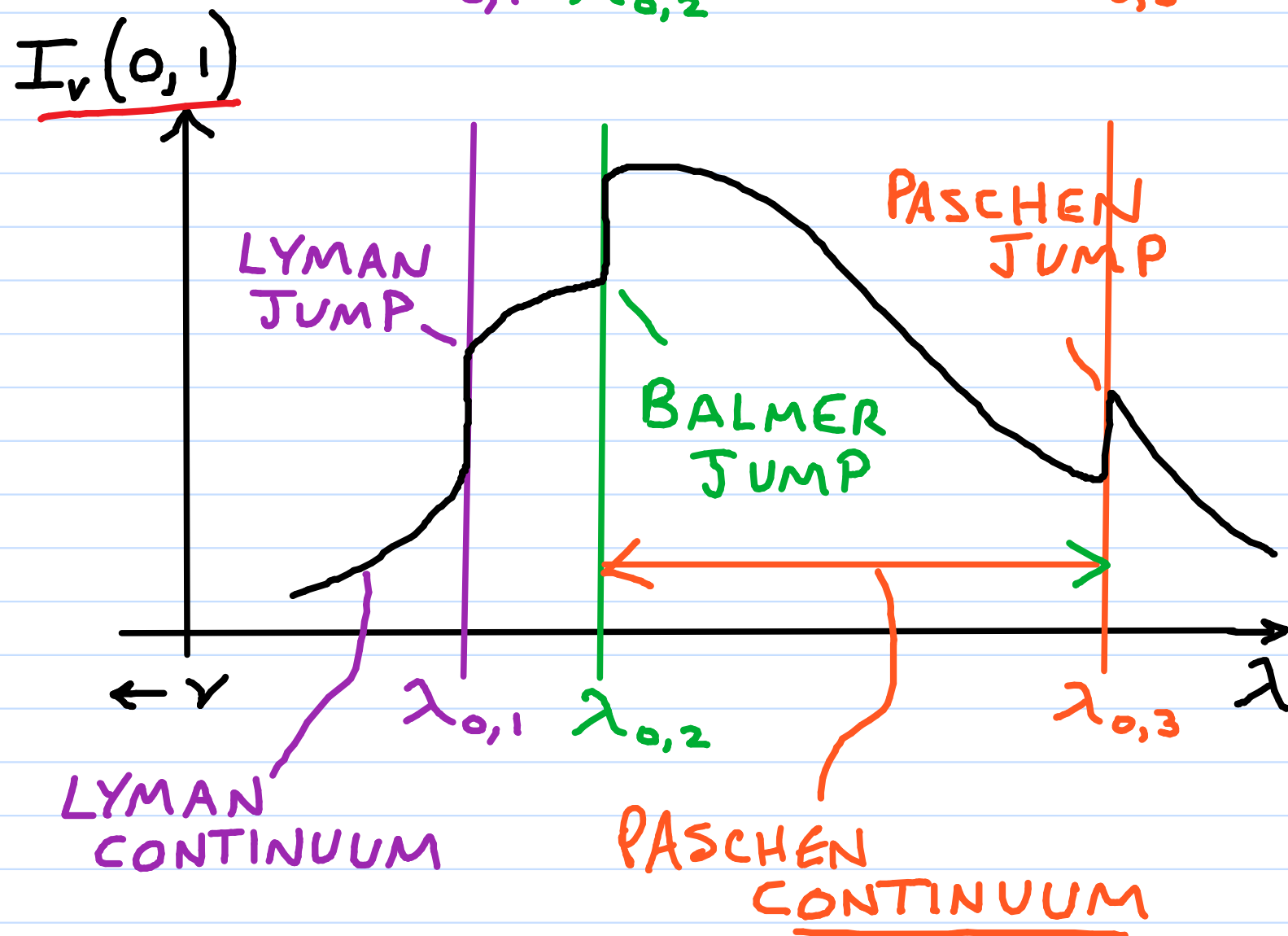
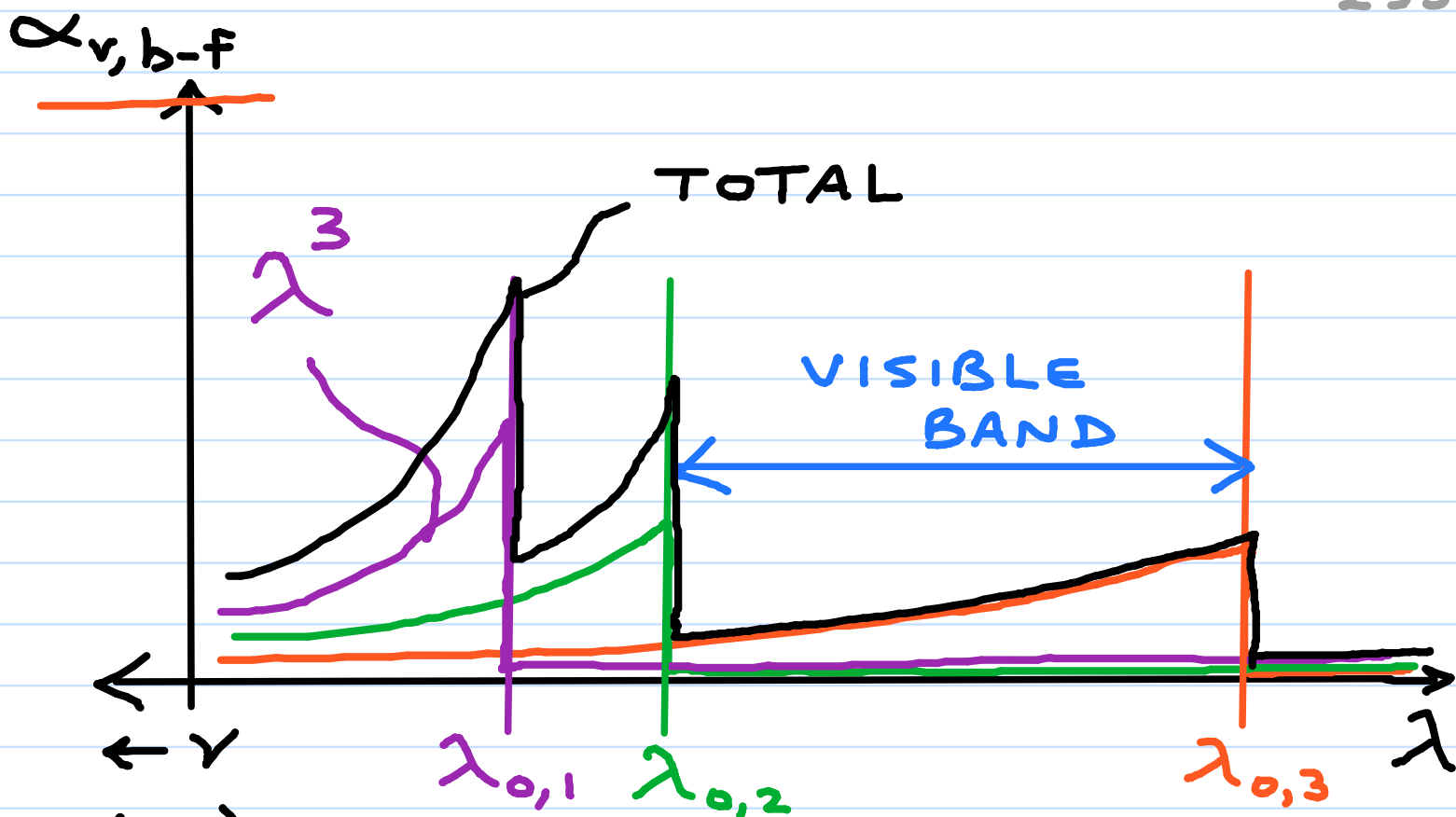
ACROSS A B-F EDGE (JUMP), ν_0 :

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

$$\therefore z(\tau_{\nu}(\nu \gtrsim \nu_0)=1) > z(\tau_{\nu}(\nu \lesssim \nu_0)=1)$$

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

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



SIGNIFICANCE:

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

PASCHEN CONT.: $j=3 \rightarrow$ CONT.

$$\text{HI: } \chi_{\text{I}} = 13.6 \text{ eV}; \quad \chi_{\underline{3}} = 12.1 \text{ eV}$$

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

\rightarrow SAHA DIST.:

$$\frac{N_{\text{HII}}}{N_{\text{HI}}} \approx \zeta \underline{T}^{3/2} e^{-\underline{\chi}_{\text{I}}/RT} \approx \Theta(1)$$

\rightarrow BOLTZMANN DIST.:

$$\frac{n_{j=3}}{n_{j=1}} = \frac{g_3}{g_1} e^{-\chi_3/RT} > 0$$

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

$$H^- : \chi_I = 0.77 \text{ eV}$$

FOR $T_{\text{KIN}} < 8000 \text{ K}$:



- FREE e^- 's FROM METAL e^- DONORS

$\therefore [H^-]$ DEPENDS ON $\left[\frac{A_2}{H}\right]$

$$\underline{\lambda_0} = \frac{hc}{\chi_I} = 1644 \text{ nm} = 1.64 \underline{\mu\text{m}} - \text{NIR}$$

SAHA:

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

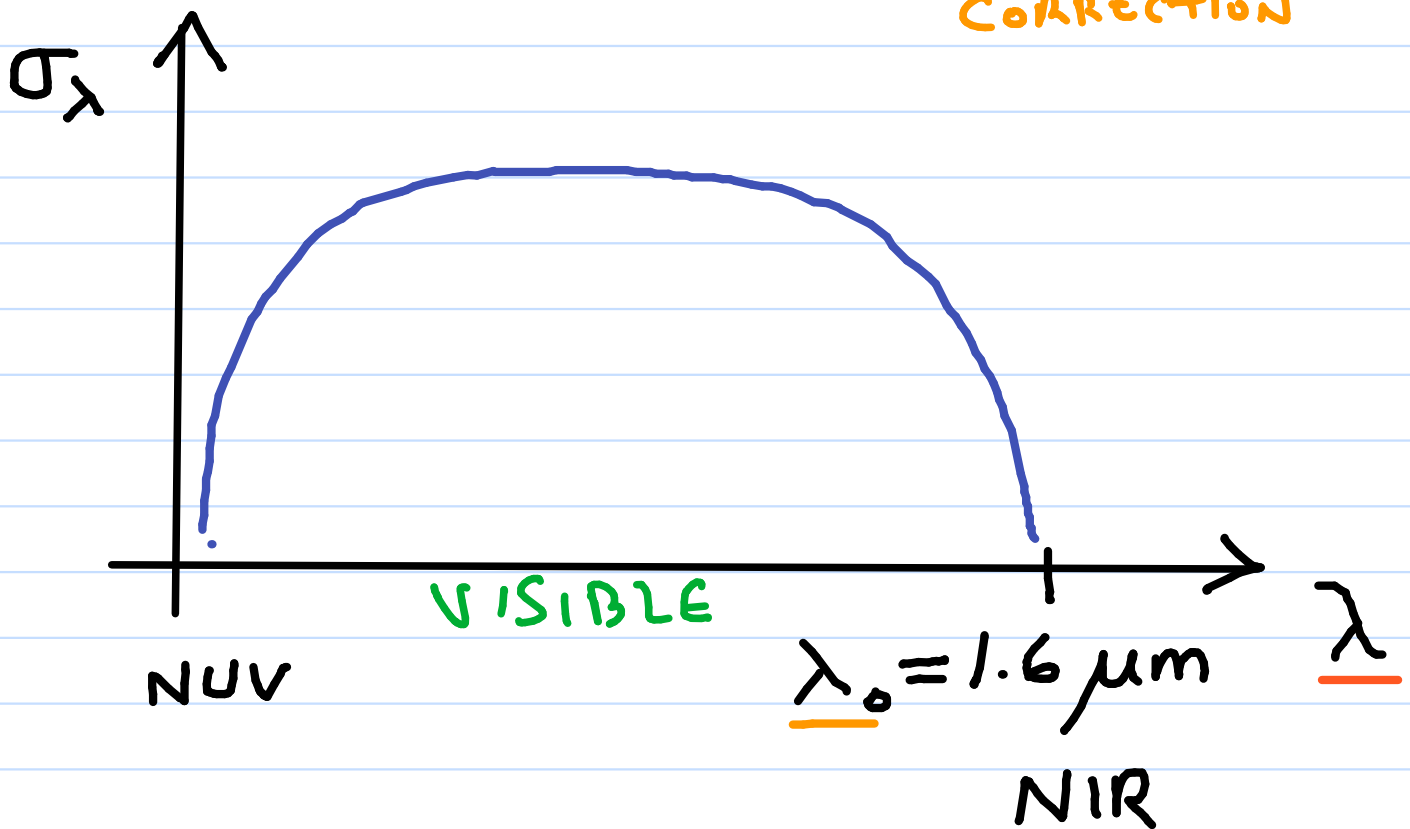
NON-HYDROGENIC:

PARAMETERIZED EMPIRICAL FIT:

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

$$\therefore \alpha_{\lambda} \approx N_{H^-} \sigma_{\lambda} (1 - e^{-hc/\lambda kT}) \quad (\text{cm}^{-1})$$

STIM. EM.
CORRECTION



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

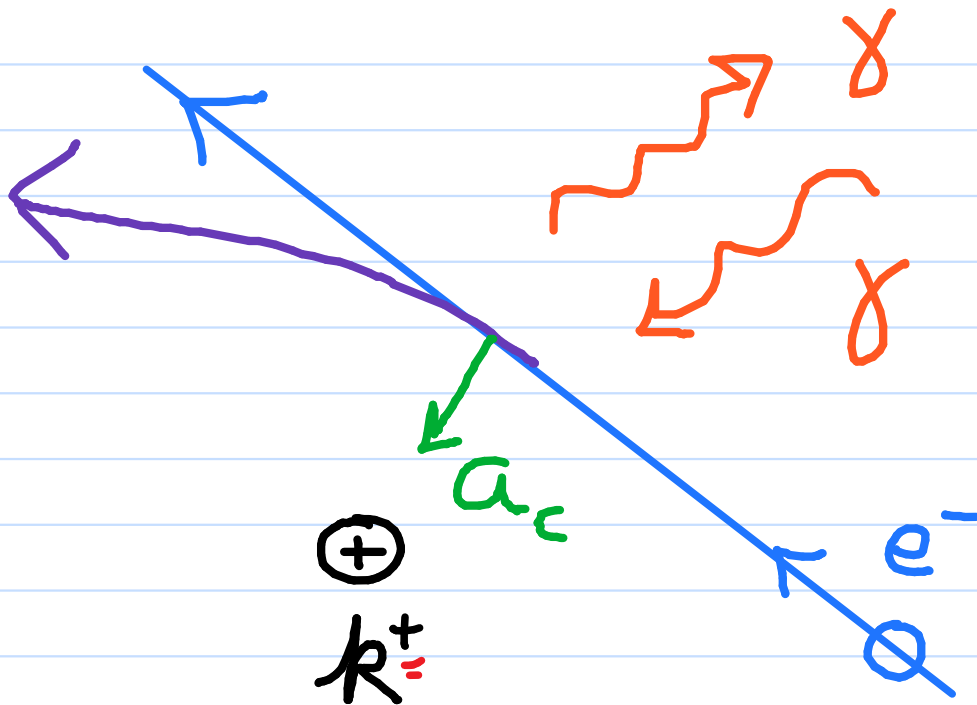
$\therefore z(\tau_v^c=1)$ SMALLEST IN SOLAR ATMOSPHERE AT $\approx 1.6 \mu\text{m}$

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

FREE-FREE (f-f) TRANSITIONS

BREMSTRAHLUNG
BRAKING RADIATION

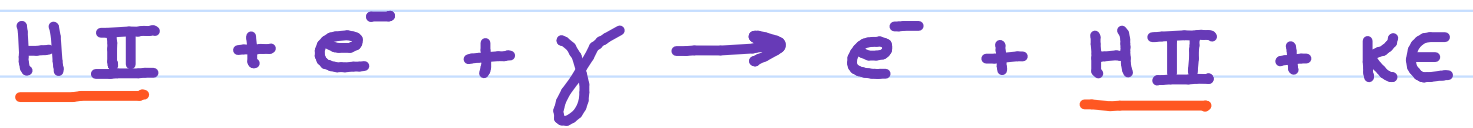
k f-f:



$$\underline{\alpha}_v^c \text{ IF } \Delta KE > 0$$

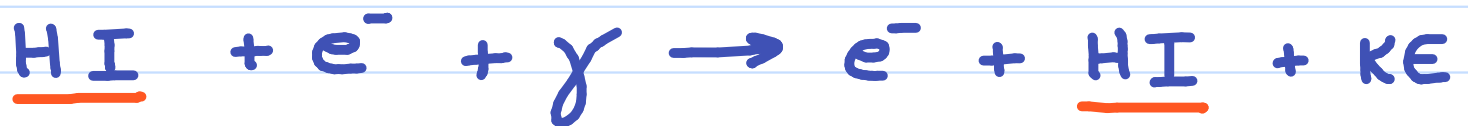
$$\underline{j}_v^c \text{ IF } \Delta KE < 0$$

Eg. H I f-f EXTINCTION:



- B, A, F STARS

Eg. H⁻ f-f EXTINCTION



- G, K STARS

He I & He⁻ f-f OF MINOR

IMPORTANCE IN OB STARS

FOR HYDROGENIC SPECIES:

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

- $C = 3.7 \times 10^8$

- $Z =$ CHARGE OF k^+

- $g_{f-f} =$ f-f GAUNT FACTOR

$$\therefore \underline{\alpha_\nu} = \underline{N_k} \sigma_\nu \underbrace{(1 - e^{-h\nu/kT_{\text{KIN}}})}_{\text{LTE STIM. EM. CORRECTION}} \quad (\text{cm}^{-1})$$

LTE STIM. EM.
CORRECTION

SCATTERING PROCESSES:

THOMSON SCATTERING:



NON-RELATIVISTIC LIMIT:

THOMSON CROSS-SECTION:

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

- GRAY OPACITY SOURCE

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

MOST IMPORTANT IN O STARS

- LARGE N_e

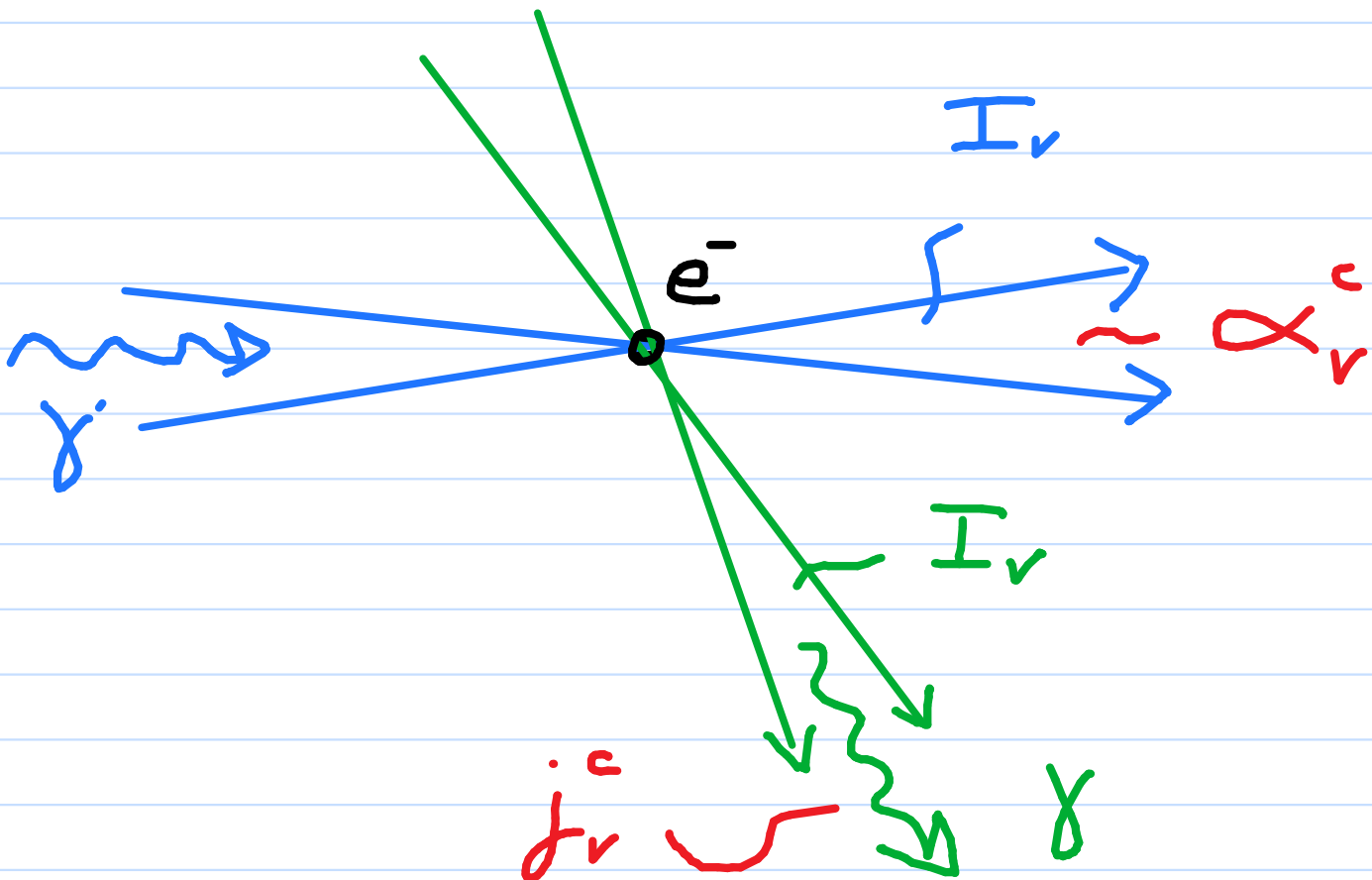
RAYLEIGH SCATTERING:

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

$$k = \text{HI}, \text{He I}$$

-MINOR IMPORTANCE

SCATTERING GENERALLY:



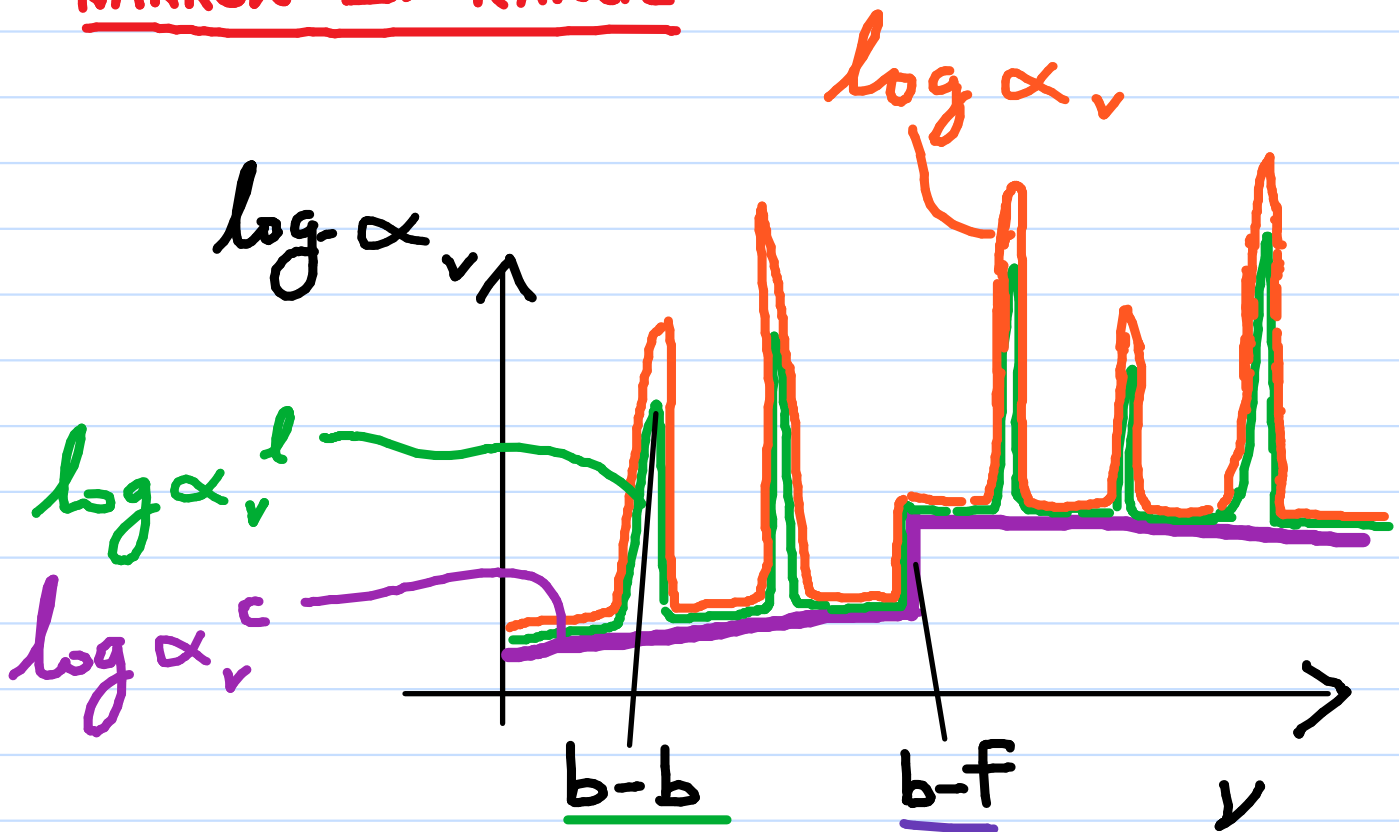
TOTAL α_v AT FREQ. ν IN VISIBLE BAND:

$$\alpha_v = \alpha_v^l + \alpha_v^c$$

$$= \sum_k^{\text{SPECIES}} \alpha_{v,k}^l + \sum_k^{\text{HI, H}^-, \text{He I} \dots} \alpha_{v, \text{b-f}}^c$$

$$+ \sum_k^{\text{HI, H}^-, \text{He}^- \dots} \alpha_{v, \text{f-f}}^c + \alpha_{v, \text{THOM.}}$$

$$+ \sum_k^{\text{HI, He I} \dots} \alpha_{v, \text{RAYL}} + \dots$$

NARROW ΔV RANGE:

TOTAL CONTINUUM EMISSIVITY, j_v^c :

$$S_v = \frac{j_v}{\alpha_v} = \frac{j_v^c + j_v^l}{\alpha_v}$$

LTE : $S_v(T_v) = B_v(T_v)$

$$\therefore \underline{j_v^c(T_v)} = \alpha_v(T_v) B_v(T_v) - \underbrace{j_v^l(T_v)}_{n_u A_{ul} \phi_v}$$

