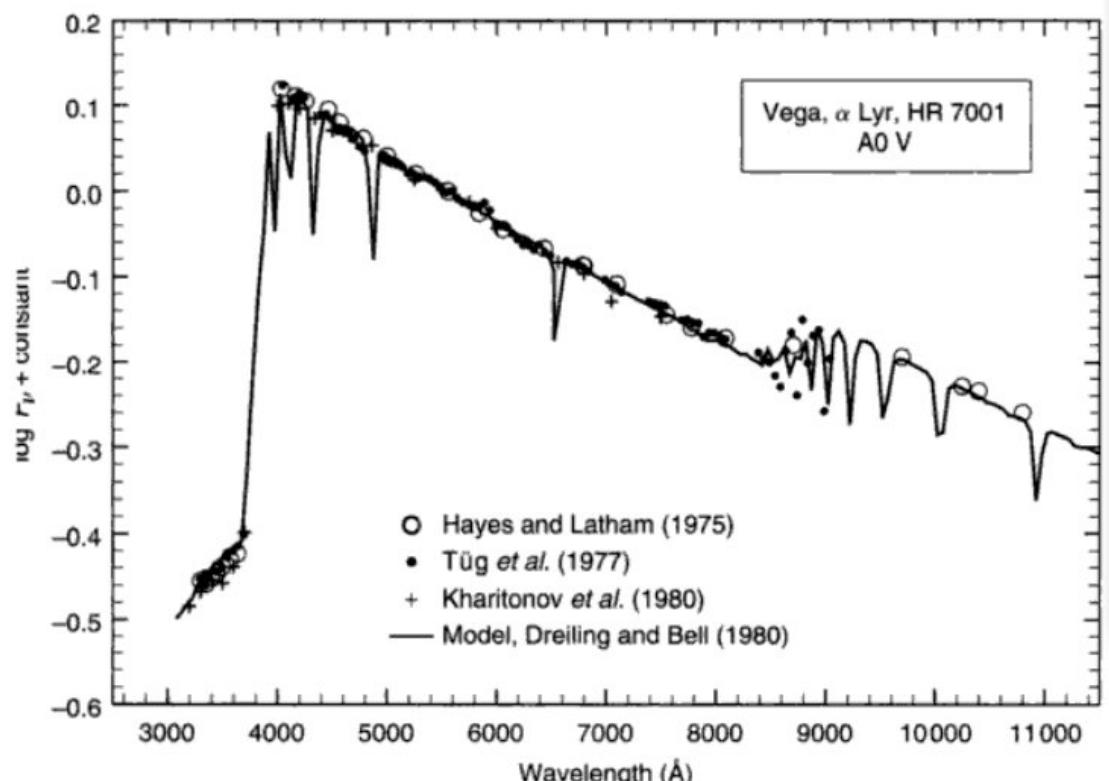


Lecture 19

Stellar Atmospheres
prof. Marcos Diaz

treasure map:

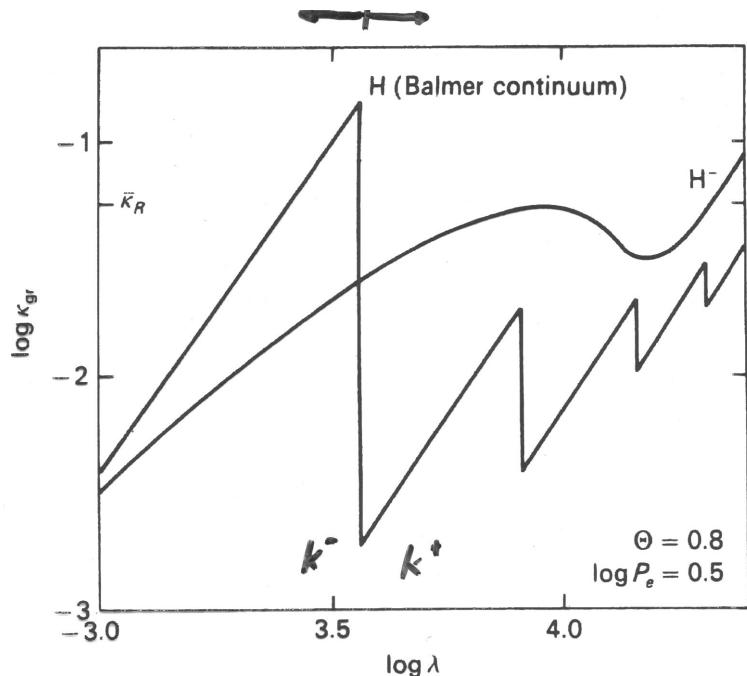


from Gray 2005

Bohm-Vitense: pg. 87, 140
Gray: pg. 314, 350, 372
Rutten: pg. 111

Sample diagnostic of T_{eff} and $\log(g)$

i. Temperature via Balmer jump

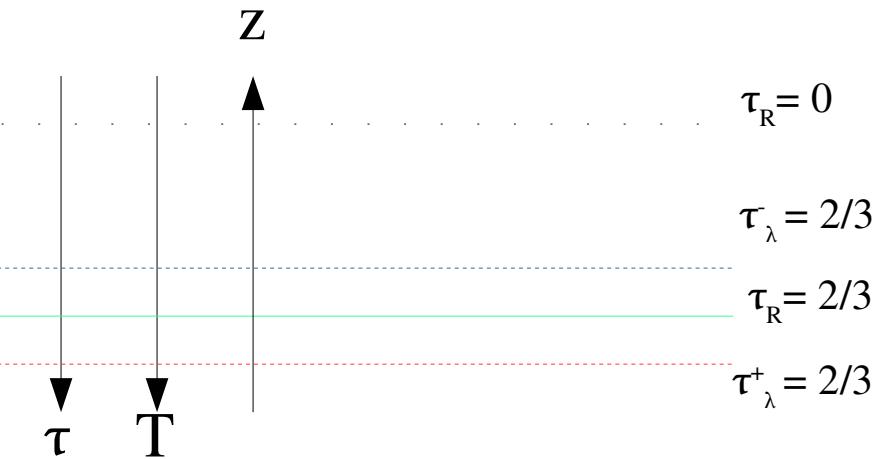


$$F_{\lambda}^- = \frac{4}{3} \frac{1}{k_{\lambda}^-} \frac{dB}{dz}$$

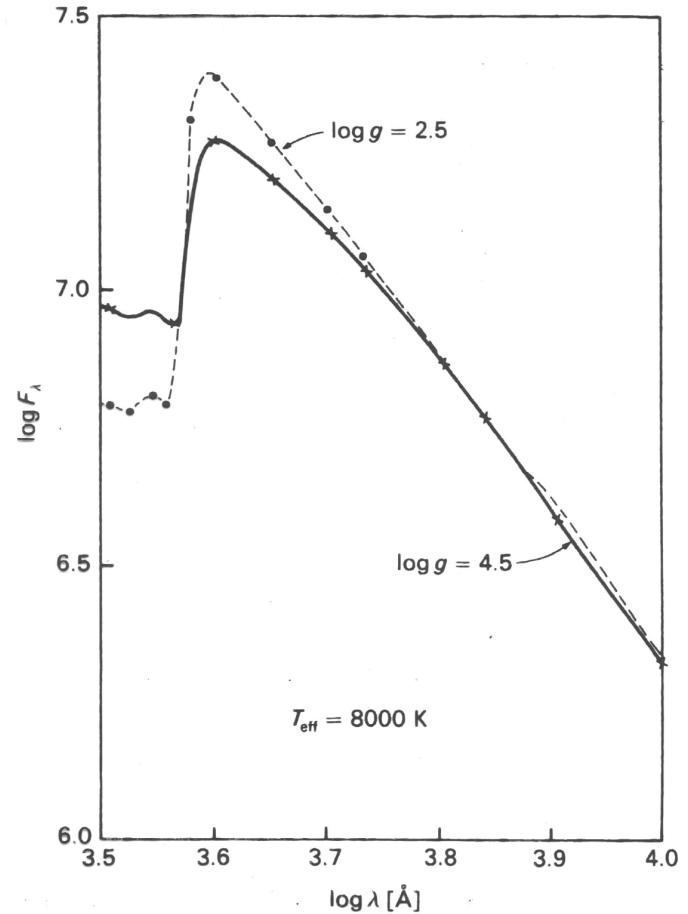
$$\frac{F_{\lambda}^-}{F_{\lambda}^+} = \frac{k_{\lambda}^+}{k_{\lambda}^-}$$

$$F_{\lambda}^+ = \frac{4}{3} \frac{1}{k_{\lambda}^+} \frac{dB}{dz}$$

$$\sigma_{b-f} \propto \frac{1}{n^5 v^3}; \quad (v > v_{\text{edge}} \quad n = \text{excitation level})$$



Eddington-Barbier $\rightarrow F(0) = S(\tau=2/3)$



$$k^+ = N_H (\sigma_{H^- b-f} + \sigma_{H^- f-f}) + \sum_{i=3}^{\infty} \sigma_{b-f}(i) N_H(n=i) + n_e a_{Th}$$

$$k^- = N_H (\sigma_{H^- b-f} + \sigma_{H^- f-f}) + \sum_{i=2}^{\infty} \sigma_{b-f}(i) N_H(n=i) + n_e a_{Th}$$

with

$$N_{r-1} = N_r f(T_{ion}) n_e \quad \text{and} \quad N_i = N_1 \frac{g_i}{g_1} e^{-\chi_i/kT_{ex}}$$

a) hot stars ($12,000 < T_{\text{eff}} < 25000$ K)

- Negligible Thomson scattering when compared to b-f opacities
- $N_{\text{H}}^- \sim 0$
- $\sigma_{\text{b-f}}(n=2) \gg \sigma_{\text{b-f}}(n=3) \gg \sigma_{\text{b-f}}(n=4)$ $(\sigma \propto n^{-5})$

$$\frac{F^-}{F^+} = \frac{k^+}{k^-} = \frac{N_H(n=3)\sigma_{b-f}(n=3)}{N_H(n=2)\sigma_{b-f}(n=2)} = \frac{\sigma_{b-f}(n=3)N_H(n=1)g_3/g_1 e^{-\chi_3/kT}}{\sigma_{b-f}(n=2)N_H(n=1)g_2/g_1 e^{-\chi_2/kT}}$$

$$\frac{F^-}{F^+} = \frac{\sigma_{b-f}(n=3)g_3}{\sigma_{b-f}(n=2)g_2} e^{-\frac{(\chi_3 - \chi_2)}{kT_{ex}}}$$

mag difference is a function of temperature only

$$T_{\text{eff}} = T_{\text{eff}}(T_{\text{ex}}, \tau_{\text{line}}) \quad \leftarrow \quad \text{model atmosphere}$$

b) moderately cool stars ($T_{\text{eff}} < 9000 \text{ K}$)

- Negligible Thomson scattering when compared to b-f opacities
- $N_H (n \geq 3) \sim 0$
- $k_{H^-} \gg k_{b-f}$
 $k^+_{H^-} \sim k^-_{H^-}$ (flat continuum opacity curve over jump)
- $\sigma_{b-f} (n=2) \gg \sigma_{b-f} (n=3)$ ($\sigma \propto n^{-5}$)

$$\frac{F^-}{F^+} = \frac{k^+}{k^-} = \frac{N_H \sigma_{H^-} + \sum_{i=3} N_H(n=i) \sigma_{b-f}(n=i)}{N_H \sigma_{H^-} + \sum_{i=2} N_H(n=i) \sigma_{b-f}(n=i)}$$

$$= \frac{N_H(r=0) f(T_{ion}) n_e k_{H^-}}{N_H(r=0) f(T_{ion}) n_e \sigma_{H^-} + \sigma_{b-f}(n=2) N_H(n=1) g_2/g_1 e^{-\chi_2/kT_{exc}}}$$

mag. diff. $f(T, \log(g))$

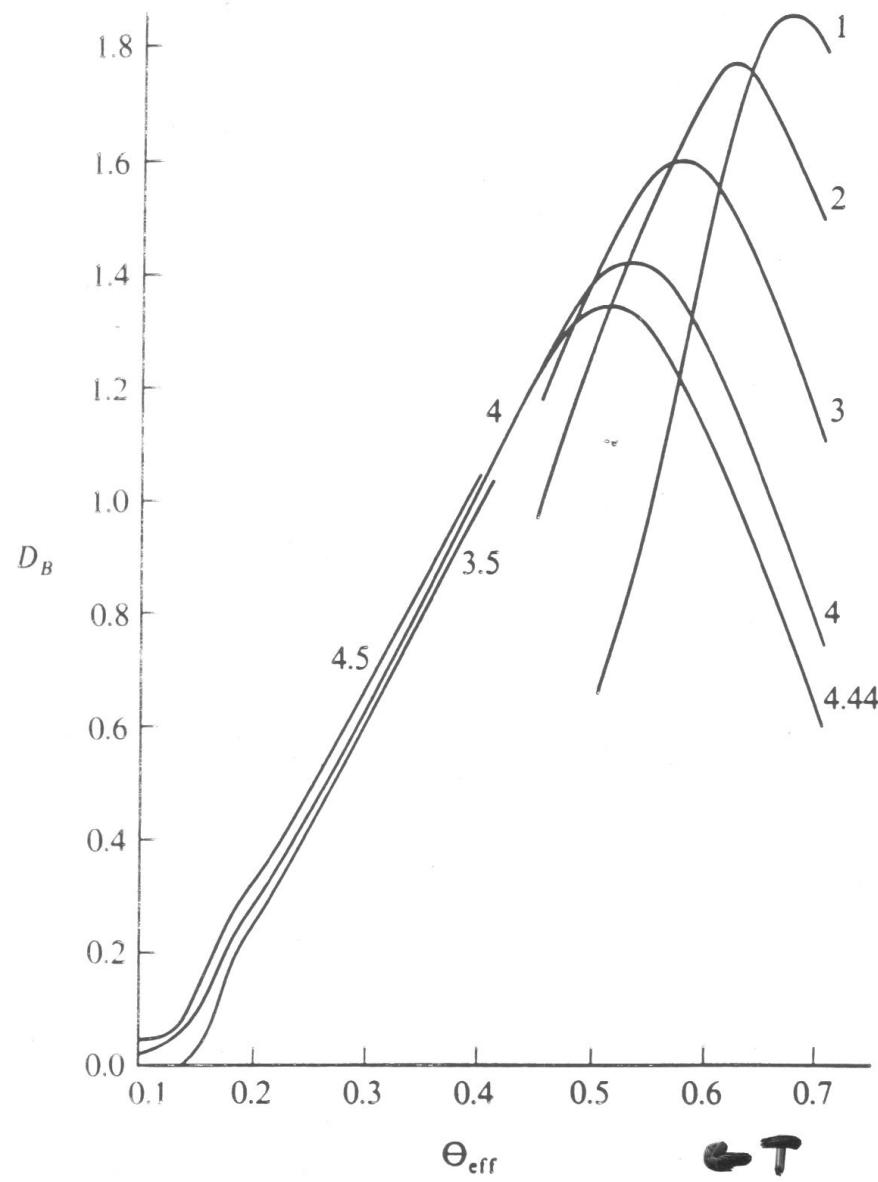


FIG. 6-3. Balmer jumps computed from LTE model atmospheres, as a function of effective temperature and gravity. Ordinate: Balmer jump in magnitude units; abscissa: $\theta_{\text{eff}} = 5040/T_{\text{eff}}$. Curves are labeled with $\log g$.

$$D = \log F_+ / F_-$$

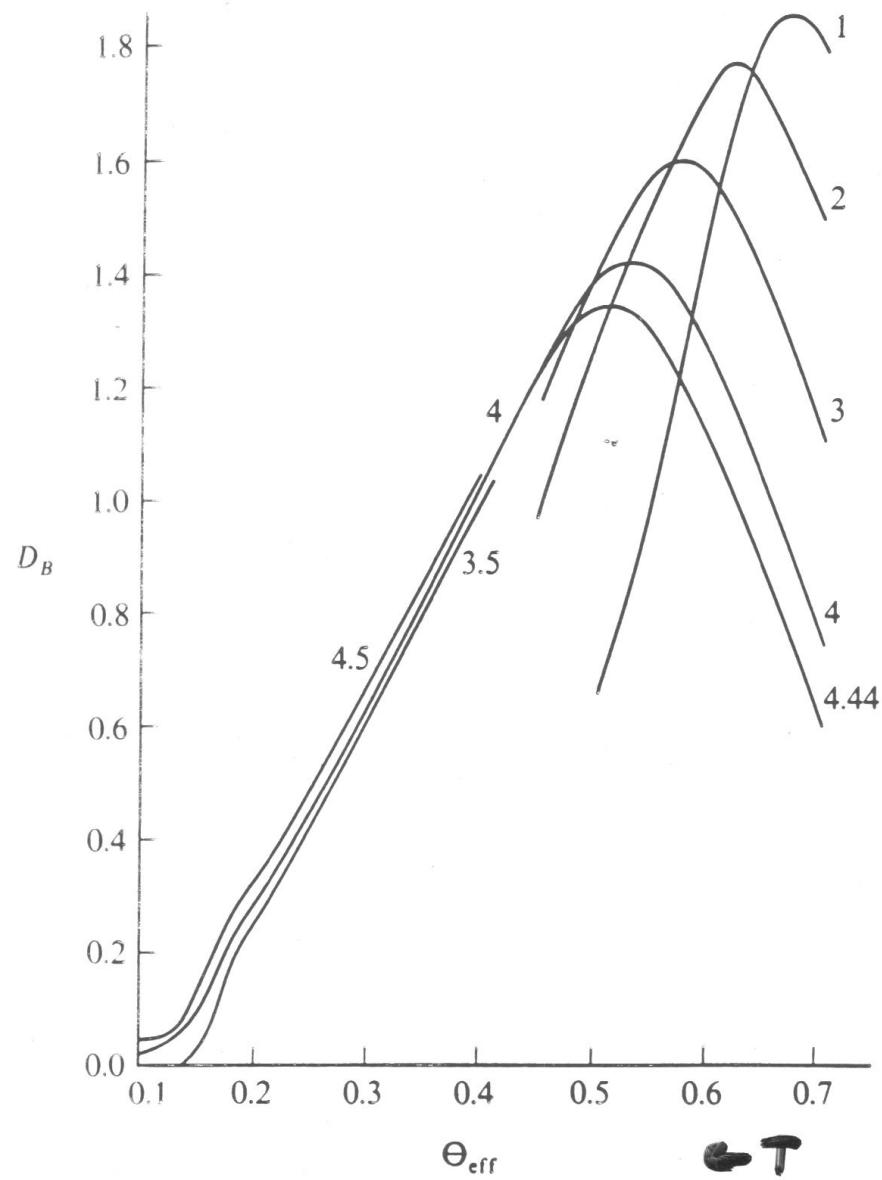


FIG. 6-3. Balmer jumps computed from LTE model atmospheres, as a function of effective temperature and gravity. Ordinate: Balmer jump in magnitude units; abscissa: $\theta_{\text{eff}} = 5040/T_{\text{eff}}$. Curves are labeled with $\log g$.

$$D = \log F_+ / F_-$$

ii. Temperature from Balmer R

$$R_\lambda = \frac{2}{3} \frac{k_L}{k_c} \left(\frac{d \ln B_\lambda}{d \tau_c} \right)$$

a) hot stars ($10000 < T_{\text{eff}} < 25000$)

- Negligible Thomson scattering when compared to b-f opacities
- $N_H^- \sim 0$
- $k_c \sim k_{b-f}(n=3)$ (Paschen continuum)
- $k_L \sim k_{b-b}(n=2)$ (Balmer lines)
- $\sigma_{b-f}(n=2) \gg \sigma_{b-f}(n=3)$ ($\sigma_{b-f} \propto n^{-5}$)

$$R_\lambda \propto \left(\frac{N_H(n=2) * n_e * \text{const}}{\sigma_{b-f}(n=3) N_H(n=3)} \right) \propto n_e \frac{g_2}{g_3} e^{-(\chi_2 - \chi_3)/kT_{\text{exc}}}$$

b) cool stars ($T_{\text{eff}} < 9000$)

$$\rightarrow N_H(n=3) \sim 0$$

$$\rightarrow k_c \sim k_{H^-} \gg k_{b-f}(n=3)$$

$$k_L \sim k_{b-b}(n=2)$$

r = ionization state

(Balmer lines)

$$R_\lambda \propto \frac{k_L}{k_c} \propto \frac{n_e N_H(n=2) * \text{const}}{N_H(r=0) f(T_{ion}) n_e \sigma_{H^-}} = \frac{n_e N_H(n=1) g_2 / g_1 e^{-\chi_2 / kT_{exc}}}{N_H(r=0) f(T_{ion}) n_e \sigma_{H^-}}$$

$$N_H(n=1) \approx N_H(r=0)$$

most H at ground state

$$R_\lambda \propto \frac{g_2 / g_1 e^{-\chi_2 / kT_{exc}}}{f(T_{ion}) k_{H^-}}$$

Balmer line intensities relative to continuum depend only on temperature

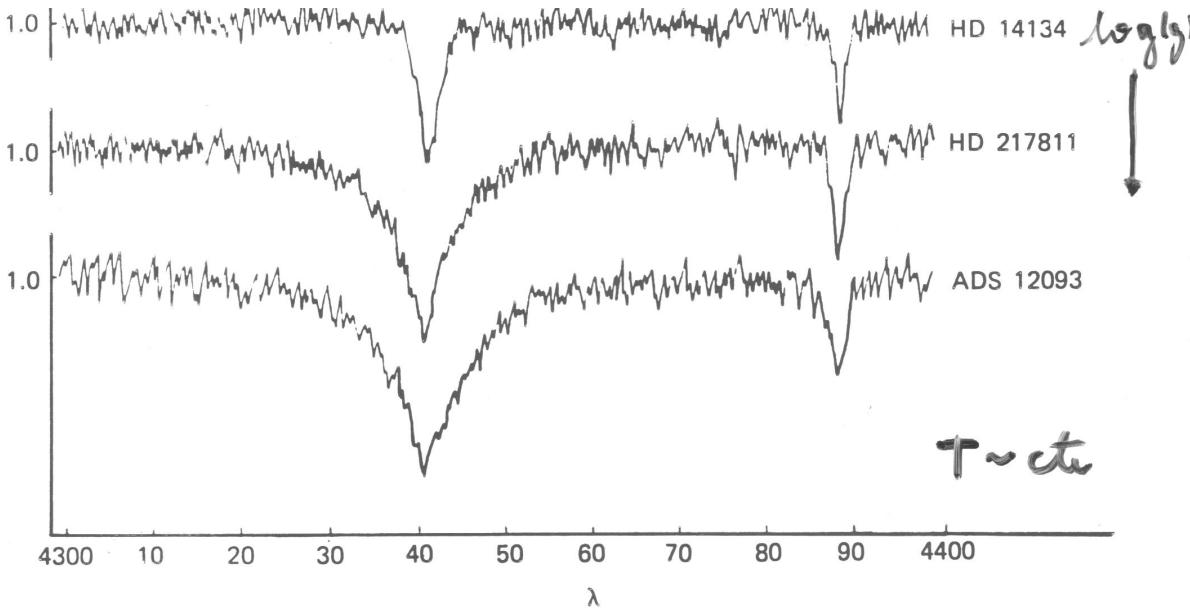
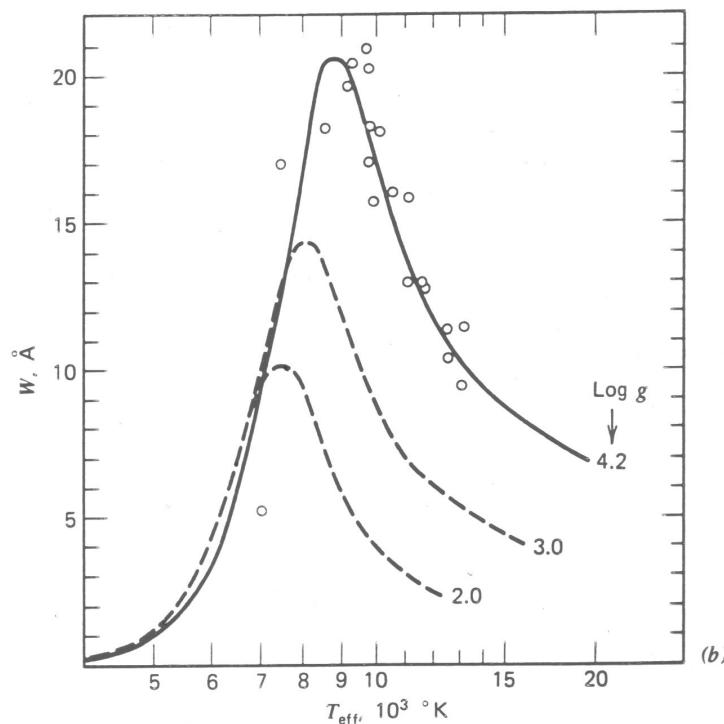


Fig. 13.11. These data of Petrie (1953) for early B stars shows the pressure variation in H_γ . The supergiant is at the top, the dwarf at the bottom. Petrie found the absolute visual magnitudes to these stars to be -6.5 , -2.0 , and -0.4 . ADS 12093 is HD 178849.



(from Gray 2005)

iii. Gravity from metal lines in cool stars

gravity indicators usually depend on temperature

$$N_z(r) = N_z(r+1)f(T_{ion})n_e$$

with most Z element at ionization $r+1 \rightarrow N_z(r+1) \sim N_z$

$$k_L(r+1) \propto N_z g f \lambda_{ij}^2 e^{-\chi_i/kT_{exc}}$$

$$\frac{k_L}{k_c} \propto \frac{N_z f(T_{exc}, \chi_i)}{N_H f'(T_{ion}) n_e};$$

$$R_{\lambda_0} \propto \frac{A_z \hat{f}(T, \chi_i)}{n_e}$$

depends on gravity

With fixed A_z abundance \rightarrow compute model series with different $T_{\text{eff}} = f(T)$ and $\log(g) = f(n_e)$ that match the observed R_0 or EW within uncertainties.

