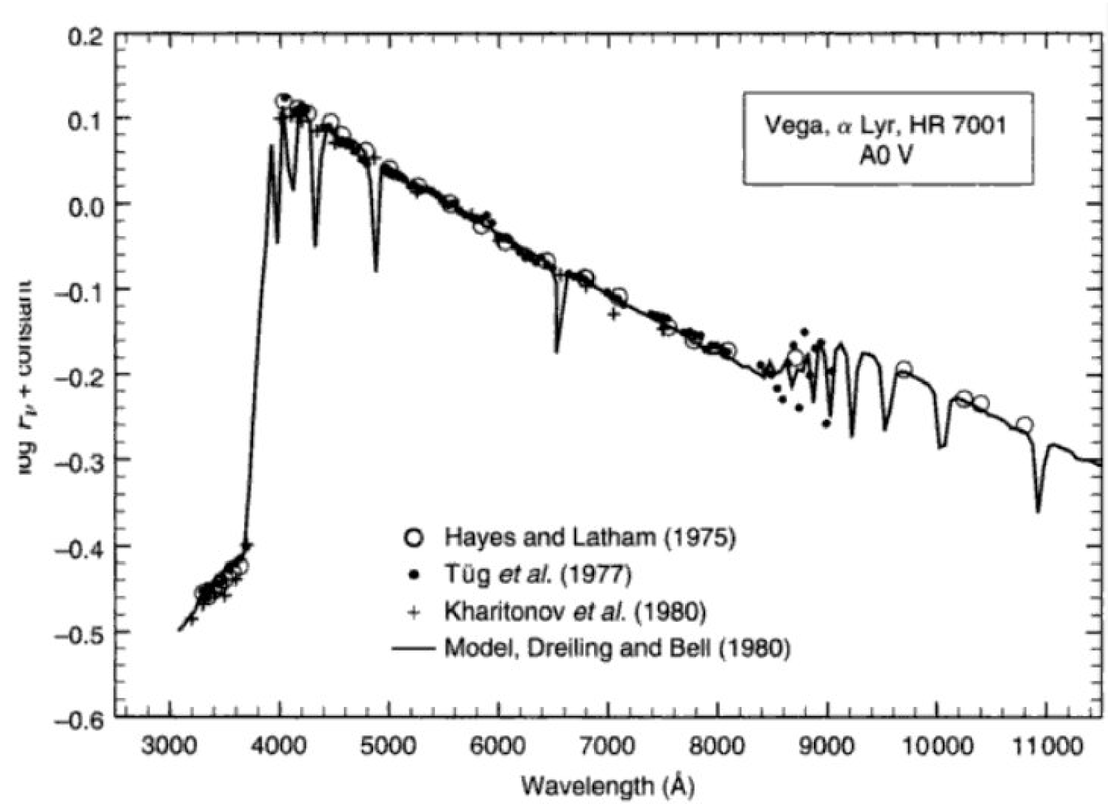
Lecture 19

Stellar Atmospheres
prof. Marcos Diaz



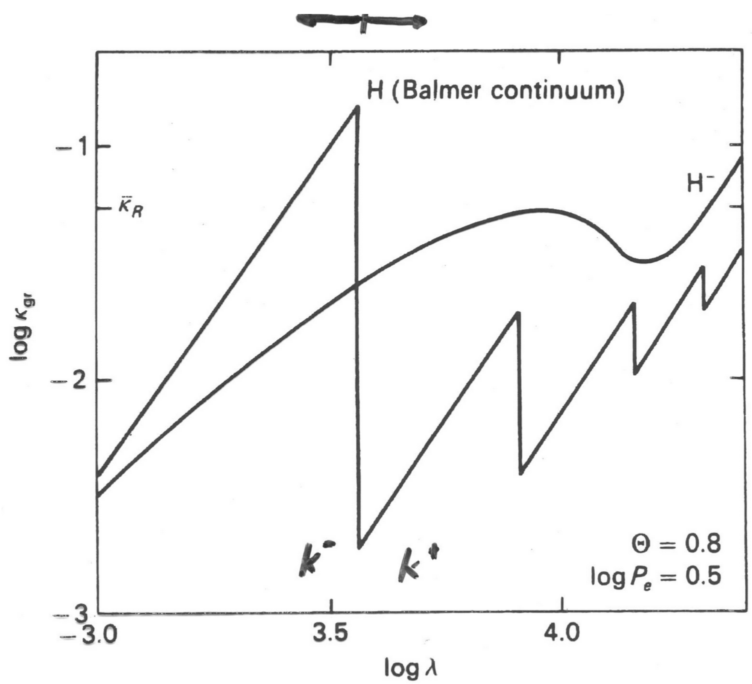
from Gray 2005

treasure map:

Bohn-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

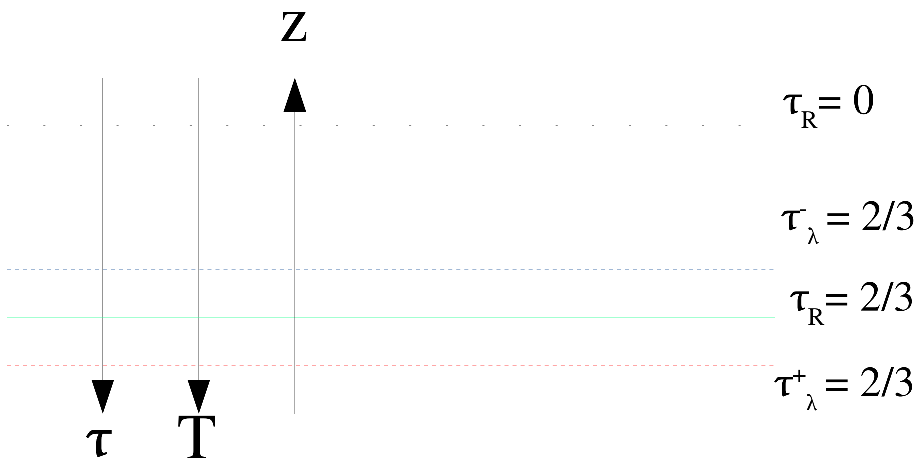


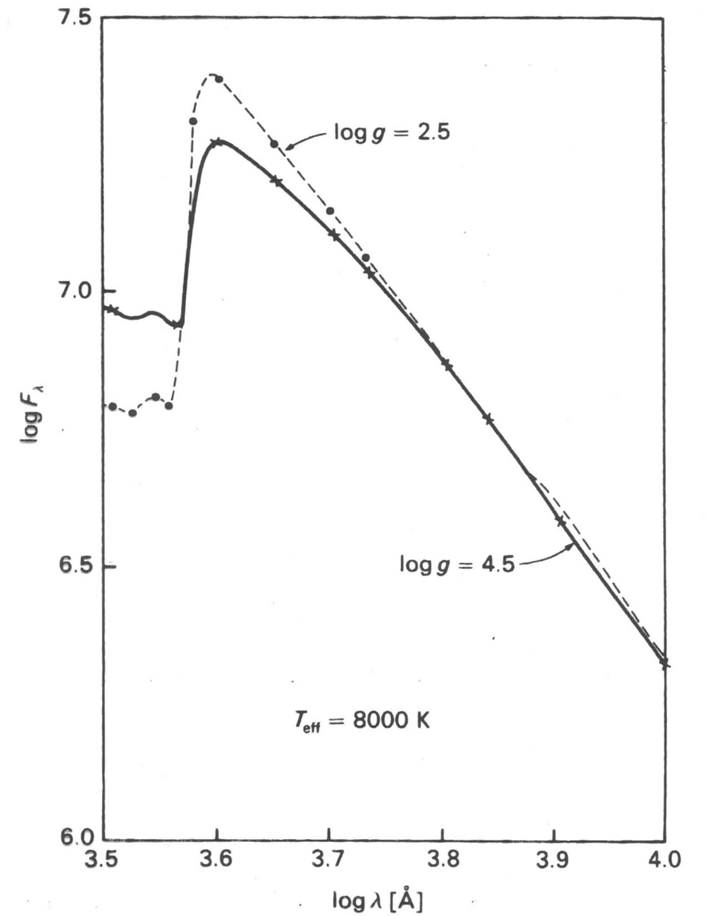
$$F_\lambda^- = \frac{4}{3}\frac{1}{k_\lambda^-}\frac{dB}{dz}$$

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

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

$$\sigma_{b\text{-}f} \propto \frac{1}{n^5\nu^3}; \qquad (\nu > \nu_{edge})$$





Eddington-Barbier → F(0) = S(τ=2/3)

$$k^{+} = N_{H^-}\left(k_{H^-\ b\text{-}f} + k_{H^- f\text{-}f}\right) + \sum_{i=3}^{\infty} k_{b\text{-}f}(i)\, N_H(n=i) + a_{Th}$$

$$k^{-} = N_{H^-}\left(k_{H^-\ b\text{-}f} + k_{H^- f\text{-}f}\right) + \sum_{i=2}^{\infty} k_{b\text{-}f}(i)\, N_H(n=i) + a_{Th}$$

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

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

→ Negligible Thomson scattering when compared to b-f opacities

→ $N_{H^-} \sim 0$

$k_{b\text{-}f}(n=2) >> k_{b\text{-}f}(n=3) >> k_{b\text{-}f}(n=4)$ ($\sigma \propto n^{-5}$)

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

$$\frac{F^-}{F^+} = \frac{k_{b\text{-}f}(n=3)\, g_3}{k_{b\text{-}f}(n=2)\, g_2}\, e^{-\frac{(\chi_3-\chi_2)}{kT_{exc}}}$$

mag difference is a function of temperature only

$T_{eff} = (T_{ex}, \tau_{line})$ ← model atmosphere

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

→ Negligible Thomson scattering when compared to b-f opacities

→ N_H (n>=3) ~ 0

→ $k_{H^-} >> k_{b\text{-}f}$

$k^+_{H^-} \sim k^-_{H^-}$ (flat continuum opacity curve over jump)

$k_{b\text{-}f}$ (n=2) >> $k_{b\text{-}f}$ (n=3) ($\sigma \propto n^{-5}$)

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

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

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

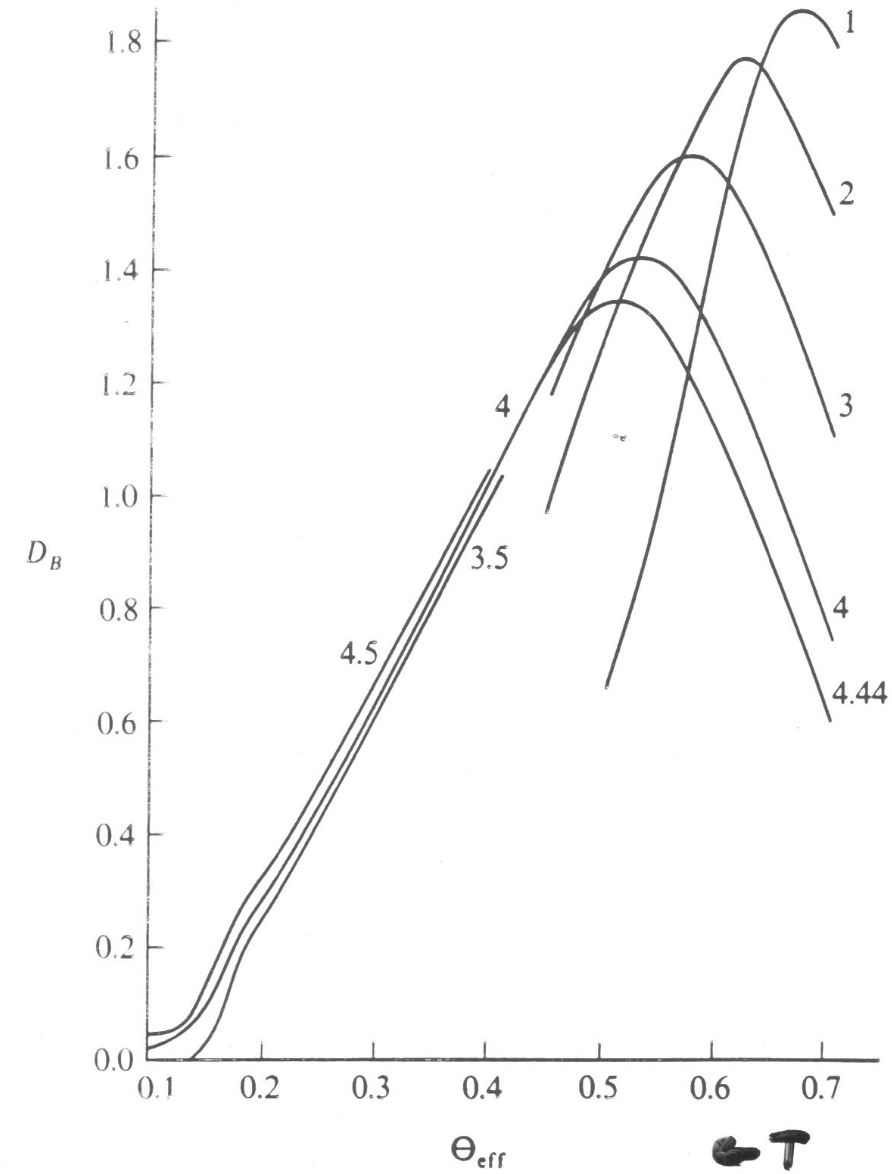


FIG. 6-3. Balmer jumps computed from LTE model atmospheres, as a function of effective temperature and gravity. Ordinate: Balmer jump in magnitude units; abscissa: $\theta_{eff} = 5040/T_{eff}$. Curves are labeled with log g.

$D = \log F_+ / F_-$

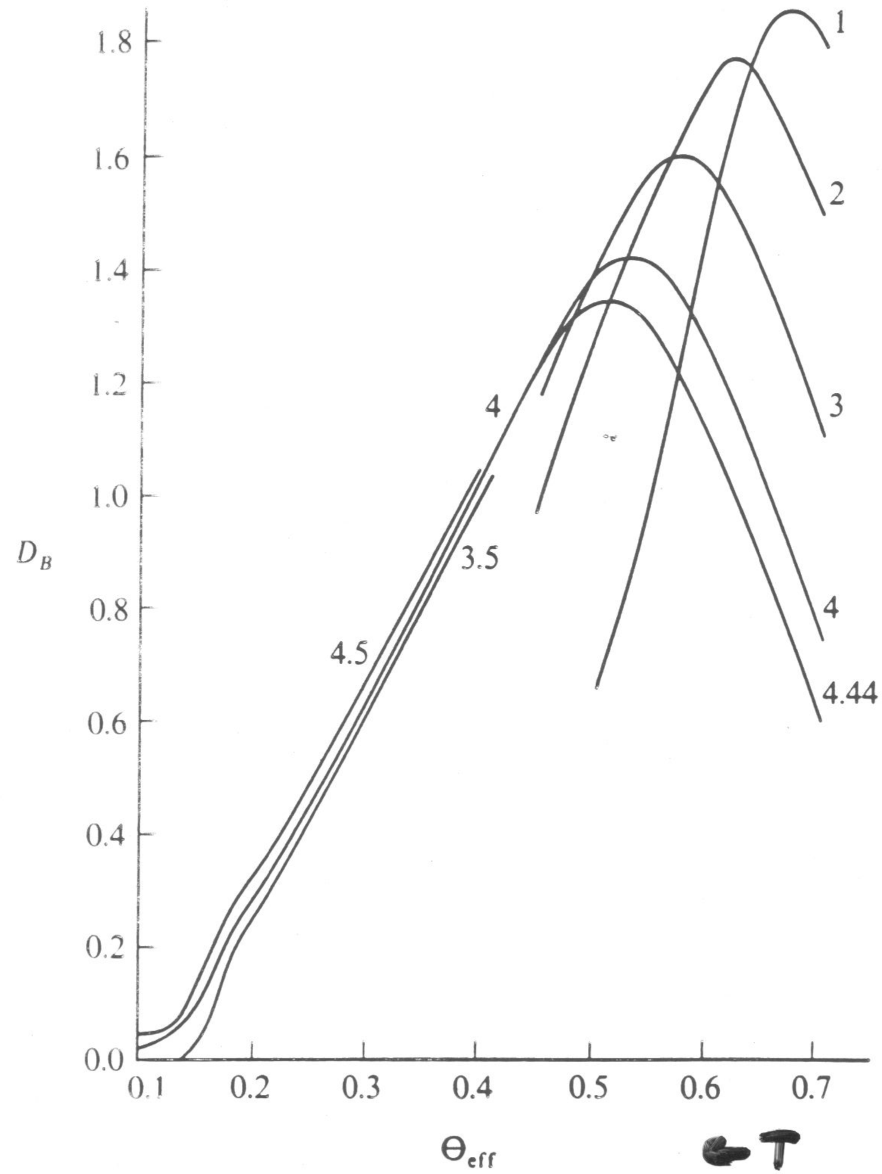


FIG. 6-3. Balmer jumps computed from LTE model atmospheres, as a function of effective temperature and gravity. Ordinate: Balmer jump in magnitude units; abscissa: $\theta_{eff} = 5040/T_{eff}$. Curves are labeled with log g.

$D = \log F_+ / F_-$

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 ($10000 < T_{eff} < 25000$)

→ Negligible Thomson scattering when compared to b-f opacities
→ $N_{H^-} \sim 0$
→ $k_c \sim k_{b\text{-}f}(n=3)$ (Paschen continuum)
$k_L \sim k_{b\text{-}b}(n=2)$ (Balmer lines)
$k_{b\text{-}f}(n=2) >> k_{b\text{-}f}(n=3)$ ($\sigma \propto n^{-5}$)

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

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

→ N_H (n=3) ~ 0

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

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

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

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

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

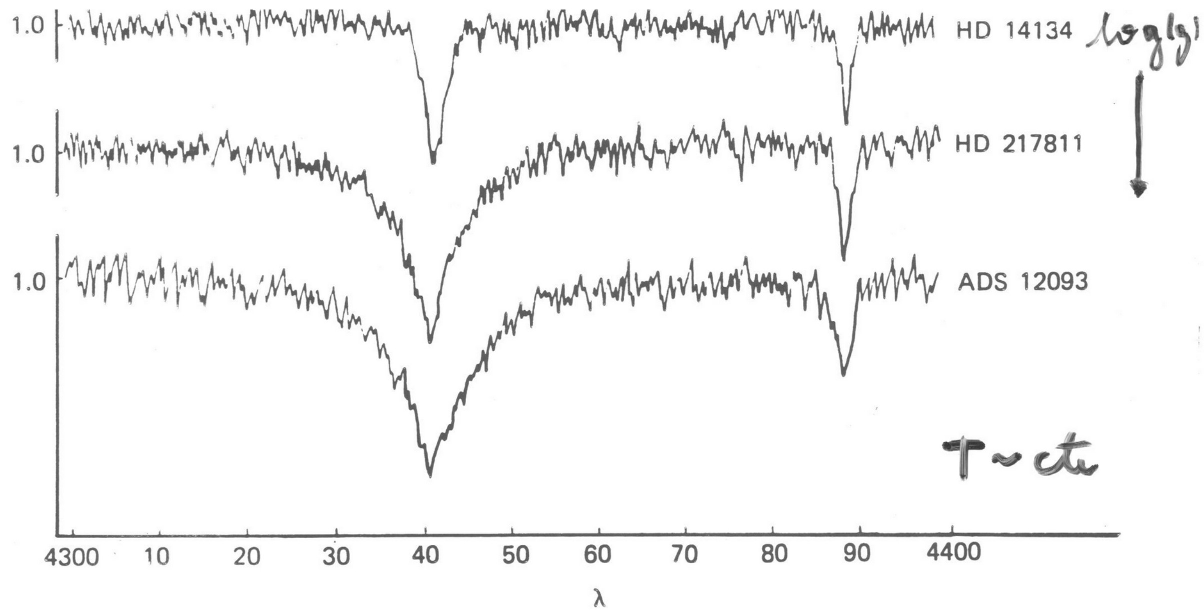
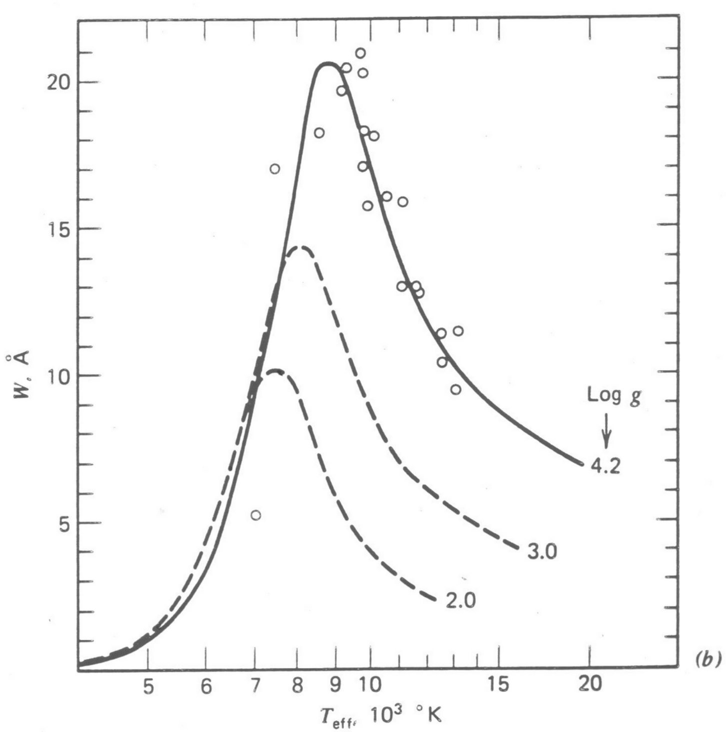


Fig. 13.11. These data of Petrie (1953) for early B stars shows the pressure variation in H_γ. The supergiant is at the top, the dwarf at the bottom. Petrie found the absolute visual magnitudes to these stars to be −6.5, −2.0, and −0.4. ADS 12093 is HD 178849.



(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 → $N_z(r+1) \sim N_z$

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

$$\frac{k_L}{k_c} \propto \frac{N_z f(T_{exc}, \chi_i)}{N_H f'(T_{ion}) n_e}; \qquad R_{\lambda_0} \propto \frac{A_z \hat{f}(T, \chi_i)}{n_e}$$

depends on gravity

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