Interpreting Spectra

- Pure hydrogen atmosphere => doesn’t look like solar spectrum
- Dominant optical opacity in Sun?
- Dominant optical opacity in A stars?
- Temperature & pressure diagnostics

Negative Hydrogen

- H^- identified as dominant solar opacity
- Only 1 in 10^7 H atoms in solar photosphere is H^-, so why is it so important?
- In optical, only H atoms in level $n = 3$ can contribute to absorption
- 3646 A < λ < 8206 A => absorption to $n = 3$
- λ > 8206 A => absorption to $n = 4$
- Ionization potential of H^- is 0.754 eV, $\lambda < 1.65\mu m$
- All H^- ions contribute to visual opacity

Compare density of H^- ions with neutral hydrogen in the $n = 3$ level at $T = 6000$ K. Use Boltzmann equation

$$\log \frac{n_{0,s}}{n_{0,1}} = \log \frac{g_{0,s}}{g_{0,1}} - \theta\, \chi_{0,s}$$

$\chi_{0,2} = 10.15$ eV (Balmer) $g_{0,2} = 2^2$
$\chi_{0,3} = 12.10$ eV (Paschen) $g_{0,3} = 3^2$

Boltzmann gives:

$$\log \frac{n_{0,2}}{n_{0,1}} \cong -7.9 \qquad \frac{n_{0,2}}{n_{0,1}} \cong 1.2 \times 10^{-8}$$

$$\log \frac{n_{0,3}}{n_{0,1}} \cong -9.2 \qquad \frac{n_{0,3}}{n_{0,1}} \cong 6 \times 10^{-10}$$

At T = 6000 K, only about 1 in 10^8 H atoms is not in ground level

Approximate total hydrogen number density as

$$n_0(H) \approx n_{0,1}(H) \Rightarrow \frac{n_{0,3}(H)}{n_0(H)} = \frac{n_{0,3}(H)}{n_{0,1}(H)}$$

Calculate relative importance of H^- in optical from

$$\frac{n_{0,3}(H)}{n(H^-)} = \frac{n_{0,3}(H)}{n_0(H)} \Big/ \frac{n(H^-)}{n_0(H)}$$

$$\frac{n_{0,3}(H)}{n(H^-)} = \frac{6 \times 10^{-10}}{3 \times 10^{-8}} = 2 \times 10^{-2}$$

Where $n(H^-)/n_0(H)$ calculated before (LTE lecture)
H^- absorption ~100 times more than Paschen continuum, ($3646 < \lambda < 8206$) since cross sections are similar.
Absorption ~ $n\sigma$

What about Balmer continuum ($912 < \lambda < 3646$) ?

$$\frac{n_{0,2}(H)}{n(H^-)} = \frac{1.2\times10^{-8}}{3\times10^{-8}} = 0.4$$

So in Balmer continuum bound-free opacity due to absorptions to $n = 2$ is comparable to H^- opacity

Opacity determined by $n\sigma$. σ from atomic physics.
n depends on species present and level populations

In solar type stars ($T \sim 6000$ K), shown that in optical H^- opacity dominates over Paschen continuum opacity (photoionization from $n = 3$), but in Balmer continuum ($n = 2$) H bound-free is comparable to H^-

How does stellar type effect H^- opacity?

Recall Saha equation using electron pressure

$$\log\frac{N(H^0)P_e}{N(H^-)} = \log\frac{2g_0}{g_-} + 2.5\log T - \theta\,\chi_r - 1.48$$

$$\log\frac{N(H^-)}{N(H^0)} = \log P_e - \log\frac{2g_0}{g_-} - 2.5\log T + \theta\,\chi_r - 1.48$$

Depends on P_e, so H^- more important in main sequence stars than giants of same temperature due to P_e proportionality

H and H^- Opacity in A Stars

A star: $T = 10^4$ K, $\log P_e = 2.0$, $\log T = 4.0$, $\theta = 0.5$

$$\log \frac{N(H^0)}{N(H^-)} = \log \frac{2g_0}{g_-} + 2.5 \log T - \theta\,\chi_r - 1.48 - \log P_e \approx +6.7$$

$$\frac{N(H-)}{N(H^0)} \approx 2 \times 10^{-7}$$

So $n(H^-)/n_0(H)$ is about six times more than solar value

Compare H atoms in $n = 3$ (Paschen continuum)

$$\frac{N_{0,3}}{N_{0,1}} \approx 10^{-5} \Rightarrow \frac{N_{0,3}}{N(H^-)} = \frac{10^{-5}}{2 \times 10^{-7}} \approx 0.5 \times 10^2$$

About 100 times more H atoms in $n = 3$ than H^- ions

Neutral H is dominant optical opacity in A stars

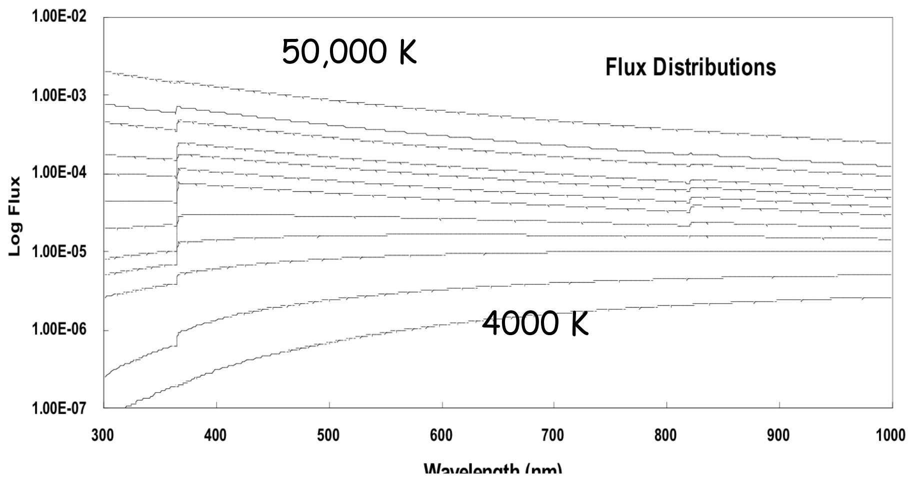
Large changes in opacity across Paschen and Balmer limits

Prominent Balmer and Paschen jumps in spectra of A stars

The Paschen Continuum

- The Paschen continuum slope (B-V) is a good temperature indicator
- Varies smoothly with changing temperature
- Slope is negative (blue is brighter) for hot stars and positive (visual is brighter) for cooler stars
- B-V works as a temperature indicator from 3500K to 9000K (but depends on metallicity)
- For hotter stars, neutral H and H- opacities diminish, continuum slope dominated by Planck function, and the Rayleigh-Jeans approximation gives little temperature discrimination

Paschen Continuum vs. Temperature



The Balmer Jump

- The Balmer Jump is a measure of the change in the continuum height at 3647A due to hydrogen bound-free absorption
- Measured using U-B photometry
- Sensitive to temperature BUT ALSO
- Sensitive to pressure or luminosity (at lower gravity, the Balmer jump is bigger – recall that κ_{bf} depends on ionization, and hence on P_e)
- Works for 5000 < Teff < 10,000 (where H_{bf} opacity is significant)

Flux Distributions at T=8000