Effective Temperature Determination

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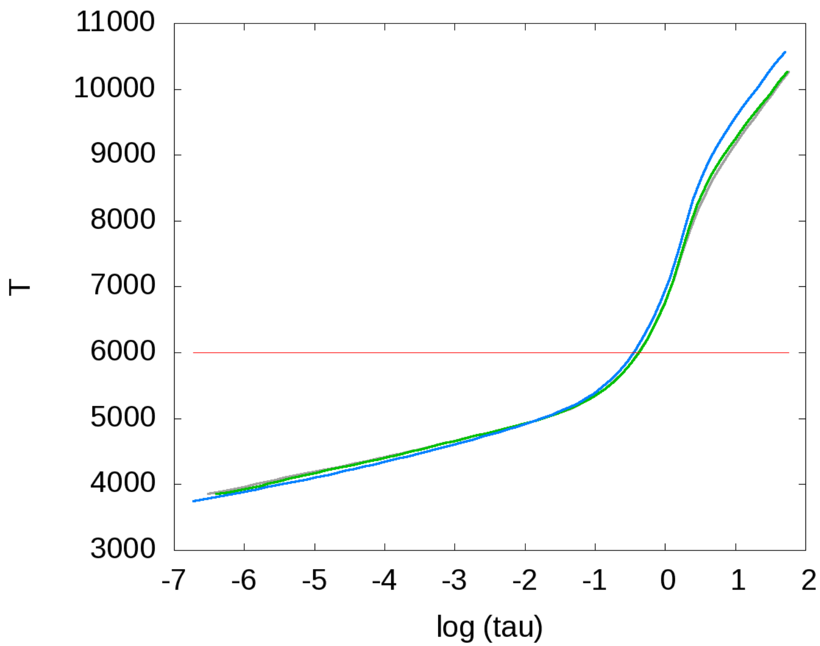
Effective Temperature

$$\sigma T_{eff}^4 \equiv \int_0^\infty F_\nu \, d\nu = F_\star = \frac{L}{4\pi R^2}$$

- It is the temperature of a black body that gives the same total power per unit area.
- Physically related to $F_\star$ total radiant power per unit area at stellar surface.
- **Directly** given by stellar luminosity and radius.

Depth Dependence

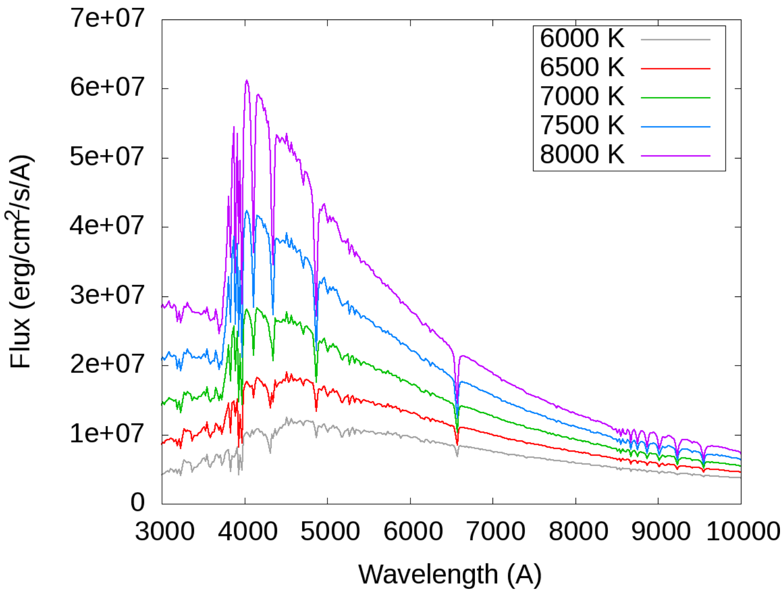
- Temperature of line forming region is lower than T_{eff}
- Spectral lines are formed at different depths and temperatures.



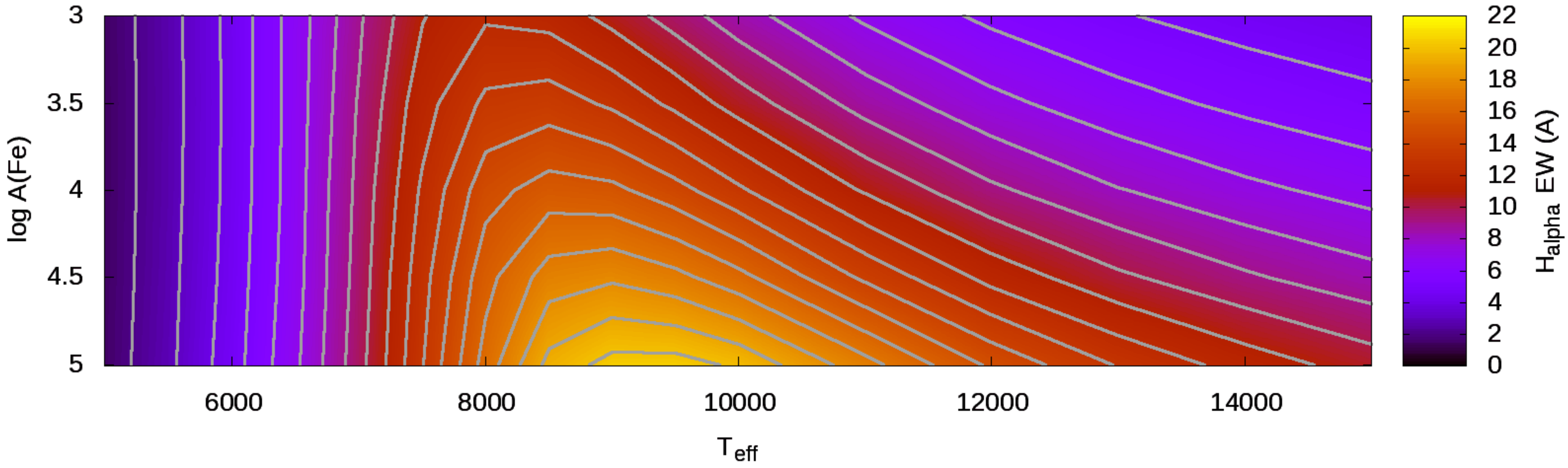
T_{eff} 6000, log g 4.5

Paschen Continuum

- Using stellar fluxes to determine Teff
- Requires accurate moderate-resolution flux-calibrated spectra or spectrophotometry.
- Basis for T_{eff} – colour calibrations
    - More in later lecture



Balmer Profiles

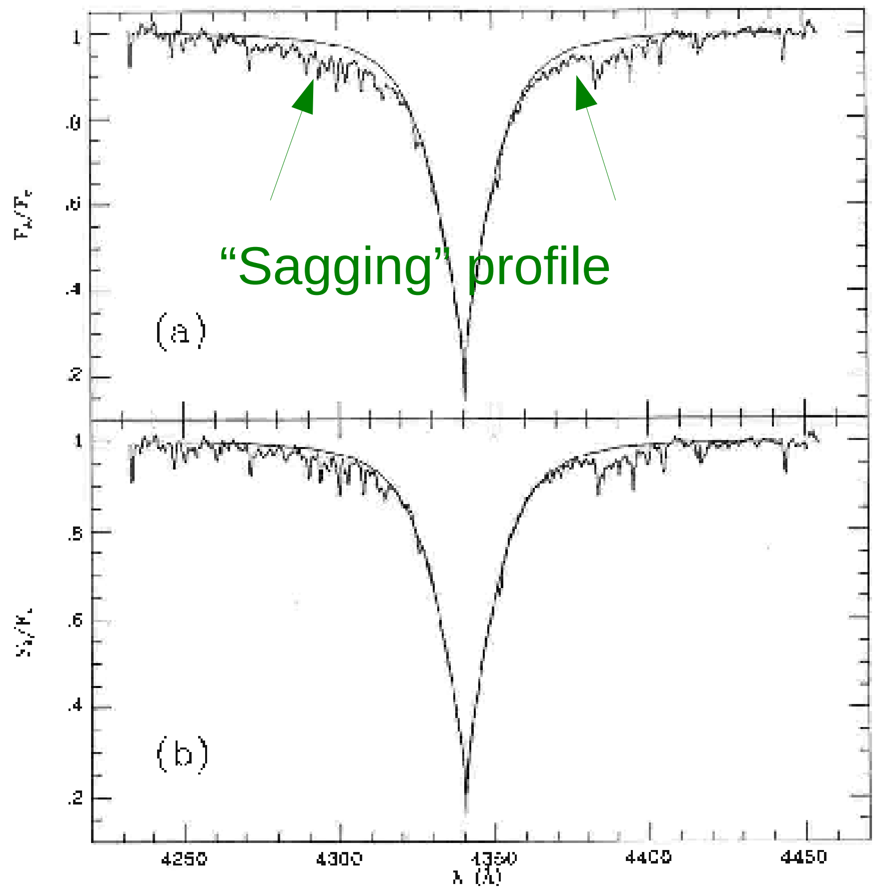


- The Balmer lines provide good T_{eff} diagnostic below around 8000K due to low sensitivity to surface gravity.
- For hotter stars sensitivity to both T_{eff} and log g.

Balmer Line Normalization

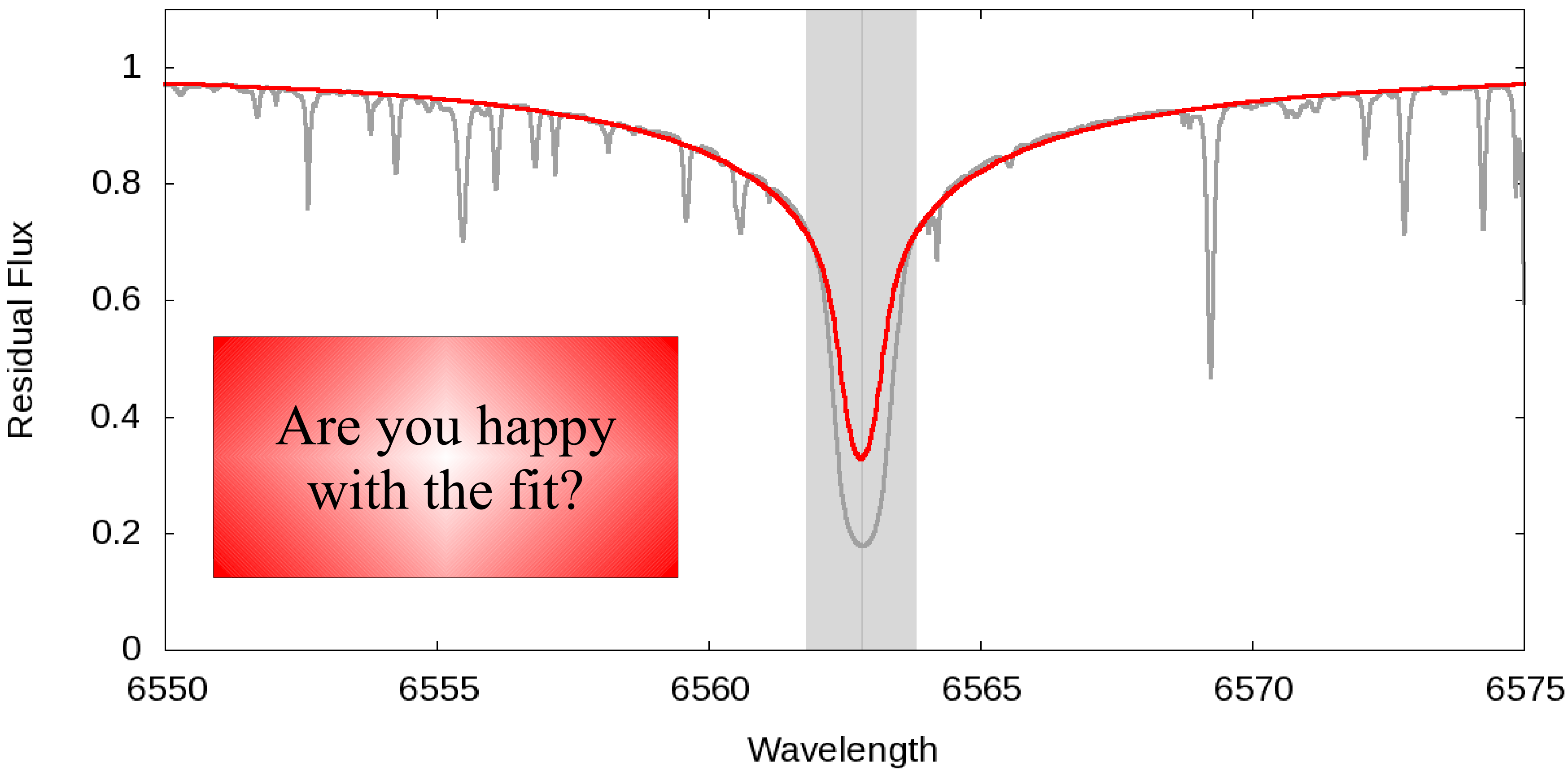
- Broad lines require careful continuum determination
  - Must preserve true profile shape
- Echelle spectra usually give poor profiles due to curved orders
- Medium-resolution single order spectra preferred

Vega



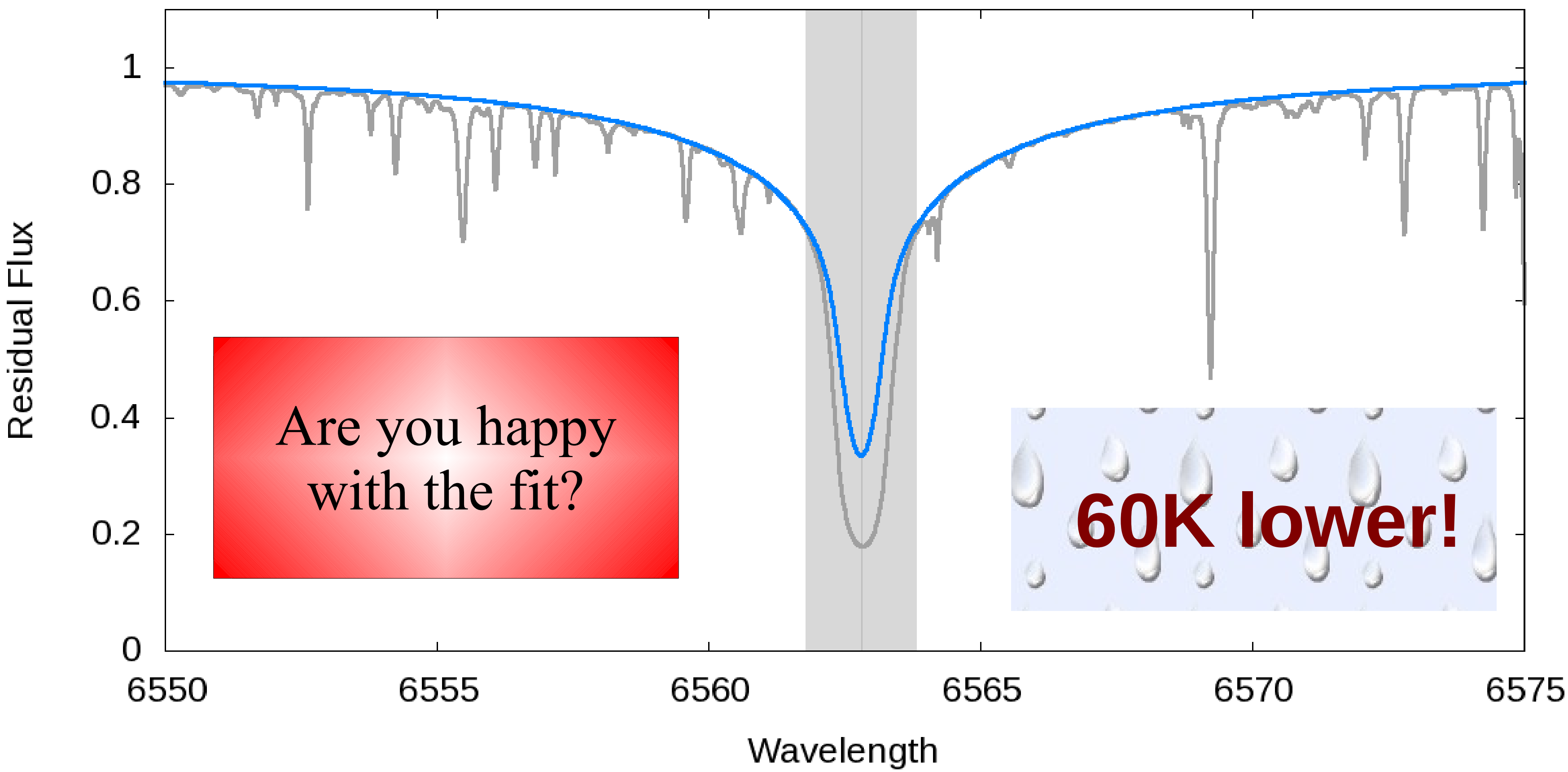
Smalley 1992 PhD Thesis

Solar H_α



T_{eff} 5777 log g 4.44

Solar H_α



3-d, Convection, Line broadening

T_{eff} 5720 log g 4.44

See for example Cayrel et al., 2011, A&A, 531, 83

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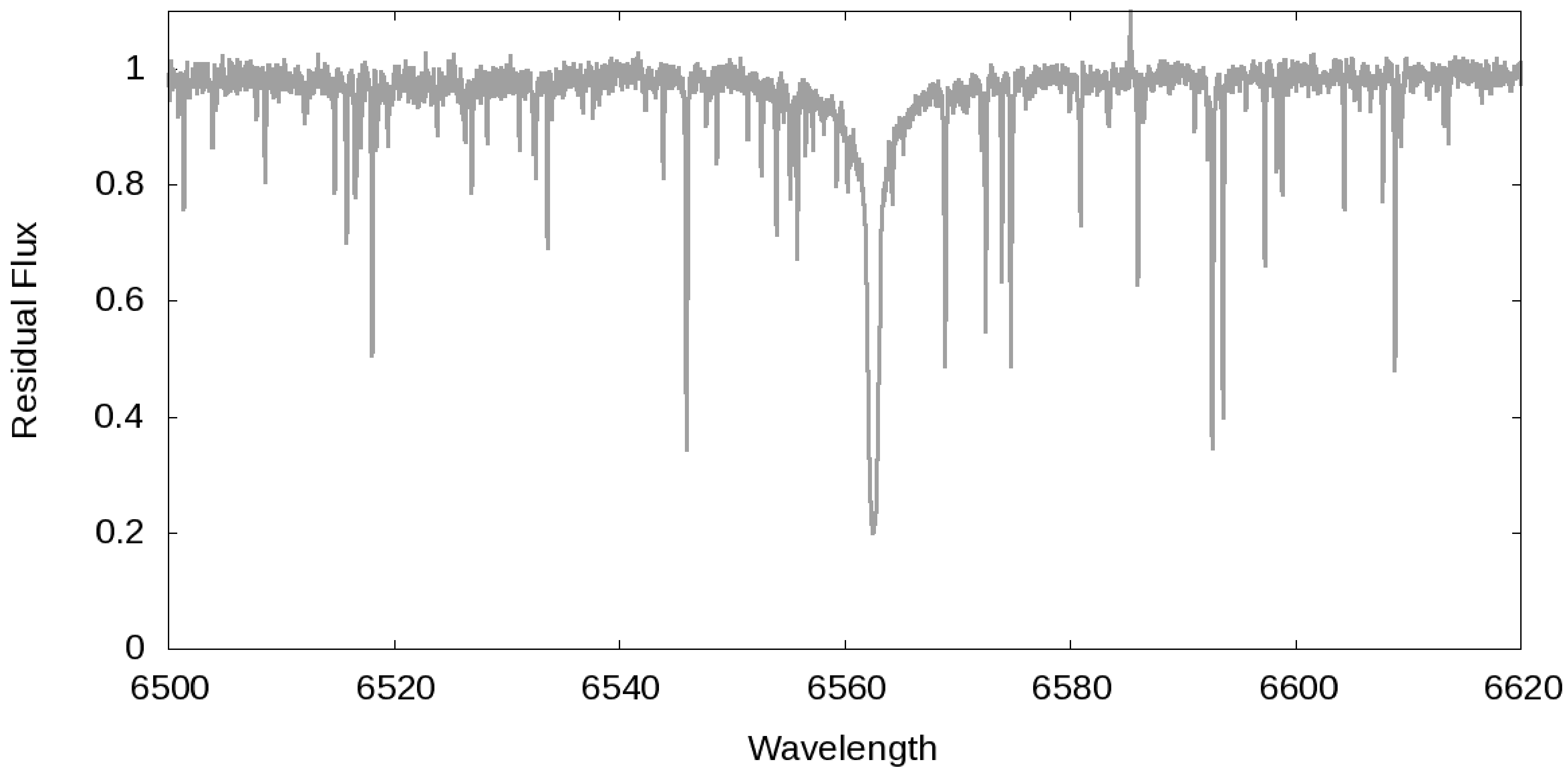

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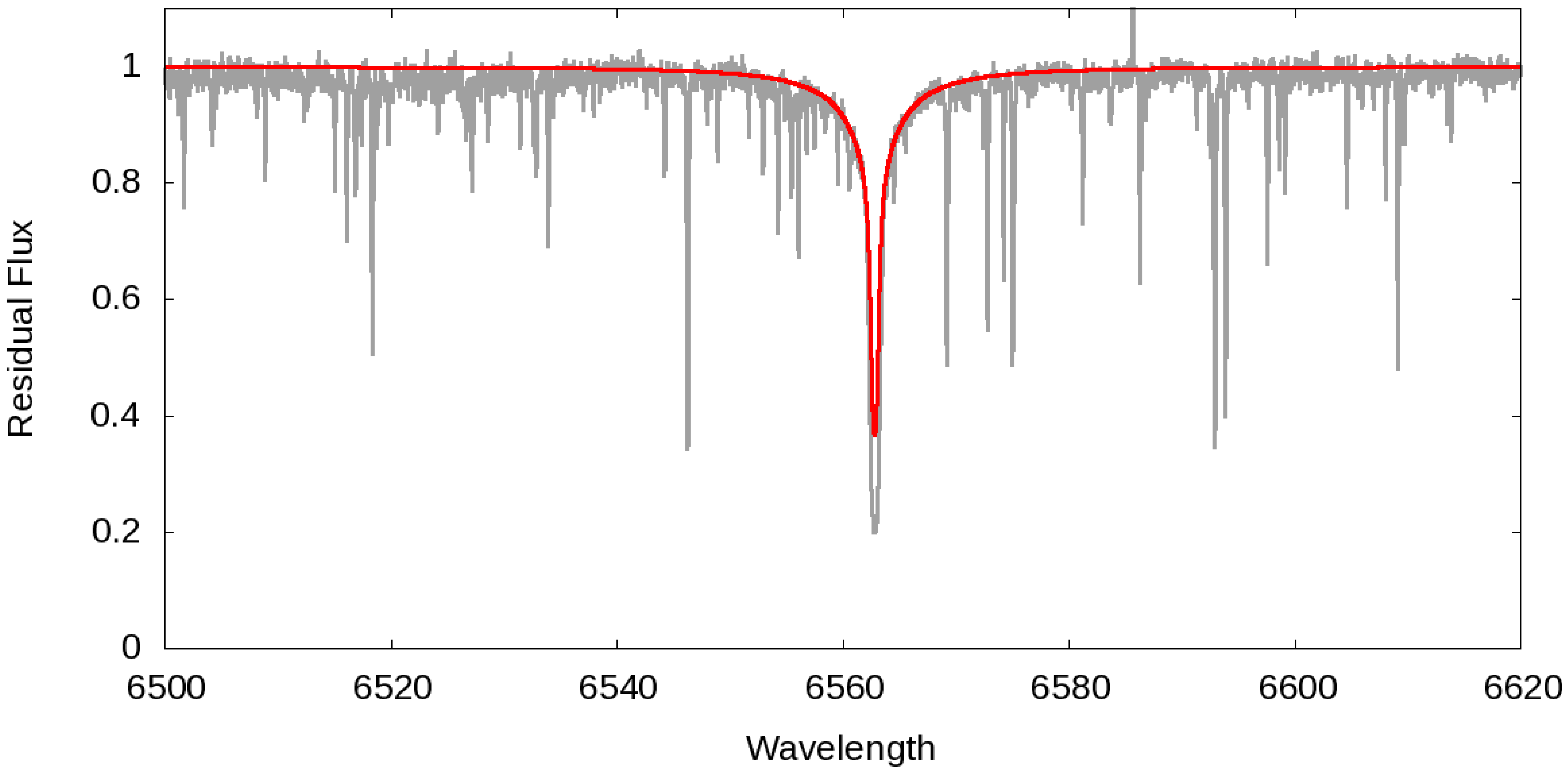

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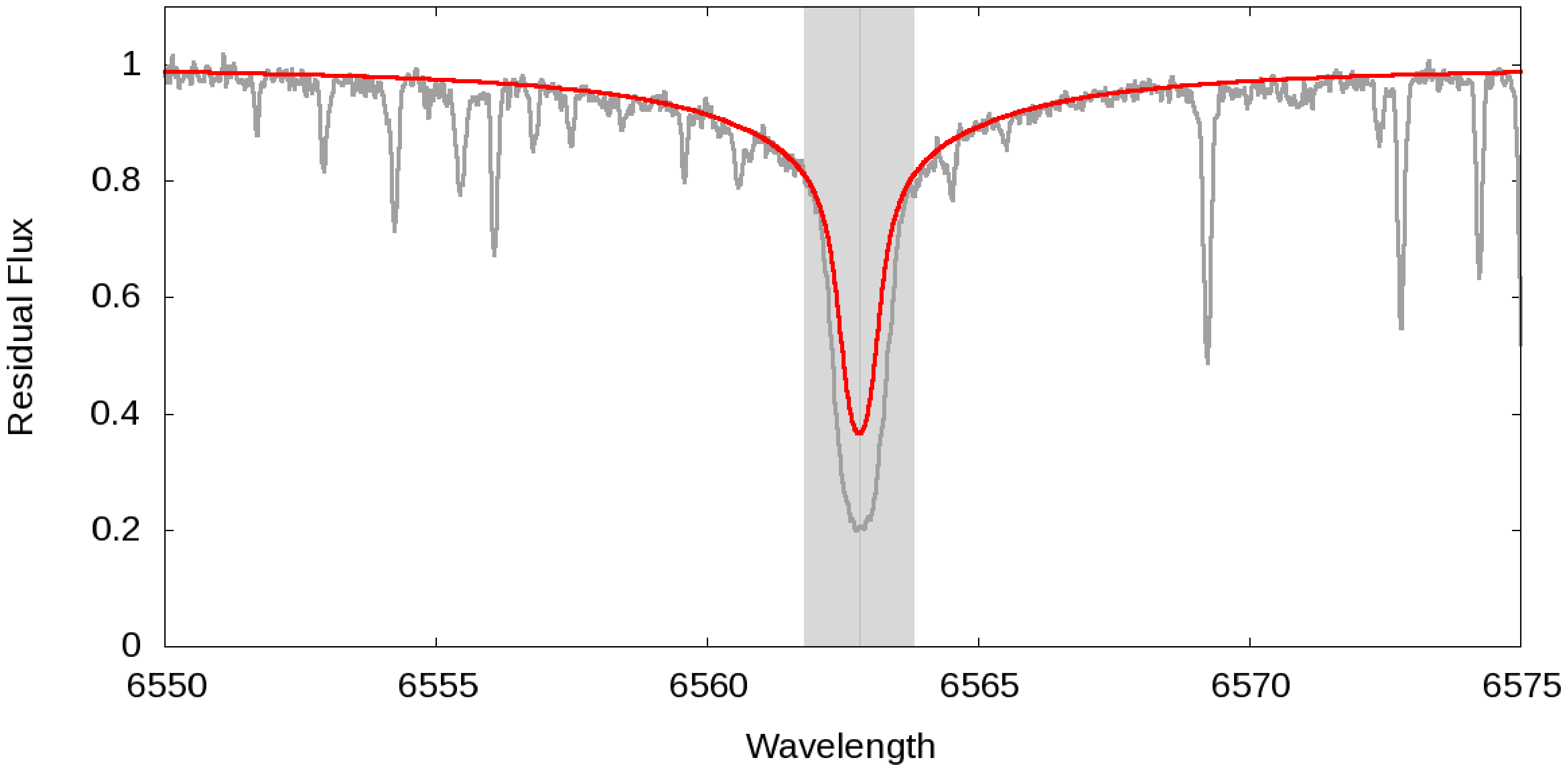

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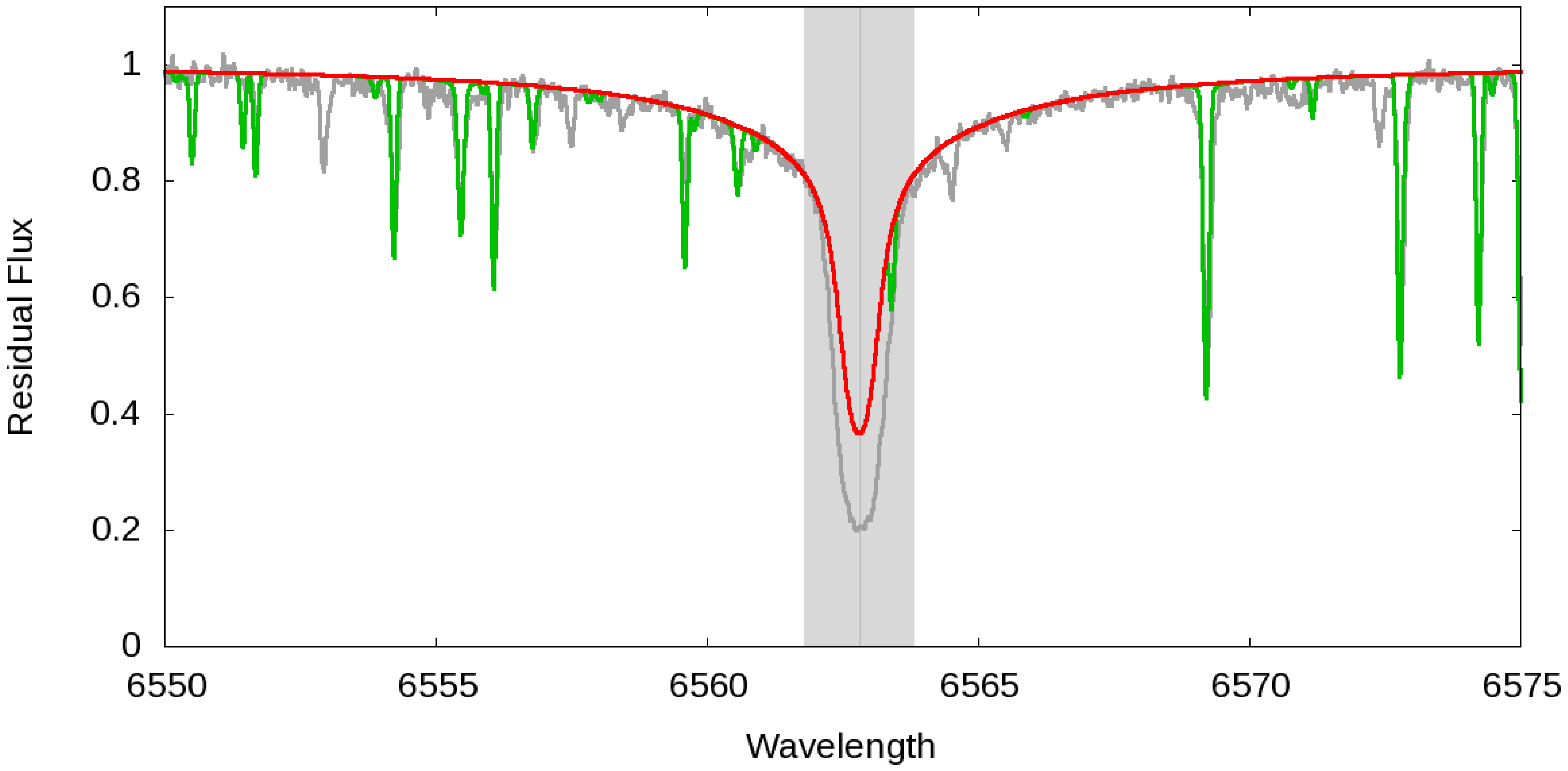

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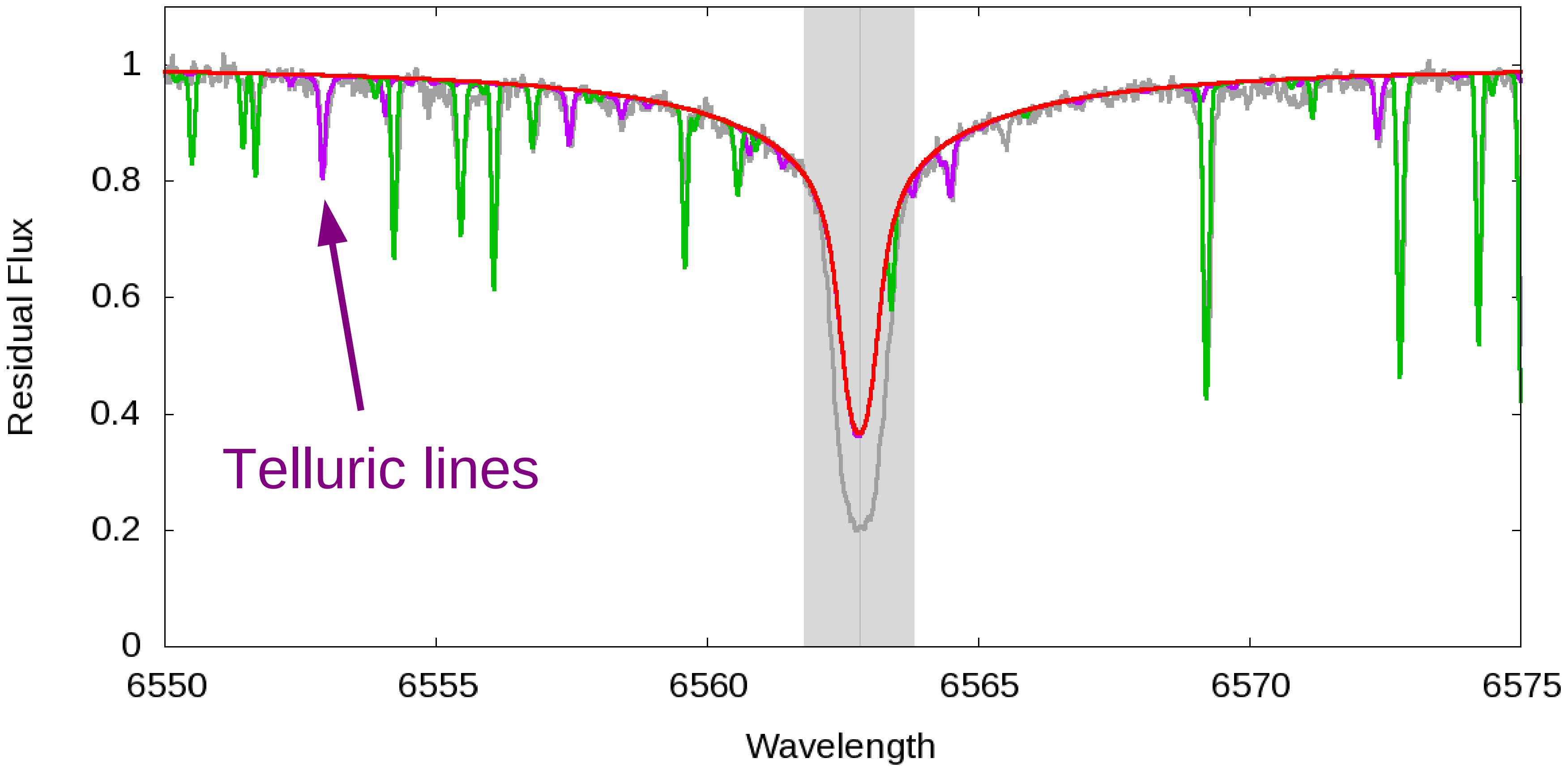

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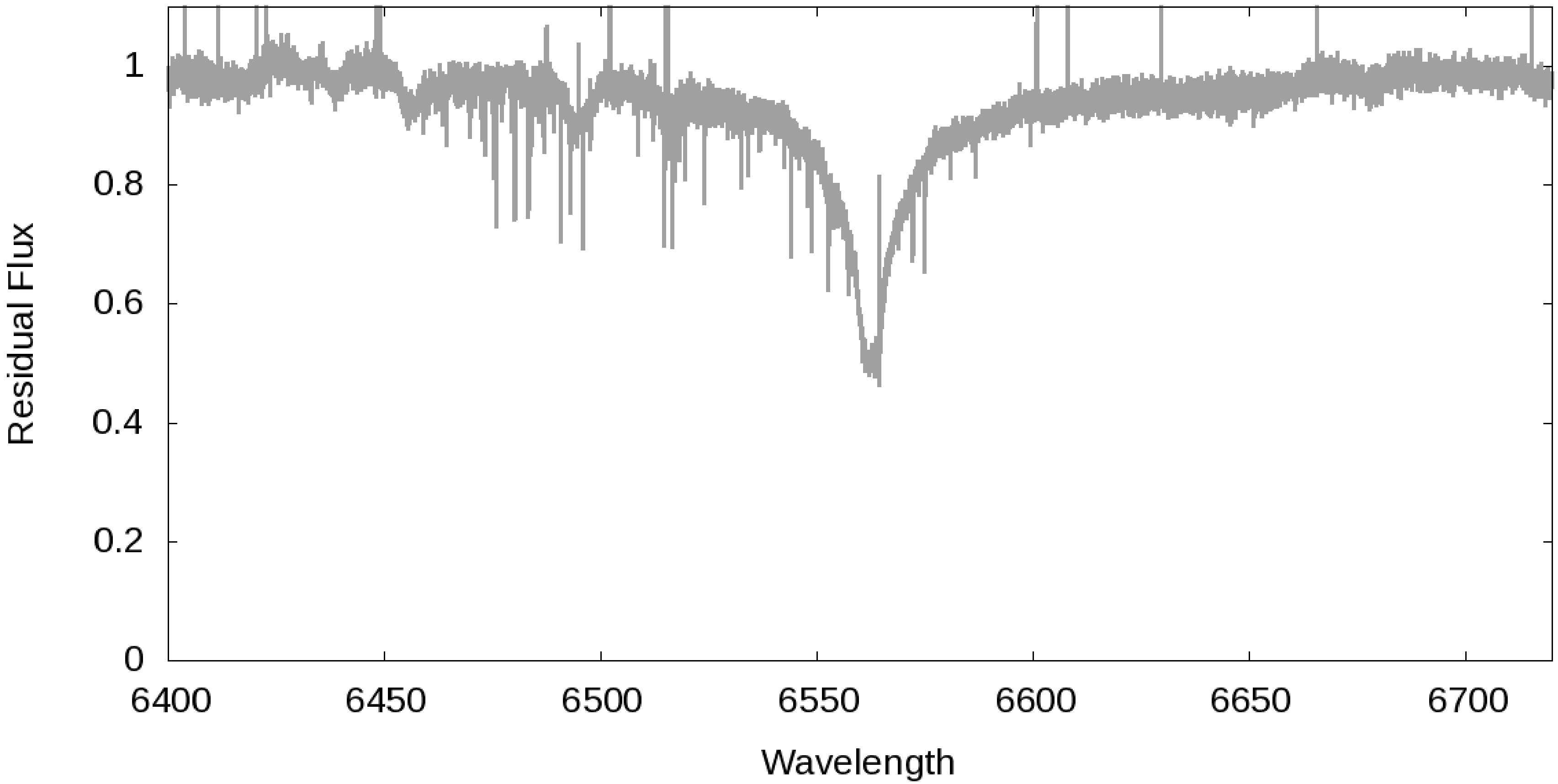

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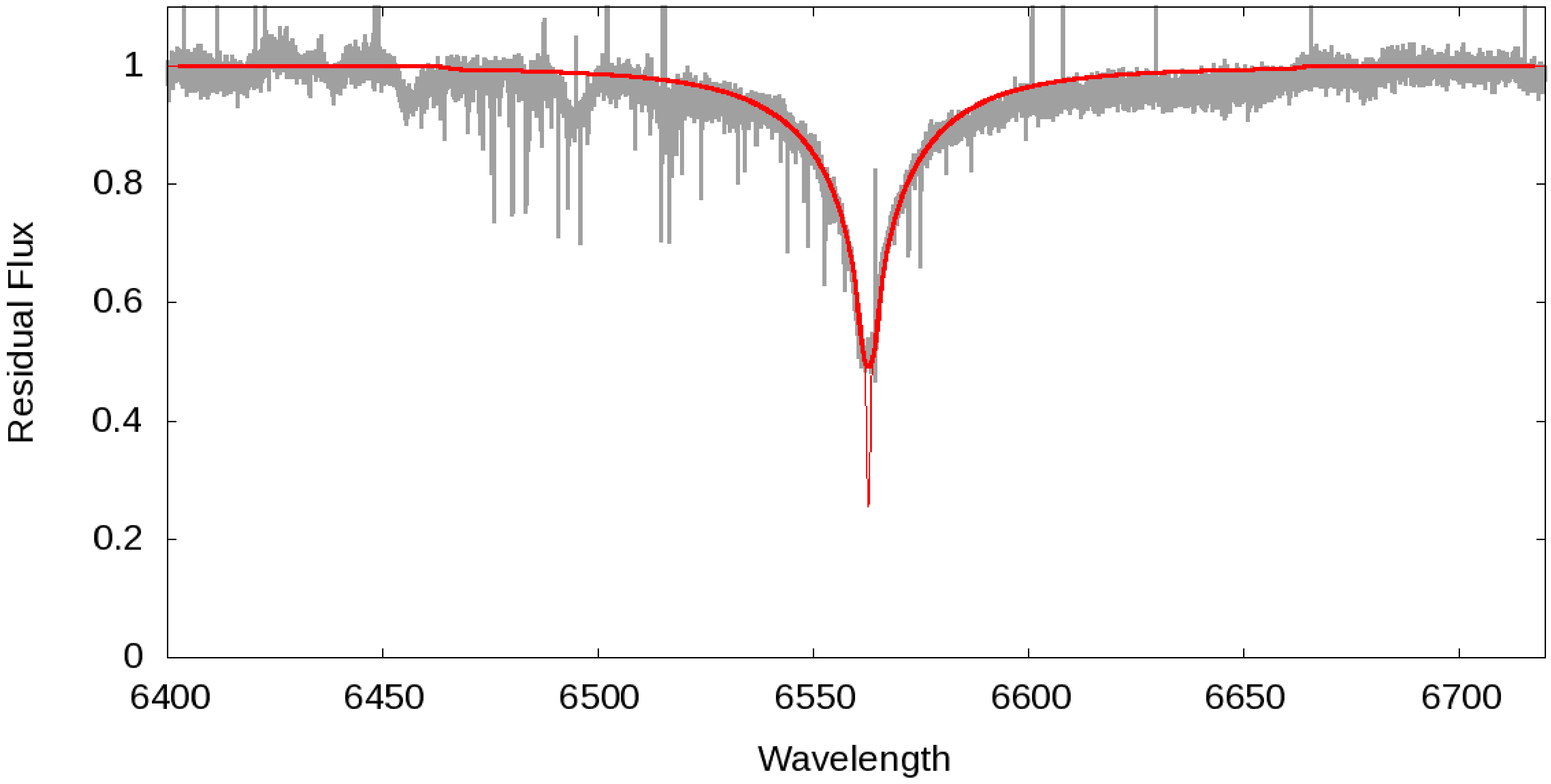

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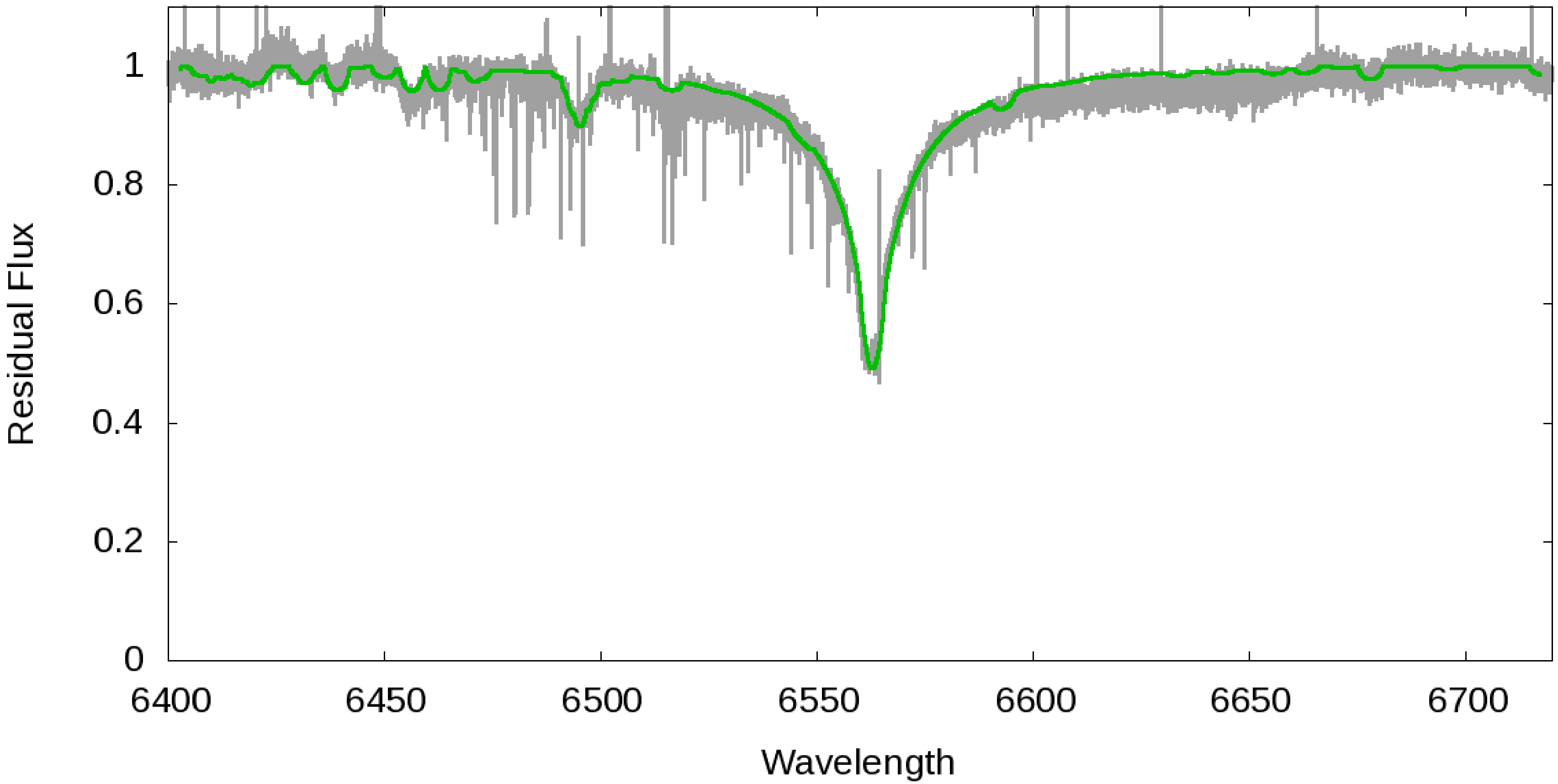
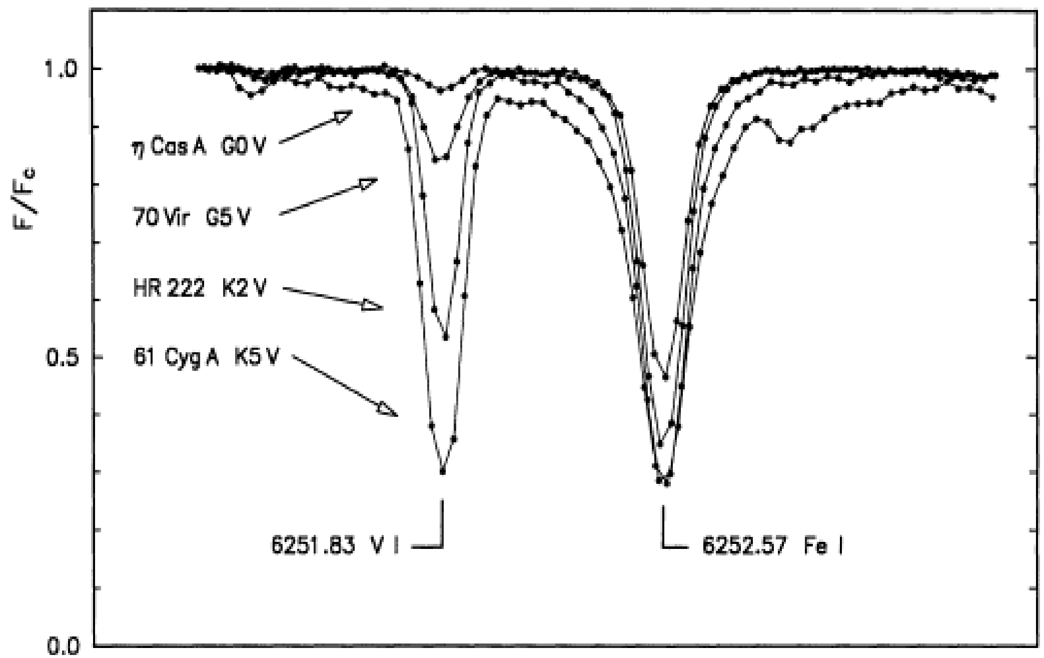


Spectral Line depth ratios



Gray & Johanson, 1991, PASP, 103, 439

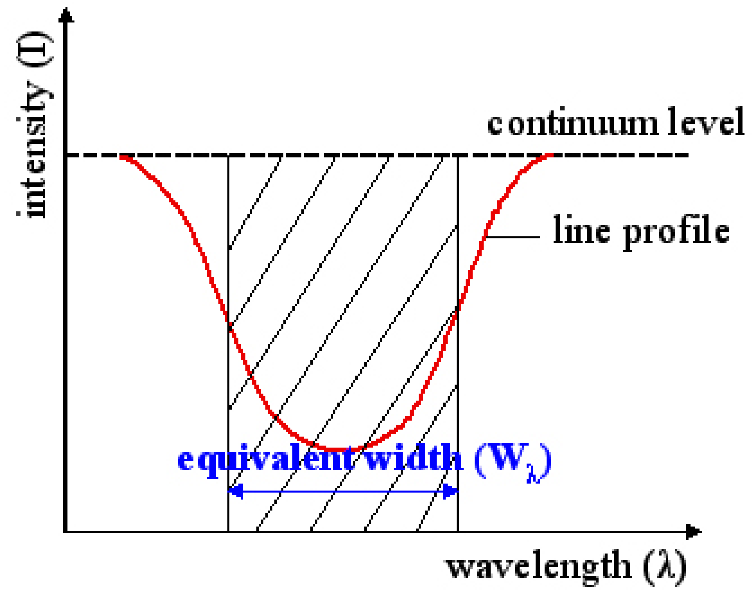
- Line depth ratios
  - Differing excitation potentials
  - Precise to ±10K
- A measure of temperature in line forming regions
  - Model dependent

Tied to T_{eff} scale by empirical calibrations.

Good for looking for T_{eff} variations in a given star

Equivalent Width

- Measure of number of absorbers
  - Abundance
- BUT
  - No information on profile shape
  - Wings can affect measurement



$$W_\lambda = \int (1 - F_\lambda / F_0) d\lambda$$

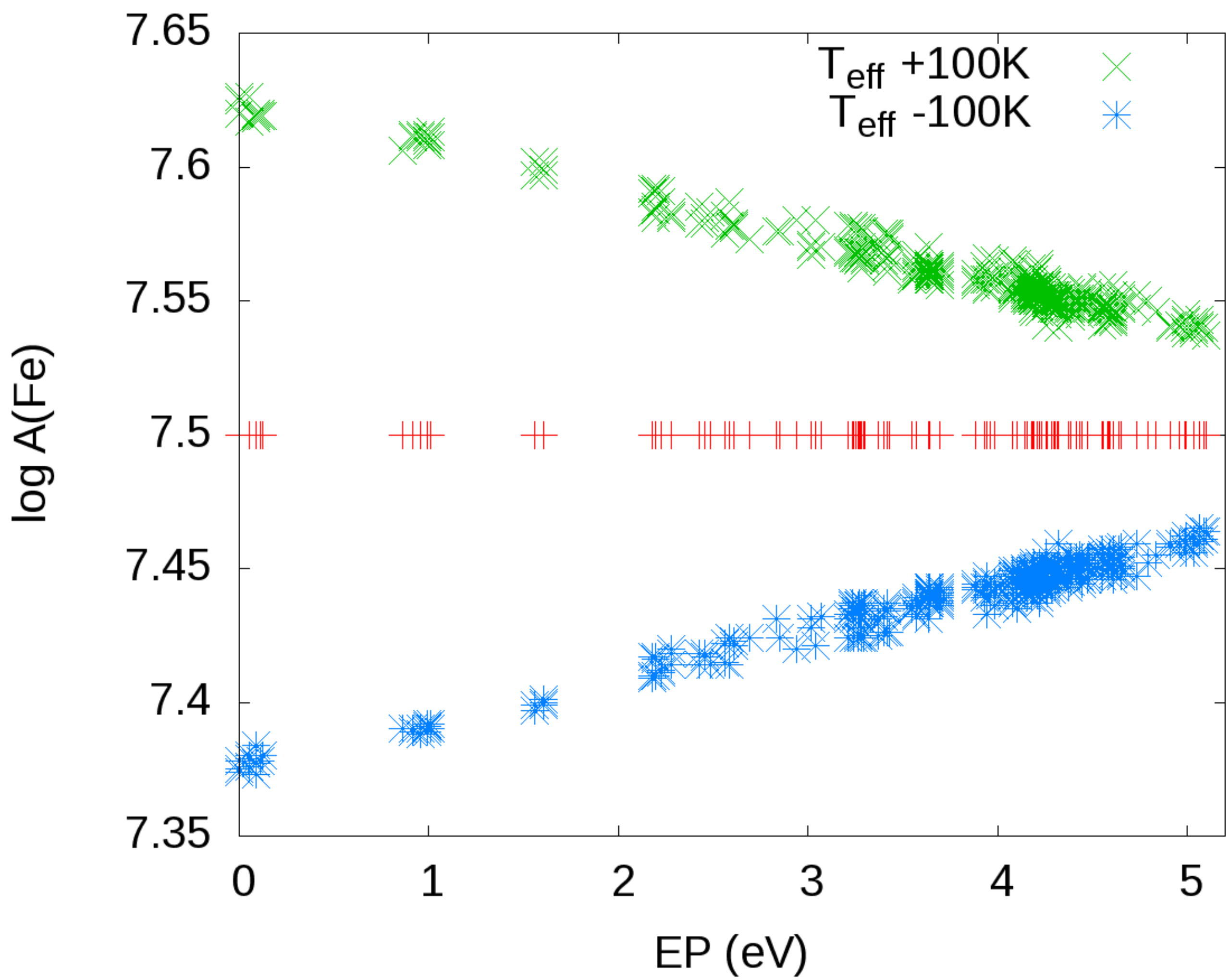
Metal Line Diagnostics

- Excitation Potential
  - Abundances from the same element should agree for all excitation potentials
- Ionization Balance
  - The abundances obtained from differing ionization stages of the same element <u>must</u> agree
  - Fe I/Fe II ratio can be used as a T_{eff} – log g diagnostic

Exploring Excitation Potential

- Use lines that are not pressure sensitive
  - Solar-type stars, use neural metals
  - In hotter stars, use ionised metals
  - Weak lines to avoid saturation effects
- Generated a simulated set of “observed” equivalent widths (W_0/λ).
  - Model: T_{eff} 6000 K, log *g* 4.5, log A(Fe)7.50
  - Take Fe I lines taken from Kurucz gfall linelist in wavelength range 5000 – 6000 Å
  - Select those with 5 < EW < 100 mÅ

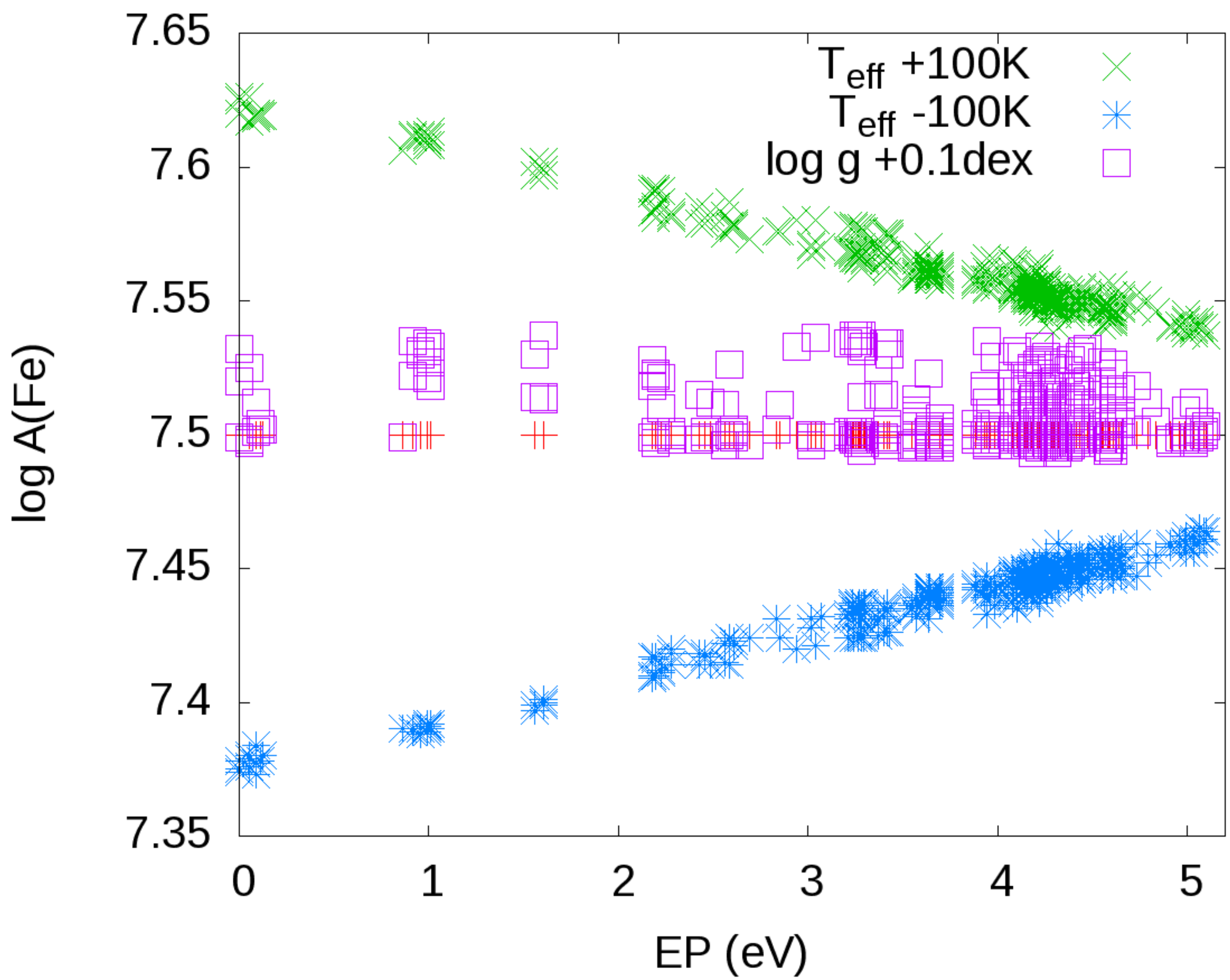
Change Temperature



Base model
Teff = 6500
log g = 4.5
log A(Fe) = 7.50

Note change in mean log A(Fe) by ±0.18 dex

Change Surface Gravity



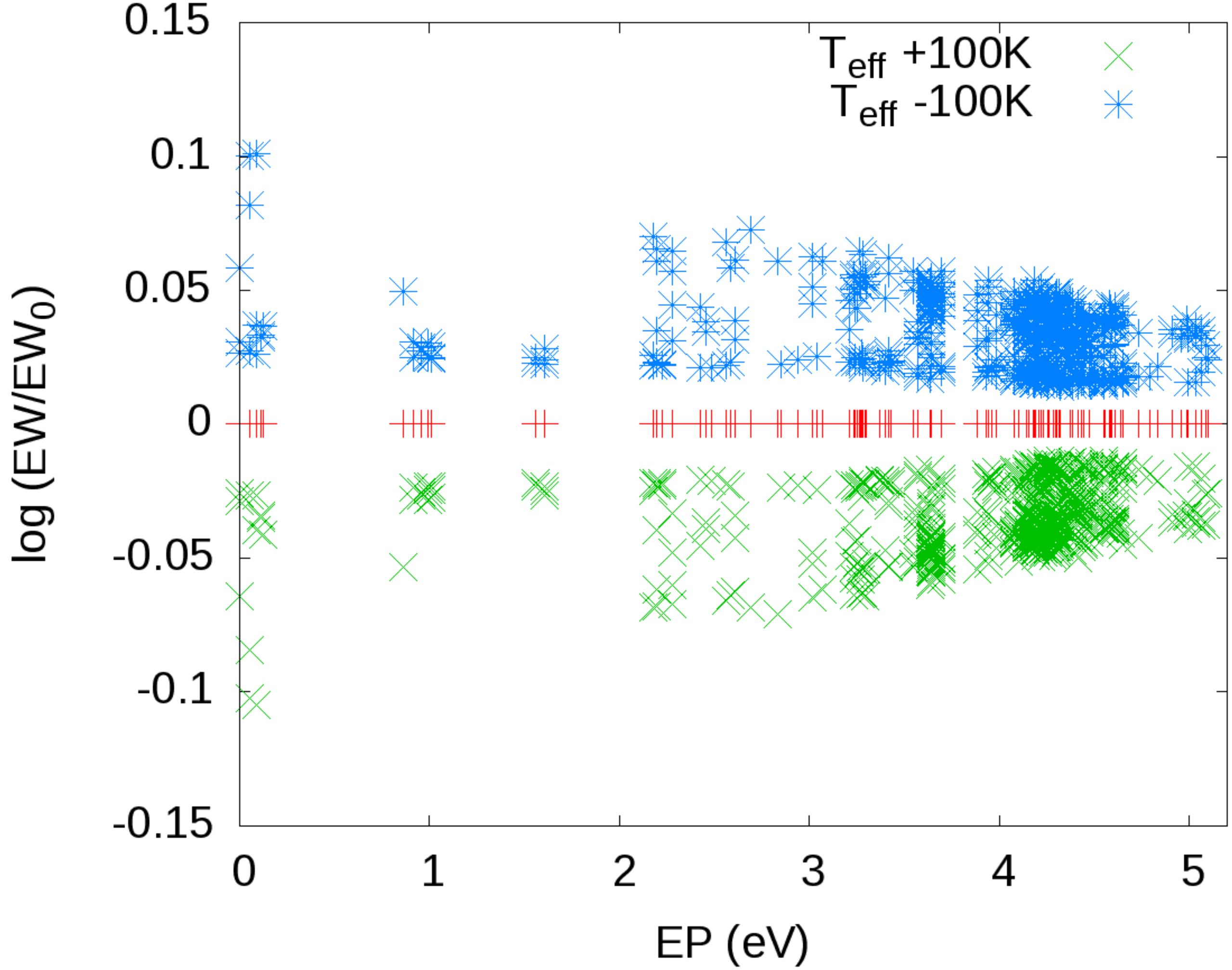
A lack of abundance correlation

- Analysis method searches for zero correlation between log A and EP:
  - Regression fit and find where gradient is zero
  - Could use where correlation coefficient is zero
- Error estimates
  - 1-sigma error on gradient or correlation coefficient
  - 1% error in W_λ gives ~10K in T_{eff}
    - 5% , 50K; 10%, 100K
  - ±0.1dex in log g gives ±20K in T_{eff}

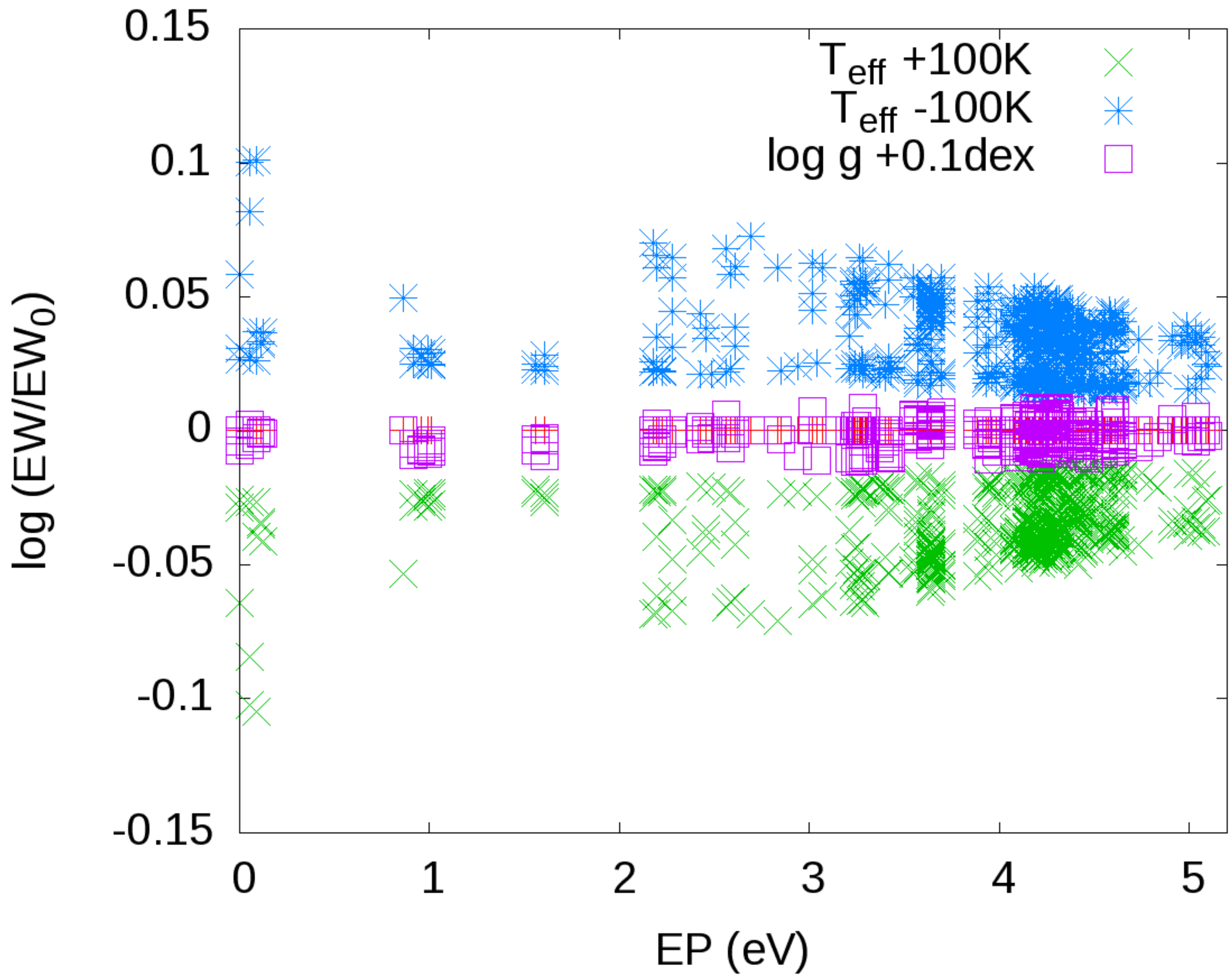
Equivalent width correlation

- From a "*philosophical*" viewpoint all Fe I lines in the atmosphere should have the same abundance.
- Since $\log\left(\frac{w}{\lambda}\right) \propto \log A$ we can change the procedure to using equivalent width differences.
- Let us use $\log\left(\frac{w}{\lambda}\right) - \log\left(\frac{w_0}{\lambda}\right) = \log\left(\frac{w}{w_0}\right)$
- Now plot this against EP
  - Assume an abundance: log A(Fe) = 7.50

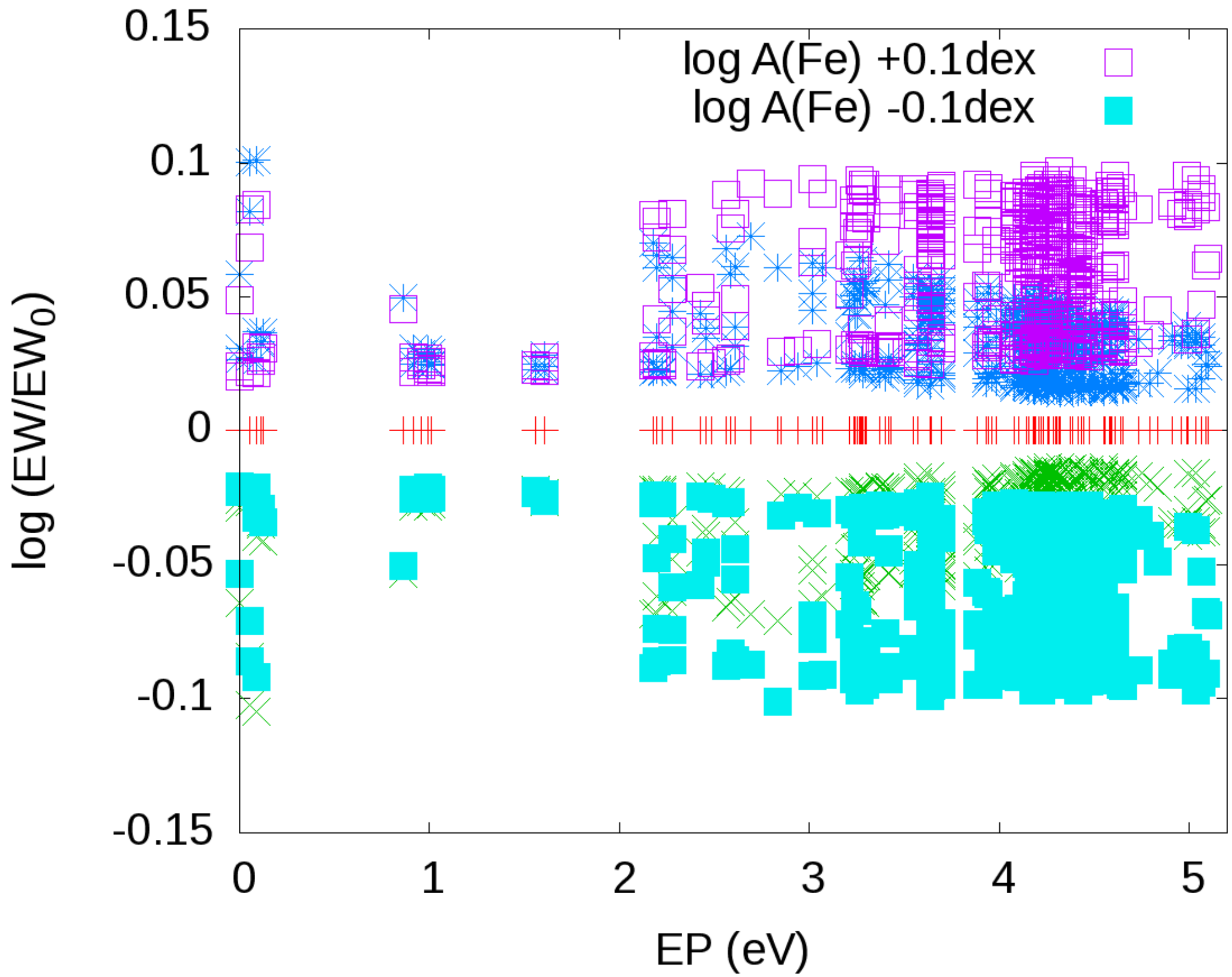
Change Temperature



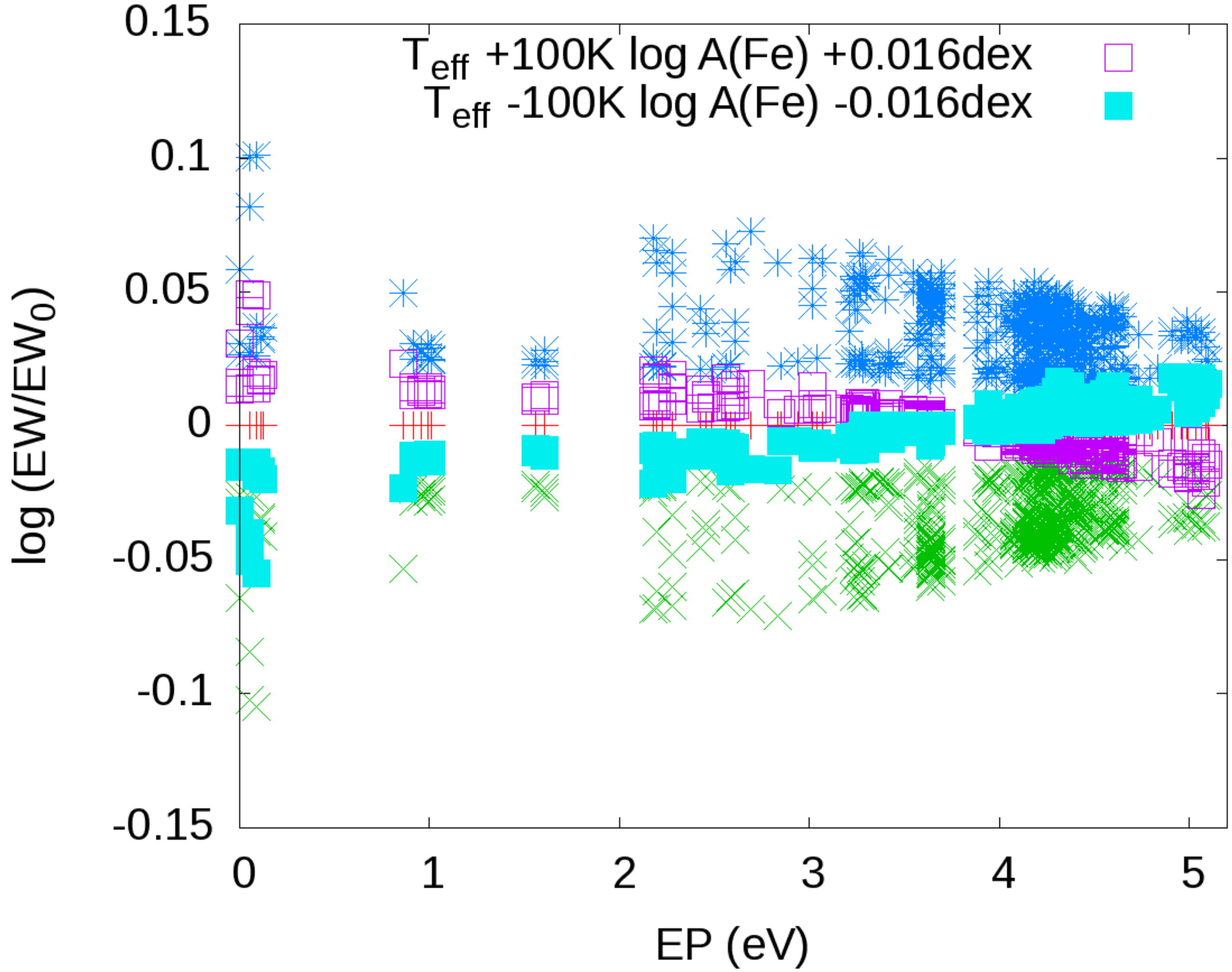
Change surface gravity



Change Abundance



Change Teff and log A(Fe)



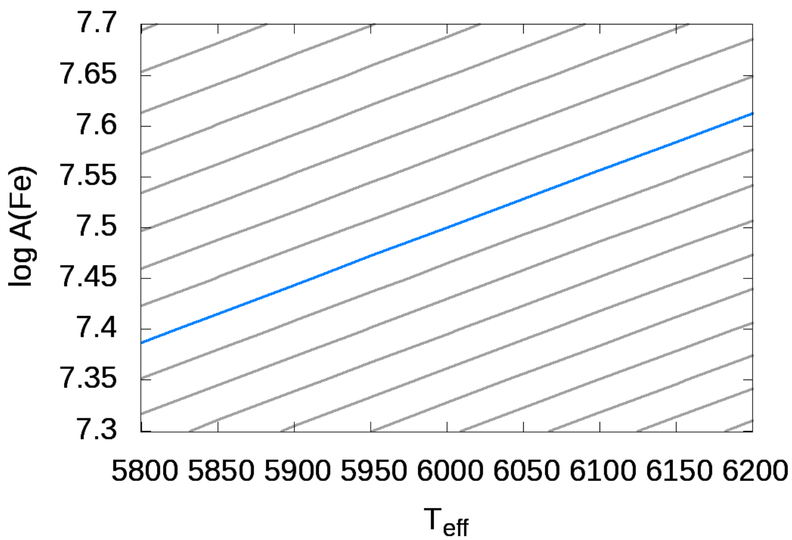
“Total” Equivalent Width

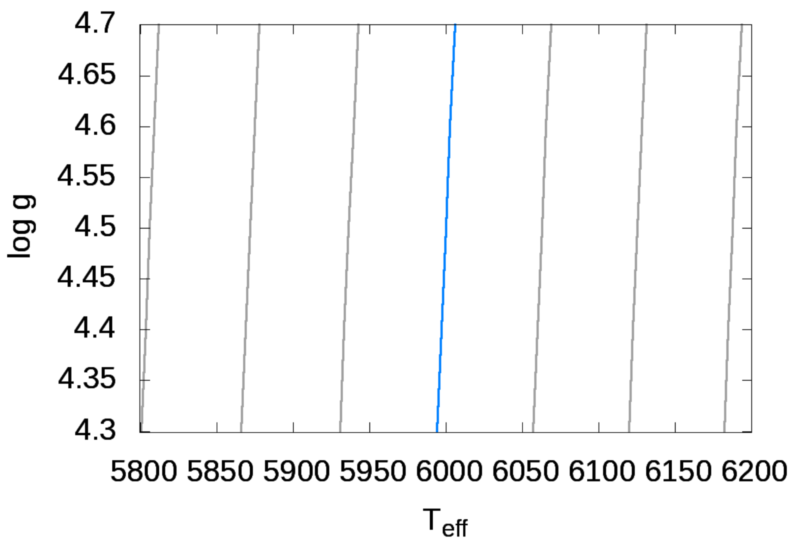
- Rather than using individual equivalent width differences, now use sum of the differences:

$$\sum \log\left(\frac{W}{W_0}\right)$$

- Rather than trend with EP, just have one number
  - Would appear to be a loss of information?

Total EW Trends



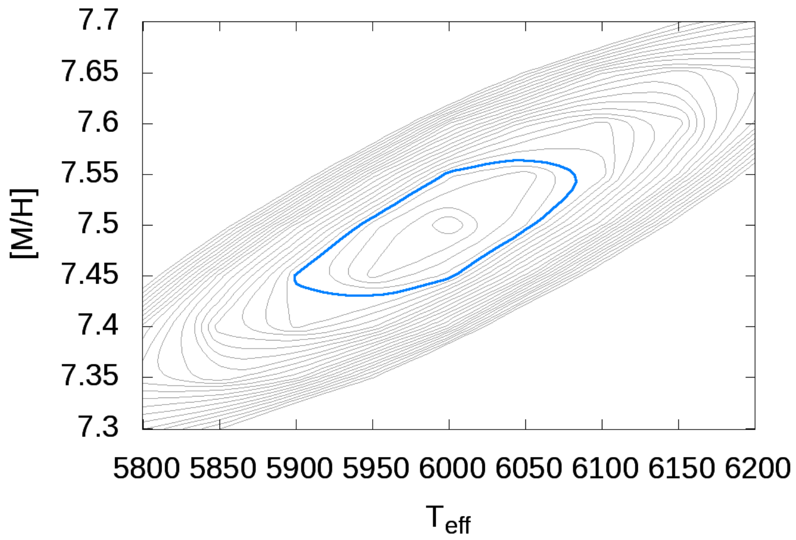


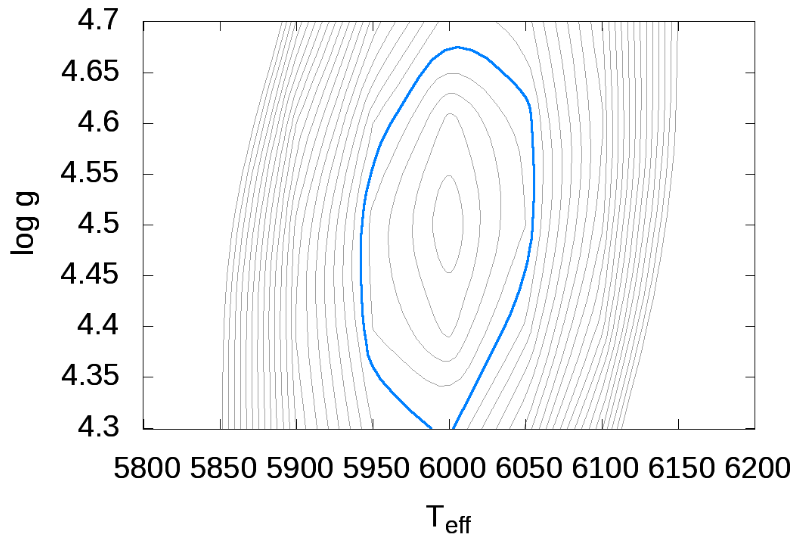
- Trend in log A(Fe) with T_{eff}
- T_{eff} virtually insensitive to log *g*

Using χ2 instead

- Measuring equivalent widths might not always be practical.
  - Blending, high rotation, etc.
- Now consider T_{eff} determination using χ^2 fitting to spectrum
    - Generated with ***all*** lines >5mÅ in range 5000-6000Å
    - Same Model: T_{eff} 6000 K, log *g* 4.5, log A(Fe)7.50
  - Assume S/N 100:1 for χ^2 calculation

χ^2 Correlations





- Correlation between [M/H] and T_{eff}
- Weak sensitivity to log *g*

Conclusions on Simulation

- Using log A(Fe) versus EP provides a good determination of T_{eff} visual diagnostic diagram
  - Low sensitivity to log g
- Using EW has log A(Fe) complication
  - "Total" EW has T_{eff} correlated with log A(Fe)
- Using χ^2 gives T_{eff} might be coupled with log A(Fe), but not (significantly) with log g.

At least in this simulated example!

Global Spectral Fitting

- Take a large grid of synthetic spectra with varying T_{eff}, log g, [M/H], etc.
- Locate the best-fitting synthesis
  - Hence obtain T_{eff}, log g, [M/H], etc.
- Issues to consider
  - How reliable are these parameters?
  - What are the hidden dangers?
  - What are realistic error estimates, over and above the internal precision?

Do we care about T_{eff}?

- The effective temperature of a star is not important!
- It is the $T(\tau_0)$ relationship that determines the spectral characteristics.
  - The parameters obtained from spectroscopic methods alone ***may not*** be consistent with the true values
    - Not necessarily important for abundance analyses
    - Important when interested in fundamental properties

Summary

- Currently T_{eff} determinations are generally accurate to no more than 1~2% (50~100K)
- Possible to get an internal precision on measurements that are sensitive to temperature variations of ±10K
  - but accuracy on the true T_{eff} scale is *significantly* less.

Beware T_{eff} values without errorbars!