Composite Spectra

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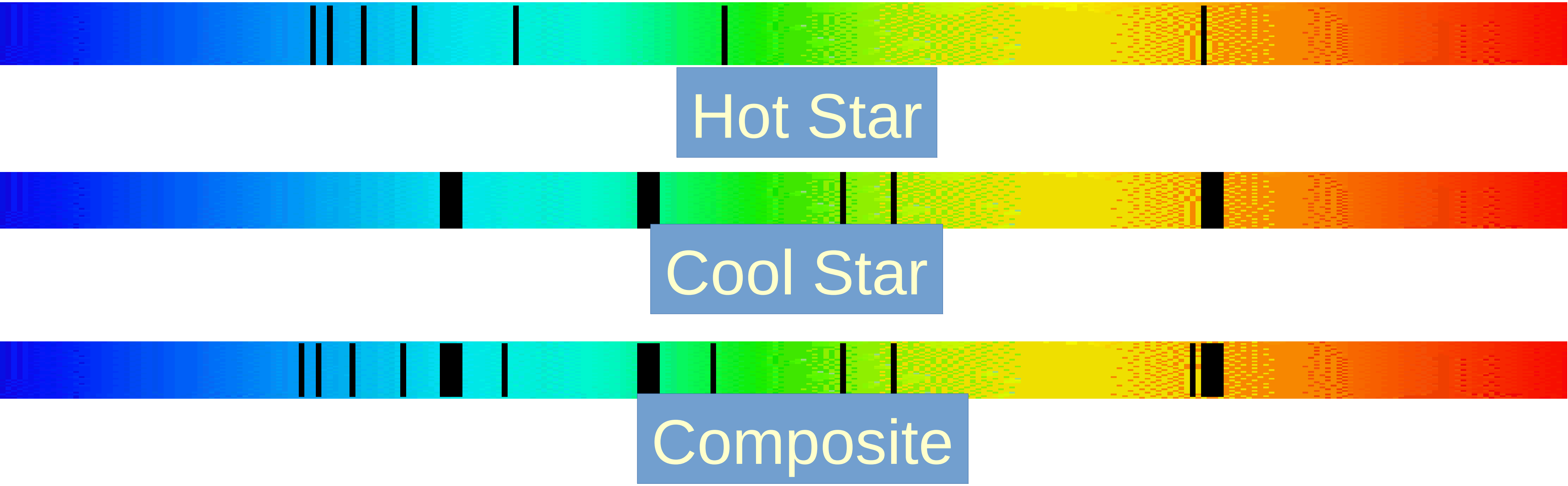
Composite Spectrum



- Spectrum appears to represent two stars
  - composite spectrum

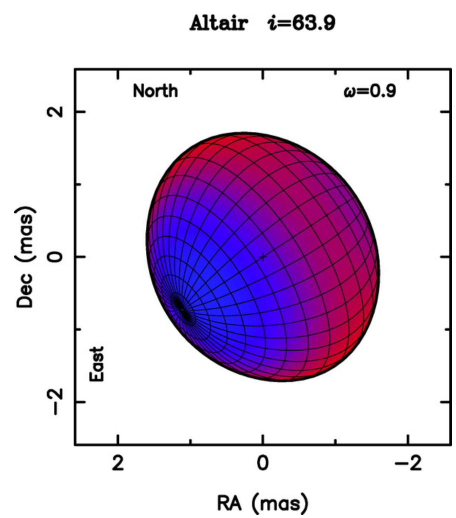
A broader definition

- Spectra which are composed of intensities indicative of more than one T_{eff} (and log g)
  - Surface inhomogeneities
    - Granulation
    - Spots
- Spectra composed of light from more than one object
  - Binaries
  - Background/foreground contamination

A perfect spherical star

- Normally we assume a perfect spherical star
  - They represent “average” values
    - $\langle T_{\rm eff} \rangle$ and $\langle \log g \rangle$

	Pole	Equator
Temperature	8740 K	6890 K
log g	4.266	3.851
Radius	1.636 $R_\odot$	1.988 $R_\odot$

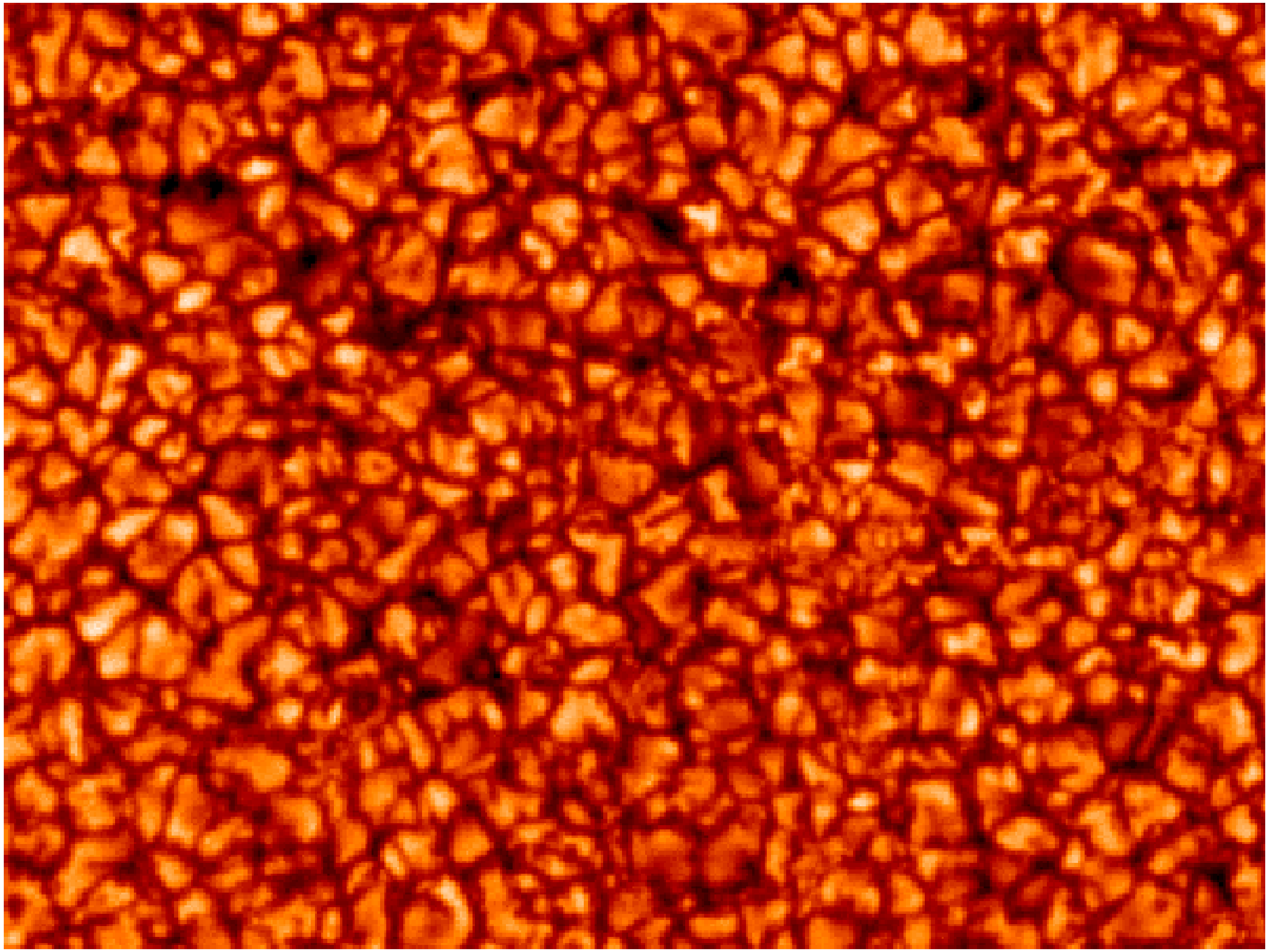


Peterson et al., 2006, ApJ, 636, 1087

Crazy oblate A-type stars !

Cool spotted stars

Solar Granulation



http://zeus.nascom.nasa.gov/~dmueller/gran_intro.htm

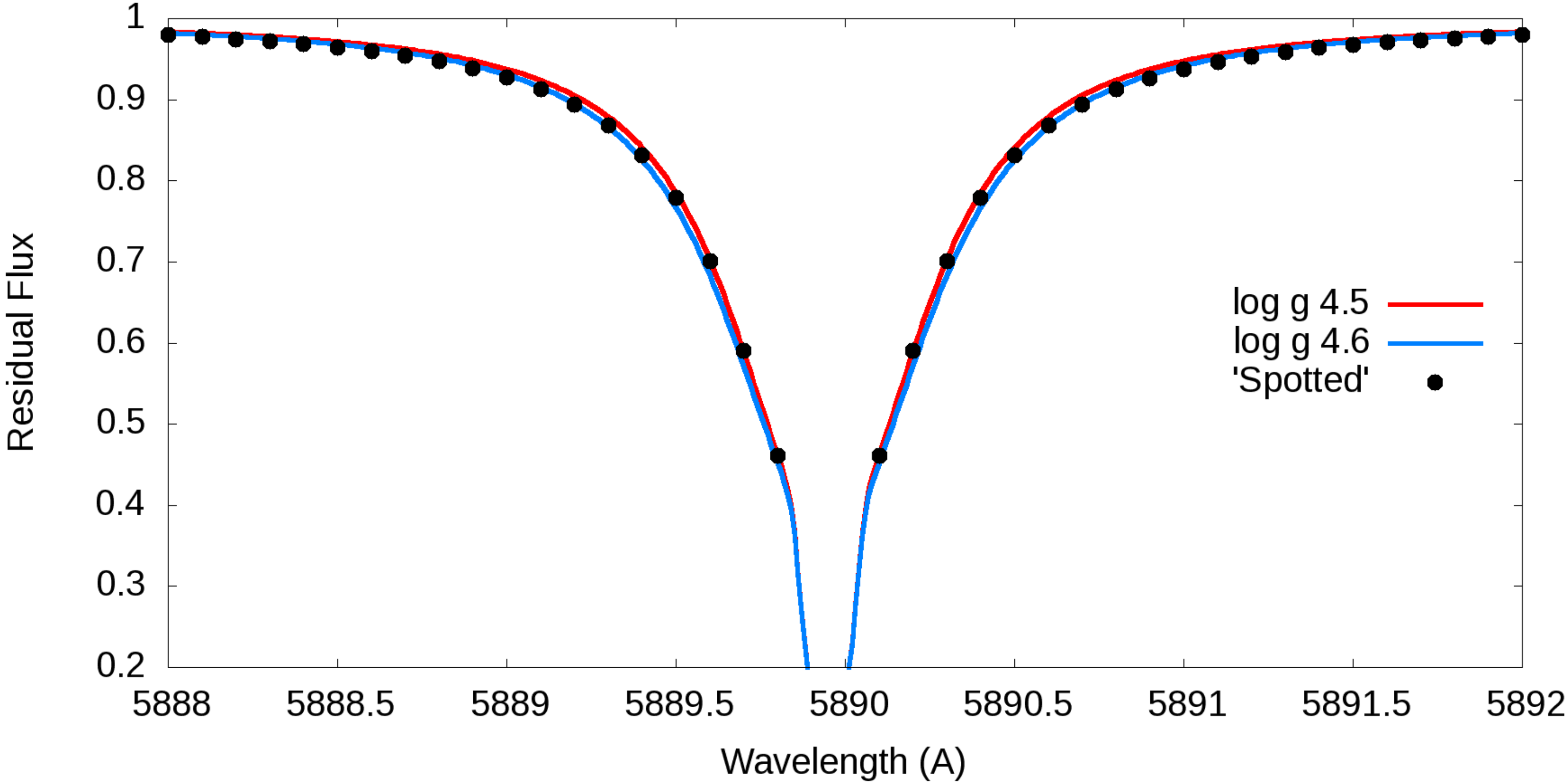
Starspots

- Simulate a spotted star with 5% spot coverage.
- Take two models: T_{eff} = 6000 K and T_{eff} = 5000 K
  - Both with log g =4.5
- Generate spectra and combine 95% and 5%
- Fit using a single T_{eff} model
- H_α gives 5950 K. Agrees with Stefan's Law:

$$(0.95 \times 6000^4 + 0.05 \times 5000^4)^{1/4} = 5953$$

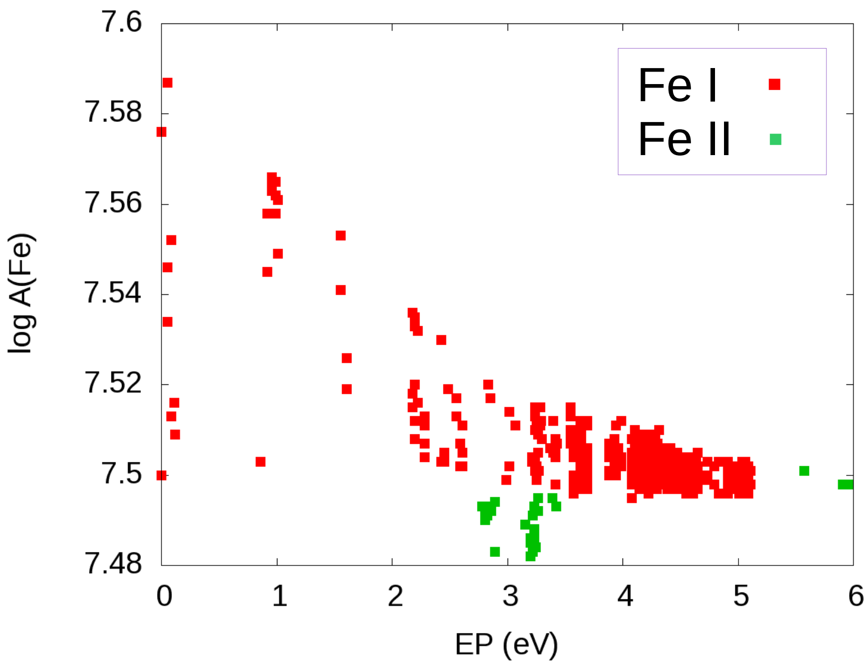
- But, what log g does Na D give?

Effect of “Spot” on Na D line

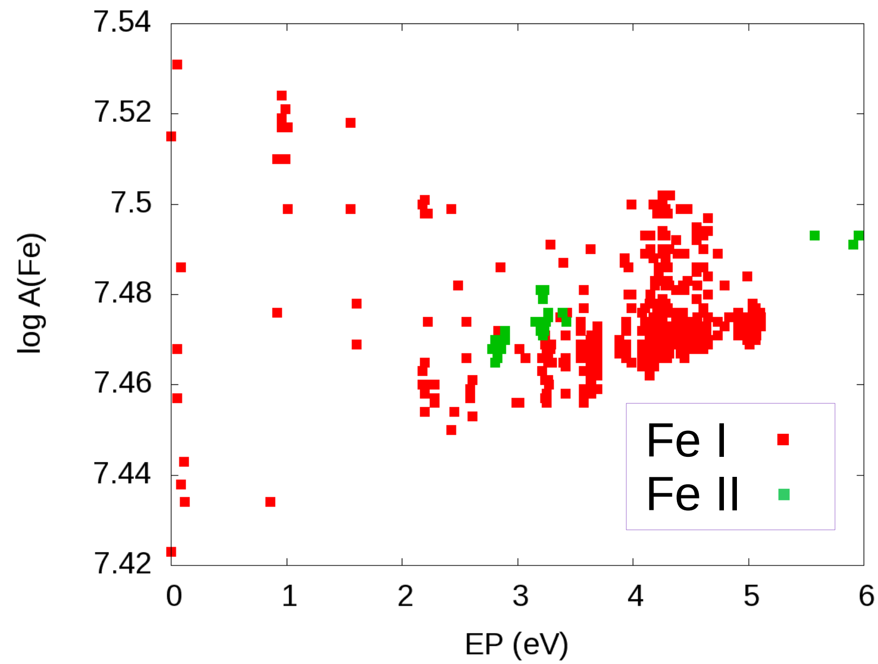


Spectroscopic log *g* overestimated in spotted stars?

Spots and EWs



T_{eff} = 5953 K, log g = 4.5

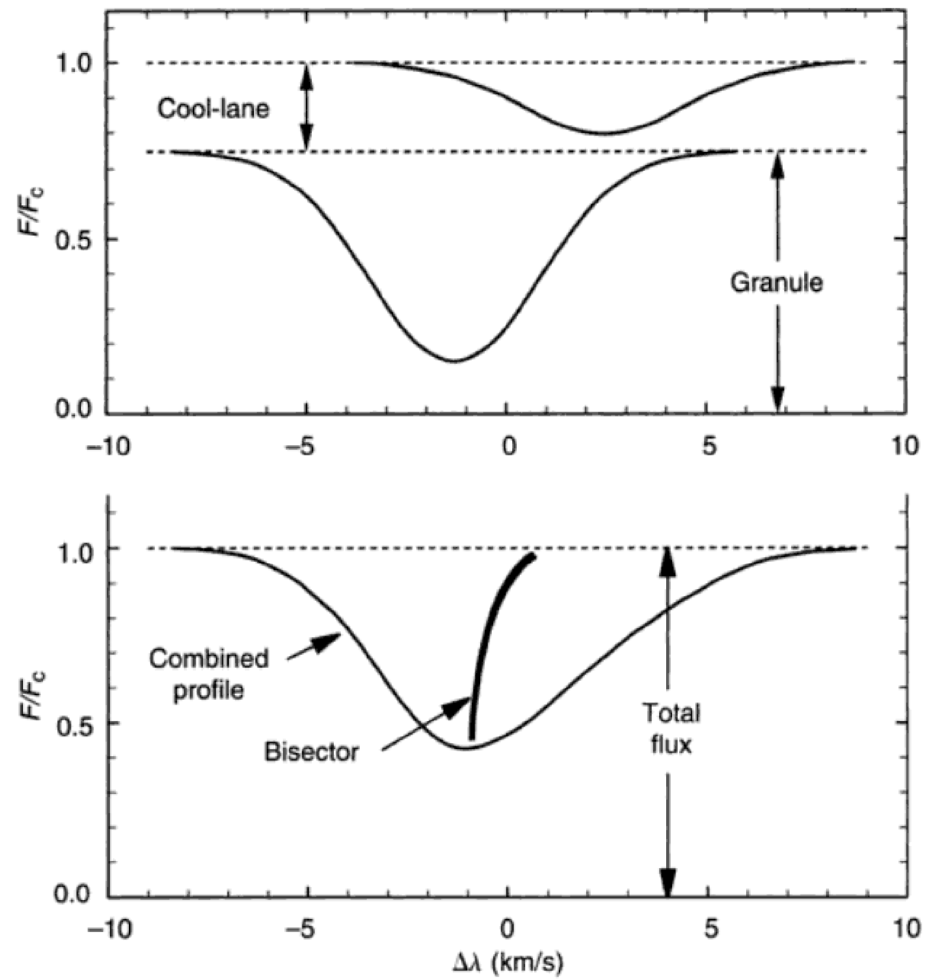


T_{eff} = 5890 K, log g = 4.42

- Effect on determination of T_{eff} and log g
  - depends on choice of lines.

Line Asymmetries

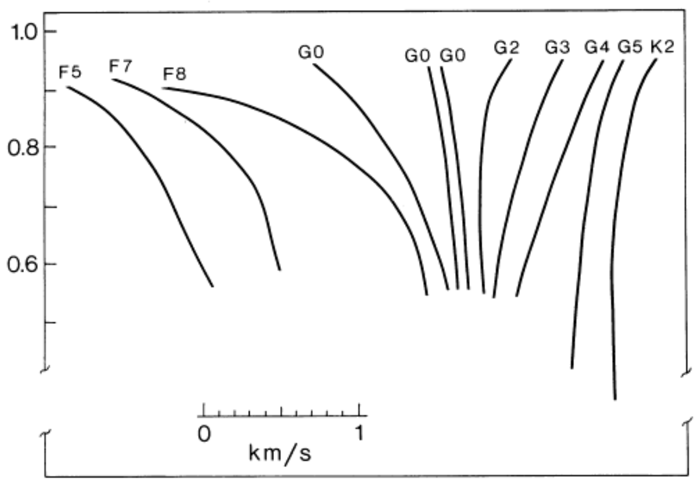
- Line Bisectors
- Velocity fields in atmosphere
  - Rising elements blue shifted
  - Falling elements red shifted
- A-type Stars
  - small rising columns of hot gas
  - larger cooler downdrafts
  - velocities consistent with microturbulence

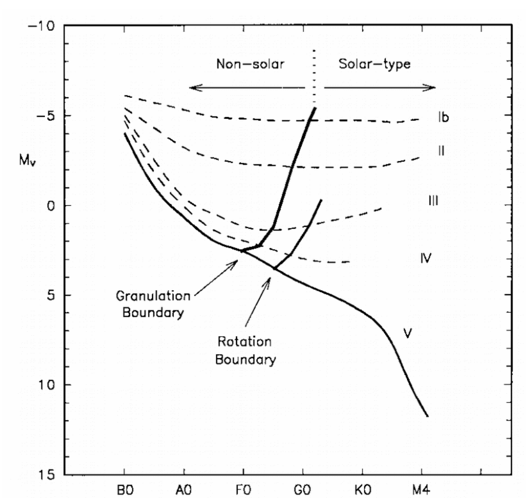


Landstreet, 1998, A&A, 338, 1041

Gray (2008) Book

Line Bisector Variations

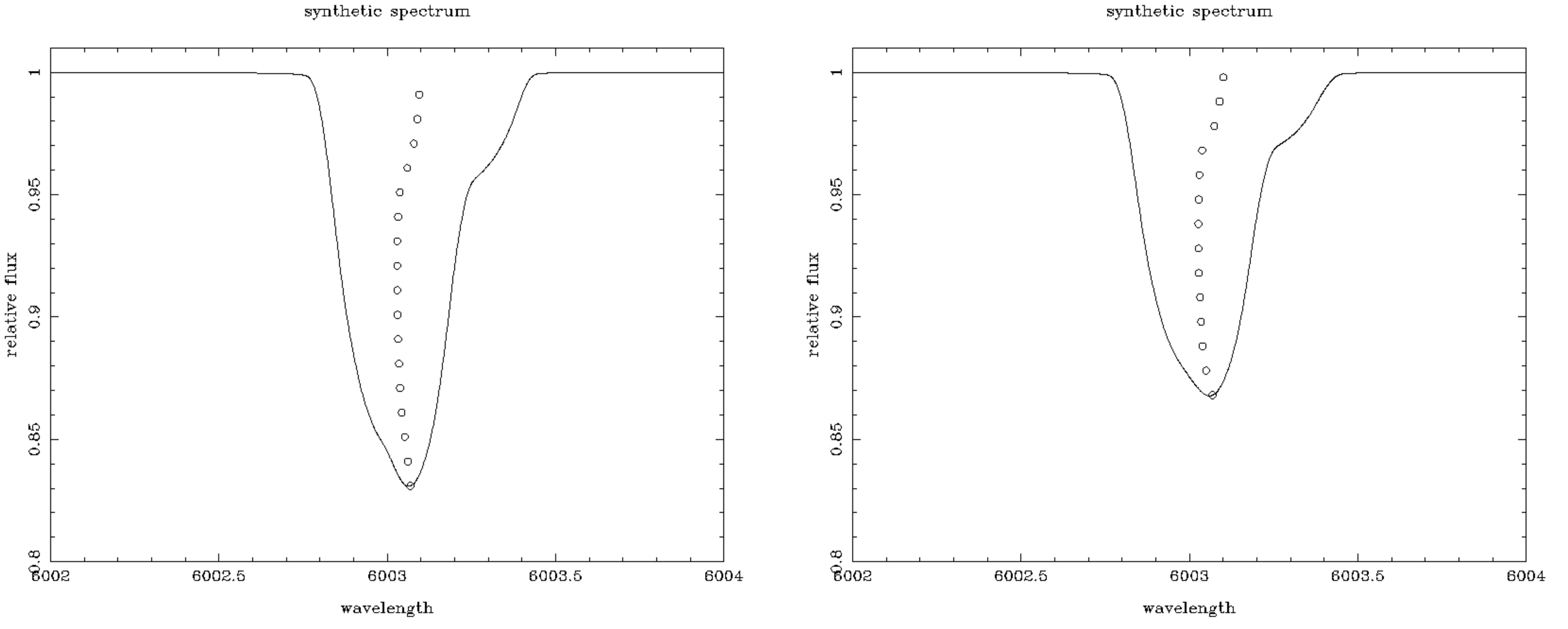




Gray 2008 Book

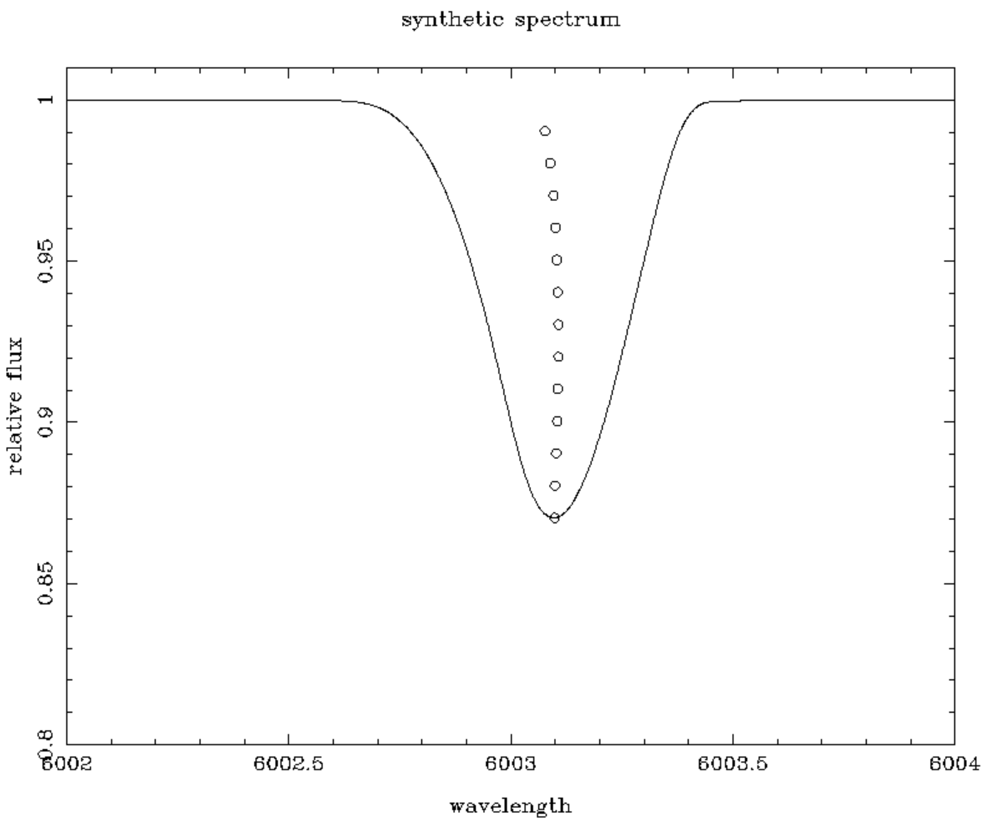
- Bisectors are reversed for early-F and A stars
  - No curvature in B stars
- Granulation Boundary
  - Changing from fully convective to weak subsurface convection

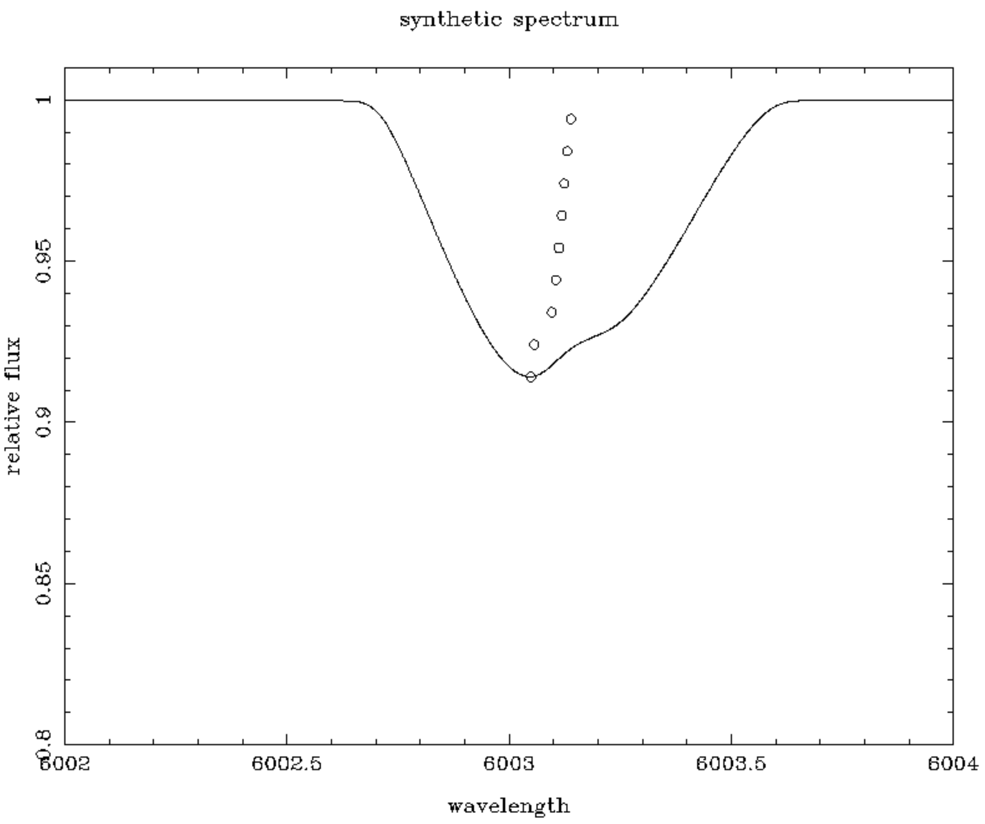
Examples of Bisectors



Blend versus Binary

Examples of Bisectors



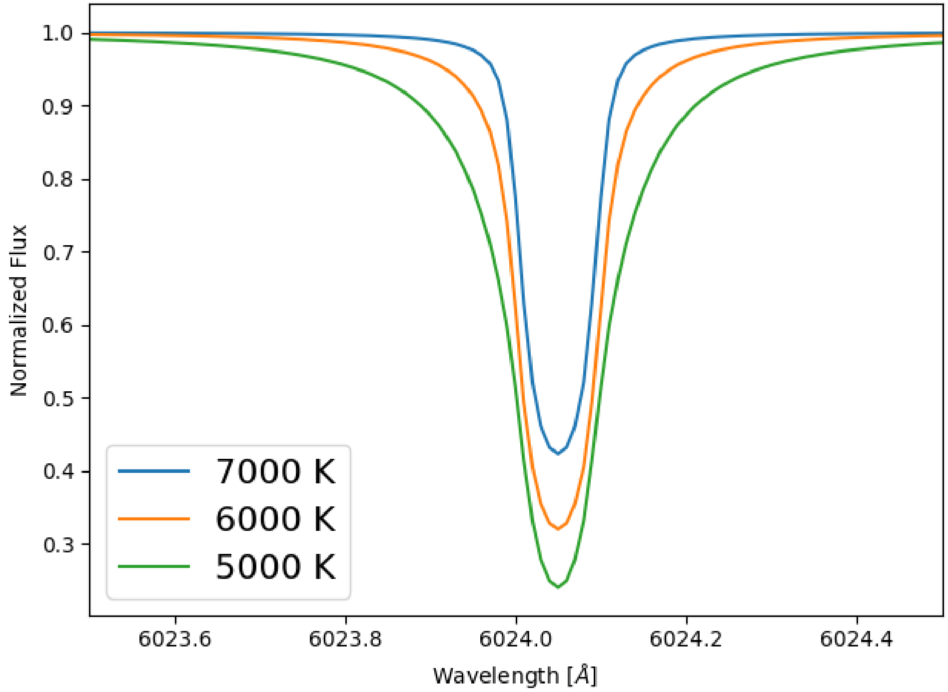


Radial versus Non-radial Pulsation

Binary stars and blending

- The presence of another star in a stellar spectrum can sometimes be obvious
  - SB2 binaries.
- Other times, it can be less obvious
  - Lines (almost) lost in the noise
  - Overlapping and blended.
- Spectral lines appear weaker (diluted) compared to a single star of same parameters

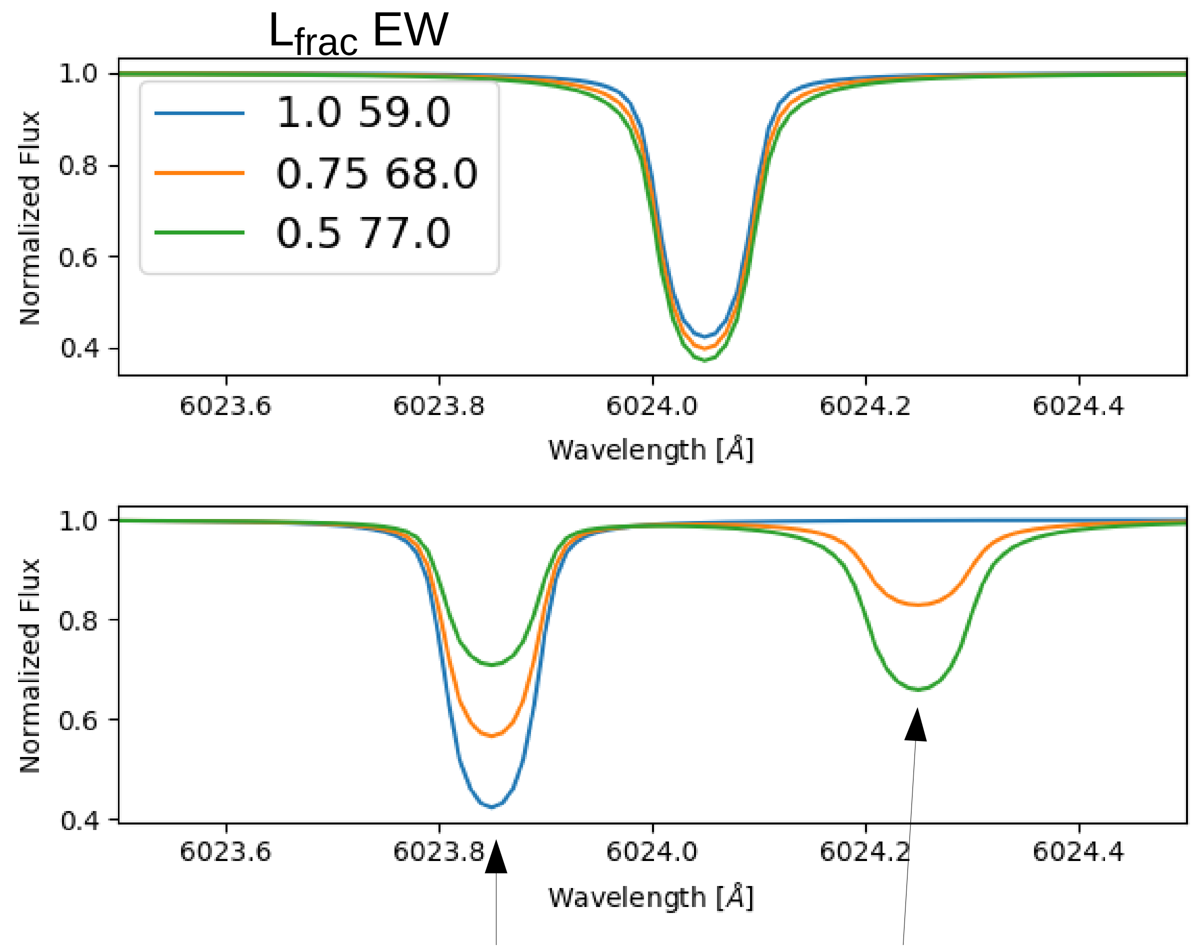
Same spectral line, different T_{eff}



Now combine two spectra (stars A and B):

- f_combined = $f_A * L_{frac} + f_B*(1-L_{frac})$
  - L_{frac} is fraction of light from star A

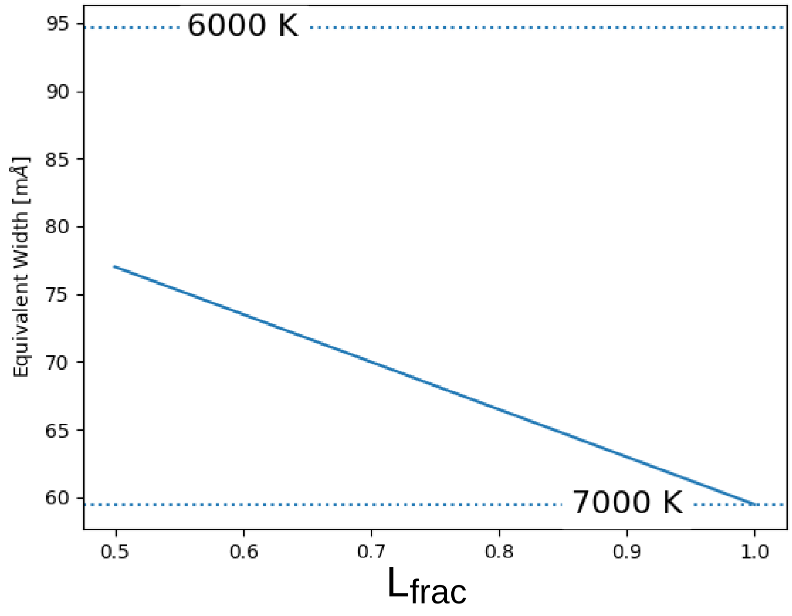
Simulated Binary Spectrum

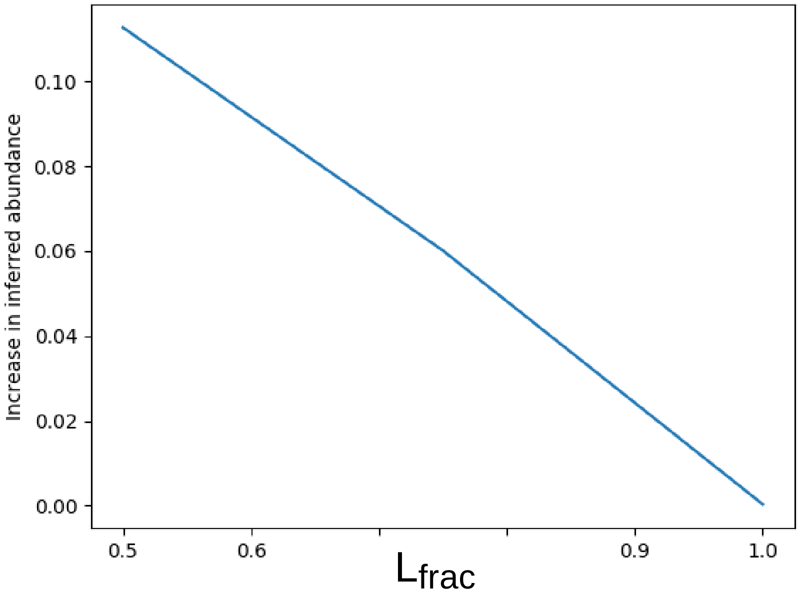


Offset to show the individual profiles

Star A is 7000 K and Star B is 6000 K.

Effects of dilution





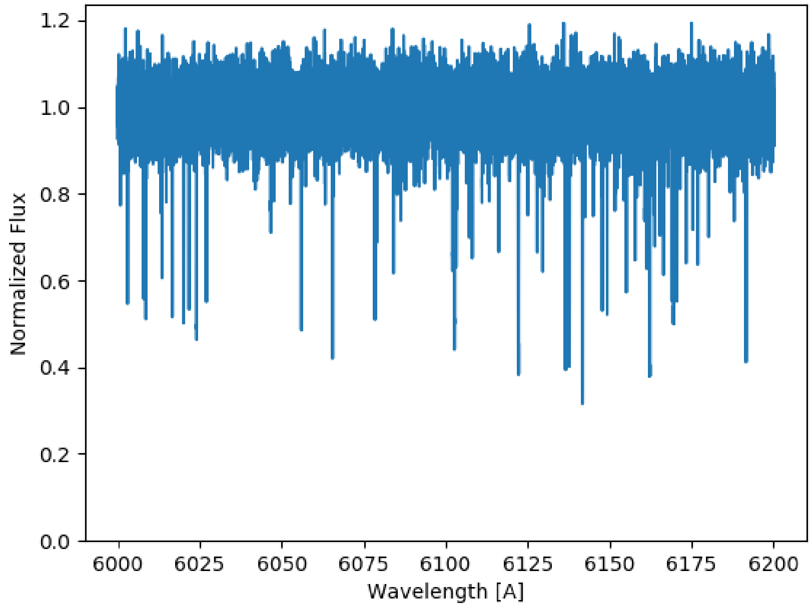
- Increasing dilution
  - Weaker spectral line
- If not known or accounted for
  - Incorrect parameters
  - In this example
    - Lower Teff

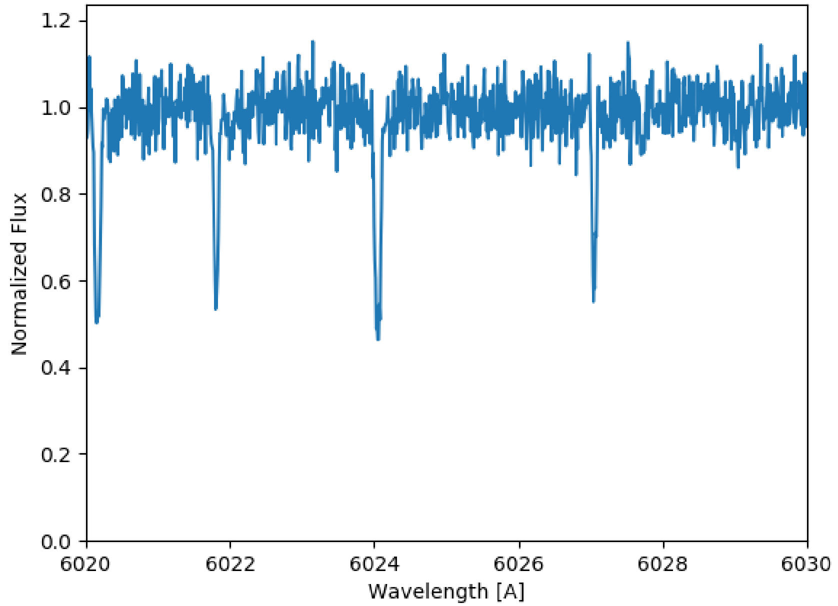
      or
    - Higher abundance

Fitting lines for radial velocity

- Fit a single line to get parameters:
  - Abundance, rotation and line shift (radial velocity)
- Do it for multiple lines
  - Take average to improve precision
  - Fit all lines simultaneously
- Leads to use of cross-correlation…
  - Radial velocities
  - Stellar parameters 2017MNRAS.469.3965M
    - https://github.com/LucaMalavolta/CCFpams
    - But, see 2005ESASP.576..623Z

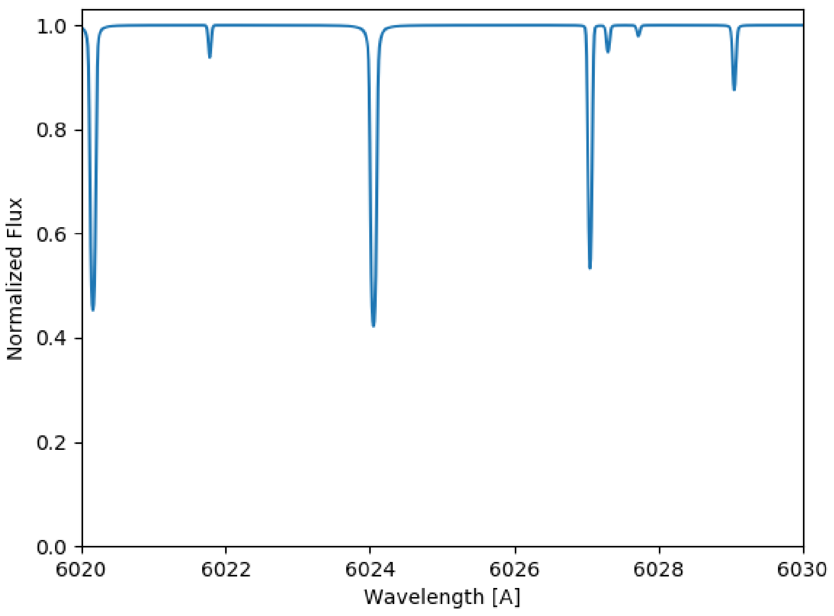
Cross Correlation Example





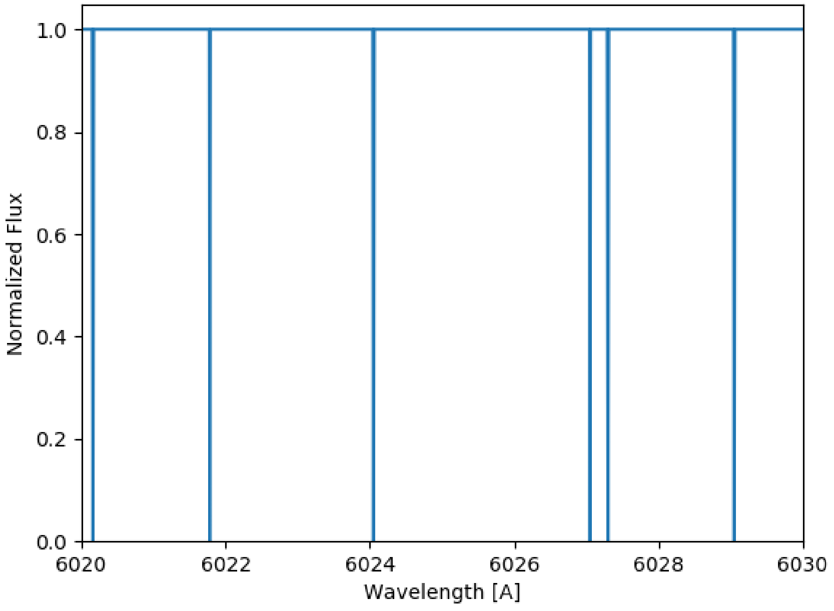
Templates: synth

- A synthetic Spectrum.
- Could use an actual reference stellar spectrum.



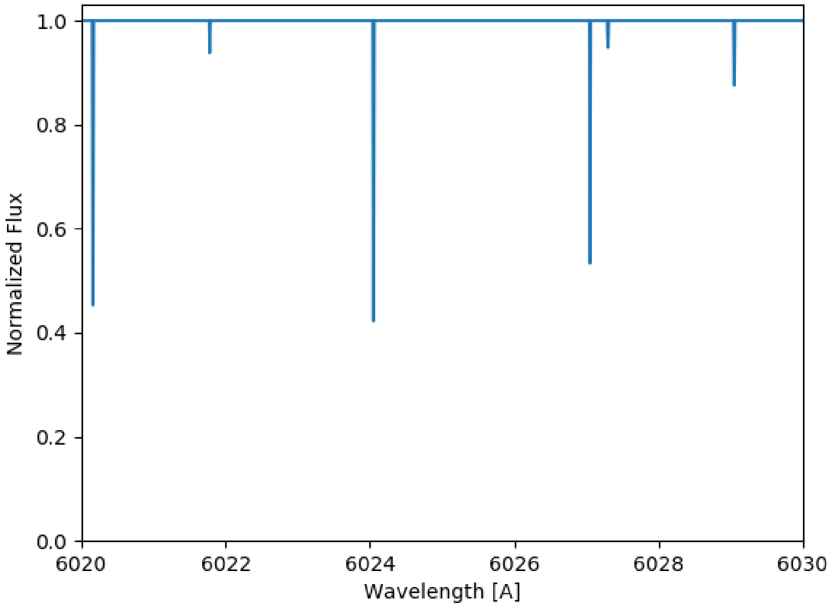
Template: zeros

- Based on wavelengths of known spectral lines
- Pixels set to zero where there is a line in that pixel
- All lines are given equal weight

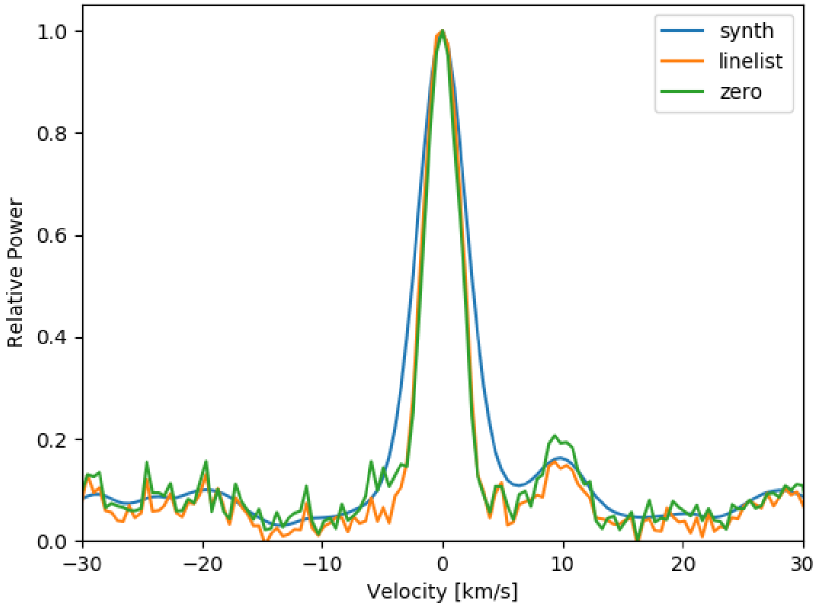


Template: linelist

- Based on wavelengths of known spectral lines
- Pixels set to depth of the line where there is a line in that pixel.
- Gives more weight to stronger lines.



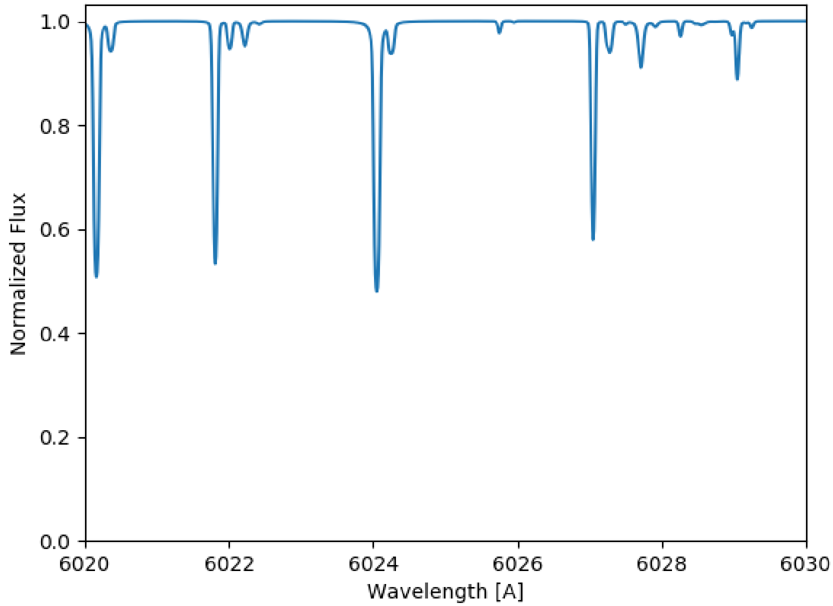
The Cross Correlation



- Normalized to unity
- Strong peak (1.0) at 0 km/s and weaker peak (~0.2) at +10 km/s
- Synthesis result broader due to intrinsic width of the template, but smoother.

Conclusion: Binary Star

Actual Spectrum



- Synthesis using Teff 7000 K log g 4.5 for both A and B
  - $L_{frac} = 0.9$
  - B shifted by +10 km/s.
- As found by the cross correlation!

Radial Velocity Determinaton

- Cross correlation function (CCF)
  - e.g. 2002A&A...388..632P, 1996A&AS..119..373B
- **TODCOR** 1994ApJ...420..806Z
  - See also CCF vs TODCOR 2017sf2a.conf...79H
  - https://github.com/iancze/Hot-TODDY
- Disentangling
  - **Spectangular**: https://github.com/DPSablowski/spectangular (2017A&A...597A.125S)
  - **FDbinary**: sail.zpf.fer.hr/fdbinary/ (2004ASPC..318..107I)
  - **KOREL**: http://www.asu.cas.cz/~had/korel.html (2009arXiv0909.0172H)
  - Using Gaussian Processes (2017ApJ...840...49C): https://github.com/iancze/PSOAP

Summary

- We normally analyse stars using models with a single T_{eff} and log g.
  - For most analyses, this is a reasonable approximation.
- However, when the parameters obtain appear more uncertain than normal, then, maybe, the star is composite.