Tips for measuring Equivalent Widths

SAMPA
Stellar Atmospheres, Planets and Abundances

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Line profile is convolution of Gaussian & Lorentzian: Voigt profile

- The natural, Stark, and van der Waals broadening coefficients all have the form of a dispersion profile:

$$\partial_\nu = a \frac{b}{\Delta\nu^2 + b^2}$$

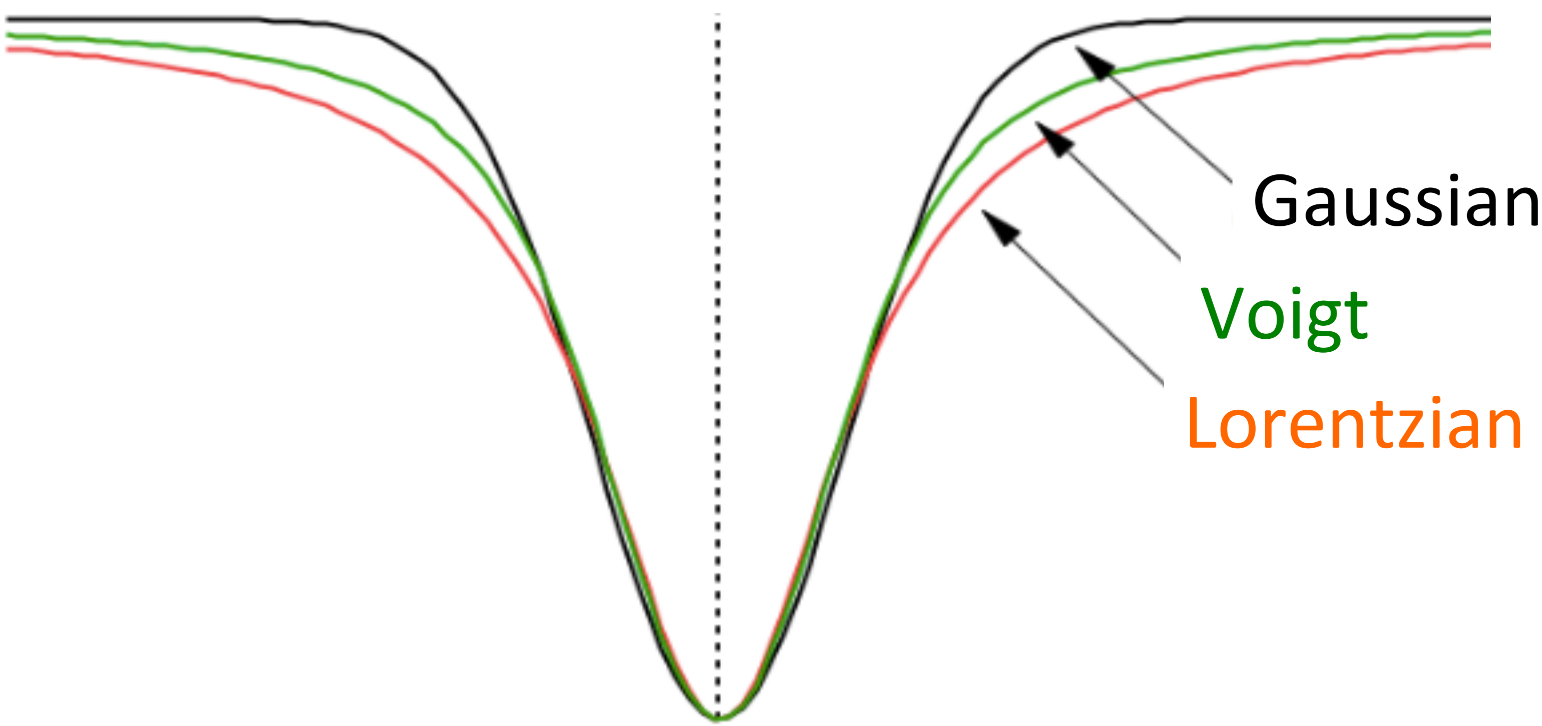
- With damping constants (γ_{rad}, γ_2, γ_4, γ_6) one simply adds them up to get the total damping constant:

$$\partial_\nu = \frac{\pi e^2}{mc} f \frac{\gamma_{total} / 4\pi^2}{\Delta\nu^2 + (\gamma_{total} / 4\pi)^2}$$

- The thermal profile is a Gaussian profile: $\alpha_\nu = \frac{1}{\pi^{1/2}\Delta\nu_D} e^{-\left(\frac{\Delta\nu}{\Delta\nu_D}\right)}$

- Instrumental profile is ~ Gaussian

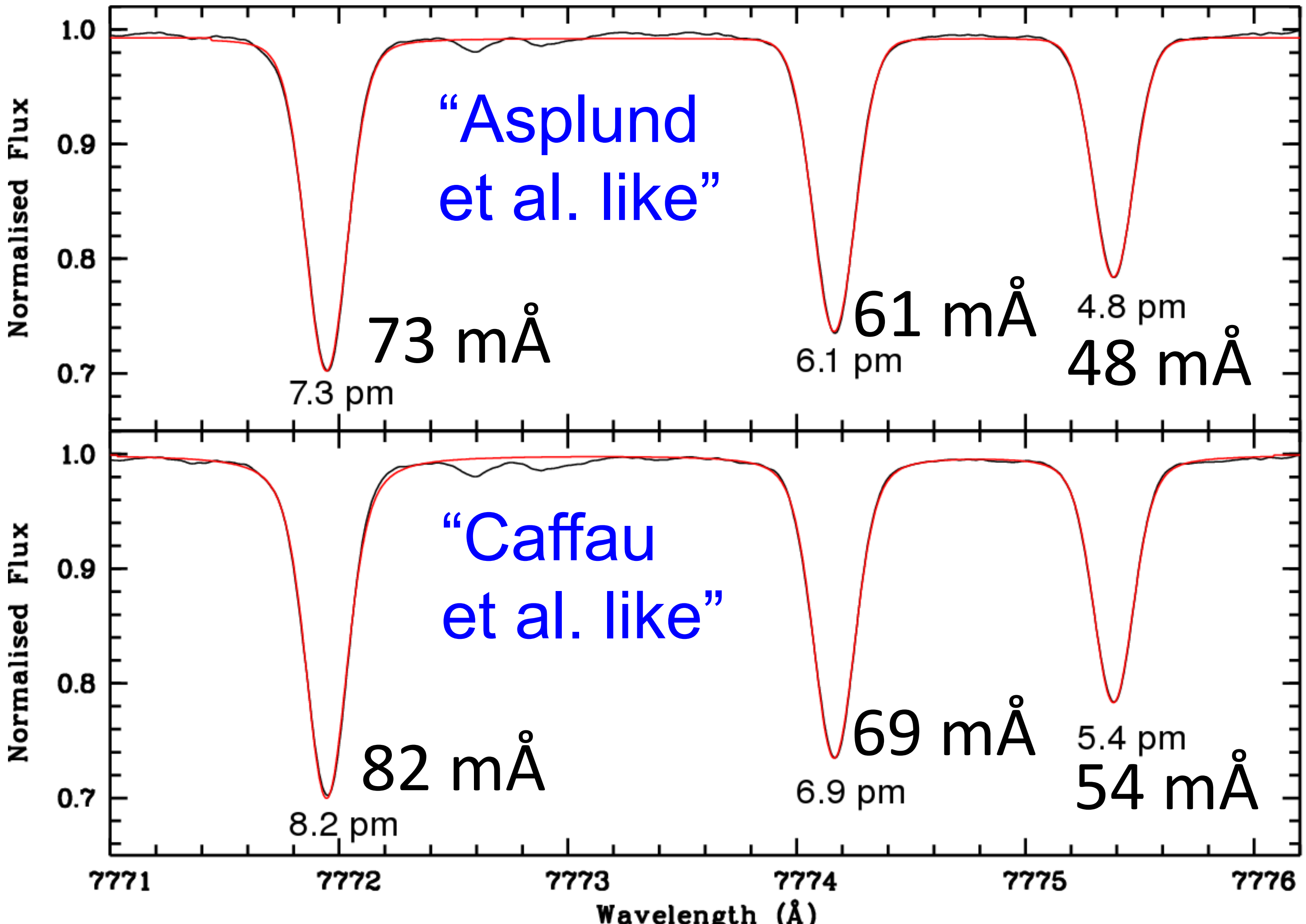
Equivalent Width (EW) measurements: not trivial



Equivalent Width (EW) measurements: not trivial

Oxygen triplet in the Sun

EW using Voigt profiles for both Asplund & Caffau

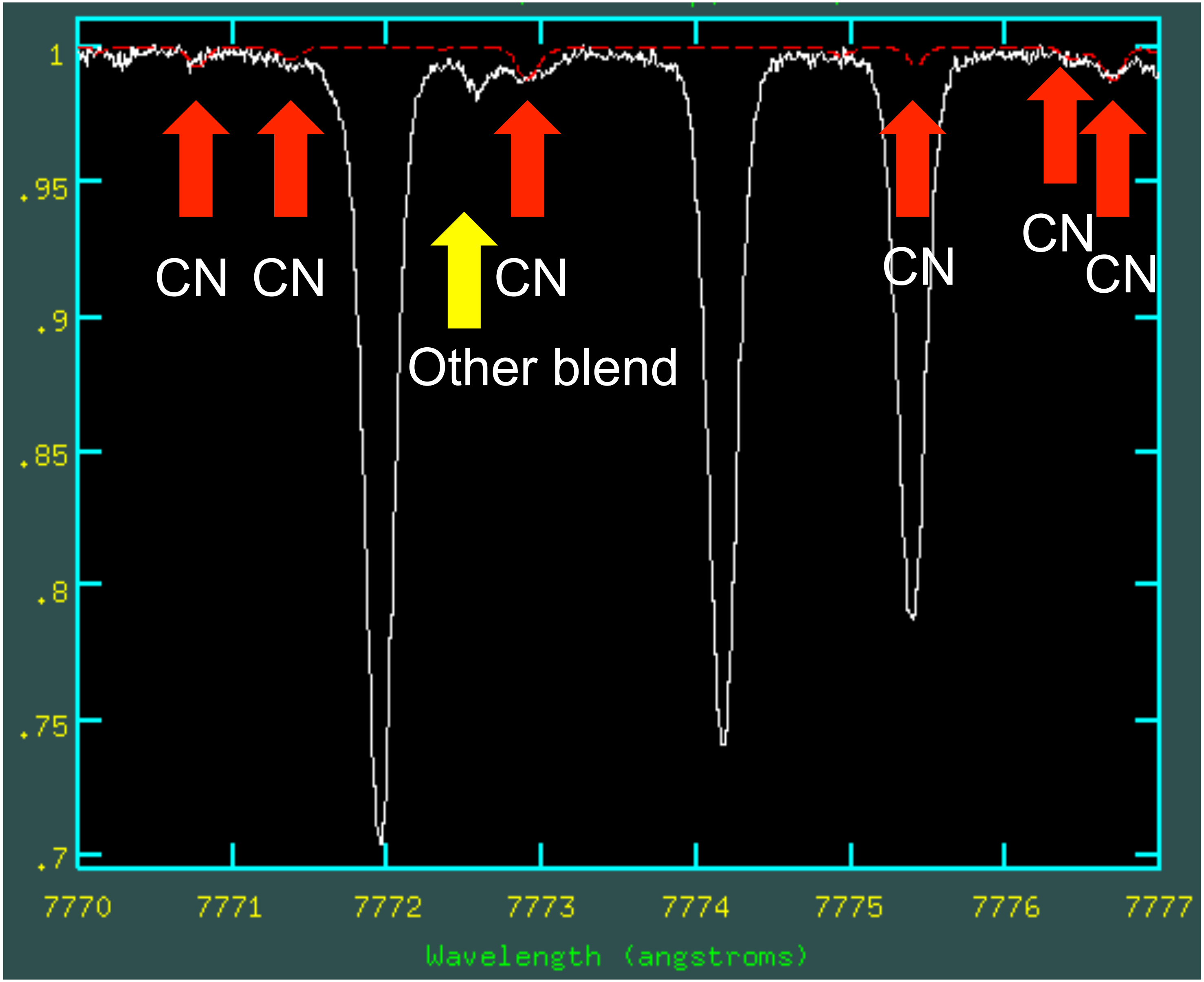


H.-G. Ludwig, 2012

CN blends for O I triplet

(Meléndez, IAU Symp)

CN blends must be taken into account, otherwise the EW may be over or underestimated



Voigt profile requires both Lorentzian & Gaussian broadening

$$V(\Delta\nu, \Delta\nu_D, \gamma) = \int_0^\infty \frac{\gamma/4\pi^2}{(\Delta\nu - \Delta\nu_1)^2 + (\gamma/4\pi)^2} * \frac{1}{\pi^{1/2}\Delta\nu_D} e^{-\left(\frac{\Delta\nu}{\Delta\nu_D}\right)^2} d\nu_1$$

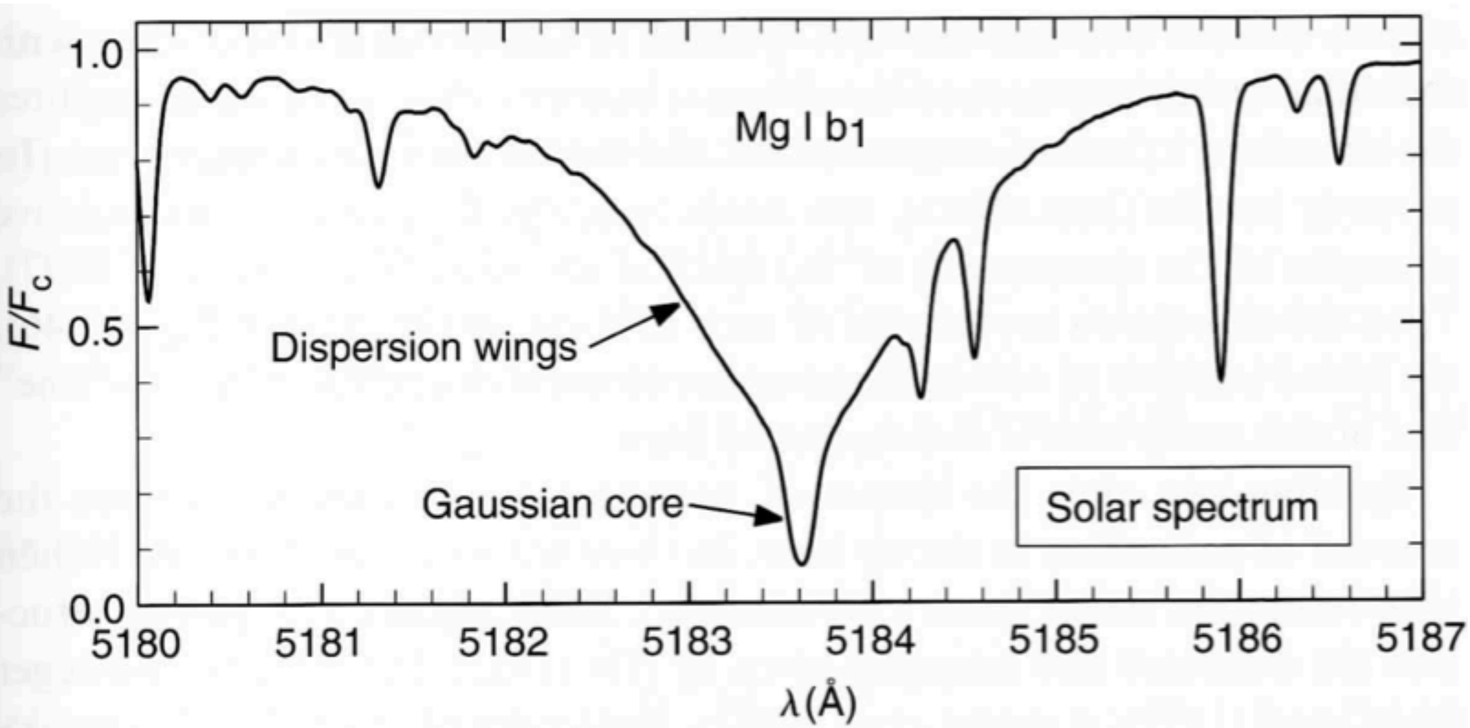
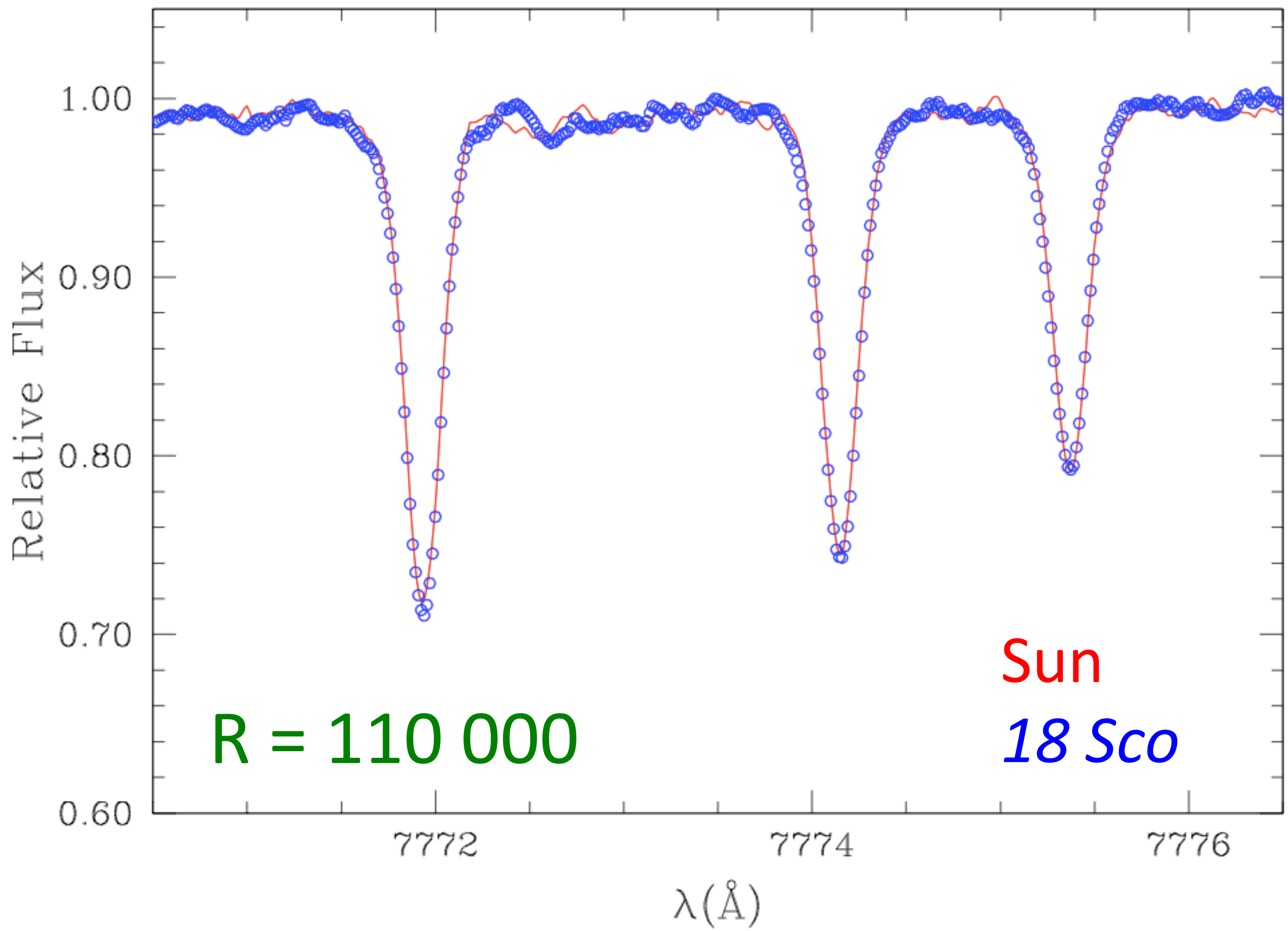


Fig. 11.11. In a few cases spectral lines, like this magnesium line in the solar spectrum, clearly show the Gaussian core and the dispersion wings with a relatively sharp transition between the two near $F/F_c \approx 0.3$.

D. Gray

Oxygen triplet in the Sun and solar twin 18 Sco



Gaussian profiles are preferred: more precise differential measurements

Jorge Melendez, from UVES spectra

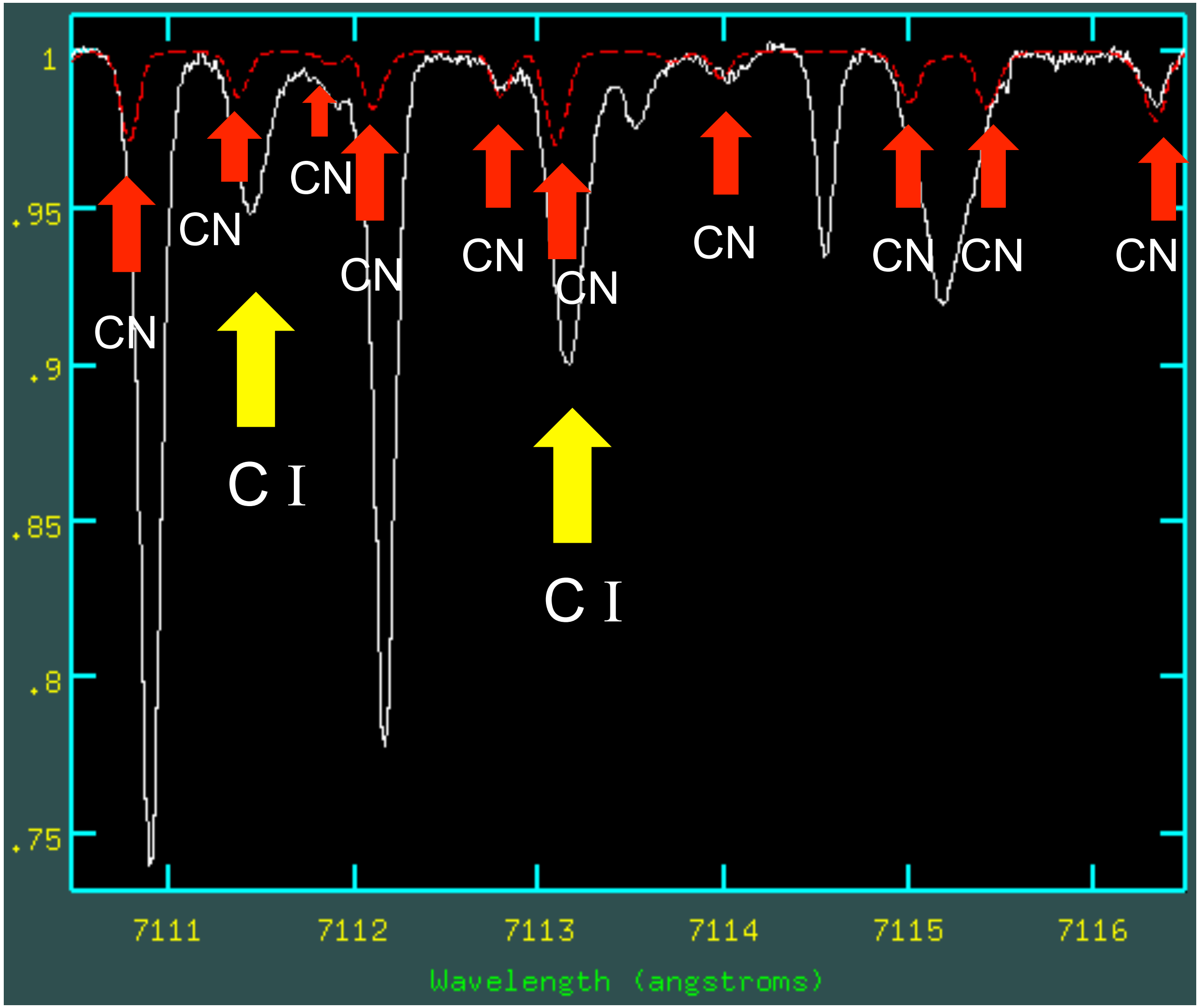
The most important (and demanding) part in the differential work are the EW measurements

- Even if you're using sophisticated model atmospheres or line formation, your results will be wrong if the measurements are wrong
- Differential measurements: make the same (sensible) choices for your star & standard
- All starts with a careful line selection

Case study: carbon

Higher absolute abundances!

C I lines at 7111,4 & 7113,2 Å



Equivalent Widths for Precision Spectroscopy

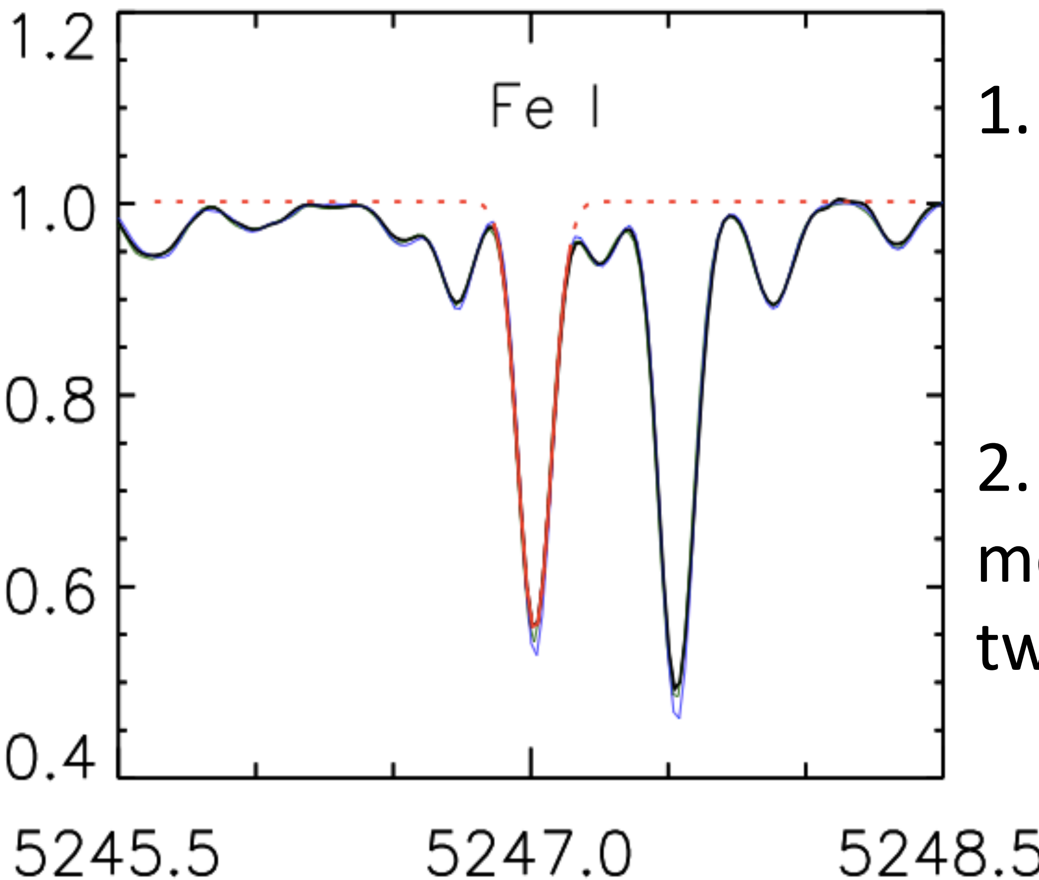
Hand (manual measurements).

For automatic EW: DAOSPEC, iSpec, ARES ….

Differential abundances A_X (element X)

$$\log (W/\lambda) = cte + A_X + \log (g f) + \log \lambda - \theta \chi_{exc} - \log k_{cont,\lambda}$$

$$\log (W_1/W_2) = A^1_X - A^2_X - (\theta^1 - \theta^2) \chi_{exc} - \log (k^1_{cont} / k^2_{cont})$$



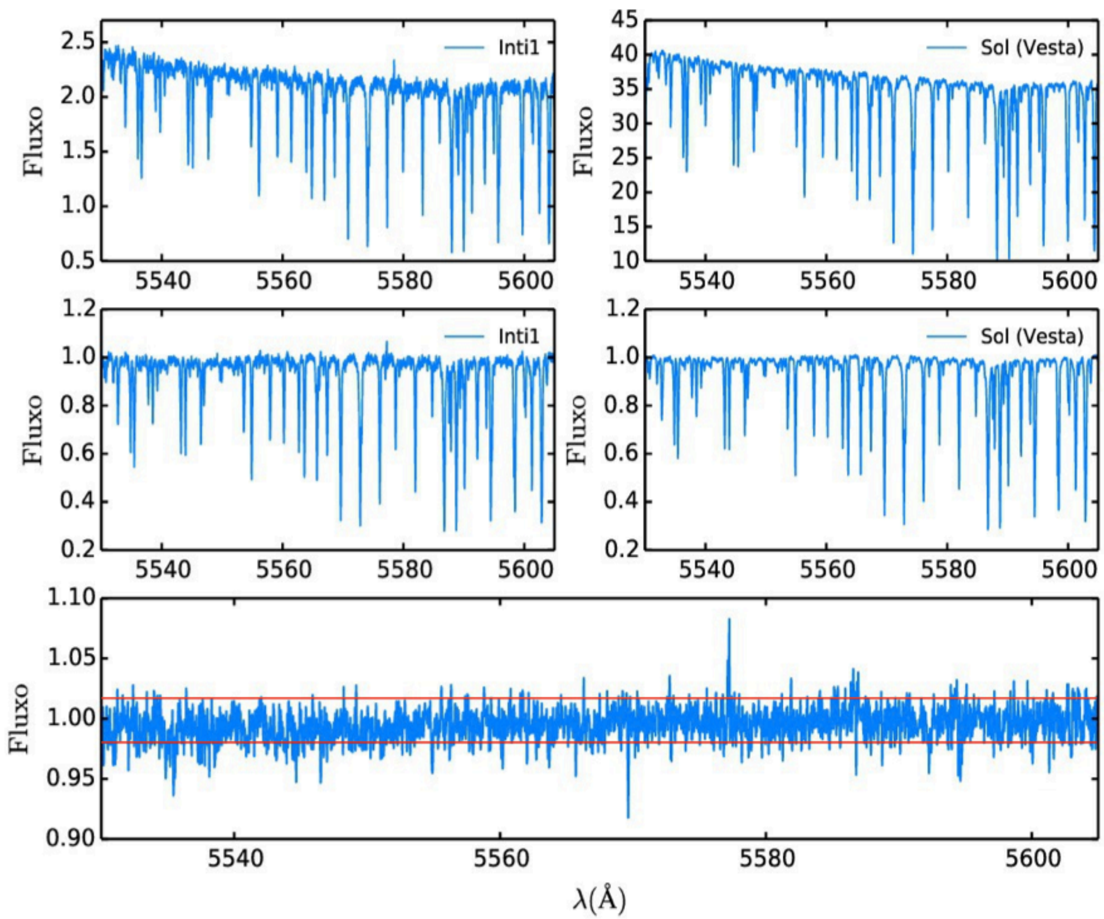
Bedell, Meléndez, Bean et al. 2014

1. Precise differential EW measurements are key for Precise Abundances

2. Line-by-line differential method works better for twin stars

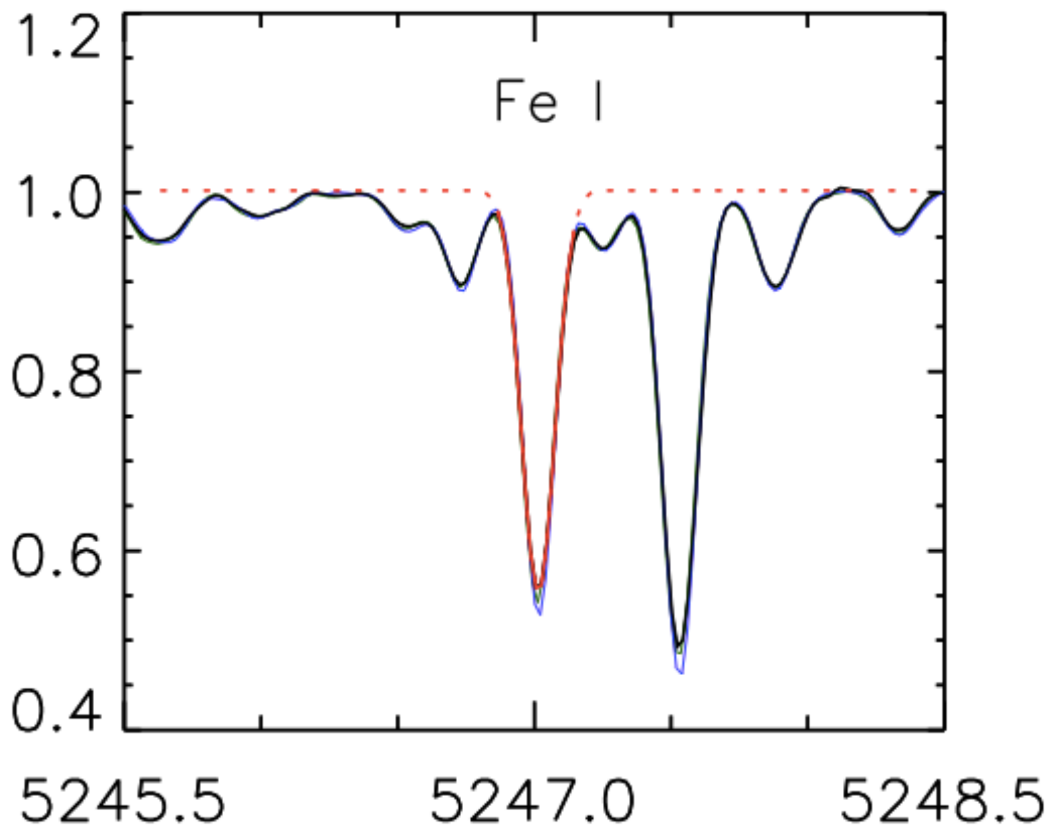
Some tips

- Try to do consistent observations using the same instrument/configuration.
- Verify your relative continuum normalization



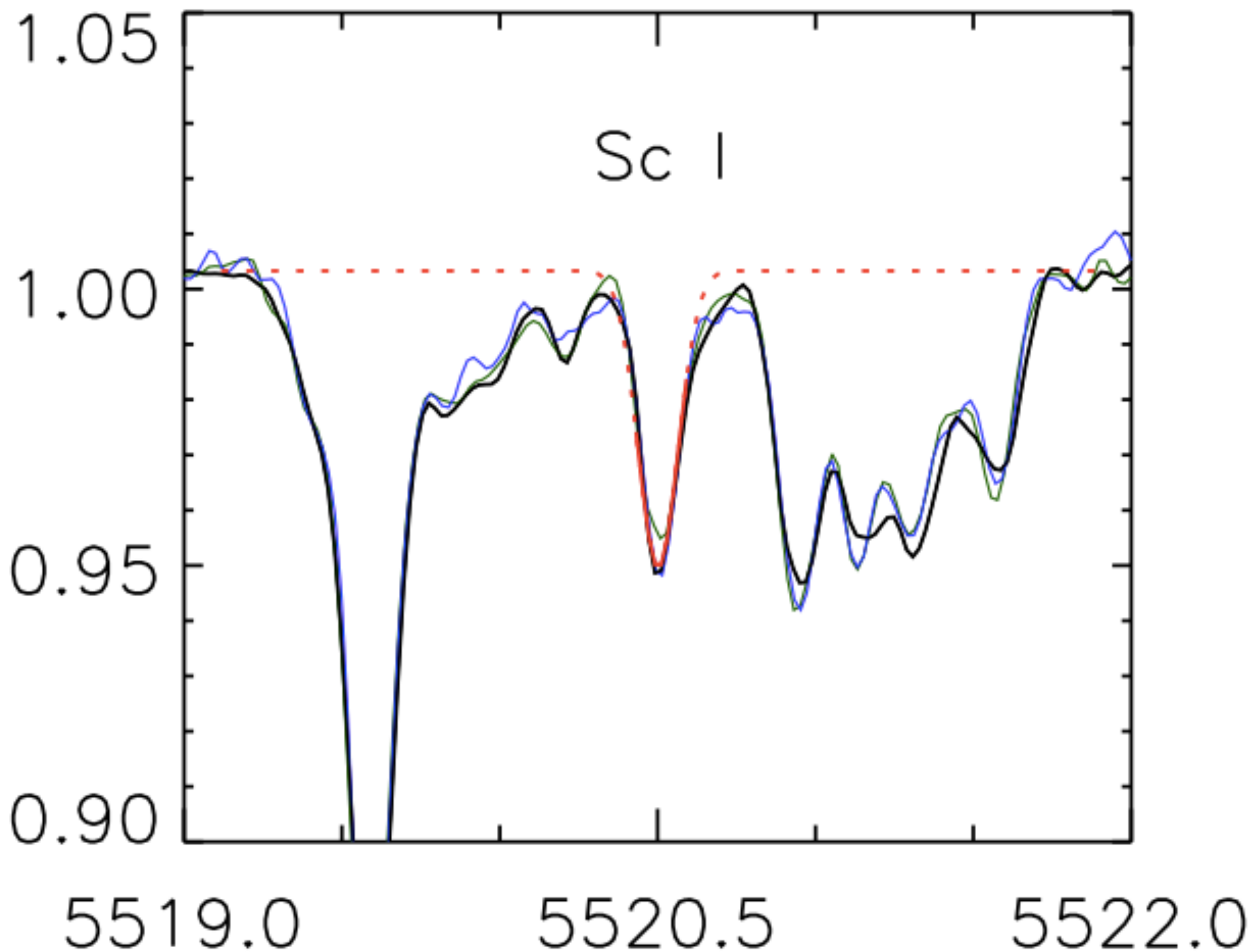
Measuring lines

- Whenever possible choose the cleanest lines
- If the lines are not perfectly clean, try to choose a line close to a continuum region



Bedell et al. 2014, ApJ, 795, 23

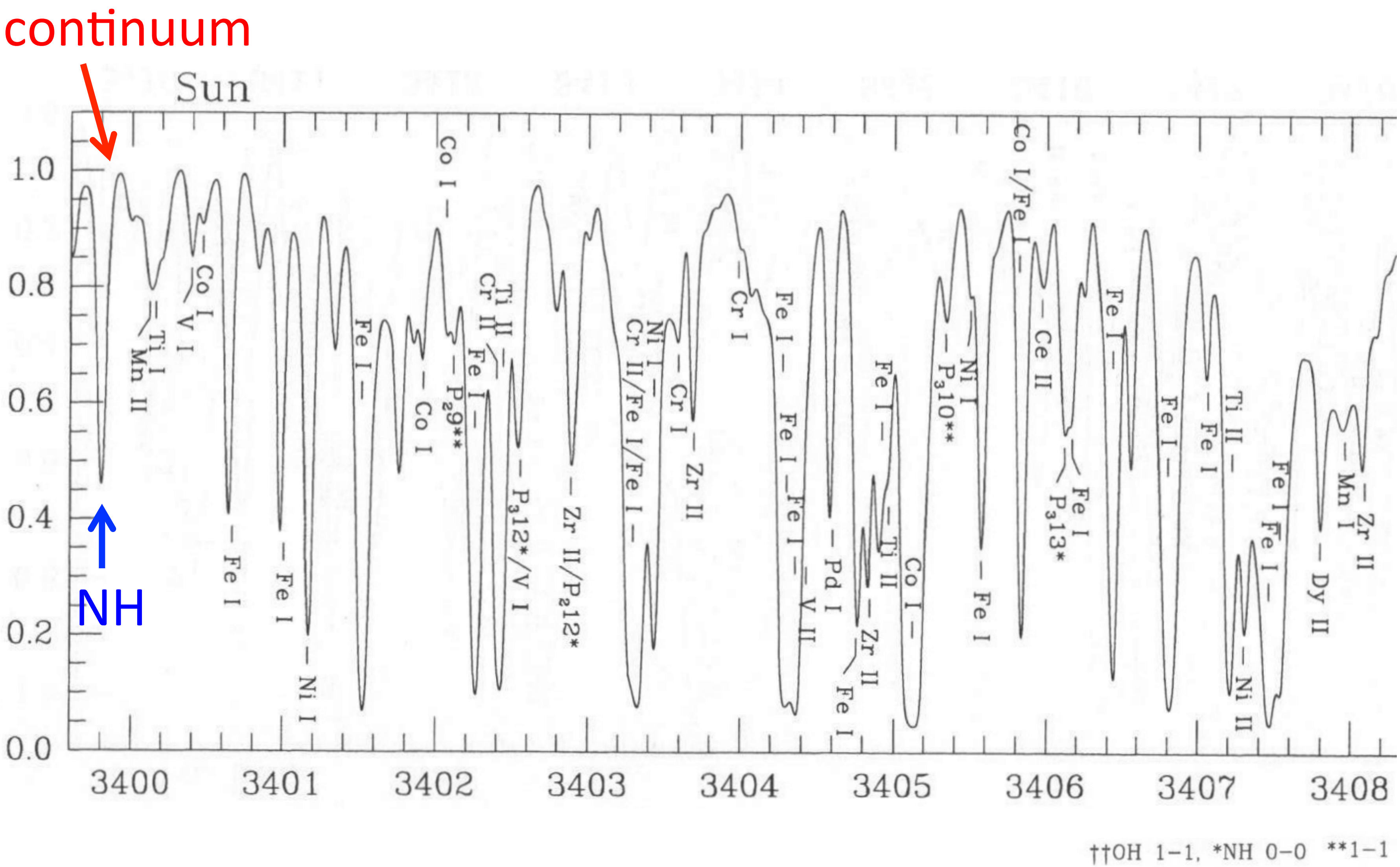
Measuring lines



Bedell et al. 2014, ApJ, 795, 23

NH in the ultraviolet, to obtain nitrogen abundances

UV Atlas of the Arcturus (and Solar) Spectrum 1150-3800 A, Hinkle et al. 2005



Solar twin spectra

- HIP79672.fits (18 Sco, 3 Gyr)
- Juno.fits (Sun, 4.6 Gyr)
- HIP102152.fits (old solar twin, 7 Gyr)

Line list (sun2015_05_18.moog)

Lambda ion exc.pot log_gf C6 0.0 EW comment

4788.757 26.0 3.237 -1.763 0.175E-31 0.0 67.7 FeI I

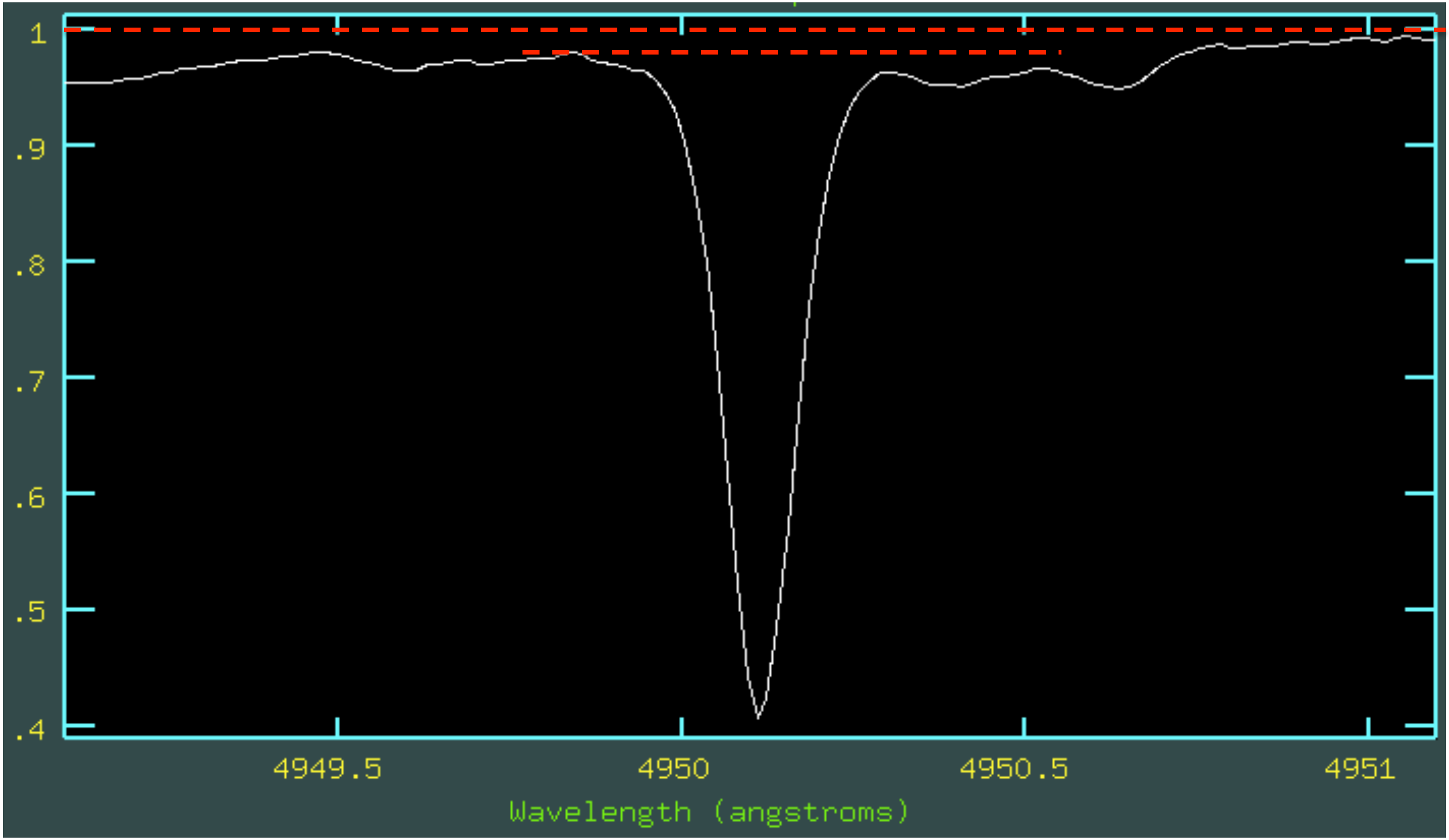
- Plot star and standard to choose best continuum region

- Use a window of ~ 5 - 6 Å, meaning ±3 Å from line center (in some cases a larger window may be needed)

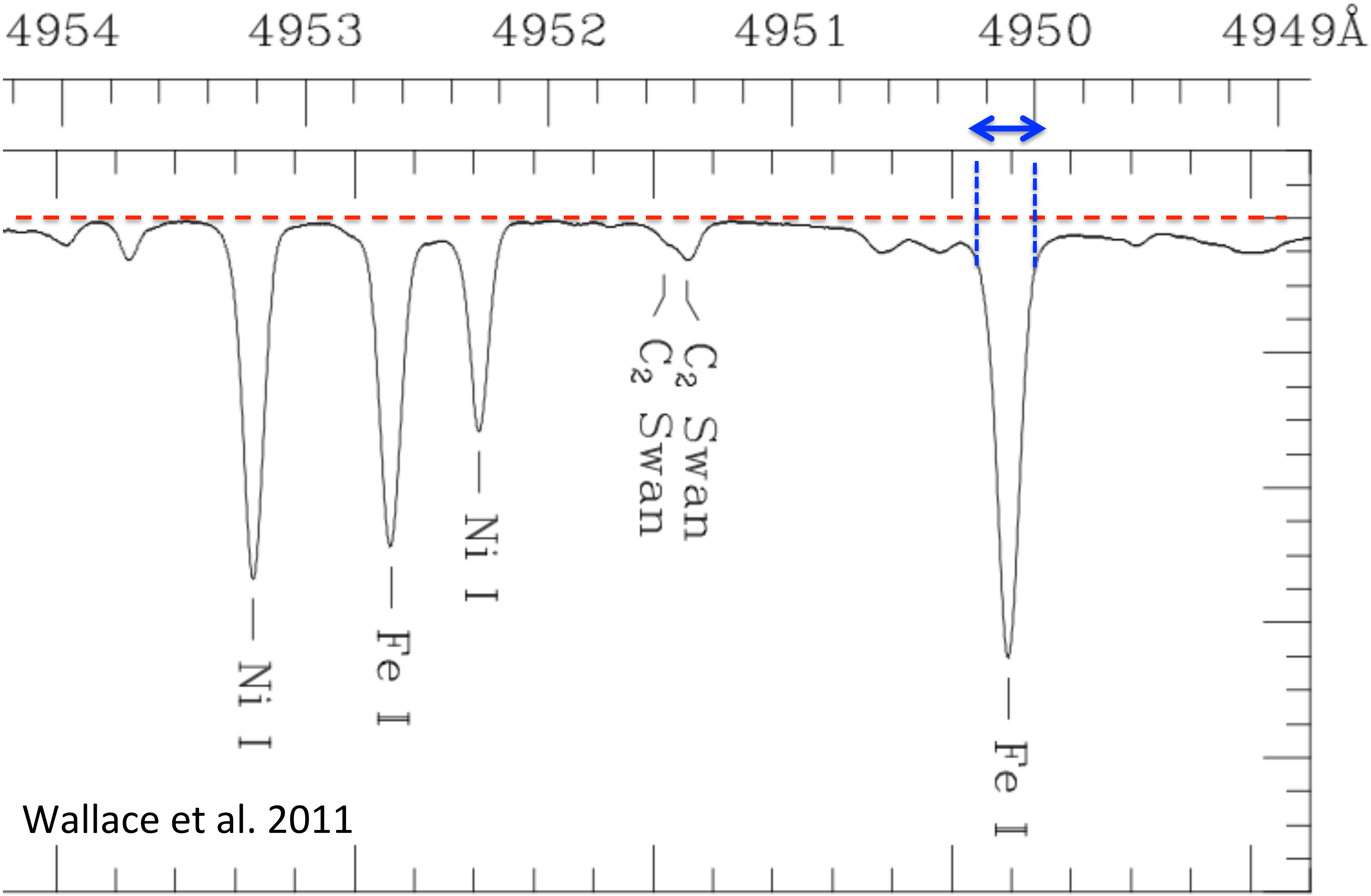
Ex.: FeI 4950.1 Å (using UVES spectra):

splot HIP102152 xmin=4947.1 xmax=4953.1

Continuum region too small (±1Å)



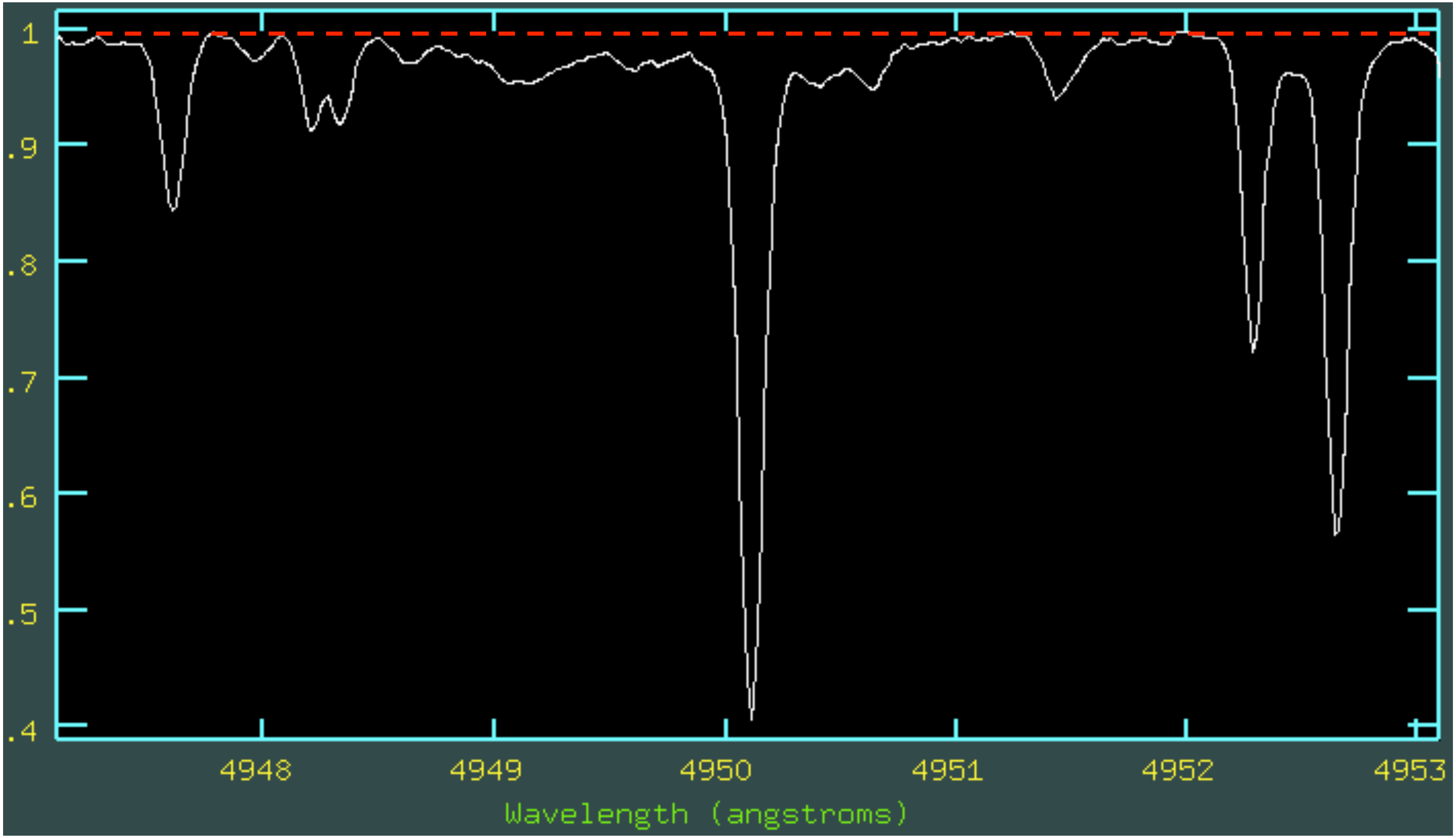
Verifying continuum with solar atlas



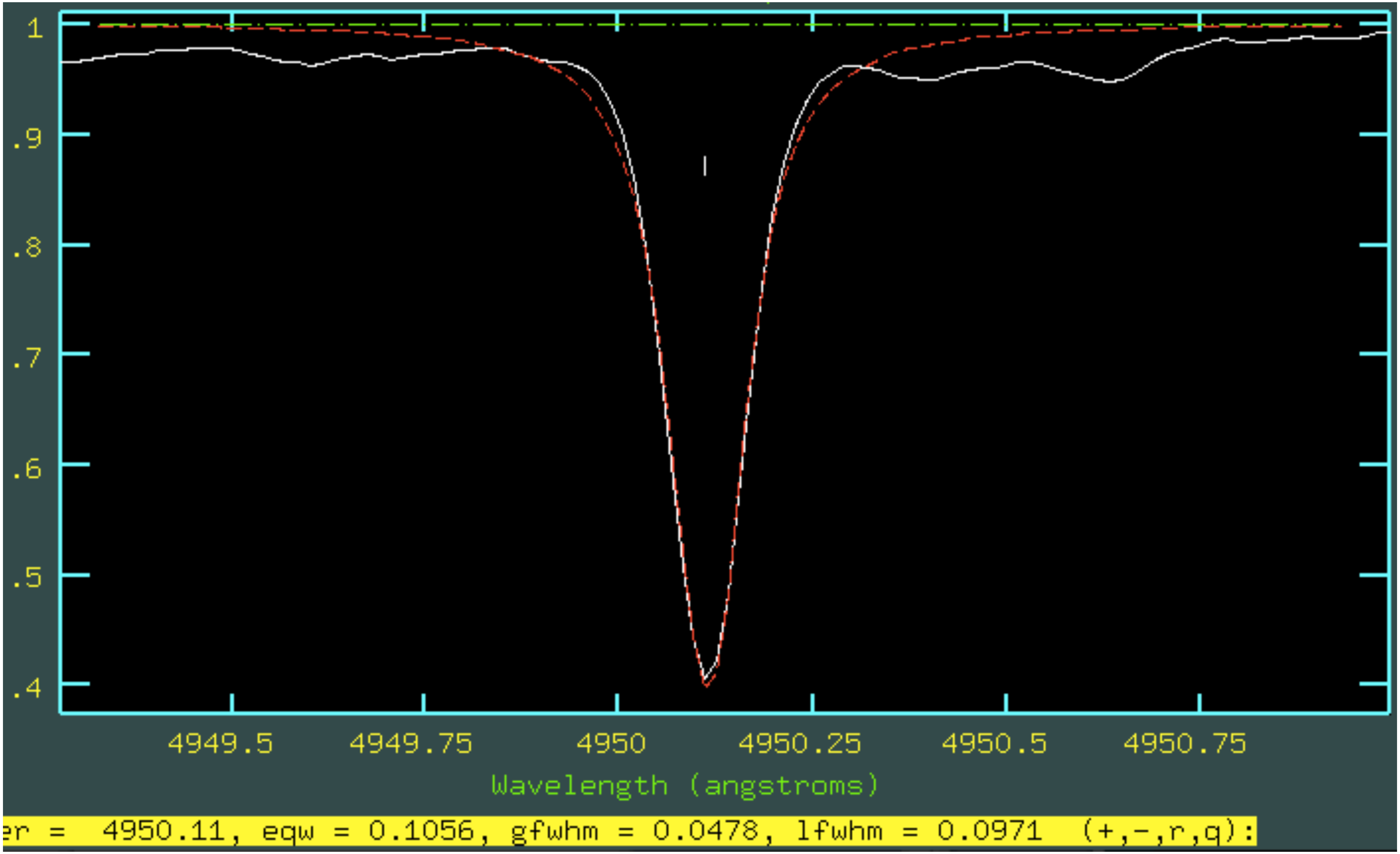
Wallace et al. 2011

Better, ±2,5Å or ±3 Å

```
onedspec> splot HIP102152 xmin=4947.1 xmax=4953.1
```

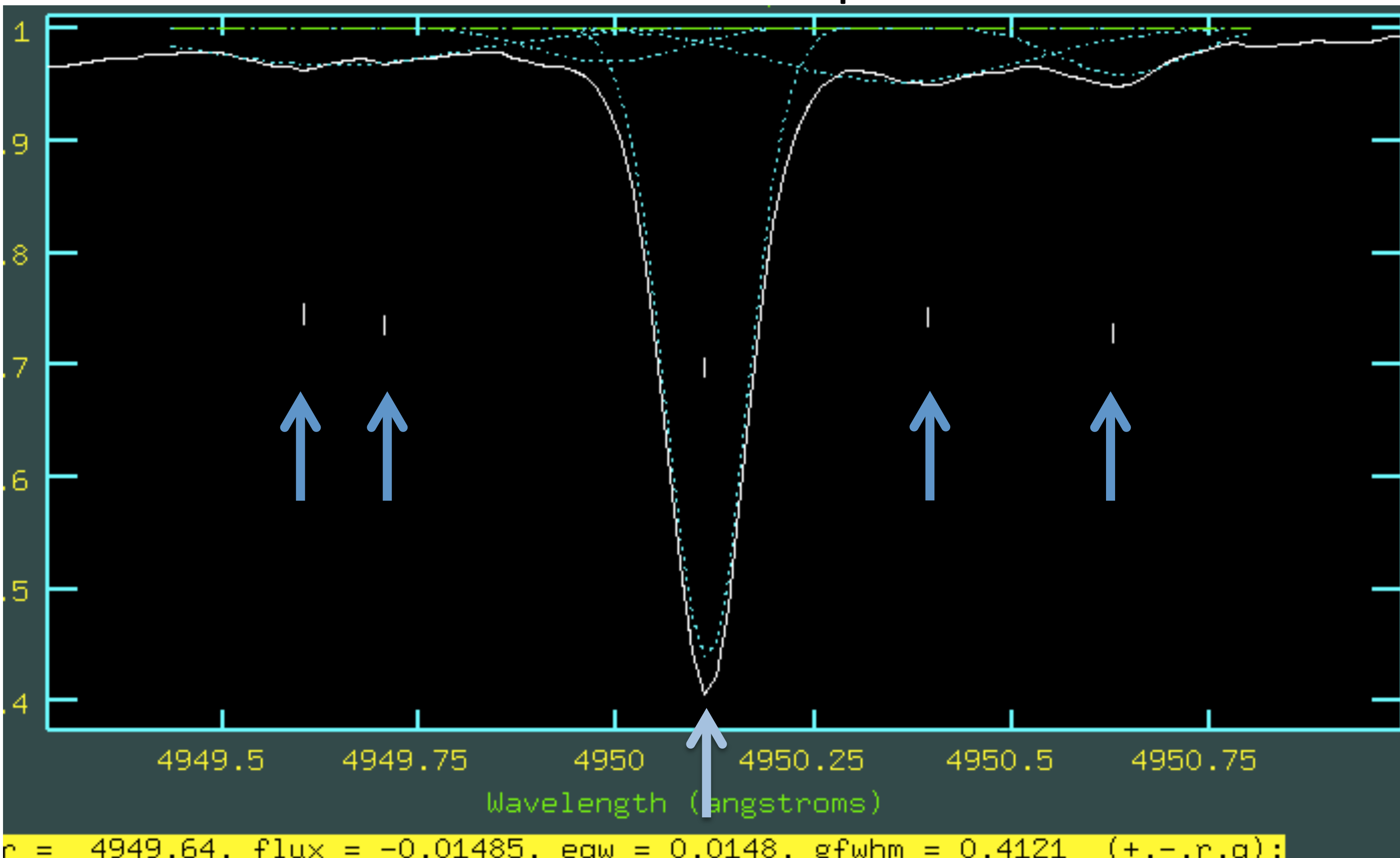


Fitting a Voigt profile: uncertain wings

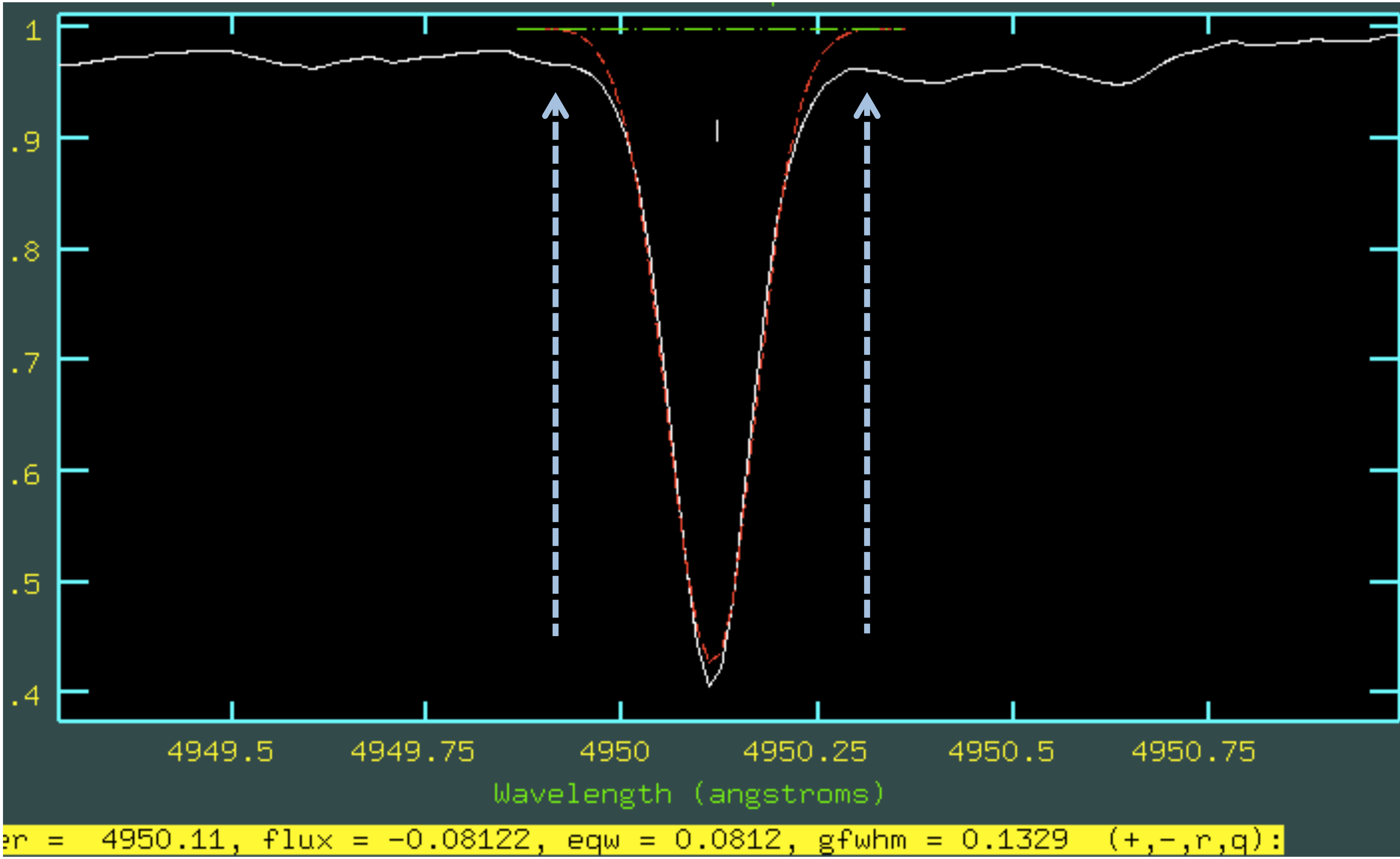


Deblending using gaussians:

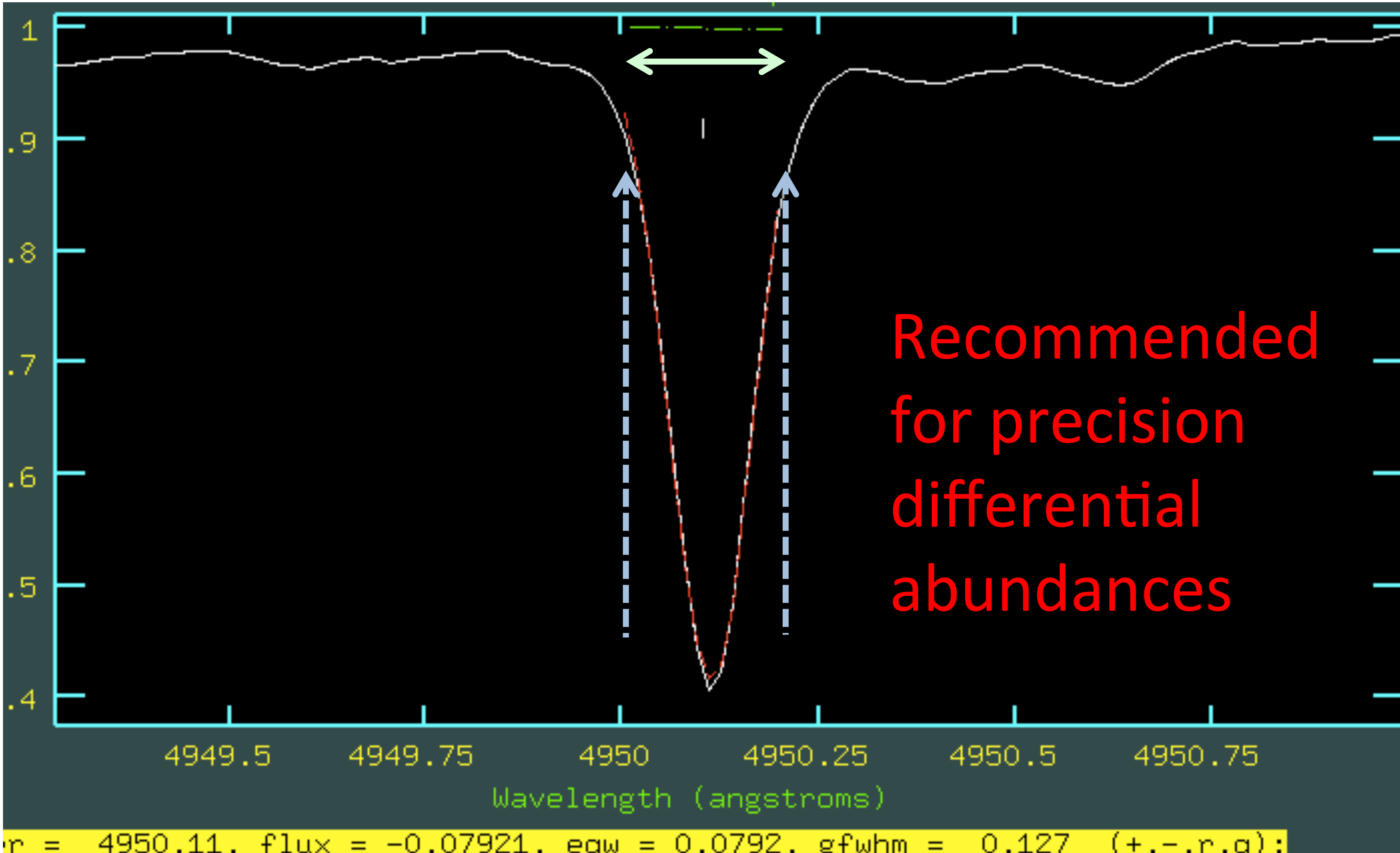
careful about uncertainties in (exaggerated) contribution of components!



Using a single gaussian: careful about using the whole wings (blends contribute)

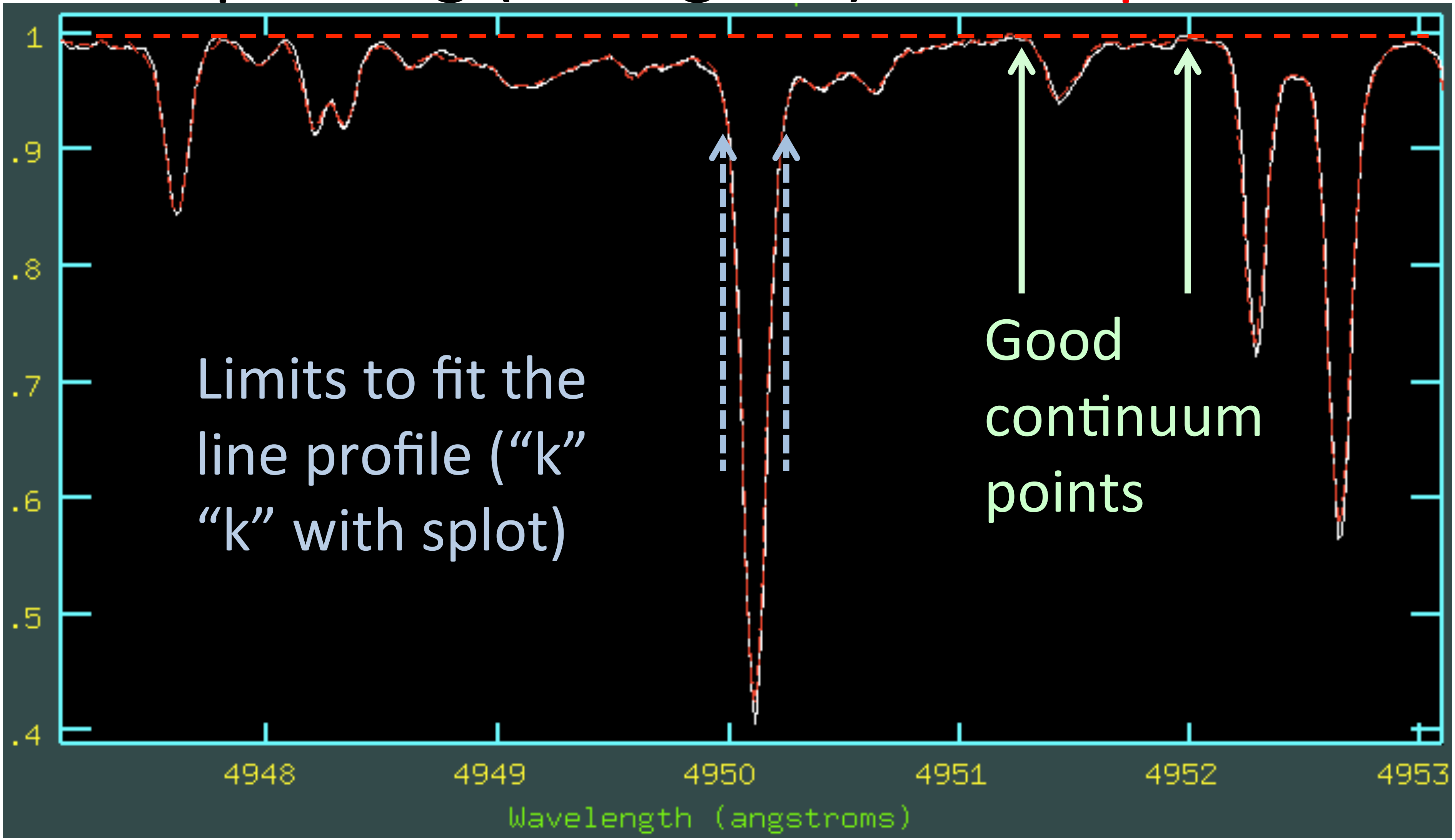


Using a single gaussian: careful about using the whole wings (blends contribute)



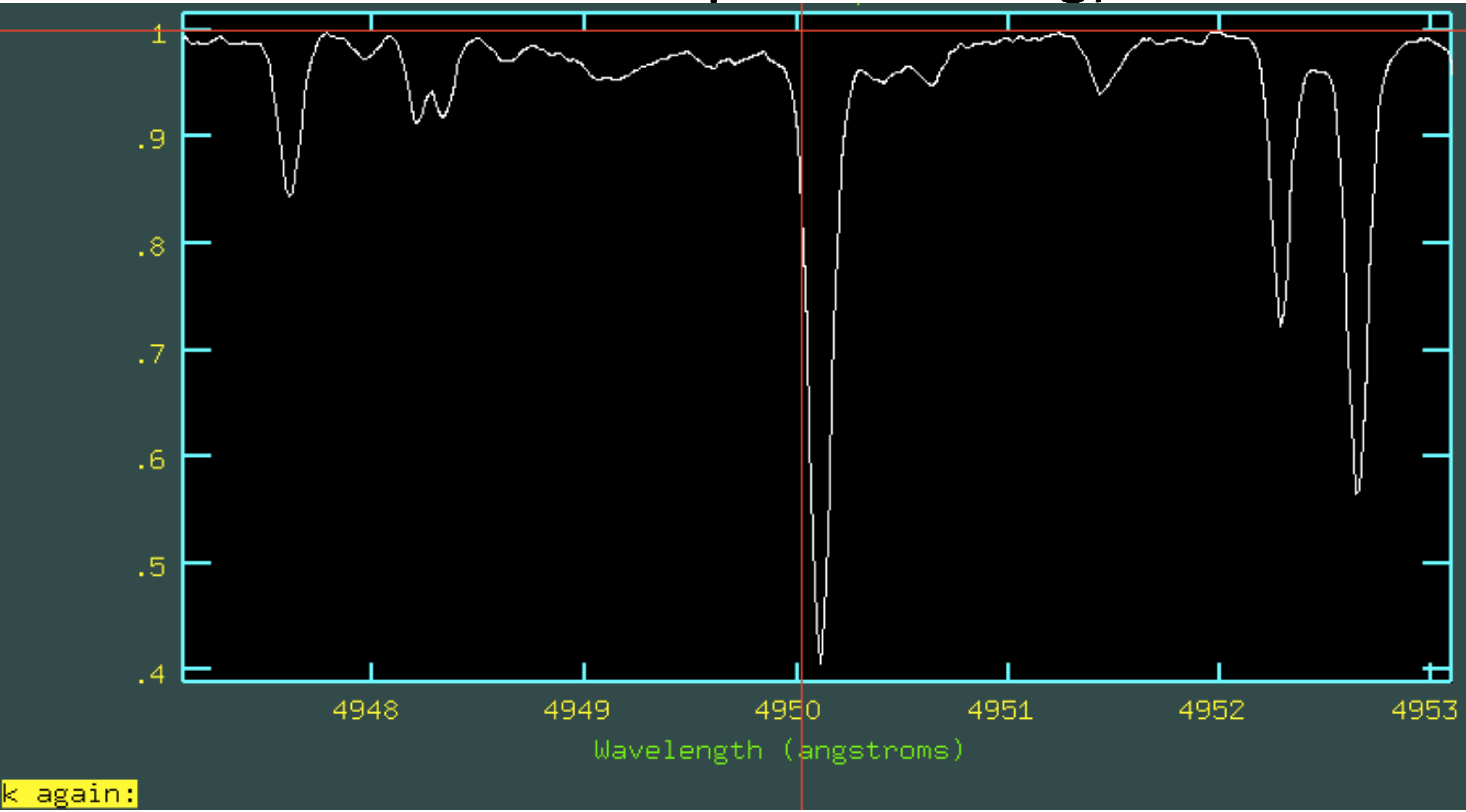
HIP 102152

Overplotting ("o" "g" ...) Sun's spectrum



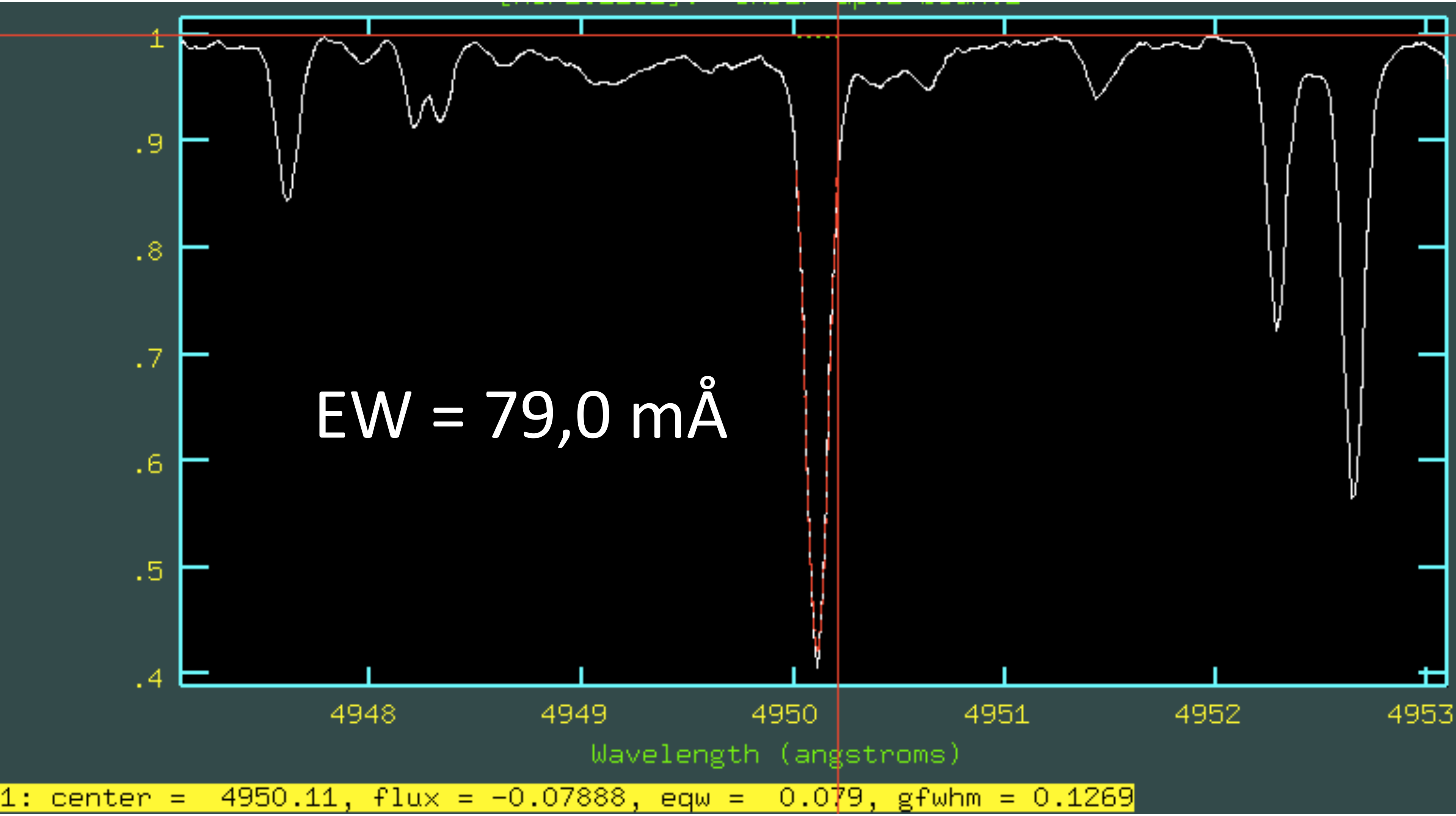
Measuring FeI line in HIP102152

"k" in splot (at the chosen continuum and left limit for profile fitting)

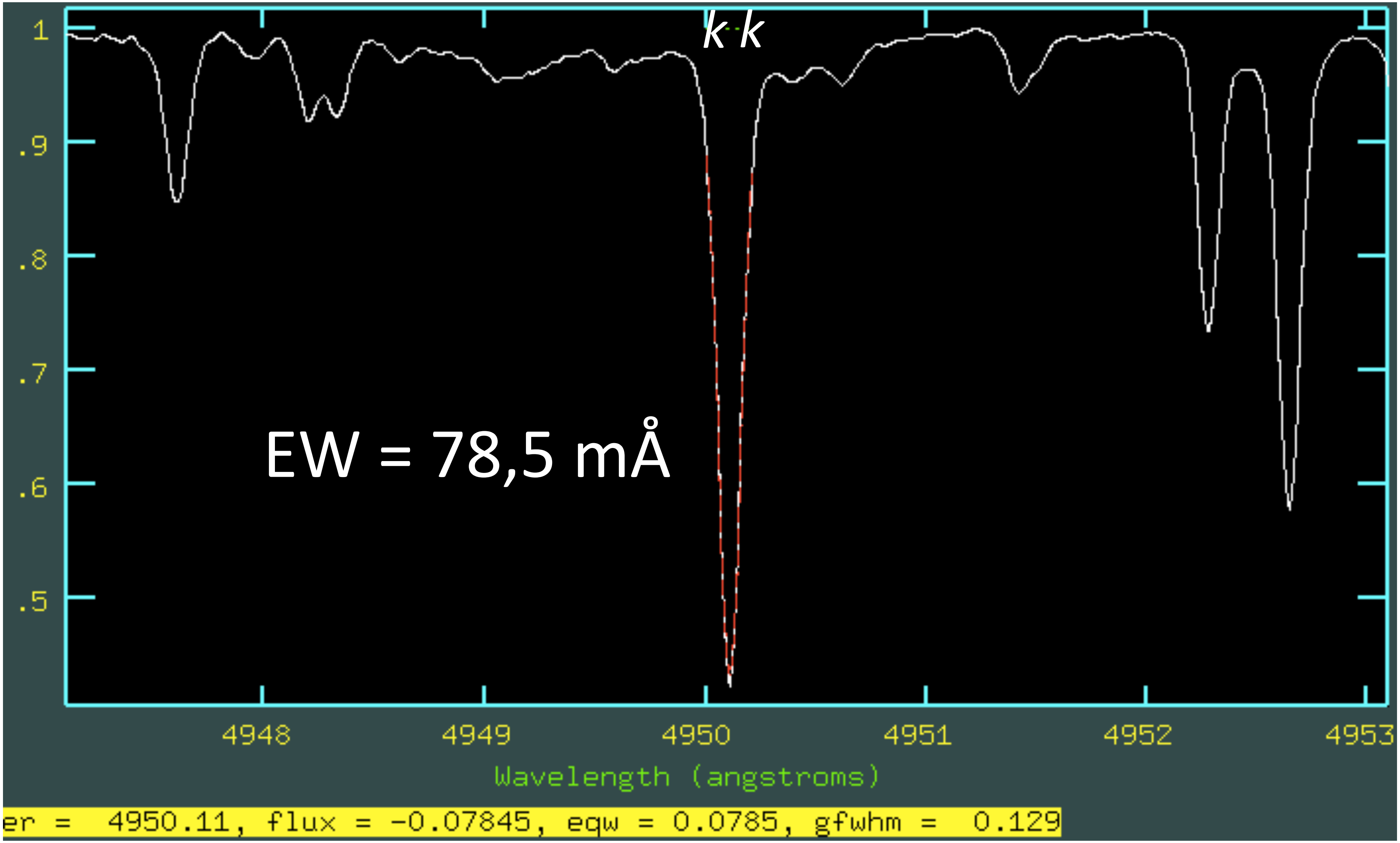


Measuring FeI line in HIP102152

"k" in splot (at the chosen continuum and right limit for profile fitting)



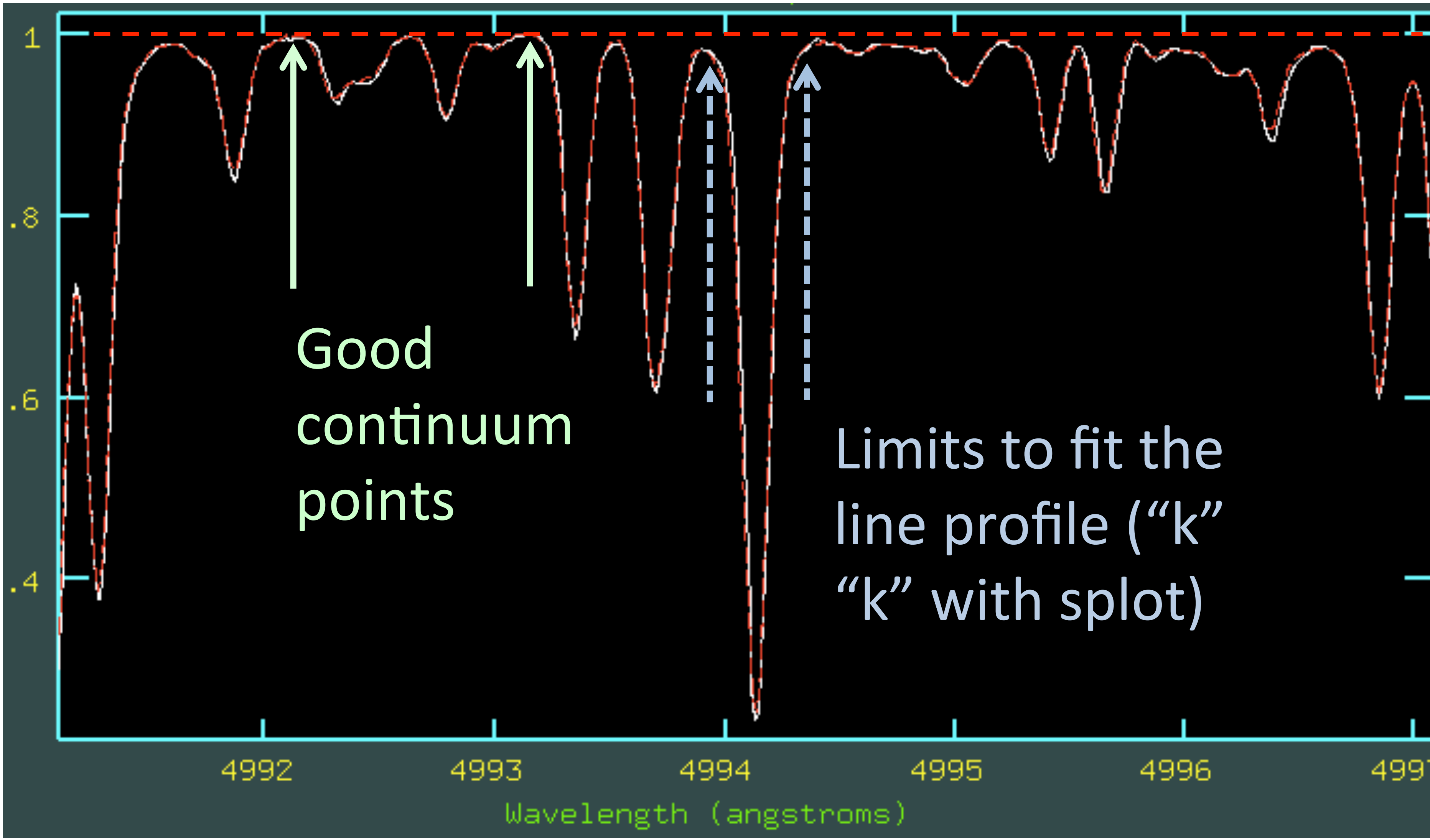
Measuring FeI line in the Sun
"k" at chosen continuum and left/right limits



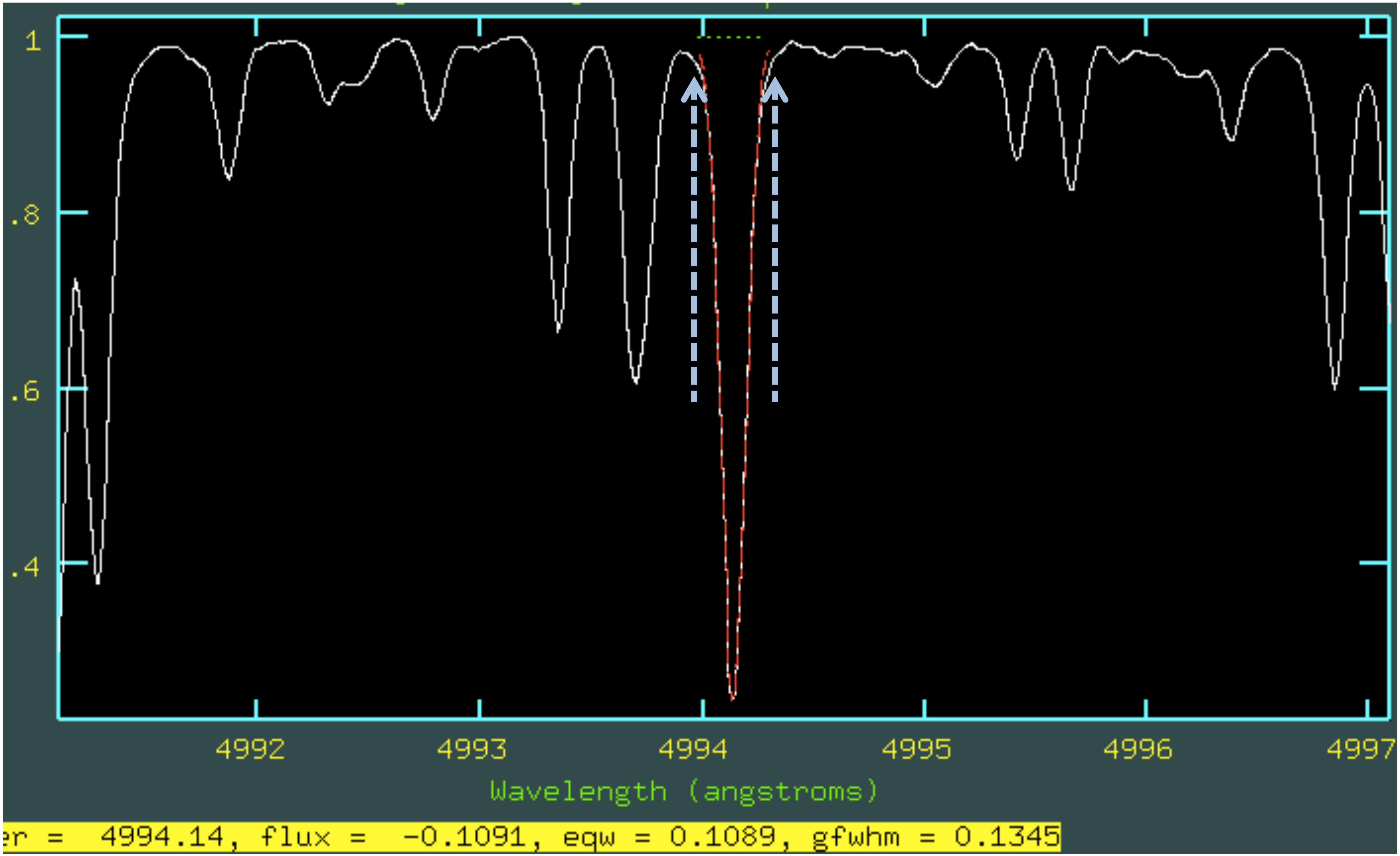
splot HIP102152 xmin=4991.1 xmax=4997.1

HIP 102152 | Sun

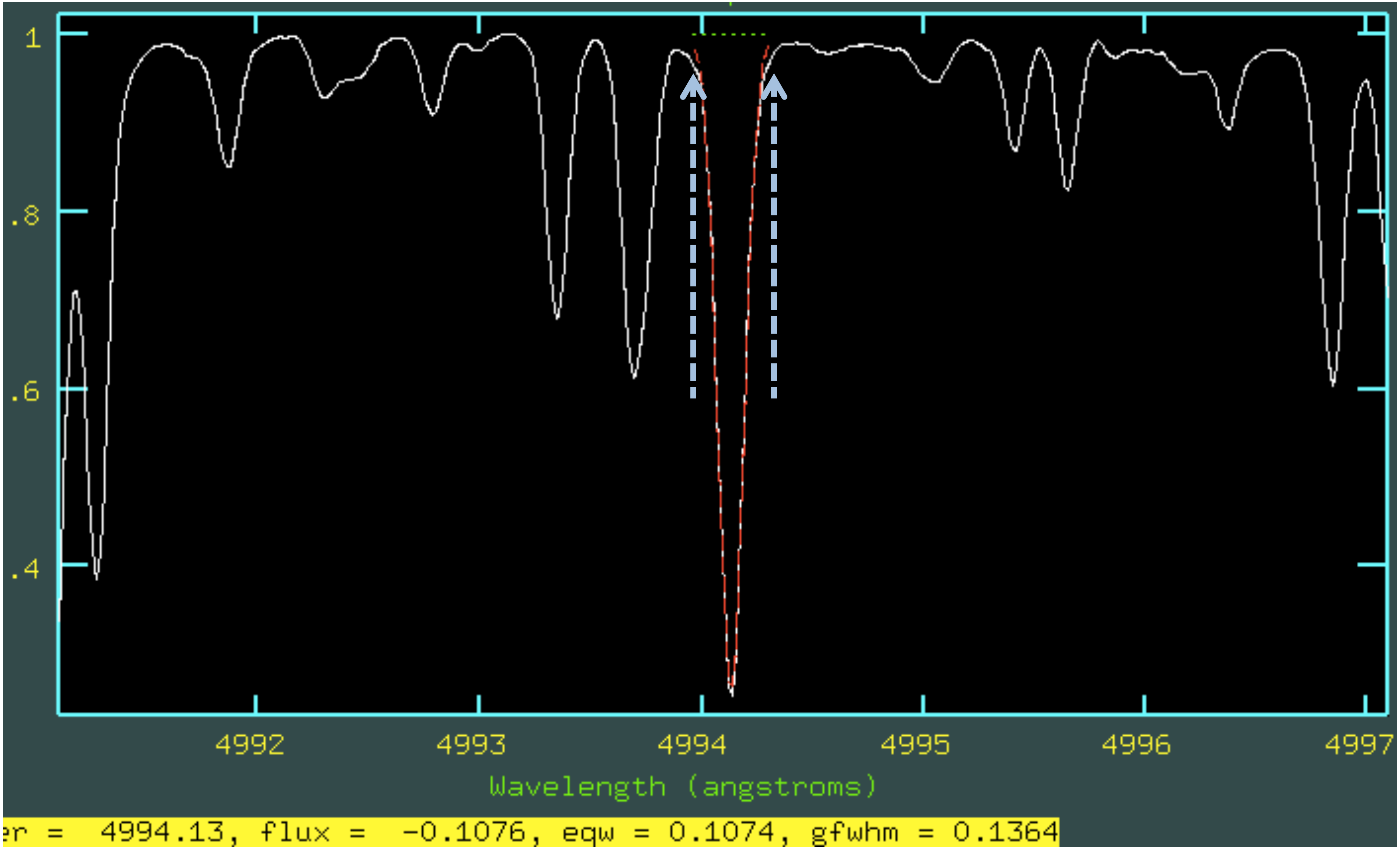
FeI 4994,1 Å



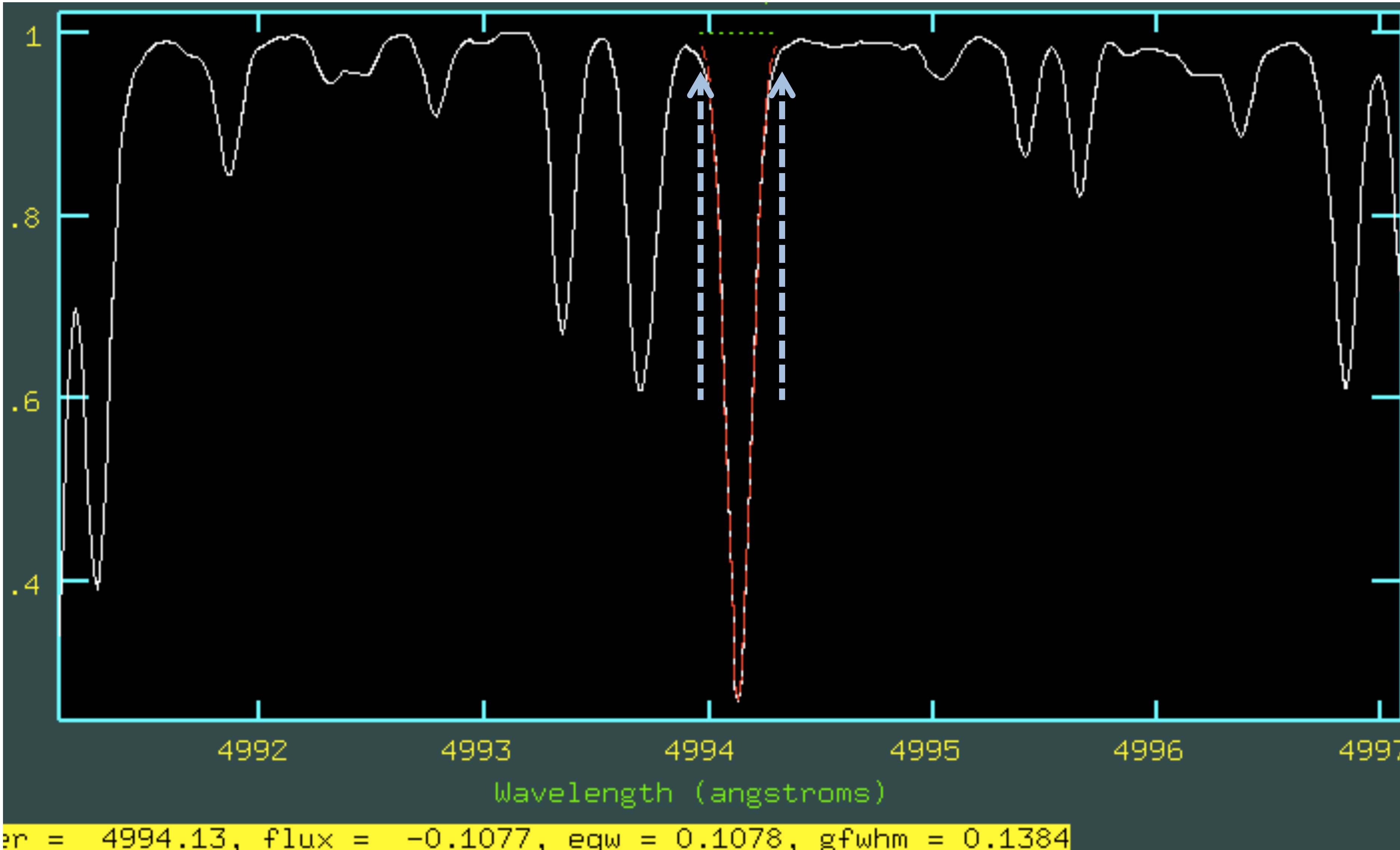
EW = 108,9 mÅ in HIP 102152



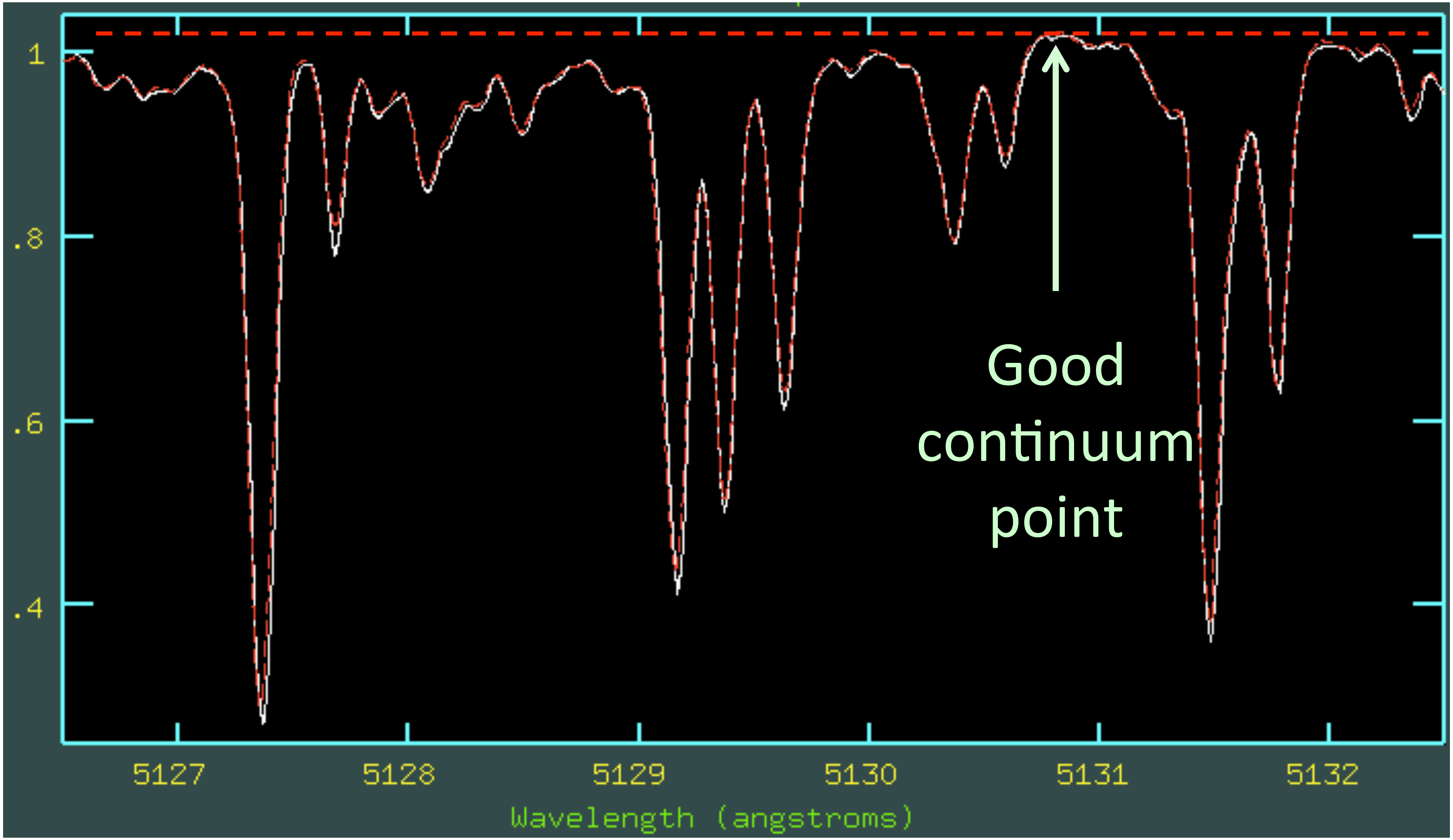
EW = 107,4 mÅ in Sun



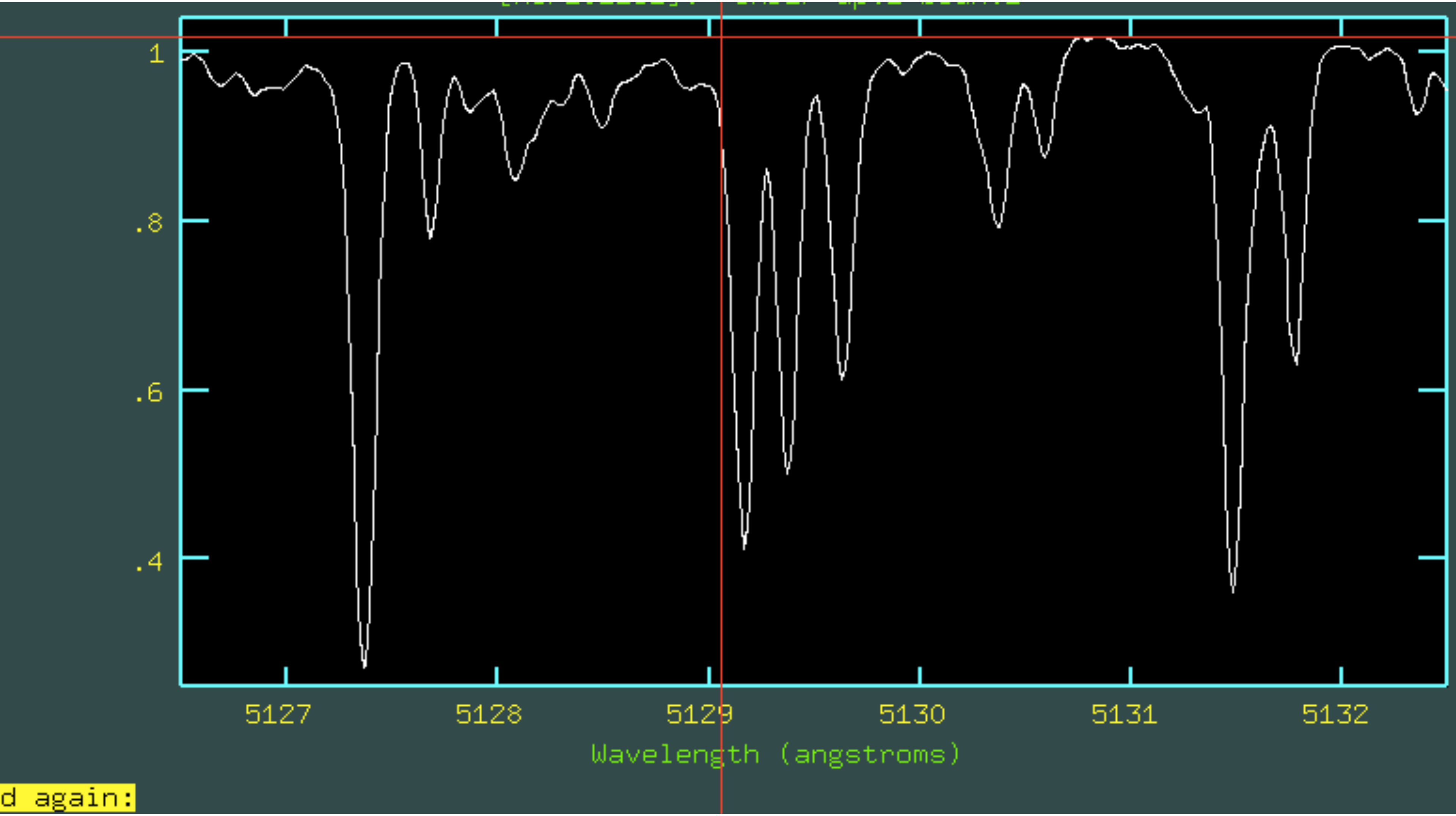
EW = 107,8 mÅ in HIP79672 (18 Sco)



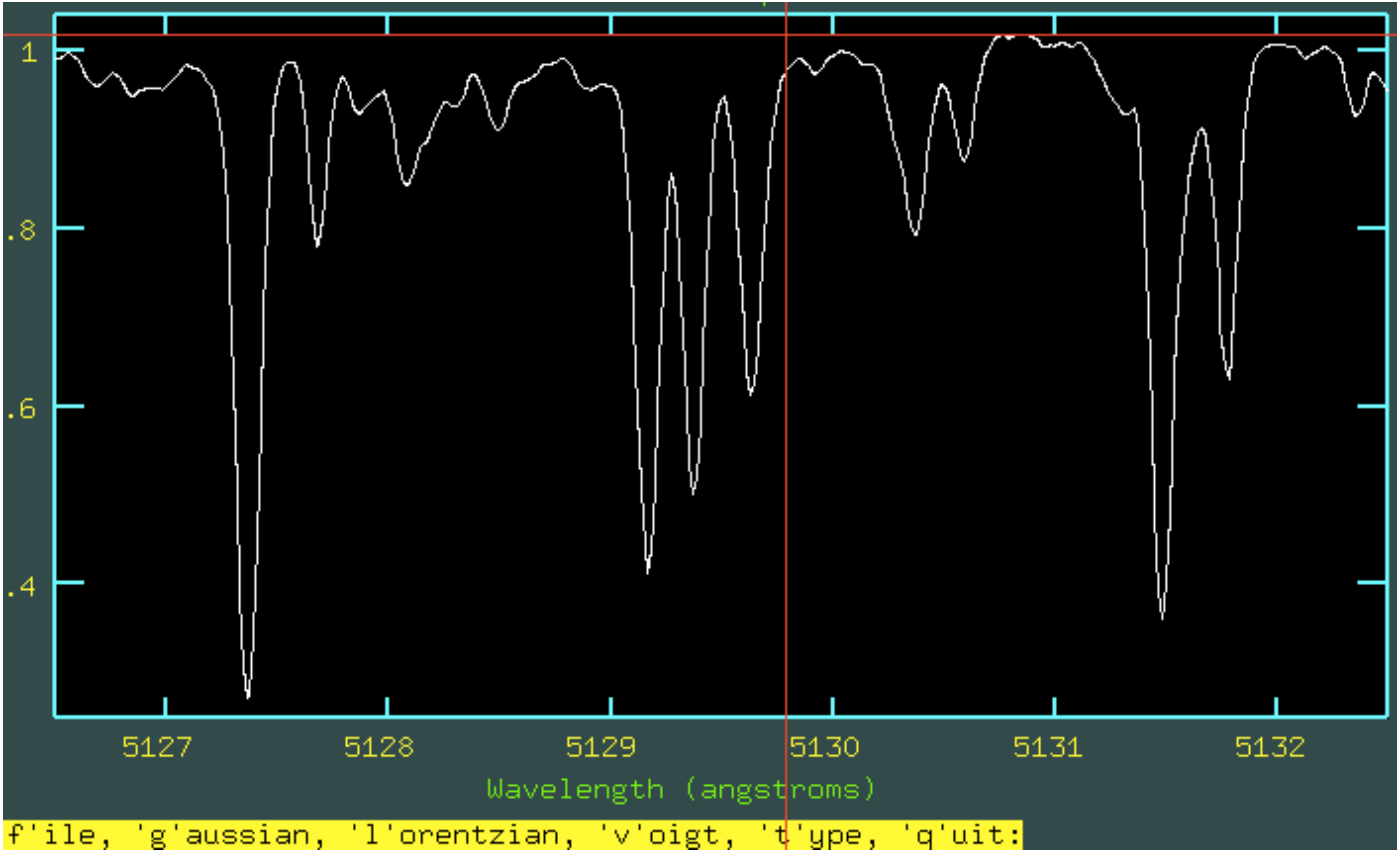
HIP 102152 Sun



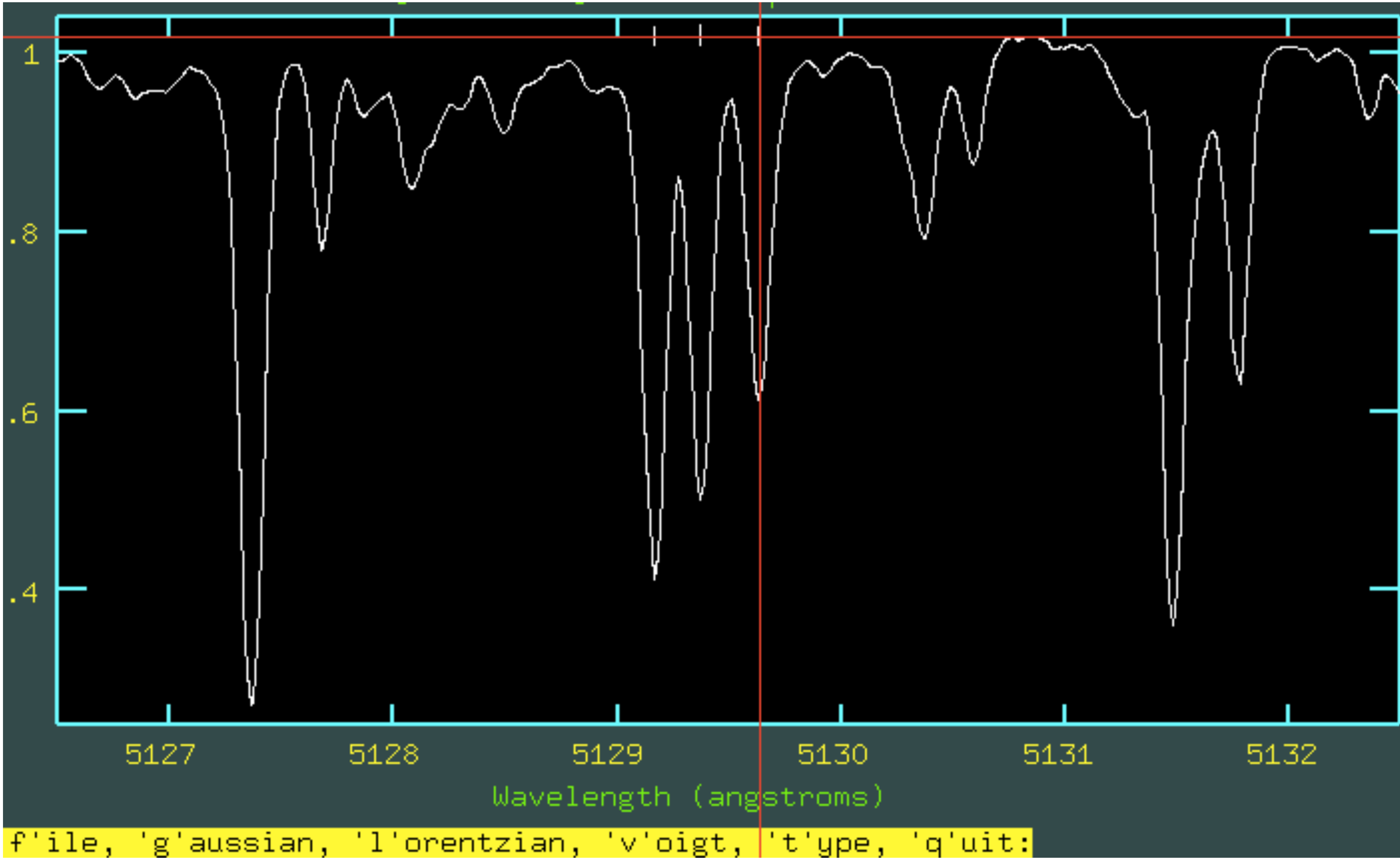
Deblending 3 lines in HIP102152



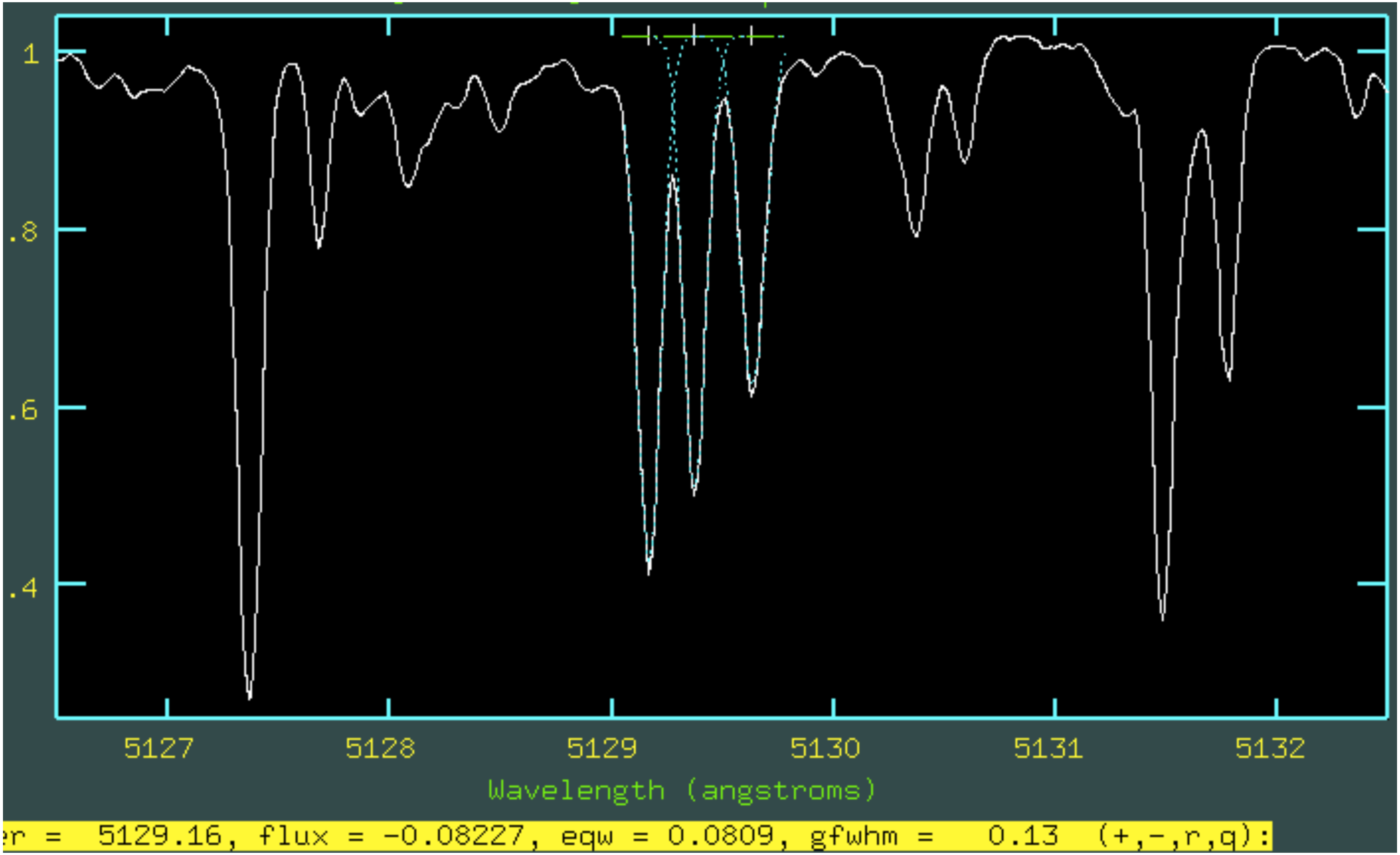
Deblending 3 lines in HIP102152



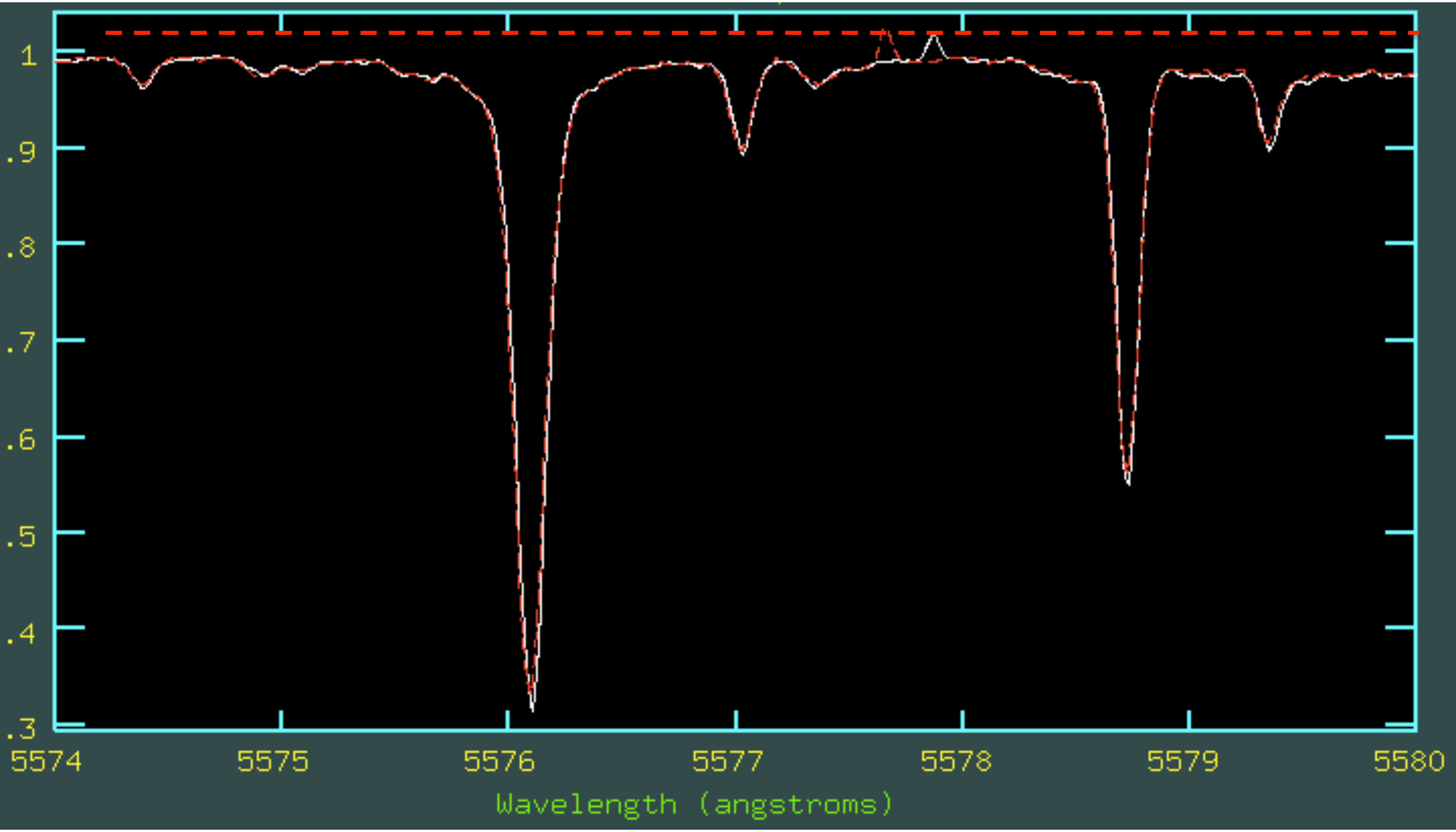
Deblending 3 lines in HIP102152



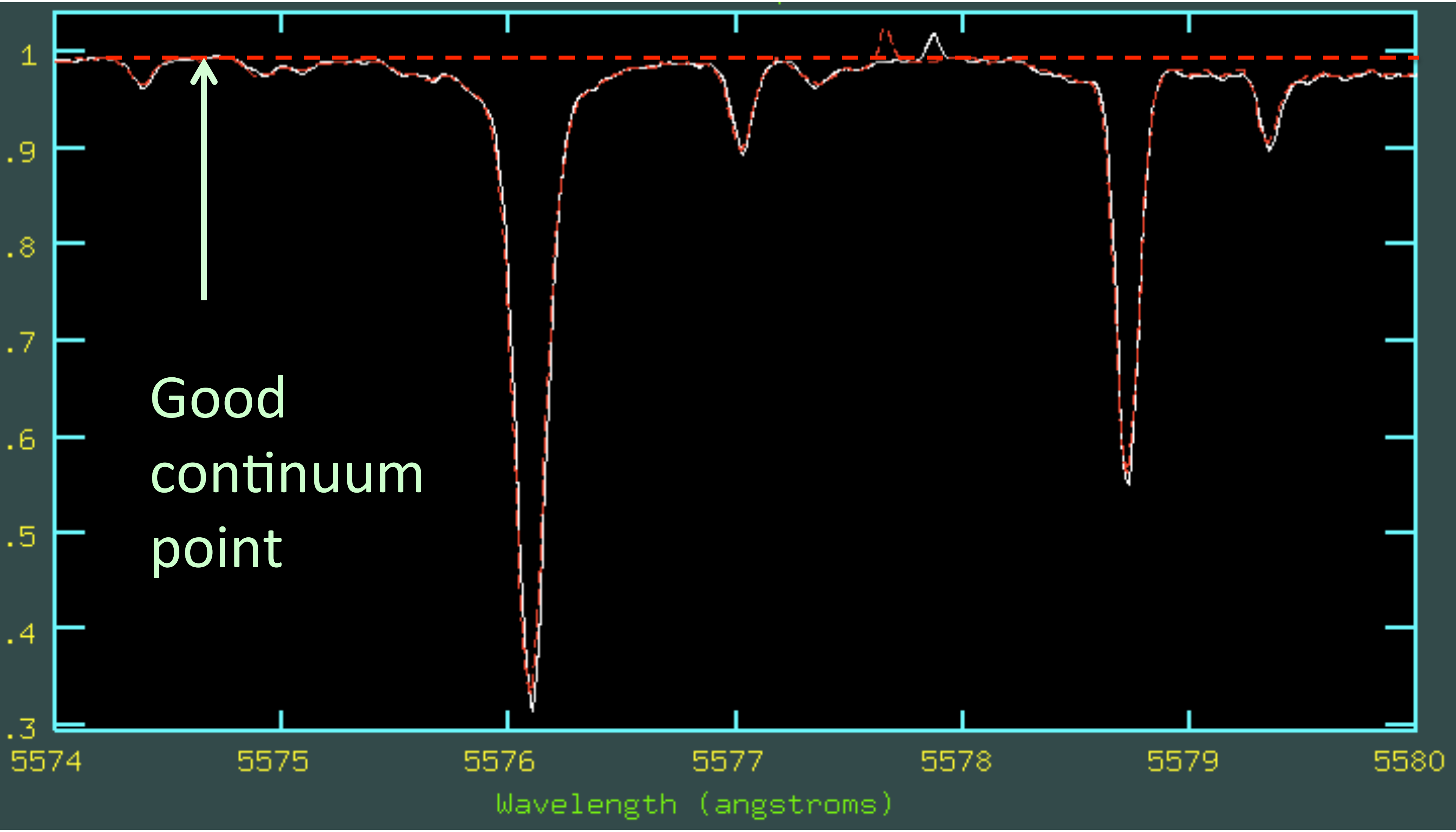
Deblending 3 lines in HIP102152



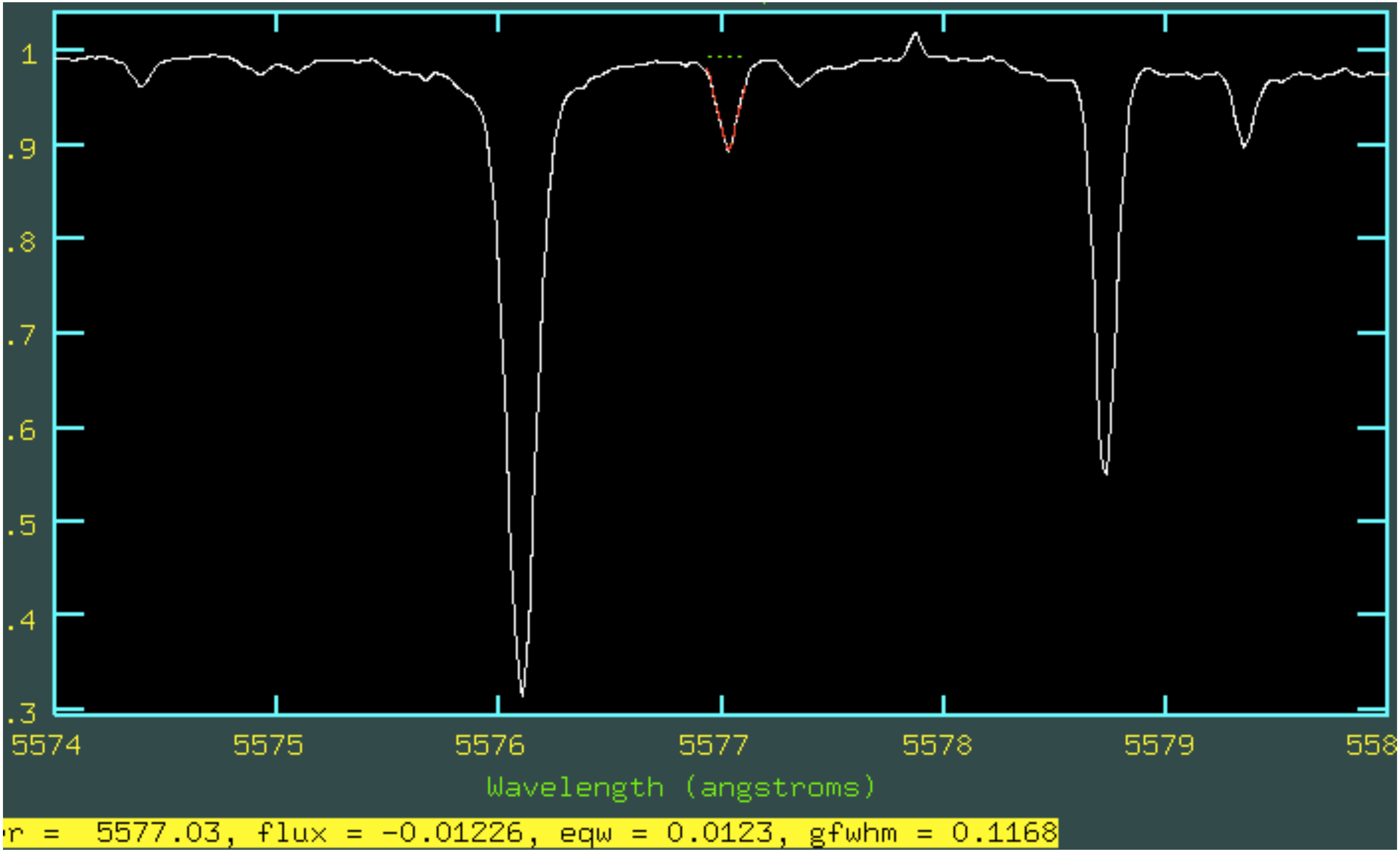
FeI line at 5577 Å



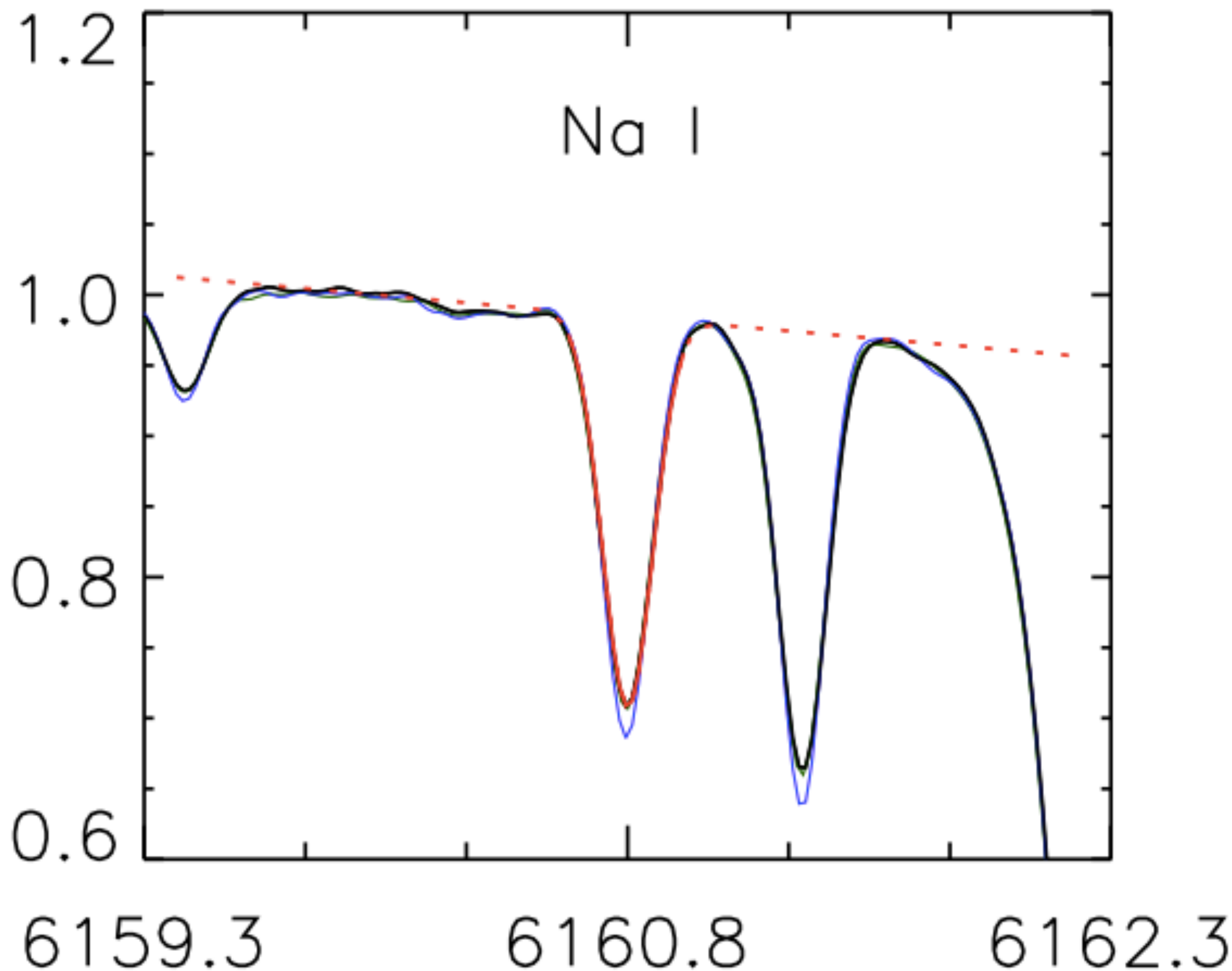
FeI line at 5577 Å



HIP102152: 12,3 mÅ, Sun (Juno): 11,8 mÅ
18 Sco (HIP79672): 12,9 mA

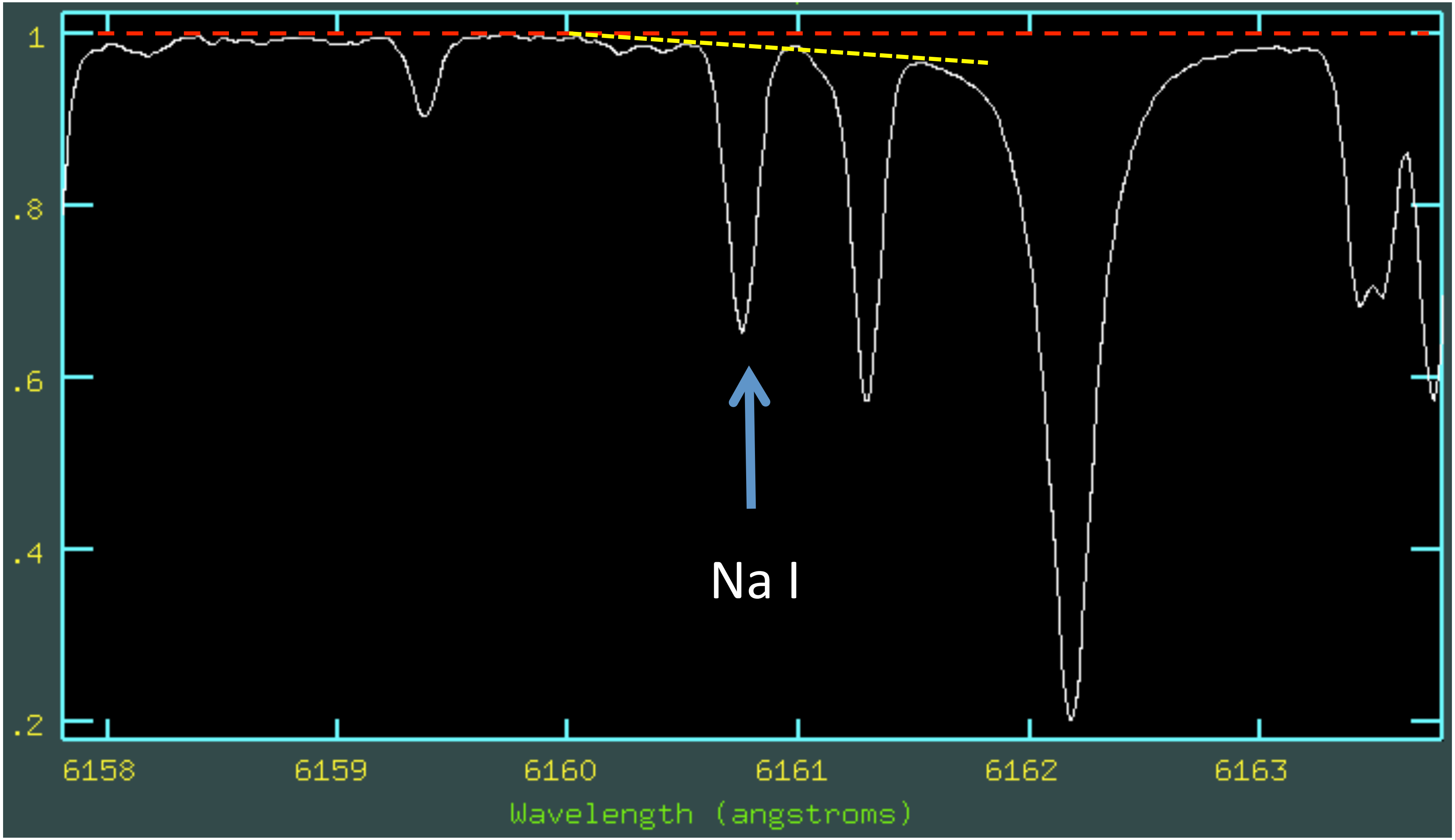


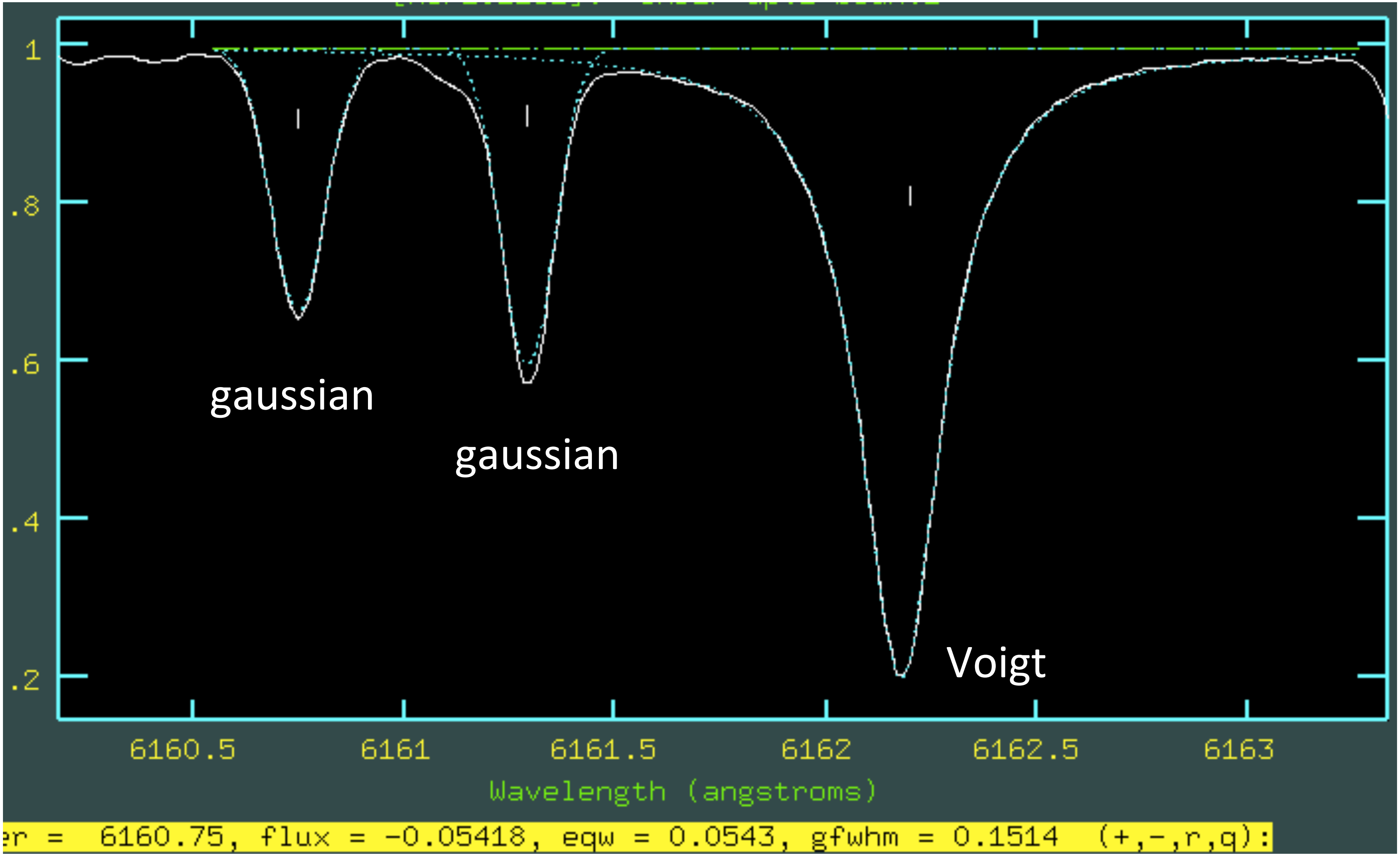
NaI at 6160.8Å: inclined continuum



Bedell et al. 2014, ApJ, 795, 23

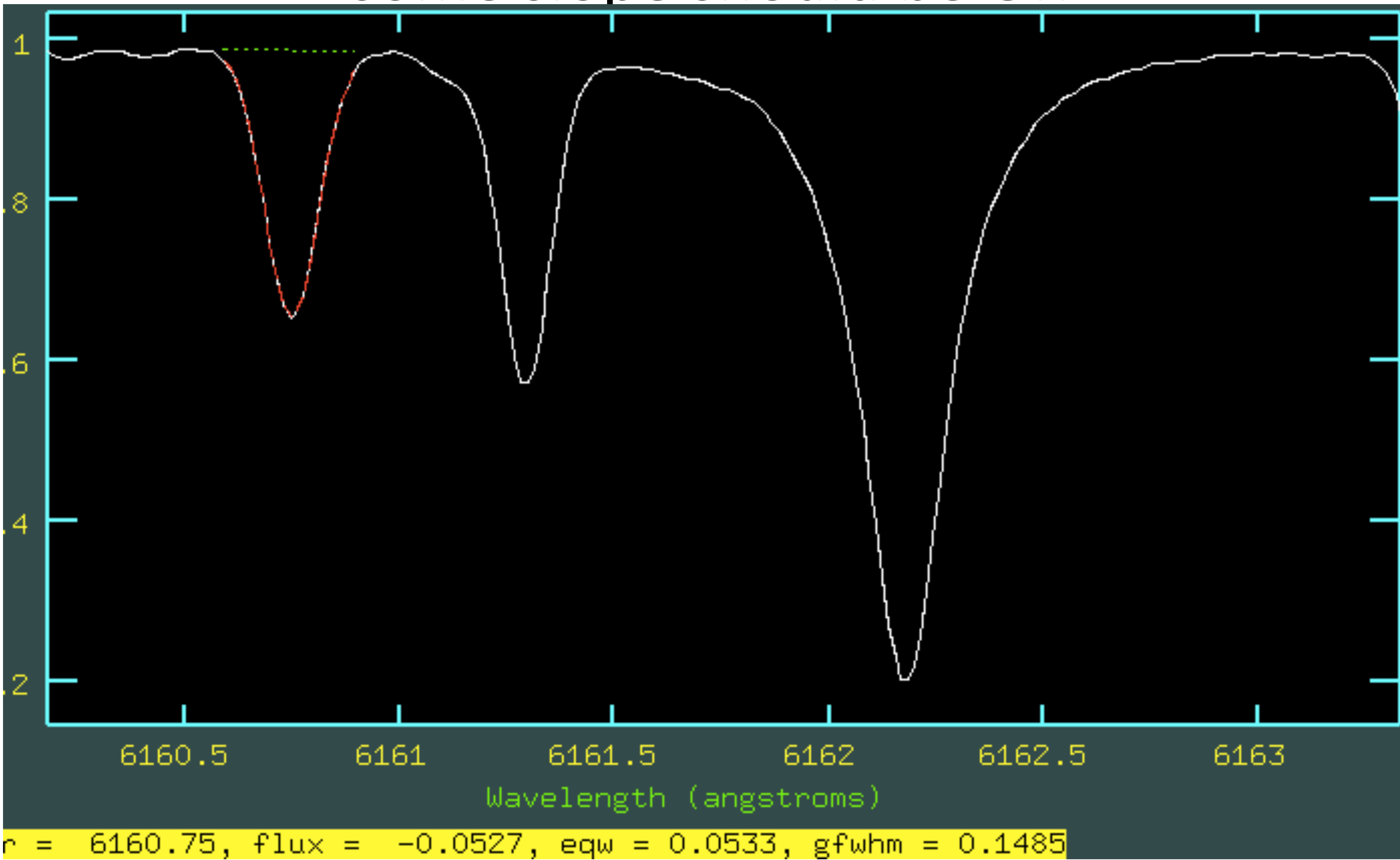
Continuum has slope due to (Lorentzian) wing of strong nearby line





1
.8
.6
.4
.2
gaussian
gaussian
Voigt
6160.5
6161
6161.5
6162
6162.5
6163
Wavelength (angstroms)
er = 6160.75, flux = -0.05418, eqw = 0.0543, gfwhm = 0.1514 (+,-,r,q):

Perhaps try a single gaussian with local continuum. Borderline case: either flat or some slope should be OK



Final tip: try to have a good sample of lines (different exc.pot and line strengths)