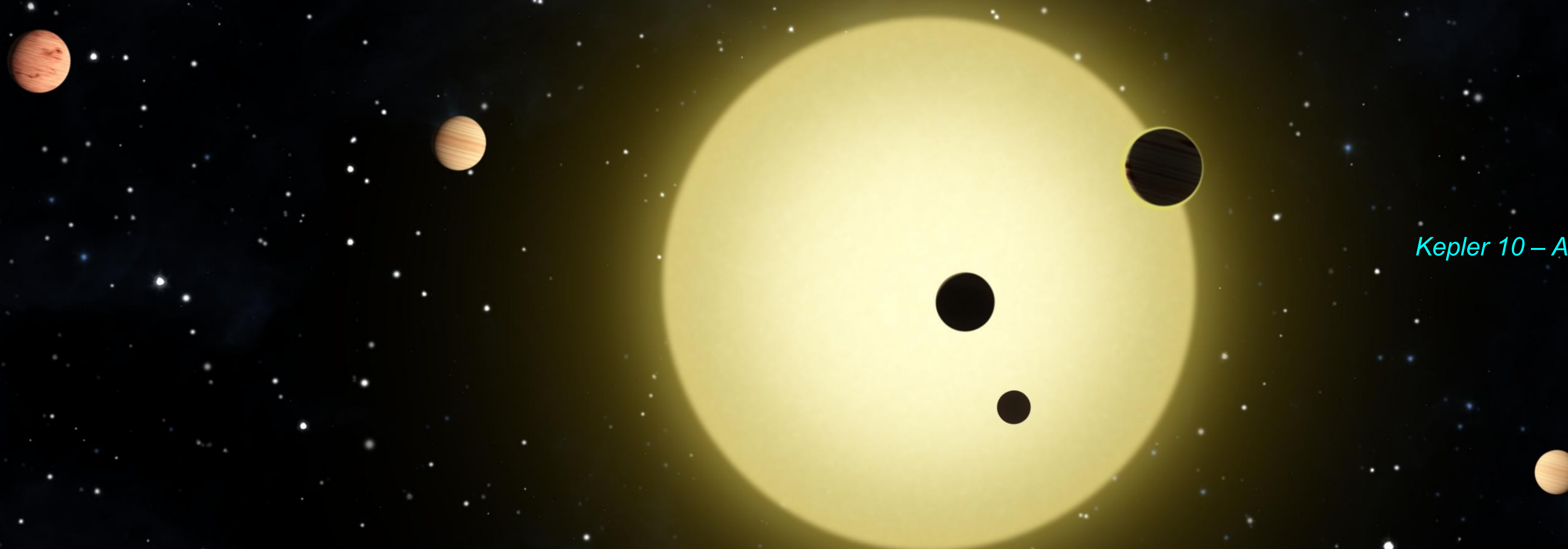
ARES+MOOG
From EWs to stellar parameters



Kepler 10 – Artistic View

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FCT Fundação para a Ciência e a Tecnologia
MINISTÉRIO DA CIÊNCIA E DO ENSINO SUPERIOR

Wroclaw – Poland – 2013

Homogeneous Analysis

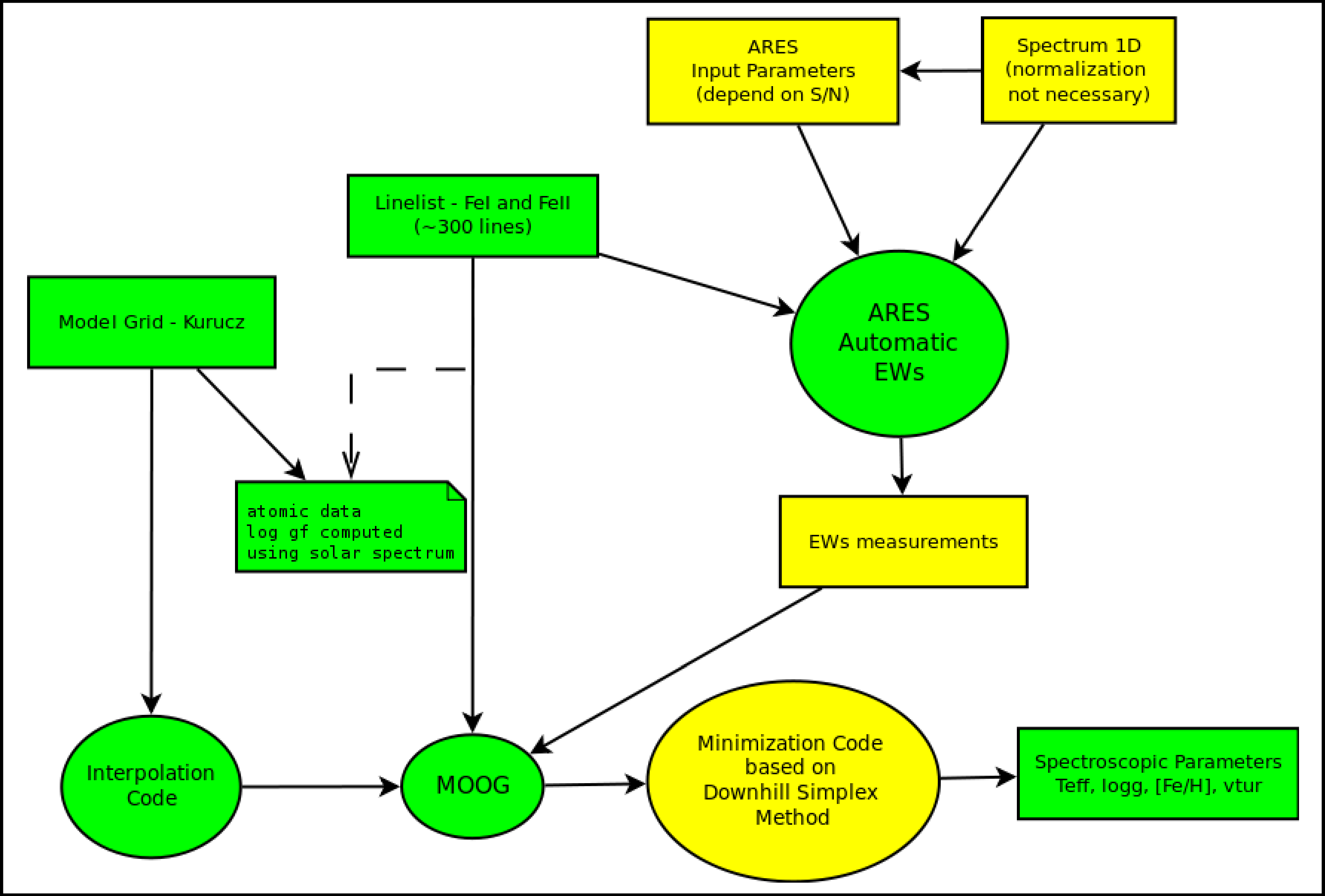
Spectroscopic Stellar Parameters Determination – Our method:

We determine **Teff**, **log g**, **[M/H]** using a standard technique based on the excitation and ionization balance using the Equivalent Widths (EWs) measurements for many iron lines. (We use ARES to compute EWs)

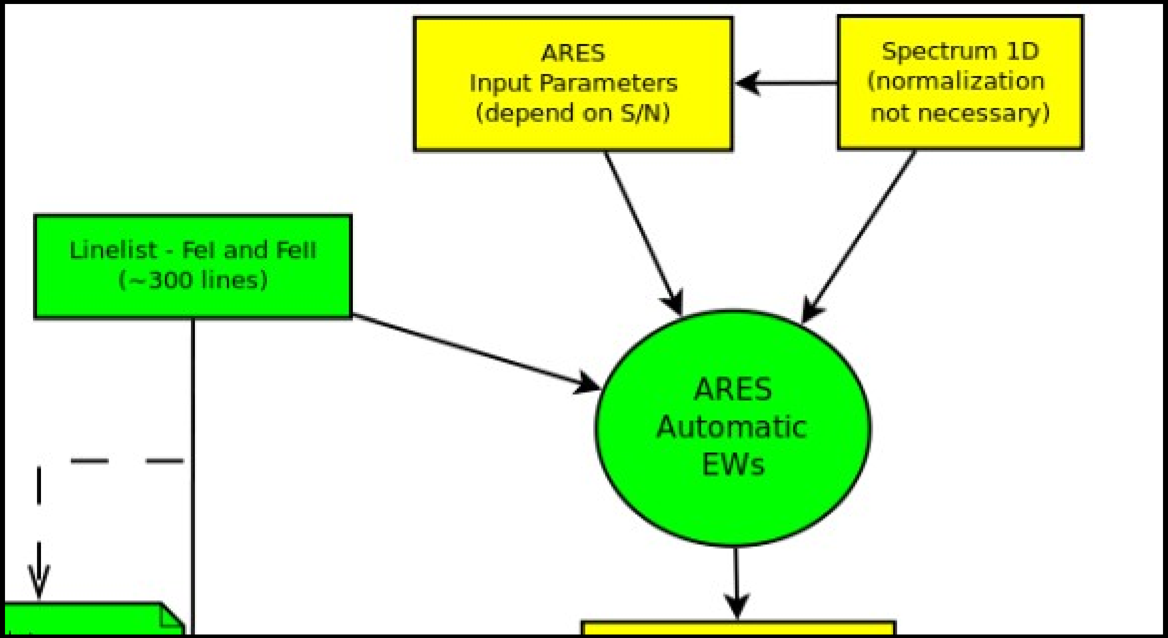
Abundance determination is done in LTE. (MOOG with Kurucz models)

Spectral Analysis done differentially to the Sun

Homogeneous and Automatic Analysis
Overview Sketch



Homogeneous and Automatic Analysis Overview Sketch



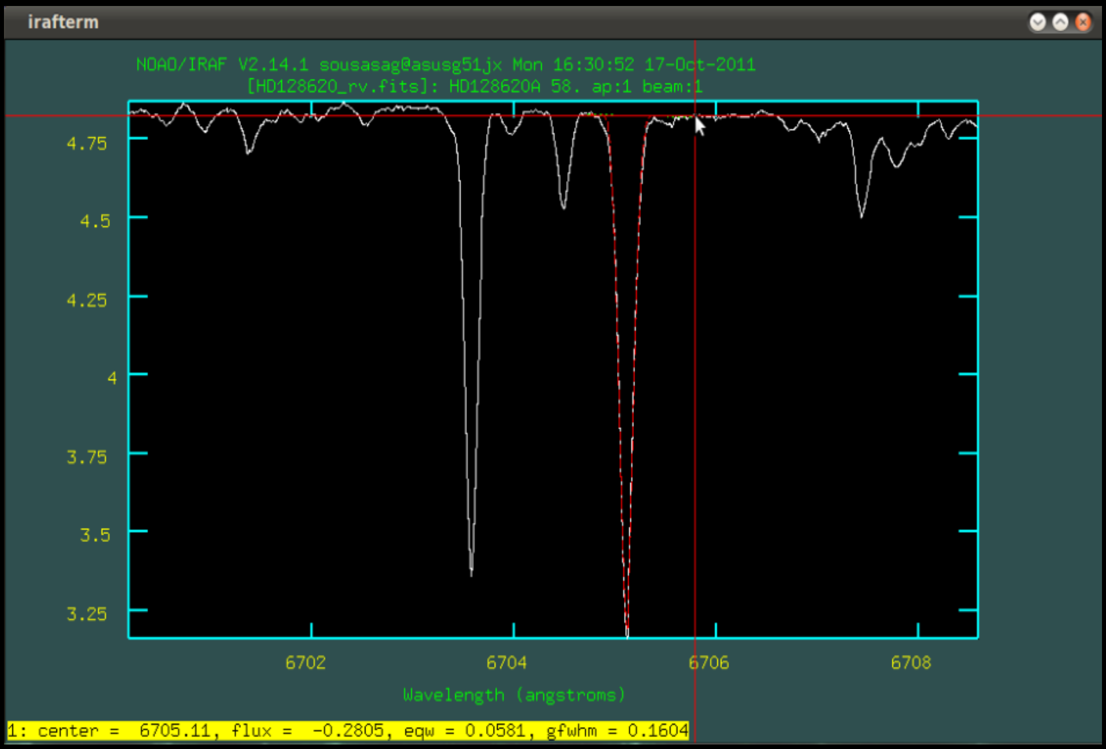
The first step is to determine the EWs for the iron lines.

Two ways to get EWs:

- Old fashion way: Use interactive routines (e.g. splot from IRAF (noao-imred-echelle));
- Modern/Faster way: Use automatic tools (e.g. ARES)

Homogeneous and Automatic Analysis

Equivalent Widths measurements – <u>Old fashion</u>



IRAF – splot routine...

Problems:

- Many spectra to analyze

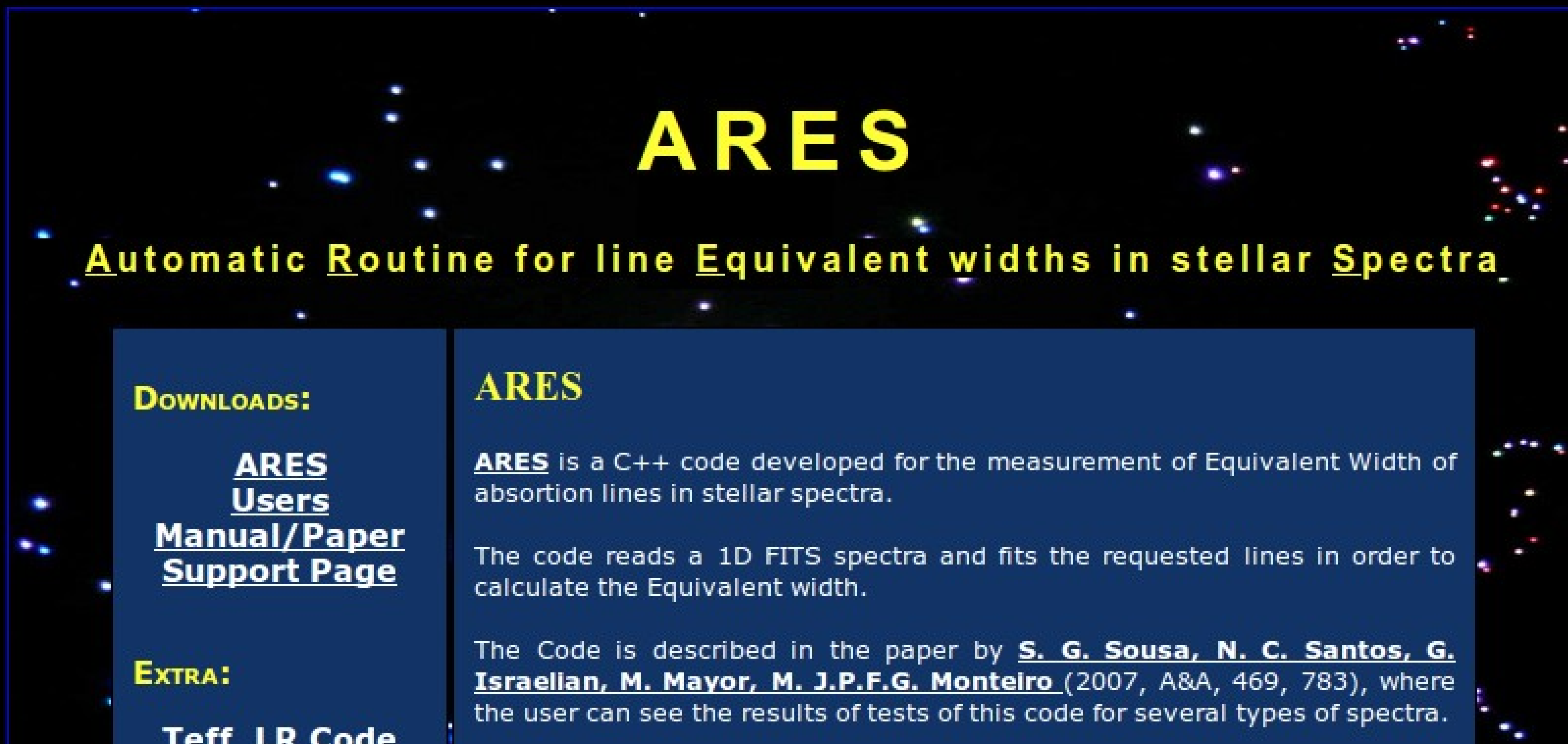
- “Manual” measurements are subjective

Problems in automatic measurements:

- Continuum position
- Blended Lines

Homogeneous and Automatic Analysis

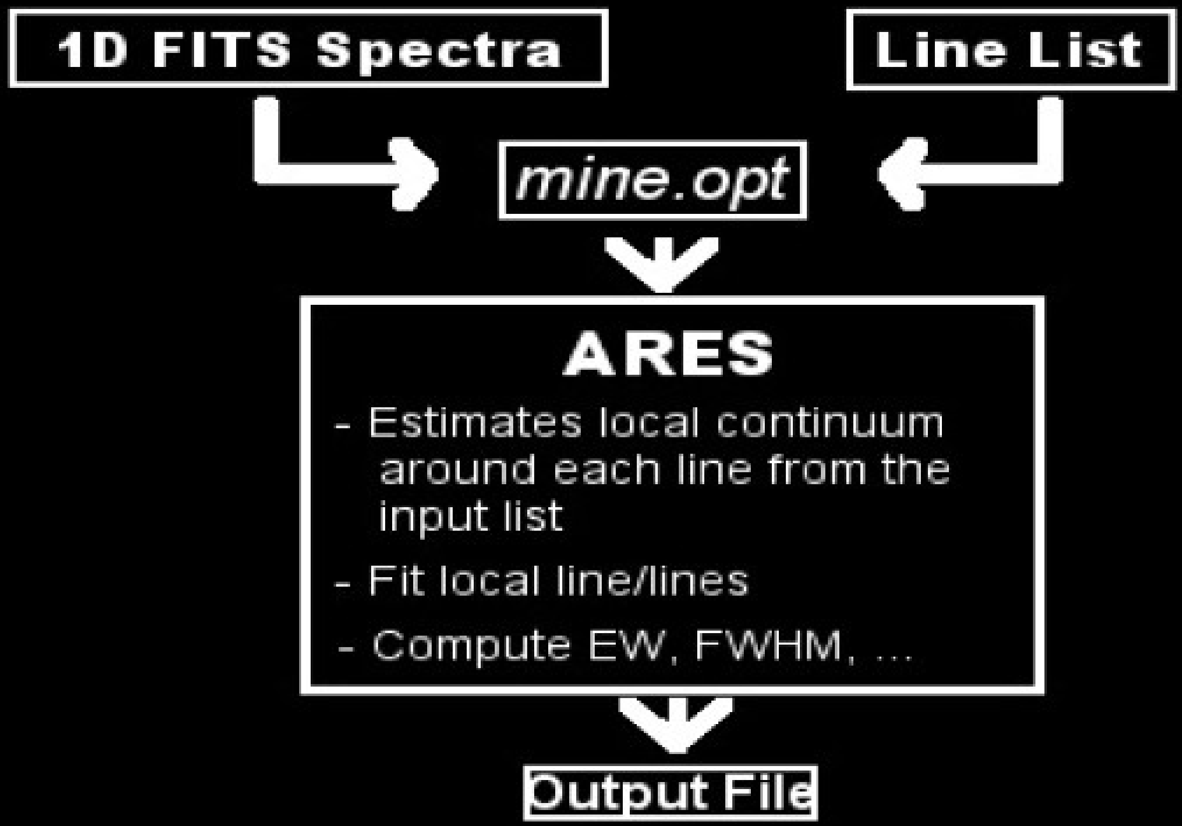
Modern/Faster way:



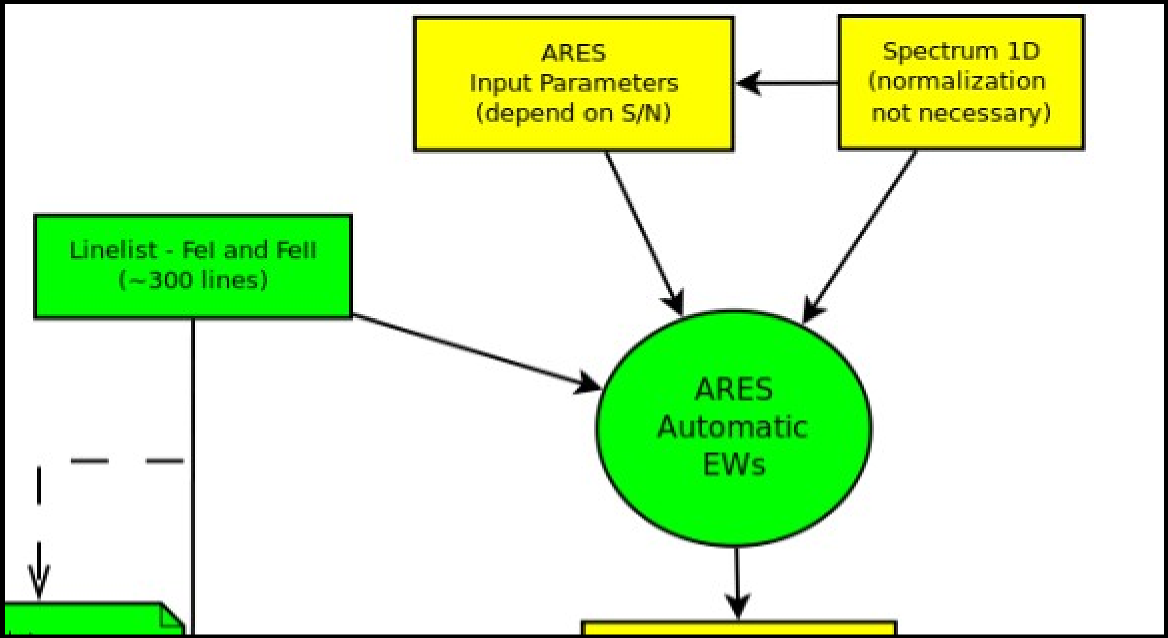
http://www.astro.up.pt/~sousasag/ares/

ARES Workflow

ARES PROCEDURE



Homogeneous and Automatic Analysis Overview Sketch



Summarizing again, to run ARES you need:

1- The file *mine.opt* with the input parameters;
2- A 1D Fits spectra, corrected in radial Velocity. (normalization not required)
3- A list of iron lines to measure the EWs

ARES INPUT FILE
mine.opt

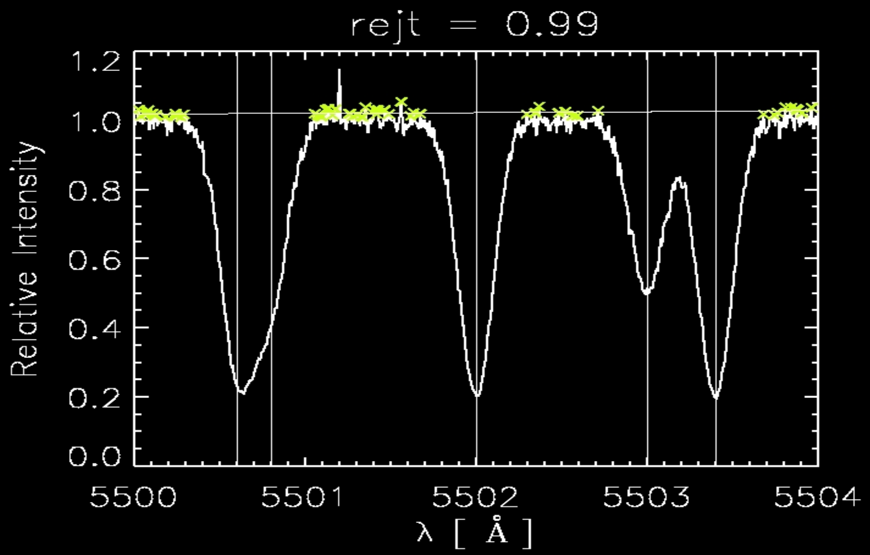
5- INPUT PARAMETERS 'mine.opt' FILE:

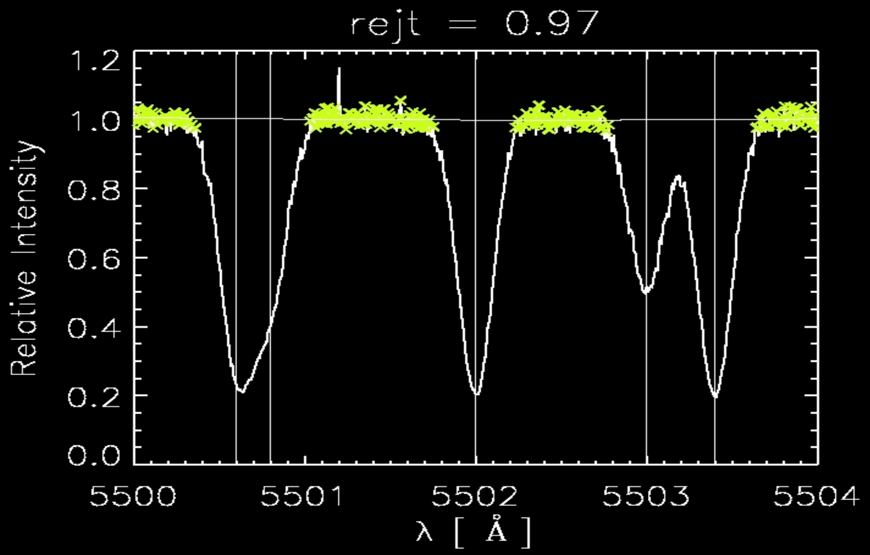
specfits:	1D fits spectrum for the analysis.
readlinedat:	Line list for the analysis.
fileout:	Output file for the results.
lambdai:	Initial wavelength for the search of the lines.
lambdaf:	Final wavelength for the search of the lines.
smoothder:	Parameter for the calibration of the search of the lines. Noise smoother for the derivatives.
space:	Interval in Angstrom for the computation for each line.
rejt:	Parameter for the calibration of the continuum position.
lineresol:	This parameter sets the line resolution of the input spectra. If the code finds two lines closer than the value set for this parameters, then we take the two lines as one line alone.
miniline:	Weaker line strength to be printed in the output file.
plots_flag:	Flag for the plots. 0-runs in batch, 1-shows the plots and stops for each line calculation.

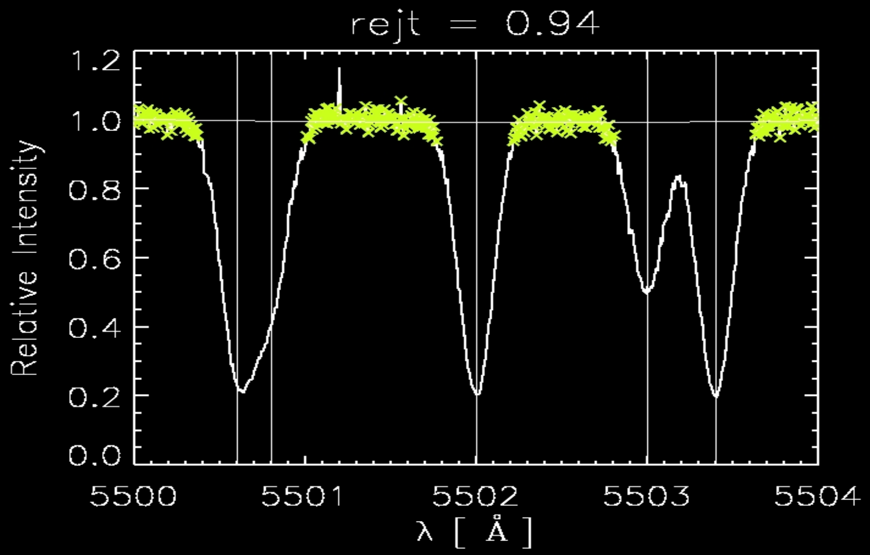
ARES Continuum position

Rejt input parameter:

calibrates position of the continuum level

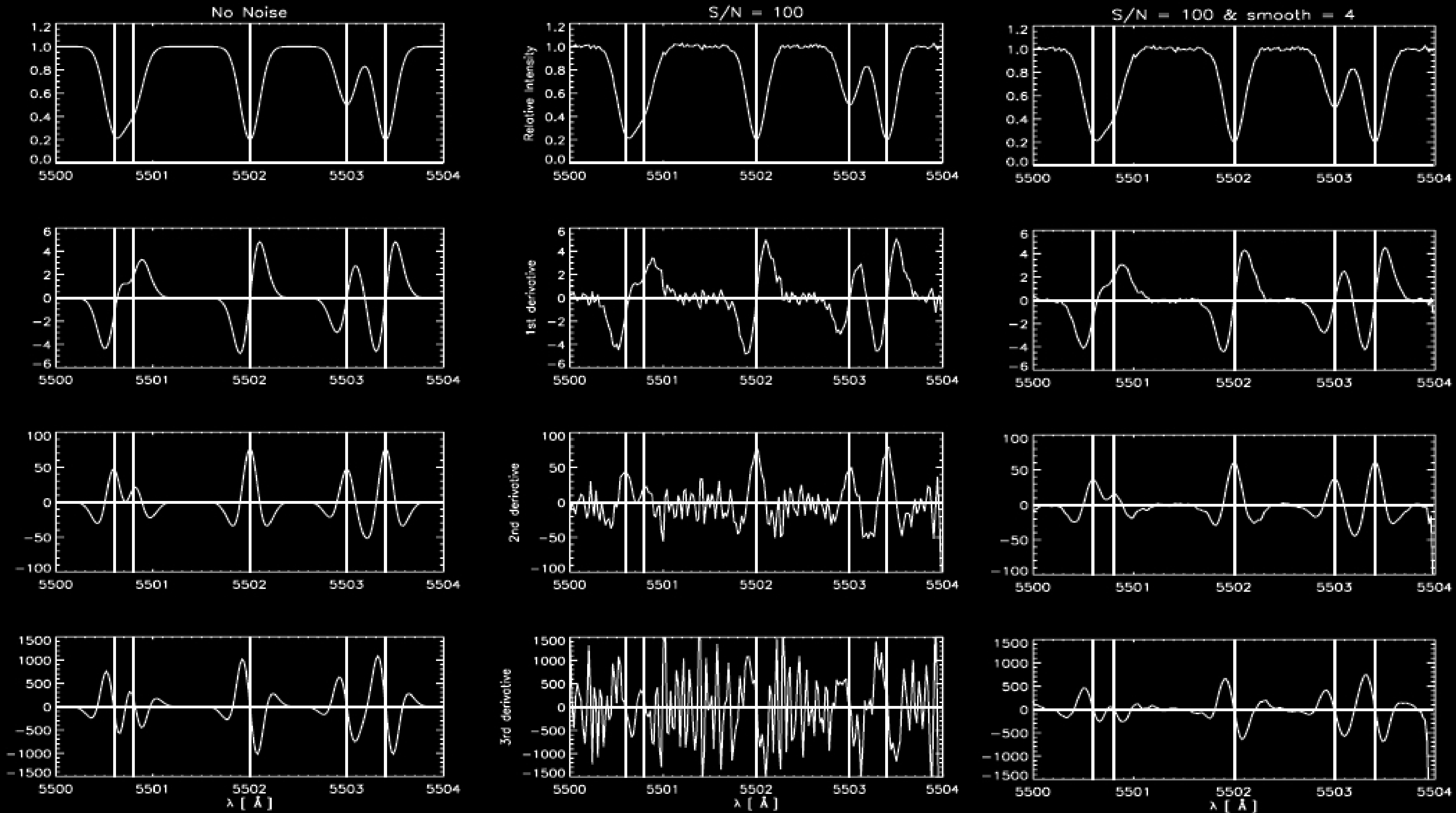




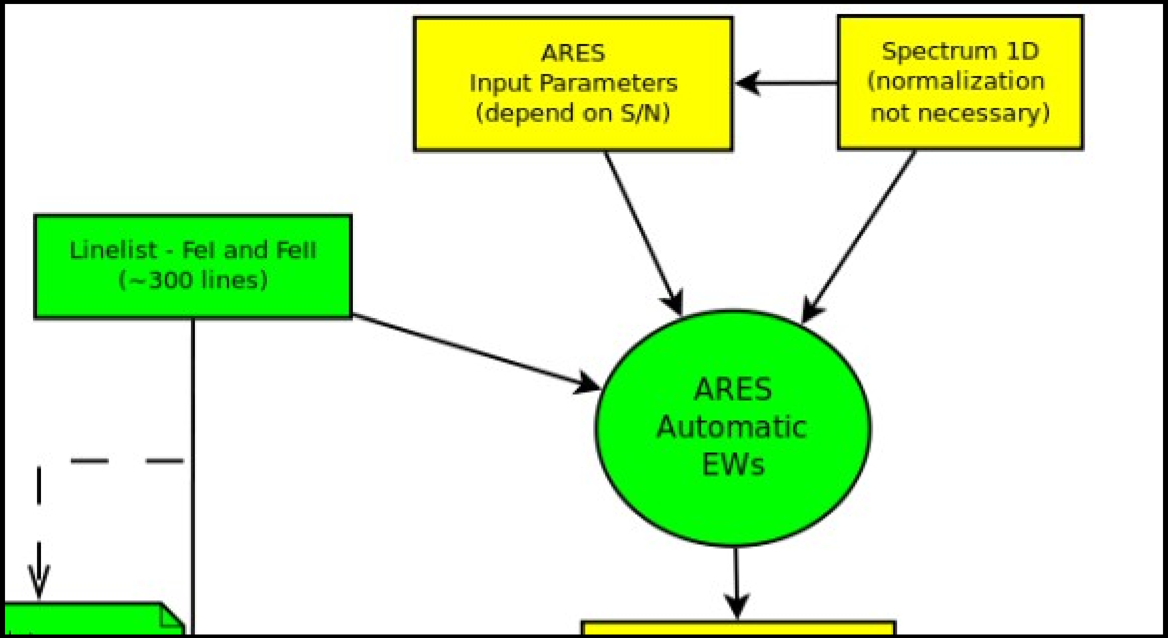


ARES vs Noise

Smoothder input parameter: deals with the noise



Homogeneous and Automatic Analysis
Overview Sketch

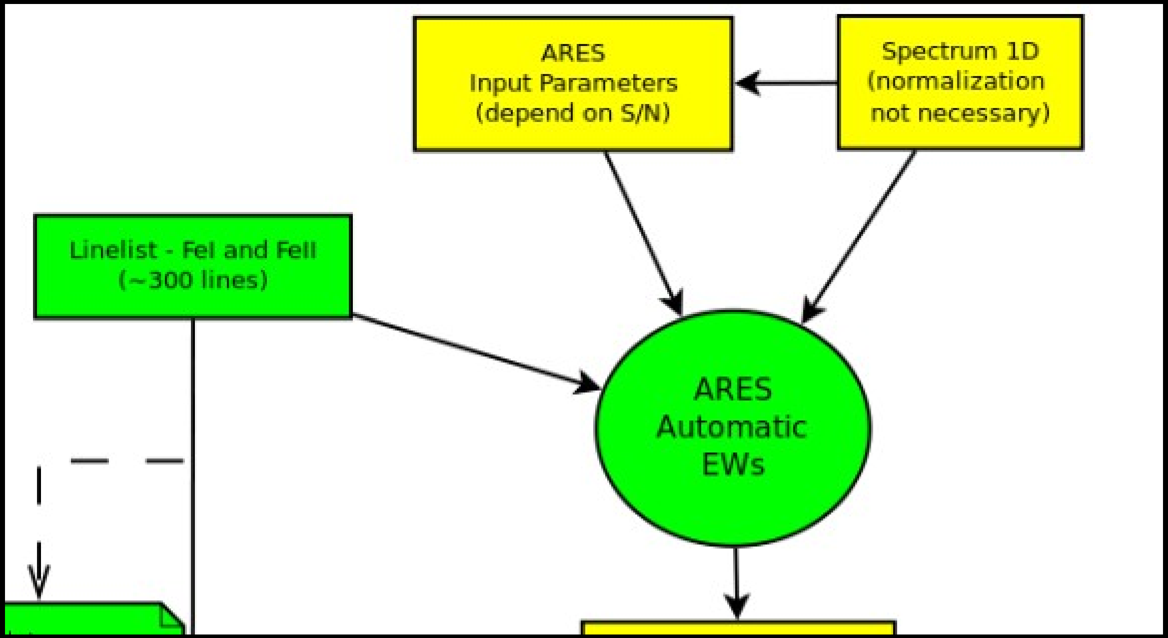


To run ARES you need:

1- The file *mine.opt* with the input parameters;
2- A 1D Fits spectra, corrected in radial Velocity. (normalization not required)
3- A list of iron lines to measure the Ews

The available ARES version only deals with Fits 1D spectra. The spectra should be corrected in wavelenght in order to identify the correct location of the lines to be measured.

Homogeneous and Automatic Analysis Overview Sketch

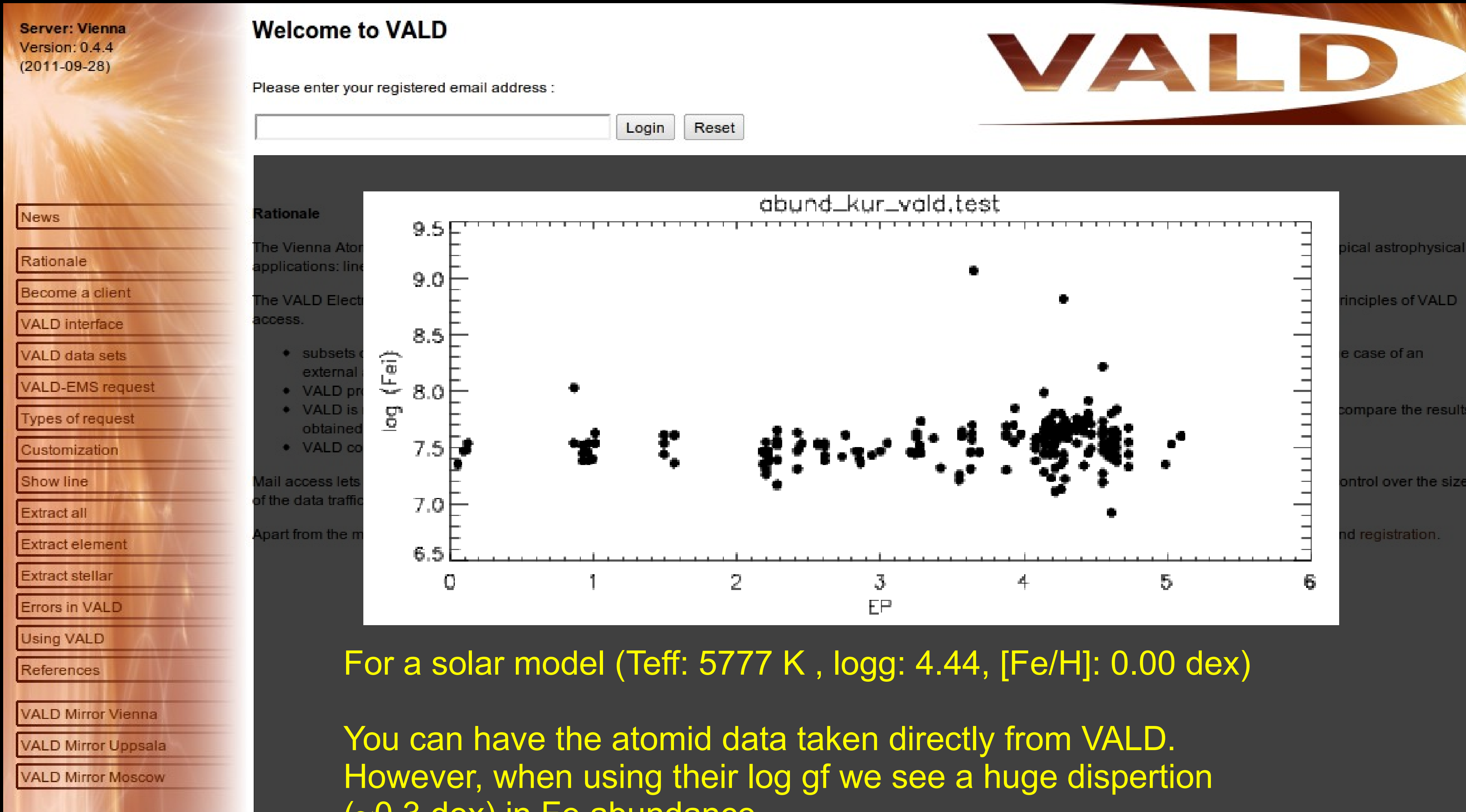


To run ARES you need:

1- The file *mine.opt* with the input parameters;
2- A 1D Fits spectra, corrected in radial Velocity. (normalization not required)
<u>3- A list of iron lines to measure the Ews</u>

The list of lines to be measure is only a list of the wavelenght to get the EW. However this is an important step of the method. You have to make a careful selection of the lines and have atomic data for each line to derive abundances later with MOOG.

Homogeneous Analysis



For a solar model (Teff: 5777 K , logg: 4.44, [Fe/H]: 0.00 dex)

You can have the atomid data taken directly from VALD. However, when using their log gf we see a huge dispertion (~0.3 dex) in Fe abundance.

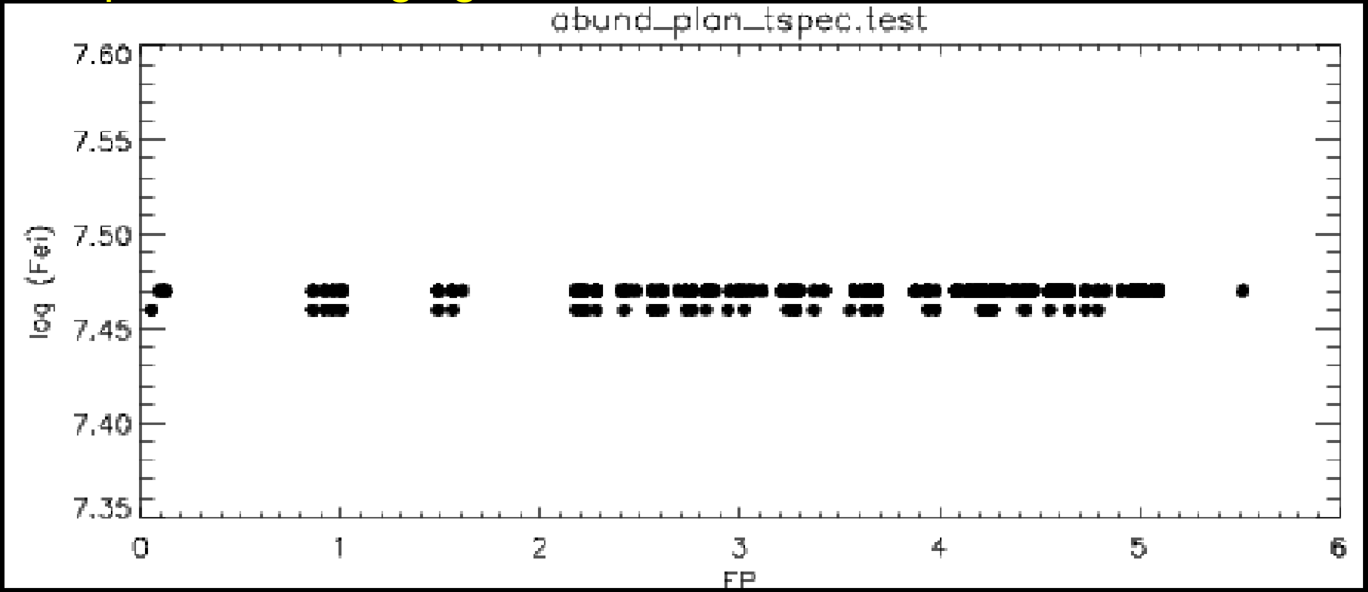
Homogeneous Analysis

Differential analysis to the Sun

Using the Solar Spectrum

Perform a reverse analysis to compute **new log gf** for each FeI and FeII line in our linelist

This allow us to be very precise and accurate for solar-type stars. However we should be careful when dealing with stars to much different from the Sun. This works well for stars with temperatures ranging from 4500 K to 6500 K.

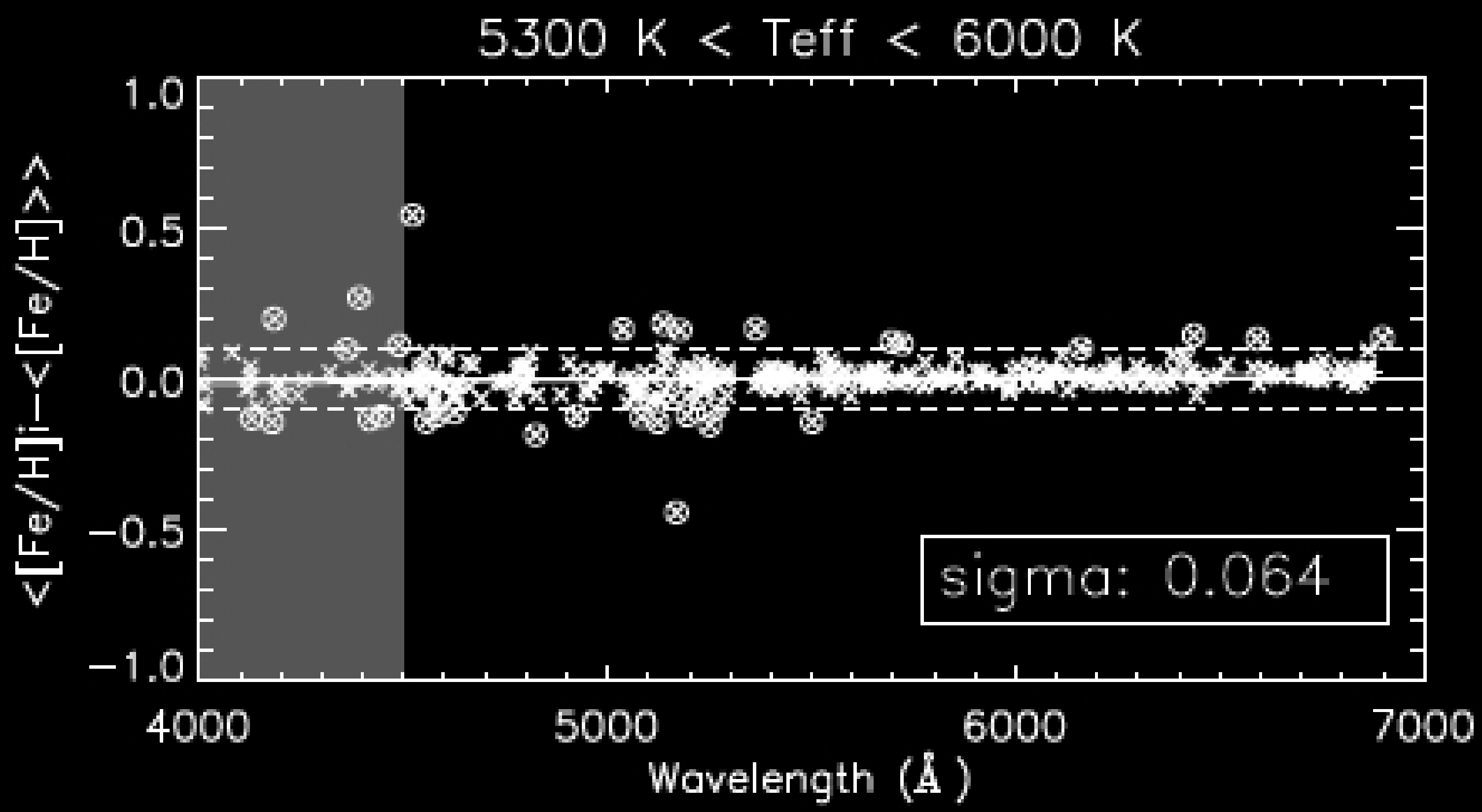


Homogeneous and Automatic Analysis

Since you are using automatic tools, you should choose carefully the lines. Check Sousa et al (2008) for these details.

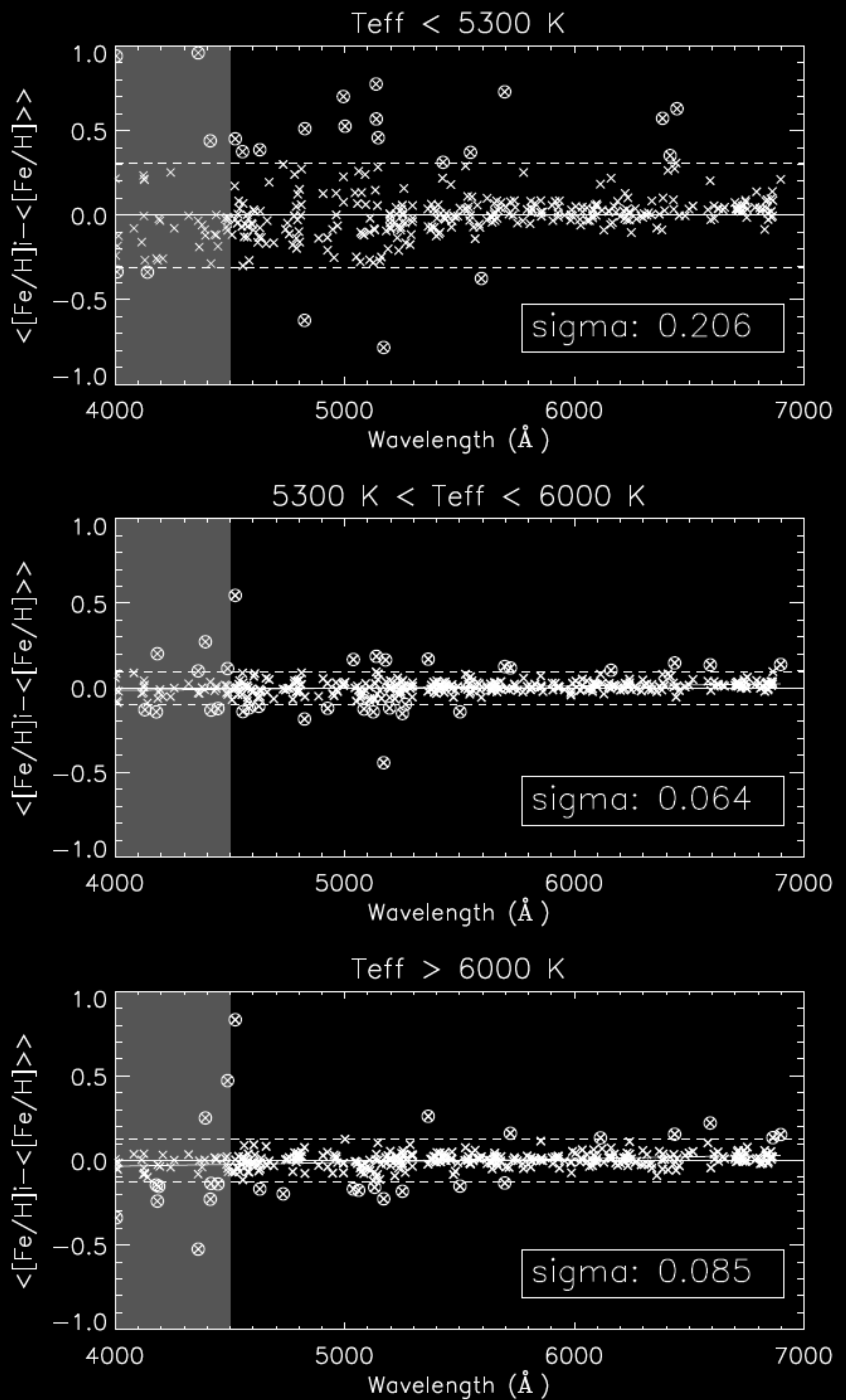
Taking out systematic bad lines, checked in iron abundance analysis for the HARPS spectra sample

Final line list: 263 FeI, 36 FeII

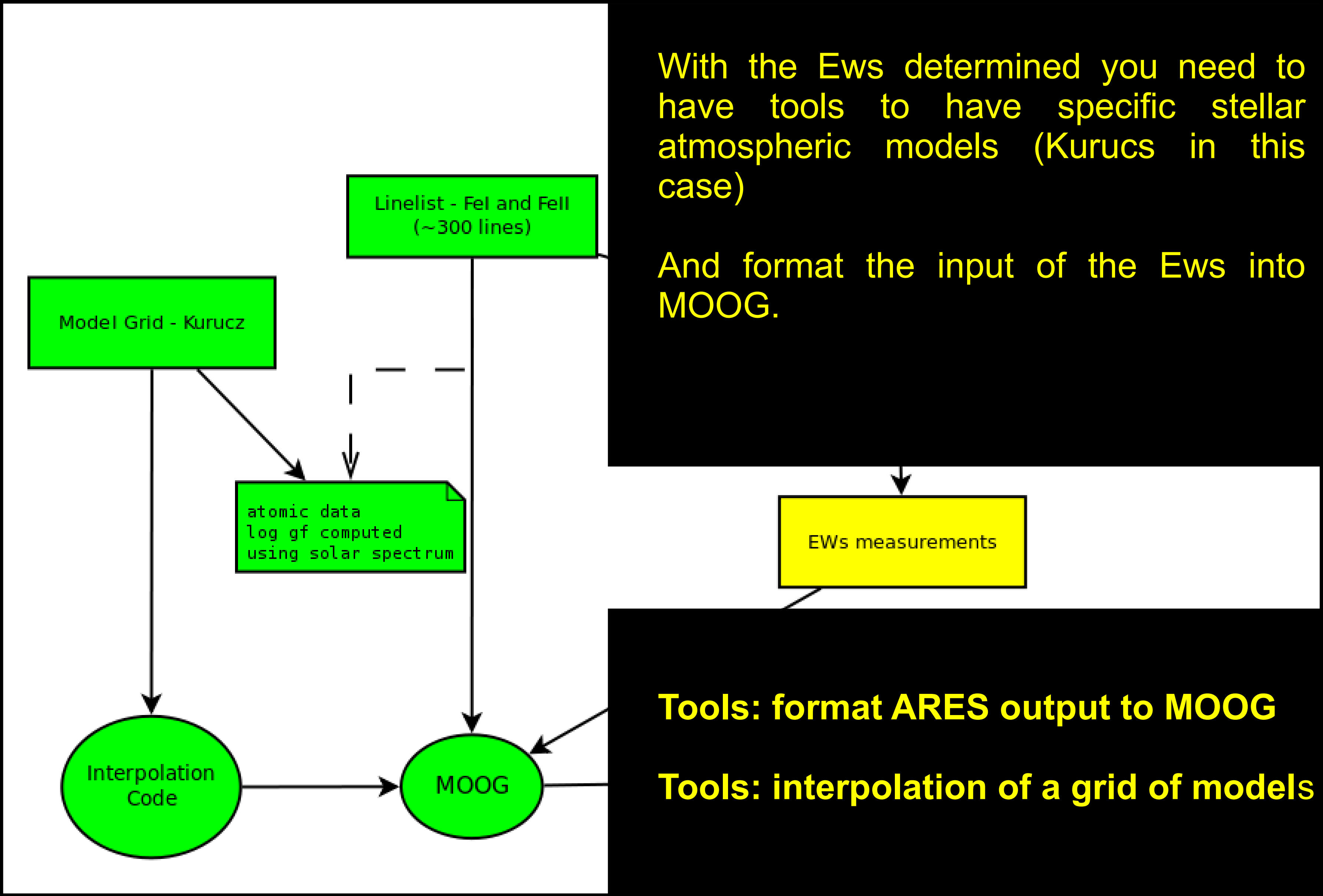


Taking out systematic bad lines, checked in iron abundance analysis for the HARPS spectra sample

Final line list: 263 FeI, 36 FeII



Homogeneous and Automatic Analysis
Overview Sketch



With the Ews determined you need to have tools to have specific stellar atmospheric models (Kurucs in this case)

And format the input of the Ews into MOOG.

Tools: format ARES output to MOOG

Tools: interpolation of a grid of models

Tools: format ARES output to MOOG

Directory: make_moog_ares_list

make_linelist_tmplocal.f: fortran code that transforms the output of ARES into an input of MOOG.
make_linelist_local.bash: script to launch the code.

Compilations can be done with: ifort, g77, or gfortran

Running example: Having a ARES output file: TestA.ares
And a linelist with the atomic parameters: extra_dir/Final_Harps_linelist.rdb

```
$ ./make_linelist_local.bash extra_dir/Final_Harps_linelist.rdb TestA.ares
```

Output will be a file: lines.TestA.ares

```
 TestA.ares
  4523.40    26.0        3.65     -1.871                          53.2
  4531.62    26.0        3.21     -1.801                          79.8
  4537.67    26.0        3.27     -2.870                          25.9
  4551.65    26.0        3.94     -1.928                          37.0
...
```

Tools: interpolation of a grid of models

Directory: interpol_models

There are to fortran codes to be used to interpolate the Kurucz grid in the directory and format the model to feed into MOOG:

intermod.f: selects the 4 models and interpolates them maintaining the same format.

transform.f: formats the interpolated model and include the microtubulence to be used in MOOG

Both can be compiled with g77 or ifort. Check README file.

There is also a script file:

make_model.bash

Use of the script for the case of a solar model atmosphere:

```
$./make_model.bash 577 4.44 0.0 1.0
```

It generates a file: out.atm which will be read by MOOG

```
KURUCZ
          Teff= 5777          log g= 4.44
NTAU        72
 0.50274684E-03   3704.8 0.138E+02 0.275E+10 0.265E-03 0.783E-01 0.200E+06
 0.65798400E-03   3728.1 0.181E+02 0.355E+10 0.308E-03 0.823E-01 0.200E+06
 0.83702774E-03   3750.0 0.231E+02 0.445E+10 0.355E-03 0.849E-01 0.200E+06
…
```

Using MOOG Directory: MOOG2013

The code MOOG2013 provided was modified to take out the SuperMongo plots. This was necessary for the school.
In order to install the code, you can follow the manual. But typically you just need to adjust the path in the Moog.f and Moogsilent.f, edit the Makefile and modify accordingly with your system and compilers.
You should have executable files MOOG and/or MOOGSILENT

There is a directory to test MOOG. For this method you only need the driver abfind.par
Check manual for contents of the file, and other drivers.

Requisites for running MOOG:
abfind.par : driver for MOOG
out.atm: atmosphere model (generated as before)
lines.TestA.ares: list of lines with EW

Running MOOG: $../../MOOG

Will create an output file defined in abfind.par (abund_plan_tspec.test):

```
 TestA.ares
        Teff= 5748         log g= 4.80           vt= 1.00 M/H= 0.19

Abundance Results for Species Fe I        (input abundance =   7.66)
wavelength       EP     logGF       EW     logRW     abund     del avg
   4523.40      3.65    -1.871      53.2     -4.93      7.62      -0.00
   4531.62      3.21    -1.801      79.8     -4.75      7.67       0.04
```

Using MOOG Directory: MOOG2013

The file abund_plan_tspec.test can be used to see some plots with a provided Python script.

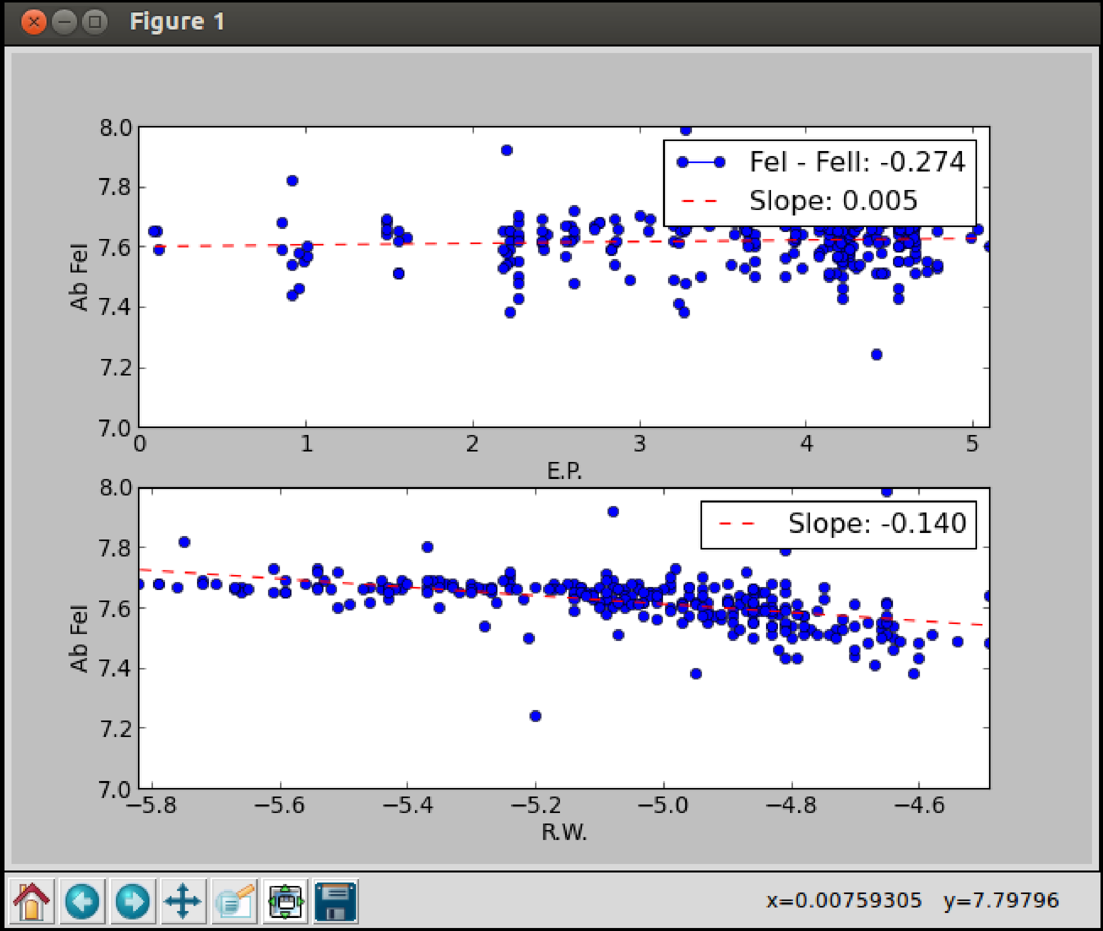
Directory: plot_moog_result

Example: $./read_moog_plot.py ../MOOG2013/testMOOG/abund_plan_tspec.test 1
or just checking the correlations from the slopes:
$./read_moog_plot.py ../MOOG2013/testMOOG/abund_plan_tspec.test 0

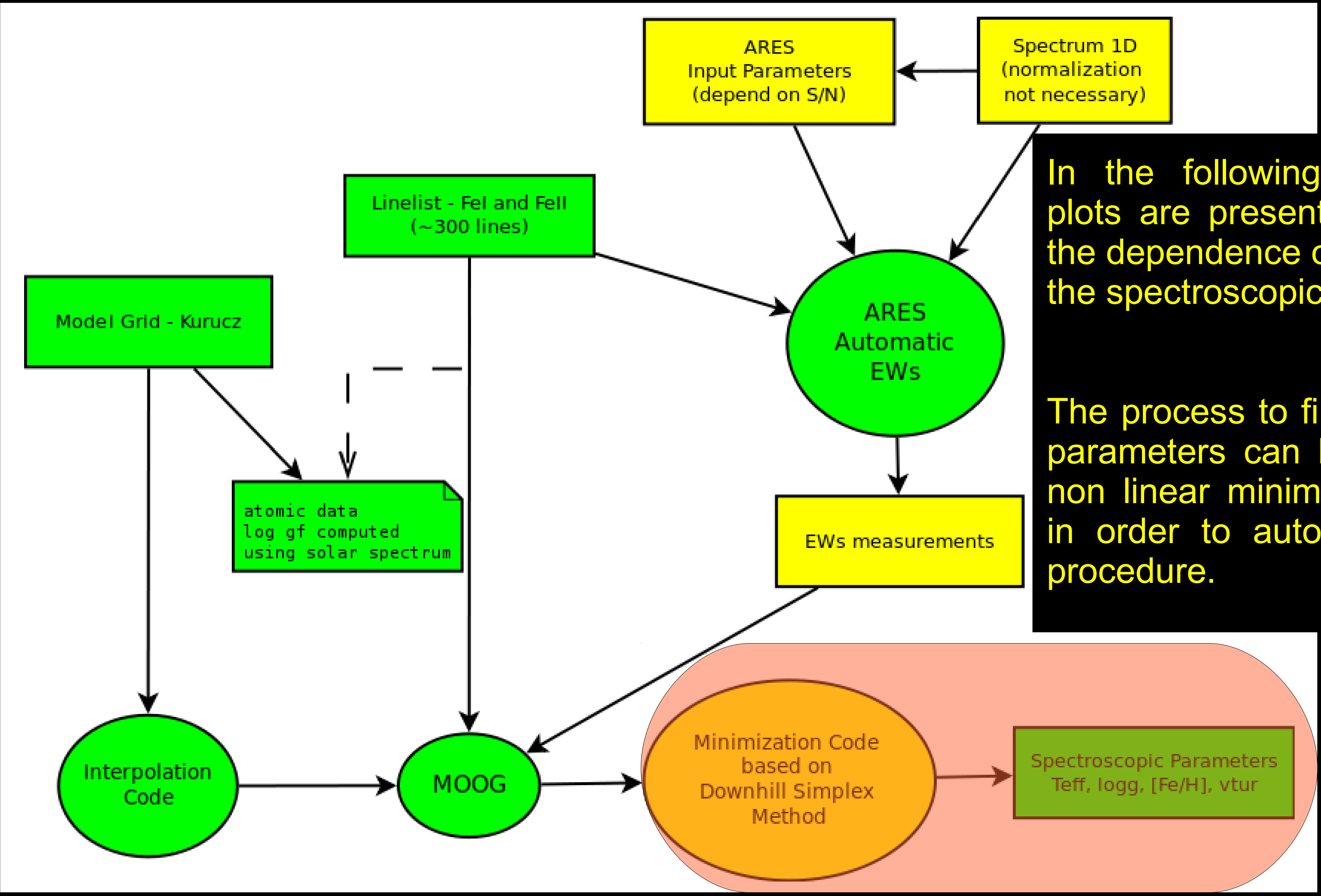
```
-----------------------------
|  Slope  E.P. :0.005
|  Slope  R.W. :-0.139
|  Fe I - Fe II:-0.28
-----------------------------
```

The idea is to iterate with different atmospheric models until we find no correllations between:

- Abundances vs. Excitation potential (fitting the temperature)
- Abundances vs. Reduced Wavelenght (fitting microturbulence)
- Abundances of Fe I and Fe II consistent forcing ionization balance (fitting the surface gravity)



Homogeneous and Automatic Analysis Overview Sketch



In the following slides some plots are presented to express the dependence of the slopes in the spectroscopic parameters.

The process to find the correct parameters can be done using non linear minimization models in order to automatize all the procedure.

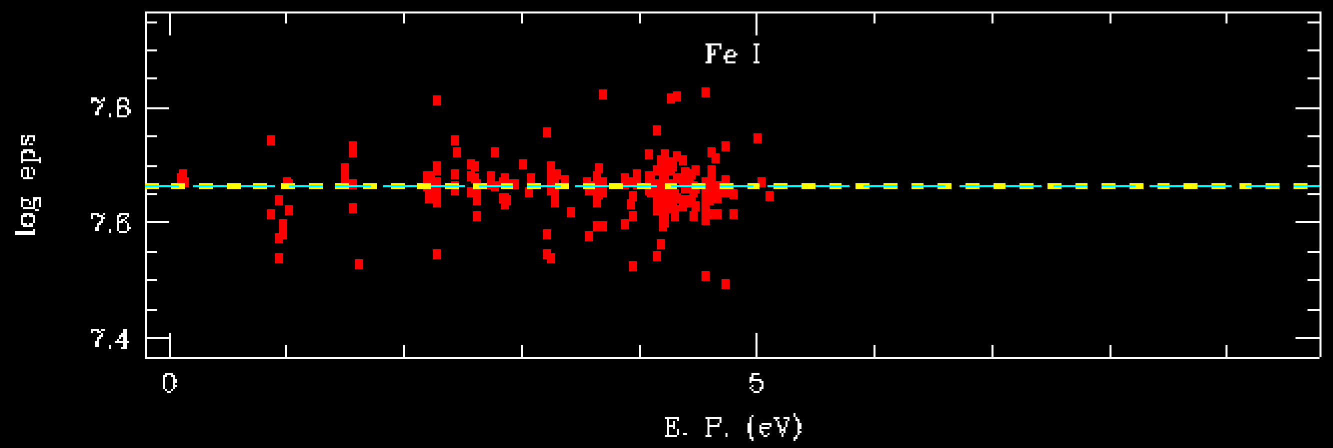
Deriving parameters: Temperature – MOOG example

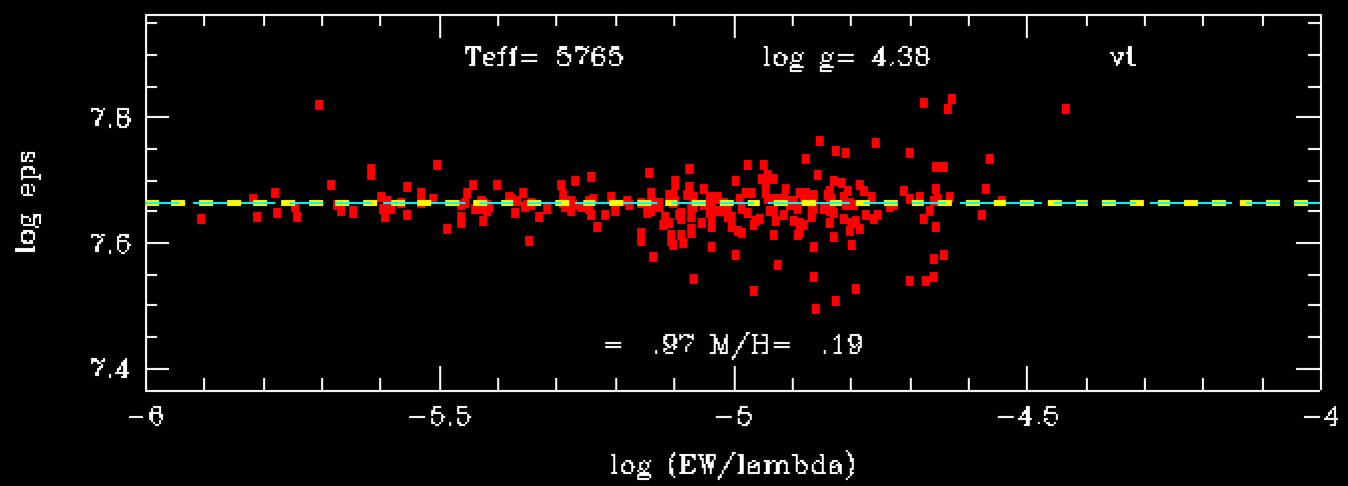
Test Star:

HD1461

Good set of parameters:

Teff: 5765
Logg: 4.39
[Fe/H]: 0.19
Vt: 0.97





FeI:

```
average abundance =   7.66      std. deviation =  0.05     #lines = 258
E.P. correlation:  slope =   0.000  intercept =    7.662  corr. coeff. =    0.002
R.W. correlation:  slope =   0.001  intercept =    7.665  corr. coeff. =    0.004
```

FeII:

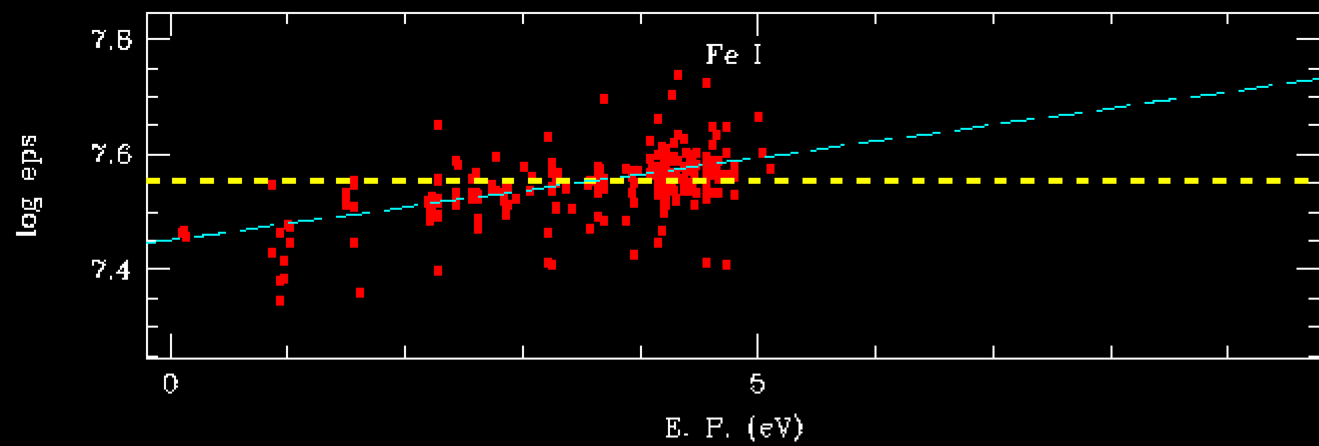
```
average abundance =   7.66      std. deviation =  0.07     #lines =  35
E.P. correlation:  slope =  -0.010  intercept =    7.693  corr. coeff. =  -0.119
```

Deriving parameters: Temperature – MOOG example

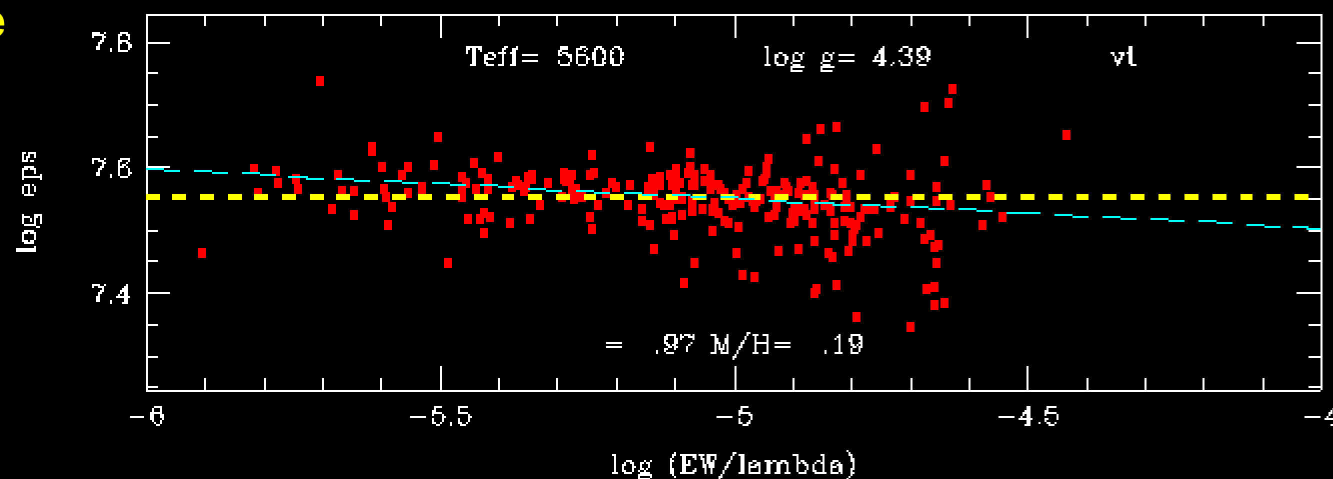
Test Star:

HD1461

Teff: 5765
Logg: 4.39
[Fe/H]: 0.19
Vt: 0.97



Using lower Temperature for the model Teff: 5600 K.



Slope Ab vs Ep > 0

If this slope is positive, then temperature of the correct model should be higher

FeI:

```
average abundance =  7.55     std. deviation =   .06     #lines = 258
E.P. correlation:  slope =    .029  intercept =   7.448  corr. coeff. =    .566
R.W. correlation:  slope =   -.047  intercept =   7.313  corr. coeff. =   -.252
```

FeII:

```
average abundance =  7.66     std. deviation =  0.07     #lines =  35
E.P. correlation:  slope =  -0.010  intercept =   7.693  corr. coeff. =  -0.119
```

Deriving parameters: <u>Temperature</u> – MOOG example

Test Star:

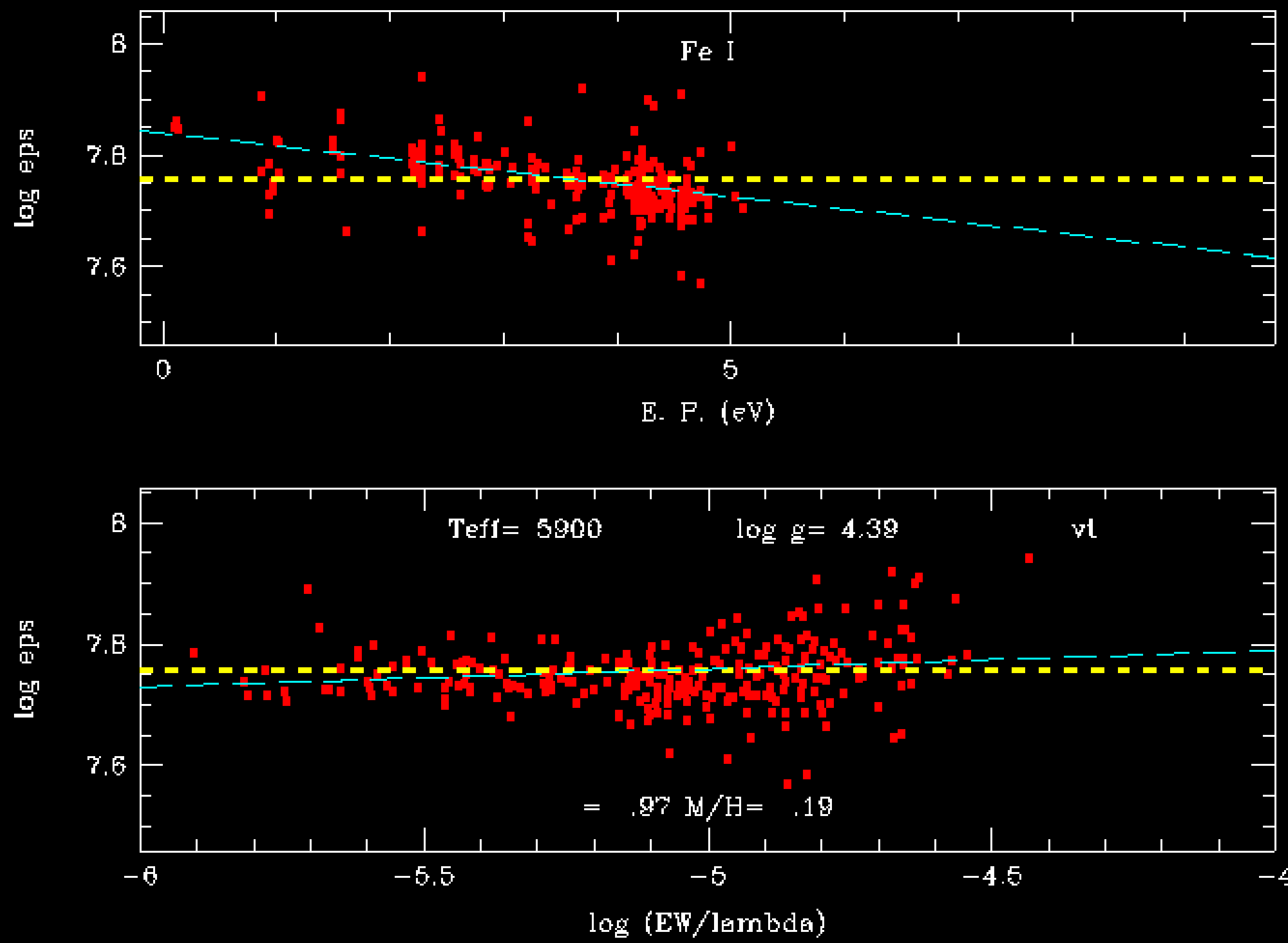
HD1461

Teff: 5765
Logg: 4.39
[Fe/H]: 0.19
Vt: 0.97

Using higher Temperature Teff: 5900 K.

Slope Ab vs Ep < 0

<u>If this slope is negative, then temperature of the correct model should be lower</u>



FeI:

```
average abundance =  7.75      std. deviation =   .05     #lines = 258
E.P. correlation:  slope =   -.023  intercept =   7.836  corr. coeff. =   -.476
R.W. correlation:  slope =    .030  intercept =   7.905  corr. coeff. =    .168
```

FeII:

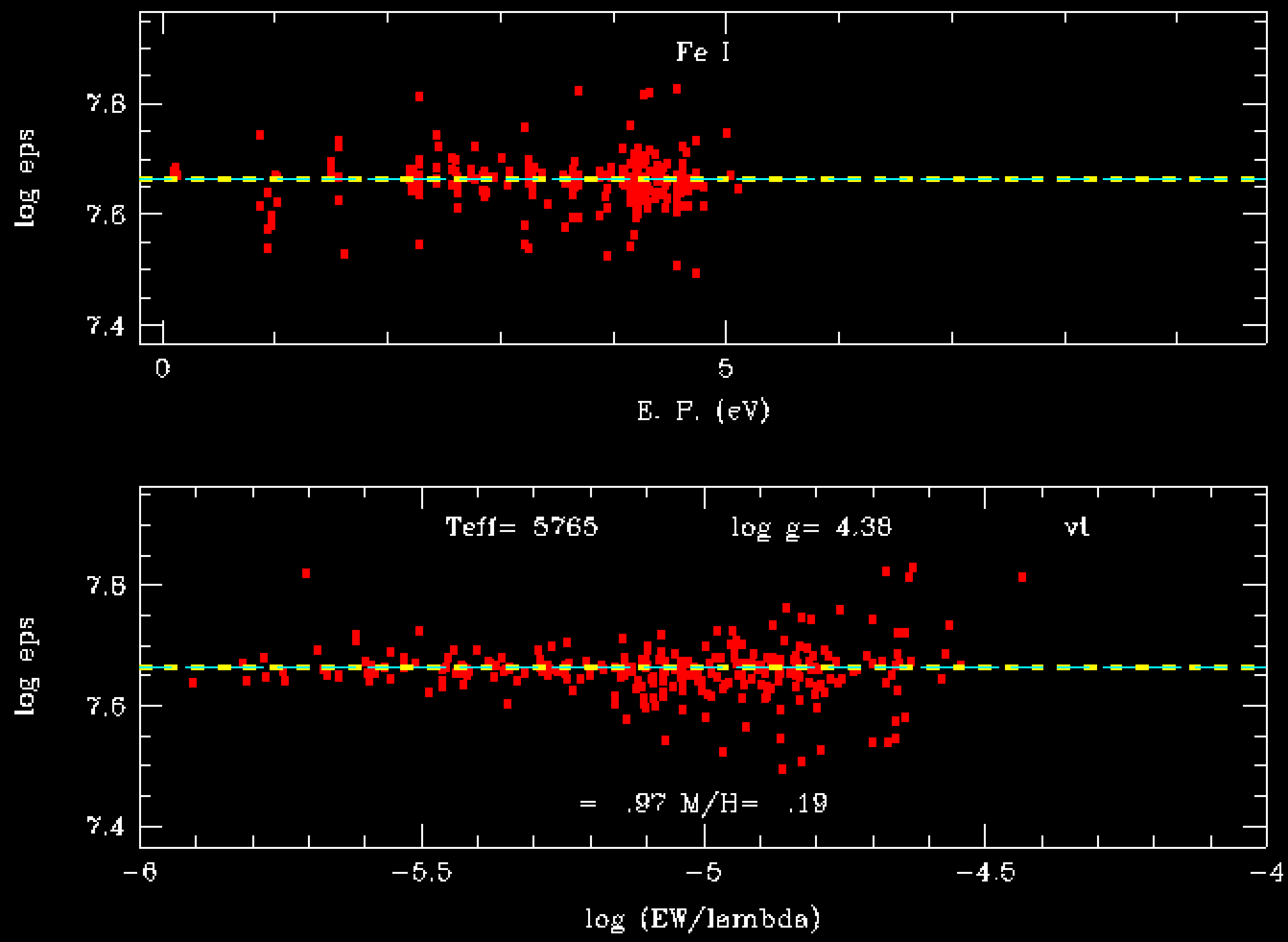
```
average abundance =  7.62      std. deviation =   .07     #lines =  35
E.P. correlation:  slope =   -.023  intercept =   7.699  corr. coeff. =   -.274
```

Deriving parameters: surface gravity – MOOG example

Test Star:

HD1461

Teff: 5765
Logg: 4.39
[Fe/H]: 0.19
Vt: 0.97



FeI:

```
average abundance =   7.66      std. deviation =  0.05      #lines = 258
E.P. correlation:  slope =   0.000  intercept =   7.662  corr. coeff. =   0.002
R.W. correlation:  slope =   0.001  intercept =   7.665  corr. coeff. =   0.004
```

FeII:

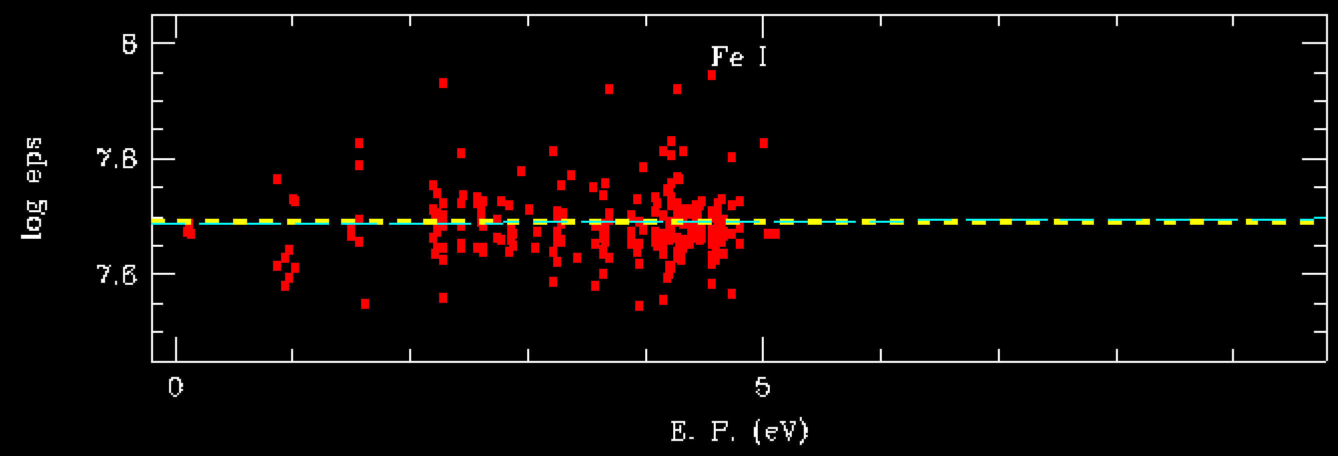
```
average abundance =  7.66      std. deviation =  0.07      #lines =  35
E.P. correlation:  slope =  -0.010  intercept =   7.693  corr. coeff. =  -0.119
```

Deriving parameters: surface gravity – MOOG example

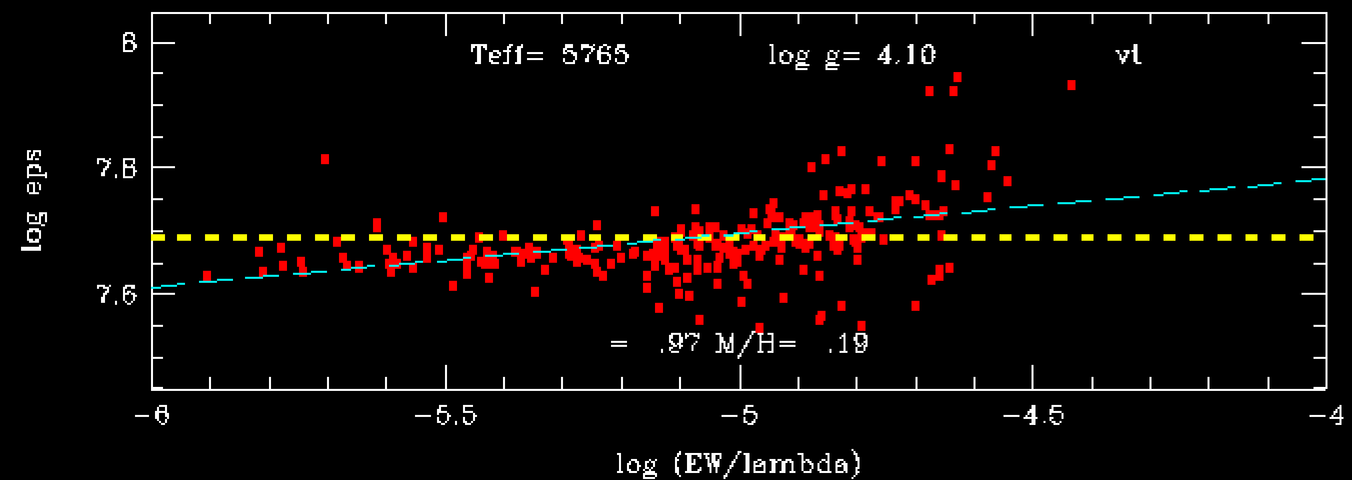
Test Star:

HD1461

Teff: 5765
Logg: 4.39
[Fe/H]: 0.19
Vt: 0.97



Using lower surface gravity
Log g: 4.10 dex



AbFe1 – AbFeII > 0

FeI:

```
average abundance =  7.69     std. deviation =   .06     #lines = 258
E.P. correlation:  slope =    .001  intercept =    7.684  corr. coeff. =    .018
R.W. correlation:  slope =    .086  intercept =    8.121  corr. coeff. =    .437
```

FeII:

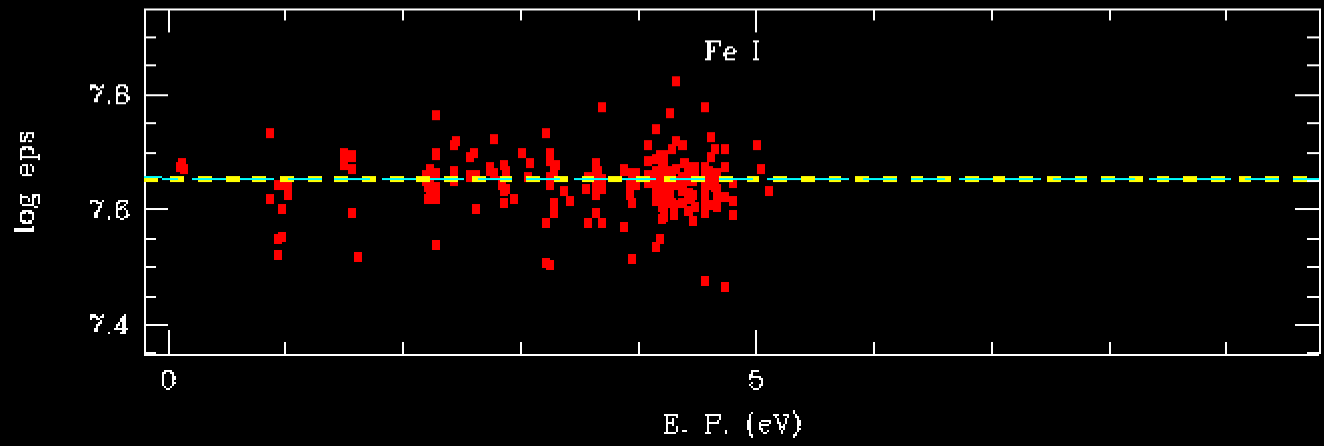
```
average abundance =  7.55     std. deviation =   .07     #lines =  35
E.P. correlation:  slope =  -.015  intercept =    7.604  corr. coeff. =   -.173
```

Deriving parameters: surface gravity – MOOG example

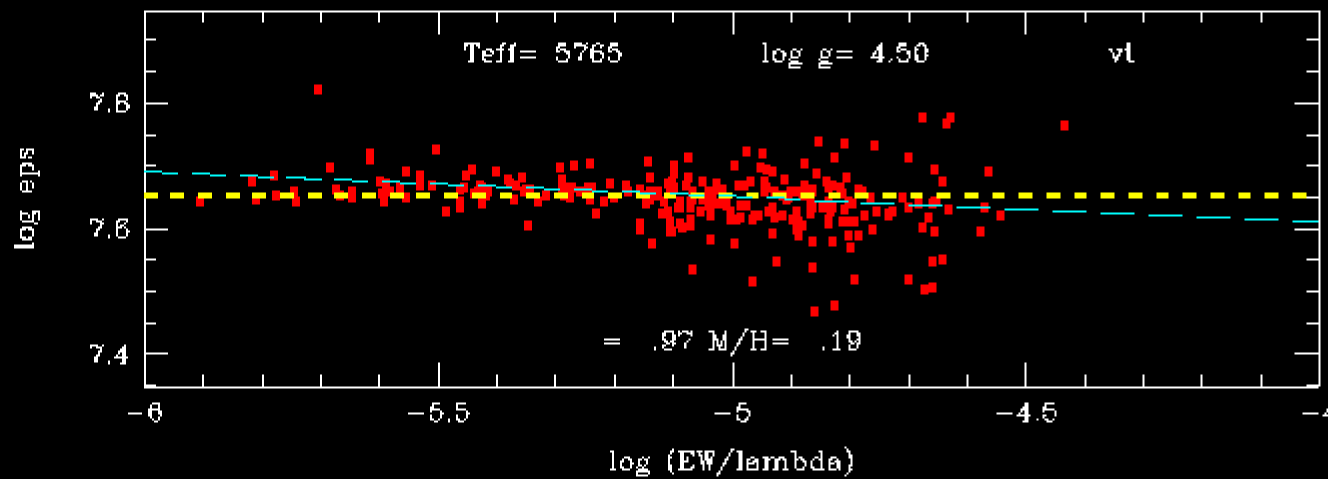
Test Star:

HD1461

Teff: 5765
Logg: 4.39
[Fe/H]: 0.19
Vt: 0.97



Using higher surface gravity
Log g: 4.50 dex



AbFe1 – AbFeII < 0

FeI:

```
average abundance =  7.65     std. deviation =   .05     #lines = 258
E.P. correlation:  slope =  .000  intercept =   7.652  corr. coeff. =   -.008
R.W. correlation:  slope =  -.040  intercept =   7.449  corr. coeff. =   -.255
```

FeII:

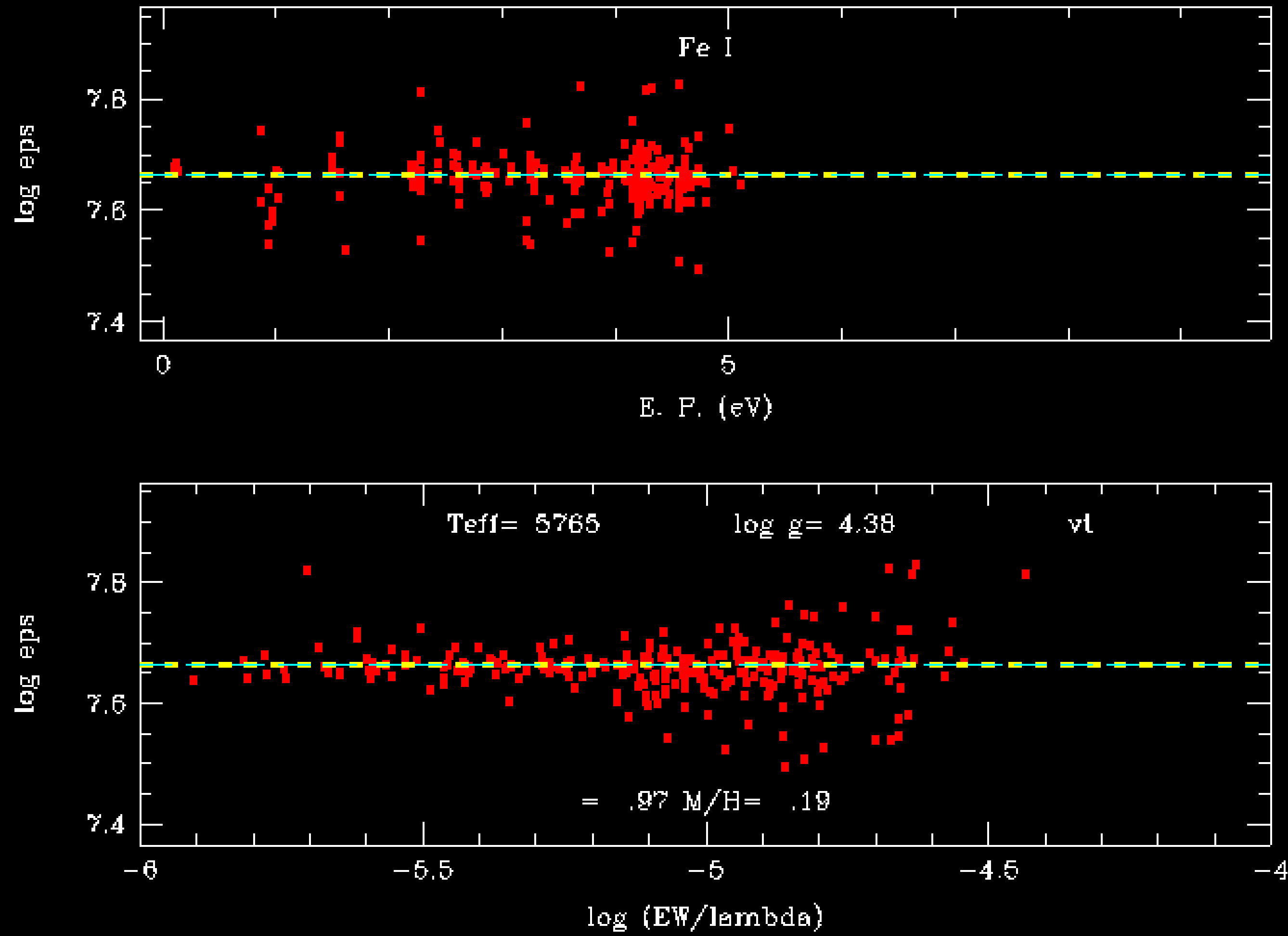
```
average abundance =  7.70     std. deviation =   .07     #lines =  35
E.P. correlation:  slope =  -.007  intercept =   7.727  corr. coeff. =   -.081
```

Deriving parameters: microturbulence – MOOG example

Test Star:

HD1461

Teff: 5765
Logg: 4.39
[Fe/H]: 0.19
Vt: 0.97



FeI:

```
average abundance =  7.66      std. deviation =  0.05      #lines = 258
E.P. correlation:  slope =   0.000  intercept =    7.662  corr. coeff. =   0.002
R.W. correlation:  slope =   0.001  intercept =    7.665  corr. coeff. =   0.004
```

FeII:

```
average abundance =  7.66      std. deviation =  0.07      #lines =  35
E.P. correlation:  slope =  -0.010  intercept =    7.693  corr. coeff. =  -0.119
```

Deriving parameters: microturbulence – MOOG example

Test Star:

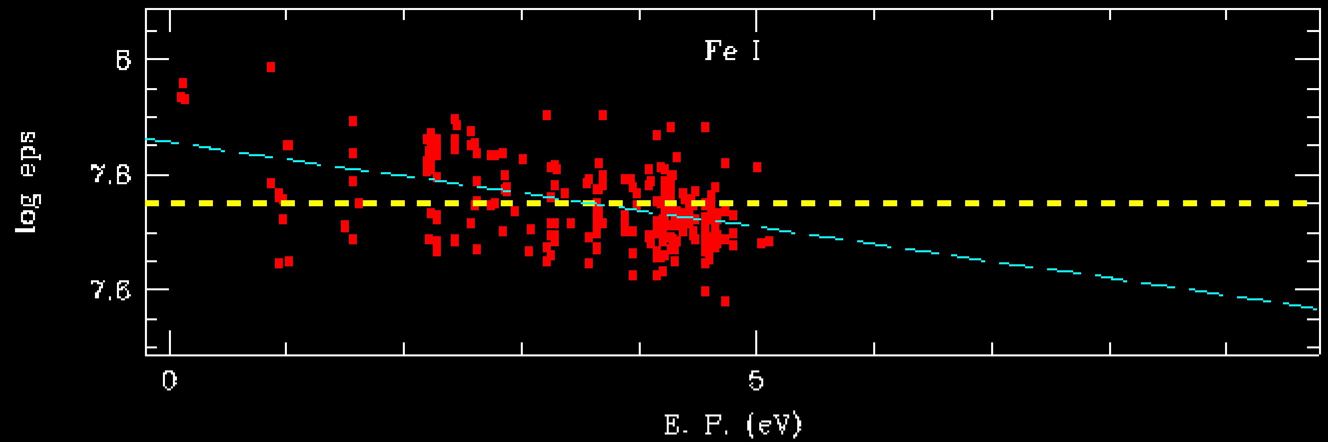
HD1461

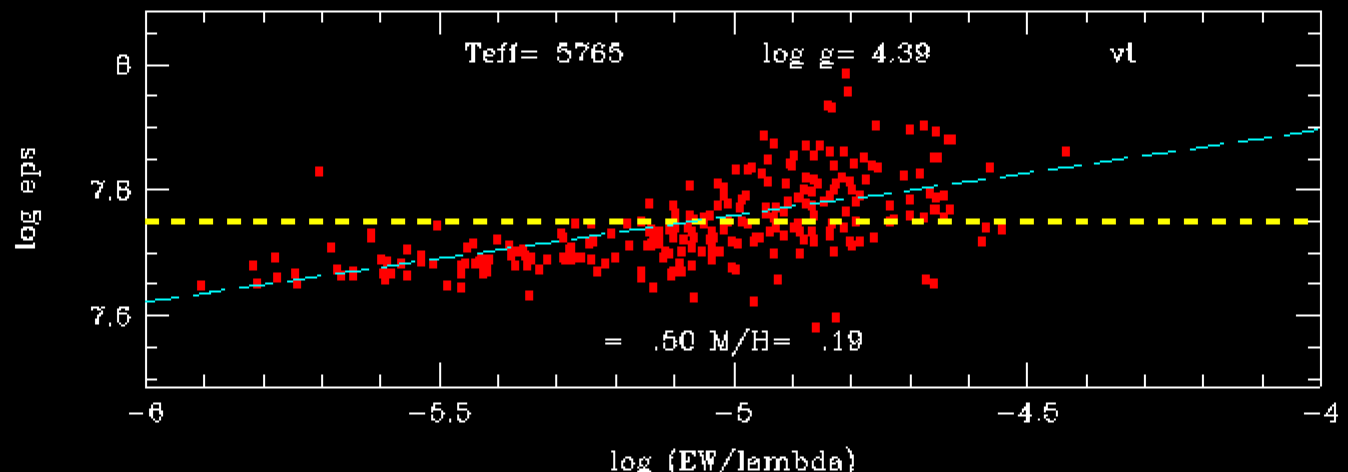
Teff: 5765
Logg: 4.39
[Fe/H]: 0.19
Vt: 0.97

Using lower microturbulence

vt: 0.5

Slope Ab vs R.W > 0





FeI:

```
average abundance =  7.75     std. deviation =    .07     #lines = 258
E.P. correlation:  slope =   -.029  intercept =   7.853  corr. coeff. =   -.471
R.W. correlation:  slope =    .137  intercept =   8.441  corr. coeff. =    .592
```

FeII:

```
average abundance =  7.77     std. deviation =    .09     #lines =  35
E.P. correlation:  slope =   -.039  intercept =   7.900  corr. coeff. =   -.360
```

Deriving parameters: <u>microturbulence</u> – MOOG example

Test Star:

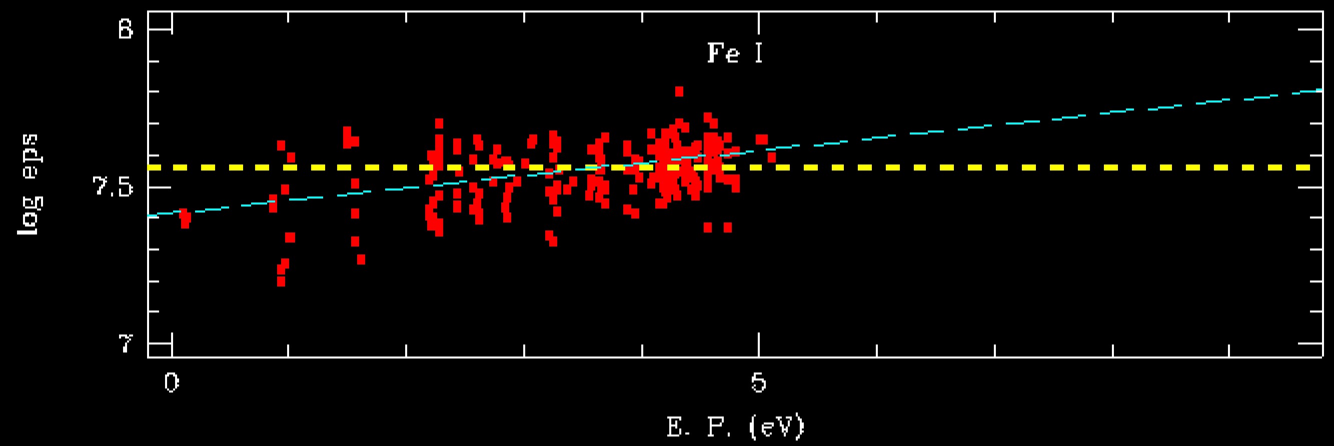
HD1461

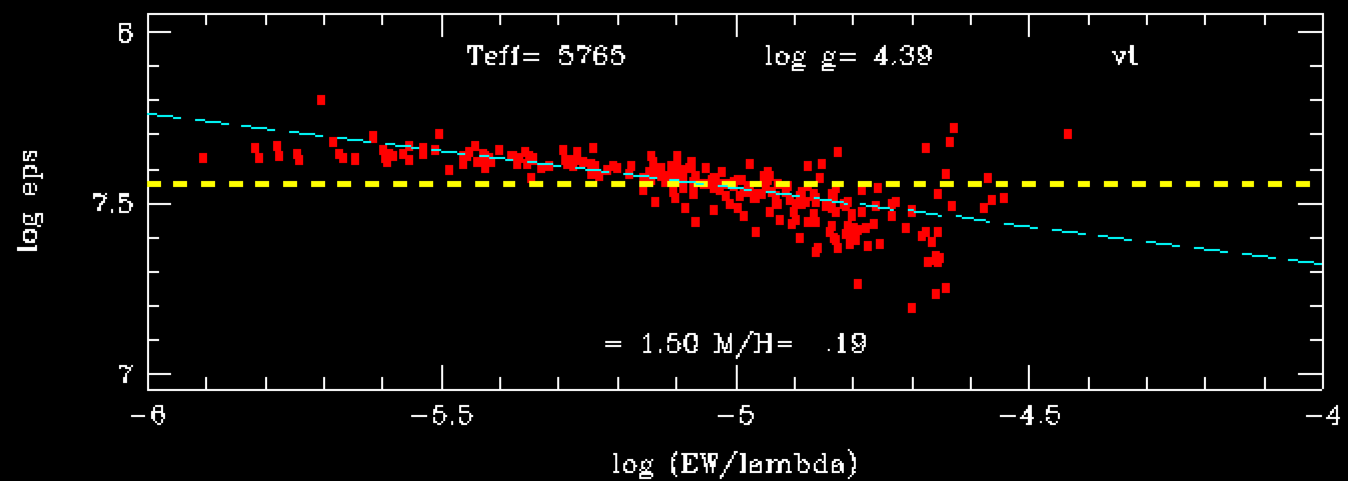
Teff: 5765
Logg: 4.39
[Fe/H]: 0.19
Vt: 0.97

Using higher microturbulence

vt: 1.5

Slope Ab vs R.W < 0





FeI:

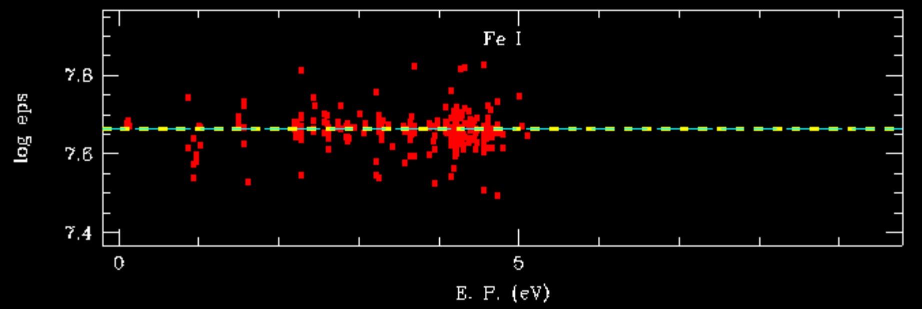
```
average abundance =  7.55      std. deviation =   .09     #lines = 258
E.P. correlation:  slope =     .040  intercept =    7.409  corr. coeff. =    .469
R.W. correlation:  slope =   -.220  intercept =    6.436  corr. coeff. =   -.701
```

FeII:

```
average abundance =  7.54      std. deviation =   .10     #lines =  35
E.P. correlation:  slope =     .030  intercept =    7.433  corr. coeff. =    .244
```

Deriving parameters: Summary of method

Test Star: HD1461
Teff: 5765, Logg: 4.39 [Fe/H]: 0.19 Vt: 0.97

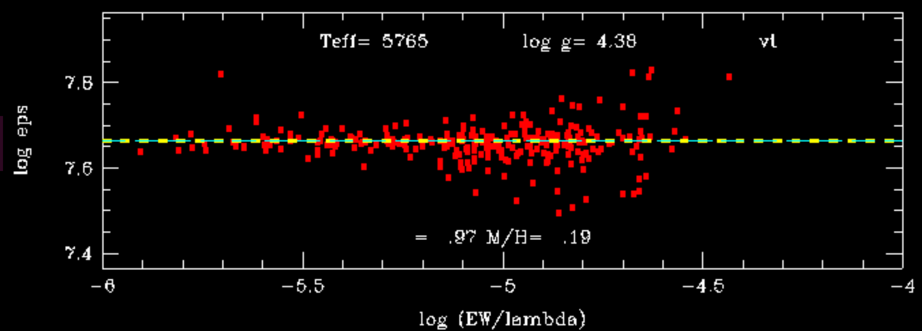


FeI:

```
average abundance =  7.66      std. deviation =  0.05      #lines = 258
E.P. correlation:  slope =    0.000  intercept =    7.662  corr. coeff. =    0.002
R.W. correlation:  slope =    0.001  intercept =    7.665  corr. coeff. =    0.004
```

FeII:

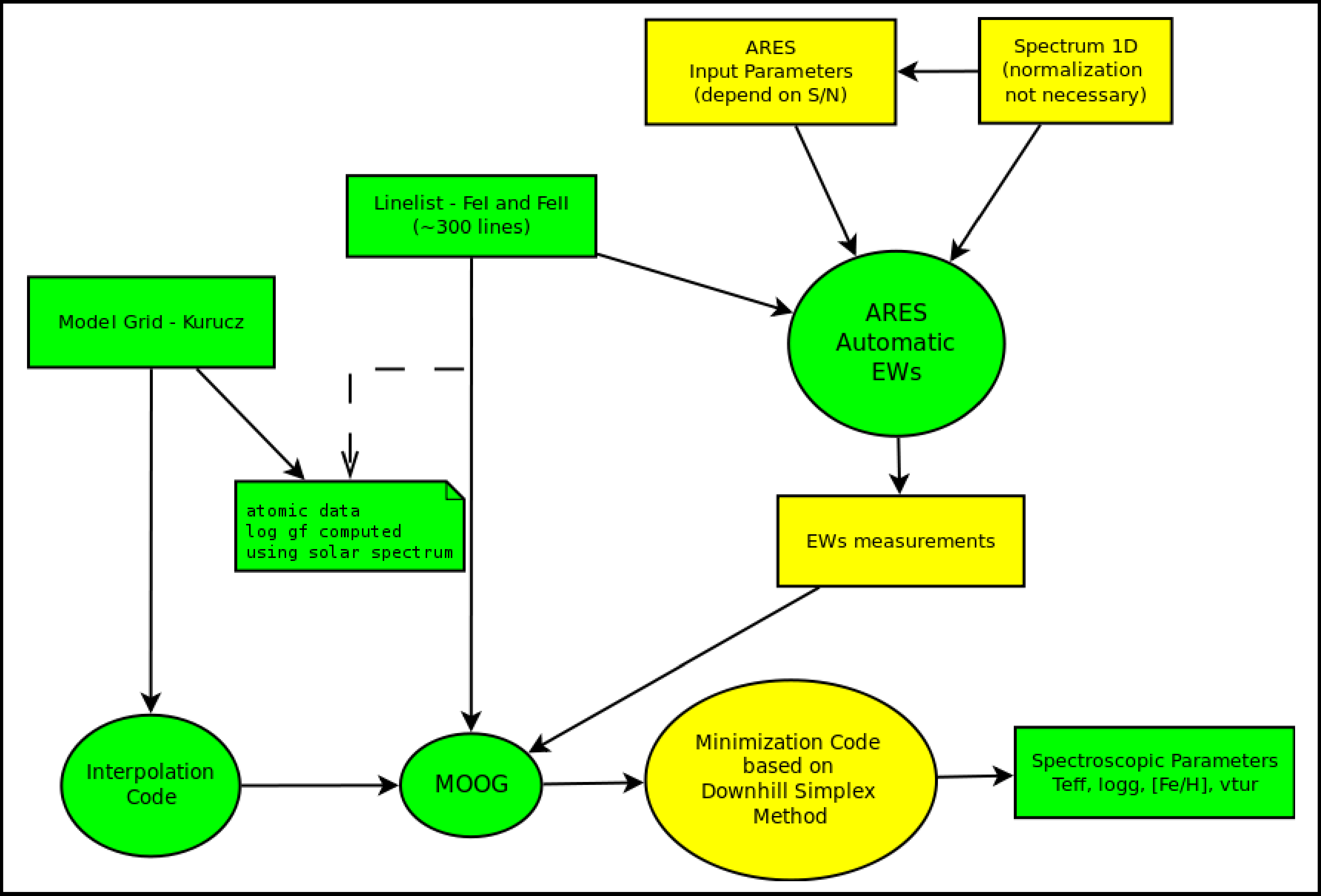
```
average abundance =  7.66      std. deviation =  0.07      #lines =  35
E.P. correlation:  slope =  -0.010  intercept =    7.693  corr. coeff. =  -0.119
```



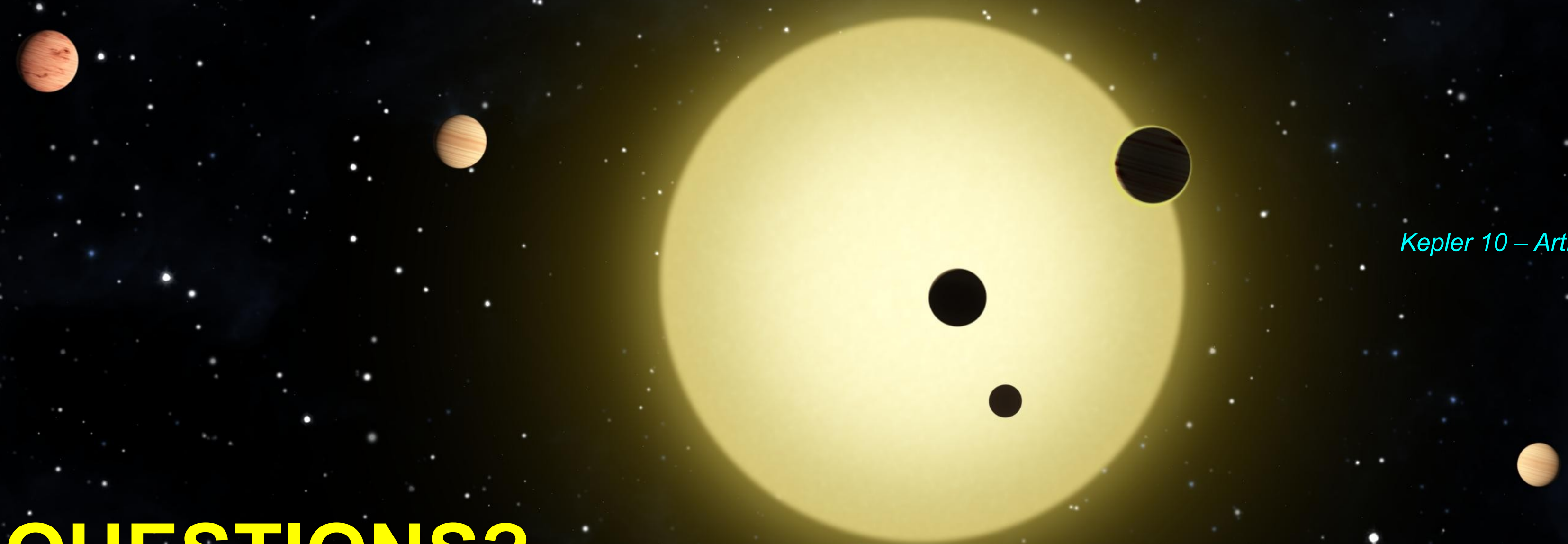
1 – Measure Ews for FeI and FeII lines
2 – Iteritive Loop:
- 2.1 – Built an atmosphere model (Teff, logg, [Fe/H], vt)
- 2.2 – Compute the abundances (LTE is fine for solar type stars)
- 2.3 – Check the slopes (AbFeI vs. EP, AbFeI vs. EW/l)
- 2.4 – Check the ionization balance (AbFeI – AbFeII)

3 – If Slopes are 0 and exists ionization balance (AbFeI – AbFeII == 0)
- 3.1 YES: Solution found
- 3.2 NO: GO TO 2

Homogeneous and Automatic Analysis Overview Sketch



From EWs to stellar parameters



Kepler 10 – Artistic View

QUESTIONS?

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ExoEarths Team (http://www.astro.up.pt/exoearths/)

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