SP_Ace
a new code for Teff, Log g and [X/H] estimation

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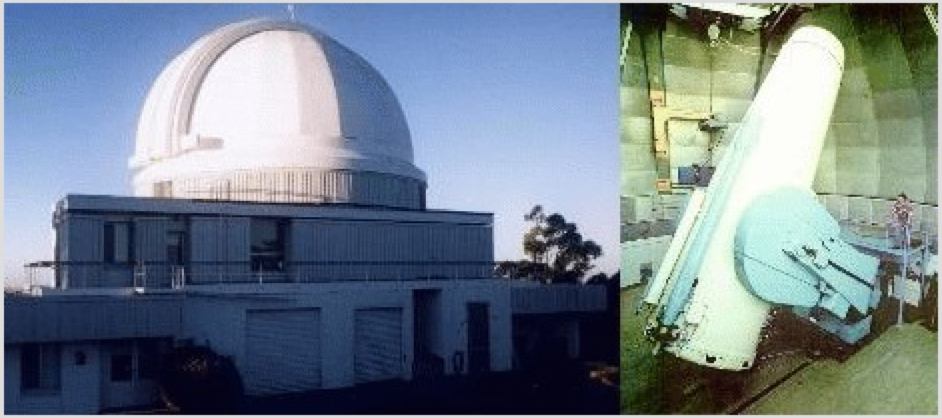
What is RAVE?

RAVE (Radial Velocity Experiment) **is a large spectroscopic survey** which observed **half million stars of the Milky Way**

RAVE spectra are secured by using the 1.2-m UK Schmidt Telescope of the Australian Astronomical Observatory (AAO)



- The 6dF instrument (six-degree-field multi-object spectroscopy system)
- fiber optic technology
- up to 150 objects in one shot
- up to 800 spectra in 1 clear night

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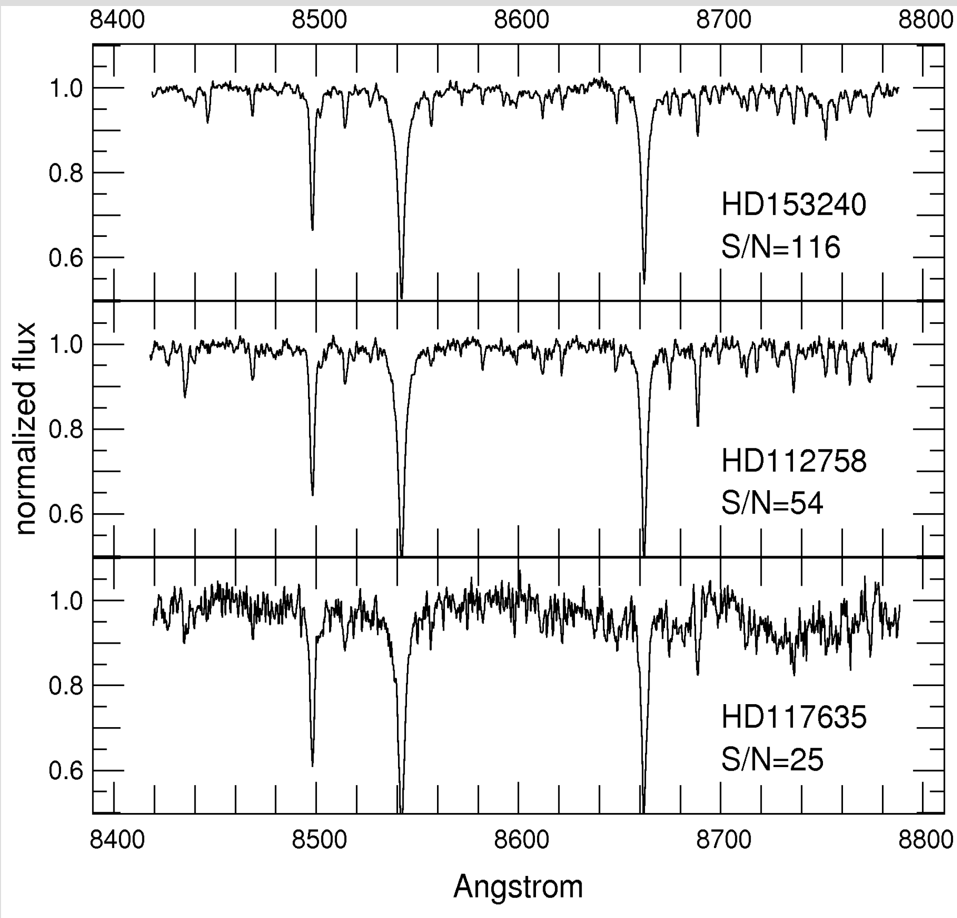
What is RAVE?

[b] range: 8410-8795Å (Gaia wavelength range)
Resolution R=7500 at 8600Å
Dispersion = 0.4Å/pix



<u>From the RAVE spectra we obtain:</u>

- radial velocities, σ(RV)~2 km/sec
- stellar parameters Teff, log g, [M/H]
  σ(Teff)~200K, σ(logg)~0.5, σ(M/H)~0.1 dex
- chemical abundances for Mg, Al, Si, Ti, Fe, Ni, σ(X/H)~0.1-0.2 dex

<u>The RAVE stars have:</u>

- Proper motions (Tycho2, PPMXL, UCAC)
- Distances (by Breddel+, Zwitter+, Binney+)

==> **we can locate the stars in the 6D phase-space and chemical space**

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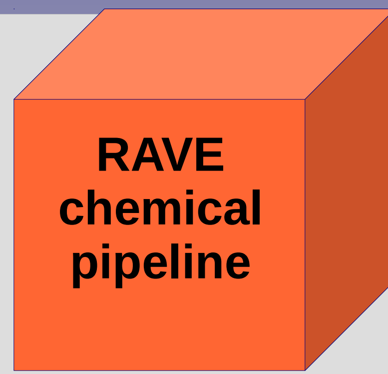
The RAVE chemical pipeline

input

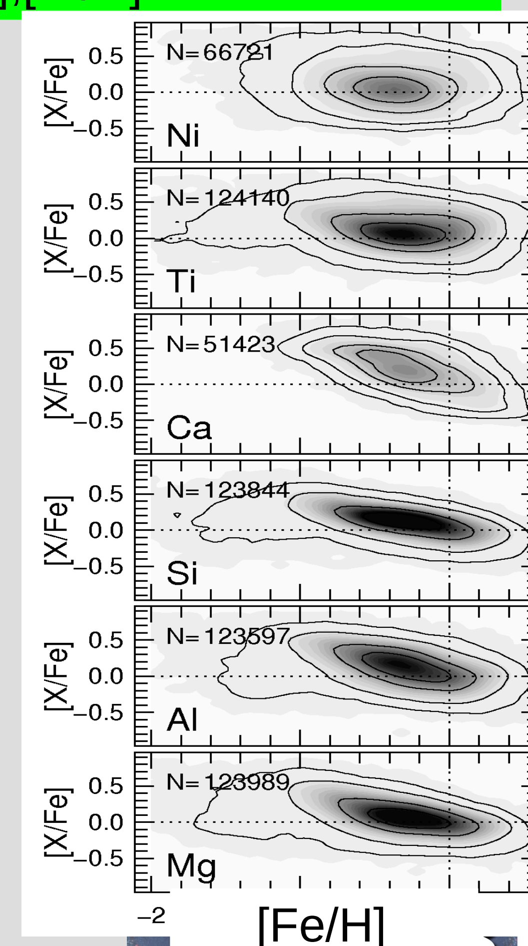
- normalized spectrum
- wavelength range
- resolution (guess)
- Teff
- log g
- [m/H] (guess)



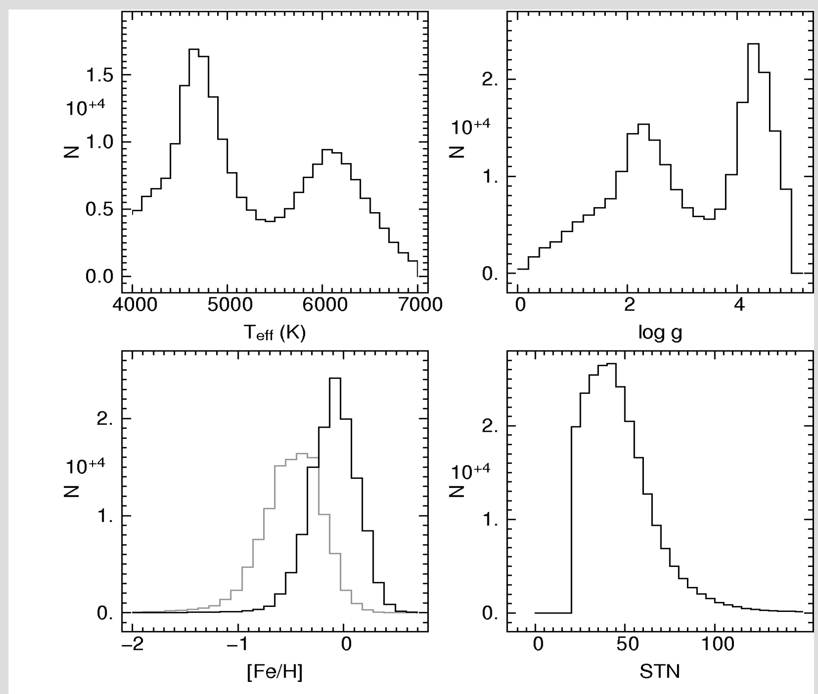
1D LTE analysis

output

chemical abundances
[Fe/H], [Mg/H],[Al/H][Si/H],
[Ti/H],[Ni/H]



the 7 more reliable elements
Mg, Al, Si, Ca, Ti, Fe, Ni



The RAVE chemical catalogue holds chemical abundances for ~400,000 stars of the Milky Way

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The relation between chemical and and kinematics of the MW disc (Boeche et al., 2013, A&A 553, 19)

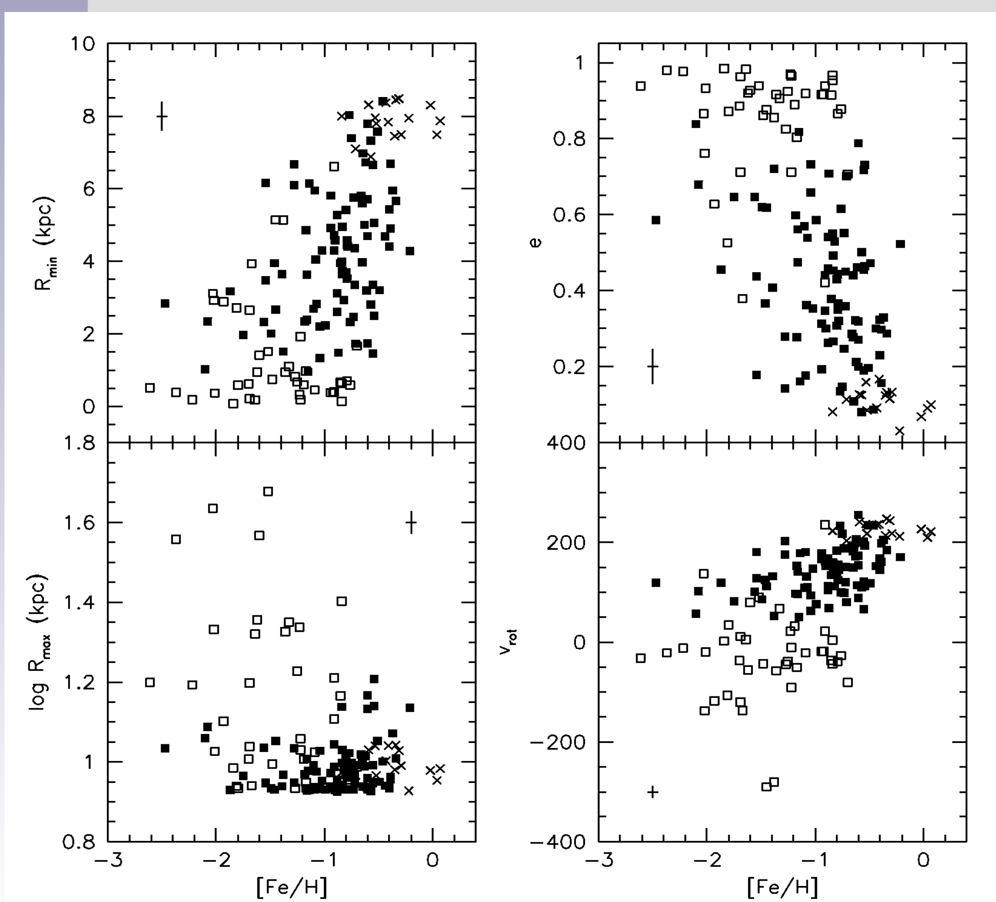
Gratton et al., 2003, A&A 406, 131
150 subdwarfs,
high resolution spectroscopy

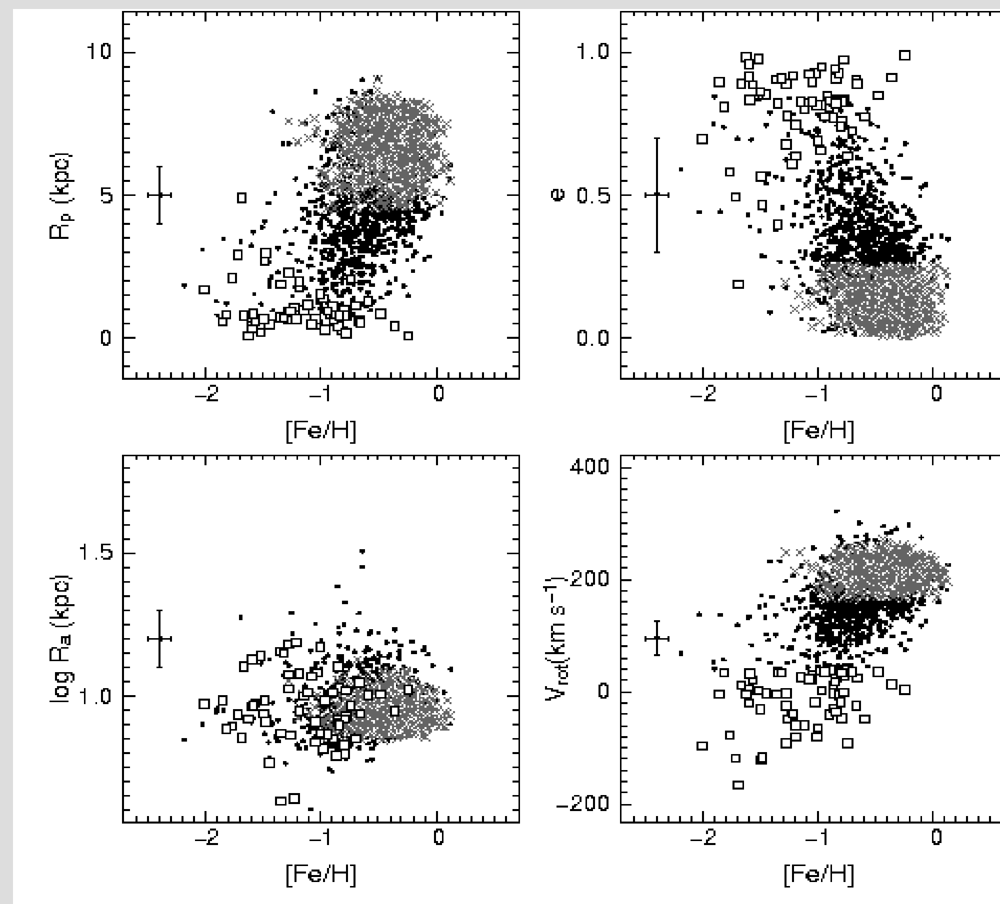
sample of 2167 RAVE giant stars

X **Thin disc:** e<0.25, Zmax<0.8 kpc (1079 stars)

● **Thick disc:** VΦ>40 km/sec (1024 stars)

□ **Halo:** VΦ<40 km/sec (64 stars)





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S/N>75

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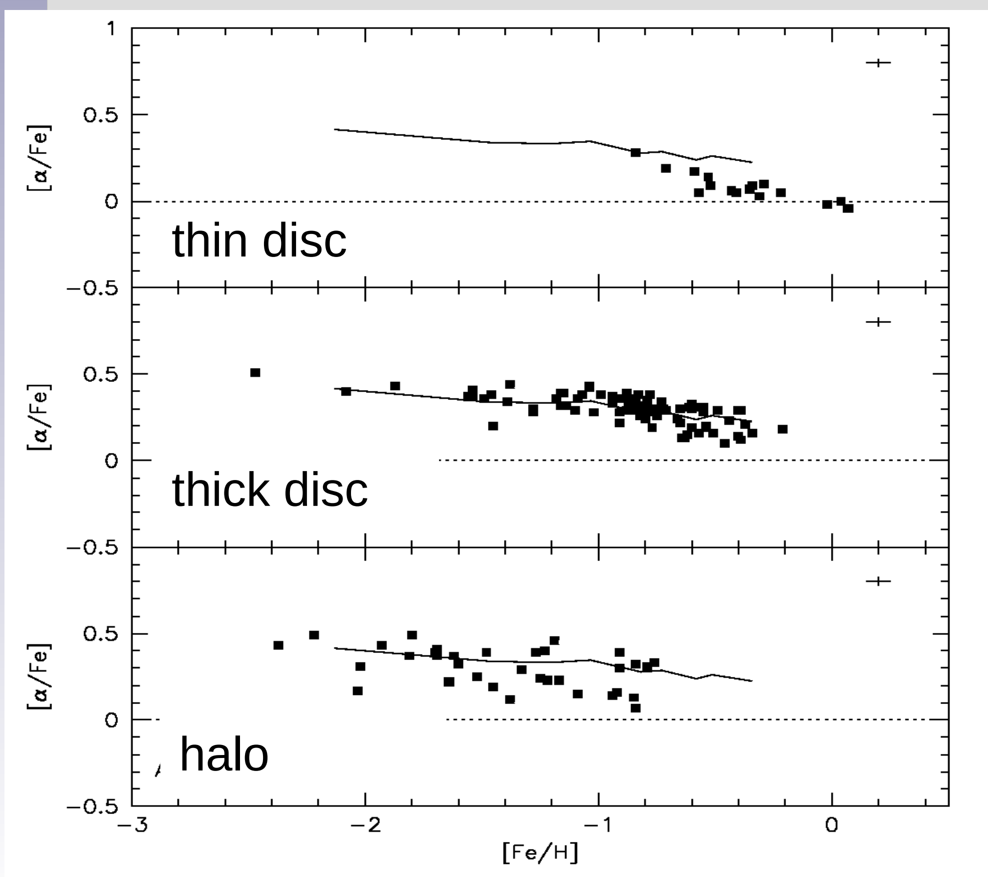
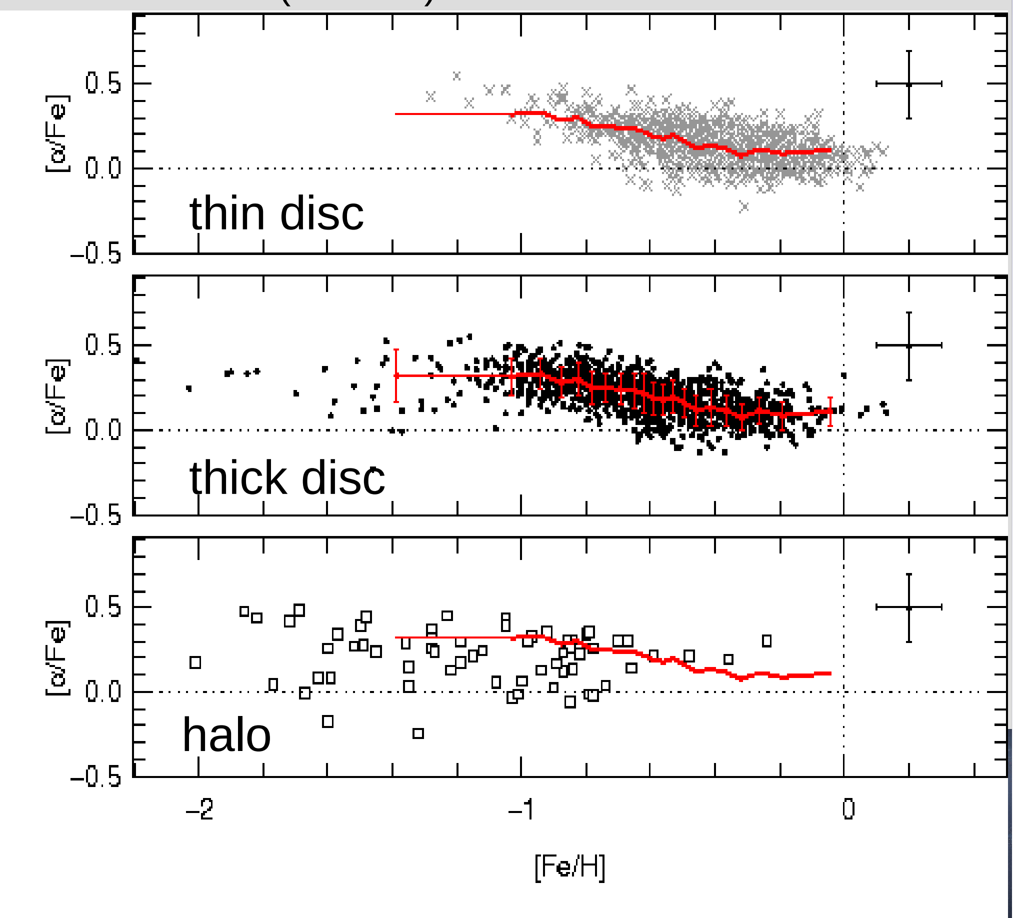
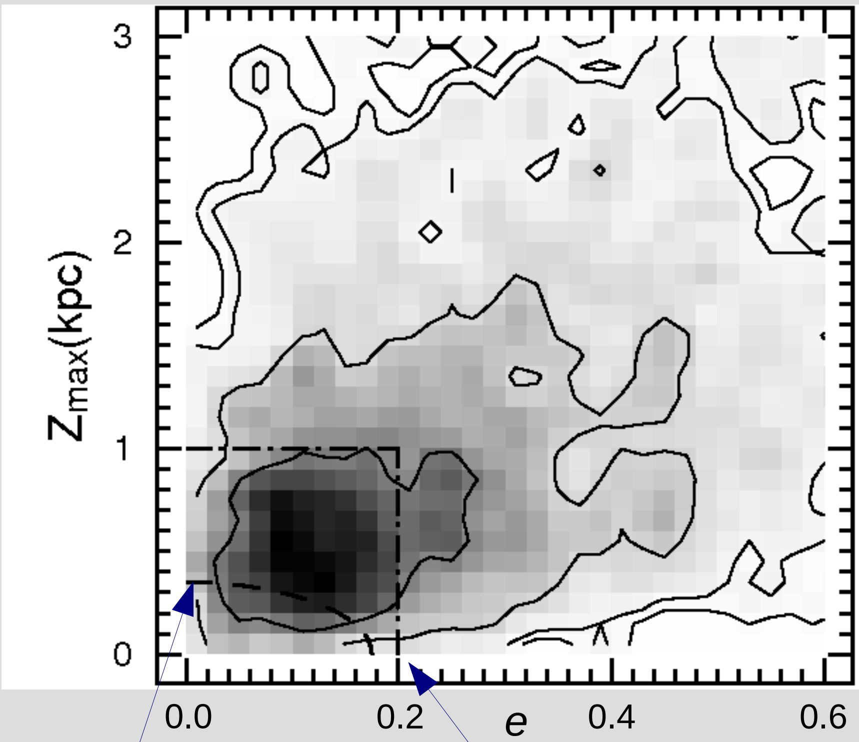




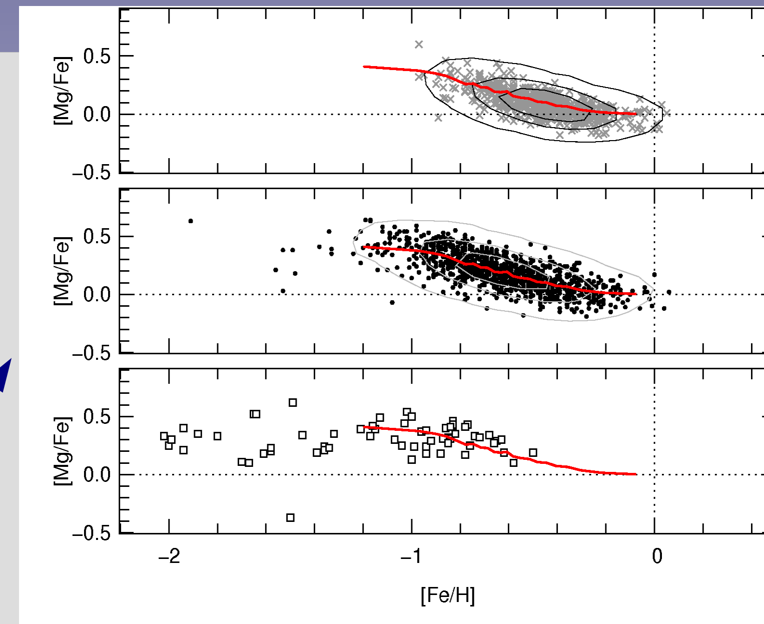
Disentangling Galactic stellar populations

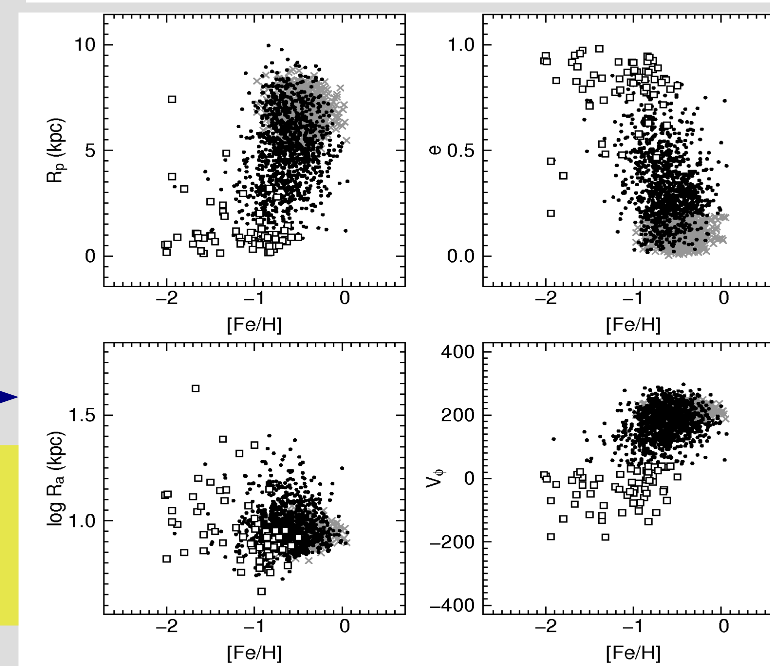


Gratton's selection criteria

$\sqrt{Zmax^2+4e^2}<0.35$

Our modified selection criteria





Different population cannot be disentangled with pure kinematic criteria

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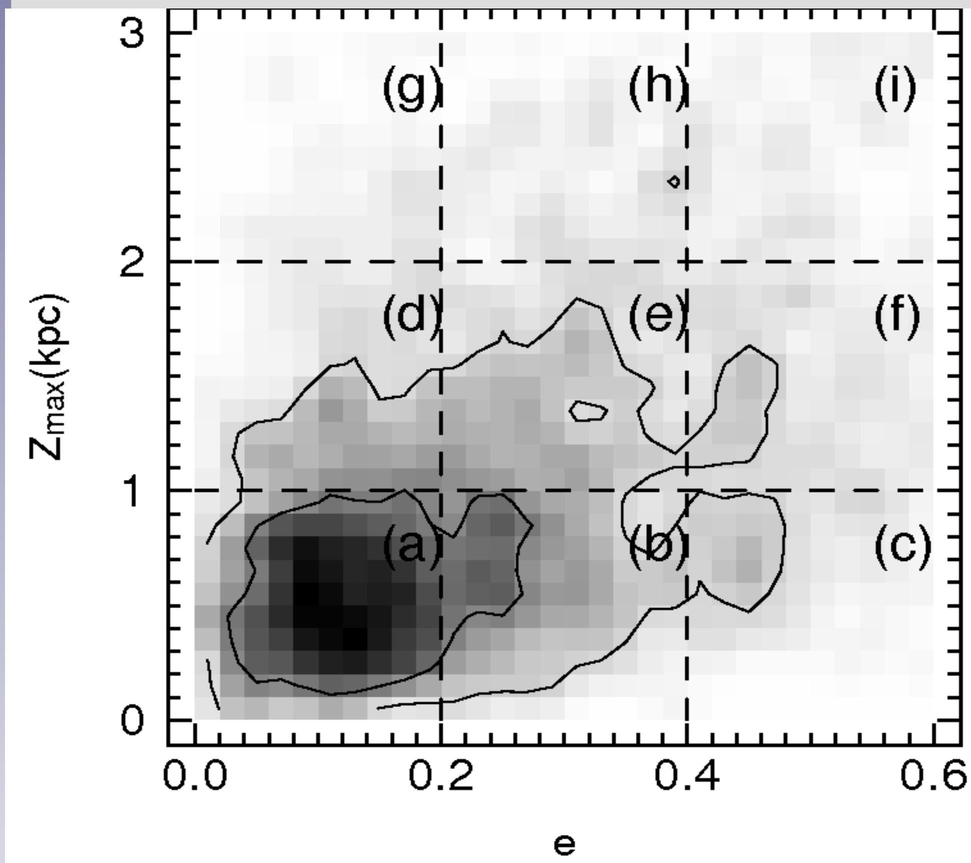
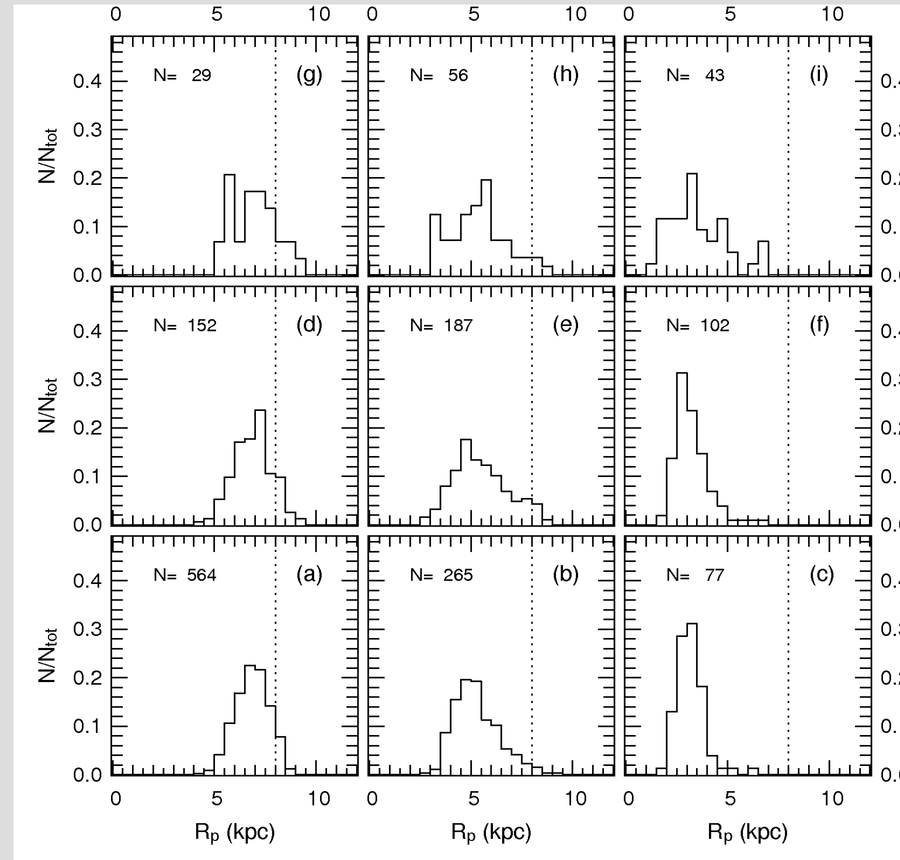
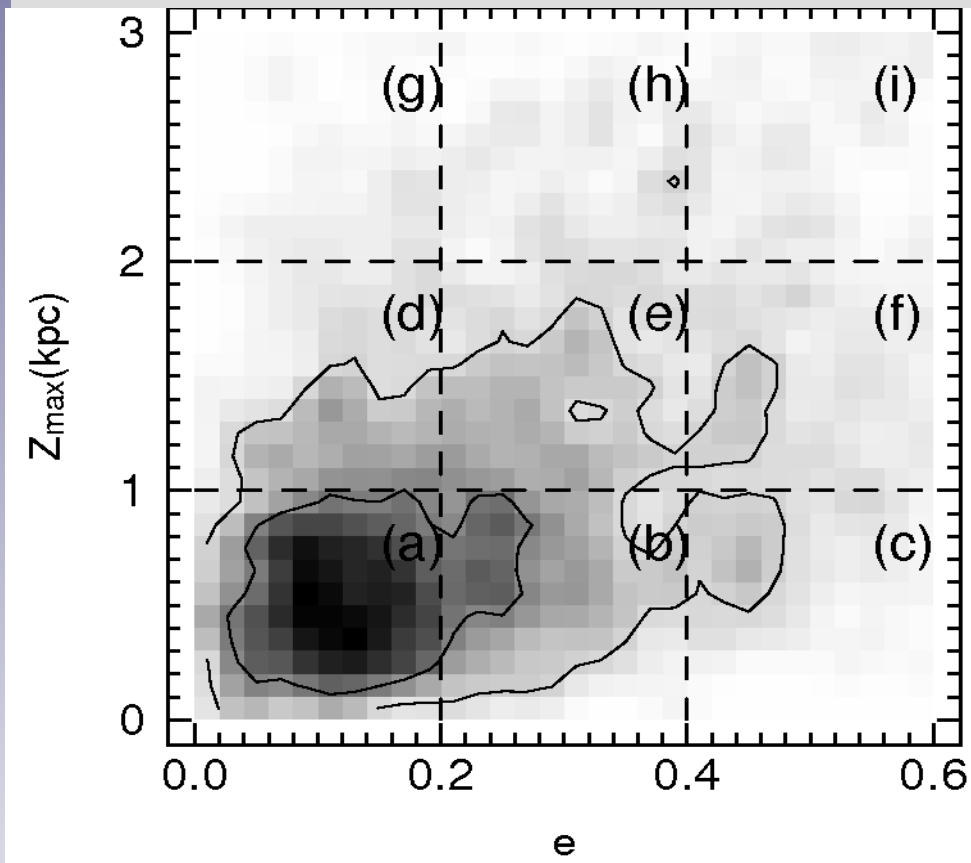
Let's try a different approach...

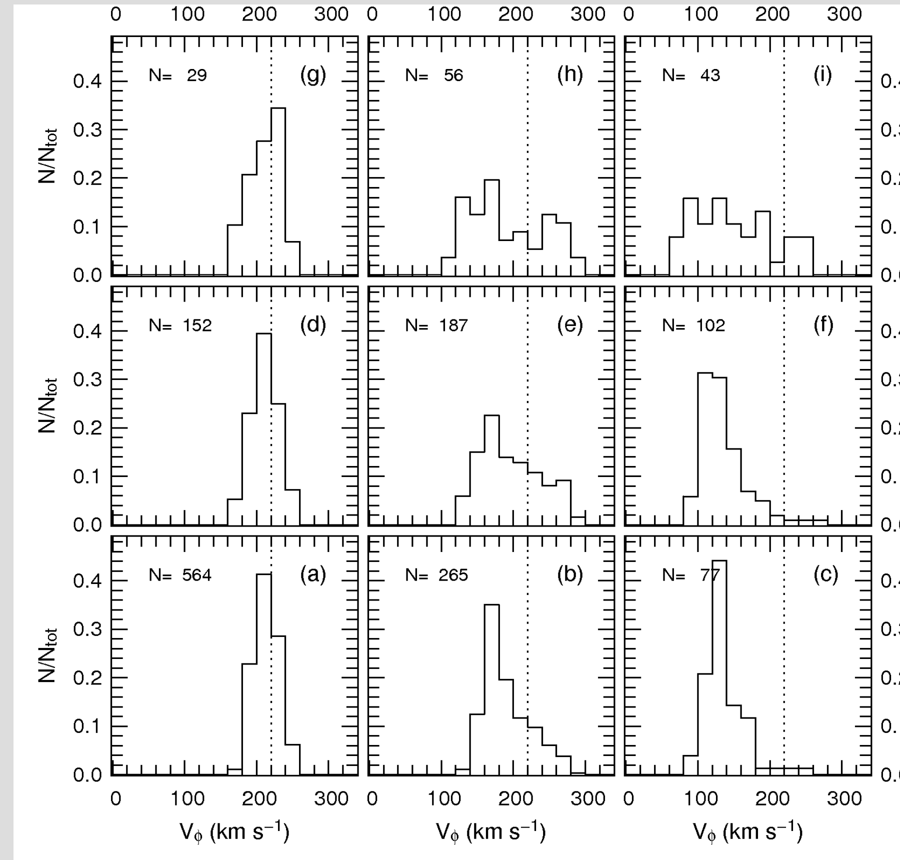




Rp=perigalactic

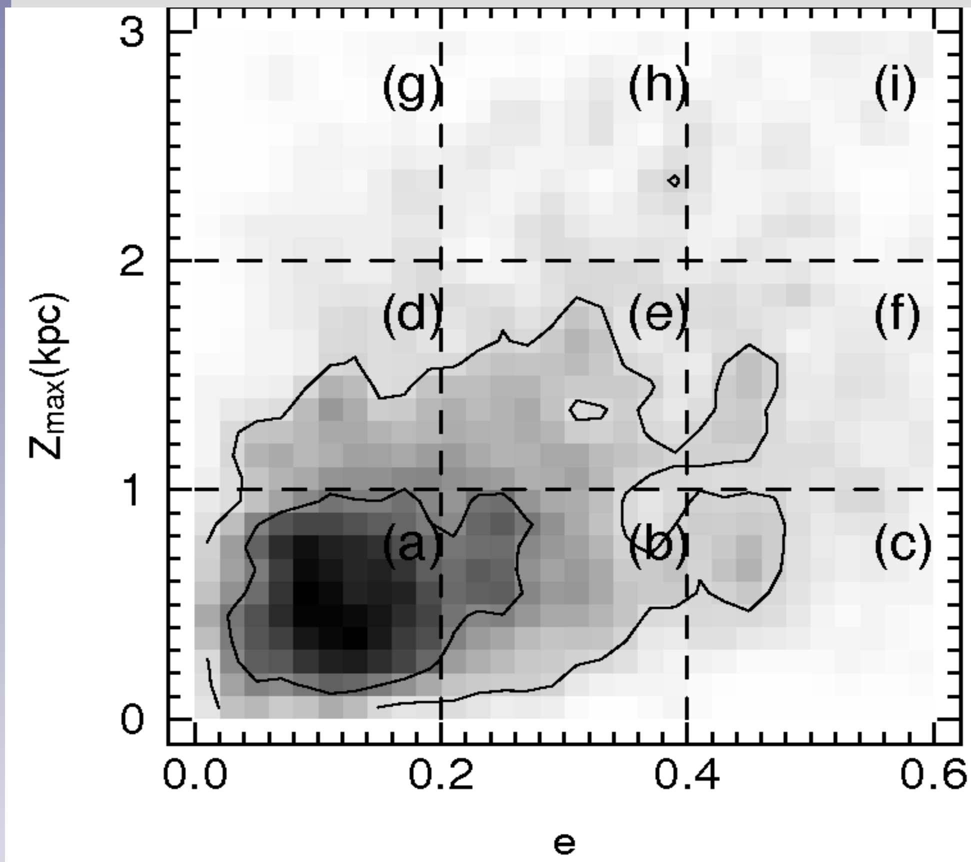
Let's try a different approach...

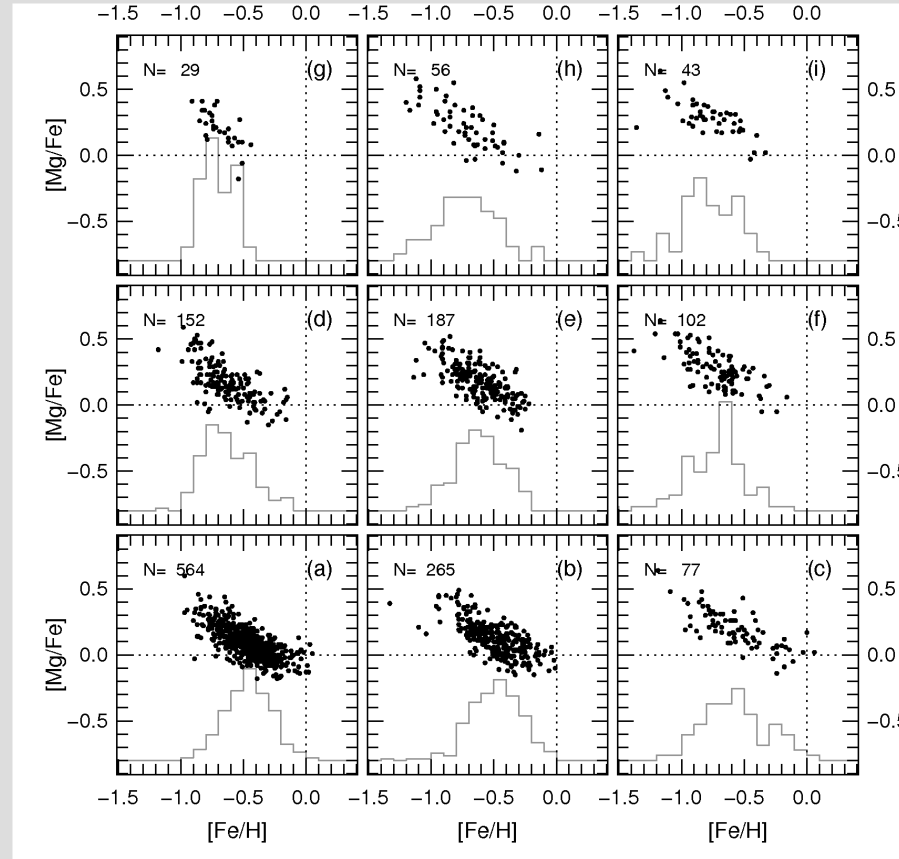




VΦ=velocity tangential to the orbit

Let's try a different approach...





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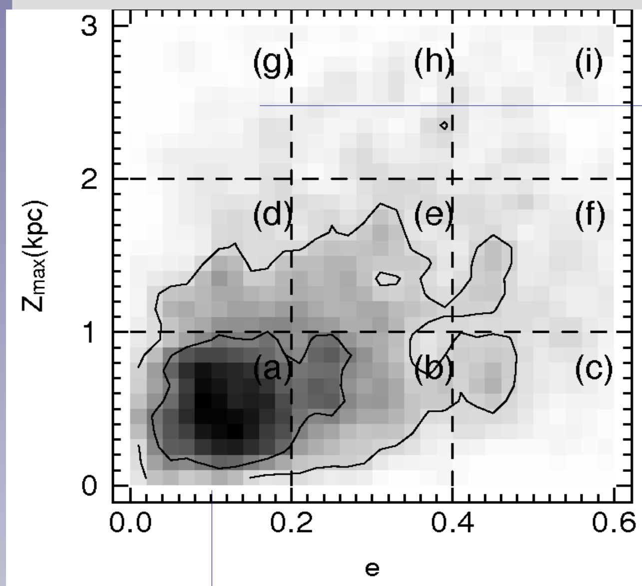
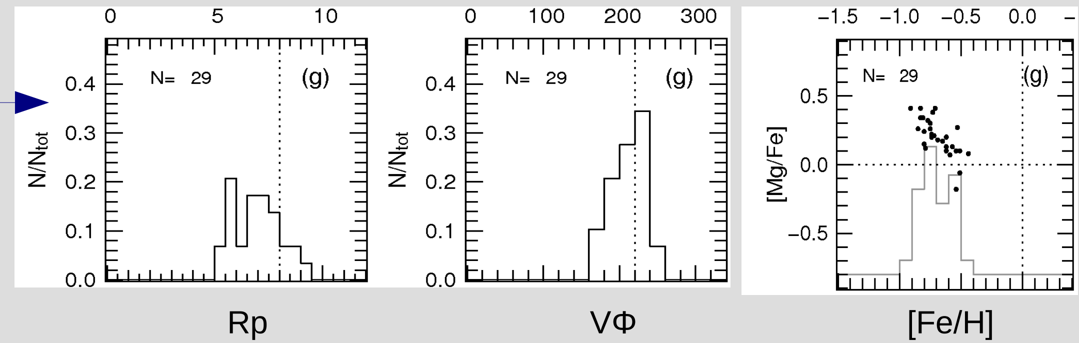
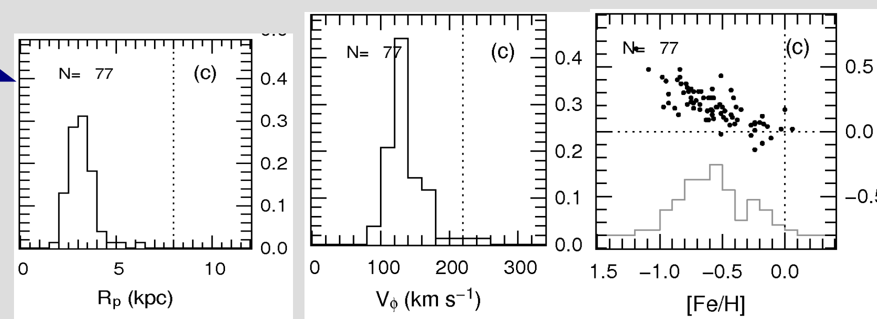
Interpretation

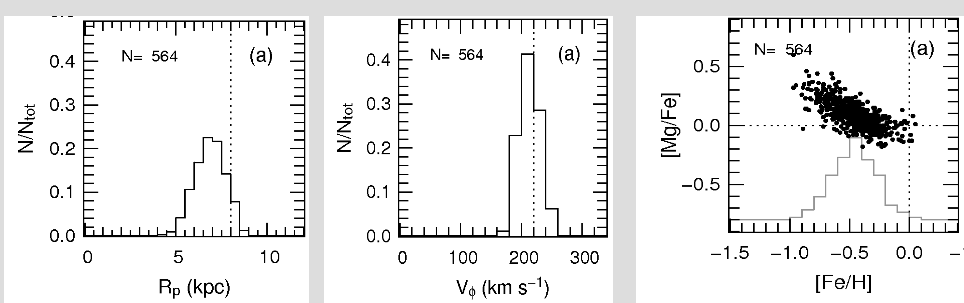




Heated thin disk



Scattered thin +thick disk



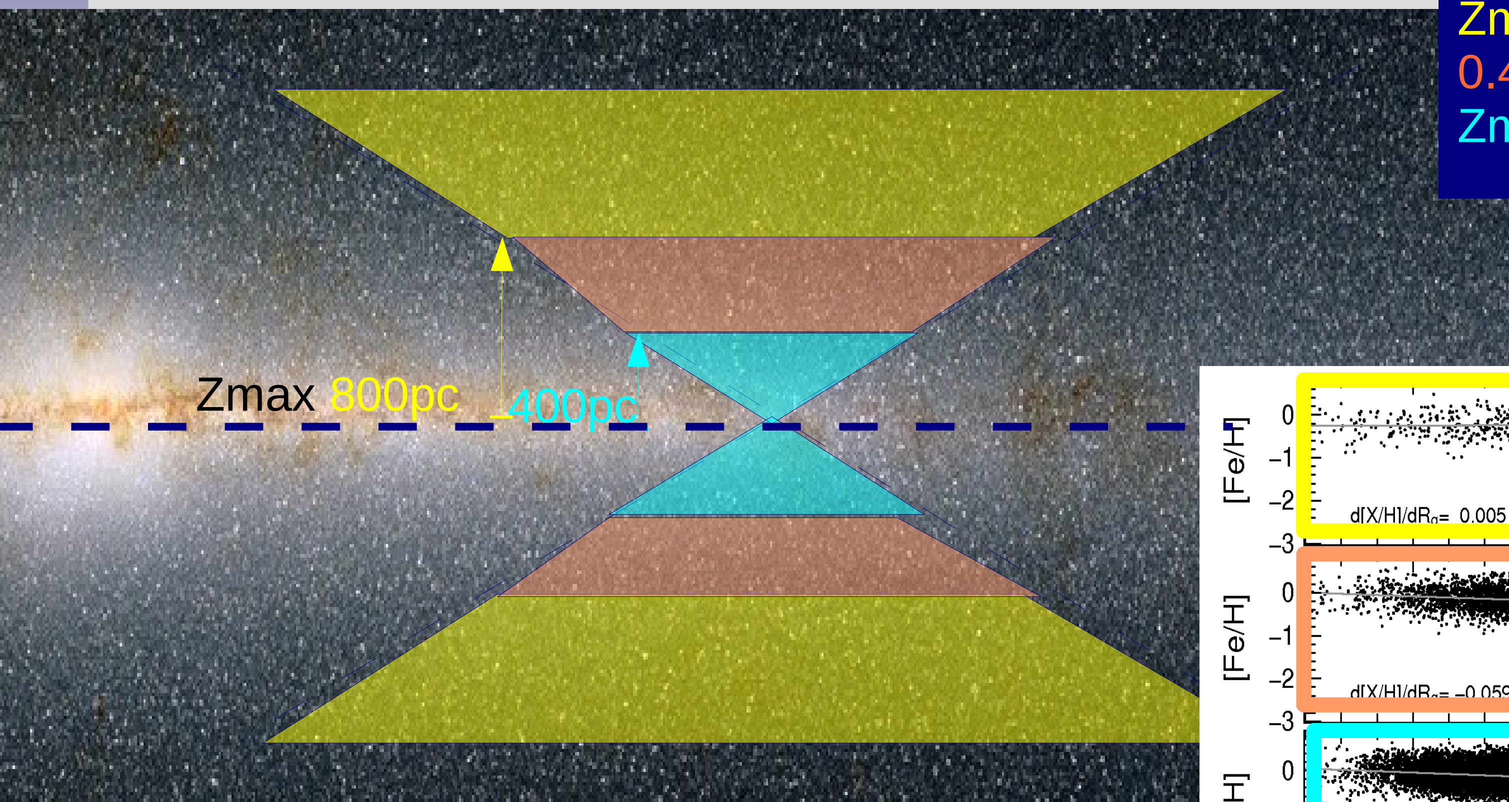
Thin disk

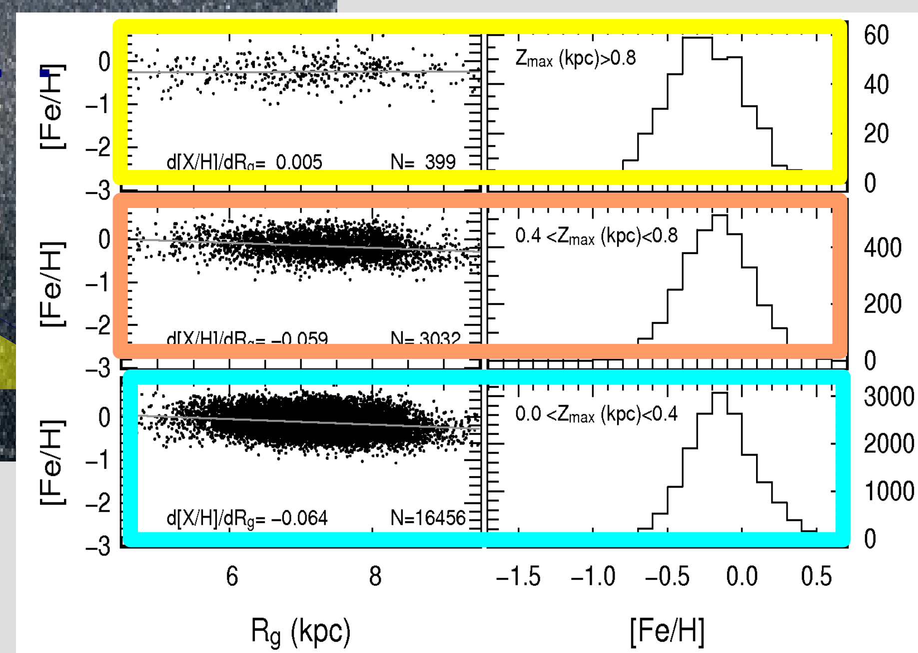
Radial chemical gradient of the MW with RAVE (Boeche et al., 2013, A&A 553, 19)

For all samples we used guiding radius (Rg) and maximum distance from the Galactic plane (Zmax) of the integrated orbits

We divide the samples in 3 subsamples as function of Zmax:

Zmax>0.8 kpc
0.4<Zmax<0.8 kpc
Zmax<0.4 kpc





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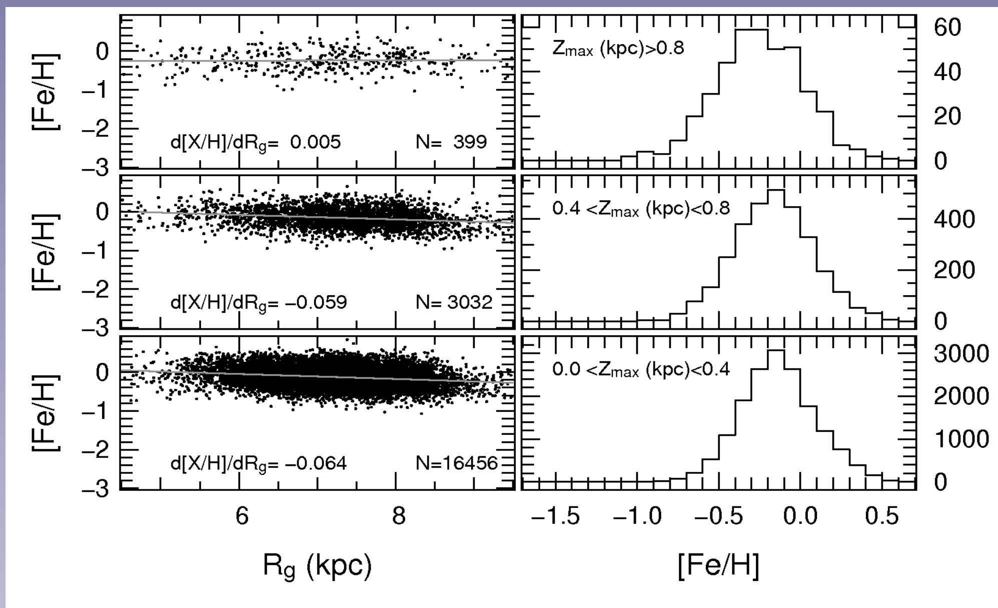
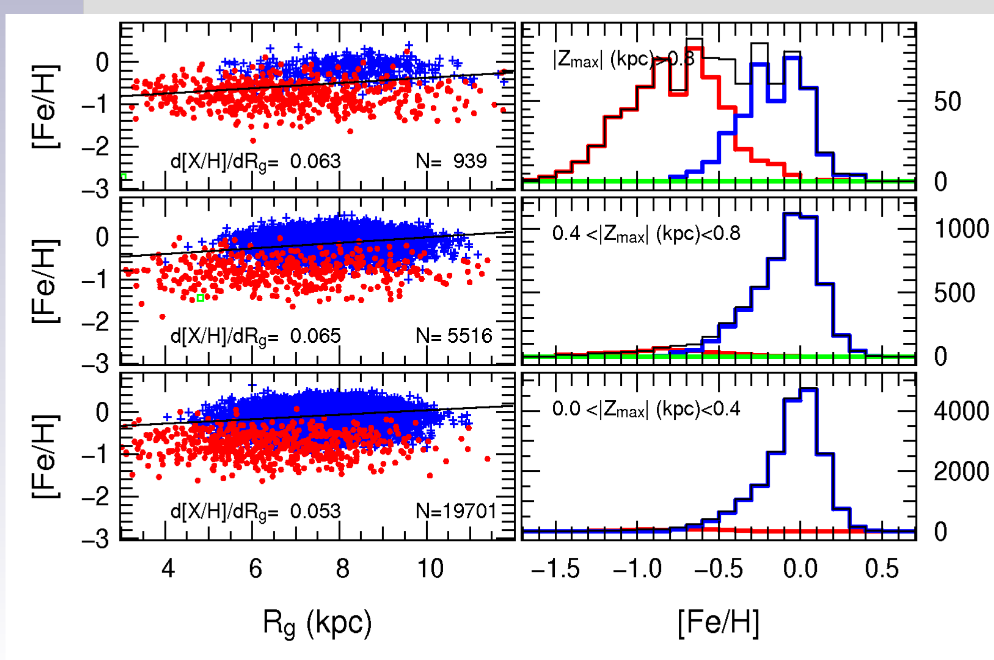


RAVE



mock sample

for the GALAXIA/Besancon mock sample we learn that:

•the mock sample seems to have:
1) too many thick disc stars w.r.t the RAVE sample
2) [Fe/H]_thick=-0.78dex is too low (-0.5dex would fit better)

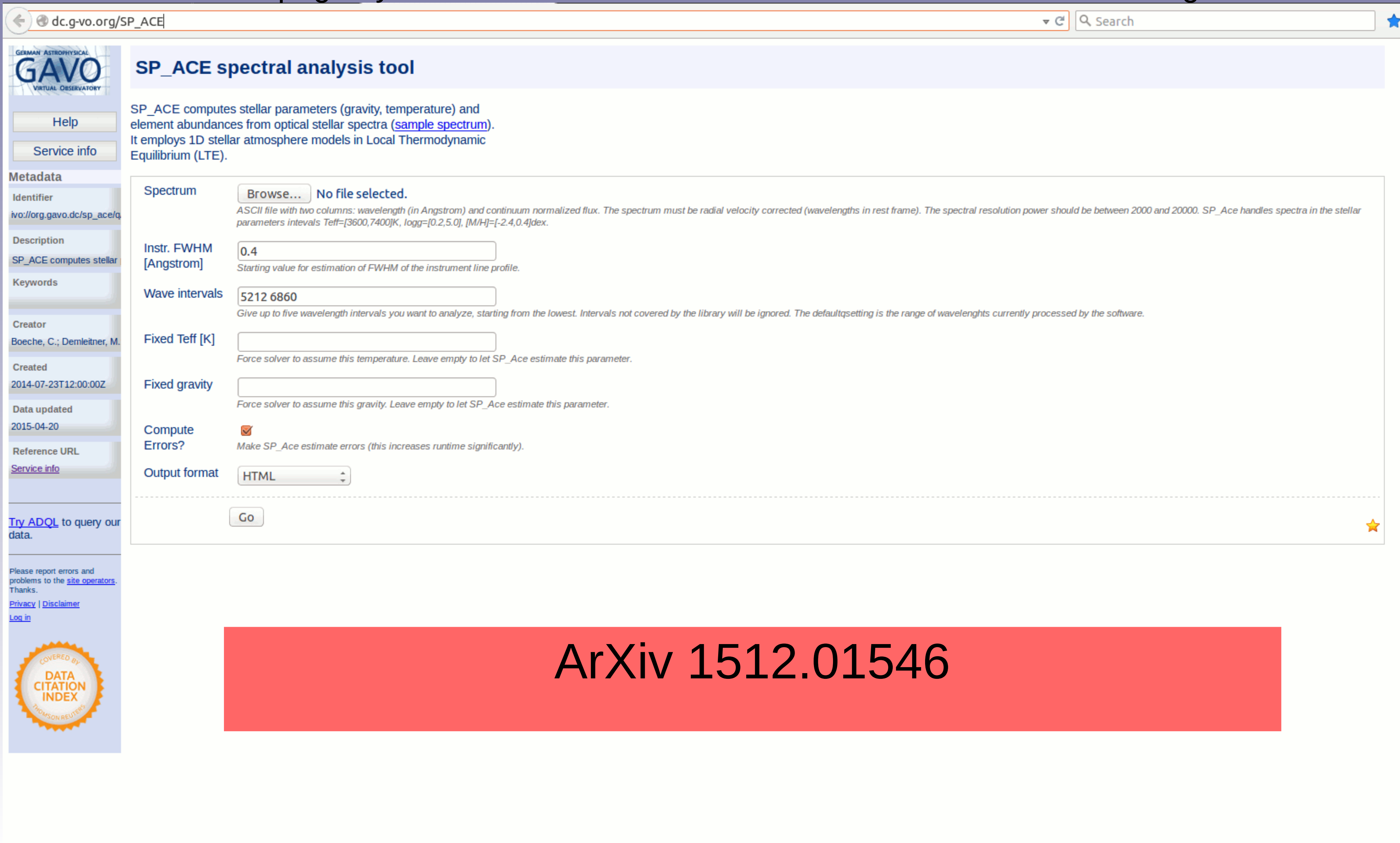
• thick disc stars shift to low left in (Rg,[Fe/H]) plane because the larger asymmetric drift and lower metallicity
→ ***fictitious flatter/positive gradient which is function of the ratio thin/thick in the sample***

• the thin disc (mock sample) has d[Fe/H]/d**R**=-0.07dex/kpc but d[Fe/H]/d**Rg**=0.00dex/kpc
→ ***in the Besancon model there is no correlation between kinematic and metallicity***

SP_Ace front end web page

http://dc.g-vo.org/SP_ACE

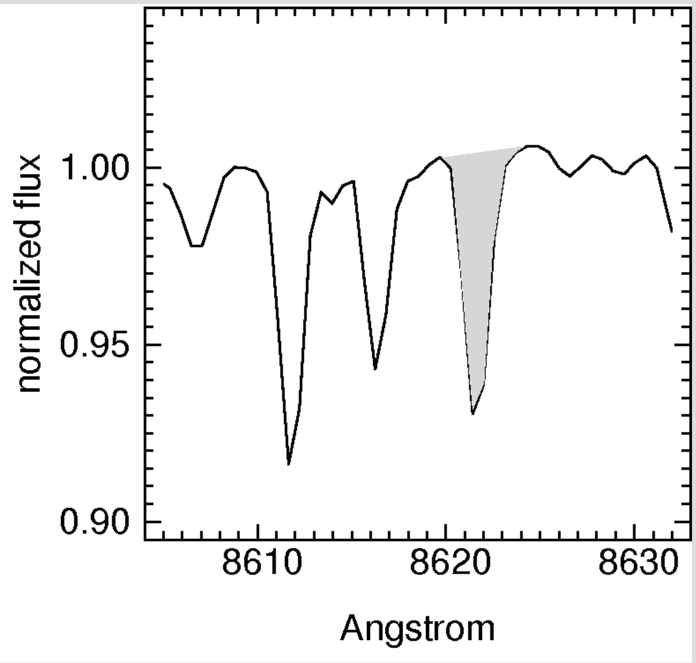
Webpage by Markus Demleitner and Hendrik Heinl at ARI Heidelberg



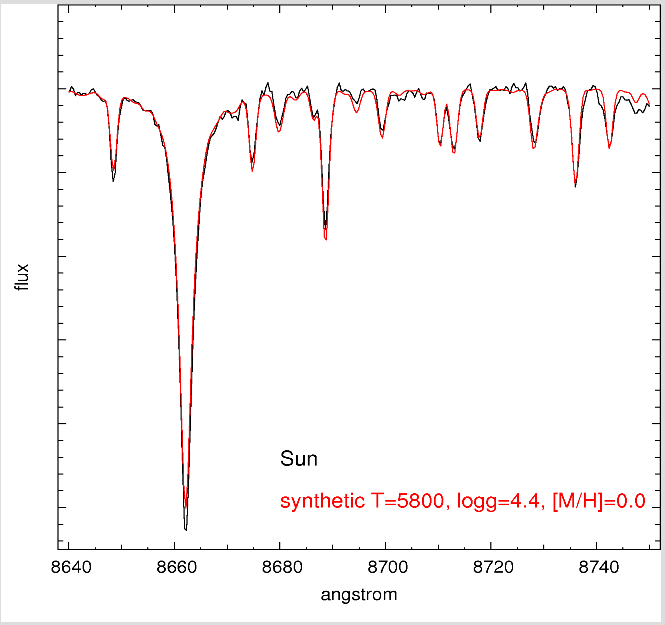
ArXiv 1512.01546

How do we measure stellar parameters and chemical abundances?

1) Equivalent Width (EW) measurement:
measure the EW of the lines and recover the [X/H] from their curve of growth (MOOG *abfind* driver)



2) Spectrum synthesis:
synthesize a spectrum with the proper atmosphere model and change the [X/H] until the best match with the observed spectrum is found



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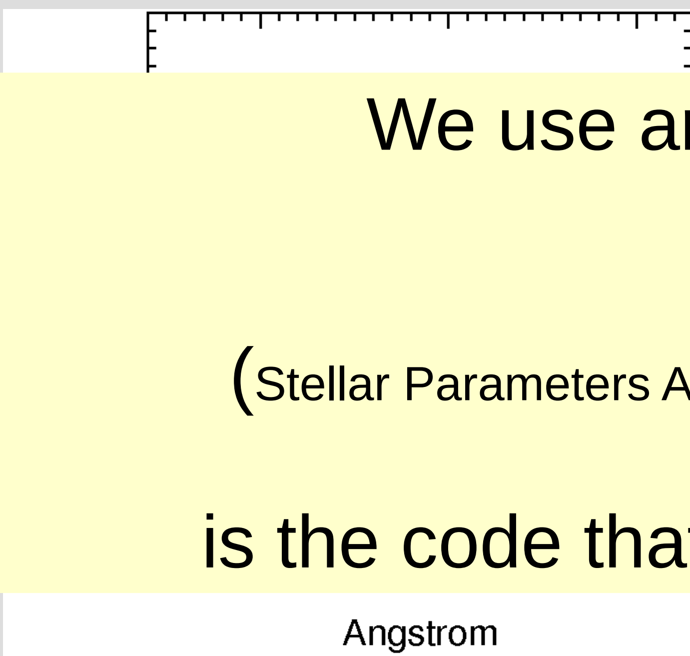

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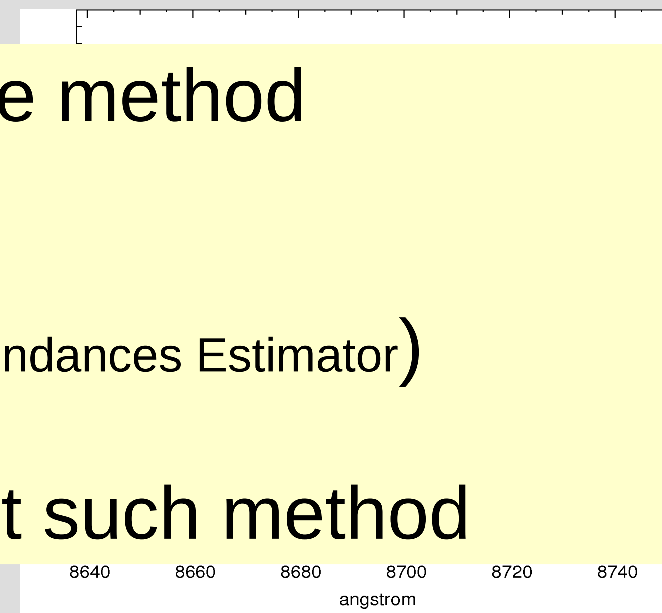

We use an alternative method

SP_Ace

(Stellar Parameters And Chemical abundances Estimator)

is the code that implement such method

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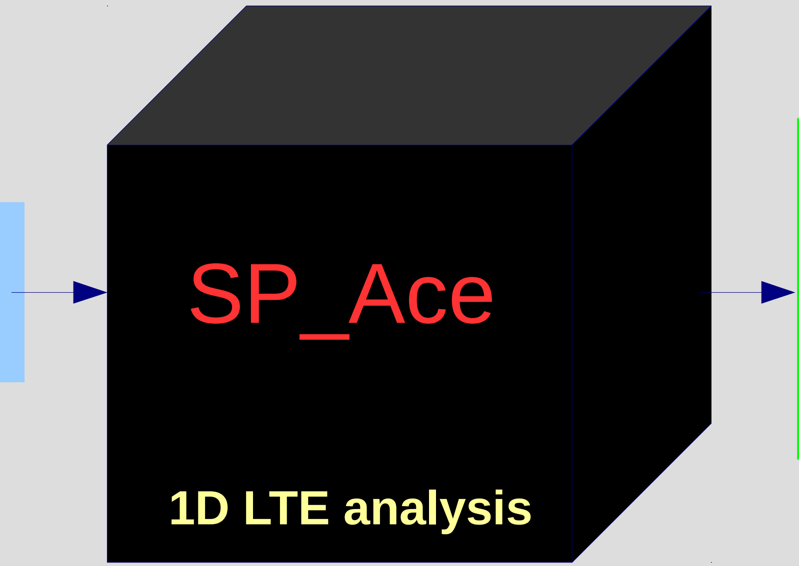
SP_Ace

a new code for Teff, Log g and [X/H] estimation

<u>SPACE is the evolution of the RAVE chemical pipeline</u>

input

- normalized spectrum
- wavelength range
- resolution (guess)



output

Teff
log g
chemical abundances
[Fe/H],[Mg/H],[Si/H],[Ca/H],
[Ti/H],[Cr/H],[Co/H],[Ni/H]
and more....

Algorithm (simplified)

1. Construct spectra models on-the-fly
2. X^2 analysis model vs. observed spectrum looking for the best match
3. The model with the smallest X^2 has the most probable the stellar parameters

How to construct a spectrum model

given
- stellar parameters
- EW of the lines
- **Voigt** profiles of the lines

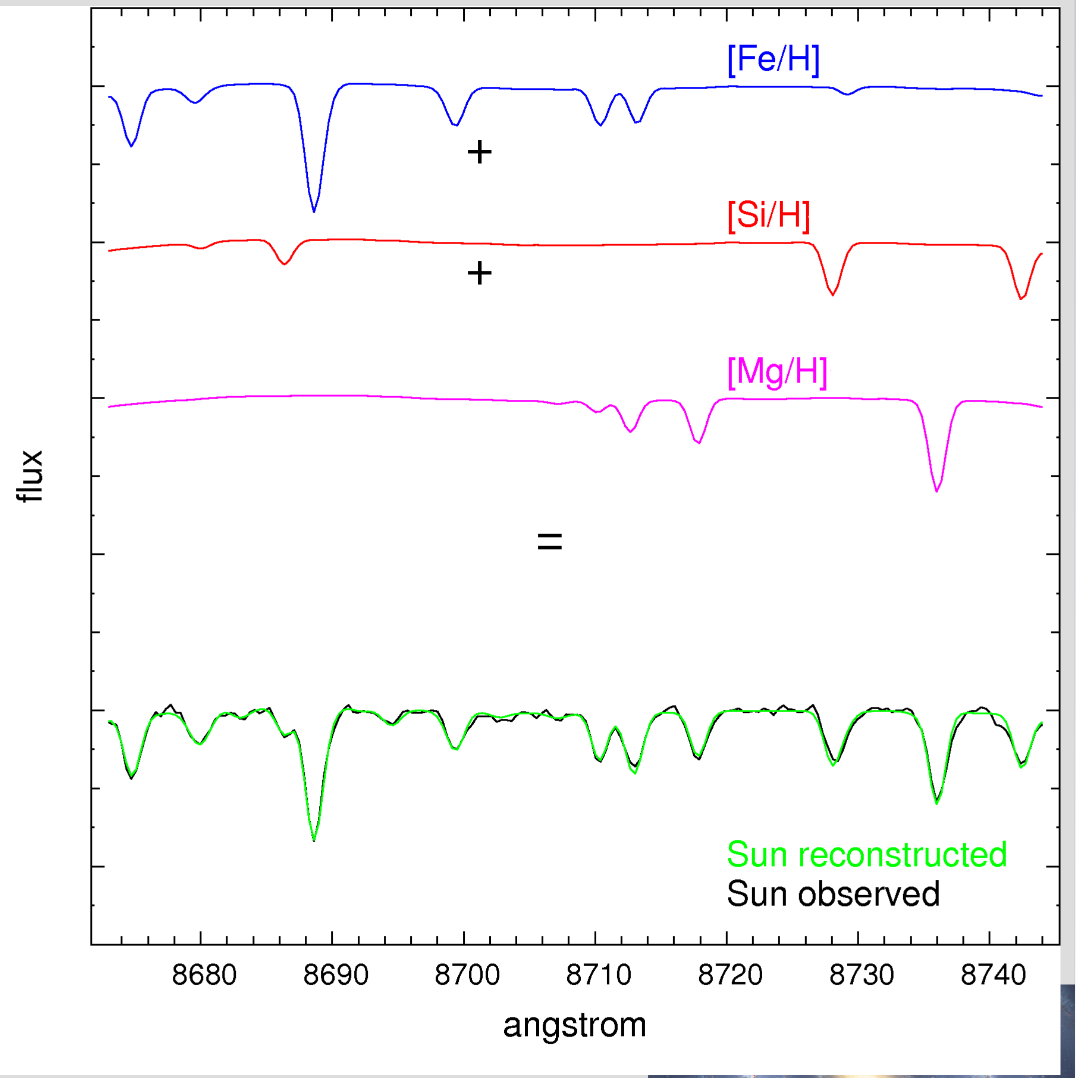
V(λ,μ,σ,EW) (μ=central wavelength)

the reconstructed spectrum can be described as

$$spectrum(\lambda) = \sum_i V_i(\lambda, \mu_i, \sigma_i, EW_i)$$

This is valid only under weak line approximation!

(Solution: correction for the opacity of the neighbor lines, see later...)

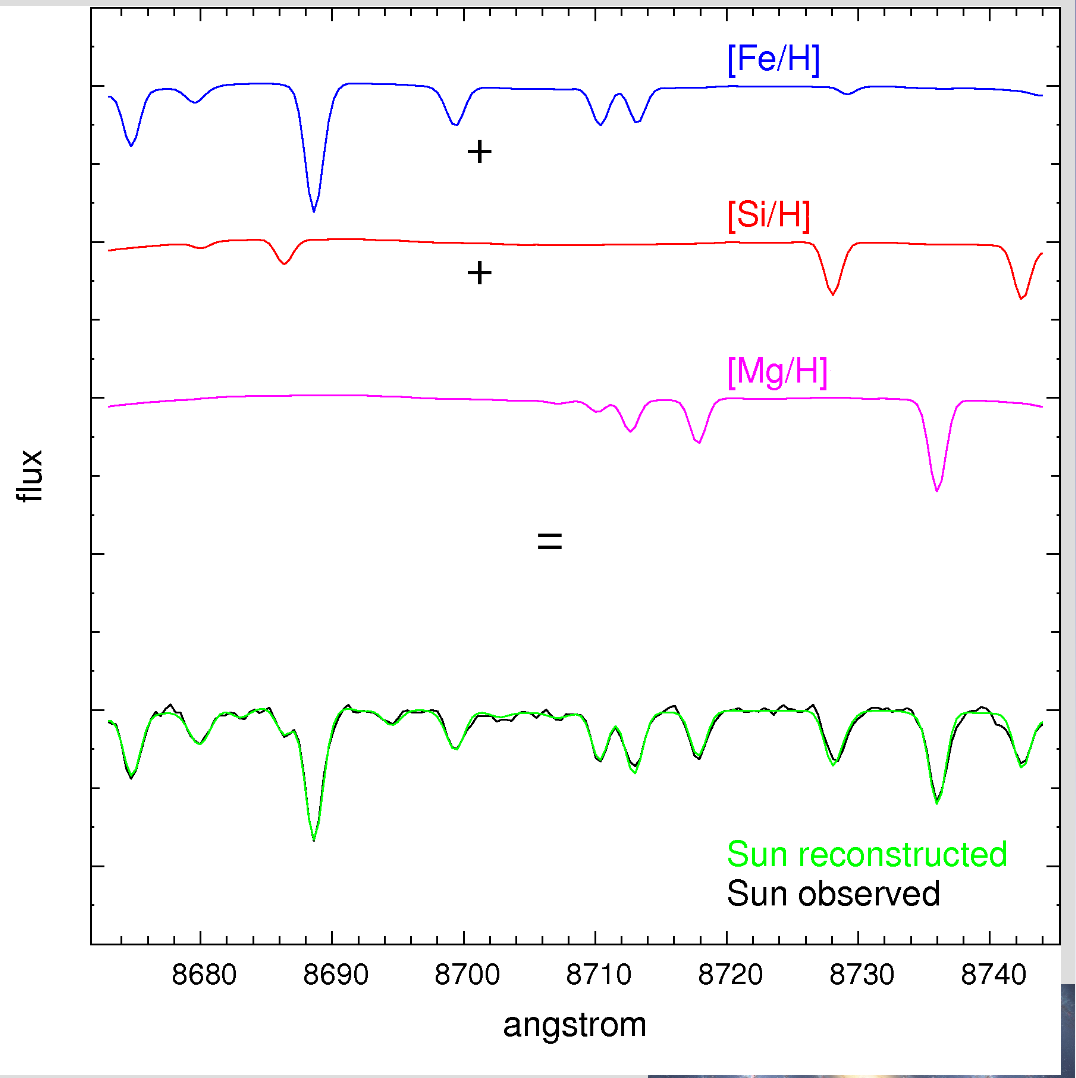


How to construct a spectrum model

If we know the expected EWs of the lines we can reconstruct a spectrum model that match the observed spectrum

The EW of every lines is described by a function that we call
General Curve of Growth

$$EW_{ij} = GCOG(T_{eff}, \log g, [X_j/H])$$



What do we need to construct a realistic spectrum model?

at present the whole work is based on 1D atmosphere models and LTE assumptions (but extension to 3D-NLTE are possible)

1) Line list

2) A library that contains the expected EWs for a grid of stellar parameters (EW library)

2a) Complication: Correction for the opacity of the neighbour lines (corrected EW library)

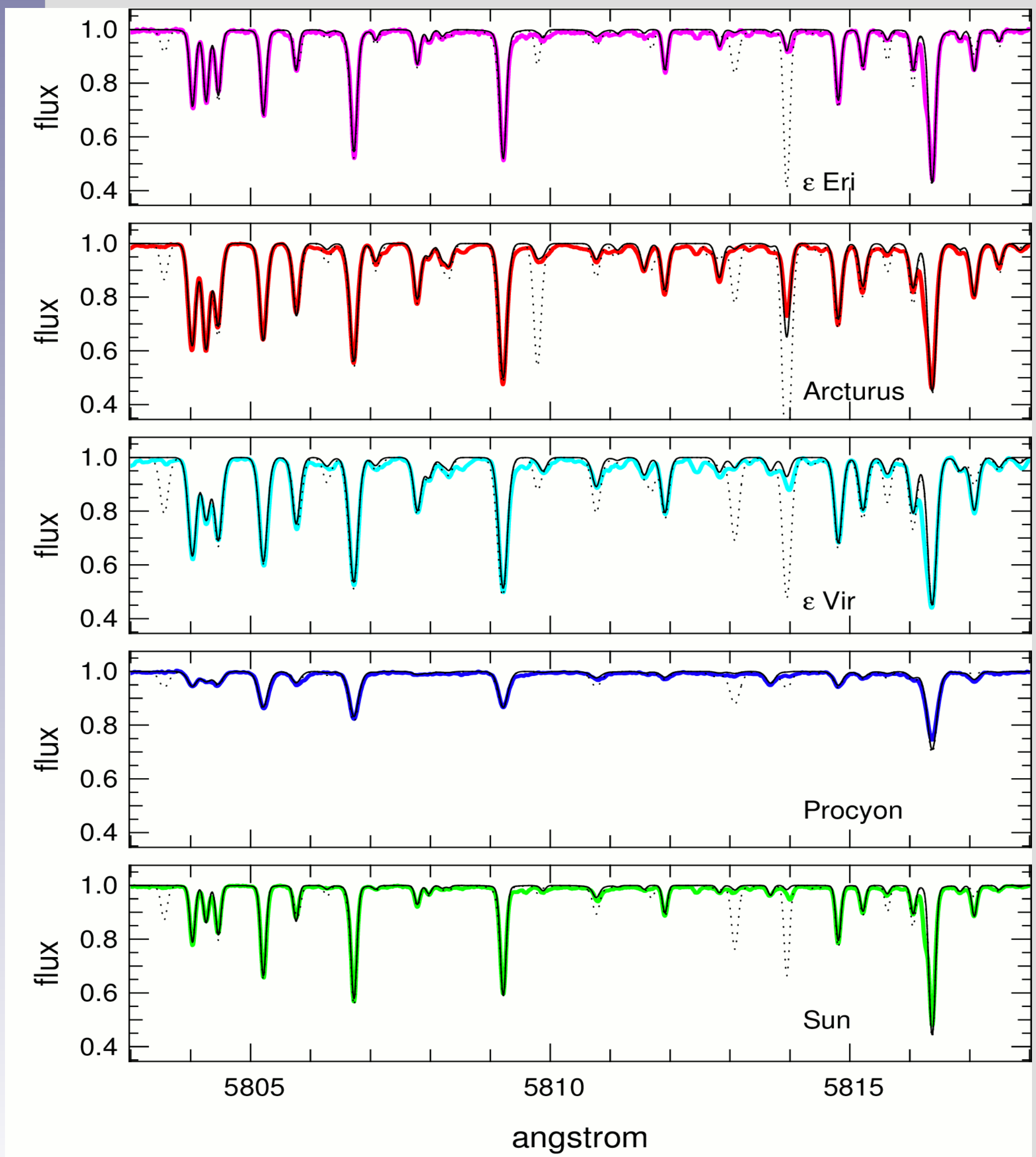
3) Creation of the General Curve-Of-Growth (GCOG) library
(that permit to continuously vary the EW of the lines as function of the stellar parameters in order to construct spectrum models of any stellar parameters and chemical abundances)

1) The line list

1) Select from the VALD database all the lines in the wavelength range 5212-6860A and 8400-8900A that has strength > 1% of the flux on the spectra of the Sun, Arcturus, Procyon (8424 atomic+molecular lines)

2) Calibrate the oscillator strengths (log gf) by matching at best the intensity of the lines with 5 spectra (astrophysical calibration).
After calibration the line list counts 4620 lines

1) The line list: log gf calibration



Eps Eri
Teff=5050K logg=4.60 [M/H]=-0.09dex

Arcturus
Teff=4286K logg=1.66 [M/H]=-0.52dex

Eps Vir
Teff=4983K logg=2.77 [M/H]=+0.15dex

Procyon
Teff=6554K logg=3.99 [M/H]=-0.04dex

Sun
Teff=5777K logg=4.44 [M/H]=0.00dex

observed

VALD log gf

calibrated log gf

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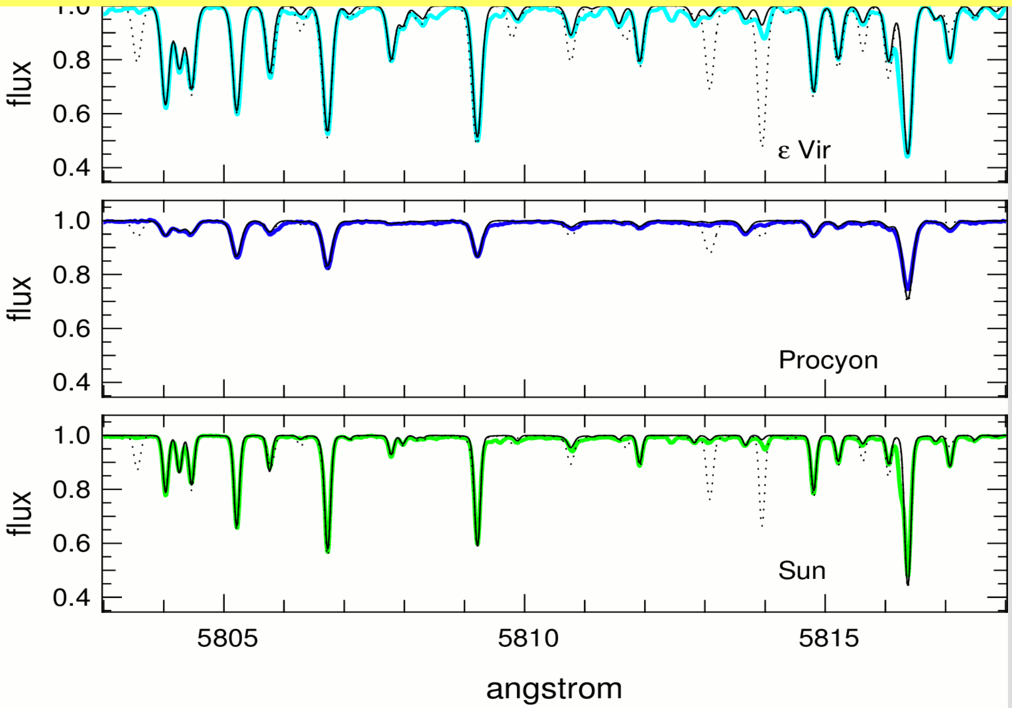
Why do we calibrate log gfs?

We do not expect to improve the (few) good and reliable log gfs from laboratory measurements, but

We calibrate log gfs to amend the badly wrong log gfs of some lines that can spoil the whole analysis



Eps Vir
Teff=4983K logg=2.77 [M/H]=+0.15dex

Procyon
Teff=6554K logg=3.99 [M/H]=-0.04dex

Sun
Teff=5777K logg=4.44 [M/H]=0.00dex

observed

VALD log gf

calibrated log gf

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2) The EW library

The EWs can be obtained from *ewfind* driver of MOOG (Sneden, 1973) for different Teff, log g and [X/H]

I built the EW library which holds the EW of every absorption lines considered for the grid of stellar parameters and abundances

3600<Teff(K)<7400 step 200K
0.2<logg<5.4 step 0.4dex
-2.4<[M/H](dex)<0.4 step 0.2dex
-0.4<[X/M](dex)<+0.6 step 0.2dex

a) Microturbulence is defined as a function of Teff and log g

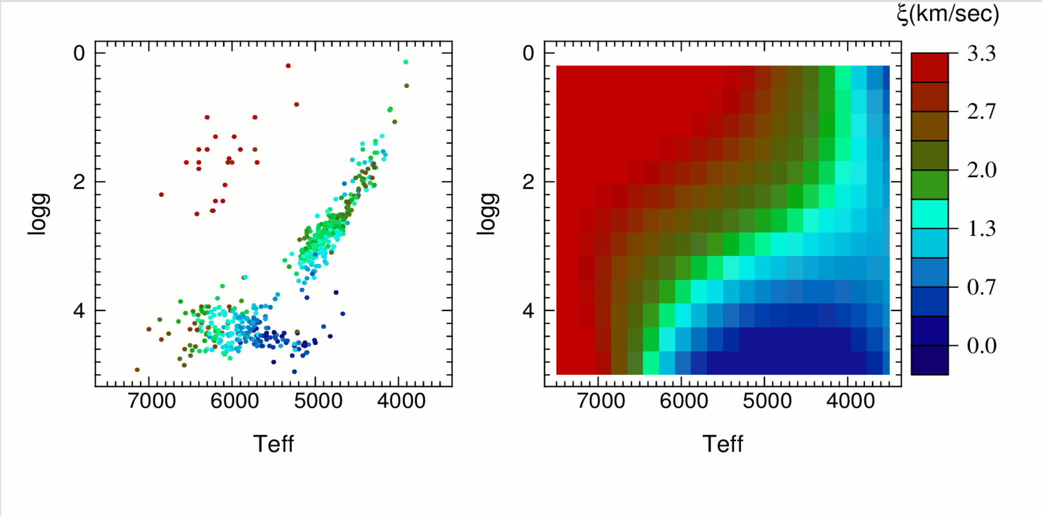
b) All the EWs contained in the library are computed as the lines were ***isolated***!

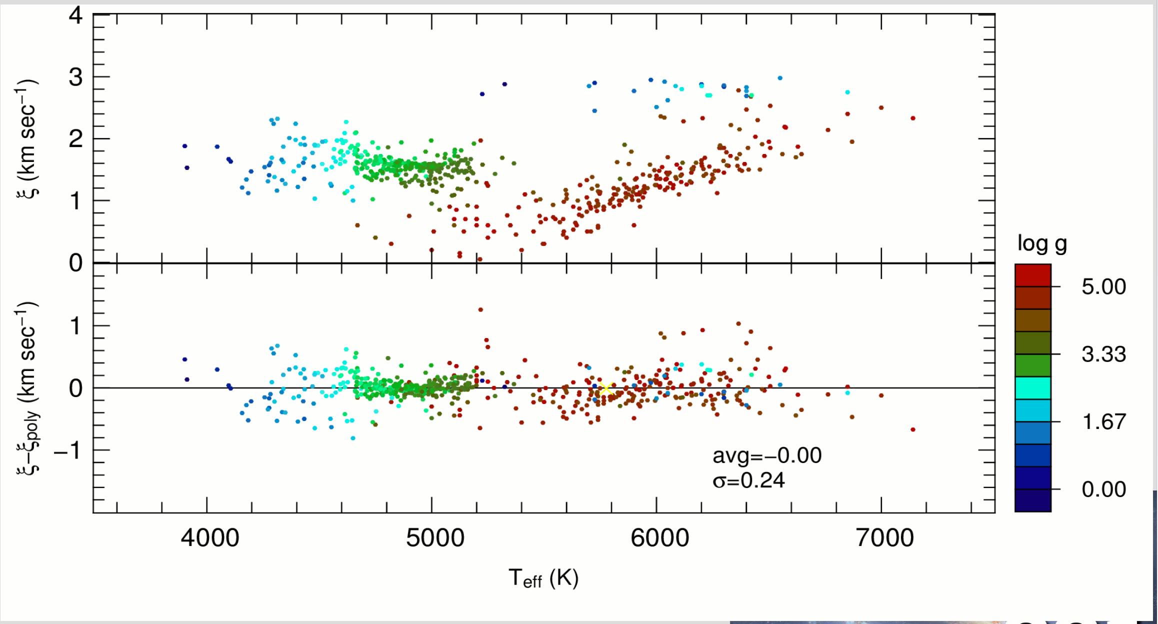
2a) EW library: microturbulence ξ

We employed 620 stars which ξ has been measured in high-res works (Fuhrmann 1998;AllendePrieto+2004;Bensby+2005; Fulbright+2006,Luck+2006,2007)

The microturbulence has been approximated with a polynomial function over the plane (Teff, log g)

The EW library has been computed by using this polynomial microturbulence.





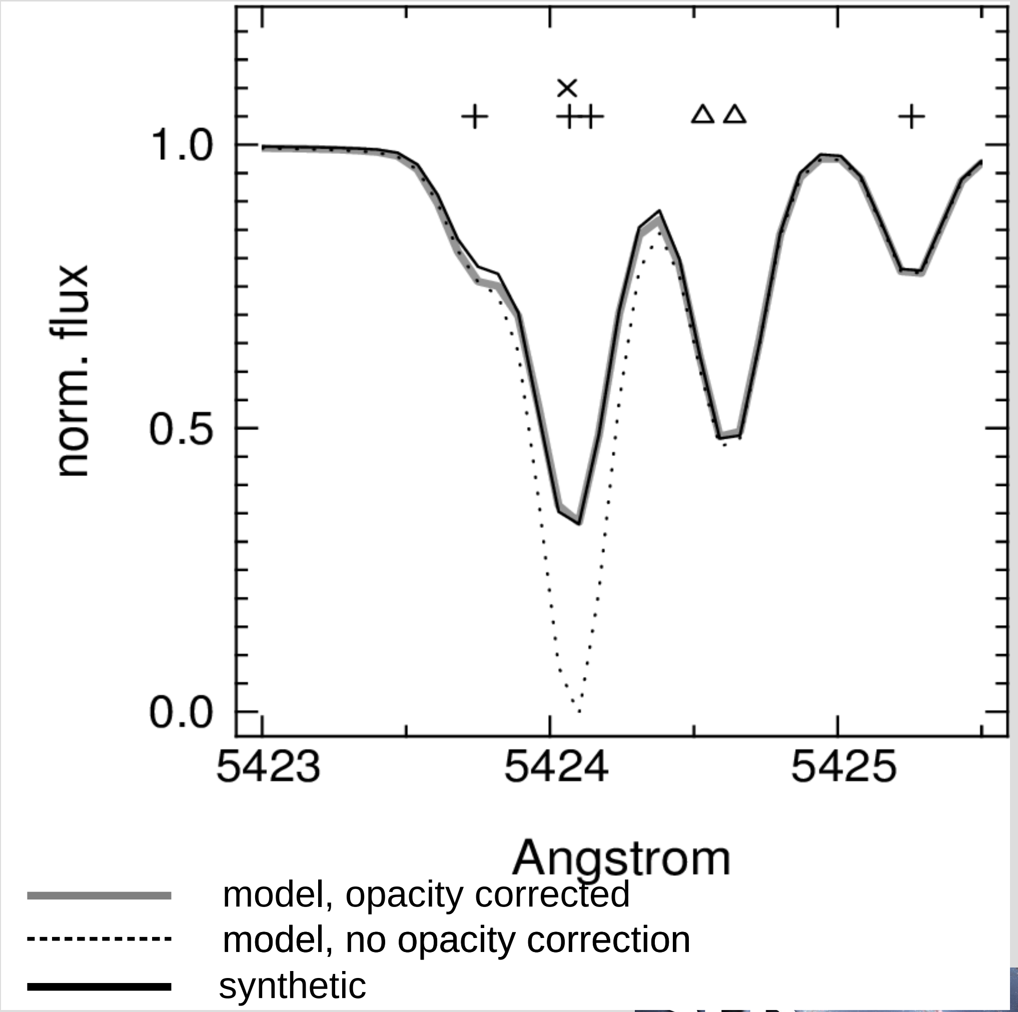
2b) Correction for the opacity of the neighbor lines

If the opacity of the neighbor lines is neglected in a blend (i.e. the EWs of the lines are computed as isolated) then the total EW is underestimated

$$EW_{blend} < \sum EW_i^{iso}$$

We need corrected EWs so that

$$EW_{blend} = \sum EW_i^{c}$$



Empirical correction

$$EW_{iso}^{i,c} = \frac{EW_{iso}^{i} \cdot (\delta COG\, i_{blend})}{(\delta COG\, i_{iso})}$$

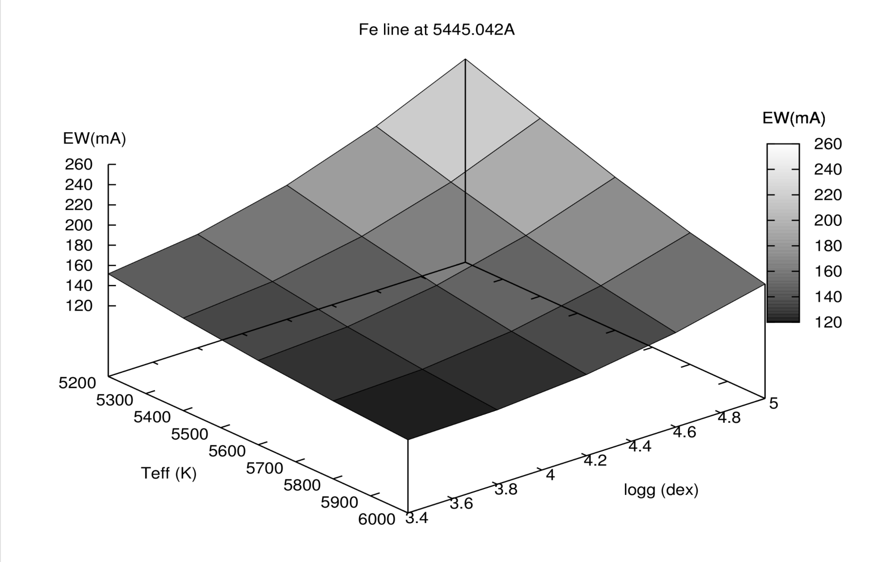
$$EW^{i,c} = EW\, i_{blend} \cdot \left(\frac{EW_{iso}^{i,c}}{EW_{blend}^{i,c}}\right)$$

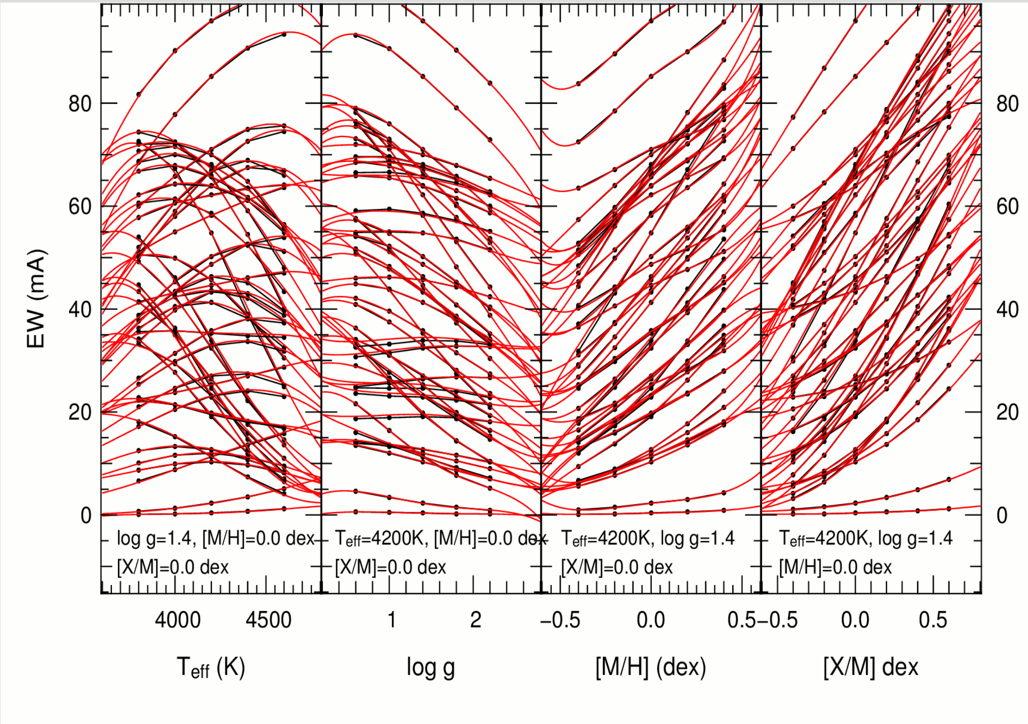
3) Construction of the GCOG library

For each absorption line the EW library (corrected for the opacity of the neighbor lines) provides the expected (synthesis) EW which covers the stellar parameters space with a grid of points. We want a continuum solution.

We fit the EWs of every line with a polynomial function in the parameter space, so that this function represent the GCOG

The coefficients of the polynomials are stored in the GCOG library





The code SP_Ace

SP_Ace is a FORTRAN95 code

It assumes an initial starting point in the parameter space
[Teff, logg, [M/H],[El/M]] = [5000, 3.0,-0.4,0.0]

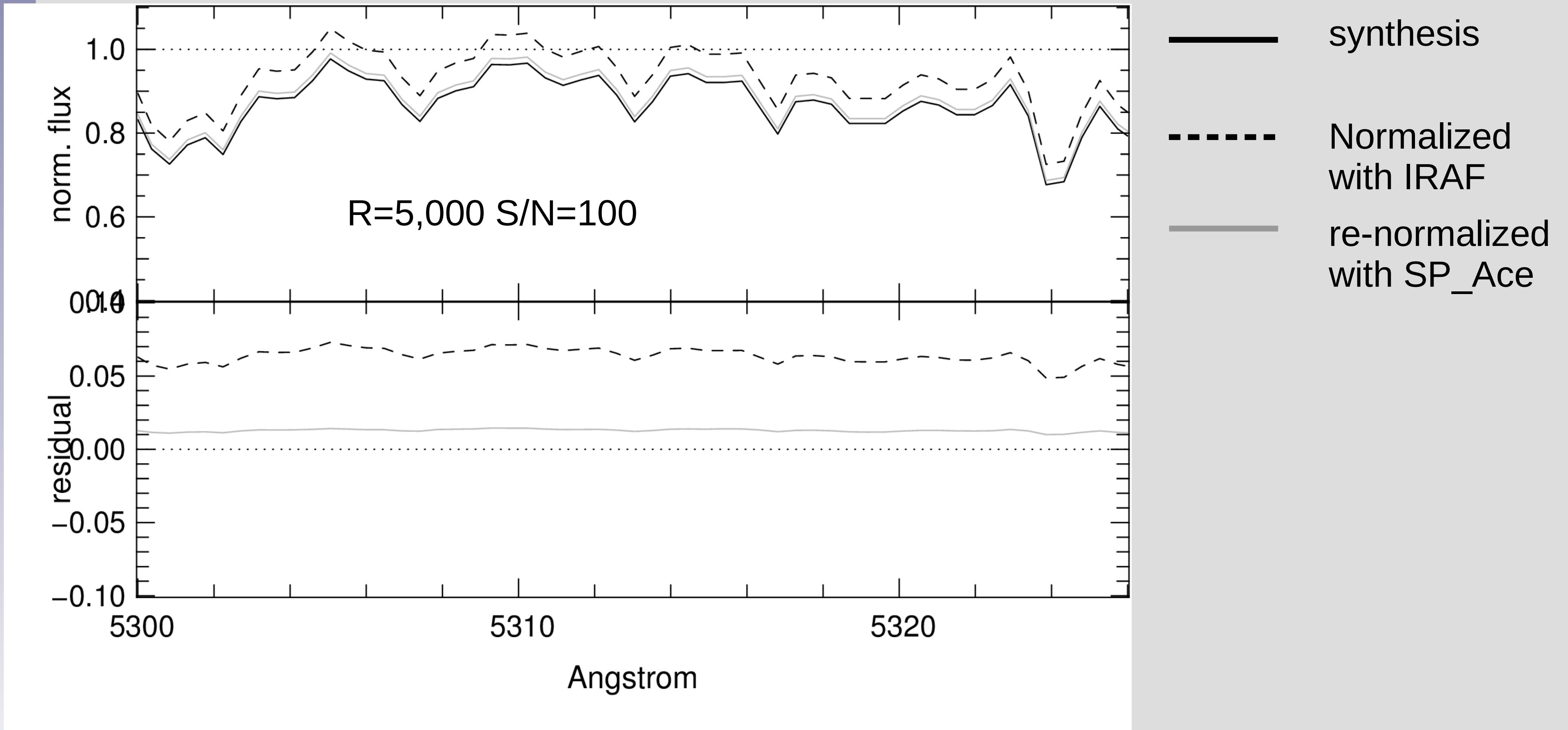
1) put these values into the polynomial GCOG to obtain the expected EWs for these stellar parameters

2) construct the spectrum model by using the EWs provided

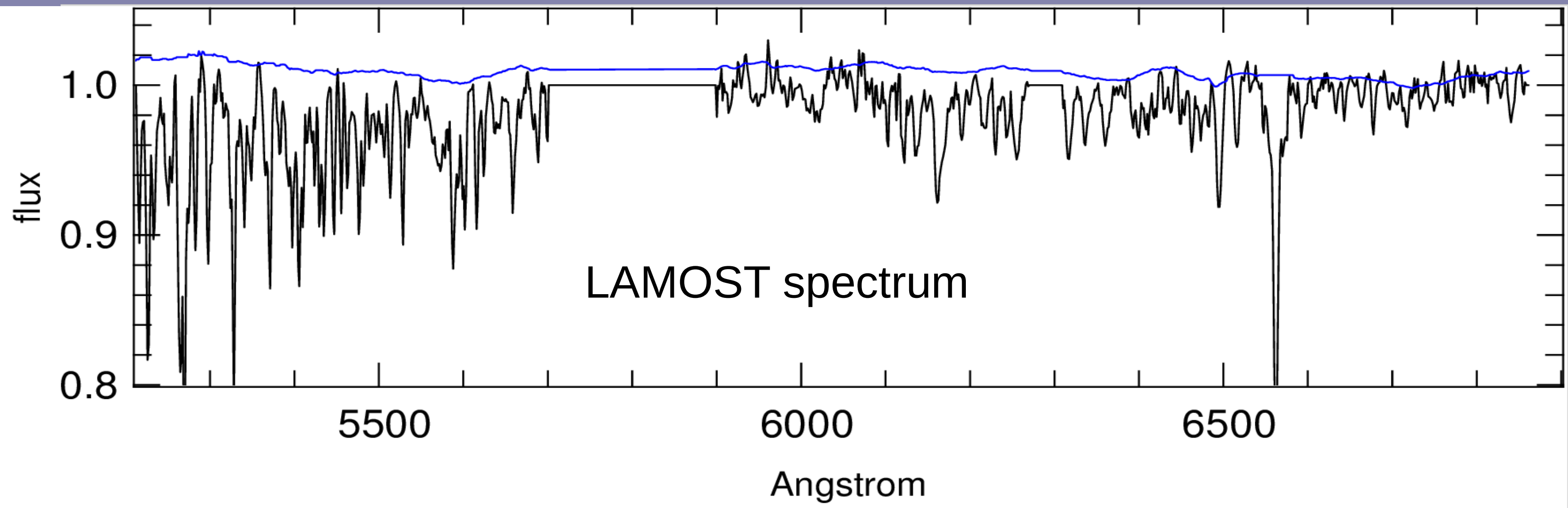
3) Compute the χ^2 between the observed and the model spectra

4) Change the point in the parameter space and repeat 2) and 3) until minimization

The code SP_Ace: internal re-normalization

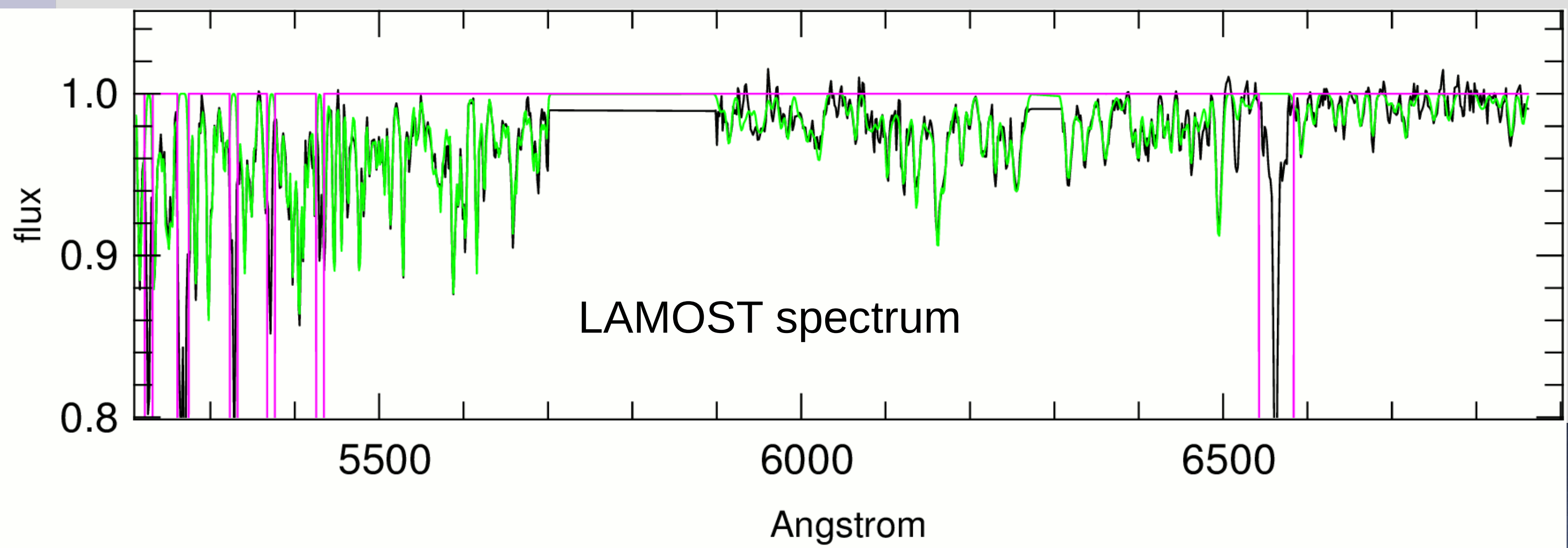


how the continuum and spectrum model look like



Normalized with IRAF

SP_Ace continuum



Re-normalized by SP_Ace

Best matching model

weights

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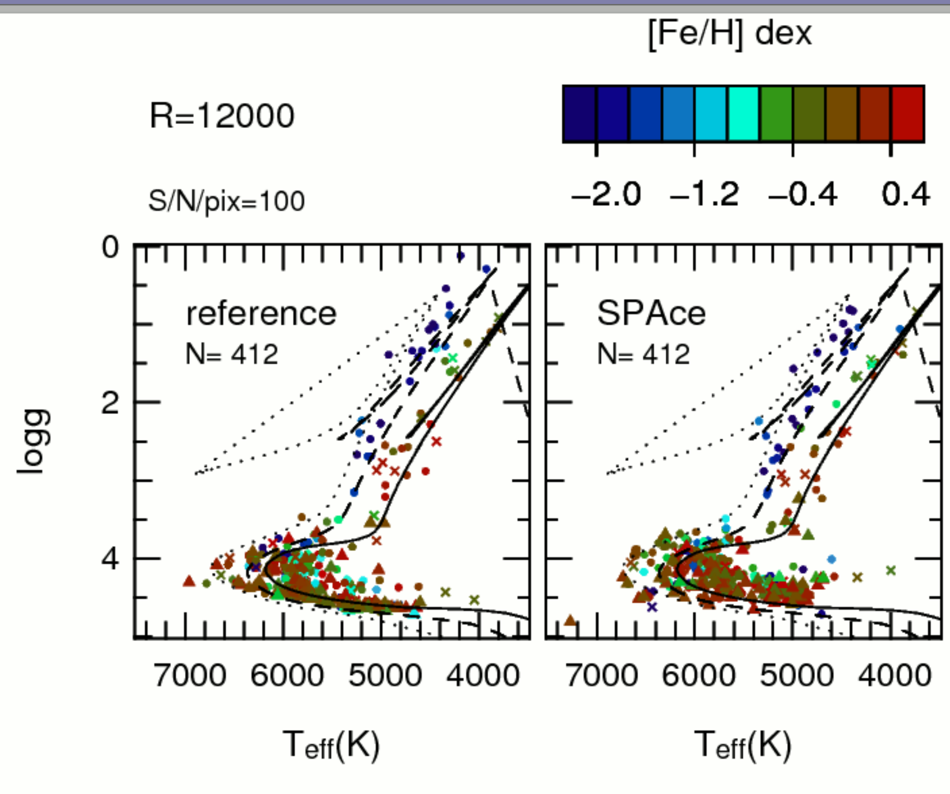
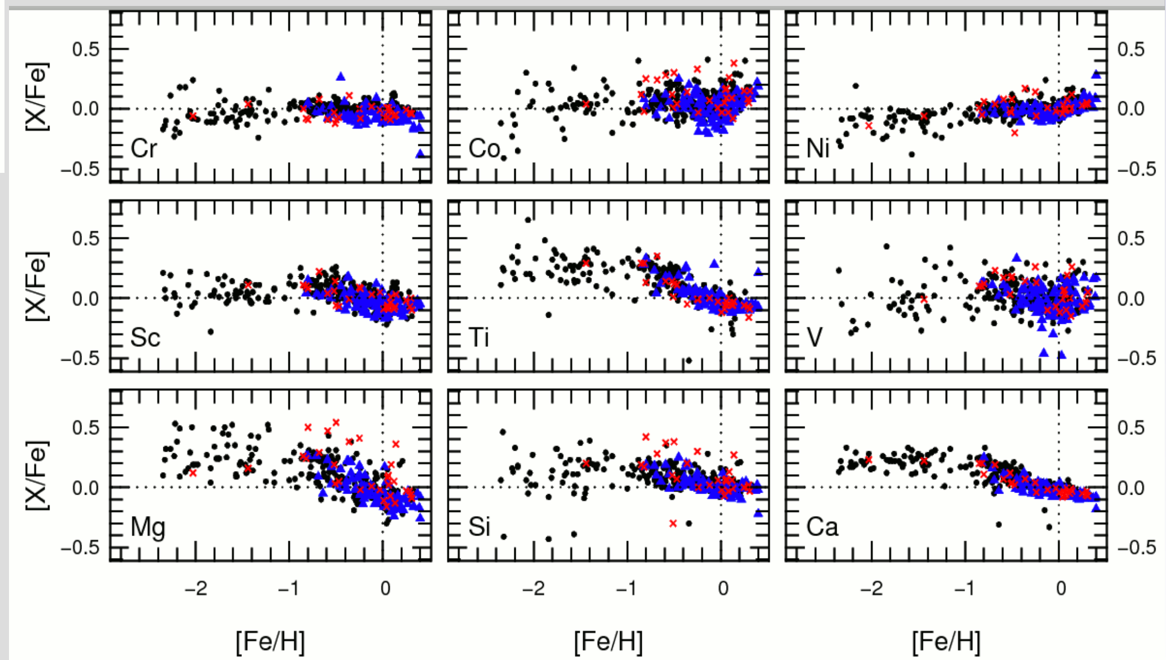
Tests on real spectra



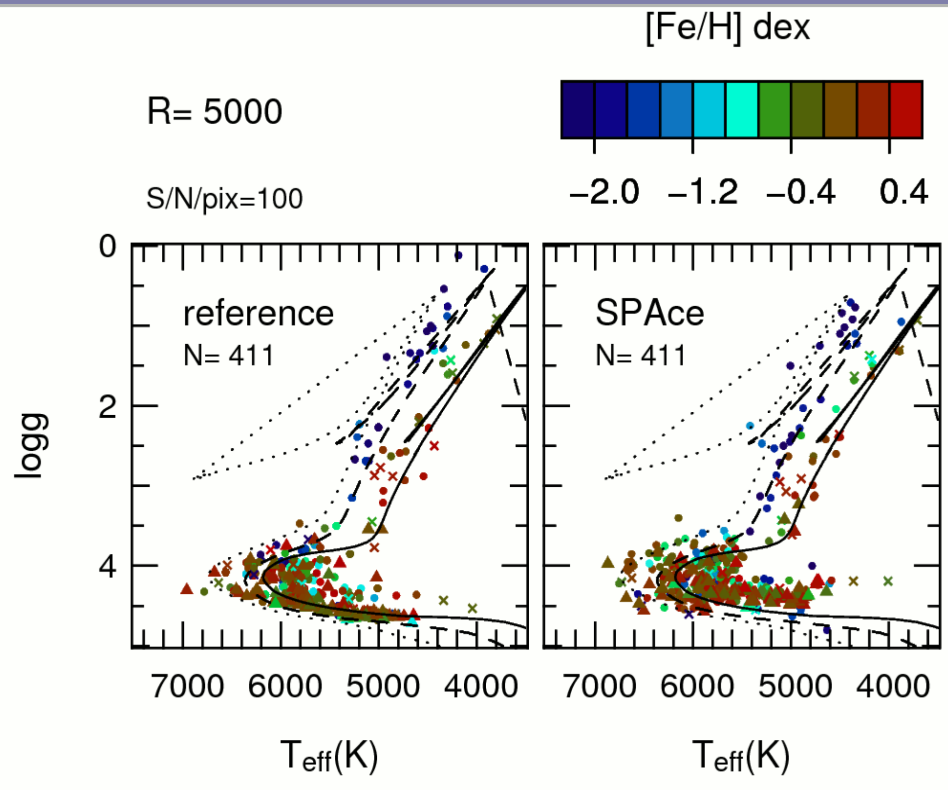
Wave=[5212-6270,6310-6860]Å

R=12,000
S/N=100



- ● S4N (Allende Prieto+, 2004)
- X Benchmark stars (Jofre'+, 2014)
- ● ELODIE spectra (Prugniel+, 2007)

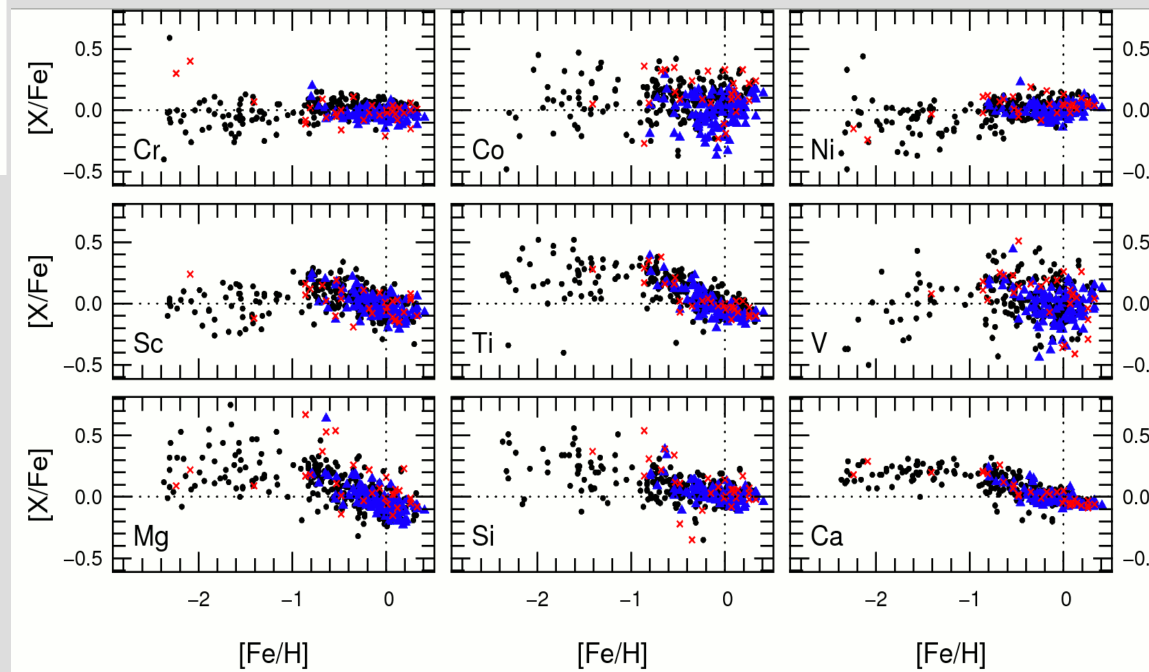
Tests on real spectra



Wave=[5212-6270,6310-6860]Å

R=5,000

S/N=100

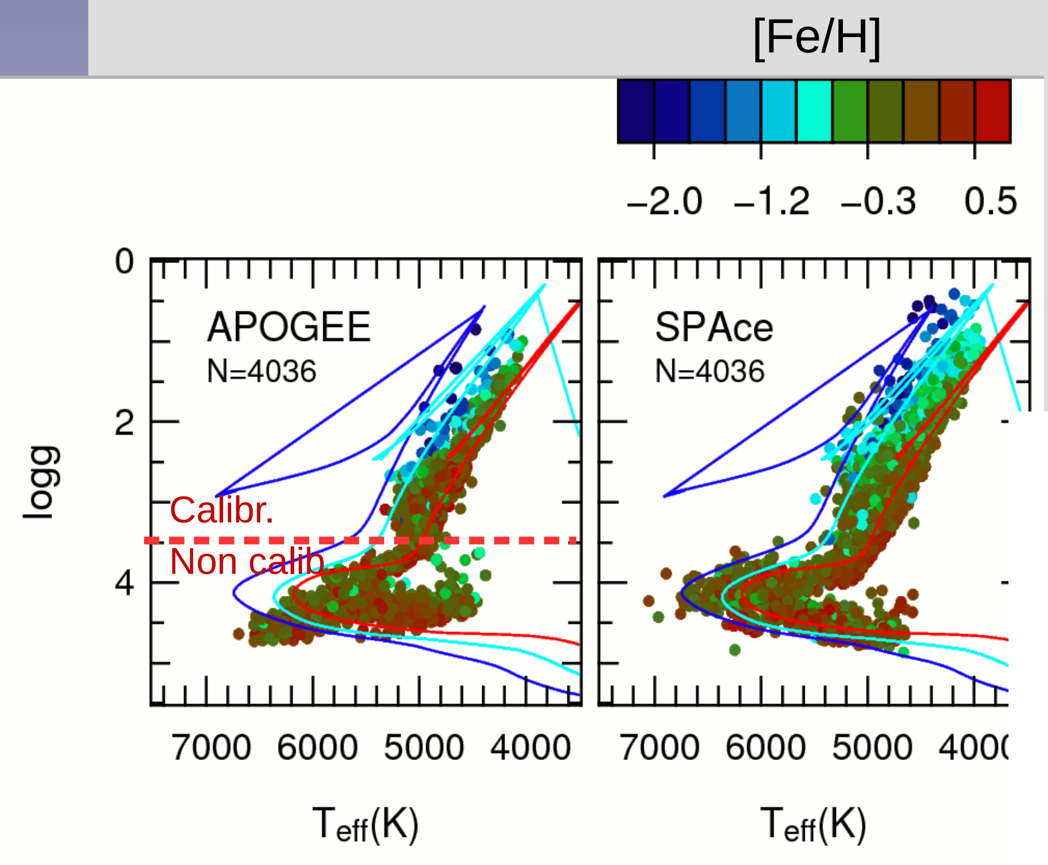


- S4N (Allende Prieto+, 2004)
- Benchmark stars (Jofre'+, 2014)
- ELODIE spectra (Prugniel+, 2007)

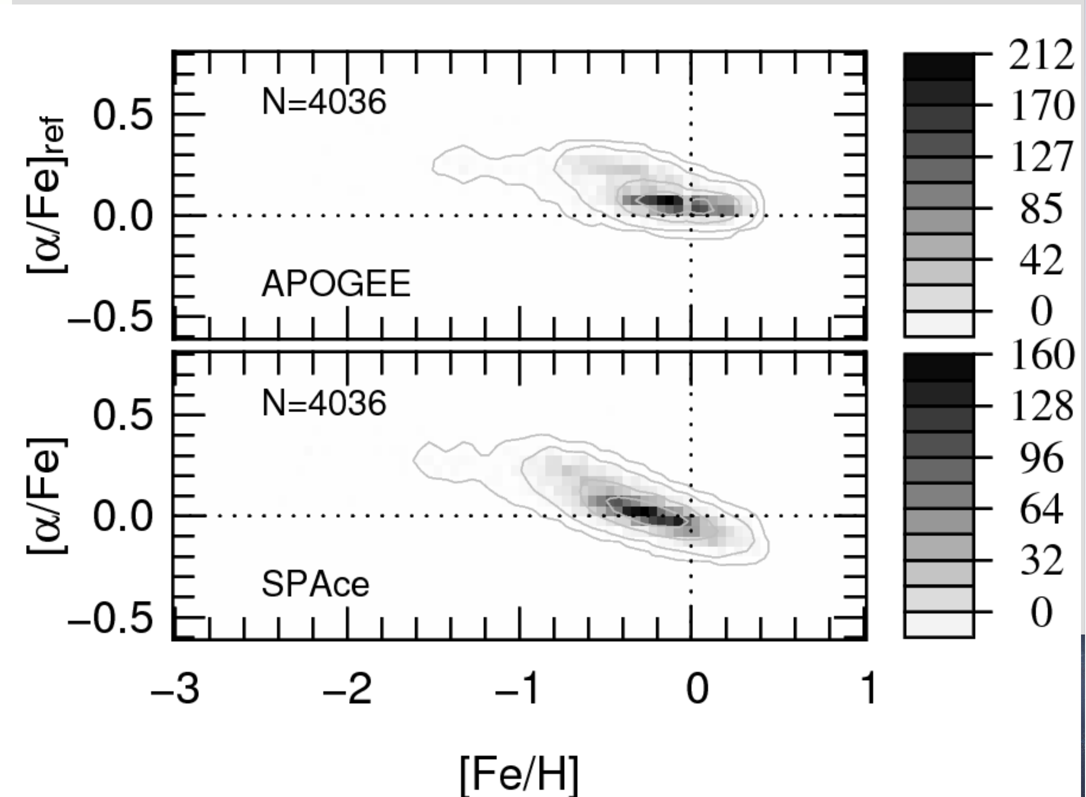
Corrado Boeche

Tests on LAMOST spectra

(with M. Smith and J. Hou from Shanghai Astr. Obs.)



LAMOST spectra
R=1800, S/N>100
Wave=[5212-5700, 5900-6270, 6310-6860]Å



Isochrone 10Gyr, [M/H]=-2.0dex
Isochrone 10Gyr, [M/H]=-1.0dex
Isochrone 5Gyr, [M/H]= 0.0dex

Corrado Boeche

The code SP_Ace: features

• SP_Ace is highly automatized. No human supervision is needed during processing. Suitable for spectroscopic surveys.

• Possibility to constrain the Teff and/or log g values by the user

• SP_Ace estimates stochastic errors (but not systematic errors)

• Relatively fast (few seconds to process one spectrum at R=2,000, up to ~40 seconds (with no error estimation) for R=20,000

• Possibility to extend the wavelength coverage (at present 5212-6860A and 8400-8920A)

• Extension to NLTE and/or 3D atmosphere models possible

•The code will be publicly available soon

SP_Ace front end web page
http://dc.g-vo.org/SP_ACE

Webpage by Markus Demleitner and Hendrik Heinl at ARI Heidelberg

dc.g-vo.org/SP_ACE

SP_ACE spectral analysis tool

SP_ACE computes stellar parameters (gravity, temperature) and element abundances from optical stellar spectra (sample spectrum). It employs 1D stellar atmosphere models in Local Thermodynamic Equilibrium (LTE).

Spectrum: Browse... No file selected.
ASCII file with two columns: wavelength (in Angstrom) and continuum normalized flux. The spectrum must be radial velocity corrected (wavelengths in rest frame). The spectral resolution power should be between 2000 and 20000. SP_Ace handles spectra in the stellar parameters intevals Teff=[3600,7400]K, logg=[0.2,5.0], [M/H]=[-2.4,0.4]dex.

Instr. FWHM [Angstrom]: 0.4
Starting value for estimation of FWHM of the instrument line profile.

Wave intervals: 5212 6860
Give up to five wavelength intervals you want to analyze, starting from the lowest. Intervals not covered by the library will be ignored. The defaultqsetting is the range of wavelenghts currently processed by the software.

Fixed Teff [K]:
Force solver to assume this temperature. Leave empty to let SP_Ace estimate this parameter.

Fixed gravity:
Force solver to assume this gravity. Leave empty to let SP_Ace estimate this parameter.

Compute Errors? ☑
Make SP_Ace estimate errors (this increases runtime significantly).

Output format: HTML

Go

Help | Service info

Metadata

Identifier: ivo://org.gavo.dc/sp_ace/q

Description: SP_ACE computes stellar

Keywords

Creator: Boeche, C.; Demleitner, M.

Created: 2014-07-23T12:00:00Z

Data updated: 2015-04-20

Reference URL: Service info

Try ADQL to query our data.

Please report errors and problems to the site operators. Thanks.

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Log in

ArXiv 1512.01546

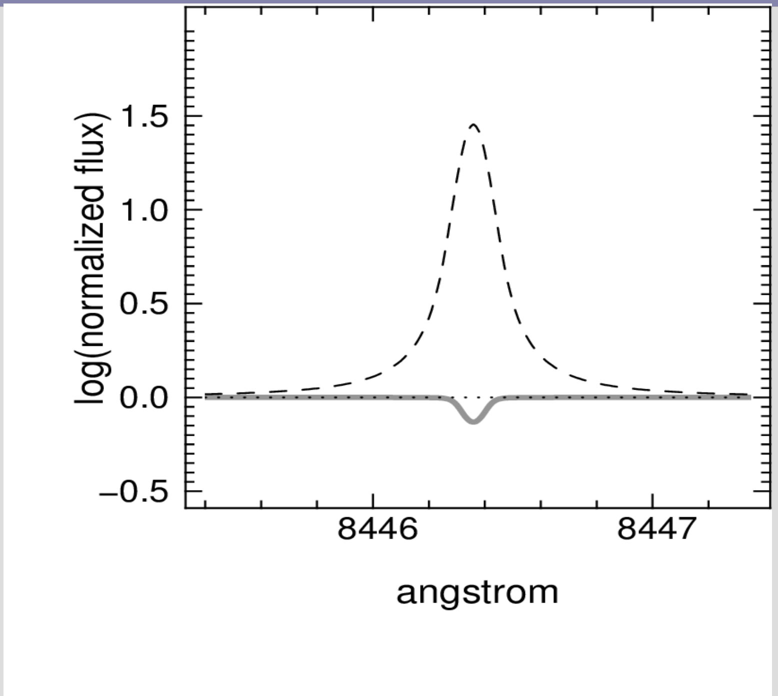
2b) Correction for the opacity of the neighbor lines

If the opacity of the neighbor lines is neglected in a blend (i.e. the EWs of the lines are computed as isolated) then the total EW is underestimated

$$EW_{blend} < \sum EW_i^{iso}$$

We need corrected Ews so that

$$EW_{blend} = \sum EW_i^{c}$$



Can we find such corrected Ews?

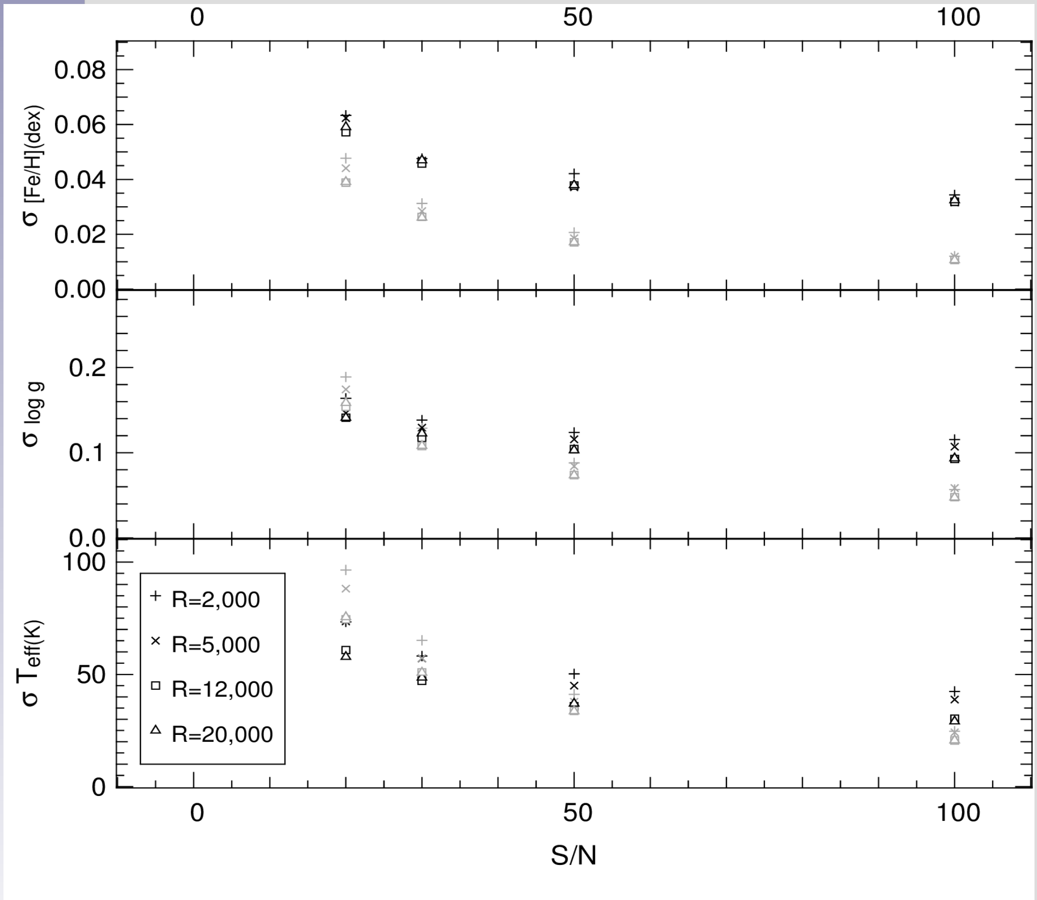
Good news: these corrected EW can be exactly computed
Bad news: we cannot use them!

Solution: approximation!

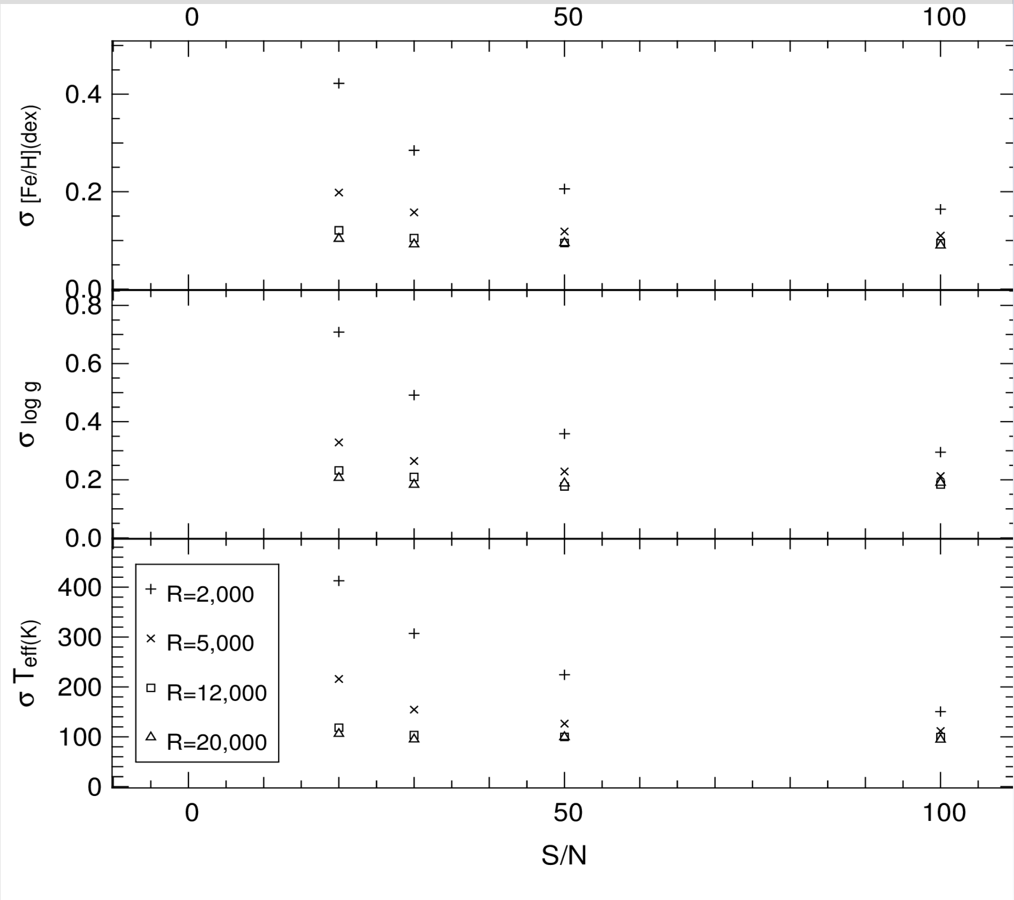
SFB 881

Expected uncertains

Estimated errors in synthetic spectra



Estimated errors in real spectra



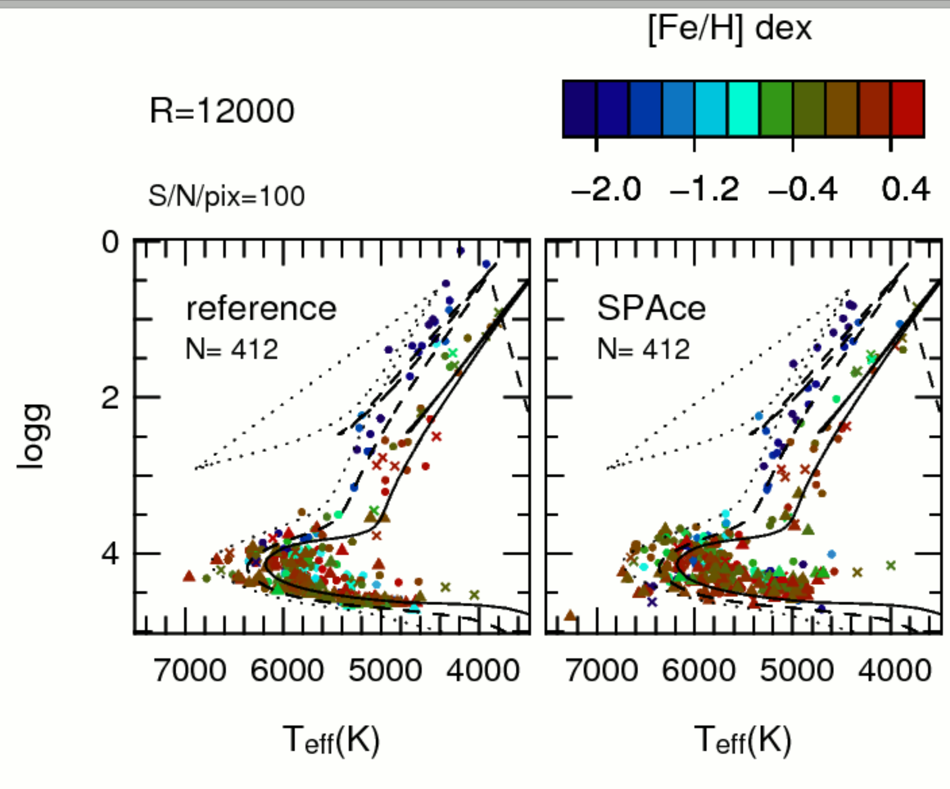
Corrado Boeche

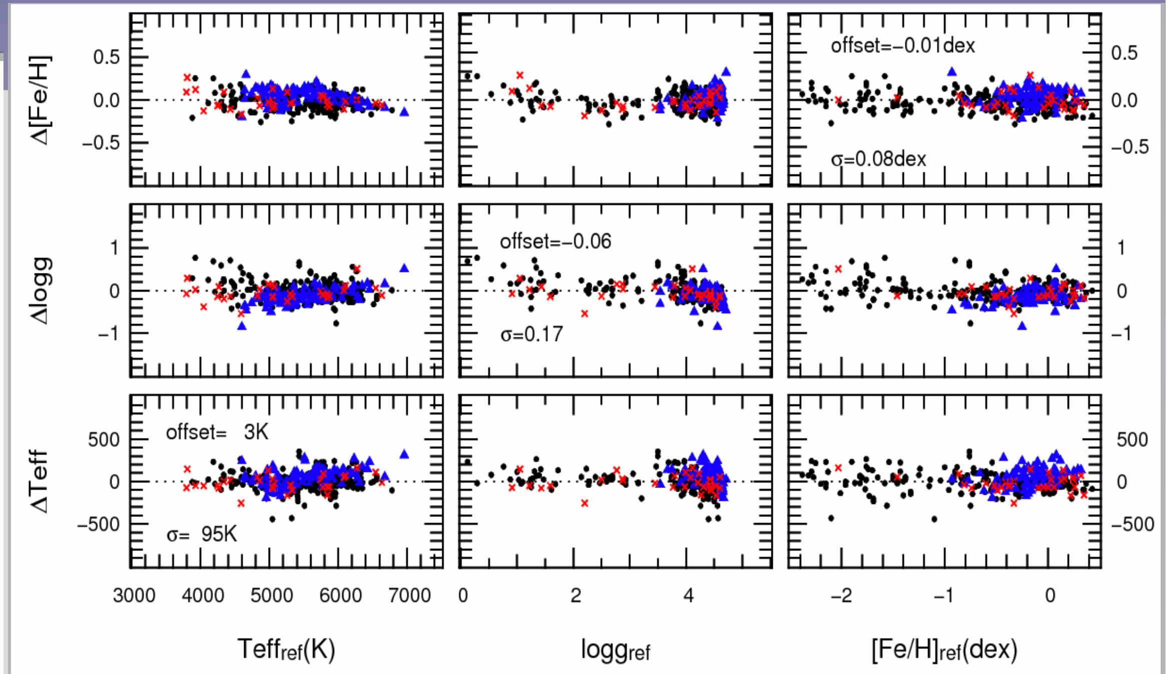
SFB 881

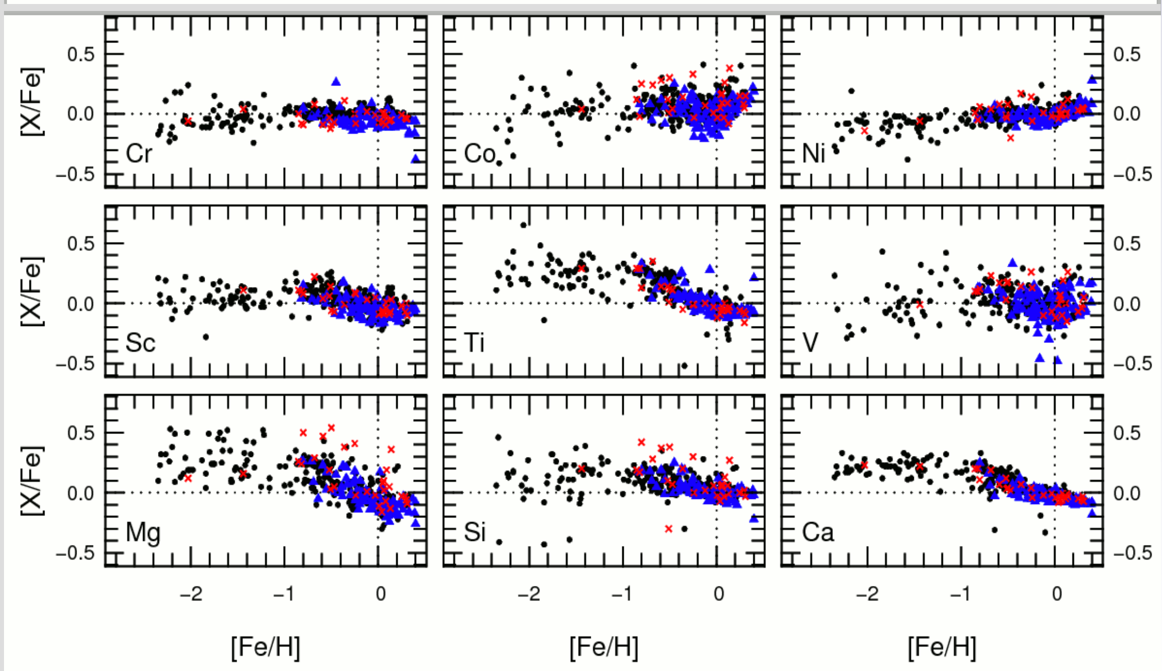
Tests on real spectra

Wave=[5212-6270,6310-6860]Å

R=12,000







● S4N (Allende Prieto+, 2004)

X Benchmark stars (Jofre'+, 2014)

● ELODIE spectra (Prugniel+, 2007)

Corrado Boeche

The code SP_Ace: the line profile

Voigt function $I(\lambda) = \int G(\lambda')L(\lambda - \lambda')\,d\lambda'$

Gaussian $G(\lambda) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left(\frac{-\lambda^2}{2\sigma^2}\right)$

Lorentzian $L(\lambda) = \frac{a_L}{1 + 4(\lambda/\gamma_L)^2}$

Implementation by McLean (1994)

$$I(\lambda) = \frac{\gamma_L}{\gamma_G} a_L \sqrt{\pi \ln(2)}\, V(X, Y)$$

$$a_L = \frac{EW}{(\gamma_L * 0.5 * \pi)}$$

The code SP_Ace: the line profile

Implementation by McLean (1994)

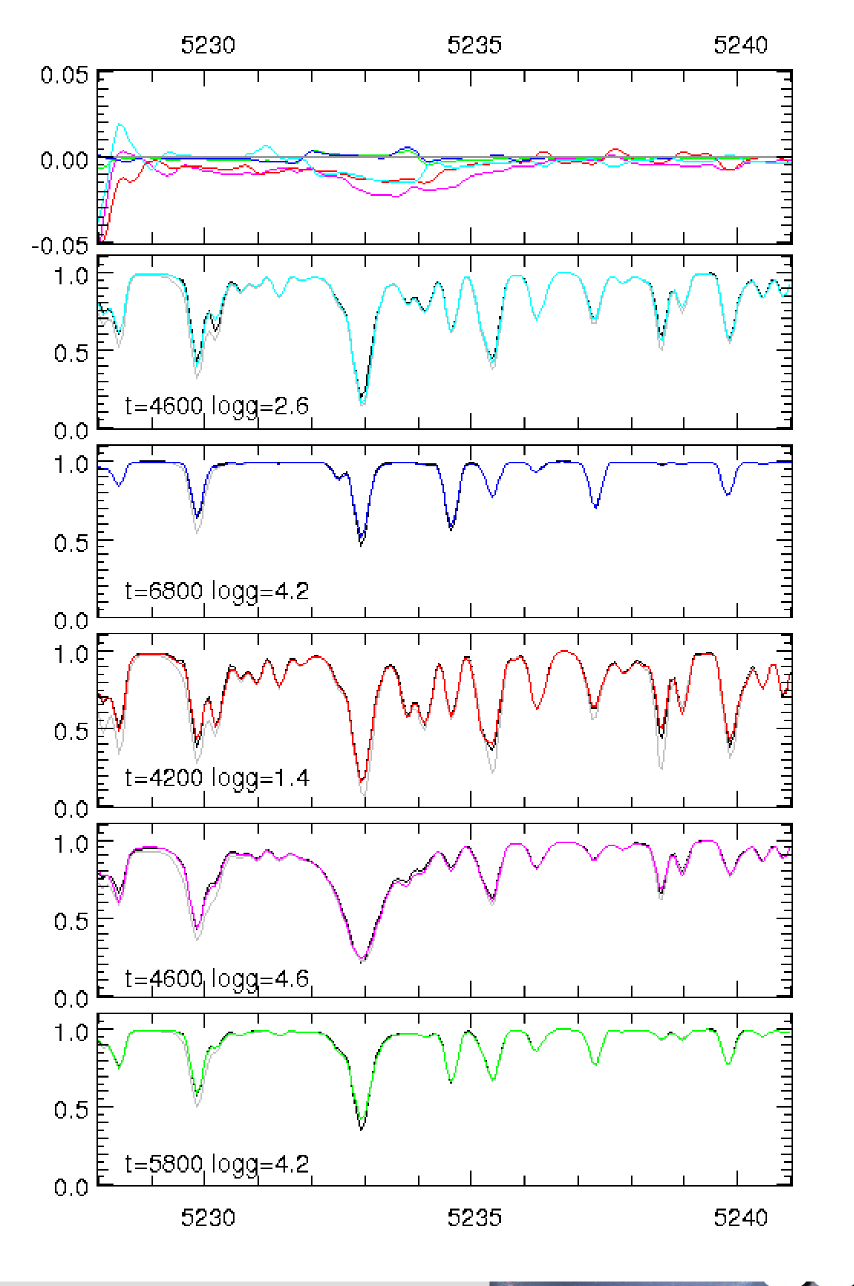
$$I(\lambda)=\frac{\gamma_L}{\gamma_G}a_L\sqrt{\pi\ln(2)}V(X,Y)$$

γ_G =instrumental FWHM

$$a_L=\frac{EW}{(\gamma_L*0.5*\pi)}$$

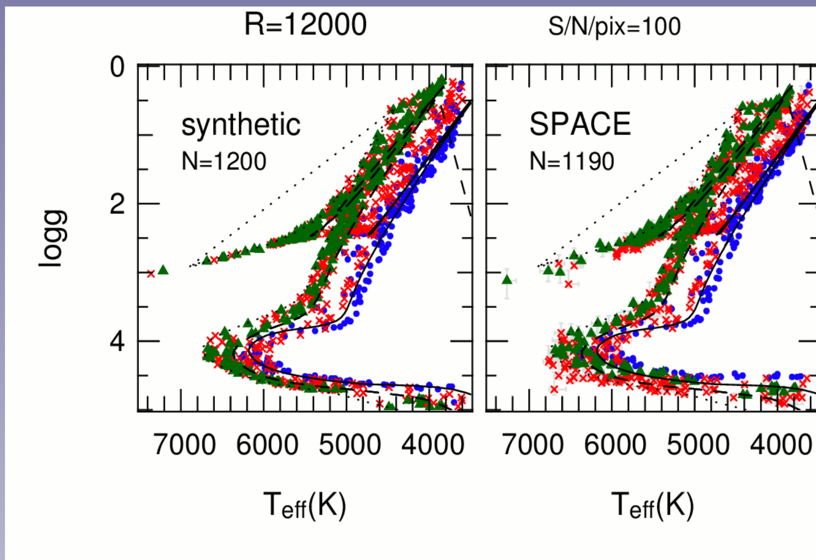
$$\gamma_L=dl\cdot EW\cdot dp\left(1-\exp\left(-\left[\frac{EW\cdot dp}{\sigma}\right]\right)^2\right)$$

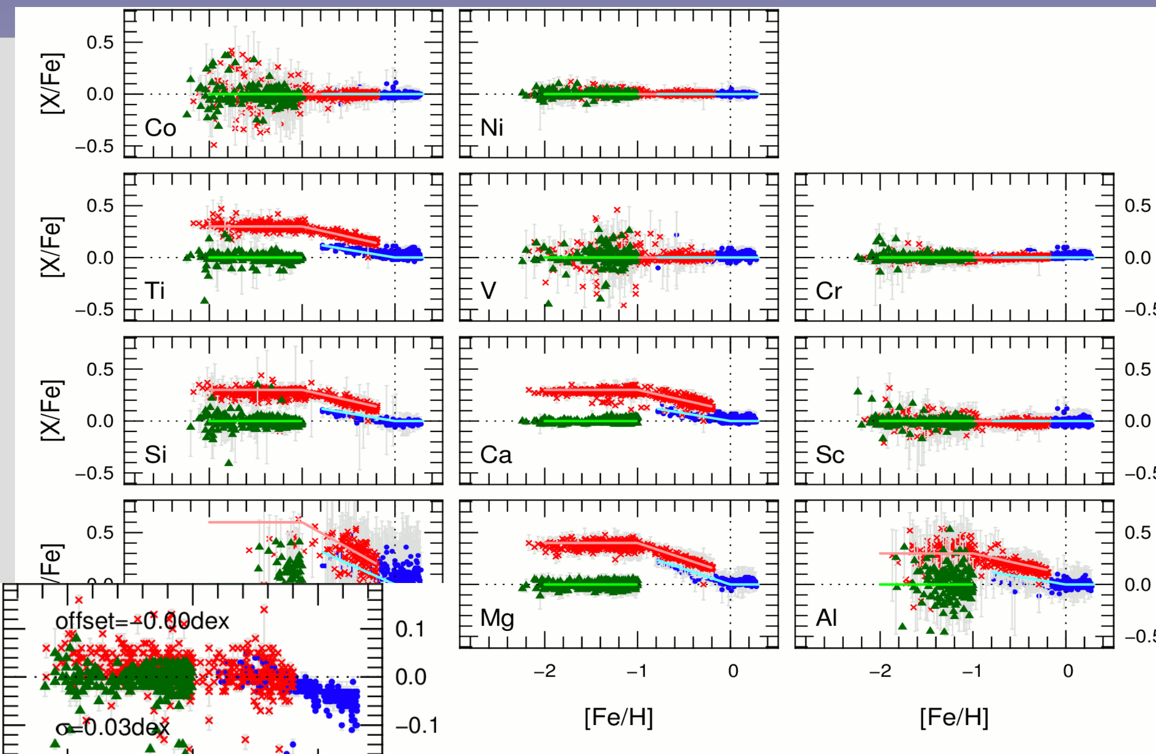
σ=0.14, dl=0.8	if log g>4.5
σ=0.16, dl=0.7+(log g-3.5)*0.1	if 3.5<log g<4.5
σ=0.20, dl=0.6+(log g-2.5)*0.1	if 2.5<log g<3.5
σ=0.20, dl=0.6	if 1.5<log g<2.5
σ=0.20, dl=0.6+(1.5-log g)*0.1	if log g<1.5

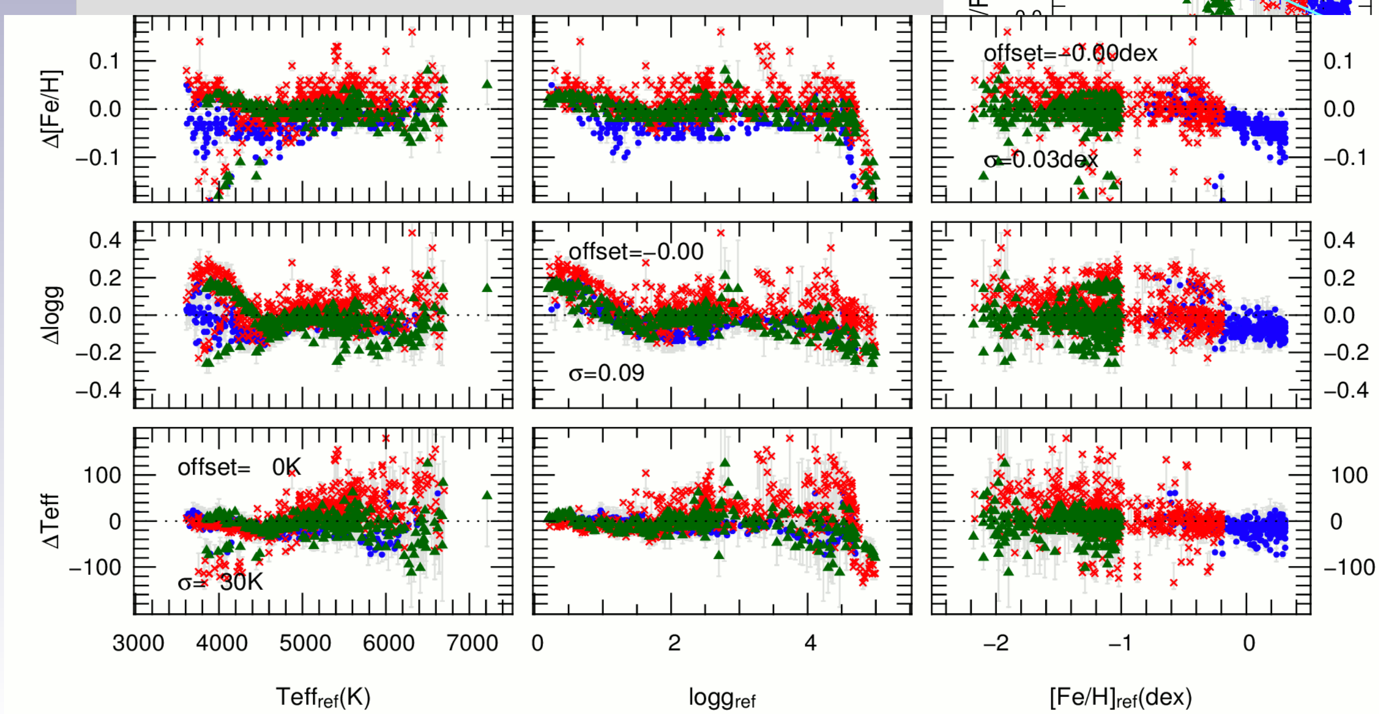


Synthetic spectra
Wave=[5212-6860]Å

R=12,000
S/N=100







● Mock Thin disk

X Mock Thick disk

▲ Halo/accreted

1) The line list: log gf calibration. comparison