Perspective in detailed element abundance determination

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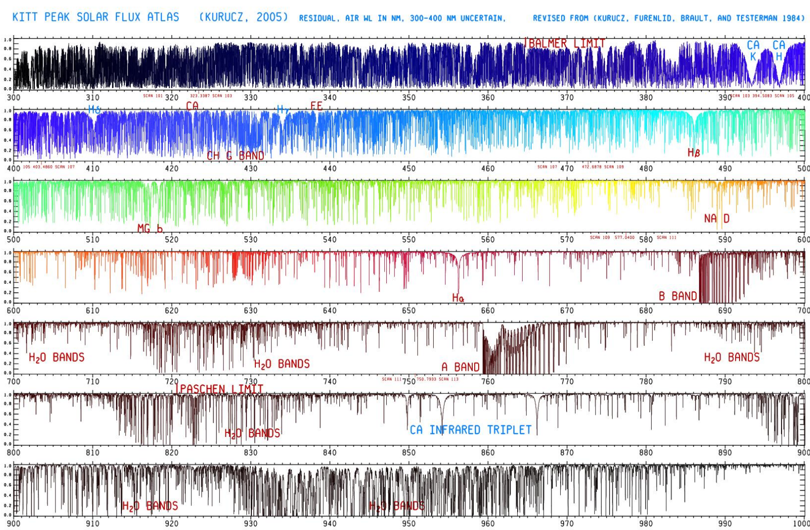
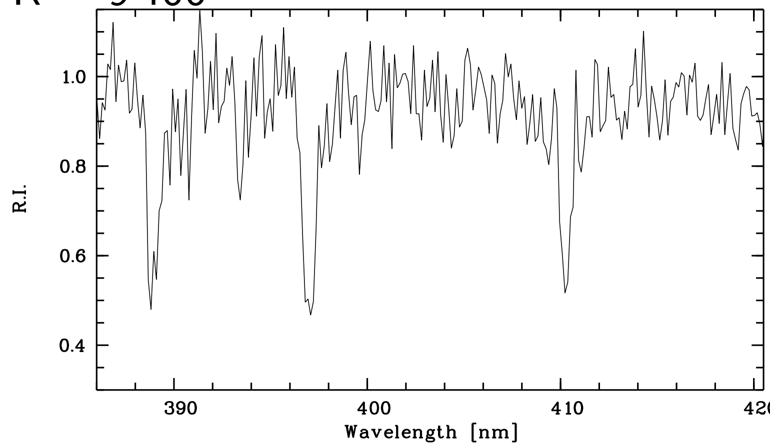
Informations from Stellar Spectra

- A number of stellar properties can be derived from spectra
  - radial velocity
  - $V_{\sin i}$
  - Teff
  - gravity
  - chemical composition (photosphere)

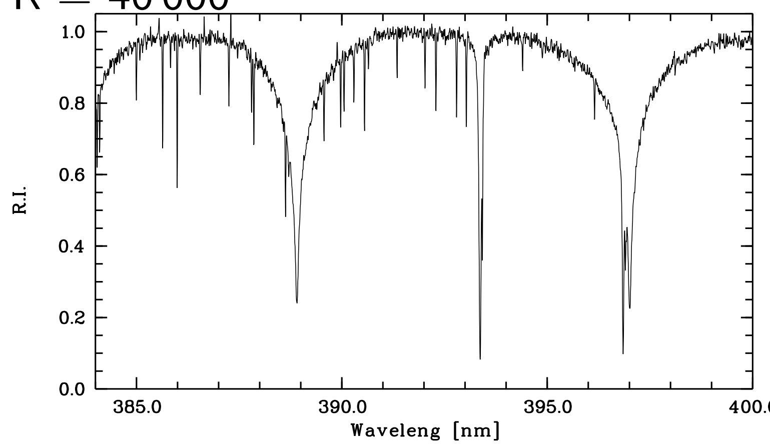


- Quality and extent of spectra influence their information content
  - spectral resolution R
  - signal-to-noise ratio
  - wavelength range

R = 9 400

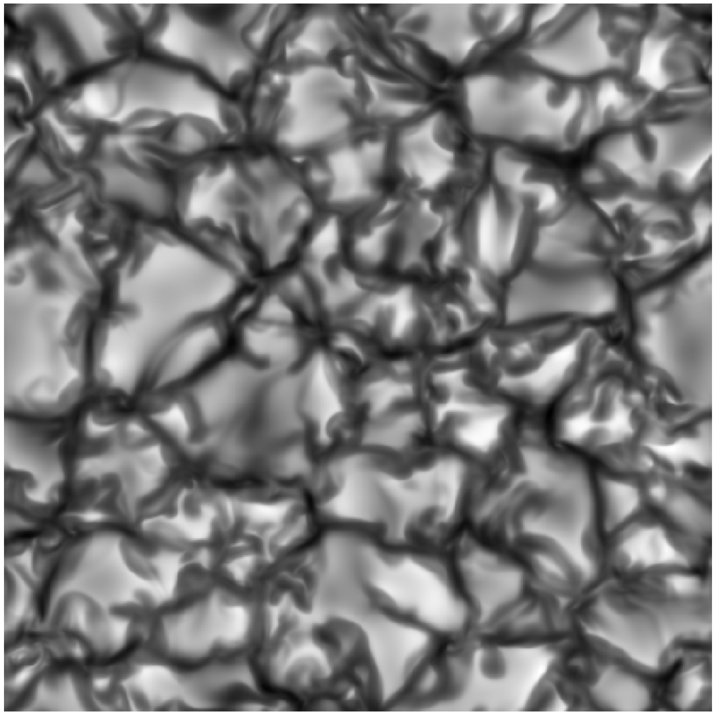


R = 40 000



Model atmospheres

- for the abundance determination a model of the stellar atmosphere is necessary
- model atmosphere: a representation of the physical state of the stellar atmosphere
- usually physical variable as a function of one geometrical variable 1D model
- new generation 3D models CO^5BOLD (by B. Freytag, M. Steffen, H.-G. Ludwig)



- CO^5BOLD models
  - physical variable as a function of time in a box of Cartesian geometry
  - a constant gravitational field
  - perfect compressible gas including H, He ionisation, H_2 molecular formation
  - some simplifications:
    - gas is a chemically homogeneous mixture
    - no magnetic field present
    - no rotation present

Model atmospheres

- for the chemical abundance determination of low resolution spectra (SDSS data) we considered ATLAS models

- For the chemical abundance determination of high resolution spectra we considered
  - 3D-CO^{5}BOLD models
  - temporal and horizontal average on surfaces of equal optical depth of 3D models ($\langle 3\mathrm{D} \rangle$ models)
  - $1\mathrm{D}_{\mathrm{LHD}}$ models that share the micro-physics with CO^{5}BOLD
  - ATLAS models
  - the Holweger-Müller model (for the Sun)

Usually with high resolution spectra (X-Shooter, UVES) we apply 3D corrections to 1D analysis.
With observed spectra of particularly good quality, high resolution, high signal-to-noice ratio spectra, the analysis is completly performed with 3D models

3D abundance corrections

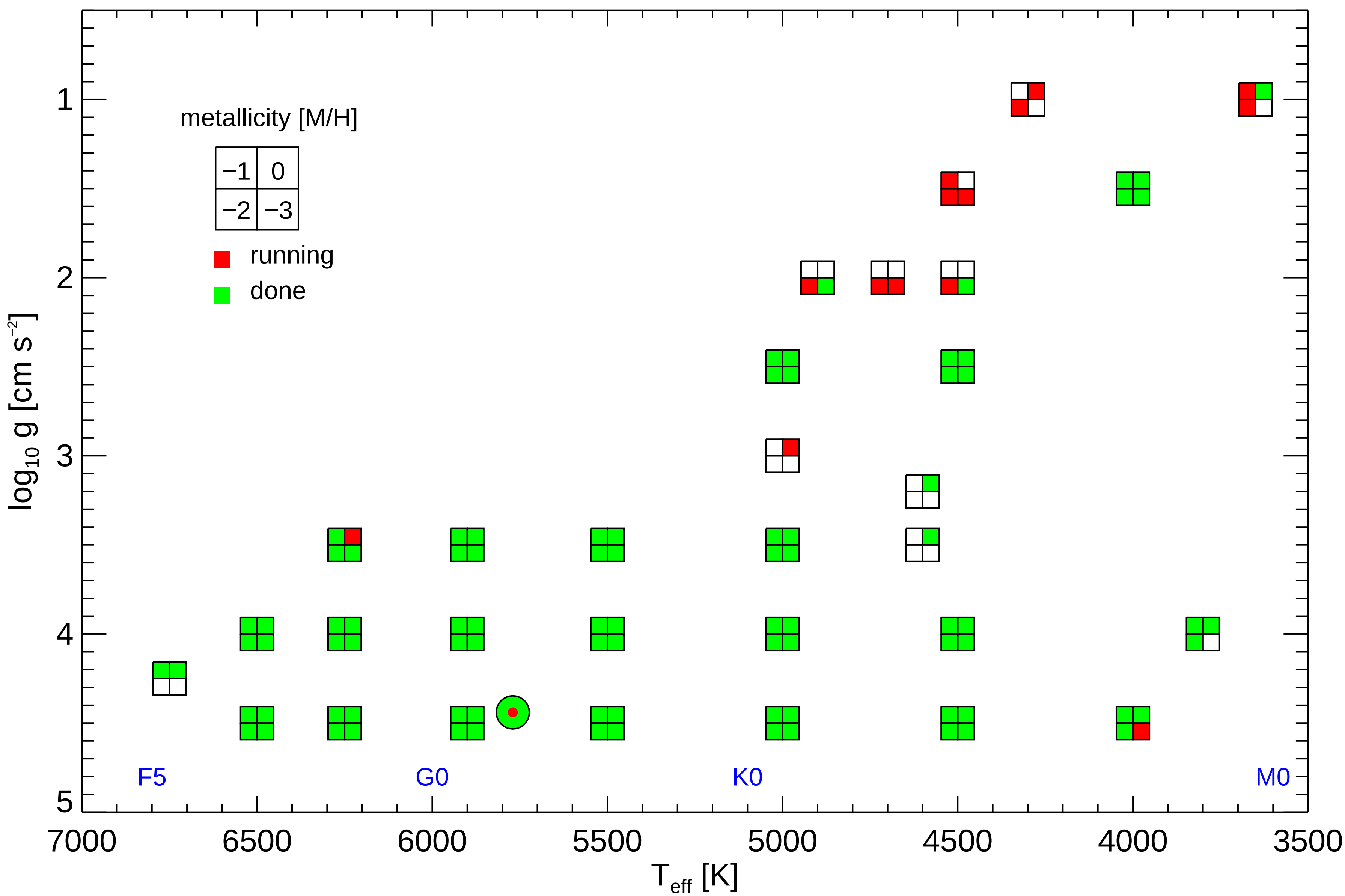
- 3D abundance corrections take into consideration hydro-effects on the abundance determination.

- The abundance of Y being A(Y)$=\log\frac{n_{\rm Y}}{n_{\rm H}}+12$
  - quantity related to the line strength:
    - a ratio of a quantity related to the line opacity $n_{\rm Y}$ over one related to the continuum opacity mainly due to H^{-} in the cool dwarfs.

- We define them as:
  - $\mathrm{A(Y)}_{\rm 3D}-\mathrm{A(Y)}_{\rm 1D_{LHD}}$
    takes into consideration the effects of convection on 3D temperature structure
  - $\mathrm{A(Y)}_{\rm 3D}-\mathrm{A(Y)}_{\langle\rm 3D\rangle}$
    takes into consideration effects of fluctuations around the mean stratification

Both are function of mictorutbulence and the first one of the mixing length parameter.

The CIFIST grid



Low resolution stellar spectra

- Only limited information, augmented by photometry, can be derived from R=2 000 resolution spectra

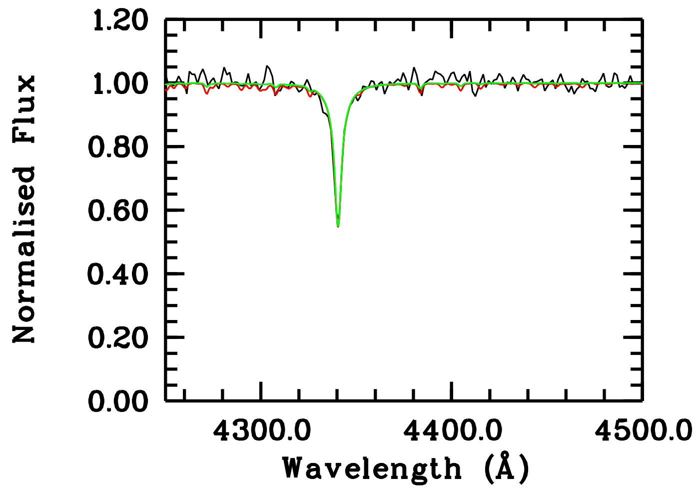
- Many such spectra are/will be available from several surveys

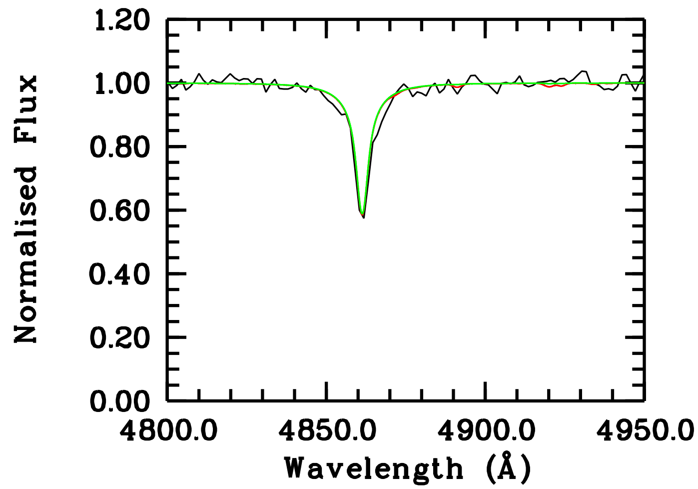
- Essential for searching for rare objects

- Extremely metal-poor stars can be extracted from low resolution surveys
  - Too many spectra to be analysed in traditional way
  - Developed automatic code to exploit Sloan Digital Sky Survey (SDSS) (Bonifacio & Caffau 2003)
  - Analysed 125 000 spectra selected as
    - objects classified as stars with photometric and spectroscopic data
    - selection in dereddened colour: $0.18 < g - z < 0.7$
    - translates into 5500 K$<$ $\mathrm{T_{eff}}$ $<$6600 K
    - $u - g > 0.70$ to exclude majority of White Dwarfs and horizontal branch stars
    - objects in large majority Turn-Off stars $\Longrightarrow$ we assume log g=4.0 when determining metallicity

SDSS: final selection by visual inspection

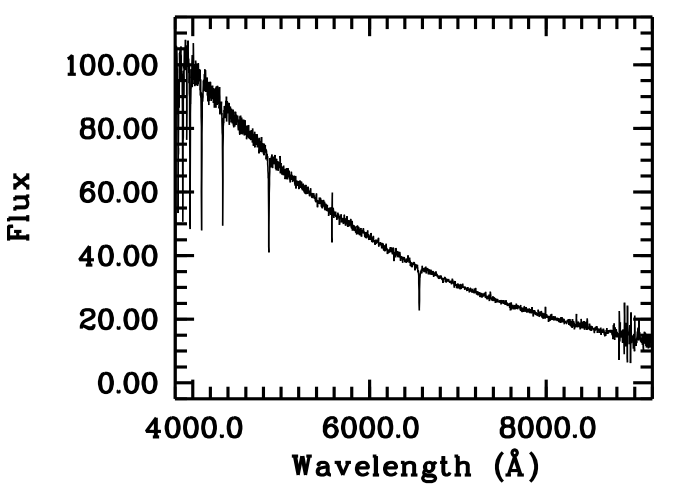
Observed spectrum (solid black) compared to two synthetic spectra (solid red and green) with temperature within 100 K of the temperature derived from $g - z$ colour, and metallicities enclosing the value assigned to the observed spectrum.

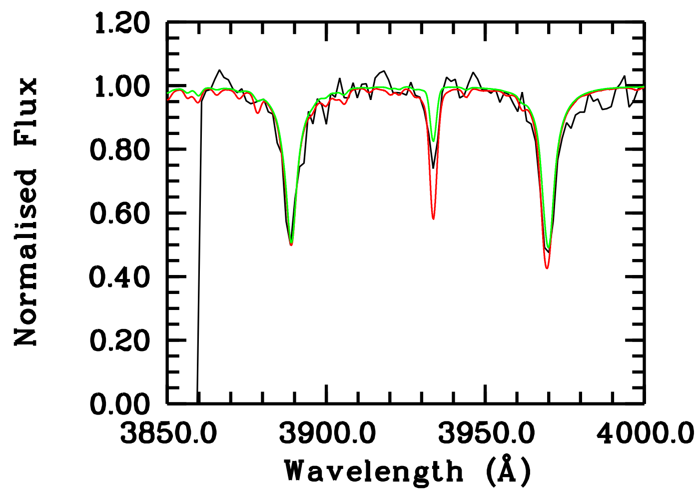




H-γ and G-band

H-β

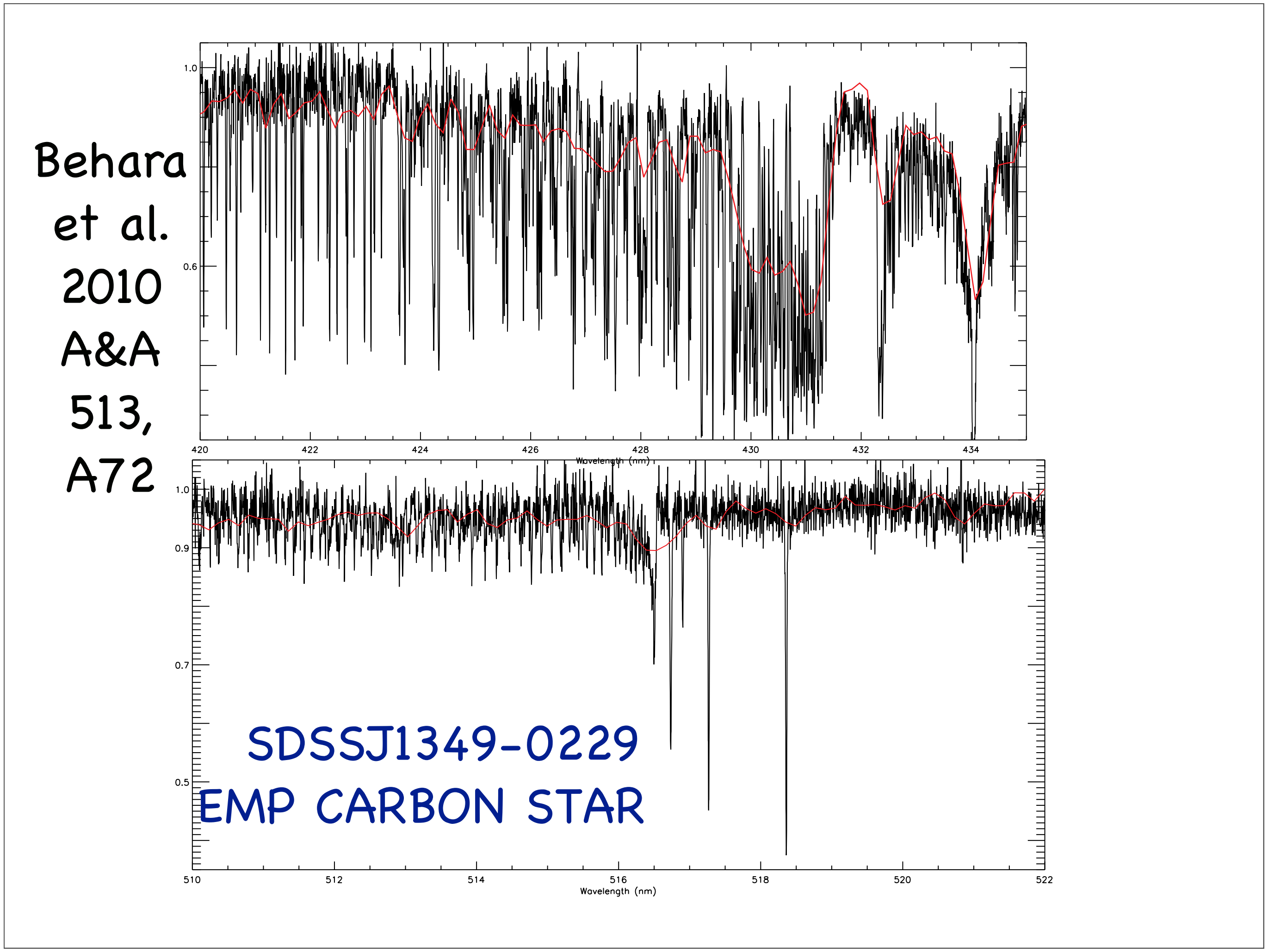




Complete spectrum

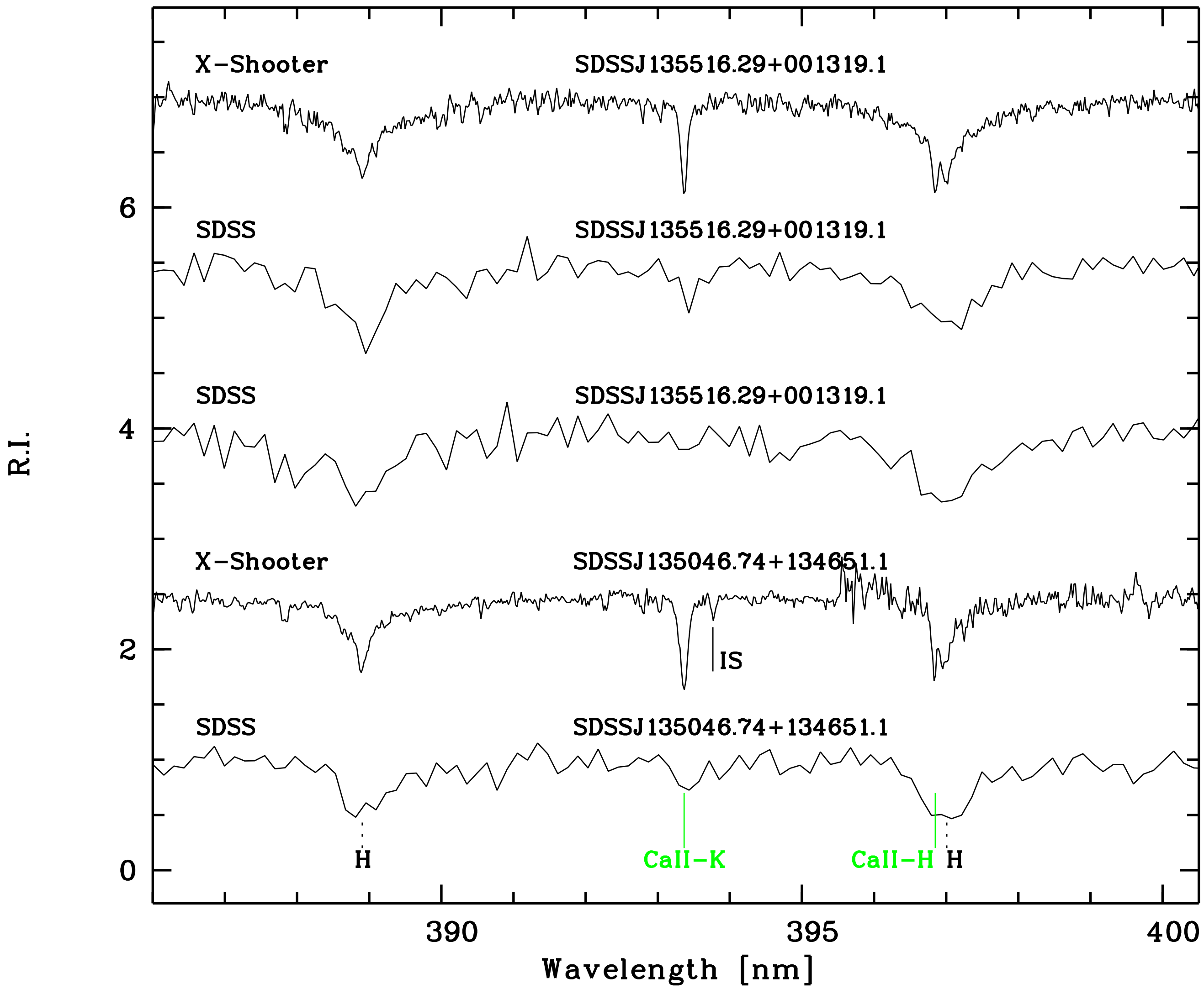
Ca H and Ca K

Carbon enhanced extremely metal-poor star selected from SDSS and observed with UVES at VLT



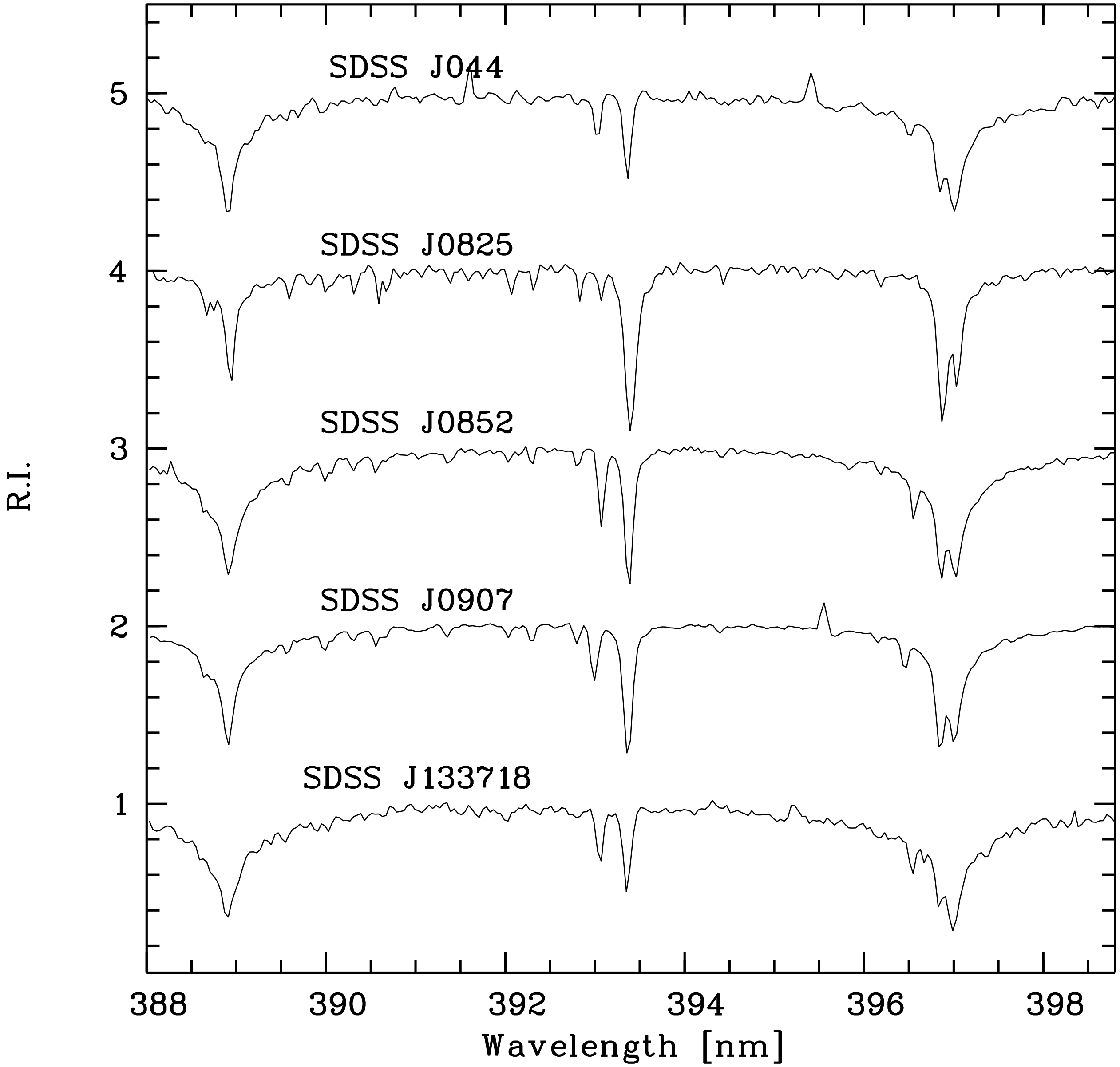
- large radial-velocity variation ($\approx 30 \mathrm{km\,s^{-1}}$) indicating it is a member of a binary system
- strong C enhancement
- from three abundance indicators (CH, C2, CI) not consistent results, either in 1D or in 3D analysis

Metal-poor star selected from SDSS and observed with X-Shooter at VLT - June 2010



- SDSS J135516
  - $g = 18.97$
  - distance 9.1 Kpc
- SDSS J135046
  - $g = 18.29$
  - distance 3.9 Kpc

Metal-poor star selected from SDSS and observed with X-Shooter at VLT - February 2011



$[Fe/H] = -3.71 \pm 0.27$

$[Fe/H] = -3.22 \pm 0.24$

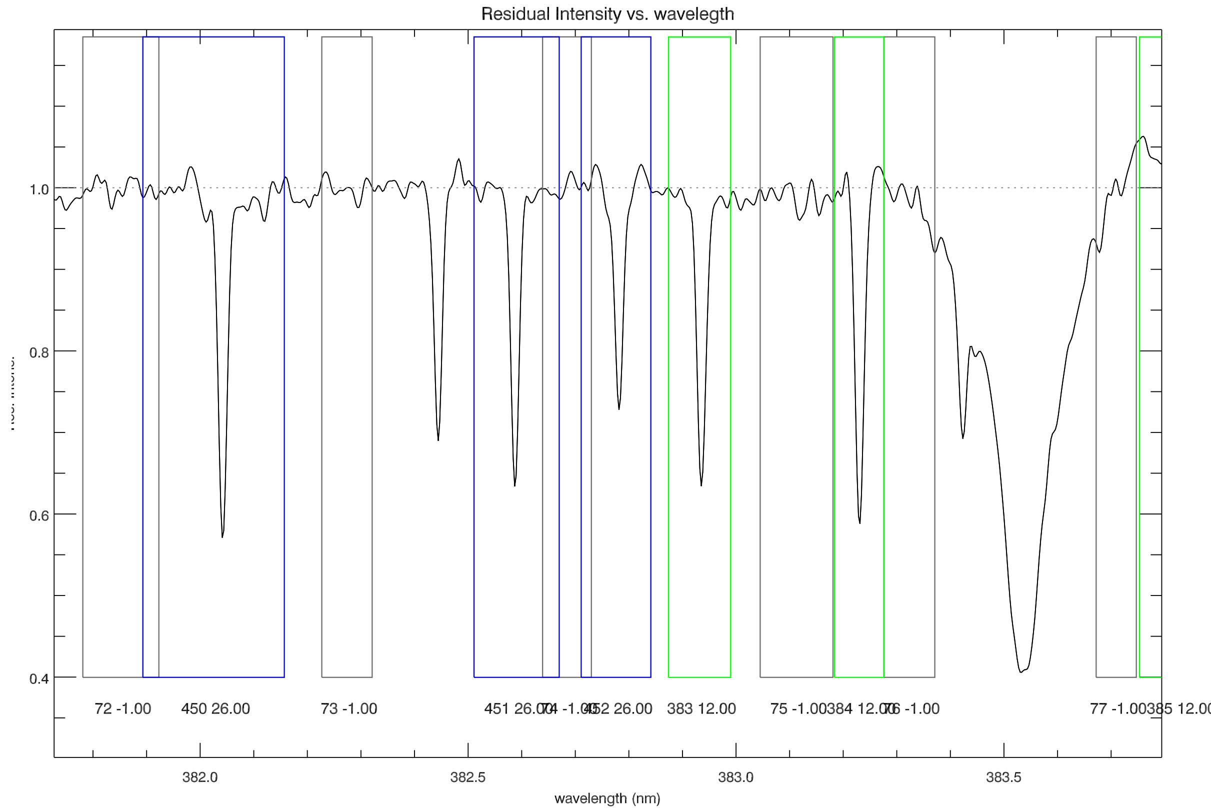
$[Fe/H] = -3.24 \pm 0.24$

$[Fe/H] = -3.52 \pm 0.14$

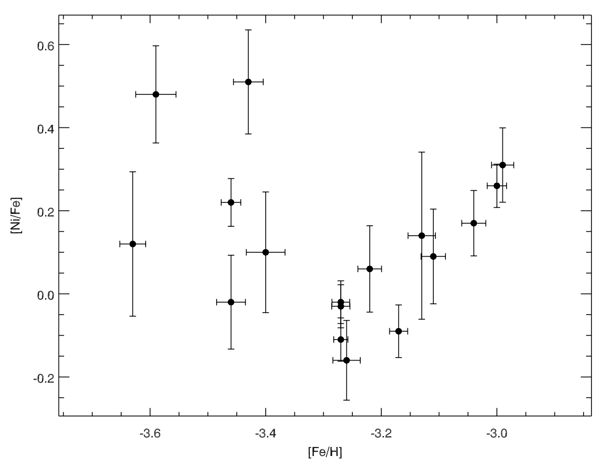
$[Fe/H] = -3.49 \pm 0.32$

Automatic analysis

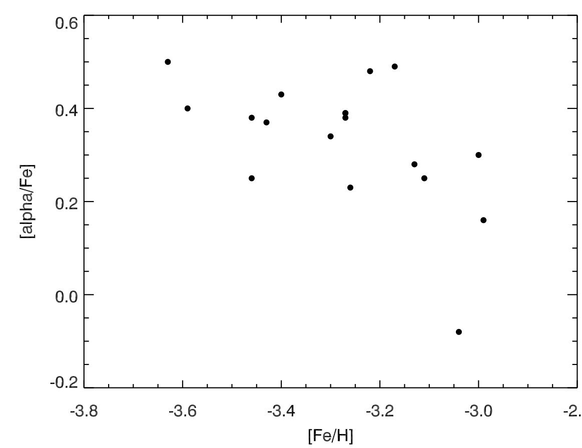
Sometimes also too many high resolution observed spectra



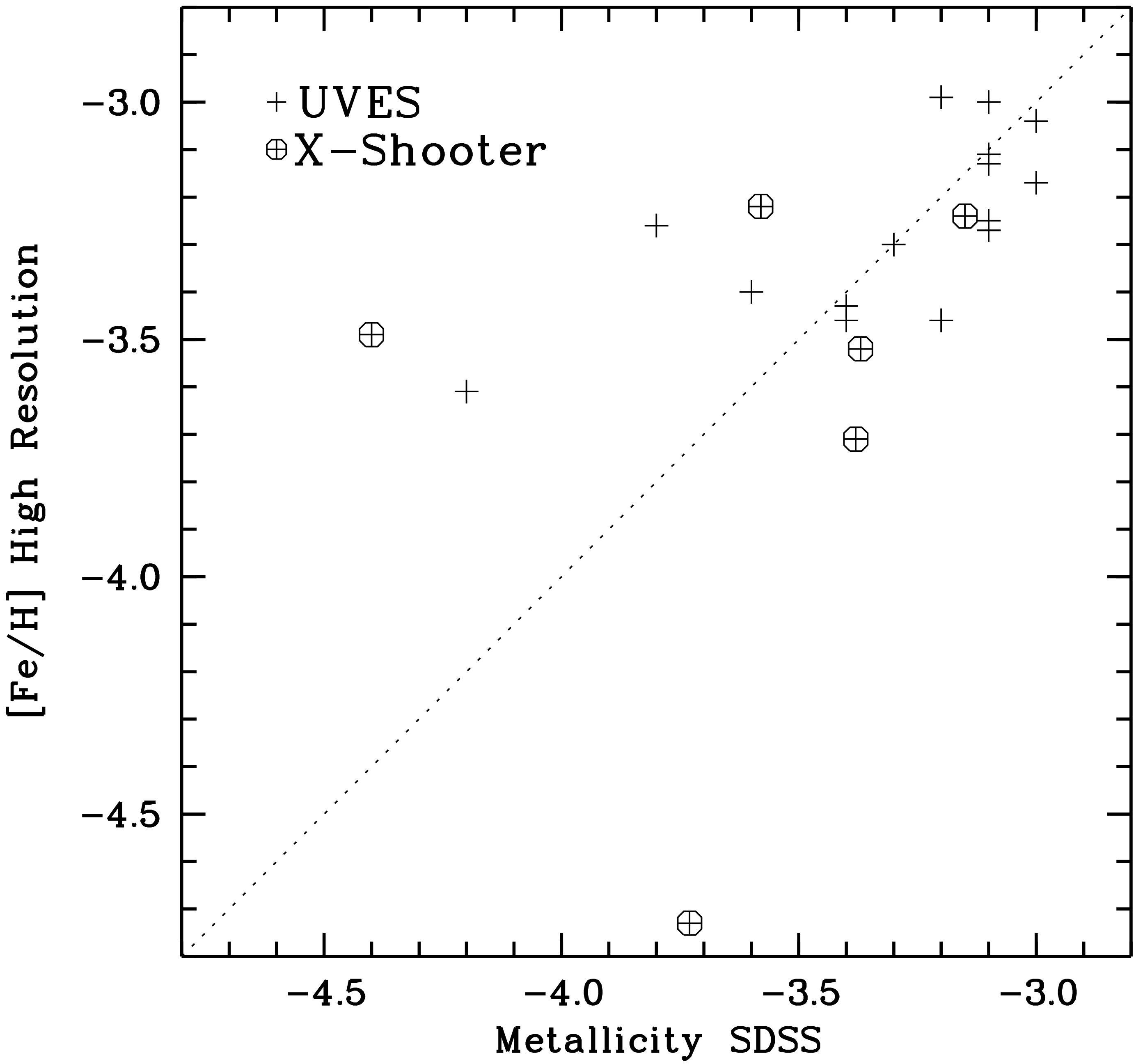
- MyGIsFOS
  - Designed to automate chemical analysis and parameter determination
  - Optimized for cool stars and high resolution (>15 000) spectra
  - Replicates "manual" analysis



16 stars in SDSS, observed with UVES, analysed with MyGIsFOS



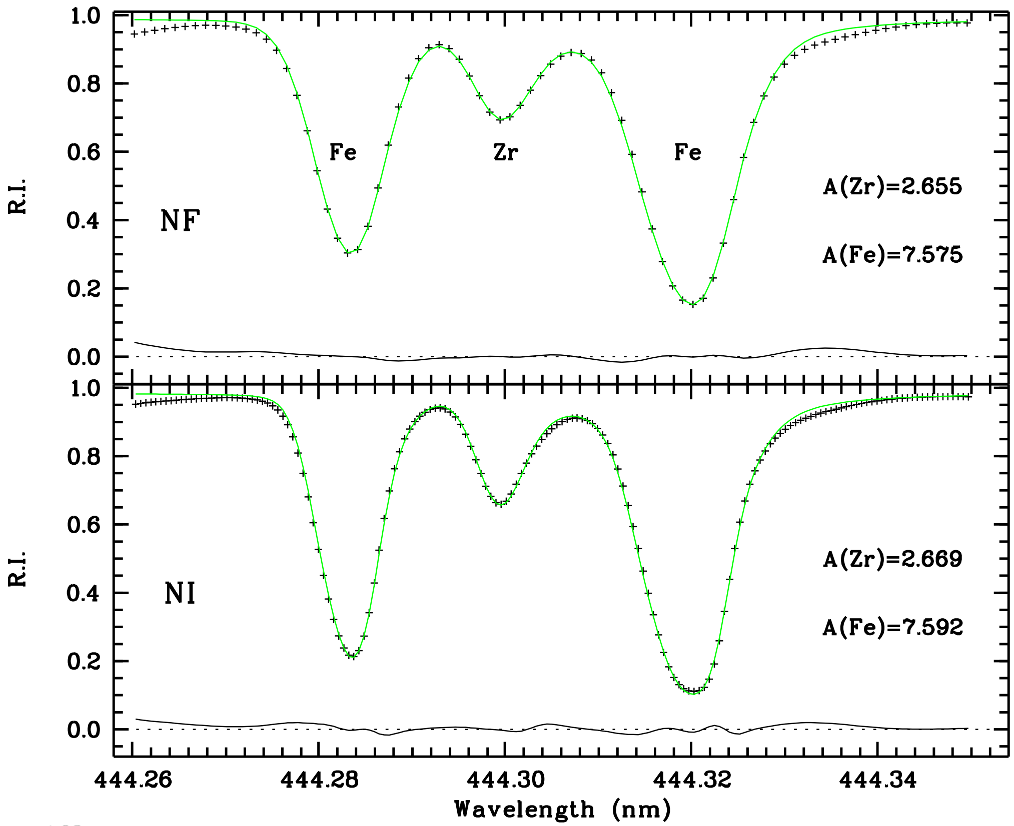
Comparison high-low resolution

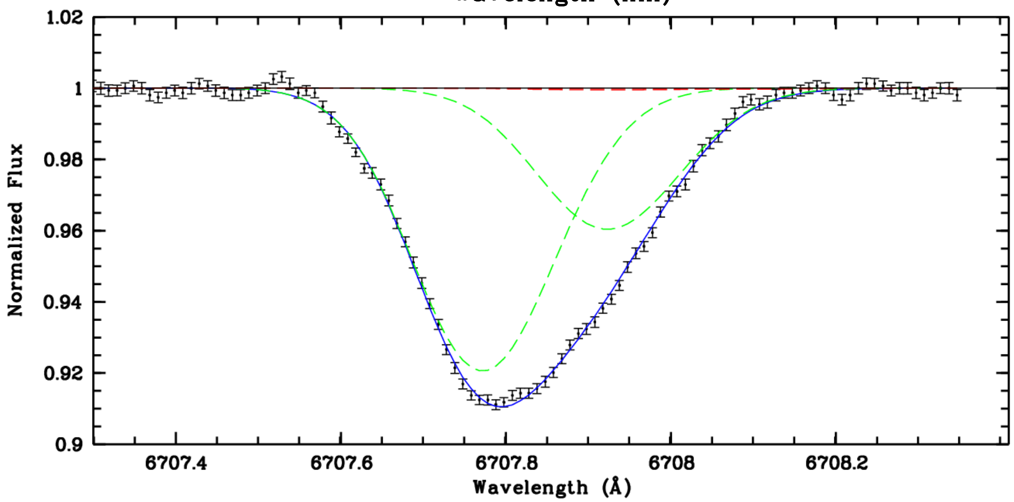


Automatic abundance analysis

- Good performance of the automatic abundance analysis
- Introduction of 3D-corrections after 1D analysis
- Future application
  - GAIA-ESO Survey
    - 300 nights in 4+1 years of FLAMES@VLT
    - 100000-300000 stars observed with Giraffe
    - about 10000 UVES spectra
  - as available GAIA observed spectra

High resolution stellar spectra

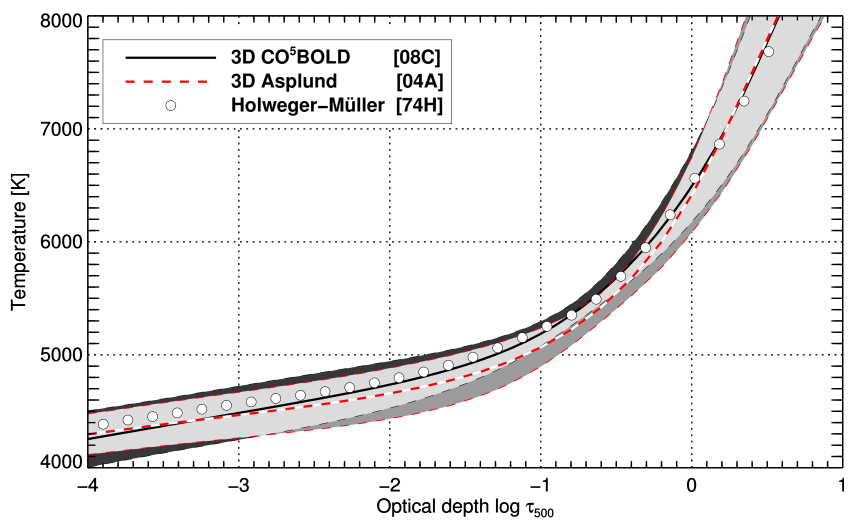




- In some cases sophisticated model atmospheres are necessary to model the shape of the line correctly
  - solar abundances
  - the asymmetry effect can simulate the existence of a ^{6}Li
  - metal-poor stars

Solar abundance

- Our analysis of the abundance of the solar photosphere trigerred
  - to know the detailed chemical composition of the solar photosphere to have a good reference
  - to test the models of the solar atmosphere
- Also interested in
  - The importance of 3D models in the abundances determination
  - If 3D models are responsible for the downward revision of the solar metallicity over the last six years



CO5BOLD solar abundances

Photospheric solar abundance of 13 elements

EL	N	CO^5BOLD	AG89	GS98	AGS05	AGSS09
Li	1	1.03 ± 0.03	1.16 ± 0.10	1.10 ± 0.10	1.05 ± 0.10	1.05 ± 0.10
C	43	8.50 ± 0.06	8.56 ± 0.04	8.52 ± 0.06	8.39 ± 0.05	8.43 ± 0.05
N	12	7.86 ± 0.12	8.05 ± 0.04	7.92 ± 0.06	7.78 ± 0.06	7.83 ± 0.05
O	10	8.76 ± 0.07	8.93 ± 0.035	8.83 ± 0.06	8.66 ± 0.05	8.69 ± 0.05
P	5	5.46 ± 0.04	5.45 ± 0.04	5.45 ± 0.04	5.36 ± 0.04	5.41 ± 0.03
S	9	7.16 ± 0.05	7.21 ± 0.06	7.33 ± 0.11	7.14 ± 0.05	7.12 ± 0.03
K	6	5.11 ± 0.09	5.12 ± 0.13	5.12 ± 0.13	5.08 ± 0.07	5.03 ± 0.09
Fe	15	7.52 ± 0.06	7.67 ± 0.03	7.50 ± 0.05	7.45 ± 0.05	7.50 ± 0.04
Zr	15	2.62 ± 0.06	2.60 ± 0.03	2.60 ± 0.02	2.59 ± 0.05	2.58 ± 0.04
Eu	5	0.52 ± 0.03	0.51 ± 0.08	0.51 ± 0.08	0.52 ± 0.06	0.52 ± 0.04
Hf	4	0.87 ± 0.04	0.88 ± 0.08	0.88 ± 0.08	0.88 ± 0.08	0.85 ± 0.04
Os	3	1.36 ± 0.19	1.45 ± 0.10	1.45 ± 0.10	1.45 ± 0.10	1.25 ± 0.07
Th	1	0.08 ± 0.03	0.12 ± 0.06	$\mathit{0.09 \pm 0.02}$	$\mathit{0.06 \pm 0.05}$	0.02 ± 0.10
Z		0.0154	0.0189	0.0171	0.0122	0.0134
Z/X		0.0211	0.0267	0.0234	0.0165	0.0183

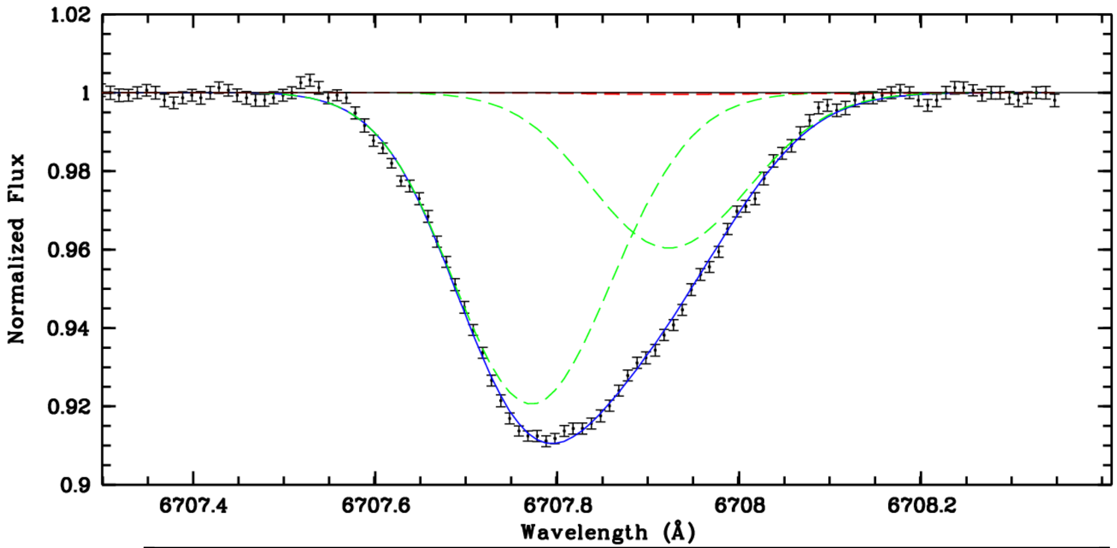
AG89 Anders & Grevesse Geochemica et Cosmochimica acta, 1989 Vol. 53

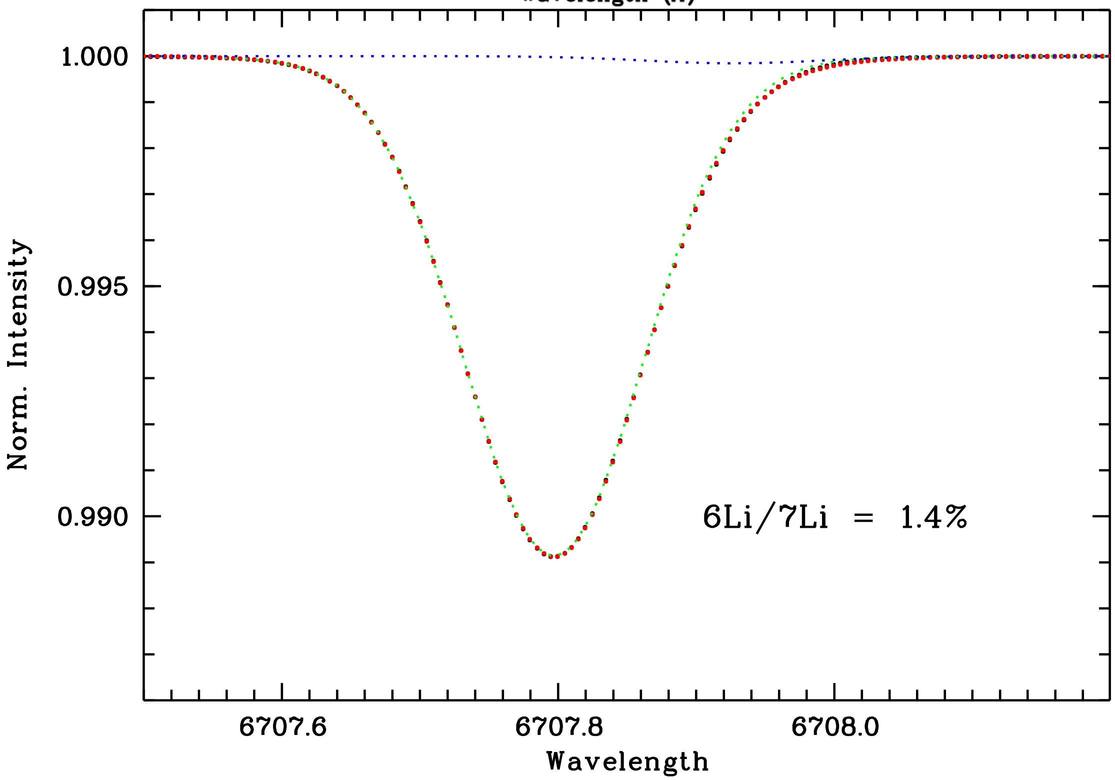
GS98: Grevesse et Sauval; Space Science Reviews 85: 161-174, 1998

AGS05: Asplund et al; ASP Conferences Series, Vol. 336, 2205

AGGS09: Asplund, Grevesse, Sauval, & Scott, ARA&A 2009

Line asymmetry

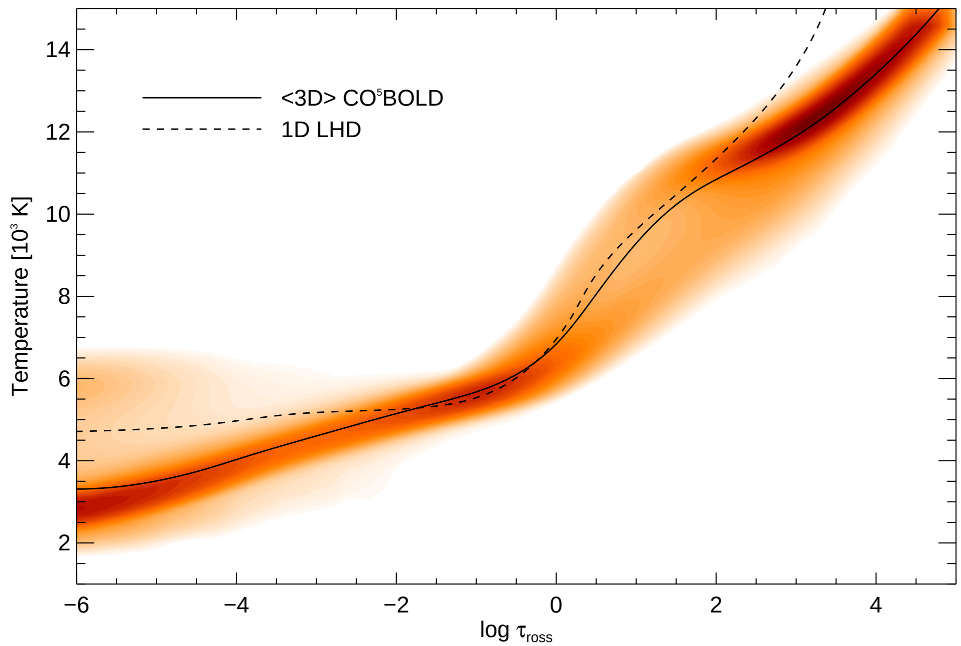




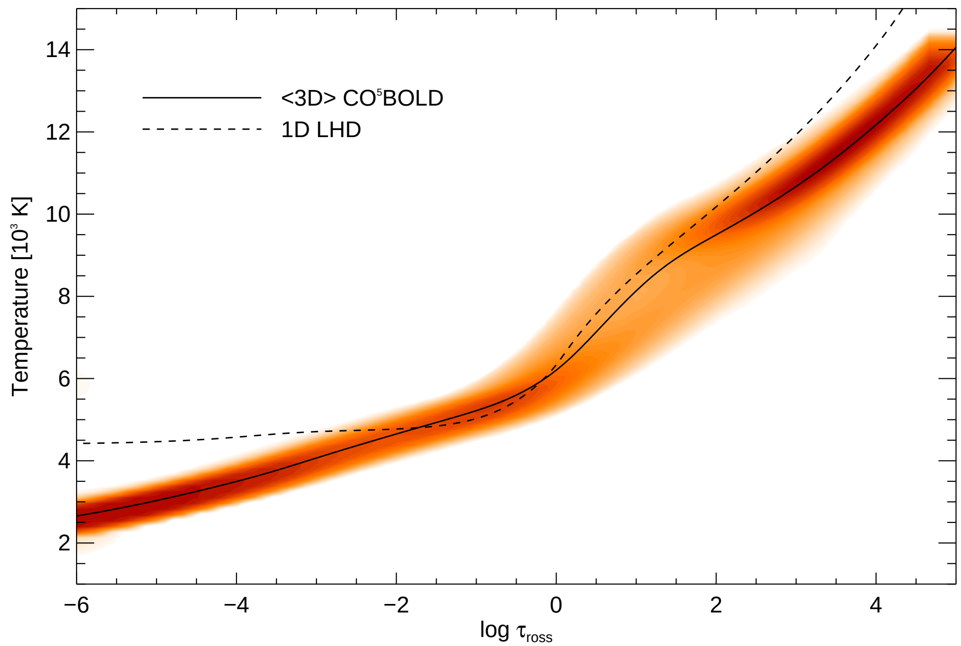
In some cases sophisticated model atmospheres are necessary to model the shape of the line correctly

Asplund et al. 2006 suggest the existence of a ^{6}Li plateau

When the asymmetry effect is taken into account the existence of a ^{6}Li plateau appears questionable (Cayrel et al. 2007, Steffen et al. 2010)

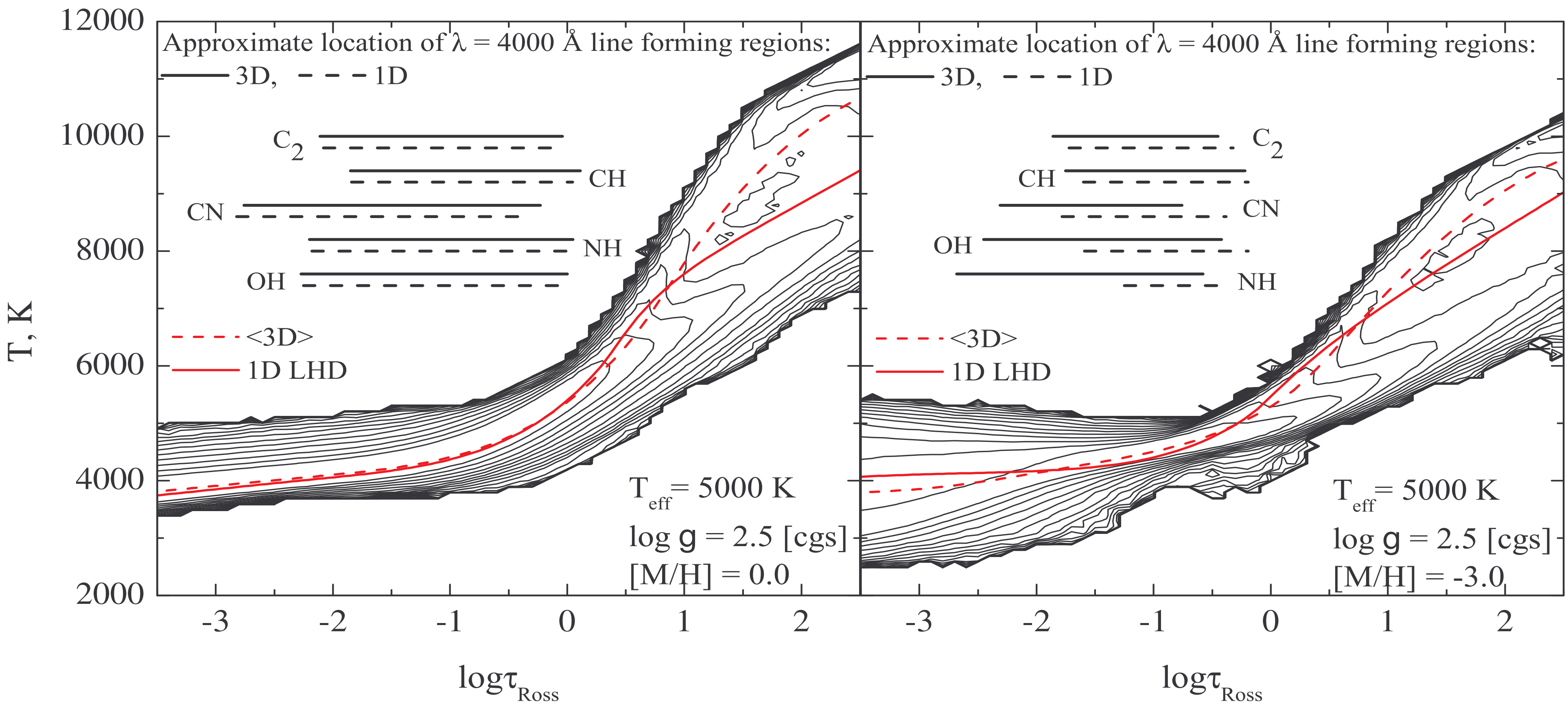


6500K/4.0/-3.0



5900K/4.0/-3.0

Metal-poor stars



Ivanauskas et al. 2011

Metal-poor stars (Gonzalez-Hernandez et al. 2008)