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
  - $V_{\text{sini}}$
  - $T_{\text{eff}}$
  - gravity
  - chemical composition (photosphere)

Quality and extent of spectra influence their information content

- spectral resolution $R$
- signal-to-noise ratio
- wavelength range

For $R = 9400$:

For $R = 40000$:

Stellar Spectra ▶ TOC ▶ FIN
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$^5$BOLD (by B. Freytag, M. Steffen, H.-G. Ludwig)

CO$^5$BOLD 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 ($\langle 3D \rangle$ models)
  - 1D$_{LHD}$ 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-noise ratio spectra, the analysis is completely performed with 3D models.
3D abundance corrections

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

The abundance of Y being $A(Y) = \log \frac{n_Y}{n_H} + 12$

quantity related to the line strength:
- a ratio of a quantity related to the line opacity $n_Y$ over one related to the continuum opacity mainly due to $H^-$ in the cool dwarfs.

We define them as:

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

Both are function of microturbulence and the first one of the mixing length parameter.
The CIFIST grid

Teff [K]

log$_{10}$ g [cm s$^{-2}$]

metallicity [M/H]

-1 0
-2 -3

- running
- done

M0 K0 G0 F5

CIFIST grid
Low resolution stellar spectra

- Only limited information, augmented by photometry, can be derived from \( R=2000 \) 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 \( 5500 \, \text{K} < T_{\text{eff}} < 6600 \, \text{K} \)
    - \( u - g > 0.70 \) to exclude majority of White Dwarfs and horizontal branch stars
    - objects in large majority Turn-Off stars \( \implies \) 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 ($\approx 30 \text{ km s}^{-1}$) 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 ± 0.27

[Fe/H] = −3.22 ± 0.24

[Fe/H] = −3.24 ± 0.24

[Fe/H] = −3.52 ± 0.14

[Fe/H] = −3.49 ± 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

![Comparison high-low resolution](image-url)

- UVES
- X-Shooter
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 triggered
  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

<table>
<thead>
<tr>
<th>EL</th>
<th>N</th>
<th>CO5BOLD</th>
<th>AG89</th>
<th>GS98</th>
<th>AGS05</th>
<th>AGSS09</th>
</tr>
</thead>
<tbody>
<tr>
<td>Li</td>
<td>1</td>
<td>1.03 ± 0.03</td>
<td>1.16 ± 0.10</td>
<td>1.10 ± 0.10</td>
<td>1.05 ± 0.10</td>
<td>1.05 ± 0.10</td>
</tr>
<tr>
<td>C</td>
<td>43</td>
<td>8.50 ± 0.06</td>
<td>8.56 ± 0.04</td>
<td>8.52 ± 0.06</td>
<td>8.39 ± 0.05</td>
<td>8.43 ± 0.05</td>
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<tr>
<td>N</td>
<td>12</td>
<td>7.86 ± 0.12</td>
<td>8.05 ± 0.04</td>
<td>7.92 ± 0.06</td>
<td>7.78 ± 0.06</td>
<td>7.83 ± 0.05</td>
</tr>
<tr>
<td>O</td>
<td>10</td>
<td>8.76 ± 0.07</td>
<td>8.93 ± 0.035</td>
<td>8.83 ± 0.06</td>
<td>8.66 ± 0.05</td>
<td>8.69 ± 0.05</td>
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<tr>
<td>P</td>
<td>5</td>
<td>5.46 ± 0.04</td>
<td>5.45 ± 0.04</td>
<td>5.45 ± 0.04</td>
<td>5.36 ± 0.04</td>
<td>5.41 ± 0.03</td>
</tr>
<tr>
<td>S</td>
<td>9</td>
<td>7.16 ± 0.05</td>
<td>7.21 ± 0.06</td>
<td>7.33 ± 0.11</td>
<td>7.14 ± 0.05</td>
<td>7.12 ± 0.03</td>
</tr>
<tr>
<td>K</td>
<td>6</td>
<td>5.11 ± 0.09</td>
<td>5.12 ± 0.13</td>
<td>5.12 ± 0.13</td>
<td>5.08 ± 0.07</td>
<td>5.03 ± 0.09</td>
</tr>
<tr>
<td>Fe</td>
<td>15</td>
<td>7.52 ± 0.06</td>
<td>7.67 ± 0.03</td>
<td>7.50 ± 0.05</td>
<td>7.45 ± 0.05</td>
<td>7.50 ± 0.04</td>
</tr>
<tr>
<td>Zr</td>
<td>15</td>
<td>2.62 ± 0.06</td>
<td>2.60 ± 0.03</td>
<td>2.60 ± 0.02</td>
<td>2.59 ± 0.05</td>
<td>2.58 ± 0.04</td>
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<tr>
<td>Eu</td>
<td>5</td>
<td>0.52 ± 0.03</td>
<td>0.51 ± 0.08</td>
<td>0.51 ± 0.08</td>
<td>0.52 ± 0.06</td>
<td>0.52 ± 0.04</td>
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<tr>
<td>Hf</td>
<td>4</td>
<td>0.87 ± 0.04</td>
<td>0.88 ± 0.08</td>
<td>0.88 ± 0.08</td>
<td>0.88 ± 0.08</td>
<td>0.85 ± 0.04</td>
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<tr>
<td>Os</td>
<td>3</td>
<td>1.36 ± 0.19</td>
<td>1.45 ± 0.10</td>
<td>1.45 ± 0.10</td>
<td>1.45 ± 0.10</td>
<td>1.25 ± 0.07</td>
</tr>
<tr>
<td>Th</td>
<td>1</td>
<td>0.08 ± 0.03</td>
<td>0.12 ± 0.06</td>
<td>0.09 ± 0.02</td>
<td>0.06 ± 0.05</td>
<td>0.02 ± 0.10</td>
</tr>
</tbody>
</table>

AG89 Anders & Grevesse Geochemica et Cosmochimica acta, 1989 Vol. 53
AGS05: Asplund et al; ASP Conferences Series, Vol. 336, 2205
AGSS09: Asplund, Grevesse, Sauval, & Scott, ARA&A 2009
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

Approximate location of $\lambda = 4000$ Å line forming regions:

- $3D$, $- - - - 1D$

- $C_2$
- $CN$
- $OH$
- $CH$
- $NH$

$T_{\text{eff}} = 5000$ K
$log g = 2.5$ [cgs]
$[M/H] = 0.0$

$T_{\text{eff}} = 5000$ K
$log g = 2.5$ [cgs]
$[M/H] = -3.0$

Ivanauskas et al. 2011
Metal-poor stars (Gonzalez-Hernandez et al. 2008)

Giants: Cayrel et al. (2004)
Subgiants: Garcia Perez et al. (2006)
Dwarfs: Nissen et al. (2002)