Tutorial
Stellar Parameters and Abundances

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Purpose of this tutorial

- get some hands-on experience with quantitative spectroscopy
- learn how spectroscopic stellar parameters are derived in practice
- get to know some of the limitations of standard 1D LTE abundance analyses
- explore and have (spectroscopist's) fun!

Spectral Investigation Utility

- SIU is an interactive software suite to visualize and manipulate observed spectra and confront it to synthetic spectra. The latter are computed on-the-fly based on a pre-computed grid of MAFAGS model atmospheres (Gehren 1975, Grupp 2004).
- SIU was written by Johannes Reetz in the 1990s and is maintained by Frank Grupp (linux version) and AK (Windows version).
- It is written in IDL (except for the line formation which is in Fortran and is derived from LINFOR written by Hartmut Holweger).

How to get started

- Open a terminal window, you are now in your HOME directory
- Issue the command *tcsh* (starts the turbo c-shell)
- Issue the command *source .login_siu*
- Issue the command *siu*
- You will now see the main SIU menu. From here click your way through (see presentation)
- Watch the terminal window, the OS task bar and the content of the windows: you will get some hints on what to do (e.g. which window is active, what operations the mouse buttons perform etc.)

Star of the day: HD 19445

- This is a classical metal-poor star which has been analysed numerous times since the 1950s (CDS lists more than 500 references). The observations we have are from 1999 using FOCES on the Calar Alto 2.2m.
- It has T_{eff} and log g quite similar to the Sun, but the metallicity is significantly different (you will find out just how different)
- You will use spectroscopic techniques to derive T_{eff}, log g, [Fe/H] and [Mg/H].
  Usually the microturbulence ξ needs to be derived as well, but this is tedious when done interactively.
- But let's start with our very own star…

The Sun

- We want to look at Hα, Hβ, Mg I 5528/5172 and Fe II 5316
- Load parts of the Solar spectrum [Å]:

  6513 – 6613 (wavelength range interactive)

  4811 – 4911 (wavelength range interactive)

  5528 (reference wavelength)

  5172 (reference wavelength)

  5316 (reference wavelength)
- Let's start with Hα

Table 1. Atomic data for Mg I line synthesis

λ [Å]	transition	E_{low} [eV]	E_{up} [eV]	$\log gf$	$\log C_6$
4571.096	$3s\,^1S - 3p\,^3P^o$	0.00	2.70	−5.690	−31.25
4730.029	$3p\,^1P^o - 6s\,^1S$	4.33	6.94	−2.290	−29.12
5711.091	$3p\,^1P^o - 5s\,^1S$	4.33	6.49	−1.724	−30.18
11828.19	$3p\,^1P^o - 4s\,^1S$	4.33	5.37	−0.333	−30.10
4702.990	$3p\,^1P^o - 5d\,^1D$	4.33	6.95	−0.377	−29.88
5528.409	$3p\,^1P^o - 4d\,^1D$	4.33	6.56	−0.498	−30.35
8806.770	$3p\,^1P^o - 3d\,^1D$	4.33	5.73	−0.215	−31.03
8213.020	$3d\,^1D - 6f\,^1F^o$	5.73	7.23	−0.509	−29.15
8923.570	$4s\,^1S - 5p\,^1P^o$	5.37	6.75	−1.580	−29.38
5167.322	$3p\,^3P^o - 4s\,^3S$	2.70	5.09	−0.876	−30.86
5172.697	$3p\,^3P^o - 4s\,^3S$	2.70	5.09	−0.399	−30.86
5183.620	$3p\,^3P^o - 4s\,^3S$	2.70	5.09	−0.177	−30.88
7657.600	$4s\,^3S - 5p\,^3P^o$	5.09	6.70	−1.178	−29.90
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Zhao et al. (1998)

Solar Hα

- Select the Hα spectrum (select spectrum, left click)
- Zoom to roughly 6523 – 6603 (x) and 0.5 – 1.1 (y), the ZOOM RANGE window appears, finish by a right click in the SPECTRUM COMPARISON window
- Start the line formation (Line-ID / -formation)
- Click (roughly) at the line centre in the ZOOM RANGE window
- In the LINEDATA window, click LINFOR
- In the LINEFORMATION window, click START
- Do the theoretical wings fit the observations (down to 0.8 in normalized flux)?

Hβ and Mg lines

- If the Balmer lines don't not fit, change T_{eff} in the LINEFORMATION window (explore also how log g and [Fe/H] change the profile)
- For the metal lines, you will need to apply external broadenings: take ROT 1.8 km/s, RadTan 3.5 km/s, thereafter middle mouse button.
  If the metal lines don't fit, check your atomic data or change log ε(X): enter "12 0.3" in ELEMENT ABUNDANCE VARIATION to increase the Mg abundance by a factor of 2 ($10^{0.3} \approx 2$).

  NB: SIU assumes the Solar log ε(Mg) to be 7.53 and log ε(Fe, A=26) to be 7.51.
- See what T_{eff} and log g do. Can you tell apart log ε(X) and T_{eff} /log g variations?

Bookkeeping

Take down your results, you may need them later.

line	T_{eff} (fixed/variable?)	log g (fixed/variable?)	log eps (fixed/variable?)
Hα			
Hβ			
Mg I 5528			
Mg I 5172			

You can also create postscript plots (PLOT), but you need to issue "mkdir siu/ps" from a terminal window first (once).

HD 19445

- Load HD 19445: Load Observed Spectra, mark and use wavelength range interactive or reference wavelength. Repeat for all lines.
- Let's again start with T_{eff}. Start with Solar stellar parameters (but set ξ (xi) to 1.75 km/s).

  Follow the same procedure you used when fitting the Solar Balmer-line wings.
- Do $H\alpha$ and $H\beta$ return identical T_{eff} values?

  Can you get clues to what is going wrong from these spectral regions? Hint: look at the metal lines!

Constraining log g

- Use Mg I 5528 to set the magnesium abundance. At this stage, do this via [Fe/H] to simultaneously set the overall metallicity assumed (NB: Below [Fe/H] < –0.59, the MAFAGS grid includes so-called α–enhancement and [Mg/Fe] is set to +0.4.

  Example: if you fit the Mg lines at [Fe/H]=–1, then [Mg/H] is –0.6 (log ε(Mg) = 6.93). Check the log g sensitivity of Mg I 5528.

  For the external broadening, now use a Gaussian with 3 – 5 km/s (this suffices, as you cannot easily tell rotation from macroturbulence at this resolving power).

  Check that this procedure (changing [Fe/H]) works using Fe II 5316. If not, adjust [Fe/H].

Putting it all together

- Go to Mg I 5172. Using the metallicity determined from Mg I 5528 fit the wings of this broad line. Assume the same external broadening (but you may also vary it a little).

  Why can you not fit the line core?
  Hint: where does it form in the atmosphere?

  With what precision can you constrain log *g*?

  Iterate the T_{eff} determination, if you changed one of the stellar parameters significantly.
- What are your best stellar parameters for HD 19445? You may want to compare with literature values...