S2 - Estimating the magnetic field strength in a sunspot

Task

Estimate the magnetic field strength in a sunspot, using the Zeeman splitting of spectral lines.

Observation

The observation will be performed with the solar telescope in the "Einsteinturm".

Data reduction

Data reduction for data taken before 2016:

Login at the Laboratory Course computer. Copy the observational data (TIFF files) from the directory `~/data/<date>` to your own directory (see name conventions). Use the command `ls` to view the directory's content. After the copying there should be at least two TIFF files, possibly with names that represent the meaning of the image.

The TIFF images can be viewed in *ImageMagick* with the console command

```
display filename.TIF
```

(The default contrast settings are generally unfavorable, as the image appears extremely dark.)

We use *GDL* for the data reduction. The program need to do the following steps:

- Convert TIFF to FITS
- Read-in the FITS file
- Rearrange the byte order of the 16-bit numbers (First check if this is required for data from the Einsteinturm!)
- Rotate the images for further data reduction in Python (the dispersion must be oriented horizontally/in X direction), i.e. rotate the image matrix
- Save the converted and rotated image as FITS files

Luckily, the required program (`konvert.pro`) is already prepared and can be found in the scripts directory. Copy it to your own directory. At the end of this program a few lines need to be adjusted. Use a text editor, i.e.

```
kate konvert.pro &
```

to open the script and change the parameters that describe the input files (filenames, dimensions). To

compile the program, start *GDL*

```
gdl
```

then compile the program via

```
gdl> .compile konvert.pro
```

The program itself is started in *GDL* by calling the program name, which in this case should be

```
gdl> konvert
```

The program converts and rotates the images, then saves the FITS files. They can be viewed (outside of *GDL*) with

```
ds9 filename.fits &
```

The image should be clearer and rotated in comparison to the TIFF file.

Analysis

The analysis can be performed with the Python script *comparespecs.py* that is already known from S1. The input (filename, lines) need to be adjusted accordingly. Use an editor of your choice. Note, that both spectra are in one file now. Mind that pixel errors can best be avoided by averaging over a number of lines of the image, but choose the regions with the maximal splitting.

Save the script and execute it by

```
python comparespecs.py
```

This will produce a PDF file with the overlaid spectra which can be viewed with

```
okular spectrum.pdf &
```

To avoid overwriting the output of S1 it is possible to change the filename of the output. Determine the shift of the Zeeman components $\Delta \lambda$. The wavelength calibration is done using telluric oxygen lines (see Table below). The magnetic field strength can then be calculated:

$B[\mathrm{T}] = \frac{4\pi m_\mathrm{e} c}{e} \cdot \frac{\Delta \lambda}{g\lambda_0^2} = 2.142\cdot 10^7\cdot\frac{\Delta \lambda[\mathrm{nm}]}{g\lambda_0^2[\mathrm{nm}^2]} = 2.142\cdot 10^4\cdot\frac{\Delta \lambda[\mathrm{pm}]}{g\lambda_0^2[\mathrm{nm}^2]}$

with the wavelengths λ_0 and the Landé factor g:

	$\lambda_0\,[\mathrm{nm}]$	
Fe	630.151	$g = \frac{5}{3}$
Fe	630.250	$g = \frac{5}{2}$
O_2	629.846	

	$\lambda_0\,[\mathrm{nm}]$	
O_2	629.923	
O_2	630.200	
O_2	630.276	

Report

A combined report for S1 and S2 with the usual content is to be handed in. See a general overview about the required structure and content here.

For this experiment, the theoretical overview in the report should give a short introduction to the *Einsteinturm* and its instrumentation. Describe how the rotation of the sun is calculated from an observable line shift and the physical background behind it. Mention further geometric corrections that need to be accounted for. Then describe the basics for the Zeeman effect and how we use it in this experiment. This includes a derivation of the formula above. Discuss the importance of the Zeeman splitting for this laboratory course (e.g. which polarization components are visible and which are measured in our observation).

In the methods section, describe the observations and the data extraction, highlight points that deviate from general description in here, and list all the parameters you set for the extraction. Search for an image of the investigated sunspots in the SOHO-Archive or using Sun in time. Classify the sunspot following the Waldmeier (Zurich) scheme.

The results and analysis part presents the extracted solar spectra. It also includes the measurement of the radial velocity shift and the line splitting. Do not forget to list the individual lines that you use with their respective rest frame wavelength, line shift, etc. Calculate the solar rotation and the strength of the magnetic field.
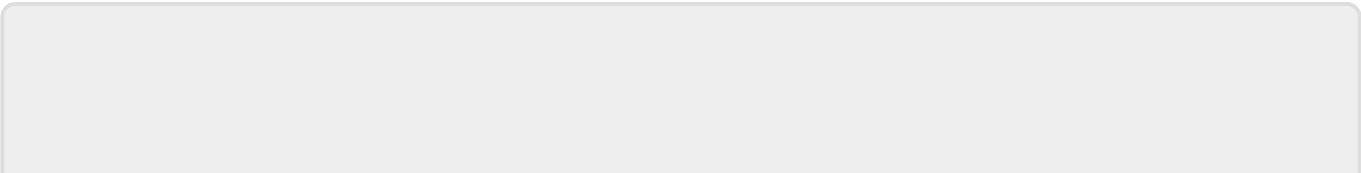
Finally, discuss your findings. Bring your results into a larger context and make a literature comparison to known solar rotation period and typical magnetic field strength in sun spots. This also includes that you identify potential problems with the data, the data reduction, or the analysis and possible solutions for them. Are their inconsistencies? Do your resulting period and field strength match your expectations? If not, what are potential reason for that?

Further tips on how to handle writing the reports can be found in this presentation.

Recommended Literature

Zeeman effect: *Joachim Stöhr - Magnetism: From Fundamentals to Nanoscale Dynamics* (available at Golm Libaray, IKMZ)

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