Leibniz-Institut für Astrophysik Potsdam

AIP

Data Calibration II

Spectropolarimetric Instruments

Christoph Kuckein

Learning goals for today

1. Familiarize with spectropolarimetric data
2. Learn how to read GRIS data
3. Represent GRIS data
4. Compute a wavelength array
5. Create a “magnetogram”
6. Learn how to normalize the Stokes profiles

Examples of Spectrographs

Examples of Spectrographs

Telescope	Instruments
GREGOR	
VTT	
DST	
DKIST	

Examples of Spectrographs

Telescope	Instruments
GREGOR	GRIS
VTT	Echelle Spectrograph
DST	FIRS
DKIST	DL-NIRSP

Examples of Imaging Instruments

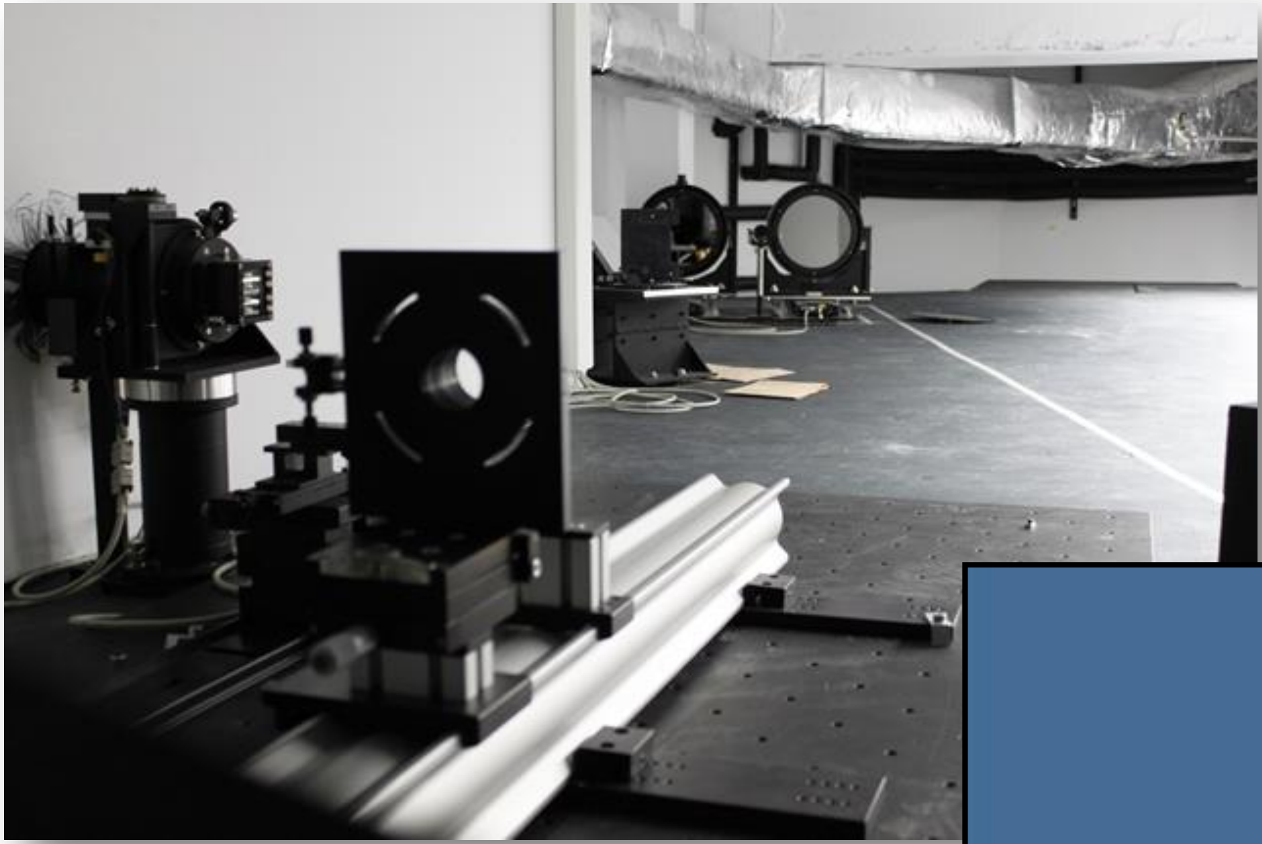
Telescope	Spectroscopy	Spectropolari metry
GREGOR	X	X
VTT	X	-
DST	X	X
DKIST	X	X

Basic Data Reduction

- Spectropolarimetric data
  - Dark correction
  - Flat-field correction
  - Polarimetric calibration
  - Instrumental profile correction
  - Normalization
  - Wavelength calibration

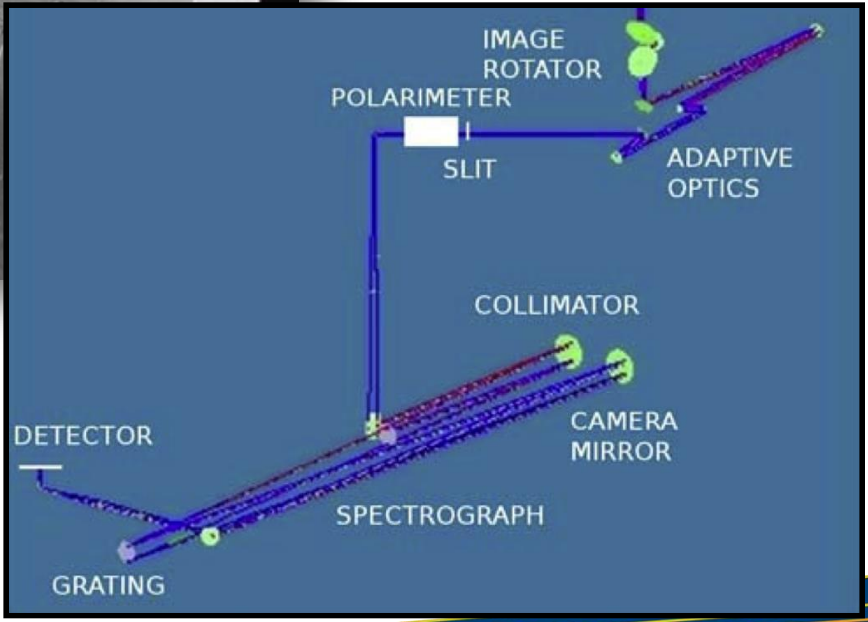
GREGOR Infrared Spectrograph (GRIS)

GREGOR Infrared Spectrograph (GRIS)



Wavelength range:
1.0 – 2.3 μm

Polarimetry:
1.0 – 1.8 μm



Dispersion @ 1083 nm: ~18 mÅ / pixel

Spectral coverage: 18 Å

Dispersion @ 1565 nm: ~44 mÅ / pixel
Spectral coverage: 44 Å

GRIS Data Archive

Data archive for the GREGOR Infrared Spectrograph

2018

April: 18 25 26 27 30
May: 04 05 07 09 10 11 13 17 18 19

2017

March: 28 29
April: 02 03 04
May: 05
June: 12 13 14 16 17 18 19 20
September: 01 02 03 07 08 09 11 12 13 22 28 29
October: 02 03 30 31
November: 01
December: 06 07 08

color coding:
1083 nm data
1565 nm data

http://archive.leibniz-kis.de/pub/gris

GRIS data we are going to analyze

Reduced data

Index of /pub/gris/20140511/level1/

../		
11may14.003-01cc	16-Oct-2014 09:11	758019200
11may14.003-01cm	16-Oct-2014 09:12	1127364
11may14.003-02cc	16-Oct-2014 09:27	758019200
11may14.003-02cm	16-Oct-2014 09:27	1127364
11may14.004-01cc	16-Oct-2014 09:40	636737280
11may14.004-01cm	16-Oct-2014 09:41	947268
11may14.004-02cc	16-Oct-2014 09:54	636737280
11may14.004-02cm	16-Oct-2014 09:54	947268
11may14.004-03cc	16-Oct-2014 10:07	621579200
11may14.004-03cm	16-Oct-2014 10:07	924756

http://archive.leibniz-kis.de/pub/gris/20140511/level1/

CASSDA GUI for TIP and GRIS

DATA ANALYSIS - CENTER FOR ADVANCED SOLAR SPECTRO-POLARIMETRIC

CASSDA

http://archive.leibniz-kis.de/pub/gris

Basic Data Reduction

- Spectropolarimetric data
  - Dark correction
  - Flat-field correction
  - Polarimetric calibration
  - Instrumental profile correction
  - Wavelength calibration

IDL Pipeline for GRIS

- File: *calddmonthyy.pro*
  - dd: day (2 numbers)
  - month: string of 3 digits
  - year: year (2 numbers)

Pipeline for GRIS

- Recent example from July 2019

```
pro cal18jul19
lambda=10830.

filecal='18jul19.004'

fileff=['18jul19.000']
map='18jul19.001'
gris_v7,map,fileff,filecal,lambda=lambda

fileff=['18jul19.003']
map='18jul19.002'
gris_v7,map,fileff,filecal,lambda=lambda

fileff=['18jul19.003']
map='18jul19.005'
gris_v7,map,fileff,filecal,lambda=lambda

return
end
```

Spectral range

Polarimetric calibration file

Flat-field file

Observation file

Output of the GRIS pipeline

```
ckuckein gre 335K Jul 18 12:27 18jul19.001-01cm
ckuckein gre  77M Jul 18 12:27 18jul19.001-01cc
ckuckein gre 1.2M Jul 18 12:44 18jul19.002-01cm
ckuckein gre 589M Jul 18 12:44 18jul19.002-01cc
ckuckein gre 589M Jul 18 12:57 18jul19.002-02cc
ckuckein gre 1.2M Jul 18 12:57 18jul19.002-02cm
ckuckein gre 757K Jul 18 13:04 18jul19.002-03cm
ckuckein gre 331M Jul 18 13:04 18jul19.002-03cc
ckuckein gre  33K Jul 18 13:09 18jul19.005cm
ckuckein gre  11M Jul 18 13:09 18jul19.005cc
```

"cm" files: Quicklook intensity and polarization maps (simple restore with IDL)

"cc" files: Reduced data in GRIS fits format

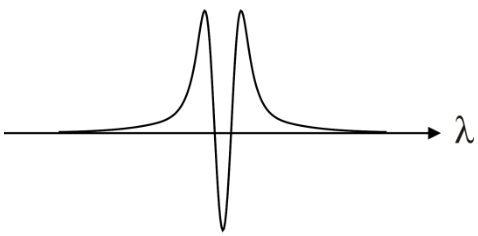
Date

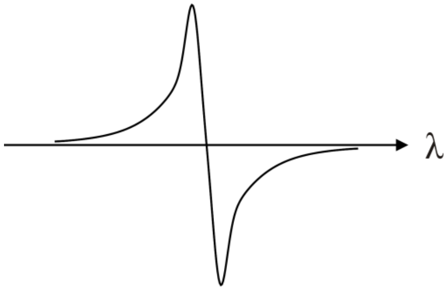
Map number

Part of the map

Read the reduced GRIS data

- The output “cc” files are **fits** files with different extensions
  - Extension 1: Stokes I
  - Extension 2: Stokes Q
  - Extension 3: Stokes U
  - Extension 4: Stokes V





Read the reduced GRIS data

- The output "cc" files are **fits** files with different extensions
  - Extension 1: Stokes I
  - Extension 2: Stokes Q
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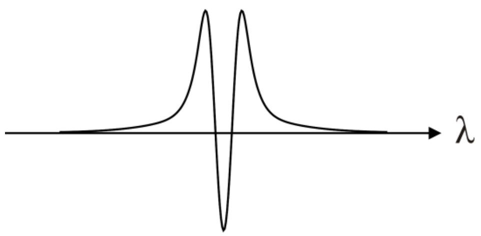
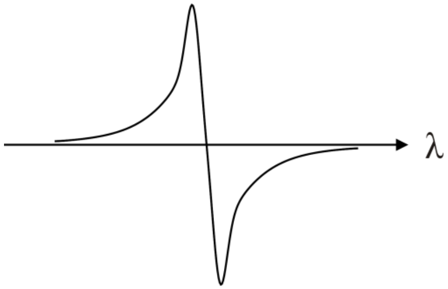
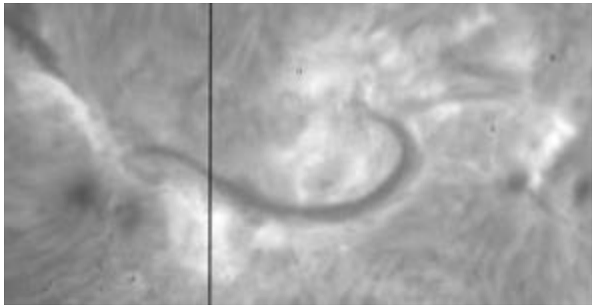
  - Extension 4: Stokes V





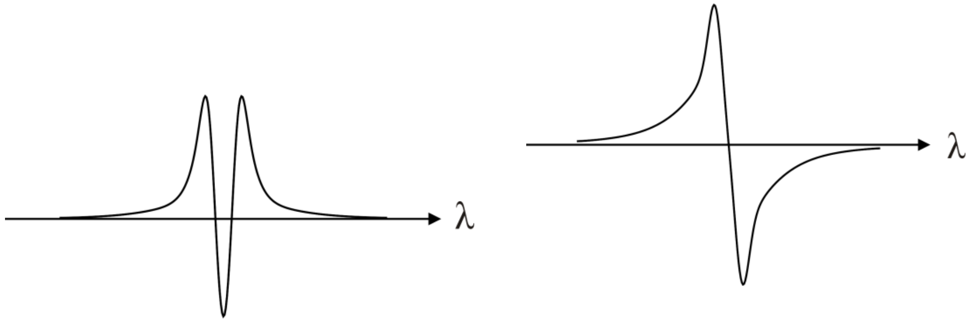
- The data cube has 3 dimensions:
  - Scan direction of the slit
  - Wavelength
  - Slit direction



Slit example

Read the reduced GRIS data

- The output "cc" files are **fits** files with different extensions
  - Extension 1: Stokes I
  - Extension 2: Stokes Q
  - Extension 3: Stokes U
  - Extension 4: Stokes V



- The data cube has 3 dimensions:
  - Scan direction of the slit (pixels?)
  - Wavelength (pixels?)
  - Slit direction (pixels?)

What is the size of the 3 dimensions?

Read the reduced GRIS data

- Use the routine: *rfits_im.pro* to read the GRIS "cc" file
  - *data = rfits_im("filename.cc",n,str,hdr)*
    - n are the extensions
    - n = 1 (Stokes I), n = 2 (Stokes Q), n=3 (Stokes U), n=4 (Stokes V), n = 5 (Stokes I), n= 6 (Stokes Q), …
    - str: IDL structure with information about the data
    - hdr: header of the fits file (lots of information)

- The data cube has 3 dimensions:
  - Scan direction of the slit (pixels?)
  - Wavelength (pixels?)
  - Slit direction (pixels?)

?

What is the size of the 3 dimensions?

Read the reduced GRIS data

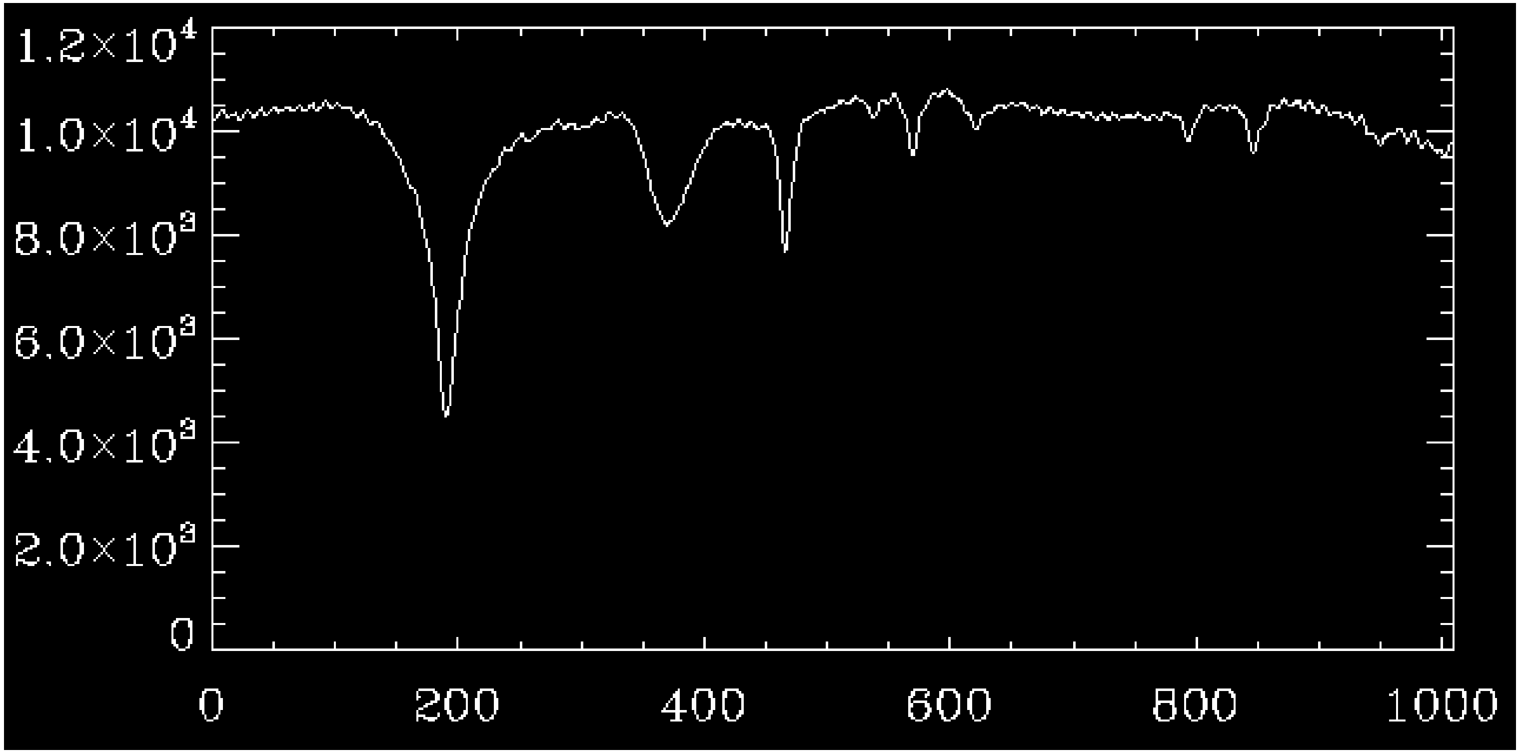
- Use the routine: *rfits_im.pro* to read the GRIS “cc” file
  - *data = rfits_im(“filename.cc”,n,str,hdr)*
  - *str:*

```
IDL> help, str,/str
** Structure <25c9348>, 24 tags, length=144, data
   OBJECT          STRING    ''
   NAXIS           INT              3
   NAXIS1          INT           1010
   NAXIS2          INT            469
   NAXIS3          INT            400
   BSCALE          FLOAT          1.00000
   BZERO           FLOAT          0.00000
   BITPIX          INT             32
   DATE            LONG          20140511
   ORIGIN          STRING    ''
   BUNIT           STRING    ''
   CDELT1          FLOAT          1.00000
   CDELT2          FLOAT          1.00000
   XTOT_START      INT              1
   XTOT_END        INT           1020
   YTOT_START      INT              1
   YTOT_END        INT           1024
   XSTART          INT              1
   XEND            INT           1020
   YSTART          INT              1
   YEND            INT           1024
   TELESCOPE       STRING    'GREGOR'
   CAMERA          STRING    'IR1024'
   FILENAME        STRING    '11may14.003-02cc'
```

Make yourself familiar with the data and spectral range

- ❑ Read the whole map using a “for” loop
  - ■ define the size of my map:
    - – *stokesI = fltarr(str.naxis3/4,str.naxis1,str.naxis2)*
  - ■ Read all Stokes I profiles of the whole map
    - – *for ii = 0, (str.naxis3/4) – 1 do stokesI[ii,*,*] = rfits_im(file, ii*4 + 1)*

Make yourself familiar with the data and spectral range



Make yourself familiar with the data and spectral range

- Read the whole map using a “for” loop
  - define the size of my map:
    - *stokesI = fltarr(str.naxis3/4,str.naxis1,str.naxis2)*

  - Read all Stokes I profiles of the whole map
    - *for ii = 0, (str.naxis3/4) – 1 do begin*
    - *stokesI[ii,*,*] = rfits_im(file, ii*4 + 1)*
    - *endfor*

  - Do the same for Stokes Q *(+2)*, U *(+3)* and V *(+4)*

Make yourself familiar with the data and spectral range

- Read the whole map using a "for" loop
  - define the size of my map:
    - *stokesI = fltarr(str.naxis3/4,str.naxis1,str.naxis2)*
    - *stokesQ = stokesI*
  - Read all Stokes I profiles of the whole map
    - *for ii = 0, (str.naxis3/4) – 1 do begin*
    - *stokesI[ii,*,*] = rfits_im(file, ii*4 + 1)*
    - *stokesQ[ii,*,*] = rfits_im(file, ii*4 + 2)*
    - *(…)*
    - *endfor*

Make yourself familiar with the data and spectral range

- You have now a 3D data cube for Stokes I, Q, U and V

?

What is showing you dimension 1, 2 and 3?

Represent the dimensions and identify what you are seen

Make yourself familiar with the data and spectral range

- You have now a 3D data cube for Stokes I, Q, U and V

Dimension 1:
- scan direction of the slit

Dimension 2:
- wavelength direction

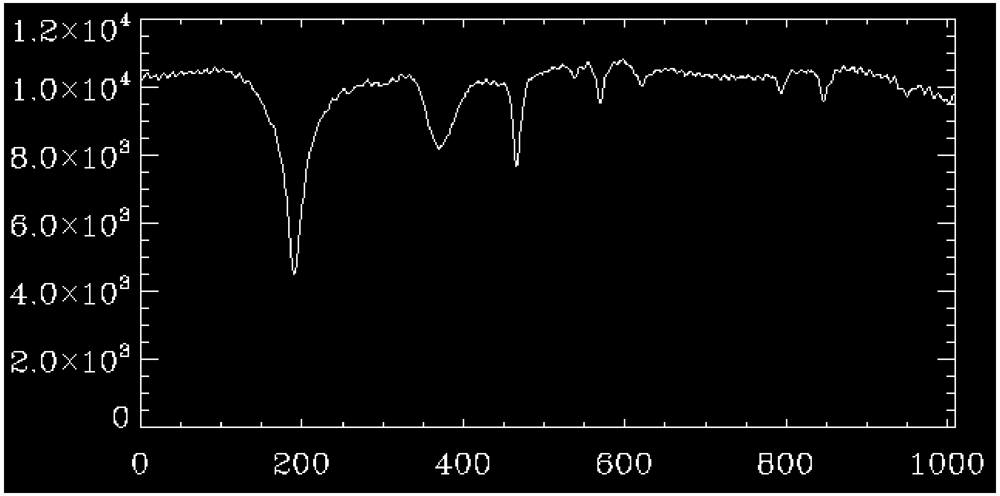
Dimension 3:
- slit direction

What is showing you dimension 1, 2 and 3?

Represent the dimensions and identify what you are seen

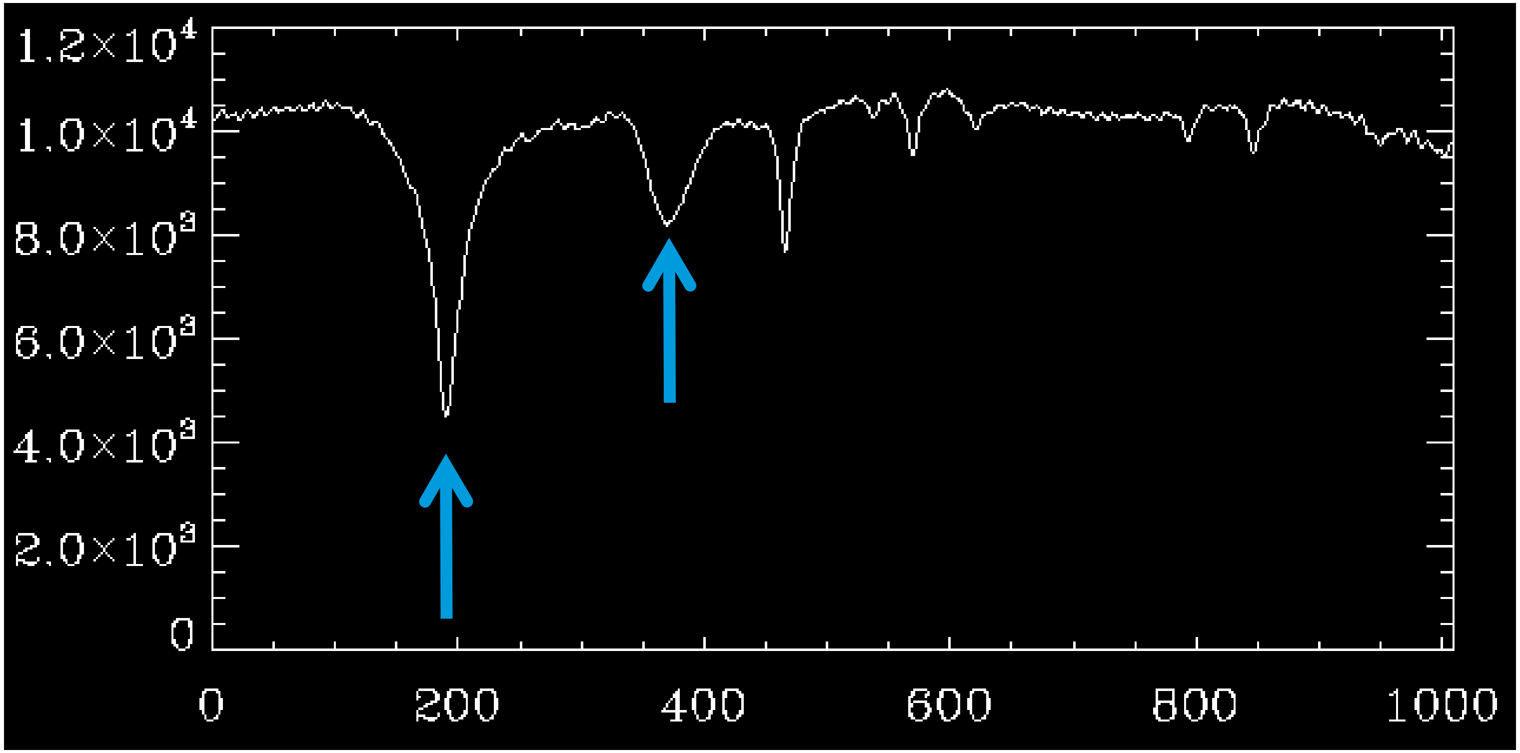
Next needed calibration steps to make the data science ready?

- Calibration:
  - Compute wavelength array
  - Normalization of the spectra
  - Instrumental profile removal (new GRIS pipeline usually takes care of this automatically)



Wavelength array

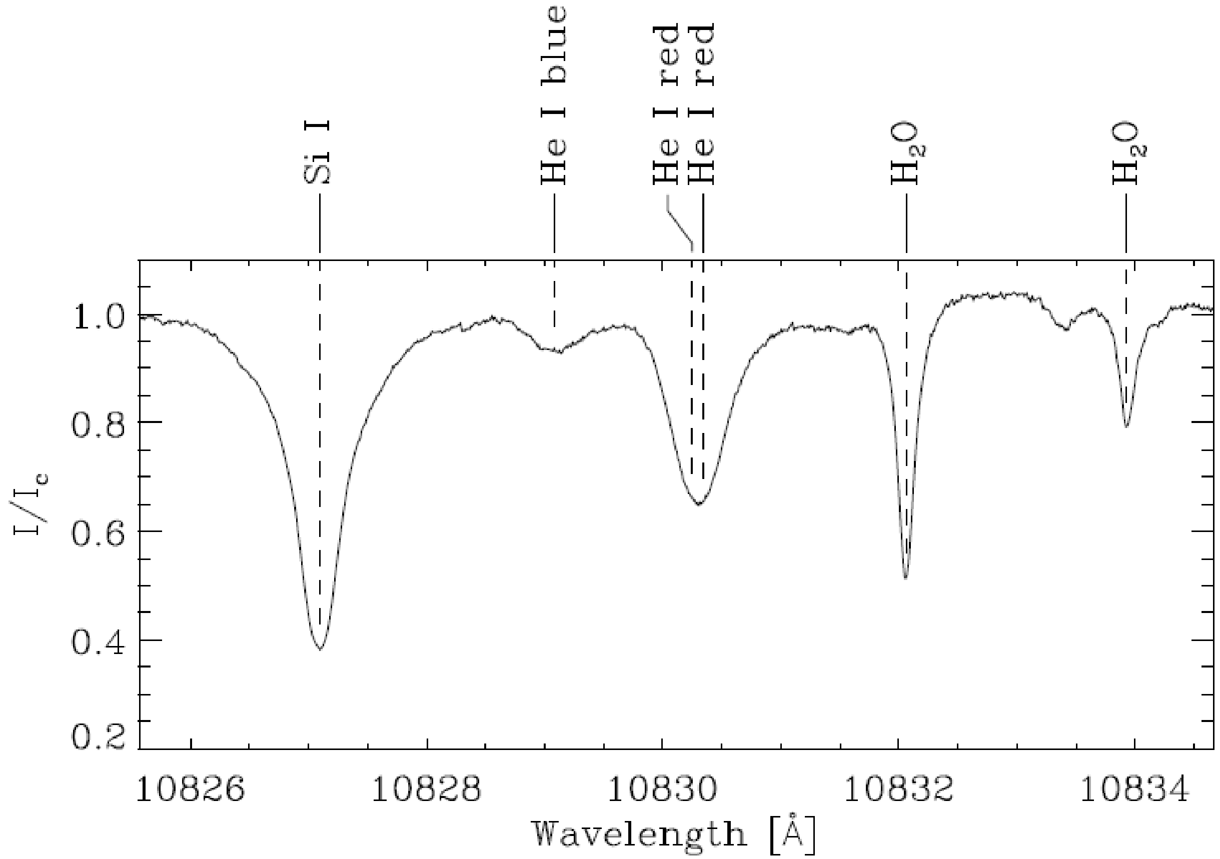
- Steps to follow:
  - Identify the lines in your spectra (use an atlas or Google “bass2000”)



Hint: Spectral window 1µm (have a look between 10825 and 10840 Å)

Wavelength array

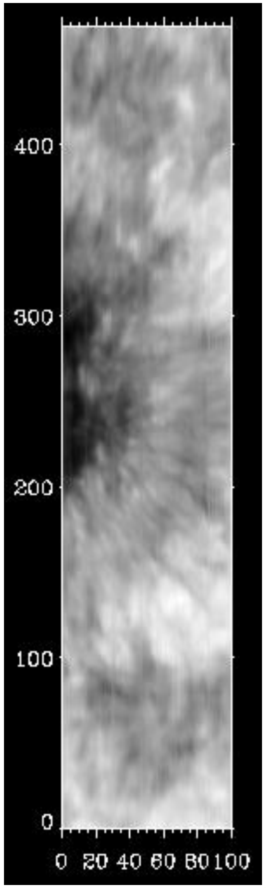
- Steps to follow:
  - Identify the lines in your spectra (use an atlas or Google “bass2000”)



Kuckein et al. 2012b

Wavelength array

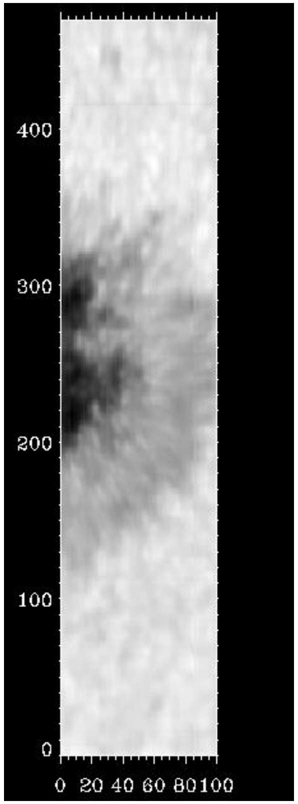
- Steps to follow:
  - Identify the lines in your spectra (use an atlas or Google "bass2000")
  - Plot a 2D slit-reconstructed image centered at the He I red line



Wavelength array

- Steps to follow:
  - Identify the lines in your spectra (use an atlas or Google "bass2000")
  - Do the same but for a spectral region without spectral lines (continuum)

Continuum



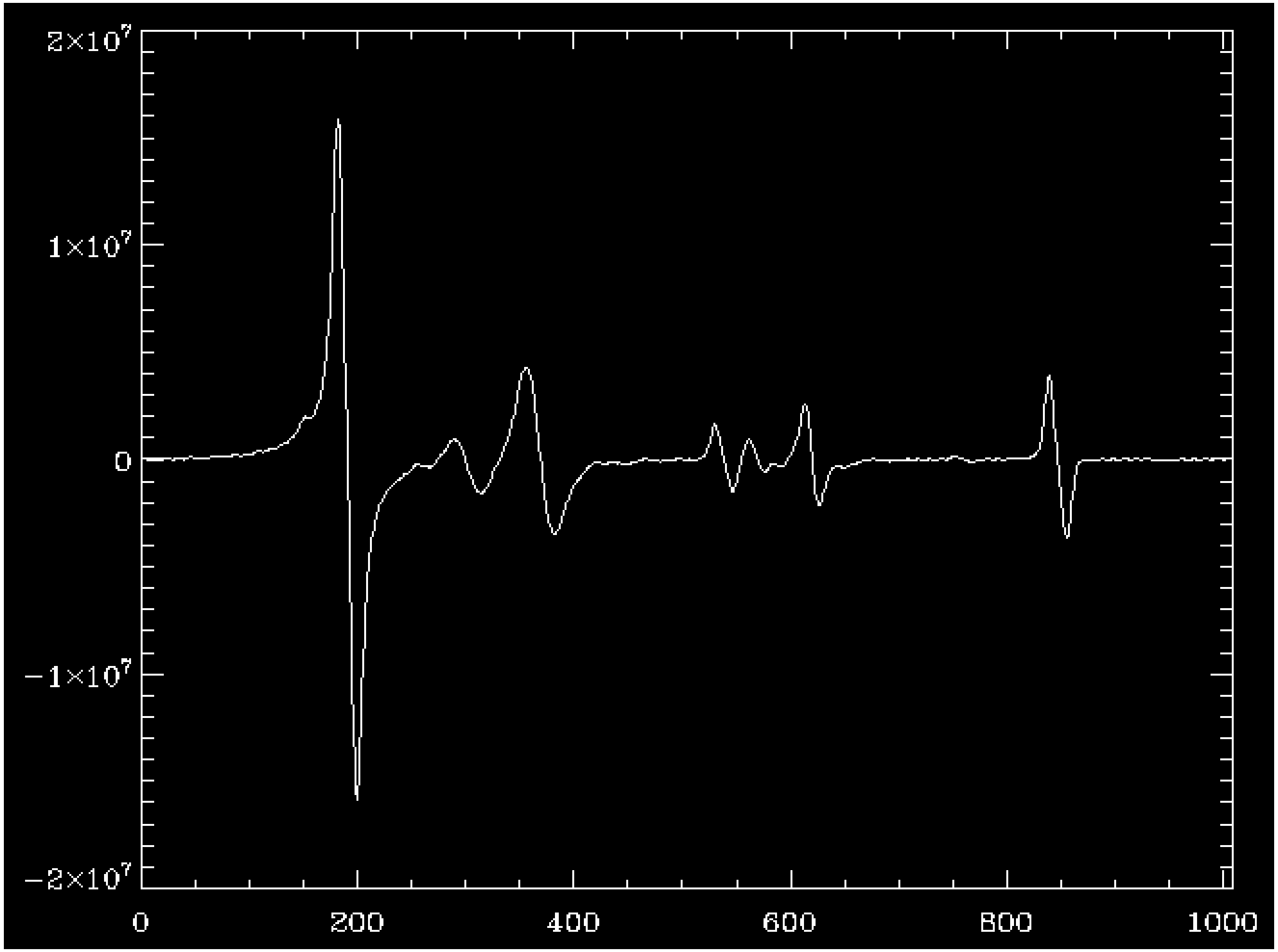
Magnetogram

- Let us construct something similar to a **magnetogram**
  - Instead of using the Stokes I cube, use the Stokes V cube which gives information about the circular polarization, which gives information about the magnetic field along the line-of-sight (hence, this is equivalent to a magnetogram but not in Gauss units)

  - Steps to follow:
    - Compute an average Stokes V spectrum across the whole field-of-view
    - Now concentrate on the largest average Stokes V profile
    - Choose the peak of one of the lobes of the Stokes V profile (which peak do you think is the correct one?)

Magnetogram

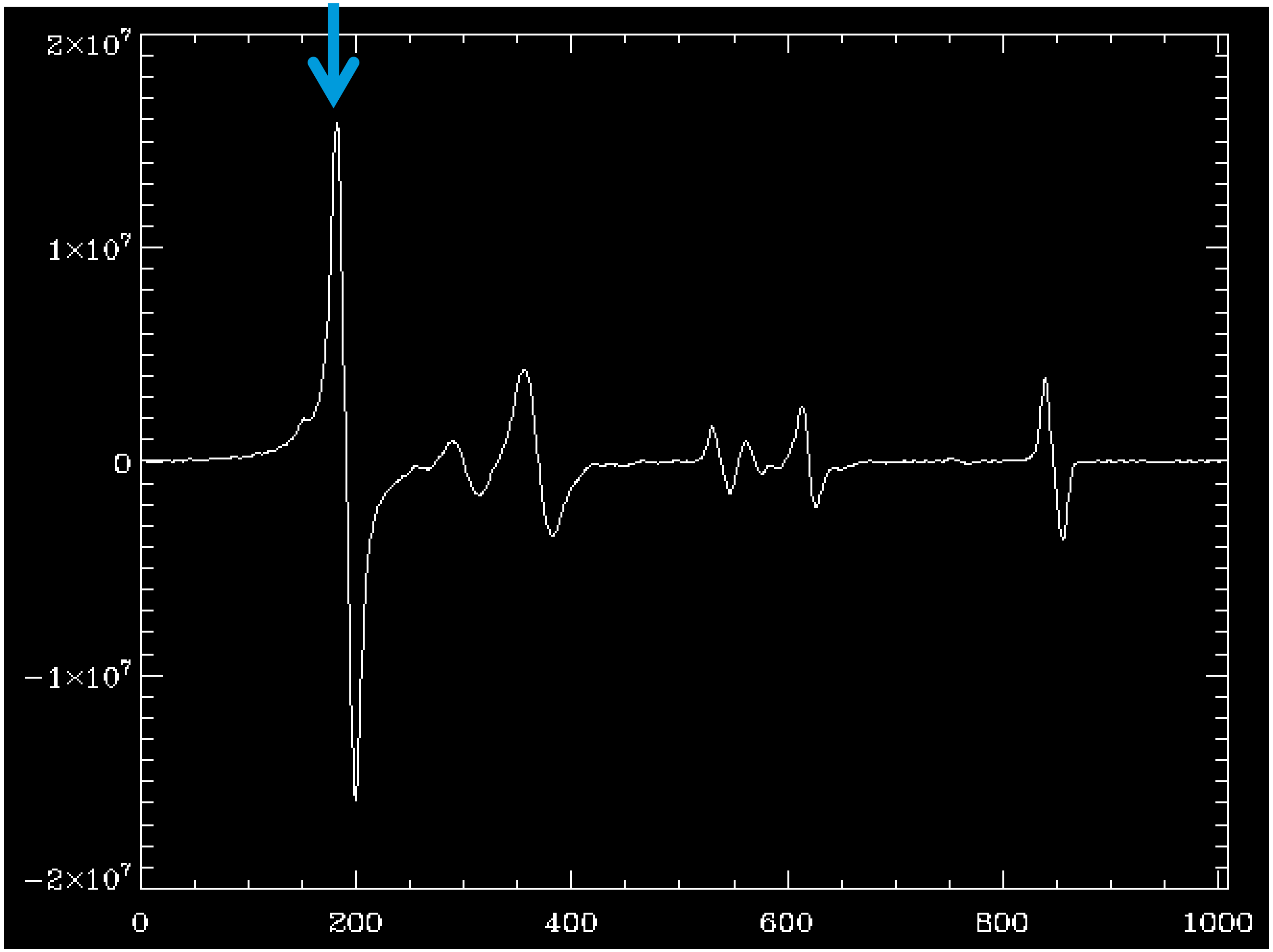
- ❑ Let us construct something similar to a **magnetogram**

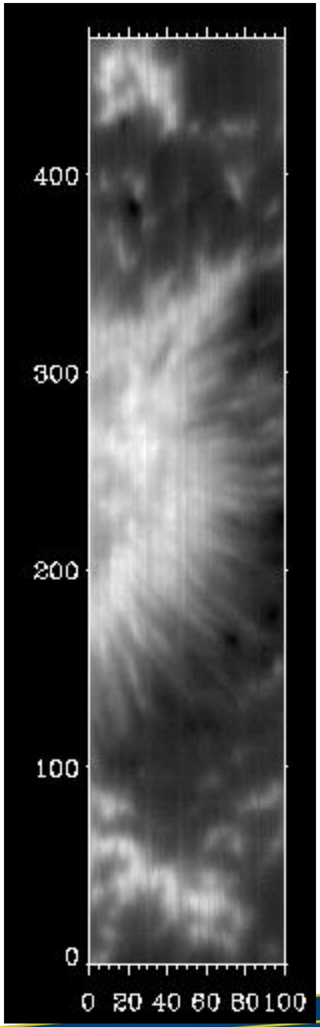


Average Stokes V spectrum across the FOV

Magnetogram

- Let us construct something similar to a **magnetogram**

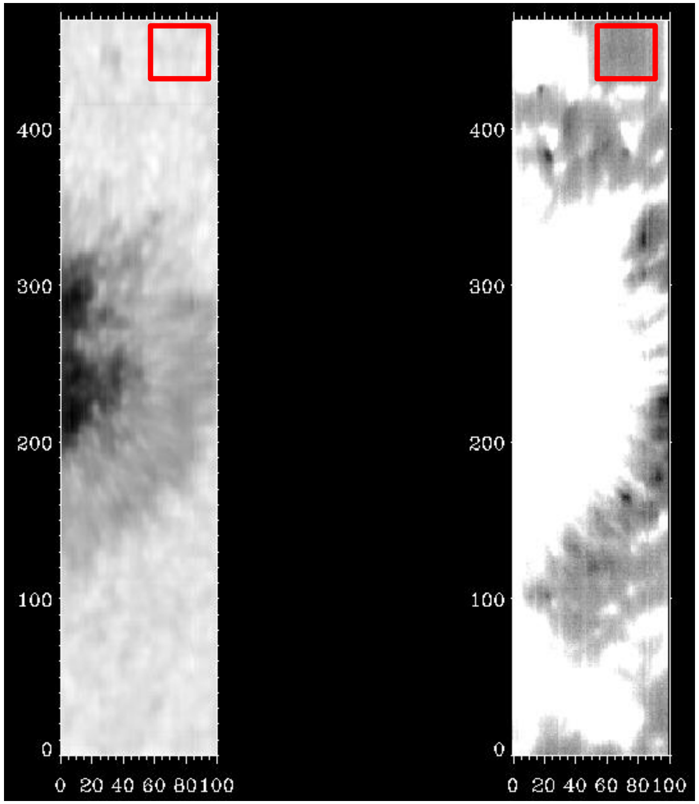




We come back to the wavelength array

- Steps to follow:
  - Identify the lines in your spectra (use an atlas or Google "bass2000")
  - Select a quiet-Sun area in the map

Continuum Stokes V

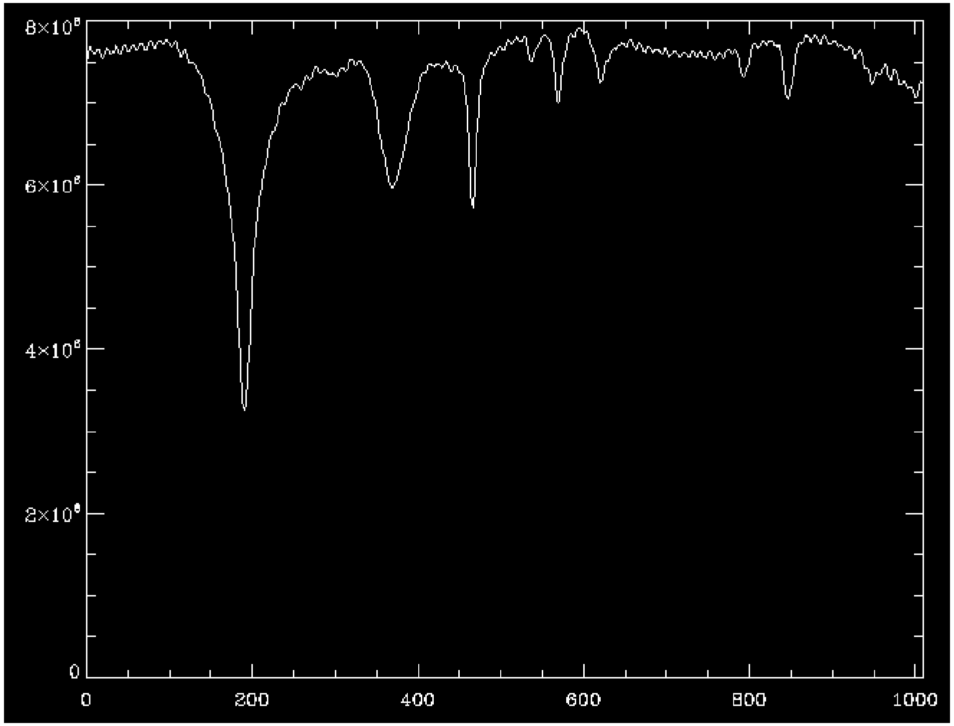


Compute an average quiet-Sun profile in the quiet-Sun area (no magnetic structures inside)

Coordinates: Stokes[55:90,*,440:460]

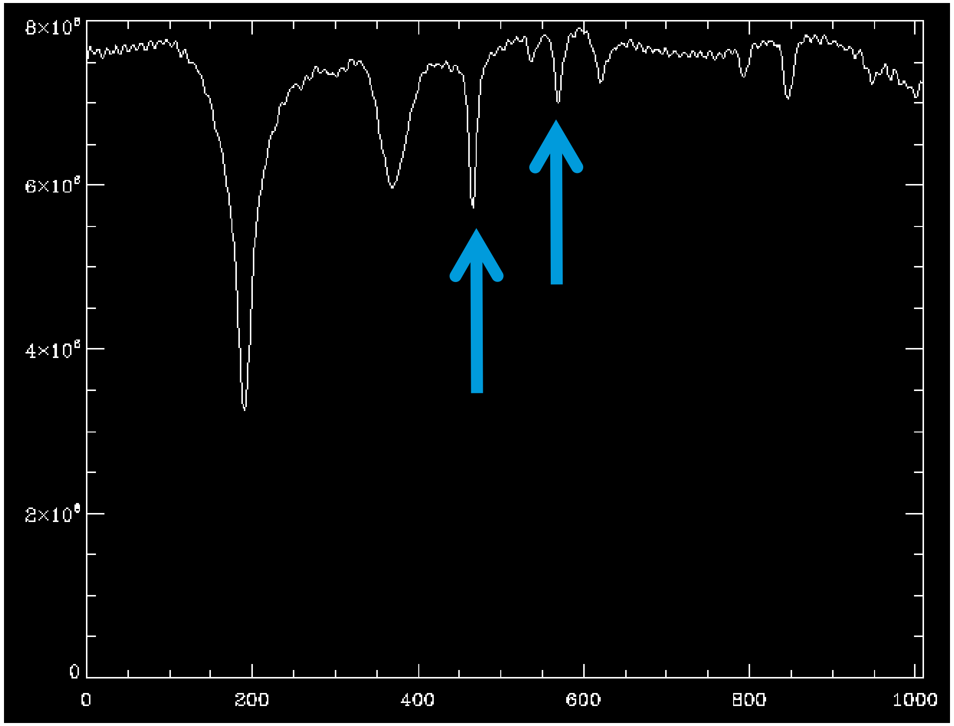
Wavelength array

- Steps to follow:
  - Identify the lines in your spectra (use an atlas or Google “bass2000”)
  - Select a quiet-Sun area in the map
  - **Compute dispersion** $$disp = \frac{\Delta\lambda}{\Delta x}$$



Wavelength array

- Steps to follow:
  - Identify the lines in your spectra (use an atlas or Google “bass2000”)
  - Select a quiet-Sun area in the map
  - **Compute dispersion** (use the two telluric lines and the provided save file with the atlas *fts_atlas_10830.sav*)

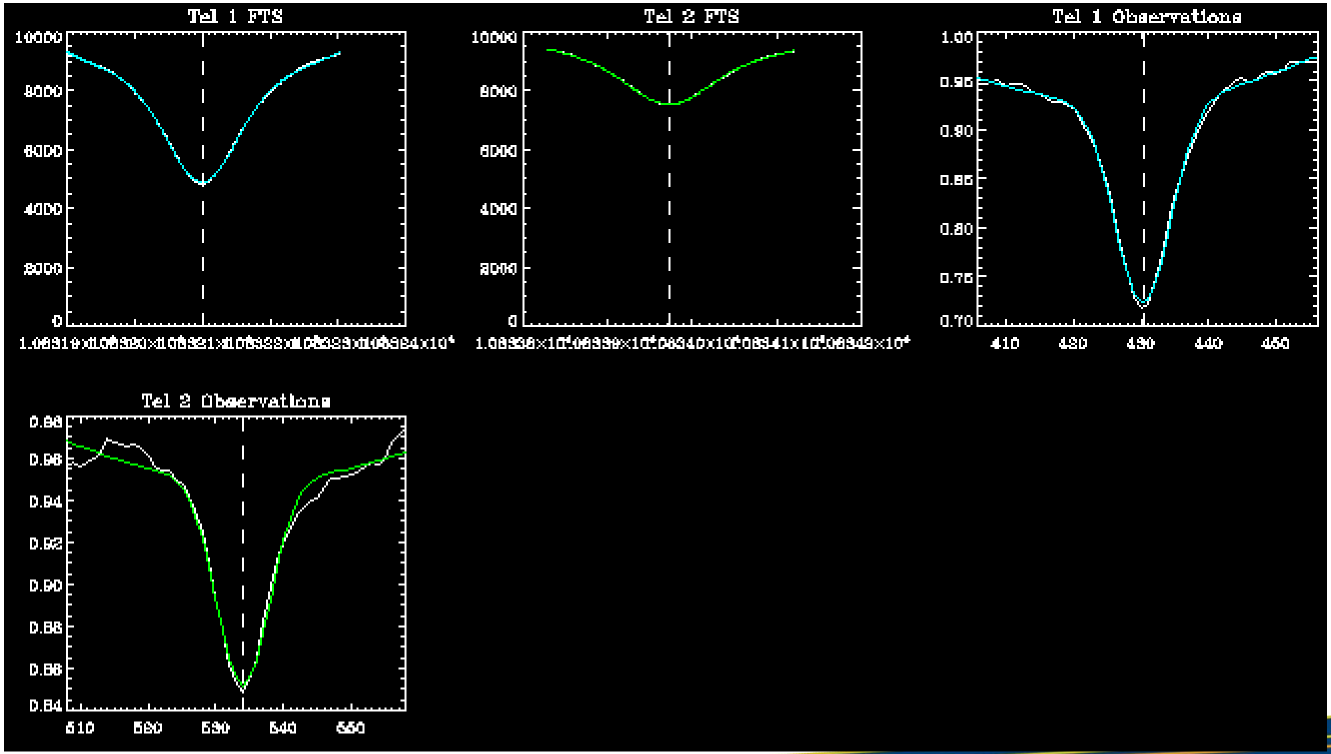


$$disp = \frac{\Delta\lambda}{\Delta x}$$

Why the telluric line?

Wavelength array

- ❑ Steps to follow:
  - ■ Identify the lines in your spectra (use an atlas or Google “bass2000”)
  - ■ Select a quiet-Sun area in the map
  - ■ **Compute dispersion** (use the two telluric lines and the provided save file with the atlas *fts_atlas_10830.sav*)



Wavelength array

- Steps to follow:
  - Identify the lines in your spectra (use an atlas or Google “bass2000”)
  - Select a quiet-Sun area in the map
  - **Compute dispersion** (use the two telluric lines and the provided save file with the atlas *fts_atlas_10830.sav*)
    - Dispersion is around 18.05 mÅ/px

Wavelength array

- Steps to follow:
  - Identify the lines in your spectra (use an atlas or Google “bass2000”)
  - Select a quiet-Sun area in the map
  - Compute dispersion (use the two telluric lines and the provided save file with the atlas *fts_atlas_10830.sav*)
    - Dispersion is around 18.05 mÅ/px
  - Construct wavelength array:

10832.108 Å

$$\vec{\lambda} = \left(\vec{x} - x_{ref}\right) * disp + \lambda_{ref}$$

Wavelength array

- Steps to follow:
  - Identify the lines in your spectra (use an atlas or Google “bass2000”)
  - Select a quiet-Sun area in the map
  - Compute dispersion (use the two telluric lines and the provided save file with the atlas *fts_atlas_10830.sav*)
    - Dispersion is around 18.05 mÅ/px
  - Construct wavelength array:

10832.108 Å

$$\vec{\lambda} = (\vec{x} - x_{ref}) * disp + \lambda_{ref}$$

$$\vec{\lambda} = \vec{\lambda} - (\Delta\lambda_{orbital\ motions} + \Delta\lambda_G)$$

$$\Delta\lambda_G = (GM_\odot / R_\odot c^2)\lambda$$

Kuckein et al. 2012b (Appendix A and B)

Wavelength array

- Steps to follow:
  - Identify the lines in your spectra (use an atlas or Google “bass2000”)
  - Select a quiet-Sun area in the map
  - Compute dispersion (use the two telluric lines and the provided save file with the atlas *fts_atlas_10830.sav*)
    - Dispersion is around 18.05 mÅ/px
  - Construct wavelength array:

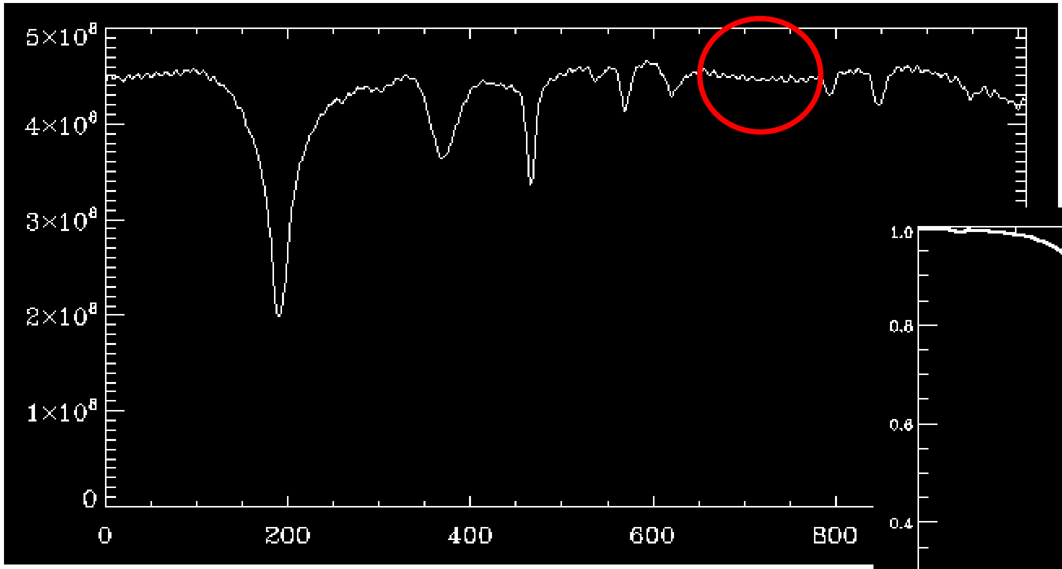
10832.108 Å

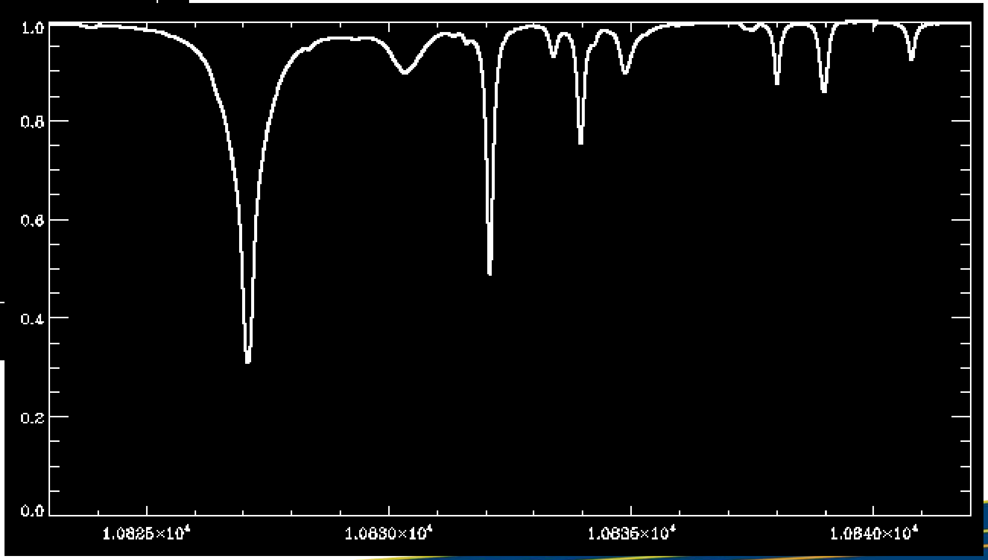
$$\vec{\lambda} = (\vec{x} - x_{ref}) * disp + \lambda_{ref}$$

Problems with this method?
- Telluric lines are not in all spectral windows

Normalization

- ❑ Divide all Stokes profiles by a constant (mean value of the continuum)
- ❑ Steps to follow: 1) Select quiet Sun area (done before)
- ❑ 2) Computer average Stokes I profile inside of quiet-Sun area
- ❑ 3) Select an area of the spectrum which corresponds to the quiet Sun
  - ■ also compare to the atlas to check that there are no spectral lines there





Normalization

- Divide all Stokes profiles by a constant (mean value of the continuum)
- Steps to follow: 1) Select quiet Sun area (done before)
- 2) Computer average Stokes I profile inside of quiet-Sun area
- 3) Select an area of the spectrum which corresponds to the quiet Sun
  - also compare to the atlas to check that there are no spectral lines there
- Compute the average in that “quiet-Sun” spectral range
- Divide your Stokes I, Q, U and V vector by that constant

Instrumental profile removal

- The new GRIS pipeline should remove the instrumental profile
- If you have the impression that your profile is not flat, you can follow these tips:
  - 1. Interpolate the atlas profile to your wavelength range
  - 2. Divide both spectra
  - 3. Make a polynomial fit to the divided spectra excluding the areas with spectral lines (only quiet Sun areas)
  - 4. The outcome polynomial you can use to flatten your spectra