Collage 2021 : Homework 2

March 1, 2021

To respect your other out-of-class commitments, a flexible deadline for this homework is 03/29/2021. However, the sooner you get to it, the easier it will be.

Problem 1: This is data processing problem. It deals with the data observed by Hinode/SP, a space-borne spectropolarimeter. This instrument observes two magnetically sensitive photospheric lines of neutral Iron.

First, download the fits file with the data at this link.

You will see that the data is a 4D array with dimensions $NX \times NY \times 4 \times 112$. 4 stands for four Stokes components, we will only need first (zeroth) one, which is intensity. The last dimension is wavelength. To do this exercise you will need a wavelength "grid". In python you can create it by doing something like:

```
ll = np.linspace(0,111,112)
ll = (6300.875156521739 + ll * 0.021573913043480192 ) # in angstrom
```

(This is something that is known and given by the instrument designers).

We briefly mentioned in class that by finding the position of the line center (minimum) we can estimate the velocity in the given pixel. Plasma in some pixels is moving toward us and is thus blueshifted. In some pixels is it moving away and the position of the minimum is redshifted.

Devise a function that, given a spectrum and corresponding wavelengths estimates the velocity from the spectrum. Use that function to estimate velocity in each pixel and to make a velocity map. Does it physically make sense, considering what we know about solar granulation?

For this, you might want to treat lines one at the time (i.e. estimate the velocity only using one spectral line and then compare with what you get using other one).

Rest frame (unshifted) wavelengths of these lines are 6301.5008 and 6302.4932 angstrom.

To make your plot look nicer, you might want to "normalize" velocities by subtracting the mean of the whole image from the velocity map. This sets your "average" velocity to zero.

Keep in mind that simply finding the wavelength where intensity is minimum is probably not precise enough and your maps will look bad! Try fitting few points around where you know minimum must be with a convenient function.

Problem 2: Using the data from the previous problem and the referent 1D atmospheric data file (that can be downloaded at the same link, and that you are already familiar with from the hands-on), we will try to perform a very simple temperature diagnostics using these lines.

Main assumption that we will use is something that we covered in homework 1: Intensity we see at a given wavelength is approximately equal to the source function at the layer where optical depth **at that wavelength** is equal to one.

- First problem is that our data is in some arbitrary units. Knowing that average continuum over the whole map should be roughly equal to Planck function corresponding to the temperature at $\log \tau = 0$ (note that this is "referent" or the continuum optical depth) in our referent model, at wavelength of these two lines (approximately 630 nm), you can convert your counts to intensity units. ($\mathrm{W/m^2} \times \mathrm{srad} \times \mathrm{m}$).
- From this you can plot a map of continuum intensity in physical units and convert each individual intensity back to a temperature. This will allow you to make a map of the temperature at $\log \tau = 0$ (photosphere). Do values make sense? Are granules hotter and intergranules cooler?
- The conversion from counts to intensities is valid for all 112 wavelengths we are considering. So in principle, from each intensity we can find a temperature (by basically "inverting" Planck funtion). The problem is: How to relate a given wavelength to a specific atmospheric layer in a referent 1D model atmosphere?
- Try to do this by comparing average temperatures at each wavelength with referent 1D model and thus ascribing a specific $\log \tau$ to each wavelength point. This will allow you to relate each temperature map, at each wavelength, to a specific $\log \tau$.
- Congratulations! You just mapped, in a very approximate way, solar atmosphere in 3D!

Notes: Referent 1D atmosphere is in the .dat file in the same link as the fits file. You will need first column ($\log \tau$) and the third column (temperature). In indexing from zero notation, these are zeroth and second column.

Good luck!