Exercises for the IRIS-7 Workshop

Release 1.0

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CONTENTS

CHAPTER

ONE

INTRODUCTION

These exercises and tutorials were prepared for the IRIS-7 Workshop taking place in Weihai in April 2016. They cover the author's tutorial on IRIS data analysis.

The answers to most of these questions will be found in the IRIS documentation or the provided slides. Some of the questions will also require the user to search in the IRIS webpage, examine some of the data files, and run some IDL commands. For these it is assumed that the user has access to a machine with IDL and the solarsoft package installed (with the IRIS branch).

The tutorials are meant to be a guided starting point to data exploration and analysis with IRIS. They provide lists and descriptions of a few basic tasks, and the users and encouraged to explore further and advance from them.

CHAPTER

TWO

EXERCISE QUESTIONS

The following list of questions is a test of your knowledge of IRIS.

2.1 IRIS and data

2.1.1 What is the recommended IRIS data level for new users?

1. Level 0 data
2. Level 1 data
3. Level 2 data
4. Level 3 data

2.1.2 Which of the following statements is TRUE?

1. Level 2 data is level 1.5 data with cosmic rays removed
2. For SJIs there is no level 3 data
3. For spectral rasters, level 3 data cubes have a maximum of three dimensions
4. Level 1 data are flat-fielded and dark-subtracted

2.1.3 Were there limb observations on the 1st of March 2014?

2.1.4 With an OBS-ID=3800111235, what is the exposure time? How many steps has the raster?

2.1.5 Which of the following statements is TRUE?

1. It is possible to observe simultaneously in the FUV and NUV slit-jaws
2. The planning for IRIS observations takes place once per week
3. IRIS level 1 data is only available from the University of Oslo
4. The eclipse season of IRIS is from November to February

2.1.6 When observing a very large sit and stare with a 10s cadence and exposing the full detectors, how long can you observe until the spacecraft memory fills up (assume it was empty)?

2.1.7 Which of the following statements is FALSE?

1. Observing with a roll angle other than 0 can decrease the telemetry rate
2. The strongest line in the FUV 1 window is the Si IV 139 nm line
3. The step size of a dense raster is about 0.35 arcsec
4. The 283.2 nm slit-jaw image is formed in the chromosphere

2.1.8 Which of the following statements is TRUE?

1. The average data upload rate of IRIS is 0.7 Mbit/s
2. IRIS has a geosynchronous orbit
3. The IRIS motors allow it to safely point anywhere in the Sun in just a few seconds
4. IRIS gets colder when orbiting over Greenland, and this shifts the spectral lines

2.2 IRIS spectral lines

2.2.1 What is the approximate temperature coverage of the spectral lines observed by IRIS?

1. 10,000 K to 20,000 K
2. 5,000 K to 50,000 K
3. 4,500 K to 10,000,000 K
4. 10,000 K to 500,000 K

2.2.2 Which of the following statements is FALSE?

1. The IRIS 279.6 nm SJI is the best channel to align with the AIA coronal channels (17.1, 9.3, 21.1 nm, etc.)
2. The IRIS 140.0 nm SJI is the best channel to align with the AIA 170.0 nm channel
3. The IRIS 283.2 nm SJI is the best channel to align with the HMI continuum image
4. The WCS keywords in the IRIS file headers are obtained by cross correlation of the slit-jaw images with AIA

2.2.3 Which of these lines is formed in higher temperatures?

2.2.4 Which of the following statements is TRUE?

1. The spectral lines in the NUV window provide velocity diagnostics for several heights from the photosphere to the mid chromosphere
2. The spectral lines in the FUV 1 window provide temperature diagnostics for several heights from the convective zone to the photosphere
3. The C II lines at 133.5 nm have a higher signal to noise ratio than the Mg II h and k lines

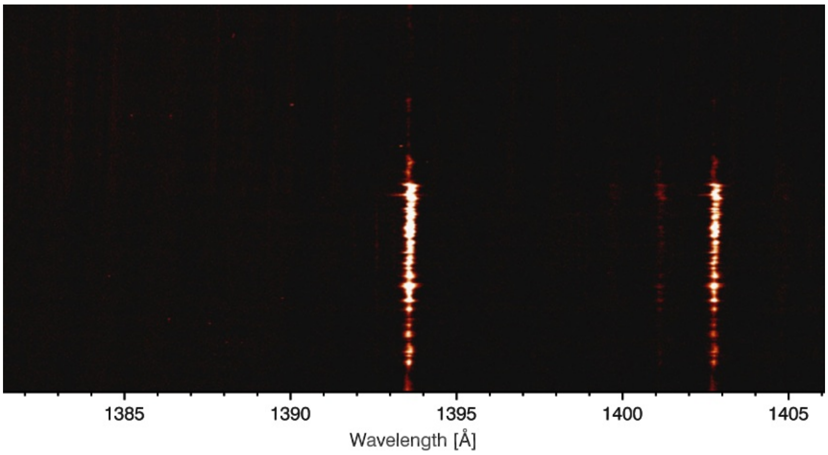


Figure 2.1: You will need to click on the correct line when answering.

4. The Fe XII line is observed only in the quiet sun

2.3 CRISPEX

2.3.1 What data formats cannot be used with CRISPEX?

1. *La Palma* cube format
2. IRIS level 3 FITS files
3. Any FITS file

2.3.2 Which of the following statements is TRUE?

1. The `im` files contain the images, while the `sp` files contain the spectra
2. The `sp` files are a transposed version of the `im` files for faster reading
3. The `im` files contain Stokes I, while the `sp` files contain Stokes U, Q, V
4. The `sp` files must always be used, while the `im` files are optional

2.3.3 Which of the following statements is FALSE?

1. CRISPEX uses the WCS keywords in the IRIS files to calculate the solar (x, y) coordinates
2. With IRIS files CRISPEX loads the first timestep into memory to calculate scaling factors
3. The y scale of the detailed spectrum window can be adjusted in the *Displays* tab
4. The maximum animation speed is 10 frames per second

CHAPTER

THREE

TUTORIALS

These tutorials comprise step-by-step instructions and exercises to perform some tasks with IRIS data and CRISPEX. As time allows, these will be done by participants in the tutorial session. Most of these tutorials are also included in section 8 of the User's Guide to IRIS Data Analysis (ITN 26).

> **Warning:** Several of the tutorials (in particular CRISPEX) require a minimum of 4 Gb of RAM, and a 64-bit version of IDL. If you have 4 Gb of RAM or more, make sure you have a 64-bit version of IDL. If you have less than 4 Gb of RAM, please sit next to someone that has such a laptop so you can work in groups. To check if your IDL is 64-bit, start IDL from the command line and look for the first line, eg: `IDL Version 8.5 (linux x86_64 m64)` (if it was 32-bit, it would say `x86_32 m32`).

3.1 Preparation

The data files for these tutorials were hopefully passed on to participants before. Otherwise, they can be downloaded from http://folk.uio.no/tiago/iris7/IRISdata.zip. This file contains several datasets from IRIS. Throughout the tutorials it is assumed that this file is unpacked into a directory in your home directory named `data_temp/`. If you want to use a different directory, just replace the name when necessary.

> **Note:** The data file is 2.6 Gb. If you can, please download it before the workshop (or copy from someone) it to prevent any network bottlenecks at the workshop.

> **Warning:** The data file upacks to about 6 Gb in size. Please make sure you have at least 10 Gb of free disk space (ideally 12 Gb) to keep all the data and temporary files. Unpacking will take about 5-15 minutes.

To start, create a directory called `data_temp` and unzip the data in there. In the Unix terminal, you can do it like this:

```
% mkdir ~/data_temp
% cp IRISdata.zip ~/data_temp
% cd ~/data_temp
% unzip IRISdata.zip
(...)
```

Make sure you are in the same directory as the `IRISdata.zip` file. This will create a directory `~/data_temp/iris` with three subdirectories, one per dataset.

You will need to make sure that you have an up-to-date version of SolarSoft IDL with the IRIS branch. You'll need to have included `iris` in the `SSW_INSTR` environment variable, e.g.:

```
setenv SSW_INSTR "sot iris ontology"
```

If you have a working version of SolarSoft with the IRIS package you don't need to do anything else.

It is outside the scope of these tutorials to help you install and configure SolarSoft. If you don't have it already in your system we provide a tar file with a minimal version that can be used to run the tutorials. This minimal version of SolarSoft has not been tested in many platforms, and is not guaranteed to work. It should be used as a last resort only for those who didn't have time to do a proper installation. To install it, download the file http://folk.uio.no/tiago/iris5/ssw_iris_minimal.tar.bz2 (483 Mb) and unpack it to your home directory:

```
tar jxvf ssw_iris_minimal.tar.bz2 -C ~/
```

(Again we assume the you are in the same directory as the file) This will create a directory `~/ssw` with an installation of SolarSoft. Now configure the startup file for your shell, typically `~/.cshrc` or `~/.tcshrc` (you MUST use csh or tcsh – bash et al. will not work). Add the following lines to your configuration file:

```
setenv SSW $HOME/ssw
setenv SSW_INSTR "sot iris ontology"
```

After that, start a new shell and type `sswidl`. If all went well you have SolarSoft working and are ready to run the tutorials!

3.2 IRIS xfiles

This tutorial will guide you step-by-step into some features of `iris_xfiles`, a quicklook tool. Go to the directory with the IRIS data, open solarsoft IDL and launch `iris_xfiles`:

```
% cd ~/data_temp/iris
% sswidl
(...)
IDL> iris_xfiles
```

Note: It is important that you start IDL on the `~/data_temp/iris` directory, and from the command line. Not doing so will result in files you create later being saved in a different directory, and some of the instructions here will not be correct. If you do not run IDL from the `~/data_temp/iris` directory, make note of where you run it from, so you can find your files later on.

In the middle panel, next to **Search Directory:** press **Change**. Then navigate to the directory `~/data_temp/iris/20131226_171752_3840007146`, press **OK** when this directory is selected. Notice that **Search Pattern** changed to **free search**. Make sure the time of these observations (2013 December 26, 17:17 UT) is contained in between the **Start Time** and **Stop Time** range, adjust if necessary.

Now press **Start Search**, and you should see the list of files appear. Feel free to check the slit-jaw movies and then double click on the raster file. What can you say about the line list?

Select the Si IV 1403 line and under **Line fit** select **Profile Moments**. On the **Moments Prep Tool** window adjust the reference wavelength so that it matches the core of the line, and set the line start and stop so that it covers the line. Set the continuum to be about 5-10 pixels wide on a region with no lines. Press **Finished** (and wait a while...). What do you see?

The result for intensity should look like this (set *log(HistoOpt Value)* to -1.65):

Now select the Mg II k 2796 line instead, and choose again **Profile moments**. Set the line start and stop so that it is about 5 pixels wide around k3. Set the continuum to be about 5 pixels wide on the right side of the plot, in a region with no absorption lines. The result for intensity should look like this:

Note: The single or double Gauss fit options in Line fit are not currently working.

Go back to the `IRIS_Xcontrol` window of the raster file. Select the Si IV 1403 and Mg II k 2796 lines and press **Generate level3 files**. In the next dialog select only *add "20131226_171752_3840007146/" to save directory*, so that the level 3 file is saved in the existing directory. We will use this level 3 file later with CRISPEX. Note that no `sp` file was created, as these observations comprise only a single 400-step raster.

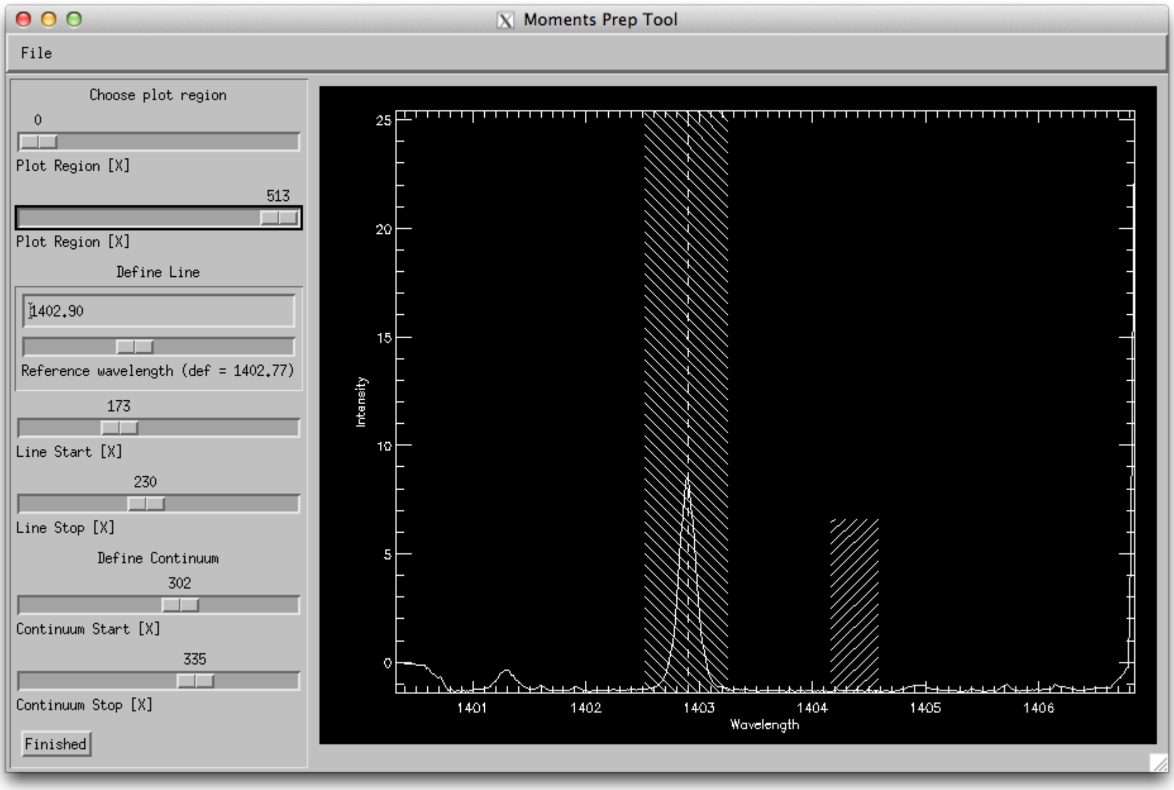


Figure 3.1: How the wavelength selection `iris_xfiles` moment tool should look like.

3.3 Mg II Dopplergrams

In this tutorial we are going to produce a Dopplergram for the Mg II k line from an IRIS 400-step raster. The Dopplergram is obtained by subtracting the intensities at symmetrical velocity shifts from the line core (e.g. ±50 km/s). For this kind of analysis we need a consistent wavelength calibration for each step of the raster.

The data set directory should be:

```
IDL> data_dir = '~/data_temp/iris/20140708_114109_3824262996'
```

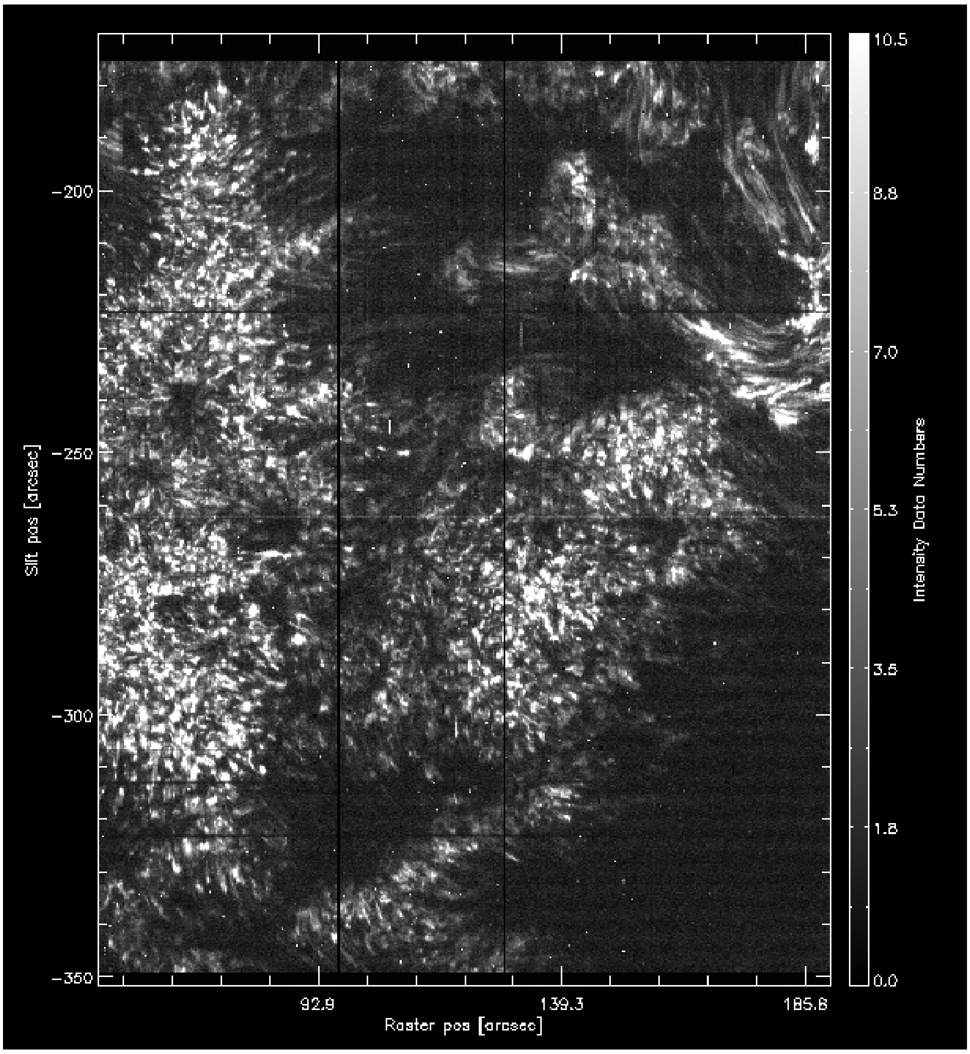
Feel free to examine these data in `iris_xfiles`. This very large dense raster took more than three hours to complete the 400 scans (30 s exposures), which means that the orbital velocity and thermal drifts were changed during the observations. This means that any precise wavelength calibration will need to correct for those shifts. In most cases level 2 data have already been corrected for these shifts, but this example shows a dataset for which the automatic calibration still left a significant component which must be corrected for.

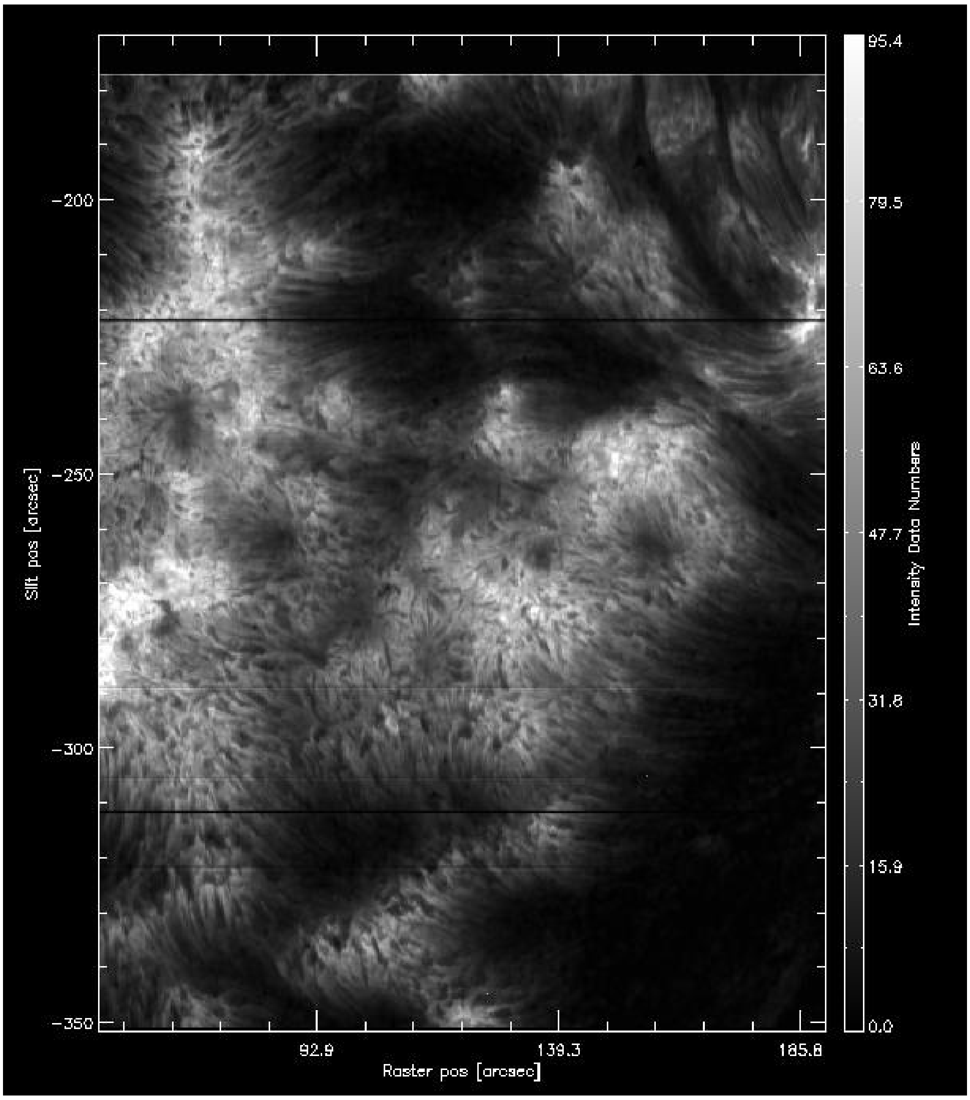
First lets load the data using the IDL object interface:

```
IDL> filename = 'iris_l2_20140708_114109_3824262996_raster_t000_r00000.fits'
IDL> filename = data_dir + '/' + filename
IDL> d = iris_obj(filename)
```

Let us see the lines that are saved in this raster:

```
IDL> d->show_lines
Spectral regions(windows)
0   1335.71   C II 1336
1   1349.43   Fe XII 1349
2   1355.60   O I 1356
3   1393.78   Si IV 1394
4   1402.77   Si IV 1403
5   2832.70   2832
```


-200
-250
-300
-350
Slit pos [arcsec]
92.9
139.3
185.8
Raster pos [arcsec]
10.5
8.8
7.0
5.3
3.5
1.8
0.0
Intensity Data Numbers



95.4
79.5
63.6
47.7
31.8
15.9
0.0
Intensity Data Numbers
−200
−250
−300
−350
Slit pos [arcsec]
92.9
139.3
185.8
Raster pos [arcsec]

```
6   2814.43   2814
7   2796.20   Mg II k 2796
```

Let us load the Mg II k line into memory:

```
IDL> wave = d->getlam(7)
IDL> data = d->getvar(7, /load)
```

We can see how the the spatially averaged spectrum looks like:

```
IDL> mspec = total(total(data, 2), 2)
IDL> plot, wave, mspec
IDL> plot, wave, mspec, xrange=[2794, 2799], /xst
```

To better understand the orbital velocity problem let us look at how the line intensity varies for a strong Mn I line at around 280.2 nm, in between the Mg II k and h lines. For this dataset, the line core of this line falls around index 350. To plot it in the correct orientation we will make use of IDL's `rotate`, and the procedure `pih` (available in the IRIS tree of solarsoft) to make the plot:

```
IDL> pih, rotate(reform(data[350, *, *]), 1), min=0, max=200, scale=[0.35, 0.1667]
```

The result should look like this:

You can see that the left side of the figure is brighter, and indication that its intensities are not taken at the same position in the line because of wavelength shifts.

To calculate the wavelength shifts from the orbital velocity and thermal drifts we do the following:

```
IDL> wavecorr = iris_prep_wavecorr_l2(filename)
```

This routine measures the wavelength position of 5 neutral lines (3 NUV, 2 FUV) whose rest wavelengths are reasonably well known, and saves the shifts (in Ångström) into the structure variable called `wavecorr`.

The wavelength shift in the i-th line in the j-th frame of the k-th input file is stored in `wavecorr.corrs[k, j, i]` . Averaged and smoothed corrections for the NUV and FUV are stored in `corr_nuv` and `corr_fuv`. To plot the per-frame measured wavelength shift and the smoothed correction in the NUV and FUV one would do:

```
IDL> utplot, wavecorr.times, wavecorr.corrs[0,*,0], psym = 4, chars = 1.5, title = 'NUV', ytitle =
IDL> outplot, wavecorr.times, wavecorr.corr_nuv, col = 2, thick = 2
```

To look at intensities at any given scan we only need to subtract this shift from the wavelength scale, but to look at the whole image at a given wavelength we must interpolate the original data to take this shift into account. Here is a way to do it (note that array dimensions apply to this specific set only!):

```
IDL> new_data = fltarr(536, 1094, 400, /n)
IDL> ; subtract mean shift
IDL> wavecorr.corr_nuv = wavecorr.corr_nuv - mean(wavecorr.corr_nuv)
IDL> .r
for i=0, 399 do begin
   for j=0, 1093 do begin
       new_data[*, j, i] = interpol(data[*, j, i], wave + wavecorr.corr_nuv[i], wave)
   endfor
endfor
end
```

(This double loop will take a while to complete.)

Once you have the calibrated data, we can compare again how it looks at the Mn I line wavelength:

```
IDL> pih, rotate(reform(new_data[350, *, *]), 1), min=0, max=200, scale=[0.35, 0.1667]
```

And now we can see that the intensity map is uniform along the solar disk:

We can use this calibrated data for example to calculate dopplergrams. A dopplergram is the difference between the intensities at two wavelength positions at the same (and opposite) distance from the line core. For example,

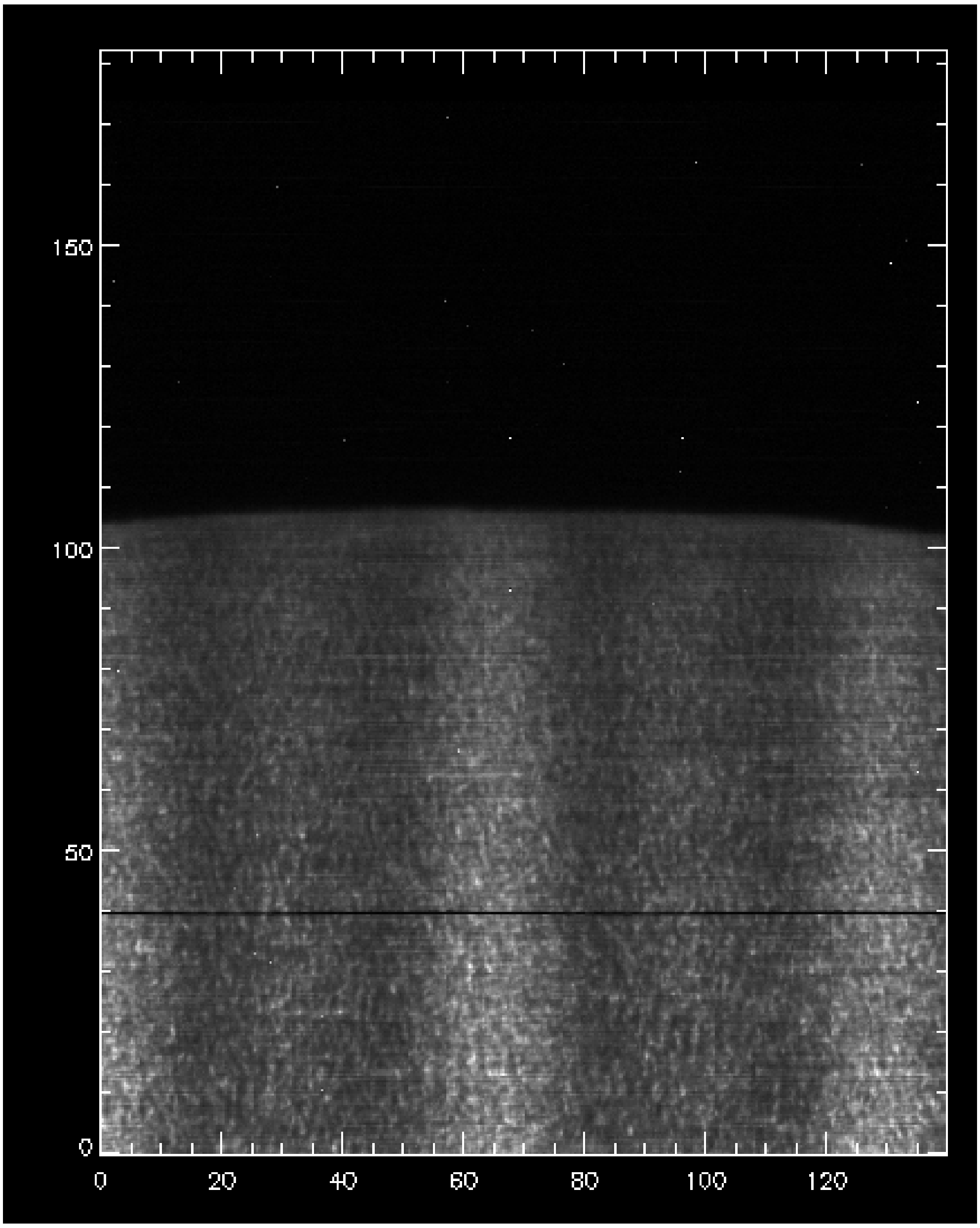


Figure 3.2: Intensity at Mn I 280.2 nm line when orbital velocity and thermal drifts are **not** accounted for.

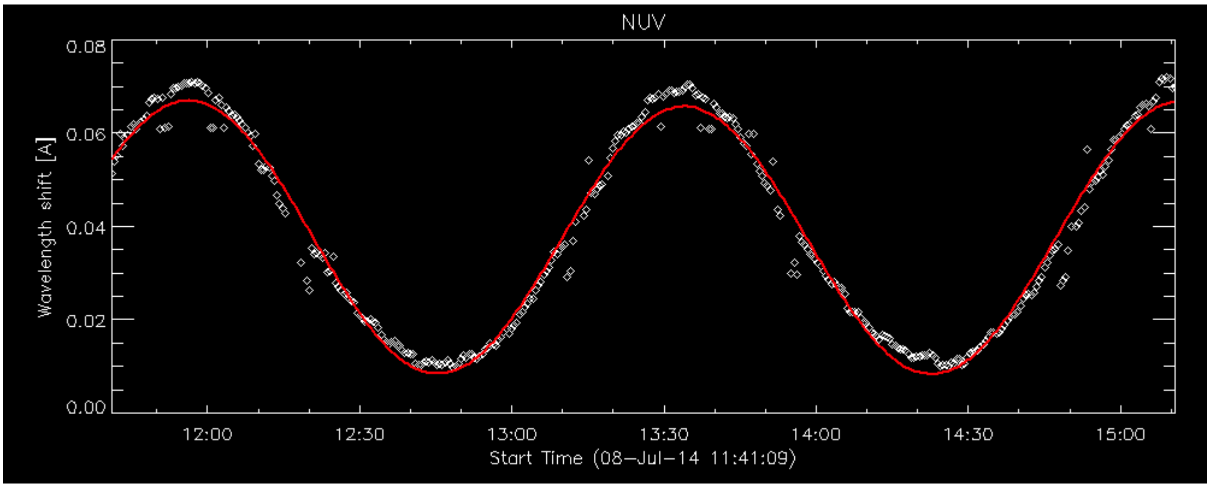


Figure 3.3: Fit to the orbital velocity/thermal shifts from `iris_prep_wavecorr_l2`. Your colours may appear different from this figure, depending on which color table you loaded.

at +/- 50 km/s from the Mg II k3 core. To do this, let us first calculate a velocity scale for the k line and find the indices of the -50 and +50 km/s velocity positions:

```
IDL> k_centre = 2796.31
IDL> vel = (k_centre - wave) * 3e5 / h_centre
IDL> ; find index of -50 and 50 km/s
IDL> tmp = min(abs(vel - 50), i50p)
IDL> tmp = min(abs(vel + 50), i50m)
```

Now get the dopplergram and plot it:

```
IDL> doppgr = rotate(reform(new_data[i50m, *, *] - new_data[i50p, *, *]), 1)
IDL> pih, doppgr, min=-80, max=80, scale=[0.35, 0.1667]
```

3.4 Mg II spectral feature identification

In this tutorial we will measure the intensities and velocity shifts of the Mg II k3 and k2 features. We will make use of the `iris_get_mg_features_lev2` procedure, which is included in the IRIS SSW package.

Here we will use the same dataset as for the tutorial *IRIS xfiles* above. The files can be loaded like this:

```
IDL> data_dir = '~/data_temp/iris/20131226_171752_3840007146'
IDL> filename = 'iris_l2_20131226_171752_3840007146_raster_t000_r00000.fits'
IDL> filename = data_dir + '/' + filename
```

We can calculate the properties of the Mg II k line in the following manner:

```
IDL> iris_get_mg_features_lev2, filename, 3, [-40, 40], lc, rp, bp, /onlyk
```

The output was saved in the arrays *lc* (line centre), *rp* (red peak), and *bp* (blue peak). To save time we calculated only for the k line. We can then visualise both the derived velocities and intensities. For the intensities:

```
IDL> pih, rotate(reform(lc[0, 1, *, *]), 1), min=0, max=500,  scale=[0.35, 0.1667]
IDL> pih, rotate(reform(bp[0, 1, *, *]), 1), min=0, max=750,  scale=[0.35, 0.1667]
IDL> pih, rotate(reform(rp[0, 1, *, *]), 1), min=0, max=750,  scale=[0.35, 0.1667]
```

and for the velocities:

```
IDL> pih, rotate(reform(lc[0, 0, *, *]), 1), min=-15, max=15,  scale=[0.35, 0.1667]
IDL> pih, rotate(reform(rp[0, 0, *, *]), 1), min=0, max=30,  scale=[0.35, 0.1667]
IDL> pih, rotate(reform(bp[0, 0, *, *]), 1), min=-30, max=0,  scale=[0.35, 0.1667]
```

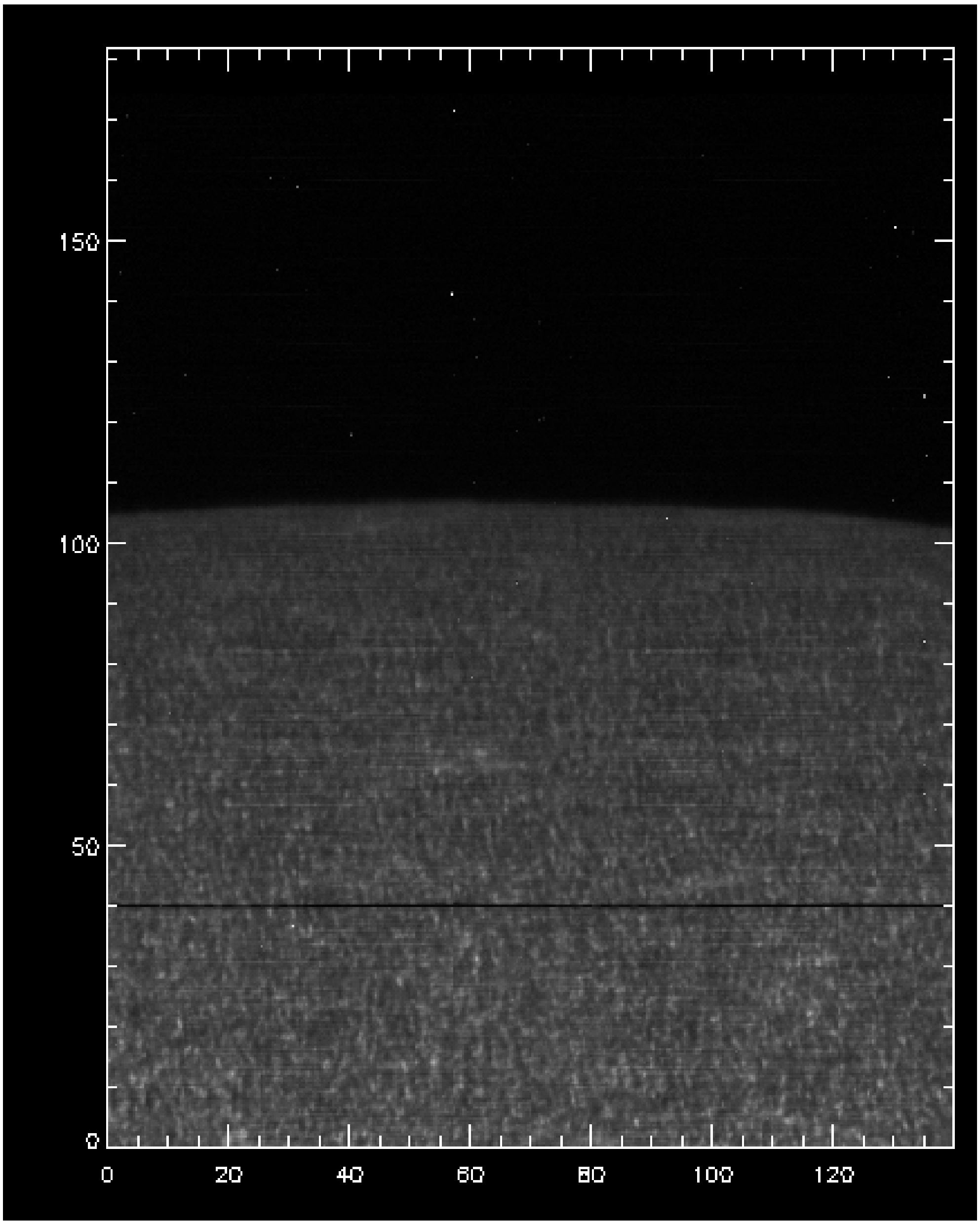


Figure 3.4: Intensity at Mn I 280.2 nm line when orbital velocity and thermal drifts are accounted for.

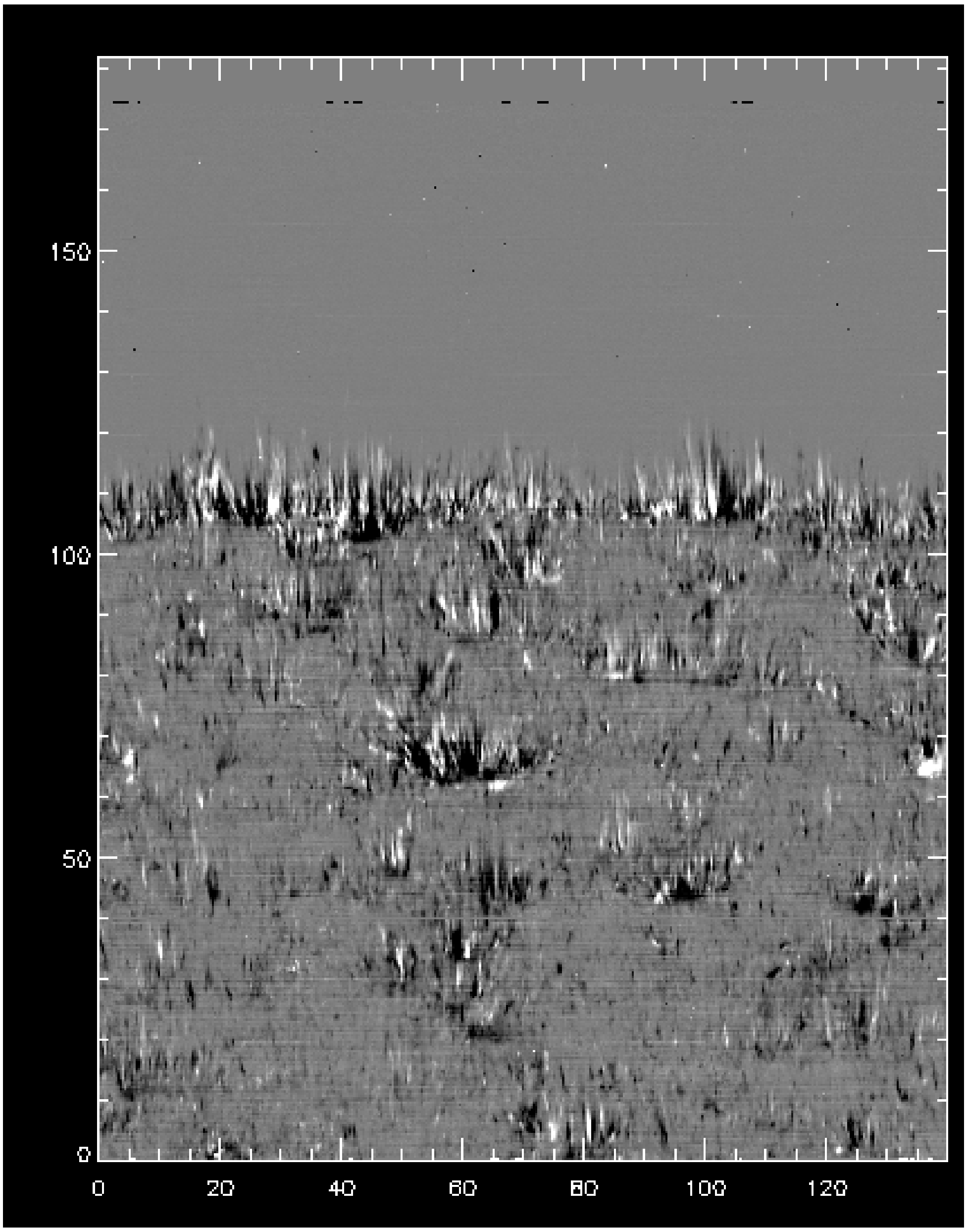


Figure 3.5: Dopplegram for Mg II k at +/- 50 km/s.

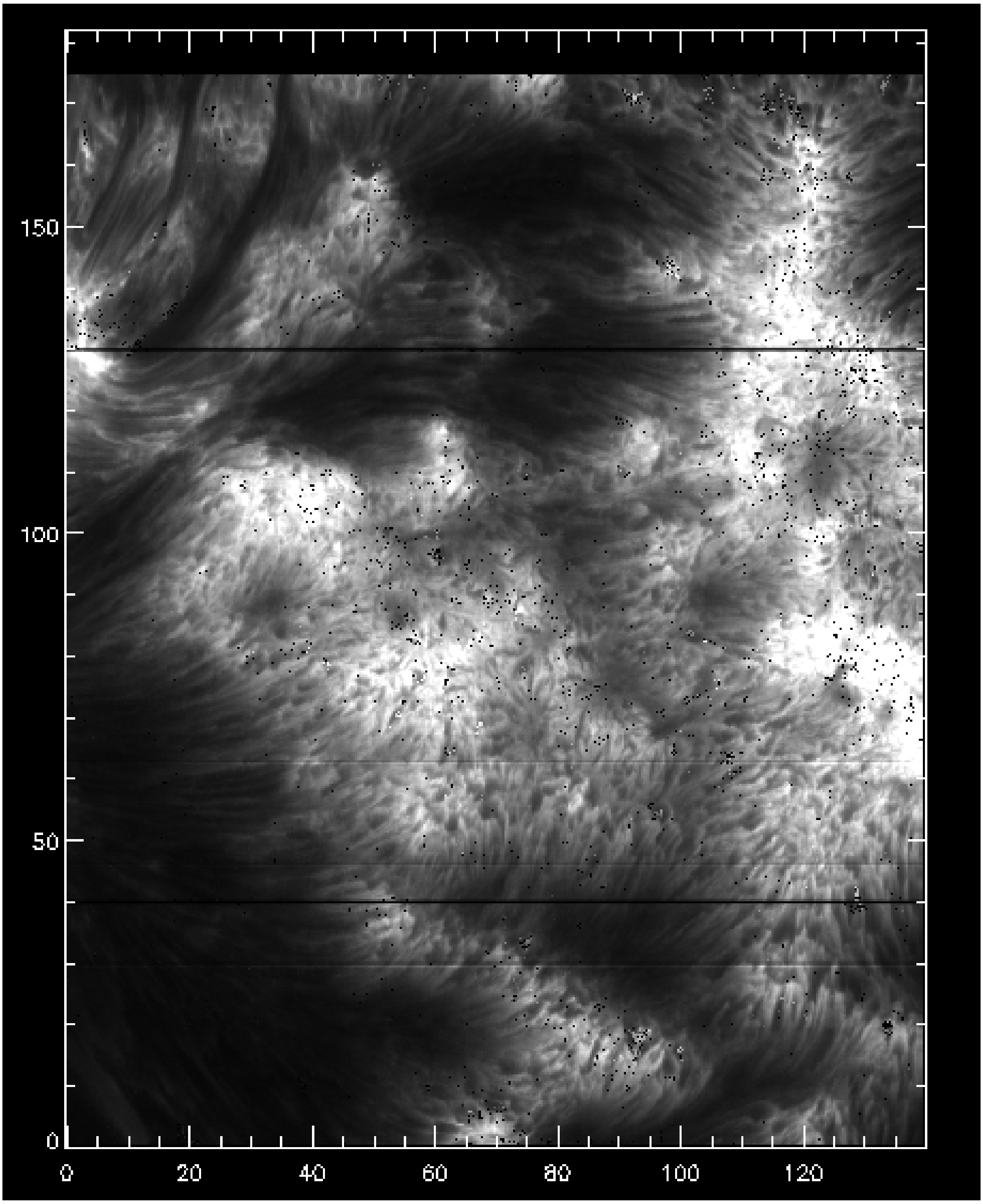


Figure 3.6: Intensity for the k3 peak from `iris_get_mg_features`.

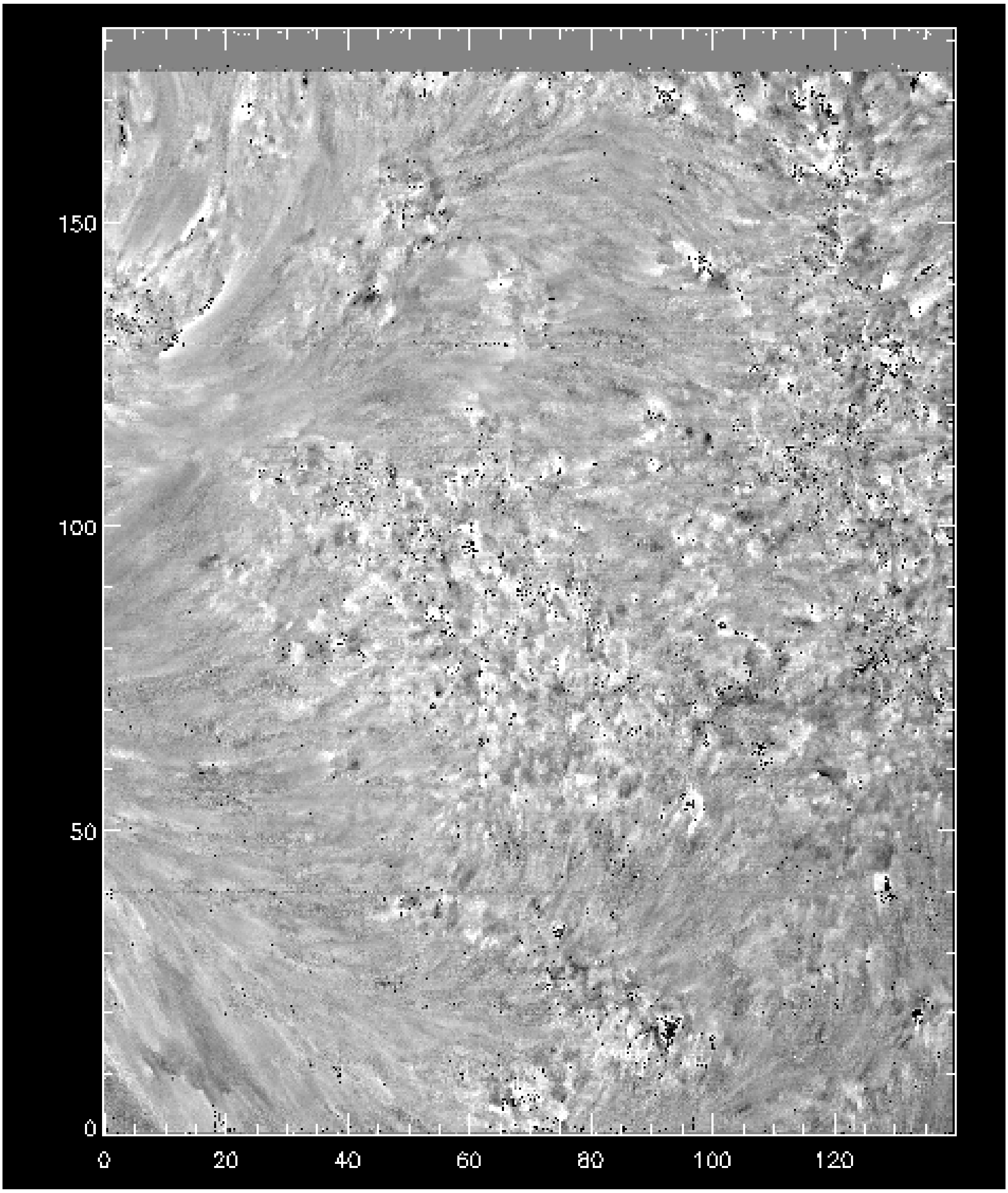


Figure 3.7: Velocity shifts for the k3 peak from `iris_get_mg_features`.

3.5 CRISPEX

3.5.1 Active region 400-step raster

Let us go back to the directory of the first dataset we worked with, and run CRISPEX on the level 3 file:

```
IDL> cd, '~/data_temp/iris/20131226_171752_3840007146'
IDL> crispex, 'iris_l3_20131226_171752_3840007146_t000_SiIV1403_MgIIk2796_im.fits'
```

Note: If you haven't created the level 3 file with `iris_xfiles`, you can create it quickly from the IDL command line (assuming you are at the directory with the level 2 files):

```
IDL> f = iris_files('*raster*')
IDL> iris_make_fits_level3, f, [1, 3]
```

Explore the dataset with CRISPEX, and go through the following tasks/questions:

- Adjust the scaling of the spectral plot so that the lines are visible (*Displays* tab, lower/upper y-values, and also multipliers in *Scaling* tab under *Detailed spectrum*)
- Look at the main image in the cores of the Mg II k and Si IV lines. Adjust scaling for Si IV 1403 so that it becomes visible (change *Histogram optimisation* to 0.001 and/or set gamma lower than 1)
- Blink the image between the spectral positions of the cores of the Si IV and Mg II k lines (use animation speed of about 2 frames/s)
- Can you find a large dot where Si IV is greatly enhanced but Mg II is not too unusual? What are its solar (x, y) coordinates?
- Is there a sunspot or a pore in these observations? How do you find out?

3.5.2 Penumbral 16-step raster

Now let us look at a different type of IRIS observation, a 16-step dense raster with 100 repeats. We have not yet produced the level 3 files for this dataset, so let us change directory and do that from IDL:

```
IDL> cd, '~/data_temp/iris/20140630_205235_3820255482'
IDL> f = iris_files('*raster*')
IDL> ; make level 3 files with C II, Si IV, and Mg II (indices 0, 3, 7)
IDL> iris_make_fits_level3, f, [0, 3, 7], /sp
```

Let us now run CRISPEX using both im and sp files, and also use a slit-jaw image:

```
IDL> l3files = iris_files('iris_l3*')
IDL> sji = iris_files('*SJI*')
IDL> crispex, l3files[0], l3files[1], sjicube=sji[0]
```

When CRISPEX opens, you can see multiple windows, including the slit-jaw image with the 16 raster positions superimposed.

In CRISPEX the visualisation of this dataset has both a time domain and a main image with 16 columns. Feel free to explore this dataset, first by creating the level 3 files and loading them in CRISPEX. When used with a `sjicube` option, one can see the 16 positions superimposed in the slit-jaw image.

Explore the dataset with CRISPEX, and go through the following tasks/questions:

- Start running the time sequence. At what time does this observation finish?
- Adjust the scaling in of the detailed spectra so you can see the C II and S IV lines
- Where can you find the strongest brightenings in TR lines?
- Show only the Mg II k line (*Diagnostics* tab, unselect other lines and then *Spectral* tab, narrow down Doppler minimum/maximum values)

- Lock the mouse at a given position, see how the temporal evolution goes through the *Spectral T-slice* window
- Can you find a location with shock signatures in Mg II?