AGA5802
Reduction of Spectroscopic Data

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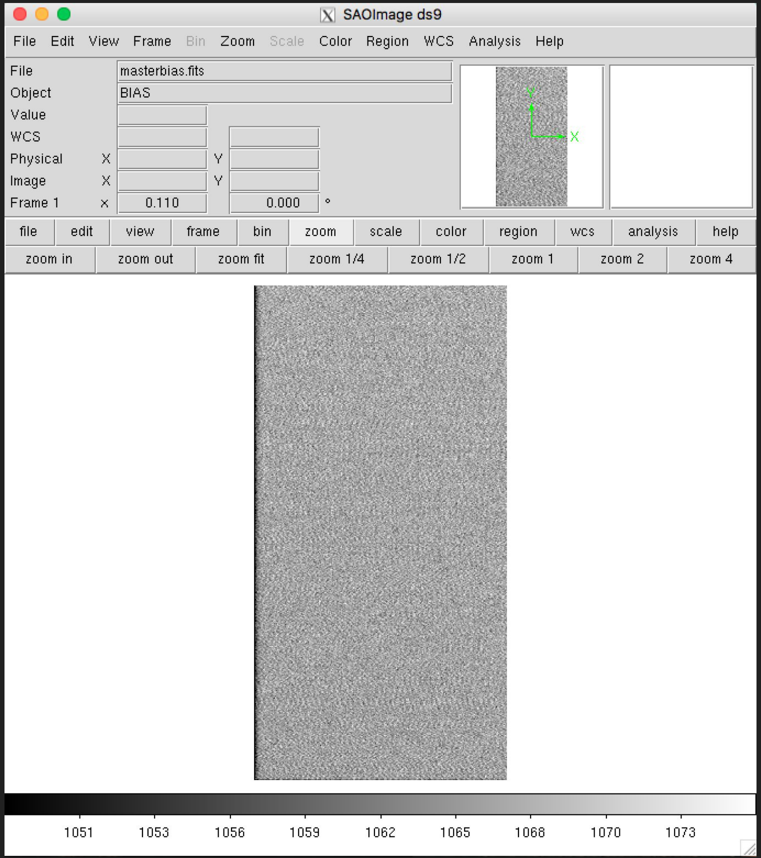
Reducing a spectrum (long slit)

- Bias or overscan subtraction
- Flat removal
- Wavelength calibration
- Flux calibration

The bias

```
ccdred> imstat bias*
#               IMAGE      NPIX      MEAN    STDDEV       MIN       MAX
           bias1.fits   2151499     1067.     36.72        0.     8648.
           bias2.fits   2151499     1067.     36.68        0.    12471.
           bias3.fits   2151499     1067.     36.71        0.     9853.
```

```
ccdred> zerocombine bias*.fits output=masterbias.fits ccdtype=""
ccdred> imstat masterbias.fits
#               IMAGE      NPIX      MEAN    STDDEV       MIN       MAX
      masterbias.fits   2151499     1065.     35.12        0.     1081.
```



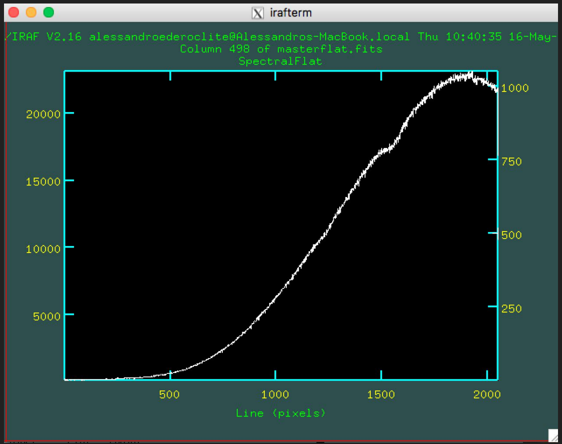
The flat field

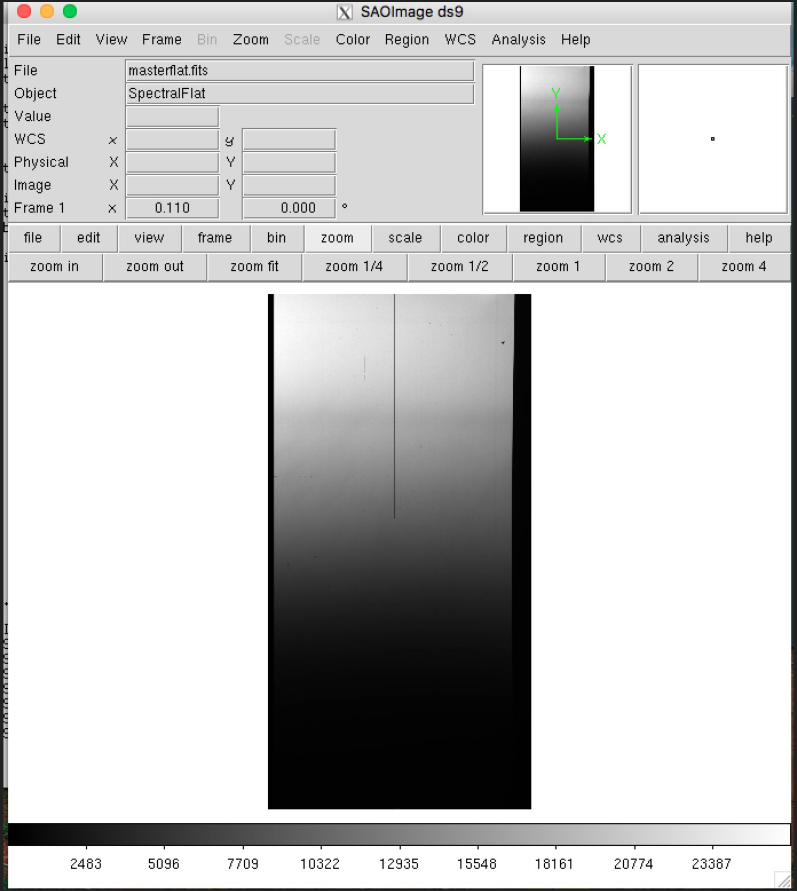
```
ccdred> ccdproc @flats.lis output=b//@flats.lis ccdtype="" fixpix- overscan- trim- zerocor+ \
darkcor- flatcor- zero=masterbias.fits
```

```
ccdred> flatcombine b//@flats.lis output=masterflat.fits ccdtype="" process- subsets-
```

```
ccdred> imstat *lat*fits
```

# IMAGE	NPIX	MEAN	STDDEV	MIN	MAX
bflat1.fits	2151499	8433.	8568.	-26.	28985.
bflat2.fits	2151499	8337.	8482.	-24.5	28546.
bflat3.fits	2151499	8292.	8443.	-17.5	28384.
flat1.fits	2151499	9498.	8570.	0.	30057.
flat2.fits	2151499	9401.	8484.	0.	29618.
flat3.fits	2151499	9357.	8445.	0.	29456.
masterflat.fits	2151499	8354.	8498.	-16.46	28638.

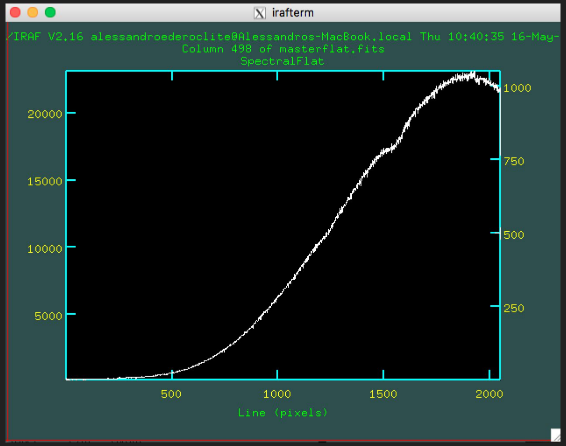


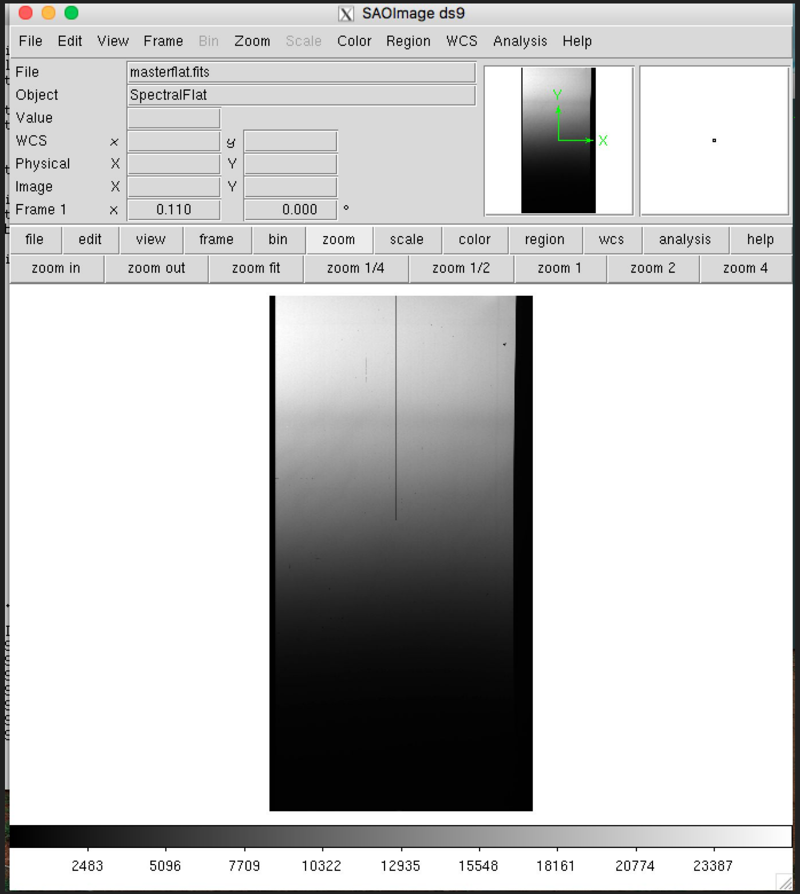


The flat field

Image of a halogen lamp to get “white light” through the spectrograph.

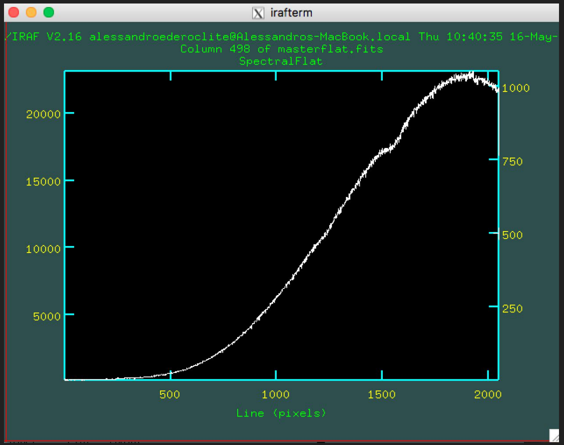
In one direction you get the illumination across the slit and in the other direction the spectral response of your optical system.





The flat field

```
ccdred> imstat *lat*fits
#               IMAGE      NPIX      MEAN    STDDEV       MIN       MAX
           bflat1.fits   2151499     8433.     8568.      -26.    28985.
           bflat2.fits   2151499     8337.     8482.     -24.5    28546.
           bflat3.fits   2151499     8292.     8443.     -17.5    28384.
            flat1.fits   2151499     9498.     8570.        0.    30057.
            flat2.fits   2151499     9401.     8484.        0.    29618.
            flat3.fits   2151499     9357.     8445.        0.    29456.
       masterflat.fits   2151499     8354.     8498.    -16.46    28638.
```



In general, spectroscopic flat fields are either taken in the dome or within the instrument.

It is much easier to have a stable level.

In general, you would have to rescale the flats to a similar level! (I noticed I did not explain this in the imaging reduction).

If you observe an extended object, you may want to take a sky flat as well, to take into account properly the illumination along the slit.

Normalize flat #1

```
ccdred> imcopy masterbias.fits[100:400,*] t_masterbias.fits
masterbias.fits[100:400,*] -> t_masterbias.fits
ccdred> imcopy masterflat.fits[100:400,*] t_masterflat.fits
masterflat.fits[100:400,*] -> t_masterflat.fits
ccdred> imcopy arc.fits[100:400,*] t_arc.fits
arc.fits[100:400,*] -> t_arc.fits
ccdred> imcopy std.fits[100:400,*] t_std.fits
std.fits[100:400,*] -> t_std.fits
```

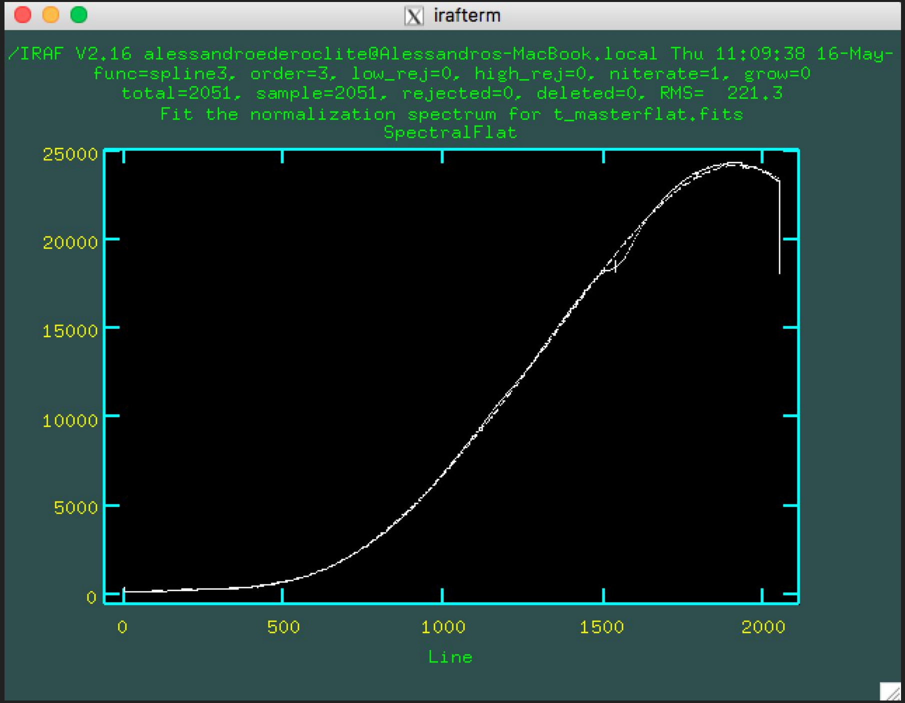
Normalize flat

```
ccdred> twod
      apextract.  longslit.

twodspec> longsli
      aidpars@        demos           fitcoords       lscombine       sensfunc        specshift
      autoidentify    deredden        fluxcalib       reidentify      setairmass      splot
      background      dopcor          identify        response        setjd           standard
      bplot           extinction      illumination    sarith          sflip           transform
      calibrate       fceval          lcalib          scopy           specplot
```

```
longslit> longslit.dispaxis=2
longslit> lpar longslit
     dispaxis = 2               Dispersion axis (1=along lines, 2=along columns, 3=along z)
        (nsum = "1")            Number of lines/columns to sum
 (observatory = "observatory")  Observatory of data
  (extinction = "onedstds$kpnoextinct.dat") Extinction file
      (caldir = "onedstds$spec50cal/") Standard star calibration directory
      (interp = "poly5")        Interpolation type
     (records = "")             Record number extensions
     (version = "February 1993")
        (mode = "ql")
      ($nargs = 0)
```

Normalize flat #2

```
longslit> lpar response
  calibration =                  Longslit calibration images
 normalizatio =                  Normalization spectrum images
     response =                  Response function images
 (interactive = yes)             Fit normalization spectrum interactively?
   (threshold = INDEF)           Response threshold
      (sample = "*")             Sample of points to use in fit
    (naverage = 1)               Number of points in sample averaging
    (function = "spline3")       Fitting function
       (order = 3)               Order of fitting function
  (low_reject = 0.)              Low rejection in sigma of fit
 (high_reject = 0.)              High rejection in sigma of fit
    (niterate = 1)               Number of rejection iterations
        (grow = 0.)              Rejection growing radius
    (graphics = "stdgraph")      Graphics output device
      (cursor = "")              Graphics cursor input
        (mode = "al")
longslit> response t_masterflat.fits t_masterflat.fits n_t_masterflat.fits
Fit the normalization spectrum for t_masterflat.fits interactively (yes):
Dispersion axis (1=along lines, 2=along columns, 3=along z) (1:3) (2):
```

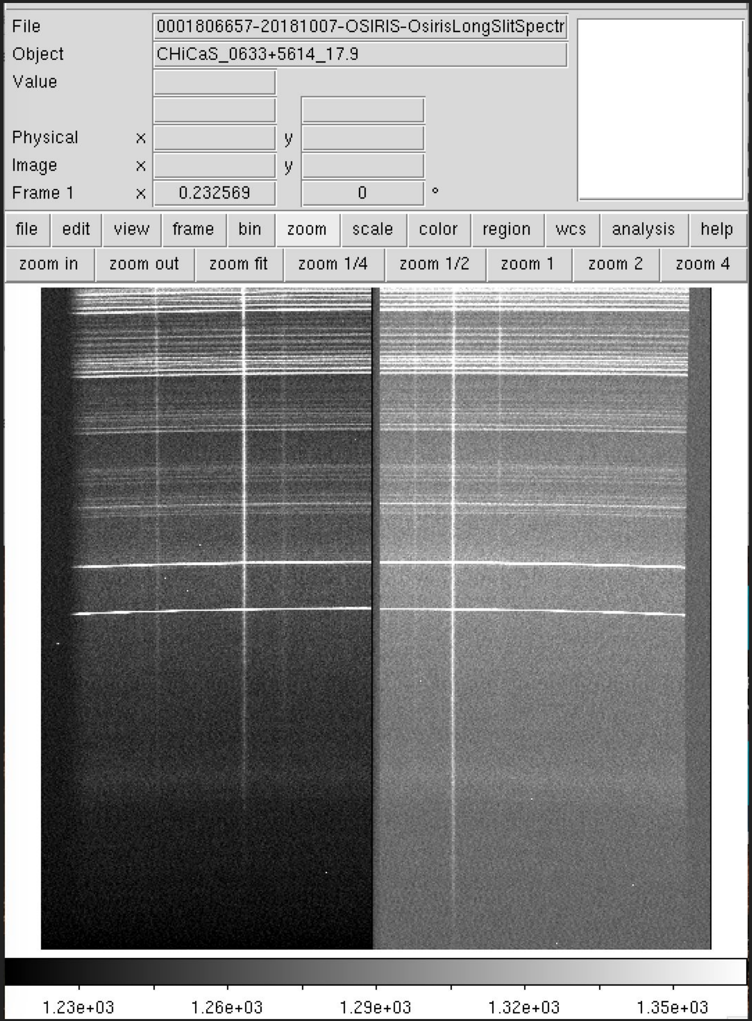


Spectrum reduction

This is an object i observed with GTC/OSIRIS.My object is the long spectrum on the right.

You can see that the are other vertical lines: these are other spectra.

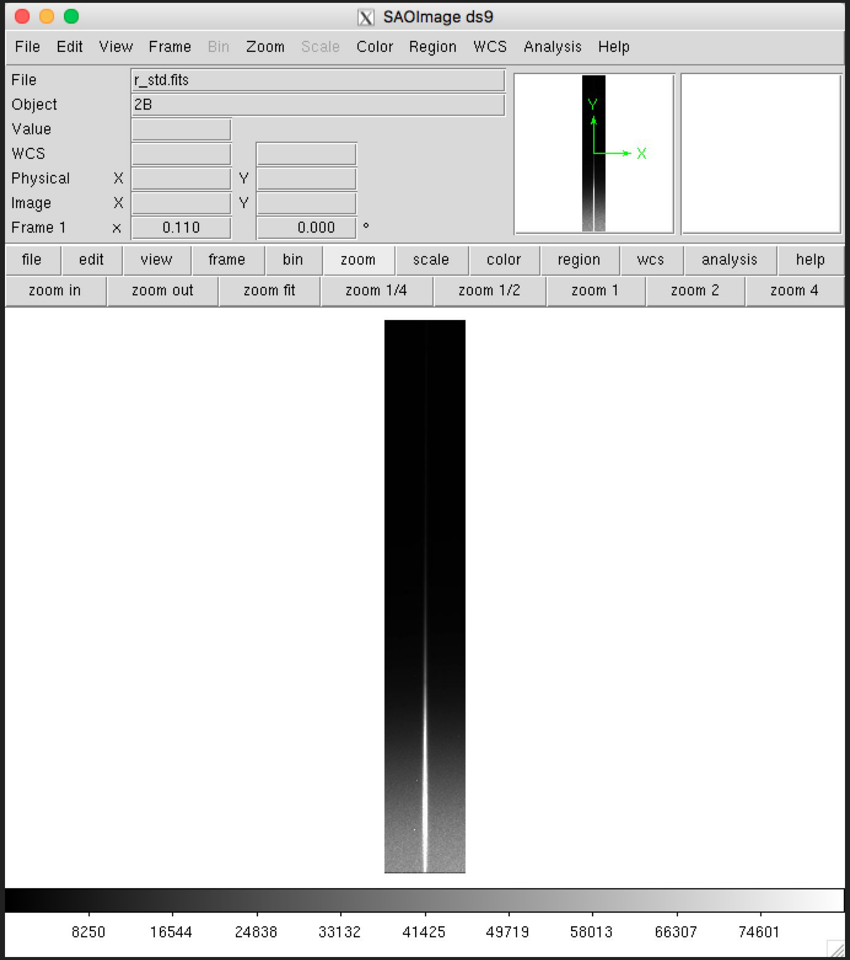
Spectra are slightly curved (more later). The curvature depends on their position along the slit. If it was an extended object, I should model this curvature (either with a pinhole mask or by taking spectra of several point sources along the slit)



Spectrum reduction

I like to make an aggressive trimming of my spectrum and only get with the spectrum and a little more space (the extra space guarantees me that I will have space for background subtraction).

This is bias and flat subtraction as in an image.



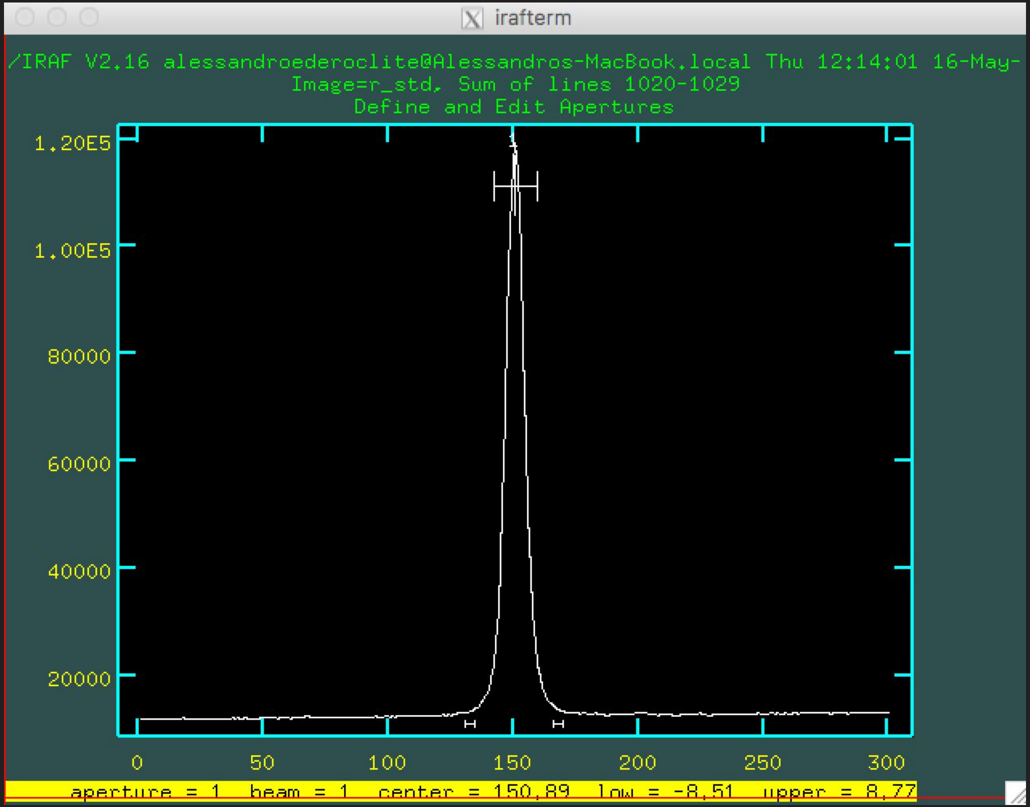

```
longslit> ccdproc t_std.fits output=r_std.fits ccdtype="" fixpix- overscan- trim- zerocor- \
>>> darkcor- flatcor+ zero=t_masterbias.fits flat=t_masterflat.fits
```

Extract the spectrum

```
longslit> specred
      aidpars@        aprecenter      continuum       lscombine       scopy           specplot
      apall           apresize        deredden        msresp1d        sensfunc        specshift
      apdefault@      apscatter       dispcor         odcombine       setairmass      splot
      apedit          apsum           dofibers        refspectra      setjd           standard
      apfind          aptrace         dopcor          reidentify      sfit            telluric
      apfit           autoidentify    doslit          response        sflip           transform
      apflatten       background      fitprofs        sapertures      skysub
      apmask          bplot           identify        sarith          skytweak
      apnormalize     calibrate       illumination    scombine        slist
```

```
specred> apall r_std.fits
Find apertures for r_std?  (yes):
Number of apertures to be found automatically (1):
Resize apertures for r_std?  (yes):
Edit apertures for r_std?  (yes):
```

Identify spectrum ("aperture")



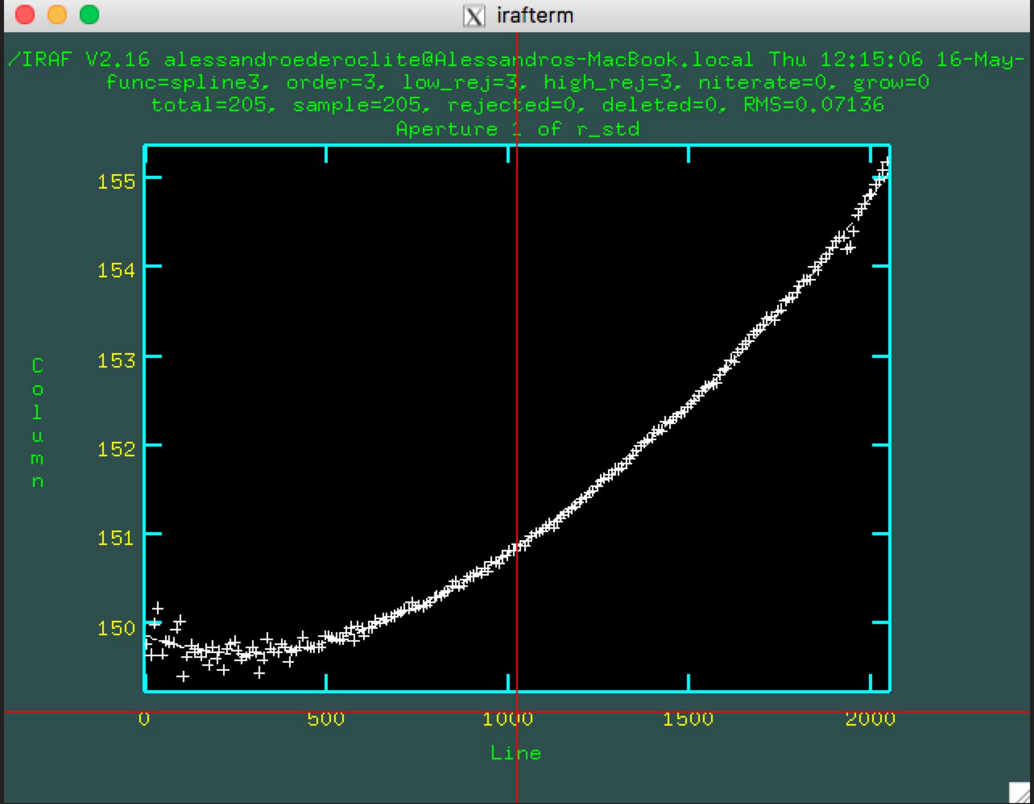
This is perpendicular to the dispersion. In fact, what you are seeing here is the psf of your image at a specific wavelength.

The "aperture" is the region within which you are integrating the spectrum.

As in photometry, you define the aperture and the background.

You want both to be big (better sampling) and small (don't include noise) at the same time!

“Trace”

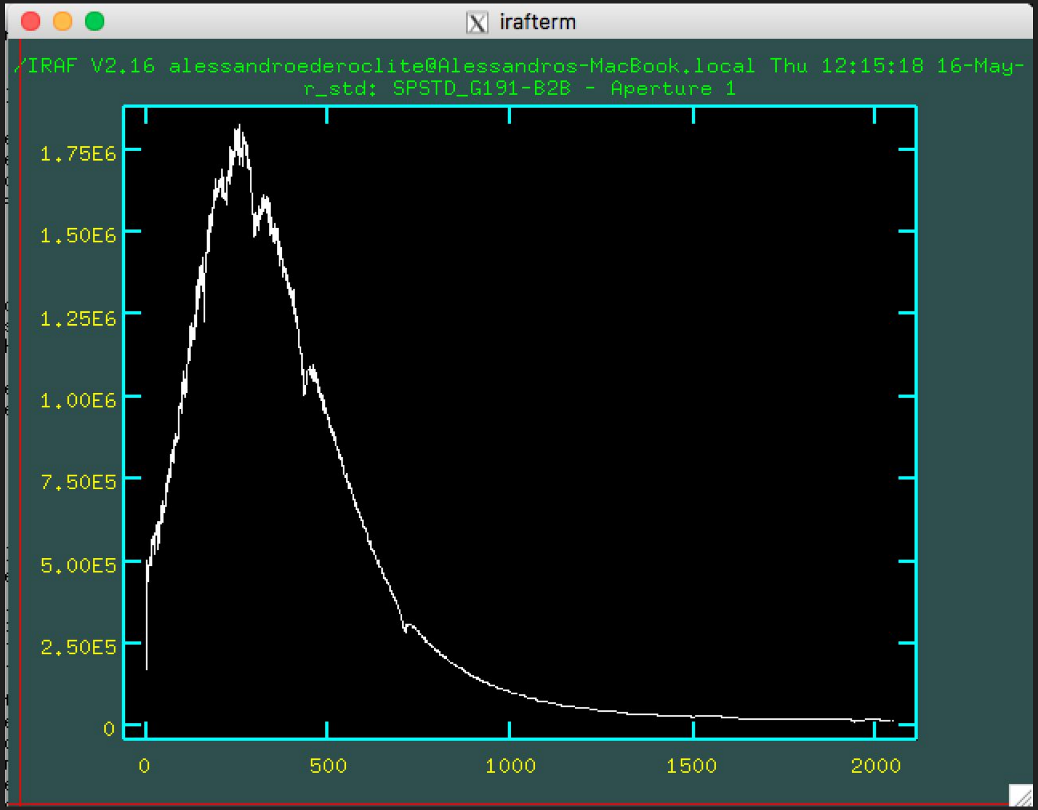


This is the position of the centroid of your spectrum along the CCD.

Note the bad fit at the right extreme (it’s the blue end, in this case).

You will have to adjust a function to this (normally a low order spline does the trick).

Preview



After tracing, IRAF “extracts” the spectrum.

This means that it integrates within the interval you defined, considering the variation of the centroid as it was traced and subtracting the background that you defined.

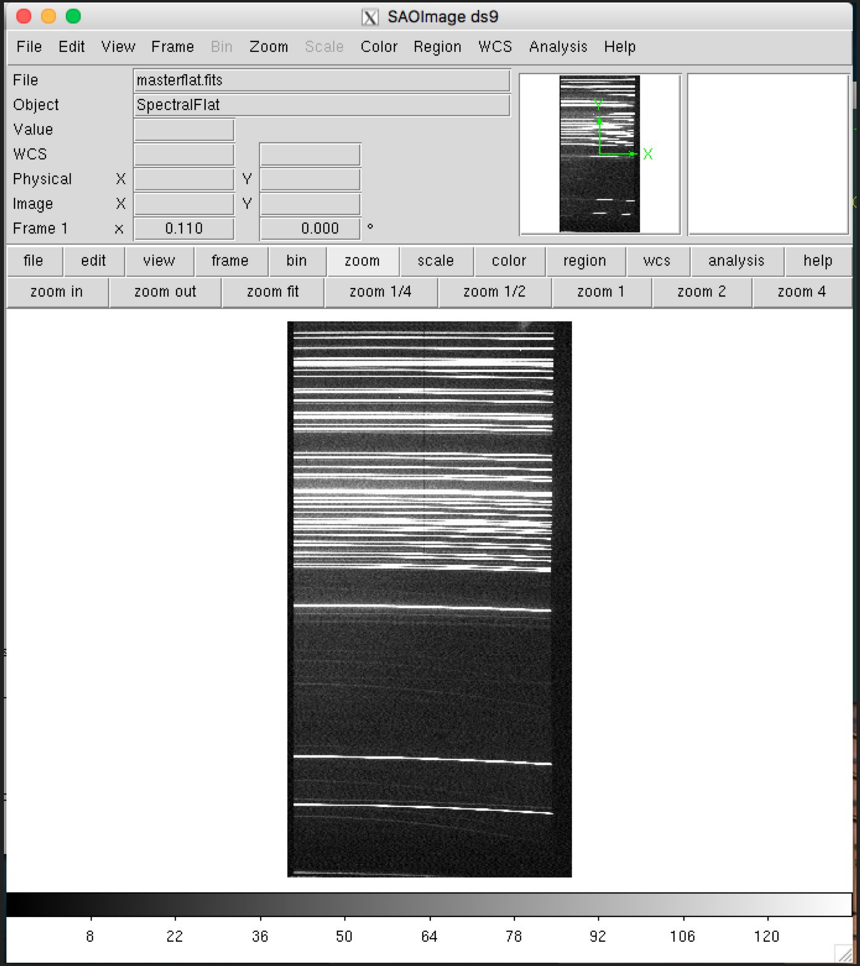
(mind you that background subtraction is not the default parameter in the `apall` function)

But we still have to calibrate in wavelenght.

The “arc”

Now you know on which pixel(s) your spectrum is but you need to make a connection between pixel(s) and wavelentgh (and position along the slit).

This is done using lamps which emit an emission line spectrum (e.g. Neon, Argon, Thorium, Helium...) and identifying these lines.



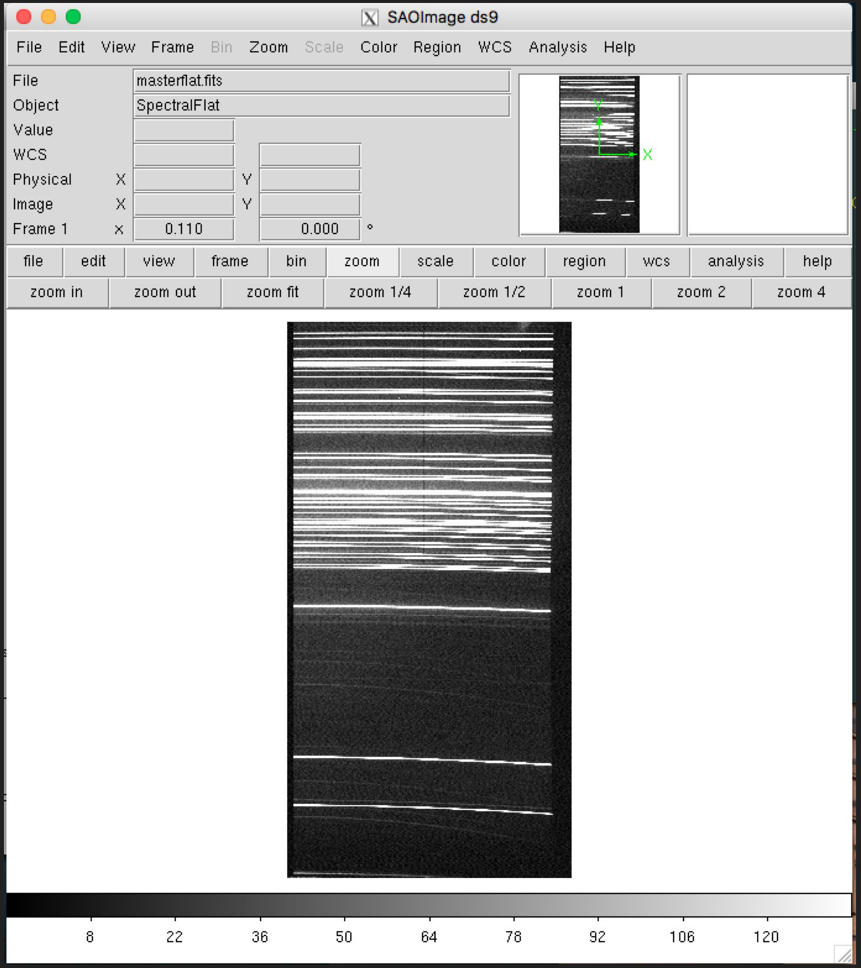
The “arc”

The first step is to reduce these images (these are images, after all, and all come with bias and flats).

In some cases, the lamps are taken independently, and we need to **sum** them.

```
ccdred> ccdproc @arcs.lis output=b//@arcs.lis ccdtype="" fixpix- overscan- trim- zerocor+ \
darkcor- flatcor- zero=masterbias.fits
```

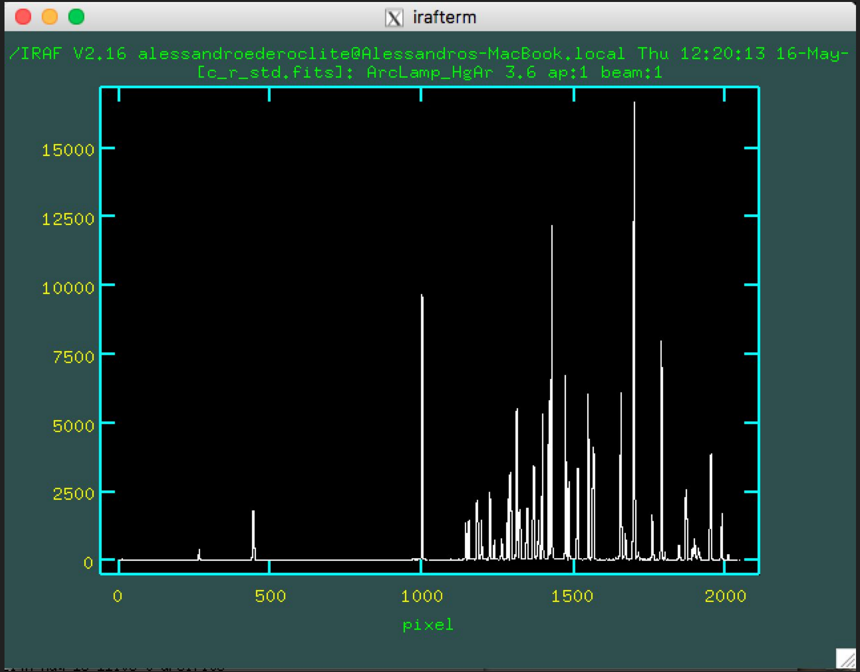
```
ccdred> imcombine b//@arcs.lis arc.fits

May 16 10:47: IMCOMBINE
  combine = average, scale = none, zero = none, weight = none
  blank = 0.
                Images
             barc1.fits
             barc2.fits

  Output image = arc.fits, ncombine = 2
```



Extract the “arc”

```
specred> apall t_arc.fits output=c_r_std  ref=r_std  recenter- trace- back- interactive-
Warning: Coordinate system ignored (rotated?). Using pixel coordinates.
```

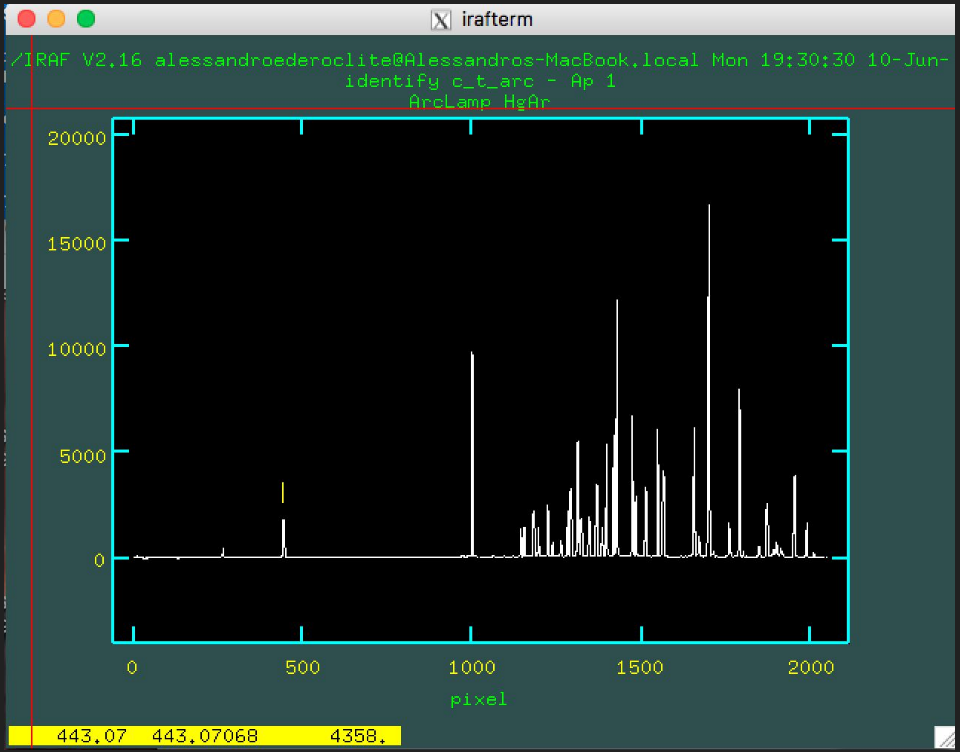
Extraction is a delicate step. You want to make sure you use the same trace as the object you are calibrating. Only like this you are sure that you are associating the right pixel to the right wavelength.



Calibrate in wavelength

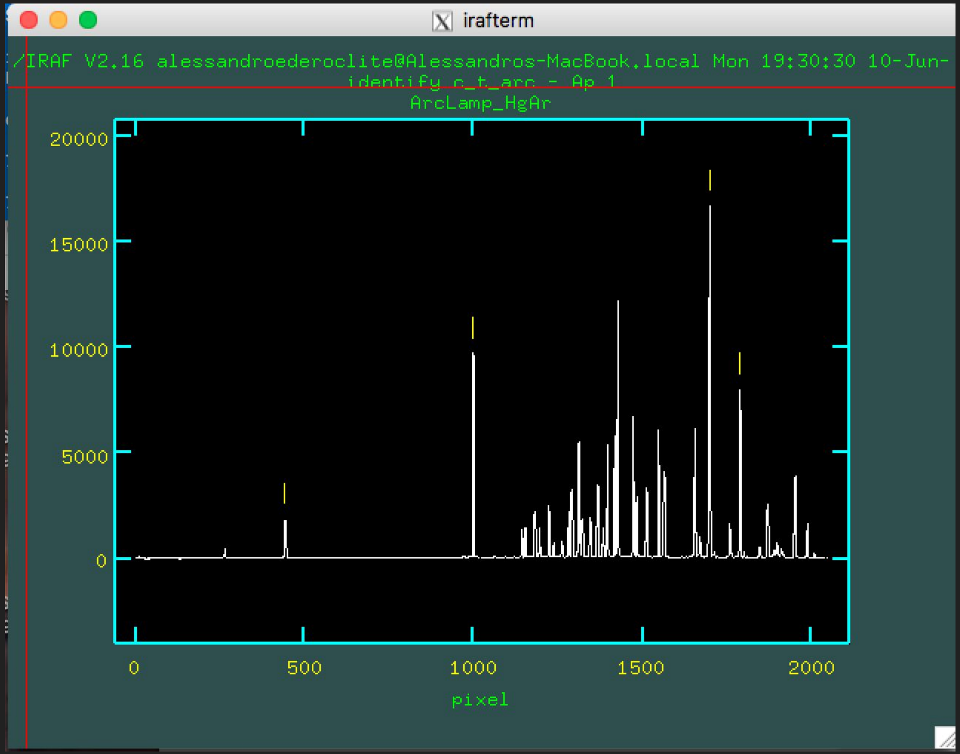
Identify lines.

Pick lines and compare with an atlas (all spectrographs have one).



Calibrate in wavelength

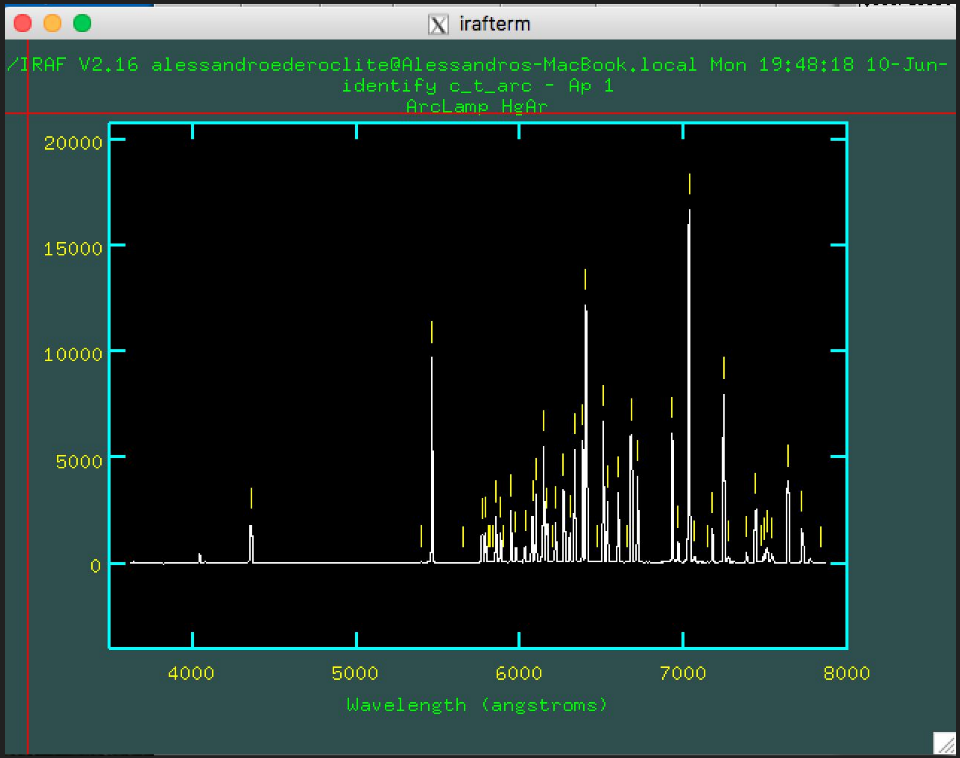
I normally start by identifying 3 or four lines across the wavelenth range and make a first fit...



Calibrate in wavelength

… then I let IRAF do the rest.

Mind you that often you don't have lines spread all across the wavelength range. You do the best you can.



Calibrate in wavelength

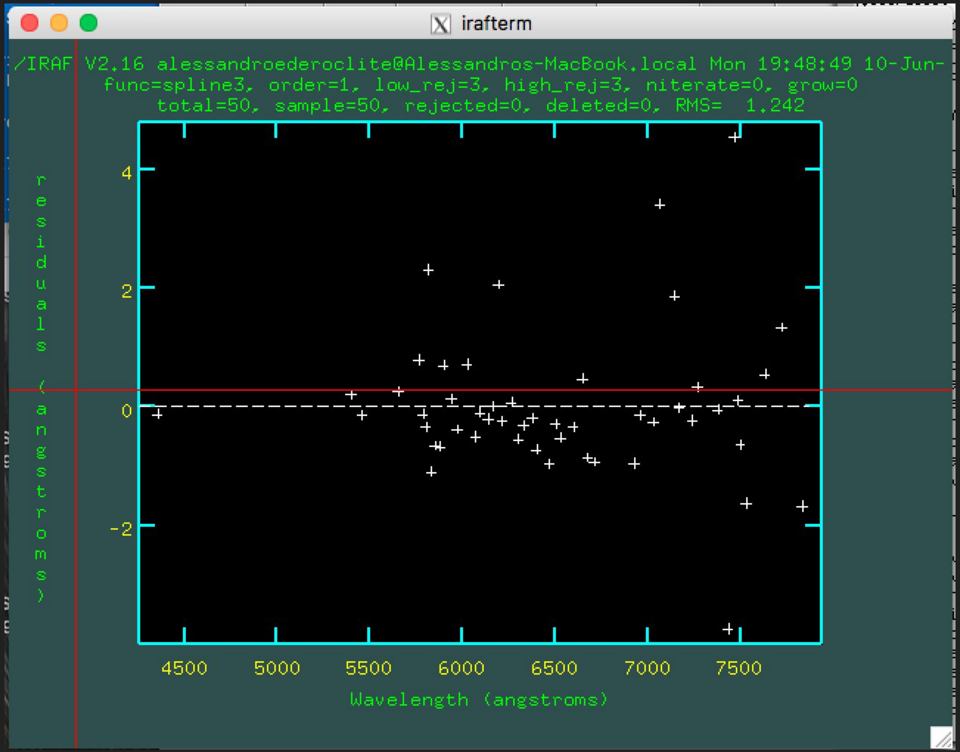
Your fit will have an rms; this should be of the order of your “δ λ”.

Remember that the resolution is defined as:

$R = \lambda / \delta \lambda$

?

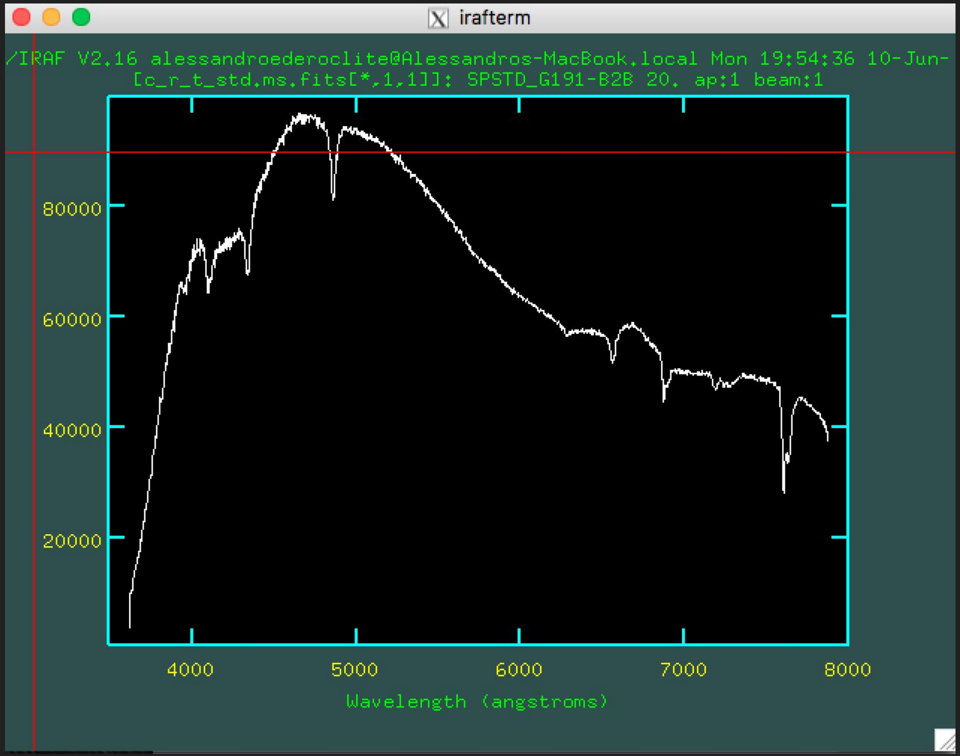
Here is a good moment to check if you are doing things right.



Calibrate in wavelength

Once you have a wavelength calibration, it is mostly a matter of linking the science spectrum to the wavelength calibration.

In IRAF this is a process a bit dull but works.



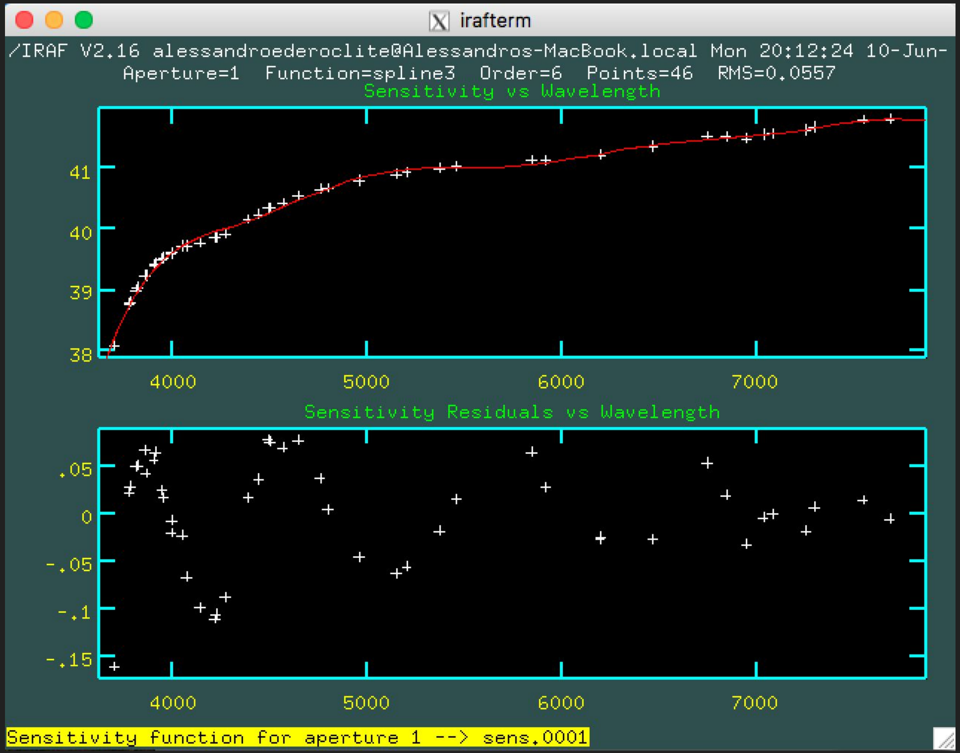
Flux calibration

Now you need to pick a spectrophotometric standard star (often it's white dwarfs or hot stars).

You extract the spectrum as if it was a science spectrum but then you use the fact that the flux at specific wavelengths is available in the literature (IRAF makes avialable some of these for you).

Mind you, often it is bright stars!

Again, the process is dull but can be followed.

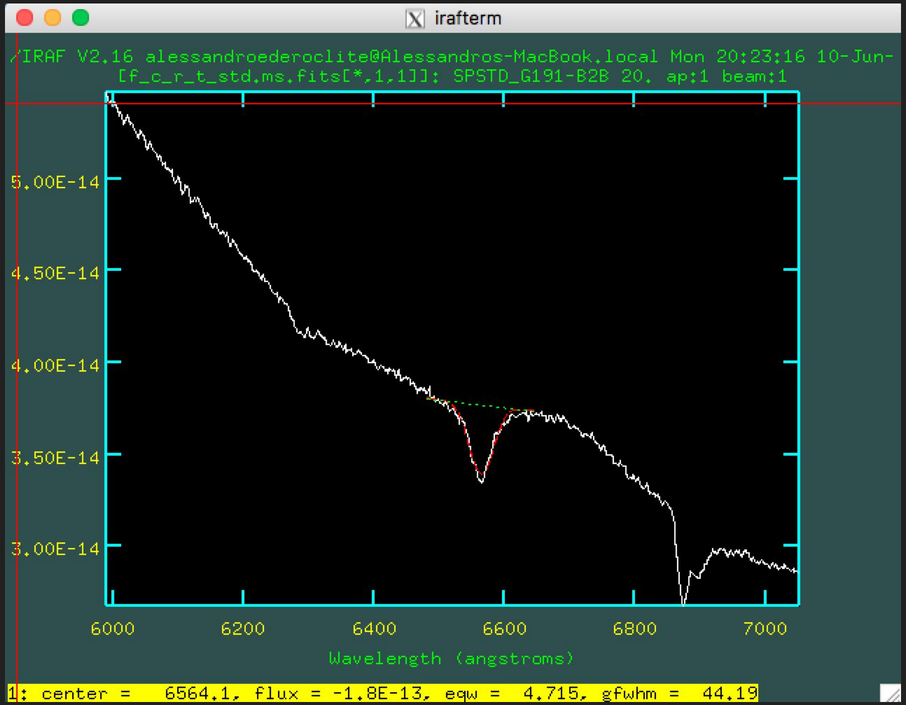


Measuring lines

In IRAF, you measure lines (and you do much more) with “splot”.

k - k will make a gaussian fit

e - e will compute the integral of the line (and the equivalent width)

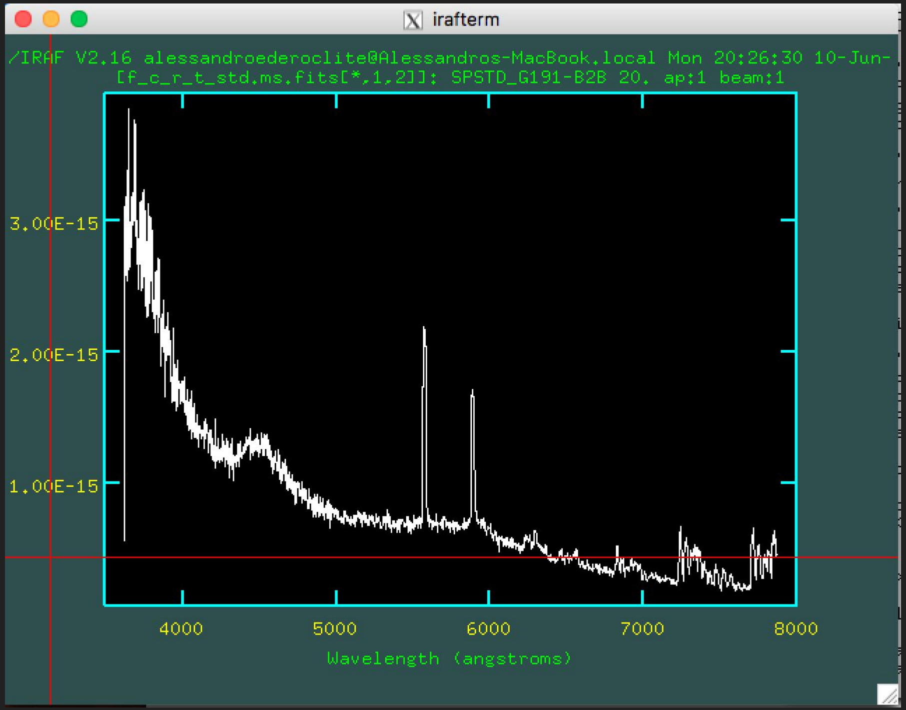


Check the background

IRAF default is the “multispectrum” format.

You get several bands, the first one of which is your spectrum and the second one of which is your background.

It can be a good thing to check if your background makes sense.



Identifying lines

This is a game of experience but one can get trained.

Some lines are obvious (especially in stars).

Learn your relevant lines and their common relative intensities.

In general, I like to measure the line and then try to identify it (unless it is super-super-obvious).

E.g.

A SDSS star https://dr16.sdss.org/optical/spectrum/view?plateid=3843&mjd=55278&fiberid=104&run2d=v5_13_0

A SDSS galaxy https://dr16.sdss.org/optical/spectrum/view?plateid=285&mjd=51930&fiberid=184&run2d=26