Data Reduction - Spectroscopy

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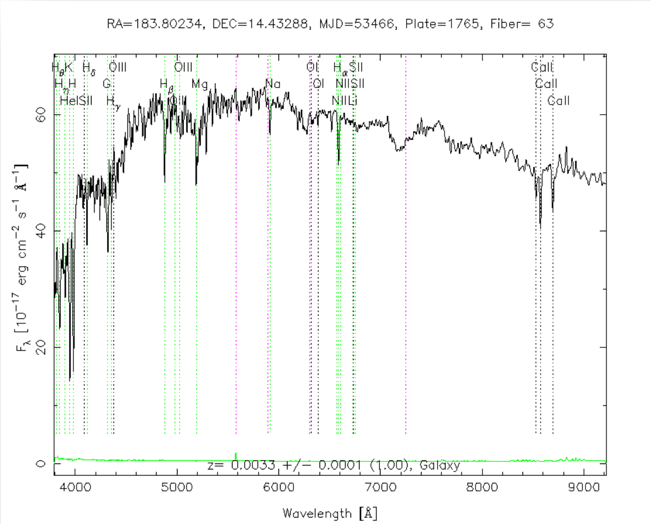
OCW113 & OCW111

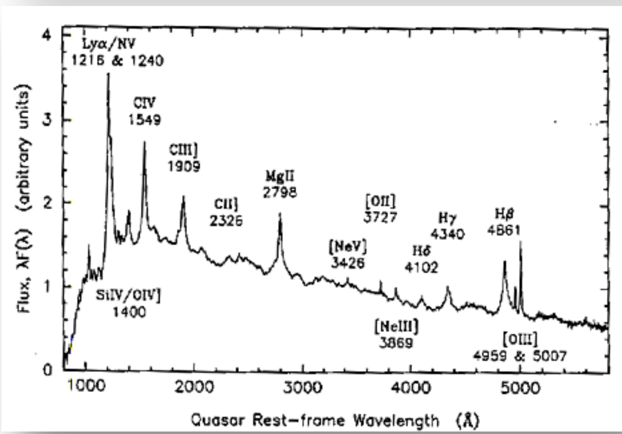
Spectroscopy



Lots to be learnt:

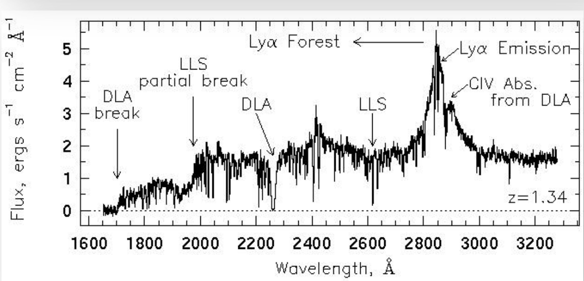
Galaxies/AGN:

- Redshift / distances
- Metallicity (chemical composition / masses)
- Ionisation state / gas temperatures
- Stellar populations
- Star formation rates
- BH masses / Eddington Ratios
- Kinematics (stellar dynamics, mergers, outflows, …)
- Clustering
- ….



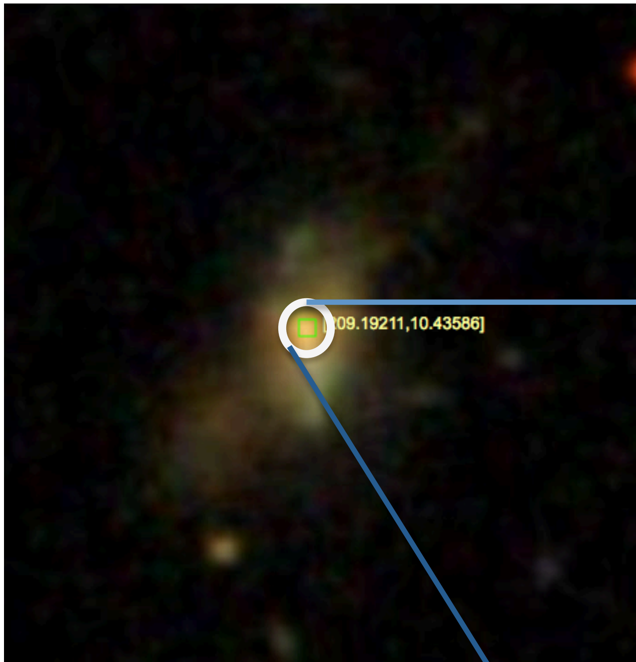
Inter-galactic medium:

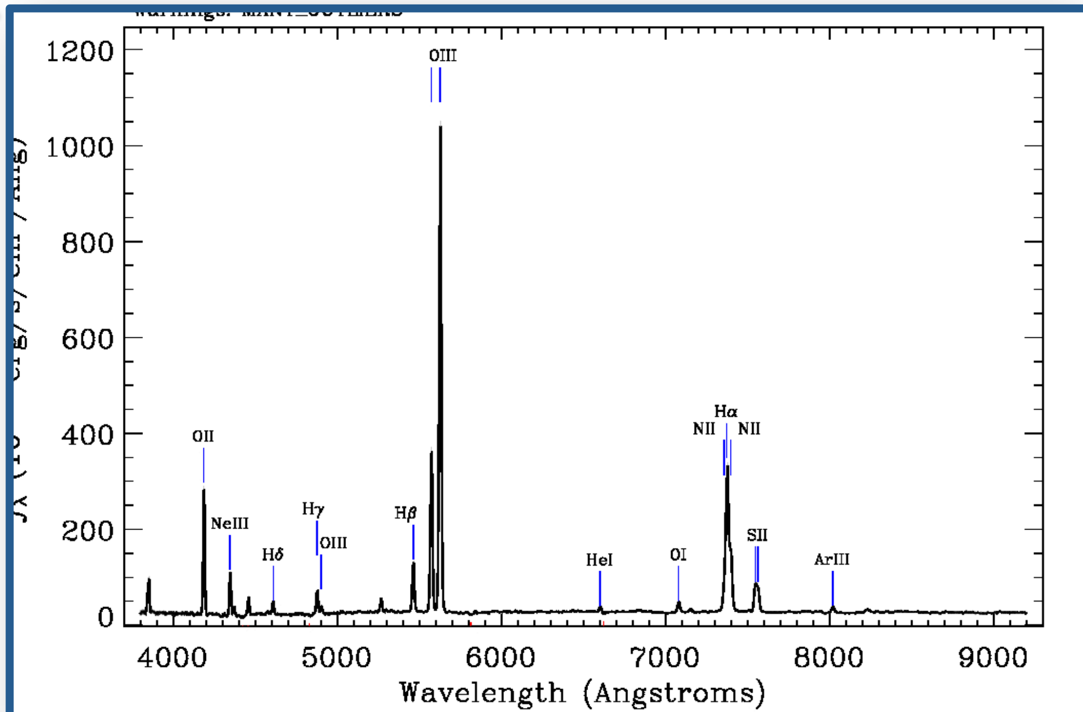
- Ionisation
- Metallicity / chemical composition
- number and properties of dense absorbers
- ….



Spectroscopy – 1 Dimension

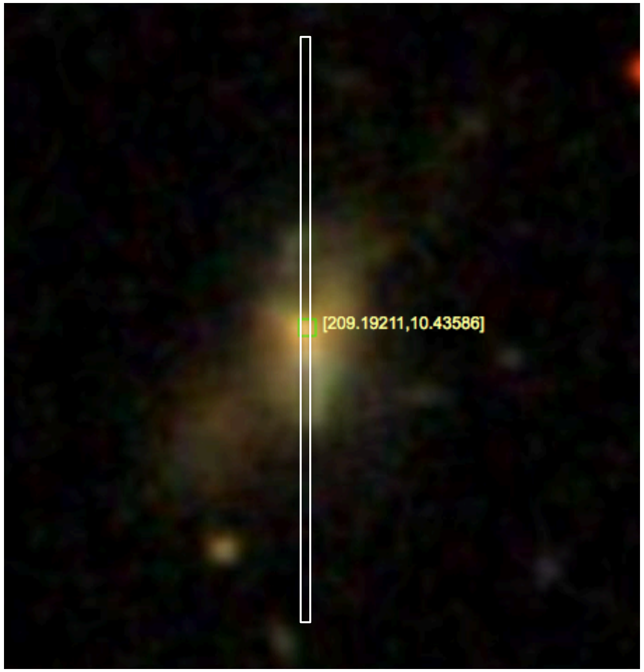
+ Get one spectrum for an object.
+ Gives the total spectrum within an aperture
+ Might miss a lot of the object
+ Doesn't give any spatial information





Spectroscopy – 2 Dimensions

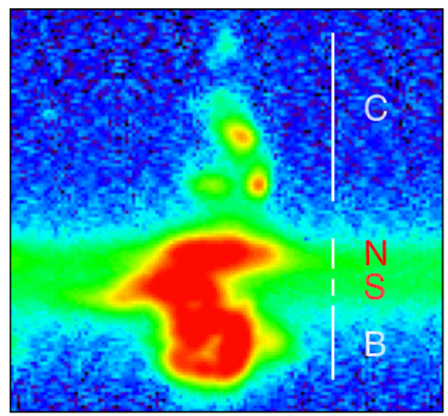
(e.g. longslit spectroscopy)



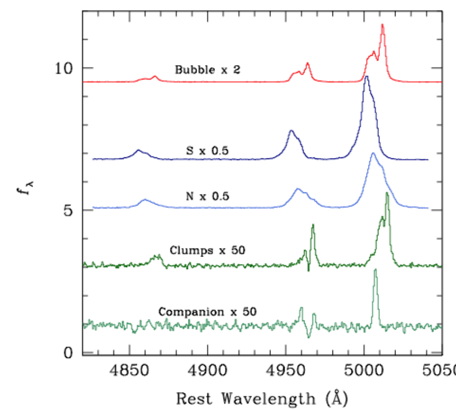
Get spatial information in one direction (along the slit)

Zoom in around [O III] emission line:

Position →



Wavelength →

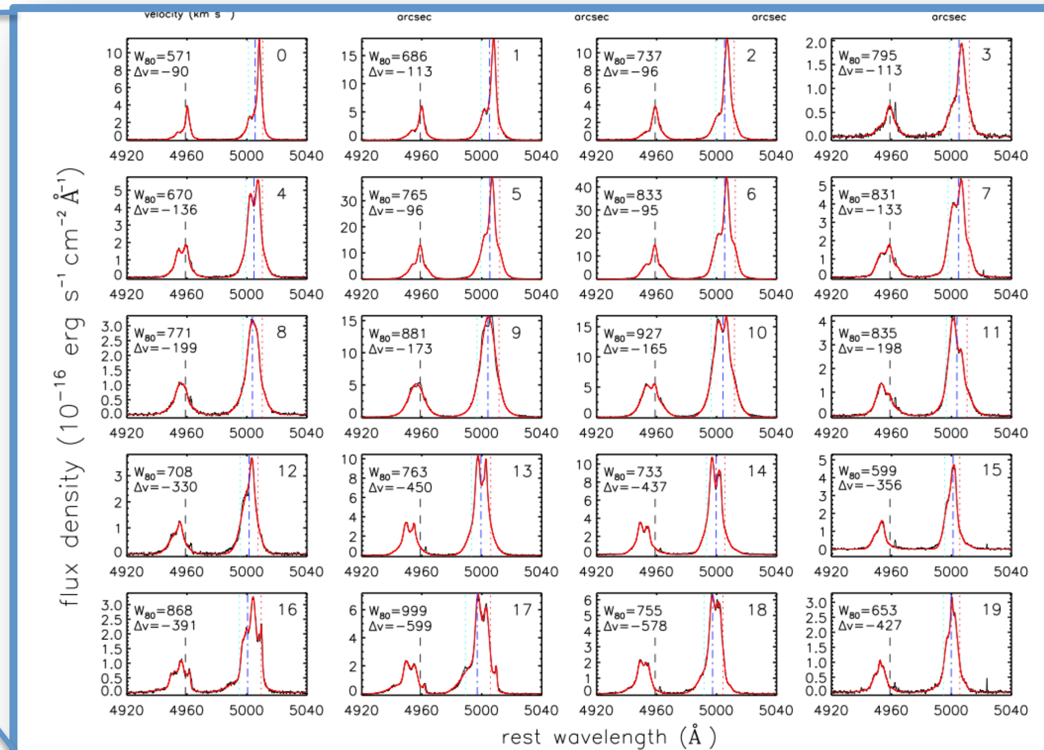


Greene+12

Spectroscopy – 3 Dimensions

(IFU data)

Get spatial information in two directions:
i.e., get a spectrum at each pixel:



Harrison+14a

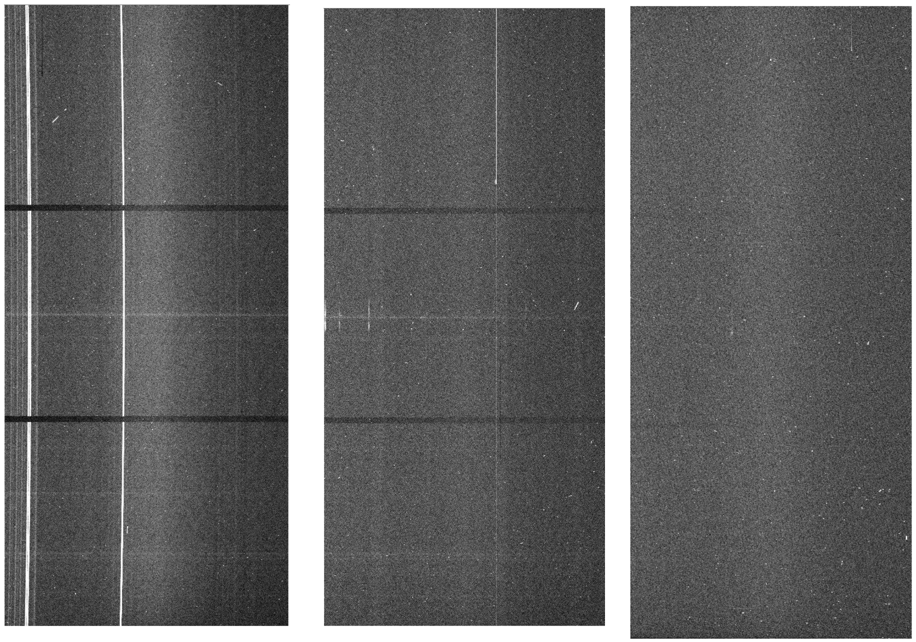
Reducing Spectroscopic Data

We will use Gemini-GMOS longslit data as an example for this course; however, the process is fairly general for all spectroscopic data. We will do every step "by hand".

(Nowadays) most telescope have automated pipelines to do most of the data reduction for you. However, this is not always the case (e.g. Gemini Observatory). Furthermore, it is important that you understand the individual steps. It is sometimes required to "hack" pipelines that are broken or are not performing to your requirements.

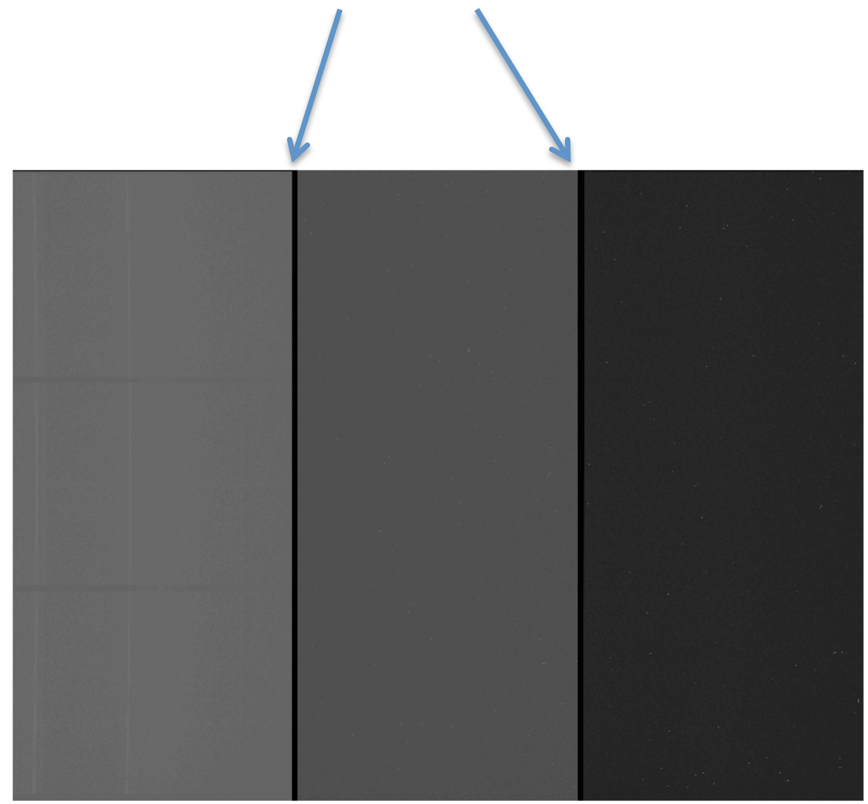
GMOS Longslit Data

The detector has three separate CCDs:



These need to be stitched together:
(this has been done for your)

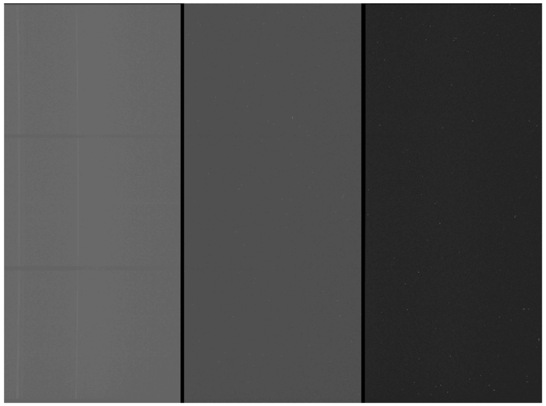
Chip gaps:



GMOS Longslit Data

Bias subtraction

Science Frame:



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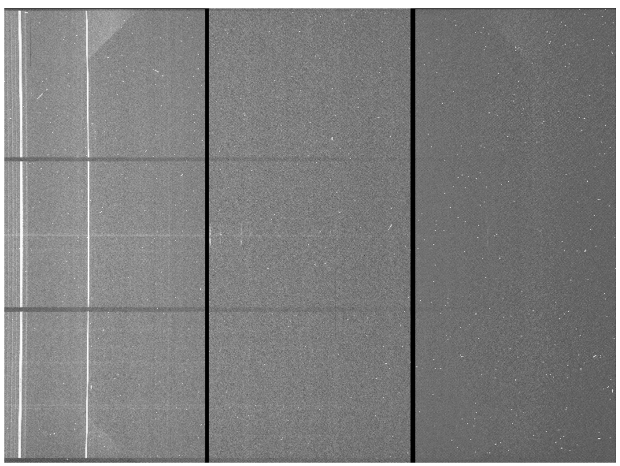
Bias Frame:

=

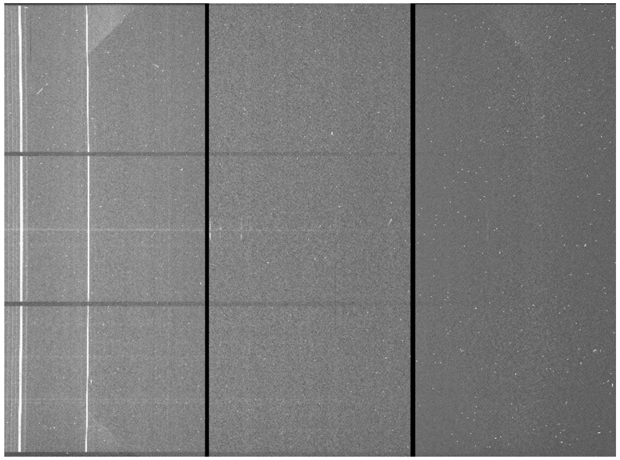


+ A positive bias is added to the signal to ensure a positive read-out value.
+ A zero second frame will tell you what this value is
+ This needs to be subtracted from the science frames

"Dark Frames" are also sometimes required to be subtracted – especially for long exposures and IR data. These are frames with the shutter closed with the same exposure time as the science. This remove the effect of artificial counts due to thermal processes etc.

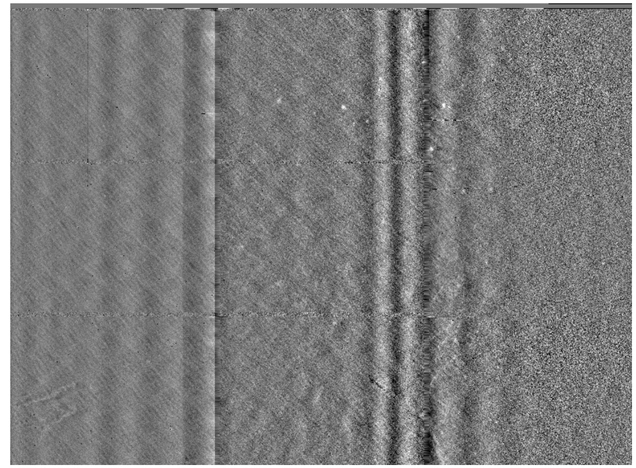
Flat Fielding

(Bias subtracted) Science Frame:



/

Flat-Field Frame:



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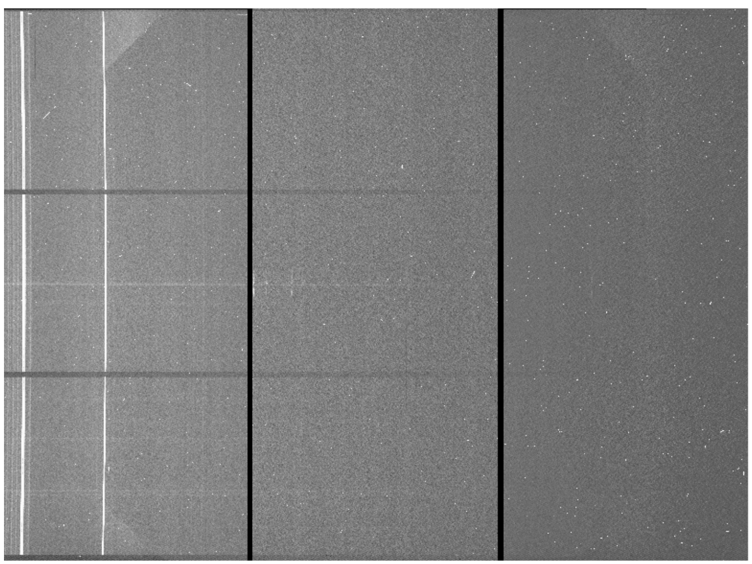
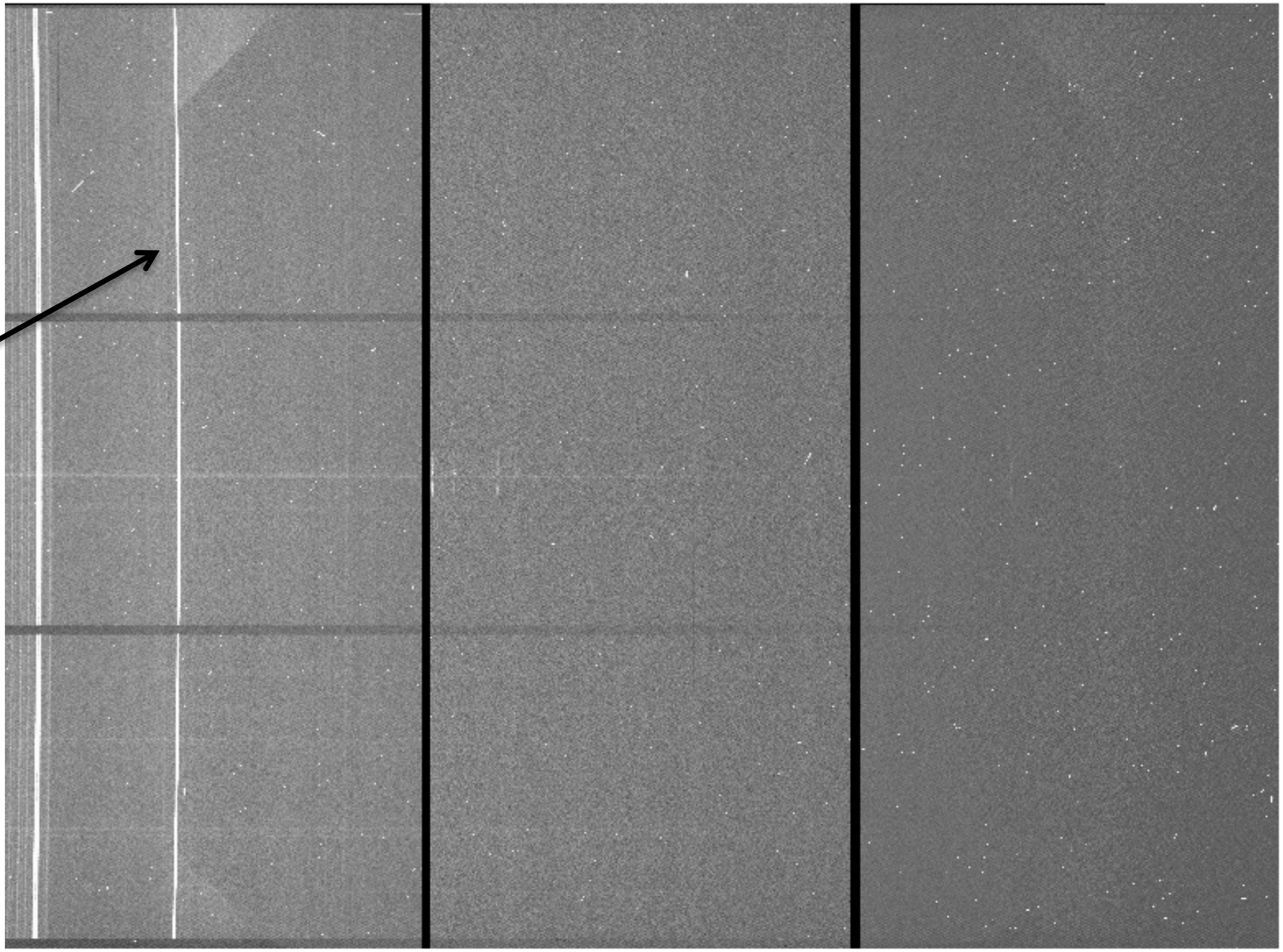


+ Due to the optics of the telescope and the properties of the detector, the response across the CCD is non-uniform.
+ An image of a uniform “white board” will show you the varying response (i.e., the “flat field frame”
+ This flat field frame needs to be normalised to give “1” on average
+ The science frame is divided by the normalised flat field.

GMOS Longslit Data

Wavelength transformation

+ Currently there science frame has no wavelength information.
+ There is also curvature that needs to be removed.



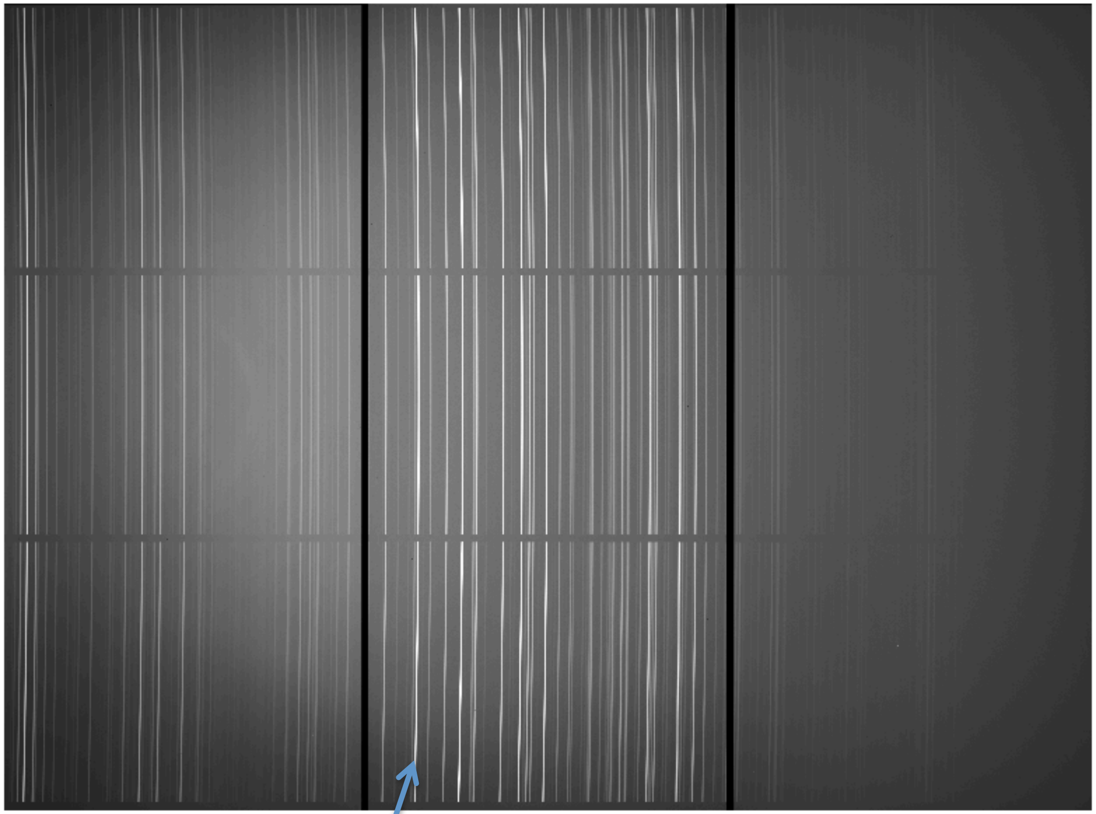
Curved skylines. Need to remove curvature

Wavelength solution needs to be applied

GMOS Longslit Data

Wavelength transformation

+ Image of an arc lamp with well known emission lines:

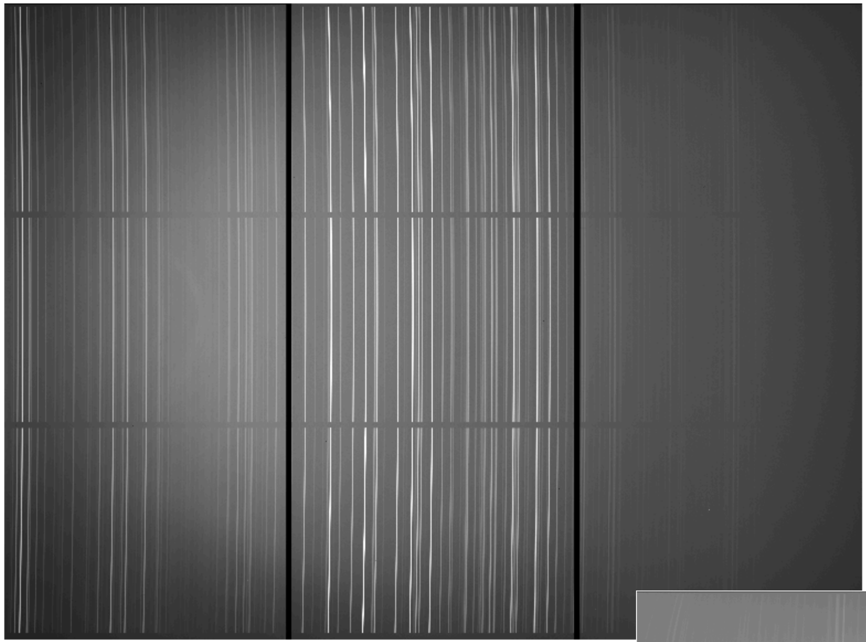


We need to identify the wavelengths of these emission lines

We then need to "trace" these emission lines up and down the image. We produce a model to assign every pixel a wavelength.

GMOS Longslit Data

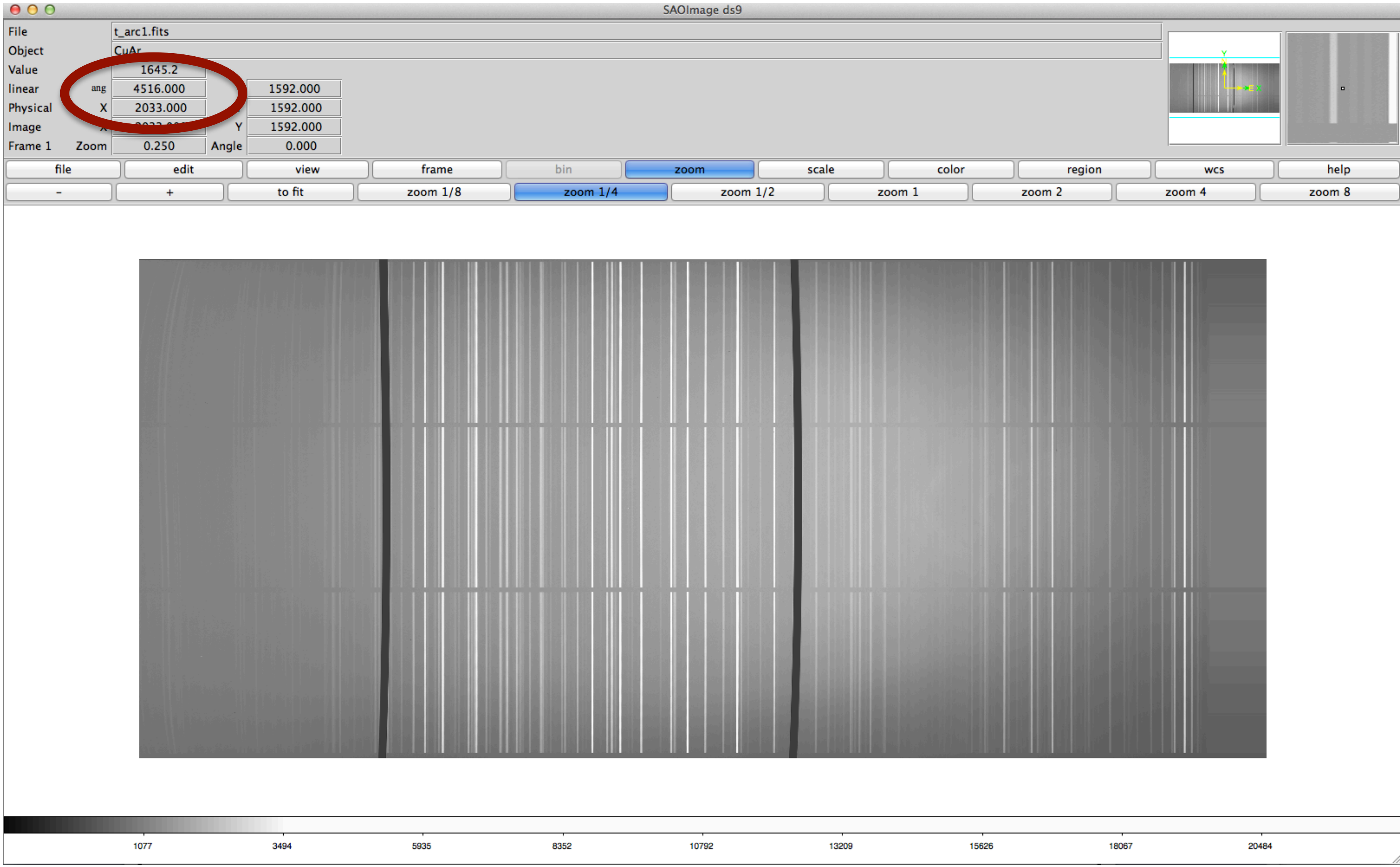
Original arc frame:



"Transformed" arc frame with curvature removed and a wavelength solution applied:

Wavelength transformation

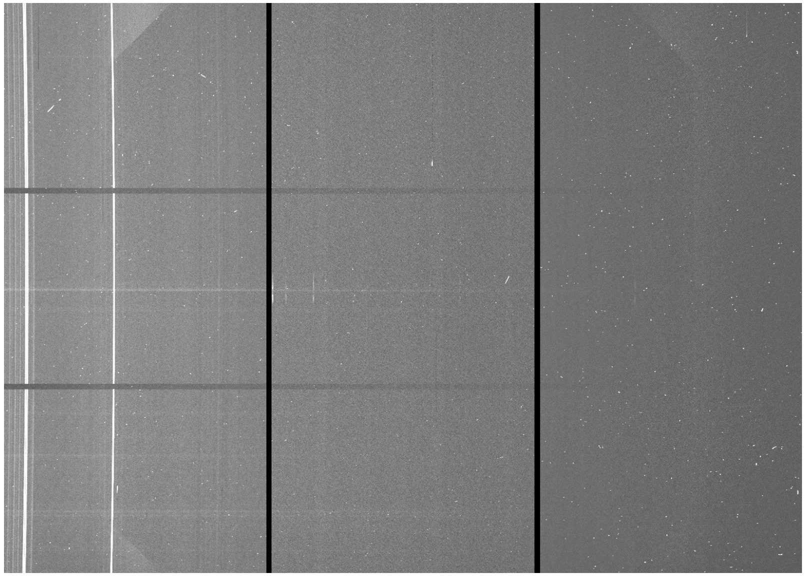
GMOS Longslit Data



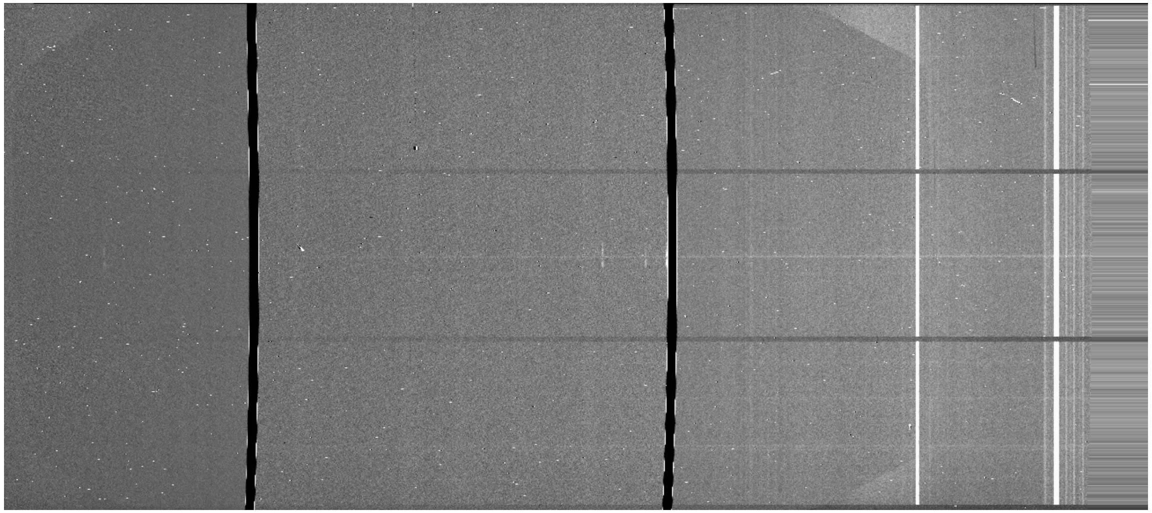
GMOS Longslit Data

Wavelength transformation

Science frame before wavelength transformation:



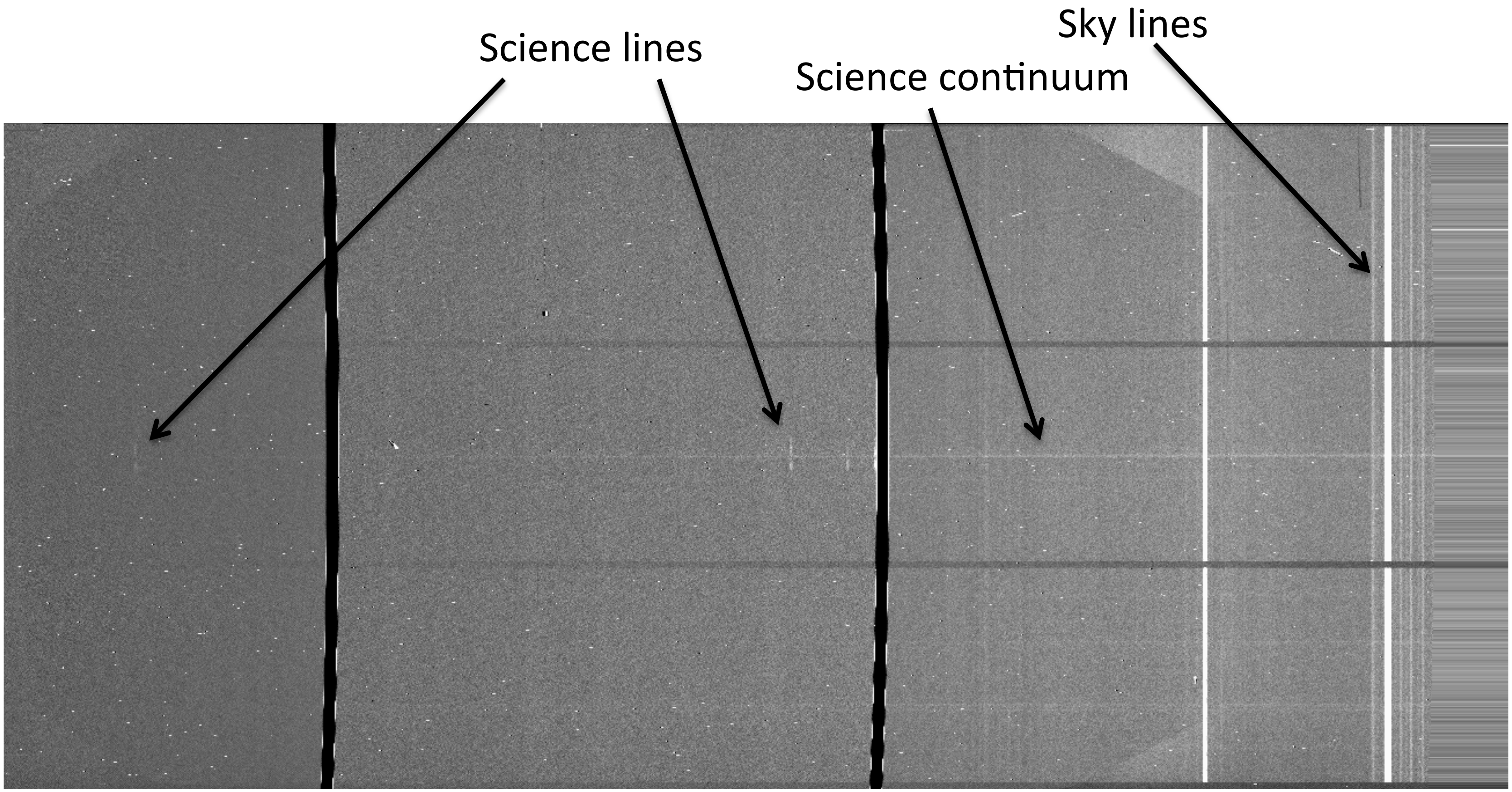
Science frame after wavelength transformation:



Sky subtraction

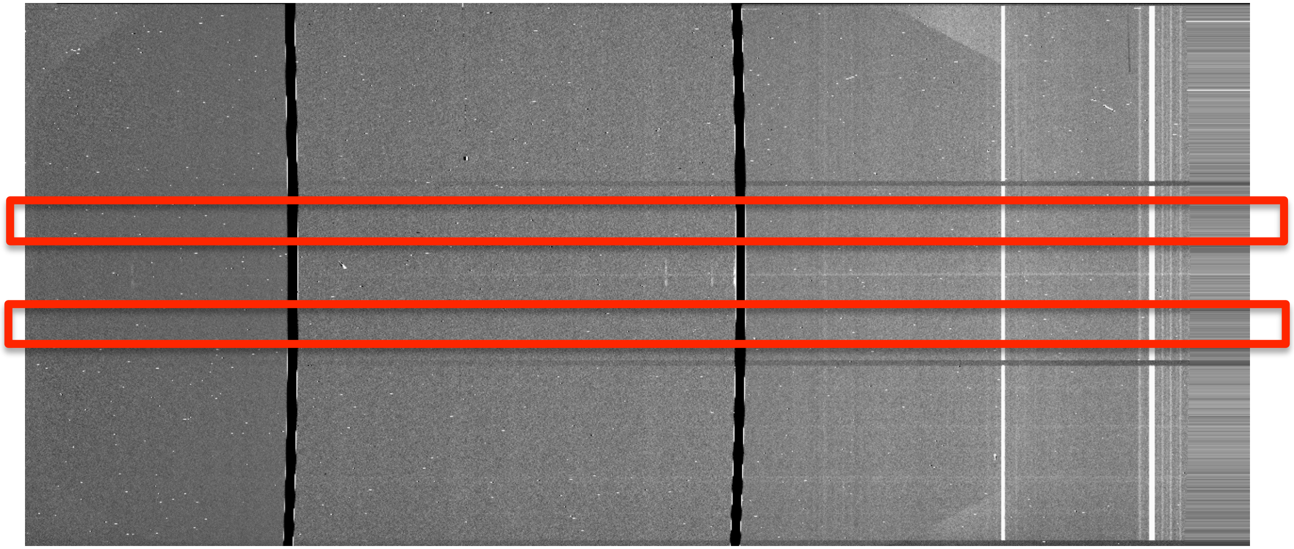
GMOS Longslit Data

+ The sky is not perfectly "black" (Moon, light pollution…). We need to remove this sky glow/continuum. In the IR, the sky is usually brighter than the object itself!
+ Molecules in the atmosphere also produce emission lines. This is particularly bad in the IR but there are some bright lines in the optical as well.



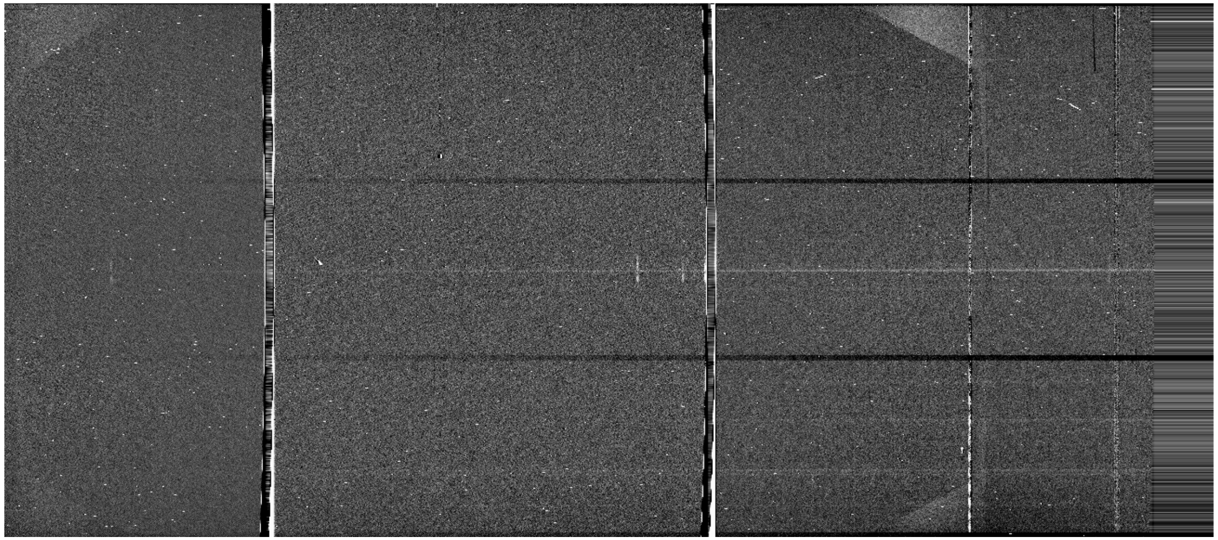
Sky subtraction

GMOS Longslit Data



+ Create a sky model/ spectrum by selecting regions of sky near the science object but definitely not including the science object.

+ Subtract this off the whole frame:

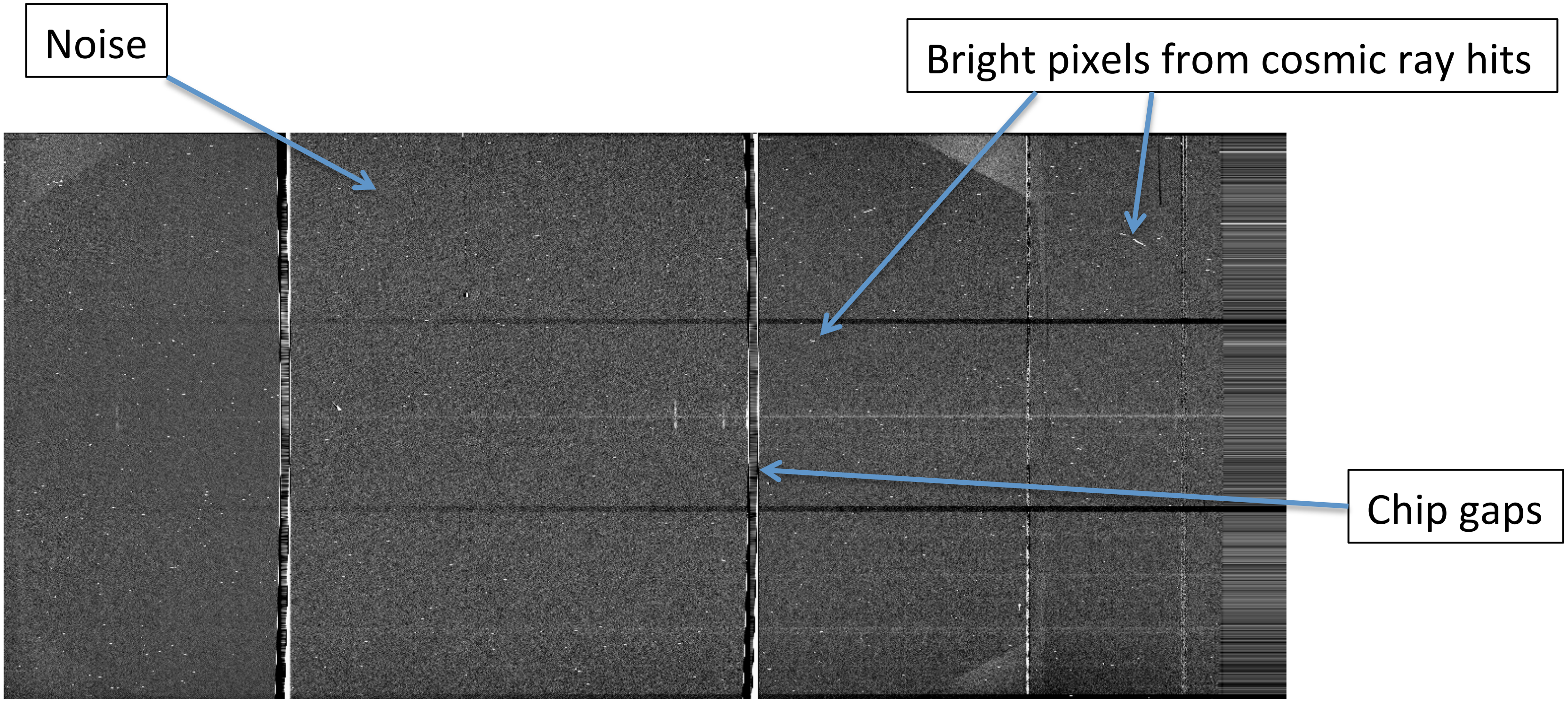


+ Notice that the sky lines have gone (except some small residual.

+ The science data how sticks out more from the background

GMOS Longslit Data

Other issues

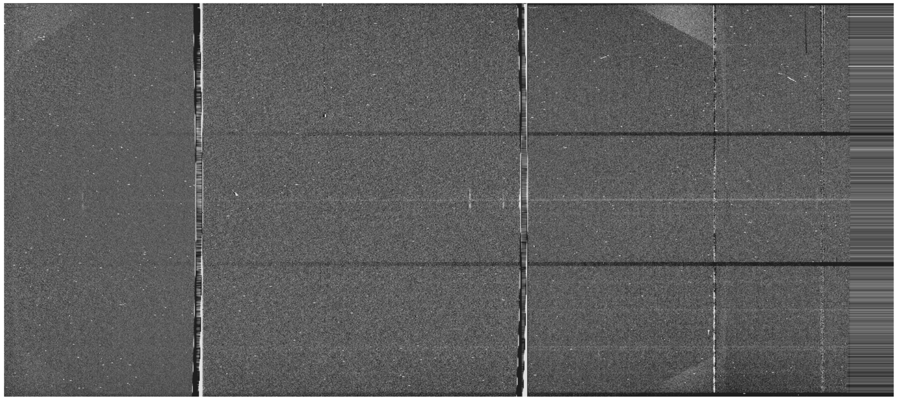


+ We can reduce (random) noise and the effect of (random) cosmic ray events by stacking multiple observations of the same target.
+ The chip gaps mean that we are missing data in the wavelength regions they cover. The way around this is to have taken multiple observations but dither the wavelength position, so that they gaps are in different positions on each frame.
+ Dithering observations and stacking them is also useful if there are issues with bad pixels or other defects on the detectors.

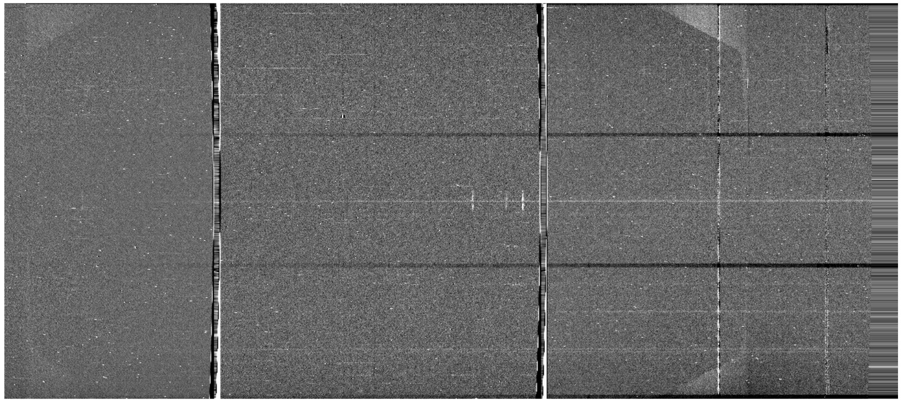
GMOS Longslit Data

Other issues

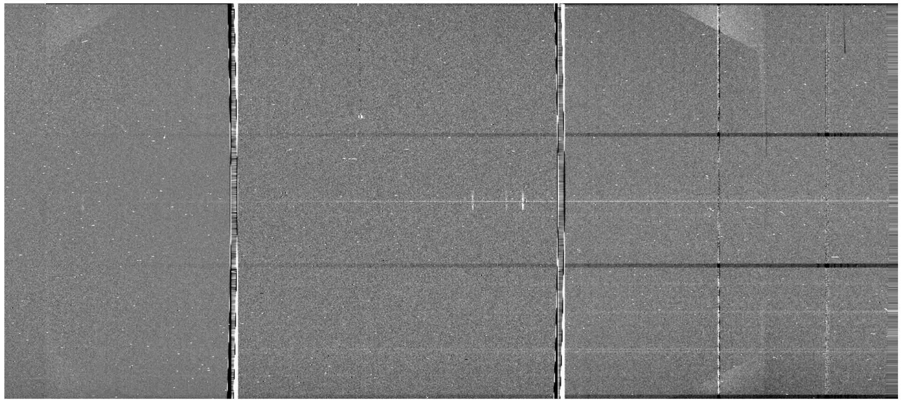
Dither pattern:



x2



x2

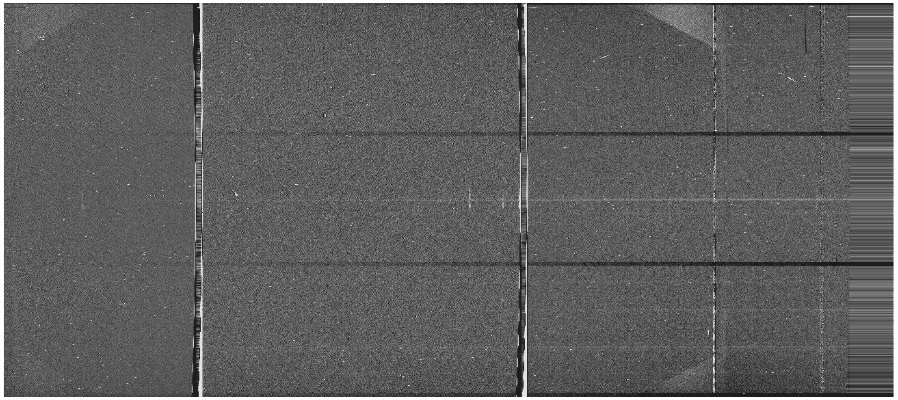


x2

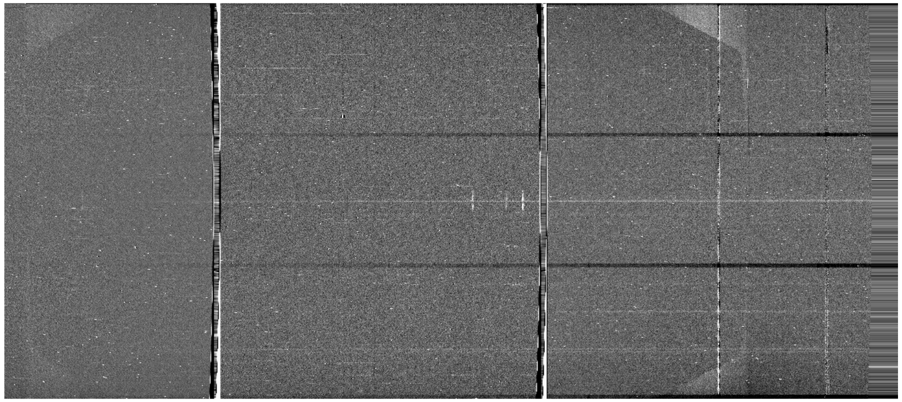
Other issues

GMOS Longslit Data

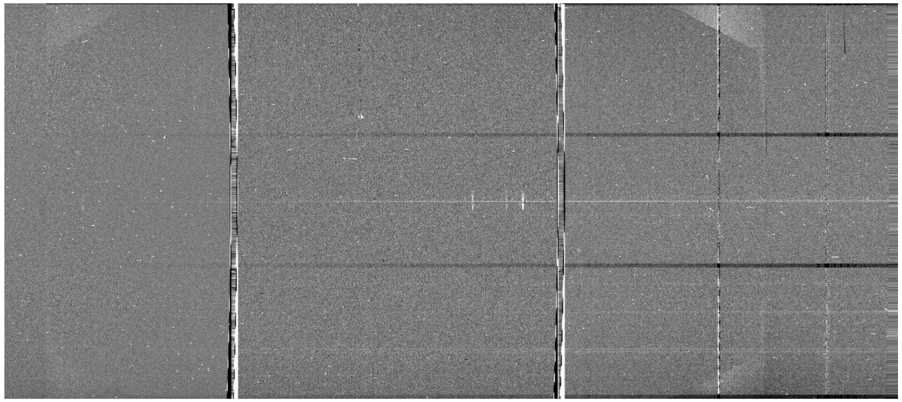
Dither pattern:



x2



x2

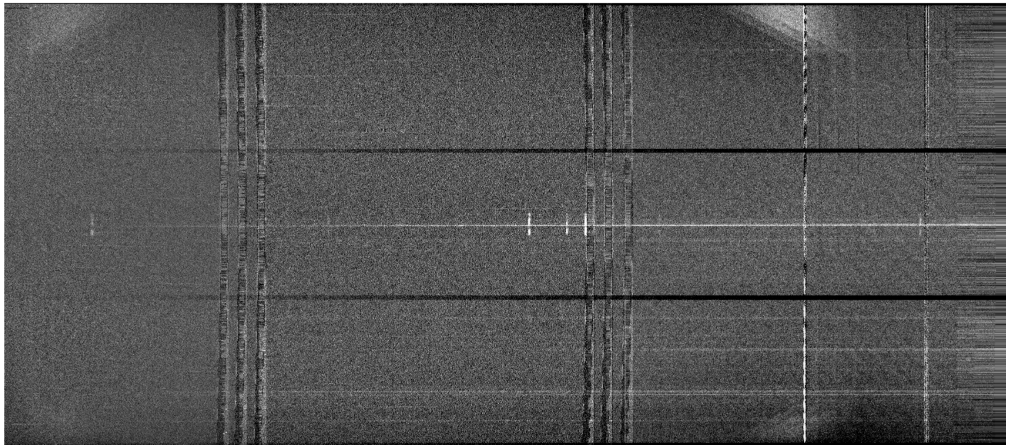


x2

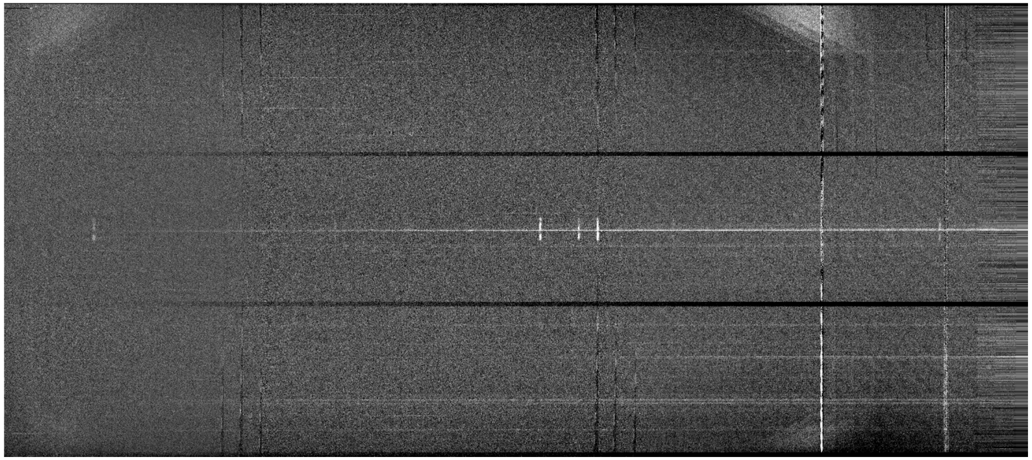
GMOS Longslit Data

Other issues

Stacking without masking chip gaps:



Stacking with masking chip gaps:

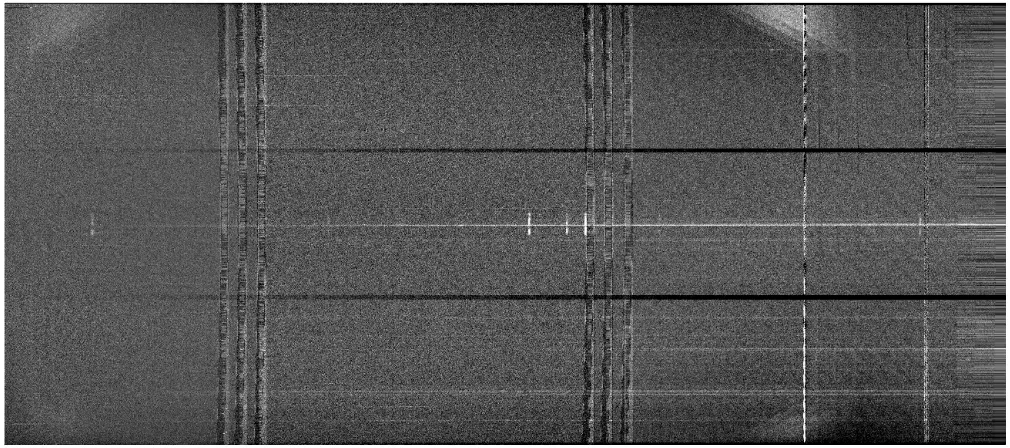


Notice that the target spectrum is now very bright above the background (good S/N)
Also the cosmic ray events can no longer be seen.

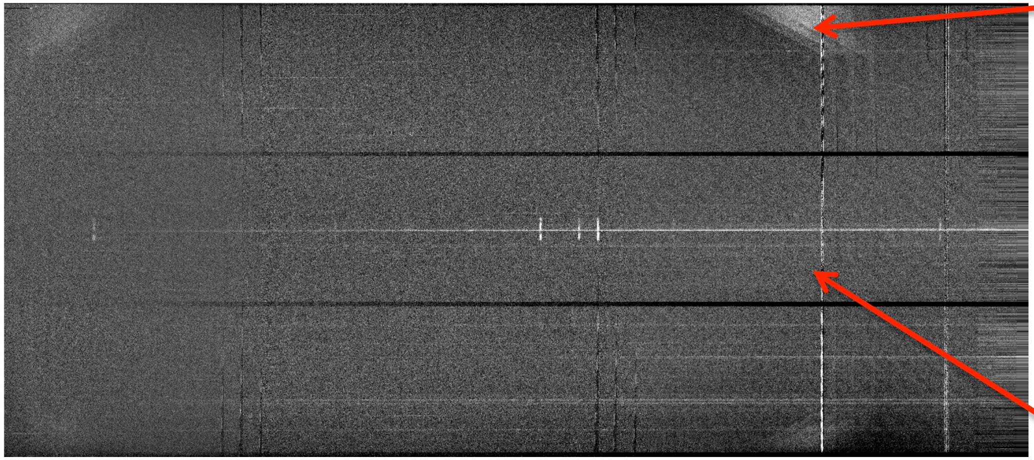
GMOS Longslit Data

Other issues

Stacking without masking chip gaps:



Stacking with masking chip gaps:



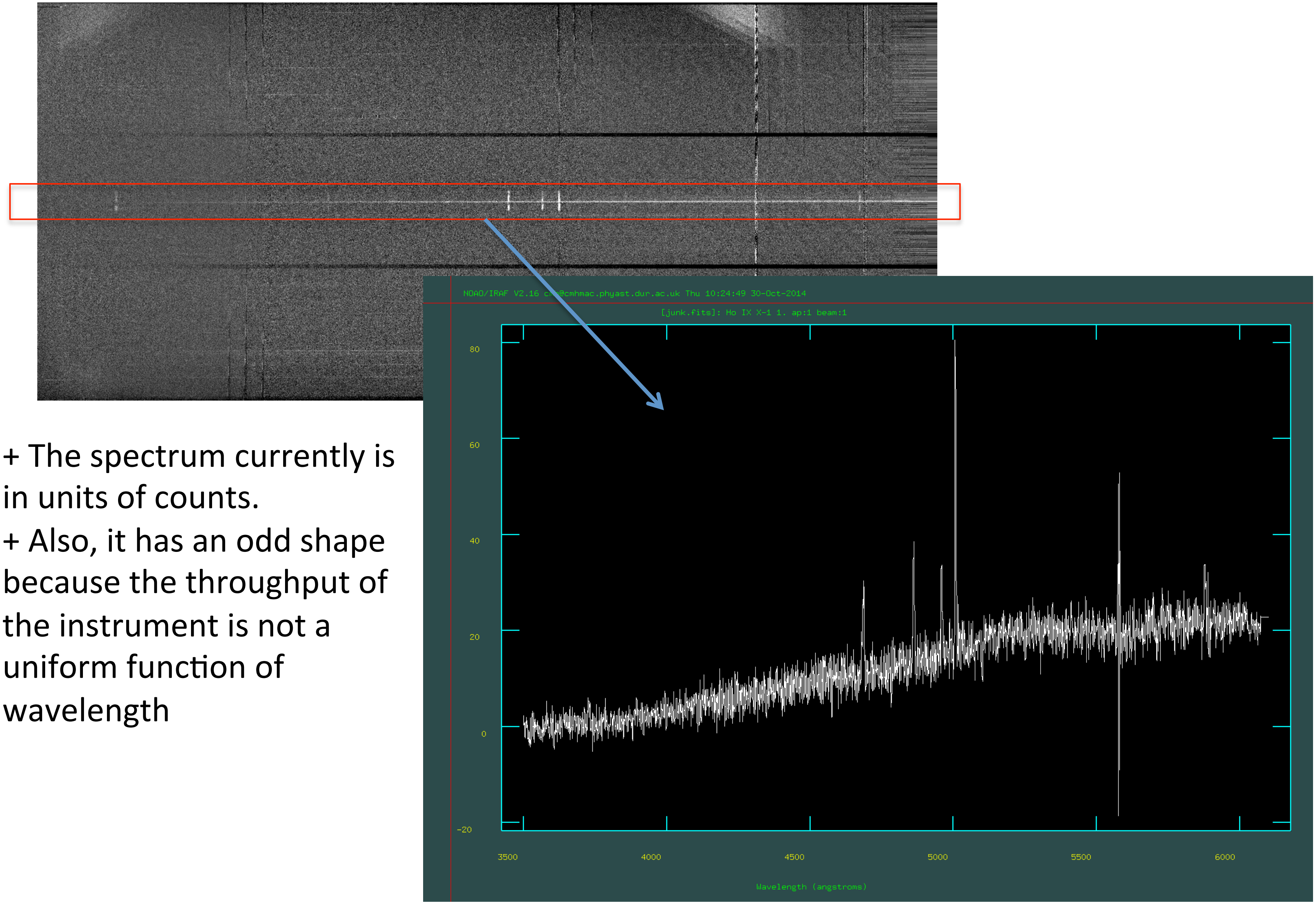
Non-perfect flat fielding

Non-perfect sky subtraction

Notice that the target spectrum is now very bright above the background (good S/N)
Also the cosmic ray events can no longer be seen.

GMOS Longslit Data

Flux Calibration / Filter Response



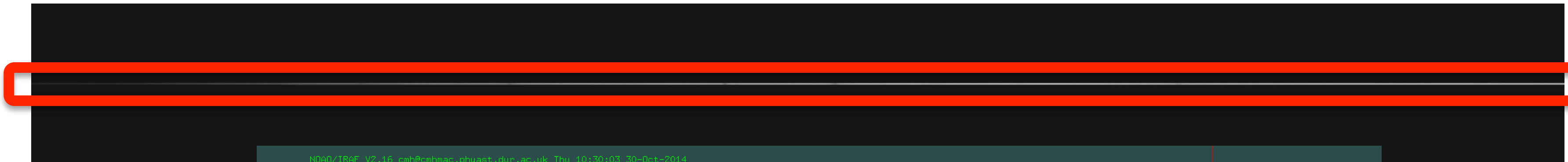
+ The spectrum currently is in units of counts.
+ Also, it has an odd shape because the throughput of the instrument is not a uniform function of wavelength

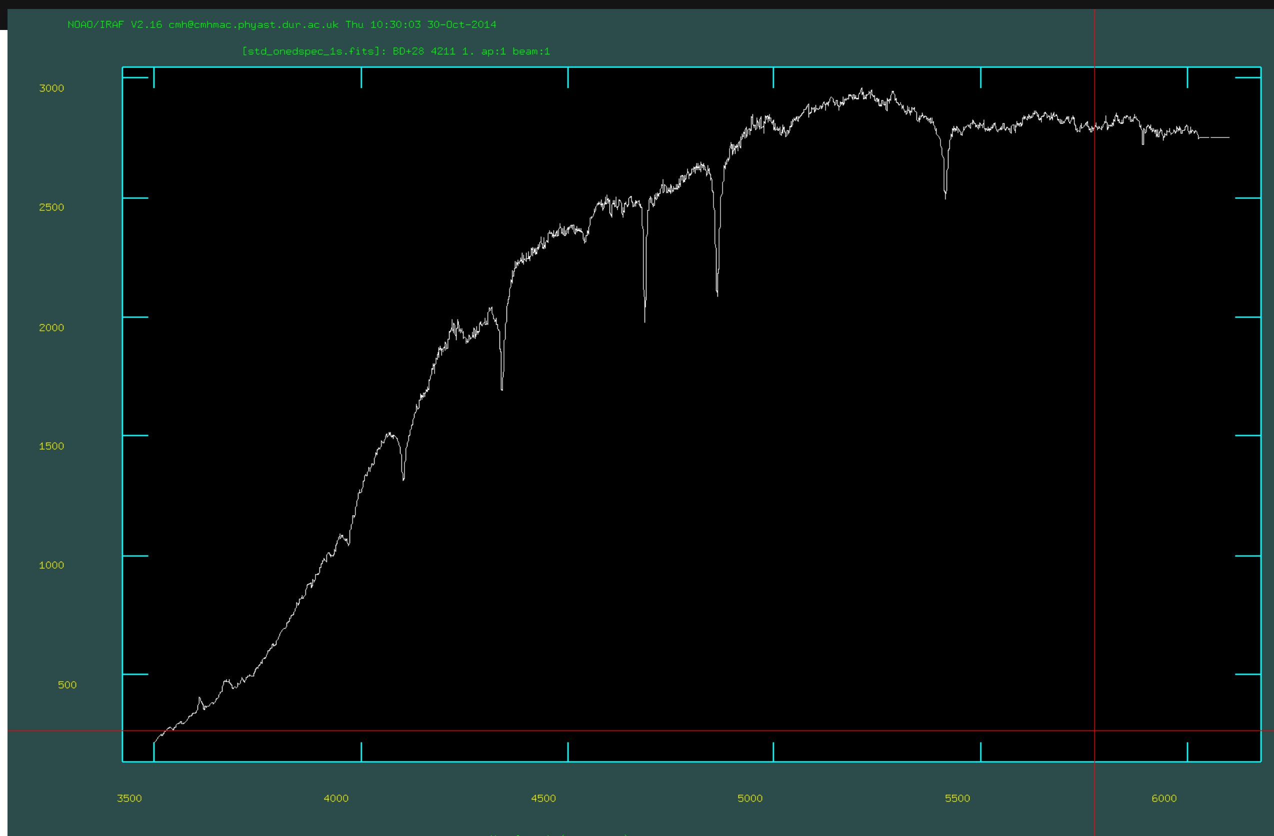
Flux Calibration / Filter Response

GMOS Longslit Data

+ We use observations of a standard star, under equivalent observing conditions and instrumental set-up

+ The stars have well know spectra. Therefore you can correct for the filter response (throughput) and convert between telescope counts and flux density units.

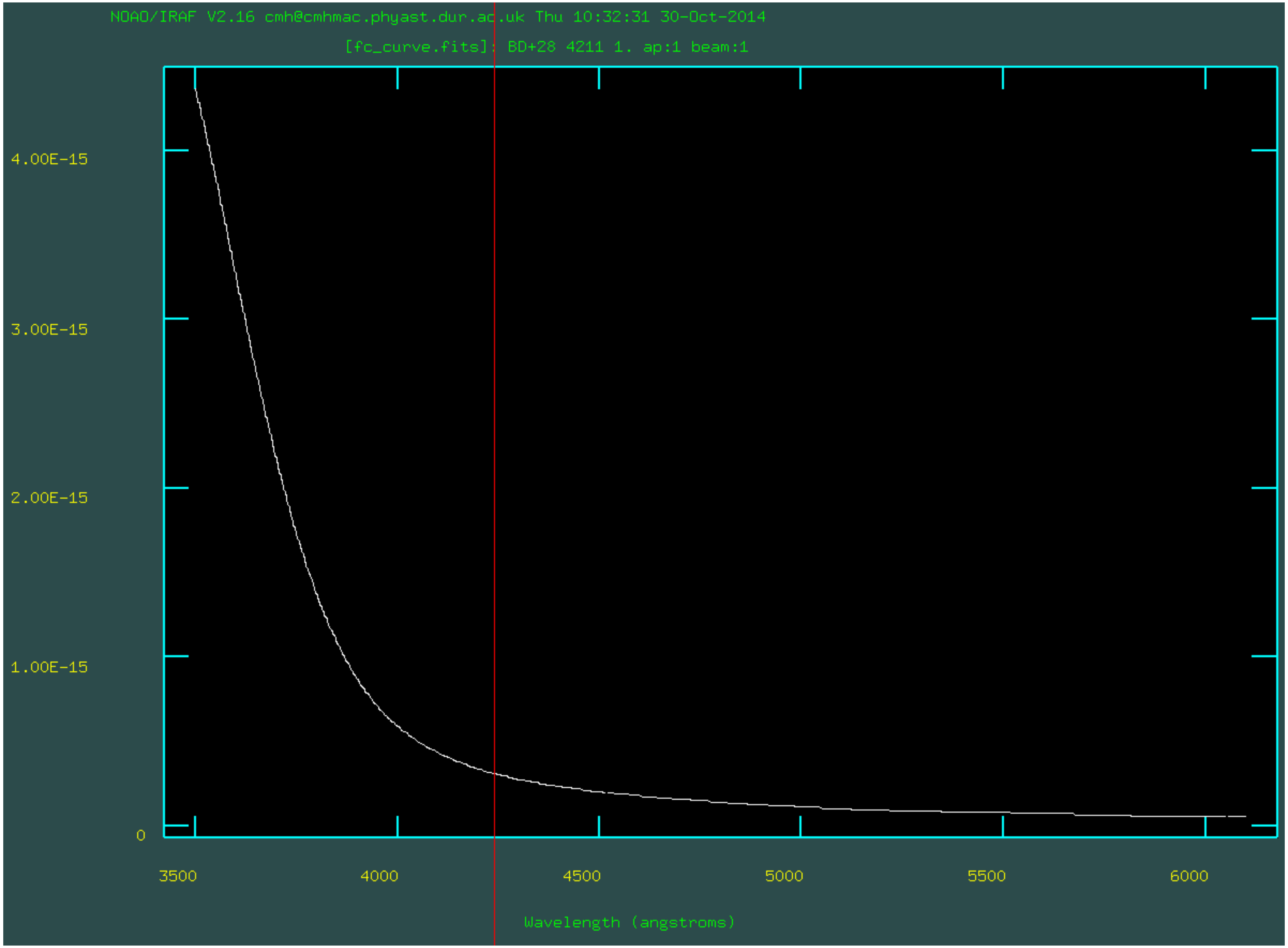




Flux Calibration / Filter Response

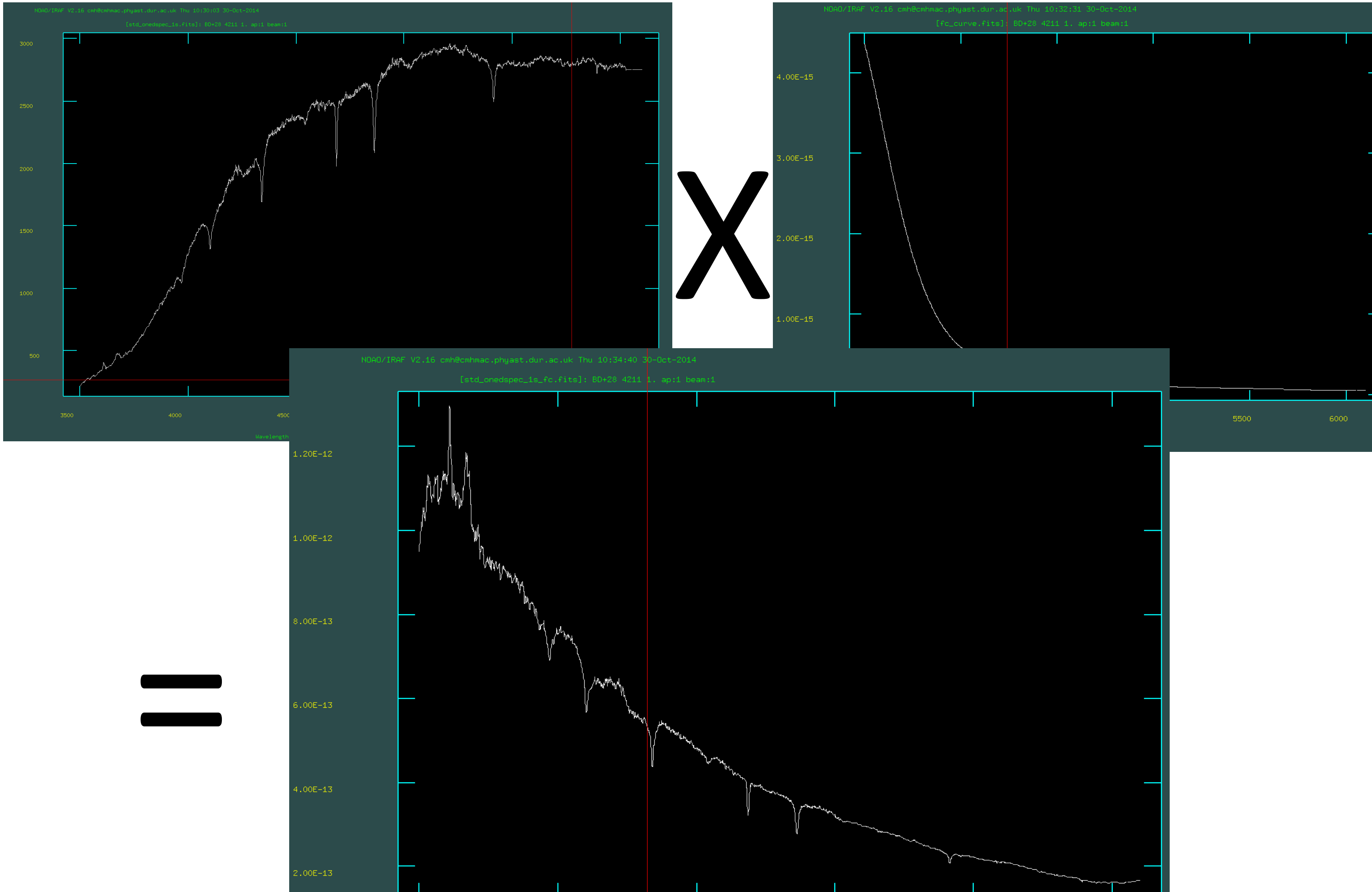
GMOS Longslit Data

Filter response to convert counts/s to erg/s/cm2/A as a function of wavelength:



GMOS Longslit Data

Flux Calibration / Filter Response

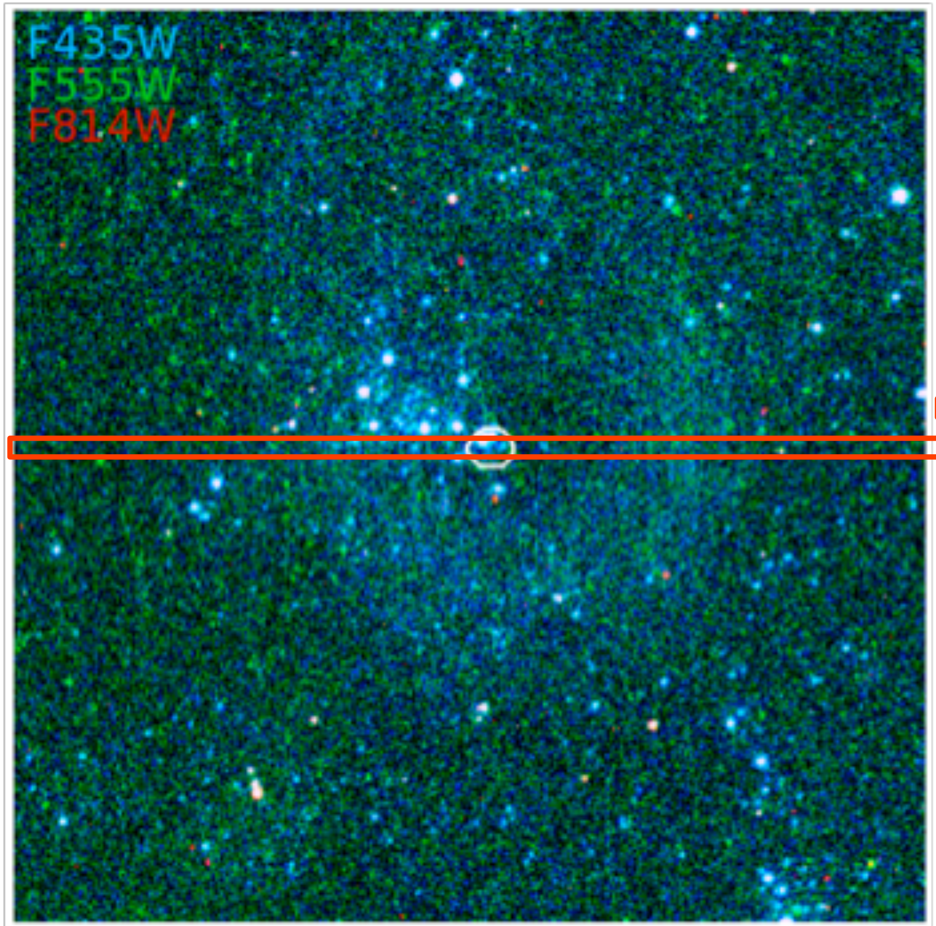


Once you have your filter response curve, you can apply this to your science spectra

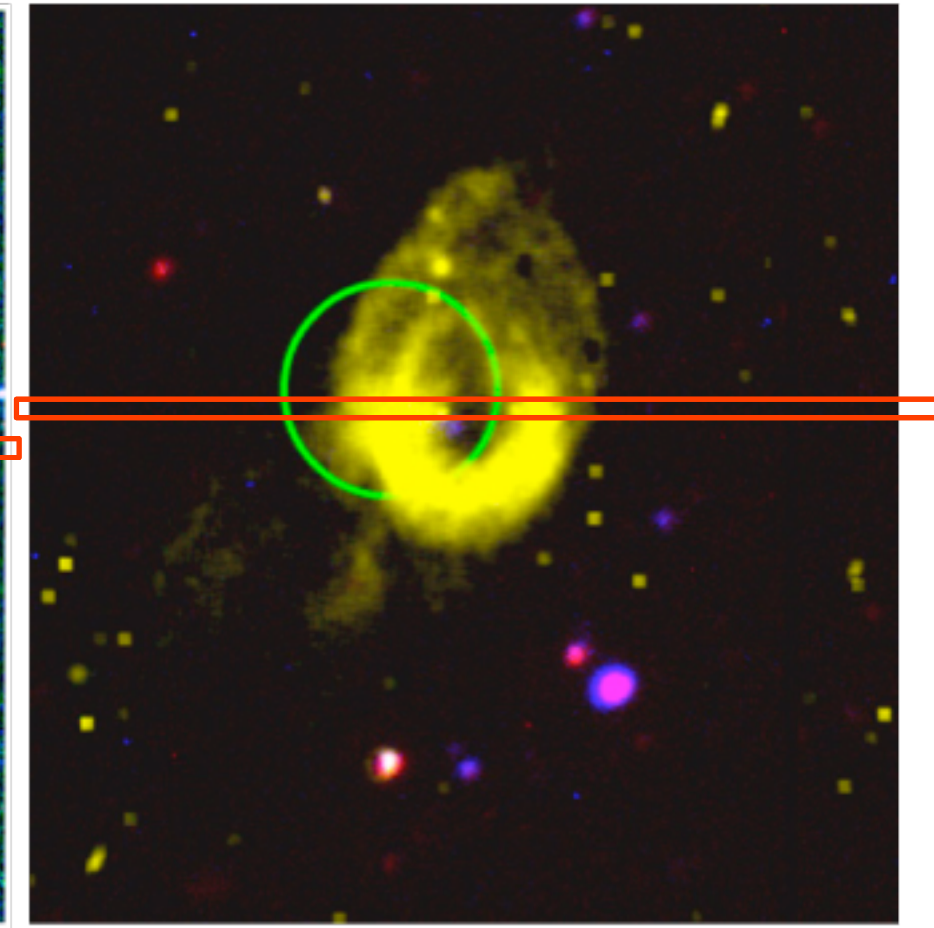
The data for the workshop

Ho IX-X1 : a ULX inside a nebula. A candidate intermediate black hole

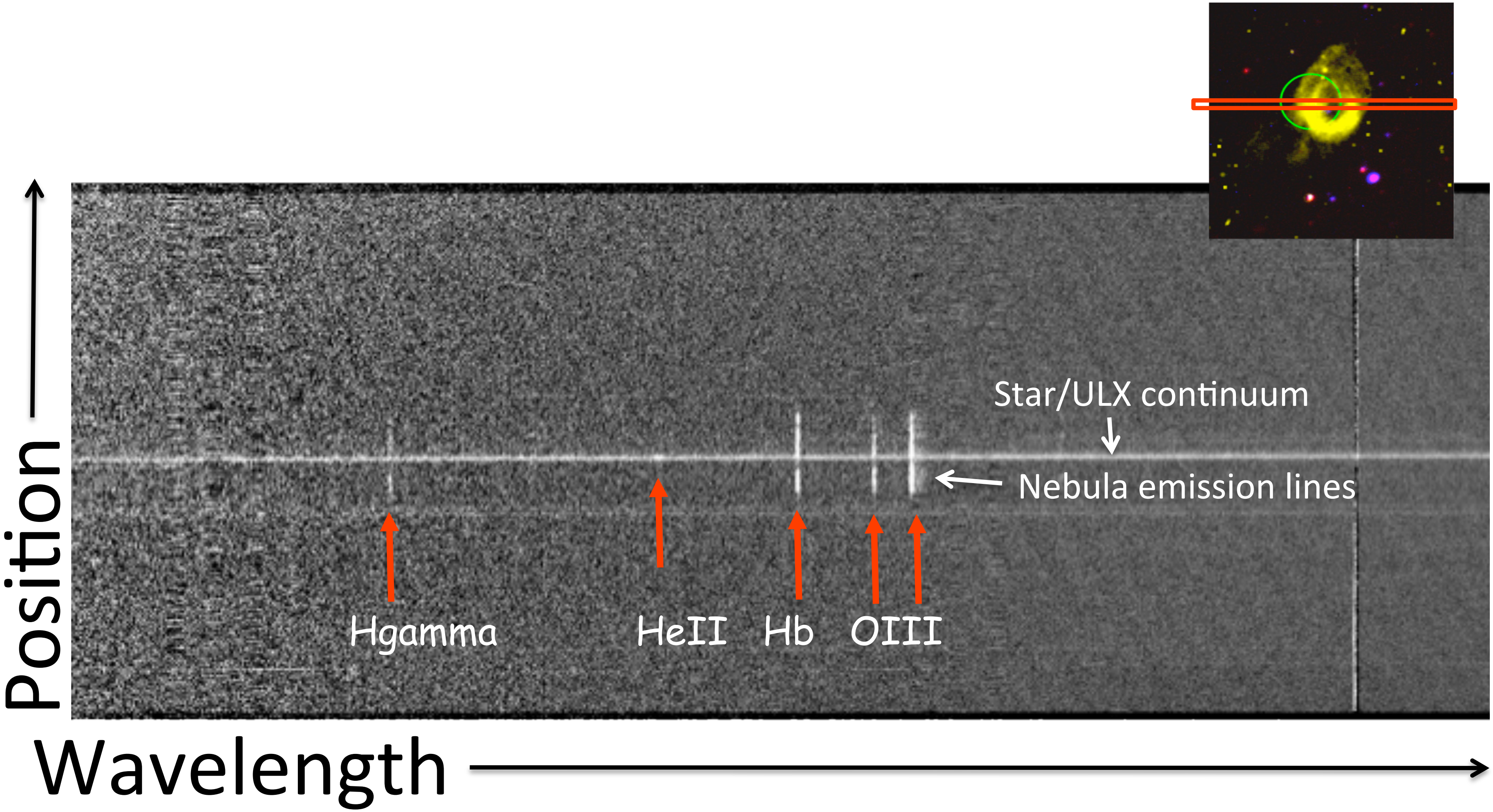
HST 3-colour image



[O III] narrow band image



The data for the workshop



+ There is emission from the nebula and from the ULX

- By now you should have IRAF/GAIA/ds9/wcstools working?
- Workshops in R216 (Monday/Tuesday, 14.00-17.00 – recommend getting starting early at 13.00)
- Step by step instructions are on the website: http://astro.dur.ac.uk/~cpnc25/pg_dr_intro.html
- Hand-in problems are on the website (at the bottom of the page). These are due in before **10th December 2015**
- You will present your answers to the rest of the class on **Thursday 10th December** in the lecture and we will discuss the answers
- If there are any problems, email me (c.m.harrison@durham.ac.uk) or TC (chian-chou.chen@durham.ac.uk), or come and see us (Room 333/ Room 319). **Do not struggle on your own / give up!**