

Gemini Multi-Object Spectrograph (GMOS)

Gemini Data Workshop

Topics

- Basic on GMOS
- Imaging
- Longslit spectroscopy
- MOS spectroscopy
- Nod & Shuffle (Kathy Roth)
- IFU (Richard McDermid)

GMOS Overview

- GMOS detectors:
 - three 2048x4608 E2V chips (6144×4608 pixels)
 - 0.0727" (GMOS-N) and 0.073" (GMOS-S) per pix
 - Gaps between CCDs – 37 unbinned pixels.
 - Field of view: 5.5' \times 5.5' (imaging)
- Filters
 - Sloan u' (GMOS-S only) g' r' i' z' and CaIII
 - H α , H α C, HeII, HeIIC, OIII, OIIIC, SII (Narr. band)
 - Others: GG445, OG515, RG610, RG780, DS920
- Spectroscopy
 - Longslits (0.5" – 5.0"), MOS and IFU
 - Nod & Shuffle

GMOS Overview

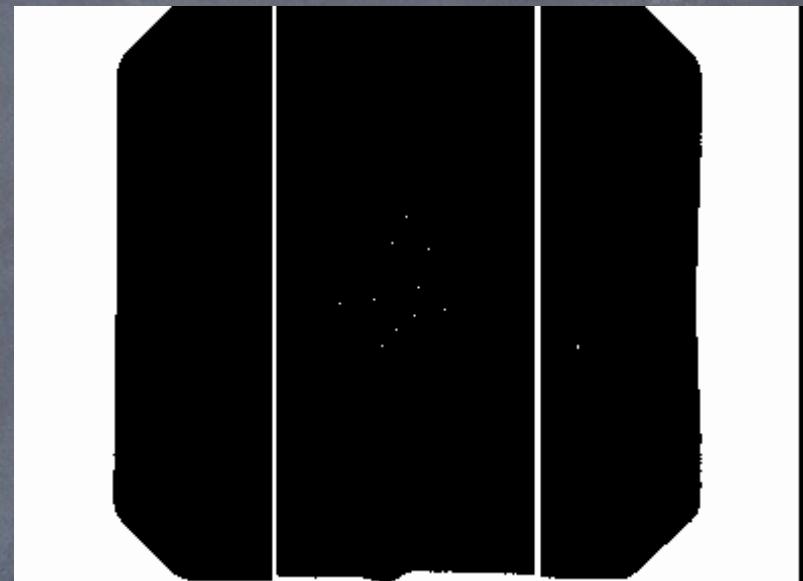
- Available gratings

Grating	Blaze wav. [Ång]	R (0.5" LS)	Coverage [Ång.]	Dispersion [Ång/pix]
B1200	4630	3744	1430	0,23
R831	7570	4396	2070	0,34
R600	9260	3744	2860	0,45
R400	7640	1918	4160	0,47
B600	4610	1688	2760	0,67
R150	7170	631	10710	1,74

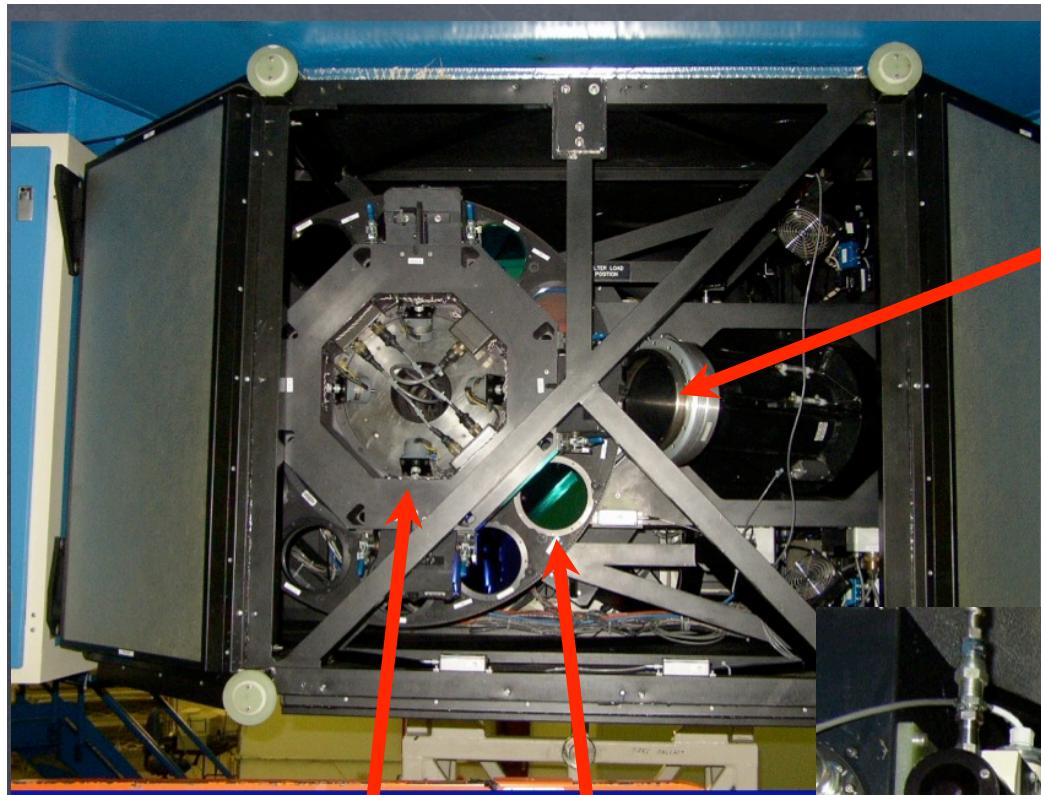
Grating turret supports only 3 gratings + mirror

GMOS Overview

- GMOS detectors characteristics
 - Good cosmetic, with only few bad pixels
 - Bad pixels masks for imaging - provided by the observatory (1x1 and 2x2) - `gmos$data/ directory`
- Saturation level: ~64000 ADU
- Linearity - ~60.000 ADU (<1%)
- CCD readouts and gains configurations
 - Slow readout/low gain (science)
 - Fast readout/low gain (bright obj.)
 - Fast readout/high gain
 - Slow readout/high gain (eng. only)
- Readout time:
 - 1x1 slow/low - 129 sec
 - 2x2 slow/low - 37 sec



SDSU Gain number			1 (High)		2 (Low)		5 (High)		6 (Low)	
CCD	Rate	Amp	Gain	Noise	Gain	Noise	Gain	Noise	Gain	Noise
1	F	L					5.054	6.84	2.408	4.49
1	F	R					5.253	6.54	2.551	5.07
1	S	L	4.954	5.70	2.372	3.98				
1	S	R	4.862	5.19	2.403	4.01				
2	F	L					5.051	7.35	2.295	4.42
2	F	R					4.954	11.37	2.288	5.03
2	S	L	4.532	4.81	2.076	3.85				
2	S	R	4.592	4.96	2.131	3.83				
3	F	L					4.868	8.56	2.264	4.63
3	F	R					4.833	7.88	2.260	4.09
3	S	L	4.381	4.81	2.056	3.27				
3	S	R	4.411	4.34	2.097	3.16				
Ave	F						5.002	8.09	2.344	4.622
Ave	S		4.622	4.968	2.189	3.683				

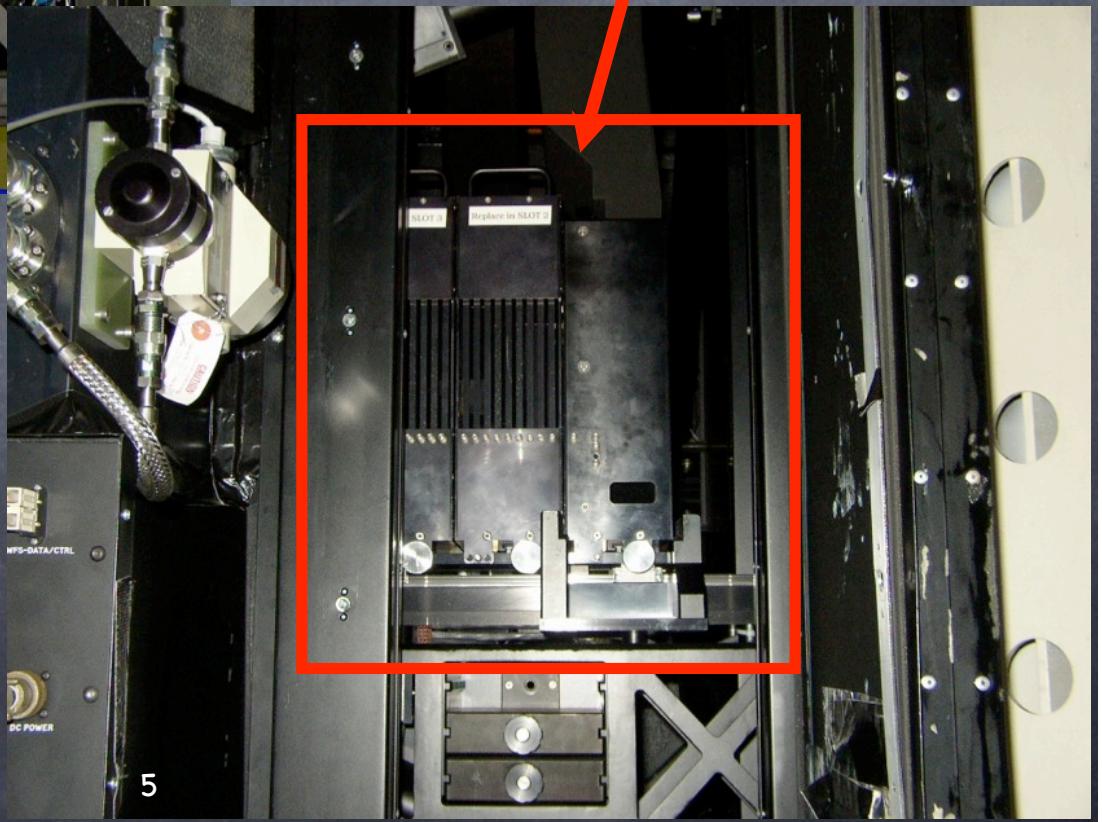


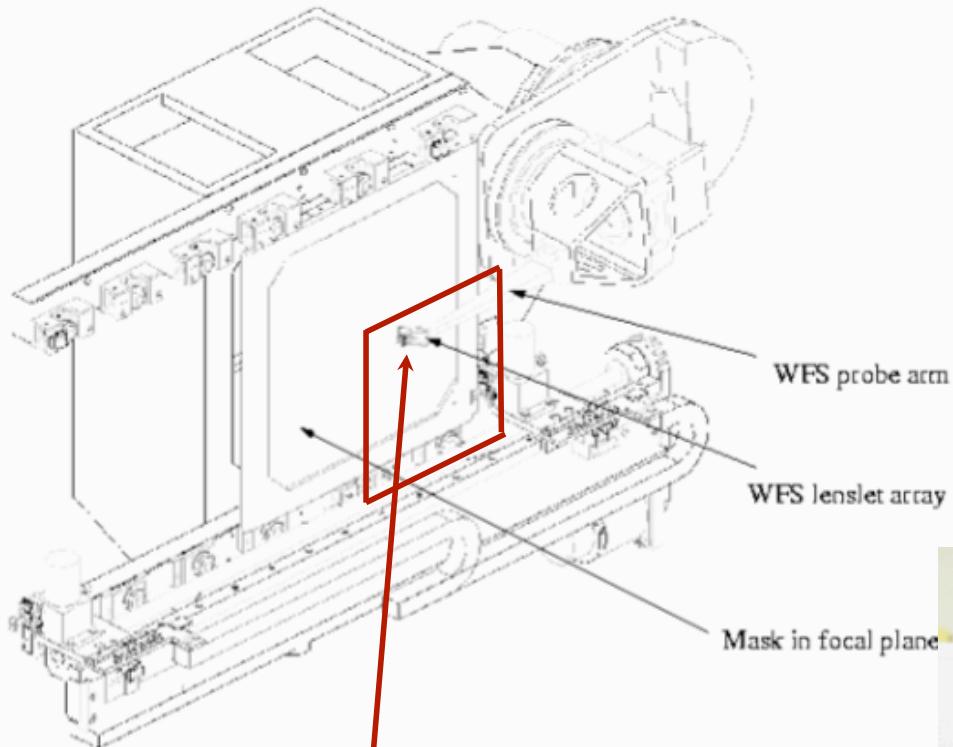
Grating turret

Filter wheels

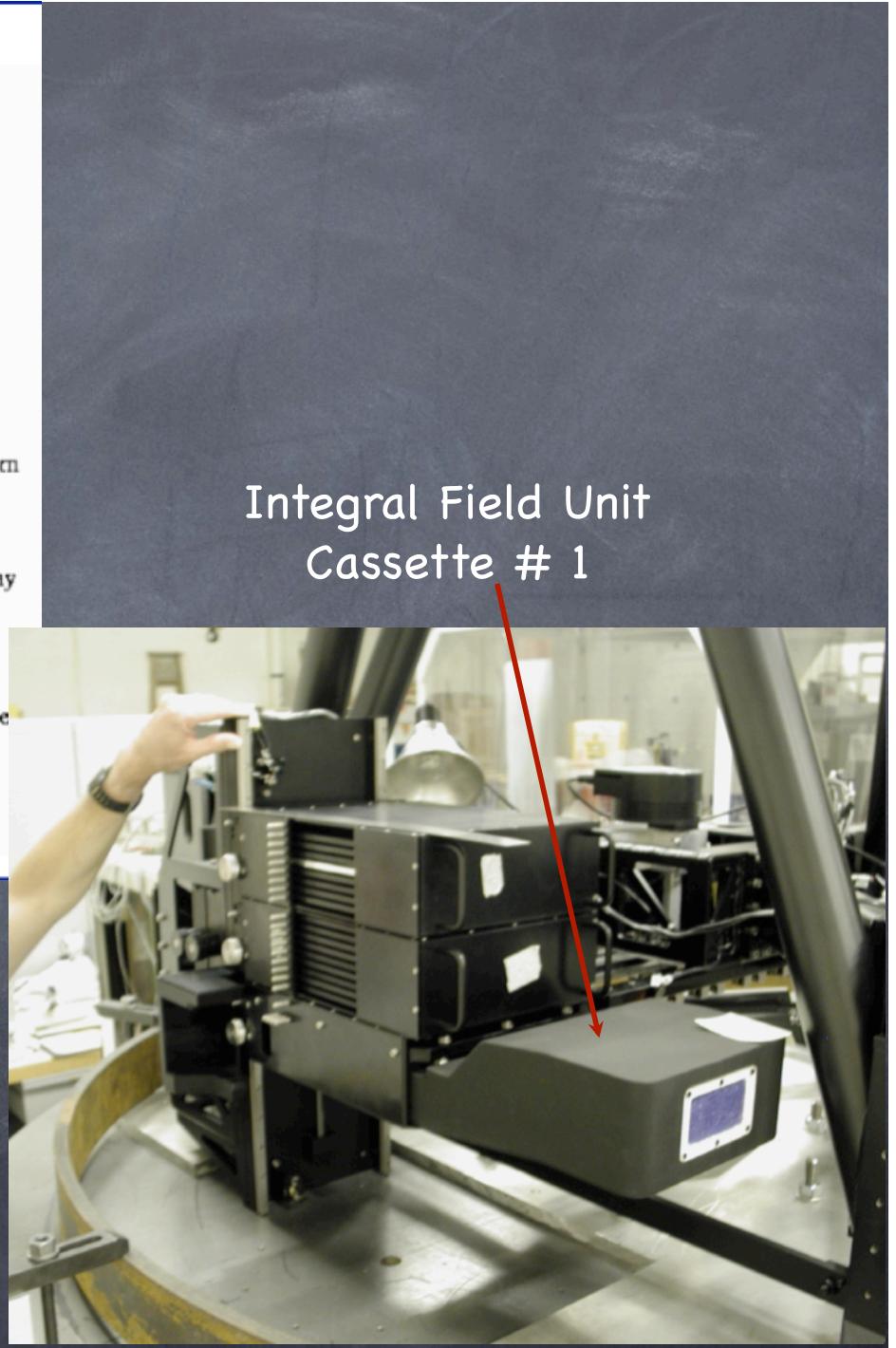
to the detector

Mask assembly with
cassettes and masks





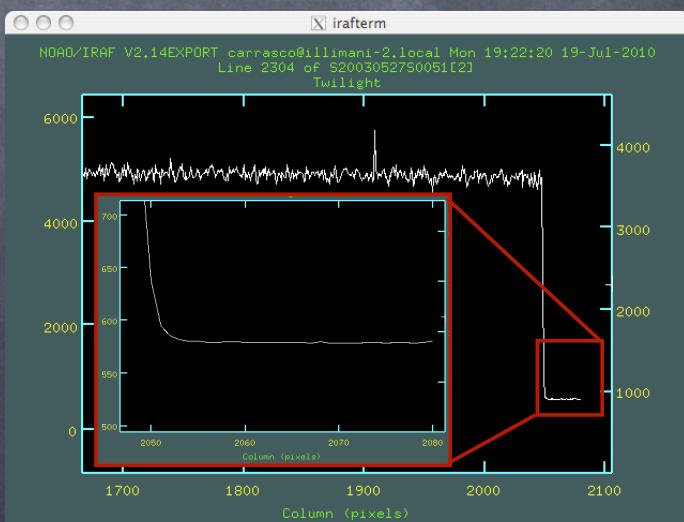
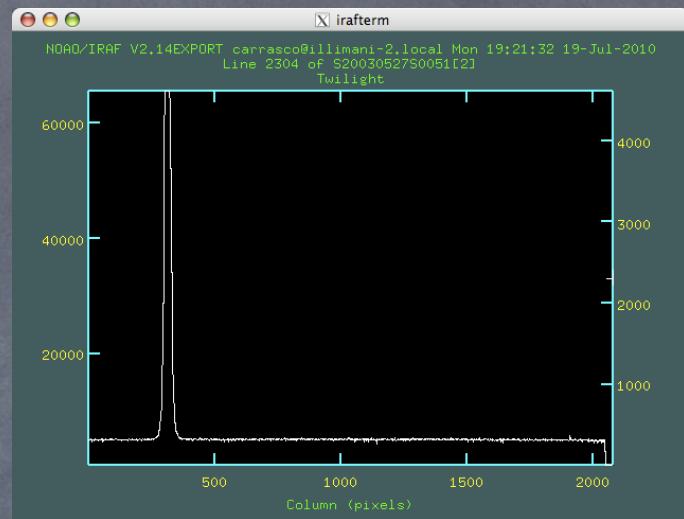
OIWFS and patrol field area



GMOS Data Reduction

General guidelines

- ◆ Fetch your program using the OT
- ◆ Check for any note added by the observer(s) and/or the Queue Coordinator(s) regarding your observations
- ◆ Check the observing log (you can use the OT)
- ◆ Look at your raw data
 - ◆ Check all frames
 - ◆ use imstatistic, implot or other IRAF tasks to check the data



GMOS Data Reduction

Calibrations

- ♦ Set of Baseline Calibrations provided by the observatory
 - ♦ Bias for all modes of observations
 - ♦ Twilight flats: imaging and spectroscopy
 - ♦ Spectroscopic flats from GCAL unit
 - ♦ CuAr Arcs for spectroscopy (GCAL unit)
- ♦ Nighttime calibrations (baseline)
 - ♦ Photometric standard stars - zero point calibrations
 - ♦ Flux standard - flux calibration
- ♦ Other calibrations (charged to the program)
 - ♦ Radial velocity standards
 - ♦ Lick standards, etc.

GMOS Images: example

HCG 87: g', r' and i' filters, 1 × 1 (no binning)

# Reducing HCG87	g	-	-	300
#157-159 HGC87	r	-	-	180
#161-163 HGC87	i	-	-	120

Calibrations

# Bias										
# GS-CAL20030525-2	10:37	212-221	Bias	-	-	-	1	1	1	1x1,full/slow/low
<hr/>										
# Twilight flats										
# GS-CAL20030527-3	22:15	39-48	Twilight	g	-	-	5,5,7,20,35,50	1	1	1x1,full,slow,low,best
# GS-CAL20030530-6	22:38	45-47	Twilight	r	-	-		1	1	1x1,full,slow,low,best
# GS-CAL20030527-4	22:38	49-52	Twilight	i	-	-	30,80,120,160	1	1	1x1,full,slow,low,best
<hr/>										
# Blank field - fringing correction										
# GS-CAL20030525-10	9:15	173-177	Blank21h	i	-	-	180	1	1	1x1,full,slow,low,best

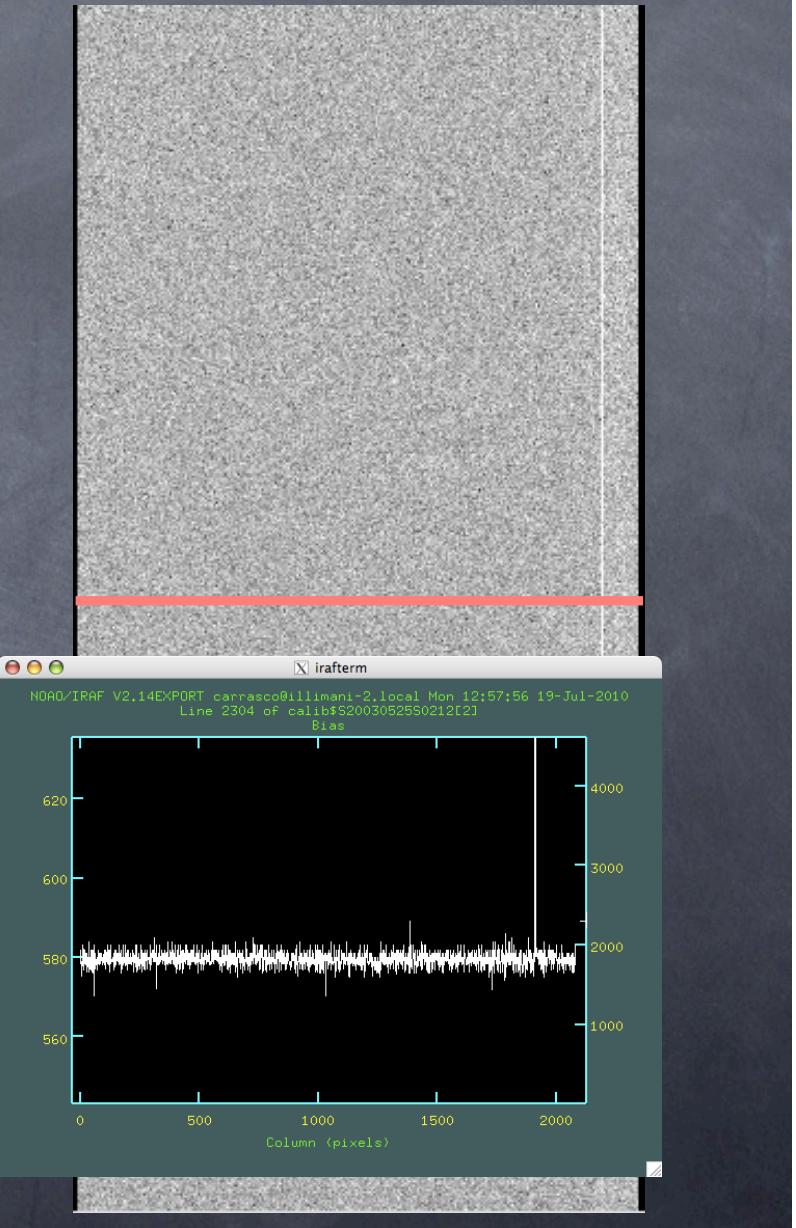
Reduction Steps

- * Combine bias (trim, overscan)
- * Twilight flats : subtract bias, trim, overscan, combine
- * Reduce images: bias, overscan, trimmed, flatfield
- * Fringing correction: i'-band only
- * Mosaic the images and combine the frames by filter

Reducing GMOS Images

Bias reductions (for all modes)

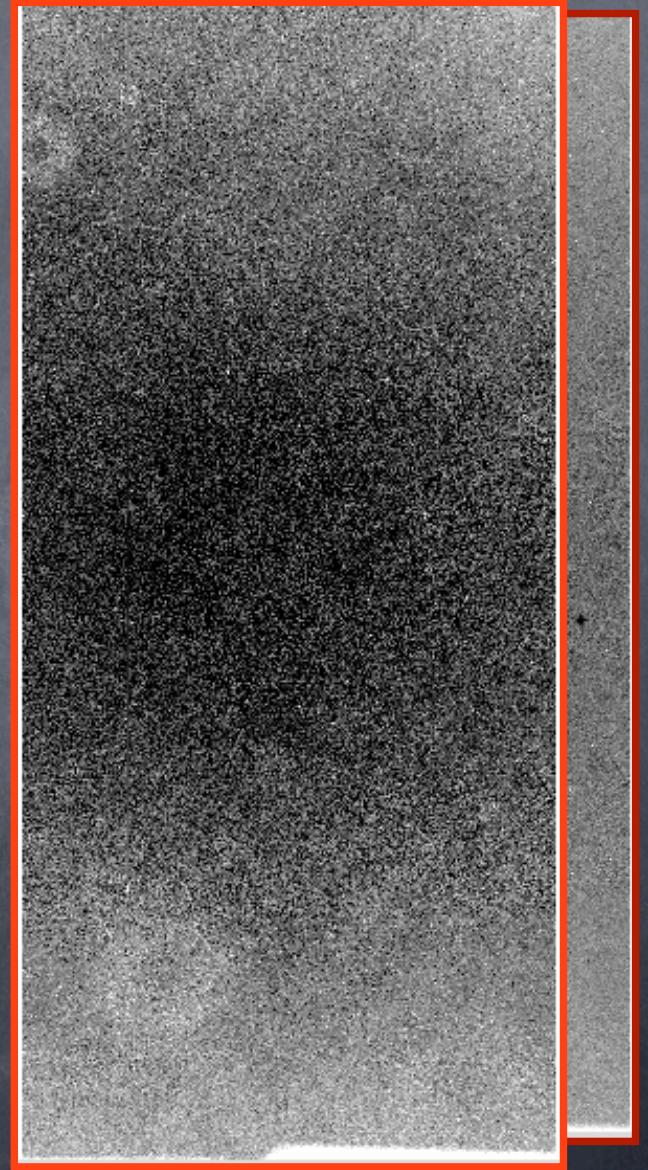
- ★ Be sure to use the correct bias
 - ★ slow readout/low gain
 - ★ binning: 1x1
- ★ Tip: check keyword AMPINTEG in the PHU
 - ★ AMPINTEG = 5000 - Slow
 - ★ AMPINTEG = 1000 - fast
 - ★ Gain -- in the header
 - ★ CCDSUM - binning
- ★ Bias reductions -- uses gbias
- ★ Overscan subtr. - recommended
- ★ gbias @bias.list bias_out.fits fl_trim+ fl_over+ rawpath=dir\$
- ★ Check the final combined bias image



Reducing GMOS Images

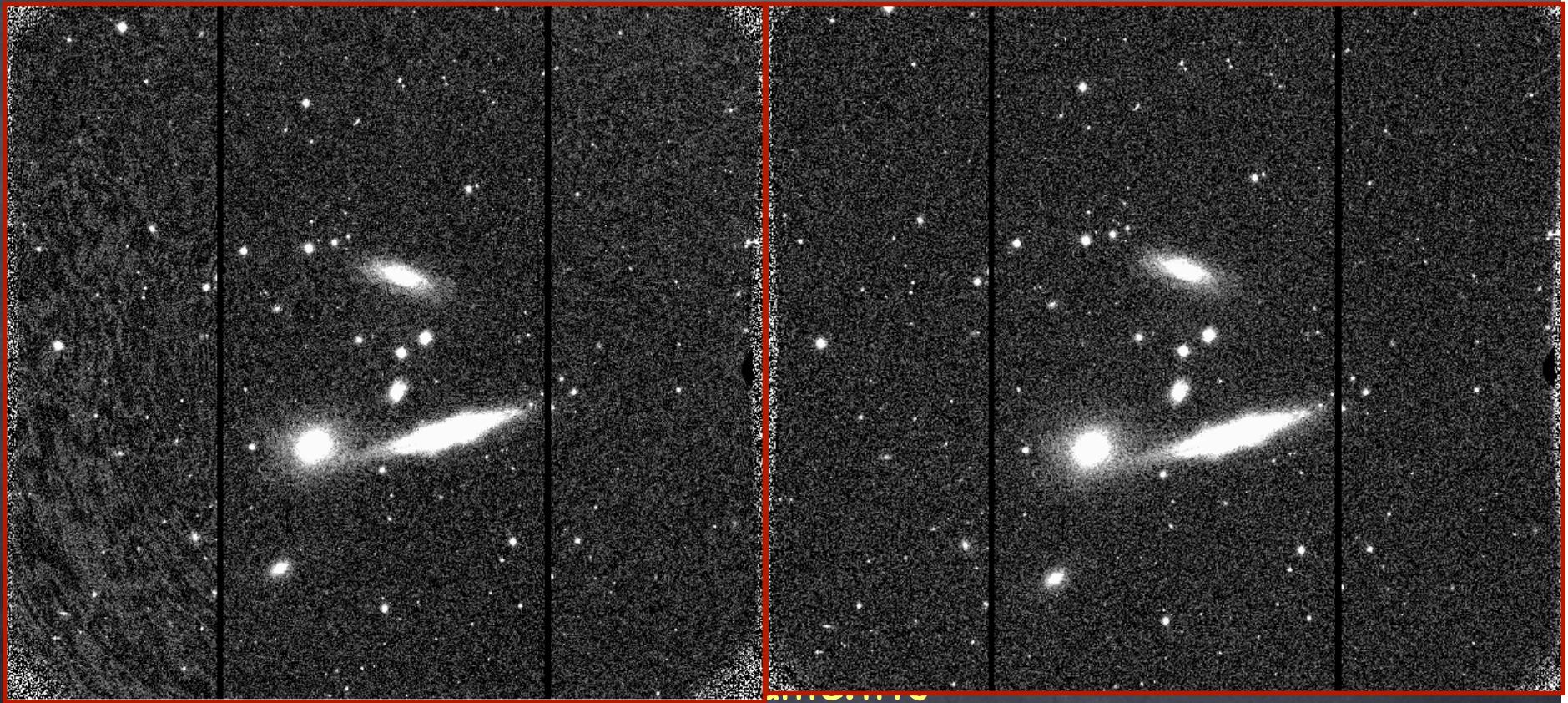
Twilight flats

- ◆ Twilight flats are used to flat field the images
- ◆ twilight flats are observed periodically for all filters
 - ◆ Special dithering pattern
- ◆ Constructing flat field with giflat
 - ◆ `giflat @flat_g.lst outflat=gflat fl_trim+ fl_over+ rawpath=dir$`
 - ◆ The default parameters work ok for most cases
- ◆ Final flat is normalized



Reducing GMOS Images

Fringing correction



$$\text{◆ Output} = \text{Input} - s * F$$

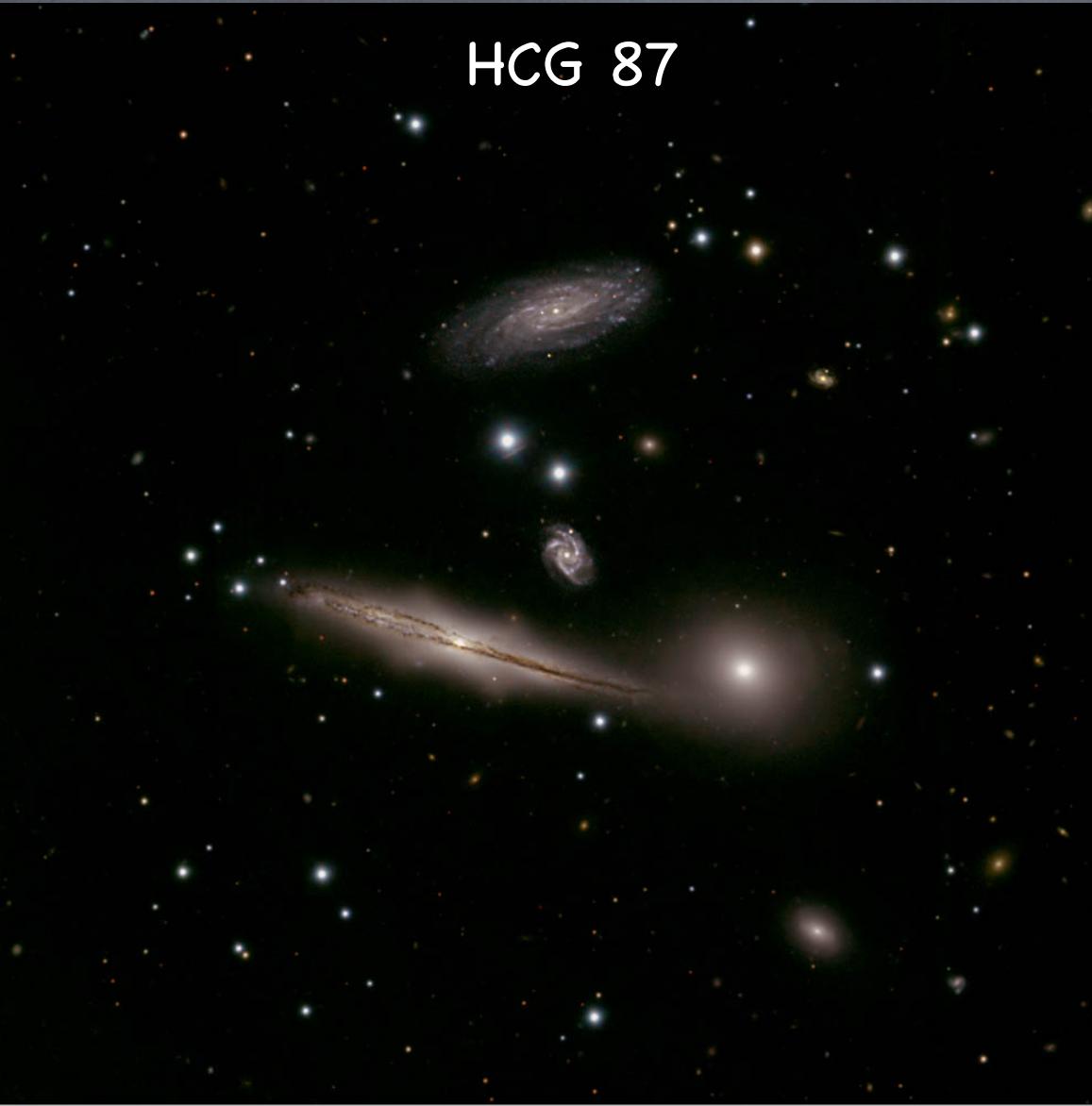
Reducing GMOS Images

Science images

- Reducing the images with **gireduce**
 - **gireduce**: gprerare, bias, overscan and flatfield the images
 - **gireduce @obj.lst fl_bias+ fl_trim+ fl_flat+ fl_over+**
bias=bias.fits flat1=flatg flat2=flatr flat3=flatl rawpath=dir\$
- Removing fringing with **girmfringe** (*i'* band images only)
- Inspect all images with “**gdisplay**”
- Mosaicing the images with **gmosaic** -> **gmosaic @redima.lst**
- Combining your images using **imcoadd**
- **imcoadd** - search for objects in the images, derive a geometrical trasformation (shift, rotation, scaling), register the objects in the images to a common pixel position, apply the BPM, clean the cosmic ray events and combine the images

Final GMOS image

HCG 87



Gemini Observatory / NRC / AURA / Christian Marois, et al.

Gemini Observatory Legacy Image

GMOS MOS Spectroscopy

```
#  
# Brief data description: MOS observations of Group 97 at redshift 0.5  
# Data obtained in 2003 May 29 UT - GMOS-S Science verification  
#  
#GS-2003A-SV-206-41 22:10 85-87 Group 97 twilight R400/670/675 GS2003ASV206-01 30  
#GS-2003A-SV-206-38 23:40 133-137 Group 97 mask 1 acquisition mirror none r 10  
#GS-2003A-SV-206-43 00:04 138-141 Group 97 mask 1 acquisition mirror none r 10  
#GS-2003A-SV-206-44 00:26 142-146 Group 97 mask 1 acquisition mirror none r 10  
#GS-2003A-SV-206-14 00:43 147-150 Group 97 mask 1 none R400/670/675 GS2003ASV206-01 1800  
# 165-166 Group 97 mask 1 none R400/670/675 GS2003ASV206-01 1800  
#  
#S20030529S0147.fits GCALflat 670  
#S20030529S0148.fits CuAr 670  
#S20030529S0149.fits Group097-mask1 670  
#S20030529S0150.fits Group097-mask1 675  
#S20030529S0165.fits GCALflat 675  
#S20030529S0166.fits CuAr 675  
#  
# Set up the logfile for this reduction  
#  
# Calibration: Bias 2x2/slow/low  
#  
#gS20030529S0040_bias.fits  
#
```

GCAL flats + CuAr arc – inserted in the sequence

GMOS Mask Definition File (MDF)

Contains information about

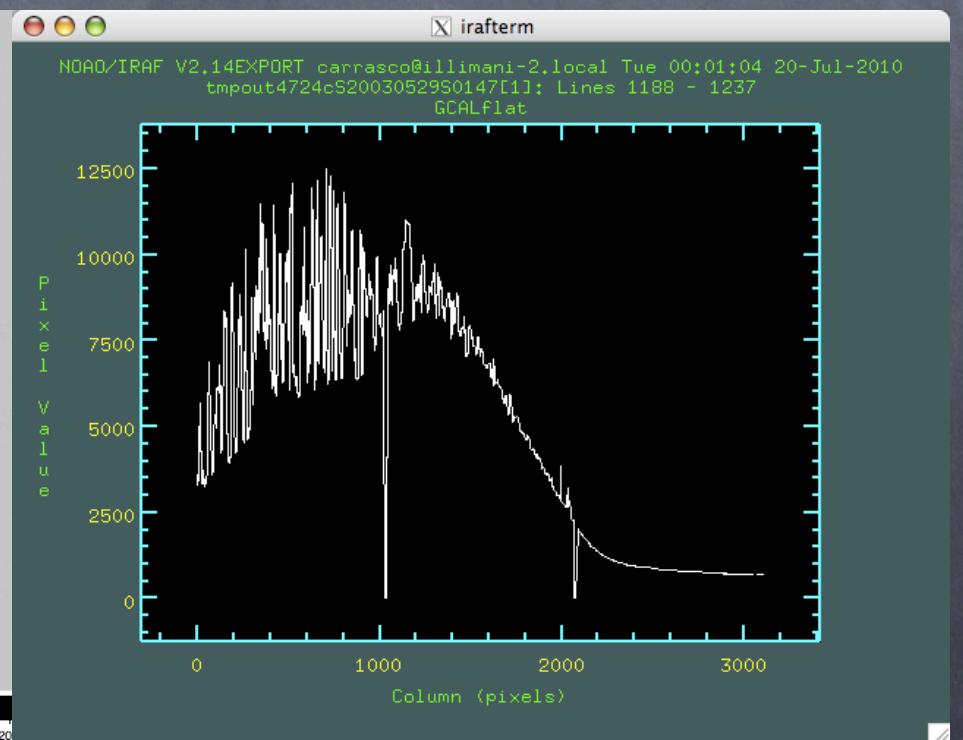
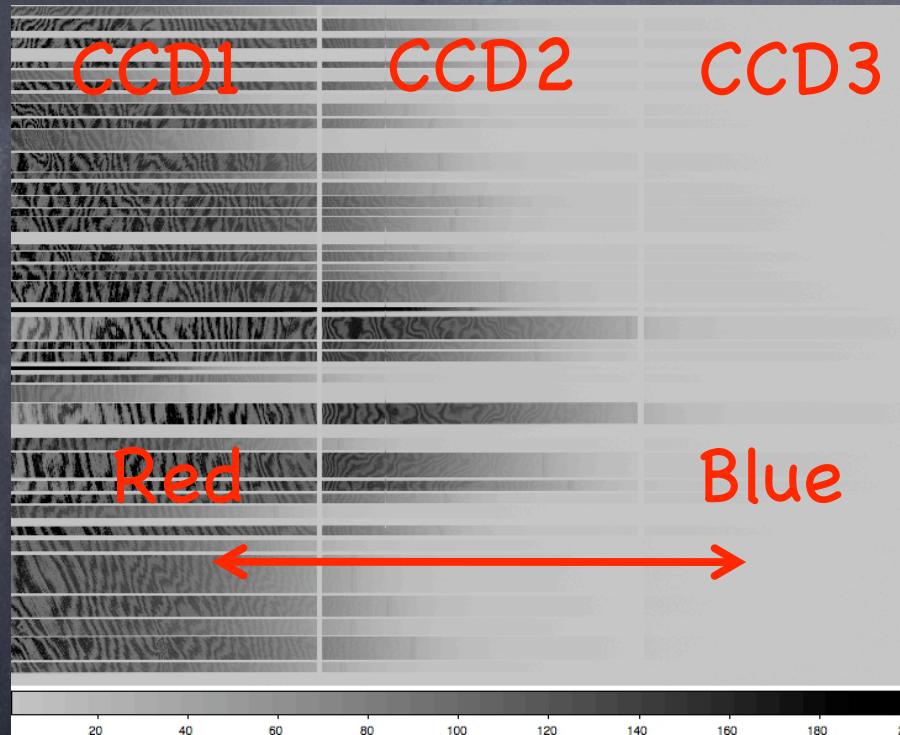
- ◆ Slit locations, slit width, slit length, tilt angle, etc
- ◆ RA, Dec position of the objects
- ◆ X, Y position of the objects in the pre-imaging

Necessary for data reduction

Column	1	2	3	4	5	6
Label	ID	RA	DEC	x_ccd	y_ccd	specpos_x
1	043	11.29326	7.74637	602.238	1063.694	330.9022
2	1590	11.29039	7.73961	1655.822	1251.335	-263.7965
3	75	11.29167	7.78504	1182.375	104.992	3.442139
4	3	11.29158	7.78015	1216.208	225.876	-15.65503
5	5	11.29096	7.78257	1442.532	165.153	-143.4043
6	558	11.29196	7.76952	1075.628	489.391	63.6958
7	2	11.29157	7.77326	1217.811	396.227	-16.55981
8	1	11.29121	7.77685	1350.787	306.925	-91.61853
9	617	11.29069	7.7675	1541.656	537.38	-199.3552
10	1102	11.2933	7.74991	586.68	976.439	339.6838
11	619	11.29236	7.76508	929.617	599.725	146.1121
12	552	11.28964	7.75871	1929.212	753.053	-418.1123
13	994	11.28872	7.75214	2267.867	914.247	-719.7552
14	1346	11.2919	7.7479	1099.225	1023.904	50.37646
15	927	11.29172	7.75646	1165.684	811.853	12.8634
16	775	11.29063	7.76342	1563.11	638.313	-211.4648
17	855	11.28937	7.76163	2026.095	680.707	-477.9834
18	1261	11.28973	7.74453	1898.727	1104.069	-400.9049
19	1164	11.28878	7.74183	2245.893	1169.38	-697.7815
20	1501	11.28973	7.74314	1896.697	1138.421	-399.759
21	2892	11.291	7.73334	1433.284	1382.557	-137.5876
22	1864	11.29068	7.73408	1548.174	1363.824	-203.0342
23	2823	11.2906	7.73149	1580.359	1427.768	-221.2013
24	1661	11.29009	7.73629	1767.55	1308.345	-326.8617

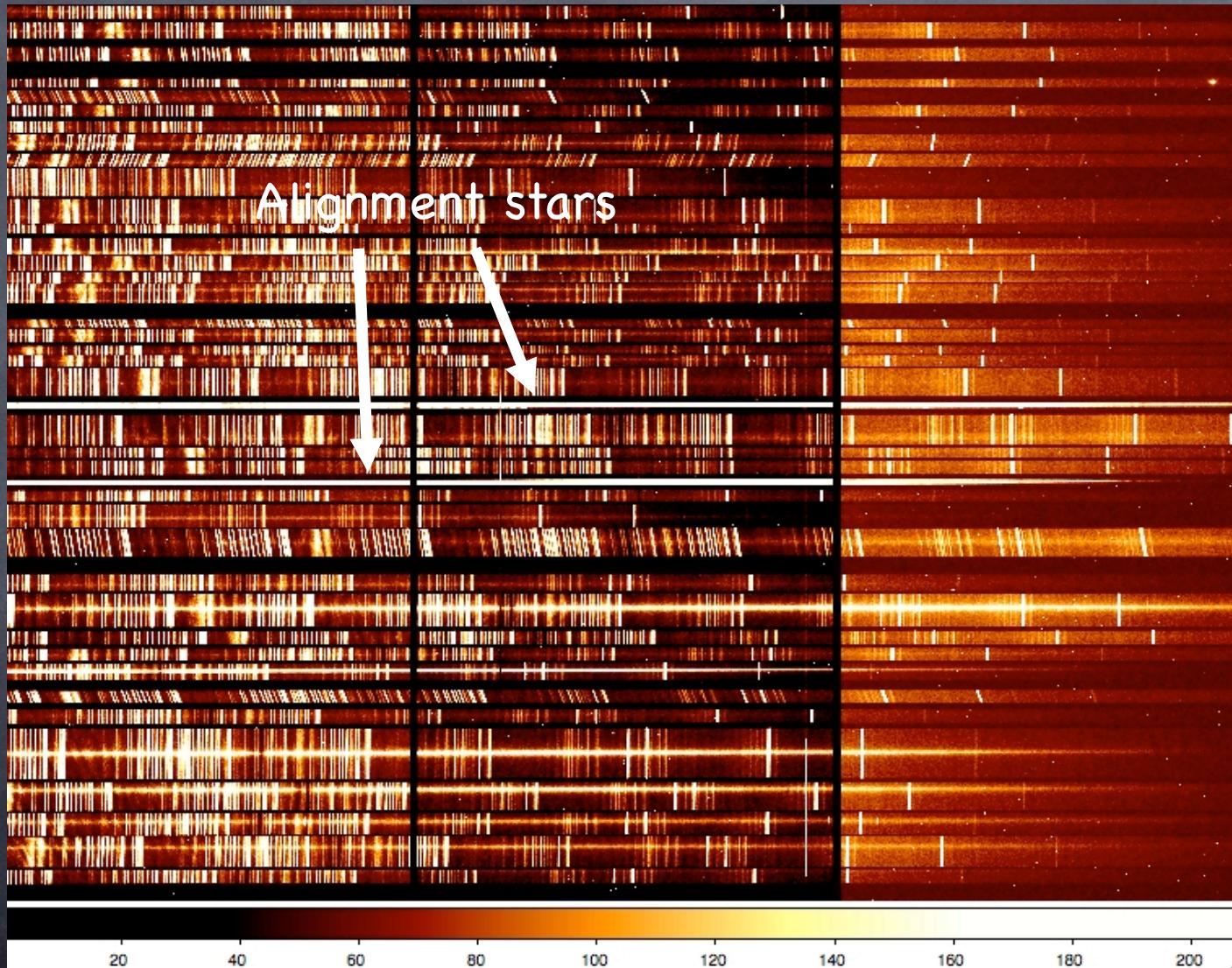
GMOS MOS Gcal flat

Wavelength coverage: \sim 456nm – 884nm



Significant fringing above 700nm

GMOS MOS Spectra



GMOS MOS reduction

Basic reduction steps

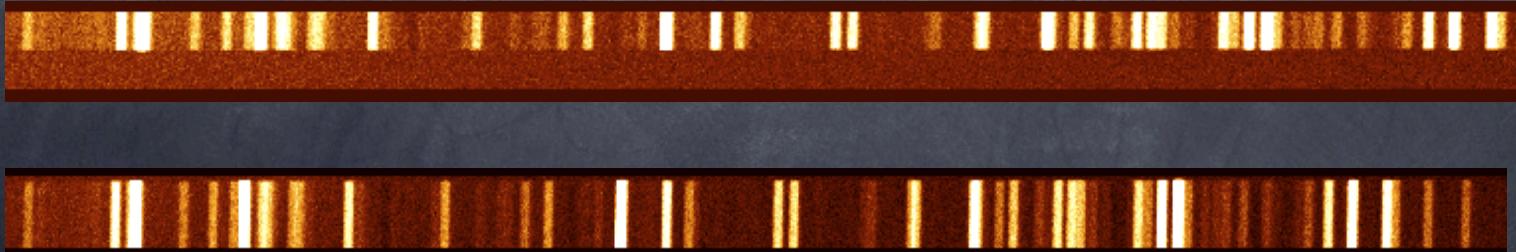
- Prepare the images by adding the MDF file with *gprepare*
- Bias subtraction for all images, including the CuAr arcs
 - CuAr arcs observed during the day - then an overscan subtraction is enough.
- Bias subtraction is performed with *gsreduce*
 - *gsreduce @obj.lst fl_flat- fl_gmosaic- fl_fixpix- \ fl_gsappw- fl_cut- fl_over+ fl_bias+ bias=biasima.fits \ rawpath=dir\$ mdfdir=dir\$*

```
gmos> fxheader S20030529S0149.fits
EXT# EXTTYPE EXTNAME          EXTVE DIMENS      BITPI INH OBJECT
0     S20030529S0149.fits
1     IMAGE
2     IMAGE
3     IMAGE
gmos> fxheader gsS20030529S0149.fits
EXT# EXTTYPE EXTNAME          EXTVE DIMENS      BITPI INH OBJECT
0     gsS20030529S0149.fil
1     IMAGE      SCI
2     IMAGE      SCI
3     IMAGE      SCI
4     BINTABLE   MDF
gmos>
```

GMOS MOS reduction

Wavelength Calibration

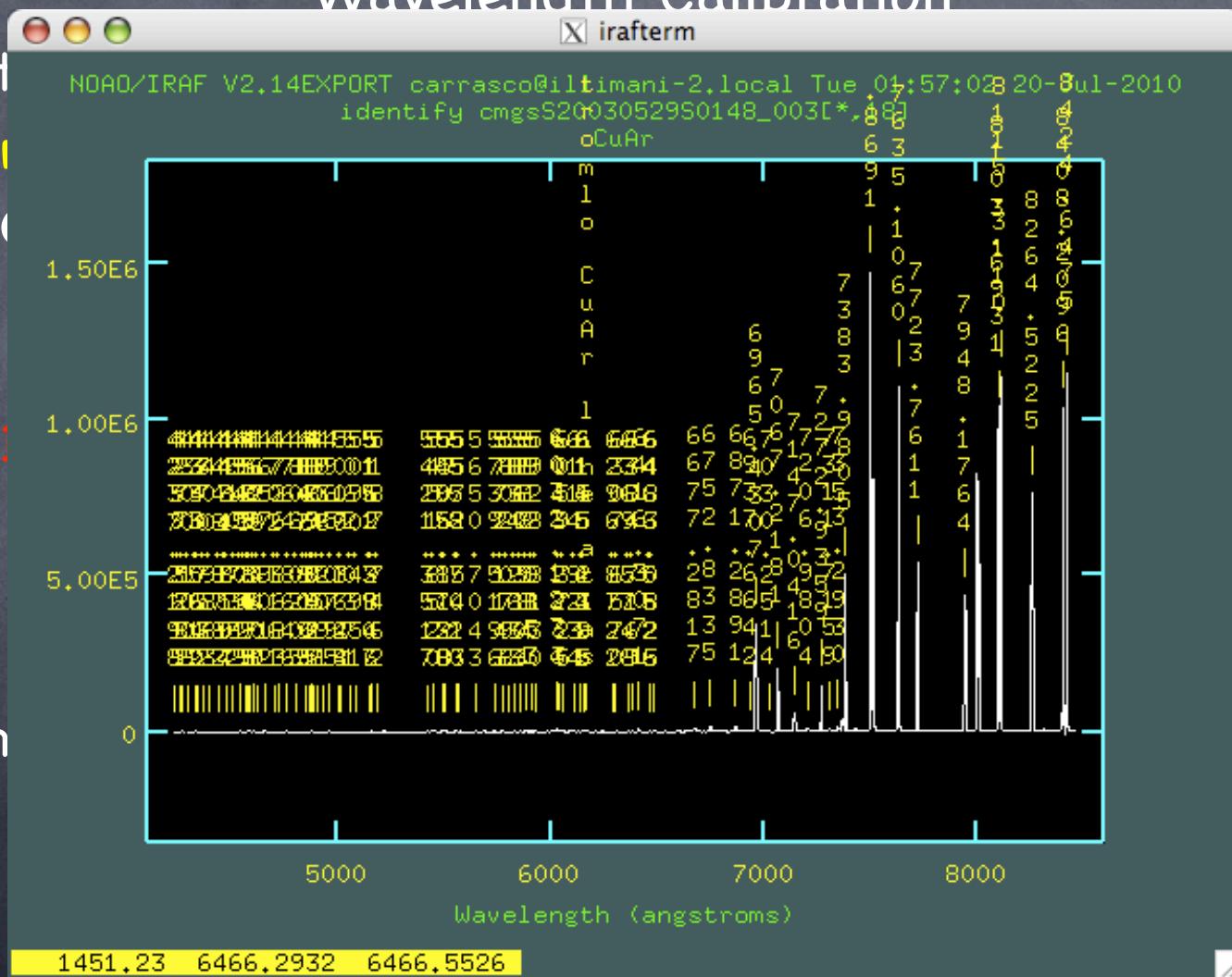
- Wavelength calibration is performed slit by slit
- Do the calibration interactively - recommended
 1. Mosaic the CuAr arc with *gmosaic*
 2. cut the spectra with *gscut*
 3. *gscut mCuArarc outimage=cmCuAr secfile=cmCuAr.sec*
 4. Inspect the cmCuAr.sec file and the image to see if the cut is good
 5. If the cut is not good, then adjust the *yoffset* param.



GMOS MOS reduction

Wavelength Calibration

- Estimate wavelength
- *gsfidentify*
- 1. Open spectrum
- 2. Identify
- 3. Identify
- 4. Identify
- Import
- Export
-



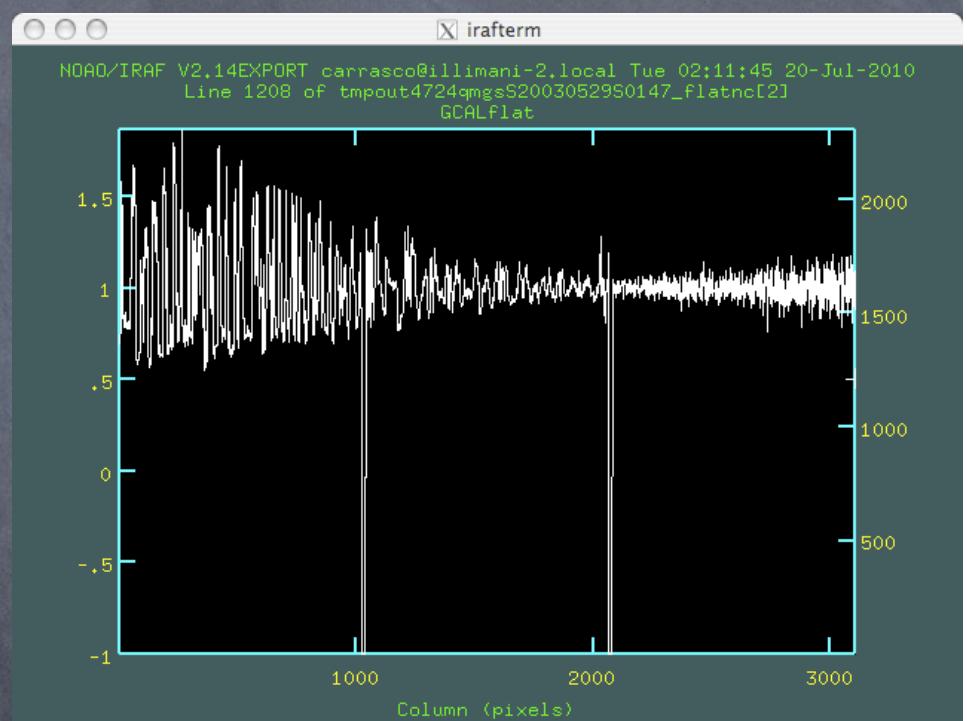
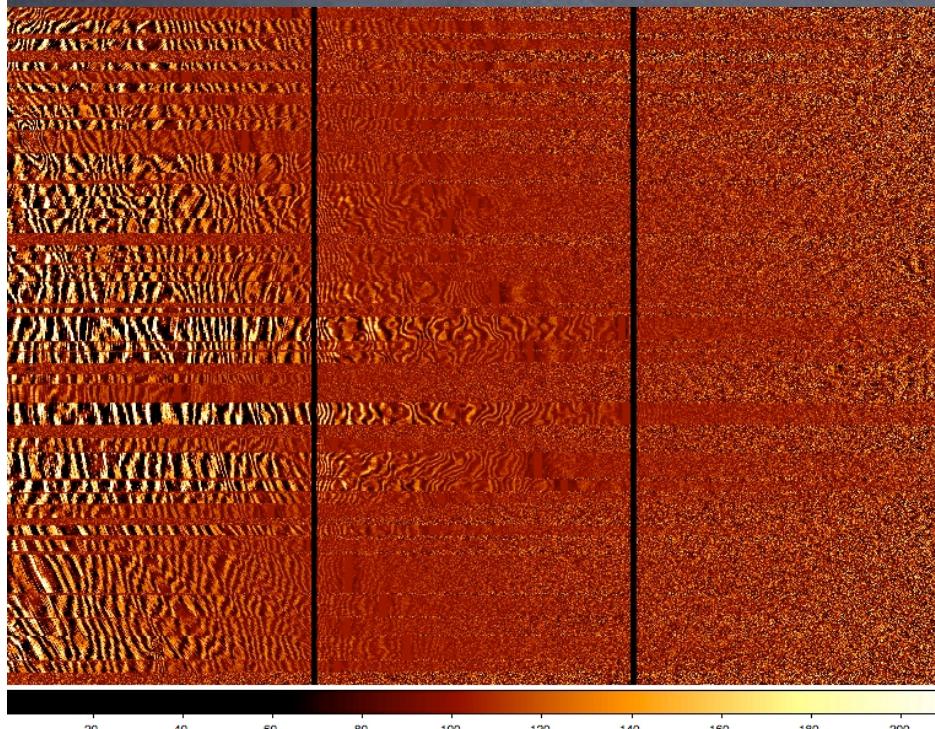
GMOS MOS reduction

Flat field

- Use **gsflat** to derive the flat field for the spectra
 1. **gsflat** - generate a normalized GCAL spectroscopic flatfield.
 2. **gsflat** - remove the GCAL+GMOS spectral response and the GCAL uneven illumination from the flat-field image and leave only the pixel-to-pixel variations and the fringing.
- **gsflat inpflat outflat.fits fl_trim- fl_bias- fl_fixpix- \ fl_detect+ fl_inter+ order=19**
 - Function **spline3** and **order=19** work ok (you don't want to remove the fringing from the flat)
 - Test with other orders and functions.

GMOS MOS reduction

Normalized Flat field



GMOS MOS reduction

Bad Pixel Mask

- There is not BPM for spectroscopy
 - *gbpm* works only for direct imaging
- You can minimize the effect of the bad pixels in your spectra by generating your own BPM
 - The BPM will contain only bad pixels, not hot pixels.
- An example is given in the GMOS MOS Tutorial MOS data
- The BPM is constructed separately for each CCD.

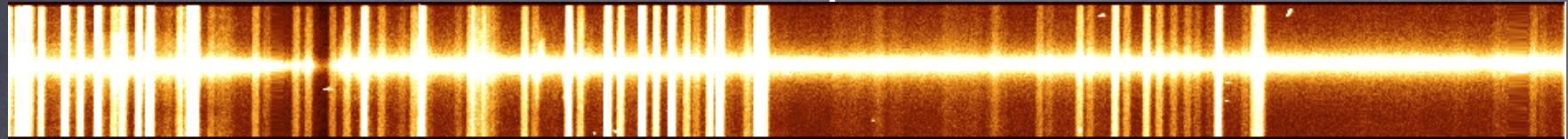
GMOS MOS reduction

Reducing the spectra

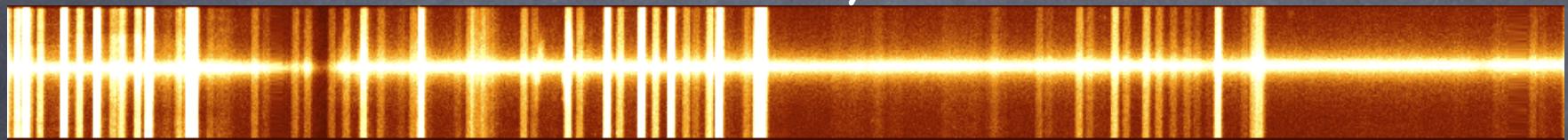
- Calling `gsreduce` and `gscut` to flatfield and cut the slits
 - `gsreduce specimage fl_trim- fl_bias- fl_gmosaic+ fl_fixpix+ fl_cut+ fl_gsappwave- flat=flatnorm.fits`
- Cleaning cosmic rays using the Laplacian Cosmic Ray Identification routine by P. van Dokkum
 - see <http://www.astro.yale.edu/dokkum/lacosmic/>
- Calibrating in wavelength and rectifying the spectra using `gstransform`
 - `gstransform crcleanspecimage wavtrancode="refarc" fl_vardq-`

GMOS MOS reduction

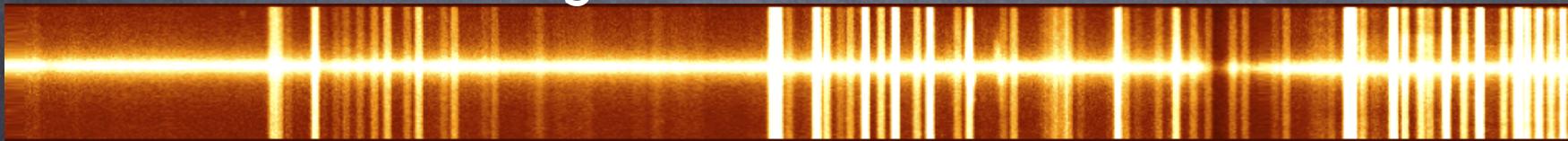
Reduced spectra



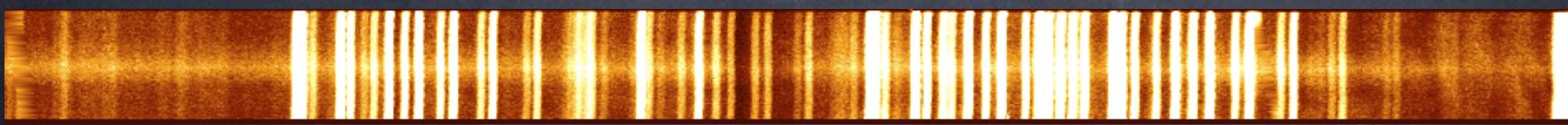
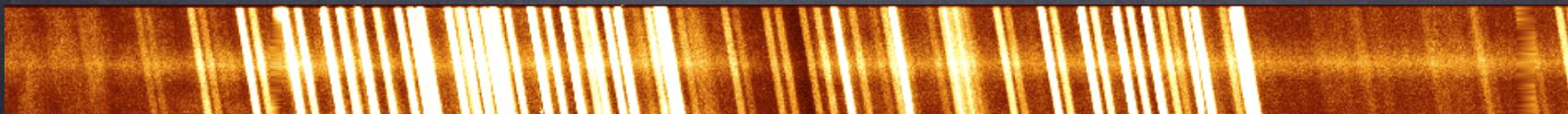
After cosmic ray removal



gstransform-ed



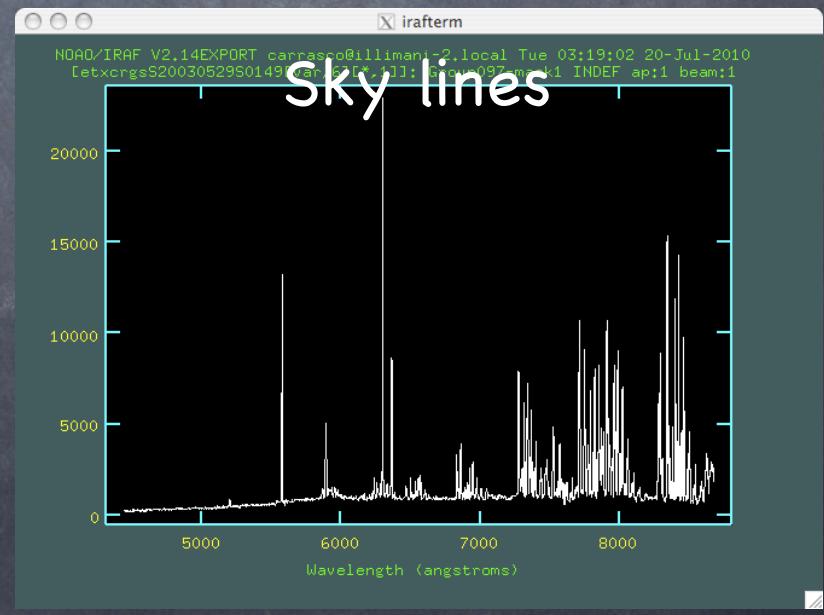
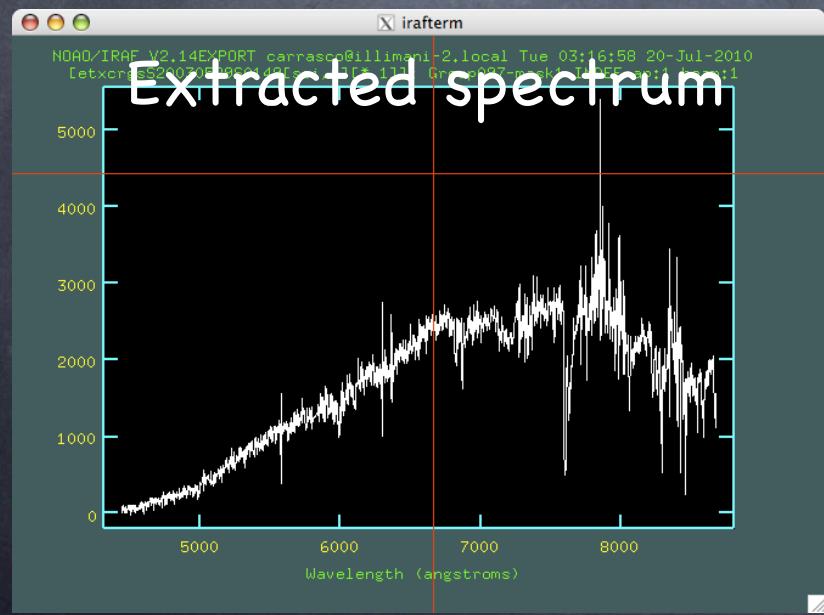
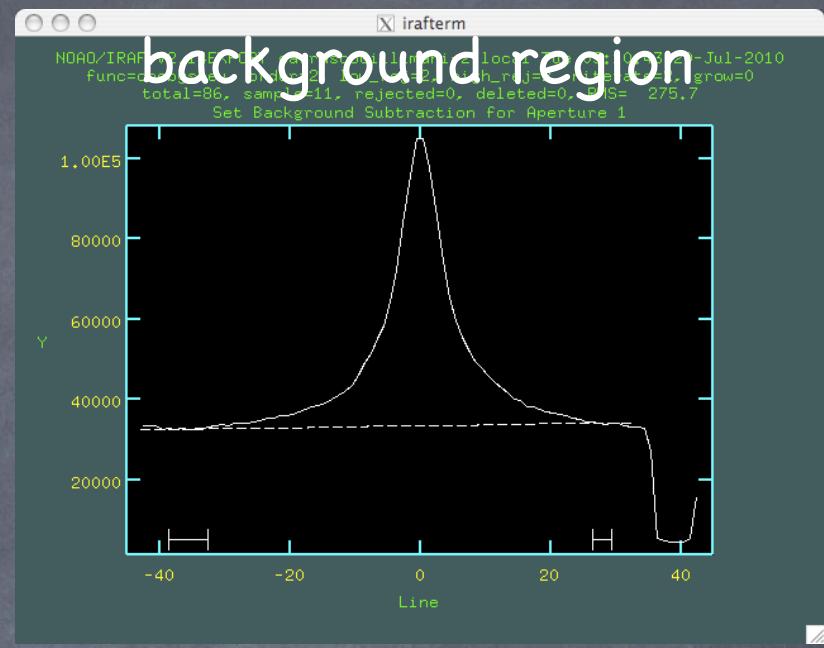
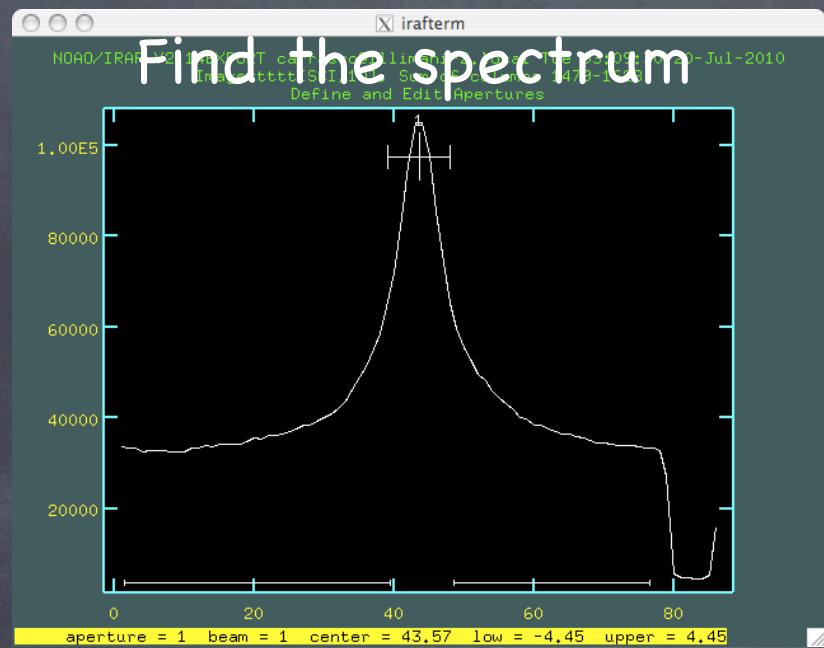
Tilted slit



GMOS MOS reduction

Extracting the spectra

- Sky subtraction
 - can use gsskysub on 2-D transformed image
 - can use gsextract to perform the sky subtraction
- Using gsextract
 - `gsextract txspec.fits fl_inter+ background=fit torder=5 tsum=150 tstep=50 find+ apwidth=1.3 recenter+ trace+ fl_vardq- weights="variance" border=2`
 - Critical parameters: `apwidth`, `background` region and `order` of the background fit (1 or 2)
 - Background region can be selected interactively
 - In this example the aperture width is 1.3"



GMOS MOS reduction

What is next ...

- Check all spectra
- Check wavelength calibrations using the sky lines
- Combining the spectra – **scombine** recommended
- Analyze the results

GMOS Longslit reduction

- Longslit reduction is a particular case of MOS reduction for ONE slit
- The reduction is performed exactly in the same way as for MOS spectroscopy.
 - gprepare the images by adding the MDF file
 - Bias subtraction for all images
 - Establish wavelength calibration and flat normalization
 - *gsreduce* to reduce the spectrum
 - Cosmic ray removal
 - Calibrating in wavelength and rectifying the spectra using *gstransform*
 - Extracting the spectrum
- Tutorial data for Flux standard
- Additional steps - derive sensitivity function (*gsstandard*)