

# Reducing GMOS Spectroscopic data

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*With thanks to Rodrigo Carrasco & Kathy Roth*

# Contents

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- Image treatment (bias, darks, flats)
- MOS
- Nod & Shuffle
- Long slit

# General Principles

- Record everything that you do. Refrain from changing parameters with “epar” before running tasks
- **Experiment.** Verify the impact of varying different reduction parameters on the final results
- Attention to files in the “database” directory. They contain important information
- **Make sure you understand what each task does in detail**
- Do not trust iraf (or any data reduction package, for that matter)
- **You don't want to reinvent the wheel, but always ask the question: could I do this in a better way?**

# Basic Reduction Steps

- Build master bias – `gsbias`
- Build master dark (N&S only) – `gsdark`
- Build master flats – `gsflat`
- Subtract bias, dark, flat-correct, and trim science images - `gsreduce`
- Sky subtraction – `gsskysub`
- Determine wavelength solution - `gswavelength`
- Apply wavelength solution and rectify image - `gstransform`
- Extract (and sky-subtract) spectra - `gsextract`

# Notes on Bias and Dark

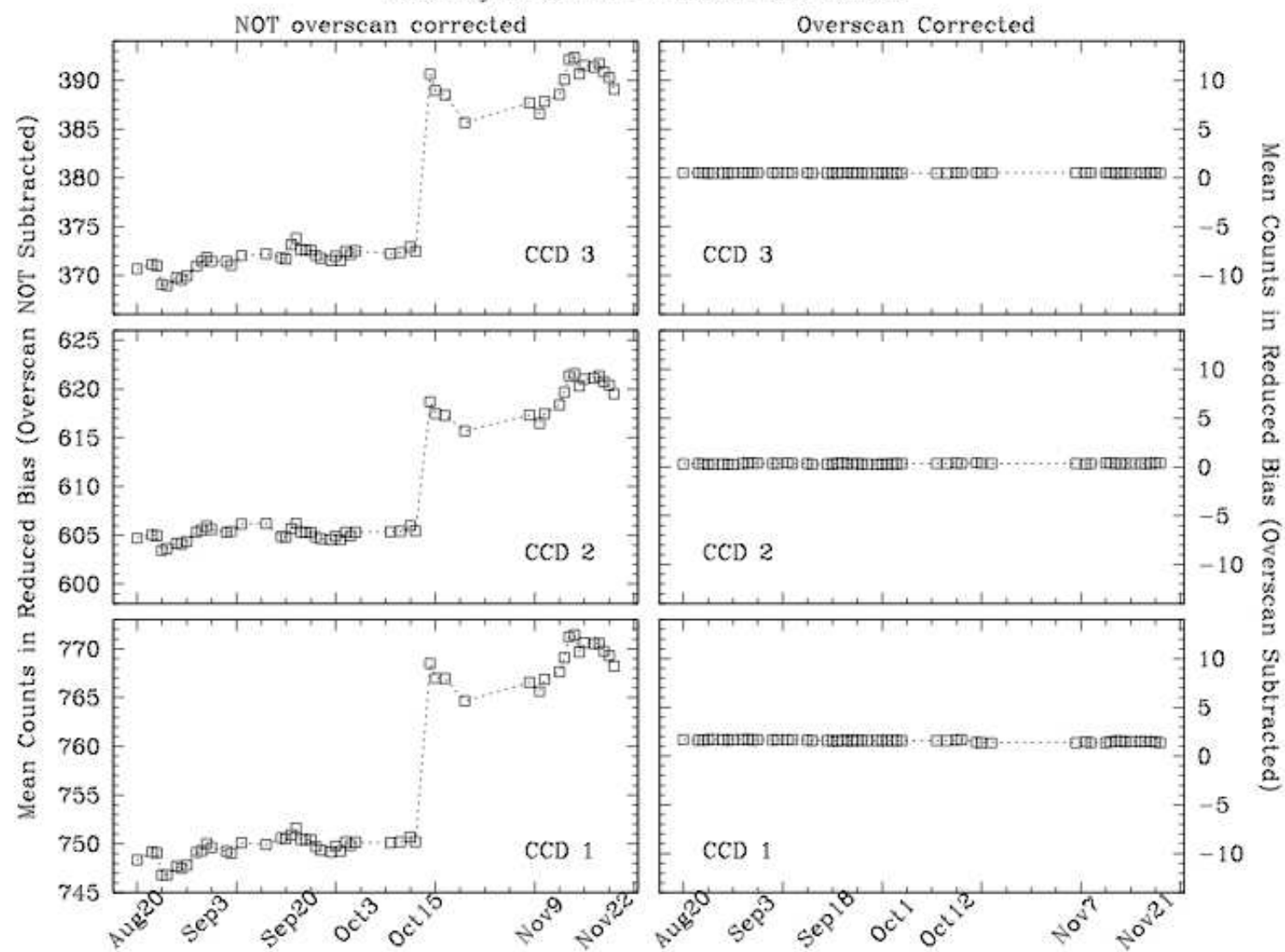
---

- Standard procedure for treatment of CCD data
- Due to fluctuations of zero-point level, overscan correction is recommended for low counts



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## Stability of GMOS-N Mean Bias Levels



# Notes on Bias and Dark

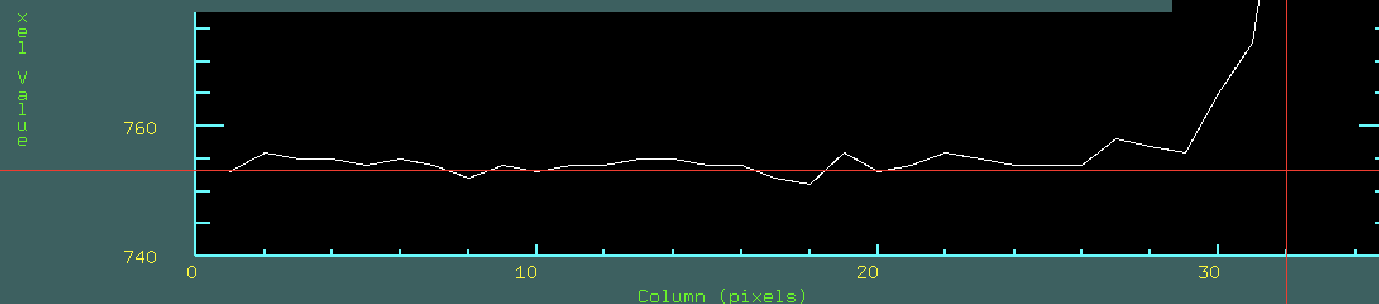
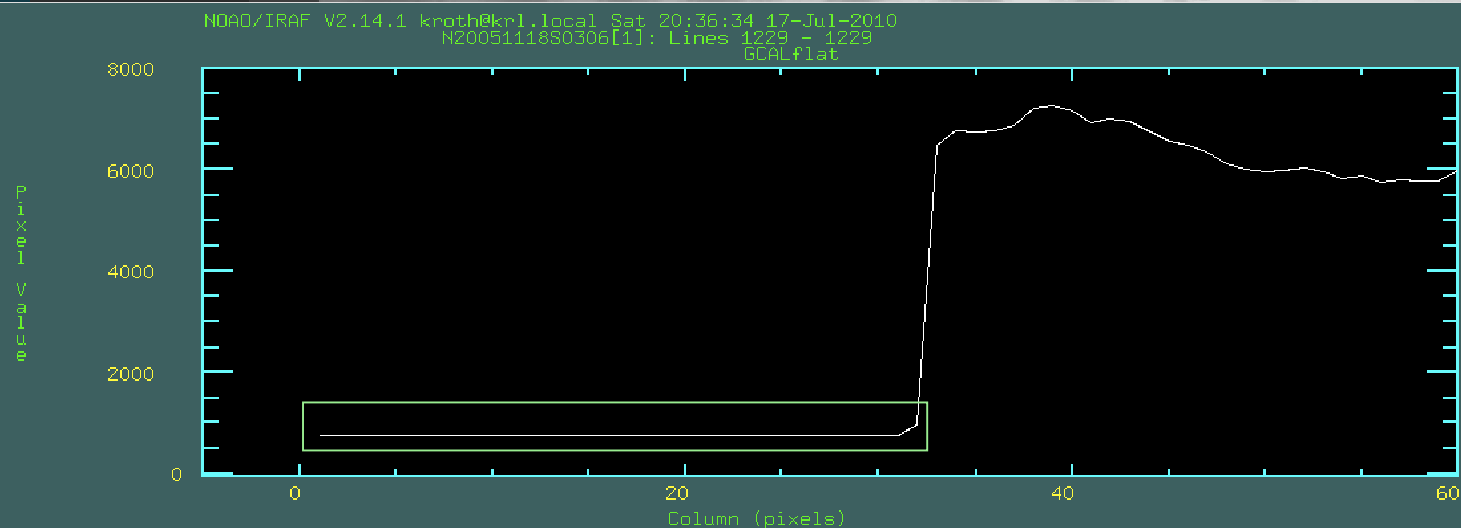
---

- Standard procedure for treatment of CCD data
- Due to fluctuations of zero-point level, overscan correction is recommended for low counts
- No dark correction needed for standard GMOS observations (but see N&S)



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# Overscan “Spillover”



R400 grating spectral GCALflat, GMOS-N CCD1, 32 pixel overscan region on the left, note the fringing (central wavelength 810nm).

~ 4 overscan pixels bordering the data are contaminated (low-level).



# gbias

```
gbias @biaslist out=Bias.fits logfile=gmos.logfile,  
rawpath="rawdata$" fl_over+ fl_trim+  
nbiascontam=4 fl_inter+ fl_vardq+
```

**gbiaslist**: text file containing filenames of raw bias images (one per line)

**Bias.fits**: name of output combined bias image

**gmos.logfile**: user-defined name of output logfile

(eg. gmos.logfile = "GN-2005B-Q-20-13.log")

**rawdata\$**: user-defined directory containing the raw fits files

(eg. rawdata = "../rawdata/")

**fl\_over+**: turn on overscan subtraction

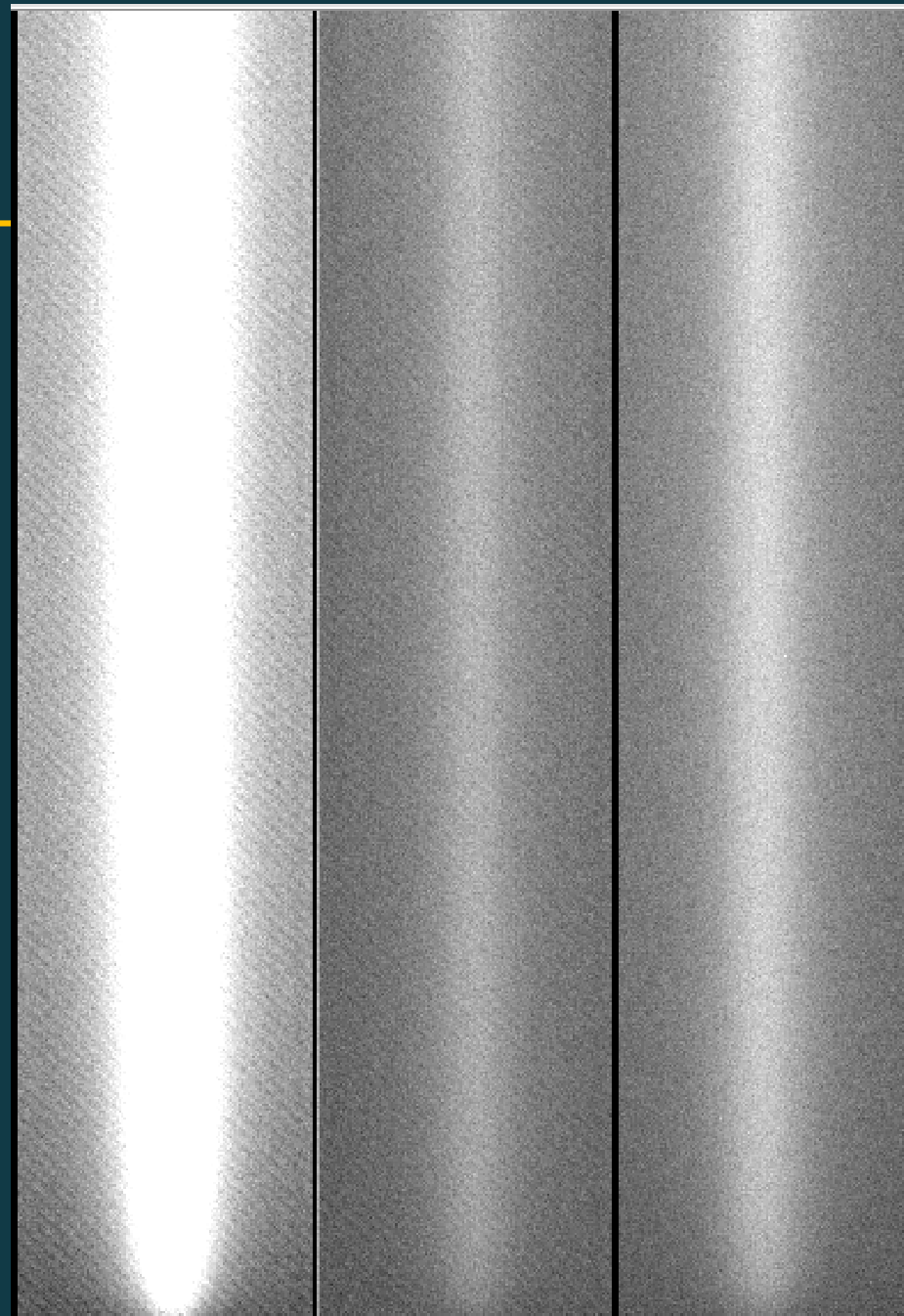
**fl\_trim+**: trim off the overscan region after fitting and subtraction

**nbiascontam=4**: throw away the four columns of the bias section bordering the data section, charge "bleeds" into the overscan region when the detector is exposed to high light levels

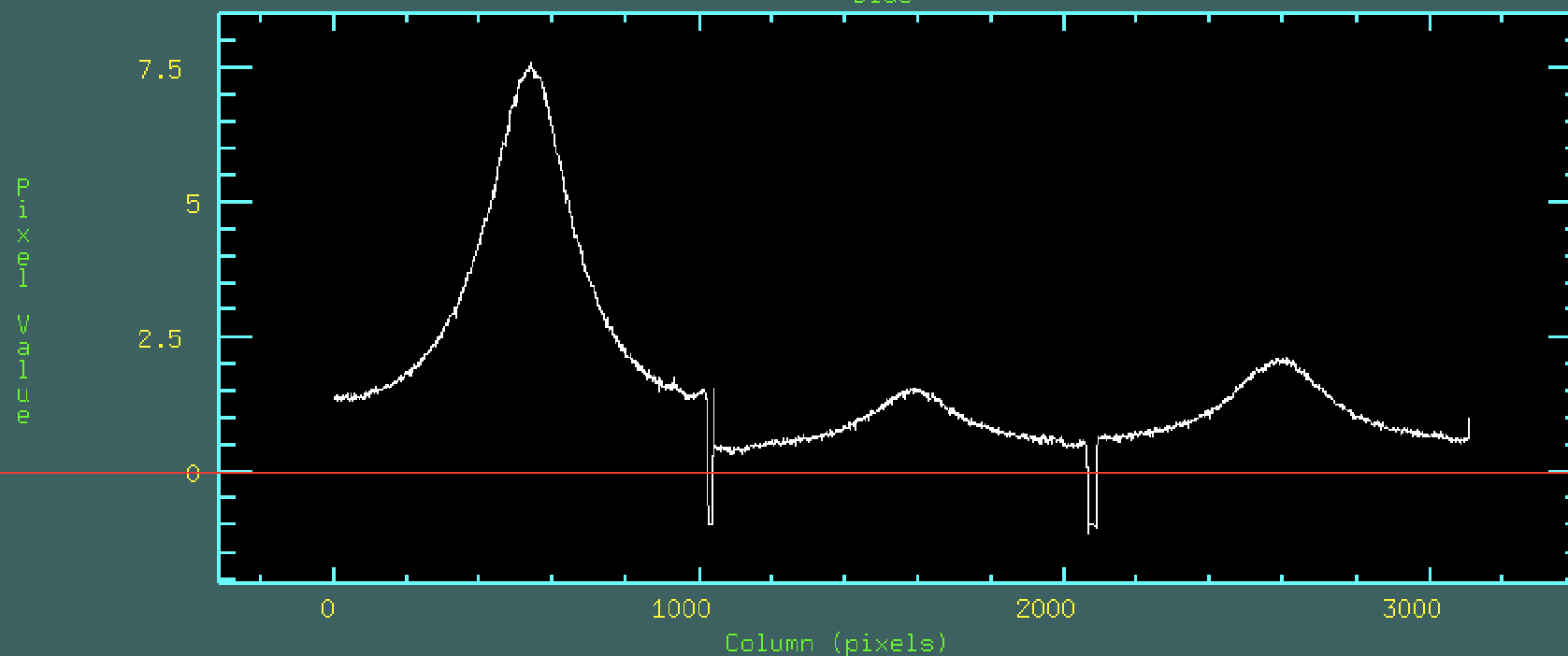
**fl\_inter+**: interactively fit the overscan region

**fl\_vardq+**: create/propagate variance and data quality planes

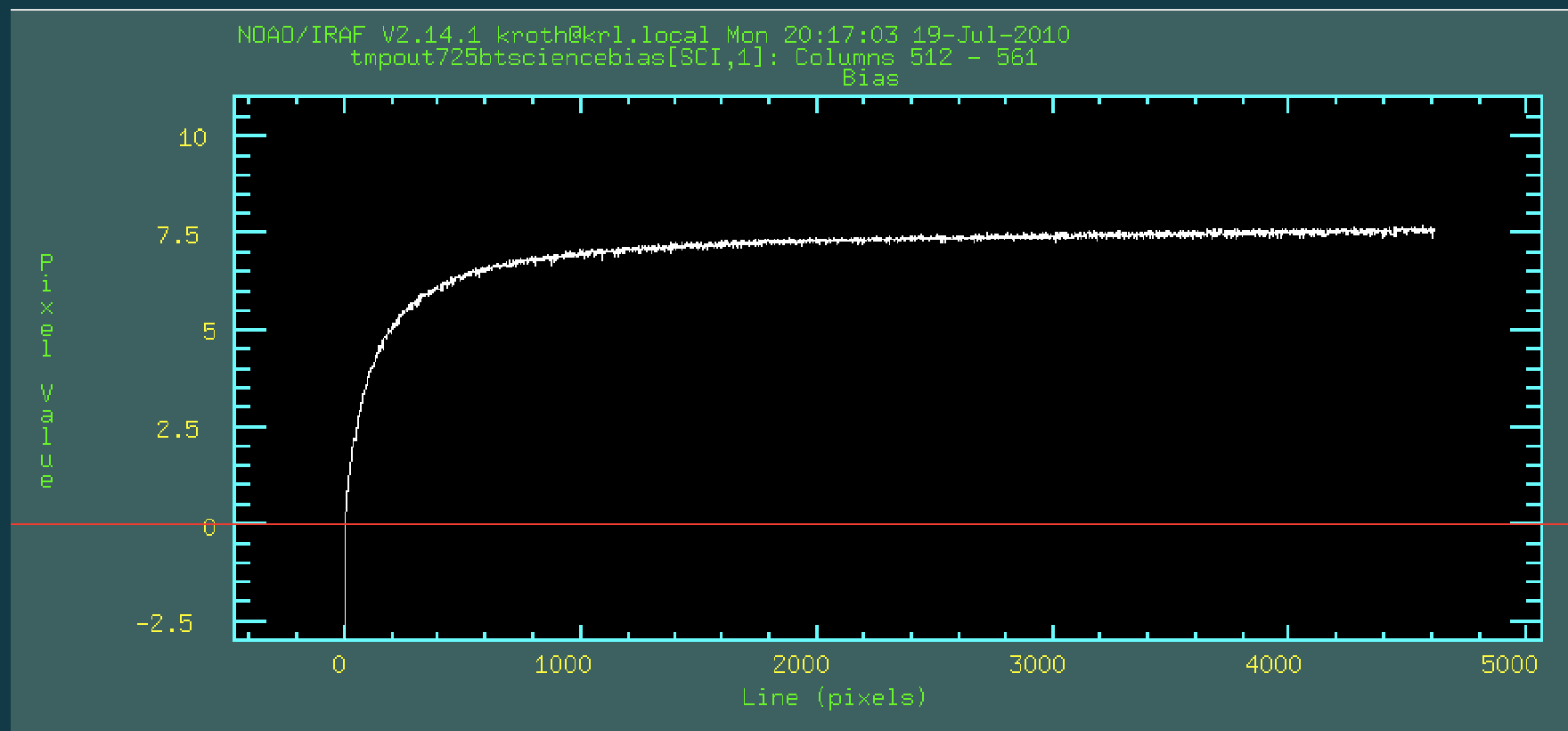
Reduced combined 2x1 bias  
image, consisting of 85  
individual bias images  
obtained  
over a period of 2.5 months



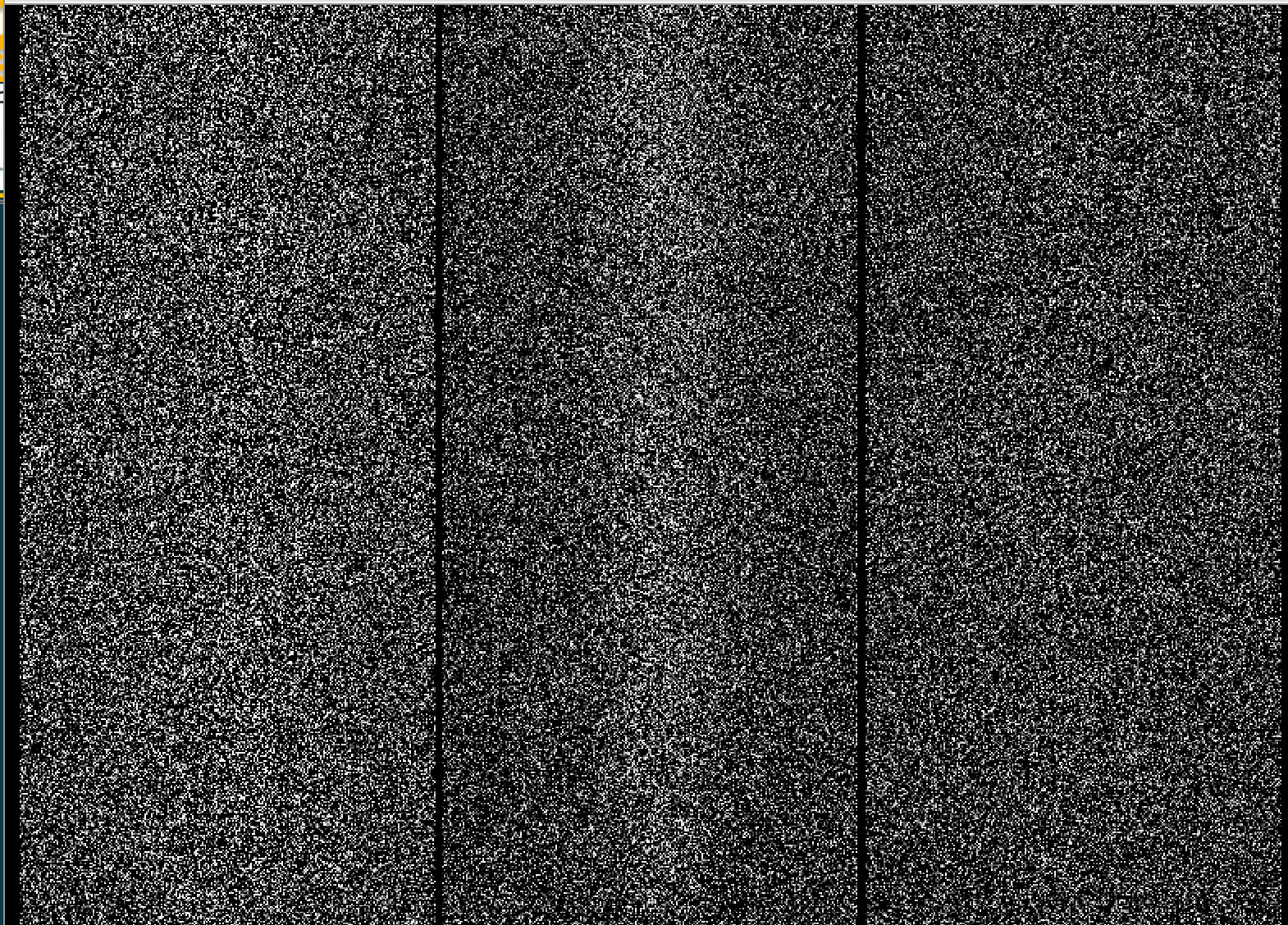
NOAO/IRAF V2.14.1 kroth@krl.local Mon 20:15:35 19-Jul-2010  
tmpout725btsciencebias[SCI,1]: Lines 2736 - 2785  
Bias



Column plot (CCD1) for reduced combined 2x1 bias, 50 lines averaged.

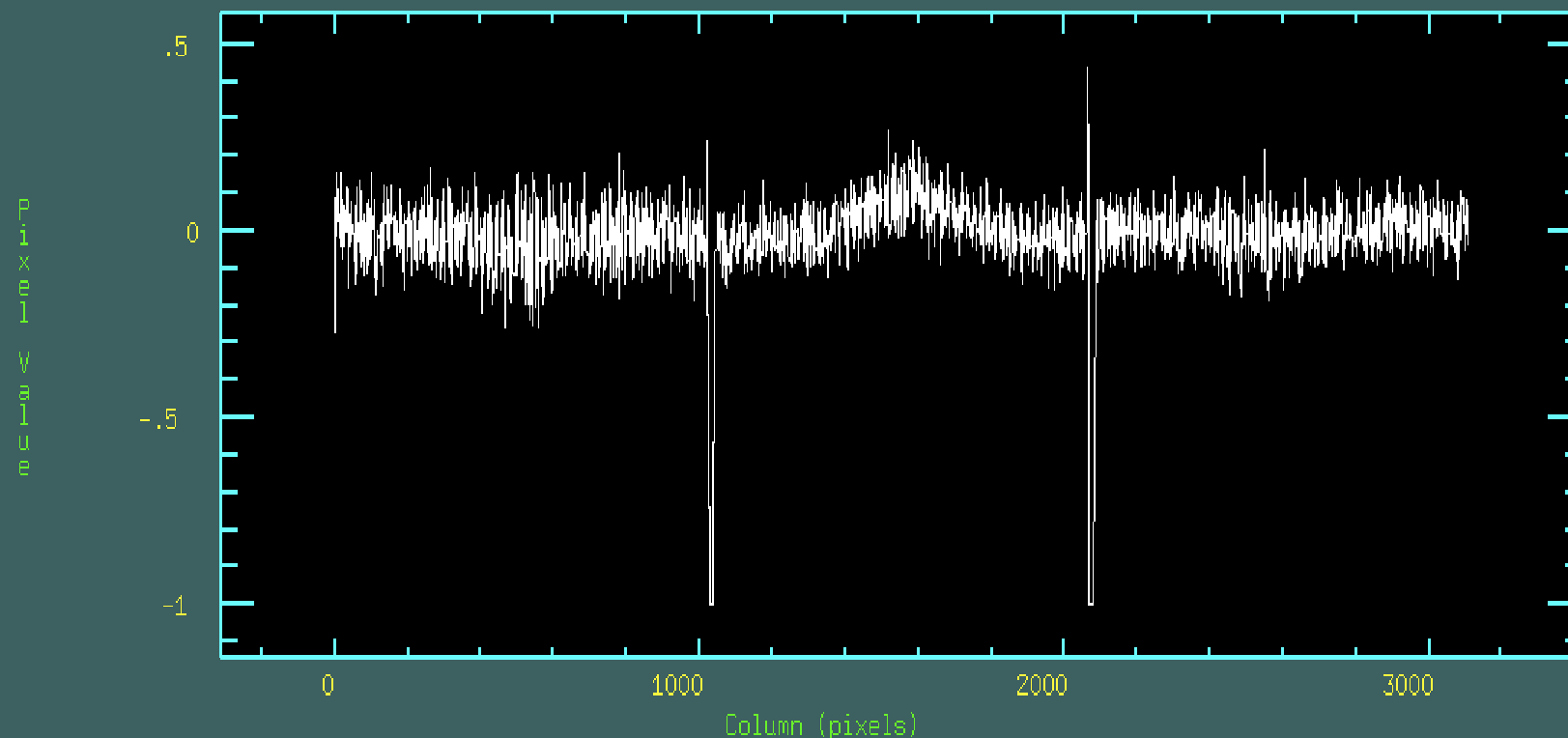


Line plot for reduced combined 2x1 bias, 50  
lines averaged.



Difference image of two reduced stacked bias images. Each bias consists of 35 combined individual exposures. These biases were taken over a period of  $\sim 1.5$  months separated by  $\sim 2$  months

NOAO/IRAF V2.14.1 kroth@kr1.local Sat 10:51:59 17-Jul-2010  
tmpout688orabiasdiff[SCI,1]: Lines 1188 - 1237  
Bias



Line cut through difference image. Bias stability is very good over a period of several months. 50 lines averaged.

# Flatfield Correction

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- Flats may be useful for removal of pixel-to-pixel variations
- In the red part of the spectrum, flats are important for removal of fringing in bright objects
- Not yet known how much fringing in Hamamatsu and/or new E2V CCD data (should be less since these back illuminated devices are thicker than the old E2Vs).

# gsflat

```
gsflat @flatfiles_460 out=Flat_460.fits  
      logfile=gmos.logfile rawpath="rawdata$"  
      fl_over+ fl_trim+ nbiascontam=4  
      fl_bias+ bias="sciencebias" fl_dark-  
      fl_fixpix- fl_inter+ function="chebyshev"  
      order=15 fl_detec+ ovs_flinter+ fl_vardq+)
```

@flatfiles\_460: text file containing list of flat field files

Flat\_460.fits: name of output flat image

fl\_dark-: do not subtract a dark image

fl\_fixpix-: do not fix pixels in the gaps (cannot do this with fl\_detect+)

fl\_inter+: examine fits to spectral shape interactively

chebyshev: type of polynomial to use in fits to spectral shape

order=18: order of polynomial fit to spectral shape (varies from case to case)



# gsflat

```
gsflat @flatfiles_460 out=Flat_460.fits  
logfile=gmos.logfile rawpath="rawdata$"  
fl_over+ fl_trim+ nbiascontam=4  
fl_bias+ bias="sciencebias" fl_dark-  
fl_fixpix- fl_inter+,function="chebyshev"  
order=15 fl_detec+ ovs_flinter+ fl_vardq+)
```

**fl\_detec+:** do not mosaic, fit each detector independently

**ovs\_flinter+:** examine fits to overscan region interactively



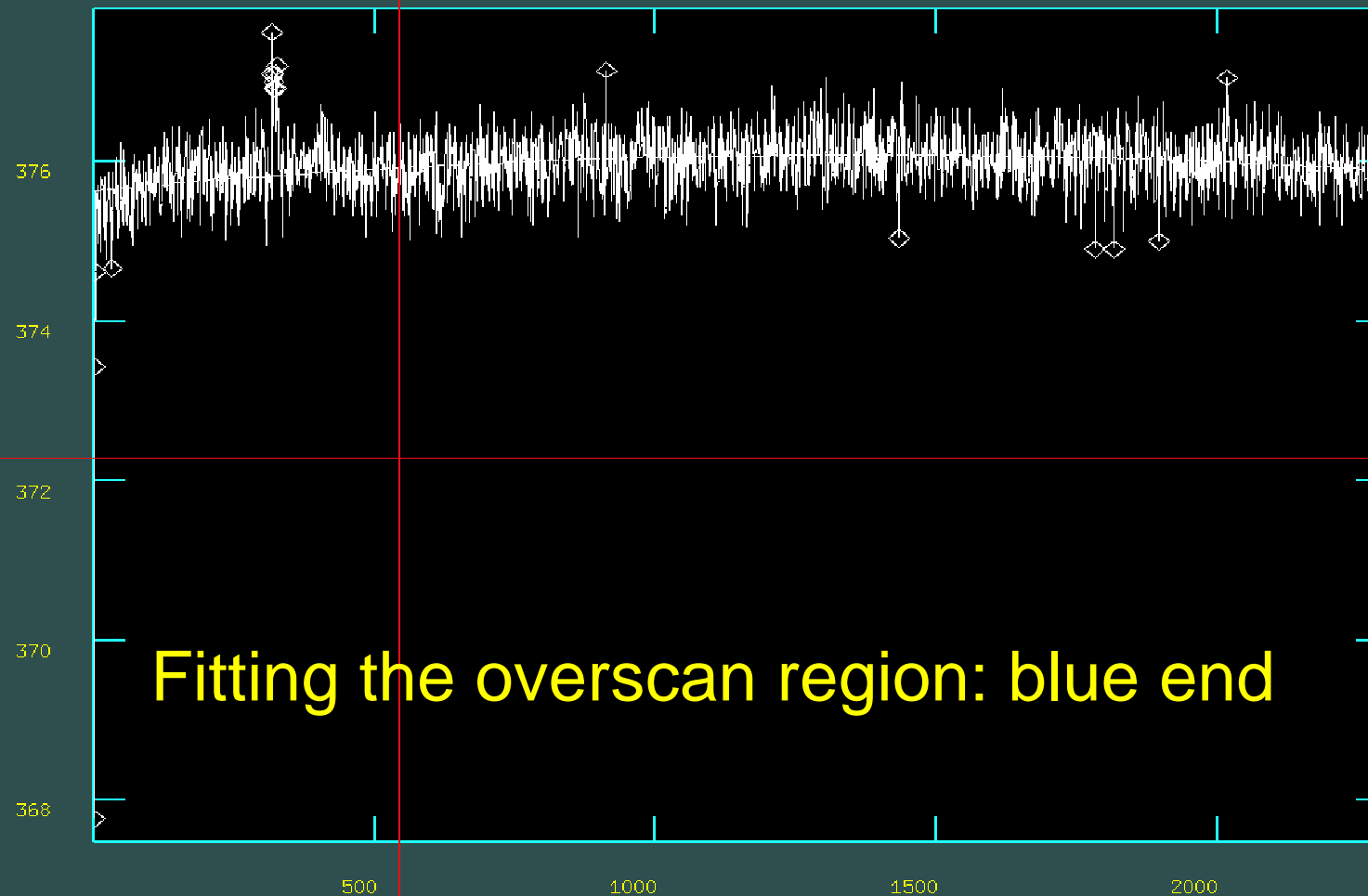
GEMINI  
OBSERVATORY

irafterm

gsflat

```
NDAO/IRAF V2.14.1 rschiavo@sphaerus-2.local Sat 21:56:21 22-Oct-2011  
func=chebyshev, order=3, low_rej=3, high_rej=3, niterate=8, grow=0  
total=2304, sample=2304, rejected=18, deleted=0, RMS= 0.3274  
colbias gH20081129S0094[SCI,3]
```

B  
i  
a  
s



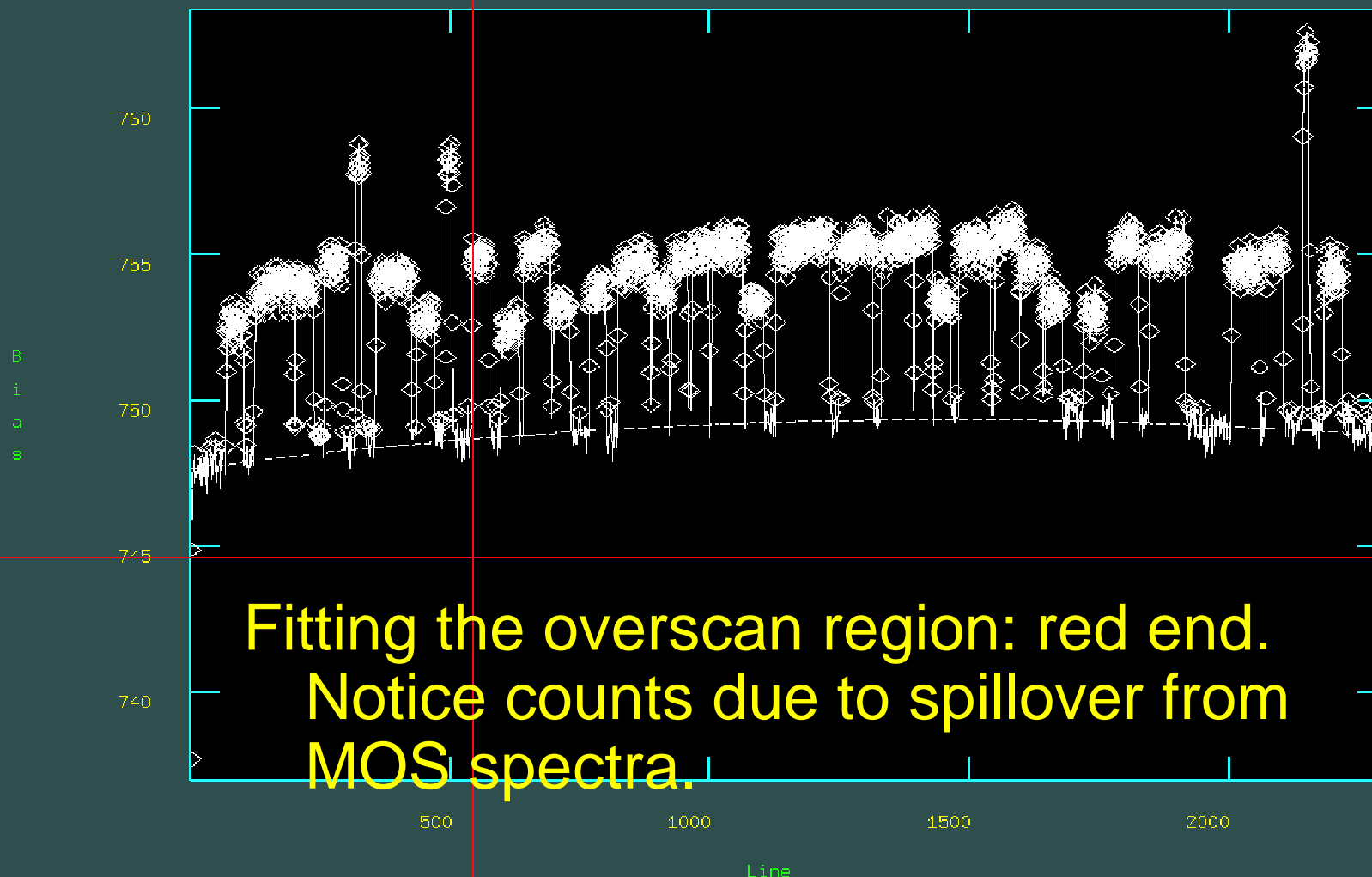


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OBSERVATORY

irafterm

# gsflat

```
NDAO/IRAF V2.14.1 rschiavo@sphaerus-2.local Sat 21:56:07 22-Oct-2011  
func=chebyshev, order=3, low_rej=3, high_rej=1, niterate=8, grow=0  
total=2304, sample=2304, rejected=1668, deleted=0, RMS= 0.3343  
colbias gH20081129S0094[SCI,1]
```



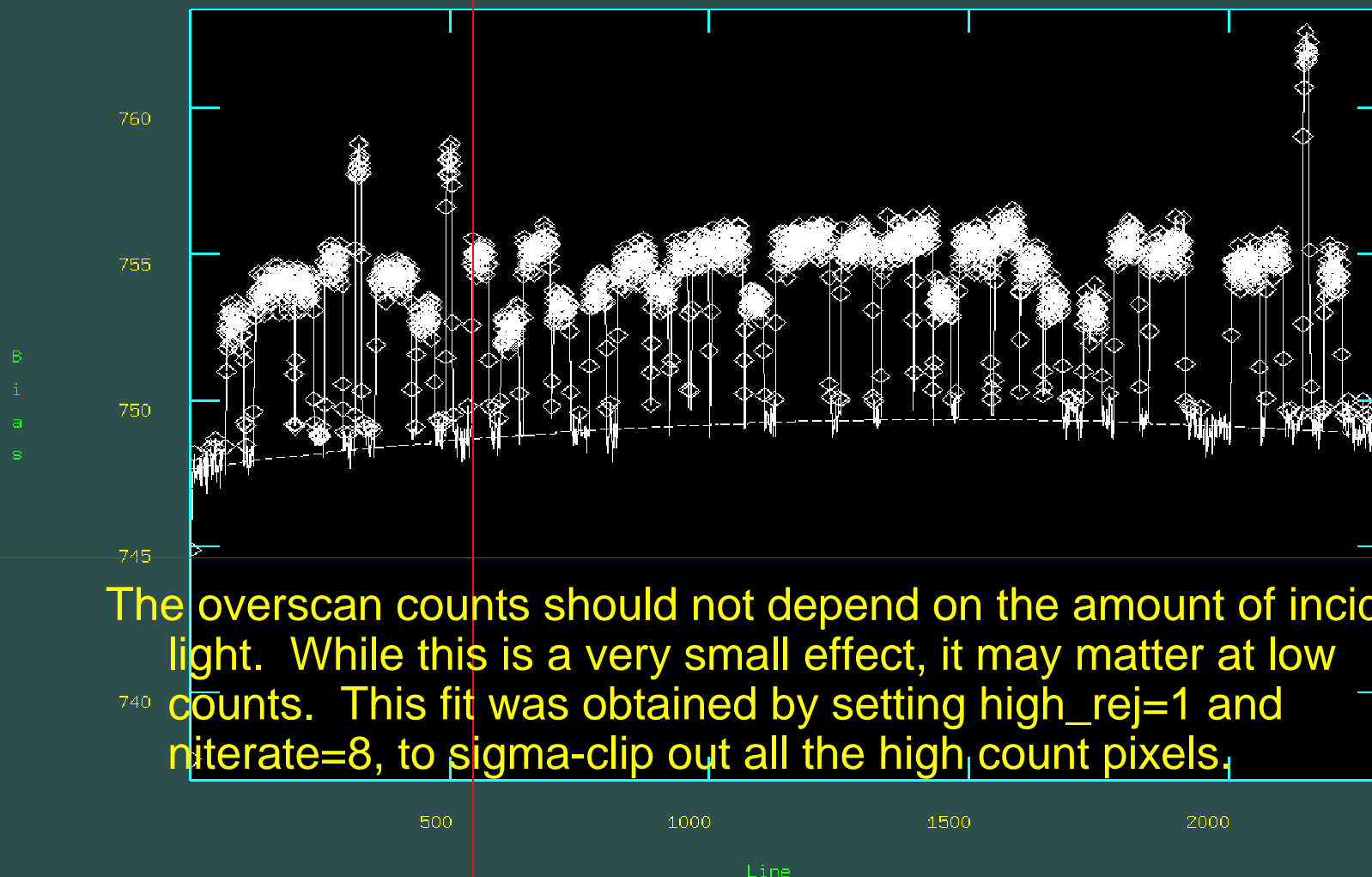


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irafterm

# gsflat

```
NDAO/IRAF V2.14.1 rschiavo@sphaerus-2.local Sat 21:56:07 22-Oct-2011  
func=chebyshev, order=3, low_rej=3, high_rej=1, niterate=8, grow=0  
total=2304, sample=2304, rejected=1668, deleted=0, RMS= 0.3343  
colbias gH20081129S0094[SCI,1]
```



The overscan counts should not depend on the amount of incident light. While this is a very small effect, it may matter at low counts. This fit was obtained by setting `high_rej=1` and `niterate=8`, to sigma-clip out all the high count pixels.

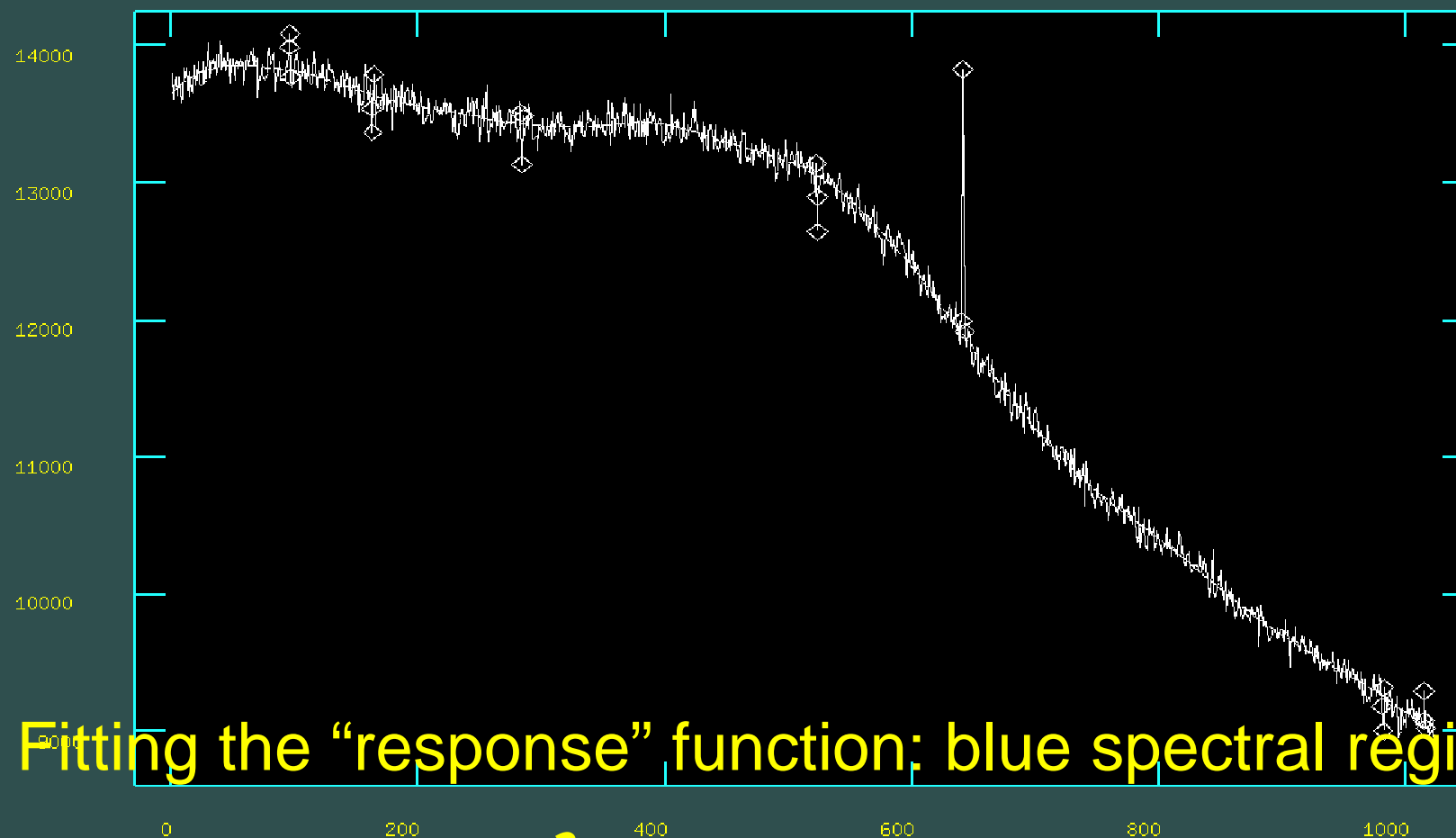


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OBSERVATORY

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# gsflat

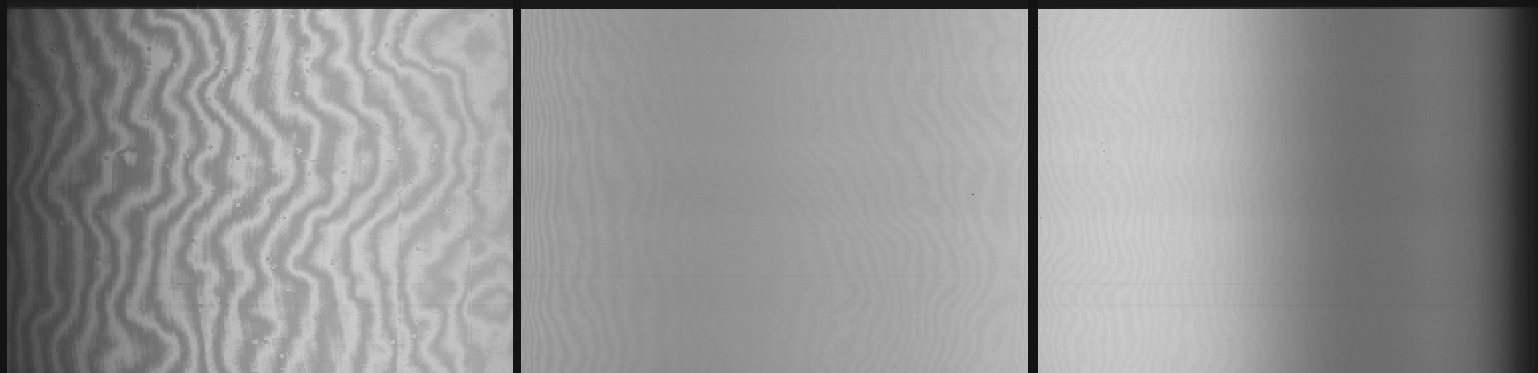
```
NDAD/IRAF V2.14.1 rschiavo@sphaerus-2.local Sat 22:01:06 22-Oct-2011  
func=spline3, order=18, low_rej=3, high_rej=3, niterate=2, grow=1  
total=1024, sample=1024, rejected=21, deleted=0, RMS= 78.47  
tmpcombflat939sd[SCI,2]: Fit line = 1000 - 1000  
GCALflat
```



Fitting the “response” function: blue spectral region.

←  $\lambda$

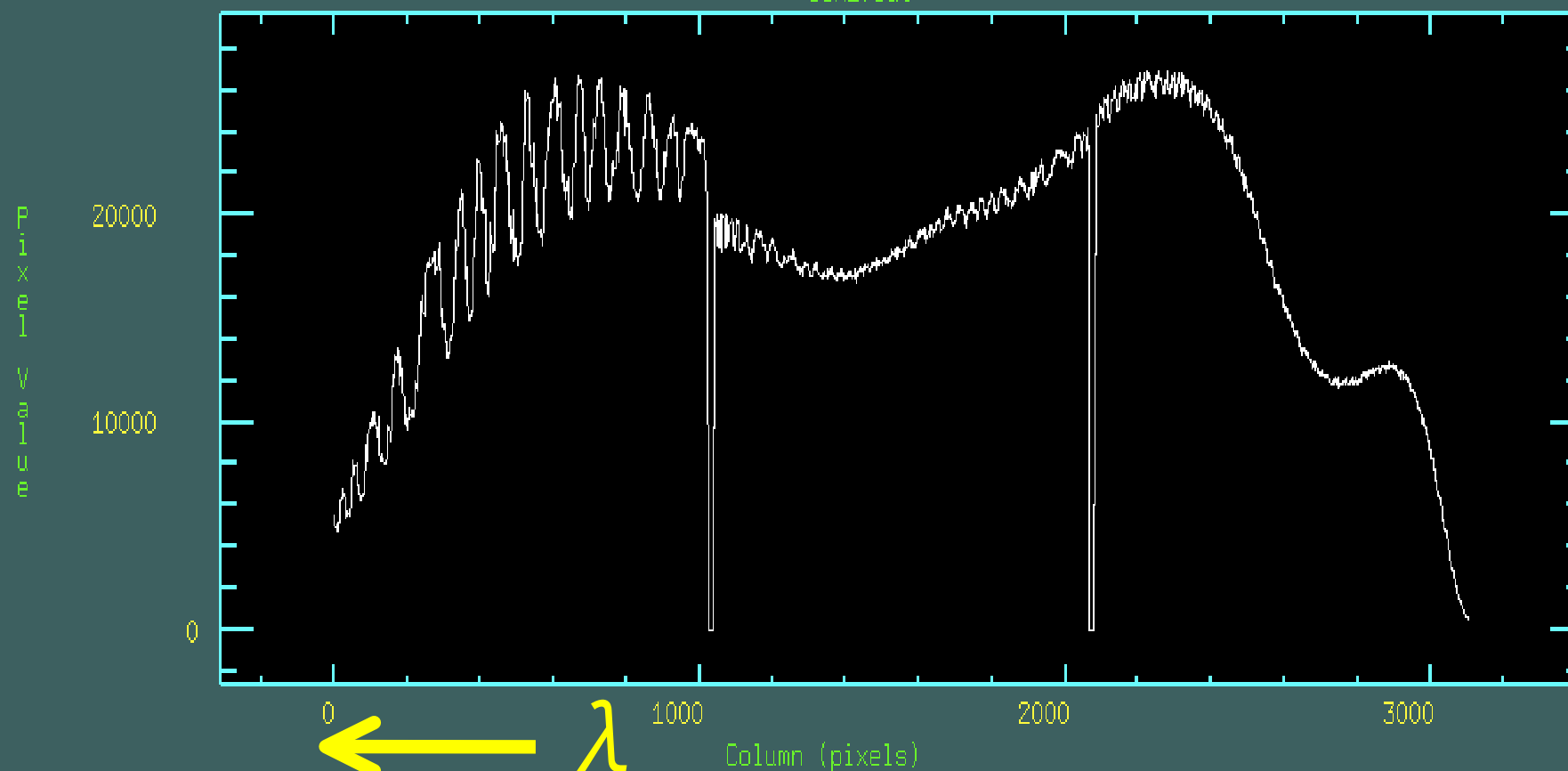
Column



Raw GCALflat R400 spectral flat, 810nm, NS0.75arcsec longslit.  
GCALflats are not shuffled, and do not inherit the **NODPIX** header  
keyword parameter of the associated science exposures.

# gsflat

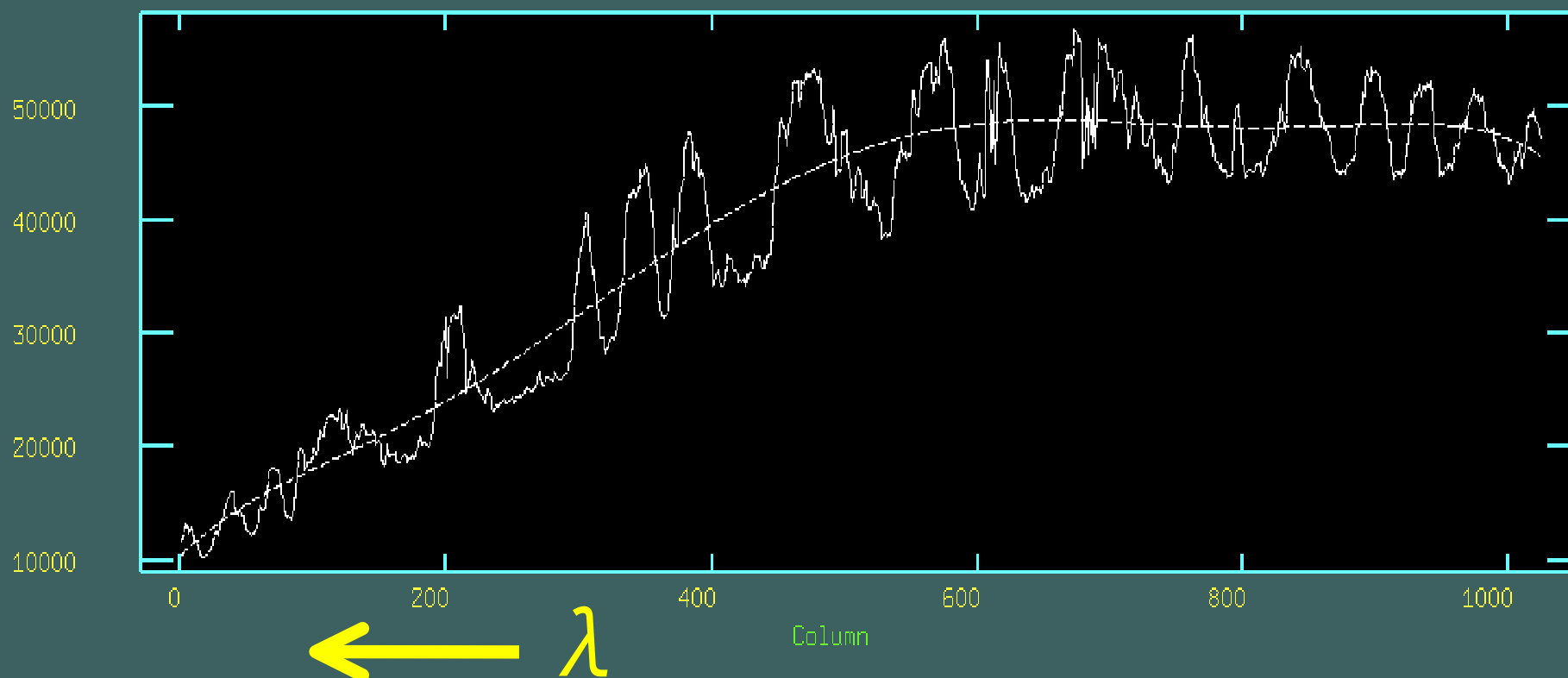
NOAO/IRAF V2.14.1 knoth@krl.local Sun\_05:07:00 18-Jul-2010  
tmpout688mhbN20051118S0306[SCI,1]: Lines 1148 - 1148  
GCALflat



Red flat field along the spectral direction. Note fringes on the red detector.

# gsflat

```
NOAO/IRAF V2.14.1 kroth@krl.local Sun 00:12:58 18-Jul-2010  
func=chebyshev, order=7, low_rej=3, high_rej=3, niterate=2, grow=1  
total=1024, sample=1024, rejected=0, deleted=0, RMS= 4124.  
tmpcombflat688hab[SCI,1]: Fit line = 1200 - 1200  
GCALflat
```



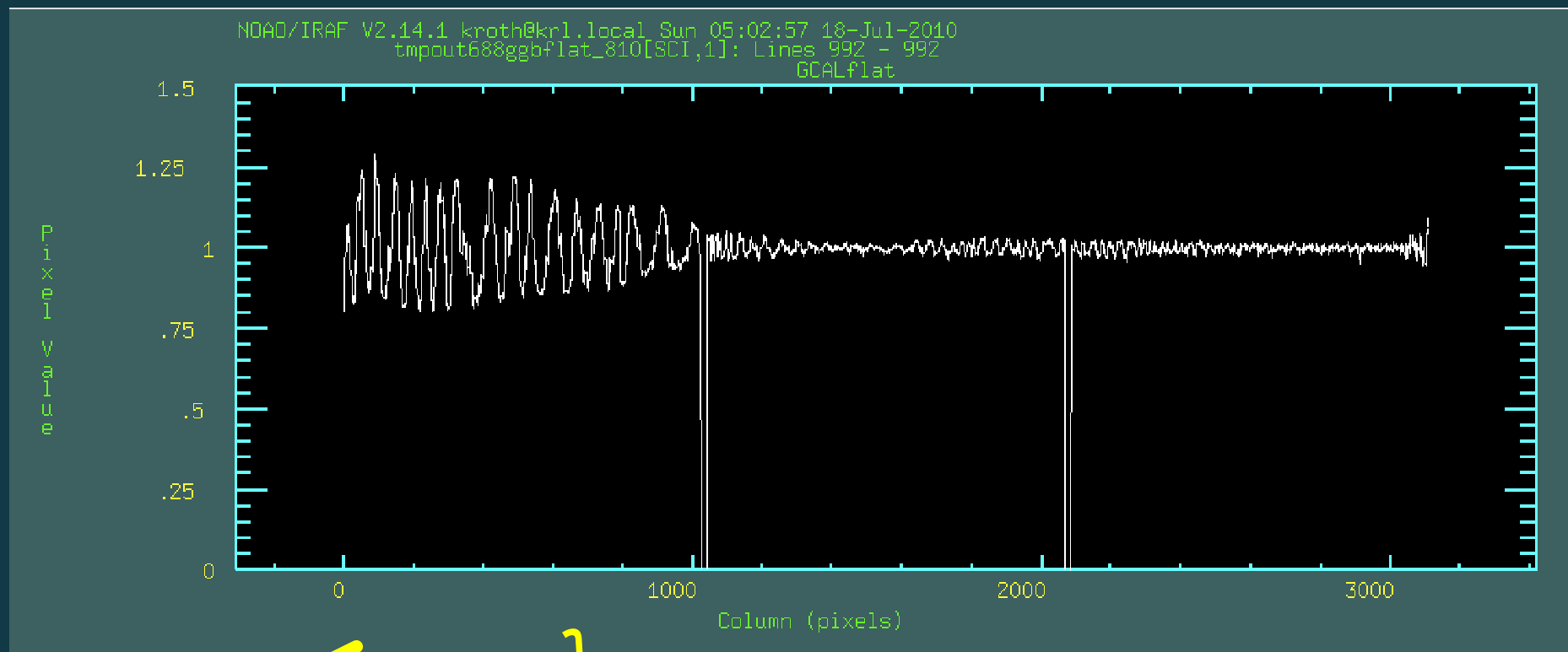
Fitting the “response” function in the red. Low polynomial order to avoid fitting the fringe pattern.



# gsflat

There is a trade off between, on one hand, correctly reproducing the combination of the spectral response of the instrument and the GCAL spectral energy distribution (which may require higher order fits) and, on the other hand, leaving features in the instrument response, such as fringes, which that should be left untouched, to guarantee that the flat correctly reproduces those features in the science data (which may require lower order fits). **Flux calibration is key to minimize impact of errors.**

# gsflat

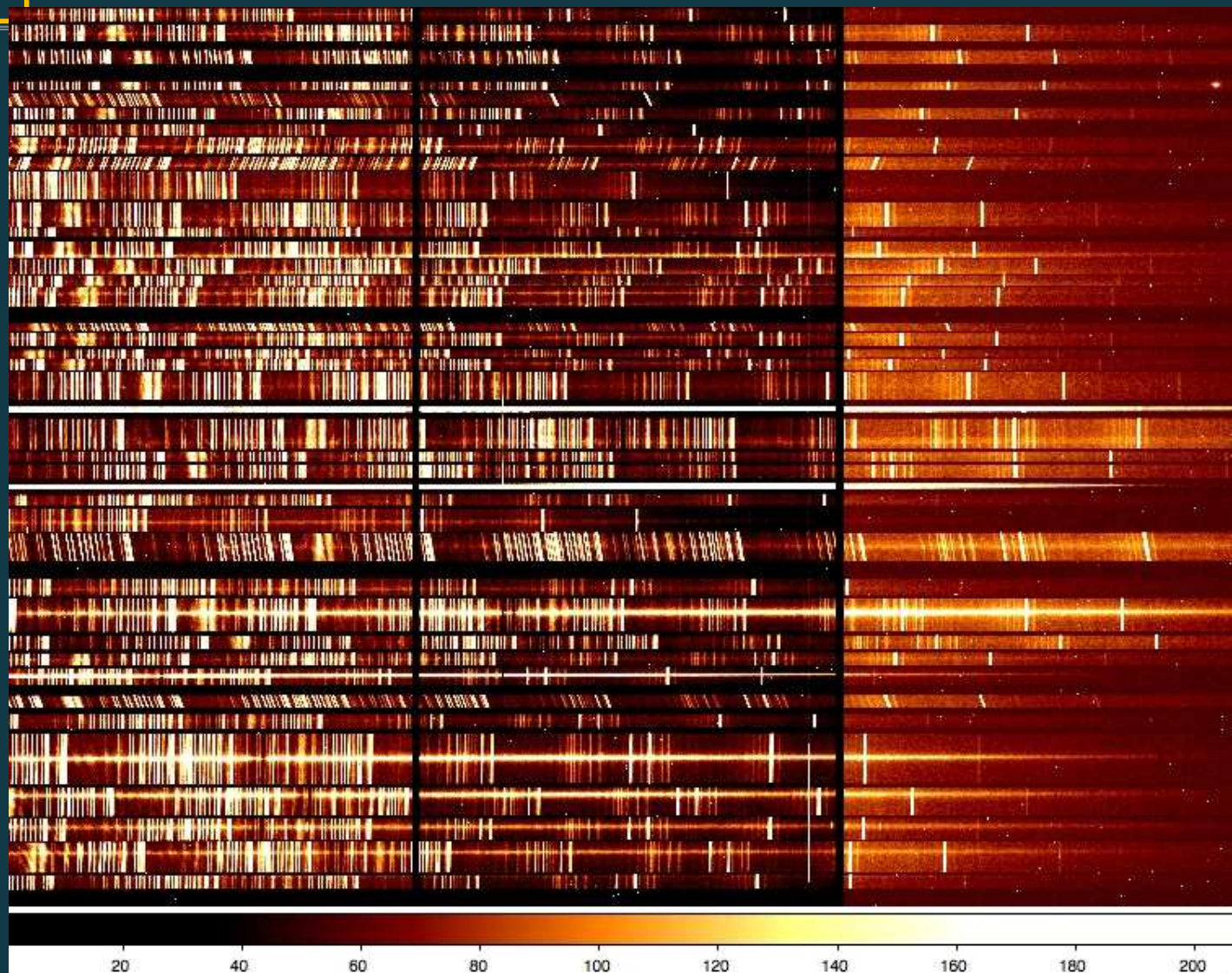


←  $\lambda$

Line cut through final reduced GCALflat.

# GMOS MOS Spectra

Alignment stars



# gsreduce

```
gsreduce @objfiles_460 logfile=gmos.logfile fl_inter+  
rawpath=rawdata$ fl_over+ fl_trim+ nbiascontam=4  
fl_bias+ bias="Bias.fits" fl_dark- fl_flat+  
flatim="Flat_460.fits" fl_gmosaic+ fl_fixpix+ fl_cut+  
fl_gsappwave+ ovs_flinter+ ovs_fun="chebyshev"  
ovs_order=3 fl_vardq+ mdffdir=rawdir$  
mdffile=MDFfilename.fits yoffset=5.0
```

@objfiles\_460: text file containing list of science data file names

fl\_flat+: apply flat correction (Flat\_460.fits is the flat-field file)

fl\_gmosaic+: mosaic detectors together

fl\_fixpix+: interpolate across chip gaps (if gmosaic+)

fl\_gsappwave-: do not apply a first order wavelength solution based on the header

fl\_cut+: cut the slit spectra into separate extensions (superfluous for longslit)

mdffdir/file: name of directory location and name of fits file containing slit-mask  
definition (required if fl\_cut+)

ovs\_flinter+: examine fits to overscan region interactively

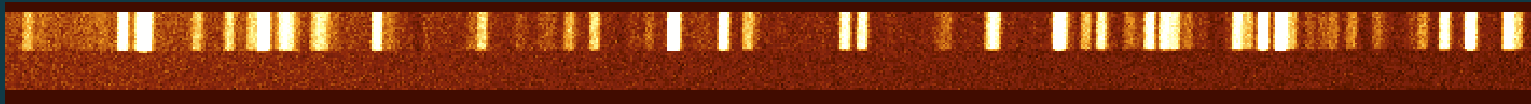


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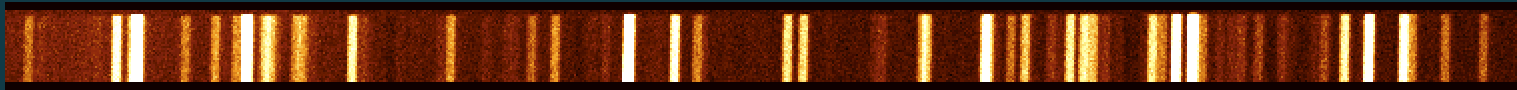


# GMOS MOS reduction

The yoffset parameter adjusts the vertical positions of the slit spectra, in case gscut doesn't cut the spectra correctly. Value for yoffset determined through inspection of gsreduced images. If dealing with faint spectra in the blue, you may want to use the arc spectra to determine offsets



Wrong cut



yoffset-adjusted cut



# Wavelength calibration

Arc spectra must first be “gsreduced”:

```
gsreduce @arcfiles fl_over- fl_trim+ fl_bias- fl_dark-  
fl_flat- fl_cut+ fl_gsappwave+ mdffile=MDFfilename.fits  
yoffset=5.0
```

Notice that there is no need for bias/dark subtraction or flat-fielding.

# gswavelength

```
gswavelength @gsNarcfiles logfile=gmos.logfile fl_inter+  
  nsum=5 step=5 function="chebyshev" order=6 fitxcord=6  
  fitcyord=4
```

**@gsNarcfiles:** list of "gsreduced" arc spectra

**step=5:** vertical separation between lines of spectra for which wavelength solutions are determined

**nsum=5:** number of lines summed to generate input spectra

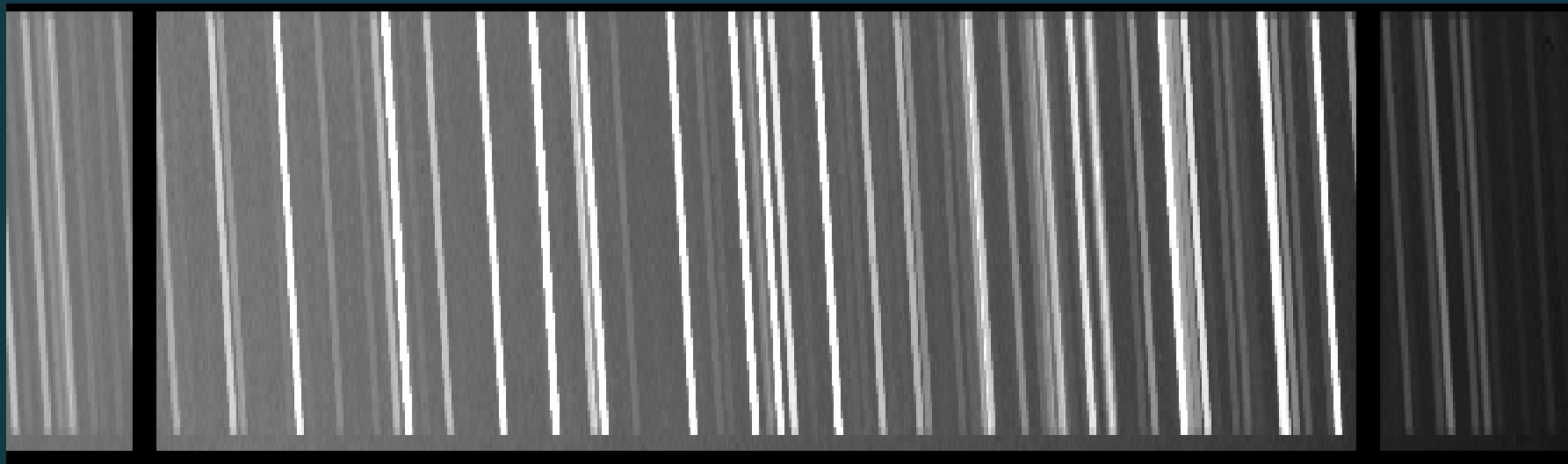
**function:** function fitted to wavelength vs. pixel relation

**order:** order of function fitted to wavelength vs. pixel relation

**fitxcord=6:** order of fit in x direction

**fitcyord=4:** order of fit in y direction

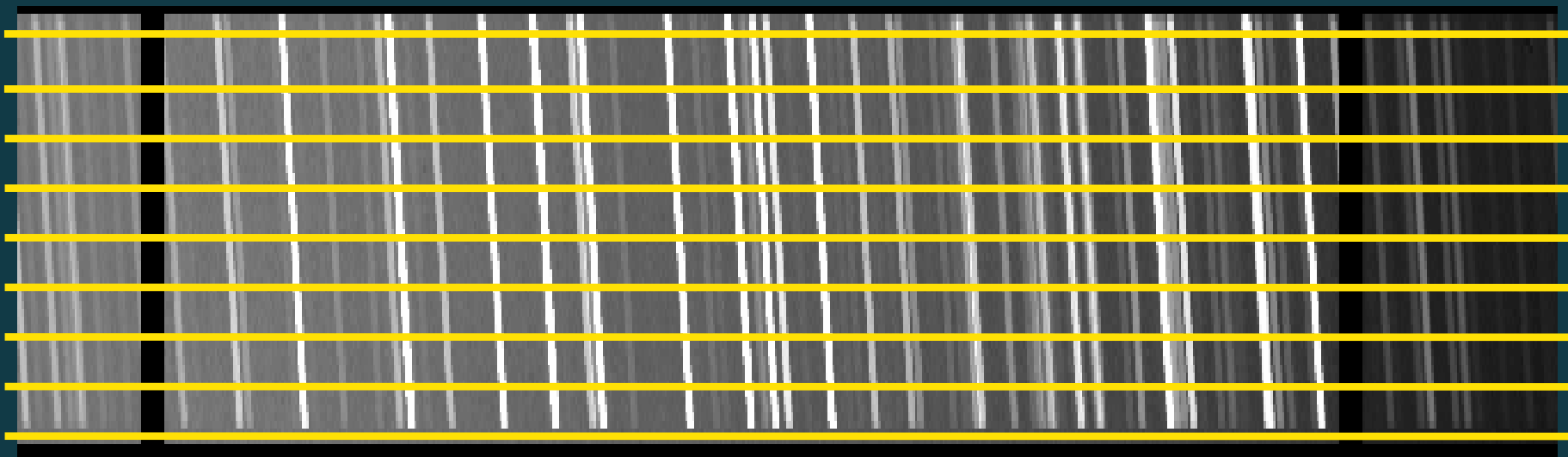
# gswavelength



Determine wavelength solution  
along spatial direction



# gswavelength



Determine wavelength solution for arc spectra along lines separated by  $n_{\text{step}}$  pixels. Each arc spectrum obtained by summing  $n_{\text{sum}}$  adjacent lines

# gswavelength

```
gswavelength @gsNarcfiles logfile=gmos.logfile fl_inter+  
  nsum=5 step=5 function="chebyshev" order=6 fitxcord=6  
  fitcyord=4
```

**@gsNarcfiles:** list of "gsreduced" arc spectra

**step=5:** vertical separation between lines of spectra for which wavelength solutions are determined

**nsum=5:** number of lines summed to generate input spectra

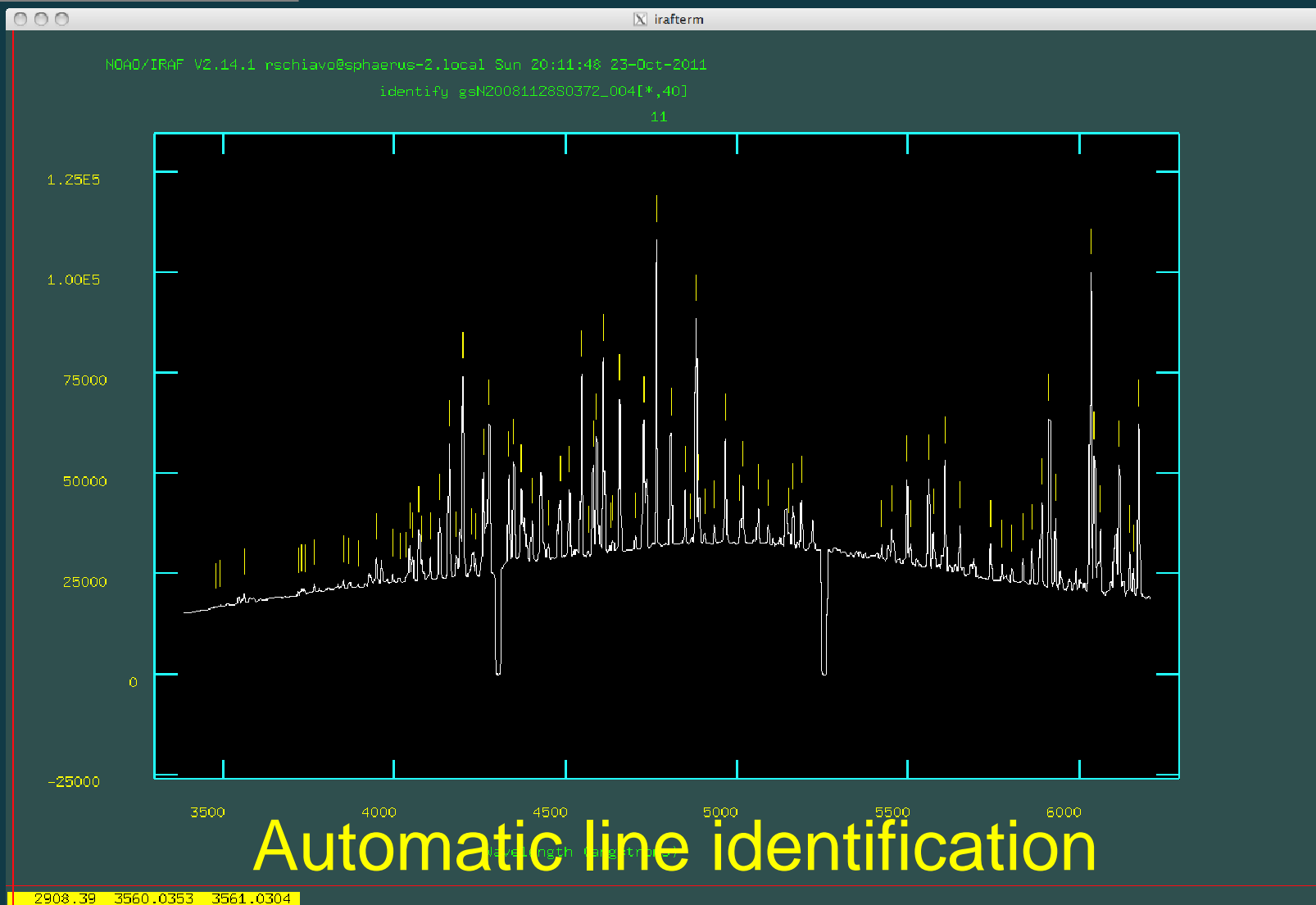
**function:** function fitted to wavelength vs. pixel relation

**order:** order of function fitted to wavelength vs. pixel relation

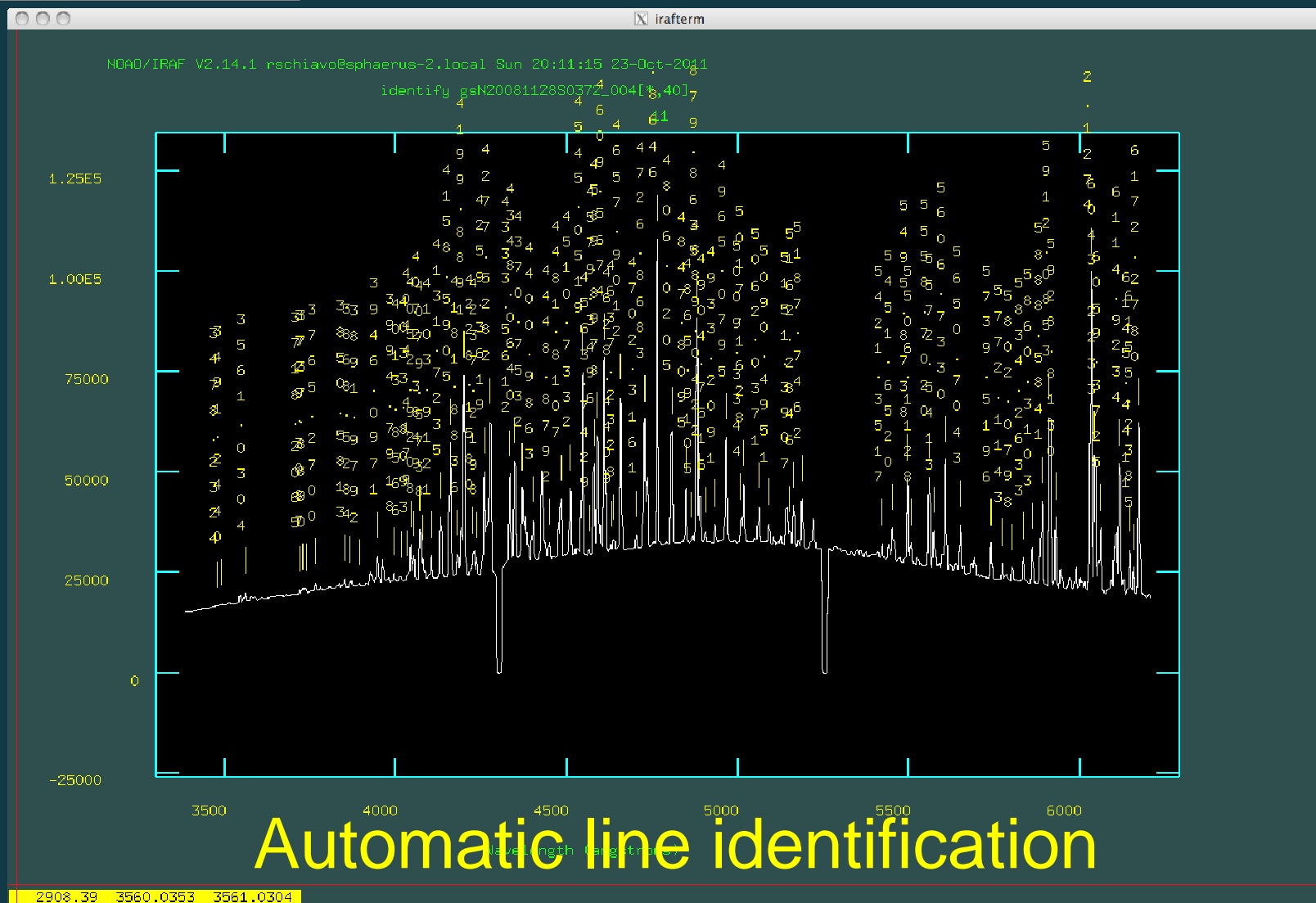
**fitxcord=6:** order of fit in x direction

**fitcyord=4:** order of fit in y direction

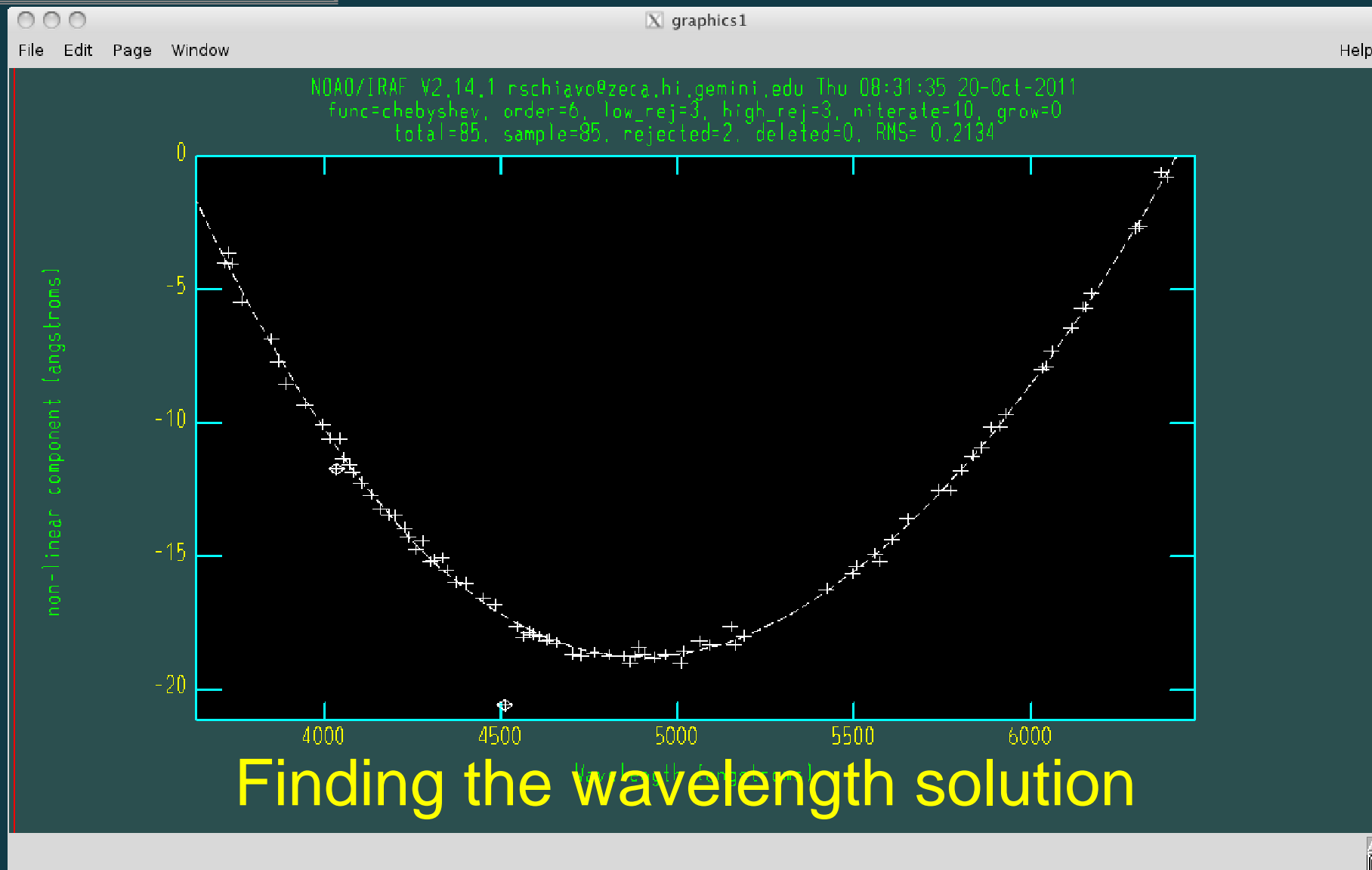
# gswavelength



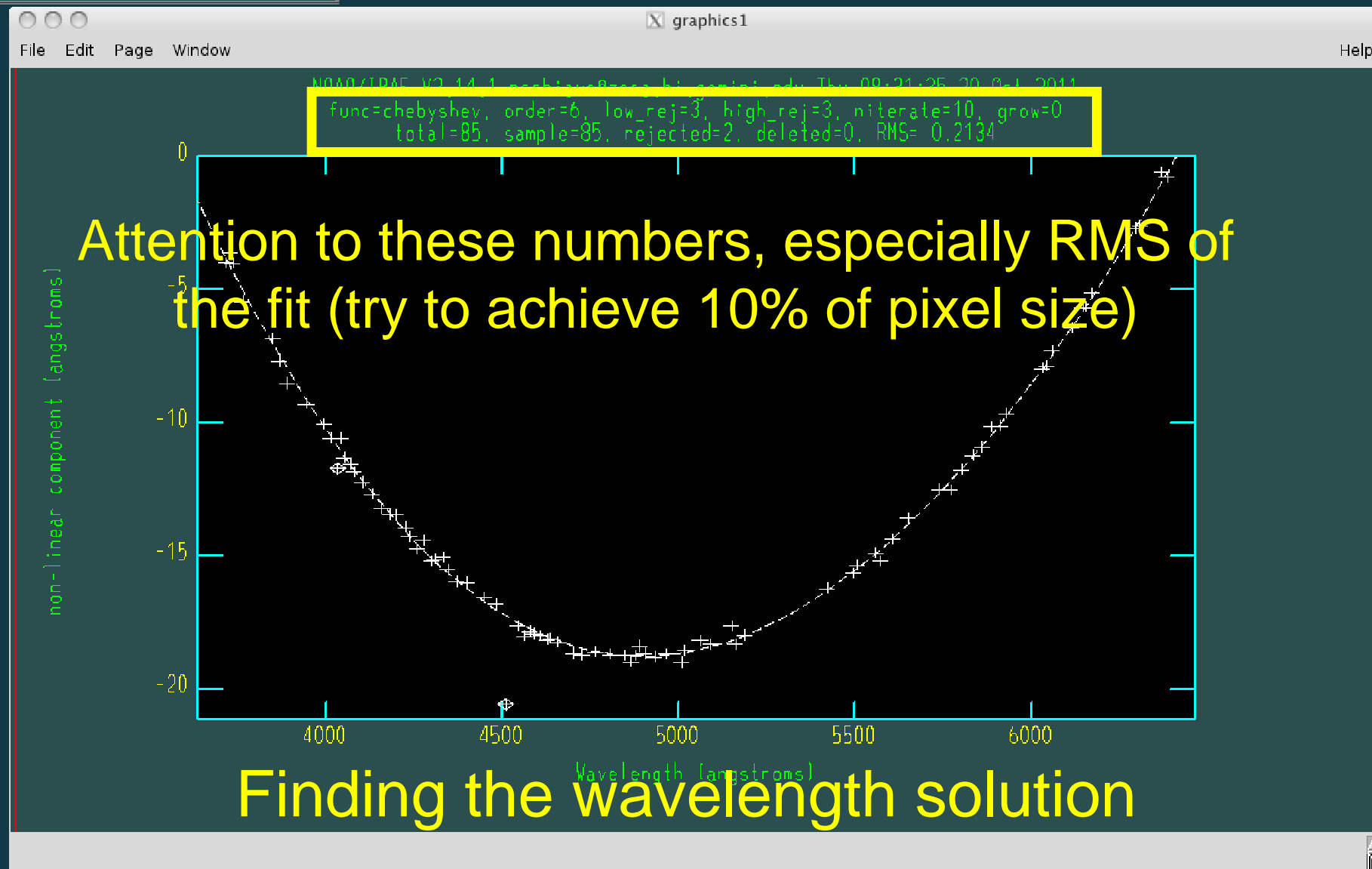
# gswavelength



# gswavelength



# gswavelength



# gswavelength

```

xgterm
AUTOIDENTIFY: NDAO/IRAF V2.14.1 rschiavo@zeca.hi.gemini.edu Thu 08:31:03 20-Oct-2011
Spectrum          # Found   Midpoint Dispersion      RMS
gsN20081128S0374_004[* ,40]      85    4976.2    -0.913    0.213
gsN20081128S0374_004[* ,40]: Examine identifications interactively?
REIDENTIFY: NDAO/IRAF V2.14.1 rschiavo@zeca.hi.gemini.edu Thu 08:31:55 20-Oct-2011
Reference image = gsN20081128S0374_004, New image = gsN20081128S0374_004, Refit = yes
      Image Data      Found      Fit Pix Shift User Shift Z Shift      RMS
gsN20081128S0374_004[* ,35] 84/85    82/84    -0.0638    0.0585    1.16E-5    0.184
Fit dispersion function interactively? (no|yes|NO|YES) ('NO'):
gsN20081128S0374_004[* ,35] 84/85    82/84    -0.0638    0.0585    1.16E-5    0.184
gsN20081128S0374_004[* ,30] 84/84    83/85     -0.098    0.089    1.88E-5    0.202
gsN20081128S0374_004[* ,25] 85/85    84/85     -0.0772    0.0705    1.42E-5    0.225
gsN20081128S0374_004[* ,20] 84/85    82/84     -0.0856    0.0778    1.63E-5    0.199
gsN20081128S0374_004[* ,15] 84/84    83/85     -0.0753    0.0685    1.44E-5    0.193
gsN20081128S0374_004[* ,10] 85/85    83/85     -0.0791    0.0721    1.47E-5    0.197
gsN20081128S0374_004[* ,5]  85/85    83/85     -0.0618    0.056    1.22E-5    0.215
gsN20081128S0374_004[* ,45] 85/85    83/85     0.0876    -0.0796   -1.7E-5    0.204
gsN20081128S0374_004[* ,50] 85/85    83/85     0.0648    -0.0591   -1.2E-5    0.201
gsN20081128S0374_004[* ,55] 85/85    83/85     0.0941    -0.0855   -1.8E-5    0.203
gsN20081128S0374_004[* ,60] 84/85    82/84     0.0675    -0.0617   -1.2E-5    0.203
gsN20081128S0374_004[* ,65] 84/84    83/85     0.0742    -0.0675   -1.4E-5    0.207
gsN20081128S0374_004[* ,70] 85/85    83/85     0.083     -0.0755   -1.6E-5    0.204
gsN20081128S0374_004[* ,75] 85/85    83/85     0.101     -0.0919   -2.0E-5    0.204
Fit gsN20081128S0374_004 interactively (yes): ☐
  
```

Output after fitting wavelength solution

# gswavelength

```

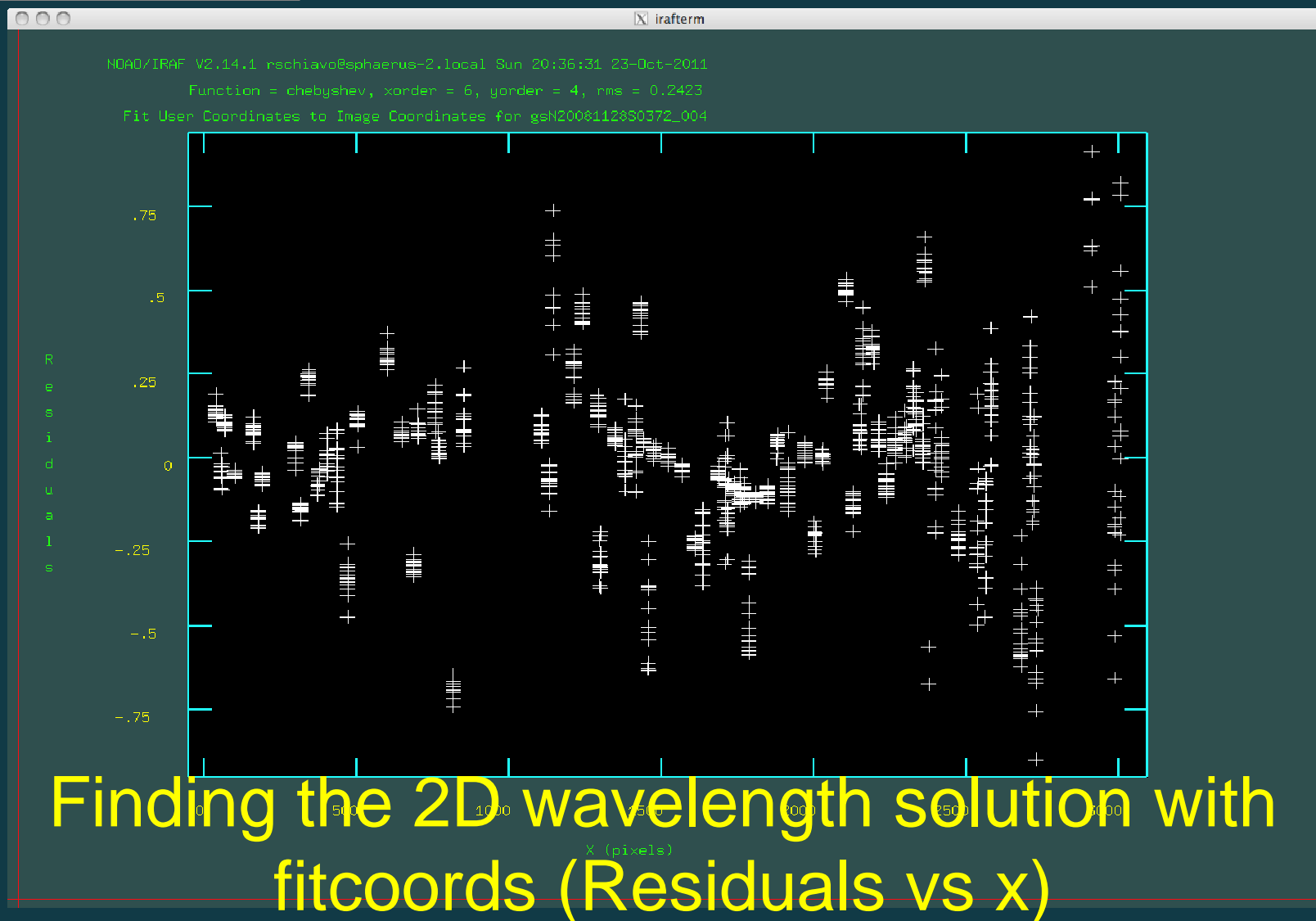
xgterm
AUTOIDENTIFY: NDAO/IRAF V2.14.1 rschiavo@zeca.hi.gemini.edu Thu 08:31:03 20-Oct-2011
Spectrum          # Found   Midpoint Dispersion      RMS
gsN20081128S0374_004[*;40]      85    4976.2    -0.913    0.213
gsN20081128S0374_004[*;40]: Examine identifications interactively?
REIDENTIFY: NDAO/IRAF V2.14.1 rschiavo@zeca.hi.gemini.edu Thu 08:31:55 20-Oct-2011
Reference image = gsN20081128S0374_004, New image = gsN20081128S0374_004, Reference
Image Data      Found   Fit Pix Shift User Shift Z Shift      RMS
gsN20081128S0374_004[*;35] 84/85   82/84   -0.0638    0.0585  1.16E-5    0.184
Fit dispersion function interactively? (no=yes|NO|YES) ('NO'):
gsN20081128S0374_004[*;35] 84/85   82/84   -0.0638    0.0585  1.16E-5    0.184
gsN20081128S0374_004[*;30] 84/84   83/85   -0.098     0.089  1.88E-5    0.202
gsN20081128S0374_004[*;25] 85/85   84/85   -0.0772    0.0705  1.42E-5    0.225
gsN20081128S0374_004[*;20] 84/85   82/84   -0.0856    0.0778  1.63E-5    0.199
gsN20081128S0374_004[*;15] 84/84   83/85   -0.0753    0.0685  1.44E-5    0.193
gsN20081128S0374_004[*;10] 85/85   83/85   -0.0791    0.0721  1.47E-5    0.197
gsN20081128S0374_004[*;5] 85/85   83/85   -0.0618    0.056   1.22E-5    0.215
gsN20081128S0374_004[*;45] 85/85   83/85    0.0876   -0.0796 -1.7E-5    0.204
gsN20081128S0374_004[*;50] 85/85   83/85    0.0648   -0.0591 -1.2E-5    0.201
gsN20081128S0374_004[*;55] 85/85   83/85    0.0941   -0.0855 -1.8E-5    0.203
gsN20081128S0374_004[*;60] 84/85   82/84    0.0675   -0.0617 -1.2E-5    0.203
gsN20081128S0374_004[*;65] 84/84   83/85    0.0742   -0.0675 -1.4E-5    0.207
gsN20081128S0374_004[*;70] 85/85   83/85    0.083    -0.0755 -1.6E-5    0.204
gsN20081128S0374_004[*;75] 85/85   83/85    0.101    -0.0919 -2.0E-5    0.204
Fit gsN20081128S0374_004 interactively (yes): [

```

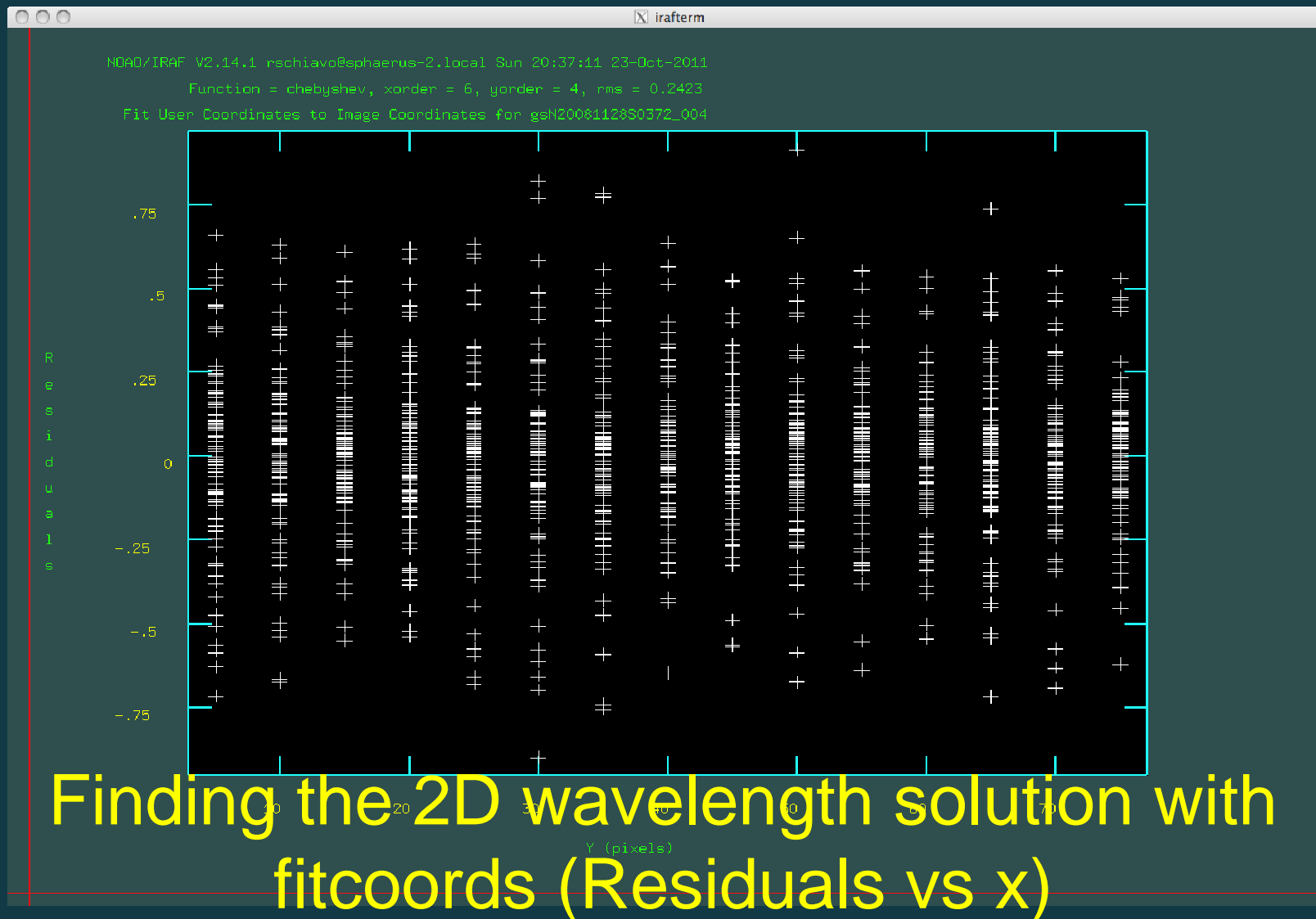
Attention to rms and number of lines used in solutions for various spectra



# gswavelength



# gswavelength





# gstransform

```
gstransform gsNarcfile.fits wavetraname=gsNarcfile.fits
```

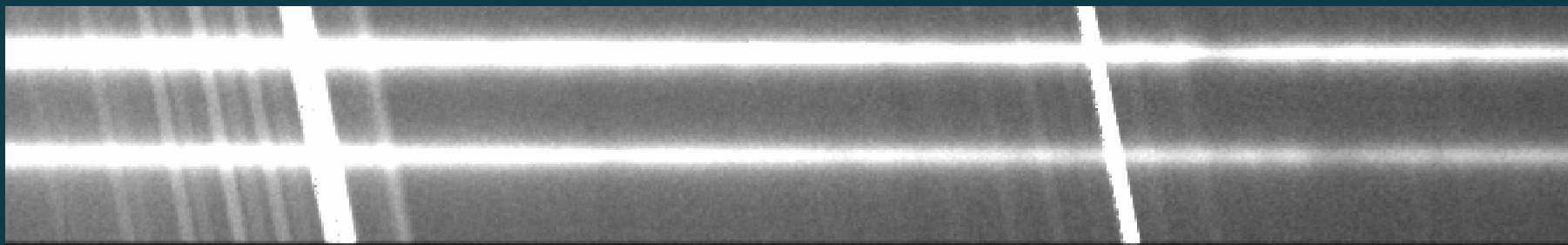
```
gstransform @gsNsciencefile wavetraname=gsNarcfile.fits  
fl_var dq+
```

Apply gstransform first to arc files, to verify that transformation went well (good in case you have tilted slits in not many sky lines)

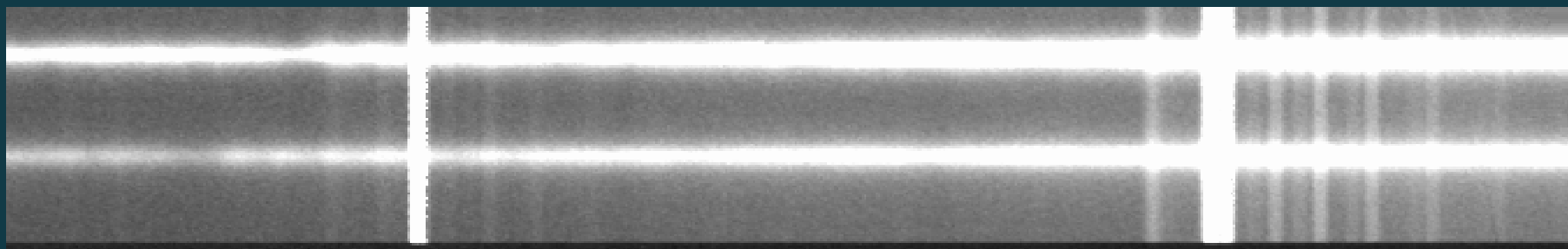
**@gsNsciencefile:** list of science files associated with arc file “gsNarcfile.fits”

# gstransform

Original tilted spectrum (pixel scale)



“gtransformed” spectrum (wavelength scale)



# gsextract

```
gsextract @tgsNsciencefile fl_inter+ find+ back=fit  
          bfunct="chebyshev" border=1 tfunct="spline3" torder=5  
          tnsun=20 tstep=50 refimage="" apwidth= 1.3 recent+  
          trace+ fl_vardq+ weights="variance"
```

**@tgsNsciencefiles:** list of "gtransformed" science spectra

**find+:** find spectra automatically

**back=fit:** subtract the fit to the background region

**trace+:** trace spectra

**b/tfunct:** function to fit to background/trace

**b/torder:** order of function to fit to background/trace

**tnsum:** number of dispersion lines to sum for trace

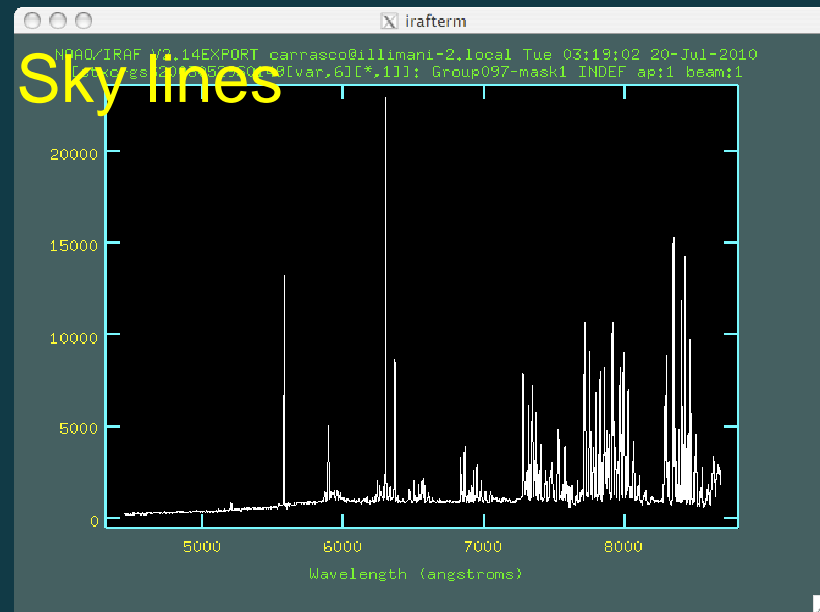
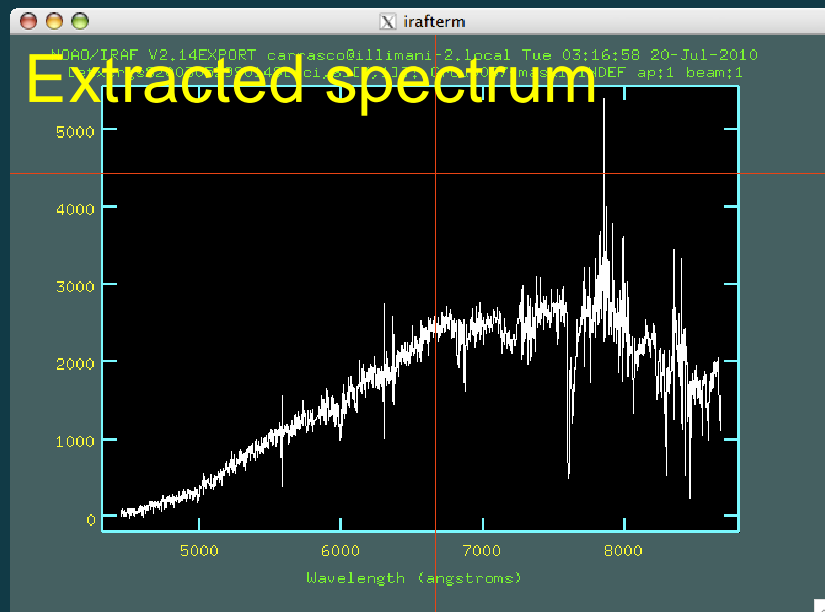
**tstep:** trace sampling

**refimage:** reference image for tracing (useful for low counts)

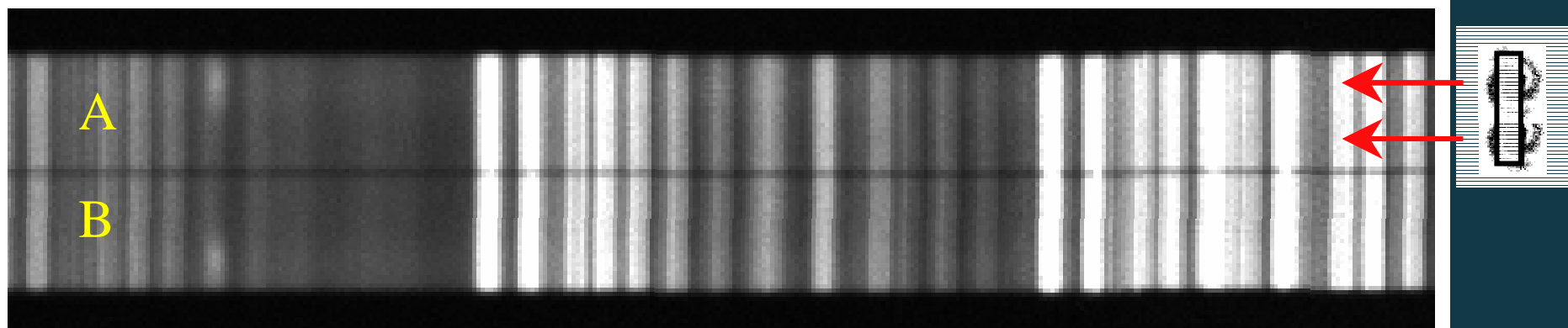
**apwidth:** width of extraction aperture, in arcseconds

**recent+:** recenter spectrum automatically

**weights:** type of extraction weighting



# Sky cancellation: Nod & Shuffle Demonstration



A-B

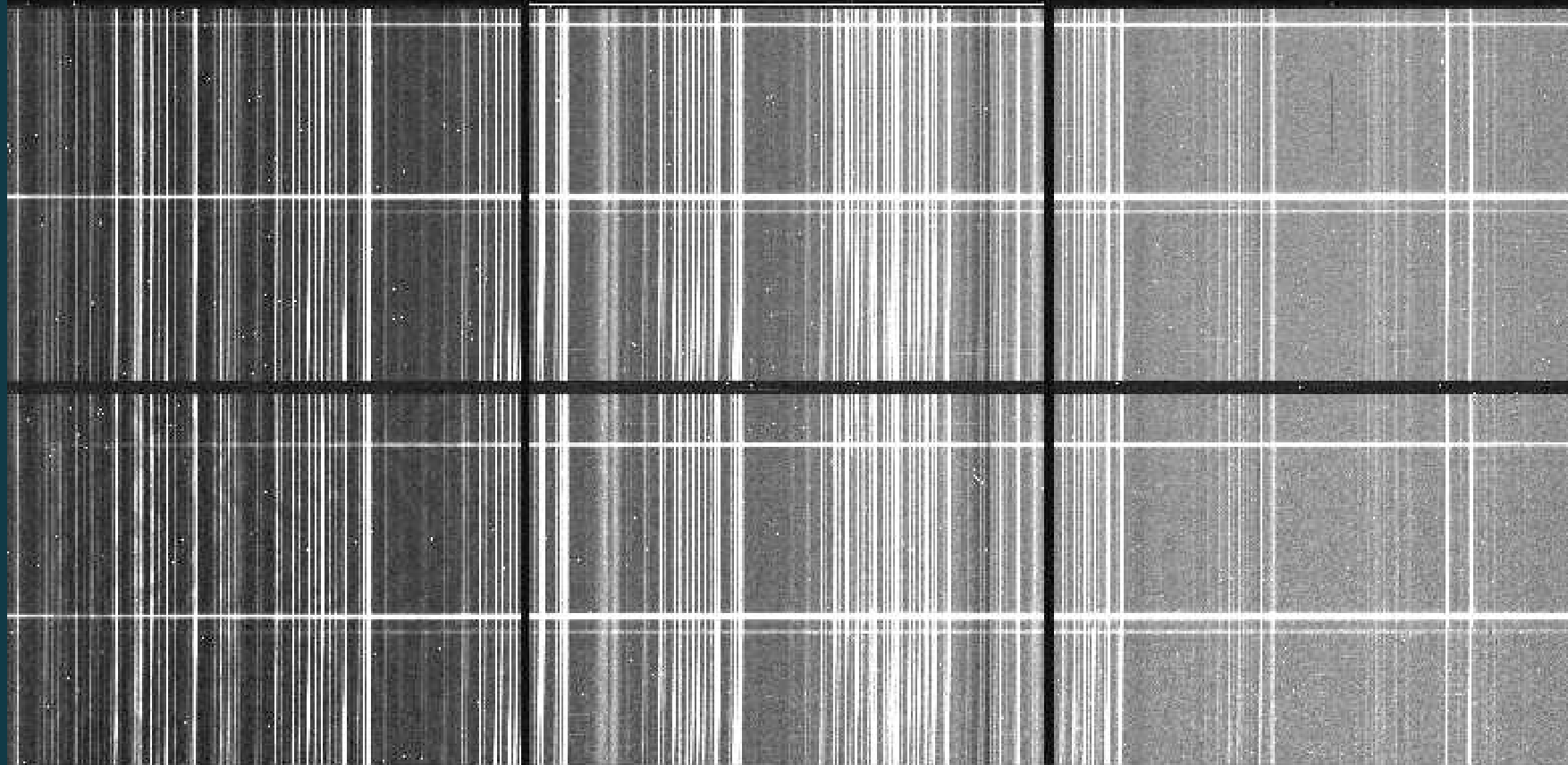
Repeat the process many times...

Typically A=60s/15 cy: 1800s exposure  $\Rightarrow 10^{-3}$  subtraction



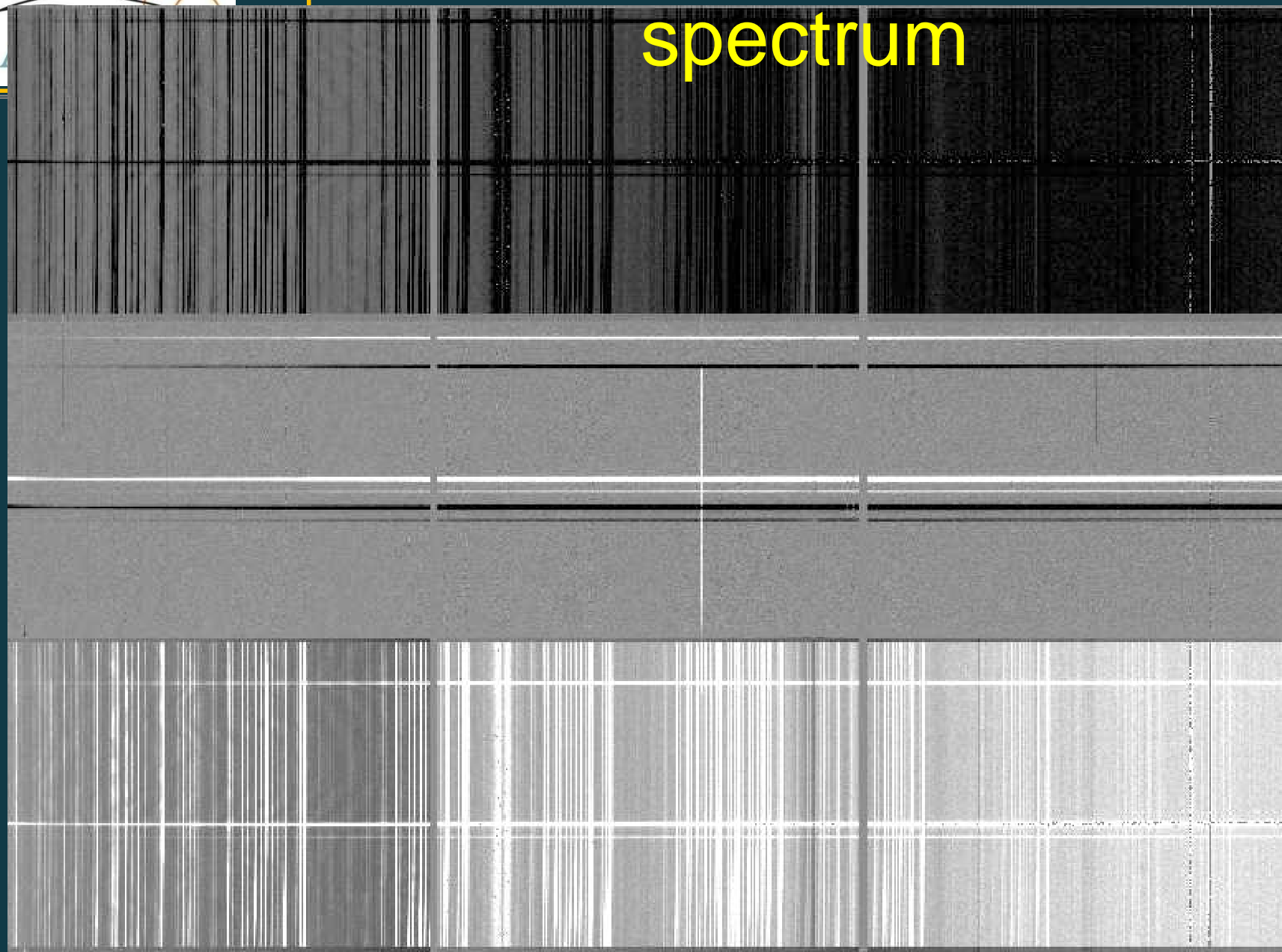
**GEMINI**  
OBSERVATORY

# Raw Longslit N&S Spectrum





# Reduced Longslit spectrum



## Gemini Multi-Object Spectrograph (North)

# Component

2010B

The GMOS North instrument is configured with this component.

Filter  Exposure Time (sec)

Disperser  Central Wavelength (nm)

Order  ☐ MOS pre-imaging ☒ Use Nod & Shuffle

CCD manufacturer

Position Angle  ☒ Set to (deg E of N)

☐ Use Average Parallactic Angle

☐ Follow in Parallactic Angle

Focal Plane Unit  ☒ Custom Mask MDF

CCD Readout Translation Stage Regions of Interest ISS Port Nod & Shuffle

### Nod (arcsec)

p	<input type="text" value="0.0"/>	#	p	q	OIWFS
q	<input type="text" value="-0.8"/>	0	0.0	-0.8	guide
OIWFS	<input type="text" value="guide"/>	1	0.0	0.8	guide

☒ Use Electronic Offsetting?

Offset (arcsec)

Offset (detector rows)

Number of N&S Cycles

Total Observe Time (sec)

# N&S: Which Steps Differ?

---

- Bias - There may be no need to bias correct
- Dark - Should dark correct **New CCDs?**
- Flatfield - Fit the flat chip-by-chip and create a special N&S flat
- Sky subtract - done within the script gnscombine or gnsskysub *before* wavelength calibration
- DTA dithers - removed using look-up table (manually generated) with gnscombine
- Extract spectra - if nodding within the slit must extract both positive and negative spectra

# N&S Dark Correction

- N&S darks taken with the same shuffle distance, exposure time, number of cycles and binning do a very good job at removing features induced by the “charge traps.”
  - N.B. normal darks can also be used to correct regular science data that sometimes show these features (eg. blue spectral IFU spectral data taken immediately after a GCALflat)
- N&S Darks are defined by PI in science program, this ensures they are taken and makes it easier to associate the correct darks with the program.
- N&S Darks are taken by queue observers during closed dome. Extra shielding around the detector prevents light leaks although usually there is sufficient closed dome time at night.
- N&S darks are quite stable, can be used for data taken many months separated in time.
- Do not yet know if new CCD data will need dark correction

# gnsdark

```
gnsdark @darklist "Nsdark" logfile=gmos.logfile  
rawpath="rawdata$" fl_over+ fl_trim+  
nbiascontam=4 fl_bias+ bias="darkbias"  
fl_inter+ fl_vardq+)
```

**darklist:** text file containing filenames of raw dark images (one per line)

**NSdark:** name of output combined dark image

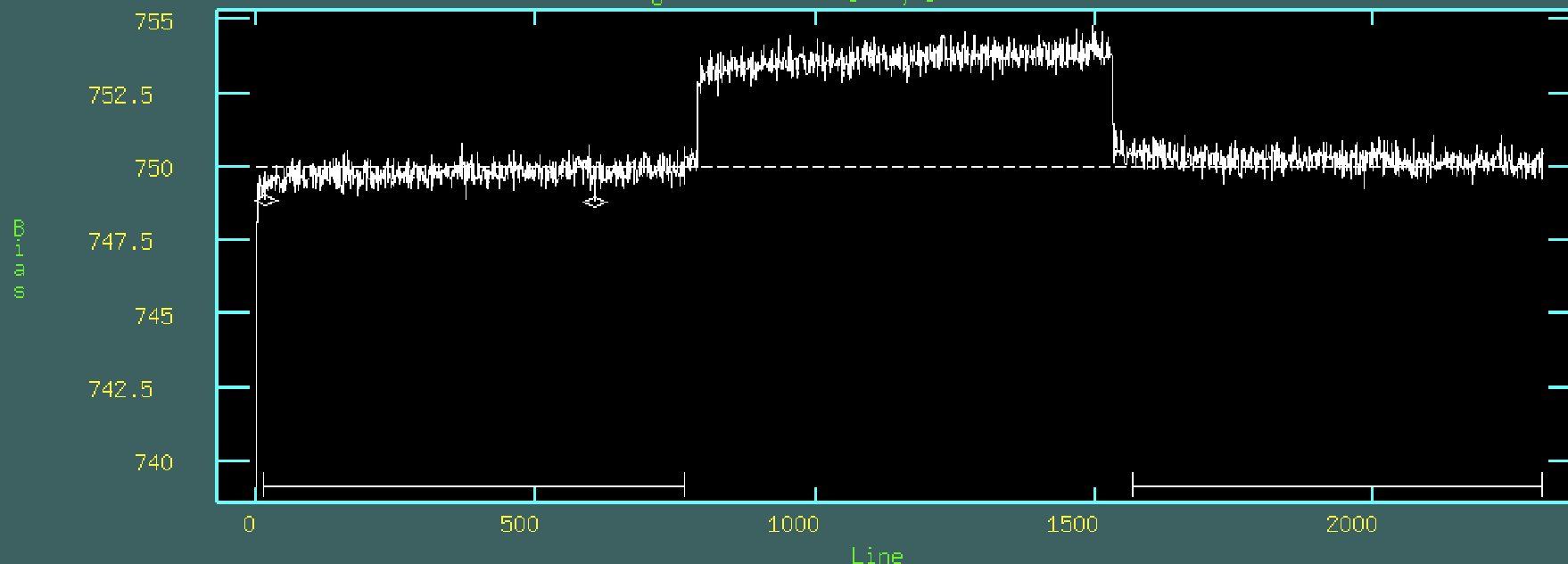
**fl\_bias+:** subtract a bias image

**Bias="darkbias":** name of the bias images to use

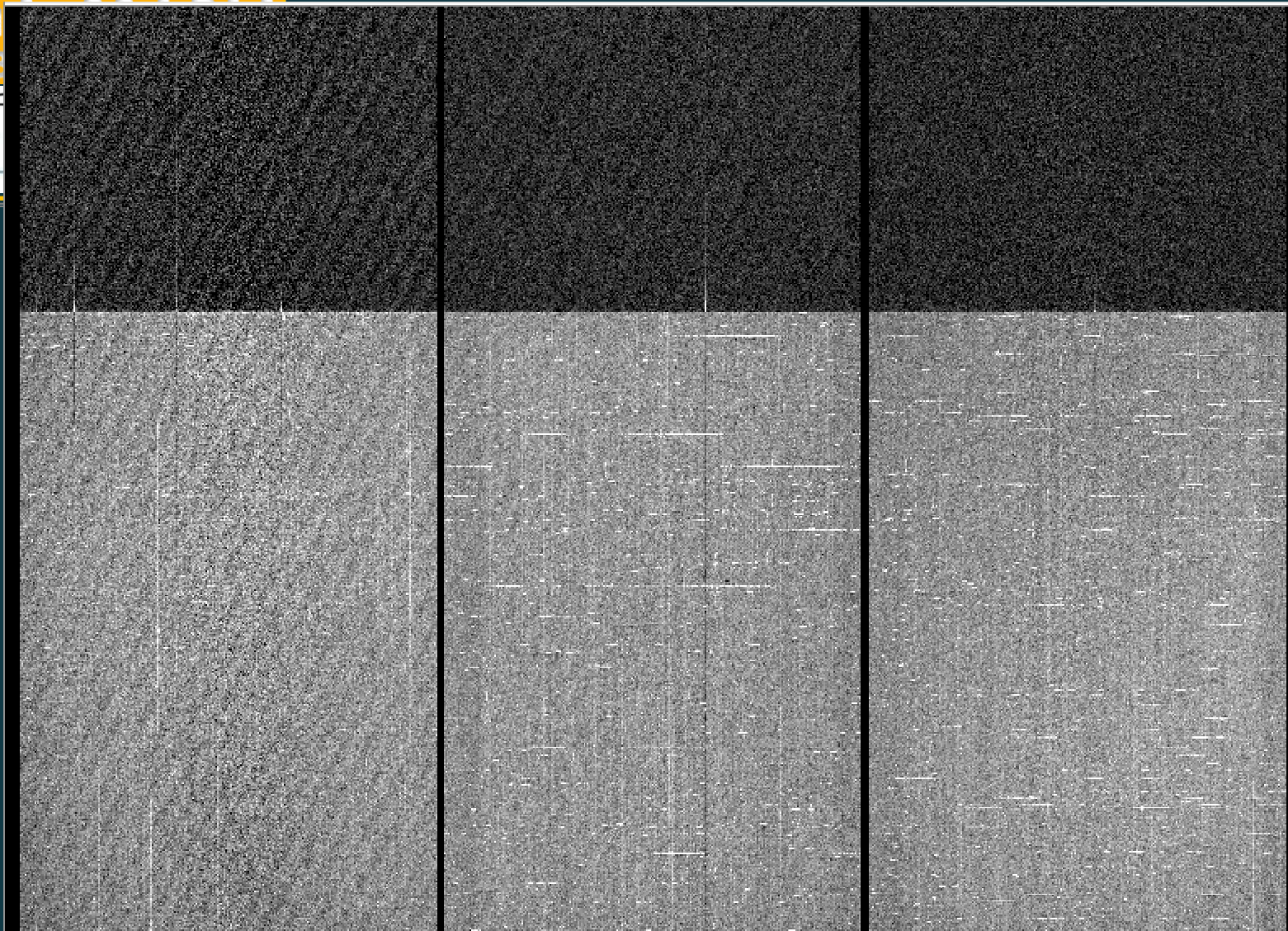
```

NDAO/IRAF V2.14.1 kroth@krl.local Sat 23:48:50 17-Jul-2010
func=chebyshev, order=1, low_rej=3, high_rej=3, niterate=2, grow=0
total=2304, sample=1487, rejected=2, deleted=0, RMS= 0.377
colbias gN20051118S0306[SCI,1]

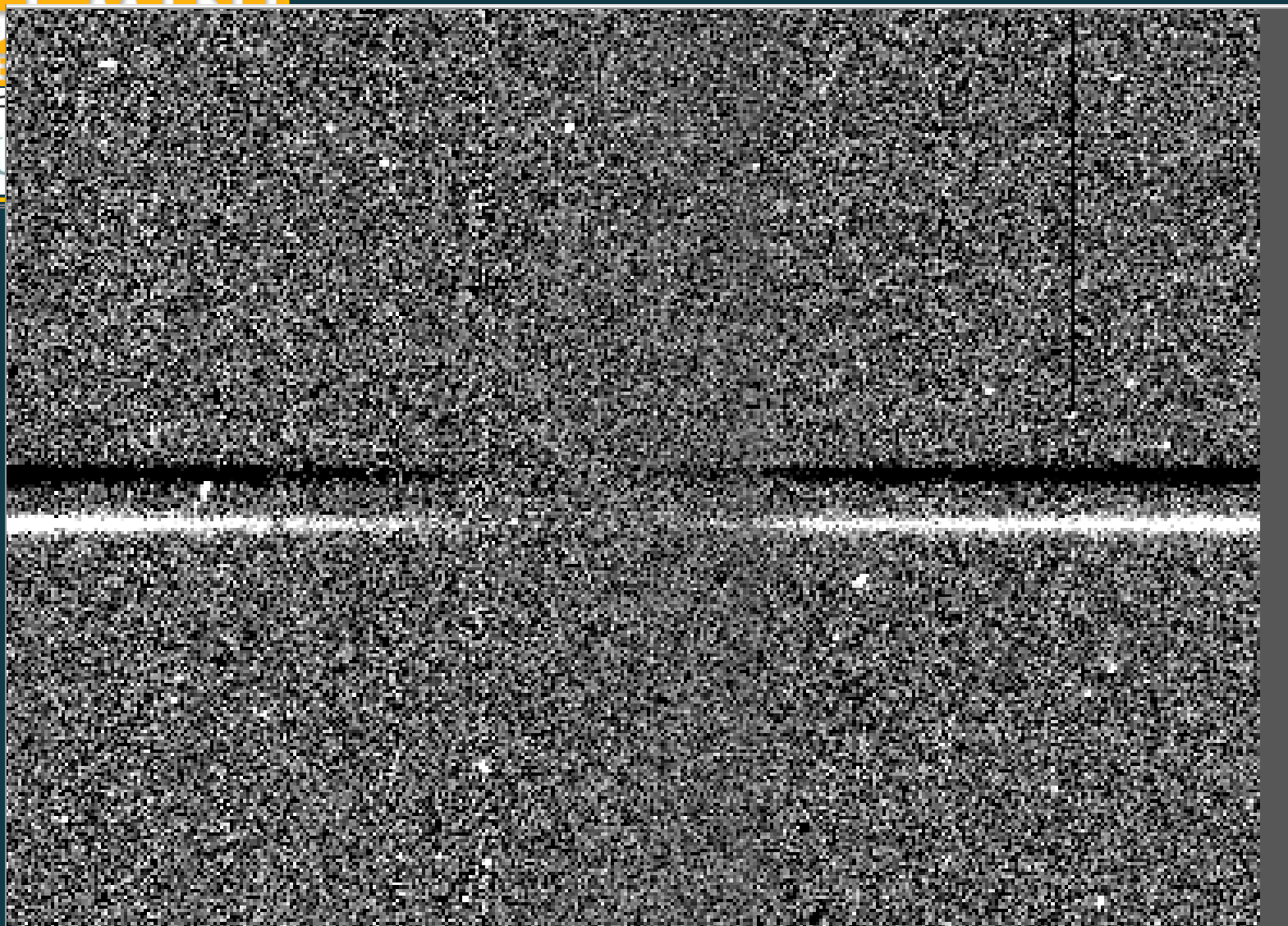
```



Overscan fit for CCD1. By utilizing the “s” cursor command one can select specific regions to fit. Use a “t” to initialize back to the full spectrum. The selected regions are indicated at the bottom of the plot. The fit excludes pixels not selected. A first order chebyshev polynomial (constant) is recommended.



Nod & Shuffle longslit (shuffle offset = 1536 pixels) dark. A = 60s, number of cycles = 8, total exposure time = 960s.



Zoom of reduced spectral image where source spectrum is weak and charge traps were prevalent.





Zoom of the same region of image reduced identically except for having no dark subtraction.

# Flatfield Correction

- GCALflats for Nod & Shuffle programs are not shuffled when they are taken  $\Rightarrow$  use **fl\_double+** option in **gsflat**.
- When constructing Nod & Shuffle GCALflats with **fl\_double+**, must specify the shuffle distance in the parameter **nshuffle** to match the value given in the **NODPIX** keyword in the science data.
- Flats are useful for removal of pixel-to-pixel variations in brighter targets
- Flats are important for removal of fringing in bright objects
- **gnscombine** applies flatfield before sky subtraction  $\Rightarrow$  flat cannot be **gmosaic'd**  $\Rightarrow$  use **fl\_detec+** option in **gsflat**
  - N.B. in general it is good practice to use **fl\_detec+** when working with long wavelength data because any function of high enough order to fit the full spectral range for most gratings will also start to fit the fringing.

# gsflat (N&S)

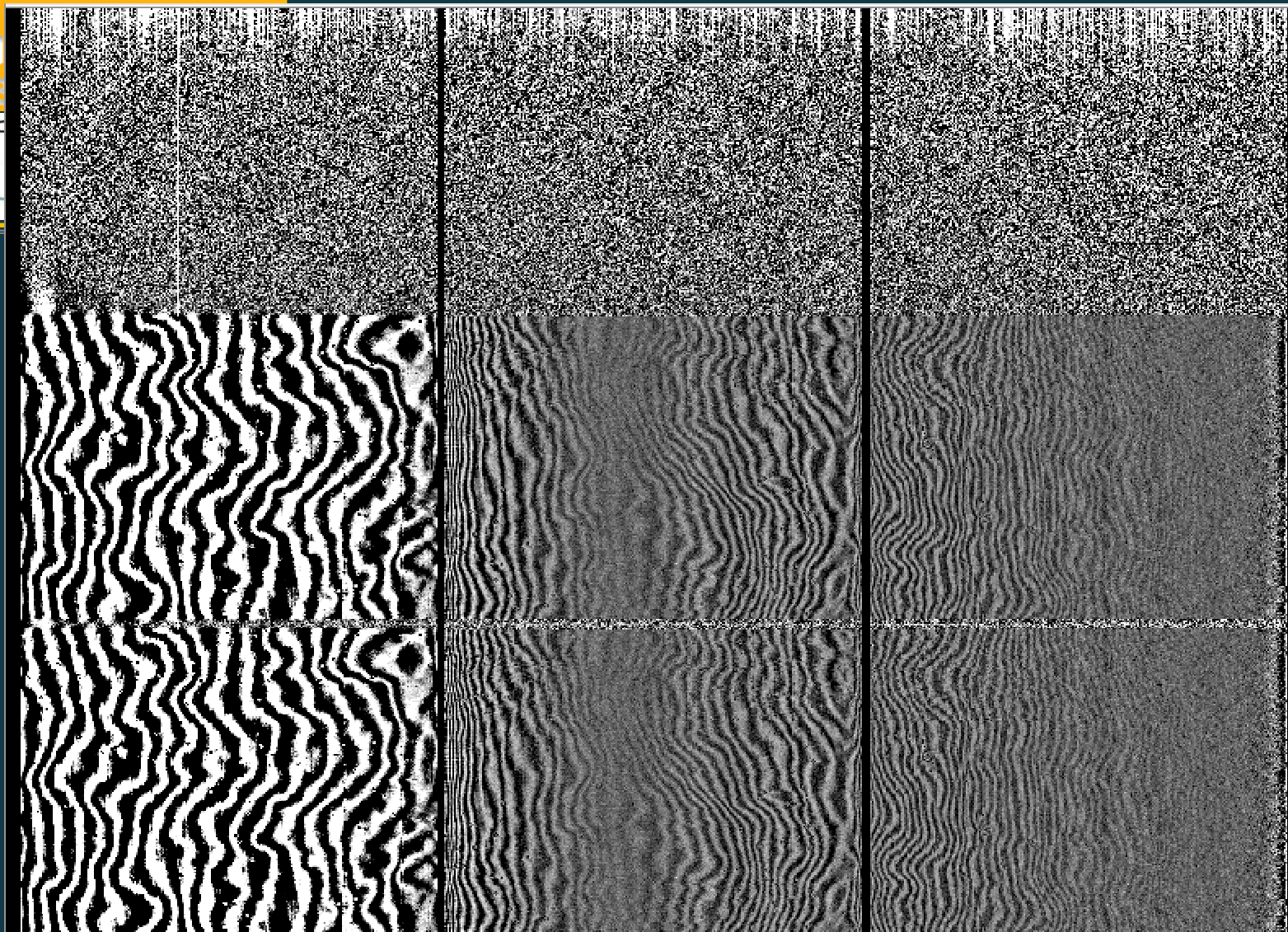
```
gsflat @flatfiles_460 out=Flat_460.fits  
logfile=gmos.logfile rawpath="rawdata$"  
fl_over+ fl_trim+ nbiascontam=4  
fl_bias+ bias="sciencebias" fl_dark-  
fl_fixpix- fl_inter+ function="chebyshev"  
order=15 fl_detec+ fl_double+  
nshuffle=1536 ovs_flinter+ fl_vardq+
```

fl\_detec+: do not mosaic, fit each detector independently

ovs\_flinter+: examine fits to overscan region interactively

fl\_double+: create double flat shifted by same amount as science data

nshuffle=1536: shuffle distance (unbinned pixels) from NODPIX header keyword in science data



Final normalized spectral image. Minimal fringing is visible in CCD2 and CCD3, and the GCALflat image has been reproduced, displaced 1536 pixels below the original, simulating a shuffled GCALflat.



# gsreduce (N&S)

```
gsreduce N20051118S0305.fits logfile=gmos.logfile  
rawpath="rawdata$" fl_over+ fl_trim+  
nbiascontam=4 fl_bias+ bias="sciencebias" fl_dark+  
dark="Nsdark" fl_flat- fl_gmosaic- fl_fixpix-  
fl_gsappwave- fl_cut- ovs_flinter+ fl_vardq+
```

N20051118S0305.fits: raw science image (810nm)

fl\_gmosaic-: do not mosaic, leave the detectors as separate extensions

fl\_gsappwave-: do not apply a first order wavelength solution based on the header

fl\_cut-: do not cut the slits into separate extensions (superfluous for longslit)

ovs\_flinter+: examine fits to overscan region interactively

\*\* attempting to fl\_flat+ in the first gsreduce call produces an error, will discuss this with the experts and clean it up before posting cookbook \*\*

# N&S Sky Subtraction

- Sky subtraction is done on a pixel by pixel basis by subtracting the shuffled image pixels from those obtained with no shuffle.
- Because the telescope is pointing at a different position when the pixels are shuffled the result is either a sky subtracted object spectral image (if nodding was off to sky) or two sky subtracted spectra, one position and one negative.
- Higher noise introduced by the sky subtraction compensated for by far lower sky-line residuals.
- `gnsskysub` is useful for sky subtracting individual exposures. The image is duplicated, shifted by the appropriate number of rows (from the `NODPIX` header keyword), and subtracted from itself.
- If combining more than one spectral image (including DTA-X dithers) use `gnscombine` which calls `gnsskysub`.

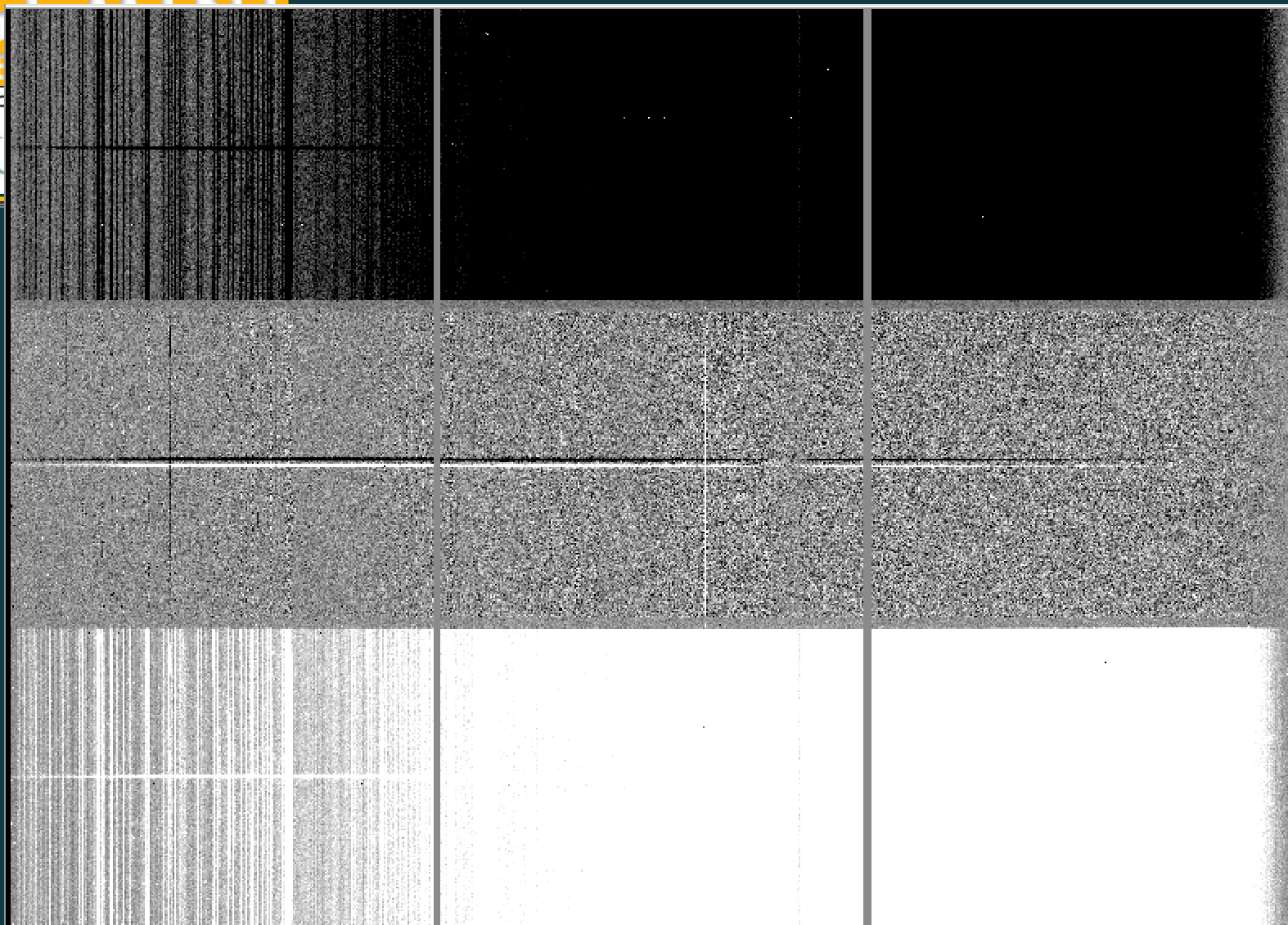
```
gnsskysub "science_810"  
  outimages="science_810_skysub" fl_fixnc+  
  logfile=gmos.logfile
```

**science\_810:** gsreduced science image

**outimages="science\_810\_skysub":** output sky subtracted image, still MEF with separate extensions for each detector, variance and data quality planes (gnsskysub does not propagate errors, just copies them from original image)

**fl\_fixnc+:** correct for incorrect shuffle count. On occasion (not rare, but does not happen all the time, the GMOS detectors will not shuffle for the first sub-exposure of a new Nod & Shuffle exposure. The sky subtraction will not be good, this parameter corrects for the imbalance by scaling the shuffle images properly. Note that photometry is *not* preserved, but since the telescope nodded when the detector refused to shuffle the photometry is messed up from the beginning.





Bias corrected, dark subtracted, flat fielded, overscan subtracted, trimmed, sky subtracted Nod & Shuffle longslit spectral image (810nm, nod  $q = \pm 1$  arcsec).



# 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)

# Bias Correction

- Not talking about overscan correction here - recommendation is to always overscan correct all Nod&Shuffle data.
  - Nod & Shuffle implies the science target is faint and correct sky subtraction is important  $\Rightarrow$  overscan correct
- There is no need to bias correct Nod & Shuffle data if using the same bias to correct the N&S Darks
- If Nod & Shuffle Darks were taken sufficiently offset in time from the science data there may be some advantage to bias correcting the darks using a different bias from that used to bias correct the science data
  - In practice not much advantage to this as the bias level is very stable over a period of months