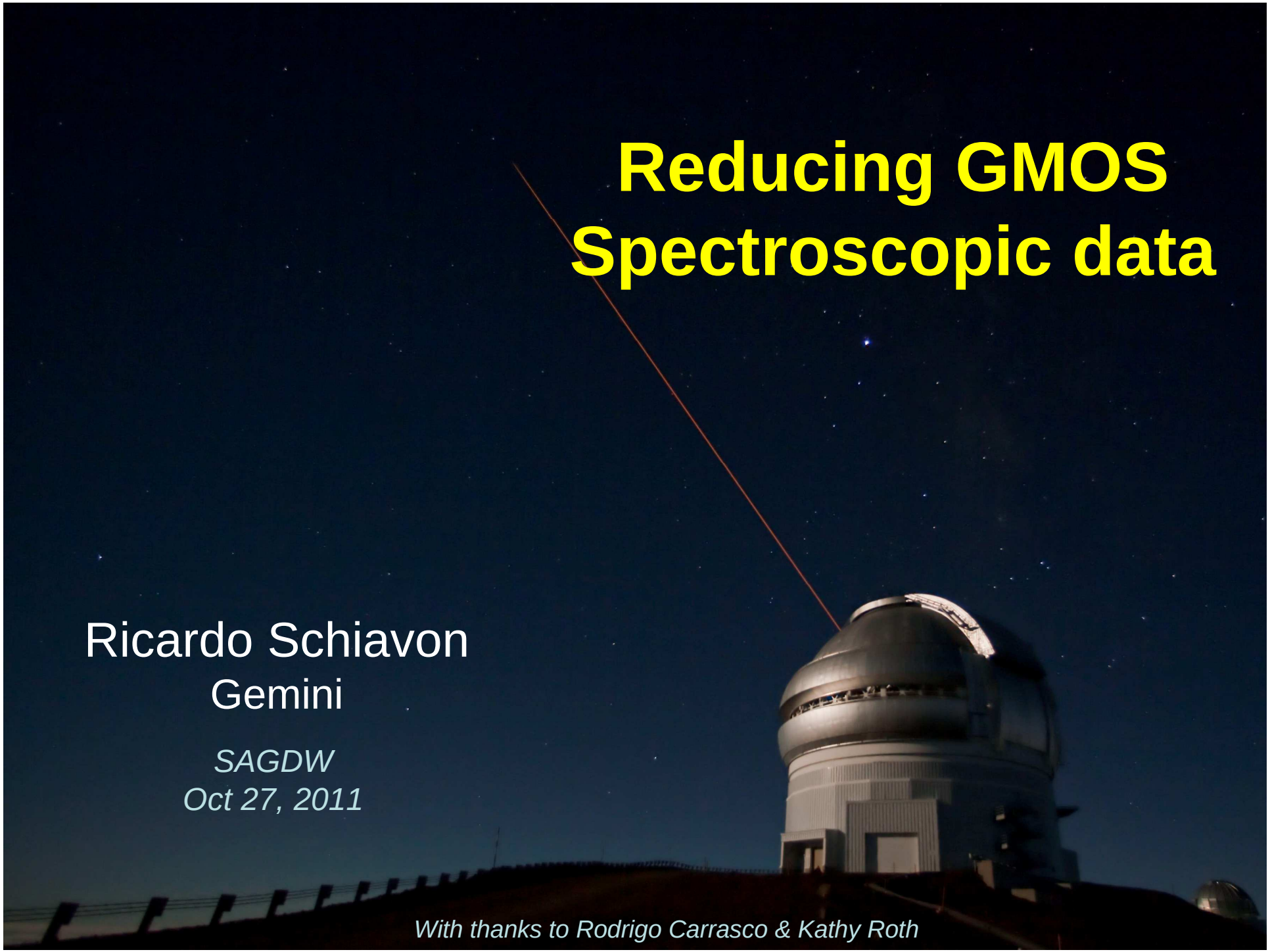


Reducing GMOS Spectroscopic data

Ricardo Schiavon
Gemini

SAGDW
Oct 27, 2011

With thanks to Rodrigo Carrasco & Kathy Roth

Contents

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

General Principles

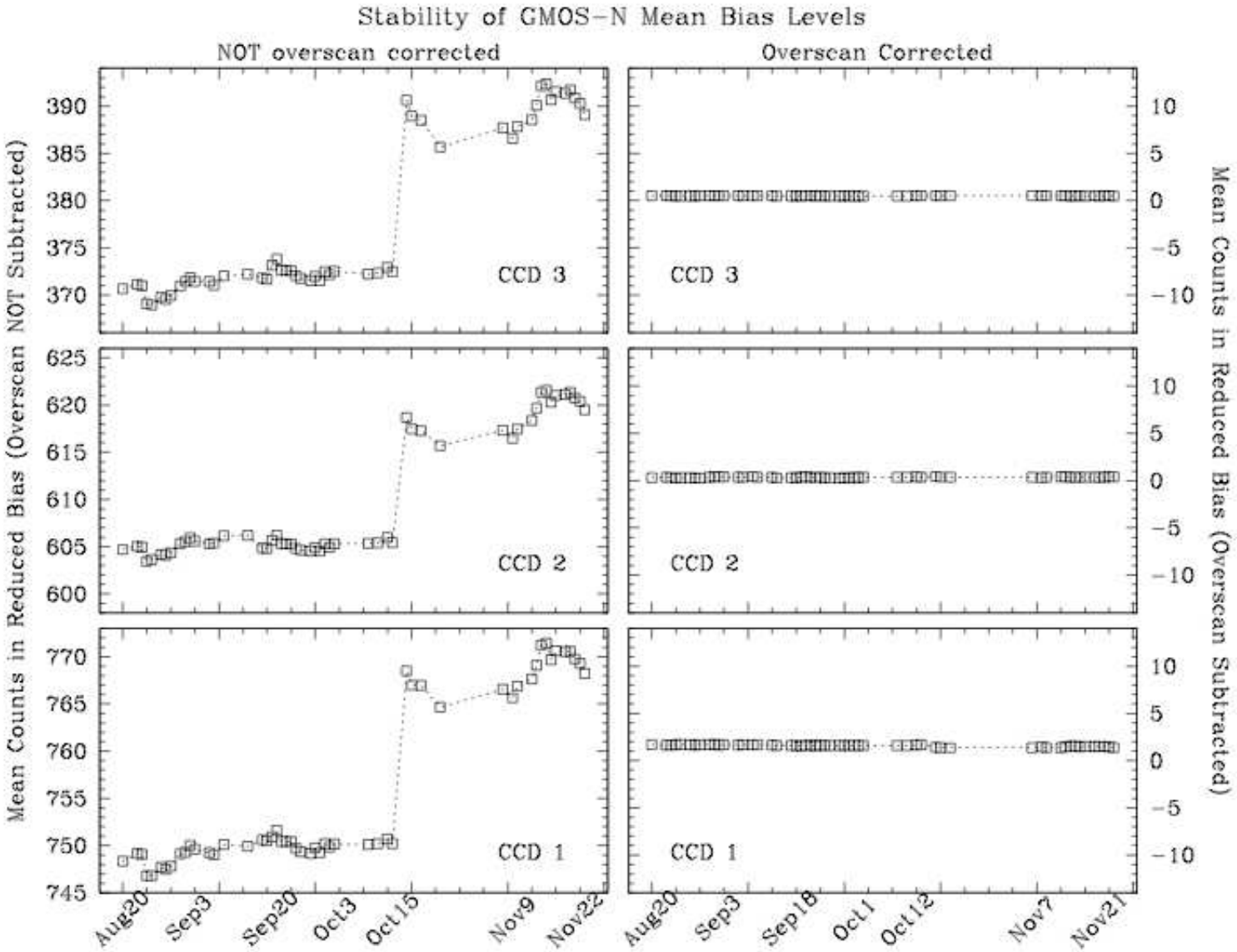
- Record everything that you do. Refrain from changing parameters with “epar” before running tasks
- Experiment. Verify the impact of varying different reduction parameters on the final results
- Attention to files in the “database” directory. They contain important information
- Make sure you understand 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

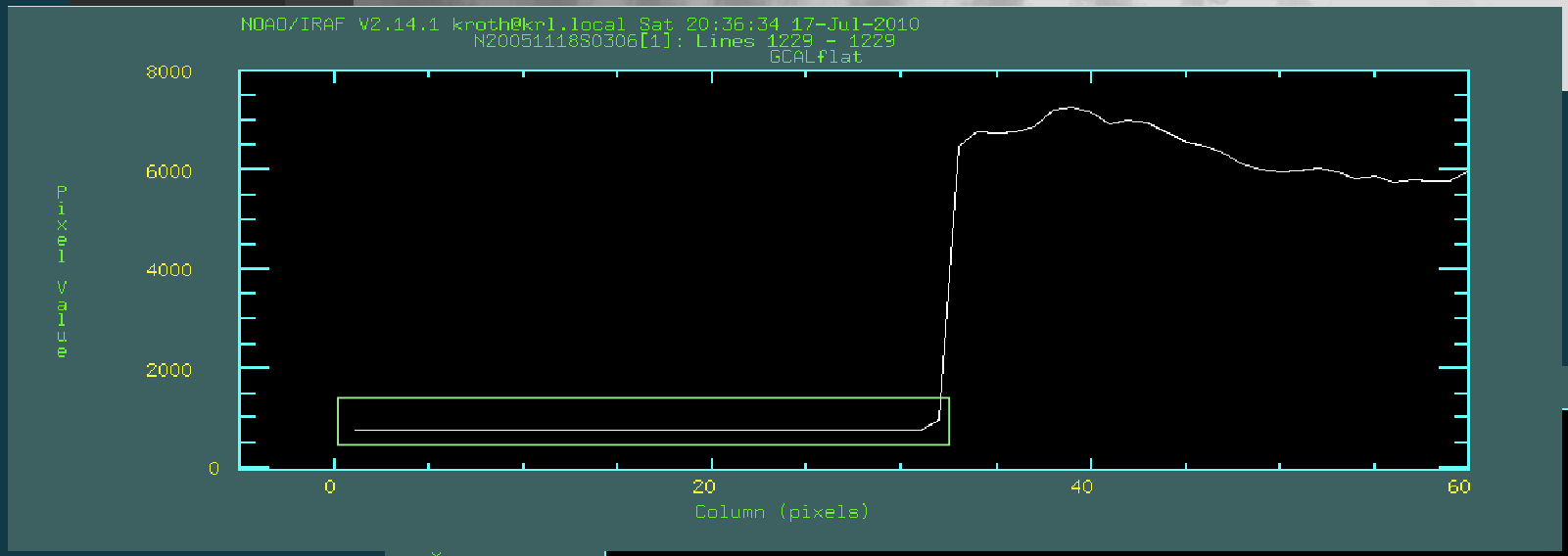
- Standard procedure for treatment of CCD data
- Due to fluctuations of zero-point level, overscan correction is recommended for low counts

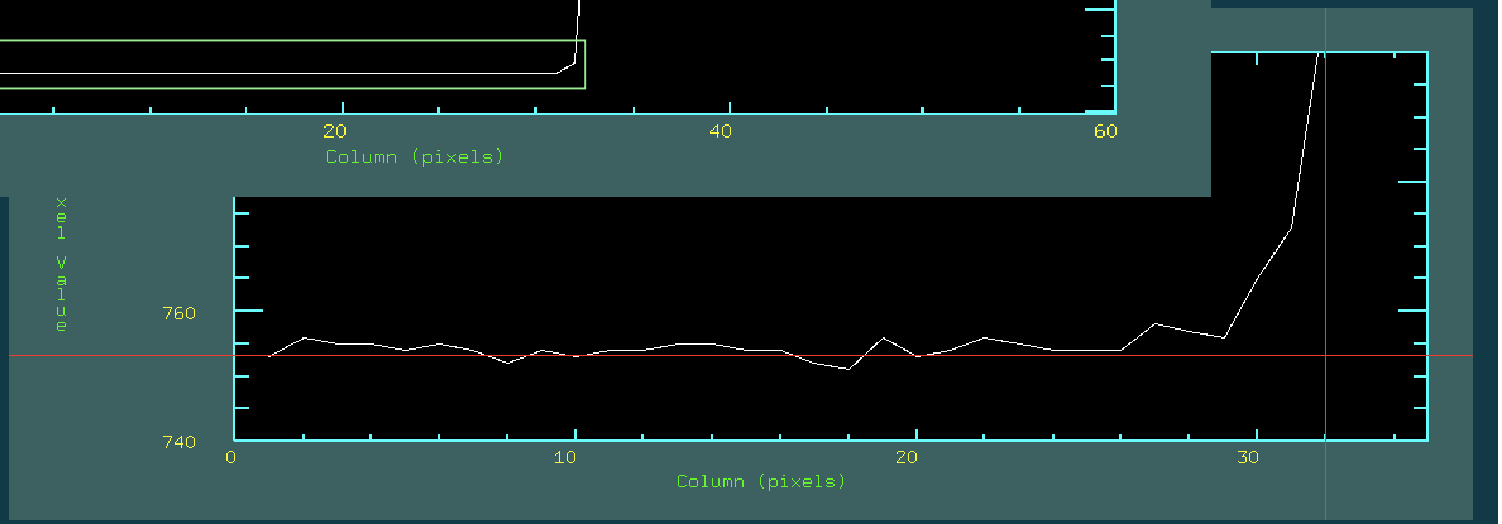

Stability of GMOS-N Mean Bias Levels
NOT overscan corrected
Overscan Corrected
Mean Counts in Reduced Bias (Overscan NOT Subtracted)
Mean Counts in Reduced Bias (Overscan Subtracted)
CCD 3
CCD 2
CCD 1
390
385
380
375
370
625
620
615
610
605
600
770
765
760
755
750
745
10
5
0
−5
−10
Aug20
Sep3
Sep20
Oct3
Oct15
Nov9
Nov22
Aug20
Sep3
Sep18
Oct1
Oct12
Nov7
Nov21

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)

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+

biaslist: 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

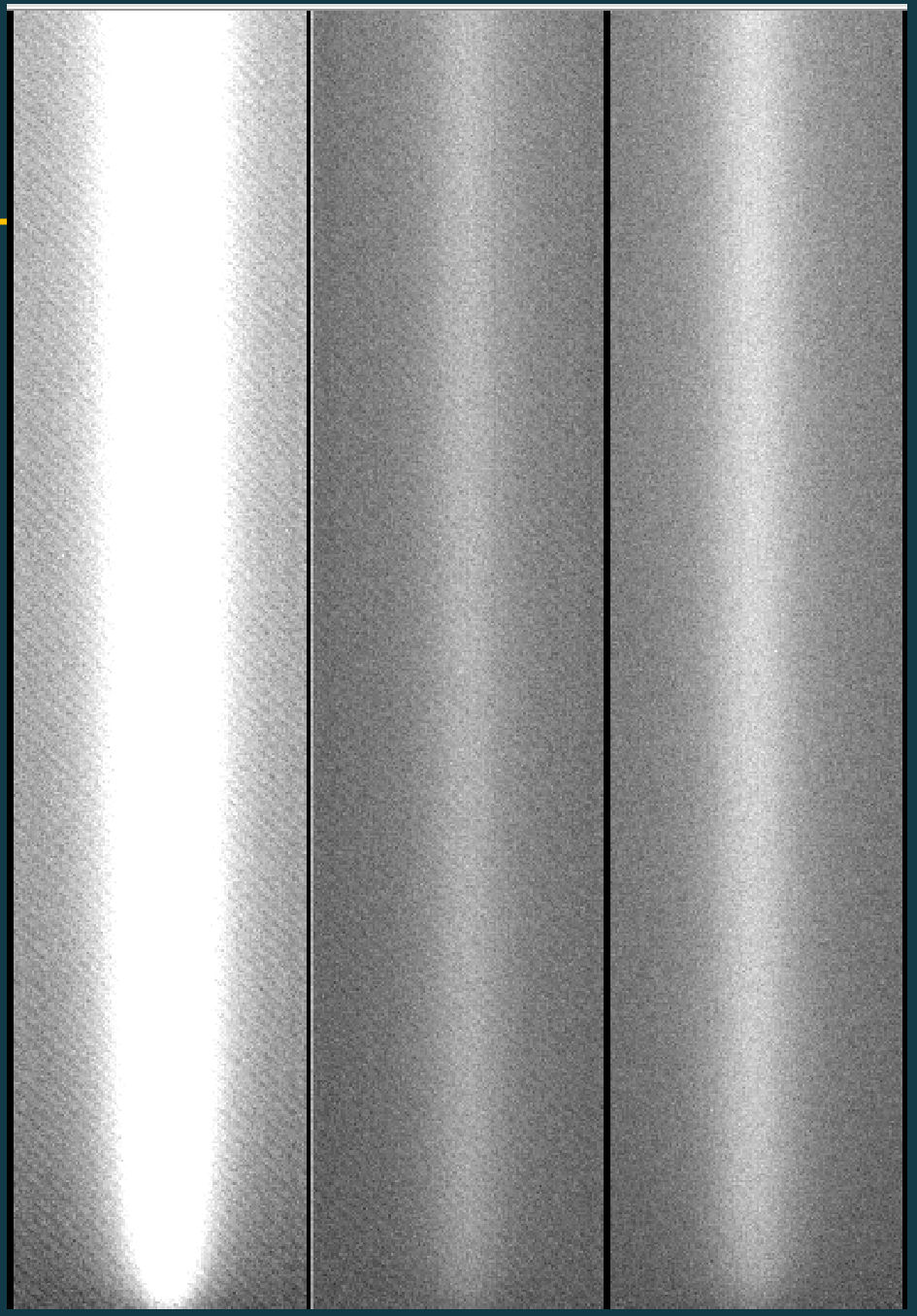
fl_trim+: trim off the overscan region after fitting and subtraction

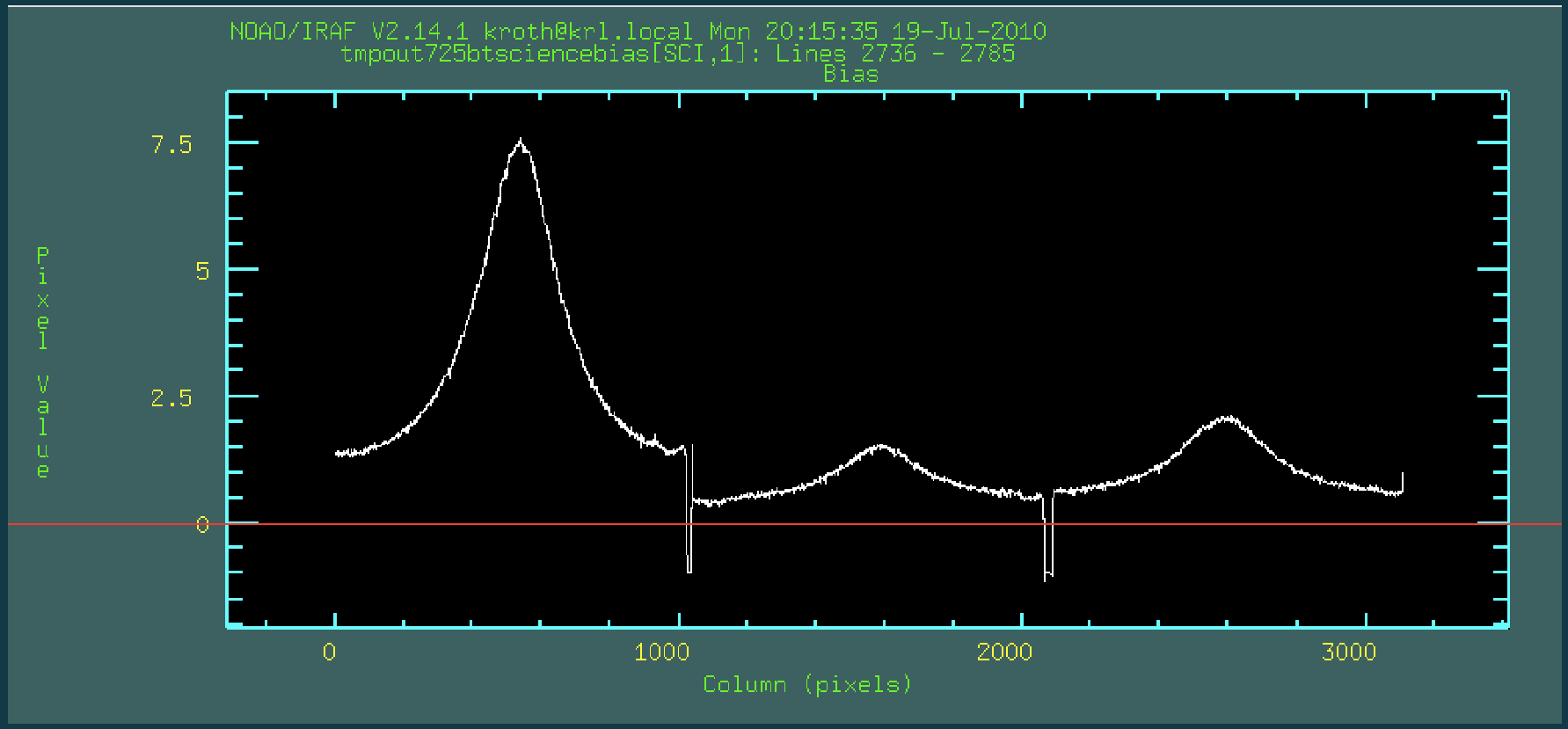
nbiascontam=4: throw away the four columns of the bias section bordering the data section, charge "bleeds" into the overscan region when the detector is exposed to high light levels

fl_inter+: interactively fit the overscan region

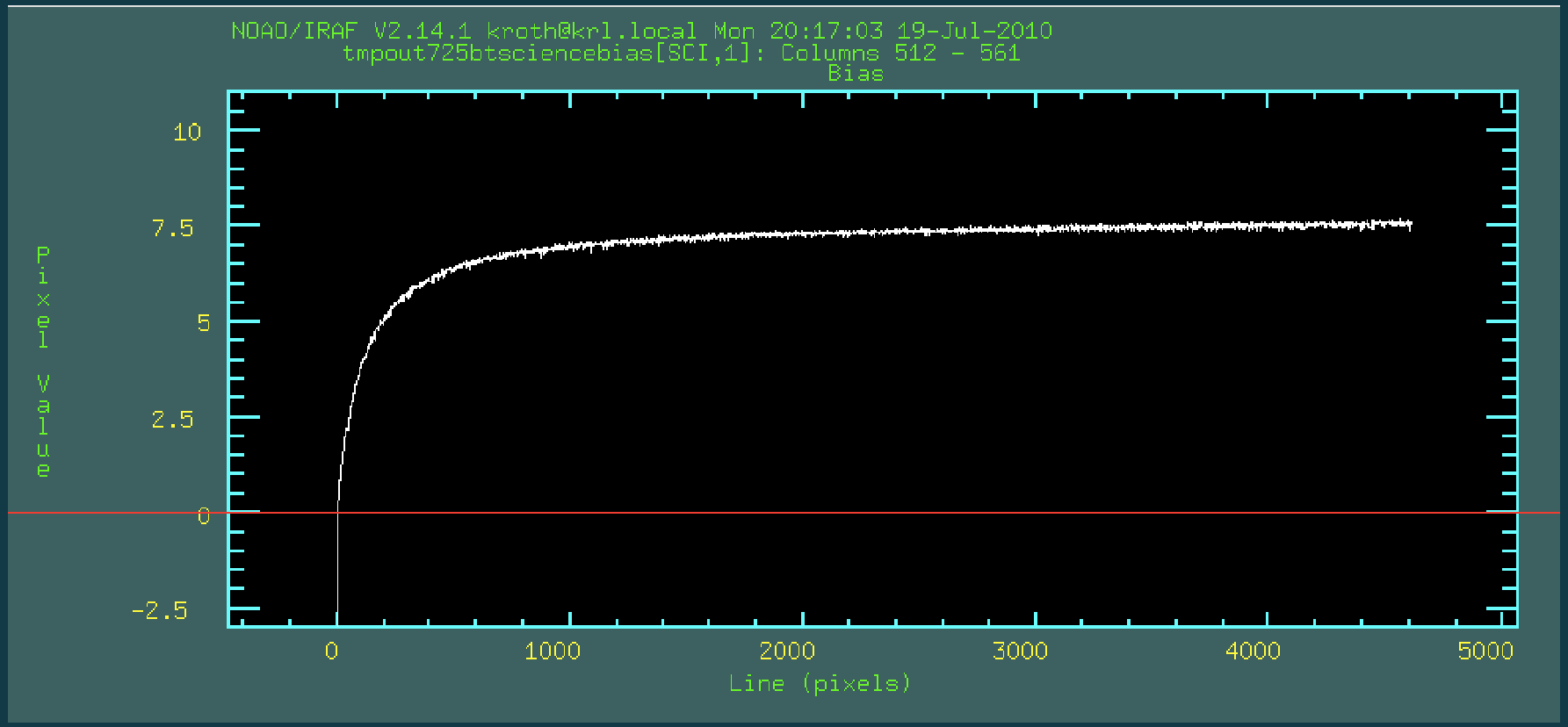
fl_vardq+: create/propagate variance and data quality planes

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

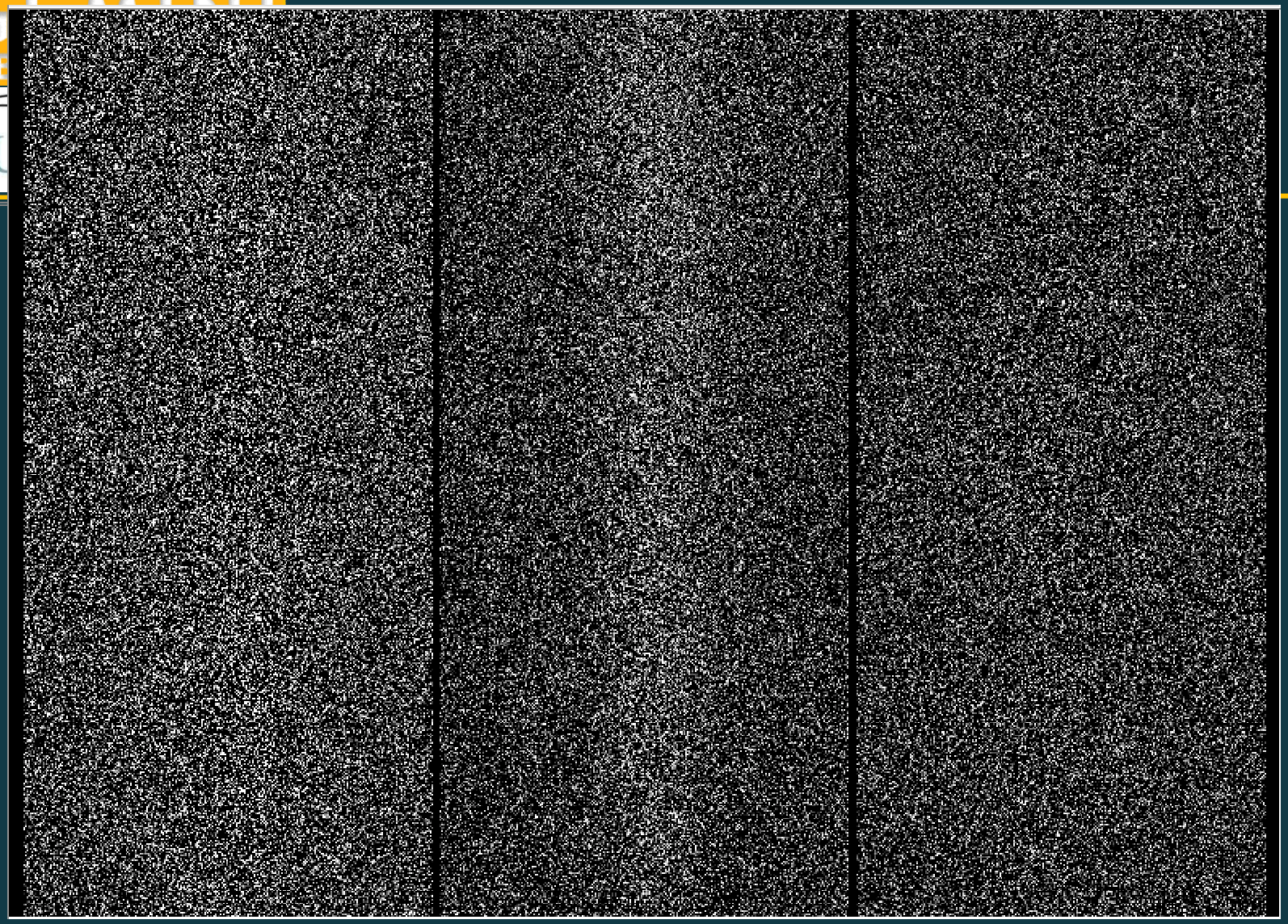




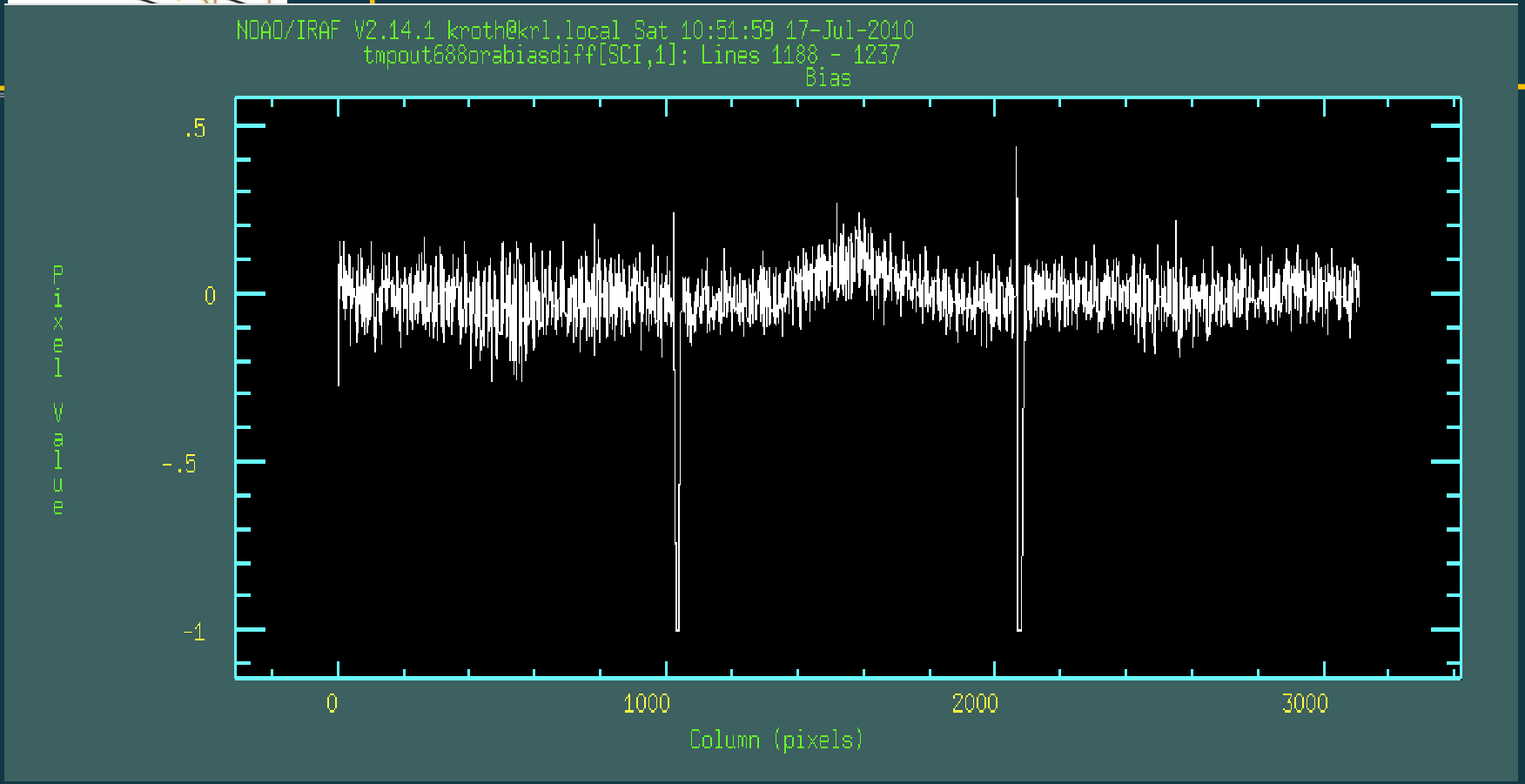
Column plot (CCD1) for reduced combined 2x1 bias, 50 lines averaged.



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 ~ 1.5 months separated by ~ 2 months



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

Flatfield Correction

- 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+)

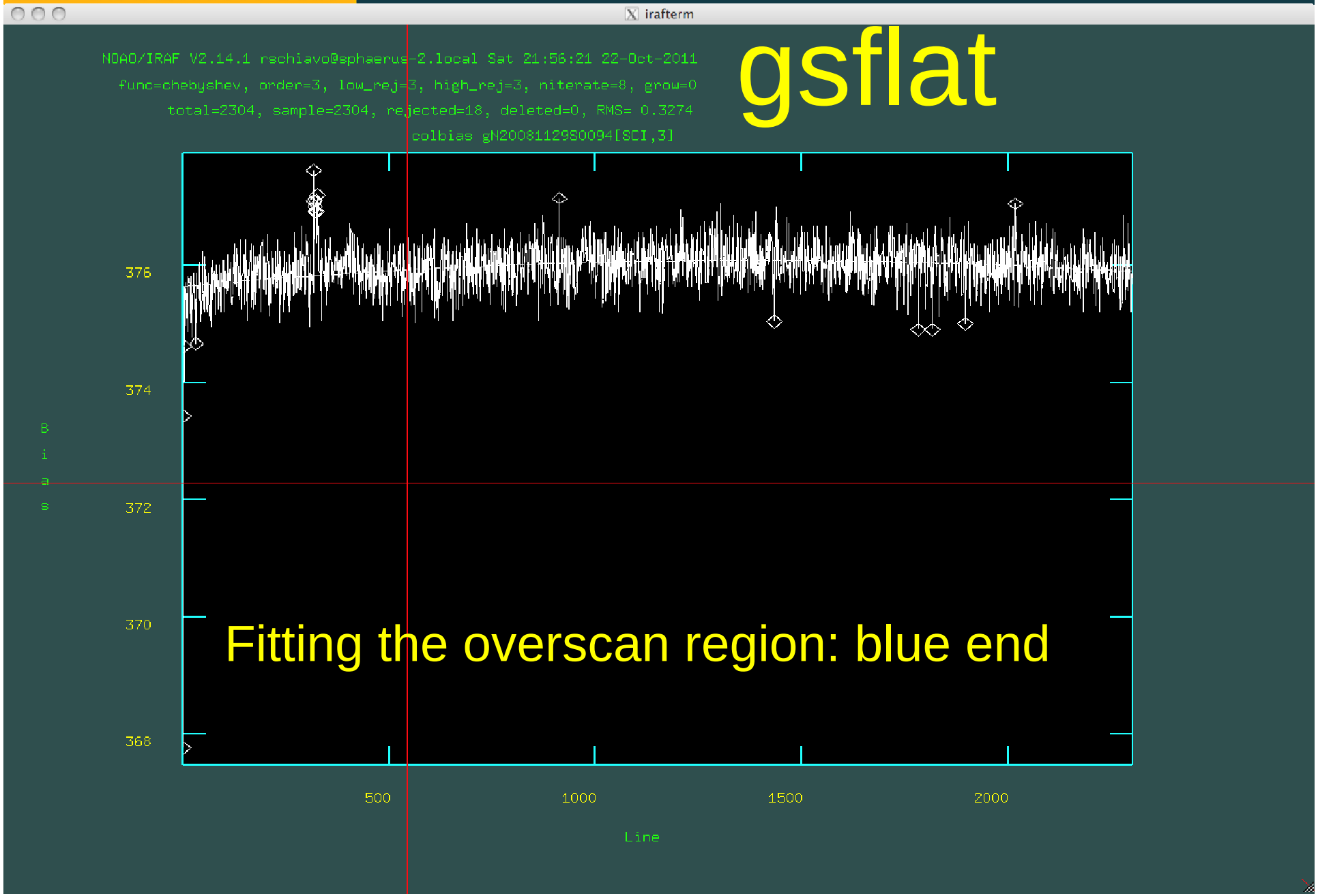
@flatfiles_460: text file containing list of flat field files
Flat_460.fits: name of output flat image
fl_dark-: do not subtract a dark image
fl_fixpix-: do not fix pixels in the gaps (cannot do this with fl_detect+)
fl_inter+: examine fits to spectral shape interactively
chebyshev: type of polynomial to use in fits to spectral shape
order=18: order of polynomial fit to spectral shape (varies from case to case)

gsflat

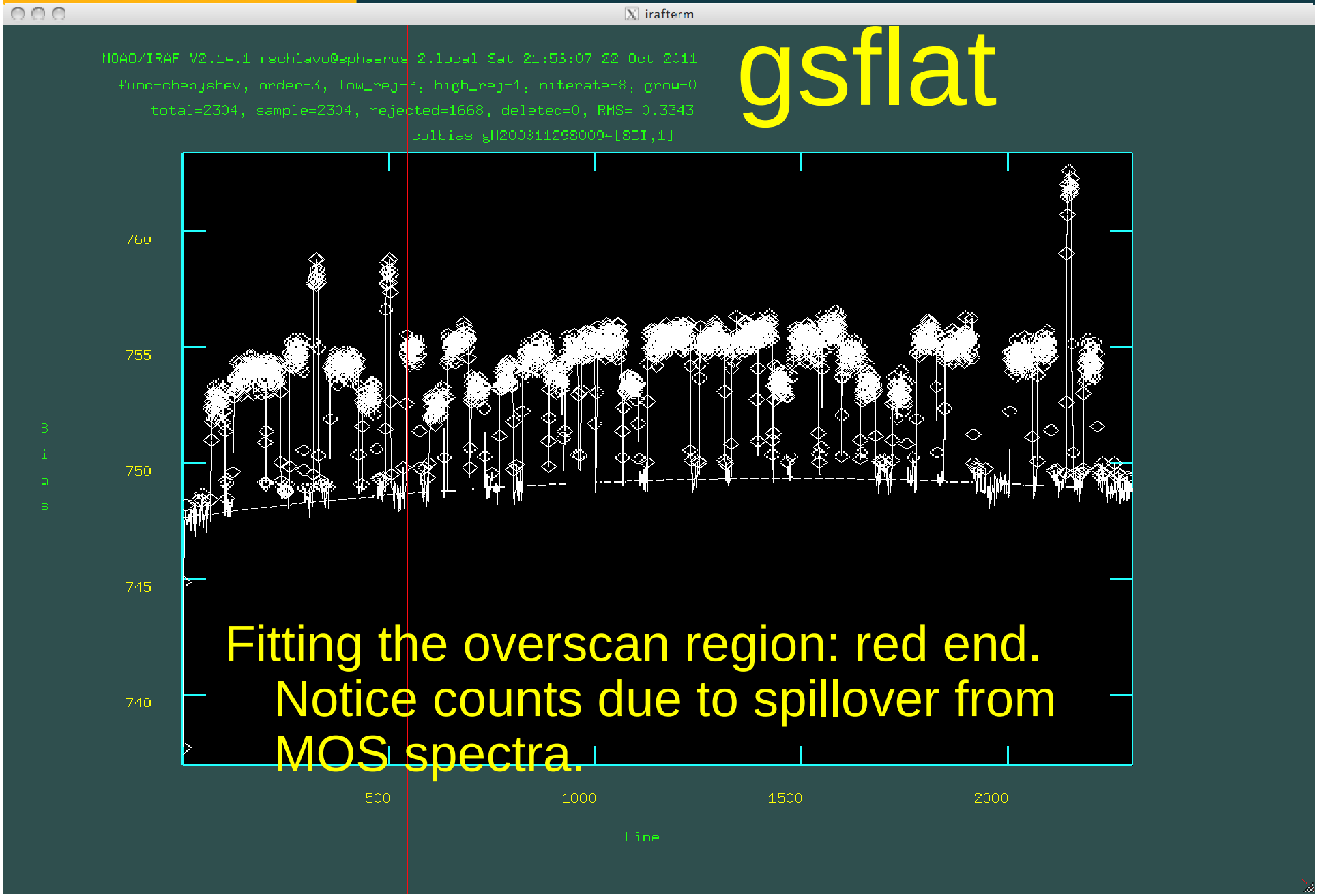
gsflat @flatfiles_460 out=Flat_460.fits
logfile=gmos.logfile rawpath="rawdata$"
fl_over+ fl_trim+ nbiascontam=4
fl_bias+ bias="sciencebias" fl_dark-
fl_fixpix- fl_inter+,function="chebyshev"
order=15 fl_detec+ ovs_flinter+ fl_vardq+)

fl_detec+: do not mosaic, fit each detector independently
ovs_flinter+: examine fits to overscan region interactively

GEMINI OBSERVATORY



GEMINI OBSERVATORY



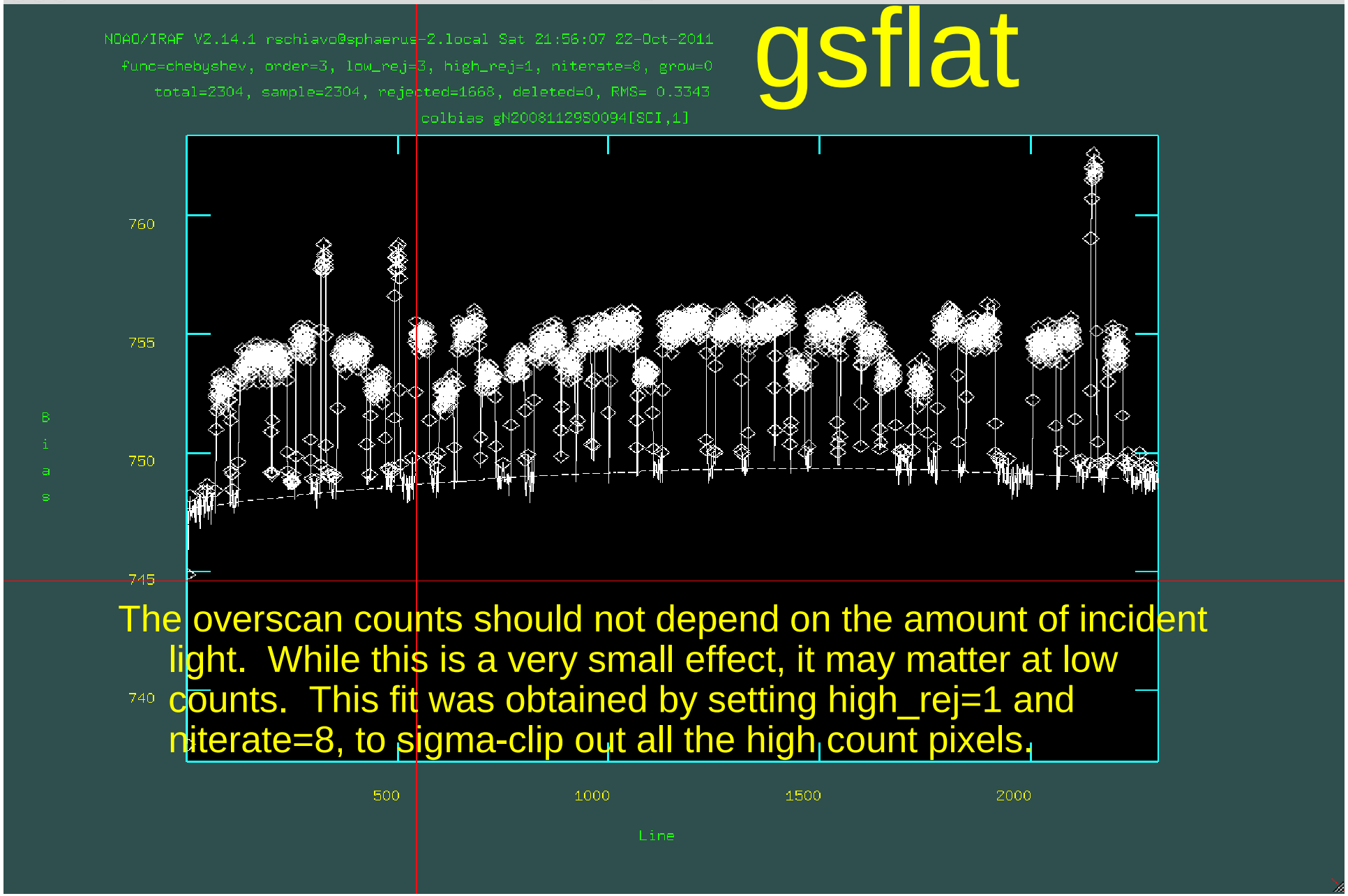
gsflat

Fitting the overscan region: red end. Notice counts due to spillover from MOS spectra.

GEMINI OBSERVATORY

irafterm

gsflat



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.

GEMINI OBSERVATORY

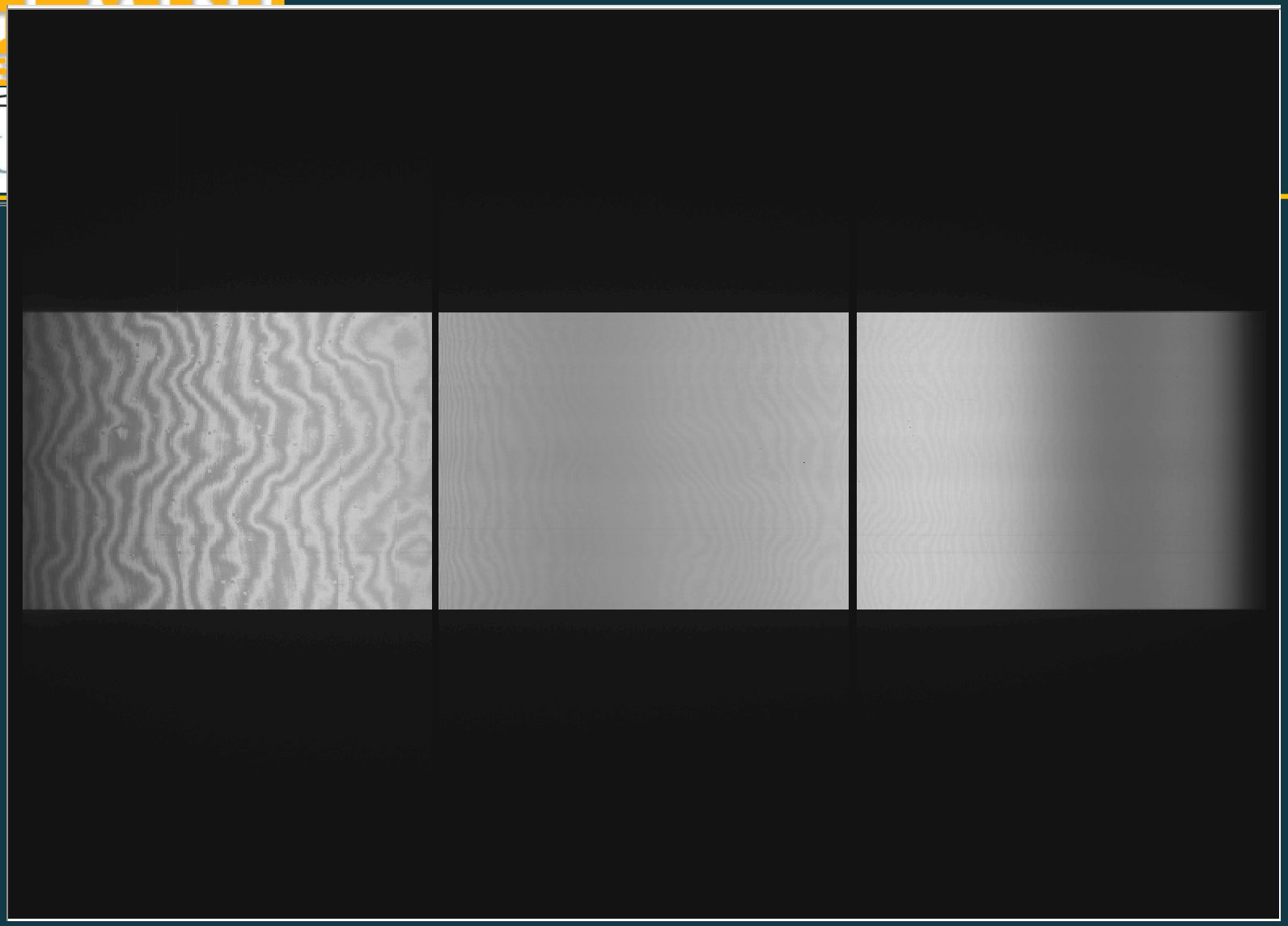
irafterm

gsflat

NOAO/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

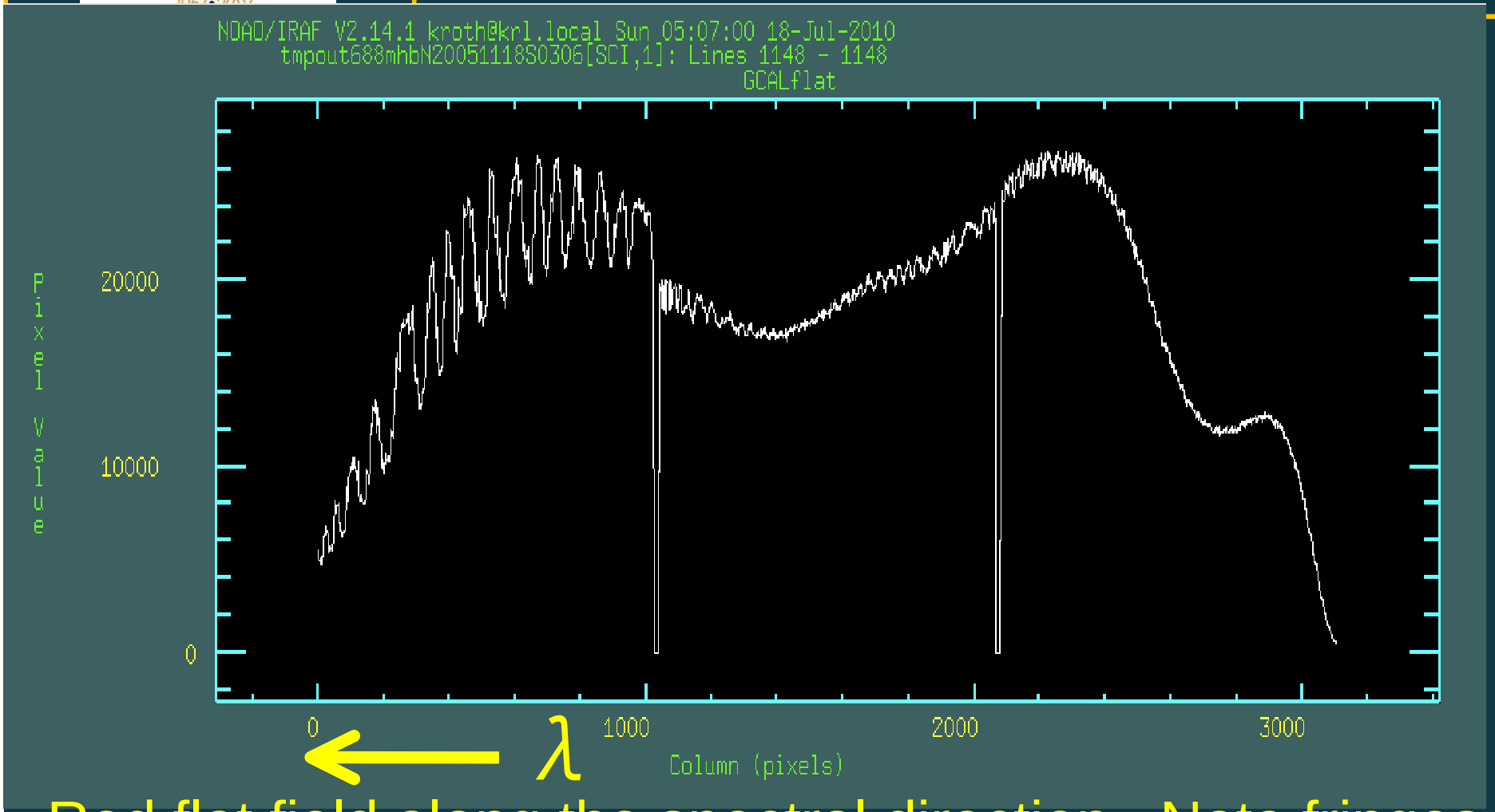
Fitting the “response” function: blue spectral region.

$\leftarrow \lambda$



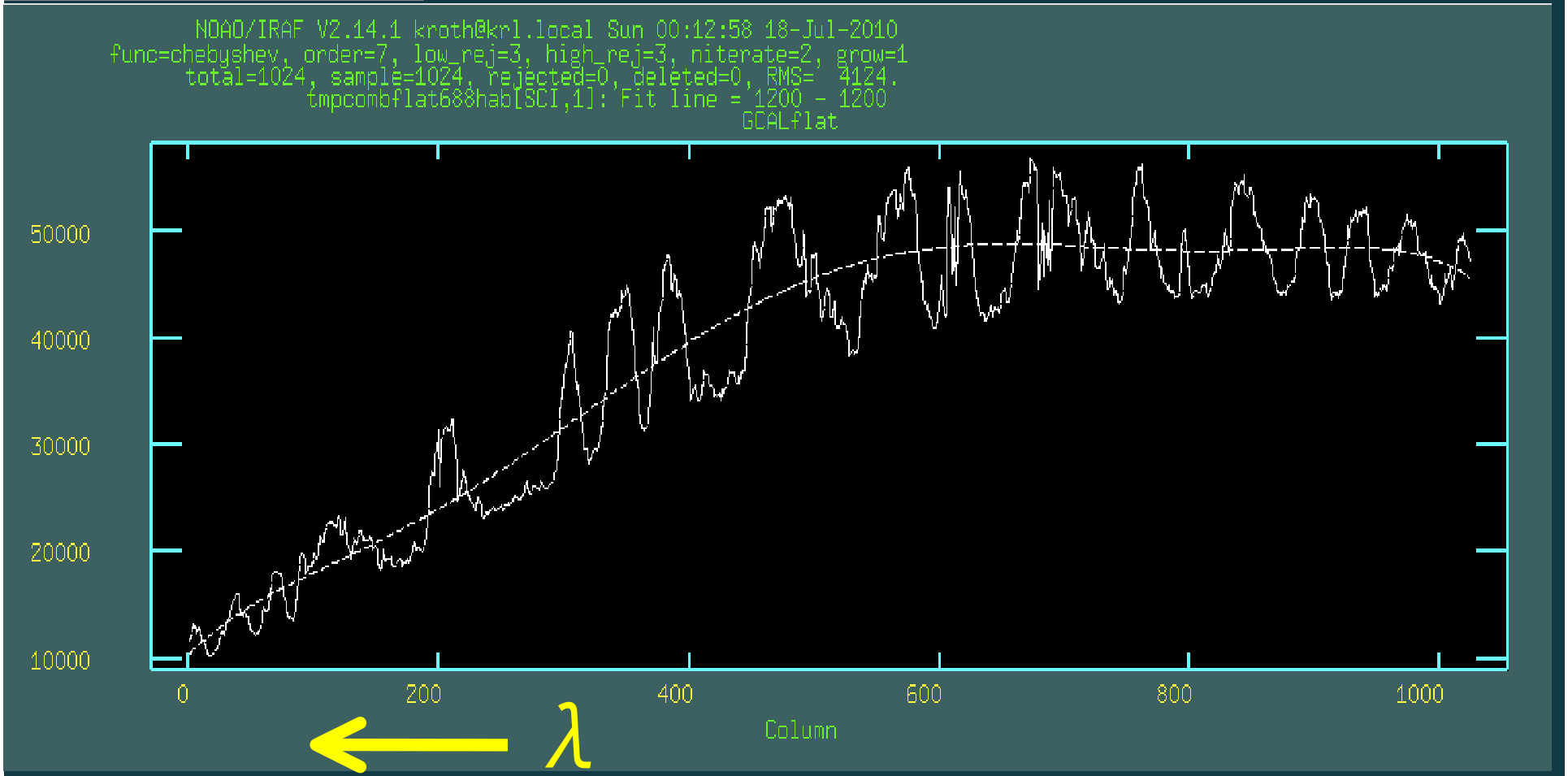
Raw GCALflat R400 spectral flat, 810nm, NS0.75arcsec longslit.
GCALflats are not shuffled, and do not inherit the NODPIX header keyword parameter of the associated science exposures.

gsflat



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

gsflat

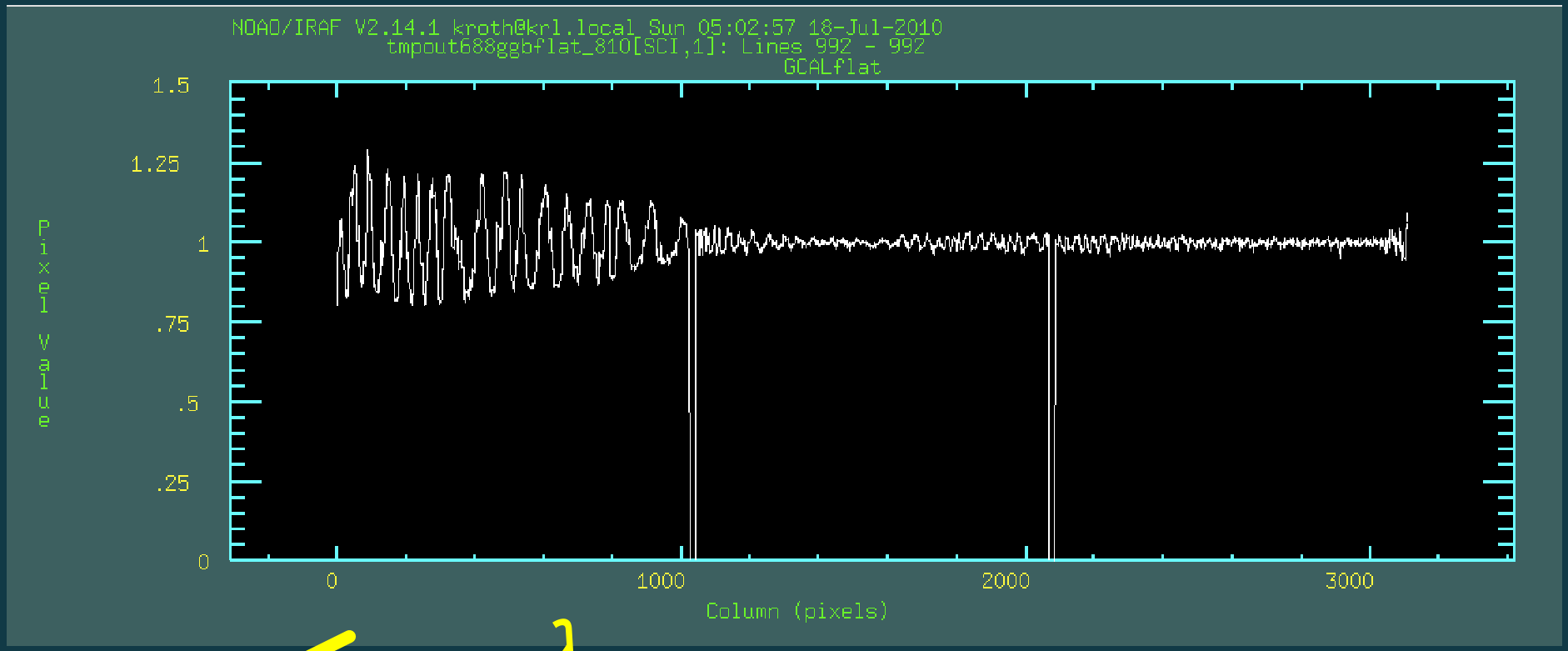


Fitting the “response” function in the red. Low polynomial order to avoid fitting the fringe pattern.

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

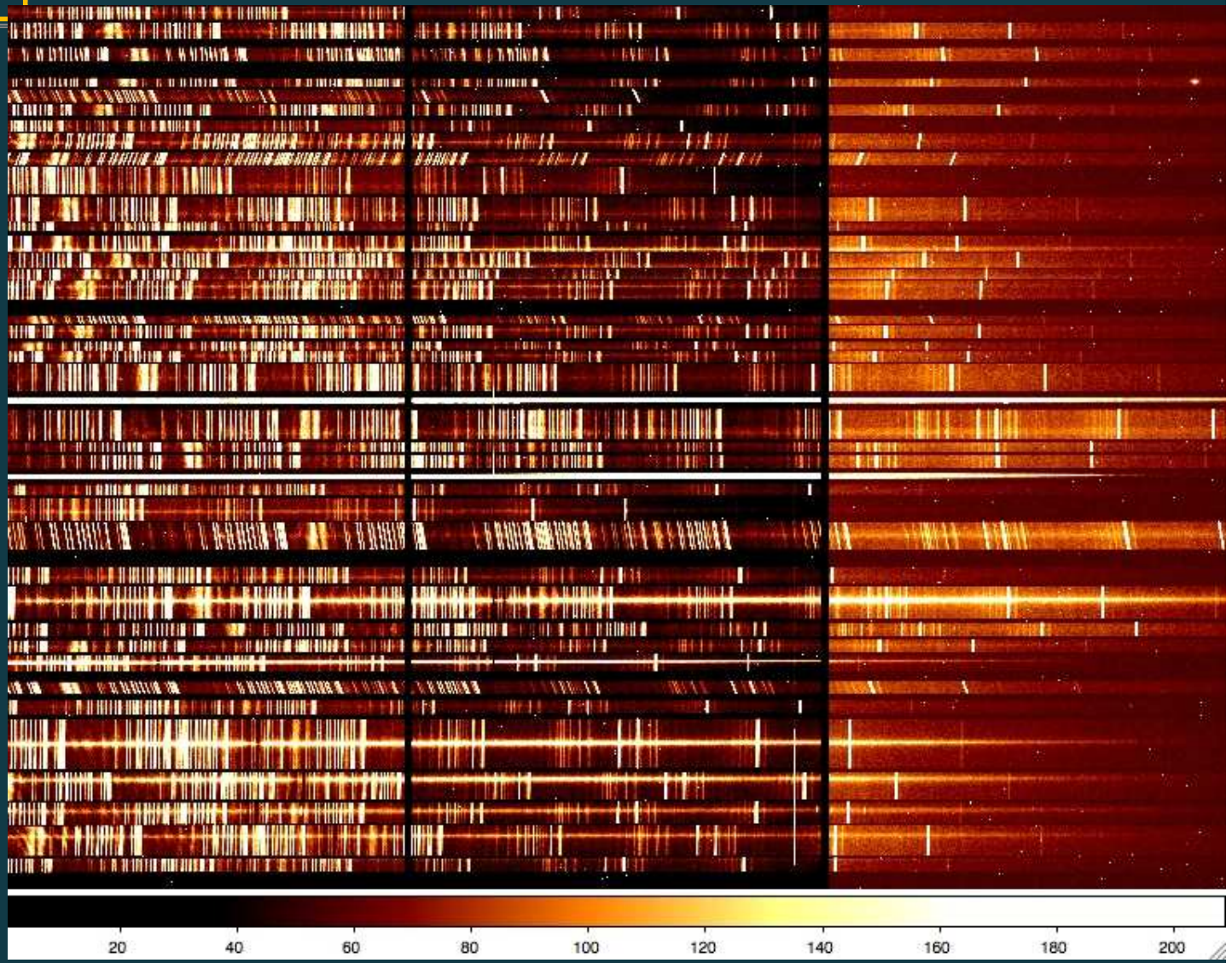


λ

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+ mdfdir=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

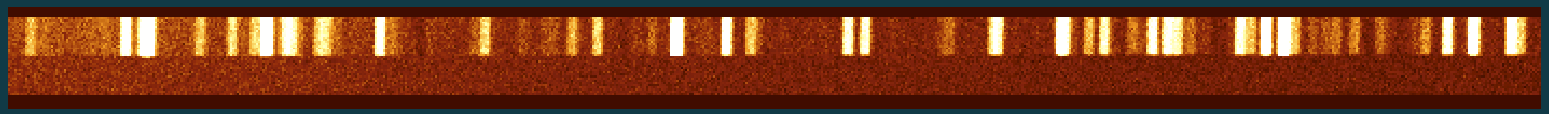
fl_cut+: cut the slit spectra into separate extensions (superfluous for longslit)

mdfdir/file: name of directory location and name of fits file containing slit-mask definition (required if fl_cut+)

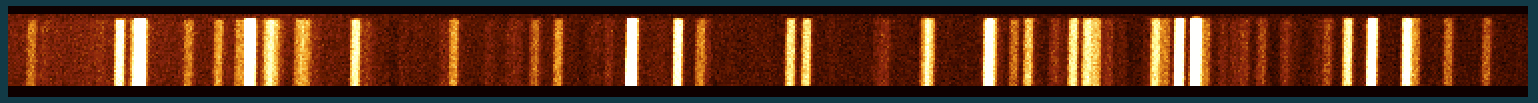
ovs_flinter+: examine fits to overscan region interactively

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

gswavelenth @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

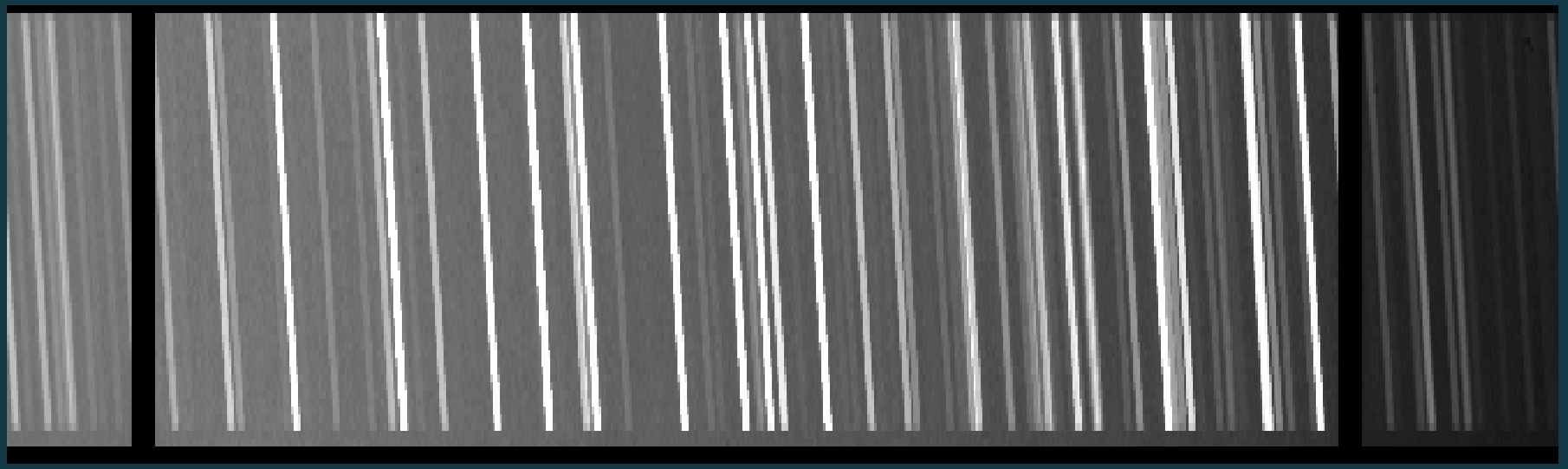
function: function fitted to wavelength vs. pixel relation

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

fitxcord=6: order of fit in x direction

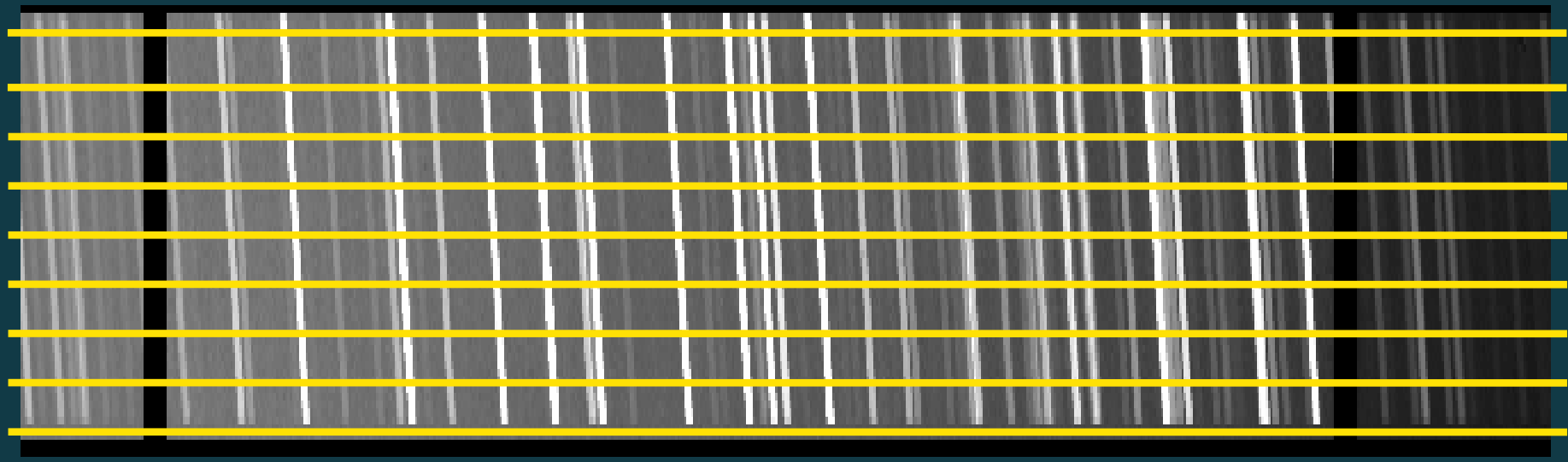
fitcyord=4: order of fit in y direction

gswavelength



Determine wavelength solution
along spatial direction

gswavelength



Determine wavelength solution for arc spectra along lines separated by nstep pixels. Each arc spectrum obtained by summing nsum adjacent lines

gswavelength

gswavelenth @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

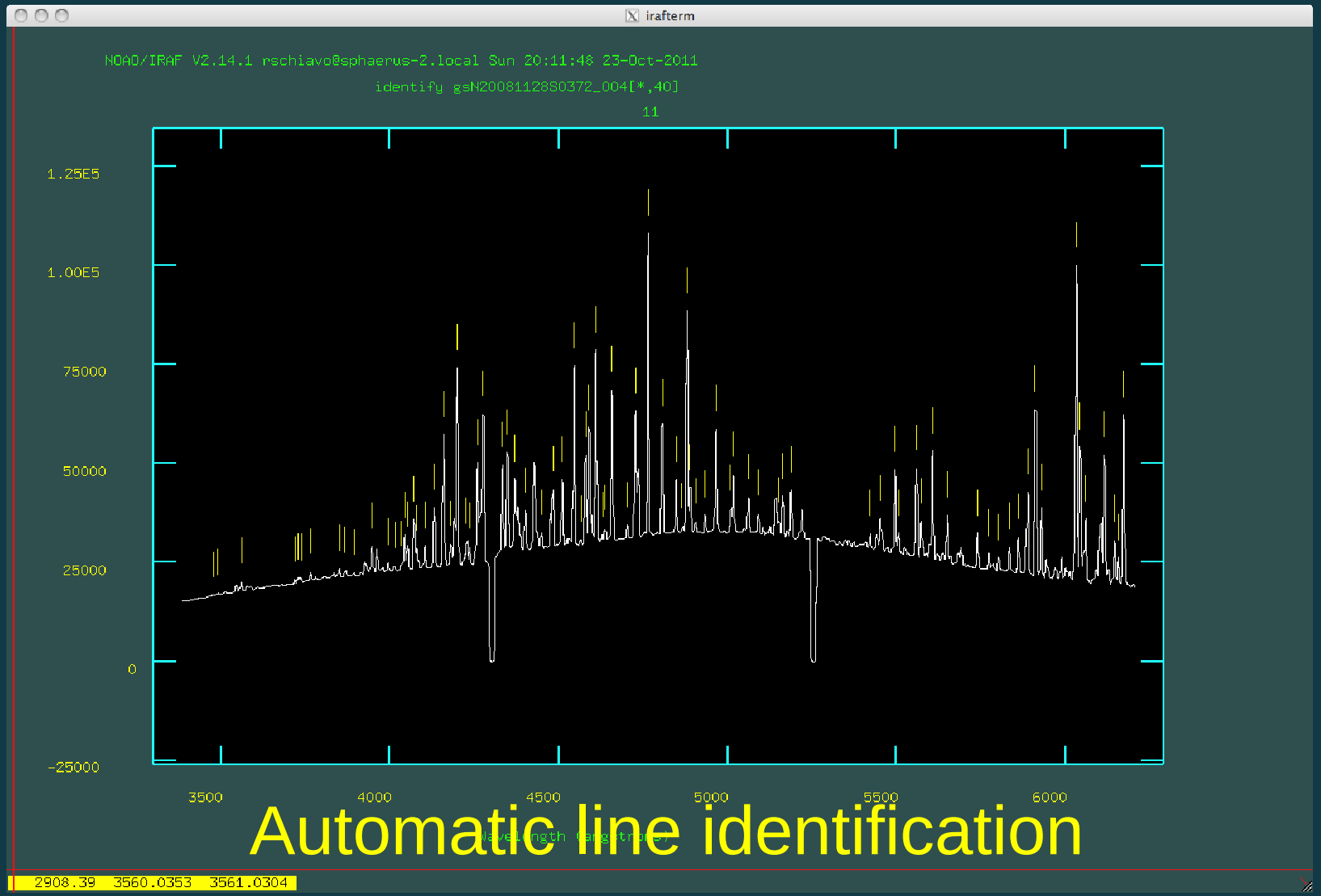
function: function fitted to wavelength vs. pixel relation

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

fitxcord=6: order of fit in x direction

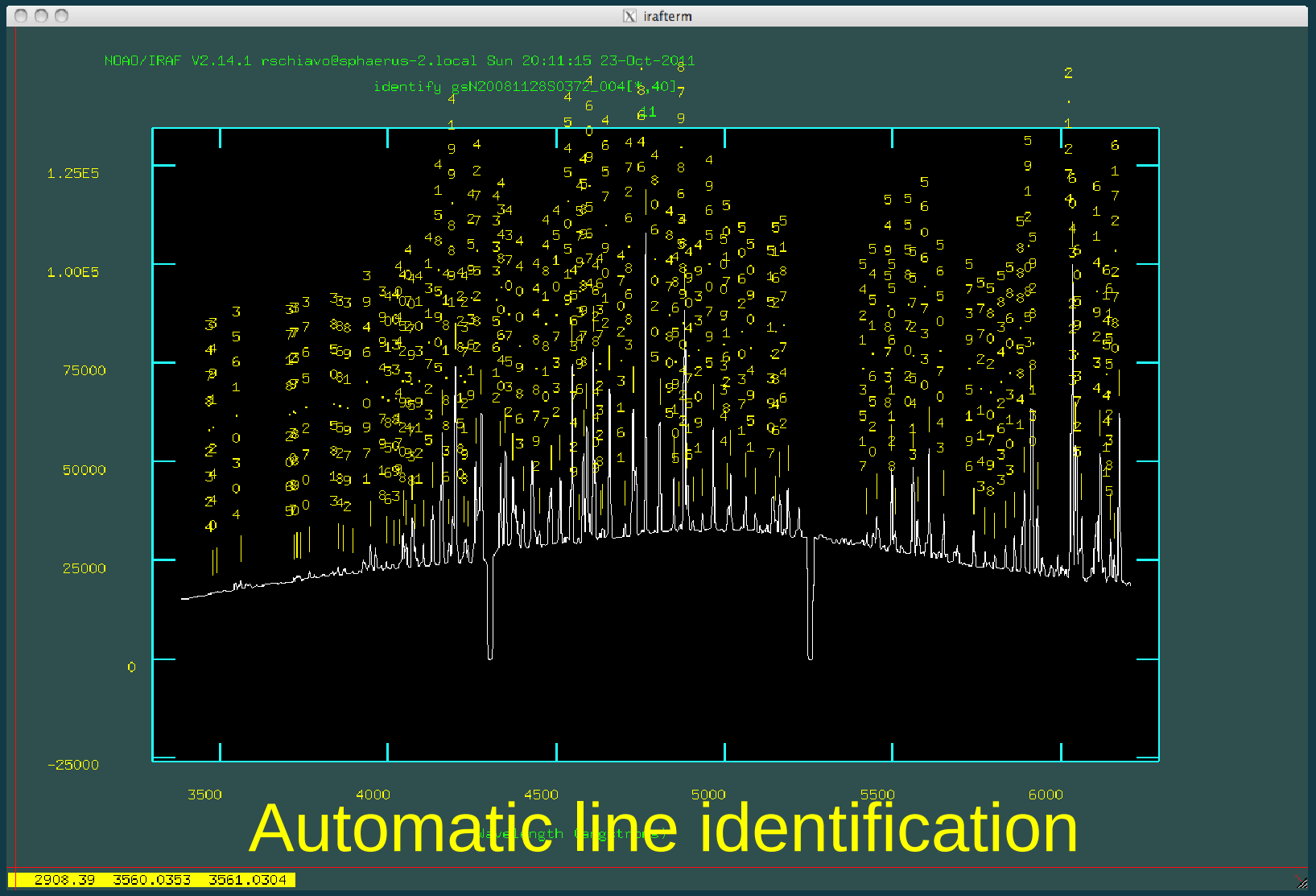
fitcyord=4: order of fit in y direction

gswavelength



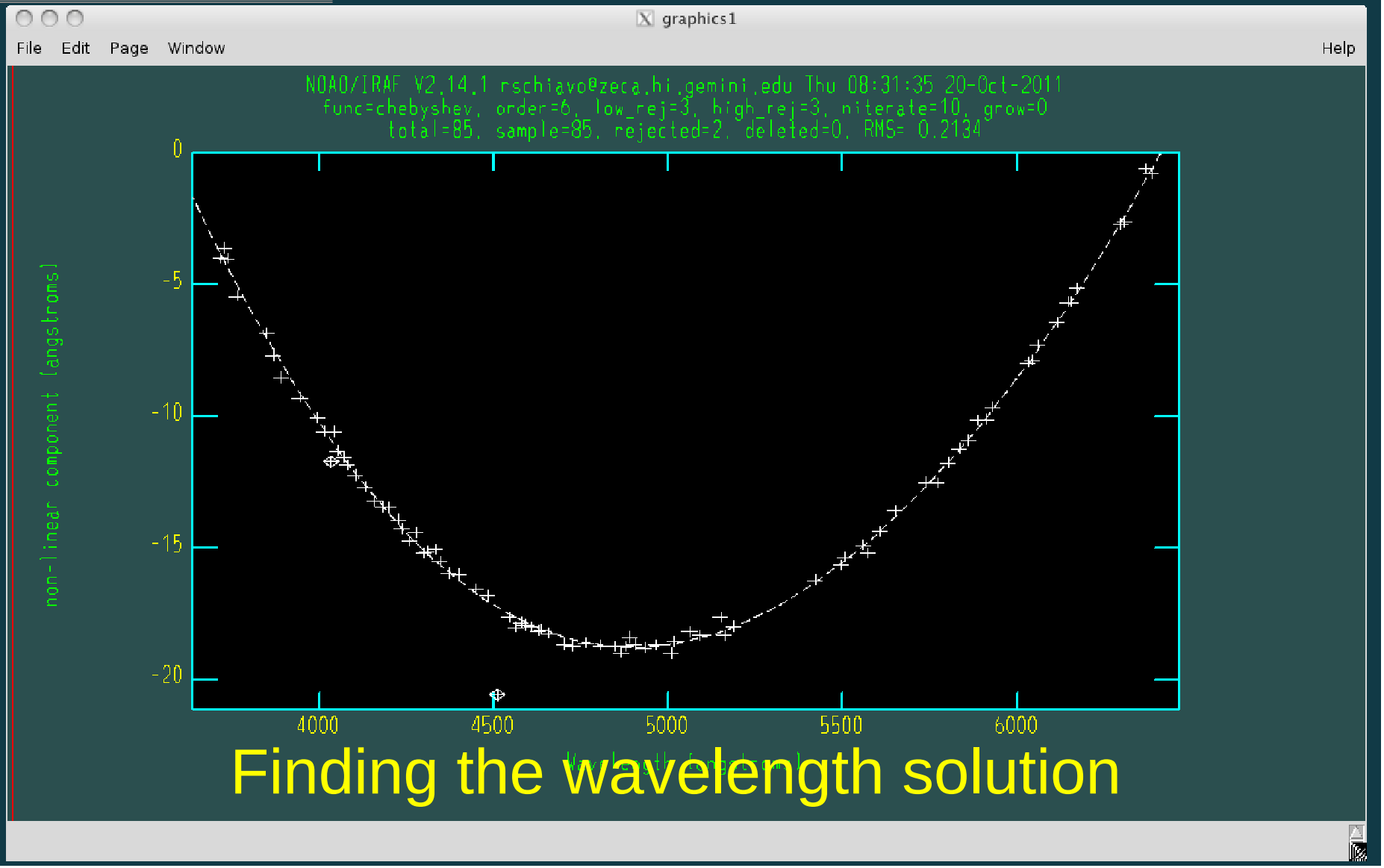
Automatic line identification

gswavelength



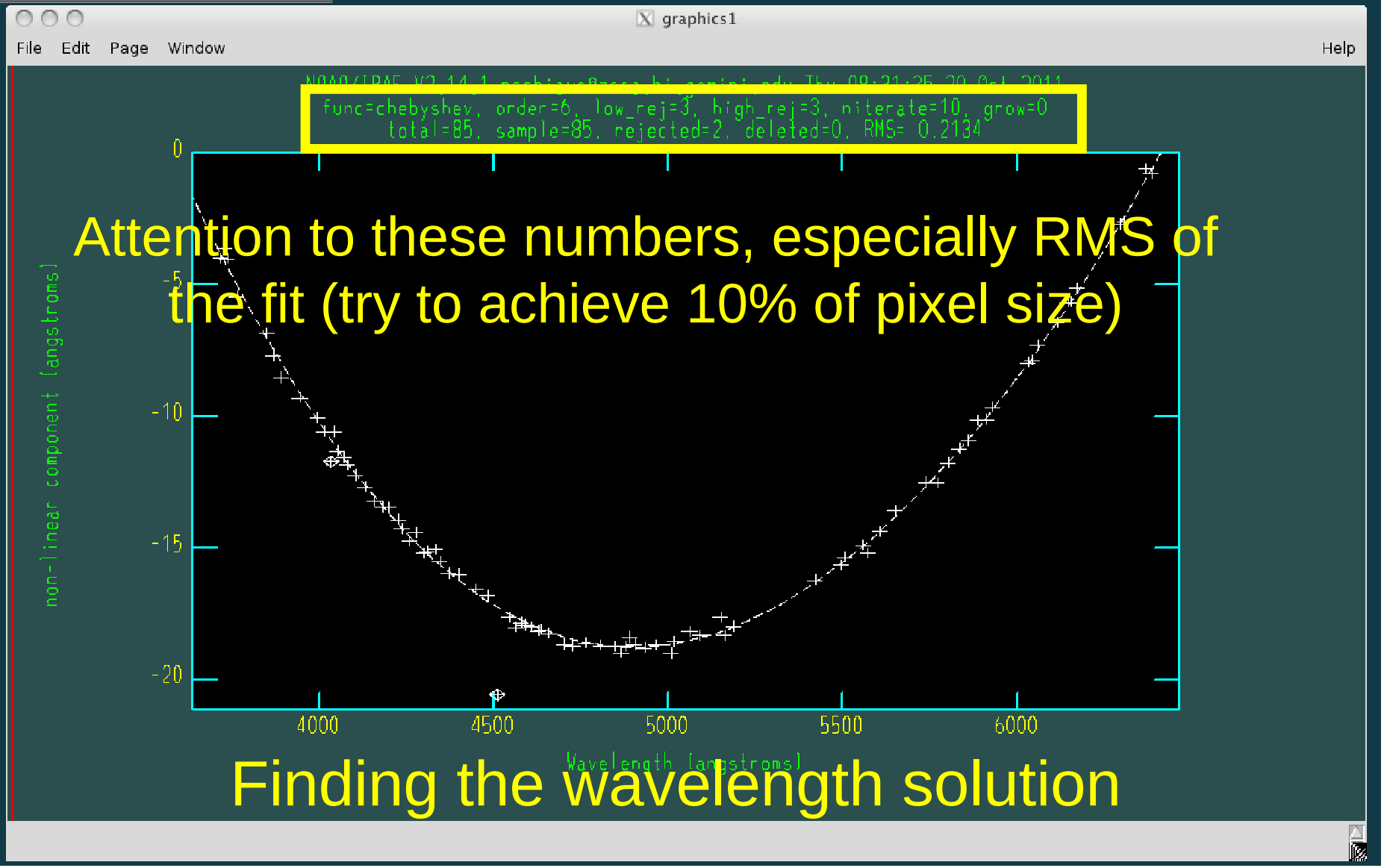
Automatic line identification

gswavelength



Finding the wavelength solution

gswavelength



Attention to these numbers, especially RMS of the fit (try to achieve 10% of pixel size)

Finding the wavelength solution

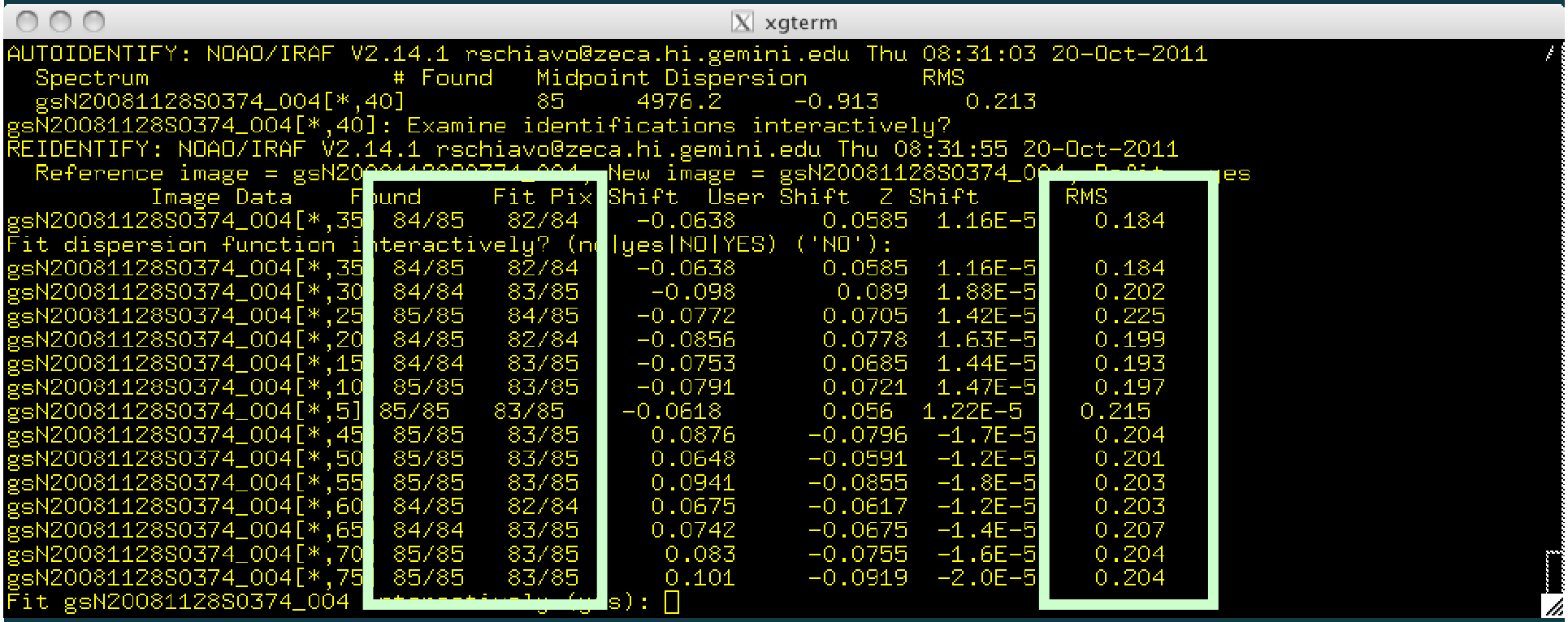
gswavelength

xgterm

```
AUTOIDENTIFY: NOAO/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: NOAO/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):
```

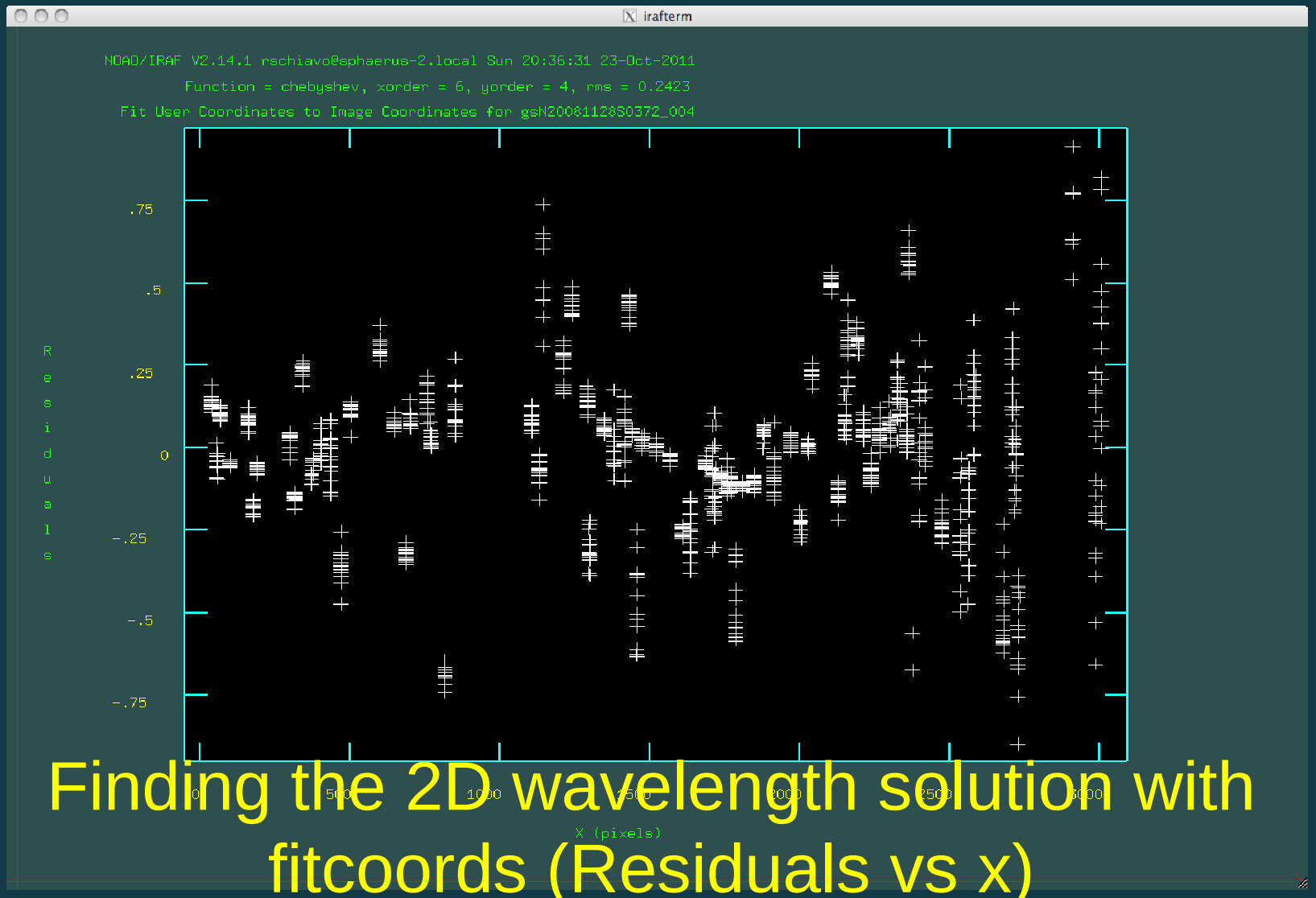
Output after fitting wavelength solution

gswavelength



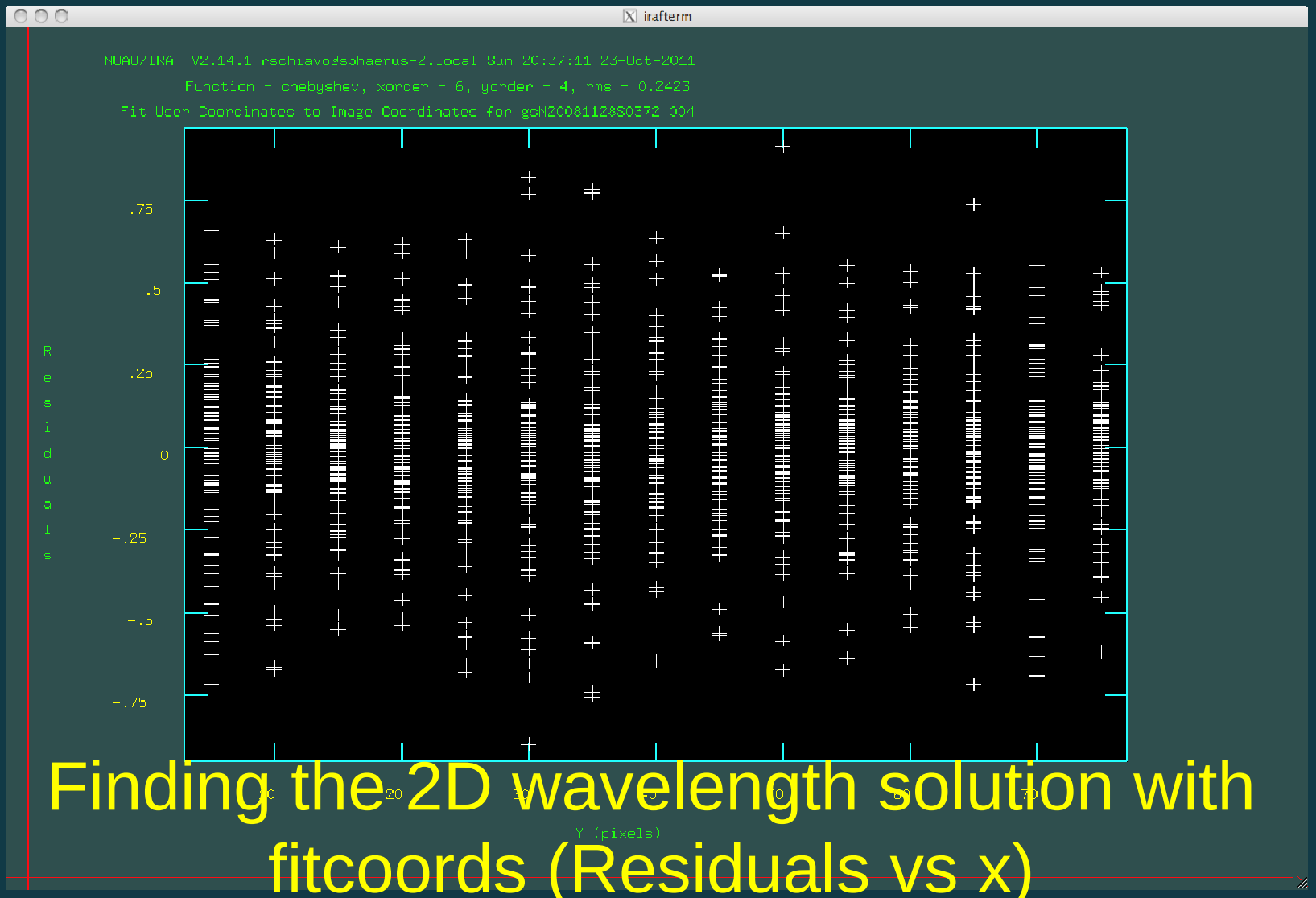
Attention to rms and number of lines used in solutions for various spectra

gswavelength



Finding the 2D wavelength solution with fitcoords (Residuals vs x)

gswavelength



Finding the 2D wavelength solution with fitcoords (Residuals vs x)

gstransform

gstransform gsNarcfile.fits wavetraname=gsNarcfile.fits

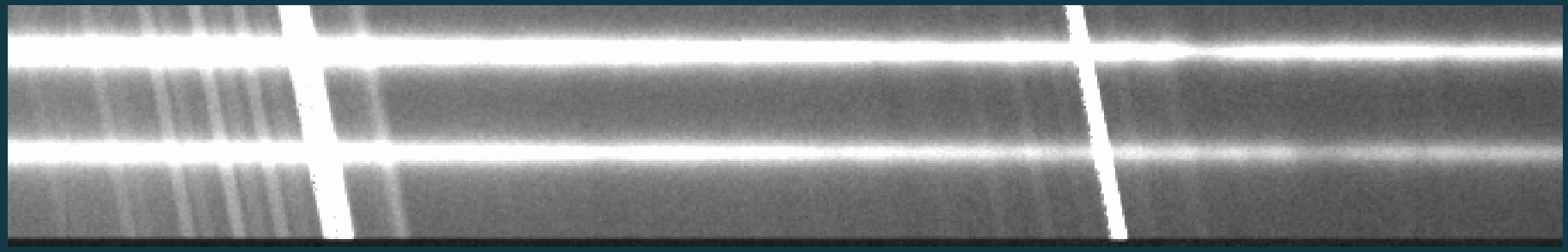
gstransform @gsNsciencefile wavetraname=gsNarcfile.fits
fl_vardq+

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

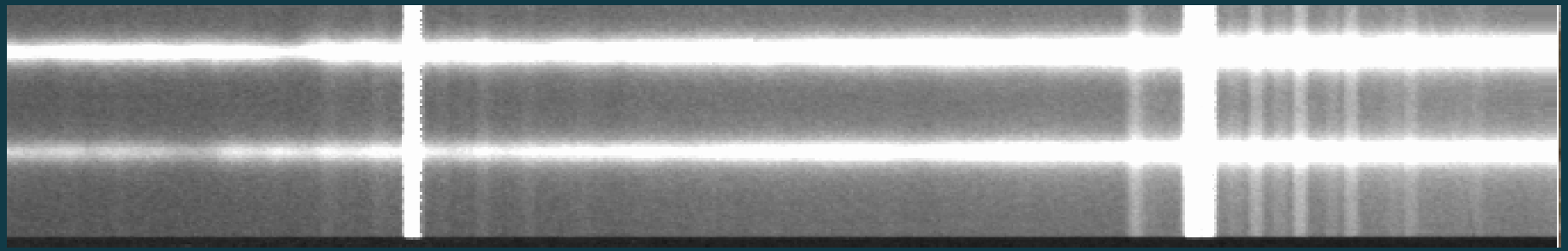
@gsNsciencefile: list of science files associated with arc file “gsNarcfile.fits”

gstransform

Original tilted spectrum (pixel scale)



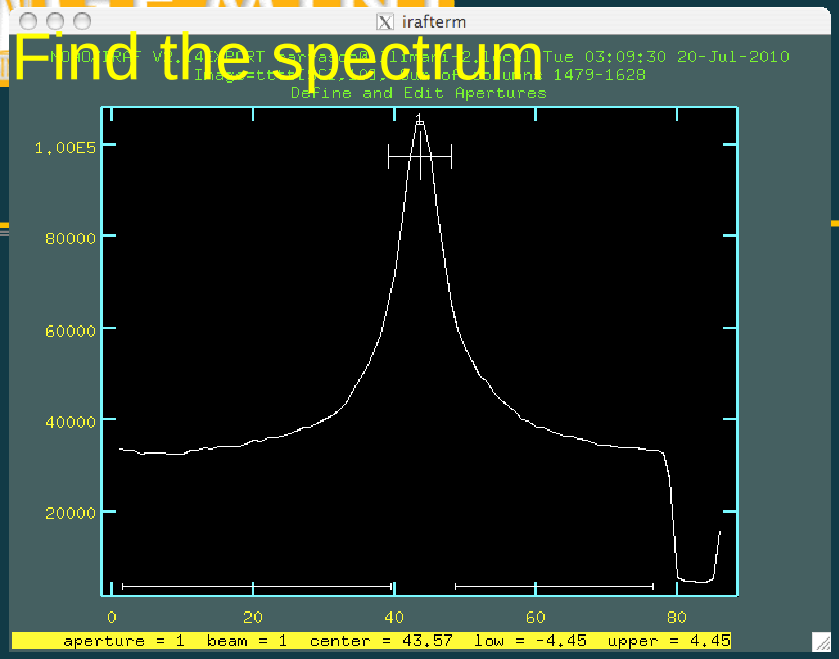
“gtransformed” spectrum (wavelength scale)



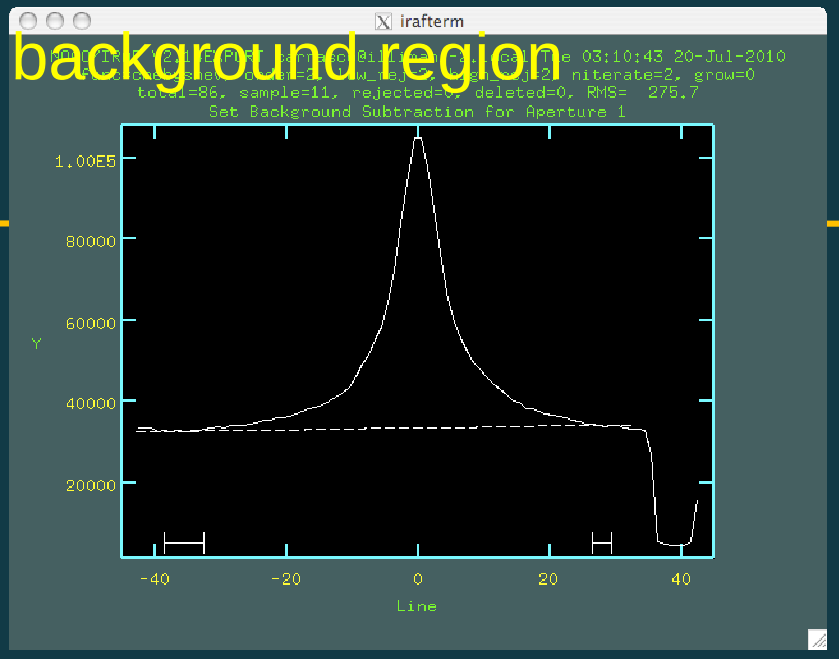
gsextract

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

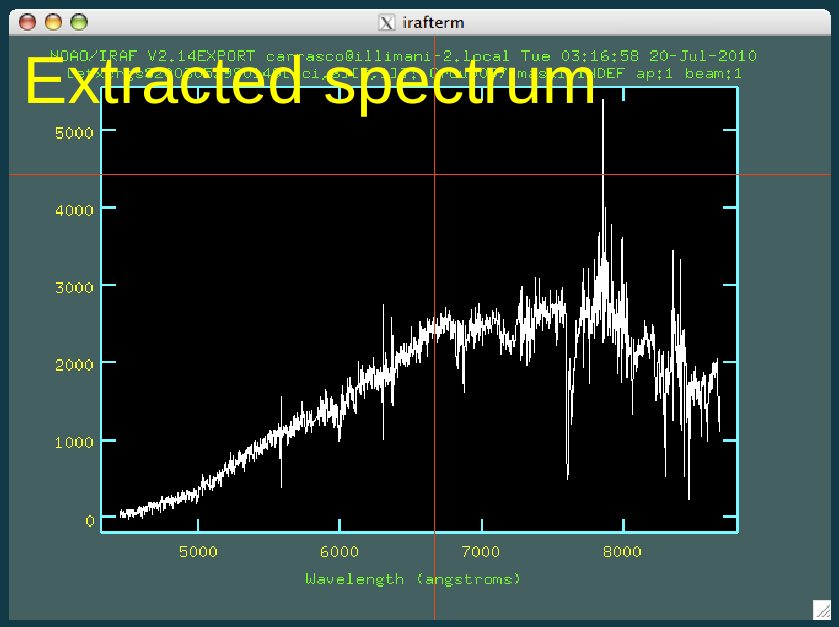
@tgsNsciencefiles: list of "gtransformed" science spectra
find+: find spectra automatically
back=fit: subtract the fit to the background region
trace+: trace spectra
b/tfunct: function to fit to background/trace
b/torder: order of function to fit to background/trace
tnsum: number of dispersion lines 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



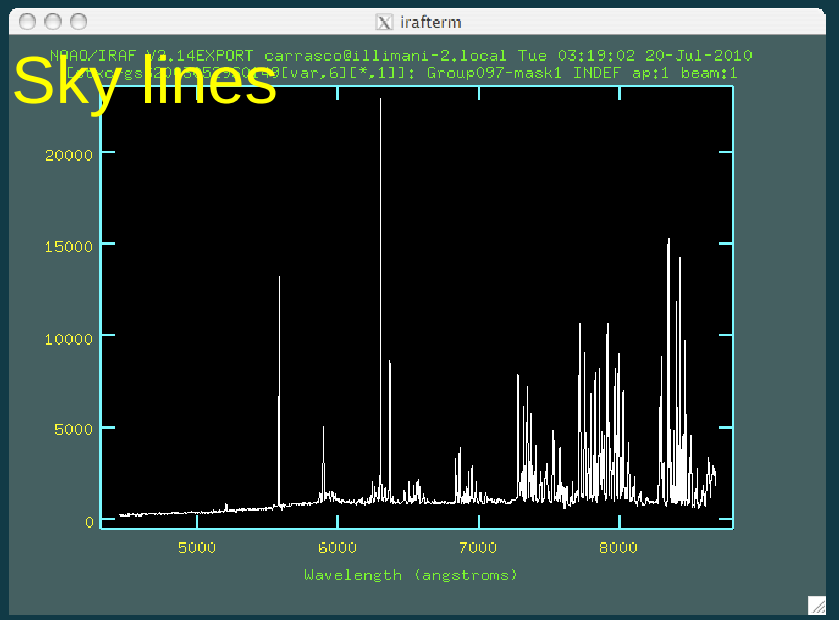
Find the spectrum



background region

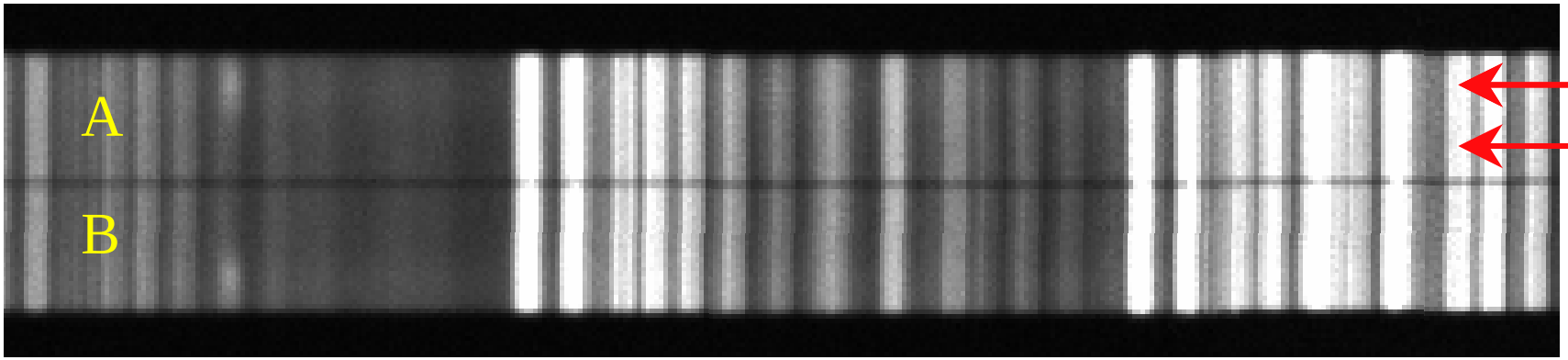


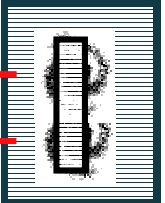
Extracted spectrum



Sky lines

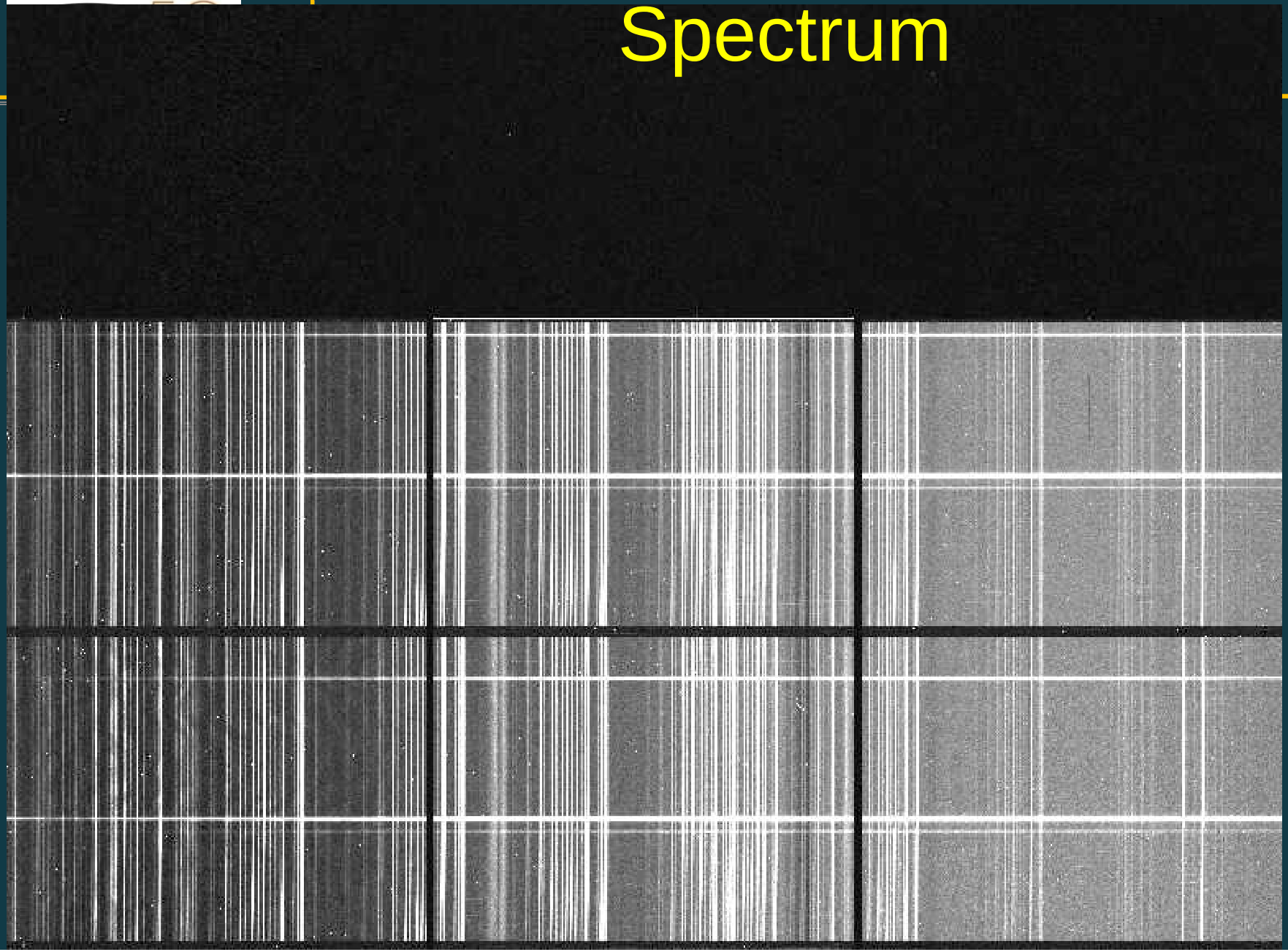
Sky cancellation: Nod & Shuffle Demonstration



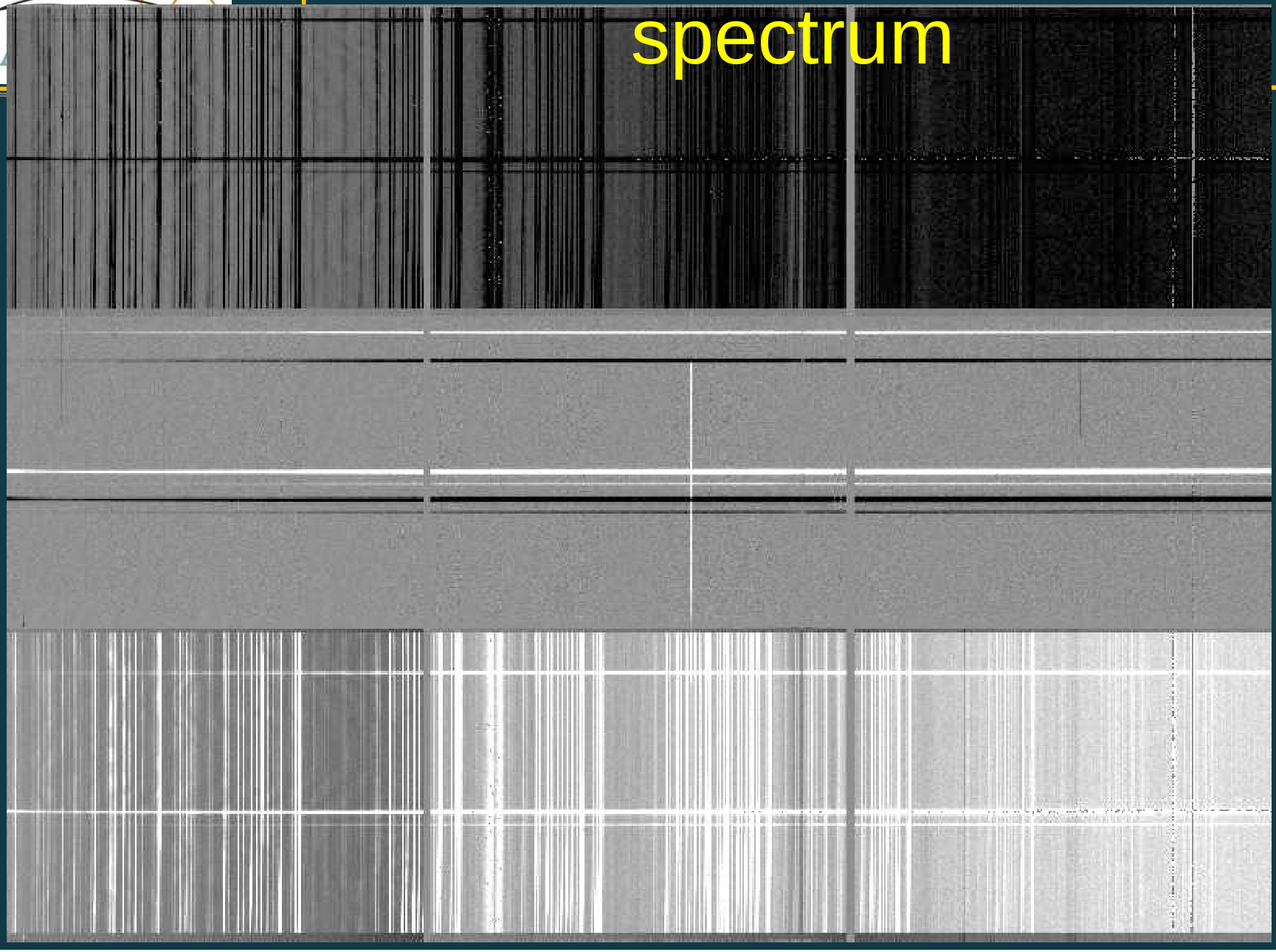


Typically A=60s/15 cy: 1800s exposure $\Rightarrow 10^{-3}$ subtraction

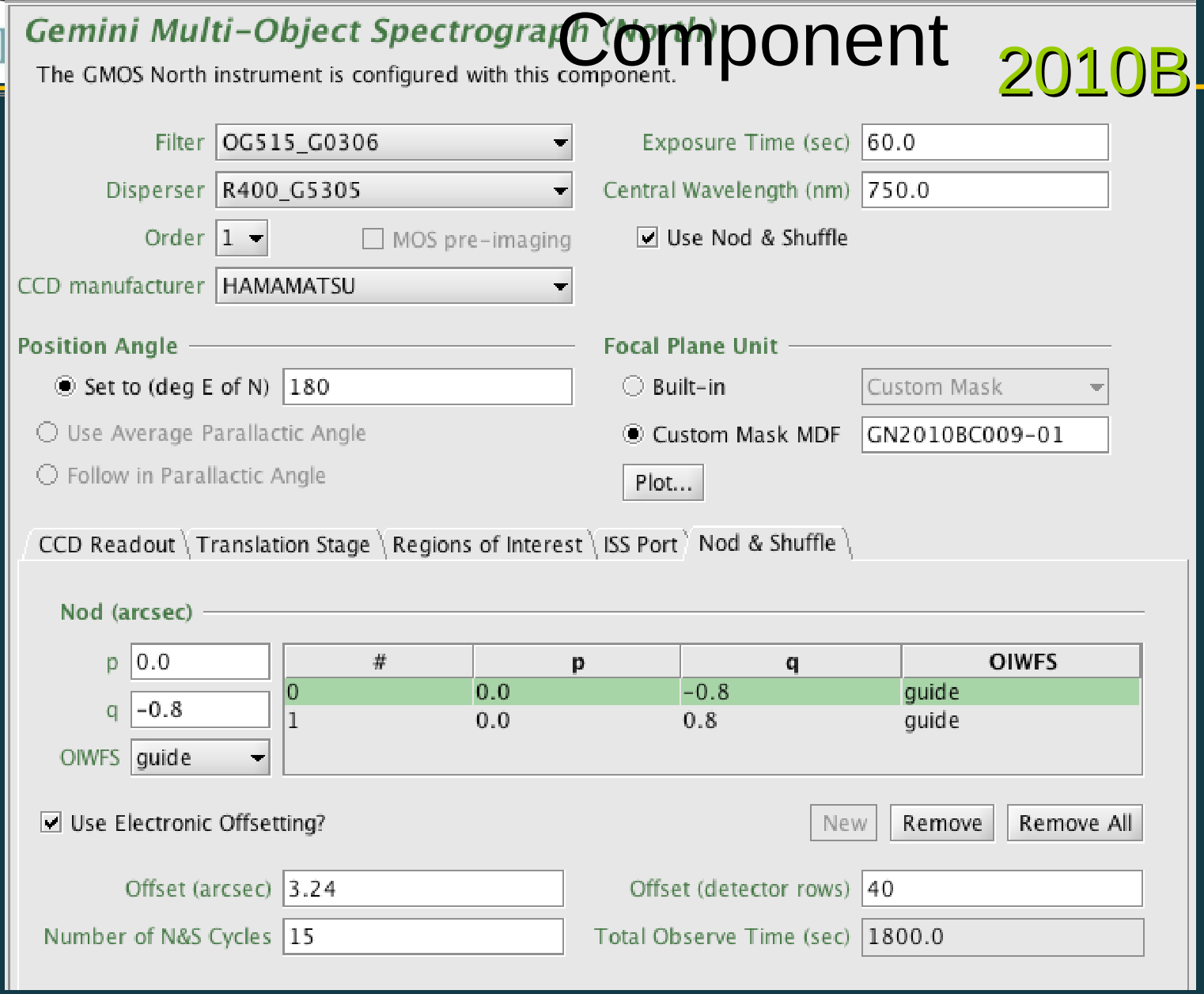
Raw Longslit N&S Spectrum



Reduced Longslit spectrum



Observing Tool N&S Component 2010B



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

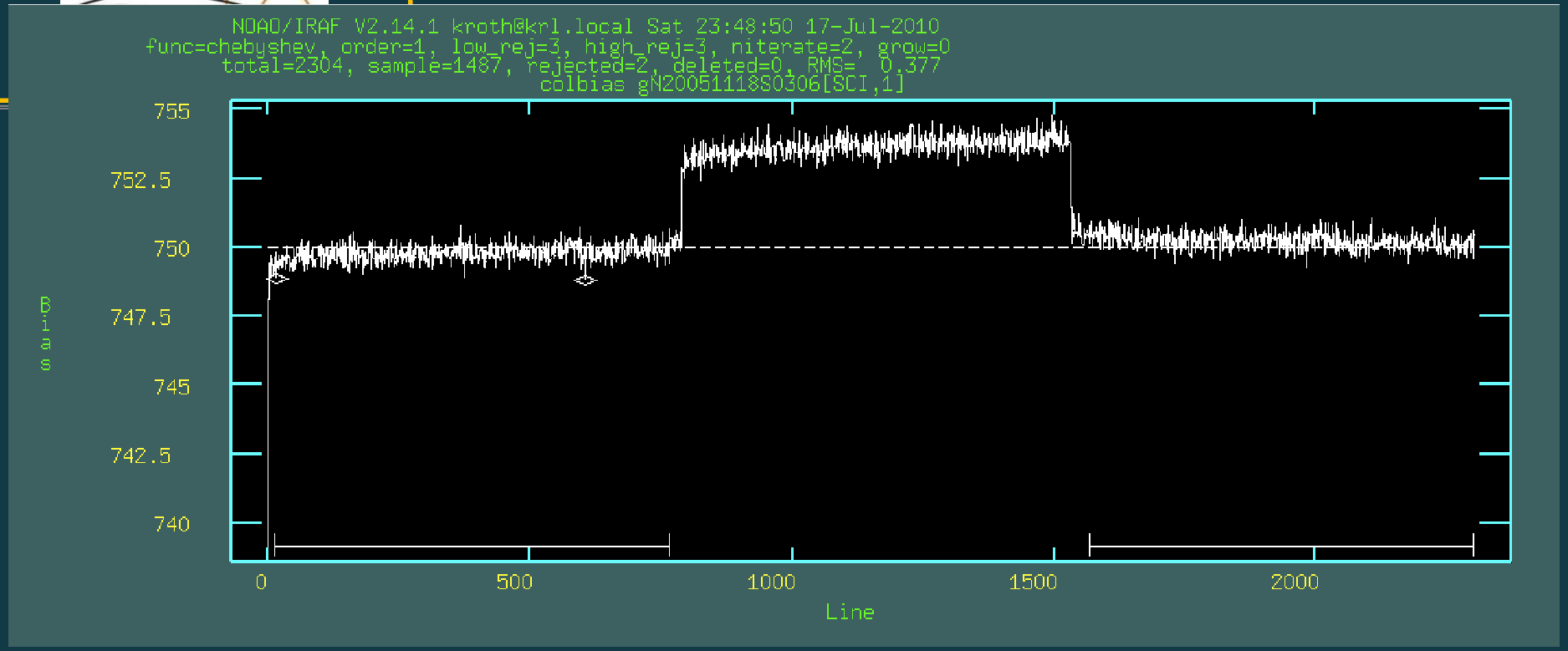
gnsdark @darklist ”Nsdark” logfile=gmos.logfile
rawpath="rawdata$” fl_over+ fl_trim+
nbiascontam=4 fl_bias+ bias=“darkbias”
fl_inter+ fl_vardq+)

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

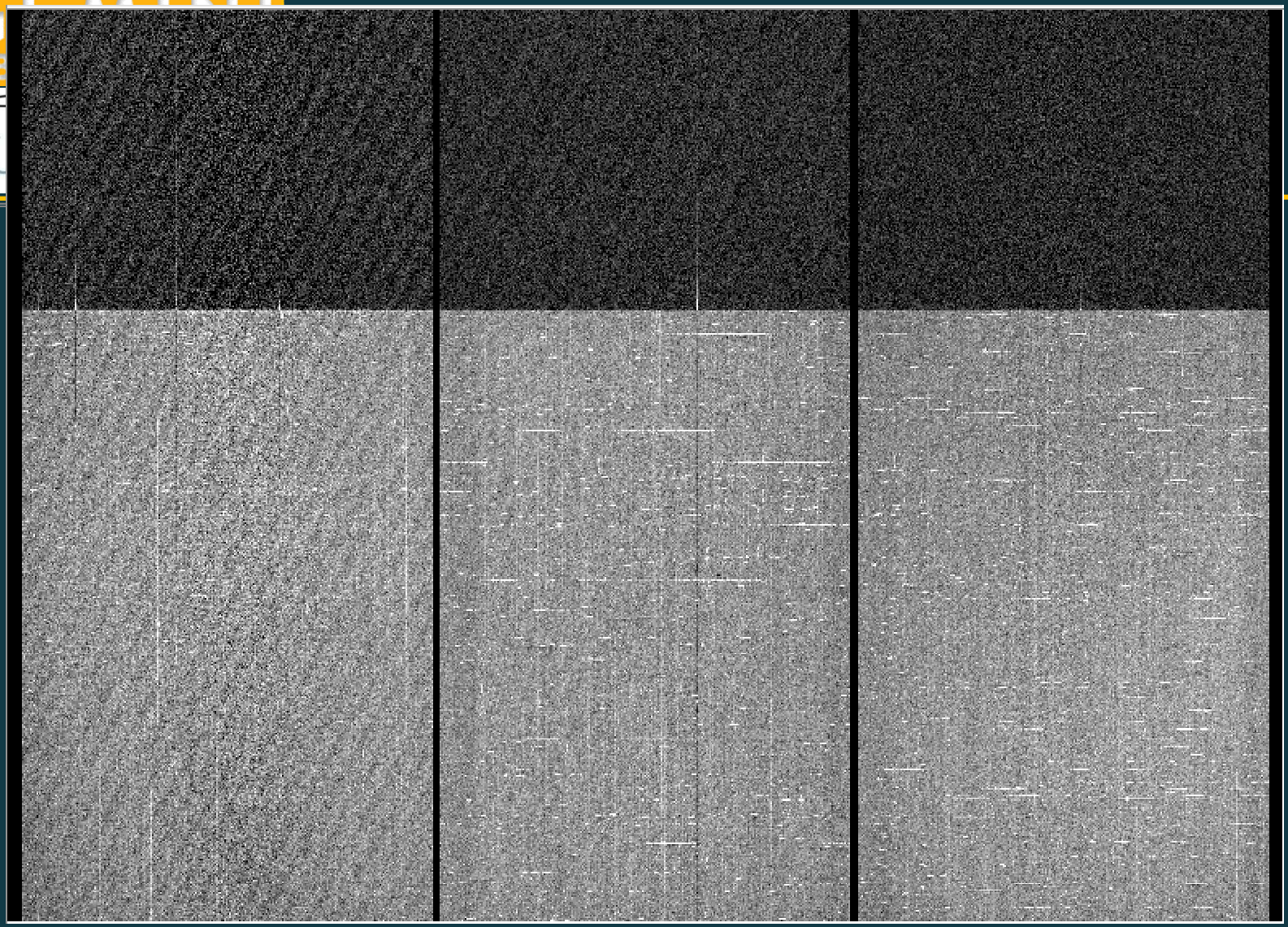
NSdark: name of output combined dark image

fl_bias+: subtract a bias image

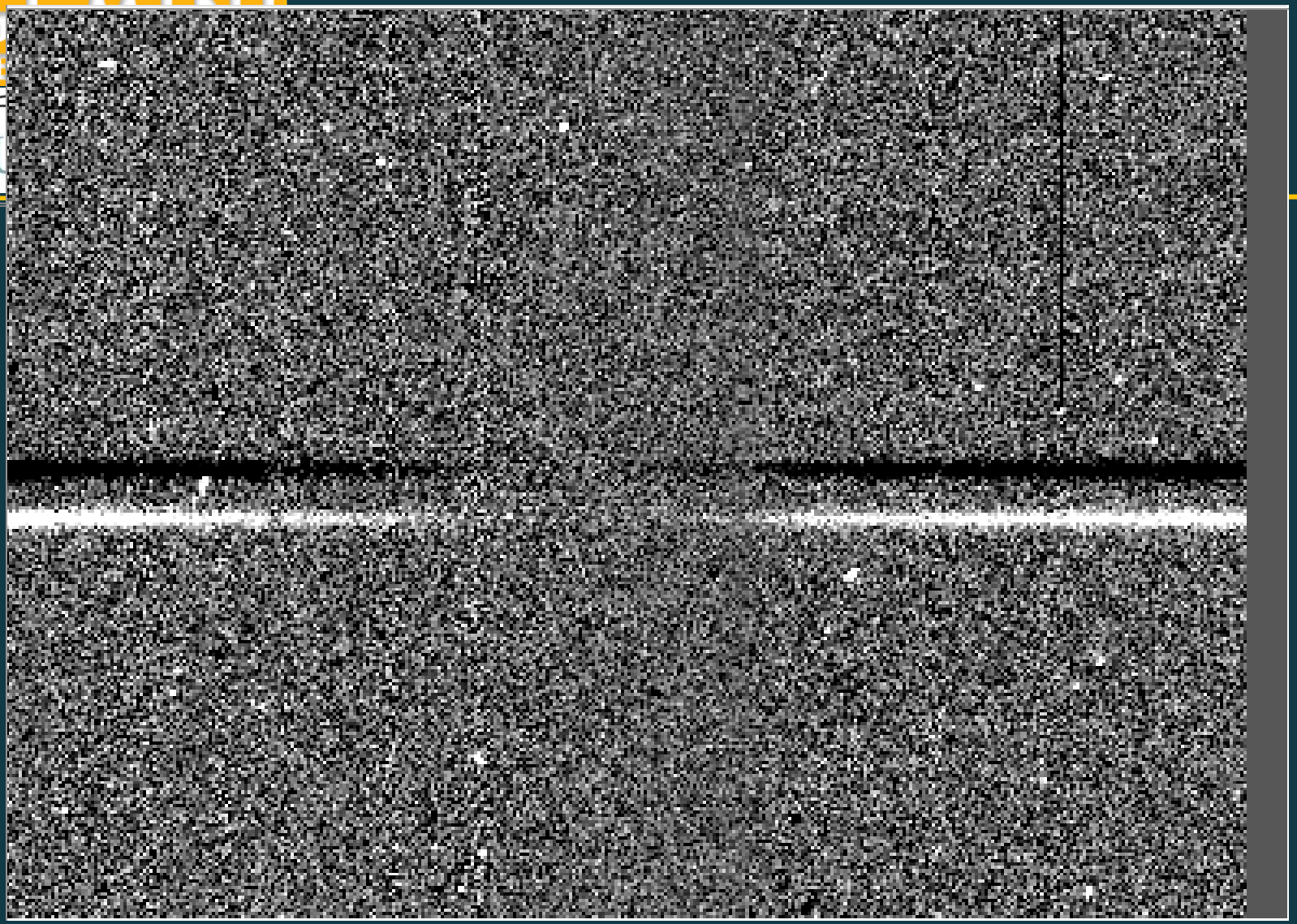
Bias=“darkbias”: name of the bias images to use



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 ⇒ 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 ⇒ flat cannot be gmosaic'd ⇒ 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)

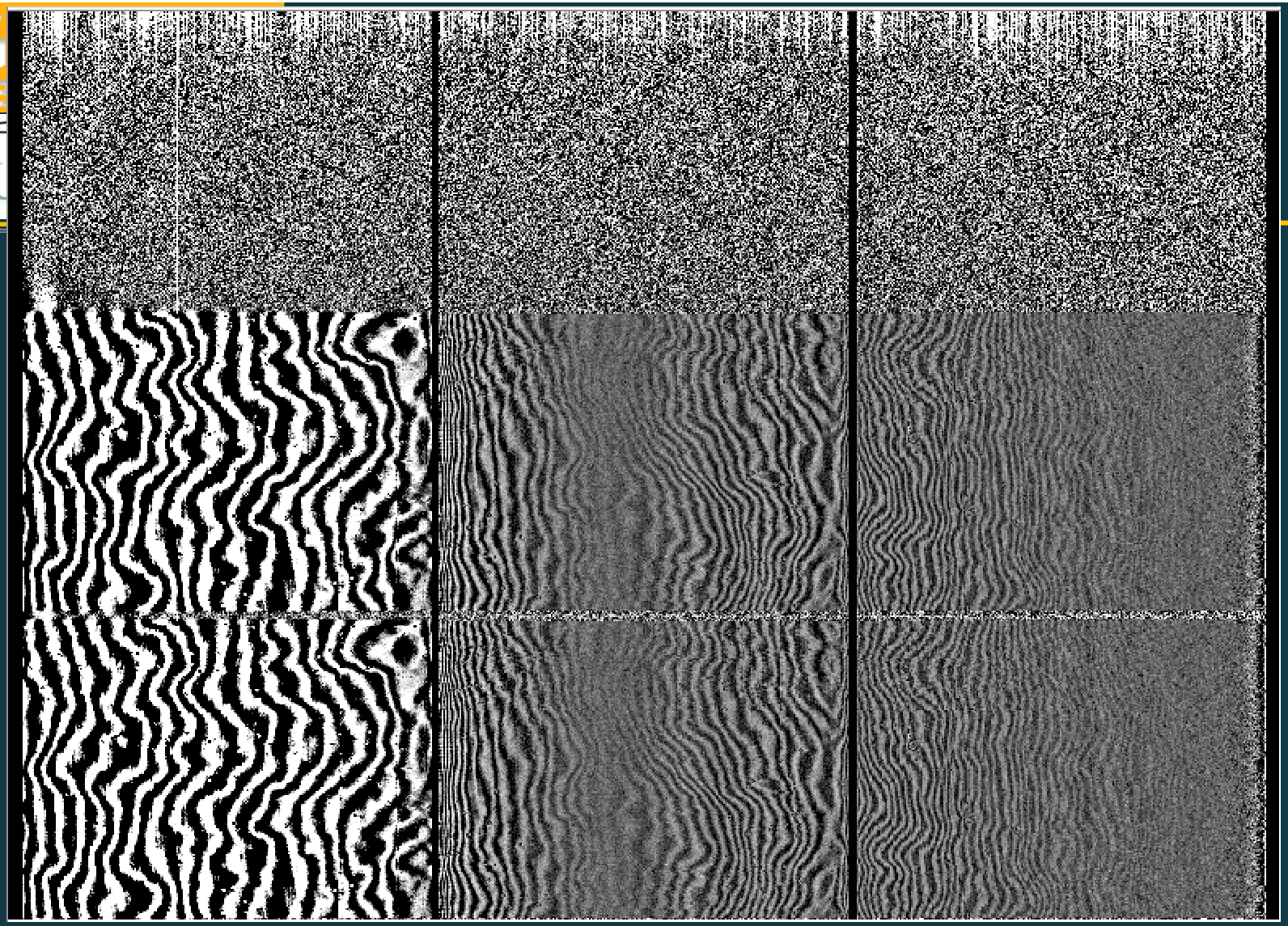
gsflat @flatfiles_460 out=Flat_460.fits
logfile=gmos.logfile rawpath="rawdata$"
fl_over+ fl_trim+ nbiascontam=4
fl_bias+ bias="sciencebias" fl_dark-
fl_fixpix- fl_inter+ function="chebyshev"
order=15 fl_detec+ fl_double+
nshuffle=1536 ovs_flinter+ fl_vardq+

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

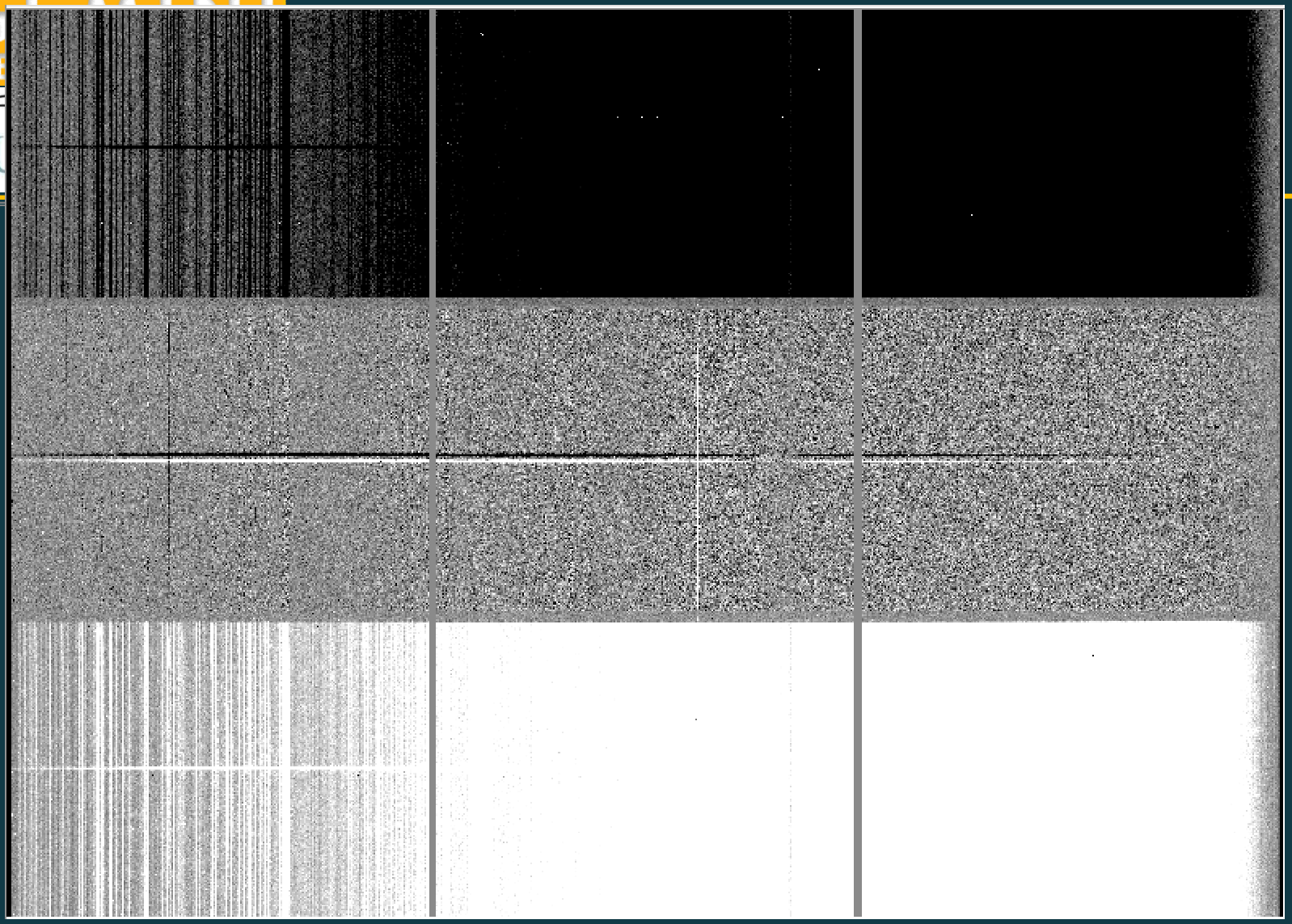
- Sky subtraction is done on a pixel by pixel basis by subtracting the shuffled image pixels from those obtained with no shuffle.
- Because the telescope is pointing at a different position when the pixels are shuffled the result is either a sky subtracted object spectral image (if nodding was off to 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 = ± 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 ⇨ 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