Reducing GMOS Nod & Shuffle Data

In particular, how does it differ from reducing regular longslit and MOS data

Kathy Roth - NOAO / Gemini Data Workshop
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Which Steps Differ?

- Bias - There may be no need to bias correct
- Dark - Should dark correct Hamamatsu 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

Upgraded GMOS-N Science Detectors: Schedule and Commissioning Plans

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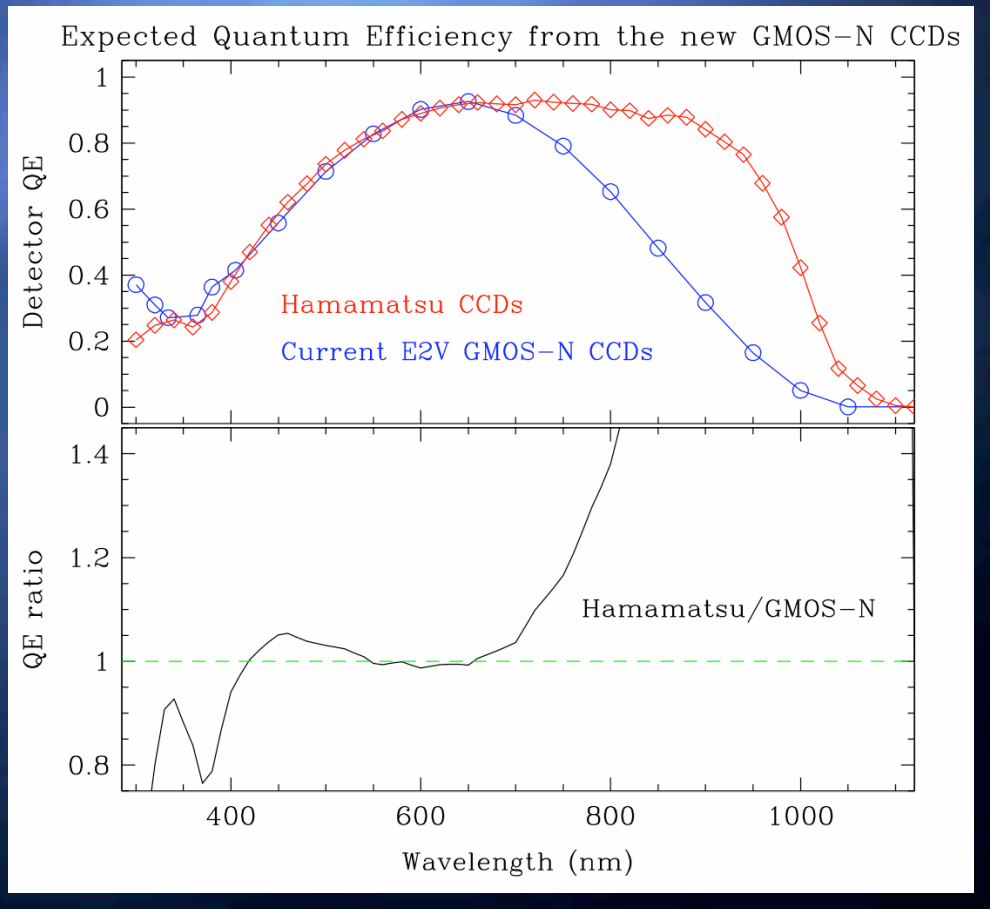
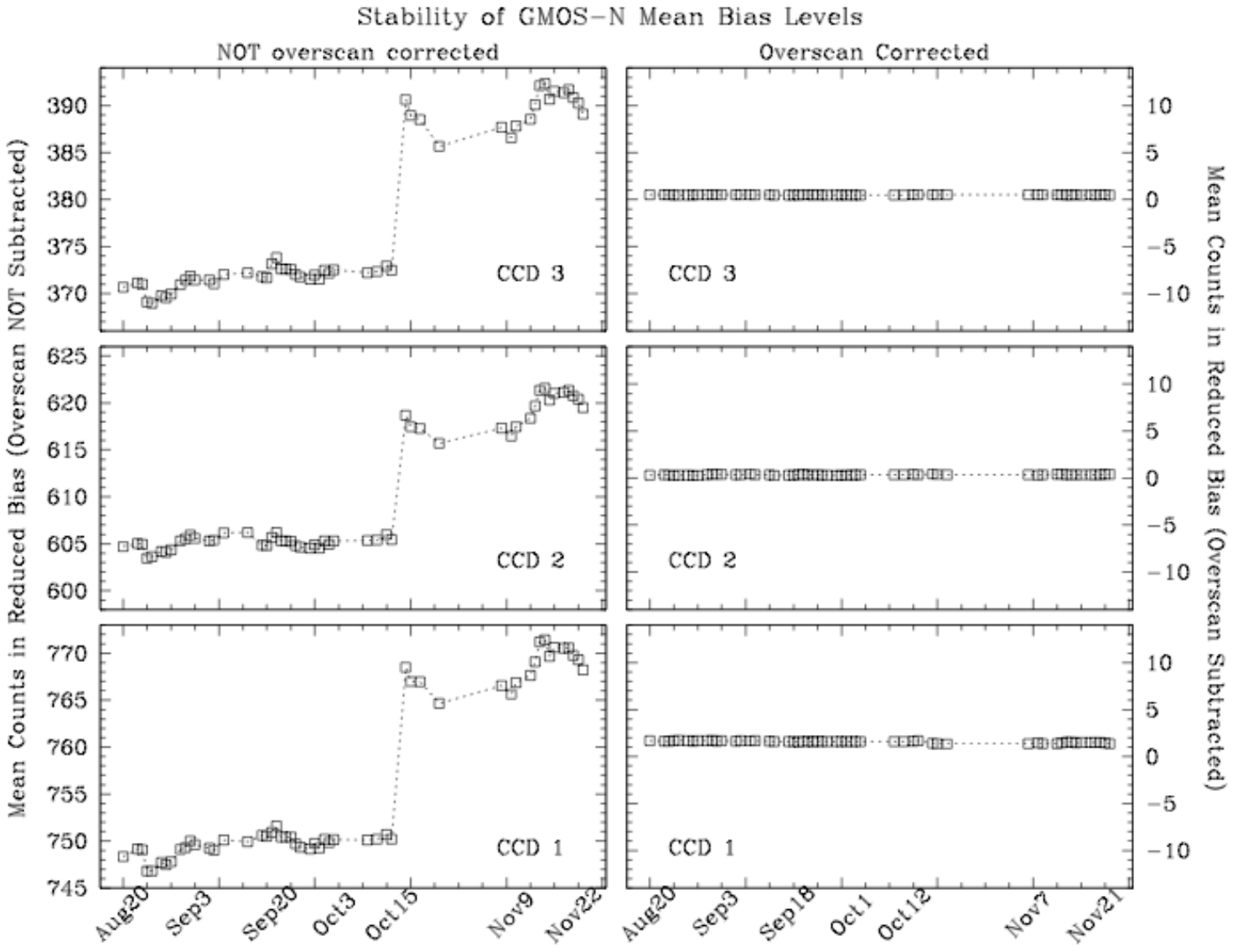
- Original GMOS-N E2V CCDs (in use since Oct 2001) to be replaced with Hamamatsu CCDs, scheduled for Oct/Nov 2010
- Primary gain expected is increased QE in the red
  - Significantly higher QE longward of ~800nm
  - Slightly poorer QE blueward of ~420nm
- Secondary gain is faster readout allowing for time domain research (needs verification)
- GMOS-N expected to be unavailable ~ 4-5 weeks from Oct 11, on-sky commissioning from mid Nov mixed with queue observing (schedule subject to change)



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


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
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Sep3
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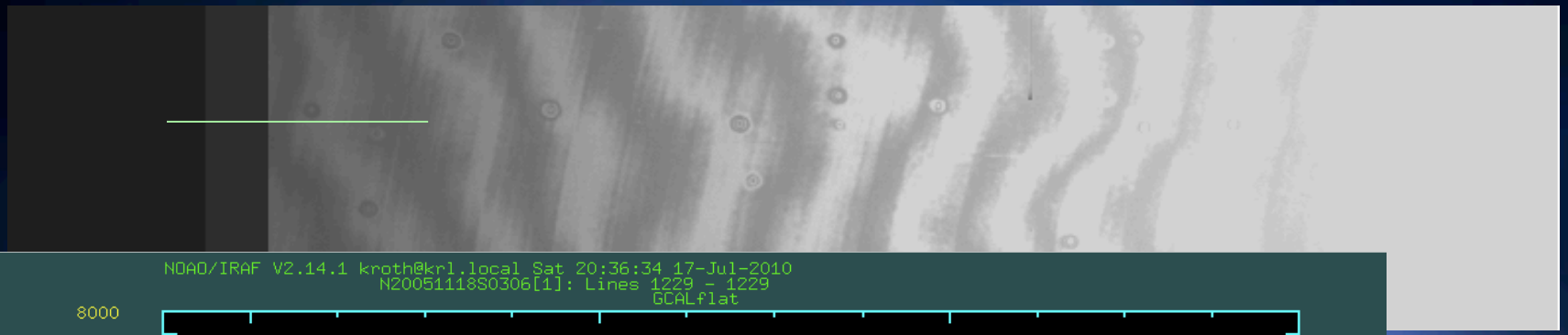
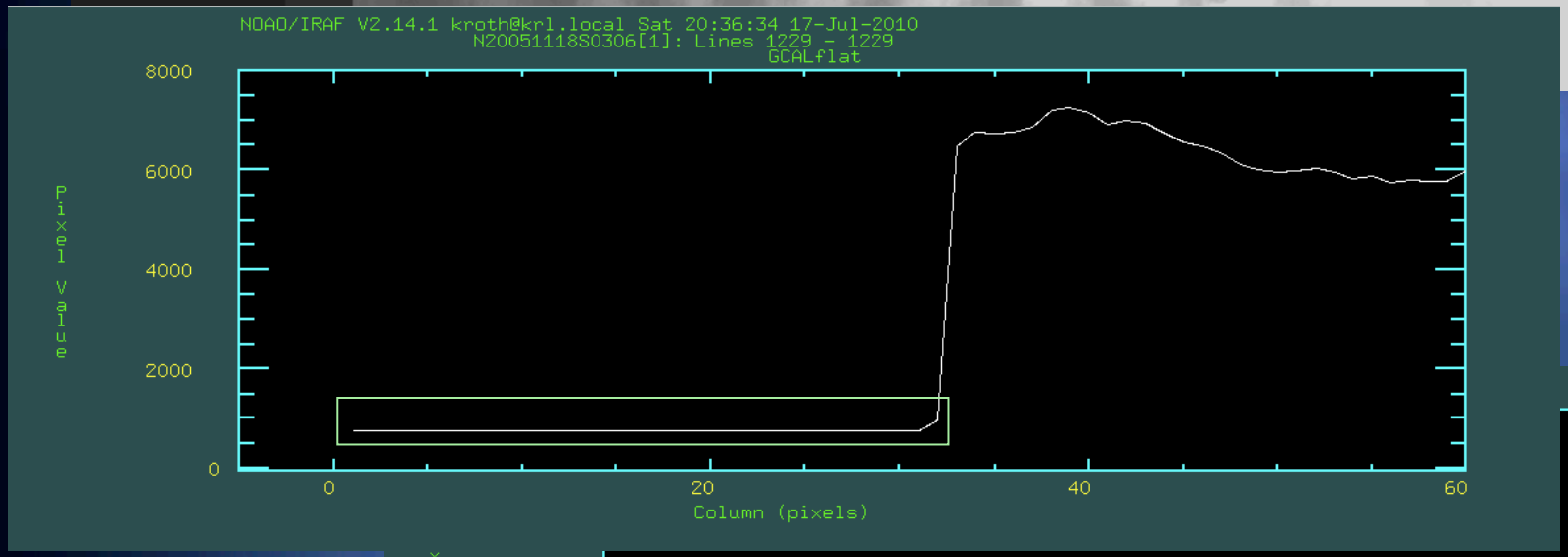
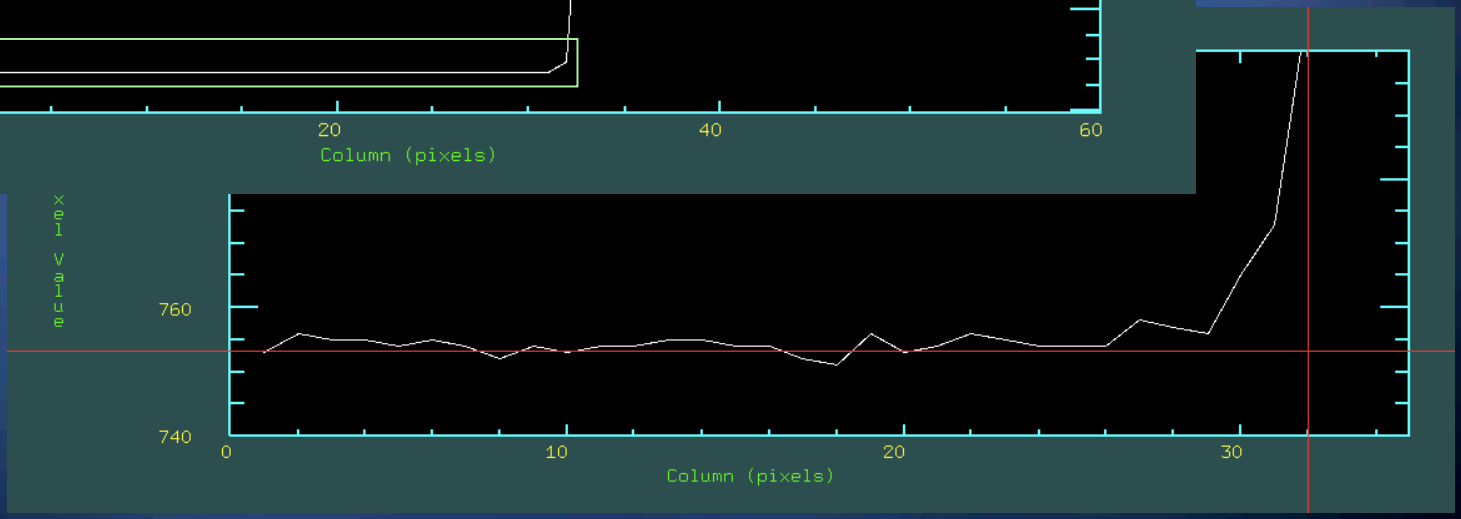
Oct1
Oct12
Nov7
Nov21







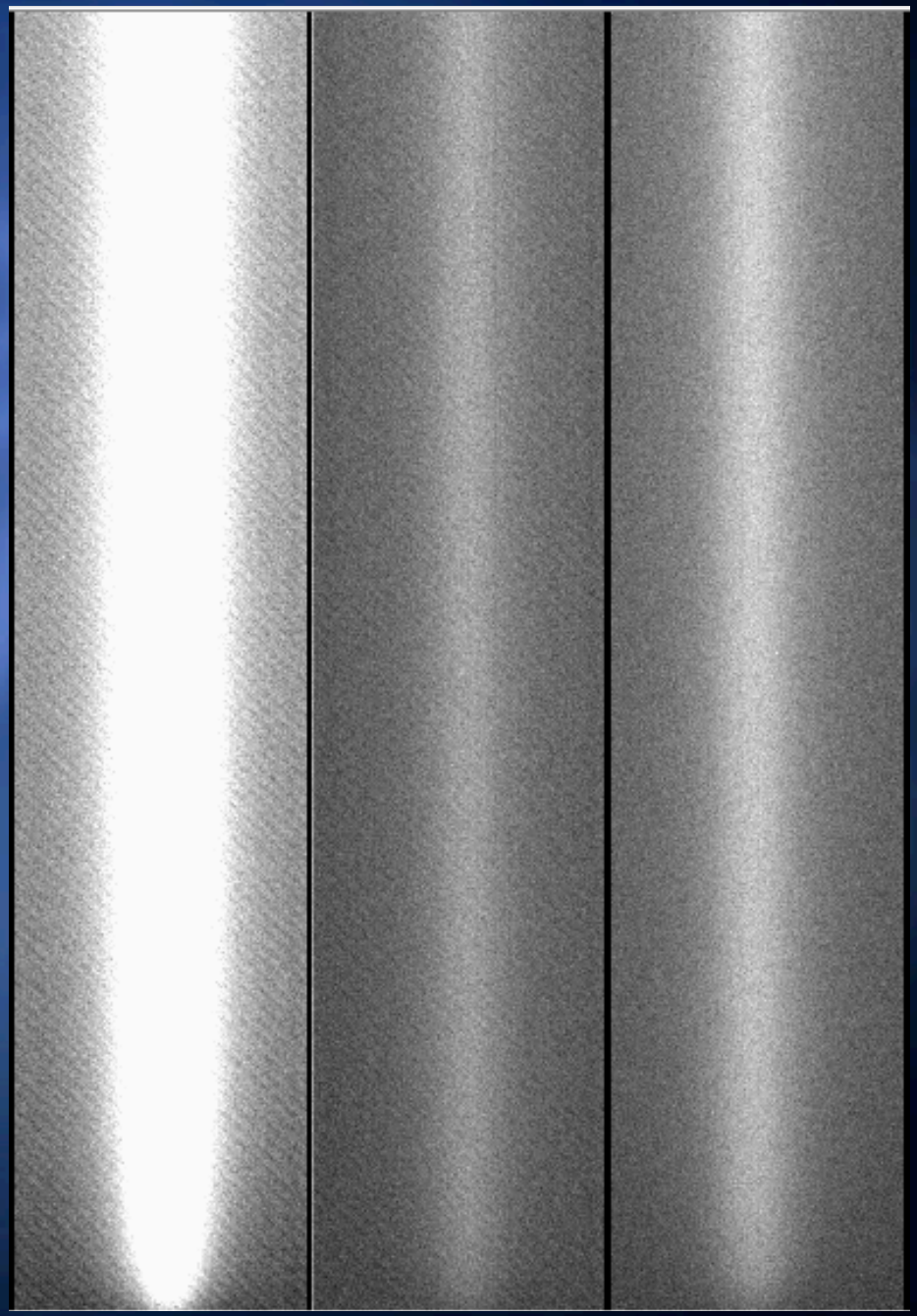
R400 grating spectral GCALflat, GMOS-N CCD1, 32 pixel overscan region on the left, note the fringing (central wavelength 810nm).

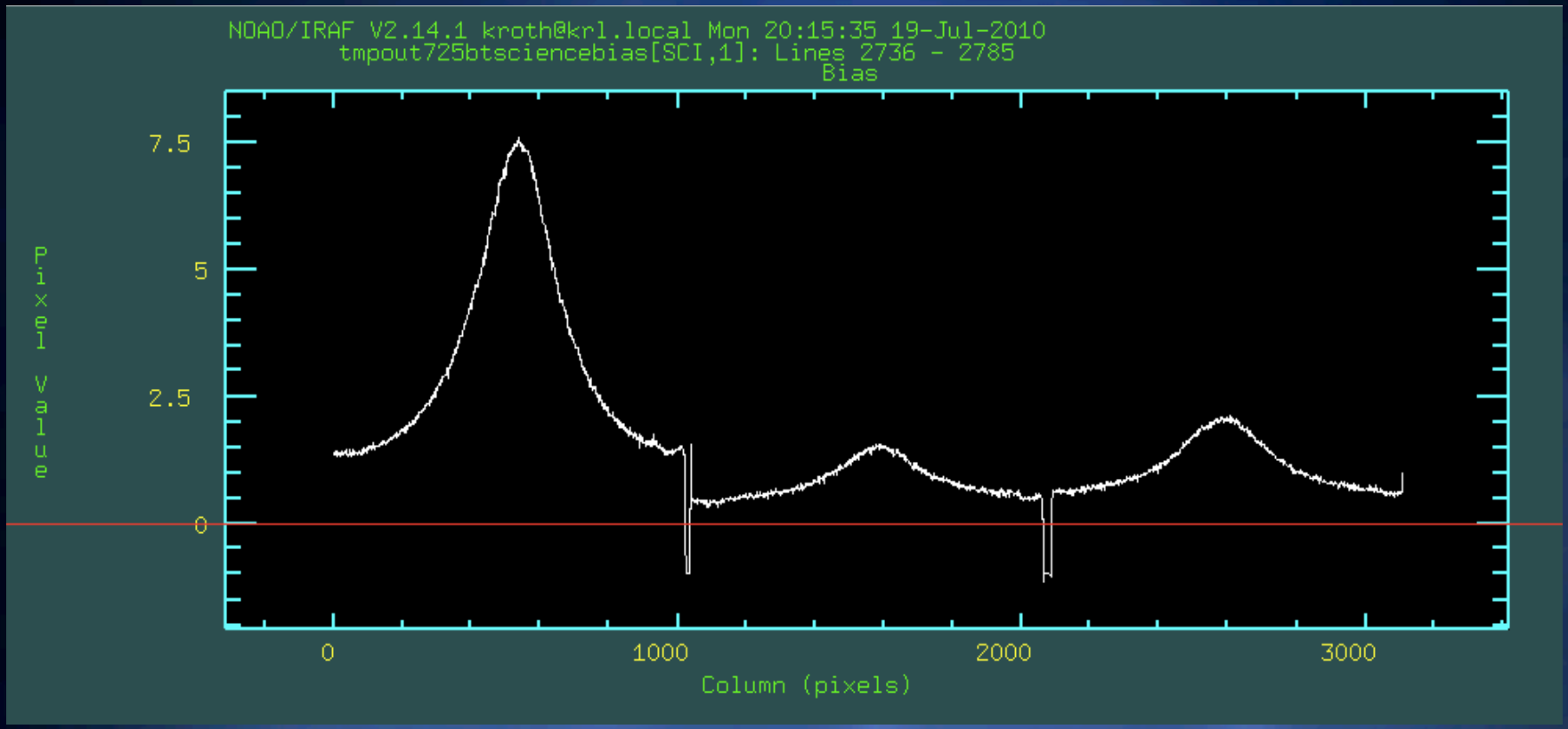
~ 4 overscan pixels bordering the data are contaminated (low-level).

gbias("@biaslist","sciencebias",logfile=gmos.logfile, rawpath="rawdata$",fl_over+,fl_trim+, nbiascontam=4,fl_inter+,fl_vardq+)

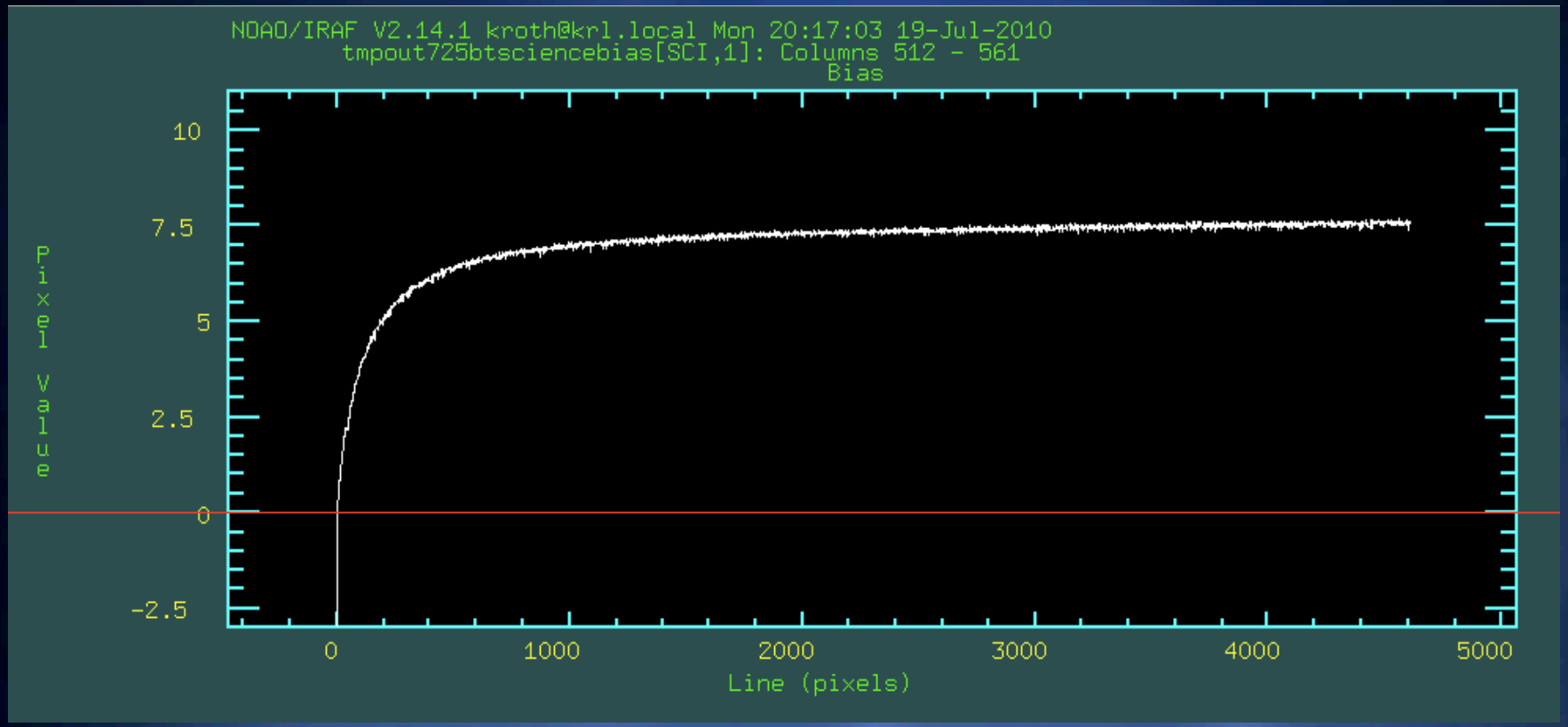
biaslist: text file containing filenames of raw bias images (one per line)
sciencebias: name of output combined bias image
gmos.logfile: user defined name of output logfile
(eg. gmos.logfile = "GN-2005B-Q-20-13.log")
rawdata$: user defined directory containing the raw fits files
(eg. rawdata = "../rawdata/")
fl_over+: turn on overscan subtraction
fl_trim+: trim off the overscan region
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

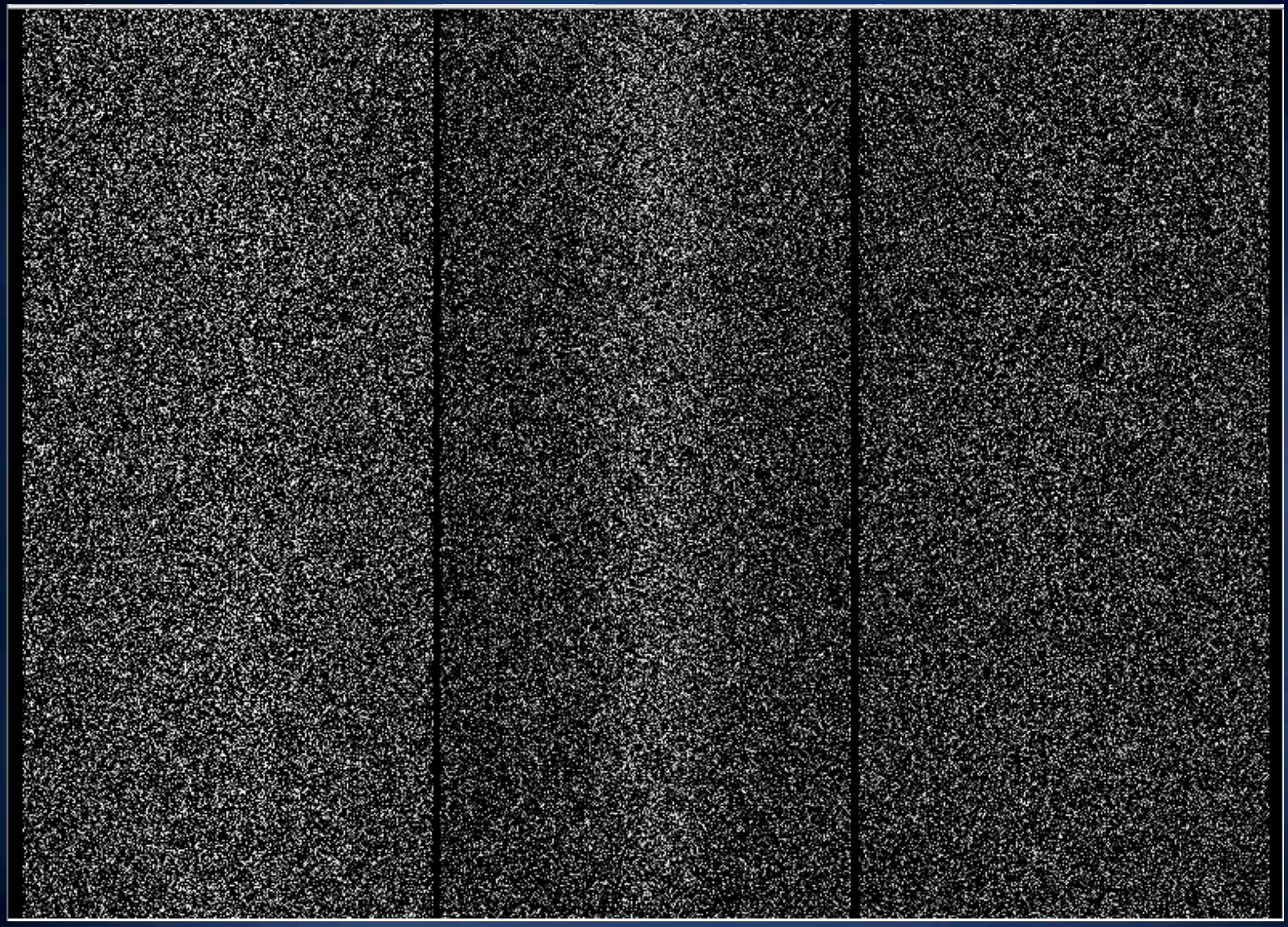




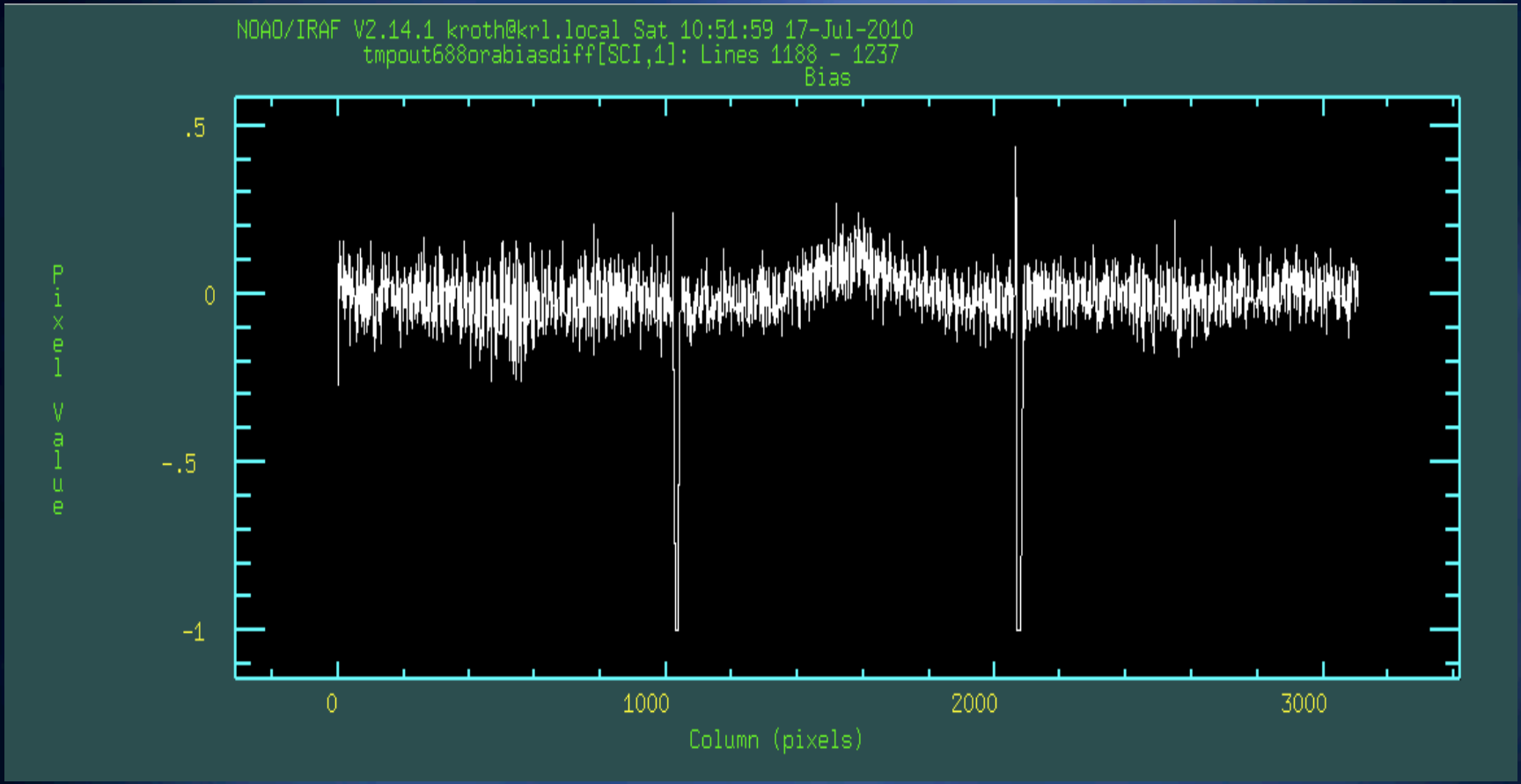
Column plot (CCD1) for reduced combined 2x1 bias, 50 lines averaged.



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



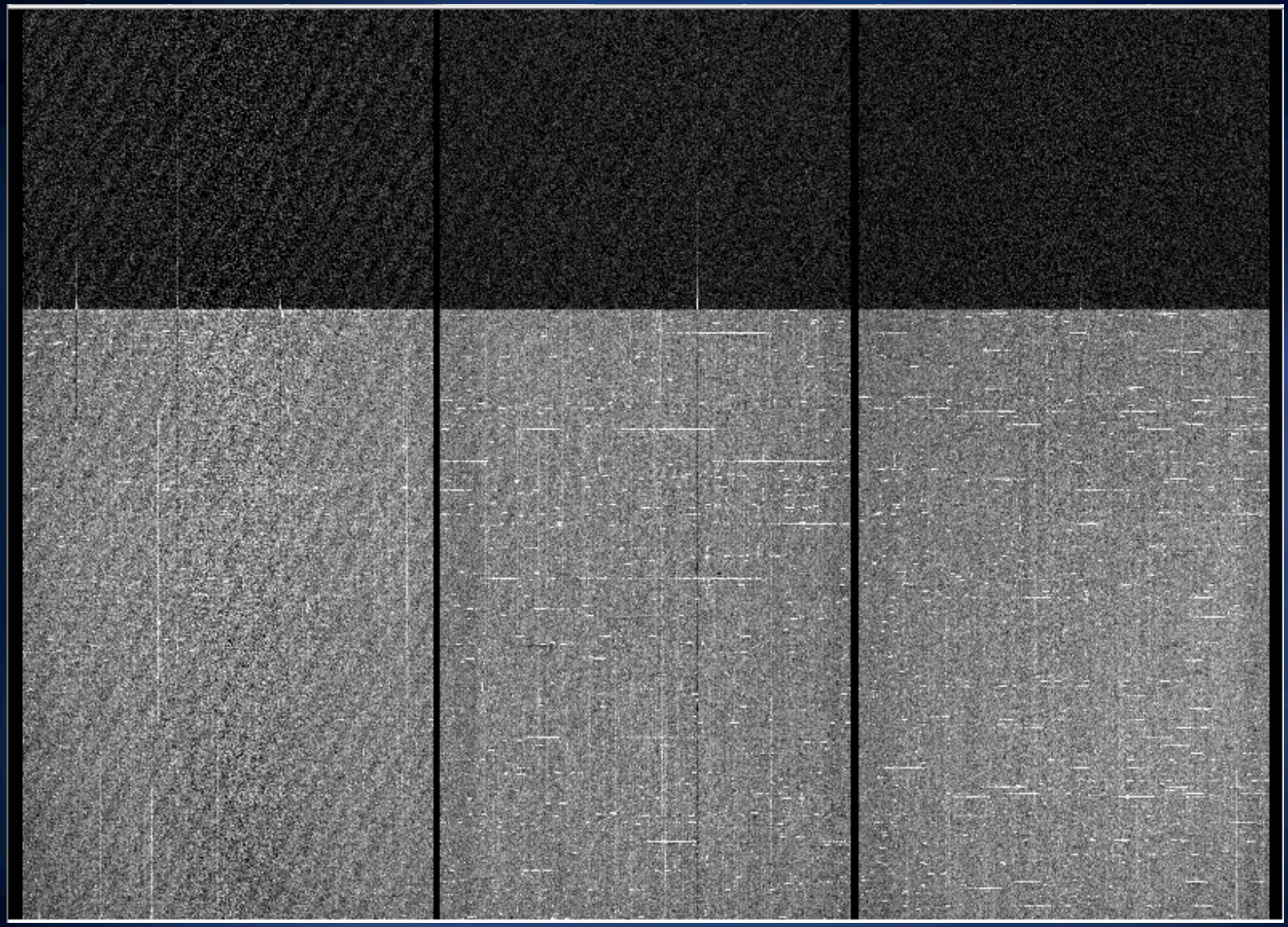
Line cut through difference image. Bias stability is very good over a period of several months. 50 lines averaged.

Dark Correction

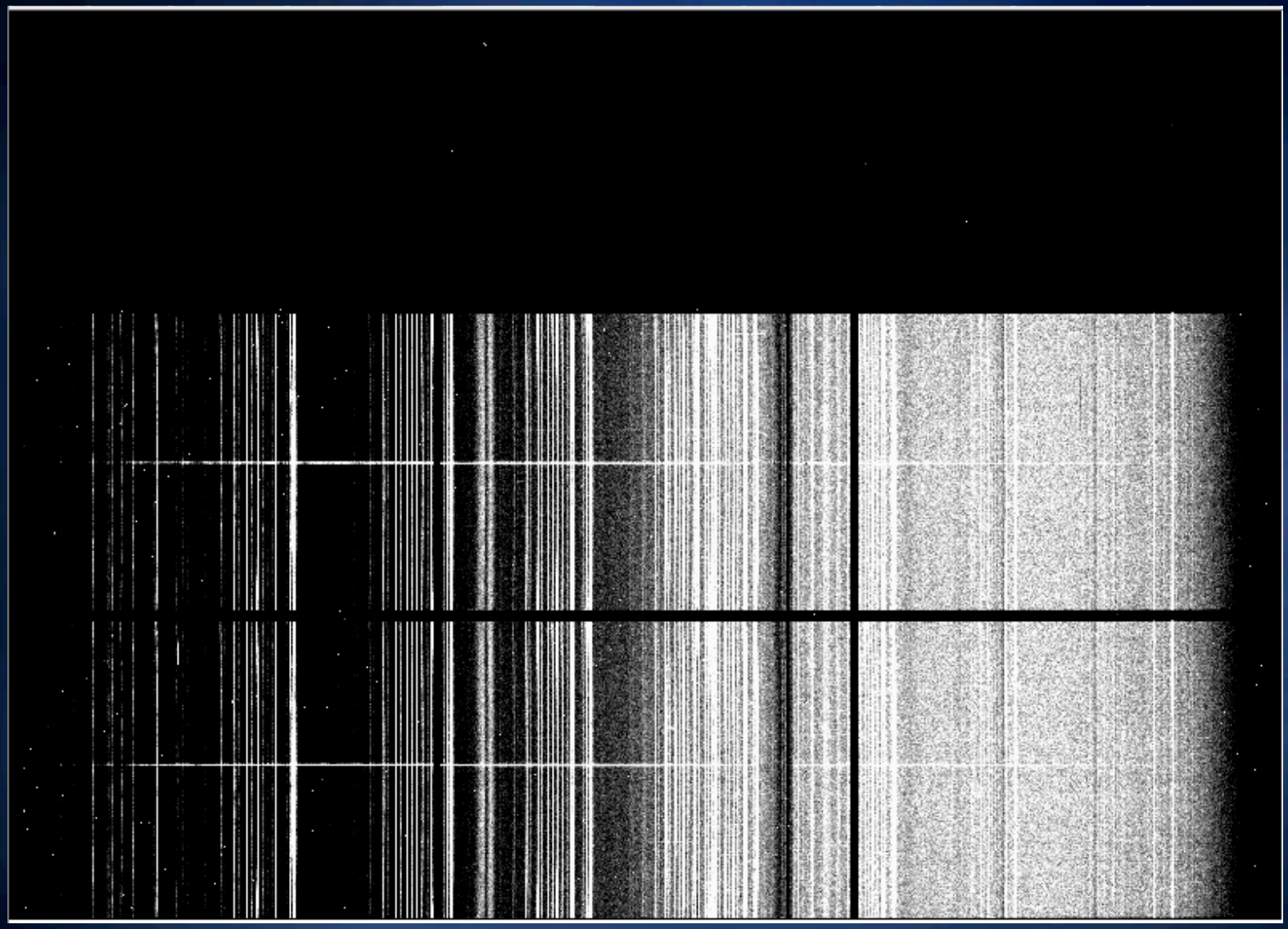
- Nod & Shuffle darks taken with the same shuffle distance, exposure time, number of cycles and binning do a very good job at removing features induced by the "charge traps."
  - N.B. normal darks can also be used to correct regular science data that sometimes show these features (eg. blue spectral IFU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

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

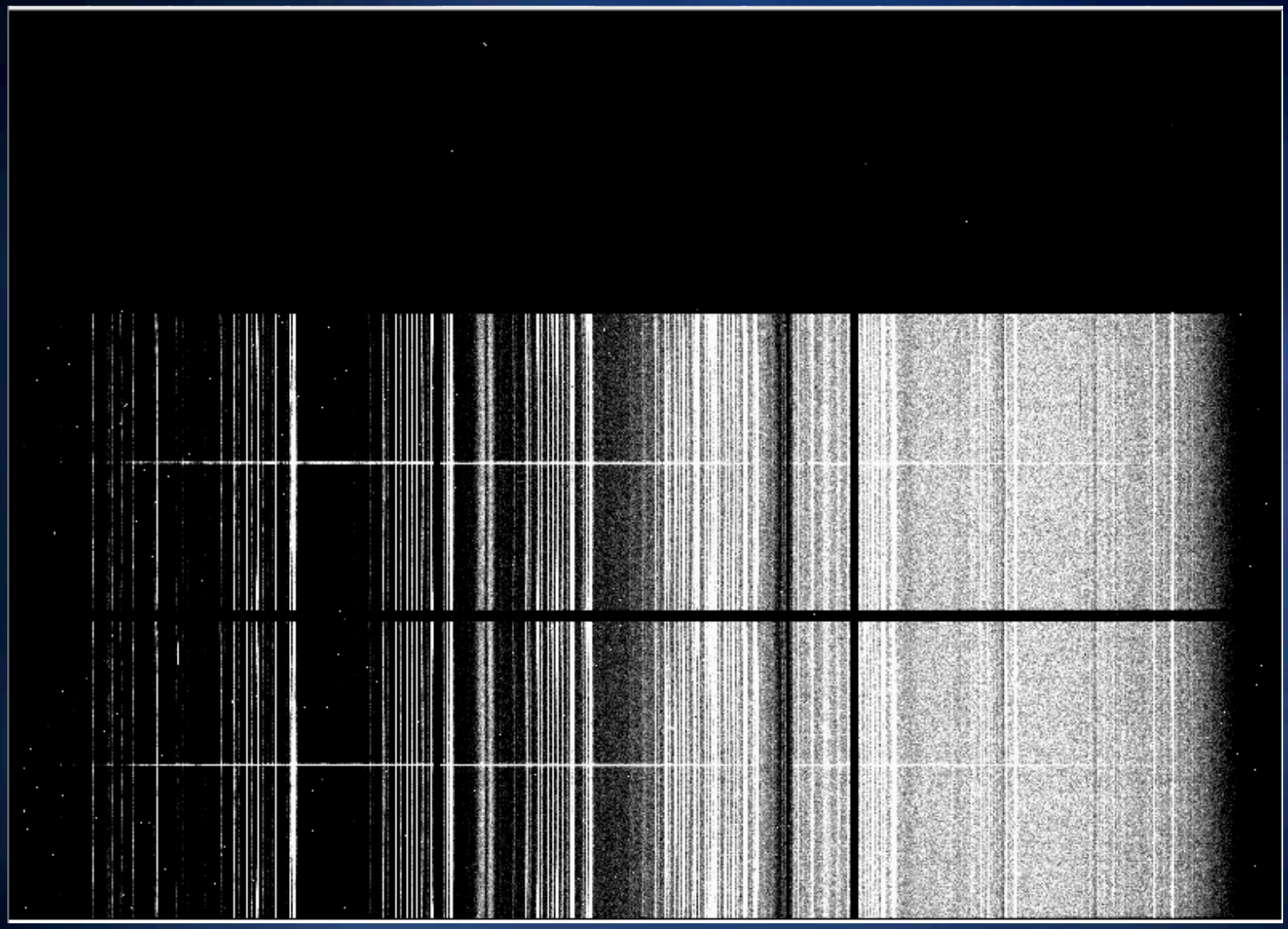
darklist: text file containing filenames of raw dark images (one per line)
NSdark: name of output combined dark image
fl_bias+: subtract a bias image
Bias="darkbias": name of the bias images to use



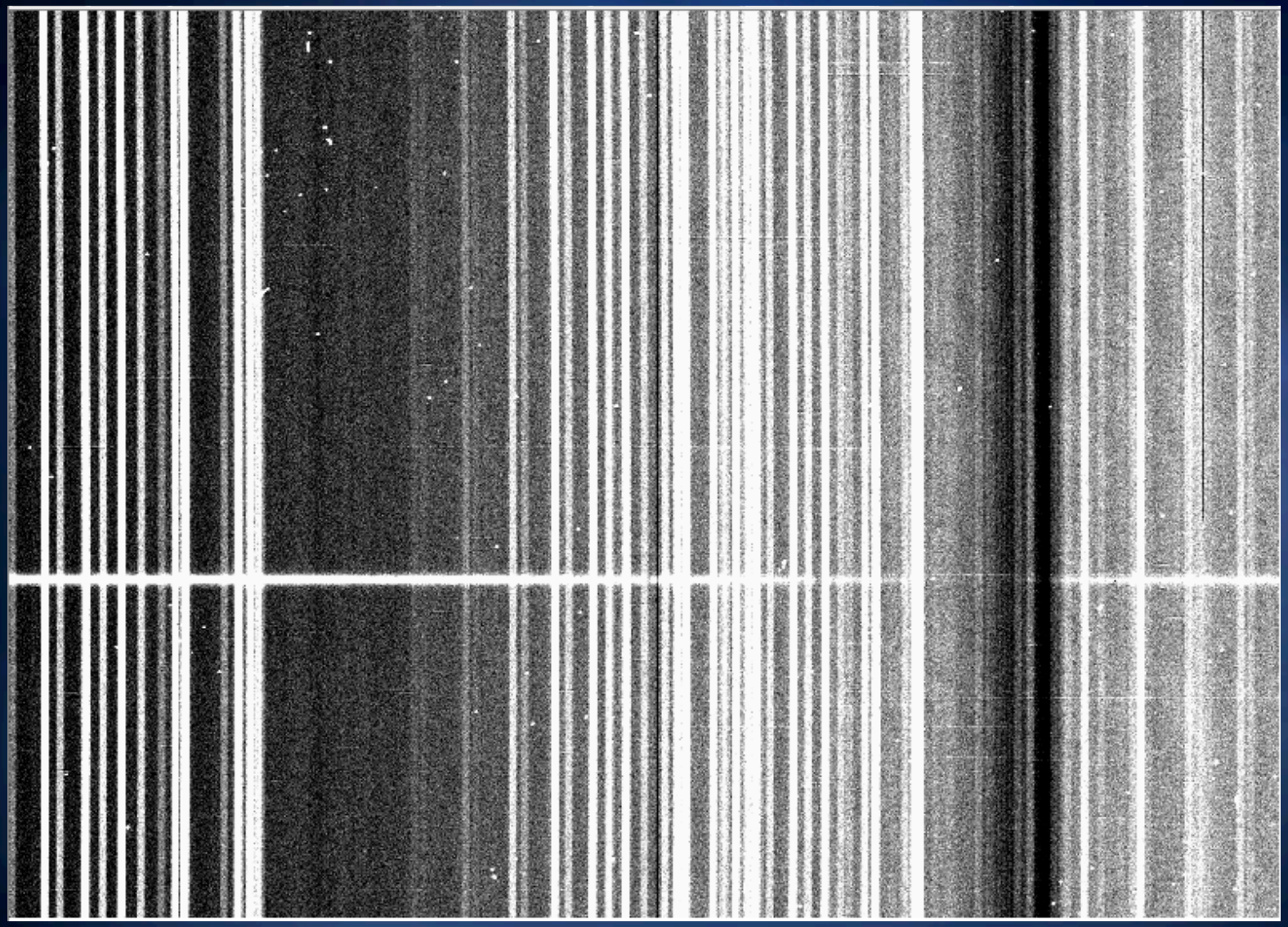
Nod & Shuffle longslit (shuffle offset = 1536 pixels) dark. A = 60s, number of cycles = 8, total exposure time = 960s.



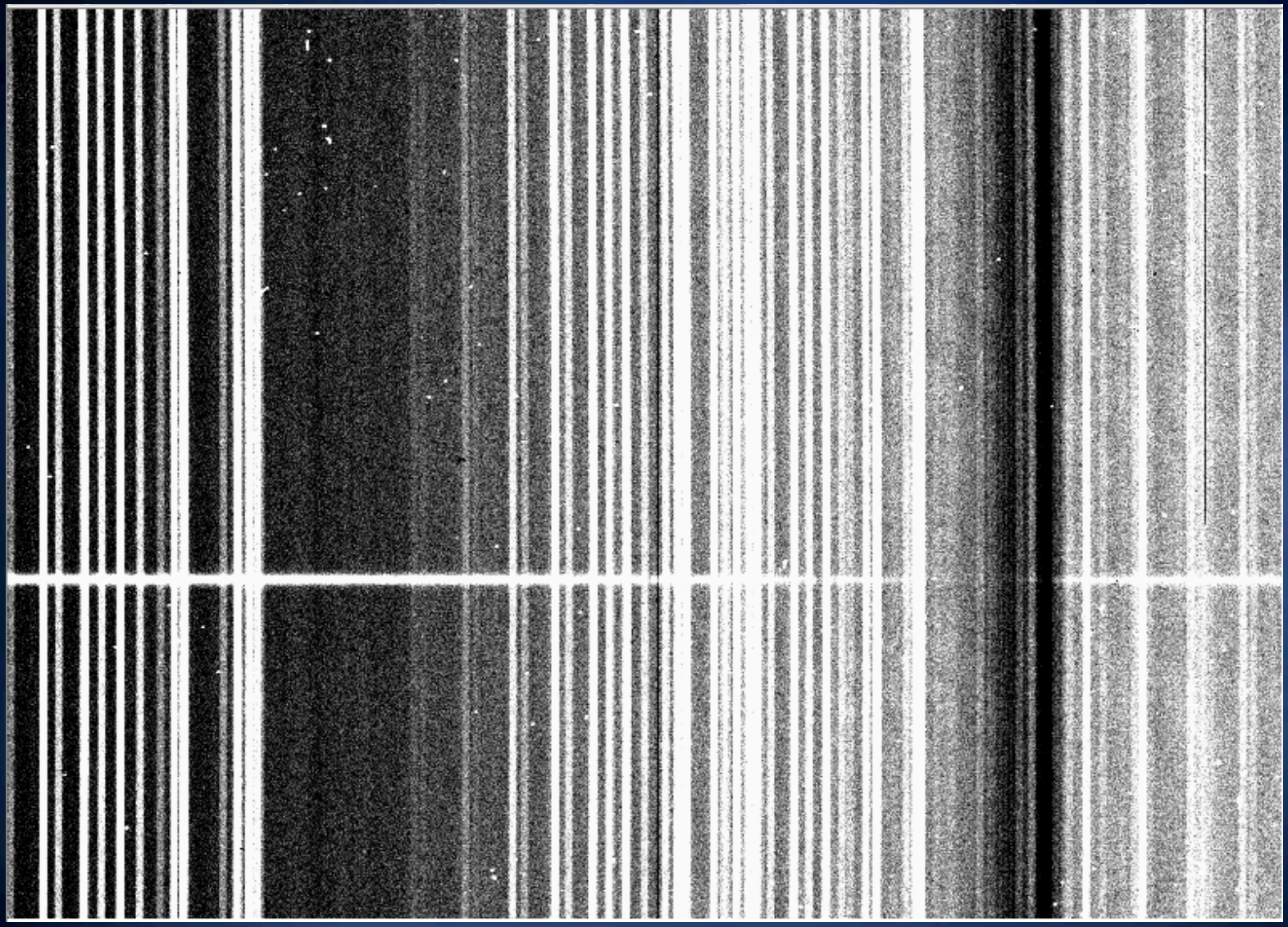
Bias corrected Nod & Shuffle science exposure.



Bias and dark corrected Nod & Shuffle science exposure.



Bias corrected Nod & Shuffle science exposure (zoom).



Bias and dark corrected Nod & Shuffle science exposure (zoom).

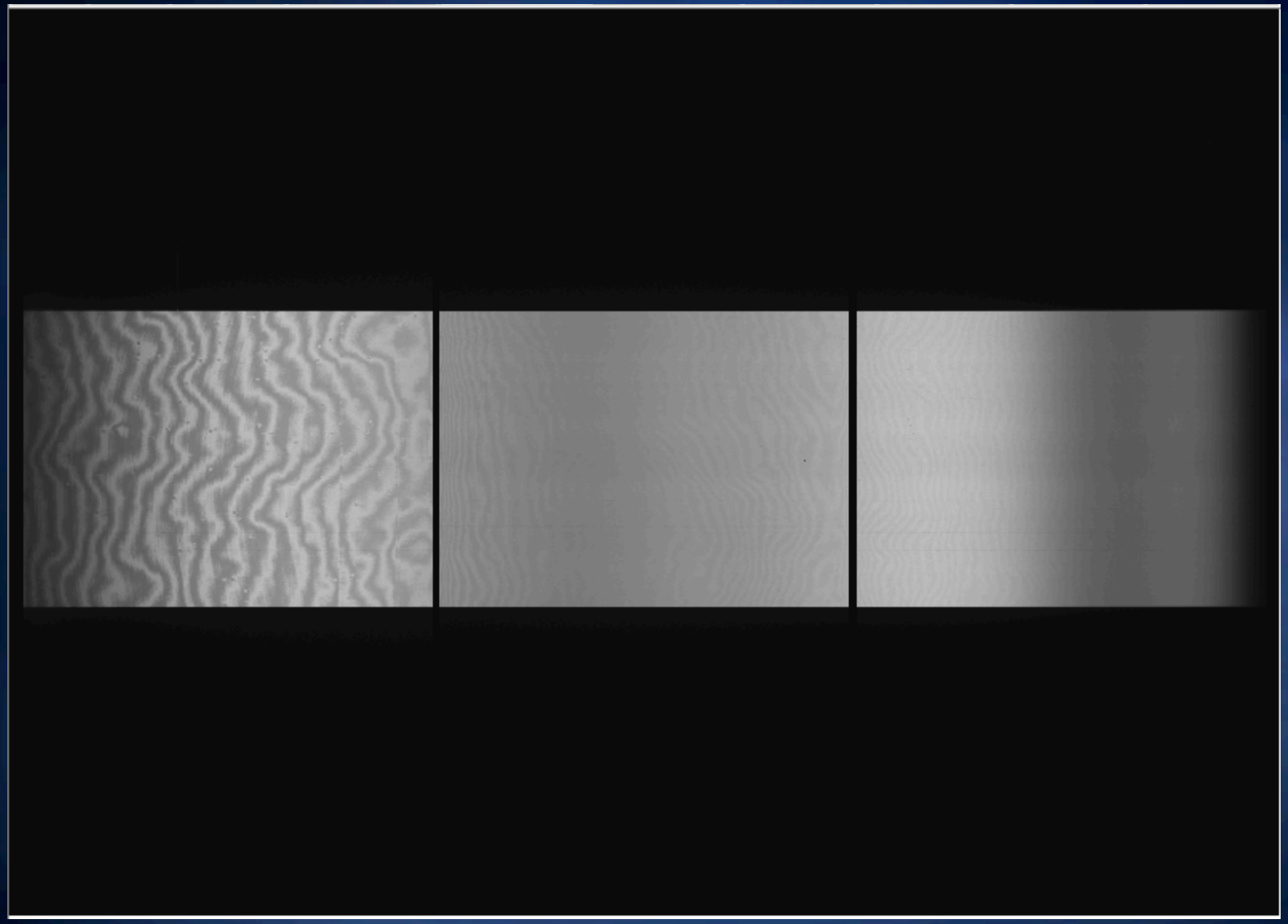
Come back to this a bit later, easier to see the effect in skysubtracted data.

Flatfield Correction

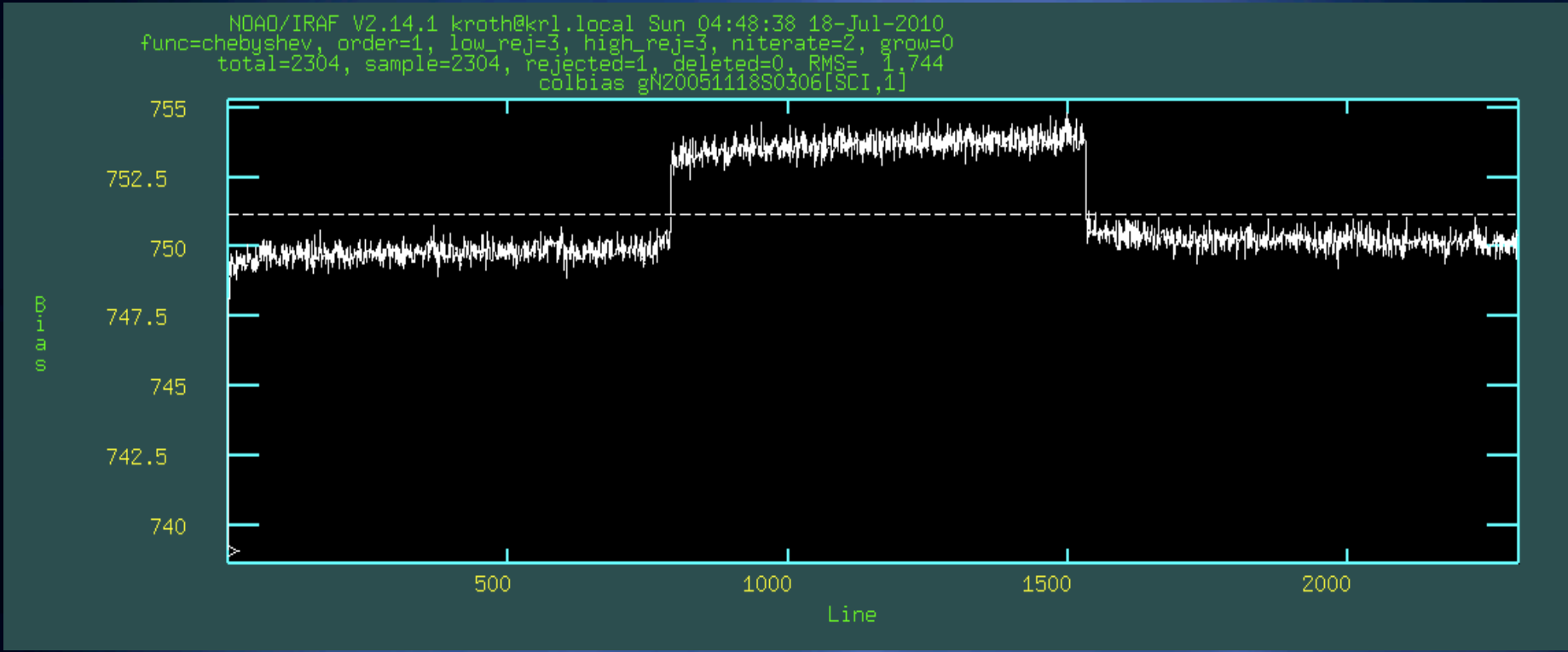
- GCALflats for Nod & Shuffle programs are not shuffled when they are taken ⇒ use fl_double+ option in gsflat.
- When constructing Nod & Shuffle GCALflats with fl_double+, must specify the shuffle distance in the parameter nshuffle to match the value given in the NODPIX keyword in the science data.
- Flats may be useful for removal of pixel-to-pixel variations in brighter targets
- Flat 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.
- Not yet known how much fringing in Hamamatsu CCD data (should be less since these back illuminated devices are thicker than the E2Vs).

```
gsflat("N20051118S0306.fits","flat_810",
       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+)
```

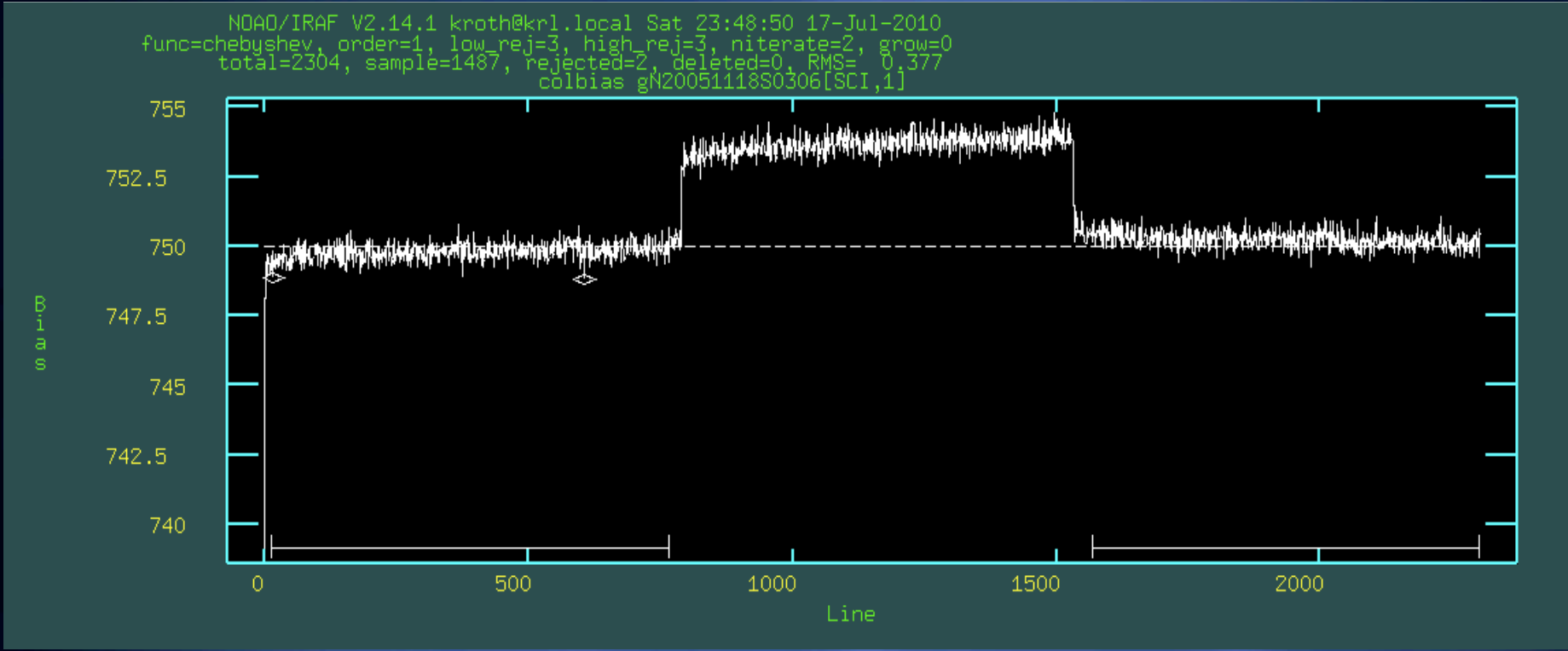
N20051118S0306.fits: raw GCALflat images (810nm)
flat_810: name of output flat image
fl_dark-: do not subtract a dark image
fl_fixpix-: do not fix pixels in the gaps (cannot do this with fl_detect+)
fl_inter+: examine fits to spectral shape interactively
chebyshev: type of polynomial to use in fits to spectral shape
order=15: order of polynomial fit to spectral shape
fl_detec+: do not mosaic, fit each detector independently
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
ovs_flinter+: examine fits to overscan region interactively



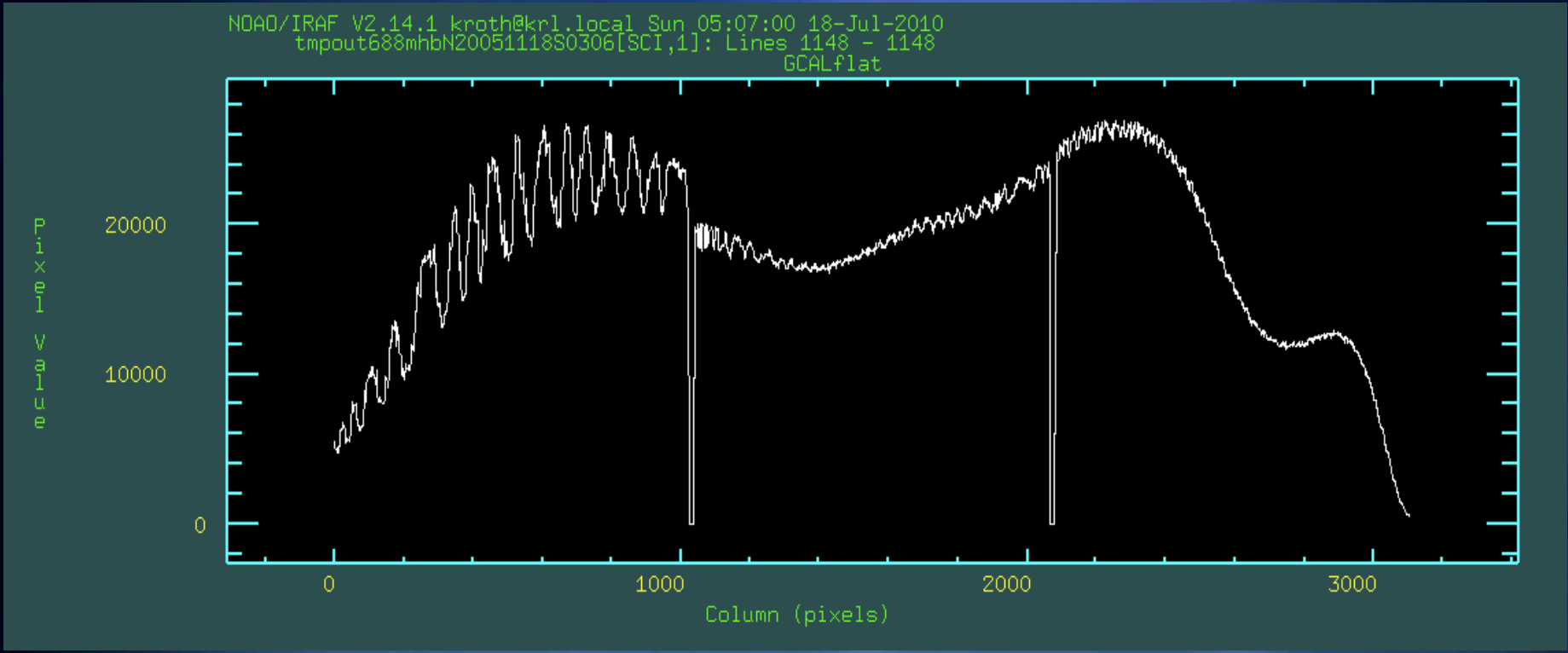
Raw GCALflat R400 spectral flat, 810nm, NS0.75arcsec longslit. GCALflats are not shuffled, and do not inherit the NODPIX header keyword parameter of the associated science exposures.



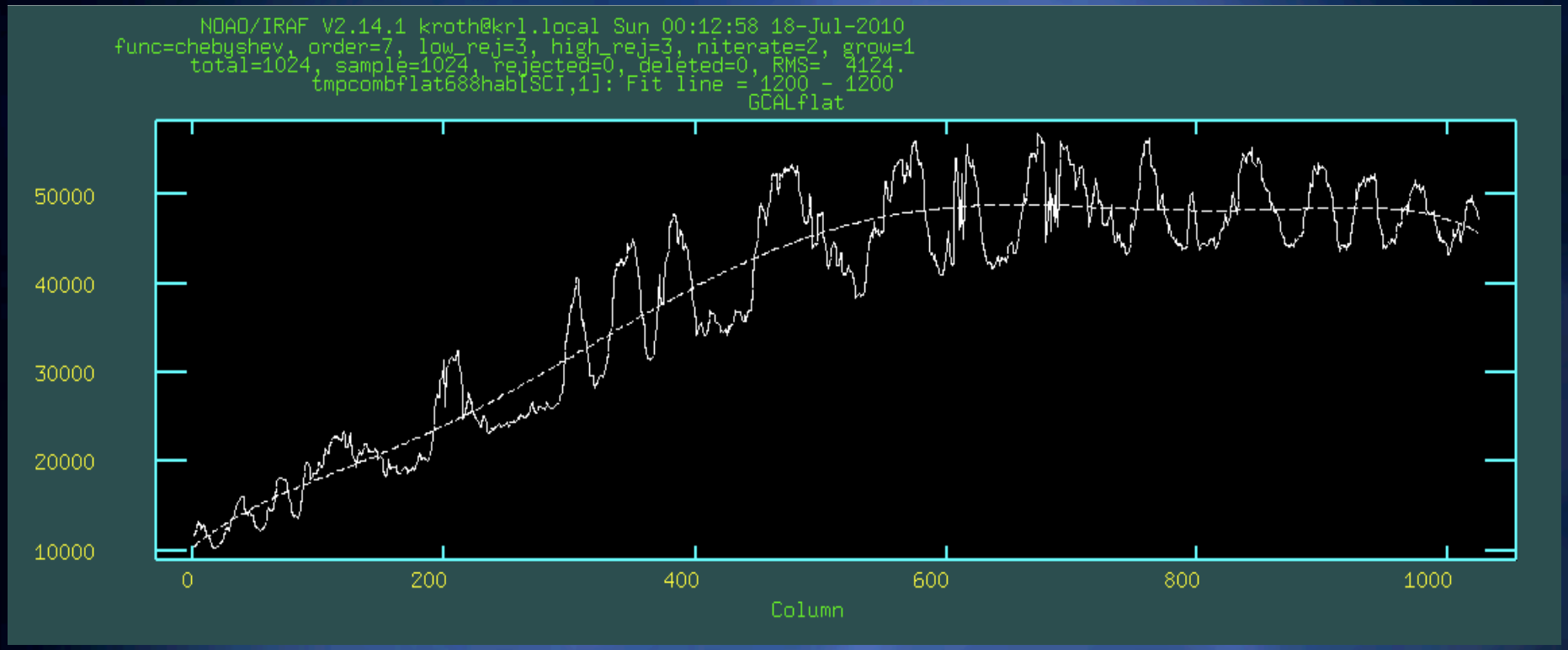
Overscan fit for CCD1. The bias region adjacent to the illuminated pixels are contaminated - the bias level of a CCD image should not depend on the amount of light incident on the pixels. The default behavior of the overscan subtraction is to fit all the pixels, but should really only be fitting the region adjacent to the non-illuminated pixels (when possible). Note this is a very small effect.



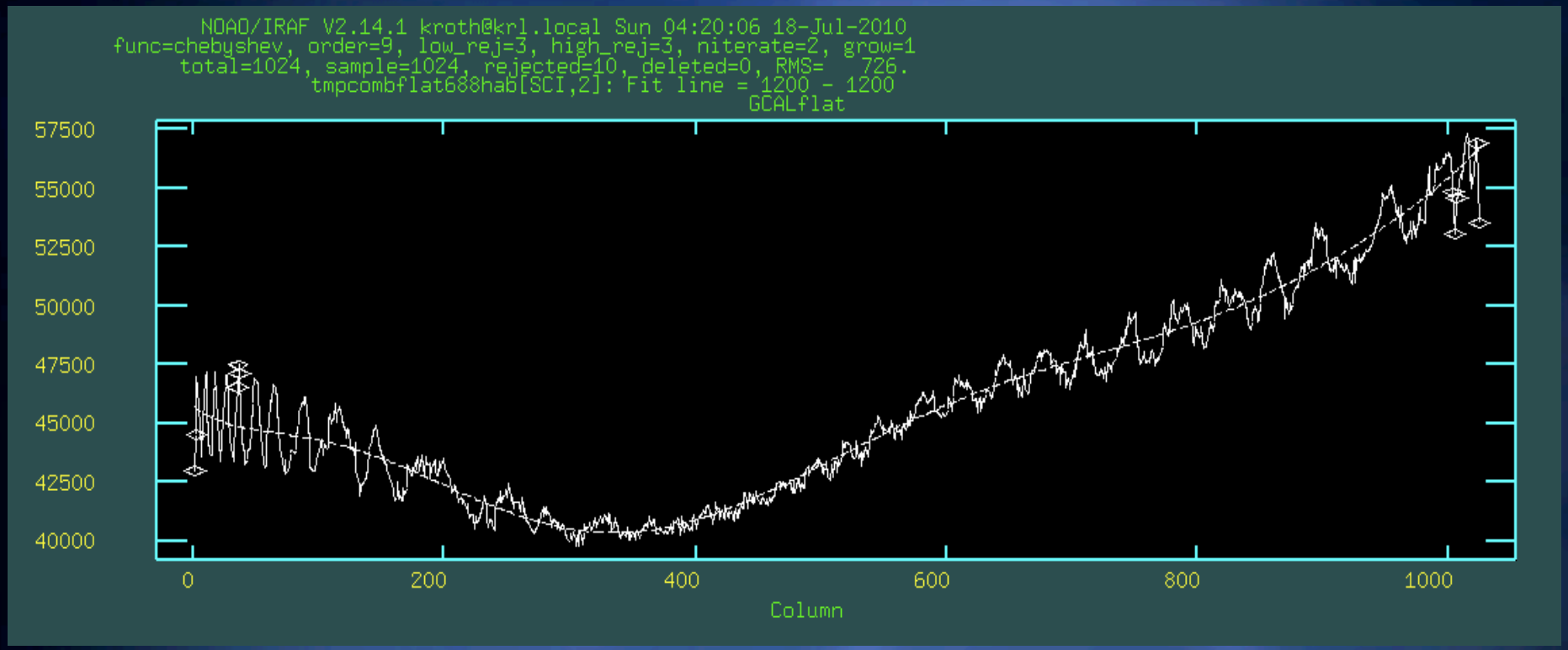
Overscan fit for CCD1. By utilizing the "s" cursor command one can select specific regions to fit. Use a "t" to initialize back to the full spectrum. The selected regions are indicated at the bottom of the plot. The fit excludes pixels not selected. A first order chebyshev polynomial (constant) is recommended.



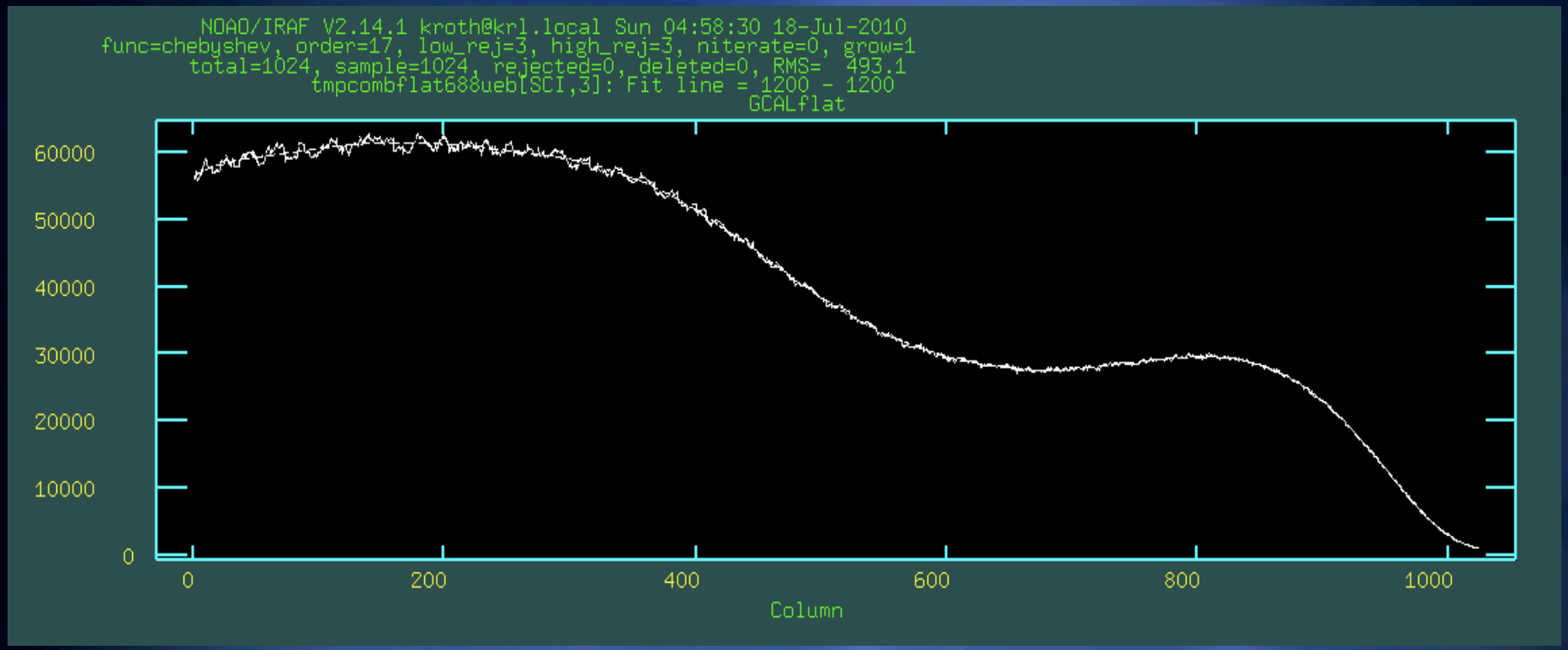
Line cut through raw GCALflat. Wavelength is decreasing left to right, strong fringing in the red is evident. The red part of the spectrum requires a low order fit to normalize the spectral shape without removing the fringing. The blue part of the spectrum requires a high order fit to remove the spectral shape induced by the GCALbalance filter within the GCAL unit.



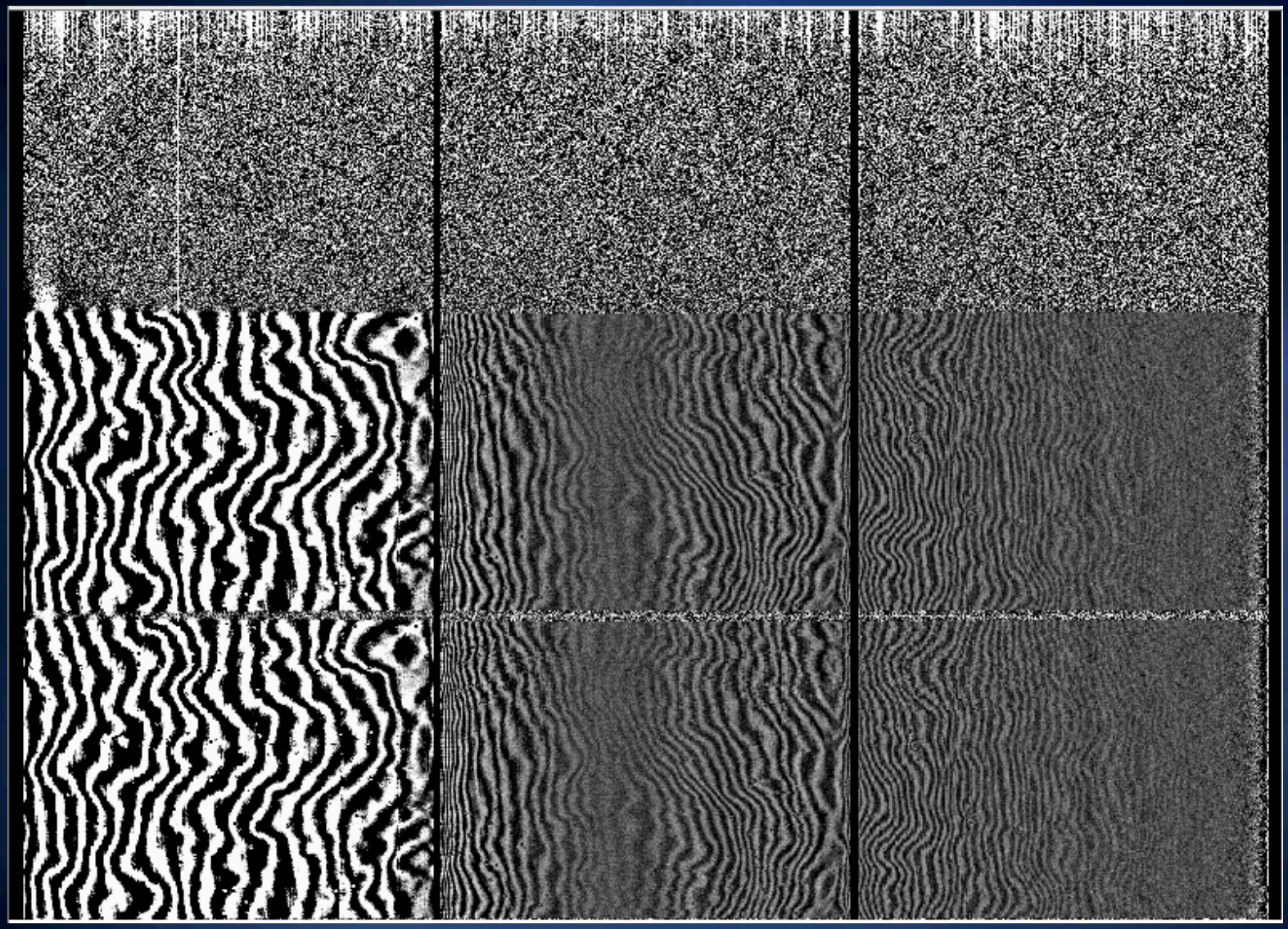
Normalization fit for CCD1. This very red part of the spectrum shows strong fringing (GMOS-N E2V CCDs, GMOS-S fringing even more pronounced, Hamamatsu CCDs unknown at this time but expected to be weaker). A relatively low order fit is necessary to avoid fitting the fringing - do not want to normalize out the fringing because then it will not flatfield out of the science spectra. In this case a seventh order chebyshev polynomial works fairly well.



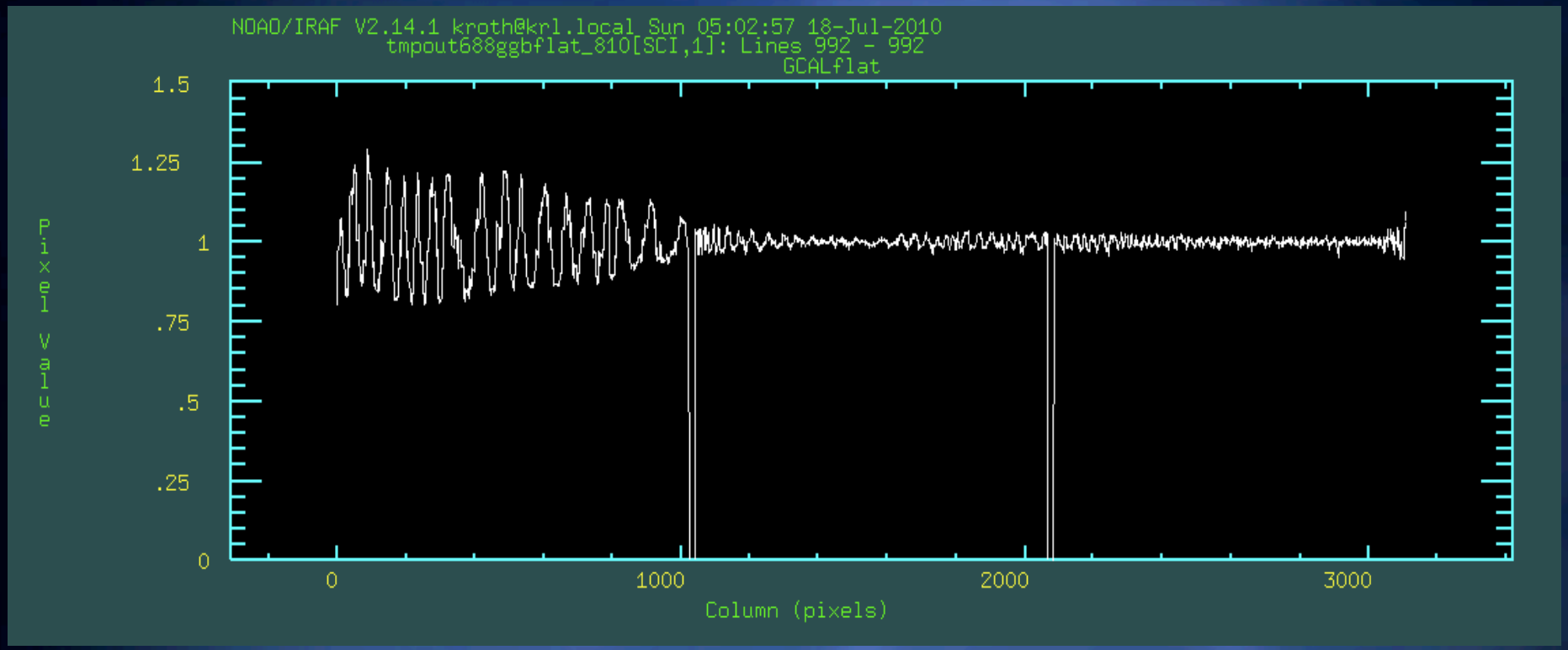
Normalization fit for CCD2. Still some fringing because the central wavelength of this example is very red (810nm) but the effect is decreasing. In this case a ninth order Chebyshev polynomial works fairly well.



Normalization fit for CCD3. Minimal fringing. The spectral shape introduced by the GMOSbalance filter in GCAL is fairly steep and requires a high order fit to prevent ringing. The number of iterations (niterate) has been set to 0 since otherwise the fit was not going through the center of the fringes at the long wavelength end. In this case a seventeenth order Chebyshev polynomial is satisfactory.



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



Line cut through final reduced GCALflat.

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+)

gsreduce("gsN20051118S0305.fits",logfile=gmos.logfile,
outimage="science_810", fl_over-,fl_trim-,fl_bias-,
fl_dark-,fl_flat+,flat="flat_810",fl_gmosaic-,
fl_fixpix-,fl_gsappwave-,fl_cut-,fl_vardq+)

N20051118S0305.fits: raw science image (810nm)

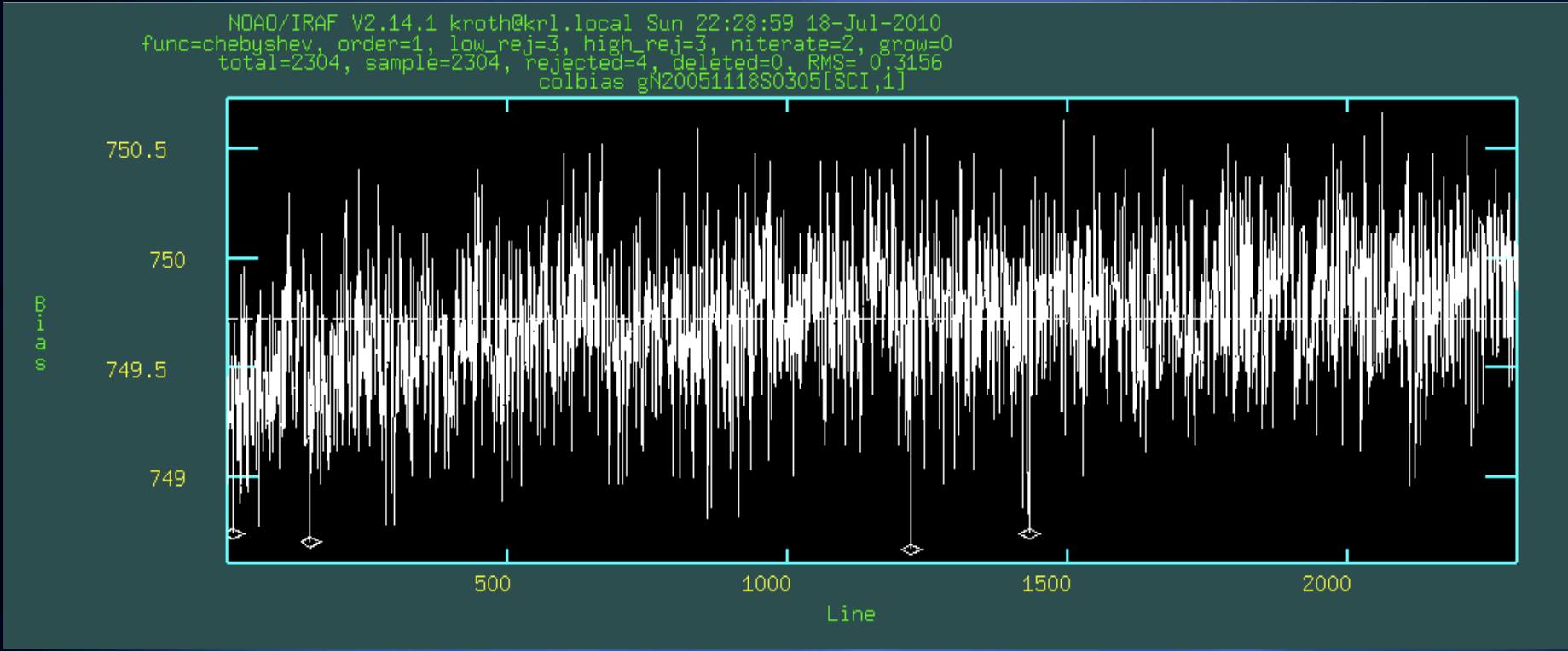
fl_gmosaic-: do not mosaic, leave the detectors as separate extensions

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 **



Overscan fit for CCD1. There is no contamination of the overscan region because the light illumination levels on the detector are low. A first order chebyshev polynomial (constant) is recommended.

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.

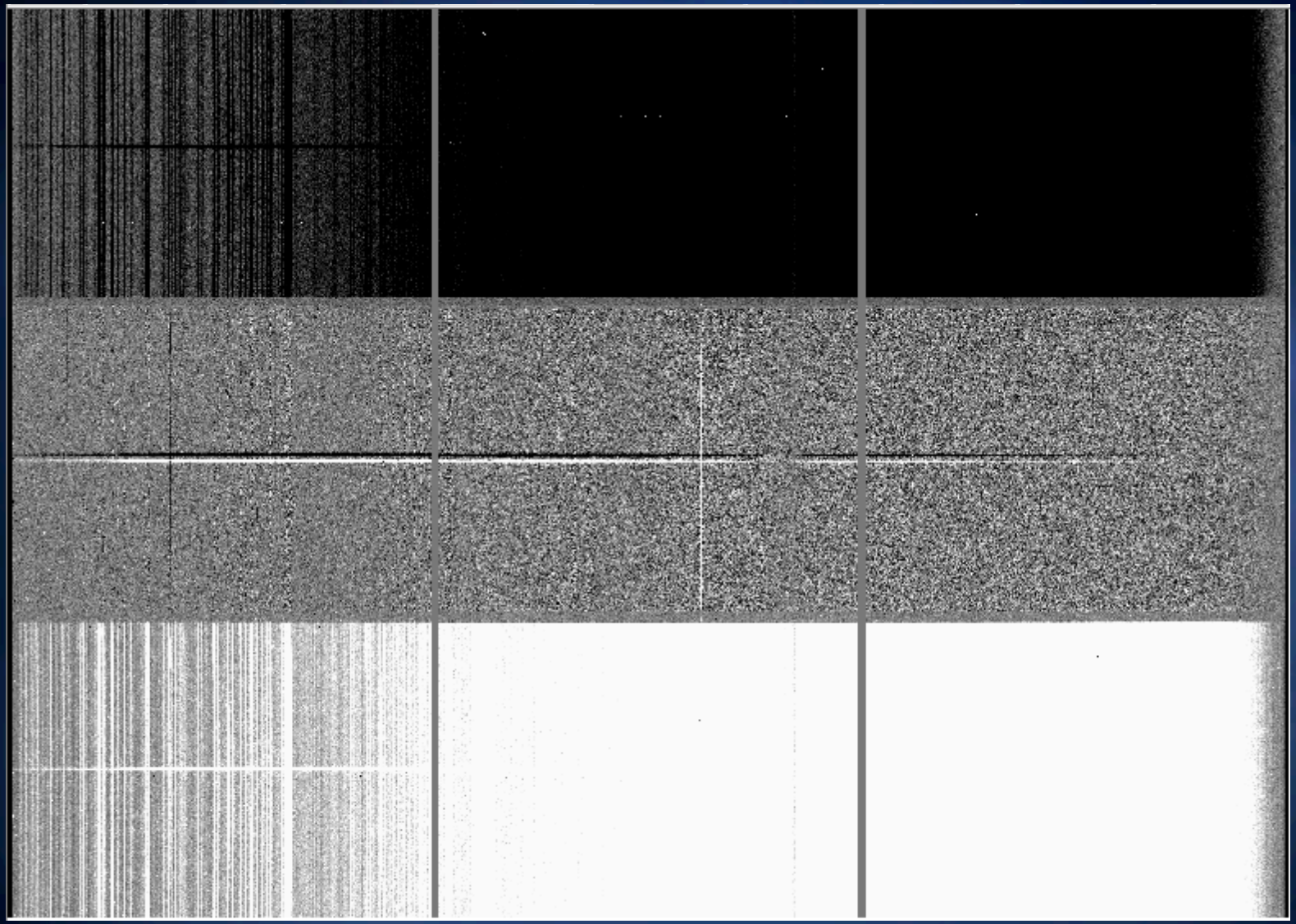
gnsskysub("science_810",
outimages="science_810_skysub",
fl_fixnc+,logfile=gmos.logfile)

science_810: bias corrected, dark subtracted, flat fielded, overscan corrected and trimmed science image (810nm)

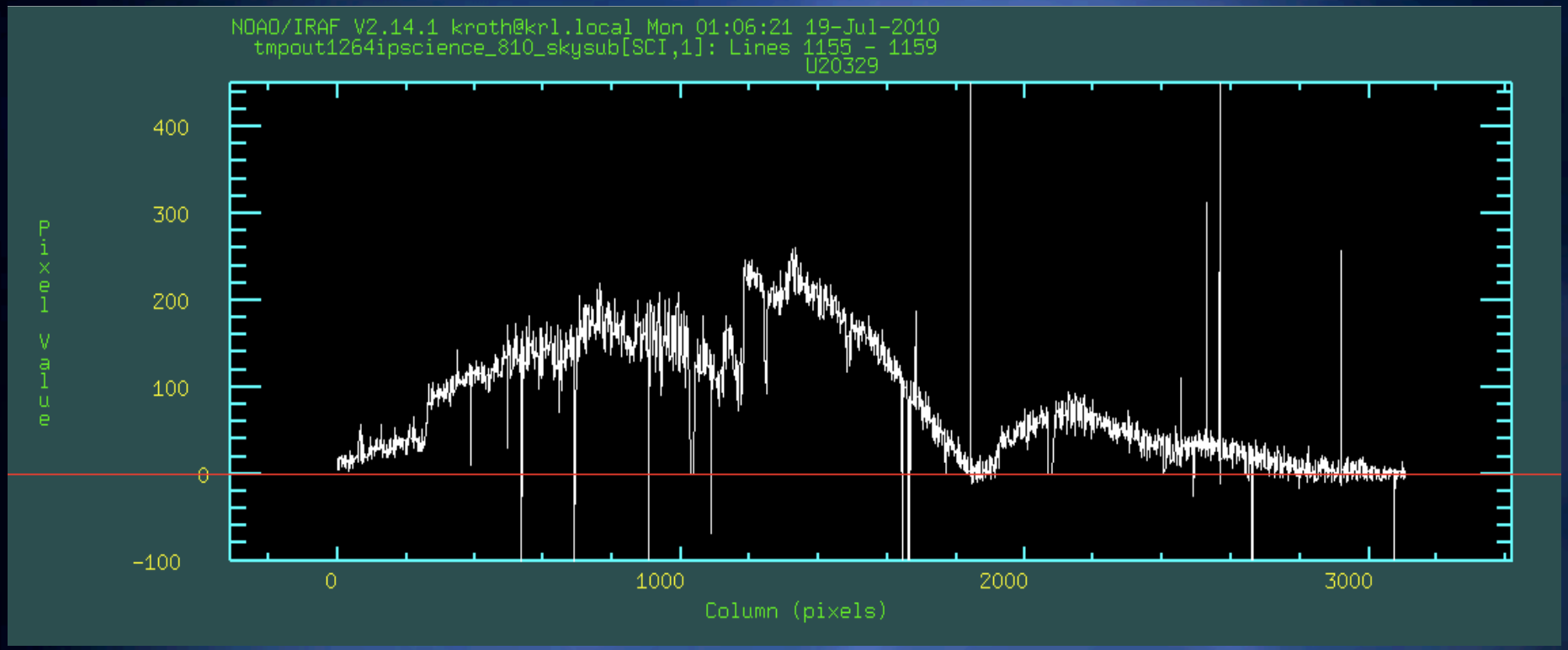
outimages="science_810_skysub": output sky subtracted image, still MEF with separate extensions for each detector, variance and data quality planes propagated (no fl_vardq parameter for this task*)

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.

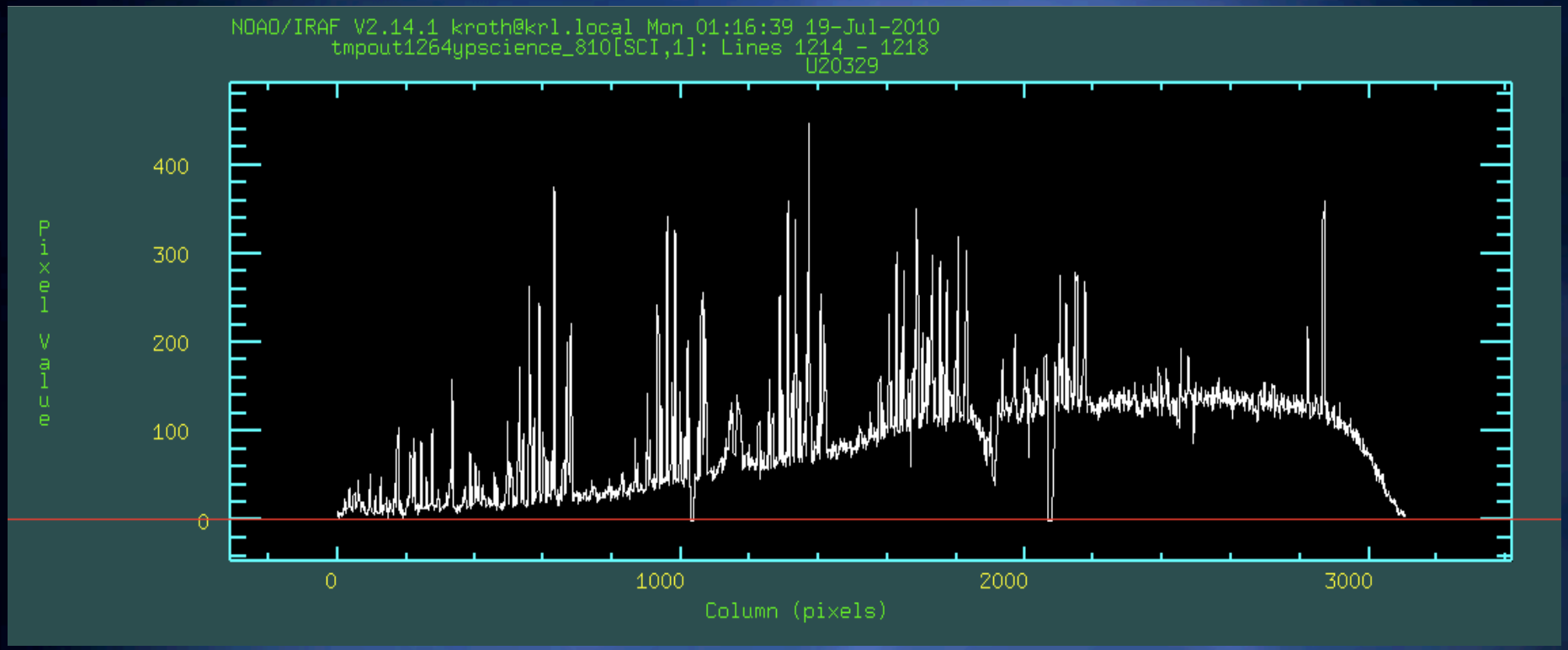
*Kathleen confirms that the gnsskysub task has *not* been modified to support variance and data quality planes, the variance and data quality planes in the output image "science_810_skysub" have not been modified but simply copied from the input image "science_810"



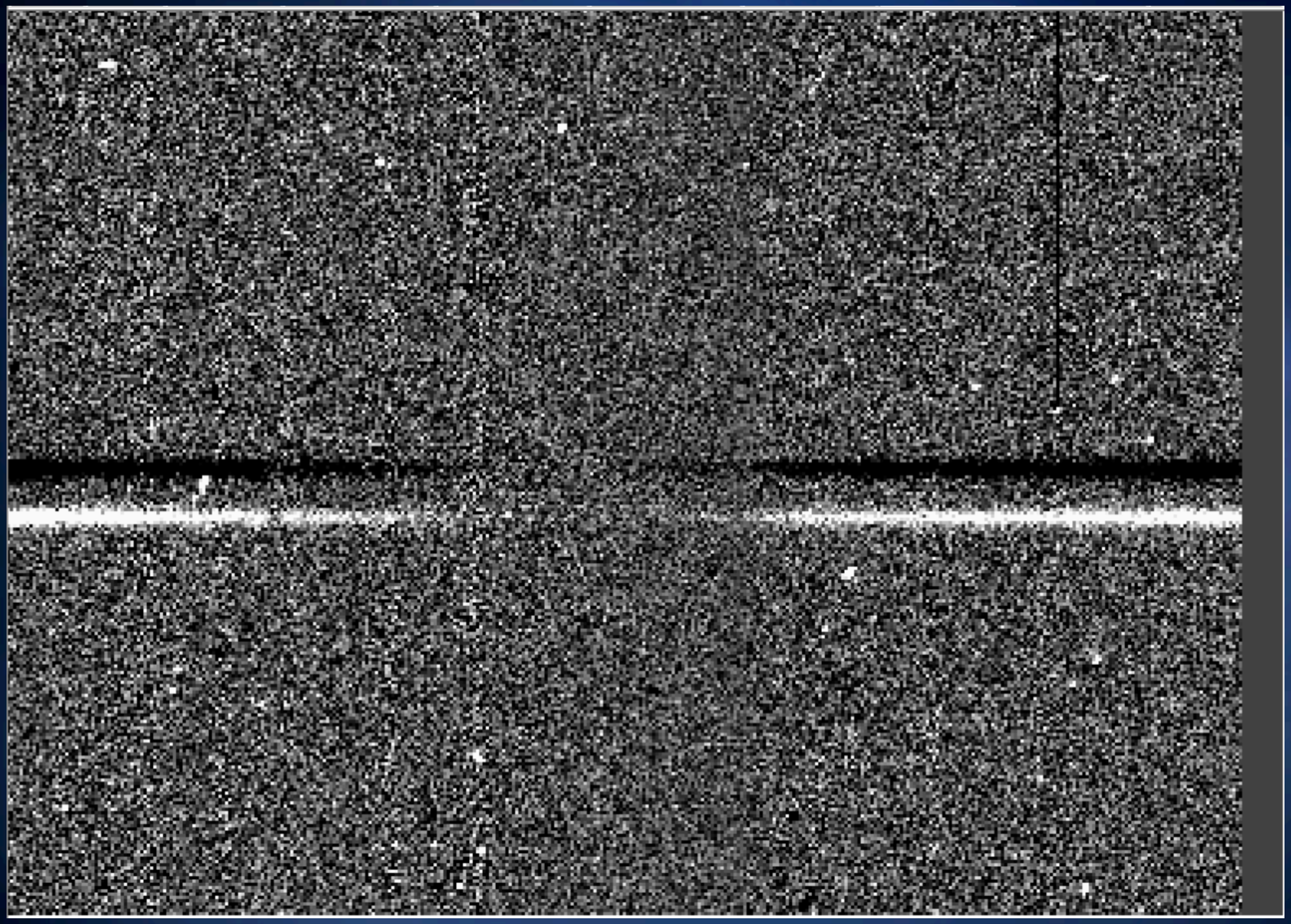
Bias corrected, dark subtracted, flat fielded, overscan subtracted, trimmed, sky subtracted Nod & Shuffle longslit spectral image (810nm, nod q = ± 1 arcsec).



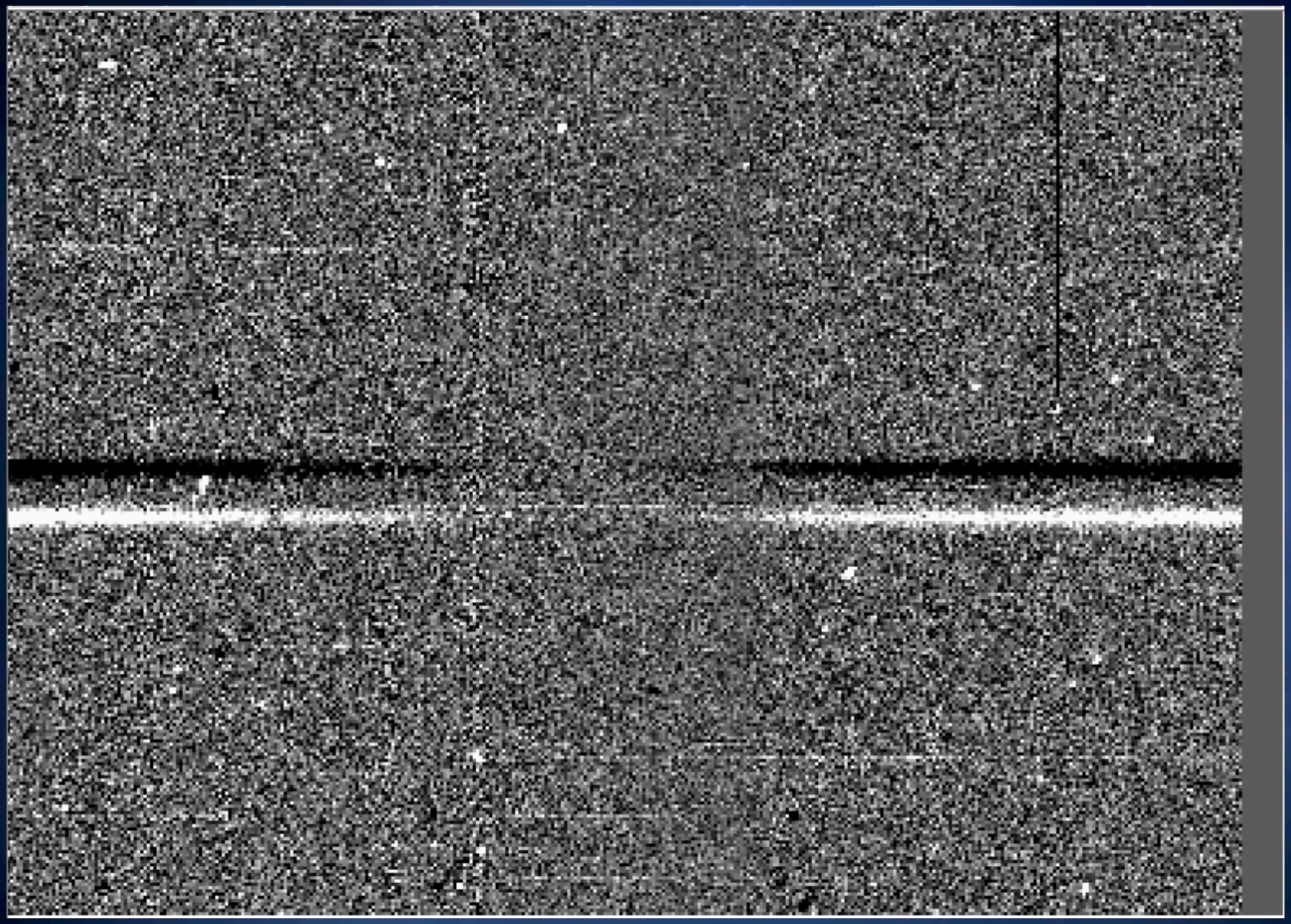
Line plot of sky subtracted reduced image. Five rows summed, no cosmic ray rejection.



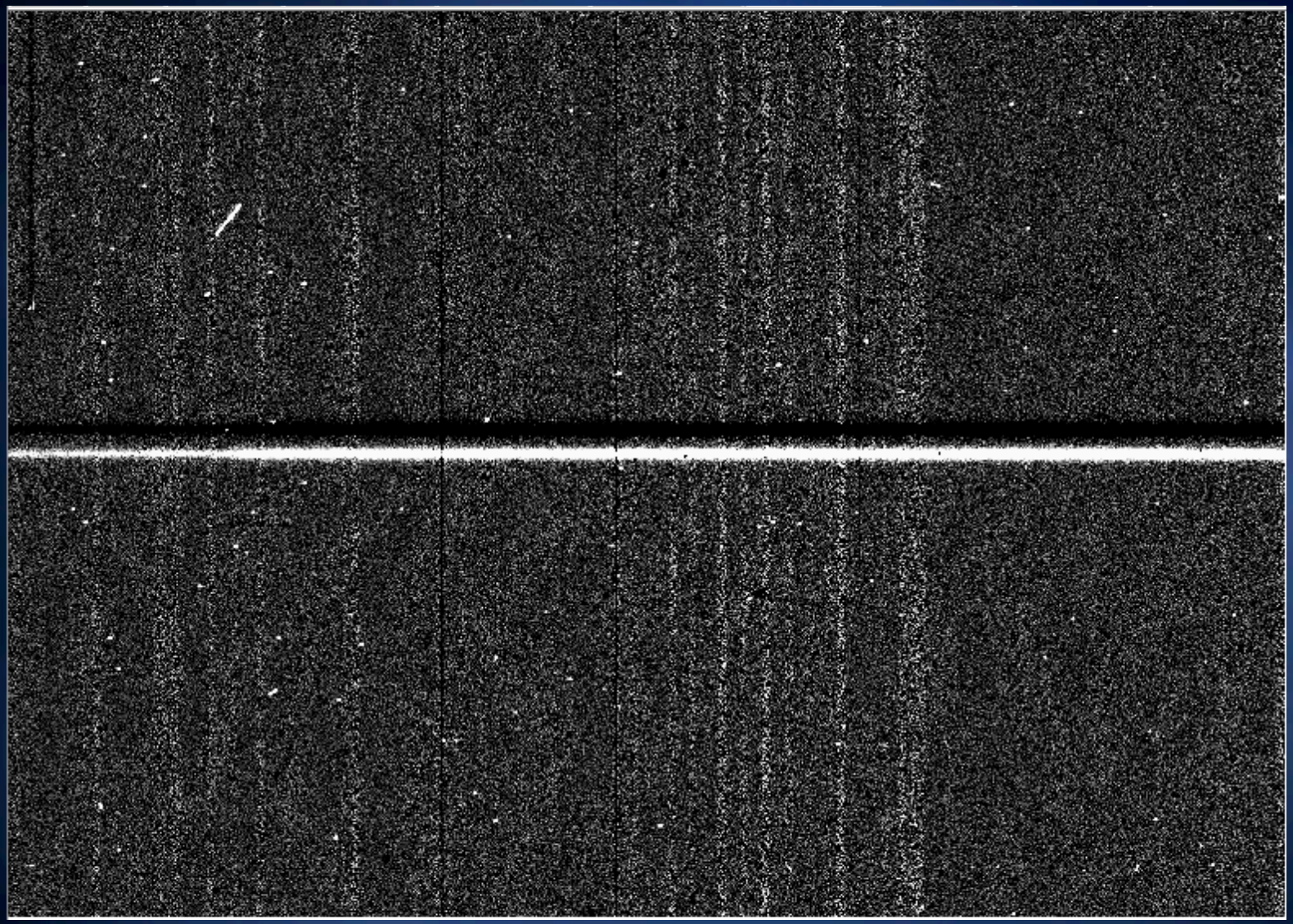
Line plot of sky adjacent to source. Five rows summed, no cosmic ray rejection. Tail off of sky continuum in the blue (right) is due to the RG610 second order blocking filter.



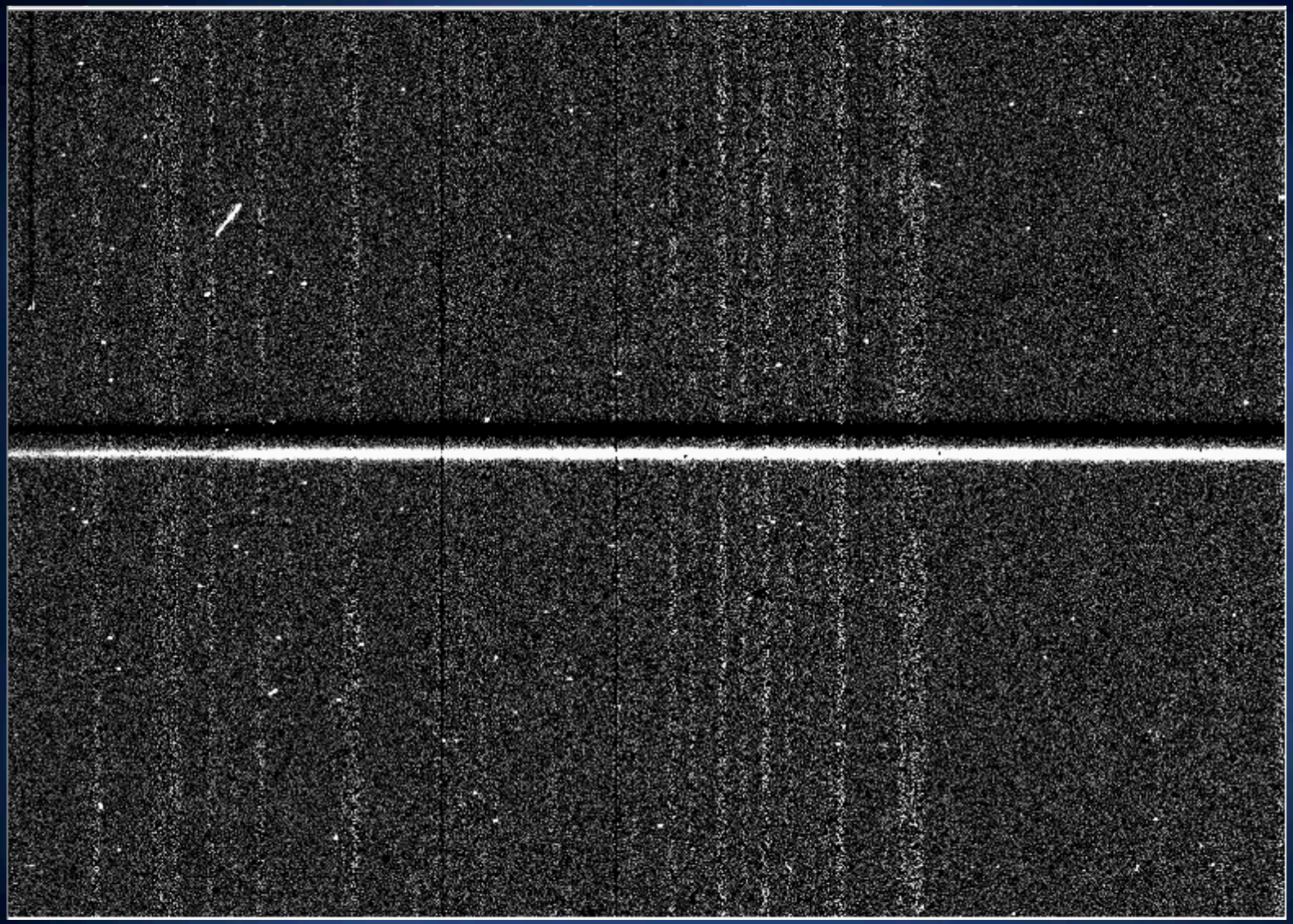
Zoom of reduced spectral image where source spectrum is weak and charge traps were prevalent.



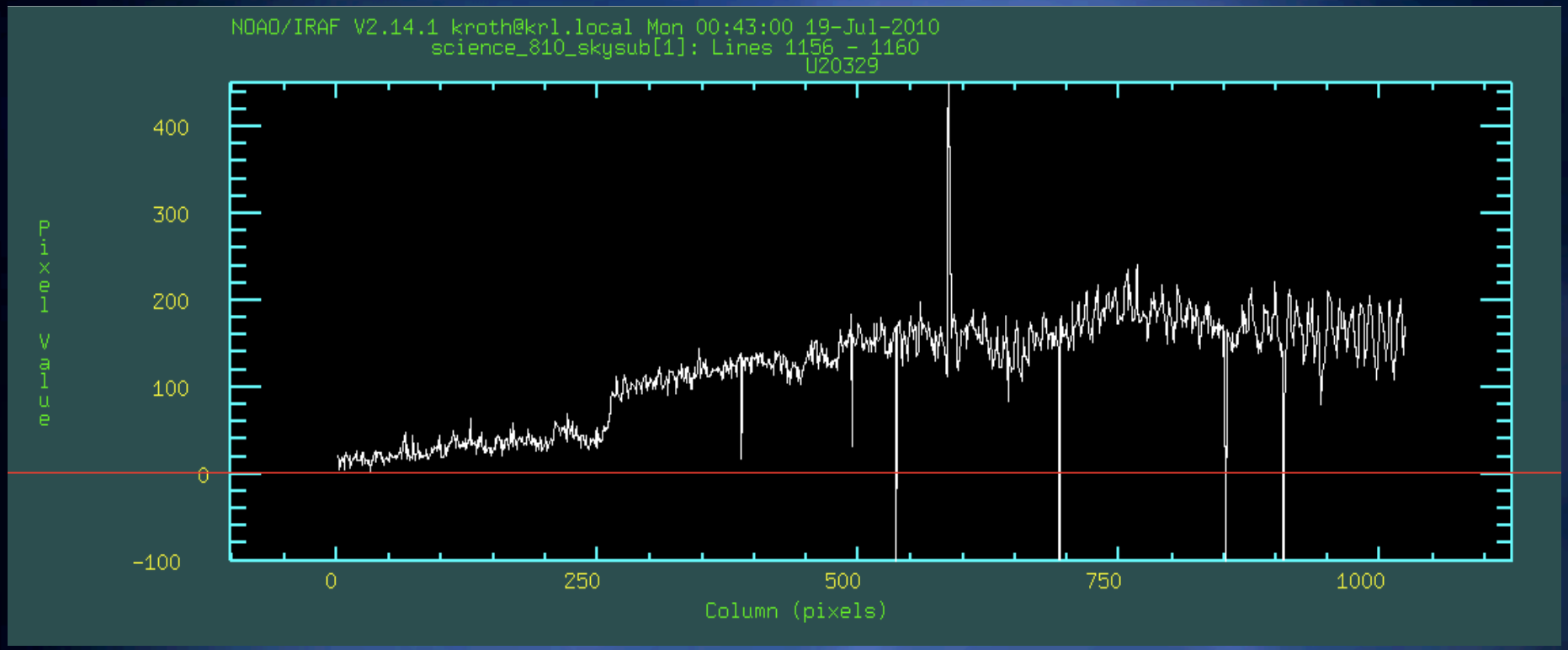
Zoom of the same region of image reduced identically except for having no dark subtraction.



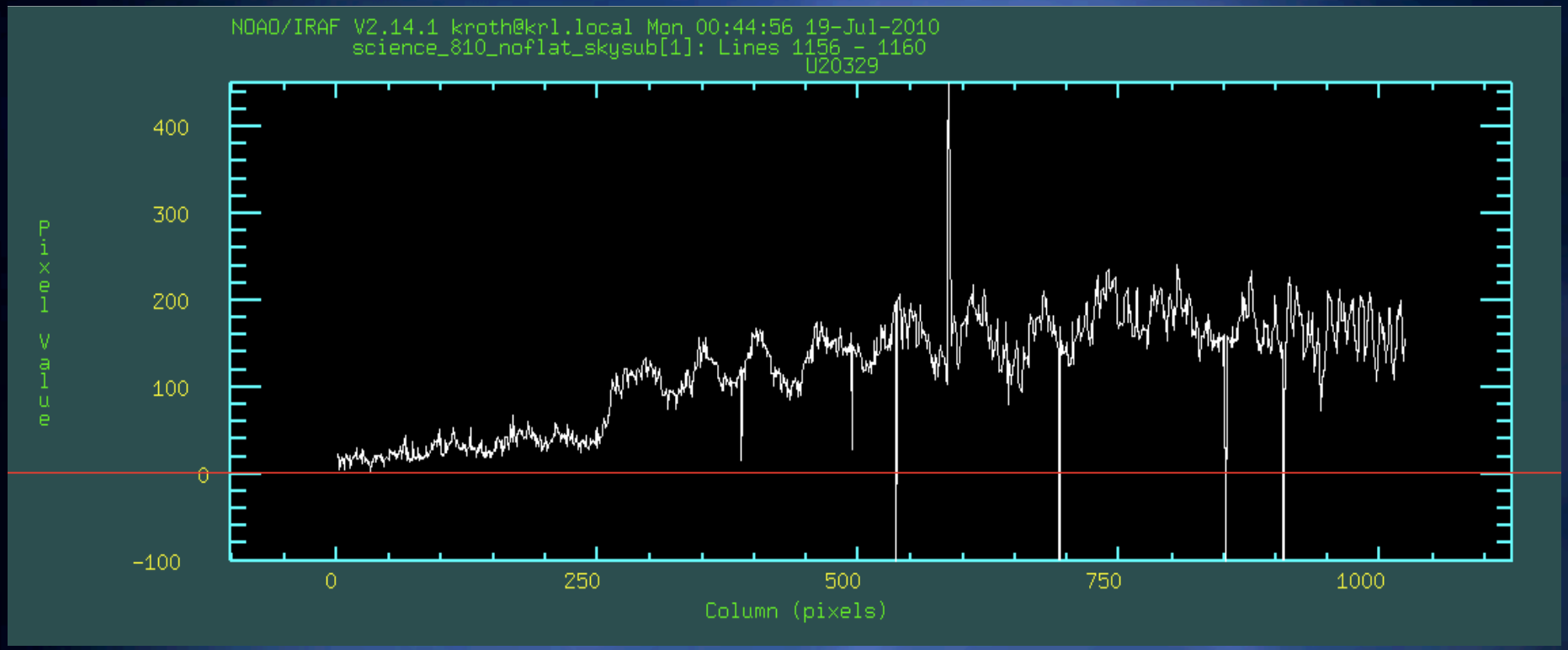
Sky subtracted fully reduced image, zoom of the far red wavelength region on CCD1 where fringing was strongest.



Sky subtracted reduced image except for having no flat fielding, zoom of the far red wavelength region on CCD1 where fringing was strongest.



Line plot, 5 rows summed, of fully reduced sky subtracted image (CCD1 only).



Line plot, 5 rows summed, of reduced sky subtracted image except for flat fielding (CCD1 only).

Cosmic Ray Rejection

Be Careful! It is much easier to obtain multiple exposures with the same parameters (spatial position, central wavelength) and median combine them for cosmic ray rejection. This is not always practical.

```
gscrrej("science_810_skysub","science_810_skysub_crrej",
        datares=4.0,fnsigma=8.0,niter=5,tnsigma=10.0,
        fl_inter+,logfile=gmos.logfile)
```

science_810_skysub_crrej: output image with cosmic rays rejected (no fl_vardq parameter for this task, only science extensions affected*)

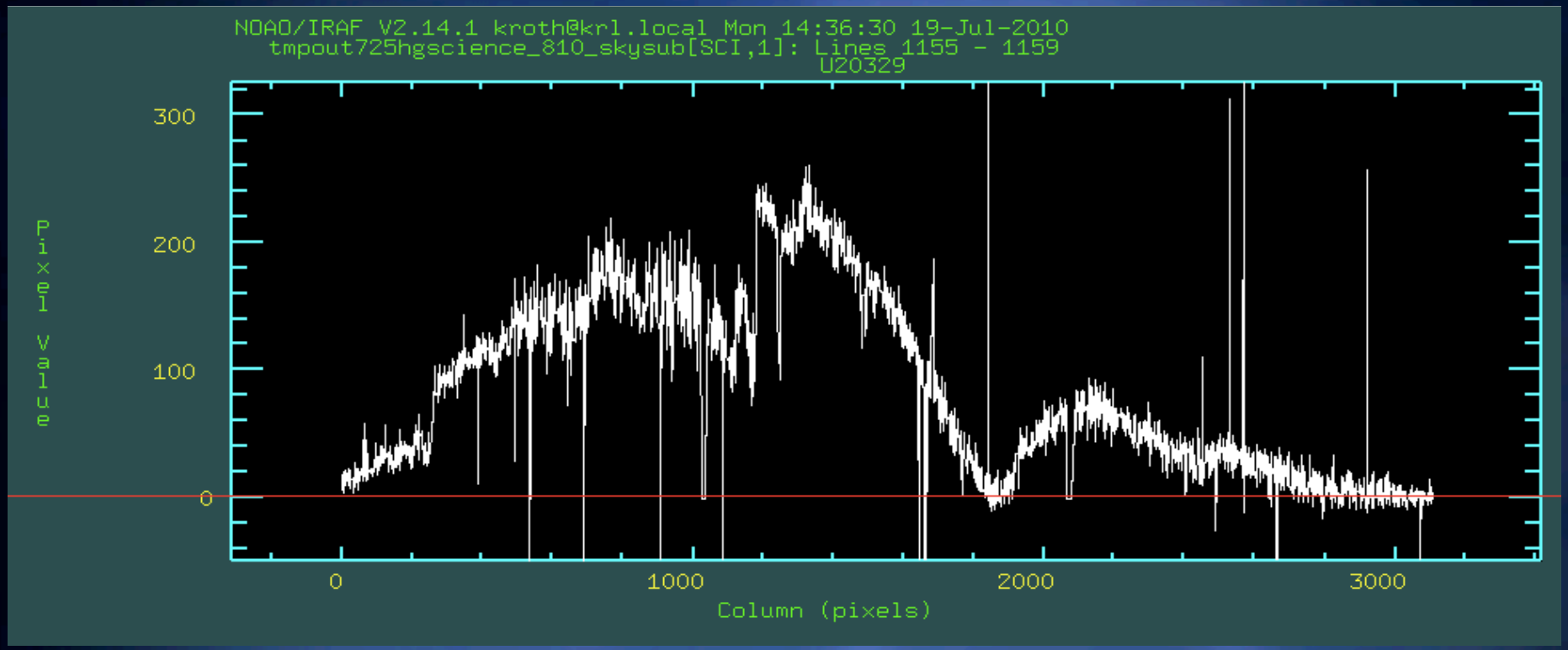
datares=4.0: instrumental spectral FWHM

fnsigma=8: sigma rejection for spline fit

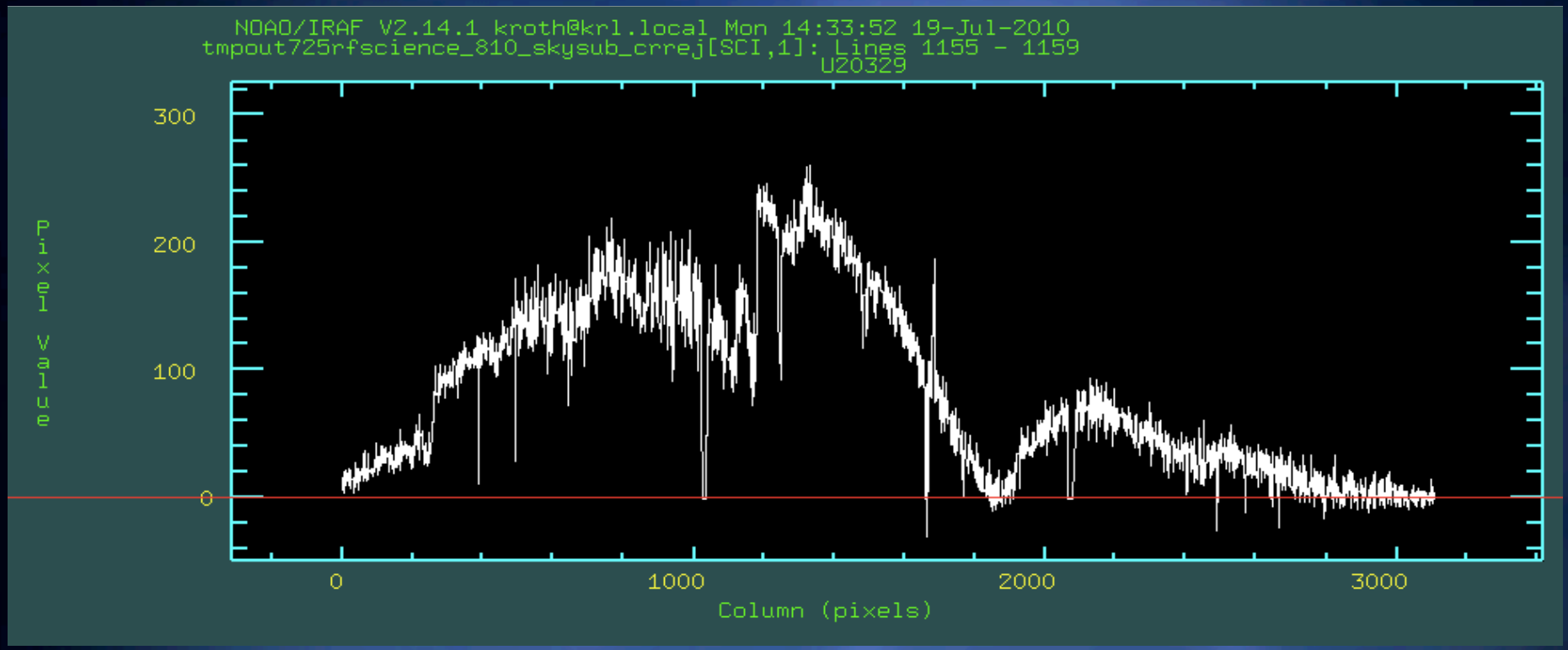
niter=5: number of fit iterations

tnsigma=10.0: sigma rejection for pixel replacement

*Ideally the data quality plane would be updated to flag the pixels that have been rejected by the gscrrej task, this has not been implemented.



Line plot of sky subtracted reduced image prior to cosmic ray rejection. Five rows summed.



Line plot of cosmic ray rejected sky subtracted reduced image. Five rows summed.

```
gsreduce("science_810_skysub_crrej",
        logfile=gmos.logfile,fl_over-,fl_trim-,fl_bias-,
        fl_dark-,fl_flat-,fl_gmosaic+,fl_fixpix+,
        fl_gsappwave+,fl_cut+,fl_title-,fl_vardq+)
```

science_810_skysub_crrej: reduced science image (810nm)

fl_over-,fl_trim-,fl_bias-,fl_dark-,fl_flat-: all the basic reductions already done, may not be necessary to specify this on the command line

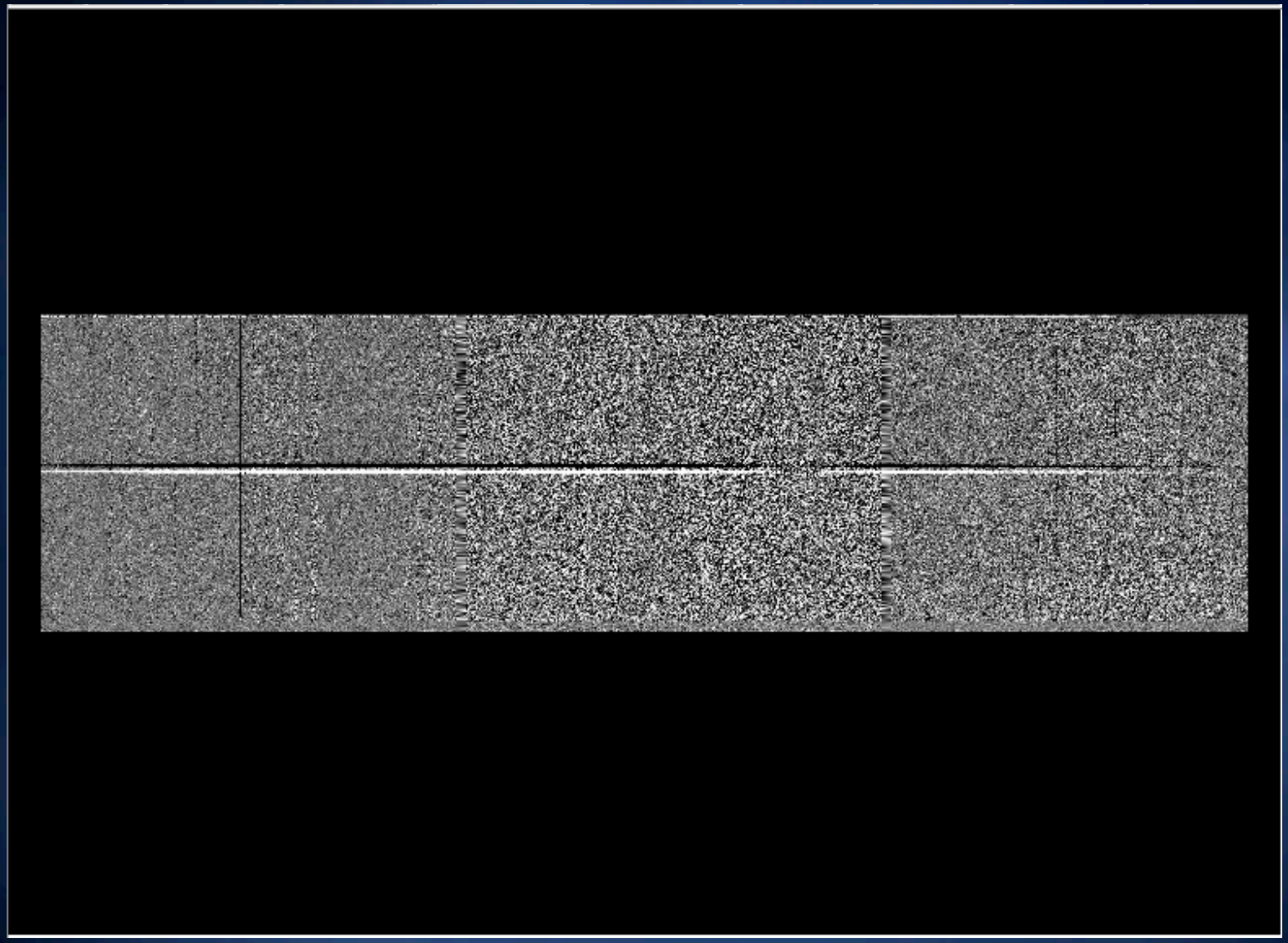
fl_gmosaic+: mosaic the three science extensions into one extension. Uses the known distortion mapping, interpolates CCD1 and CCD3 relative to CCD2

fl_gsappwave+: apply a first order wavelength solution based on the header values for grating, central wavelength and focal plane mask

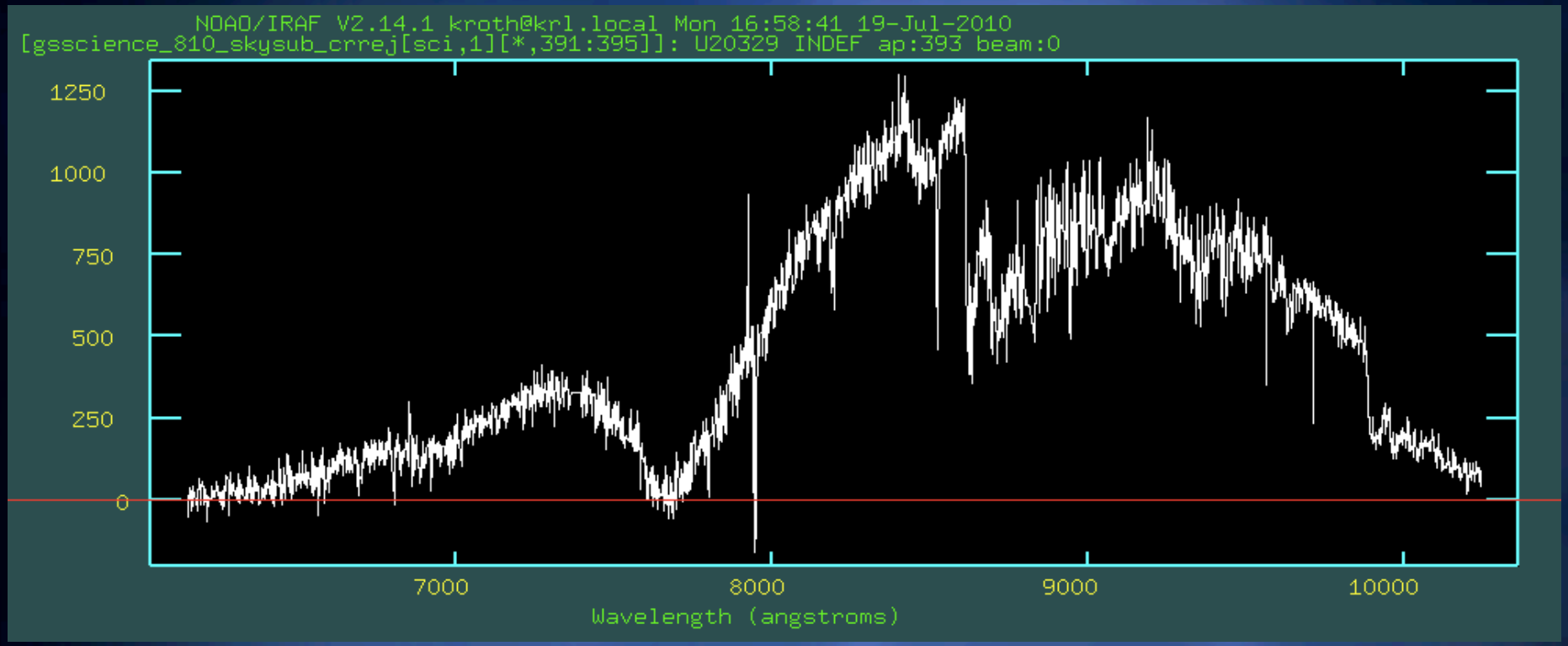
fl_cut+: cut individual slits into separate extensions, for longslit this results in only one science extension and throws away the area on the detector not covered by the slit

fl_title-: for MOS data this replaces the object keyword for the science extension with the object ID from the MDF. Since for longslit data only one slit is in use this is not necessary

fl_vardq+: propagate all changes to variance and data quality planes



Science image after final pass through gsreduce. The noise is smoothed in CCD1 and CCD2 due to gsmosaic interpolation. The extra pixels beyond the length of the NS0.75arcsec longslit have been thrown away due to gscut, using filter and grating wavelength ranges in gmos$data/GMOSfilters.dat and gmos$data.



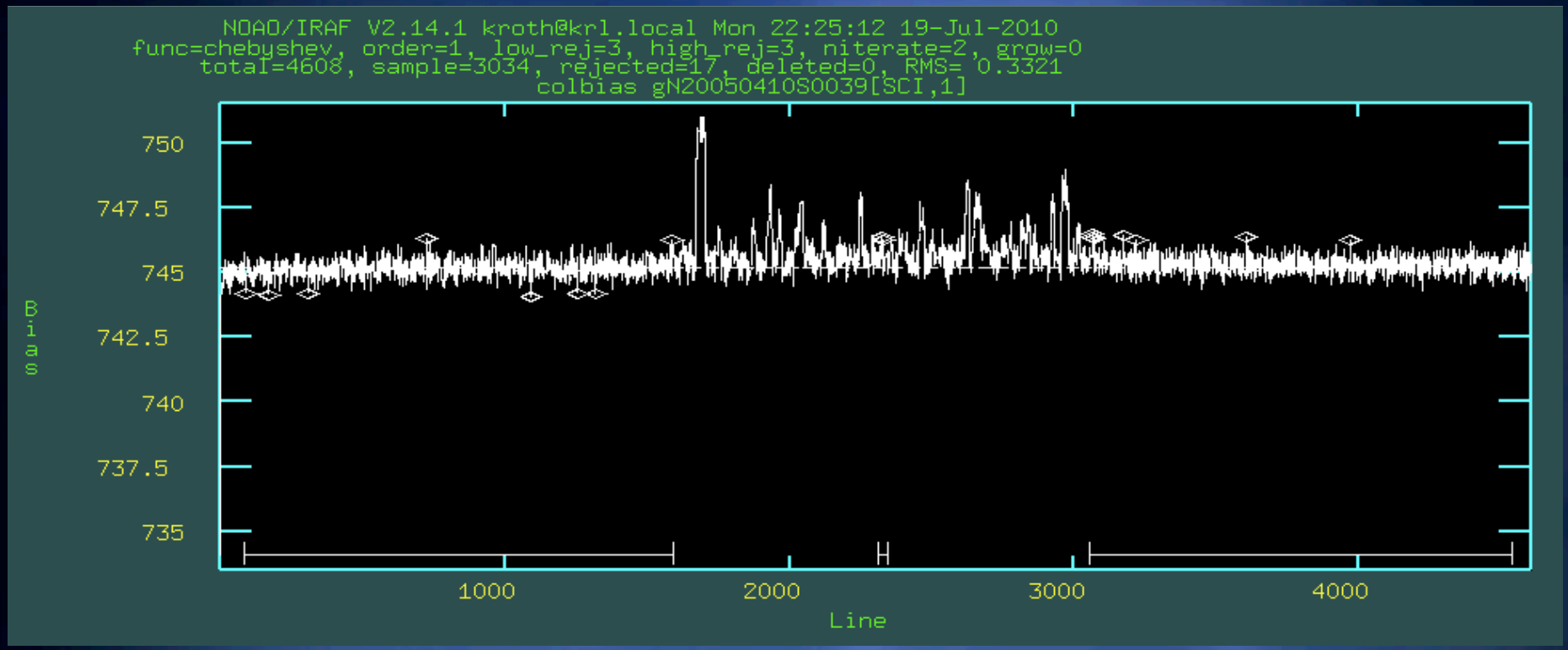
Line plot (5 rows summed) of final reduced science image (810nm), approximate wavelength solution applied (dispersion direction flipped).

Not covered

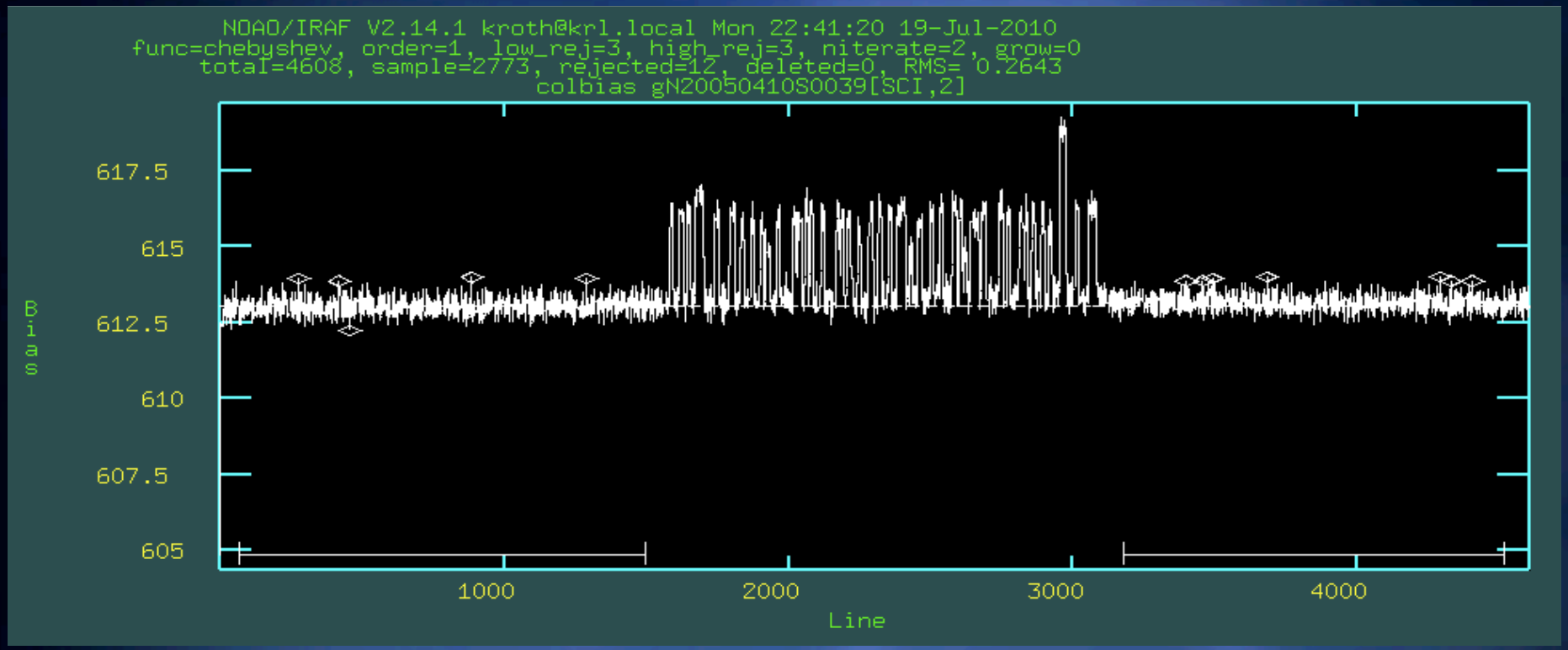
- Using a bad pixel mask: "Bad pixel mask filename is an empty string Only saturated pixels will be flagged"
- Propagating cosmic ray rejection information to data quality plane.
- Wavelength solution, transformation, and 1d spectrum extraction (these steps are identical to those for normal longslit or MOS data with the exception that longslit or MOS data where the object is nodded along the slit (either band or microshuffling modes) will have two spectra that need extracting (one positive, one negative).
- Combination of spectra taken at different central wavelengths (scombine can be used to combine simple fits files with different central wavelengths, no MEF equivalent?)
- Flux calibration

MOS/longslit differences

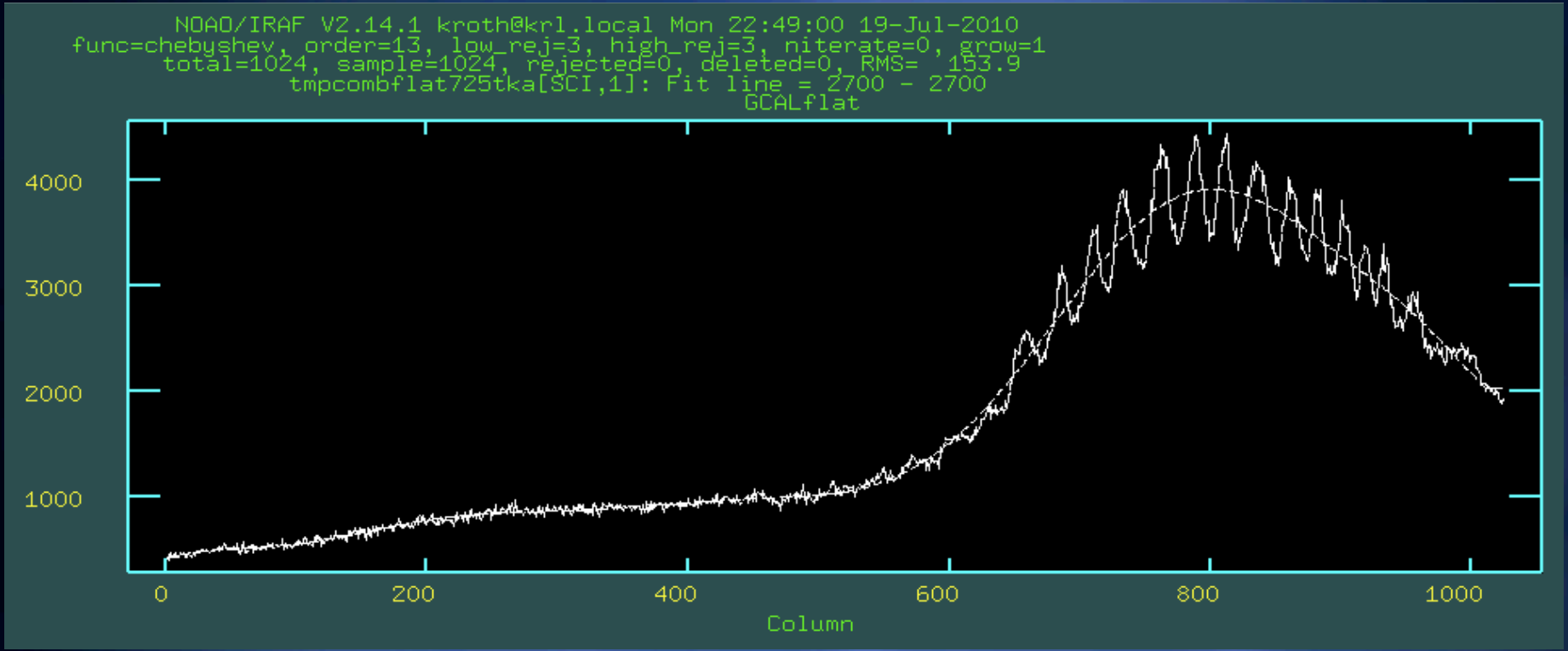
- Must also retrieve MDF file from GSA and include directory in calls to gsflat, gsreduce (eg. mdfdir="rawdata$")
- In gscut (or alternatively when selecting fl_cut+ in gsreduce) should select fl_title+ so that science extension OBJECT header keyword is overwritten to the object ID from the MDF.
- After gscut there will be a separate science extension (with associated var and DQ extensions) for every science object in the MDF.
- These differences have nothing to do with Nod & Shuffle.



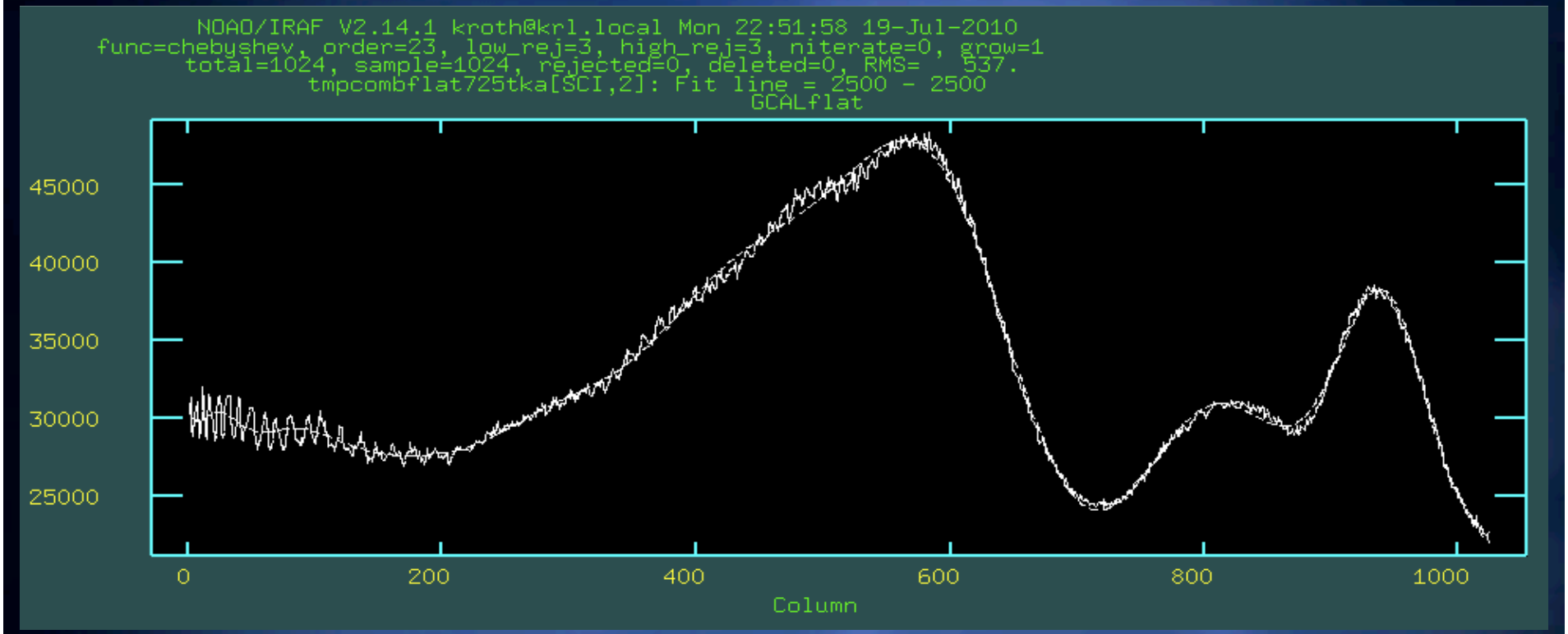
Overscan fit to spectral GCALflats for Nod & Shuffle MOS data will look different from longslit data because the detector is only illuminated where there are slitlets (may be spread across the detector for micro-shuffled masks)



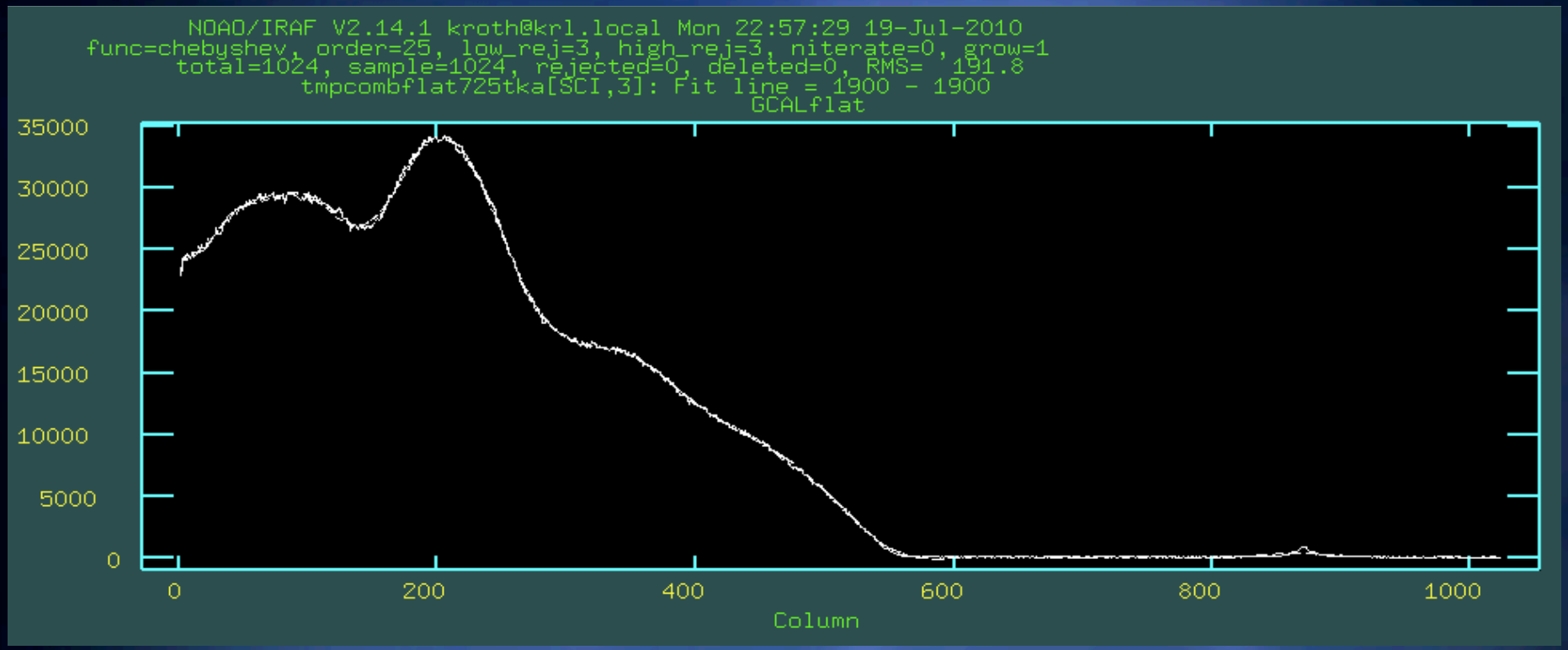
Overscan fits may look different for different CCDs because of the variable illumination depending on the position of the slit in the GMOS focal plane (especially true with R150 data or any band limited spectral configuration).



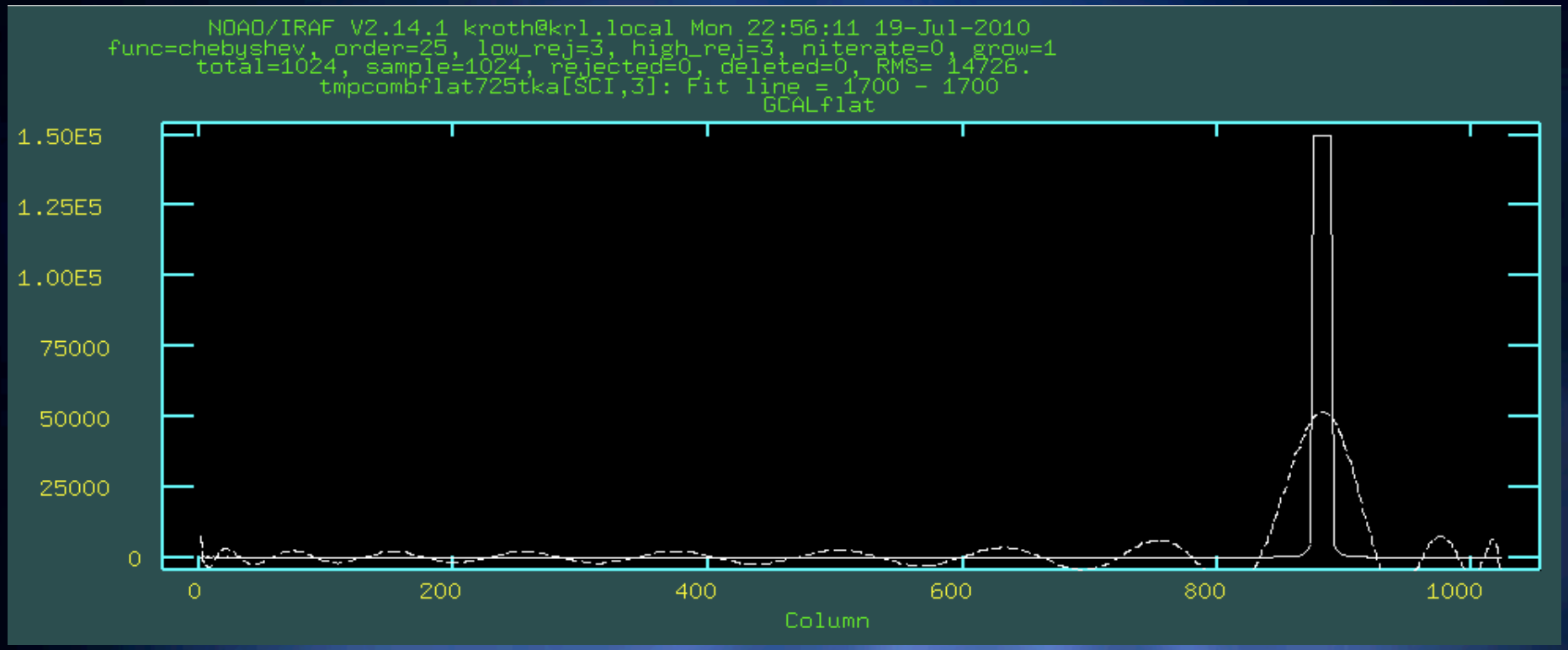
Spectral flat fitting is challenging for MOS data when using fl_detec+ because since the slit positions change different spectral regions (requiring different order fits) will land on different CCDs. Sometimes creativity may be needed (creating more than one spectral flat and reducing the images more than once). The limitation is that the function order is associated with the CCD, not with each slit per CCD.



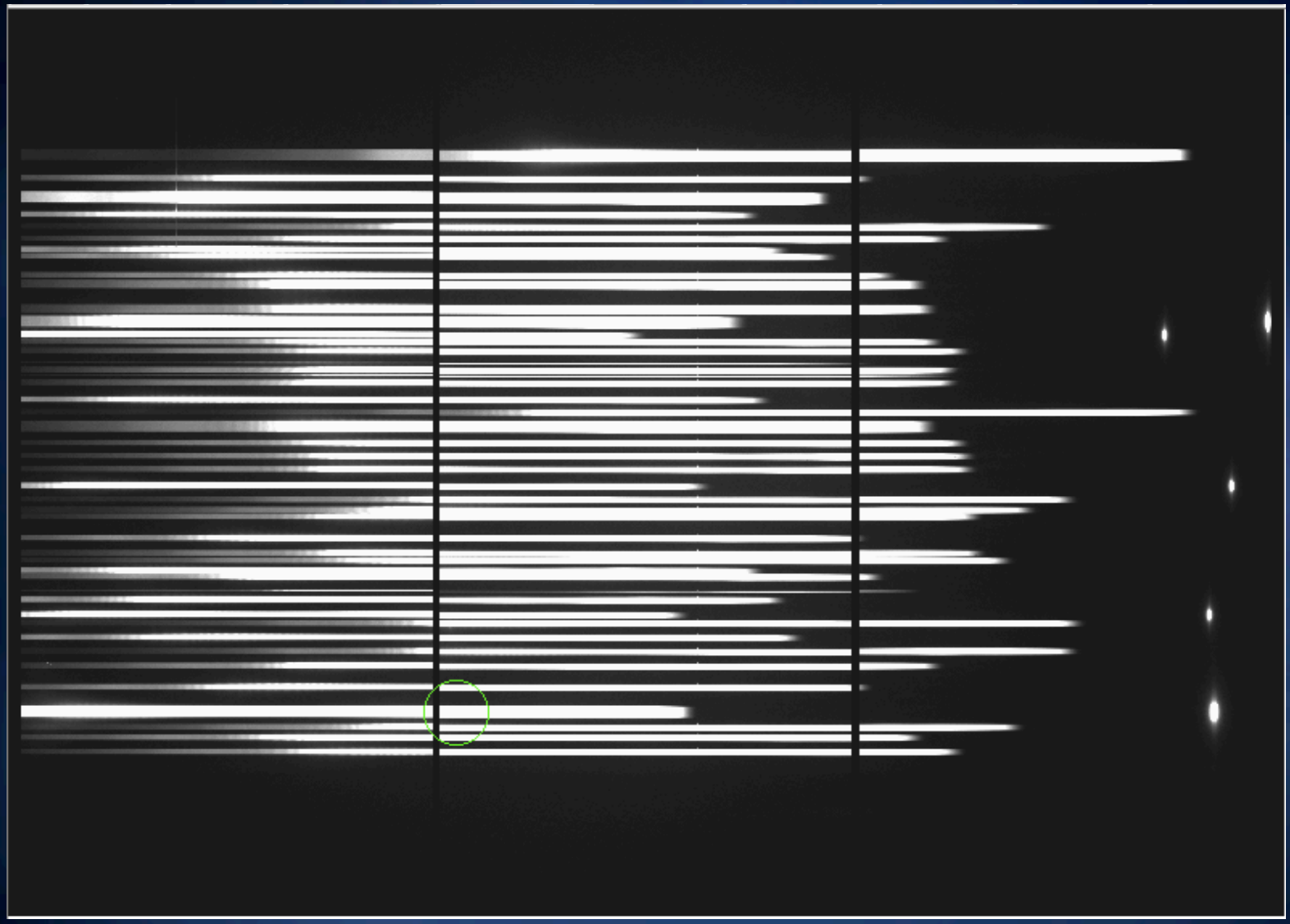
CCD2 most likely to contain the bulk of the R150 spectrum, the blue end needs high order (little fringing to worry about).



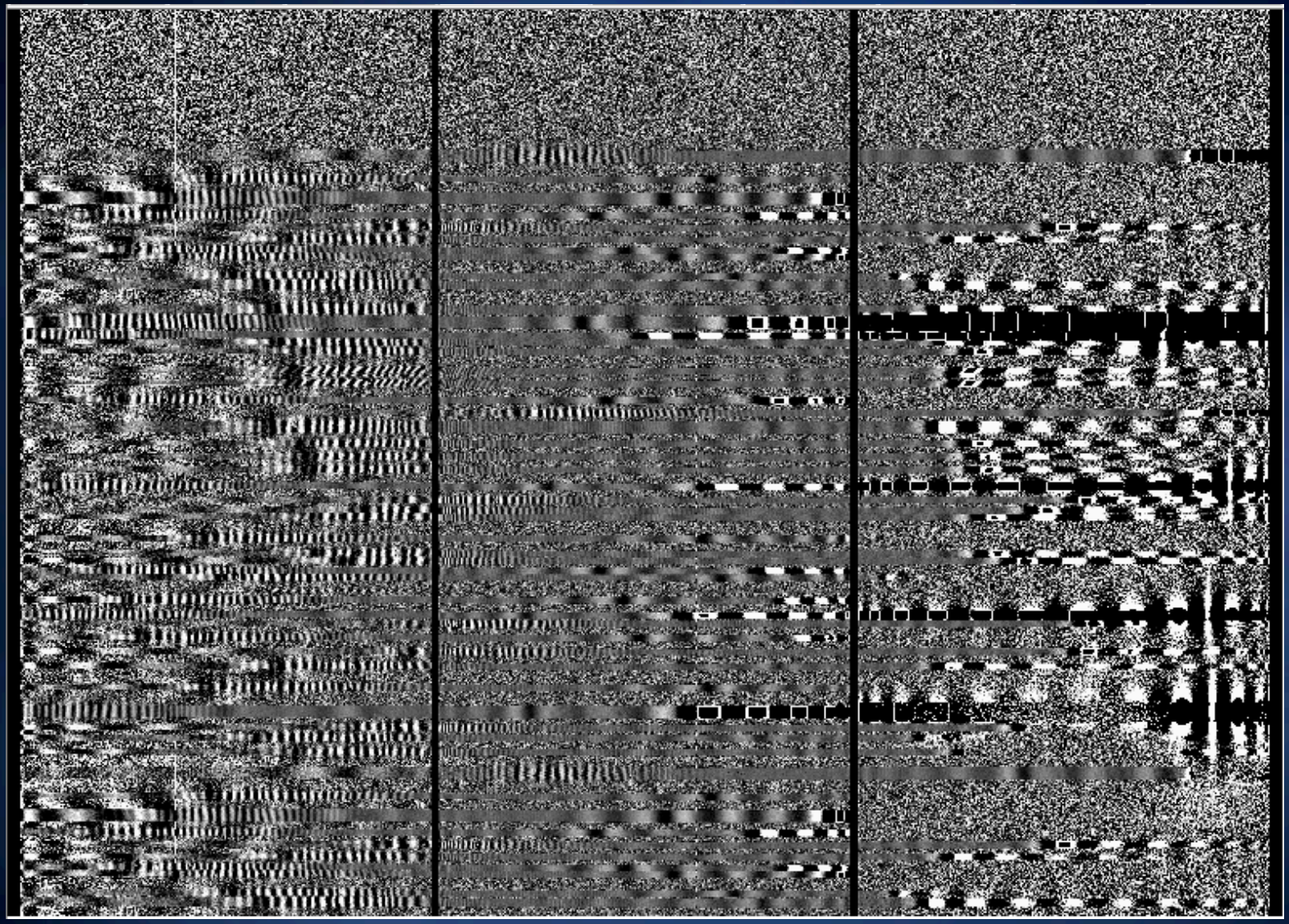
CCD3 most likely only contains the blue end of the spectrum...



... but also likely to contain the zero order image (and second order if no blocking filter used). The bright zero order image can really mess up the fit. Suggestion from Knut: mask out the zero-order images in the GCALflat so that they will not mess up the fit. These regions are already marked as bad pixels in the DQ extension, but gsflat does not incorporate that information and fits the whole spectrum by default. Suggestion from Frank: Why not just fit the GCALflat with a constant and not remove any of the shape at this stage? This will work but then requires one to flux calibrate the data with a standard star in order to remove the GCAL spectral signatures. In the end, this effect is fairly low-level and in some cases you may choose to not flatfield or flux calibrate your data (if you are only after redshifts or relative absorption, for example).



and a perfectly fine looking MOS R150 GCALflat (note the zero order images on the right-hand side of CCD3)...



…can end up looking positively dreadful. But don't be scared; it looks worse than it is. The really awful bits correspond to regions where there is no flux so it really may make no difference at all. Can always choose not to flatfield, but if targets have bright continuum may need to get creative (could be painful).

gnscombine("science_DTA0,science_DTA6,science_DTAn6", offsets="DTAoffsets",outimage="science_combined", logfile=gmos.logfile)

science_DTA0,science_DTA6,science_DTAn6: list of input files which have been processed with gsreduce (gprepare'd, overscan corrected, bias subtracted, dark subtracted and flat fielded). Data should not be mosaic'd as any pixel interpolation will compromise the sky subtraction.

offsets="DTAoffsets": text file, one line per input file with x and y shift (in pixels) separated by a space character. The optional x shift is measured by hand and useful for removing small shifts in wavelength solution (flexure, spectral shift). The y shift corresponds to the opposite of the DTA-X offset dither position used for each image. The x and y shifts must only be integer pixels, as any interpolation will compromise the sky subtraction.

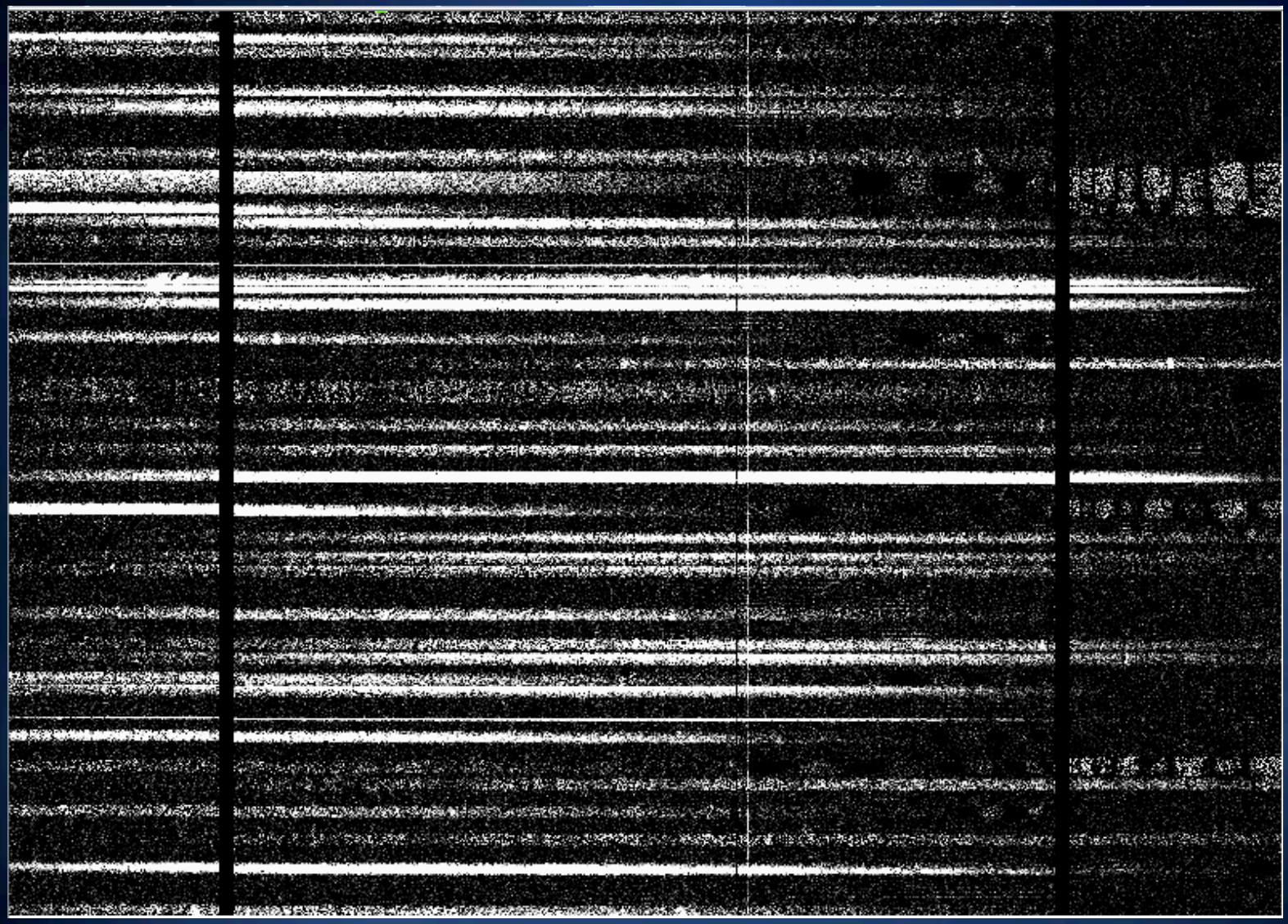
outimage="science_combined": output file, sky subtracted, optimally combined and cosmic ray rejected. Variance and DQ extensions are not supported at this time and will be stripped from the output image even if they existed in the input files.

DTA offsets

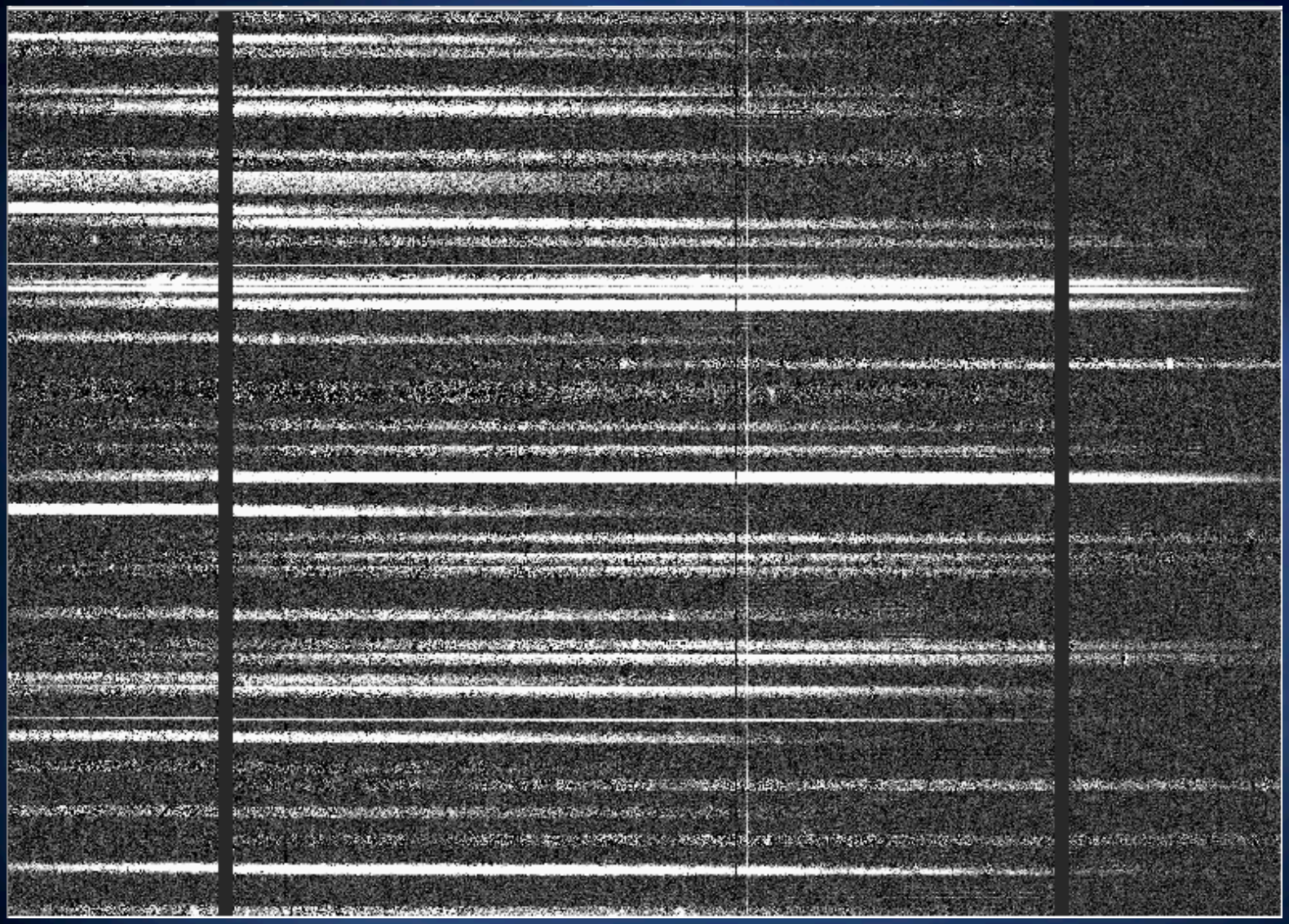
- Are they in the header? Sort of…
- The header keyword DTAX does give the current value of the X-position of the detector translation stage. BUT…
  - The value is in μm instead of pixels (13.5 μm pixels)
  - The DTA is tracking to compensate for flexure within the instrument so the change in DTAX between two subsequent exposures will not exactly equal the offset in pixels
- gsN20050410S0040.fits[0],DTAX = 84.8, DTAY = 94.4
  gsN20050410S0041.fits[0],DTAX = 167.6, DTAY = 95.84
  gsN20050410S0044.fits[0],DTAX = 7.6, DTAY = 96.64
- GMOS DTA coordinate frame rotated 90 degress wrt images!
- The y-offsets given in your offsets file (eg. DTAoffsets) have the opposite sign of the DTA-xoffsets specified in the OT sequence.
- gmos> cat DTAoffsets
  0 0
  0 -6
  0 6

Sequence | Text Sequence | Timeline

Data Label	Class	Exposure Time	Dta XOffset	Object
GN-2005A-Q-40-5-001	Nighttime Partner Calibration	1.0	0	GCALflat
GN-2005A-Q-40-5-002	Science	60.0	0	Q0809+483(O3,O4)
GN-2005A-Q-40-5-003	Science	60.0	6	Q0809+483(O3,O4)
GN-2005A-Q-40-5-004	Nighttime Partner Calibration	1.0	6	GCALflat
GN-2005A-Q-40-5-005	Nighttime Partner Calibration	1.0	-6	GCALflat
GN-2005A-Q-40-5-006	Science	60.0	-6	Q0809+483(O3,O4)



The final 2d sky subtracted cosmic ray rejected overscan, bias and dark subtracted flat fielded spectral image.



And here is the same image without the flatfielding. No bright continuum sources so flatfielding isn't necessary. Could manually flatfield any objects that show a continuum as necessary.

Enjoy!

- Final gsreduce call to gmosaic the data, cut the slits, and put the rough wavelength calibration.
- Unfortunately must use fl_vardq- since the output from gnscombine has lost the variance and DQ planes…
- Needed to use a yoffset parameter to have the cut extensions contain the data (tiny slits)
- Next is to wavelength calibrate 43 science extensions, trace and extract the spectra, and apply a relative flux calibration.
- Note: this MOS sequence was nodding off to sky so only one spectrum to extract per slitlet.