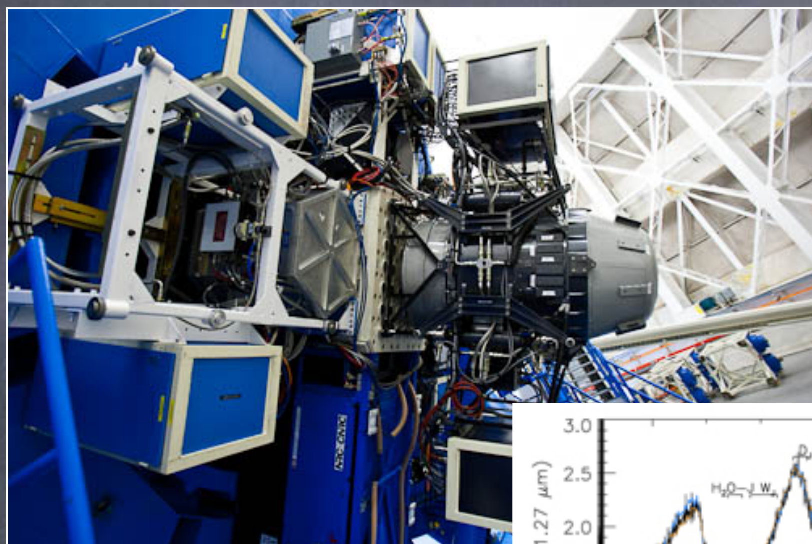
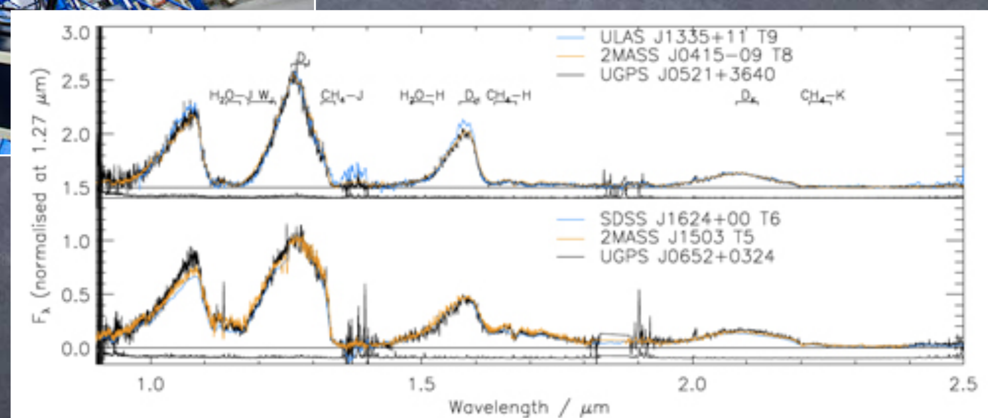
Reducing GNIRS data





Rachel Mason, GNIRS Instrument Scientist, October 27th 2011

What we'll cover

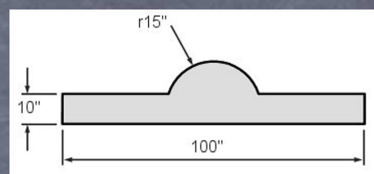
- Briefly: How GNIRS works & what GNIRS can do
- How to reduce XD data from GNIRS at GN
- Disclaimers
  - No single reduction procedure will be optimal for all data sets
  - Can't cover every possible aspect of the data – ask questions, look at the GNIRS web pages (esp. the "known issues" page)
    - www.gemini.edu/sciops/instruments/gnirs/

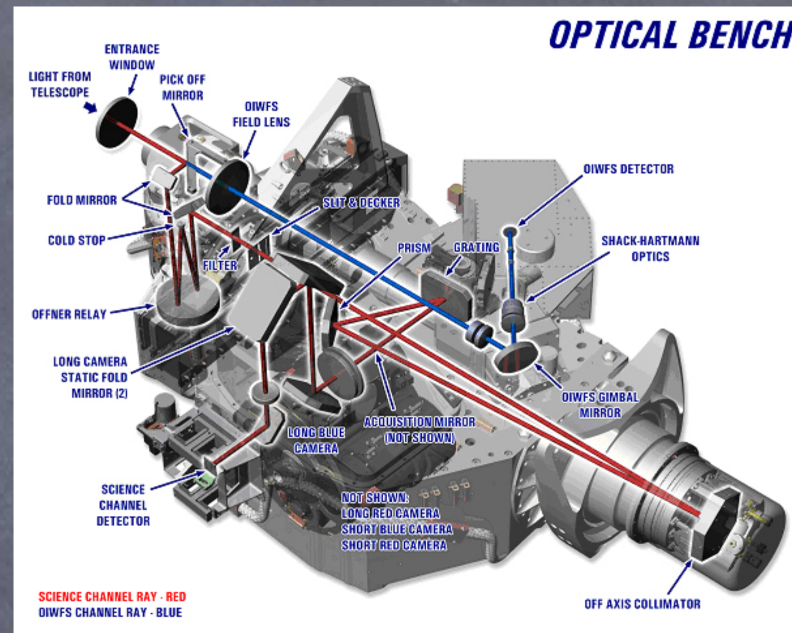
Where to get help

- About GNIRS
  - The Gemini web pages, your NGO, the helpdesk
- About data reduction
  - Within the Gemini/GNIRS IRAF package
    - Type "gnirsinfo" for general data reduction steps + info
    - Type "gnirsexamples help" for example scripts (v. similar to commands shown in this presentation)
  - Help pages for individual GNIRS IRAF tasks
  - Will put the worked example from this talk on the Gemini web pages
  - Submit a helpdesk request if having trouble

This is GNIRS

- Entry window
- Pickoff mirror → OIWFS (not commissioned
- Filter wheels (2)
- Slit & decker
- Acq mirror (dashed arrows to the step after Slit & decker and to Cameras (4))
- Prism turret
- Grating turret
- Cameras (4)
- Detector

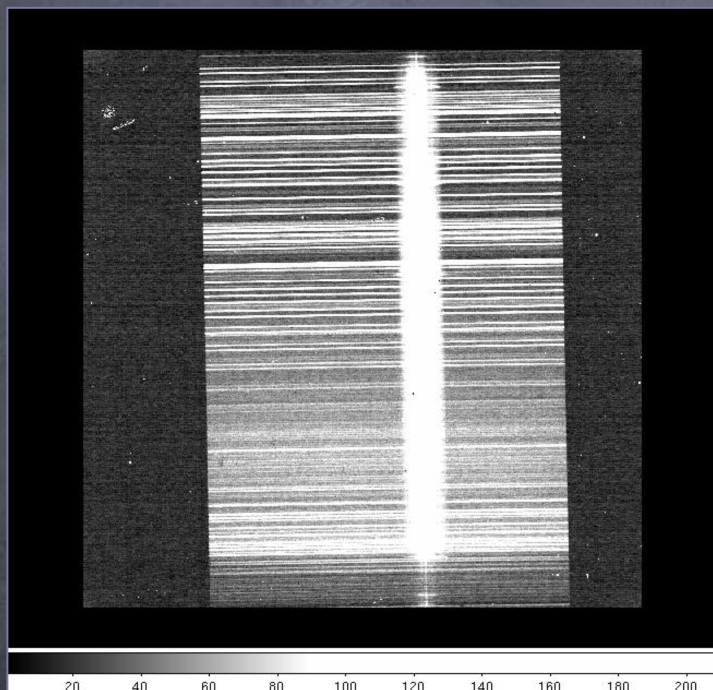


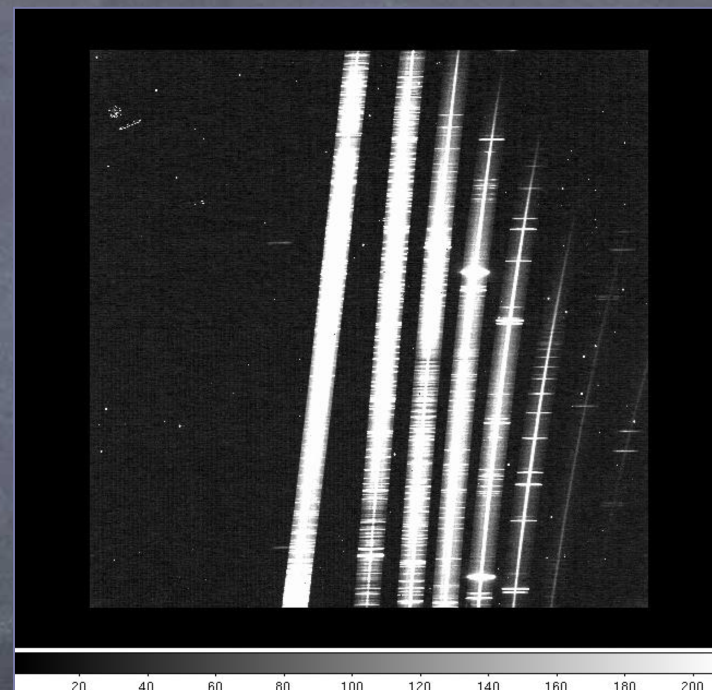


More details: www.gemini.edu/sciops/instruments/gnirs/documents/optical-path

Two basic modes: long-slit and XD

- Cross-dispersing (XD) prism in prism turret separates orders





Long-slit mode: 99” or 49” slit, 0.9 – 5 mm, single atmospheric window (or part thereof)

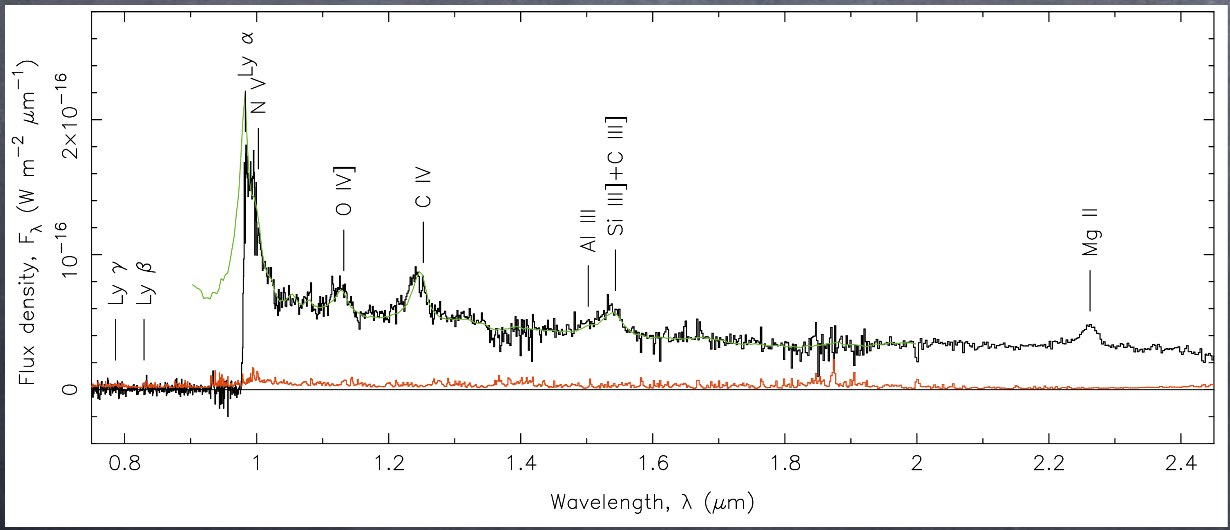
XD mode: 5” or 7” slit, 0.9 – 2.5 mm in one go (or bits of each order at high spectral resolution)

Many spatial and spectral resolution options

- Four cameras
  - "Long" cameras: 0.05"/pix
    - Long blue camera, 0.9 – 2.5 μm; long red camera, 3-5 μm
  - "Short" cameras: 0.15"/pix
    - Short blue camera, 0.9 – 2.5 μm; short red camera, 3-5 μm
- Three gratings
  - 10 l/mm, 32 l/mm, 111 l/mm
  - Spectral resolution depends on grating + camera
    - "Workhorse" SB/R+32 l/mm → R~1800
    - Highest spectral resolution: LB/R + 111 l/mm → R~18000
    - High angular, low(ish) spectral resolution: LB/R + 10 l/mm + Altair → FWHM~0.15", R~1800

Science uses

- Thermal IR long-slit observations of Solar System objects
- Cross-dispersed spectroscopy of z=7 quasar (below)
- And everything in between!



Mortlock et al. 2011, Nature

An example data set: NGC 4736

- NGC 4736 = M96; D=4.3 Mpc
- Post-starburst galaxy
- LINER galaxy
- 2 variable nuclear UV sources
  - AGN + ??

- Expect many NIR spectral features
  - Stellar absorption bands, e.g. CO, CN
  - H recombination, H_2, Fe, etc.
  - Dust continuum
- Observed in XD mode as poor weather "filler" observation

A "typical" observing sequence

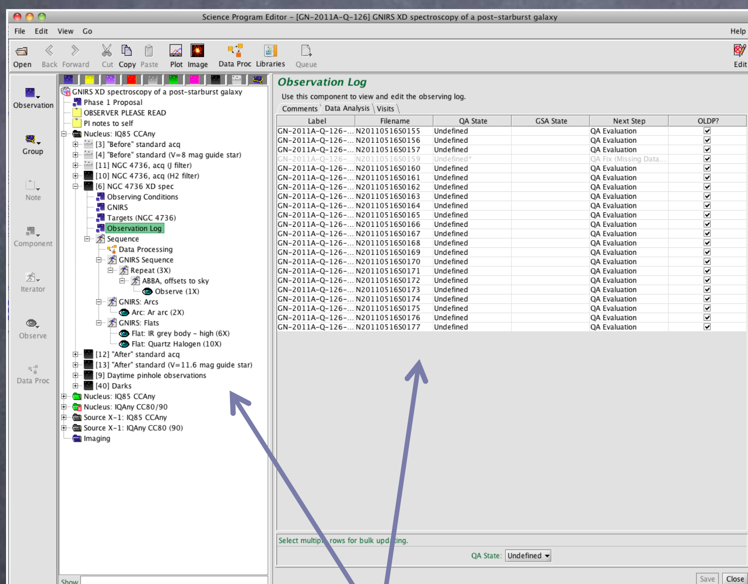
- Depends, but usually goes something like this:
  - Acquire telluric standard star using imaging mode
  - Take spectra of telluric standard star
  - Acquire science target (image through slit)
  - Take spectra of science target
  - If long observation, check target centering in slit
  - Continue taking spectra
  - Take arcs and flats
  - If long observation, acquire and observe 2nd standard
  - If XD mode, take pinhole spectra in the morning

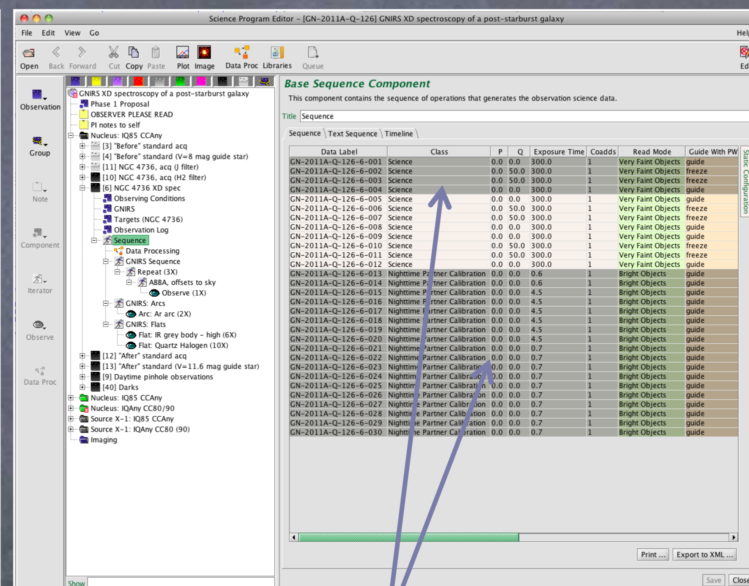
Step 1: Download your data from the archive

- Data go to the Gemini Science Archive within minutes of being observed (Claudia's talk)
- Archive help:
  - www.gemini.edu/sciops/data-and-results/science-archive/using-archive
- Let your Contact Scientist know if you want automatic email notifications of data taken for your program

What are these files? (1)

- Use the OT, fetch your programme





Black = executed observation. Galaxy, standard star and pinhole flats observed. Filenames, QA states, observer comments also available

Observed 1 x ABBA, offsetting to blank sky, skipped ahead to take arcs and flats

What are these files? (2)

- Look at the observing log from the archive
- Shows filenames, times, instrument configuration, observer comments etc.

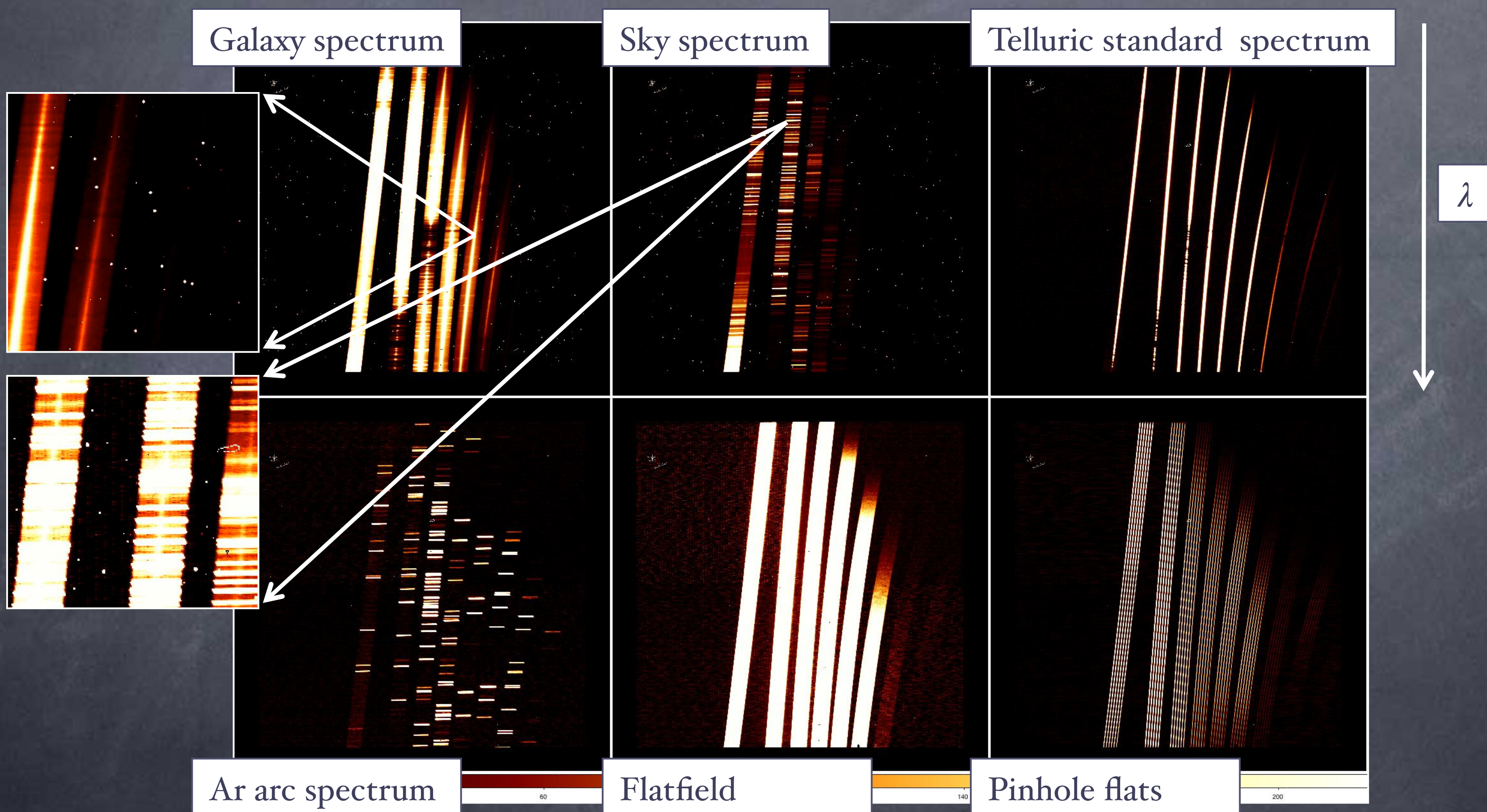
```
GNIRS Observing Log
---------------------------------------------------------------------------------------------------------------------------------------------------
Observation ID     Data Labels  File Numbers  Dataset UT  Target Name  Filters  Slit  Grating/Wavelength  Camera/Prism  ExpTime/LNR/Coadds  ACQ
---------------------------------------------------------------------------------------------------------------------------------------------------
GN-2011A-Q-126-10   1           151           09:57:36    NGC 4736          H        0.675   32/1.65            SB/MIR        4.0/1/1             Y
GN-2011A-Q-126-10   2-3         152-153       09:58:15    NGC 4736          H2       ACQ     32/1.65            SB/MIR        5.0/1/1             Y
GN-2011A-Q-126-10   Offsets sent: P=-2.8396  Q=-1.9161  IAA=89.7000  IPA=357.6000
GN-2011A-Q-126-10-003     Offsets sent: P=-0.0838  Q=-0.0078  IAA=89.7000  IPA=357.6000
GN-2011A-Q-126-10   4           154           10:00:49    NGC 4736          H2       0.675   32/1.65            SB/MIR        5.0/1/1             Y
GN-2011A-Q-126-10   OFFSETS (arcsec):  P = -0.014    Q = 0.025
GN-2011A-Q-126-10   Send offsets to TCC? (yes): no
GN-2011A-Q-126-10   Offsets NOT sent
GN-2011A-Q-126-6    1-4         155-159       10:02:50    NGC 4736          H        0.675   32/1.65            SB/MIR        300.0/32/1
GN-2011A-Q-126-6    13-14       160-161       10:29:04    Ar                H        0.675   32/1.65            SB/MIR        0.6/1/1
GN-2011A-Q-126-6    15-20       162-167       10:29:37    GCALflat          H        0.675   32/1.65            SB/MIR        4.5/1/1
GN-2011A-Q-126-6    21-30       168-177       10:31:36    GCALflat          H        0.675   32/1.65            SB/MIR        0.7/1/1
GN-2011A-Q-126-12   1           178           10:37:31    HIP65159          H        0.675   32/1.65            SB/MIR        4.0/1/1             Y
GN-2011A-Q-126-12   2-3         179-180       10:38:10    HIP65159          H2       ACQ     32/1.65            SB/MIR        0.2/1/10            Y
GN-2011A-Q-126-12   Offsets sent: P=0.6444  Q=-2.3045  IAA=89.7000  IPA=90.0000
GN-2011A-Q-126-12   4           181           10:40:02    HIP65159          H2       0.675   32/1.65            SB/MIR        0.2/1/10            Y
GN-2011A-Q-126-13   1-2         182-183       10:41:39    HIP65159          H        0.675   32/1.65            SB/MIR        4.0/1/3
GN-2011A-Q-126-13   saturated at 4 sec
GN-2011A-Q-126-13-002     saturated
GN-2011A-Q-126-13   3-4         184-185       10:42:48    HIP65159          H        0.675   32/1.65            SB/MIR        2.0/1/3
GN-2011A-Q-126-13   saturated
GN-2011A-Q-126-13-004     saturated
GN-2011A-Q-126-13   5-8         186-189       10:43:40    HIP65159          H        0.675   32/1.65            SB/MIR        1.0/1/5
```

What are these files? (3)

- Look at the file headers

```
-   hselect N20110516*[0] field=$I,OBJECT,OBSTYPE,OBSCLASS expr=yes
…
N20110516S0155.fits[0]  "NGC 4736"      OBJECT   science
N20110516S0156.fits[0]  "NGC 4736"      OBJECT   science
N20110516S0157.fits[0]  "NGC 4736"      OBJECT   science
N20110516S0159.fits[0]  "NGC 4736"      OBJECT   science
N20110516S0160.fits[0]  Ar              ARC      partnerCal
N20110516S0161.fits[0]  Ar              ARC      partnerCal
N20110516S0162.fits[0]  GCALflat        FLAT     partnerCal
N20110516S0174.fits[0]  GCALflat        FLAT     partnerCal
…
N20110516S0182.fits[0]  HIP65159        OBJECT   partnerCal
N20110516S0183.fits[0]  HIP65159        OBJECT   partnerCal
N20110516S0184.fits[0]  HIP65159        OBJECT   partnerCal
N20110516S0185.fits[0]  HIP65159        OBJECT   partnerCal
N20110516S0379.fits[0]  GCALflat        FLAT     dayCal
…
```

Take a closer look at the data



The data reduction steps

- Set up the environment
- "Clean" files with pattern noise, if present
- "Prepare" the data, locate the spectral orders
- Create the flatfield
- Flatfield and sky-subtract the data, "cut" the orders, stack the reduced data into a single file
- Straighten and wavelength-calibrate
- Extract spectra
- Divide by telluric standard, multiply by blackbody
- Steps in red only apply to XD spectra

Getting started (1)

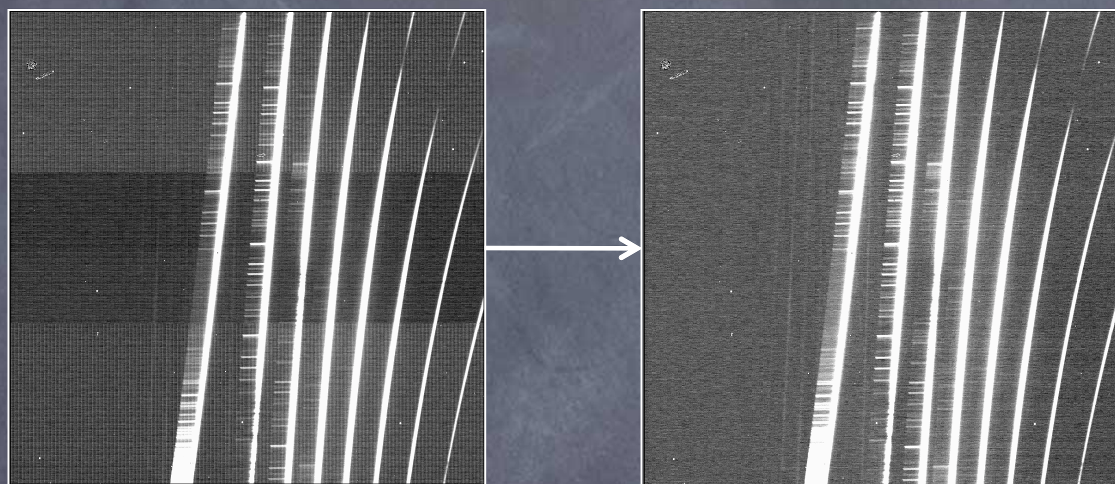
- Must use “beta2” version of Gemini IRAF
- In IRAF, load and reset packages
  - gemini
  - gnirs
  - unlearn gemini
  - unlearn gemtools
  - unlearn gnirs
- Optionally, define log file, database file, data directories
  - gnirs.logfile = ”NGC4736.log”
  - gnirs.database = ”NGC4736_database”
  - set rawdir = "./”
- Set header keywords
  - nsheaders gnirs

Getting started (2)

- Identify types of XD flats (QH, IR, pinholes)
  - `hselect N20110516*[0] field=$I,GCALLAMP,SLIT expr='OBSTYPE=="FLAT”`
  - `N20110516S0162.fits[0]  IRhigh  0.68arcsec_G5530`
  - …
  - `N20110516S0168.fits[0]  QH      0.68arcsec_G5530`
  - …
  - `N20110516S0379.fits[0]  QH      LgPinholes_G5530`
- Make data lists
  - `delete *.lis ver- >& dev$null`
  - `gemlist N20110516S 155-157,159 > obj.lis`
  - `gemlist N20110516S 186-189 > telluric.lis`
  - `gemlist N20110516S 168-177 > QHflats.lis`
  - `gemlist N20110516S 162-167 > IRflats.lis`
  - `gemlist N20110516S 160-161 > arcs.lis`
  - `concat *lis > all.lis`
  - `gemlist N20110516S 168-177,162-167,160-161,379-383 > cals.lis`

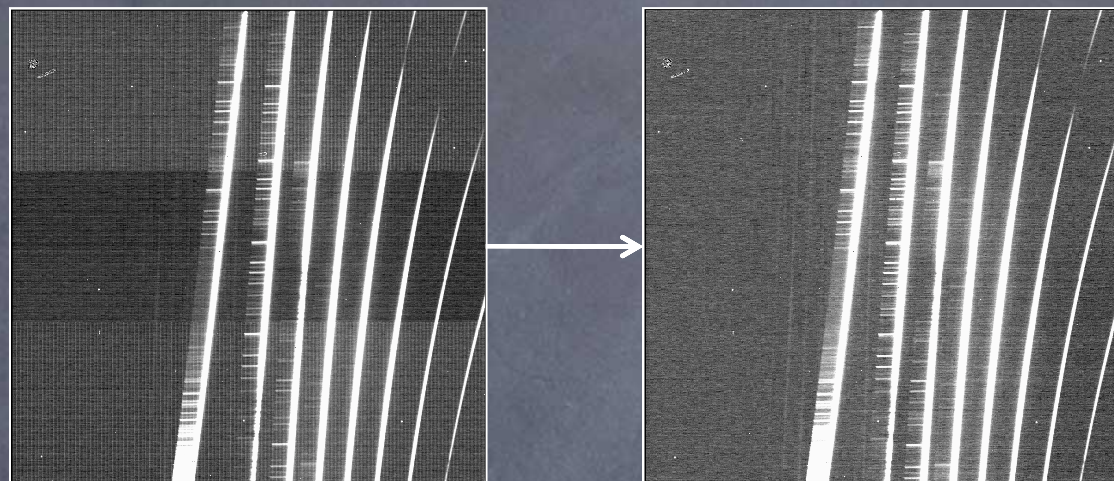
“Clean” the data of pattern noise

- Detector controller sometimes adds “stripes”



- Remove with cleanir script or **nvnoise** task
  - Cleanir is a standalone python script (outside IRAF)
  - GNIRS web pages → data format and reduction
  - nvnoise is part of the GNIRS IRAF package

“Clean” the data of pattern noise

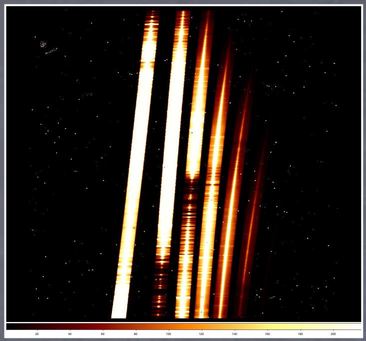


- Syntax:
  - `cleanir.py -fq N20110516S\*`
  - `nvnoise @obj.lis`
- For long-slit data, often best to run cleanir on sky-subtracted spectra
- See cleanir web page for lots of options

Radiation event removal

- Caused by thorium isotopes in short camera lens coatings, rate ~0.4/sec
- Look like cosmic ray hits
- Several options for dealing with them
  - Cosmic ray detection/removal algorithms (e.g. IRAF's crutil package)
  - Use the fl_cravg option in nsprepare (adds events to data quality array)
  - Use pixel rejection algorithms when combining files (e.g. nslfat, nscombine)
  - Ignore them (may be fine for arcs, for example)
  - Interpolate over spikes in extracted, 1D spectra
- The more individual files, the better!

"Preparing" the data



- The **nsprepare** task adds data quality and variance arrays, flags saturated pixels, etc.
- The nonlinearity correction should be disabled
- Use the array data table available at www.gemini.edu/sciops/data-and-results/processing-software/releases/downloads/prereleases
- A flatfield is used to find the orders on the array so they can correctly be "cut" into separate extensions later
- Run nsprepare on all data in one pass:
  - nsprepare @all.lis shiftx=INDEF shifty=INDEF fl_correct-arraytable=myarraytable.fits

```
…
NSPREPARE: Will measure MDF offset using N20110516S0162
NSOFFSET: Shifting gnirsn-sxd-short-32-mdf-1508_12.fits[1] in X by
   36.0 pixels.
```

"Cutting" the calibration data

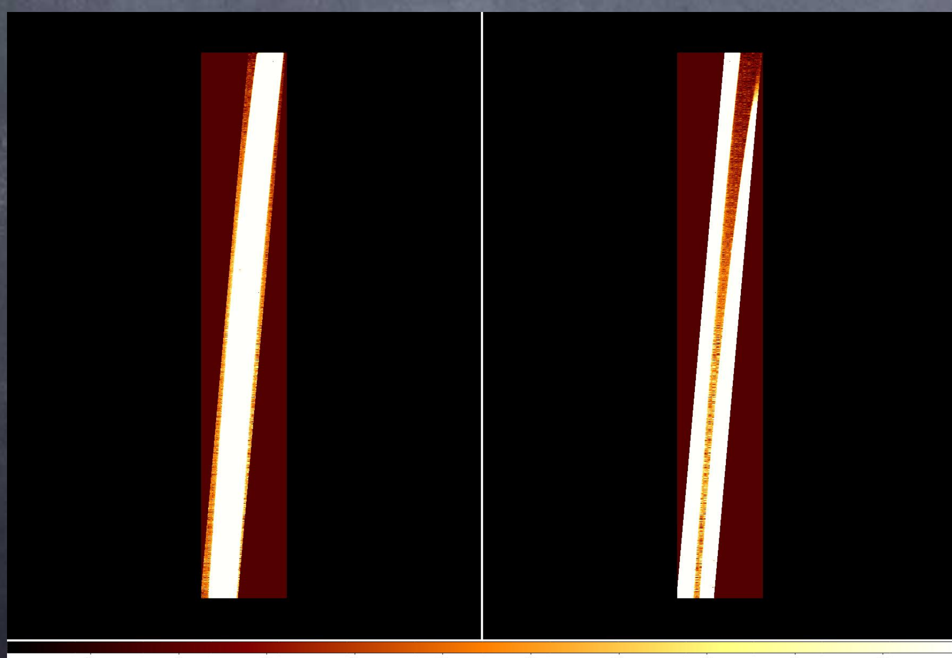
- After running nsprepare, this is the file format
  - gemextn nN20110516S0168

```
nN20110516S0168[0]
nN20110516S0168[1][MDF]
nN20110516S0168[2][SCI,1]
nN20110516S0168[3][VAR,1]
nN20110516S0168[4][DQ,1]
```

- We now use **nsreduce** to "cut" the orders into separate extensions (cal. data only, will do sci. data later)
  - nsreduce n@cals.lis fl_sky- fl_nscut+ fl_flat- fl_dark- fl_nsappwave- fl_corner+
- Instead of 5 extensions, the nsreduced files have 20 (!)
  - The PHU, MDF, and (SCI, VAR and DQ) extensions for each of the 6 orders

Were the files cut properly?

- Use **nxdisplay** to display all orders at once
  - `nxdisplay rnN20110516S0168`
- To display e.g. extension 3 (order 5, ~ J-H band) of one of the flats:
  - `display rnN20110516S0168[SCI,3]`



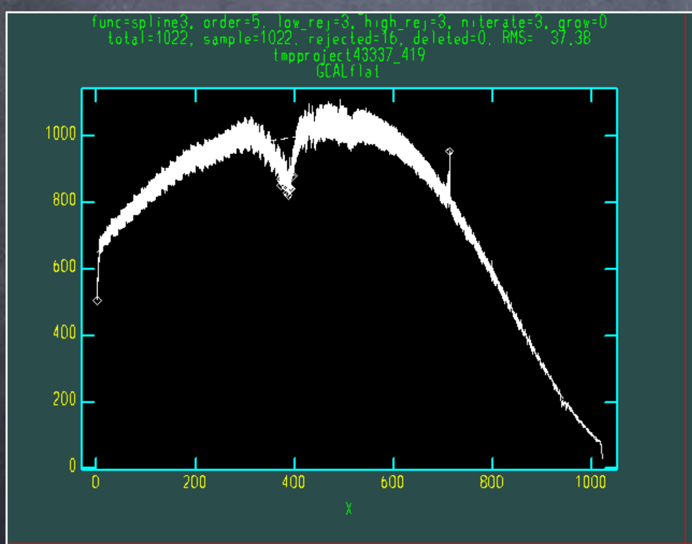
- Left: whole of illuminated area of order 3 cut properly
- Right: wrong portion of array cut, parts of two orders visible. Check nsprepare parameters.

Explaining the flatfield data

- We take two types of nighttime flatfield for XD data: quartz halogen and IR
- The QH flats illuminate all the orders, but there is a strong spectral feature in order 3 (~K band)
  - Can fit with high-order polynomial when normalising, but possible edge effects
  - Or live with "lumpy" spectrum until divide by standard
- Instead, use the IR lamp to illuminate order 3, then combine with QH into single flat

Creating the flatfield (1)

- First, we combine and normalise the individual QH flat files using **nsflat**
  - `nsflat rn@QHflats.lis flatfile="QHflat.fits" fl_corner+ process="fit" fitsec="MDF" order=5 lthresh=50. thr_flo=0.35 thr_fup=4.0 fl_inter+`
- nsflat applies a clipping algorithm when combining the flats, which rejects pixels affected by radiation events

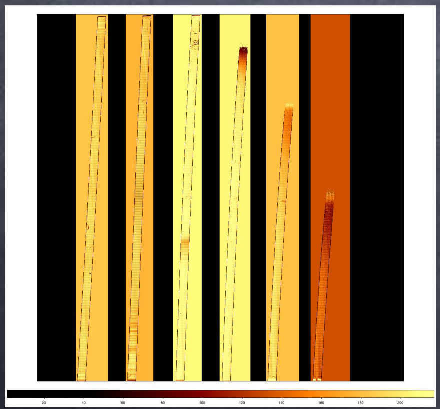


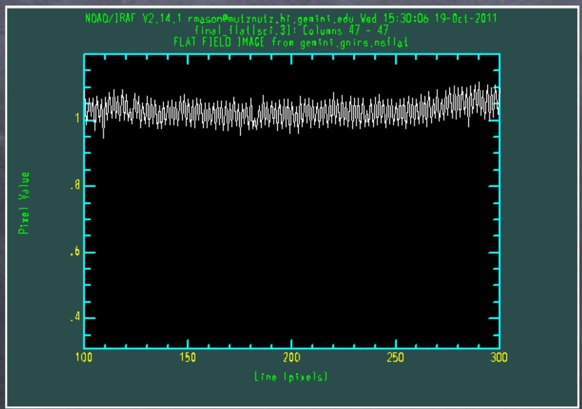
When running nsflat interactively it will show this kind of plot for each order. The spline fit, used to normalise the flat, should look reasonable.

The "fuzz" in the data is an intrinsic detector property (the "odd-even effect") which divides out by the end of the reduction.

Creating the flatfield (2)

- Next, we run nsflat on the IR flats. We only care about order 3 (extension 1) in these flats.
  - nsflat rn@IRflats.lis flatfile="IRflat.fits" fl_corner+ process="fit" fitsec="MDF" order=10 lthresh=100. thr_flo=0.35 thr_fup=1.5 fl_inter+
- Then we combine order 3 of the IR flat with orders 4-8 of the QH flat:
  - `fxcopy IRflat.fits final_flat.fits "0-3" new_file+`
  - `fxinsert QHflat.fits final_flat.fits[3] groups="4-9”`
  - `fxinsert QHflat.fits final_flat.fits[9] groups="10-18"`





LEFT: the final flat, displayed using nxdisplay as before.
RIGHT: cut through part of one order, showing the "odd-even effect"

Removing radiation events from the science and standard star data

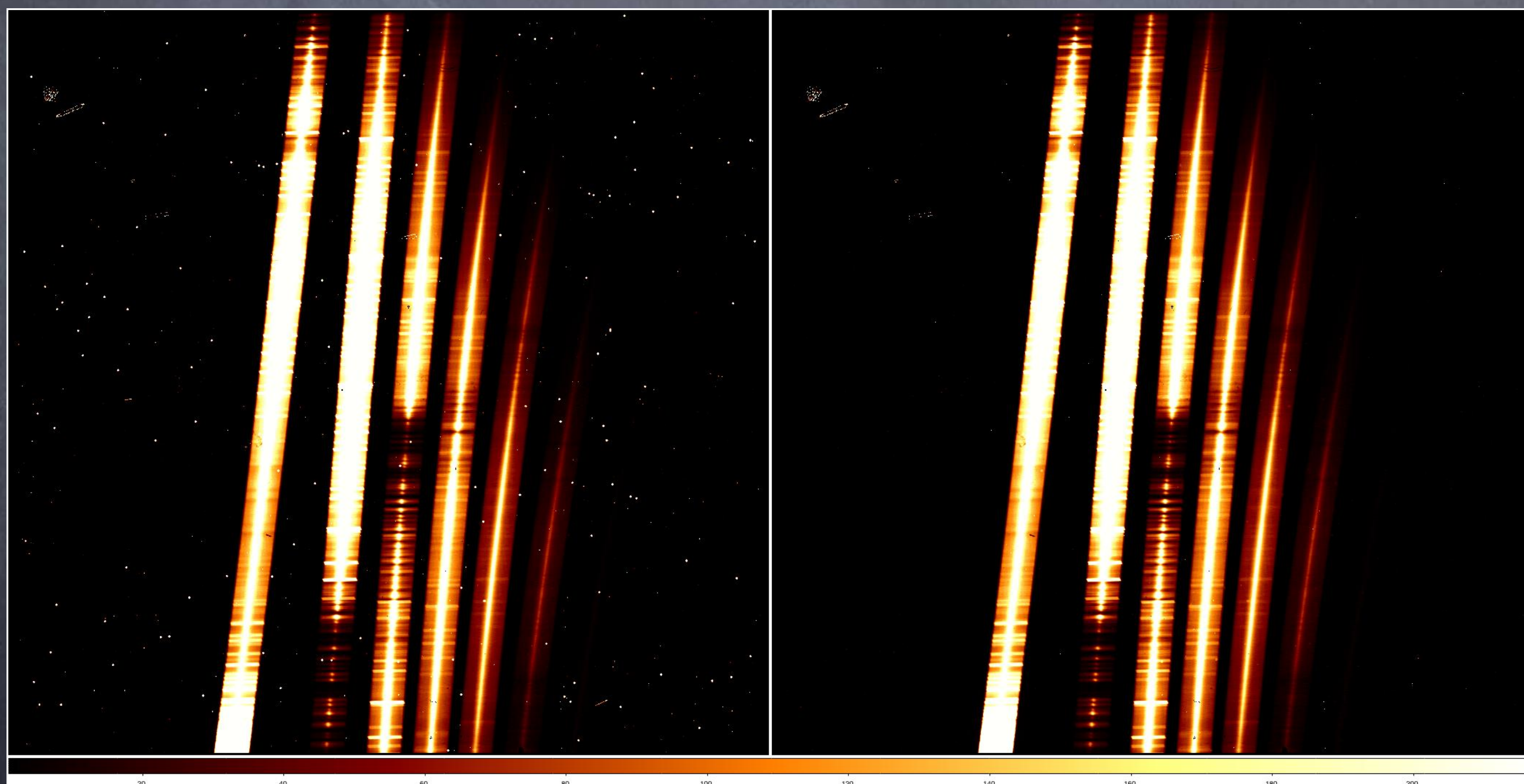
- Can remove events using sigma clipping algorithms in tasks such as **nscombine** (later)
- BUT, in this data set we only have 2 exposures at each nod position
- Strategy:
  - Create a “minimum” image from the two exposures at each nod
  - Estimate the noise in the images from array info in the headers
  - ID + mask pixels deviating by some amount above the noise
  - “Grow” the masked pixels to cover the “haloes” of the events
  - Replace the masked pixels with unaffected pixels from the minimum image
  - Need to preserve file format throughout

Radiation events removal

```
-   gemcombine nN20110516S0155,nN20110516S0159 output=min155 combine=median
    reject=minmax nhigh=1 nlow=0
-   gemcombine nN20110516S0156,nN20110516S0157 output=min156 combine=median
    reject=minmax nhigh=1 nlow=0
-   hselect n@obj.lis field=$I,RDNOISE,GAIN expr=yes
     nN20110516S0155 6.19    13.50
-   imexpr expr= "(a-b)>30*sqrt(6.19**2+2*b/13.50) ? 1 : 0" output=mask155.pl
    a=nN20110516S0155.fits[sci] b=min155.fits[sci]
-   imexpr expr= "(a-b)>100*sqrt(6.19**2+2*b/13.50) ? 1 : 0" output=mask159.pl
    a=nN20110516S0159.fits[sci] b=min155.fits[sci]
-   imexpr expr= "(a-b)>20*sqrt(6.19**2+2*b/13.50) ? 1 : 0" output=mask156.pl
    a=nN20110516S0156.fits[sci] b=min156.fits[sci]
-   imexpr expr= "(a-b)>20*sqrt(6.19**2+2*b/13.50) ? 1 : 0" output=mask157.pl
    a=nN20110516S0157.fits[sci] b=min156.fits[sci] > files mask15?.pl
-   masks.lis--> imdel g@masks.lis--> crgrow @masks.lis g@masks.lis rad=
-   copy nN20110516S0155.fits clnN20110516S0155.fits
-   copy nN20110516S0156.fits clnN20110516S0156.fits
-   copy nN20110516S0157.fits clnN20110516S0157.fits
-   copy nN20110516S0159.fits clnN20110516S0159.fits
-   imexpr "c=1 ? b : a   " output=clnN20110516S0155.fits[sci,overwrite]
    a=nN20110516S0155.fits[sci] b=min155.fits[sci] c=gmask155.pl
-   imexpr "c=1 ? b : a   " output=clnN20110516S0159.fits[sci,overwrite]
    a=nN20110516S0159.fits[sci] b=min155.fits[sci] c=gmask159.pl
-   imexpr "c=1 ? b : a   " output=clnN20110516S0156.fits[sci,overwrite]
    a=nN20110516S0156.fits[sci] b=min156.fits[sci] c=gmask156.pl
-   imexpr "c=1 ? b : a   " output=clnN20110516S0157.fits[sci,overwrite]
    a=nN20110516S0157.fits[sci] b=min156.fits[sci] c=gmask157.pl
```

Radiation events removal

- Before and after:



“Reducing” the science and standard star data

- At this stage we can use **nsreduce** to flatfield, sky-subtract and cut the science and standard star spectra
  - `nsreduce cln@obj.lis fl_corner+ fl_process+ fl_nsappwave- fl_sky+ skyrange=INDEF fl_flat+ flatimage="final_flat.fits"`
  - `nsreduce cln@telluric.lis fl_corner+ fl_process+ fl_nsappwave- fl_sky+ skyrange=INDEF fl_flat+ flatimage="final_flat.fits"`
- With skyrange=INDEF, nsreduce will attempt to find appropriate sky data to subtract
- Check the nsreduce output to make sure it worked OK
- For more control, use the “skyrange”, “nodsize” and/or “skyimages” parameters

nsreduce output: correct skies?

```
NSREDUCE: Generating the sky frame(s) using the other nod positions
          (separations greater than 1.5 arcsec) from neighbouring exposures.
WARNING - NSSKY: Will take sky from input images
NSSKY: Obs time for clnN20110516S0155-67773_1409.fits[0]: 10:02:46.4
NSSKY: Obs time for clnN20110516S0156-67773_1410.fits[0]: 10:08:26.9 0:05:40.5
NSSKY: Obs time for clnN20110516S0157-67773_1411.fits[0]: 10:14:03.9 0:05:37.0
NSSKY: Obs time for clnN20110516S0159-67773_1412.fits[0]: 10:22:53.9 0:08:50.0
NSSKY: Min/max:  0:05:37.0/ 0:08:50.0
NSSKY: Using observations within 530.0s as sky.
NSSKY: Grouping images (please wait).
NSSKY exit status:  good.
n input            --> output            sky image
1 clnN20110516S0155 --> rclnN20110516S0155 clnN20110516S0156-67773_1410
2 clnN20110516S0156 --> rclnN20110516S0156 clnN20110516S0155-67773_1409
3 clnN20110516S0157 --> rclnN20110516S0157 clnN20110516S0159-67773_1412
4 clnN20110516S0159 --> rclnN20110516S0159 clnN20110516S0157-67773_1411
```

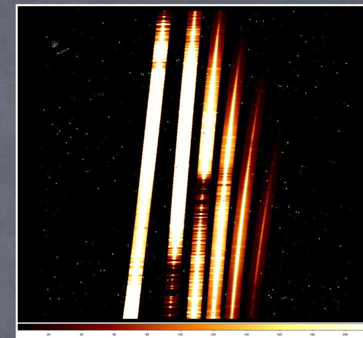
- The selected skies correspond to the ABBA pattern defined in the OT – good!

Combine the individual, reduced 2D data files

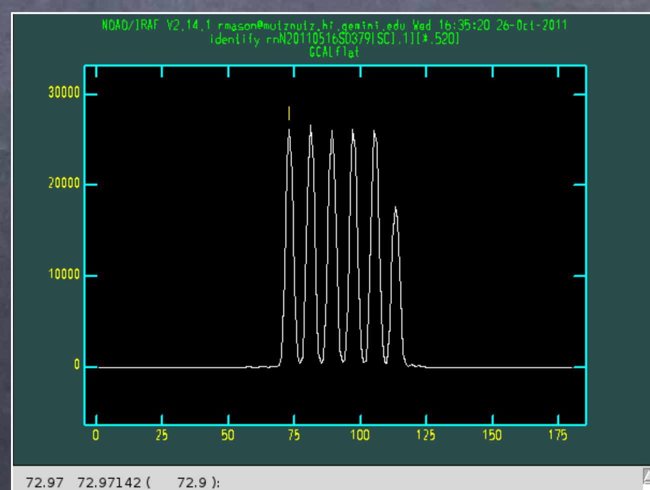
2 on-source galaxy spectra + 2 blank sky spectra	→	2 sky-subtracted galaxy spectra, at same nod position
4 standard star spectra, nodded along slit (ABBA)	→	4 sky-subtracted spectra, 2 different nod positions

- Can use **nsstack** to simply average galaxy spectra, **nscombine** to shift and average standard star spectra
  - `nsstack rclnN20110516S0155,rclnN20110516S0159 combtype=average`
  - `nscombine rcln@telluric.lis combtype=average`
- Now we have a single star file and single galaxy file
- If we had several spectra at each nod position, recall that we could use the “rejtype” parameter for pixel rejection and radiation event exclusion

Measuring the s-distortion

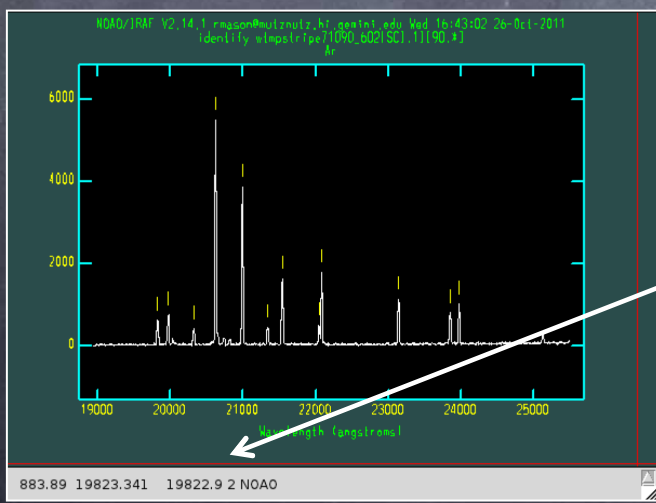


- The orders are tilted and curved
- Run **nssdist** on a daytime pinhole flat (or standard star) to measure and correct
  - nssdist rnN20110516S0379 section="[*,100]" coordlist=gnirs$data/pinholes-short-dense-north.lis function="legendre" order=5 minsep=5 thresh=1000 nlost=0 fl_inter+
- Manually identify a pinhole in each order (just hit “m” and accept the coordinate stated)



Finding the pixel-λ relation

- Use **nswavelength** to identify arc lines
  - `nscombine rn@arcs.lis output="arc_comb"`
  - `nswavelength arc_comb coordlist="gnirs$data/lowresargon.dat" fl_median+ refit- threshold=300. nlost=10 fwidth=5. fl_inter+ outspectra=warc_comb_median`
- Asks "Examine identifications interactively?", say "yes", use m key to mark lines and check wavelengths assigned to them (can answer "NO" to everything else)

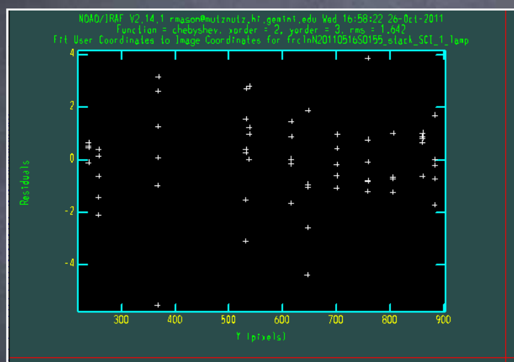


Fitted line wavelength vs wavelength in linelist

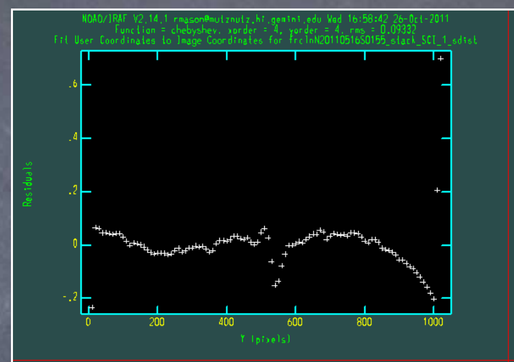
Straightening and wavelength-calibrating the data

- Have measured the distortion and the pixel-wavelength relation
- Now use **nsfitcoords** and **nstransform** to apply the results to the galaxy and standard star data
- Need to run nsfitcoords interactively
  - `nsfitcoords rclnN20110516S0155_stack lamptrans="warc_comb_median" sdisttrans="rnN20110516S0379" fl_inter+ lxorder=1 lyorder=3 sxorder=4 syorder=4`
  - `nsfitcoords rclnN20110516S0186_comb lamptrans="warc_comb_median" sdisttrans="rnN20110516S0379" fl_inter+ lxorder=1 lyorder=3 sxorder=4 syorder=4`
  - `nstransform frclnN20110516S0155_stack`
  - `nstransform frclnN20110516S0186_comb`

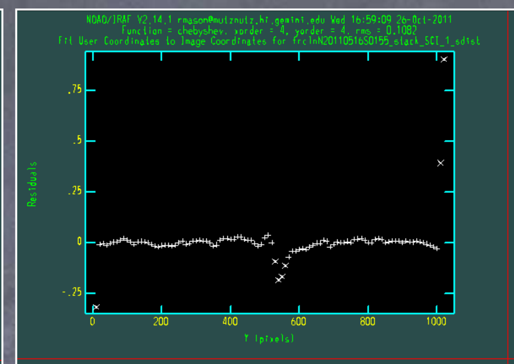
Straightening and wavelength-calibrating: nsfitcoords plots



Arc lamp fit, residuals



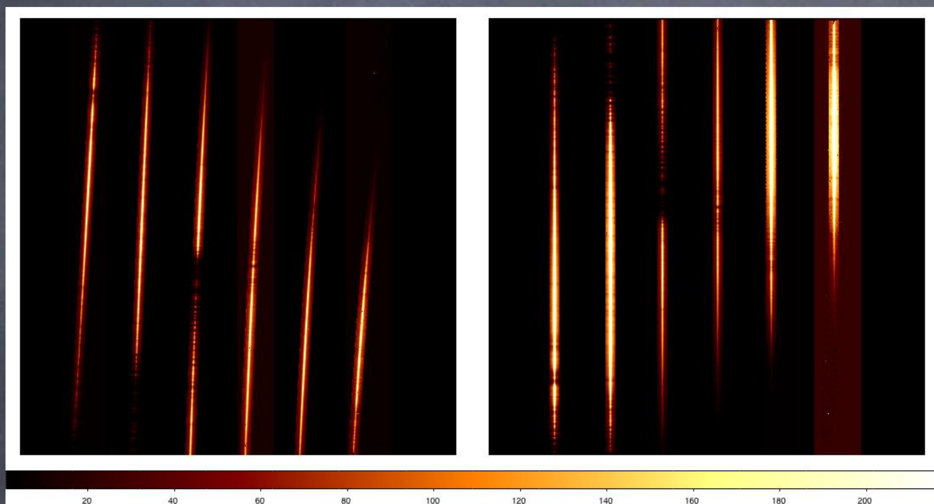
Pinhole fit: delete bad pts



After deleting bad pts

- Above: nsfitcoords interactive plots for order 3 (extension 1, ~K band)
- Expect more discrepant points in pinhole fit in higher orders (lack of flux at short-wavelength ends of orders)
- Make sure to zoom into same y scale for each order

The straightened, wavelength-calibrated data

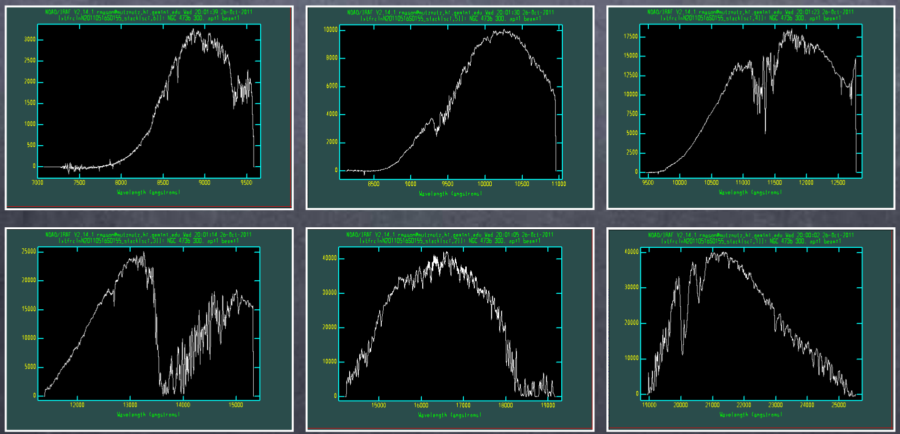


LEFT: before λ-calibration and rectification, the spectra are curved and tilted and λ increases towards lower pixel numbers
RIGHT: the spectra are straight and the wavelength scale inverted

- Possible checks:
  - Run reduced arc through nsfitcoords + nstransform and check line wavelengths (e.g. www.jach.hawaii.edu/UKIRT/astronomy/calib/spec_cal/arcmaps.html)
  - Imexam "j" fit to spectra should give same centre all the way down the orders

Extracting the spectra

- Use **nsextract** to extract all orders in one go:
  - nsextract tfrclnN20110516S0186_comb nsum=20 up=6 low=-6 ylevel=INDEF background="none" fl_addvar- fl_trace- fl_inter+
  - nsextract tfrclnN20110516S0155_stack nsum=20 up=6 low=-6 ylevel=INDEF background="none" fl_addvar- fl_trace- fl_inter+
- Lots of possible options depending on the characteristics of your data and what you want to do with it!



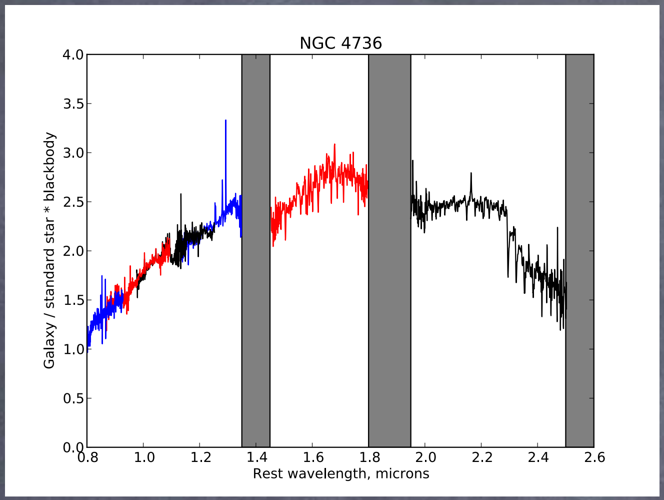
Telluric line cancellation

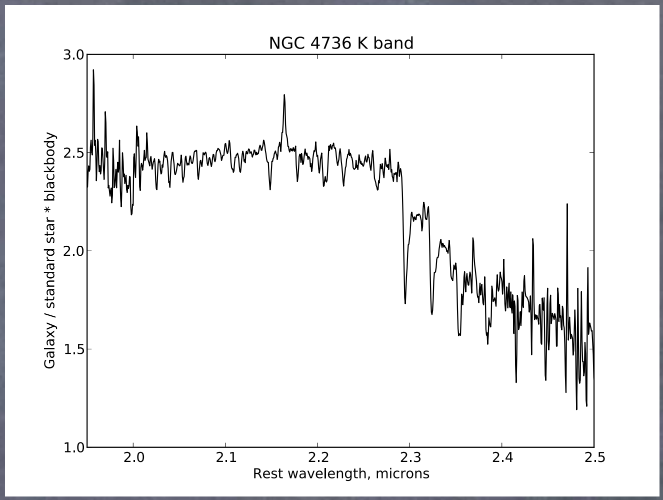
- A couple of options
- 1) Use **nstelluric** + **nscalibrate**
  - nstelluric allows shifting and scaling spectra wrt standard star
  - Quite involved; see this web page for tips:
  - www.gemini.edu/sciops/instruments/midir-resources/data-reduction/spectroscopy-reduction
- 2a) Simply divide by standard and multiply by blackbody
- 2b) Could cross-correlate star and galaxy spectra to improve cancellation
  - Use fxcor task in rv package, then imshift

Telluric line cancellation

- Using order 3 (extension 1) as an example:
  - `imarith xtfrclnN20110516S0155_stack[sci,1]  / xtfrclnN20110516S0186_comb[SCI,1] result=N4736_3`
- Look up the magnitude and temperature of the standard star
- Find the start and end wavelengths of the orders
  - `onedspec`
  - `wspectext xtfrclnN20110516S0155_stack[sci,1] temp header-`
- Make the appropriate blackbody spectrum
  - `mk1dspec order3_6100K ncols=1022 wstart=18924 wend=25533 continuum=4.5 fnu=yes temperature=6100`
- Multiply, write out text file if desired
  - `imarith N4736_3 * order3_6100K result=N4736_3_bb`
  - `wspectext N4736_3_bb N4736_3_bb.txt header-`

NGC 4736: The spectrum





- “Noise” in K band is (I think) actually lots and lots of lines from carbon stars in the galaxy!