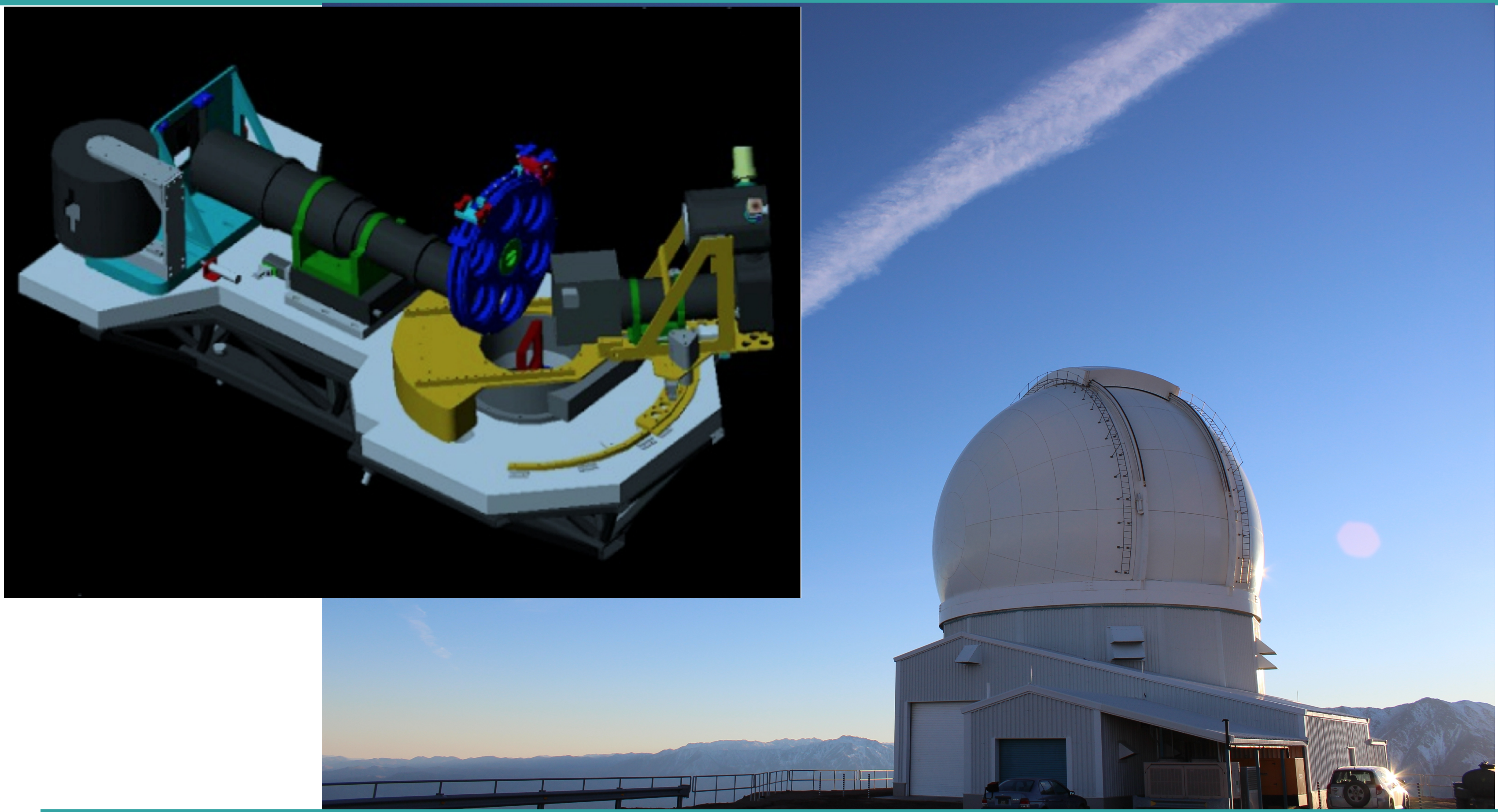
Multi-Object Slit Spectroscopy with the Goodman Spectrograph

César Briceño – CTIO/SOAR



Workshop: New Instruments at Gemini & SOAR
Aug 8-10, 2014 – Guaruja - Brasil

The Goodman Spectrograph: an overview

- **Imaging spectrograph for SOAR**, built by J. Christopher Clemens (University of North Carolina, Chapel Hill) and collaborators.

- Employs all-transmissive optics and Volume Phase Holographic (VPH) gratings to achieve high throughput for low-resolution spectroscopy from the atmospheric cutoff **~320nm out to 850nm**.

- 4K x 4K Fairchild CCD with 15 micron pixels.

- Currently, overheads are significant → 3 images required to center targets on slit(s).

- **MOS mode commissioned during late 2013/early 2014. First offered for regular scientific use in the 2014B period.**

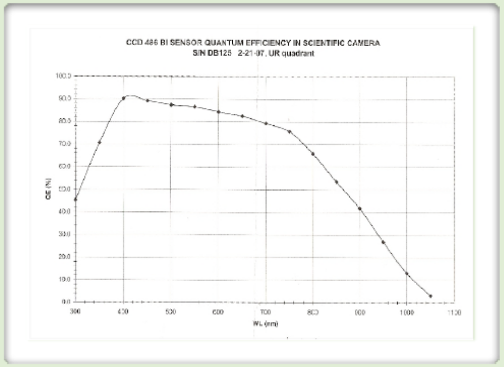
Goodman Laboratory

Observer's Cheat Sheet

CCD Characteristics

Read Rate	Analog ATTN	Gain (e-/ADU)	Read Noise (e-)	50%Full Well (ADU)
50 kHz	0	0.25	3.33	279600*
	2	0.47	3.35	148723*
	3	0.91	3.41	76813*
100 kHz	0	0.56	3.69	124821*
	2	1.06	3.72	65943*
	3	2.06	3.99	33932
200 kHz	0	1.4	4.74	49928
	2	2.67	5.12	26179
400 kHz	0	5.67	8.62	12328

* digital saturation reached before 50% full well



Other Info:

Digital Saturation: 65,536 e-
Single Pixel Full Well: 139,800 e-
Linearity: 0-80% Full Well
Dark Current: 0.0003 e-/pixel/sec
Pixel Size: 15 microns

Standard ROI Modes

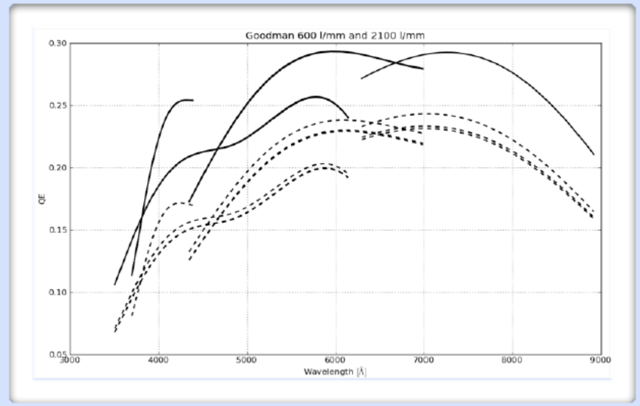
Mode	Binning	Serial Origin	Serial Length	Parallel Origin	Parallel Length	Approx. Image Size
Imaging 1x1	1x1	516	3096	500	3096	19 MB
Imaging 2x2	2x2	516	1548	500	1548	5 MB
Imaging 3x3	3x3	516	1032	500	1032	2 MB
Spectroscopic 1x1	1x1	0	4142	1100	1896	16 MB
Spectroscopic 2x2	2x2	0	2071	1100	948	4 MB
Spectroscopic 3x3	3x3	0	1381	1100	632	2 MB
Slit Imaging/Alignment	1x2	1250	1200	1100	948	800 KB

Note: Origins are given in un-binned, absolute pixels; lengths are given in binned pixels

Spectroscopic Info

Available Gratings:

Grating (lines/mm)	Dispersion (Å/pixel)	Approx. Range (Å)
300	1.3	5370
600	0.65	2670
1200	0.33	1300
2100	0.17	650



Available Long Slits:

Slit Widths	Max R*
0.46"	12,600
0.84"	6,700
1.03"	5,400
1.35"	4,200
1.68"	3,300
2.0"	2,800
3.0"	1,800
10.0"	560
40.0"	140

* with 2100 l/mm grating

Imaging Info

Available Filters:

Dedicated: **UBV** (Johnson), **R** (Cousins), **GG385, GG455, GG495, OG570, S8612** (order-sorting)

Available from SOI by request: **UBVRI** (Bessel), **ubvy** (Stromgren), **ugriz** (Sloan), **H-alpha**

Goodman/SOI Comparison:

Filter	Goodman-to-SOI Throughput Ratio
U	1.17 +/- 0.09
B	1.15 +/- 0.06
V	1.23 +/- 0.06
R	1.70 +/- 0.07

Other Info:

Field of view: 7.2' diameter circle
Pixel Scale: 0.15" / pixel

http://www.goodman-spectrograph.org/observers.html

Workshop: New Instruments at Gemini & SOAR
Aug 8-10, 2014 – Guaruja - Brasil

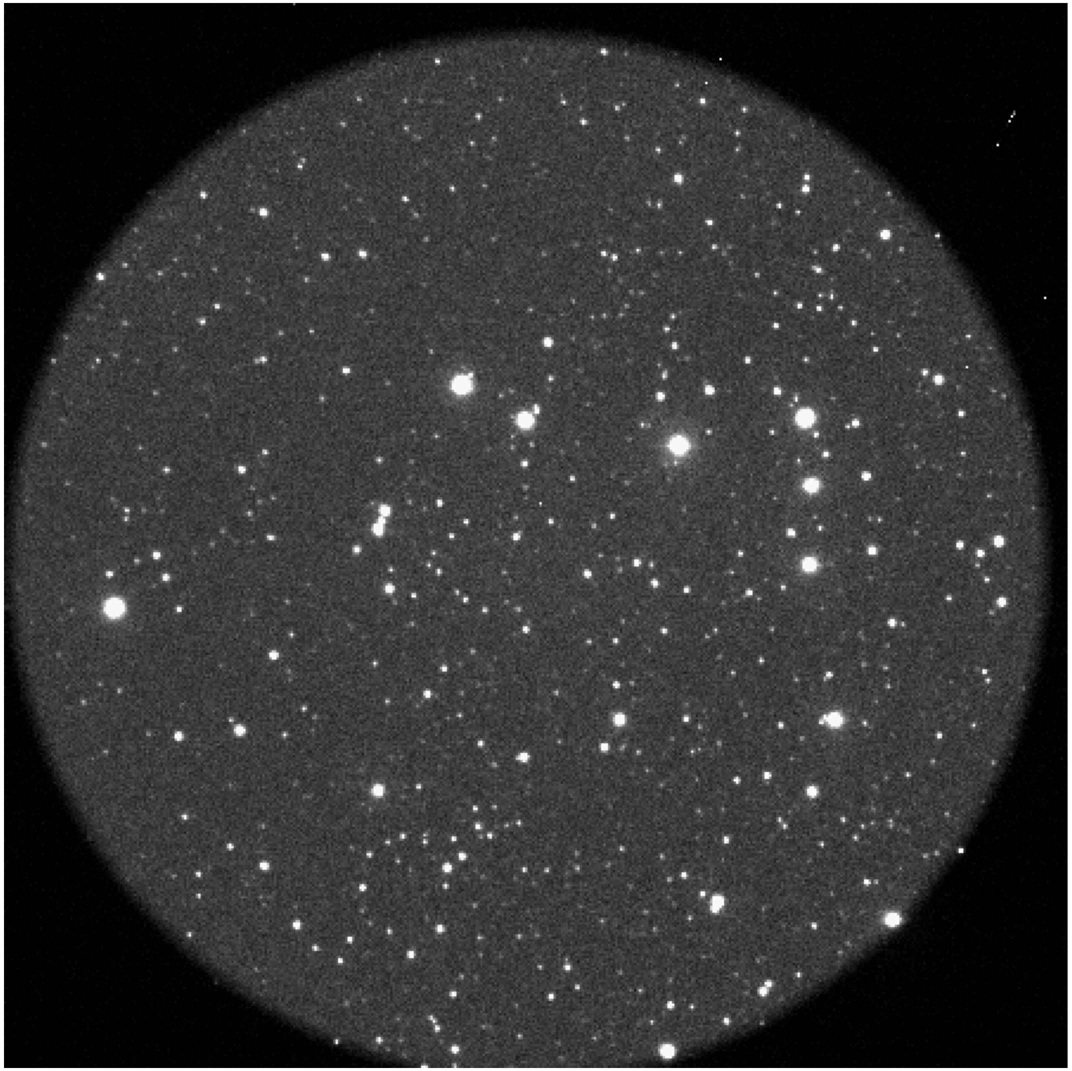
Imaging: FOV and filters

- Plate scale = 0.15 "/pixel

- FOV = 7.2 arcmin diameter (3096 x 3096 unbinned pixels)

- FILTERS:
  - UBVRc
  - SDSS ugriz
  - Stromgren ubvy
  - Hα

DIQ in imaging mode can be as good as 0.5"

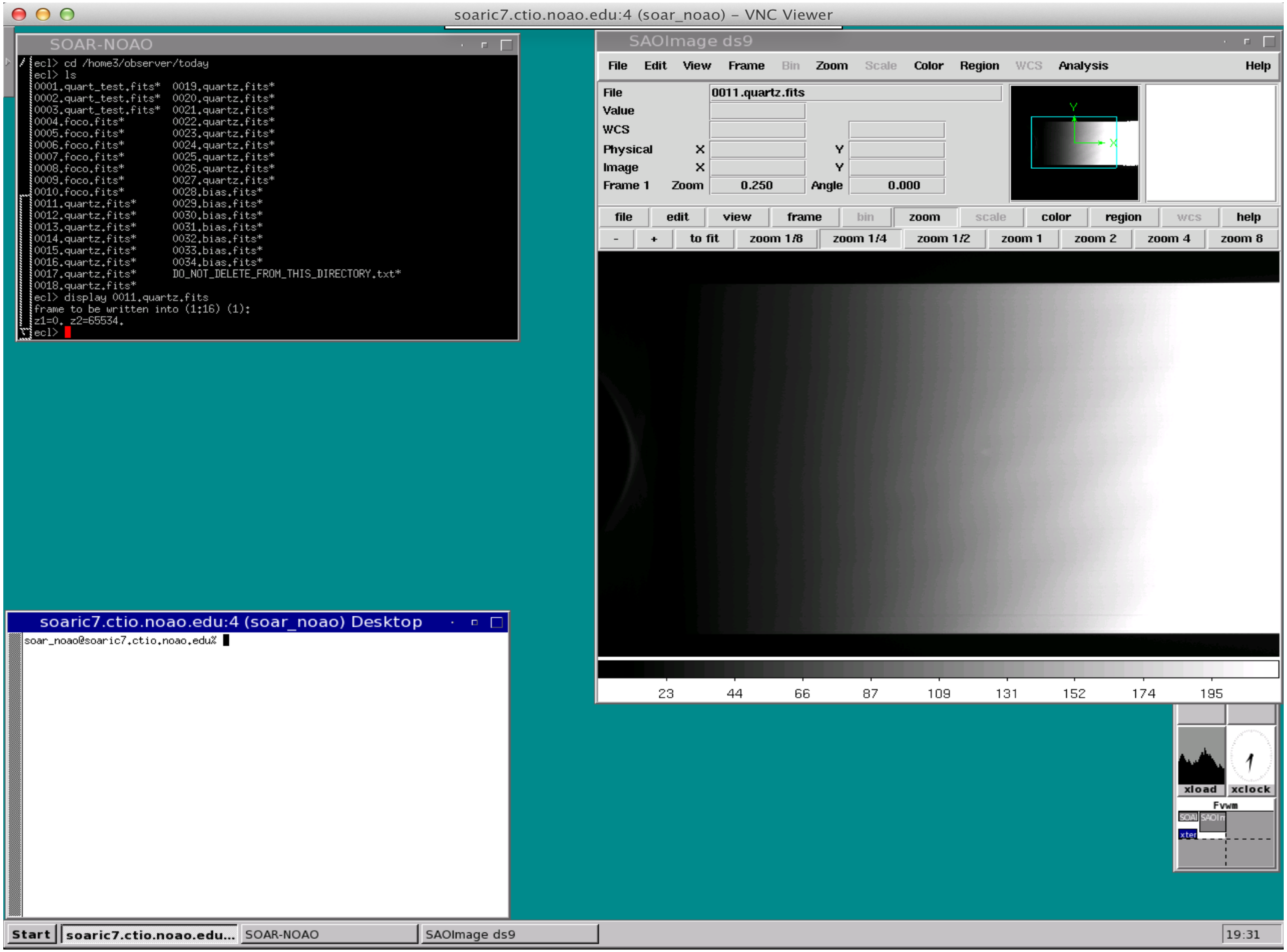


Spectroscopy:

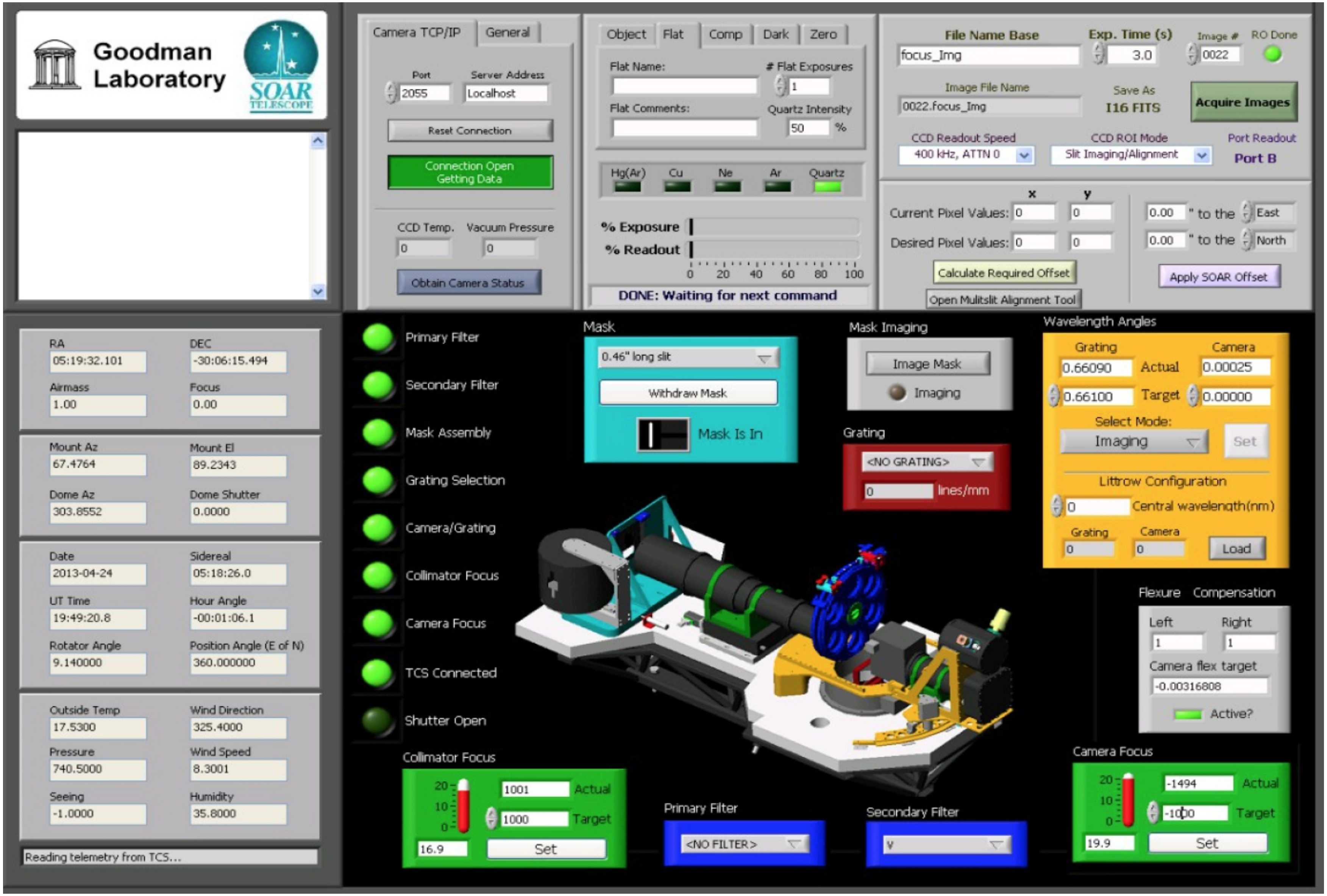
Grating	Dispersion	Wavelength Coverage (for preset modes)	Maximum R at 550nm (3 pixel with 0.45"slit)	Blocking Filter
300 l/mm	1.3Å/pixel	355-892 nm	1410	GG-385
400 l/mm	1.00Å/pixel	M1: 300-705 nm M2: 500-905 nm	1833	- GG-455
600 l/mm	0.65Å/pixel	UV: 301-569 nm Blue: 350-616 nm Mid: 435-702 nm Red: 630-893 nm	2820	- - GG-385 GG-495
930 l/mm	0.42Å/pixel	M1: 300-470 nm M2: 385-555 nm M3: 470-640 nm M4: 555-725 nm M5: 640-810 nm M6: 725-895 nm	4470	- - GG-385 GG-495 GG-495 OG-570
1200 l/mm	0.31Å/pixel	M0: 302-436 nm M1: 350-485 nm M2: 420-550 nm M3: 490-615 nm M4: 555-685 nm M5: 625-750 nm M6: 695-815 nm M7: 765-880 nm	5915	- - - - GG-455 GG-455 GG-495 OG-570
2100 l/mm	0.19Å/pixel	Bandwidth ≈ 65nm	9650	As needed

http://www.soartelescope.org/observing/documentation/goodman-high-throughput-spectrograph/goodman-manual/overview

Using Goodman: Data visualization environment - IRAF -



Using Goodman: Spectrograph GUI



Using Goodman: Remote Observing

Requirements (aside from familiarity with Goodman!):

• **A good VNC connection.** This should be tested at least 1 week before your observing run. E.g. some people have had some issues with VNC on Mac OS. You will work better if you can have two monitors (or two laptops) so you can display both the spectrograph GUI (running on **soaric4**) and the VNC with IRAF (running on **soaric7**)

• **Skype**

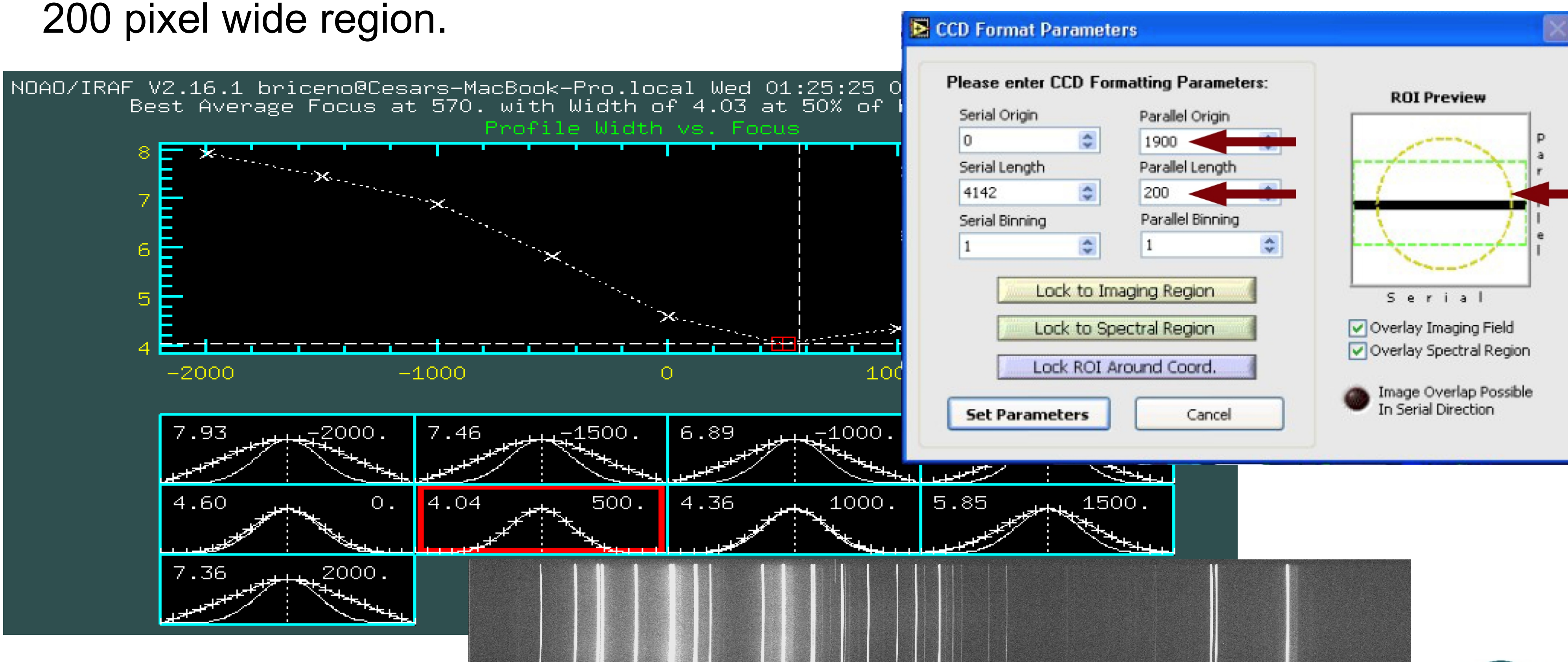
Please (re)read the Goodman Manual and documentation. We are currently working on a complete rework of the SOAR website, that will include improved documentation for the observer.

Contact your Instrument Scientist well ahead of time! Preparing for MOS observing will require more preparation

Focusing the spectrograph

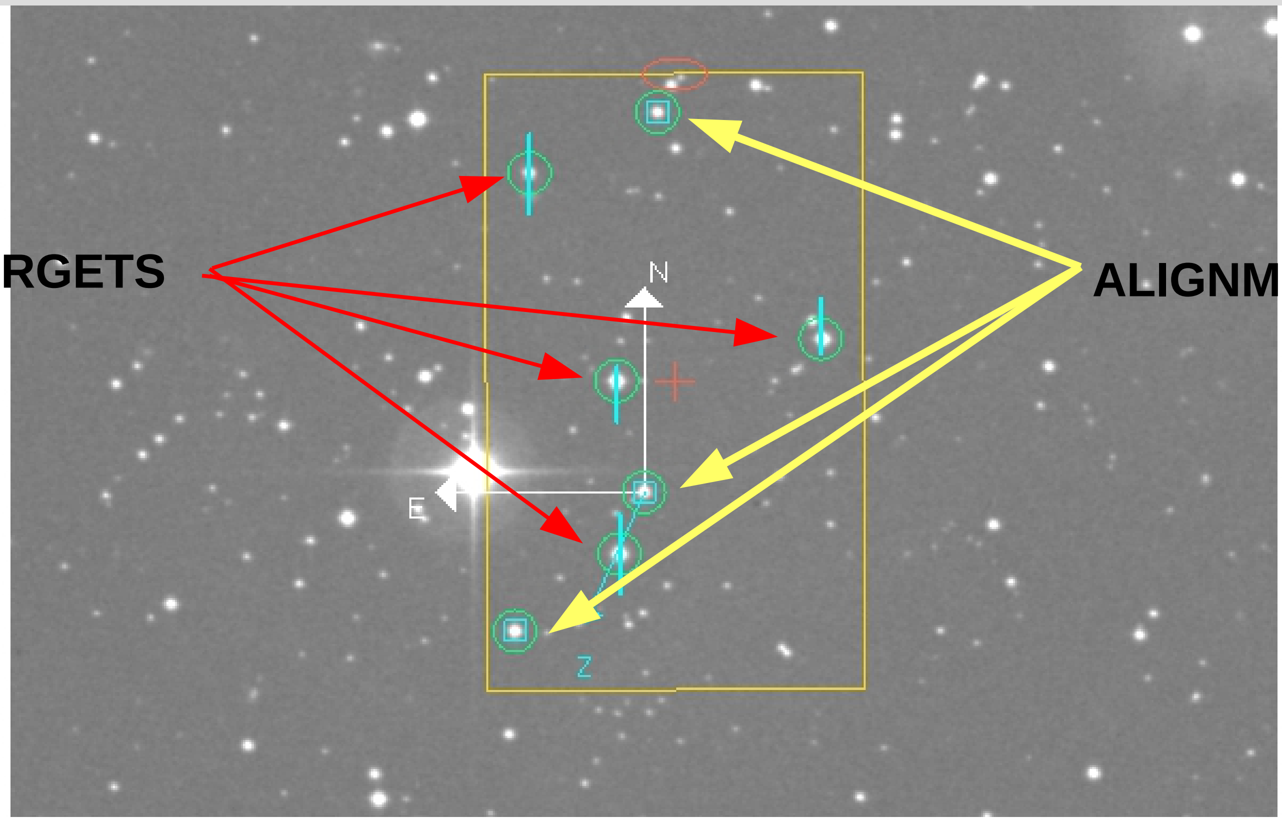
-2000 to +2000 in steps of 500, Exp=1s for Hg(Ar) lamp. 400M2 + G455
Use the 400 KHz ATTN0 readout.

You can also read a smaller region to save time: modify the values “Parallel Origin” and “Parallel Length” to 1900 and 200, respectively will readout only a 200 pixel wide region.



The Goodman HTS MOS mode

- **Brings multiplexing capability to Goodman over a 3x5 arcmin FOV**
- Objects should not be closer than ~5'' in the spatial direction, to avoid overlap
- 3 alignment stars with V~< 15, and preferably similar magnitudes.
- Best to avoid very bright stars (V<10), so scattered light will not be an issue
- Alignment stars should form a sort of “L” pattern



Observing with the Goodman MOS mode: practical considerations

The **overhead** determined during Science Verification is **~15-20 min per MOS field**, measured from the moment the Telescope Operator has centered the target and acquired a guide star, to start of the science integration

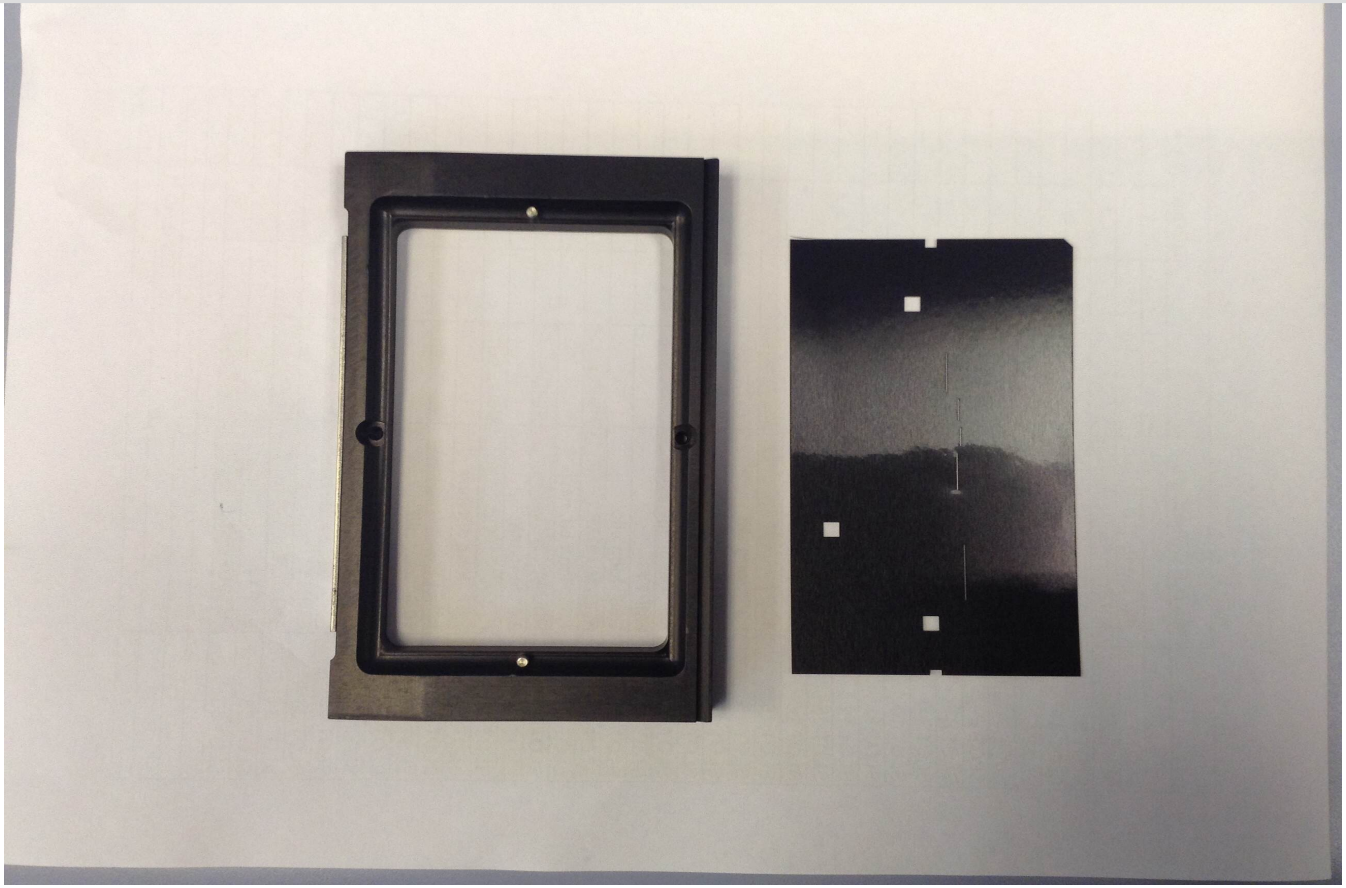
→ **MOS observations are most efficient when observing >~several objects with moderate/long integrations**

This includes time spent for initial field acquisition (1st image), imaging the mask (2nd image), operating the MOS Alignment module to calculate offsets/rotation and applying these, taking 3rd image of the mask on the field to verify alignment.

Tell the TO the PA you used to design your mask. Since you will likely have to adjust the PA, ask the TO not to find the guide star until after the PA has been adjusted

Goodman MOS masks

Goodman MOS masks are designed with the Slit Designer software, developed at UNC. Presently they are cut on carbon fiber sheets, on the same laser cutting machine used for GMOS @Gemini South.



Goodman MOS masks

Because the individual slits may be located at differing locations in the dispersion direction, the central wavelength shifts as a function of position of each slit.

In the dispersion direction, the Goodman masks are 3'' wide (1200 pix). The central slit position is at pixel x=600. Slits to the left of the central slit will see the center wavelength of the spectrum shift toward the blue. Slits to the right of the central position will see the central wavelength shift to the red. If the slits are oriented NS and East is left and West is right, then for slits located 1 arcmin east and west of the central position (1 arcmin = 60 arcsec = 400 pixel at a scale 0.15 arcsec/pixel) spectra are shifted to the blue and to the red by 400 pixels respectively.

Goodman MOS masks

The simple formula is: $\mathbf{D_{pixel} = -1 * 400. * (\Theta_{offset}[arcsec] / 60.)}$

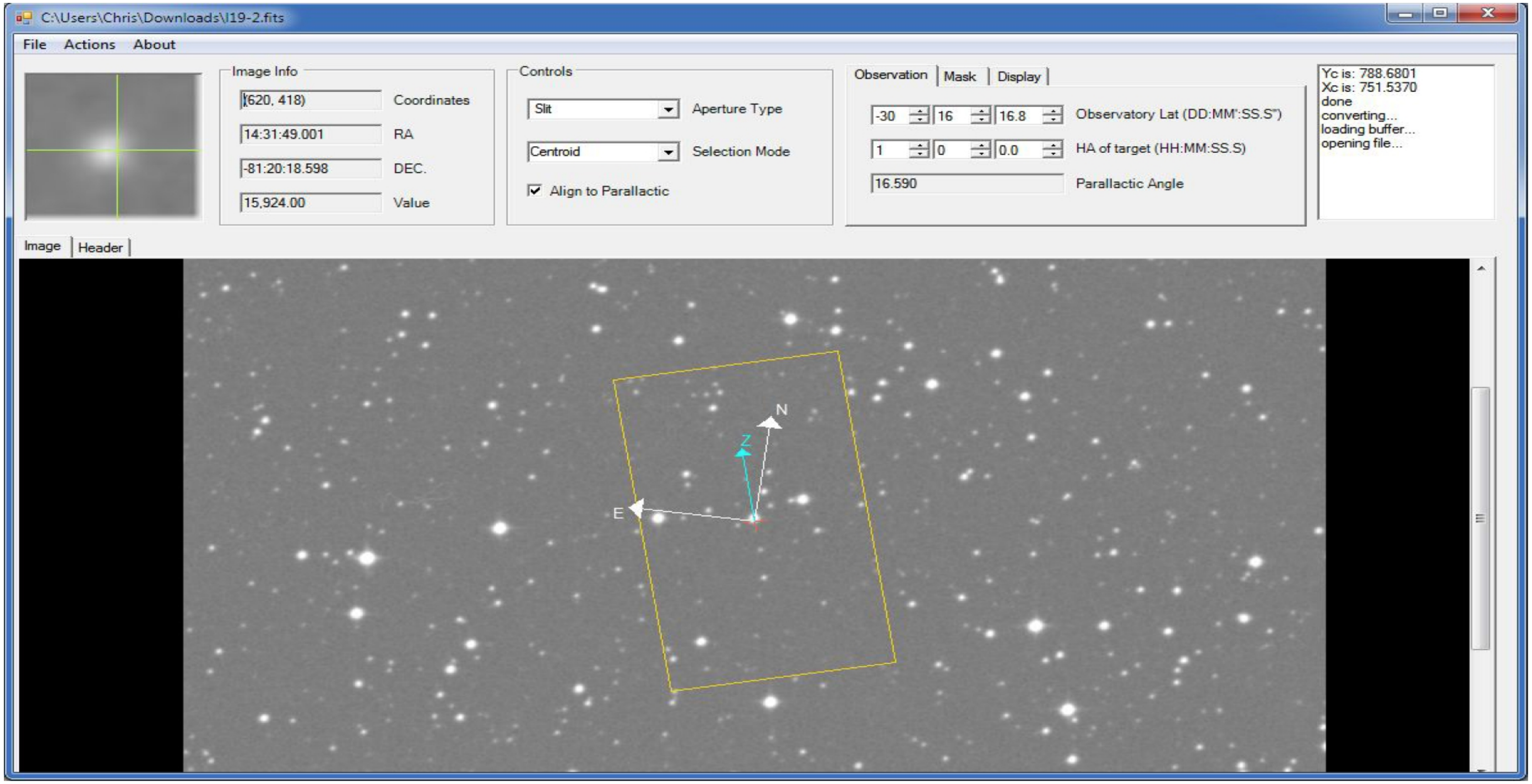
where east offsets are positive and west offsets are negative.

Once the D_{pixel} is calculated, one can find the D_{lambda} by multiplying by the dispersion for the grating in use.

400l/mm: ± 400A
600l/mm: ± 260A
930l/mm: ± 170A
1200l/mm: ± 125A
2100l/mm: ± 75A

1) Preparing your MOS mask with SlitDesigner

• FITS file with image of your field: DSS or Goodman pre-image. Should have a suitable WCS
• If using DSS be aware of proper motion!
• Need Windows box to run the *Slit Designer* software; we have tested it on **Windows XP and Windows 7** (32, 64-bit)....**a MacOS X version is in the works**



Upcoming features in Slitmask Designer

1) Port to Mac OS X
2) When loading saved masks, read and preserve HA, PA, slit length, type and width.

3) When reloading saved masks, turn off centroiding if selected and leave display slit locations as in file.
4) Upload target lists from text files.
5) Implement csv format target list, check which targets are on the current image, and mark those as selected. Offer user the choice to either centroid or not upon loading.
6) Add dotted outline of clear aperture of mask to rectangular representation
7) Try to add contrast, brightness, stretch functionality.
8) Show cut off corner on displayed mask to match fabricated assembly
9) Circles around targets should be a fixed size in arcsec, not in pixels.

Possible New functions

1) Manual repositioning of slitlets.
2) Allow positioning of slitlet at mask center (where directional are now).
3) Allow fine positioning of cursor with arrow keys or other keystrokes.
4) In addition to setting PA to parallactic angle, allow setting PA to a specified number that is entered in a box.

2) Submitting your MOS masks and checking them prior to your run

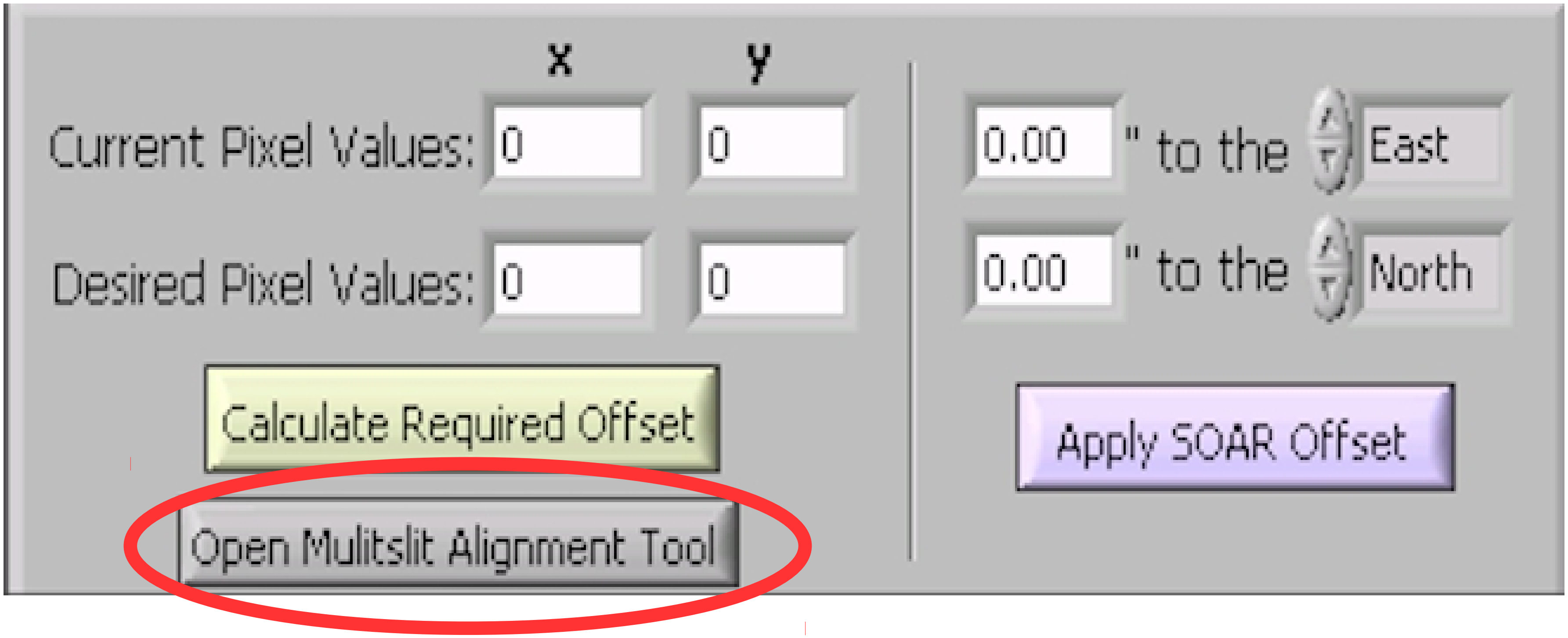
Masks should be sent at least 1 month in advance of the observations, to: goodman_mos@ctio.noao.edu.

Masks not sent by the 1 month deadline, are not guaranteed to be cut and installed in time for your run.

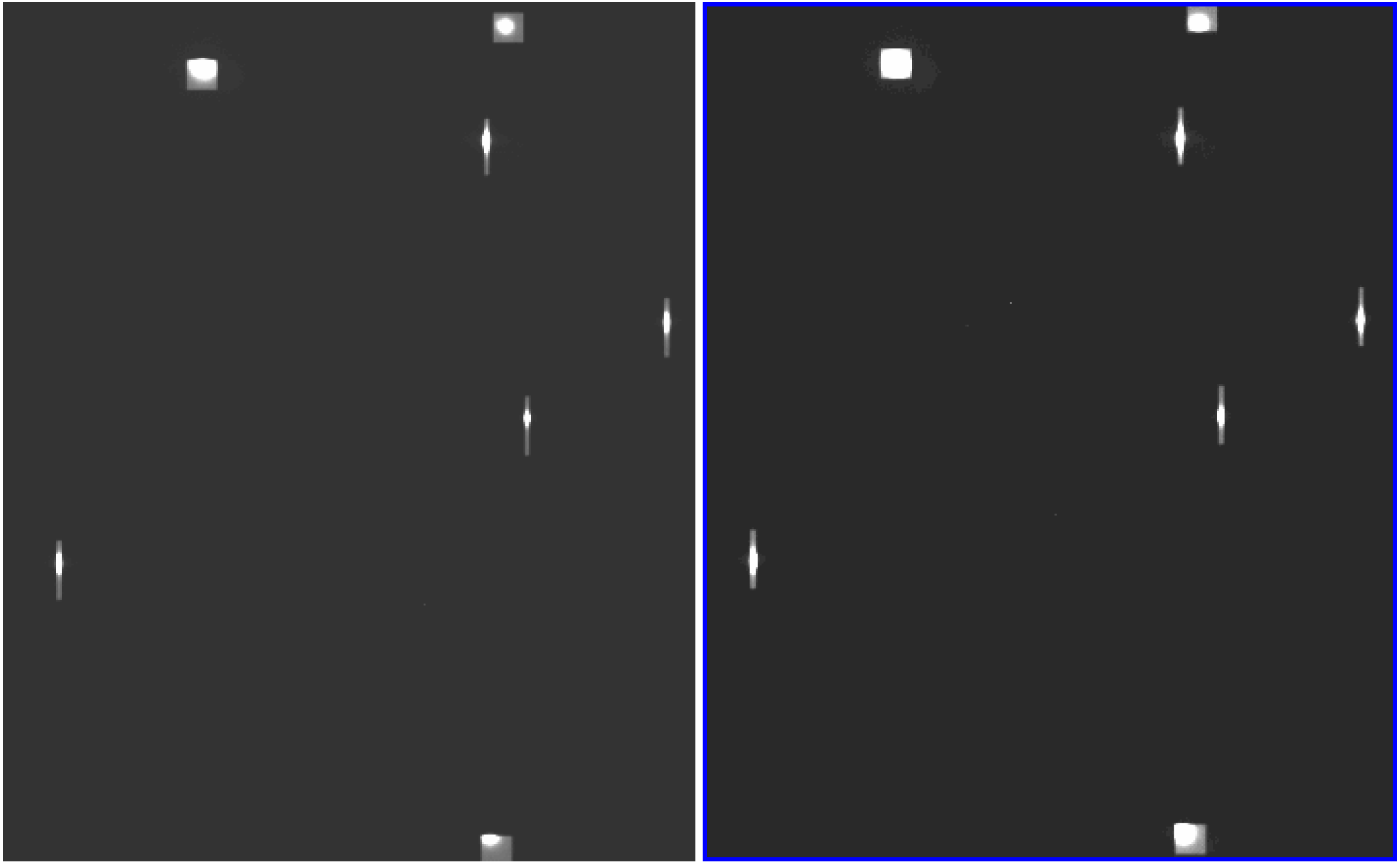
You should send the following files:

- The **FITS file of your mask field**, either from the DSS or a Goodman pre-image.
- The **.msk, .emf and G-code files produced by the Goodman MOS design software** (note that the G-code files will have no extension, but will be recognized as text files in Windows).
- **A screenshot (jpg, png or gif file) of your final mask** as seen in the Sli tDesigner software, i.e., showing your field with the mask, slits and alignment slots on it.

MOS mode:
Centering/aligning your mask



MOS mode:
Centering/aligning your mask



The MOS mode:
4) Reducing your MOS spectra with IRAF

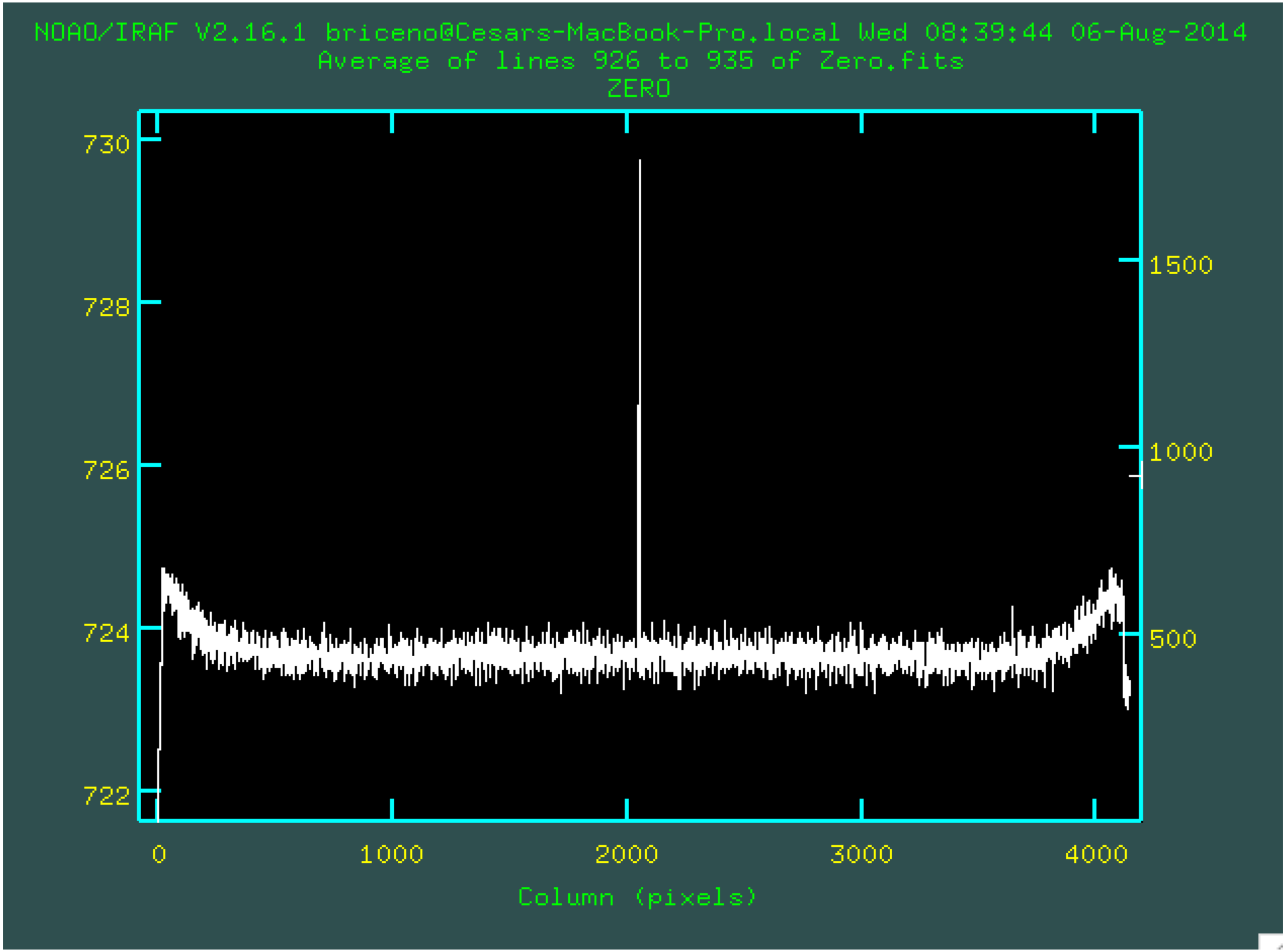
I) Determining the characteristics of your data

The BIAS

Single BIAS: Spec Mode 1x1, 100KHz ATTN3 (Gain=2.06 e/ADU, Noise=3.99 e)

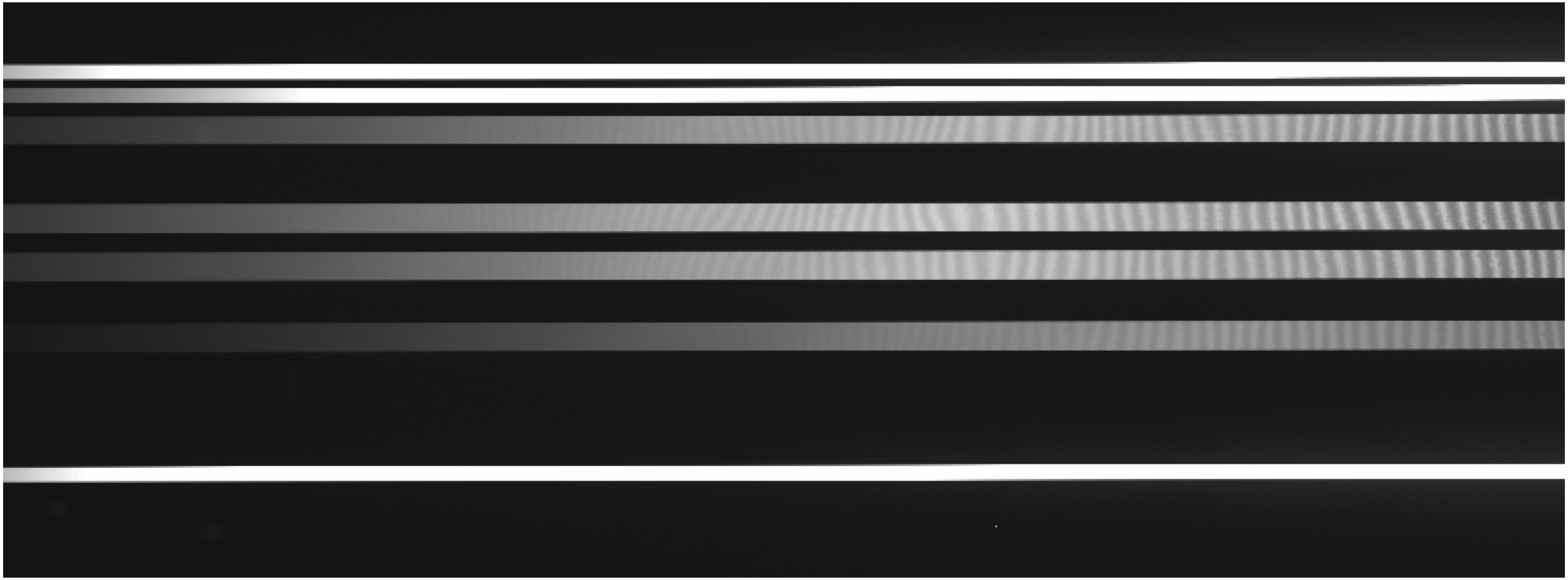
Combination of 20 BIAS frames: IRAF *combine*
→
combine=average
reject=crreject
scale=none

The BIAS

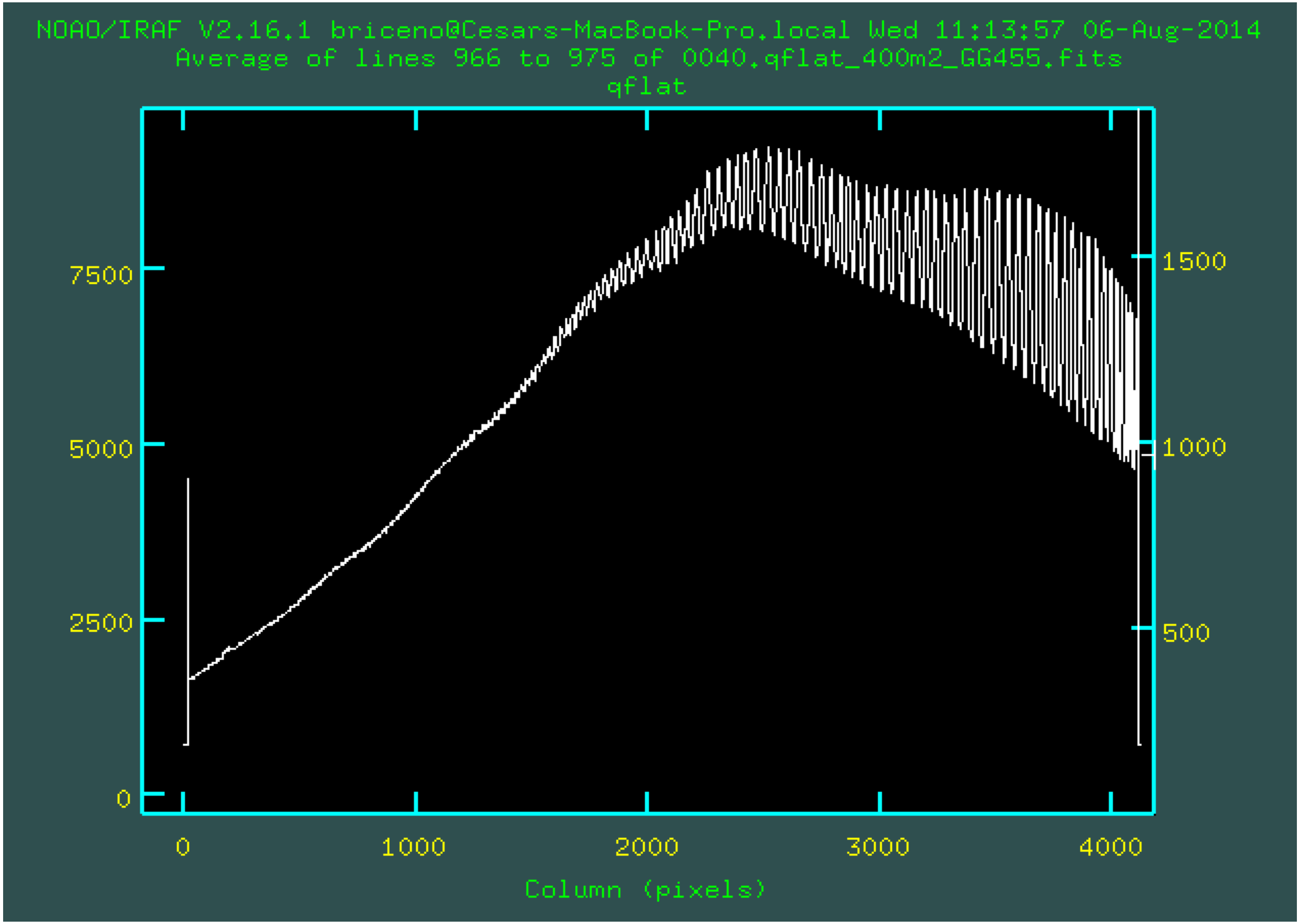


NOAO/IRAF V2.16.1 briceno@Cesars-MacBook-Pro.local Wed 08:39:44 06-Aug-2014
Average of lines 926 to 935 of Zero.fits
ZERO
730
728
726
724
722
1500
1000
500
0
1000
2000
3000
4000
Column (pixels)

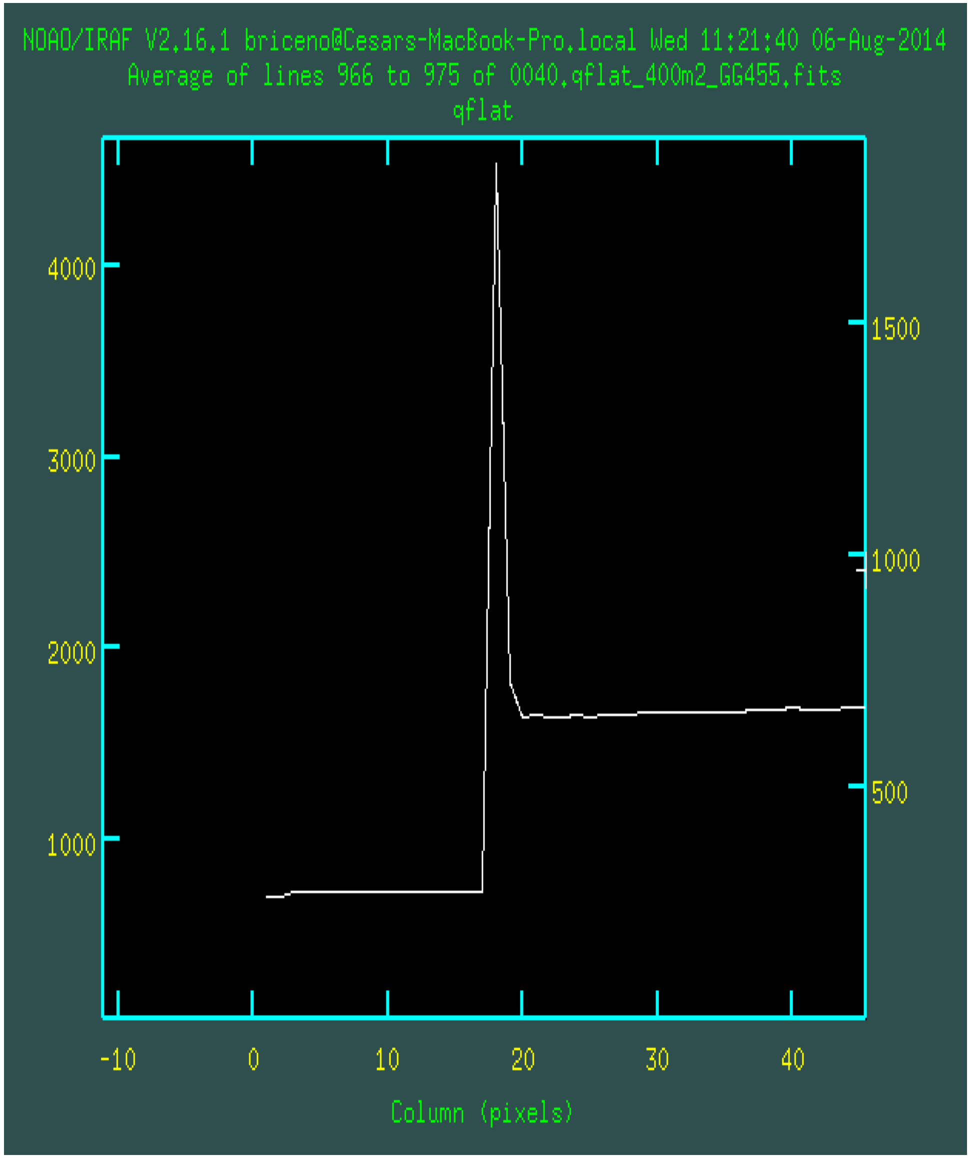
Quartz lamps: 400M2 + GG455

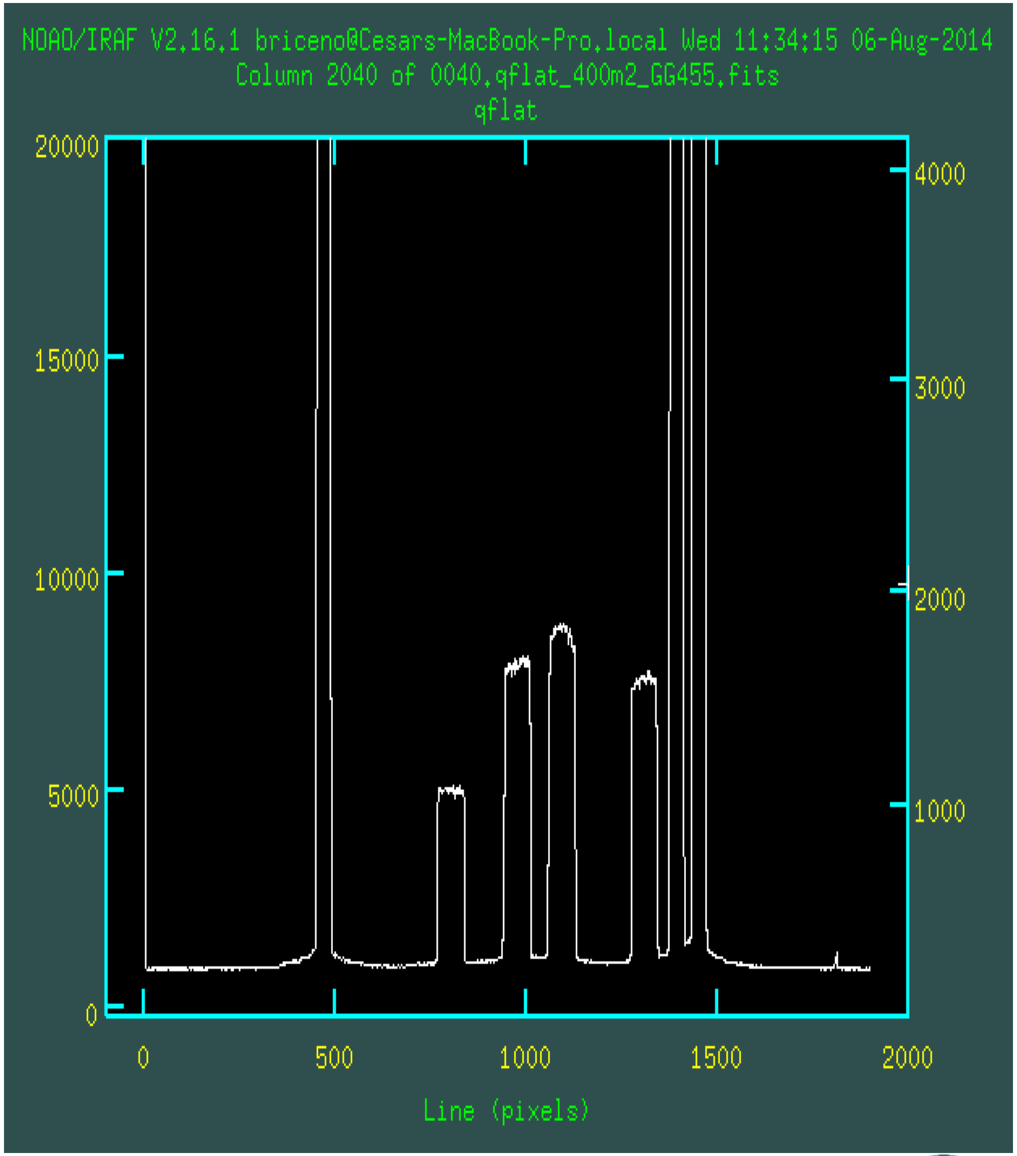


Quartz lamps: 400M2 + GG455

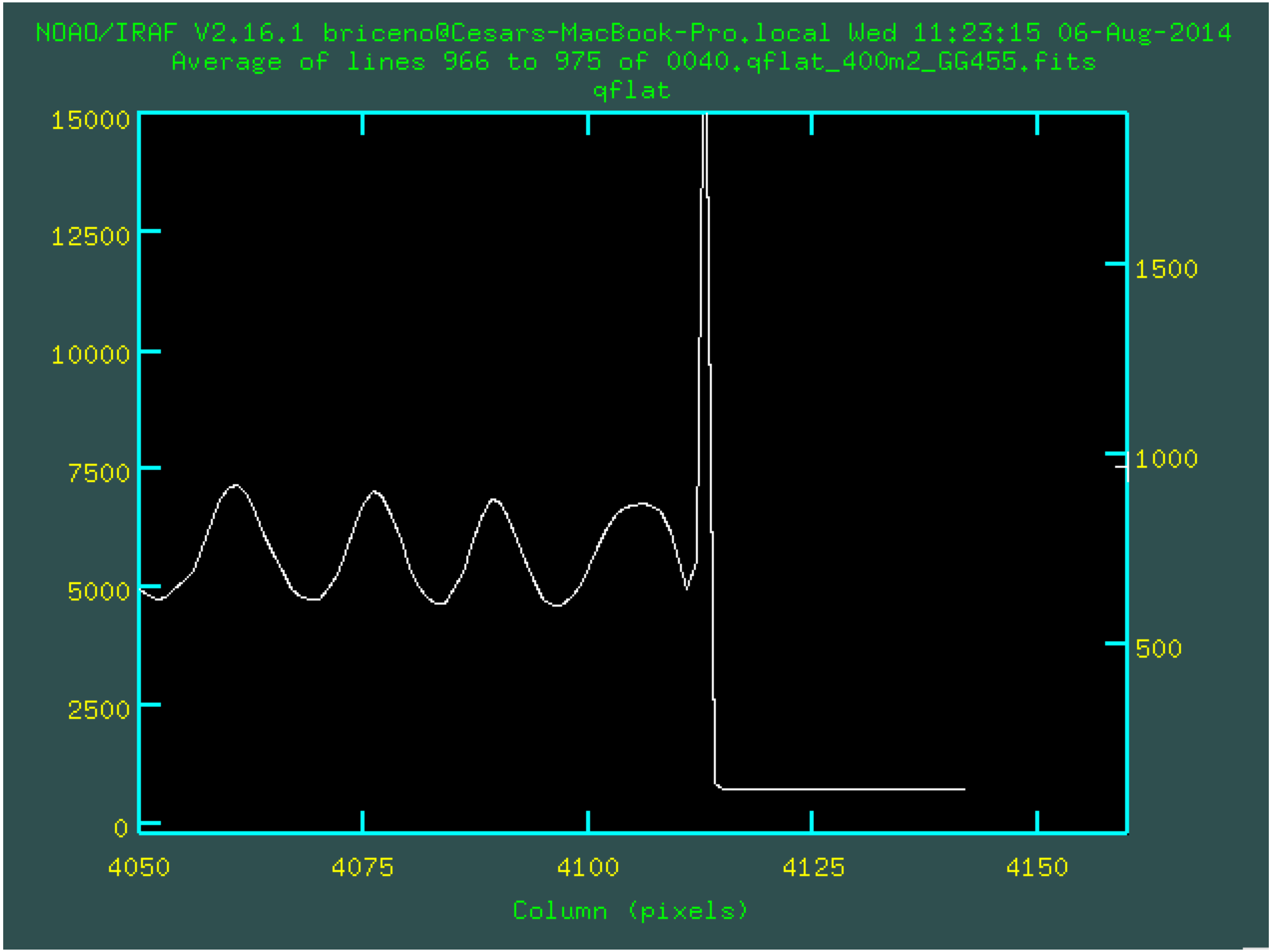


Trim section: [30:4100,10:1850]





Overscan section: [4115:4140,50:1750]



CCDPROC: trimming, overscan & bias correction

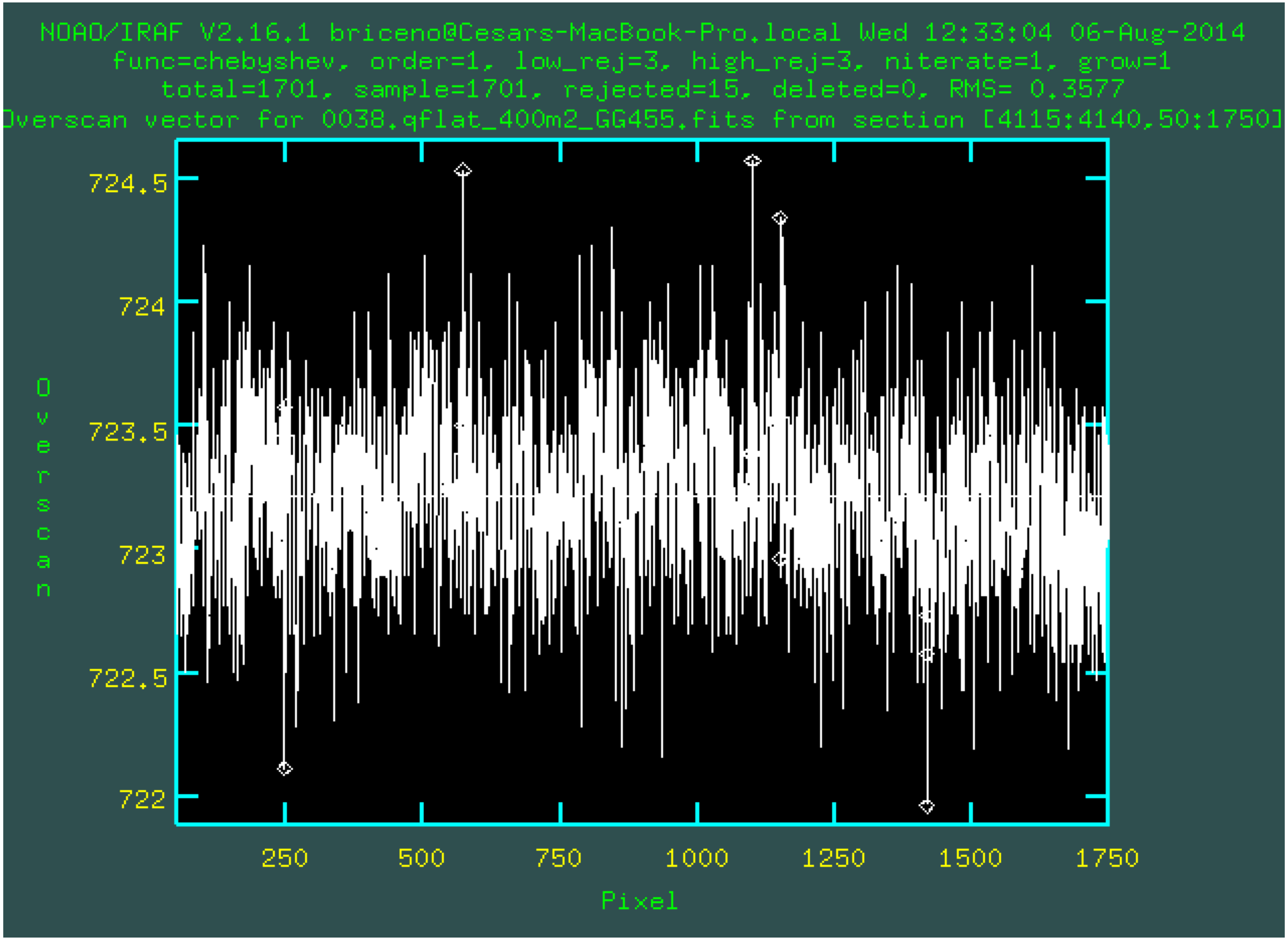
I R A F
Image Reduction and Analysis Facility

PACKAGE = ccdred
TASK = ccdproc

images = **@list1** List of CCD images to correct
(output =) List of output CCD images
(ccdtype=) CCD image type to correct
(**oversca=** **yes)** Apply overscan strip correction?
(**trim =** **yes)** Trim the image?
(**zerocor=** **yes)** Apply zero level correction?
(**biassec= [4115:4140,50:1750])** Overscan strip image section
(trimsec= [30:4100,50:1750]) Trim data section
(**zero =** **Zero)** Zero level calibration image
(**interac=** **yes)** Fit overscan interactively?
(**functio=** **chebyshev)** Fitting function
(**order =** **1)** Number of polynomial terms or spline pieces

Where **list1** contains <u>quartz lamp flats, comp lamps and science frames</u>.

CCDPROC: overscan correction



Combine quartz, comparison lamps and science target frames (if appropriate)

combine **@comp_lamps** output=**comp_HgA**r ccdtype="" combine=median reject=none scale=mode rdnoise=3.99 gain=2.06

combine **@ori2** output=**ori2_comb** ccdtype="" combine=median reject=none scale=mode rdnoise=3.99 gain=2.06

combine **@quartz_lamps** output=**qfla**t ccdtype="" combine=median reject=none scale=mode rdnoise=3.99 gain=2.06

combine **@quartz_lamps_nograting** output=**qflat_nograting** ccdtype="" combine=median reject=none scale=mode rdnoise=3.99 gain=2.06

Extract the 2-D spectra

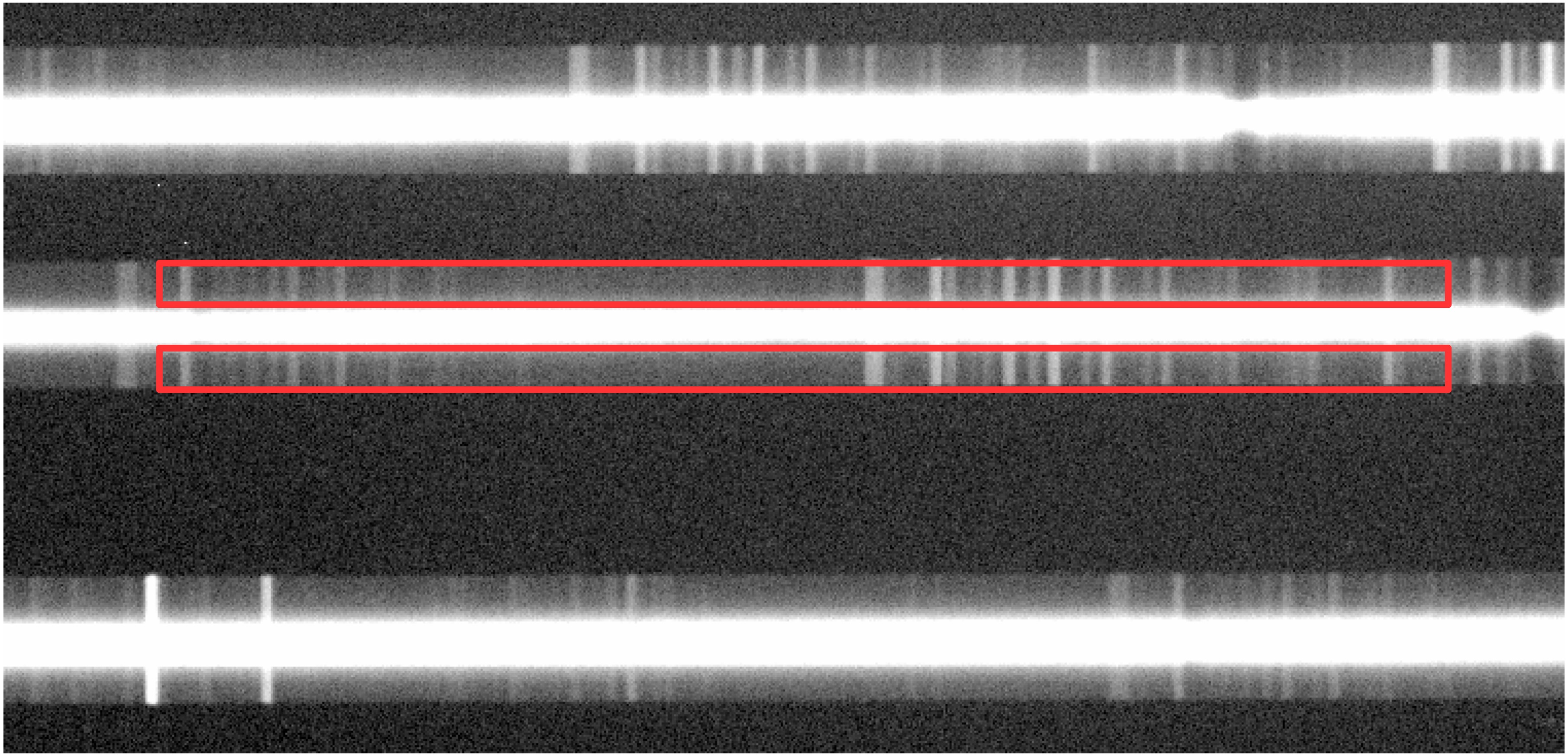
Use **APALL** in package TWODSPEC – APEXTRACT:

twodspec> apextract

apall	apedit	apflatten	apnormalize	apscatter
apdefault@	apfind	apmask	aprecenter	apsum
apdemos.	apfit	apnoise	apresize	aptrace

Examine the 2-D spectra

Determine the background region.



Parameters for APALL (1)

I R A F

Image Reduction and Analysis Facility

PACKAGE = **apextract**

TASK = **apall**

```
input   =          ori2_comb       List of input images
(output =          ori2_comb_1d) List of output spectra
(format =              onedspec) Extracted spectra format
(interac=                   yes) Run task interactively?
(find   =                   yes) Find apertures?
(recente=                   yes) Recenter apertures?
(resize =                   yes) Resize apertures?
(edit   =                   yes) Edit apertures?
(trace  =                   yes) Trace apertures?
(fittrac=                   yes) Fit the traced points interactively?
(extract=                   yes) Extract spectra?
(extras =                   yes) Extract sky, sigma, etc.?
(review =                   yes) Review extractions?
```

Parameters for APALL (2)

DEFAULT BACKGROUND PARAMETERS

```
(b_funct=          chebyshev) Background function
(b_order=                  3) Background function order
(b_sampl=        -10:-5,5:10) Background sample regions
(b_naver=                 -3) Background average or median
```

APERTURE CENTERING PARAMETERS

```
(width  =                 5.) Profile centering width
(radius =                10.) Profile centering radius
(thresho=                 0.) Detection threshold for profile centering
```

Parameters for APALL (3)

AUTOMATIC FINDING AND ORDERING PARAMETERS

Nfind = **4** Number of apertures to be found automatically
(minsep = 5.) Minimum separation between spectra
(maxsep = 100000.) Maximum separation between spectra

TRACING PARAMETERS

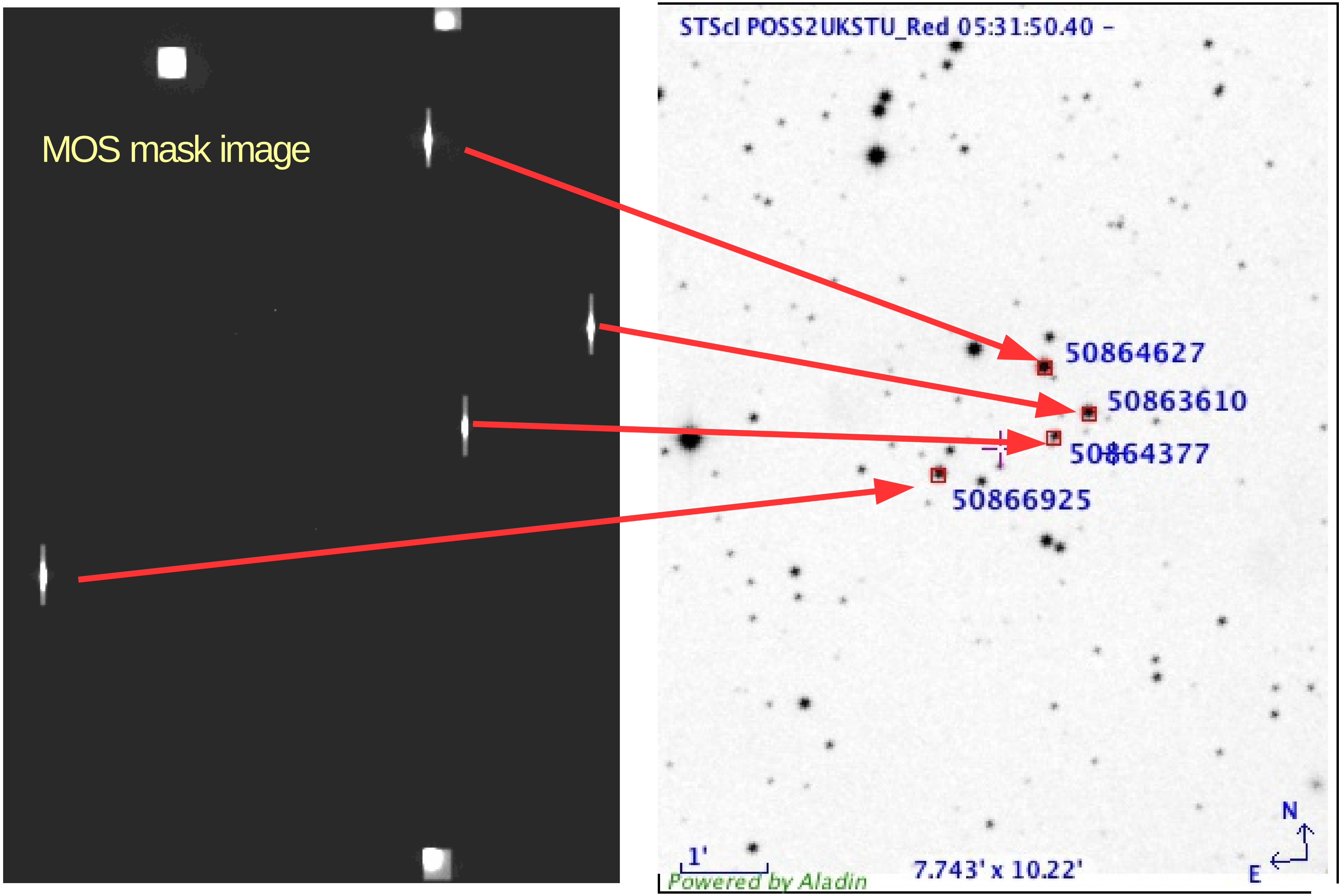
(t_nsum = 10) Number of dispersion lines to sum
(t_step = 10) Tracing step
(t_nlost= 3) Number of consecutive times profile is lost b
(t_funct= legendre) Trace fitting function
(t_order= 3) Trace fitting function order
(t_sampl= *) Trace sample regions
(t_naver= 1) Trace average or median

Parameters for APALL (4)

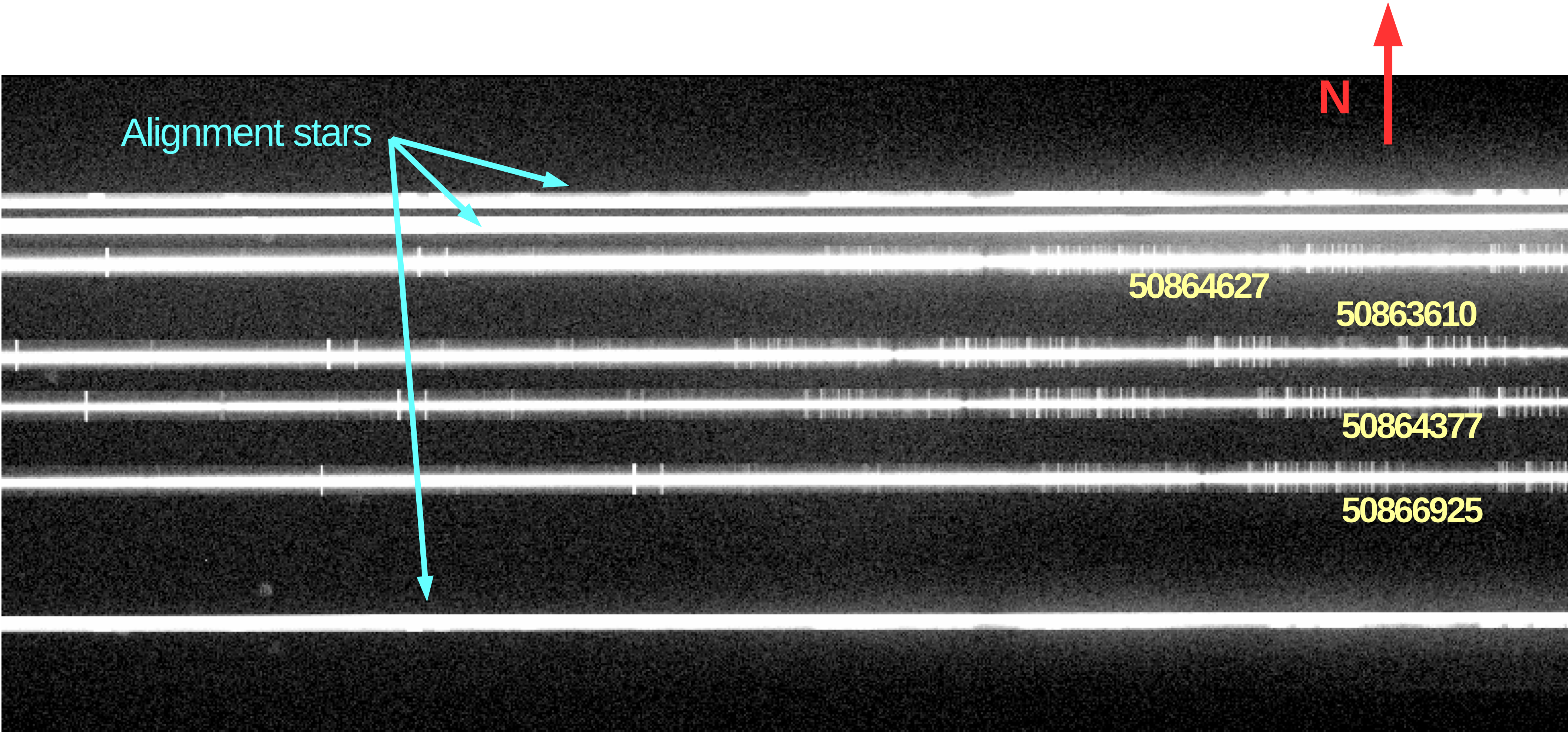
EXTRACTION PARAMETERS

(backgro= **average**) Background to subtract
(skybox = 1) Box car smoothing length for sky
(weights= none) Extraction weights (none|variance)
(pfit = fit1d) Profile fitting type (fit1d|fit2d)
(clean = no) Detect and replace bad pixels?
(saturat= INDEF) Saturation level
(readnoi= **3.99**) Read out noise sigma (photons)
(gain = **2.06)** Photon gain (photons/data number)
(lsigma = 4.) Lower rejection threshold
(usigma = 4.) Upper rejection threshold
(nsubaps= 1) Number of subapertures per aperture
(mode = ql)

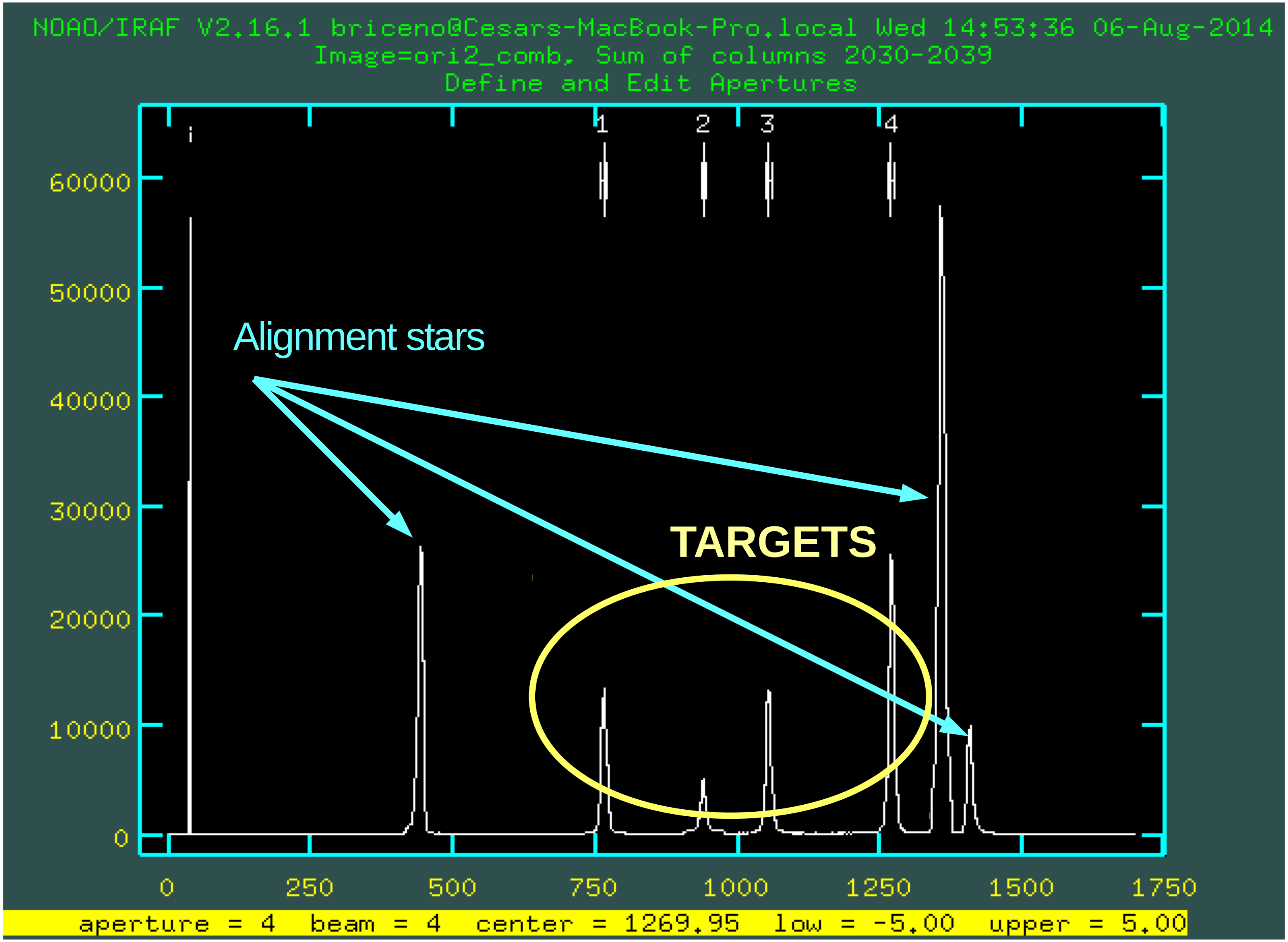
Identify your targets in your mask



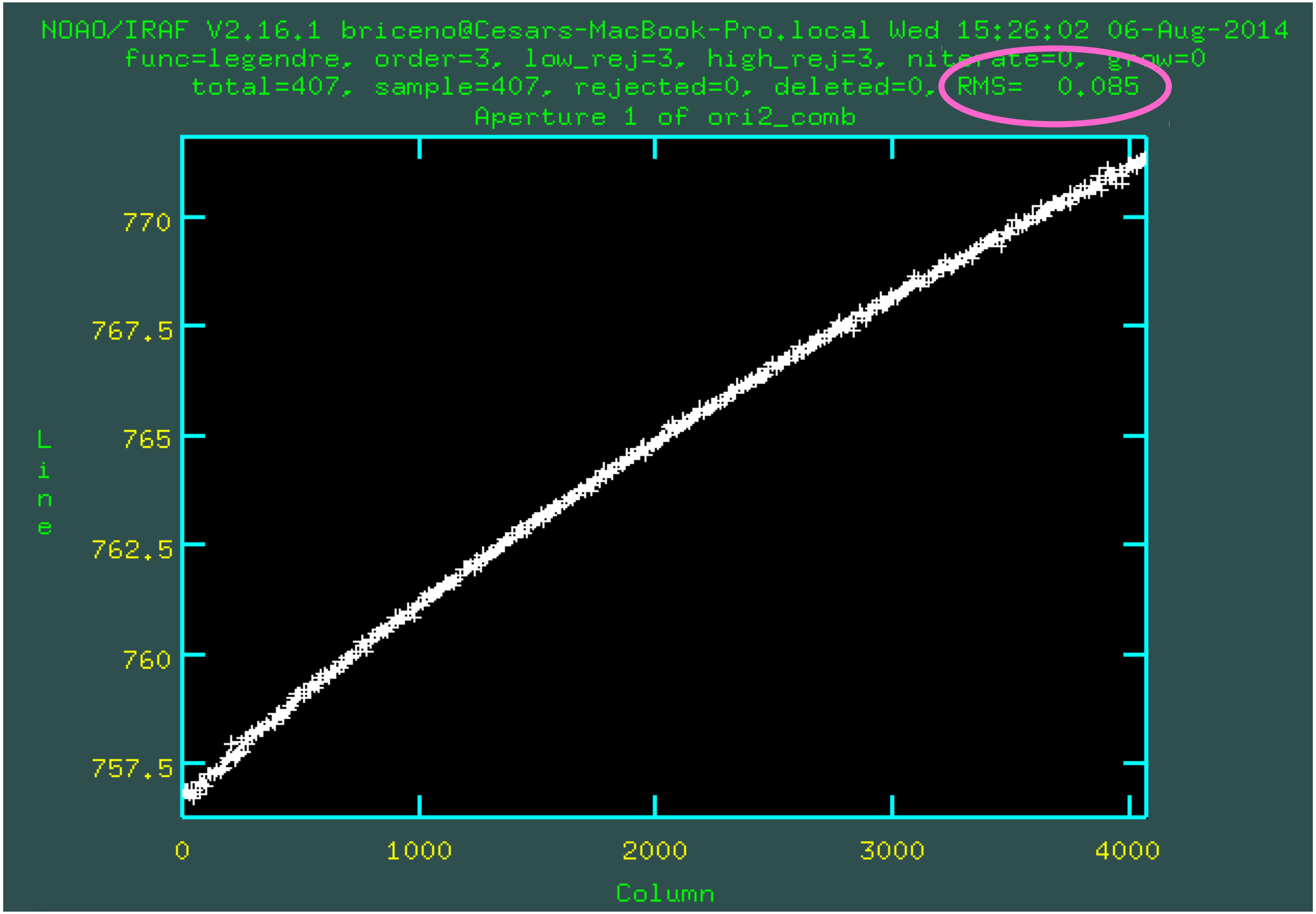
Identify your targets in your spectra



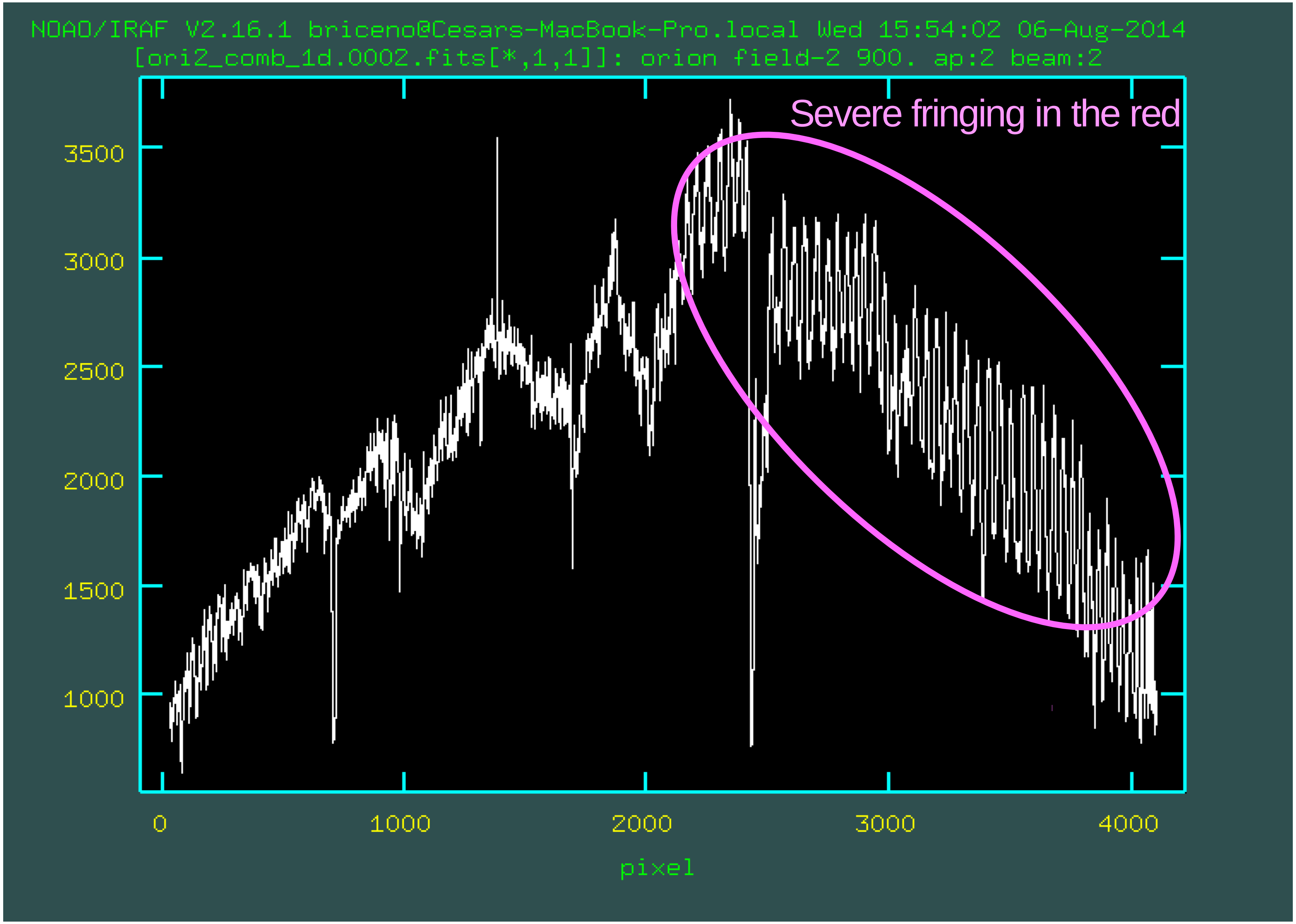
Running APALL (1): select/check apertures



Running APALL (2): trace apertures

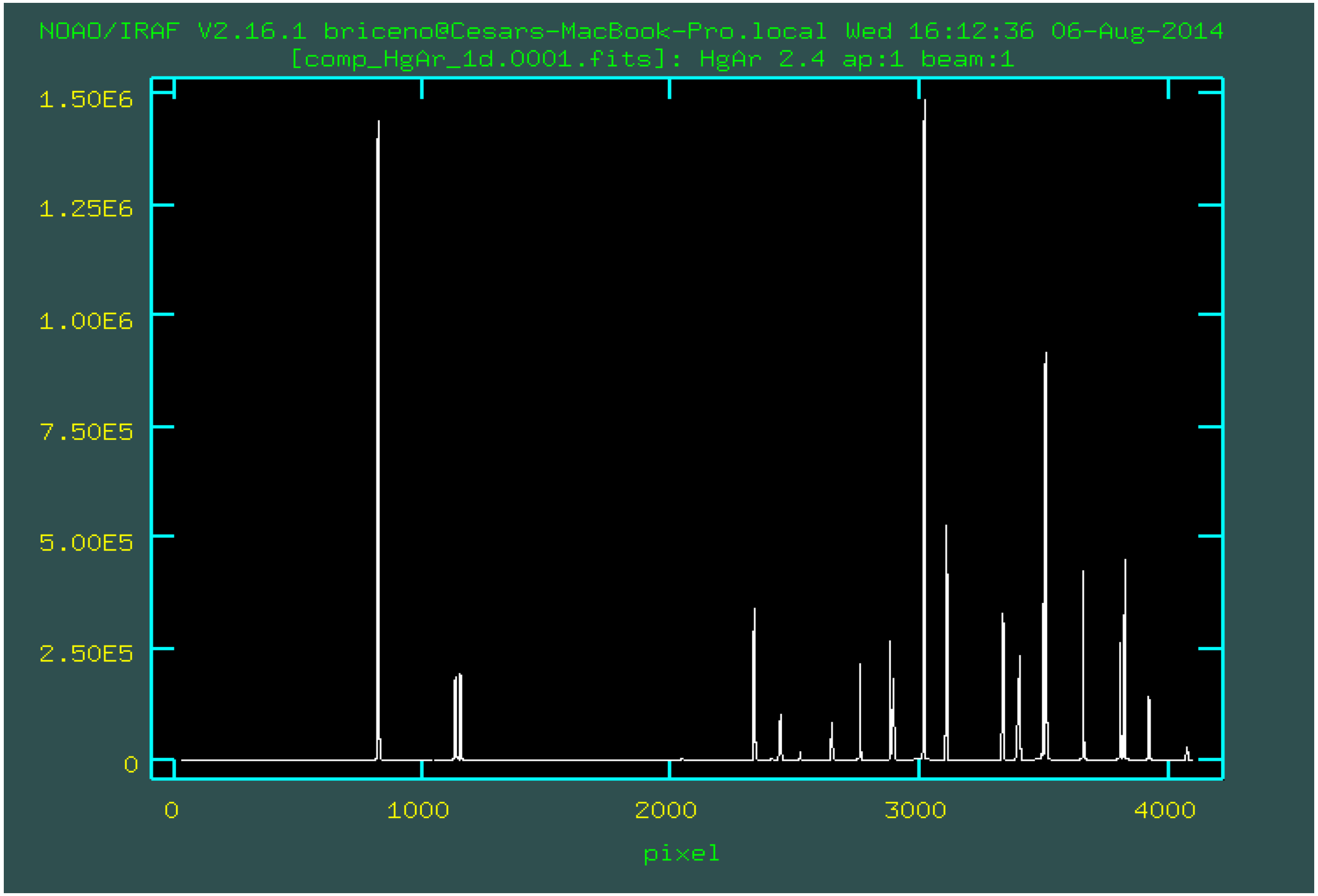


Running APALL (3): extract spectra



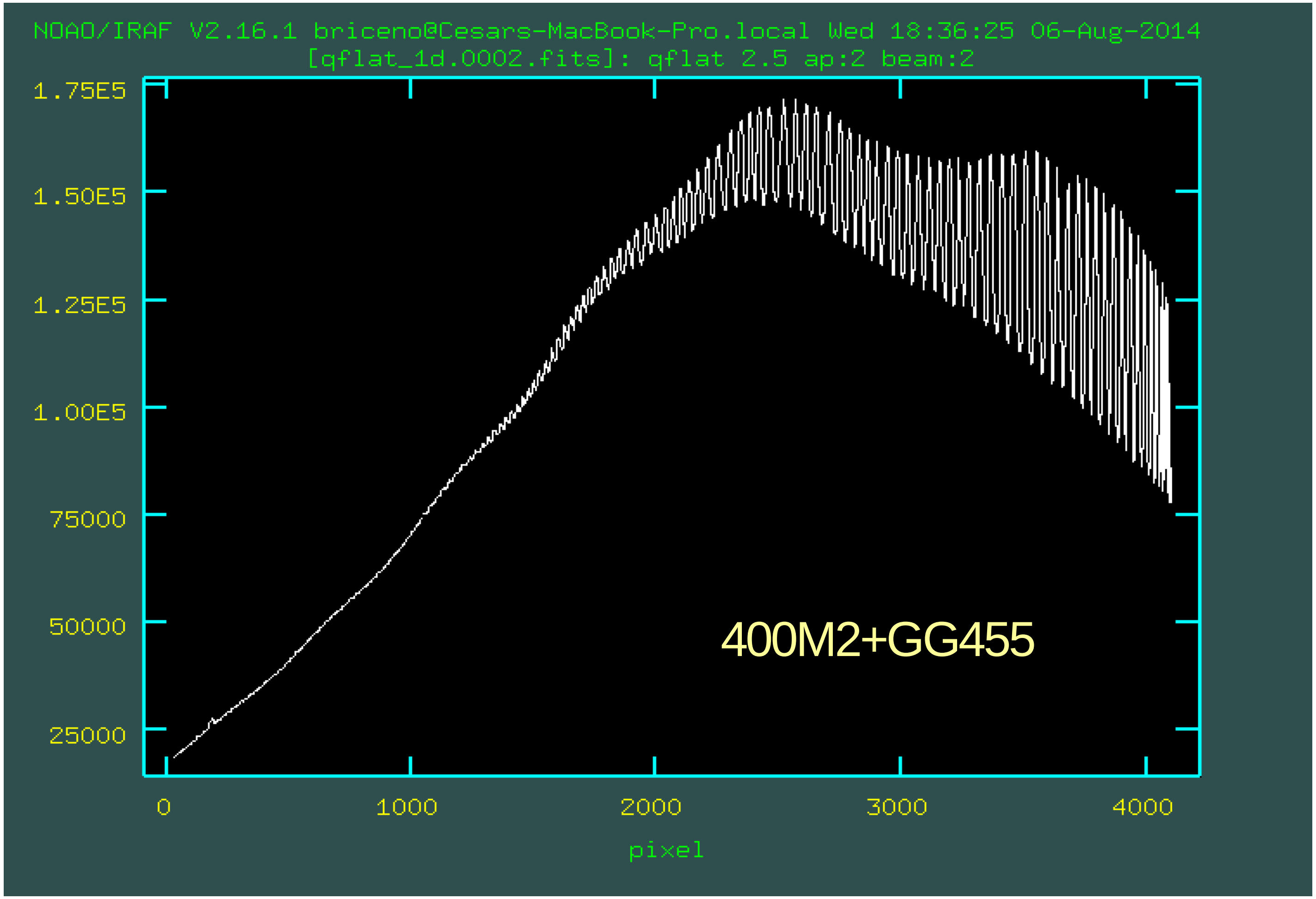
Running APALL (5): extract comp for each slit

apall comp_HgAr output=comp_HgAr_1d format=onedspec referen=ori2_comb interac- find- recenter- resize- edit- trace- fittrace- extract+ review- extras- backgro=none



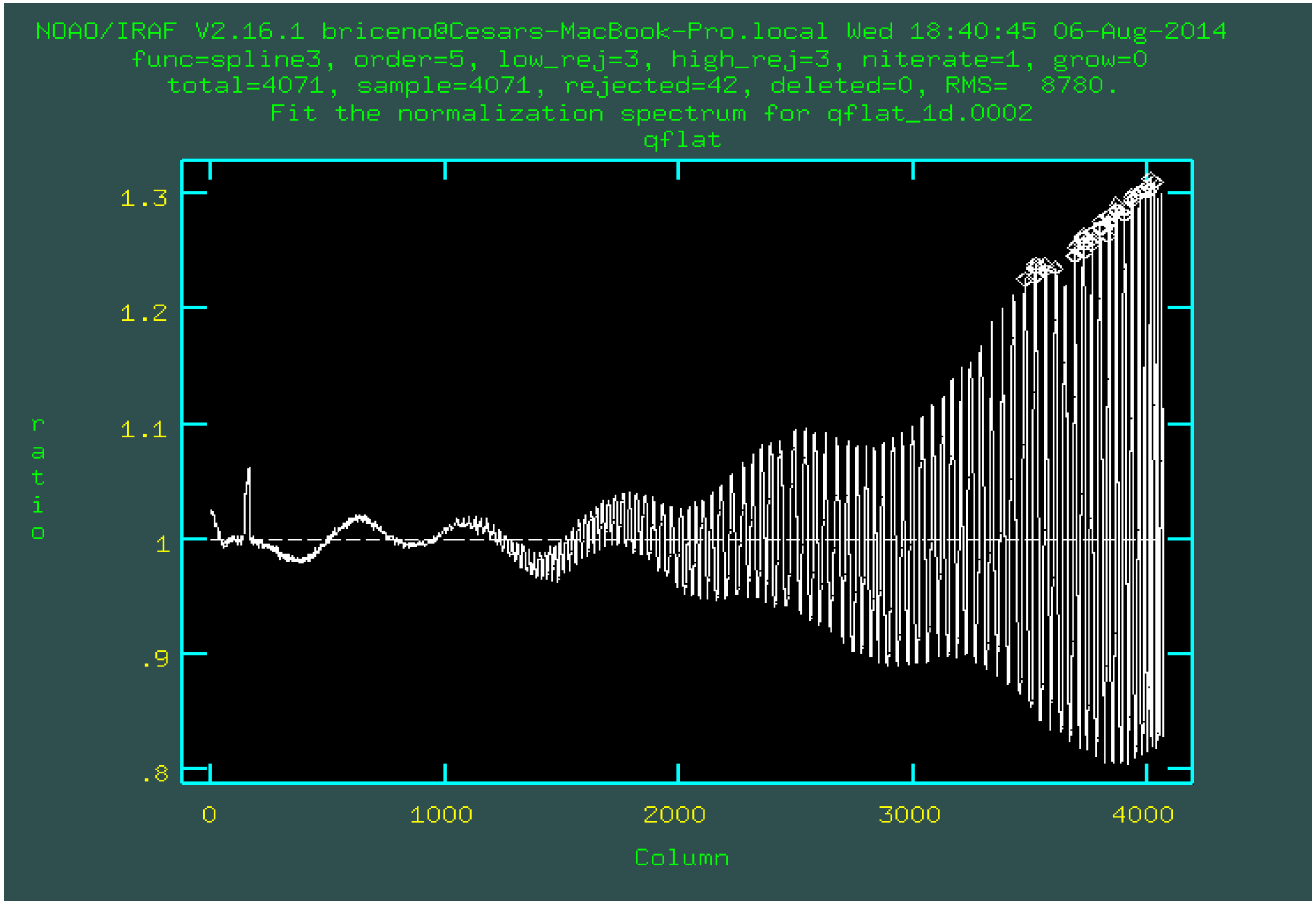
Running APALL (6): extract quartz lamps for each slit

apall qflat output=qflat_1d format=onedspec referen=ori2_comb inter find- recenter- resize- edit- trace- fittrace- extract+ review- extras- backgro=none

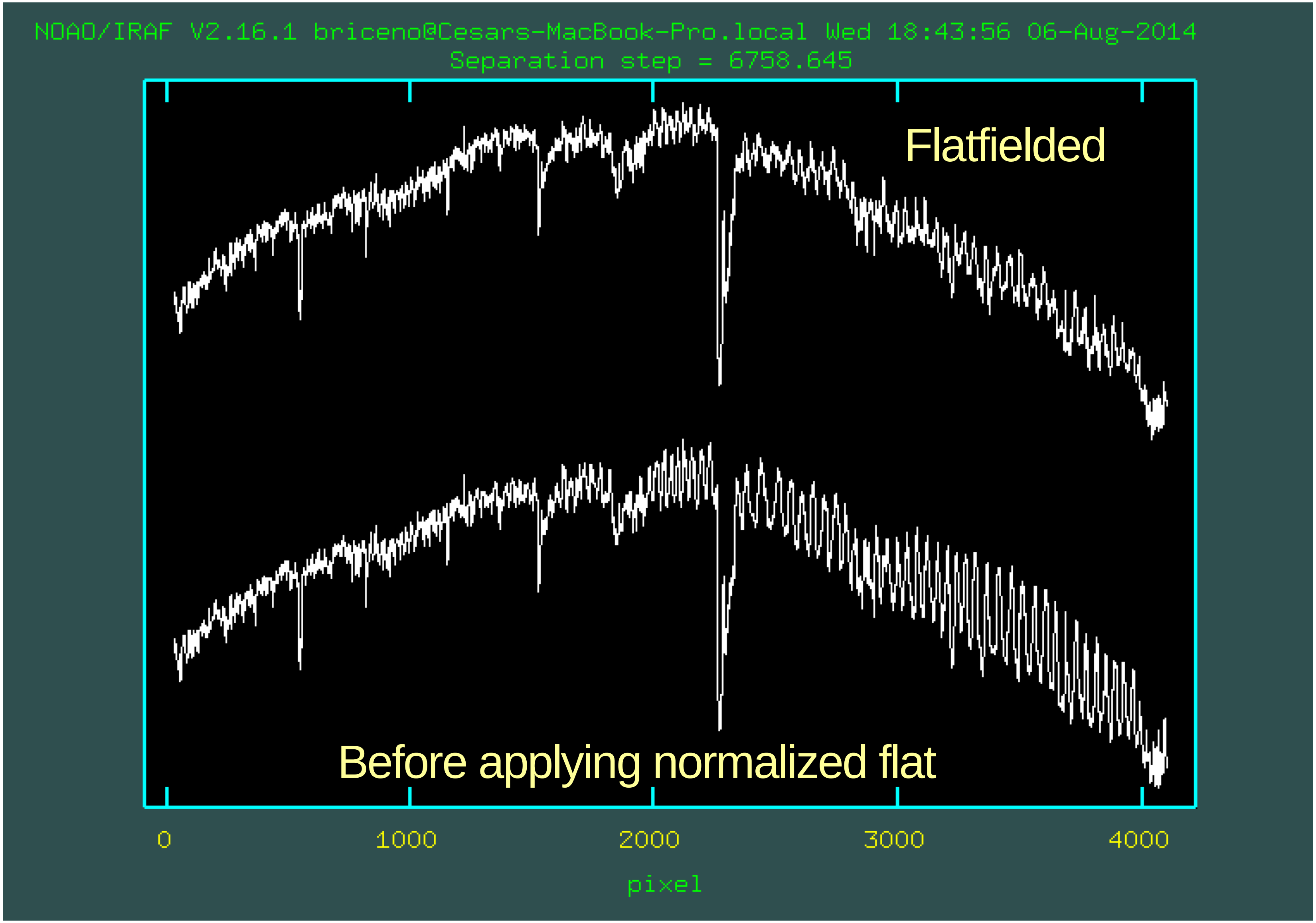


Normalize your spectroscopic flats: RESPONSE

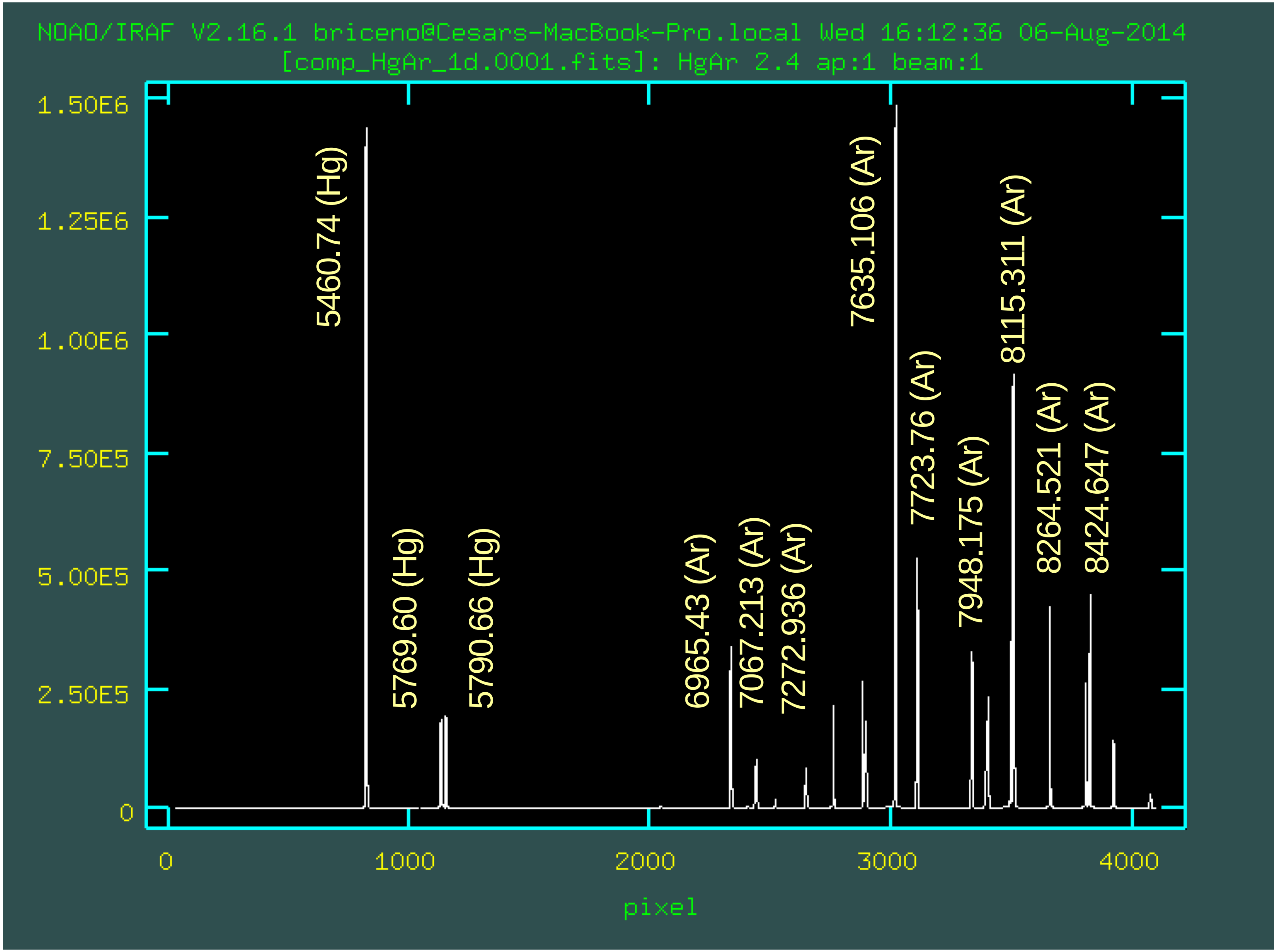
response qflat_1d.0002 normaliz=qflat_1d.0002 response=qflat_1d_norm.0002 interac+ functio=spline3 order=5



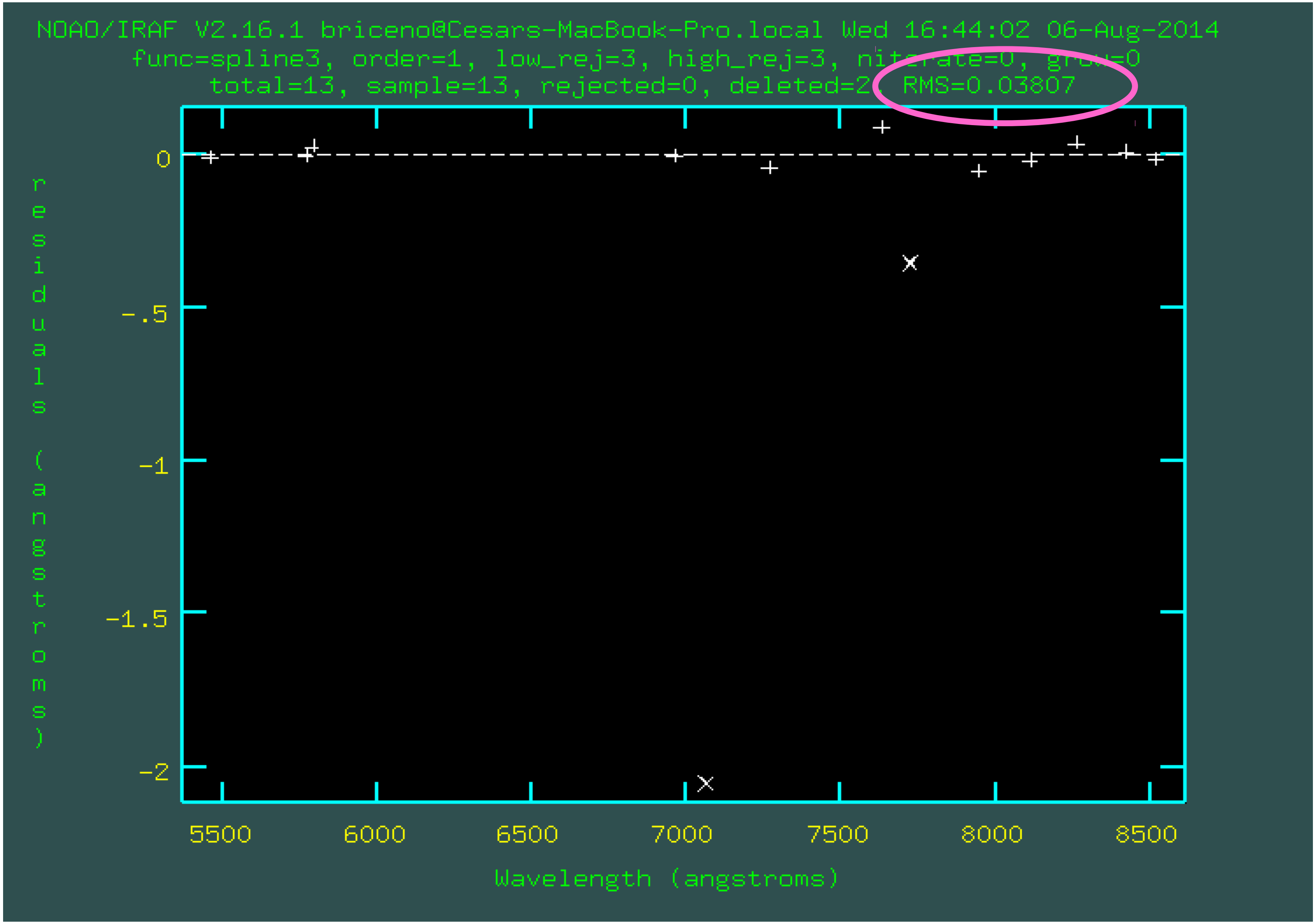
Flatfield your spectra



Goodman Hg(Ar) lamp with 400M2 + GG455



Running **Identify** on each slit comp spectrum



Applying the dispersion solution

Run **REFSPEC** to assign the corresponding calibrated comparison lamp to the appropriate target

```
refspec ori2_comb_1d.0002
reference=comp_HgAr_1d.0002 select=match sort=""
time=no confirm- verbose+
```

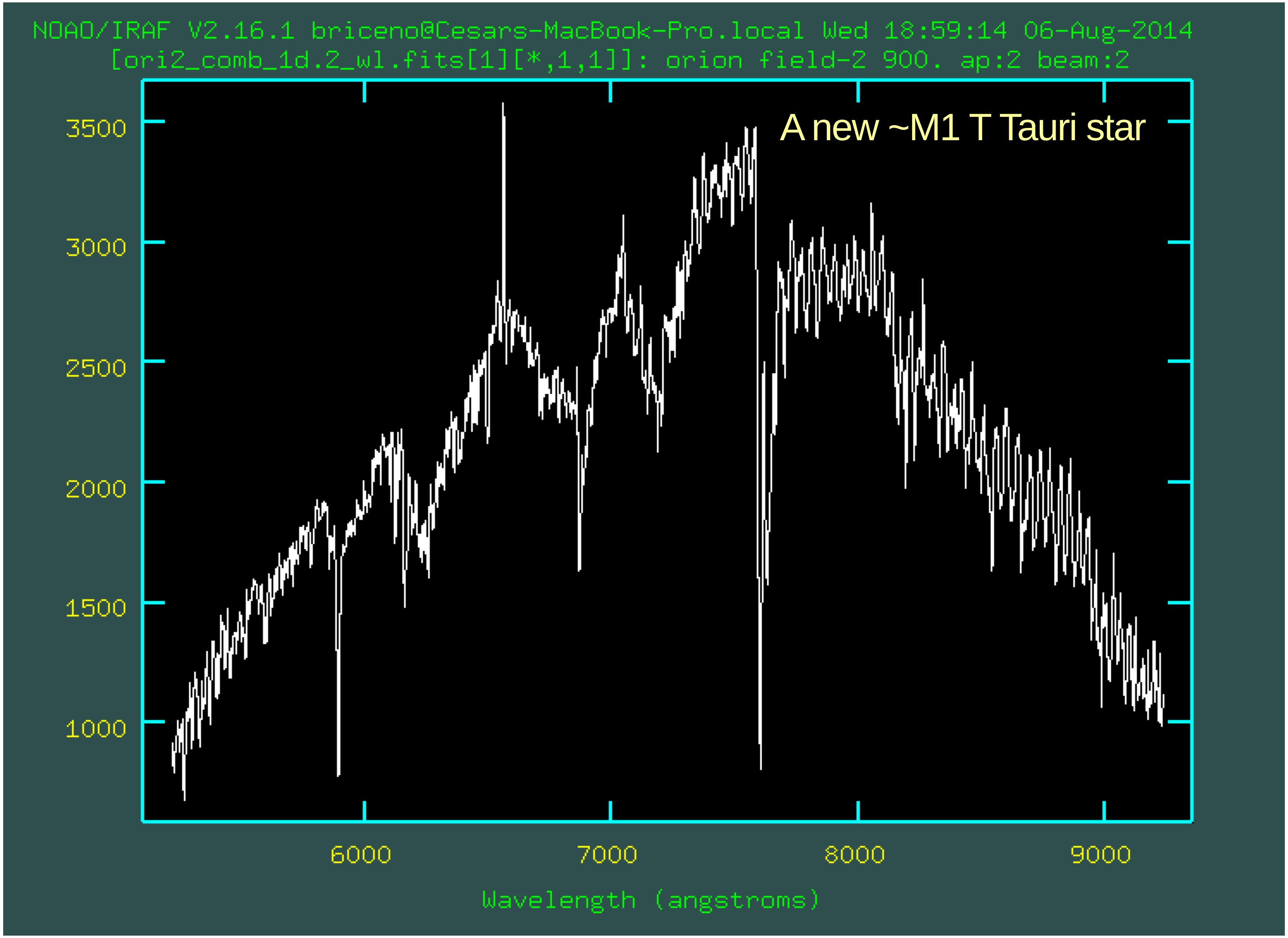
Run **DISPCOR** to apply the dispersion solutions to each target spectrum

```
dispcor ori2_comb_1d.0002 output=ori2_comb.2_wl
lineari=yes flux=yes samedis=no global=no confirm-
verbose+
```

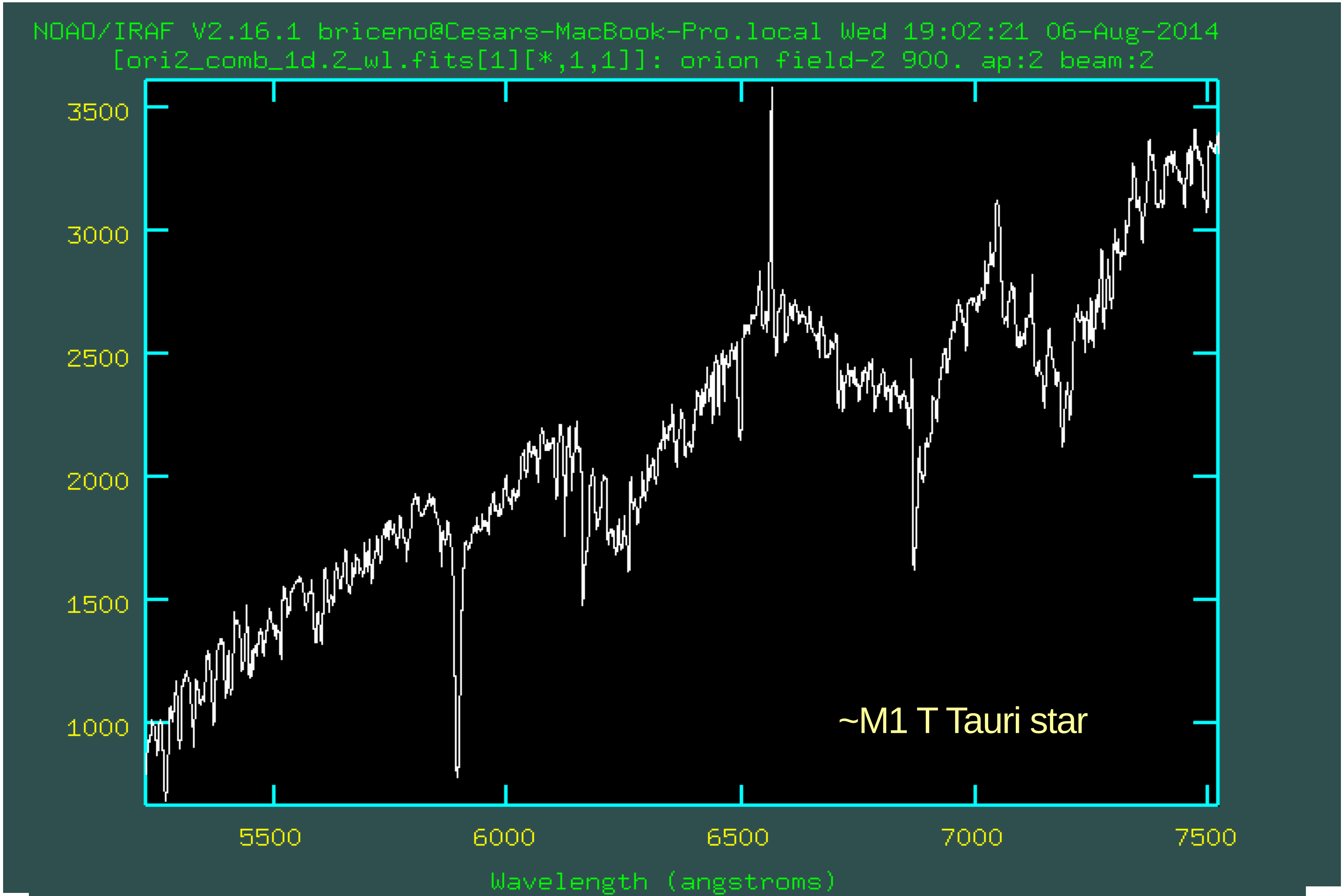
Applying the dispersion solution

```
apextract> cl < dodispcor.cl

ori2_comb_1d.0001: REFSPEC1 = 'comp_HgAr_1d.0001 1.'
ori2_comb_1d.1_wl: ap = 1, w1 = 4671.559, w2 =  8693.73, dw = 0.988249,

ori2_comb_1d.0002: REFSPEC1 = 'comp_HgAr_1d.0002 1.'
ori2_comb_1d.2_wl: ap = 2, w1 = 5216.887, w2 = 9238.728, dw = 0.988167,

ori2_comb_1d.0003: REFSPEC1 = 'comp_HgAr_1d.0003 1.'
ori2_comb_1d.3_wl: ap = 3, w1 = 5378.805, w2 = 9400.968, dw = 0.988246,

ori2_comb_1d.0004: REFSPEC1 = 'comp_HgAr_1d.0004 1.'
ori2_comb_1d.4_wl: ap = 4, w1 = 5169.038, w2 = 9190.513, dw = 0.988077,
```

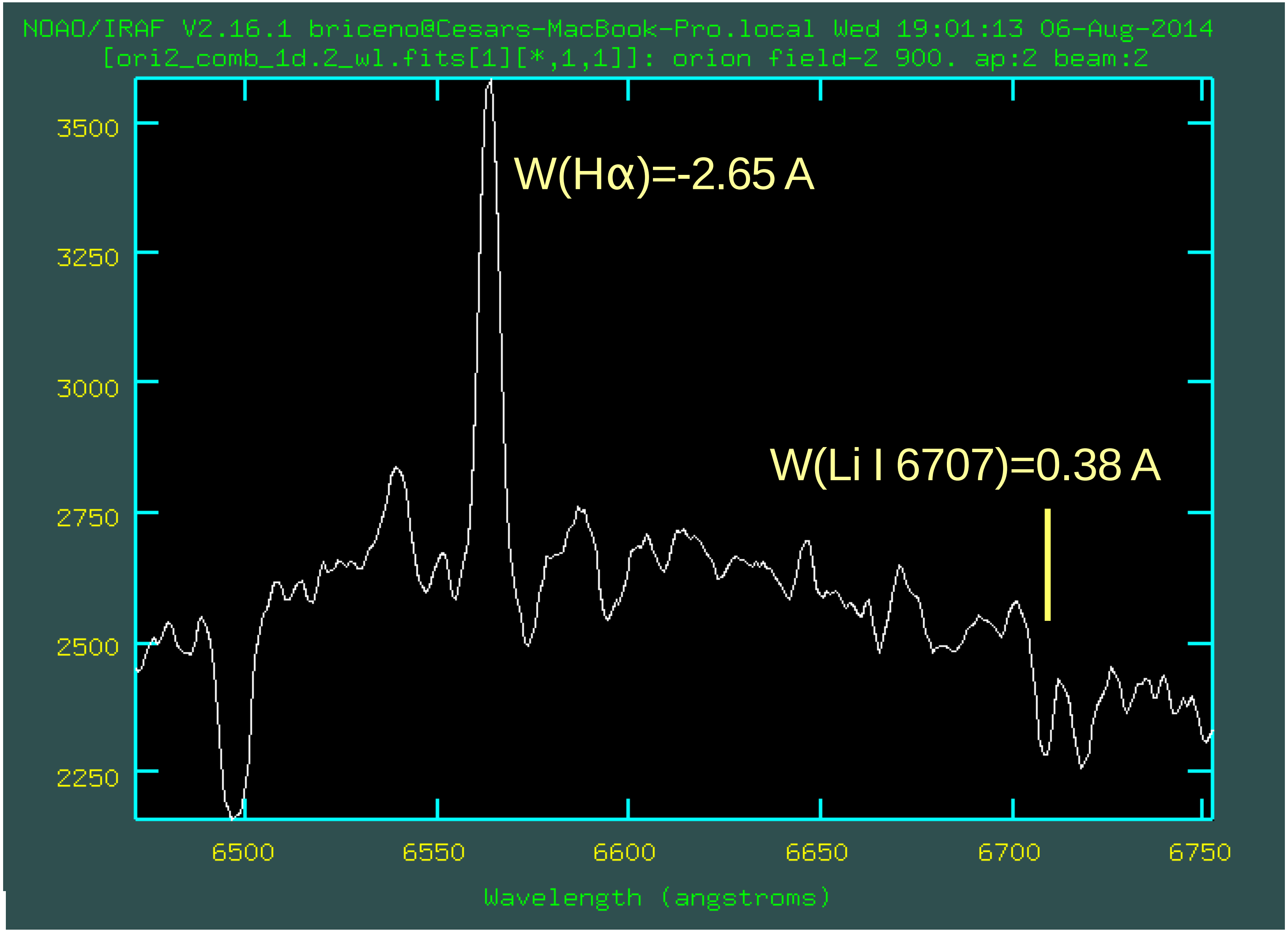
Wavelength-calibrated spectra



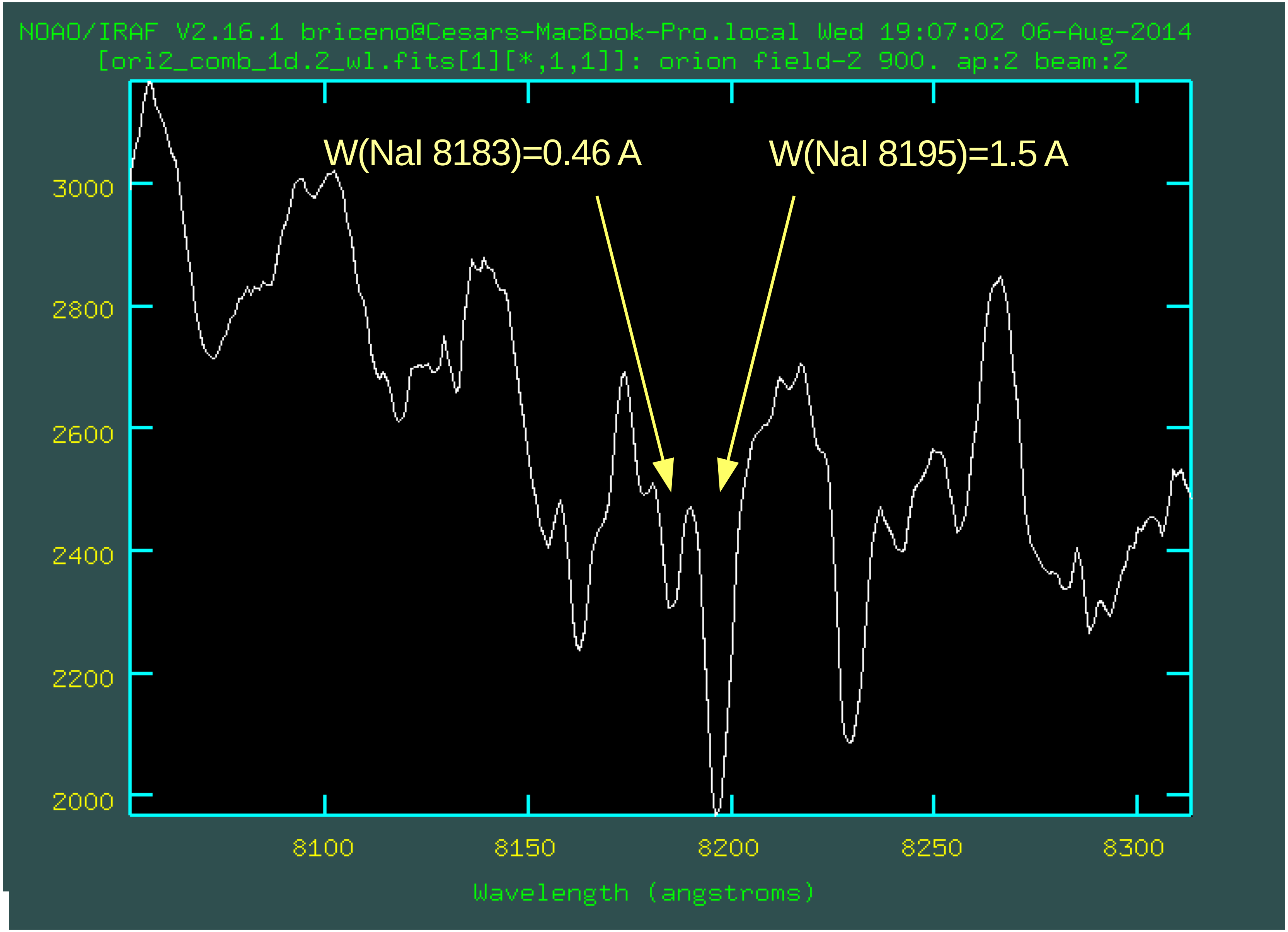
Wavelength-calibrated spectra



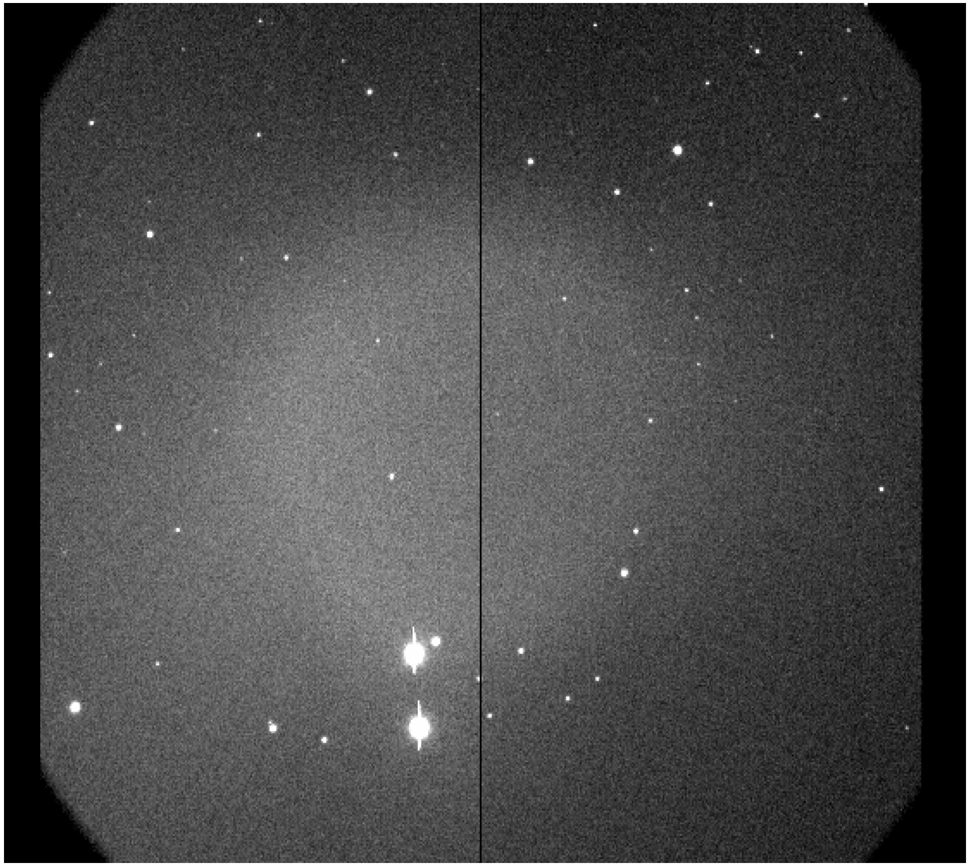
Wavelength-calibrated spectra



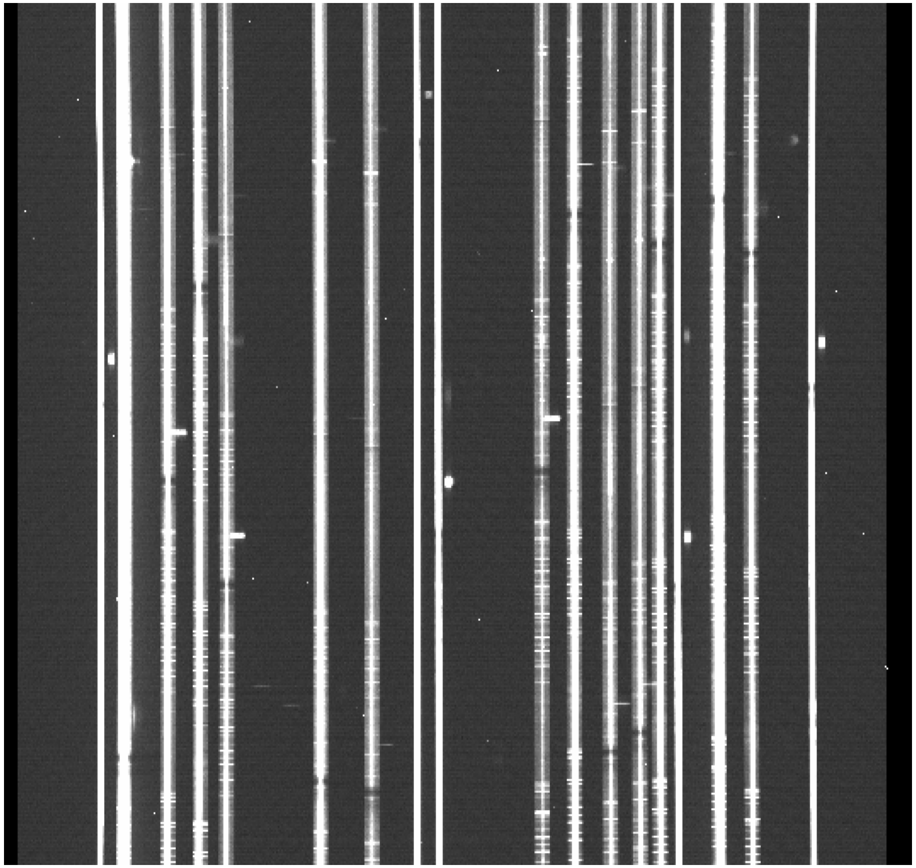
Wavelength-calibrated spectra



Other MOS systems at CTIO:
The Cerro Tololo Ohio State Multi-Object Spectrograph (COSMOS) on the Blanco 4m

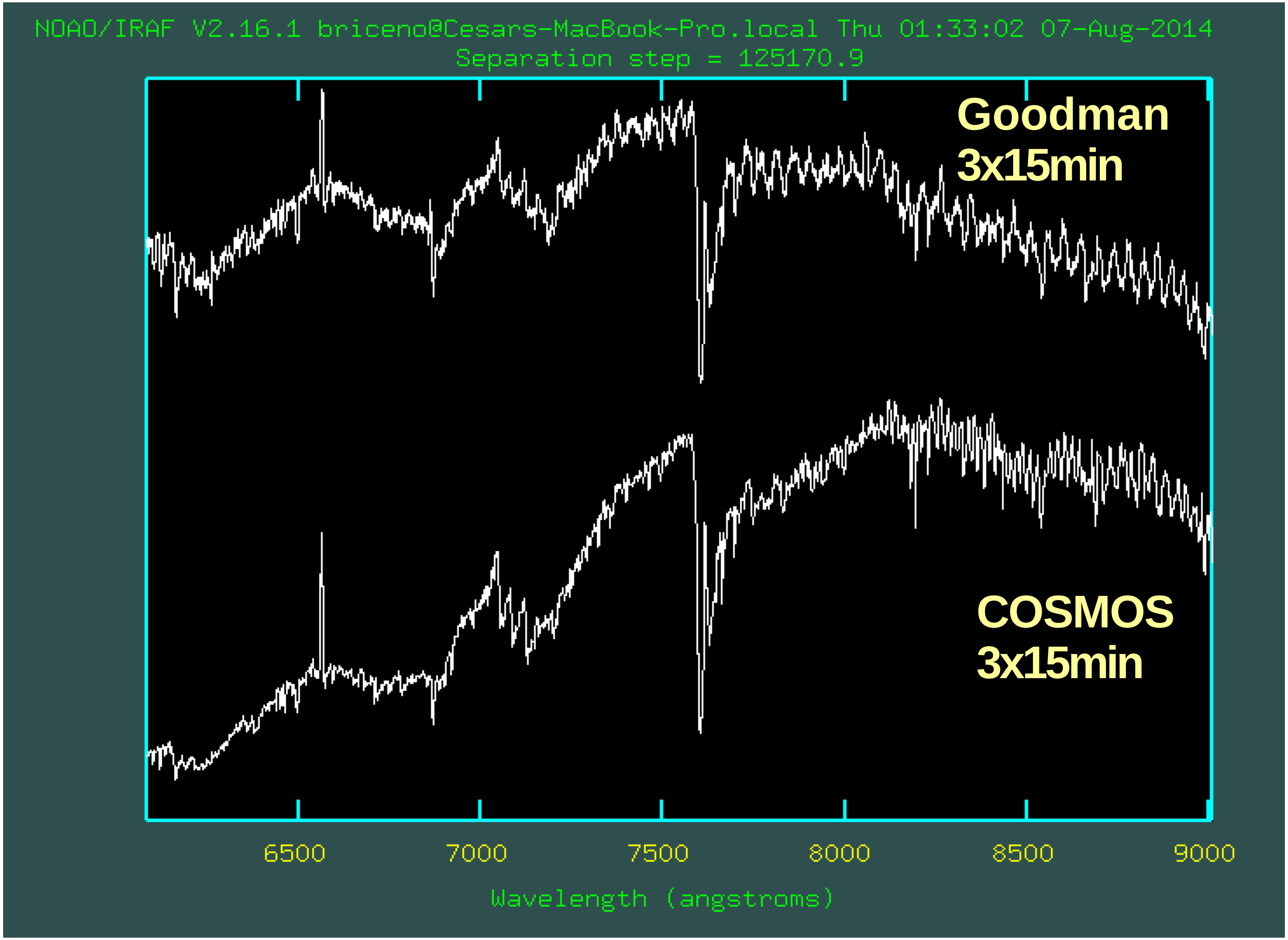


~12 arcmin diam. FOV

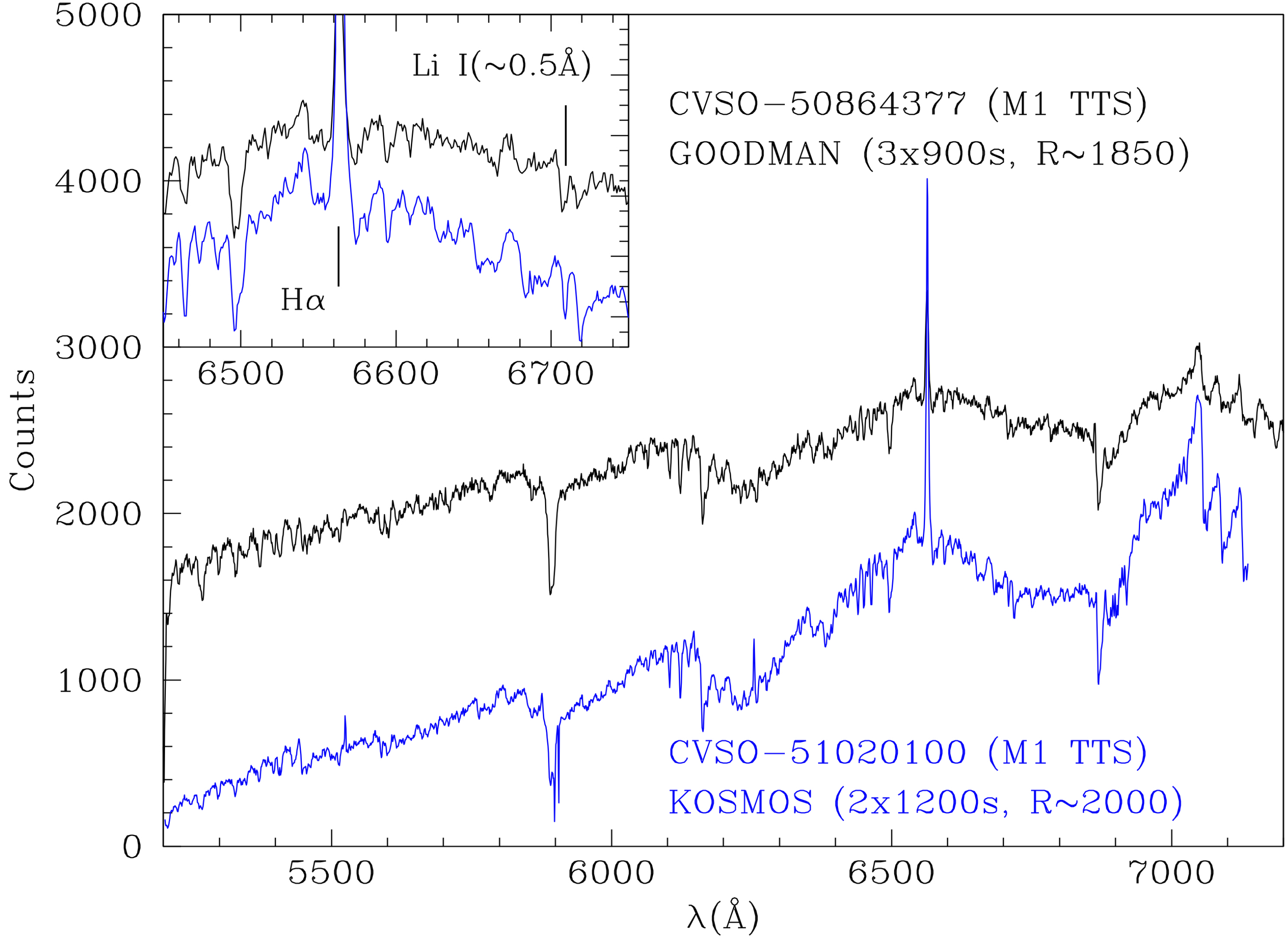


R ~ 2000

Goodman MOS vs COSMOS MOS



Comparing Goodman with COSMOS



New and upcoming

- **SOAR ADC is now commissioned.**
  Will be released for regular use in 2014B

- **NEW GRATING CHANGER is almost ready. Could be installed by end of 2014.** → more gratings can be installed

- **NEW 2400 l/mm grating**

- **NEW "Red" CCD Camera for Goodman (no fringing): 2014-2015**

- **SOAR TCS UPGRADE:** ongoing

- **SOAR optics correction improvements**: ongoing

- Concept of **Acquisition Camera for Goodman**

Which MOS system to use at NOAO-S?

- **Using either system requires advance preparation of masks**

- **Goodman MOS on SOAR:**
  - **Instrument is always on the telescope!**
  - Optimized for best performance in the blue-UV, but with new “Red” camera, will provide much better results out to ~900nm
  - Better image quality than Blanco → take advantage of nights with very good seeing (e.g., two masks of same field: one with narrower slits, other with wider slits)

- **COSMOS on the Blanco 4m:**
  - Larger FOV
  - Better performance (at present) in the red end
  - Only available during f/8 time (which is relatively little, since DeCam is taking up most of the time for the next few years)

Documentation

Goodman manual at the (current) SOAR webpage
http://www.soartelescope.org/observing/documentation/goodman-high-throughput-spectrograph/goodman-manual/manual

Summary of Goodman
http://www.soartelescope.org/observing/documentation/goodman-high-throughput-spectrograph/goodman-manual/overview

Goodman webpage at UNC
http://www.goodman-spectrograph.org/

Luciano Fraga's excellent tutorial:
http://www.lna.br/obsresoar/Apresentacao/goodman2013.pdf

You can download the *current* MOS documentation by doing an anonymous ftp to: ftp.ctio.noao.edu:pub/soar/

MOS documentation is currently evolving!....ask us for the latest version or download it from the ftp site above