XXVIII CANARY ISLANDS WINTER SCHOOL OF ASTROPHYSICS

SOLAR SYSTEM EXPLORATION

Reduction of spectra from ground-based telescopes

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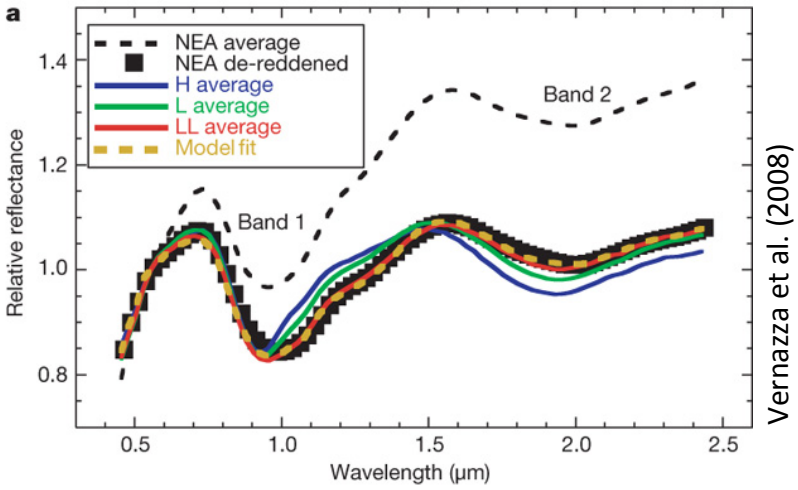
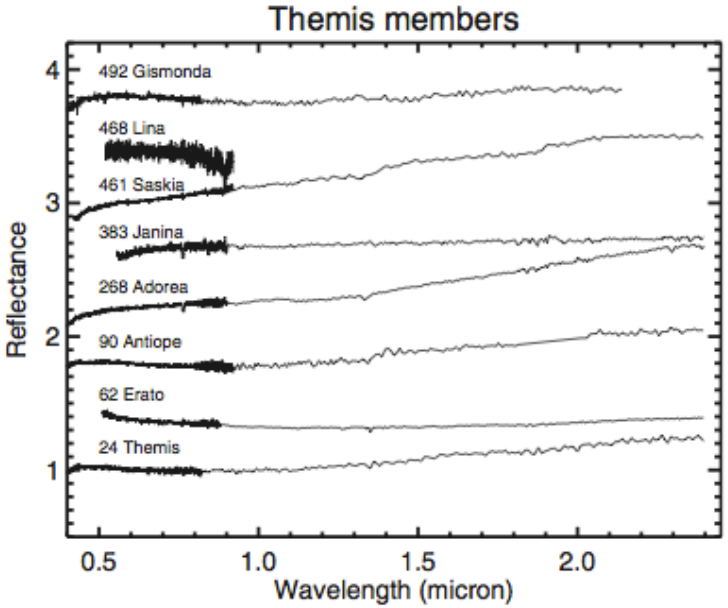
November 15, 2016. Tuesday 15:00 – 17:30

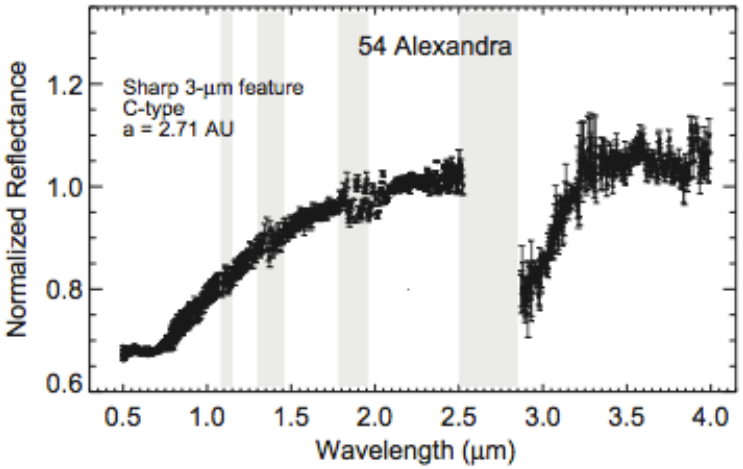
The composition of asteroids is inferred by the study of the reflectance spectra of their surfaces, mainly in the UV-VIS-NIR wavelength range (0.3-2.5 microns)



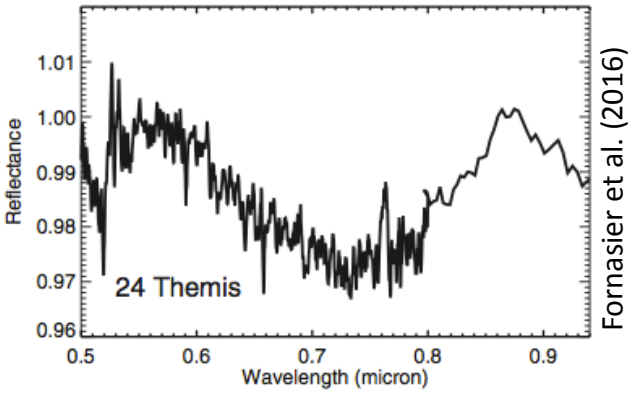
Vernazza et al. (2008)



Fornasier et al. (2016)

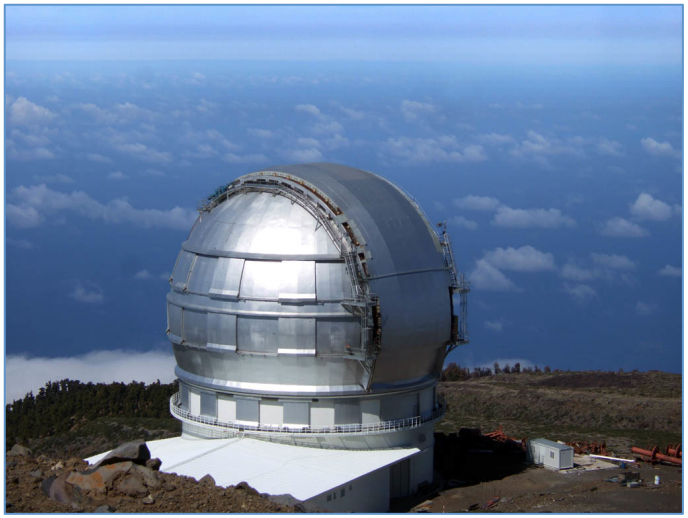


Takir and Emery (2012)



Fornasier et al. (2016)

Spectra have been obtained using the 10.4m Gran Telescopio Canarias – GTC, located at the "El Roque de los Muchachos" Observatory (La Palma, Spain). We used the OSIRIS camera-spectrograph that works in visible wavelengths.



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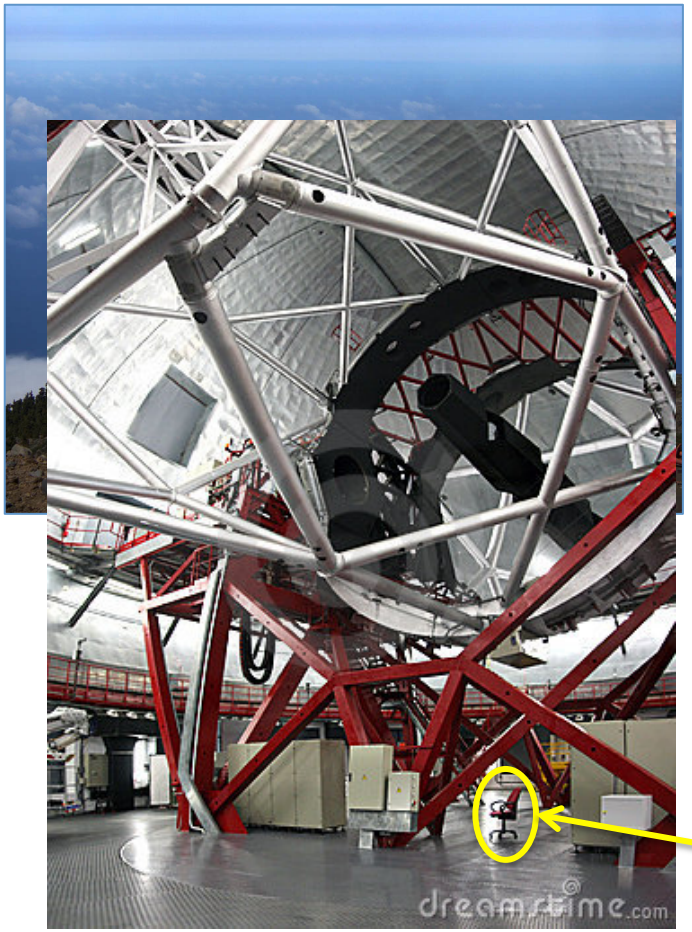
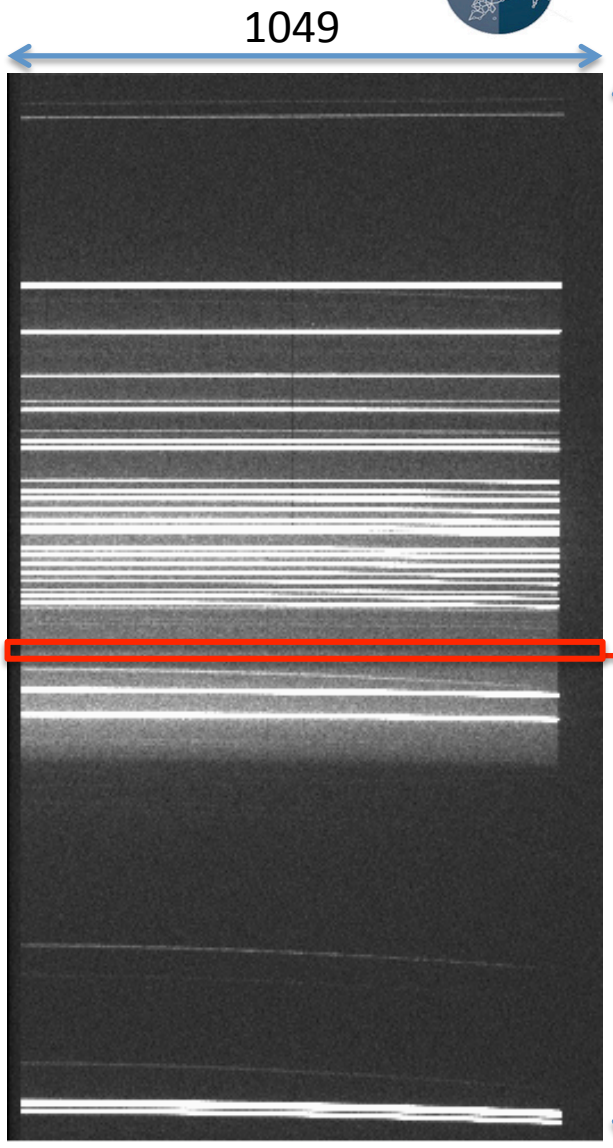
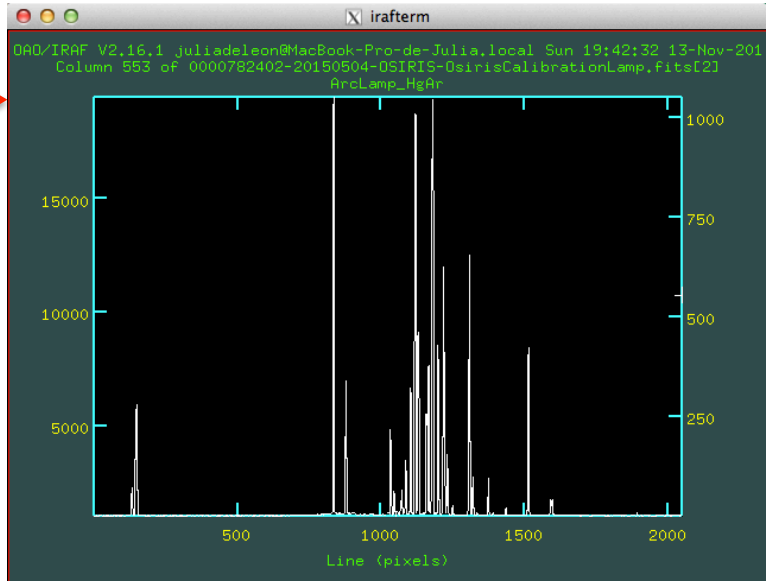
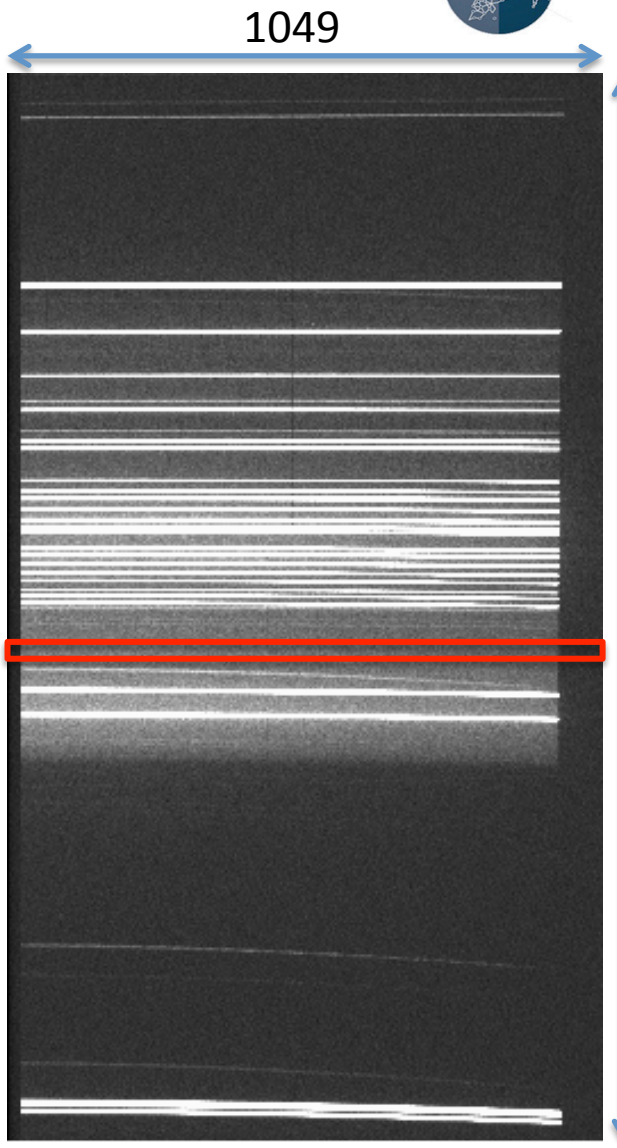




OSIRIS has 2 CCDs (1049 x 2051)
Science data is located commonly at CCD_2
Total FOV of 7.8 x 8.5 arcmin

Imaging	Spectroscopy
Broad Band Imaging	LongSlit Spectroscopy
Medium Band Imaging: SHARDS Filters	Multi-Object Spectroscopy
Narrow Band Imaging: Tunable Filters	
Fast Photometry	
Frame Transfer Photometry	





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Imaging	Spectroscopy
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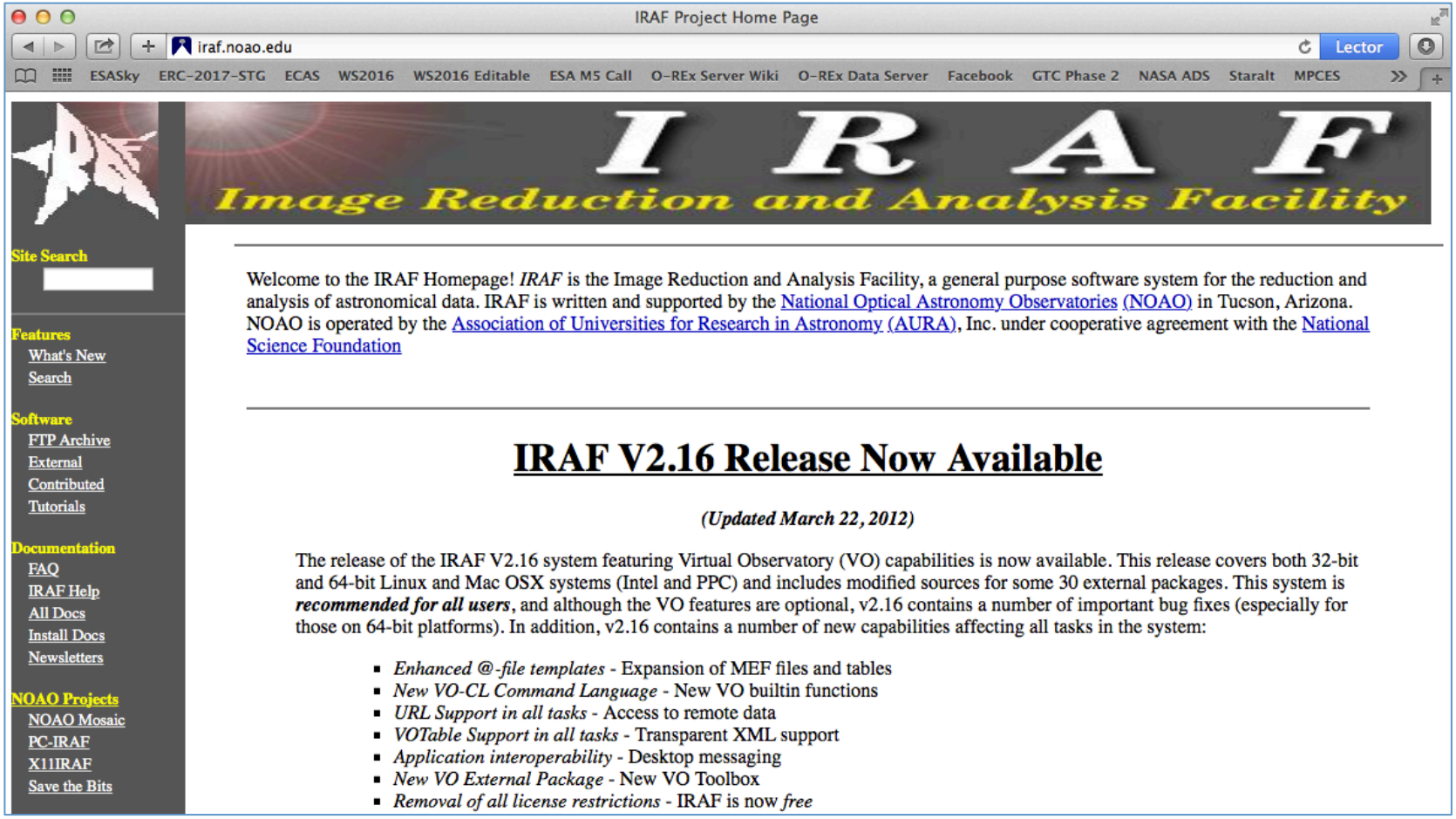
Narrow Band Imaging: Tunable Filters	
Fast Photometry	
Frame Transfer Photometry	

ID	λ_c(A)	λ range (A)	D (A/pix)	Resolution	Peak Efficiency	Type	Efficiency
R300B	4405	3600 -7200	4.96	360	70%	Grism	graph
R300R	6635	4800 - 10000	7.74	348	70%	Grism	graph
R500B	4745	3600 - 7200	3.54	537	68%	Grism	graph
R500R	7165	4800 - 10000	4.88	587	67%	Grism	graph
R1000B	5455	3630 - 7500	2.12	1018	65%	Grism	graph
R1000R	7430	5100 - 10000	2.62	1122	65%	Grism	graph
R2000B	4755	3950 - 5700	0.86	2165	87%	VPH	graph
R2500U	3975	3440 - 4610	0.62	2555	70%	VPH	graph
R2500V	5185	4500 - 6000	0.80	2515	80%	VPH	graph
R2500R	6560	5575 - 7685	1.04	2475	80%	VPH	graph
R2500I	8650	7330 - 10000	1.36	2503	80%	VPH	graph

IRAF: Image Reduction and Analysis Facility

Written and supported by the National Optical Astronomy Observations (NOAO)



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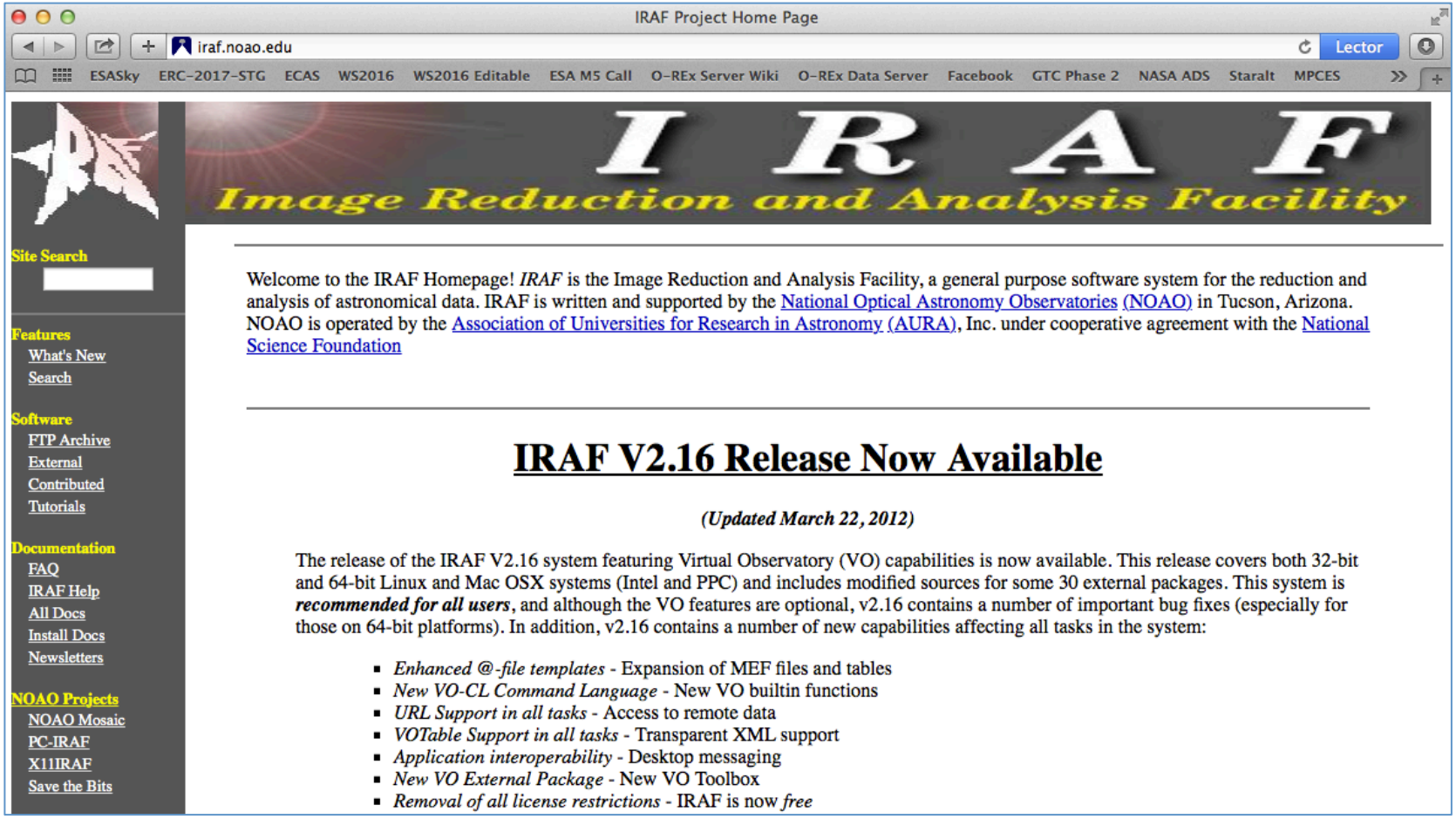

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STScI > PyRAF

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Space Telescope Science Institute PyRAF

- Astronomer's Proposal Tool
- HSTCAL
- IUETOOLS
- Drizzlepac
- OPUS
- PyFITS
- PyRAF
  - Description

PyRAF is a command language for running IRAF tasks that is based on the Python scripting language. It gives users the ability to run IRAF tasks in an environment that has all the power and flexibility of Python. PyRAF can be installed along with an existing IRAF installation; users can then choose to run either PyRAF or the IRAF CL.

PyRAF is part of the stsci_python package of astronomical data analysis tools, and is a product of the Science Software Branch at the Space Telescope Science Institute.

The current release of PyRAF is **v2.1.11** and can be downloaded from the stand-alone PyRAF download page.

PyRAF can also be found bundled with stsci_python which can be downloaded from the stsci_python download page.

The release notes can be found here

Contact

For further information, contact help@stsci.edu

python™ search

» Package Index > pyraf > 2.1.11

PACKAGE INDEX

- Browse packages
- Package submission
- List trove classifiers
- RSS (latest 40 updates)
- RSS (newest 40 packages)
- PyPI Tutorial
- PyPI Security
- PyPI Support
- PyPI Bug Reports
- PyPI Discussion
- PyPI Developer Info

pyraf 2.1.11

Provides a Pythonic interface to IRAF.

Download pyraf-2.1.11.tar.gz

PyRAF is a command language for IRAF based on the Python scripting language that can be used in place of the existing IRAF CL.

For more information on PyRAF - release notes, installation instructions, the FAQ, tutorials and other documentation, etc. - please visit:

> http://www.stsci.edu/resources/software_hardware/pyraf

Not Logged In

- Login
- Register
- Lost Login?
- Use OpenID
- Login with Google

Status

Nothing to report

CREATE A DIRECTORY TO STORE YOUR DATA:

> mkdir /scratch/WSTuesday15
> cd /scratch/WSTuesday15
> cp –r /home/jmlc/WS2016/Spectra .

EXECUTE IRAF

> cd
> mkdir iraf
> cd iraf
> mkiraf (*select xgterm when requested for a terminal*)

NOW TYPE ON YOUR TERMINAL:

> xgterm –sb &

ON YOUR XGTERM:

> cd iraf
> ecl

Open the text file “Nightlog.txt”:

```
<GTC18-15A_0064>
-------------------

    IMAGE                                                              GTCPROGID                          GTCOBID     OBJECT                    RA
DEC          EXPTIME   AIRMASS   HBIN VBIN FILTERW1 FILTERW2 FILTERW3  IPA        ROTANG GRISMW  Z_ekw6 Z_ekw7 OS-FILTER      SLITW TIME-START
OUTMODE               GAIN      RSPEED     INSMODE                               TFWAVEL TFBANDW  MASKNAME

0000782528-20150504-OSIRIS-OsirisLongSlitSpectroscopy.fits           GTC18-15A                    0064  85727
13:27:42.456     -03:01:45.836      10.00    1.178  true  true      OPEN  Sloan_r     OPEN   62.916   -55.69    OPEN     31950          0  NULL
0. 23:41:56.649 TWOCCDS_A               0.95    200 OsirisLongSlitSpectroscopy      0.00      0.00 NOMASK
0000782529-20150504-OSIRIS-OsirisLongSlitSpectroscopy.fits           GTC18-15A                    0064  85727
13:27:42.496     -03:01:46.313      10.00    1.177  true  true      OPEN  Sloan_r     OPEN   62.916   -56.50    OPEN     31950          0  NULL
0. 23:43:58.170 TWOCCDS_A               0.95    200 OsirisLongSlitSpectroscopy      0.00      0.00 NOMASK
0000782530-20150504-OSIRIS-OsirisLongSlitSpectroscopy.fits           GTC18-15A                    0064  85727
13:27:42.438     -03:01:46.352      10.00    1.177  true  true      OPEN  Sloan_r     OPEN   62.916   -57.05    OPEN     31950          0  NULL
5. 23:45:20.085 TWOCCDS_A               0.95    200 OsirisLongSlitSpectroscopy      0.00      0.00 LongSlits5.0Arcsec
0000782531-20150504-OSIRIS-OsirisLongSlitSpectroscopy.fits           GTC18-15A                    0064  85727
13:27:42.356     -03:01:46.402     250.00    1.177  true  true      OPEN       GR     OPEN   62.916   -57.83    R300R    31950          0  NULL
5. 23:47:14.354 TWOCCDS_A               0.95    200 OsirisLongSlitSpectroscopy      0.00      0.00 LongSlits5.0Arcsec
0000782532-20150504-OSIRIS-OsirisLongSlitSpectroscopy.fits           GTC18-15A                    0064  85727
13:27:42.241     -03:01:36.335     250.00    1.177  true  true      OPEN       GR     OPEN   62.916   -59.72    R300R    31950          0  NULL
5. 23:51:47.824 TWOCCDS_A               0.95    200 OsirisLongSlitSpectroscopy      0.00      0.00 LongSlits5.0Arcsec
0000782533-20150504-OSIRIS-OsirisLongSlitSpectroscopy.fits           GTC18-15A                    0064  85727
13:27:42.076     -03:01:26.270     250.00    1.178  true  true      OPEN       GR     OPEN   62.916   -61.65    R300R    31950          0  NULL
5. 23:56:21.296 TWOCCDS_A               0.95    200 OsirisLongSlitSpectroscopy      0.00      0.00 LongSlits5.0Arcsec
```

Know your data:

cl> imhead Obj1.fits

```
Obj1.fits[901,751][real]: 49859
```

cl> imhead Obj1.fits l+

```
Obj1.fits[901,751][real]: 49859
No bad pixels, min=0., max=0. (old)
Line storage mode, physdim [901,751], length of user area 7047 s.u.
Pixel file "Obj1.fits" [ok]
EXTEND  =                    F / File may contain extensions
DATE    = '2016-11-10T18:26:39' / Date FITS file was generated
IRAF-TLM= '2016-11-10T18:26:39' / Time of last modification
OBJECT  = '49859    '           / Name of the object observed
ORIGFILE= 'May04_233047.fits'   / Filename
INSTRUME= 'OSIRIS   '           / Instrument Name
DETECTOR= 'E2V CCD44_82_BI'     / Detectors Model
DETSIZE = '[1:4096,1:4102]'     / Maximum Imaging Pixel Area
....
```

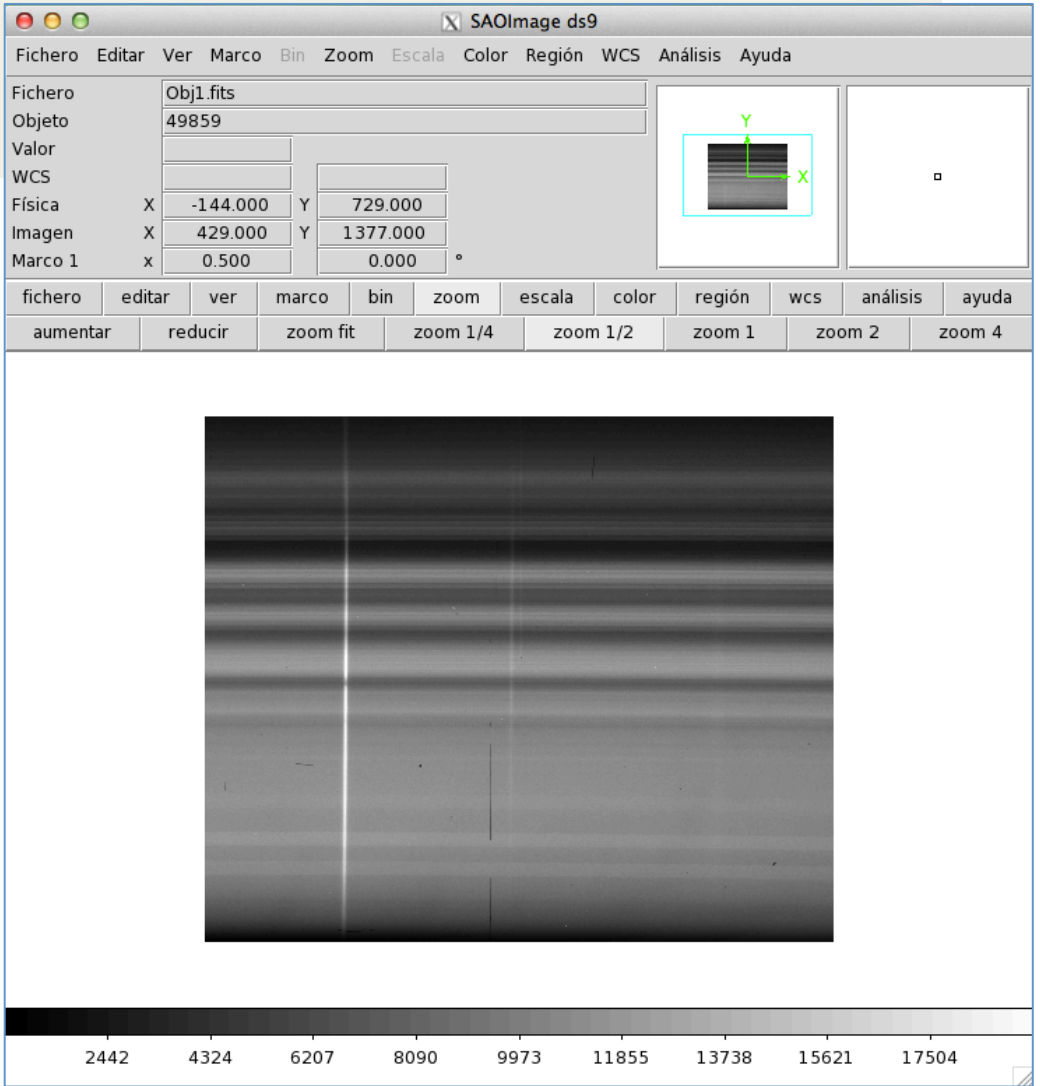
cl> hselect Obj1 AIRMASS yes

```
1.30028967312208
```

GO BACK TO YOUR WORKING DIRECTORY:

cl> cd /scratch/WSTuesday15/Spectra/
cl> !ds9 &

Any Linux command can be executed from IRAF using the ! symbol



SAOImage DS9

SAOImage DS9 is an astronomical imaging and data visualization application. DS9 supports FITS images and binary tables, multiple frame buffers, region manipulation, and many scale algorithms and colormaps. It provides for easy communication with external analysis tasks and is highly configurable and extensible via XPA and SAMP.

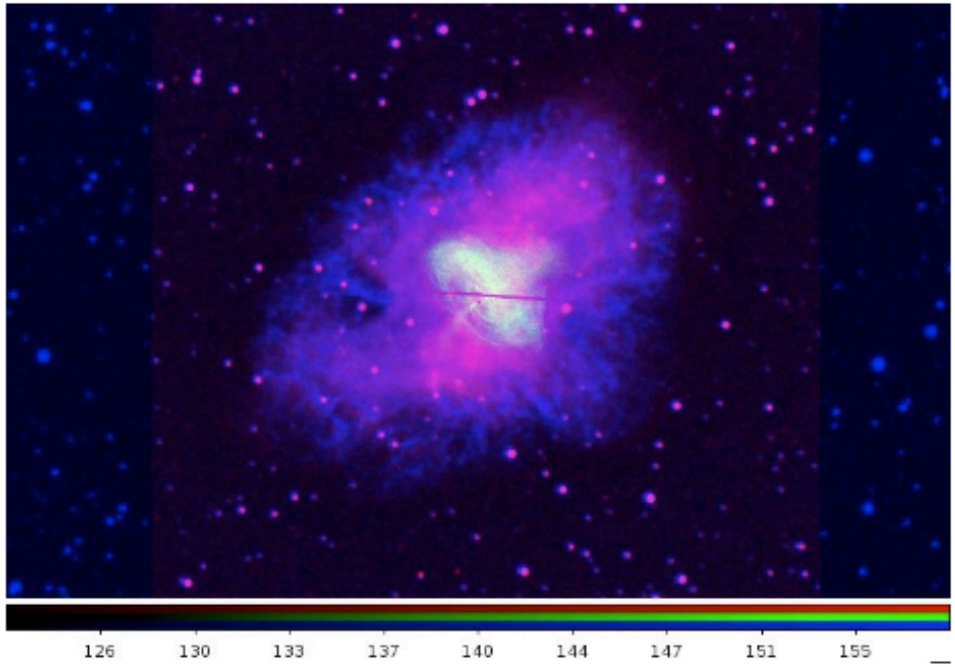
DS9 is a stand-alone application. It requires no installation or support files. All versions and platforms support a consistent set of GUI and functional capabilities.

DS9 supports advanced features such as 2-D, 3-D and RGB frame buffers, mosaic images, tiling, blinking, geometric markers, colormap manipulation, scaling, arbitrary zoom, cropping, rotation, pan, and a variety of coordinate systems.

The GUI for DS9 is user configurable. GUI elements such as the coordinate display, panner, magnifier, horizontal and vertical graphs,

SAOImage DS9 Version 7.4

DS9 version 7.4 is now available on the **Download** page. New to version 7.4 is image blocking and reordering of data cube axes. Please see the **What's New** page for more details. *News Flash-- Version 7.5rc2 is now available*



Tweets by @SAOImageDS9

SAOImage DS9 Retweeted

Eric Mandel
@astrosoftware

JS9 v1.10: keyboard actions, full window display, session management, alternate wcs, and a more modern look @ js9.si.edu

11 Oct

SAOImage DS9
@SAOImageDS9

SAOImage DS9 version 7.5rc2 is now available for download at ds9.si.edu/site/Beta.html

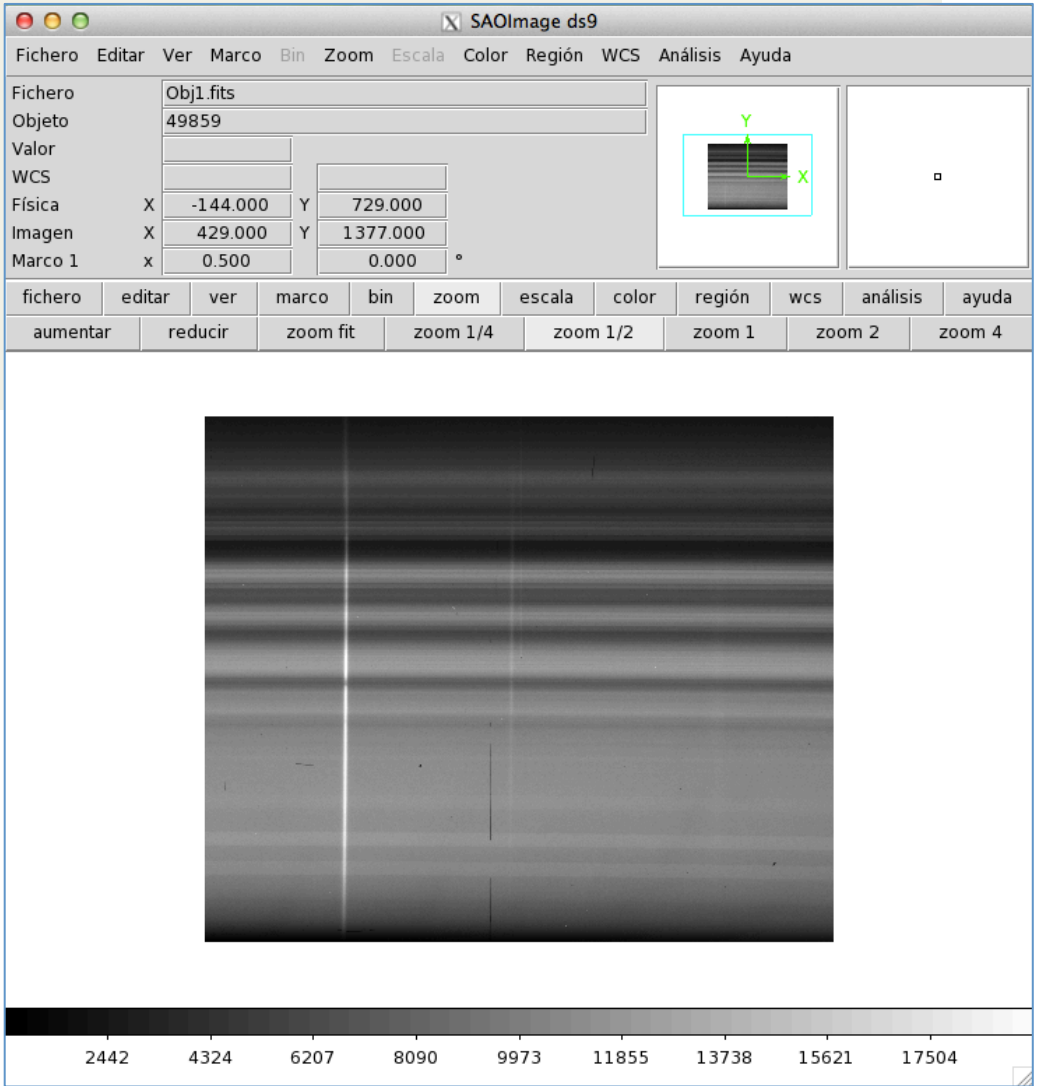
07 Oct

SAOImage DS9
@SAOImageDS9

Embed View on Twitter

GO BACK TO YOUR WORKING DIRECTORY:

cl> cd /scratch/WSTuesday15/Spectra/
cl> !ds9 &
cl> display Obj1.fits 1



GO BACK TO YOUR WORKING DIRECTORY:

cl> cd /scratch/WSTuesday15/Spectra/
cl> !ds9 &
cl> display Obj1.fits 1
cl> epar display

To exit from *epar*, you can type
:q → Exit without saving changes
:wq → Save changes and exit
:go → Save changes and execute

```
      PACKAGE = tv
         TASK = display

         image    =             Obj1.fits  image to be displayed
         frame    =                     1  frame to be written into
         (bpmask =                   BPM) bad pixel mask
         (bpdispl=                  none) bad pixel display (none|overlay|interpolate)
         (bpcolor=                   red) bad pixel colors
         (overlay=                     ) overlay mask
         (ocolors=                 green) overlay colors
         (erase  =                   yes) erase frame
         (border_=                    no) erase unfilled area of window
         (select_=                   yes) display frame being loaded
         (repeat =                    no) repeat previous display parameters
         (fill   =                    no) scale image to fit display window
         (zscale =                   yes) display range of greylevels near median
         (contras=                  0.25) contrast adjustment for zscale algorithm
         (zrange =                   yes) display full image intensity range
         (zmask  =                     ) sample mask
         (nsample=                  1000) maximum number of sample pixels to use
```

If you have doubts on any specific task, type help *and then the name of the task:*

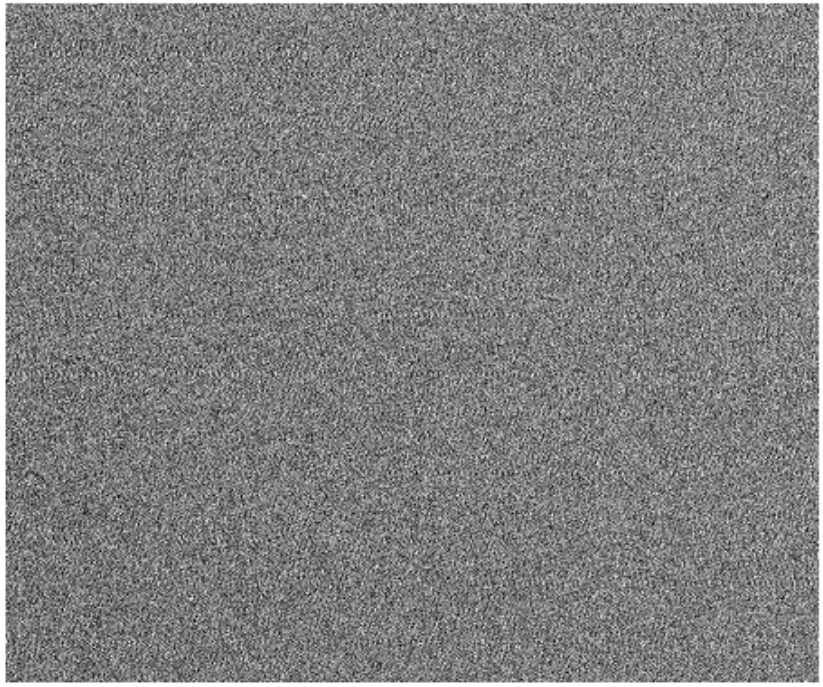
cl> help display

```
DISPLAY (Mar97)                    images.tv                    DISPLAY (Mar97)

NAME
    display -- Load and display images in an image display

USAGE
    display image frame

PARAMETERS

    image
        Image to be loaded.

    frame
        Display frame to be loaded.

    bpmask = "BPM"
        Bad pixel mask.  The bad pixel mask is used to exclude bad
        pixels from the automatic intensity mapping algorithm.  It may
        also be displayed as an overlay or to interpolate the input
        image as selected by the bpdisplay parameter.  The bad pixel
        mask is specified by a pixel list image (.pl extension) or an...
```

Basics on data reduction:

- **Bias subtraction**: the bias level is an electronic offset added to the signal from the CCD that makes sure that the Analogue-to-Digital Converter (ADC) always receives a positive value.

A bias frame is obtained with the shutter closed and 0 seconds exposure time



Basics on data reduction:

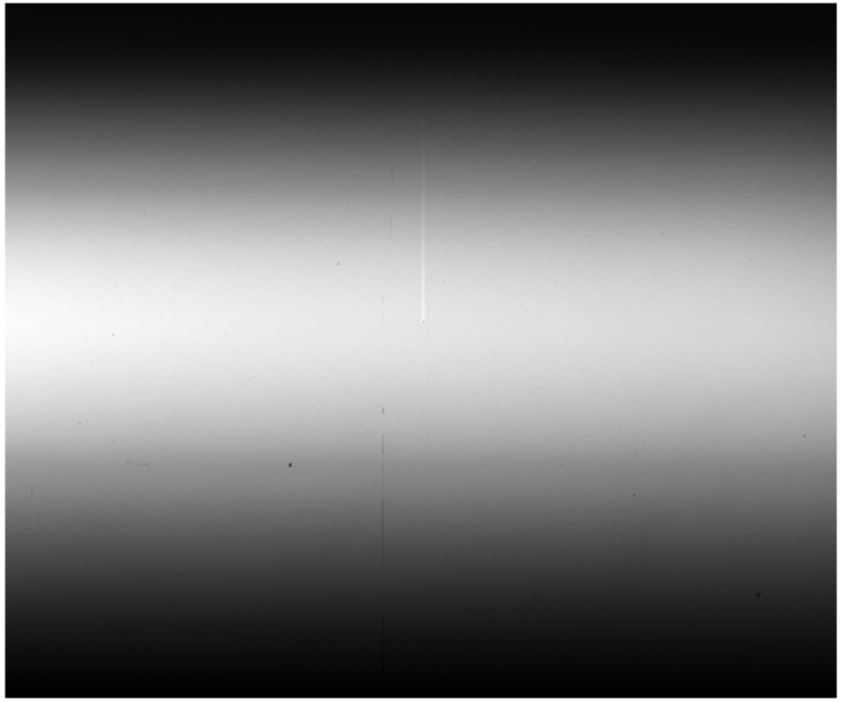
- **Bias subtraction**: the bias level is an electronic offset added to the signal from the CCD that makes sure that the Analogue-to-Digital Converter (ADC) always receives a positive value.

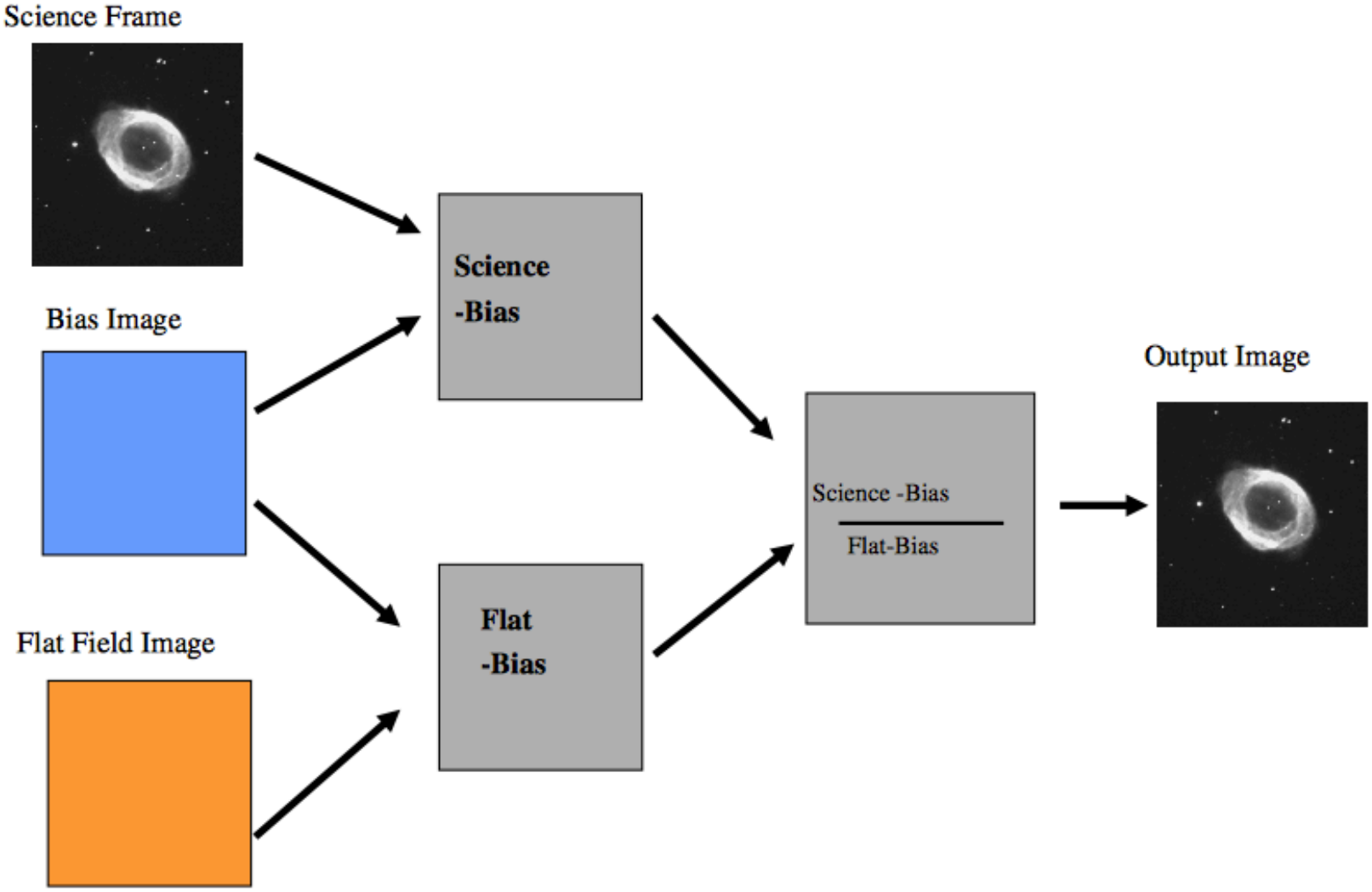
A bias frame is obtained with the shutter closed and 0 seconds exposure time

- **Flat field correction**: the sensitivity of CCDs varies from point to point (i.e. the recorded signal per unit of incident flux – photons – is not uniform).

A flat frame is obtained using a photometrically flat source.

In spectroscopy, we use a source of "white" light (same brightness at all wavelengths). In practice, halogen lamps used still has some wavelength-dependent variation that has to be characterized and removed.




Science Frame
Bias Image
Flat Field Image
Science
-Bias
Flat
-Bias
Science -Bias
Flat-Bias
Output Image

Our images are already bias-subtracted. So let's flat-field correct them:

cl> twodspec
cl> longslit
cl> epar response

```
PACKAGE = longslit
   TASK = response

calibrat=                 Flat  Longslit calibration images
normaliz=                 Flat  Normalization spectrum images
response=                nFlat  Response function images
(interac=                  yes) Fit normalization spectrum interactively?
(thresho=                INDEF) Response threshold
(sample =                    *) Sample of points to use in fit
(naverag=                    1) Number of points in sample averaging
(functio=              spline3) Fitting function
(order  =                    5) Order of fitting function
(low_rej=                   0.) Low rejection in sigma of fit
(high_re=                   0.) High rejection in sigma of fit
(niterat=                    1) Number of rejection iterations
(grow   =                   0.) Rejection growing radius
(graphic=              stdgraph) Graphics output device
(cursor =                     ) Graphics cursor input
(mode   =                   ql)
```

First, we have to normalize our flat-field, to remove the wavelength dependence that our "white" light is showing

A cubic spline with a low order (10-25) will work

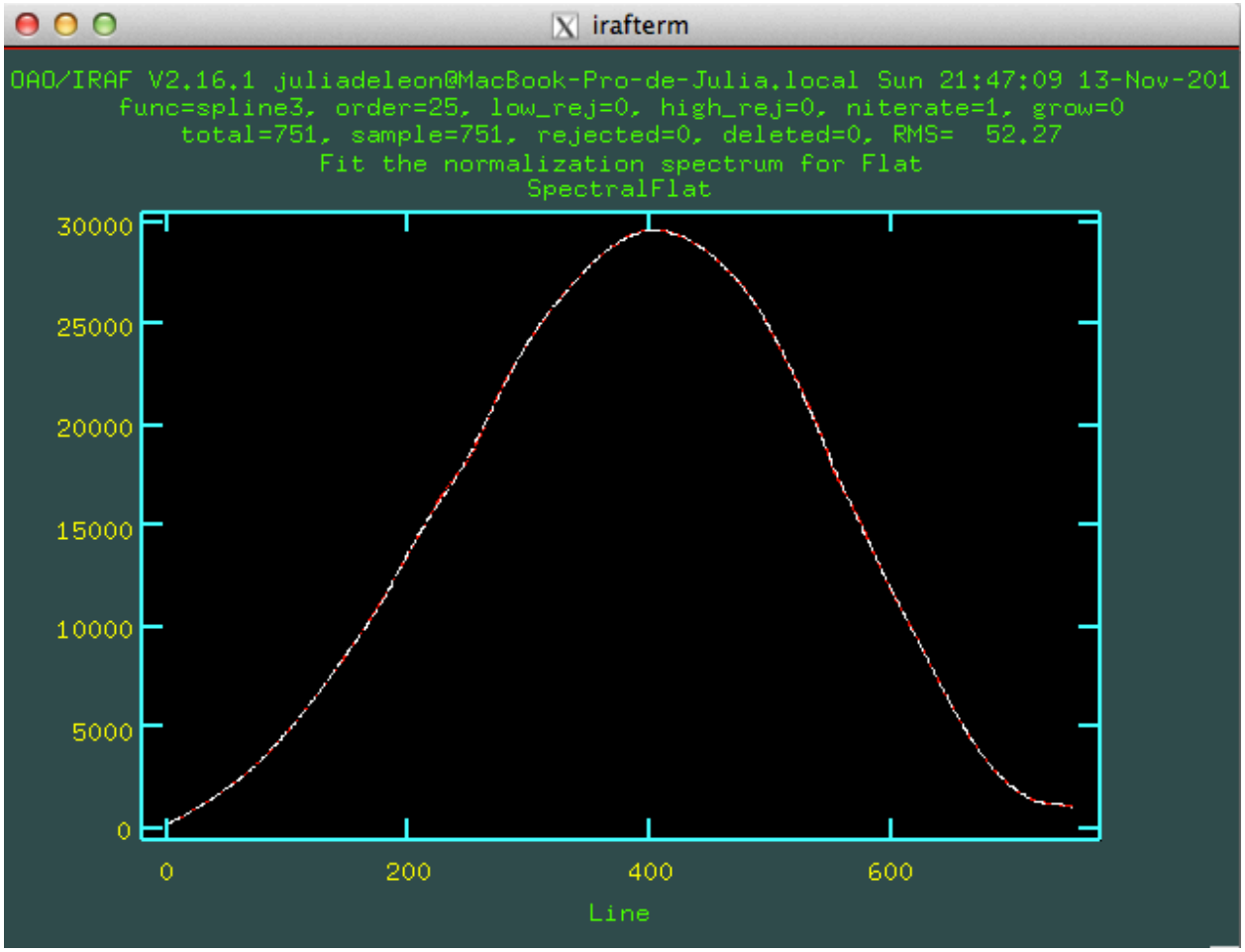
```
Fit the normalization spectrum for Flat interactively (yes):
Dispersion axis (1=along lines, 2=along columns, 3=along z) (1:3) (2): 2
```

Now you are in the interactive interface.
You can change the function or the order doing

:function legendre (enter)
:order 25 (enter)

and then type *f* to execute the changes

Type *q* to exit



Now we divide our images (not the arcs!!!!) by the normalized flat. Make a list with your images (list.txt):

Obj1.fits
Obj2.fits
SA1.fits
SA2.fits

```
cl> imarith  @list.txt  /  nFlat  f//@list.txt
```

Now we divide our images (not the arcs!!!!) by the normalized flat. Make a list with your images (list.txt):

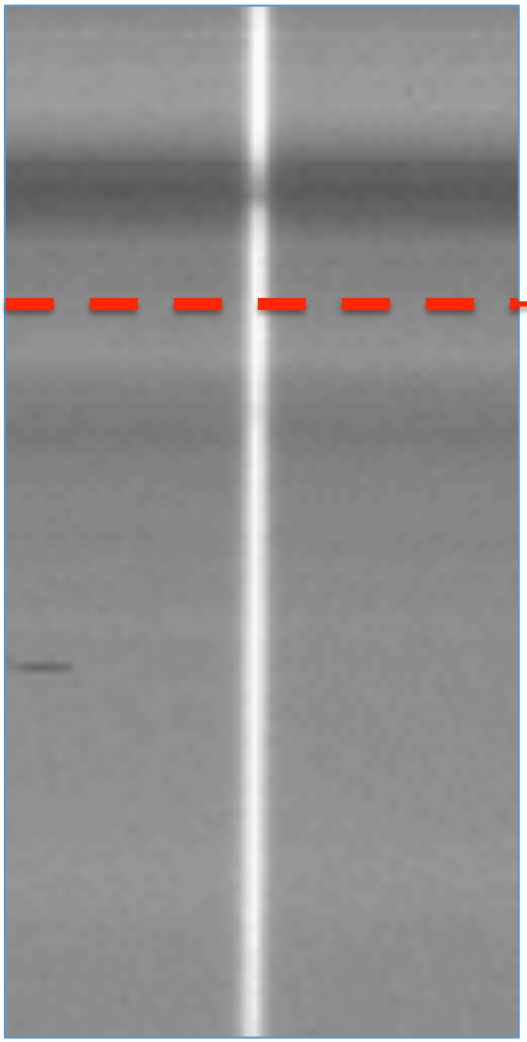
Obj1.fits
Obj2.fits
SA1.fits
SA2.fits

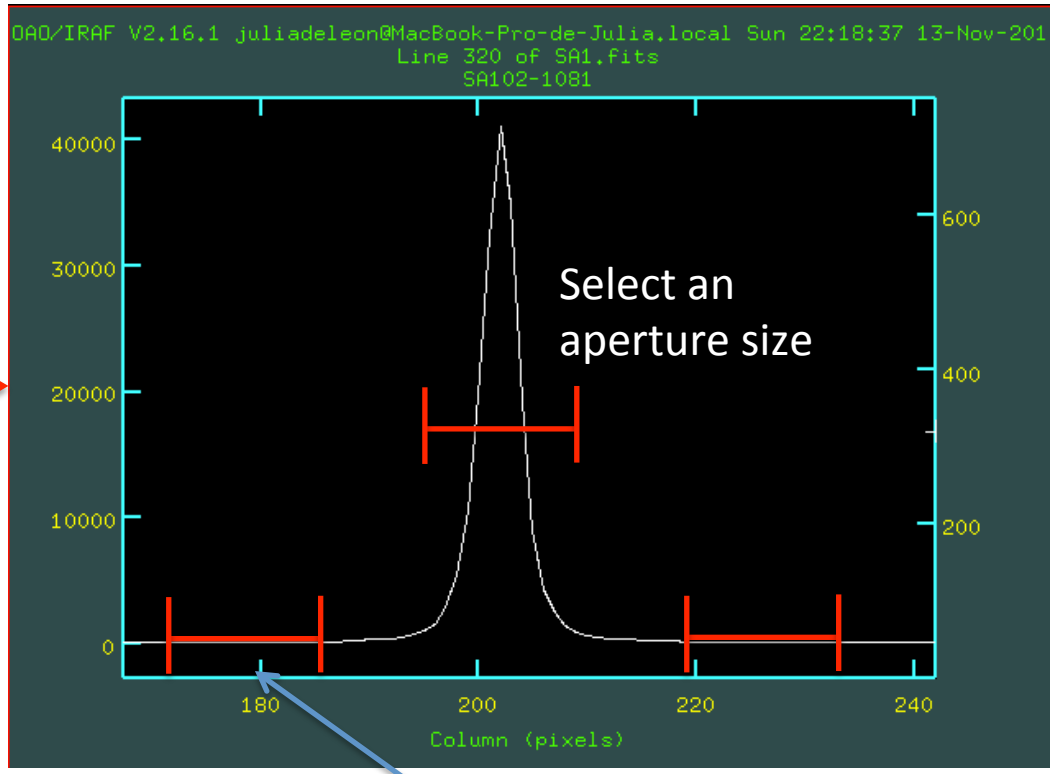
```
cl> imarith  @list.txt  /  nFlat  f//@list.txt
```

Once the images have been bias and flat-field corrected, the next step is to EXTRACT your spectra and collapse them from 2D to 1D. This is done using the **apall** task:

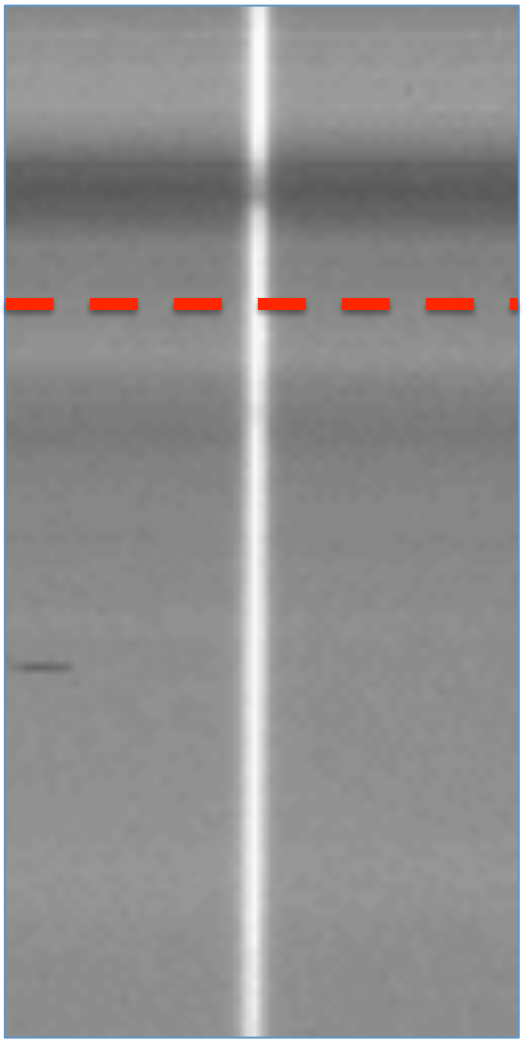
```
cl> twodspec
cl> apextract
```

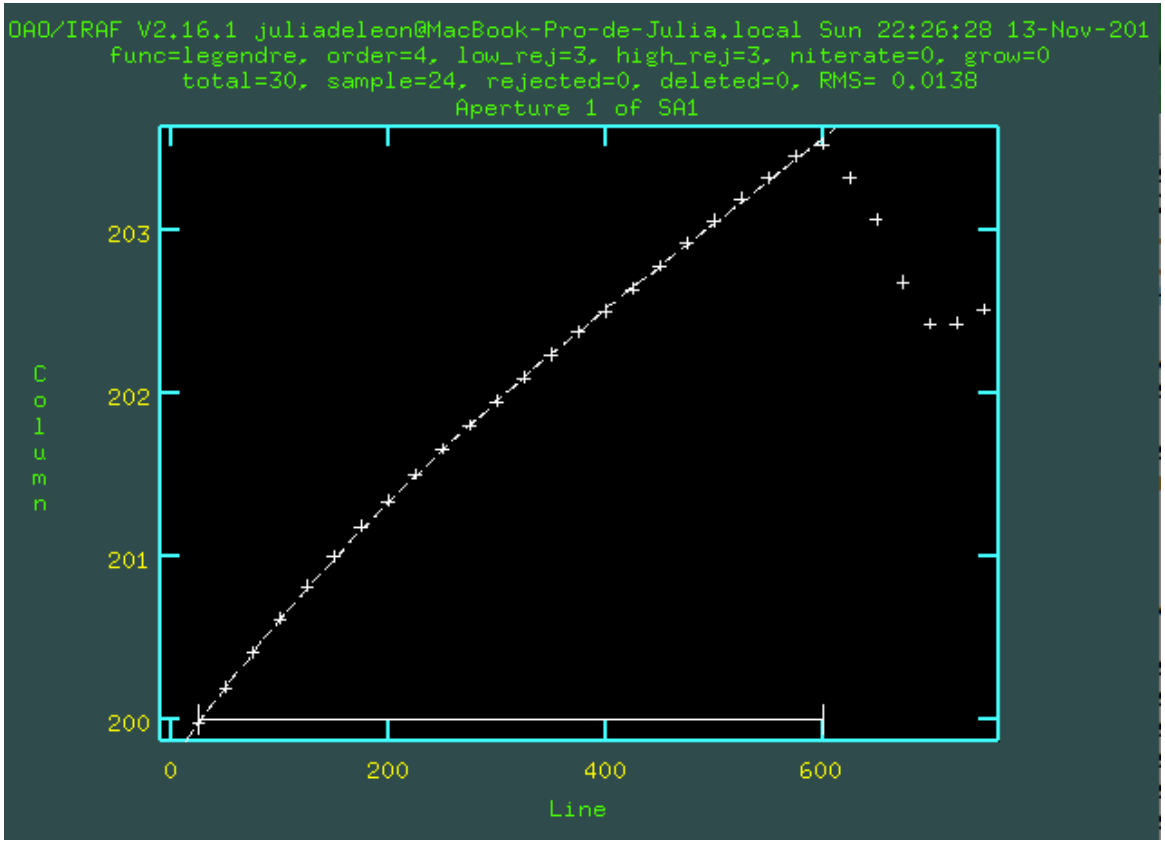
apall	apedit	apflatten	apnormalize	apscatter
apdefault@	apfind	apmask	aprecenter	apsum
apdemos.	apfit	apnoise	apresize	aptrace





Define two regions to subtract background signal





And trace the center of the profile through the spatial axis to properly sum the columns and collapse the spectrum.

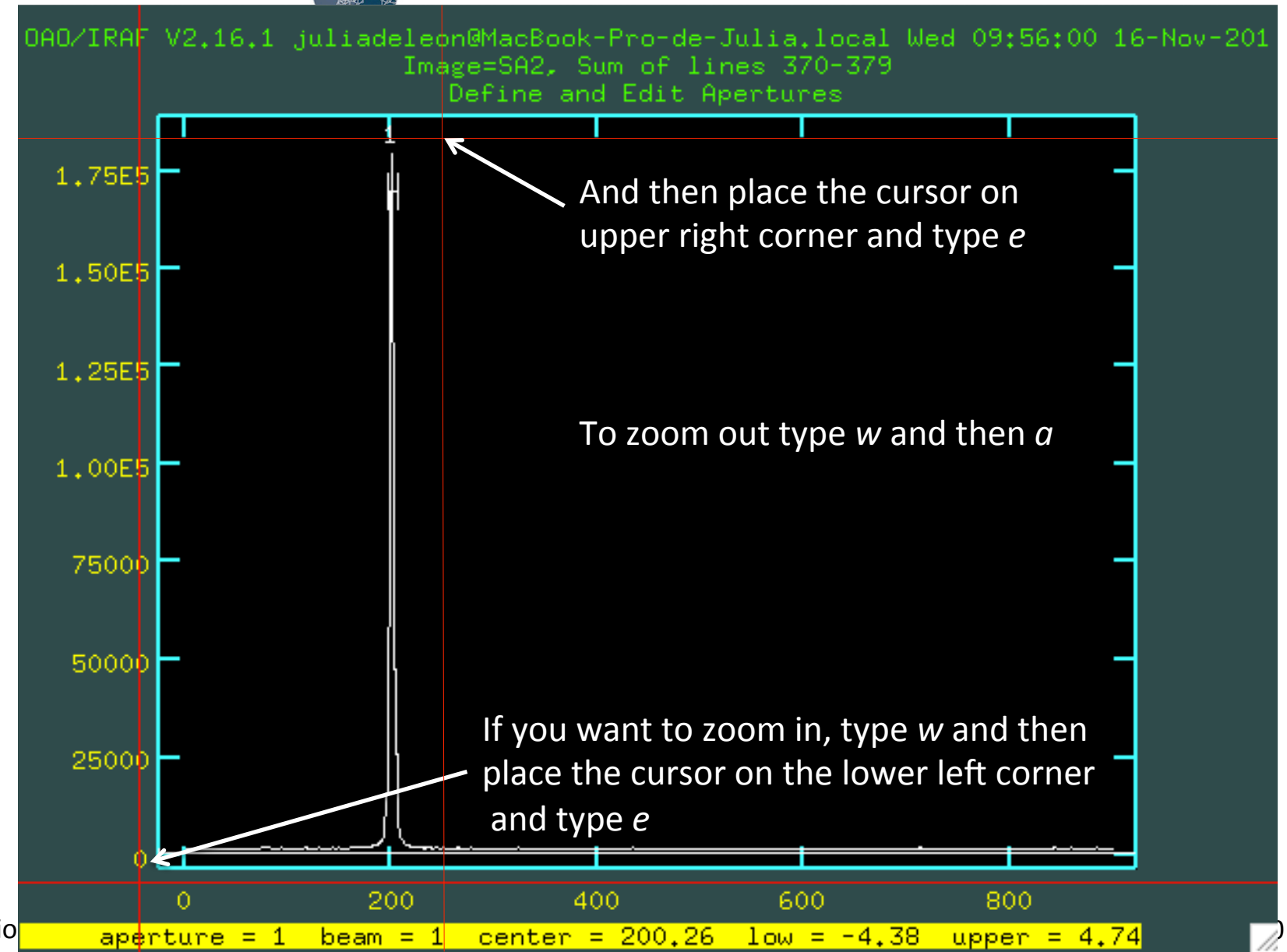
cl> epar apall

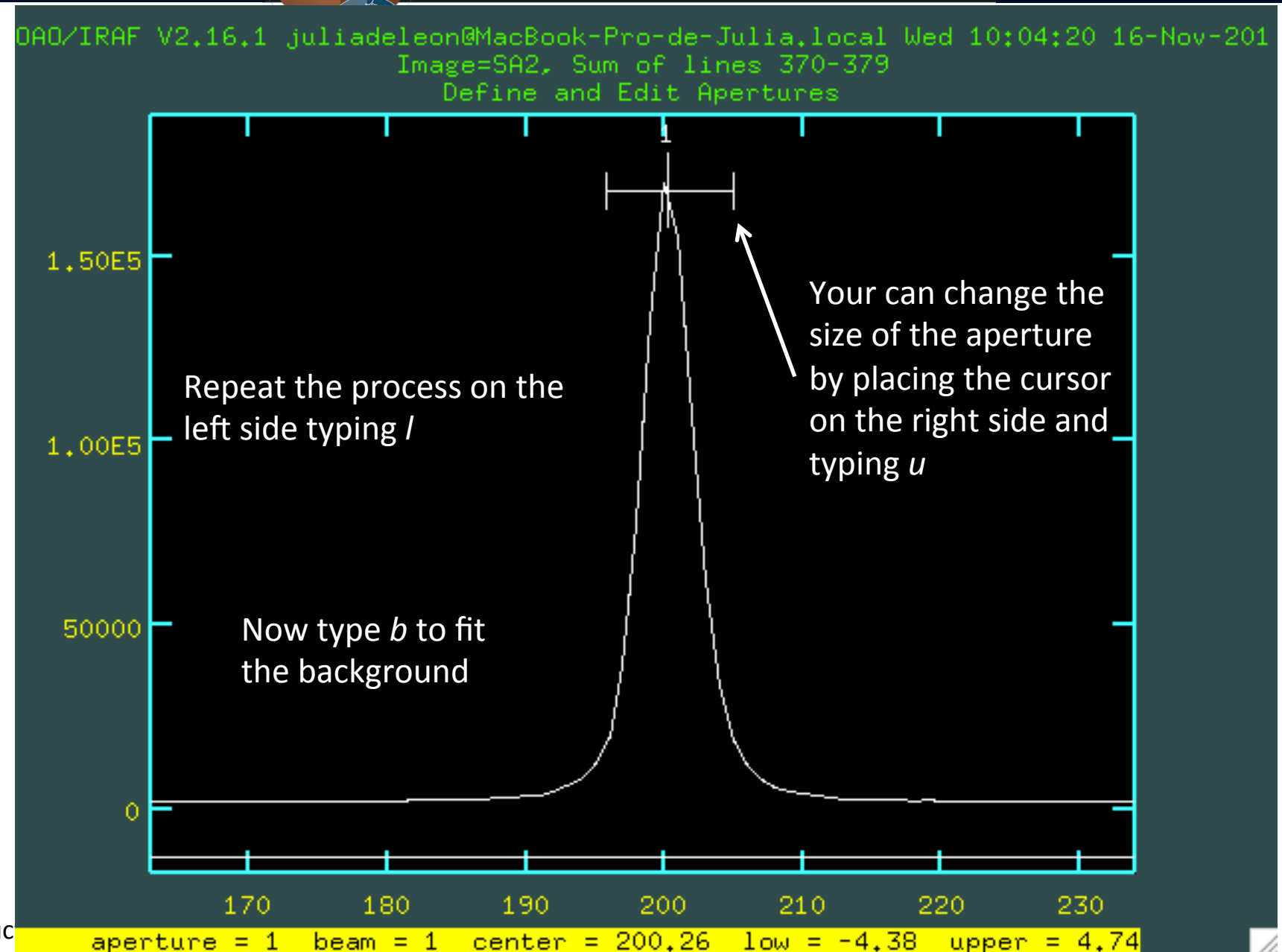
```
input   =              fSA1.fits  List of input images
(output =                      ) List of output spectra
(apertur=                      ) Apertures
(format =             multispec) Extracted spectra format
(referen=                      ) List of aperture reference images
(profile=                      ) List of aperture profile images

(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?
```

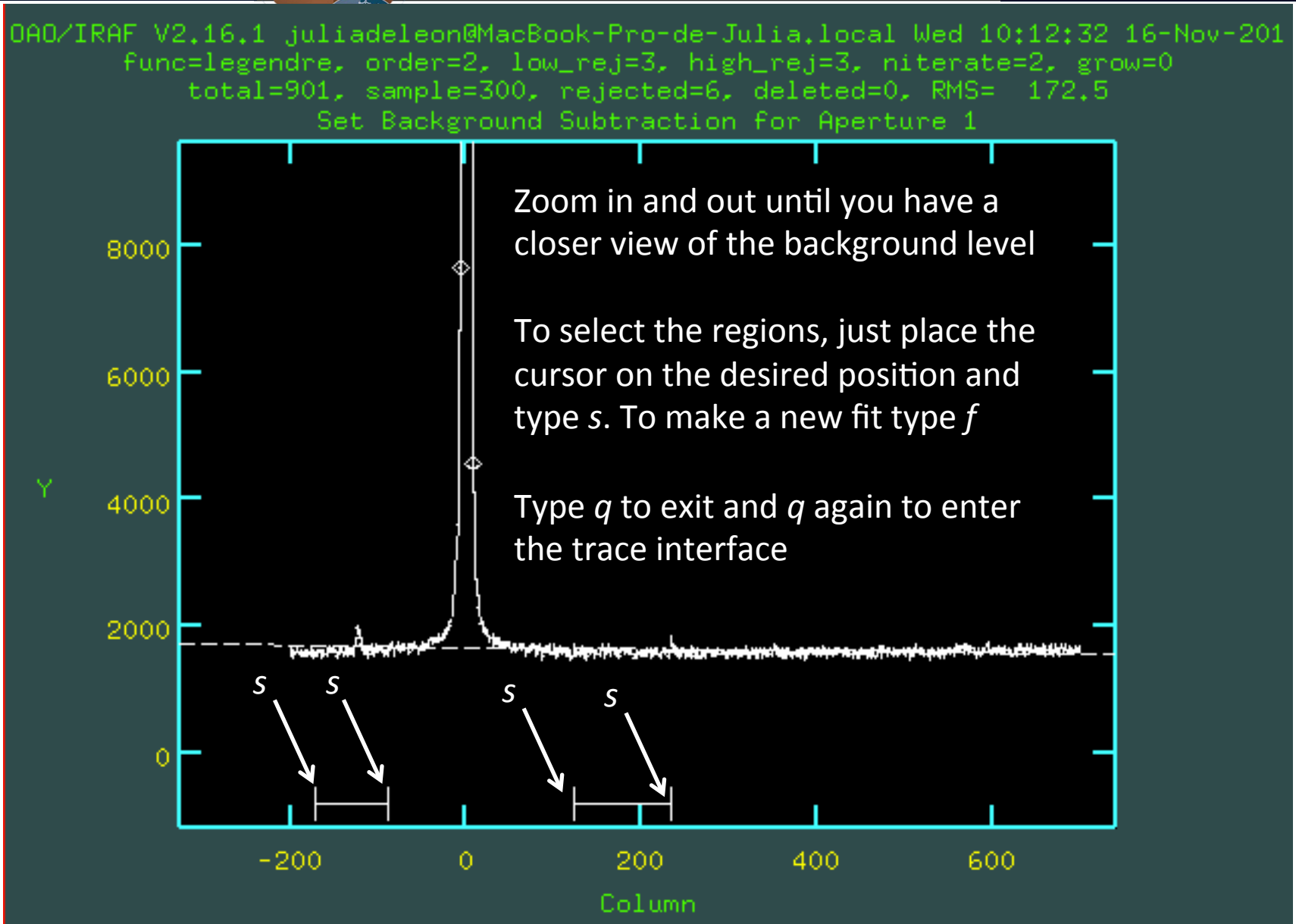
```
# DEFAULT BACKGROUND PARAMETERS

(b_funct=                legendre) Background function
(b_order=                       2) Background function order
(b_sampl=                       *) Background sample regions
(b_naver=                      -3) Background average or median
(b_niter=                       2) Background rejection iterations
(b_low_r=                      3.) Background lower rejection sigma
(b_high_=                      3.) Background upper rejection sigma
(b_grow =                      0.) Background rejection growing radius

# TRACING PARAMETERS

(t_nsum =                       25) Number of dispersion lines to sum
(t_step =                       25) Tracing step
(t_funct=                legendre) Trace fitting function
(t_order=                       4) Trace fitting function order

(backgro=                     fit) Background to subtract
```

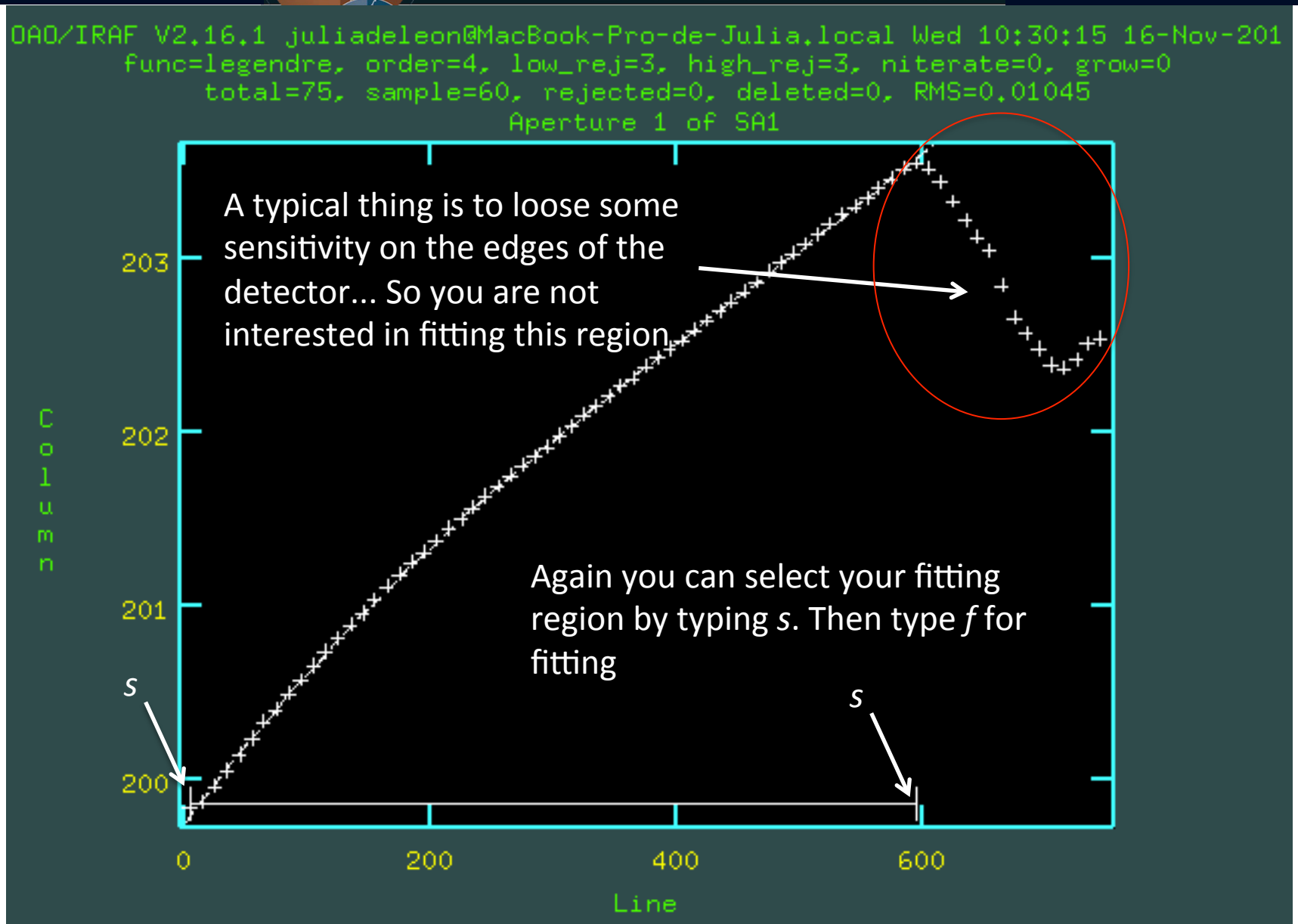
Type *:go* to execute the task

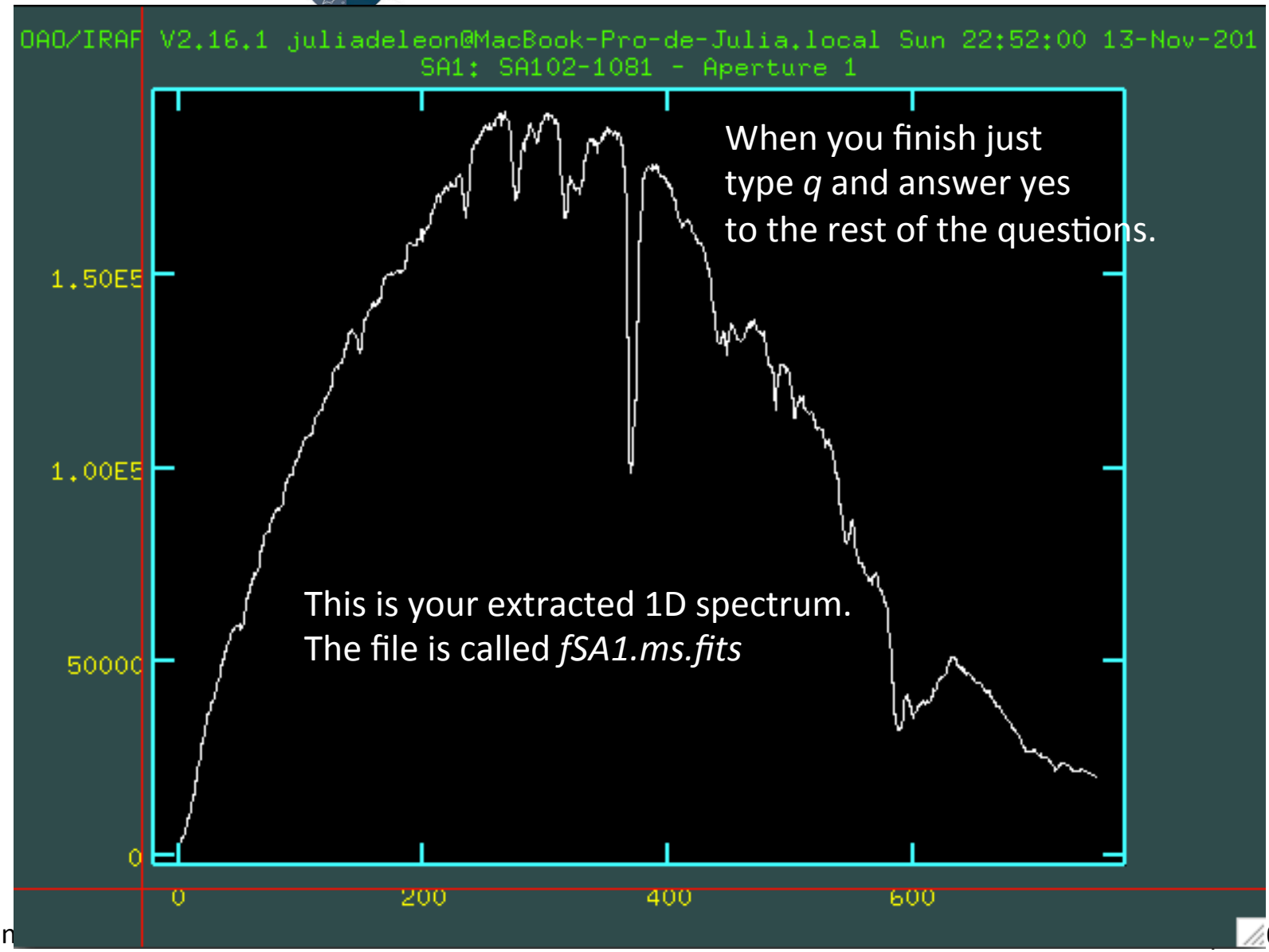
```
Find apertures for SA2?  (yes):yes
Number of apertures to be found automatically (1):1
Resize apertures for SA2?  (yes): yes
Edit apertures for SA2?  (yes): yes
```


OAO/IRAF V2.16.1 juliadeleon@MacBook-Pro-de-Julia.local Wed 09:56:00 16-Nov-201
Image=SA2, Sum of lines 370-379
Define and Edit Apertures
1.75E5
1.50E5
1.25E5
1.00E5
75000
50000
25000
0
0
200
400
600
800
aperture = 1 beam = 1 center = 200.26 low = -4.38 upper = 4.74
And then place the cursor on upper right corner and type e
To zoom out type w and then a
If you want to zoom in, type w and then place the cursor on the lower left corner and type e


OAO/IRAF V2.16.1 juliadeleon@MacBook-Pro-de-Julia.local Wed 10:04:20 16-Nov-201
Image=SA2, Sum of lines 370-379
Define and Edit Apertures
1
1.50E5
1.00E5
50000
0
Repeat the process on the left side typing *l*
Your can change the size of the aperture by placing the cursor on the right side and typing *u*
Now type *b* to fit the background
170
180
190
200
210
220
230
aperture = 1 beam = 1 center = 200.26 low = -4.38 upper = 4.74


OAO/IRAF V2.16.1 juliadeleon@MacBook-Pro-de-Julia.local Wed 10:12:32 16-Nov-201
func=legendre, order=2, low_rej=3, high_rej=3, niterate=2, grow=0
total=901, sample=300, rejected=6, deleted=0, RMS= 172.5
Set Background Subtraction for Aperture 1
Zoom in and out until you have a closer view of the background level
To select the regions, just place the cursor on the desired position and type s. To make a new fit type f
Type q to exit and q again to enter the trace interface
8000
6000
4000
2000
0
Y
s
s
s
s
-200
0
200
400
600
Column


OAO/IRAF V2.16.1 juliadeleon@MacBook-Pro-de-Julia.local Wed 10:30:15 16-Nov-201
func=legendre, order=4, low_rej=3, high_rej=3, niterate=0, grow=0
total=75, sample=60, rejected=0, deleted=0, RMS=0.01045
Aperture 1 of SA1
A typical thing is to loose some sensitivity on the edges of the detector... So you are not interested in fitting this region
Again you can select your fitting region by typing s. Then type f for fitting
s
s
203
202
201
200
Column
0
200
400
600
Line


OAO/IRAF V2.16.1 juliadeleon@MacBook-Pro-de-Julia.local Sun 22:52:00 13-Nov-201
SA1: SA102-1081 - Aperture 1
1.50E5
1.00E5
50000
0
0
200
400
600
When you finish just type *q* and answer yes to the rest of the questions.
This is your extracted 1D spectrum.
The file is called *fSA1.ms.fits*

A new directory has been created, called **database**. There you will find information on the extractions, the wavelength calibration, etc.

```
cl> ls  database/

apfSA1    aparcHgAr    aparcNe     aparcXe     aplast
```

aperture

A new directory has been
on the extractions, the w

```
cl> ls  database/

apSA1     aparcHgA
```

aperture

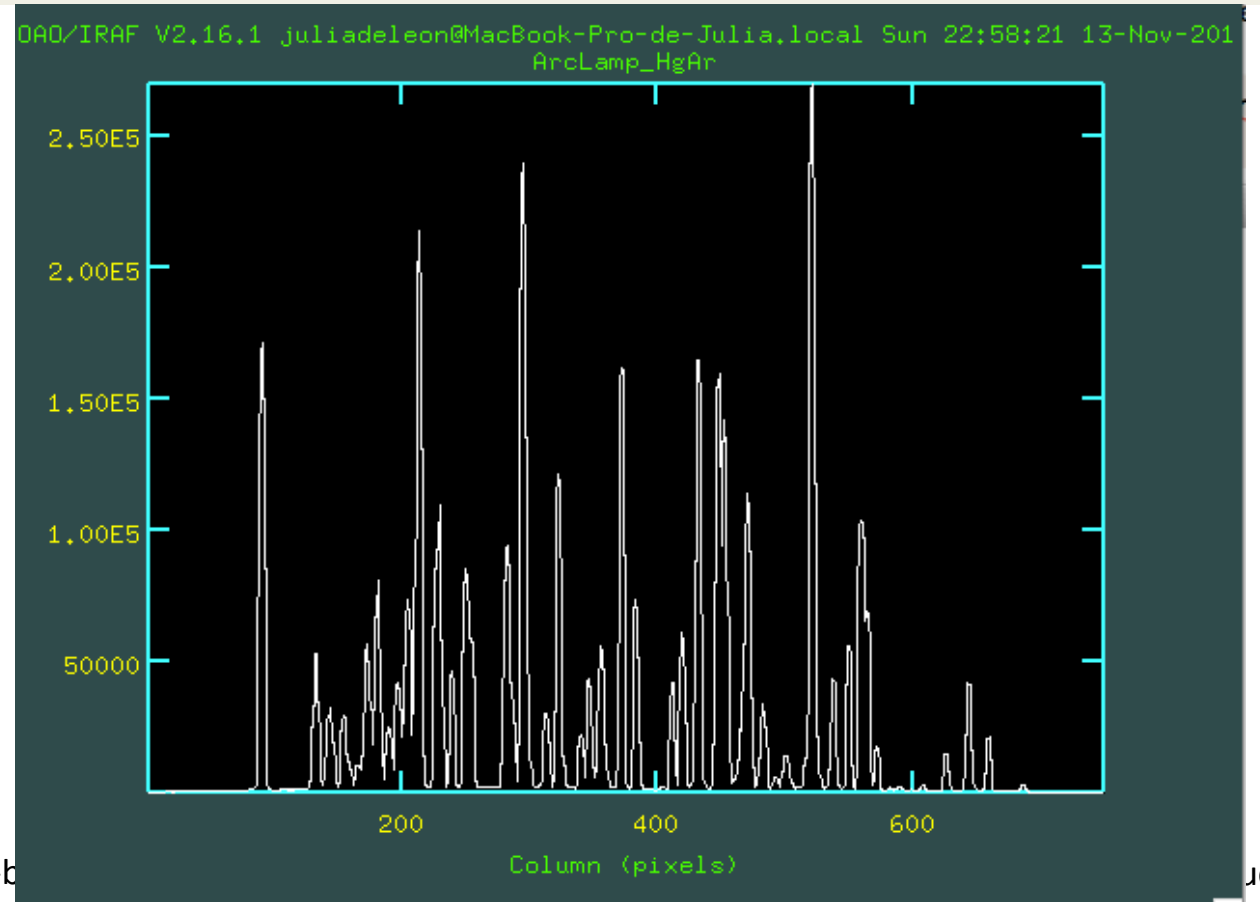
```
# Sun 22:51:58 13-Nov-2016
begin   aperture SA1 1 202.3782 375.
        image   SA1
        aperture        1
        beam    1
        center  202.3782 375.
        low     -4.556763 -374.
        high    4.097412 376.
        background
                xmin -176.1466
                xmax 197.2405
                function legendre
                order 2
                sample  -176.1466:-95.40266 97.24863:197.2405
                naverage -3
                niterate 2
                low_reject 3.
                high_reject 3.
                grow 0.
        axis    1
        curve   8
                2.
                4.
                5.
                585.
                -0.5453721
                1.797959
                -0.1794658
                0.07168905
```

Now extract the arc lamps using the extraction of one object as a reference:

```
input   =              arcNe.fits  List of input images
(output =                       ) List of output spectra
(apertur=                       ) Apertures
(format =             multispec) Extracted spectra format
(referen=                 fSA1) List of aperture reference images
(profile=                       ) List of aperture profile images

(interac=                   no) Run task interactively?
(find   =                   no) Find apertures?
(recente=                   no) Recenter apertures?
(resize =                   no) Resize apertures?
(edit   =                   no) Edit apertures?
(trace  =                   no) Trace apertures?
(fittrac=                   no) Fit the traced points
                                interactively?
(extract=                  yes) Extract spectra?
(extras =                   no) Extract sky, sigma, etc.?
(review =                  yes) Review extractions?

(backgro=                 none) Background to subtract
```

Add all the arcs to create the calibration file we are going to use to do the wavelength calibration:

cl> imexpr "a+b+c" arc.ms arcHgAr.ms arcNe.ms arcXe.ms
cl> implot arc.ms

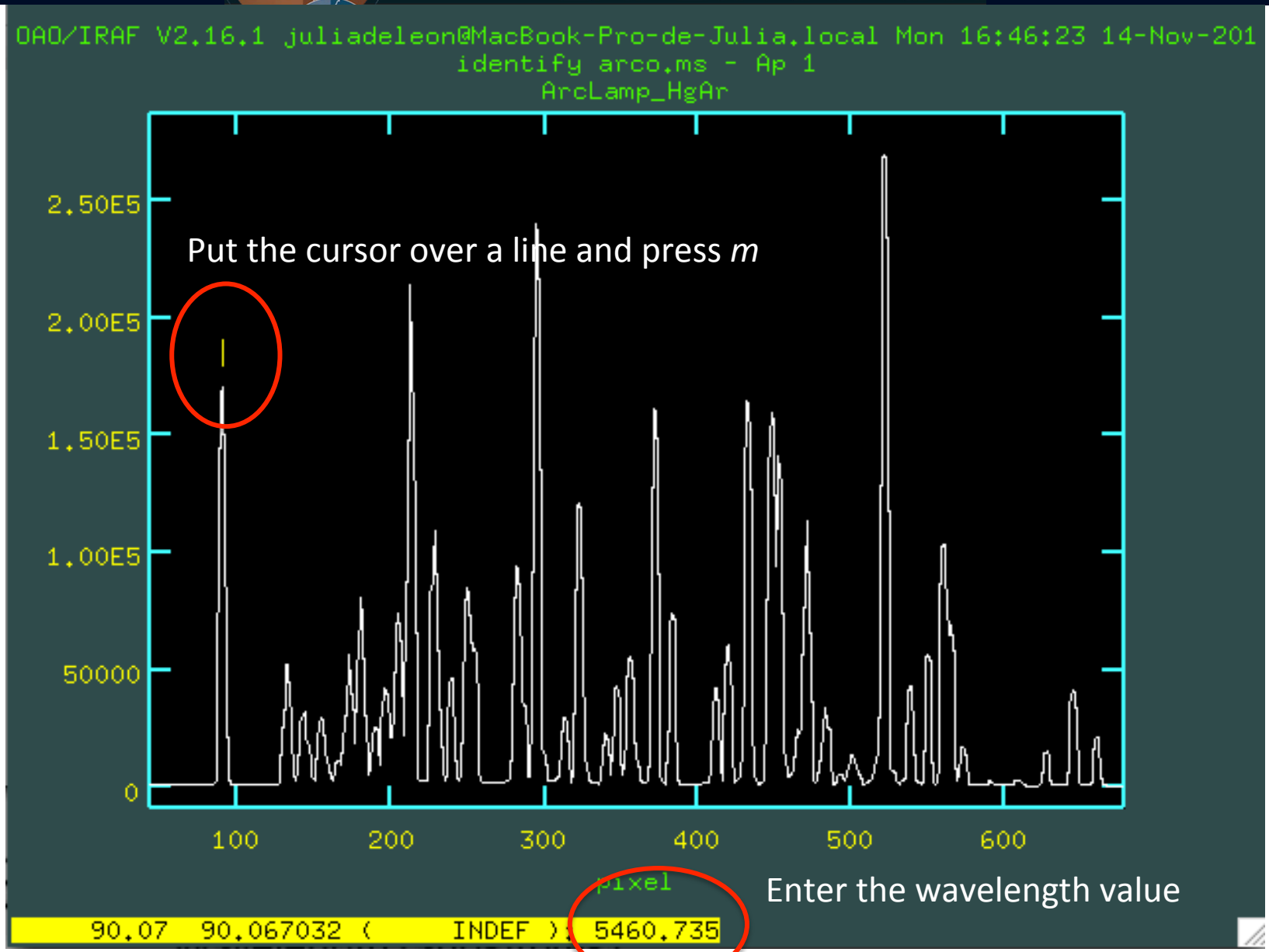


To perform the wavelength calibration we use the task **identify**:

cl> onedspec

cl> epar identify

```
images  =                  arc.ms  Images containing features to be identified
(section=           middle line) Section to apply to two dimensional images
(databas=              database) Database in which to record feature data
(coordli= linelists$idhenear.dat) User coordinate list
(units  =                      ) Coordinate units
(nsum   =                    10) Number of lines/columns/bands to sum in 2D image
(match  =                  -3.) Coordinate list matching limit
(maxfeat=                    50) Maximum number of features for automatic identif
(zwidth =                 100.) Zoom graph width in user units
(ftype  =             emission) Feature type
(fwidth =                   4.) Feature width in pixels
(cradius=                   5.) Centering radius in pixels
(thresho=                   0.) Feature threshold for centering
(minsep =                   2.) Minimum pixel separation
(functio=             legendre) Coordinate function
(order  =                    2) Order of coordinate function
(sample =                    *) Coordinate sample regions
```


OAO/IRAF V2.16.1 juliadeleon@MacBook-Pro-de-Julia.local Mon 16:46:23 14-Nov-201
identify arco.ms - Ap 1
ArcLamp_HgAr
2.50E5
2.00E5
1.50E5
1.00E5
50000
0
100
200
300
400
500
600
Put the cursor over a line and press *m*
pixel
90.07 90.067032 (INDEF): 5460.735
Enter the wavelength value

You can find the information on the calibration lamps on the webpage of the telescope:
http://www.gtc.iac.es/instruments/osiris/osiris.php

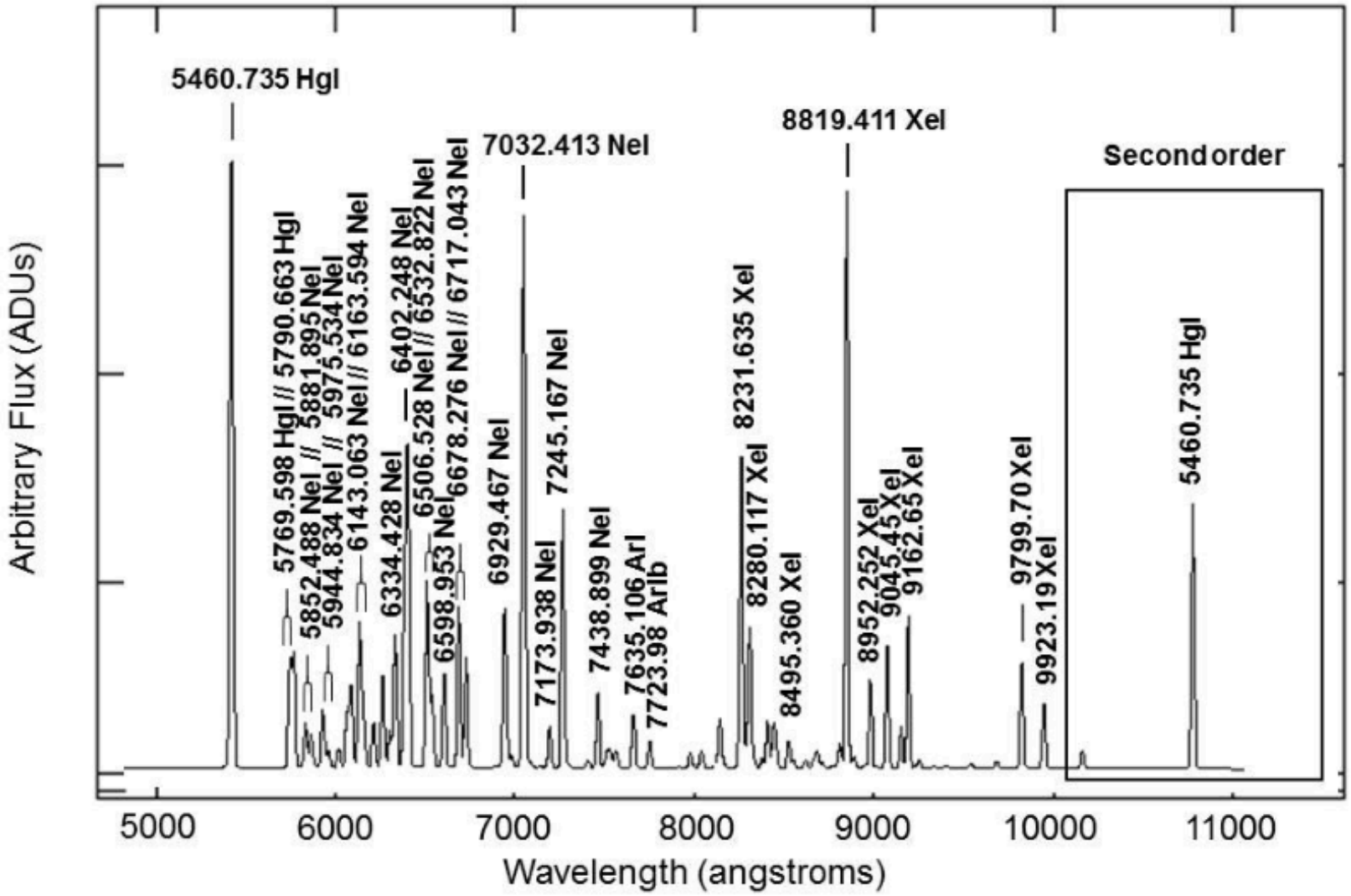
Arc Line maps

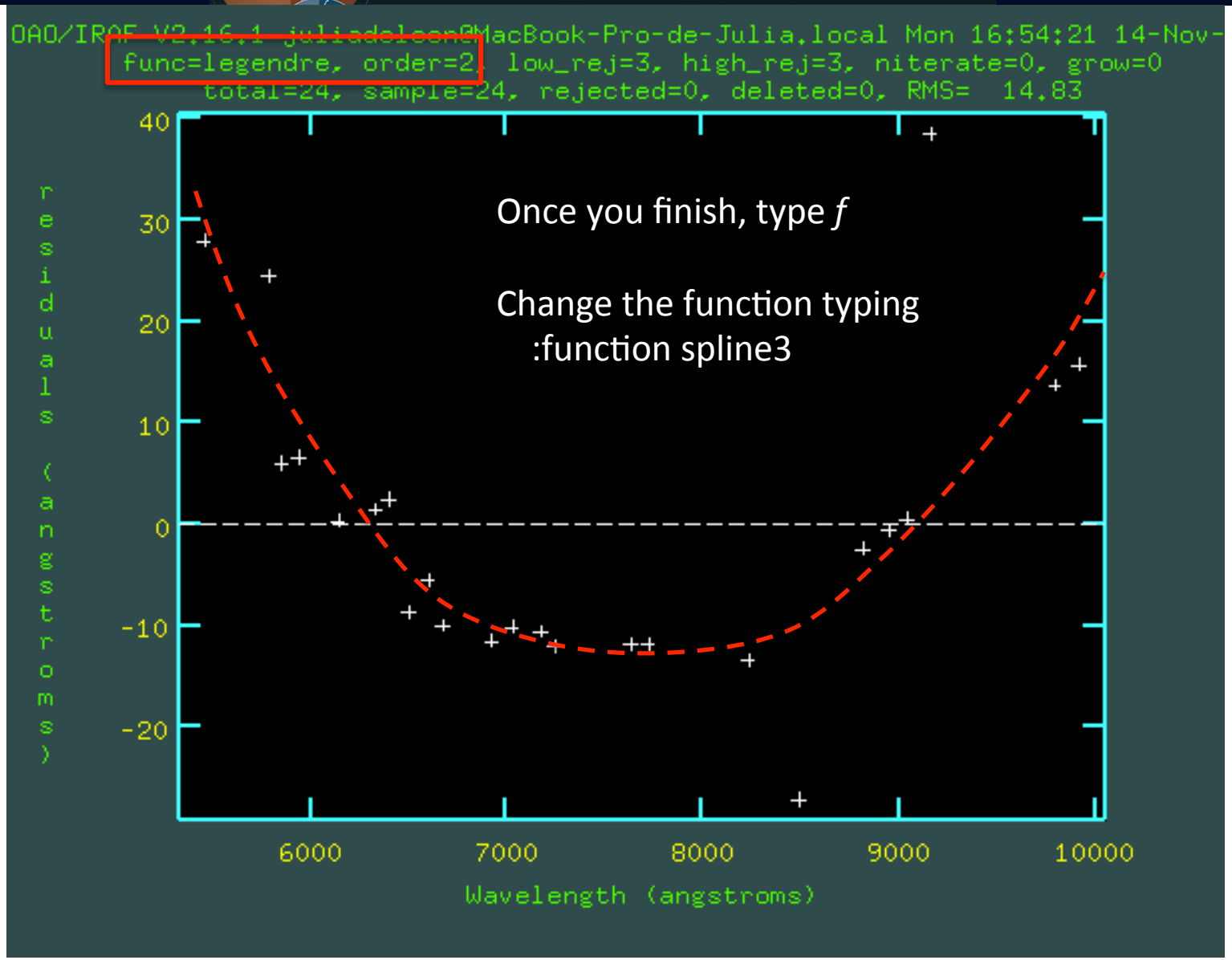
A complete arc linelist for all the lamps available at the OSIRIS Instrument Calibration Module (ICM) can be retrieved here. As addtional help in the wavelength calibration, some sky spectra at the resolutions covered by OSIRIS are available: R300, R500, R1000, R2000, and R2500.

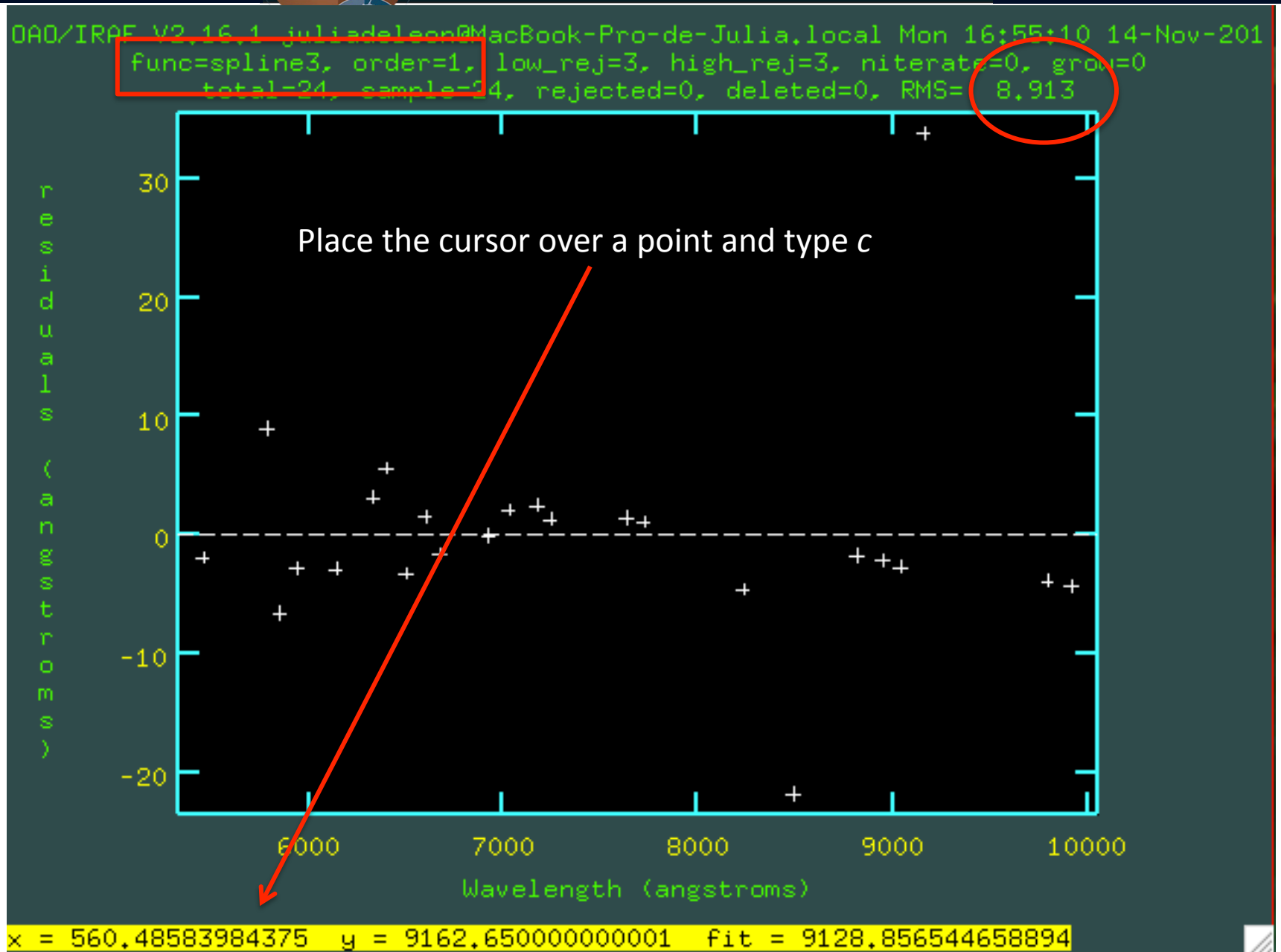
Spectral Line List and Calibration ARCs			
R300B LineList & ARC (HgAr, Ar, Ne, Xe)	R500B LineList & ARC (HgAr, Ar, Ne)	R1000B LineList & ARC (HgAr, Ar, Ne)	R2000B LineList & ARC
R300R LineList & ARC (HgAr, Ar, Ne, Xe)	R500R LineList & ARC (HgAr, Ar, Ne, Xe)	R1000R LineList & ARC (HgAr, Ar, Ne, Xe)	
R2500U LineList & ARC	R2500V LineList & ARC	R2500R LineList & ARC	R2500I LineList & ARC

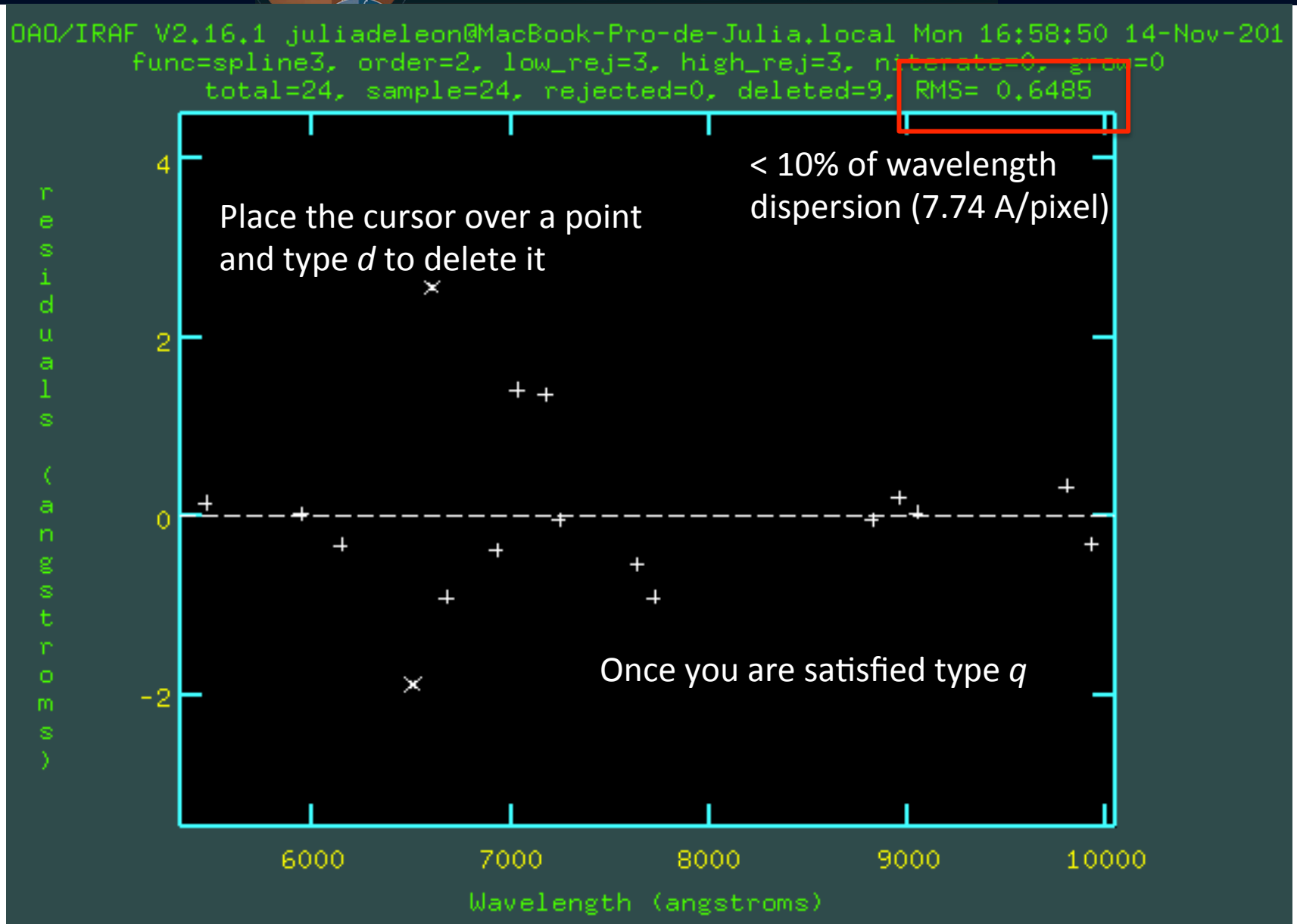
click here

OSIRIS R300R: HgAr + Xe + Ne calibration lamps




OAO/IRAF V2.16.1 juliadeleon@MacBook-Pro-de-Julia.local Mon 16:54:21 14-Nov-
func=legendre, order=2, low_rej=3, high_rej=3, niterate=0, grow=0
total=24, sample=24, rejected=0, deleted=0, RMS= 14.83
residuals (angstroms)
40
30
20
10
0
-10
-20
6000
7000
8000
9000
10000
Wavelength (angstroms)
Once you finish, type *f*
Change the function typing
:function spline3


OAO/IRAF V2.16.1 juliadeleon@MacBook-Pro-de-Julia.local Mon 16:55:10 14-Nov-201
func=spline3, order=1, low_rej=3, high_rej=3, niterate=0, grow=0
total=24, sample=24, rejected=0, deleted=0, RMS= 8.913
Place the cursor over a point and type c
residuals (angstroms)
30
20
10
0
-10
-20
6000
7000
8000
9000
10000
Wavelength (angstroms)
x = 560.48583984375 y = 9162.650000000001 fit = 9128.856544658894


OAO/IRAF V2.16.1 juliadeleon@MacBook-Pro-de-Julia.local Mon 16:58:50 14-Nov-201
func=spline3, order=2, low_rej=3, high_rej=3, niterate=0, grow=0
total=24, sample=24, rejected=0, deleted=9, RMS= 0.6485
< 10% of wavelength dispersion (7.74 A/pixel)
Place the cursor over a point and type d to delete it
Once you are satisfied type q
residuals (angstroms)
4
2
0
-2
6000
7000
8000
9000
10000
Wavelength (angstroms)

cl> ls database/

```
apSA1    aparcHgAr    aparcNe    aparcXe    aplast    idarc.ms
```

```
# Mon 16:59:26 14-Nov-2016
begin   identify arco.ms - Ap 1
        id      arco.ms
        task    identify
        image   arco.ms - Ap 1
        aperture        1
        aplow   197.82
        aphigh  206.48
        units   Angstroms
        features        15
                 90.07 5460.59337   5460.735    8.0 1 1
                154.48 5944.81793  5944.8342    8.0 1 1 NeI(1)
                180.54  6143.3851  6143.0623    8.0 1 1 NeI(1)
                250.05 6679.11616     6678.2    8.0 1 1 blend HeI 6678.149 with NeI 6678.2764
                282.26 6929.85237   6929.468    8.0 1 1 NeI(6)
                295.21 7031.00153  7032.4127    8.0 1 1 NeI(1)
                313.30 7172.58756   7173.939    8.0 1 1 NeI(6)
                322.56 7245.21611   7245.167    8.0 1 1 NeI(3)
                372.23 7635.64756   7635.105    8.0 1 1 AI(1)
                383.54 7724.70862     7723.8    8.0 1 1 blend AI(1) 7723.760 and AI(6) 7724.206
                521.96 8819.45969   8819.411    8.0 1 1
                538.64 8952.04893   8952.252    8.0 1 1
                550.38 9045.41245    9045.45    8.0 1 1
                644.82 9799.36867     9799.7    8.0 1 1
                660.31 9923.51016    9923.19    8.0 1 1
        function spline3
        order 2
        sample *
        naverage 1
        niterate 0
        low_reject 3.
        high_reject 3.
        grow 0.
        coefficients    9
                3.
                2.
                1.
                750.9999999999999
                380.4459396198231
                788.3566357150674
                1276.031312328298
                1772.835151635517
                2286.32677550035
```

idarc.ms

Add the information on the wavelength calibration to the header of the image using **hedit**, and then apply the wavelength calibration using **dispcor**:

cl> hedit fSA1.ms REFSPEC1 "arc.ms" add+ up+
cl> dispcor fSA1.ms cfSA1.ms

```
cfSA1.ms: ap = 1, w1 = 4809.904, w2 =  10653.7, dw = 7.791727, nw = 751
```

This value should be similar to the dispersion of your grism, in this case the R300R grism has a dispersion of 7.74 A/pix so our wavelength calibration is satisfactory.

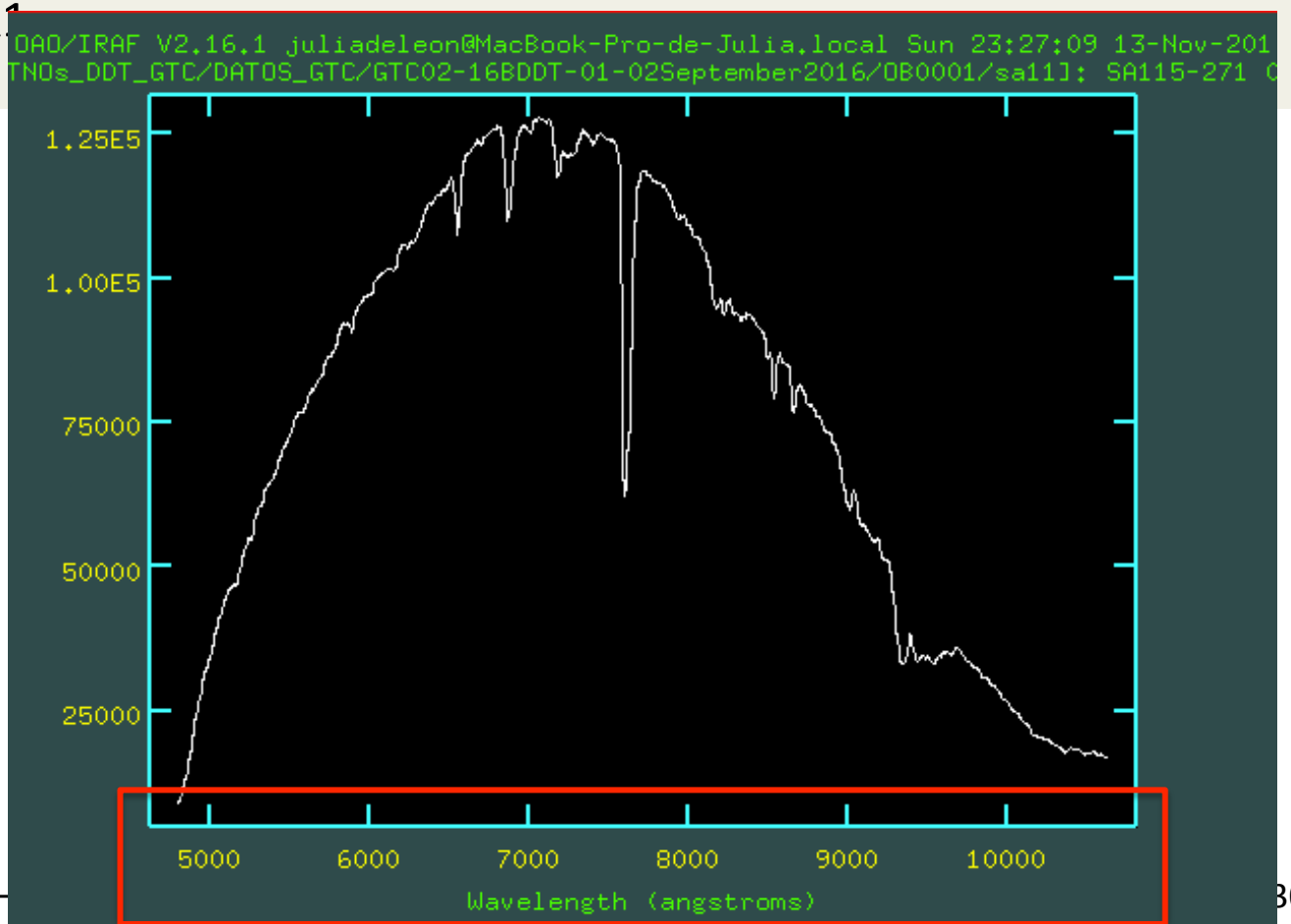
Add the information on the wavelength calibration to the header of the image using **hedit**, and then apply the wavelength calibration using **dispcor**:

cl> hedit fSA1.ms REFSPEC1 “arc.ms” add+ up+

cl> dispcor fSA1.ms cfSA1

```
cfSA1.ms: ap = 1, w1
```

Have a look at the result using **splot**:

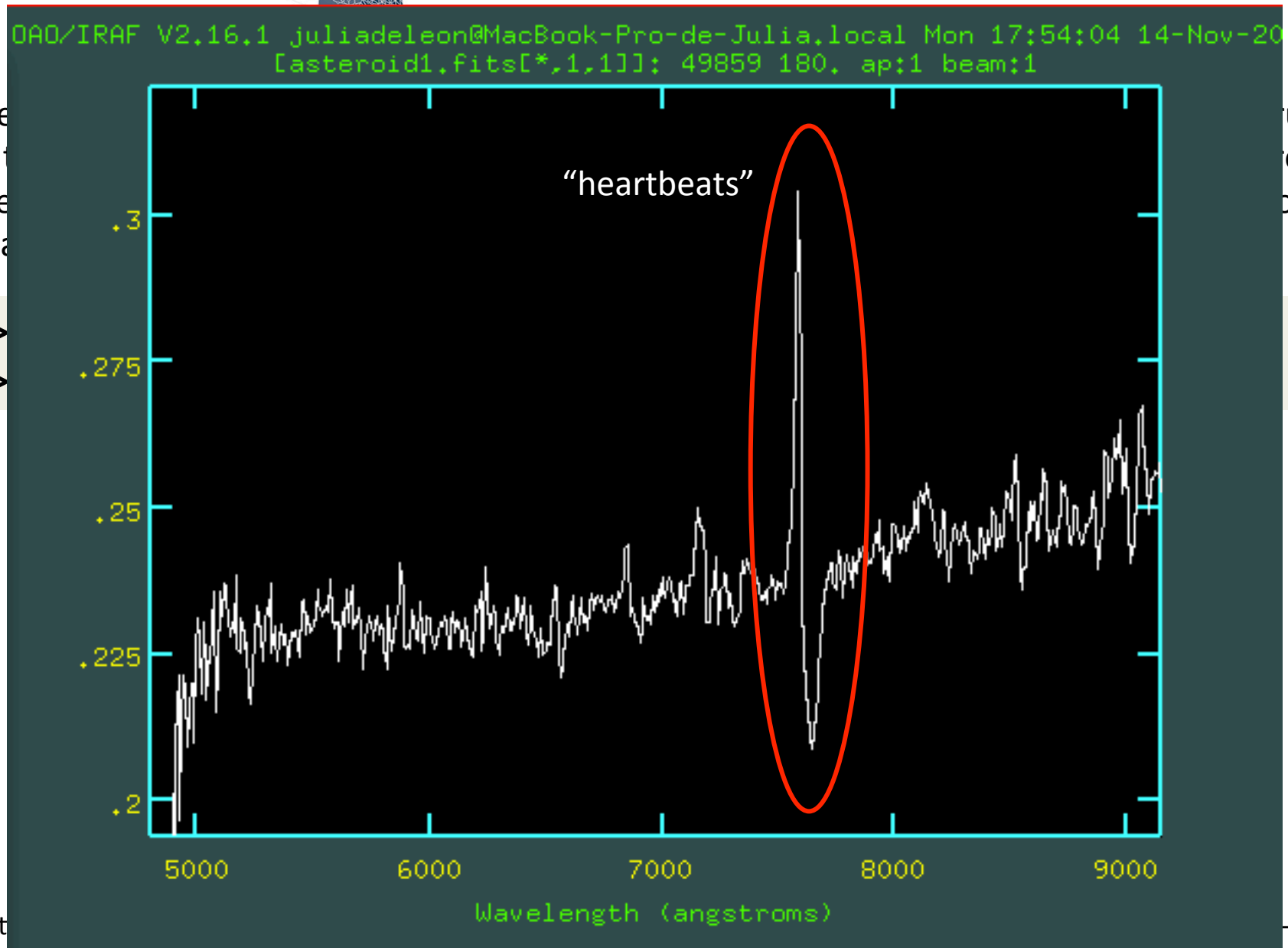


We do not have to do any flux calibration, as we are interested in the reflectance spectrum of the asteroid. So, to obtain it and to "remove" the contribution of the reflected light from the Sun, we simply divide the spectrum of the asteroid by the spectrum of the solar analogue star:

```
cl> sarith  cfObj1.ms  /  cfSA1.ms  asteroid1
cl> splot  asteroid 1
```

We
of t
the
ana

cl>
cl>



Reduct

You can download the lectures from the Winter School in PDF format here:

http://www.iac.es/winterschool/2016/pages/about-the-school/program.php