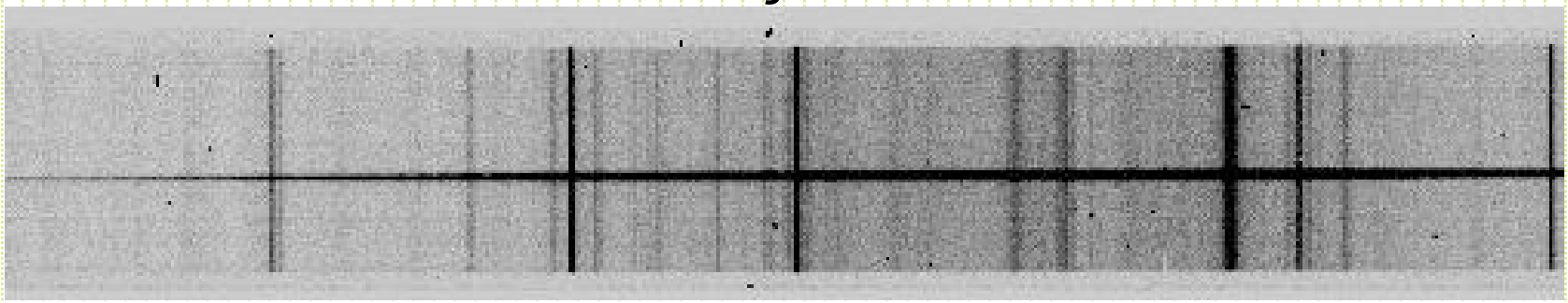
Spectral Reduction Procedures

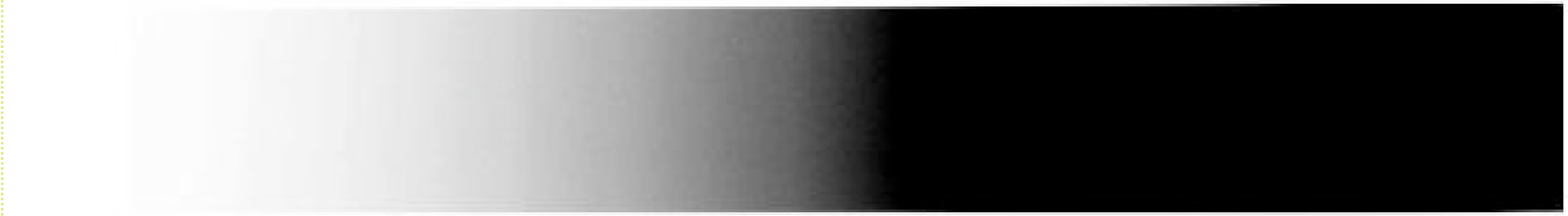
- There are good introductions/cookbooks available from the IRAF folks. The introduction to spectral reductions is at the class WWW site.
- There are many ways to accomplish most tasks. Will run through a basic approach to reducing long slit spectra.

- Steps:
  - Bias and overscan correction
  - Flat-fielding
    - Note: need to remove large-scale variations in the spectral dimension
  - Identify location of the spectrum
  - Identify location of sky samples
  - Extract spectrum
    - Trace
    - Collapse lines
    - Interpolate sky and subtract
  - Use stellar aperture to extract arc spectrum
    - Note: sometimes do the flat-fielding here
  - Fit pixel-wavelength map and apply to spectrum
  - Derive flux calibration and apply to spectrum

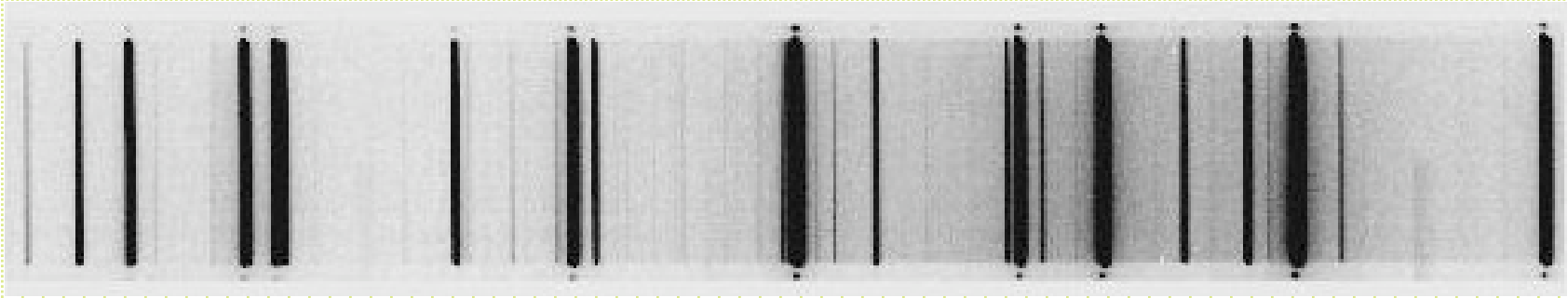
Star+sky



Quartz lamp flat



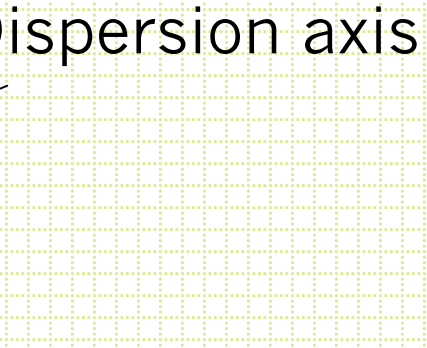
HgCdNe line lamps



Note about Observing

- If spectrometer is not flexture compensated, the usual procedure is to obtain a line lamp spectrum (or two) and flat-field spectrum (or two) at the position of your program object. Sometimes even bracket the program exposures with arcs and flats.
- Depending on program, observe:
  - Flux standard
  - Radial velocity standard
  - Hot rapid rotator to identify terrestrial atmospheric absorption
- If no ADC, pay attention to position angle!

- Packages in noao.twodspec.apextract
  - Need to set the dispersion axis

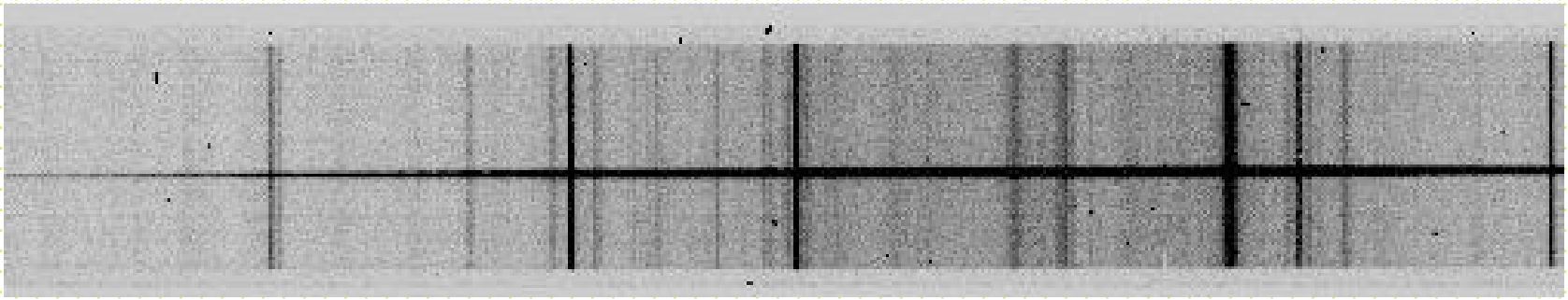



```
tw>epar apextract

    PACKAGE = twodspec
    TASK = apextract

(dispaxi=                1) Dispersion axis (1=along lines, 2=along columns)
(databas=           database) Database
(verbose=                no) Verbose output?
(logfile=                ) Text log file
(plotfil=                ) Plot file
(version= APEXTRACT V3.0: August 1990)
(mode   =                ql)
($nargs =                0)
```

- noao.twod.apextract

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

apall combines parameter files for all the rest of the tasks



Dispersion axis along lines (`1' to IRAF)

PACKAGE = apextract
TASK = apall

input = 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?

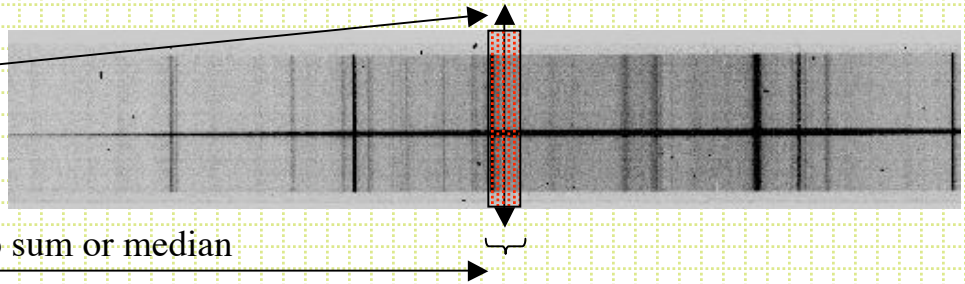
Multispec: star, sky, S/N

Useful for arcs/faint spectra/discontinuous spectra

Usually “no”

keep spectrum, sky and S/N in 3-d output fits file

Default is center



(line = INDEF) Dispersion line

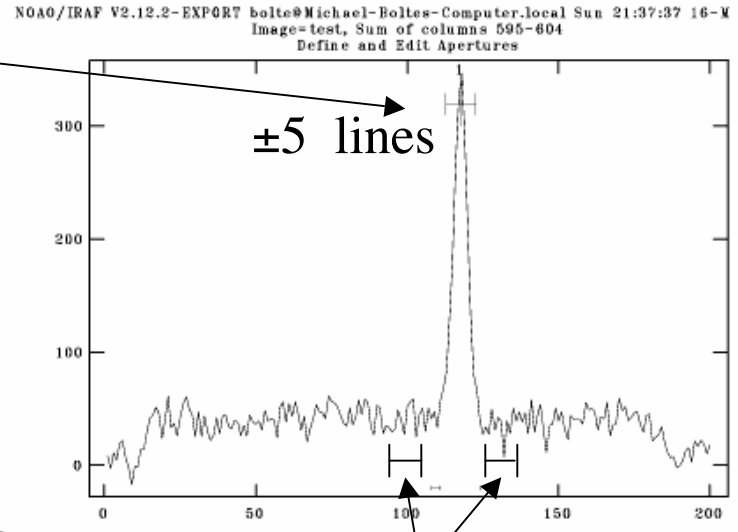
(nsum = 10) Number of dispersion lines to sum or median

DEFAULT APERTURE PARAMETERS

(lower = -5.) Lower aperture limit relative to center

(upper = 5.) Upper aperture limit relative to center

(apidtab=) Aperture ID table (optional)



DEFAULT BACKGROUND PARAMETERS

(b_funct= chebyshev) Background function

(b_order= 1) Background function order

(b_sampl= -10:-6,6:10) Background sample regions

(b_naver= -3) Background average or median

(b_niter= 0) Background rejection iterations

(b_low_r= 3.) Background lower rejection sigma

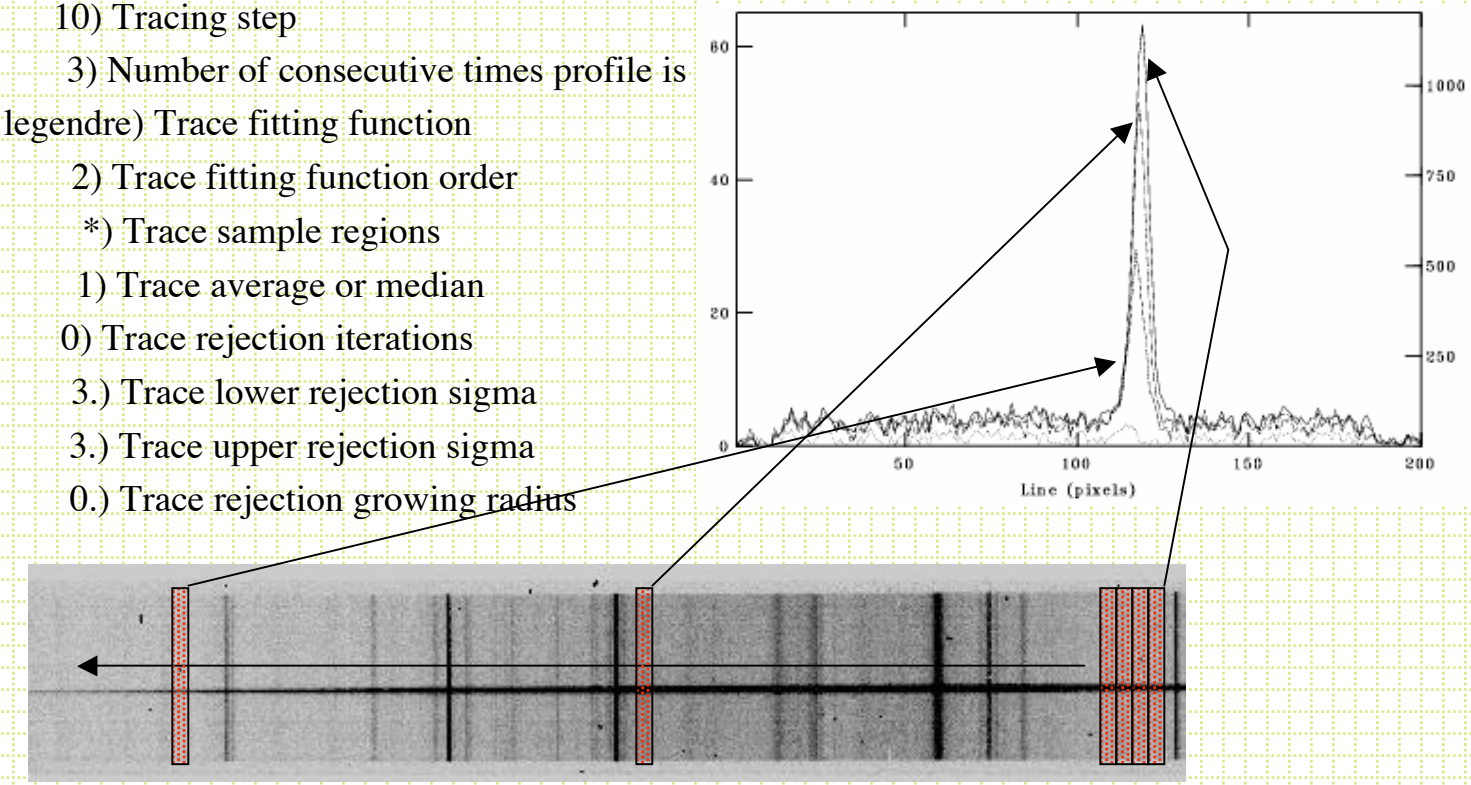
(b_high_= 3.) Background upper rejection sigma

(b_grow = 0.) Background rejection growing radius

APERTURE CENTERING PARAMETERS
AUTOMATIC FINDING AND ORDERING PARAMETERS
RECENTERING PARAMETERS
RESIZING PARAMETERS
TRACING PARAMETERS

Skipping the details of these for now

(t_nsum = 10) Number of dispersion lines to sum
(t_step = 10) Tracing step
(t_nlost= 3) Number of consecutive times profile is
(t_funct= legendre) Trace fitting function
(t_order= 2) Trace fitting function order
(t_sampl= *) Trace sample regions
(t_naver= 1) Trace average or median
(t_niter= 0) Trace rejection iterations
(t_low_r= 3.) Trace lower rejection sigma
(t_high_= 3.) Trace upper rejection sigma
(t_grow = 0.) Trace rejection growing radius



Trace finds the `y' position of the peak as a function of x position

(backgro= fit) Background to subtract (none,average,median,min,fit)
(skybox = 1) Box car smoothing length for sky
(weights= none) Extraction weights (none|variance)
(pfit = fit1d) Profile fitting type (fit1d|fit2d)
(clean = yes) Detect and replace bad pixels?
(saturat= 31000.) Saturation level
(readnoi= 0.) Read out noise sigma (photons)
(gain = 1.) Photon gain (photons/data number)
(lsigma = 4.) Lower rejection threshold
(usigma = 4.) Upper rejection threshold
(nsubaps= 1) Number of subapertures per aperture

Example Extraction

cl>apall b188 output=b188.ms

Find apertures for b188? (yes):

Number of apertures to be found automatically (1):

Edit apertures for b188? (yes):

Commonly used options:

? -- help

l -- set lower ap limit

u -- set upper ap limit

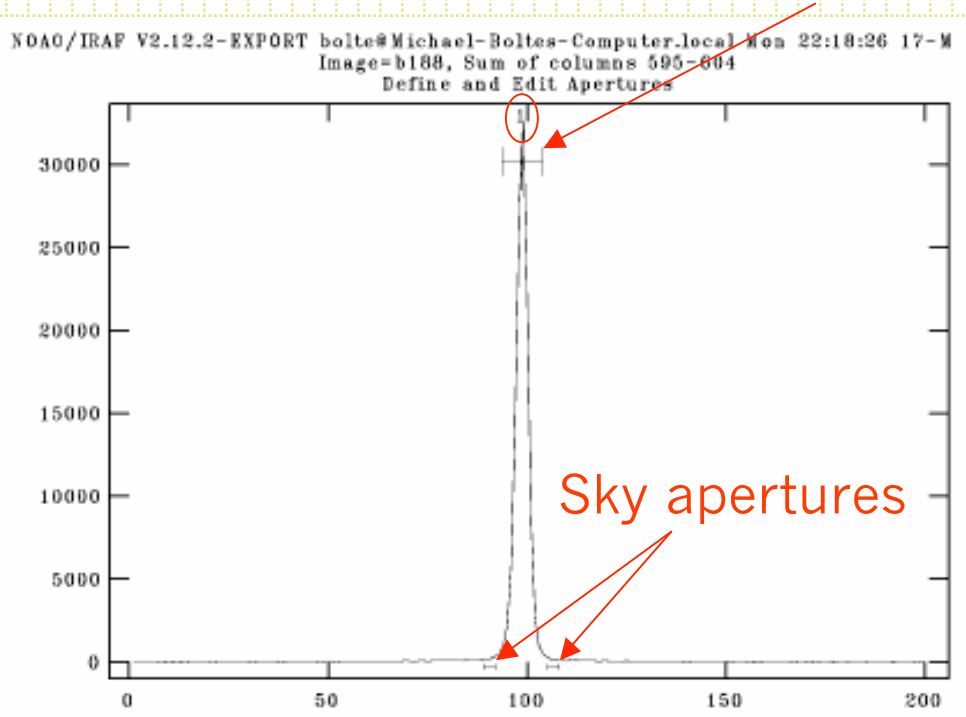
b -- to tweak sky aperture

w -- window the plot

? -- window help

e -- expand plot

q -- happy, continue



`b' option:

Commonly-used commands:

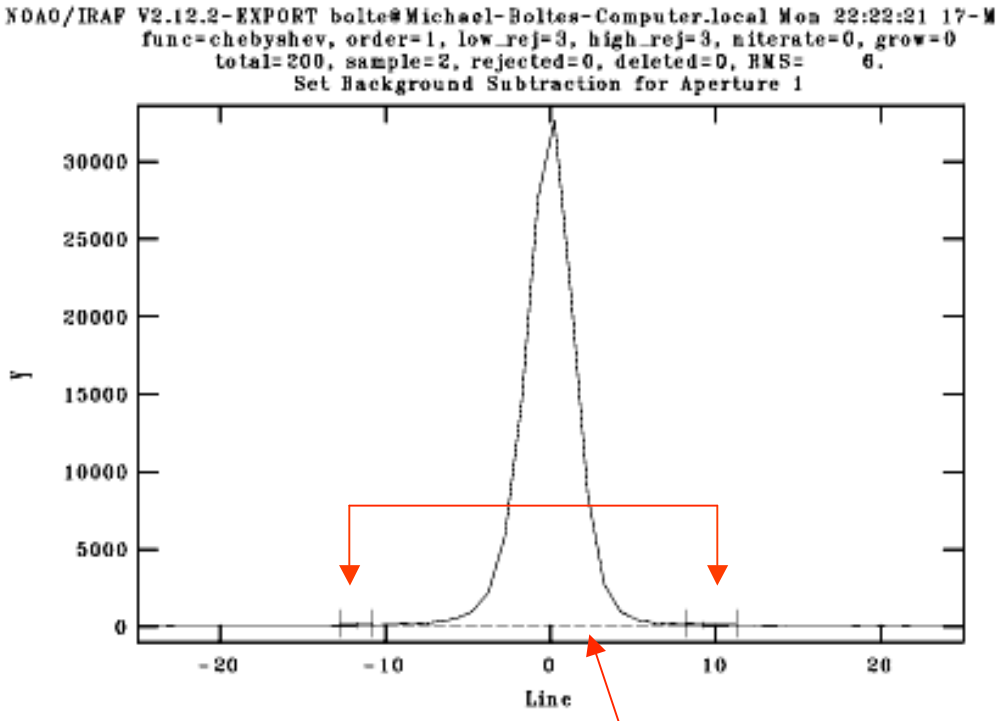
z -- deletes nearest aperture

s -- define new aperture

f -- redo fit

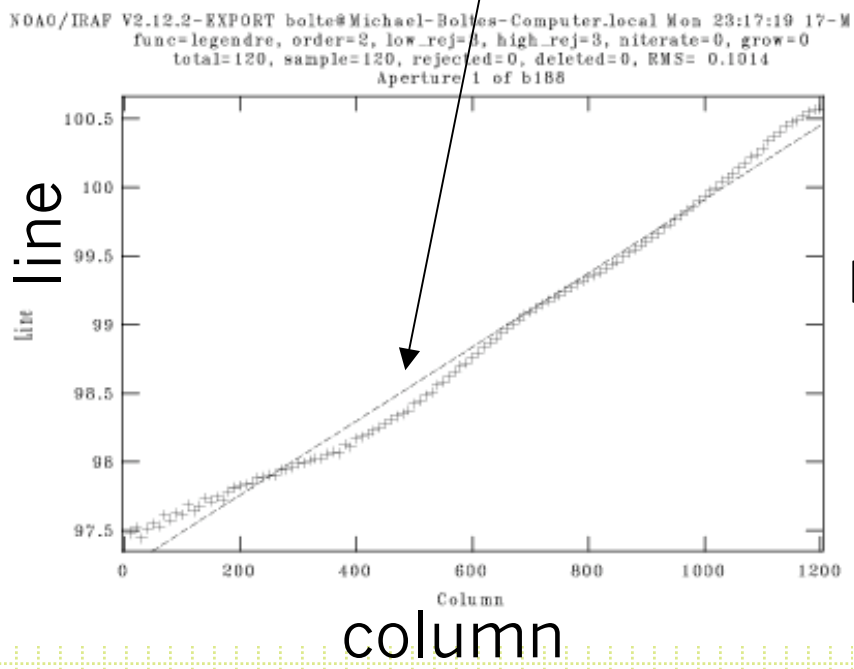
:order n -- set order of fit

q -- accept fit and go to previous panel



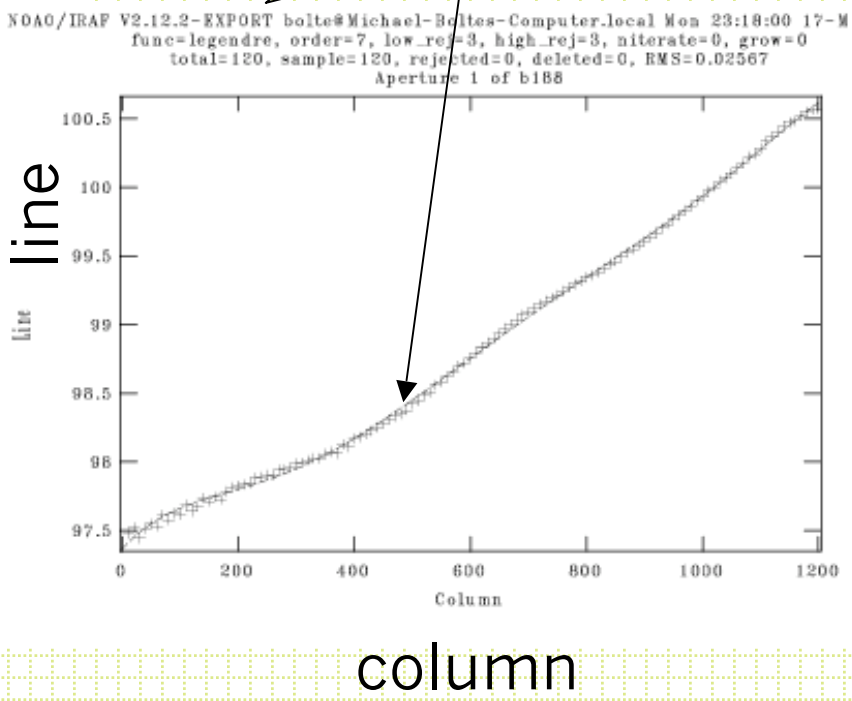
Fitted sky value

Trace: order 2 fit



:o 7
f

order 7 fit



Splot:

cl>splot b188.ms

Common splot options:

? -- lists all the options

%-- select new band

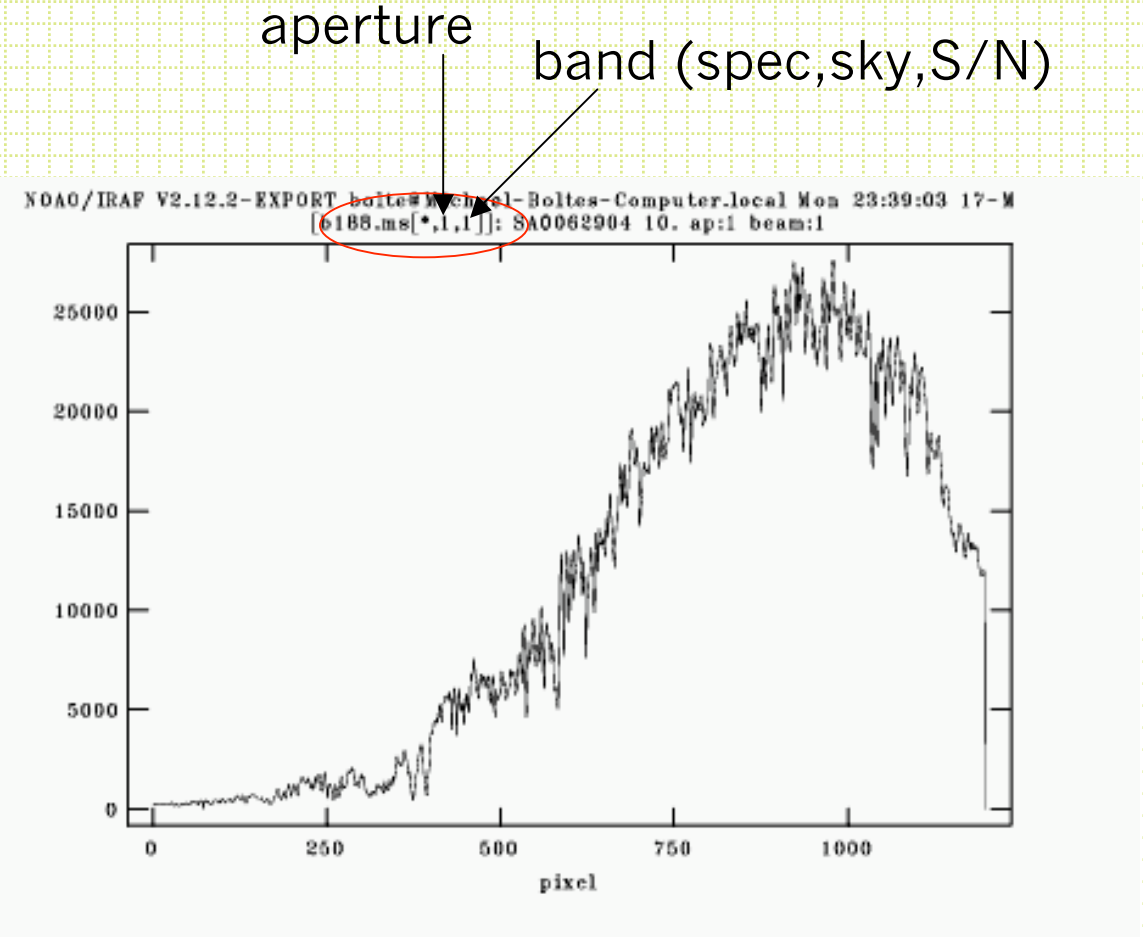
m-- gives statistics

e-- eq. width, line centers

s-- smooth

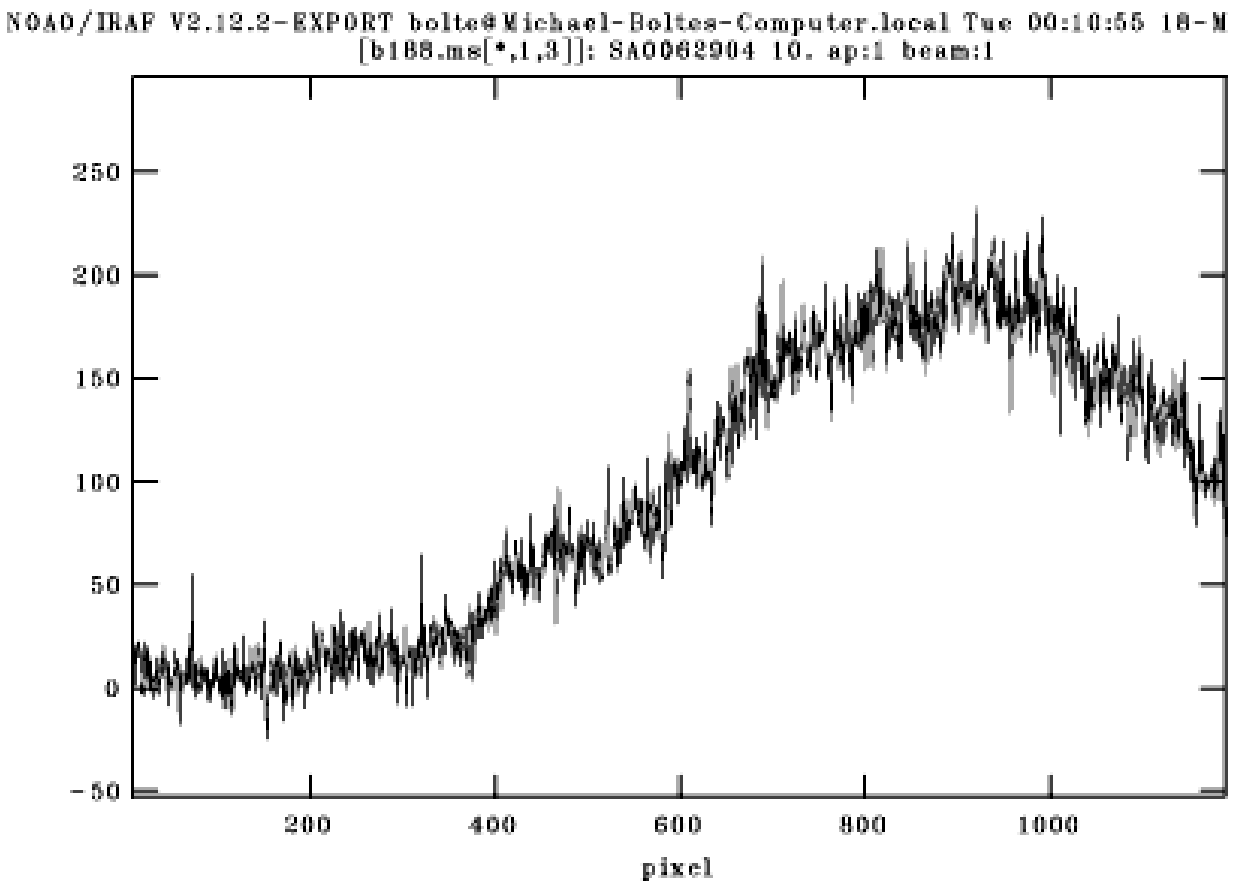
t-- fit continuum

w--window plot

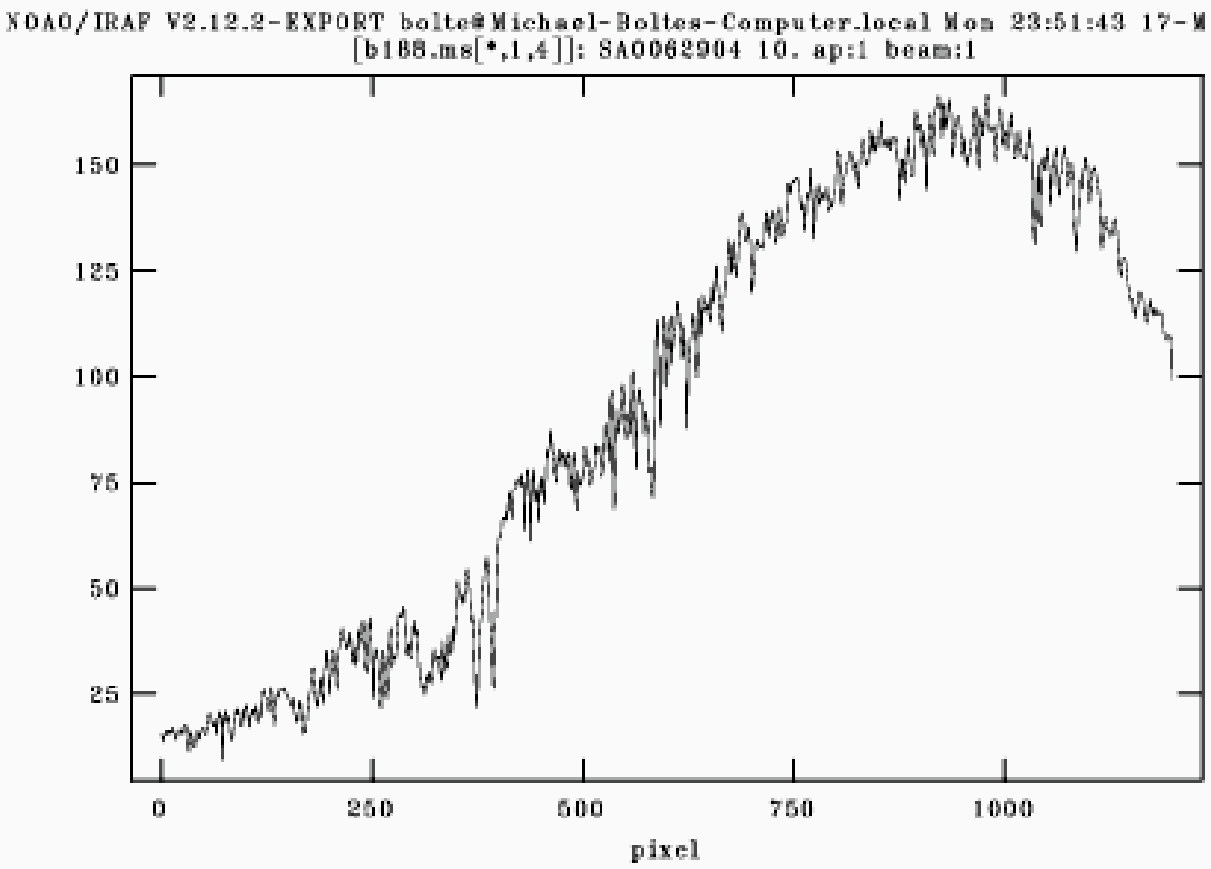


Extracted spectrum in pixel space

Sky

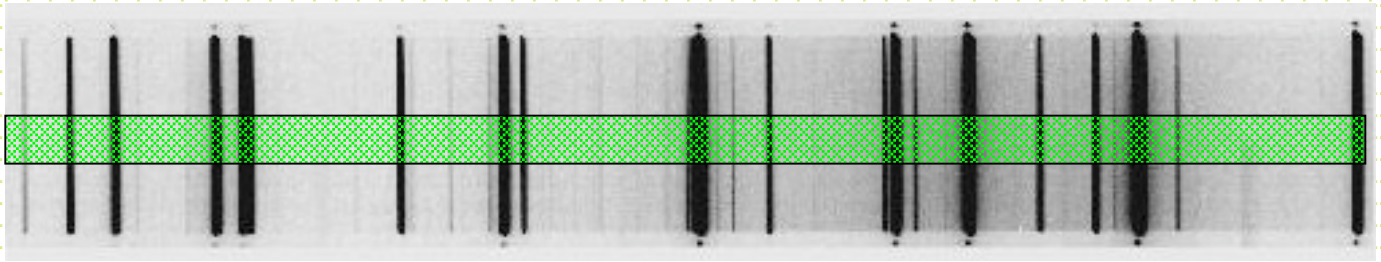

NOAO/IRAF V2.12.2-EXPORT bolte@Michael-Boltes-Computer.local Tue 00:10:55 18-M
[b188.ms[*,1,3]]: SA0062904 10. ap:1 beam:1
250
200
150
100
50
0
-50
200
400
600
800
1000
pixel

Band #4: S/N

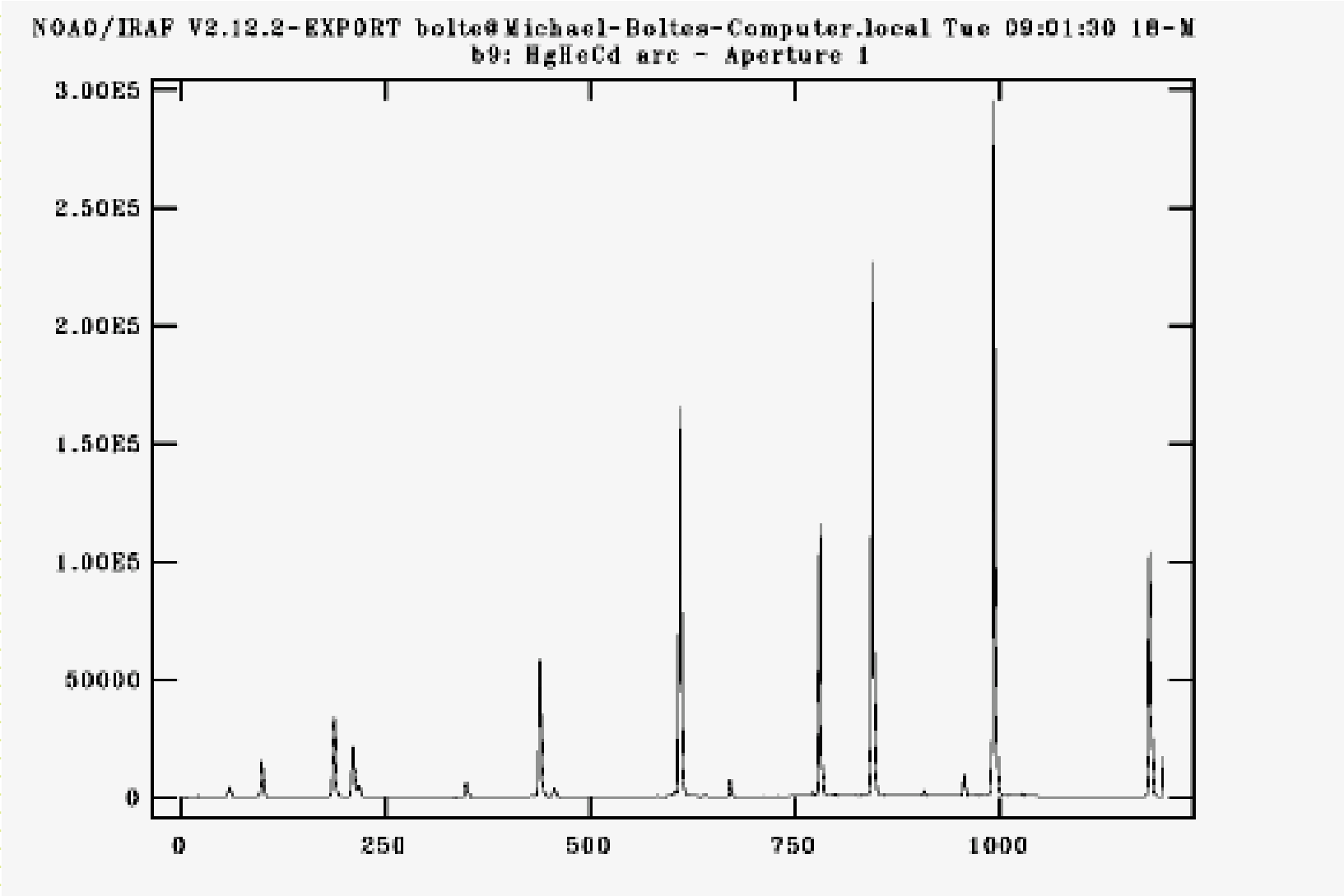

NOAO/IRAF V2.12.2-EXPORT bolte@Michael-Boltes-Computer.local Mon 23:51:43 17-M
[b188.ms[*,1,4]]: SA0062904 10. ap:1 beam:1
150
125
100
75
50
25
0
250
500
750
1000
pixel

Line Lamps

- Use a pre-defined aperture, trace for extracting arcs. Lines are often tilted or curved.



cl>apall arc output=arc.ms ref=b188 find- trace- background=none

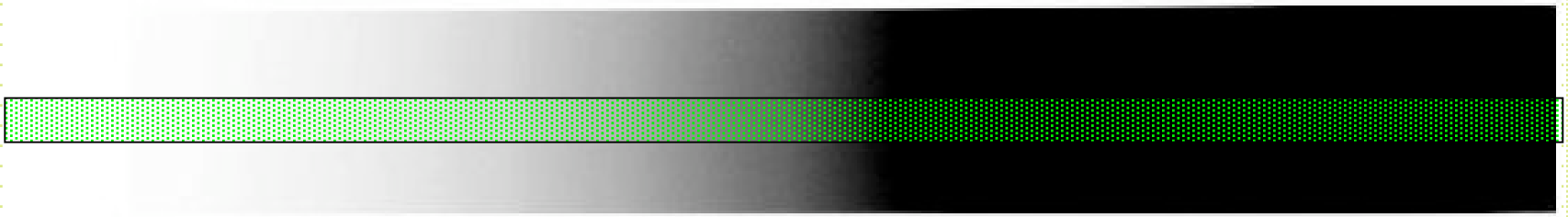


Sometimes fit a master arc taken in the afternoon and use arcs taken adjacent to program objects to make a zeropoint shift to the wavelength solution.

Flat-fields

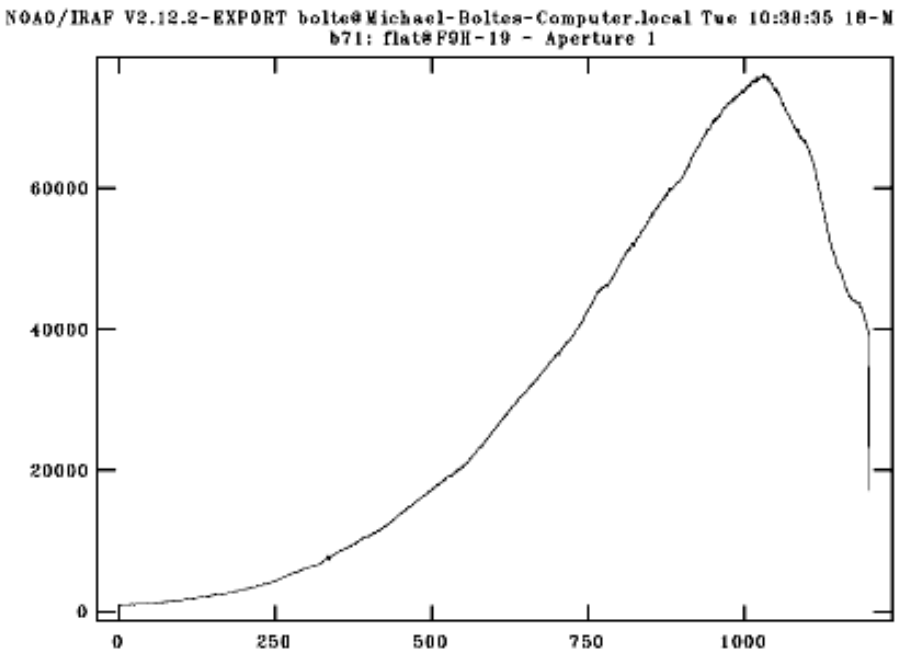
- Can flat-field original frames in 2-D format, but more commonly, the flat-field image is extracted with the same aperture as the program object.
- In the spirit of flat-fielding for direct images, you would like a source that is uniform in the spatial direction AND has a flat spectrum. In practice, all flat-field lamps (usually a hot quartz lamp) have a strong spectral (continuum) signature.
- So, usually extract flat, then fit a function in the spectral direction and divide this out to leave the pixel-to-pixel response.

Quartz lamp



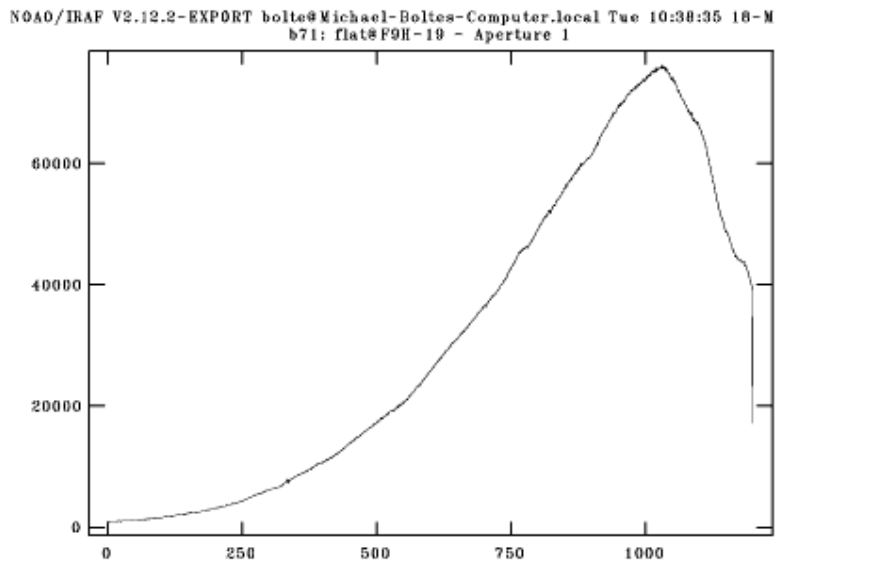
Blue

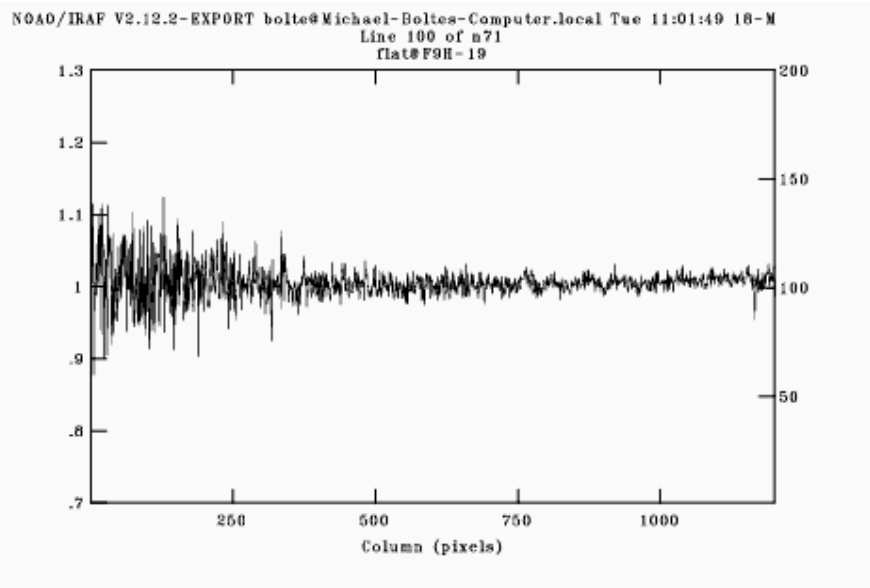
Red



Can do any of the following:

(1) Divide by extracted flat and normalized later
(2) Fit extracted flat and normalize, then divide
(3) Use twod.longslit.response and approximate the aperture (returns normalized, extracted flat response from 2-D spectrum

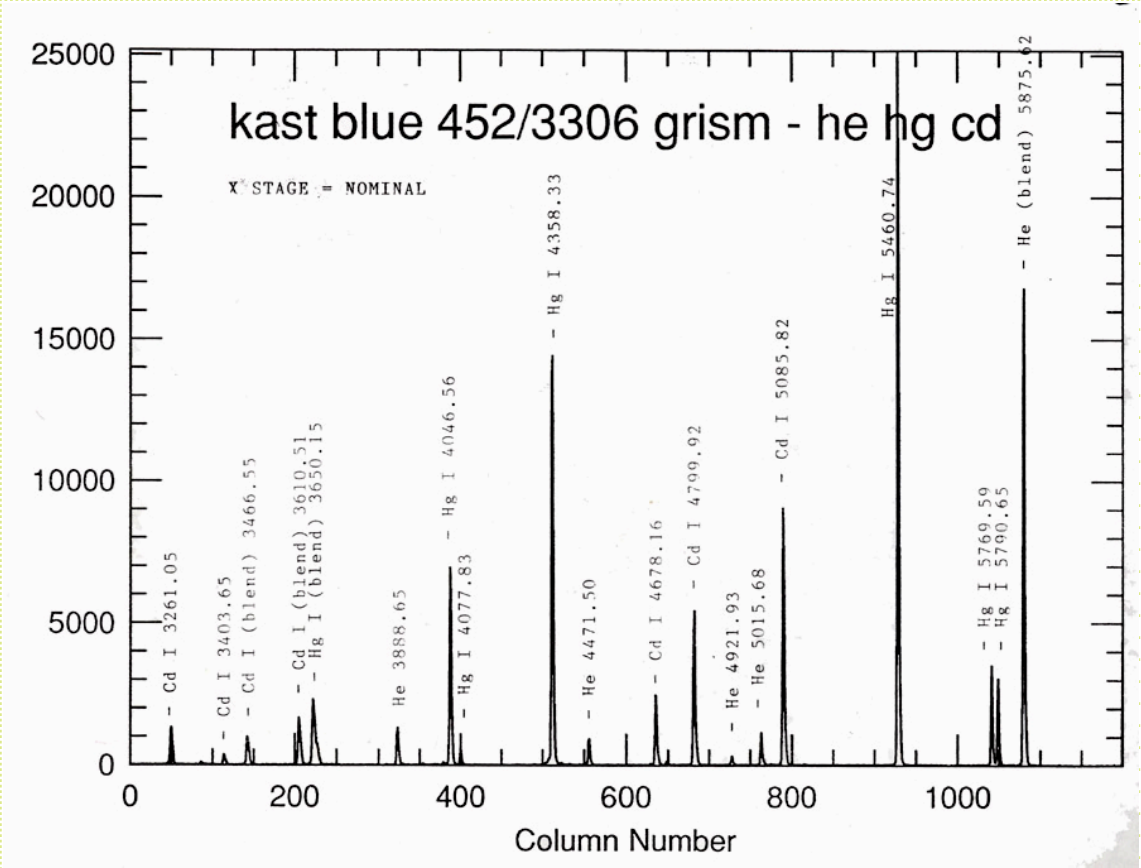




Wavelength Calibration

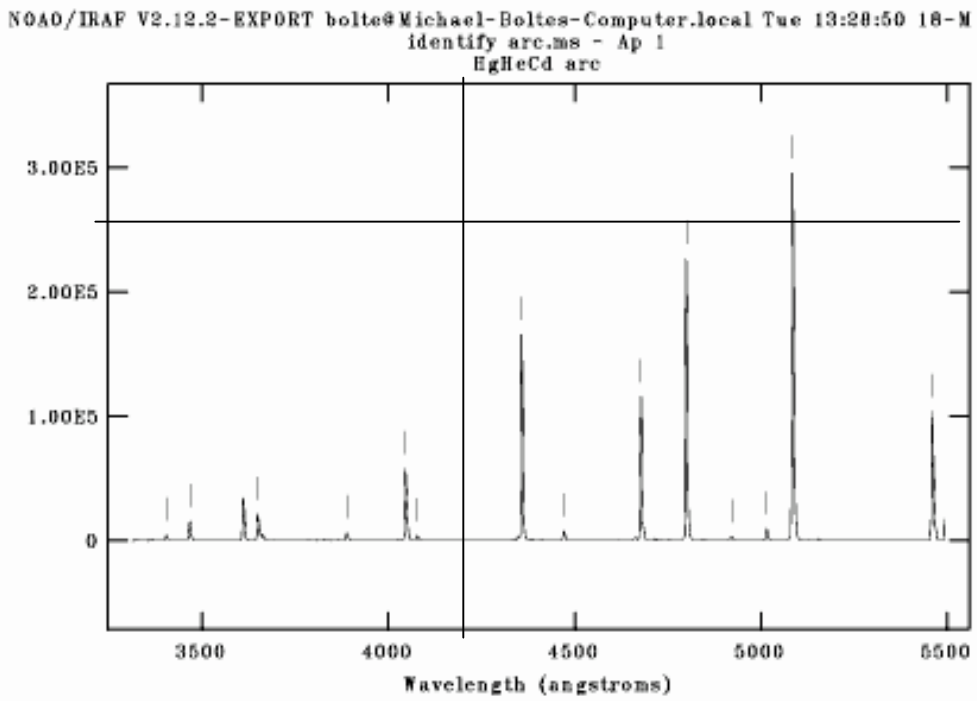
- Identify the lines in your lamp-line spectrum
- Fit line centers, derive function to map pixel scale to wavelength scale
- Associate arc+solution with program spectra
- Apply the `dispersion' solution, usually writing a short version of the solution to the header

Example, from Lick KAST WWW pages



- IRAF wavelength fitting routine:
  - noao.oned.*identify*

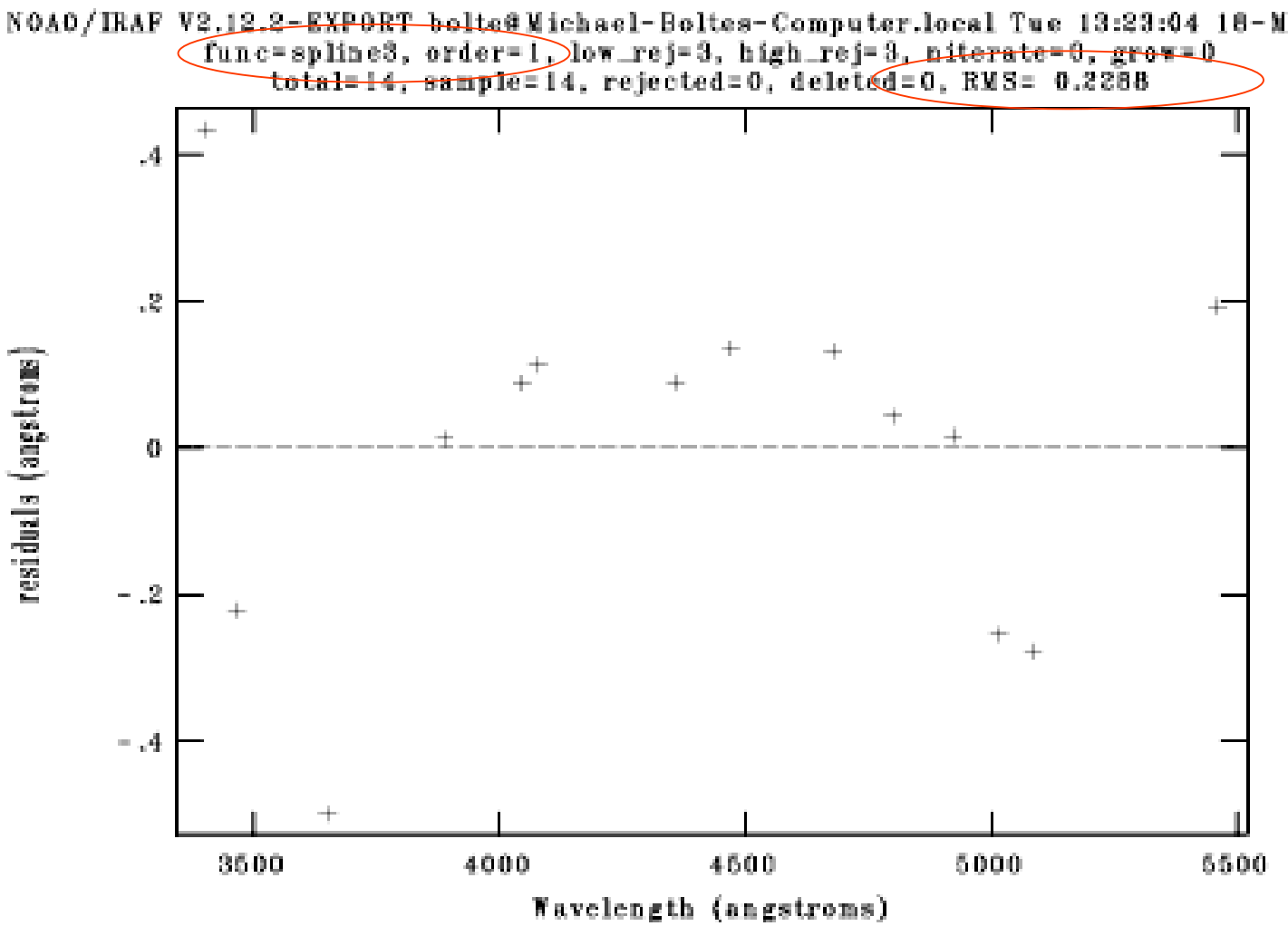
```
PACKAGE = onedspec
  TASK = identify

images  =                   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 (typically user uses their own 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=           spline3) Coordinate function
(order  =                   1) Order of coordinate function
(sample =                   *) Coordinate sample regions
```

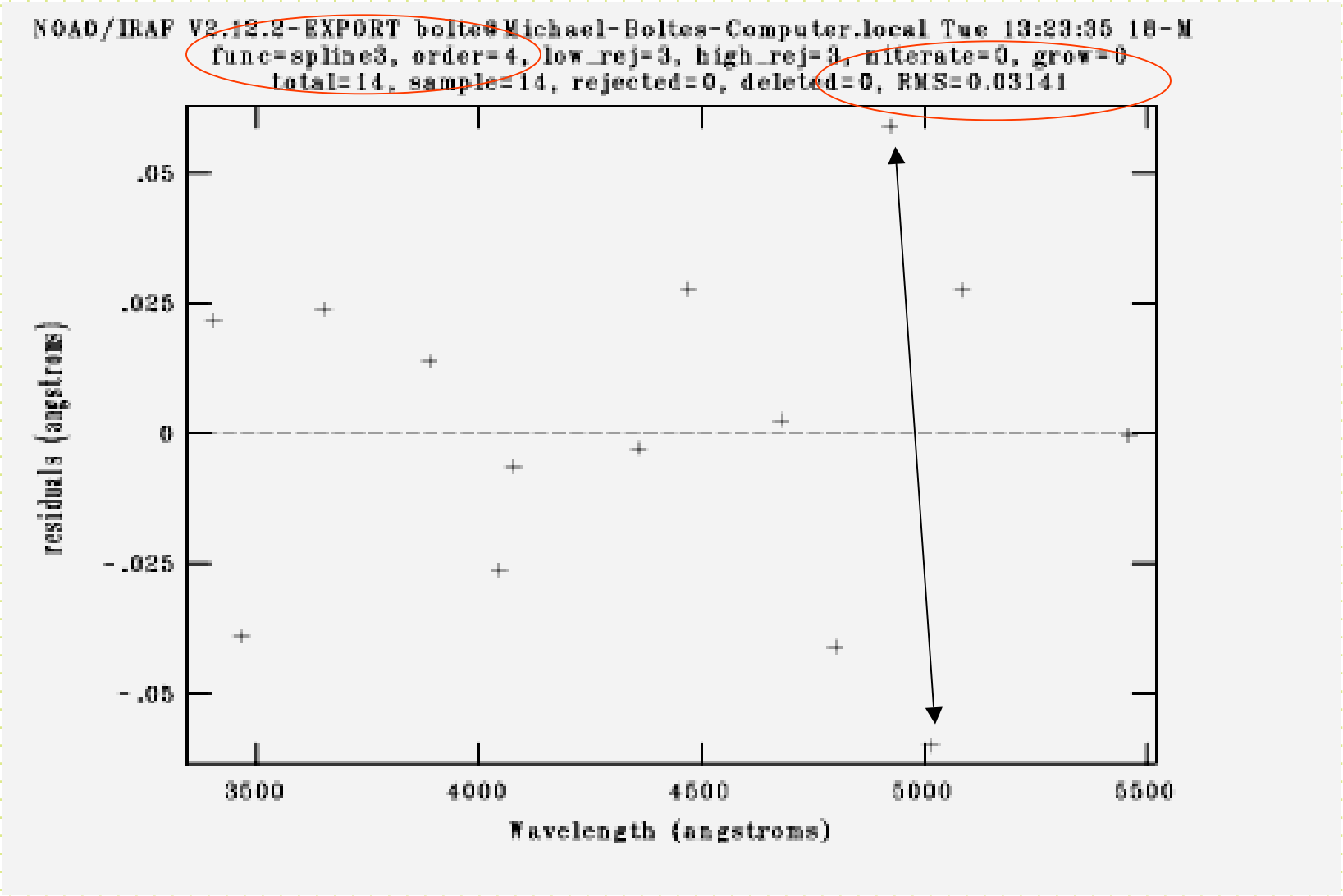


First *identify* window

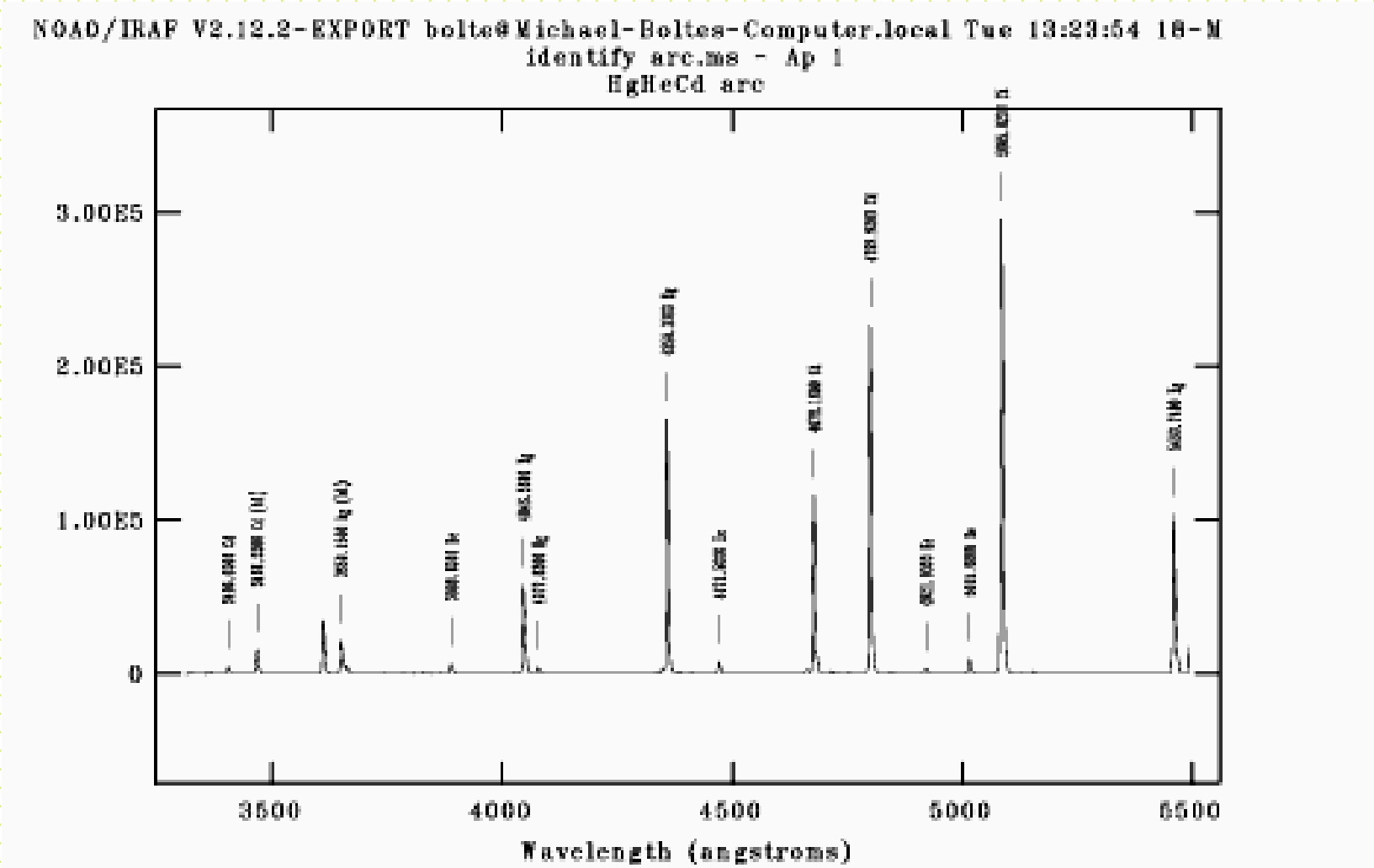
Commonly-used commands:

? -- help
m -- mark a line
c -- center next feature
l -- locate the rest of the lines
d -- delete a line
f -- fit (brings up new window)
w -- window


NOAO/IRAF V2.12.2-EXPORT holte@Michael-Holtes-Computer.local Tue 13:23:04 18-M
func=spline3, order=1, low_rej=3, high_rej=3, niterate=0, grow=0
total=14, sample=14, rejected=0, deleted=0, RMS= 0.2288
.4
.2
0
-.2
-.4
residuals (angstroms)
3500
4000
4500
5000
5500
Wavelength (angstroms)


NOAO/IRAF V2.12.2-EXPORT bolte@Michael-Boltes-Computer.local Tue 13:23:35 18-M
func=spline3, order=4, low_rej=3, high_rej=3, niterate=0, grow=0
total=14, sample=14, rejected=0, deleted=0, RMS=0.03141
.05
.025
0
-.025
-.05
residuals (angstroms)
3500
4000
4500
5000
5500
Wavelength (angstroms)

:label both


NOAO/IRAF V2.12.2-EXPORT bolte@Michael-Boltes-Computer.local Tue 13:23:54 18-M
identify arc.ms - Ap 1
HgHeCd arc
3.00E5
2.00E5
1.00E5
0
3500
4000
4500
5000
5500
Wavelength (angstroms)

Applying wavelength solution

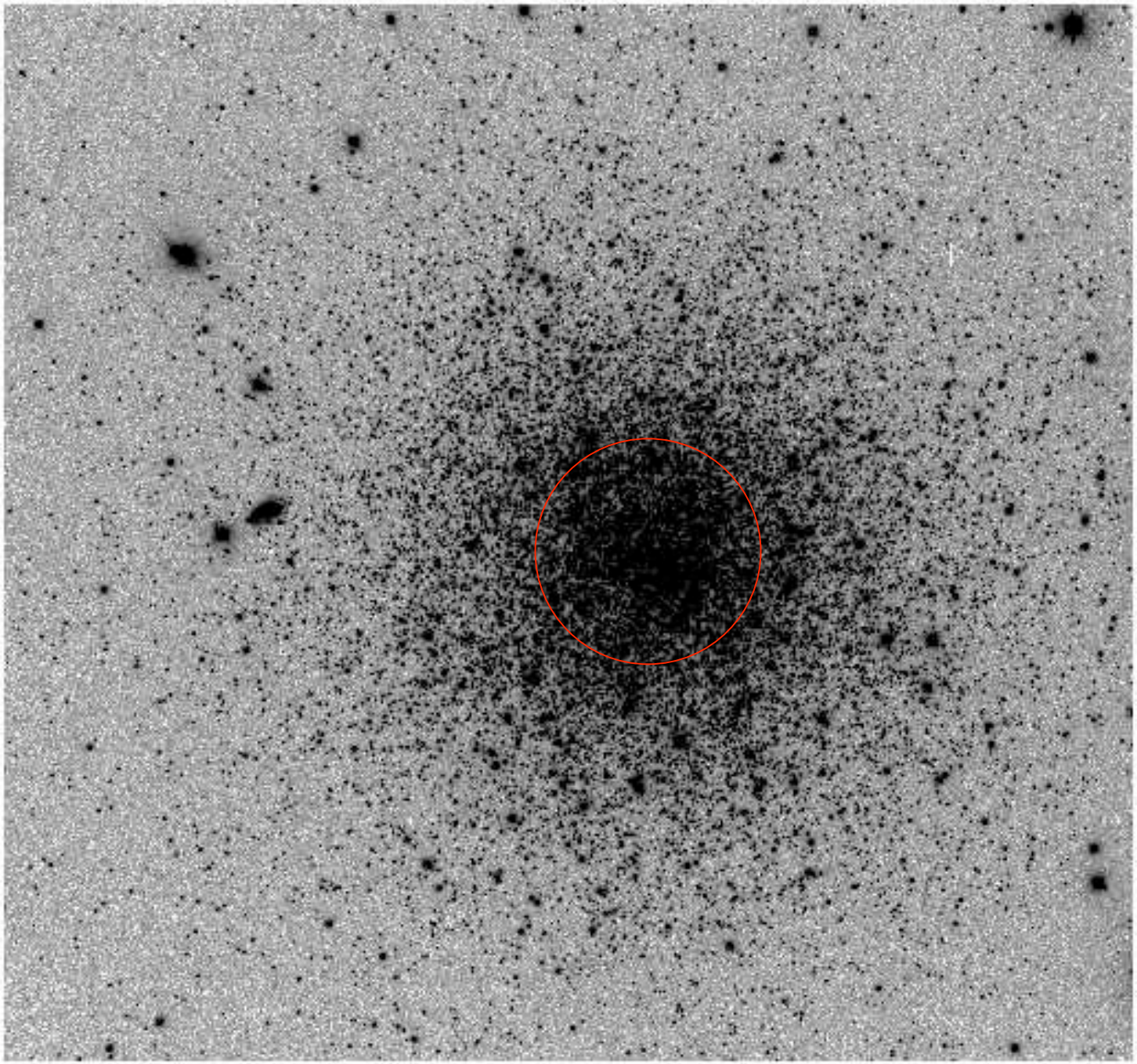
```
PACKAGE = onedspec
  TASK = refspectra

input   =   extracted_spectrum  List of input spectra
(referen=                  arc) List of reference spectra
(apertur=                    ) Input aperture selection list
(refaps =                    ) Reference aperture selection list
(ignorea=                  yes) Ignore input and reference apertures?
(select =               interp) Selection method for reference spectra
(sort   =                   jd) Sort key
(group  =                  ljd) Group key
(time   =                   no) Is sort key a time?
(timewra=                 17.) Time wrap point for time sorting
(overrid=                   no) Override previous assignments?
(confirm=                  yes) Confirm reference spectrum assignments?
(assign =                  yes) Assign the reference spectra to the input spectr
(logfile=      STDOUT,logfile) List of logfiles
(verbose=                   no) Verbose log output?
answer  =                       Accept assignment?
(mode   =                   ql)
```

Sophisticated auto assignment options

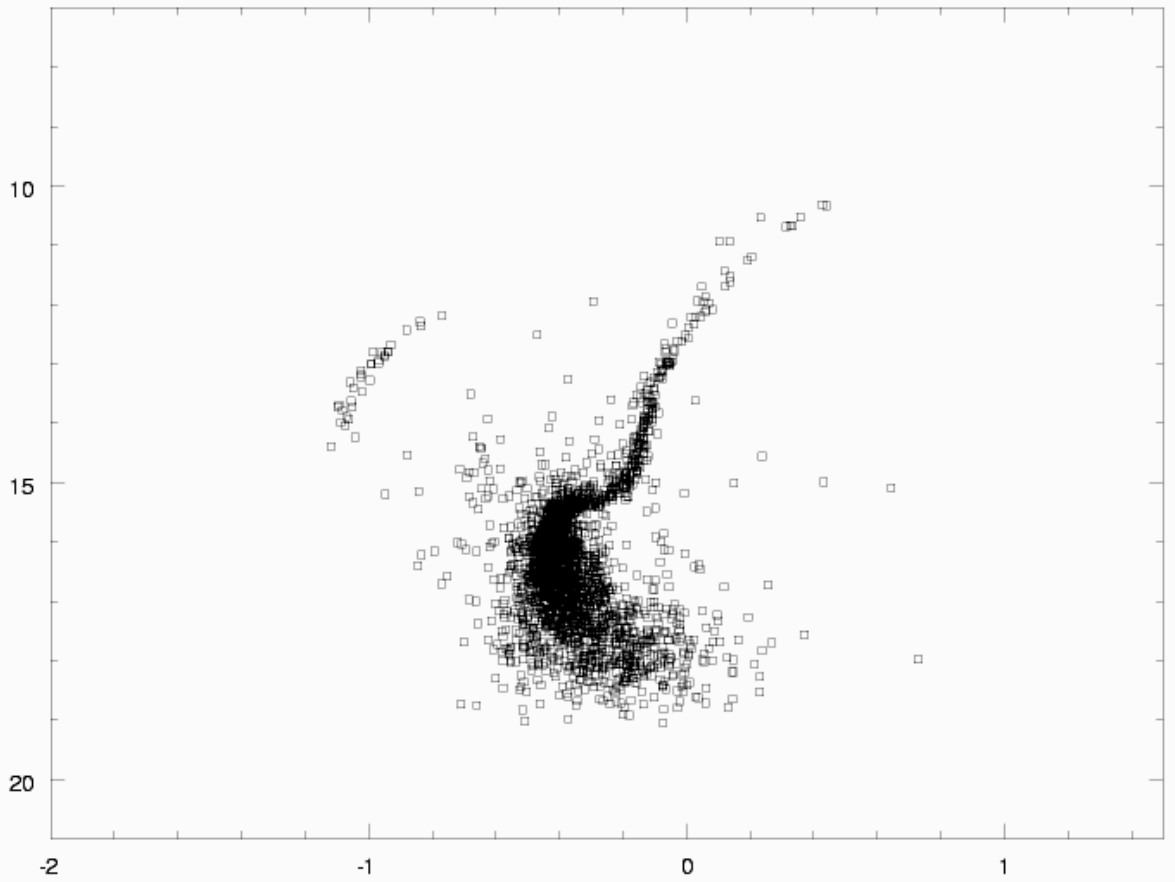
Last step: apply dispersion solution. In IRAF, done in header

```
PACKAGE = onedspec
  TASK = dispcor

input   =                List of input spectra
output  =                List of output spectra
(lineari=              yes) Linearize (interpolate) spectra?
(databas=          database) Dispersion solution database
(table  =                ) Wavelength table for apertures
(w1     =           INDEF) Starting wavelength
(w2     =           INDEF) Ending wavelength
(dw     =           INDEF) Wavelength interval per pixel
(nw     =           INDEF) Number of output pixels
(log    =              no) Logarithmic wavelength scale?
(flux   =             yes) Conserve flux?
(samedis=              no) Same dispersion in all apertures?
(global =              no) Apply global defaults?
(ignorea=              no) Ignore apertures?
(confirm=              no) Confirm dispersion coordinates?
(listonl=              no) List the dispersion coordinates only?
(verbose=             yes) Print linear dispersion assignments?
```

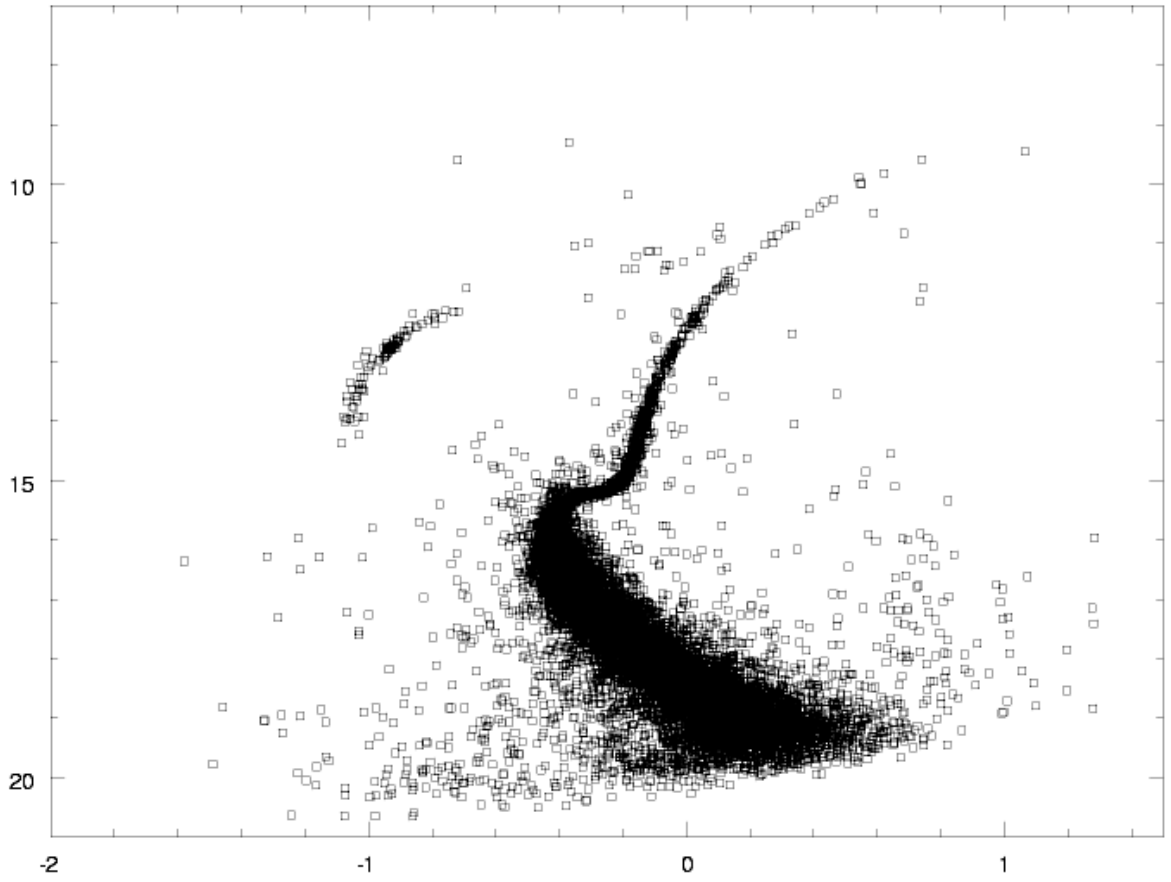
cl>dispcor b188.ms w188.ms
b188.ms: REFSPEC1 = 'arc.ms 1.'
w188.ms: ap = 1, w1 = 3312.038, w2 = 5494.508, dw = 1.820242, nw = 1200



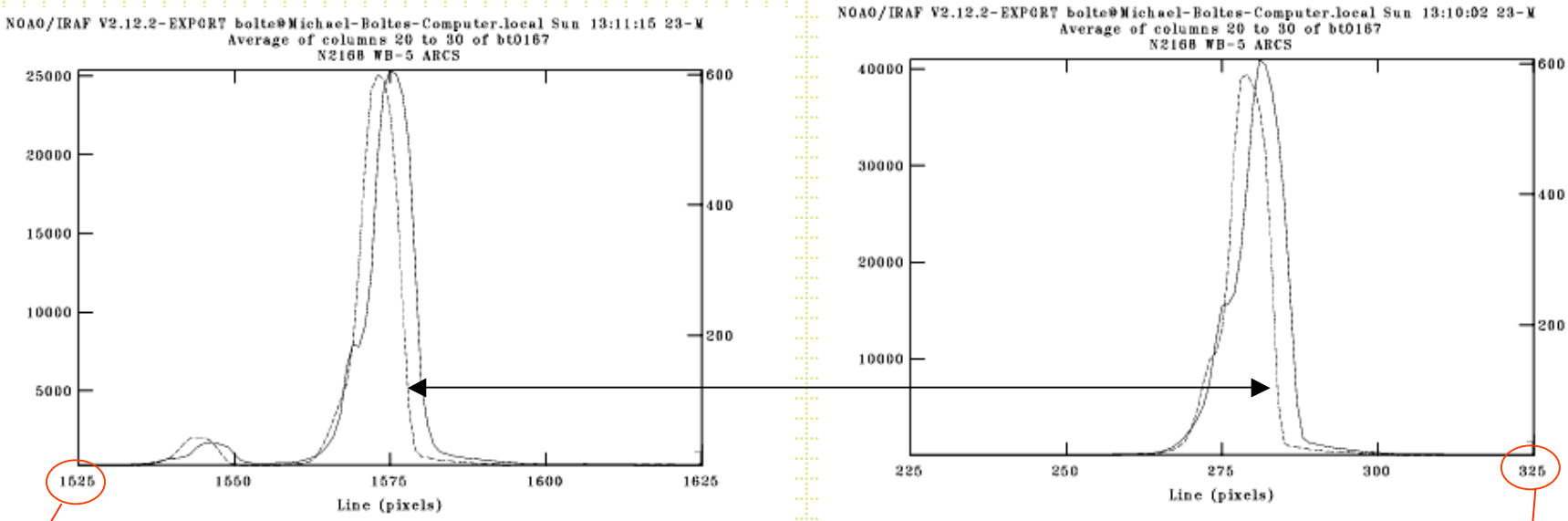
Inner 200 pixels



r > 200 pixels



Flexure

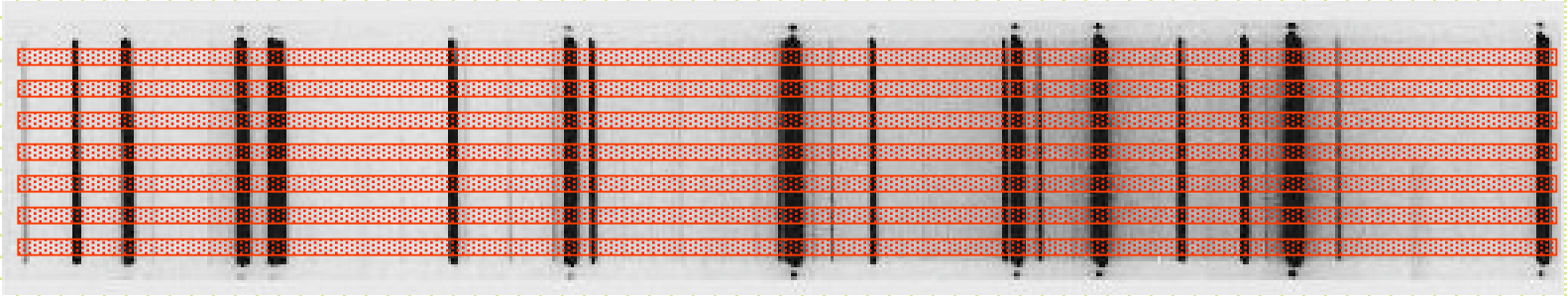


Two lamp spectra from LRIS taken at different telescope positions

Note the shift is (1) significant and (2) constant along the dispersion

reidentify allows a quick/automatic refitting of arcs taken during the night. Can also use single arc solution from afternoon calibrations and apply a zeropoint (wavelength) shift for each program spectrum based on night sky line positions

Short reidentify aside



- Can *reidentify* the line lamp spectrum at a range of line values (in a single spectrum)
- Use *fitcoords* to take the fit as a function of line number plus *transform* to remap the 2D image to be rectilinear in dispersion-spatial.
- Useful for long-slit work with resolved objects.

Flux Calibration

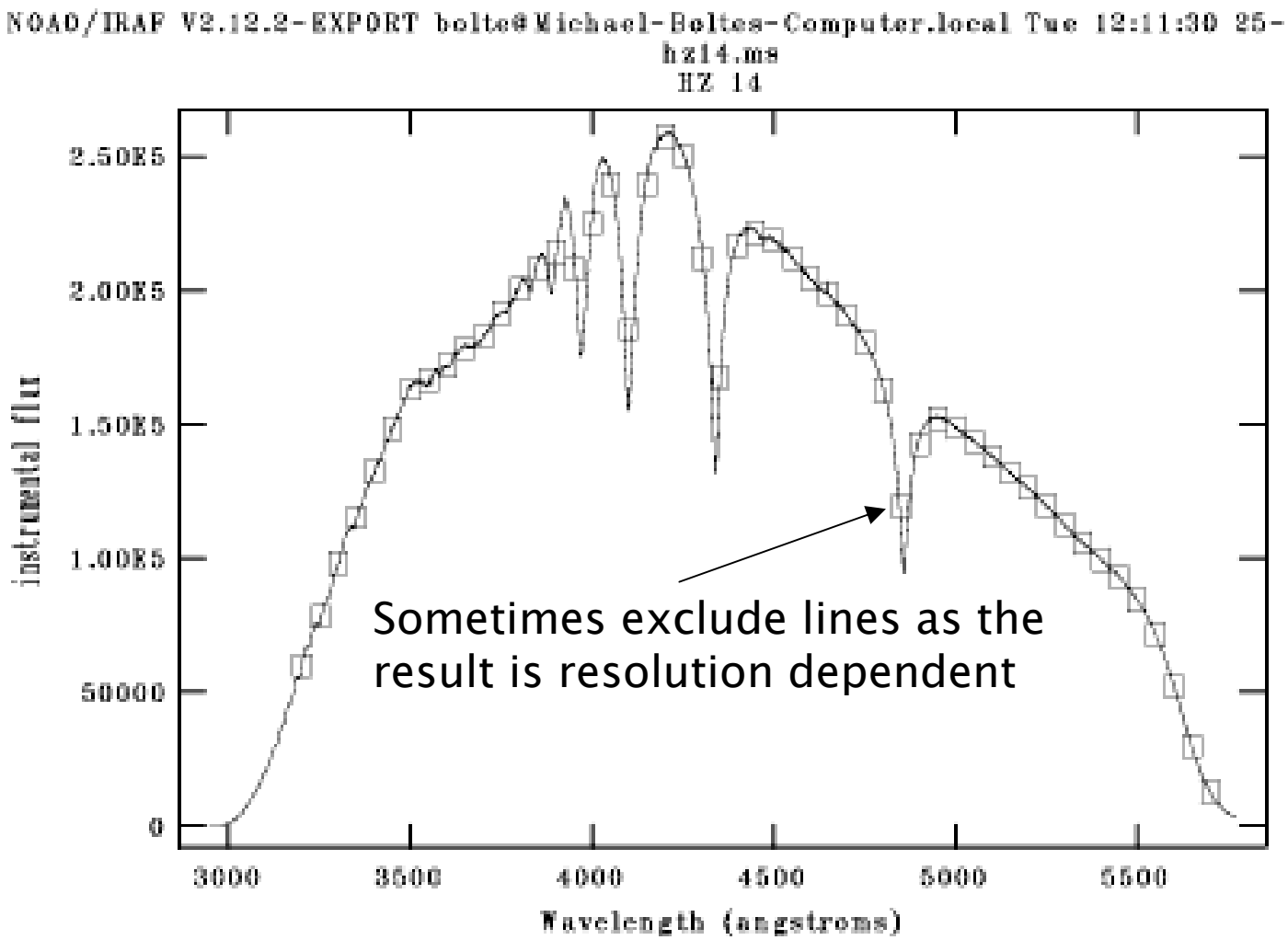
- There are lists of spectrophotometric standard stars:
  - Oke, J. B. 1990, AJ, 99, 1621
  - Stone, R. P. S. 1996, ApJS, 107, 423
  - Massey, P., & Gronwall, C. 1990, ApJ, 358, 344
  - IRAF: onedstds$

Usual zeropoint is based on Vega:

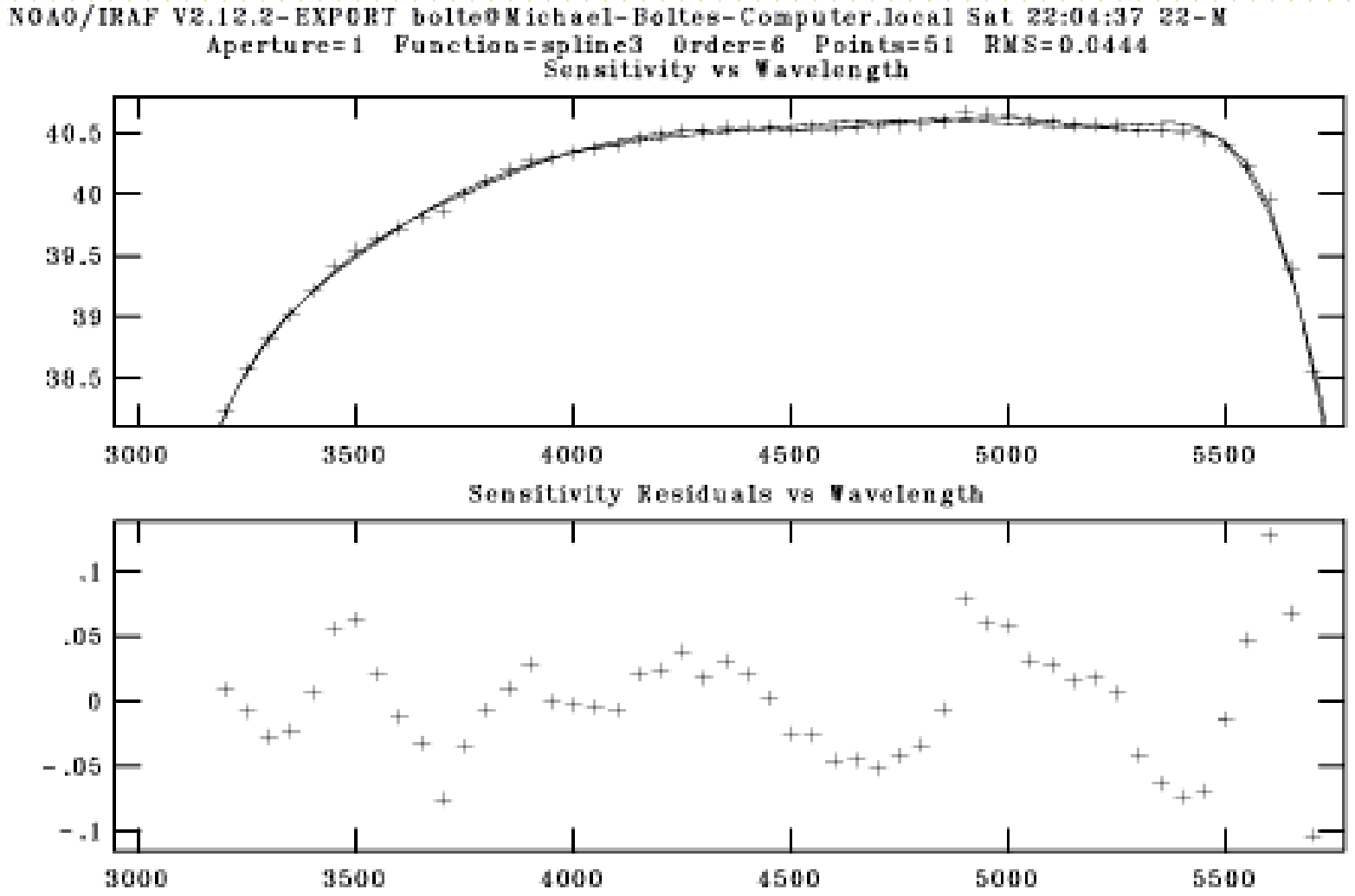
$$F_{5556Å} = 3.52 \times 10^{-20} \text{ erg/cm}^2\text{/s/Hz (V=0.048 mag)}$$

Note: In IRAF, you can specify the broadband magnitude of each star to do a rough zeropoint correction for slit losses.

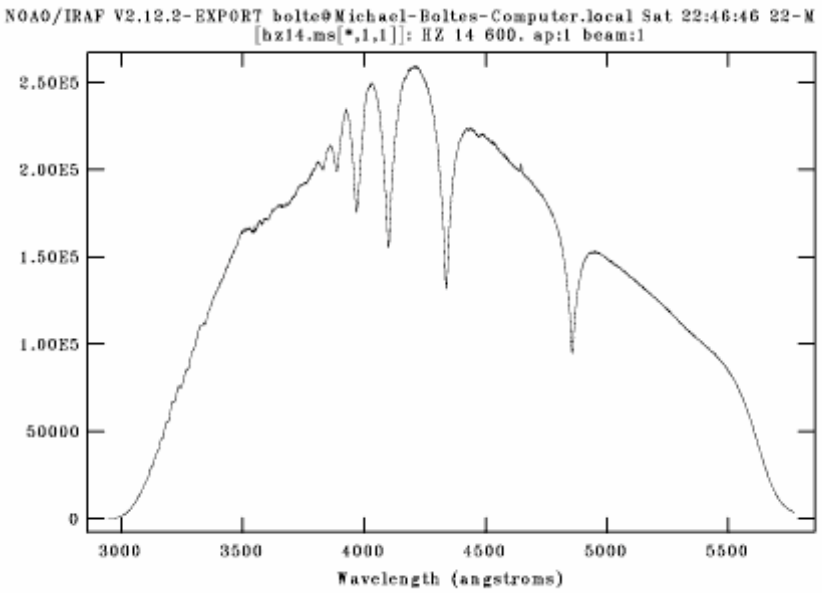
- noao.oned
  - *standard*: identifies standard stars by name, associates an extinction curve, gets airmass exposure time. Output is a file (default name std)
  - *sensfunc*: given extinction function, tabulated standard system flux and your observed spectrum calculate a sensitivity function.
  - *calibrate*: applies the sensitivity function to spectra



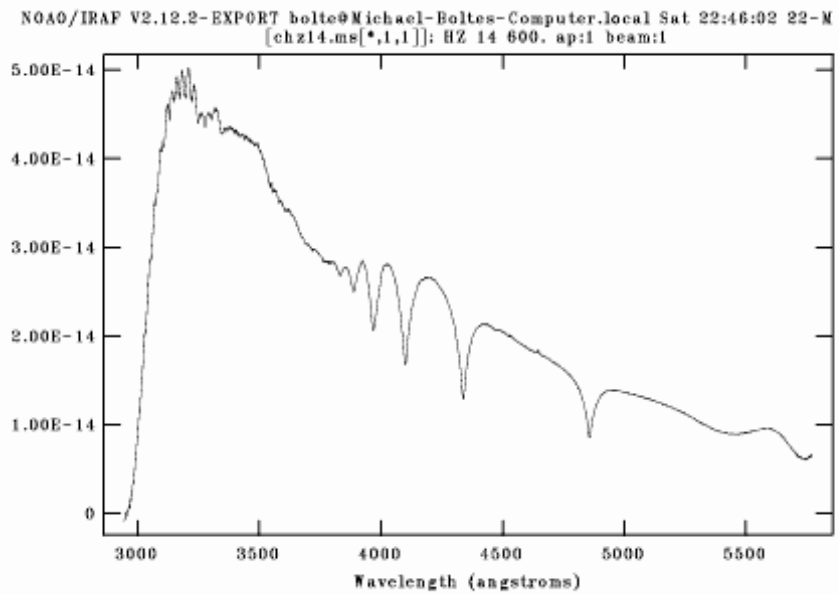
standard interactive graphic



sensfunc interative graphic

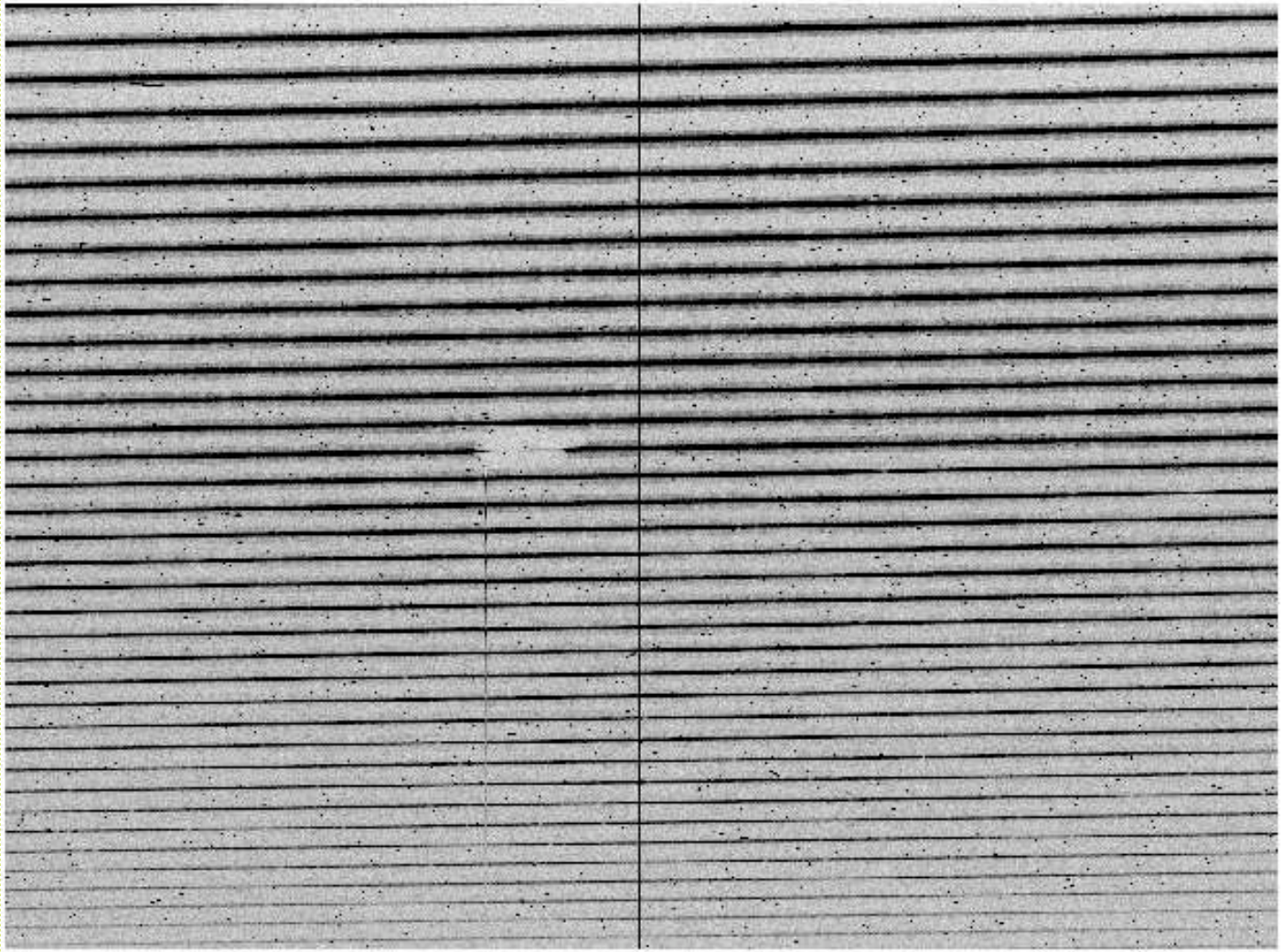


Raw extracted Spectrum



Flux calibrated

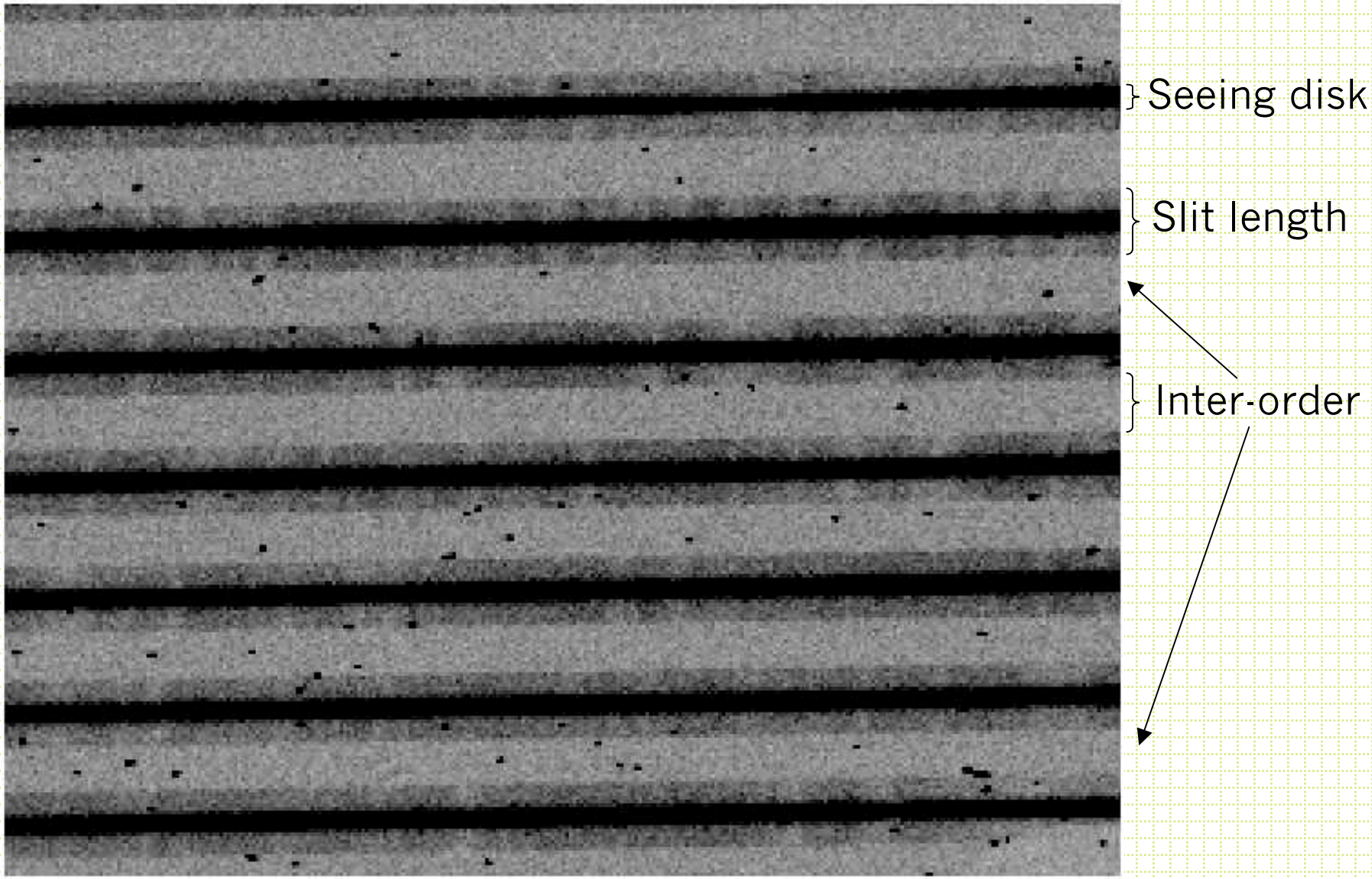
Echelle format spectra

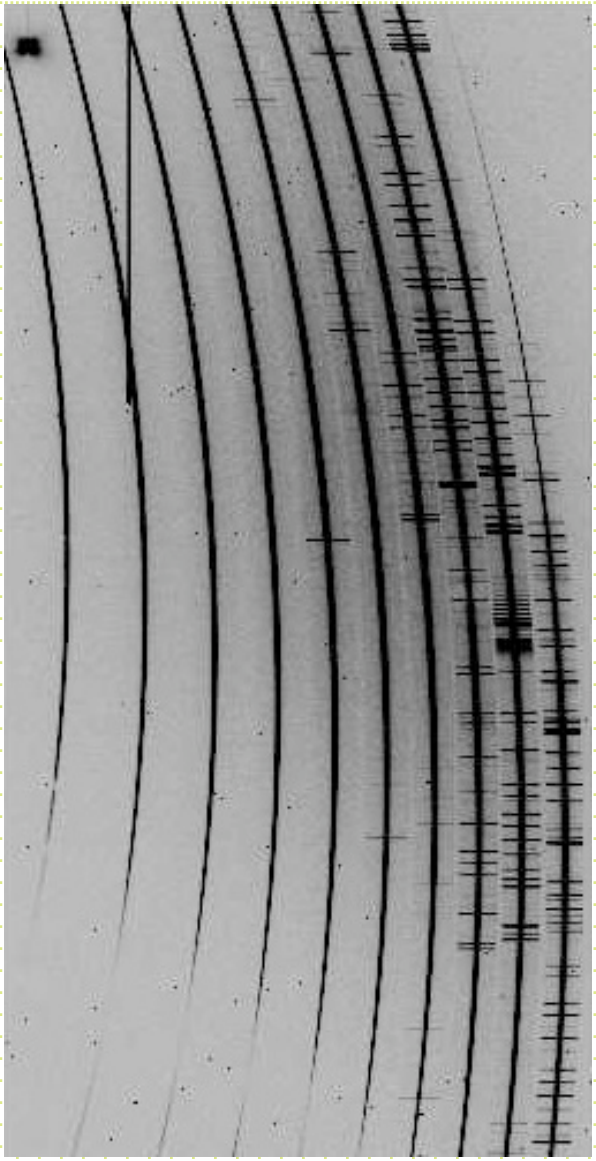


In apall, each order will be an aperture.

Each will have to be traced.

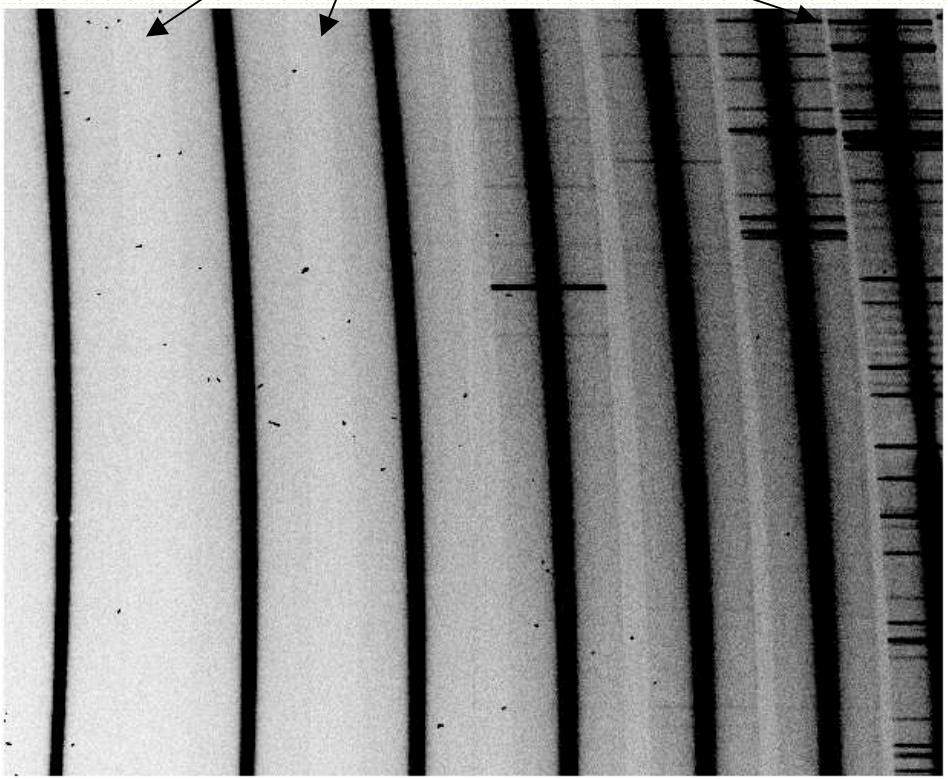
Often the background apertures need to be set for each order individually


Seeing disk
Slit length
Inter-order

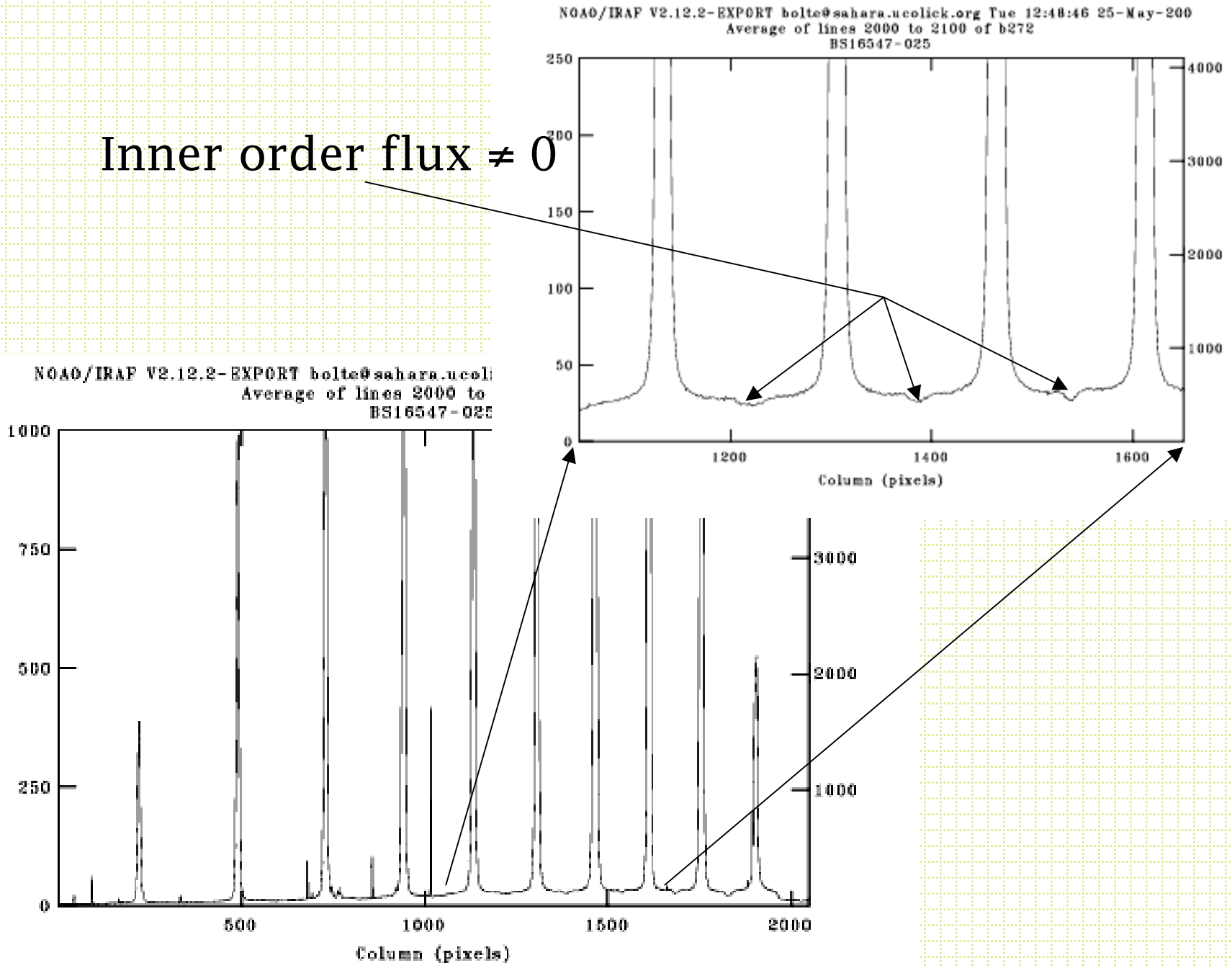


ESI spectra

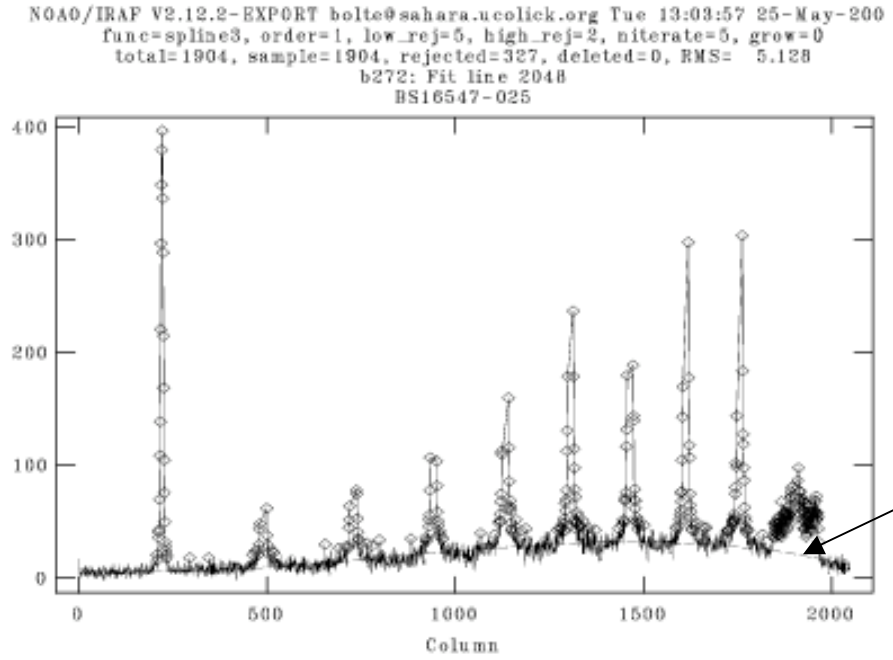
Inner order regions



Inner order flux ≠ 0



- For most echellegrams, need to take an extra step of removing scattered light. The idea is to fit a 2-d surface to the inner-order light and subtract this surface before aperture extraction.
- noao.echelle has a task *apscatter* to do this.



Need to identify and trace orders to identify the inner-order regions

Scattered light fit