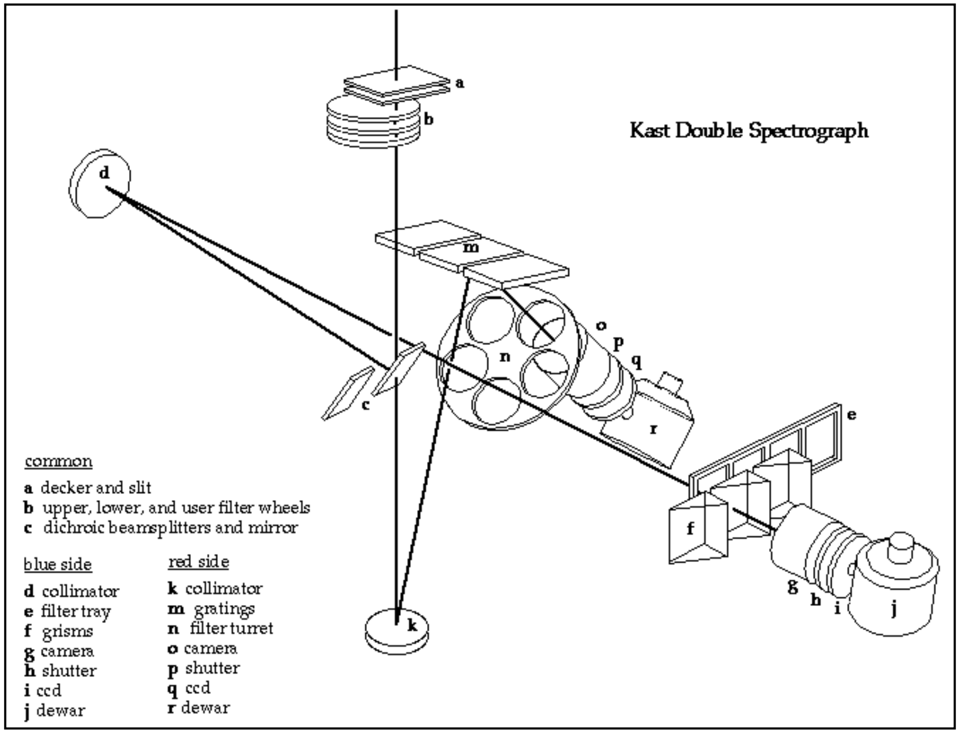
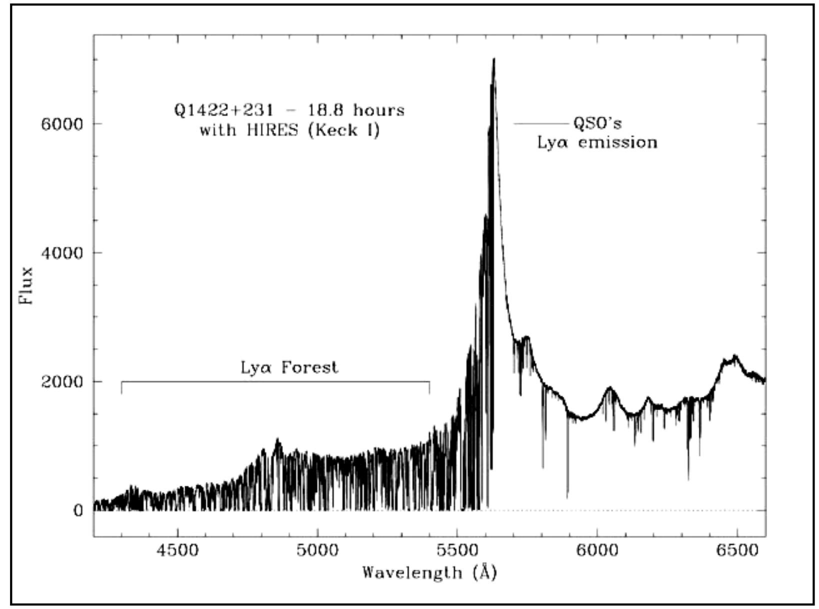
# Spectra




- Bowen, 1962, Astronomical Techniques, pg 34.
- Pogge, 1992, ASP Conf. Ser.#23, pg.160

# What are spectra good for?

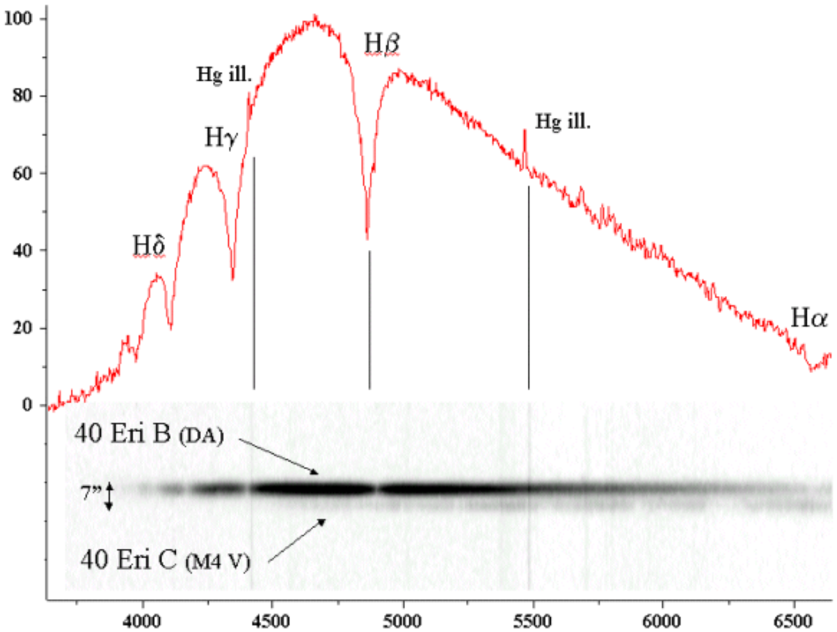
- Astrophysics!
  - Radial velocities
    - Stellar kinematics
    - Discovering extra-solar planets
    - Stellar/neutron star/stellar black hole masses
    - Rotation curves and velocity dispersion of galaxies to determine mass and mass distribution
    - Measuring the motions of galaxies in clusters
    - Measuring the expansion of the Universe

# What are spectra good for?

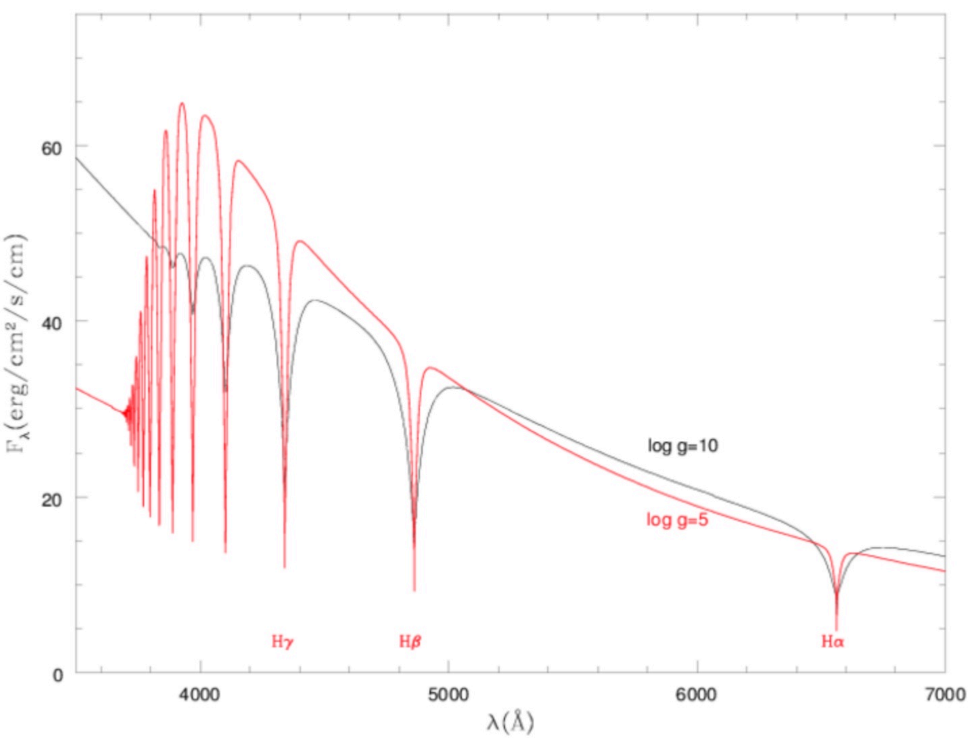
- Physical properties of gas
  - Temperature, density, chemical composition
  - Motions
- Physical properties of stars
  - Surface temperature
  - Surface pressure (mass/radius)
  - Chemical composition
  - Stellar rotation
  - winds

# What do you measure?

- Line positions (wavelength shifts)
  - Doppler motion
  - Magnetic fields
- Line strengths (in emission of absorption)
- Line profiles
- Spectral energy distribution




DA model 11500K log g=10-5 (cgs)



stars

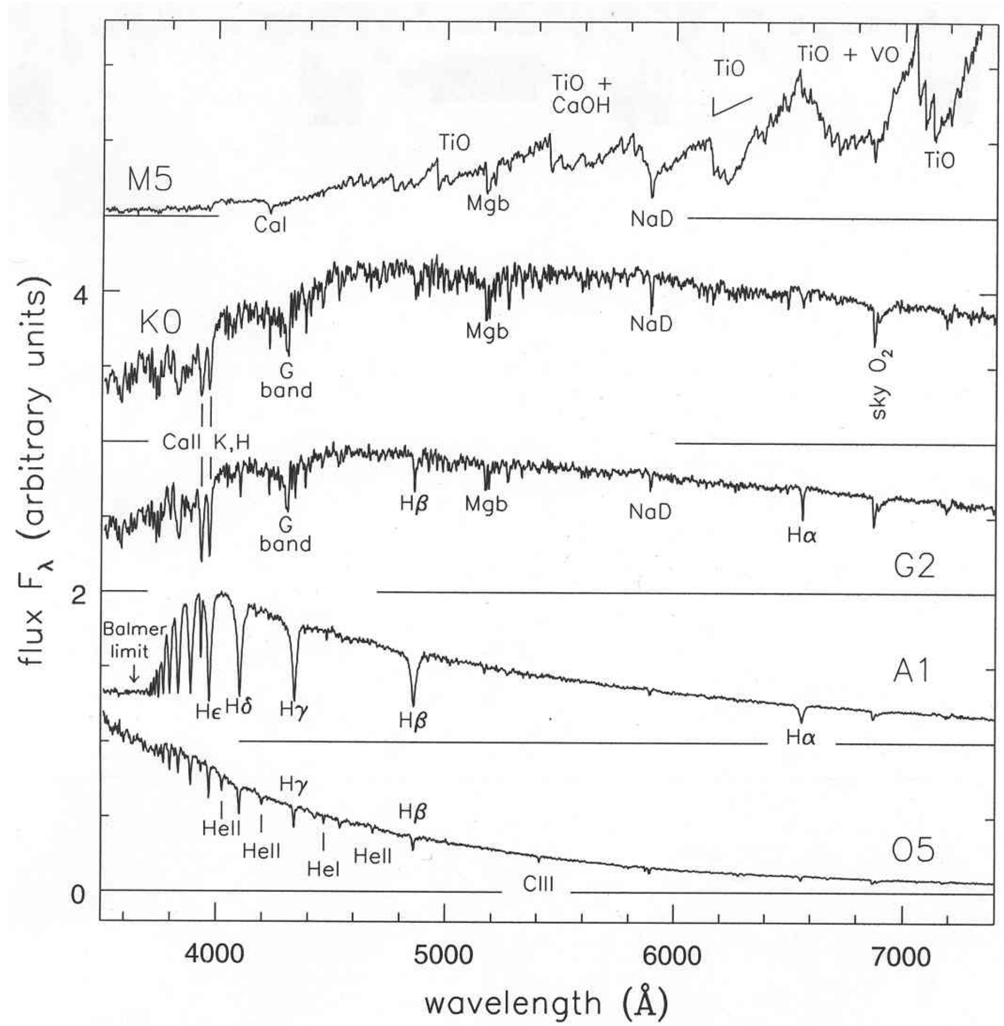



**Figure 1.1** Optical spectra of main-sequence stars with roughly the solar chemical composition. From the top in order of increasing surface temperature, the stars have spectral classes M5, K0, G2, A1, and O5 – G. Jacoby *et al.*, spectral library.

# Galaxies: elliptical

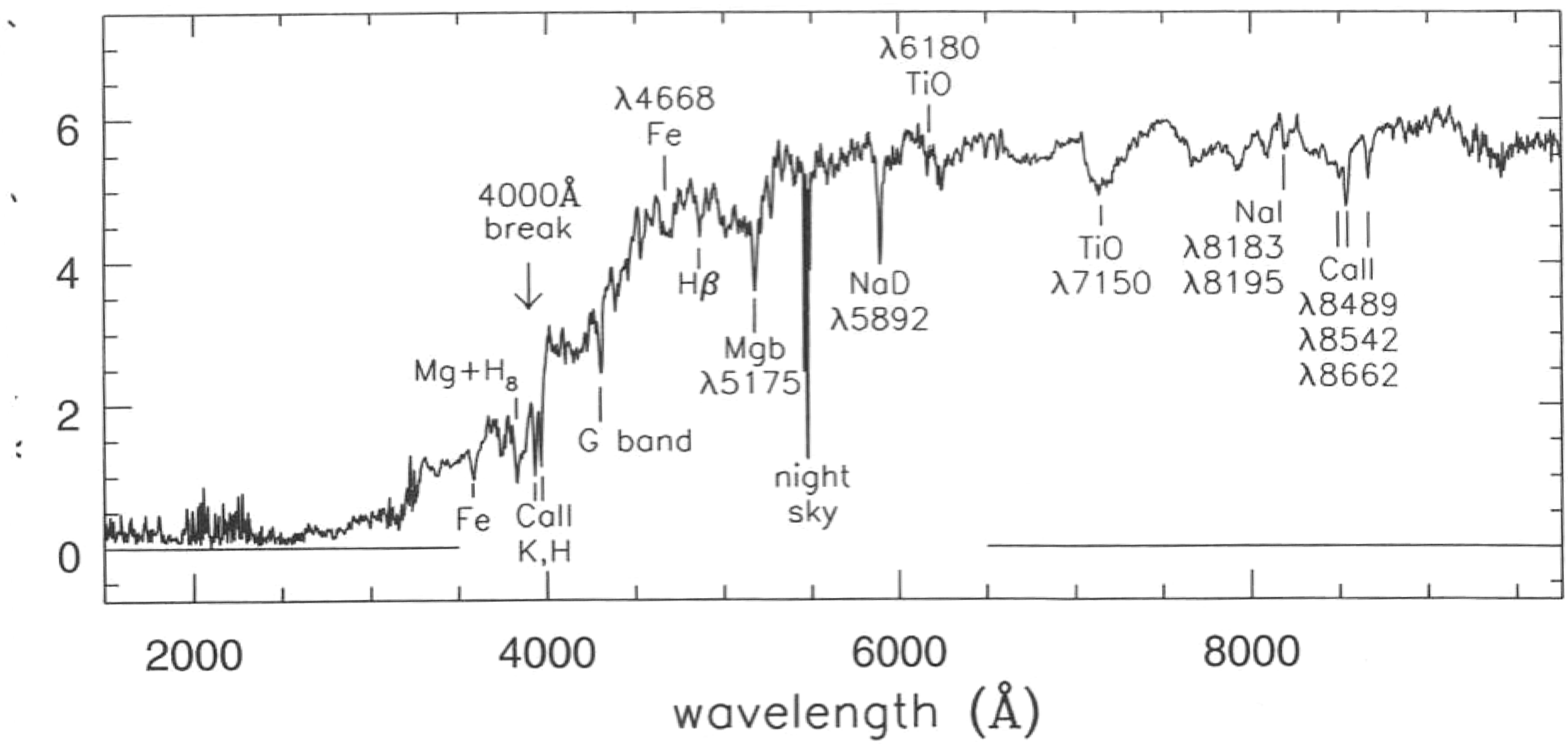
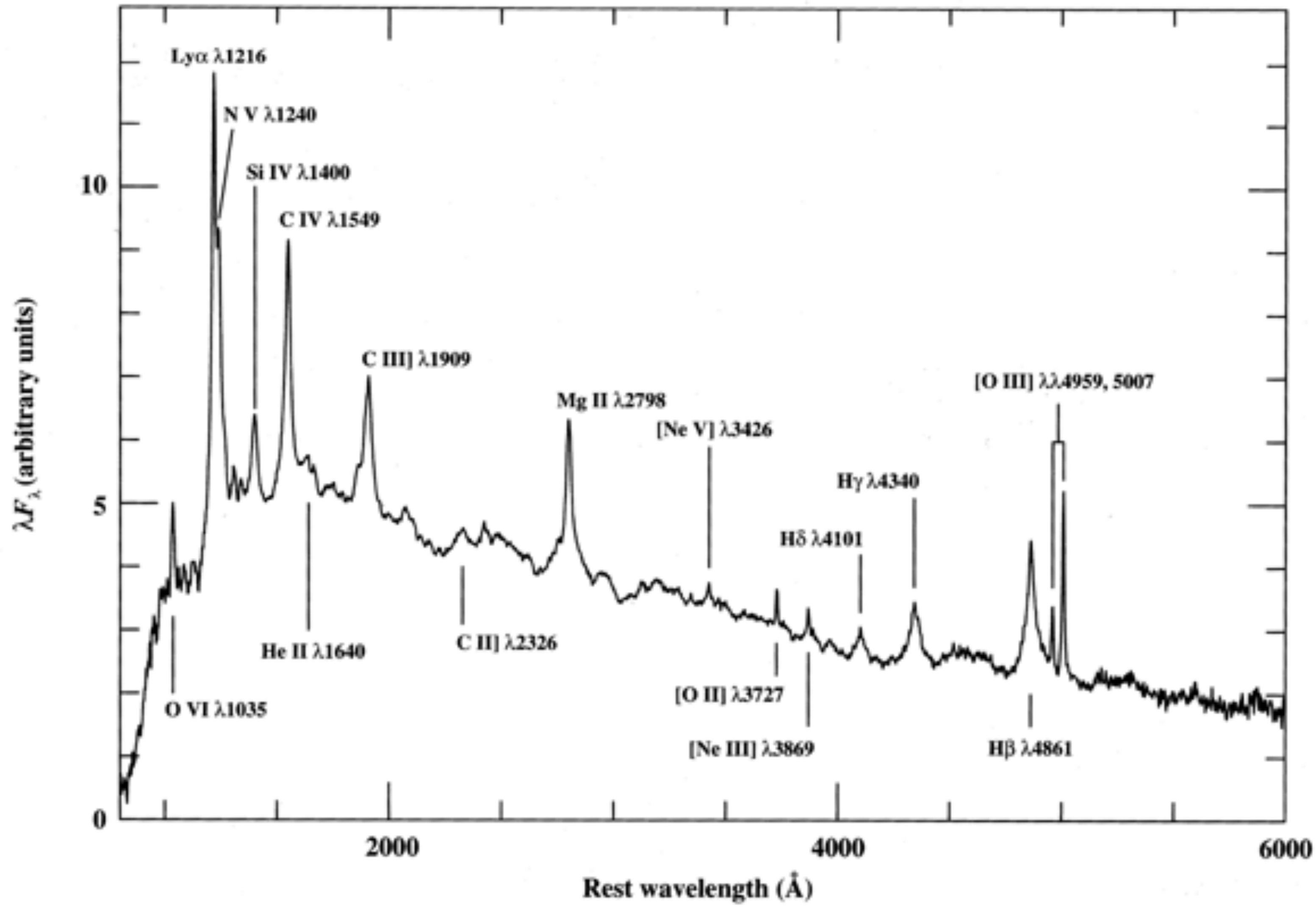



**Figure 6.17** Spectrum of an elliptical galaxy; compare with the
in Figure 1.1, and those of disk galaxies in Figure 5.24 – A. Kir




AGN, QSO continuum + emission lines from hot gas

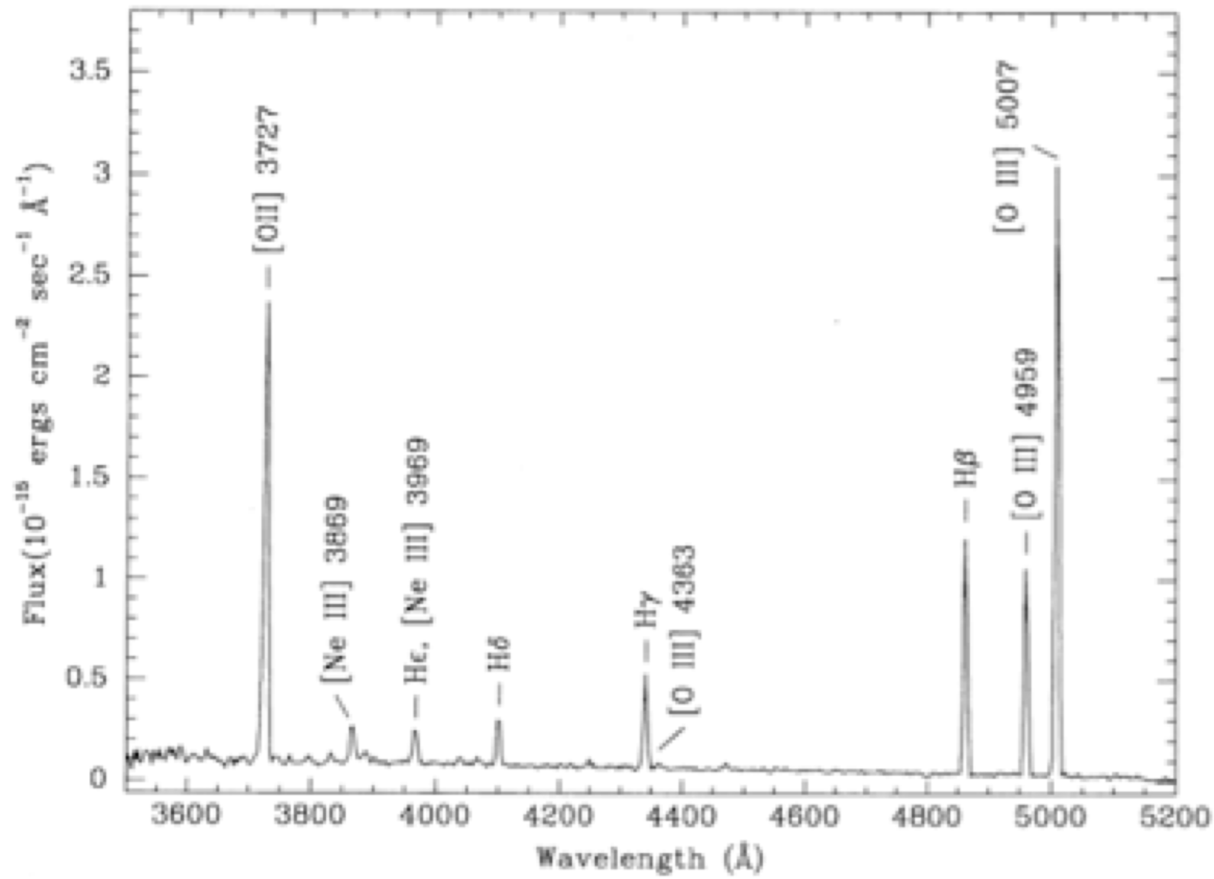
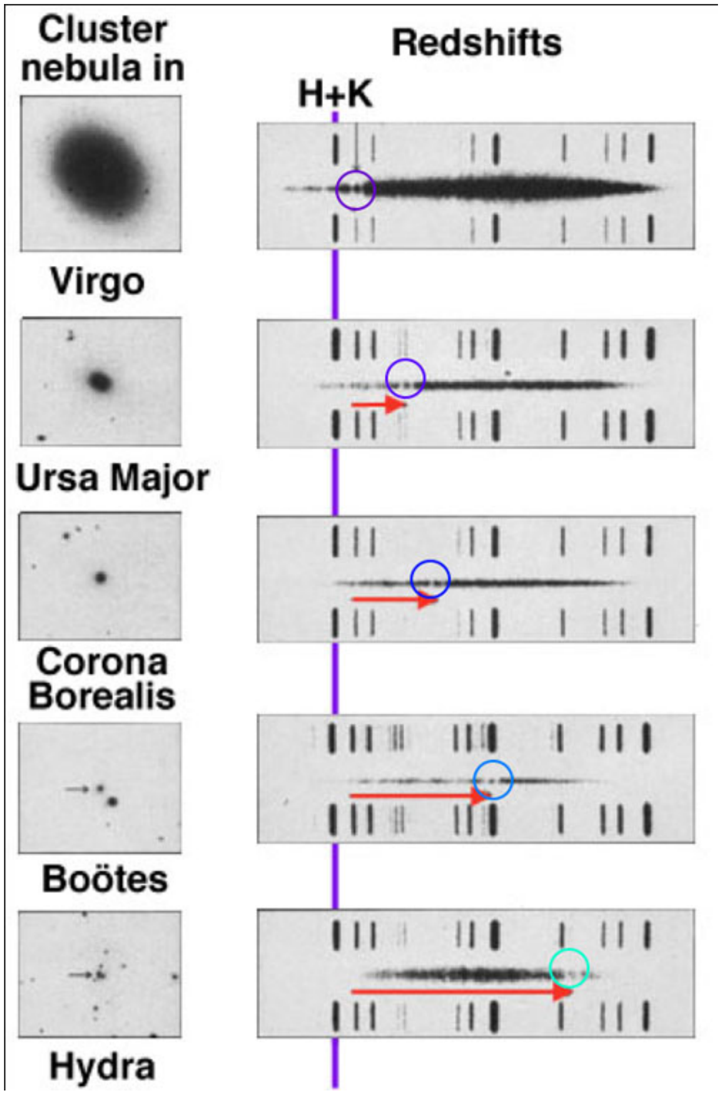
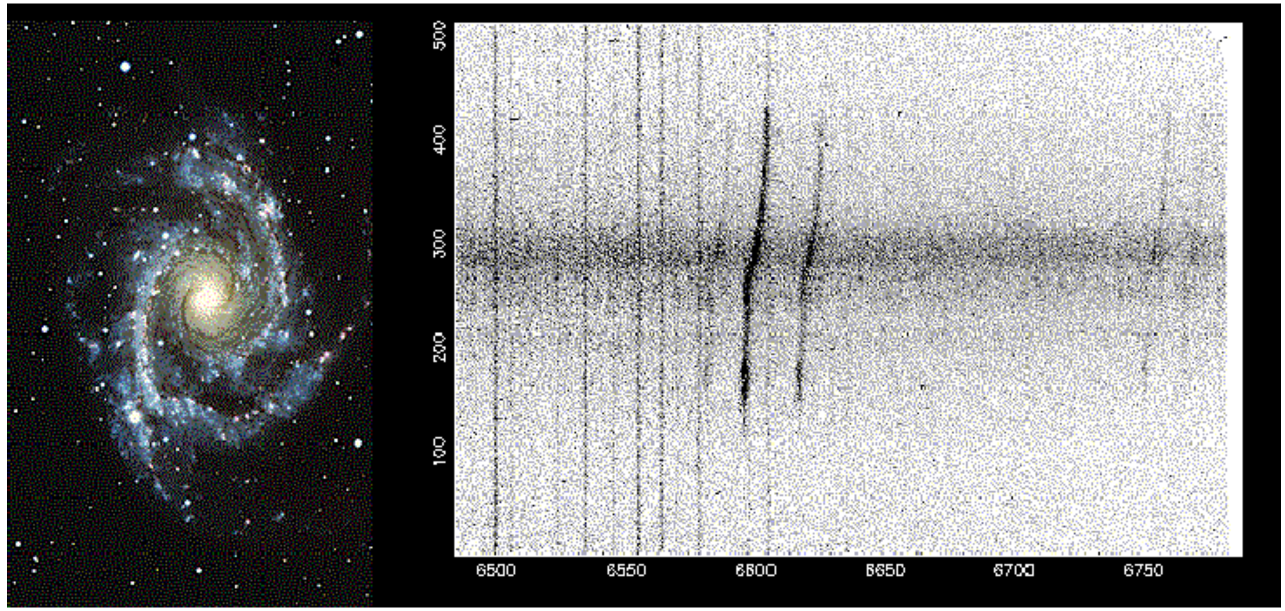
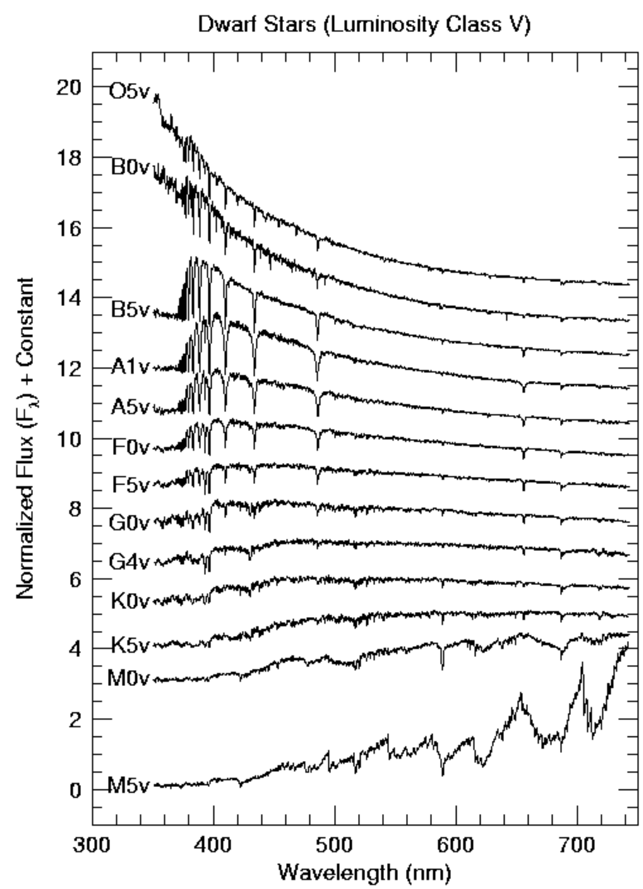


FIG. 1.—Spectrum of region No. 2 in NGC 2541 obtained in the long-slit mode. Emission lines targeted for measurement are labeled.

PN or HII region: dominated by hot gas


Cluster nebula in
Redshifts
H+K
Virgo
Ursa Major
Corona Borealis
Boötes
Hydra


500
400
300
200
100
6500
6550
6600
6650
6700
6750


Dwarf Stars (Luminosity Class V)
Normalized Flux ($F_\lambda$) + Constant
Wavelength (nm)
O5v
B0v
B5v
A1v
A5v
F0v
F5v
G0v
G4v
K0v
K5v
M0v
M5v
20
18
16
14
12
10
8
6
4
2
0
300
400
500
600
700

# Spectrometers

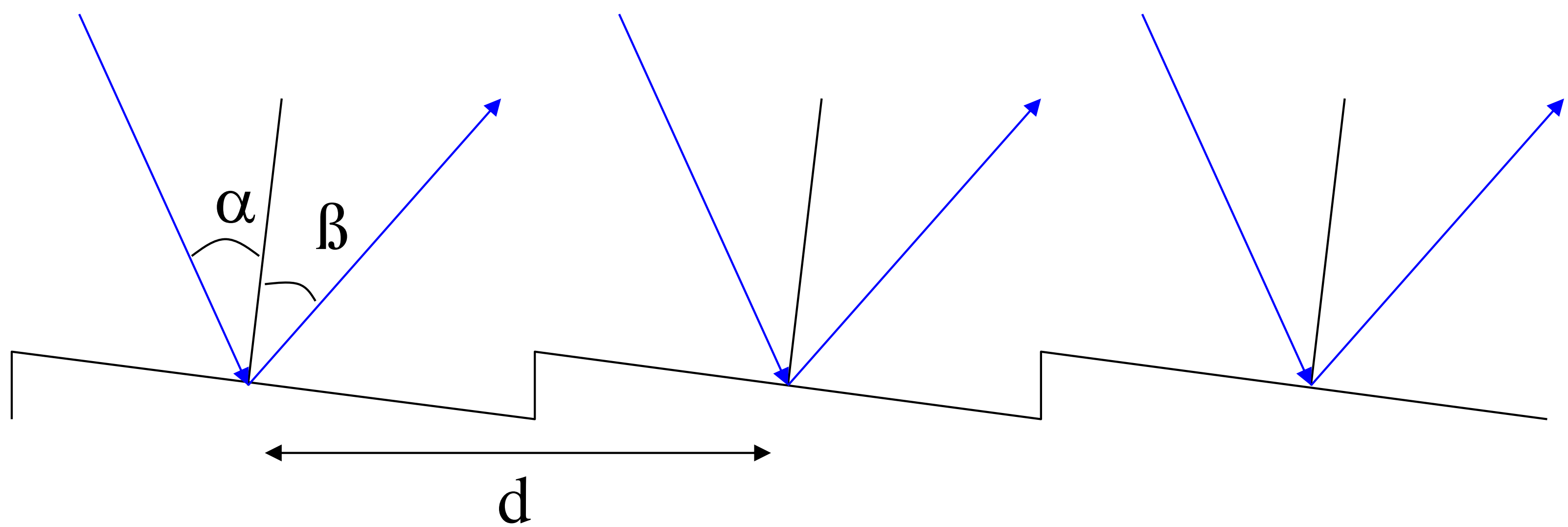
- Take light that passes through slit or into a fiber or into a lenslet at the telescope focal plane, disperses that light and image the slit onto a detector.
- Spectral resolution: $R=\lambda/\Delta\lambda$ (100 – 200,000)
- Spectral coverage: usually a trade-off with spectral resolution: $\lambda_{total} \sim n_{pixels}/2R$ (assume spectral resolution element is 2 pixels)
- Angular coverage (slit length)

# Dispersing Elements

- Most common is the *reflecting diffraction grating*.
- Grating equation: OPD=mλ = d[sin(α) + sin(ß)]

order groove spacing

Incident angle α is fixed



# Grating dispersion

- Think of the Young Double-slit experiment with many slits very closely spaced together (100 - 10,000+ lines/mm) and for non-monochromatic light - same constructive/destructive interference phenomenon from path-length differences.
- Note: ruling gratings is not easy! Spacing tolerance is ~1nm. Richardson has a machine in a room kept a constant temperature to 0.01˚C

- Differentiate the grating equation wrt outgoing angle and get the *angular dispersion*

$$\frac{d\beta}{d\lambda} = \frac{m}{d\cos(\beta)}$$

- The *linear dispersion* is:

$$\frac{d\lambda}{dx} = \frac{d\lambda}{d\beta}\frac{d\beta}{dx} = \frac{d\cos(\beta)}{mF_{camera}}$$

in camera focal plane

order

Å/mm α d/m

lines/mm

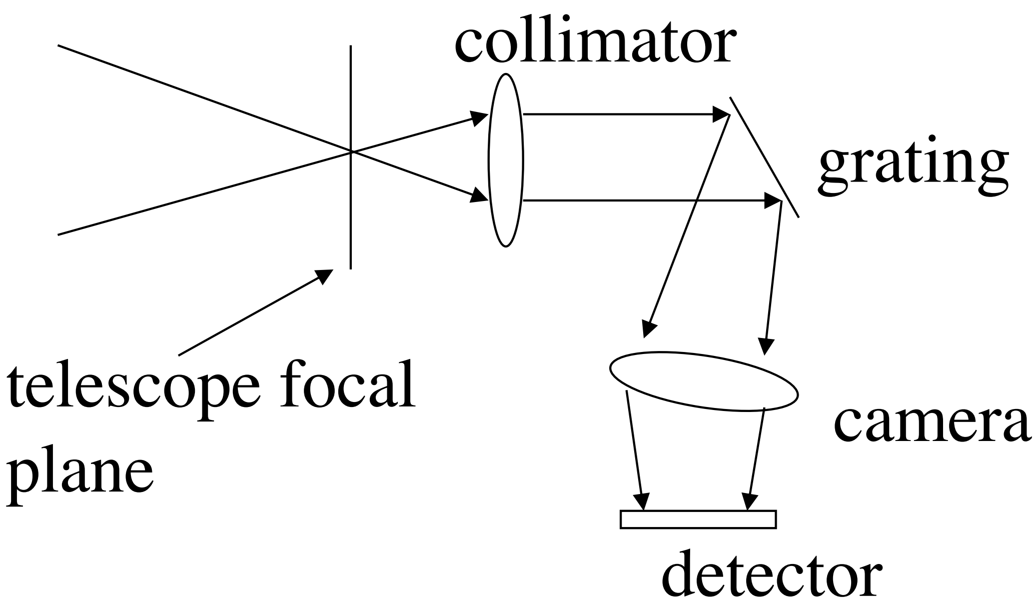
$$F_{camera} = \frac{dx}{d\beta} \equiv \text{camera focal length}$$

# Transmission gratings

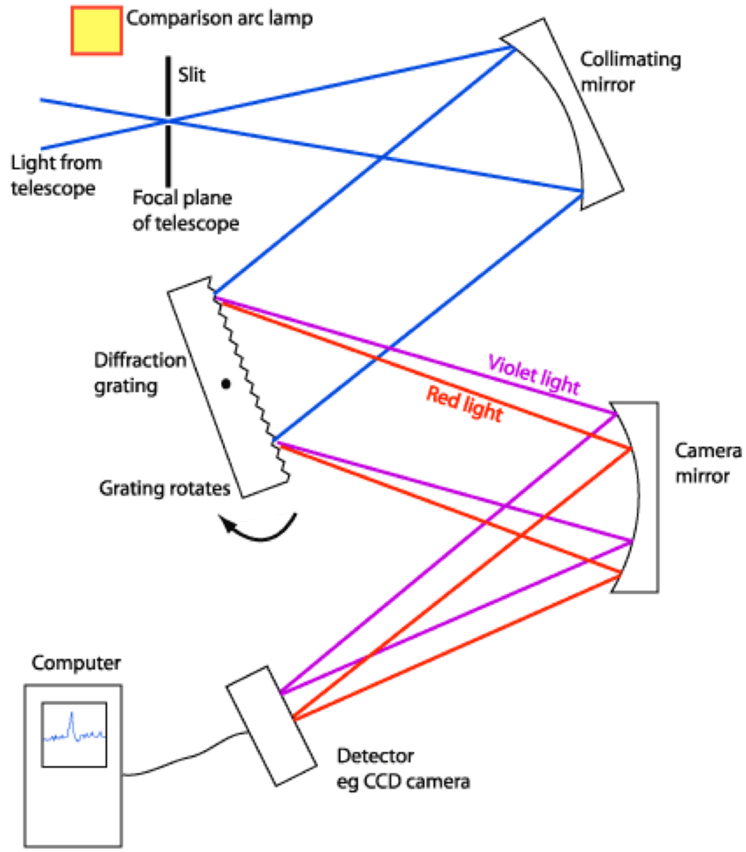
- There are also different versions of transmission gratings.
  - Transmission grating
  - *Grisms* - add a prism for *zero-deviation* transmission dispersion
  - *Volume Phase Holographic Gratings*: VPH - use modulations of the index of refraction rather than surface structures to produce dispersion. High efficiency.

# Spectrometers

- Gratings require collimated (parallel beam) light so the basic long-slit spectrometer:

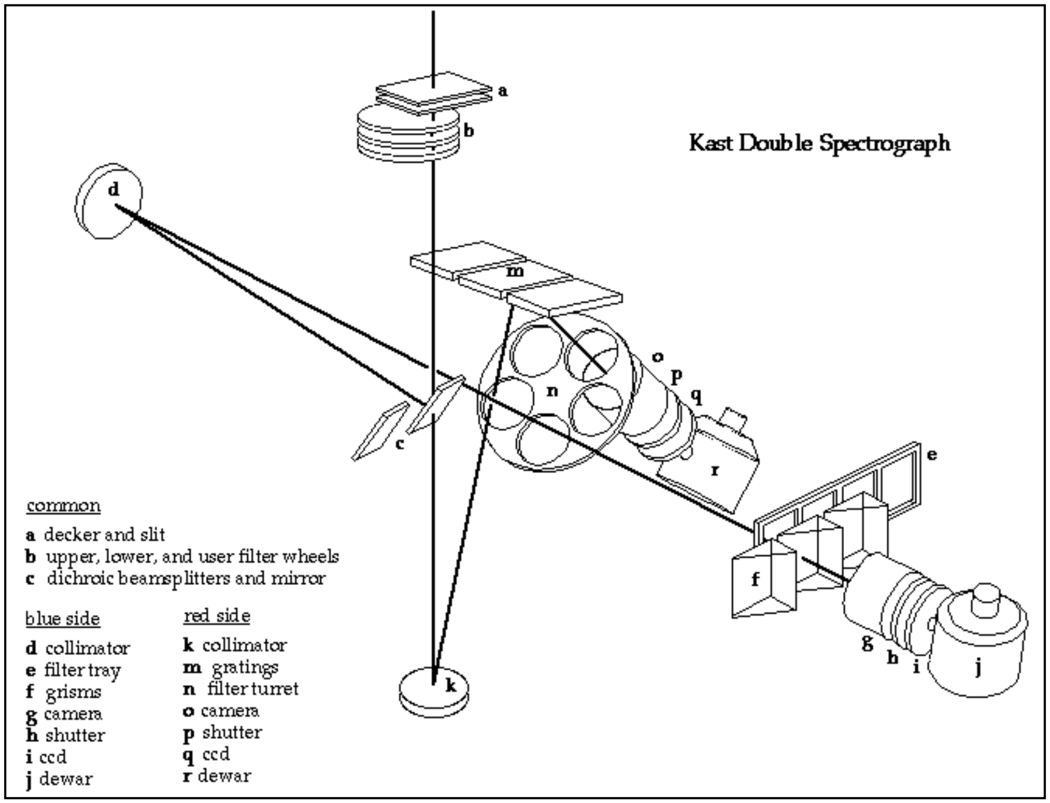



Note that the camera acceptance angle and size go up with dispersion at fixed wavelength coverage




A Schematic Diagram of a Slit Spectrograph

# Double Spectrometers




Grism dispersed on blue, grating on red, use slides or wheels with multiple gratings, grisms, dichroics

- Two-arm spectrometers developed to optimize throughput
- Glasses, coatings matched for:
  - 320nm – 550nm
  - 550nm – 1000nm
- Beam split with dichroic

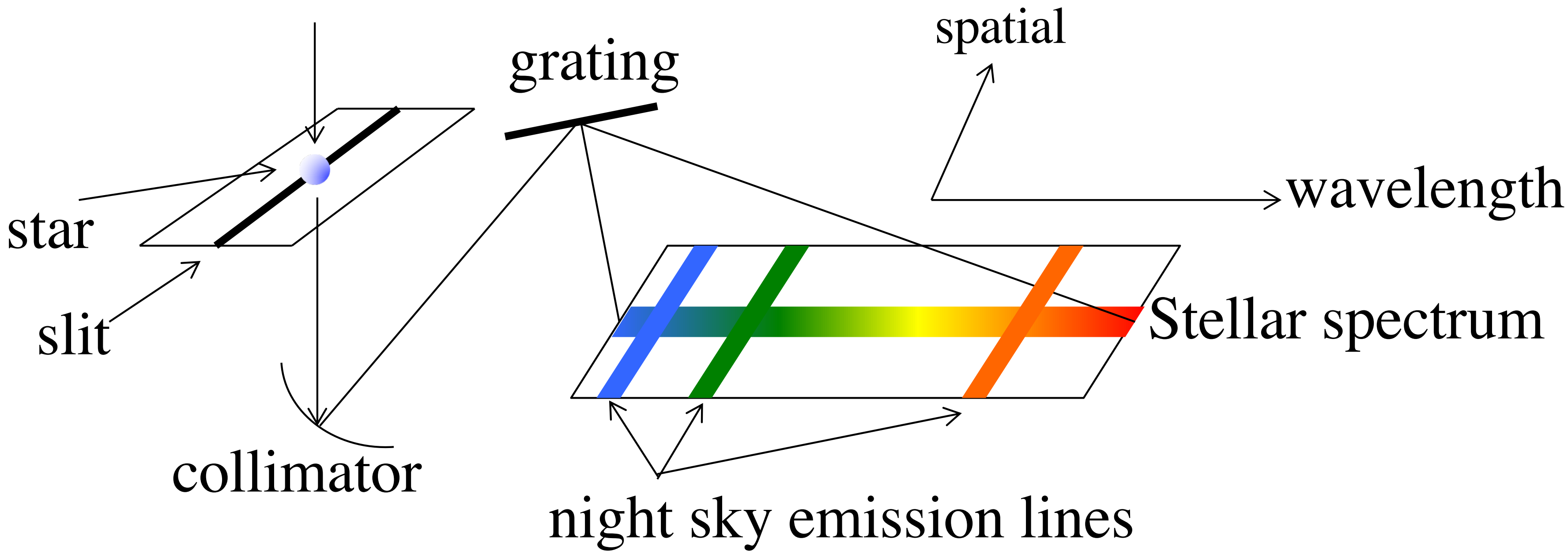
# Spectrometer efficiency

- Efficiency is usually wavelength dependent
- $\varepsilon_{total} = \varepsilon(\lambda)_{camera}\,\varepsilon(\lambda)_{collimator}\,\varepsilon(\lambda)_{detector}\,f_{slit}$
- For non-cross-dispersed spectrometers typical numbers for $\varepsilon_{total}$ are 0.1 - 0.35
- At Lick the Kast spectrometer is the workhorse long-slit spectrometer, at Keck it is LRIS and NIRSPEC

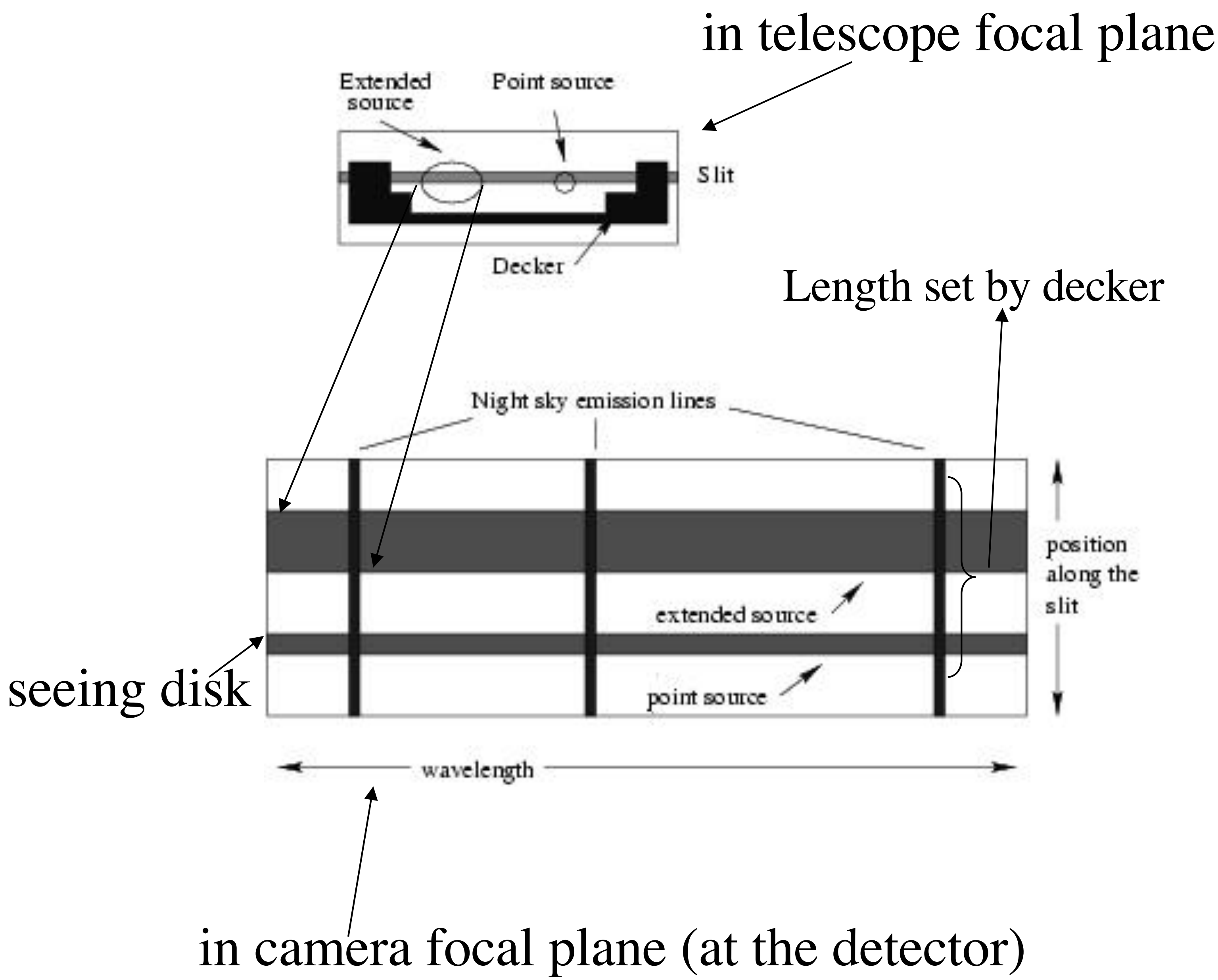
# Coude Spectrometers

- Pre-echelle the highest-spectral dispersion spectrometers were usually at coude focus, stabilized and very large

# Long-slit Spectra Geometry




In the *camera* focal plane there is the *dispersion direction* perpendicular to the slit and the *spatial direction* along the slit. Slit *width* affects spectral resolution

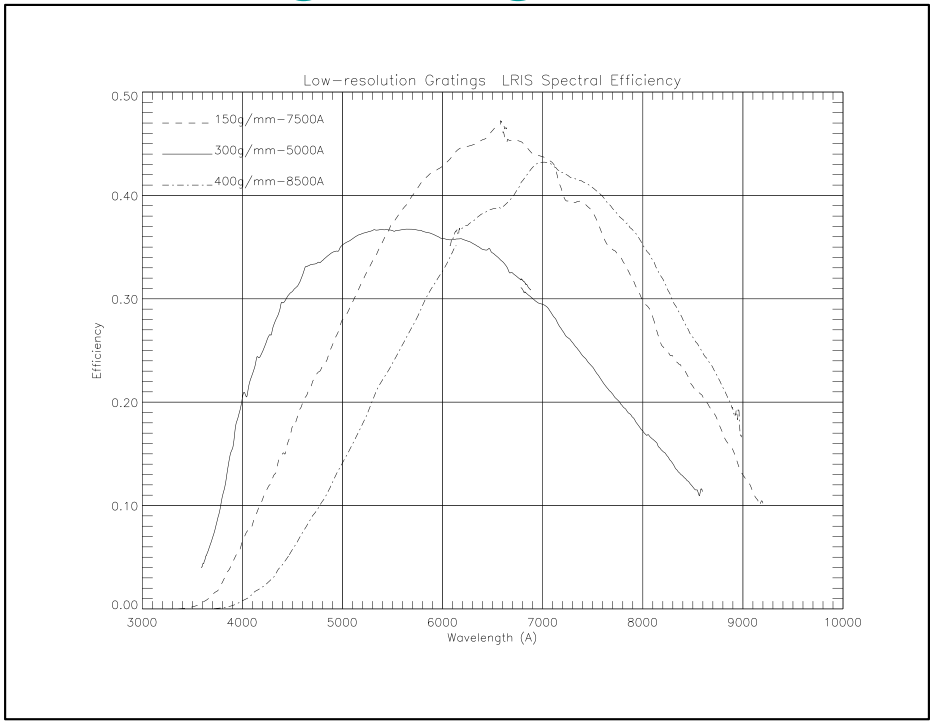

in telescope focal plane
Extended source
Point source
Slit
Decker
Length set by decker
Night sky emission lines
position along the slit
extended source
point source
seeing disk
wavelength
in camera focal plane (at the detector)

# Spectral Resolution

- $R=\lambda/\Delta\lambda$
- For slit spectral, depends on slit width and grating choice.
- Examples:
  - V filter: 5500Å/1000Å=5.5
  - LRIS-R: 1″ ~4 pixels FWHM
    - 150 l/mm grating: $R$~6500/20 ~325
    - 600 l/mm grating: $R$~6500/5 ~1300
    - 1200 l/mm grating: $R$~6500/2.6 ~2600

# Blaze function

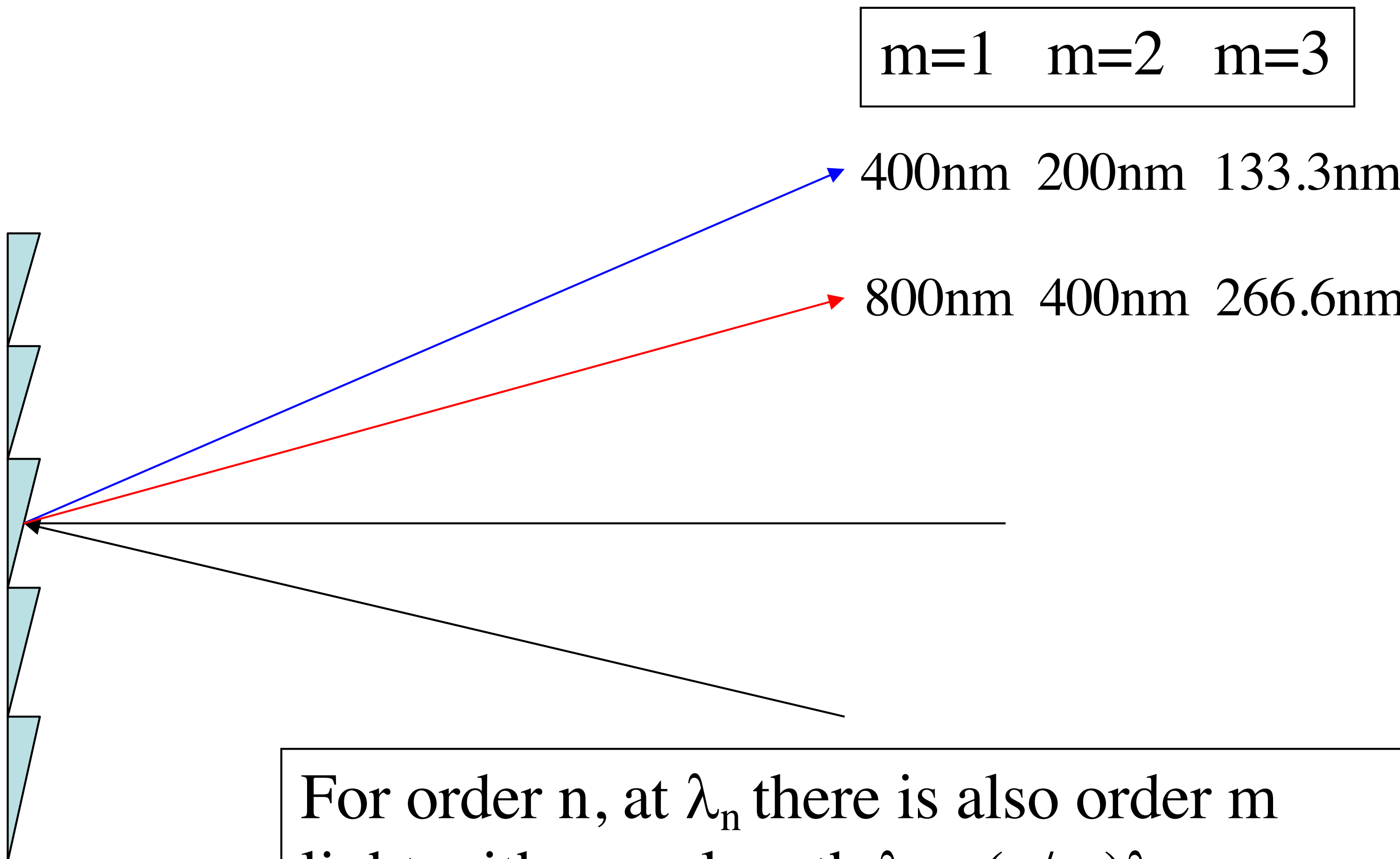
- This is the overall efficiency curve for a grating
- Keck LRIS gratings



# LRIS (Keck Obs WWW page)

| Grating Name | Grooves (l/mm) | Blaze Wave (Å) | Dispersion (Å/pix) | Spectral coverage (Å/2048 pix) |
|---|---|---|---|---|
| 150/7500 | 150 | 7500 | 4.8 | 9830 |
| 300/5000 | 300 | 5000 | 2.55 | 5220 |
| 400/8500 | 400 | 8500 | 1.86 | 3810 |
| 600/5000 | 600 | 5000 | 1.28 | 2620 |
| 600/7500 | 600 | 7500 | 1.28 | 2620 |
| 600/10000 | 600 | 10000 | 1.28 | 2620 |
| 831/8200 | 831 | 8200 | 0.93 | 1900 |
| 900/5500 | 900 | 5500 | 0.85 | 1740 |
| 1200/7500 | 1200 | 7500 | 0.64 | 1310 |

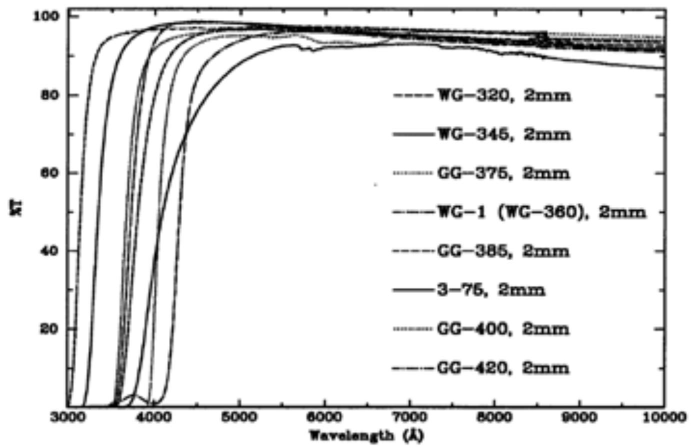
# Orders and blocking filters

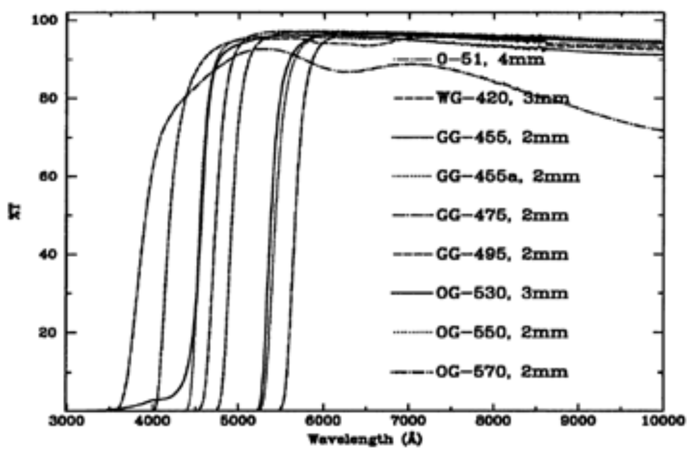


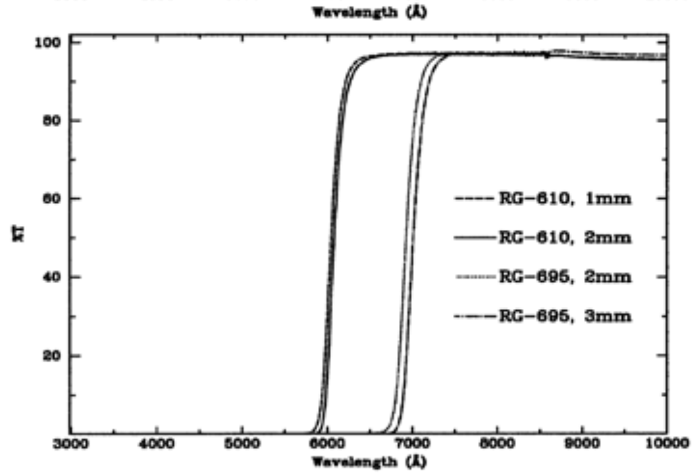

For order n, at $\lambda_n$ there is also order m light with wavelength $\lambda_m=(n/m)\lambda_n$

- For higher orders with $\lambda$<310nm it's not an issue as the atmosphere cuts out all the light (can still be an issue for calibration sources).
- But, if you are working in the red (>640nm) in 1st order, you need to block the 2nd order light.
- If you are working in a higher order, may need to block red light from lower orders.

KPNO 2.1m Goldcam blue blocking filters

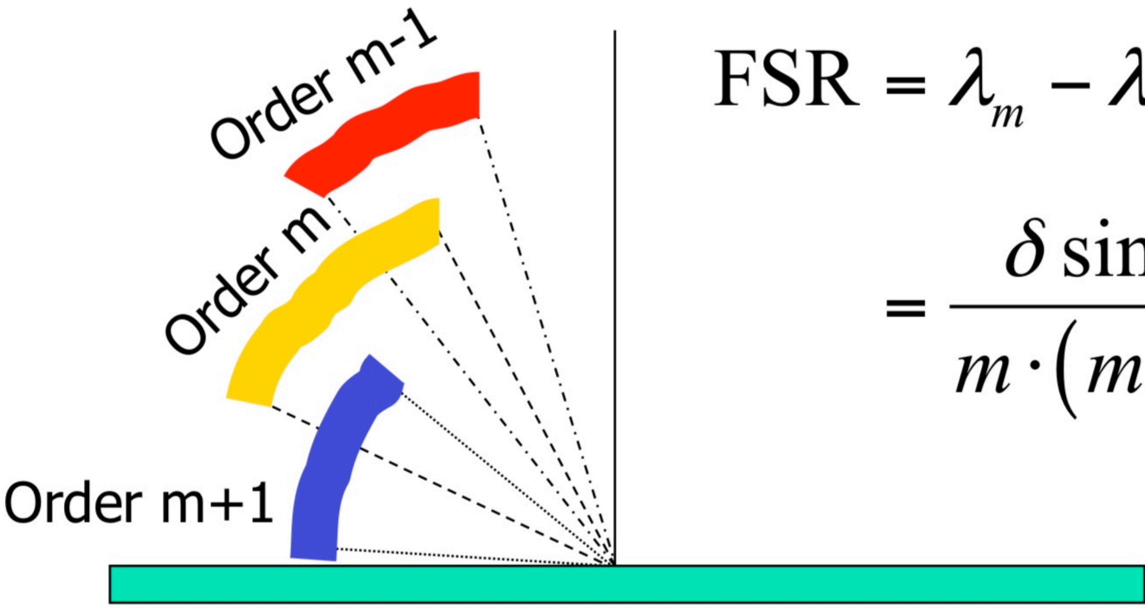


# Free Spectral Range

- Largest bandpass with no overlapping with adiacent orders




$$FSR = \lambda_m - \lambda_{m+1} = \frac{\delta \sin \beta}{m} - \frac{\delta \sin \beta}{m+1} =$$

$$= \frac{\delta \sin \beta}{m \cdot (m+1)}$$

For a prism FSR is the whole spectral range!

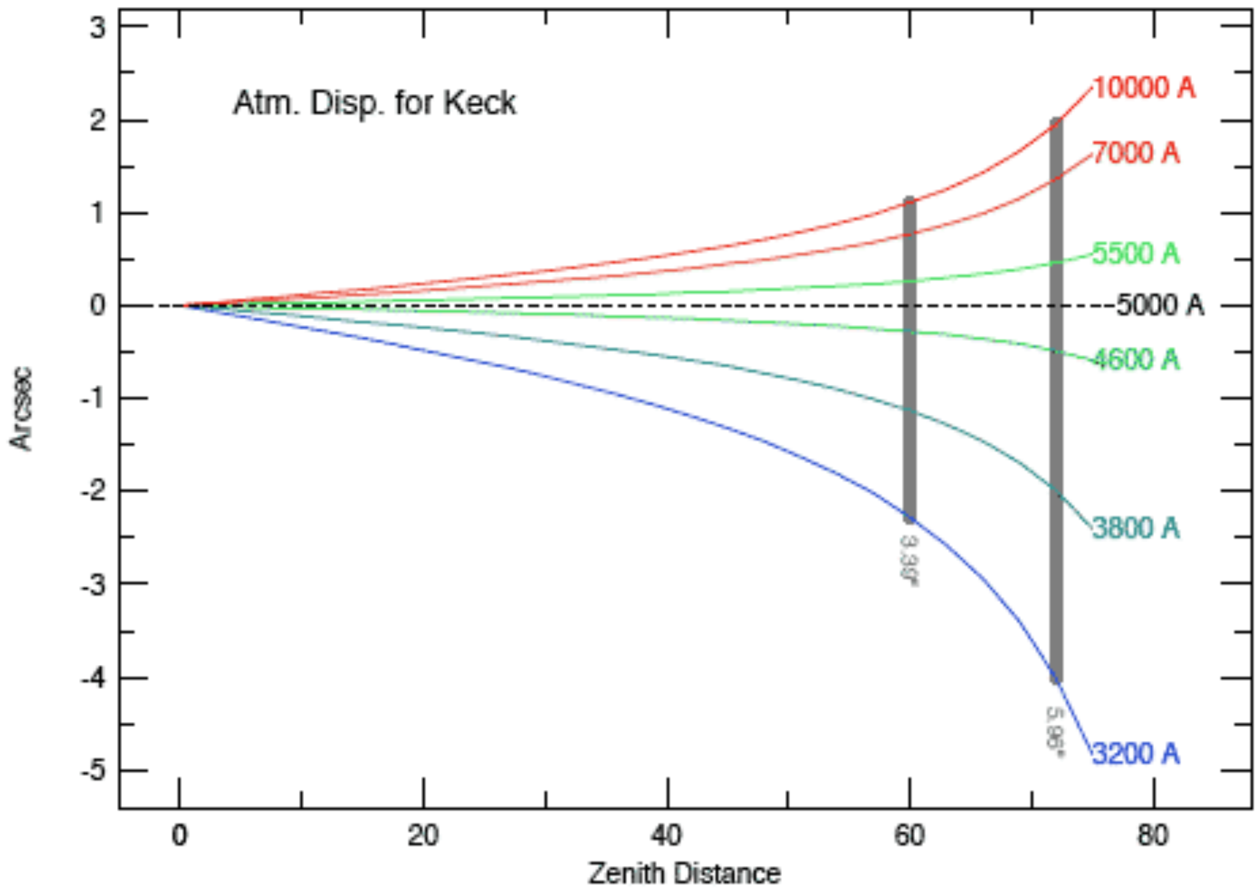
# What do you need to consider?

- Spectral dispersion for science
- Spectra dispersion for observing efficiency
- Grating tilt for wavelength range
- Grating efficiency
- Slit width for efficiency and resolution
- Calibration frames and flexure

# Note about Observing

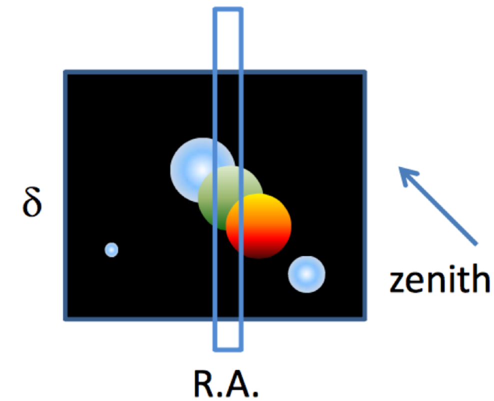
- If spectrometer is not flexure compensated, the usual procedure is to obtain a line lamp spectrum (or two) and flat-field spectrum (or two) at the position of your program object. Sometimes even bracket the program exposures with arcs and flats.
- Depending on program, observe:
  - Flux standard
 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

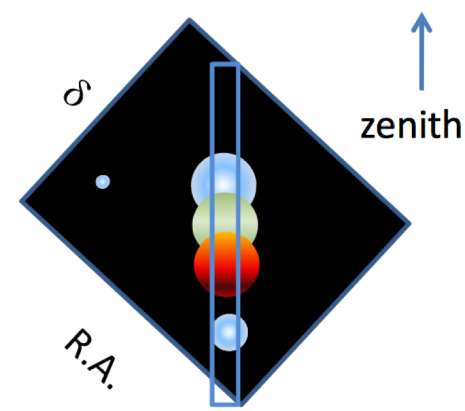
# Atmospheric Dispersion

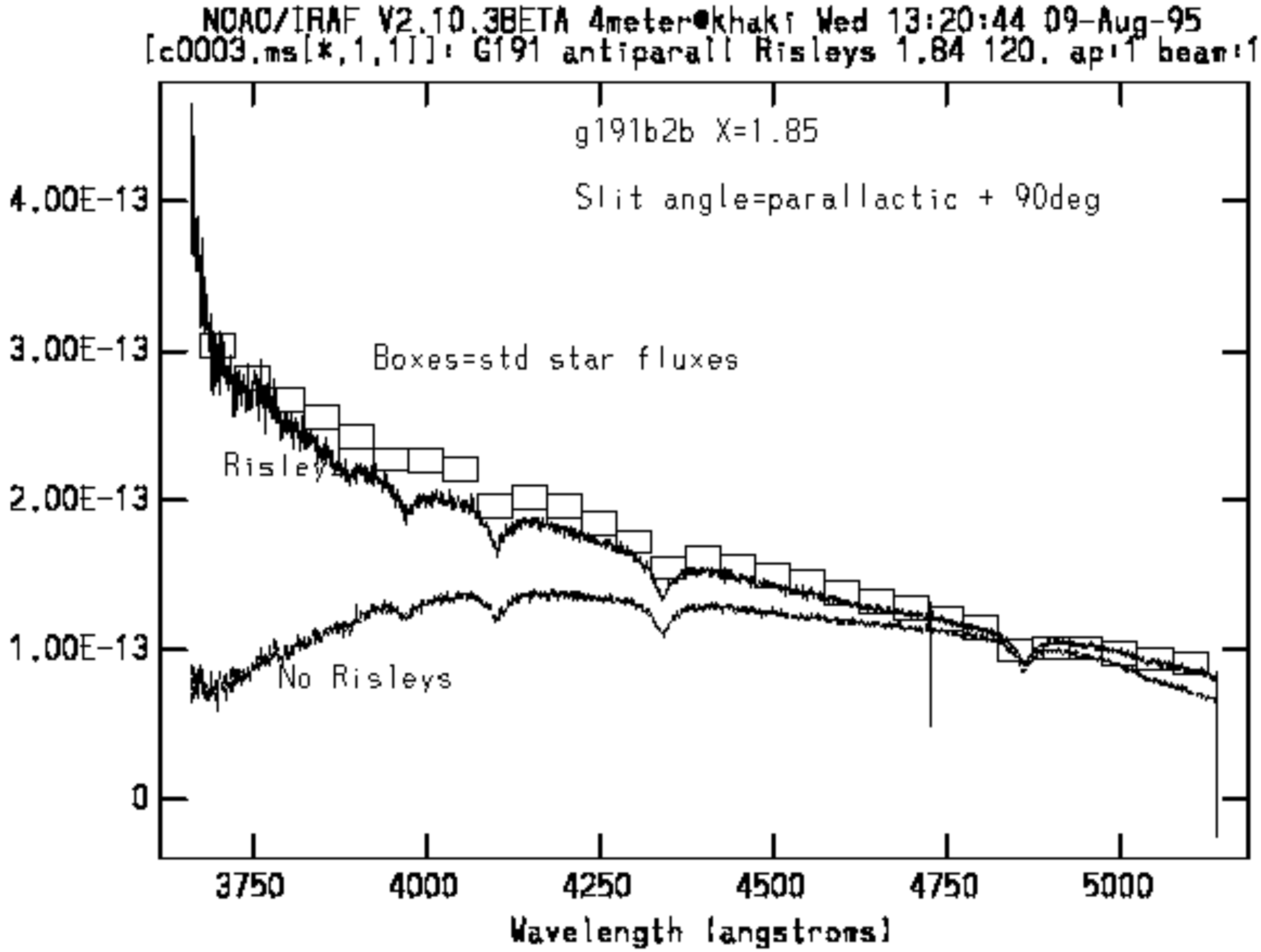


# Parallactic Angle

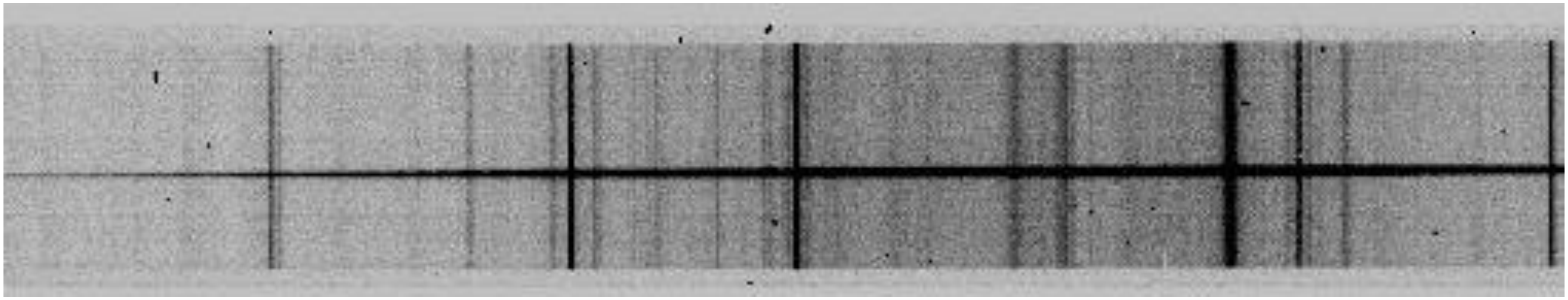
- The "parallactic" angle is perpendicular to the horizon and allows you to capture all the light in an atmospheric-dispersed object (but increasingly displaced along the slit with increasing airmass)



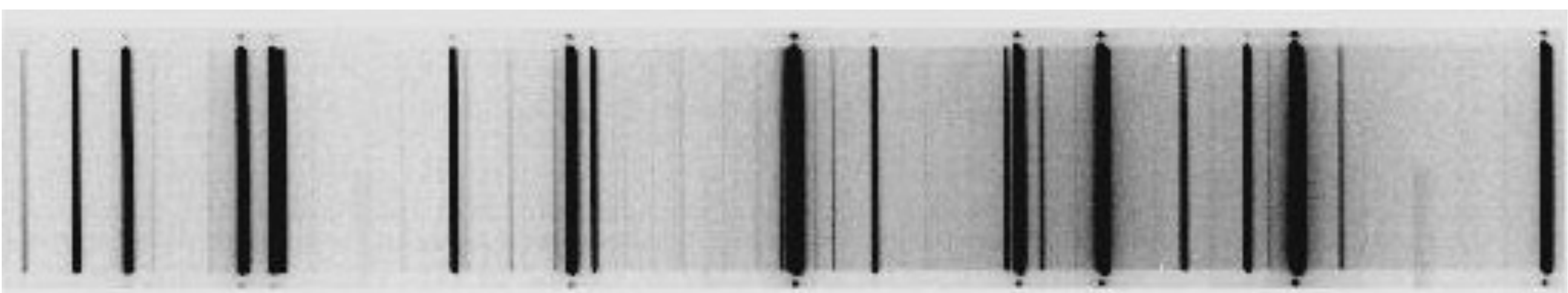

NOAO/IRAF V2.10.3BETA 4meter@khaki Wed 13:20:44 09-Aug-95
[c0003.ms[*,1,1]]: G191 antiparall Risleys 1.84 120. ap:1 beam:1
g191b2b X=1.85
Slit angle=parallactic + 90deg
Boxes=std star fluxes
Risleys
No Risleys
4.00E-13
3.00E-13
2.00E-13
1.00E-13
0
3750
4000
4250
4500
4750
5000
Wavelength (angstroms)

Star+sky



Quartz lamp flat

HgCdNe line lamps



# Long-slit Spectral Reduction Procedures

- There are good introductions/cookbooks available from the IRAF folks. The introduction to spectral reductions is at the class WWW site
- pyDIS python spectral reductions
- Another python example

- Steps:
  - Bias and overscan correction
  - Identify location of the spectrum
  - Identify location of sky samples
  - Extract spectrum
    - Trace
    - Collapse lines
    - Interpolate sky and subtract
  - Flat-fielding
    - Note: need to remove large-scale variations in the spectral dimension
  - 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

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

Dispersion axis

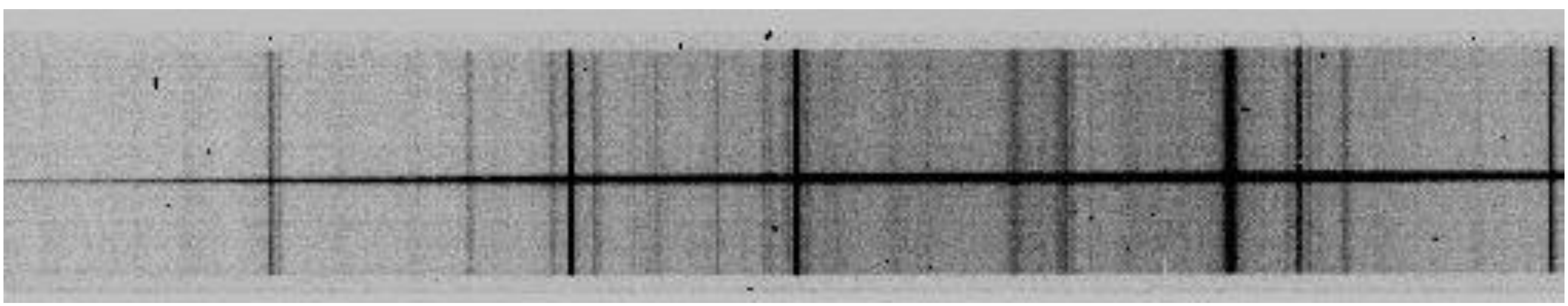
```
tw>epar apextract

    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?
```

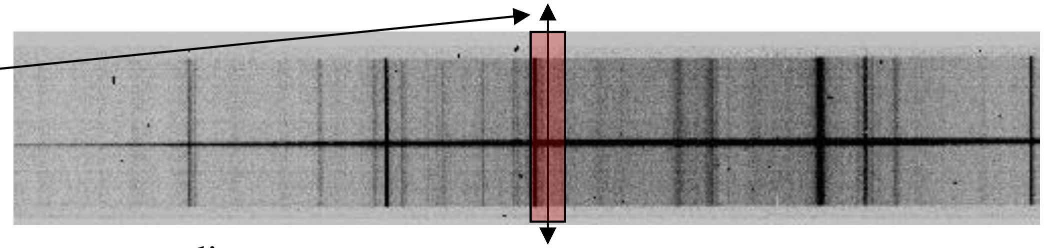
Multispec: star, sky, S/N

Useful for arcs/faint spectra/discontinuous spectra

Usually "no" (recenter, resize)

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

Default is center



(line = INDEF) Dispersion line

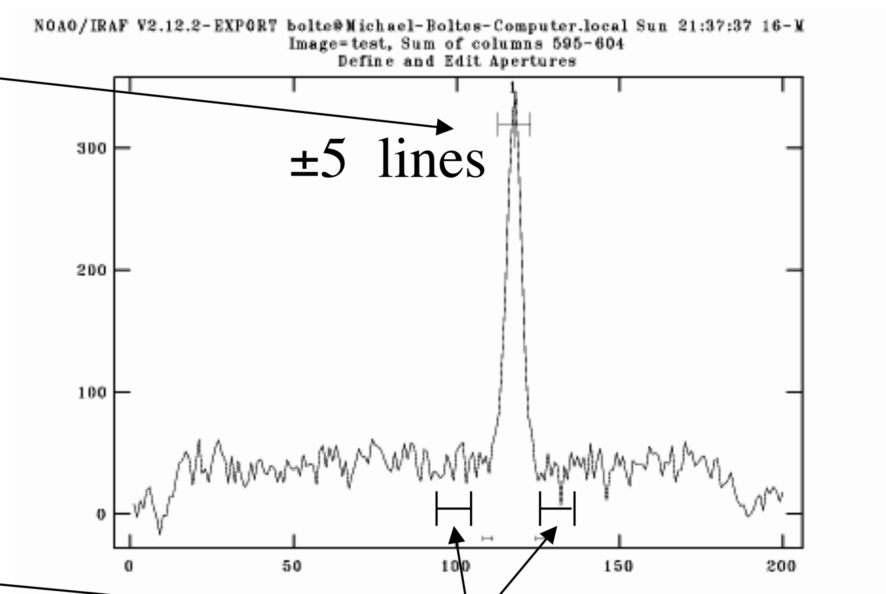
(nsum = 10) Number of dispersion lines to sum or median

# 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

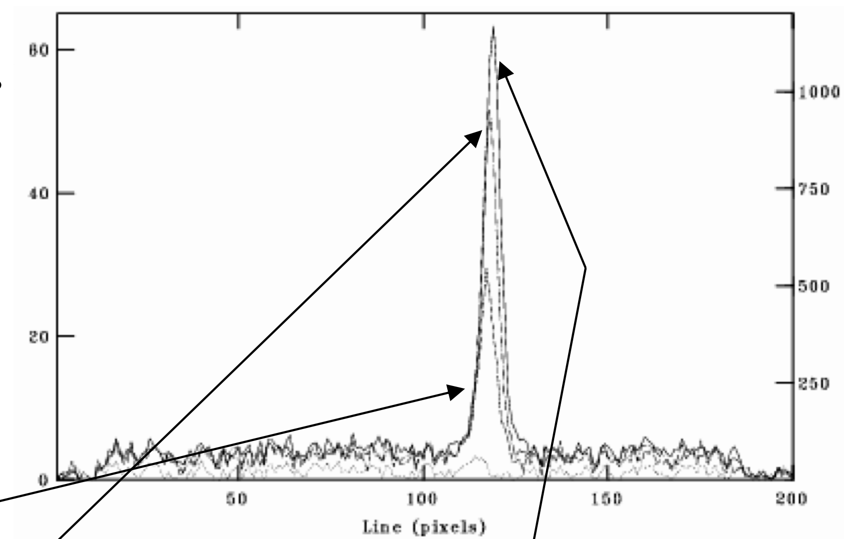
(b_high_= 3.) Background upper rejection sigma

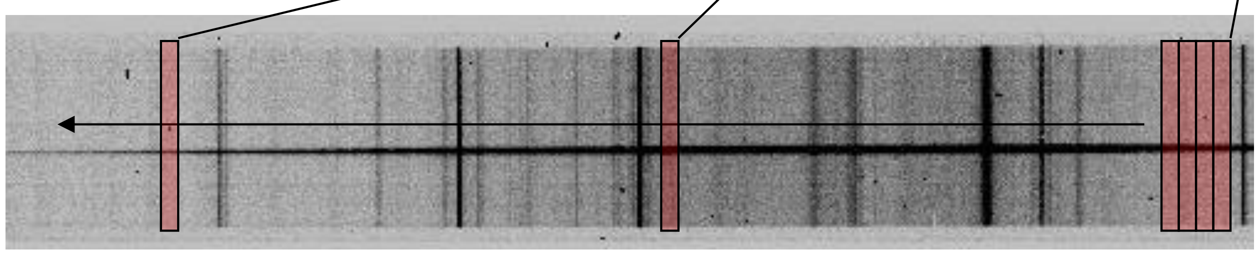
(b_grow = 0.) Background rejection growing radius

# 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
```

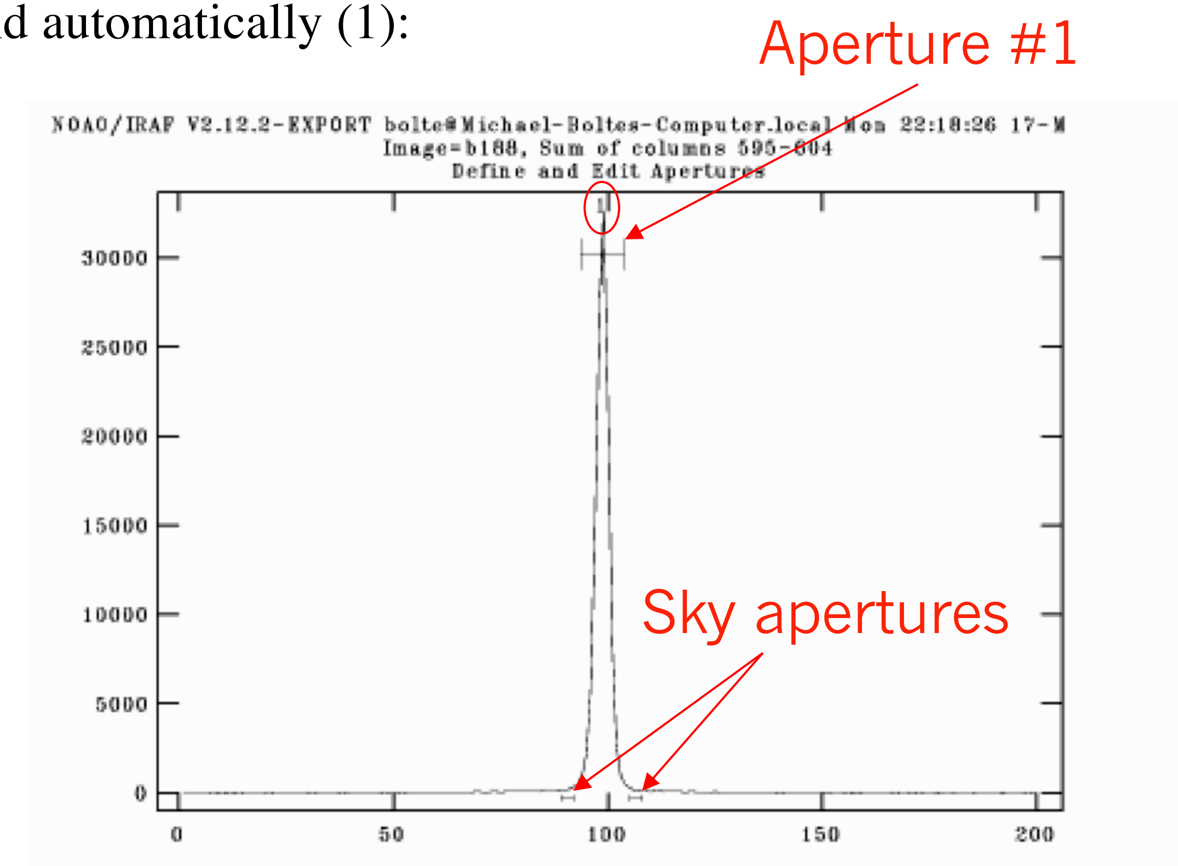
# Example Extraction

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:

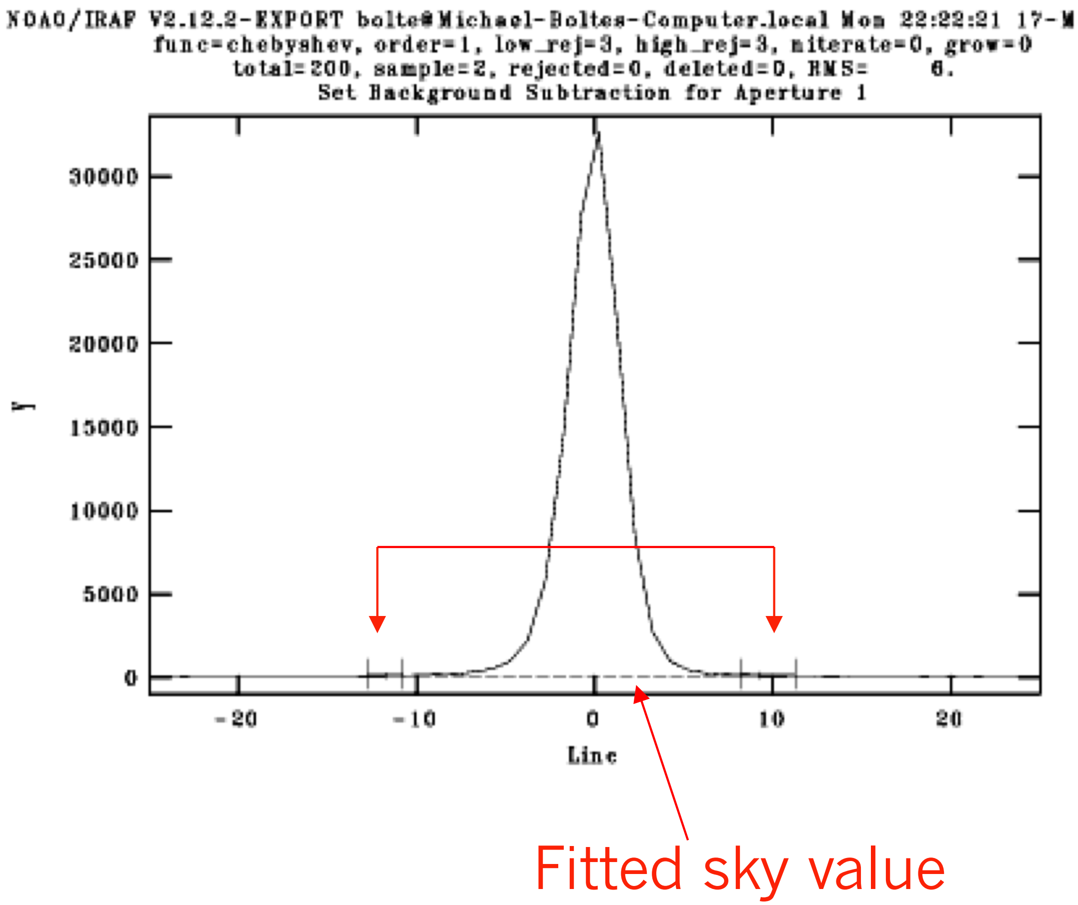
z -- deletes nearest aperture

s -- define new aperture

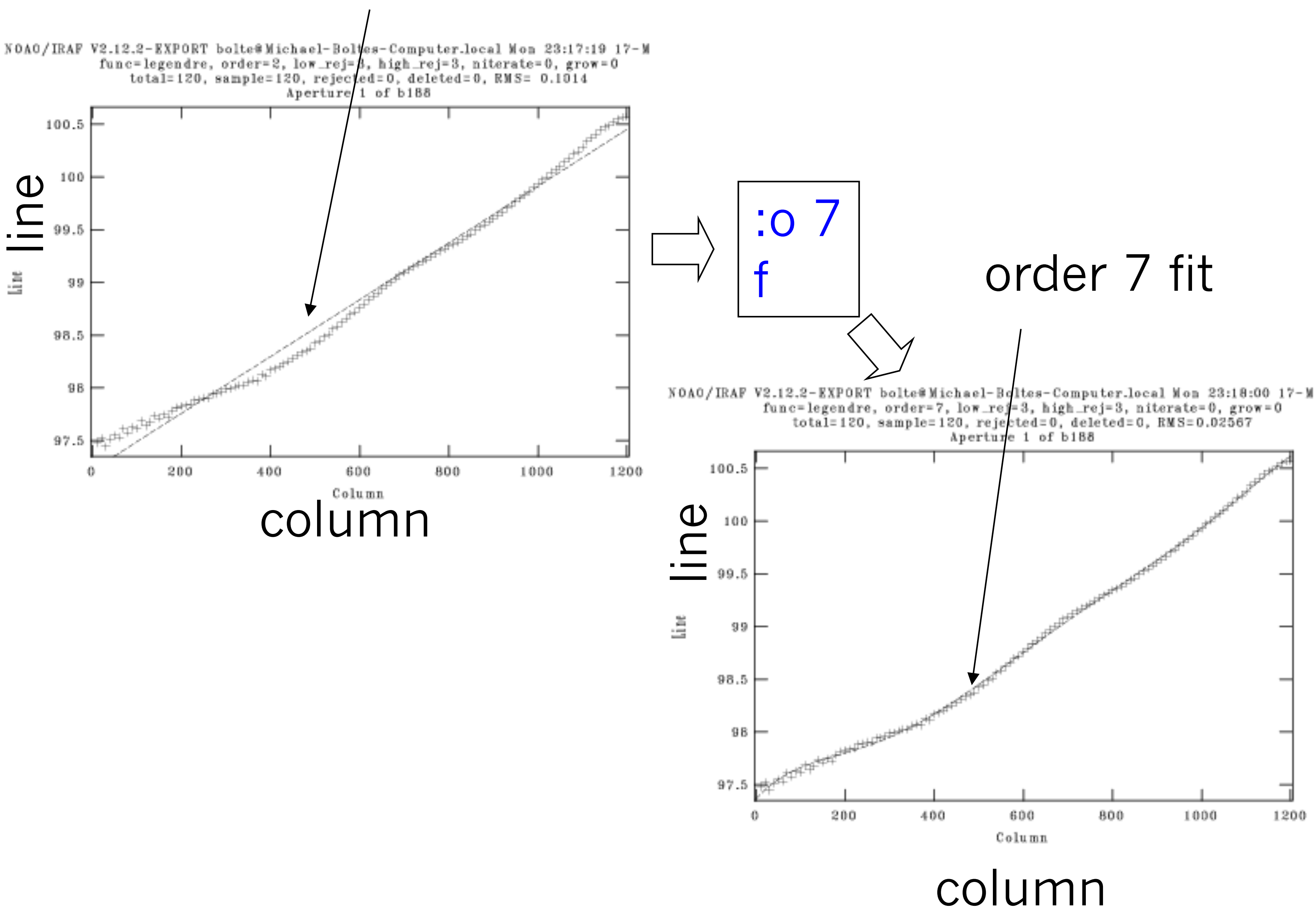
f -- redo fit

:order n -- set order of fit

q -- accept fit and go to previous panel



# Trace:

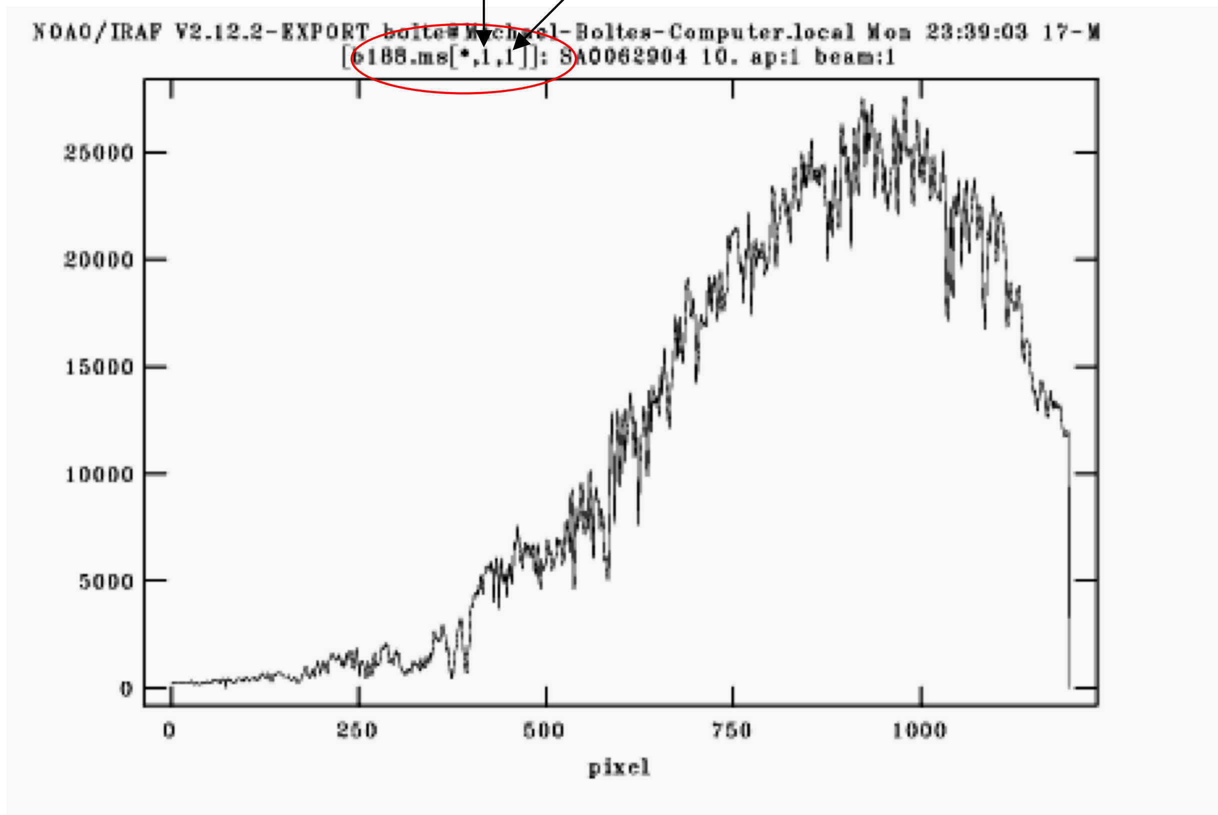

order 2 fit
NOAO/IRAF V2.12.2-EXPORT bolte@Michael-Boltes-Computer.local Mon 23:17:19 17-M
func=legendre, order=2, low_rej=3, high_rej=3, niterate=0, grow=0
total=120, sample=120, rejected=0, deleted=0, RMS= 0.1014
Aperture 1 of b188
line
Line
100.5
100
99.5
99
98.5
98
97.5
0
200
400
600
800
1000
1200
Column
column
:o 7
f
order 7 fit
NOAO/IRAF V2.12.2-EXPORT bolte@Michael-Boltes-Computer.local Mon 23:18:00 17-M
func=legendre, order=7, low_rej=3, high_rej=3, niterate=0, grow=0
total=120, sample=120, rejected=0, deleted=0, RMS=0.02567
Aperture 1 of b188
line
Line
100.5
100
99.5
99
98.5
98
97.5
0
200
400
600
800
1000
1200
Column
column

# Splot:

cl>splot b188.ms

aperture

band (spec,sky,S/N)

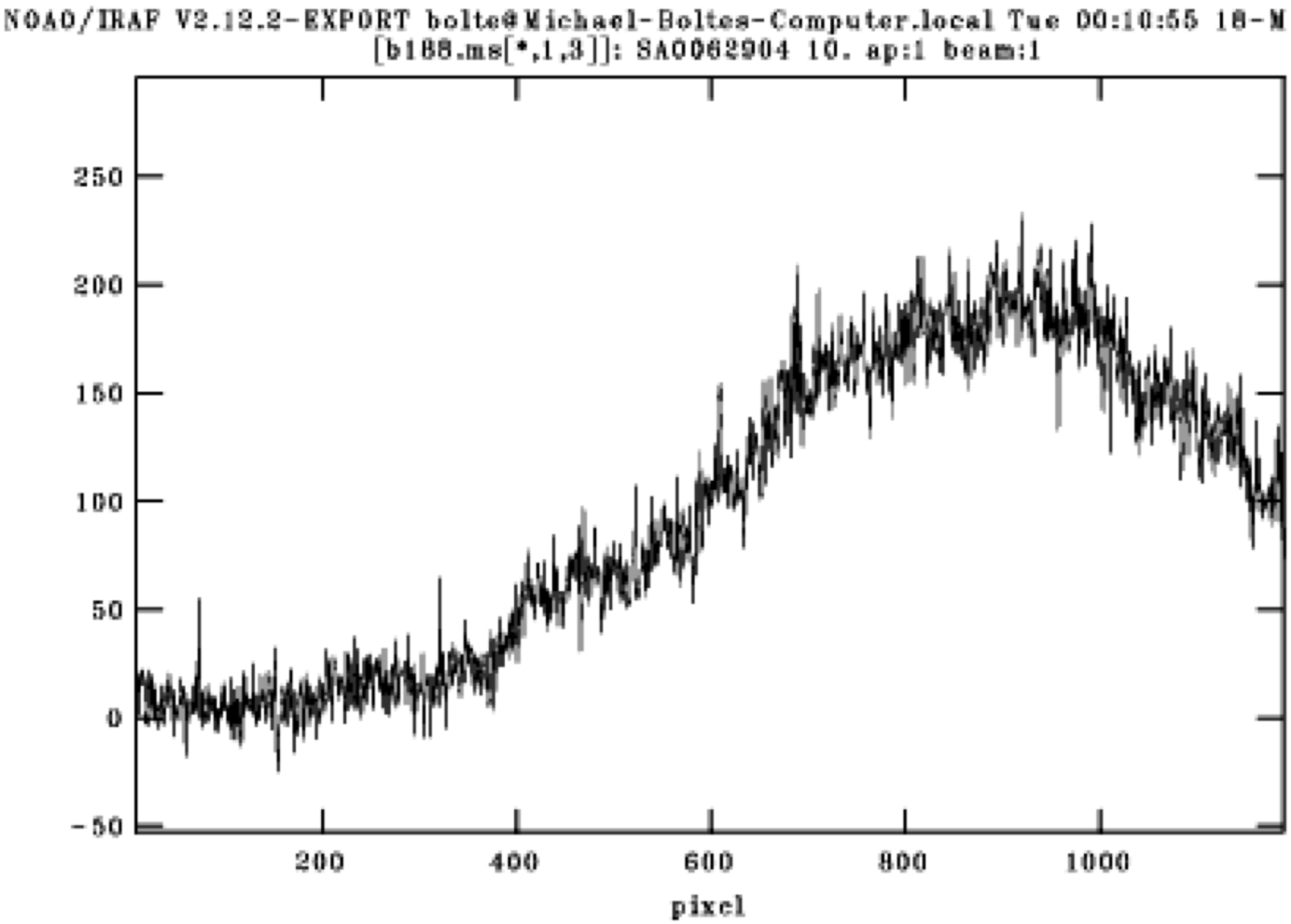



Extracted spectrum in pixel space

**Common splot options:**

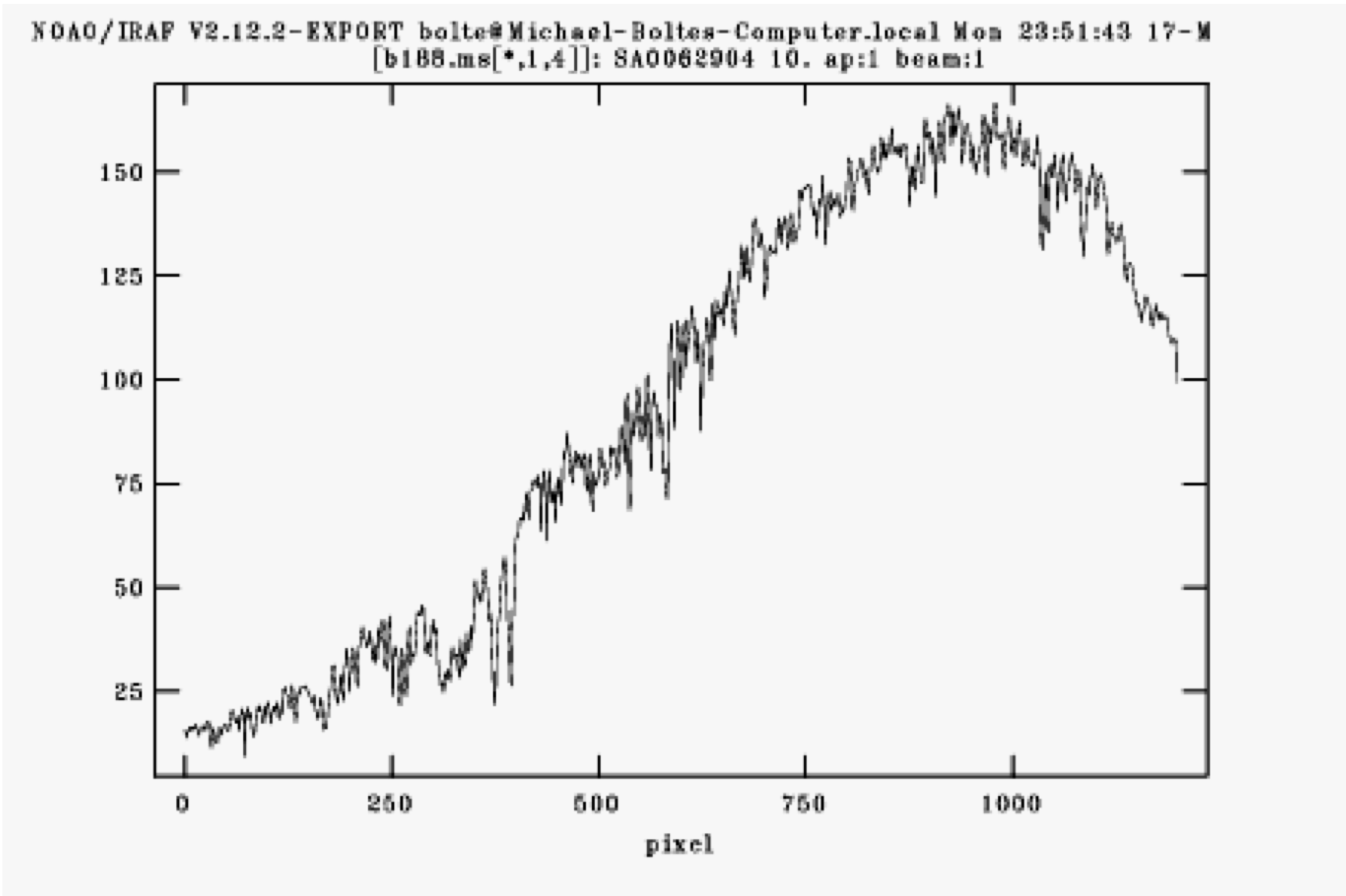
- ? -- lists all the options
- %-- select new band
- m-- gives statistics
- e-- eq. width, line centers
- s-- smooth
- t-- fit continuum
- w--window plot

# Sky



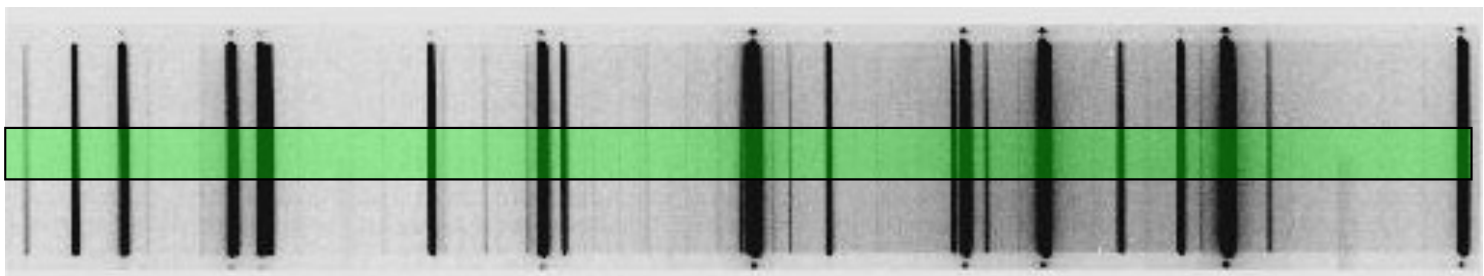
NOAO/IRAF V2.12.2-EXPORT bolte@Michael-Boltes-Computer.local Tue 00:10:55 18-M
[b188.ms[*,1,3]]: SA0062904 10. ap:1 beam:1
250
200
150
100
50
0
-50
200
400
600
800
1000
pixel

# Band #4: S/N

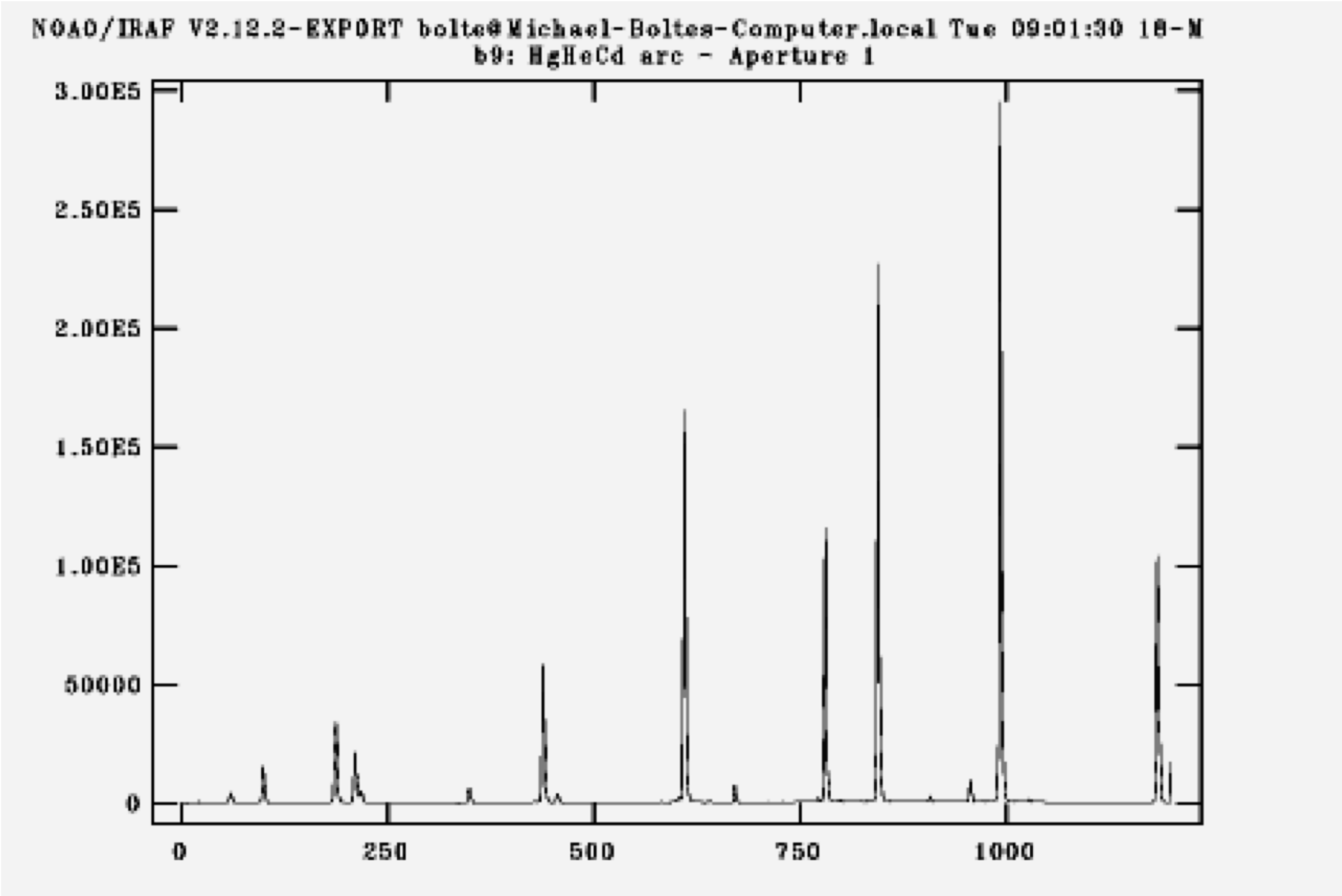

NOAO/IRAF V2.12.2-EXPORT bolte@Michael-Boltes-Computer.local Mon 23:51:43 17-M
[b168.ms[*,1,4]]: SA0062904 10. ap:1 beam:1
150
125
100
75
50
25
0
250
500
750
1000
pixel

# Line Lamps

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



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

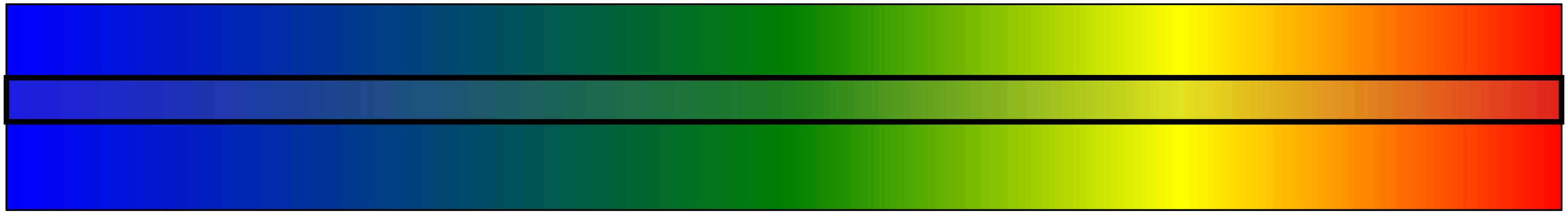



Sometimes fit a master arc taken in the afternoon and use arcs taken adjacent to program objects to make a zeropoint shift to the wavelength solution.

# Flat-fields

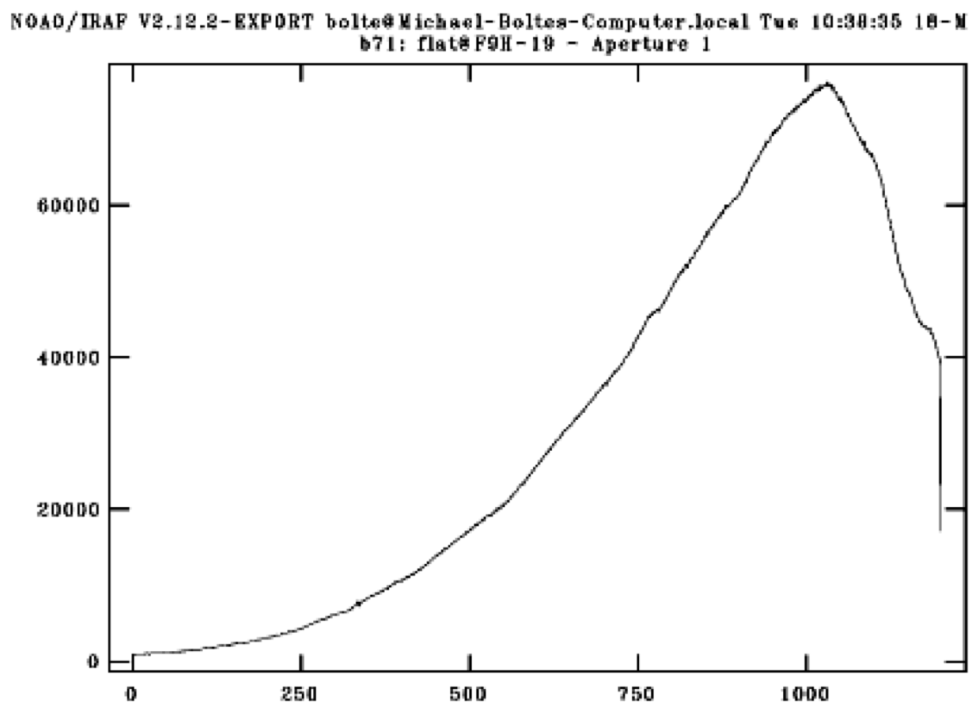
- Can flat-field original frames in 2-D format, but more commonly, the flat-field image is extracted with the same aperture as the program object.
- In the spirit of flat-fielding for direct images, you would like a source that is uniform in the spatial direction AND has a flat spectrum. In practice, 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



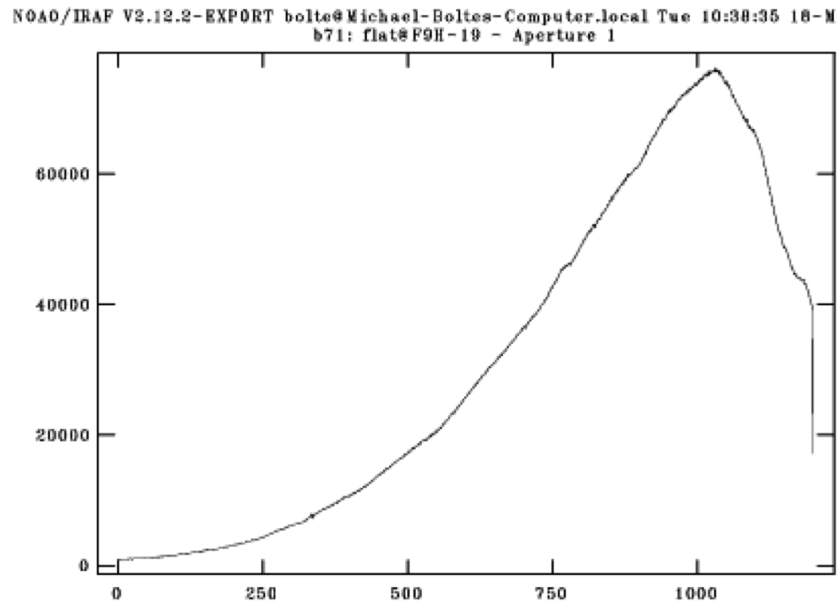
Blue

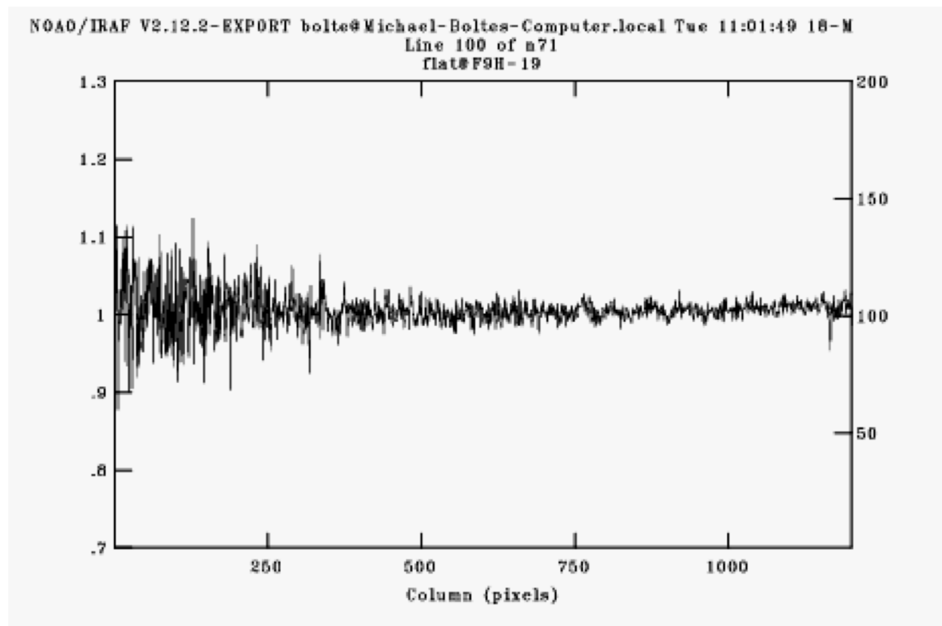
Red



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

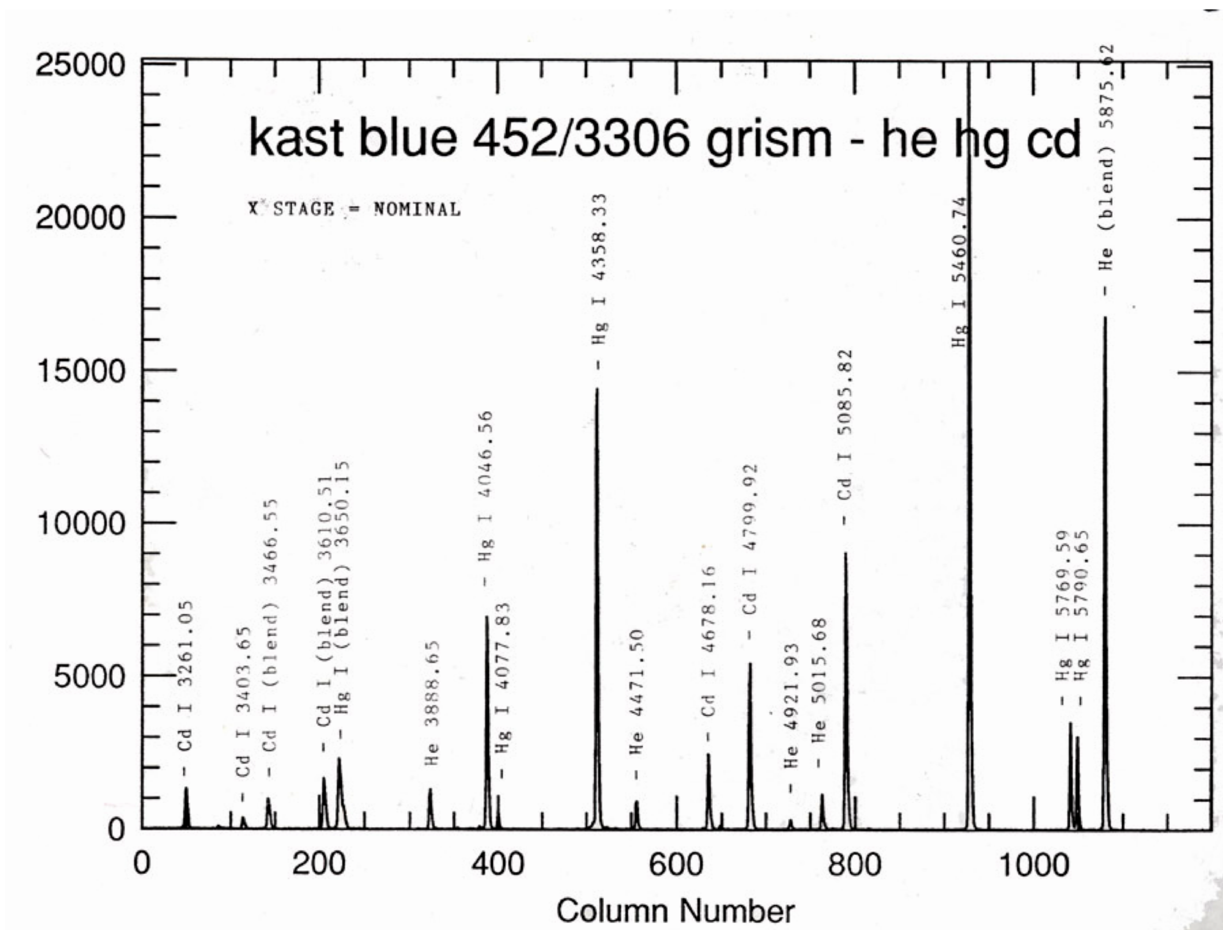


# Wavelength Calibration

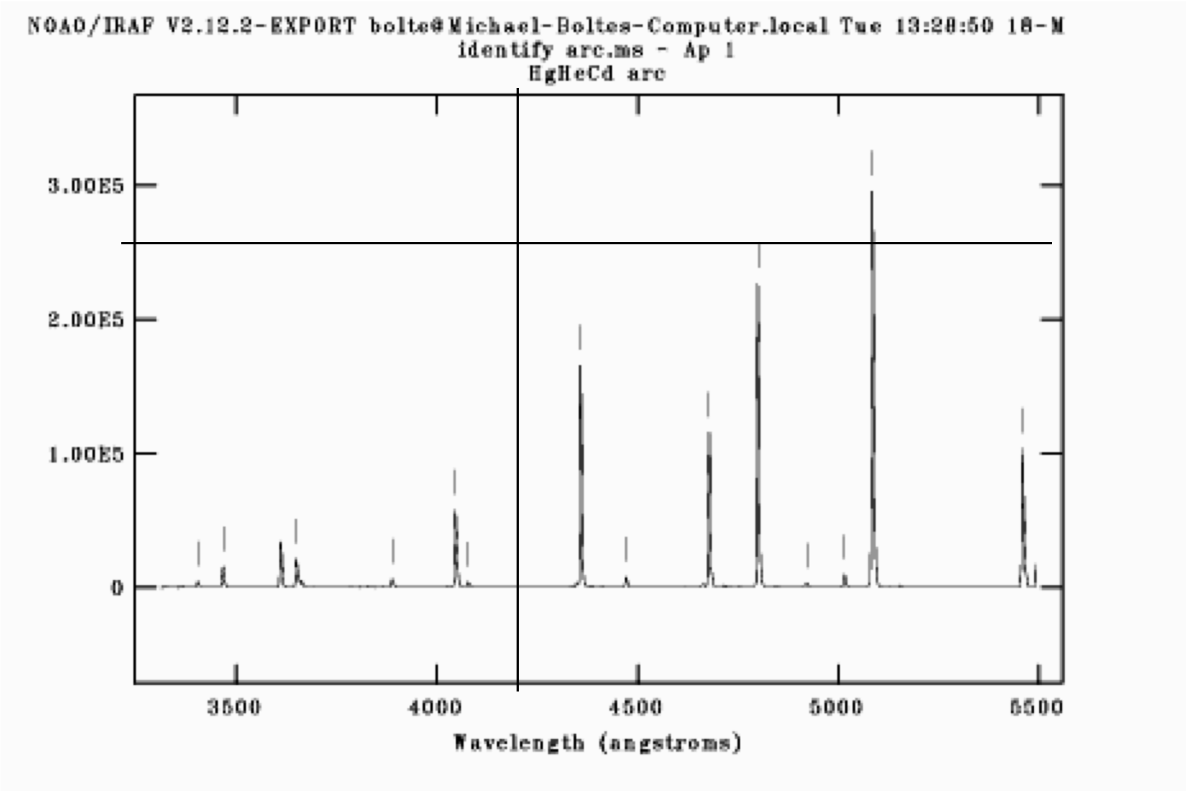
- Identify the lines in your lamp-line spectrum
- Fit line centers, derive function to map pixel scale to wavelength scale
- Associate arc+solution with program spectra
- Apply the `dispersion' solution, usually writing a short version of the solution to the header

# Example, from Lick KAST WWW pages



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

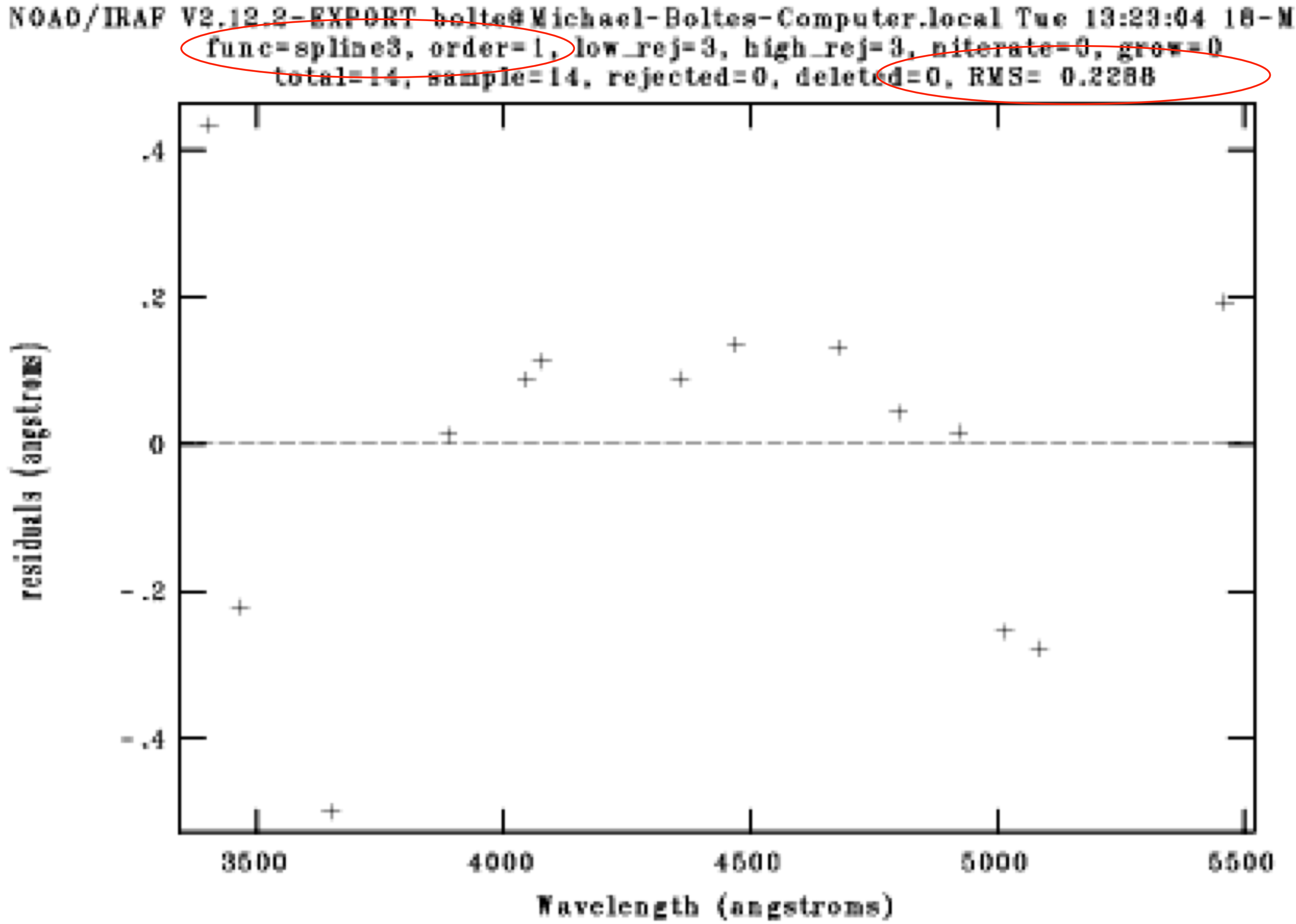
```
PACKAGE = onedspec
  TASK = identify

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
```

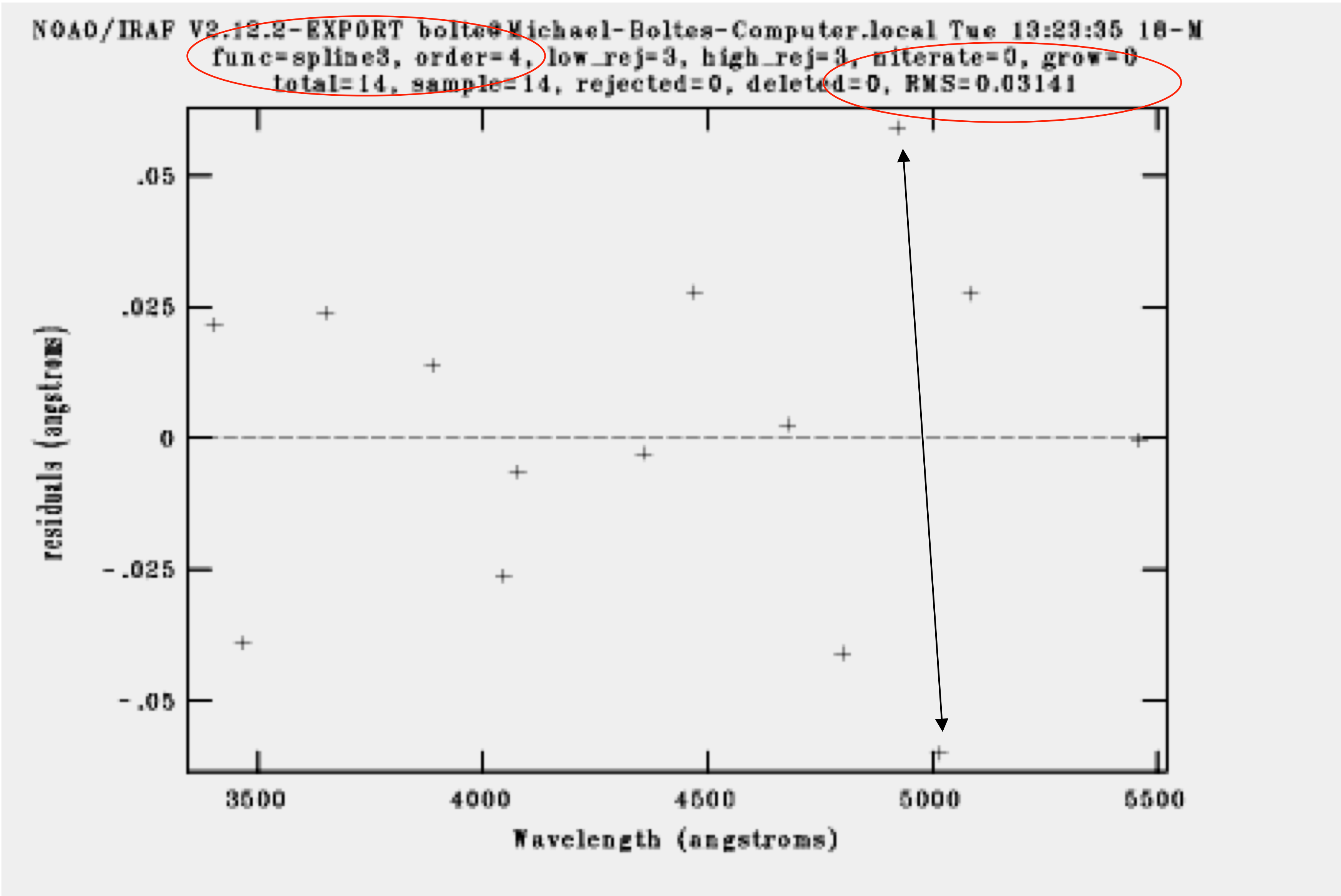



First *identify* window

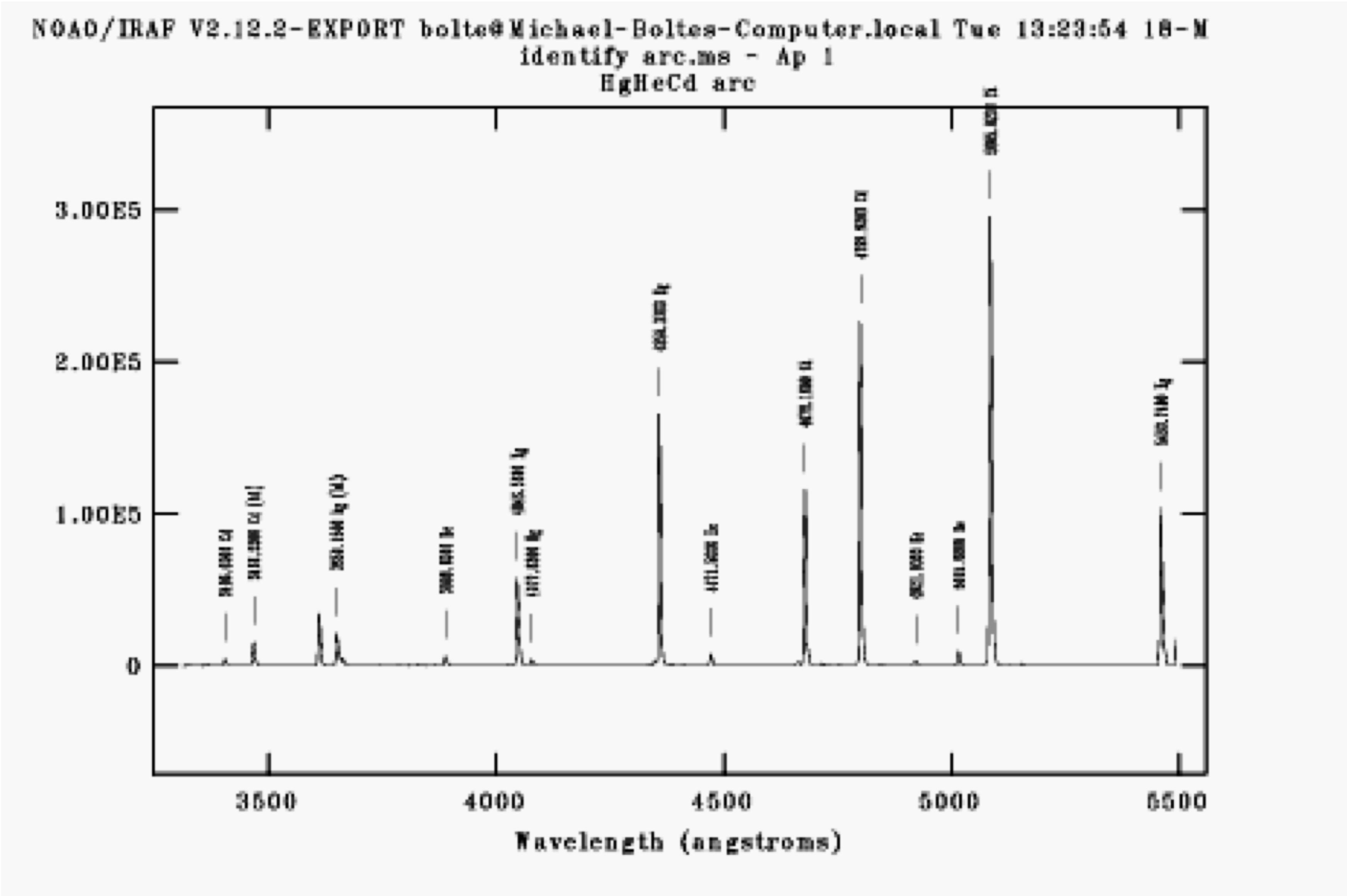
Commonly-used commands:

? -- 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 bolte@Michael-Boltes-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)
```

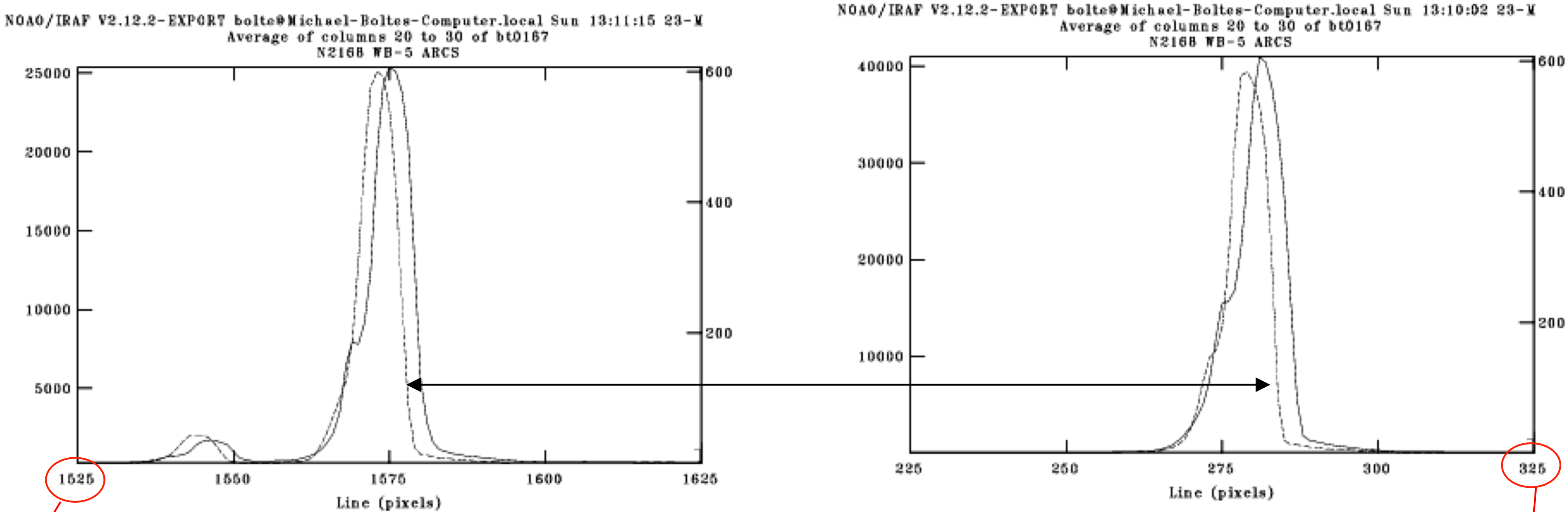
Sophisticated auto assignment options

# 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
```

# Flexure

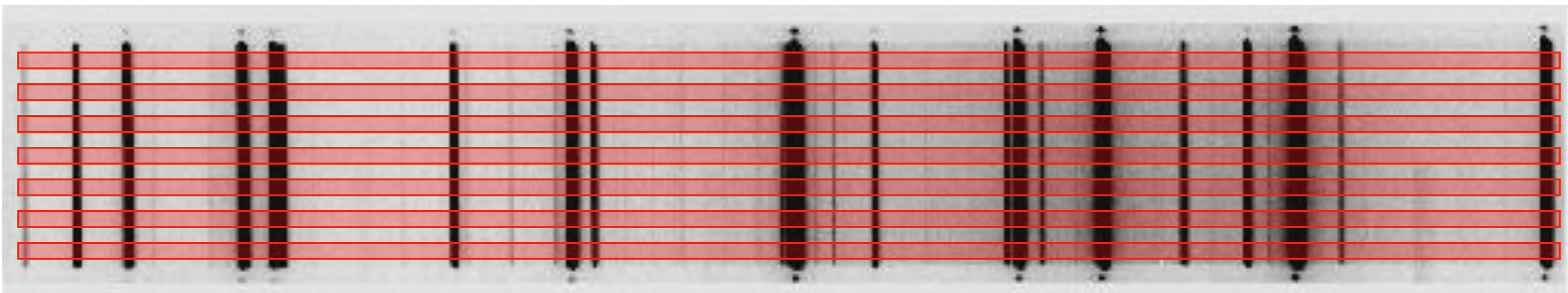



Two lamp spectra from LRIS taken at different telescope positions

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

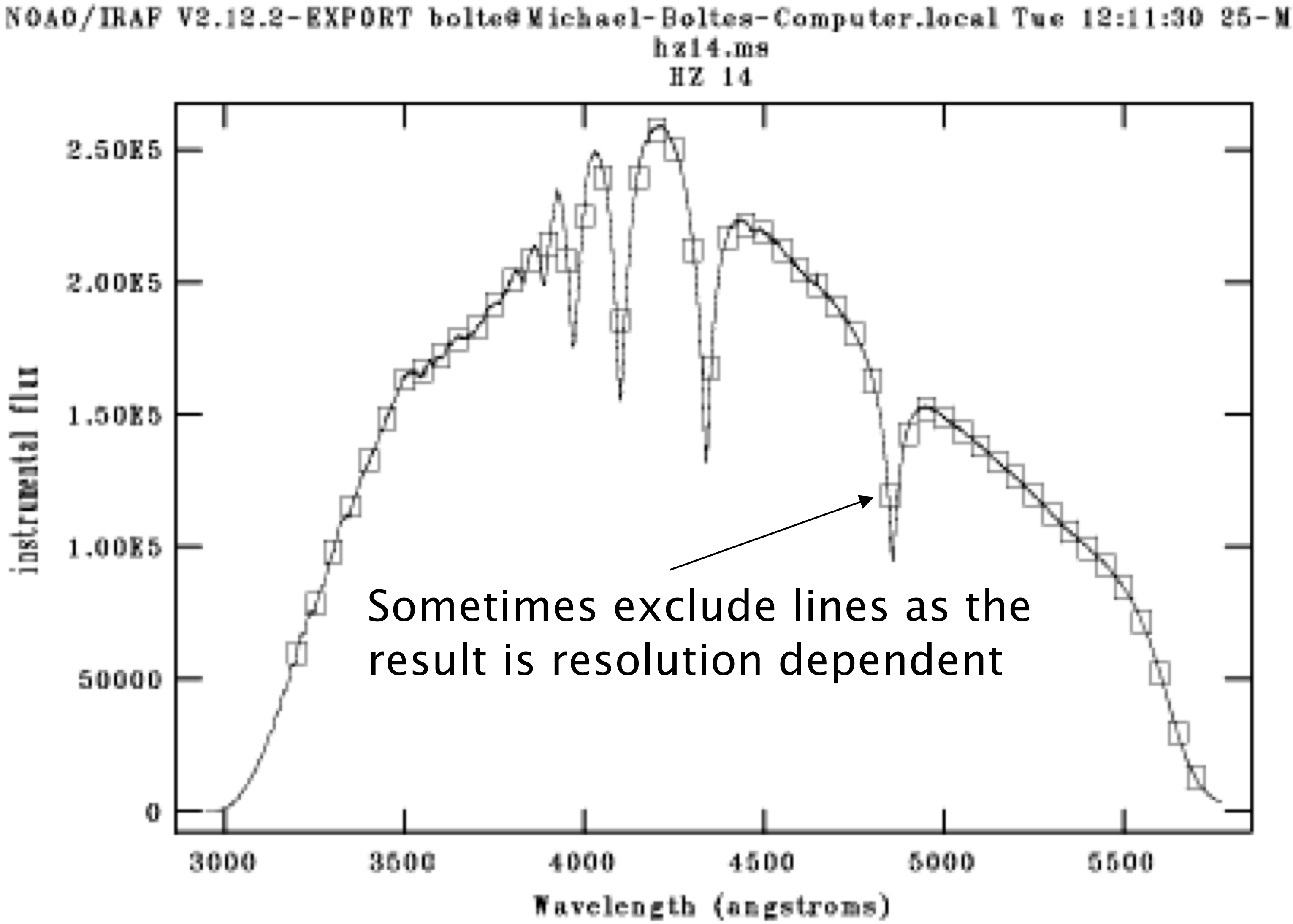
- There are lists of spectrophotometric standard stars:
  - Oke, J. B. 1990, AJ, 99, 1621
  - Stone, R. P. S. 1996, ApJS, 107, 423
  - Massey, P., & Gronwall, C. 1990, ApJ, 358, 344
  - IRAF: onedstds$

Usual zeropoint is based on Vega:

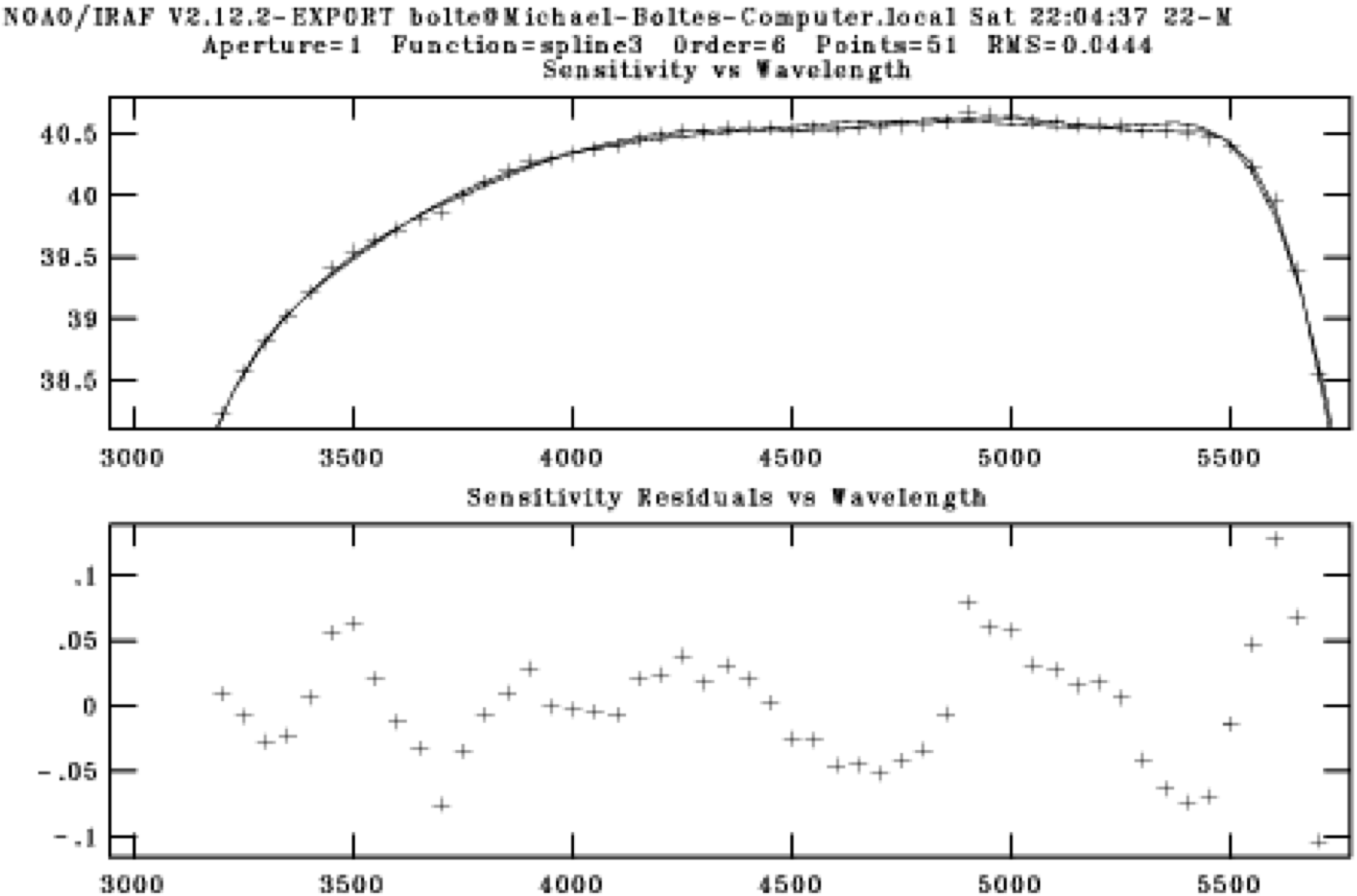
$F_{5556Å}$=3.52 x $10^{-20}$ erg/cm$^2$/s/Hz (V=0.048 mag)

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

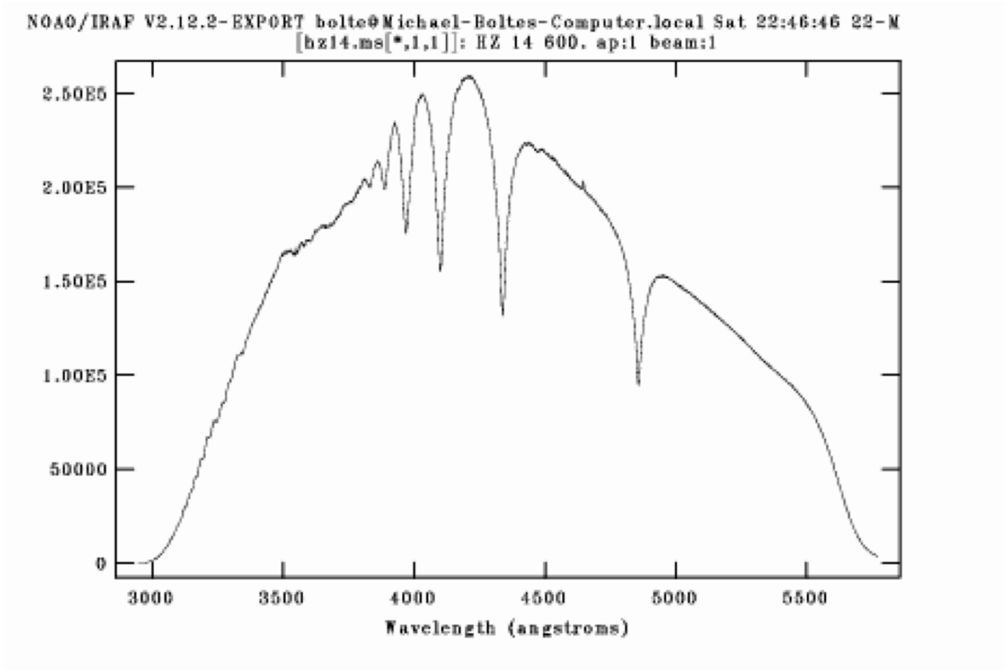
- noao.oned
  - *standard*: identifies standard stars by name, associates an extinction curve, gets airmass exposure time. Output is a file (default name std)
  - *sensfunc*: given extinction function, tabulated standard system flux and your observed spectrum calculate a sensitivity function.
  - *calibrate*: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



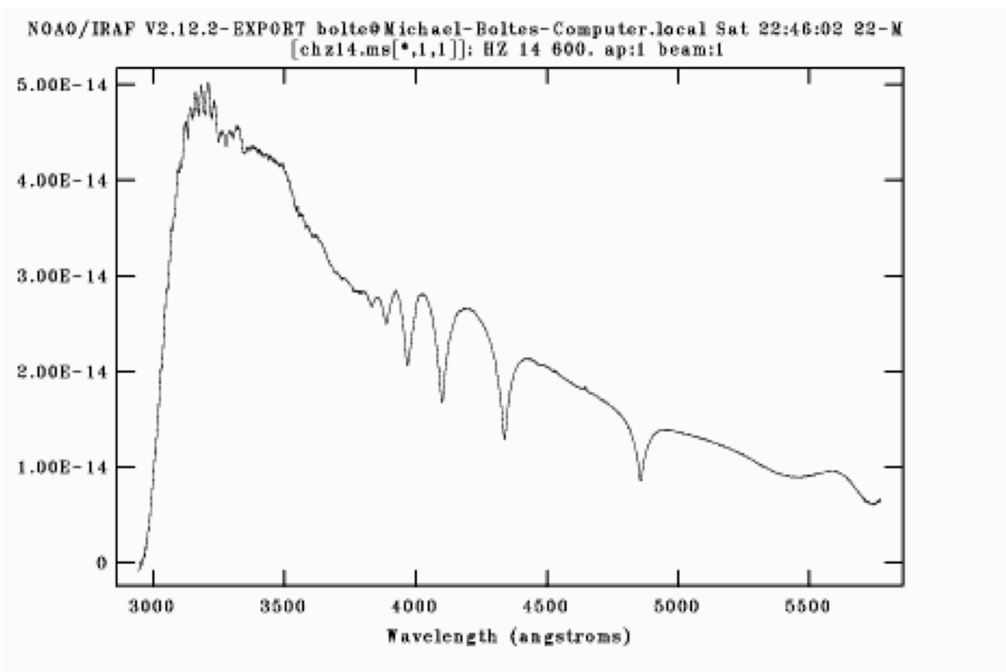

*standard* interactive graphic




*sensfunc* interative graphic

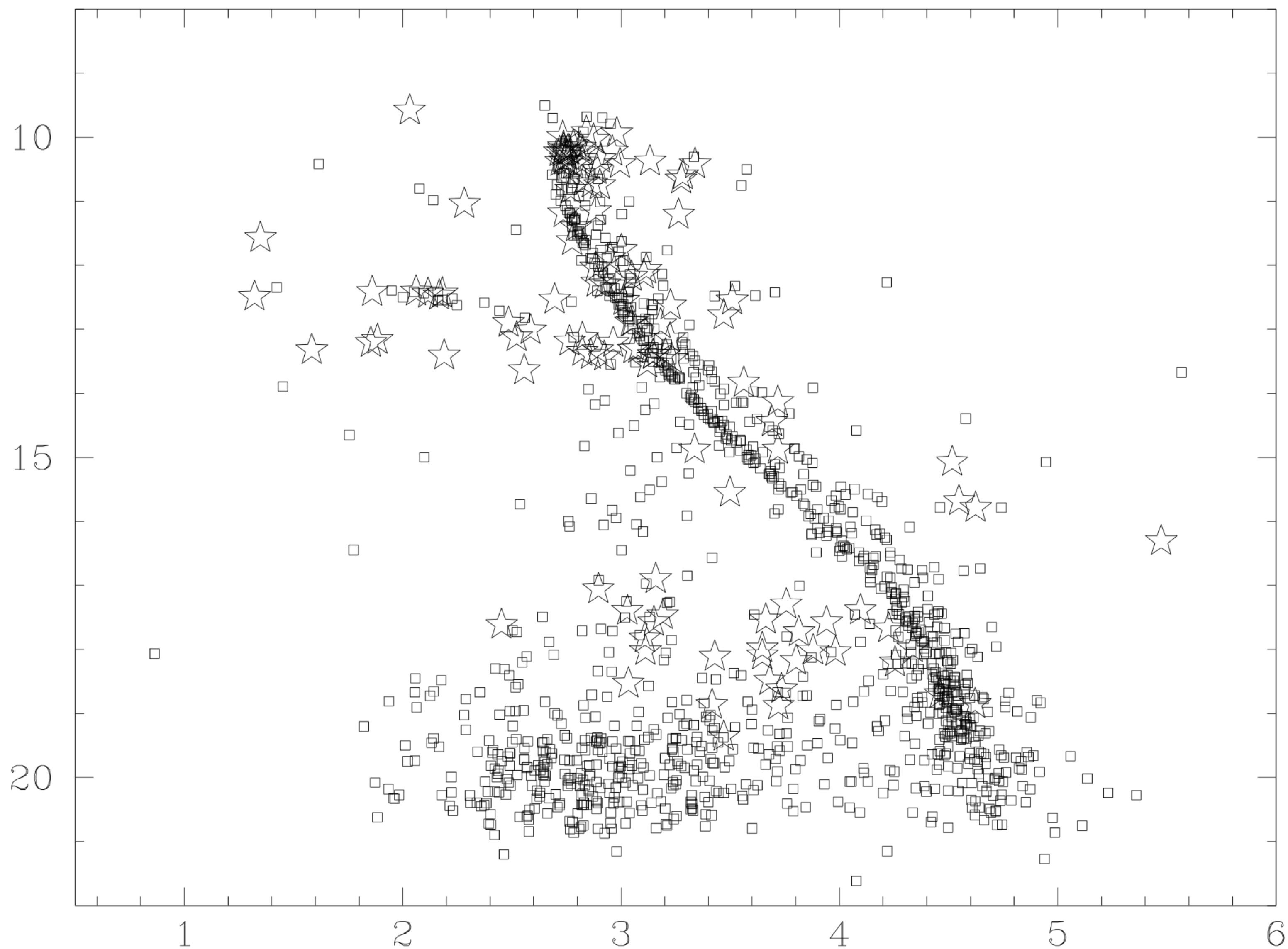



Raw extracted Spectrum




Flux calibrated

# Homework #4 result (instrumental magnitudes)

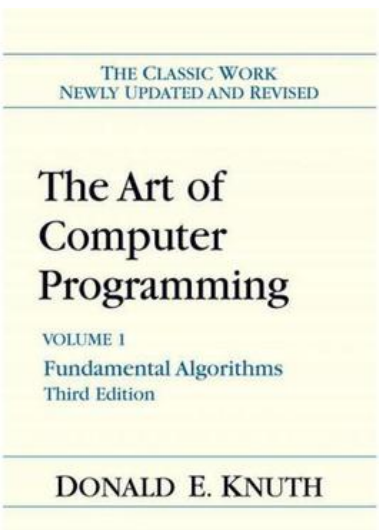


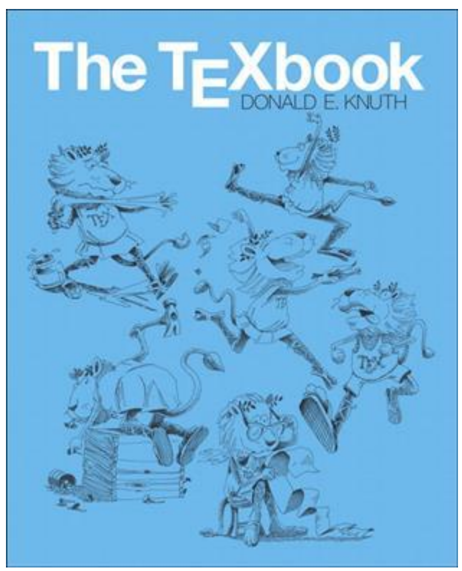
# Note about Addstars

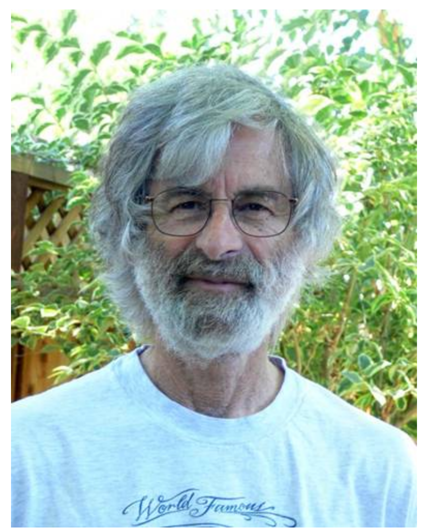
- DAOphot has an option to insert fake stars (psfs) into a frame.
- This is a very powerful option for determining completeness and accuracy of photometry

# Note about TeX/Latex

Donald Kunth wrote a 4-volume book in the late 60’s and 70’s. For the second edition wrote a type-setting package for computer: T$_\text{E}$X. Wrote an amazing book about the theory of typesetting. In particular wanted better way to write equations. Leslie LAmport wrote a wrapper that is widely used: LaTeX.



# AAS LaTeX macros

- https://journals.aas.org/aastex-package-for-manuscript-preparation/
- Need a version of TeX/LaTeX. For Macs, MacTeX
- http://www.tug.org/mactex/
- Easiest to start with the AAS paper example and edit
- Learn the difference between M-dash and hyphen! 2” and 2″