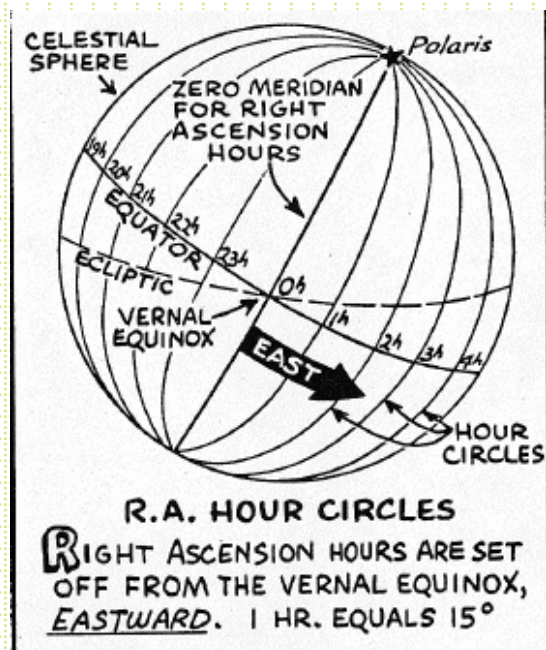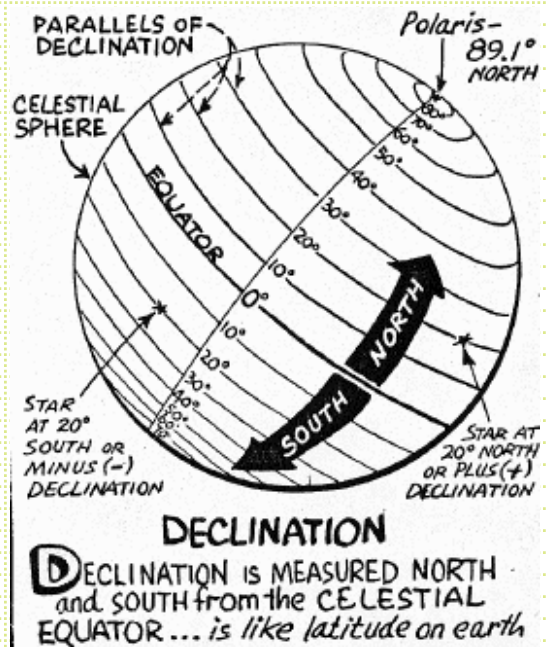# Observing

- Rule #1 -- keep collecting photons! ($210/ minute at Keck)

- Know your S/N targets

- Plan the night out carefully ahead of time

- Useful tools:
  - Aircharts

PARALLELS OF DECLINATION

Polaris– 89.1° NORTH

CELESTIAL SPHERE

EQUATOR

NORTH

SOUTH

STAR AT 20° SOUTH OR MINUS (–) DECLINATION

STAR AT 20° NORTH OR PLUS (+) DECLINATION

DECLINATION

DECLINATION IS MEASURED NORTH and SOUTH from the CELESTIAL EQUATOR... is like latitude on earth

CELESTIAL SPHERE

Polaris

ZERO MERIDIAN FOR RIGHT ASCENSION HOURS

EQUATOR

ECLIPTIC

VERNAL EQUINOX

EAST

HOUR CIRCLES

R.A. HOUR CIRCLES

RIGHT ASCENSION HOURS ARE SET OFF FROM THE VERNAL EQUINOX, EASTWARD. 1 HR. EQUALS 15°

- **Right Ascension** (RA) and **Declination** (Dec) are equatorial sky coordinates

- Like longitude and latitude (respectively) on the surface of the Earth but fixed on the sky

- Aligned with the Earth's axis so the RA and Dec for celestial objects changes as the Earth's orbit precesses. Need to specify the "epoch" of the coordinates.

Hour angles and airmass

- The *sidereal time* gives the right ascension that is passing through the meridian. My index point is 12h is overhead at local midnight on March 21. Sky advances 2 hours per month.

- The *hour angle* is the time before or after a particular RA is at the meridian. HA=LST-RA

- *Airmass* is a combination of the HA and the difference between the telescope latitude and the pointing declination. Airmass~sec(zenith angle)
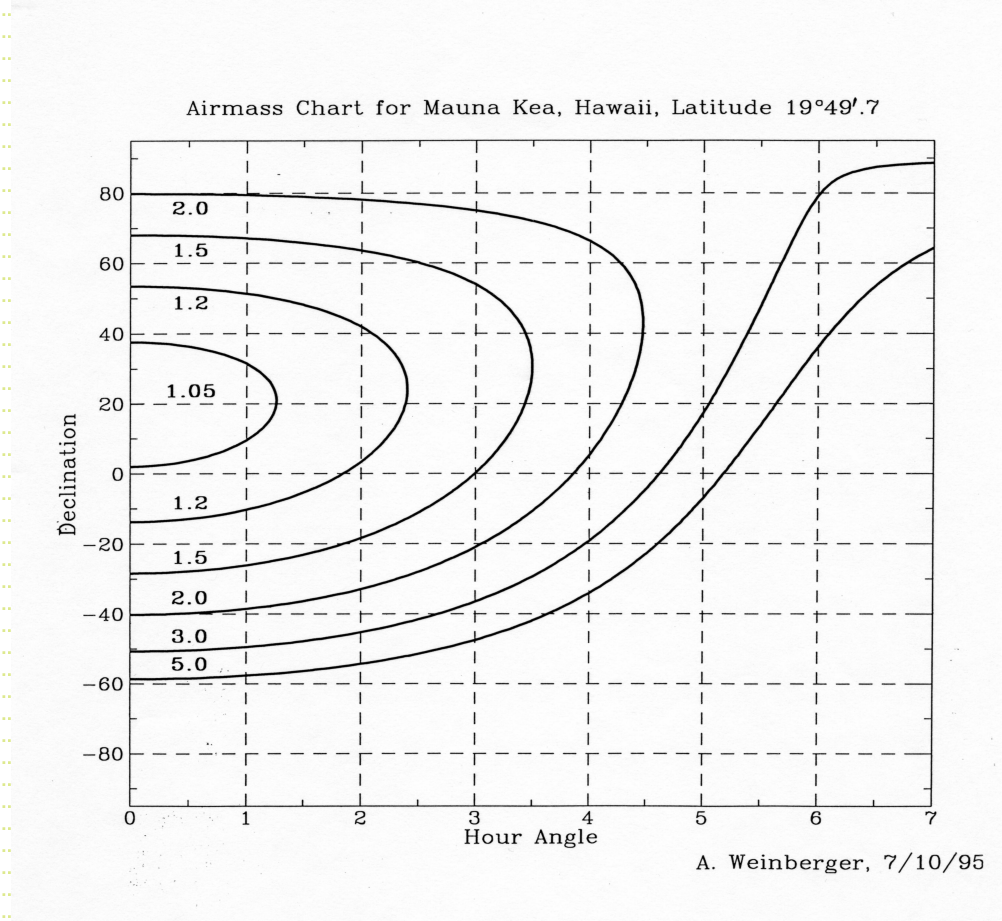
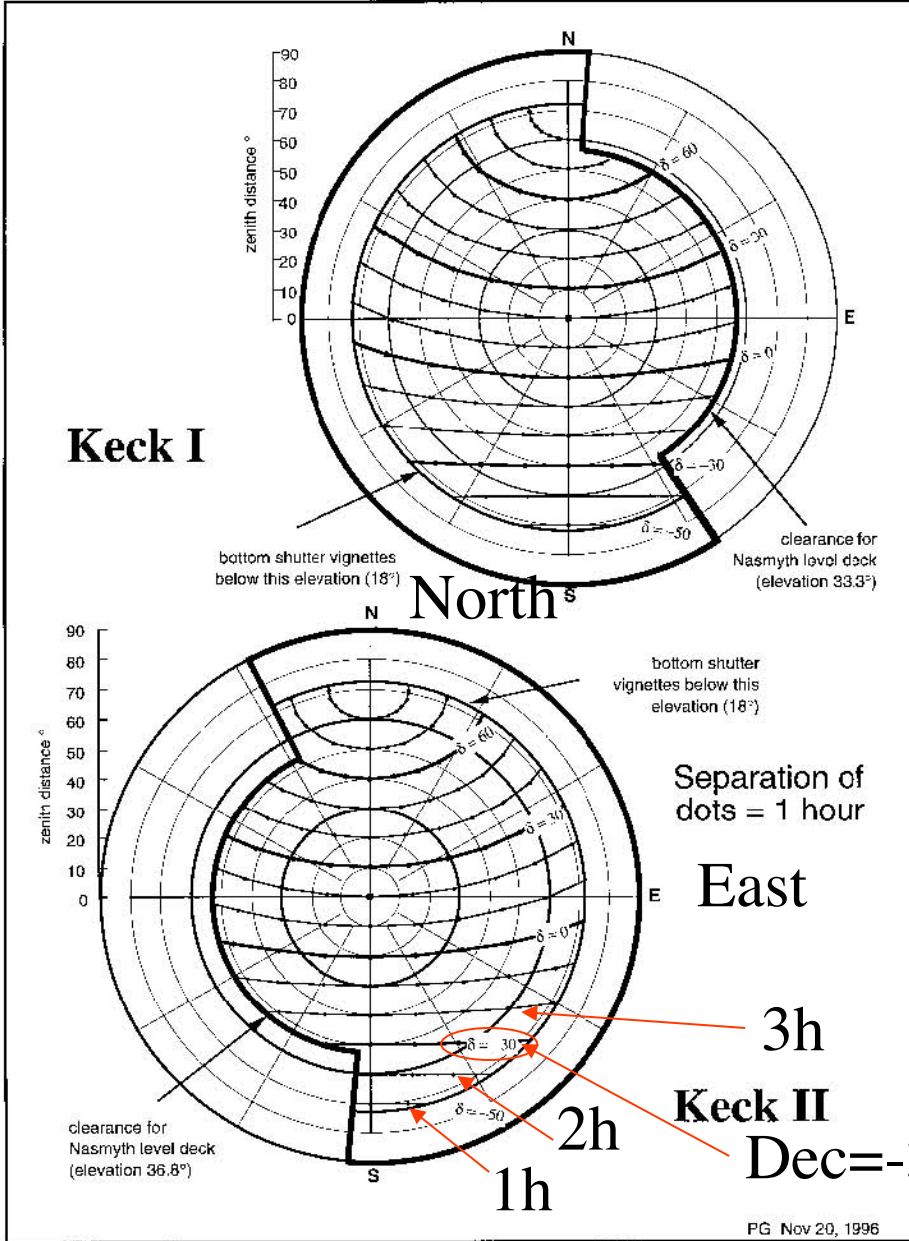Airmass Chart for Mauna Kea, Hawaii, Latitude 19°49'.7

A. Weinberger, 7/10/95
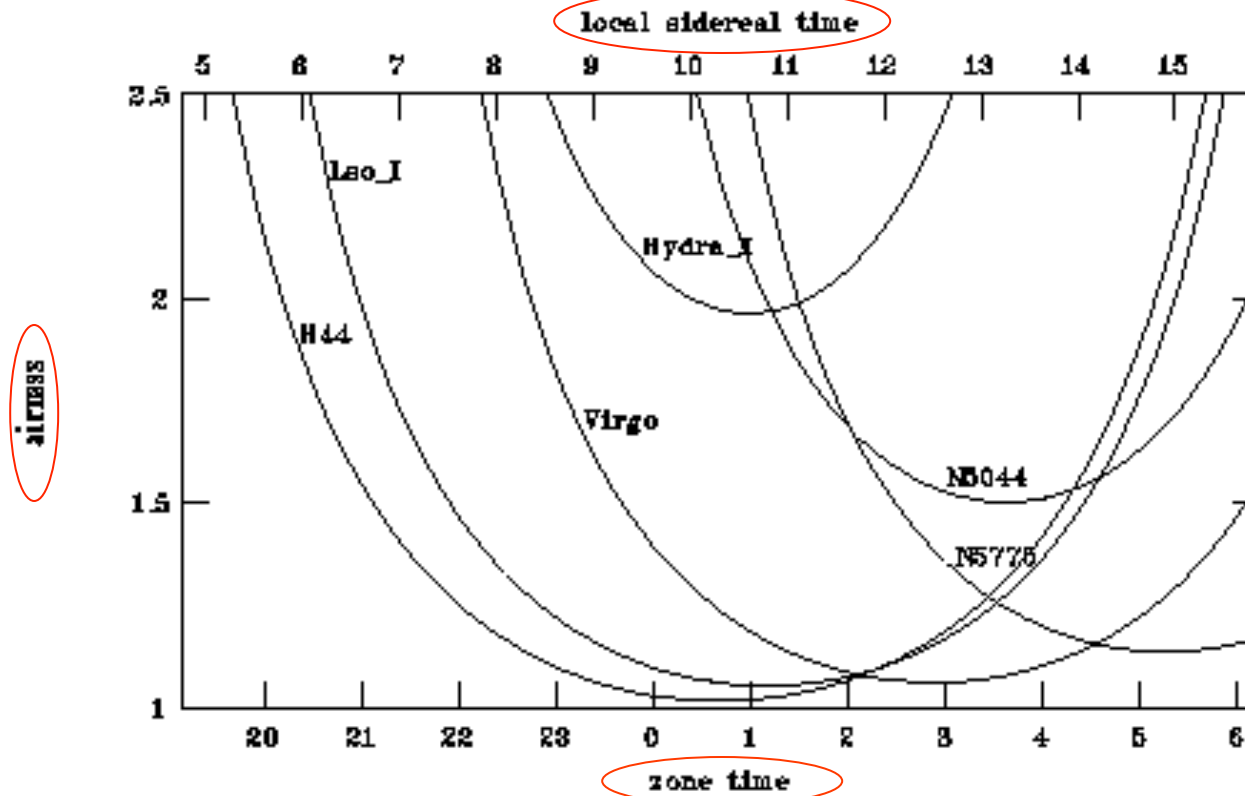
- IRAF Airchart in the mtools package.
- Typically observe with airmass=X<2
- Atmospheric dispersion can be a problem for X>1.5

Lots of options on line for airmass calculators

- https://astro.swarthmore.edu/airmass.cgi
- http://www.ucolick.org/~magee/observer/
- http://iopscience.iop.org/article/10.3847/1538-3881/aaa47e/pdf
- https://www.dartmouth.edu/~physics/labs/skycalc/flyer.html

Keck I

Keck II

North

East

Separation of dots = 1 hour

3h

2h

1h

Dec=-30

There are often other limits that govern where you can point in the sky.

Decisions before observing

- Sometimes, the gain in e-/DN for the system
- On-chip binning?
  - Smaller files (not important)
  - Faster readout time (can be important)
  - Less readout noise per area detector (can be important)
- For direct imaging in broadband filters, readnoise is very rarely an issue. You want to have the FWHM of point sources to be at least 2.5 pixels to properly sample the PSF. If you are oversampled, that doesn't usually have any dire consequences. The readout time can be a deciding factor.

Binning for spectra

slit

diffraction grating

x

sky emission lines

x

collimator

wavelength
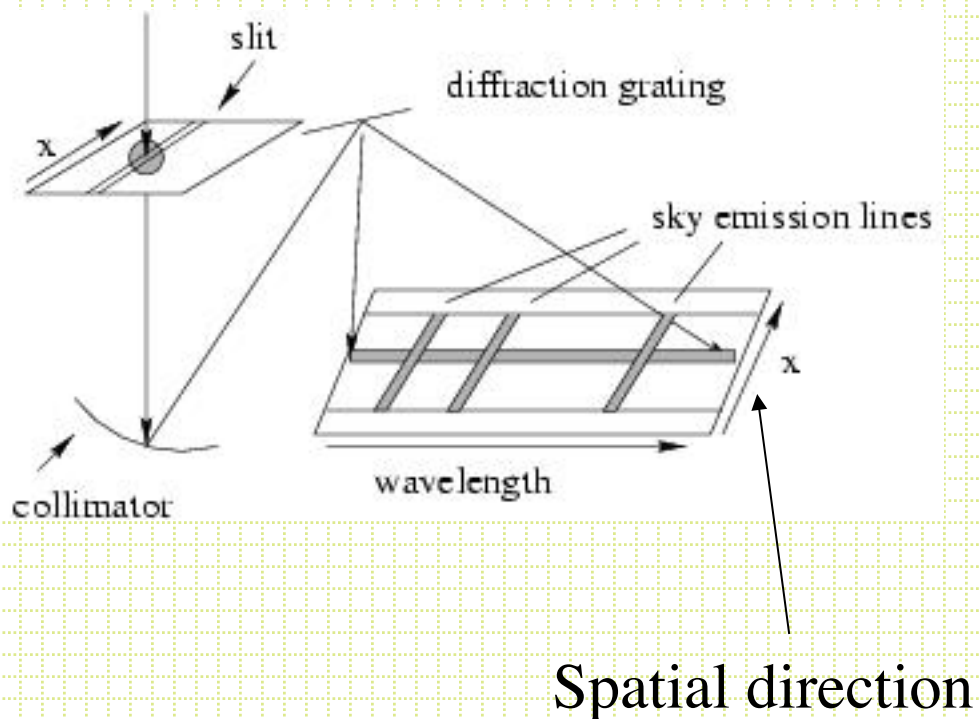
Spatial direction

- Sometimes, RN is a significant component of the noise. Having fewer pixels under the spectrum reduces the noise in a resolution element.

- Binning in *Spectral* direction can reduce resolution

- Binning in the spatial direction can compromise fitting the sky lines

Observing Checklist: Afternoon

- Bias frames - should be boring! WWW site for instrument should have an example to compare to.
  - Move filterwheels, gratings, telescope, dome during readout to see if it will be safe to do so during the night
- Dome Flats
  - Is the shutter opening?
  - Shutter timing observations
- For spectra, check the grating tilts for proper wavelength range
- Things are working- take flats, arcs, biases, darks
- Get quick-look reduction procedures in place

At Night

- Efficiency is everything!
  - Have the shutter open
  - Know your S/N goals
  - Have targets queued up
  - Check focus
  - Have the shutter open
- Be looking at your data in near real time including flat-fielding and bias subtraction
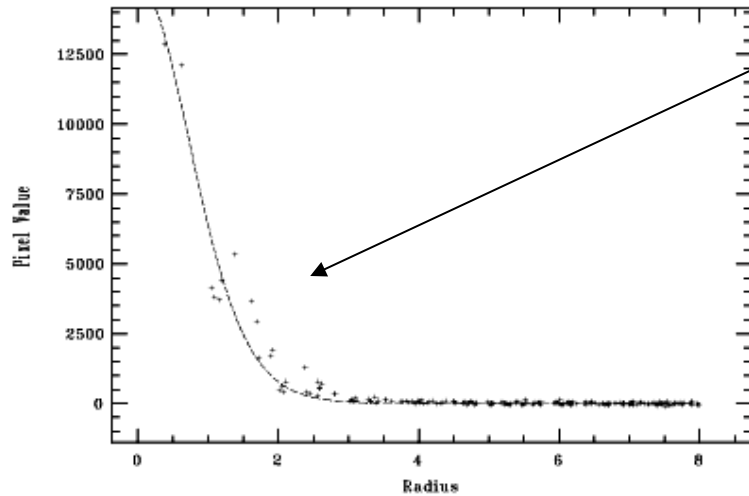
Telescope Focus

- Whether you focus yourself or the telescope operator does it for you, you need to always be checking *radial profiles*.
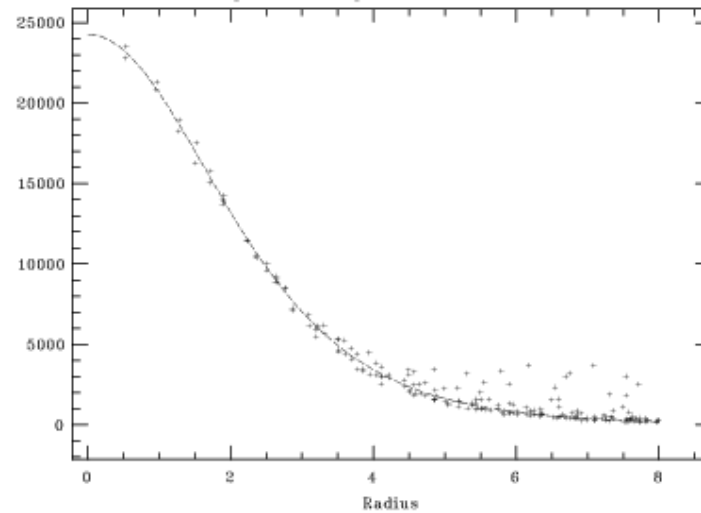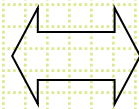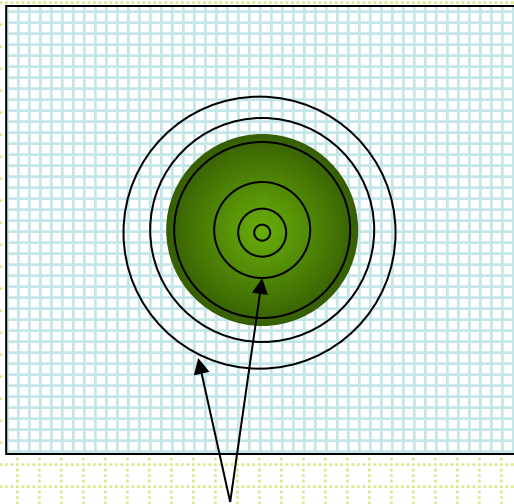
Plot intensity values for pixels that intersect circles

NOAO/IRAF V2.12.1-EXPORT bolte@atacama.ucolick.org Wed 17:18:25 31-Mar-
d29: Radial profile at 323.38 602.98
focus

Poor focus (scatter is lack of roundness and probably astigmatism)

- Using the ``r'' command in IRAF's *imexam*, you can produce radial profiles for any object in a frame. :.snap eps in the graphics window will output an .eps file.
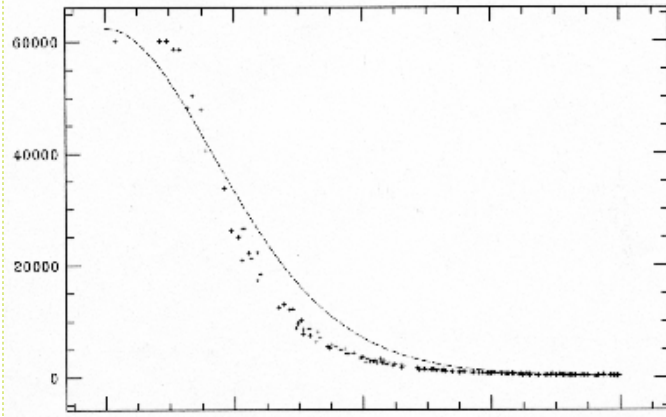
NOAO/IRAF V2.11.2EXPORT bolte@mojave.ucolick.org Tue 09:36:35 25-Jan-2
f40: Radial profile at 446.80 546.56
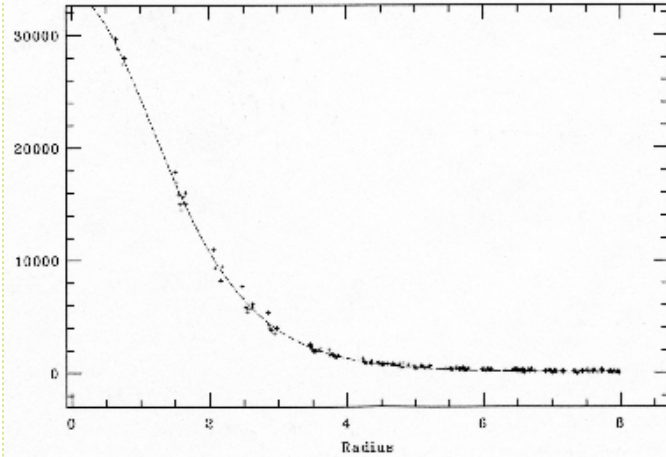M92 V 300s
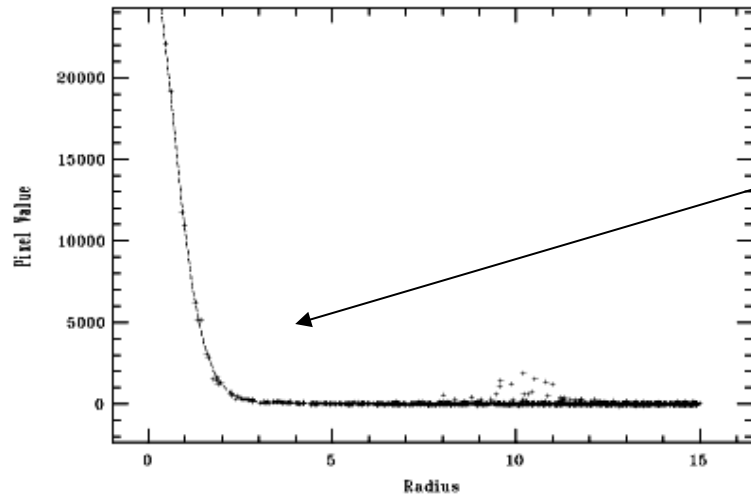
Excellent focus. Very round (and dangerously sharp) image
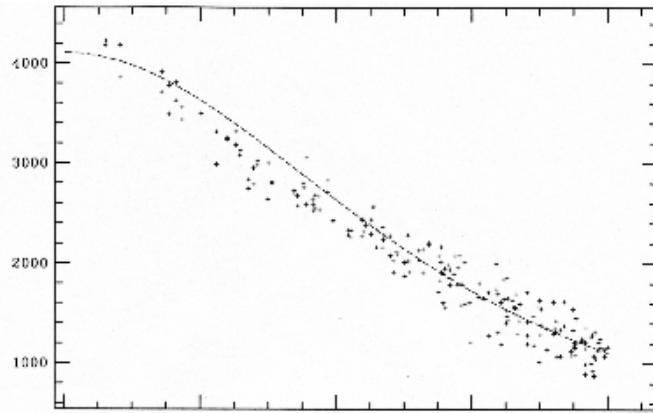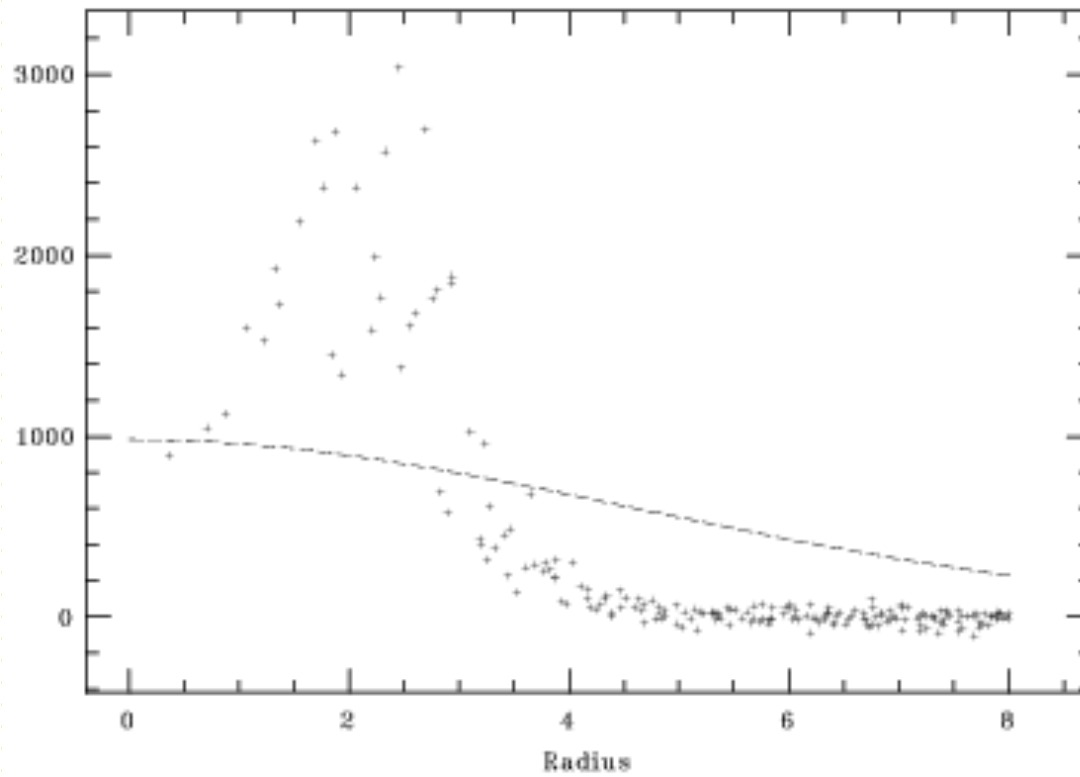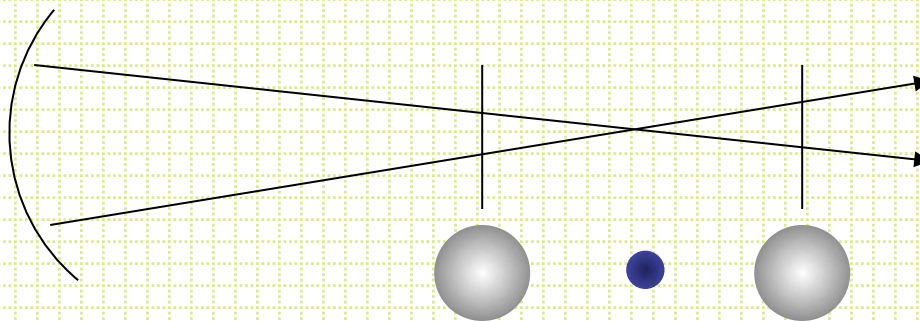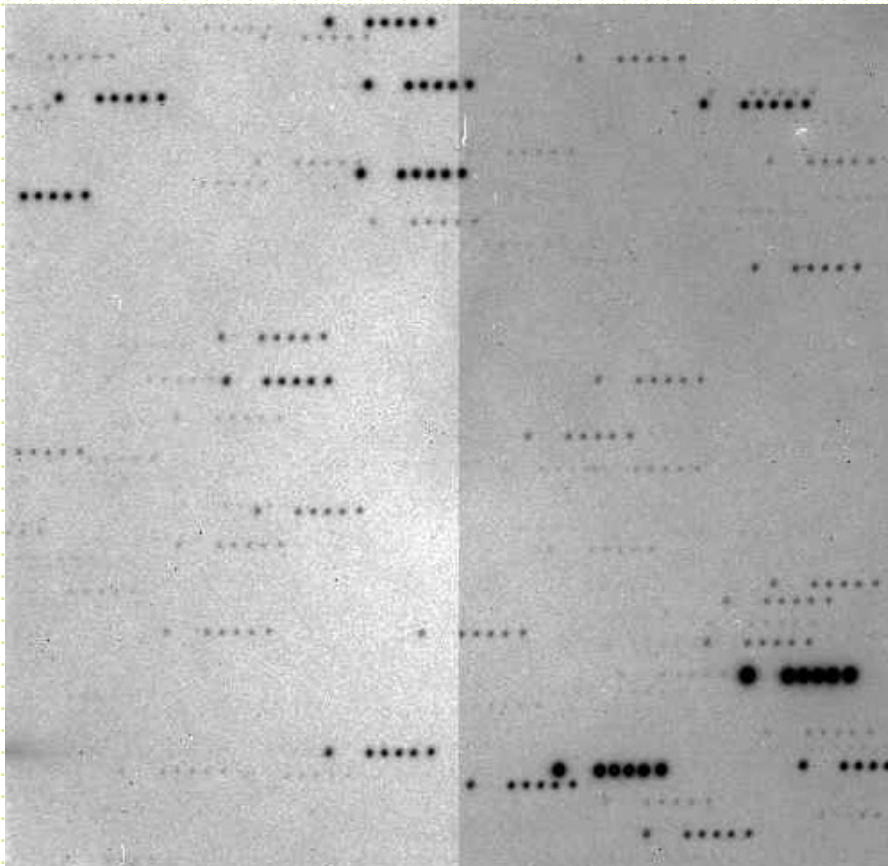
Galaxy

Saturated star

Well-focussed star

Way out of focus (donut).

Focus frames

1. Set focus, start exposure.
2. Pause exposure, move telescope, change focus
3. Repeat
4. Make a double telescope move on the last focus value, then read out

Splitting Exposures

- How long to expose? Once in the sky-limited regime, the S/N only depends on the total exposure time. There is only the CCD readout time penalty to be paid by splitting long exposures into multiple shorter exposure.

- Why do shorter exposures?
  - Cosmic ray rejection
  - Increase dynamic range
  - ``in-field dithering'' along slit or on the sky can help with flat fielding
  - Reduce risk

Preliminary Processing

- There are two types of instrumental signature to remove:
  - <u>Additive</u>:
    - Bias Level
    - Bias Structure
    - Dark Counts
    - ``charge skimming''

    Constant # of counts added independent of the brightness of the source(s).

  - <u>Multiplicative</u>:
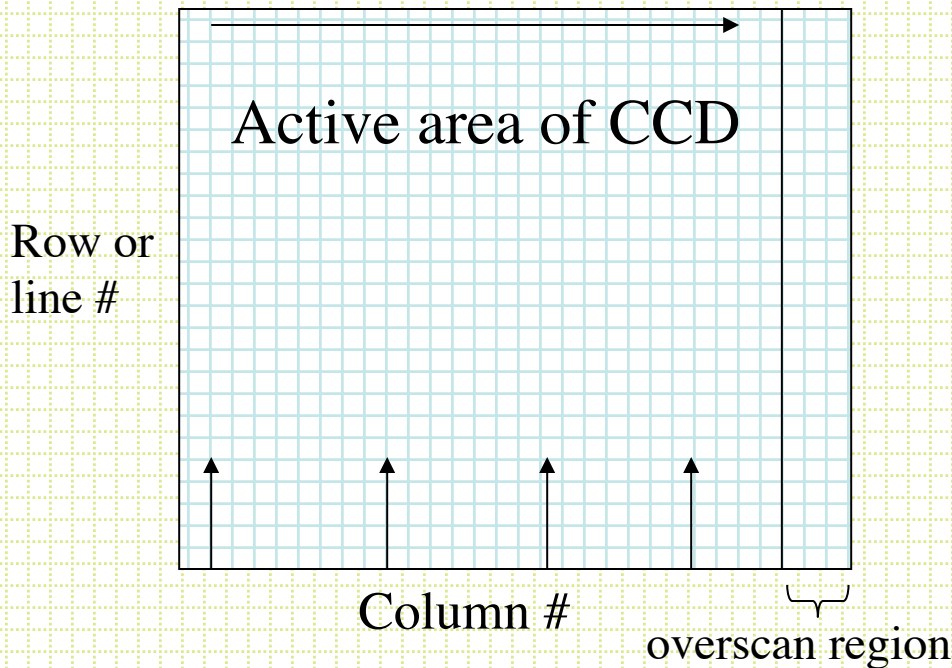   - Q.E. variations on all scales

    Constant *fractional* effect

Bias Correction

- Bias <u>level</u> and any y (along columns) gradient is taken out via *overscan* subtraction.

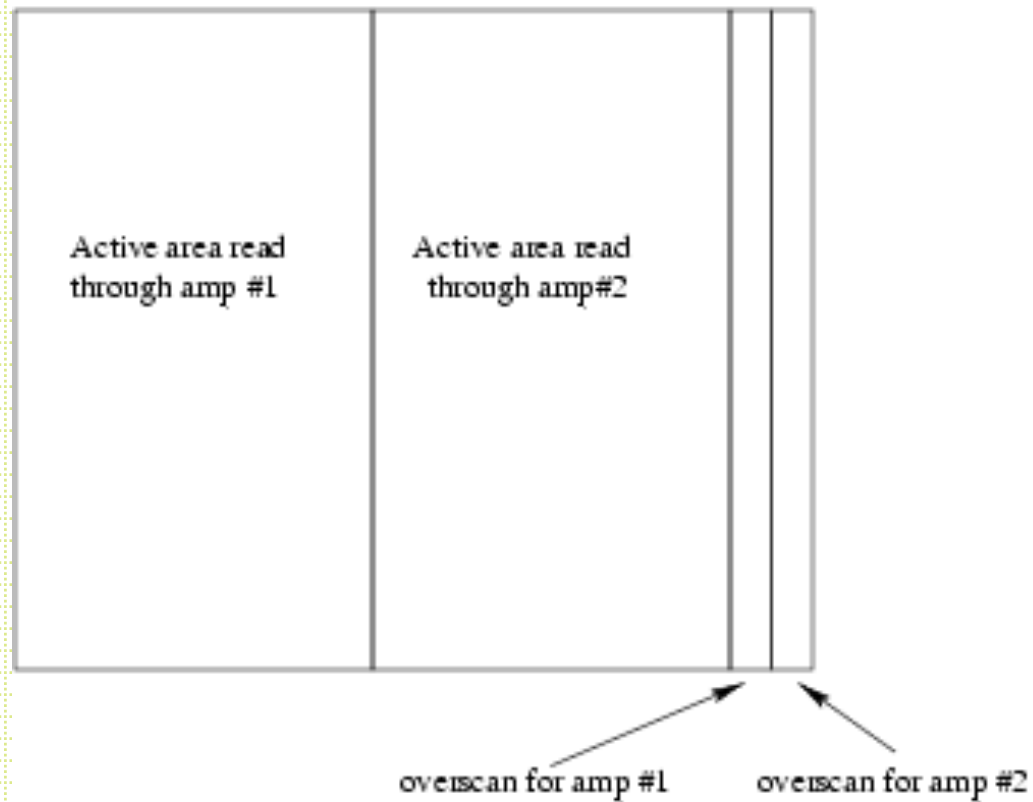- Bias <u>structure</u> is taken out by subtracting a *zero-level* frame.

Overscan

Active area of CCD

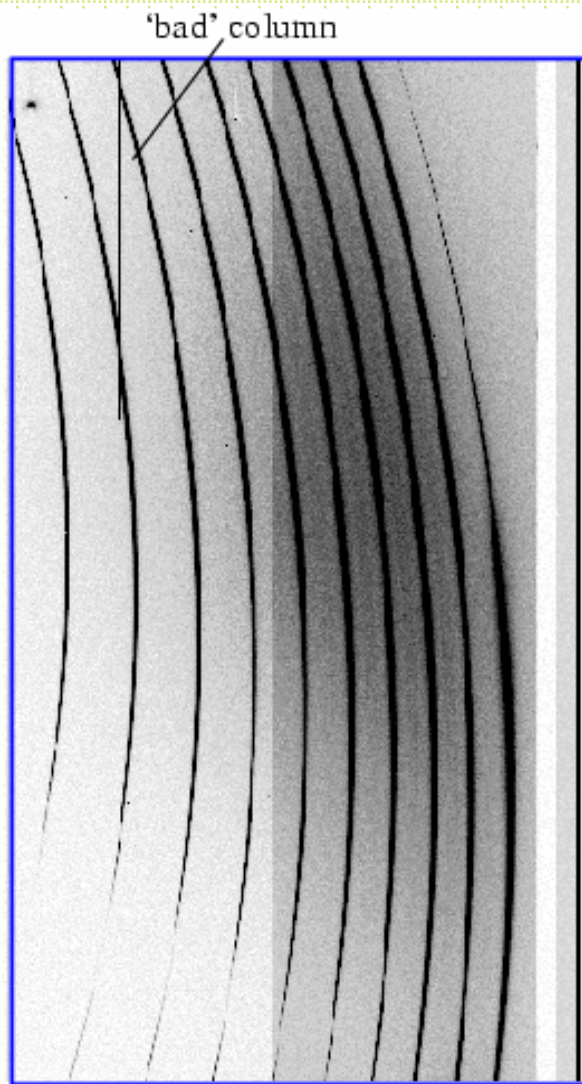Row or
line #

Column #

overscan region

- After reading out the CCD `real' pixels, you can continue to read out virtual pixels and record the bias level and read noise of the amplifiers. These virtual pixels are called the <u>overscan</u> region

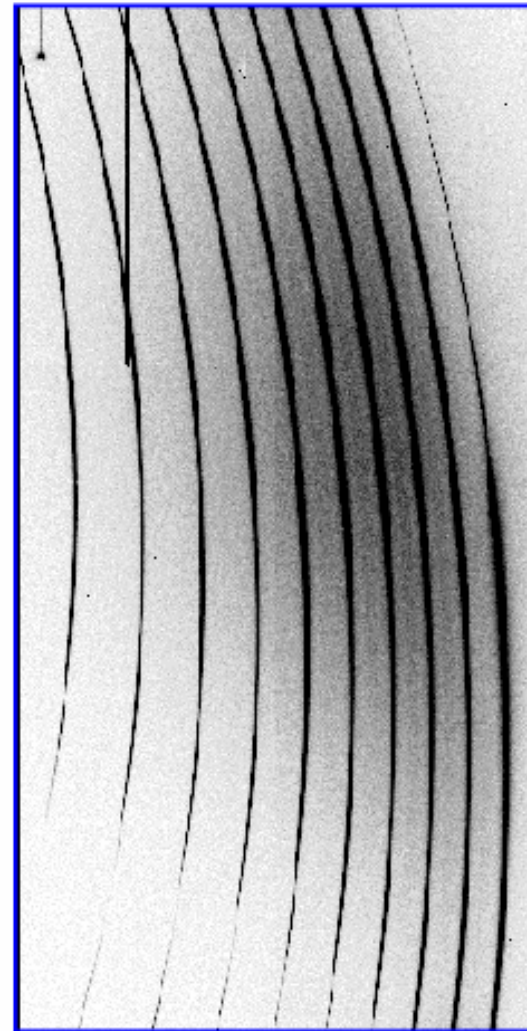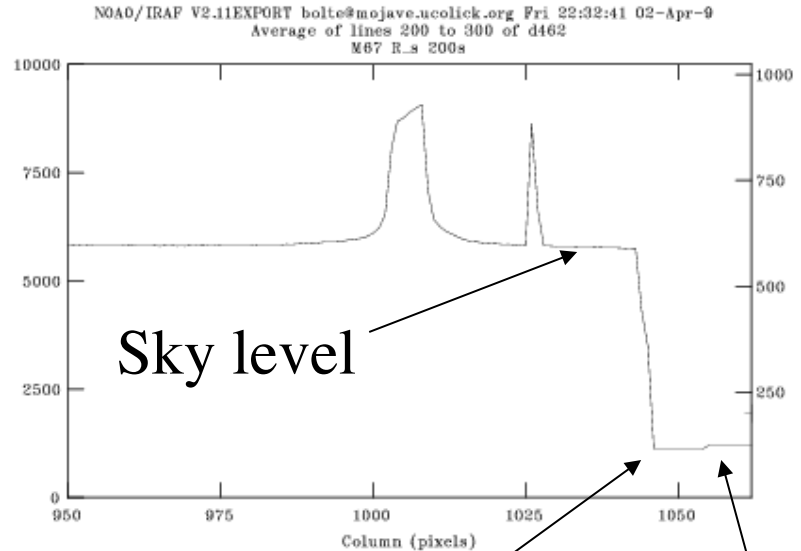# Two amplifier overscan

Dual amplifier readout

Active area read
through amp #1

Active area read
through amp#2

overscan for amp #1   overscan for amp #2

'bad' column

RAW FRAME

OVERSCAN CORRECTED/TRIMMED

overscan for Amp#1

overscan for Amp#2

Overscan subtraction

NOAO/IRAF V2.11EXPORT bolte@mojave.ucolick.org Fri 22:32:41 02-Apr-9
Average of lines 200 to 300 of d462
M67 R_s 200s

Sky level

Overscan#1

Oscan#2

- First you need to identify the relevant columns.
- In IRAF use the format:

  [x1,x2:y1,y2]

In IRAF, plots like this are made using *implot*

Colbias task

- The overscan subtraction is accomplished by fitting a smooth function to the average of several columns in the overscan region.

- The value of the fitted curve is subtracted from each row ("line"). This accounts for a mean bias level and any gradient in along columns.
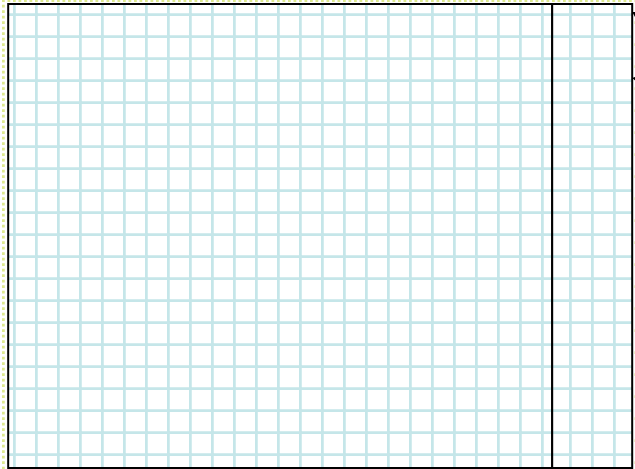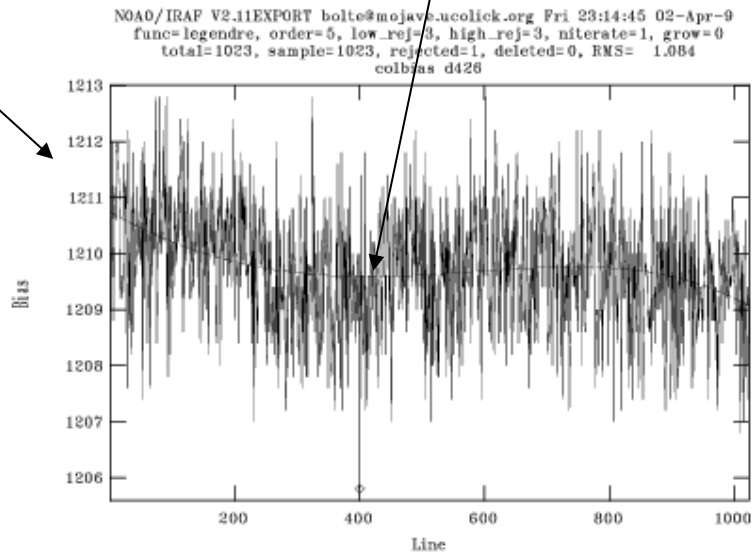
In IRAF,
lines are horizontal,
columns vertical

Smooth fit is subtracted
from each row

Average over
several columns

Bias level

NOAO/IRAF V2.11EXPORT bolte@mojave.ucolick.org Fri 23:14:45 02-Apr-9
func=legendre, order=5, low_rej=3, high_rej=3, niterate=1, grow=0
total=1023, sample=1023, rejected=1, deleted=0, RMS= 1.084
colbias d426

Line #

- http://mtham.ucolick.org/egates/2016GradWorkshop/PDFs/DataReduction/DataReductionProcedures-Python-2016.pdf
- http://www.ucolick.org/~bolte/AY257_18/esibt.cl general bias and trim
- http://www.ucolick.org/~bolte/AY257_18/esibt_2amp.cl hardwired bias and trim
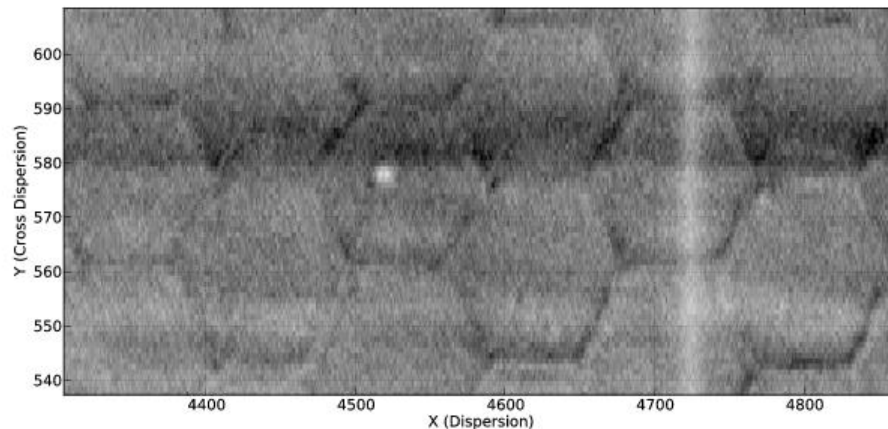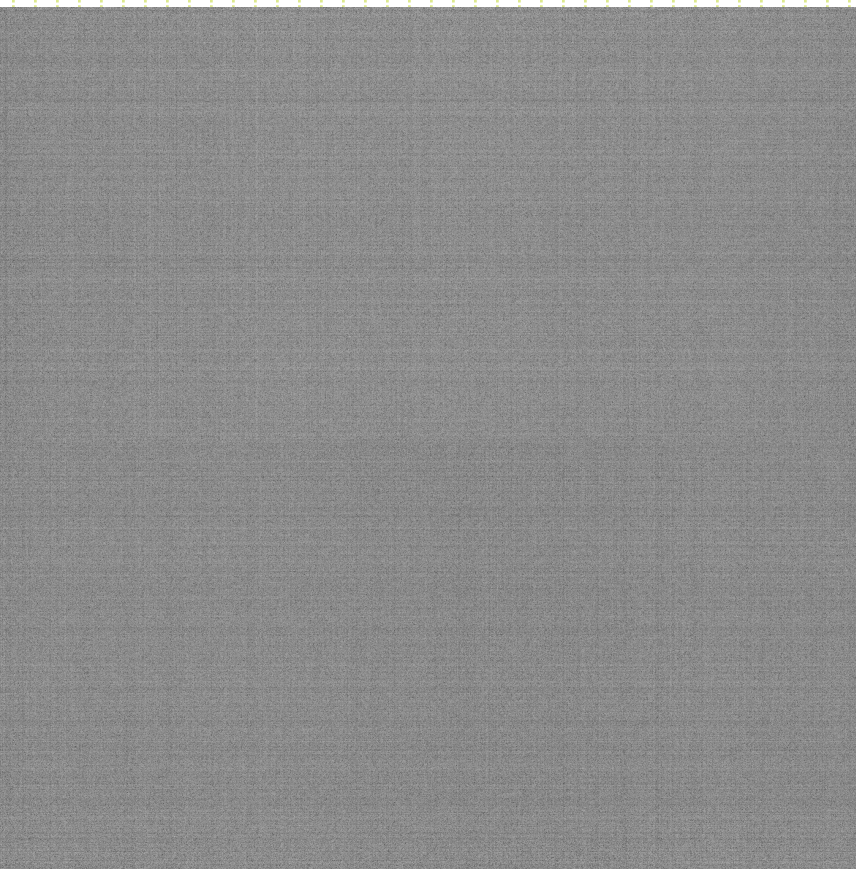
Flat Fielding

- There are pixel-to-pixel QE variations and lower spatial frequency QE variations in all electronic detectors. The goal of flat-fielding is to multiply every pixel by the correct normalizing factor to eliminate these QE differences.

- If you could illuminate the CCD uniformly, then normalize the mean to 1, this image could be divided into every frame.

Pixel-level QE variations arise from manufacturing processes and flaws.

Almost always wavelength dependent because photons of different wavelength are absorbed at different z-distances in the detector. Longer wavelength photons penetrate further in silicon devices

When imaging with different filters it is important to generate flat-fields for each filter

Flat Fielding

- Ideally, illuminate the detector with a source that is as flat on the sky as the background and collect at least a million e- per pixel. Then could flat-field to $\frac{\sqrt{10^6}}{10^6} = 0.001$ =0.1%.

- For direct imaging, usually use a combination of:
  - Dome Flats
  - Twilight Flats
  - Dark Sky Flats

Dome Flats

- Put some quartz (hot, continuum source) lamps on the telescope and illuminate a white screen or spot on the dome.
- These often don't work very well for two reasons:
  - The lamps are always too cool (red)
  - The dome is not even close to infinity and usually illuminates the primary differently than the sky
- But, you can collect a lot of photons during the day

Lamp
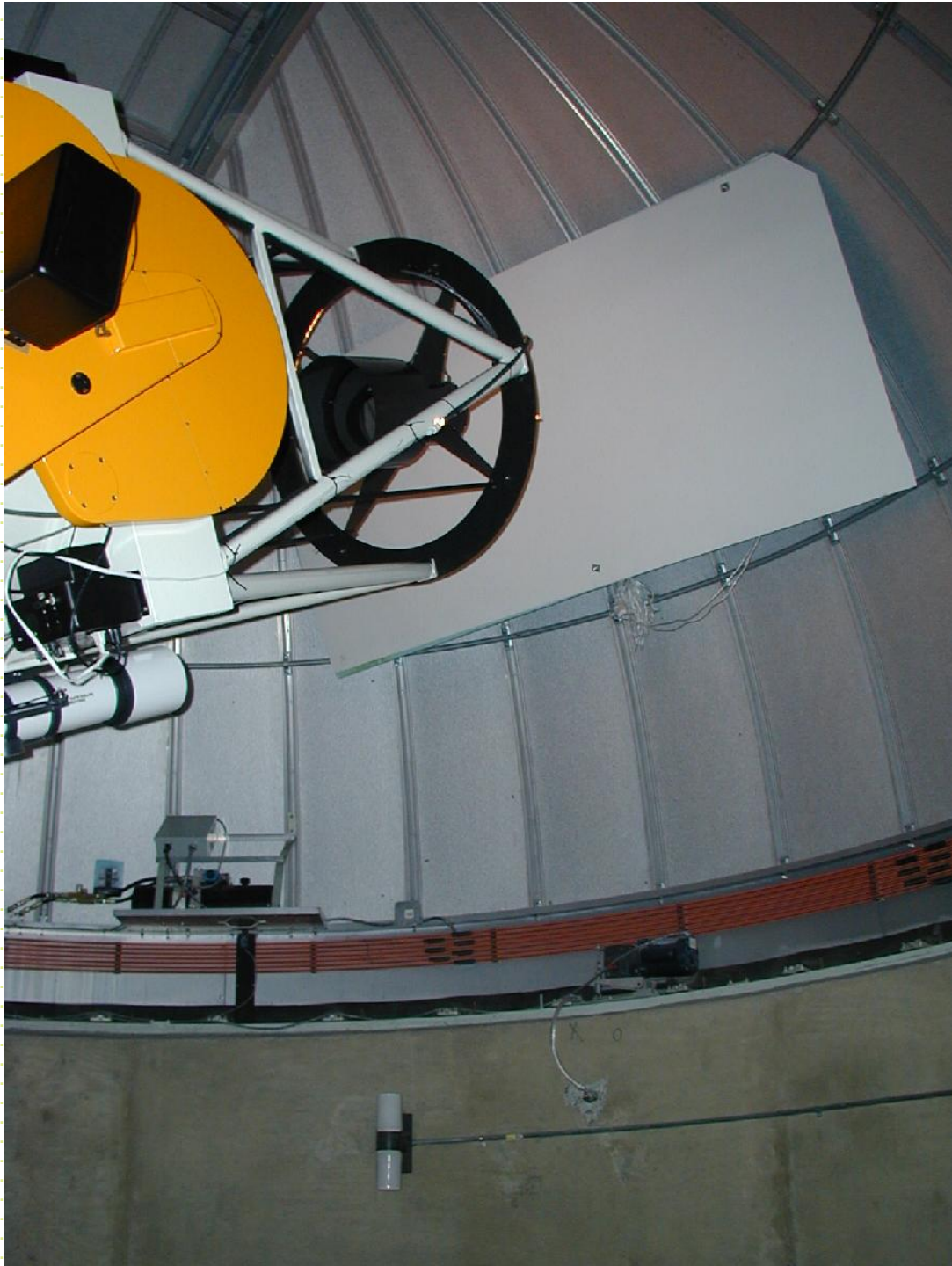
Twilight Flats

- These often work pretty well
- The Sun is pretty hot, the scattering surface illuminates the telescope just like the dark night sky
- Doesn't use dark time

Dark-sky Flats

- These tend to work very well. They match the sky perfectly
- They sometimes require useful dark time
- They sometimes contain fringes

Stars and Galaxies

- For twilight and dark sky flats you have a problem in that they contain stars and galaxies. The usual trick is to move the telescope between exposures and then do a non-registered stack of the frames in each filter.

- Median or better yet *minmax* rejection (for example, in the frame combining can effectively eliminate all the stars and galaxies in the combined flat.

Minmax rejection

Pixel value: 1000   200   180   180
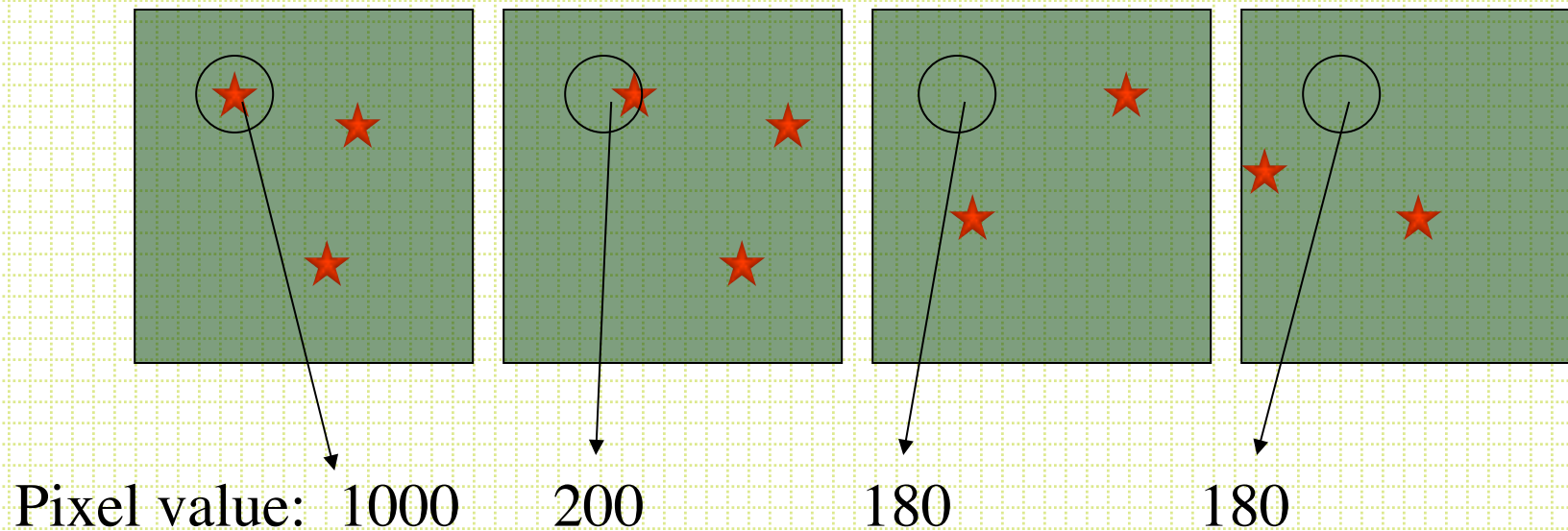
Average with minmax rejection, reject 2 highest value averaging lowest two will give the sky value. NOTE! Must normalize frames to common mean or mode before combining! Sometimes it is necessary to pre-clean the frames before combining.

Combining Frames

- In IRAF, *imcombine* is the task to combine frames.
    - combine=average
    - reject=minmax
    - scale=mode
    - nlow=0
    - nhigh=2

Flat fielding tricks

- Combine domes (high counts, bad illumination) with dark sky flats (low counts, excellent illumination).

  1. Spatially smooth (or fit low-order surface to) both combined dome and combined dark sky. > sDome, sDark

  2. Remove dome low-spatial-frequency pattern: Dome/sDome

  3. sDark is the sky flat with the low-f pattern already removed.
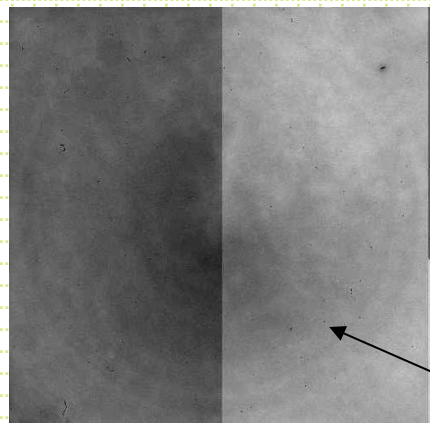
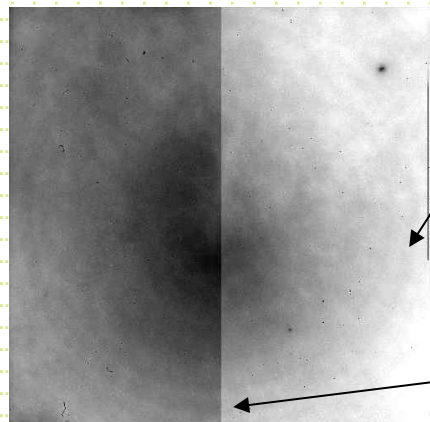 4. Best of both worlds is (Dome/sDome) x sDark
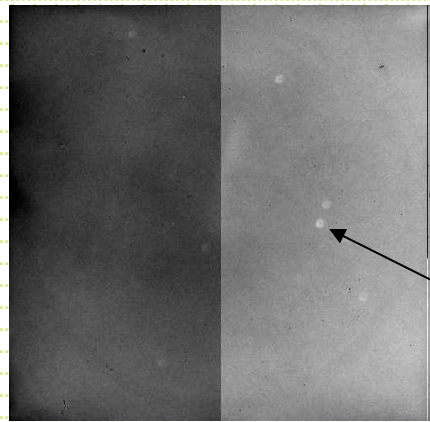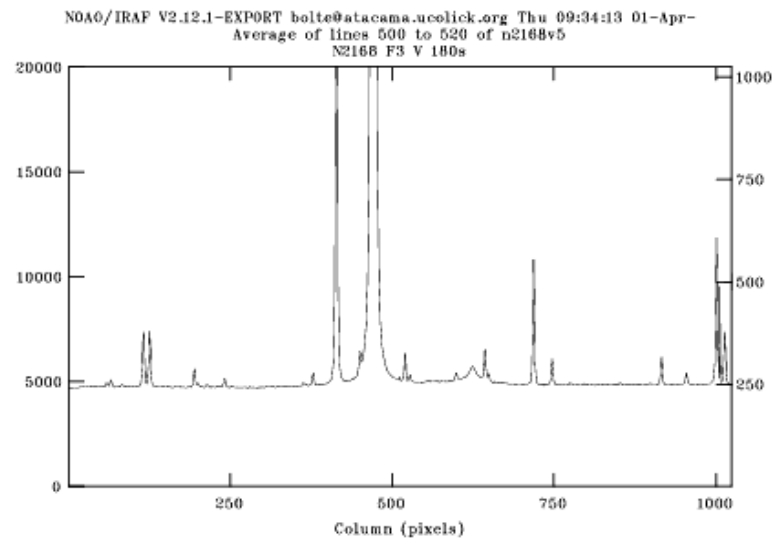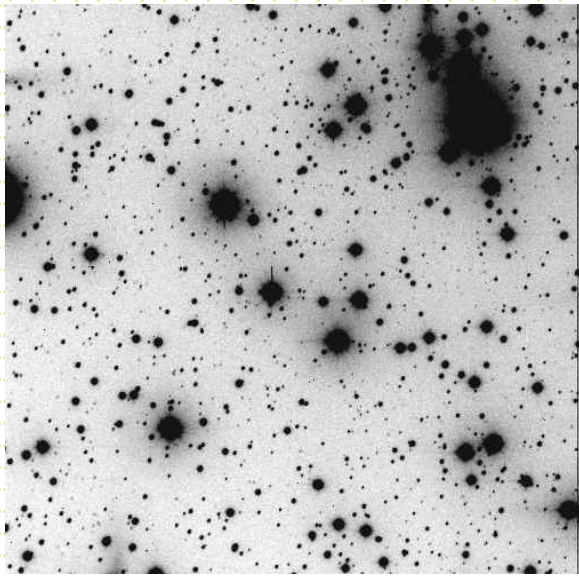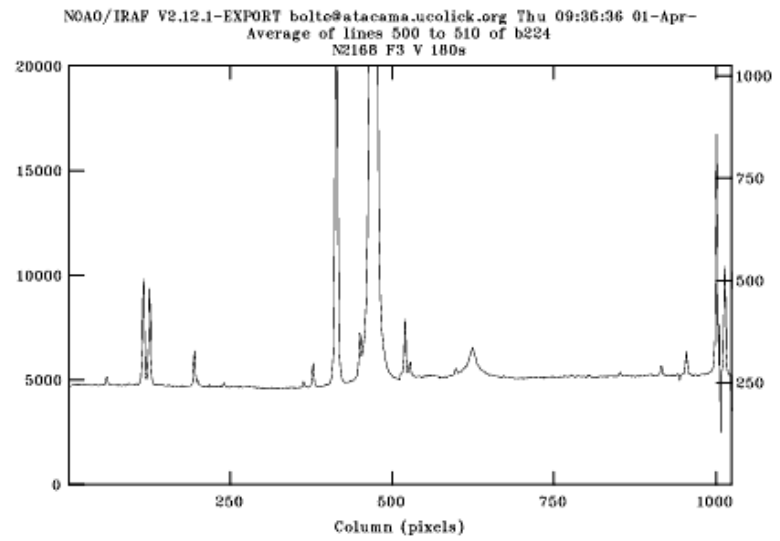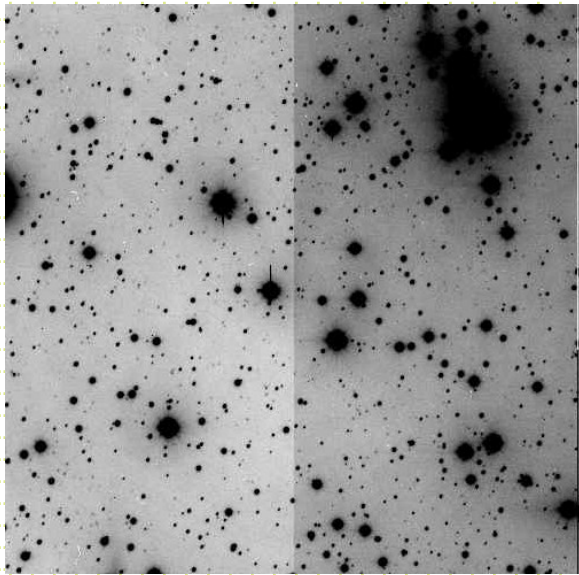
I-band

PFCam flat fields

Dust on filter

Note differences with color.
This means that objects with
different spectra will be flat-
fielded slightly incorrectly.

V-band

Rings due to non uniform thinning

U-band

Two amplifer readout

NOAO/IRAF V2.12.1-EXPORT bolte@atacama.ucolick.org Thu 09:36:36 01-Apr-
Average of lines 500 to 510 of b224
N2168 F3 V 180s

NOAO/IRAF V2.12.1-EXPORT bolte@atacama.ucolick.org Thu 09:34:13 01-Apr-
Average of lines 500 to 520 of n2168v5
N2168 F3 V 180s

Flat-field tests

1. Take cuts through your flat-fielded frames and make sure the sky is flat (check corners). IRAF *implot*

2. In blank areas, make sure the pixel-to-pixel variations are consistent with shot noise from the sky level. IRAF *imexam* and the `m' key. (take gain into account)

Reduction software

- http://www.iac.es/sieinvens/siepedia/
  pmwiki.php?n=HOWTOs.IrafMacOSX

- http://www.stsci.edu/institute/
  software_hardware/pyraf

- https://stak-notebooks.readthedocs.io/en/
  latest/

- https://media.readthedocs.org/pdf/stak-
  notebooks/latest/stak-notebooks.pdf