Astro 500

Techniques of Modern Observational Astrophysics

Matthew Bershady
University of Wisconsin

Lecture Outline

- What is the AΩ argument?
- Proposals
- Observing
  - Coordinates & visibility
  - Planning tools
  - Decisions before observing
  - At Night: efficiency, focus, and calibration
- Preliminary Data Processing

What is the AΩ argument?

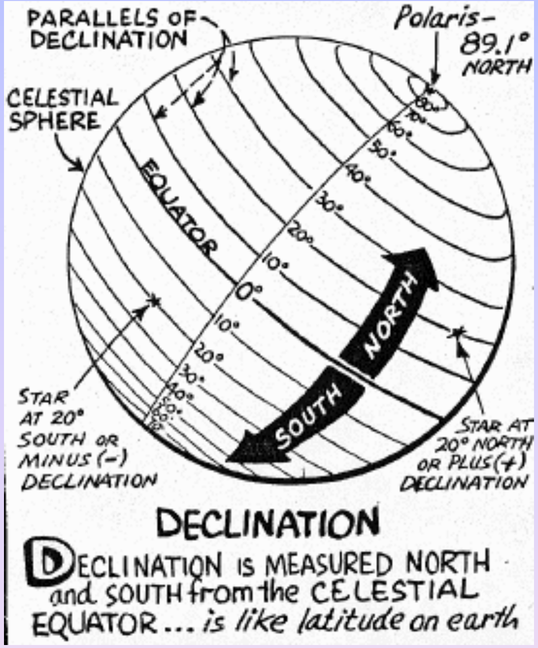
- Given the AΩ argument, why do we want to build larger telescopes?

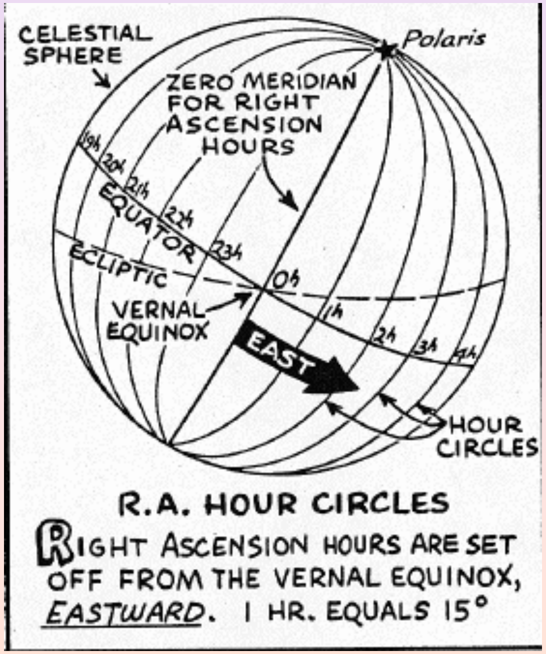
Writing Proposals

- First and foremost: Scientific Justification!
  - Give context
  - Clearly state what unanswered questions are to be addressed
  - Clearly state what you will do new or better
- Look Competent and Smart
  - Do S/N and exposure time calculations
  - Defend choice of filters/spectral resolution sample size etc.

Observing

- Rule #1 -- keep collecting photons!
- Know your S/N targets
- Plan the night out carefully ahead of time
- Useful tools:
  - Aircharts

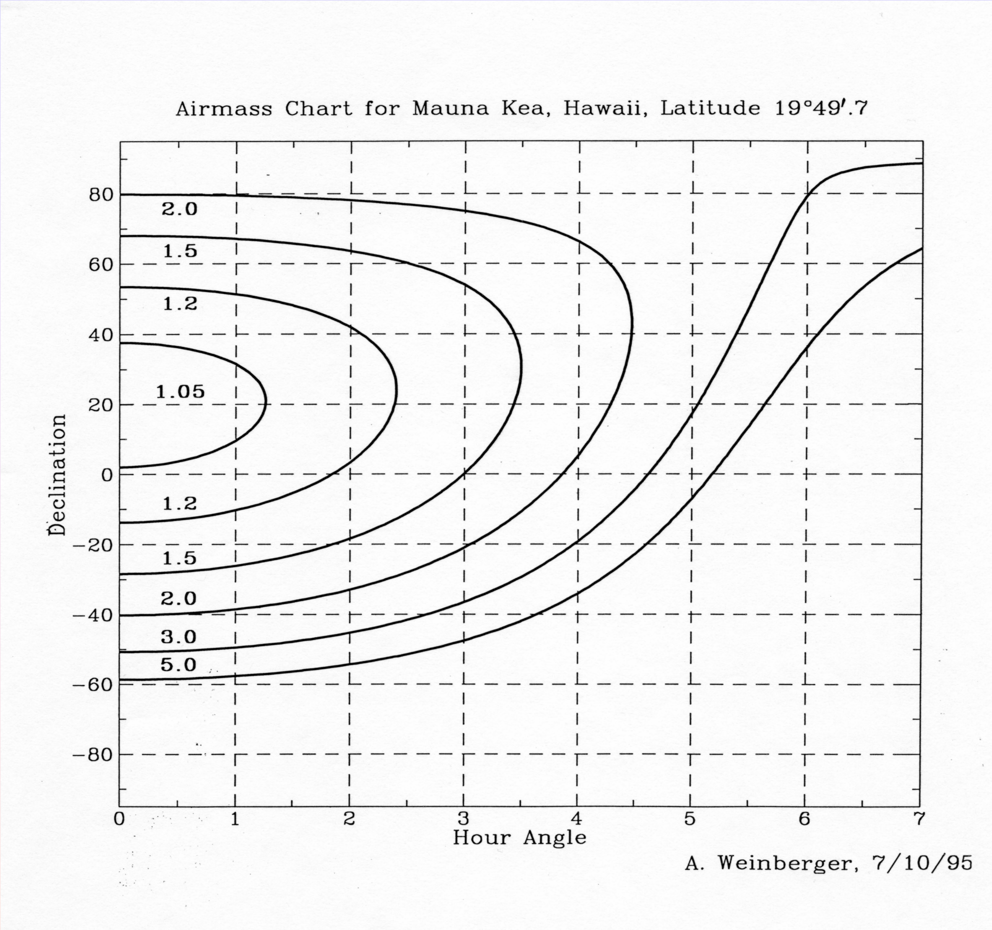


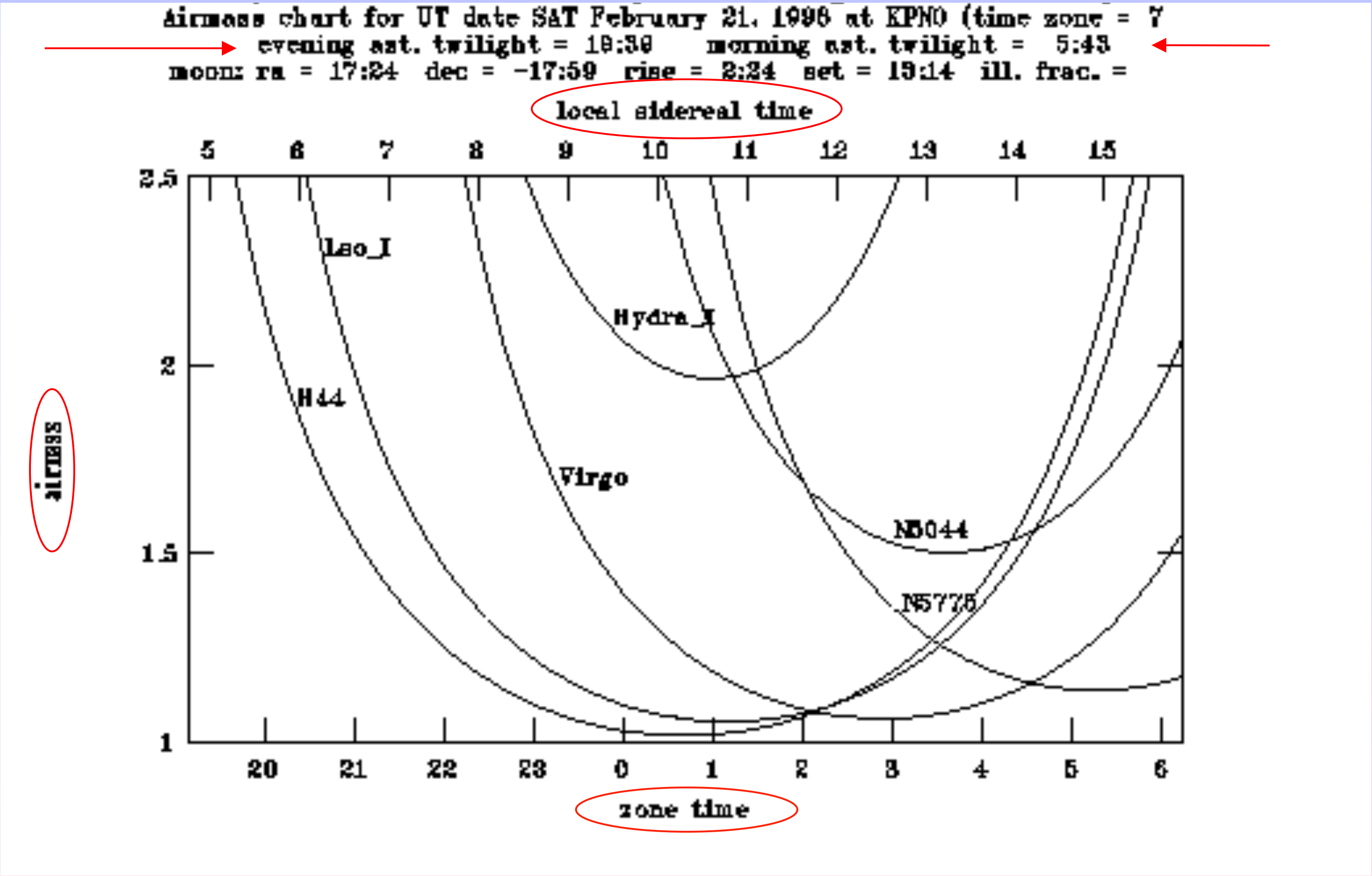


- Right Ascension (RA) and Declination (Dec) are equatorial sky coordinates
- Like longitude and latitude (respectively) on the surface of the Earth but fixed on the sky
- Aligned with the Earth's axis so the RA and Dec for celestial objects changes as the Earth's orbit precesses. Need to specify the "epoch" of the coordinates.

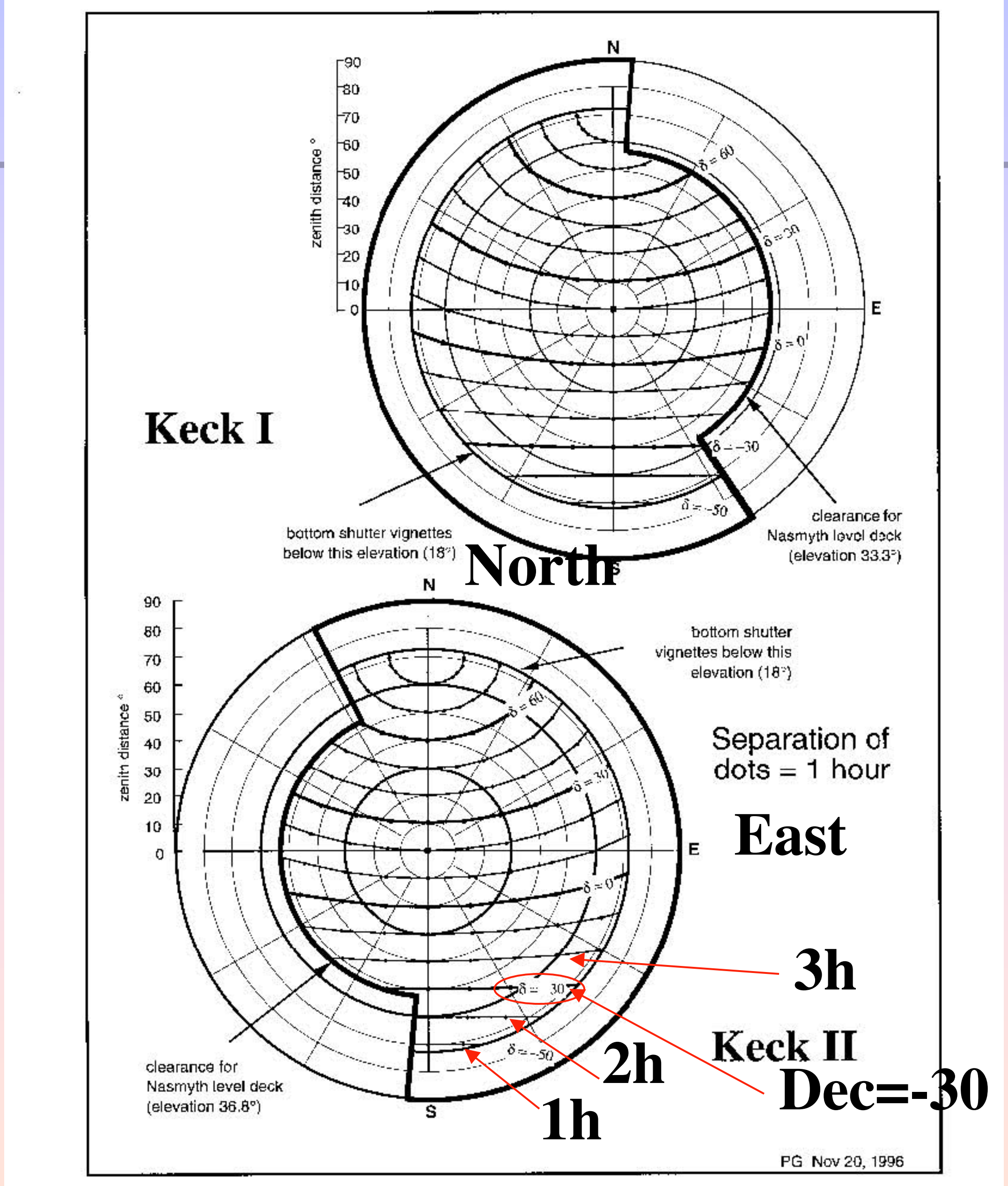
Hour angles and airmass

- 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)





- IRAF Airchart in the mtools packages is very handy.
- Typically observe with airmass = X < 2
- Atmospheric dispersion can be a problem for X > 1.5
- http://www.eso.org/observing/bin/skycalcw/airmass



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

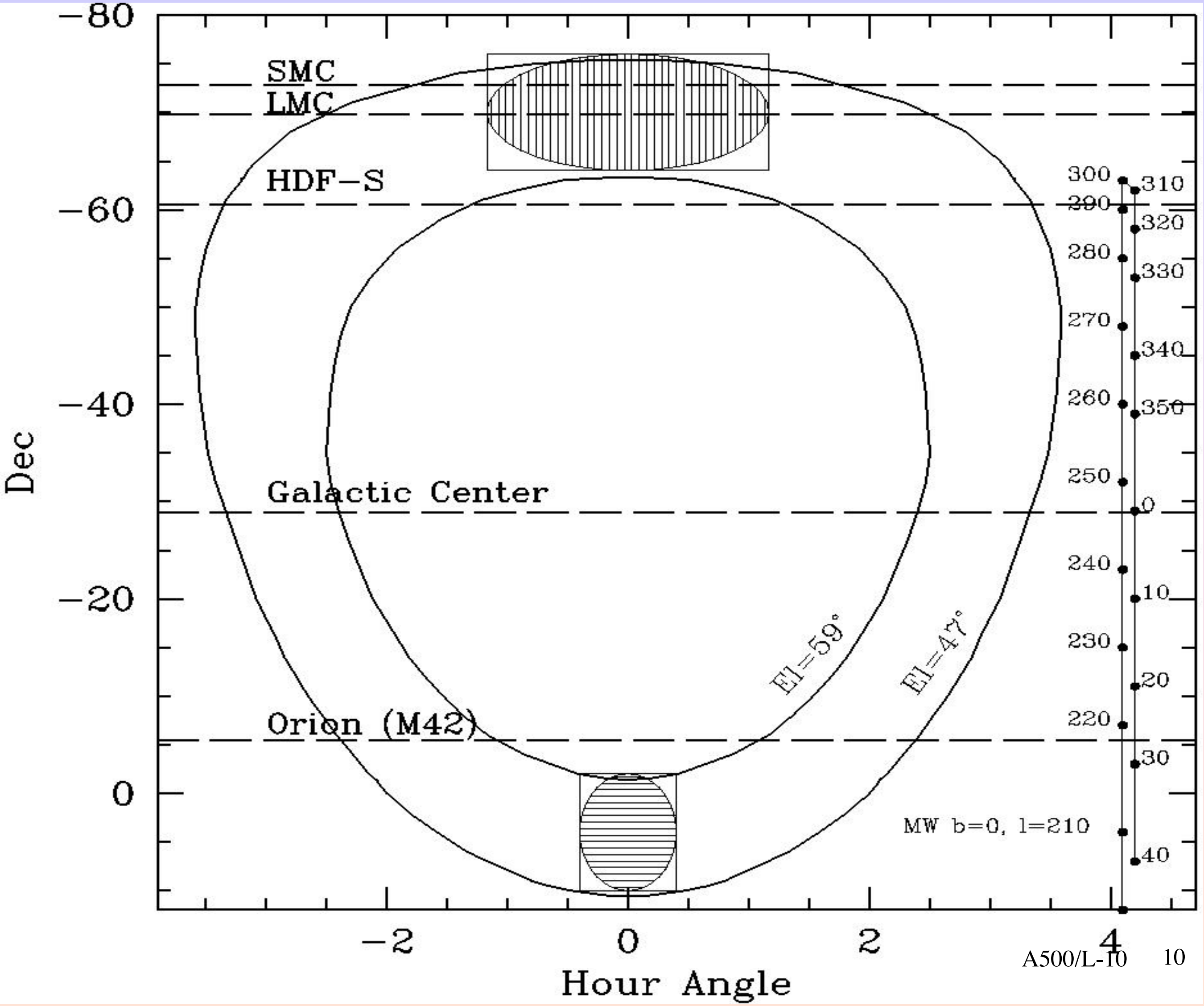
All Alt-Az telescopes cannot track well within ~30 min of zenith, including WIYN.

SALT annulus of visibility

As SALT rotates in azimuth, different areas of the sky fall within the tracker's field of view.

Annulus represents 12.5% of visible sky

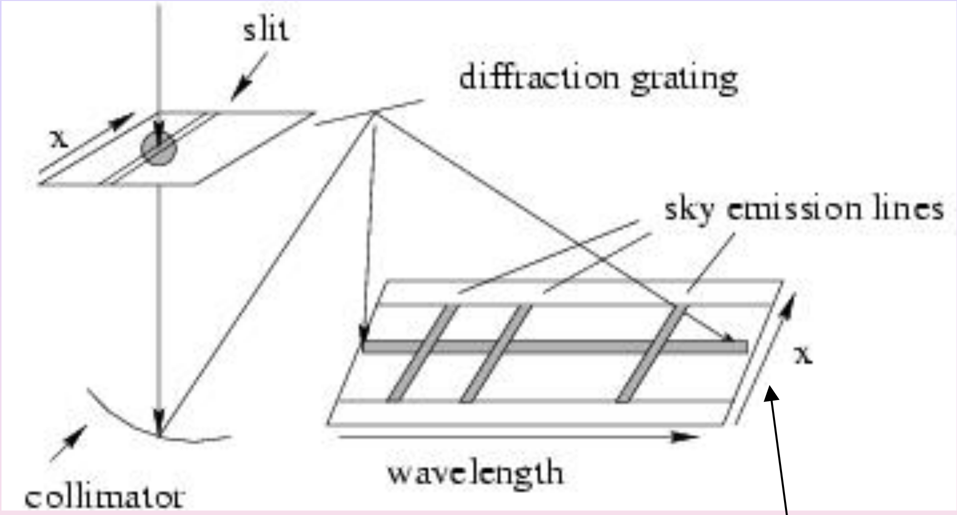
Shaded regions show continuous visibility for extreme North/South declinations



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



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

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

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

The human angle

- The telescope operator (WIYN)
  - Be kind, courteous and informed
  - Help them help you
  - Know what you are doing
  - Be firm, but polite
  - Ask questions if you don't understand

- The queue observer (SALT)
  - Provide them with the information they need
  - Make it neat, concise, and clear
  - Respond promptly to their queries
  - Ask questions if you don't understand
  - Engage them with the science – they are Ph.D. astronomers.

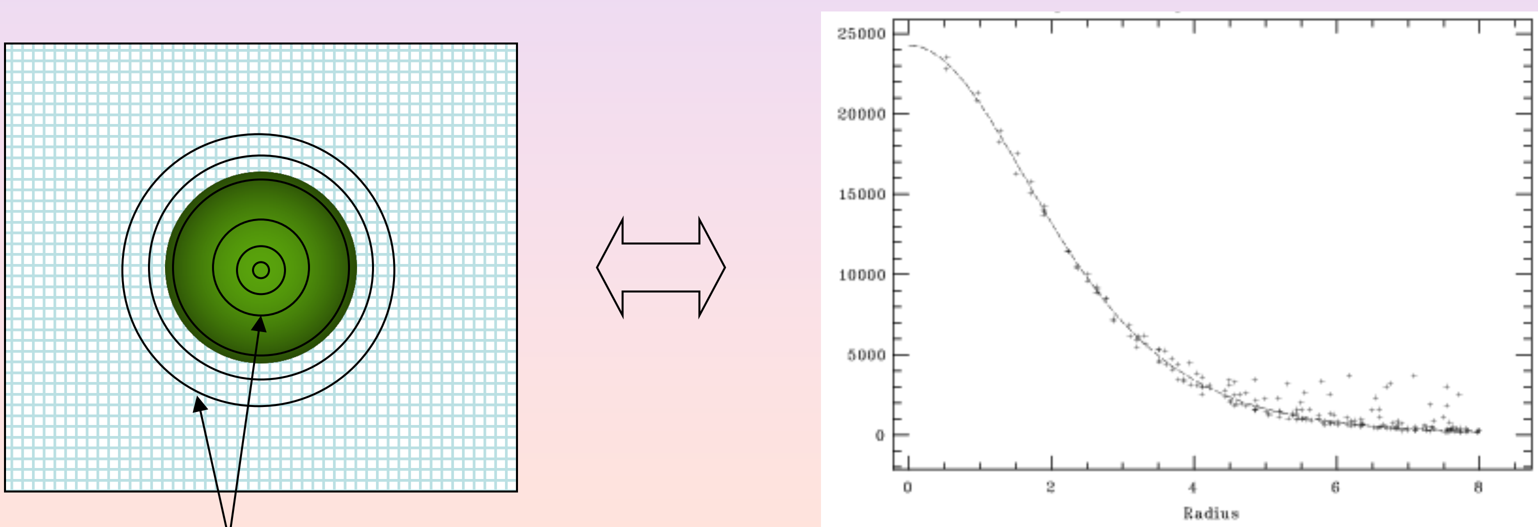
At Night

- 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

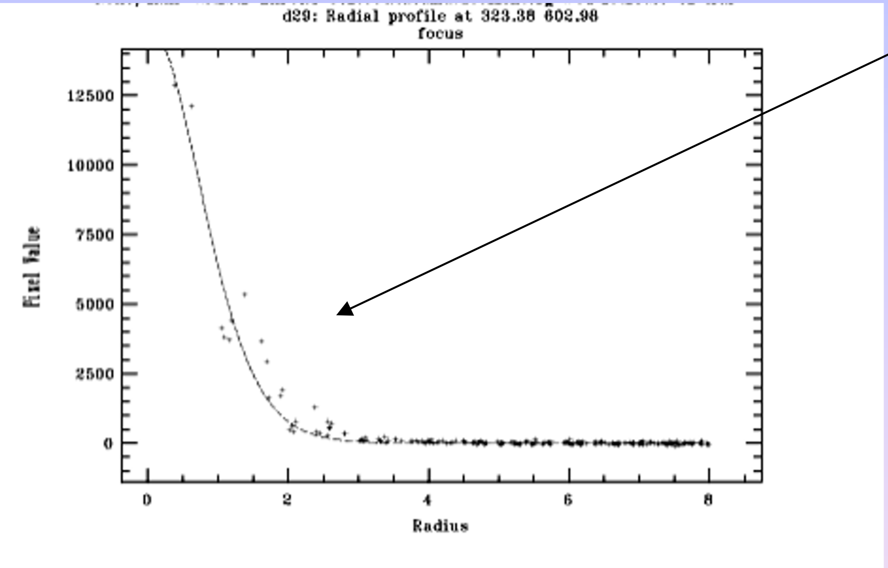
At $1000+ per hour you need to have a sense of urgency (not panic) when you observe.

Telescope Focus

- Whether you focus yourself or the telescope operator does it for you, you need to always be checking *radial profiles*.

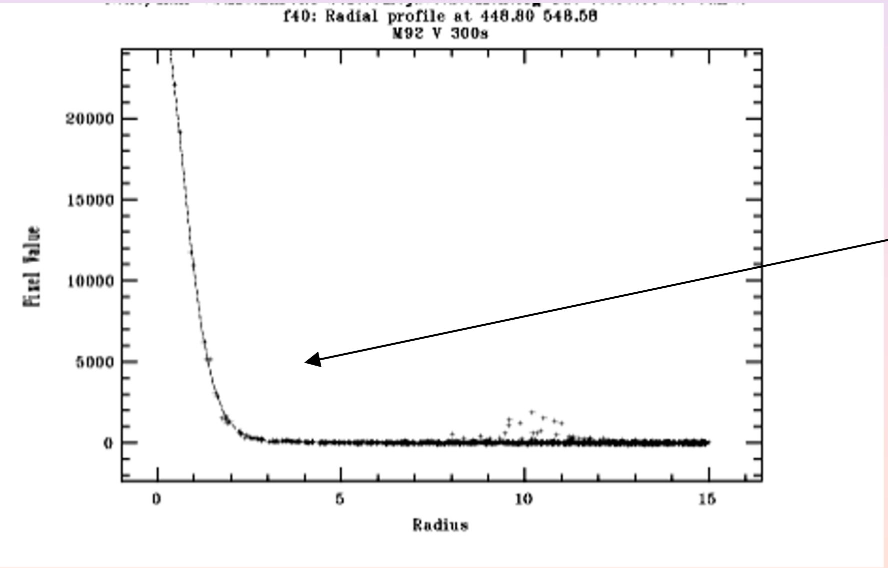


Plot intensity values for pixels that intersect circles

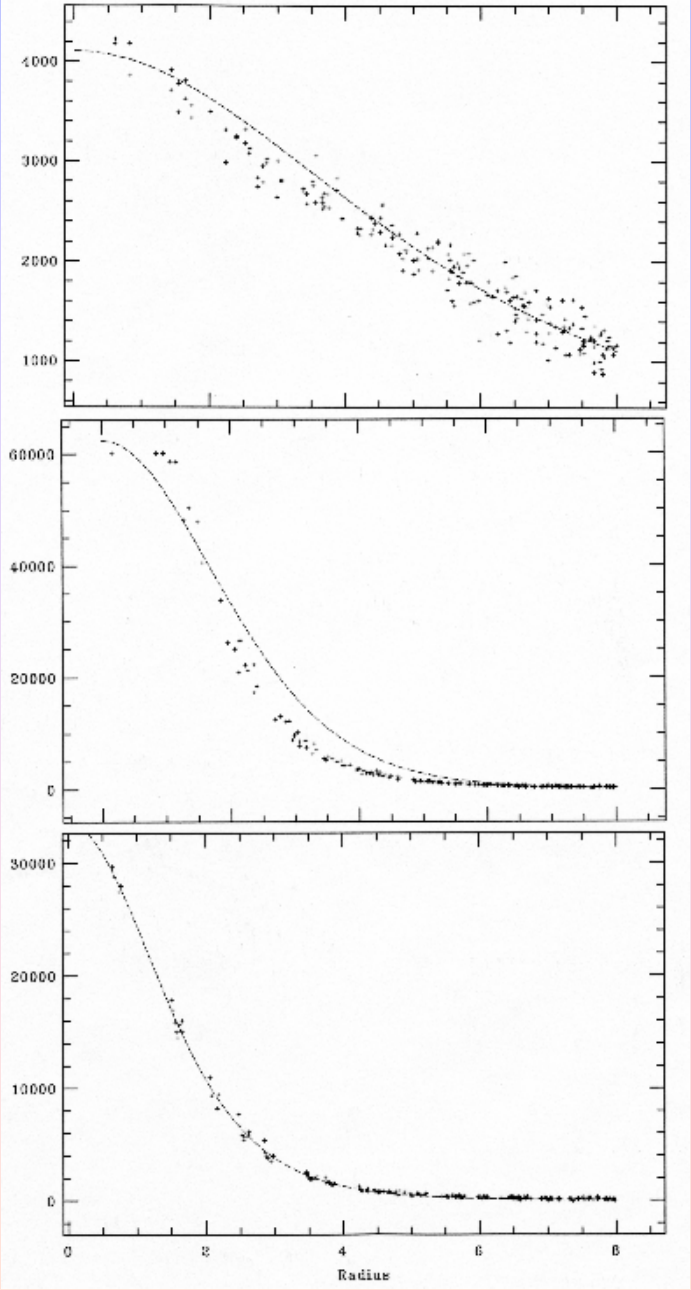


Poor focus (scatter is lack of roundness and probably astigmatism)

- 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.



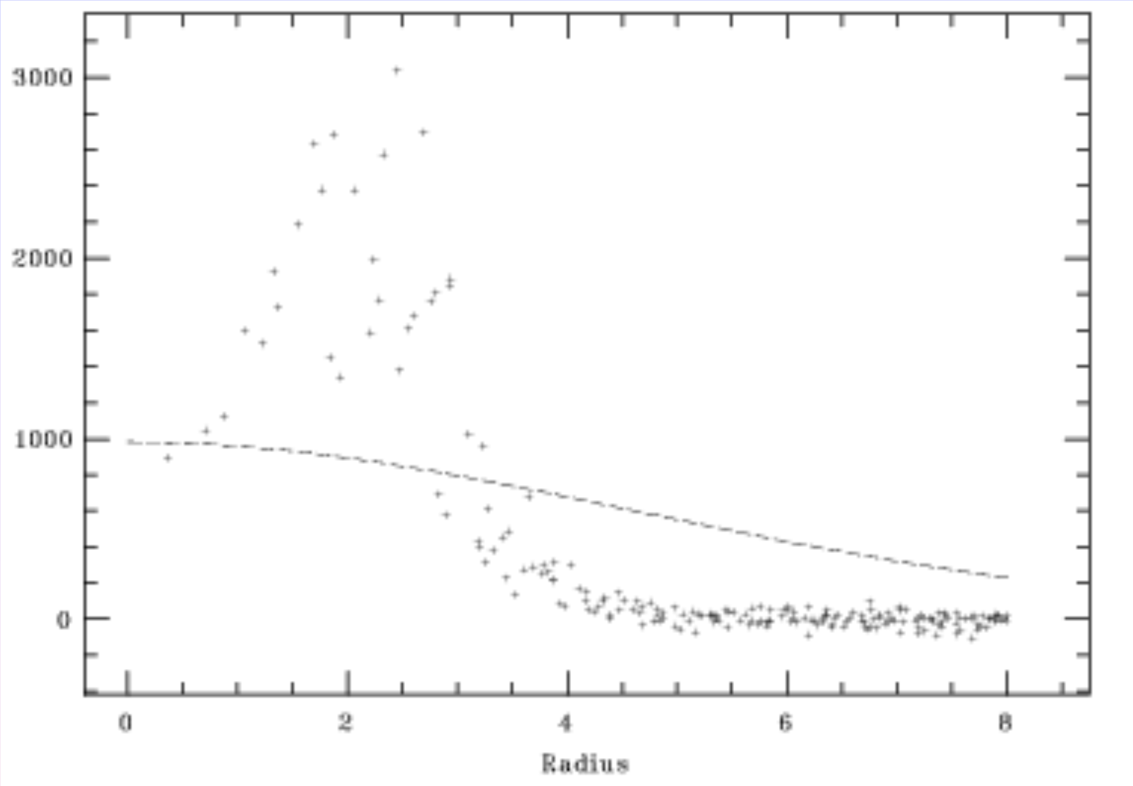
Excellent focus. Very round (and dangerously sharp) image



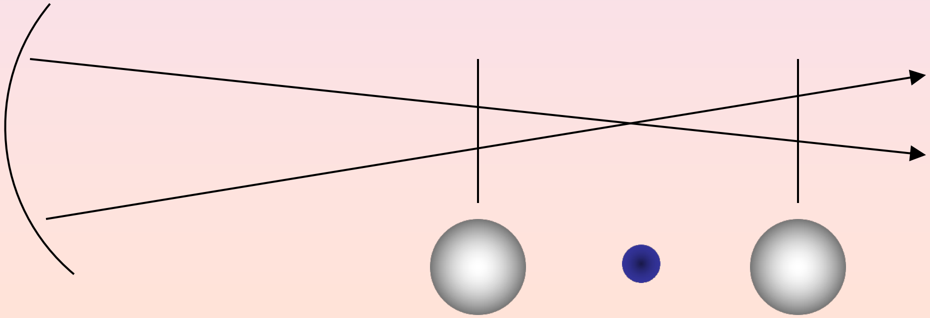
Galaxy

Saturated star

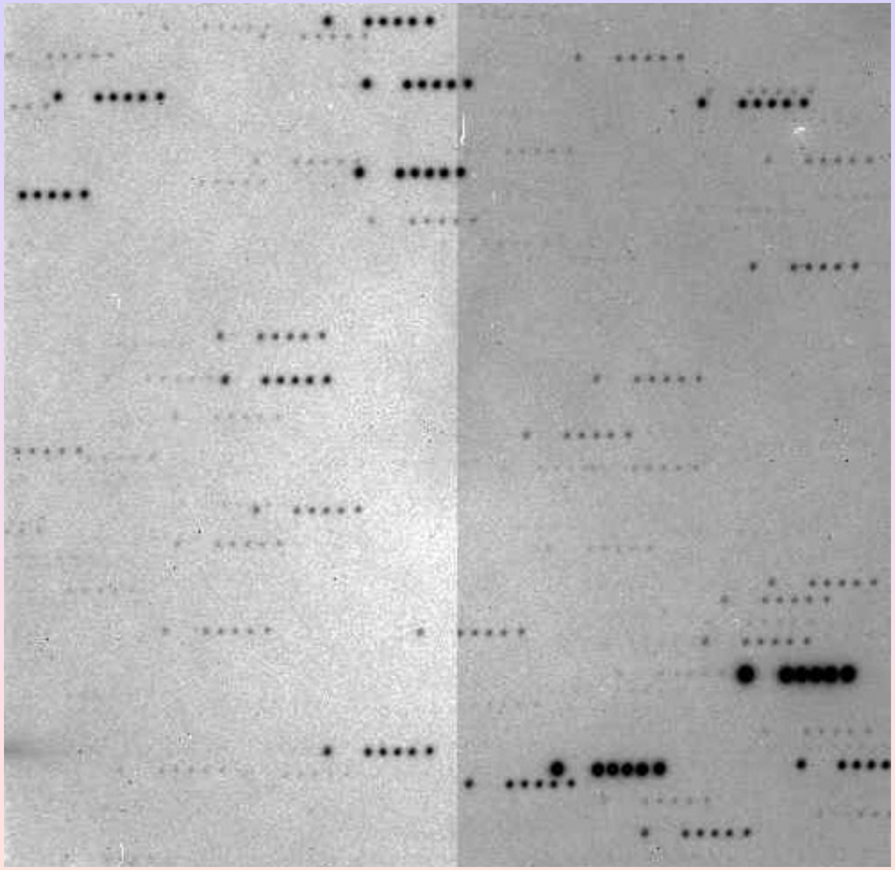
Well focused star



Way out of focus (donut).



Focus frames

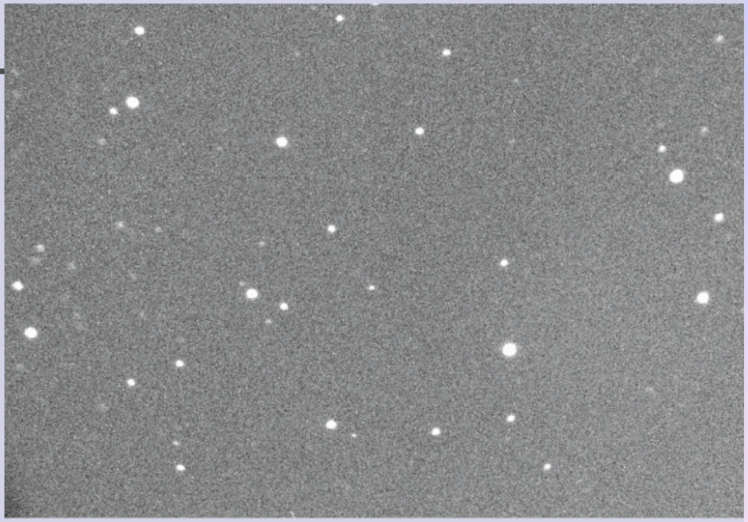


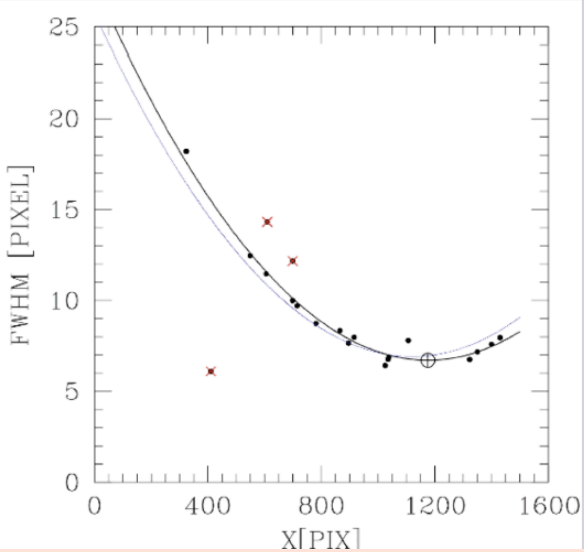
1. Set focus, start exposure.
2. Pause exposure, move telescope, change focus
3. Repeat
4. Make a double telescope move on the last focus value, then read out

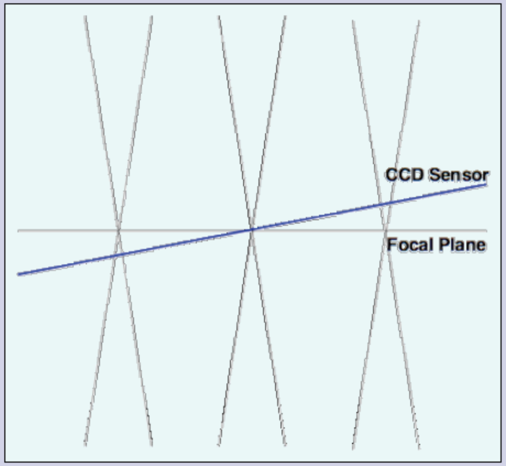
Alternate focus concept

Tilted Focus Sensor

- A new concept to monitor focus
- Differential method
- Successfully tested at WIYN 0.9m and 3.5m







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Photometric Calibration

- Imaging

➢ Measure total system efficiency for real, using a known standard through the *exact* same setup and conditions.

➢ Pre-identify a set of standard stars

❖ over a range of color that you observe for you program objects *(why?)*

❖ over a range of time *(why?)*

❖ over a range of airmass *(why?)*

Wavelength Calibration

- Spectroscopy
- Measure arc lamps, and/or night sky lines
- Fit lines to a model
- Check and modify
- Same observations can be used to establish spectrograph focus (camera and collimator)
- Want focus and rough central wave set during day; finesse wave solution (post-facto) with night sky lines if necessary

Spectrophotometric Calibration

- Spectroscopy
- Measure total system efficiency for a spectro-photometric standard under the same conditions
- Get photon count at every wavelength bin
- All other issues (color, airmass, time) apply

Preliminary Processing

- Environments / Packages
- Image display
- Data format
- Bias subtraction
- Field flattening

Astronomy Packages

- IRAF (http://iraf.noao.edu)
- IDL (astronomy users library: http://idlastro.gsfc.nasa.gov/homepage.html)
- XVISTA (http://astro.nmsu.edu/holtz/xvista)
- FIGARO
- MIDAS
- AIPS
- GIPSY

Issues: **availability, cost, philosophy, data handling (disk vs. memory), speed, ease of use (e.g., keywords vs. param files), language and access to existing code, ability to add new code, scripts/procedures (internal control language).**

Image Display

- DS9 or SAOimage with IRAF
- ATV with IDL
- Issues:
  - Dynamic Range (8-bit)
  - Sampling (spatial and depth)
  - Scaling (depth)
  - Color map
  - Overlay
  - Coordinates
  - Export

Image file formats

- FITS (Flexible Image Transport System)
- Header (80 byte ASCII records)
- Data (16-but Int, 32 bit int or 32 bit FP)
- Details of the data are contained in the header keywords, i.e.
  - Simple
  - Bitpix
  - Naxis
  - Ad infinitum

Image file formats

- IRAF uses internally defined data format (BAD!)
- Used for all (disk based) calculations
- Proprietary and subject to change!
- As an option, they now offer FITS format calculations. (I highly recommend this!)
- Not the default, need to flag imtype in your *login.cl* file

Preliminary Processing Concepts

- There are two types of instrumental signature to remove:
  - Additive:
    - o Bias Level
    - o Bias Structure
    - o Dark Counts
    - o Scattered light

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

  - Multiplicative:
    - o Q.E. variations on all scales
    - o Vignetting

    Constant *fractional* effect

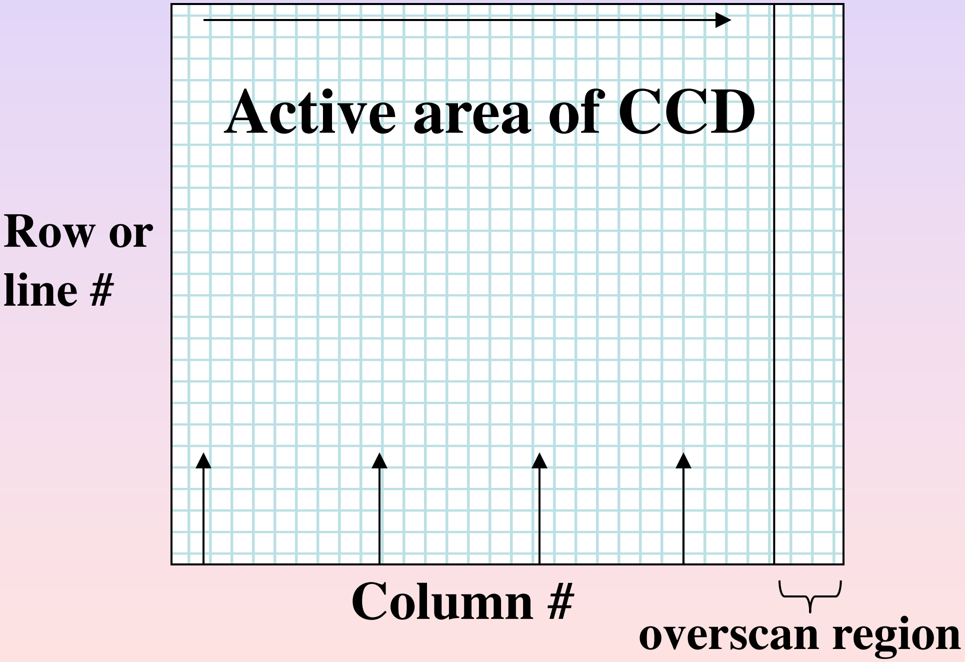
Bias Subtraction

- Bias subtraction
  - Model bias level
  - Subtract (may be different for different readout amplifiers)
  - Definitely different for mosaiced images

Bias Correction

- Bias level and any y (along columns) gradient is taken out via *overscan* subtraction.
- Bias structure is taken out by subtracting a *zero-level* frame.
- In IRAF *ccdproc* takes care of both.

Overscan

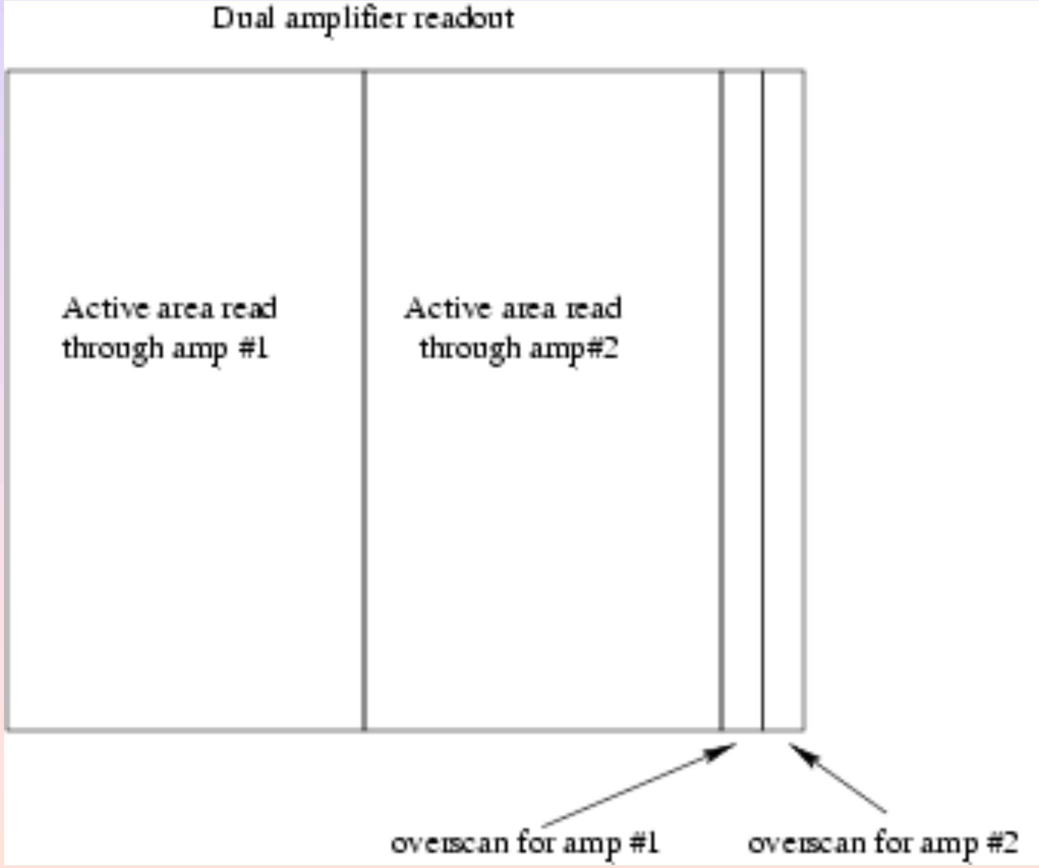


- After reading out the CCD \`real' pixels, you can continue to read out virtual pixels and record the bias level and read noise of the amplifiers. These virtual pixels are called the overscan region

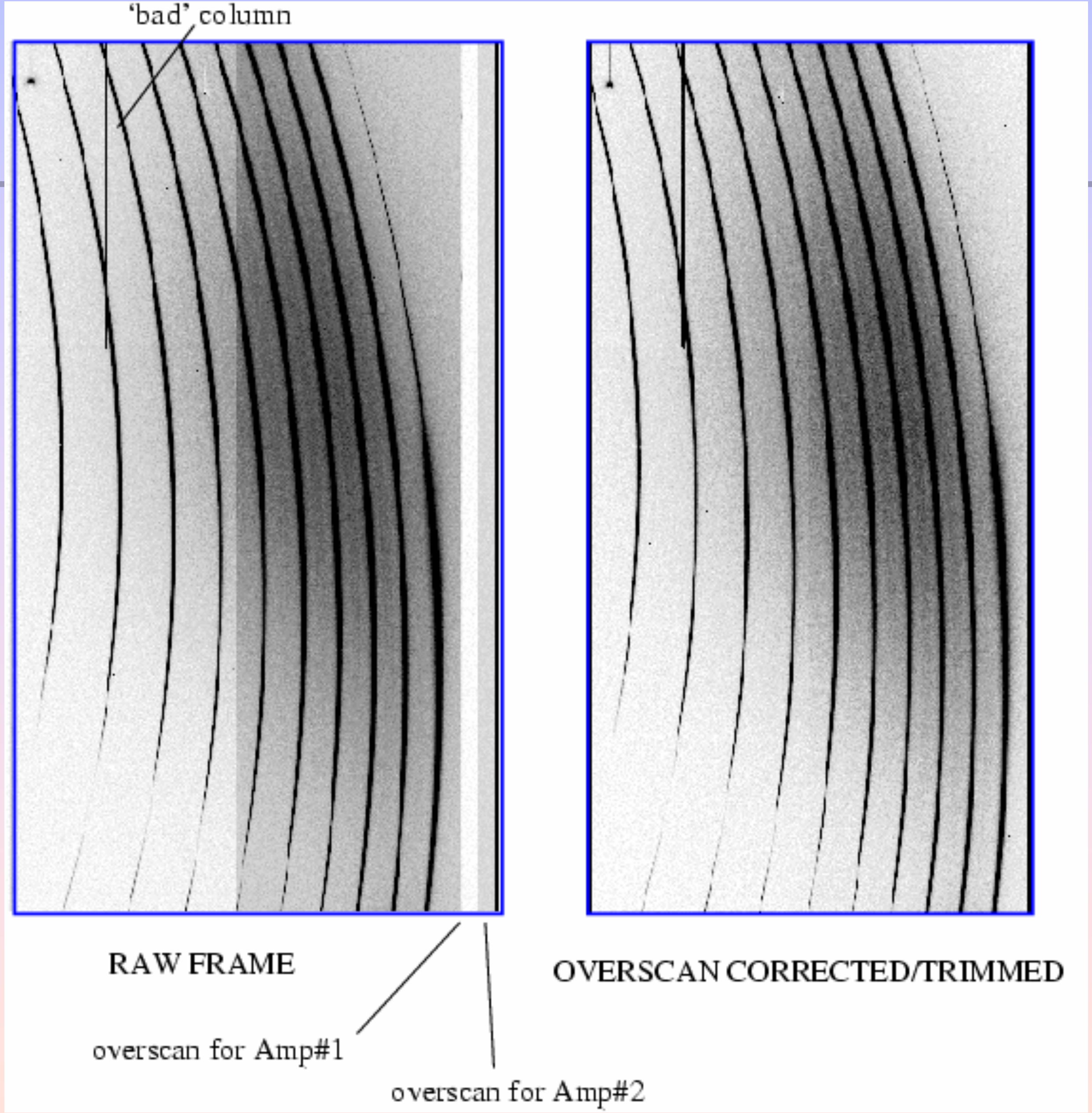
Two amplifier overscan

This is one particular example for ESI on Keck:

Where the overscan is stored is observatory dependent. For NOAO data the different read-outs and their overscan are stored as multi-extension FITS files.

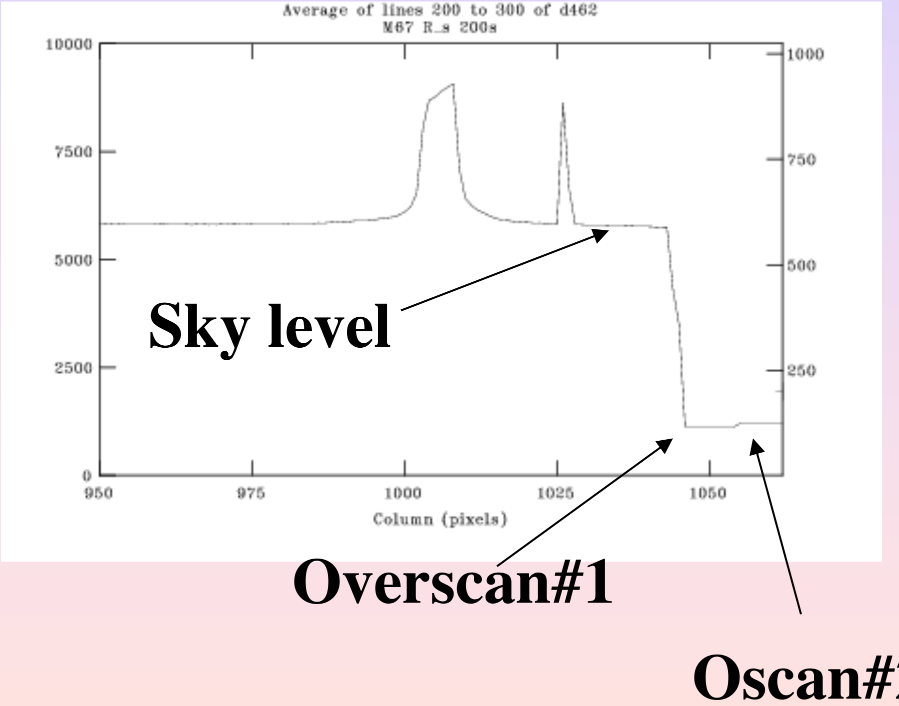


Again, the ESI example.
Note how the dark-levels are matched after subtraction.



Overscan subtraction

NB: If an NOAO detector, 1st few rows of overscan are always bad.

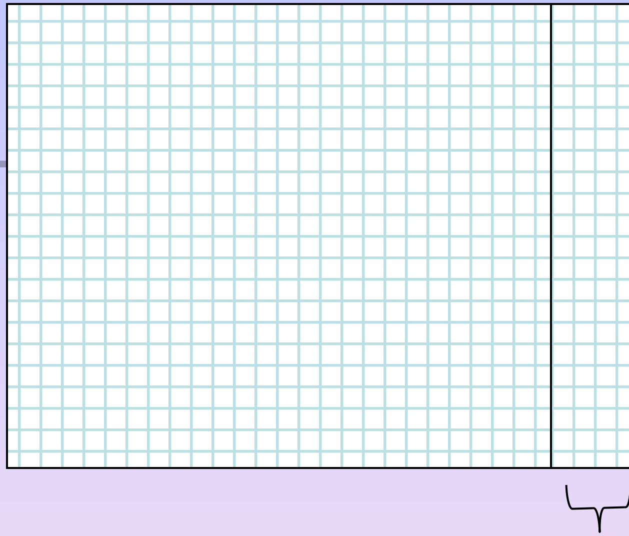


- First you need to identify the relevant columns.
- In IRAF use the format:
  [x1,x2:y1,y2]

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

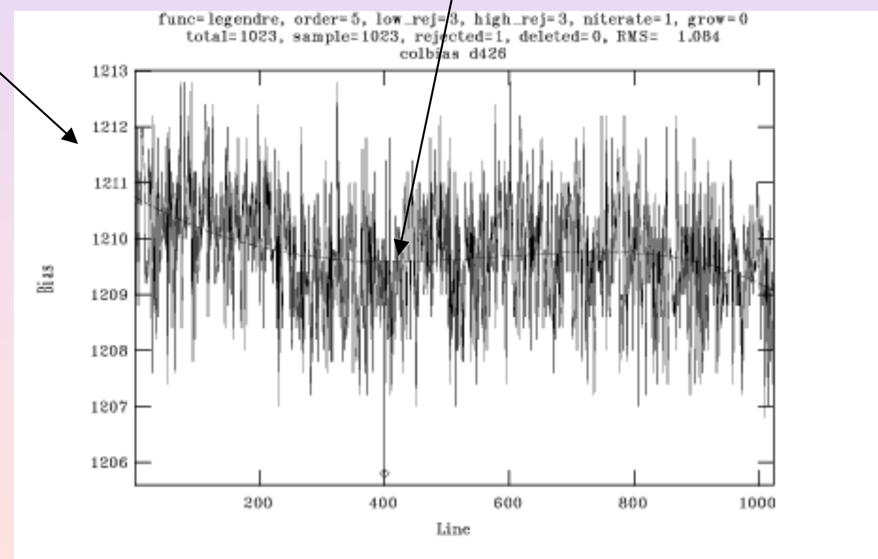
Colbias

- 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. This accounts for a mean bias level and any gradient in along columns.
- An alternative is to take the mean, median, or a clipped mean of each row of overscan, and subtract that from the data row. This is noiser, but can take out high-frequency jumps which can sometime be problematic for low surface-brightness applications. If read-time were no option, sometimes the control electronics are designed to allow you to increase the overscan size to beat down the noise.



Smooth fit is subtracted from each row

Average several



Field Flattening

- Field flattening
  - 2 kinds high order, pixel-to-pixel variations
  - Low order, sky illumination, vignetting, (scattered light)
  - Model the flat field based on dome flats, sky flats, twilight flats
  - Divide by normalized flat field

Field Flattening

- 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.
- 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

$$\frac{\sqrt{10^6}}{10^6} = 0.001 \quad = 0.1\%.$$

Field Flattening

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

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

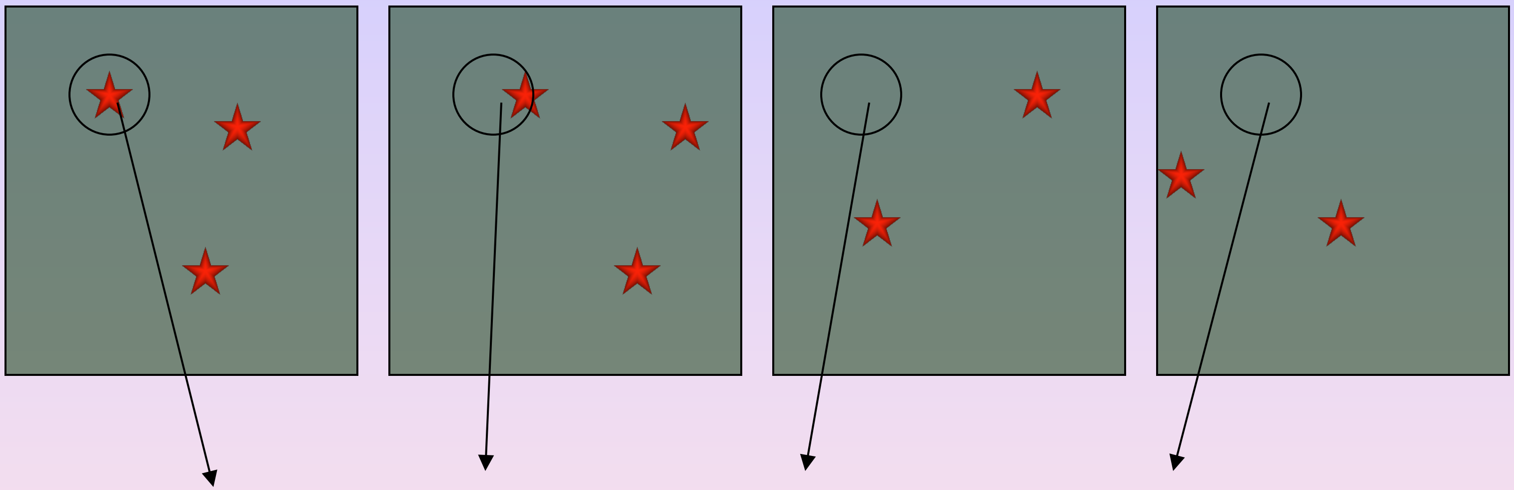
Dark-sky Flats

- 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

This is just one, simple-minded example. You should explore the behavior of these parameters as determined by their performance with your specific data.

- In IDL, just do arithmetic on the images:

  Image C = Image A + Image B

- Can use canned routines such as: “medarr,bigarray,outarray”

Frame-combination Optimization

- Think in terms of S/N and ask:

What weight would I used to optimize S/N in a weighted mean?

- Consider point sources.
- For a stack of frames with varying image quality (θ_{PSF}) and background levels, define a S/N metric proportional to these two quantities.
- Determine this quantity for each frame you wish to combine.
- Use S/N (or any quantity directly proportional to it) as the weight to created a weighted mean, i.e., use your metric.
- This will give you and image optimized to detect point sources.
- Generalize to extended sources of a given size (relative to PSF) using Gaussian-quadrature approximation to “source spread function” (SSF):

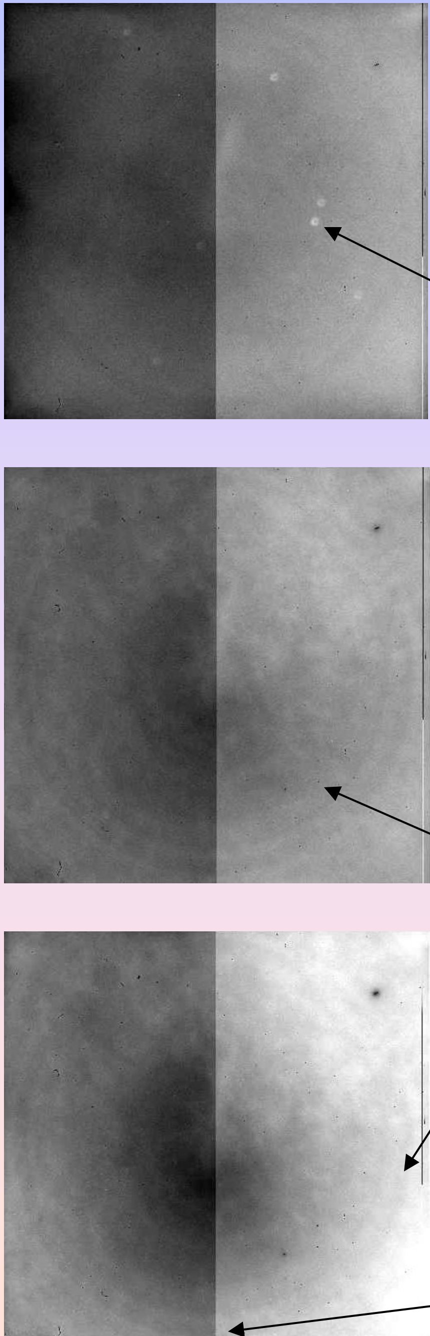
$$\theta^2_{source} \equiv \theta^2_{SSF} = \theta^2_{obs} - \theta^2_{PSF}$$

Field-flattening 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, sDarkSky
  2. Remove dome low-spatial-frequency pattern: Dome/sDome
  3. sDarkSky is the sky flat with the high-frequency pattern already removed.
  4. Best of both worlds is: (Dome/sDome) x sDarkSky

What does “bad” and “excellent” mean here, and what might be better descriptors?

PFCam flat fields



***I*-band**

Dust on filter

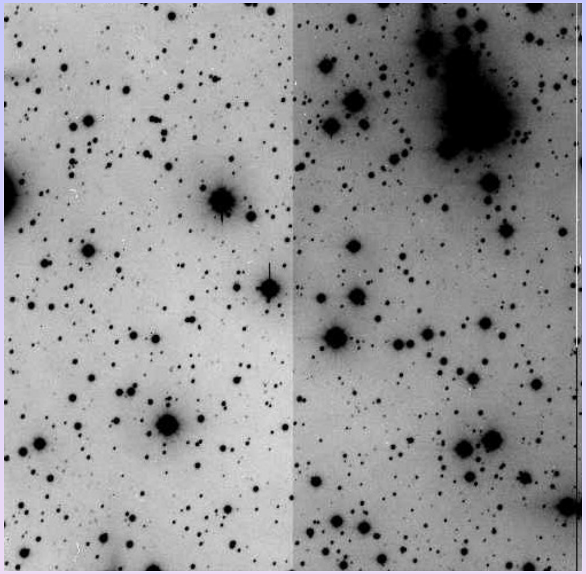
***V*-band**

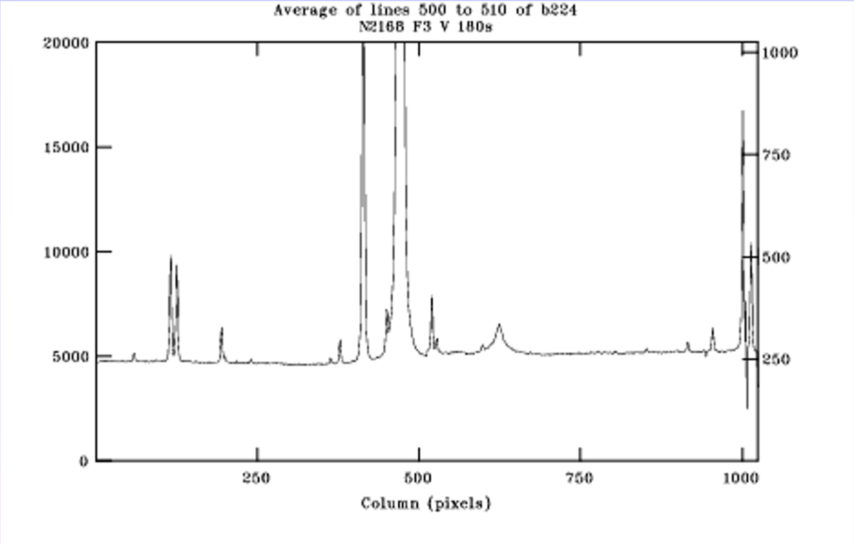
Note differences with color. This means that objects with different spectra will be flat-fielded slightly incorrectly.

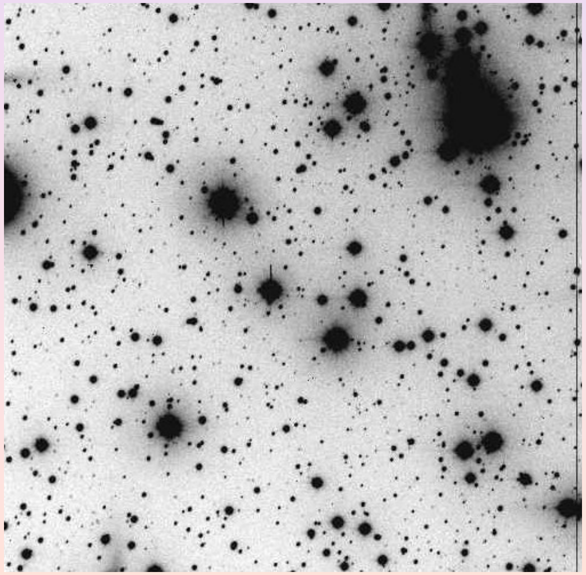
Rings due to non uniform thinning

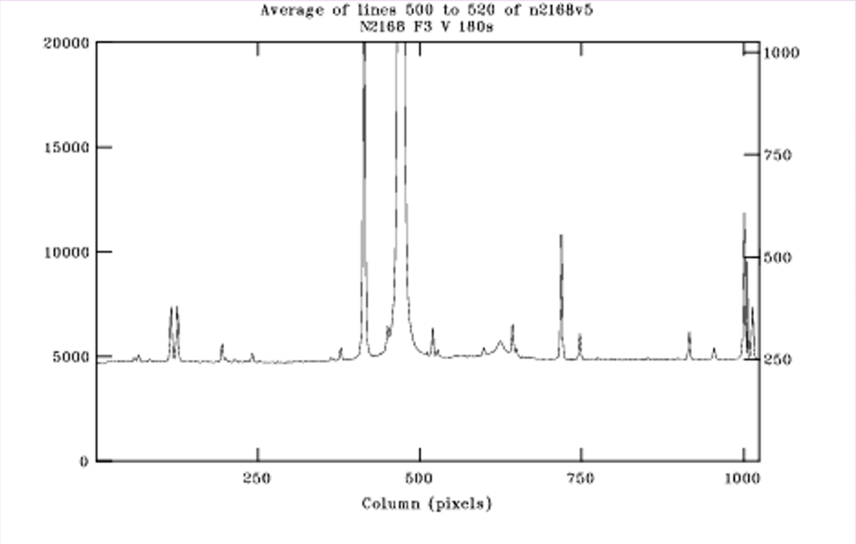
***U*-band**

Two amplifer readout




Average of lines 500 to 510 of b224
N2168 F3 V 180s
20000
15000
10000
5000
0
250
500
750
1000
Column (pixels)
1000
750
500
250




Average of lines 500 to 520 of n2168v5
N2168 F3 V 180s
20000
15000
10000
5000
0
250
500
750
1000
Column (pixels)
1000
750
500
250

Flat-field tests

1. Take cuts through your flat-fielded frames and make sure the sky is flat (check corners). IRAF *implot, IDL (ATV (r and c) 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, IDL (ATV, imexam, photometry)