Reducing CCD Imaging Data

SCIENCE AND CALIBRATION DATA

Exactly what you need will depend on the data set, but all the images generally fall into two categories.

Science Exposures: Self-explanatory -- this is the data you care about

Calibration Exposures: All the non-science images that must be taken for use in reducing your data.

Types of calibration that are typical for optical imaging include:
> Dark and Bias Frames
> Flatfields (Dome, Twilight, Sky)
> Off-source sky images for sky subtraction (only for large sources)
> Standard Stars (for photometric calibration)

Both science and calibration data can come as individual images or mosaics for multiple detector instruments. For mosaics you need to do everything described separately for each detector.

CALIBRATION IMAGES

An observed CCD image includes signals from three sources:

1. Photons imaged onto CCD by telescope
   - *Sources: Astronomical objects and sky*
   - *Generated by photoelectric effect*

2. Dark current
   - *Source: thermal electrons collected in each pixel during the exposure*

3. Bias
   - *A signal added to each pixel during readout*

Must subtract off dark current and bias.

Courtesy: John Oliver
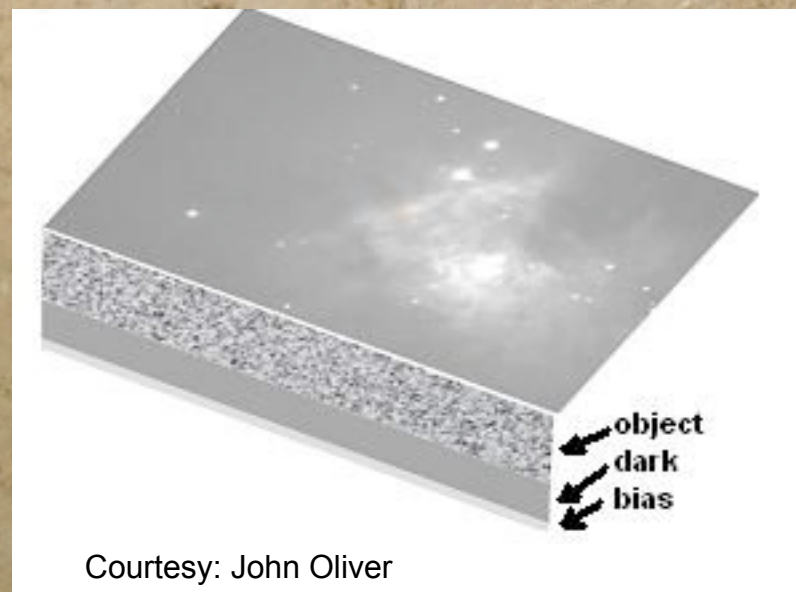
Calibration: Dark Frames

Dark Frames

What: *Exposures taken with the shutter closed (hence "dark")*
- *Darks should have the same exposure time as your science images.*
- *Darks should also be taken at the same temperature as your science images (why?).*
- *You want to take multiple dark images and (median or average) combine them.*
    - *Reduces the noise*
    - *Eliminates spurious pixels in individual frames*
    - *Combined image typically called the "master dark".*

Purpose: *Remove the dark current from thermally excited electrons.*

Application: *The master dark frame is subtracted from the science image. This dark frame will include the thermal noise from the bias, so you do not need a separate bias frame if you take darks. For this reason, you will sometimes hear people use the terms tarks and biases interchangeably.*

Calibration: Bias Frames

Bias Frames

What: *Zero second dark exposures*
- *You want to take multiple bias images and (median or average) combine them.*
  - *Reduces the noise*
  - *Eliminates spurious pixels in individual frames*
  - *Combined image typically called the "master bias".*

Purpose: *Remove the bias signal*
- *The bias is an offset level introduced when the detector is read out.*
- *Even if the output from the CCD were 0 electrons, there would still be a bias signal that varies from pixel to pixel in a repeatable fashion.*
- *This is an additive offset.*

Application: *The master bias frame is subtracted from the science image.*

Relevant IRAF Tasks: *ccdproc, imcombine, imarith*

Calibration: Overscan Regions

CCD Overscan Regions

Overscan Regions: *Many CCD images now include what are called overscan regions. Overscan regions are rows and columns along the image edge that are not exposed to light. These regions essentially act as darks that can be subtracted directly from the image. Typically you will have both overscan rows and overscan columns.* **Overscan regions can be used alone or in conjunction with dark or bias frames. If used with dark (bias) frames, then the dark (bias) should be subtracted from the overscan region as well as the rest of the image.**
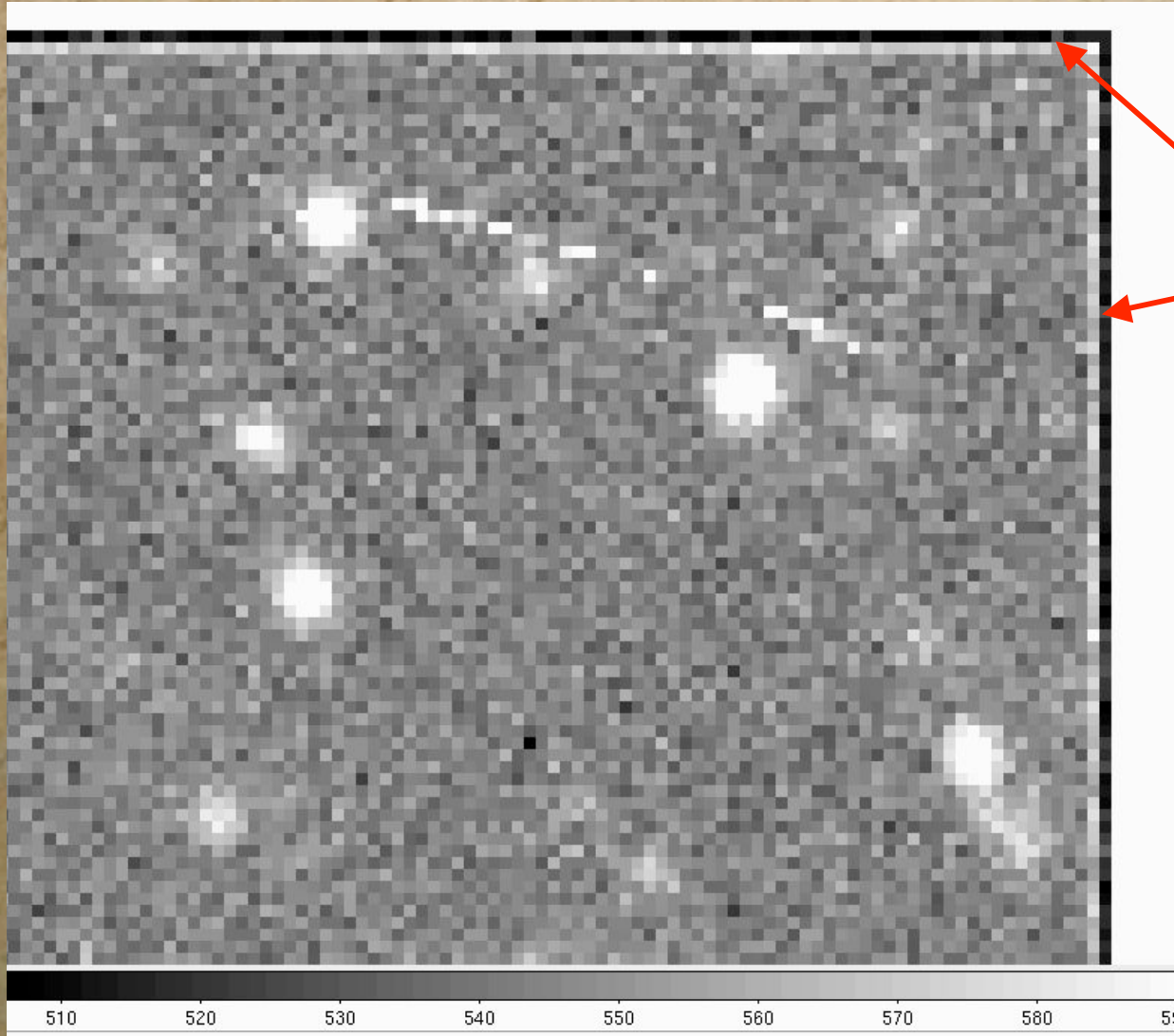
Advantages:
- *Overscan taken at same time as data, so reflects actual electronic noise and any time variability*

Disadvantages:
- *Overscan regions do not contain full 2D information contained in a dark or bias.*

CALIBRATION: OVERSCAN REGIONS

Overscan

Calibration: Overscan Regions

CCD Overscan Regions

Application:

1. For an set of overscan columns (rows) compute the average or median across the columns (rows).
2. Normally you want to smooth across a few columns (rows) to make the overscan less noisy.
3. Subtract this average/median value from all the other pixels in the image.
4. If you have both overscan colums and rows, subtract them sequentially. When you do the first subtraction -- say subtraction of the overscan columns, you will want to subtract this value from the overscan region as well as the rest of the image.

Relevant IRAF tasks:

§ colbias

§ linebias

Colbias is used in one of the IRAF tutorials that you are working through in lab.

CALIBRATION: DARK, BIAS, OVERSCAN

Practical Notes:

- *For most of the optical data sets that you download, there will not be separate dark frames.*

- *You will likely either have a bias frame or just overscan regions.*

- *It is a good idea to look at the overscan region and mask out any regions that sharply spike in brightness. These are generally spurious and will result in streaks in your images if you include them. Using the median rather than average also helps minimize the impact of these pixels*

Calibration: Flatfields

Flatfields

What: *Exposures of a uniformly illuminated source*

- *Types of flatfields: Dome, Twilight, Sky*
- *You want to use multiple flatfield images and median combine them.*
  - *Reduces the noise and eliminates spurious pixels in individual frames.*
  - *Eliminates objects for twilight and sky flats*
  - *Must normalize all images to same mean value before combining*
  - *Combined image typically called the "master flat".*
- *Normalized to have a mean value of 1.*
- *Taken in each filter*
- *For dome and twilight flats, you want to have as many counts per pixel as possible to reduce noise, but not so bright as to saturate or have concerns about nonlinearity.*

Purpose: *Correct for pixel-to-pixel sensitivity variations*

- *Each pixel has a different response*
  - *Quantum efficiency variations, dust on the optics, vignetting, …*
  - *If illuminate all pixels with the same brightness, then you can measure and correct for these variations*

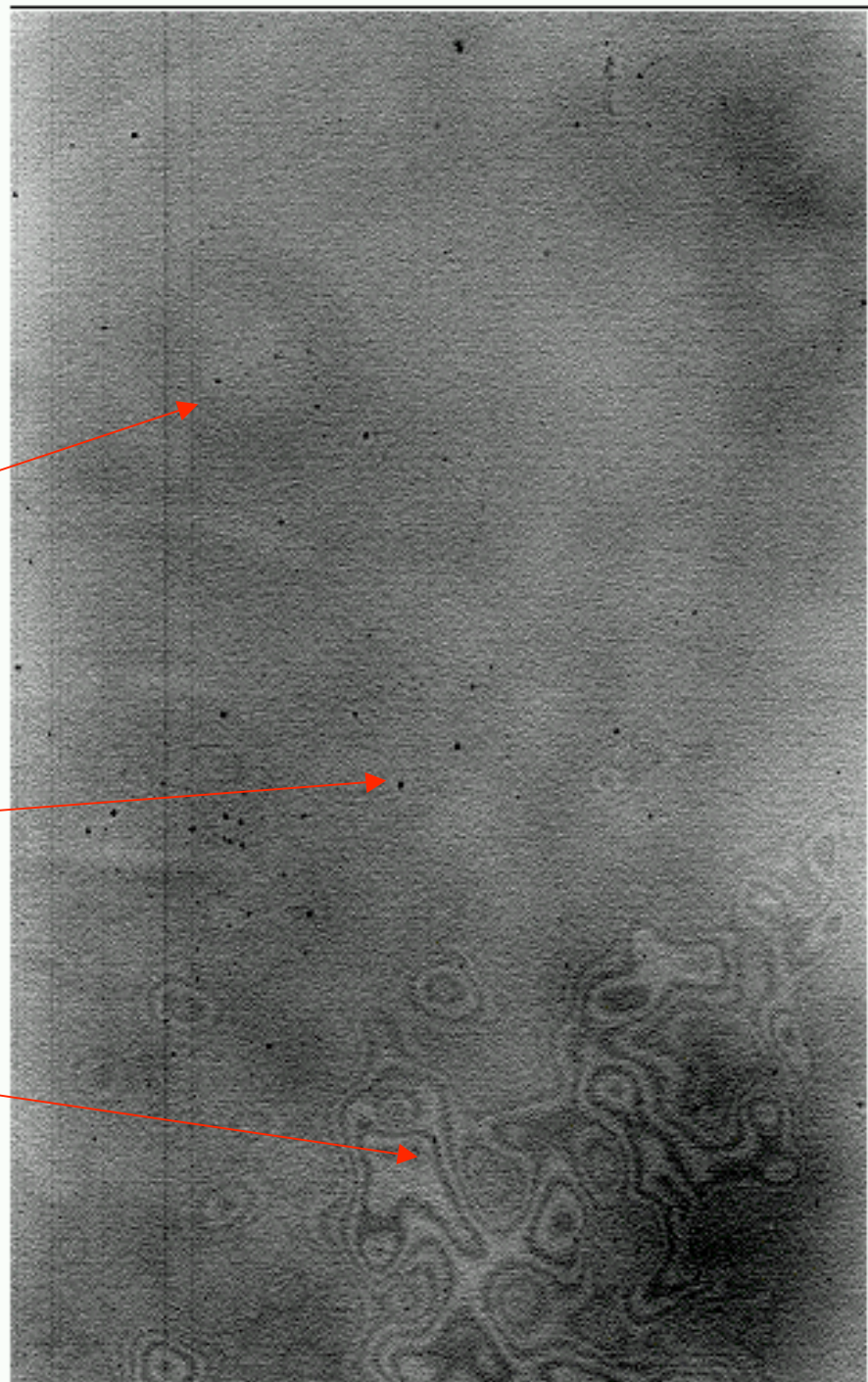**Application:** *Divide the science frame by the master flat.*

Relevant IRAF tasks: *imcombine, flatcombine, ccdproc, imarith*

Flatfields

Dust Donut

Bad Pixel

Fringing**

Calibration: Flatfields

Flatfields

Dome Flats

Images of a uniformly illuminated white screen inside the dome.

Twilight Flats

Images taken at twilight, when the sky is much brighter than astronomical sources.

Effectively using the sky as your uniformly illuminated screen.

Sky Flats

Median combination of many science exposures during the night, again using the sky as your uniformly illuminated screen.

...each has advantages and disadvantages...what you use will be determined by what's available in the archive...

CALIBRATION: STANDARD STARS

Standard Stars

What: *Images of stars with well-known magnitudes (and colors)*
- *Only relevant when the weather is photometric*
- *Each standard star should be observed multiple times during the night at different airmasses*

Purpose: *To enable photometry*
- *Need an object with known magnitude to determine the magnitudes of other sources that are your science targets*

Application for Projects: *For VLT data sets you will be able to obtain the photometric zeropoint directly from the archive without calibration. For the other telescopes rough zeropoints must be computed using standards from the same night.*

Landolt 1992, AJ, 104, 340
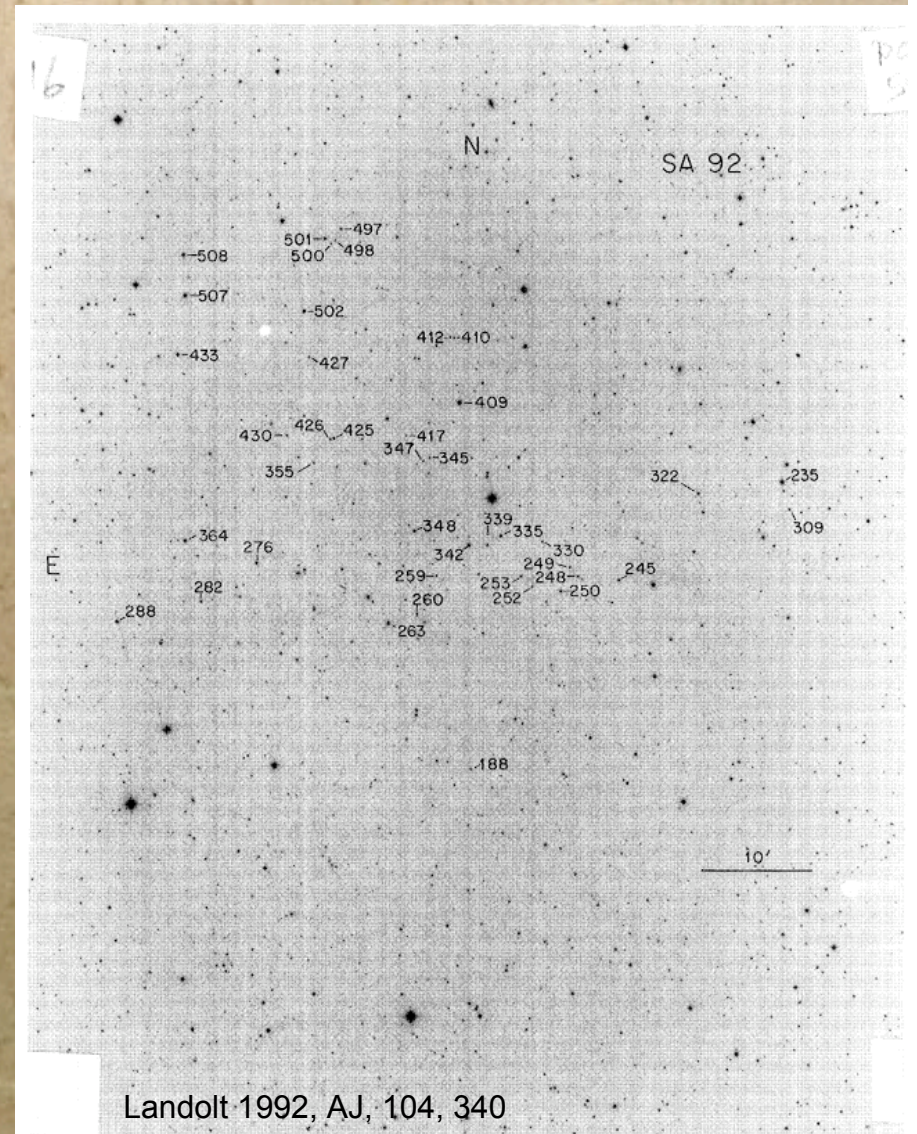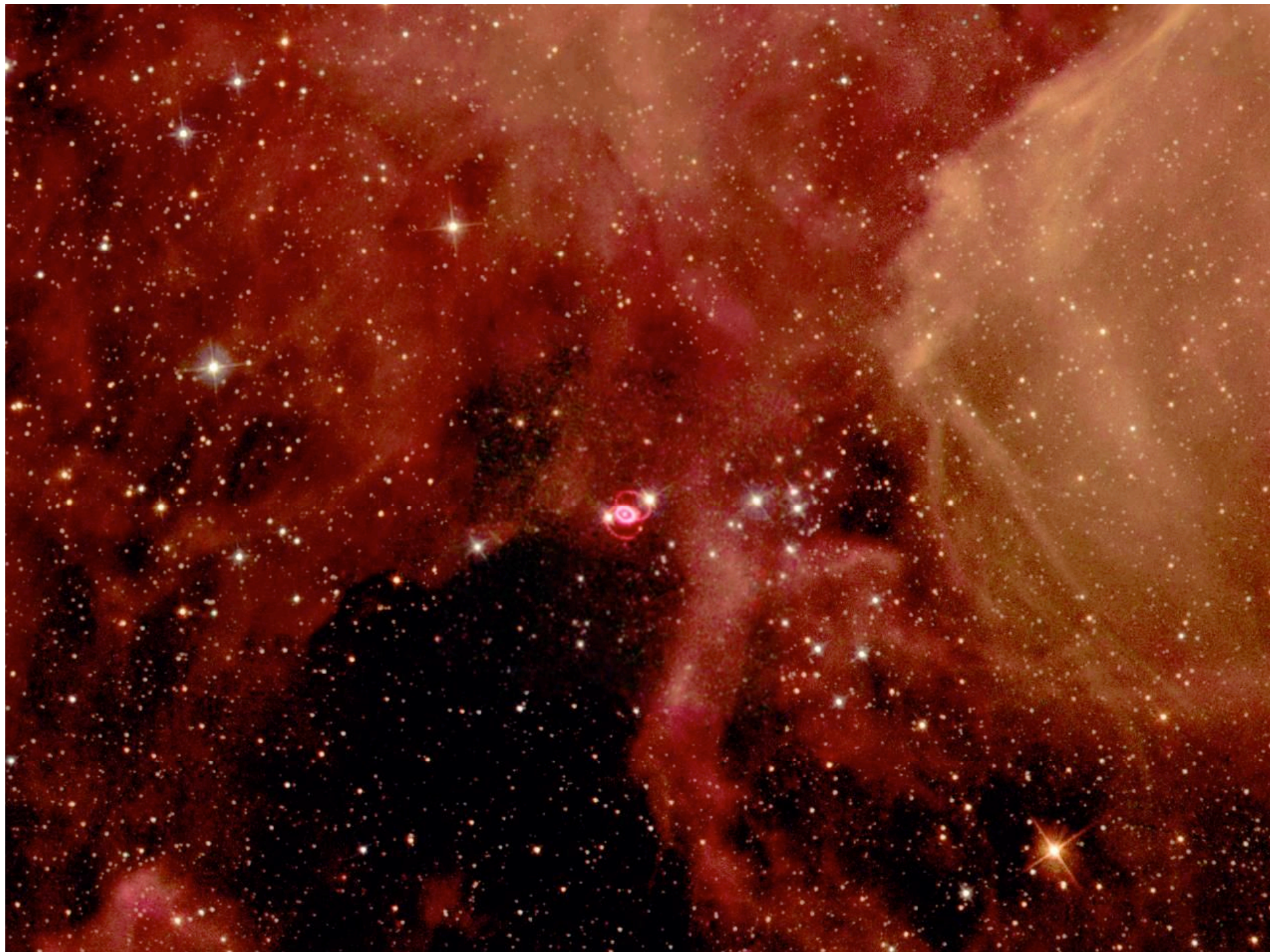
Calibration: Sky Subtraction

Off-Source Sky Subtraction Images

What: *Images of blank parts of the sky near your target.*

Purpose:

- *If the target you are observing is a nebula or other very extended source, this is the only way to cleanly remove the sky.*

Application for Projects: *You do not need to worry about off-source sky images*

Reductions: Cosmic Rays
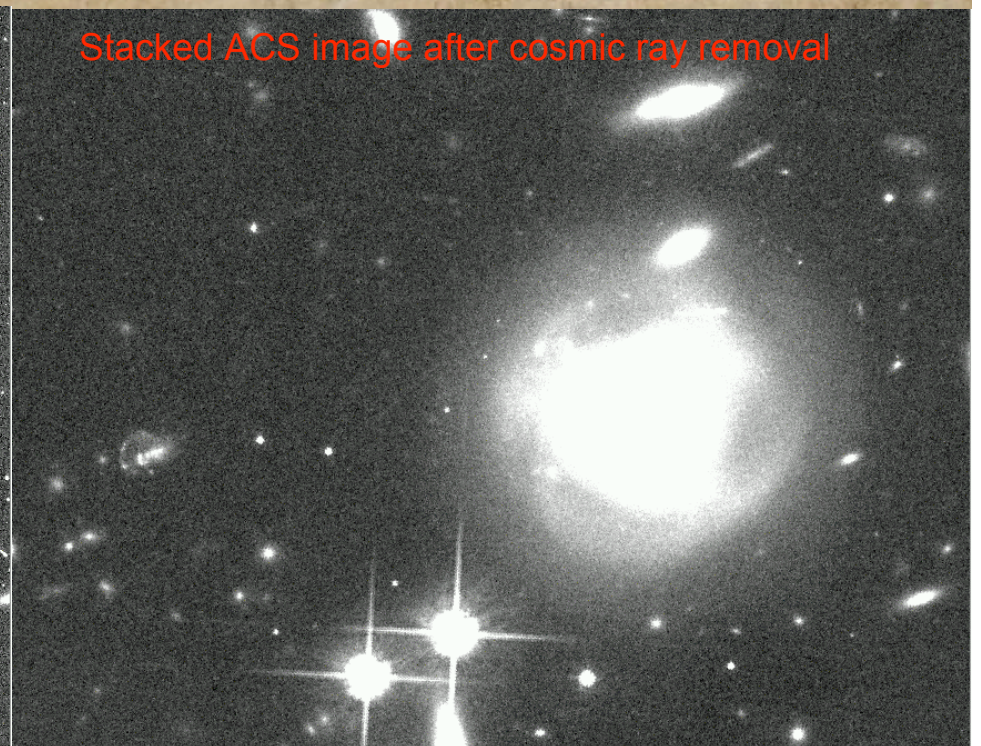
Cosmic Ray Removal

What: Elimination of cosmic ray events from images.

Purpose:
- *If not removed, cosmic rays compromise photometry and yield spurious detections.*

Application for Projects: *Cosmic rays can be removed when stacking images.*

Why would HST have lots of cosmic rays?

HST Raw Image

Stacked ACS image after cosmic ray removal

Steps In Reducing Your Data

Outline (every one of these can be discussed in great detail):

1. Download all science and calibration images
2. Average or median combine your dark or bias frames and subtract this median from the rest of your images.
3. Subtract the overscan regions (if applicable) from all your images.
4. Create a combined flatfield and divide the images by the flatfield.
5. Use the flatfield to create a bad pixel mask, and mask the bad pixels in all images.
6. Fringe removal: for red bands (e.g i,z), where fringing is an issue, you may need to construct a fringe frame and remove the fringes.
7. Depending on the wavelength and science, possibly perform a sky subtraction.
8. Determine the offsets between all the images of a given field and align the images
9. Stack the images to produce a single, deep frame for each filter. During the stacking you will want to use a clipping algorithm to remove cosmic rays.

Optimal Timeline

Below is a suggested timeline for completing different portions of the independent projects. The pace at which you proceed is left to your discretion, but you are encouraged to start early in case of setbacks.
Note that, while 7 lab periods are dedicated to the projects, you will be expected to also work on the projects outside of lab.

February Lab periods on Feb 13, 20 (note that the idl tutorial has been cancelled)
- Finish downloading data
- Perform bias subtraction and overscan subtraction
- Create and apply flatfields
- Make and apply bad pixel masks

March Lab period on March 6
- Perform fringe correction or sky subtraction if necessary
- Align and combine images

April Lab periods on April 3,10,17,24
- Photometry
- Analysis (CMD, color-color diagrams)
- Final Report

FILTERS: A REVIEW

There are a host of different filters used in astronomy, typically defined based upon some combination of the physics being studied and atmospheric transmission.

- For all filters one can define a *resolution*, $R = \lambda/\Delta\lambda$.
- Filters are generally considered "broad", "medium", or "narrowband" depending upon the resolution.

- Very Rough Guide
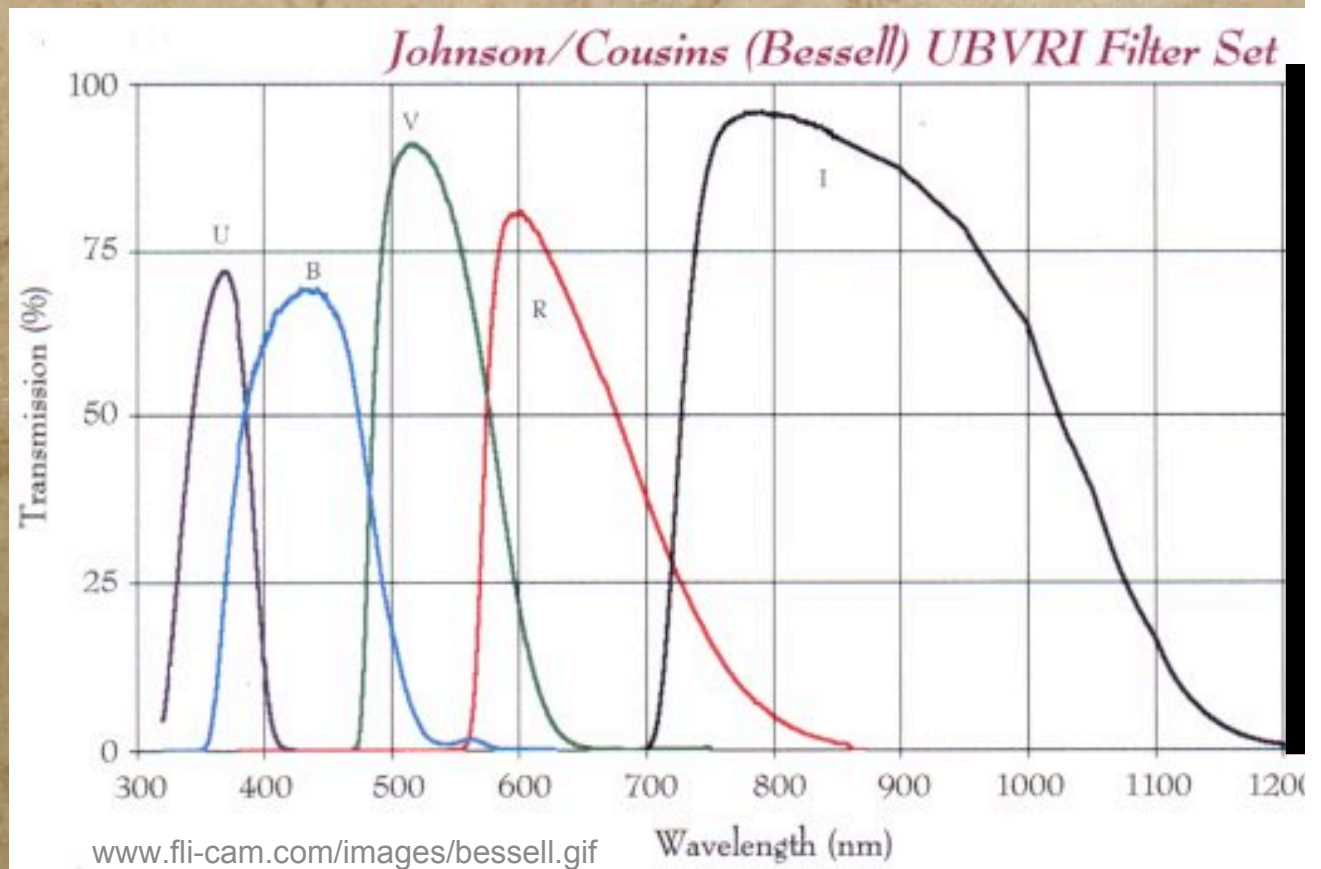 - Broad: R<10
  - Medium: R~10-50
  - Narrow: R>50

- Make sure you know which filters you are using for your projects.

www.noao.edu/kpno/mosaic/filters
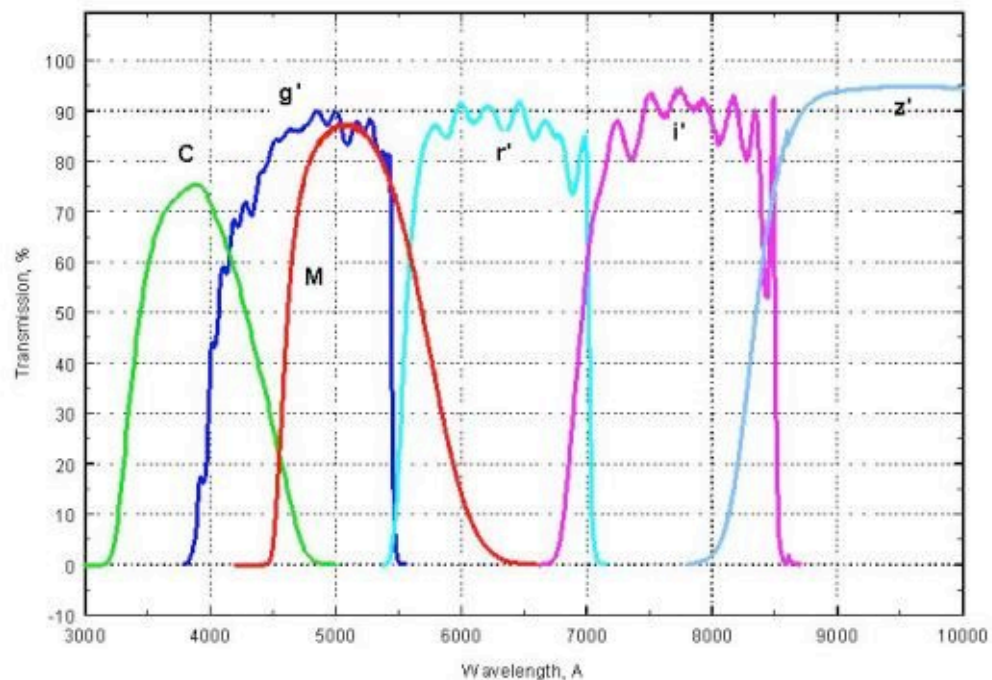
BROADBAND FILTERS

Johnson-Cousins Filter Set

- UBVRI
- Classical filter set
  - Ultraviolet (U)
  - Blue (B)
  - Red (R)
  - "Infrared" (I)
- Optical, very near IR
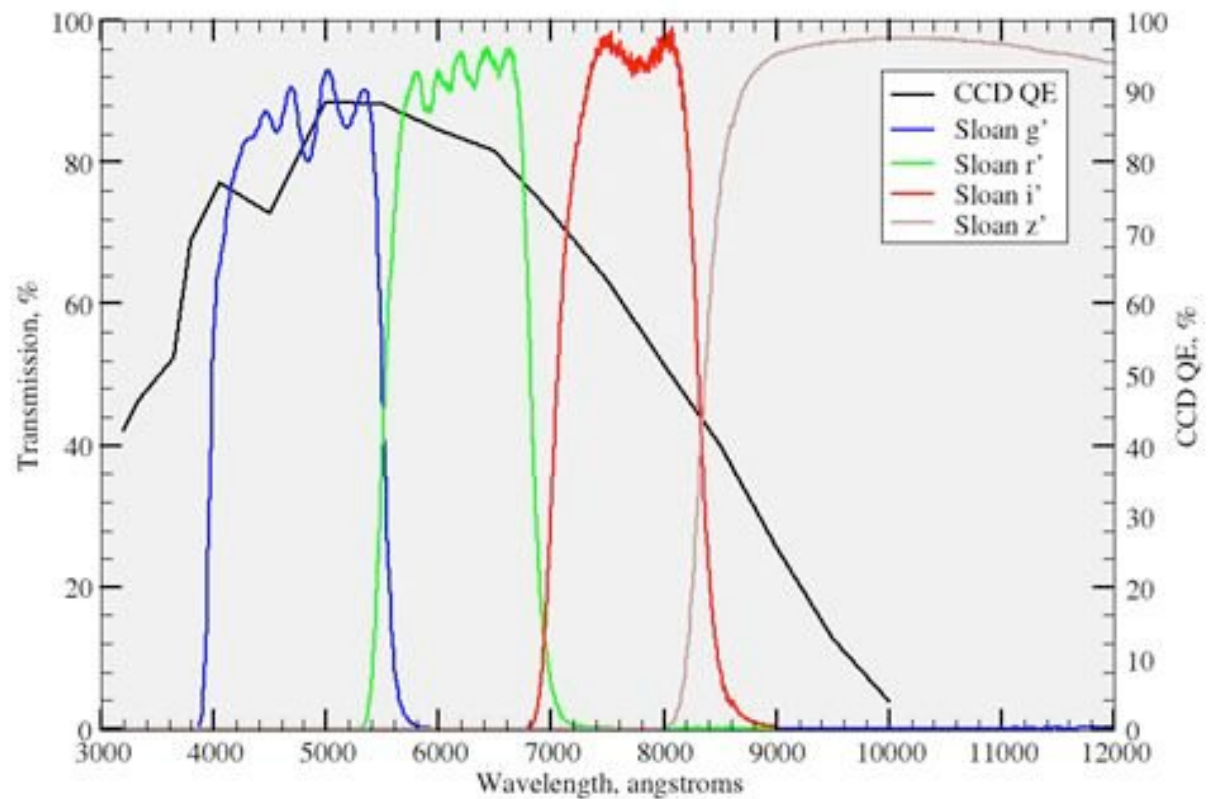- Wavelength cutoffs not very sharp

www.fli-cam.com/images/bessell.gif

BROADBAND FILTERS

Sloan Filter Set

- g'r'i'z'

- Relatively new
- Sharp cutoffs
- Used for Sloan Digital Sky Survey
- Optical and very near IR
- No red cutoff for z'

WTTM CCD QE & WTTM Sloan Filters
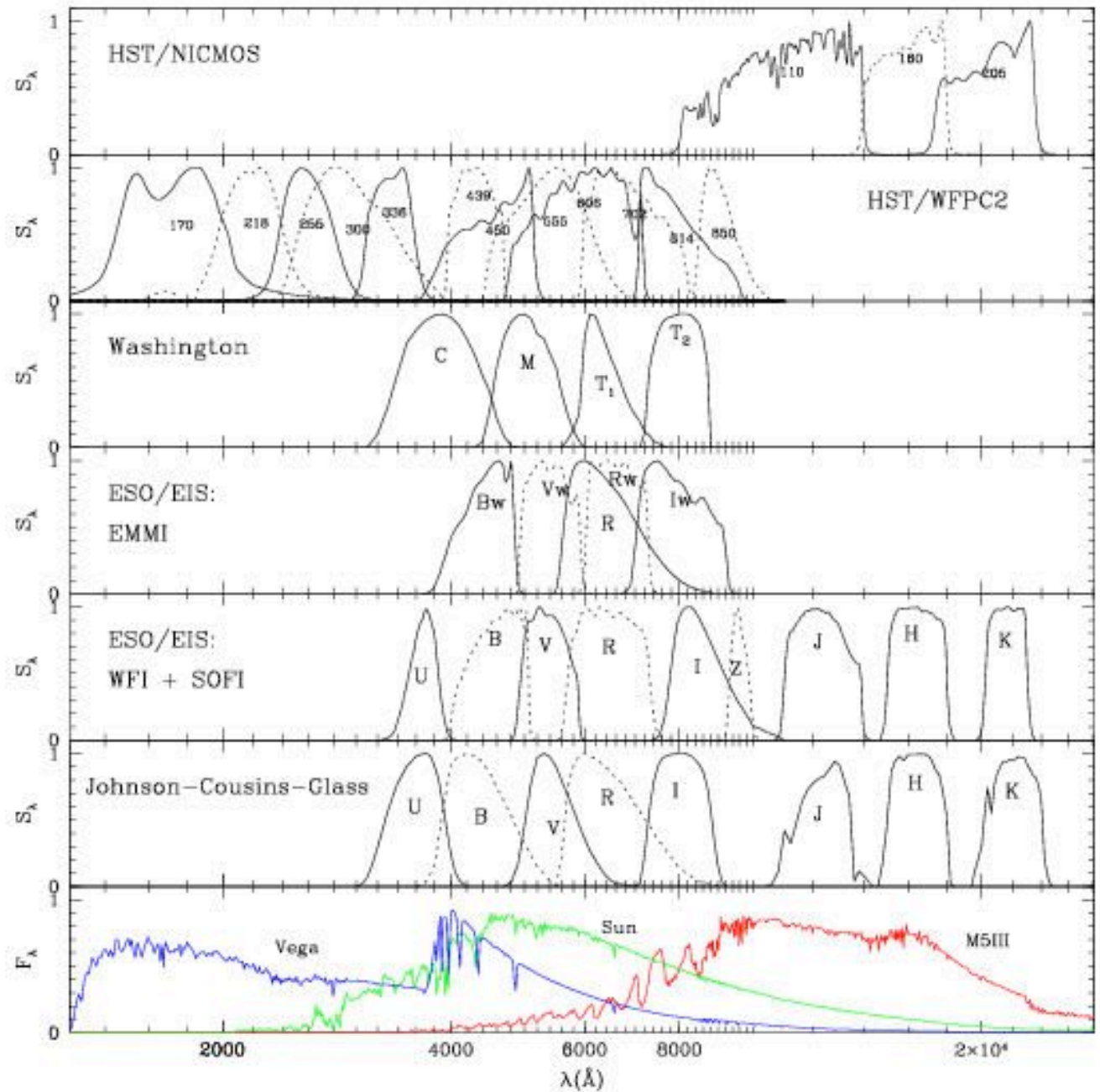
BROADBAND FILTERS

Many Different Systems

Kron
Washington
…

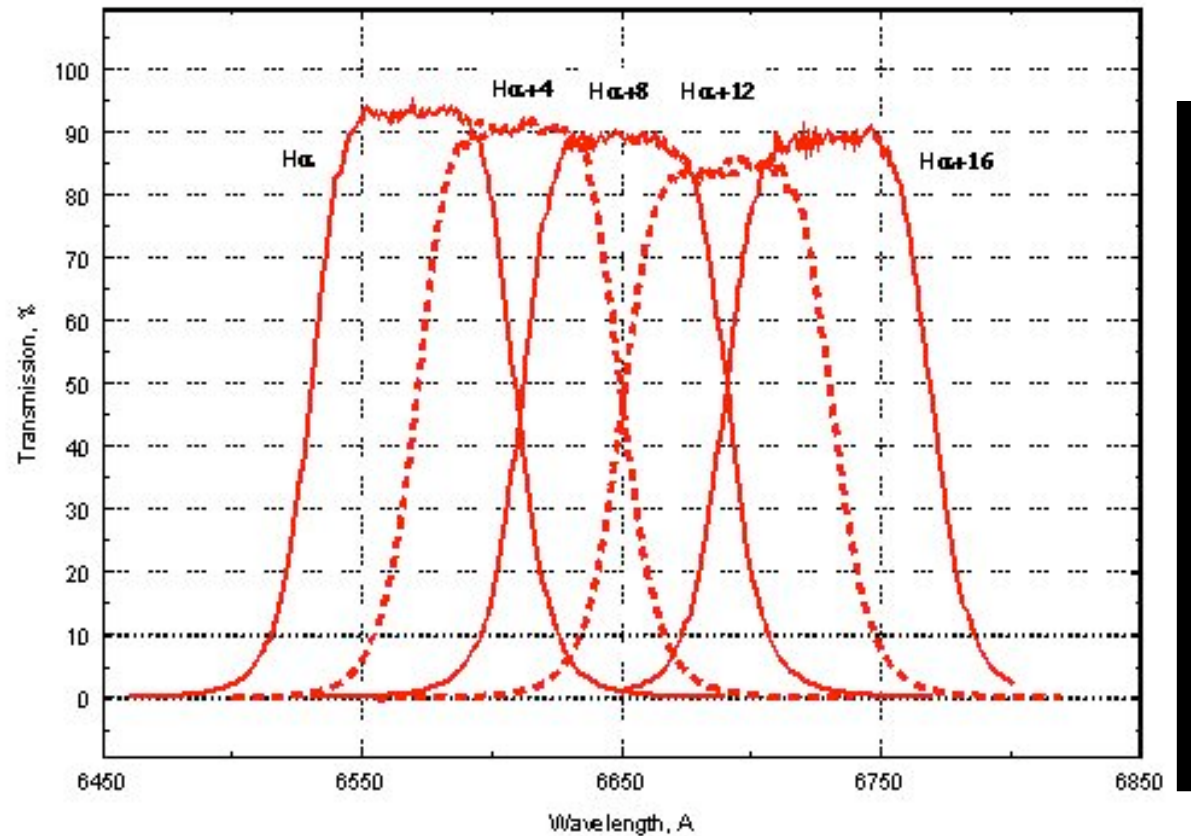*Even filters on the same system will have slightly different transmission*

KPNO MOSAIC FILTERS

http://pleiadi.pd.astro.it/isoc_photsys.00/filters1.jpg

NARROWBAND FILTERS

Typically target specific emission
    lines

- H-alpha
- Lyman-alpha
- OII
- OIII
- etc…

www.noao.edu/kpno/mosaic/filters

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Note: This lecture is largely comprised of examples that are not part of the posted notes.