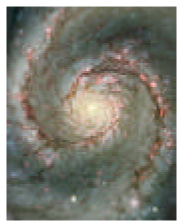
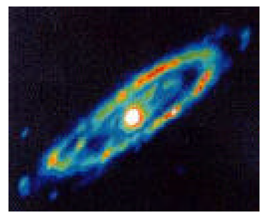
Astronomical Image Processing

- Data/Image Processing:
  *from a **raw image** to a **calibrated image***
- Data analysis
- Data reduction → calibrated data

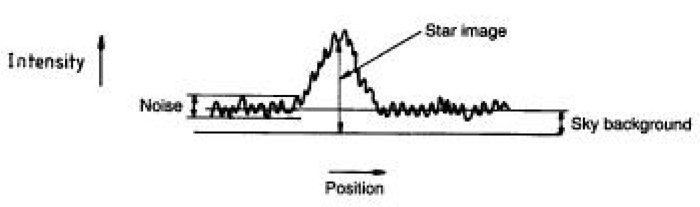




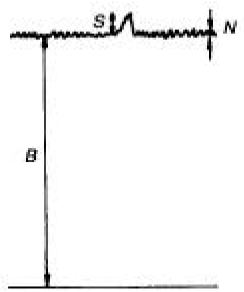
Photometric Accuracy

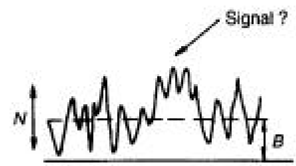
- What we measure
  = star (S) + (sky) background (B) + noise (N)
- What determines the faintest object detectable?
  $S > B$?

No!

It is the S/N (signal-to-noise ratio, SNR) that determines the photometric accuracy and the detectability of the faintest object (the detecting limit), e.g., S/N~3, a 3-sigma detection, would be a rather secured detection

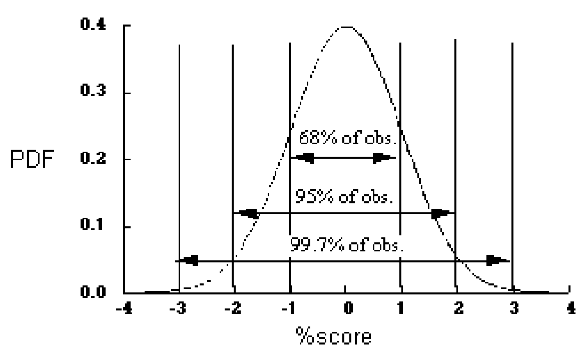






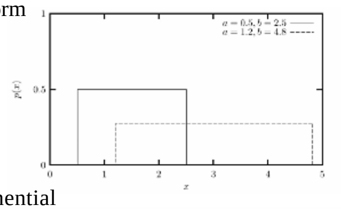
Normal Distribution

$$f(x) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left(-\frac{(x-\mu)^2}{2\sigma^2}\right)$$

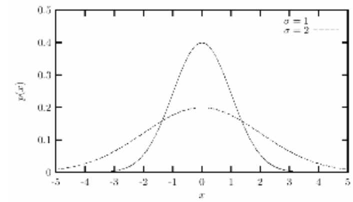


Distributions of Random Values

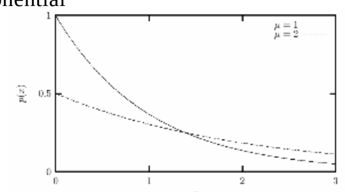
uniform



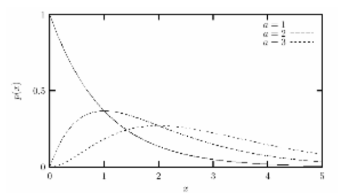
Normal (Gaussian)



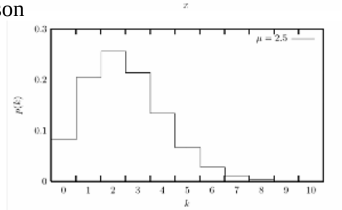
exponential



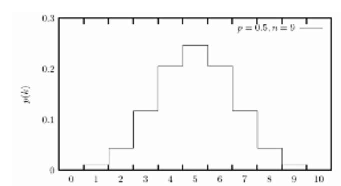
Gamma



Poisson



binormial



Poisson Distribution (1/4)

…most commonly used to model the number of random occurrences of some phenomenon in a specified unit of space or time

For example

1. number of phone calls received by a telephone operator in a 10-minute interval
2. number of flaws in a bolt of fabric
3. number of typos per page made by a secretary

http://stat.tamu.edu/stat30x/notes/node70.html

Poisson Distribution (2/4)

- For a Poisson random variable, the probability that X is some value x is given by the formula

$$P(X = x) = m^{x} e^{-m} / x!$$

where μ is the average number of occurrences in the specified interval.

- For the Poisson distribution,

$$E(X) = m, \quad Var\,(X) = m$$

- That is, SD = uncertainty = SQRT(total events)

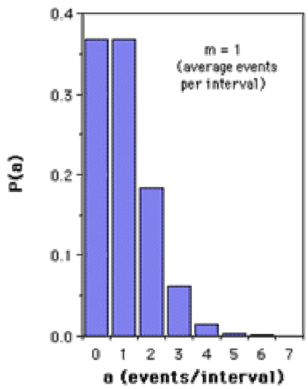
Poisson Distribution (3/4)

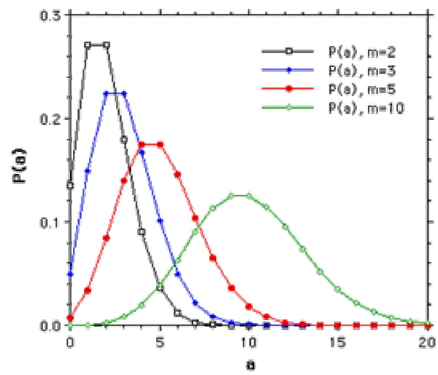
- *Example 1*: The number of false fire alarms in the suburb of Taipei averages 2.1 per day. Assuming that a Poisson distribution is appropriate, the probability that 4 false alarms will occur on a given day is estimated by

$$P(X = 4) = 2.1^{4} e^{-2.1} / 4! = 0.0992$$

Poisson Distribution (4/4)

Fifty dots distributed randomly over 50 scale divisions; **m** = 1



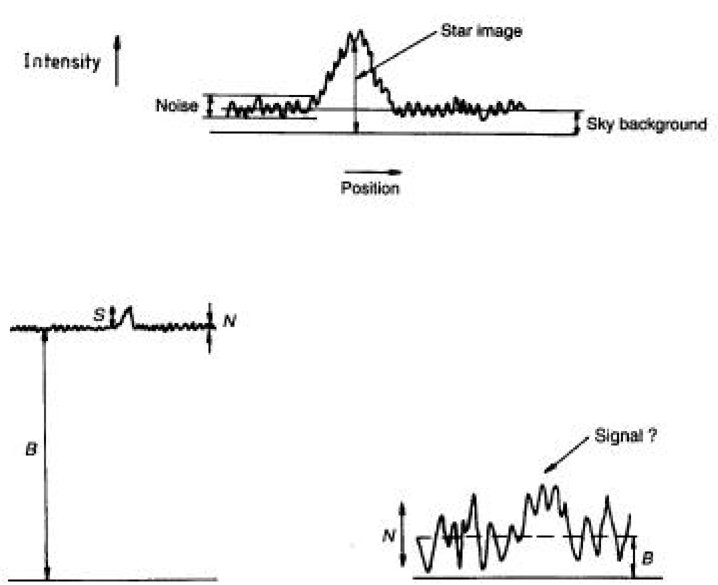


http://info.bio.cmu.edu/Courses/03438/PBC97Poisson/PoissonPage.html#Features

Poisson Distribution --- Example

The spatial distribution of craters in a particular region of the moon has a Poisson distribution with average occurrence of 900 craters per square kilometer. NASA is planning a moon landing in the region and wants to know the probability that there are no craters within a circle of 50 meters in diameter from a preselected point in the region. What diameter circle will guarantee no craters inside with probability 0.9?

For the solution, see http://amath.colorado.edu/courses/4570/2003fall/SEC001002/q5solutions.pdf



Signal-to-Noise Ratio (S/N; SNR)

- For a random Poisson noise

  $N \sim SQRT(S)$

  so $S/N = S \,/\, SQRT(S) = SQRT(S) \sim SQRT(t)$

  ∴ *S/N* increases as the square-root of the integration time.

More appropriate figure of merit for a detector

➔Detective Quantum Efficiency (DQE)

$$DQE = [\ (S/N)_{out}/(S/N)_{in}\ ]^2$$

Educated guess

A railroad company numbers its locomotives in order, *1, 2, …N*.

(a) One day, you see a locomotive, and its number is 60. What is your best guess for the total number N of locomotives which the company owns?

(b) On the following days, you see four more locomotives, all with numbers smaller than 60. What is your best guess for N based on this additional information?

Describe your reasoning carefully and in detail.

Error Analysis & Propagation

- A star has m_V=10.9 +/- 0.1 mag
- It later is resolved to be a binary system with a flux ratio of 2.1 +/- 0.2 between the components.
- What is the magnitude of each component stars in this binary system?

Effects of Sky Background

- **Scattered moonlight or sunlight**

When the moon is up, i.e., a week around Full Moon, the sky is very bright and accurate photometry is not possible.

Radio observations, and some infrared observations, are possible during the day.

An observatory often schedules 3 kinds of nights as required by project scientific contents

- **dark** — almost no moon (1 week near New Moon) sky~21 mag/sq”
- **gray** — no moon for half of the night (second ½ near First Quarter; first ½ near Third Quarter)
- **bright** – moon visible nearly all night (1 week near Full Moon) sky~13 mag/sq”!

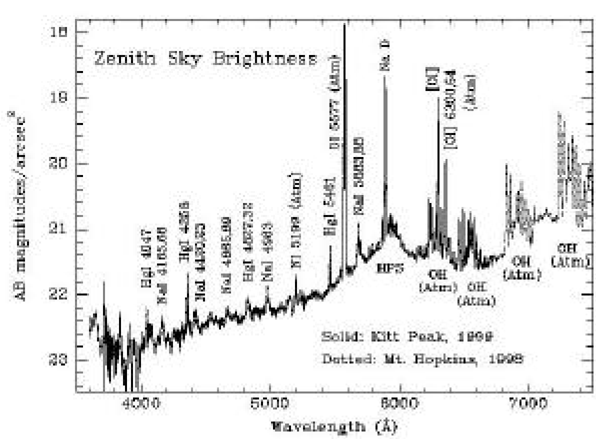
Effects of Sky Background …

- **Airglow**

Upper atmosphere of the Earth constantly bombarded by high-energy radiation or energetic particles, mostly from the sun.

atoms/molecules → excited or ionized
→ emit spectral lines

May design special filters to 'bypass' airglow lines



http://www.lowell.edu/users/massey/nightsky.html

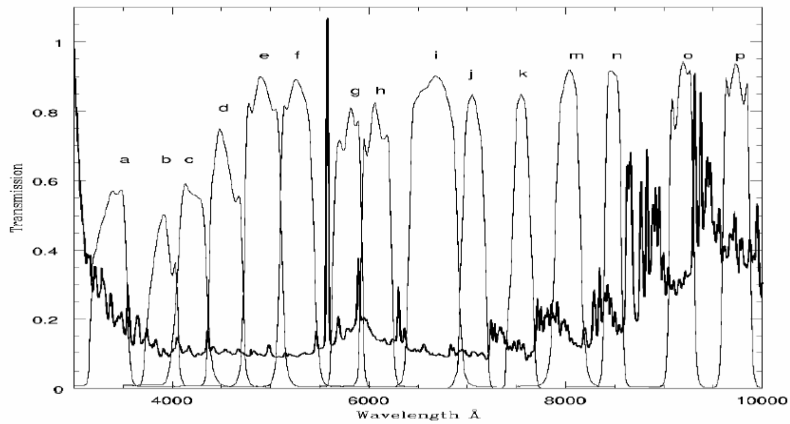
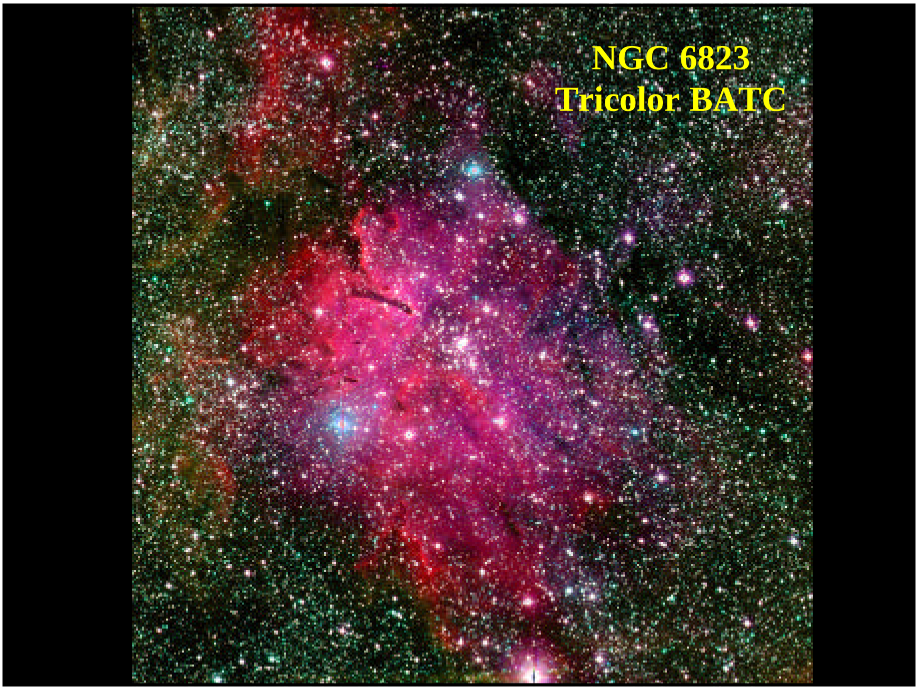
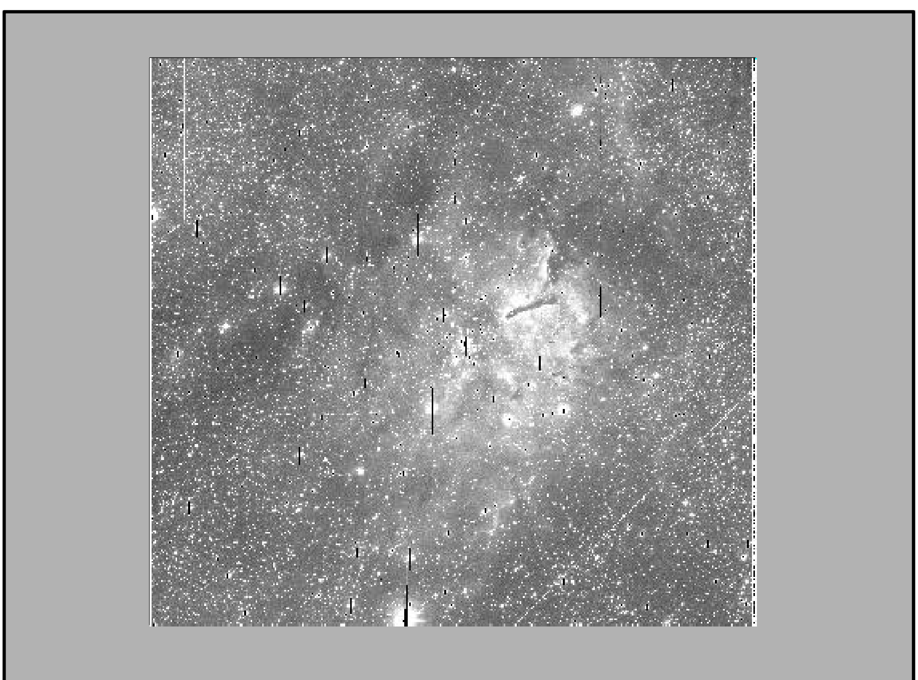


Fig.1 BATC filter system.

Effects of Sky Background …

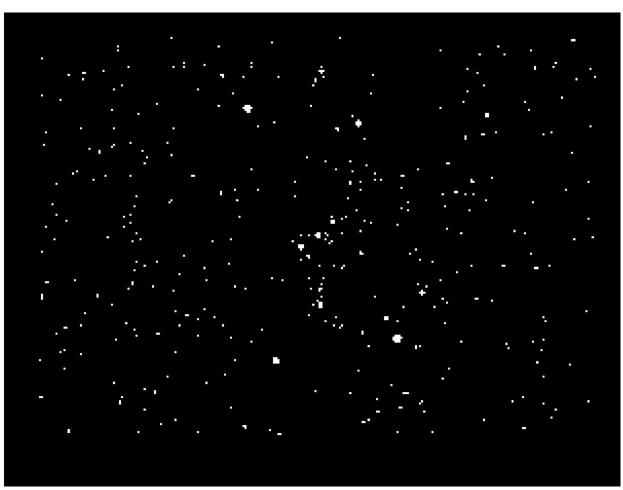
- **Light Pollution**
  - ✓ Large cities, mainly from mercury and sodium street lights, often poorly shielded
  - ✓ Artificial satellites, e.g., P2242523.FIT
  - ✓ Zodiacal light: sunlight scattered off dust particles in a band centered around the ecliptic
  - ✓ Faint, unresolved stars


NGC 6823
Tricolor BATC

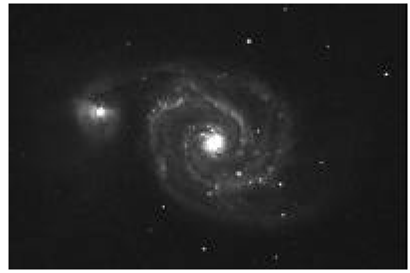


- +7.0 mag sky → a total of 14,000 stars, so a person in a perfect site can see ~7,000 stars
- +6.0 mag sky → ~2,400 stars visible
- +5.0 mag sky → ~800 stars visible, Milky Way barely visible
- +4.0 mag sky → < 250 stars visible, Milky Way not visible
- +3.0 mag sky → < 50 stars (typical in a city)
- +2.0 mag sky → < 25 stars (center of a big city)

Orion Constellation from +7.0 to 2.0 mag sky



http://www.darksky.org/infoshts/is120.html



A single exposure of the Whirlpool Galaxy

a median combine of three images

Antiblooming

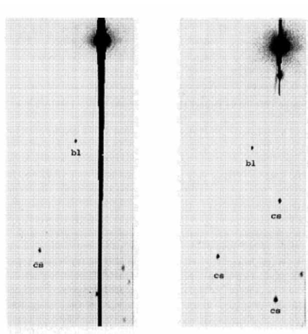
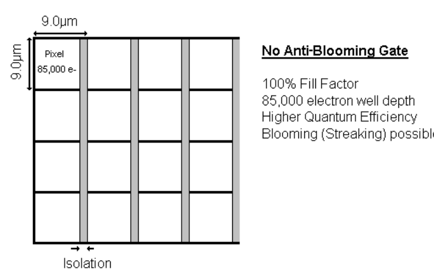
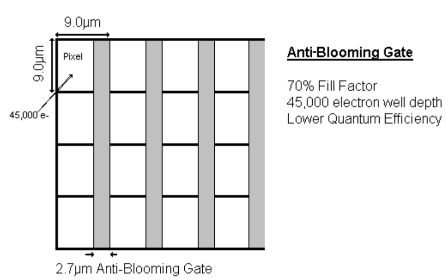


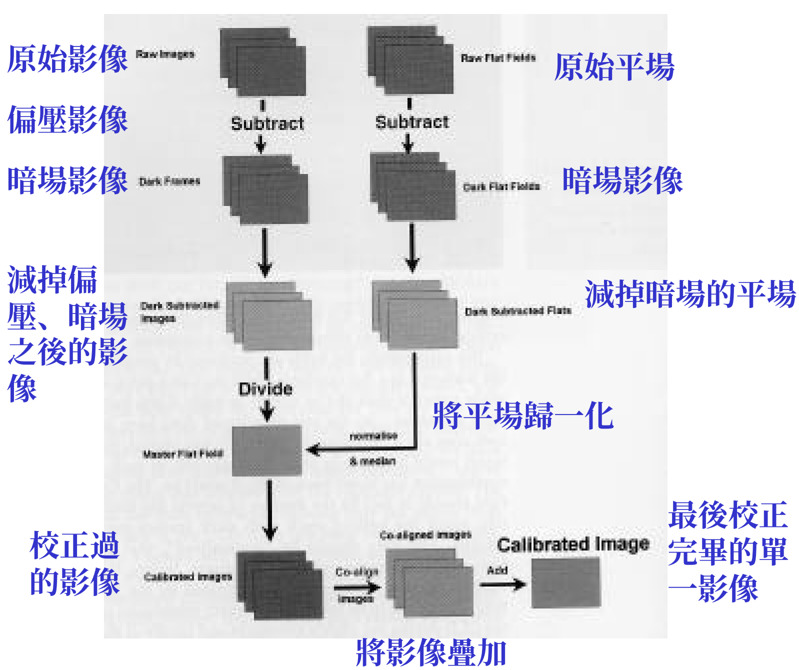
FIG. 1—480-s exposures of BL Lac PKS 0215−015 (bl). (a) normal exposure; (b) exposure with antiblooming at 100 Hz clocking rate. The comparison stars for the project have now appeared from behind the blooming. The bright star is SAO 110456.

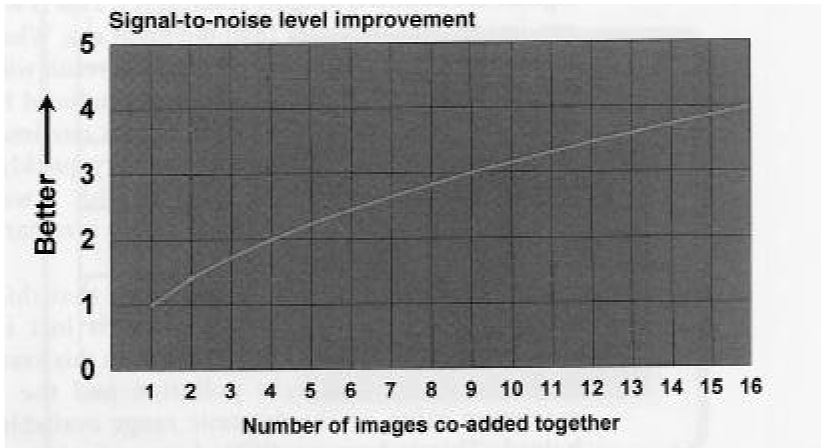




➔ **Loss of sensitivity**

- **Bias frame** --- an exposure of zero time with the CCD covered, i.e., with the shutter closed. It is an image of the electronic noise present in the camera
- **Dark frame** --- an image produced by covering the CCD and taking a blank exposure. The exposure time is normally of the same duration as that of the target frame.
- **Flat field** --- an image of a totally uniform object such as a white screen. Used to correct the image for non-uniformity caused by the CCD itself and the optics.





Noises

- **Photon (shot) noise** --- light arrives as discrete photon events → fluctuations in arrival rates
- **Thermal (Johnson or Nyquist) noise** --- generated in all resistors, from random nature of the motion of the charge carriers
- **Readout noise** --- errors introduced by stray capacitance in the (CCD) readout circuit

  ➔ $s^{2}_{total} = S_i \, s^{2}_{i}$

Arts of Imaging Processing

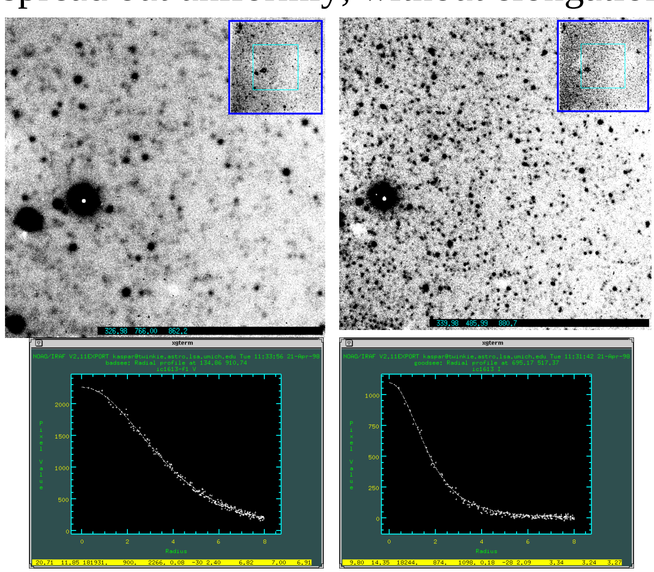
Q: What can go wrong with CCD imaging?

A: Everything!

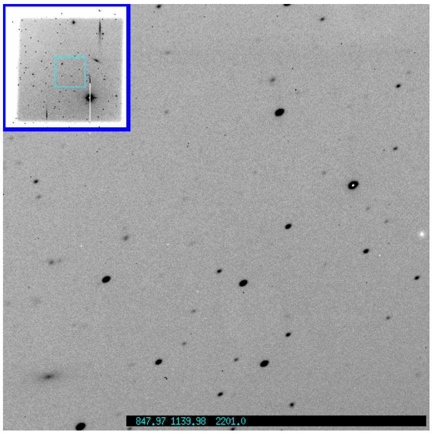
- seeing, focusing, guiding
- cosmic rays
- fringing
- dust rings
- reflections
- diffraction spikes

http://www.ciw.edu/vonbraun/obs_mishaps/mishaps.html

- **Effects of Bad Seeing** Stellar images spread out uniformly, without elongation

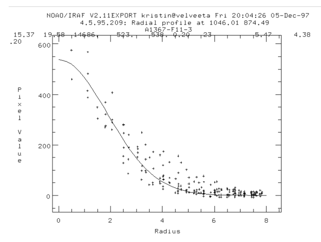


- **Effects of Bad Focus** Stellar images elongated in direction of astigmatism on some part of the frame

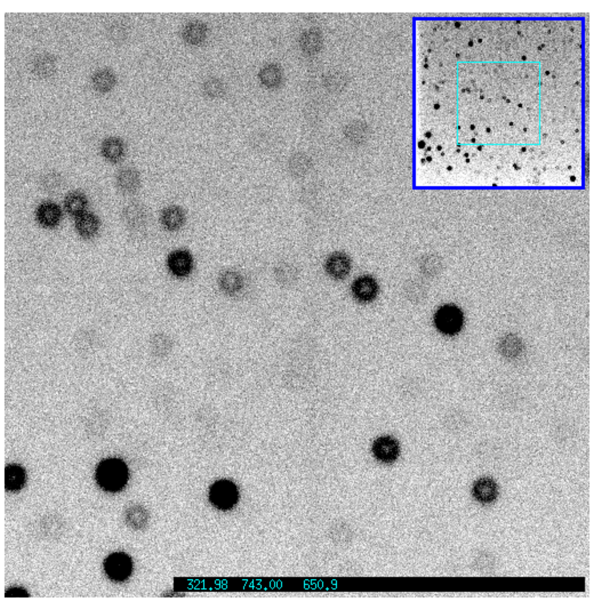


If elongation EW or NS → bad guiding?

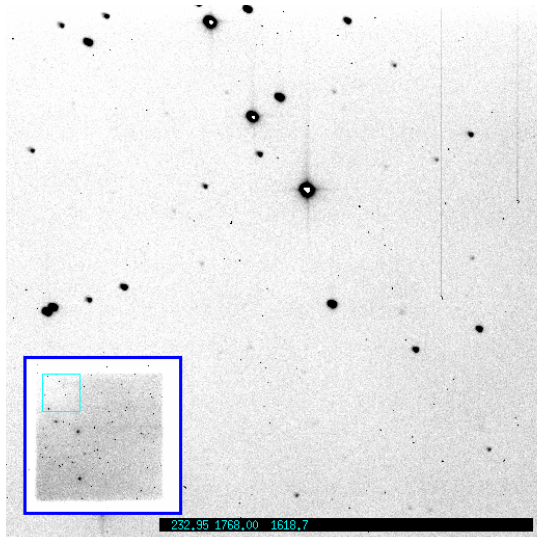
If elongation in all parts of image → bad guiding?



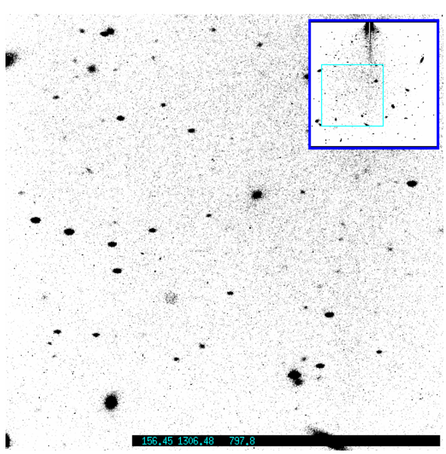
If way out of focus → donut shape



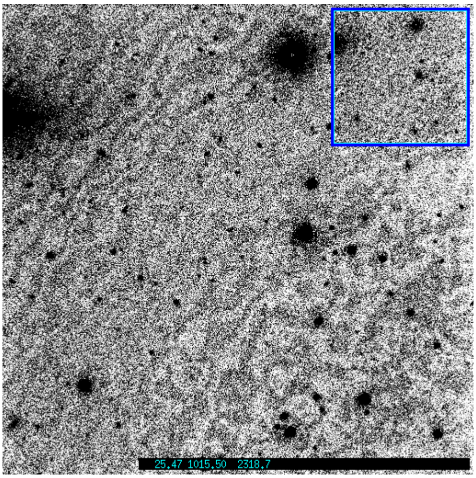
Effect of coma



- **Effects of Bad Guiding** Stellar images elongated in NS or EW uniformly in the frame

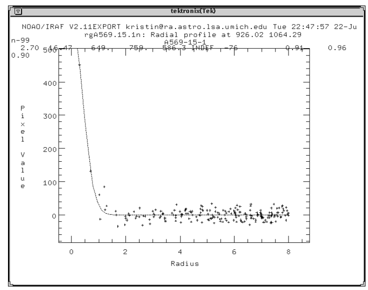


- **Interference fringes** due to (multiple) internal reflections

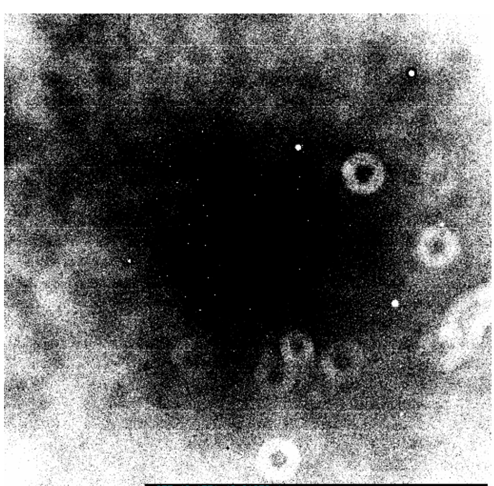


cosmic ray: point-like

star: Gaussian

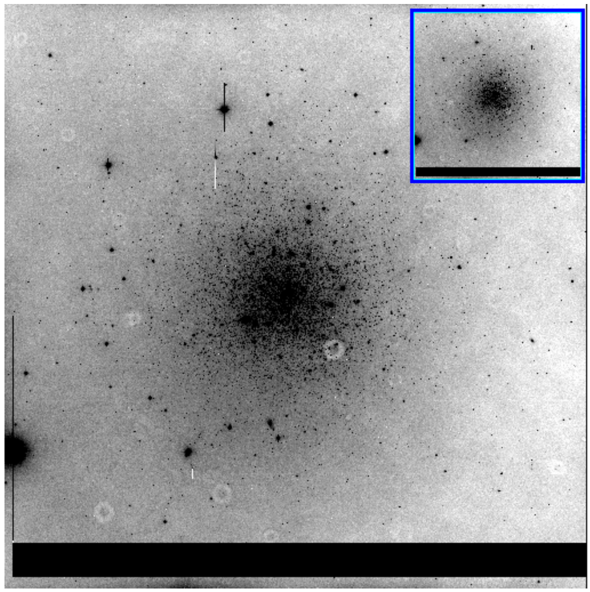


- **Dust rings** caused by dust on dewar window or filters; show up in all frames



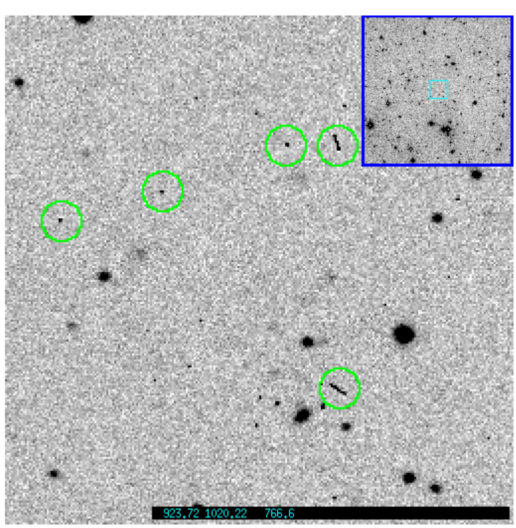
Dewar window dust → stationary

Filter dust → moved throughout run (and even in a night) → evening and dawn flats



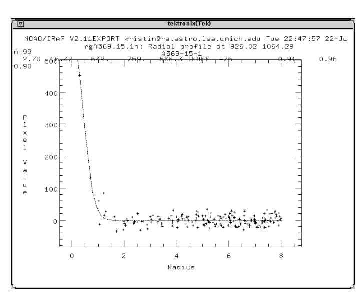
Dust ring
and readout
error

- **Cosmic rays** streaks and dots caused by energetic particles striking the CCD

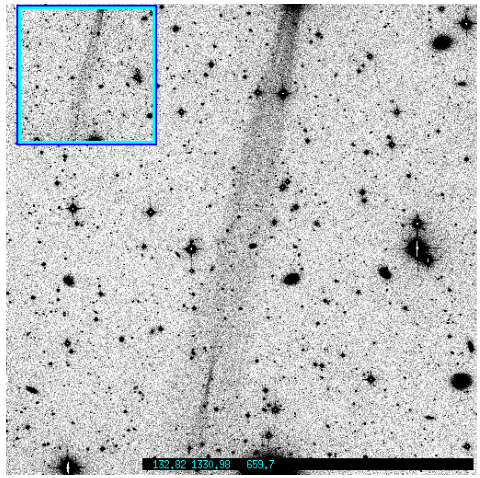


cosmic ray → point-like

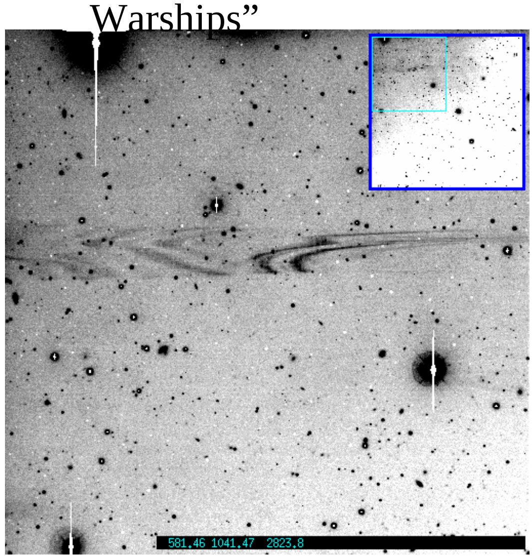
Star → Gaussian



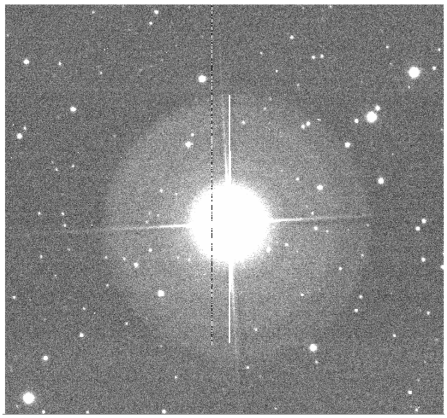
- **Reflection** caused by reflection or scattering off some part of the telescope (or dome)



“Romulan Warships”



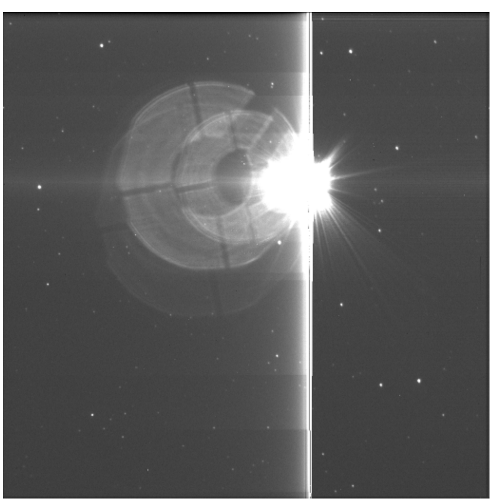
- **Diffraction spikes** caused by by (the Fourier Transform of) the support struts which hold the secondary mirror in place.



Internal reflection

Part of the light hitting the CCD surface is reflected back toward the dewar window and the filter, then reflected back toward the CCD surface where it is perceived as out of focus (thus the doughnuts).

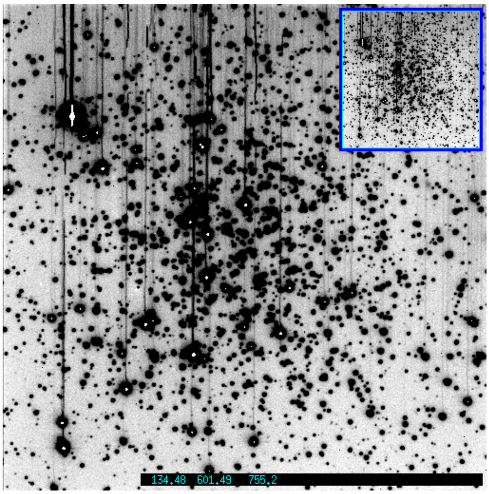
Circularly symmetric in this case



Reflecting surface or the CCD is tilted.

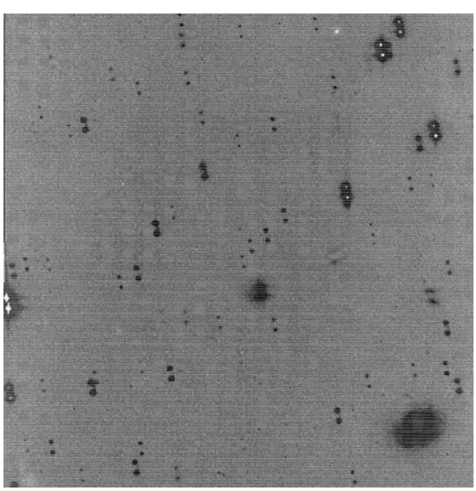
"Hole" in the center of each donut → alignment ok!

Q: What could this be caused by?



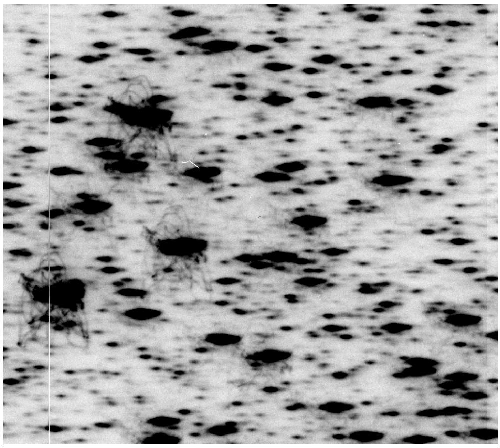
A: Shutter failure …… bright trails of stars caused by the fact that the shutter was not closed when the CCD was read out.

Q: What could this be caused by?



A: guider jumped

Q: What could this be caused by?



A: An earthquake!