Astrophotography: Tips, Tricks, and Techniques

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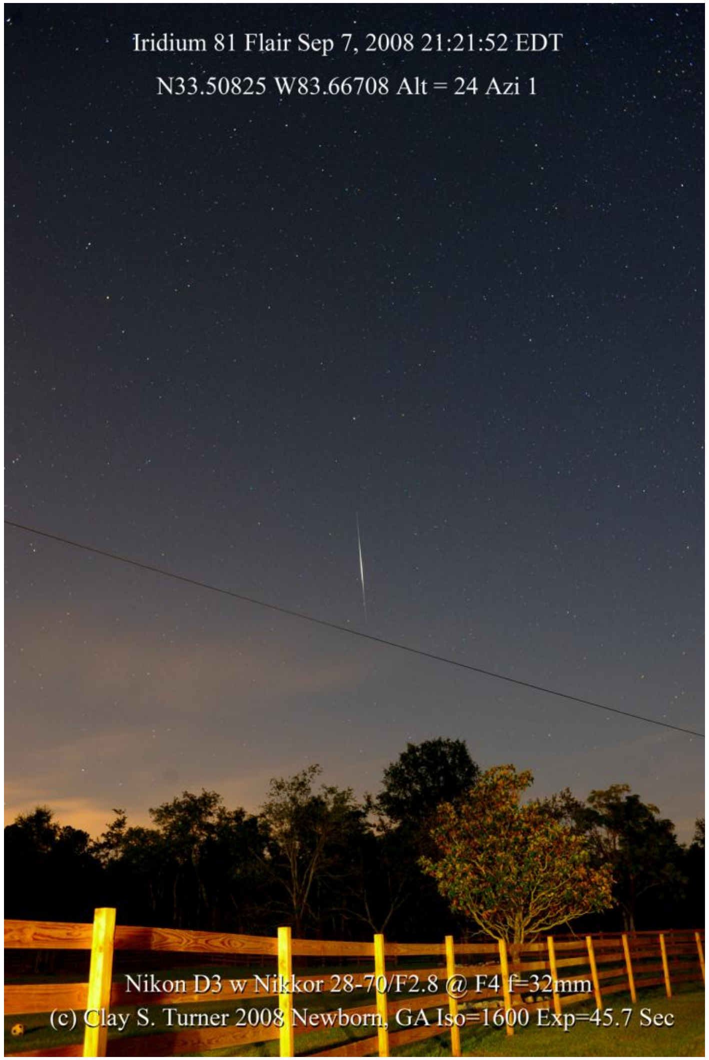
Astrophotography without a Telescope

- Use camera on a tripod
- Use remote shutter release
- Do long exposures with large apertures (“Fast Lenses”)
- Include landscape with sky to make image interesting.
- Modern low noise DSLRs allow high ISOs to facilitate short exposures.

Yellowstone National Park

Lowell Observatory

Iridium Flares



Lowell Observatory

Piggyback Astrophotography

- Here you attach your camera onto a telescope to use the scope’s tracking.
- Camera uses its own lens and not the scope’s optics.
- Useful for medium to large areas of the sky.

Shot with DSLR and 180 mm lens

Three basic ways to image through your telescope.

- Prime Focus
- Eyepiece Projection
- Afocal Photography

Prime Focus Imaging

- The telescope’s objective is used in place of a “long lens” in photography. Thus the camera, sans lens, is connected where the eyepiece normally goes.
- DSLRs are usually used in this mode of Astro-Imaging.
- Preferred method of imaging by professional astronomers.

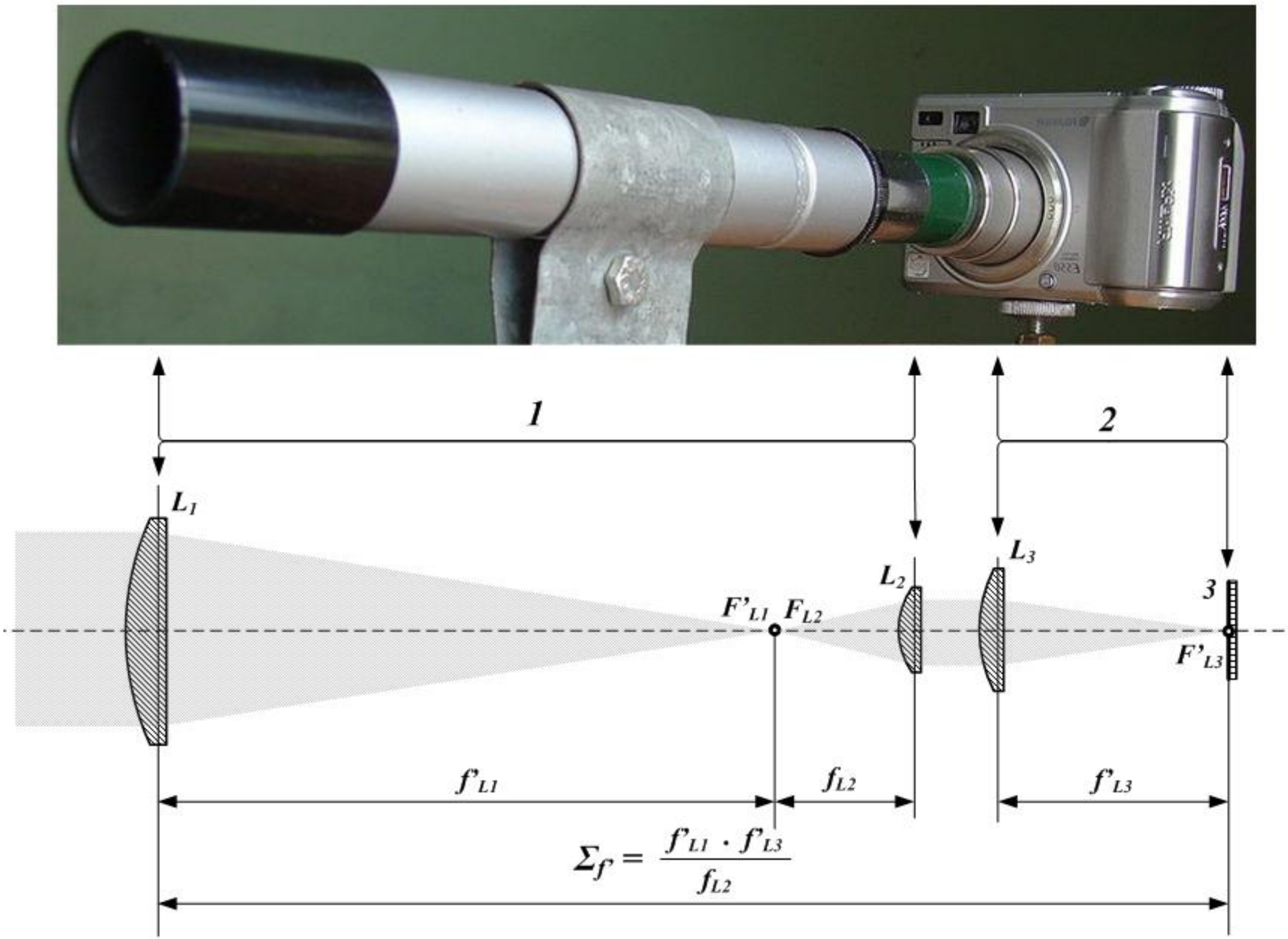

ASTRO-TECH
AT6RC 6" f/9 Ritchey-Chrétien

Eyepiece Projection

- Just like with Prime Focus photography, a camera is used without its lens. But in this case the eyepiece is used to magnify and project the image onto the camera’s sensor (film).
- There are special adaptors that will contain the eyepiece and also hold the camera with variable spacing (magnification) permitted.

Afocal Photography

- In this case the telescope with its eyepiece is focused so an observer while looking into the eyepiece sees the object clearly. Then a camera with a lens is then used to image the object while looking into the eyepiece. Birders often call this technique “digiscoping.” Simple low cost “point and shoot” cameras may be used this way.


1
2
L1
L2
L3
3
F'L1
FL2
F'L3
f'L1
fL2
f'L3
Σf' = (f'L1 · f'L3) / fL2

Angular Size and Magnification

- The two main tasks of a telescope are to increase an object’s apparent angular size and brightness.

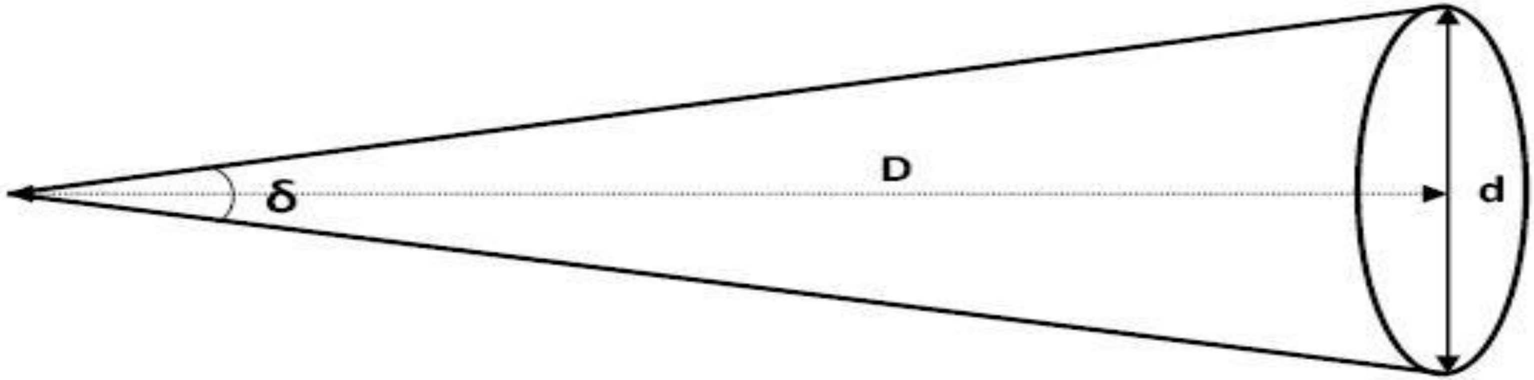
Digital Sensors

- Since a digital sensor is comprised of pixels (picture elements) and each pixel thus “sees” a small part (angle) of the image, we need to discuss angular sizes as they are a common measure in Astronomy.

Angular Diameter

- Using Trigonometry, an angular size is measured

$$\delta = 2\tan^{-1}\left(\frac{d}{2D}\right)$$



Types of Angular Measure

- Radians
- Degrees
- Minutes of Arc
- Seconds of Arc

Radians

- A circle divides into 2 pi radians
- Mathematically convenient in formulae.
- Not very convenient for direct measure since 2 pi is not a whole number!
- Thus, usually seen in theoretical equations but not in direct measurements.

Degrees

- A circle subdivides into 360 equal angles.
- 360 has a large number of divisors,
- The Earth moves approx. 1 degree per day around sun.
- Some Astronomical objects have a angular size bigger than a degree. E.g., the Andromeda Galaxy is over 4 degrees in extent – just faint!

Minutes of Arc (Arcmins)

- A degree subdivides into 60 arcminutes.
- A convenient unit for the size of the Sun, Moon, some galaxies and nebulae.
- Sun: 31.6 to 32.7 arcmins
- Moon: 29.3 to 34.1 arcmins.
- Ring Nebula: 1.4 by 1.0 arcmins

Seconds of Arc (Arcsecs)

- A minute of arc subdivides into 60 seconds of arc.
- Useful measure for sizes of planets.
- Jupiter: 29.8 to 50.115 arcsecs
- Mars: 3.49 to 25.113 arcsecs
- Used for limiting telescopic resolution.

Distance to a Dime for various angular sizes.

- 1 Radian: 0.645 Inches
- 1 Degree: 3.37 Feet
- 1 Arcminute: 202 Feet
- 1 Arcsecond: 2.3 Miles!!

10 Cent Lunar Eclipse.

- To just cover the Moon with a Dime, you will need to hold it between 6 and 7 feet away.
- This follows since the Moon is approximately half of a degree in diameter.

Small Angle Approximation

- For small angles (measured in radians), the arctangent formula may be ignored. For example:

$$\delta = 2\tan^{-1}\left(\frac{d}{2D}\right) \approx \frac{d}{D}$$

Small Angle Formula in Arcseconds

$$\delta = 206265 \frac{d}{D}$$

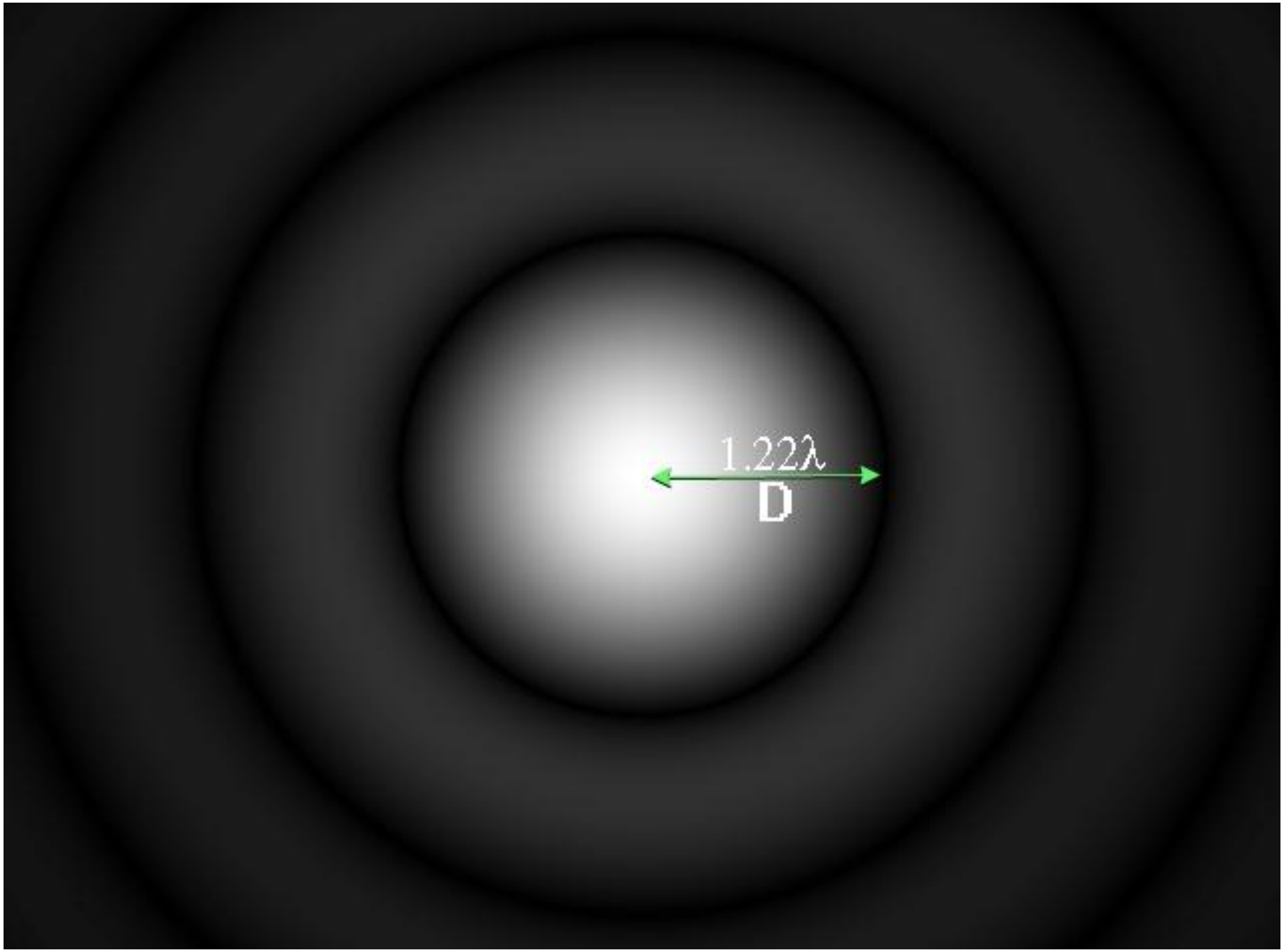
Alternative uses for Small Angle Formula

- This formula also relates a telescope's focal length, camera pixel size, and angular resolution.
- Let d=focal length and D=pixel diameter.
- Additionally this will tell you the image height on the sensor!

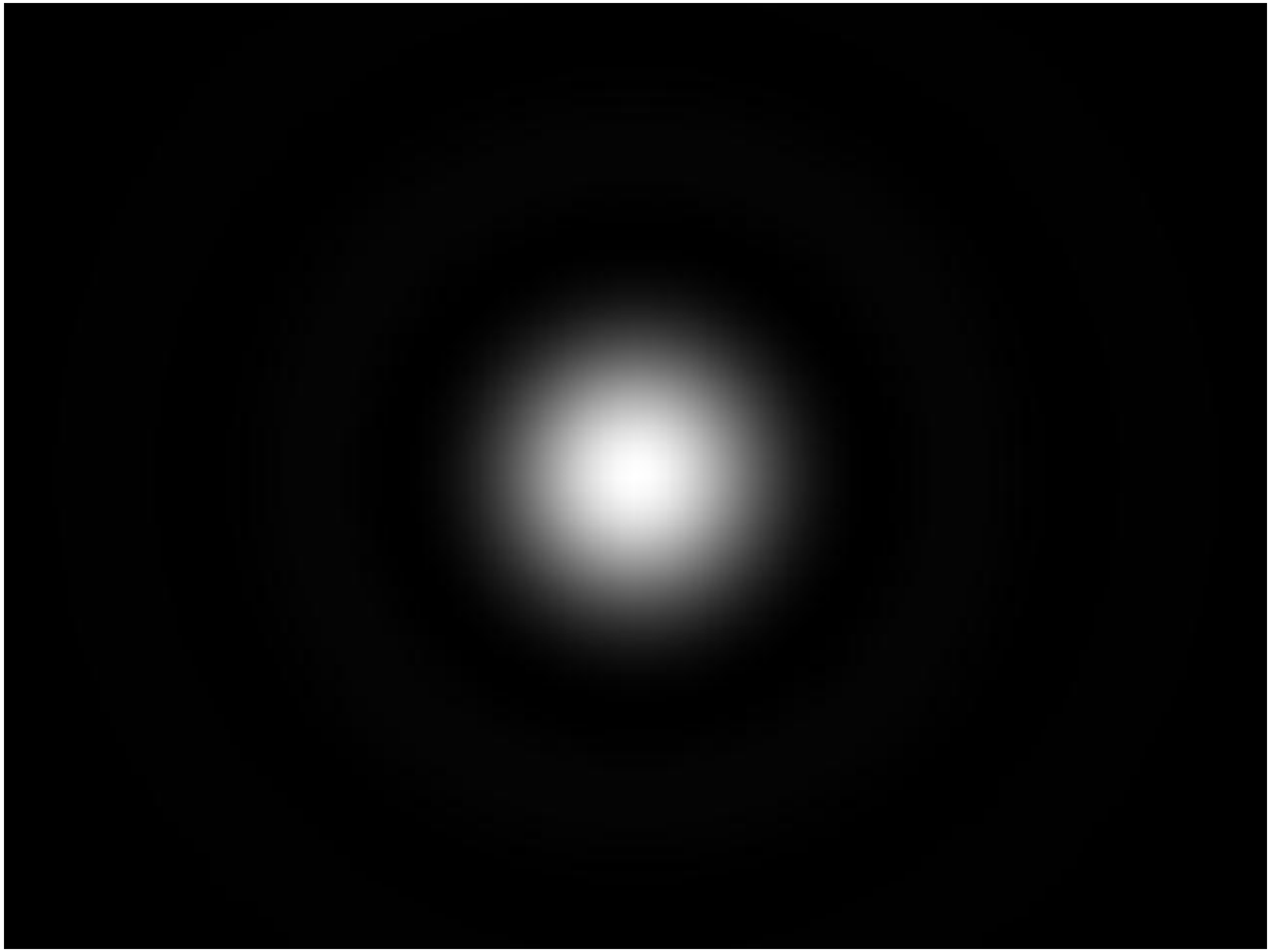
Telescopic Resolution

- Obviously we can’t just keep increasing the magnification of a telescope. It has a practical upper limit.
- The limiting is rooted in the wave nature of light.
- A point like star actually blurs into a disk – called an Airy Disk under high magnification.

Highly Magnified Star (Enhanced Contrast)



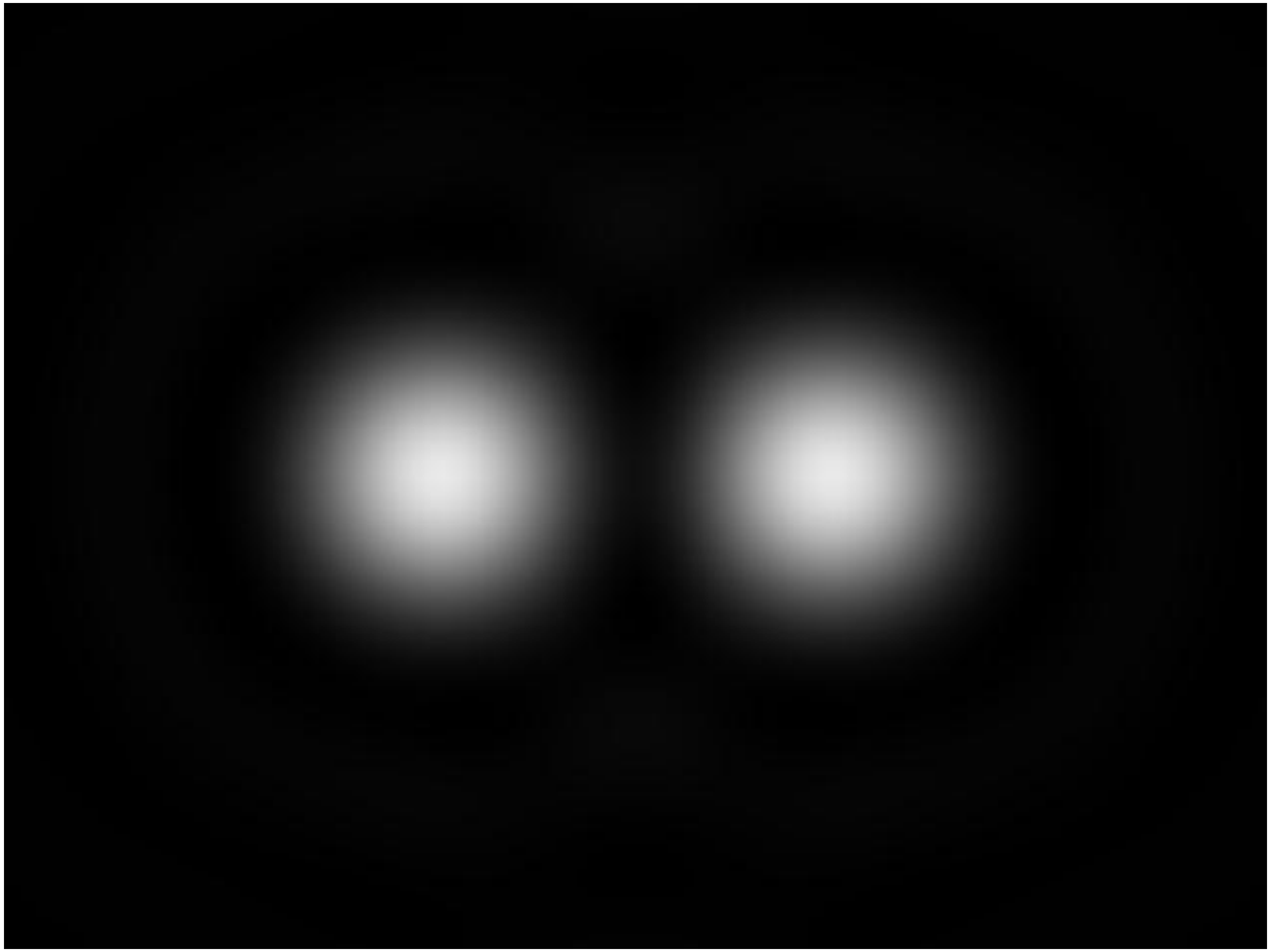
Highly Magnified Star (Normal Contrast)



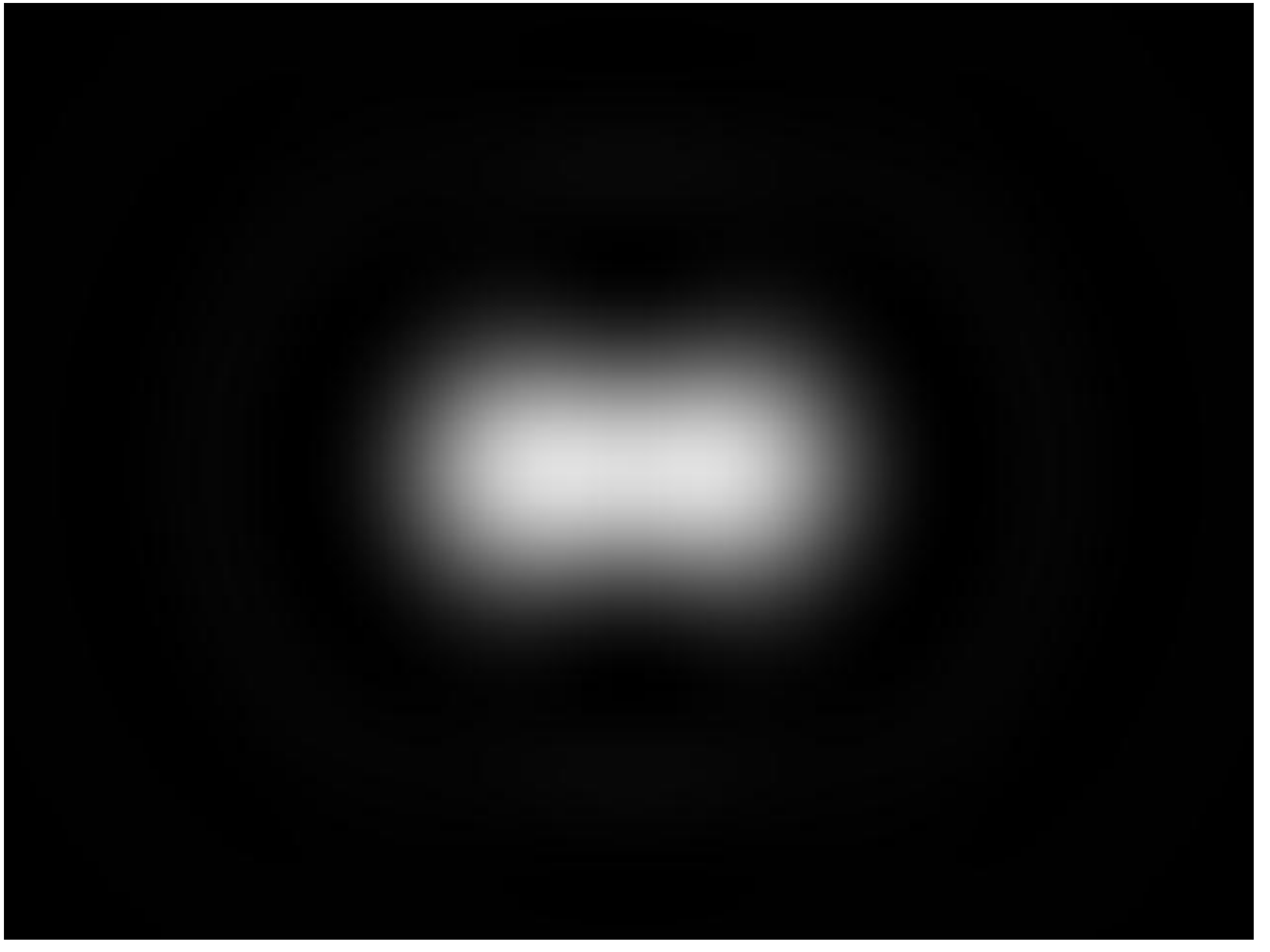
Resolution Test (Binary Stars)

- We can talk about how well a telescope resolves two closely spaced equal brightness stars)

Binary with 2*lambda/D separation



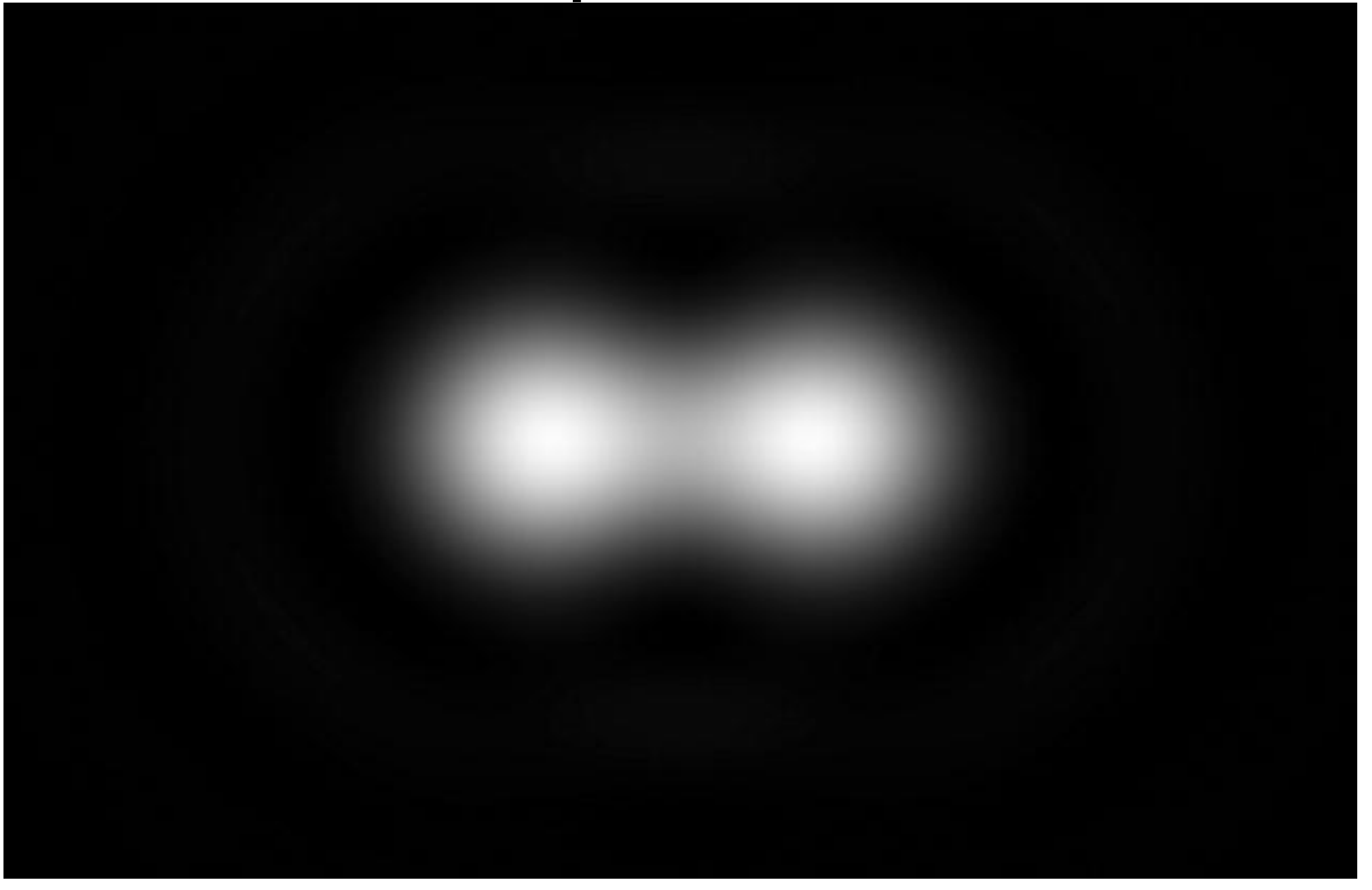
Binary with lambda/D Separation



Binary Resolution

- At 2 lambda/D separation, we easily discern two stars.
- At 1 lambda/D separation, the two stars merge into one.
- Limit to just discern two stars is at 1.22 lambda/D separation.

A Binary Star at 1.22 lambda/D separation



Rayleigh's Resolution Limit

- Delta is angle in radians
- Lambda is wavelength
- D is aperture

$$\delta = 1.22 \frac{\lambda}{D}$$

Rayleigh’s Limit

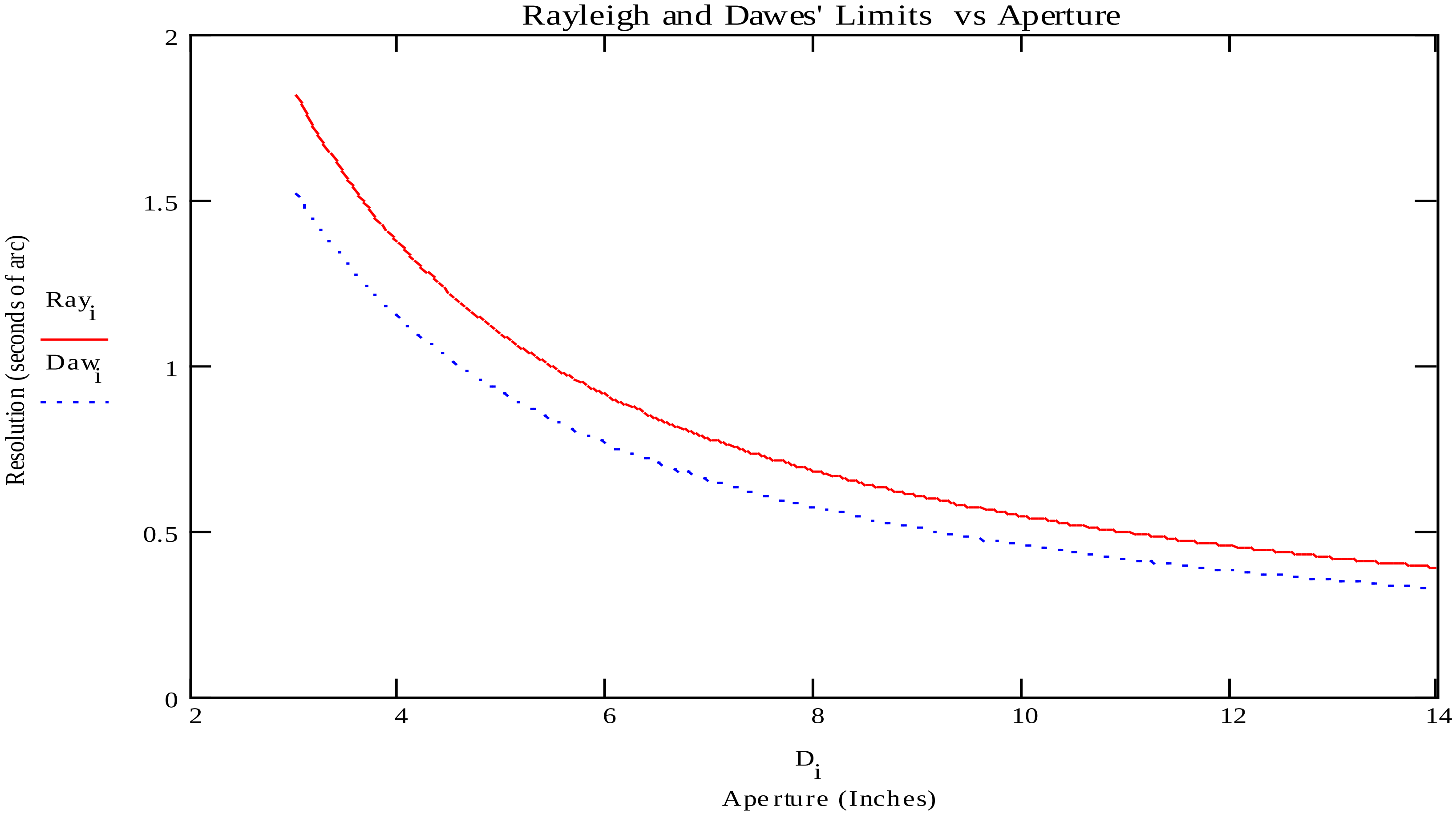
- If you assume green light (550nm) and express your limiting angular resolution in arcsecs and your telescope’s aperture in inches, then Rayleigh’s formula is:

$$\delta = \frac{5.45}{D}$$

Dawes' Limit

- This is very much like Rayleigh's formula except Dawes found it empirically whereas Rayleigh derived his.
- Since Rayleigh's formula is wavelength dependent, it matches Dawes' for 562nm.

Limiting Resolution v. Aperture



Size of Airy Disks

- The projected size of the Airy Disk is determined by the wavelength of light, and the telescope's aperture and focal length.

$$s = 2.44 \frac{\lambda f}{D} = 2.44 \lambda F$$

Airy Disk Size

- This last equation shows how the Airy disk size is determined by the telescope’s “F” ratio.
- You can change the “F” ratio by using a Field Reducer or a Barlow.

Nyquist Sampling Rate

- Nyquist theorem says you need at least two samples per sinusoidal period.
- Airy disks are not simple sinusoids.
- A rule of thumb is to use 3 pixels per the smallest thing the telescope can “see.”

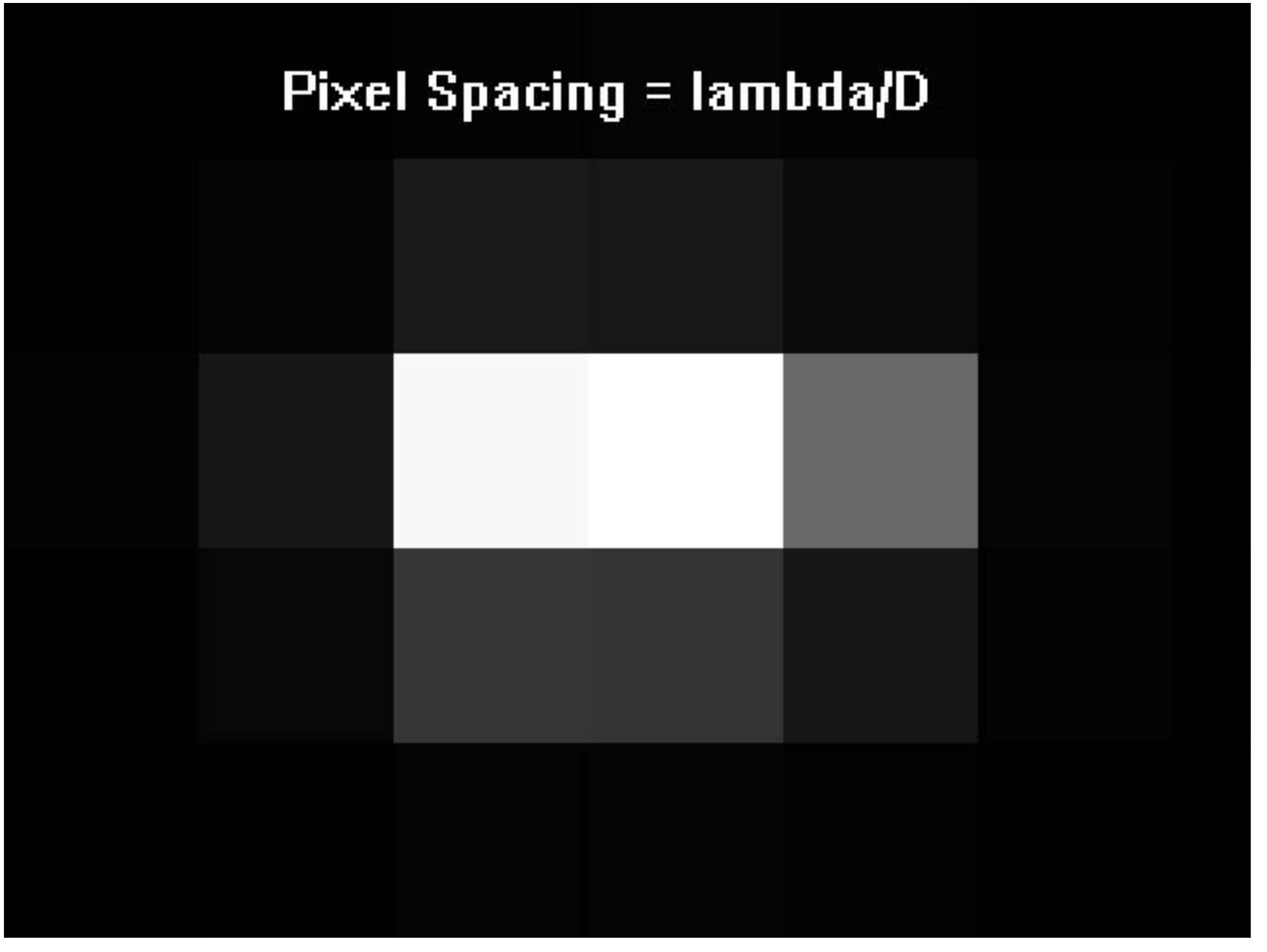
Pixelation (Digital Sampling)

- Digital Sensors sample the image
- Typical pixel sizes range from 5 to 13 microns.

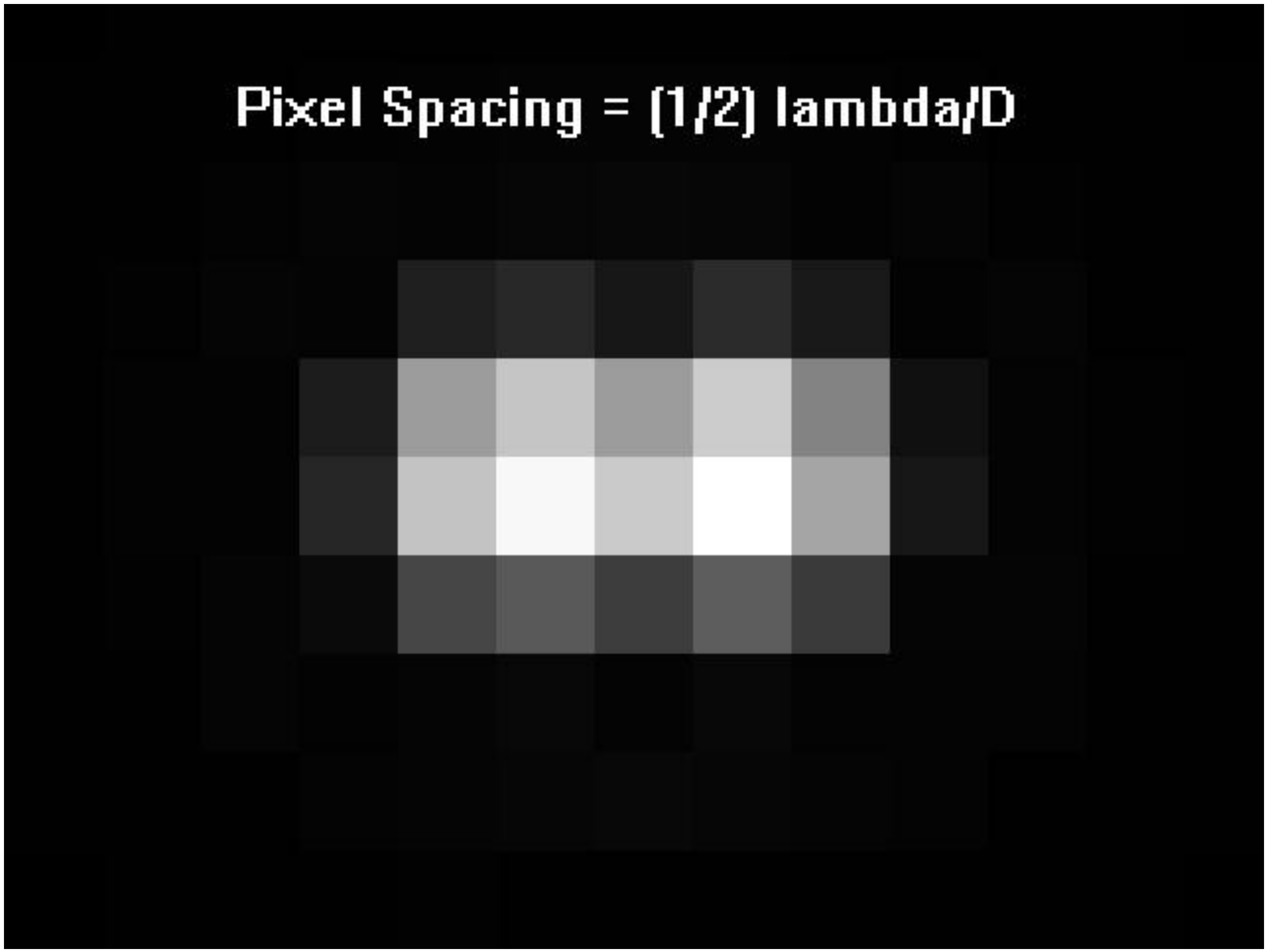
Pixelation (Digital Sampling)

- We will look at some binary stars sampled at different rates per lambda/D.

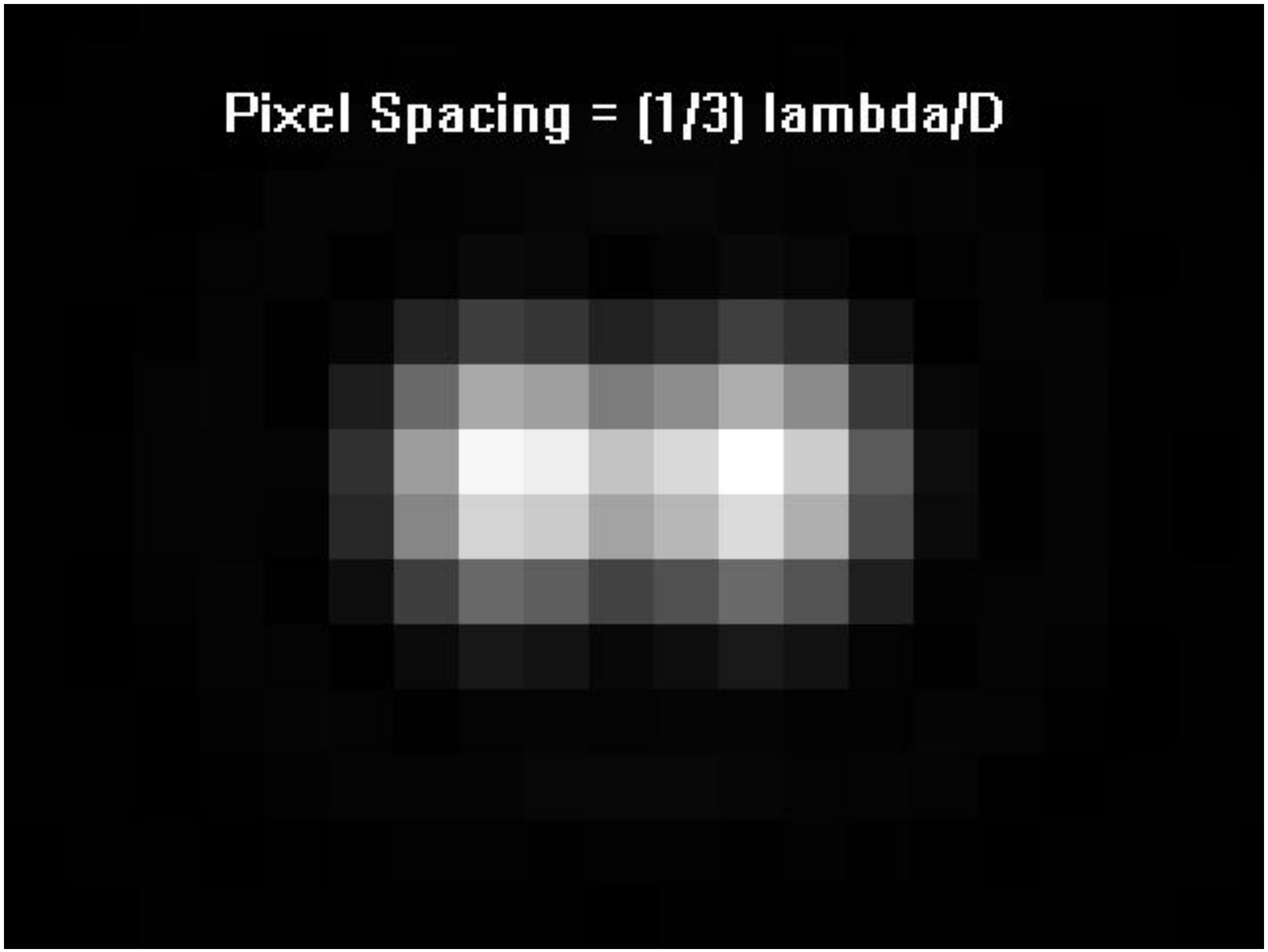
1 per



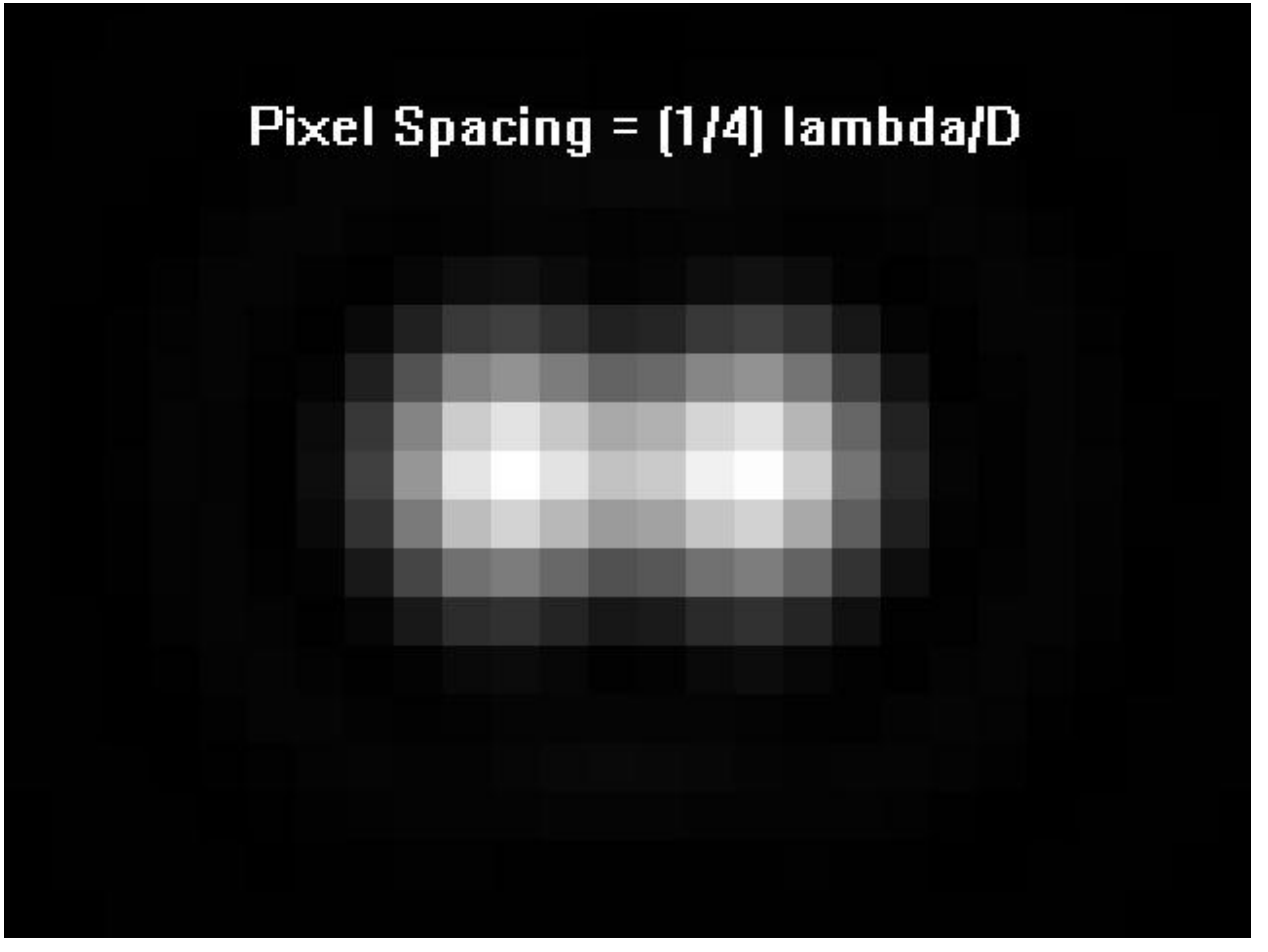
2 per



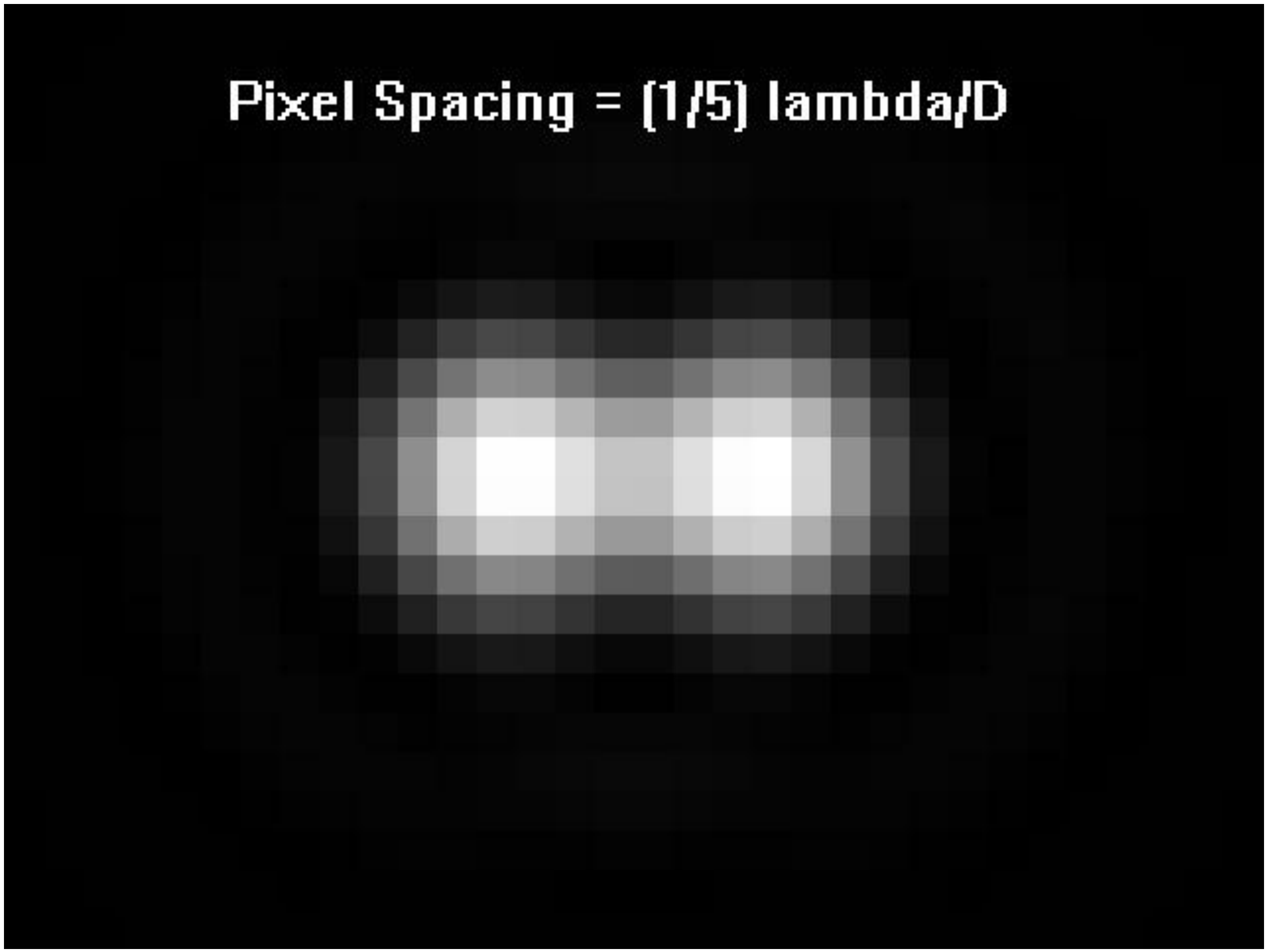
3 per



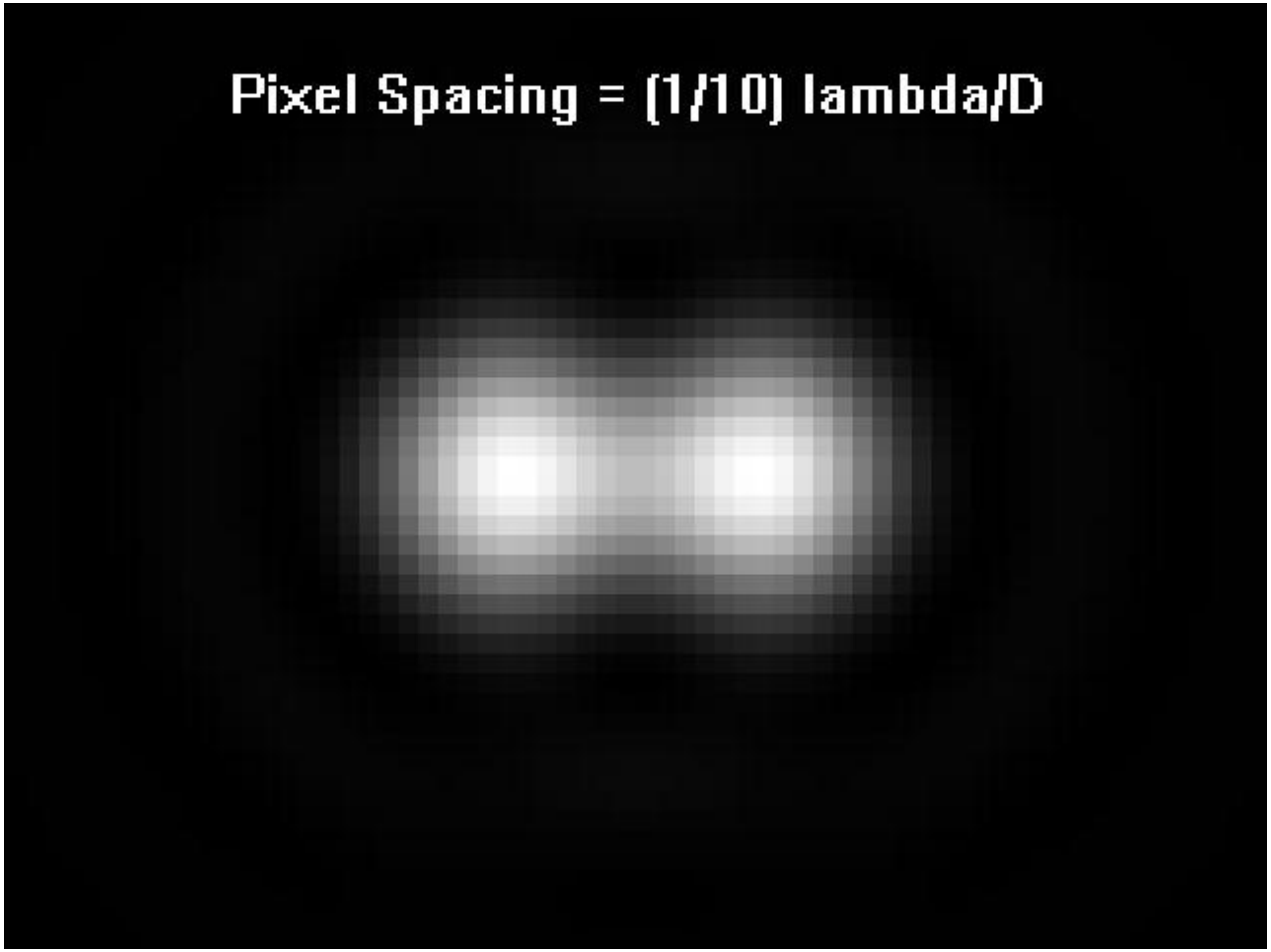
4 per



5 per



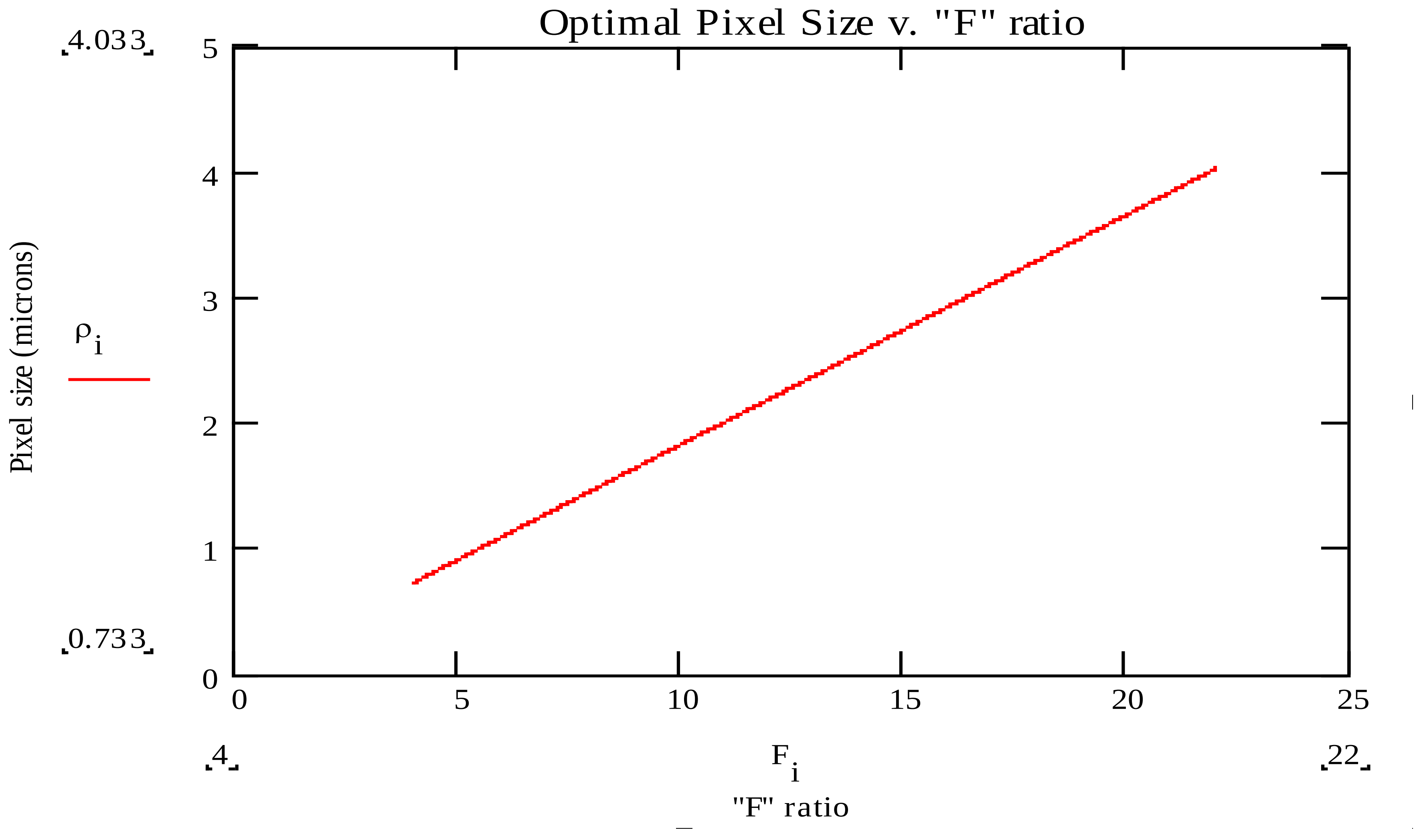
10 per



Optimal Sampling.

- In resolution limited applications, the optimal sampling rate is in the neighborhood of 3 pixels per lambda/D.
- More is okay but wasteful of pixels.
- Fewer than 3 loses information.

Optimal Sampling (Perfect World)



Optimal Sampling

Houston, We have a problem with the atmosphere!

Astronomical Seeing

- Is a measure of the blurring and twinkling of objects caused by atmospheric turbulence.
- Best Observatory locations have a seeing limit of around 0.4 Arc Secs.
- In Georgia, expect 2 or more Arc Secs of blur.

Astronomical Seeing

- Seeing is often worse on clear cold nights.
- The coming and going of weather fronts strongly affect seeing.
- When observing extended objects like the Moon, seeing makes the object appear to have waves move across it!

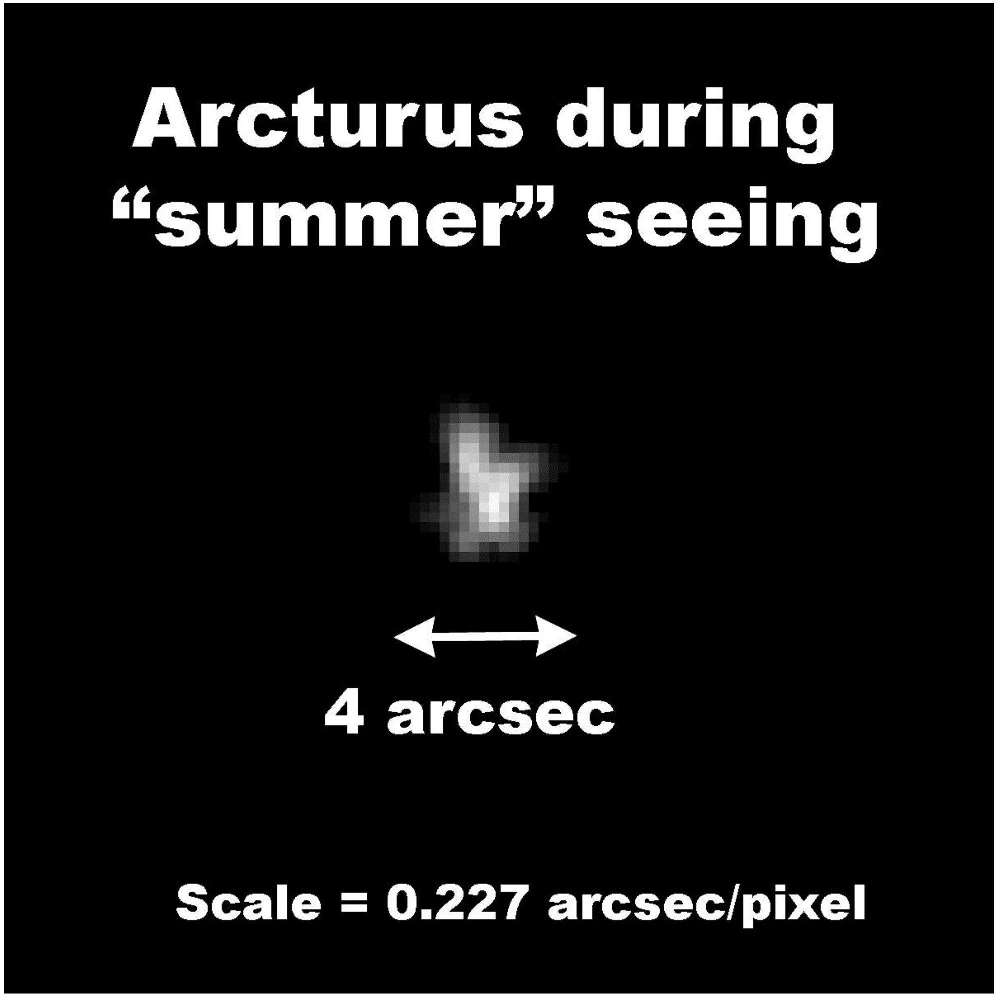
Astronomical Seeing

- Since objects appear to move, “time” exposures are blurred and the photographic resolution is limited by seeing.
- The blurring occurs on timescales of fractions of seconds.
- Exposures much shorter than a second may be used to eliminate motion blur but may still be distorted.

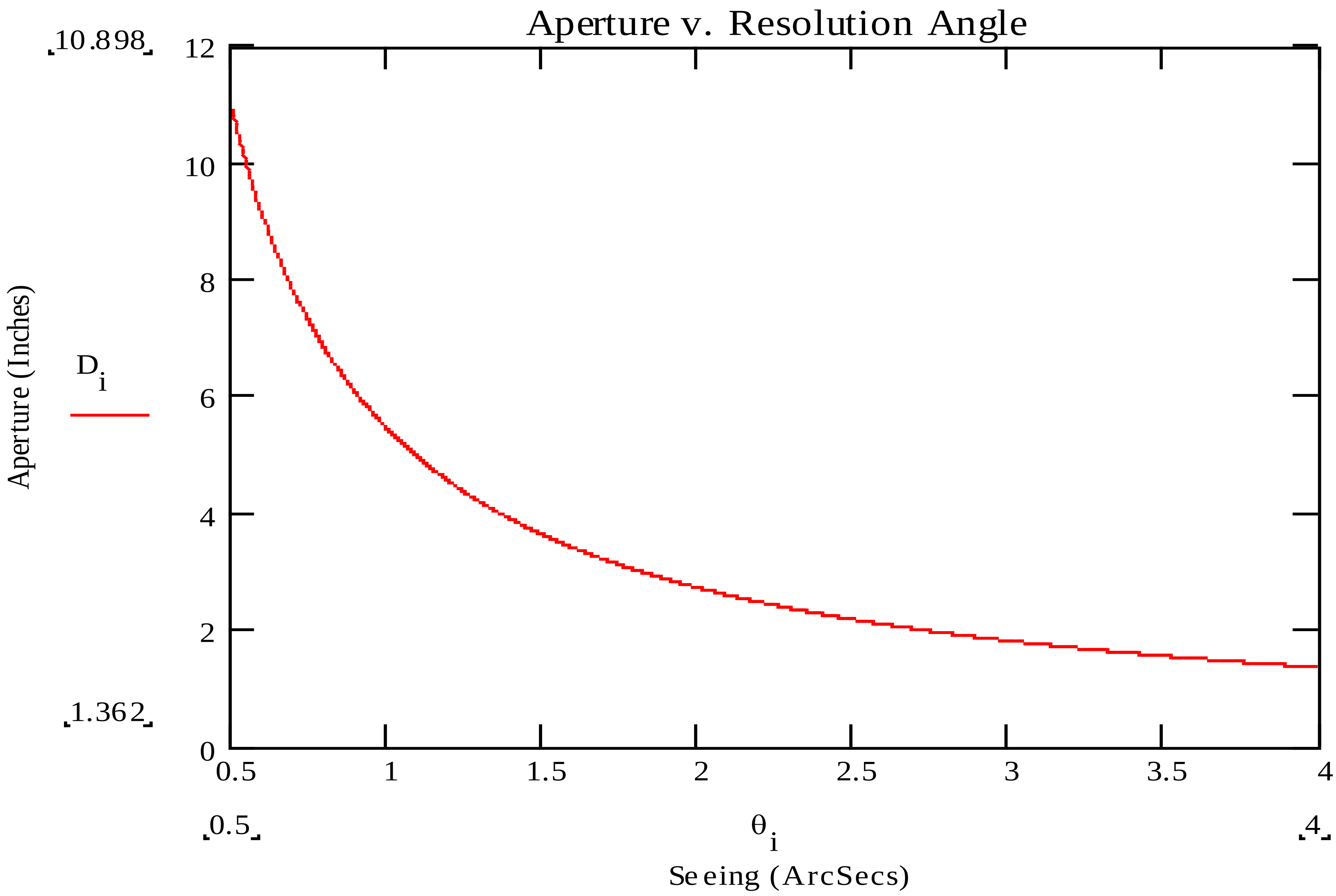
Astronomical Seeing

- Two ways to measure “seeing”
- First is by the full width half magnitude (FWHM) of the time averaged blur. (Given as an angle)
- Second is the equivalent telescope width that has the same resolution as the FWHM. (Given as an aperture size)

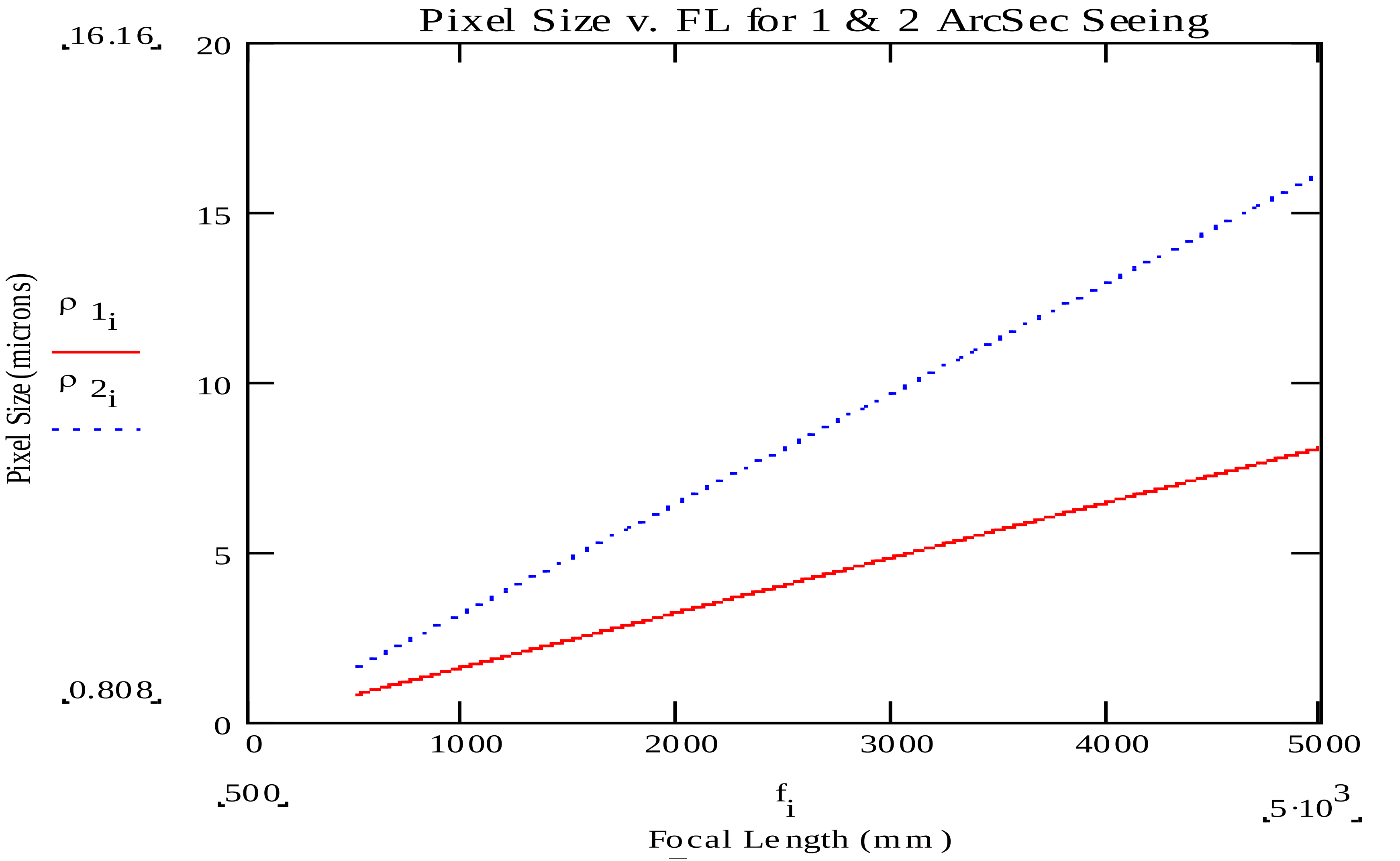
Sample Star Image from Video



Seeing (Aperture v. Angle)



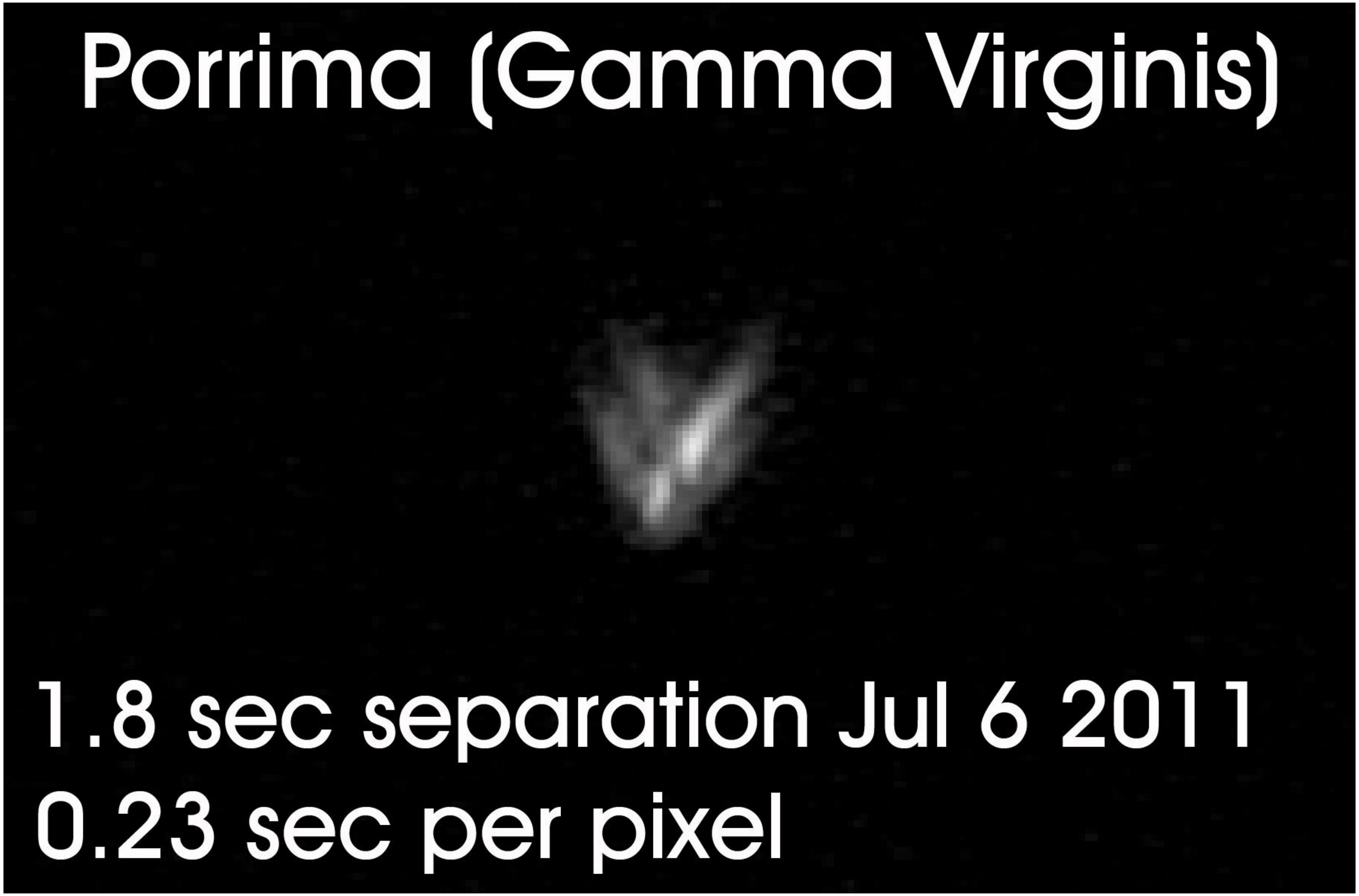
Optimal Pixel Size for Seeing and Focal Lengths



Speckle Interferometry

- Used for binary stars
- A movie is made of the binary, and a composite is made from the frames where each frame is aligned with a reference frame.
- This averages out the seeing induced blurring.

Simple Speckle Example



Lucky Imaging

- David Fried, May 1977 “Probability of getting a lucky short-exposure image through turbulence.
- Fried describes the idea of keeping the good images and throwing out the bad ones. He couples this with aperture and seeing to figure the odds of getting good images for D> 3.5* R0.

Lucky Imaging

- A video is made, and the bad frames are rejected with the undistorted ones aligned and composited together.
- If multiple alignment points for the reference image are used, the frames may each be contorted and rotated to align with each other before stacking.
- Lucky imaging in some cases allows one to achieve near theoretical resolution for imaging.

Lucky Imaging - Limitations

- Since one needs a series of very short exposures (i.e., a 30^{th} of a second or faster), one needs bright objects.
- Short exposures tend to be grainy, so many images need to be stacked to average out the noise (grain).
- Great for Lunar and Planetary Imaging.
- Not useful for Deep Sky objects ☹

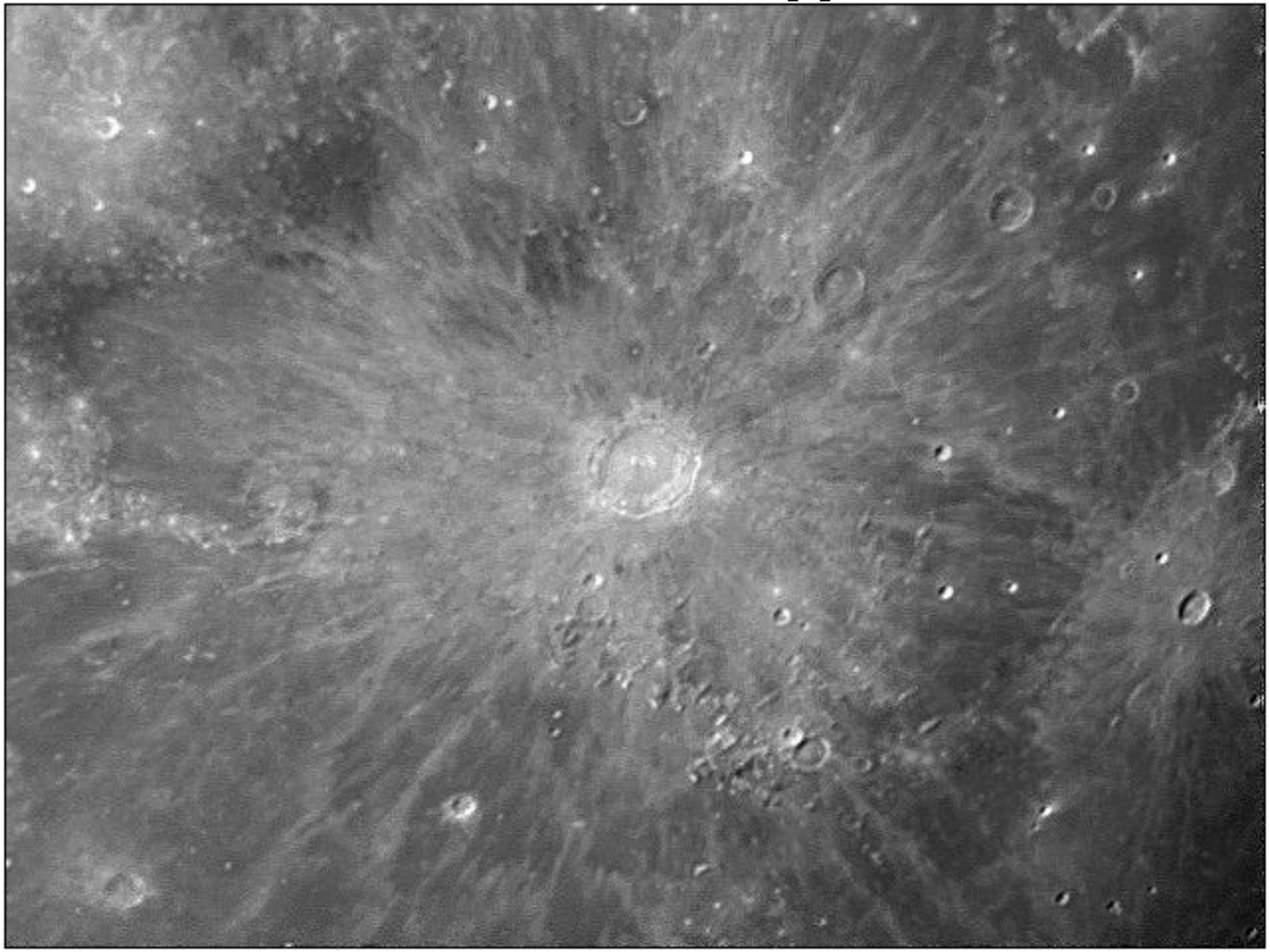
Saturn at the limit

- Next will be an image of Saturn taken with a low cost webcam and processed in Registax.
- Telescope is a F/4 Meade SN-10 barlowed to F/20!
- The 0.7 arcsec Cassini Division is just visible and scope is limited to 0.6 arcsecs. Saturn was not at its closest for this image.

Saturn (10” Meade-SN) at F/20

Jupiter with a 6" RC at F18

Image De-contortion with Stacking



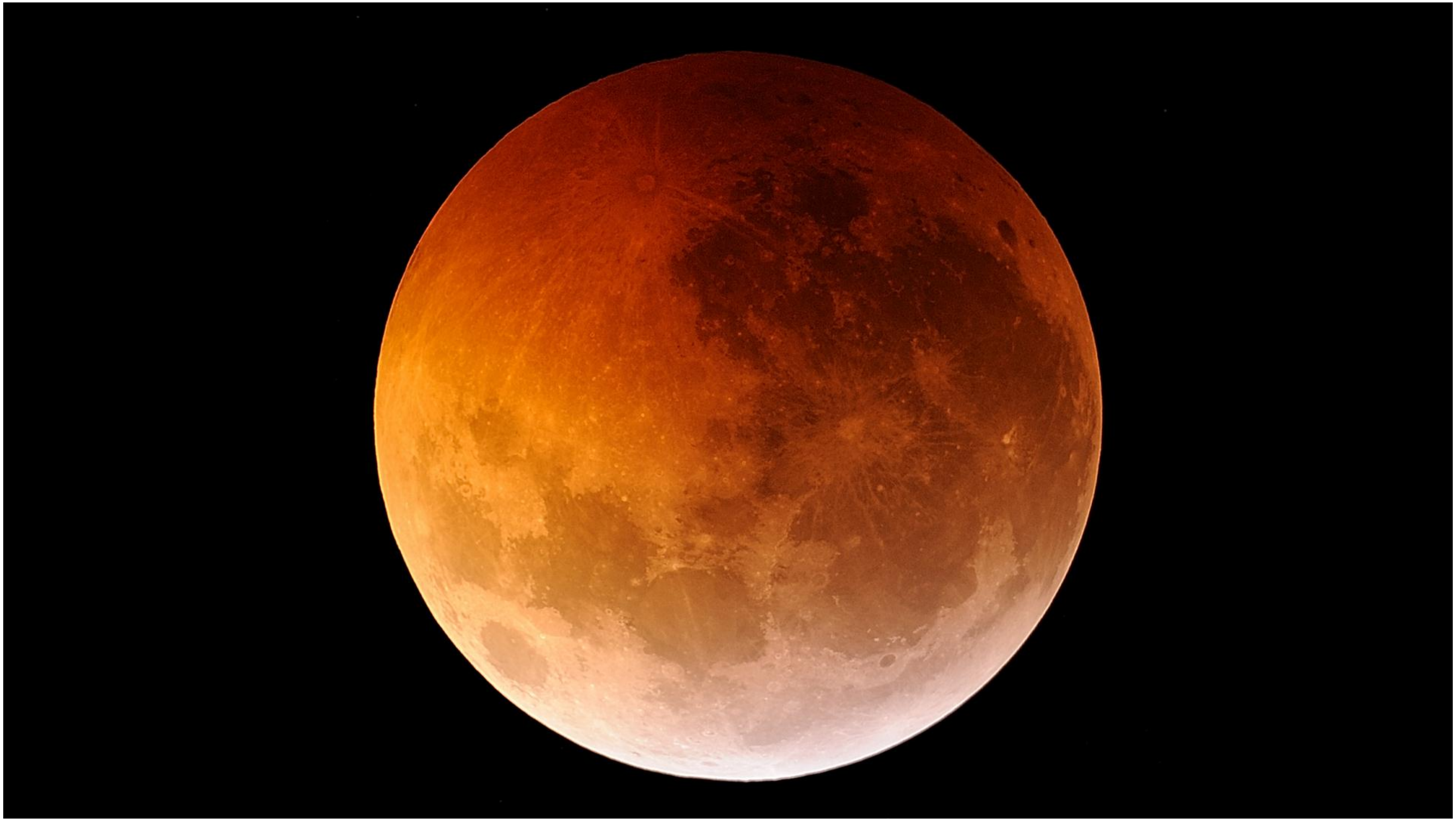
Another Lunar Example

Single Exposure Imaging

- If your object is large and bright, then it may be captured cleanly with a single exposure.
- Large objects require low magnification therefore seeing's effects are minimal.
- Bright objects require lower sensitivity to image therefore have less noise.

Single Shot of Moon (1/100 sec)

Single 30 Second Exposure



Earthshine via overexposure

Deep Sky Imaging

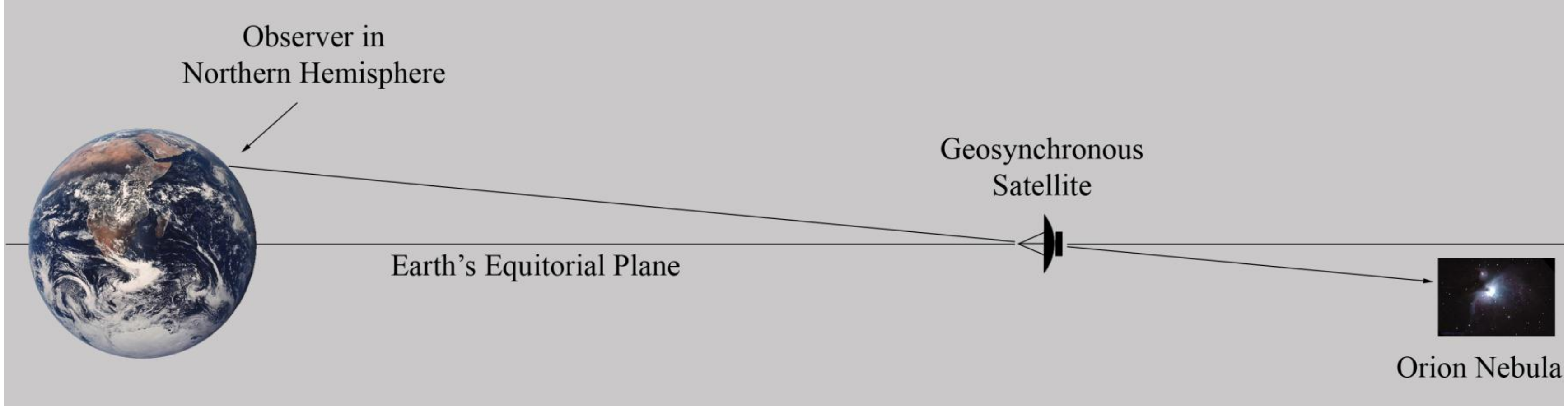
- Combine many long exposures (stacking) to reduce noise.
- Since objects are faint, high sensitivities are needed thus noise!
- Rotating and Aligning can mitigate some tracking errors.
- Auto-guiding is best to handle tracking issues for long exposures.

Tracking

- Tracking is usually limited to about 30 seconds before errors result in star trails without some sort of correction – i.e. manual or auto-guiding.
- Such short exposures require high ISOs.

Eight 30 Second Images @ ISO 2000 Stacked together

Geosynchronous Satellite Tracks



Another Stack Example

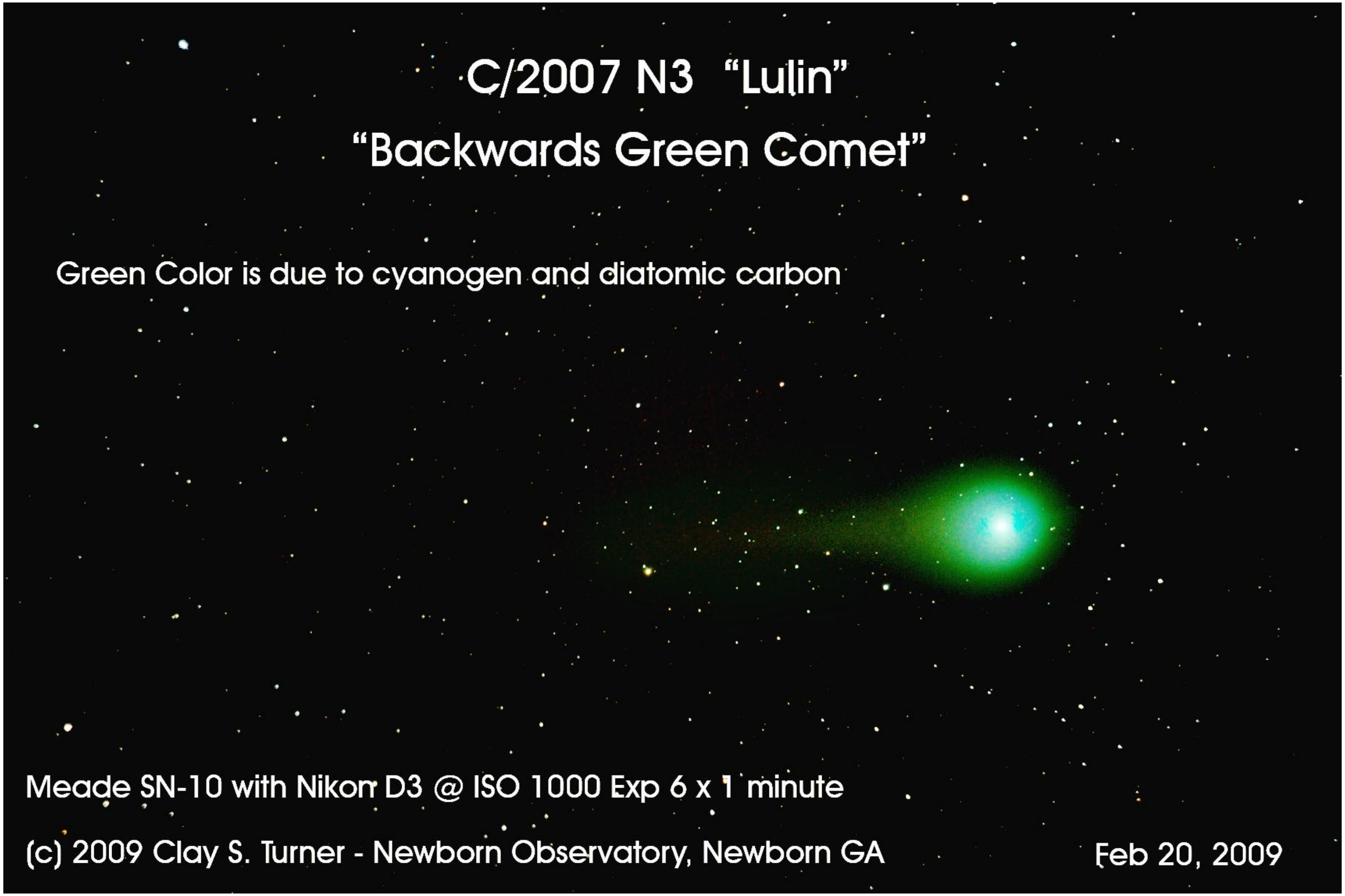


Image Frames

- Four general types of frames
- Lights
- Darks
- Flats
- Biases

“Lights”

- These are your image frames
- These may be full color or single wavelength.
- You want to expose these long enough to see background noise but not long enough to saturate your desired image detail.
- Single color frames are recorded through filters. Different colors may have different exposure times!

“Darks”

- Frames taken with the endcap on the telescope so no light hits the sensor.
- These are exposed for the same length of time as your lights.
- These record sensor noise and imperfections.
- Sensor noise may be reduced by cooling it.

“Flats”

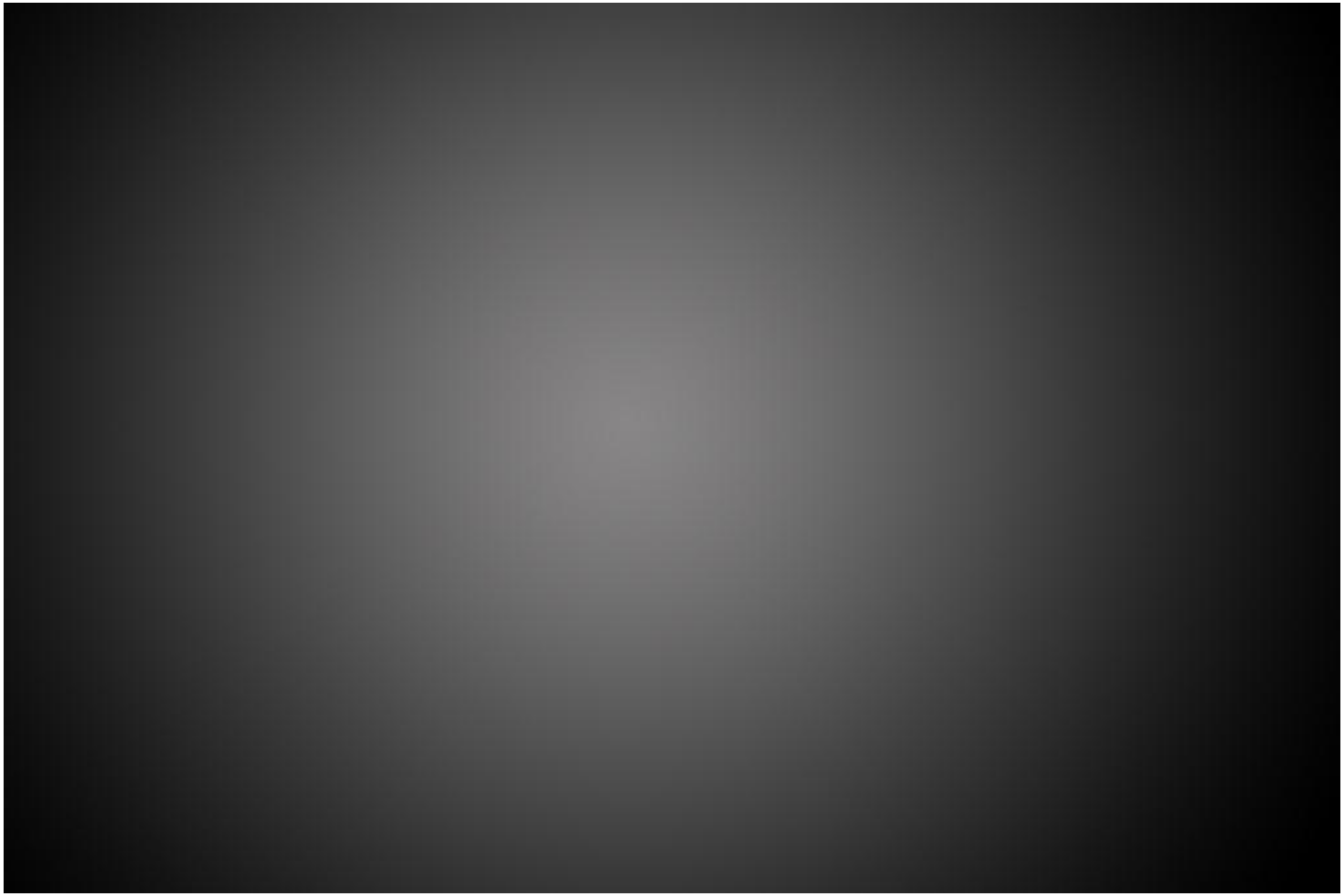
- These are shots of an evenly illuminated subject such as a screen or the sky at twilight.
- These are used to compensate for uneven illumination in the telescope.
- Many scopes suffer from vignetting.

Biases

- These are like Darks except they are exposed for an extremely short time.
- These yield the sensor’s bias and “stuck” pixels.
- Since this info is contained in the darks, biases may not be needed since subtracting the darks from the lights removes the bias.

Image with strong Vignetting

Artificial Flat made in Photoshop



Corrected Image

Astrographs

- Telescopes designed for photography
- Baffled for improved contrast
- High obstruction percentage in Newtonian and Cassegrain designs to provide evenly illuminated field.

Sample Astrograph Flat
(50% obstructed Cassegrain)
24x36mm

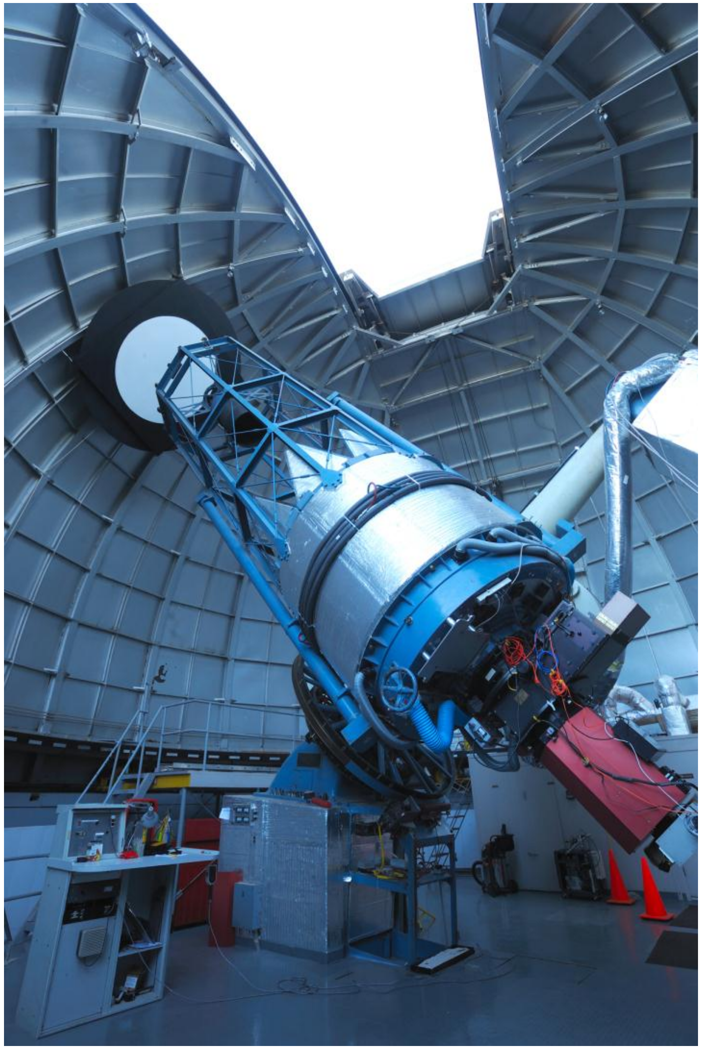
Low Noise Sensors

- Electrically Chilled (Peltier) are usually cooled to 25 to 40 degrees C below ambient or to a fixed temperature such as -25C.
- Cryogenically chilled uses Liquid Nitrogen to cool sensors down to -196C (77K)

Professional Observatory Example

- “Flat” Screen inside of dome
- Telescope accepts multiple instruments.
- Fitted here with PRISM (Perkins Re Imaging System) camera
- Cryogenically Cooled sensor

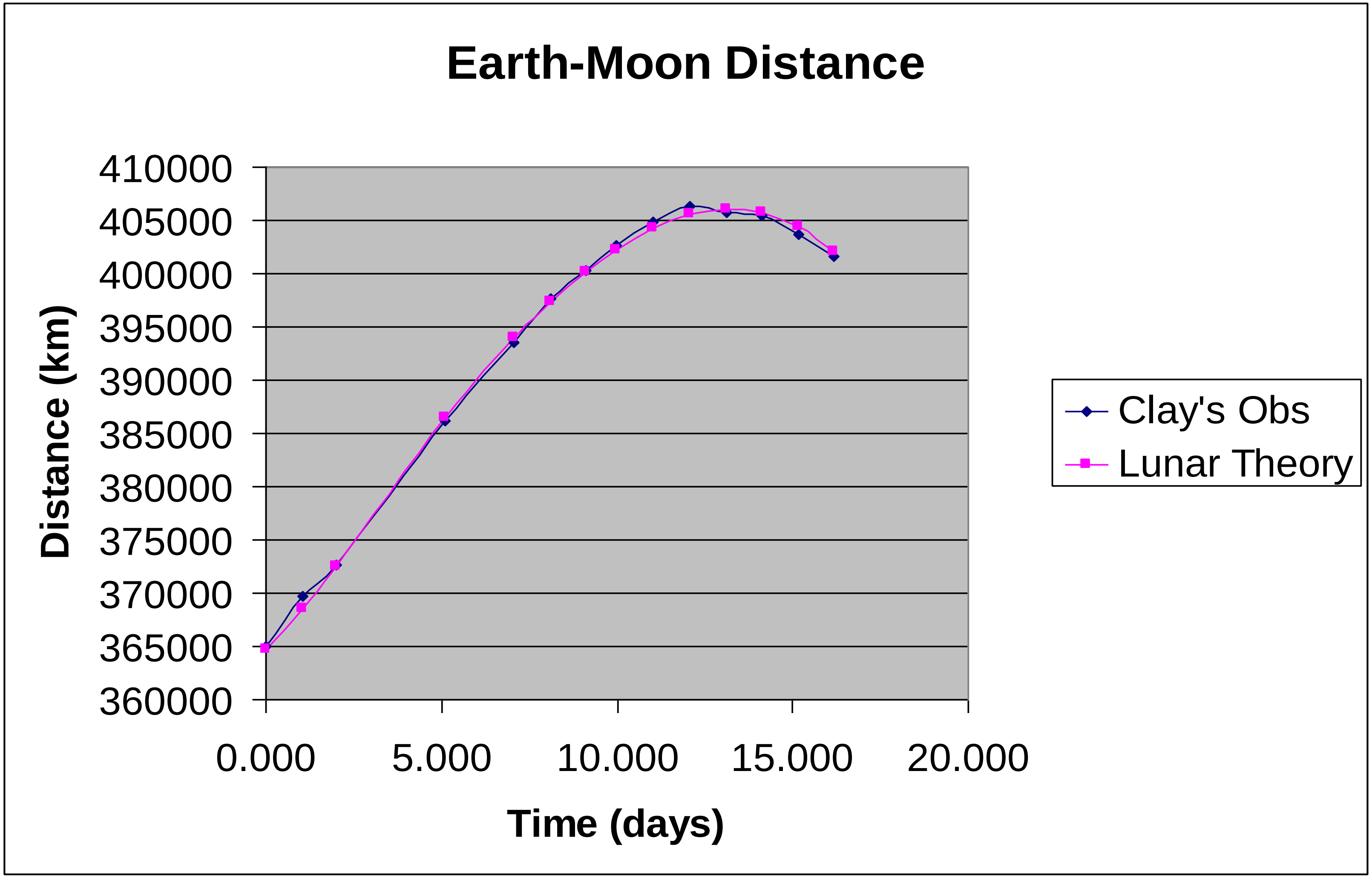
Perkins 72" Telescope



Measure Distance to the Moon

- By counting pixels an object covers, its distance may be computed from is physical size.
- Thus, one can determine the Earth-Moon Distance quite accurately with a camera and a small scope.

Earth Moon Distance for Part of September 2011



Summary

- Astrophotography is Fun!
- Low cost options are available for amateurs just starting out.
- The Sky is the Limit!

Thank You!!!!!!!

IMPORTANT!!!
RA: 16 44 42.1
DEC: +26 19 17
HA: 01 38 36W
LST: 18 23 46
2000.00
Mean
UT: 2011-May-28 09:27:36
UTJD: 2455709.8942
MOON: 113/18%/+ 0R
ZD: 22.9
AM: 1.09
DOME: 003R
PAR ANG: 61.4
Telescope Status:
Dome Control: Auto Dome Enabled
Sidereal Track: On
Filt. Wheel: Unavailable
Object:
[Keyboard GO]
Limits:
Alt Mir: Stowed
Focus: 3663A
Dome Lights: Off
Remote: On
Rates: .0 s/hr .0
Lock: Off - Guiding
Autoguider Status: Guiding at sidereal rate
Stow:
Camera Offset
RA: 16 43 54.6
DEC: +26 13 41
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336S arcsec
99258+Microns
51215+
FWHM: 3.3 2.8 arcsec
Error: .2E .4S arcsec
Delta mag: .04
Max cts: 196
Lock on fixed star
Limits:
Black Val: 58
Camera Gain: .00
Integ. Time: 0.25 s
Focus: 1.0 mm
Pick off field: 5.2 '
Instrument field: 19.0 '
Tot cts: 16320
Pick off within instrument
F1 - toggle pause; F2 - exit; F3 - toggle statistics; F4 - sky chop
F5 - Cycle time/box drag size toggle. Use keypad +/- to change highlighte
Use keypad digit keys to drag box at any time.
No. frames before coadd: 4
Drag step size (px): .33
DELL
DELL
DELL
GRAND CANYON