Lecture 2

September 13, 2018

Coordinates, Telescopes and Observing

News

- Lab time assignments are on class webpage.
- Lab 2
  - Handed out today and is due September 27.
  - Observing commences starting tomorrow.

- Rutgers Astronomical Society (RAS)
  - help with public observing nights (tonight is cancelled)
  - talks (not yet scheduled)
- Society of Physics Students (SPS)

Celestial timekeeping

Astronomers use two principal time conventions:

(1) UT = Universal Time

This is a (mean) solar time that corresponds (apart from daylight savings) to the local time in Greenwich, England. At a given moment, UT is the same everywhere.

(2) LST = Local Sidereal Time

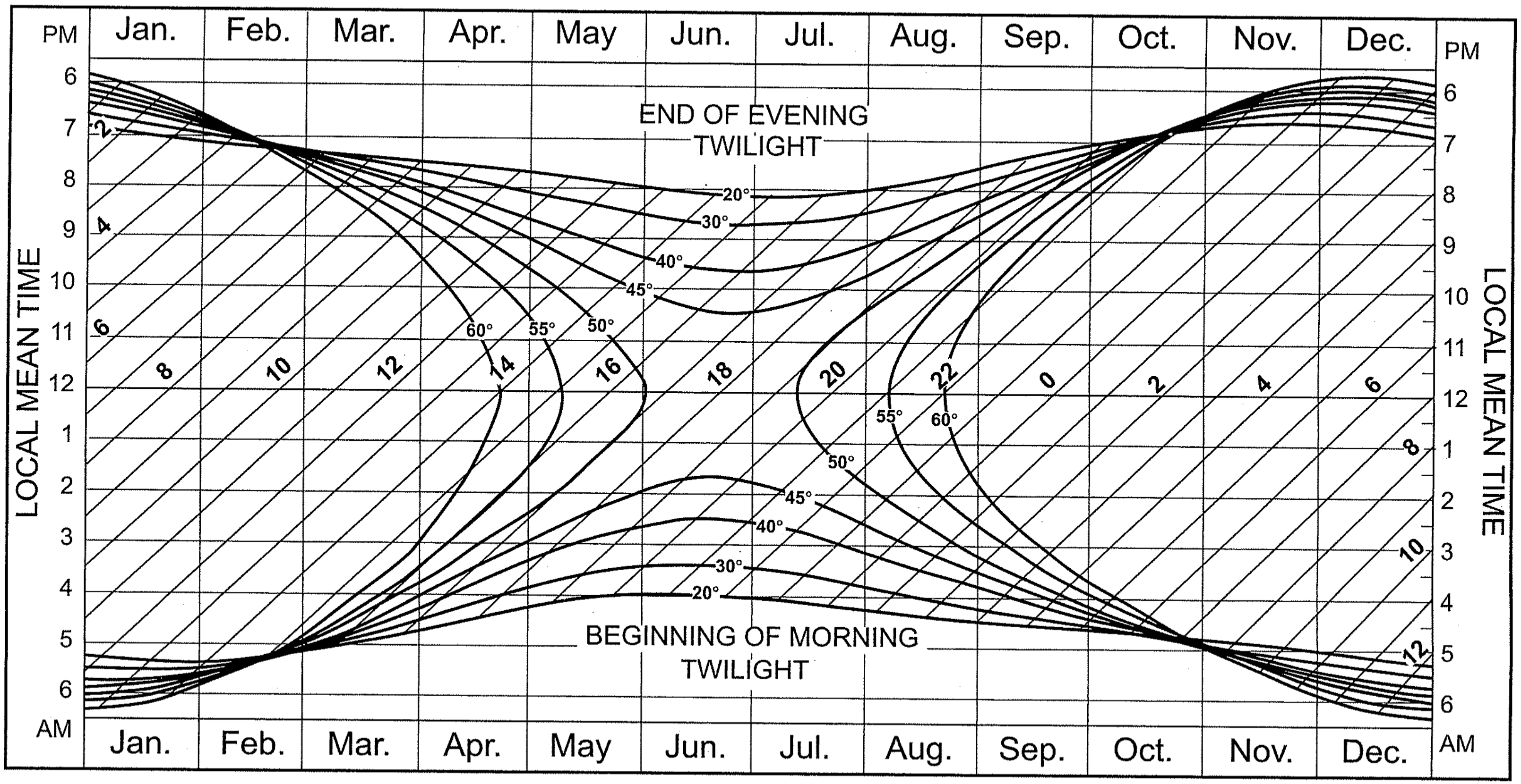
This is the R.A. of objects on the meridian right now. At a given moment, LST is different at different terrestrial longitudes.

http://www.physics.rutgers.edu/ugrad/109/demos/IF_02_14_SunPathZodiac.htm

Planning Observations

ASTRONOMICAL TWILIGHT AND SIDEREAL TIME

BY RANDALL BROOKS



The diagram gives for any day of the year: **(1)** *the local mean time (LMT) of the end and beginning of astronomical twilight at seven specified northern latitudes (curved lines);* **(2)** *the local mean sidereal time (LMST = right ascension at the observer's meridian) as a function of LMT (diagonal lines).*

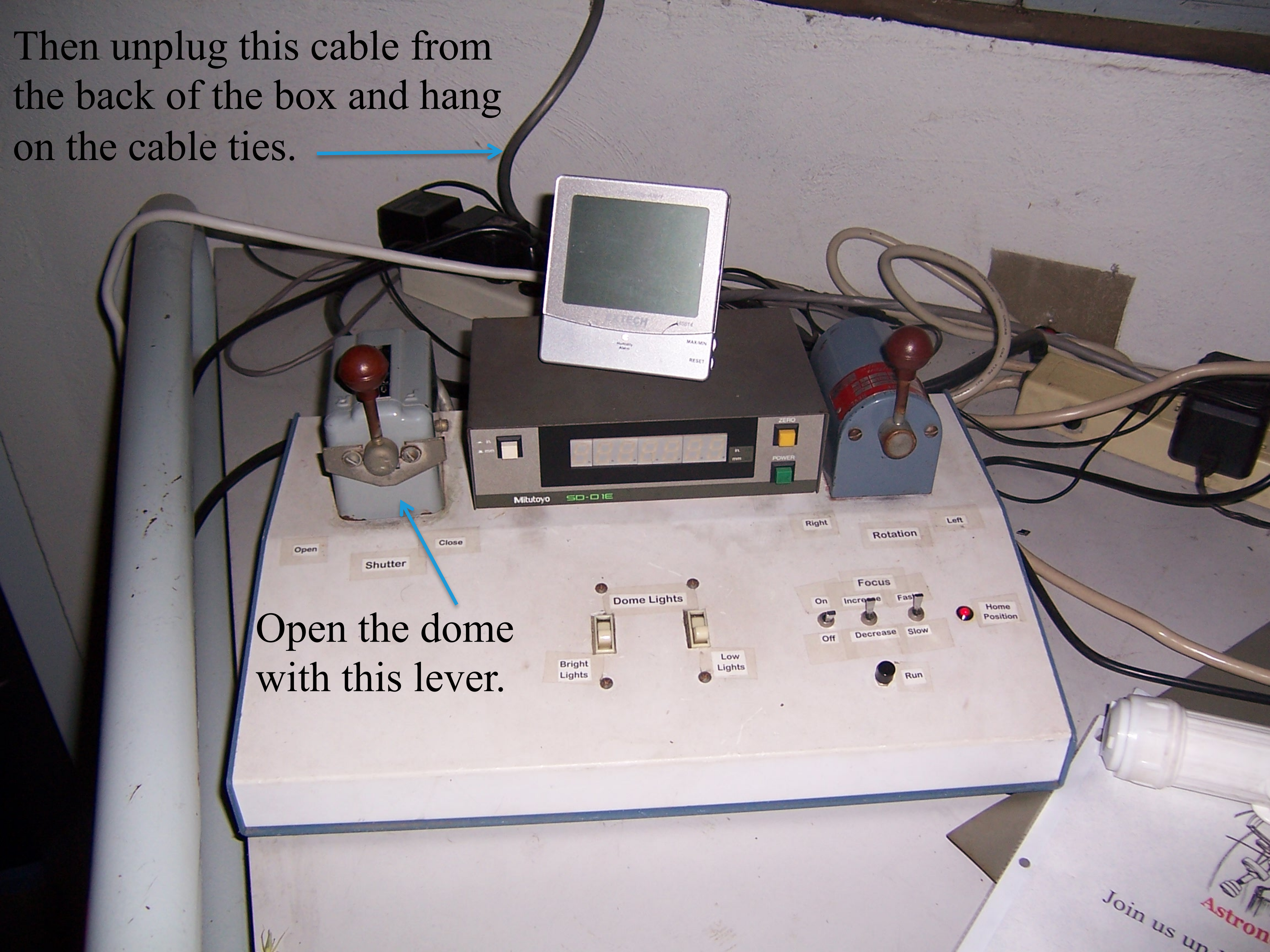
The Schommer Observatory is at 40.5 degrees N latitude.

Figure taken from the "Observer's Handbook" of the Royal Astronomical Society of Canada.

Telescope Operations – First Steps

- Open the dome.
- Carefully remove the cover from the telescope (is unbalanced with the cover on).
- Turn on the power to the telescope controller and (if necessary) the computer.
- Check that the telescope is in visual mode.
- Double-click the button on the joystick to send the telescope to the home position.
- Point the telescope at the zenith using the bubble levels.

Then unplug this cable from the back of the box and hang on the cable ties.



Open the dome with this lever.

Telescope Operations – First Steps

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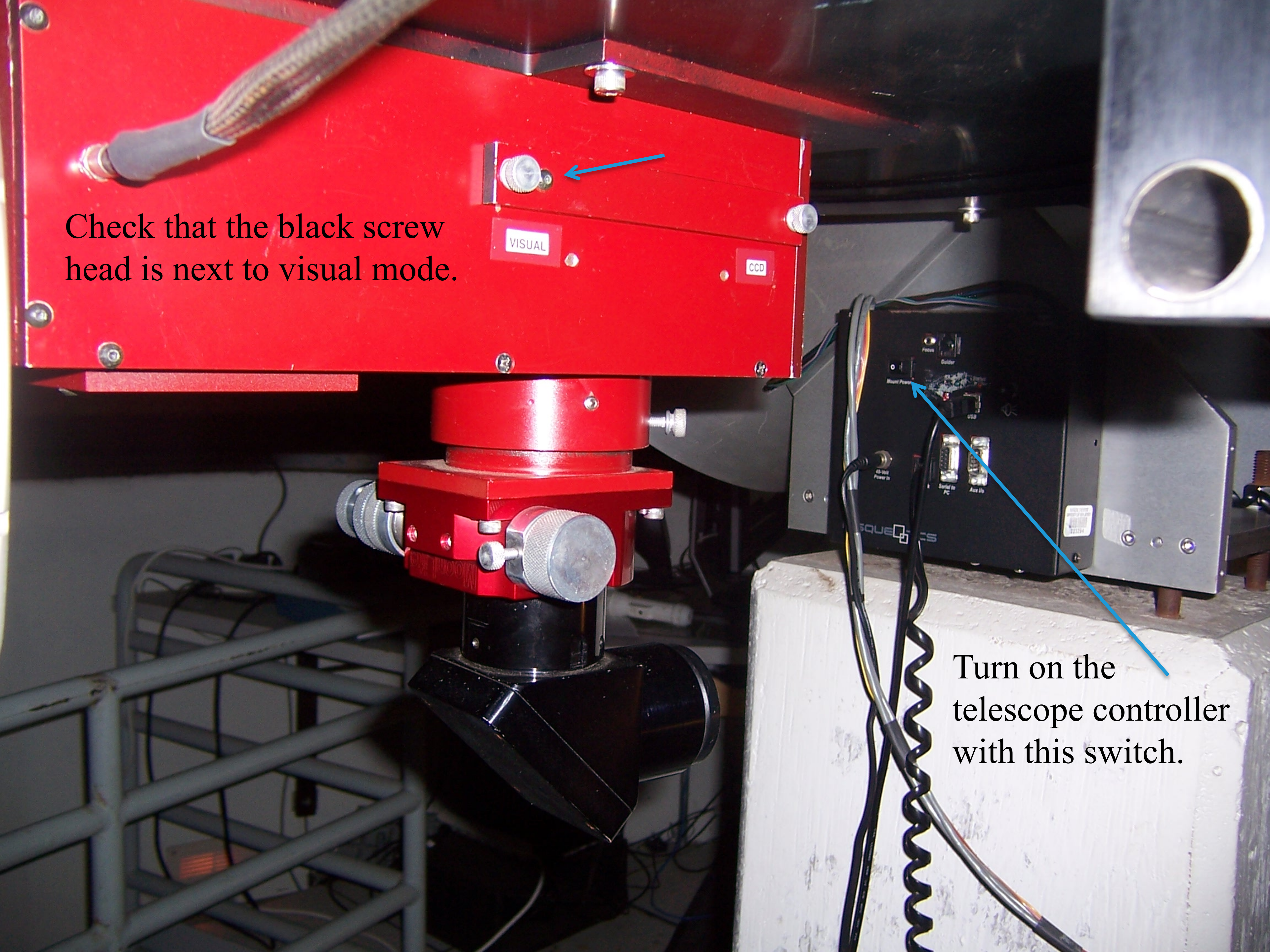
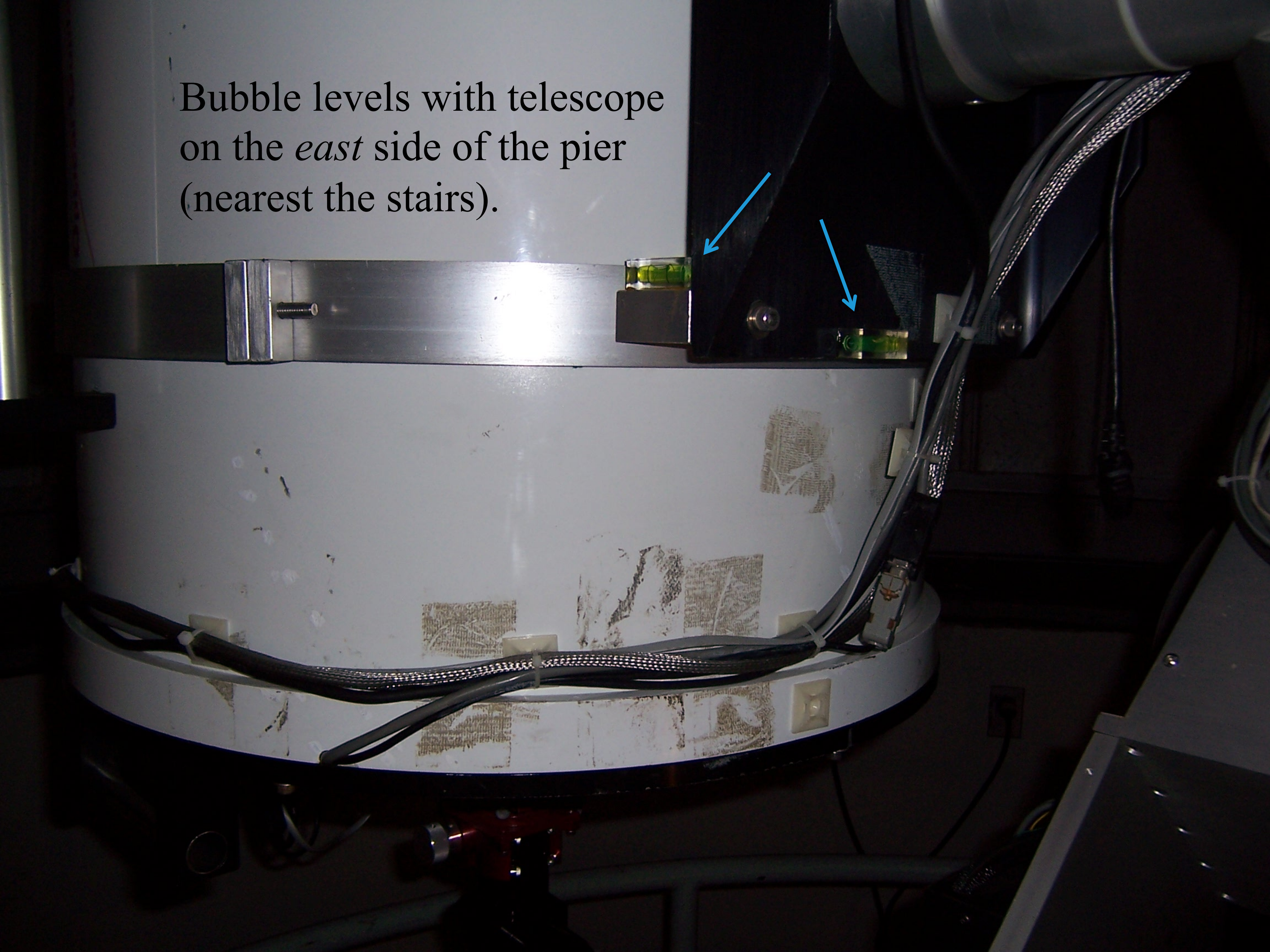
- Point the telescope at the zenith using the bubble levels.


Check that the black screw
head is next to visual mode.
VISUAL
CCD
Turn on the
telescope controller
with this switch.

Telescope Operations – First Steps

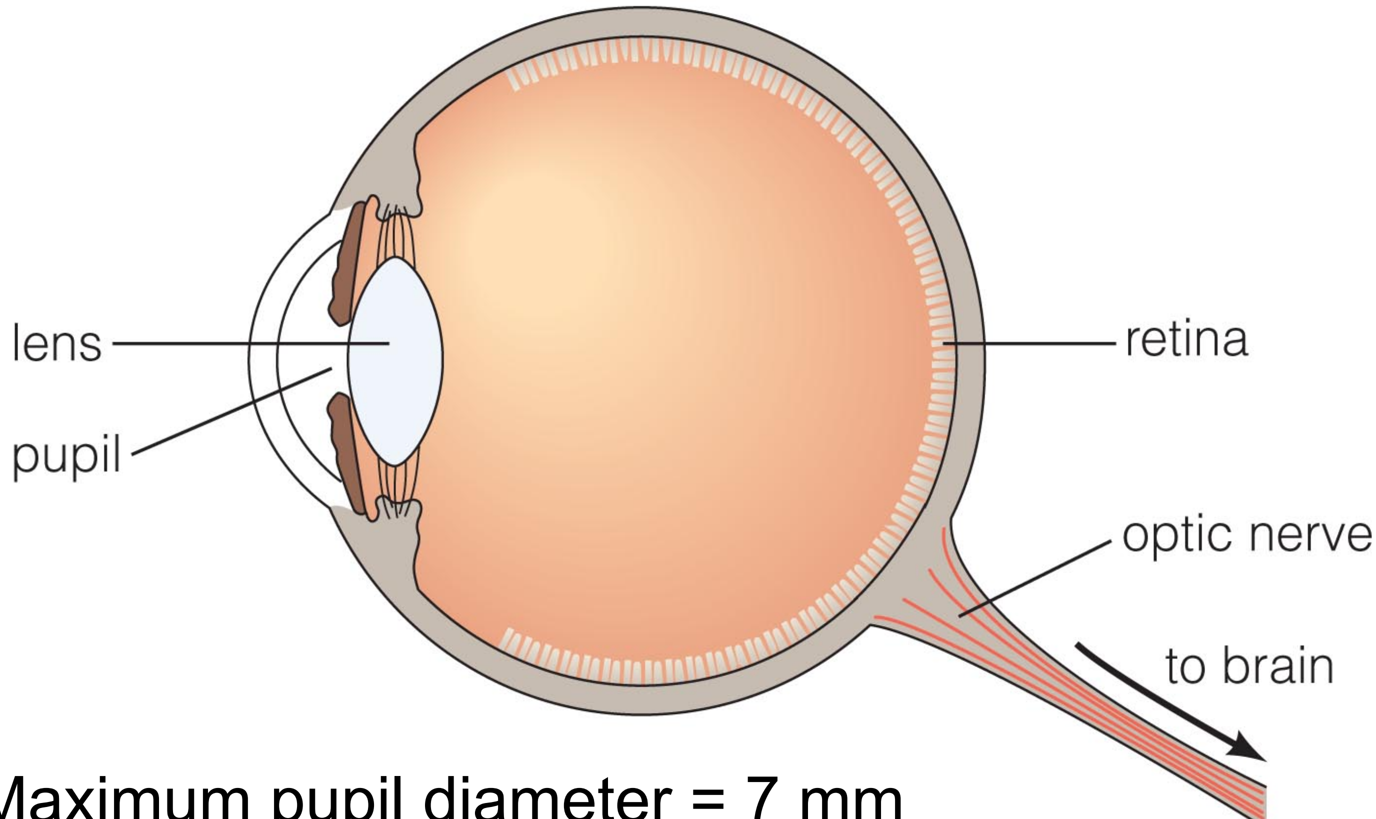
- Open the dome.
- Carefully remove the cover from the telescope (is unbalanced with the cover on).
- Turn on the power to the telescope controller and the computer.
- Check that the telescope is in visual mode.
- Double-click the button on the joystick to send the telescope to the home position.
- Point the telescope at the zenith using the bubble levels on the *east* side of the pier (closest to the stairs).


“Home” button on the joystick

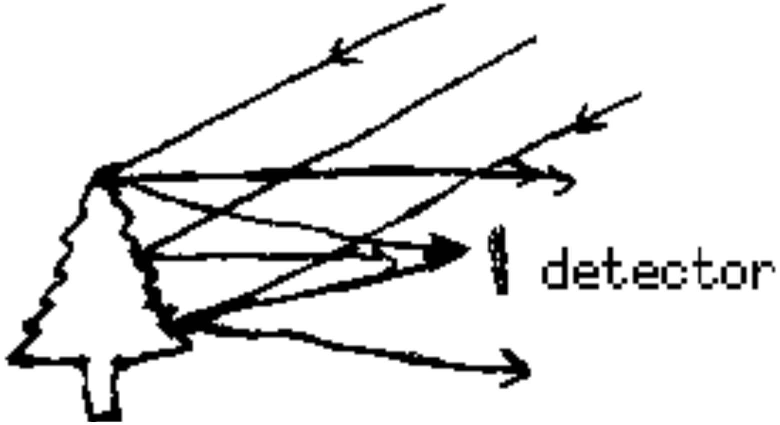

Bubble levels with telescope
on the *east* side of the pier
(nearest the stairs).

What is a telescope?

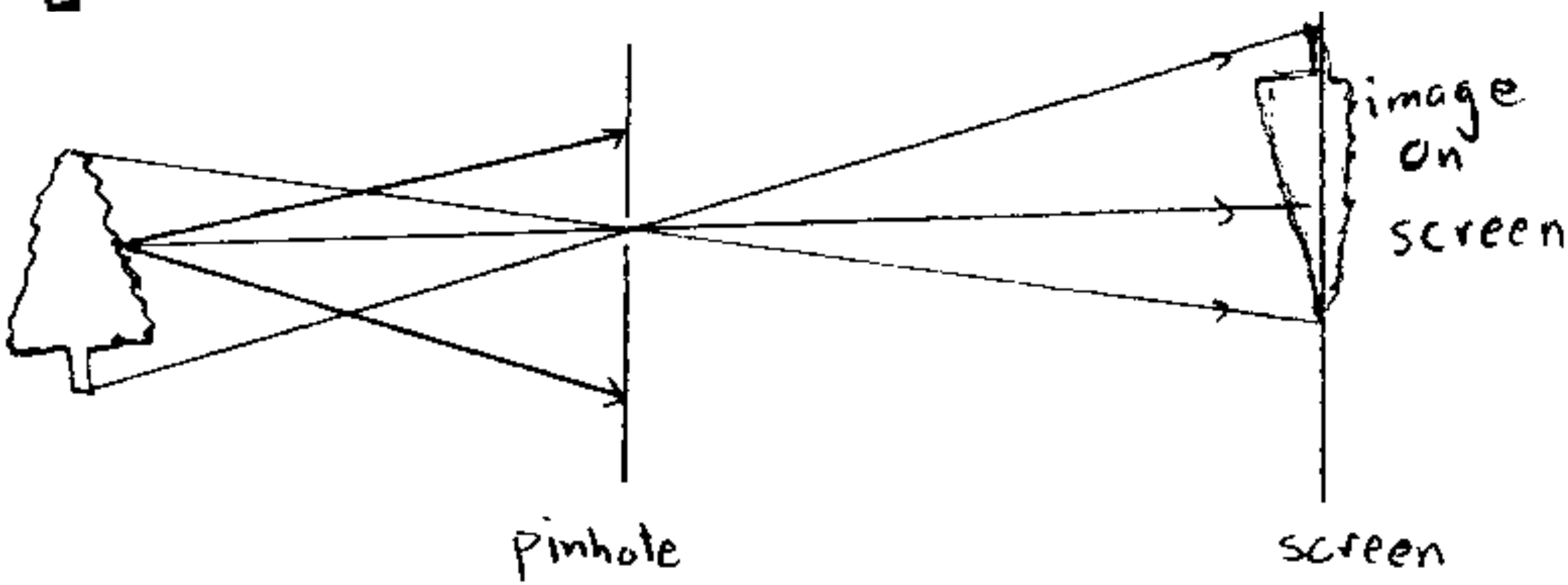
- A telescope is a big eyeball or camera.
  - A camera forms an *image*: light from on point in a scene ends up at one point in the image.



Maximum pupil diameter = 7 mm



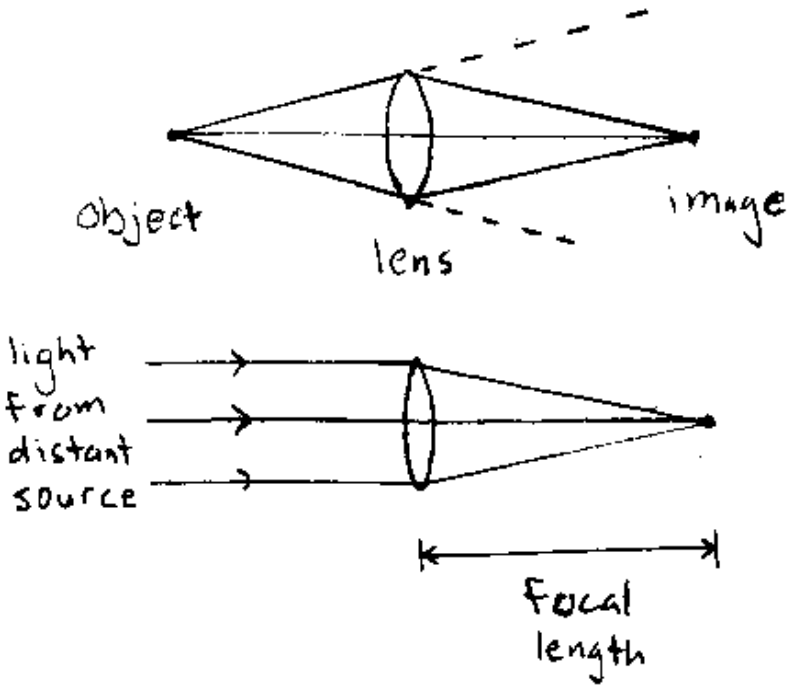
No image formation here. Some device must sort the light before it reaches the image/detector.

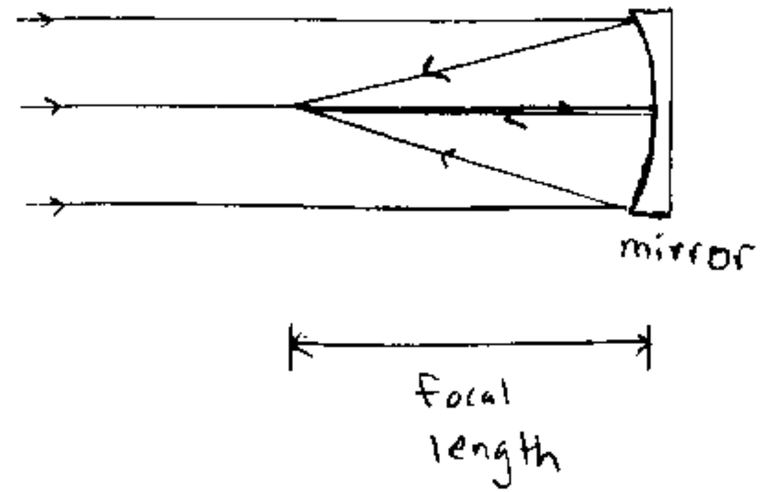


The formation of an image by a pinhole camera. Note:

- Image is inverted.
- Image size is proportional to distance from pinhole.
- If screen/detector is flat, the relation between angular size in the scene and size in the image is non-linear: $s \propto \sin(\theta)$.

Pinhole cameras admit little light, so the images are dim. Telescopes replace the pinhole by devices that allow more light to pass, but still yield a sharp image by bending (focusing) the light: a lens or a mirror.





- Distance between aperture and image is now fixed = focal length.
  - Again, a larger focal length produces a larger image.
- Focusing may not be perfect, producing image aberrations (blurring).
  - Aberrations usually reduced if the bending of light paths is small (long focal length or near the optical axis).

Most Important properties of a telescope

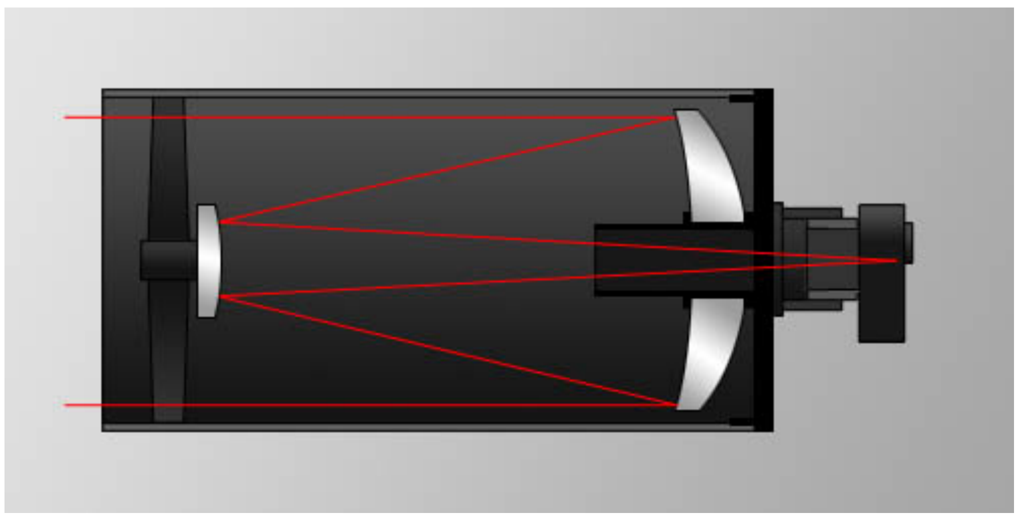
- **Light-collecting area**: Telescopes with a larger collecting area can gather a greater amount of light in a shorter time.
- **Angular resolution**: Telescopes that are larger are capable of taking images with greater detail.

Light-Collecting Area

- Is usually the area of the primary mirror or lens:

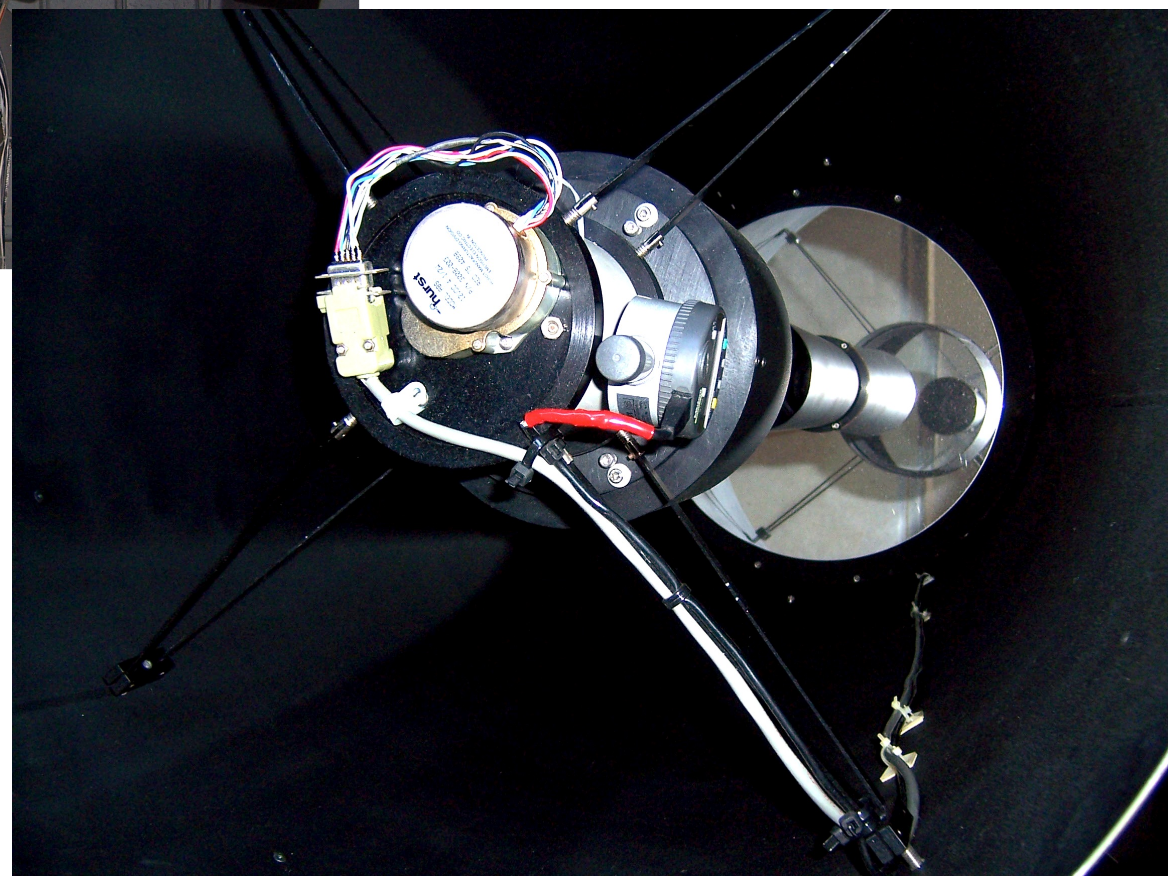
$$Area = \pi(diameter/2)^2$$

  – Precise measurements subtract the area of any obscuration (say from a secondary mirror).



- The Schommer Observatory telescope has a primary mirror with a diameter of 0.5 meters.

The Schommer Observatory 0.5 m telescope.



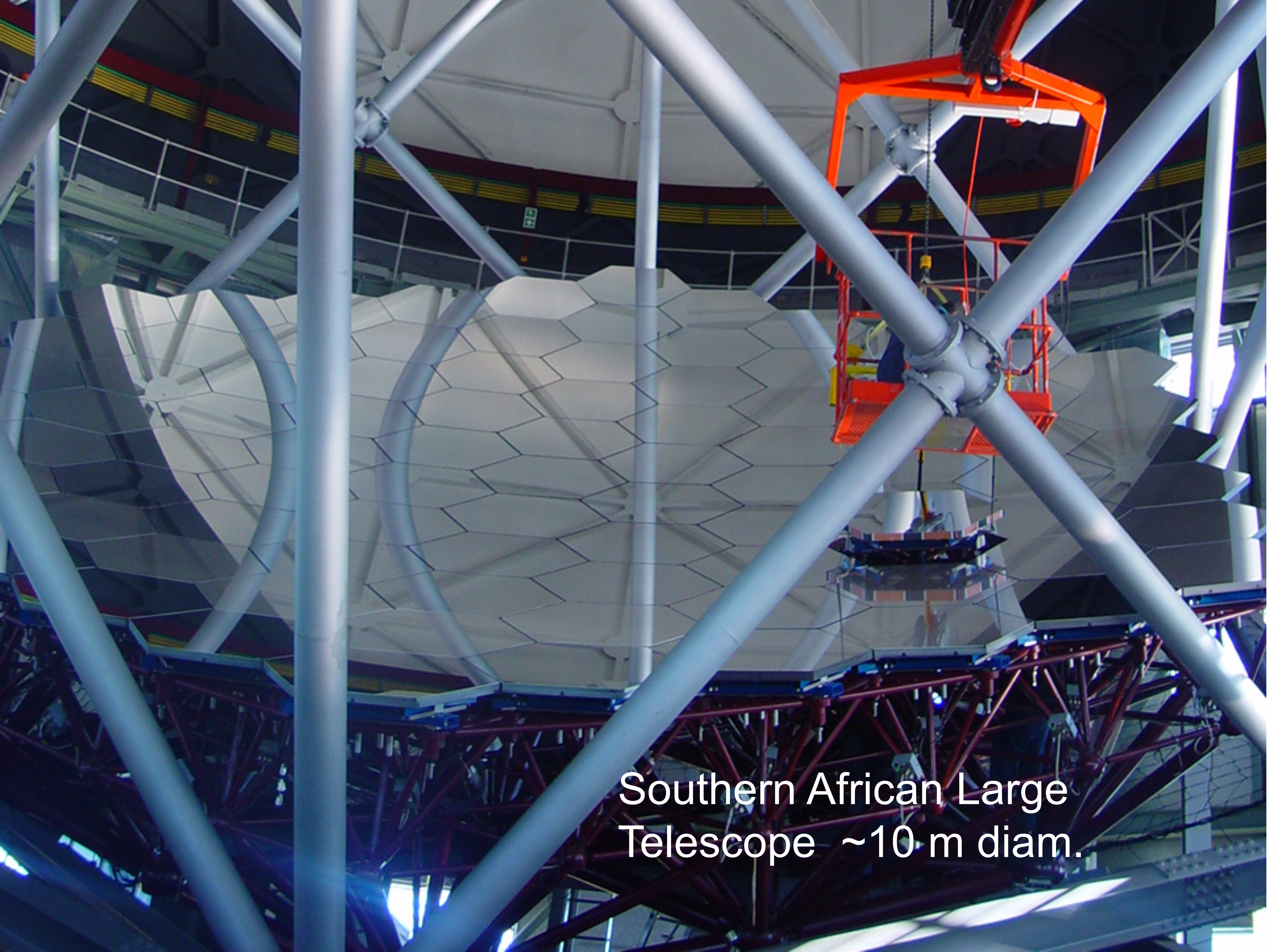
This view down the tube over-emphasizes the size of the secondary mirror (seen from behind and reflected in the primary).

Light-Collecting Area

- Is usually the area of the primary mirror or lens:

$$Area = \pi(diameter/2)^2$$

  - Precise measurements subtract the area of any obscuration (say from a secondary mirror).
- The Schommer Observatory telescope has a primary mirror with a diameter of 0.5 meters.
- The largest (visible-light) telescopes currently in use have a diameter of about 10 meters.
  - Southern African Large Telescope (SALT – 10% RU)
- Telescopes in the planning/fund-raising stage will have diameters of about 30 meters.


Southern African Large
Telescope ~10 m diam.

Light-Collecting Area

- How much more light does the 0.5 m telescope collect than the unaided eye?
  - The maximum pupil of the eye is 7 mm.

Light-Collecting Area

- How much more light does the 0.5 m telescope collect than the unaided eye?
  - The maximum pupil of the eye is 7 mm.

$$(500mm/7mm)^2 = 5102$$

- How much more light does SALT collect than the 0.5 m telescope?

$$(10m/0.5m)^2 = (20)^2 = 400$$

Light-Collecting Area

- How much more light does the 0.5 m telescope collect than the unaided eye?
  - The maximum pupil of the eye is 7 mm.

$$(500mm/7mm)^2 = 5102$$

- What magnitude difference does this correspond to?

Light-Collecting Area

- How much more light does the 0.5 m telescope collect than the unaided eye?
  - The maximum pupil of the eye is 7 mm.

$$(500mm / 7mm)^2 = 5102$$

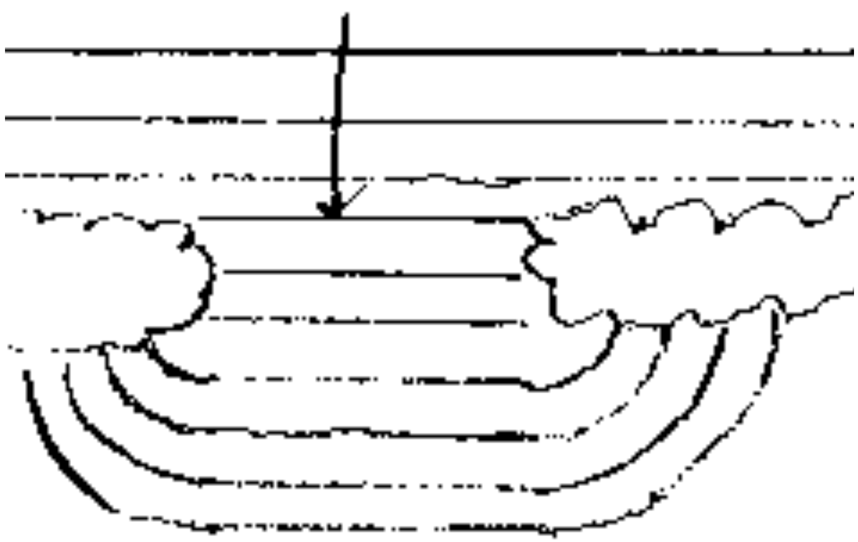
- What magnitude difference does this correspond to?

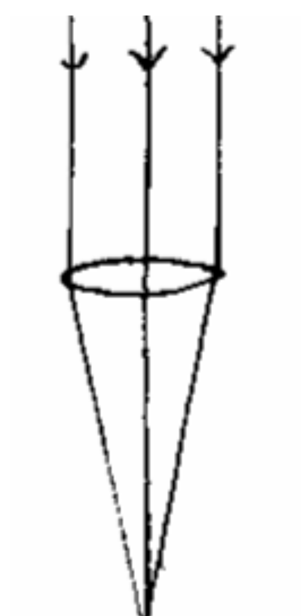
$$m_t - m_e = -2.5\log(f_t / f_e) = -2.5\log(1/5102) = 9.3$$

  - Suggests a limiting magnitude of 5.5 + 9.3 = 14.8.

Angular Resolution

- The *minimum* angular separation that the telescope can distinguish.
  - Two stars closer than this minimum appear to be a single object.
- Better angular resolution means distinguishing smaller angles.
- Ultimate limit to resolution comes from the **diffraction** of light waves entering a telescope.
  - Is like the water waves entering a harbor – the waves spread out after passing through an aperture.

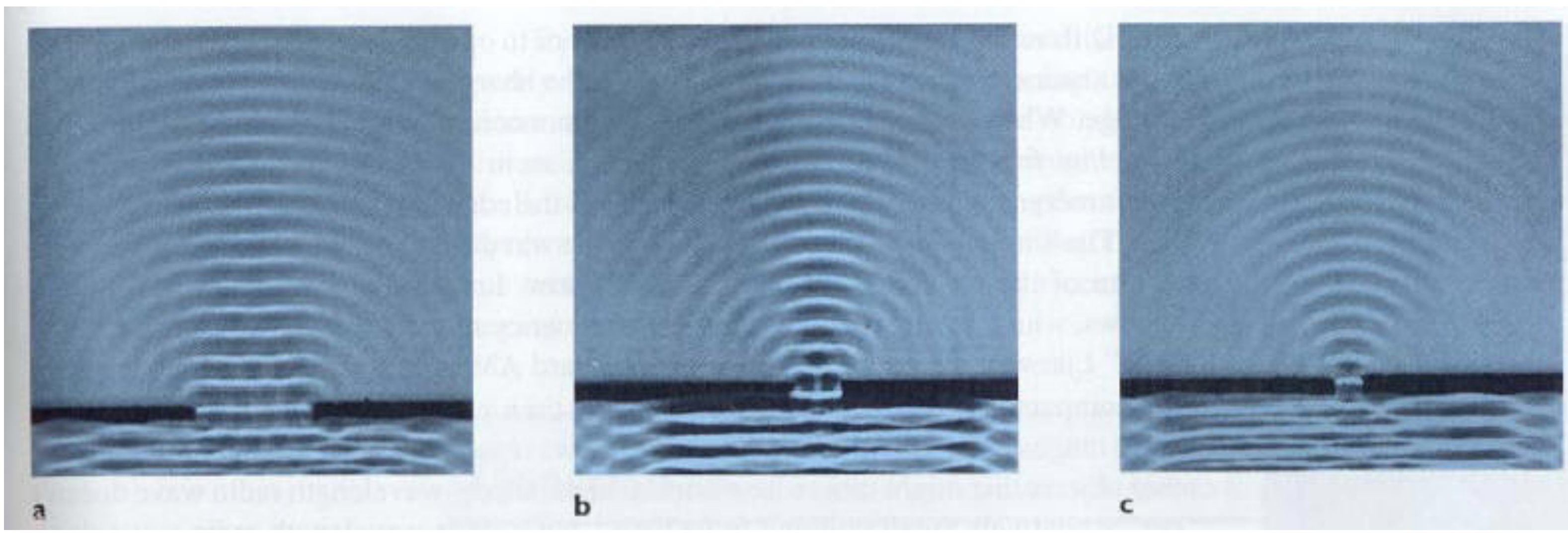




So light is not focused perfectly.

Angular resolution

- Angle resolved ≈ wavelength/diameter = λ/D
  - Large diameter ➔ better angular resolution
  - Short wavelengths ➔ better angular resolution

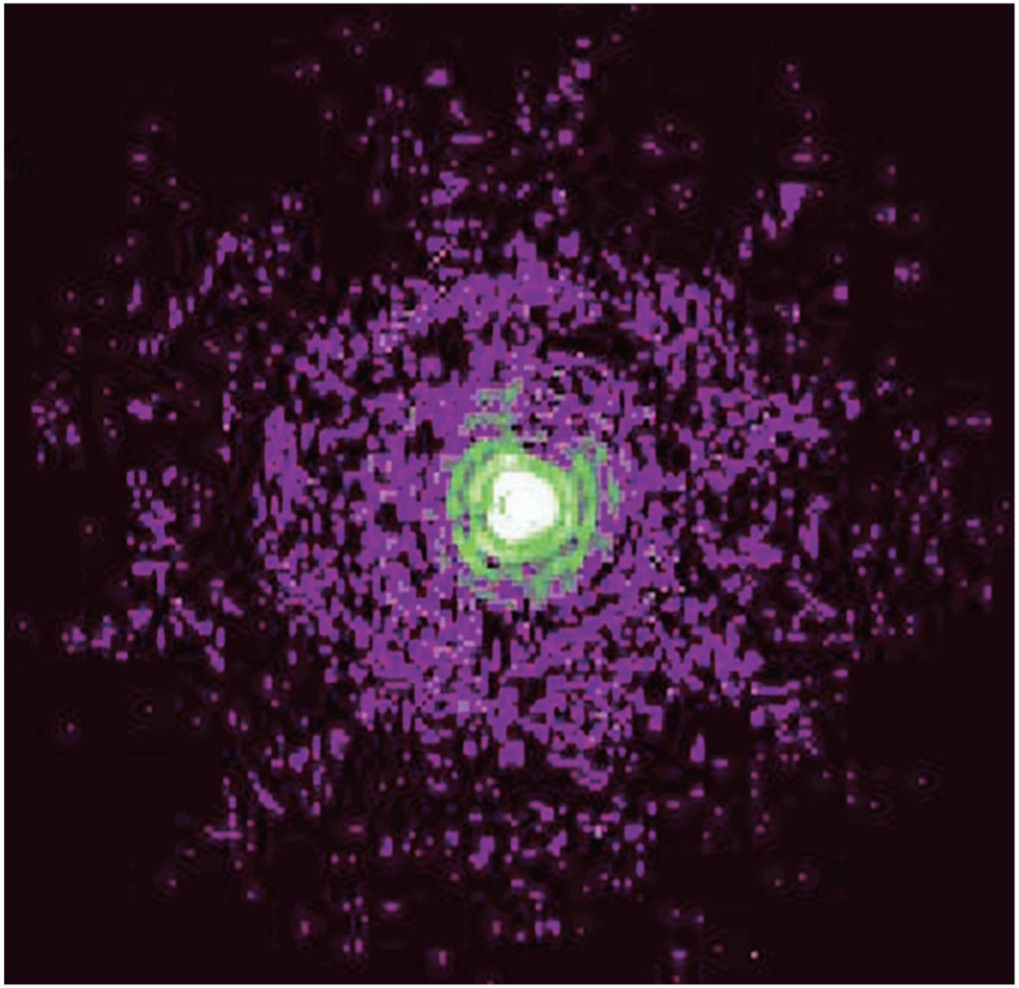


big diameter,
less diffraction

small diameter
more diffraction

Note: no focusing lenses in these apertures.

Angular Resolution



Close-up of a star (a point of light) imaged with the Hubble Space Telescope

- Diffraction broadens the image of a point of light into a disk.
  - The rings in this image of a star come from interference of light waves.

- This limit on angular resolution is known as the **diffraction limit**.

Schommer Obs. Telescope Properties

- **Light-collecting area**:
  - $Area = \pi(d/2)^2 = \pi(0.5m/2)^2 = 0.20m^2$
  - Minus the ~20% central obscuration

- **Angular resolution**:

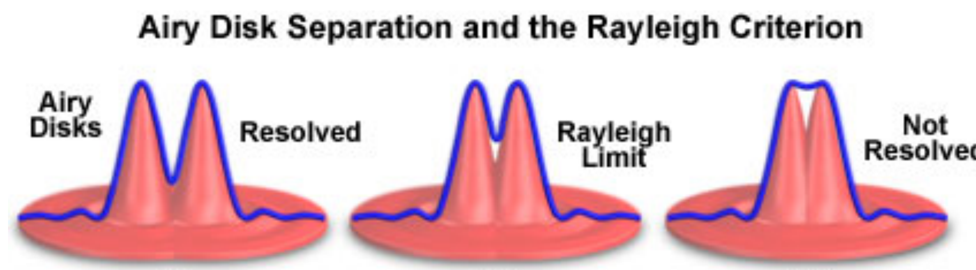


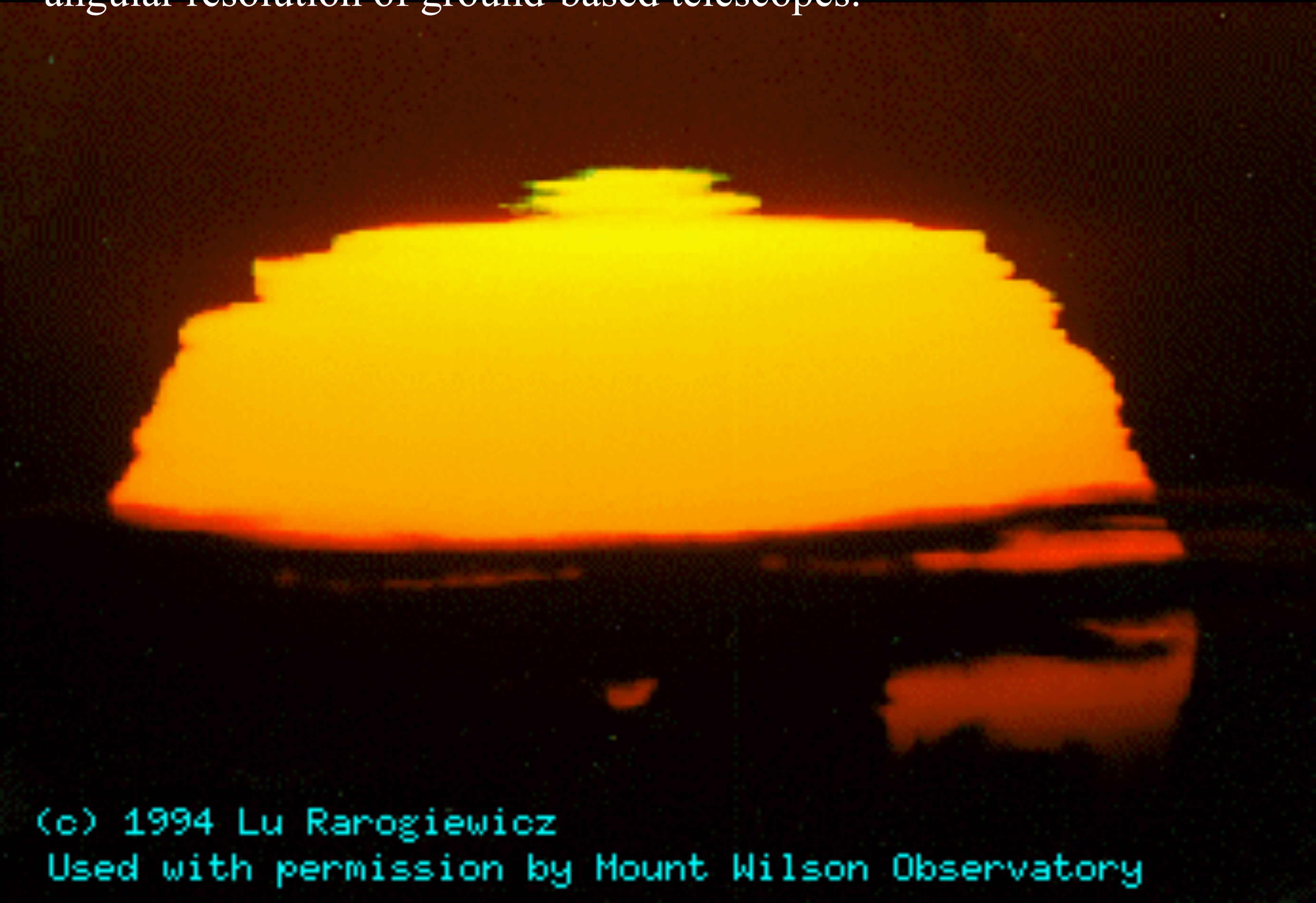
Figure 1

  - $\theta_{Rayleigh} = 1.22\left(\frac{\lambda}{d}\right)$

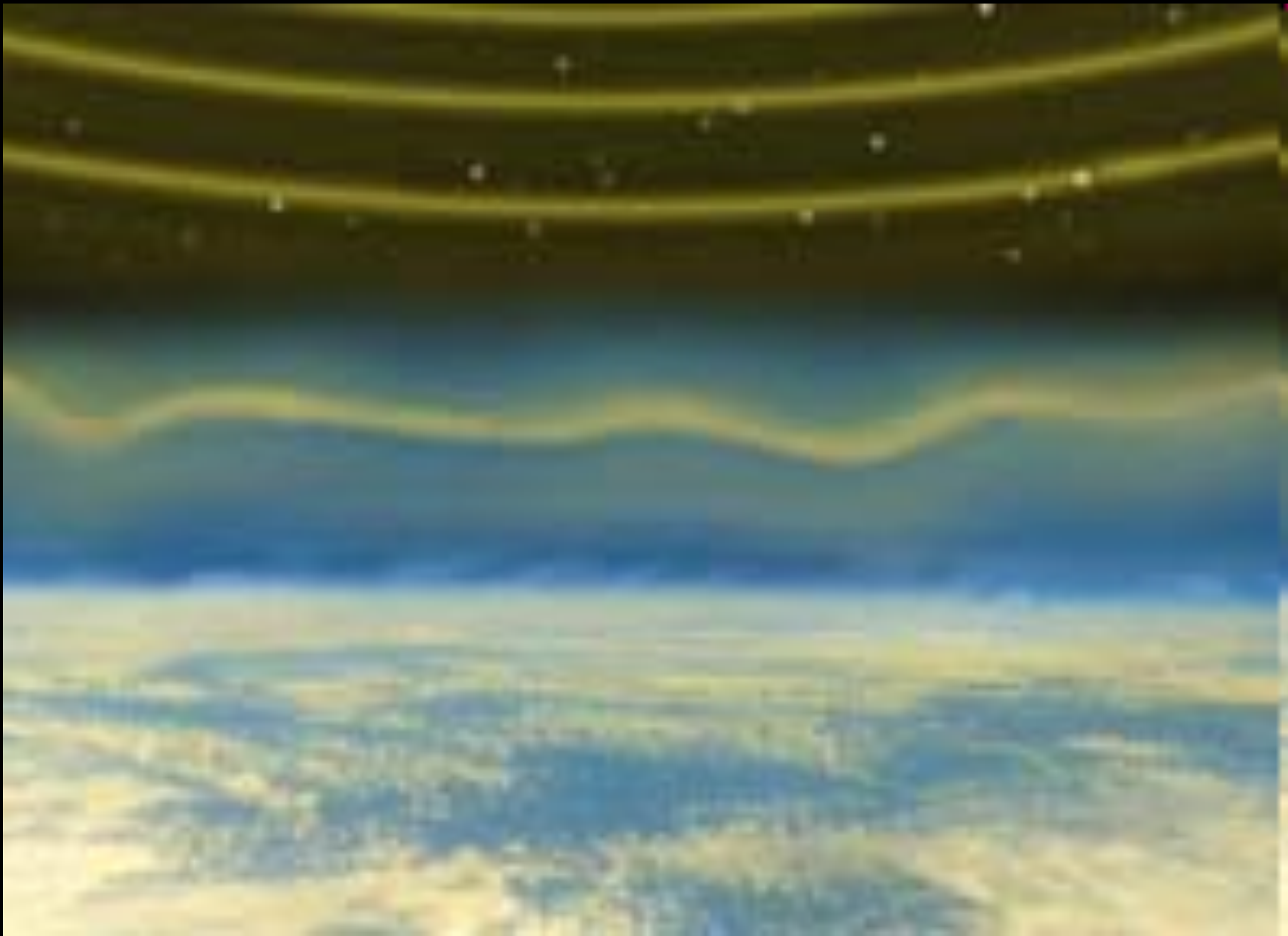
$$= 1.22\left(\frac{500nm}{0.5\times10^{9}nm}\right) = 1.2\times10^{-6}rad = 0.25''$$

  - Limited to 1–2 arcsec by atmospheric turbulence (can be as good as 0.5 arcsec at best sites).

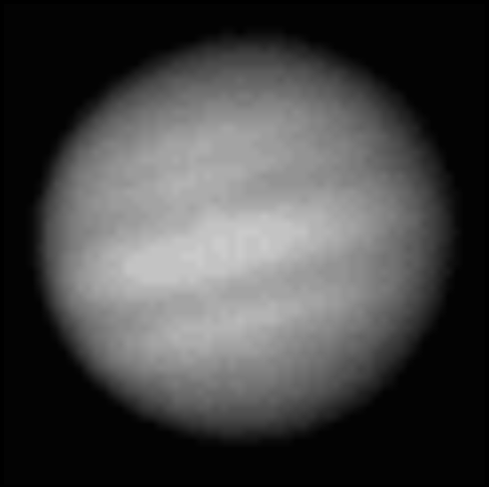
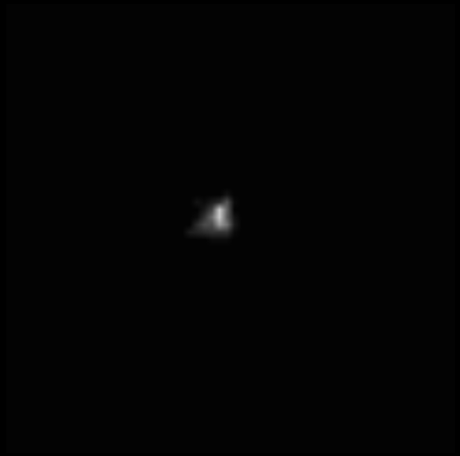
However, the atmosphere is usually more important in limiting the angular resolution of ground-based telescopes.



The atmosphere acts like many lenses, bending incoming light rays.



The result is that turbulence in the Earth's atmosphere blurs our view of the cosmos.

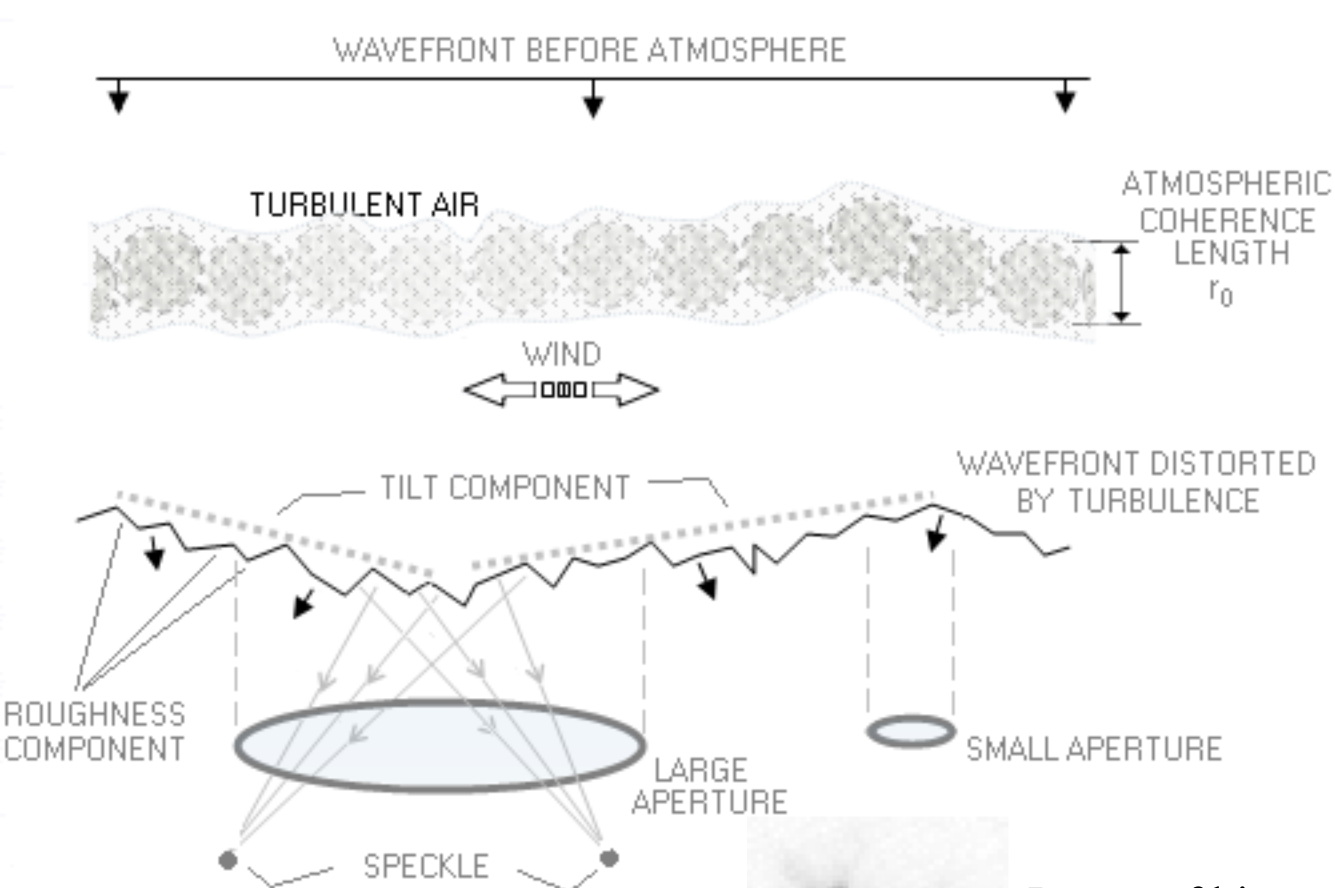



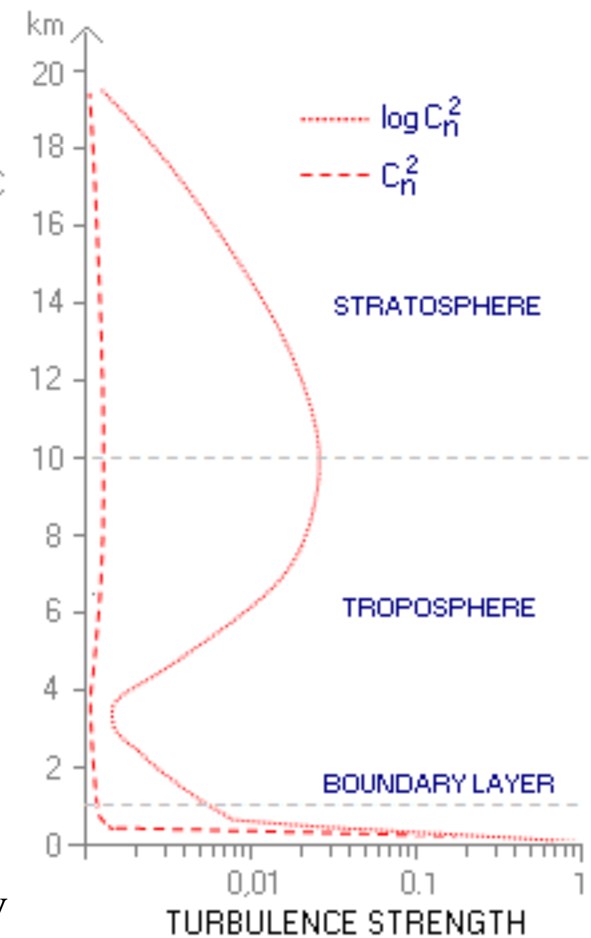

It is like looking at the bottom of a swimming pool

* still water = a clear view
* someone jumps in = a changing, distorted view

Astronomers call this blurring *seeing*. Usually limits the angular resolution to about 1 second of arc (2 or more locally).

- Seeing causes image motion in small apertures and multiple “speckles” in large apertures.





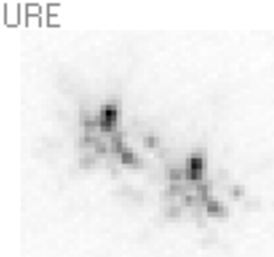
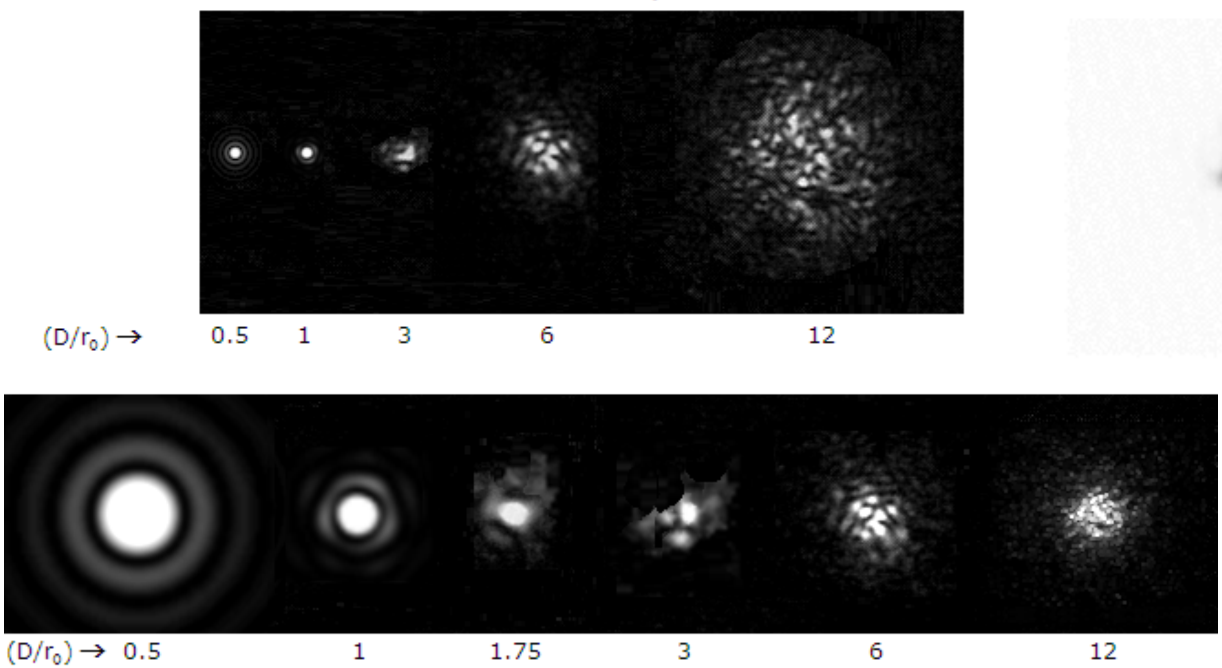


Image of binary star ζ Bootis (0.8” separation) taken with Nordic Optical Tel.

- Seeing
  - Fried parameter, r_0: 10 – 20 cm at optical wavelengths at good sites.
  - Coherence time: ~10's of milliseconds
  - Isoplanatic patch: the size on the sky over which the seeing is the same.
    - ≈ angular diameter of r_0. Usually a few tens of arcseconds.

ANGULAR DIFFRACTION PATTERN AS A FUNCTION OF D/r_0 FOR FIXED APERTURE D (TOP) AND r_0 (BOTTOM)



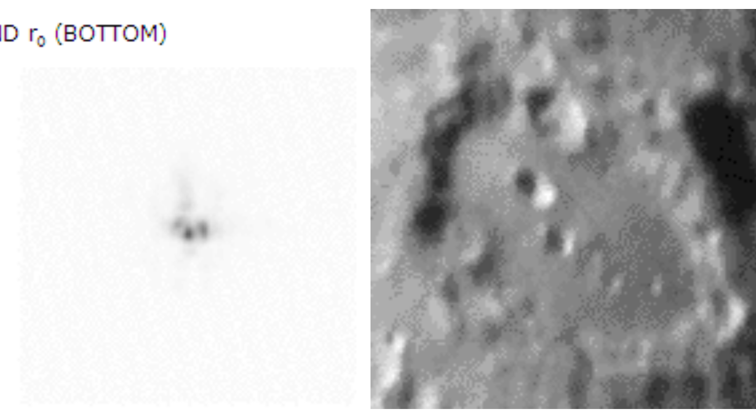
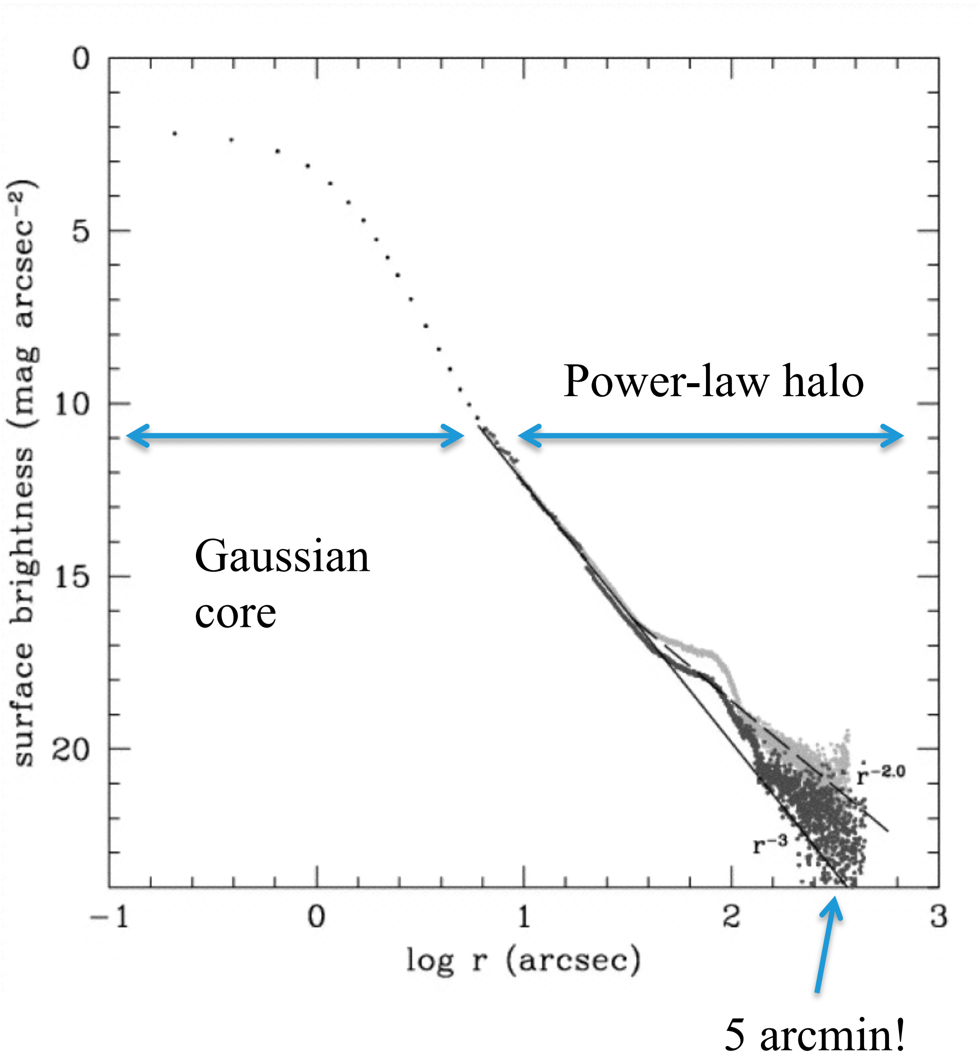


Image motion in a small telescope (ε Aql & moon)

- Shape of a stellar image – the "point spread function" (PSF)

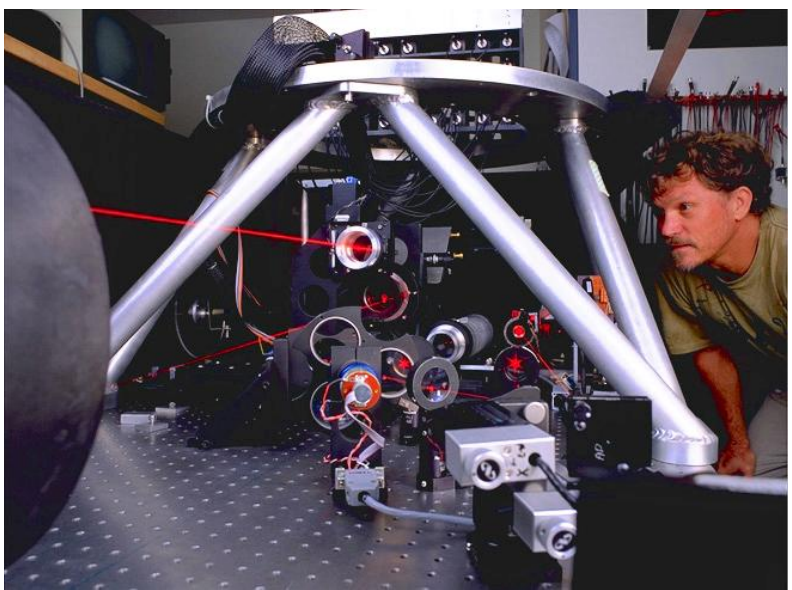


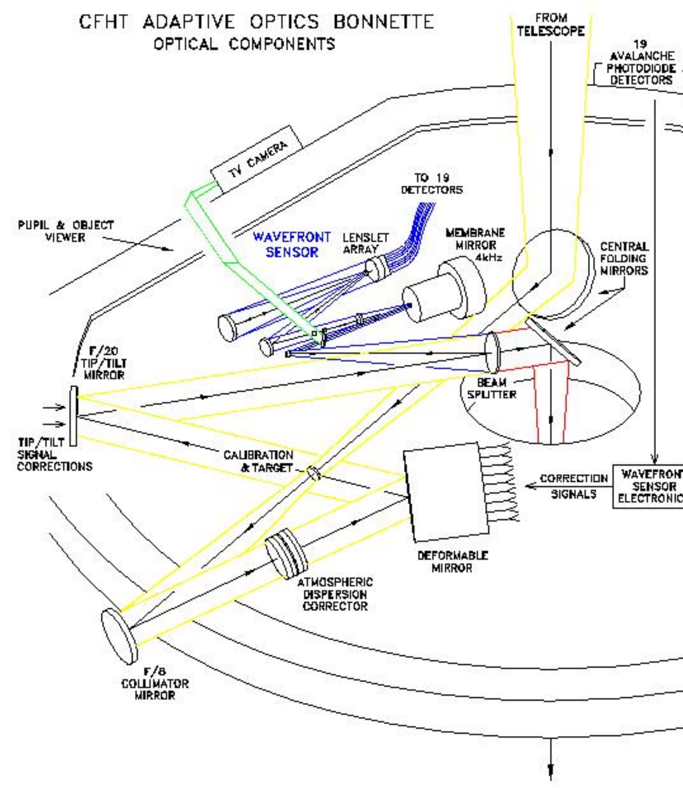
The core is caused by a) the bending of light in the rapidly changing inhomogeneous atmosphere – seeing and b) quality of the optical system (how well it is focused, …). It often varies over a night and within an image.

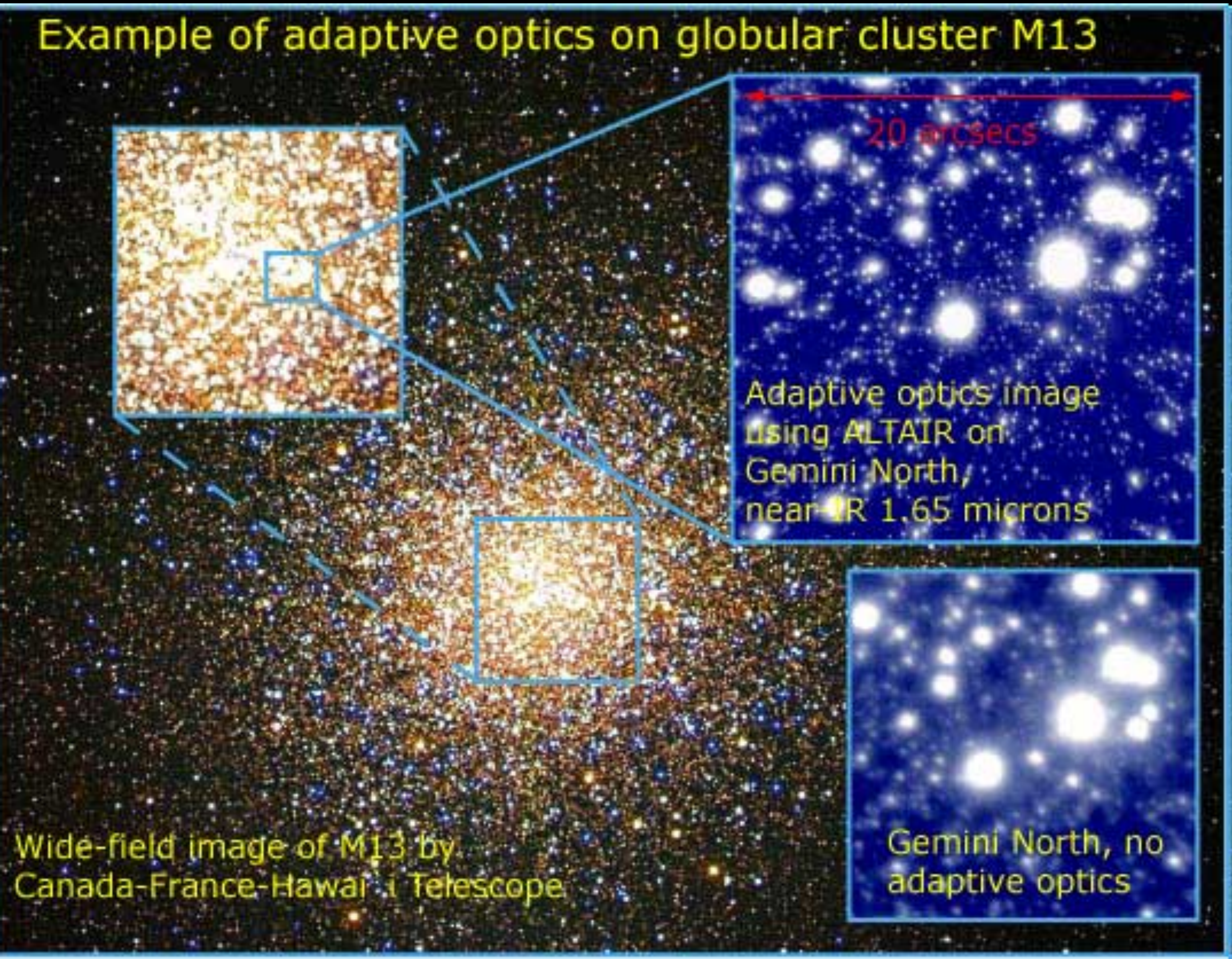
The origin of the halo is less well understood, but it is probably caused by diffraction from the telescope aperture and scattered light from dust and "micro-ripple" imperfections on surfaces of mirrors, filters, and other optical elements. The halo is constant at least over the several nights of an observing run.

Angular Resolution

- A solution to atmospheric distortion: *adaptive optics*
  - Bend your telescope mirror to remove the deflections introduced by the atmosphere.
  - Significantly increases complexity of telescope and needs fast computer processing.
  - Not perfect, but does help.



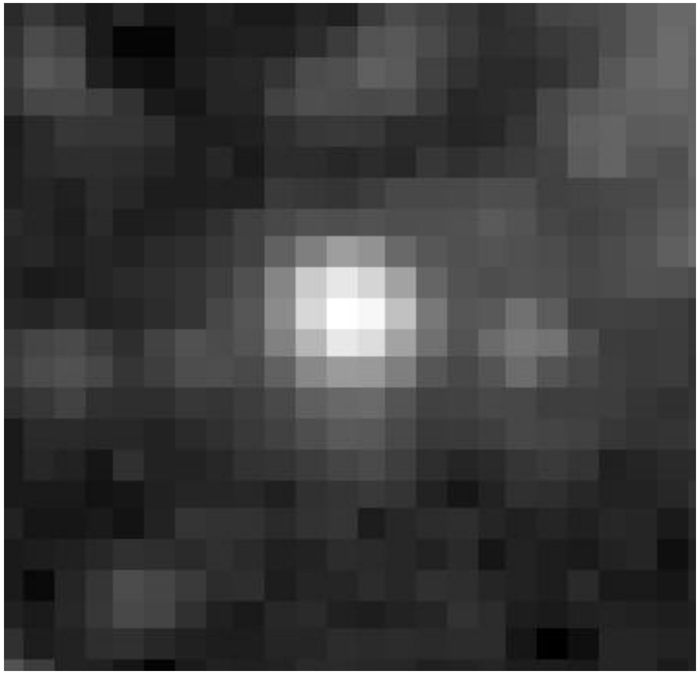




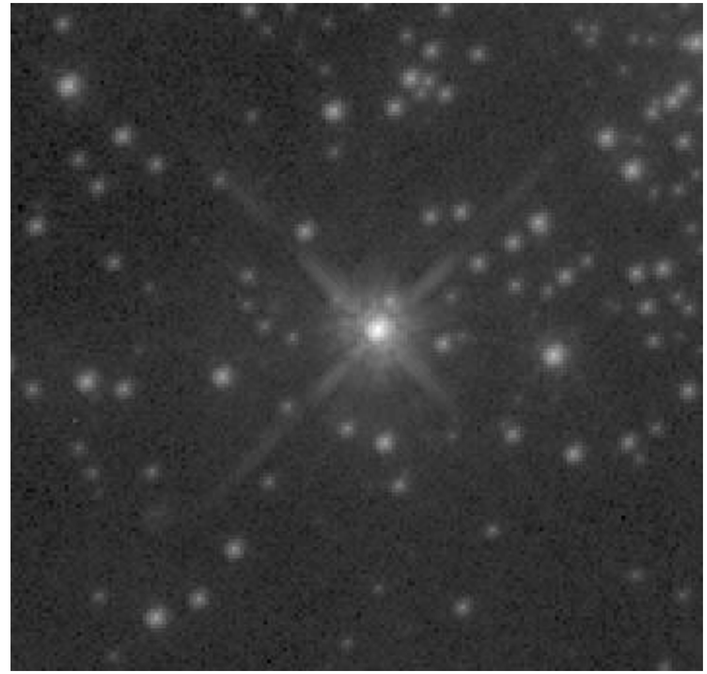
Example of adaptive optics on globular cluster M13
20 arcsecs
Adaptive optics image using ALTAIR on Gemini North, near-IR 1.65 microns
Gemini North, no adaptive optics
Wide-field image of M13 by Canada-France-Hawaii Telescope

Another solution: put your telescope in space, above the atmosphere

Main problem: very expensive. Hubble cost $1.5 billion to launch and requires $100 million/yr to run.



Bright star viewed with ground-based telescope



Same star viewed with Hubble Space Telescope

There is another reason for putting telescopes in space … observing wavelength of light that are not transmitted by the atmosphere.