Electromagnetic Radiation and Telescopes

I. **Waves** (chpt. 3)
Speed, frequency, wavelength, light, EMR etc.

II. **Spectroscopy** (chpt. 4)
Wein's Law, Doppler effect, spectral lines, etc.

III. **Telescopes** (chpt. 5)
Refractors, reflectors, resolution, magnification, etc.

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2	Solve mathematical problems involving speed, frequency, and wavelength. ✓	2 – 4
3	Describe and illustrate the nature of electromagnetic radiation. ✓	5
4	State the six major regions of the electromagnetic spectrum in order of frequency and/or wavelength. ✓	6 – 8
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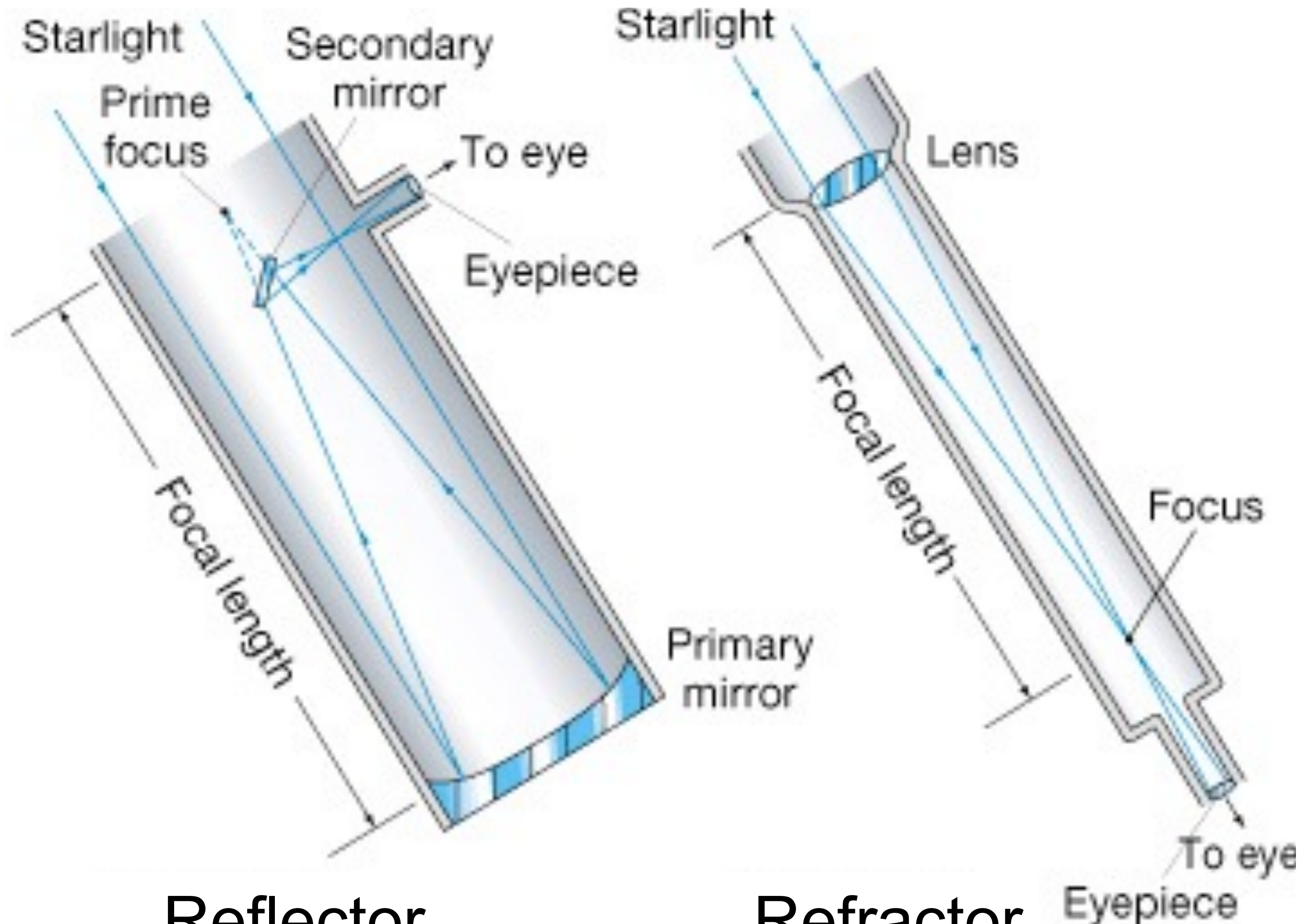
Telescope Basics

- Purpose of a telescope is to create a clarified image of a distant object.
- Telescopes can be designed for different parts of the EMR spectrum: radio, infrared, visible, UV, etc.
- The performance of any telescope can be judged in terms of: magnification, resolution, and light gathering power.

Telescope Designs

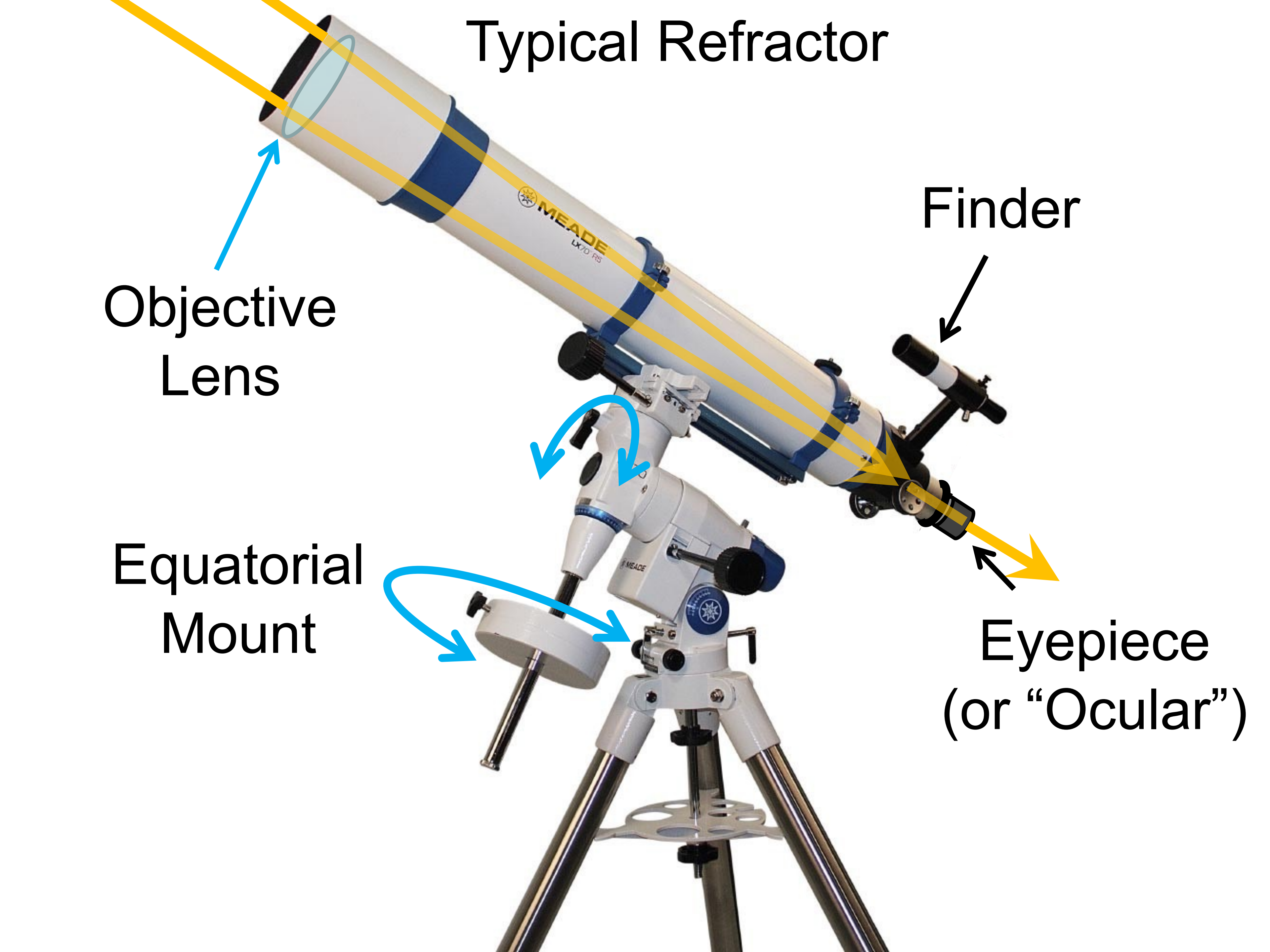
- There are primarily two types of telescopes: reflectors and refractors.
- A reflector uses a mirror to focus light (or other EMR).
- A refractor uses a lens to focus light (or other EMR).
- Refraction is the phenomenon responsible for the bending of light passing through a lens – hence the name “refractor”.

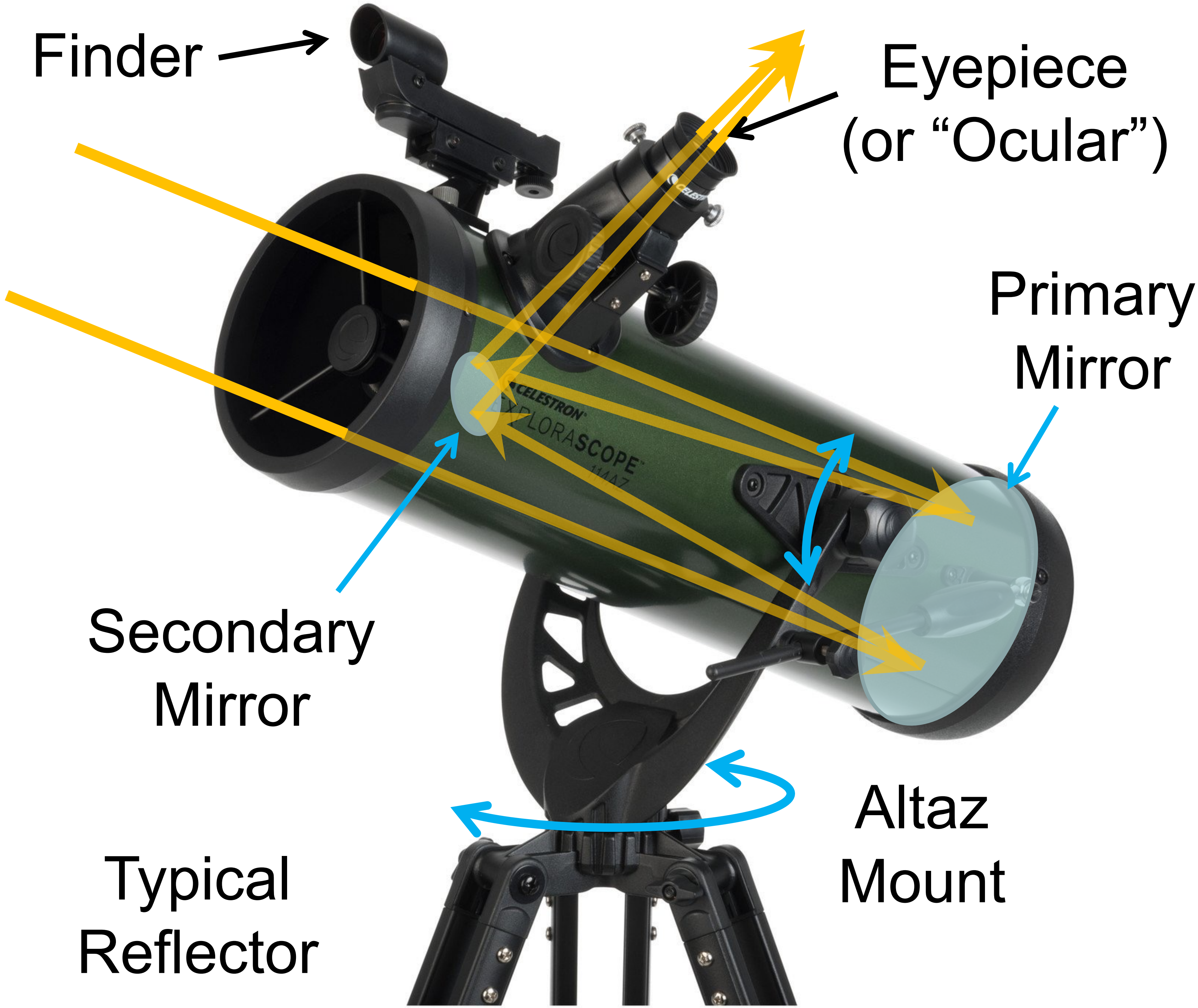


Reflector

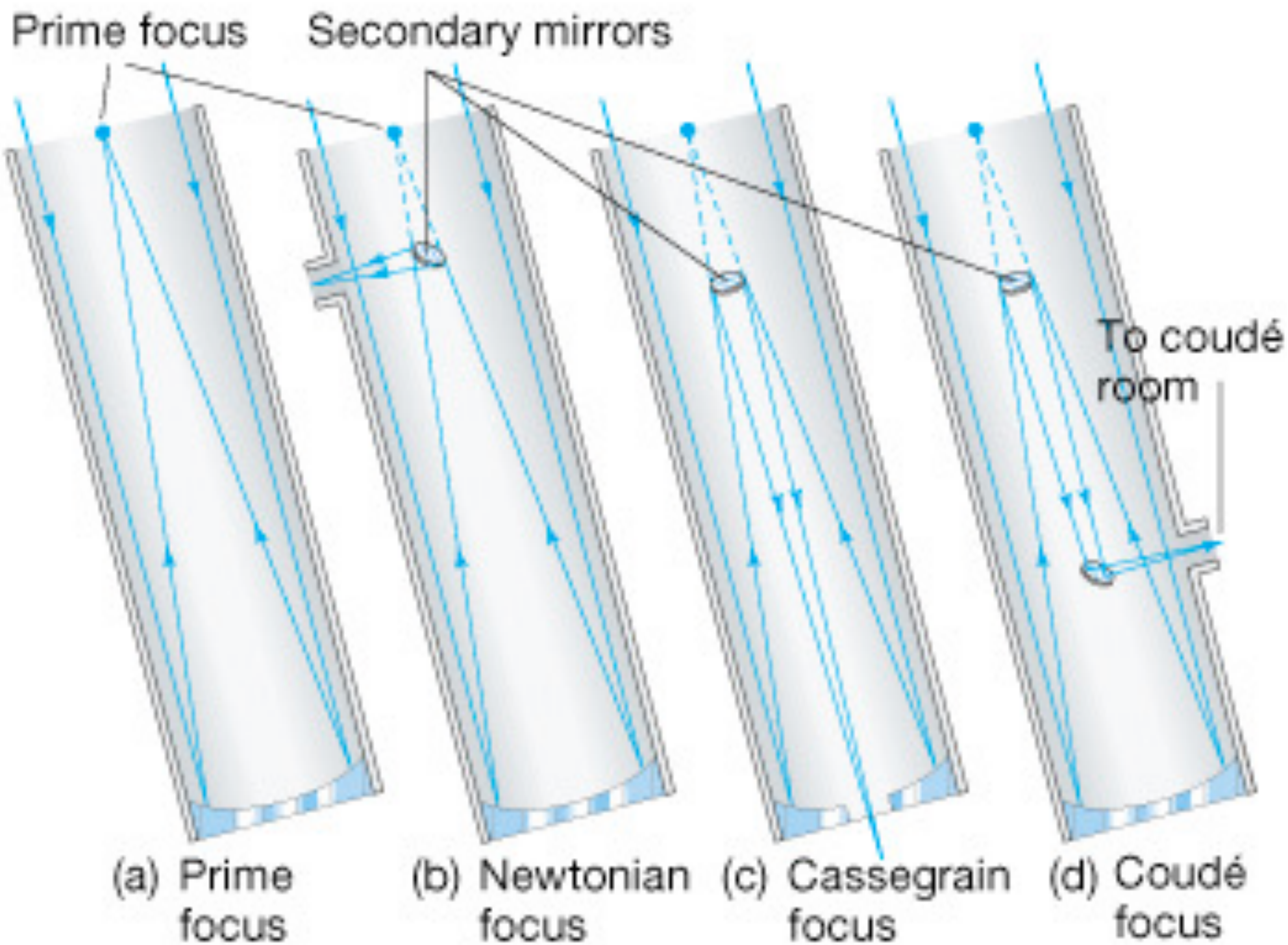
Refractor

Typical Refractor




Finder
Eyepiece
(or "Ocular")
Primary
Mirror
Secondary
Mirror
Altaz
Mount
Typical
Reflector

Common Reflector Types



Yerkes Observatory

40-inch Refractor

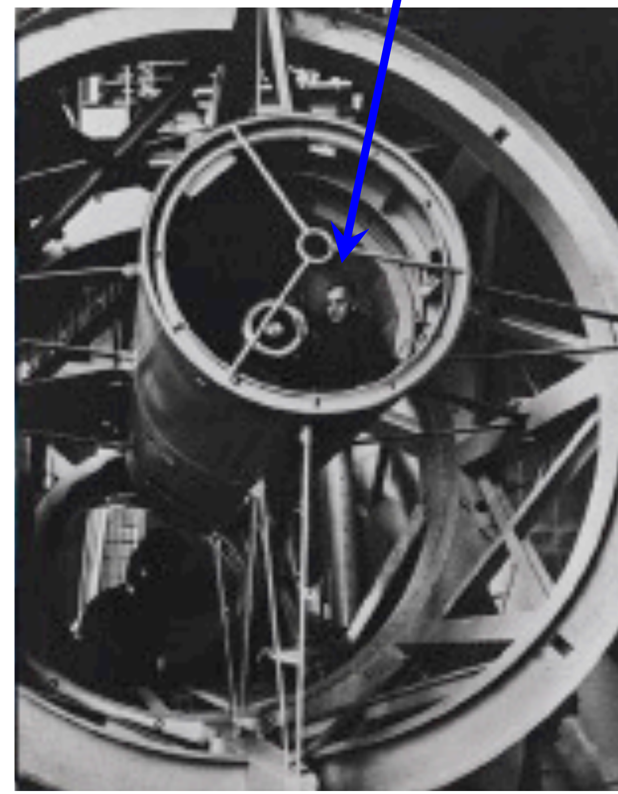
The size of a telescope refers to the diameter of its aperture (the opening through which light passes).

In this telescope, light is focused by a lens with a diameter of 40 inches.

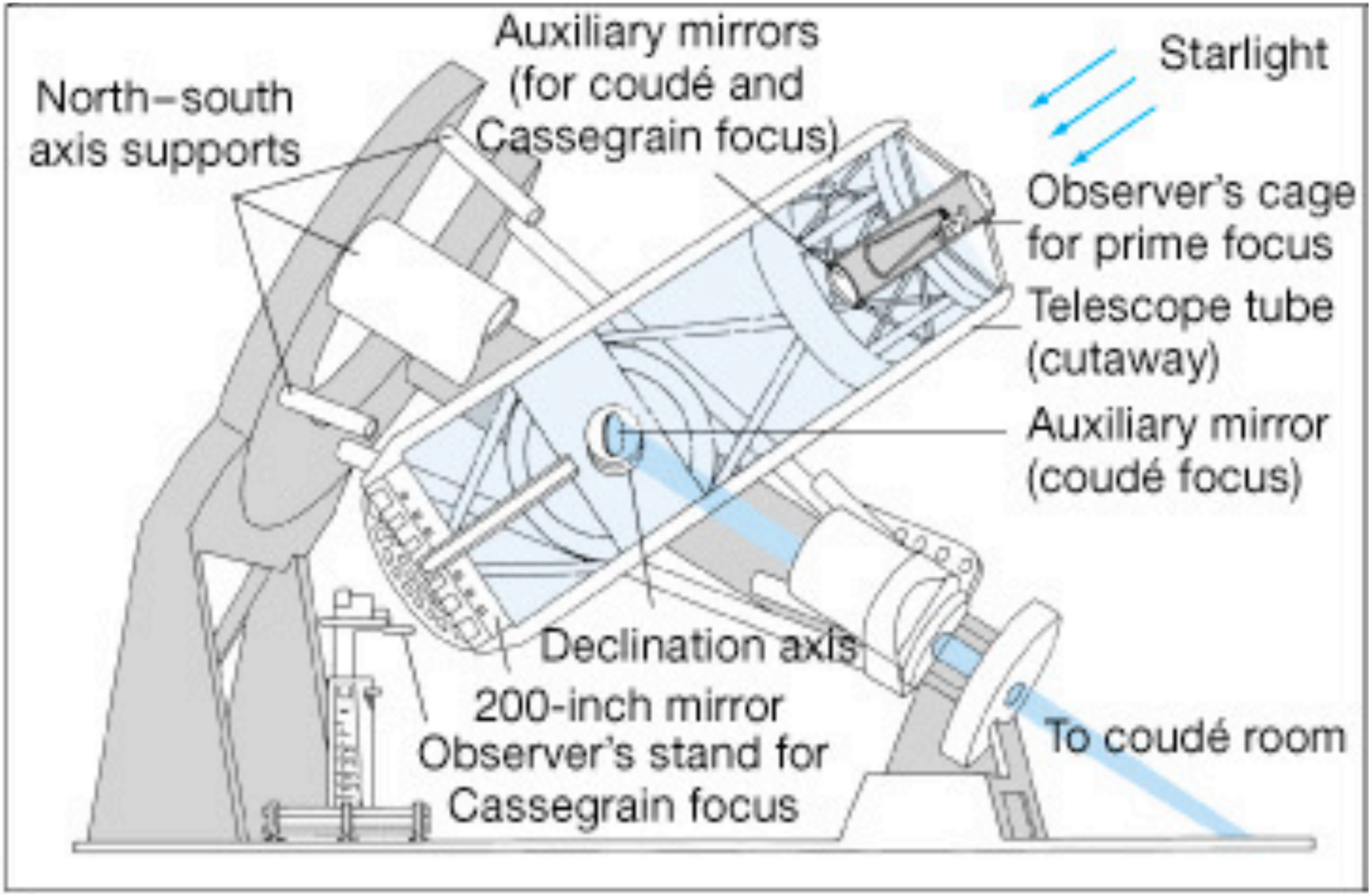
Note the size of the person! →

Palomar Observatory – 200-inch Hale Telescope

Where’s ~~Waldo~~ Edwin?



World's largest optical telescope 1948 – 1993


Auxiliary mirrors
(for coudé and
Cassegrain focus)
Starlight
North–south
axis supports
Observer's cage
for prime focus
Telescope tube
(cutaway)
Auxiliary mirror
(coudé focus)
Declination axis
200-inch mirror
Observer's stand for
Cassegrain focus
To coudé room

Telescope Performance

- Magnification – is the ratio of the apparent size of the image to the apparent size of the object.
- Resolution – refers to the ability to discern details in an image.
- Light Gathering – is a term referring to the amount of radiation that a telescope can collect and “pack into” an image.

How does it work?

- Time to build your own!
- Follow directions and build your telescope, testing the lenses as you go along.
- Questions:
  1. The objective lens serves what role(s)? What properties make it suitable for this use?
  2. The eyepiece lens serves what role(s)? What properties make it suitable for this use?

How does it work?

- The objective lens or primary mirror collects and focuses light and forms a real image.
- This image can be viewed (and magnified) with an eyepiece (or "ocular")
- Alternatively the image can be projected onto a photographic plate (*i.e.* film) or other type of detector.

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Magnification

Magnification is the ratio or factor by which the image appears larger than the object. It depends on the focal lengths of the objective and the eyepiece.

$$M = \frac{f_1}{f_2}$$

where: M = magnification factor

f_1 = focal length of objective or primary

f_2 = focal length of eyepiece or ocular

1. The primary mirror of the C-5 telescope has a focal length of 1250 mm. Determine the magnification when using eyepieces with focal length:
   (a) 50 mm, (b) 6 mm, or (c) 4 mm.
2. Suppose the same eyepieces are used in a different telescope that has an objective lens with focal length 60.0 cm. Find the magnification for each eyepiece.
3. Create a telescope by using two magnifying glasses. Determine the magnification of the telescope by measuring the focal length of each lens. Compare to the apparent magnification.

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Resolution

- **Resolution** is the degree to which the details in an image are apparent.
- High resolution images are "sharp", well defined, and focused. Lack of resolution results in a fuzzy image that appears out of focus.
- Angular resolution is a way to *quantify* this.
- **Angular resolution** is the smallest angular separation of details that can be resolved.

ABCDEFGHIJKLMNOPQRSTUVWXYZ

ABCDEFGHIJKLMNOPQRSTUVWXYZ

ABCDEFGHIJKLMNOPQRSTUVWXYZ

ABCDEFGHIJKLMNOPQRSTUVWXYZ

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ASTRONOMYISWICKEDLYAWESOME

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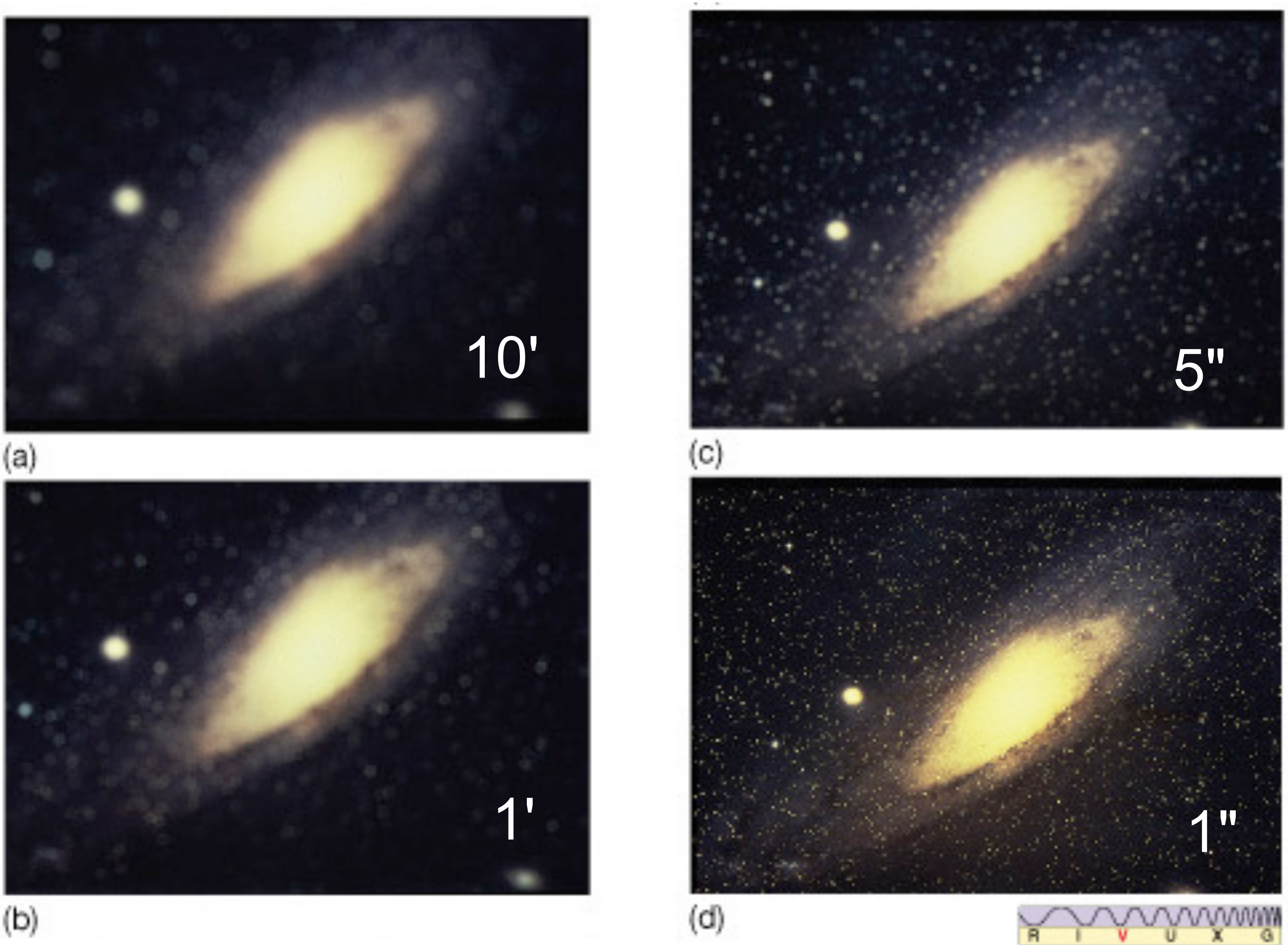
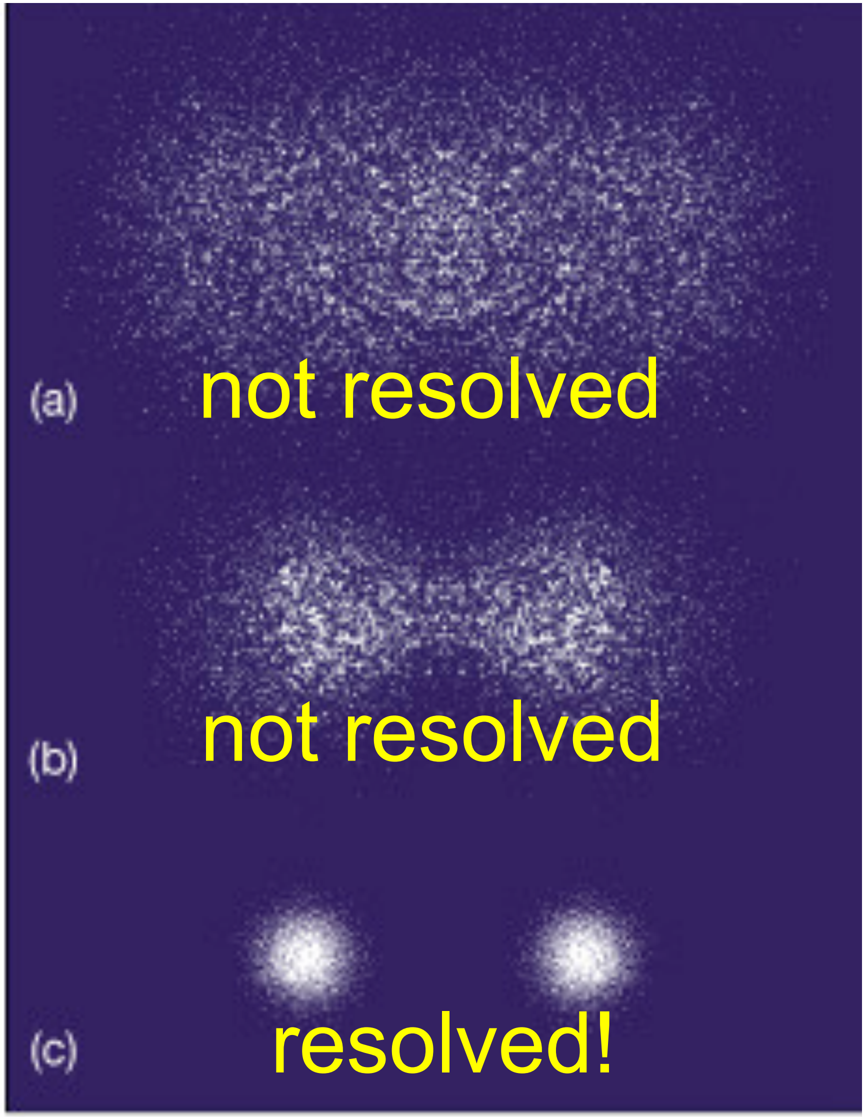
Angular Resolution of Each Photo

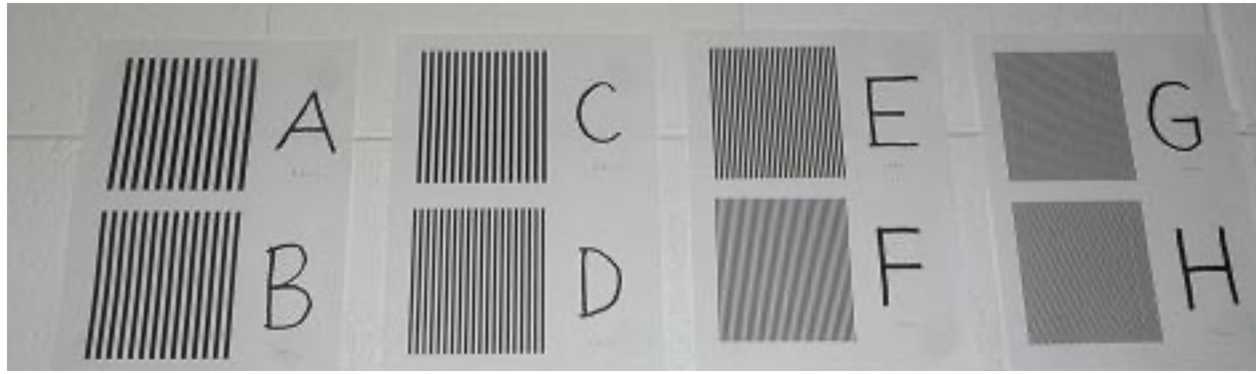




Light from two distinct objects can become merged in an image.

In order to *resolve* the objects, the telescope must completely separate and focus the light into two distinct regions of the image.

Angular Resolution of Your Eyes:

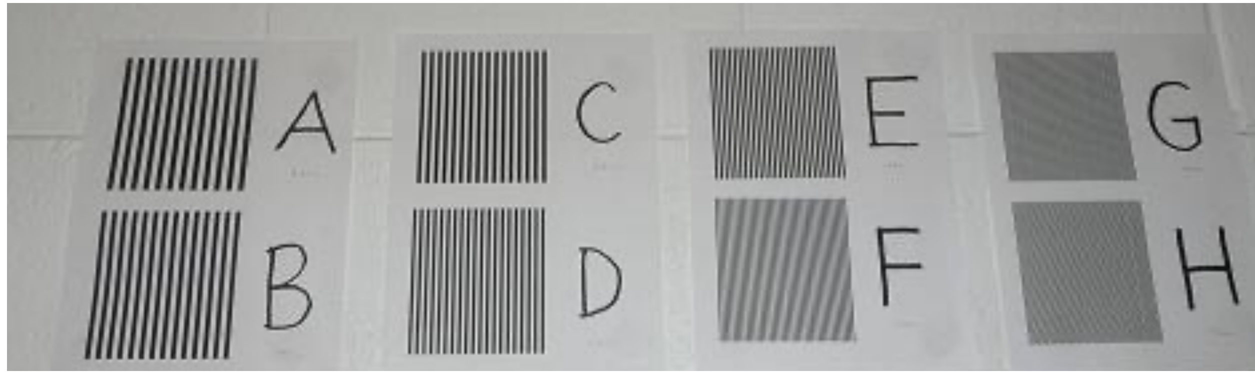


From a known distance observe the patterns A thru H. Note the letter of the pattern on which it is *just barely possible* for you to distinguish the lines.

A	4.63 mm
B	3.97 mm
C	3.31 mm
D	2.65 mm
E	1.99 mm
F	1.32 mm
G	1.06 mm
H	0.79 mm

Distances from end of hallway:
5.0 m to center of locker 2093
10.0 m to right side of locker 2077
15.0 m to center of locker 2065
20.0 m to center of locker 2048

Angular Resolution of Your Eyes:



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Example:
Joey can see the lines only on patterns A and B from 20.0 m:

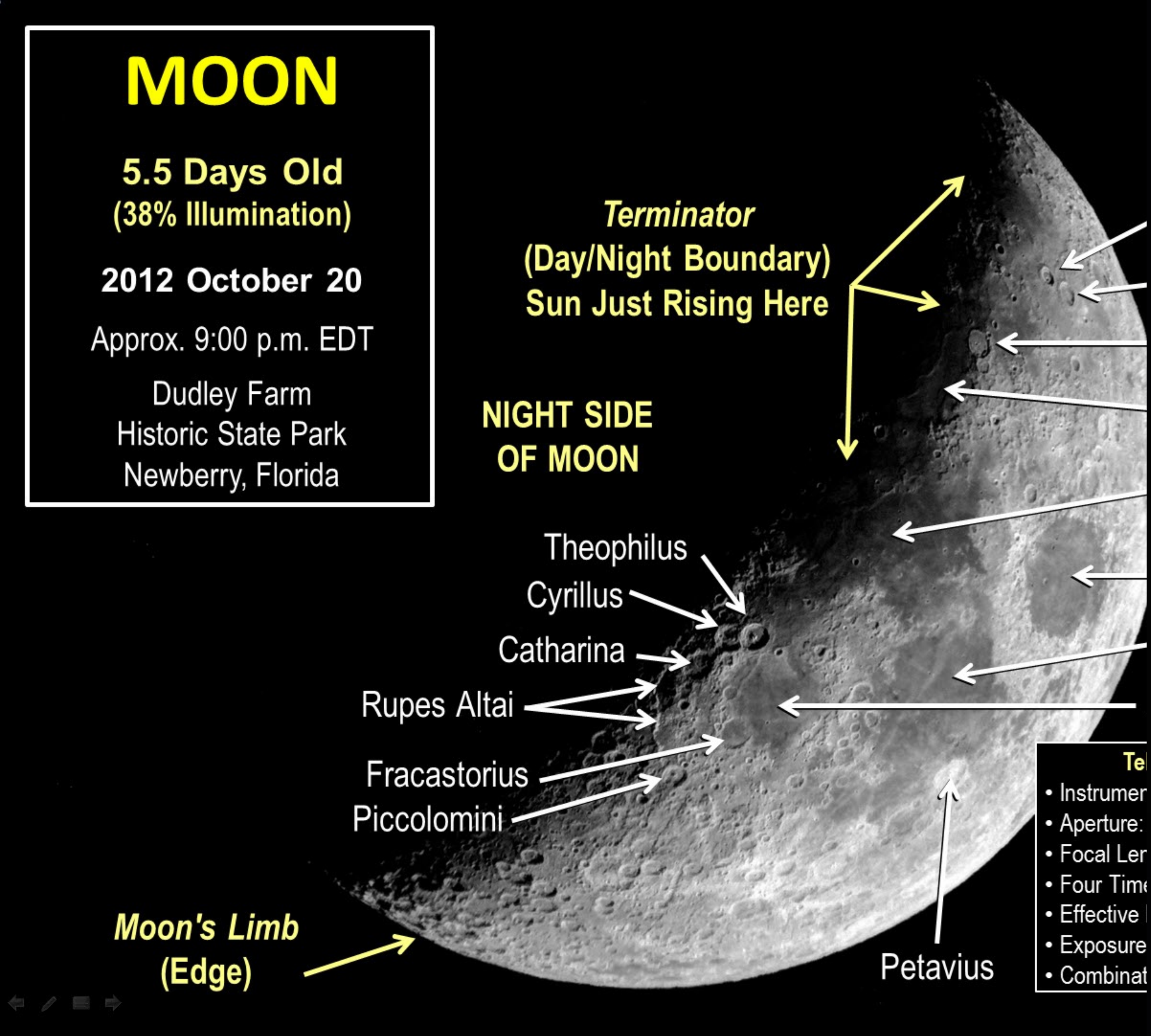
$a = 3.97$ mm; $r = 20000$ mm

$$\theta = \frac{a}{r} = \frac{3.97}{20000} = 2 \times 10^{-4}\ \text{rad}$$

$\theta = 0.7$ arc minutes

Examples of Angular Resolution		
	Resolution	EMR type
Naked Eye, typical	0.5 ′	Visible
Keck (10 m × 2)	0.04 ″	Infrared
HST (2.4 m)	0.05 ″	Visible
Greenbank (43 m)	1 ′	Radio, 1 cm
Greenbank (43 m)	6 ′	Radio, 5 cm
Arecibo (300 m)	1 ′	Radio, 6 cm
VLBI	0.001 ″	Radio
COAST	0.01 ″	Visible
Gemini (8 m)	0.1 ″	Infrared
VLT (8.2 m × 4)	0.01 ″	Infrared

image: Howard Cohen www.astroadventures.net



Angular Resolution ?

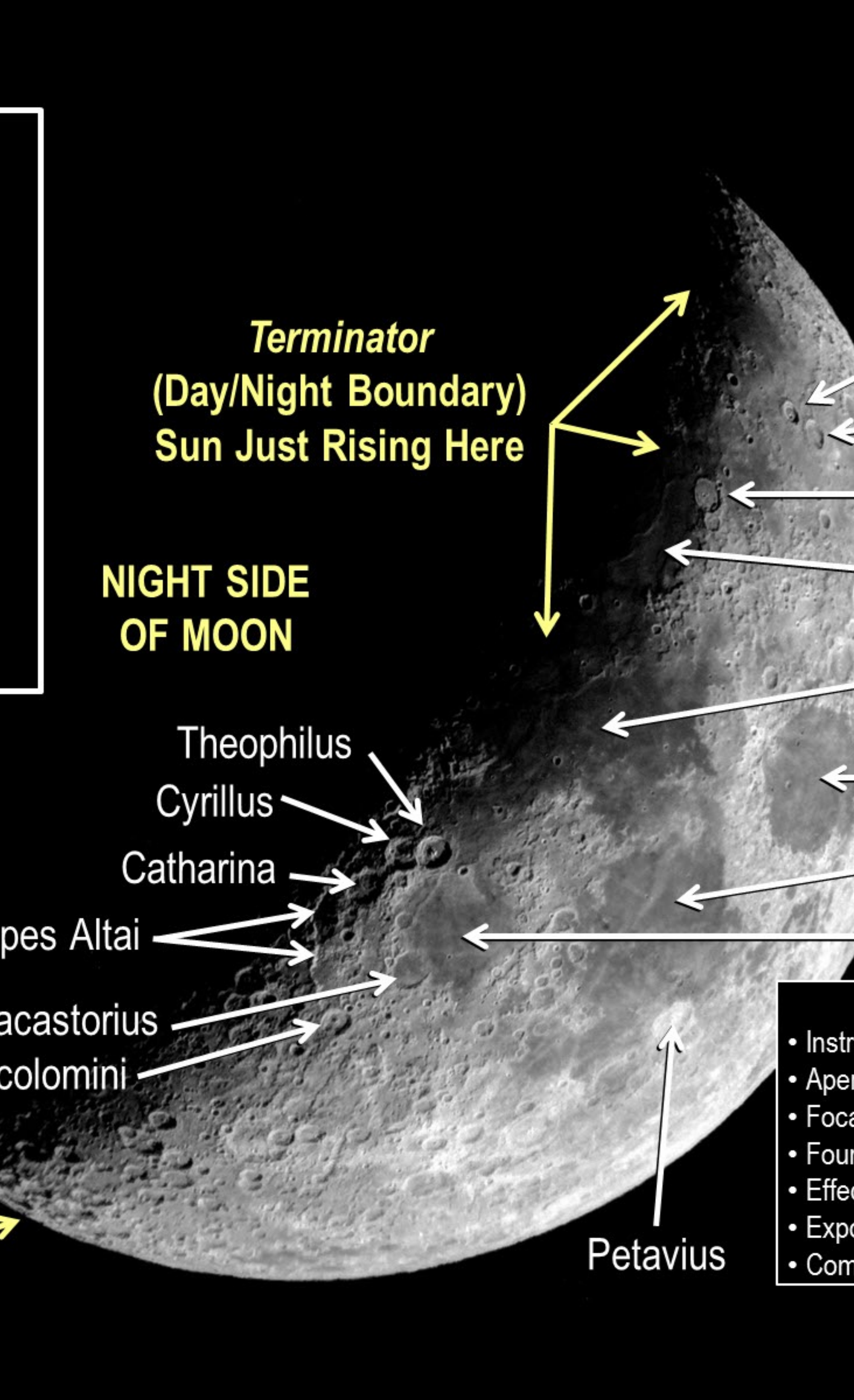
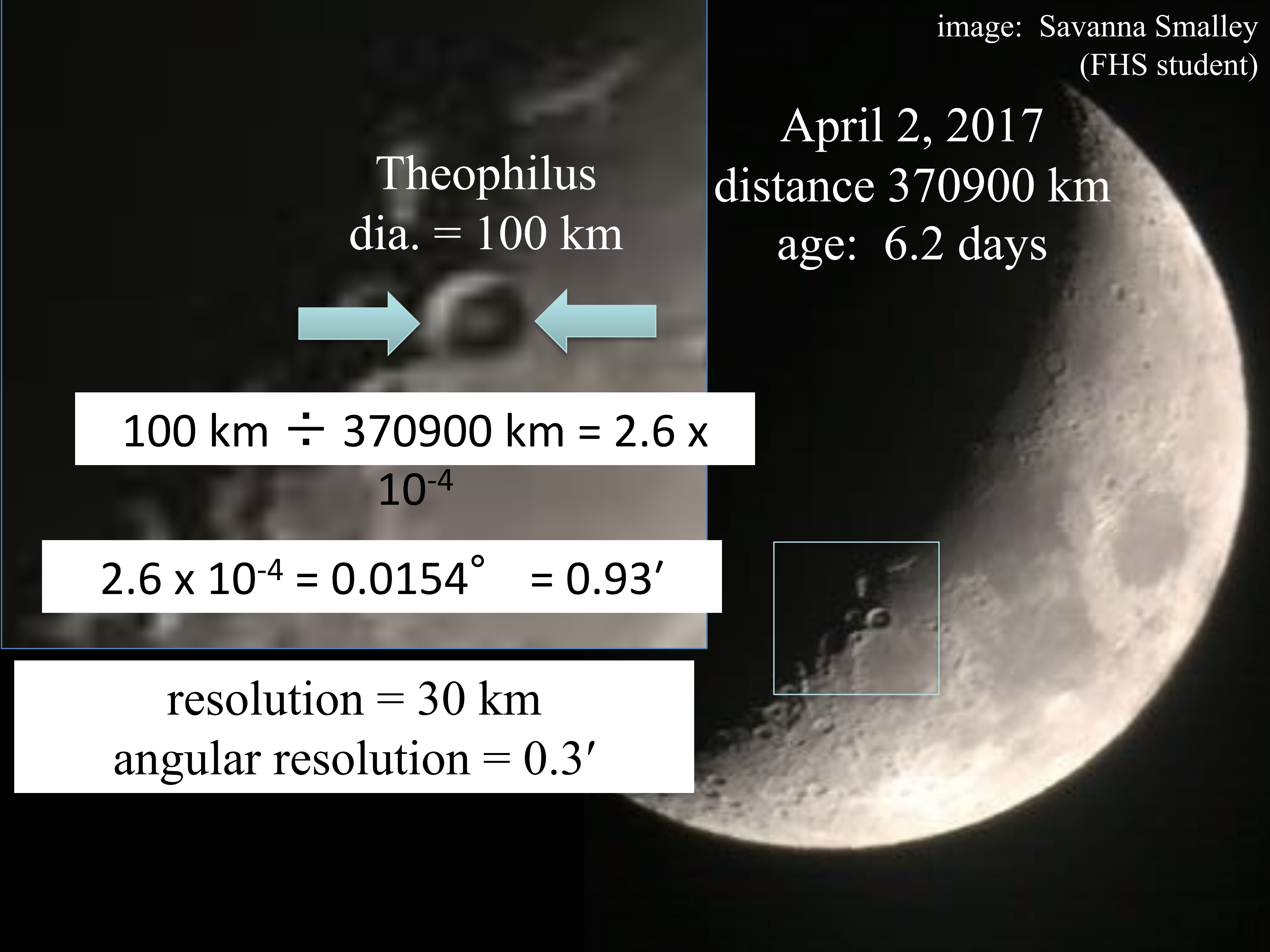


image: Savanna Smalley
(FHS student)

April 2, 2017
distance 370900 km
age: 6.2 days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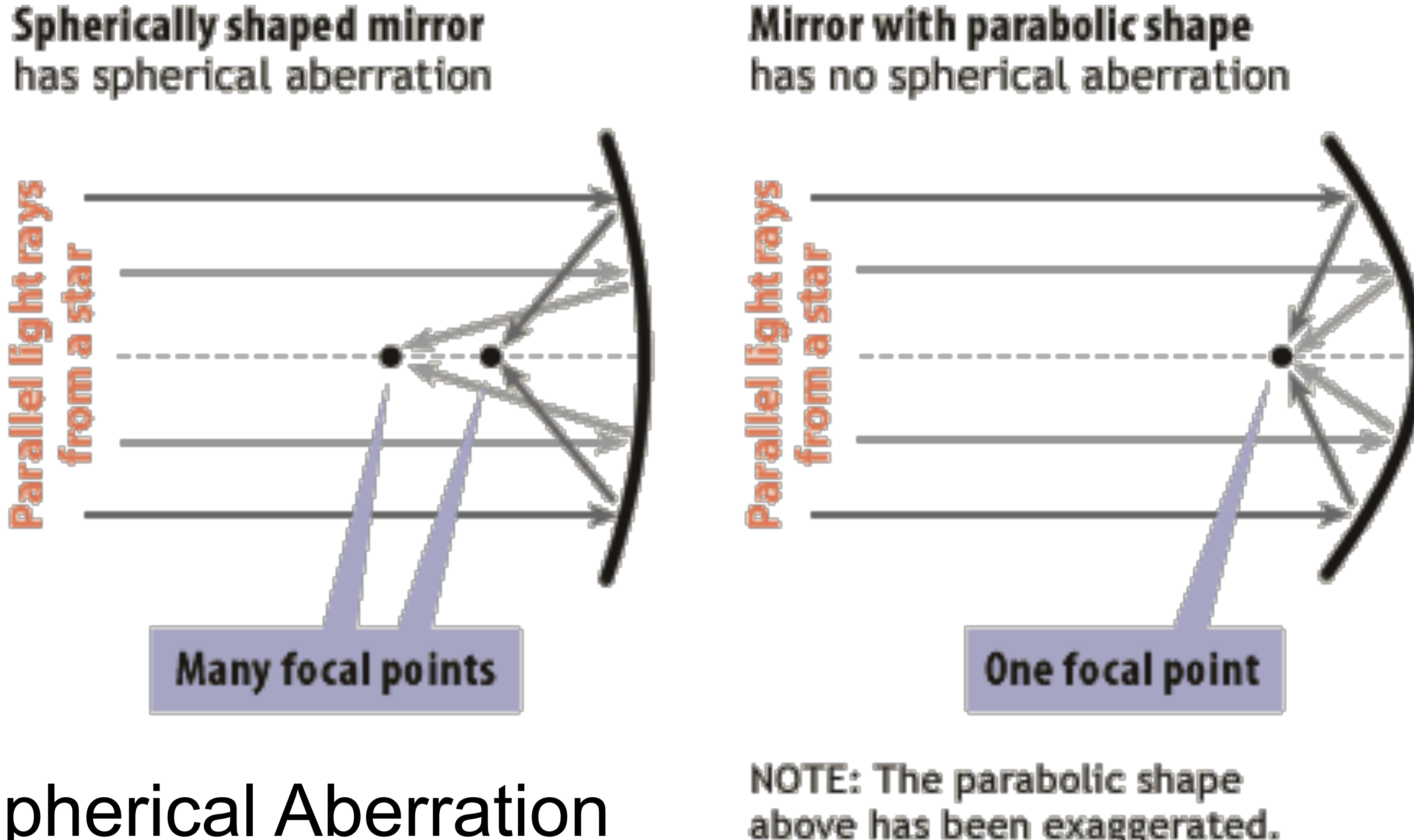
Theophilus
dia. = 100 km
100 km ÷ 370900 km = 2.6 x 10^{-4}
2.6 x 10^{-4} = 0.0154° = 0.93′
resolution = 30 km
angular resolution = 0.3′

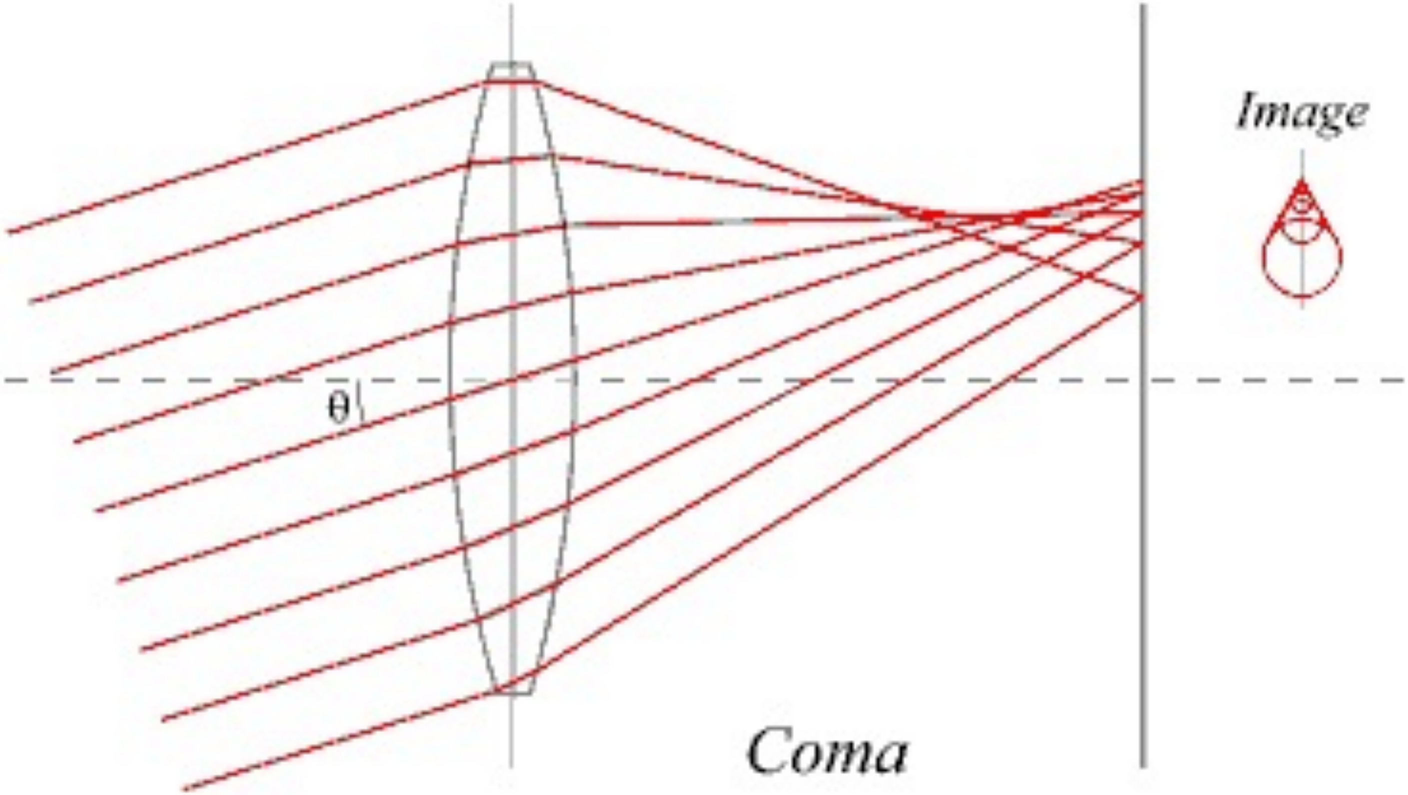
Aberrations of Lenses and Mirrors

- The ability of a lens or mirror to focus light at a precise location affects the resolution of a telescope.
- An **aberration** is a flaw that prevents perfect focus. All lenses and mirrors have aberrations.
- There are several types of aberrations: chromatic aberration, coma, and spherical aberration are common.



Spherical Aberration

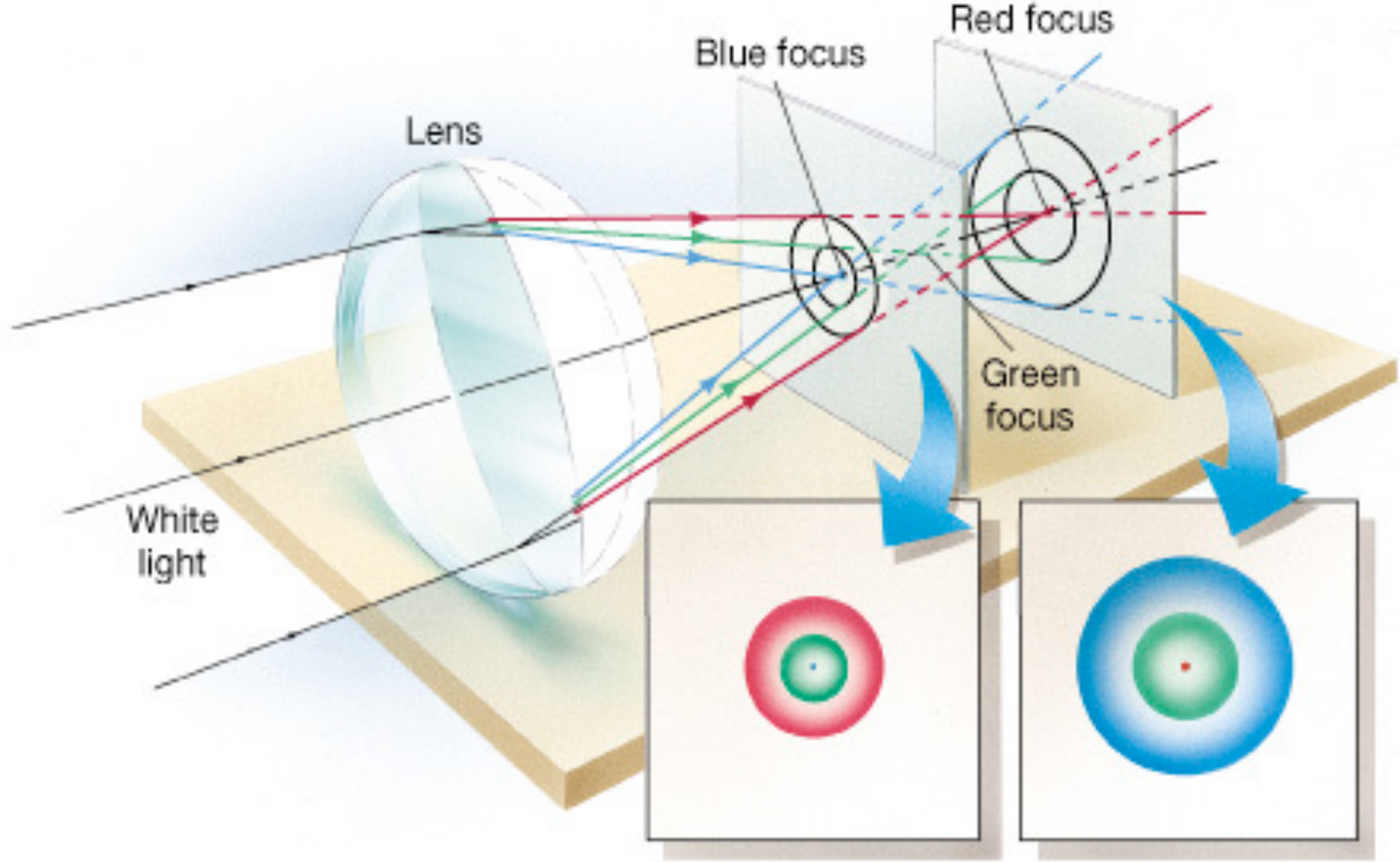
Light from the edges of a spherical surface are focused at shorter distances from the mirror. This also happens with spherical lenses.



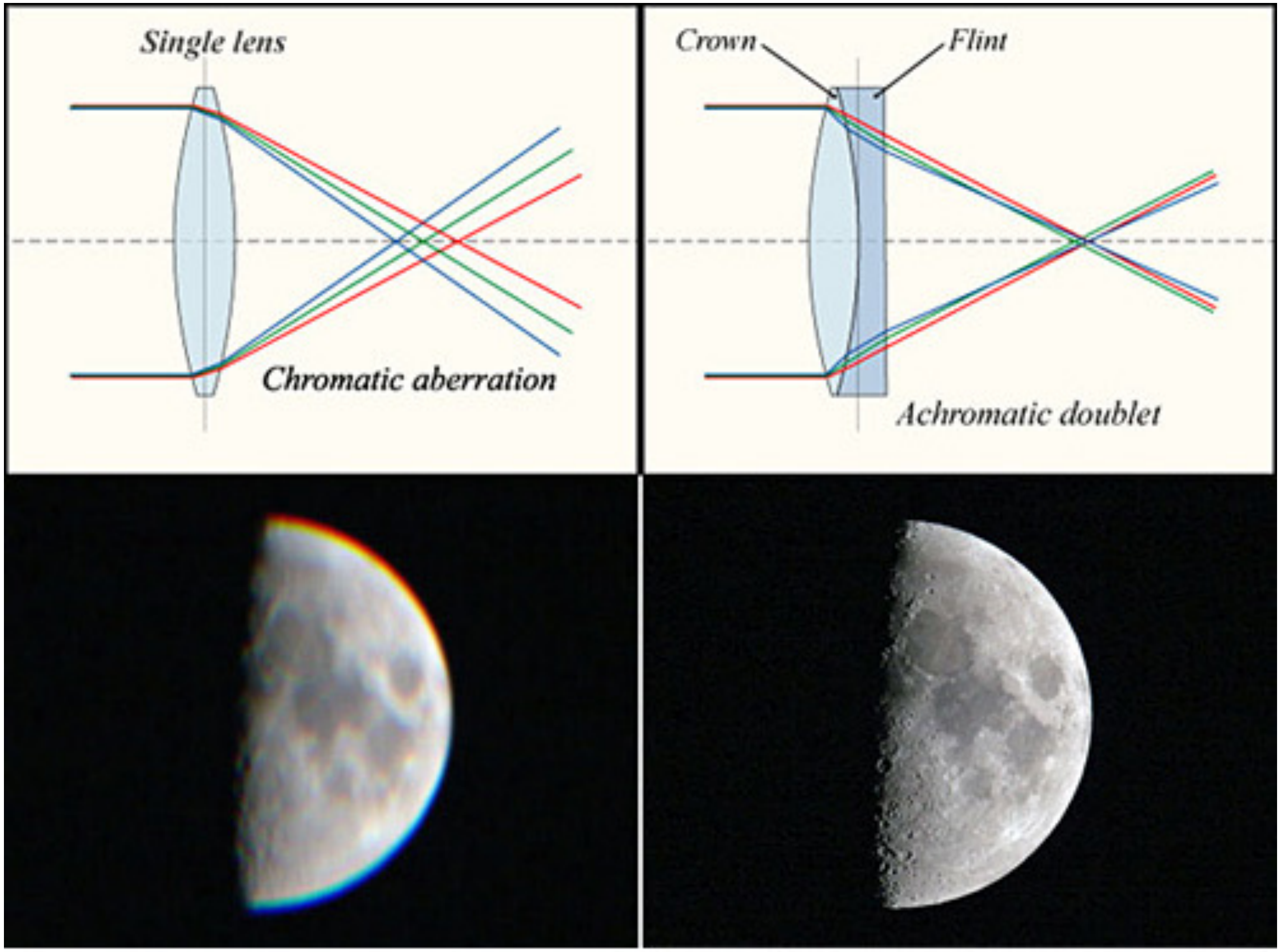
This aberration occurs when light passes through at an angle – the rays do not converge on a point. The result is that a star in the image will look somewhat like a comet – hence the name. This occurs in both refractors and reflectors.

Chromatic Aberration results in blurred colors.

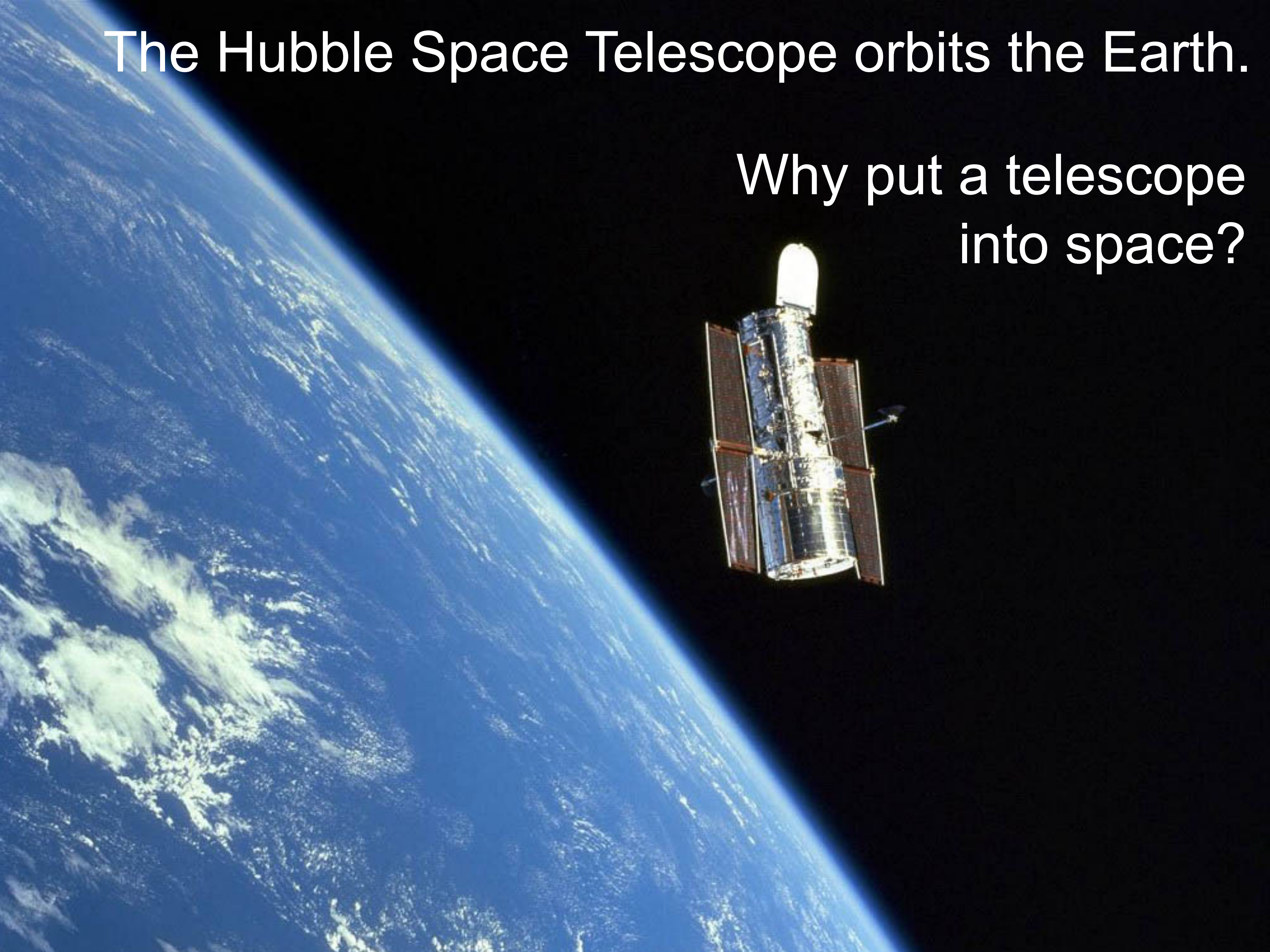
Chromatic Aberration



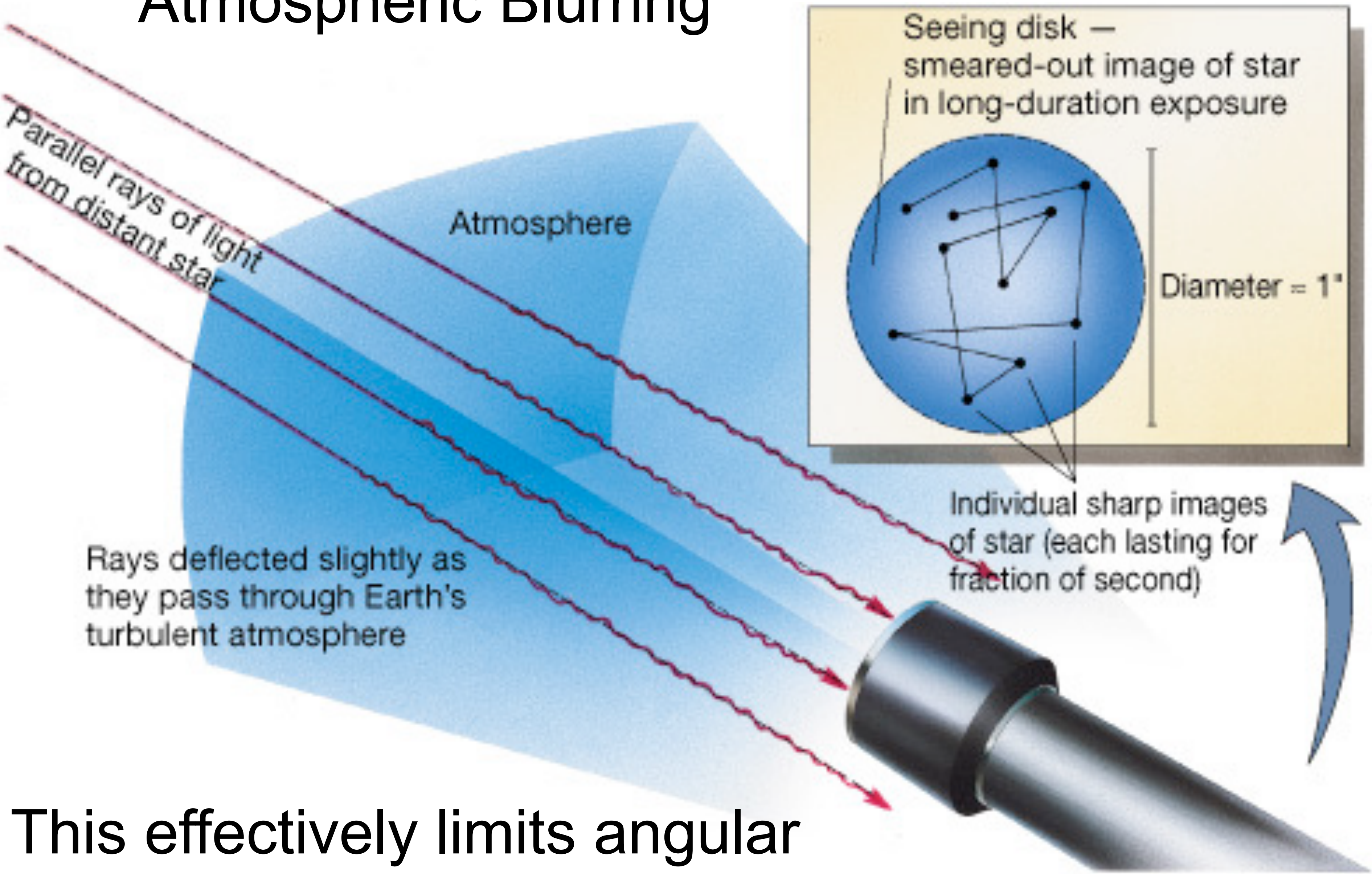
Colors focus at different points due to dispersion in the lens. This decreases resolution and produces a "rainbow effect".



This problem affects *only* images formed by *lenses*. Dispersion does not occur with mirrors and so this doesn't happen in reflectors.

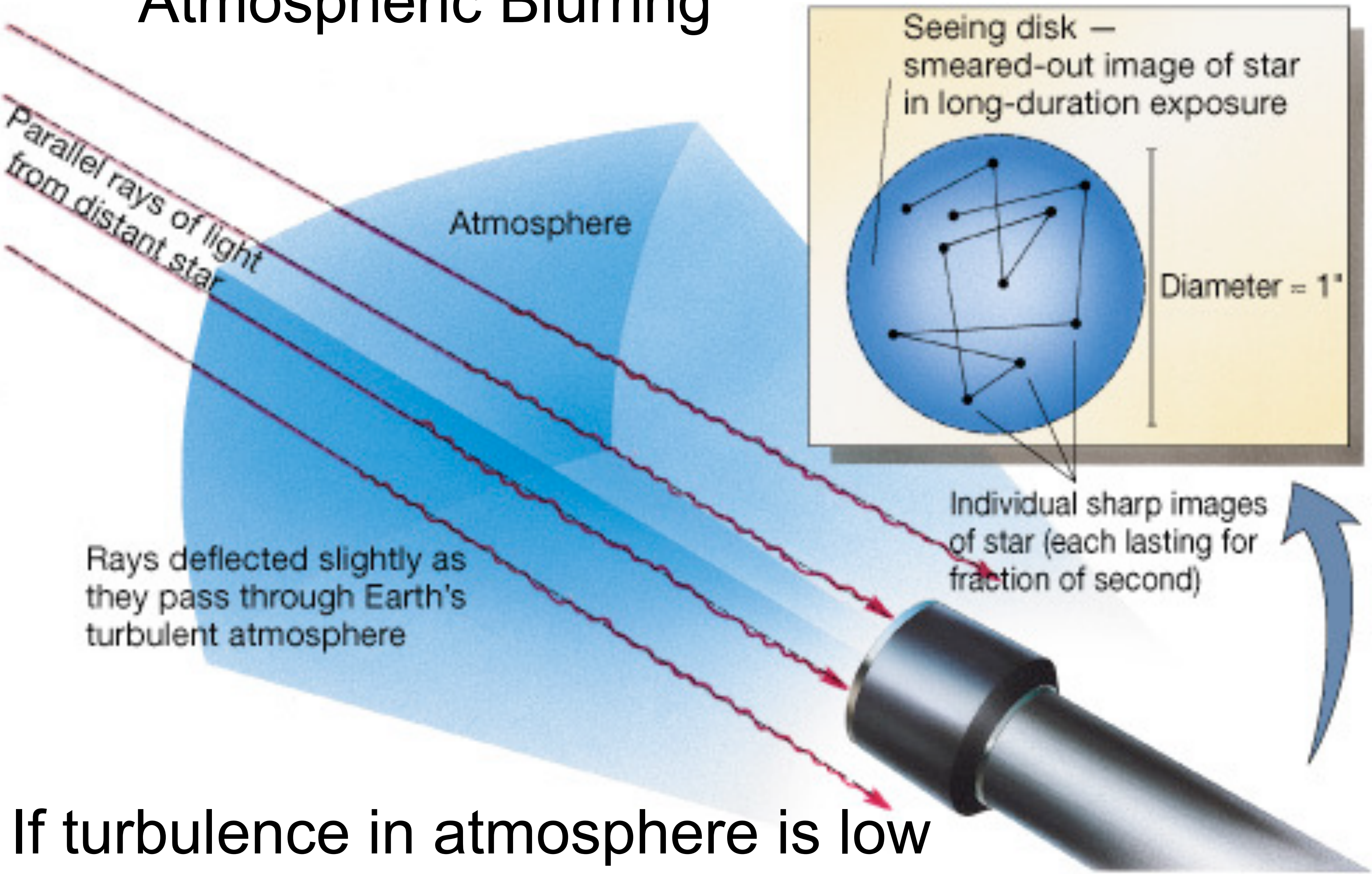

The Hubble Space Telescope orbits the Earth.
Why put a telescope into space?

Atmospheric Blurring



This effectively limits angular resolution to around 1 arc second.

Atmospheric Blurring

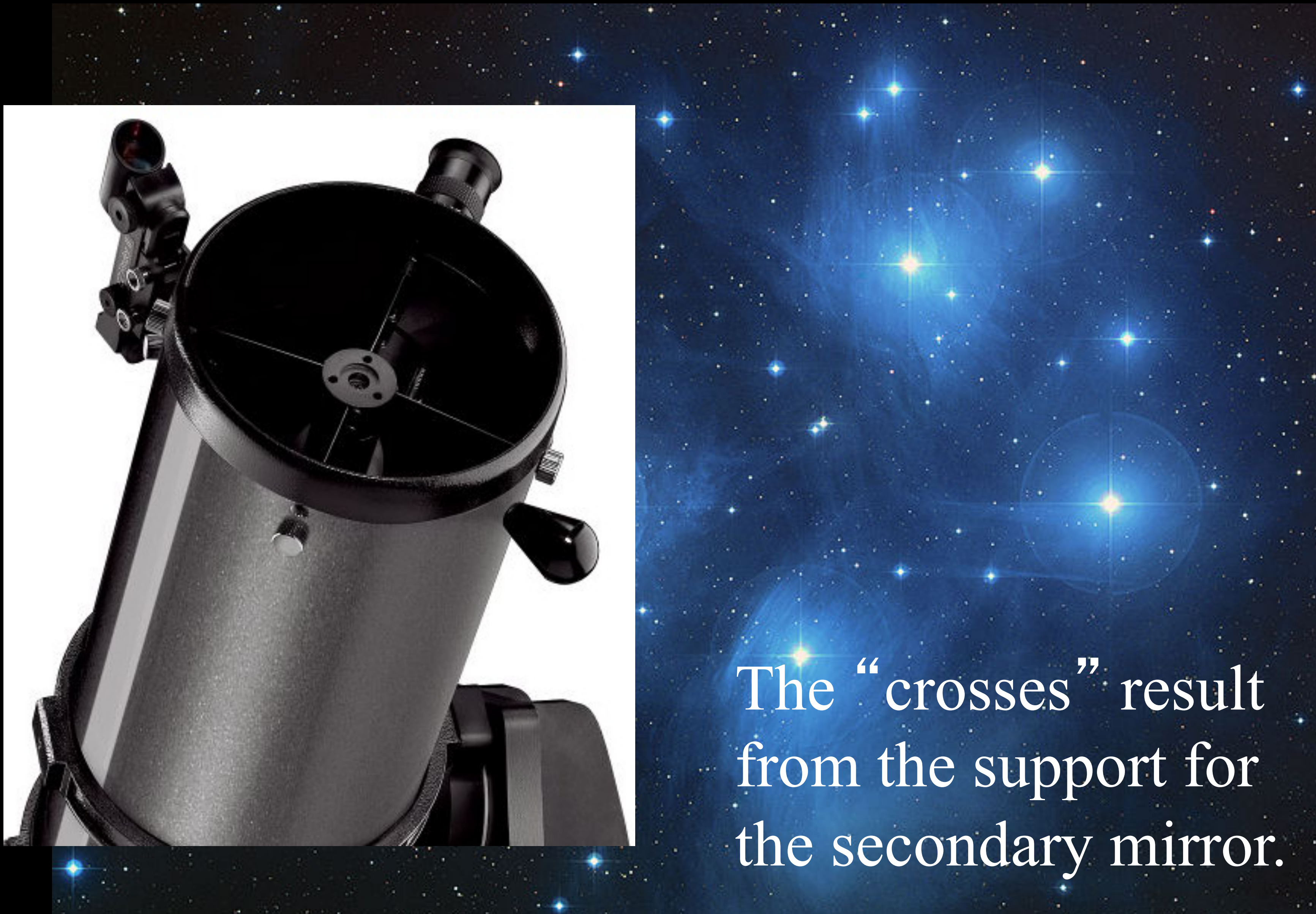


If turbulence in atmosphere is low then the *seeing* is better – less blurring!

Diffraction and Telescopes

- Diffraction is unavoidable as light bends around the various parts of the telescope.
- Diffraction decreases the resolution.
- Because of diffraction, angular resolution for a particular telescope can only be improved so far. (*i.e.* Diffraction puts a *limit* on resolution.)
- A telescope with optical performance at or above this level is said to be "diffraction limited".

Diffraction Spikes



The "crosses" result from the support for the secondary mirror.

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The Diffraction Limit

The best possible angular resolution depends on the diameter of telescope and the wavelength of the light:

$$\theta = 0.25 \cdot \frac{\lambda}{d}$$

where: θ = angular resolution (")
λ = wavelength (μm)
d = diameter (m)

4. Determine the diffraction limit of the C-5 telescope, which has diameter 5 inches. Assume a wavelength of 600.0 nm.

5. The Hubble Space Telescope's primary mirror has diameter 2.4 m. What is the dirraction limited resolution when working at 450 nm?

6. The James Webb Space Telescope has a 6.5 m primary and is designed to achieve resolution of 0.1 arc second. (a) What is the maximum wavelength at which this could occur? (b) What would be the best resolution at visible wavelengths?

7. In order to resolve a flag on the Moon, what diameter telescope would be required?

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Light Gathering

- **Light gathering** refers to a telescope’s ability to collect light and concentrate it into an image.
- Increased light gathering capability results in brighter images and the ability to detect faint objects – greater sensitivity.
- The amount of light collected by a telescope depends on the cross-sectional area (the "collecting area").
- For imaging it also depends on the time of exposure.

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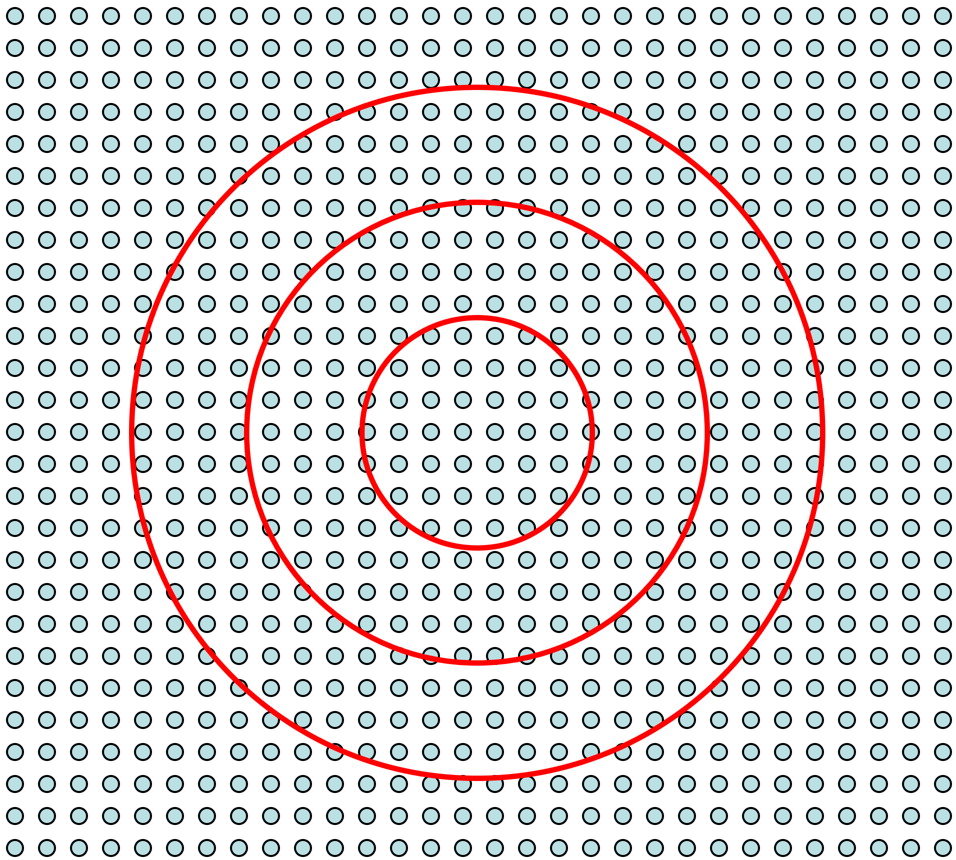
A telescope is a light "bucket" catching the "rain" of photons from the sky…

A bucket twice the diameter catches four times the rain.



Three times the diameter catches nine times the rain.

Any size bucket left in the rain twice as long catches twice as much rain.

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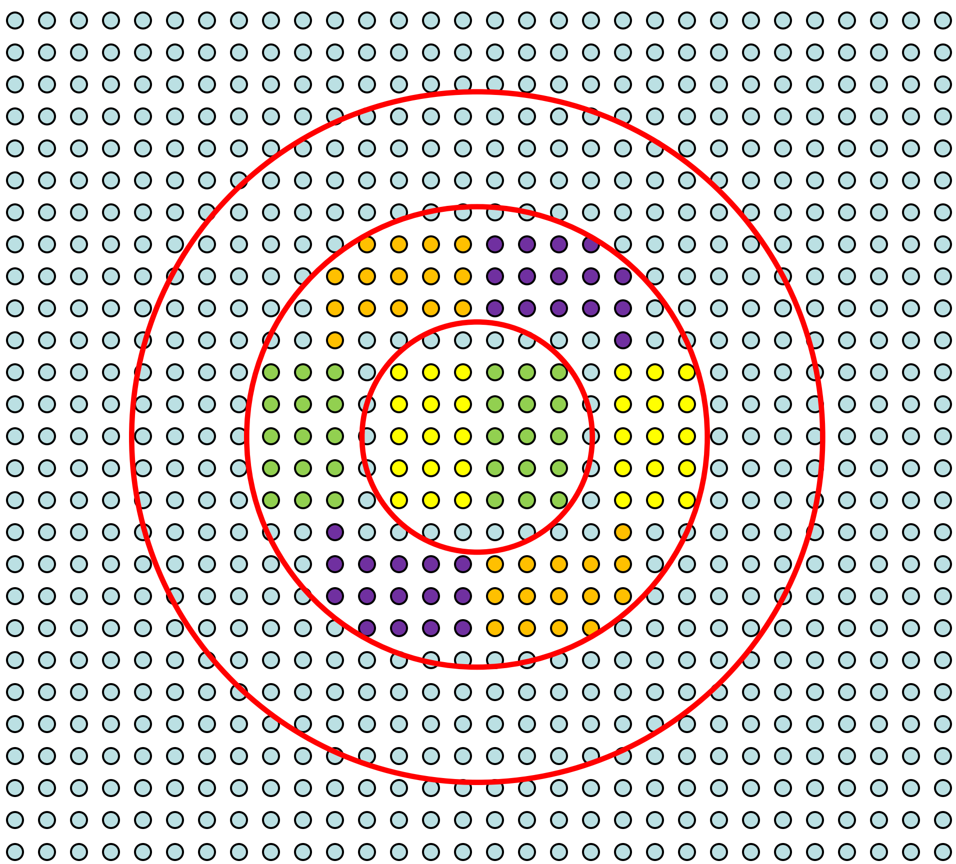

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8. The C-5 telescope gathers how much more light than a human eye with pupil diameter 4 mm?
9. Compare the light gathering capabilities of the Webb Space Telescope (6.5 m) and the Hubble Space Telescope (2.4 m).
10. An astrophotograph is made using a 6 inch telescope with an exposure of 30 seconds. How much exposure would be needed for the same result using a 10 inch telescope?
11. Suppose your eye's pupil opens to 7 mm in a dark location. In order to increase your eye's light gathering ability by a factor of ten, what size telescope is required?

Summary – Reflector vs. Refractor

- Astronomers desire telescopes with larger and larger diameters.
- A larger diameter allows for greater light gathering and increased resolution.
- For a given diameter, a reflecting telescope is less expensive than a refractor.
- Reflectors do not suffer from chromatic aberration as refractors do.
- With a few exceptions, reflectors are the best choice for professionals or amateurs.