

Astronomy

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Small 239

Office hours:

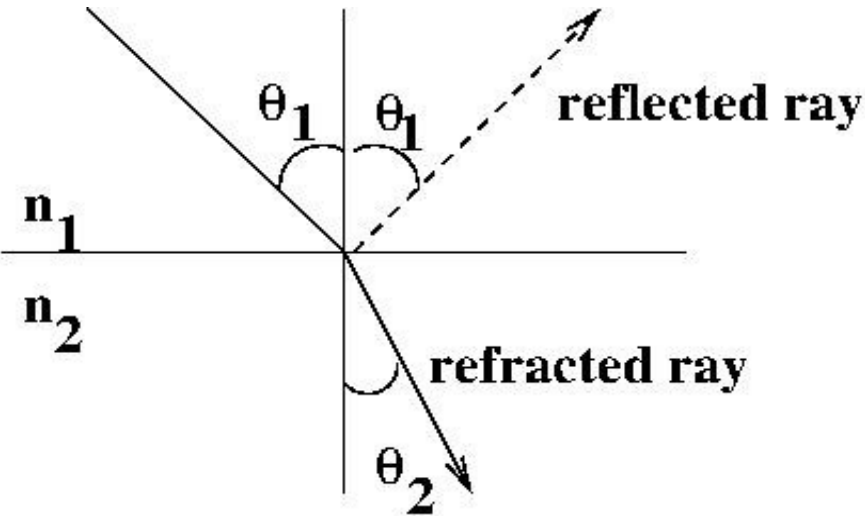
MTWR 10-11am

Optics and Telescopes

- Refraction, lenses and refracting telescopes
- Mirrors and reflecting telescopes
- Diffraction limit, telescope size and atmospheric distortion
- CCDs
- Telescopes and spectra
- Telescopes from radio waves to gamma rays
- Space telescopes

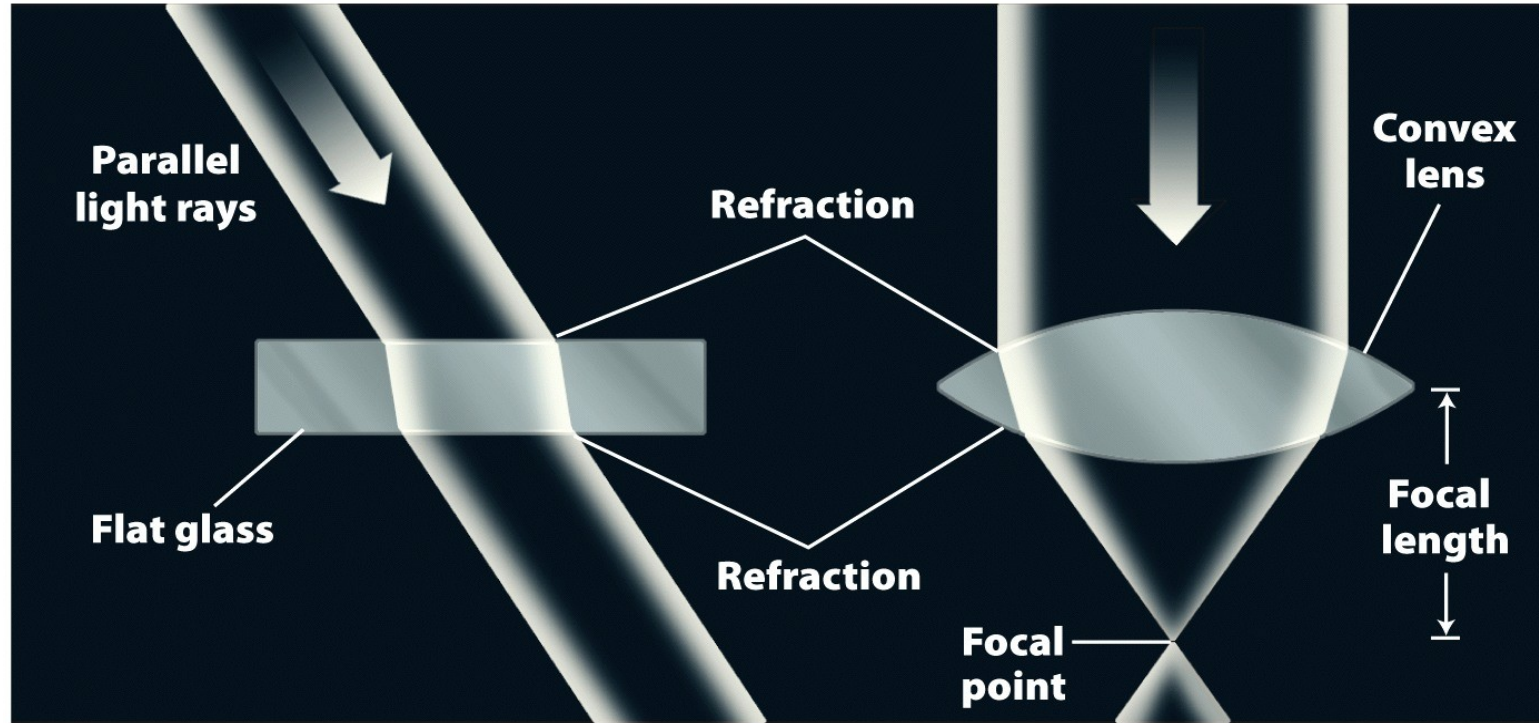
Refraction of Light

In vacuum, the speed of light is $c = 3 \times 10^8$ m/s. When light travels through a transparent medium, the speed is no longer c but some other smaller speed, v . This speed depends on the material. The ratio of these speeds is called the index of refraction, n . (When it reflects, the light comes off at the same angle on the opposite side.)



When light passes from a medium with an index of refraction, n_1 to a second medium with an index of refraction of index, n_2 , the direction of the light is changed. 2

Lenses



(a)

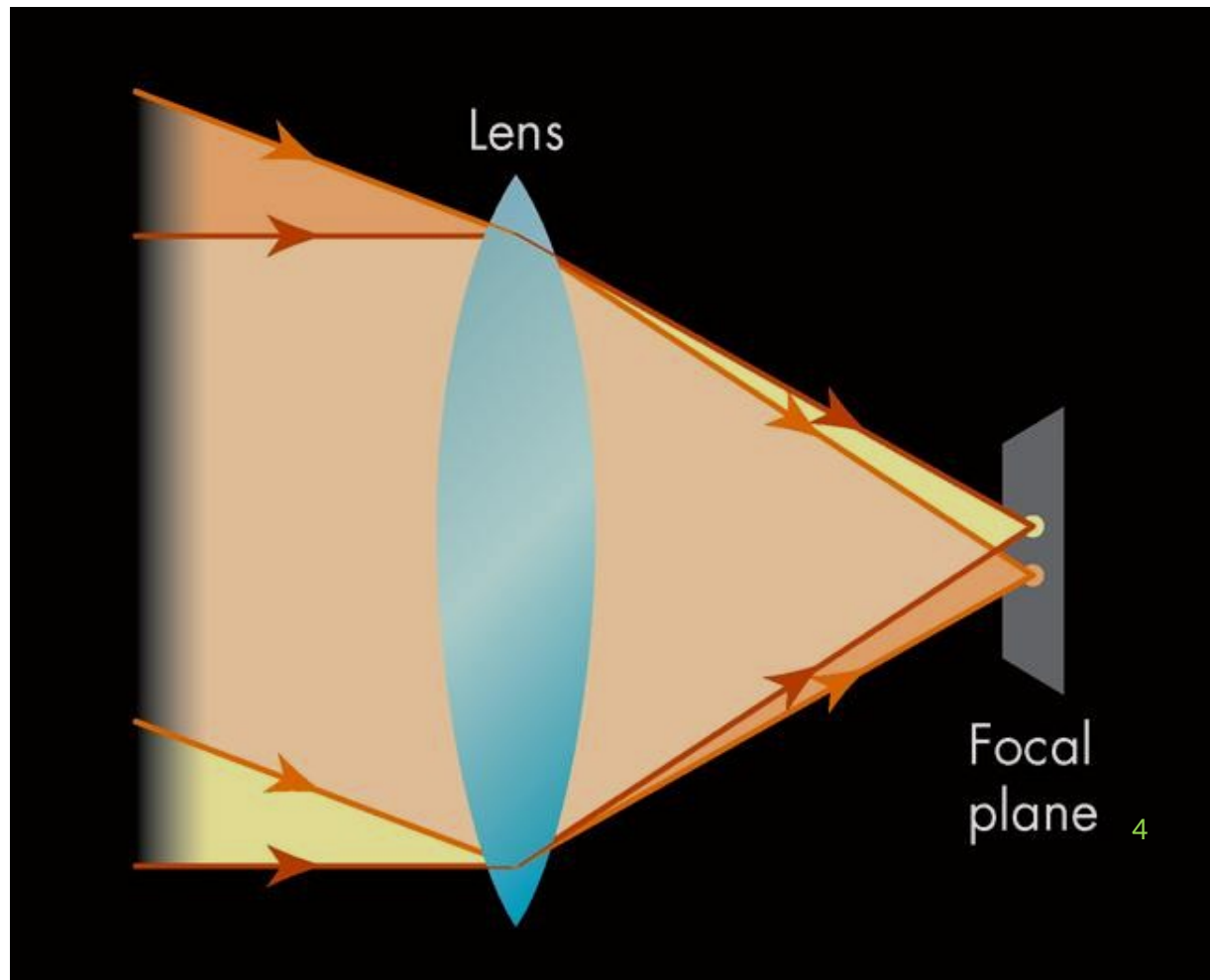
Figure 6-2
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(b)

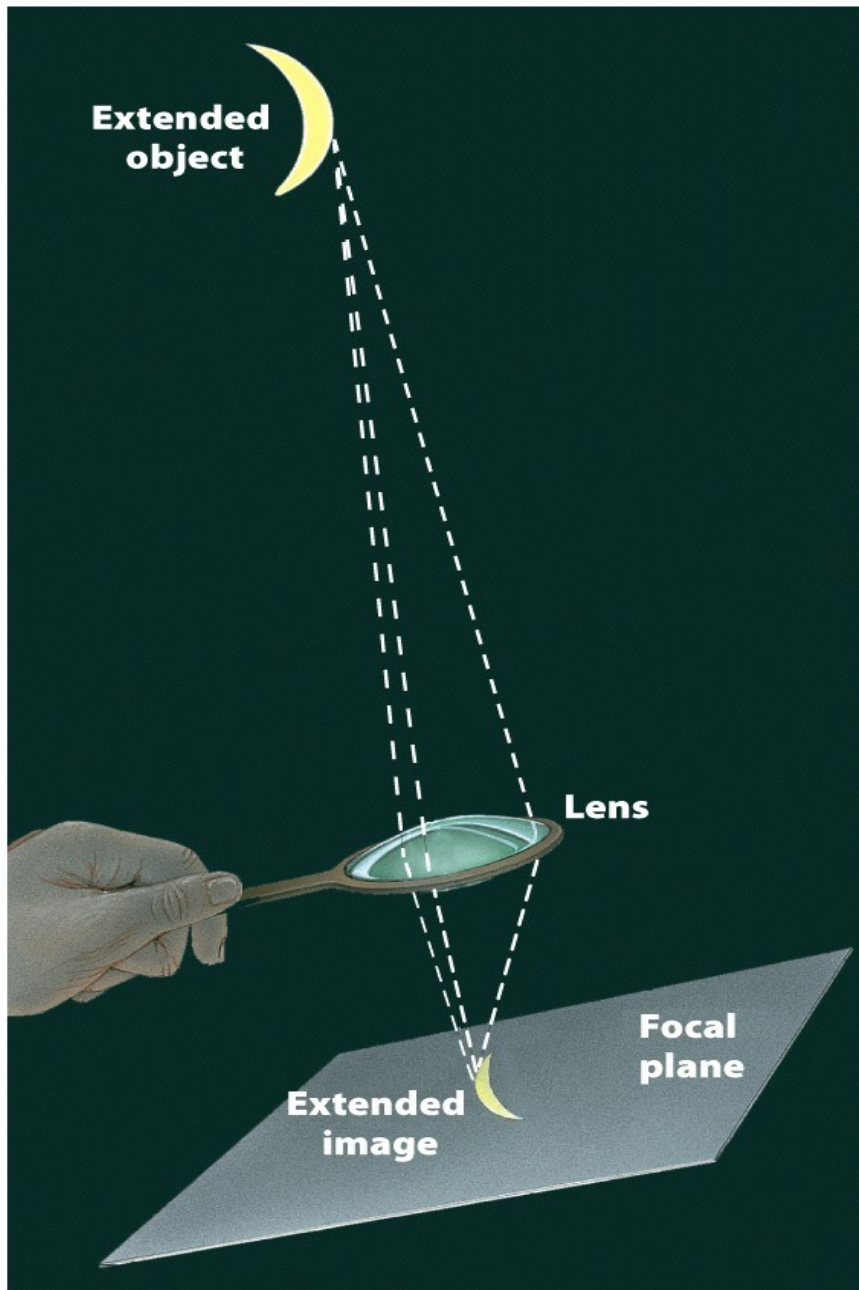
On a flat glass plate parallel light 'ray's will refract going in and coming out and emerge parallel to the original direction. If you curve the both sides of the glass, the light will bend so that it all passes through one point called the focal point. The distance from the lens to the focal point is called the focal length.

A Lens: converts angle of light to position on the focal plane

All the light from a particular direction hits at single point in the focal plane



A Lens Creates an extended image



Light from an extended object is focused with a lens, the image at the focal plane is also extended. The shape of the original object is preserved.

Figure 6-4
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Two Lenses make a Refracting Telescope

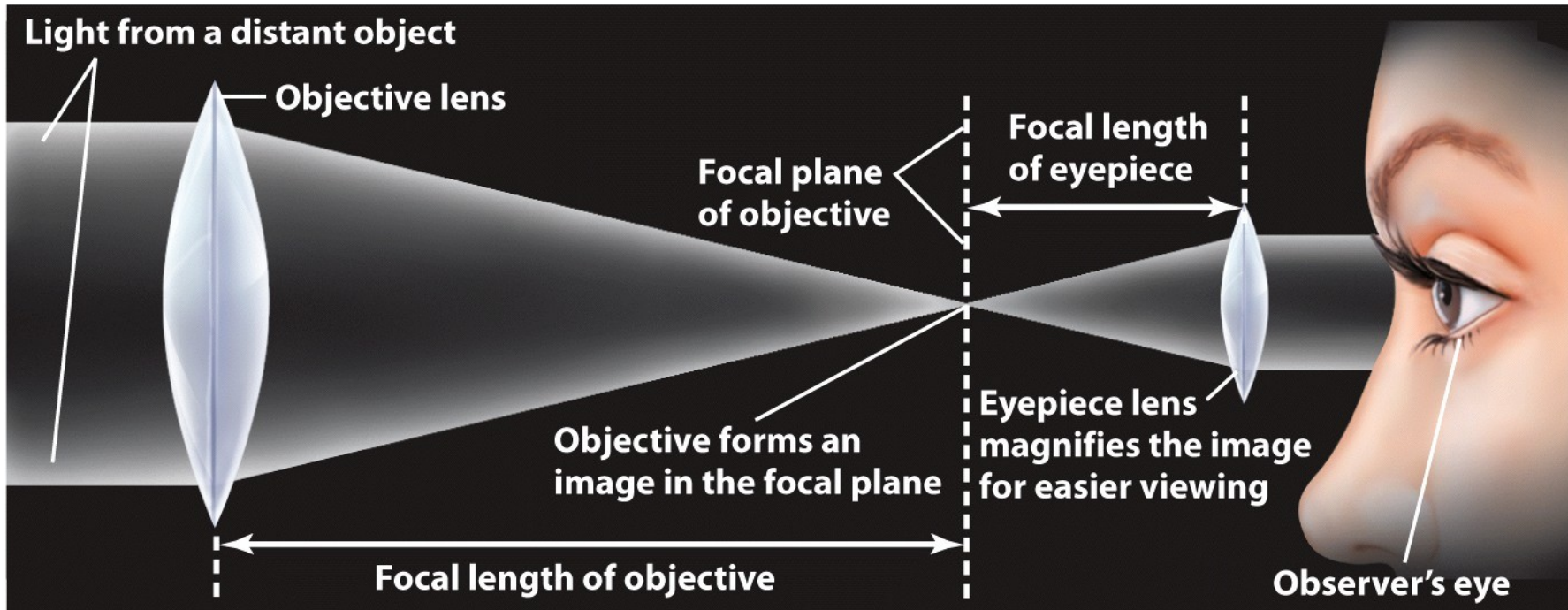
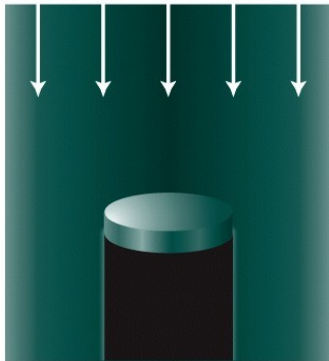


Figure 6-5
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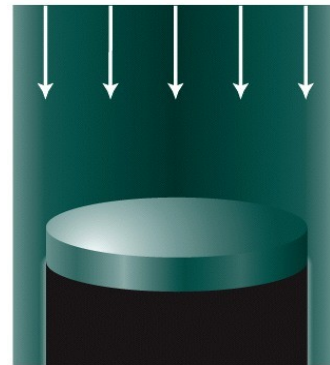
Like Galileo's telescope, when you use two lenses (the objective lenses and an eyepiece), you see an enlarged image. The distance between the two lenses is the sum of the focal lengths. The magnification is given by:

$$\text{magnification} = \frac{f_{\text{objective}}}{f_{\text{eyepiece}}}$$

Light Gathering power



**Small-diameter objective lens:
dimmer image, less detail**

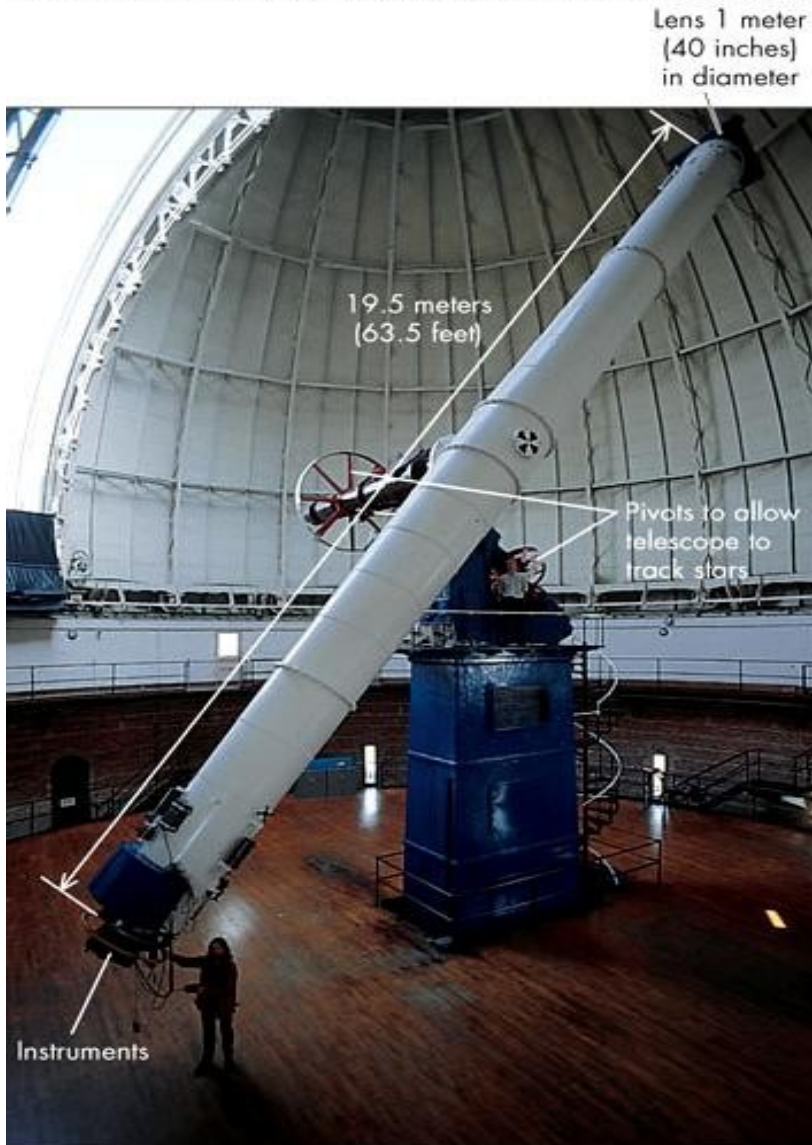


**Large-diameter objective lens:
brighter image, more detail**

As important as the magnification is the light gathering power of a telescope. The light gathering power is proportional to the area of the objective lens or the square of the lens diameter. More light into the telescope means more detailed images.

The Largest Refracting Telescope

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Chicago Yerkes Refracting Telescope

1 meter diameter lens

Construction finished on the observatory and telescope in 1897

The telescope is 19.5 meters (63.5 ft) long.

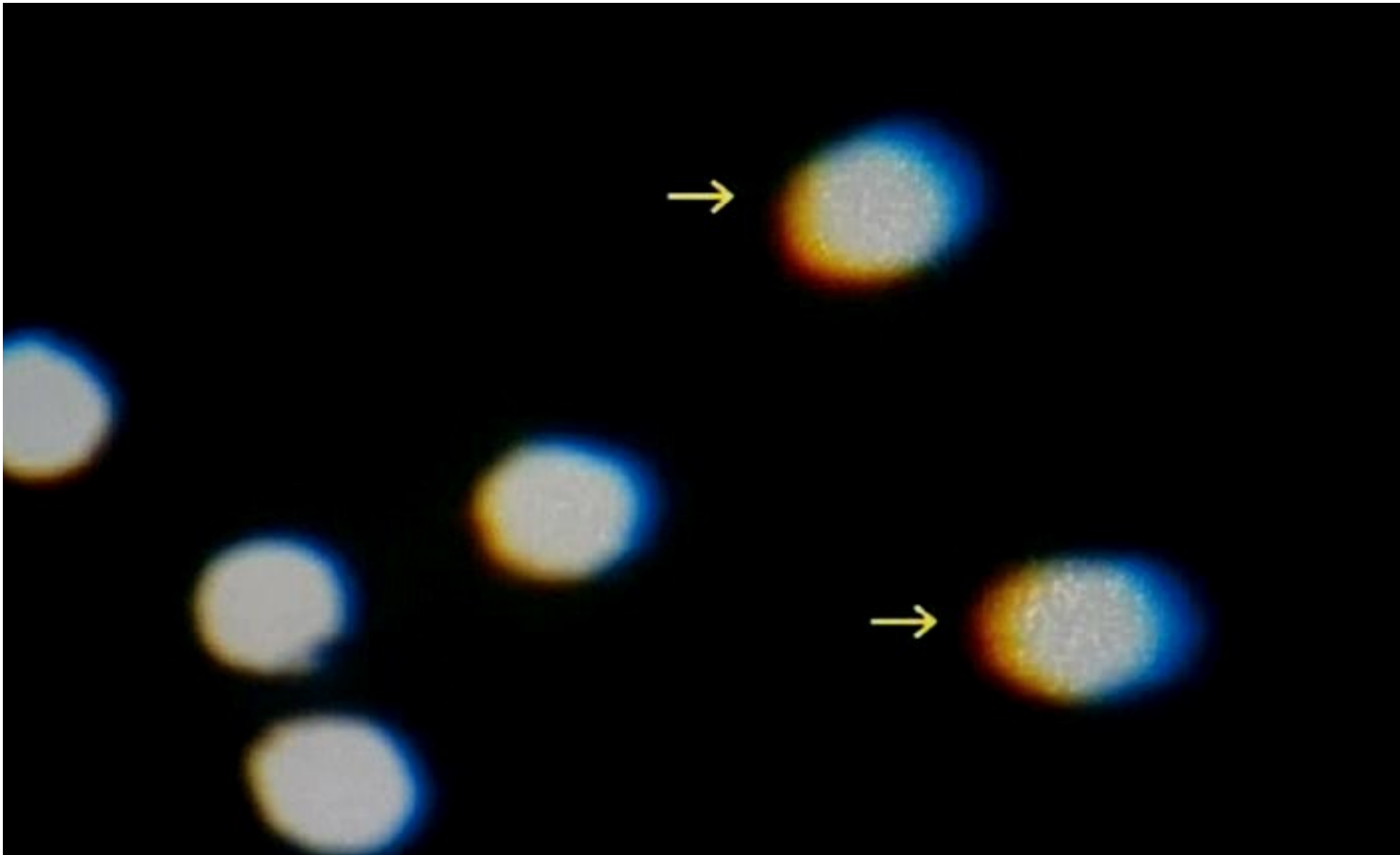
Disadvantages of Refracting Telescopes

Lenses have **disadvantages** in large telescopes!

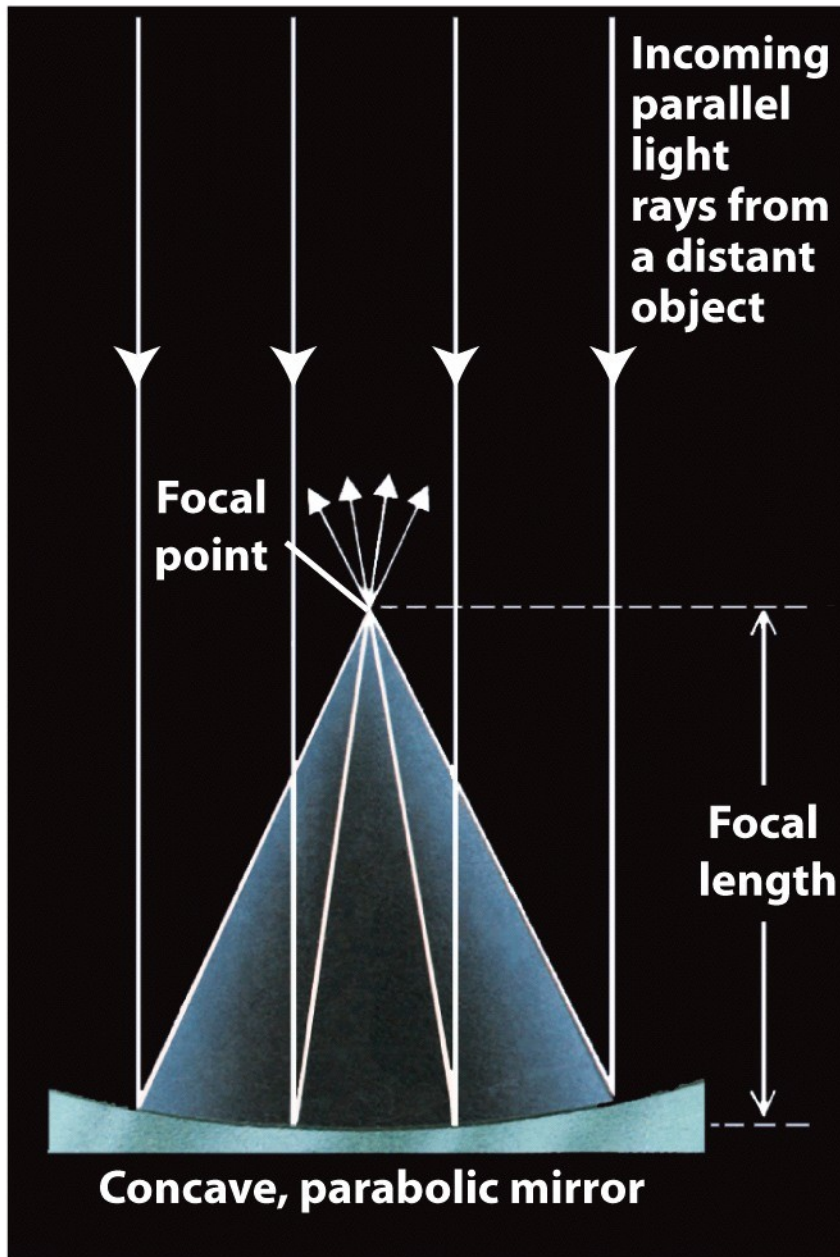
- > Large lenses are extremely expensive to fabricate
- > A large lens will sag in the center since it can only be supported on the edges (light has to get through the lens)
- > Many lens materials absorb short-wavelength light
- > Chromic aberration = colored fringes to images
 - This is just the “prism” effect

Chromatic aberration = different color at different places
(think prism's effect)

Happens for lens but **not** for mirrors

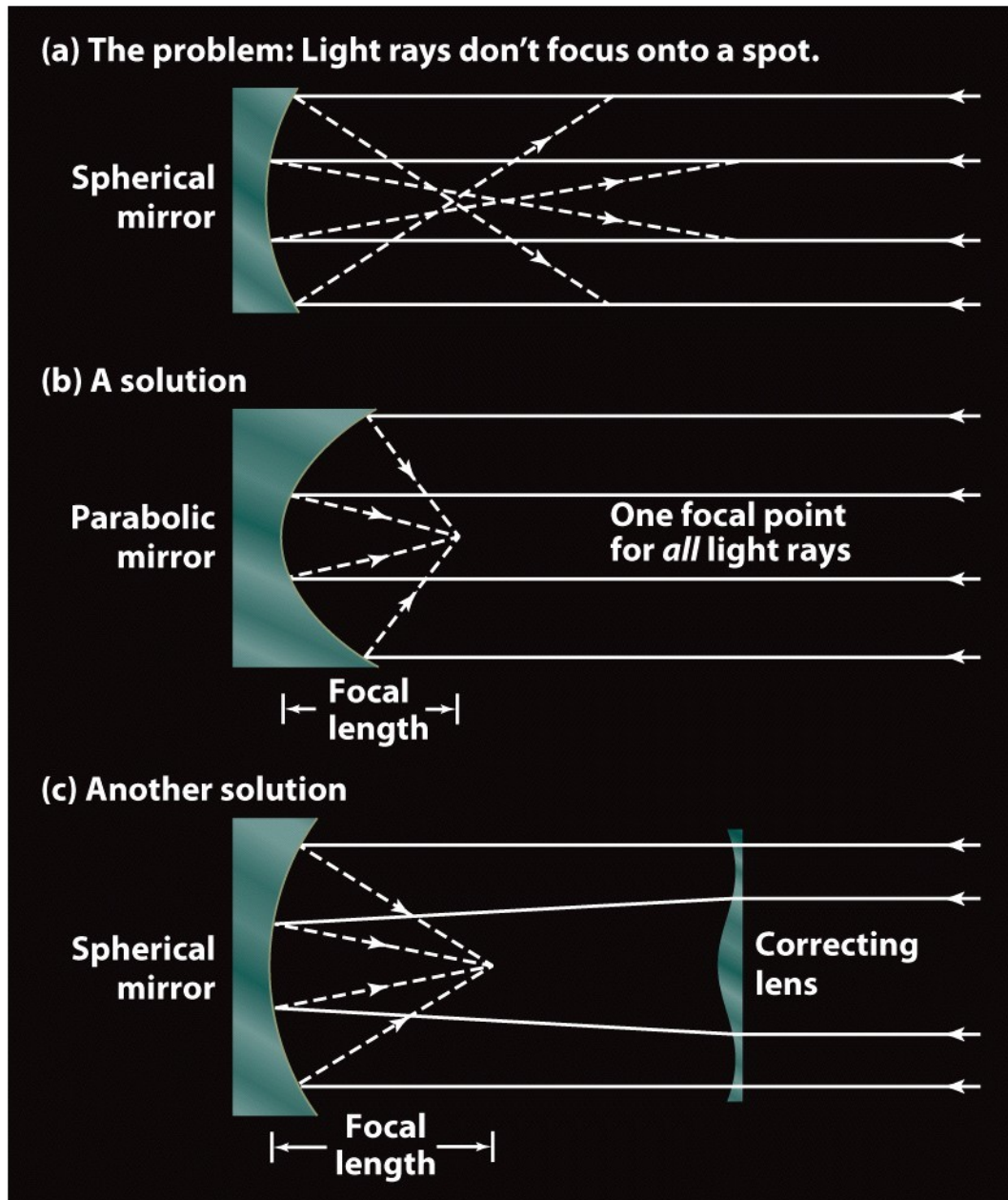


Reflecting Telescopes use Curved Mirrors



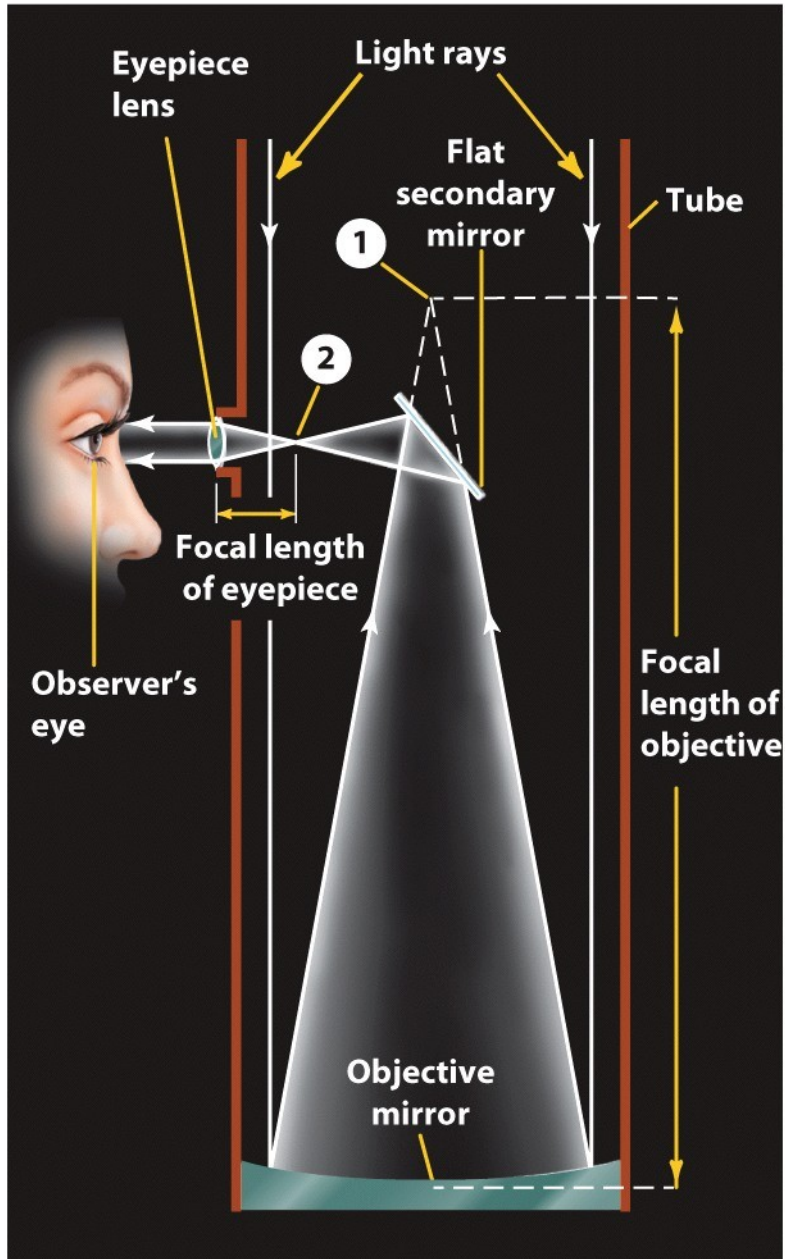
A concave, parabolic mirror reflects incoming parallel light rays back to a focal point with a focal length much like a lens but without the chromatic aberrations of a lens.

Spherical vs Parabolic Mirrors



Large mirrors can be made with a spherical or parabolic curvature. Light hitting a spherical shaped mirror surface do not all come to the same focal point. (For observing distant point like objects such as stars this is not a major problem.) Parabolic shaped mirror surfaces do have a single focal point for all incoming parallel rays.

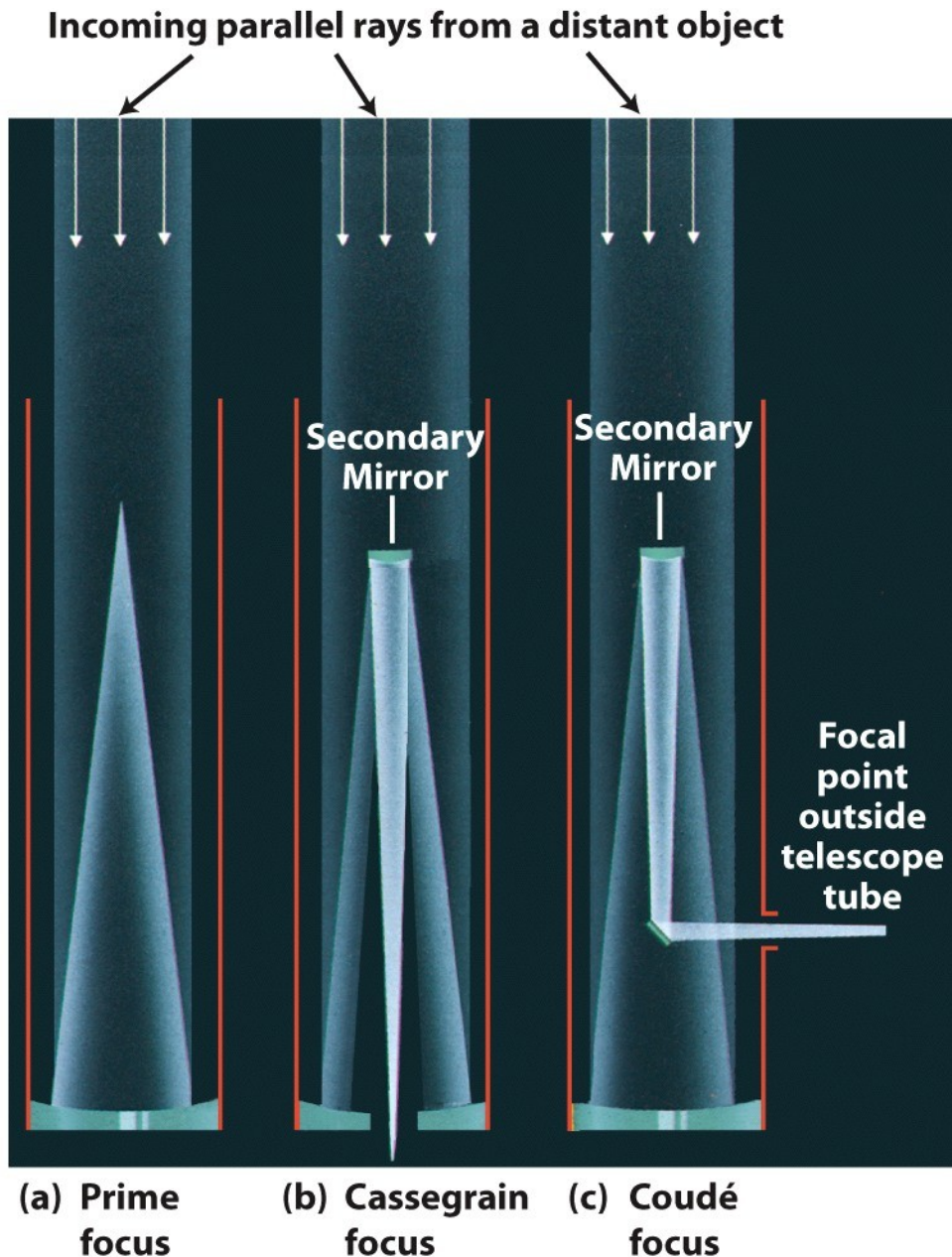
Newtonian Reflector



Invented by Issac Newton, the Newtonian reflector uses an objective mirror and a flat secondary mirror. The sum of the focal lengths of the objective mirror and eyepiece lens are folded to the side to make the telescope more compact. Compare with the Yerkes telescope.

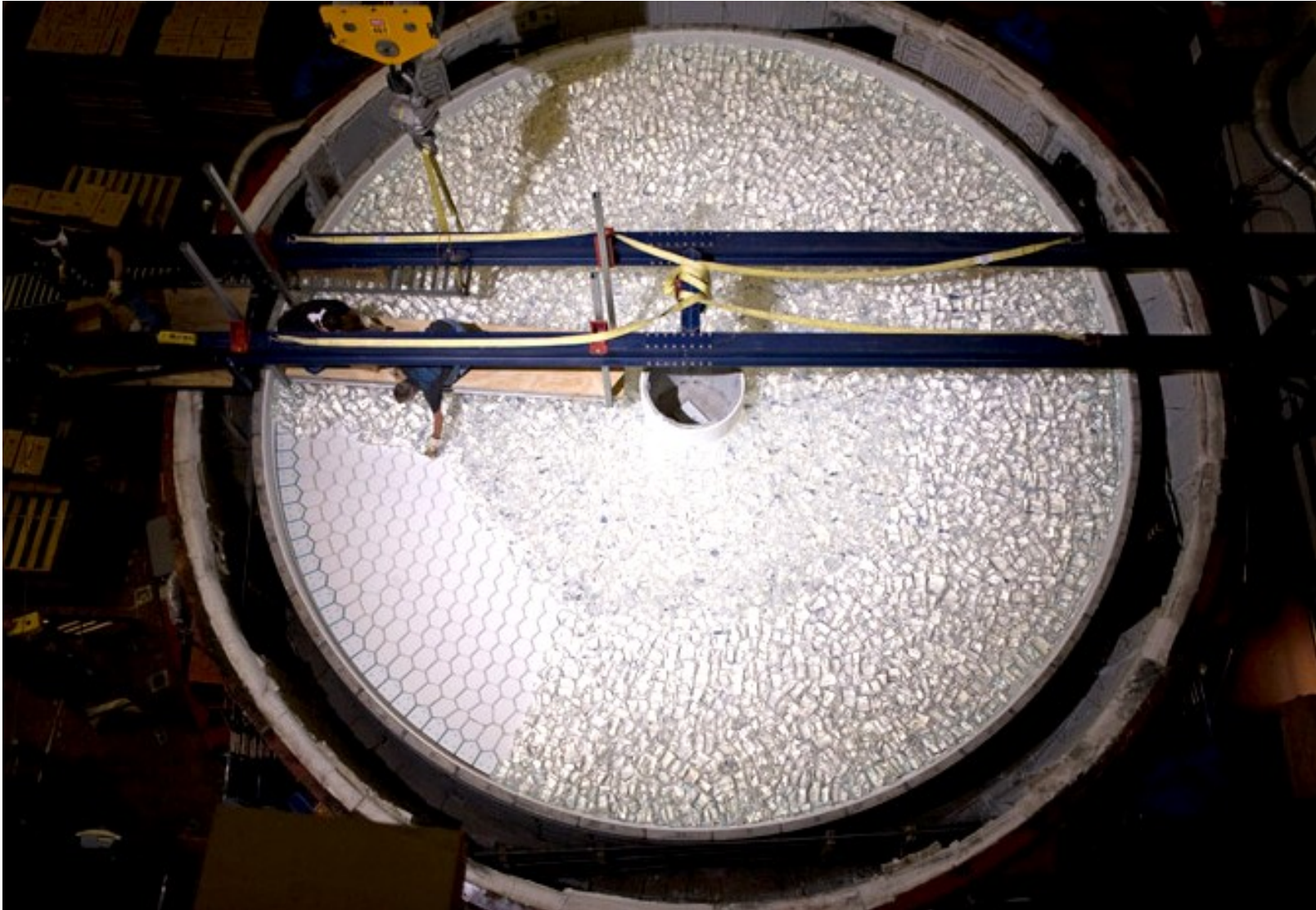
Figure 6-10a
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Other Reflecting Telescope designs

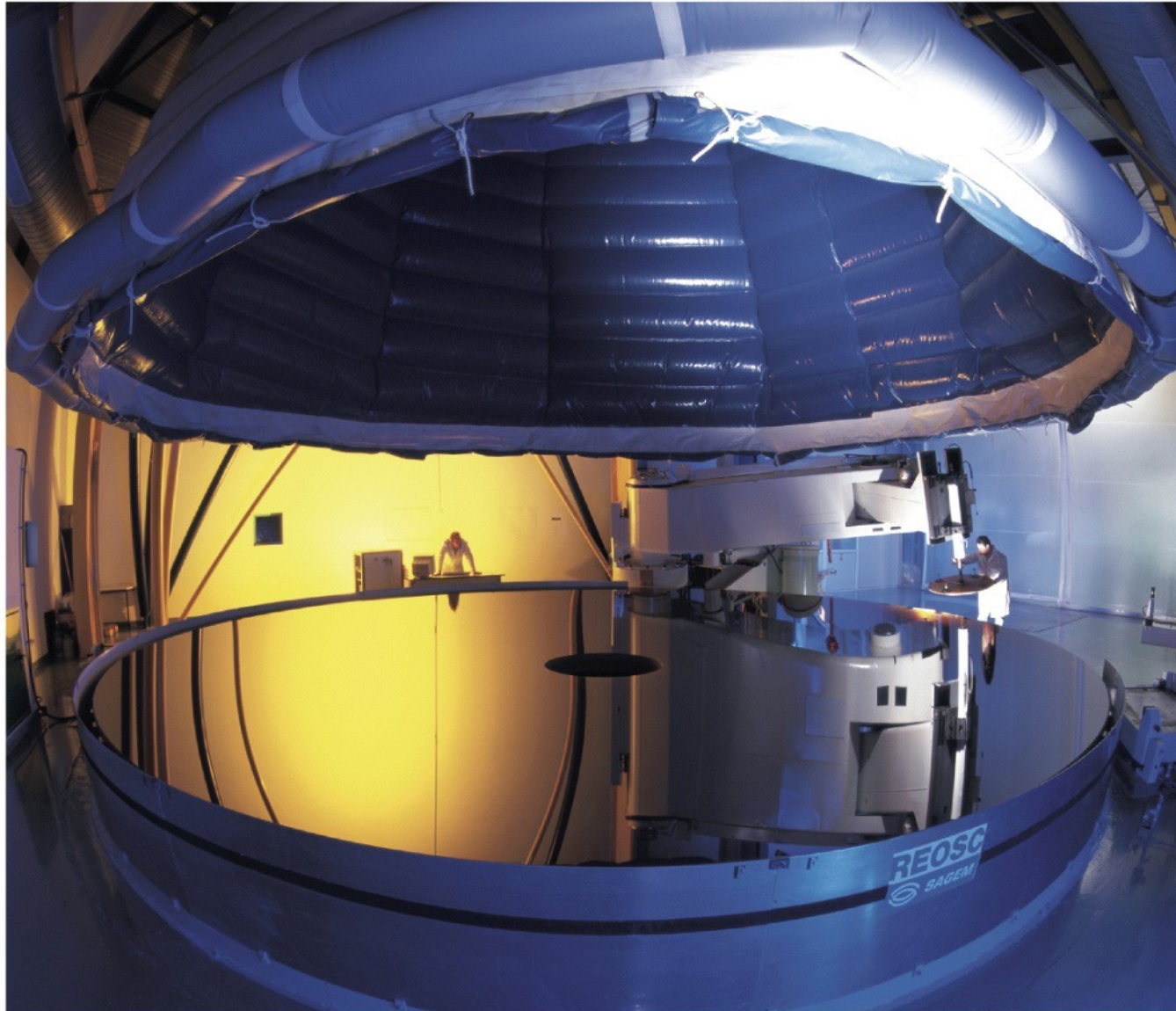


Other types of reflecting telescope designs include the 'prime focus' where the observer or instruments are located inside the telescope tube, the Cassegrain with a hole in the objective mirror and the Coude with a focal point outside of the tube. The Cassegrain is particularly compact and easy to focus. There is some small reduction of light gathering power because of the secondary mirror.

Large Mirrors are Spin Cast



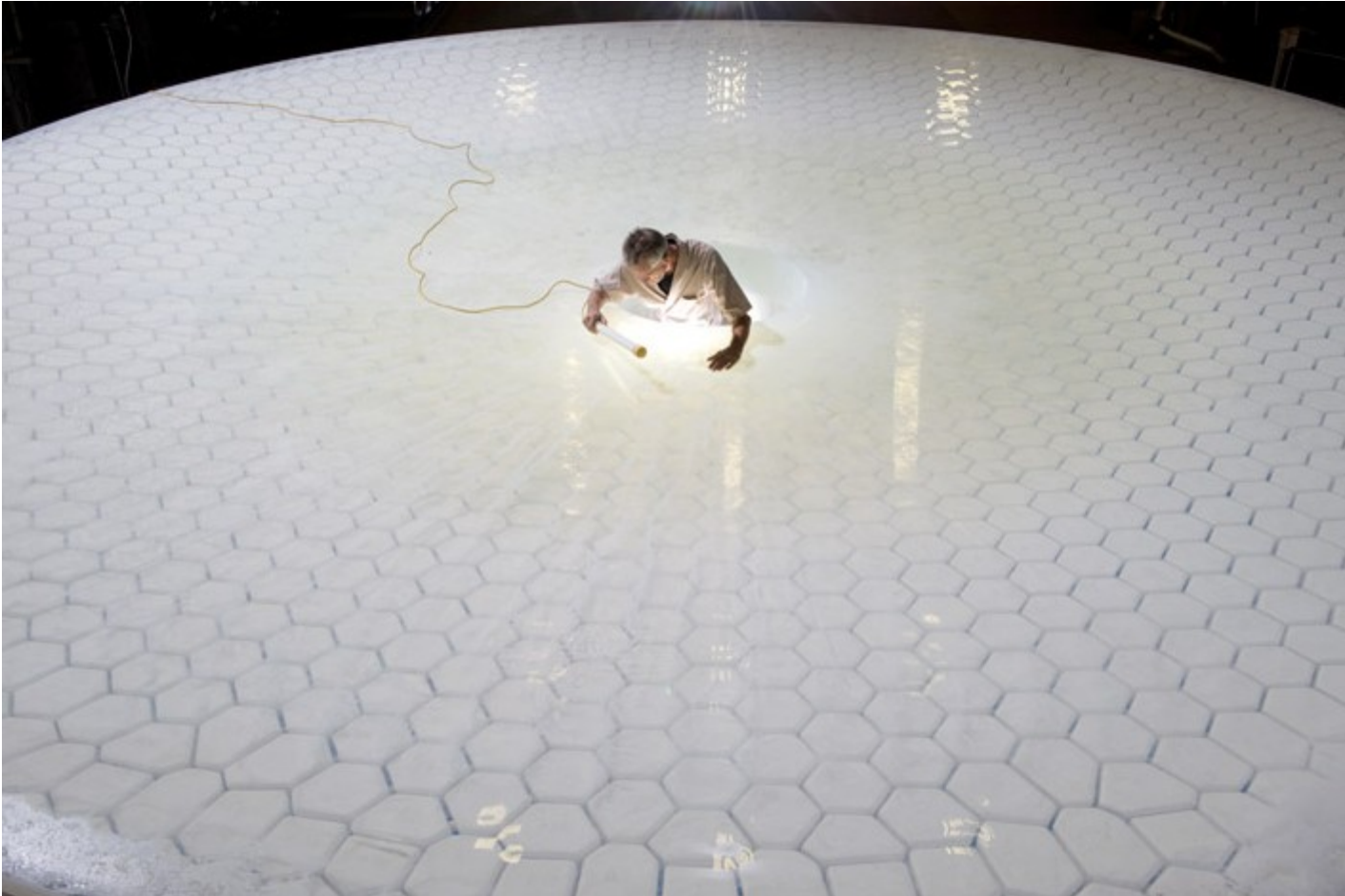
Large Mirrors



This mirror for the European Southern Observatory in Chile is 8.1 meters and is polished to a precision of 8.5 nm!

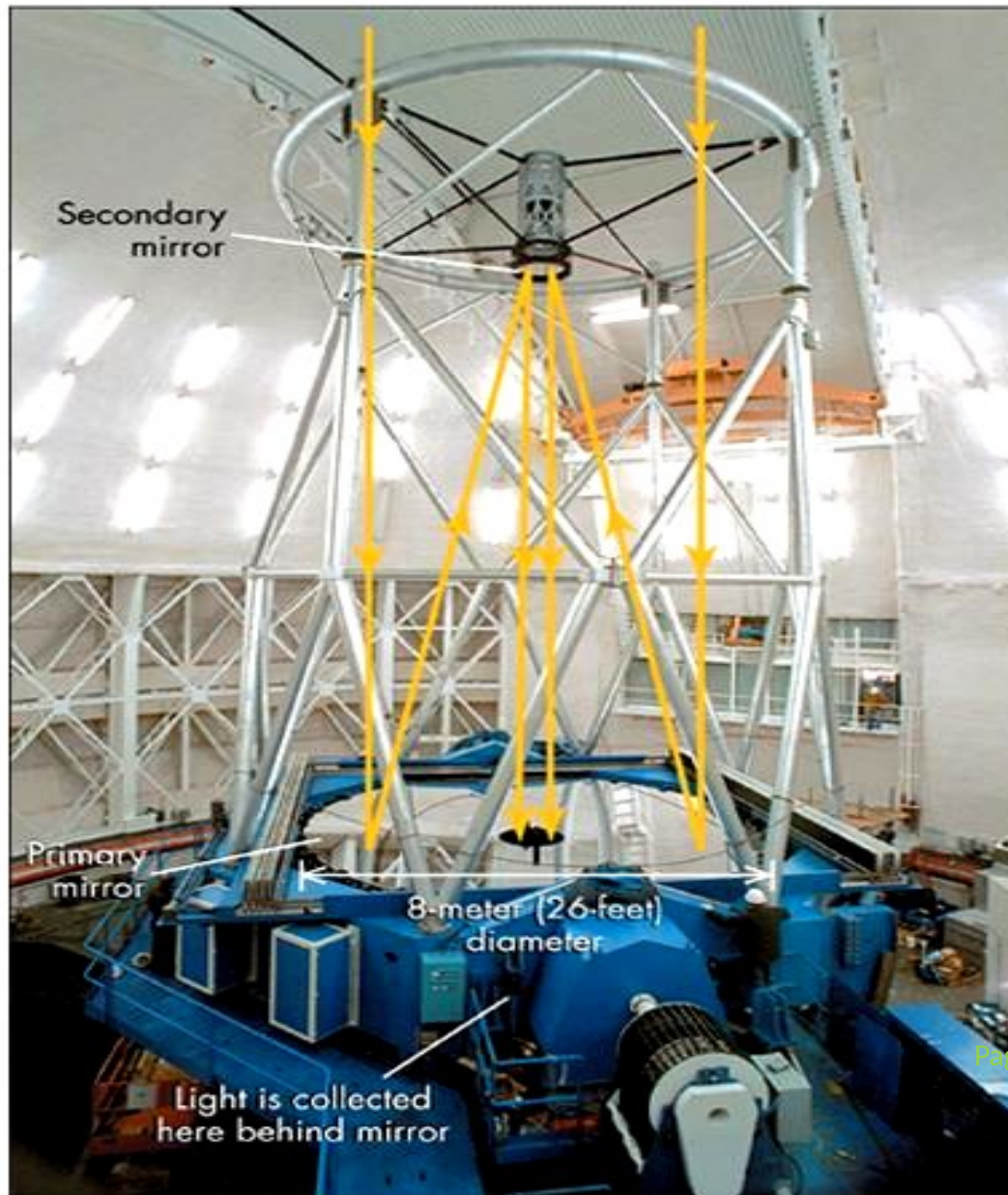
A large objective mirror

A mirror for the Large Synoptic Survey



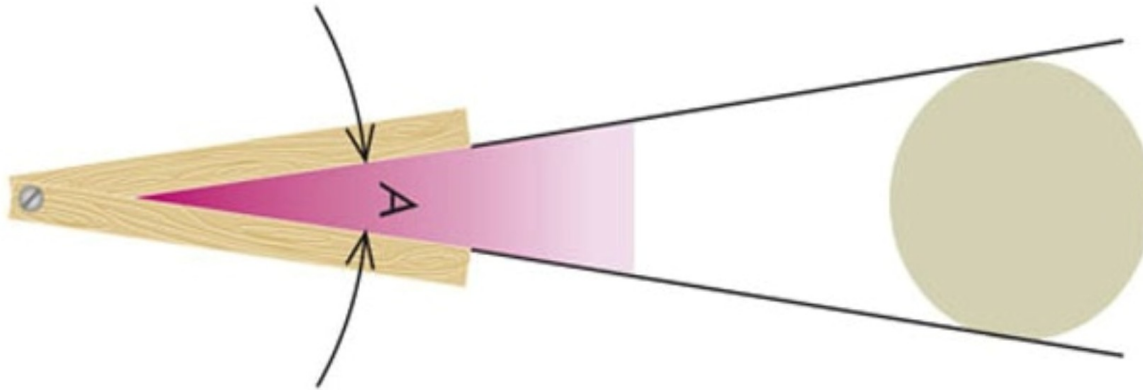
- 8.4m diameter
- Polished to within $1 \times 10^{-7} \text{m}$ (100nm)

8m mirror – one of two Gemini telescopes Mt Mauna Kea, HI



Angular Size

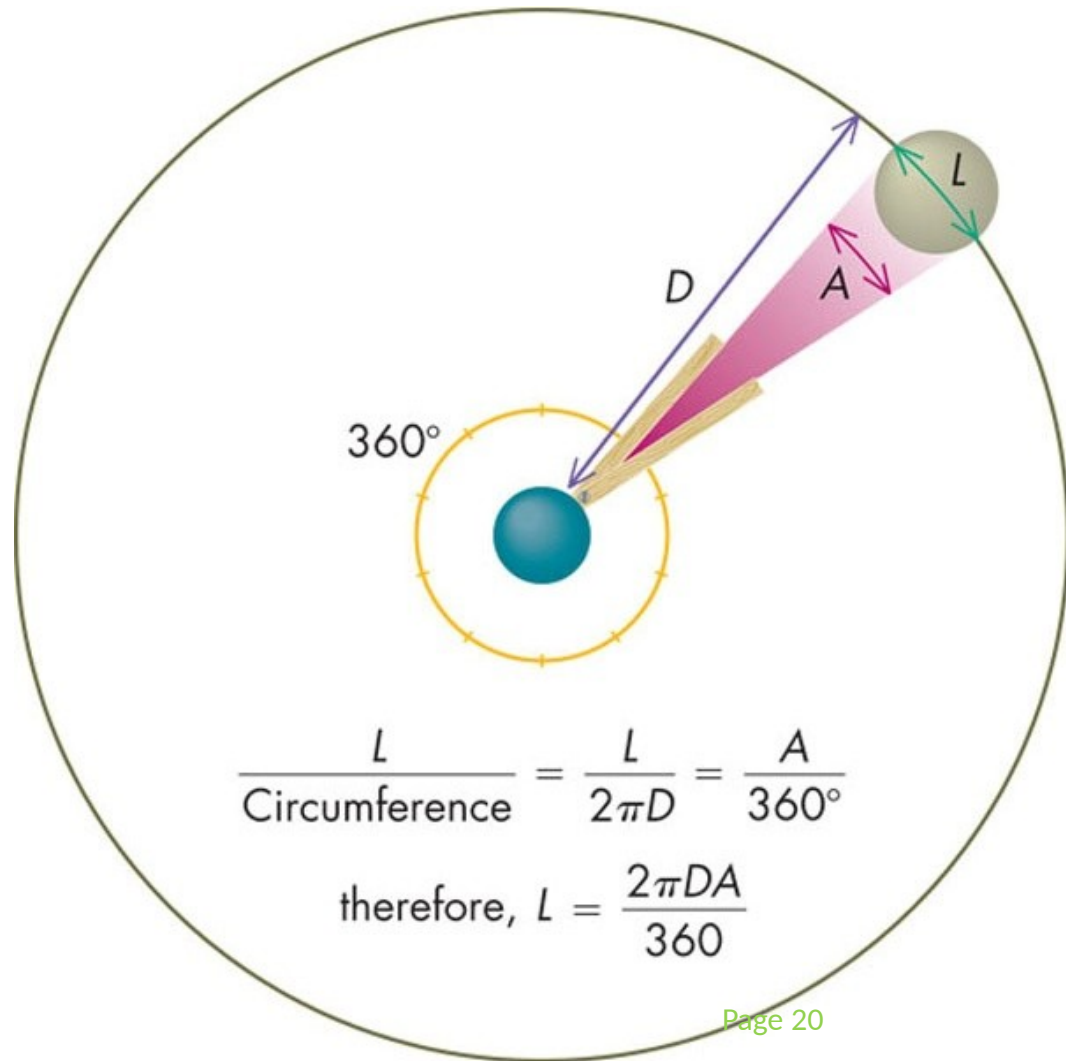
- We frequently talk about the size of objects in the sky by referring to the angle they subtend



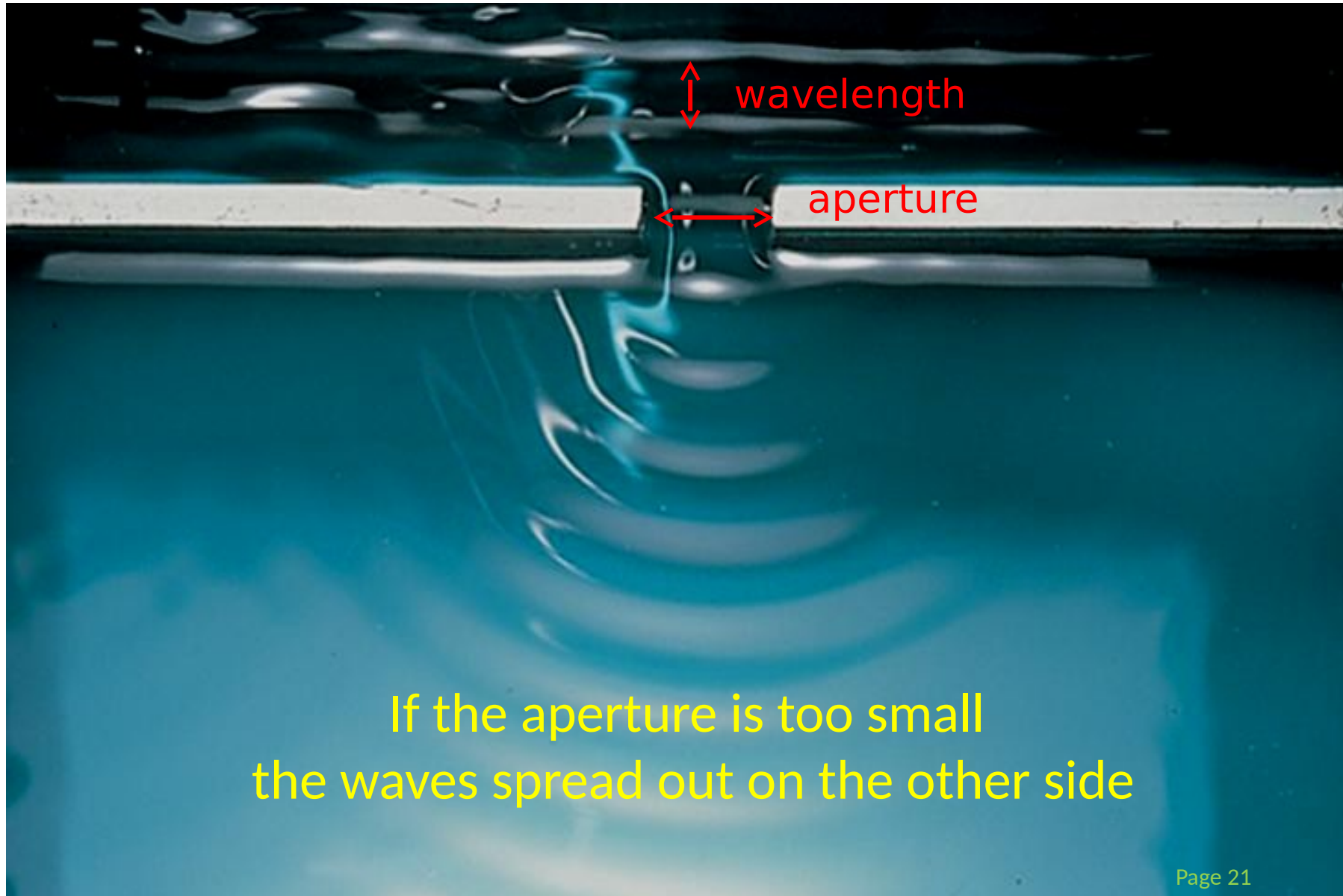
This measurement will depend on the actual size of the object and the distance to the object

Angular Size (A), Distance (D) & Linear Size (L)

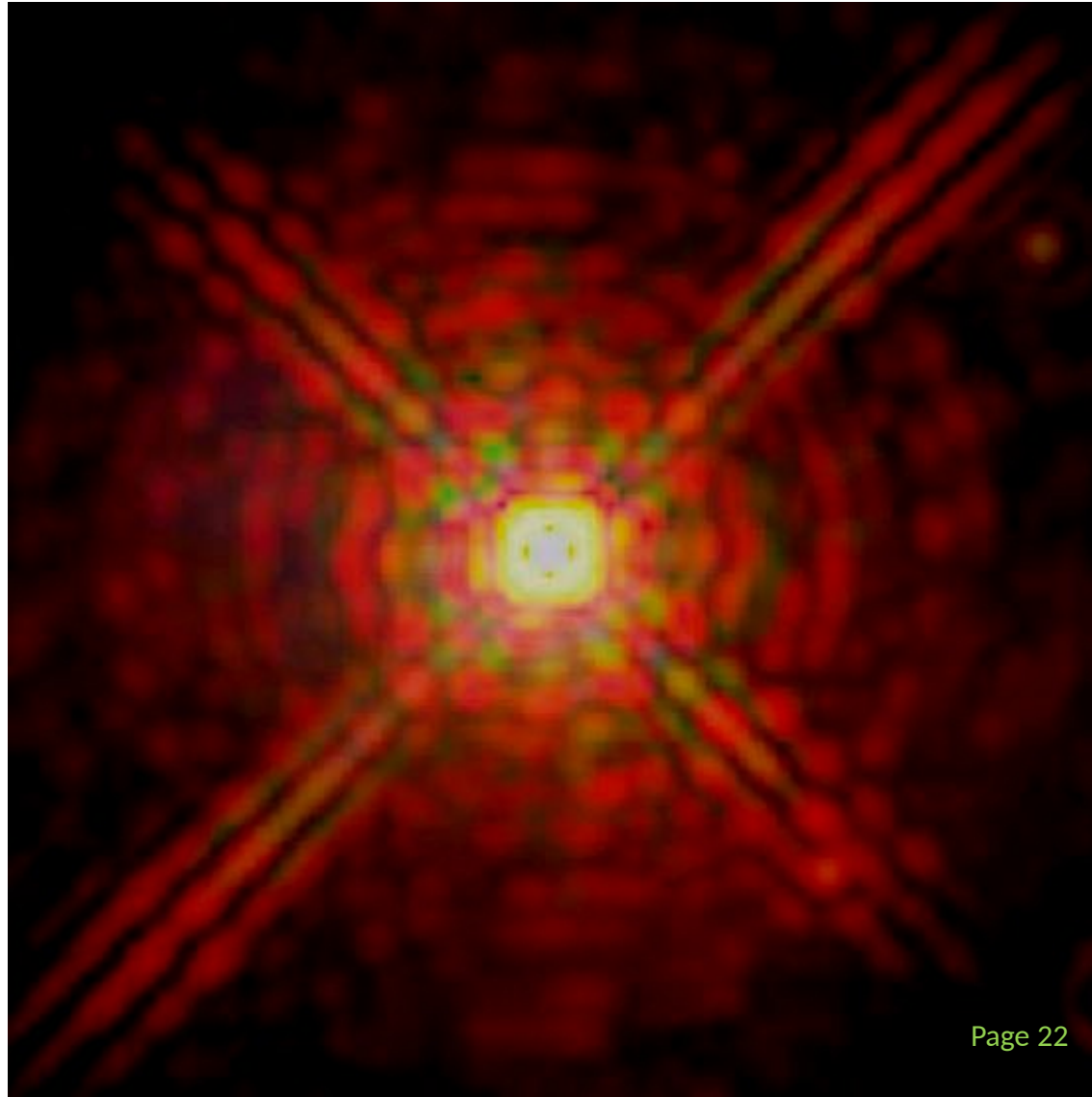
- To see this, we can use the geometry of circles



Aperture limit size is roughly the wavelength



Example of aperture limit with light



Diffraction

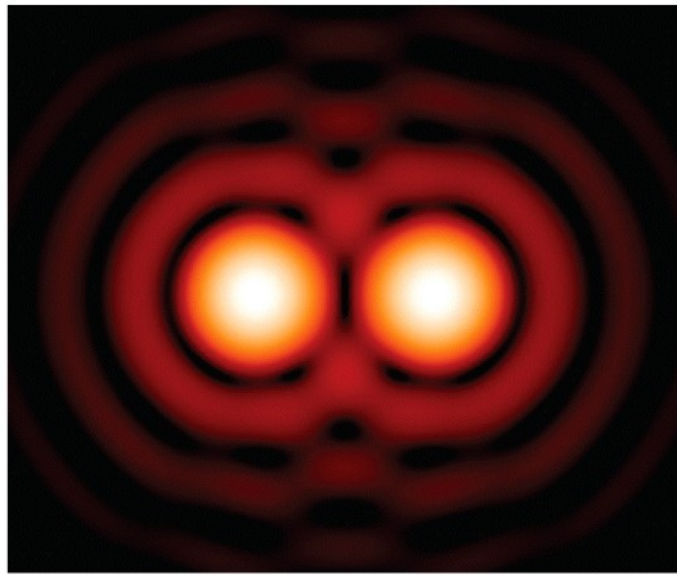
Diffraction limits the ability of any telescope to resolve two closely spaced objects. This angular size limits for resolving two objects is given by:

$$\theta = 2.5 \times 10^5 \frac{\lambda}{D}$$

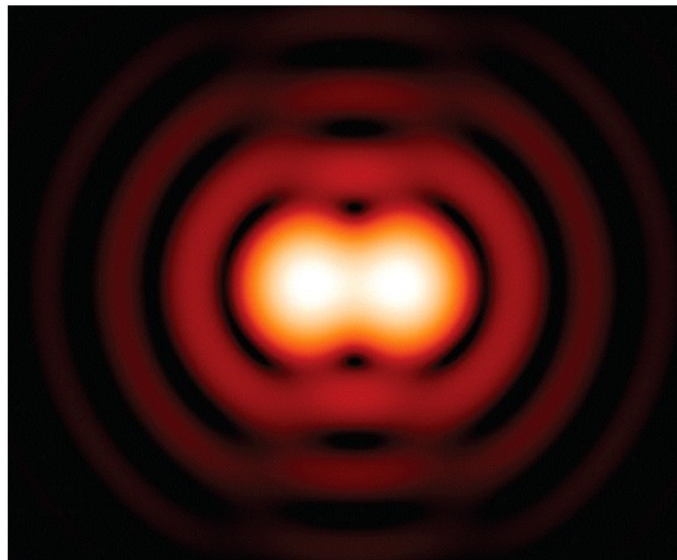
where θ is the diffraction limit in arc seconds

λ is the wavelength of the light in meters

D is the diameter of the telescope in meters



(a)



(b)

Atmospheric distortion

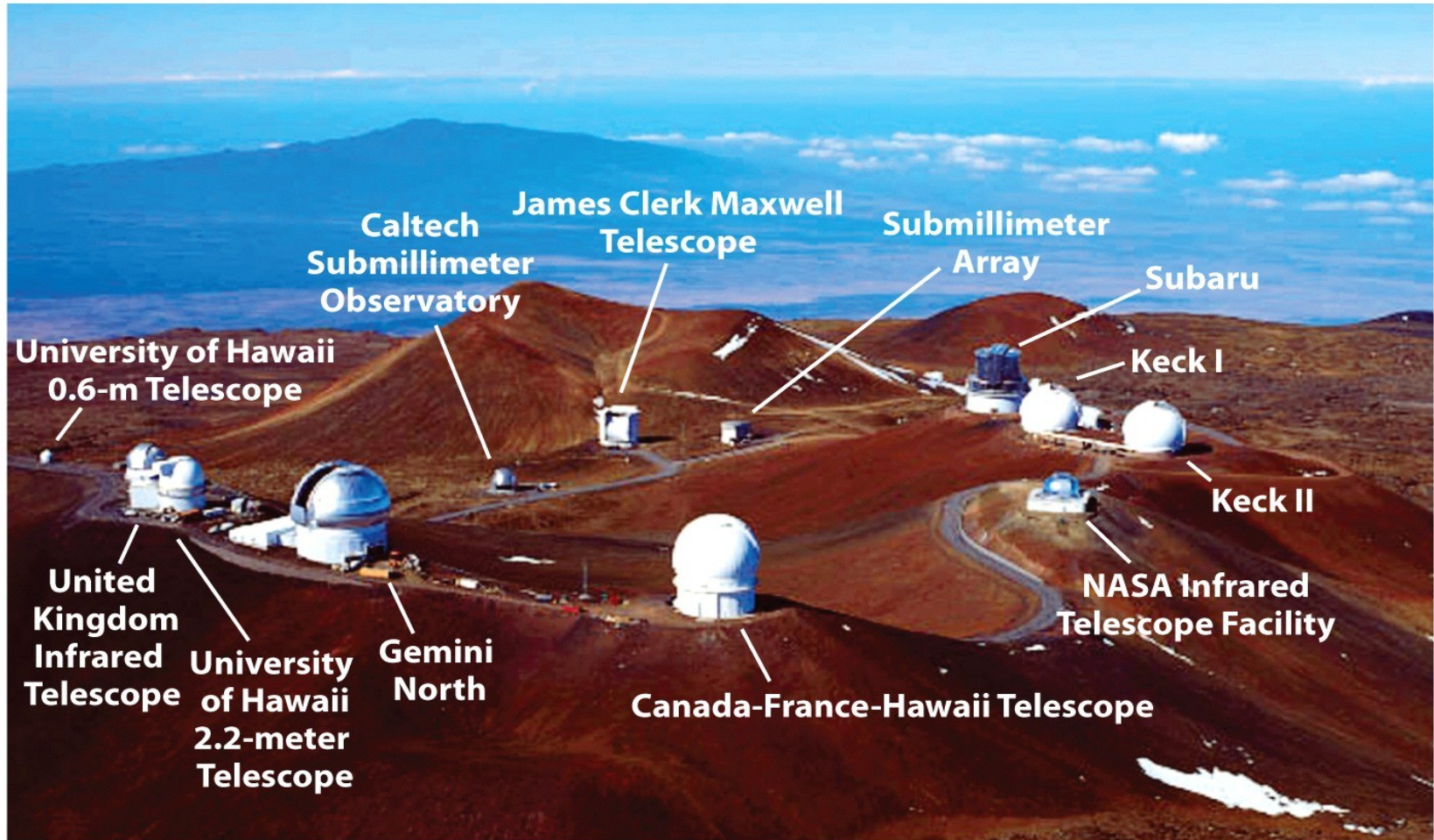
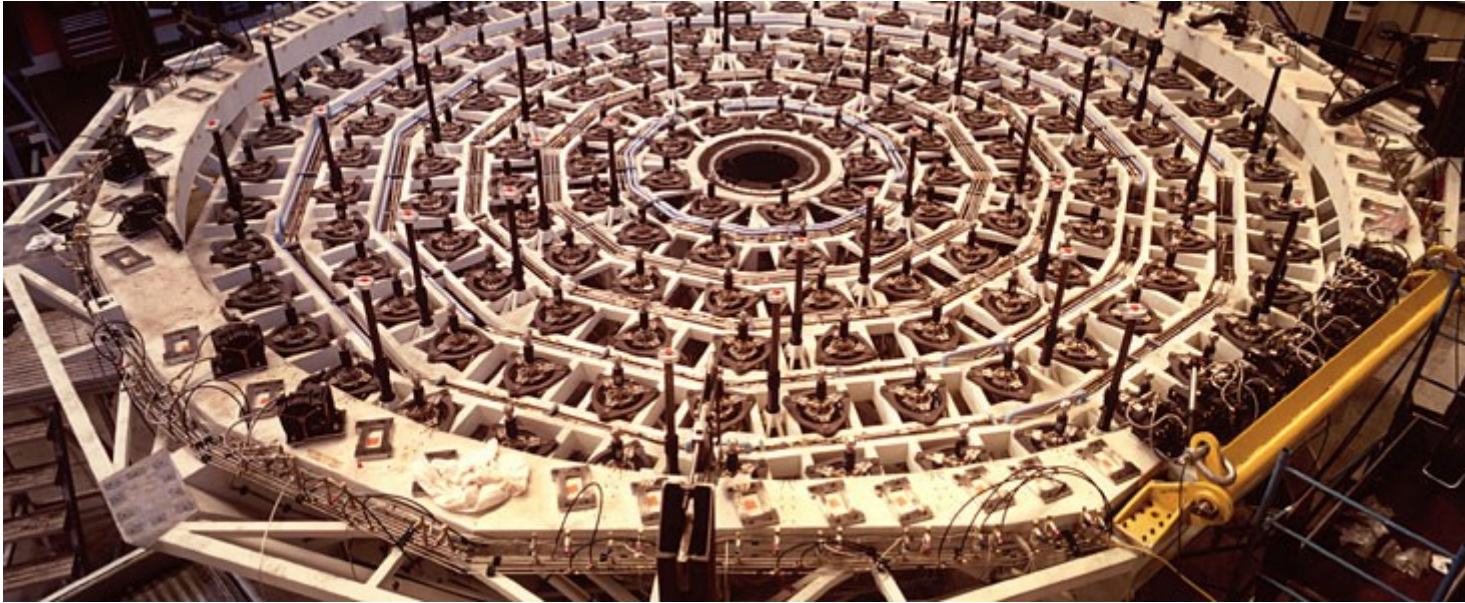


Figure 6-16
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AP Photo/University of Hawaii Institute of Astronomy, Richard Wainscoat

Turbulence in the atmosphere limits a telescopes imaging. Getting above the atmosphere is Hawaii (4100m) and Chile helps improve the viewing conditions.

Active and Adaptive Optics



Active optics are adjustments made to the telescope due to temperature changes or the slight sagging of the mirror because of gravity. Active optics slowly (seconds or minutes) adjust the mirror shape.

Adaptive Optics

Adaptive optics use high speed actuators (10 – 100 times per second) to change the shape of a secondary mirror to improve the image. This can remove the twinkling due to the atmosphere and other sources of distortion.

This requires a calibration target in the field of view. It can be a bright star. It can also be an artificial 'guide star' which uses a laser to excite certain atoms high in the atmosphere (90 km).

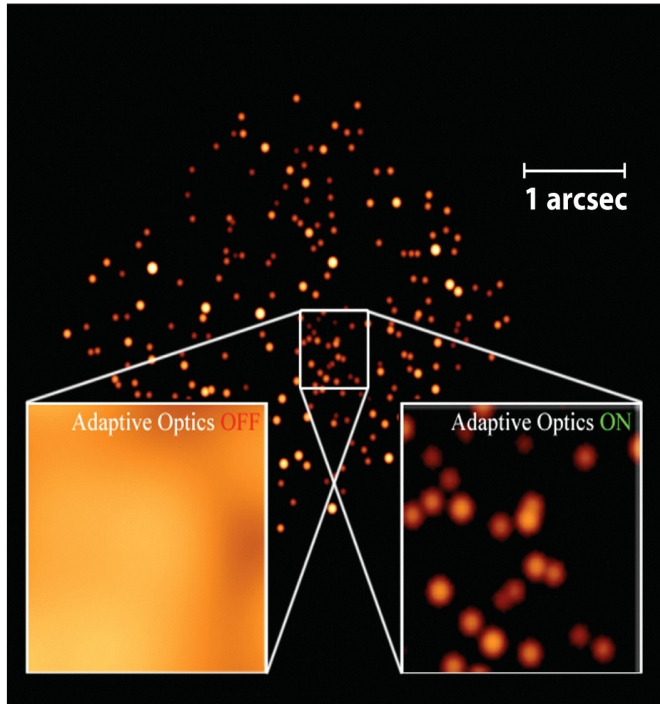
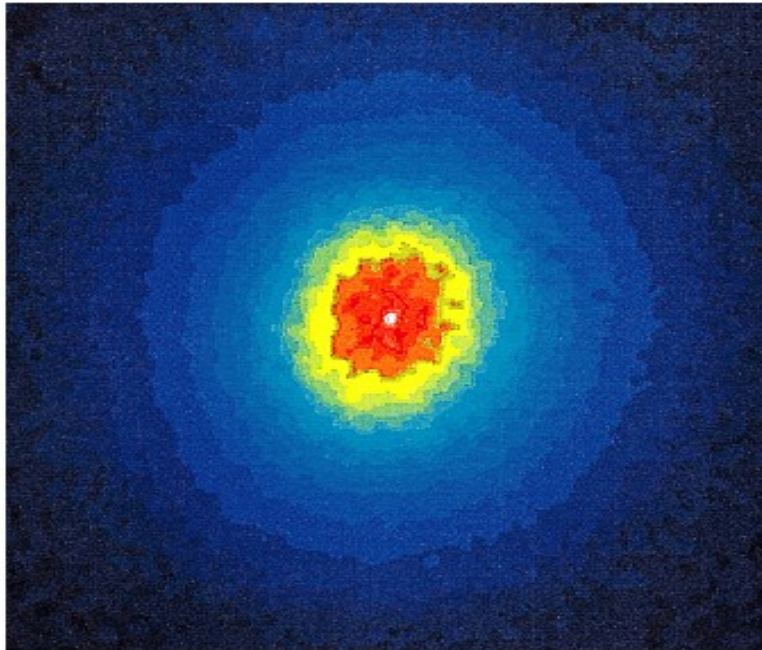


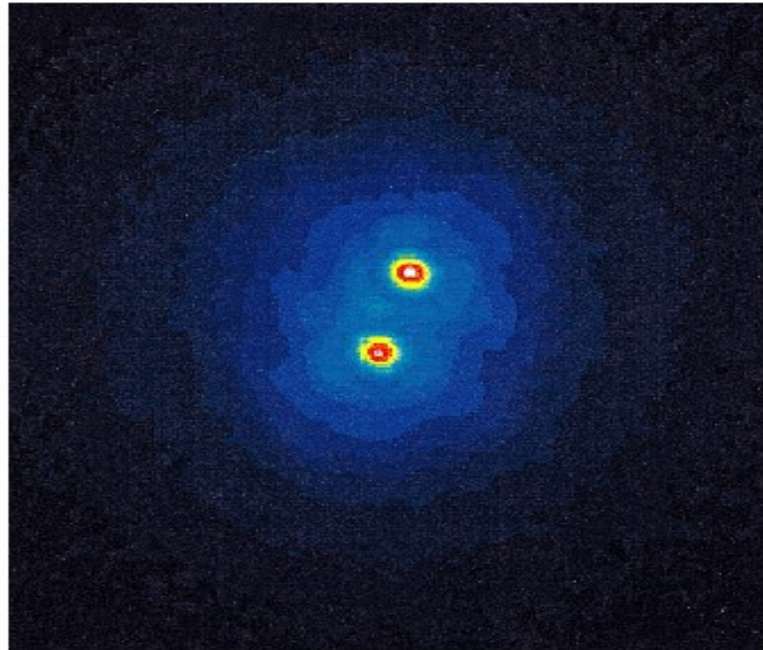
Figure 6-17
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Interferometry - beating the diffraction limit



(a)

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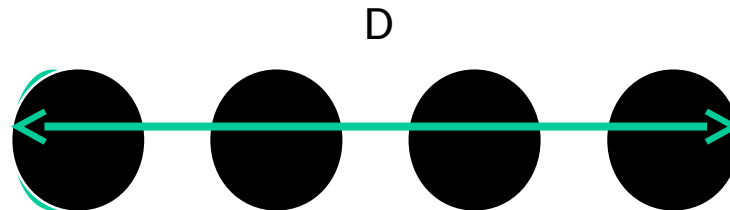


(b)

Interferometers



- It is like having parts of a much larger lens
- Gets around the aperture limit by making a giant composite lens
 - > The aperture is now the “span” of the lenses (D)
 - > The light collection power is the combined area of these individual lenses
 - > It requires very carefully combining the signals from different telescopes



Large binocular telescope

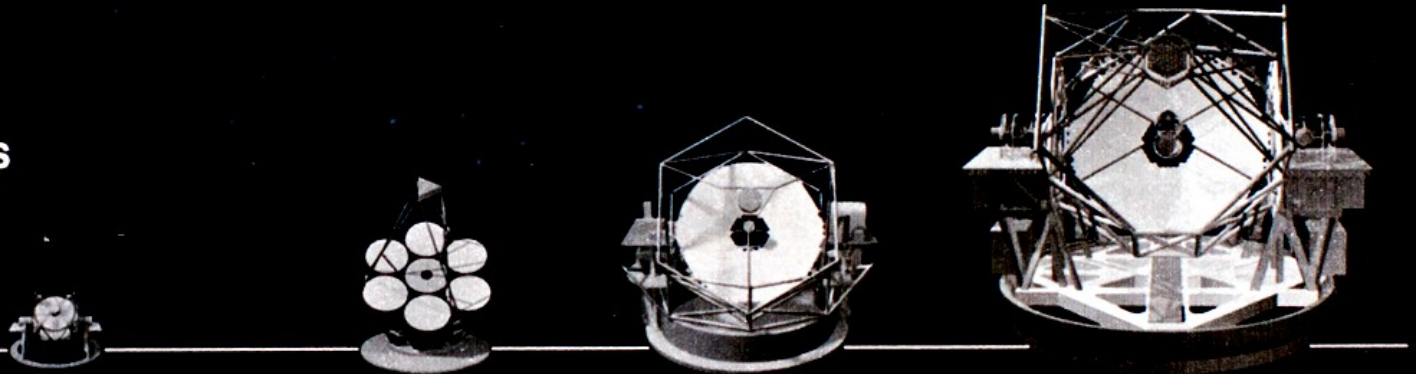
- 8.4 m mirrors
- Produces images with a resolution of a 23 m telescope



Future Telescopes

UPCOMING TELESCOPES

● — Size of today's
8-10 m largest mirrors
(26-33 ft)



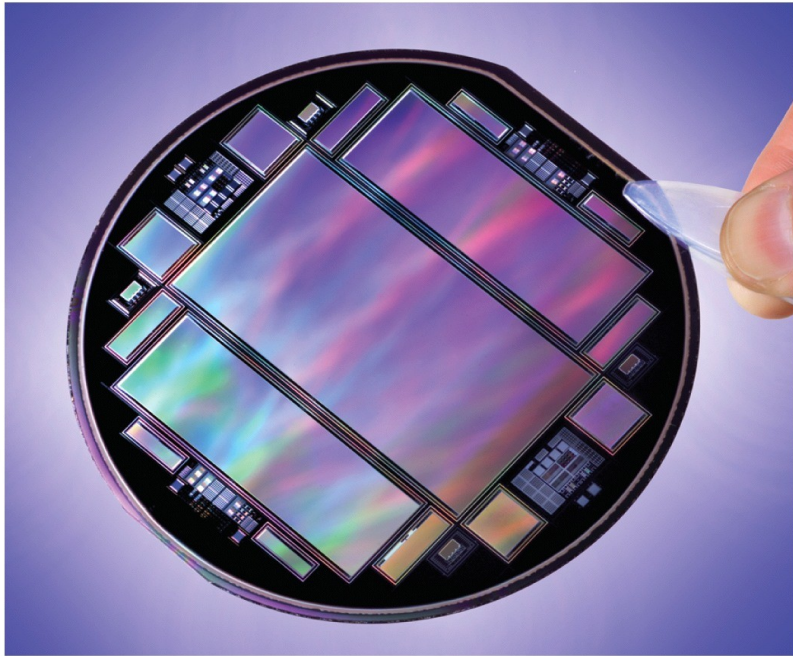
Name	Large Synoptic Survey	Giant Magellan	Thirty Meter	European Extremely Large
Location	Cerro Pachón, Chile	Las Campanas, Chile	Chile or Hawaii	Argentina, Chile, or Canary Islands
Primary mirror diameter	8.4 m	Seven 8.4-m mirrors	30 m	42 m
Estimated completion	2016	2018	2018	2018

Light Pollution



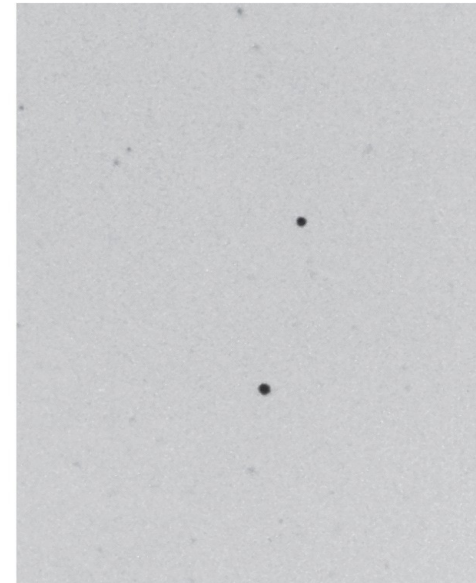
Light pollution is a major problem for astronomy. Light from cities can interfere with telescope observation. The US as seen from space gives you an idea of the problem.

Charge Coupled Device (CCD)

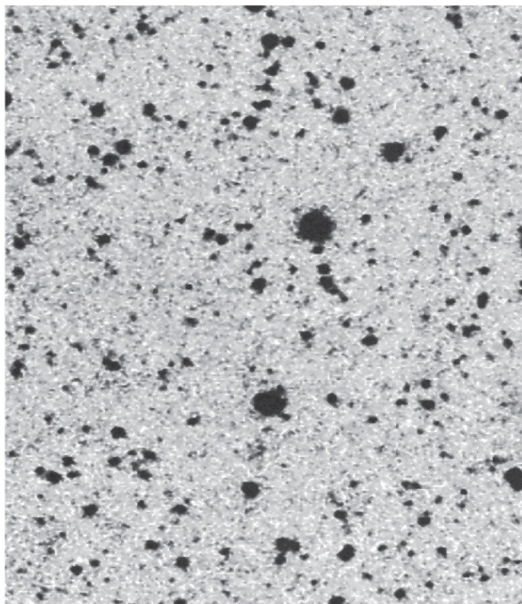


Pan-STARRS detector CCDs

A CCD is a solid state electronic imaging chip. CCD contain millions of pixels. Many CCDs may be used in the focal plane of a large telescope. The main advantage of a CCD is the 'quantum efficiency'. If a photon hits your retina (or photographic film), only about 1 in four (25%) will be detected by the retina. CCD will recorded 95-100% of the photons that strike a pixel. A CCD can be read out into a computer for storage and later analysis.



An image made with photographic film

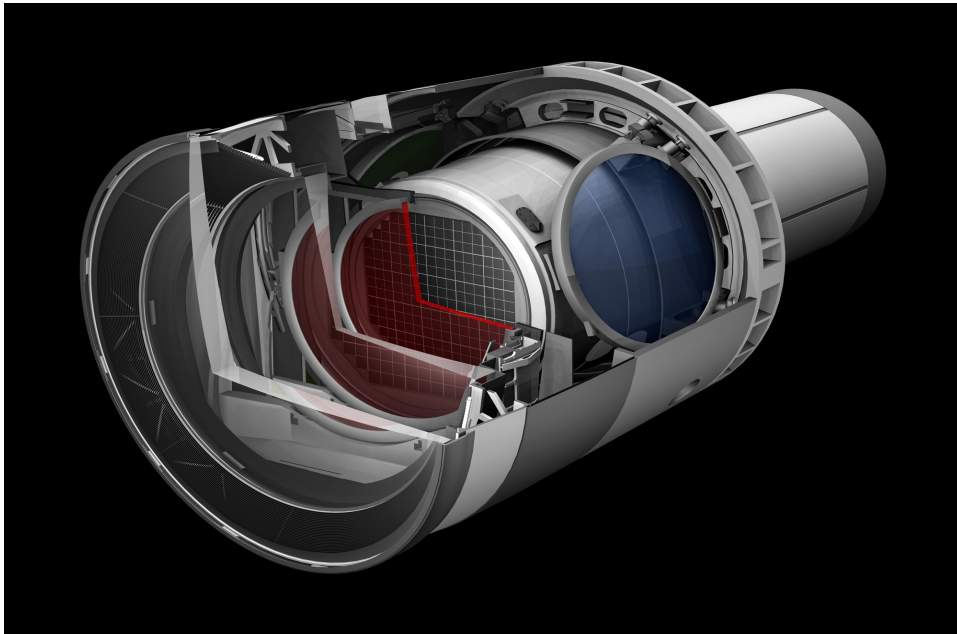


An image of the same region of the sky made with a CCD

The Large Synoptic Survey Telescope



The large synoptic survey telescope is currently being constructed in Chile. 'First light' is expected in 2019. The telescope is funded by the NSF. The telescope mirror will be 8.4 m. The camera will be 3.2 gigapixel camera. The telescope will be able to record the entire sky each night



Spectroscopy

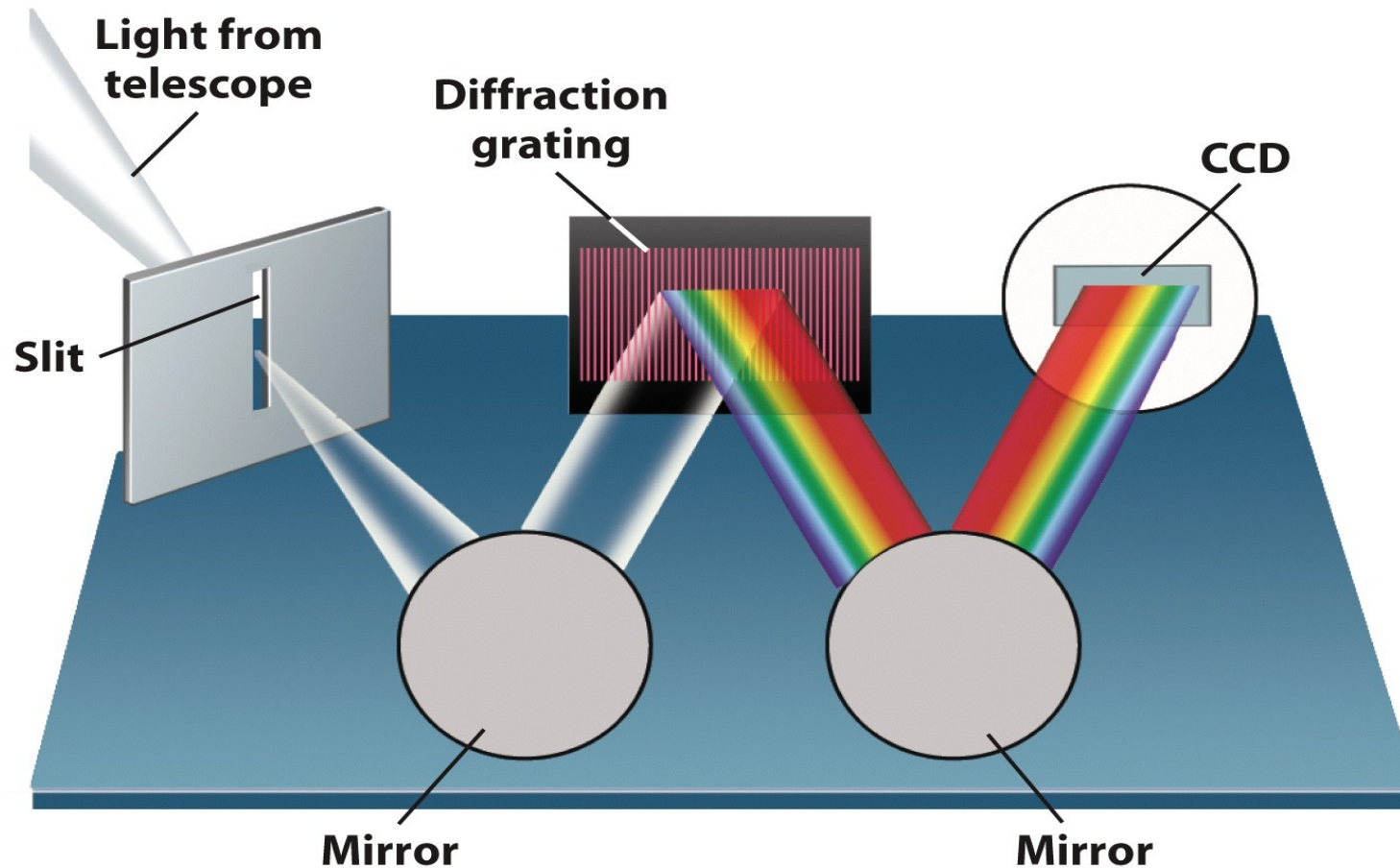
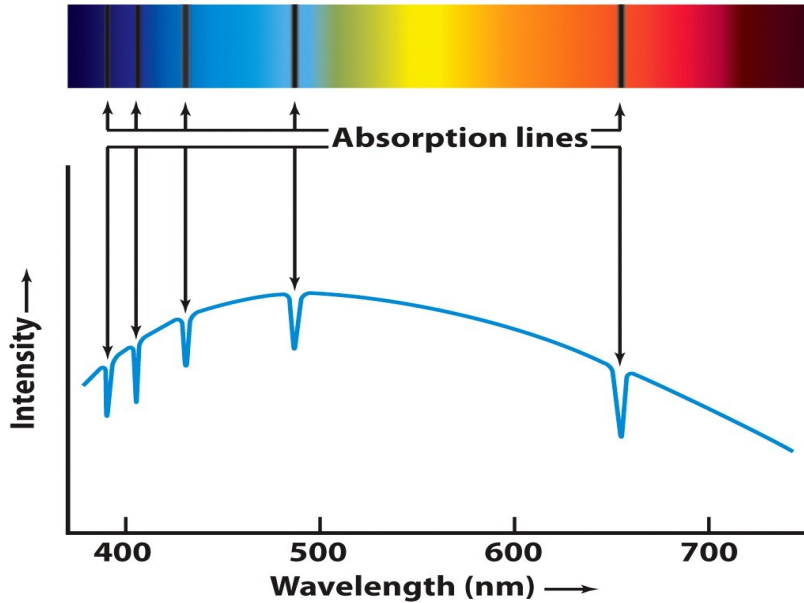


Figure 6-20a
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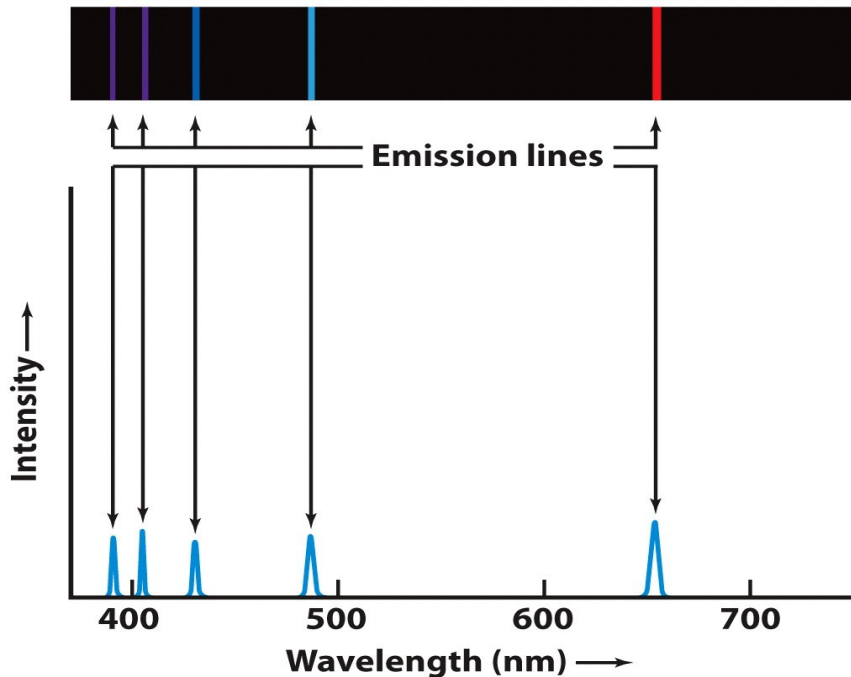
Using a spectrometer, the spectral lines of elements can be observed. Using this method, the composition of a planet's atmosphere, a star or a gas cloud can be determined. A diffraction grating is used because of better transmission than a prism.

Spectroscopy



Two representations of an absorption line spectrum

Figure 6-21a
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Two representations of an emission line spectrum

Figure 6-21b

A diffraction grating spreads the light into a spectrum without transmission losses and nonlinear dispersion. The absorption lines from an astronomical object (planet, star or gas cloud) can be compared with the emission spectrum of an element in the laboratory.

Telescopes that use EM waves



Figure 6-22
Universe, Tenth Edition
David Nunuk/Photo Researchers

Telescopes that use electromagnetic waves other than visible light started with radio waves in the 1930s. Radio telescopes use a parabolic dish antenna much like the mirrors for visible light but are much larger. Because the wavelength of radio waves are much longer than visible light, the surface of the antenna does not have to be as accurate as for a visible light telescope. Many astronomical objects like the Milky Way emit radio waves.

Radio Telescopes



Figure 6-23
Universe, Tenth Edition
Courtesy of NRAO/AUI

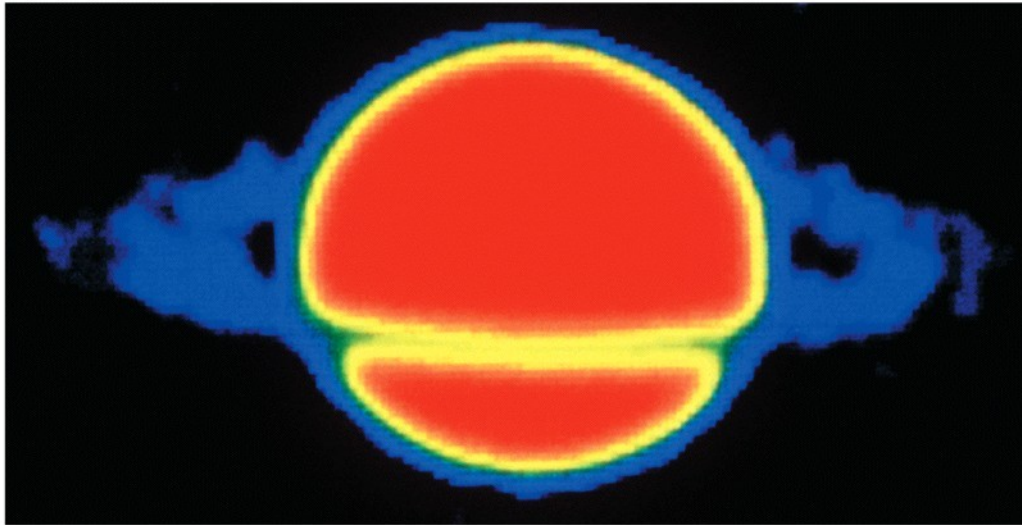
A disadvantage to radio telescopes is the wavelength of the radio waves. Their resolution is limited by the diffraction limit. To overcome this problem, interferometry is used. The Very Large Array in New Mexico uses this idea to achieve good

resolution of radio sources. In fact, it is common practice to use radio telescopes that are on different continents. This gives an effective size to the combined information like a radio telescope with a diameter of thousands of miles.

Radio Waves from a Planet



(a)



(b)

These images show Saturn with its famous rings in visible wavelengths (a) and in radio waves (b). The radio wave image was made with the VLA at $\lambda = 2 \text{ cm}$

Telescopes in Space

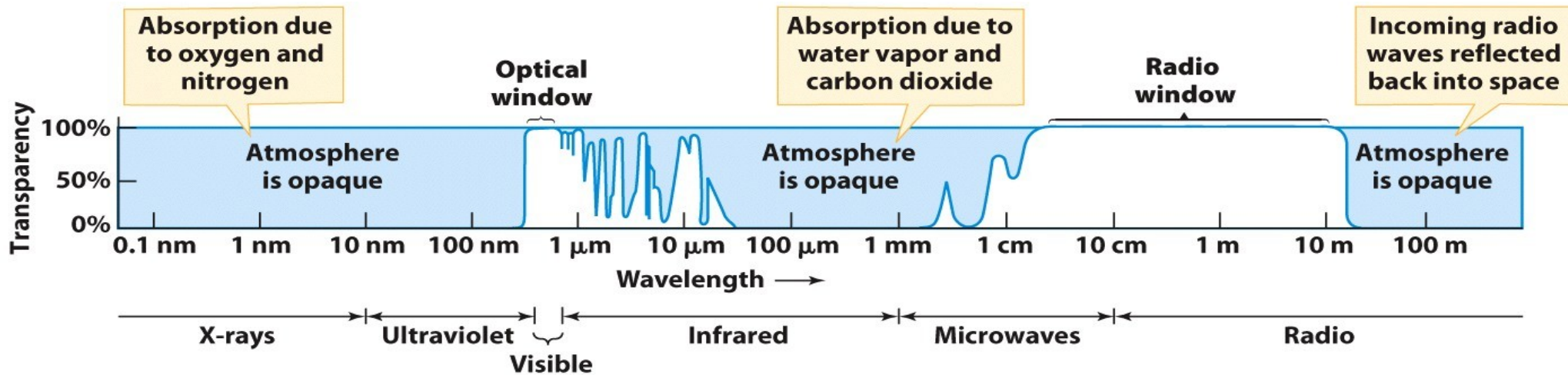
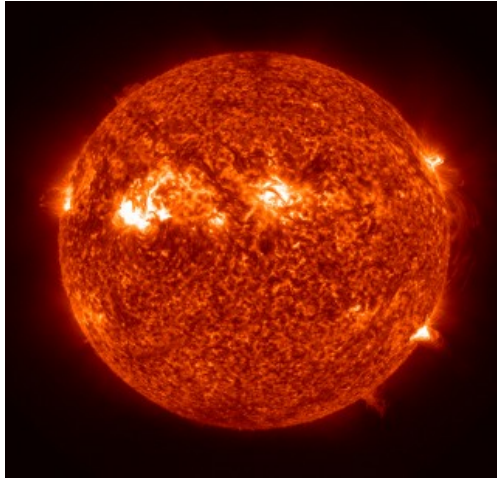


Figure 6-25
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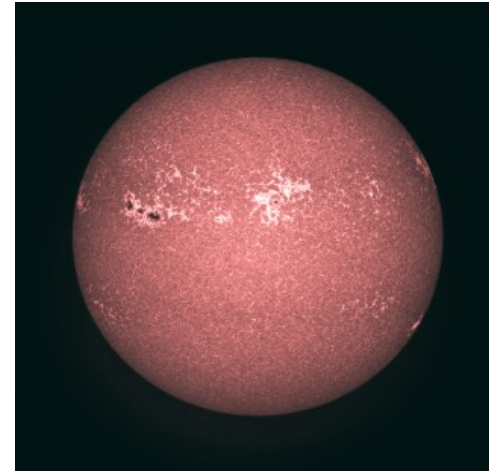
You can see from the chart why visible light and radio telescope are ground based. But that are many parts of the electromagnetic spectrum which can not be seen through the atmosphere. Infrared, ultraviolet, x-rays and gamma rays do no penetrate the Earth's atmosphere. To see the universe at these wavelength's, you have to go above the atmosphere.

The sun in different wavelengths from Solar Dynamics Observatory

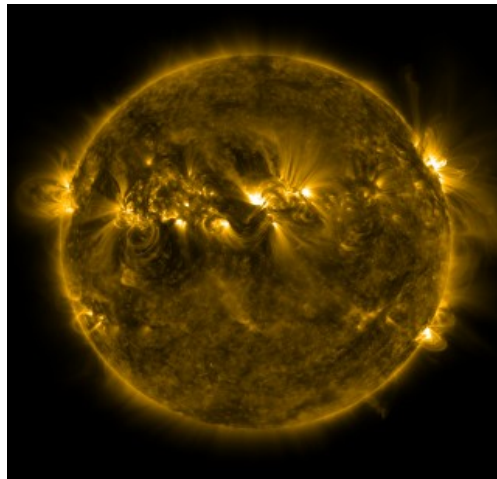
Red = 30 nm



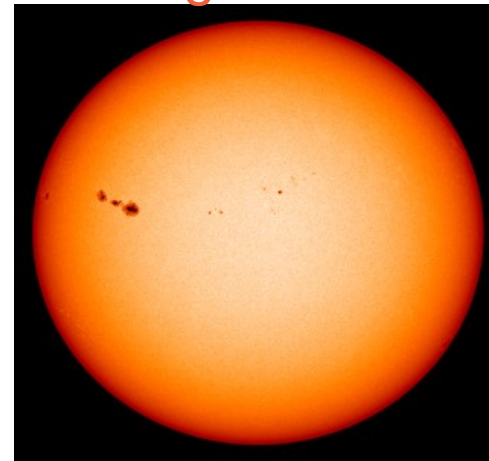
Magenta = 170 nm



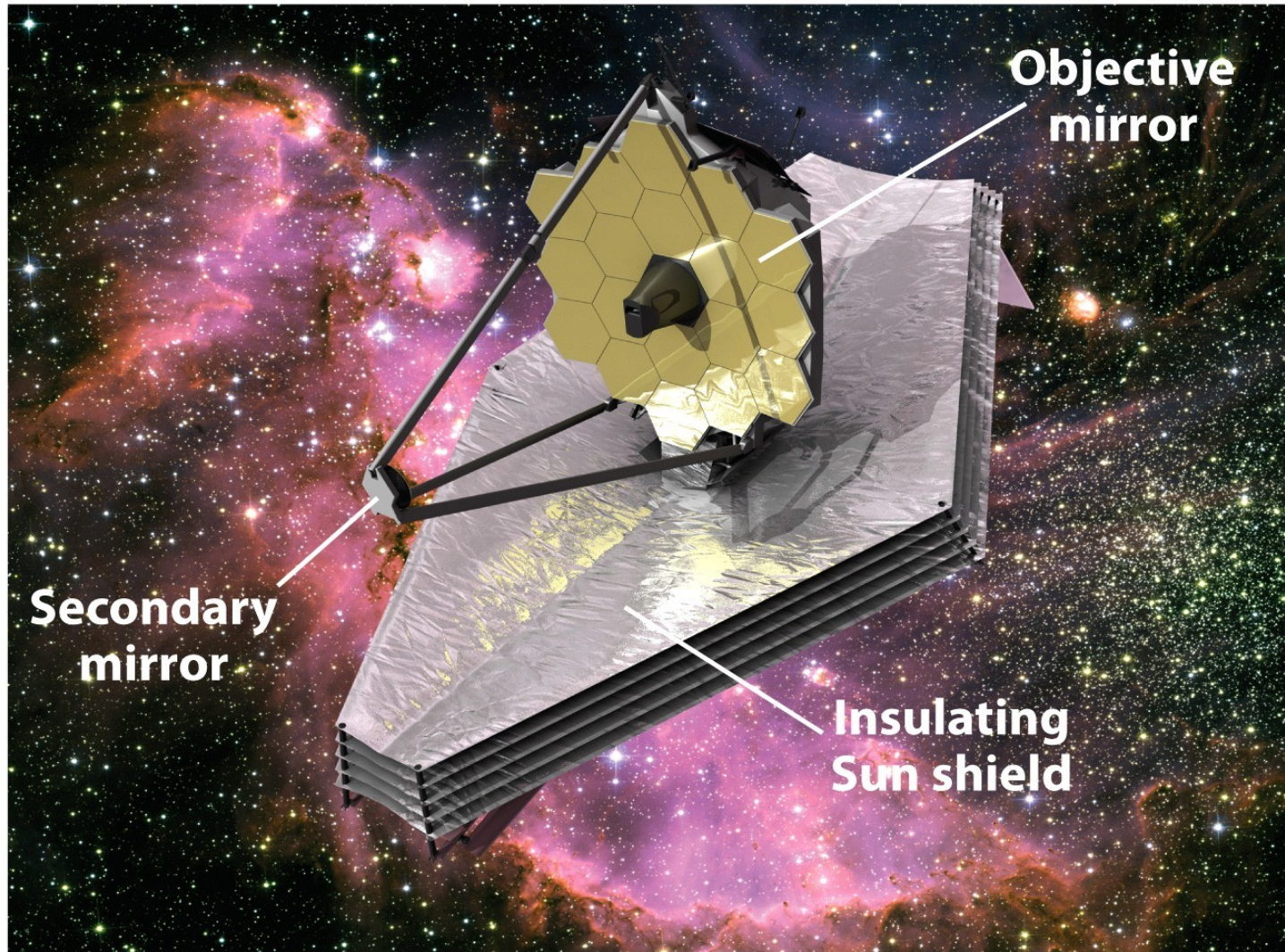
Gold = 17 nm



Orange = visible

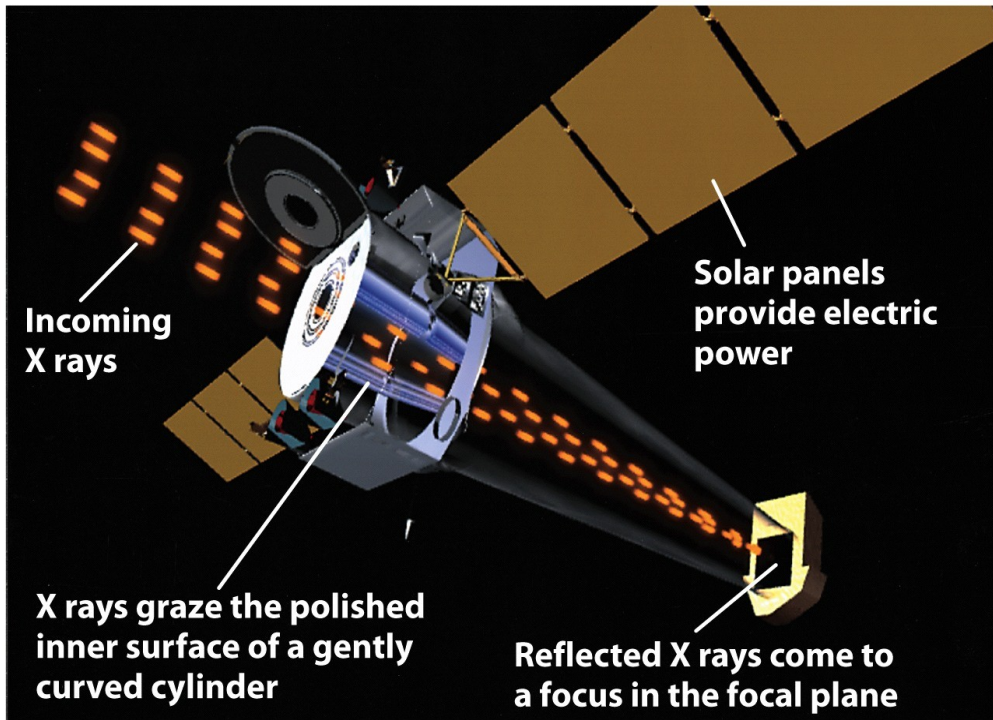


In the Infrared Wavelengths



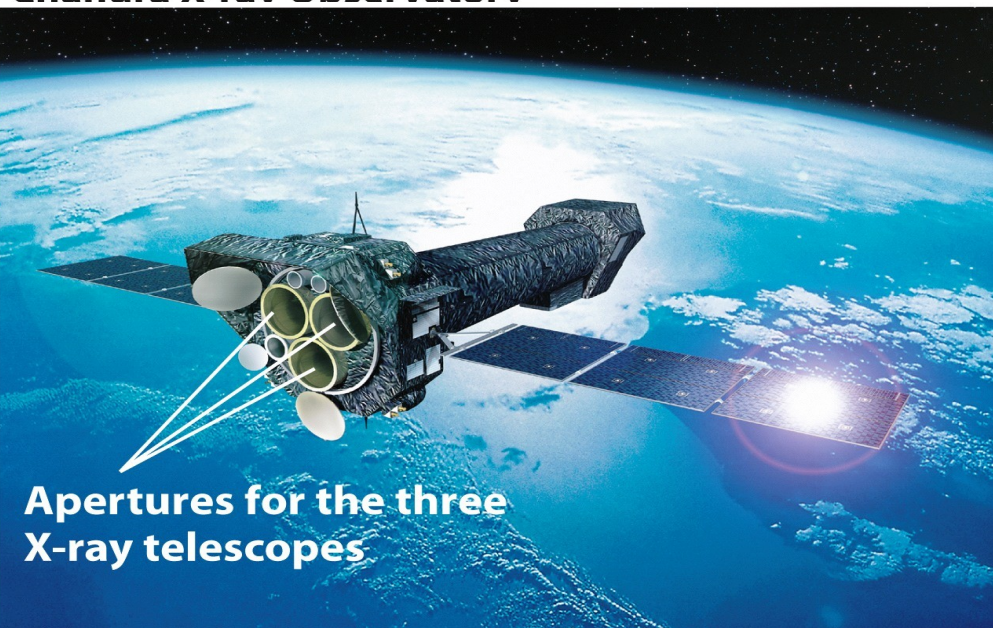
The replacement for the Hubble is the James Webb telescope which will observe in the infrared spectrum. It is scheduled to be placed in space in 2018. It will be placed 1.5 million km from Earth directly opposite the Sun.

Figure 6-29
Universe, Tenth Edition
ESA, C. Carreau



Chandra X-ray Observatory

The Chandra X-ray observatory and the XMM-Newton observe the sky in the x-ray portion of the spectrum.



XMM-Newton

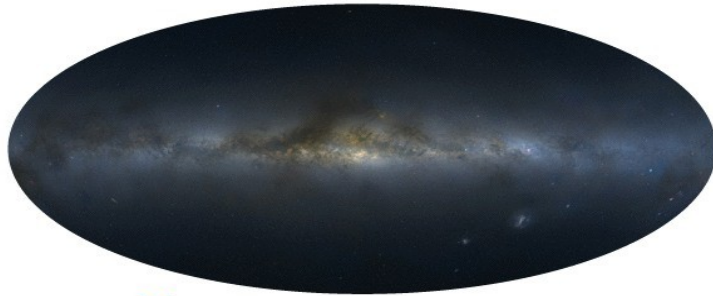
In γ -ray Wavelengths



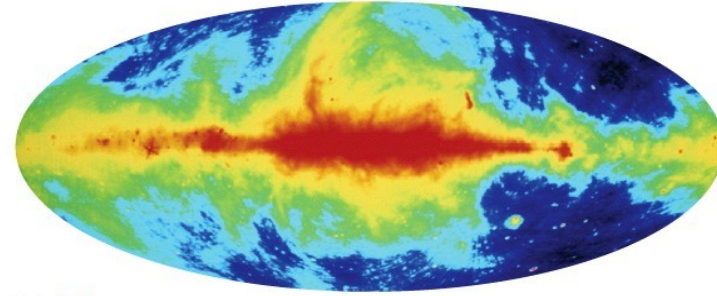
The Fermi Gamma ray space telescope looks at the universe in high energy gamma rays

Figure 6-31
Universe, Tenth Edition
NASA

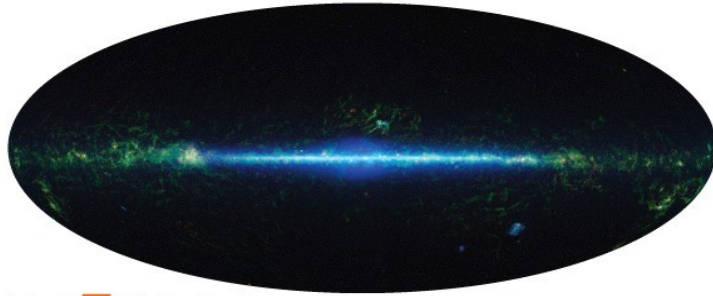
The sky in different Wavelengths



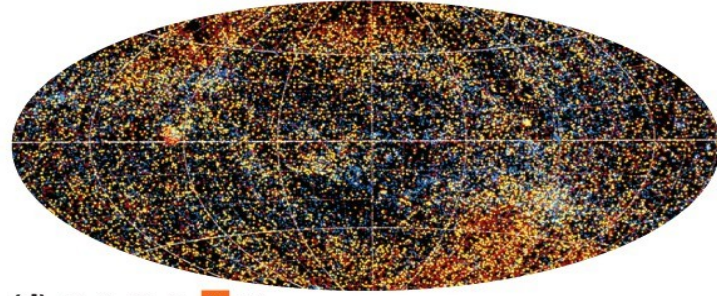
(a) R I V U X G



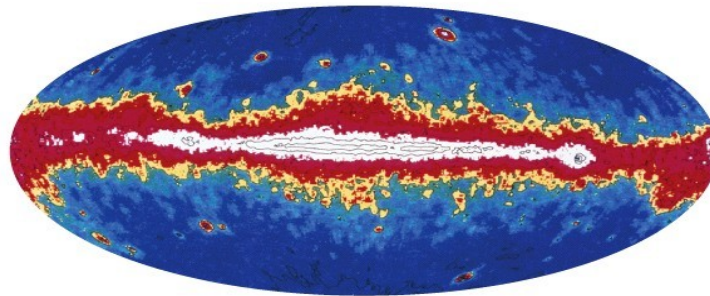
(b) R I V U X G



(c) R I V U X G



(d) R I V U X G



(e) R I V U X G

Figure 6-32

Universe, Tenth Edition

a: Axel Mellinger; b: Max Planck Institute for Radio Astronomy/Science Photo Library/Science Source; c: NASA/JPL-Caltech/UCLA; d: Max Planck Institute for Extraterrestrial Physics/Science Photo Library/Science Source; e: NASA/Science Photo Library/Science Source