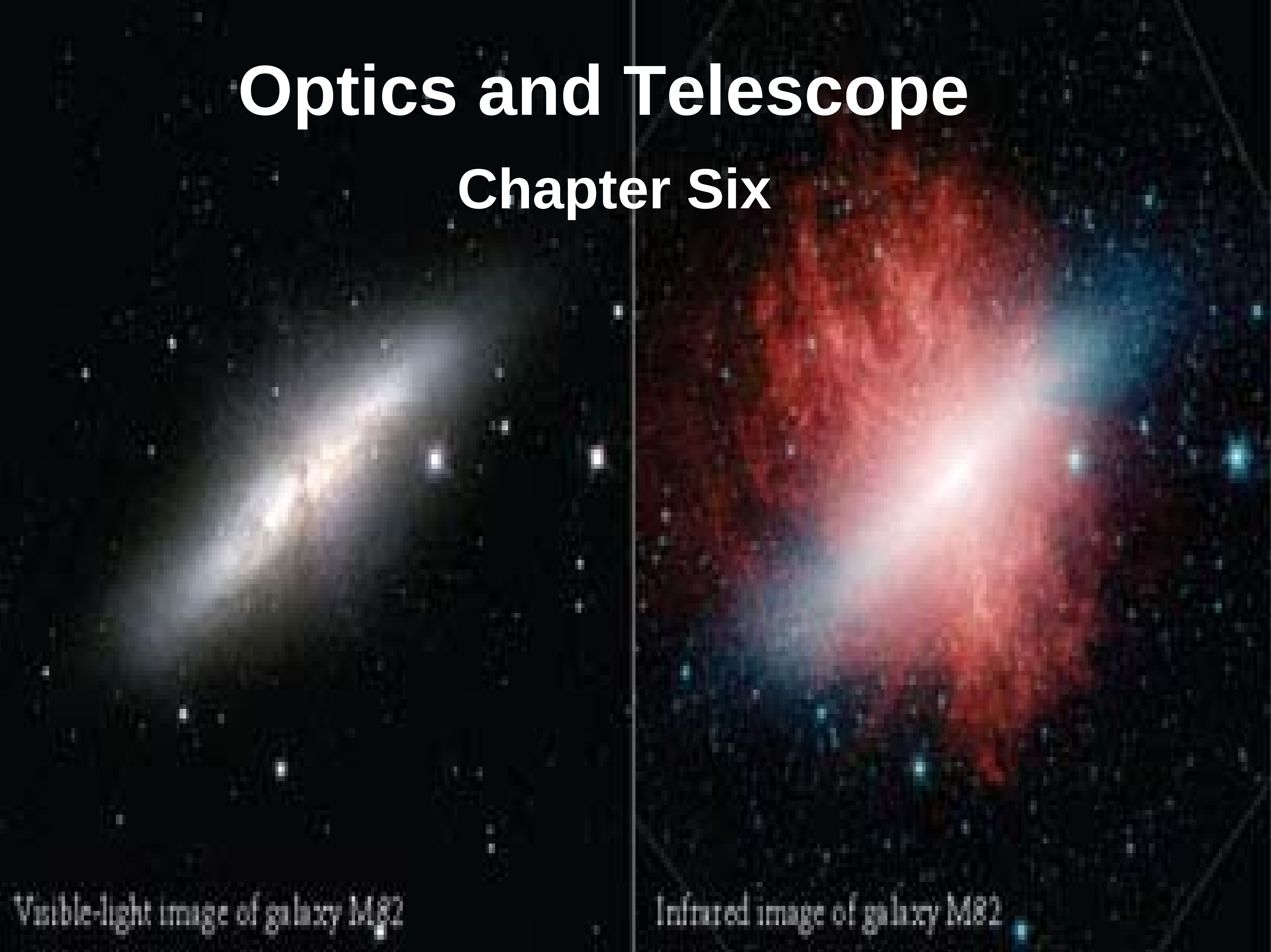
Optics and Telescope

Chapter Six



Introduction To Modern Astronomy I: Solar System

Introducing Astronomy
(chap. 1-6)

Planets and Moons
(chap. 7-15)

Chap. 16: Our Sun
Chap. 28: Search for
Extraterrestrial life

Ch1: Astronomy and the Universe
Ch2: Knowing the Heavens
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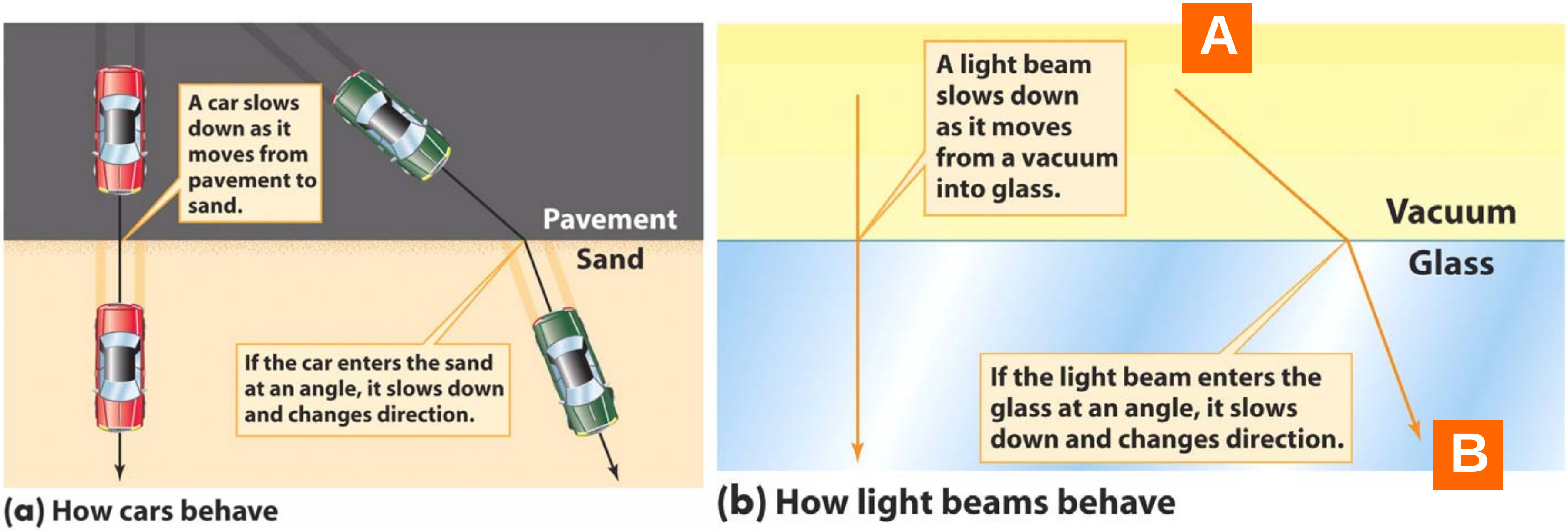
Ch4: Gravitation and
the Waltz of the Planets
Ch5: The Nature of Light

Ch6: Optics and Telescope

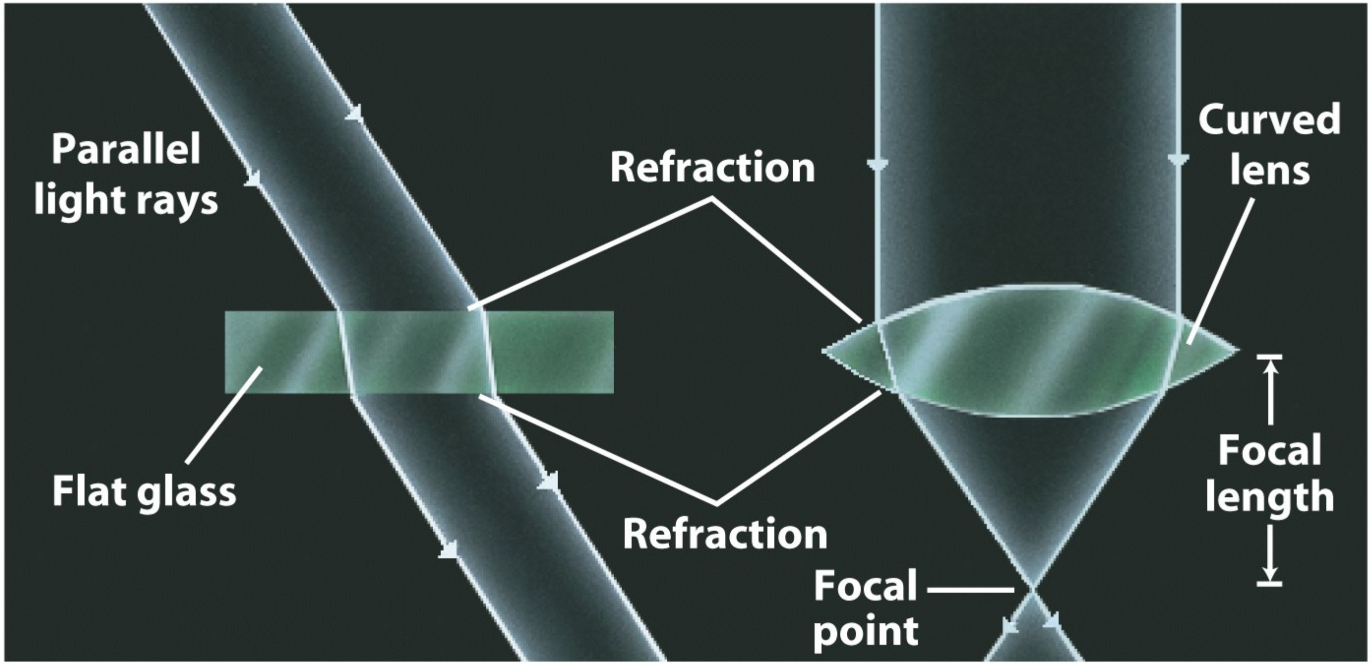
Refraction of Light

- **Refraction**: as a beam of light passes from one transparent medium into another—say, from air into glass, or from glass back into air—the direction of the light can change
- **Refraction** is caused by the change in the speed of light
  - Vacuum: 3.0×10^5 km/s
  - Glass: 2.0×10^5 km/s



Refraction Telescope

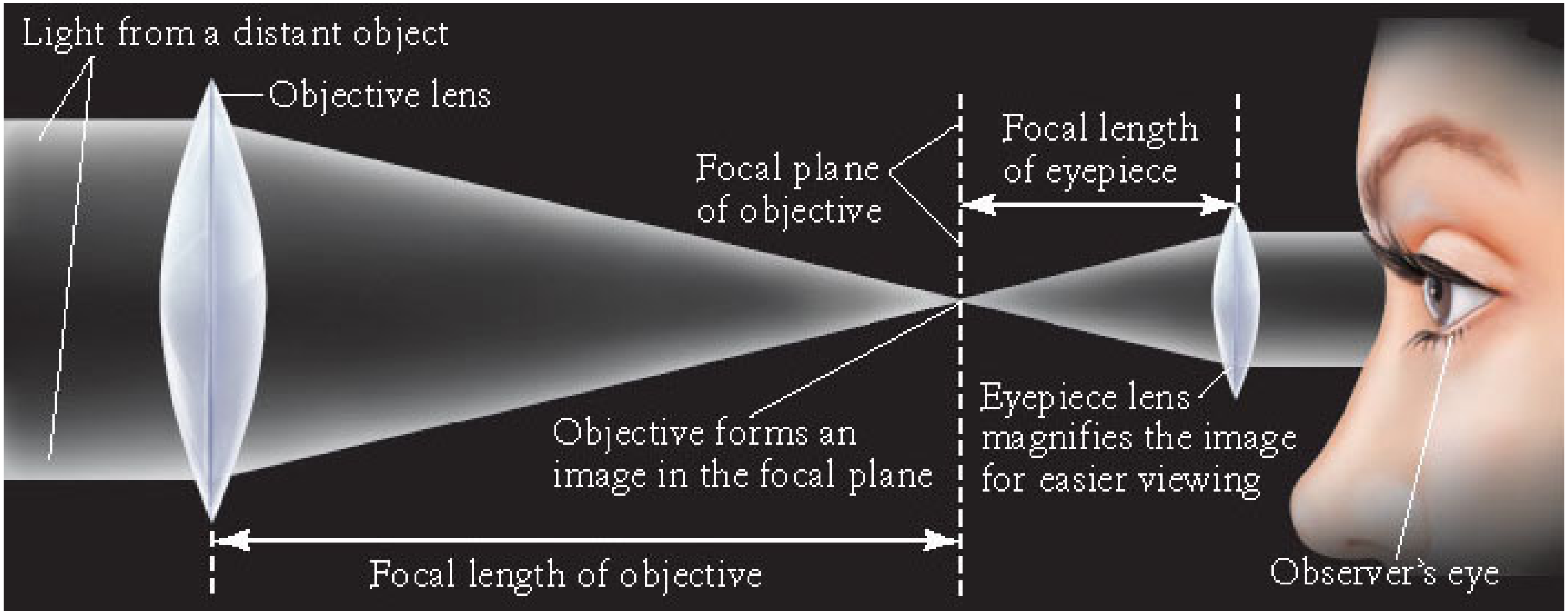
- **Refraction telescope uses a convex glass lens to form image**
- **Focal point**: when a parallel beam of light rays passes through the lens, refraction causes all rays to converge at a point called the **focus**
- **Focal length:** the distance from the lens to the focal point



(a) (b)

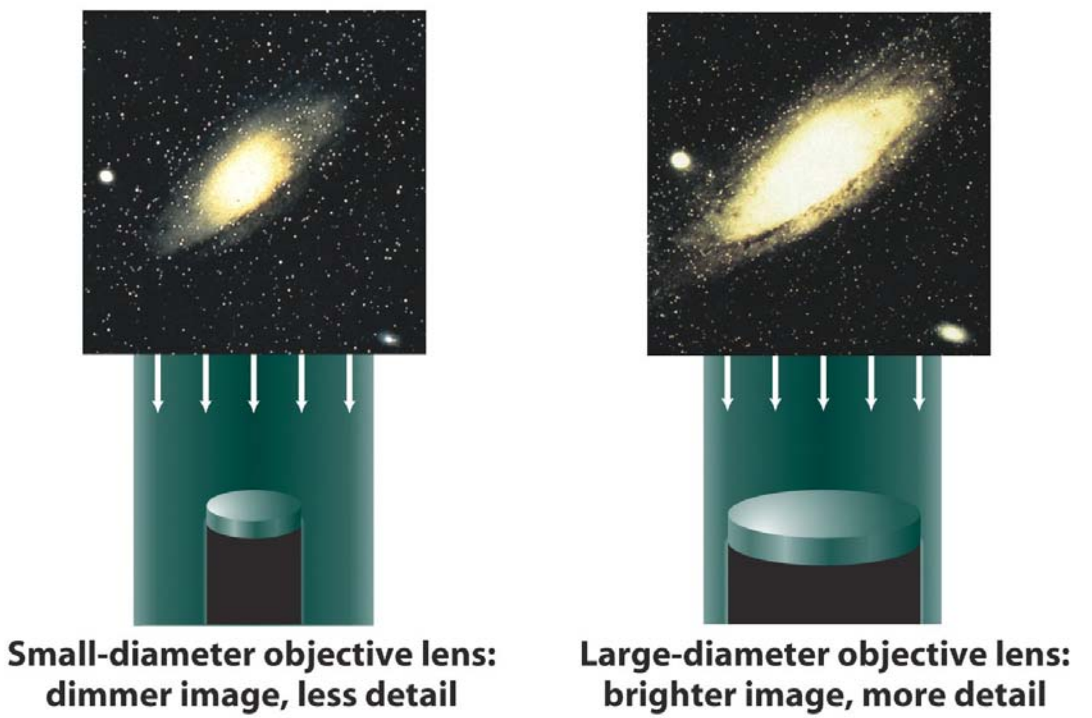
Refraction Telescope

- A refraction telescope consists of
  - a large-diameter **objective lens** with a long focal length, and
    - used to form object image at the focal plane
    - used to gather light
  - a small **eyepiece lens** of short focal length
    - Used to magnify the images for viewing by naked eyes



Telescope: Light-gathering Power

- The **light-gathering power** of a telescope is directly proportional to the area of the objective lens, which in turn is proportional to the square of the lens diameter
  - Human iris: 3 mm
  - Galileo’s refraction telescope: 3 cm ; 100 times better in gathering light
  - Modern telescope: 10 m ; 10,000,000 times



Telescope: Magnifying Power

- **Magnifying power, or magnification**, is equal to the focal length of the objective divided by the focal length of the eyepiece. It helps to see fine details of extended images.
  - e.g., Moon 0.5°, Galileo viewed as 10°; or a 20X telescope
- Magnification power is limited by the nature of light

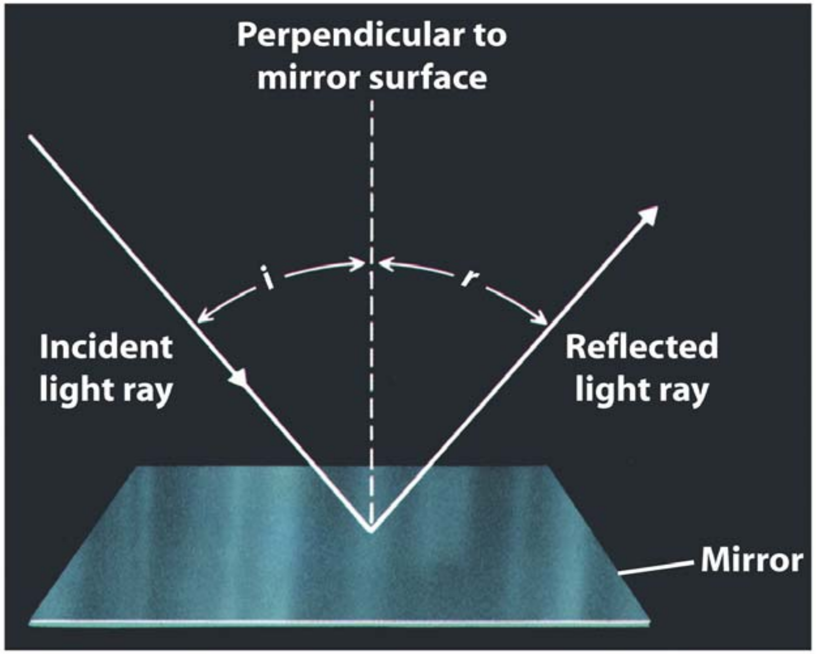
- The Primary purpose of a telescope is for its light-gathering power. The magnifying power is the secondary.

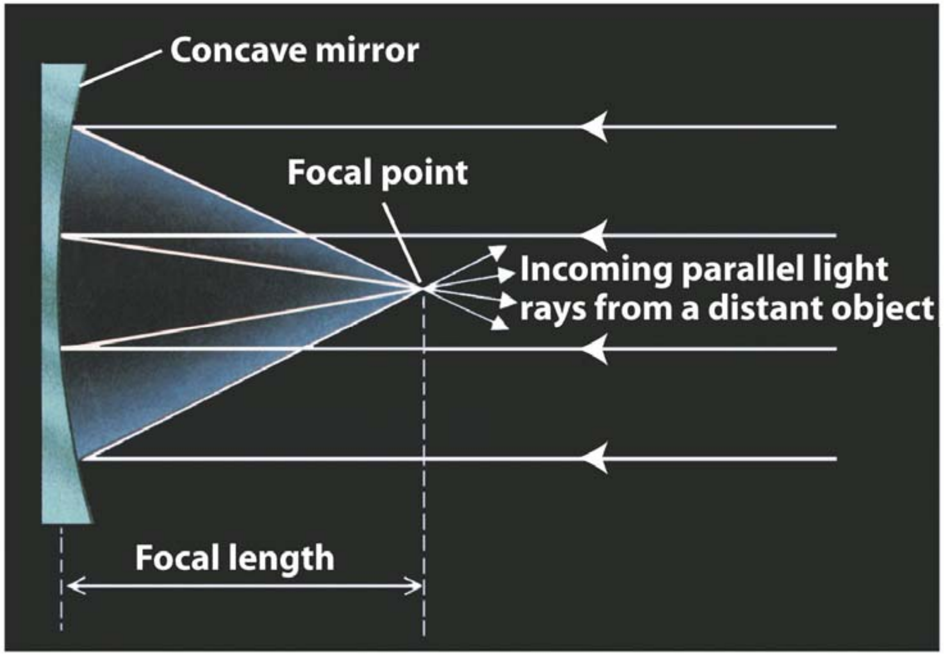
Refraction Telescope

- It is undesirable to build large refractors
  - Glass impurities in lens
  - opacity to certain wavelengths
  - Chromatic abberation
  - structural difficulties, supported only around thin edges

Reflection Telescope

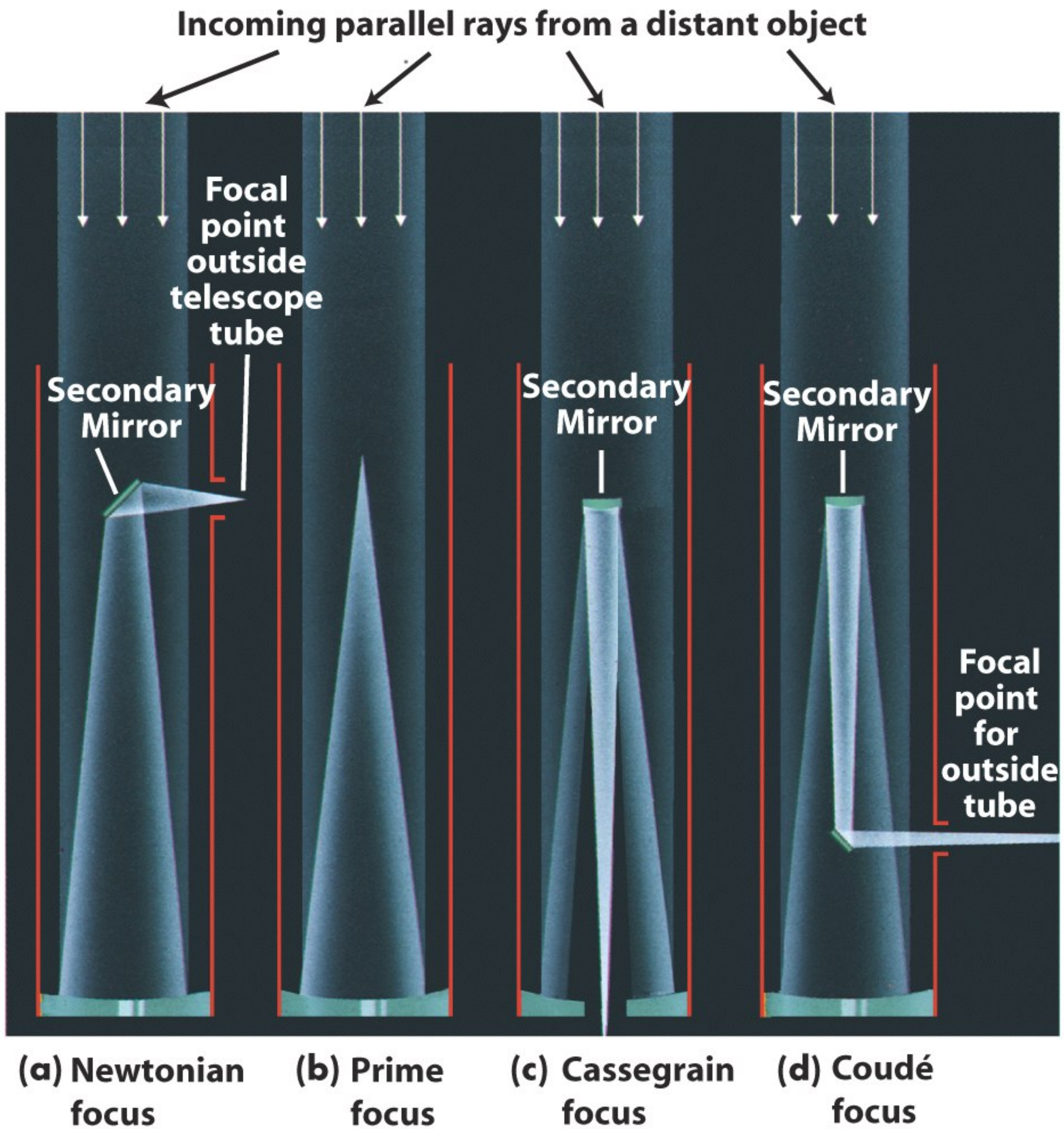
- Reflecting telescopes, or reflectors, produce images by reflecting light rays to a focus point from concave mirrors.
- Reflectors are not subject to most of the problems that limit the size of refractors.
- The mirror that forms the image is called **objective mirror**, or **primary mirror**



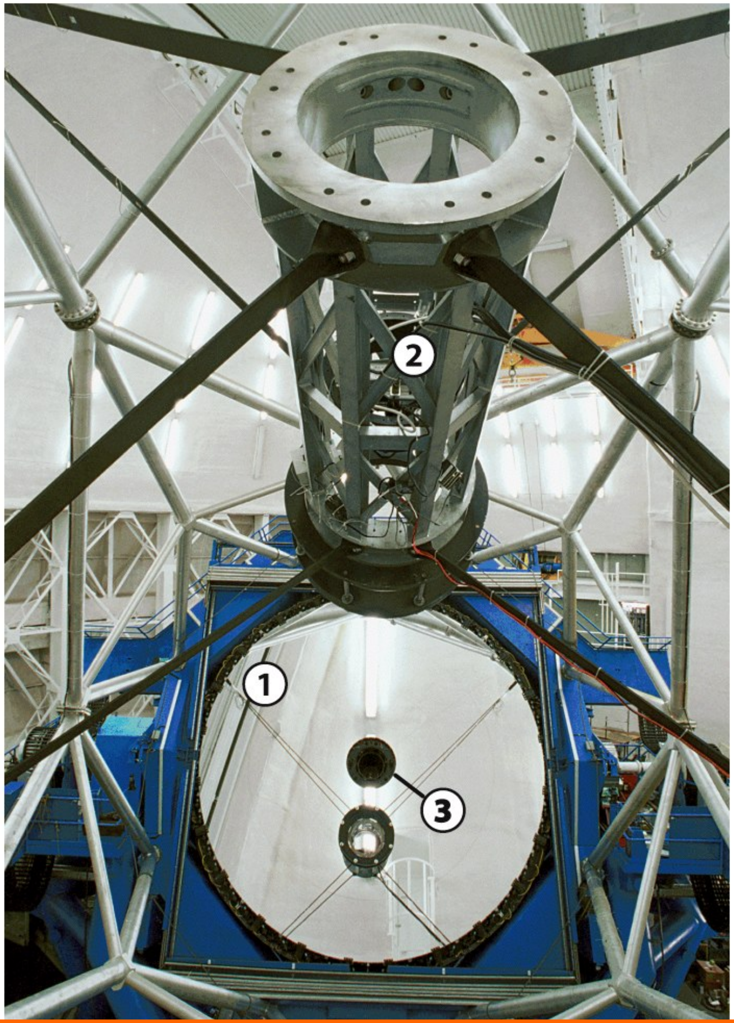


Reflection Telescope

- Four popular optical design, depending where is the viewer or detector
  1. Newtonian focus
  2. Prime focus
  3. Cassegrain focus
  4. Coude focus



Reflection Telescope



A Large Cassegrain Telescope
European Southern Obs., Chile

- **Does the hole in the primary mirror cause a hole in the image**
  - Any small portion of the primary mirror can make a complete image
- All the largest optical telescopes in the world are reflectors: 8 -10 meters in diameter

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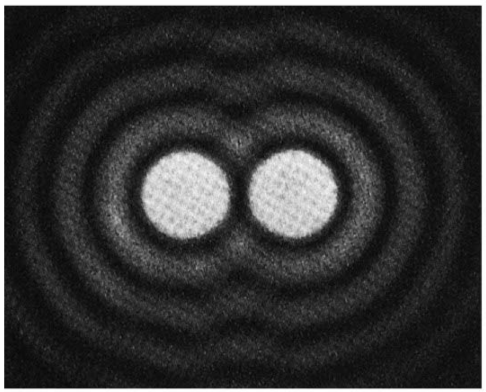
Telescope: Angular Resolution

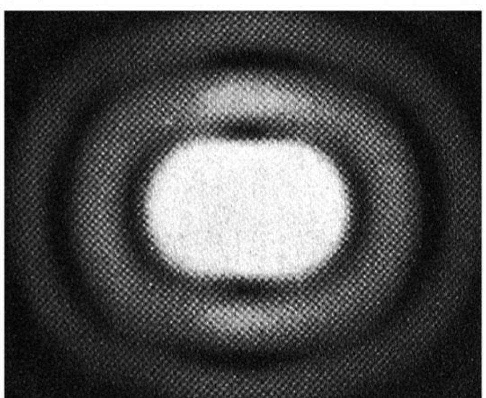
•Angular resolution: the minimum angular size two close objects can be resolved by the observations

•Angular resolution indicates the sharpness of the telescope’s image, or how well fine details can be seen



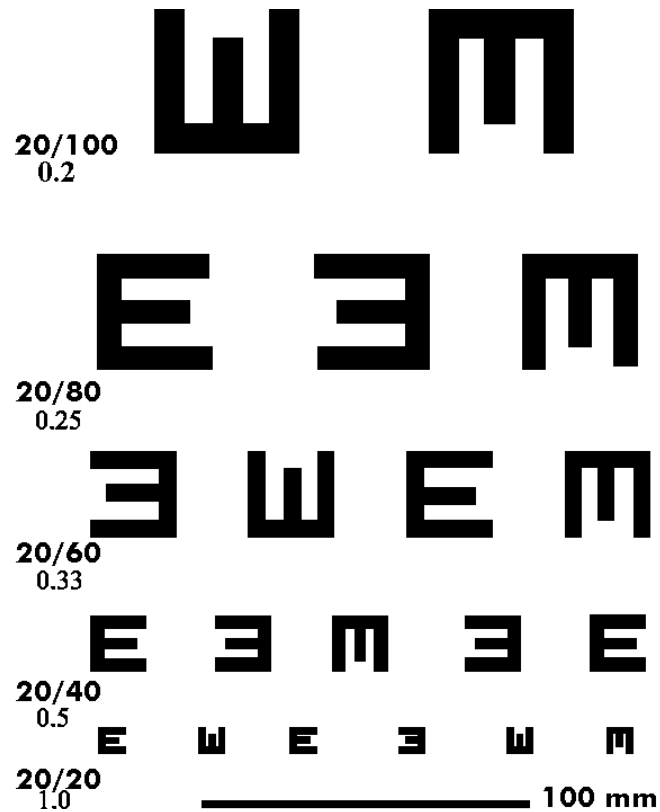
(a)

Two light sources with angular separation greater than angular resolution of telescope: Two sources easily distinguished



(b)

Light sources moved closer so that angular separation equals angular resolution of telescope: Just barely possible to tell that there are two sources



Telescope: Angular Resolution

- Diffraction-limited Angular Resolution
- **Diffraction:** the tendency of light waves to spread out when they are confined to a small area like mirrors or lenses

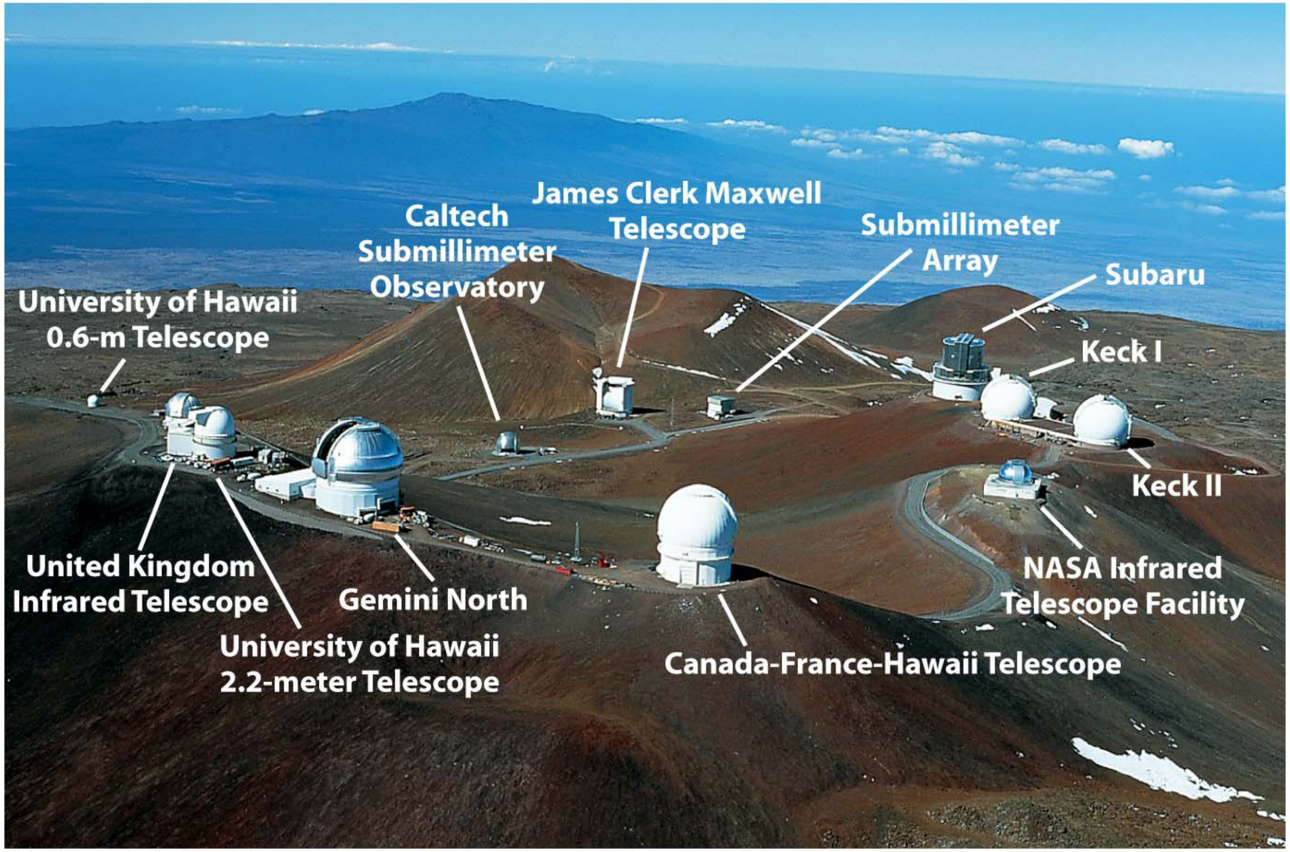
$$\theta = 2.5 \times 10^5 \frac{\lambda}{D}$$

Θ: angular resolution (arcseconds); λ: wavelength (meters); D: diameter of telescope (meters)

- the larger the size of the objective mirror, the better the angular resolution
- For instance
  - Human eyes: 3 mm, angular resolution 1 arcmin
  - Galileo telescope: 3 cm, angular resolution 6 arcsec
  - Gemini Telescope: 8 m, angular resolution 0.02 arcsec

Telescope: Angular Resolution

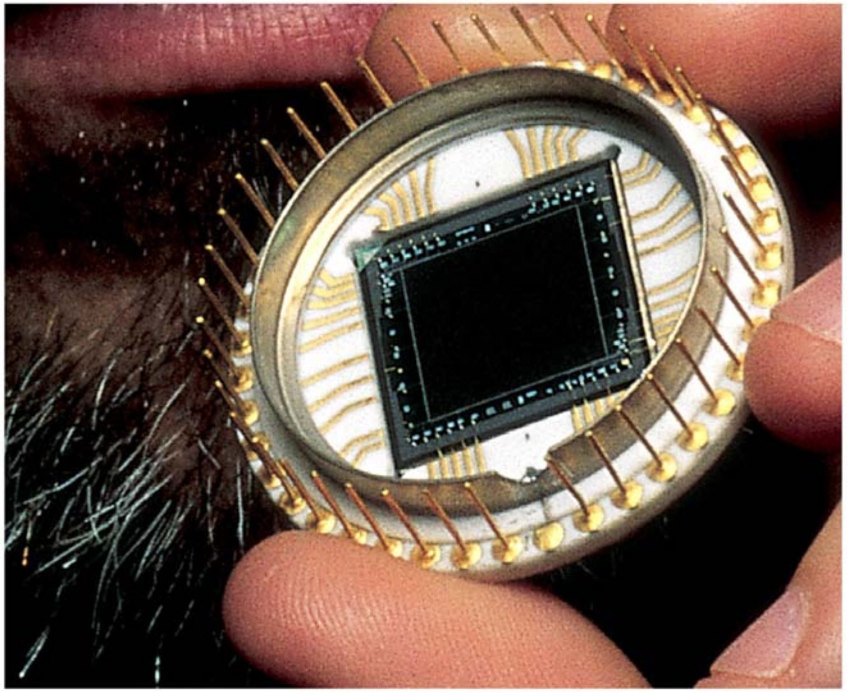
- Another limitation is from the blurring effects of atmospheric turbulence
- **Seeing:** a measure of the limit that atmosphere turbulence places on a telescope's resolution
- The best seeing is atop a tall mountain with very smooth air.



Mauna Kea in Hawaii

0.5 arcsec seeing

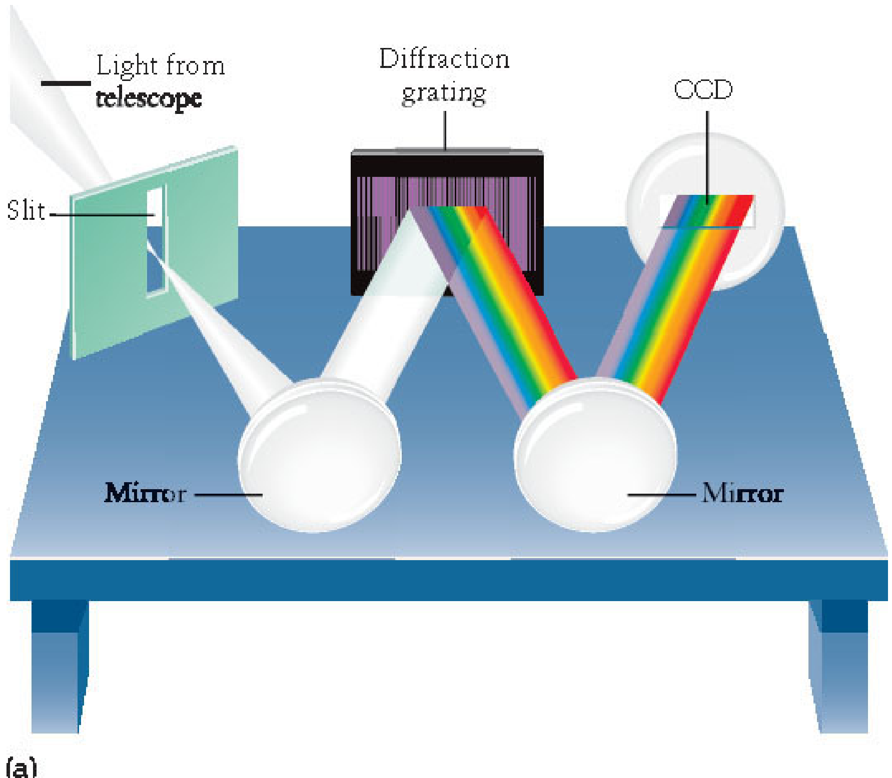
Detector: Imaging



- Charge Coupled Devices (**CCDs**) are often used at a telescope’s focus to record faint images.
- Electric charge builds up in each pixel in proportion to the number of photons falling
- CCD is far more better than the old-fashioned photographic film.

Detector: Spectrograph

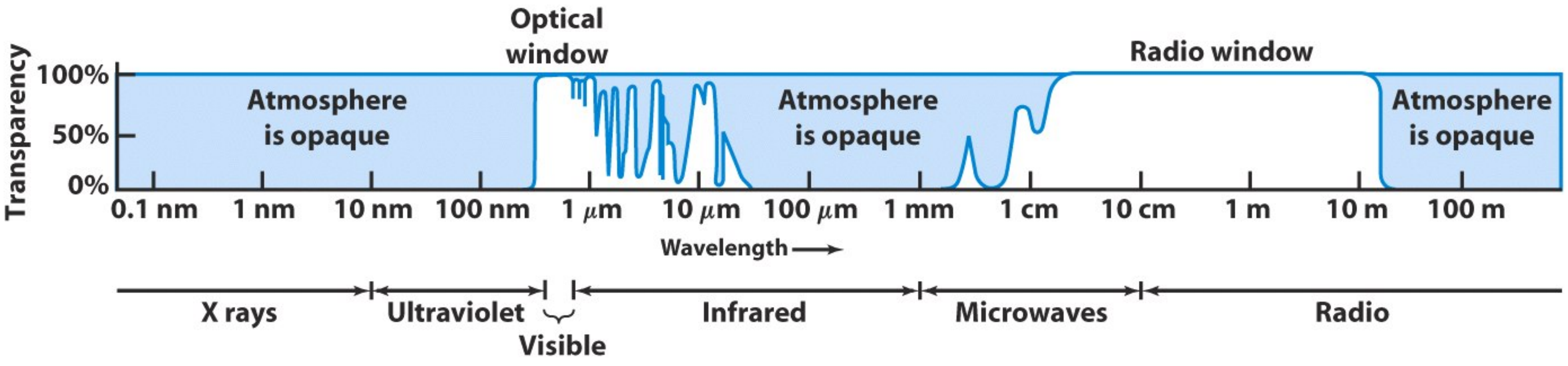
- A spectrograph records spectrum of an astronomical object
- **Grating**: a piece of glass on which thousands of very regularly spaced parallel lines have been cut. The light from the different part of the grating interfere with each other and form the spectrum



A Grating Spectrograph

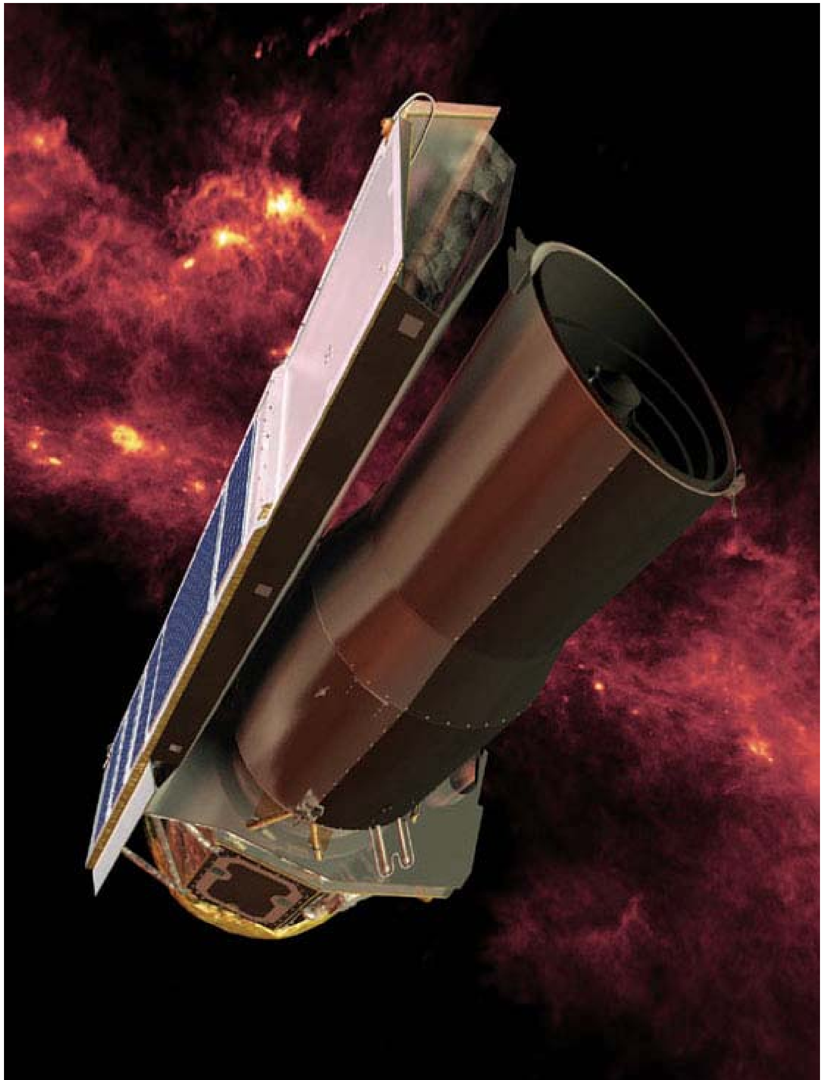
Telescopes in orbit

- Free of seeing effect of the Earth's atmosphere
- Observe in all wavelengths
  - The atmosphere is transparent mainly in two wavelength ranges known as the **optical window and the radio window**
  - The atmosphere is opaque to X-rays, EUV light, most of infrared light, and very long radio waves.



Transparency of The Earth's Atmosphere

Telescopes in orbit



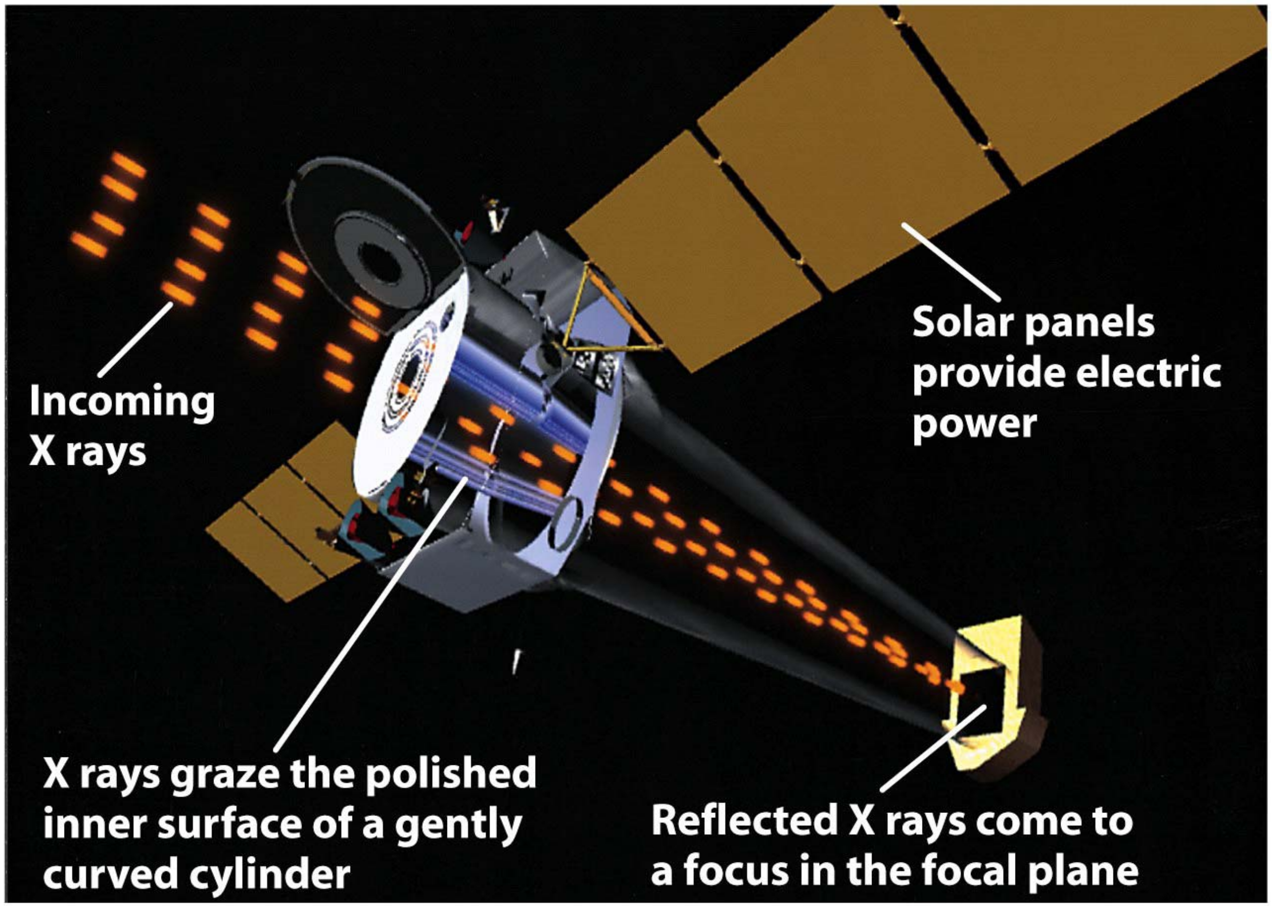
Spitzer Space Telescope

- Launched in 2003
- 85-cm primary mirror
- Infrared telescope: from 3 to 180 μm
- Kept cold by liquid helium to reduce the infrared blackbody radiation from telescope itself

Telescopes in orbit

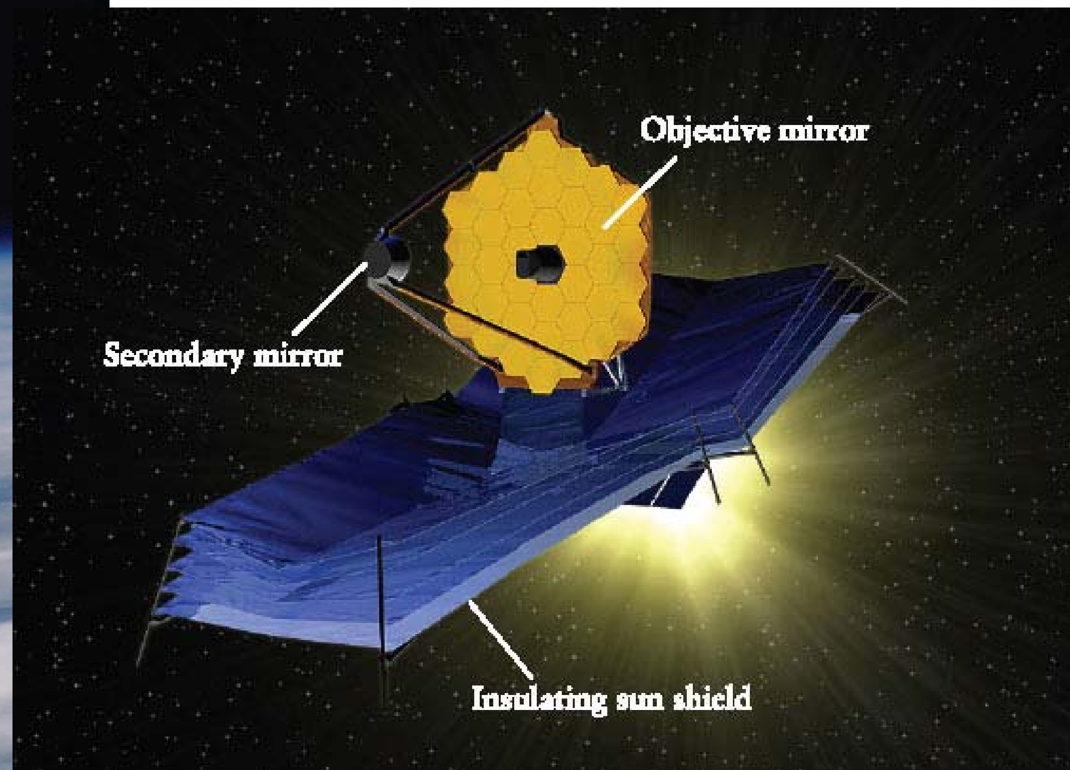
Chandra Space Telescope

- Launched in 1999;   View the X-ray sky



(a) Chandra X-ray Observatory

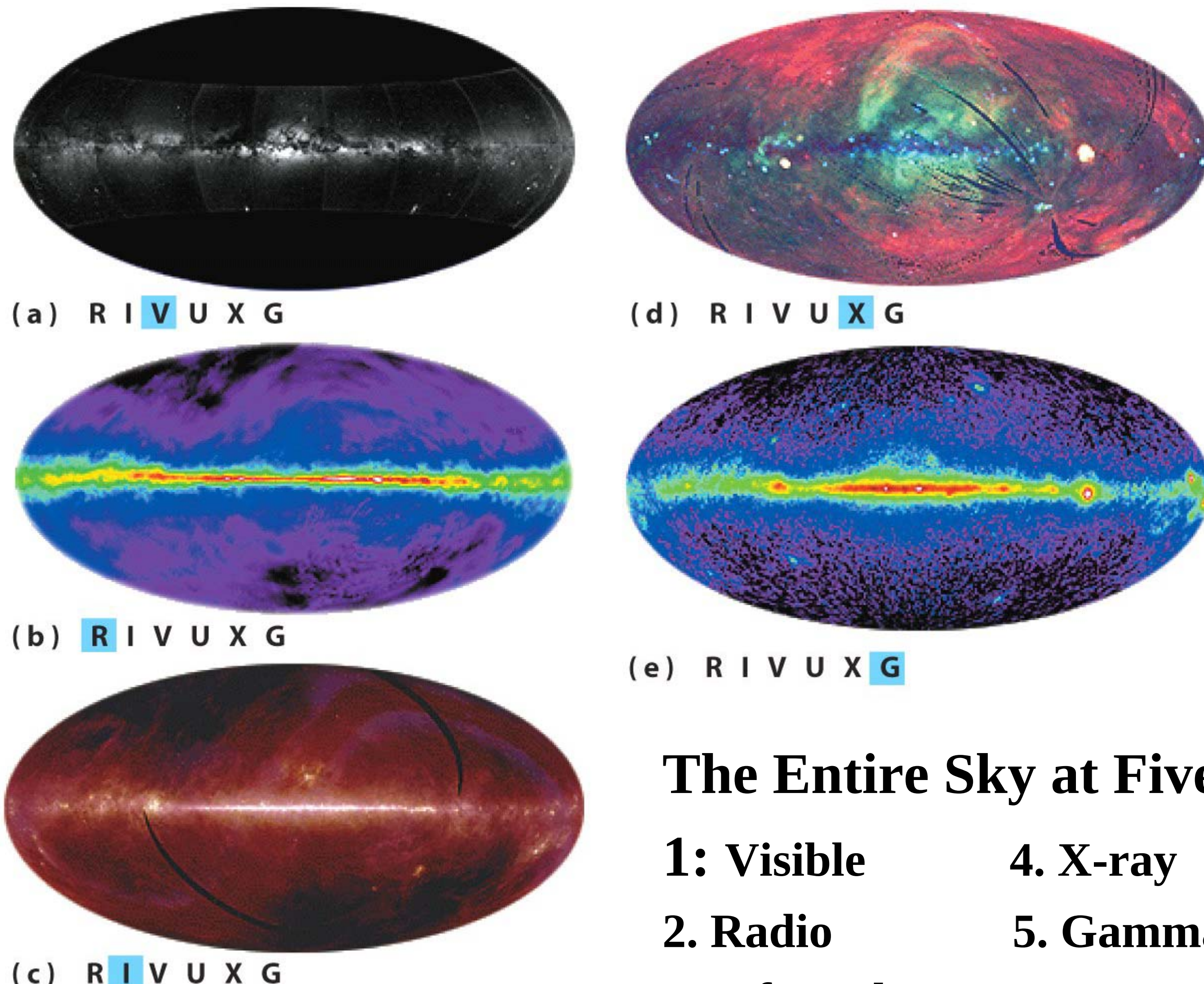
Telescopes in orbit



Hubble Space Telescope (1990 -)

James Webb Space Telescope (JWST)
Planned in 2013

Telescopes in orbit



The Entire Sky at Five Wavelength

1: Visible
2. Radio
3. Infrared
4. X-ray
5. Gamma-ray

Final Notes on Chap. 6

- There are 7 sections in total. We studied 6 of them, except section 6-6.

Advanced Question
Chap. 6, Q34 in P155

Several groups of astronomers are making plans for large ground-based telescopes.

(a) What would be the diffraction limited angular resolution of a telescope with a 40-meter objective mirror?

(b) (b) Suppose this telescope is placed atop Mauna Kea. How will the actual angular resolution of the telescope compare to that of the 10-meter Keck 1 telescope? Asumme that adapative optics is not used.