Optics and Telescopes

ASTR 111 – 003 **Fall 2006**
Lecture 07 Oct. 16, 2006

Introduction To Modern Astronomy I

Introducing Astronomy
(chap. 1-6)

Planets and Moons
(chap. 7-17)

Ch1: Astronomy and the Universe
Ch2: Knowing the Heavens
Ch3: Eclipses and
the Motion of the Moon
Ch4: Gravitation and
the Waltz of the Planets
Ch5: The Nature of Light

Ch6: Optics and Telescope

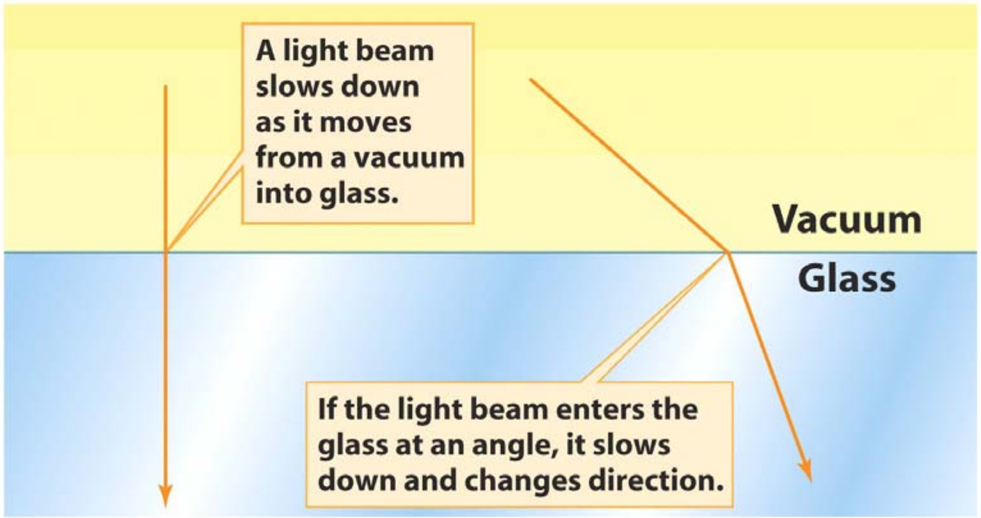
Ch7: Comparative Planetology I
Ch8: Comparative Planetology II
Ch9 – Ch 17

Guiding Questions

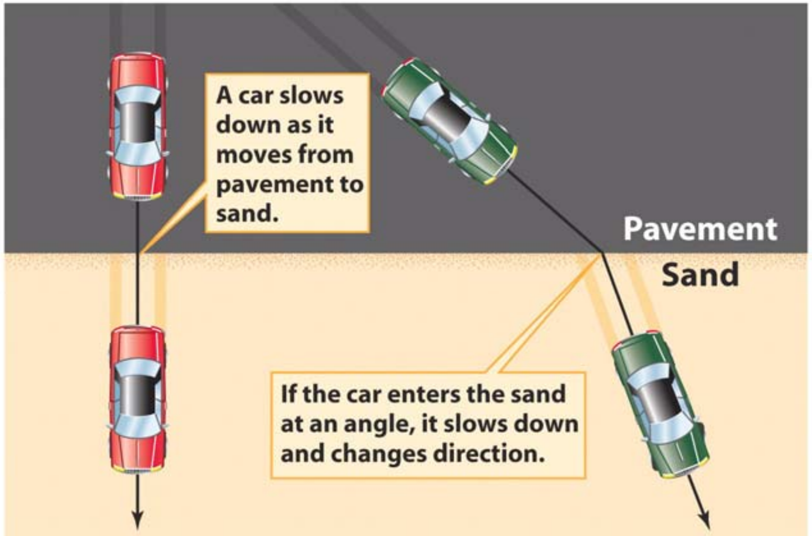
1. Why is it important that telescopes be large?
2. Why do most modern telescopes use a large mirror rather than a large lens?
3. Why are observatories in such remote locations?
4. Do astronomers use ordinary photographic film to take pictures of the sky? Do they actually look through large telescopes?
5. How do astronomers use telescopes to measure the spectra of distant objects?
6. Why do astronomers need telescopes that detect radio waves and other nonvisible forms of light?
7. Why is it useful to put telescopes in orbit?

Refraction

- **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



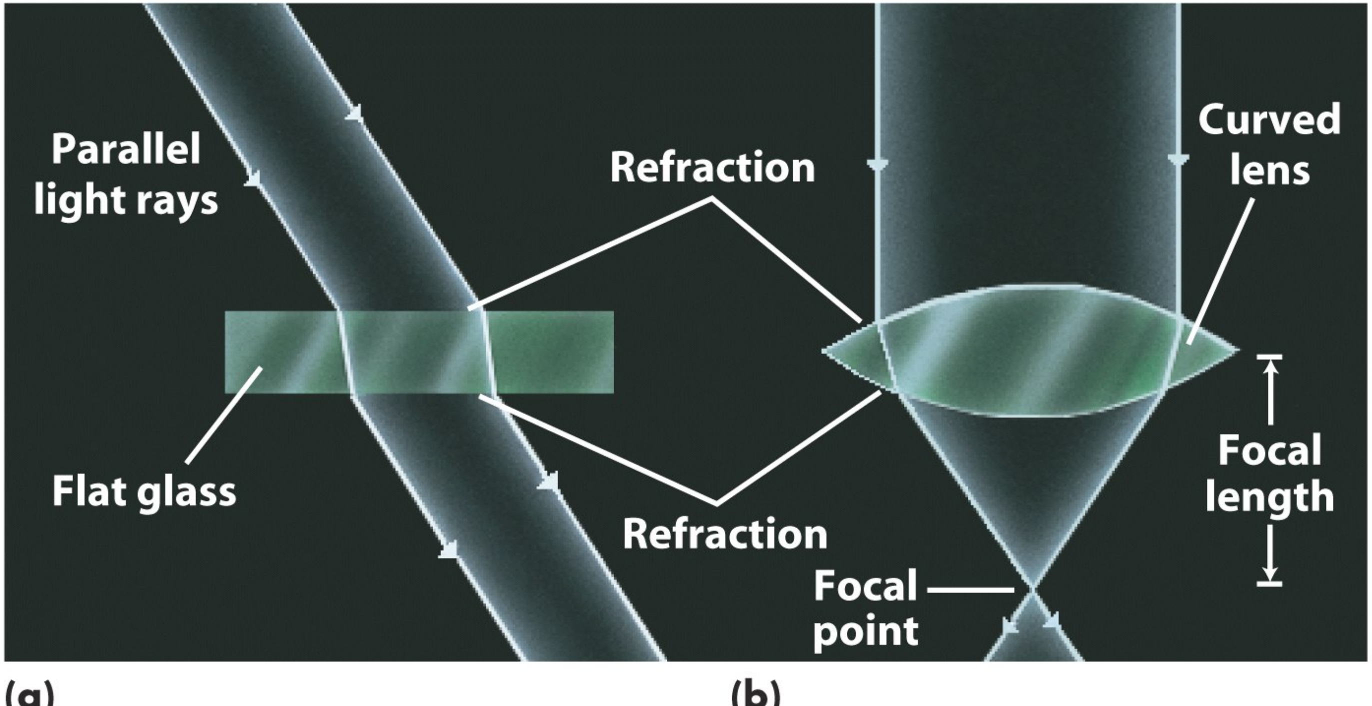
(b) How light beams behave



(a) How cars behave

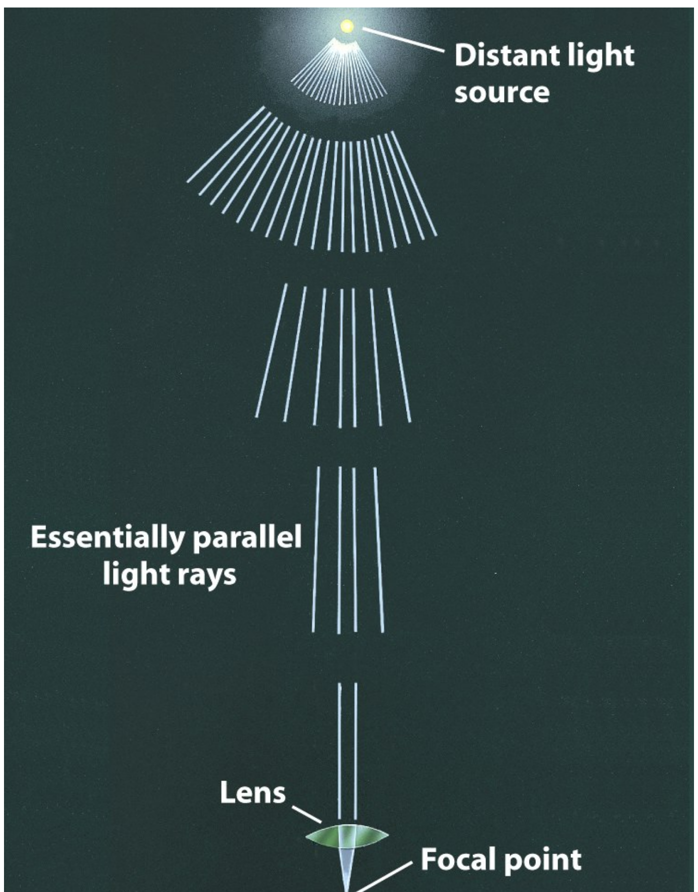
Refraction Telescope

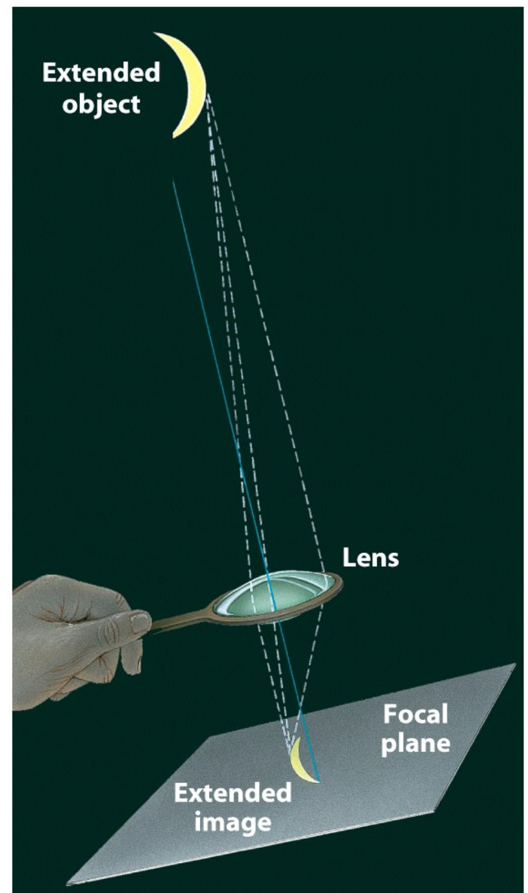
- **Refraction telescope uses a convex glass lens to form image**
- **Focal point**: when a parallel beam of light rays passes through the lens, refraction causes all rays to converge at a point called the **focus**
- **Focal length:** the distance from the lens to the focal point



Refraction Telescope

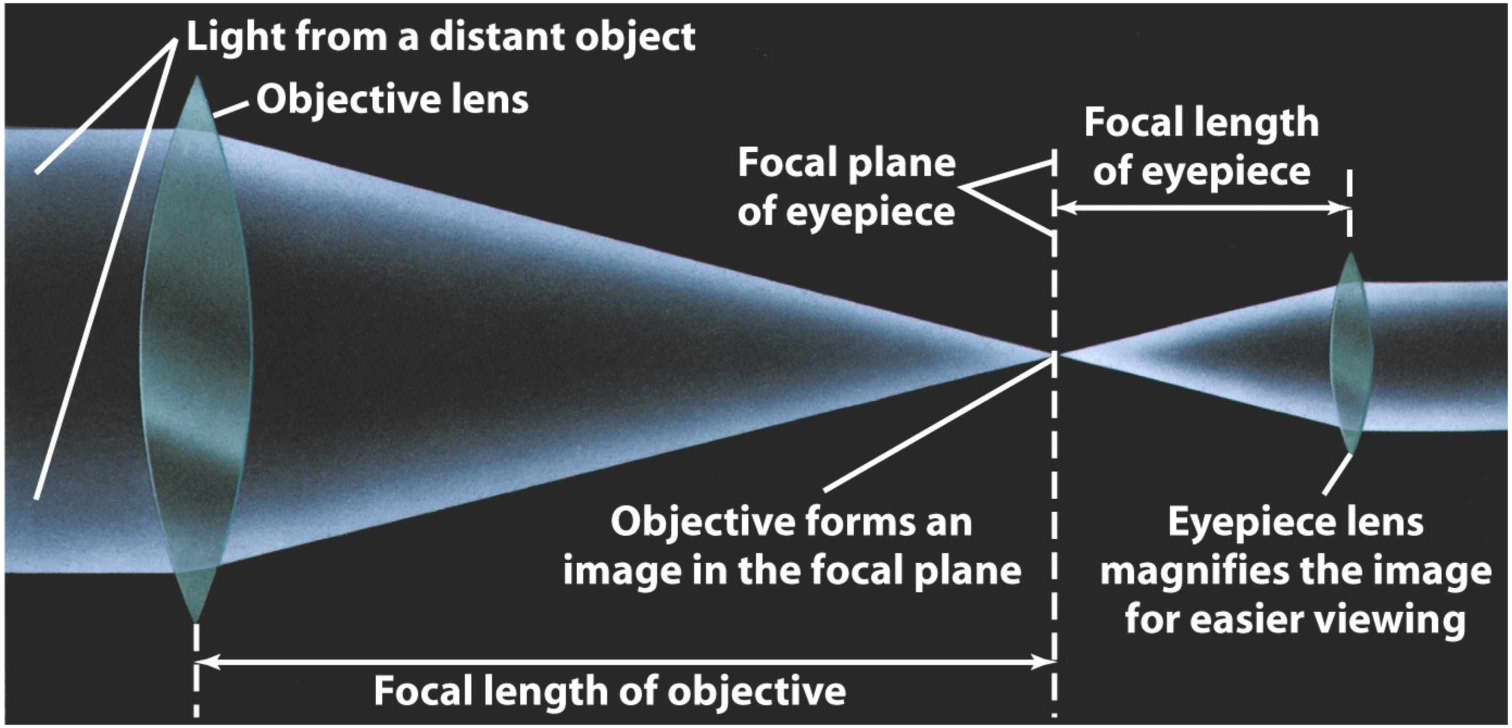
- The light rays from a distance point source, e.g., a star, is essential parallel, thus forming a point source at the focal point
- Extended objects, e.g., moon, planets, galaxy, nebula, form extended images





Refraction Telescope

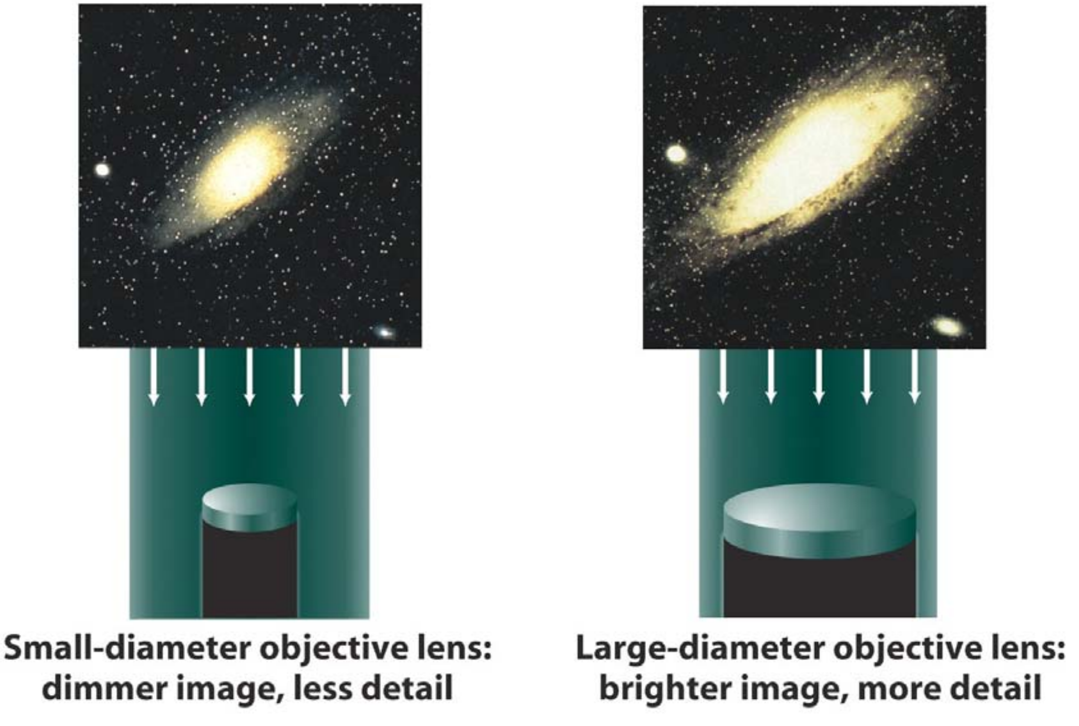
- A refraction telescope consists of
  - a large-diameter **objective lens** with a long focal length, and
    - used to gather light
    - used to form object image at the focal plane
  - a small **eyepiece lens** of short focal length
    - Used to magnify the images for viewing by naked eyes



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

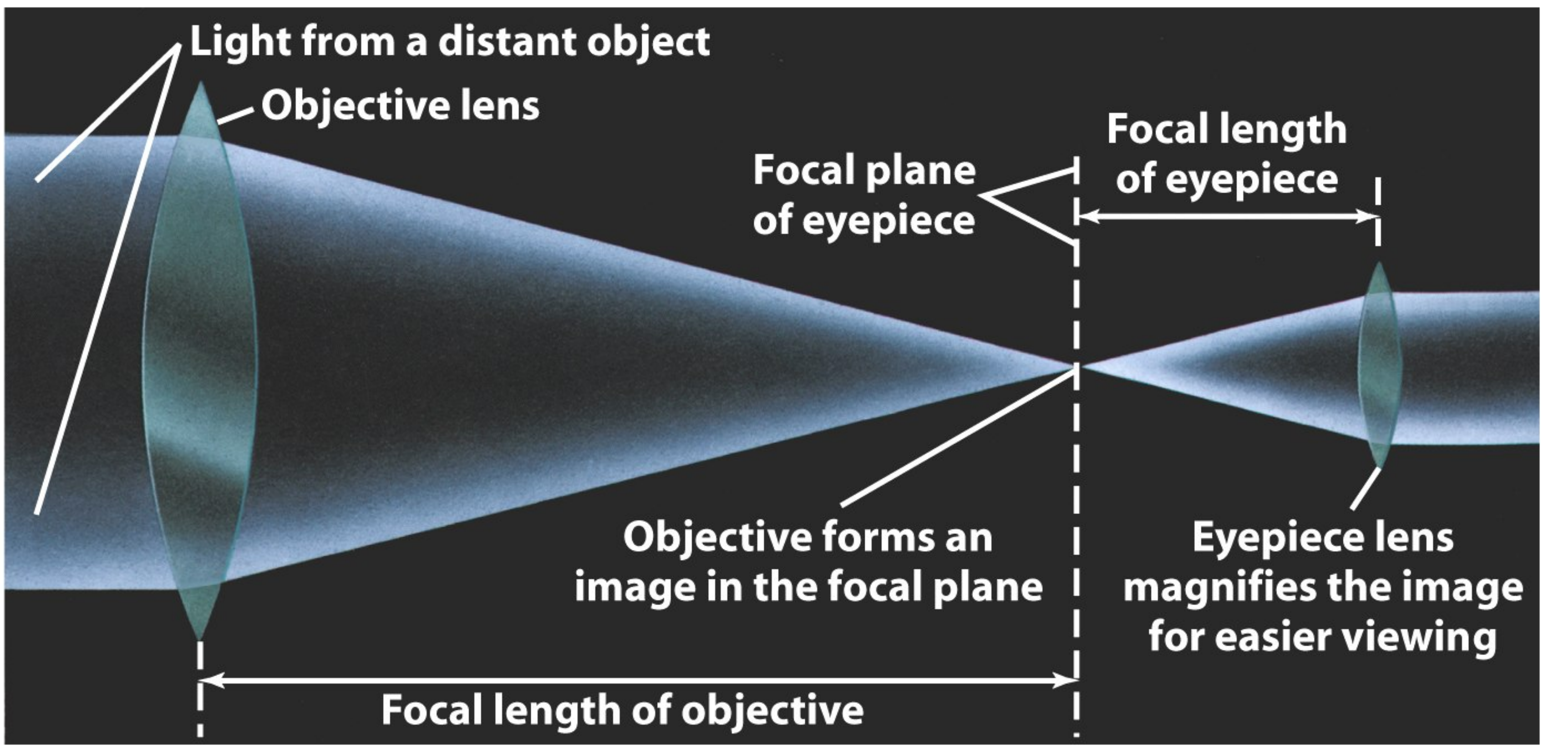
- Human iris: 3 mm
- Galileo's refraction telescope: 3 cm ; 100 times better in gathering light
- Modern telescope: 10 m ; 10,000,000 times



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

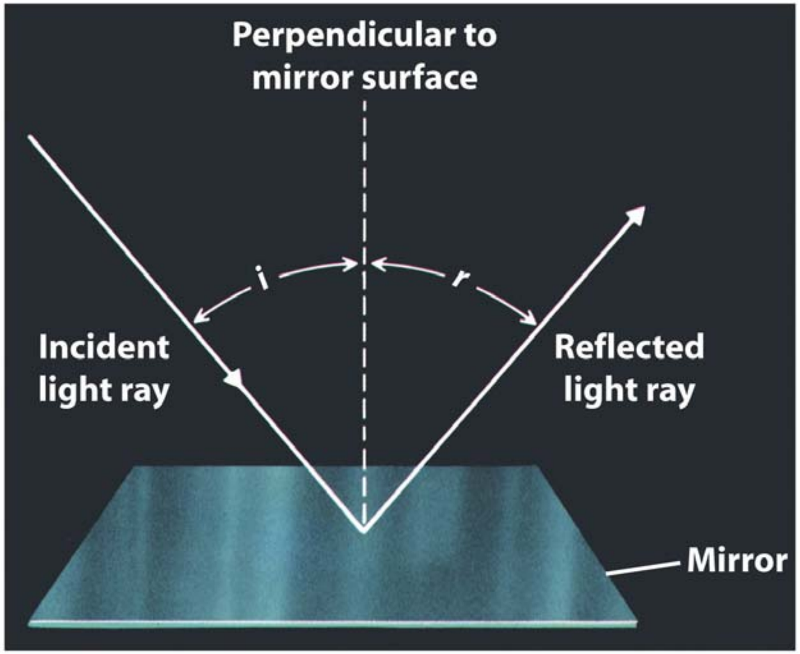


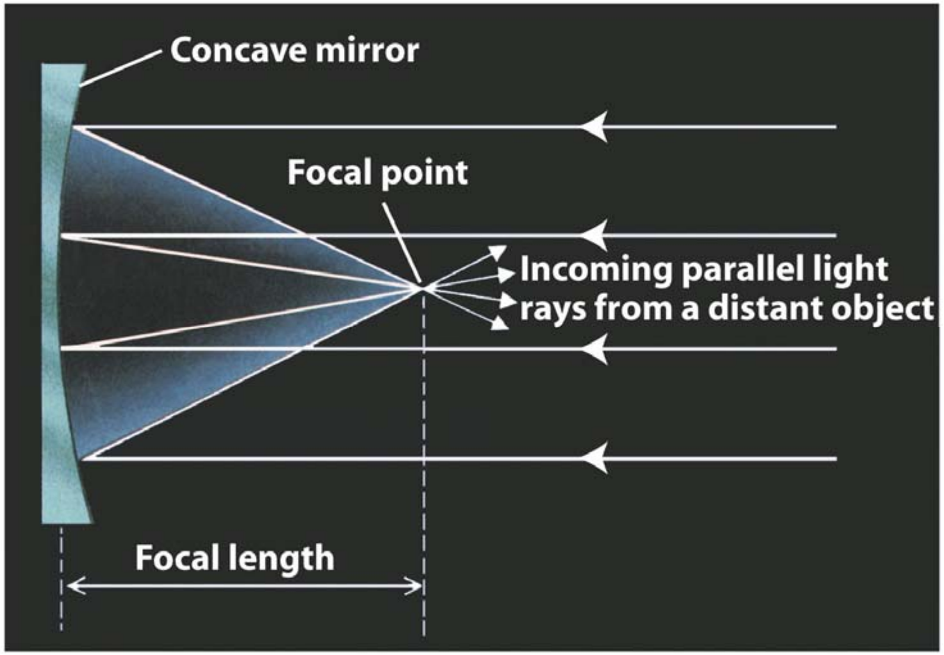
Refraction Telescope: limitation

- 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

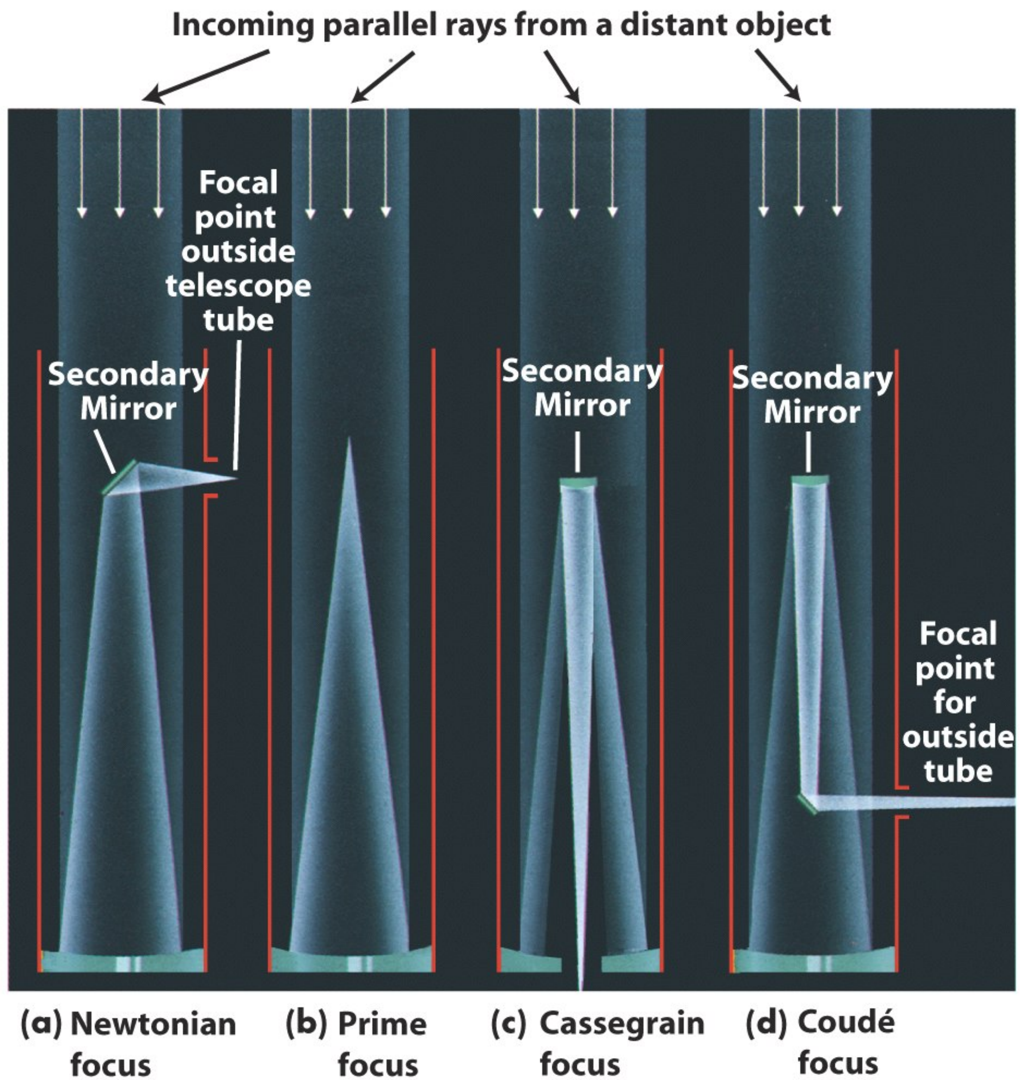
- Reflecting telescopes, or reflectors, produce images by reflecting light rays to a focus point from concave mirrors.
- Reflectors are not subject to most of the problems that limit the useful size of refractors.
- The mirror that forms the image is called **objective mirror**, or **primary mirror**



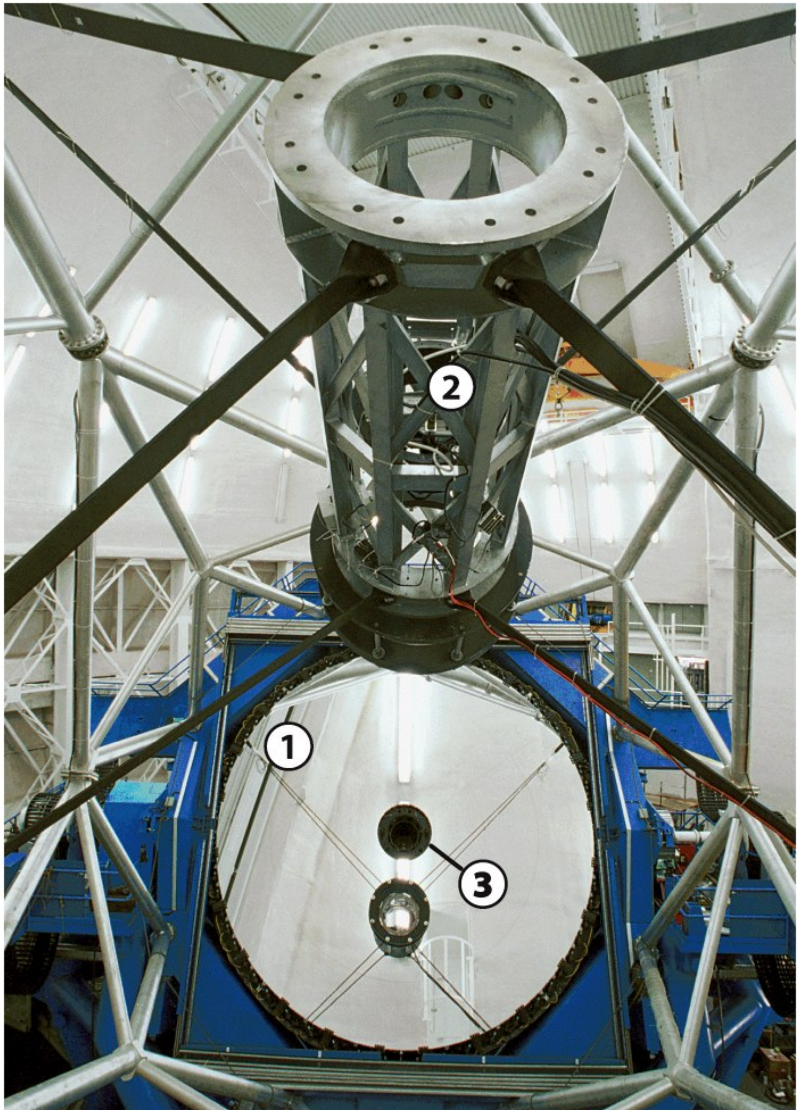


Reflection Telescope: Designs

- Four popular optical design.
  1. Newtonian focus
  2. Prime focus
  3. Cassegrain focus
  4. Coude focus
- **The secondary mirror does not cause a hole in the image**
  – Any small portion of the primary mirror can make a complete image



Reflection Telescope: Designs



Gemini North Telescope

1. The 8.1-meter objective mirror
2. The 1.0-meter secondary mirror
3. The hole in the objective mirror to the Cassegrain focus

Reflection Telescope

- All the largest optical telescopes in the world are reflectors.

table 6-1 The World's Largest Optical Telescopes

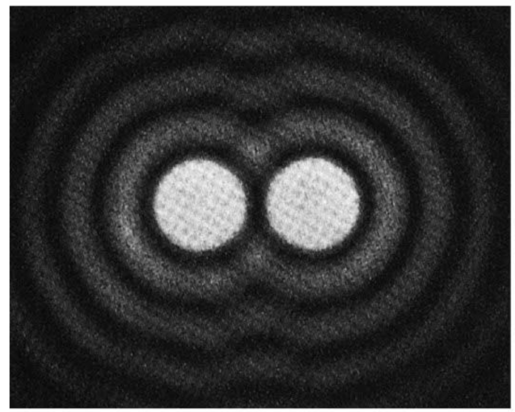
Telescope	Location	Year of completion	Mirror diameter (m)
Gran Telescopio Canarias	La Palma, Canary Islands, Spain	2004	10.4
Keck II	Mauna Kea, Hawaii	1996	10.0
Keck I	Mauna Kea, Hawaii	1993	10.0
Hobby-Eberly Telescope	McDonald Observatory, Texas	1998	11.0*
South African Large Telescope	Sutherland, South Africa	2004	9.2
Large Binocular Telescope	Mount Graham, Arizona	2004–05	Two 8.4
Subaru	Mauna Kea, Hawaii	1999	8.3
VLT UT 1–Antu	Cerro Paranal, Chile	1998	8.2
VLT UT 2–Kueyen	Cerro Paranal, Chile	1999	8.2
VLT UT 3–Melipal	Cerro Paranal, Chile	2000	8.2
VLT UT 4–Yepun	Cerro Paranal, Chile	2000	8.2
Gemini North (Gillett)	Mauna Kea, Hawaii	1999	8.1
Gemini South	Cerro Pachón, Chile	2000	8.1

**The objective mirror of the Hobby-Eberly Telescope is 11.0 m in diameter, but in operation only an area of 9.2 m in diameter is used to collect light.*

Angular Resolution

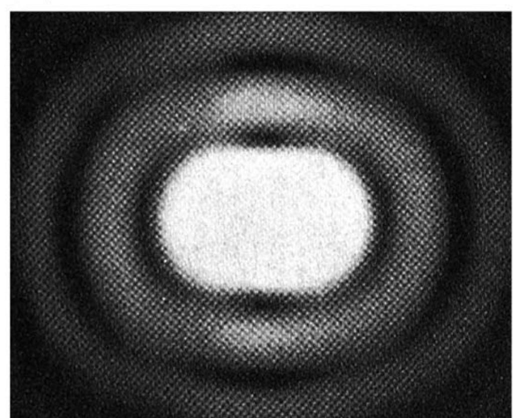
- Angular resolution: the minimum angular size two close objects can be resolved by the observations
- The second goal of a telescope is to achieve high **angular resolution**, besides the primary goal of light-gathering

- 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)

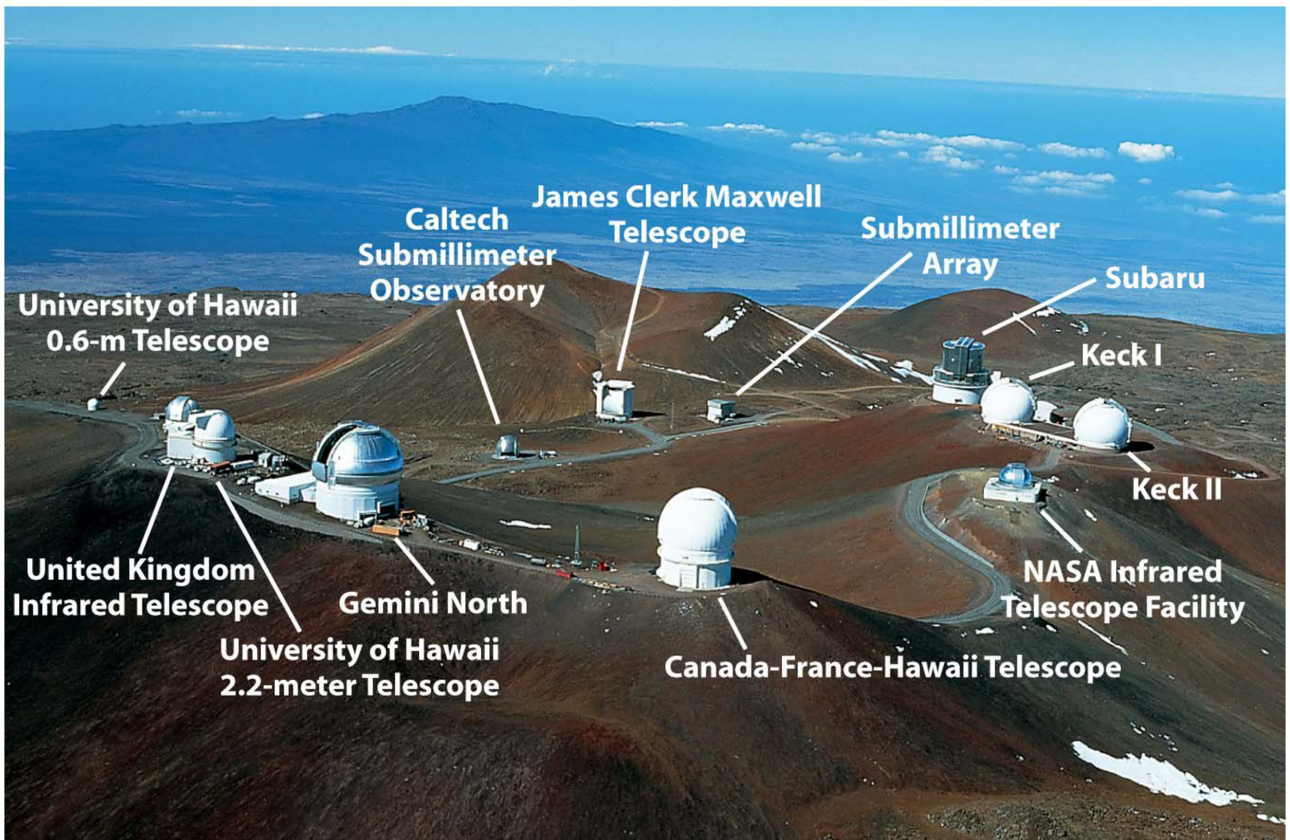
Light sources moved closer so that angular separation equals angular resolution of telescope: Just barely possible to tell that there are two sources

Angular Resolution: Diffraction Limit

- Angular resolution of a telescope can not be infinite small, instead it is limited by the size of the objective mirror or lens.
- This limitation on angular size is caused by the **diffraction** of light wave, which is a tendency of light waves to spread out when they are confined to a small area like mirrors
- Diffraction limited angular size: the larger the size of the objective mirror, the smaller 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

Angular Resolution: Seeing

- 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.

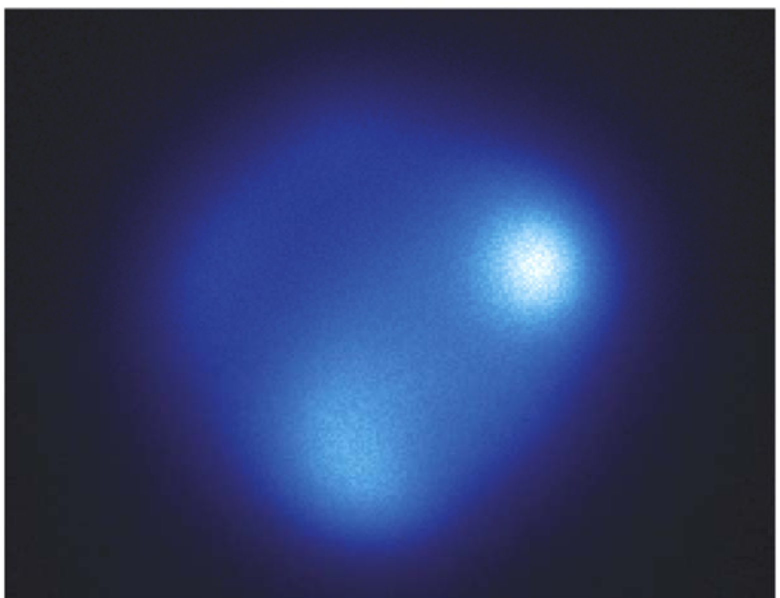


Mauna Kea in Hawaii

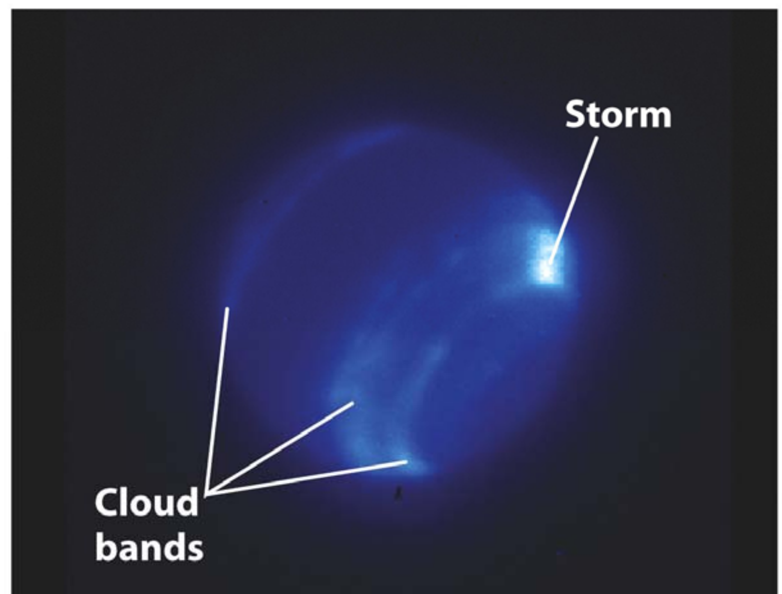
0.5 arcsec seeing

Angular Resolution

- **Adaptive optics** is an effective way for large ground-based telescope to reduce the seeing
    - Optical sensor monitor the dancing motion of celestial objects 10 to 100 times per second; the dancing motion is caused by turbulence
    - Fast-acting mechanical devices deform the mirror accordingly to make sharp focus of images
- Putting telescopes in space will completely eliminate the seeing

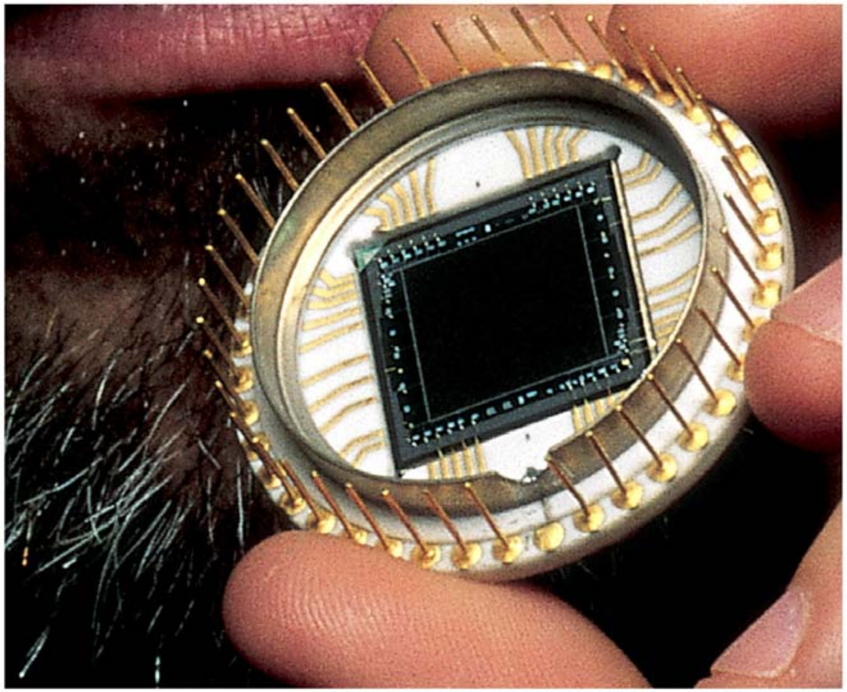


(a) Neptune viewed without adaptive optics



(b) Neptune viewed with adaptive optics

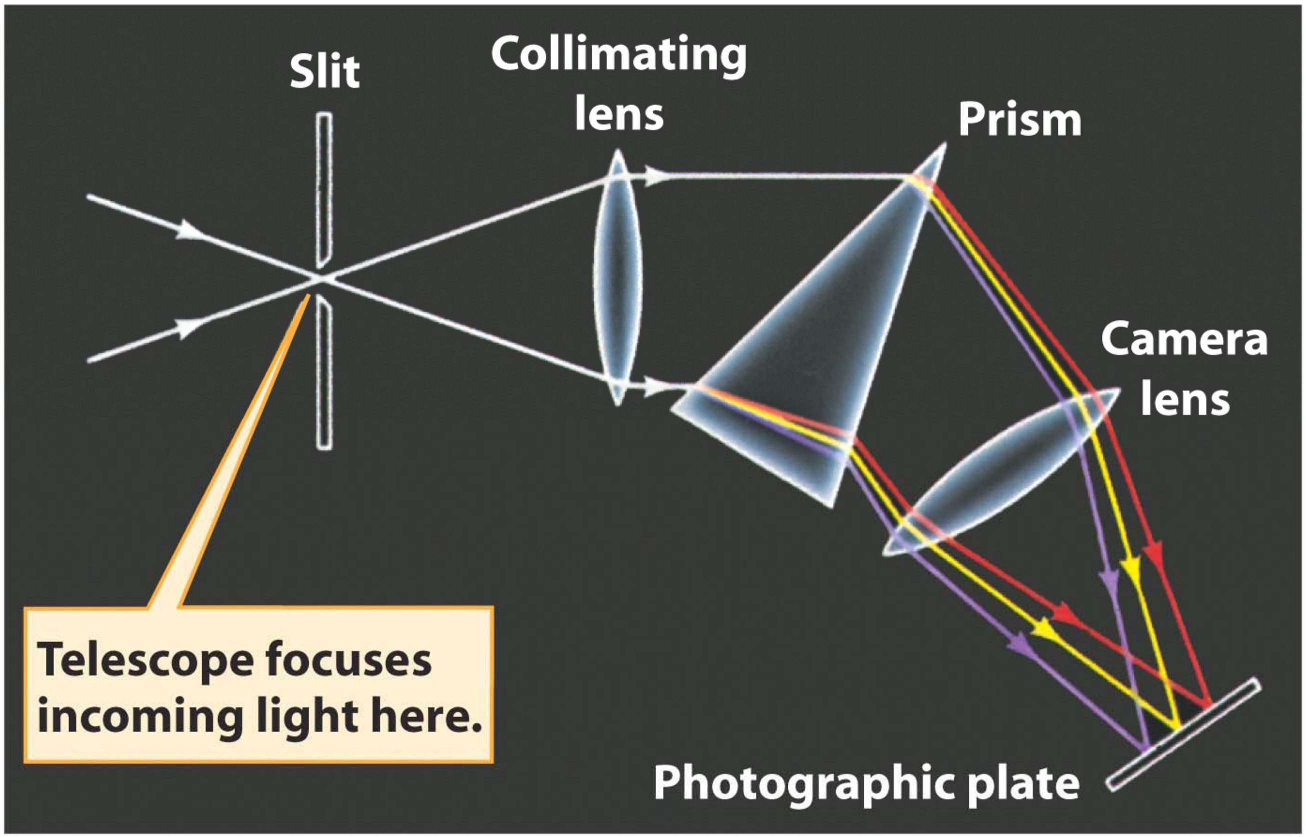
Image Recording: CCD



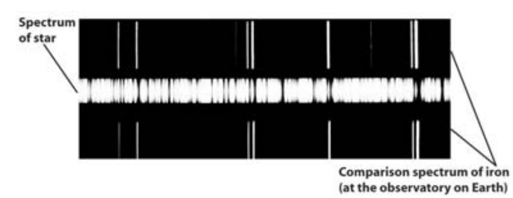
- Sensitive light detectors called charge coupled devices (**CCDs**) are often used at a telescope's focus to record faint images.
- CCD is far more better than the old-fashioned photographic film.

Spectrograph

- A spectrograph records spectrum of an astronomical object



A Classic Prism Spectrograph

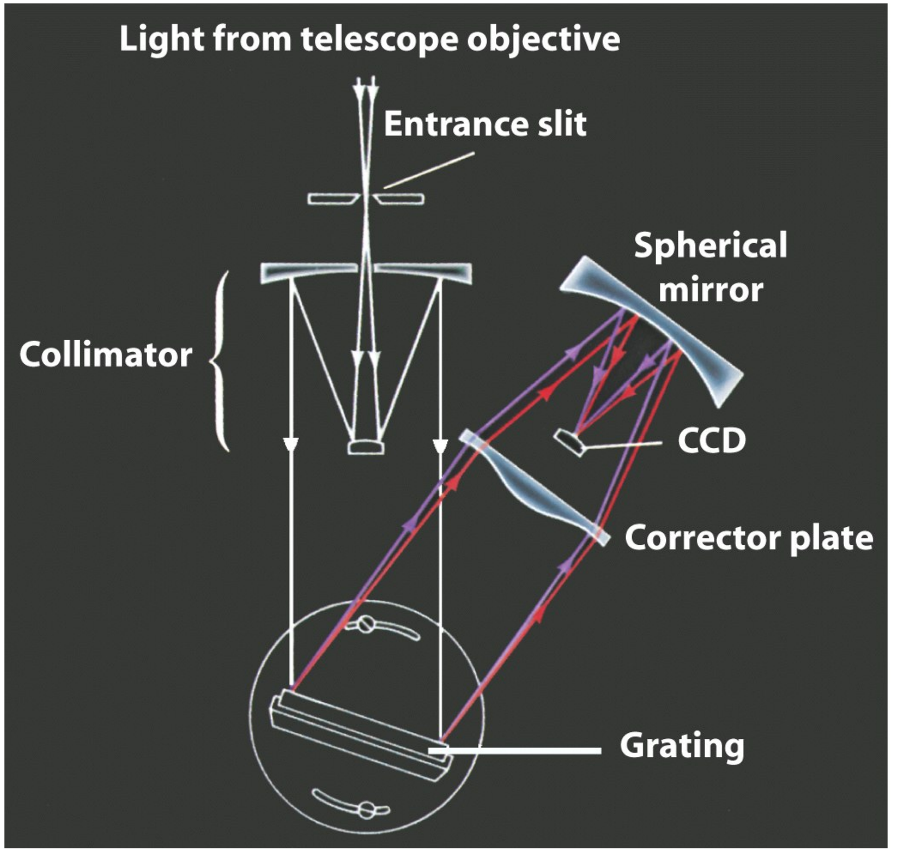


Spectrograph

•**Grating** device is a better way to break up light into spectrum, or achieving a higher spectral resolution

•**Grating** device is a piece of glass on which thousands of closely spaced parallel lines have been cut.

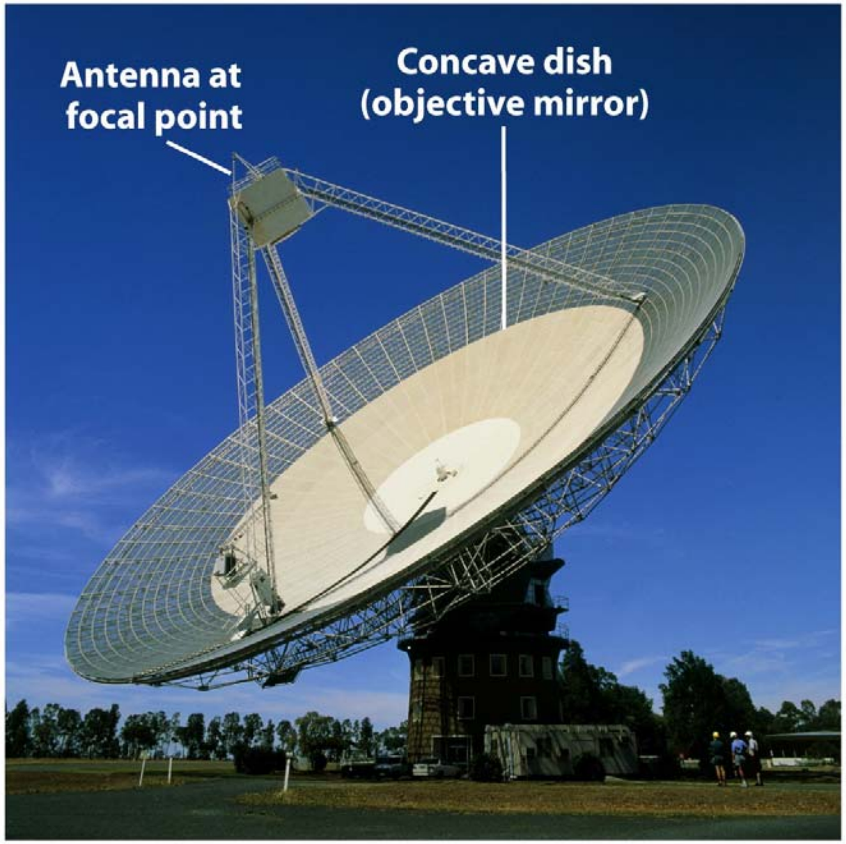
- The diffraction of light from these lines produce the spectrum.
- This is the same effect you see colors from a CD or DVD



Modern Grating Spectrograph

Radio Telescope

- Radio telescopes use large reflecting antennas or dishes to focus radio waves
- Very large dishes provide reasonably sharp radio images



Radio Telescope

•Very high angular resolution can be achieved by using multiple radio telescopes to observe the same object, and combine the signals together

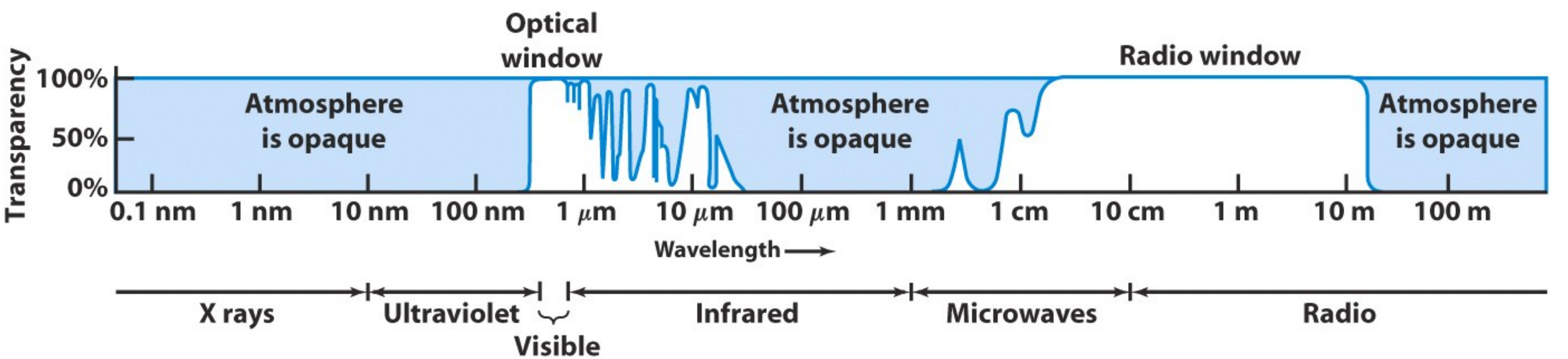
- This technique is called **interferometry**
- The longer the distance between two telescopes, the better the angular resolution

Very Large Array (VLA)

- 27 radio telescope
- Baseline 21 km long
- At New Mexico

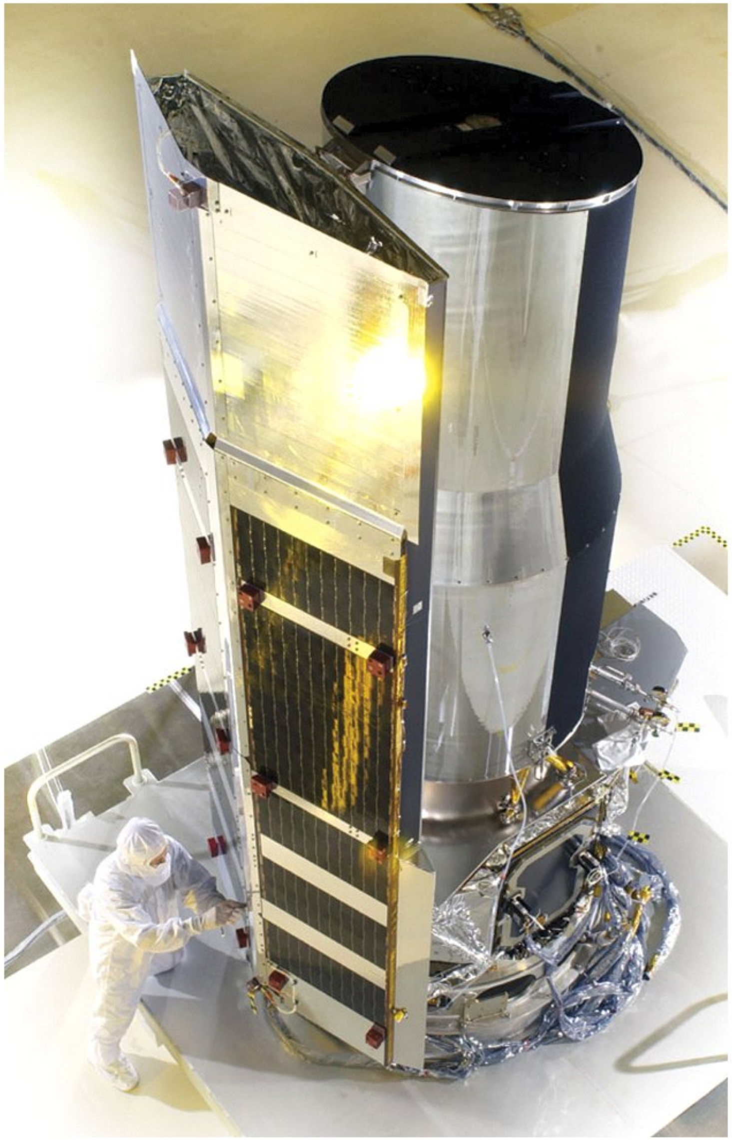
Telescopes in orbit

- The atmosphere is transparent chiefly 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.
- Ground-based telescopes are limited to optical and radio telescopes.



Transparency of The Earth's Atmosphere

Telescopes in orbit



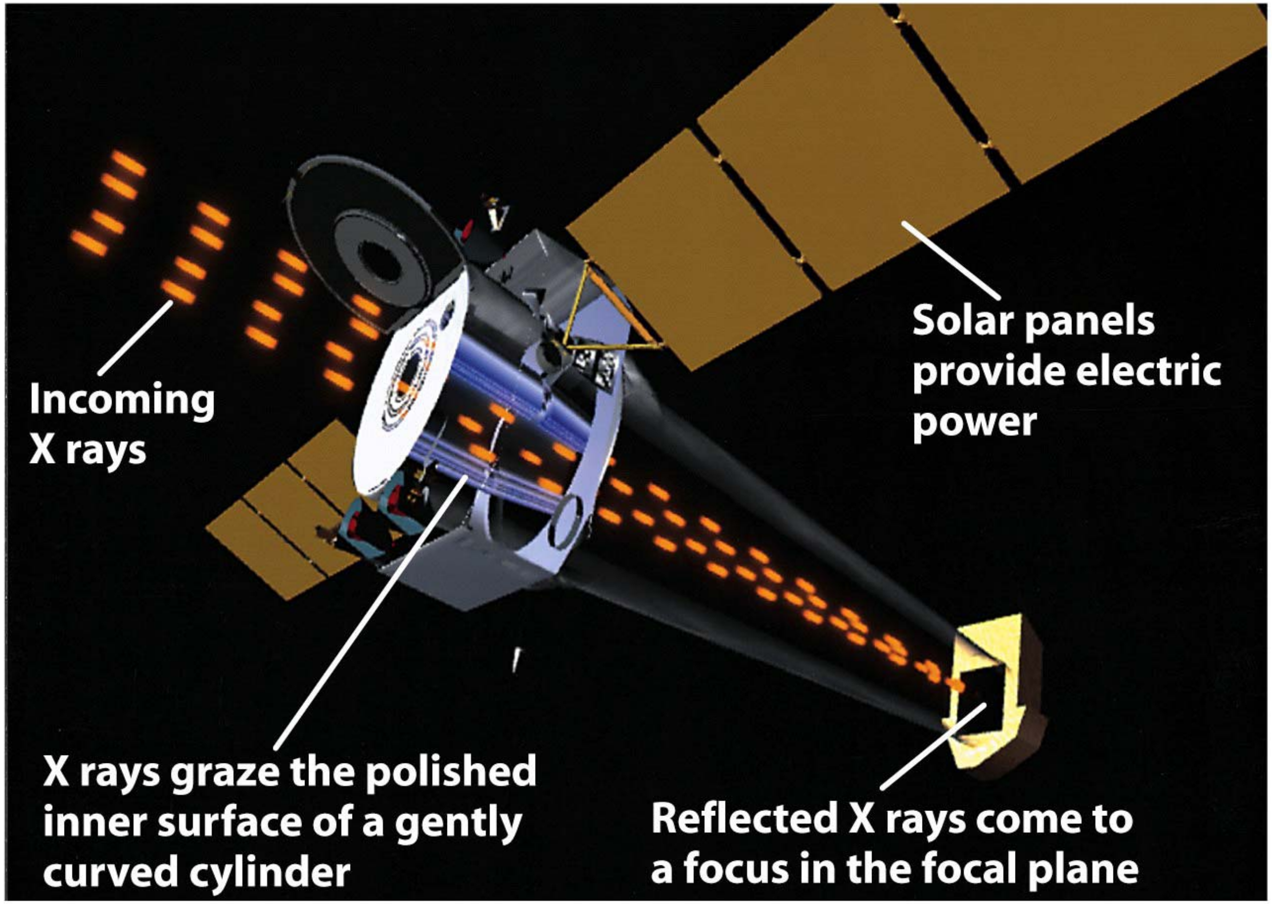
Spitzer Space Telescope

- 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

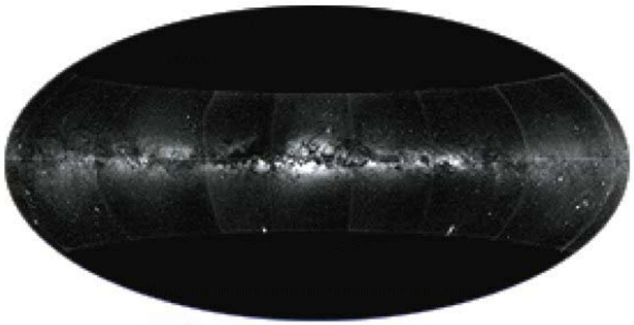
Chandra Space Telescope

- Launched in 1999;   View the X-ray sky

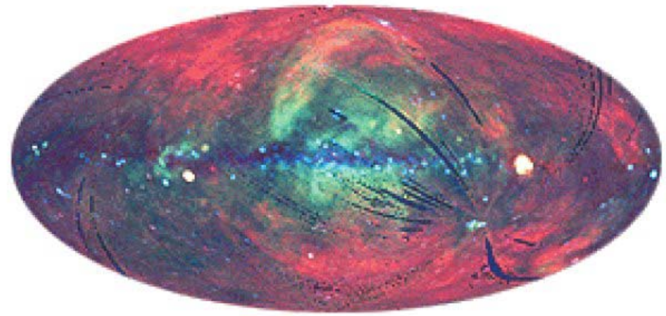


(a) Chandra X-ray Observatory

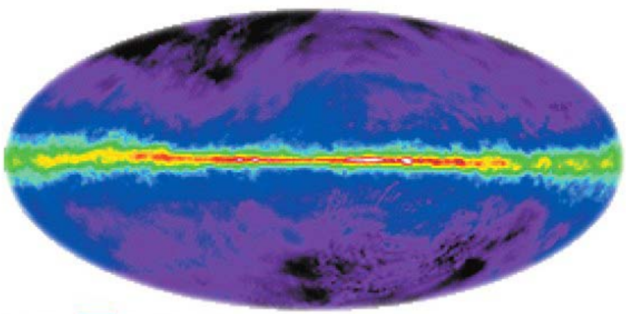
Telescopes in orbit



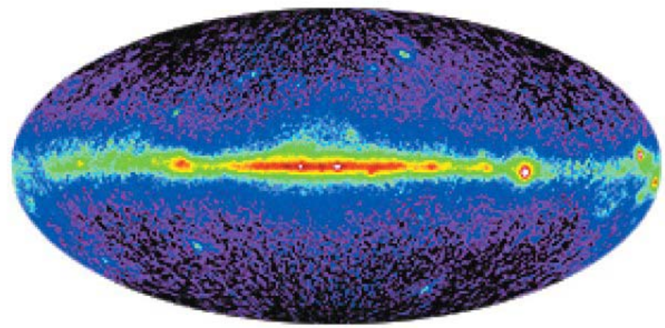
(a) R I V U X G



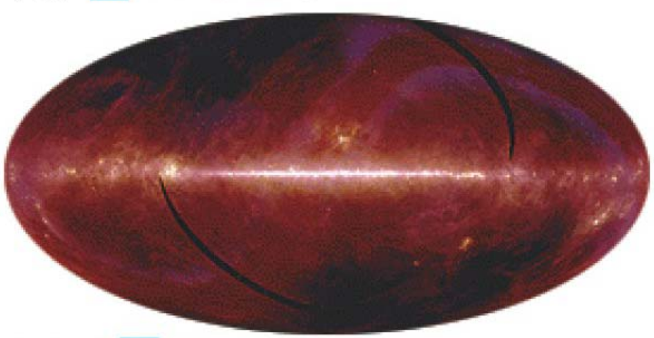
(d) R I V U X G



(b) R I V U X G



(e) R I V U X G



(c) R I V U X G

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, all studied.