Astro 377
Experimental Astronomy

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Due Today

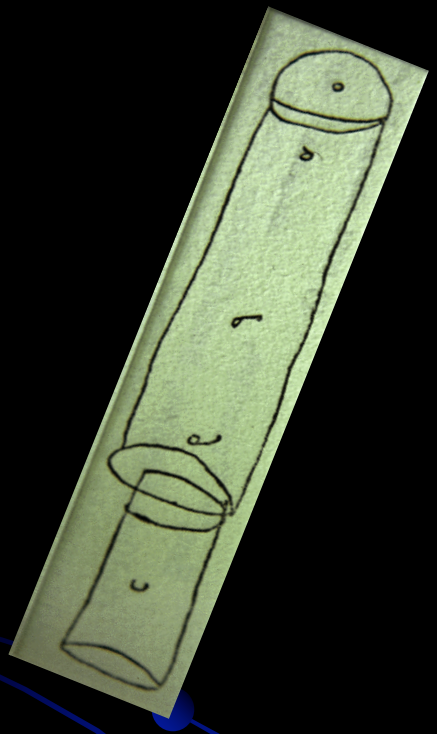
- *Assignment 1*

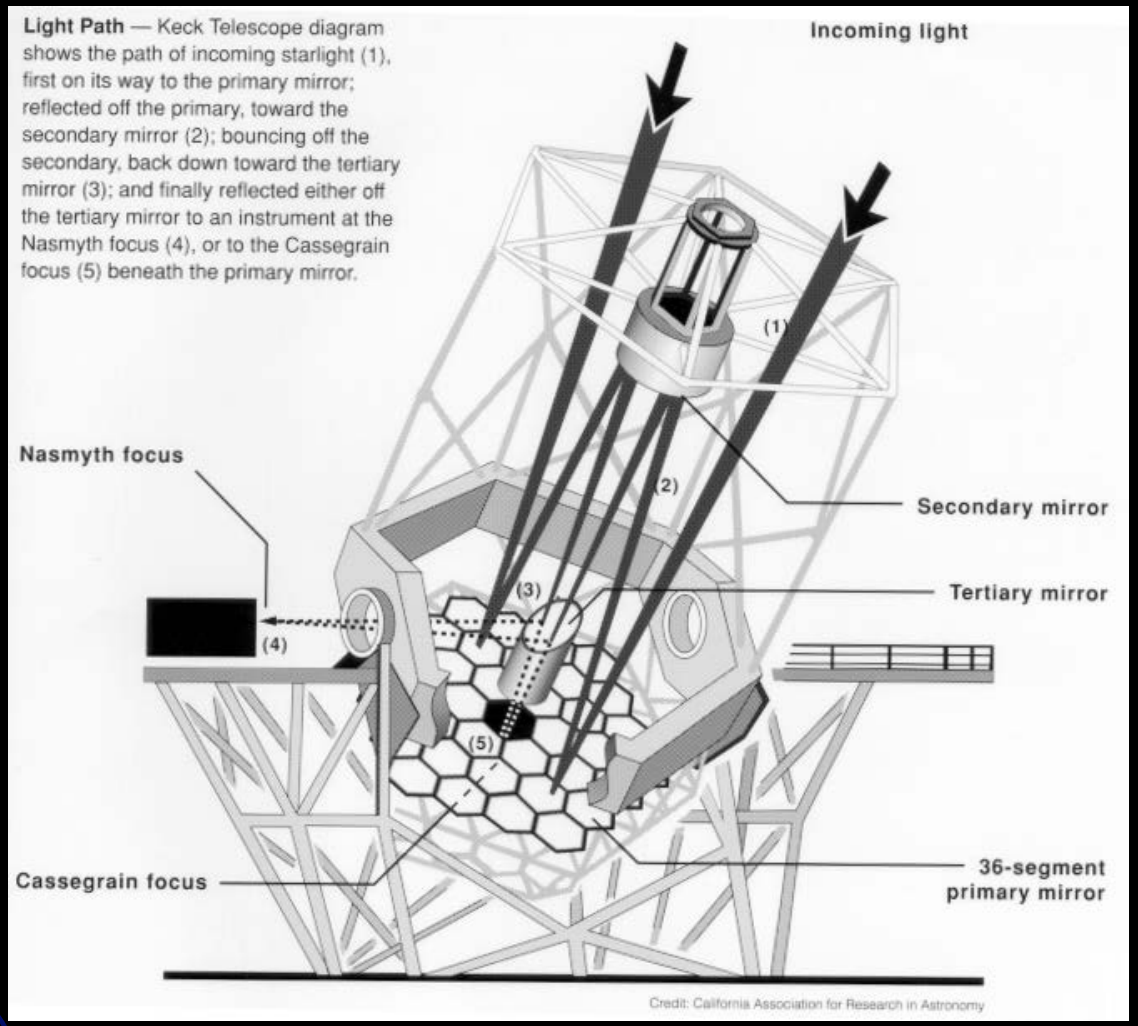
Due Aug 29

- Assignments *2*

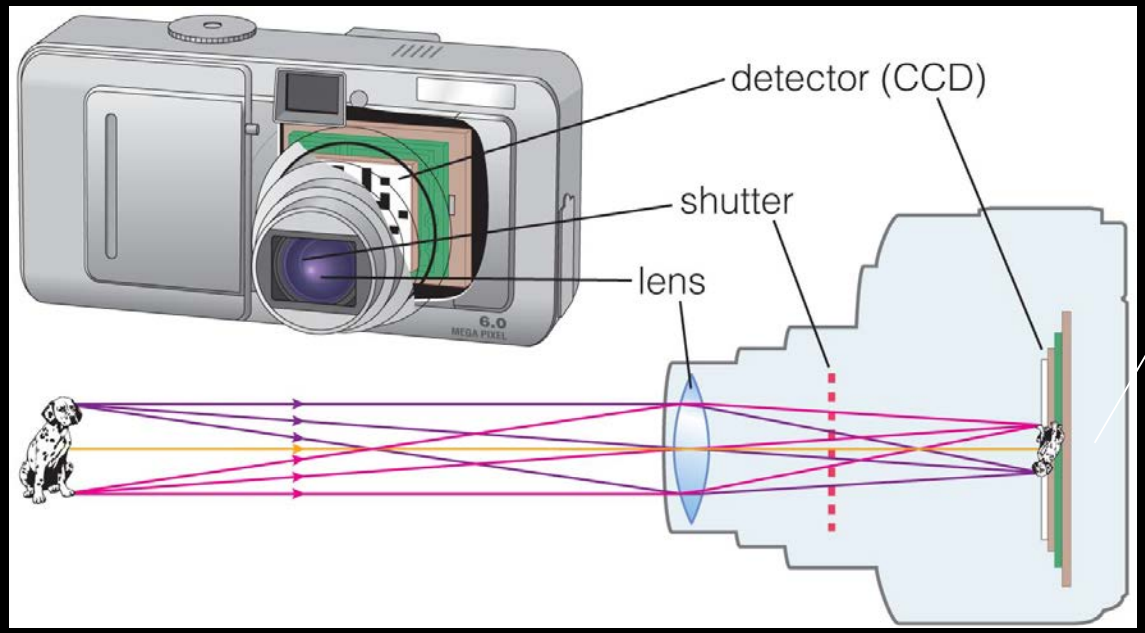
Can be found on OAKS

Telescopes Portals of Discovery





Recording Images



Digital cameras detect light with charge-coupled devices (CCDs).

- A camera focuses light like an eye and captures the image with a detector.
- The CCD detectors in digital cameras are similar to those used in modern telescopes.

Refraction

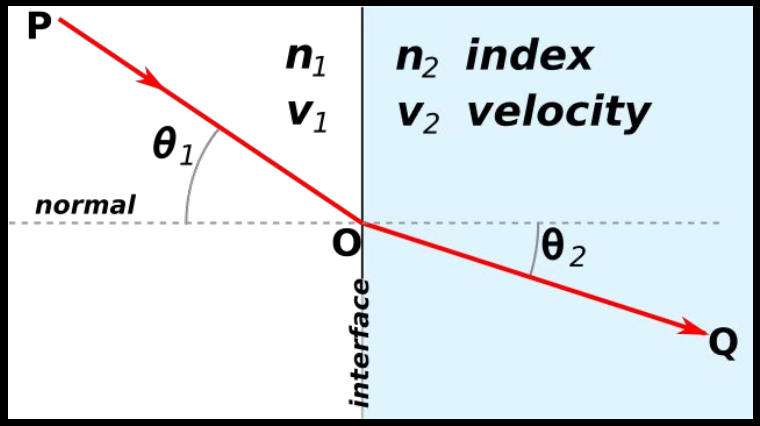
To understand telescopes we need to discuss refraction.

Refraction is the change in direction of light due to a change in its speed. This usually happens when light goes from one type of medium to another.

Refraction is described by **Snell's law**, which states that the angle of incidence θ_1 is related to the angle of refraction θ_2 by:

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2} = \frac{n_2}{n_1}$$

where n_1 and n_2 are the indices of refraction of the two media. $n = \frac{c}{v}$



Light-Collecting Area

The **light-collecting area** of a telescope is proportional to the area of the telescopes objective lens or mirror:

$$A = \pi R^2 = \frac{\pi D^2}{4}$$

where, D is the lens or mirror diameter.

Example: Each of the two Keck telescopes on Mauna Kea in Hawaii uses a concave mirror 10 m in diameter to bring starlight to a focus.

Angular Resolution

An important property of a telescope is its **angular resolution**.

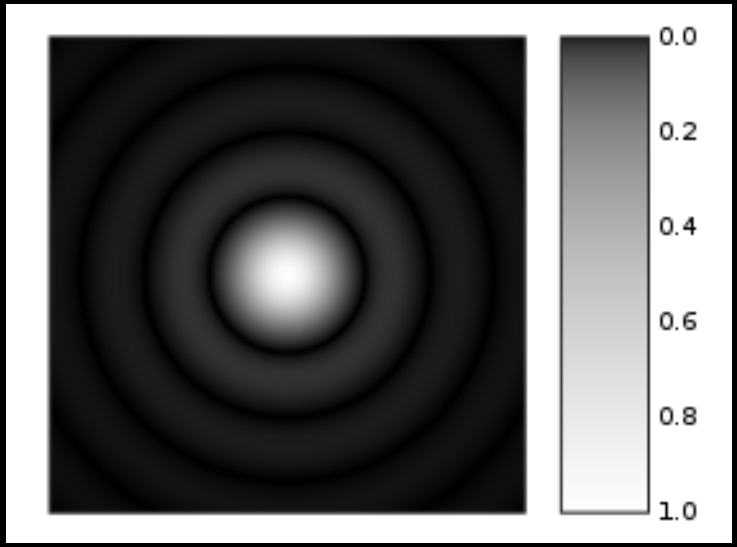
Angular resolution of a telescope is **the angular size of the smallest feature that can be distinguished**.

The angular resolution of your eye (for 20/20 vision) is about 1 arcmin. The planets have angular sizes of less than 1 arcmin and this is why they appear as points.

The angular resolution will depend on:
- **the quality of the mirrors, mirror design**
- **diffraction**
- **atmospheric turbulence (seeing)**

Diffraction

The light collected by a telescope at the focal point is not focused to a point but forms a **diffraction pattern** having a central peak with a angular size between the peak and the first null:



Diffraction by a circular aperture. Notice the variation of intensity with angle.

$$\theta(arc\,\sec) = 2.5 \times 10^5 \frac{\lambda}{D}$$

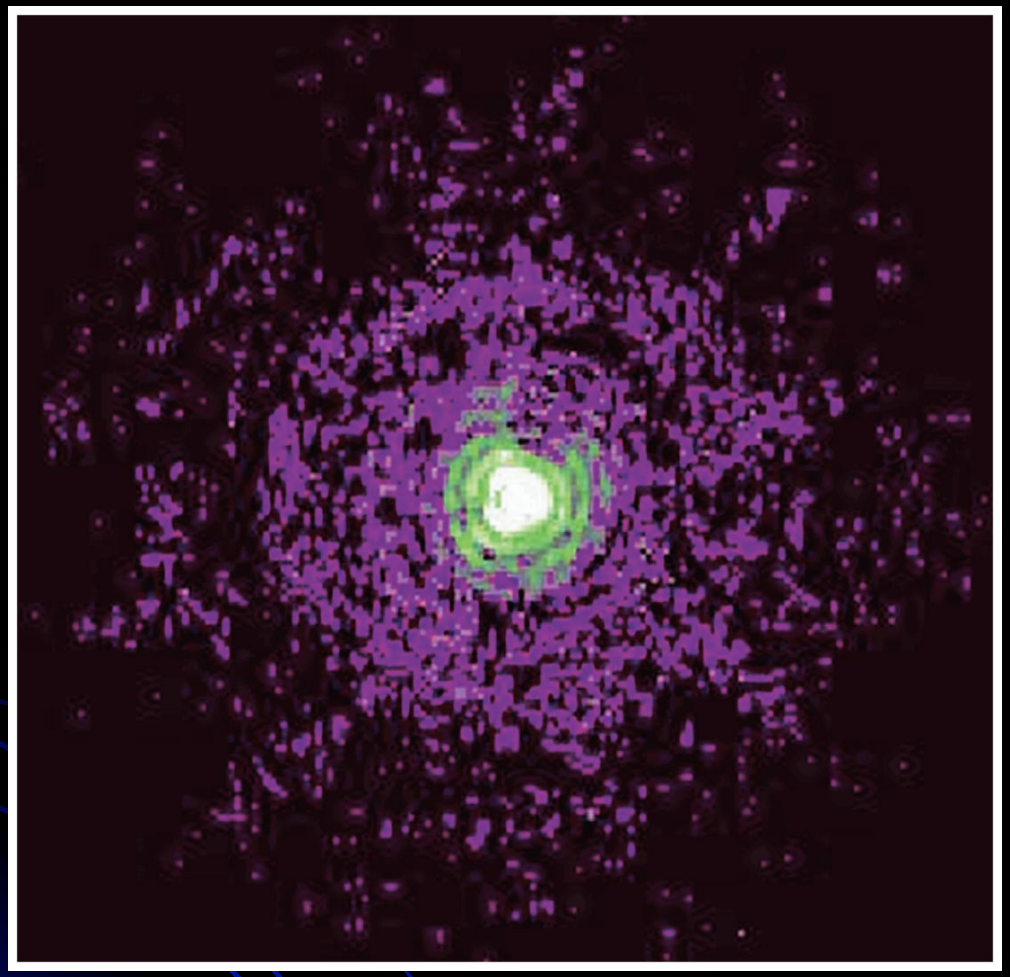
θ = diffraction-limited angular resolution of a telescope, in arcseconds

λ = wavelength of light, in meters

D = diameter of telescopes objective, in meters

Question: What is the diffraction limited angular resolution of the Keck telescope (D = 10 m) at H_α.

Angular Resolution



Close-up of a star from the Hubble Space Telescope

- The rings in this image of a star come from diffraction of light waves.
- This limit on angular resolution is known as the **diffraction limit**.

Seeing Disk

Turbulence in the atmosphere will blur an image. Even through the largest telescopes that are not limited by diffraction a point source looks like a blob.

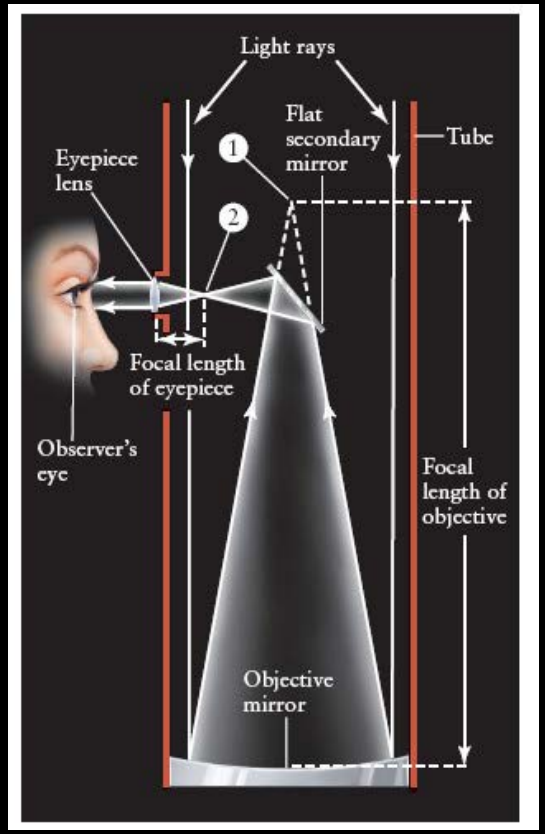
The angular size by which a stars size is broadened due to the atmosphere is called the **seeing disk**.

The size of the seeing disk depends on the location of the observations. For example, on **Kitt Peak** in Arizona and **Cerro Tololo** in Chile, the seeing disk is typically around 1 arcsec.

Types of Reflecting Telescopes

1. In a Newtonian telescope, the image made by the objective is moved from point 1 to point 2 by means of a flat mirror called the secondary. An eyepiece magnifies this image, just as for a refracting telescope.

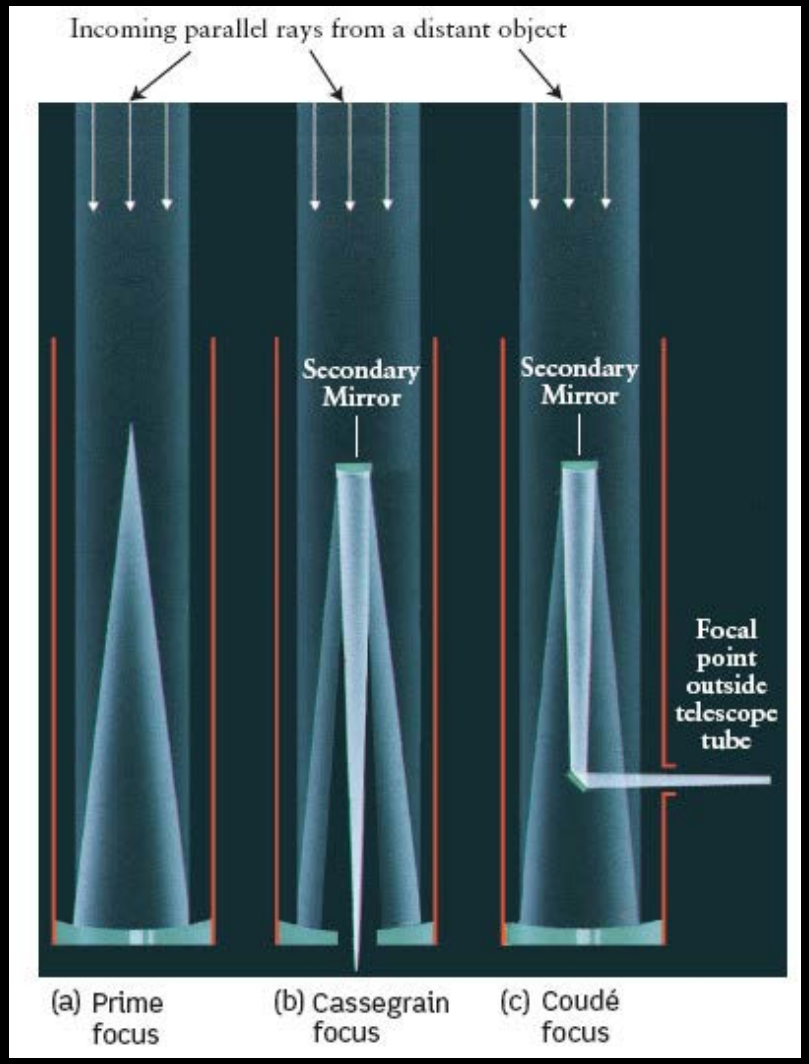
The magnification of a Newtonian is the ratio of the focal length of the objective to the focal length of the eyepiece: M = f1/f2



Types of Reflecting Telescopes

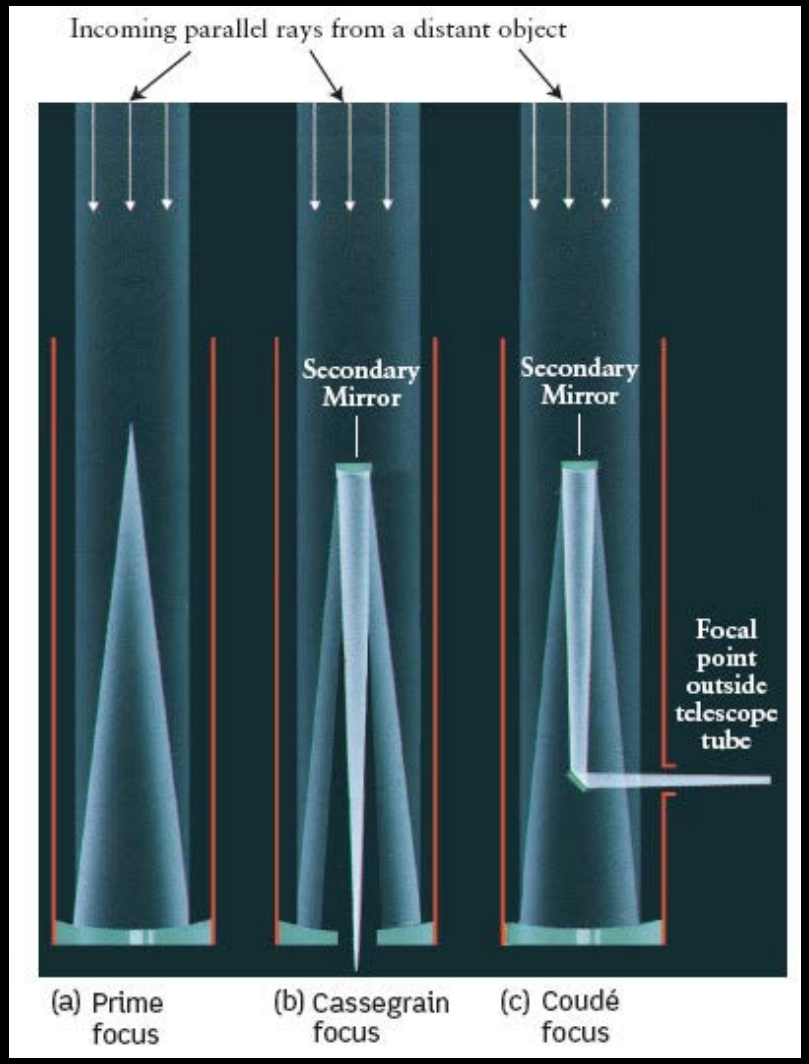
2 Prime Focus: The focal point is in front of the mirror. It has been used in some large telescopes and it usually provides the highest-quality image, because there is no need for a secondary mirror.

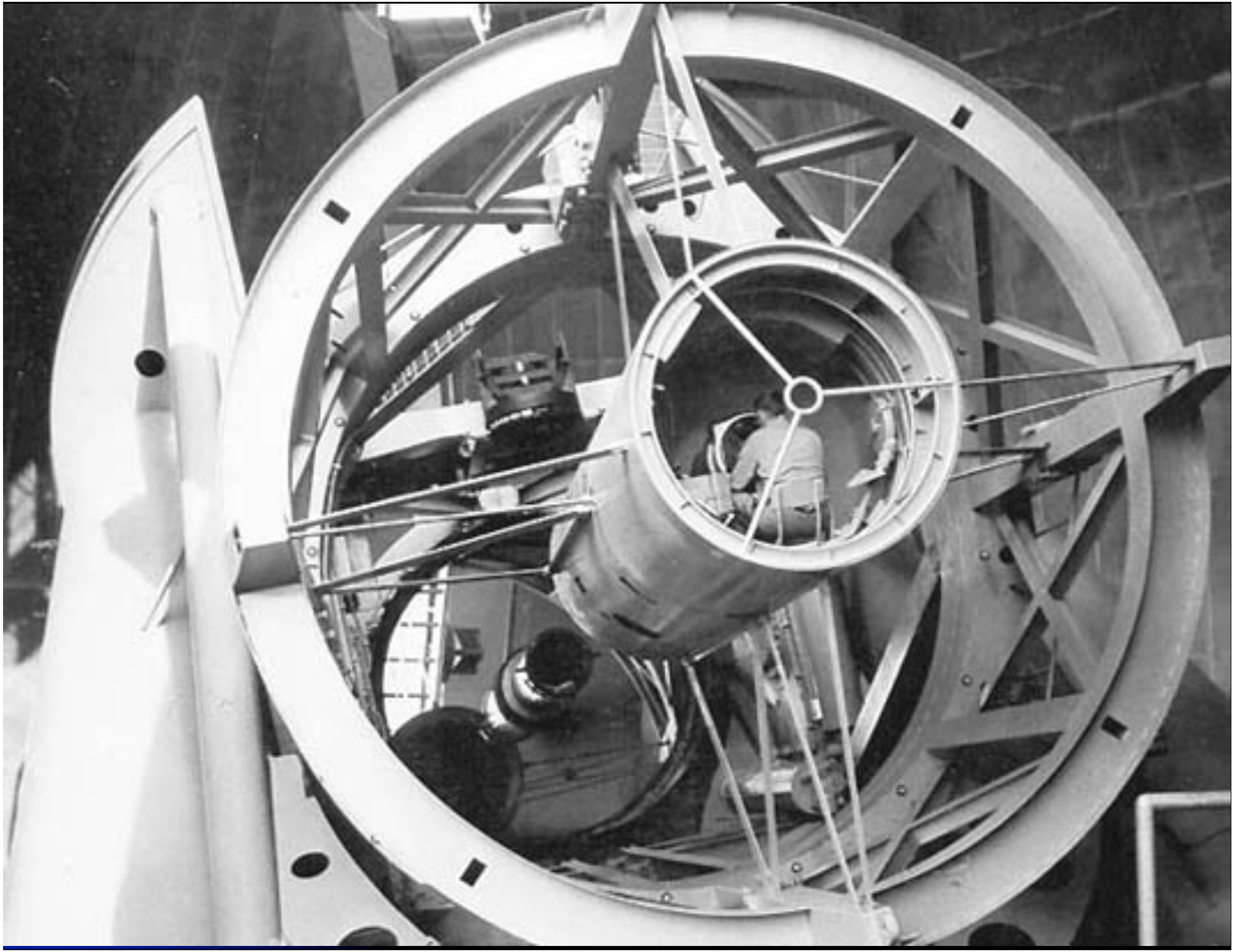
3. Cassegrain Focus: A hole is drilled directly through the center of the primary mirror, and a convex secondary mirror placed in front of the original focal point reflects the light rays back through the hole.



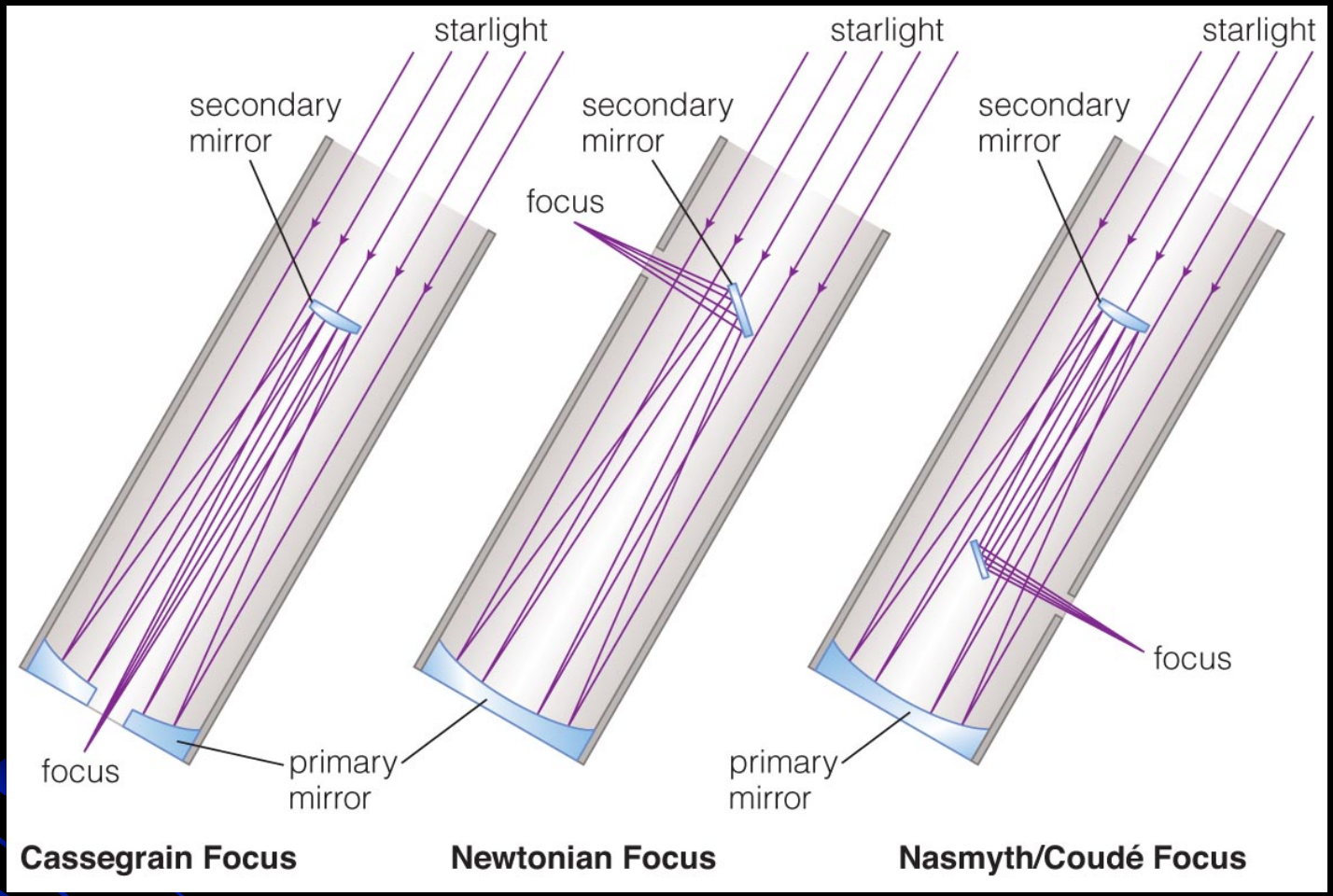
Types of Reflecting Telescopes

4 Coude Focus: a series of mirrors channels the light rays away from the telescope to a remote focal point where the equipment is located.





Designs for Reflecting Telescopes



The magnification of Newtonian and Cassegrain telescopes is the ratio of the focal length of the objective to the focal length of the eyepiece: M = f1/f2

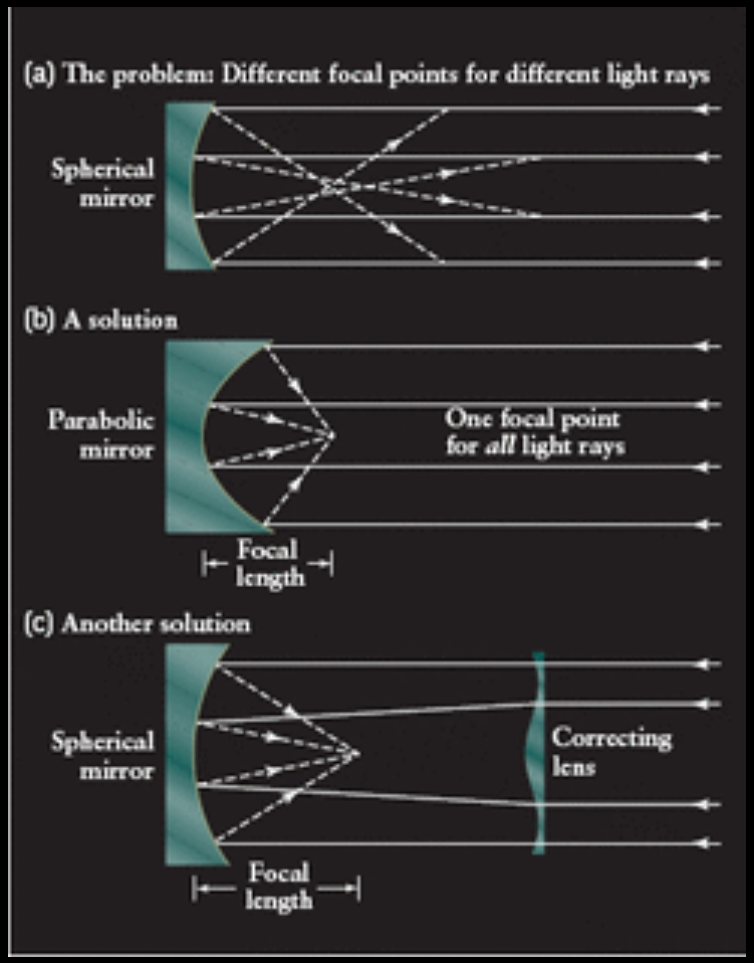
Spherical Aberration of Reflectors

Different parts of a spherically concave mirror reflect light to slightly different focal points. This effect, called spherical aberration, causes image blurring.

Spherical aberration can be corrected by using :

- a parabolic objective mirror

- or using a correcting mirror



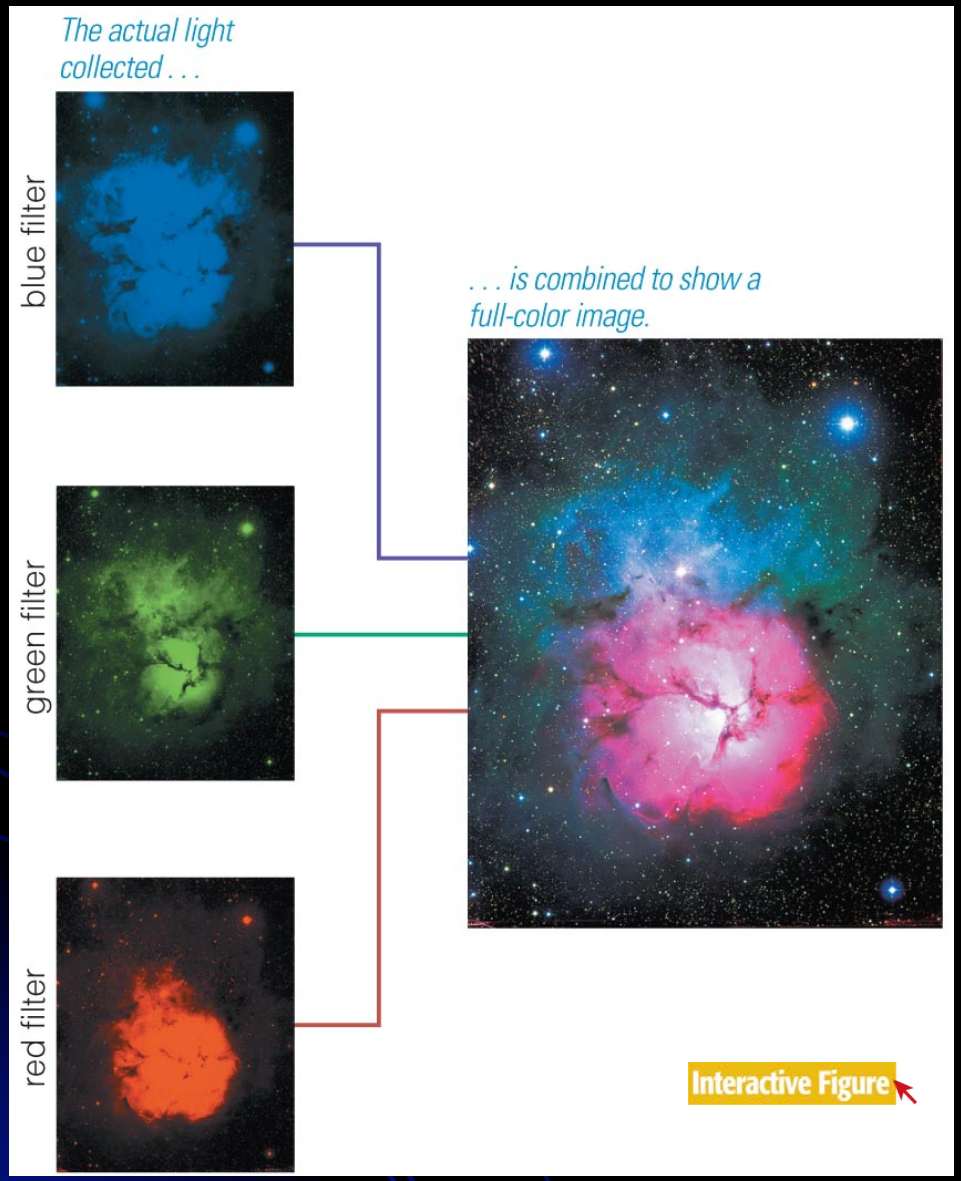
Ritchey-Chretien Reflectors

The Ritchey-Chretien telescope is a Cassegrain reflector that is specialized to eliminate coma. Coma makes off axis sources appear as tear drops.

A Ritchey-Chretien telescope has a hyperbolic primary and a hyperbolic secondary mirror.

The twin Keck telescopes on Mauna Kea are among the largest optical/near-infrared instruments currently in use around the world.

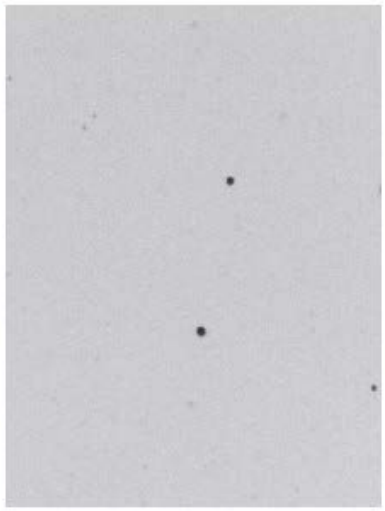
Imaging

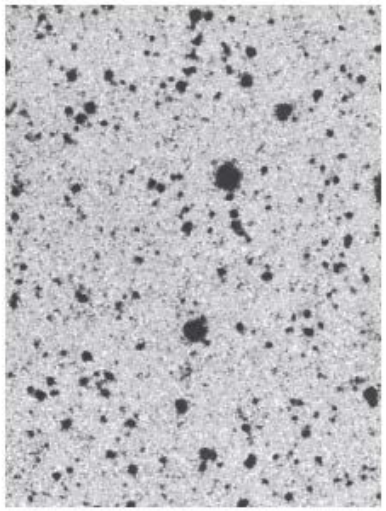


- Astronomical detectors generally record only one color of light at a time.
- Several images must be combined to make full-color pictures.

Imaging instruments used in astronomy

(a) A mosaic of 40 charge-coupled devices (CCDs)


(b) An image made with photographic film

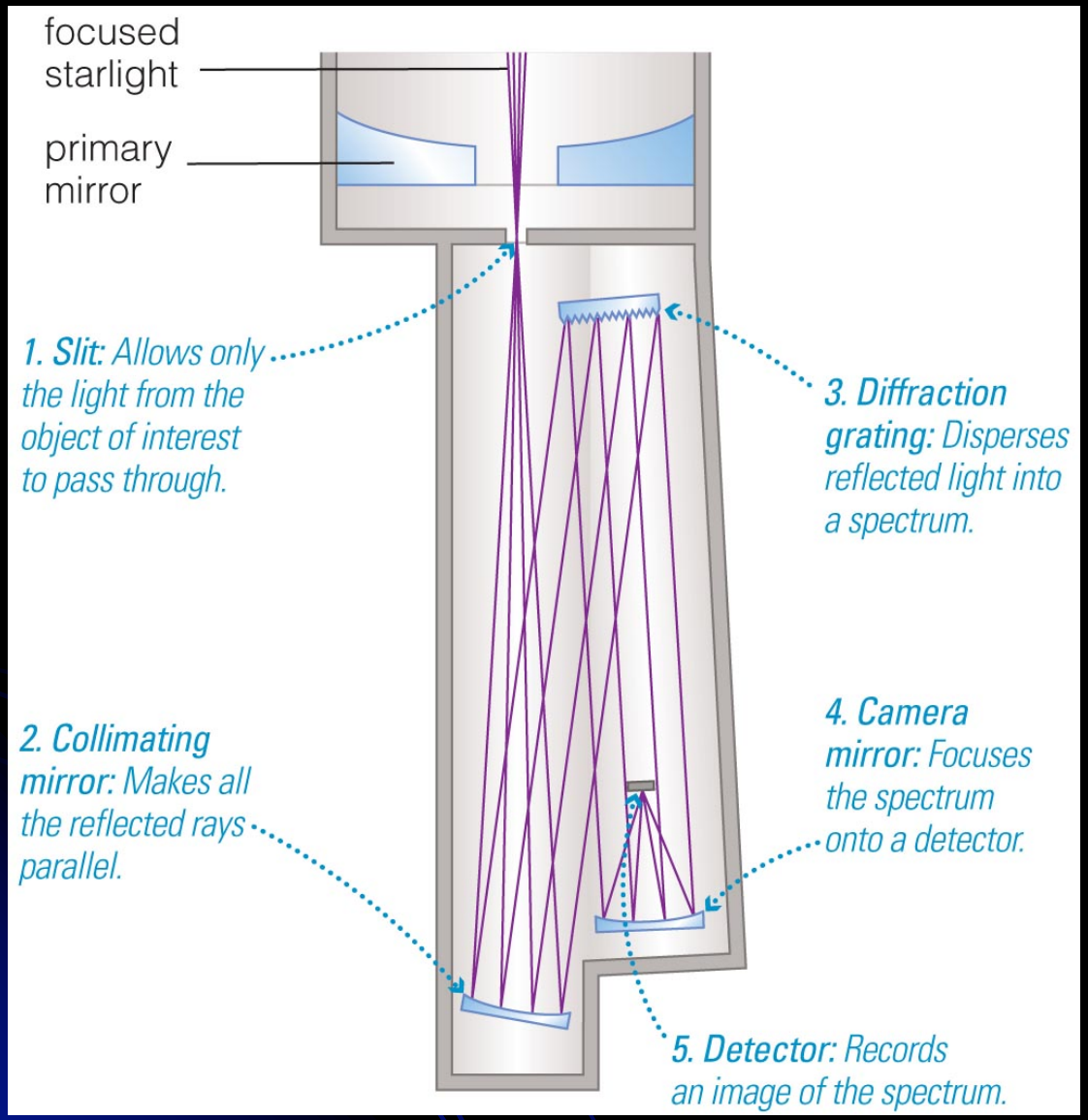

(c) An image of the same region of the sky made with a CCD

(d) Combining several CCD images made with different color filters

Telescopes can provide detailed pictures of distant objects. These images are usually recorded on **charge-coupled devices** (CCDs).

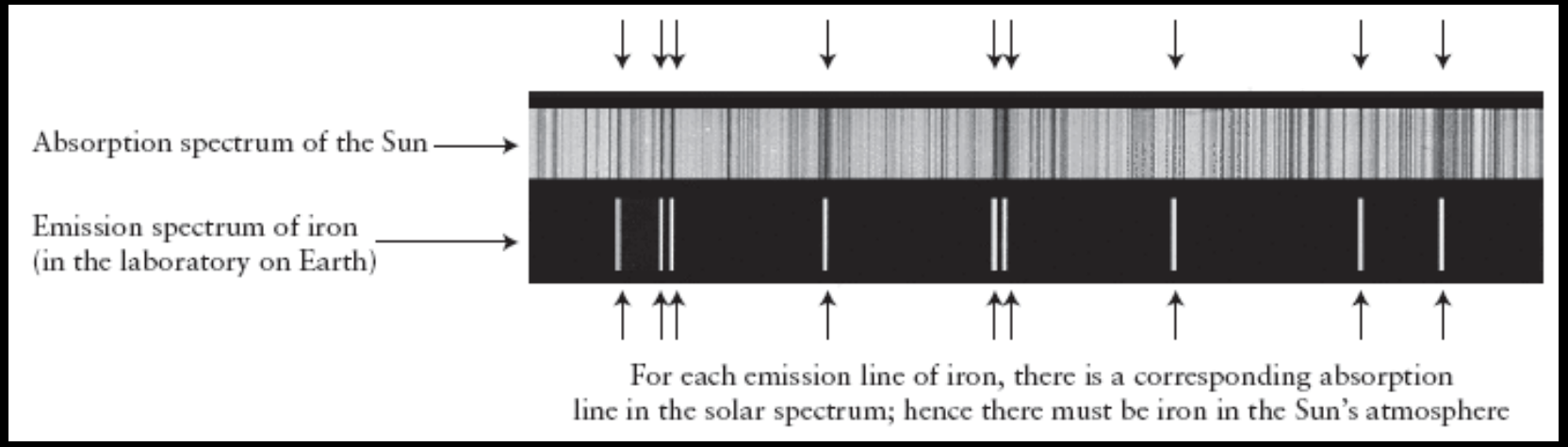
Each one of the 40 CCDs used on the Canada-France-Hawaii Telescope (panel a) has 9.4 million pixels arranged in 2048 rows by 4608 columns.

Spectroscopy



- A spectrograph separates the different wavelengths of light before they hit the detector.

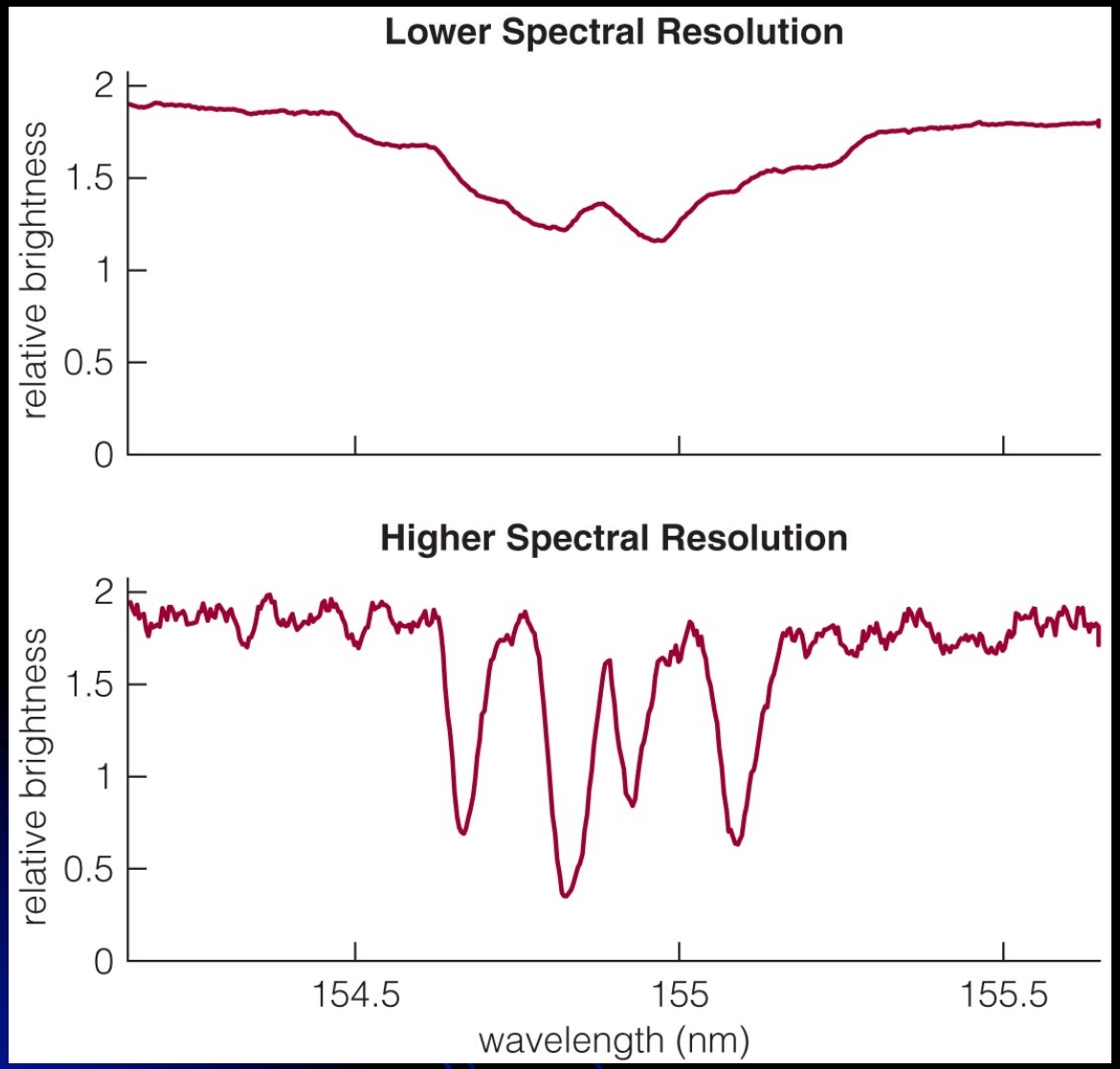
Spectroscopy



After the spectrum of the source is recorded light from hot gasses are also passed through the slit, reflected off the grating and recorded on the CCD.

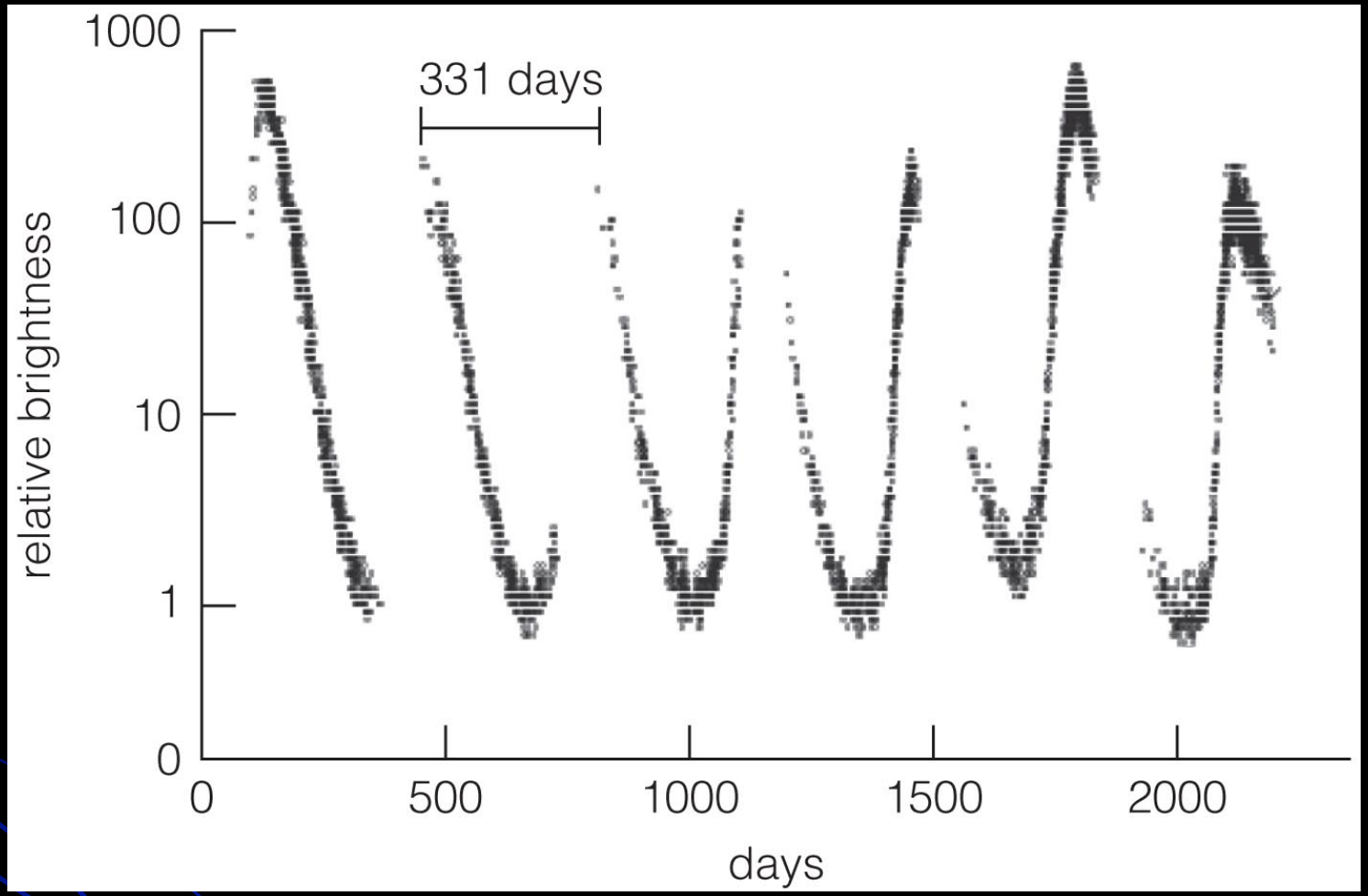
The emission lines from the hot gases serve as reference lines since the energies and elements that produce these lines are known from laboratory measurements.

Spectroscopy



- Graphing relative brightness of light at each wavelength shows the details in a spectrum.

Time Monitoring



- A light curve represents a series of brightness measurements made over a period of time.

Correcting for Turbulence: Adaptive Optics

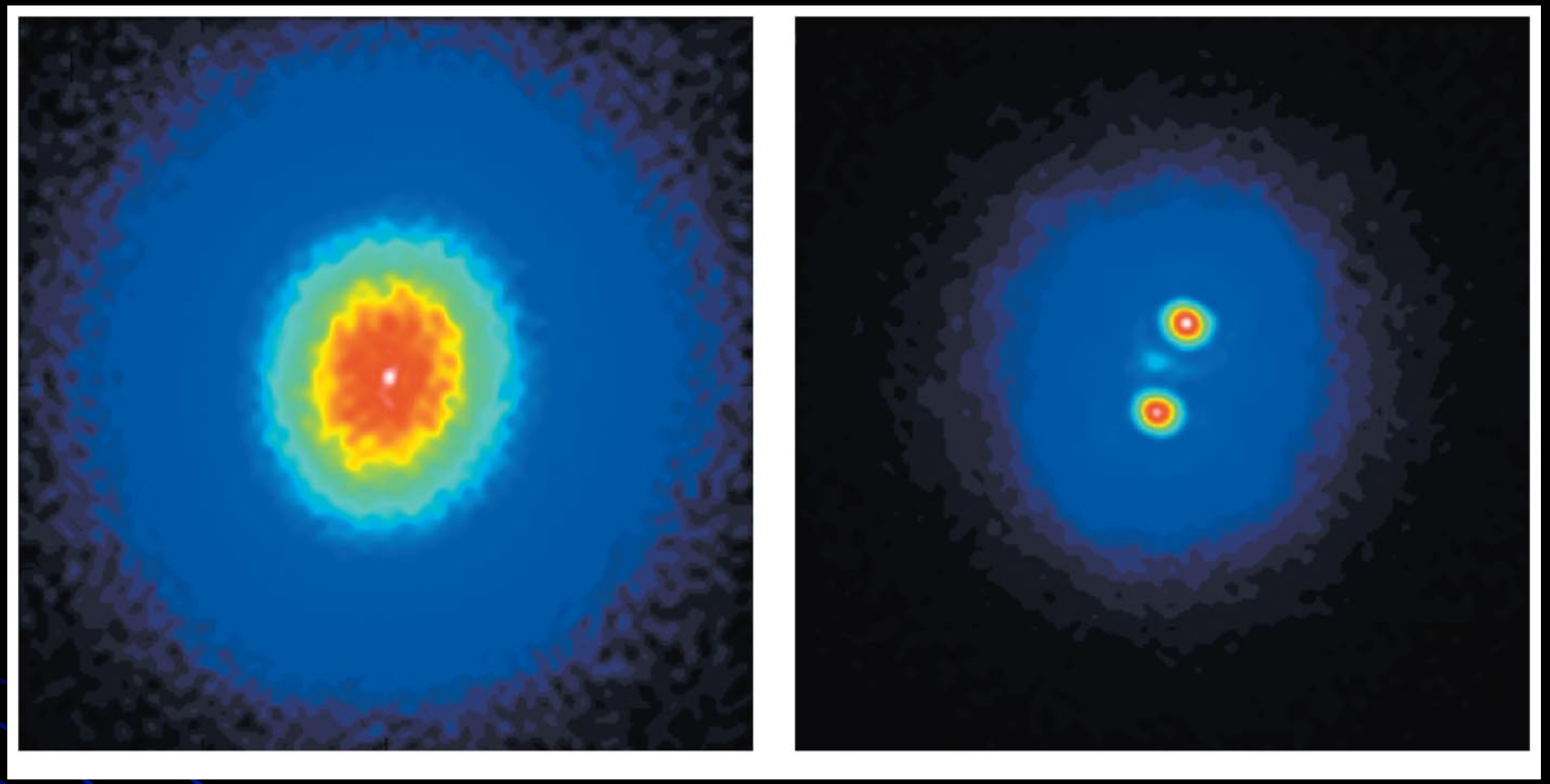
The goal of adaptive optics is to compensate for atmospheric turbulence.

In an adaptive optics system, sensors monitor the dancing motion of a star due to turbulence 10 to 100 times per second, and a powerful computer rapidly calculates the mirror shape needed to compensate.

If a bright star is not near the field of view a laser beam is used. The beam strikes sodium atoms in the sky, causing them to glow and make an artificial "star." Tracking the twinkling of this "star" makes it possible to undo the effects of atmospheric turbulence.

images.

Adaptive Optics

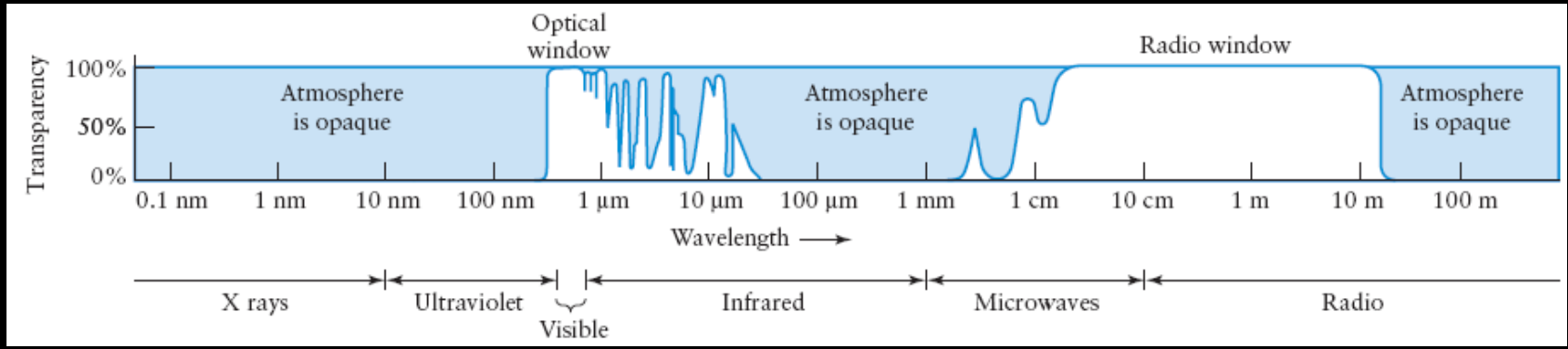


Without adaptive optics

With adaptive optics

- Rapidly changing the shape of a telescope's mirror compensates for some of the effects of turbulence.

Transmission in Atmosphere



This graph shows the percentage of radiation that can penetrate the Earth's atmosphere at different wavelengths.

At wavelengths less than about 290 nm photons are absorbed by **atmospheric oxygen and nitrogen.**

Between the optical and radio windows photons are absorbed **by water vapor and carbon dioxide.**

At wavelengths longer than about 20 m, photons are reflected back into space by **ionized gases in the upper atmosphere.**

Radio Telescopes

A modern radio telescope consists of :

- a parabolic dish

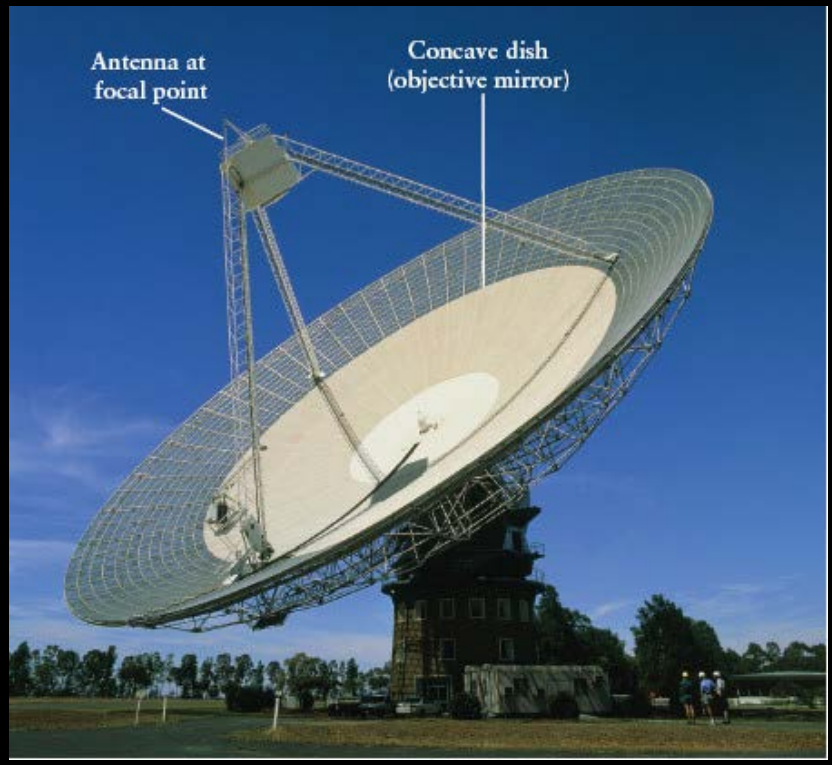
- an antenna tuned to the desired frequency located at the focus.

The signal picked up by the antenna is relayed to an amplifier and recording instruments usually located at the base of the telescope pier.

Questions:

1) What frequency does 64 m correspond to?

2) Why can't microwaves at ν = 2.45 GHz leak through a microwave door?



PARKES, NSW, Australia
(64 m diameter)

Radio Telescopes: Dealing with Diffraction

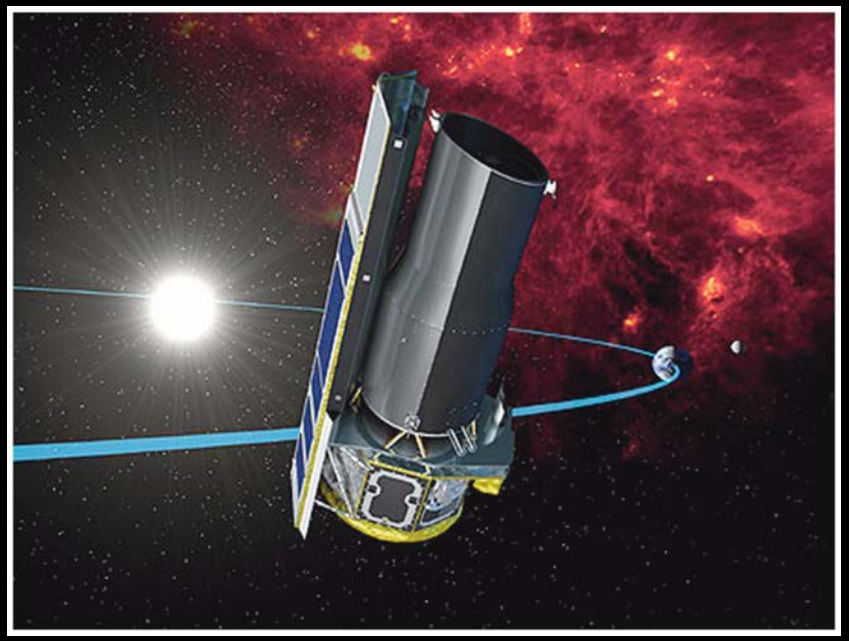
The diffraction limited angular resolution of a 25 m radio dish at λ = 21 cm is $\theta \sim 2.5 \times 10^5 \times (21\text{ cm} / 25\text{ m}) = 2100$ arcsec

To improve the angular resolution of radio telescopes astronomers use the **interferometry technique**.

The Very Large Array (VLA) consists of 27 parabolic dishes, each 25 m in diameter. By pointing all 27 telescopes at the same object and combining the 27 radio signals, the VLA can produce radio views of the sky with an angular resolution as small as 0.05 arcsec.

Infrared and Ultraviolet Telescopes

SOFIA



Spitzer

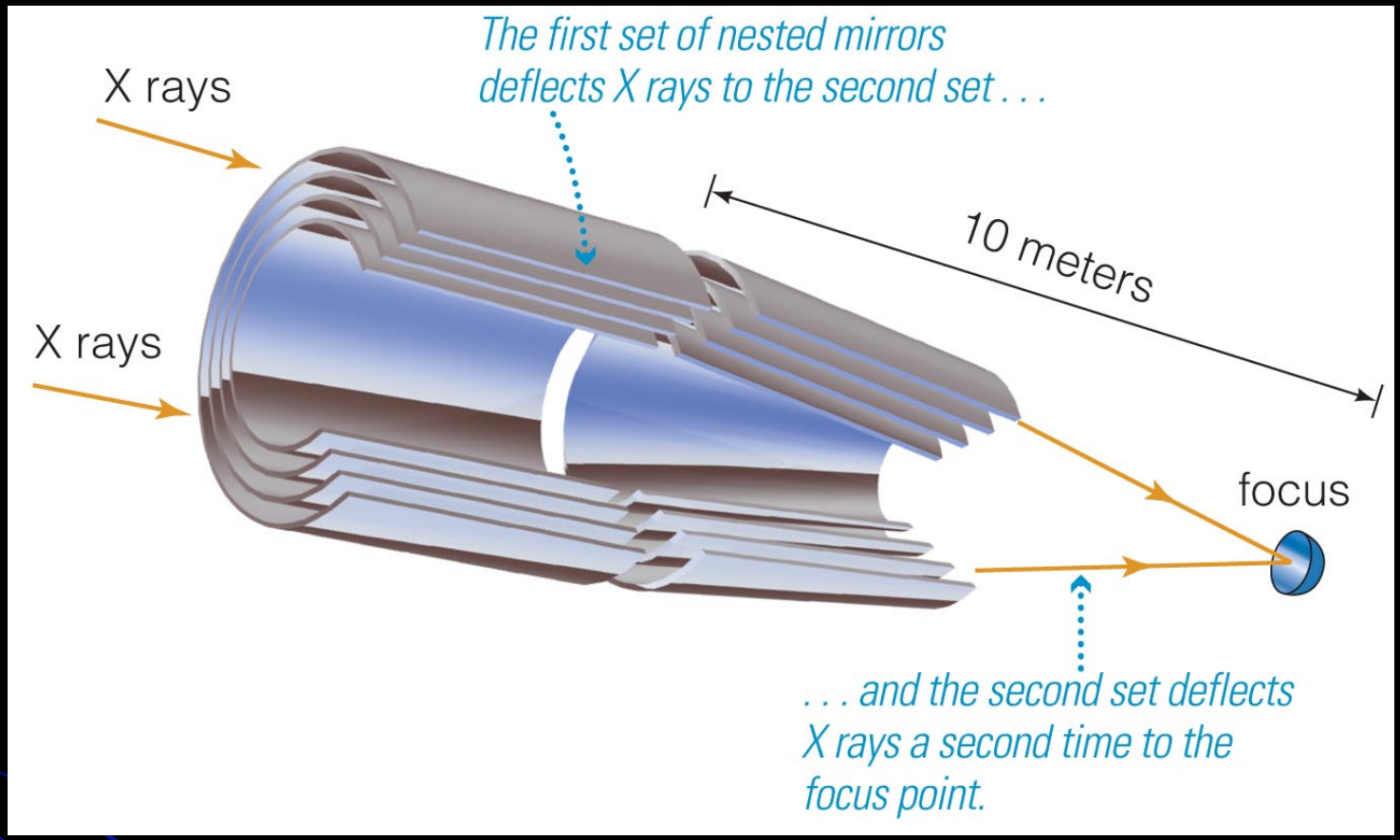
- Infrared and ultraviolet light telescopes operate like visible-light telescopes but need to be above atmosphere to see all wavelengths.

X-Ray Telescopes

Chandra X-Ray Observatory

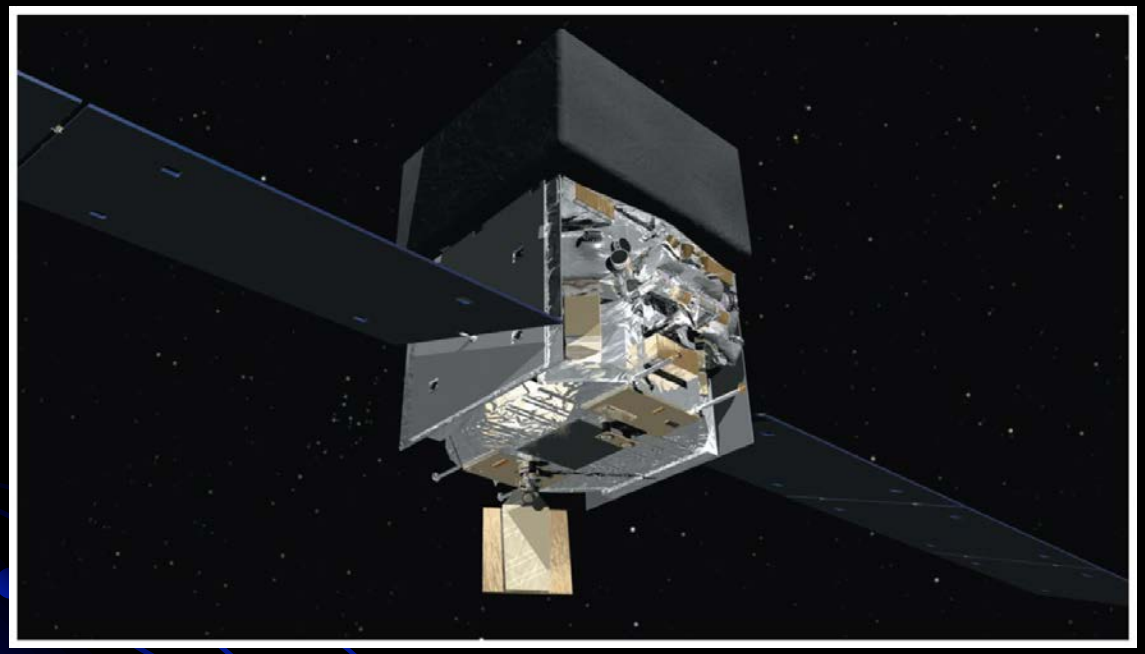
- X-ray telescopes also need to be above the atmosphere.

X-Ray Telescopes



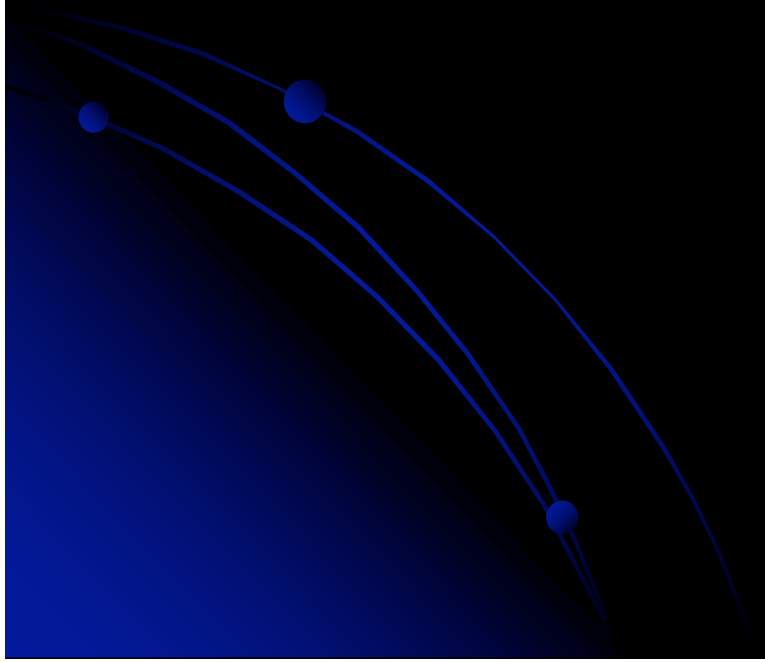
- Focusing of X-rays requires special mirrors.
- Mirrors are arranged to focus X-ray photons through grazing bounces off the surface.

Gamma-Ray Telescopes



Fermi Gamma-Ray Observatory

- Gamma-ray telescopes also need to be in space.
- Focusing gamma rays is extremely difficult.

Today's In-Class Tutorial:

See 'Assignments 2' posted on OAKS under assignments. Assignments 1 is due on Aug 25. Assignment 2 is due on Sept 1.