- **Announcements**
  - **Homework 1 due…**
  - **Make sure you give it to Kevin before he leaves**
  - **Late homeworks can be turned in class on Tuesday February 3rd for 50% credit**
  - **Kevin has set up a facebook page**
    - **“Shane Byrne's PTYS 206 class”**
    - **Can use it to organize homework/study groups etc…**

Exploring the Solar System from Earth

PTYS/ASTR 206 – The Golden Age of Planetary Exploration

Shane Byrne – shane@lpl.arizona.edu

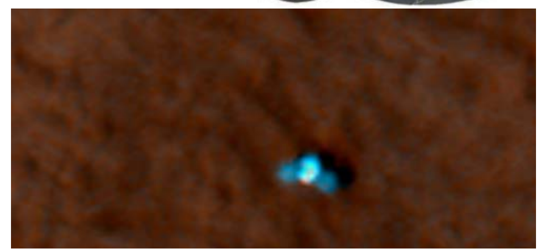
In this lecture…

- **Telescopes and how they work**
  - **Reflectors and refractors**
  - **Resolution and magnification**
  - **Atmospheric effects**

- **Spacecraft and how they work**
  - **Fly-bys, Orbiters & Landers**
  - **Tricks of the trade**

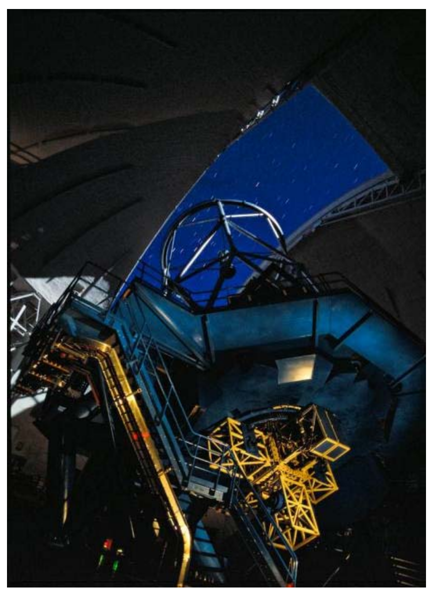
- **Why do we use telescopes?**

- **Why use telescopes?**
  - **To make things bigger**
    - **When light levels are high**
    - **Very nearby planets**
    - **Pirate ships**
    - **Spying on your neighbors**
    - **Etc…**



Phoenix lander is a few m across… but a few 100km away!

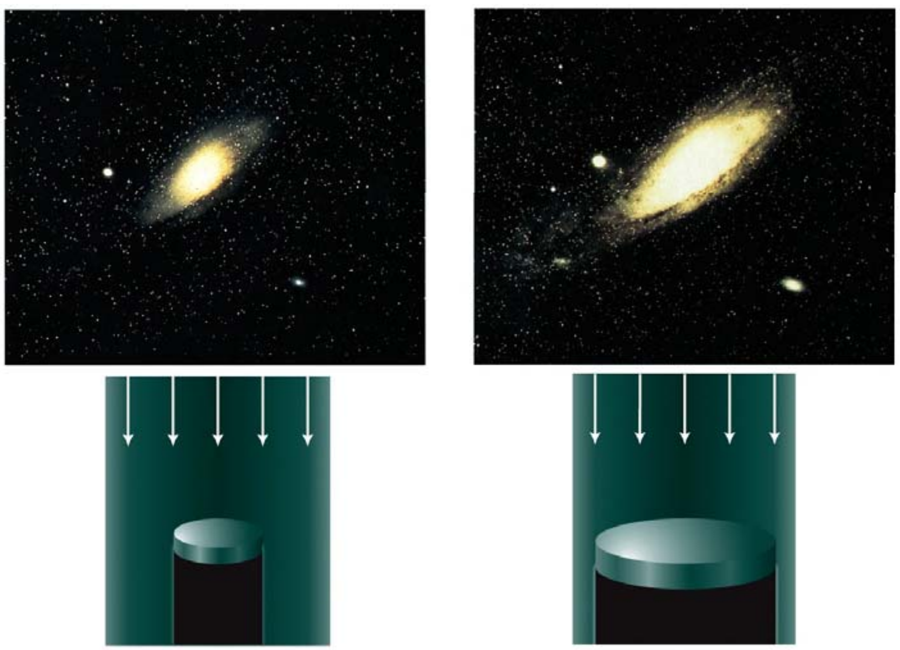
  - **To make things brighter**
    - **When light levels are low**
    - **Most of astronomy**
    - **Far away planets**
    - **Small objects**



- What have telescopes done for planetary astronomy?
  - Plenty!
  - Heliocentric vs. geocentric solar system
  - Objects visible with the naked eye
    - Sun
    - Moon
    - Mercury (if you're lucky)
    - Venus
    - Mars
    - Jupiter
    - Saturn
    - Uranus (barely) – still discovered with a telescope
  - Neptune
  - Discovery of Asteroids
  - Discovery of Kuiper Belt
  - Discovery of moons of other planets

How do telescopes work?

- They take light over a wide area and put it into a small area
- We can do this with either refraction or reflection
- Bigger is better!
  - Light from distant objects comes in parallel rays
  - The bigger the area of the telescope the more light you can collect

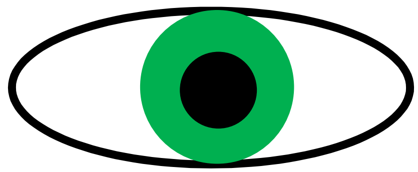


Small-diameter objective lens: dimmer image, less detail

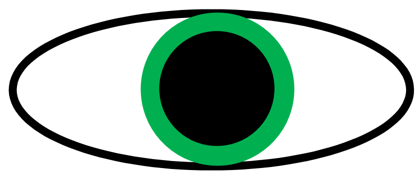
Large-diameter objective lens: brighter image, more detail

Figure 6-6
Universe, Eighth Edition

The human eye is like an adjustable-size telescope



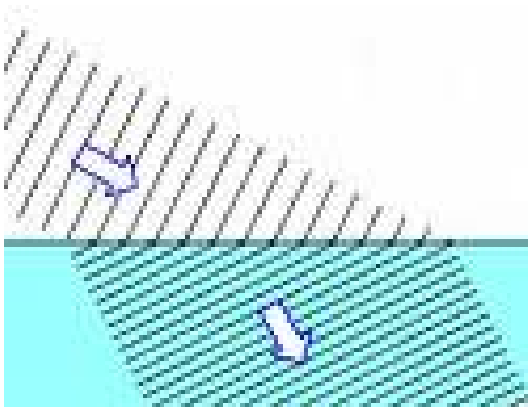
<u>Human eye in daylight</u>
•Plenty of light

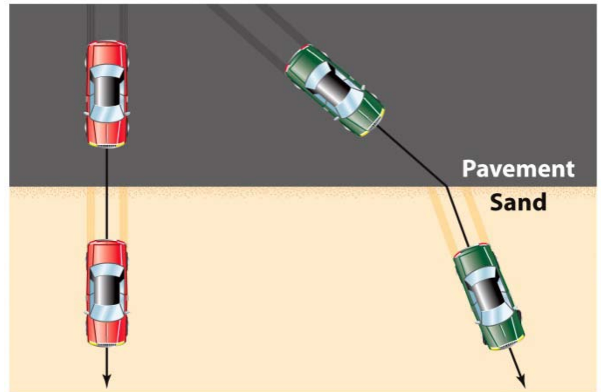


<u>Human eye at night</u>
•Iris dilates
•Bigger collecting area
•You can see fainter things

Refractors

- **Light travels slower in glass than air**
  - **Waves are extended – so they change direction**

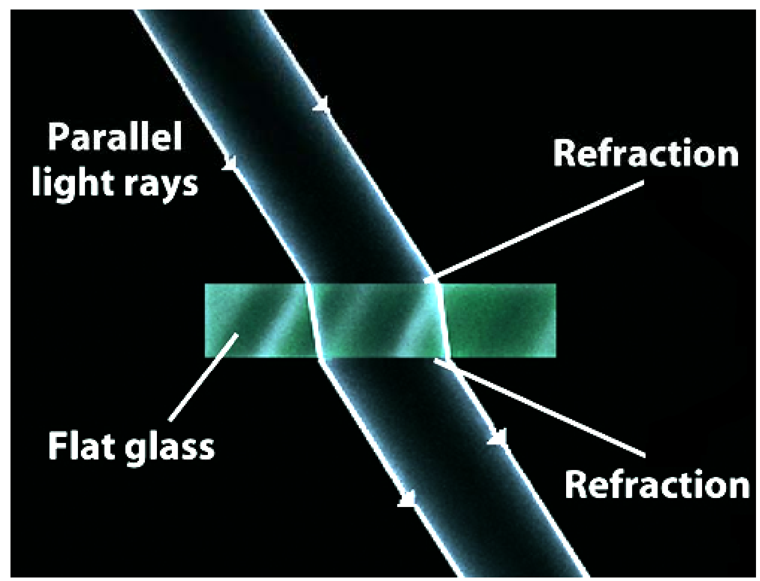




How cars behave

Figure 6-1a
Universe, Eighth Edition

- **Flat sheets of glass produce no net effect**
  - **Refraction works in reverse when light leave the glass**
  - **Light hasn't been concentrated onto a smaller area**



- **Curved pieces of glass (lenses) do produce a change**
  - **Parallel light converges on a single point – the <u>focal point</u>**
  - **Distance between the lens and the focal point – the <u>focal length</u>**
    - **Depends on the curvature of the lens and its <u>size</u>**

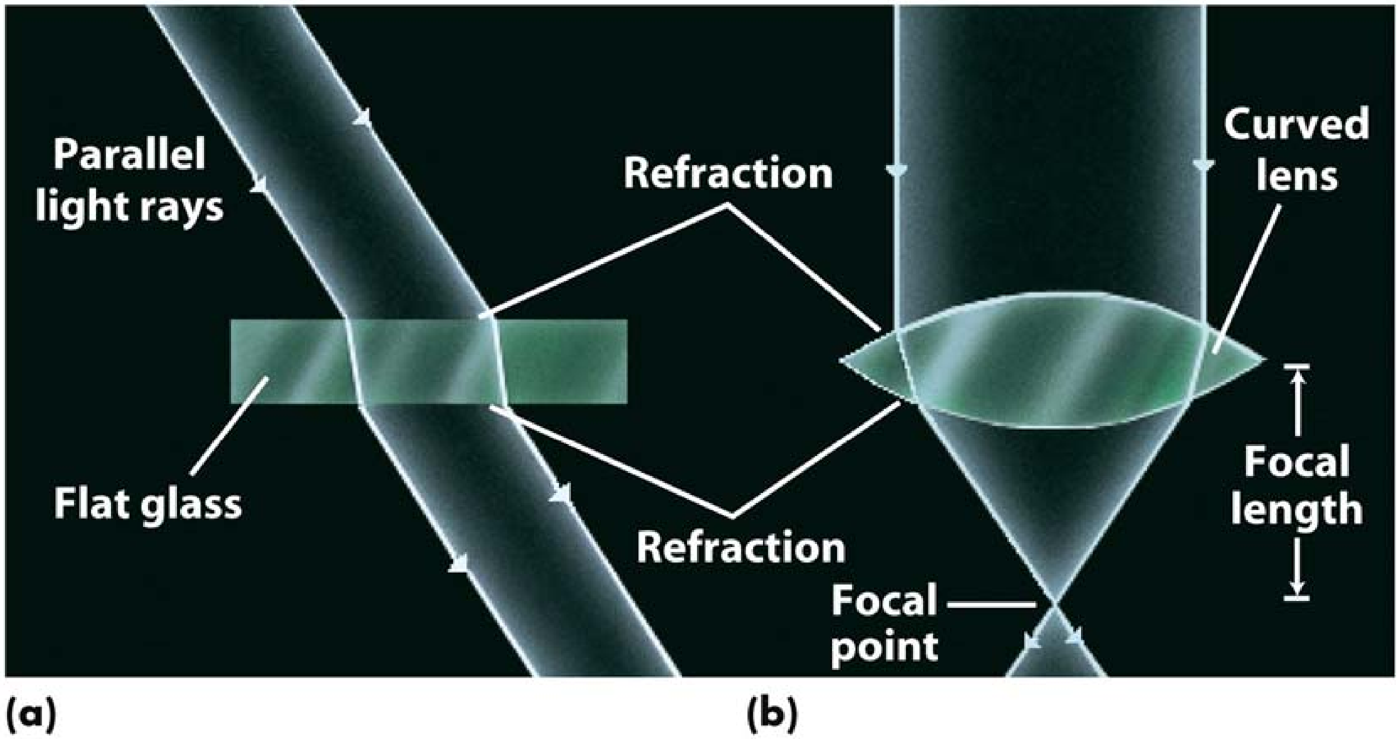
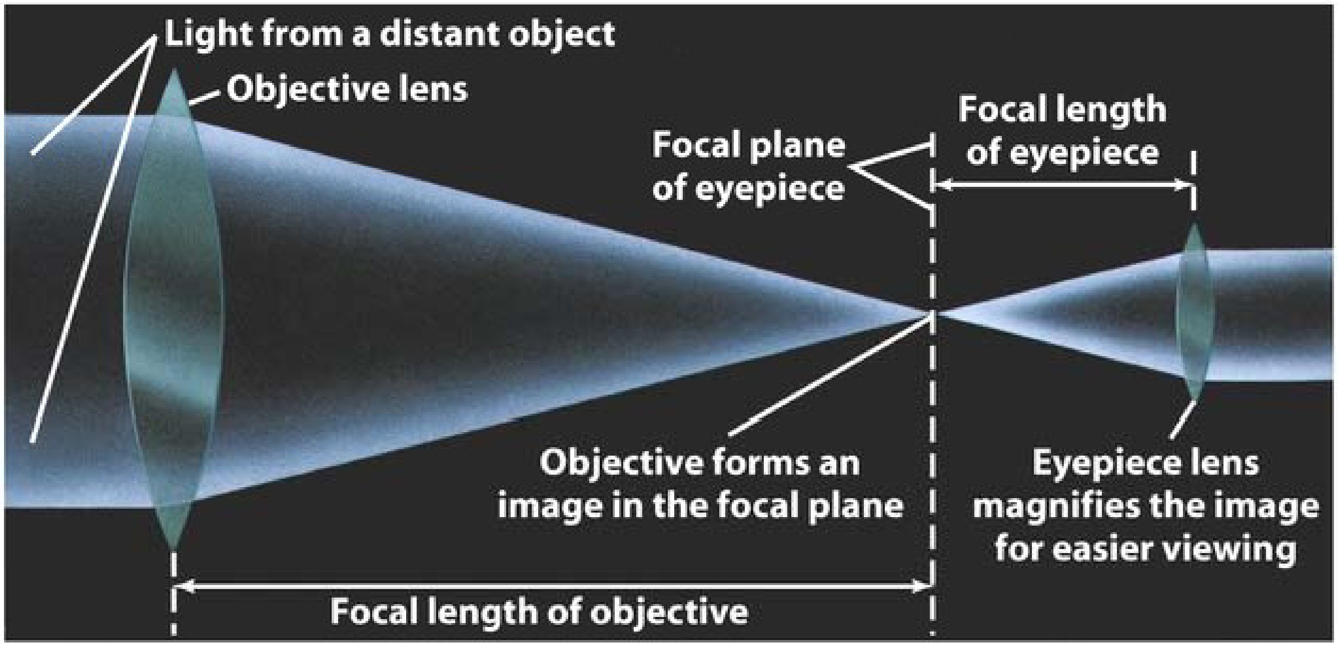


Figure 6-2
Universe, Eighth Edition

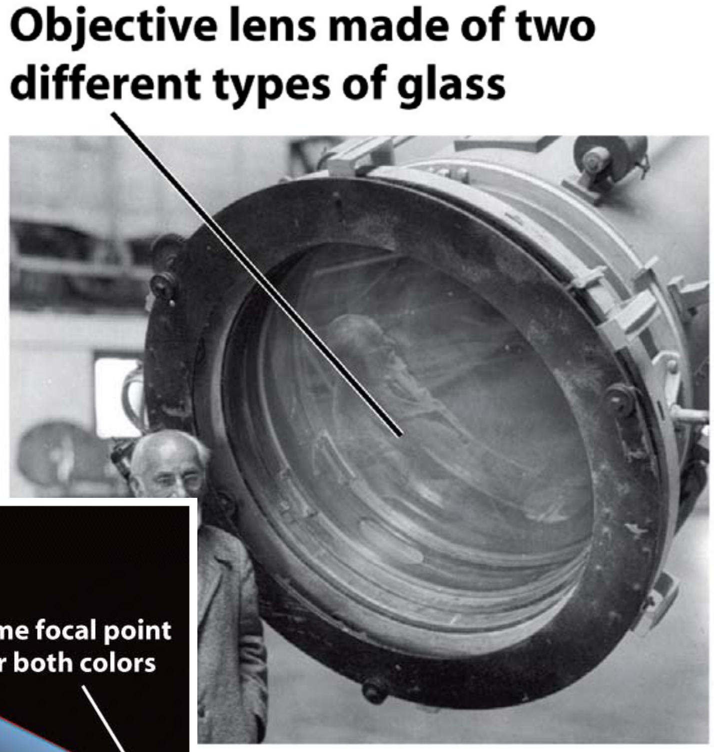
- A refracting telescope
  - First lens (objective) gathers light
  - Uses a second lens (eyepiece) to make the light parallel again
    - So the human eye can use it!

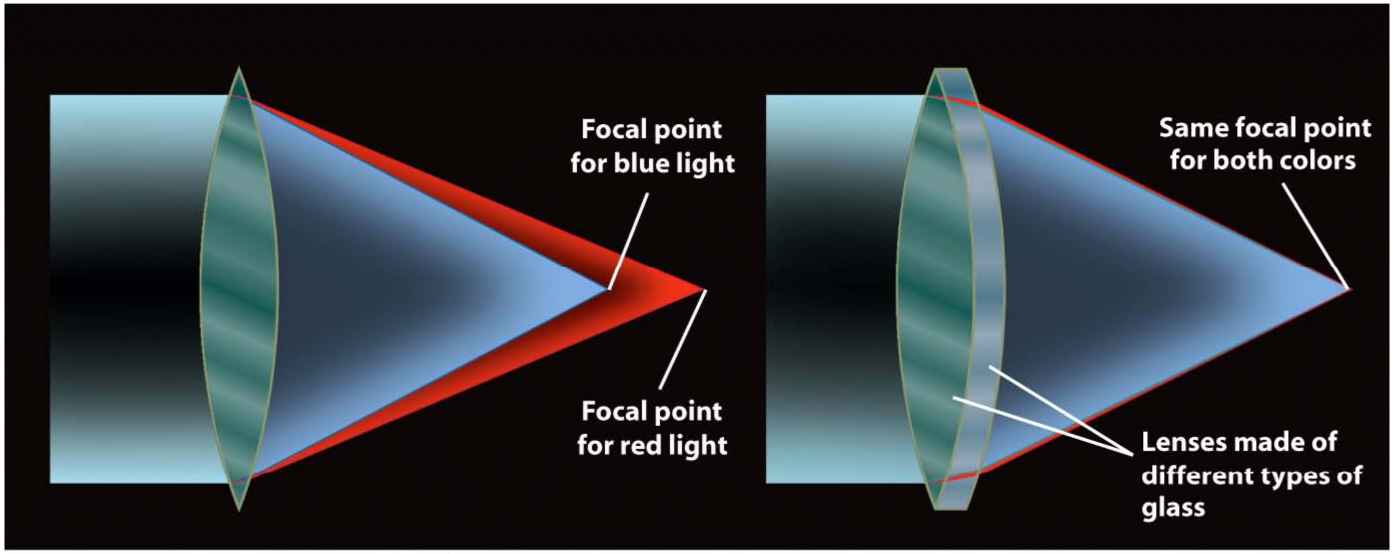


- Net effect
  - Telescope lens much bigger than eye so more light gathered
    - Things are brighter
  - Magnifies objects
    - Magnification is ratio of focal lengths

$$\text{Magnification} = \frac{\text{Focal length of objective}}{\text{Focal length of eyepiece}}$$

- The problem with refractors
  - The amount of refraction depends on wavelength
  - Red light and Blue light focus in different places
  - Image gets blurred
  - Chromatic aberration





(a) The problem: chromatic aberration (b) The solution: use two lenses

Figure 6-7
Universe, Eighth Edition

- **The problem with refractors – cont.**
  - **We need big lenses to gather a lot of light**
  - **… but big lenses have long focal lengths**
  - **Telescopes rapidly get very very unwieldy!**

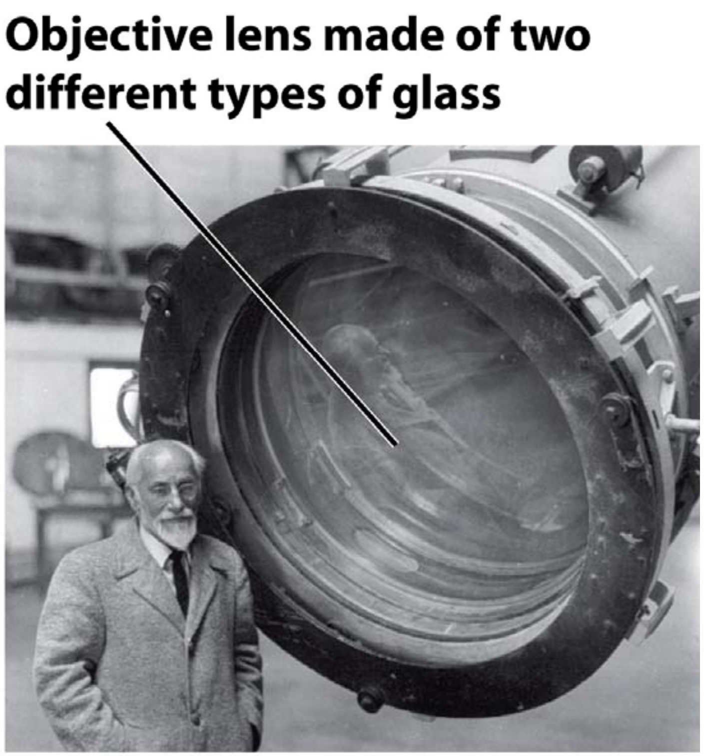


Figure 6-8b
Universe, Eighth Edition

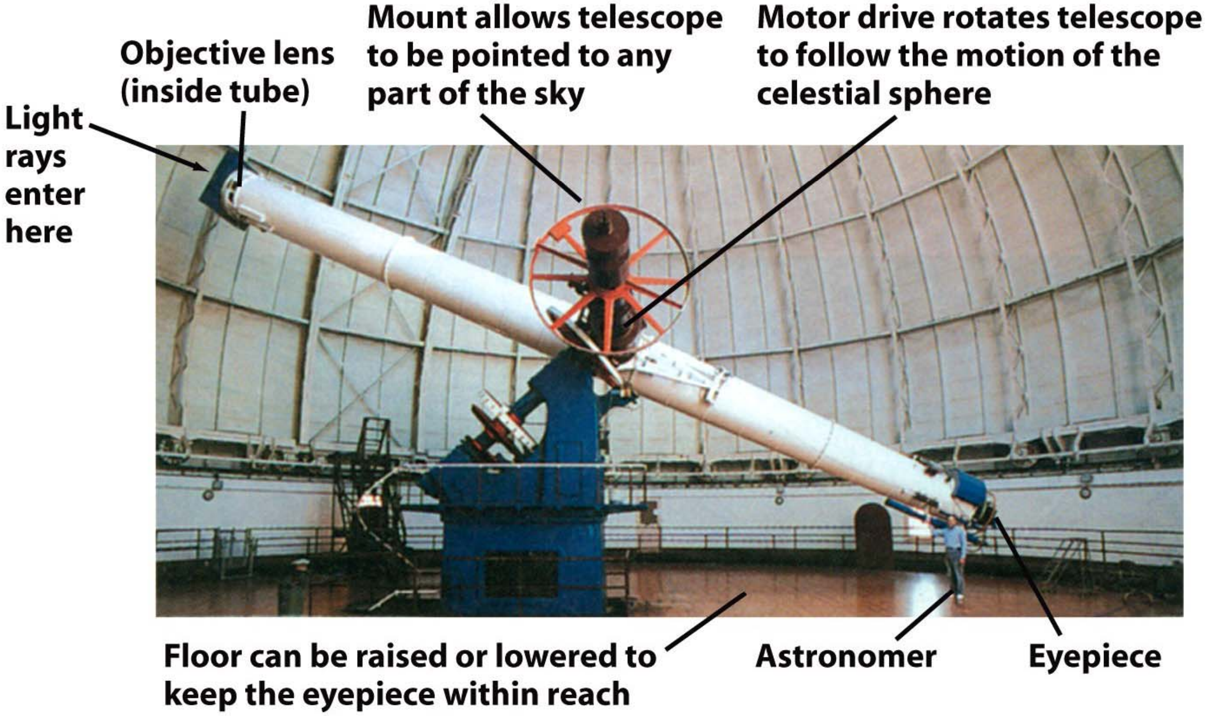


Figure 6-8a
Universe, Eighth Edition

Reflectors

- Pioneered by Isaac Newton
  - Flat mirrors don't focus light
  - Use curved mirrors to concentrate light
    - These mirrors also have a focal length

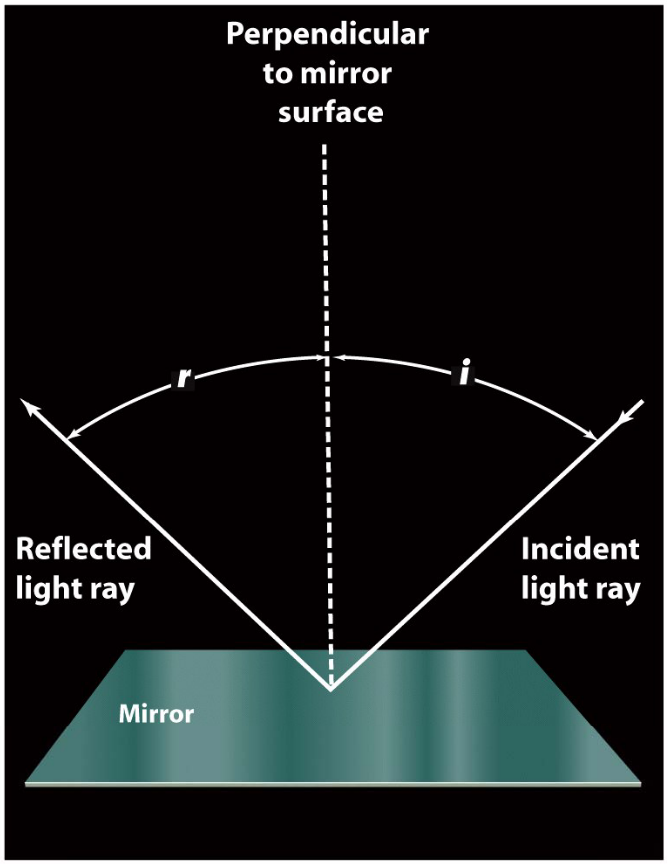


Figure 6-9a
Universe, Eighth Edition

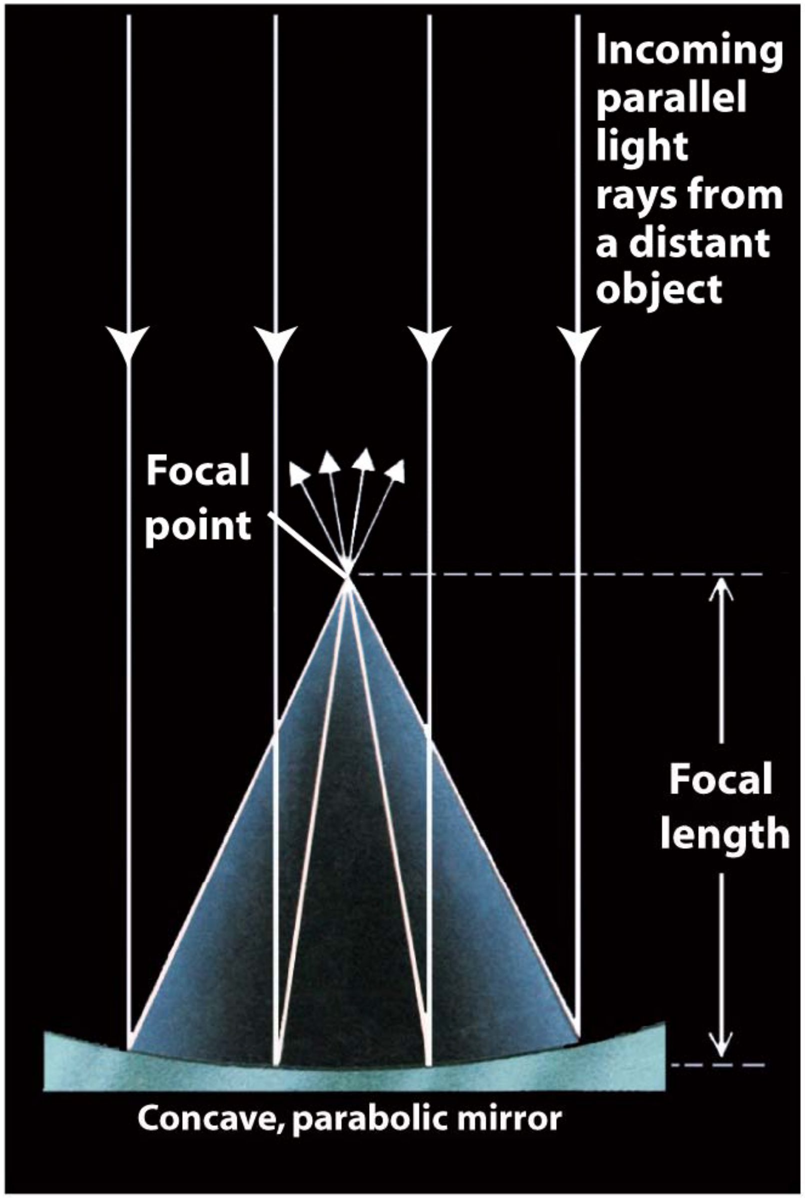


Figure 6-9b
Universe, Eighth Edition

- **Why parabolic?**
  - **Spherical mirrors are easier to make….**
  - **Spherical mirrors don't focus light well**
  - **Spherical aberration fives you a blurry image**
  - **Other aberrations can also be corrected**
    - **Coma**
    - **Astigmatism**
  - **Defects in the mirror surface should be small**
    - **Smaller than the wavelength of light**

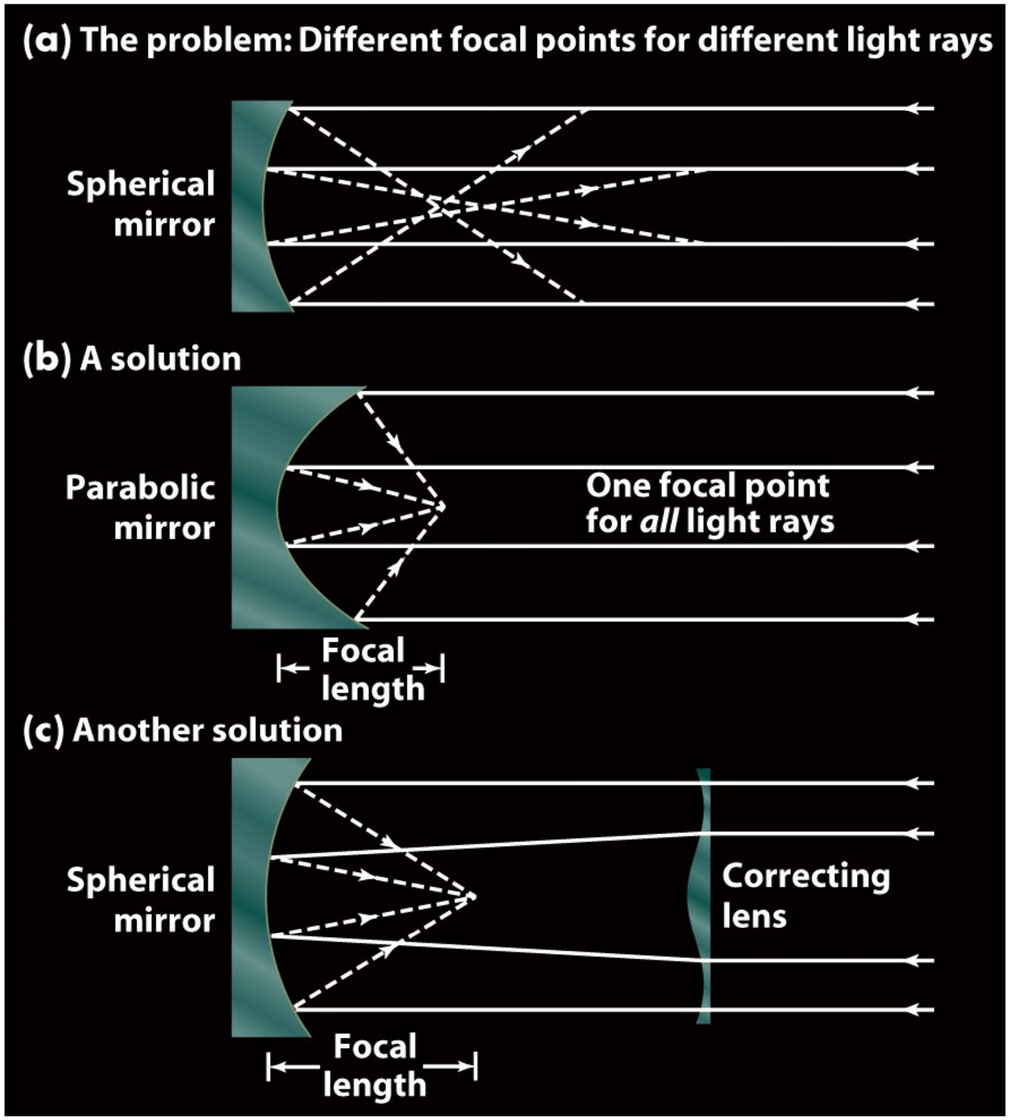


Figure 6-13
Universe, Eighth Edition

- **Focus point is in front of the mirror – usable… but unpopular**
- **Several designs to get light focused somewhere more convenient**

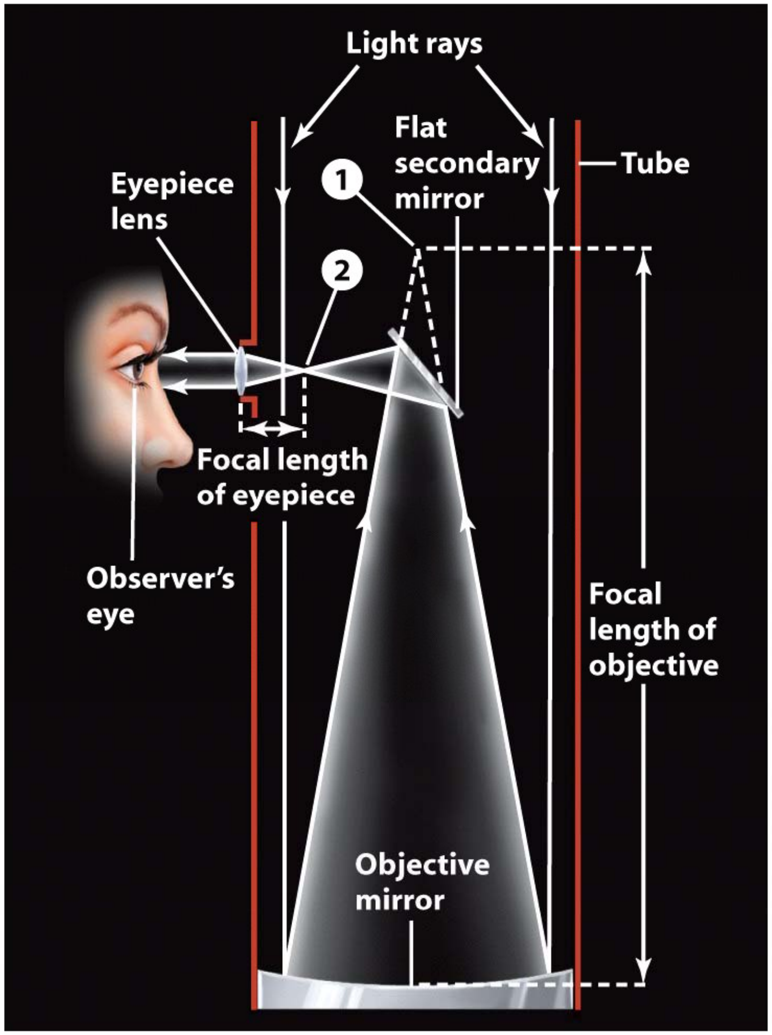


Figure 6-10a
Universe, Eighth Edition

- **Newton's original design used a flat mirror to redirect focused light to the side**
- **If you want to use your eye then you still need an eyepiece**
- **Magnification is still just the ratio of the focal lengths**

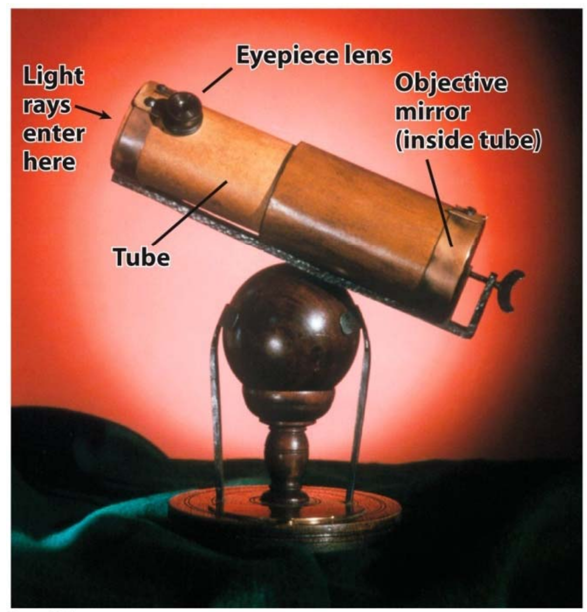


Figure 6-10b
Universe, Eighth Edition

- **Other schemes to redirect the focused light**

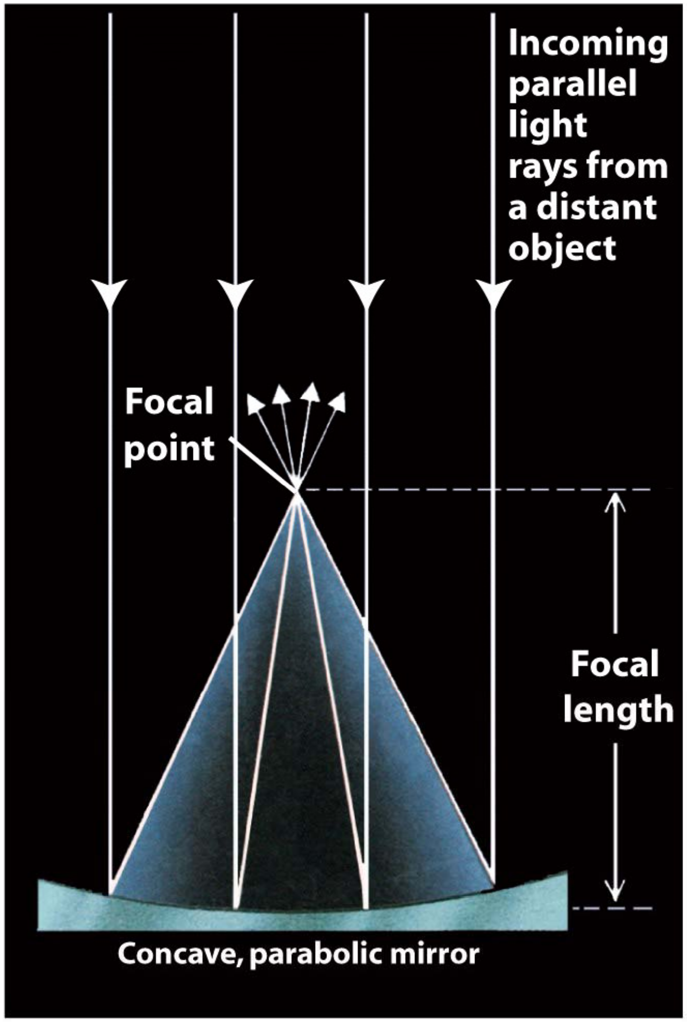


Figure 6-9b
Universe, Eighth Edition

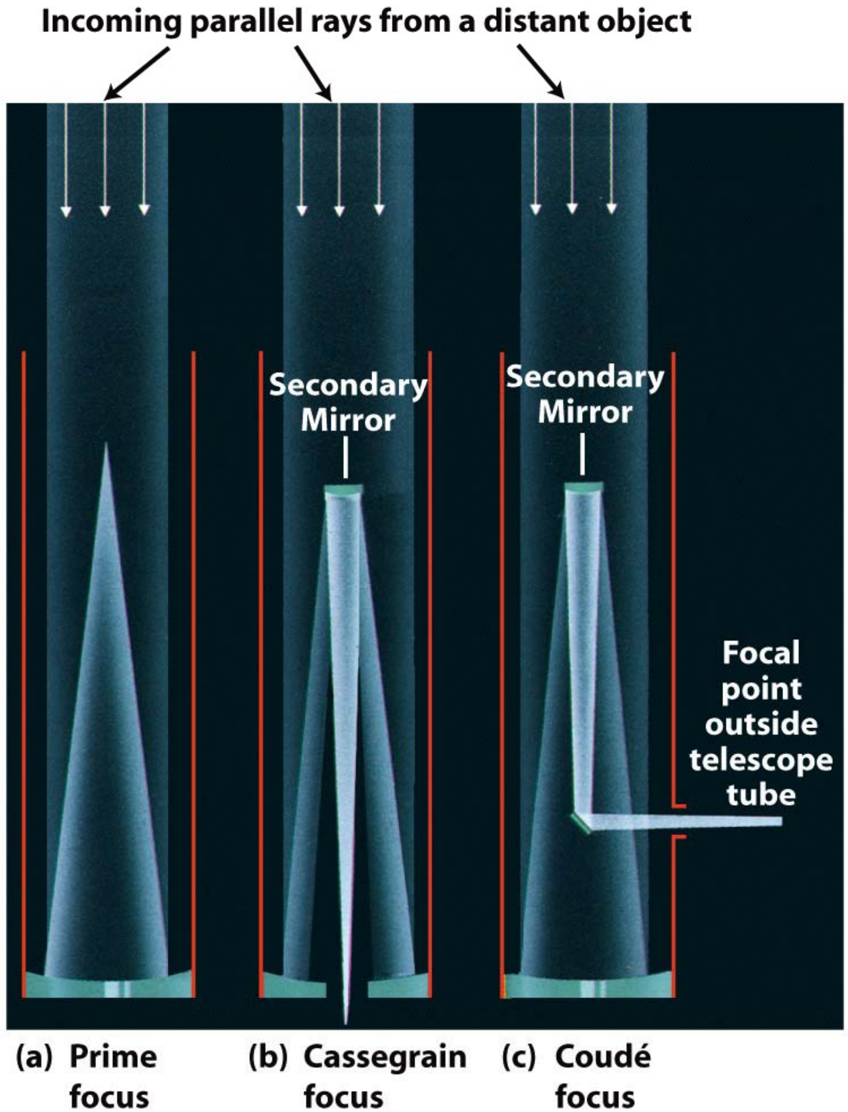
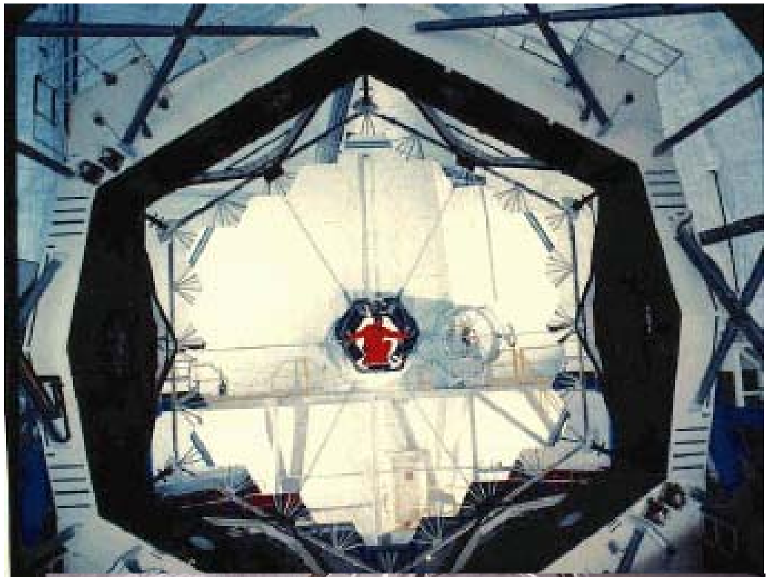


Figure 6-11
Universe, Eighth Edition

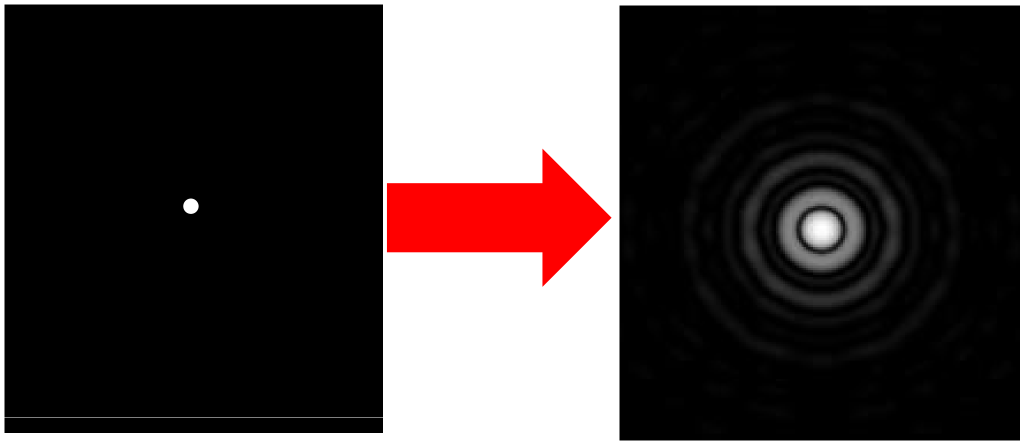
- **Benefits of reflectors**
  - **You can make the mirrors huge and the focal length short**
    - **Keck telescopes – mirrors are 10m across? (built in segments)**
  - **No chromatic aberration**
    - **All colors behave the same**



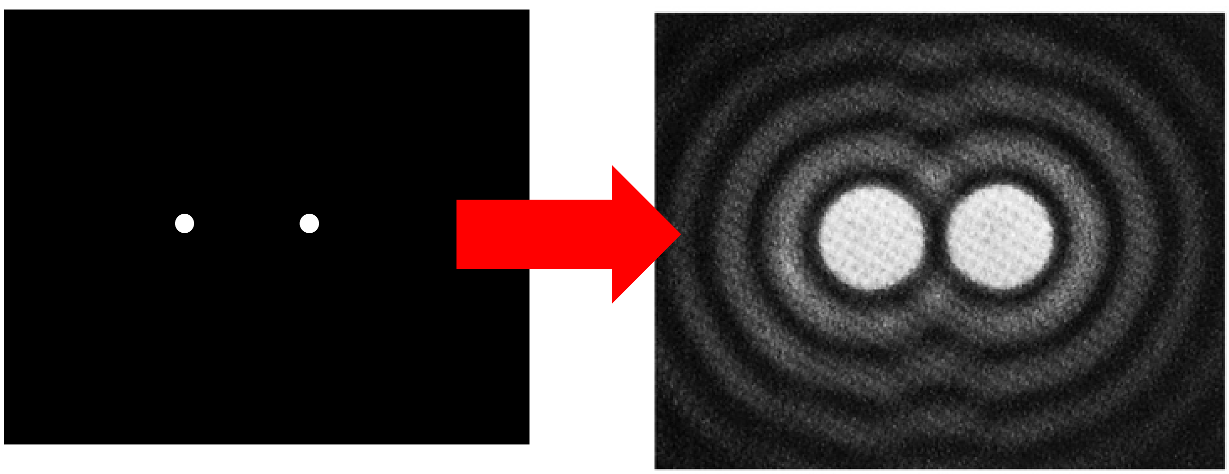
- **Plans for a 30m telescope – the CELT**
  - **California Extremely Large Telescope**
  - **3 times the size means 9 times the area!**

Resolution

- **There's a limit to what even perfect telescopes can do**
- **A single point of light gets spread out a little**
  - **Called the diffraction limit**

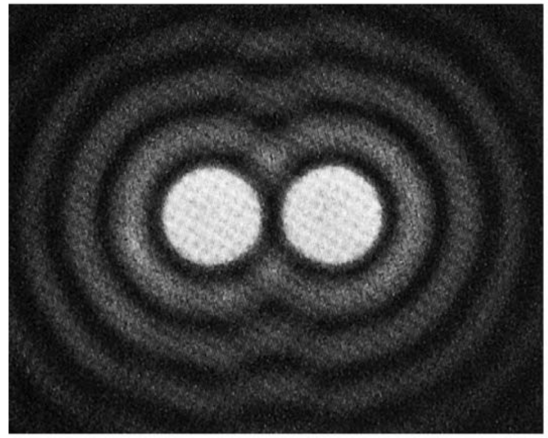


- **Resolution – how close can two things be together without joining up.**



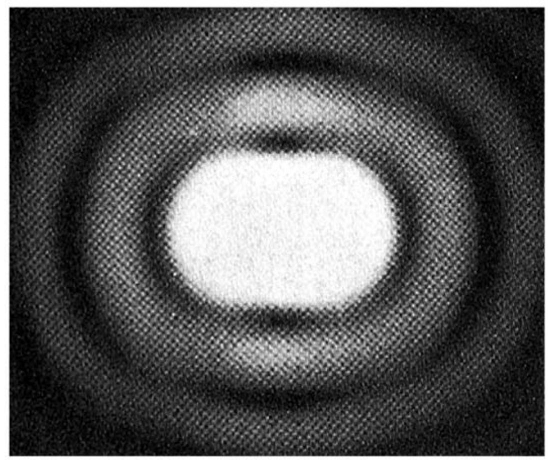
It's easy to see that there are two separate objects here.

- As things get closer together we can no longer the individual objects
- The closest angular-separation they can have and still be separate is the resolution.
  - Depends on size of telescope
  - Depends on wavelength of light
- Same principle to know what the smallest feature on a planet you can see is.



(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

Figure 6-15
Universe, Eighth Edition

- **Example**
  - **Smallest object/separation that we can resolve = $\frac{\text{wavelength}}{\text{Size of telescope}}$**
- **Warning: This formula produces radians**
  - **The textbook has a formula that produces arcseconds…**
- **Can we see the Apollo lander on the Moon?**
  - **The lander is almost 4m across**
  - **The Moon is 384,000,000m away**
  - **Angular size 10^{-8} radians**
  - **Wavelength of visible light $5*10^{-7}$ m**
  - **Size of Keck telescope is 10m**
  - **Resolution of Keck $5*10^{-8}$ radians**

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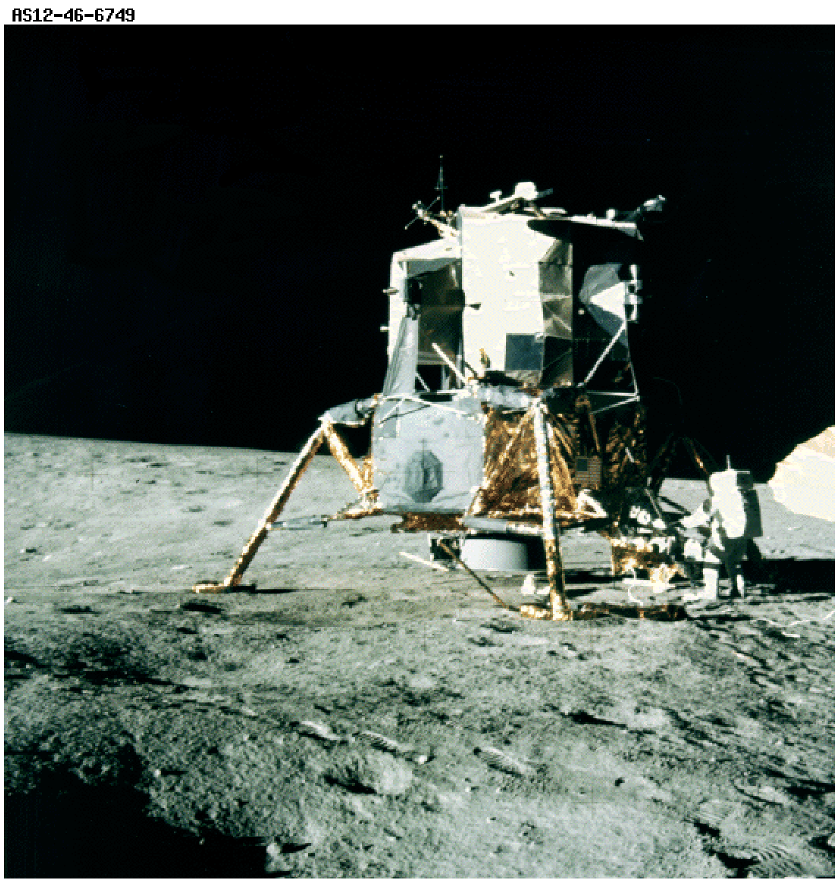
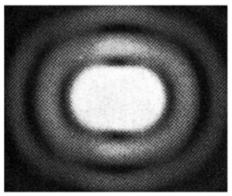
- Can we see the Apollo lander on the Moon?
  - The lander is almost 4m across
  - The Moon is 384,000,000m away
  - Angular size $1*10^{-8}$ radians
  - Wavelength of visible light $5*10^{-7}$ m
  - Size of Keck telescope is 10m
  - Resolution of Keck $5*10^{-8}$ radians

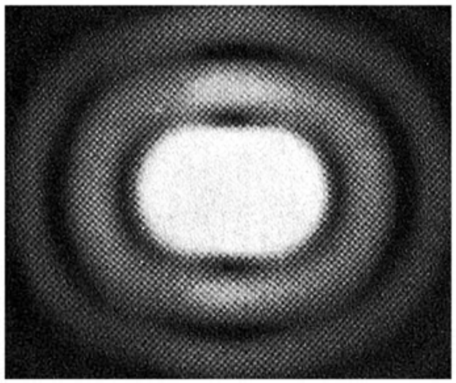


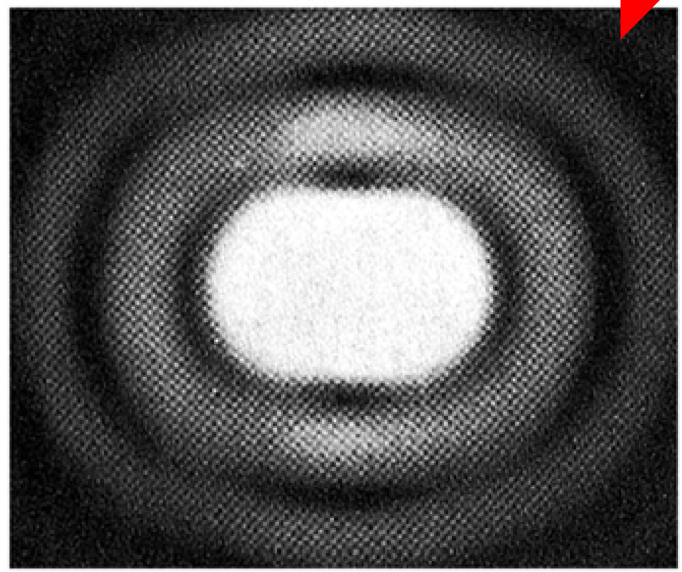
We can't resolve the lander.

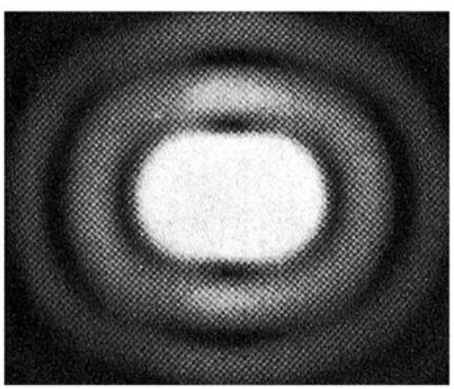
We'd need a telescope 50m across to be able to see the Apollo lander.

Increasing Magnification
But the Same Resolution

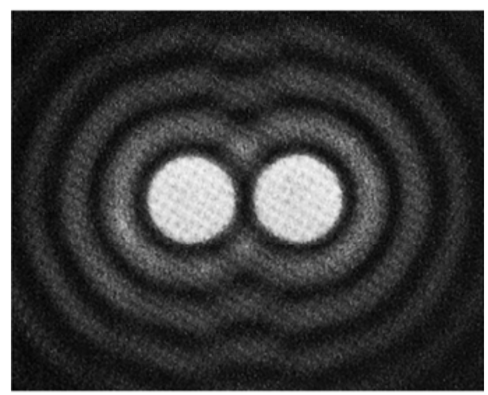






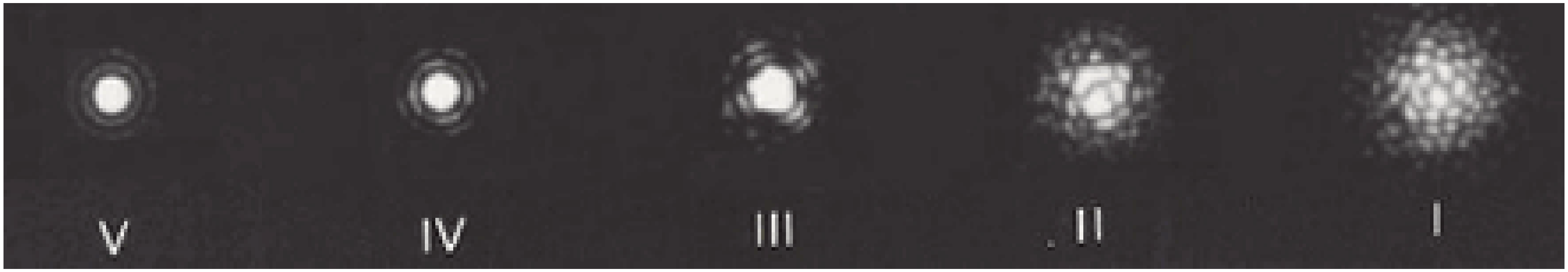


Same Magnification
Increasing Resolution



Atmospheric effects

- **The diffraction is only a theoretical 'best-case scenario'**
- **Earth's atmosphere is a pretty turbulent place**
  - **Especially the lower atmosphere – observatories are on mountains!**
  - **Makes stars twinkle**
  - **Astronomers call this effect 'seeing'**

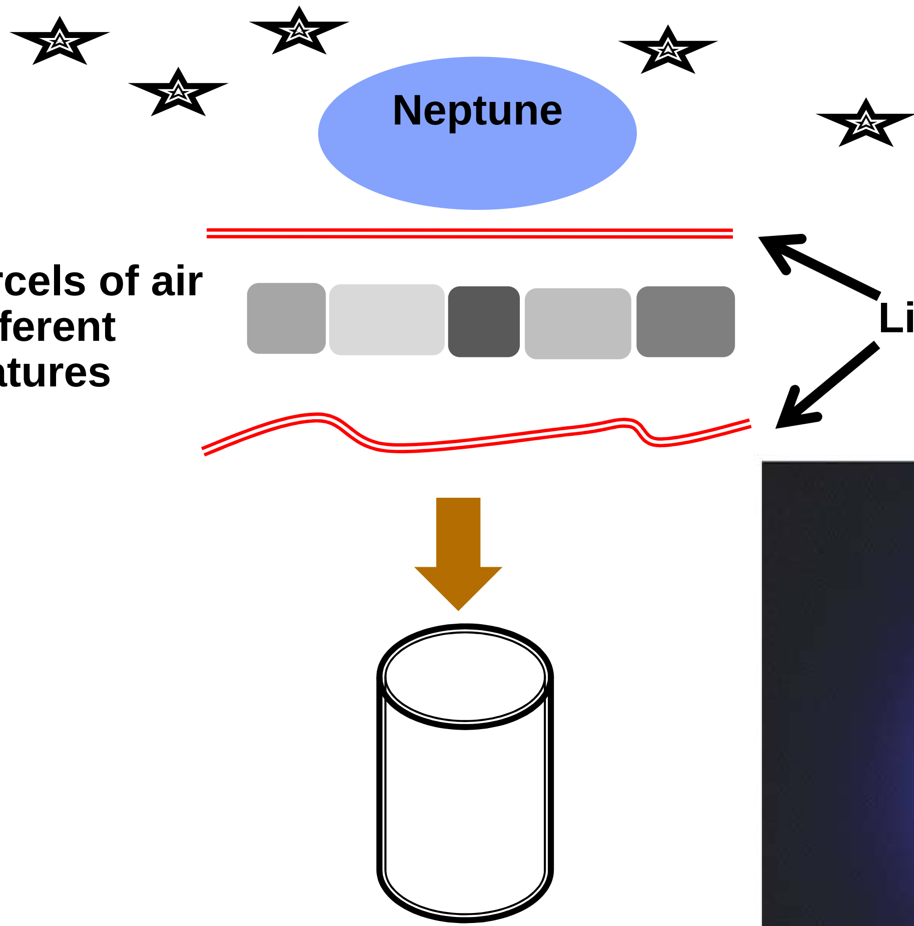


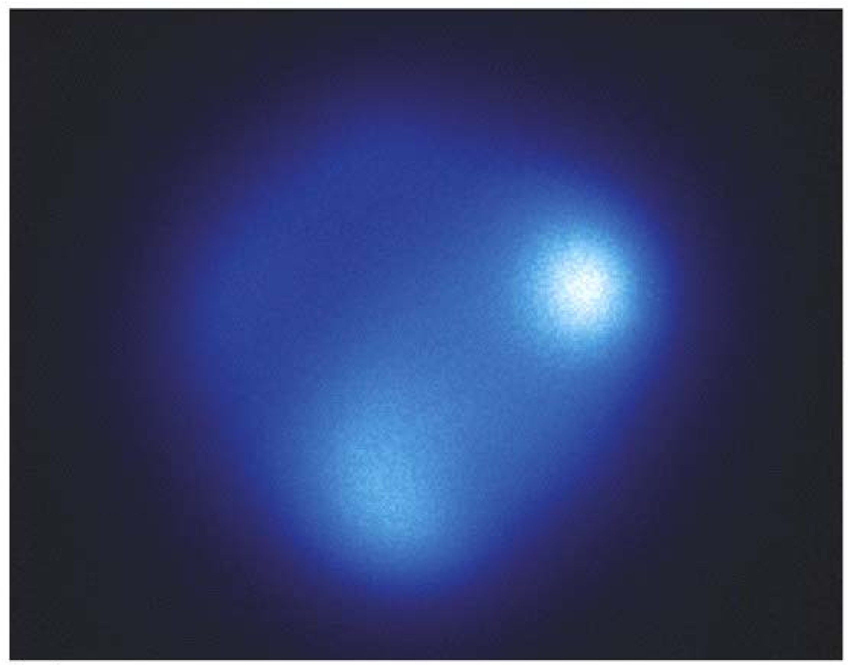
Good Seeing =Good images

Lousy seeing =Lousy images

- **Typically, seeing ~ 0.5 arcsec (~$2.5*10^{-6}$ radians)**
  - **E.g. on the Moon, that's a feature ~1km across**
  - **Equivalent to a telescope only 10cm in diameter !!!**

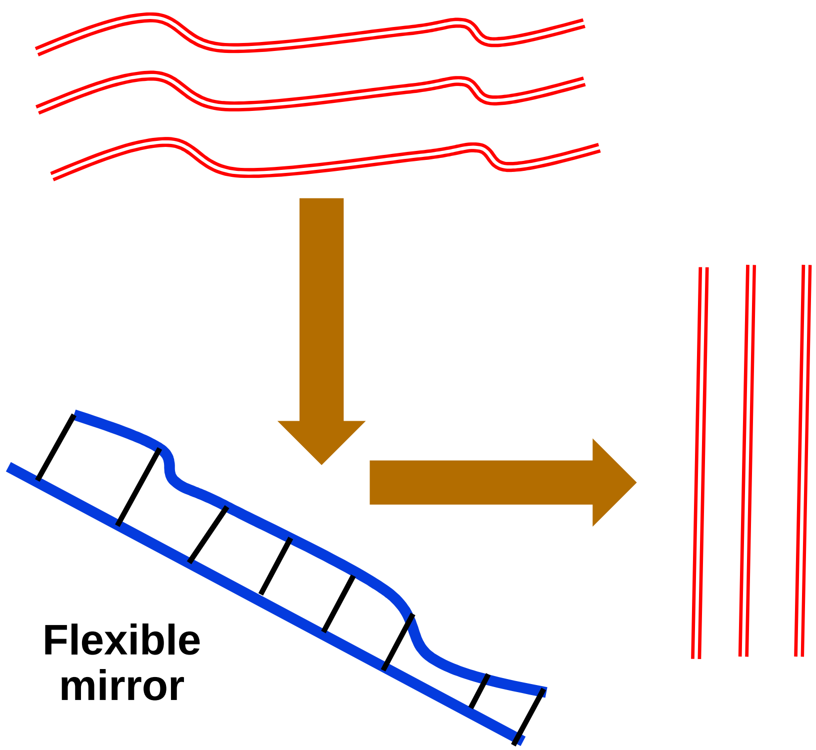
- What's the problem?

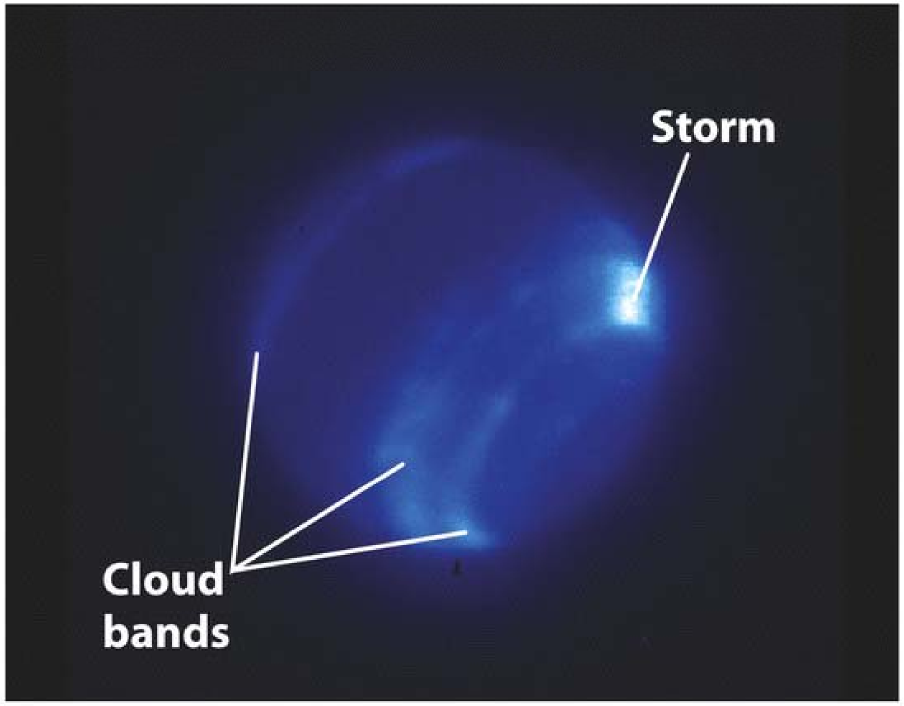




(a) Neptune viewed without adaptive optics

- What's the solution?
  - Adaptive optics - Flexible mirror





(b) Neptune viewed with adaptive optics

- Mirror deforms in a way that cancels out the
  - Atmosphere changes all the time
  - Mirror updates its shape many time per second

- **How does the mirror know what to do?**
  - **You need a nearby guide-star**
  - **Starlight passes through the same patch of atmosphere as planets light**
  - **Star is supposed to be a point**
    - **Wavefront sensor detects distortion…**
    - **…and figures out how to warp the mirror**

- **Usually there's no natural guide star**
  - **So we use a laser**
  - **Reflects of a specific layer high in the atmosphere**
    - **High sodium layer from meteorite burn ups**
    - **90-100km high**

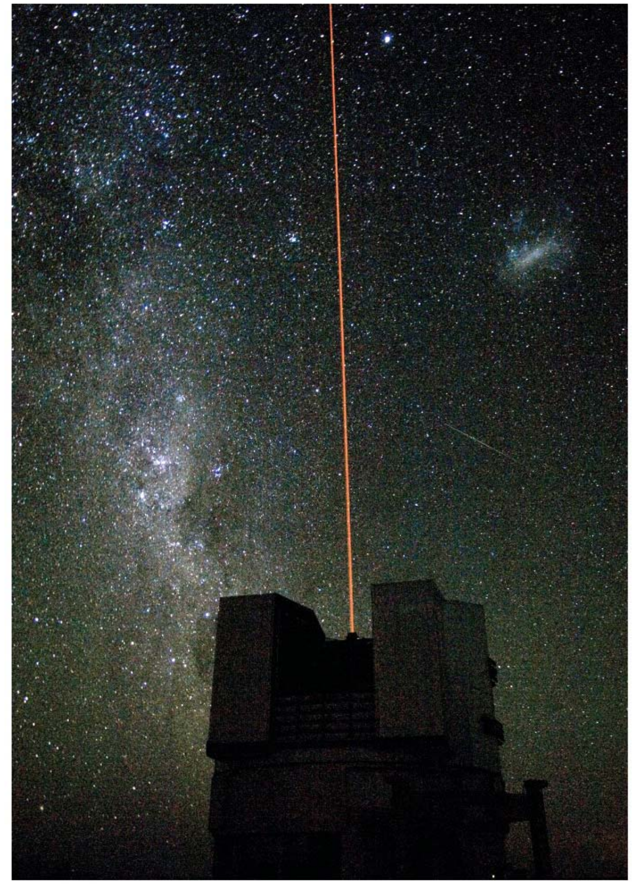
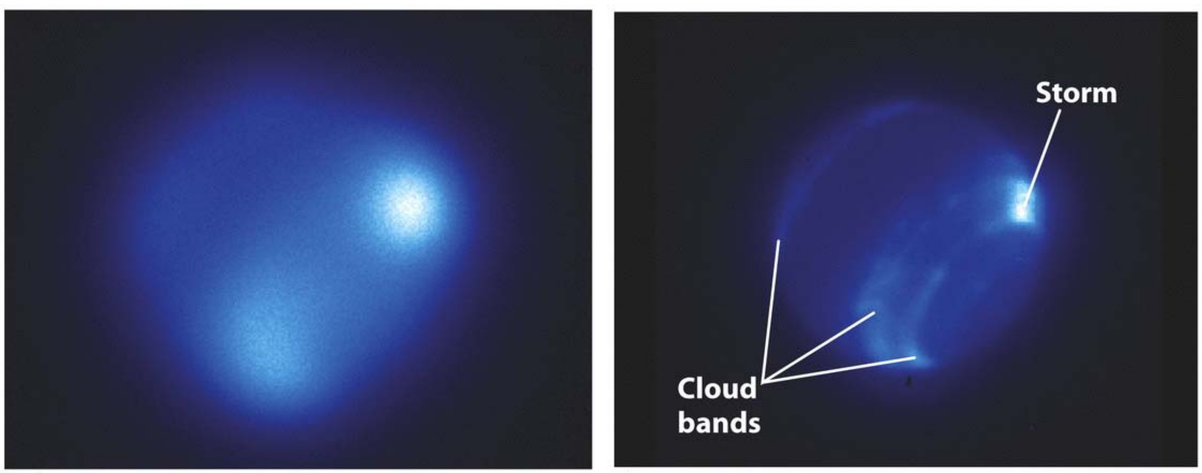


Figure 6-17
Universe, Eighth Edition



(a) Neptune viewed without adaptive optics (b) Neptune viewed with adaptive optics

Atmospheric effects – cont.

- **We can't use all wavelengths from ground-based telescopes**
  - **Gases in our atmosphere absorb light at many wavelengths**

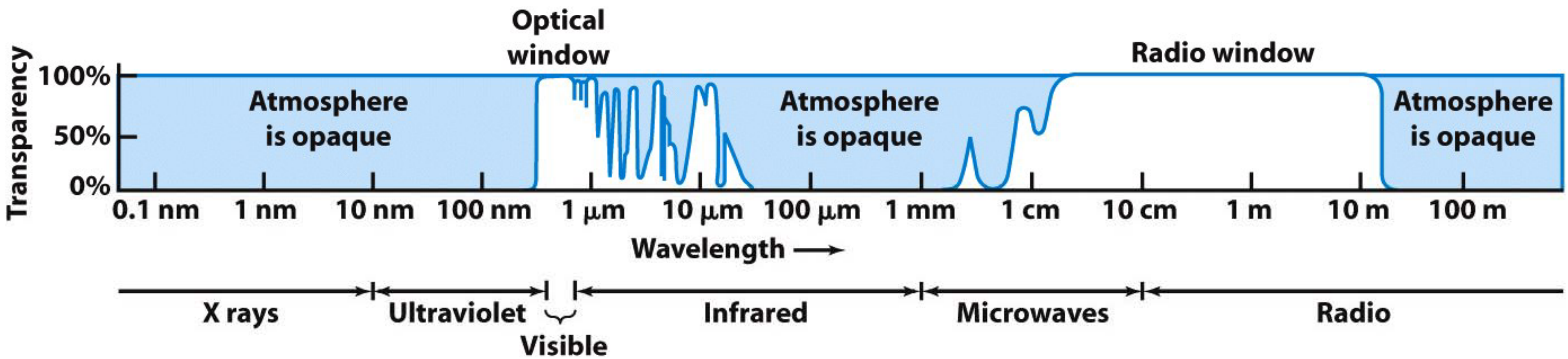


Figure 6-25
Universe, Eighth Edition

  - **This time there's no real way around the problem**
  - **Atmosphere screens out**
    - **Some infrared wavelengths**
    - **Some microwave frequencies**
    - **Most UV light – Good!**
    - **X-rays – Very Good!**
    - **Gamma Rays – Very very Good!!**

By-passing the Atmosphere is the best option…

Figure 6-28
Universe, Eighth Edition

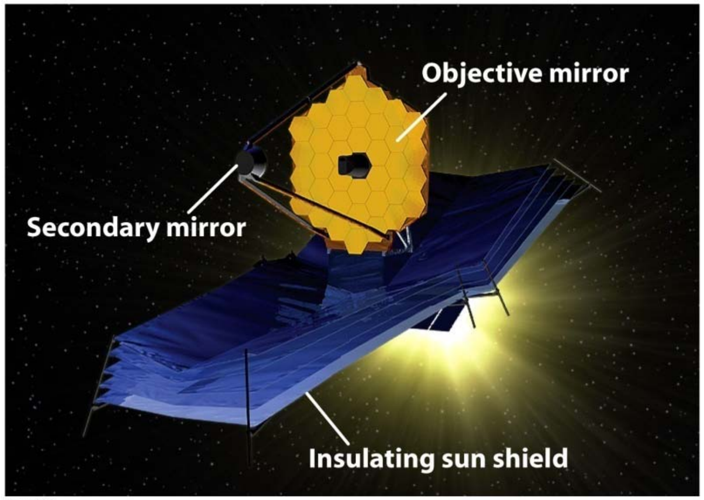
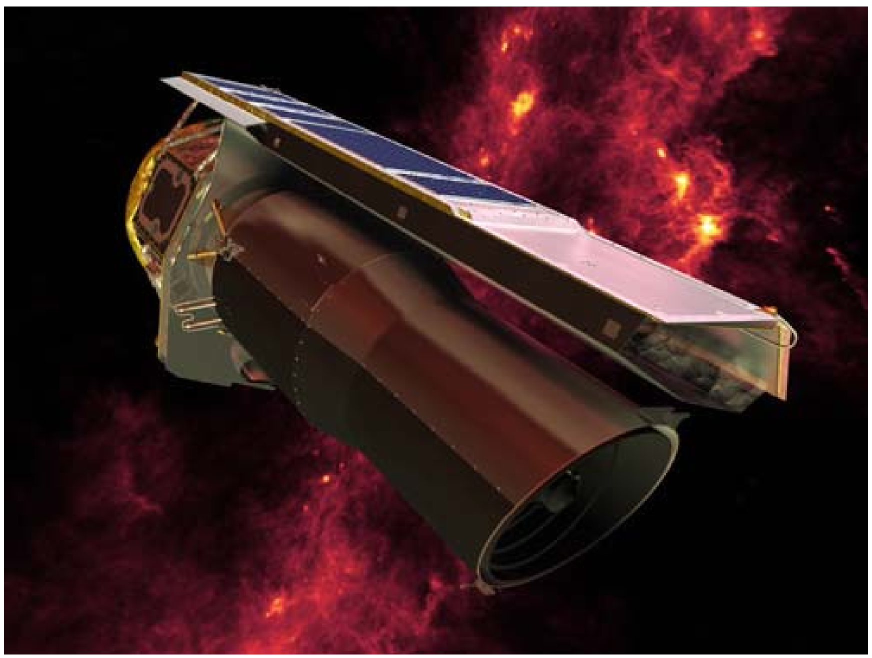
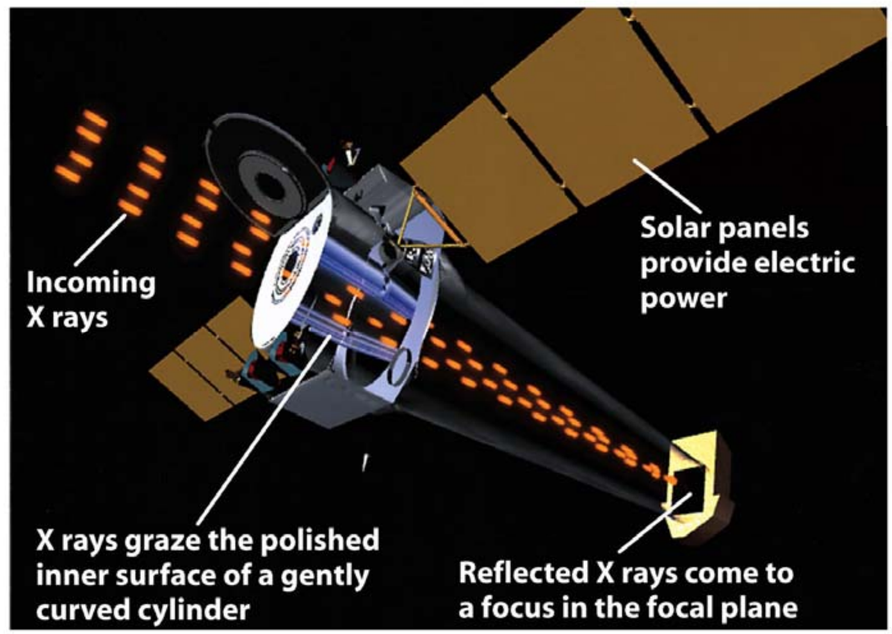


Figure 6-29
Universe, Eighth Edition

Hubble and its successor



Infrared - Spitzer



Chandra X-ray Observatory

Figure 6-30a
Universe, Eighth Edition

Spacecraft

- **Fly-bys**
  - **Usually once off encounters**
  - **Can swing by multiple planets (Voyager)**
  - **…rarely the same planet multiple times**
- **Orbiters**
  - **Usually just one destination (can't carry the fuel needed to escape)**
  - **Long-term monitoring – missions can last years**

- **Landers**
  - **Touch-down on solid planets**
  - **Parachute into gas giant planets**
  - **Different type of instrument**

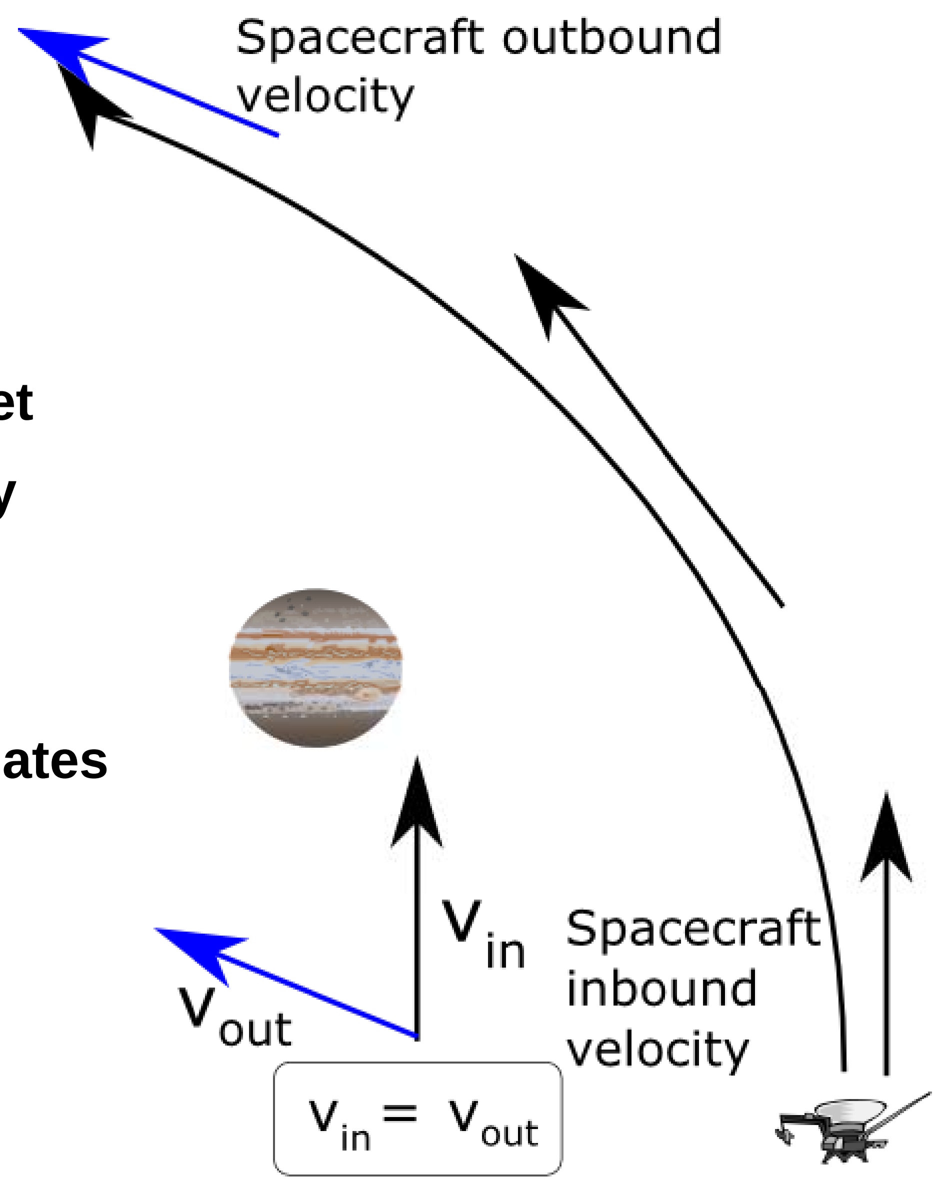
Lots of hybrids

Lander/Flyby – Deep Impact
Orbiter/Flyby - Cassini

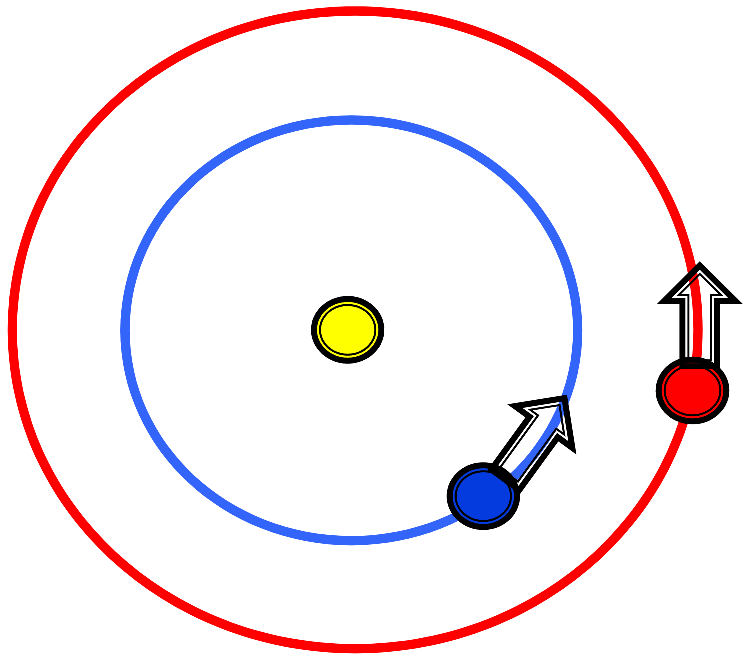
- **Gravity assist**
  - **1st tried by mariner 10**
  - **Common now for missions**

  - **Momentum transfer with a planet**
  - **Big effect on spacecraft velocity**
  - **Tiny effect on planet's velocity**

  - **Narrows your range of launch dates**



- **Launch windows**
  - **Earth moves at 27 km s^{-1}**
  - **We don't want to waste that energy**
  - **To get to Mars - Earth is in a favorable position every two years**



In this lecture…

- **Telescopes and how they work**
  - **Reflectors and refractors**
  - **Resolution and magnification**
  - **Atmospheric effects**

- **Spacecraft and how they work**
  - **Fly-bys, Orbiters & Landers**
  - **Tricks of the trade**

Next: Exploring the solar system from the Earth

- **Reading**
  - **Chapter 6 to revise this lecture**
  - **Chapter 16 for next Tuesday**