Telescopes
Collect electromagnetic radiation from the Universe!

Radiation buckets!

Can collect both visible and non-visible radiation!
Optical telescopes collect visible radiation!
Same principles apply to all telescopes!
The two types of optical telescope

1. Refractors – use lenses to collect light
2. Reflectors – use mirrors to collect light
Refracting Telescopes
Refraction

Light slows down in glass

Shorter wavelengths refracted more
Example:

Objects seen under water appear distorted
Dismembered Polar Bear?
A convex lens collects light and brings it to a focus
A Refracting Telescope

A second eyepiece lens magnifies the image.
The image formed in an astronomical telescope is upside down and back to front:

![Actual image orientation as seen with the unaided eye](image1)

![Inverted image, as viewed with the eyepiece directly in telescope](image2)
An Amateur Refracting Telescope
The 1m telescope in
Yerkes, WI
The world’s largest refractor
Chromatic Aberration
Refraction in a prism splits sunlight into its component colors!

This is unwanted in a refracting telescope!
One partial solution – a compound lens

Problem – cannot be removed completely!
Other problems with refractors

1. Large lenses deform under gravity
2. Air bubbles trapped in glass distorts images
3. Glass very expensive
4. Objective has to be held at edges, partially blocking light
Objective lens clamped at the end of the telescope
Reflecting Telescopes
Reflection

Law of reflection: i = r
A concave mirror collects light and brings it to a focus.
Newton built the first reflecting telescope
Reflectors come in many configurations!

(a) Newtonian focus  (b) Prime focus  (c) Cassegrain focus  (d) Coudé focus
An Amateur Reflecting Telescope
The 5 m Hale telescope on Mount Palomar in California
Reflectors can be made much larger than Refractors!

<table>
<thead>
<tr>
<th>Size</th>
<th>Name</th>
<th>Sponsor</th>
<th>Location</th>
<th>Opened</th>
<th>Special Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.4 m</td>
<td>Gran Telescopio Canarias</td>
<td>Spain, Mexico, U. Florida</td>
<td>Canary Islands</td>
<td>2005</td>
<td>Segmented primary mirror based on mirrors for Keck telescopes</td>
</tr>
<tr>
<td>10 m</td>
<td>Keck I and Keck II</td>
<td>Cal Tech, U. California, NASA</td>
<td>Mauna Kea, HI</td>
<td>1993/1996</td>
<td>Two identical 10-m telescopes, each with a primary mirror consisting of 36 1.8-m hexagonal segments</td>
</tr>
<tr>
<td>9.2 m</td>
<td>Hobby-Eberly</td>
<td>U. Texas, Penn State, Stanford, Germany</td>
<td>Mt. Locke, TX</td>
<td>1997</td>
<td>Consists of 91 1-m segments, for a total diameter of 11 m, but only 9.2 m can be used at a time; designed primarily for spectroscopy</td>
</tr>
<tr>
<td>9.2 m</td>
<td>South African Large Telescope</td>
<td>South Africa, Rutgers, UW–Madison, UNC–Chapel Hill, Dartmouth, Carnegie-Mellon, 5 others</td>
<td>South Africa</td>
<td>2004</td>
<td>Based on design of Hobby-Eberly telescope</td>
</tr>
<tr>
<td>2 × 8.4 m</td>
<td>Large Binocular Telescope</td>
<td>U. Arizona, Ohio State U., Italy, Germany</td>
<td>Mt. Graham, AZ</td>
<td>2006</td>
<td>Two 8.4-m mirrors on a common mount, giving light-collecting area of 11.8-m telescope</td>
</tr>
<tr>
<td>4 × 8.2 m</td>
<td>Very Large Telescope</td>
<td>European Southern Observatory</td>
<td>Cerro Paranal, Chile</td>
<td>2000</td>
<td>Four separate 8-m telescopes designed to work individually or together as the equivalent of a 16-m telescope</td>
</tr>
<tr>
<td>8.3 m</td>
<td>Subaru</td>
<td>Japan</td>
<td>Mauna Kea, HI</td>
<td>1999</td>
<td>Japan's first large telescope project</td>
</tr>
<tr>
<td>8 m</td>
<td>Gemini North and South</td>
<td>U.S., U.K., Canada, Chile, Brazil, Argentina</td>
<td>Mauna Kea, HI (North); Cerro Pachon, Chile (South)</td>
<td>1999</td>
<td>Twin telescopes, one in each hemisphere</td>
</tr>
<tr>
<td>6.5 m</td>
<td>Magellan I and II</td>
<td>Carnegie Institute, U. Arizona, Harvard, U. Michigan, MIT</td>
<td>Las Campanas, Chile</td>
<td>2000/2002</td>
<td>Twin 6.5-m telescopes, known respectively as the Walter Baade and Landon Clay telescopes</td>
</tr>
<tr>
<td>6.5 m</td>
<td>MMT</td>
<td>Smithsonian Institution, U. Arizona</td>
<td>Mt. Hopkins, AZ</td>
<td>2000</td>
<td>Replaced an older telescope in the same observatory</td>
</tr>
</tbody>
</table>
Spherical Aberration

(a) The problem

Spherical mirror
Can be completely removed!

Another advantage over refractors!
Large mirrors can take many months to fabricate!
The Hubble Space Telescope (HST)
HST was found to suffer from spherical aberration when it was launched in 1990.
In 1993 HST was serviced in order to fix the problem
It now has clear vision!
Large mirrors over 5 m in diameter deform under their own weight!
One solution:

Multiple Mirror Telescopes

Example:

The 10 m Keck telescopes on Mauna Kea in Hawaii

Made of 36 separate 1.8 m mirrors
Another Solution – Active Optics

Use a single, large thin mirror and place sensors at the back that continuously maintain its shape.
Example:
The 8 m Subaru telescope on Mauna Kea in Hawaii
Aperture = the size of a telescopes mirror or lens!
Bigger is better!
Larger apertures collect more light!
light gathering power (LGP) of a telescope depends on the area of the main mirror or lens

\[
\text{area} = \pi \frac{D^2}{4}
\]

LGP → area → \(D^2\)

D ↑ LGP ↑

D x 2 LGP x 2^2 = 4

D x 3 LGP x 3^2 = 9
Giving us brighter images and the ability to see fainter objects!
The larger the aperture, the sharper the images and the more detail that is seen!
Large telescopes are capable of seeing fine detail in images!

However, they are limited by the blurring effects of the Earth’s atmosphere!
Two stars seen from space
The same stars seen from the Earth’s surface!
Adaptive Optics (AO)

By firing a laser up into the sky close to the target object, atmospheric turbulence can be subtracted producing sharper images!
Image Sharpening using Adaptive Optics
Modern Astronomy
Atmospheric Transparency

Before radiation is collected it must first pass through the Earth’s atmosphere!

Not all wavelengths get through!!
<table>
<thead>
<tr>
<th>Wavelength</th>
<th>Transparency</th>
<th>Can observe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visible, radio</td>
<td>Good</td>
<td>from ground</td>
</tr>
<tr>
<td>far-UV, X-ray, Gamma Ray</td>
<td>Blocked by upper atmosphere</td>
<td>only from space</td>
</tr>
<tr>
<td>IR, Microwave</td>
<td>Blocked by water vapor in lower atmosphere</td>
<td>From tops of tall mountains</td>
</tr>
</tbody>
</table>
Mauna Kea, HI

Elevation: 13,700 ft