ASTR 2310: Chapter 6

• Astronomical Detection of Light
• The Telescope as a Camera
• Refraction and Reflection Telescopes
• Quality of Images
• Astronomical Instruments and Detectors
• Observations and Photon Counting
• Other Wavelengths
• Modern Telescopes
Refracting / Reflecting Telescopes

Refracting Telescope:
Lens focuses light onto the focal plane

Reflecting Telescope:
Concave Mirror focuses light onto the focal plane

Almost all modern telescopes are reflecting telescopes.
Secondary Optics

In reflecting telescopes: Secondary mirror, to redirect light path towards back or side of incoming light path.

Eyepiece: To view and enlarge the small image produced in the focal plane of the primary optics.
Disadvantages of Refracting Telescopes

• Chromatic aberration: Different wavelengths are focused at different focal lengths (prism effect). Can be corrected, but not eliminated by second lens out of different material.

• Difficult and expensive to produce: All surfaces must be perfectly shaped; glass must be flawless; lens can only be supported at the edges.
The Best Location for a Telescope

Far away from civilization – to avoid light pollution
The Best Location for a Telescope (II)

On high mountain-tops – to avoid atmospheric turbulence (seeing) and other weather effects

Paranal Observatory (ESO), Chile

http://en.wikipedia.org/wiki/Paranal_Observatory
The Powers of a Telescope: Size does matter!

1. Light-gathering power: Depends on the surface area $A$ of the primary lens / mirror, proportional to diameter squared:

$$A = \pi \left(\frac{D}{2}\right)^2$$
2. Resolving power: Wave nature of light

=> The telescope aperture produces fringe rings that set a limit to the resolution of the telescope.

Astronomers can’t eliminate these diffraction fringes, but the larger a telescope is in diameter, the smaller the diffraction fringes are. Thus the larger the telescope, the better its resolving power.

\[ \theta_{\text{min}} = 1.22 \left( \frac{\lambda}{D} \right) \text{ (radians)} \]

For optical wavelengths, this gives

\[ \theta_{\text{min}} = 11.6 \text{ arcsec} / D[\text{cm}] \]
The Powers of a Telescope (III)

3. Magnifying Power = ability of the telescope to make the image appear bigger.

A larger magnification does not improve the resolving power of the telescope!
Traditional Telescopes (I)

Traditional primary mirror: sturdy, heavy to avoid distortions.
Traditional Telescopes (II)

The 4-m Mayall Telescope at Kitt Peak National Observatory (Arizona)
Astronomical Telescopes

Often very large to gather large amounts of light.

In order to observe forms of radiation other than visible light, very different telescope designs are needed.

The northern Gemini Telescope on Hawaii
Examples of Modern Telescope Design

The Very Large Telescope (VLT)

8.1-m mirror of the Gemini Telescopes
Seeing

Weather conditions and turbulence in the atmosphere set further limits to the quality of astronomical images.
Advances in Modern Telescope Design

Lighter mirrors with lighter support structures, to be controlled dynamically by computers.

Floppy mirror

Segmented mirror

The thrusters are located behind the mirror segments in this photo of the Keck I mirror. The technician is sitting in the front of the light baffle over the Cassegrain hole in the center of the mirror.
Adaptive Optics

Computer-controlled mirror support adjusts the mirror surface (many times per second) to compensate for distortions by atmospheric turbulence.
Recall: Resolving power of a telescope depends on diameter $D$.

Combine the signals from several smaller telescopes to simulate one big mirror.
CCD Imaging

CCD = Charge-coupled device

- More sensitive than photographic plates

- Data can be read directly into computer memory, allowing easy electronic manipulations

False-color image to visualize brightness contours
Using a prism (or a grating), light can be split up into different wavelengths (colors!) to produce a spectrum. Spectral lines in a spectrum tell us about the chemical composition and other properties of the observed object.
Radio Astronomy

Recall: Radio waves of \( \sim 1 \text{ cm} - 1 \text{ m} \) also penetrate the Earth’s atmosphere and can be observed from the ground.
Radio Telescopes

Large dish focuses the energy of radio waves onto a small receiver (antenna)

Amplified signals are stored in computers and converted into images, spectra, etc.
Radio Interferometry

Just as for optical telescopes, the resolving power of a radio telescope depends on the diameter of the objective lens or mirror

$$\theta_{\text{min}} = \frac{1.22 \lambda}{D}.$$  

For radio telescopes, this is a big problem: Radio waves are much longer than visible light.

Use interferometry to improve resolution!

The Very Large Array (VLA): 27 dishes are combined to simulate a large dish of 36 km in diameter.
The Largest Radio Telescopes

The 100-m Green Bank Telescope in Green Bank, West Virginia.

The 300-m telescope in Arecibo, Puerto Rico.
Science of Radio Astronomy

Radio astronomy reveals several features, not visible at other wavelengths:

• Neutral hydrogen clouds (which don’t emit any visible light), containing ~ 90% of all the atoms in the universe.

• Molecules (often located in dense clouds, where visible light is completely absorbed).

• Radio waves penetrate gas and dust clouds, so we can observe regions from which visible light is heavily absorbed.
Infrared Astronomy

Most infrared radiation is absorbed in the lower atmosphere.

However, from high mountain tops or high-flying aircraft, some infrared radiation can still be observed.
Infrared Telescopes

WIRO 2.3m

Spitzer Space Telescope
Ultraviolet Astronomy

• Ultraviolet radiation with $\lambda < 290$ nm is completely absorbed in the ozone layer of the atmosphere.

• Ultraviolet astronomy has to be done from satellites.

• Several successful ultraviolet astronomy satellites: IUE, EUVE, FUSE

• Ultraviolet radiation traces hot (tens of thousands of degrees), moderately ionized gas in the universe.
NASA’s Great Observatories in Space

The Hubble Space Telescope

- Launched in 1990; maintained and upgraded by several space shuttle service missions throughout the 1990s and early 2000’s
- Avoids turbulence in Earth’s atmosphere
- Extends imaging and spectroscopy to (invisible) infrared and ultraviolet
Hubble Space Telescope Images

- Mars with its polar ice cap
- Nebula around an aging star
- A dust-filled galaxy
NASA’s Great Observatories in Space (II)

The Compton Gamma-Ray Observatory

Operated from 1991 to 2000

Observation of high-energy gamma-ray emission, tracing the most violent processes in the universe.
NASA’s Great Observatories in Space III

The Chandra X-ray Telescope

Launched in 1999 into a highly eccentric orbit that takes it 1/3 of the way to the moon!

X-rays trace hot (million degrees), highly ionized gas in the universe.

Two colliding galaxies, triggering a burst of star formation

Very hot gas in a cluster of galaxies
Chandra X-ray Observatory

Shuttle launched, highly eccentric orbit.

Grazing incidence mirrors – nested hyperboloids and paraboloids.
The Highest Tech Mirrors Ever!

- Chandra is the first X-ray telescope to have image as sharp as optical telescopes.
NASA’s Great Observatories in Space (IV)

The Spitzer Space Telescope

Launched in 2003

Infrared light traces warm dust in the universe.

The detector needs to be cooled to -273 °C (-459 °F).
Spitzer Space Telescope Images

A Comet

Newborn stars that would be hidden from our view in visible light

Warm dust in a young spiral galaxy
Spitzer Space Telescope

- Discovered by a Wyoming grad student and professor. The “Cowboy Cluster” – an overlooked Globular Cluster.
Kepler’s Supernova with all three of NASA’s Great Observatories

• Just 400 years ago: (Oct. 9, 1604)
• Then a bright, naked eye object (no telescopes)
• It’s still blowing up – now 14 light years wide and expanding at 4 million mph.
• There’s material there at MANY temperatures, so many wavelengths are needed to understand it.
A Multiwavelength Look at Cygnus A

- A merger product, and powerful radio galaxy.
<table>
<thead>
<tr>
<th>Under study</th>
<th>In development</th>
<th>Operating</th>
<th>Past missions</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANITA</td>
<td>AIM</td>
<td>ACE</td>
<td>Ended after 1989:</td>
</tr>
<tr>
<td>Constellation-X</td>
<td>Astro-E2</td>
<td>Cassini</td>
<td>ASCA</td>
</tr>
<tr>
<td>DUO</td>
<td>CINDI</td>
<td>Chandra</td>
<td>Astro-1 / Astro-2</td>
</tr>
<tr>
<td>EUSO</td>
<td>Dawn</td>
<td>CHIPS</td>
<td>BEXRT</td>
</tr>
<tr>
<td>GEC</td>
<td>Deep Impact</td>
<td>Cluster</td>
<td>Clementine</td>
</tr>
<tr>
<td>Geospace</td>
<td>GLAST</td>
<td>FAST</td>
<td>CGRO</td>
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<tr>
<td>IBEX</td>
<td>Herschel</td>
<td>FUSE</td>
<td>CCBE</td>
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<tr>
<td>JIMO</td>
<td>Mars 06 Orbiter</td>
<td>GALEX</td>
<td>CONTOUR</td>
</tr>
<tr>
<td>JMEX</td>
<td>New Horizons (Pluto)</td>
<td>Genesis</td>
<td>CRRES</td>
</tr>
<tr>
<td>Juno</td>
<td>Planck</td>
<td>Geotail</td>
<td>DE-1</td>
</tr>
<tr>
<td>JWST (NGST)</td>
<td>SOFIA</td>
<td>Gravity Probe B</td>
<td>Deep Space 1</td>
</tr>
<tr>
<td>Kepler</td>
<td>Solar-B</td>
<td>HETE-2</td>
<td>Deep Space 2</td>
</tr>
<tr>
<td>LISA</td>
<td>Space Tech 5</td>
<td>Hubble (HST)</td>
<td>DXS</td>
</tr>
<tr>
<td>Mag Constellation</td>
<td>Space Tech 6</td>
<td>IMAGE</td>
<td>Equator-S</td>
</tr>
<tr>
<td>Mag Multiscale</td>
<td>Space Tech 7</td>
<td>INTEGRAL</td>
<td>EUVE</td>
</tr>
<tr>
<td>Mars 2009</td>
<td>STEREO</td>
<td>Mars '03 Rovers</td>
<td>Galileo</td>
</tr>
<tr>
<td>Mars - beyond 2009</td>
<td>Swift</td>
<td>Mars Express /</td>
<td>HALCA / VLBI</td>
</tr>
<tr>
<td>Moons X-2006</td>
<td>THEMIS</td>
<td>ASPERA-3</td>
<td>Hipparcos</td>
</tr>
<tr>
<td>NEXUS</td>
<td>TWINS</td>
<td>Mars Global Surv.</td>
<td>Hubble (past)</td>
</tr>
<tr>
<td>NuSTAR</td>
<td></td>
<td>Mars Odyssey</td>
<td>IEH-3</td>
</tr>
<tr>
<td>Phoenix</td>
<td></td>
<td>MESSENGER</td>
<td>ISW-3/ICE</td>
</tr>
<tr>
<td>SDO</td>
<td></td>
<td>Polar</td>
<td>IMP-8</td>
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<tr>
<td>Sentinels</td>
<td></td>
<td>RHESSI</td>
<td>IRTS</td>
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<td>SIM</td>
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<td>Rosetta</td>
<td>ISO</td>
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<td>Solar Probe</td>
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<td>RXTE</td>
<td>IUE</td>
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<td>TPF</td>
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<td>SAMPEX</td>
<td>Kaper (KAO)</td>
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<td>WISE</td>
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<td>SOHO</td>
<td>Leeuward MAC</td>
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<td>Splitzer (SITF)</td>
<td>Lunar Prospector</td>
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<td>Stardust</td>
<td>Magellan</td>
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<td>TIMED</td>
<td>Mars Observer</td>
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<td>TRACE</td>
<td>Mars Pathfinder</td>
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<tr>
<td></td>
<td></td>
<td>Ulysses</td>
<td>Mars Polar Lander</td>
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<td>Voyager</td>
<td>NEAR</td>
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<td>Wind</td>
<td>ORFEUS</td>
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<td>preliminary concepts</td>
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The Future of Space-Based Optical/Infrared Astronomy:

The James Webb Space Telescope