Light and Telescopes
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?
Telescopes

• The fundamental purpose of any telescope is to gather more light than the unaided eye can.

• In many cases, telescopes are used to produce images far brighter and sharper than the eye alone could ever record.
A refracting telescope uses a lens to concentrate incoming light at a focus.
How Light Beams Behave

- 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.
- This phenomenon, called **refraction**, is caused by the change in the speed of light.
- Textbook compares to auto traction on differing road.
Compare Light Passing Through Flat Plate Glass versus Through a Lens

- Parallel light rays
- Flat glass
- Refraction
- Curved lens
- Focal length
- Focal point
How Does Light from a Celestial Object Pass through a Lens?
Light Gathering Power – Most Important

- The **light-gathering power** of a telescope is directly proportional to the area of the objective lens
  - it is directly proportional to the square of the lens diameter
• The magnification of a telescope is equal to the focal length of the objective divided by the focal length of the eyepiece
  – Stars are points of light and have no surface in a telescope
  – Stars are not magnified by telescopes
Chromatic Aberration – A Problem with Lenses

- Lenses bend different colors of light through different angles, just as a prism does.
- As a result, different colors do not focus at the same point, and stars viewed through a telescope that uses a simple lens are surrounded by fuzzy, rainbow-colored halos.
- If the telescope designer carefully chooses two different kinds of glass for two lenses that make up the one, different colors of light can be brought to a focus at the same point.
A Large Refractor
Glass impurities, chromatic aberration, opacity to certain wavelengths, and structural difficulties with weight and balance make it inadvisable to build extremely large refractors.
A reflecting telescope uses a mirror to gather incoming light at a focus

- Reflecting telescopes, or reflectors, produce images by reflecting light rays to a focus point from curved mirrors.
- Reflectors are not subject to most of the problems that limit the useful size of refractors.
  - But there are still some issues
    - Spherical aberration
    - Second surface vs. first surface
Reflecting Telescopes

(a) Newtonian focus  (b) Prime focus  (c) Cassegrain focus  (d) Coudé focus

Incoming parallel rays from a distant object

Focal point outside telescope tube

Secondary Mirror

Focal point for outside tube

Moon

Secondary mirror

Eyepiece

Complete image of the moon

Primary mirror
Mason Observatory and Telescope

- First observatory at GMU was built in 1975 (Herschel Observatory)
  - torn down for Field House
- Second Mason observatory built in 1980
  - vandalized and had truck driven into (1981)
- Current observatory dedicated January 2007
- 32” RC telescope due in 2009
Spherical Aberration

- A spherical surface is easy to grind and polish, but different parts of a spherical mirror have slightly different focal lengths.
- This results in a fuzzy image.
- There are two solutions used by astronomers:
  - Parabolic mirrors
  - Correcting lenses
<table>
<thead>
<tr>
<th>Telescope</th>
<th>Location</th>
<th>Year of completion</th>
<th>Mirror diameter (m)</th>
</tr>
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<tbody>
<tr>
<td>Gran Telescopio Canarias</td>
<td>La Palma, Canary Islands, Spain</td>
<td>2004</td>
<td>10.4</td>
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<tr>
<td>Keck II</td>
<td>Mauna Kea, Hawaii</td>
<td>1996</td>
<td>10.0</td>
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<tr>
<td>Keck I</td>
<td>Mauna Kea, Hawaii</td>
<td>1993</td>
<td>10.0</td>
</tr>
<tr>
<td>Hobby-Eberly Telescope</td>
<td>McDonald Observatory, Texas</td>
<td>1998</td>
<td>11.0*</td>
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<tr>
<td>South African Large Telescope</td>
<td>Sutherland, South Africa</td>
<td>2004</td>
<td>9.2</td>
</tr>
<tr>
<td>Large Binocular Telescope</td>
<td>Mount Graham, Arizona</td>
<td>2004–05</td>
<td>Two 8.4</td>
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<tr>
<td>Subaru</td>
<td>Mauna Kea, Hawaii</td>
<td>1999</td>
<td>8.3</td>
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<tr>
<td>VLT UT 1–Antu</td>
<td>Cerro Paranal, Chile</td>
<td>1998</td>
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<tr>
<td>VLT UT 2–Kueyen</td>
<td>Cerro Paranal, Chile</td>
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<td>VLT UT 3–Melipal</td>
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<td>VLT UT 4– Yepun</td>
<td>Cerro Paranal, Chile</td>
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<td>Gemini North (Gillett)</td>
<td>Mauna Kea, Hawaii</td>
<td>1999</td>
<td>8.1</td>
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<tr>
<td>Gemini South</td>
<td>Cerro Pachón, Chile</td>
<td>2000</td>
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</tr>
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</table>

*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.*
Resolution and Telescopes

• **Angular Resolution**
  – indicates ability to see fine details
  – limited by two key factors
    • Diffraction
    • Environmental turbulence

• **Diffraction Limit**
  – An intrinsic property of light waves
  – Can be minimized by using a larger objective lens or mirror

• **Environmental factors**
  – Telescope images are degraded by the blurring effects of the atmosphere and by light pollution
  – Can be minimized by placing the telescope atop a tall mountain with very smooth air
  – They can be dramatically reduced by the use of adaptive optics or by placing the telescope in orbit or some other space
Two light sources with angular separation greater than angular resolution of telescope: Two sources easily distinguished

Light sources moved closer so that angular separation equals angular resolution of telescope: Just barely possible to tell that there are two sources
Telescopes on Mauna Kea for Sky Clarity

University of Hawaii 0.6-m Telescope
United Kingdom Infrared Telescope
Gemini North
University of Hawaii 2.2-meter Telescope
Caltech Submillimeter Observatory
James Clerk Maxwell Telescope
Submillimeter Array
Subaru
Keck I
Keck II
NASA Infrared Telescope Facility
Canada-France-Hawaii Telescope
Adaptive Optics

(a) Neptune viewed without adaptive optics

(b) Neptune viewed with adaptive optics
A CCD (electronic sensor)

- Sensitive light detectors called charge coupled devices (CCDs) are often used at a telescope’s focus to record faint images.
Comparing Photographic Film to CCD

(a) Using photographic film  
(b) Using a CCD  
(c) Combined CCD image
A spectrograph uses a diffraction grating or prism and lenses to form the spectrum of an astronomical object.
Sample Spectrum

Spectrum of star

Comparison spectrum of iron (at the observatory on Earth)
Comparing Analog and Digital Spectra

Absorption lines
Radio Telescopes

• Radio telescopes use large reflecting antennas (a dish is a type of antenna) to focus radio waves
• Radio waves have longer wavelengths
  – Very large dishes are required to produce reasonably sharp radio images
    • Color-coded
    • Contour map
Higher resolution is achieved with interferometry techniques that link smaller dishes together as one larger antenna.
Optical and Radio Views of Saturn
Telescopes in Orbit

- The Earth’s atmosphere absorbs much of the radiation that arrives from space.
- The atmosphere is transparent chiefly in two wavelength ranges known as the optical window and the radio window.
- A few wavelengths in the near-infrared also reach the ground.
• For observations at wavelengths to which the Earth’s atmosphere is opaque, astronomers depend on telescopes carried above the atmosphere by rockets or spacecraft.
Next Generation (James Webb) Space Telescope

Objective mirror

Secondary mirror

Insulating sun shield
X-ray Telescopes

(a) Chandra X-ray Observatory

Incoming X rays

X rays graze the polished inner surface of a gently curved cylinder

Reflected X rays come to a focus in the focal plane

Solar panels provide electric power
Multi-wavelength Satellite-based Observatories

Together provide a better understanding of the universe
Astronomical Instrument Jargon

- active optics
- adaptive optics
- angular resolution
- baseline
- Cassegrain focus
- charge-coupled device (CCD)
- chromatic aberration
- coma
- coudé focus
- diffraction
- diffraction grating
- eyepiece lens
- false color
- focal length
- focal plane
- focal point
- focus (of a lens or mirror)
- grating
- imaging
- interferometry
- light-gathering power
- light pollution
- magnification (magnifying power)
- medium (*plural* media)
- Newtonian reflector
- objective lens
- objective mirror (primary mirror)
- optical telescope
- optical window
- photometry
- pixel
- prime focus
- radio telescope
- radio window
- reflecting telescope (reflector)
- reflection
- refracting telescope (refractor)
- refraction
- seeing disk
- spectrograph
- spectroscopy
- spherical aberration
- very-long-baseline interferometry (VLBI)