Eclipses and the Motion of the Moon
Chapter Three

Guiding Questions

1. Why does the Moon go through phases?
2. Is there such a thing as the “dark side of the Moon”?
3. What is the difference between a lunar eclipse and a solar eclipse?
4. How often do lunar eclipses happen? When one is taking place, where do you have to be to see it?
5. How often do solar eclipses happen? Why are they visible only from certain special locations on Earth?
6. How did ancient astronomers deduce the sizes of the Earth, the Moon, and the Sun?

The phases of the Moon are caused by its orbital motion

• The phases of the Moon occur because light from the Moon is actually reflected sunlight
• As the relative positions of the Earth, the Moon, and the Sun change, we see more or less of the illuminated half of the Moon.
Time and the Moon

- Two types of months are used in describing the motion of the Moon.
- With respect to the stars, the Moon completes one orbit around the Earth in a sidereal month, averaging 27.32 days.
- The Moon completes one cycle of phases (one orbit around the Earth with respect to the Sun) in a synodic month, averaging 29.53 days.
The Moon’s rotation always keeps the same face toward the Earth due to synchronous rotation.

Eclipses occur only when the Sun and Moon are both on the line of nodes.
Lunar eclipses can be either total, partial, or penumbral, depending on the alignment of the Sun, Earth, and Moon.

Time Lapse Photographic Sequence of a Lunar Eclipse
Future Lunar Eclipses

<table>
<thead>
<tr>
<th>Date</th>
<th>Type</th>
<th>Where visible</th>
<th>Duration of totality</th>
</tr>
</thead>
<tbody>
<tr>
<td>2014 May 4</td>
<td>Total</td>
<td>South America, Europe, Africa, Asia, Australia</td>
<td>1h 58m</td>
</tr>
<tr>
<td>2014 October 8</td>
<td>Total</td>
<td>Americas, Europe, Africa, central Asia</td>
<td>1h 23m</td>
</tr>
<tr>
<td>2015 April 14</td>
<td>Partial</td>
<td>Eastern Asia, Australia, Pacific, Americas</td>
<td>—</td>
</tr>
<tr>
<td>2015 October 26</td>
<td>Partial</td>
<td>Asia, Australia, Pacific, North America</td>
<td>—</td>
</tr>
<tr>
<td>2016 March 16</td>
<td>Partial</td>
<td>Americas, Europe, Africa, Asia</td>
<td>—</td>
</tr>
<tr>
<td>2016 September 7</td>
<td>Partial</td>
<td>Europe, Africa, Asia, Australia</td>
<td>—</td>
</tr>
<tr>
<td>2017 March 8</td>
<td>Total</td>
<td>Americas, Europe, Africa, Asia</td>
<td>1h 34m</td>
</tr>
<tr>
<td>2017 August 8</td>
<td>Total</td>
<td>Eastern Asia, Australia, Pacific, Americas</td>
<td>1h 33m</td>
</tr>
<tr>
<td>2018 February 26</td>
<td>Total</td>
<td>Central Pacific, Americas, Europe, Africa</td>
<td>1h 3m</td>
</tr>
<tr>
<td>2018 August 7</td>
<td>Partial</td>
<td>South America, Europe, Africa, Asia, Australia</td>
<td>—</td>
</tr>
</tbody>
</table>

*Eclipse predictions by Fred Espenak, NASA/Goddard Space Flight Center. All data are given in standard astronomical format year, month, day.
An Example of an Annular Eclipse

Future Solar Eclipses

<table>
<thead>
<tr>
<th>Date</th>
<th>Type</th>
<th>Where visible</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004 April 19</td>
<td>Partial</td>
<td>Antarctica, western Africa</td>
<td>75% eclipsed</td>
</tr>
<tr>
<td>2004 October 14</td>
<td>Partial</td>
<td>Northeast Asia, Hawaii, Alaska</td>
<td>99% eclipsed</td>
</tr>
<tr>
<td>2005 April 6</td>
<td>Annular</td>
<td>New Zealand, North and South America</td>
<td>Annular along path, maximum duration of totality 98.1 s</td>
</tr>
<tr>
<td>2005 October 3</td>
<td>Annular</td>
<td>Europe, Africa, southern Asia</td>
<td></td>
</tr>
<tr>
<td>2006 March 29</td>
<td>Total</td>
<td>Africa, Europe, western Asia</td>
<td>Maximum duration of totality 4 min 7 s</td>
</tr>
<tr>
<td>2006 September 12</td>
<td>Annular</td>
<td>South America, western Africa, Antarctica</td>
<td>—</td>
</tr>
<tr>
<td>2007 March 19</td>
<td>Partial</td>
<td>Asia, Alaska</td>
<td>97% eclipsed</td>
</tr>
<tr>
<td>2007 September 11</td>
<td>Partial</td>
<td>South America, Antarctica</td>
<td>79% eclipsed</td>
</tr>
<tr>
<td>2008 February 7</td>
<td>Annular</td>
<td>Antarctica, except Australia, New Zealand</td>
<td>—</td>
</tr>
<tr>
<td>2008 August 1</td>
<td>Total</td>
<td>Northeast North America, Europe, Asia</td>
<td>Maximum duration of totality 2 min 27 s</td>
</tr>
</tbody>
</table>

Eclipse predictions by Fred Espenak, NASA/Goddard Space Flight Center. All dates are given in standard astronomical format: year, month, day.

Paths of Future Solar Eclipses
Another Solar Eclipse

The Saros Cycle

Ancient astronomers measured the size of the Earth and attempted to determine distances to the Sun and Moon

- Observations
  - In the town of Syene, the Sun shone directly down a vertical shaft on the summer solstice
  - In Alexandria, the position of the Sun changed by 7° or about one-fiftieth of a complete circle
- Conclusion
  - Around 200 B.C., the Greek astronomer Eratosthenes used 50 x the distance between Alexandria and Syene to get a circumference of the earth of about 42000 km (the actual is about 40000 kilometers)
Aristarchus knew that the Sun, Moon, and Earth form a right triangle at first and third quarter phases. Using geometrical arguments, he calculated the relative lengths of the sides of these triangles, thereby obtaining the relative distances to the Sun and Moon.

### Table 3-3: Comparison of Ancient and Modern Astronomical Measurements

<table>
<thead>
<tr>
<th></th>
<th>Ancient measure (km)</th>
<th>Modern measure (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earth’s diameter</td>
<td>13,000</td>
<td>12,756</td>
</tr>
<tr>
<td>Moon’s diameter</td>
<td>4,300</td>
<td>3,476</td>
</tr>
<tr>
<td>Sun’s diameter</td>
<td>$9 \times 10^6$</td>
<td>$1.39 \times 10^8$</td>
</tr>
<tr>
<td>Earth-Moon distance</td>
<td>$4 \times 10^7$</td>
<td>$3.84 \times 10^7$</td>
</tr>
<tr>
<td>Earth-Sun distance</td>
<td>$10^7$</td>
<td>$1.50 \times 10^9$</td>
</tr>
</tbody>
</table>

### Key Words
- annular eclipse
- apogee
- eclipse
- eclipse path
- eclipse year
- first quarter moon
- full moon
- line of nodes
- lunar eclipse
- lunar phases
- new moon
- partial lunar eclipse
- partial solar eclipse
- penumbral eclipse
- perigee
- plane of the ecliptic
- saros
- sidereal month
- solar corona
- solar eclipse
- synchronous rotation
- syzygy month
- third quarter moon
- totality
- total lunar eclipse
- total solar eclipse
- umbra
- waning crescent moon
- waning gibbous moon
- waxing crescent moon
- waxing gibbous moon
- u m b r a
- waning crescent moon
- waning gibbous moon
- waxing crescent moon
- waxing gibbous moon