Motions of the Moon and Eclipses

- The Moon revolves around the Earth and rotates on its axis with the same period.
- The combined effect of these two motions means that one side of the Moon always faces the Earth.
- The Moon revolves around the Earth with a sidereal period of 27.3 days.
  - On account of the revolution of the Earth-Moon system around the Sun, the synodic period of the Moon is 29.5 days.
New Moon  
Waning Crescent 
Sun

Sidereal Month
= 27.3 days

Synodic Month
= 29.5 days

$$\omega_{\text{sidereal}} = \omega_{\text{synodic}} + \omega_{\text{Earth}}$$

$$\frac{1}{P_{\text{sidereal}}} = \frac{1}{P_{\text{synodic}}} + \frac{1}{P_{\text{Earth}}}$$

$$P_{\text{sidereal}} = \left[ \frac{1}{29.531^d} + \frac{1}{365.256^d} \right]^{-1} = 27.322^d$$
Motions of the Moon

• The Moon rotates on its axis with a synodic period that matches its synodic period of revolution.
  – The Moon always keeps the same face towards the Earth.

• This is a consequence of tidal friction, which has slowed the Moon’s rotation.
Moon is waning crescent: when does it (1) rise, (2) transit the meridian, and (3) set?

Moon transits meridian when observer is here, about 9 am. Dashed blue line is towards eastern horizon.

Moon sets below observer’s horizon here, about 3 pm. Dashed line shows horizon to east.

Moon first becomes visible when observer is here, about 3 am. Red line is observer’s horizon (to east).
Moon is full: when does it (1) rise, (2) transit the meridian, and (3) set?

Moon first becomes observable when observer is here, about sunset. Line shows horizon to east.

Moon transits the meridian when observer is here, about midnight. Dashed line shows horizon to east.

Moon sets when observer reaches this point, about sunrise. Dashed line shows horizon to east.
Lunar Libration

• Over time, we can actually see more than 50% of the lunar surface on account of lunar librations.
  1 Diurnal libration
    • due to rotation of the Earth
Diurnal Libration

12 hours later

Earth

Moon

2°
Lunar Libration

• Over time, we can actually see more than 50% of the lunar surface on account of lunar librations.

  1 Diurnal libration
  2 Libration in longitude
    • a consequence of Kepler’s Second Law
Libration in Longitude

Moon moves faster in its orbit at perigee; rotation doesn’t keep up.
Lunar Libration

- Over time, we can actually see more than 50% of the lunar surface on account of lunar librations.
  1. Diurnal libration
  2. Libration in longitude
  3. Libration in latitude
     - occurs because Moon’s rotation axis is inclined to axis of its orbit
Libration in Latitude

Moon’s rotation axis

6º.7

ecliptic

Earth
Lunar Librations

• Over time, we can see about 59% of the Moon’s surface on account of librations.
• A time lapse movie showing changing phases of the moon along with librations
  – Also notice the Moon’s changing angular size \( (e = 0.0549) \)
Eclipses

• Eclipses occur when Moon or Earth passes through the shadow of the other body.
  – *Lunar eclipse:* Moon passes through Earth’s shadow (Moon gets dark as seen from Earth).
    • Occurs at Full Moon
Total Lunar Eclipse
Eclipses

– *Solar eclipse:* Earth passes through Moon’s shadow (Sun gets dark as seen from Earth).

• Occurs at New Moon
Solar Eclipses

Partial solar eclipse

Total solar eclipse

sunlight
Annular Eclipse

• An *annular eclipse* can occur when the Moon is near the apogee of its orbit and thus has a smaller angular size than the Sun.
Annular Eclipse

Occurs when Moon near apogee
Conditions for Eclipses

- Eclipses (note the name!) occur when the Sun is close to a node of the Moon’s orbit.
  - *Line of nodes* is the line of intersection between the Moon’s orbit and the ecliptic.
Conditions for Eclipses

- The Moon’s orbit is slightly inclined to the ecliptic (by about 5.1°), so eclipses do not occur every two weeks.
Three months later:
Eclipses Occur When the Sun and Moon Are Near the Line of Nodes
Conditions for Eclipses

New Moon

Sun

Eclipse CANNOT occur

Full Moon

Three months later...

Earth

First quarter Moon

Third quarter Moon

Eclipse CAN occur
Conditions for Eclipses

“syzygy”

First quarter Moon

Earth

Third quarter Moon

Eclipse CAN occur
Conditions for Eclipses

• When the Sun is close to a node, an eclipse occurs when the Moon also reaches a node.
  – Moon at same node: solar eclipse.
  – Moon at opposite node: lunar eclipse.
North

East

Celestial equator

West

South

Ecliptic

Moon’s path

New Moon in May
no eclipse
Celestial equator

East

North

Ecliptic

West

Moon’s path

Full Moon in May

no eclipse

South
New Moon in June eclipse occurs

Moon’s path

Celestial equator

Ecliptic

North

South

East

West
North

South

East

West

Celestial equator

Ecliptic

Moon’s path

Full Moon in December, eclipse occurs
Solar Eclipse Conditions

Sun at node, eclipse can occur.
Solar Eclipse Conditions

Sun not at node, no eclipse.
Node precesses westward
Occurrence of Eclipses

• Eclipses thus occur in bunches.
  – Two week intervals: (e.g., Full to New Moon) Moon moves between nodes.
  – Six month intervals: Sun moves between nodes.
Occurrence of Eclipses

• The Moon’s orbit is precessing, which causes the nodes to move slowly westward (with a period of 18.6 years).

• The interval between positive eclipse conditions is thus somewhat shorter than 6 months (by about 9 days).
Eclipses

• Definitions:
  – *Umbra*: the darkest part of the shadow, inside of which the eclipse is total.
Eclipses

• Definitions:
  – *Umbra*: the darkest part of the shadow, inside of which the eclipse is total.
  – *Penumbra*: partial shadow, inside of which the eclipse is only partial.
Lunar Eclipses

- Sunlight
- Umbra
- Penumbra
- Earth
Lunar Eclipses

- Lunar eclipses can be:
  - 1 Total
Total Lunar Eclipse

- sunlight
- Earth
- penumbra
Total Lunar Eclipse

- The near totally eclipsed Moon is reddish because of red light refracted through the Earth’s atmosphere.
Scattering of Sunlight by the Earth’s Atmosphere

Sunlight
Lunar Eclipses

- Lunar eclipses can be:
  1. Total
  2. Partial
Partial Lunar Eclipse

sunlight

Earth

penumbra
Lunar Eclipses

• Lunar eclipses can be:
  1 Total
  2 Partial
  3 Penumbral (these are hardly noticeable)
Penumbral Eclipse

Penumbral eclipses are almost unnoticeable.
Solar Eclipses

• Solar eclipses can be:
  1 Total
Solar Eclipses

umbra

Total solar eclipse

sunlight
Solar Eclipses

- “Diamond ring” effect occurs as sunlight passes through lunar valleys on the limb of the Moon.
Solar Eclipses

- Solar eclipses can be:
  1. Total
  2. Partial
Solar Eclipses

Partial solar eclipse

Total solar eclipse

penumbra

umbra

sunlight
Solar Eclipses

- Umbra moves west to east because the speed of the Moon in its orbit exceeds the speed of the rotating Earth.
Solar Eclipses

• Motion of Moon’s shadow across the Earth defines a “path of totality.”
• Maximum duration of totality at any location on Earth is about 7½ minutes.
Eclipse Windows

- Since the Moon and Earth have fairly large shadows, the alignment does not have to be perfect for an eclipse to occur.
- How far from a node can the Sun be and an eclipse still occur?
  - The answer to this defines an *eclipse window*.
Eclipse Windows

- Moon’s path
- Eclipse window
- node
ecliptic
- 5°
Computation of Eclipse Windows
Eclipse Windows

Solar \[30^\circ.70 - 37^\circ.03\]
Solar central \[19^\circ.83 - 23^\circ.67\]
(total or annular)
Lunar central \[\sim 9^\circ.6\]

Solar motion along the ecliptic is 29\(^\circ.1\) per synodic month.
Frequency of Eclipses

Solar central 0 – 3 per year (total or annular) (but each seen in only a few locations)

Lunar umbral 0 – 3 per year (total or partial) (seen from many places)

At any place on Earth, a solar eclipse occurs about once every 400 years.