Moon, Sun, and eclipses

The Moon orbits the Earth and returns to the same right ascension every 27.32 days. (It moves eastward against the background of stars.) This is the *sidereal* (si-DER-e-al) period of the Moon ("time with respect to the stars"). During this time the Earth has moved along on its orbit around the Sun.

The lunar phases repeat every 29.53 days. This is the *synodic* period of the Moon.

Since the Moon takes 27.32 days to return to the same right ascension, its mean motion is

360 degrees / (27.32 days X 24 hours/day) = 0.549 deg/hour

If you are standing outside looking at the Moon, it is moving 15 degrees per hour from east to west owing to the rotation of the Earth. But it's also moving 0.549 deg/hour from west to east *against the background of stars*.

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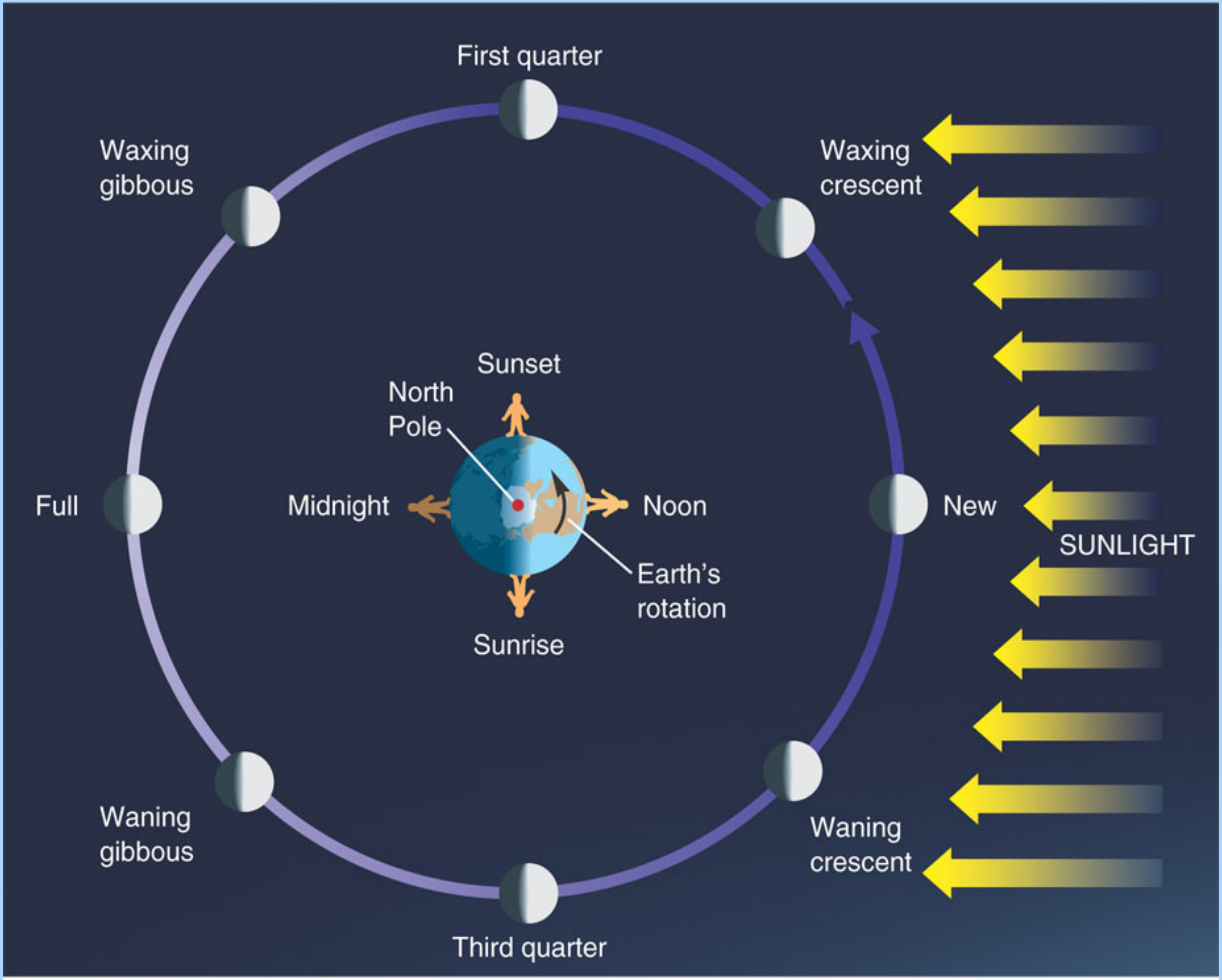
Its **net** motion is still from east to west in the horizon system of coordinates.

No matter what your latitude is, on March 21st or September 21st the Sun will set 12.0 hours after it rises. If the Moon's declination is close to 0 (i.e. if it's close to the celestial equator), it will set about 12 hours and 26 minutes after it rises. Since it moves west to east *against the background of stars*, it takes more time for the Moon to move from horizon to horizon than it takes the Sun.

But this basic fact still holds: the Moon rises in the east and sets in the west, just like the Sun.

The planet Jupiter orbits the Sun with a period of 12 years, so from our viewpoint on the Earth it passes through all the constellations of the zodiac in that time. On average it moves 0.082 degrees = 4.9 arc minutes per *day* east against the background of stars.

On any given night Jupiter rises in the east and sets in the west about 12 hours later. Because of its motion against the background of stars, in September of 2011 it will be found one constellation further east in the sky than it is found in September of 2010.

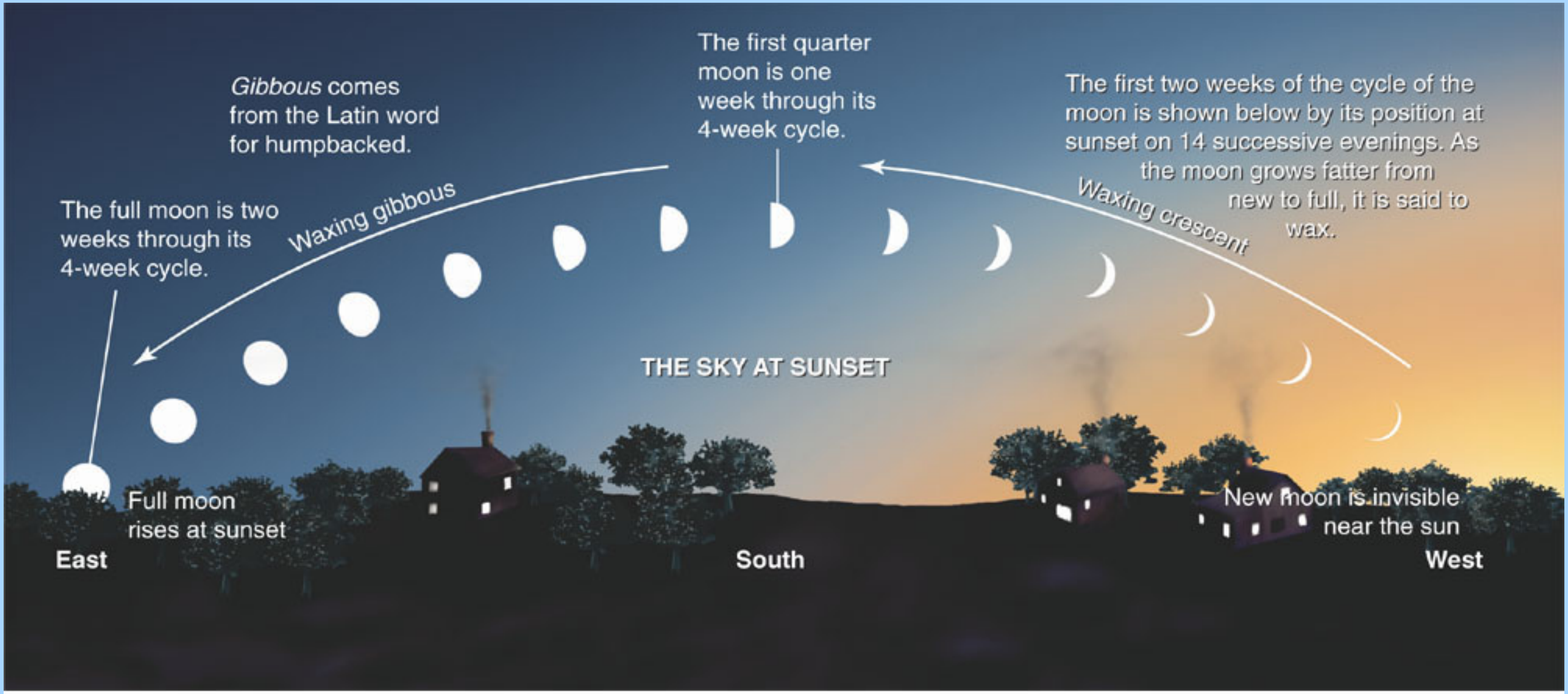

First quarter
Waxing gibbous
Waxing crescent
Sunset
North Pole
Full
Midnight
Noon
New
SUNLIGHT
Earth's rotation
Sunrise
Waning gibbous
Waning crescent
Third quarter

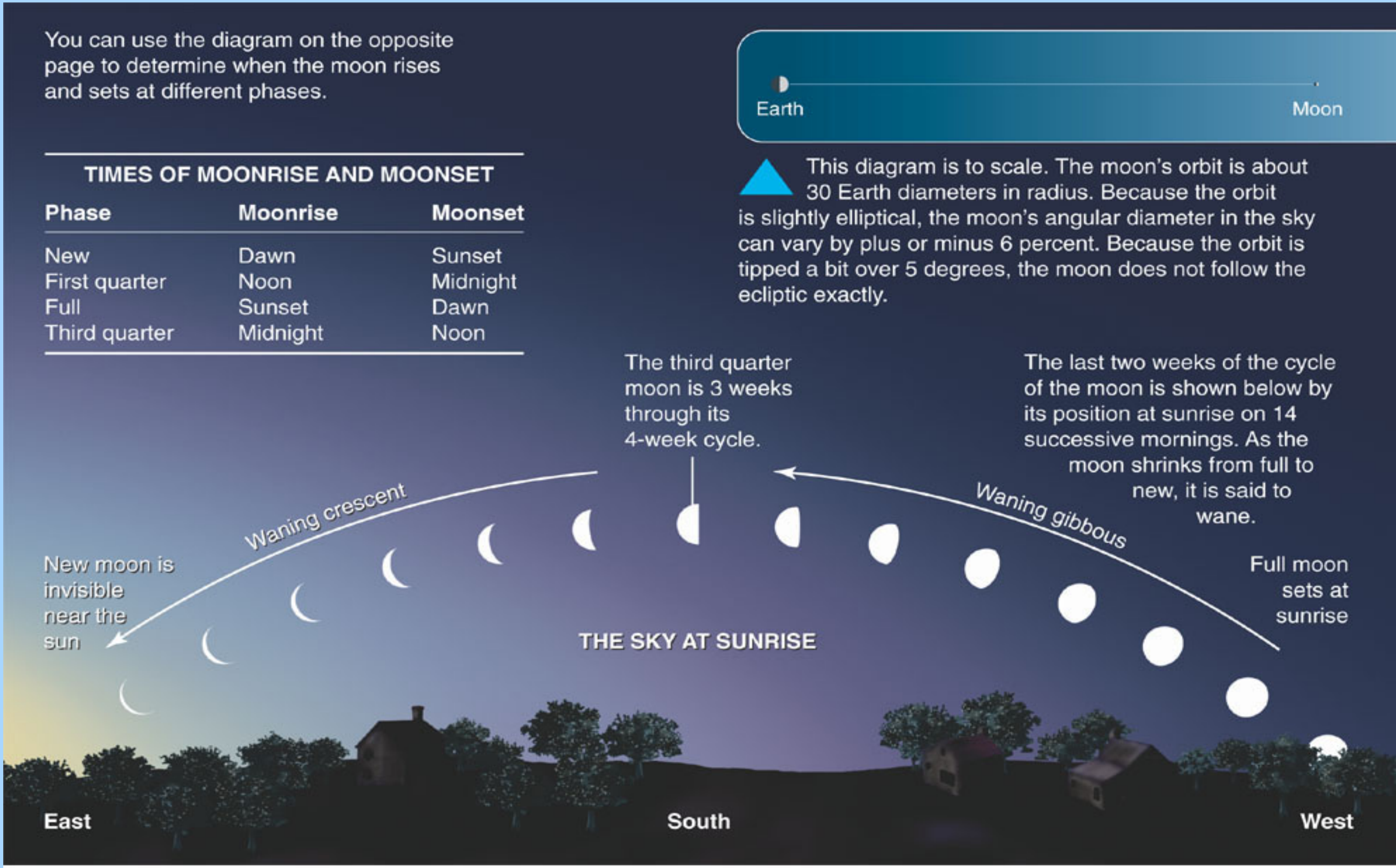
Because the Moon is close to being spherical, the Earth-Moon-Sun angle completely dictates what the lunar phase is.

Simply put, the first quarter Moon is due south at sunset.

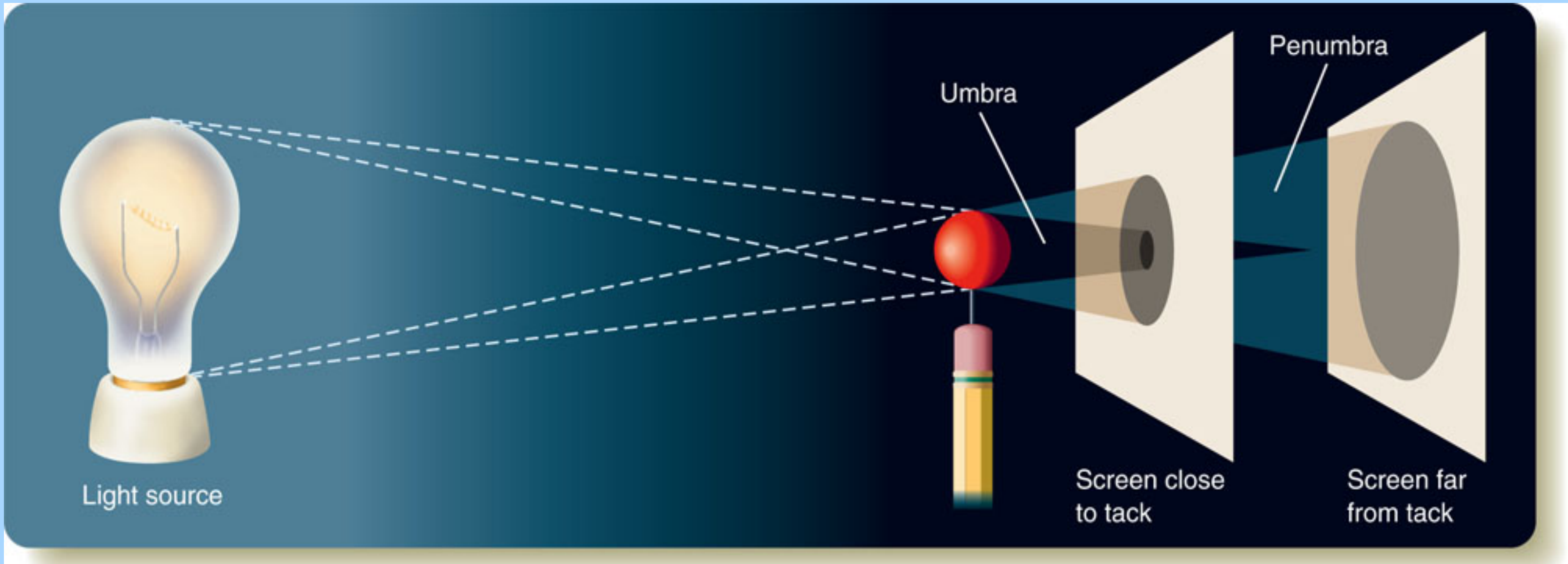
The full Moon rises at sunset, and sets at sunrise.

The third quarter Moon rises at midnight.


The first quarter moon is one week through its 4-week cycle.
Gibbous comes from the Latin word for humpbacked.
The first two weeks of the cycle of the moon is shown below by its position at sunset on 14 successive evenings. As the moon grows fatter from new to full, it is said to wax.
The full moon is two weeks through its 4-week cycle.
Waxing gibbous
Waxing crescent
THE SKY AT SUNSET
Full moon rises at sunset
New moon is invisible near the sun
East
South
West

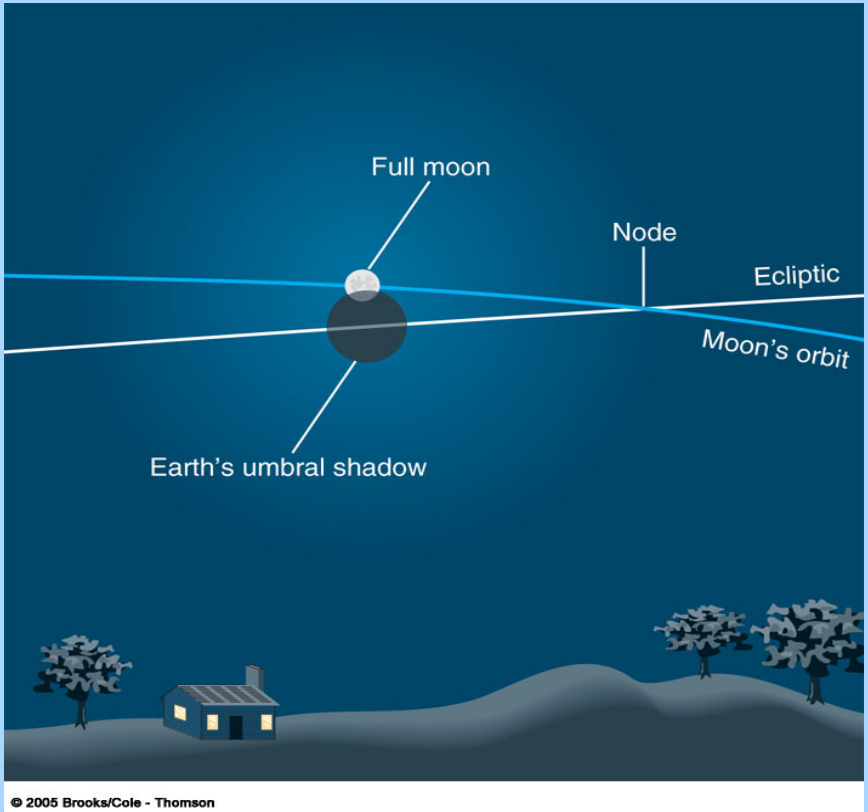

You can use the diagram on the opposite page to determine when the moon rises and sets at different phases.
TIMES OF MOONRISE AND MOONSET
Phase Moonrise Moonset
New Dawn Sunset
First quarter Noon Midnight
Full Sunset Dawn
Third quarter Midnight Noon
Earth
Moon
This diagram is to scale. The moon's orbit is about 30 Earth diameters in radius. Because the orbit is slightly elliptical, the moon's angular diameter in the sky can vary by plus or minus 6 percent. Because the orbit is tipped a bit over 5 degrees, the moon does not follow the ecliptic exactly.
The third quarter moon is 3 weeks through its 4-week cycle.
The last two weeks of the cycle of the moon is shown below by its position at sunrise on 14 successive mornings. As the moon shrinks from full to new, it is said to wane.
Waning crescent
Waning gibbous
New moon is invisible near the sun
Full moon sets at sunrise
THE SKY AT SUNRISE
East
South
West

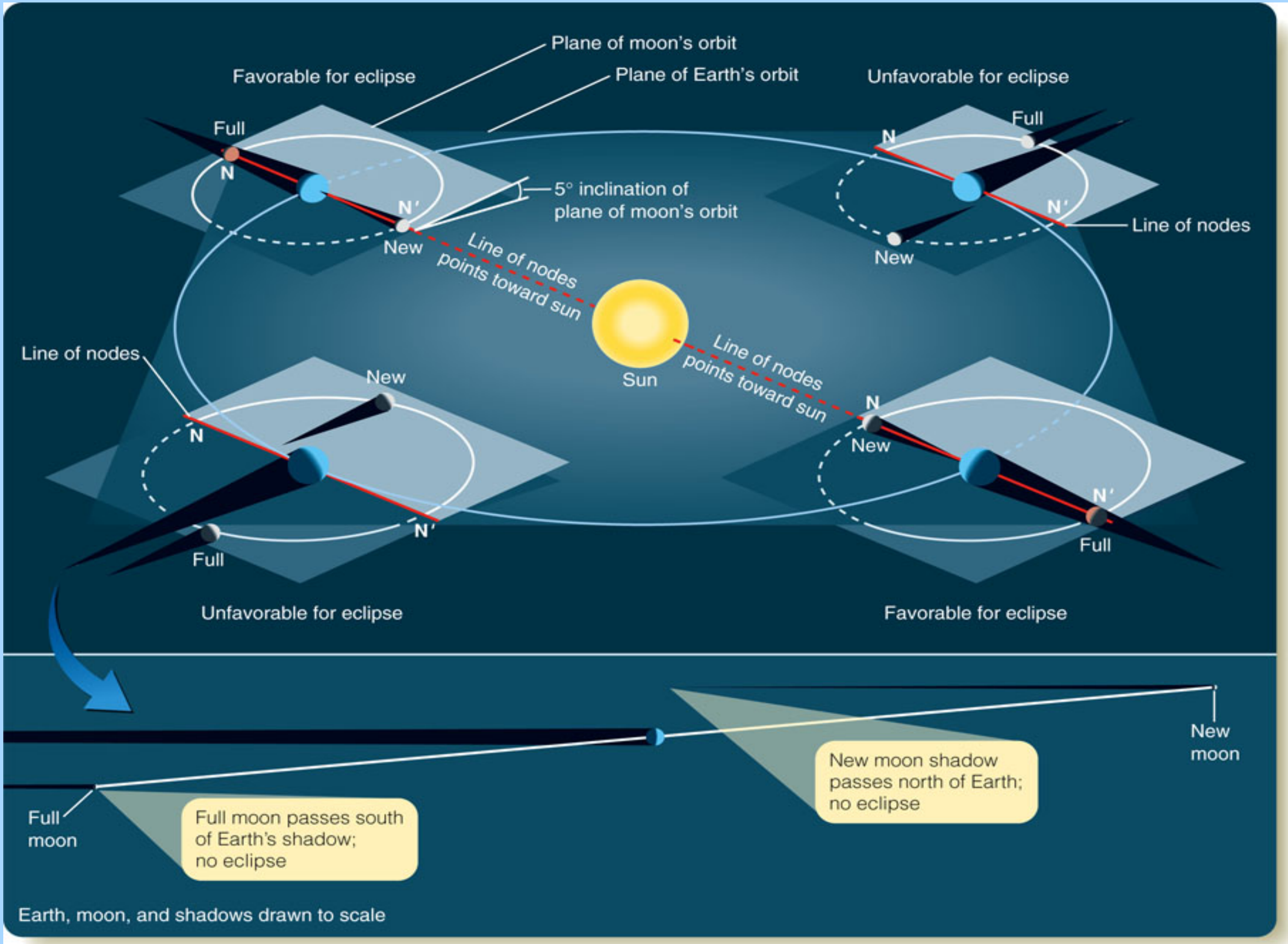
The Earth's shadow consists of a darker part, called the **umbra** (Latin for "shadow"), and a not-so-dark part called the **penumbra**.



If the Moon passes completely into the dark part of the Earth's shadow, *which can only occur at full Moon*, there is a **total lunar eclipse**. If only part of the Moon enters the umbra, we have a **partial lunar eclipse**.

At the average distance of the Moon from the Earth, the Earth's umbral shadow is 2.65 times the angular diameter of the Moon, or about 1.37 degrees. But a lunar eclipse does not occur every full Moon because of the tilt of the Moon's orbit with respect to the ecliptic.





Plane of moon's orbit
Favorable for eclipse
Plane of Earth's orbit
Unfavorable for eclipse
Full
N
N'
New
5° inclination of plane of moon's orbit
Line of nodes
Line of nodes points toward sun
Sun
Line of nodes
Line of nodes points toward sun
New
N
N'
Full
Unfavorable for eclipse
Favorable for eclipse
New moon
New moon shadow passes north of Earth; no eclipse
Full moon
Full moon passes south of Earth's shadow; no eclipse
Earth, moon, and shadows drawn to scale

In the previous millennium (1001 to 2000 AD) there were 681 total lunar eclipses and 859 partial lunar eclipses. Only 5.5 percent of the full Moons occur close enough to one of the nodes of the Moon's orbit to produce a total lunar eclipse.

If the Moon is in the Earth's shadow, *everyone* on the Earth's hemisphere facing the Moon has a chance to view the eclipse.


Total Lunar Eclipse - 2000 Jan 20-21
www.MrEclipse.com
©2000 by F. Espenak

Some definitions

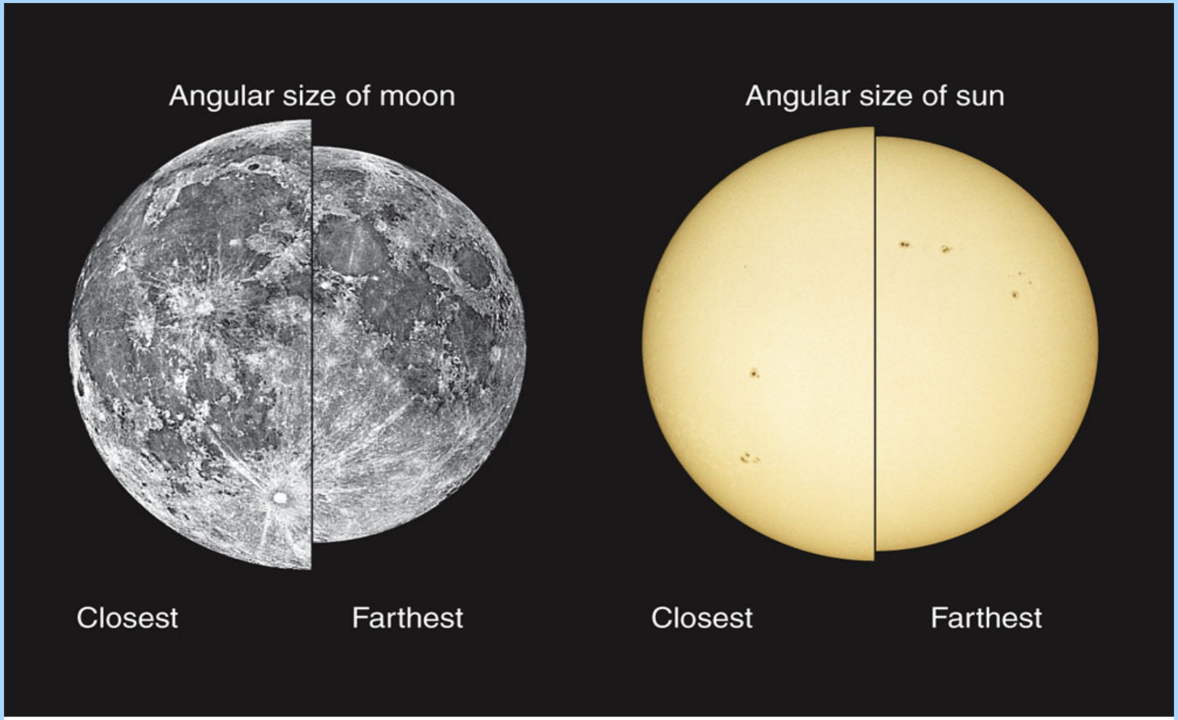
apogee – the point in the orbit of the Moon or an artificial satellite when it is farthest from the Earth

perigee – orbital position where the Moon or artificial satellite is closest to the Earth

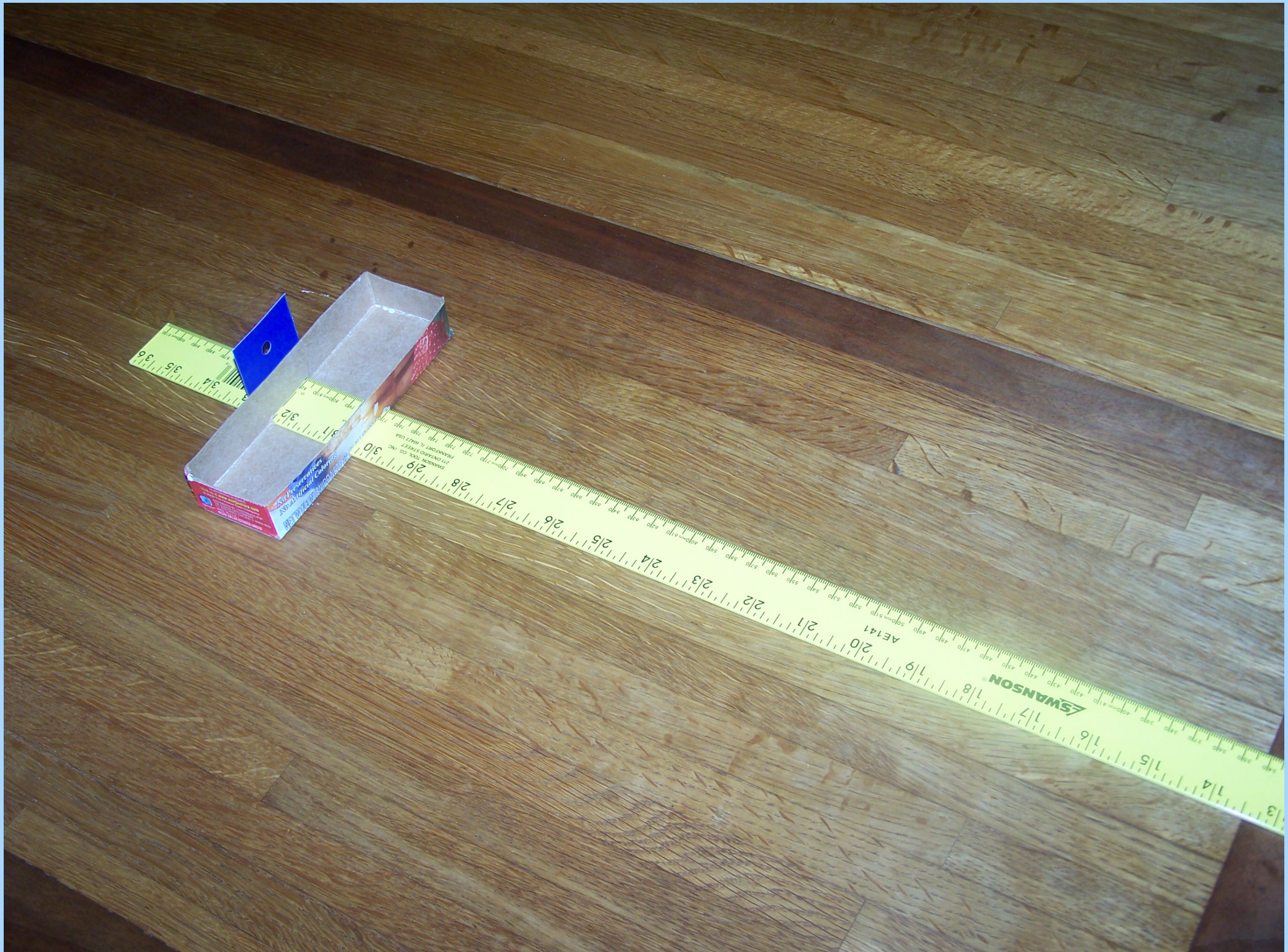
aphelion – point in the orbit of a planet when it is furthest from the Sun

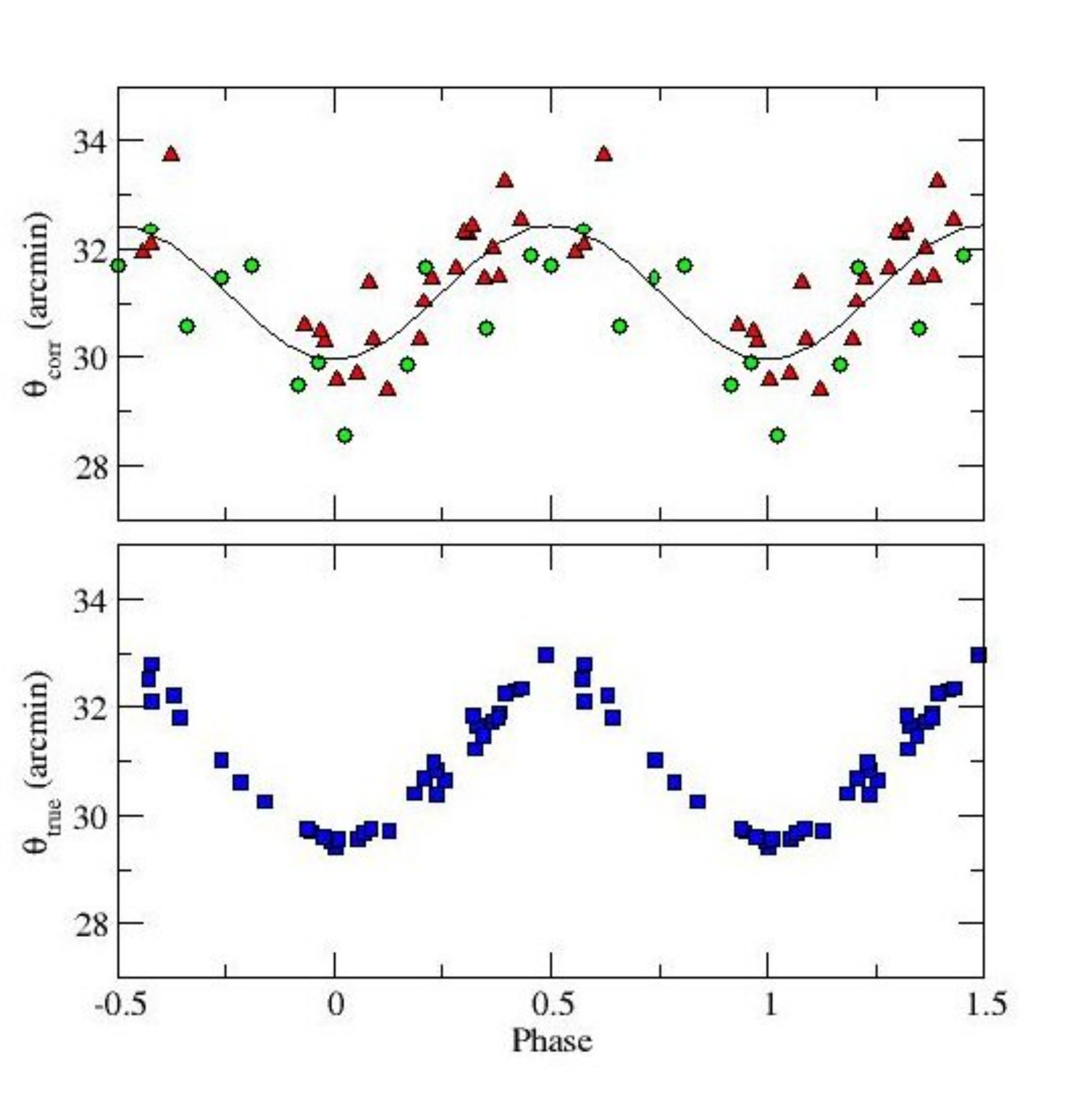
perihelion – point in the orbit of a planet when it is closest to the Sun

Because the Moon's orbit around the Earth is elliptical, the angular diameter of the Moon changes somewhat. Similarly, because the Earth's orbit about the Sun is also elliptical (but less so), the Sun's angular diameter changes.



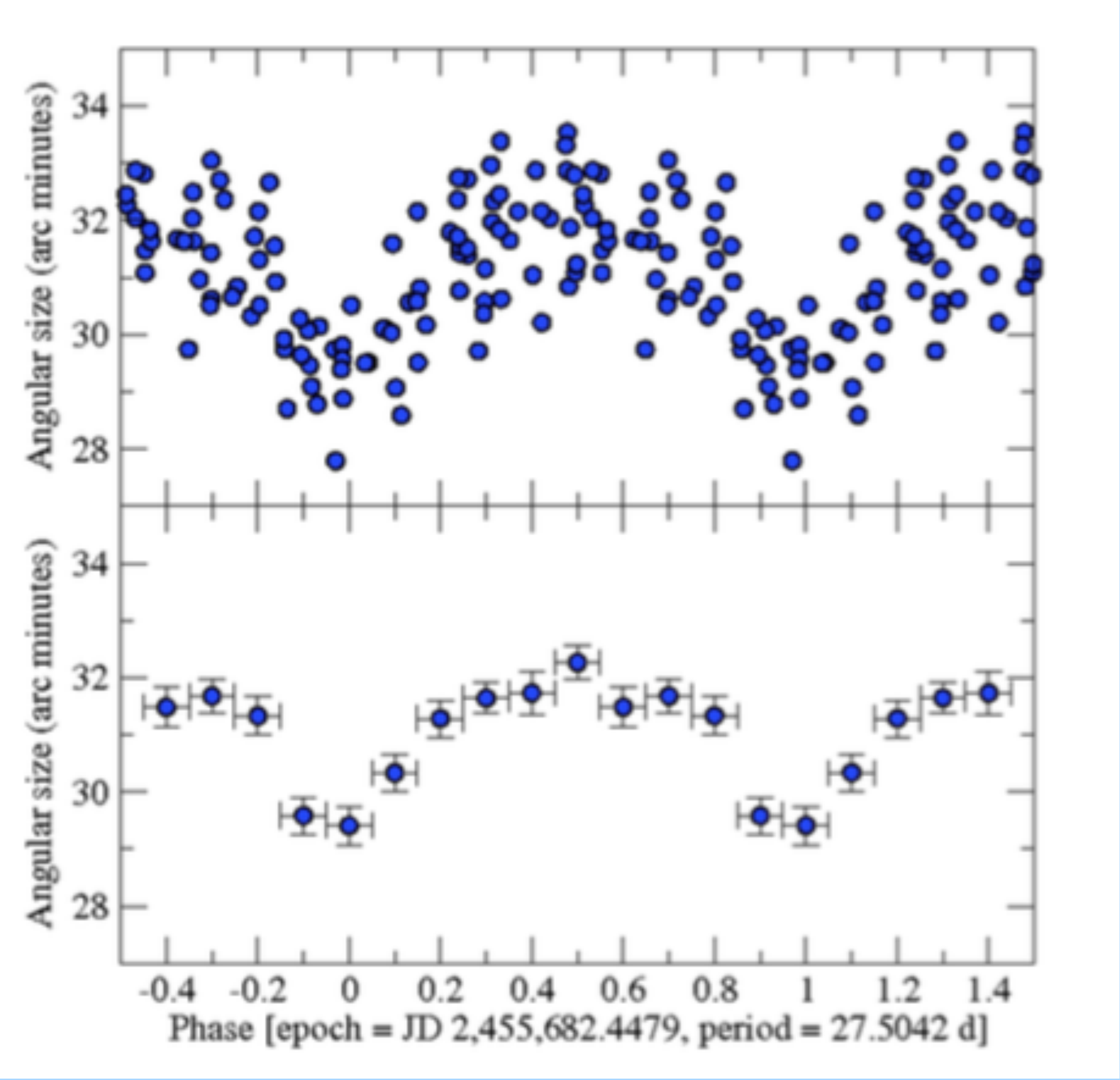
A simple sighting device that can be used to measure the Moon's angular size.





Top: actual measures of the Moon’s angular diameter, using a simple sighting device.

Bottom: values interpolated from the *Astronomical Almanac* based on a modern model of the Moon’s motion.



Roughly 3 years of measures of the Moon’s angular size (without using a telescope).

The distance between Earth and Moon varies between 356,400 and 406,700 km. That's because the Moon's orbit is elliptical, not perfectly circular. Sometimes it's less than 30 arc minutes in angular size, sometimes it's greater than 30 arcmin in angular size.

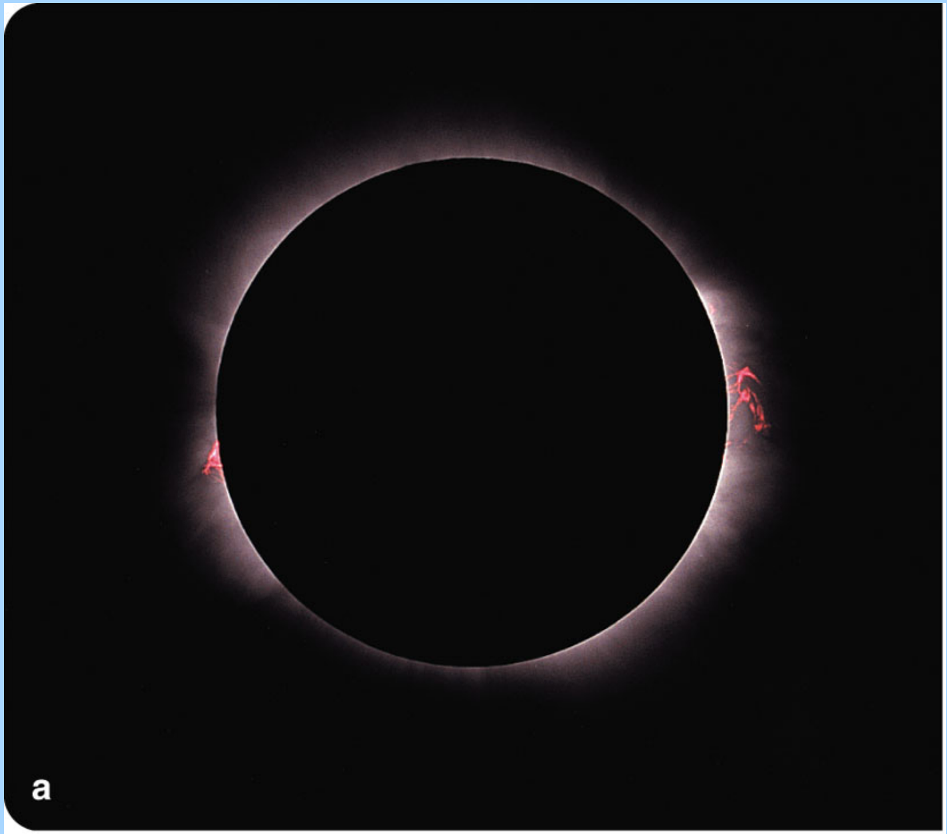
The distance between the Sun and Earth varies between 147.1 and 152.1 million km. The Earth's orbit is less elliptical than the Moon's orbit around the Earth. Given the Sun's diameter of 1,392,000 km, its angular size varies from 31.46 to 32.53 arc minutes.

In order for a total solar eclipse to occur, the new Moon must be aligned with the Sun, *and* the Moon must have a larger angular size.

If the Moon is at one of its nodes at new Moon, a **solar eclipse** can occur. There are several kinds of solar eclipses:

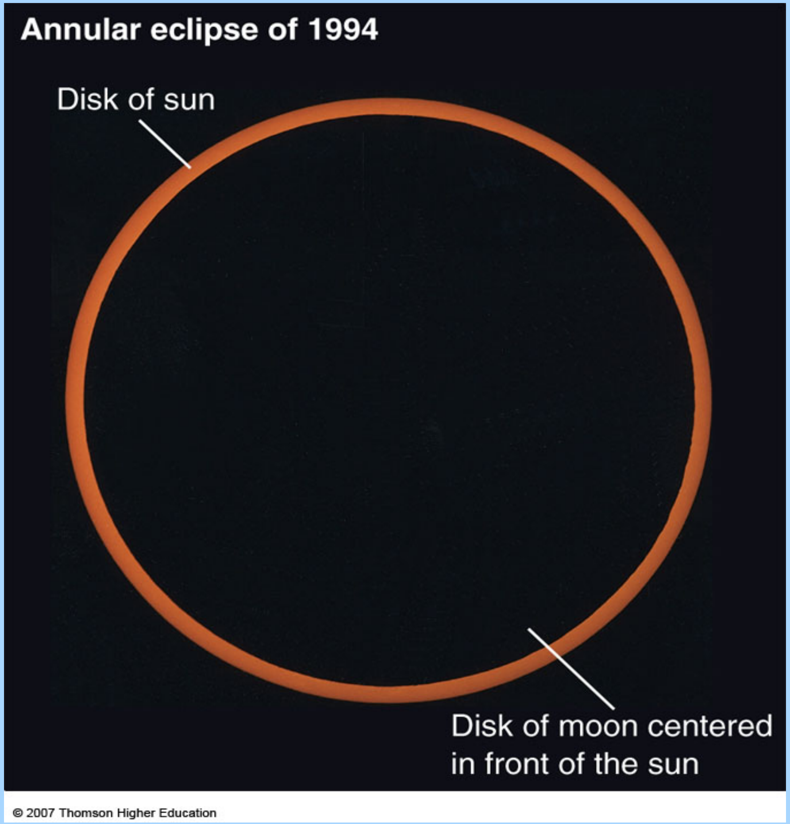
partial
total
annular
annular-total

If the Sun and Moon are aligned and the Moon's angular diameter is greater than that of the Sun, we have a *total solar eclipse*.



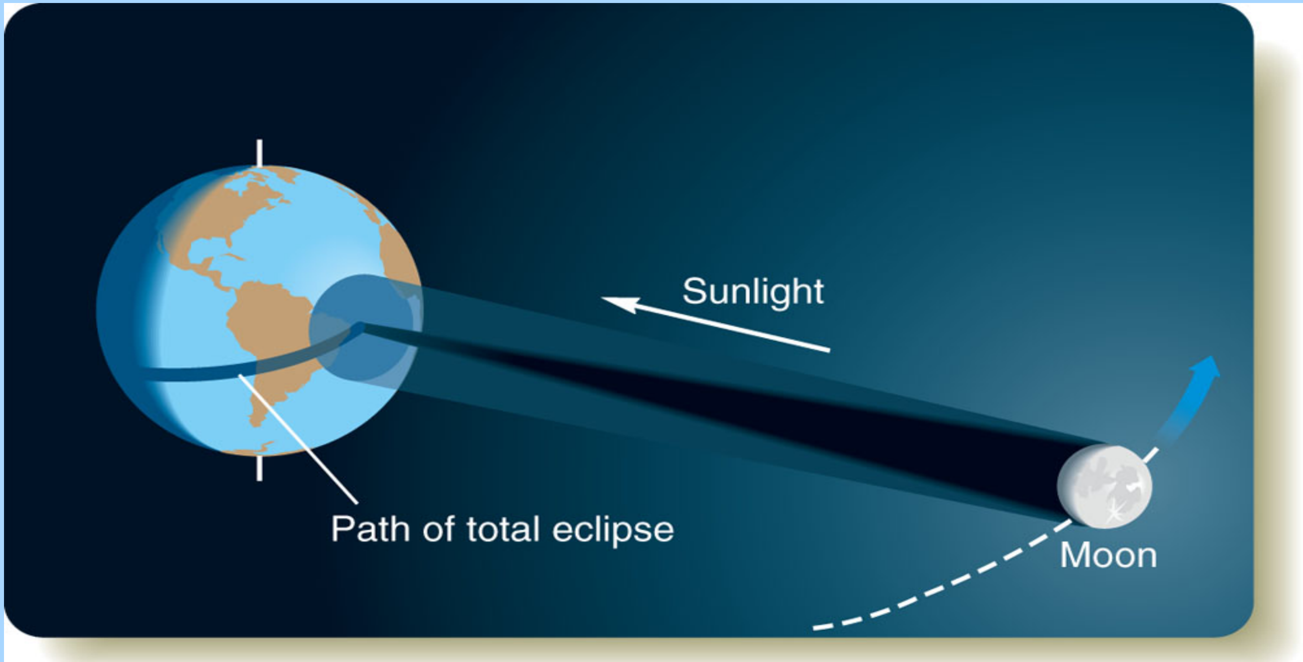
Note corona and prominences.

If the Sun and Moon are aligned, but the Moon is too far away from the Earth to completely cover the Sun's disk, we have an *annular solar eclipse*. In this case we do *not* get to see the Sun's **corona**.

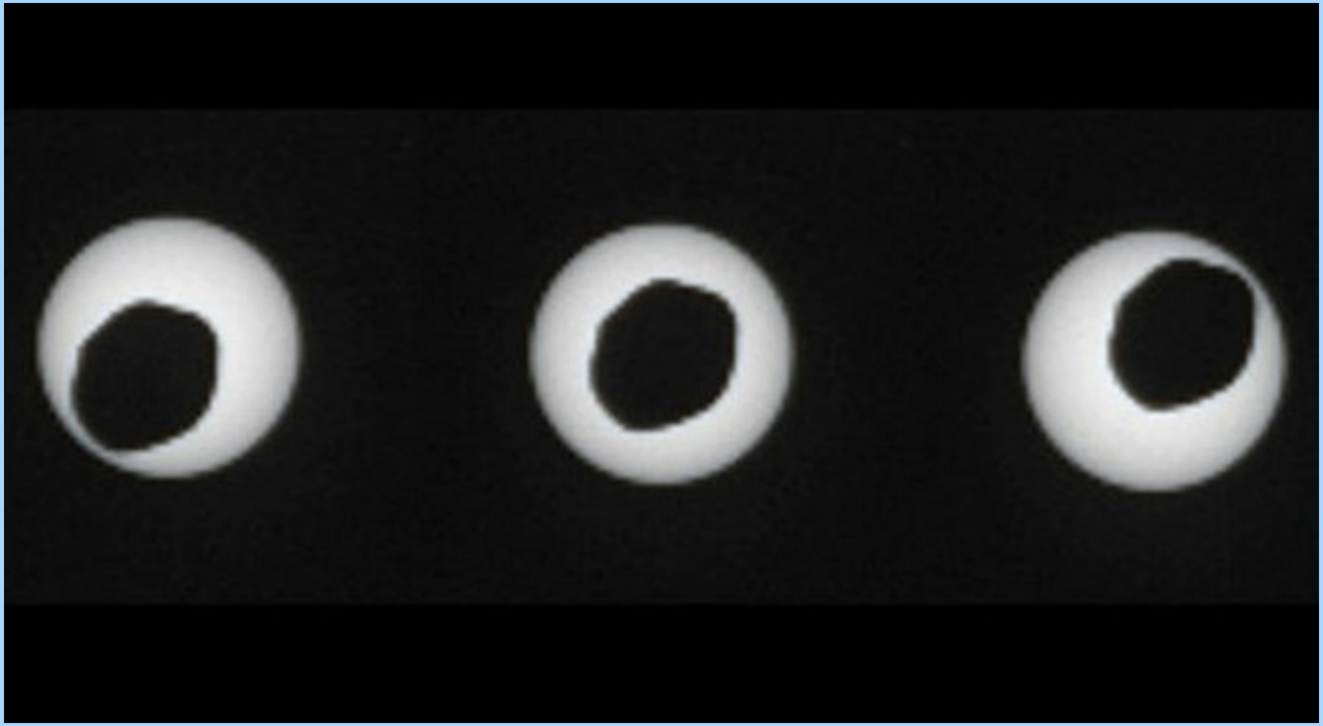


If the Moon is not quite at one of its nodes, we can also get a *partial solar eclipse*.

Some solar eclipses are such that they are annular at the start and end of the track, and total in the middle. The radius of the Earth is just big enough to make a total solar eclipse in the middle.



The Mars rover Curiosity obtained these images of an annular eclipse caused by the moon Phobos passing in front of the Sun’s disk on August 20, 2013.



In the previous millennium (1001 to 2000 AD) the following number of solar eclipses visible on Earth occurred:

625 total

837 partial

767 annular

156 annular-total

One big difference between total solar eclipses and total lunar eclipses, is that you usually have to travel to be situated in the path of totality of a solar eclipse. On average, the path of the solar eclipse crosses a location in the northern hemisphere every 350 years or so, while in the southern hemisphere it occurs on average every 450 years. On August 21, 2017, the shadow of the Moon passes across the eastern half of the United States. That is our next good opportunity to view this spectacle of Nature without travelling too far.

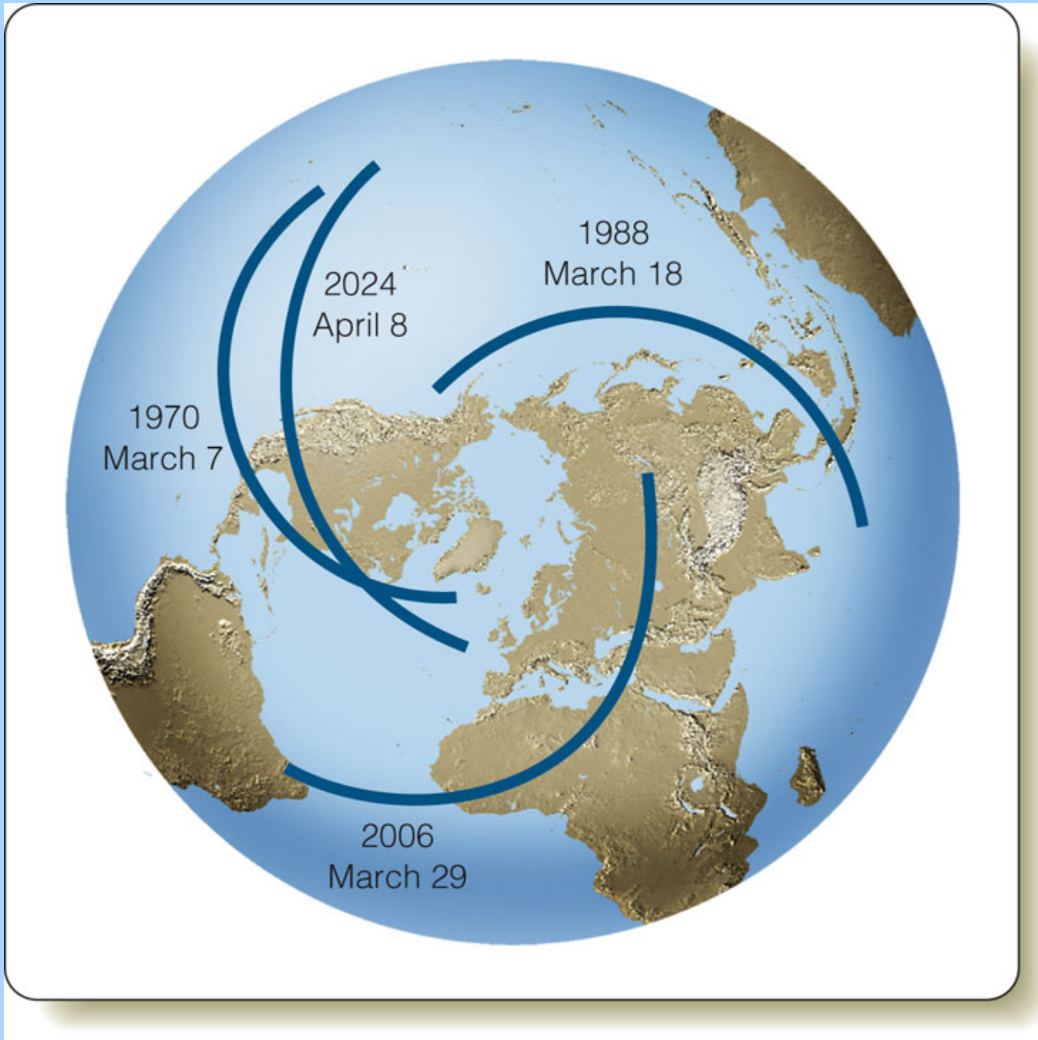
The maximum duration of a total solar eclipse is a little over 7 minutes. Some only last a couple seconds.

Eclipse prediction

It is said that Thales of Miletus (ca. 624-546 BC) predicted the total solar eclipse of 585 BC. How might he have done this?

The Babylonians discovered that there was a pattern to the occurrence of solar eclipses. They repeat with a period of 18 years 11 1/3 days (give or take a Leap Day). This is called the **saros cycle**.

The basic rule is this: if a total solar eclipse occurs on a given date at a given place, odds are very good that another total solar eclipse will occur 223 new Moons later, or 6585 1/3 days. The next eclipse in the cycle will occur 1/3 of the way around the Earth to the west.

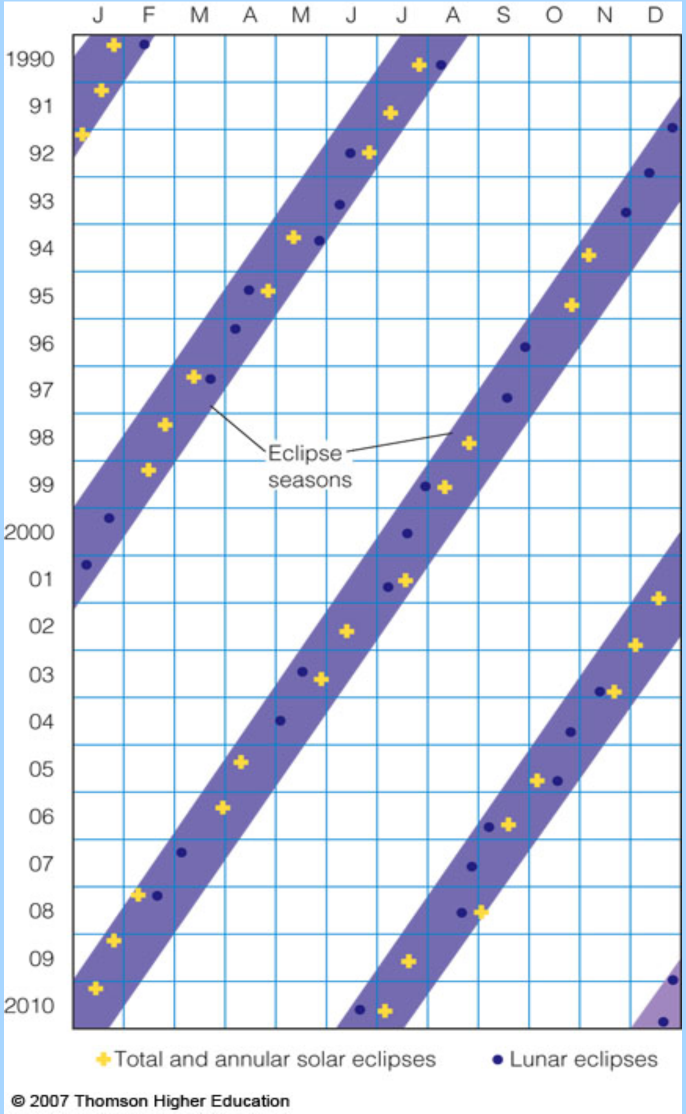


Three eclipse tracks following the total solar eclipse of March 7, 1970.

The saros cycle that includes the total solar eclipses of August 11, 1999, and August 22, 2017, began with a very unimpressive partial solar eclipse visible near the North Pole on January 4, 1639. After 14 partial solar eclipses, an annular eclipse occurred on June 6, 1891, followed by an annular-total eclipse on June 17, 1909. Then the cycle includes 41 total solar eclipse whose tracks Keep moving south on the Earth. Then there are 20 partial solar eclipses of decreasing fractional cut, ending on April 17, 3009, with a partial solar eclipse visible near the South Pole. The cycle lasts 1370 years.

Other saros cycles can progress from south to north.

The number of active saros cycles varies from 42 to 48 with a period of roughly 600 years. Suffice it to say that with good eclipse records *from the past*, it is possible to predict solar eclipses in the future. This is how eclipse “prediction” went until the beginning of the 18th century. After that we understood the orbit of the Moon in enough detail that we could make these predictions on the basis of Newton's mechanics and gravitational theory.



A calendar of eclipse seasons. Shown are the total and annular solar eclipses and the lunar eclipses.