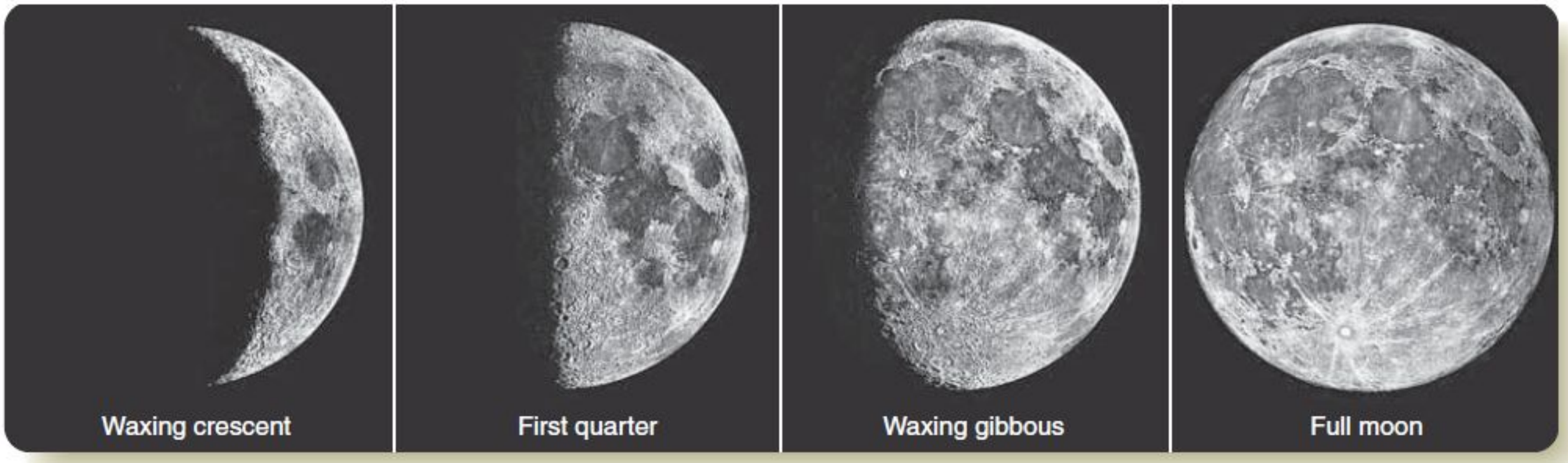
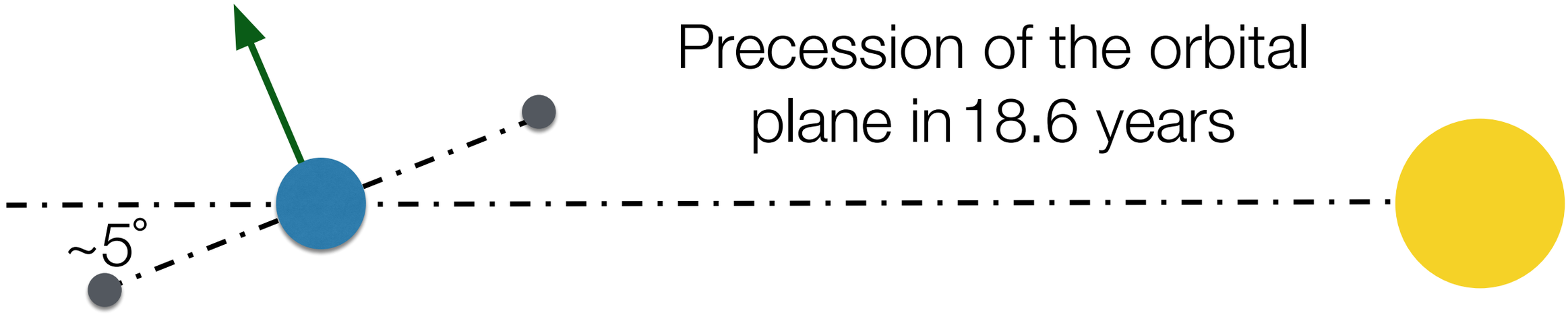
PHYS201 - Introductory Astronomy
Cycles of the Moon

Moon Phases



- Moon phases
- What causes a lunar eclipse?
- What cases a solar eclipse?
- How can eclipses be predicted?

Moon’s motion



Apogee: 405,000 km

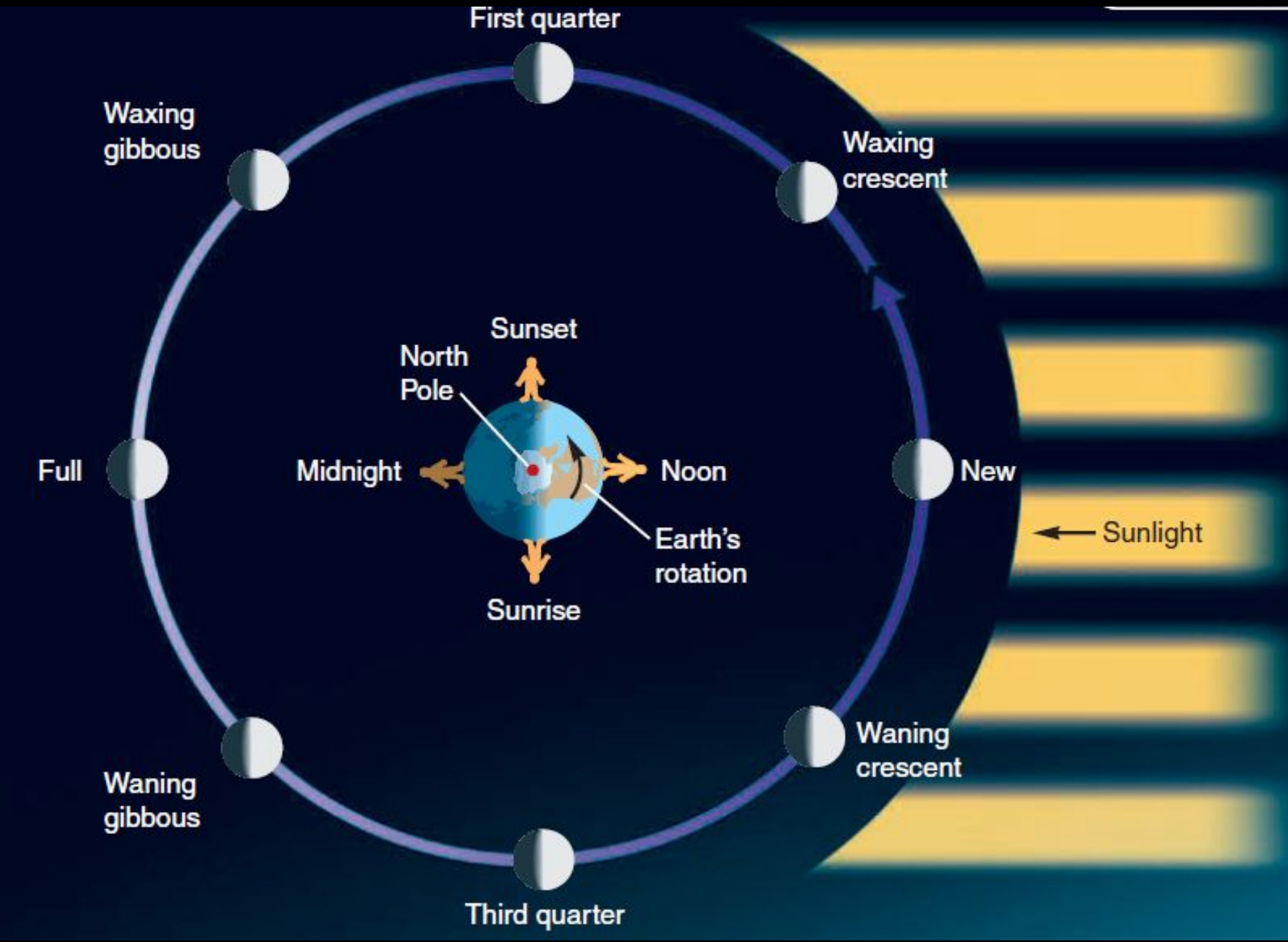
Perigee: 363,000 km

Orbital period: 27.3 days

Full cycle: 29.5 days

- The moon revolves counterclockwise around Earth as seen from the direction of the celestial north pole, similar to planets around the sun.
- Since the moon’s orbit tilted by 5° from the ecliptic plane, its path takes it slightly north and then slightly south, but it is always near the ecliptic.
- Moon moves eastward by ~0.55°/hour. In 24 hours, it moves by 13°.

New Moon and full Moon

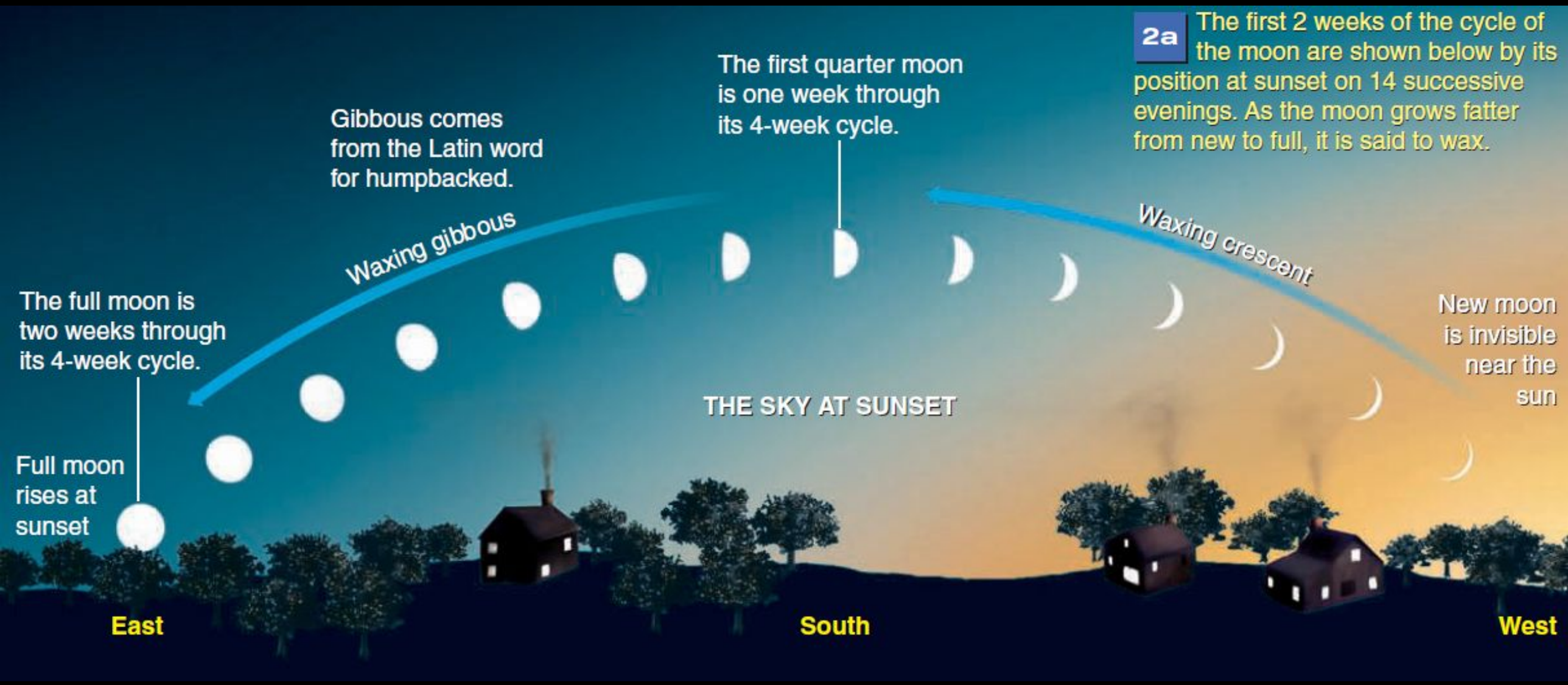


2 As seen at left, sunlight always illuminates half of the moon. Because you see different amounts of this sunlit side, you see the moon cycle through phases. At the phase called "new moon," sunlight illuminates the far side of the moon, and the side you see is in darkness. At new moon you see no moon at all. At full moon, the side you see is fully lit, and the far side is in darkness. How much you see depends on where the moon is in its orbit.

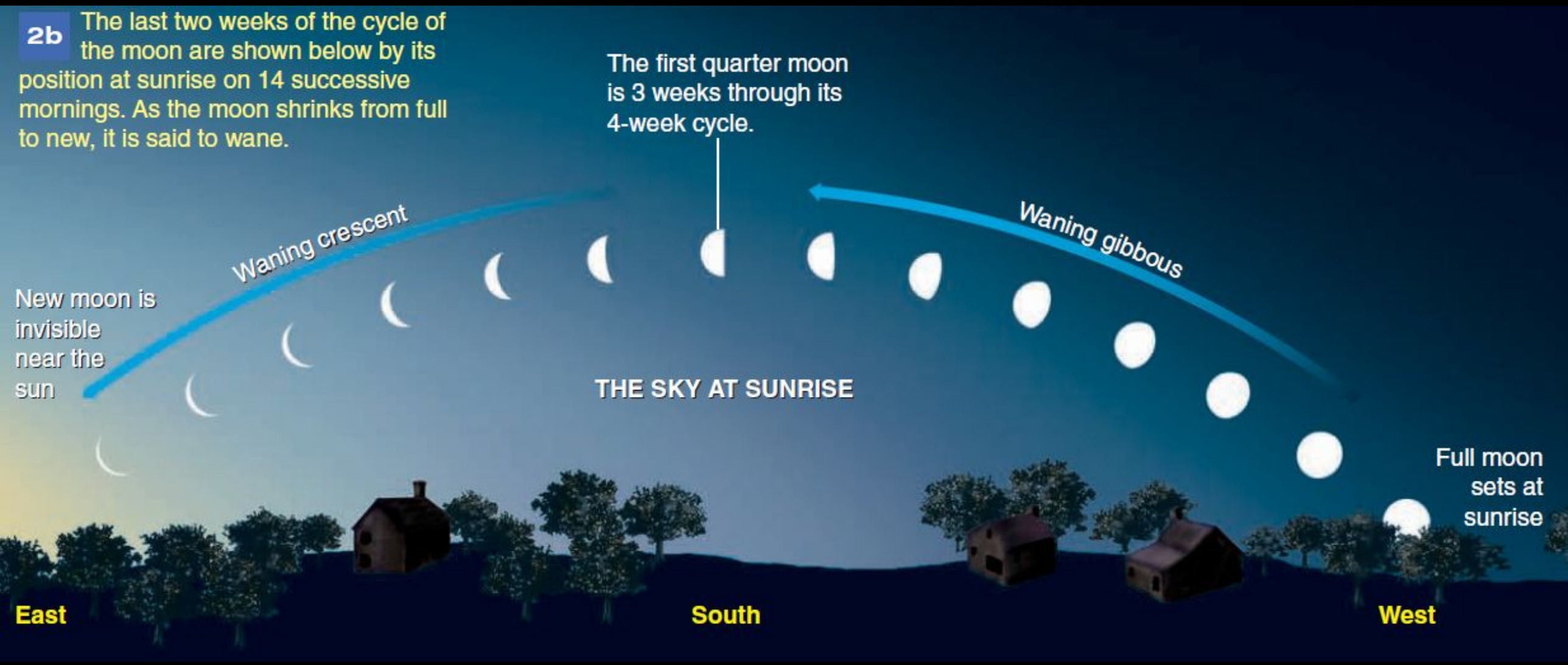
Notice that there is no such thing as the "dark side of the moon." All parts of the moon experience day and night in a month-long cycle.

In the diagram at the left, you see that the new moon is close to the sun in the sky, and the full moon is opposite the sun. The time of day depends on the observer's location on Earth.

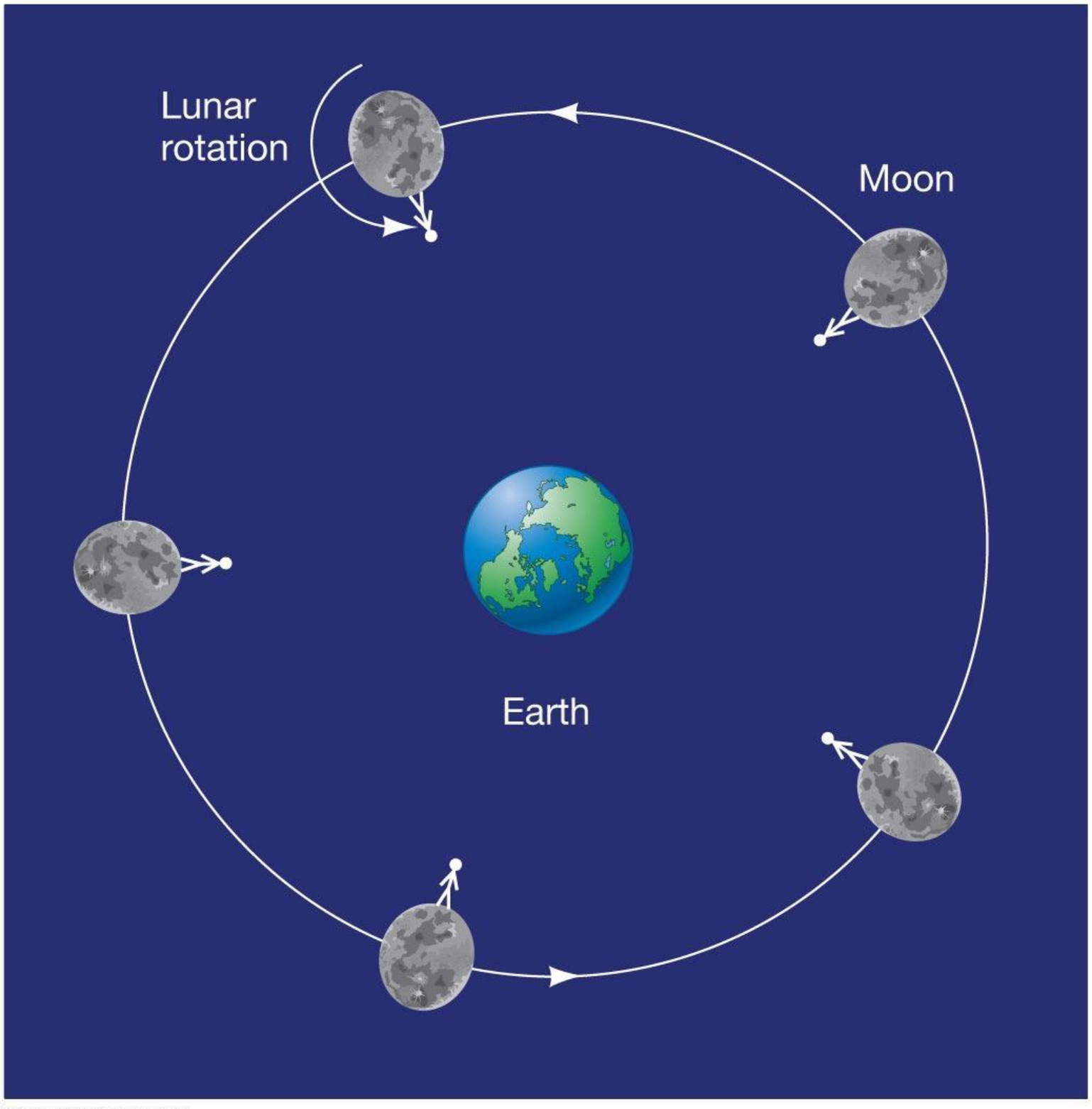
2a The first 2 weeks of the cycle of the moon are shown below by its position at sunset on 14 successive evenings. As the moon grows fatter from new to full, it is said to wax.



2b The last two weeks of the cycle of the moon are shown below by its position at sunrise on 14 successive mornings. As the moon shrinks from full to new, it is said to wane.



Why we see only one side of the moon?



Tidal locking

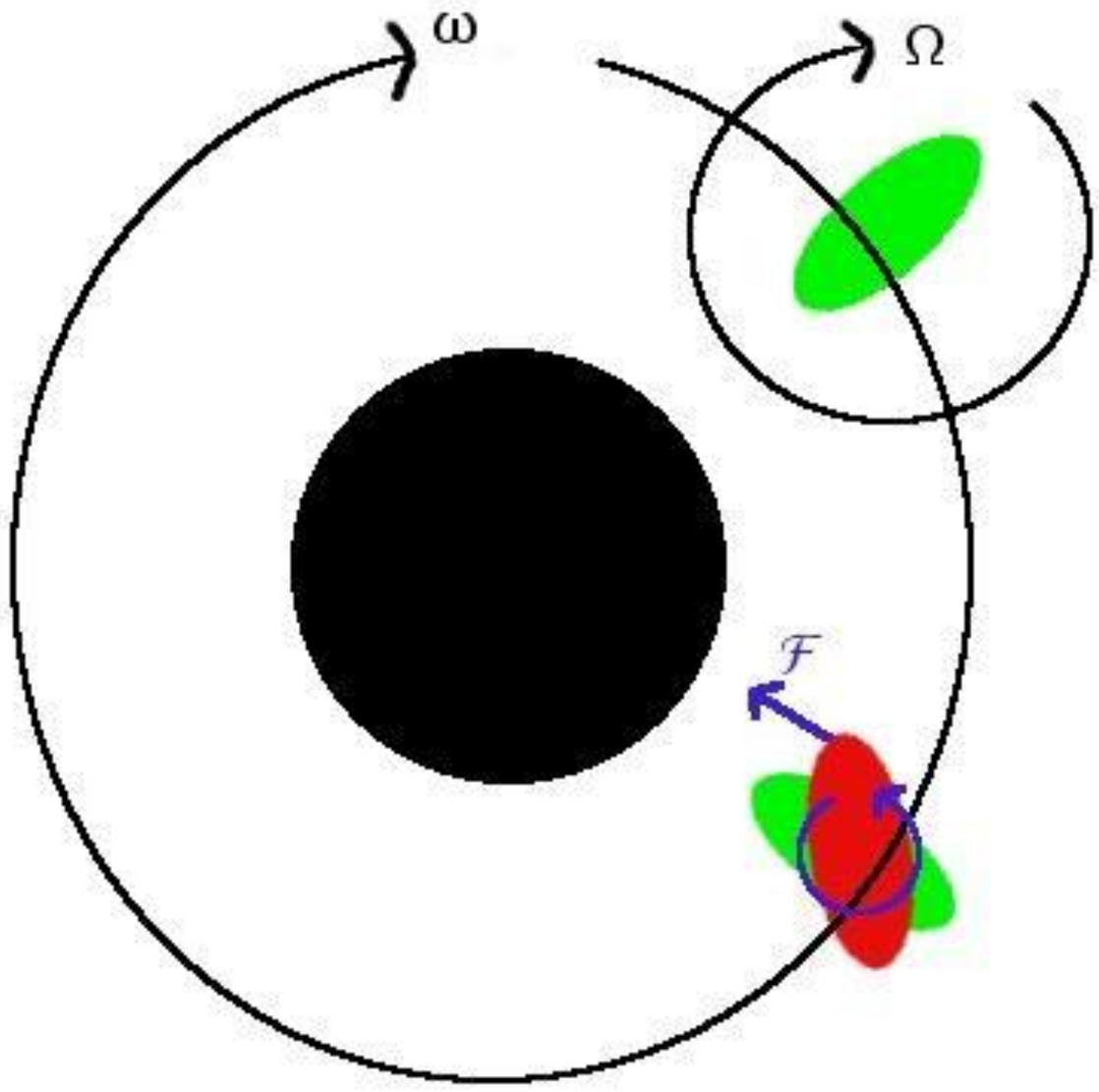
When an object's orbital period matches its rotational period.

- The Moon is almost tidally locked to the Earth.
- Mercury is tidally locked to the Sun.
- Pluto and Charon are tidally locked to each other.
- The Galilean moons are tidally locked to Jupiter.

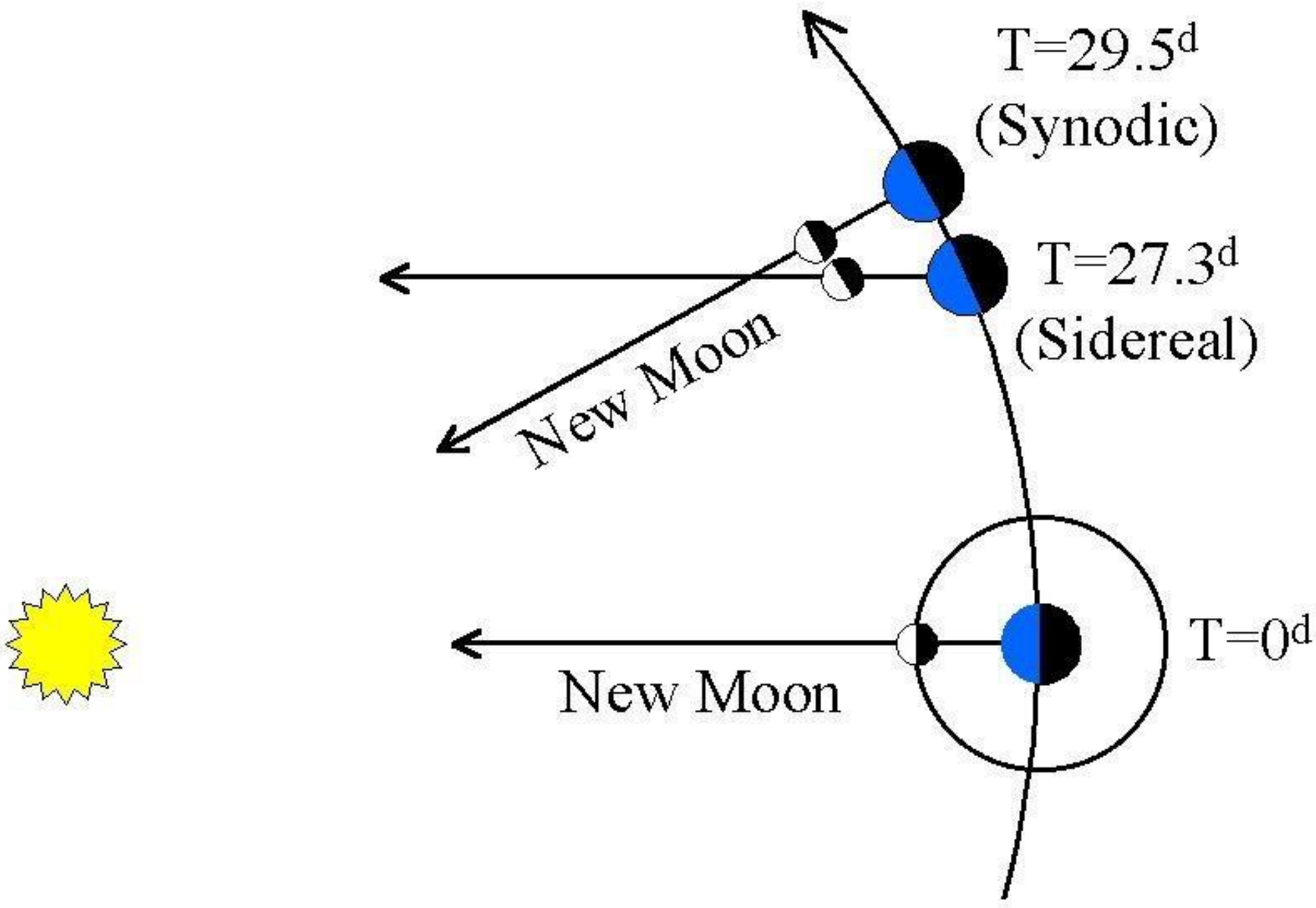
In ~50 billion years, the Earth and the moon would be tidally locked with the period of ~47 days (instead of 1 day and 27.3 days today). But before that, the Sun will become a red giant and then a white dwarf.

Tidal locking

If rotational frequency Ω is larger than orbital frequency ω, a small torque counteracting the rotation arises, eventually locking the frequencies.



Synodic and sidereal lunar periods



Eclipses: lunar and solar

- Lunar eclipses occur when the Moon's path crosses the shadow of the Earth.
- Solar eclipses occur when the Earth’s path crosses the shadow of the Moon.

Shadows

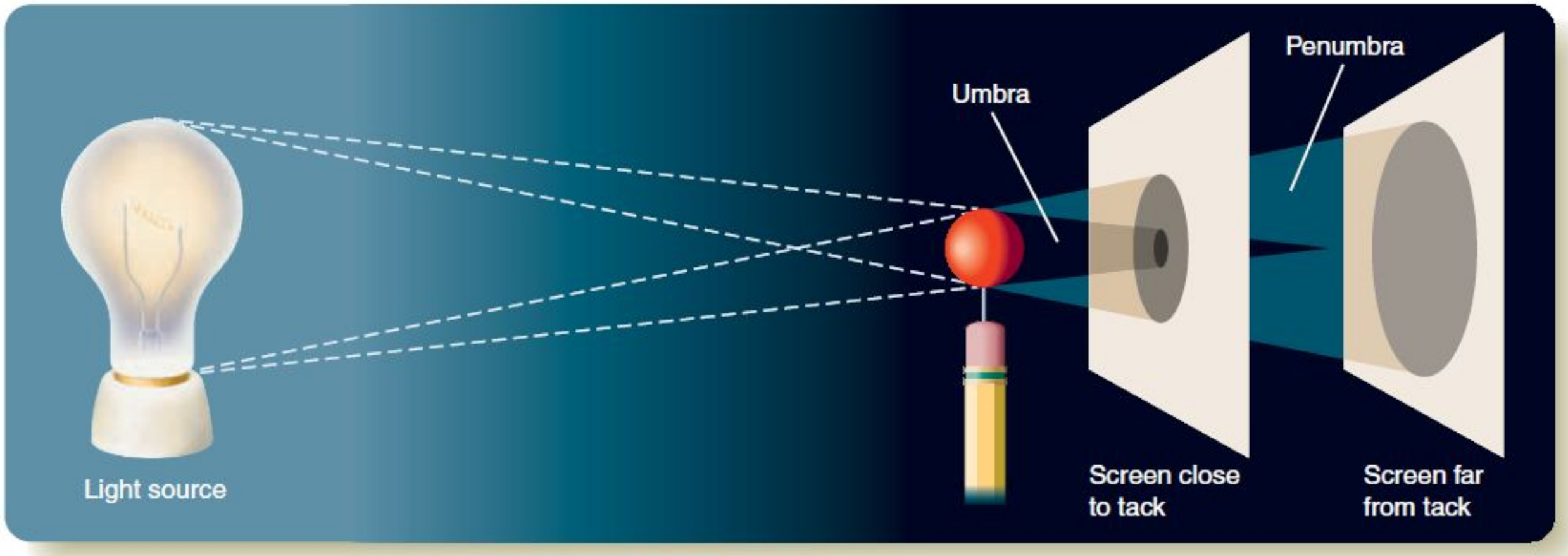


Figure 3-2

The shadows cast by a map tack resemble the shadows of Earth and the moon. The umbra is the region of total shadow; the penumbra is the region of partial shadow.

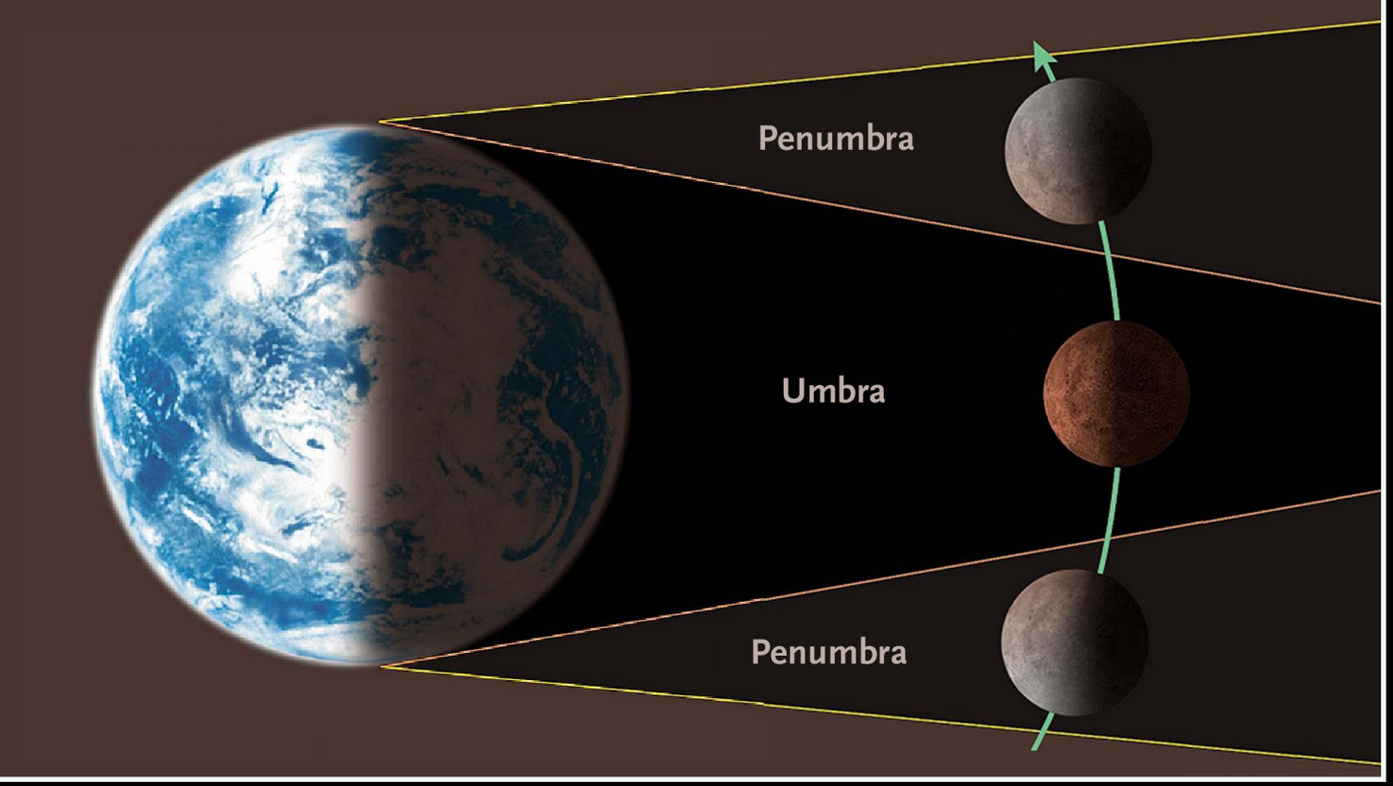
Lunar eclipses

- Lunar eclipse can occur only during full moon when the Moon's path crosses the shadow of the Earth.

- The umbra of the Earth’s shadow is ≃3 times longer than the average distance to the Moon.

- The shadow is ≃2.5 times the diameter of the moon at the average distance of the Moon.

- The faint outer edges of the penumbra would mark a circle ≃4.6 times the diameter of the Moon.



Total Lunar Eclipse. April 14-15, 2014 Alberto Levy

www.skyandtelescope.com

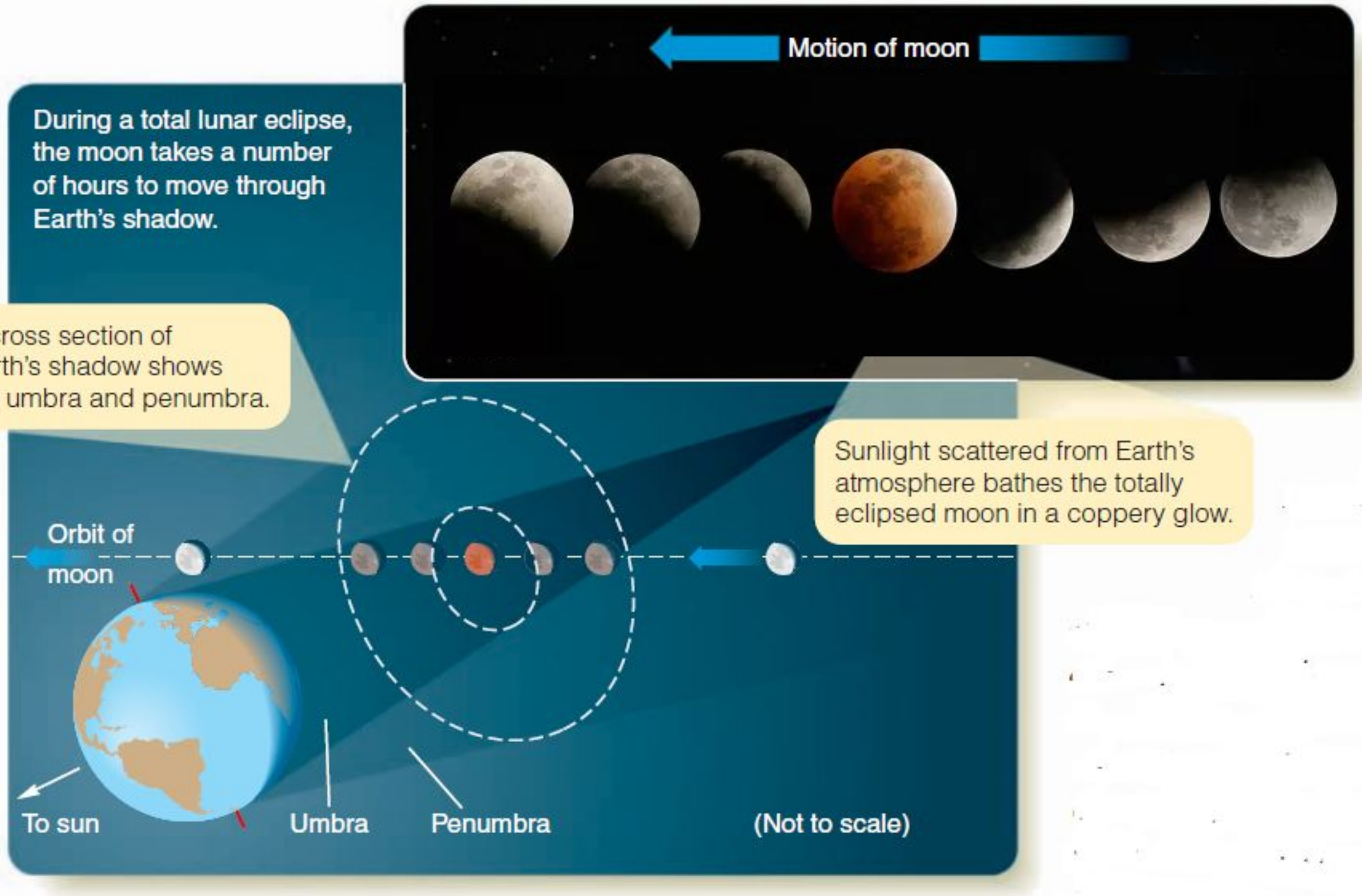


Figure 3-3

During a total lunar eclipse, the moon passes through Earth's shadows. A multiple-exposure photograph shows the moon passing through the umbra of Earth's shadow. A longer exposure was used to record the moon while it was totally eclipsed. The moon's path appears curved in the photo because of photographic effects. (© 1982 Dr. Jack B. Marling)

Partial and Penumbral Lunar Eclipses

Because the moon's orbit is inclined by a bit over 5° to the plane of Earth's orbit, the moon does not always pass through the center of the umbra.

If the moon passes a bit too far north or south, it may only partially enter the umbra, and you see a **partial lunar eclipse.**

If the orbit of the moon carries it far enough north or south of the umbra, the moon may pass through only the penumbra and never reach the umbra. This is called **penumbral lunar eclipses.**

Length of Lunar Eclipses

The timing of a lunar eclipse depends on where the moon crosses Earth's shadow.

Crosses through the center of the umbra has the maximum length given by the sum of ~1 hour crossing the penumbra and ~1 hour entering the umbra, 1 hour 45 min in umbra, followed by the emergence of the moon into the penumbra and then full sunlight.

Thus, a total lunar eclipse can take nearly 6 hours from start to finish.

N

E -

- W

Ecliptic

P4: 23:01 UT

U4: 22:02 UT

U3: 21:03 UT

MAX: 20:13 UT

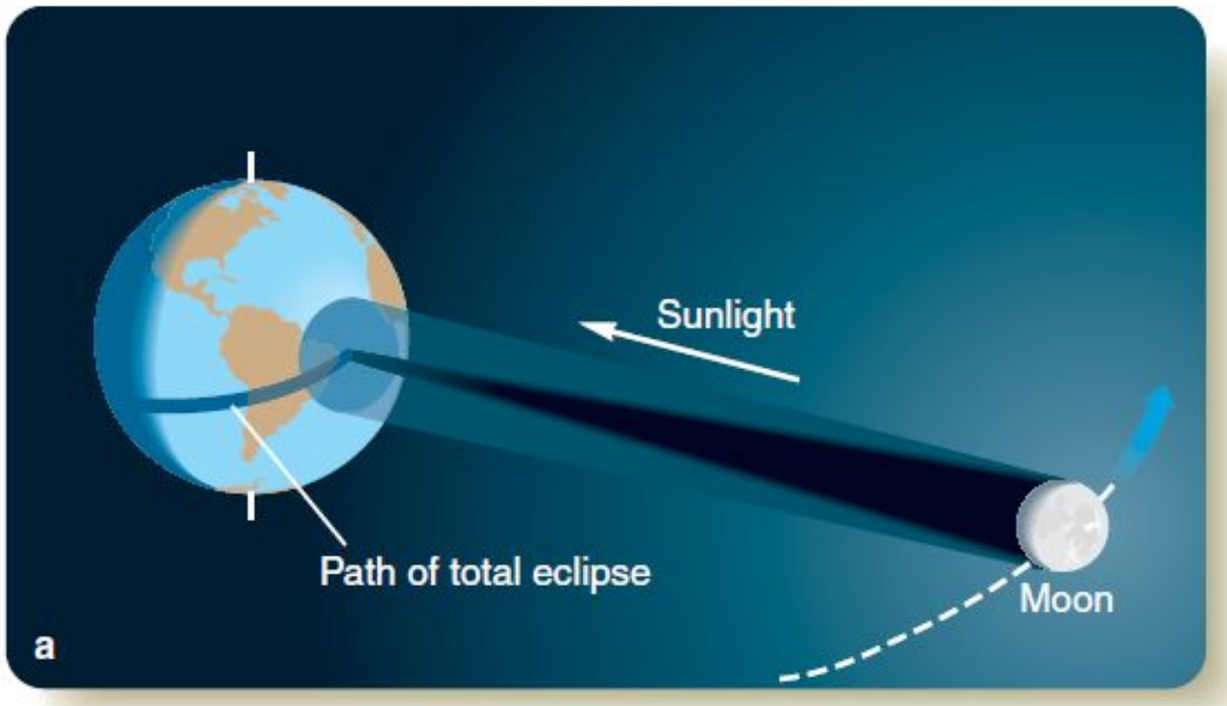
U2: 19:22 UT

U1: 18:23 UT

P1: 17:24 UT

S

Solar eclipses



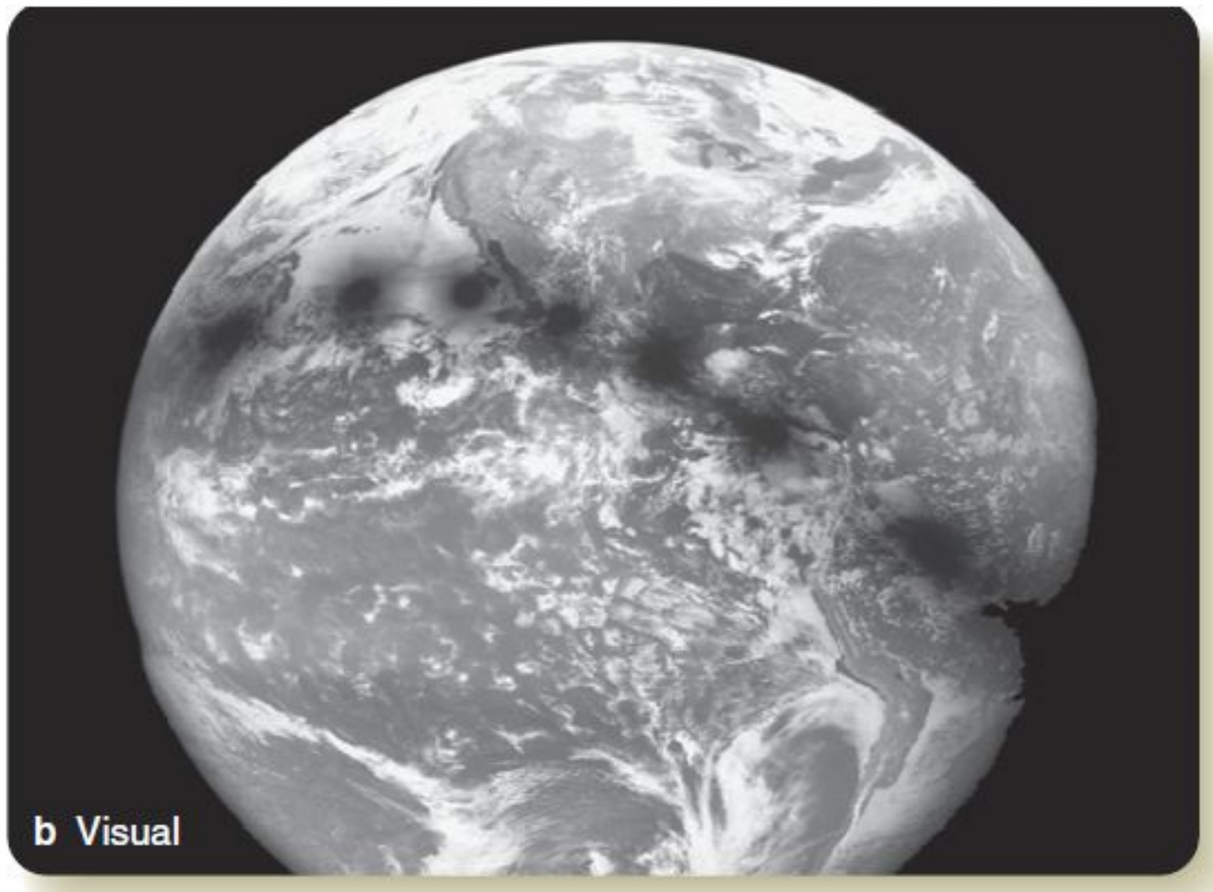
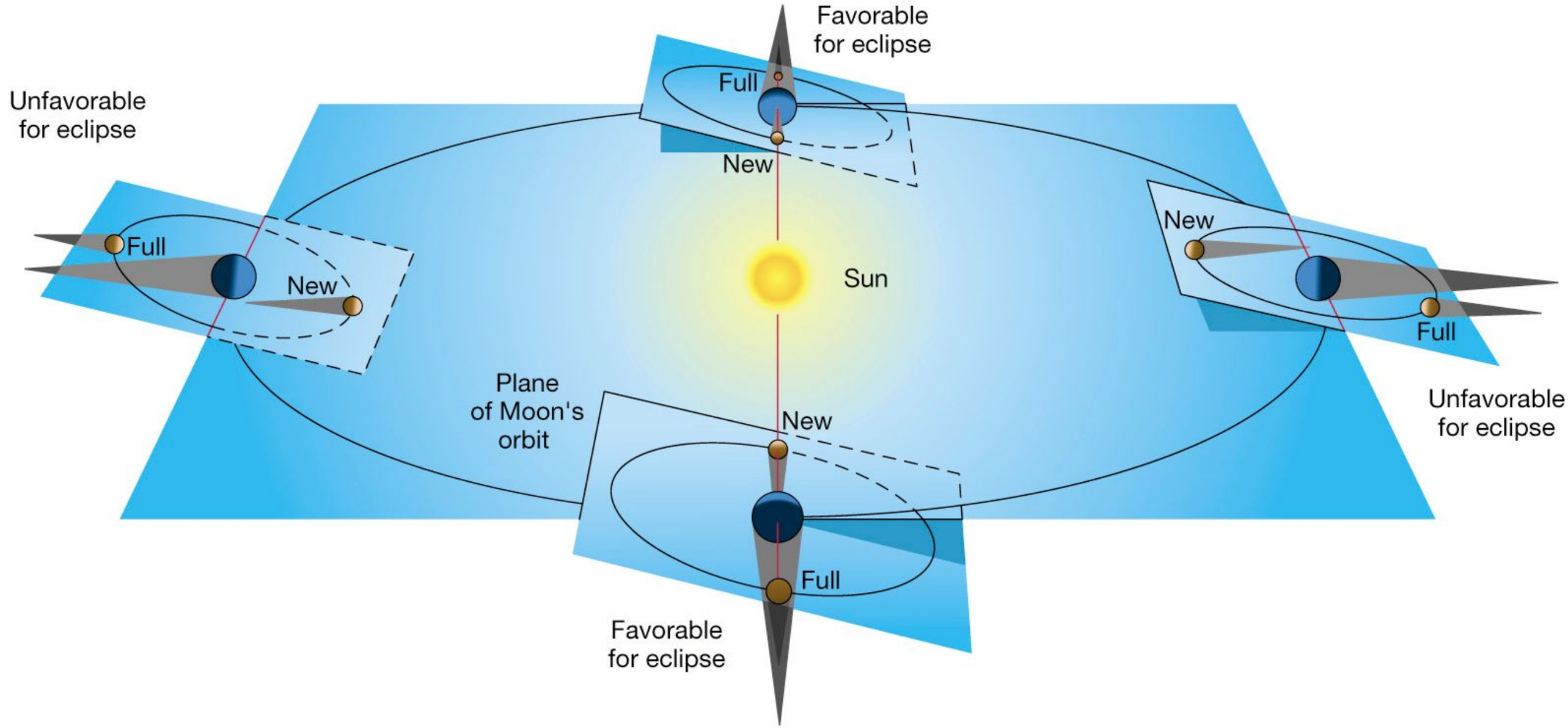


Figure 3-8

(a) The umbra of the moon's shadow sweeps from west to east across Earth, and observers in the path of totality see a total solar eclipse. Those outside the umbra but inside the penumbra see a partial eclipse. (b) Eight photos made by a weather satellite have been combined to show the moon's shadow moving across Mexico, Central America, and Brazil. (NASA GOES images courtesy of MrEclipse.com)

The angular diameter of the Moon is 1860 arcsec.
The angular diameter of the Sun is 1910 arcsec.

Solar eclipses



Moon’s shadow

- The moon’s umbral shadow produces a spot of darkness of ≈270 km in diameter on Earth’s surface.

- The moon’s shadow moves at ≈1799 km/h sweeping the path totality.

- The moon’s elliptical orbit is 5.5% smaller/larger at apogee/perigee than the average.

- The Earth’s elliptical orbit is 1.7% smaller/larger at aphelion/perihelion than the average.

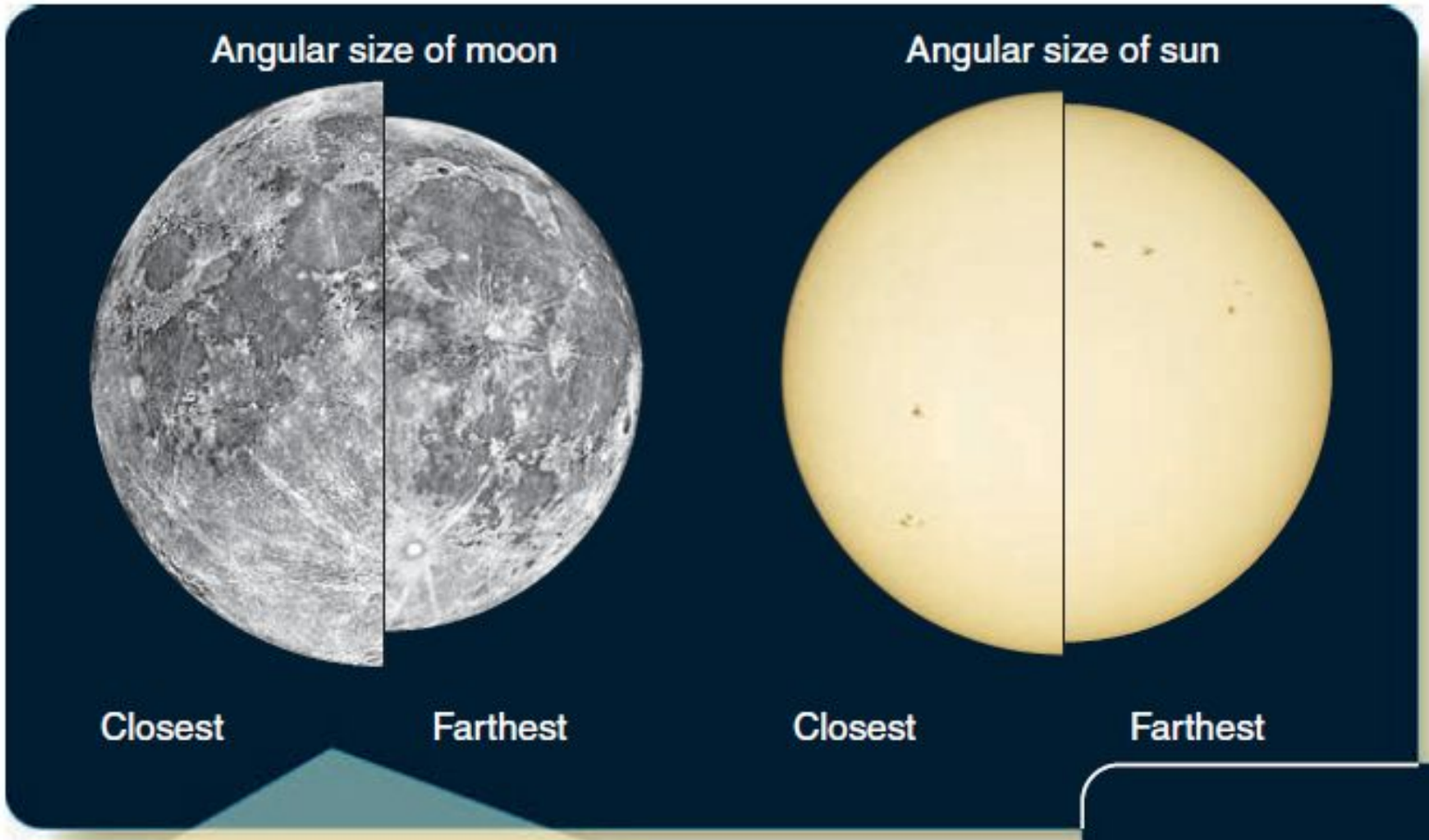


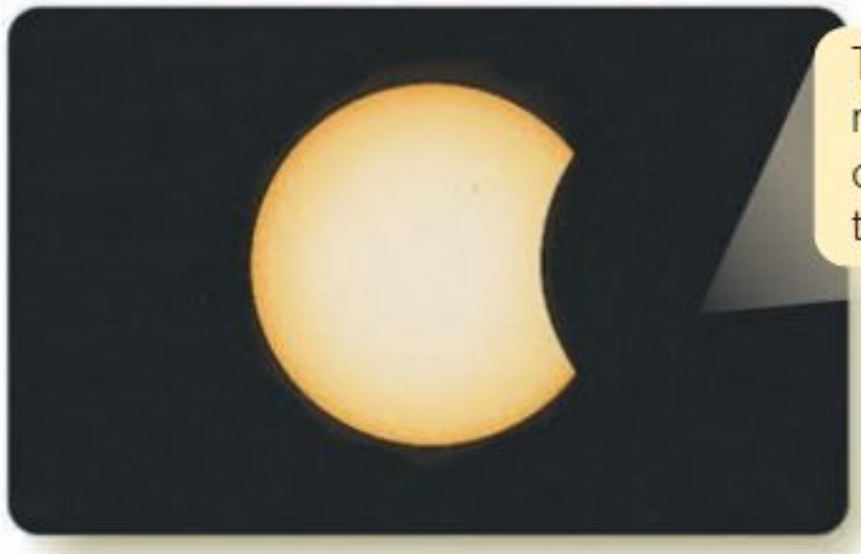
Figure 3-9

An annular eclipse occurs when the moon is far enough from Earth that its umbral shadow does not reach Earth's surface. From Earth, you see an annular eclipse because the moon's angular diameter is smaller than the angular diameter of the sun. In the photograph of the annular eclipse of 1994, the dark disk of the moon is almost exactly centered on the bright disk of the sun. (Daniel Good)

A Total Solar Eclipse

The moon moving from the right just begins to cross in front of the sun.

During totality, pink prominences are often visible.



The disk of the moon gradually covers the disk of the sun.

A longer-exposure photograph during totality shows the fainter corona.

Totality can last for a maximum of 7.5 minutes.

http://art-sheep.com/

How to look at an eclipse

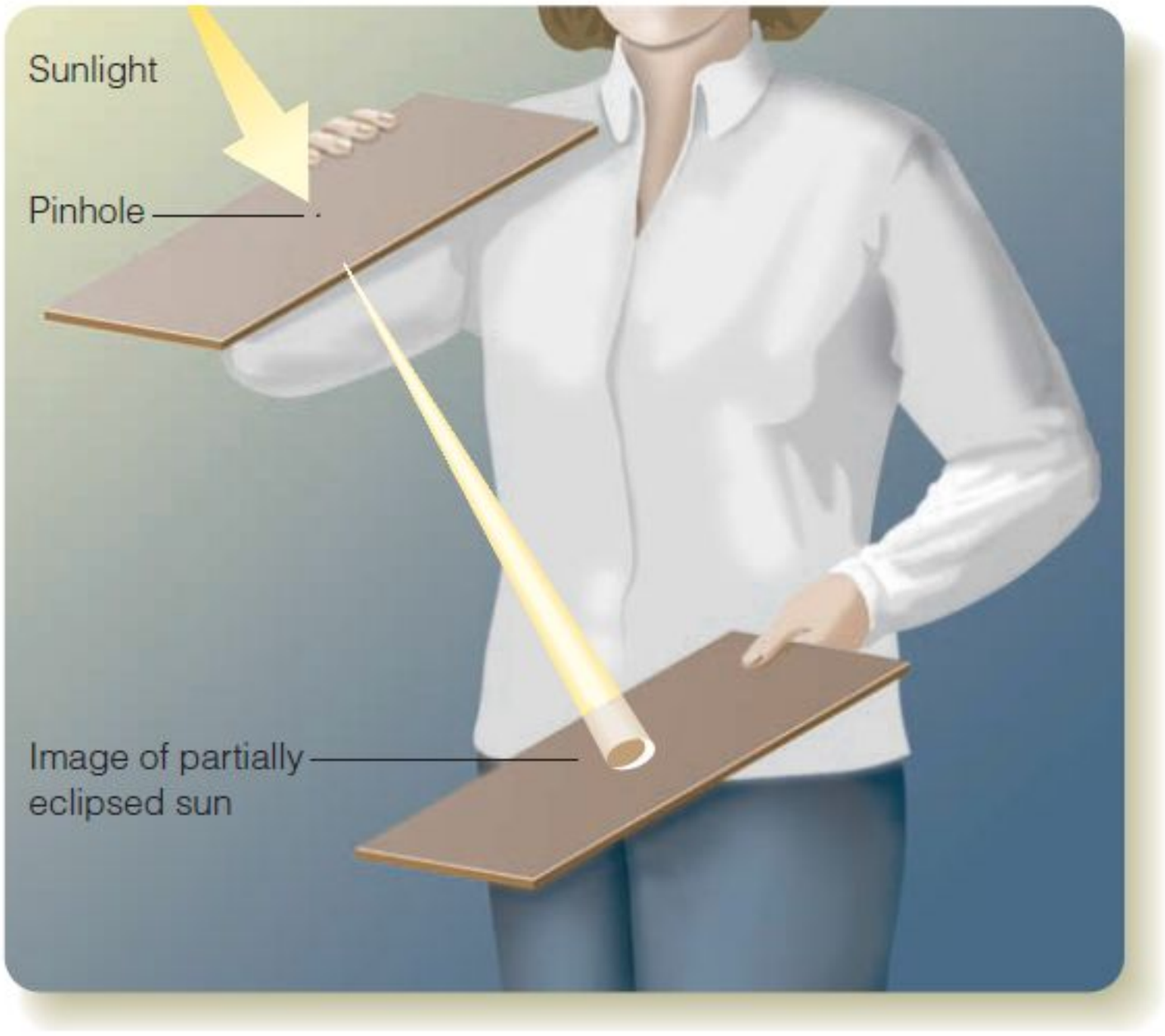


Figure 3-12

A safe way to view the partial phases of a solar eclipse. Use a pinhole in a card to project an image of the sun on a second card. The greater the distance between the cards, the larger (and fainter) the image will be.

Conditions for an eclipse

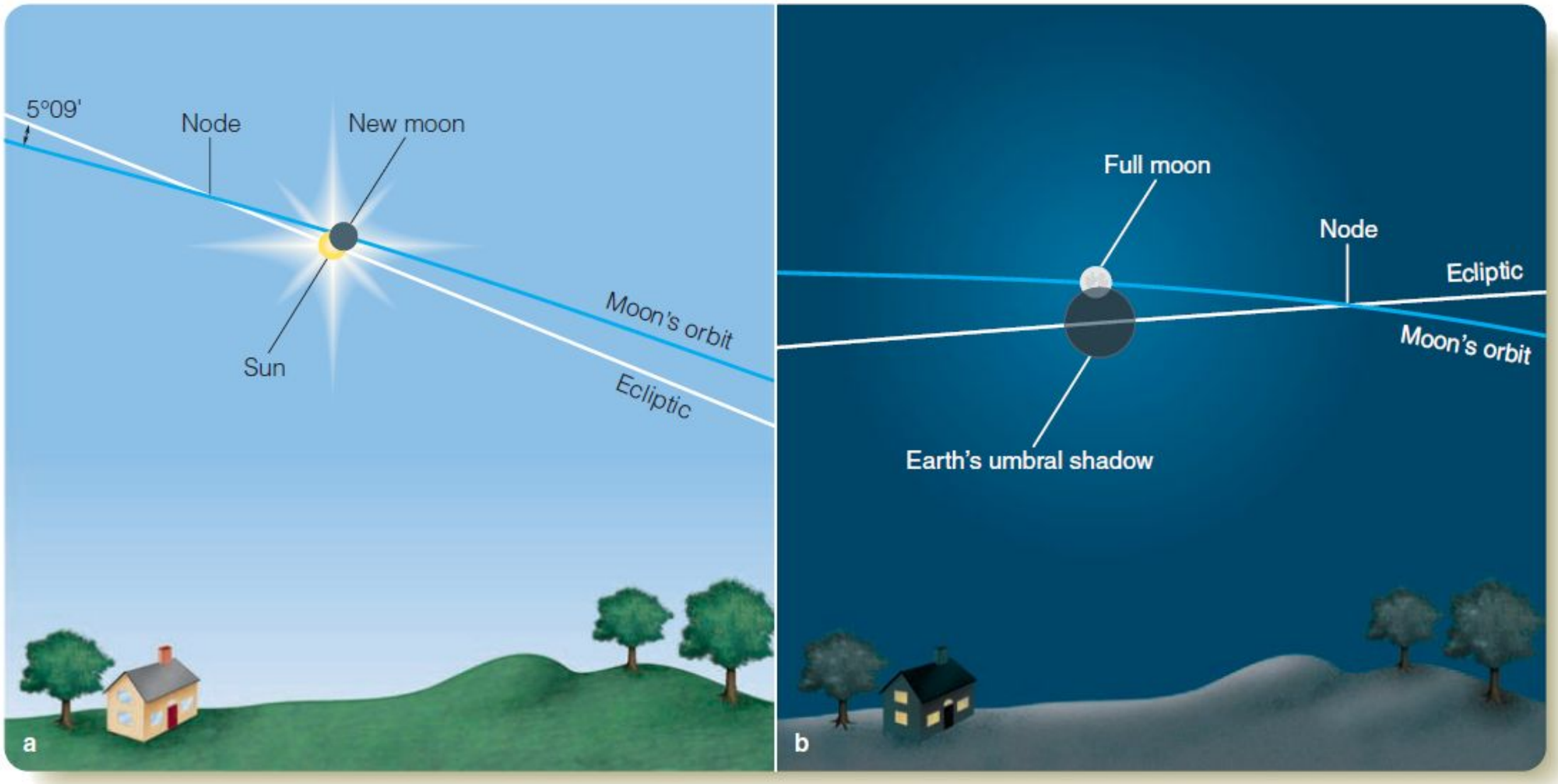
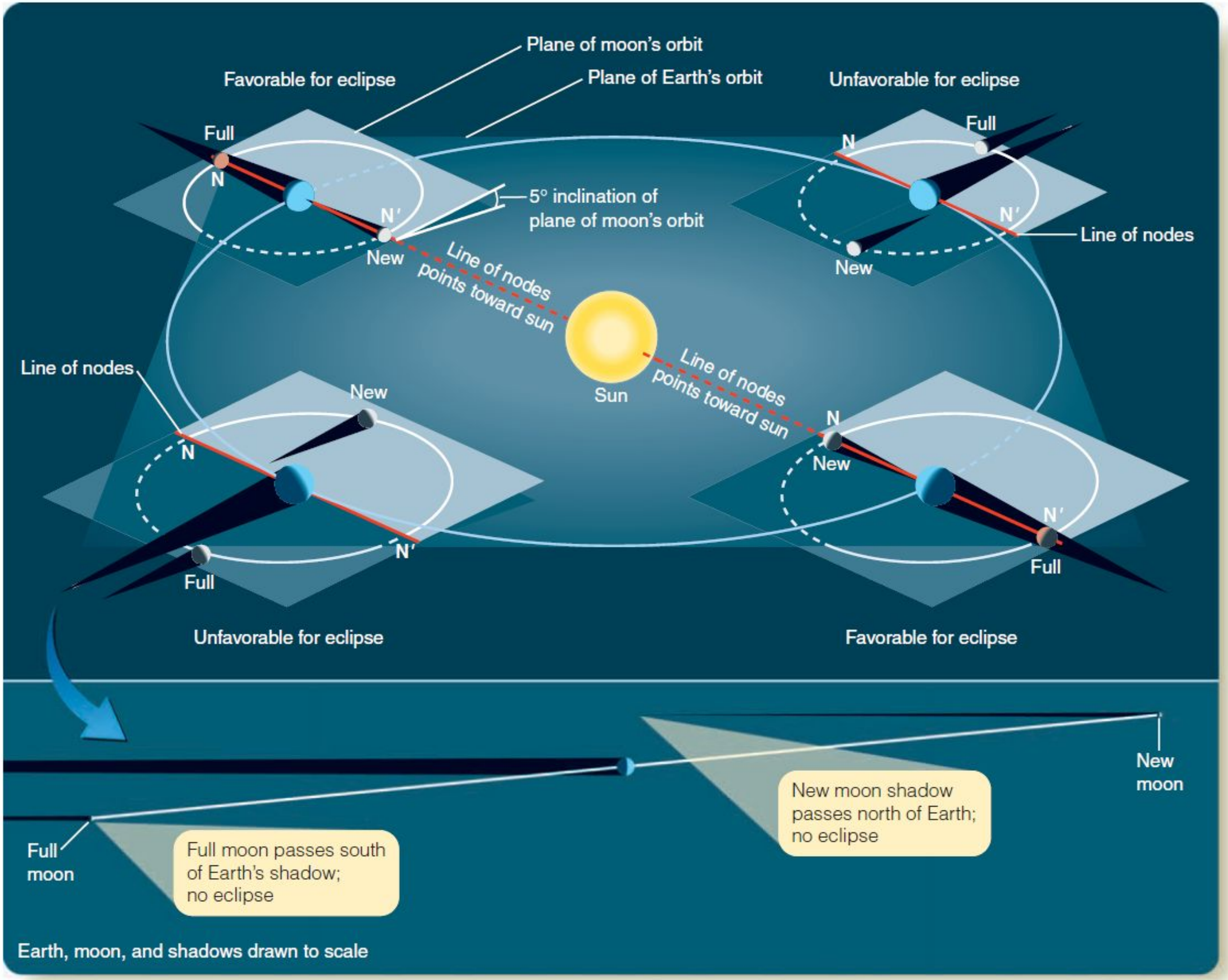


Figure 3-13

Eclipses can occur only near the nodes of the moon's orbit. (a) A solar eclipse occurs when the moon meets the sun near a node. (b) A lunar eclipse occurs when the sun and moon are near opposite nodes. Partial eclipses are shown here for clarity.


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

Eclipse predictions

- Exact eclipse predictions require precise computer simulations, but approximate estimates can be made.

- An eclipse can occur only in a period called an **eclipse season**, during which the sun is close to the node of moon's orbit.

- The solar eclipse season is 32 days long. Any new moon in this period will produce solar eclipse.

- The lunar eclipse season is 22 days long. Any full moon in this period will encounter Earth's shadow and be eclipsed.

- This makes eclipse prediction easy: all you have to do is keep track of where the moon crosses the ecliptic. This system works fairly well, and ancient astronomers may have used such a system.

Eclipse predictions

- The moon orbit precesses with period of 18.6 years. On Earth, we see the nodes slipping westward along the elliptic 19.4˚/year.

- Thus, it takes 346.6 days (less than a year) to go from one node crossing to another. This is called ecliptic year.

- Therefore, eclipse occurs 19 days earlier next year. New moon and full moon near that date is a candidate for eclipse.

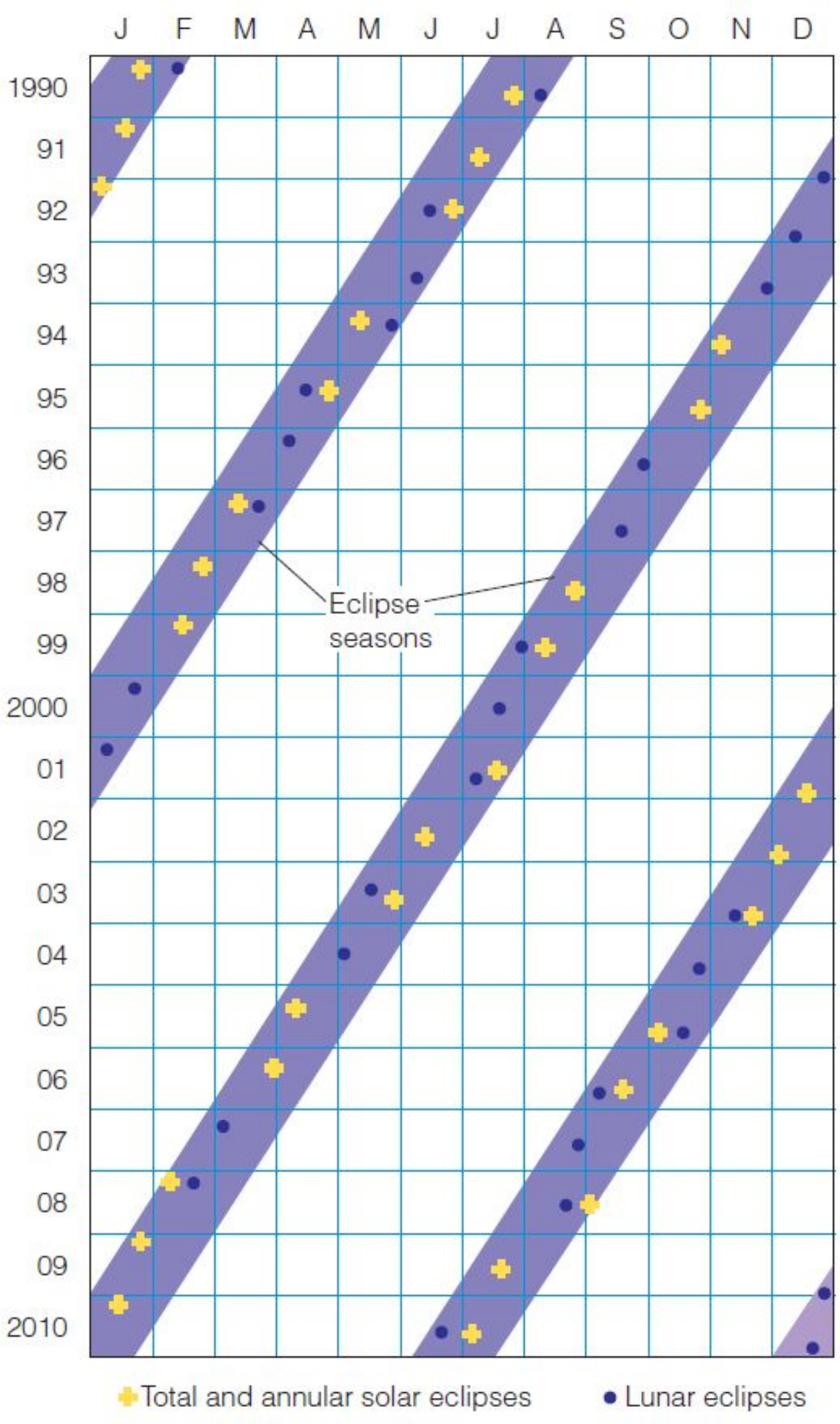


Figure 3-15

A calendar of eclipse seasons. Each year the eclipse seasons begin about 19 days earlier. Any new moon or full moon that occurs during an eclipse season results in an eclipse. Only total and annular eclipses are shown here.

The Saros Cycle

- After one Saros cycle of 18 years and 11.3 days (=6585.321 days), the eclipse pattern repeats.

- After 1 Saros cycles, the same eclipse occurs around the same part of the Earth shifted by 120 degrees East (because of the 1/3 day). Thus, after 3 Saros cycles, eclipse repeats around the same time and place.

- One Saros cycle is equal to 223 lunar synodic months and 19 ecliptic years. After one Saros cycle, the moon is back to the same phase it had when the cycle began and the sun returns to the same place it occupied with respect to the nodes of the moon’s orbit.

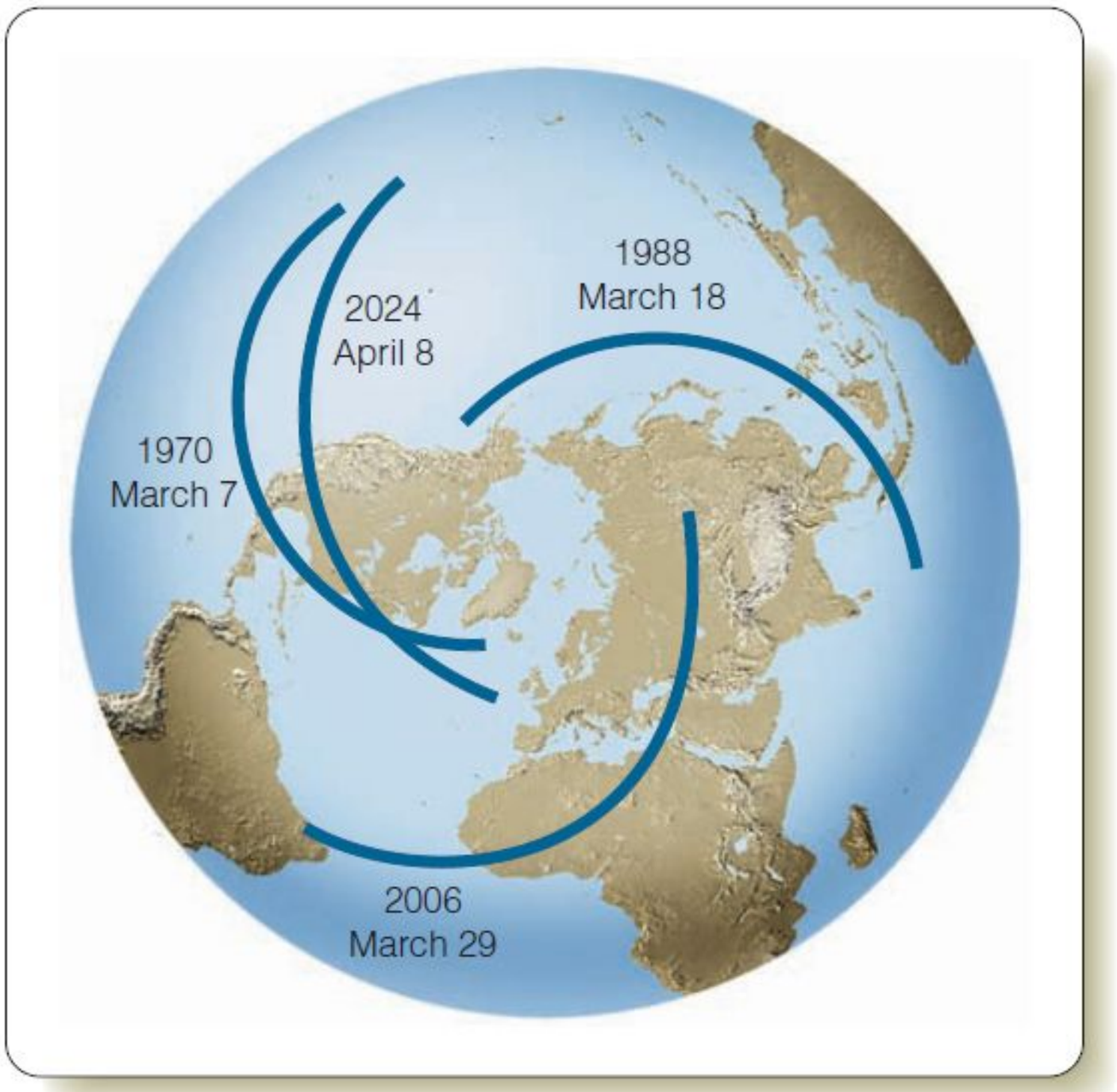


Figure 3-16

The saros cycle at work. The total solar eclipse of March 7, 1970, recurred after 18 years 11⅓ days over the Pacific Ocean. After another interval of 18 years 11⅓ days, the same eclipse was visible from Asia and Africa. After a similar interval, the eclipse will again be visible from the United States.


BBC TWO