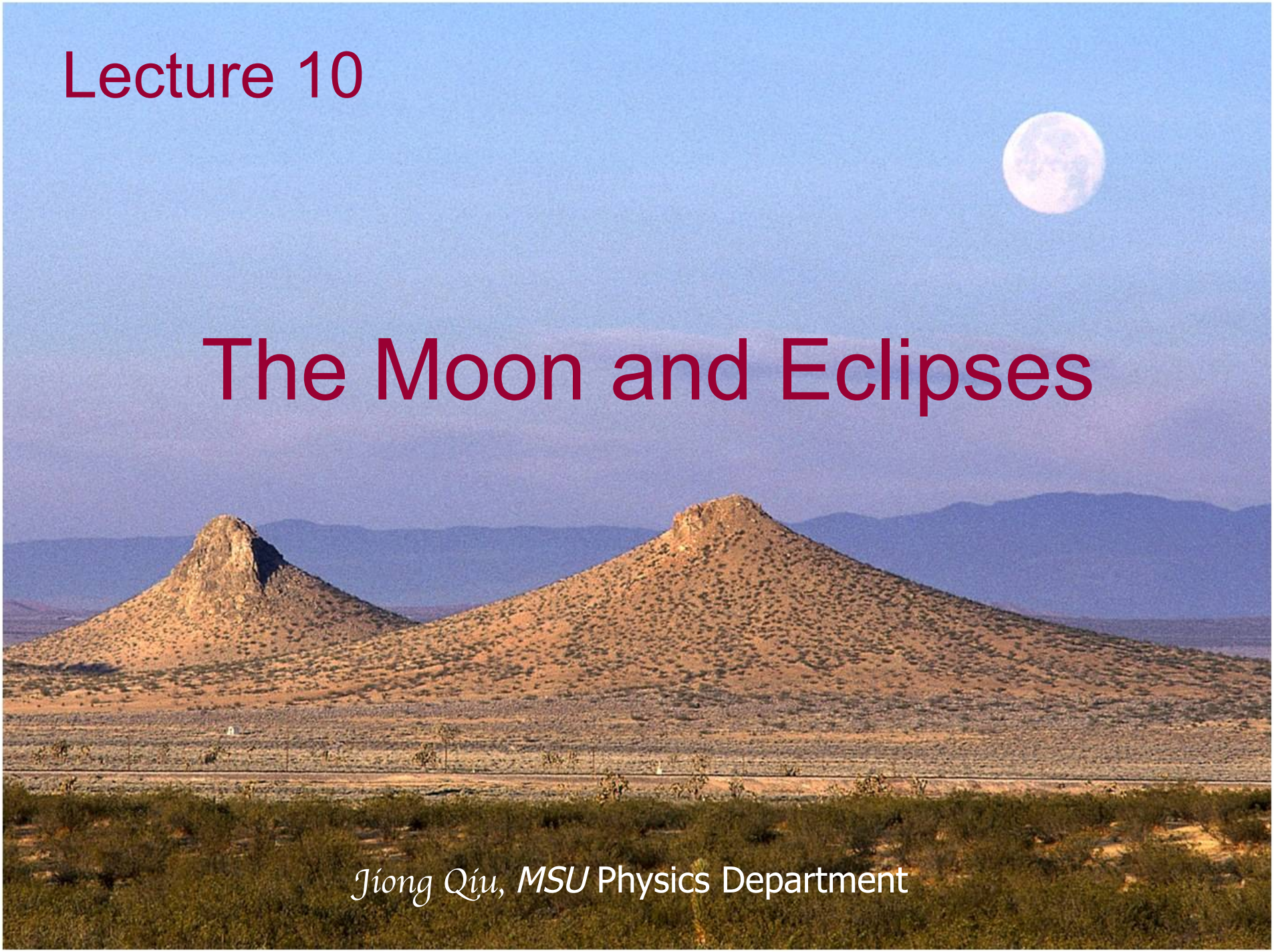
Lecture 10

The Moon and Eclipses



Jiong Qiu, *MSU* Physics Department

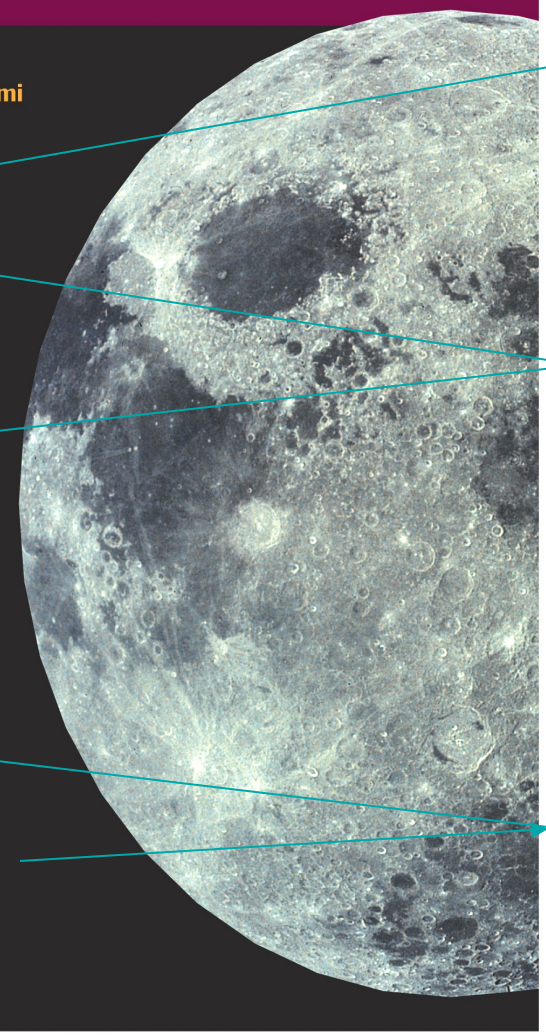
Guiding Questions

1. Why does the Moon keep the same face to us?
2. Is the Moon completely covered with craters? What is the difference between highlands and maria?
3. Does the Moon's interior have a similar structure to the interior of the Earth?
4. Why does the Moon go through phases? At a given phase, when does the Moon rise or set with respect to the Sun?
5. What is the difference between a lunar eclipse and a solar eclipse? During what phases do they occur?
6. How often do lunar eclipses happen? When one is taking place, where do you have to be to see it?
7. How often do solar eclipses happen? Why are they visible only from certain special locations on Earth?

10.1 Introduction

table 10-1 | Moon Data

Distance from Earth (center to center):	Average: 384,400 km = 238,900 mi Maximum (apogee): 405,500 km Minimum (perigee): 363,300 km
Eccentricity of orbit:	0.0549
Average orbital speed:	3680 km/h
Sidereal period (relative to fixed stars):	27.322 days
Synodic period (new moon to new moon):	29.531 days
Inclination of lunar equator to orbit:	6.68°
Inclination of orbit to ecliptic:	5.15°
Diameter (equatorial):	3476 km = 2160 mi = 0.272 Earth diameter
Mass:	7.349×10^{22} kg = 0.0123 Earth mass
Average density:	3344 kg/m^3
Escape speed:	2.4 km/s
Surface gravity (Earth = 1):	0.17
Albedo:	0.11
Average surface temperatures:	Day: 130°C = 266°F = 403 K Night: −180°C = −292°F = 93 K
Atmosphere:	Essentially none



The moon looks 14% bigger at perigee than at apogee.

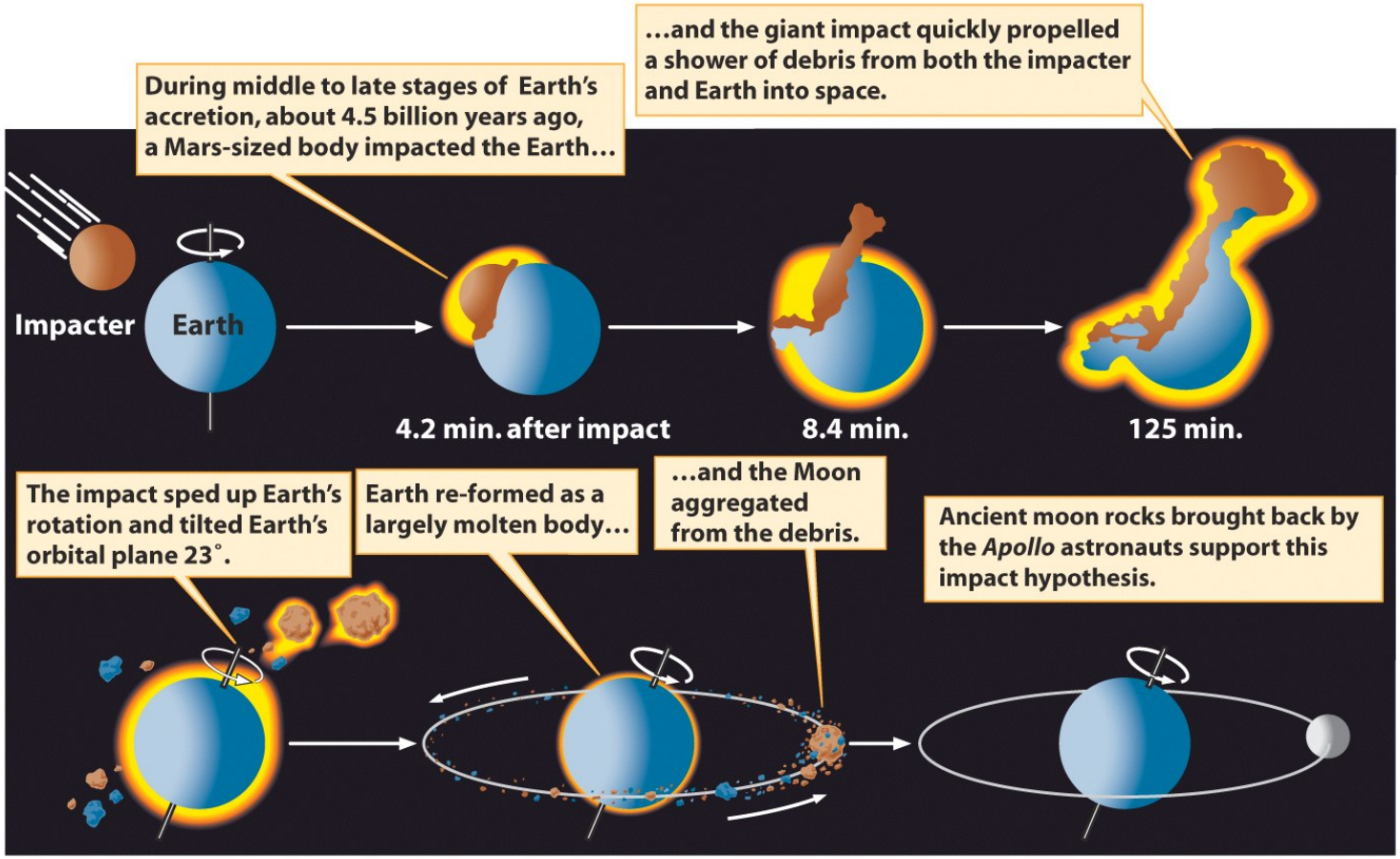
The Moon wobbles. 59% of its surface can be seen from the Earth.

The Moon can not hold the atmosphere

The Moon does NOT have an atmosphere and the Moon does NOT have liquid water.

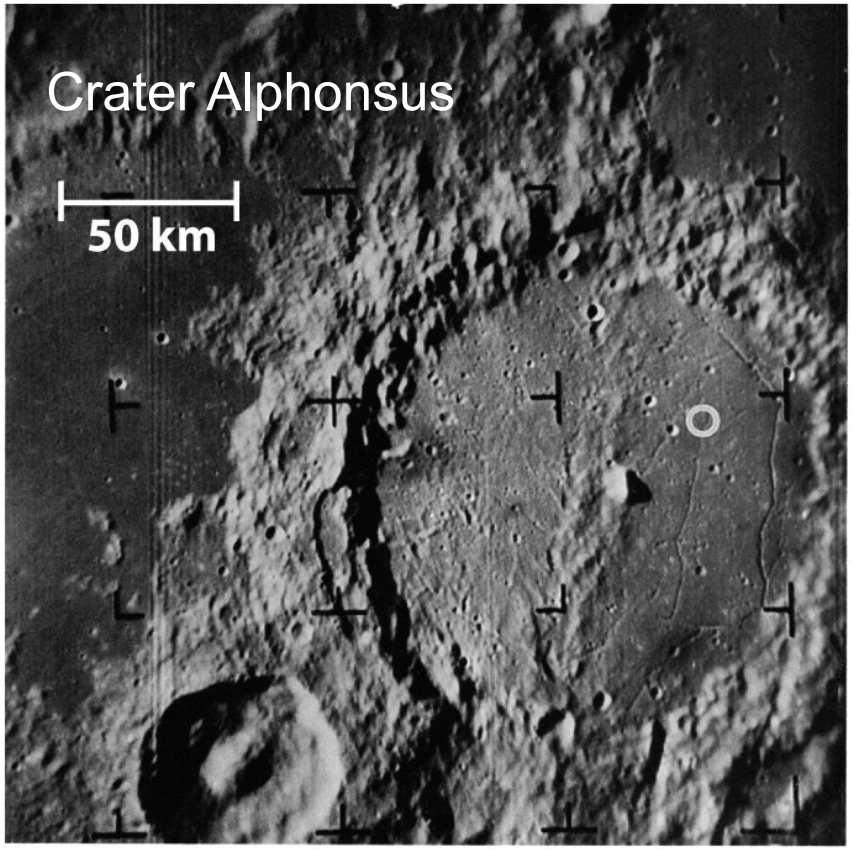
Q: what factors determine the presence of an atmosphere?

The Moon probably formed from debris cast into space when a huge planetesimal struck the proto-Earth.

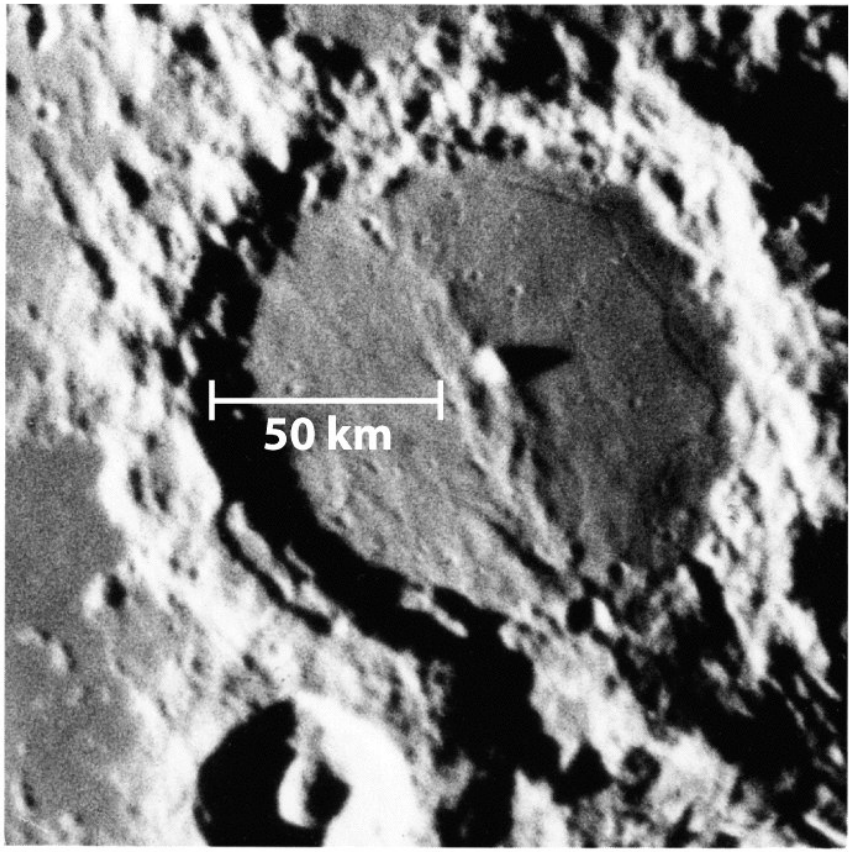


10.2 Exploration of the Moon

Unmanned exploration: 1950, Lunas 1-3 -- 1960s, Ranger -- 1966-67, Lunar Orbiters -- 1966-68, Surveyors (first soft landing) -- 1966-76, Lunas 9-24 (soft landing) -- 1989-93, Galileo -- 1994, Clementine -- 1998, Lunar Prospector
Achievement: high-resolution lunar surface images; surface composition; evidence of ice patches around the south pole.

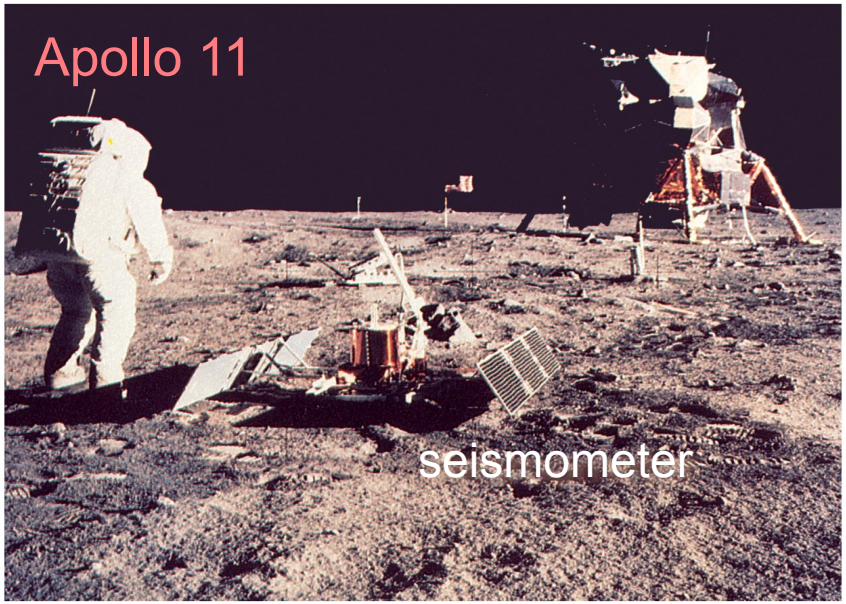


(a) View from *Ranger 9*

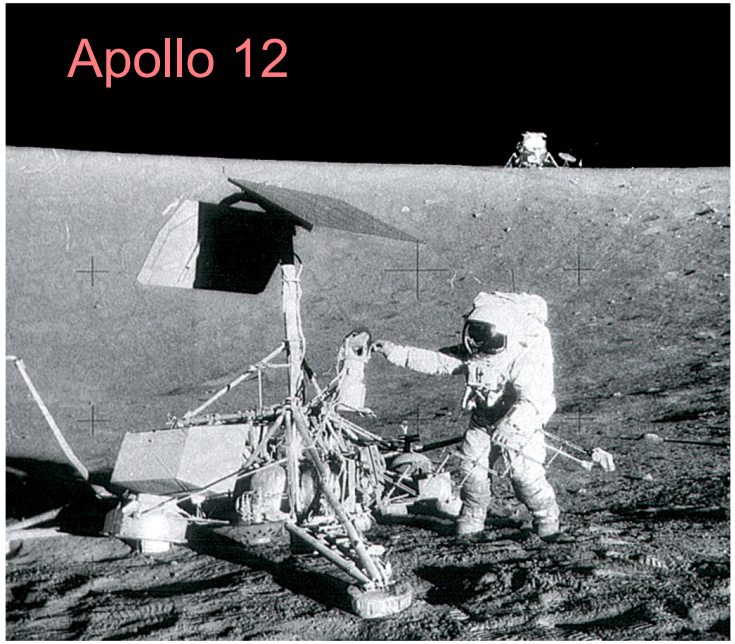


(b) Same view from Earth

Manned exploration of the Moon - **Apollo Mission**: the first of the six manned lunar landing took place on July 20, 1969 with Apollo 11.



Much of our knowledge about the Moon has come from manned exploration 3-4 decades ago and from recent observations by unmanned spacecraft carrying state-of-the-art instruments, such as a **seismometer.**

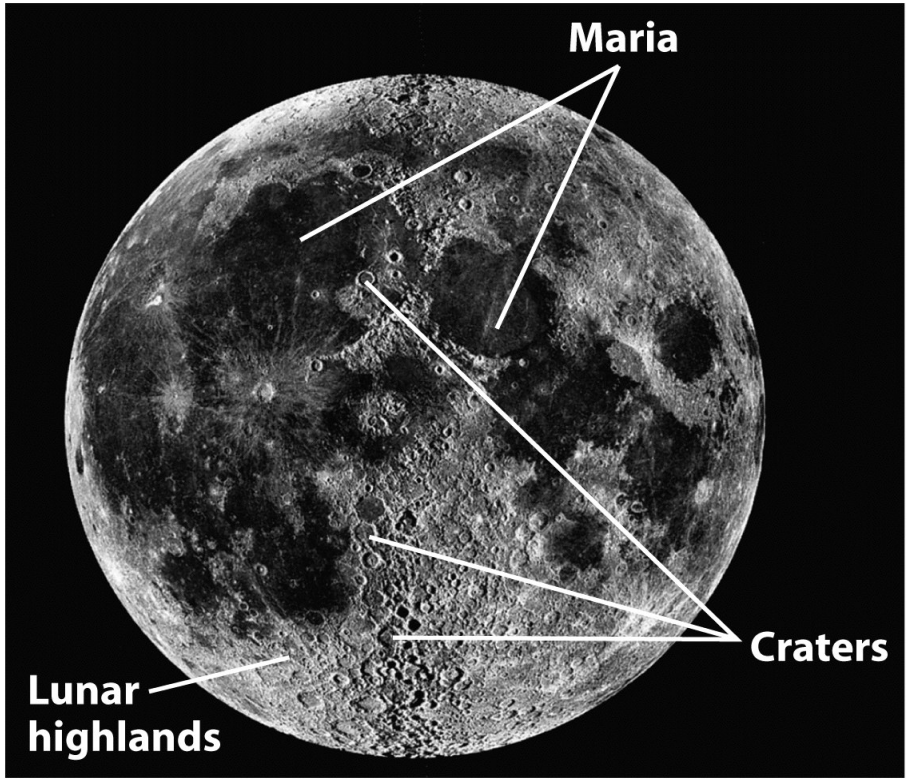


One small step for a man, one giant leap for mankind.

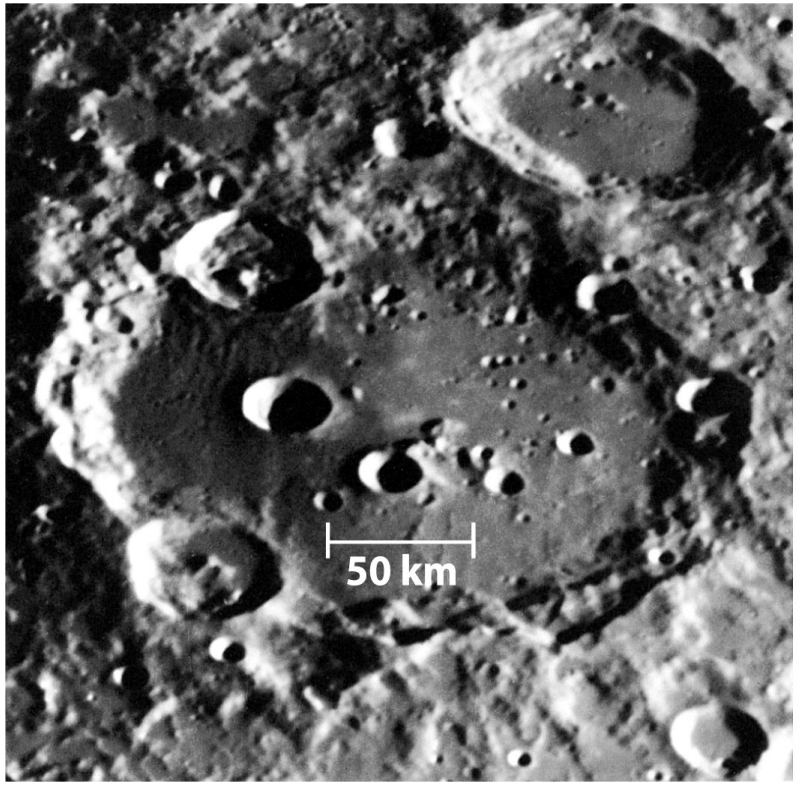
10.3 The Moon's surface

The Moon's airless, dry surface is covered with **highlands** and **maria**, with more than 30,000 **impact craters**.

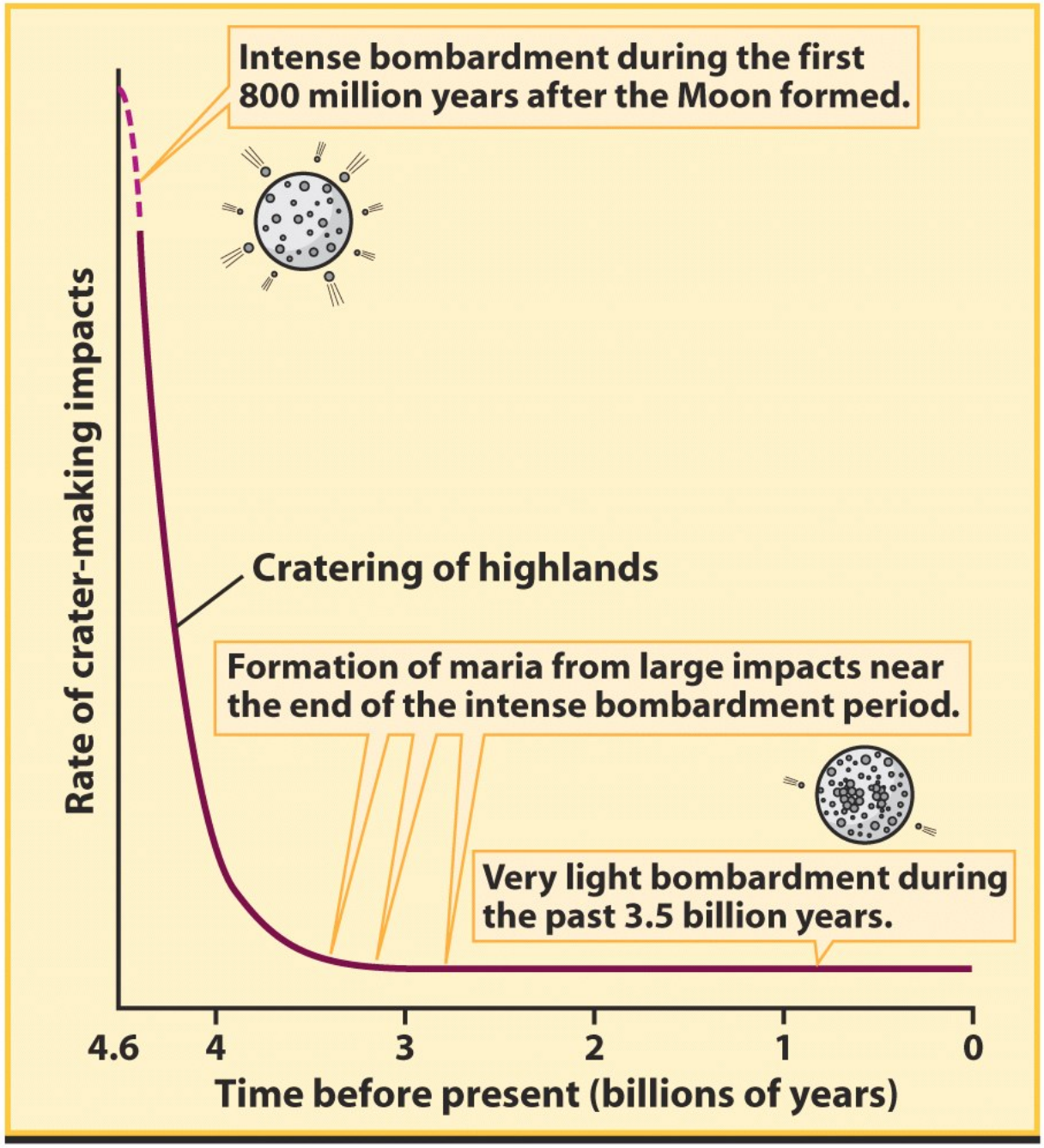
Moon observed at Lick Observatory.



Moon observed at Palomar Observatory.



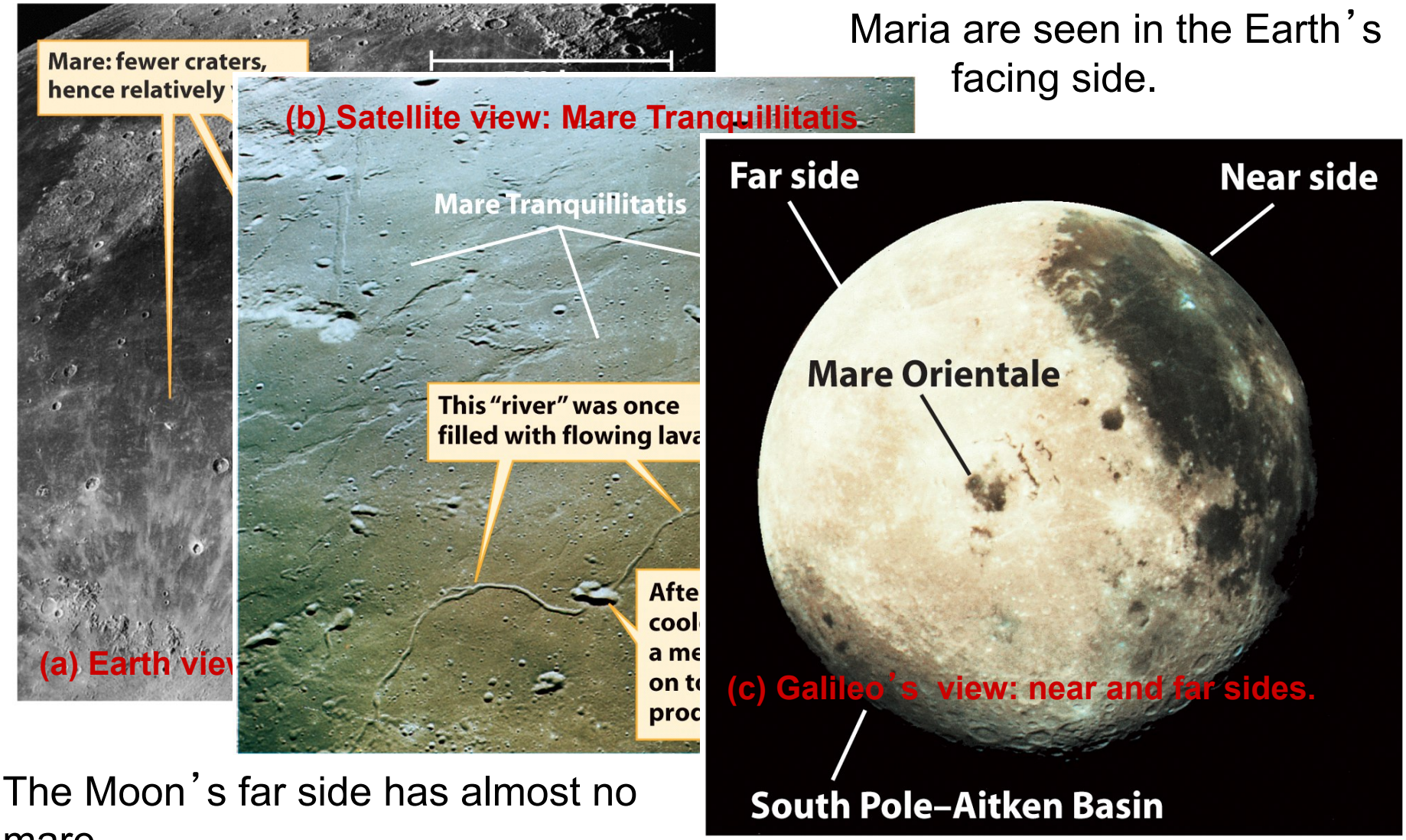
- Lunar **craters** were caused by space debris striking the surface.
- There is no evidence of **plate tectonic activity** and earth-like **weathering** and **erosion** (why?) on the Moon to reshape the surface and erase the craters -- the Moon is a better keeper of the history of the Solar system.



The rate of Crater Formation

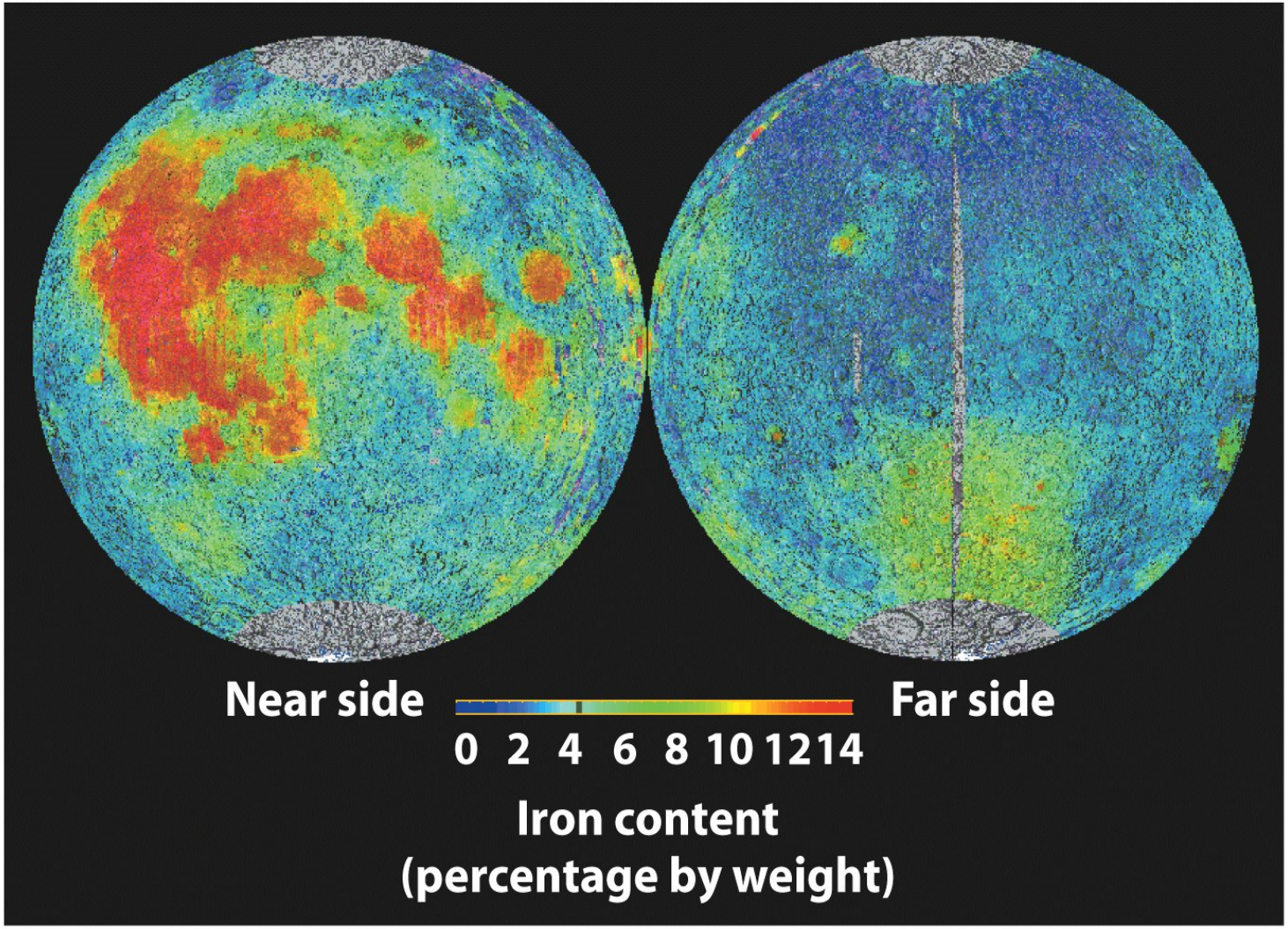
Much fewer craters are found in **maria.** The **maria** formed - impact by very large objects and **lava** flow - after the surrounding terrain, so they have not been exposed to meteoritic bombardment for as long.

Maria are seen in the Earth's facing side.

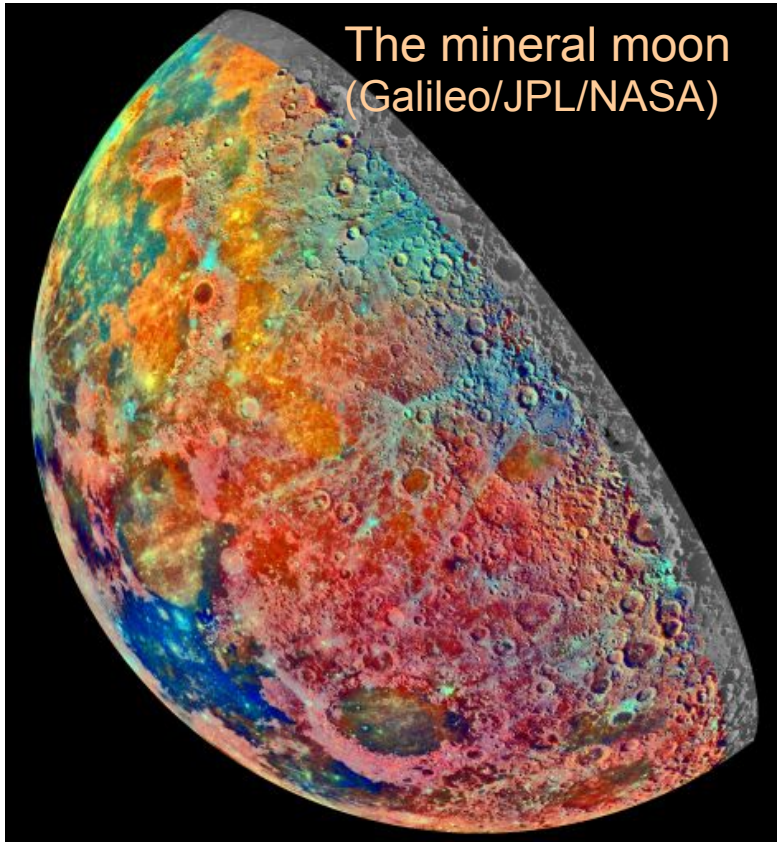


The Moon's far side has almost no mare.

Iron on the Moon: map of iron concentration from spectral observations by Clementine spacecraft. **Iron concentration** coincides with **maria**, confirming that maria formed from **iron-rich lava.**



Blue to orange shades indicate volcanic lava flows. The dark blue Mare Tranquillitatis at the lower left is richer in titanium bearing minerals than the green and orange maria above it. Near the bottom of the image and to the right of Tranquillitatis is the dark oval-shaped Mare Crisium surrounded by shocking pink colors indicating material of the lunar highlands.

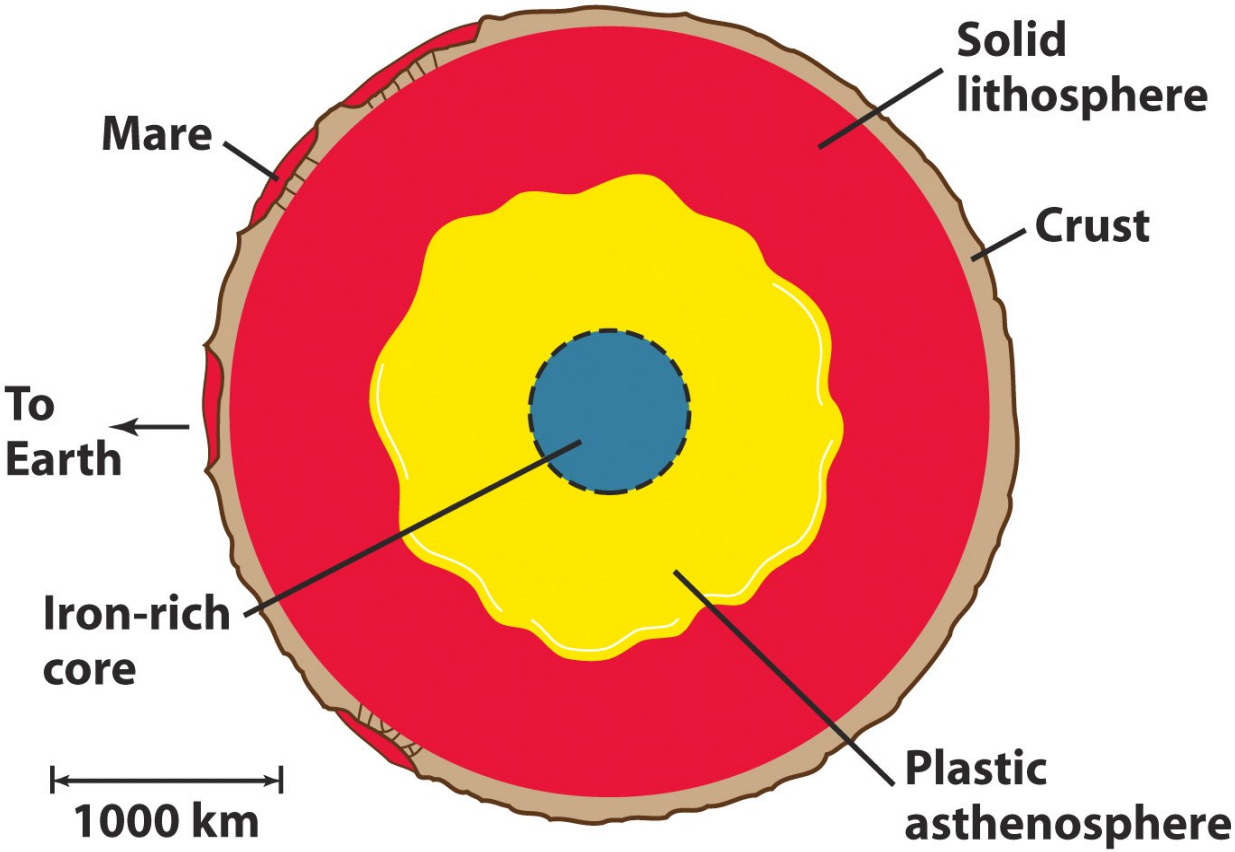


The different colors are recognized to correspond to real differences in the chemical makeup of the lunar surface - blue hues reveal titanium rich areas while orange and purple colors show regions relatively poor in titanium and Iron. (Astronomical Picture of the Day)

10.4 The interior of the Moon

-- The Moon has **no global magnetic field** but has a small partially-liquid iron-rich core beneath a thick mantle.

-- The crust on the far-side is thicker than on the Earth-facing side -- explanation of much fewer maria on the far side.



Internal structure of the Moon

o The interior structure of the Moon is revealed by **lunar seismology** (see Lecture 5).

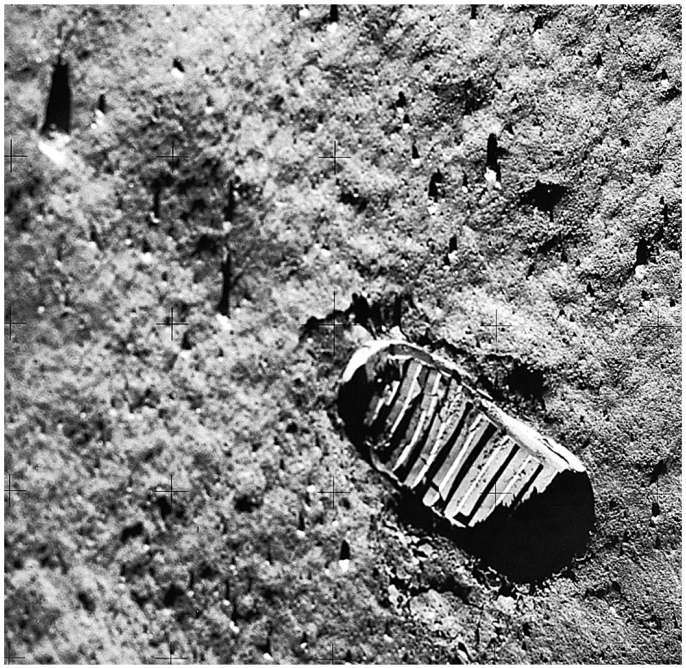
o **Moonquakes** were produced by the Earth's **tidal force** and are most frequent near the perigee

Ex.1: how does this compare with earthquakes?

o Moonquakes are much weaker than earthquakes

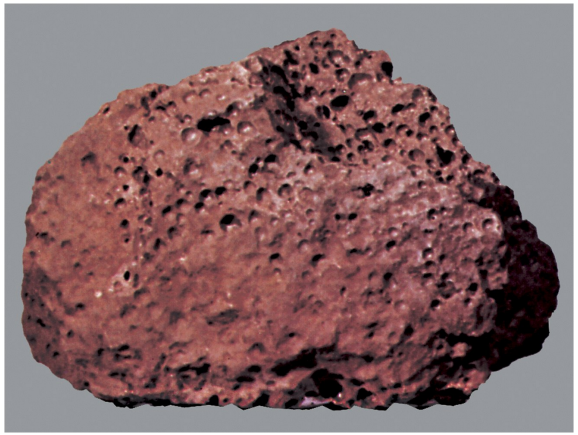
10.5 The Moon's rocks (reading assignment)

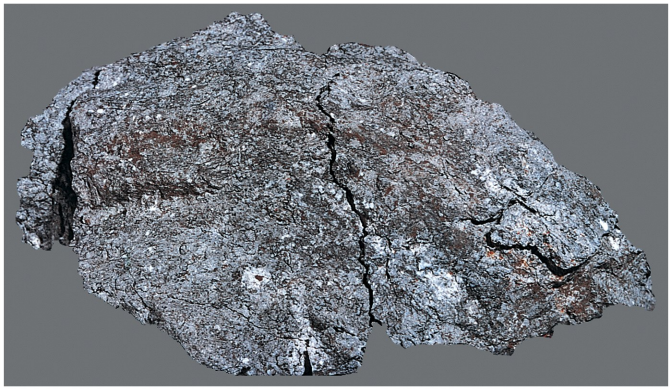
Rocks on the Moon are telltale of the geological history of the Moon, the Earth-Moon system, and the solar system.



- Meteoroid impacts have been the only significant "weathering" agent on the Moon.
- The Moon's **regolith,** or surface layer of powdered and fractured rock, was formed by meteoritic action.
- All lunar samples are **igneous rocks** formed largely of minerals found in terrestrial rocks.

The lunar rocks contain **no water**.



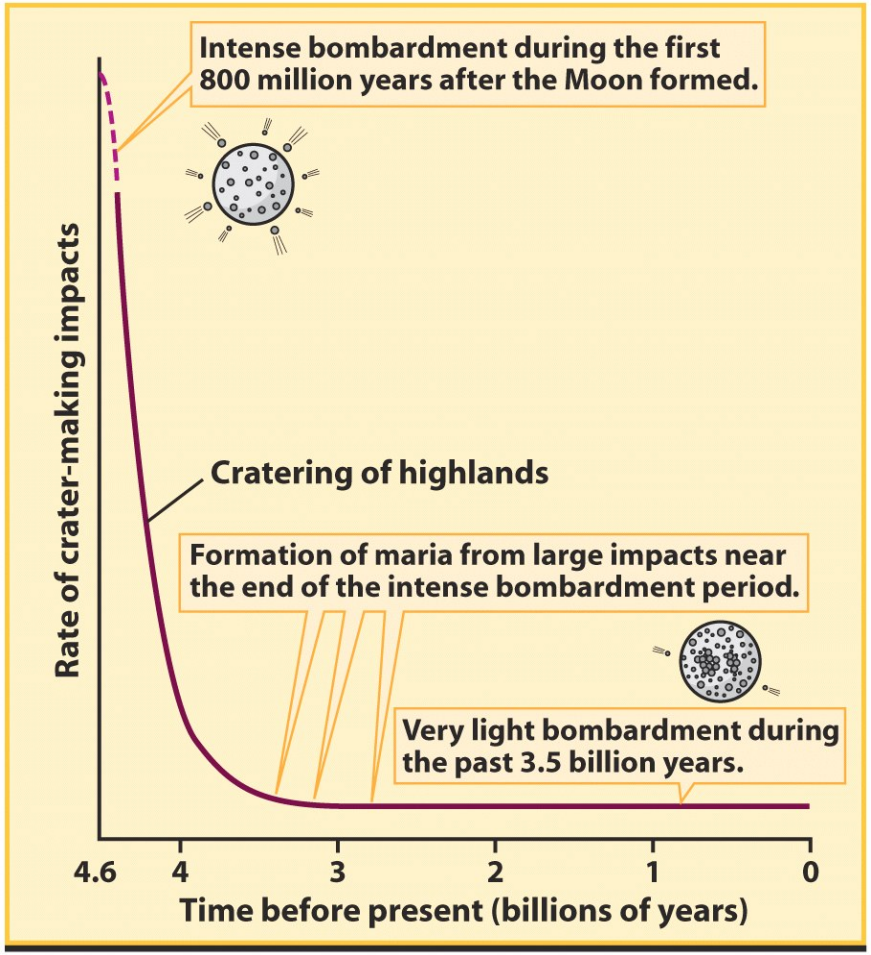


Different rock samples brought back by Apollo.

- The ages of lunar rocks are determined by radioactive age-dating
- The **highland anorthositic** crust was formed between 4.0 and 4.3 billion years ago
- The **mare basalts** solidified between 3.1 and 3.8 billion years ago
- The Moon's surface has undergone very little change over the past 3 billion years

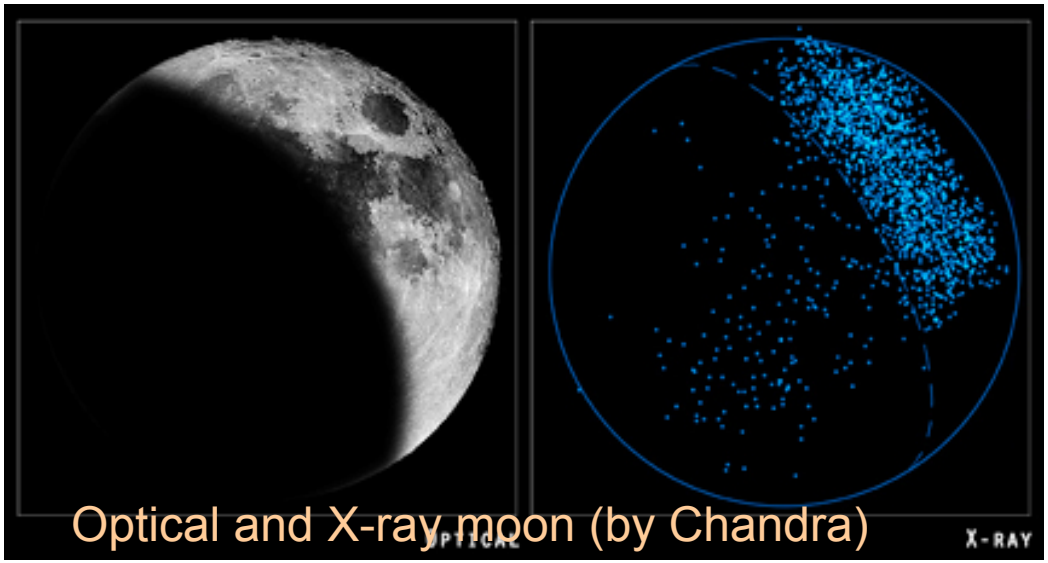
Ex.2: Summarize observational facts about Maria and what these facts tell us about the properties of the Moon.

The rate of Crater Formation

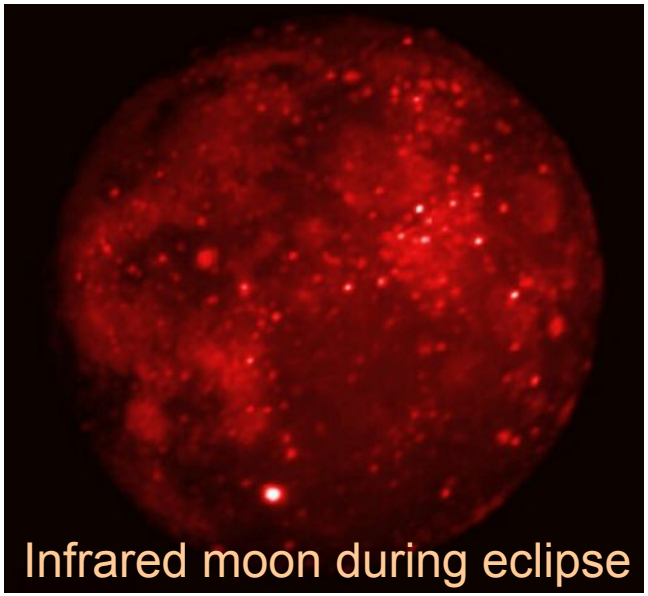


Cool bits for today: moon in "colors"

(All images from Astronomical Picture of the Day)

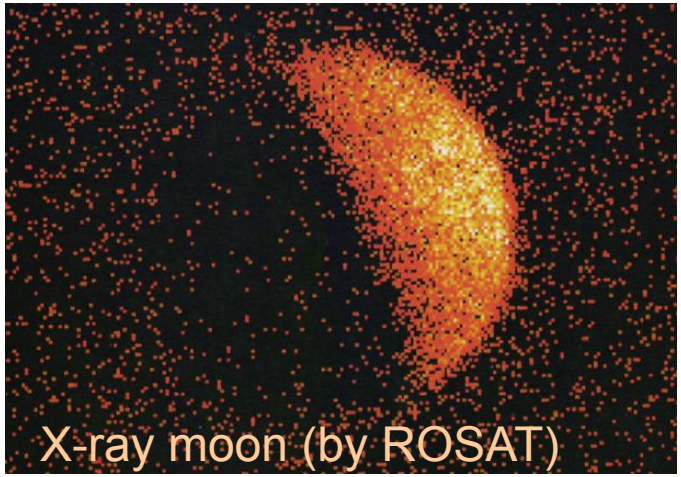


Optical and X-ray moon (by Chandra)



Infrared moon during eclipse

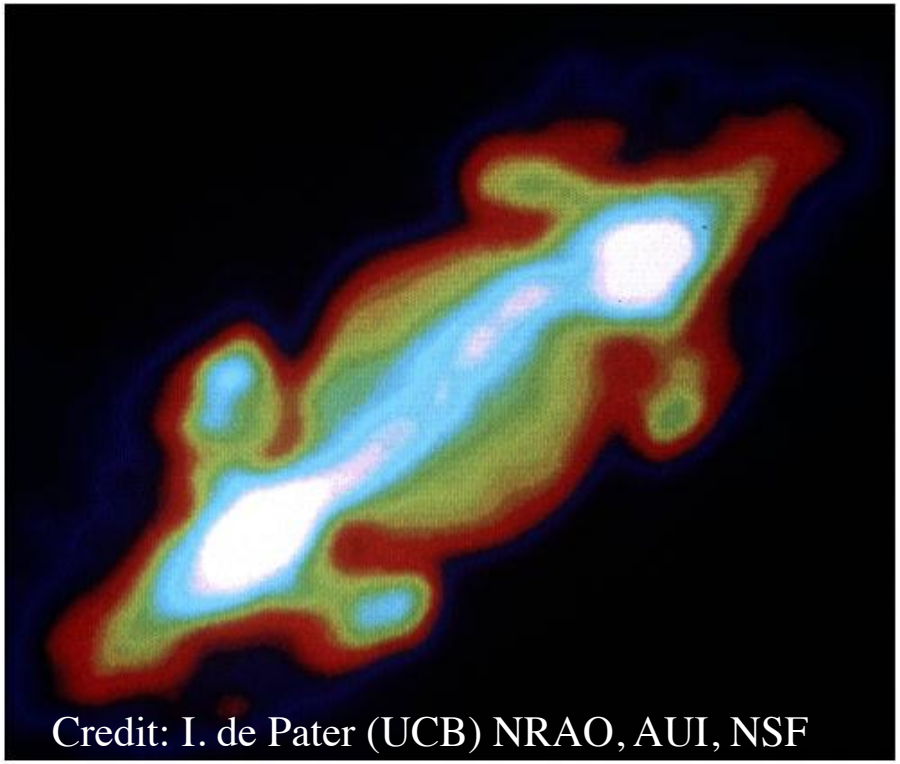
Gamma-ray moon (by EGRET)



X-ray moon (by ROSAT)

Q: why can we see the Moon in X-rays and Gamma-rays?

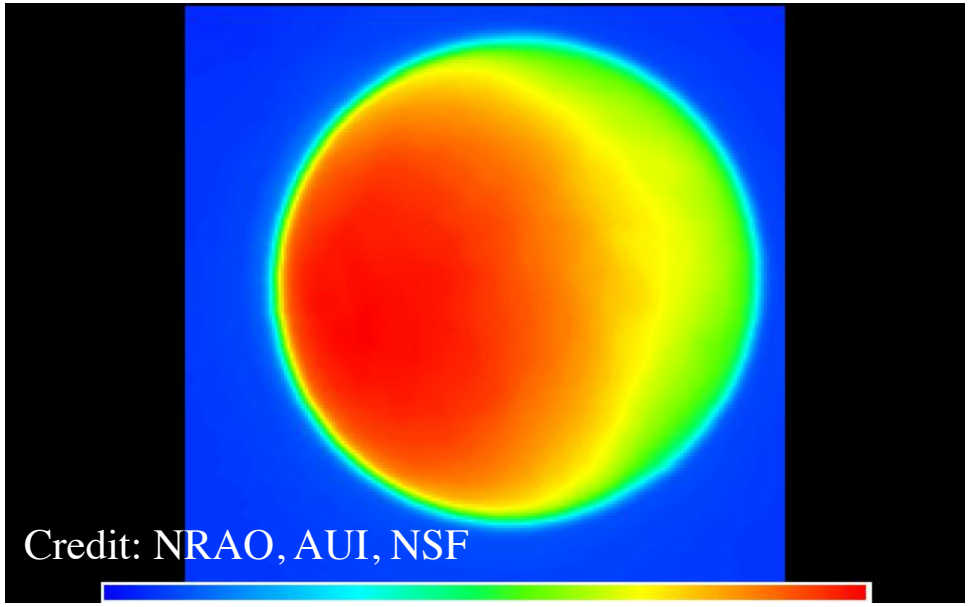
Q: Would the radio Moon look like the radio Jupiter?

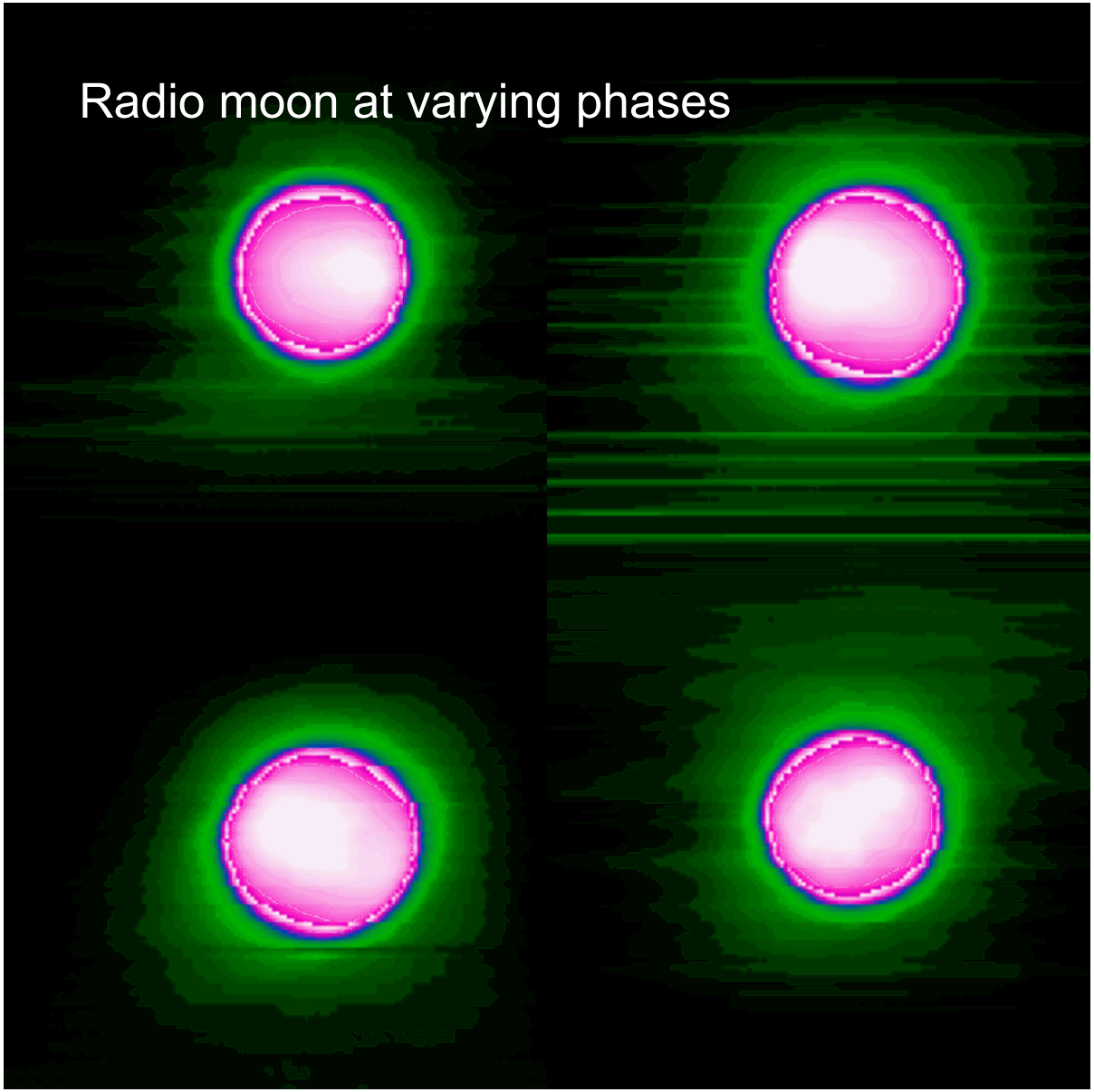


Radio Jupiter does not look too familiar…

Donut-like radio emission is produced by electrons trapped in Jupiter's magnetosphere.

Radio Moon is also different from what we usually know: it is always full. Why?





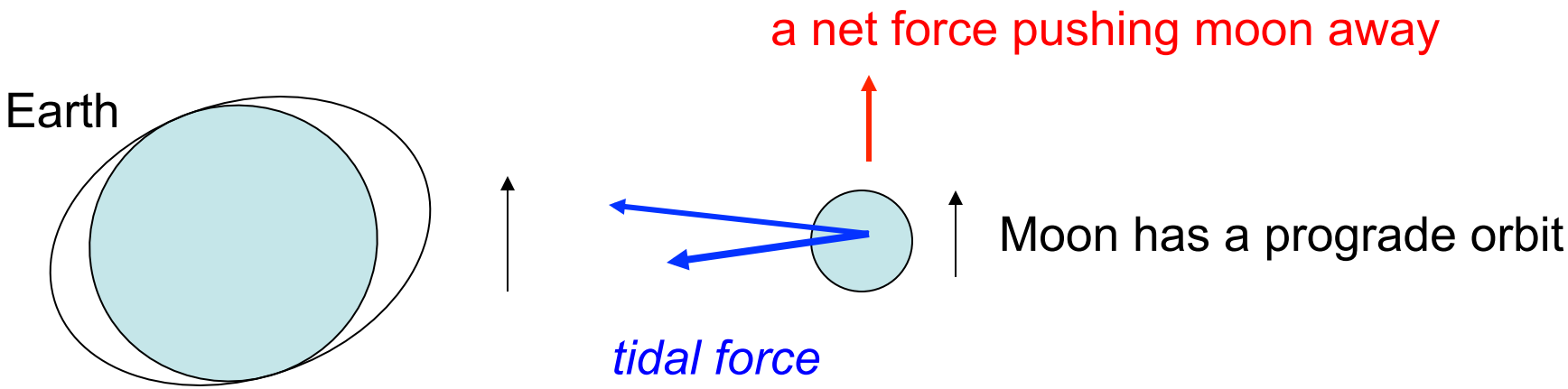
These brightness maps are temperature maps.

(http://www.gb.nrao.edu/epo/rmoon.html)

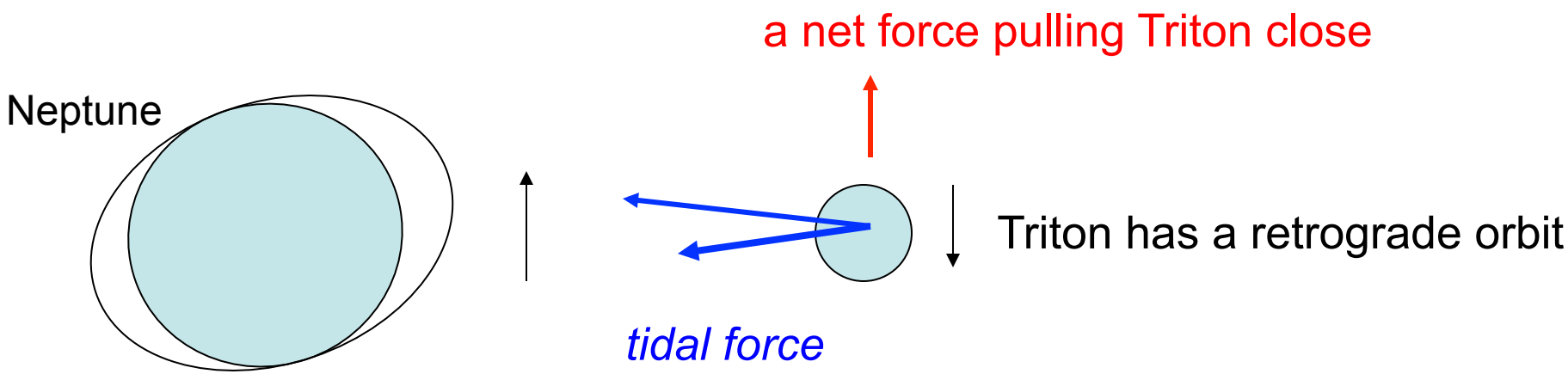
10.6: effects of gravity in the Earth-moon system

- Earth and the Moon both orbit around a point between their centers called the **center of mass** of the Earth-Moon system.
- The center of mass then follows an elliptical orbit around the Sun.
- Gravity of the Moon produces tides and wobbling of the Earth, and gradual evolution of Earth's rotation.
- The tidal force of Earth causes the synchronous rotation of the moon and pushes moon away from Earth.

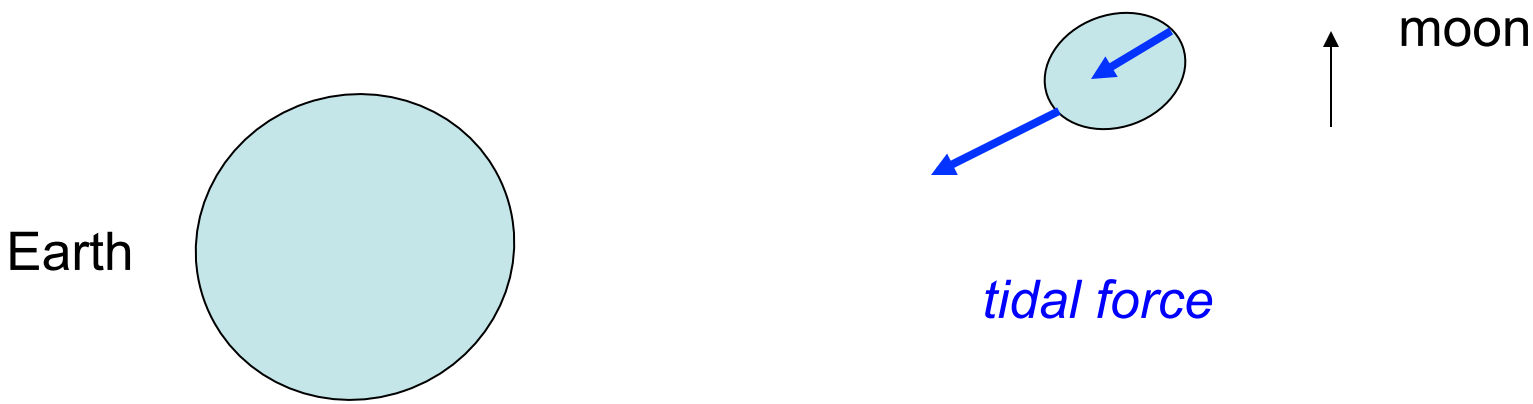
tidal force and future of the Moon and Triton



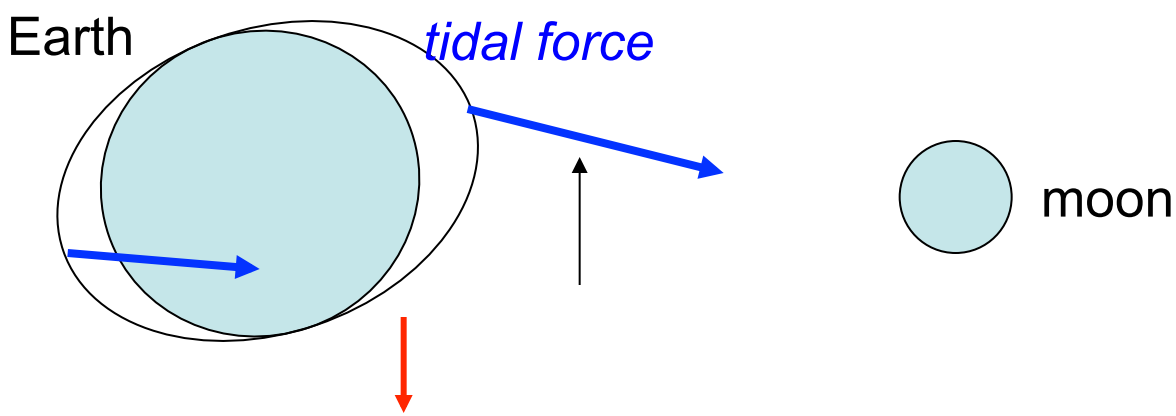
Tidal force also stretches the planet!



The tidal force causes synchronous rotation of the moon



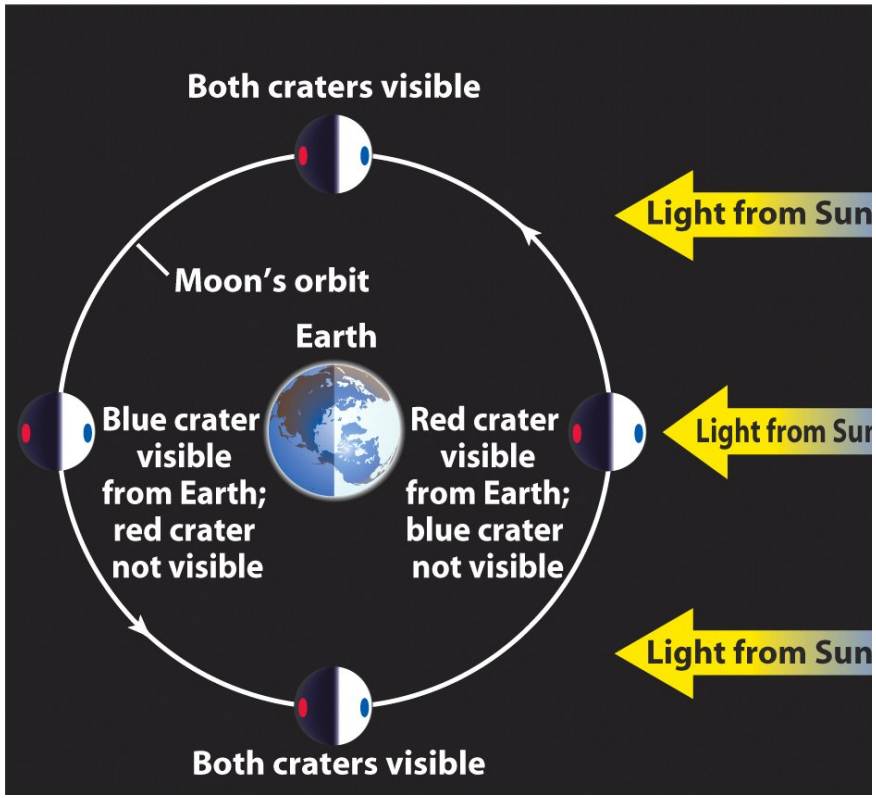
The tidal force slows down Earth's rotation



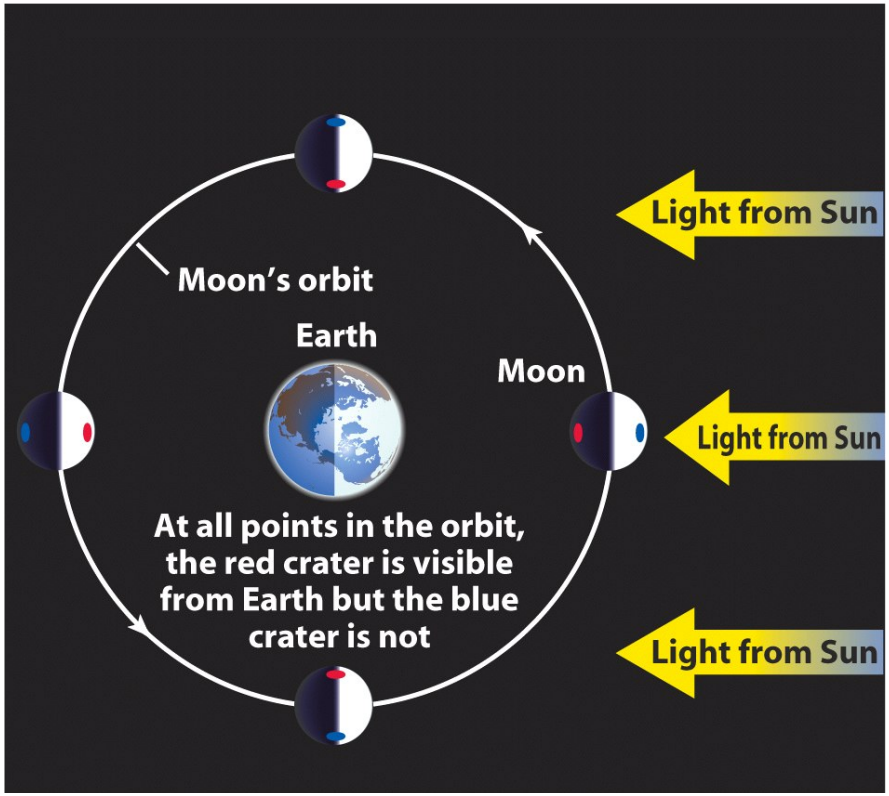
The moon almost always keeps the same face, or hemisphere, toward th **nous rotation** of the moon s and orbits around the earth at the same rate.

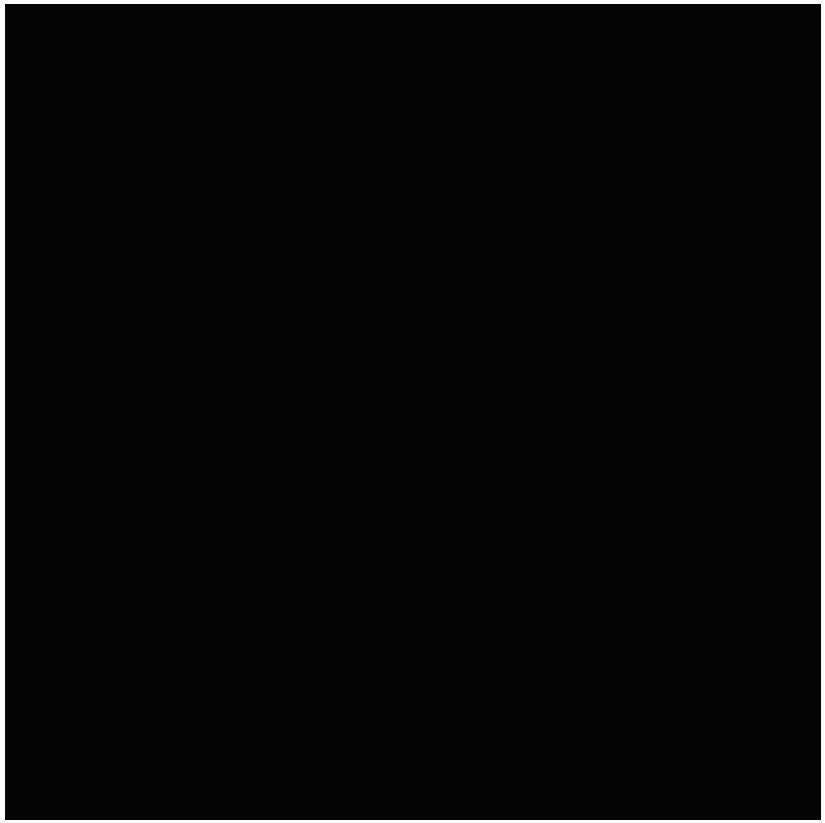
Q: how long is one day on the Moon?
what if the Moon does not rotate?

If the Moon did not rotate, we could see all sides of the Moon

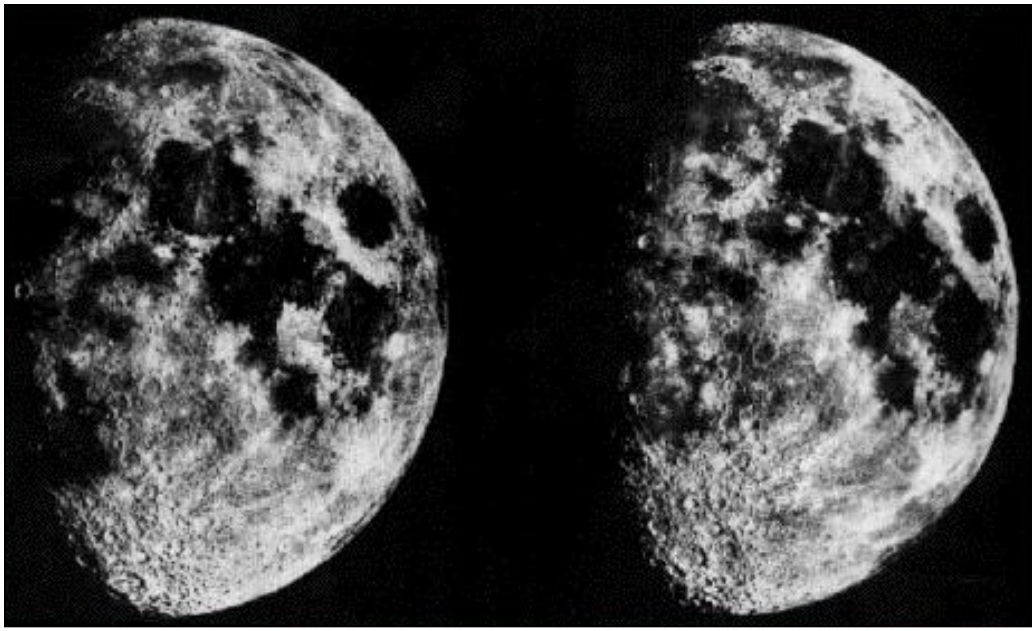


In fact the Moon does rotate, and we see only one face of the Moon





- The Moon almost always keeps the same face toward the Earth - **tidal force**.
- Wobbling of the Moon slightly changes its appearance. This effect is called **libration**.



As the result of **libration**, 59% of the Moon's surface is visible from the Earth.

10.7 Phases of the Moon

- Like the earth, the moon is illuminated by the sun light.
- The sun light illuminates half of the Moon's sphere, and we on earth see half of the Moon's sphere, both appear as a circular disk as projected to the plane of the sky.
- Relative positioning of the Sun (light source), the moon (reflector), and the observer determines the Moon's phase, or the illuminated potion of the observed disk.
- With the Moon's orbital motion, we see the cyclic variation of the Moon's phase.

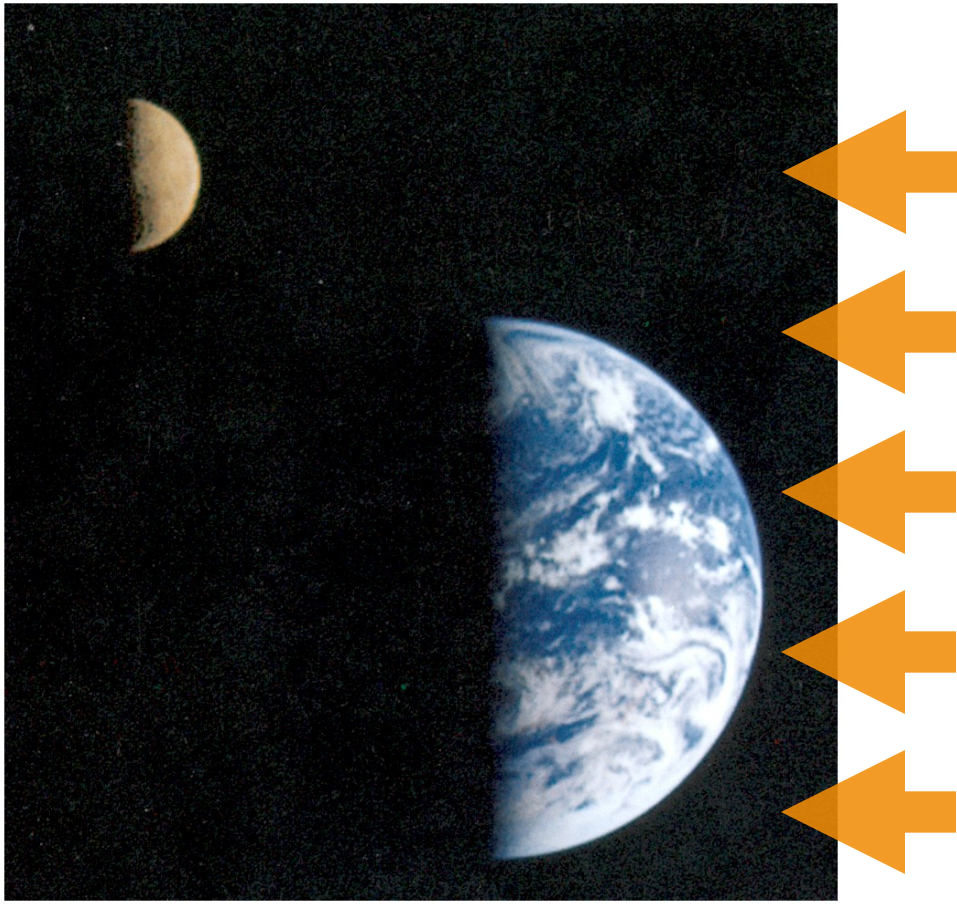
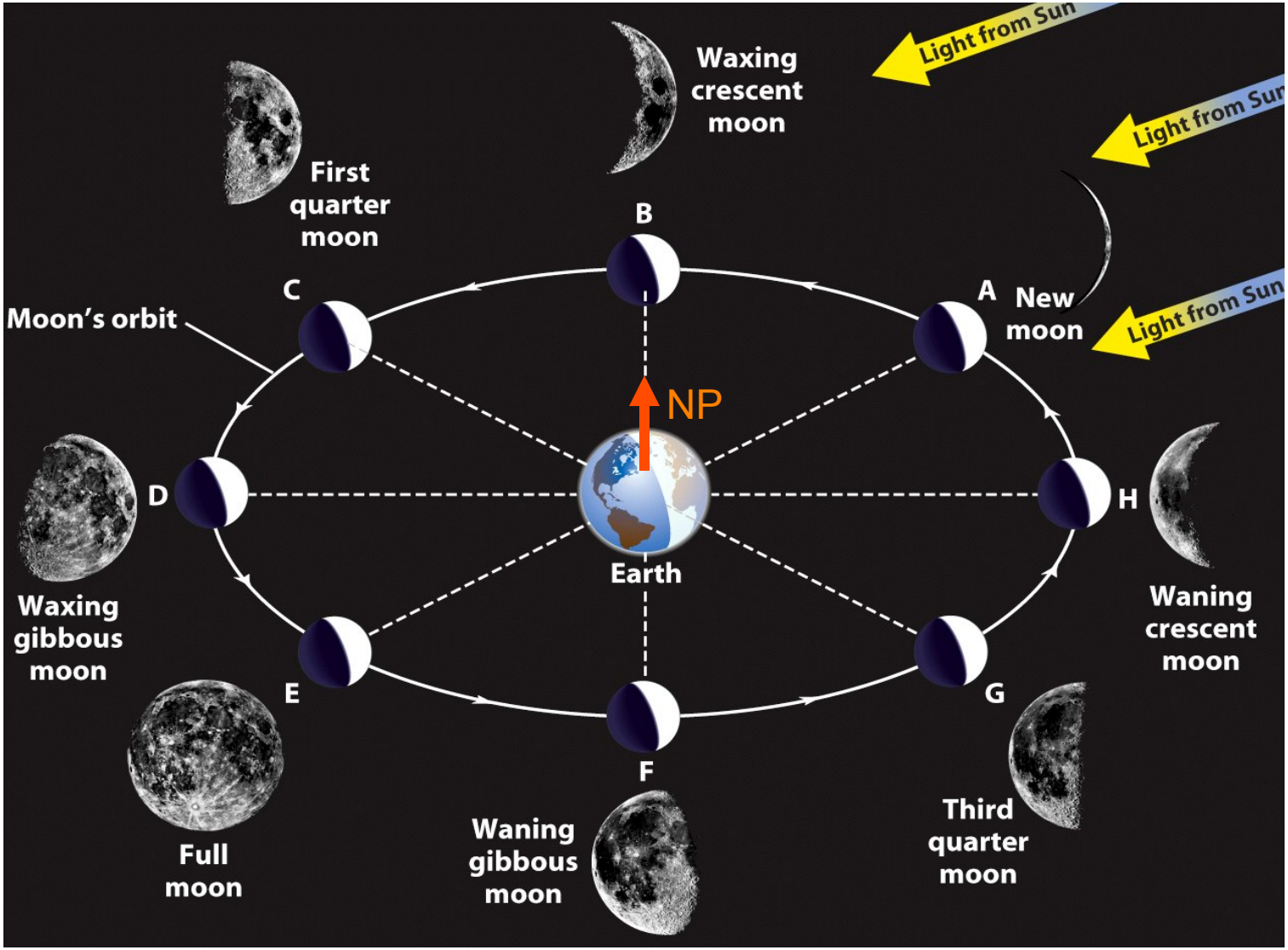


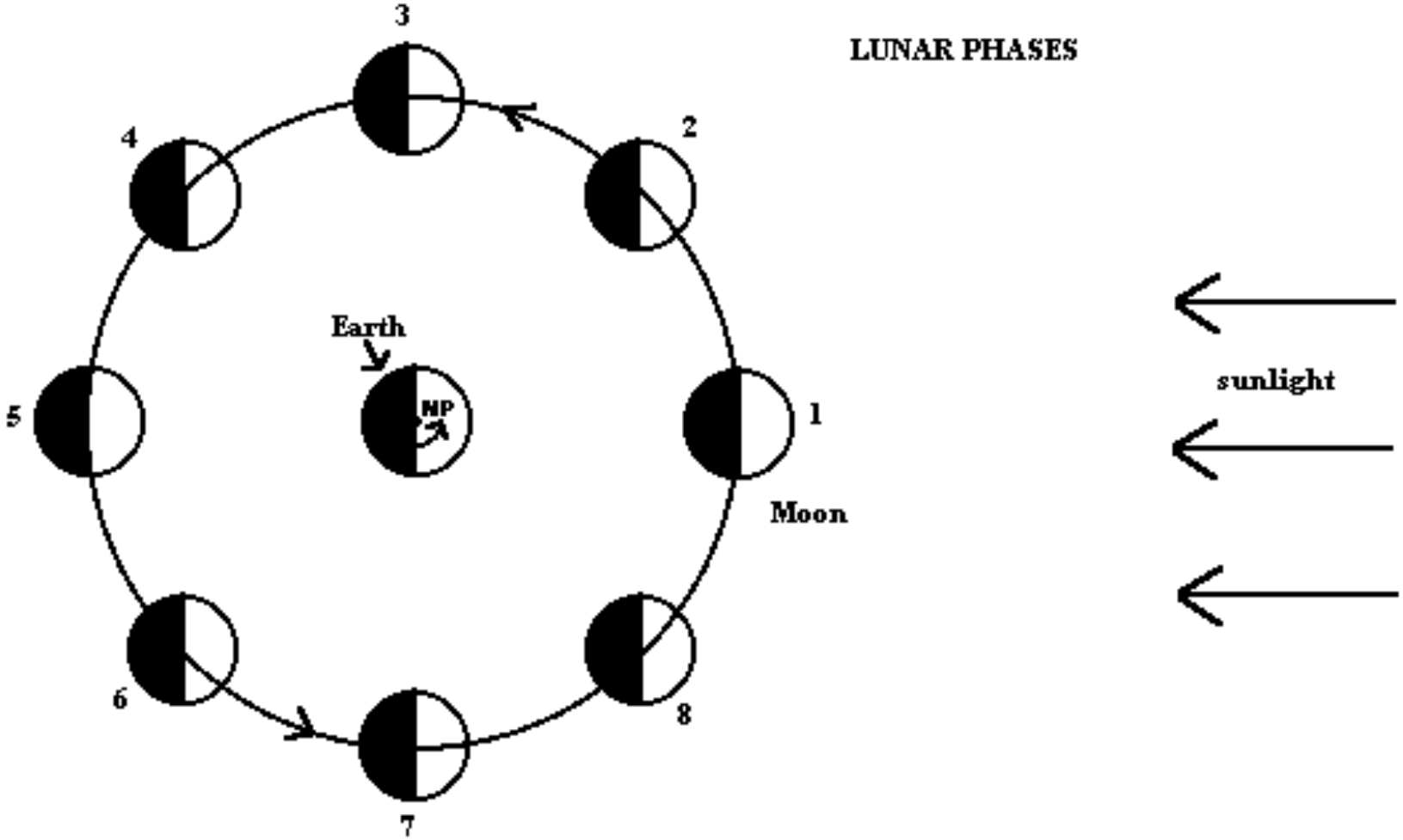
Photo of the Earth and the Moon by Galileo (NASA/JPL).

Caution: what "dark" means?

Why the Moon goes through phases?



LUNAR PHASES



1	2	3	4	5	6	7	8
New Moon	waxing Cresent	First Quarter	waxing Gibbous	Full Moon	waning Gibbous	Last Quarter	waning Cresent

Relative positions of Sun, Earth, and Moon determines the phase, as well as timing of sunrise and moon rise.

We can translate the difference in angular positions of Sun and Moon into lunar phase, into number of days in the phase cycle: (360^0 <=> 1 month), and into number of hours between sunrise and moon rise (360^0 <=> 24 hrs).

- New moon is at the same position as the Sun (0^0 apart). It rises and sets together with the Sun.
- Waxing moon rises <12 hrs after sunrise ($0\text{-}180^0$ apart), and is still up after sunset. (The first quarter moon is therefore the "evening moon".)
- Full moon rises 12 hrs (180^0) after sunrise, or at sunset.
- Waning moon rises >12 hrs ($>180^0$) after sunrise, i.e., after sunset. (The third quarter moon is the "morning moon", rising after midnight.)

Q: now let's switch positions: standing on the Moon, what's Earth's phase variation, or is there any?

new moon <==> full earth

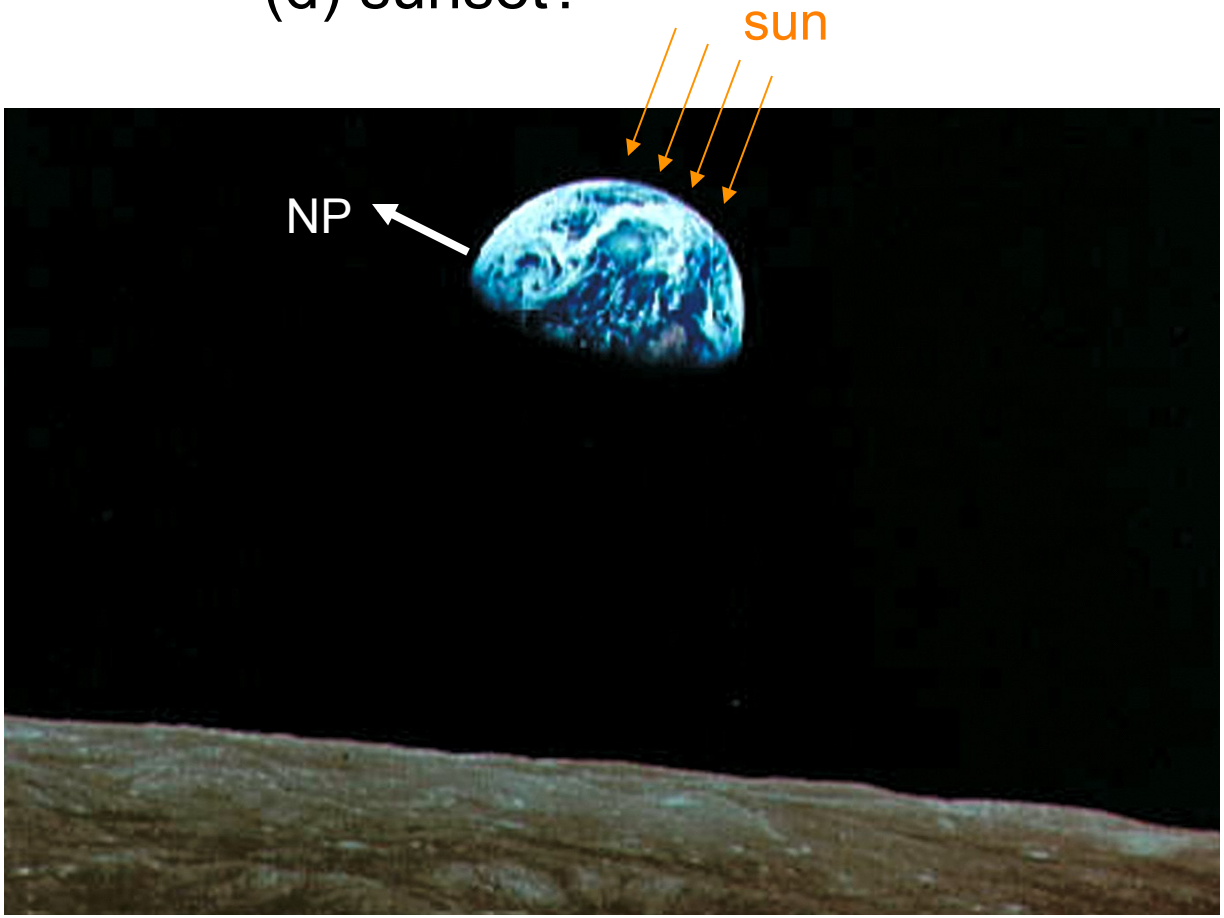
waxing moon

waning earth

full moon <==> new earth

Ex.4: What is the phase of the moon if it rises at

(a) midnight
(b) sunrise
(c) noon
(d) sunset?



Ex.5: When this photo was taken, was the Moon waxing or waning as seen from

Earth?

Q: in the case of new moon when the moon and the Sun are exactly 0^0 apart, what indeed will we see?

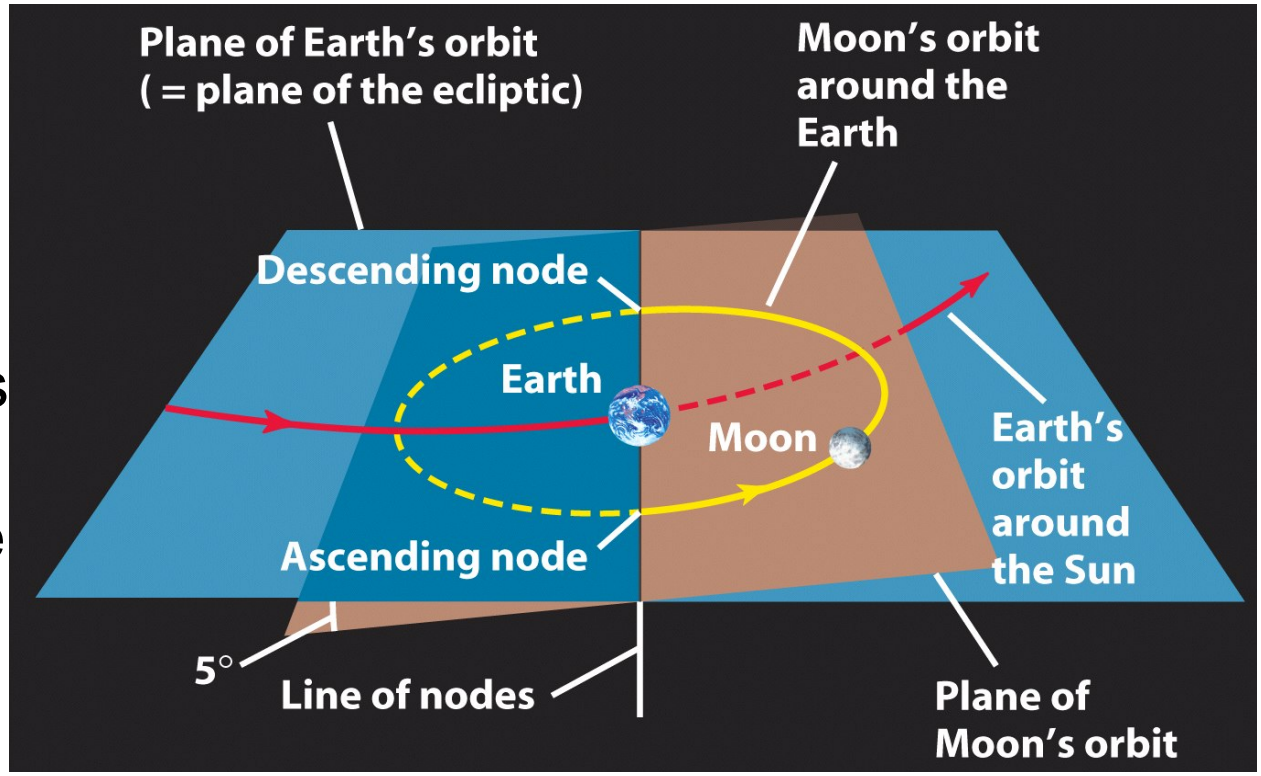
Q: in the case of full moon when the moon and the Sun are exactly 180^0 apart, what indeed will we see?

10.8 Eclipses

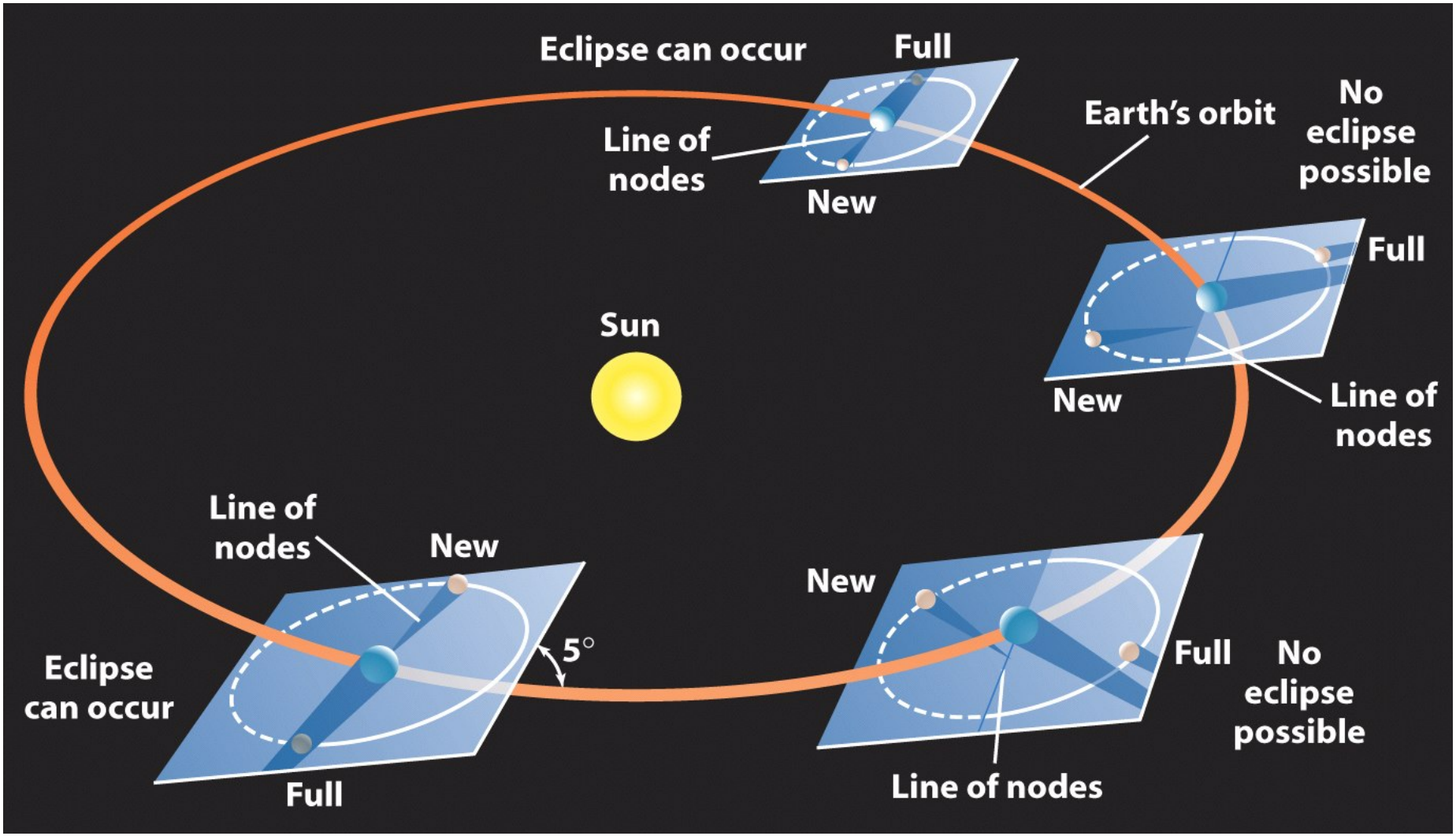
Eclipses occur only when the Sun, the Moon, and the Earth are on a straight line.

Lunar eclipse: Earth between Sun & Moon (full moon)
Solar eclipse: Moon between Sun & Earth (new moon)

We do NOT (!) see a lunar eclipse and a solar eclipse every month because the orbit of the earth and the orbit of the moon are NOT in the same plane.
The two planes cross each other at **nodes**. Both the Sun and the Moon have to be on the line of nodes for eclipses to occur.

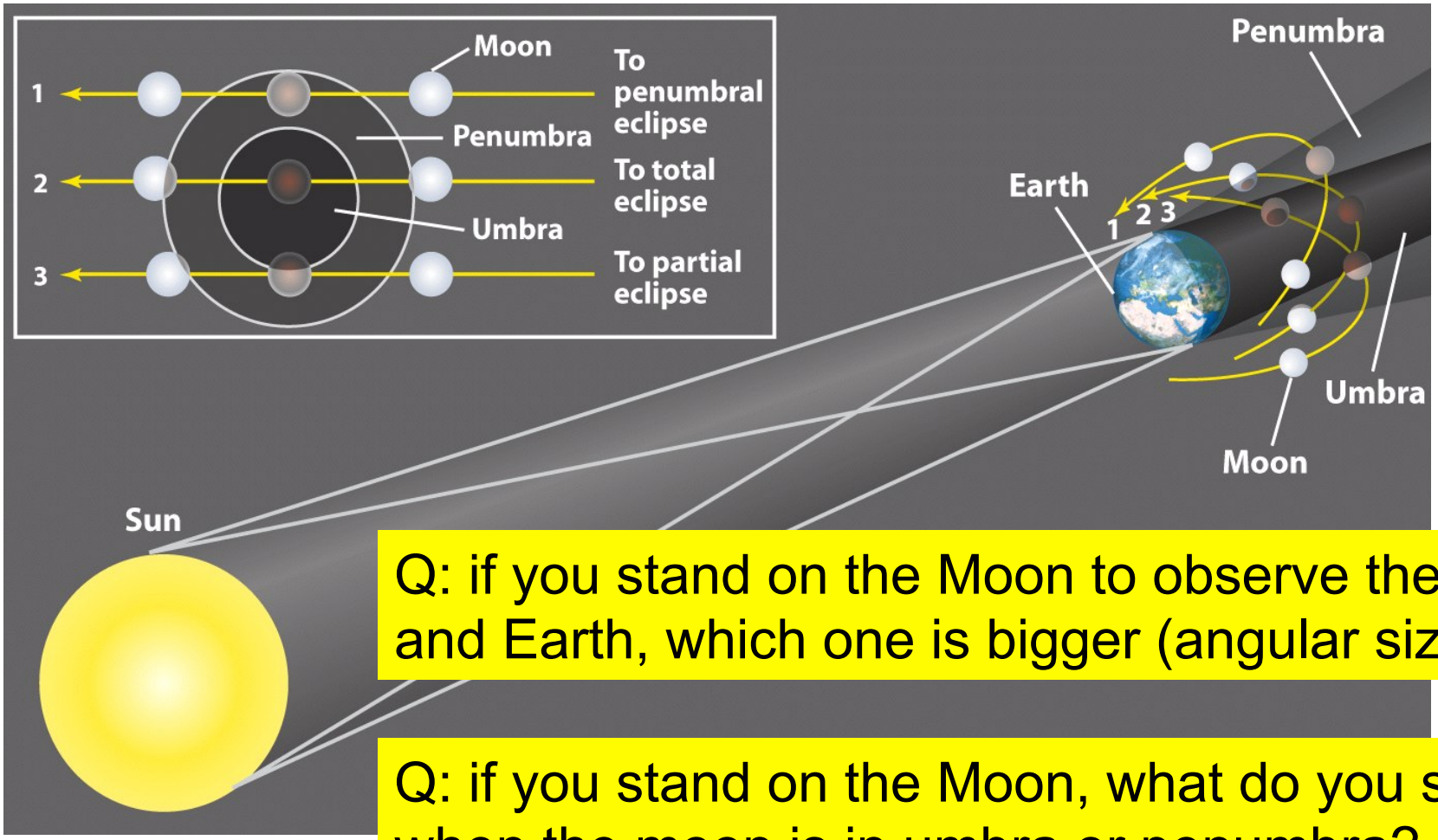


Geometry of Solar and Lunar eclipses



Note: The plane of the Moon's orbit is not fixed, so positions of possible eclipsed changes from year to year.

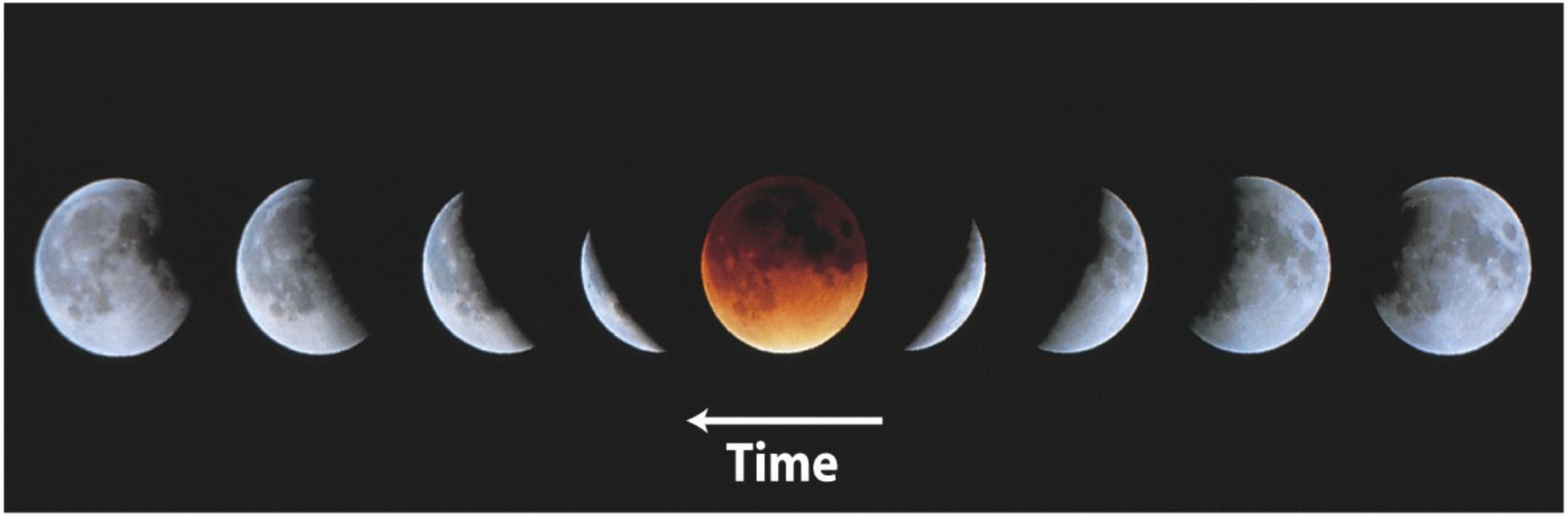
Lunar eclipses - shadow of the Earth - can be either total, partial, or penumbral, depending on the alignment of the Sun, Earth, and Moon.



Q: if you stand on the Moon to observe the Sun and Earth, which one is bigger (angular size)?

Q: if you stand on the Moon, what do you see when the moon is in umbra or penumbra?

Progress of a Lunar eclipse. The red glow is refracted red light from the earth's atmosphere, much like the red glow we see before sunrise and after sunset.



Ex.6: Observations of lunar eclipses, like above, led Ancient Greeks to thinking that the Earth is a sphere and not flat.

Recent and Future Lunar Eclipses

Lunar Eclipses, 2004-2008

Date	Type	Where visible	Duration of totality (h = hours, m = minutes)
2004 May 4	Total	South America, Europe, Africa, Asia, Australia	1h 16m
2004 October 28	Total	Americas, Europe, Africa, central Asia	1h 21m
2005 April 24	Penumbral	Eastern Asia, Australia, Pacific, Americas	—
2005 October 17	Partial	Asia, Australia, Pacific, North America	—
2006 March 14	Penumbral	Americas, Europe, Africa, Asia	—
2006 September 7	Partial	Europe, Africa, Asia, Australia	—
2007 March 3	Total	Americas, Europe, Africa, Asia	1h 14m
2007 August 28	Total	Eastern Asia, Australia, Pacific, Americas	1h 31m
2008 February 21	Total	Central Pacific, Americas, Europe, Africa	51m
2008 August 16	Partial	South America, Europe, Africa, Asia, Australia	—

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

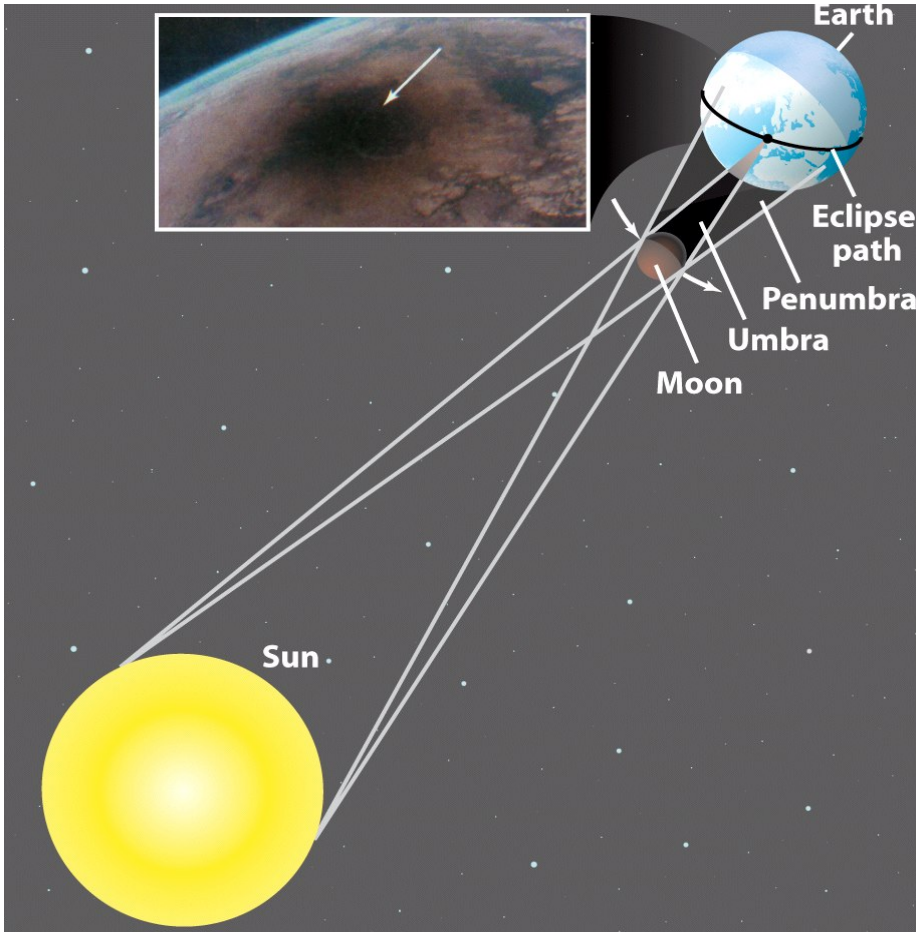
http://eclipse.gsfc.nasa.gov/LEdecade/LEdecade2011.html

Q: from this Table, how often do lunar eclipses occur? Why?

Solar eclipses can be either total, partial, or annular, depending on the alignment of the Sun, Earth, and Moon

Solar eclipses only visible if along the path of totality. If within moon's penumbra then a partial eclipse will occur.

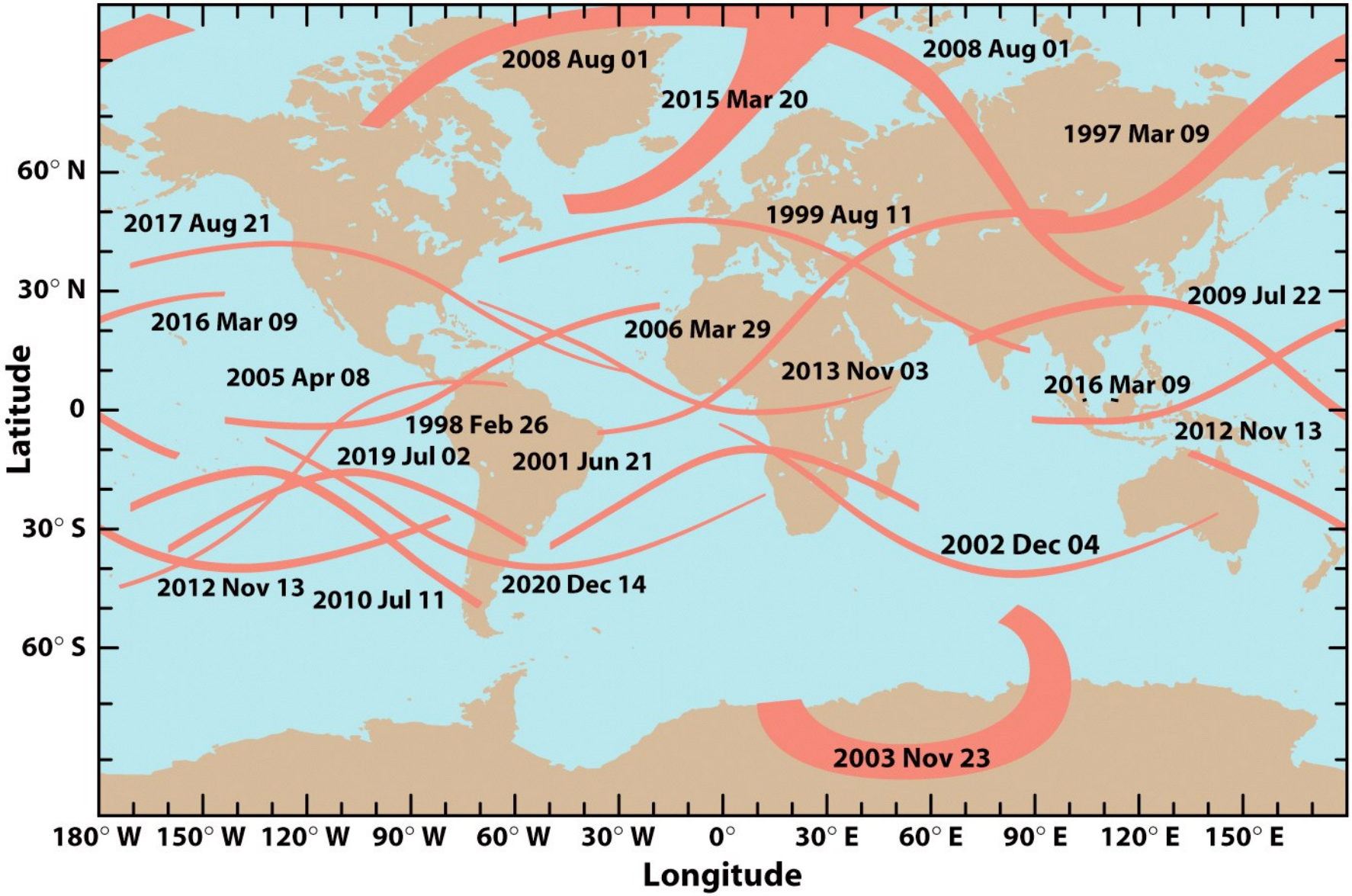
An annular eclipse occurs when the moon is near **apogee**, so that the moon is slightly smaller than the sun in the sky.



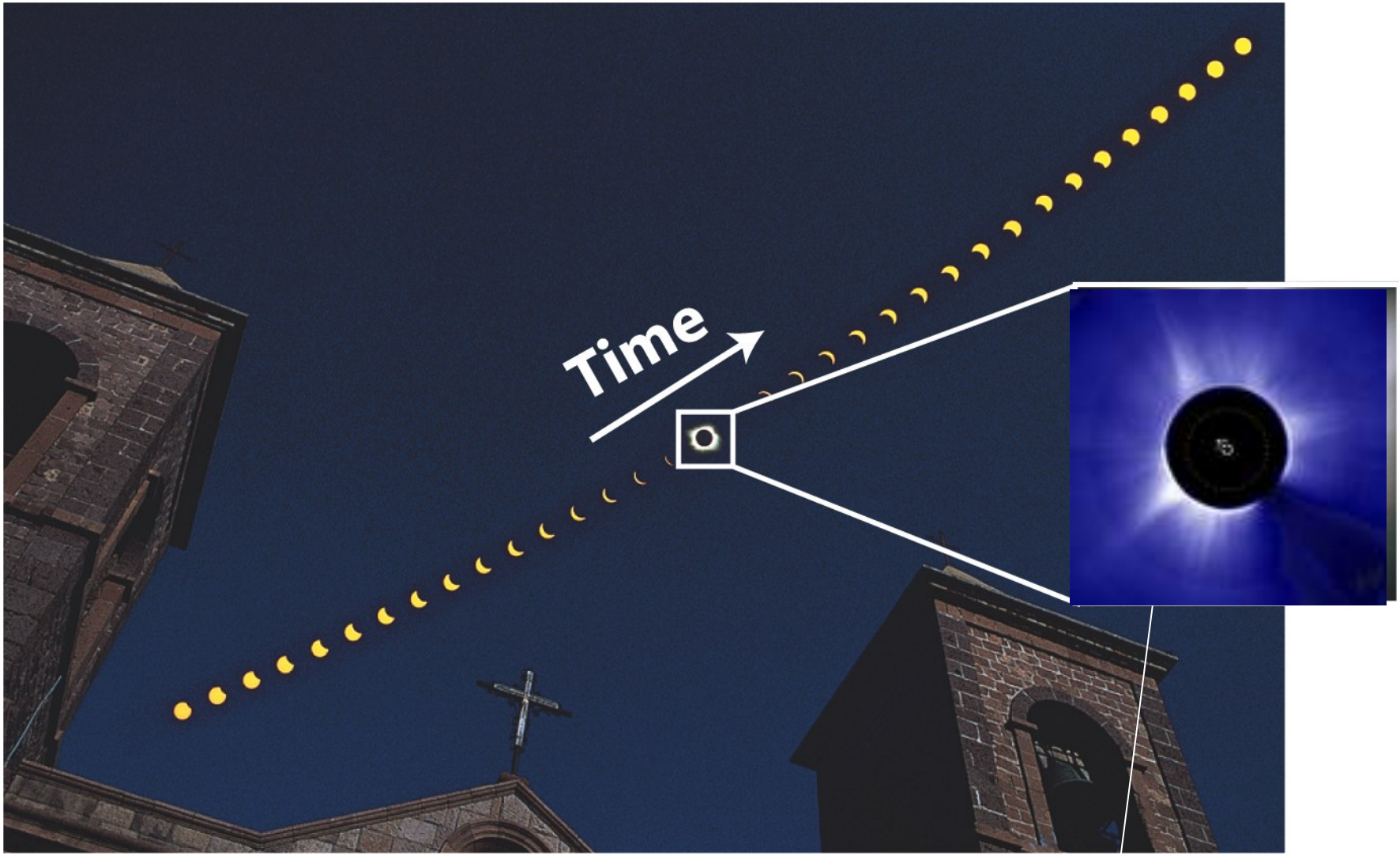
Ex.7: revisit the small-angle formula and the apparent size of the Sun and the Moon.

Q: how to find the size of the area on earth to see the total solar eclipse? How to calculate the duration of the total eclipse – what are the factors to take into account?

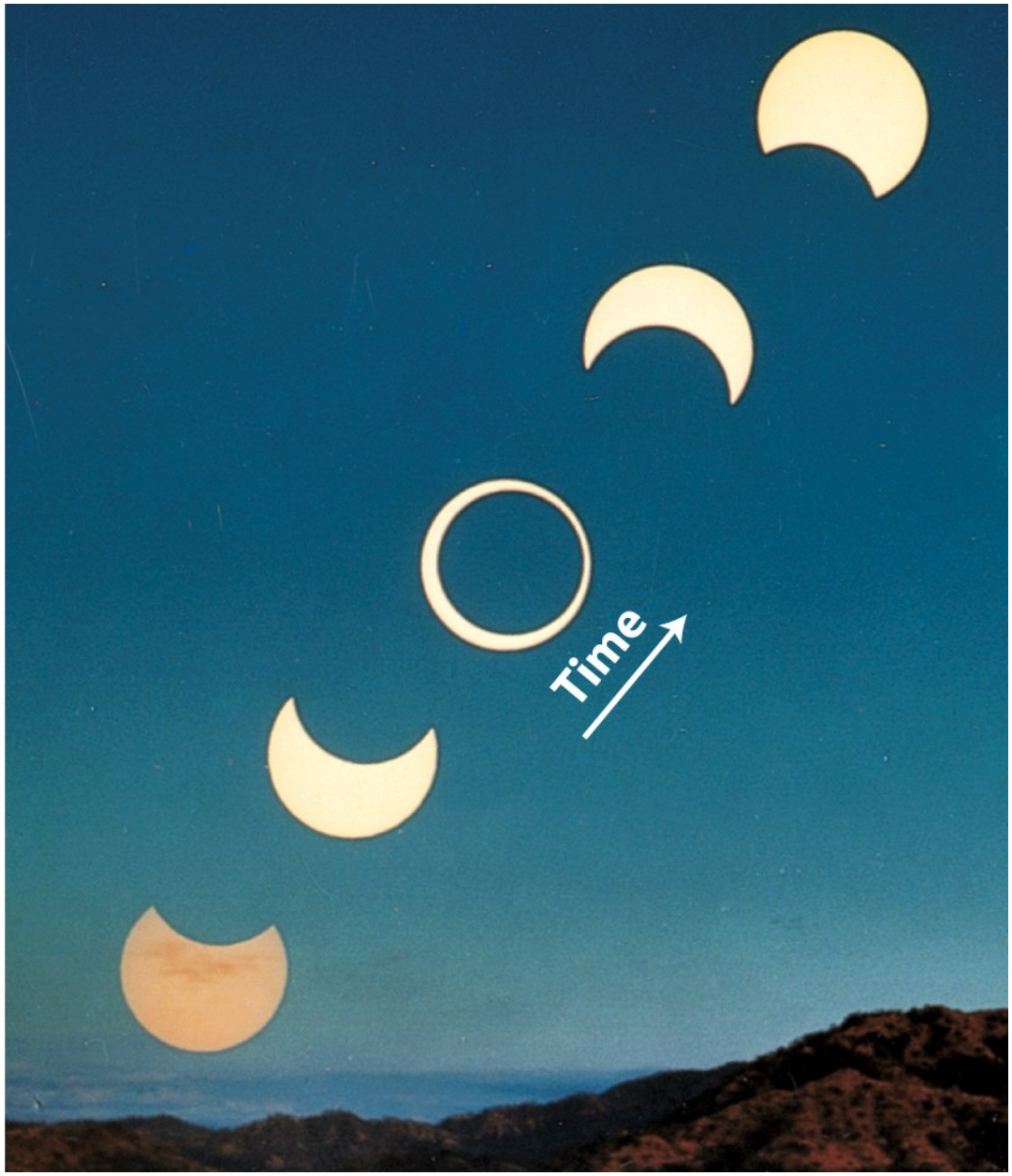
Paths of total solar eclipses in recent and future years.



A Total Solar Eclipse



The Sun's corona: a natural coronagraph



An annular solar eclipse is so called

Q: what would be the chance to find an annular eclipse if the Moon were farther, closer, larger, smaller than it is now?

moon is further away from the earth

Q: why do we never see annular lunar eclipse?

Recent and Future Solar Eclipses

Solar Eclipses, 2004–2008

Date	Type	Where visible	Notes
2004 April 19	Partial	Antarctica, southern Africa	74% eclipsed
2004 October 14	Partial	Northeast Asia, Hawaii, Alaska	93% eclipsed
2005 April 8	Annular and Total	New Zealand, North and South America	Annular along part of path; maximum duration of totality 0m 42s
2005 October 3	Annular	Europe, Africa, southern Asia	—
2006 March 29	Total	Africa, Europe, western Asia	Maximum duration of totality 4m 7s
2006 September 22	Annular	South America, western Africa, Antarctica	—
2007 March 19	Partial	Asia, Alaska	87% eclipsed
2007 September 11	Partial	South America, Antarctica	75% eclipsed
2008 February 7	Annular	Antarctica, eastern Australia, New Zealand	—
2008 August 1	Total	Northeast North America, Europe, Asia	Maximum duration of totality 2m 27s

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

http://eclipse.gsfc.nasa.gov/SEdecade/SEdecade2011.html

Q: from this Table, how often do solar eclipses occur? Why?

Q: suppose you observed a lunar eclipse on the evening of August 28. When will you likely see a solar eclipse?

on August 29?

3 days later?

7 days later?

14 days later?

Solar eclipses take place at new moon.
Lunar eclipses take place at full moon.

Key Words

- crater
- far side (of the Moon)
- full moon
- highlands
- libration
- line of nodes
- lunar eclipse
- lunar phases
- mare (*plural* maria)
- moonquake
- new moon
- quarter moon
- regolith
- synchronous rotation
- solar eclipse
- synchronous rotation
- terminator
- tidal force
- waning moon
- waxing moon

summary

- The Moon has no liquid water, no atmosphere, no plate tectonics, no global magnetic field. Meteoroids impacts have been the only weathering on the Moon.
- The Moon's rotation is synchronous with its orbital motion.
- The moon's surface is covered by light-colored and heavily cratered highlands and dark-colored maria with fewer craters, formed from impact of large debris and filled with lava flow. The far side of the Moon has almost no maria.
- The Moon has a thick crust, very thick mantle, and a small iron core. Moonquakes are caused by the Earth's tidal force.
- Lunar phase is caused by the orbital motion of the moon and the subsequent variation in the relative positions of the Sun, the Moon, and the Earth.
- The lunar orbit and the earth orbit are not in the same plane. Solar and lunar eclipses take place when the Sun and the Moon are both on the line of nodes.
- Lunar eclipses take place at full moon, and are visible from half the earth. Solar eclipses occur at new moon, and are visible only at certain locations on the earth.

Moon over Antarctica, James Behrens (IGPP, Scripps Institution of Oceanography)