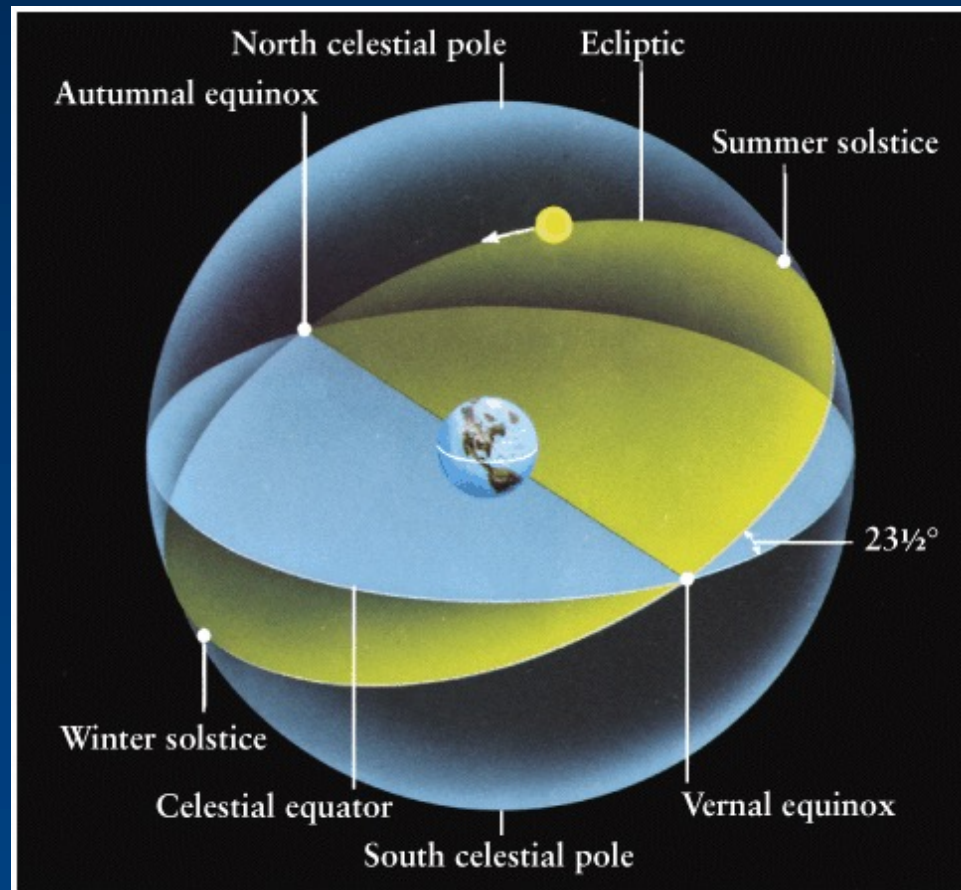
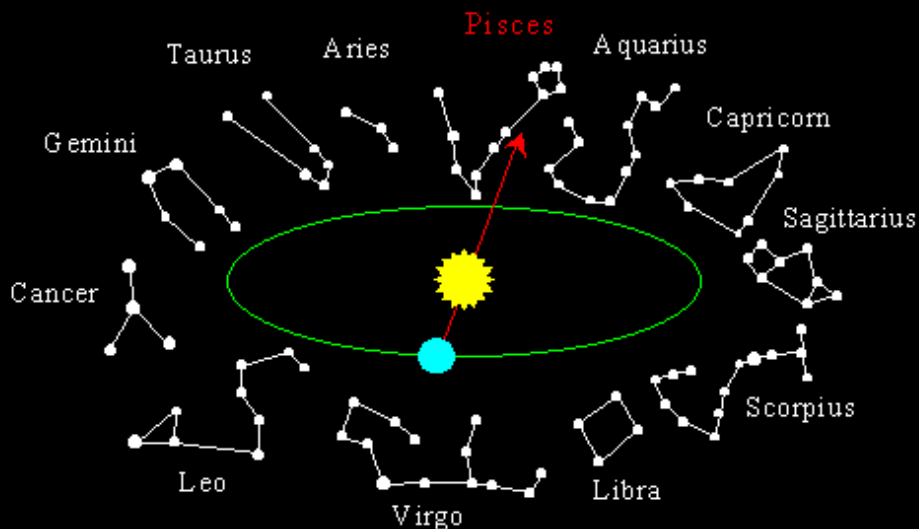


# The Zodiac

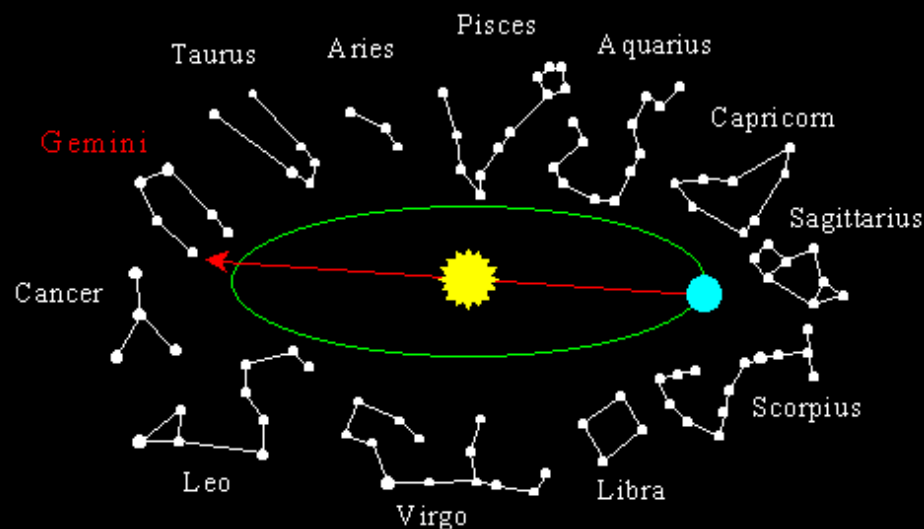
- As the Sun moves along the Ecliptic it passes through 12 constellations known as the *Zodiac*



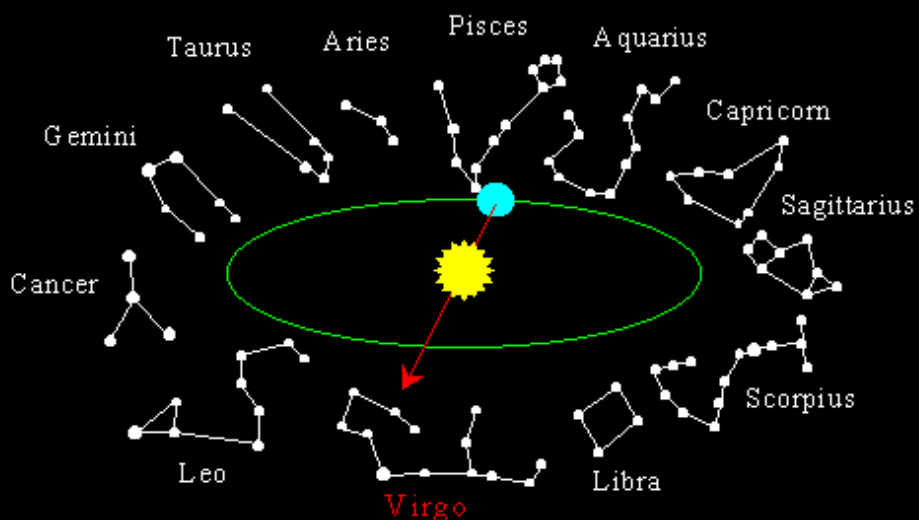
### March 2000: Sun in Pisces



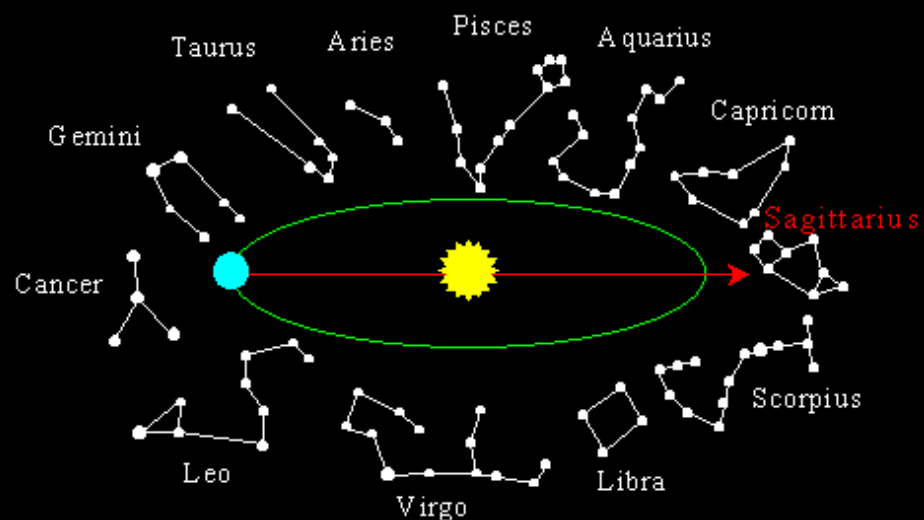
### June 2000: Sun in Gemini



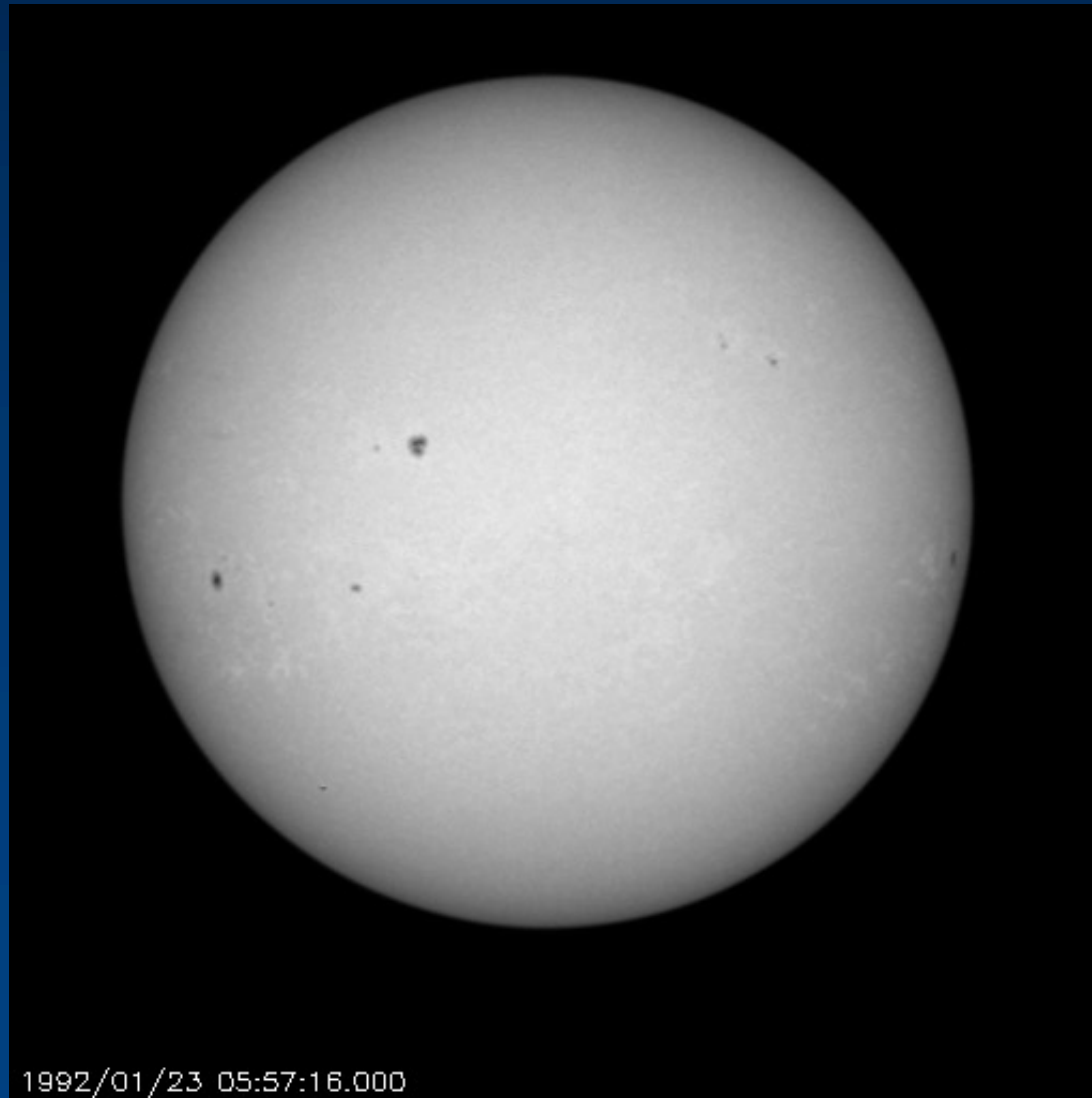
### September 2000: Sun in Virgo



### December 2000: Sun in Sagittarius

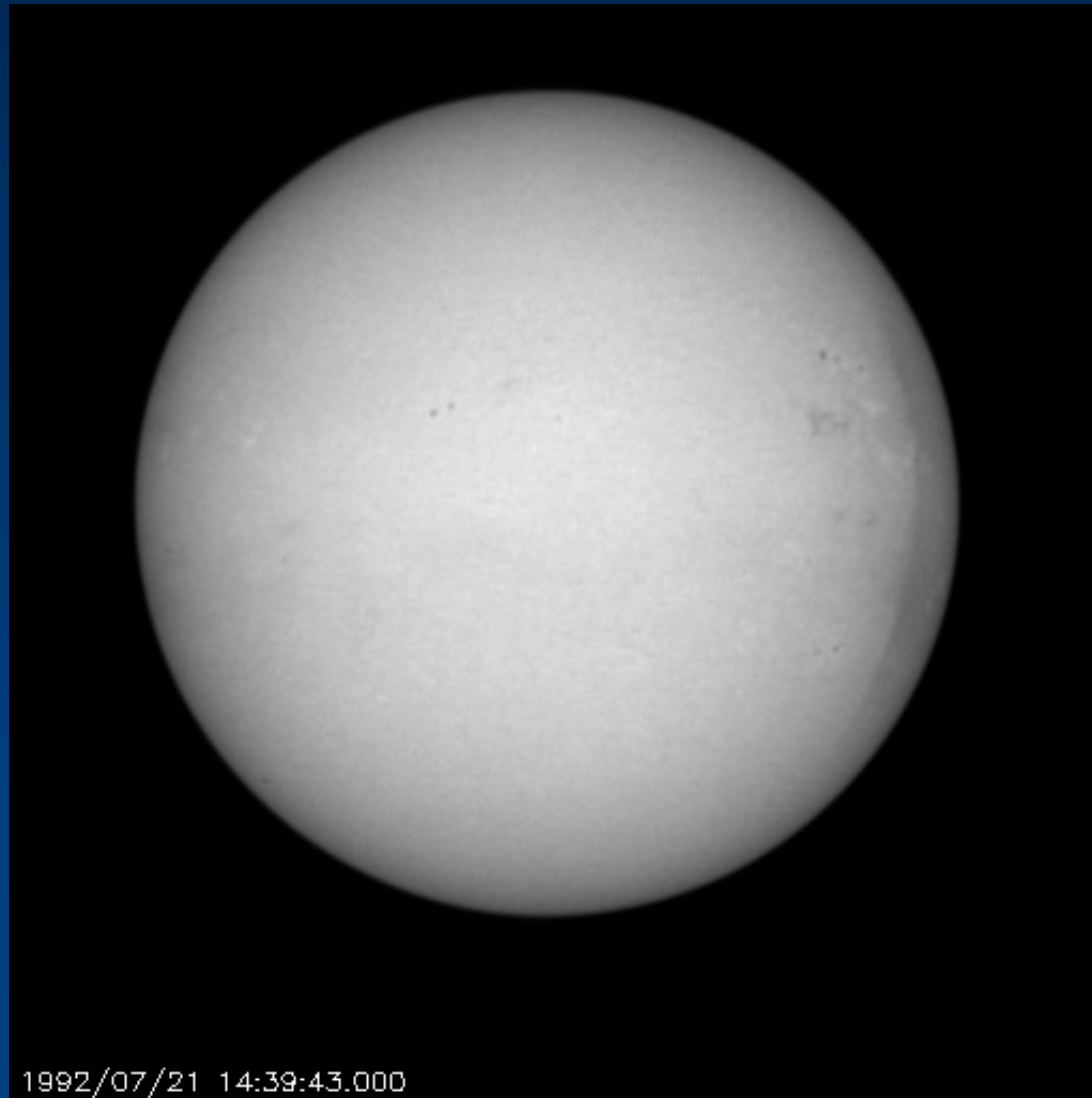


# The Sun in January



1992/01/23 05:57:16.000

# The Sun in July



# Announcements

- **Homework 2 is due on Thursday (2/1/2024) by 11am printed out and delivered in class**

- **Remember help is available for the homework:**

**TA office hours (all in PAIS lobby):**

**Wednesday 1-2pm : Dustin Edgeman**

**Wednesday 3-4pm : Evan David**

**Thursday 9:30-10:30am: Rachel Weller**

# Dimensional Analysis or (is your answer in the right units?)

Suppose John has 2 gallons of gas in his truck which gets 15 mpg and the next station is 50 km away.

Can he make it?

Note: 1 mile = 1.61 km

# Phases, Motions of the Moon and Eclipses



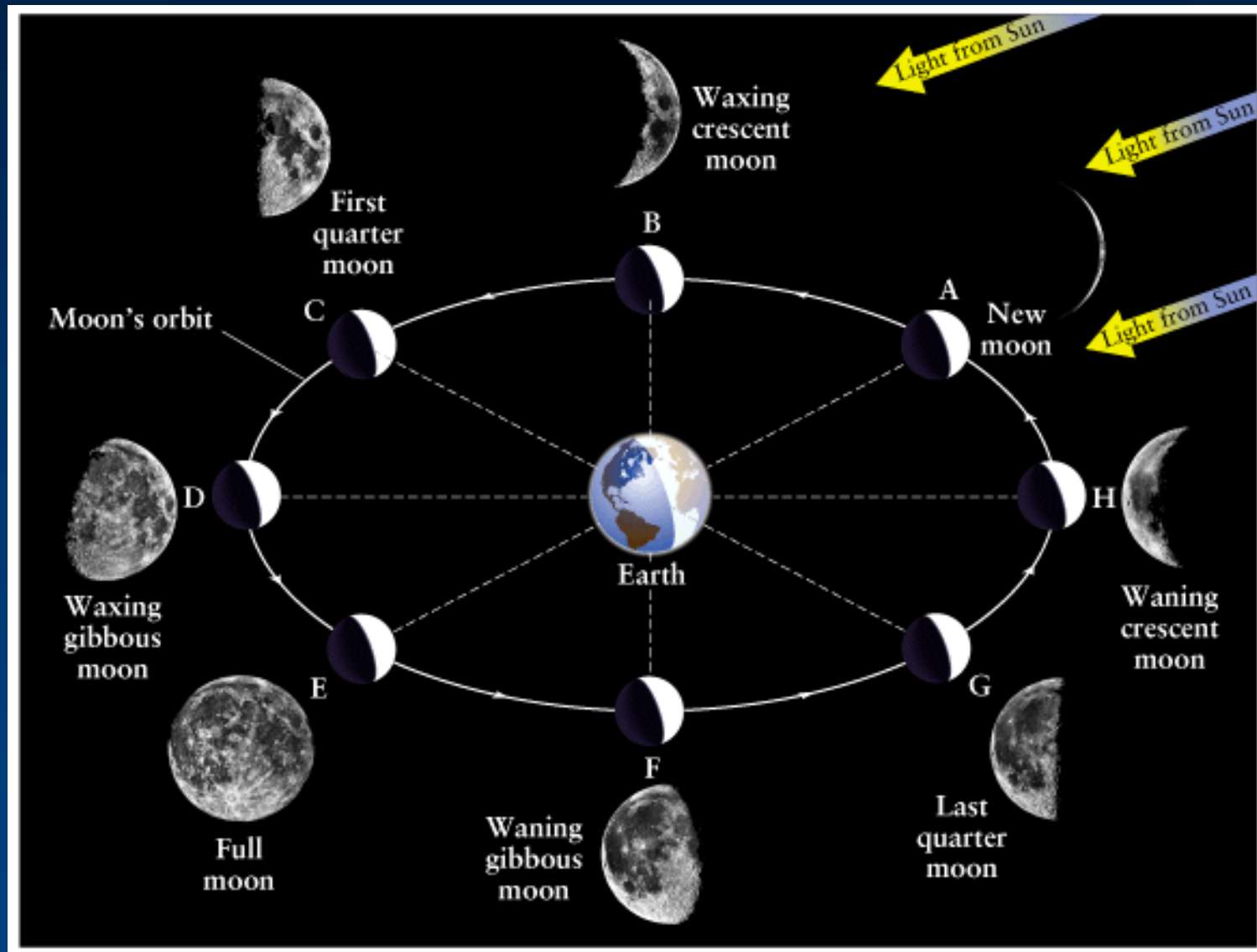
# The Moon

- The Moon's appearance changes significantly over the period of a "month" (to be carefully defined later)
- Shines by reflected sunlight. What we see depends on geometry of the Earth-Moon-Sun system.
- The different appearances of the Moon are called lunar phases.
- What phase is the Moon today?





Half of the Moon is always illuminated, it's just not necessarily the half we can see.



This cycle of phases takes about 29 1/2 days.

- "Waxing" means "increasing"
- "Waning" means "decreasing"
- "Gibbous" means "swollen"
  
- Note: a first, or last quarter Moon appears half illuminated, not  $\frac{1}{4}$  illuminated. The "quarter" refers to how far along in the cycle of phases it is.
  
- Historical comment: the curved shape of lunar phases indicated to Aristotle (c. 350 B.C.) that the Moon must be a sphere!

This picture is of a rising full Moon.

Questions: Where is the Sun? Is it rising or setting?



Sunrise

Moonset

Noon  Midnight 

Sunset

Moonrise

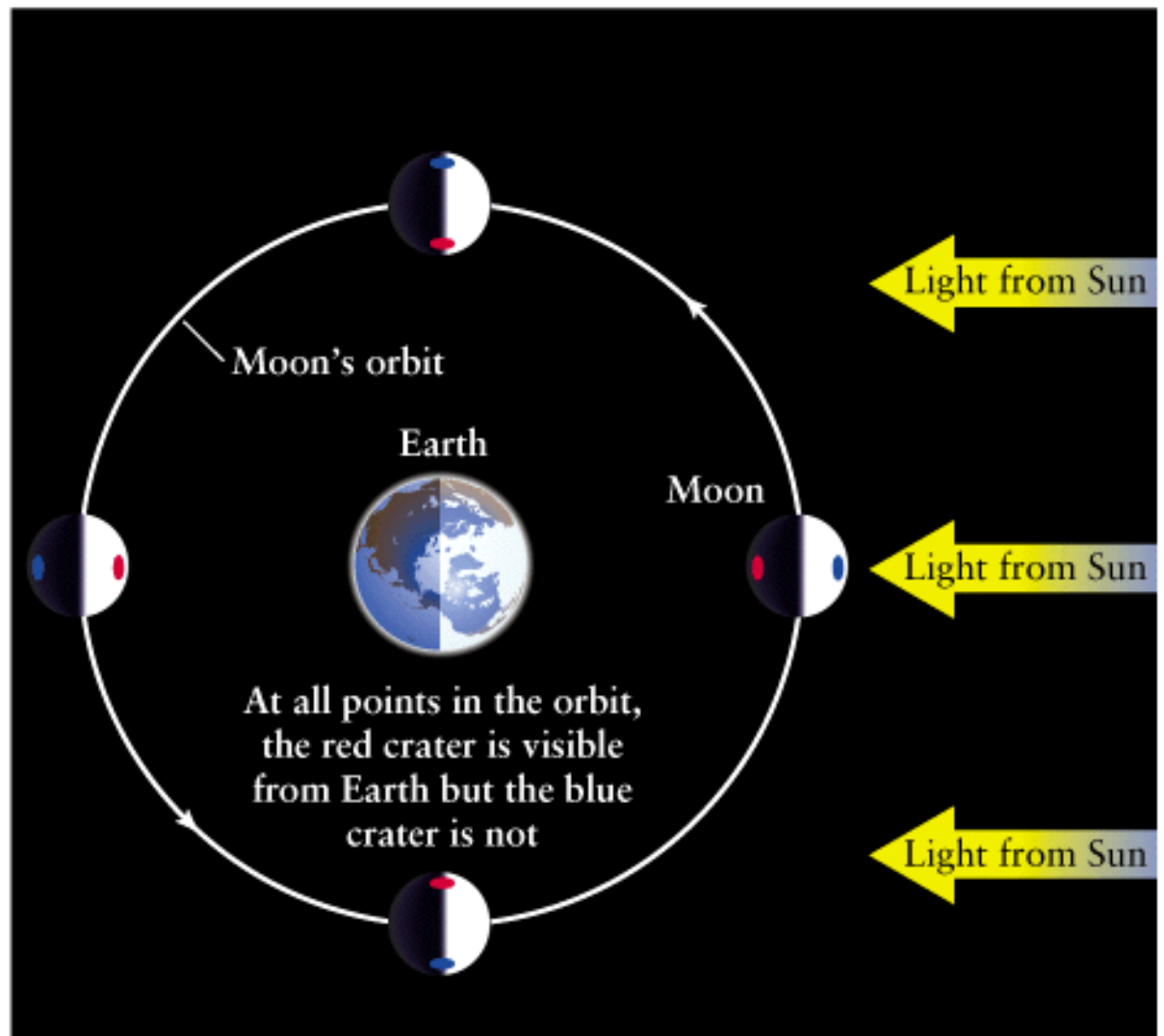
**Notice the lunar features in common for different phases: we always see the same (physical) face of the moon, but different fractions are sunlit during different phases**



The Moon rotates in exactly the same time it makes one orbit around the Earth.

Rotation and revolution are **synchronous**.

This is very common behavior in the Solar System, called "**synchronous rotation**", or "**tidal locking**". We'll talk about this more when we talk about tidal force.



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

The **near side** is the hemisphere facing toward us, and the **far side** is the hemisphere facing away from us.

There isn't a permanent **dark side** of the moon

- “Libration” We’re seeing a bit more than one hemisphere because: Moon’s equator isn’t exactly in plane of orbit, and orbit isn’t exactly circular.

(Moon’s size does not depend on its phase)



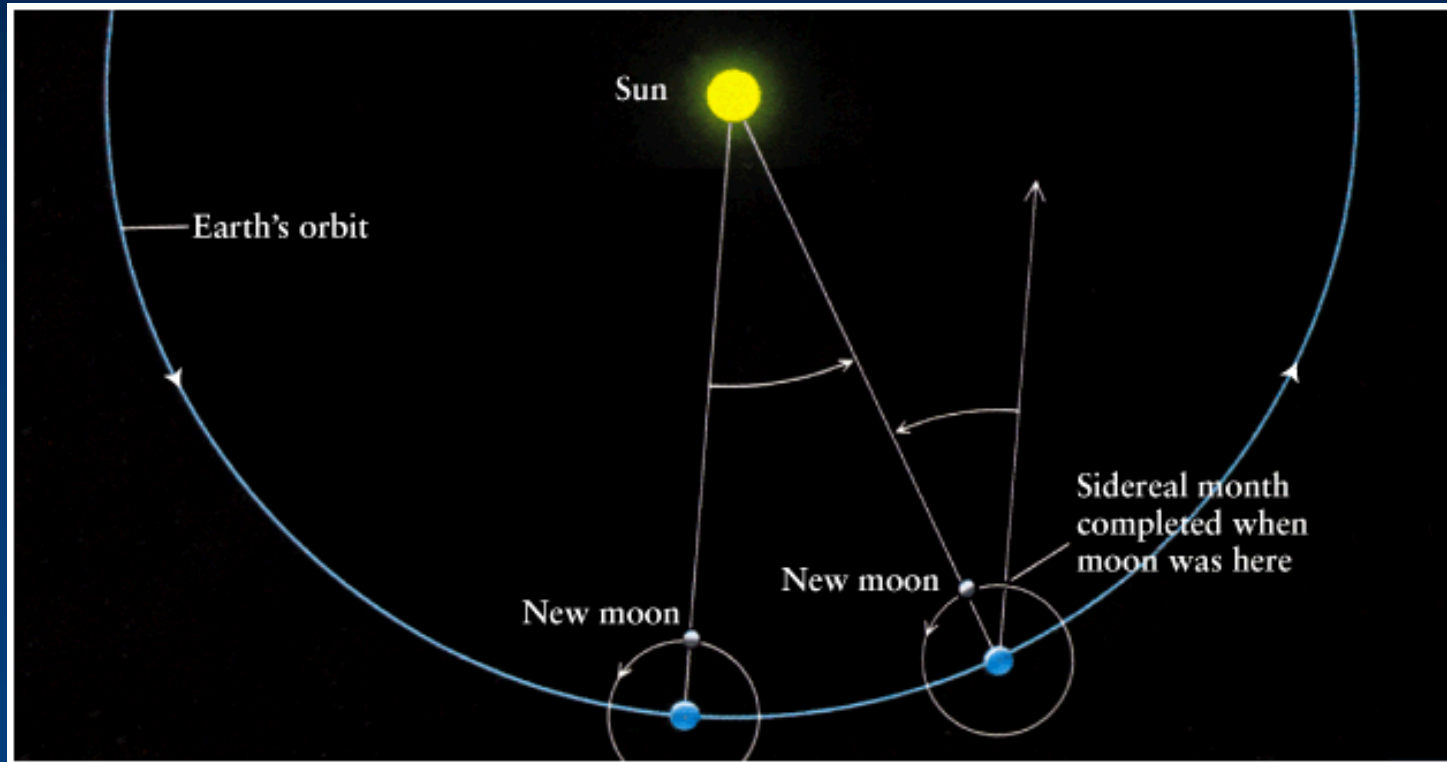
# The "Month"

There are actually three kinds of "months":

1. The *sidereal month* is the length of time it takes the Moon to orbit the Earth with respect to the background stars. It is about 27.32 days, and is the true orbital period.

("Period" always refers to a length of time.)

2. The *synodic month*, or *lunar month* is the time it takes the Moon to complete one cycle of phases, about 29.53 days. Note this is longer than a sidereal month.



3. The months in our calendar are neither of these! Varying lengths, averaging longer than sidereal or synodic.

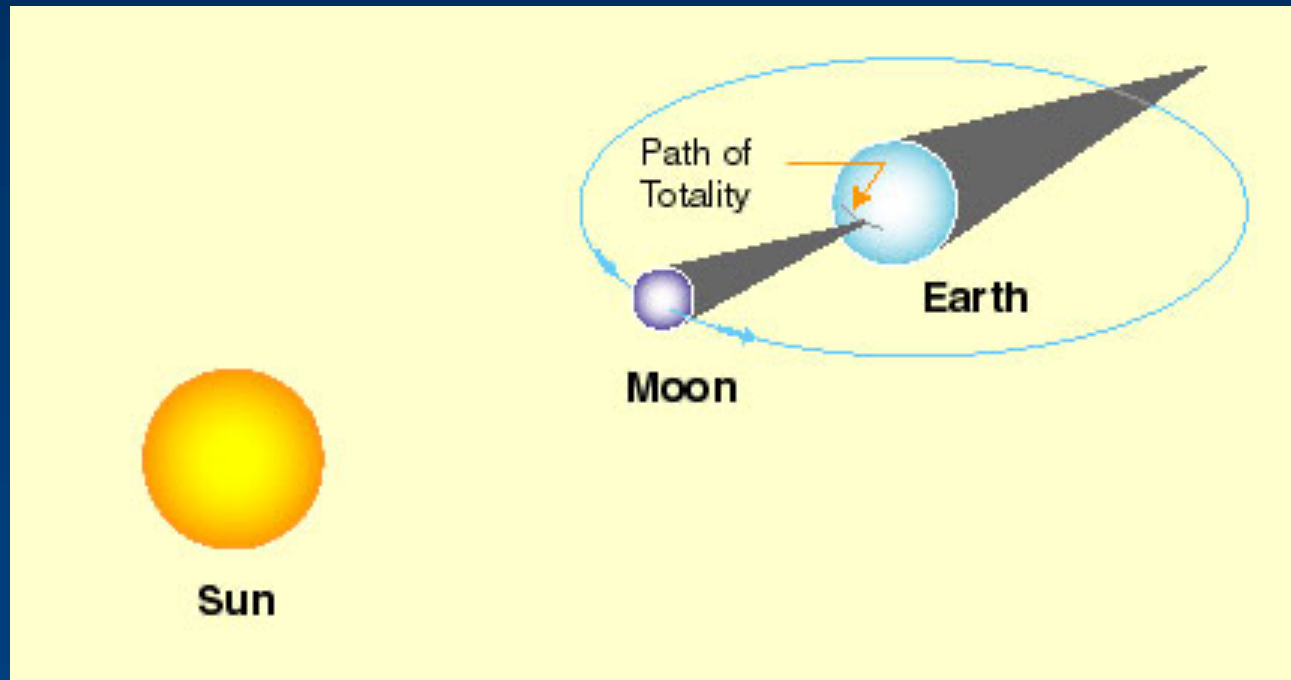


# Eclipses

- Lunar eclipse
- Solar eclipse

# Solar eclipses

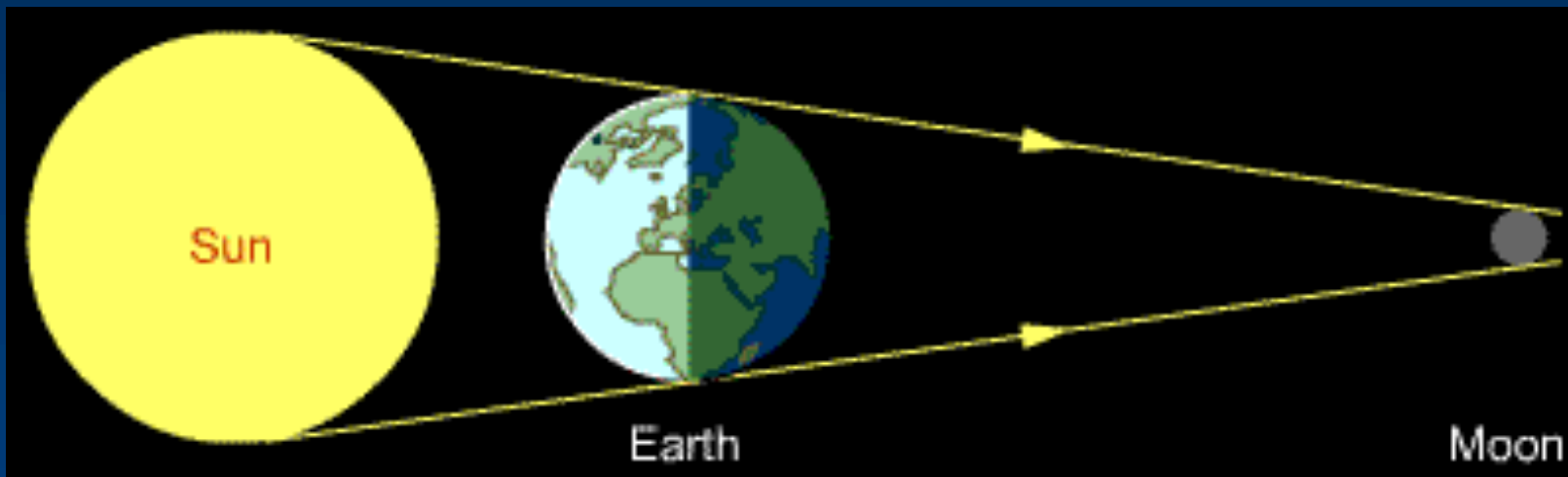
*A solar eclipse is seen if the Earth is passing through the shadow of the Moon.*



**The whole Earth does not fit in the shadow of the Moon.**

# Lunar eclipses

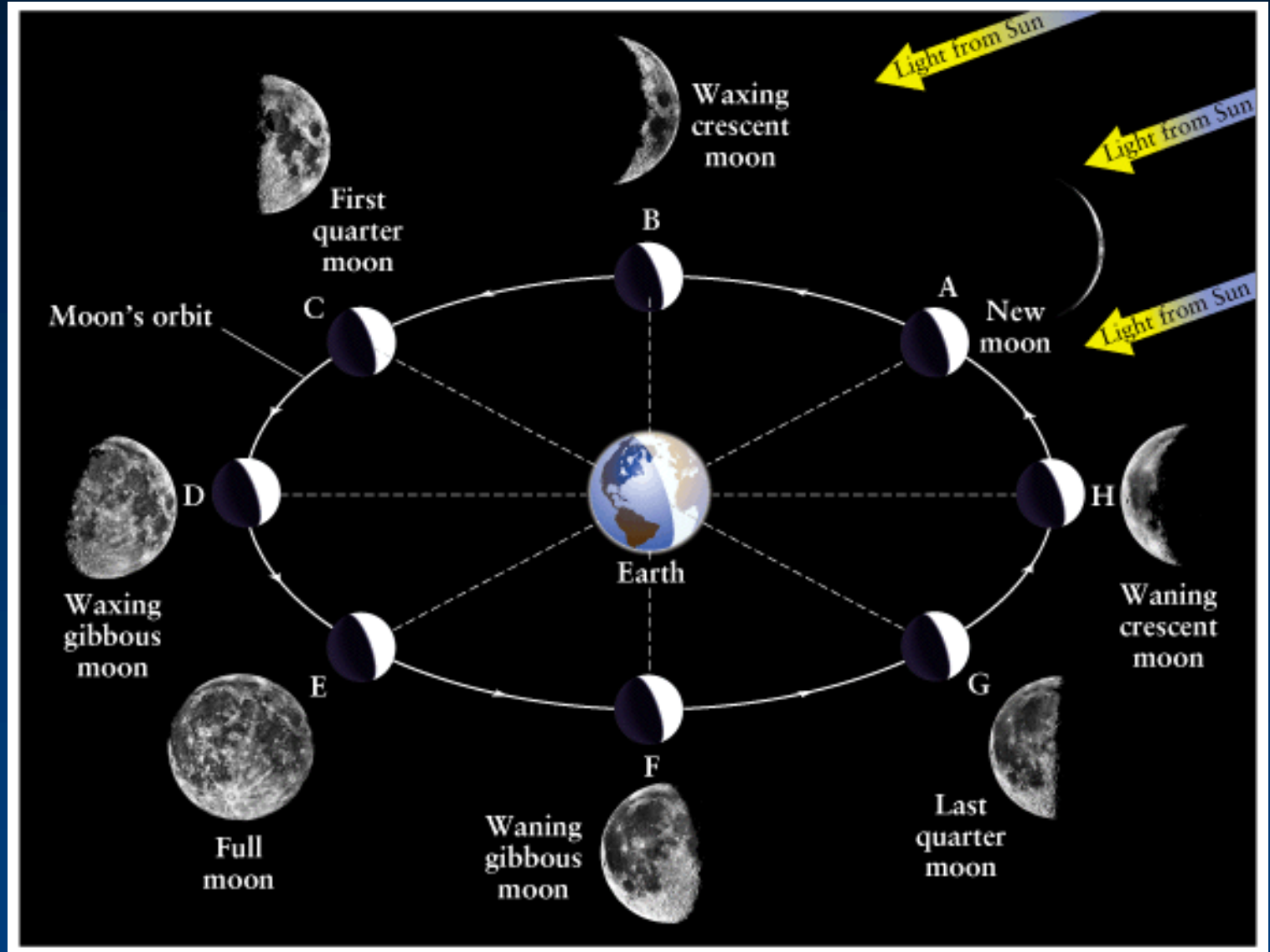
A *lunar eclipse* is seen if the Moon is passing through the shadow of the Earth.



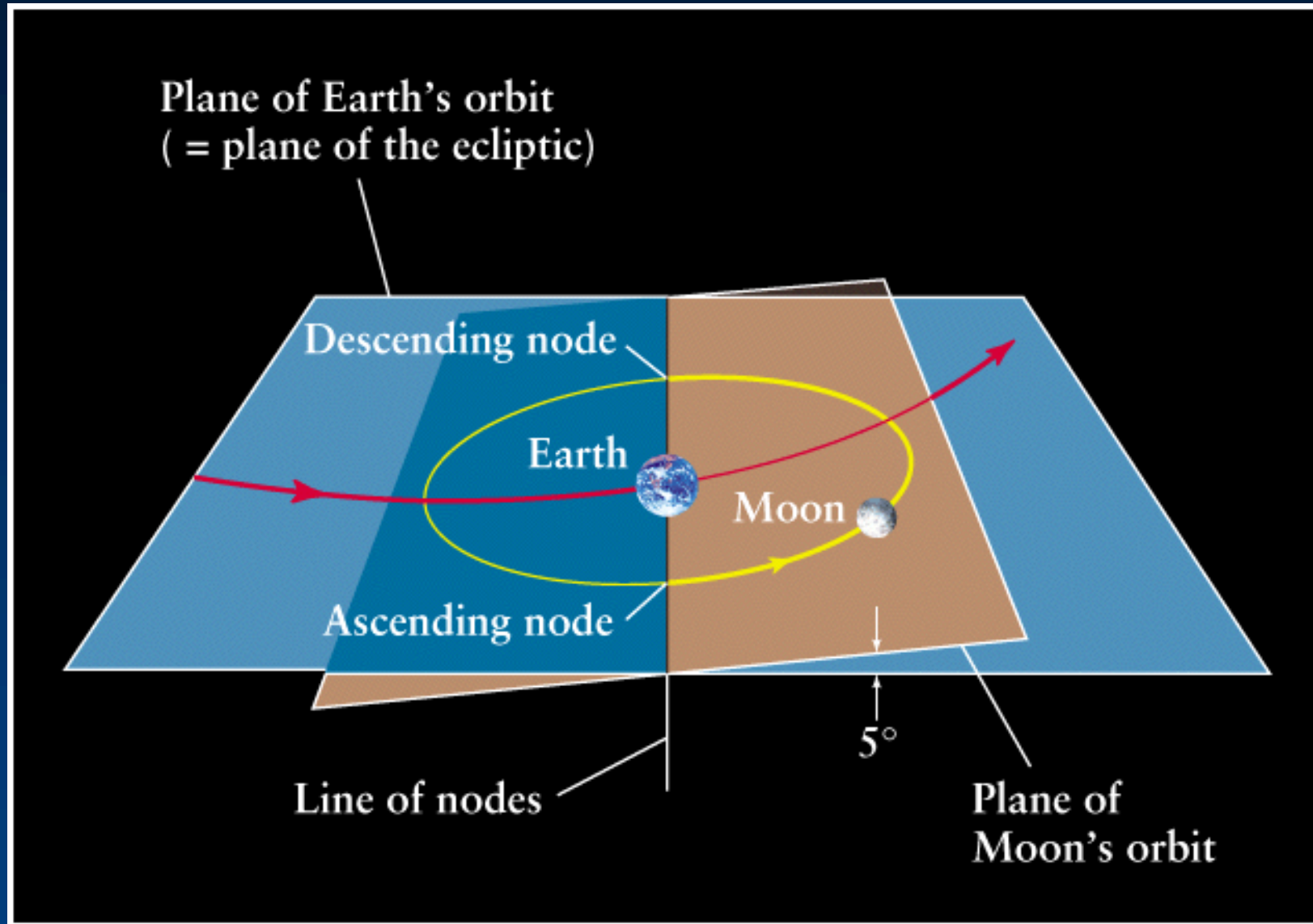
Geometrically, corresponds to a full Moon.



**Why don't we see an eclipse with every full Moon?**

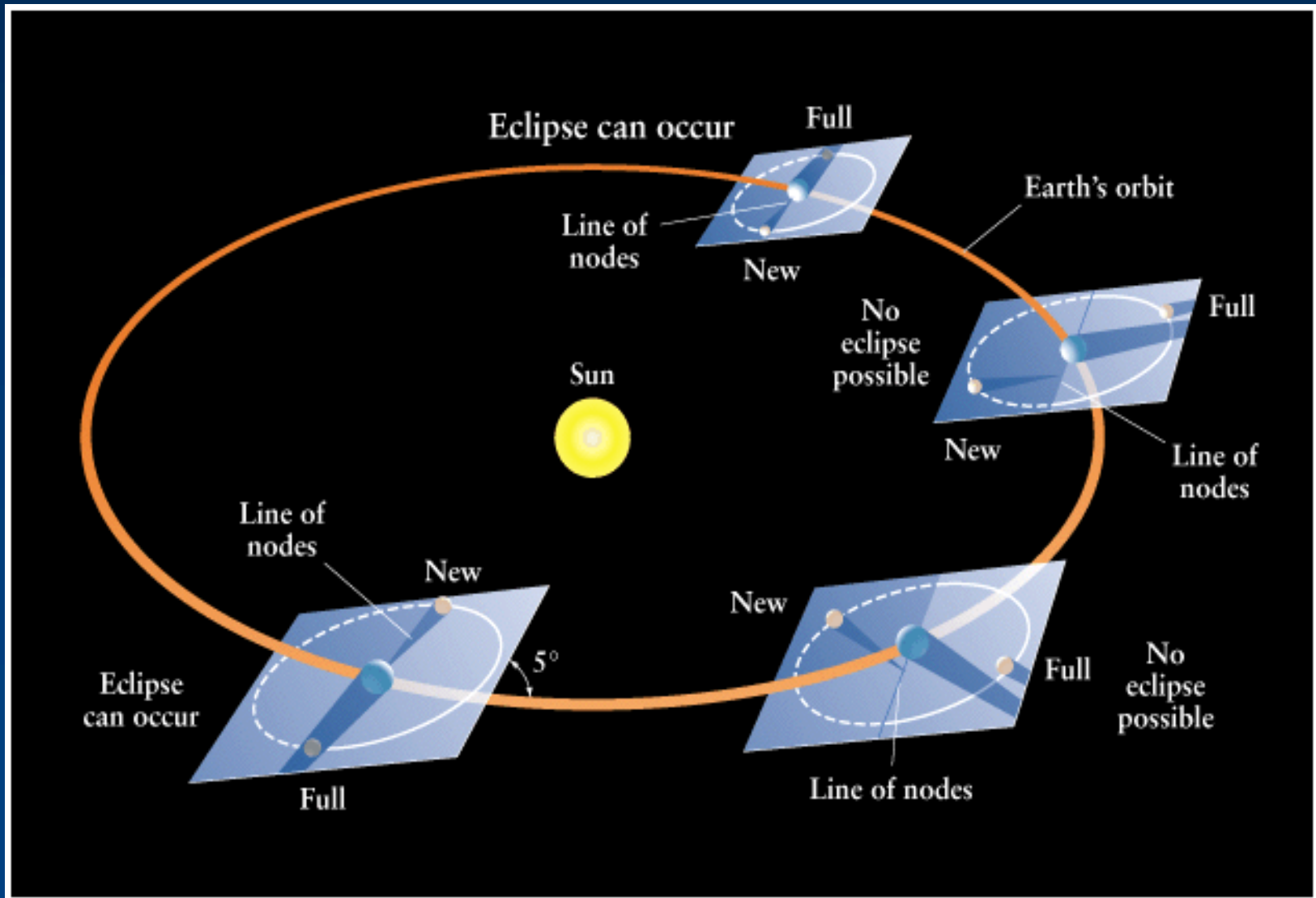


**=> Because the plane of the Moon's orbit around the Earth is not exactly in the plane of the Earth's orbit around the Sun.**



Plane of Moon's orbit is tilted about  $5^\circ$  to ecliptic.  
Intersection of the two planes is the "line of nodes".

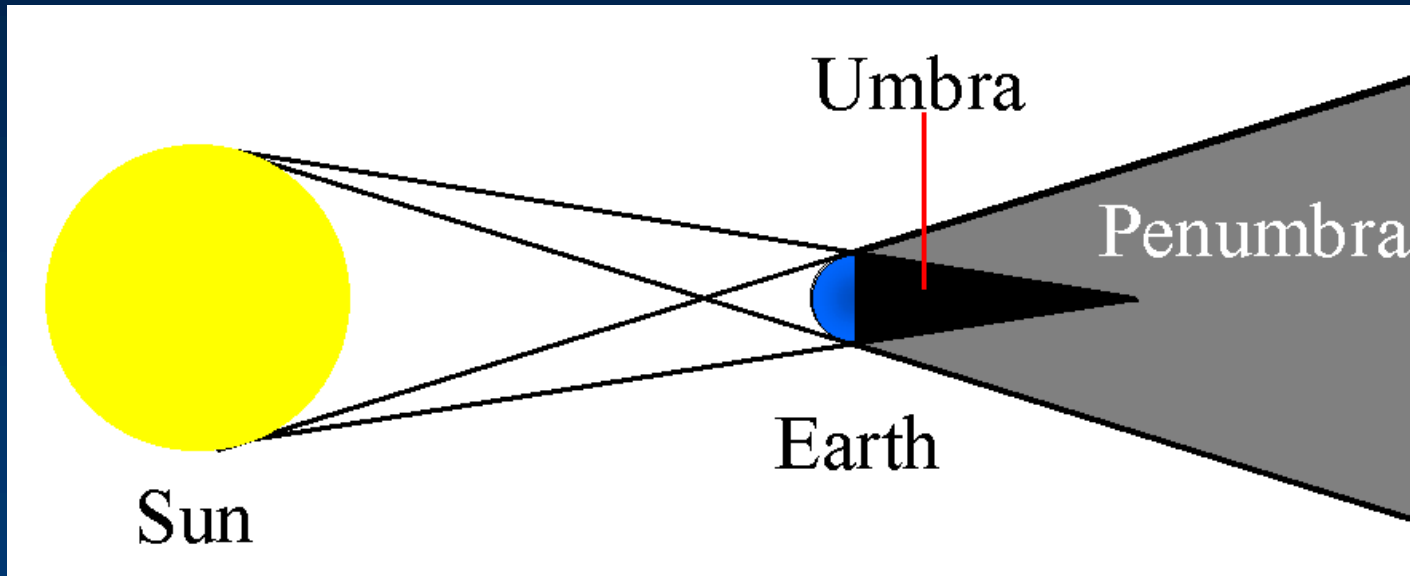
Only when the Sun and Moon are on the line of nodes is an eclipse possible. In order for an eclipse to occur, the Moon must be in the same plane as the Sun – the ecliptic!



# Types of lunar eclipses

- Lunar eclipses can be *total*, *partial*, or *penumbral*, depending on the Earth – Moon – Sun geometry.
- The Earth's shadow has two parts:
  - The **umbra** is the darkest part, where the Sun is completely blocked.
  - The **penumbra** is not as dark, since some of the Sun's light gets by.

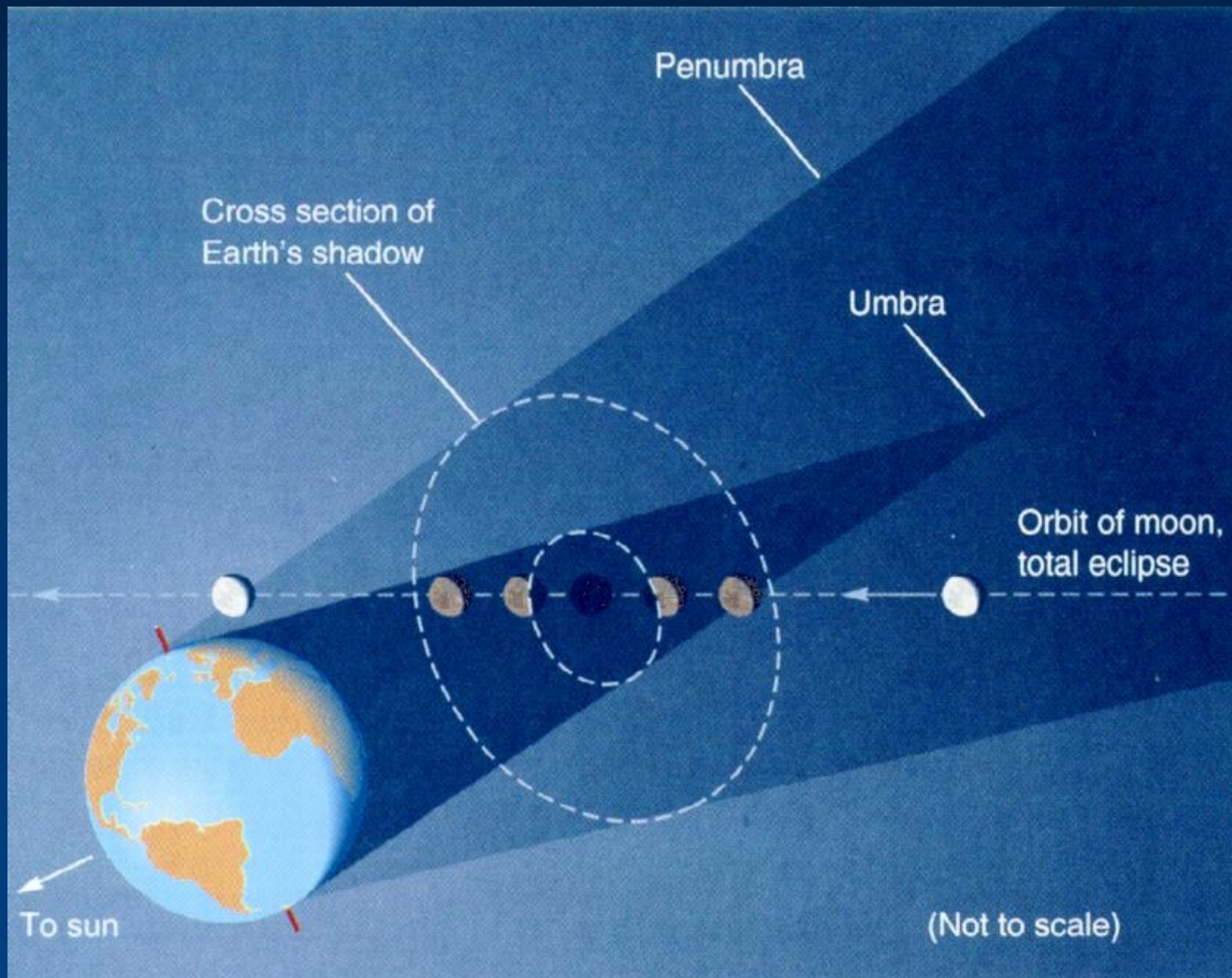
# Umbra and Penumbra



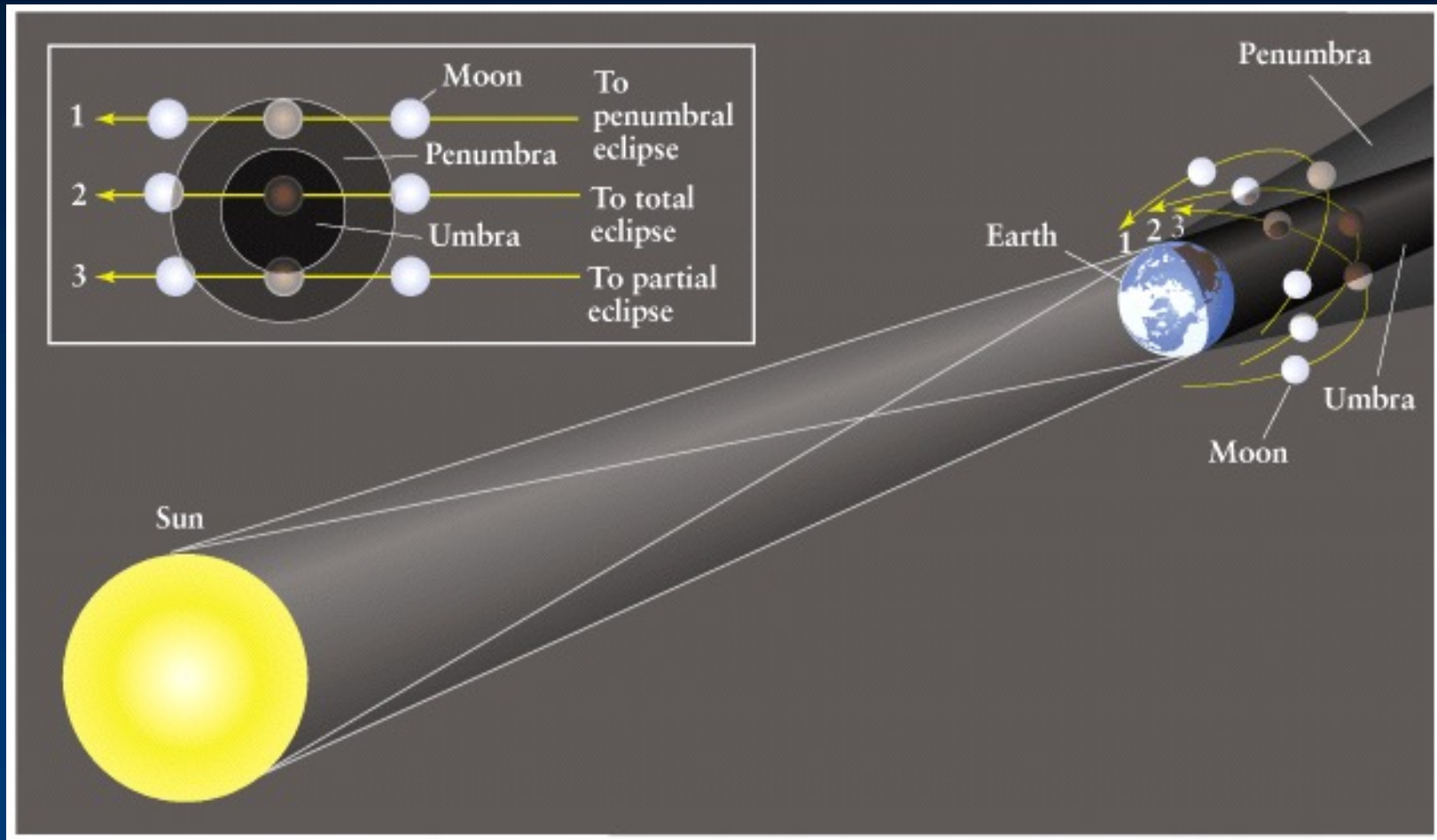
- Umbra: the disk of the Sun is completely blocked.
- Penumbra: the disk of the Sun is only partially blocked.



# Lunar eclipses



Note Earth's umbra extends far beyond Moon's orbit



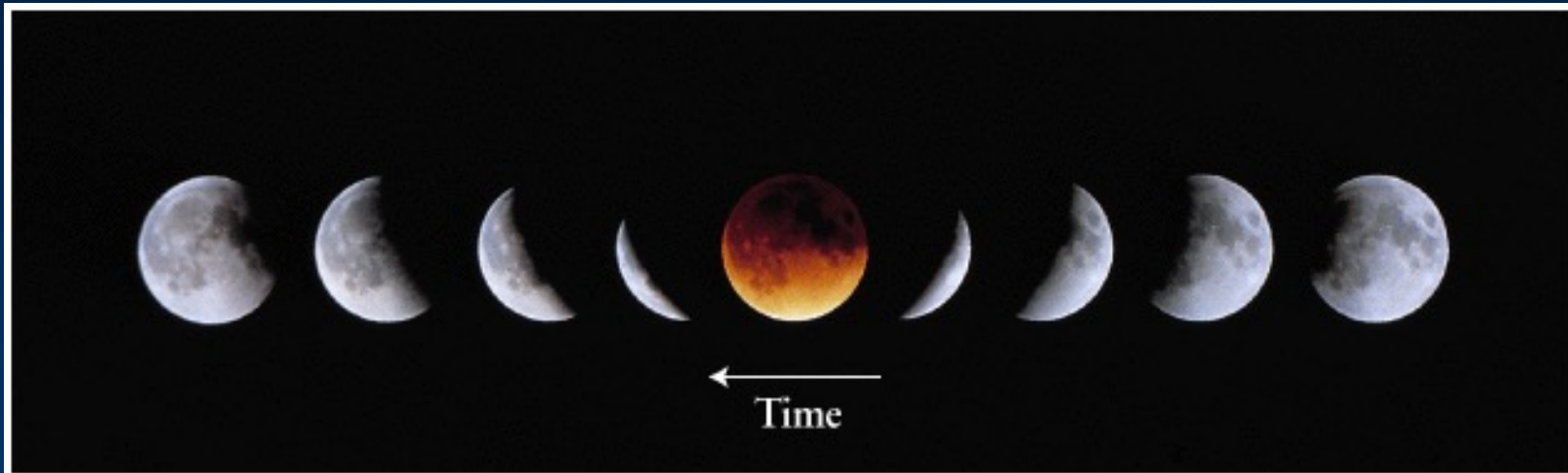
Path 1 produces a penumbral lunar eclipse.

Path 2 produces a total lunar eclipse.

Path 3 produces a partial lunar eclipse.

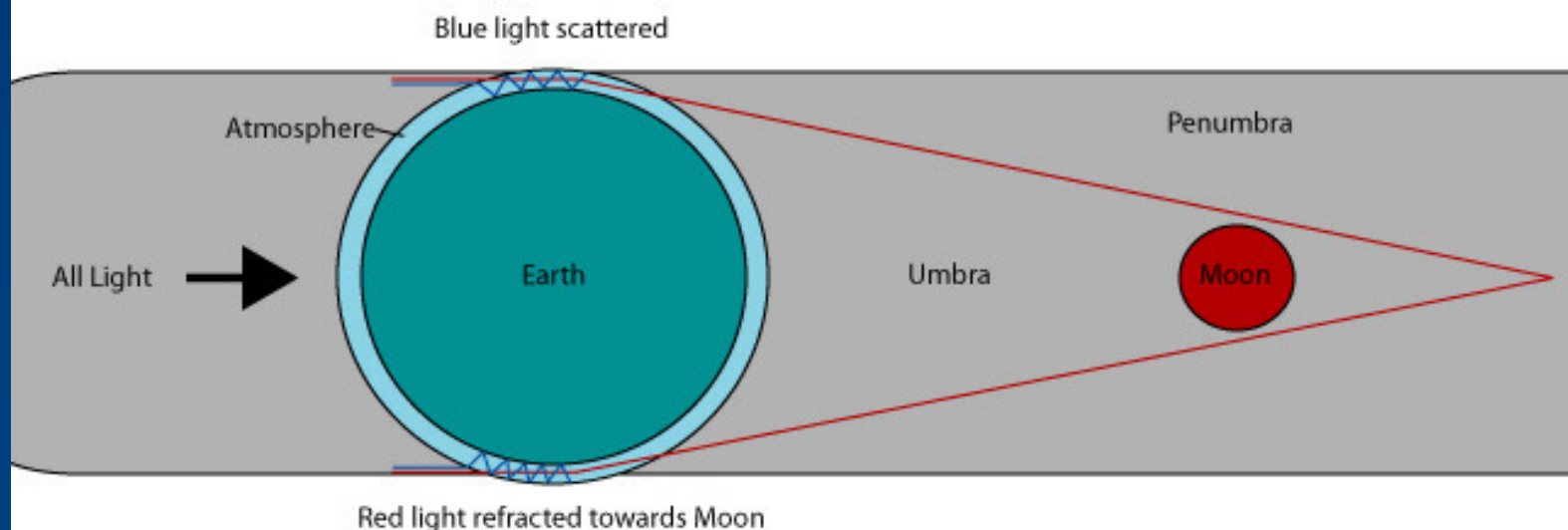
**Question: will lunar eclipses be visible in daytime or nighttime?**

# Photos taken during the course of a total lunar eclipse:



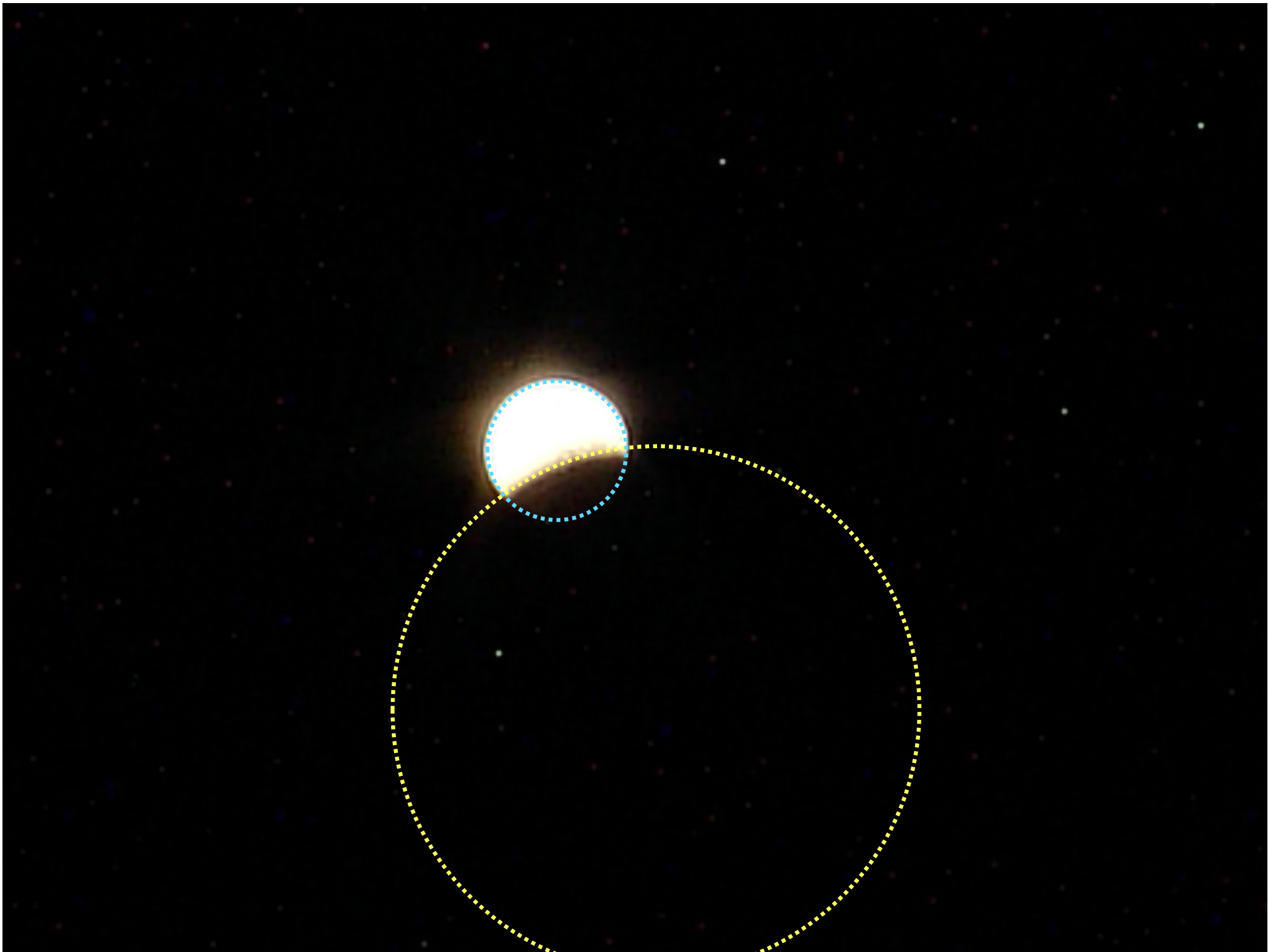
**Note reddish color during totality – some light gets around Earth. Why red? Because shorter wavelength light is scattered out of path. This is same physics that produces red sunsets – more later.**

## Why a Lunar Eclipse is red



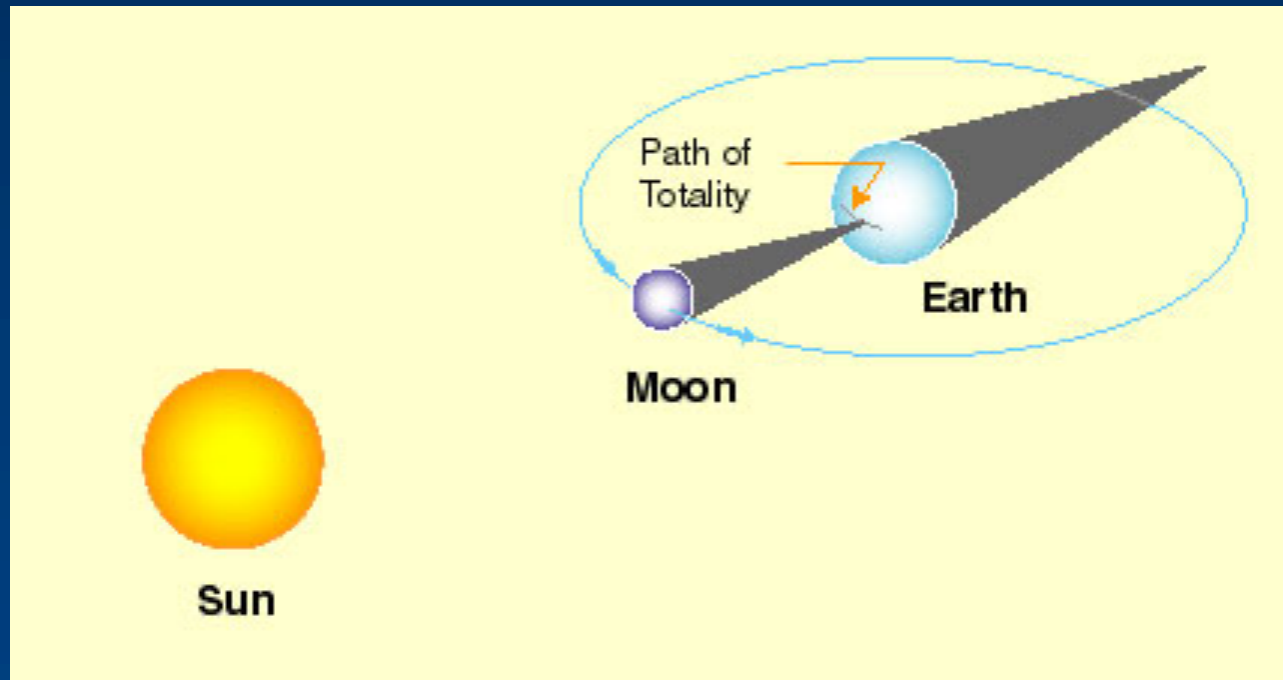
## Lunar Eclipses: 2021 - 2030

Calendar Date	TD of Greatest Eclipse	Eclipse Type	Saros Series	Umbral Magnitude	Eclipse Duration	Geographic Region of Eclipse Visibility
<a href="#"><u>2021 May 26</u></a>	11:19:53	Total	<a href="#"><u>121</u></a>	1.009	03h07m 00h15m	e Asia, Australia, Pacific, Americas
<a href="#"><u>2021 Nov 19</u></a>	09:04:06	Partial	<a href="#"><u>126</u></a>	0.974	03h28m	Americas, n Europe, e Asia, Australia, Pacific
<a href="#"><u>2022 May 16</u></a>	04:12:42	Total	<a href="#"><u>131</u></a>	1.414	03h27m 01h25m	Americas, Europe, Africa
<a href="#"><u>2022 Nov 08</u></a>	11:00:22	Total	<a href="#"><u>136</u></a>	1.359	03h40m 01h25m	Asia, Australia, Pacific, Americas
<a href="#"><u>2023 May 05</u></a>	17:24:05	Penumbral	<a href="#"><u>141</u></a>	-0.046	-	Africa, Asia, Australia
<a href="#"><u>2023 Oct 28</u></a>	20:15:18	Partial	<a href="#"><u>146</u></a>	0.122	01h17m	e Americas, Europe, Africa, Asia, Australia
<a href="#"><u>2024 Mar 25</u></a>	07:13:59	Penumbral	<a href="#"><u>113</u></a>	-0.132	-	Americas
<a href="#"><u>2024 Sep 18</u></a>	02:45:25	Partial	<a href="#"><u>118</u></a>	0.085	01h03m	Americas, Europe, Africa
<a href="#"><u>2025 Mar 14</u></a>	06:59:56	Total	<a href="#"><u>123</u></a>	1.178	03h38m 01h05m	Pacific, Americas, w Europe, w Africa



# Solar eclipses

*A solar eclipse* is seen if the shadow of the Moon reaches the Earth.



**The whole Earth does not fit in the shadow of the Moon.**

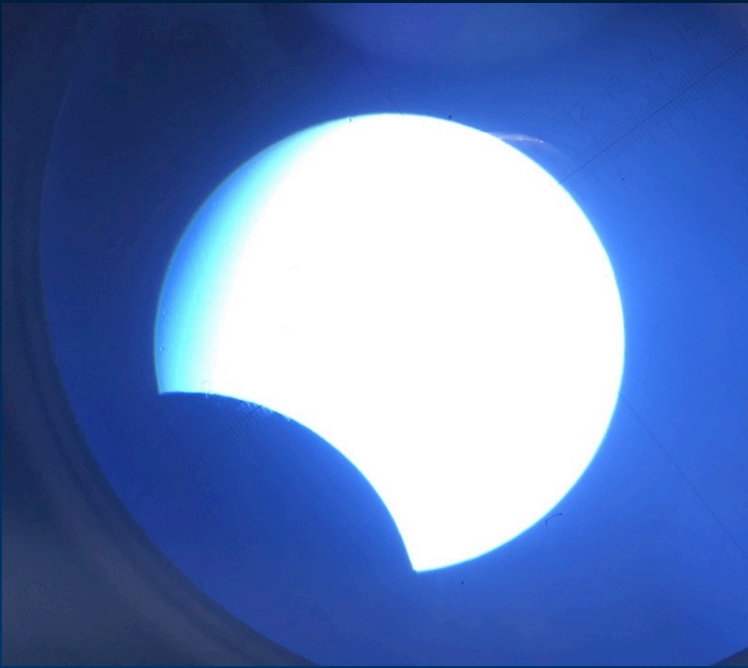
# August 21, 2017

## Fort Laramie, Wyoming





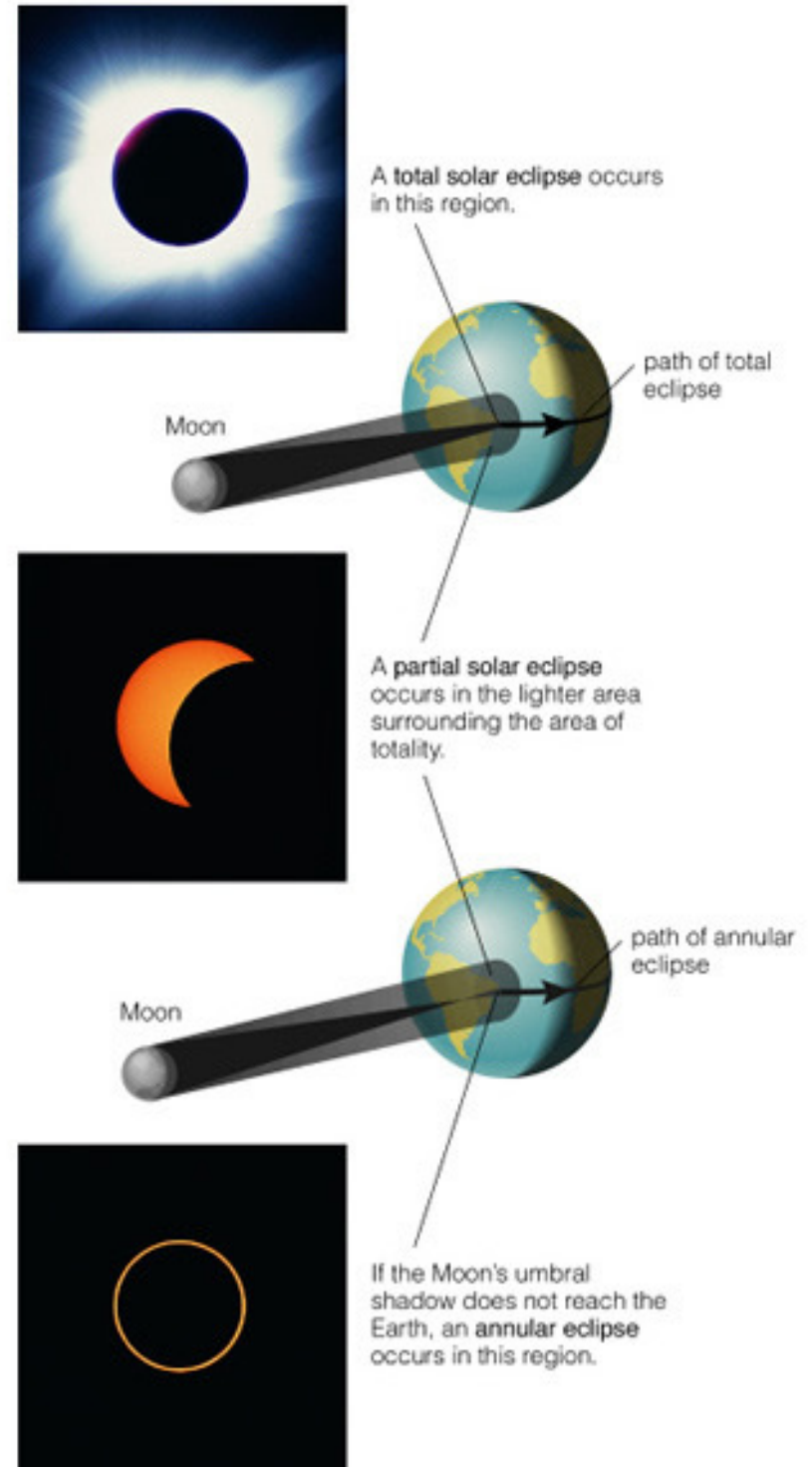




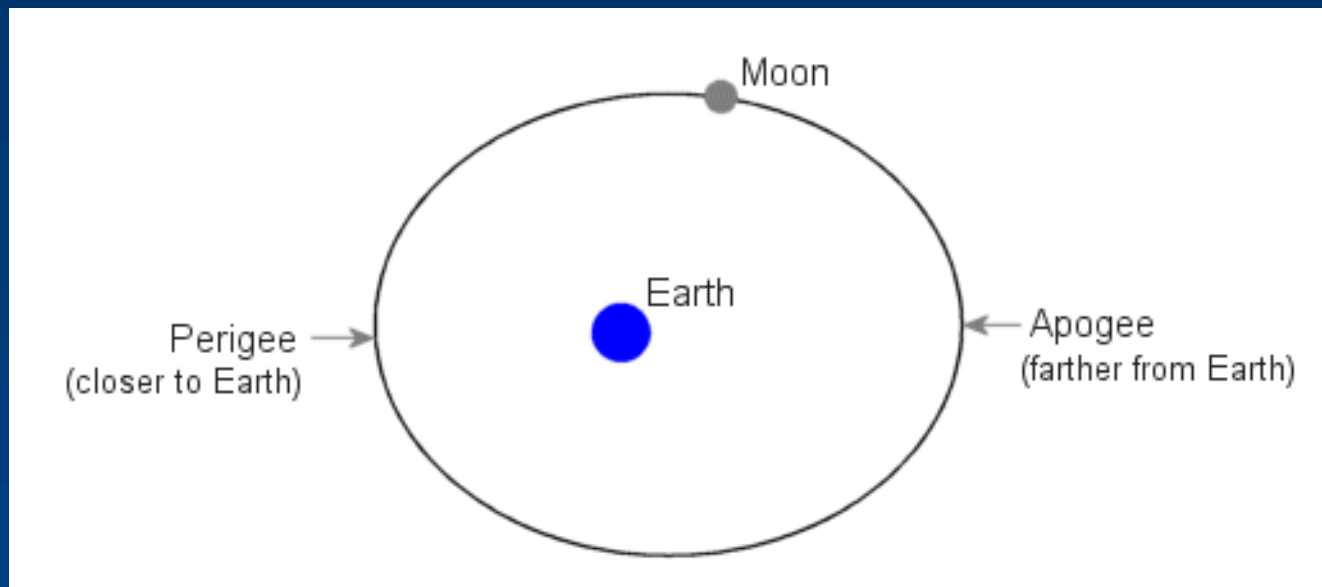


# Types of solar eclipses

- Solar eclipses can be *total*, *partial*, or *annular*, depending on geometry.
- Angular diameter of Moon is about  $1/2^\circ$  = angular diameter of Sun
- $\Rightarrow$  can block the Sun's disk from view.

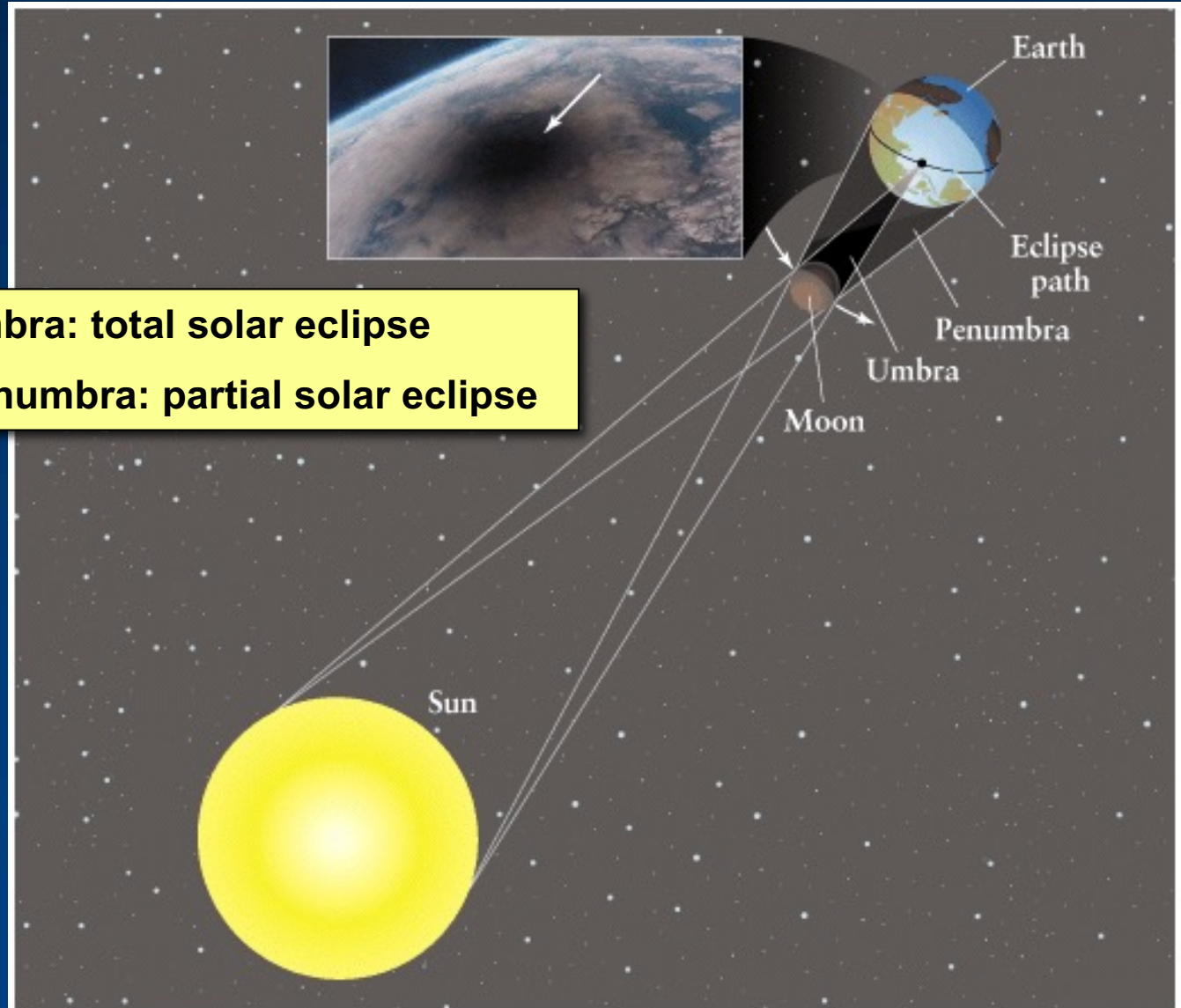


- Actually, angular size of the Moon varies because Earth-Moon distance varies (orbit not perfect circle), 29.37 arcmin to 33.52 arcmin
- The nearest point in the orbit to Earth is called "perigee". The farthest point is called "apogee".



- Q: when is angular size the biggest?

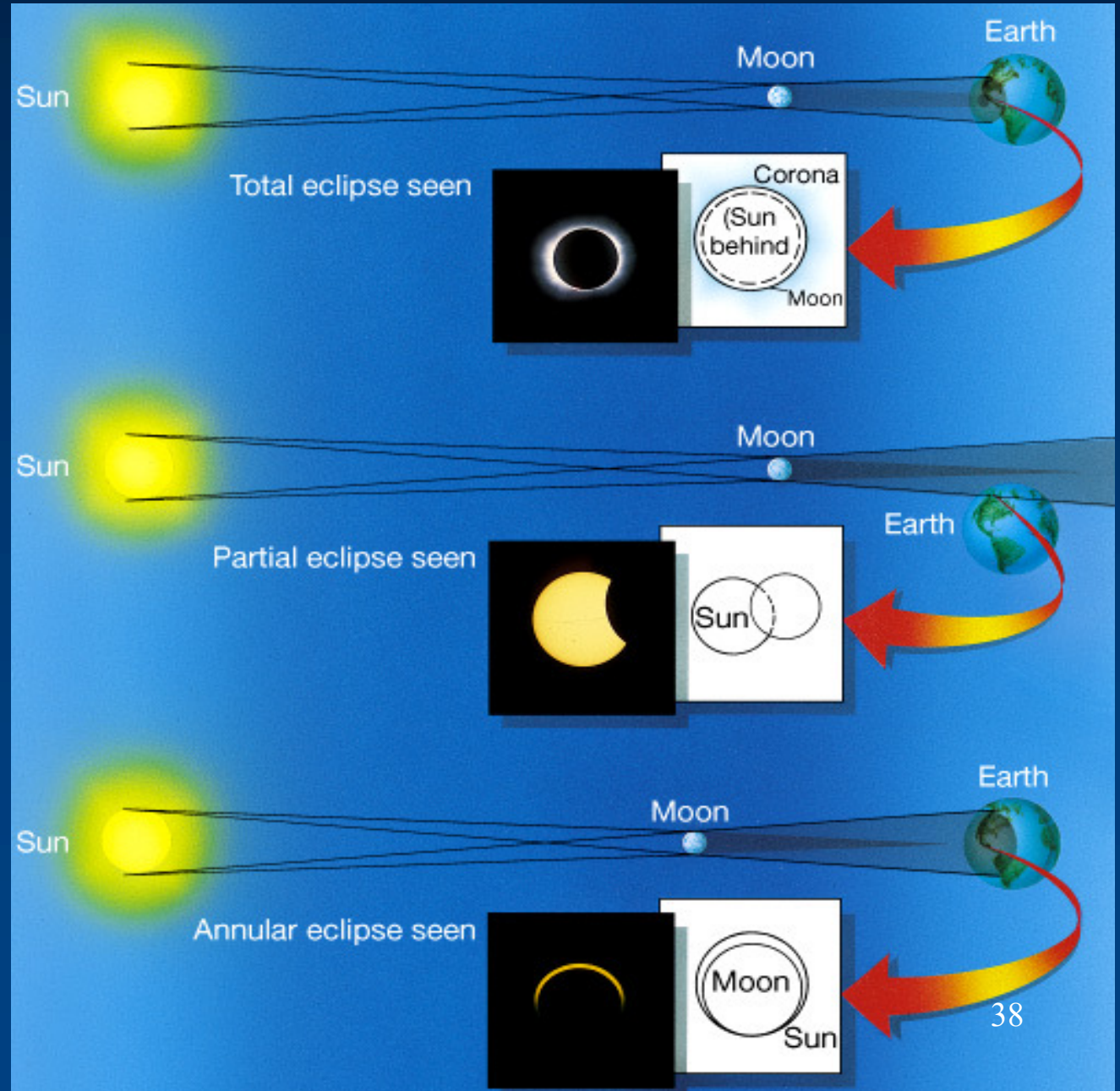
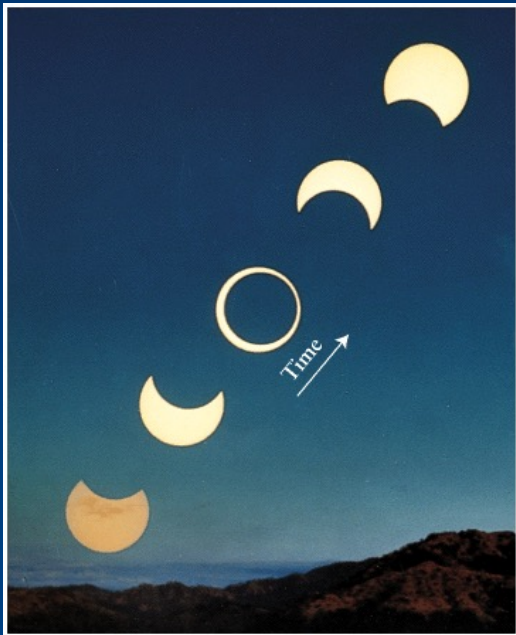
The Moon's shadow also consists of an umbra and penumbra. Only when the umbra reaches the Earth will the eclipse be total.



**Observer inside the Moon's umbra: total solar eclipse**

**Observer inside the Moon's penumbra: partial solar eclipse**

When eclipse occurs when moon is relatively far from Earth, umbra does not reach Earth's surface. Eclipse not total but annular.



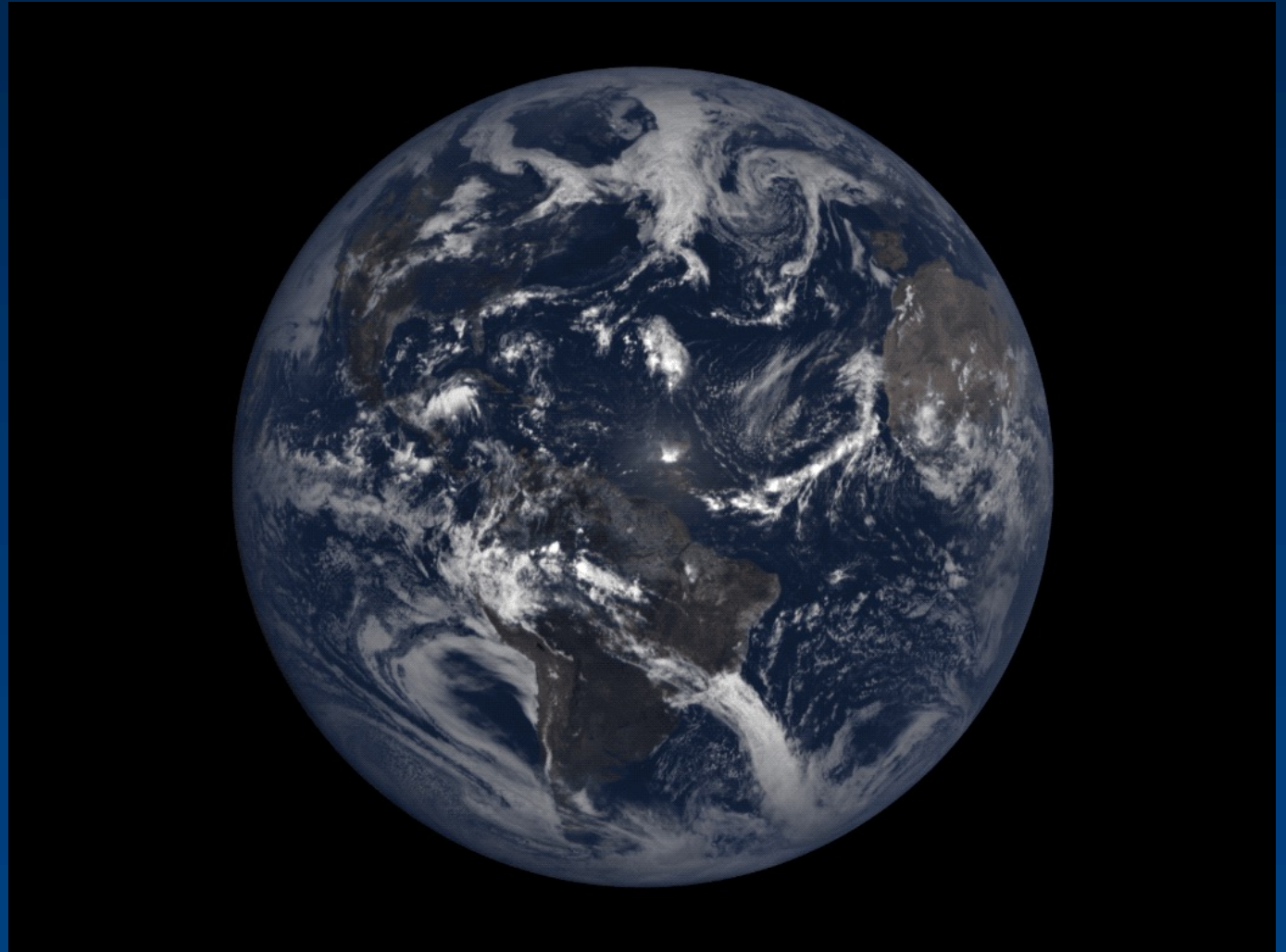
# The penumbra is not uniform

- Gradually gets brighter going outwards
- That's because you see more and more of the Sun



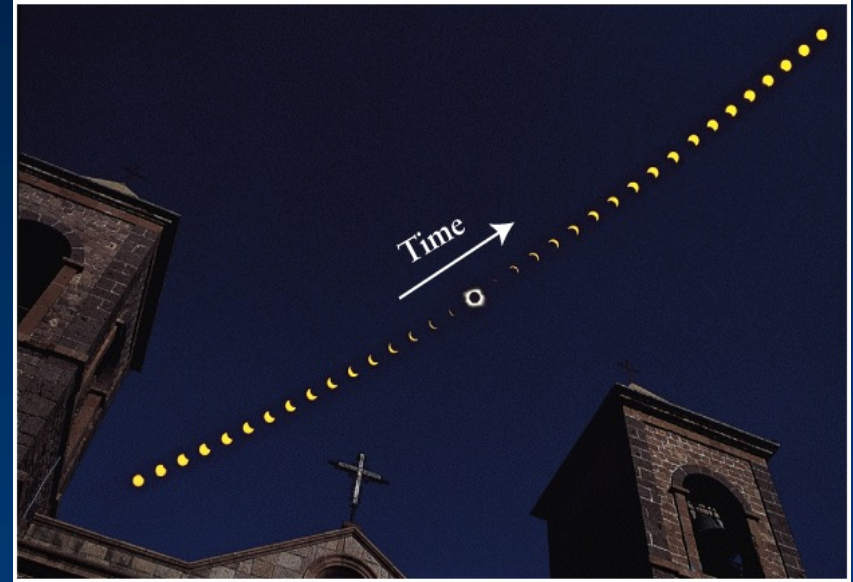
# Penumbra moves across Earth

- NASA's Earth Polychromatic Imaging Camera (EPIC) captured 12 natural color images of the moon's shadow crossing over North America on Aug. 21, 2017.





# Total Solar eclipses



Photos taken 5 min apart:

- Localized and short:
  - Moon's umbra 270 km across at most
  - Totality lasts at most 7.5 min, with a fast sweeping shadow west to east

## Solar Eclipses: 2021 - 2030

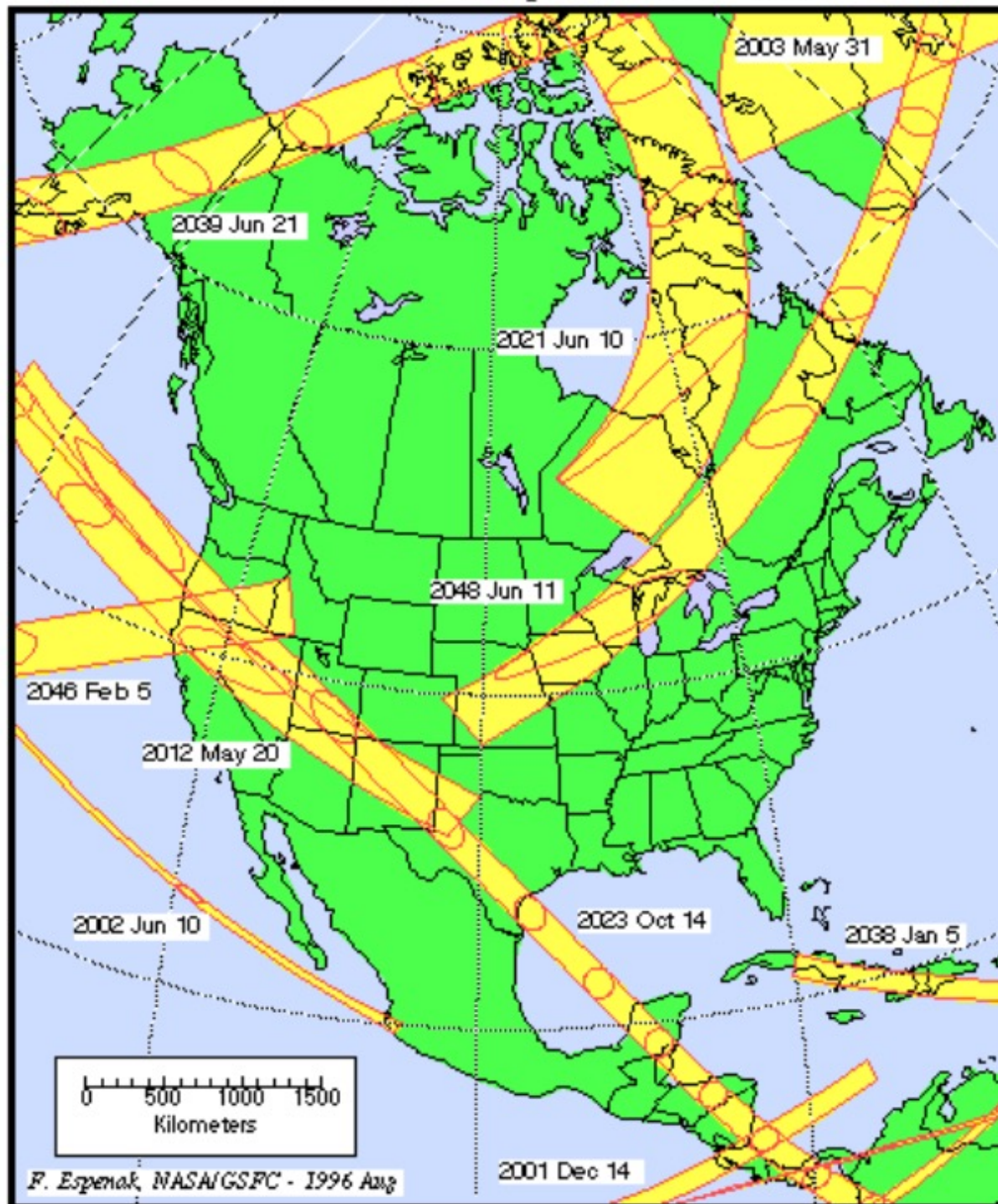
Calendar Date	TD of Greatest Eclipse	Eclipse Type	Saros Series	Eclipse Magnitude	Central Duration	Geographic Region of Eclipse Visibility
<i>(Link to Global Map)</i>	<i>(Link to Animation)</i>	<i>(Link to Google Map)</i>	<i>(Link to Saros)</i>		<i>(Link to Path Table)</i>	
<a href="#">2021 Jun 10</a>	<a href="#">10:43:06</a>	<a href="#">Annular</a>	<a href="#">147</a>	0.943	<a href="#">03m51s</a>	n N. America, Europe, Asia <b>[Annular: n Canada, Greenland, Russia]</b>
<a href="#">2021 Dec 04</a>	<a href="#">07:34:38</a>	<a href="#">Total</a>	<a href="#">152</a>	1.037	<a href="#">01m54s</a>	Antarctica, S. Africa, s Atlantic <b>[Total: Antarctica]</b>
<a href="#">2022 Apr 30</a>	<a href="#">20:42:36</a>	<a href="#">Partial</a>	<a href="#">119</a>	0.640	-	se Pacific, s S. America
<a href="#">2022 Oct 25</a>	<a href="#">11:01:19</a>	<a href="#">Partial</a>	<a href="#">124</a>	0.862	-	Europe, ne Africa, Mid East, w Asia
<a href="#">2023 Apr 20</a>	<a href="#">04:17:55</a>	<a href="#">Hybrid</a>	<a href="#">129</a>	1.013	<a href="#">01m16s</a>	se Asia, E. Indies, Australia, Philippines. N.Z. <b>[Hybrid: Indonesia, Australia, Papua New Guinea]</b>
<a href="#">2023 Oct 14</a>	<a href="#">18:00:40</a>	<a href="#">Annular</a>	<a href="#">134</a>	0.952	<a href="#">05m17s</a>	N. America, C. America, S. America <b>[Annular: w US, C. America, Colombia, Brazil]</b>
<a href="#">2024 Apr 08</a>	<a href="#">18:18:29</a>	<a href="#">Total</a>	<a href="#">139</a>	1.057	<a href="#">04m28s</a>	N. America, C. America <b>[Total: Mexico, c US, e Canada]</b>
<a href="#">2024 Oct 02</a>	<a href="#">18:46:13</a>	<a href="#">Annular</a>	<a href="#">144</a>	0.933	<a href="#">07m25s</a>	Pacific, s S. America <b>[Annular: s Chile, s Argentina]</b>
<a href="#">2025 Mar 29</a>	<a href="#">10:48:36</a>	<a href="#">Partial</a>	<a href="#">149</a>	0.938	-	nw Africa, Europe, n Russia
<a href="#">2025 Sep 21</a>	<a href="#">19:43:04</a>	<a href="#">Partial</a>	<a href="#">154</a>	0.855	-	s Pacific, N.Z., Antarctica

Next total solar eclipse visible close to here: 2024 Apr 8.  
Will be a partial eclipse in Albuquerque

# Total Solar Eclipses: 2001 - 2050



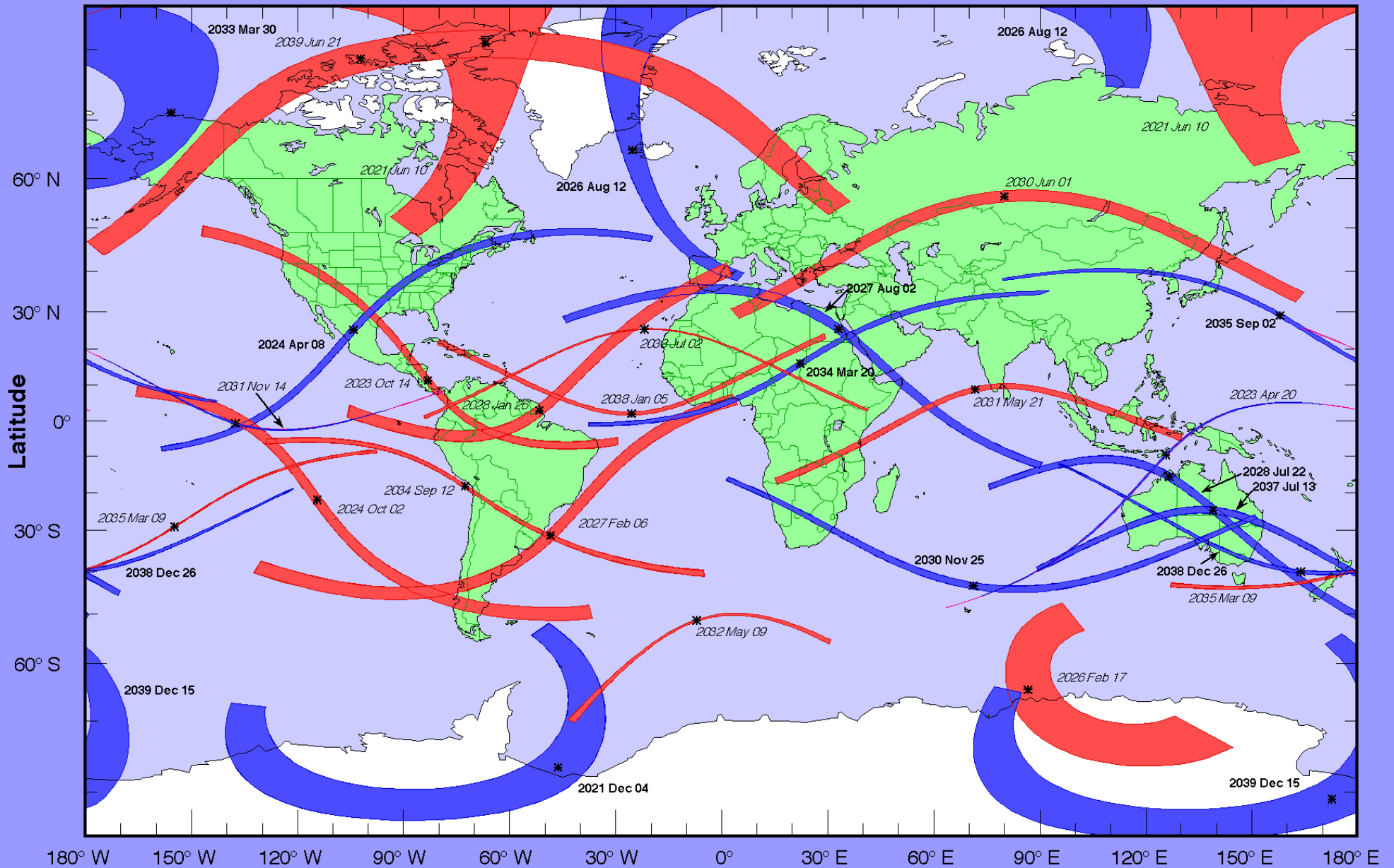
# Annular Solar Eclipses: 2001 - 2050



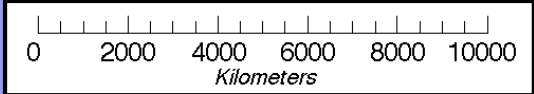
# How do we predict eclipses?

- Using geometry and mechanics of the Earth and Moon orbiting the Sun (influenced by gravitational fields).
- Computers work out the motion (Newton's laws).
- Need to know exact speeds and position of the objects involved.
- Every 18 yr 11 1/3 days (223 lunar months), the Moon returns to nearly the identical configuration relative to Earth and Sun - "Saros cycle".
- The 1/3<sup>rd</sup> of a day shifts these 1/3<sup>rd</sup> of the way around the Earth.

# Total and Annular Solar Eclipse Paths: 2021 – 2040



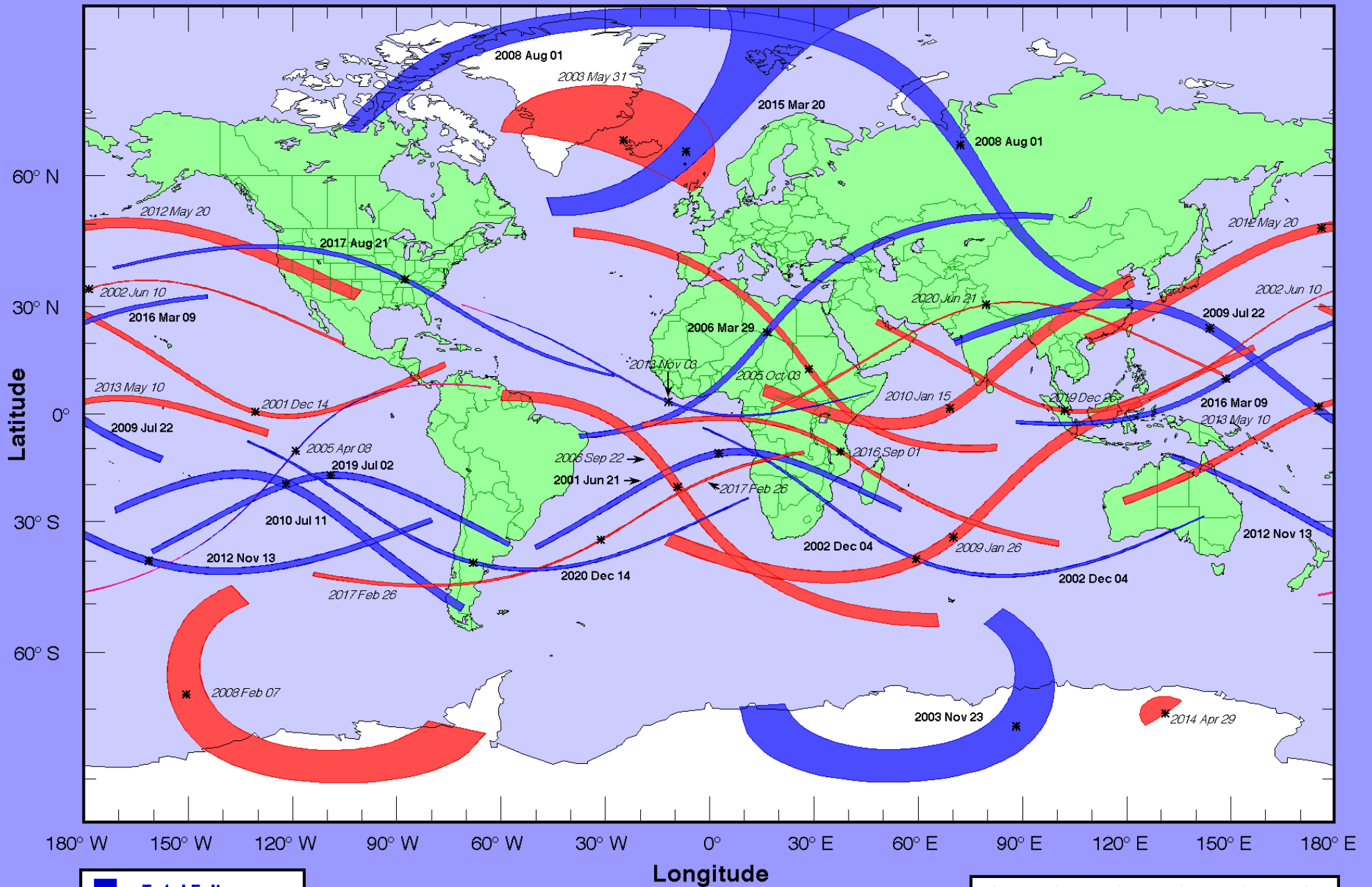
- Total Eclipse
- Annular Eclipse
- Hybrid Eclipse



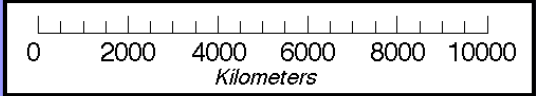
[sunearth.gsfc.nasa.gov/eclipse/eclipse.html](http://sunearth.gsfc.nasa.gov/eclipse/eclipse.html)

Fred Espenak, NASA/GSFC - 2002 July

# Total and Annular Solar Eclipse Paths: 2001 – 2020



- Total Eclipse
- Annular Eclipse
- Hybrid Eclipse



# 2023 Oct 14 Annular Eclipse



Mallory Harris (UNM) talks at eclipse event





# Experiencing a Total Solar Eclipse

- During the partial phase, examine cast images—small holes act as “pinhole cameras”
- Do you see effects of the cooling? Does it seem later than your watch is saying? Do animals behave oddly?



# Experiencing a Total Eclipse: Approaching Totality

- Some beautiful pictures are made with partial clouds, but maintain eye safety!
- May be able to see the shadow approaching from the west at a thousand miles per hour.
- Look for shadow bands on the ground as totality begins.



# Totality begins...

Baily's beads and the diamond ring occur as bits of the photosphere remain visible through valleys along the edge ("limb") of the Moon.



# Totality

- Chromosphere
- Corona



# Prominences or flares



## Questions:

When a lunar eclipse happens, from what fraction of the globe can it be seen?

How about for a solar eclipse?

# For how long will we be able to see total solar eclipses?

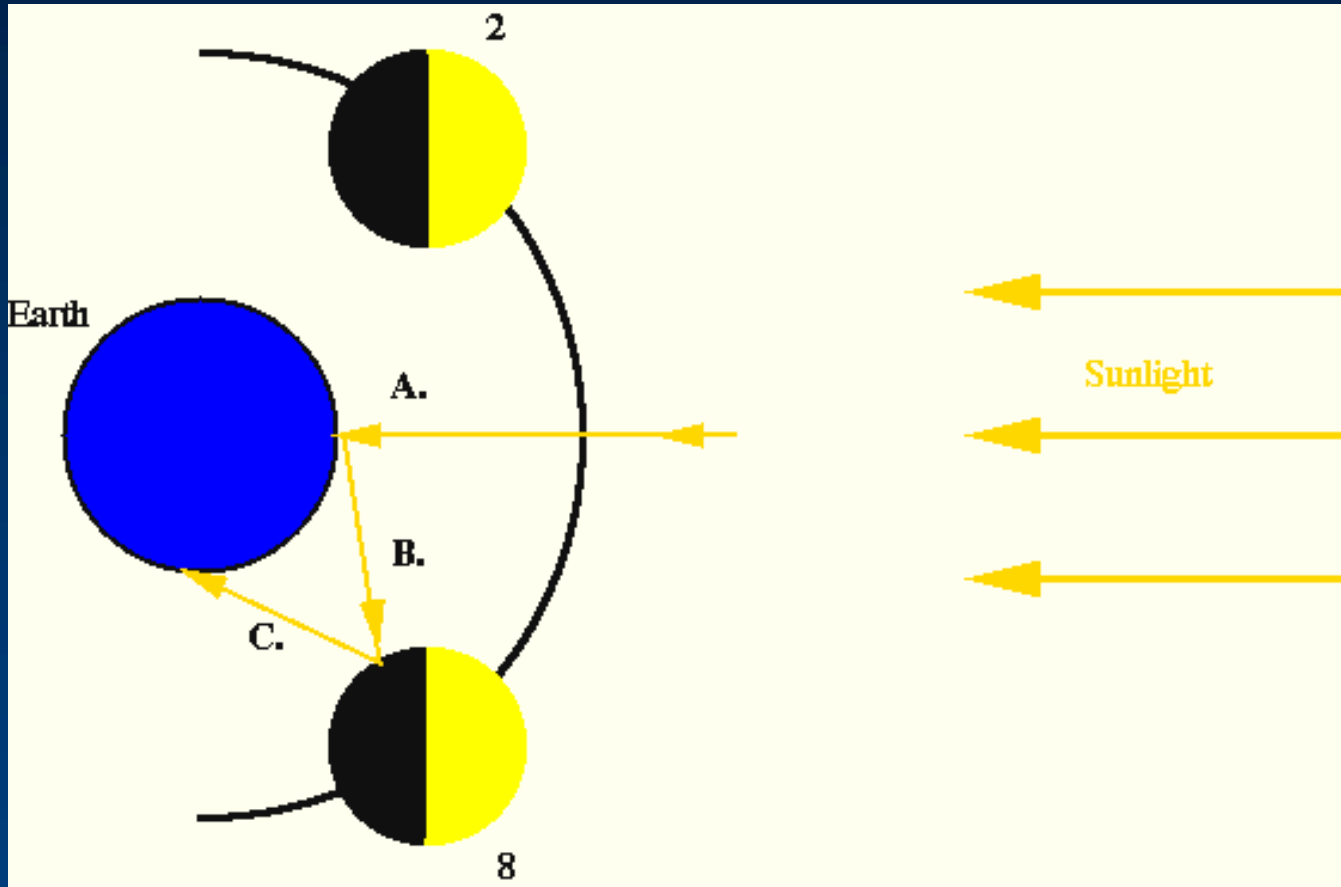
- Because of tidal friction, the orbit of the Moon is growing larger by about 3.8 cm/yr.
- At the current rate, the Moon will be too far away in about 600 million years.

# "Earthshine"





# Earthshine is reflected light



**Only seen in crescent phases because:**

- Only small part of the Moon is directly illuminated by the Sun**
- The Moon is in the right position to reflect back light to the Earth.**