Eclipses

Interactions of Sun, Earth, & Moon

the Visible Sky

I. Stars and Celestial Sphere
Constellations & Coordinates

II. Sun
Time, Seasons, Precession

III. Moon
Phase, Orbit, etc.

IV. Eclipses
Solar & Lunar

	The student will be able to:	HW:
1	Explain and utilize constellations and asterisms as means of mapping and organizing the stars.	1 – 4
2	Explain and utilize the concept of the celestial sphere as a means of understanding the appearance of the universe as seen from Earth.	
3	Explain the significance of the pole star, Polaris, and its connection with the apparent motion of the celestial sphere.	
4	Explain, define, and utilize the celestial equatorial coordinate system of right ascension and declination, celestial equator and celestial poles.	
5	Describe changes in position and appearance of the stars through time and explain in terms of the actual motion and position of the Earth.	5
6	Define, apply, and relate to astronomical events or cycles the following time concepts: sidereal and solar day, sidereal and tropical year, mean solar time, standard time, daylight savings time, and universal time.	6
7	Use a planisphere to locate celestial objects for a particular date and time and/or determine the date and time of certain celestial events.	7 – 8
8	Describe changes in position and appearance of the Sun through time and explain in terms of the actual motion and position of the Earth.	9
9	State the constellations of the zodiac in order and explain the relation between the zodiac and the Sun.	10 – 14
10	Explain, define, and utilize the concept of the ecliptic and the ecliptic plane.	
11	Illustrate and describe the connection between the seasons and the motion and orientation of the Earth in its orbit.	15
12	Explain the cause and effect of Earth's precession and state and apply the period of this cycle to solve problems.	16
13	Describe changes in the appearance of the Moon over the course of one day and night, from one night to the next, from one week to the next, from one month to the next, and from year to year.	17 – 20
14	Explain the apparent motion and changing appearance of the Moon in terms of the actual motions of the Earth and Moon relative to the Sun.	
15	Explain and illustrate how the motion and position of the Moon relative to the Earth and the Sun result in the phases: new Moon, waxing crescent, first quarter, waxing gibbous, full Moon, waning gibbous, third quarter, and waning crescent.	
16	Define, apply, and relate to astronomical events or cycles the following concepts: sidereal month, synodic month, lunar sidereal and solar days.	21 – 22
17	Explain and illustrate how the motions and positions of the Earth, the Sun, and the Moon result in lunar and solar eclipses – partial, total, and annular.	23
18	Explain and illustrate the concepts of umbra and penumbra in relation to eclipses.	24

Solar Eclipse

The Sun is blocked (eclipsed) by the Moon.

Lunar Eclipse

The Moon is blocked (eclipsed) by the Earth (*i.e.* Earth's *shadow*).

Solar Eclipses

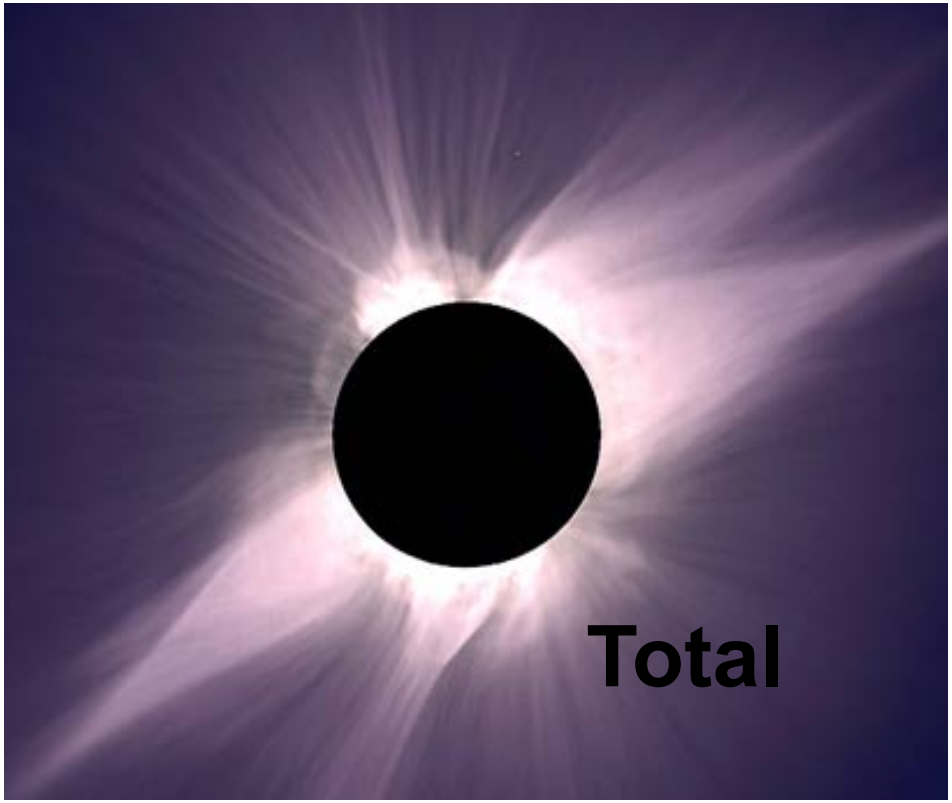
Partial

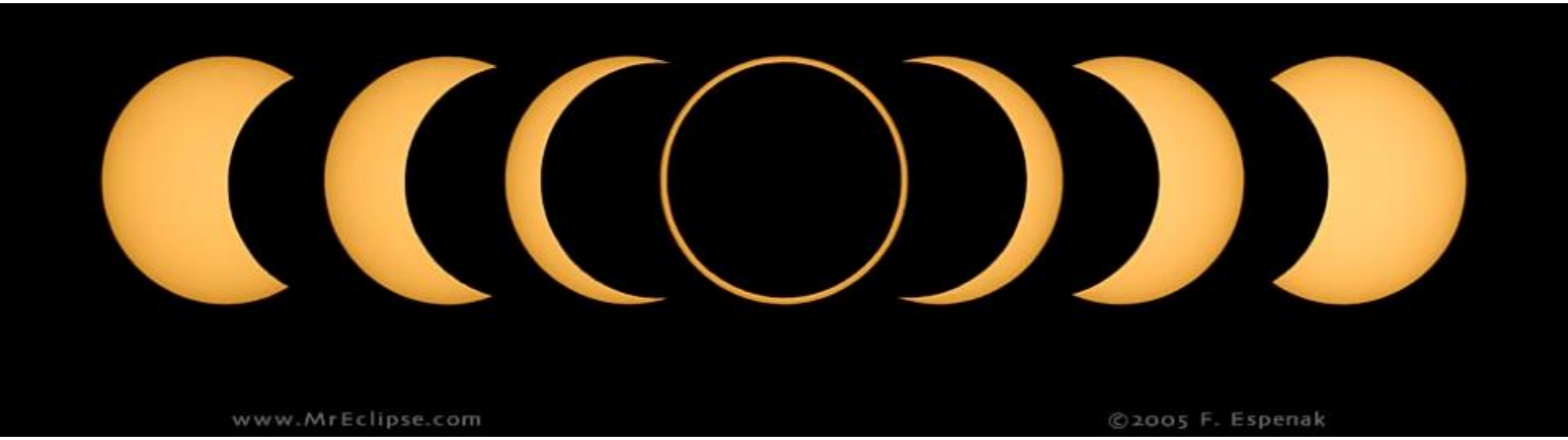
Annular

What phase is the Moon? New!

New Moon at *every* solar eclipse? Yes!

Solar eclipse at *every* New Moon? No!





Time lapse sequence of an annular eclipse.

The Moon isn't "big enough" during this type of eclipse to *completely* block out the Sun. Why not?!

This occurs when the Moon is far enough away from Earth and/or the Sun is close enough to Earth. These distances vary because neither orbit is perfectly circular.

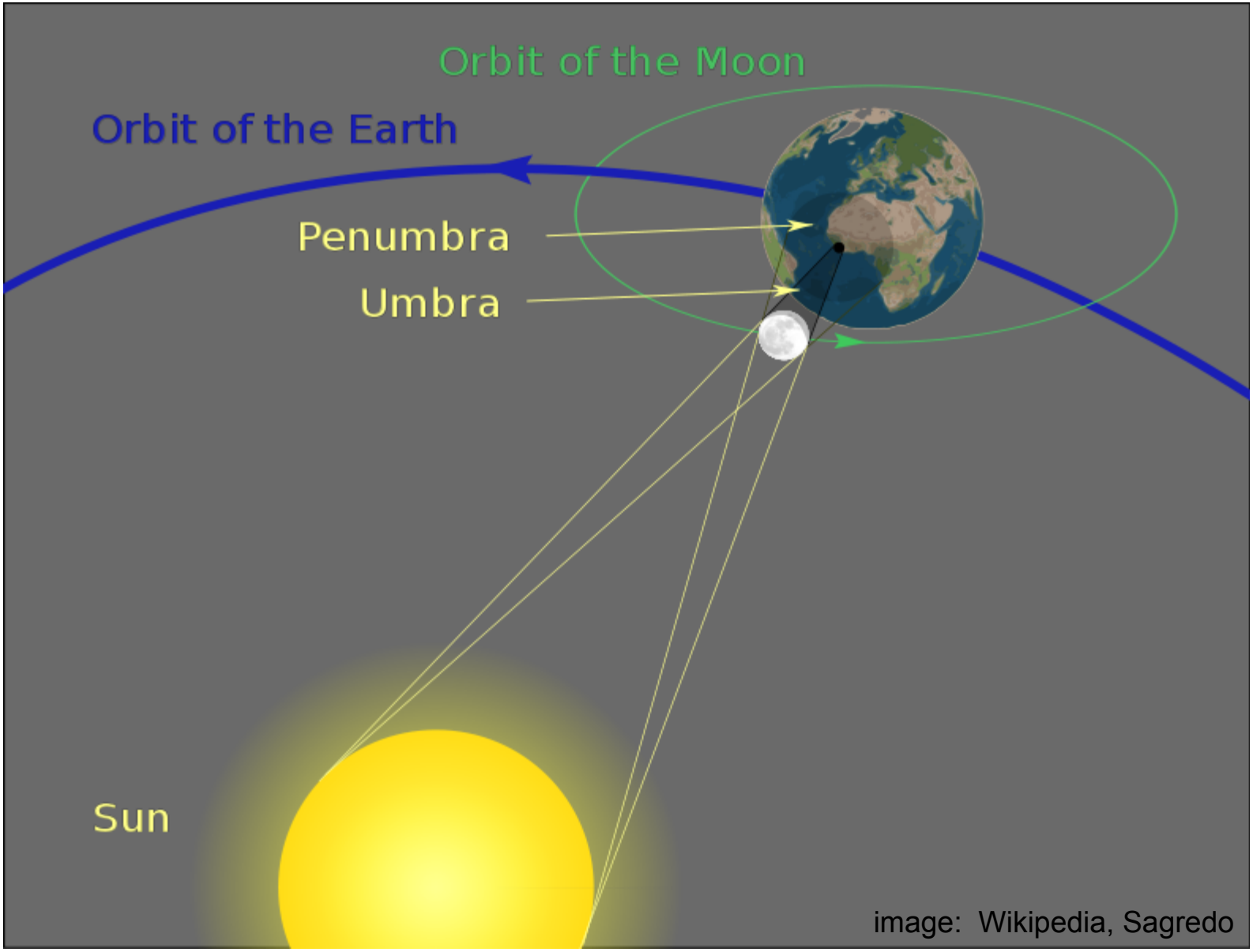
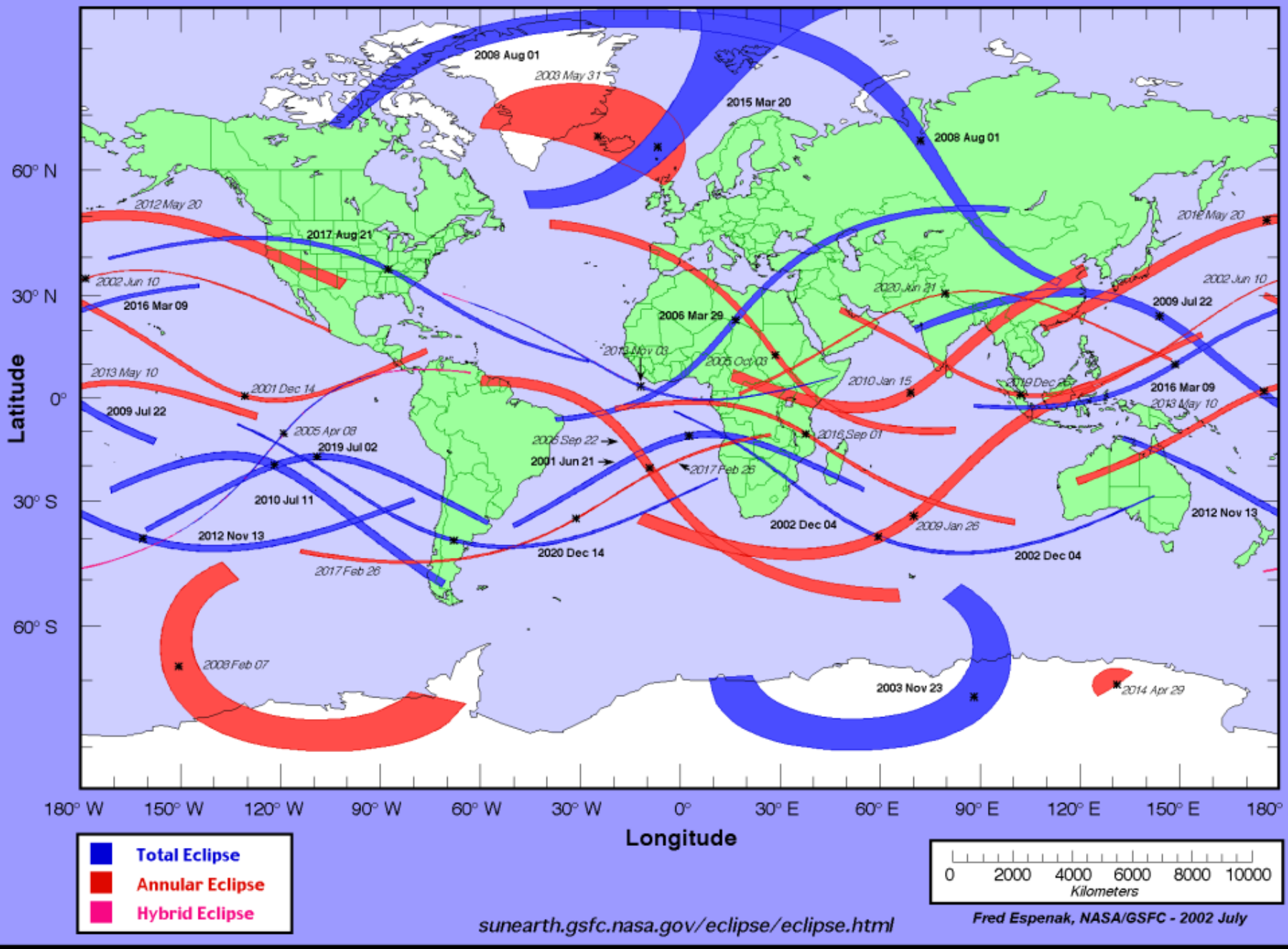


image: Wikipedia, Sagredo

Seeing a Solar Eclipse

- In order to witness a total solar eclipse you must be somewhere within the Moon's shadow at the time of New Moon.
- Because the Moon's shadow is relatively small, an eclipse is visible only in certain locations on Earth.
- The Moon's shadow moves rapidly over the surface of the Earth (up to 2000 mph).
- The maximum time possible for *totality* (when the Sun is totally eclipsed) is only about 6 minutes. But the entire process can take a couple of hours to observe.

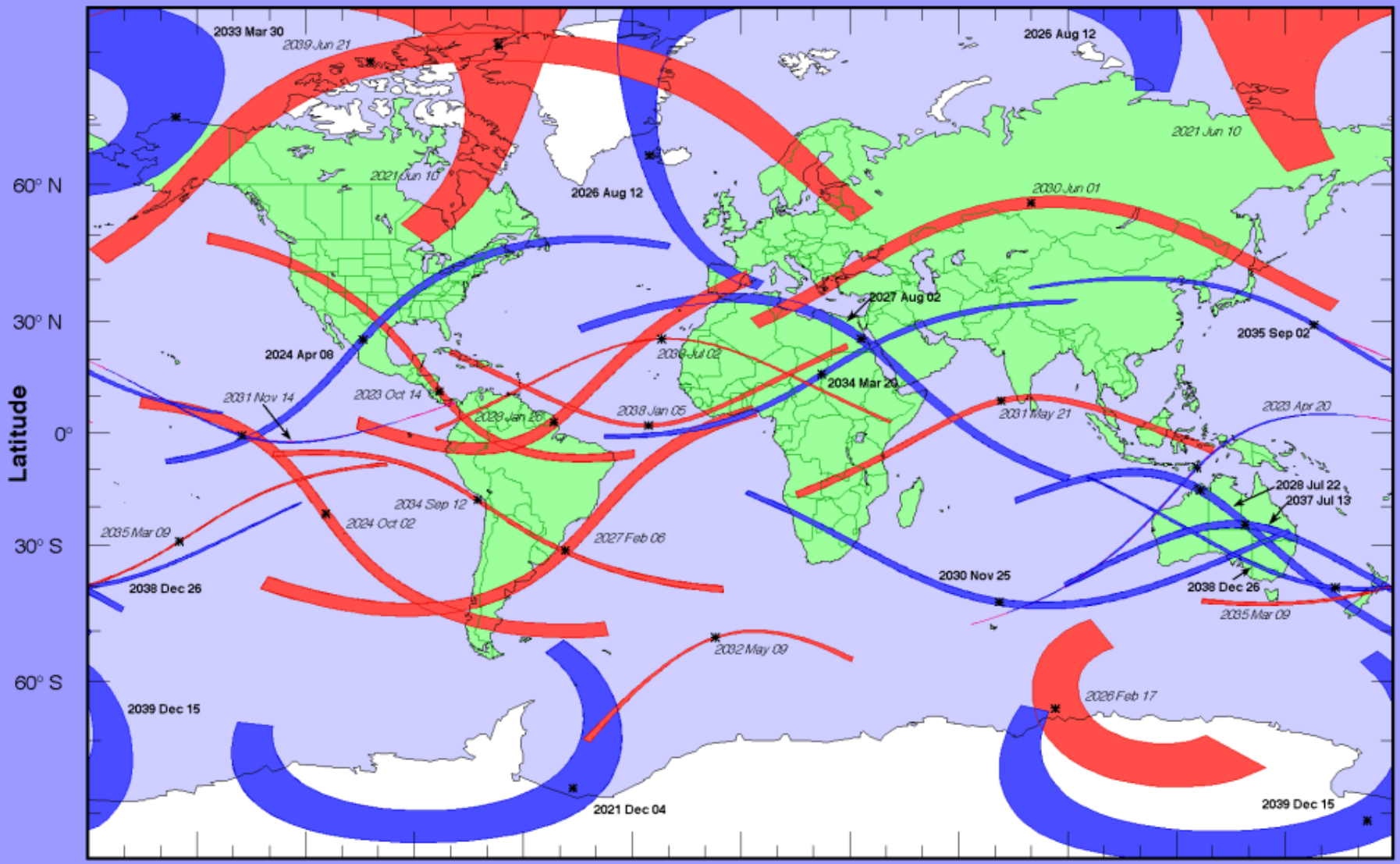
Total and Annular Solar Eclipse Paths: 2001 – 2020



sunearth.gsfc.nasa.gov/eclipse/eclipse.html

Fred Espenak, NASA/GSFC - 2002 July

Total and Annular Solar Eclipse Paths: 2021 –2040



sunearth.gsfc.nasa.gov/eclipse/eclipse.html

Fred Espenak, NASA/GSFC - 2002 July

Partial

Total

What phase is the Moon? Full!

Full Moon at *every* lunar eclipse? Yes!

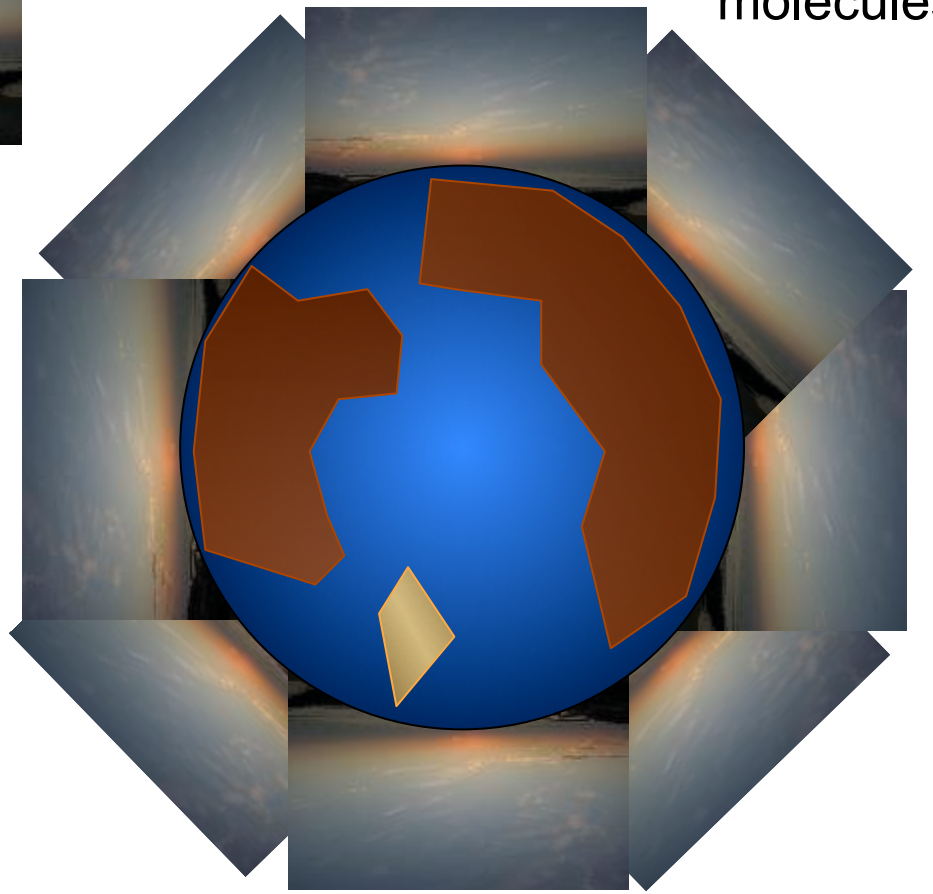
Lunar eclipse at *every* Full Moon? No!

Penumbral Lunar Eclipse: Moon is slightly dimmed but misses the darkest part of Earth's shadow

Why the color (seen *only* during total)?

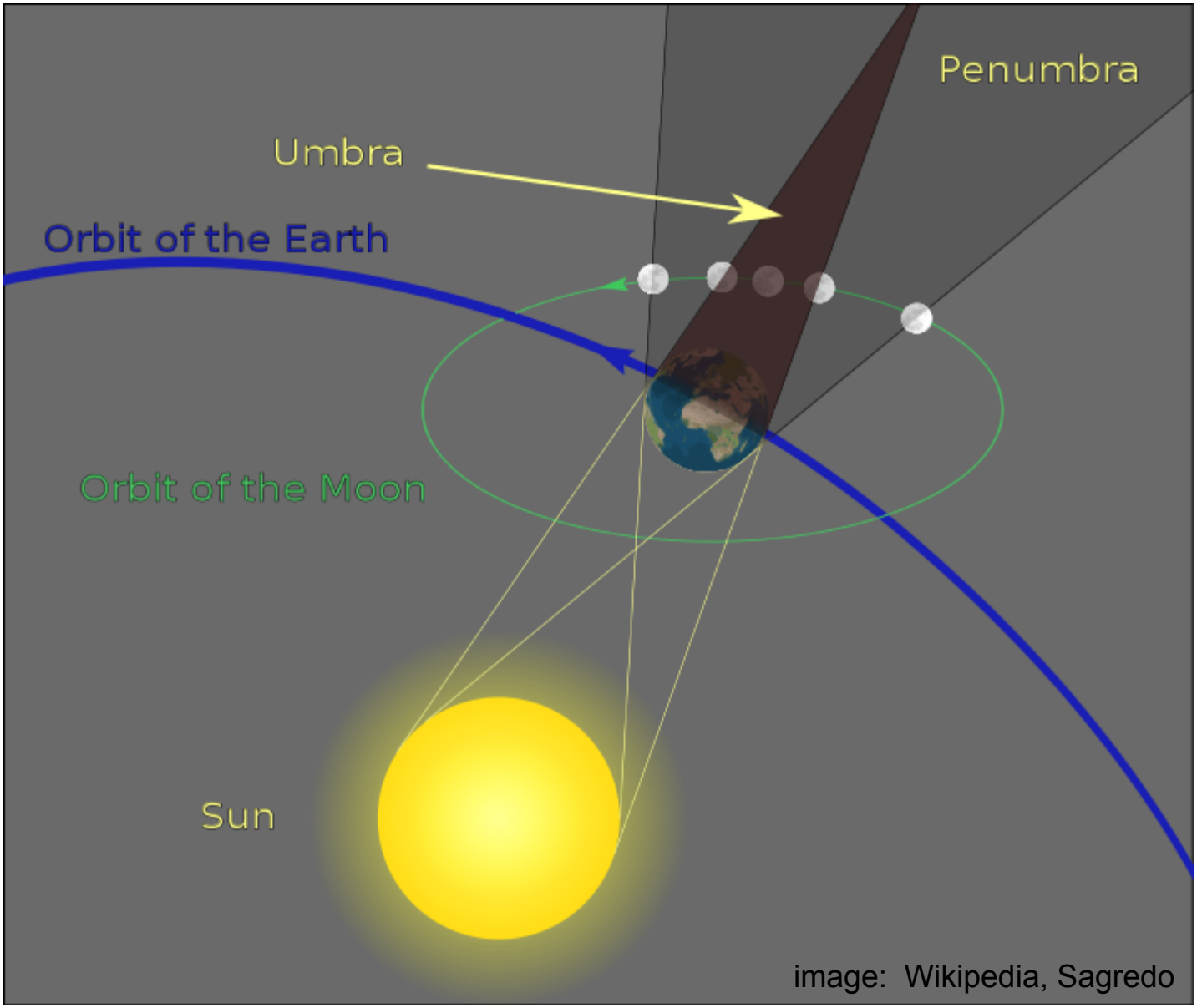
The orange/copper color of a total lunar eclipse is due to the same phenomenon as that which causes a sunset or sunrise to appear orange – the scattering of blue light by molecules in the atmosphere.

On one side of the Earth the Sun is setting…



…on the other the Sun is rising.

An observer on the Moon during a total lunar eclipse would see the Earth blocking the Sun, facing the night side of it. Light from the Sun bends through the atmosphere around all sides and illuminates the Moon.

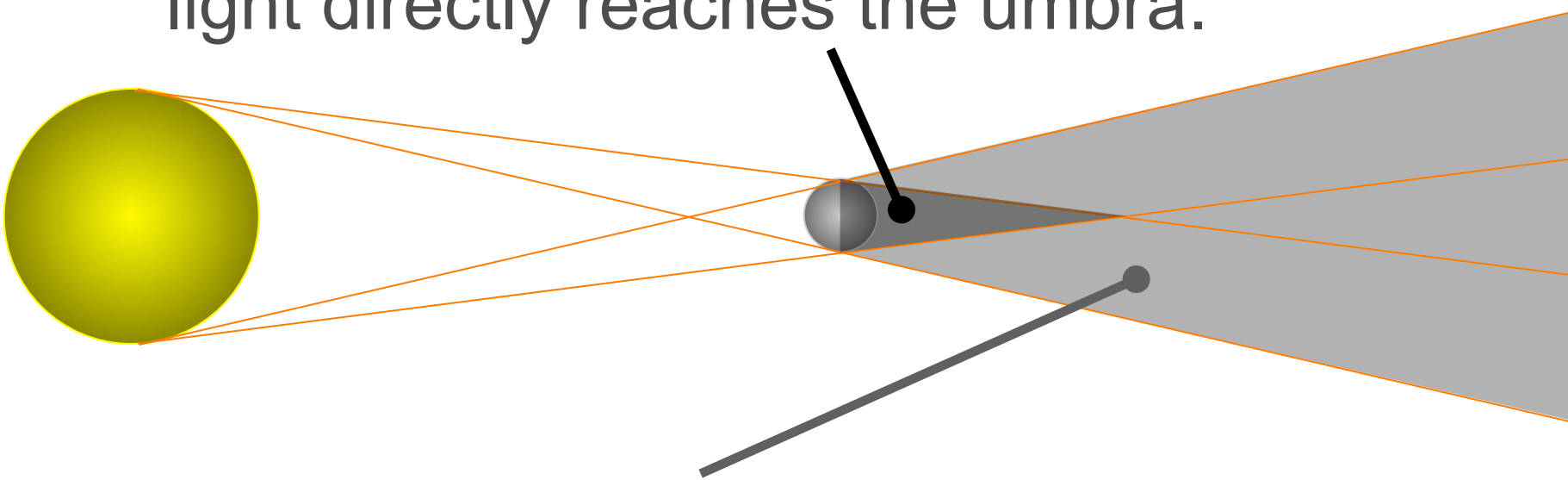

Penumbra
Umbra
Orbit of the Earth
Orbit of the Moon
Sun
image: Wikipedia, Sagredo

Seeing a Lunar Eclipse

- In order to witness a lunar eclipse, you must be somewhere on the night side of Earth while the Full Moon is in the Earth's shadow.
- Because the Earth's shadow is relatively large a lunar eclipse progresses slowly.
- A lunar eclipse can last several hours from beginning to end.
- A penumbral eclipse causes such a slight change in the Moon's brightness that it is nearly impossible to notice.

The Science of Shadows!

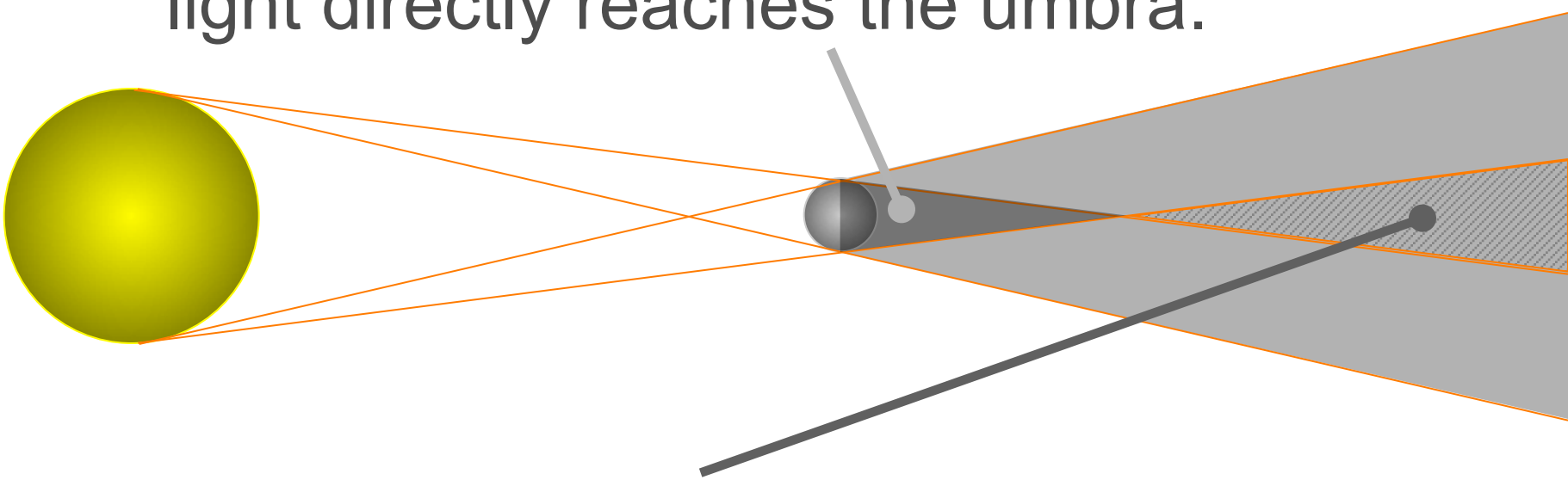
The **umbra** is the darkest part of the shadow. None of the Sun's light directly reaches the umbra.



The **penumbra** is a "partial shadow". Some, but not all, of the Sun's light reaches the penumbra.

The Science of Shadows!

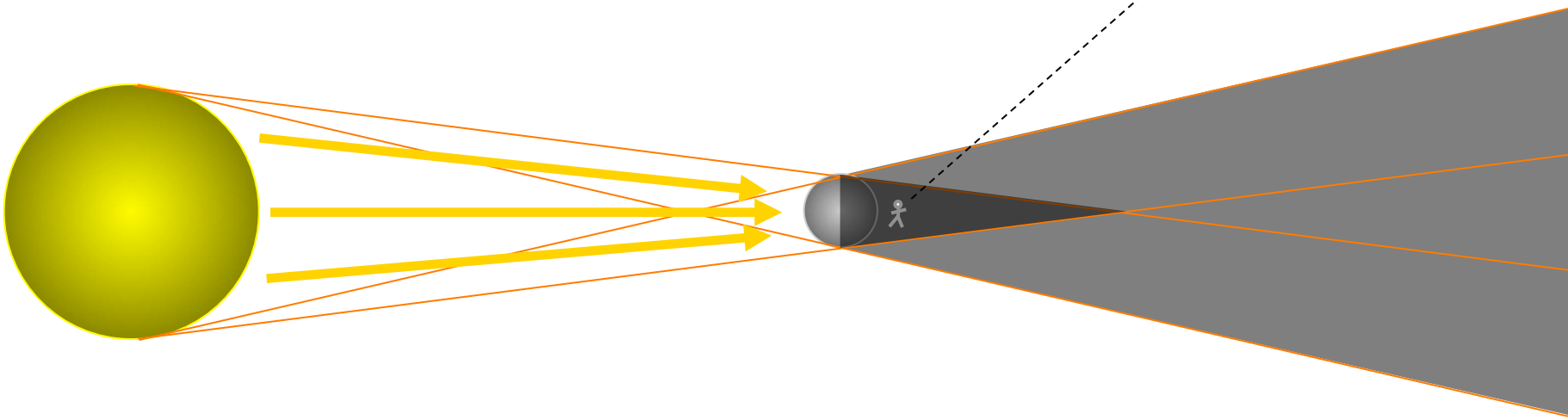
The **umbra** is the darkest part of the shadow. None of the Sun's light directly reaches the umbra.



The **antumbra** is the "inverse" of the umbra's cone. Like the penumbra, it is also a "partial shadow".

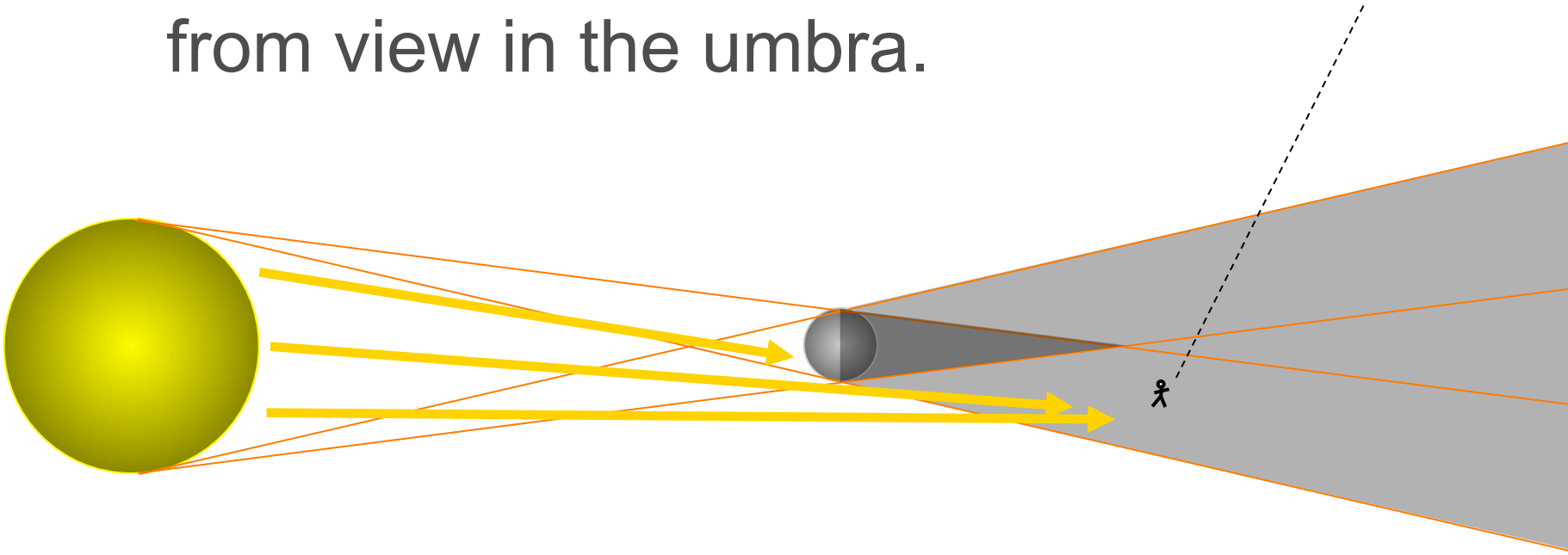
The Science of Shadows!

All parts of the Sun are blocked from view in the umbra.



The Science of Shadows!

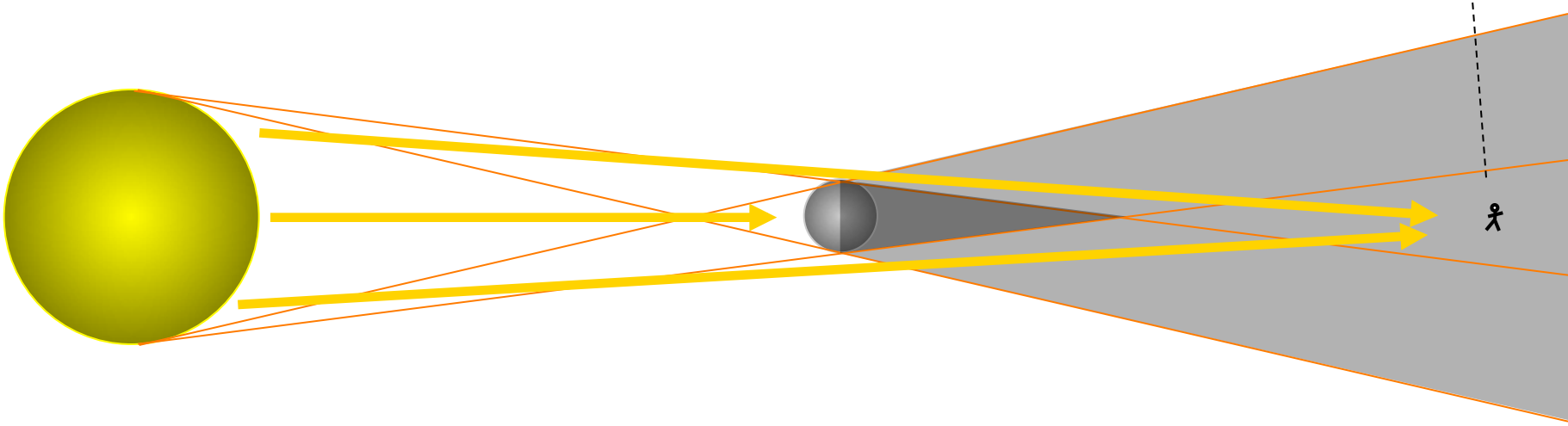
All parts of the Sun are blocked from view in the umbra.



Only *part* of the Sun is blocked from view in the penumbra.

The Science of Shadows!

Only the *middle* part of the Sun is blocked from view in the antumbra.



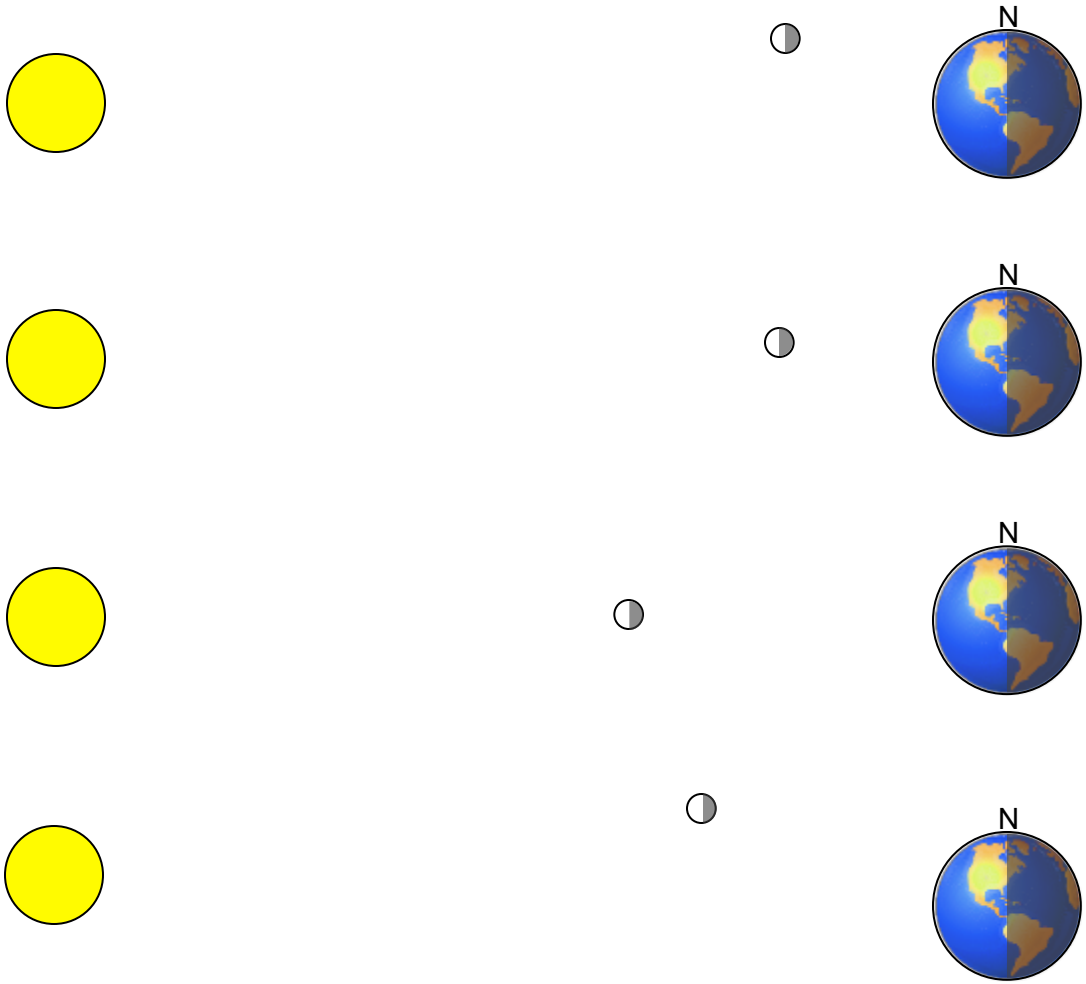
Only *part* of the Sun is blocked from view in the penumbra.

1.

2.

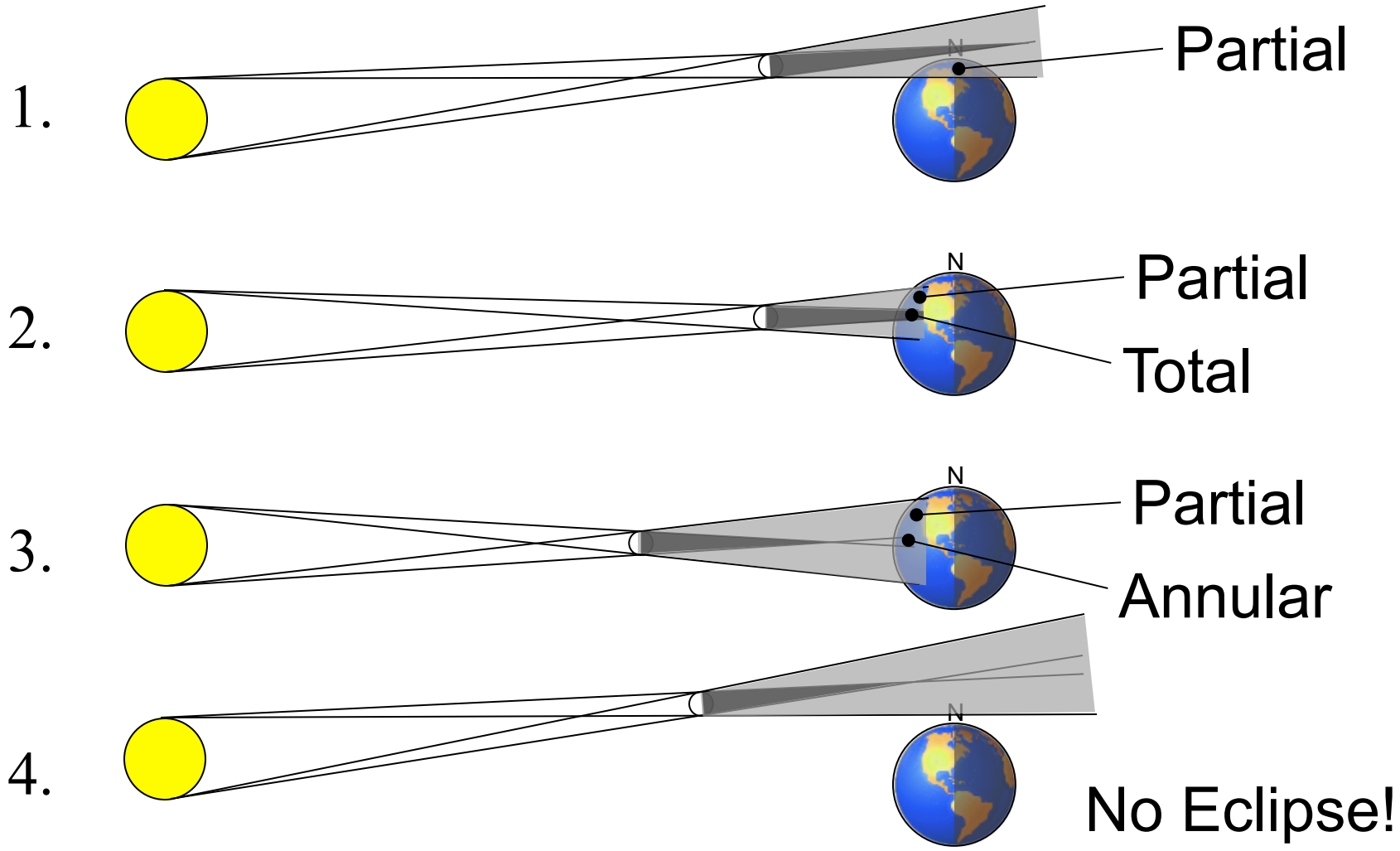
3.

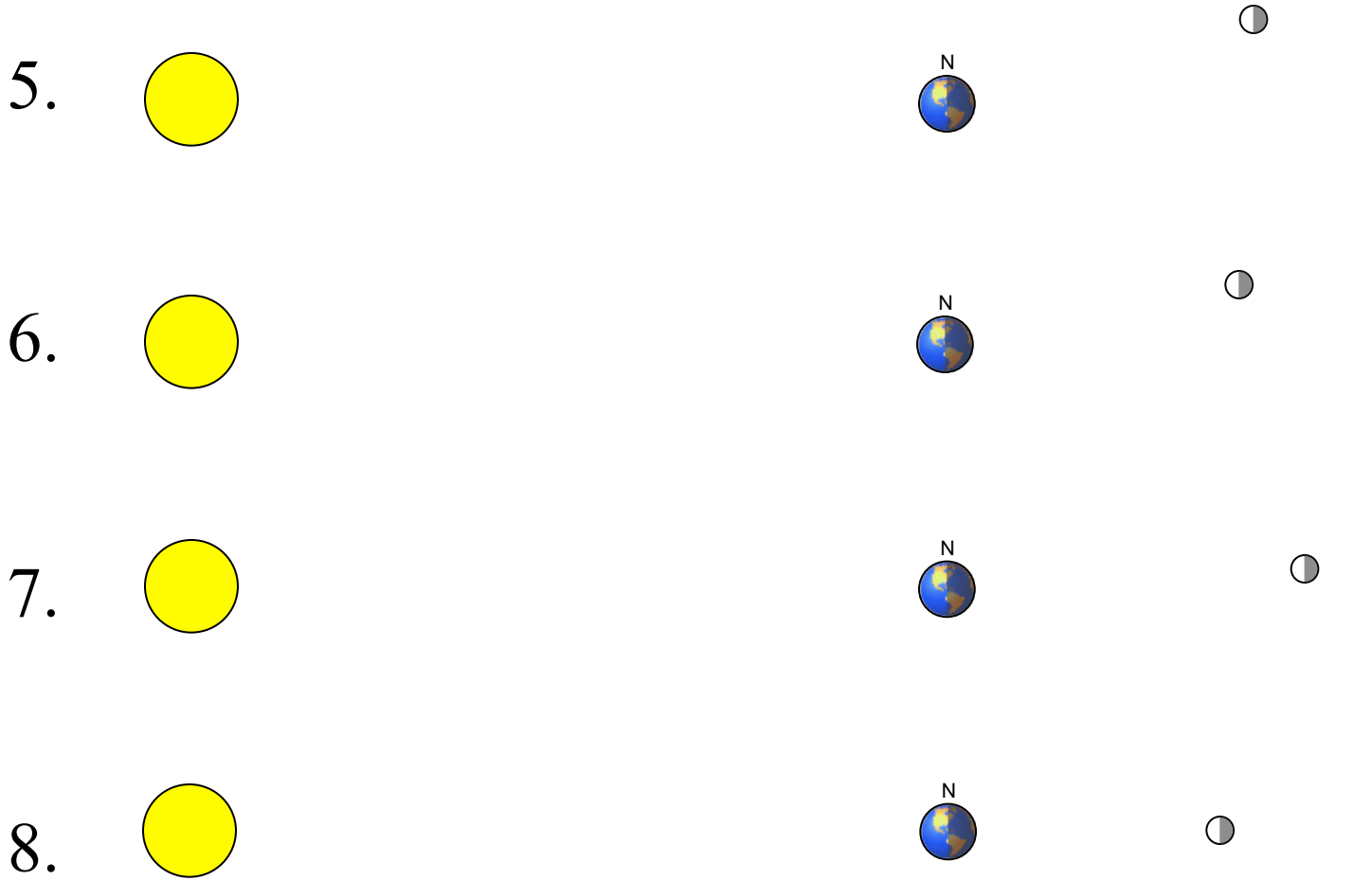
4.



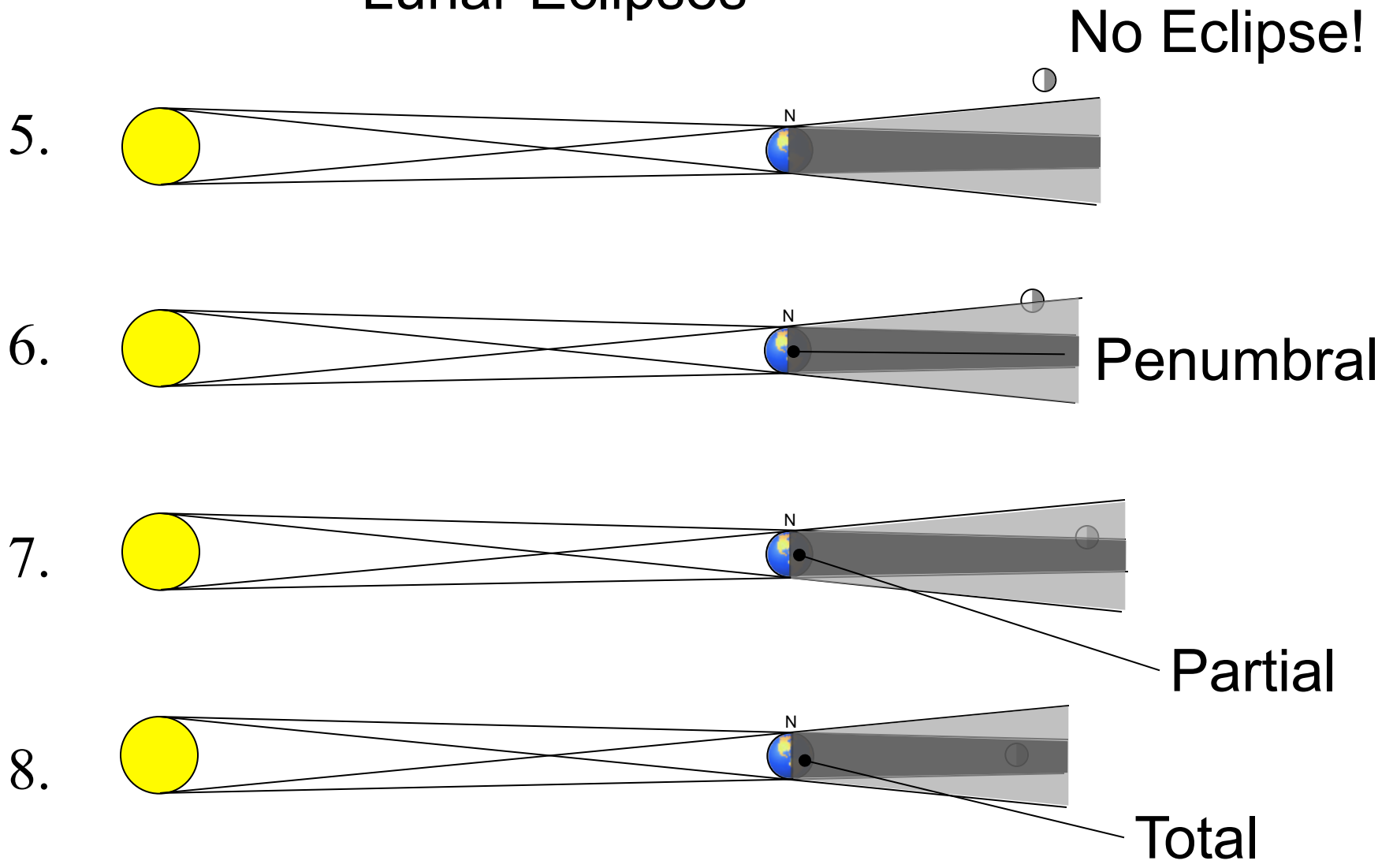
Sun Moon Earth

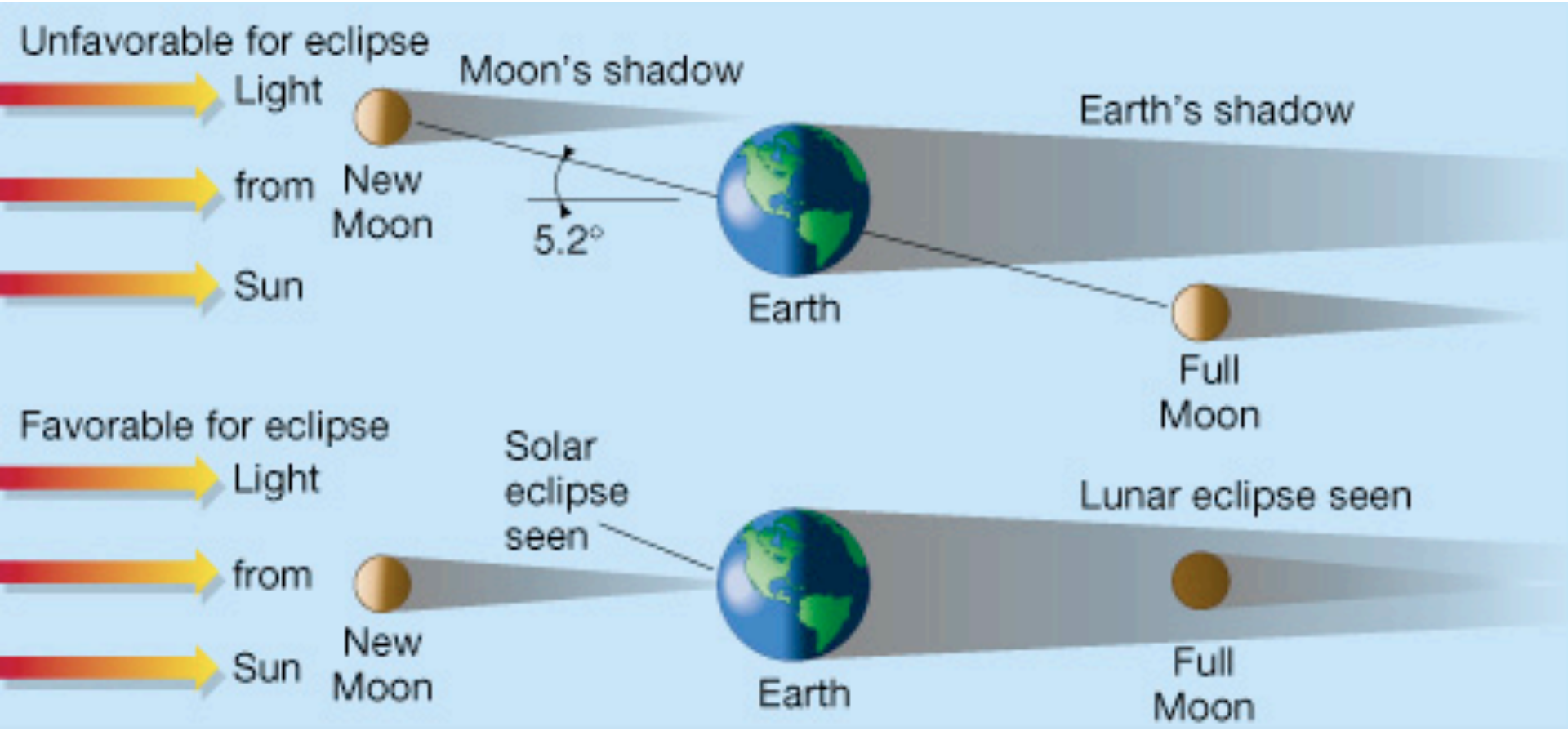
Solar Eclipses





Lunar Eclipses




Unfavorable for eclipse
Light
from
Sun
New
Moon
Moon's shadow
5.2°
Earth
Earth's shadow
Full
Moon
Favorable for eclipse
Light
from
Sun
New
Moon
Solar
eclipse
seen
Earth
Lunar eclipse seen
Full
Moon

Frequency of Eclipses

- Approximately how often does a solar eclipse occur? How about a lunar eclipse?
- Consider sets of eclipses that occur within the same season of the same year – what patterns do you notice?
- Why do these patterns exist? Explain and relate to: ecliptic, synodic month, tropical year, Moon phases & age, etc.

2007	Mar 3	Lun – Tot
	Mar 19	***Sol – Part***
	Aug 28	Lun – Tot
	Sep 11	***Sol – Part***
2008	***Feb 7***	***Sol – Ann***
	Feb 21	Lun – Tot
	Aug 1	***Sol – Tot***
	Aug 16	Lun – Part
2009	***Jan 26***	***Sol – Ann***
	Feb 9	Lun – Pen
	July 7	Lun – Pen
	Jul 22	***Sol Total***
	Aug 6	Lun – Pen

	Dec 31	Lun – Part
2010	***Jan 15***	***Sol – Ann***
	Jun 26	Lun – Part
	Jul 11	***Sol – Tot***
	Dec 21	Lun – Tot
2011	***Jan 4***	***Sol – Part***
	Jun 1	***Sol – Part***
	Jun 15	Lun – Tot
	Jul 1	***Sol – Part***
	Nov 25	***Sol – Part***
	Dec 10	Lun – Tot
2012	***May 20***	***Sol – Ann***
	Jun 4	Lun – Part

	Nov 13	***Sol – Tot***
	Nov 28	Lun – Pen
2013	Apr 25	Lun – Part
	May 10	***Sol – Ann***
	May 25	Lun – Pen
	Oct 18	Lun – Pen
	Nov 3	***Sol – Hyb***
2014	Apr 15	Lun – Tot
	Apr 29	***Sol – Ann***
	Oct 8	Lun – Tot
	Oct 23	***Sol – Part***
2015	***Mar 20***	***Sol – Tot***
	Apr 4	Lun – Part

	Sep 13	***Sol – Part***
	Sep 28	Lun – Tot
2016	***Mar 9***	***Sol – Tot***
	Mar 23	Lun – Pen
	Sep 1	***Sol – Ann***
	Sep 16	Lun – Pen
2017	Feb 11	Lun – Pen
	Feb 26	***Sol – Ann***
	Aug 7	Lun – Part
	Aug 21	***Sol – Tot***
2018	Jan 31	Lun – Tot
	Feb 15	***Sol – Part***
	Jul 13	***Sol – Part***

2021	May 26	Lun – Tot
	Jun 10	***Sol – Ann***
	Nov 19	Lun – Part
	Dec 4	***Sol – Tot***
2022	***Apr 30***	***Sol – Part***
	May 16	Lun – Tot
	Oct 25	***Sol – Part***
	Nov 8	Lun – Tot
2023	***Apr 20***	***Sol – Hyb***
	May 5	Lun – Pen
	Oct 14	***Sol – Ann***
	Oct 28	Lun - Part

2024	Mar 25	Lun – Pen
	Apr 8	***Sol – Tot***
	Sep 18	Lun – Part
	Oct 2	***Sol – Ann***
2025	Mar 14	
	Mar 29	
	Sep 7	
	Sep 21	
2026	***Feb 17***	***Sol – Ann***
		Lun – Tot
		Sol – Tot
		Lun – Part

2021	May 26	Lun – Tot
	Jun 10	***Sol – Ann***
	Nov 19	Lun – Part
	Dec 4	***Sol – Tot***
2022	***Apr 30***	***Sol – Part***
	May 16	Lun – Tot
	Oct 25	***Sol – Part***
	Nov 8	Lun – Tot
2023	***Apr 20***	***Sol – Hyb***
	May 5	Lun – Pen
	Oct 14	***Sol – Ann***
	Oct 28	Lun - Part

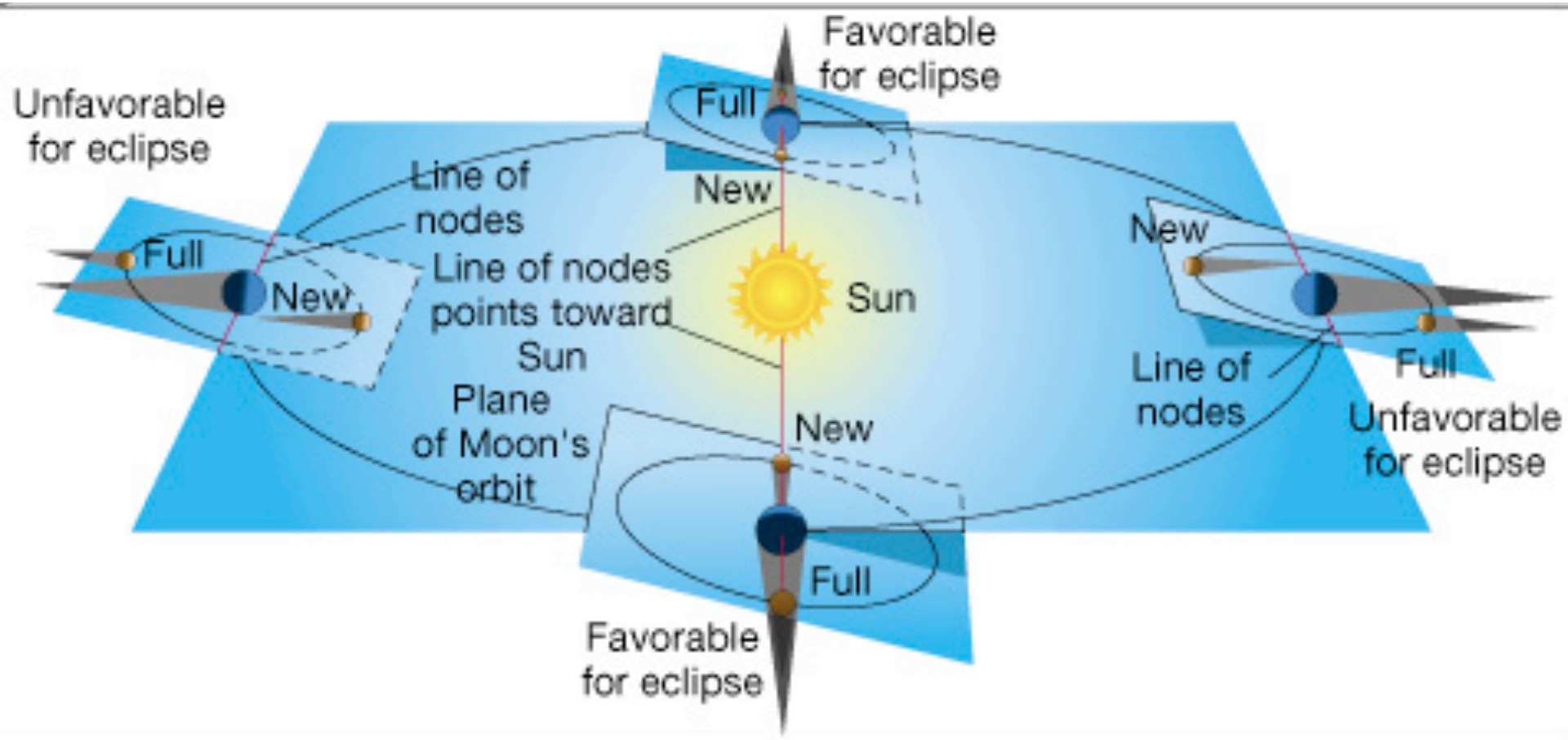
2024	Mar 25	Lun – Pen
	Apr 8	***Sol – Tot***
	Sep 18	Lun – Part
	Oct 2	***Sol – Ann***
2025	Mar 14	Lun – Tot
	Mar 29	***Sol – Part***
	Sep 7	Lun – Tot
	Sep 21	***Sol – Part***
2026	***Feb 17***	***Sol – Ann***
	Mar 3	Lun – Tot
	Aug 12	***Sol – Tot***
	Aug 28	Lun – Part

Frequency of Solar Eclipses

- A solar eclipse can *only* occur during a *new* Moon, but does not occur at *every* new Moon.
- In order to occur, the Moon must be new at about the same time it is crossing the ecliptic.
- There are typically two solar eclipses per year, occurring about 6 months apart.

Frequency of Lunar Eclipses

- A lunar eclipse can *only* occur during a *full* Moon, but does not occur at *every* full Moon.
- In order to occur, the Moon must be full at about the same time it is crossing the ecliptic.
- There are typically two lunar eclipses per year, occurring about 6 months apart.
- A lunar eclipse is followed two weeks later by a solar eclipse, or vice versa – most often a pair with one of each, but sometimes a triplet. These are the alternating “eclipse seasons” shown by the shading in the preceding tables.


Favorable
for eclipse
Unfavorable
for eclipse
Full
New
Line of
nodes
Line of nodes
points toward
Sun
Plane
of Moon's
orbit
Sun
Full
New
New
Line of
nodes
Full
Unfavorable
for eclipse
New
Full
Favorable
for eclipse

A simplified 3-D view of Moon orbiting Earth while Earth orbits the Sun

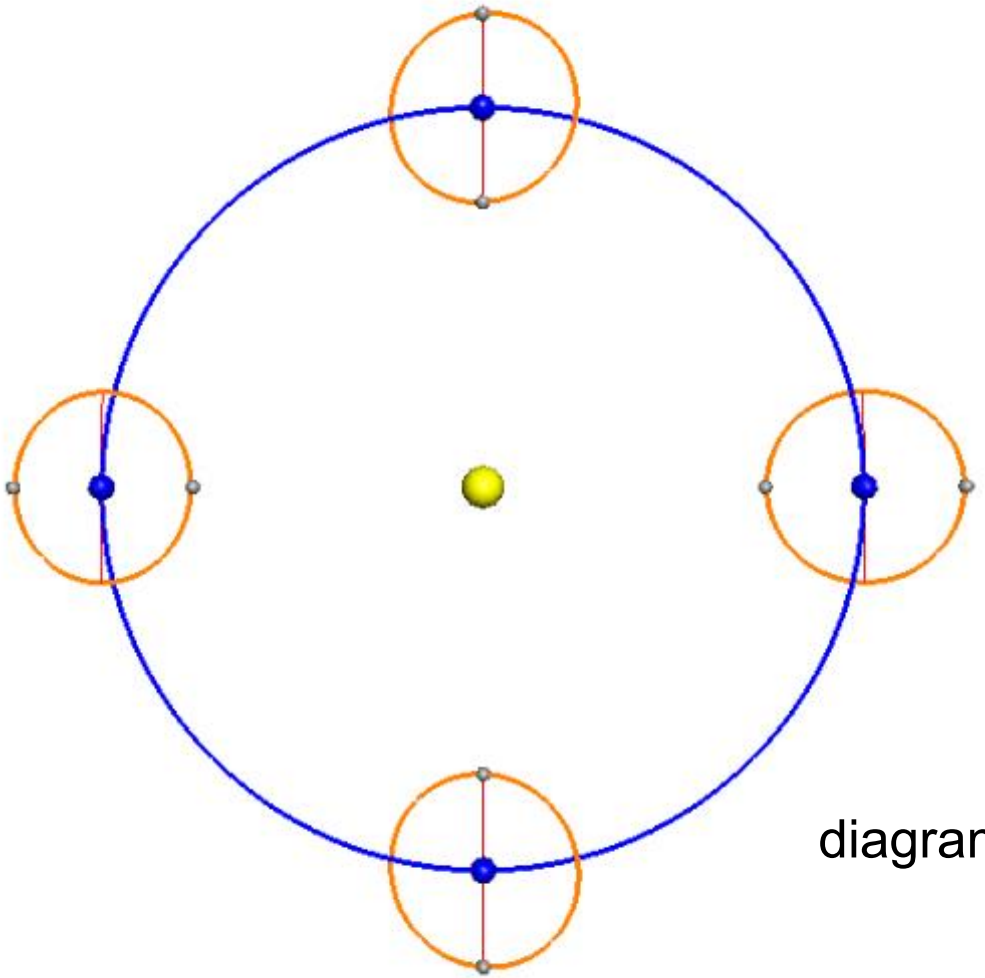


diagram is not to scale

The red line shows the orientation of the intersection of the plane of Earth's orbit with the plane of Moon's orbit – this is called the "line of nodes".

A simplified 3-D view of Moon orbiting Earth while Earth orbits the Sun

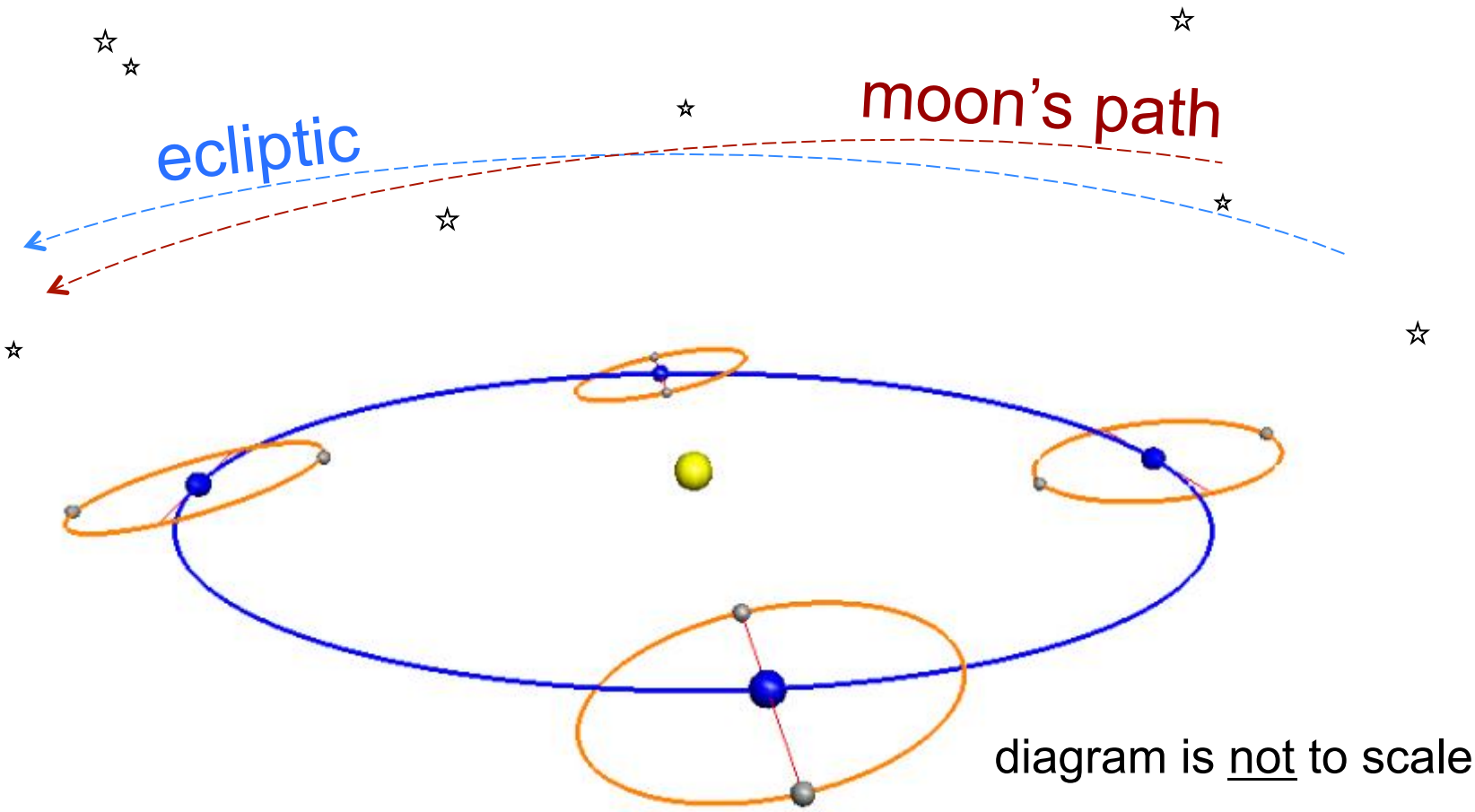
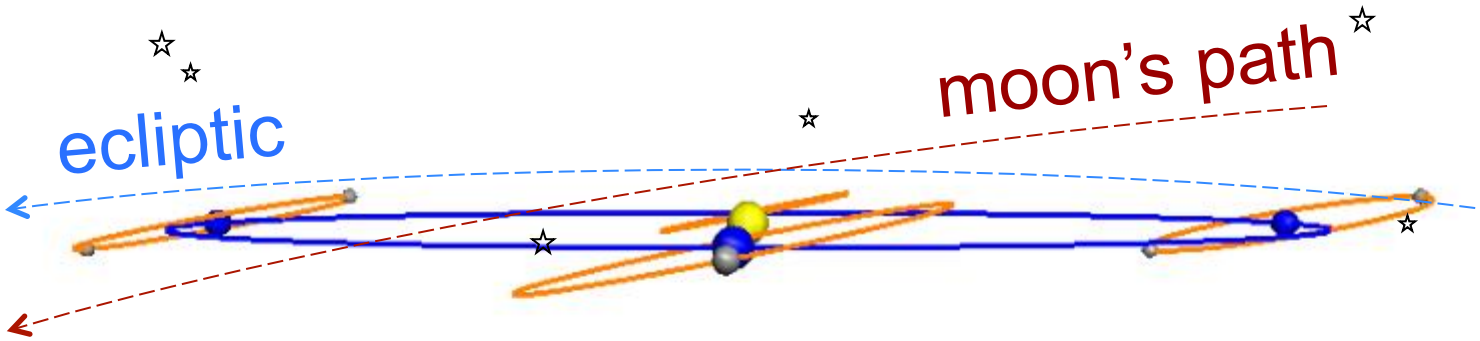


diagram is <u>not</u> to scale

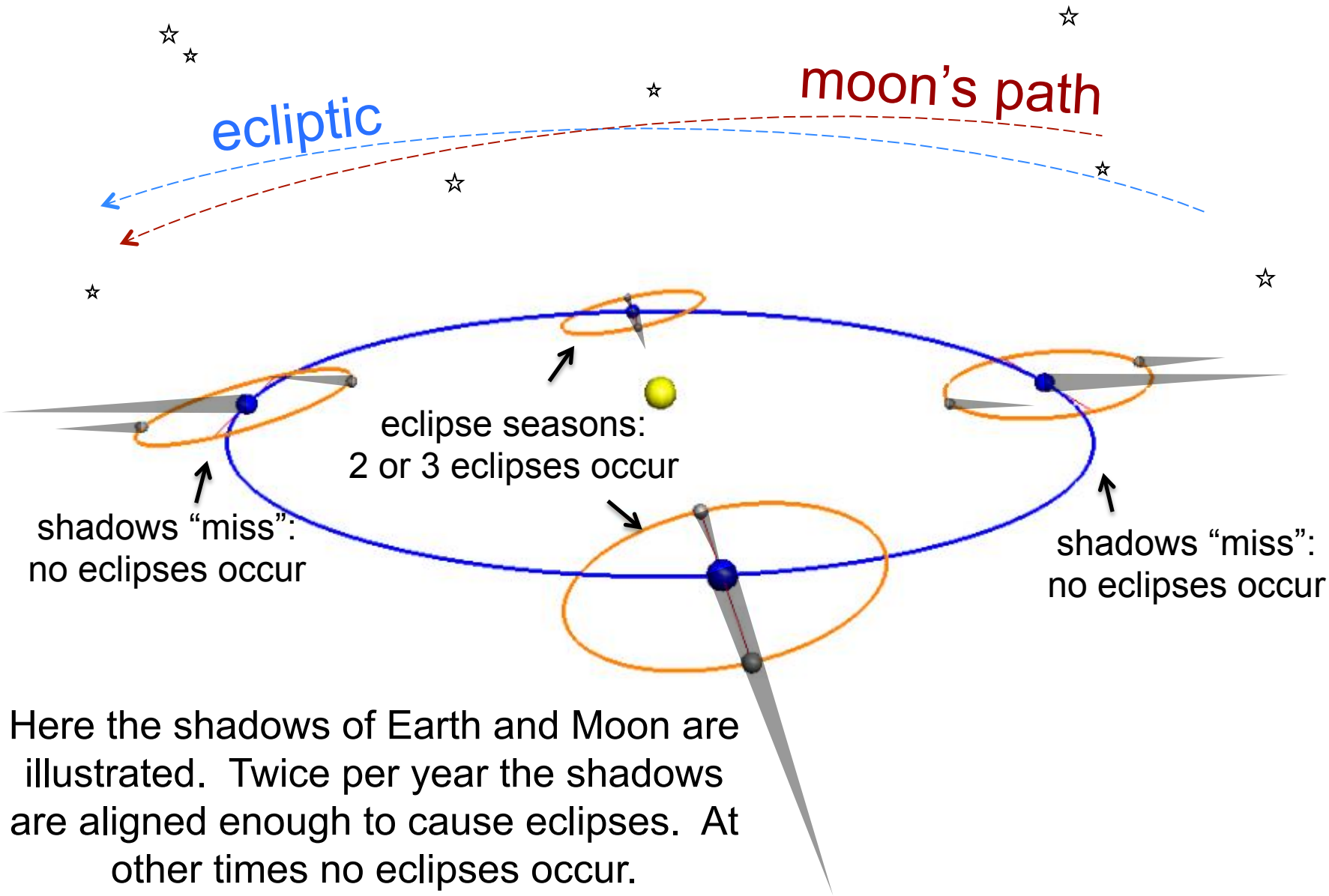
An observer on the Earth shown on "this side" of the orbit would see the ecliptic and Moon's path on the celestial sphere "background of stars" as illustrated here.

A simplified 3-D view of Moon orbiting Earth while Earth orbits the Sun



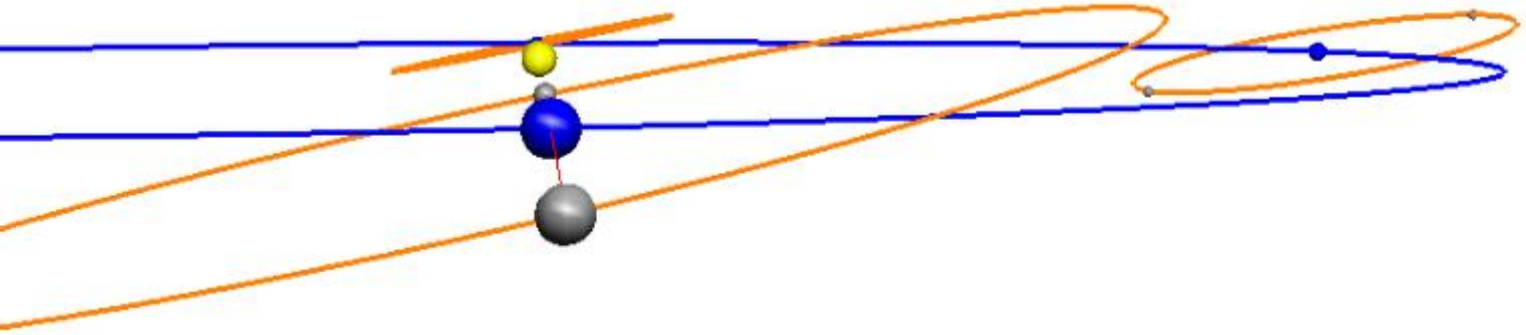
An observer on the Earth shown on "this side" of the orbit would see the ecliptic and Moon's path on the celestial sphere "background of stars" as illustrated here.

diagram is <u>not</u> to scale

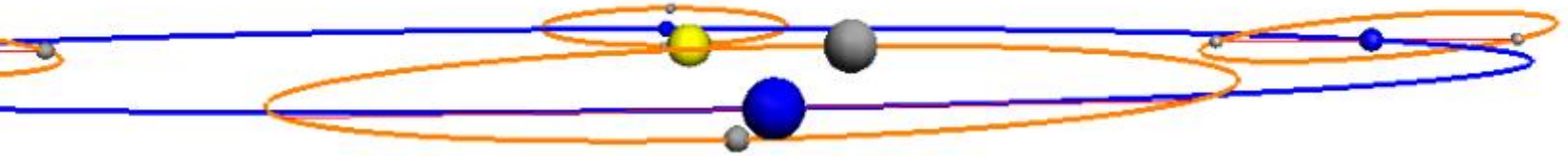


Here the shadows of Earth and Moon are illustrated. Twice per year the shadows are aligned enough to cause eclipses. At other times no eclipses occur.

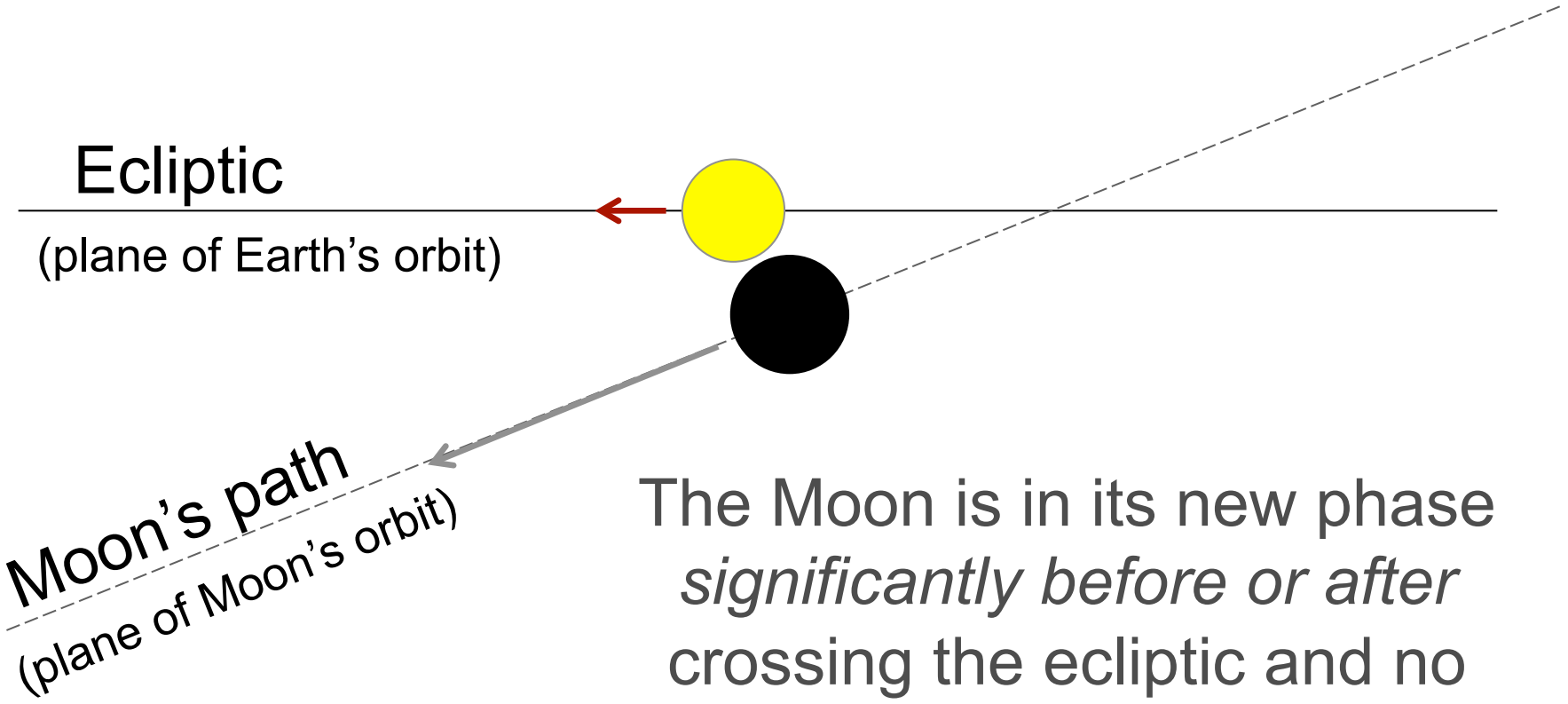
A simplified 3-D view of Moon orbiting Earth while Earth orbits the Sun



diagrams are <u>not</u> to scale

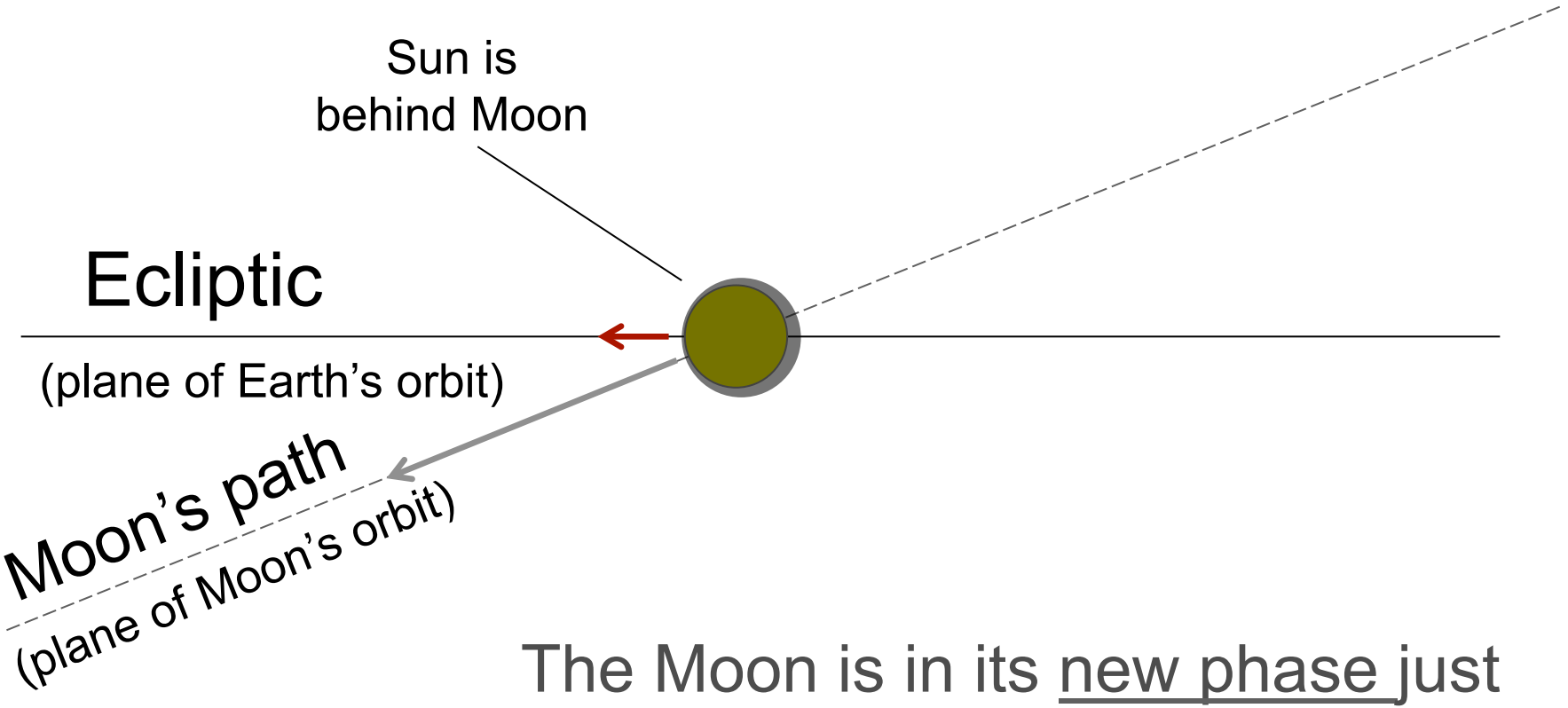


No Eclipse!



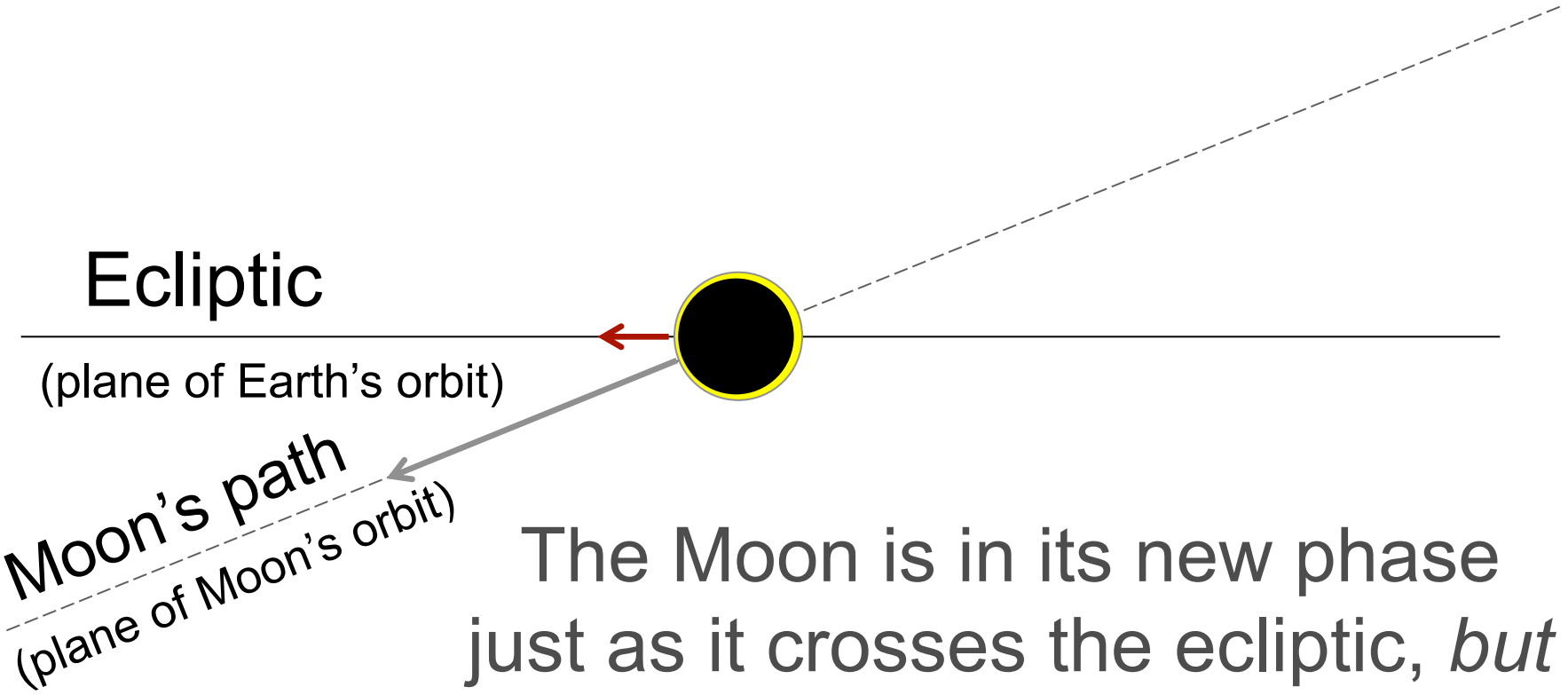
The Moon is in its new phase *significantly before or after* crossing the ecliptic and no part of the Sun is covered by it.

A Total Solar Eclipse



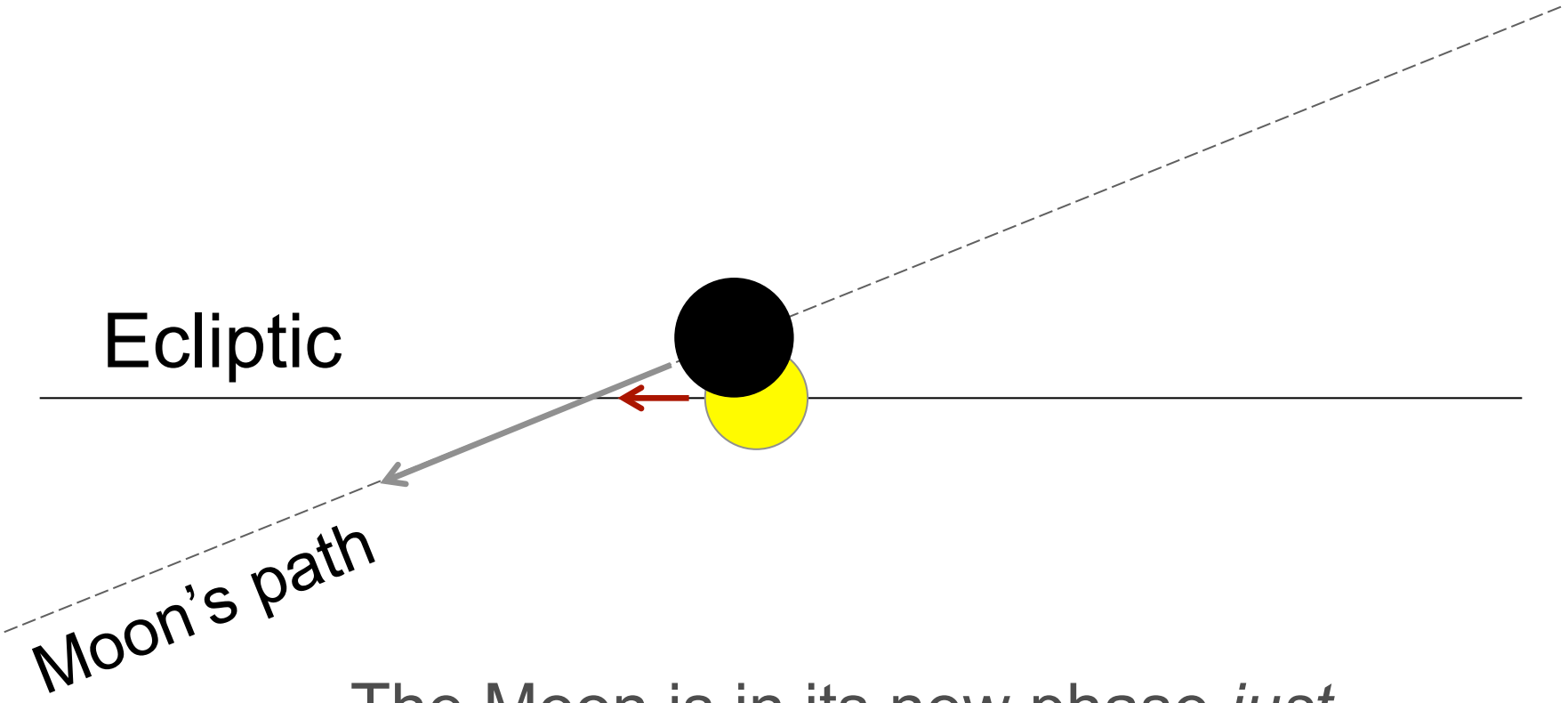
The Moon is in its <u>new phase</u> just as it crosses the ecliptic and at some point completely obscures the bright surface of the Sun.

An Annular Solar Eclipse

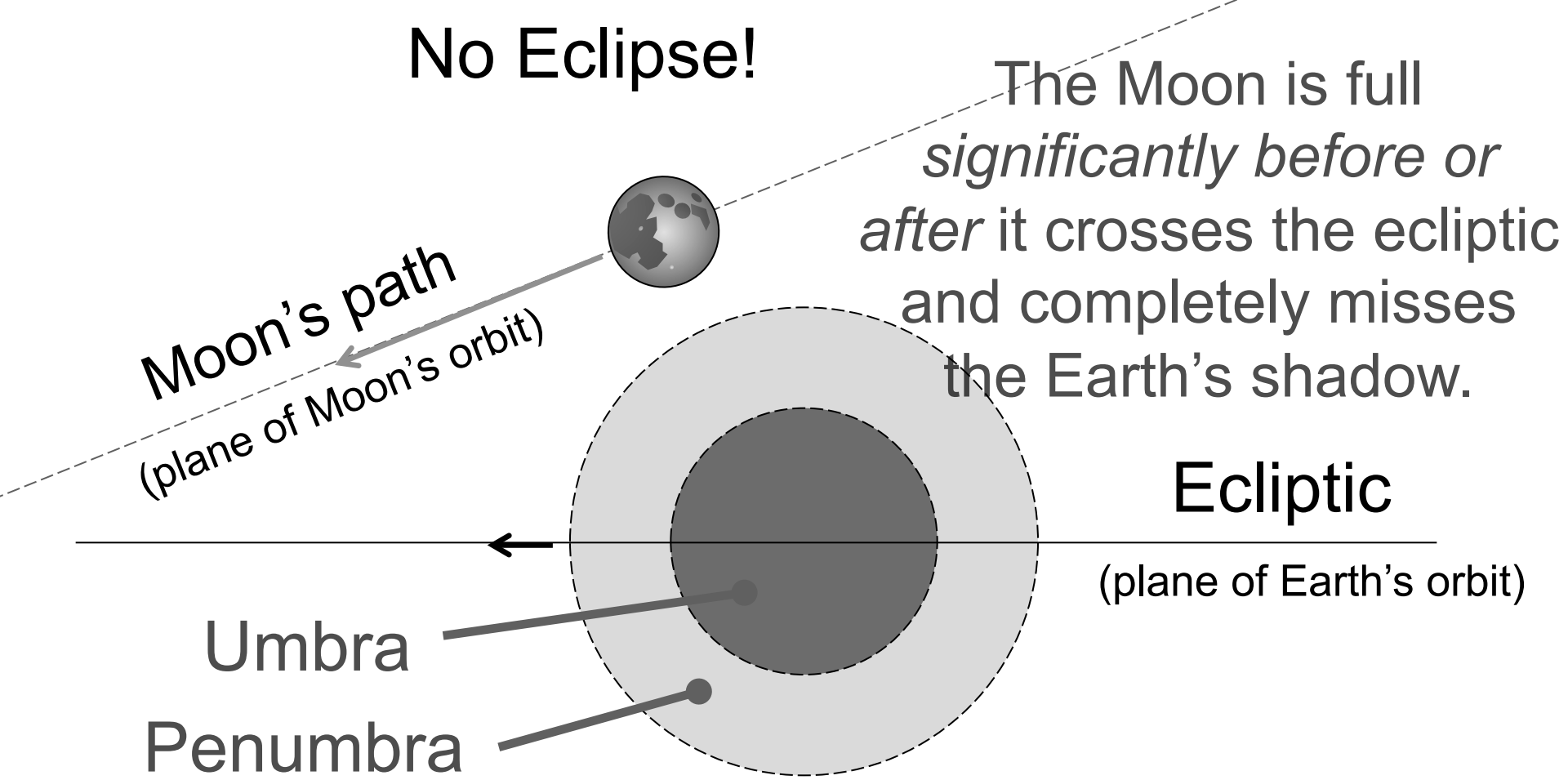


The Moon is in its new phase just as it crosses the ecliptic, *but* the Sun's angular diameter is greater and at a certain point it appears like a bright ring.

A Partial Solar Eclipse

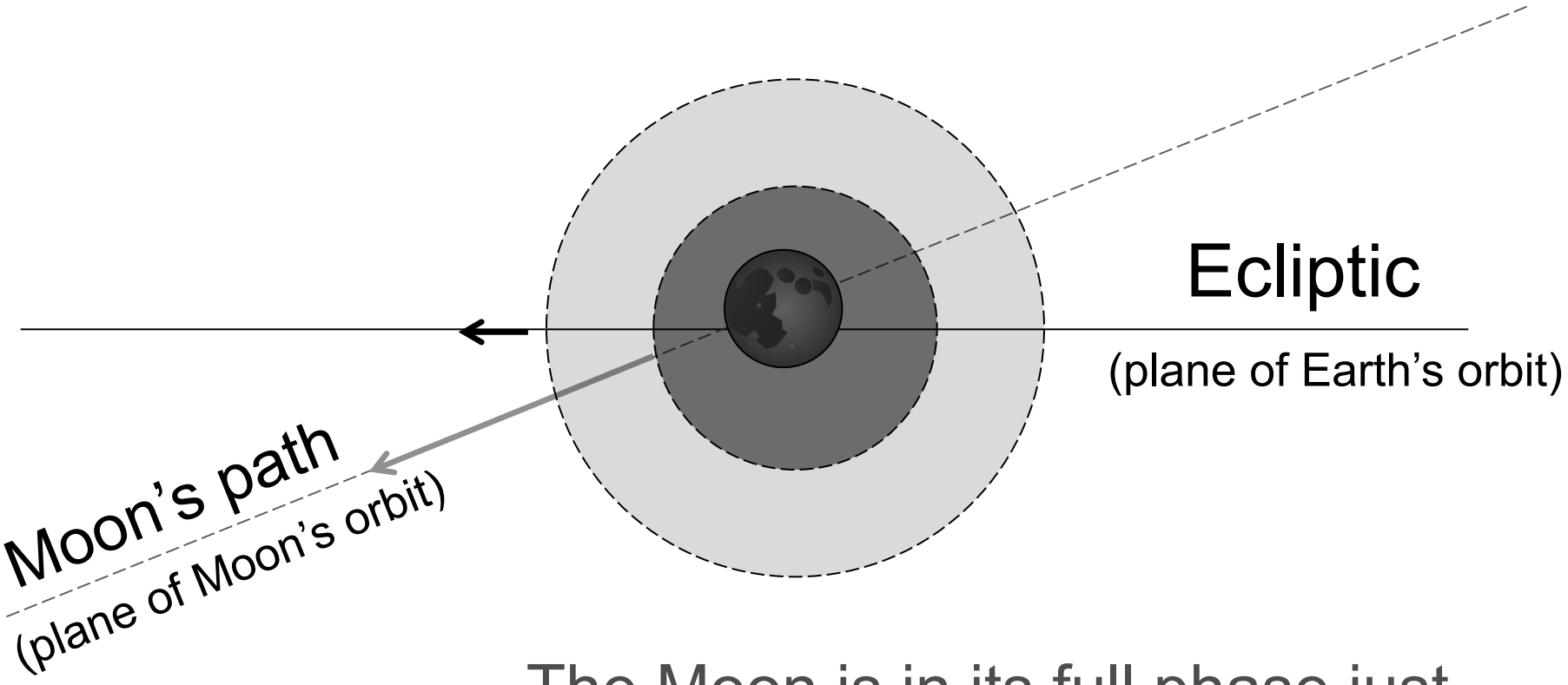


The Moon is in its new phase *just before* or *just after* crossing the ecliptic and obscures only part of the bright surface of the Sun.



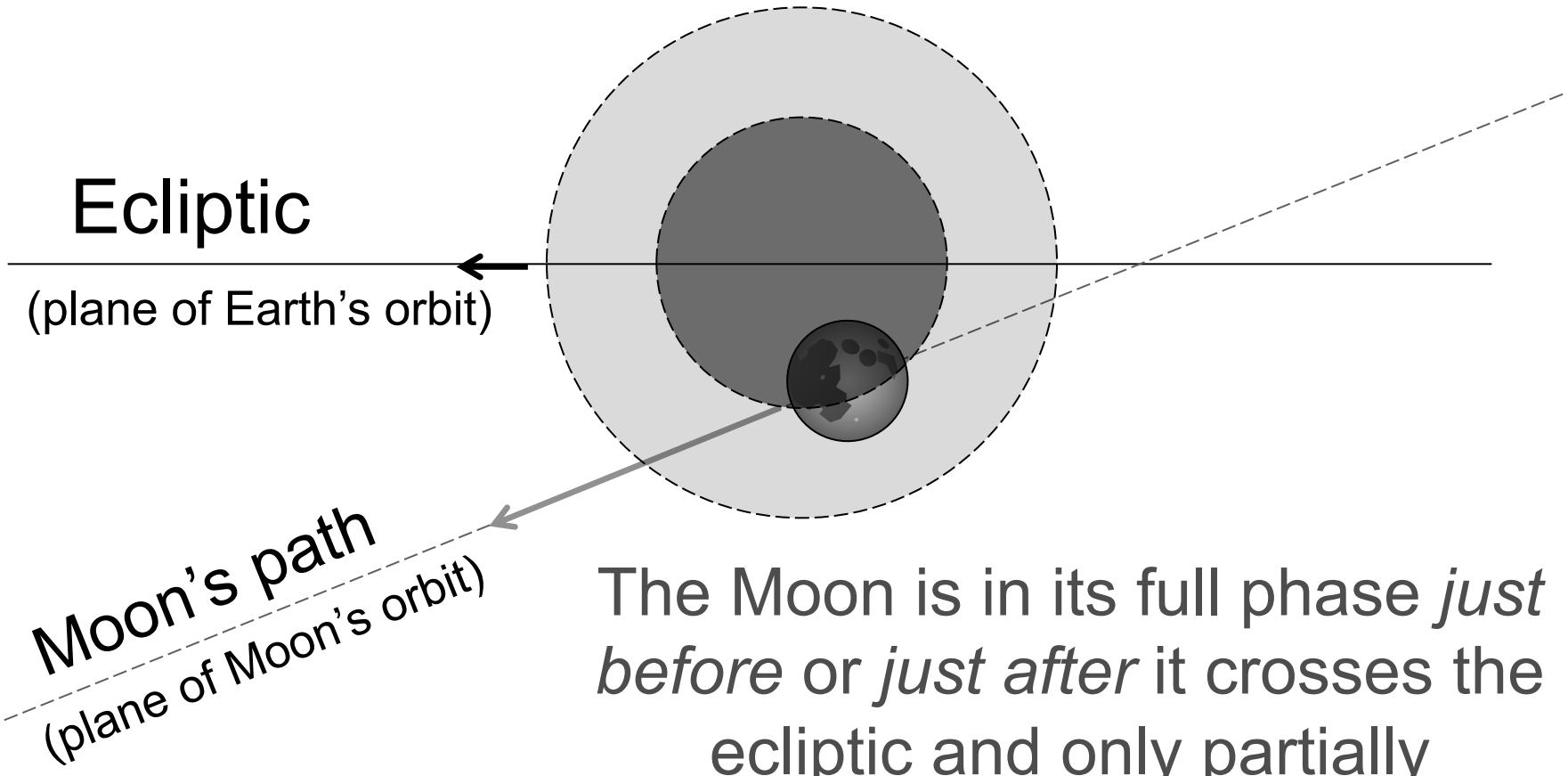
The Earth's shadow always lies in the plane of its orbit. Therefore its umbra and penumbra are always located centered on the ecliptic exactly opposite the Sun's location on the ecliptic. As the Sun traverses the ecliptic, so too does the Earth's shadow, in link step on the opposite side of the ecliptic.

A Total Lunar Eclipse



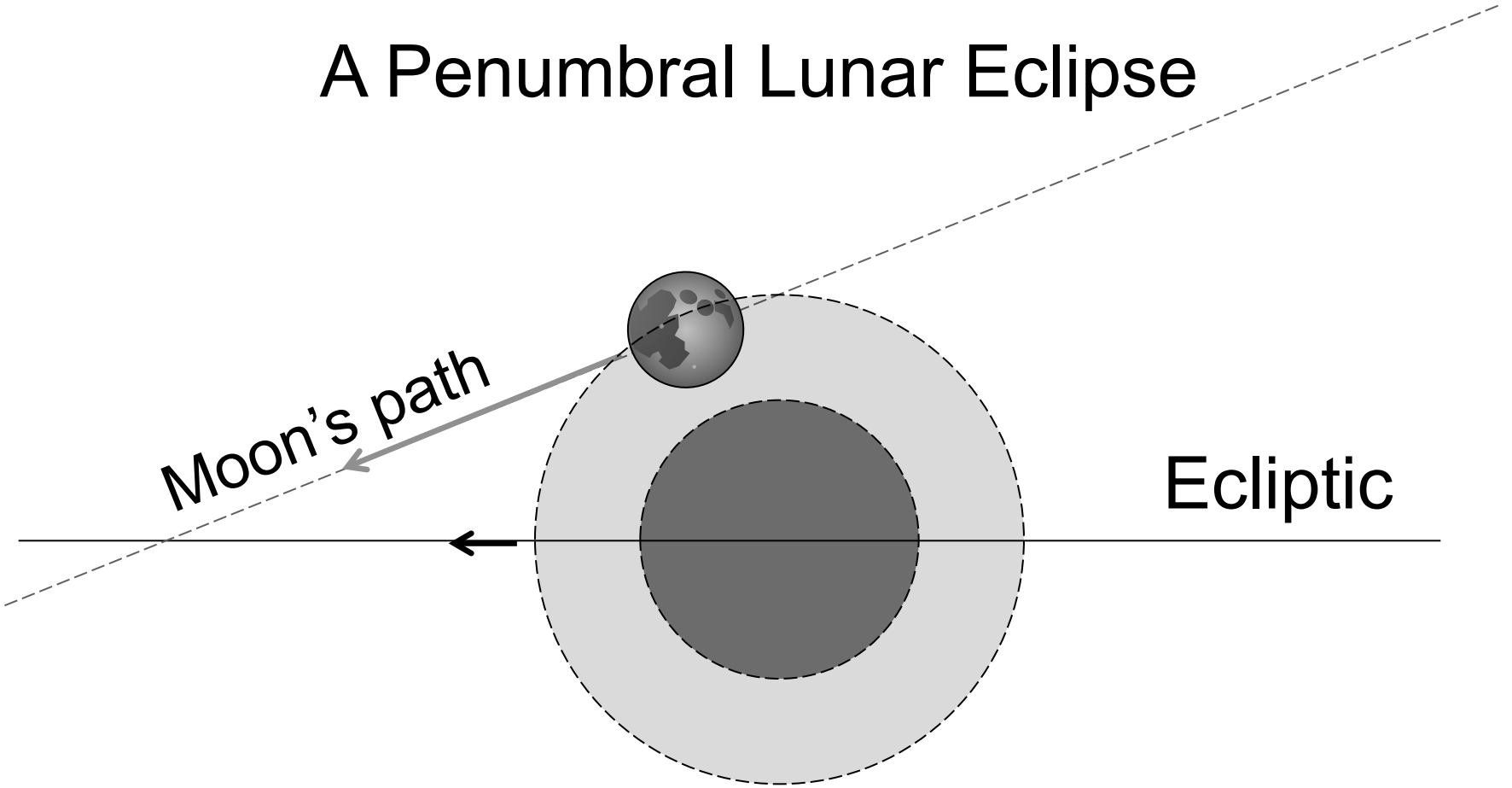
The Moon is in its full phase just as it crosses the ecliptic and is fully enveloped in the umbra.

A Partial Lunar Eclipse

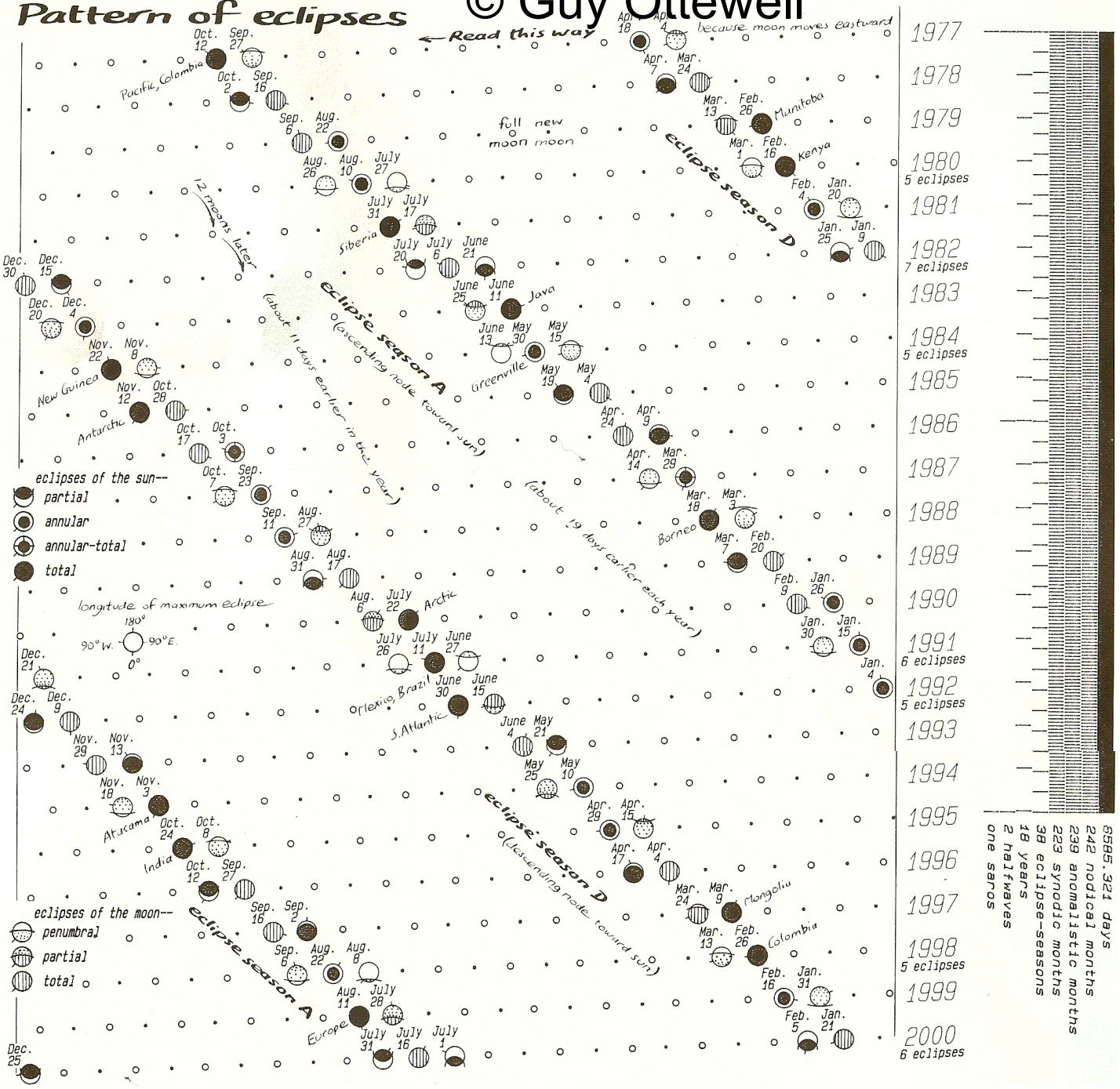


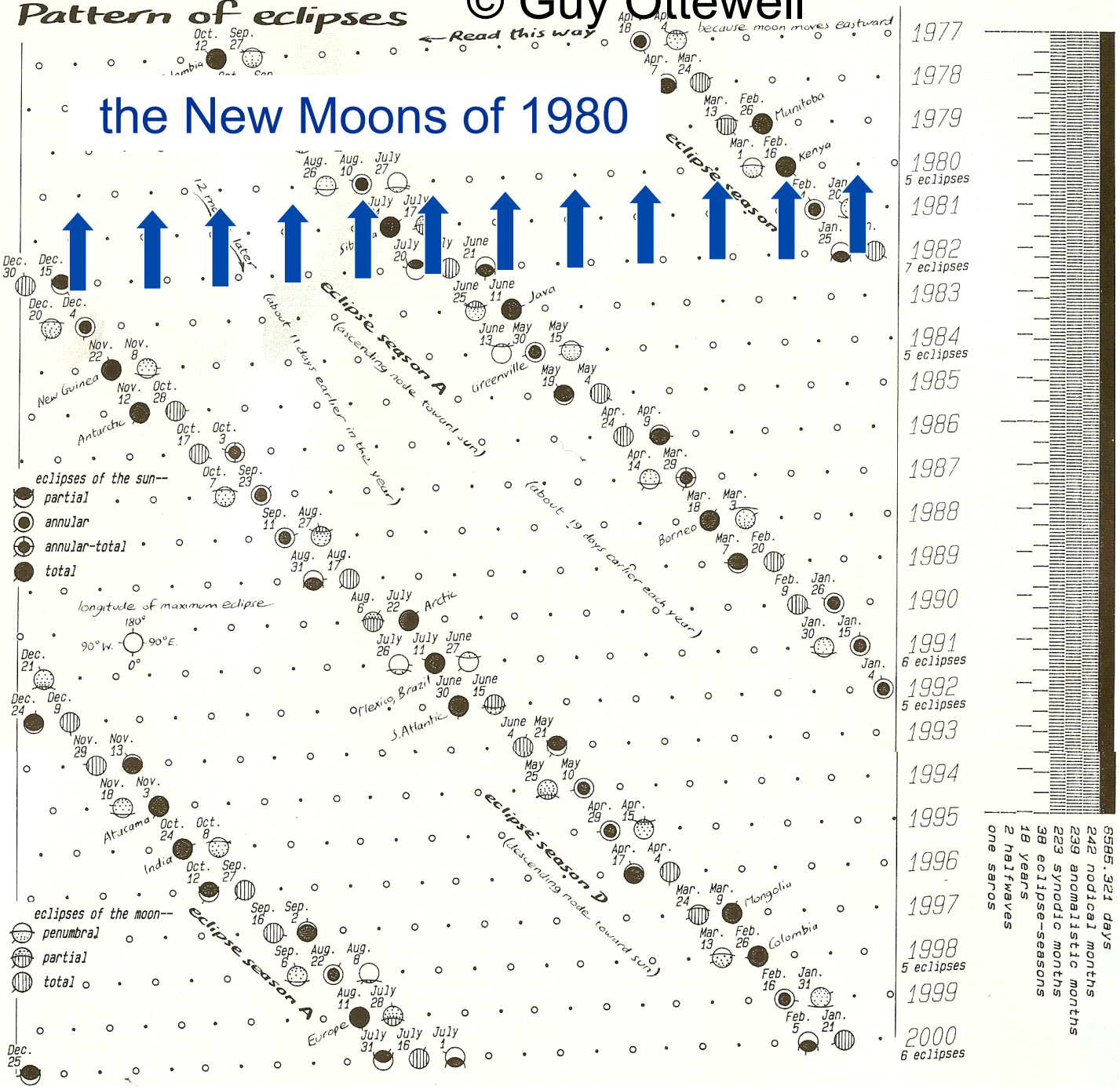
The Moon is in its full phase *just before* or *just after* it crosses the ecliptic and only partially encounters the umbra.

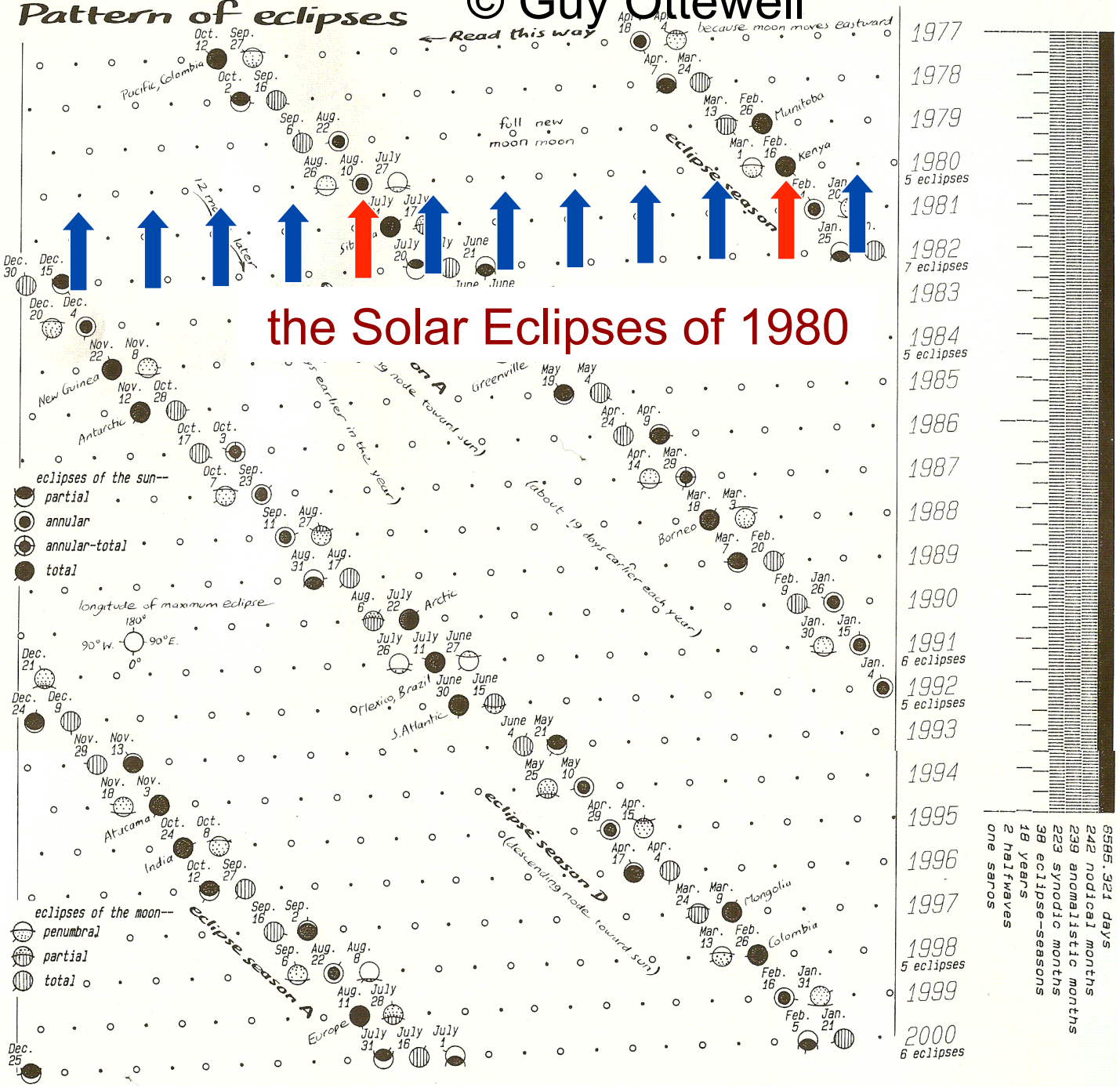
A Penumbral Lunar Eclipse



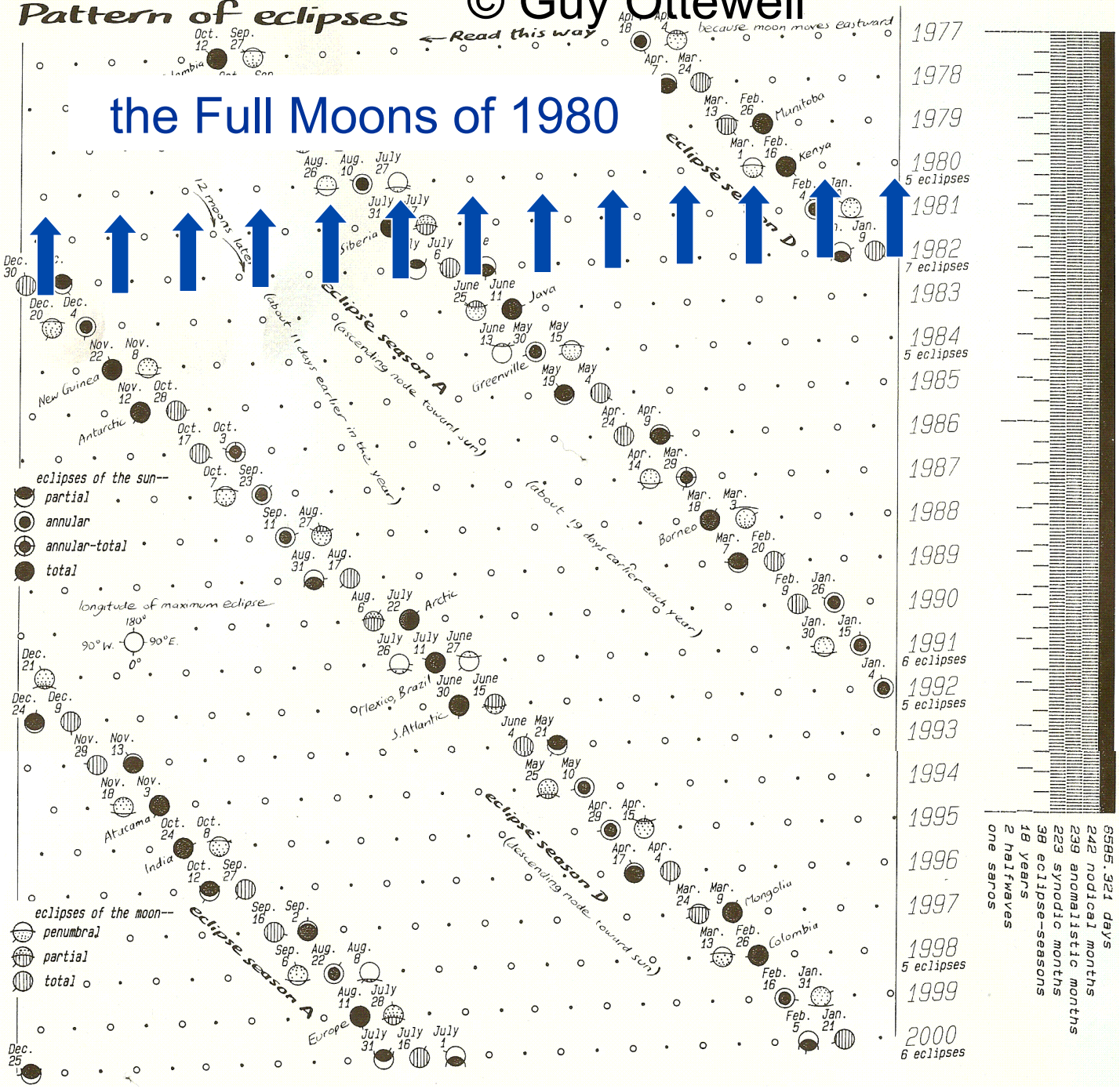
The Moon is in its full phase *significantly before or after* it crosses the ecliptic and encounters at least some part of the penumbra but never touches the umbra.

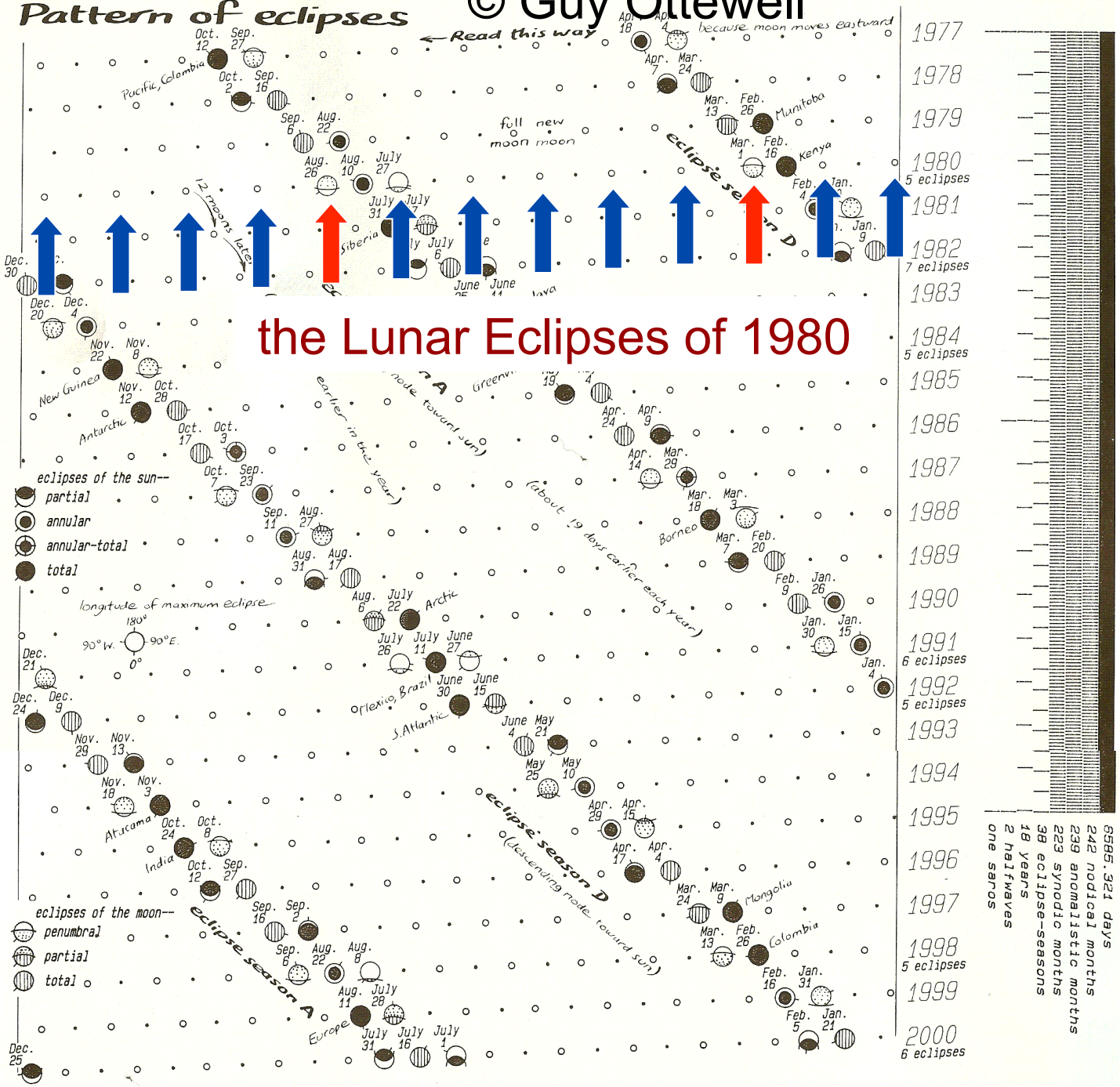




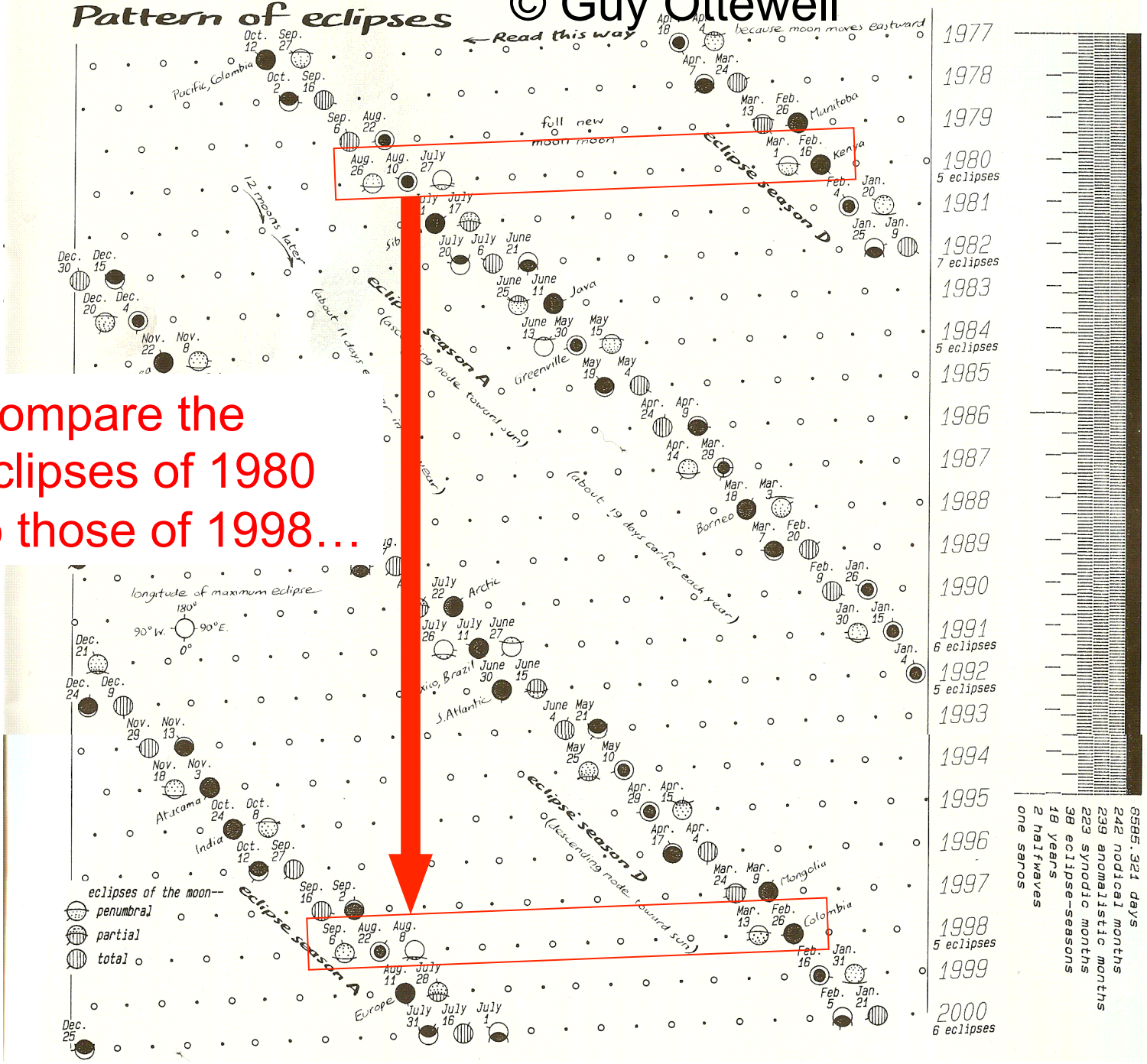


the Solar Eclipses of 1980

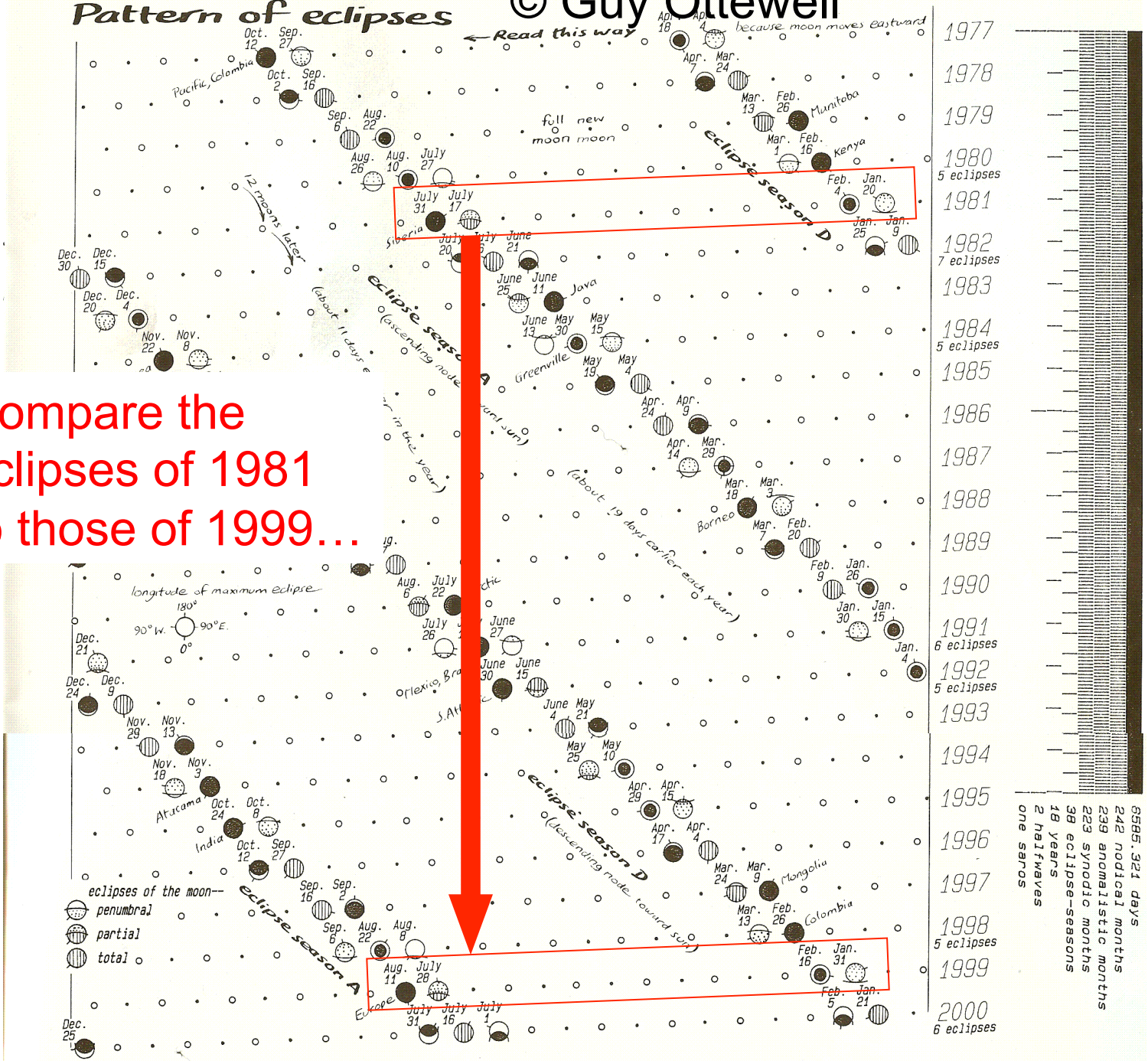




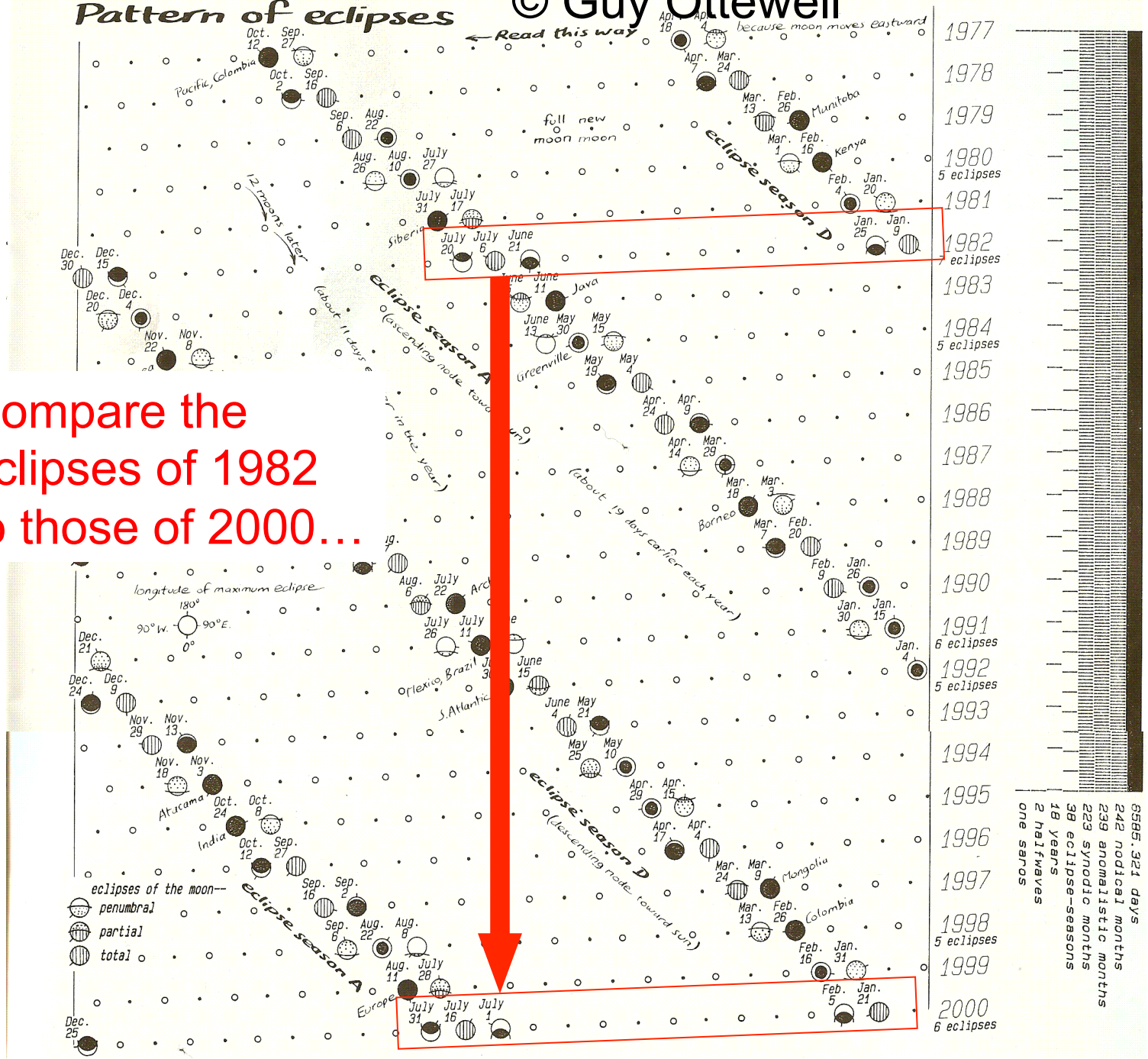
the Lunar Eclipses of 1980



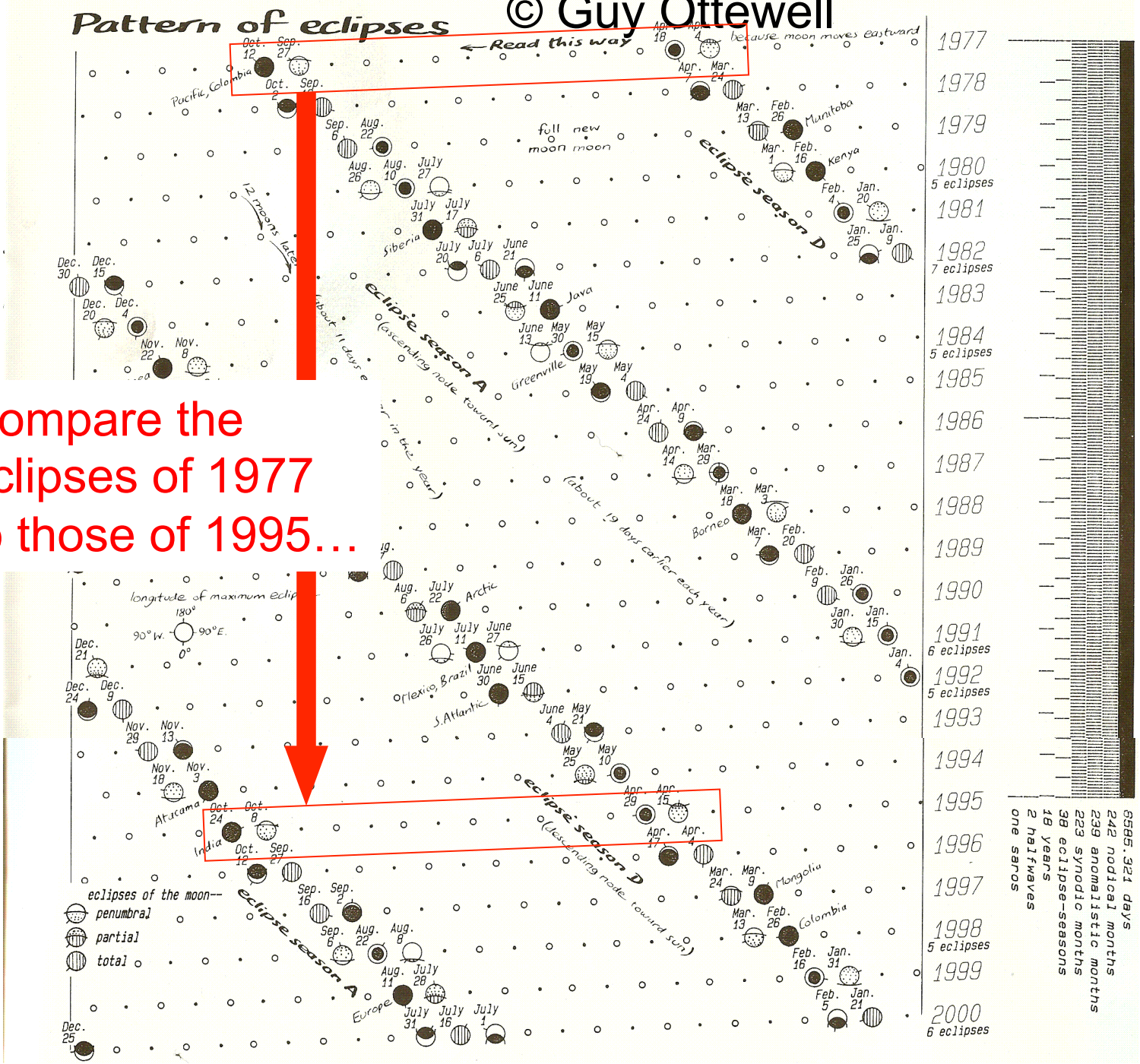
Compare the eclipses of 1980 to those of 1998…



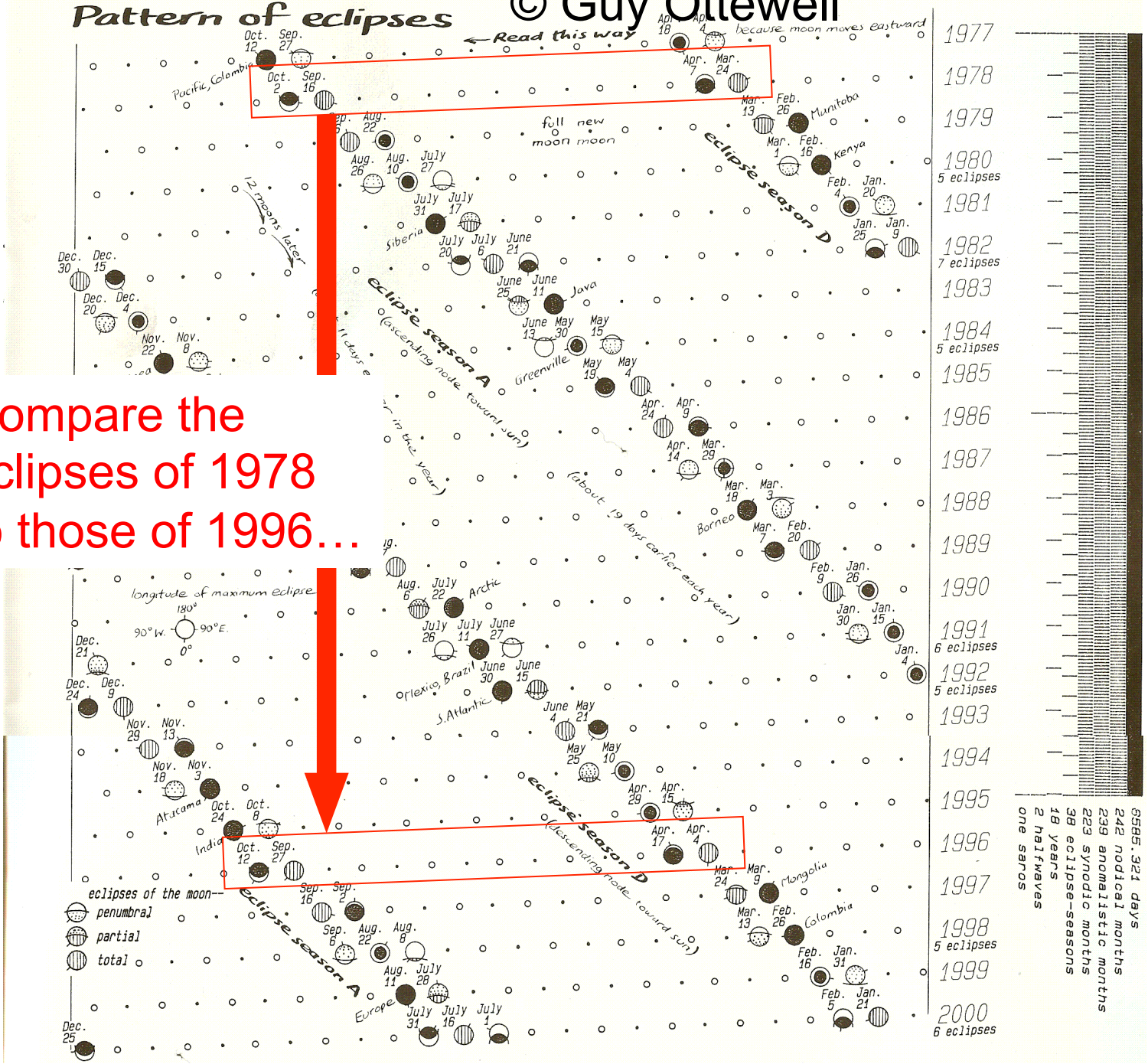
Compare the eclipses of 1981 to those of 1999…



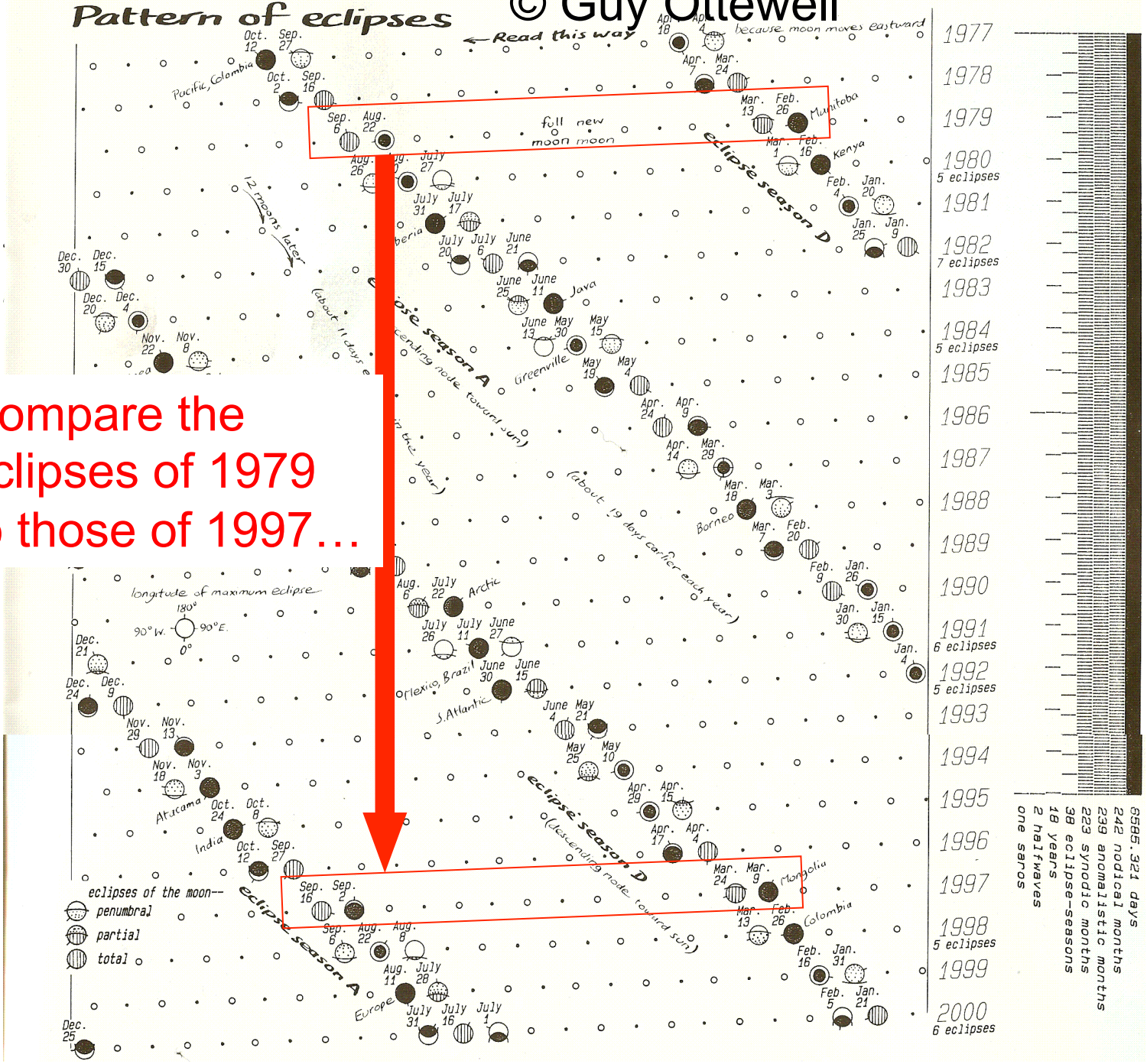
Compare the eclipses of 1982 to those of 2000…



Compare the eclipses of 1977 to those of 1995…



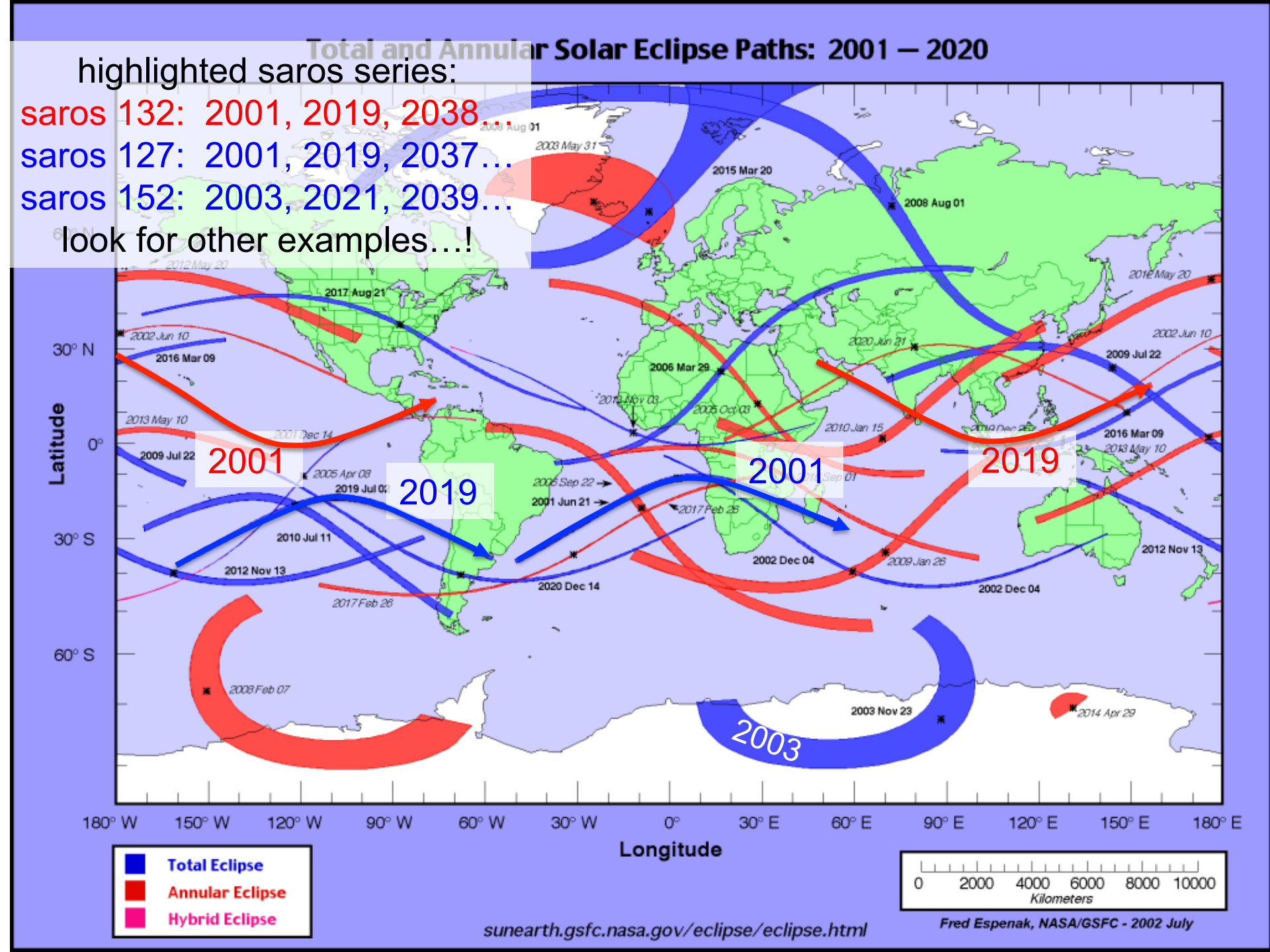
Compare the eclipses of 1978 to those of 1996…

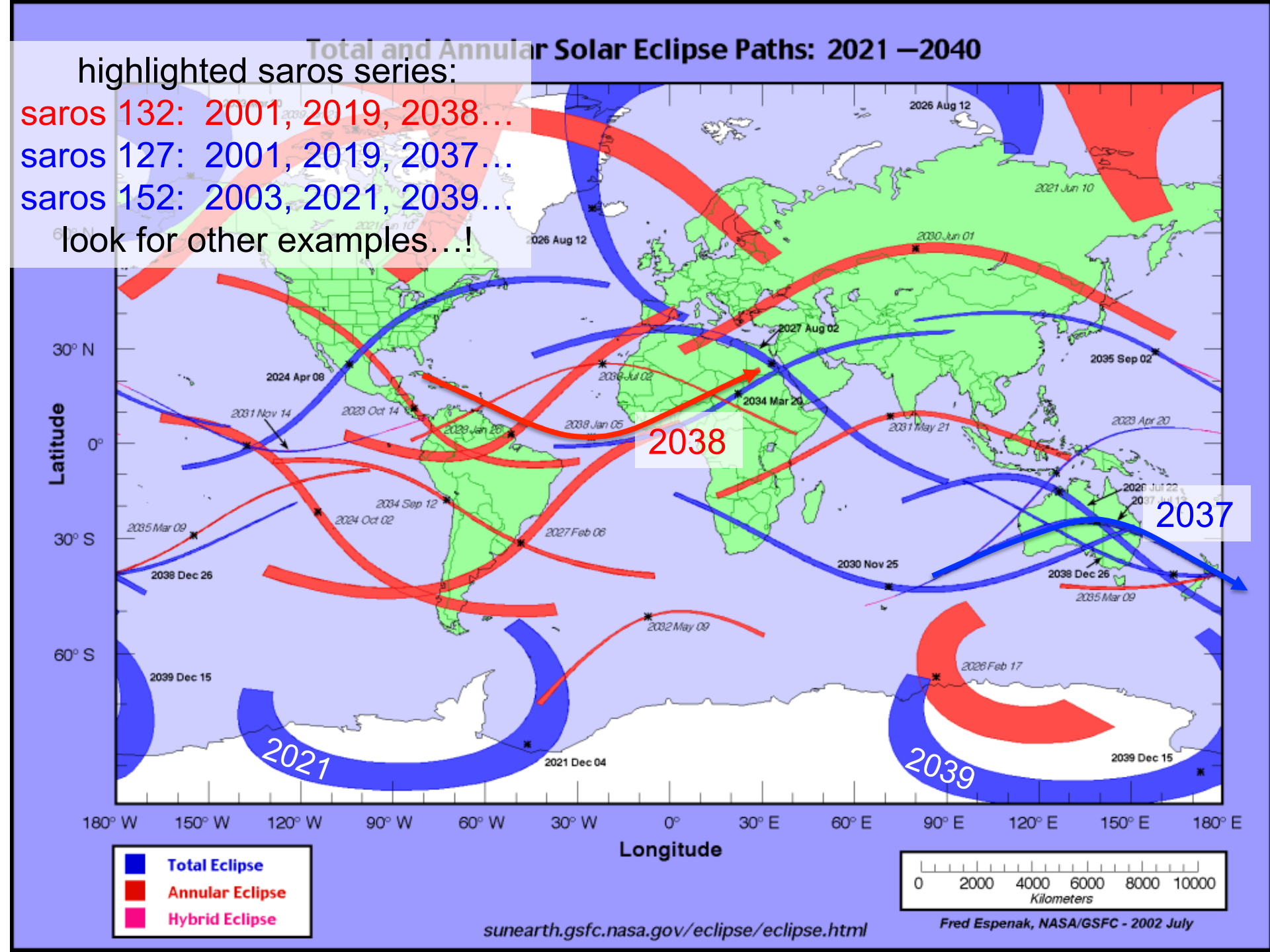


Compare the eclipses of 1979 to those of 1997…

the Saros

- Every 18 years 11 days a pattern of eclipses is repeated. This is called “the Saros”.
- The solar eclipses every 18 years are of the same type, similar duration, and follow similar paths across Earth. However, the path will be about 120º farther west in longitude.
- A similar 18 year pattern exists for the lunar eclipses as well.
- Each saros series is numbered and studied by astronomers.


Total and Annular Solar Eclipse Paths: 2001 – 2020
highlighted saros series:
saros 132: 2001, 2019, 2038…
saros 127: 2001, 2019, 2037…
saros 152: 2003, 2021, 2039…
look for other examples…!
2001
2019
2001
2019
2003
2015 Mar 20
2008 Aug 01
2017 Aug 21
2016 Mar 09
2006 Mar 29
2020 Jun 21
2009 Jul 22
2010 Jan 15
2016 Mar 09
2019 Jul 02
2010 Jul 11
2012 Nov 13
2020 Dec 14
2001 Jun 21
2017 Feb 26
2002 Dec 04
2009 Jan 26
2002 Dec 04
2012 Nov 13
2003 Nov 23
2014 Apr 29
2008 Feb 07
30° N
0°
30° S
60° S
Latitude
180° W
150° W
120° W
90° W
60° W
30° W
0°
30° E
60° E
90° E
120° E
150° E
180° E
Longitude
Total Eclipse
Annular Eclipse
Hybrid Eclipse
0
2000
4000
6000
8000
10000
Kilometers
sunearth.gsfc.nasa.gov/eclipse/eclipse.html
Fred Espenak, NASA/GSFC - 2002 July


highlighted saros series:
saros 132: 2001, 2019, 2038…
saros 127: 2001, 2019, 2037…
saros 152: 2003, 2021, 2039…
look for other examples…!
Total and Annular Solar Eclipse Paths: 2021 –2040
2026 Aug 12
2021 Jun 10
2030 Jun 01
2027 Aug 02
2035 Sep 02
2024 Apr 08
2031 Nov 14
2023 Oct 14
2034 Mar 20
2031 May 21
2023 Apr 20
2038
2037
2034 Sep 12
2024 Oct 02
2035 Mar 09
2027 Feb 06
2030 Nov 25
2038 Dec 26
2032 May 09
2026 Feb 17
2039 Dec 15
2021
2021 Dec 04
2039
30° N
0°
30° S
60° S
Latitude
180° W
150° W
120° W
90° W
60° W
30° W
0°
30° E
60° E
90° E
120° E
150° E
180° E
Longitude
Total Eclipse
Annular Eclipse
Hybrid Eclipse
0
2000
4000
6000
8000
10000
Kilometers
sunearth.gsfc.nasa.gov/eclipse/eclipse.html
Fred Espenak, NASA/GSFC - 2002 July