

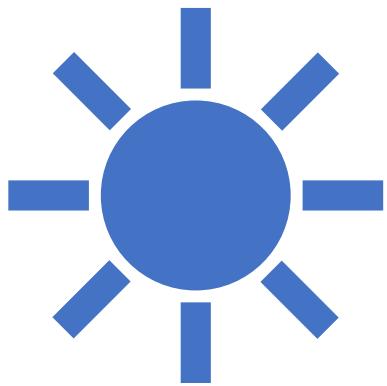
# AWE: Astronomy Workshop for Everyone

From Bangalore Astronomy Society  
At BMS College of Engineering, Bengaluru  
24 November 2024

## Eclipses: A Game of Light and Shadows

Sankar Viswanathan

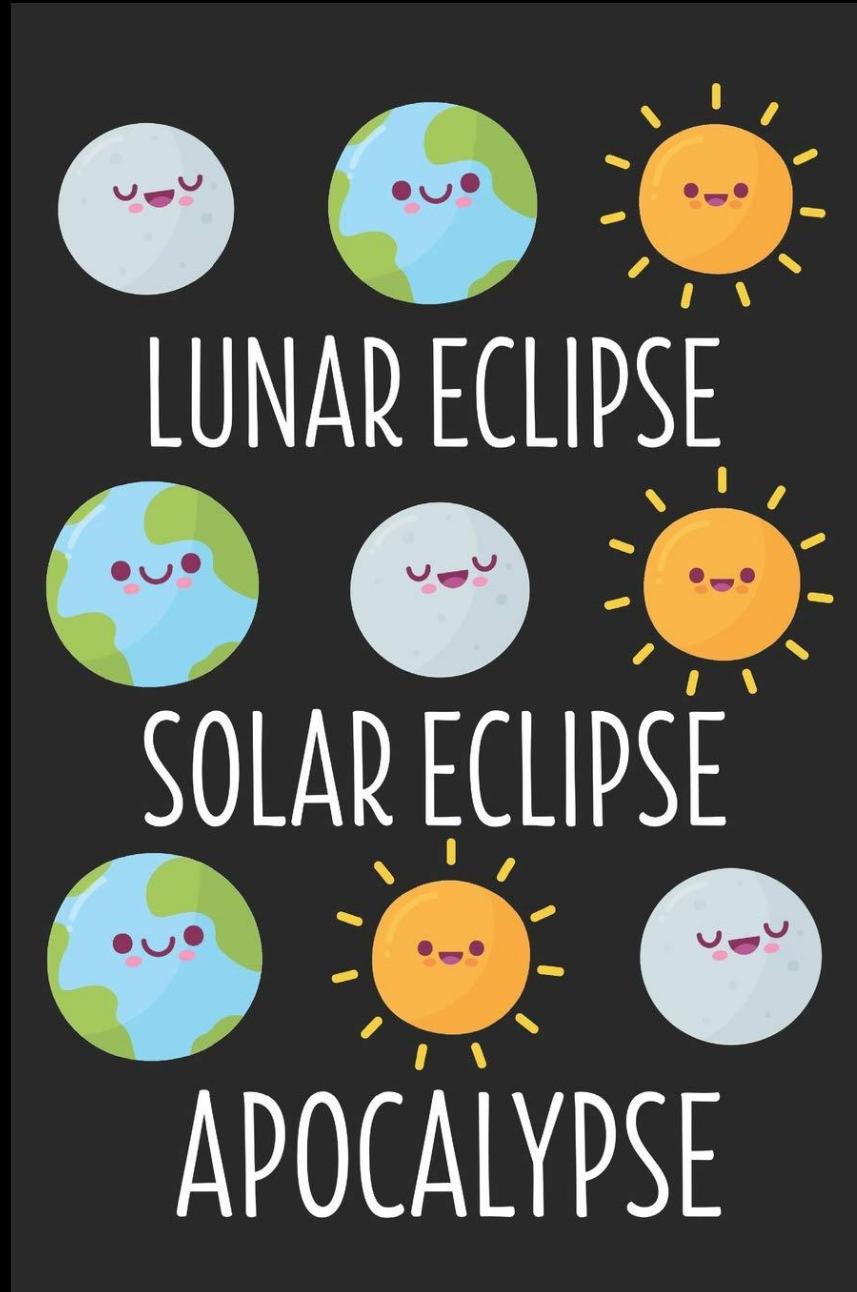




What's a solar eclipse?



What's a lunar eclipse?



Source: <https://www.amazon.in/Lunar-Eclipse-Solar-Apocalypse-Astronomer/dp/107444535X>

# Objectives of this Talk

- Gain a perspective on solar and lunar eclipses
- Focus on
  - Geometry
  - Light and shadows
  - Orbits and motion
  - Temporal patterns
- What this talk is *not* about
  - History of eclipse predictions
  - Eclipse photography
  - Science during eclipses

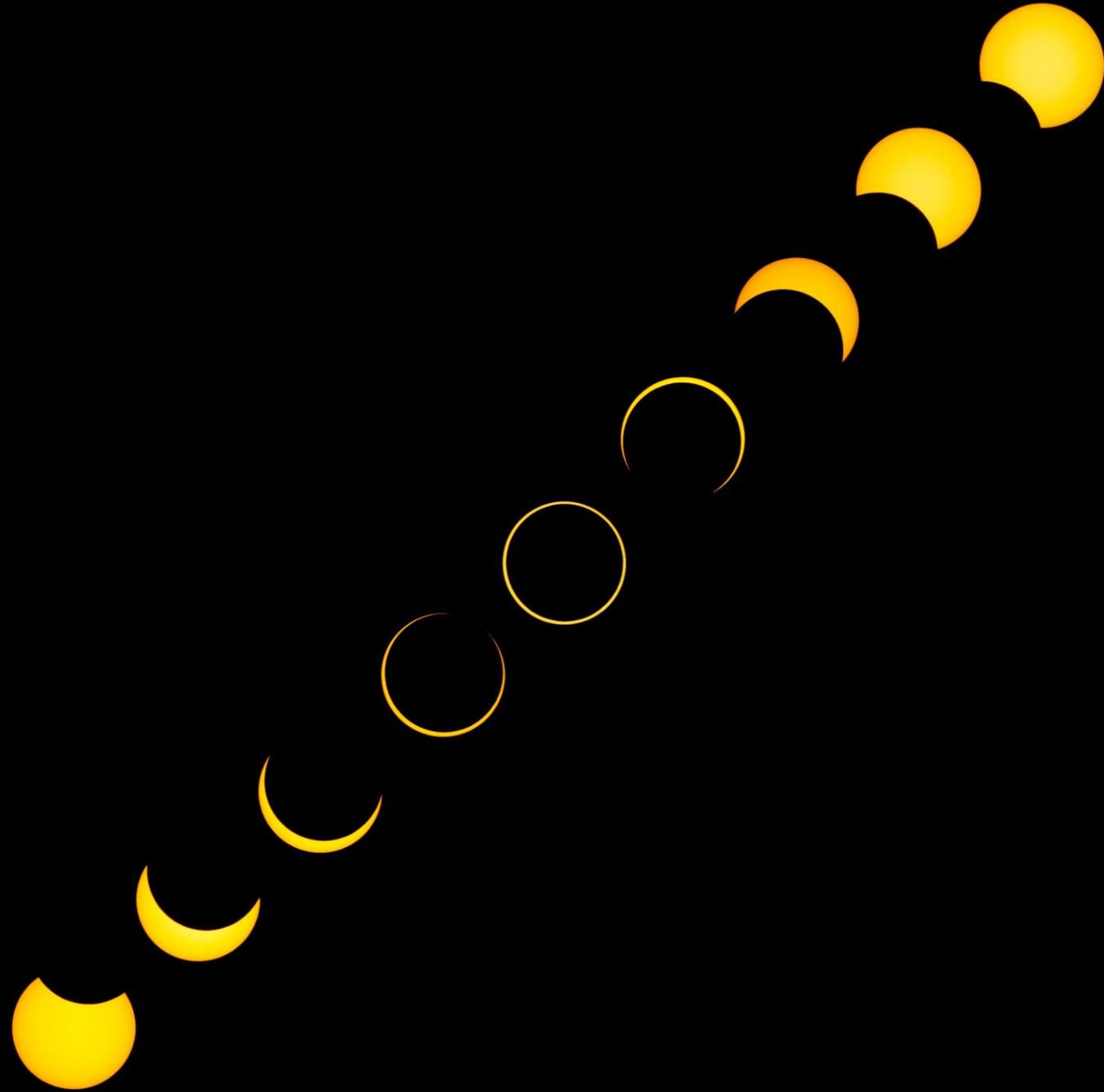
# Outline

- Introduction (Slides 1-14; 10')
- Geometry (Slides 15-23; 10'-15')
- Actual and Apparent Sizes (Slides 24-47; 10'-15')
- Predicting Eclipses (Slides 48-64; 15'-20')
- Resources

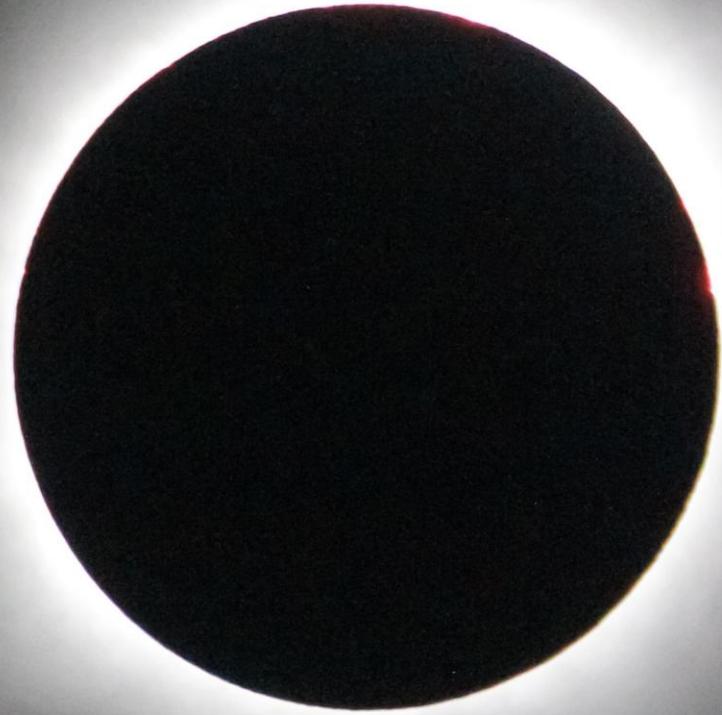
# Let's See Some Eclipse Photos...



*Image credit and © Subhendu Malakar. A composite image of the partial solar eclipse of 2020.*



*Image credit and © Mihir Athale. Composite Image of Annular Eclipse of 2019 as seen from Kerala.*



© Obuli Chandran

*Image credit and © Obuli Chandran. Total Eclipse 2024 – Totality from Plano, Texas.*



*Image credit and © Obuli Chandran. Total Eclipse 2024 – Prominences Seen from Plano, Texas.*  
© Obuli Chandran



© Obuli Chandran *Image credit and © Obuli Chandran. Total Eclipse 2024 – Diamond Ring from Plano, Texas.*



*Image credit and © Gautham Ramachandra. Partial lunar eclipse of October 28, 2023, from Bangalore, India.*



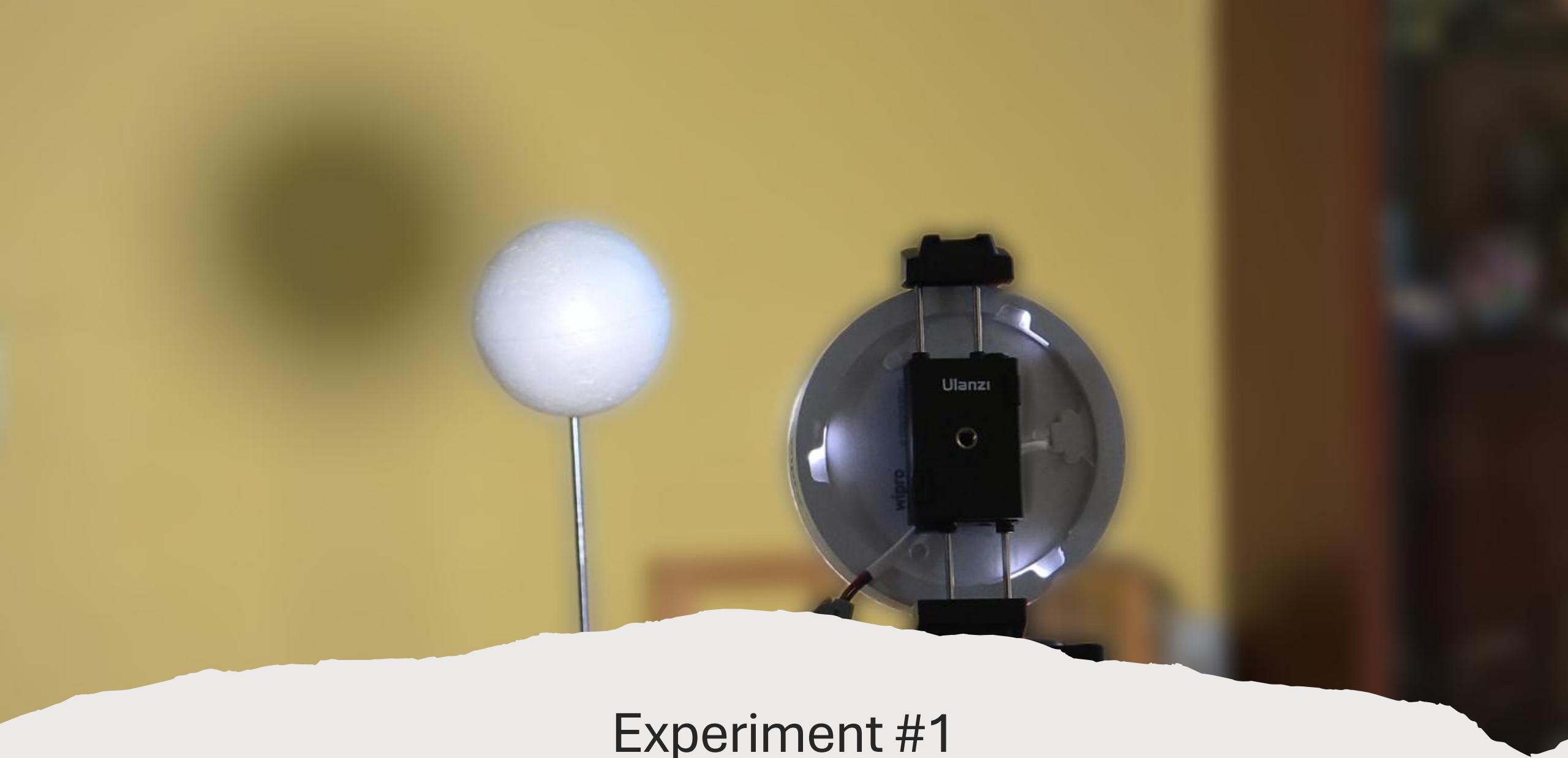
*Image credit and © Akarsh Simha. Lunar eclipse of May 26, 2021, from California, US.*

# Solar Corona

Source: <https://apod.nasa.gov/apod/ap240402.html>  
Image credit and © Phil Hart

# Geometry





# Experiment #1

Umbra and Penumbra



# Participants of an Eclipse

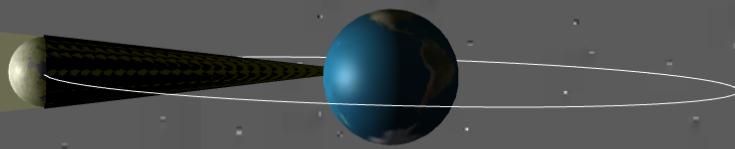
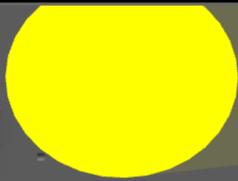
| Role            | Solar Eclipse   | Lunar Eclipse   |
|-----------------|---|---|
| Light Source    | Sun    | Sun    |
| Occluder        | Moon   | Earth  |
| Shadow Receiver | Earth  | Moon   |

The observer being on Earth makes solar eclipses dramatically different from lunar eclipses because solar eclipses involve observing the Sun being obscured, while lunar eclipses involve observing Earth's shadow on the Moon.

# Let's Try an Animation...



View from the Earth (equator, high noon)



## Solar and Lunar eclipses

Support this website and buy me a coffee! :-)

Explore the mechanism of the Solar and Lunar eclipse! Why does the eclipse not occur every month?

Try a new [April 2024 Solar Eclipse Quiz!](#)

The Moon's orbit around the Earth

Rotation of the Earth

Distances and dimensions in scale

Eclipse – view from the Earth

Show the ecliptic plane

Position of the Moon:



The course of a [saros](#) (approx 18 years):



Using mouse you can move in space and rotate the scene.

The animation is speeded up.



**Earth Space Lab.com**

(c) Václav Černík 2017–2024

This app is based on diploma thesis (Charles University, Faculty of Science).

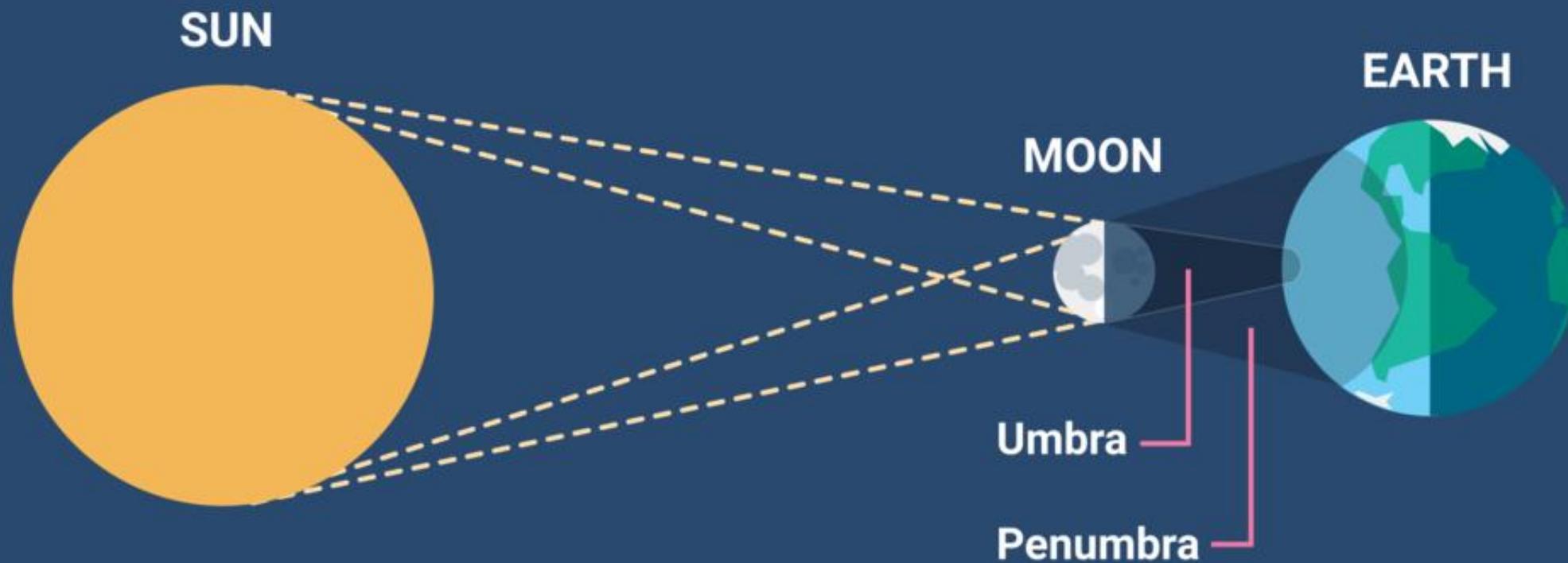
[Main page](#)

<https://www.earthspacelab.com/app/eclipse/>

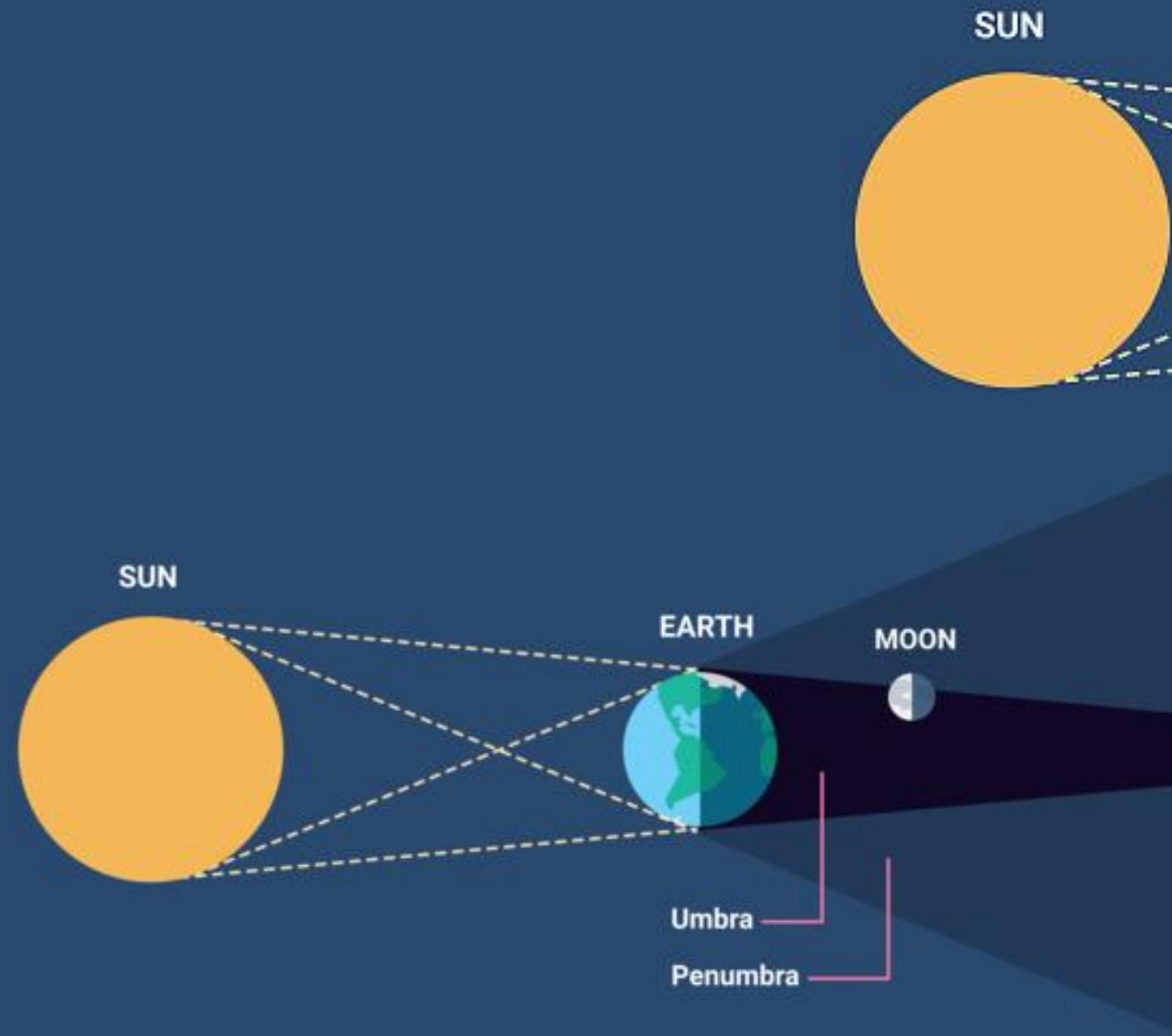
Indicates the shadow of the moon that hits the Earth (solar eclipse)

The penumbra is not shown. Earth's orbit around the Sun and orbit around barycenter are neglected. Distances and dimensions are not in scale.

# Solar Eclipse



# Total and Partial Lunar Eclipses



© timeanddate.com

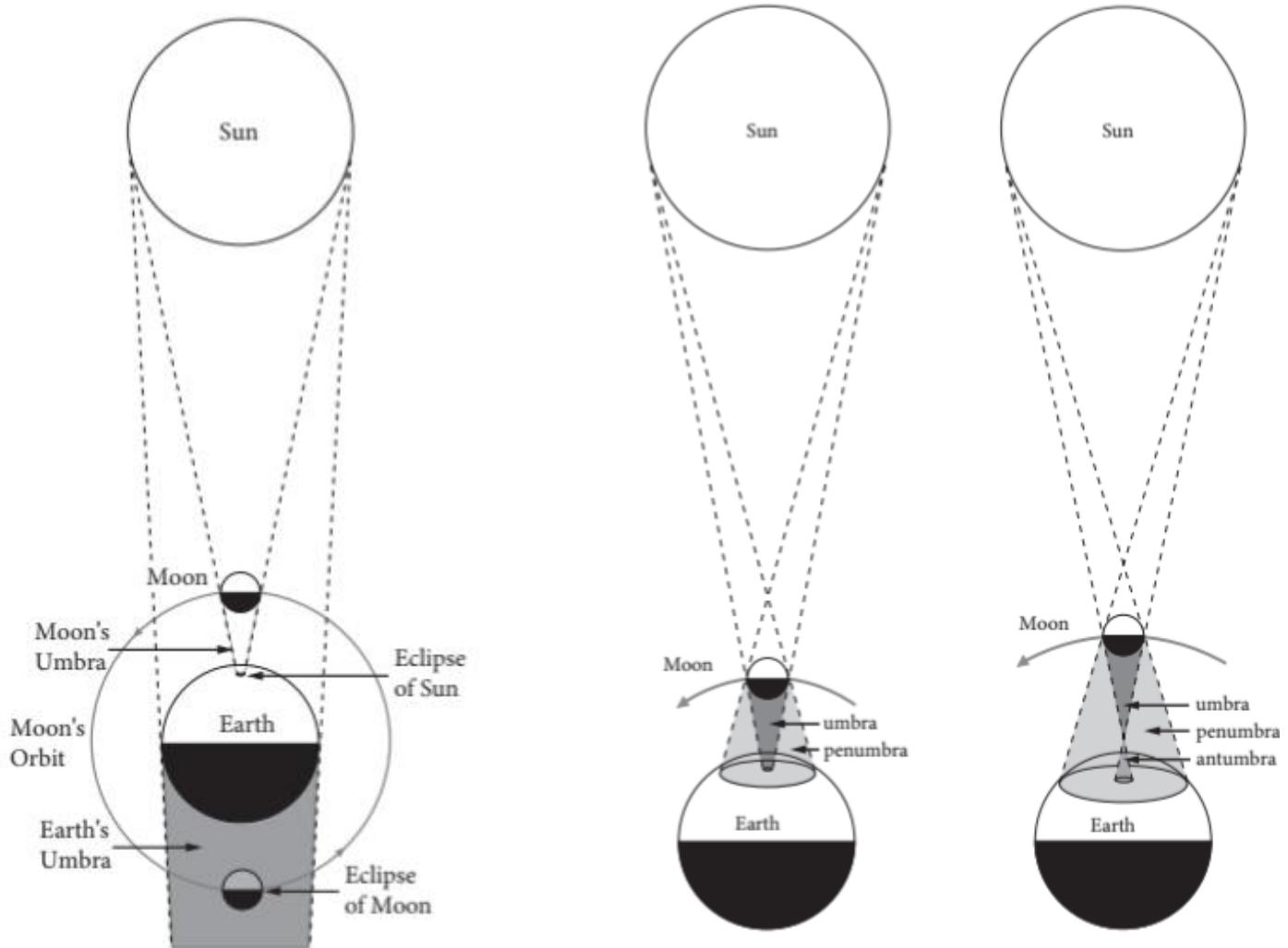
d Shadows

© timeanddate.com

# Eclipse Geometry

*Image credit and © Mark Littman and Fred Espenak: Totality, The Great North American Eclipse of 2024.*

*Diagram is **not** to scale.*



# Actual and Apparent Sizes



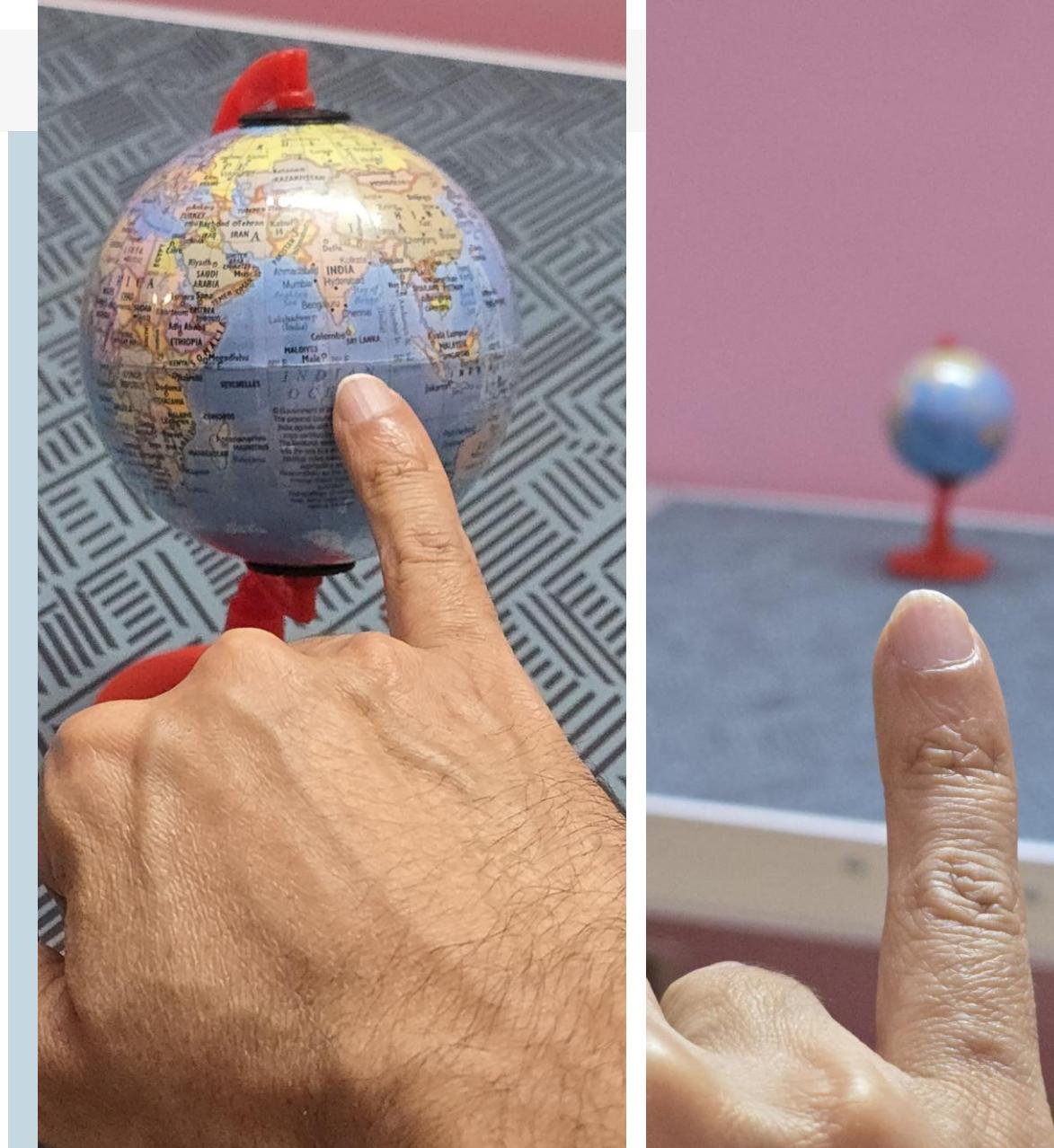
*Images credit and © Sankar Viswanathan.*

# Relative Sizes of Sun, Earth, and Moon

- Diameters of Moon, Earth, and Sun
  - Moon – 3,500 km
  - Earth – 13,000 km (~4x Moon)
  - Sun – 1,400,000 km (~100x Earth; 400x Moon)
- How can the Moon block the Sun which is 400x larger in size?

# Experiment #2

Angular diameter of Sun and Moon





# How Big is the Moon?



Source: <https://commons.wikimedia.org/wiki/File:KarvaChauthMoon1.jpg>

23-Nov-2024

Eclipses: A Game of Light and Shadows

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# How Big Is the Sun?

*Image credit and © EYÜP BELEN.*

*Source: <https://www.pexels.com/photo/woman-across-sun-during-dawn-1428634/>*



# How Big is the Sun?



*Image credit and Copyright © Joshua Cripps.*

*Source: <https://www.nikonusa.com/learn-and-explore/c/tips-and-techniques/photographing-an-annular-solar-eclipse-in-the-desert>*

*Why doesn't a solar eclipse look like this?*



*Image credit and © Sankar Viswanathan. Venus Transit 2012.*

*Cibiana di Cadore (Bl) Italy*

*Sun and Moon rise from the same point  
Sole e Luna sorgono dallo stesso punto*



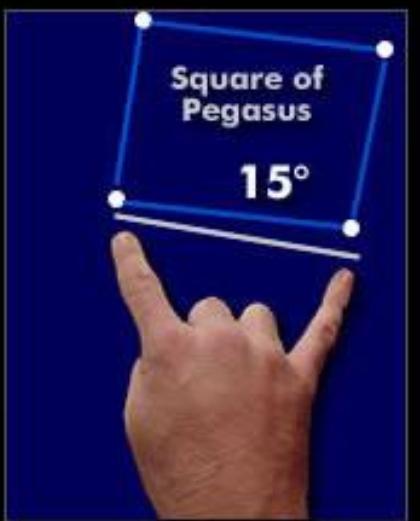
*Image credit and copyright © Marcella Giulia Pace. Source: <https://greenflash.photo/portfolio/sun-and-moon-rise-from-the-same-point/>*

*26 September 2015 - 8.37 a.m.*

*27 September 2015 - 8.21 p.m.*

## MEASURE THE SKY WITH YOUR HAND

Outstretch your arm and measure the angular measurement of sky objects.  
This is a good approximate figure whatever size your arms and hands are.



space fm

Source: <https://www.space.fm/astronomy/starsgalaxies/angles.html>

# Lunar Orbit

Apogee  
406,700 km

Perigee  
356,500 km



Source: [https://en.wikipedia.org/wiki/Orbit\\_of\\_the\\_Moon#/media/File:Lunar\\_perigee\\_apogee.png](https://en.wikipedia.org/wiki/Orbit_of_the_Moon#/media/File:Lunar_perigee_apogee.png)

# Angular Sizes in a Solar Eclipse

| Body | Diameter               | Distance from Earth                                 | Length of Moon's Shadow Cone | Angular Diameter (arc minutes) | Eclipse Type     |
|------|------------------------|---|------------------------------|--------------------------------|------------------|
| Moon | 3,476 km               | Min (perigee): 356,500 km                           | 367,230 km                   | 33' 31.8"                      | Total            |
|      |                        | Average: 384,400 km                                 | 373,540 km                   | 31' 05.3"                      | Annular          |
|      |                        | Max (apogee): 406,700 km                            | 379,870 km                   | 29' 23.0"                      | Annular          |
| Sun  | 1,392,000 km<br>400x 🌈 | Min (perihelion): 147,100,000 km<br>362x 🌈 – 413x 🌈 |                              | 32' 31.9"                      | Annular or Total |
|      |                        | Average: 149,598,000 km<br>368x 🌈 – 420x 🌈          |                              | 31' 59.3"                      | Annular or Total |
|      |                        | Max (Aphelion): 152,100,000 km<br>374x 🌈 – 427x 🌈   |                              | 31' 27.7"                      | Annular or Total |

| Solar Eclipse Type     | Frequency<br>2000 BCE to 3000 CE |
|------------------------|----------------------------------|
| Total                  | 26.7%                            |
| Annular                | 33.2%                            |
| Hybrid (Annular/Total) | 4.8%                             |
| Partial                | 35.3%                            |

*Total solar eclipses occur less often than annular solar eclipses.*



Eclipse of Sun by Phobos  
as Seen By Perseverance Rover



Source: <https://sundials.org/index.php/all-things-sundial/solar-alignments/352-eclipse-of-sun-by-phobos-seen-by-perseverance-rover>

# Questions...

- Don't absolute sizes matter?
- How large is Moon's shadow on Earth?

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The Moon's orbit around the Earth

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 [Earth Space Lab.com](#)

(c) Václav Černík 2017–2024

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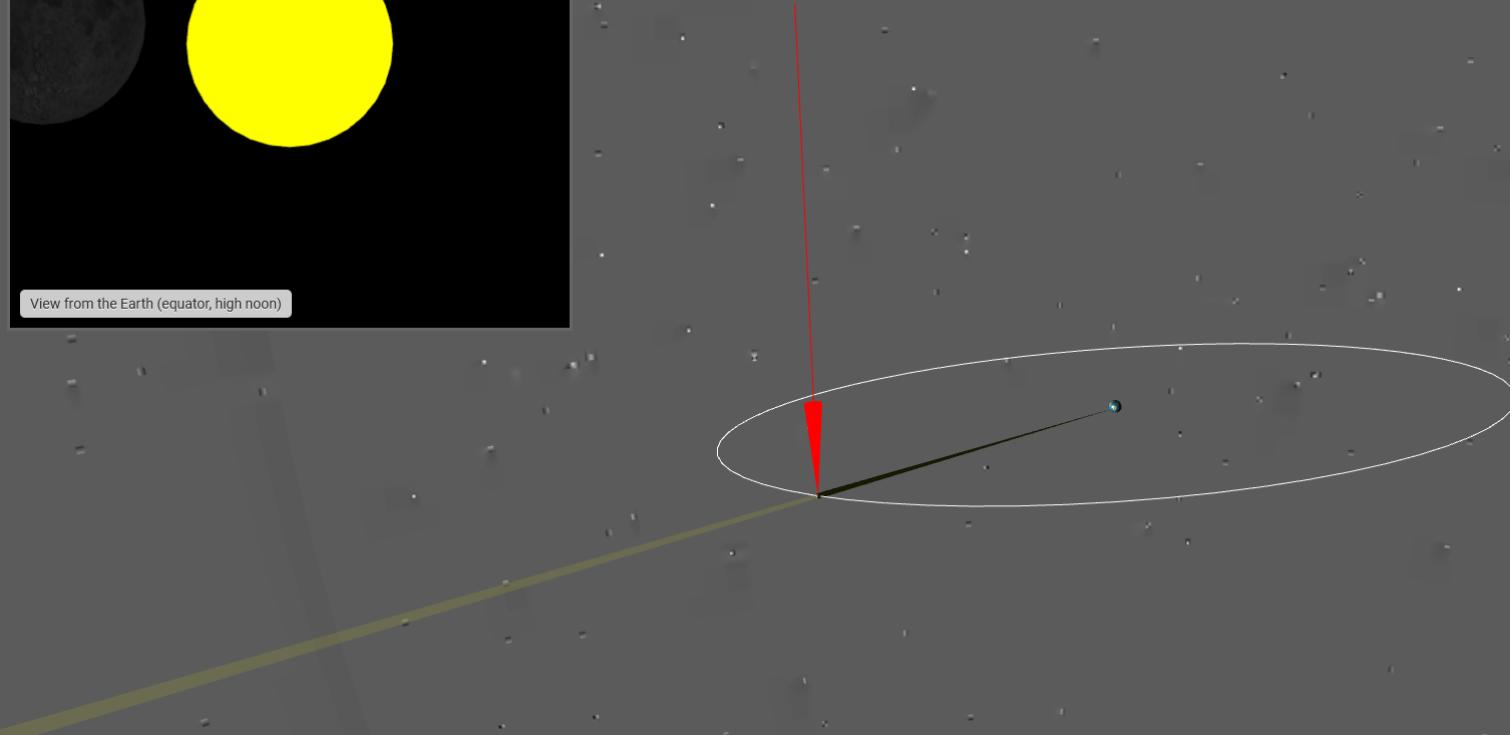
[Main page](#)

# Let's Try that Animation ... now at 1:1 Scale

Solar eclipse



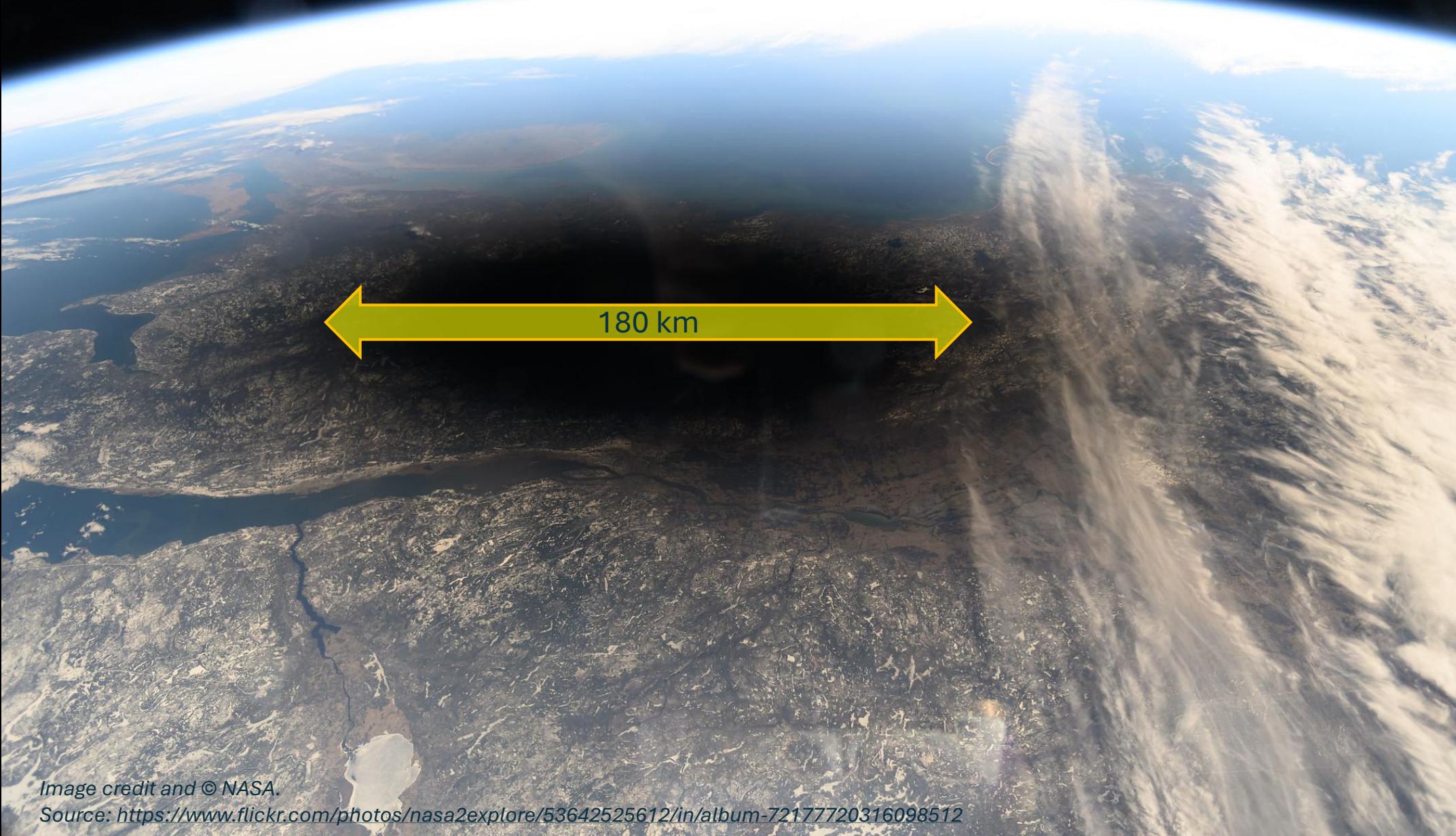
View from the Earth (equator, high noon)



<https://www.earthspacelab.com/app/eclipse/>

Indicates the shadow of the moon that hits the Earth (solar eclipse)  
The penumbra is not shown. Earth's orbit around the Sun and orbit around barycenter are neglected.

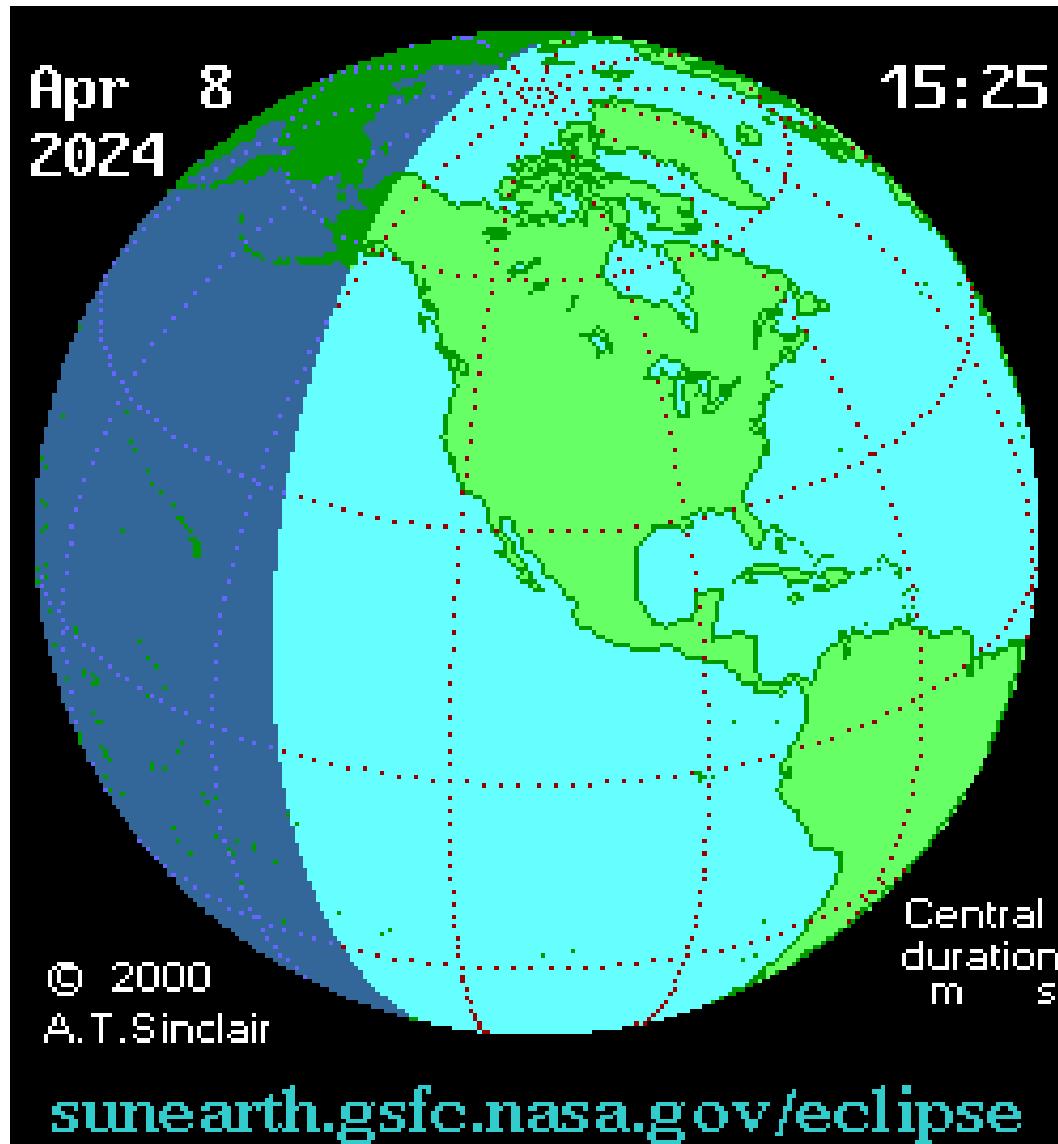
# 2024 Total Solar Eclipse: Lunar Shadow as Seen from the ISS



*Image credit and © NASA.*

*Source: <https://www.flickr.com/photos/nasa2explore/53642525612/in/album-72177720316098512>*

# Path of the 2024 Total Solar Eclipse



## Total Solar Eclipse of 2024 Apr 08

Geocentric Conjunction = 18:36:02.5 UT      J.D. = 2460409.275029  
 Greatest Eclipse = 18:17:13.1 UT      J.D. = 2460409.261957

Eclipse Magnitude = 1.0565      Gamma = 0.3432

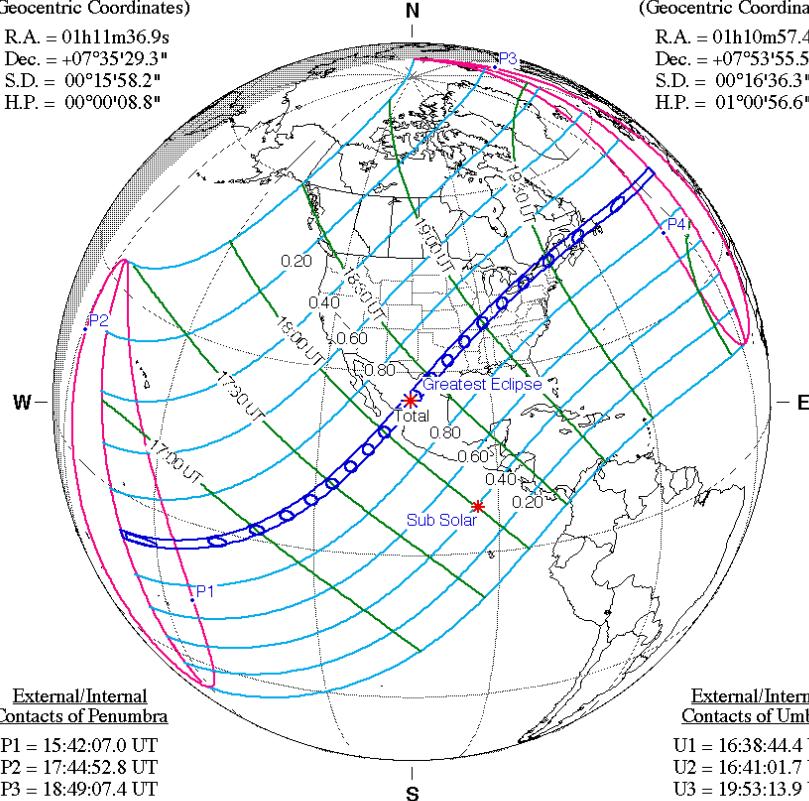
Saros Series = 139      Member = 30 of 71

### Sun at Greatest Eclipse (Geocentric Coordinates)

R.A. = 01h11m36.9s  
 Dec. = +07°35'29.3"  
 S.D. = 00°15'58.2"  
 H.P. = 00°00'08.8"

### Moon at Greatest Eclipse (Geocentric Coordinates)

R.A. = 01h10m57.4s  
 Dec. = +07°53'55.5"  
 S.D. = 00°16'36.3"  
 H.P. = 01°00'56.6"



### External/Internal Contacts of Penumbra

P1 = 15:42:07.0 UT  
 P2 = 17:44:52.8 UT  
 P3 = 18:49:07.4 UT  
 P4 = 20:52:13.8 UT

### External/Internal Contacts of Umbra

U1 = 16:38:44.4 UT  
 U2 = 16:41:01.7 UT  
 U3 = 19:53:13.9 UT  
 U4 = 19:55:29.1 UT

### Local Circumstances at Greatest Eclipse

|                       |                       |                   |
|-----------------------|-----------------------|-------------------|
| Ephemeris & Constants | Lat. = 25°17.5'N      | Sun Alt. = 69.8°  |
|                       | Long. = 104°07.2'W    | Sun Azm. = 149.4° |
| Eph. = Newcomb/ILE    | Path Width = 197.5 km |                   |
| ΔT = 81.2 s           | Duration = 04m28.1s   |                   |
| k1 = 0.2724880        |                       |                   |
| k2 = 0.2722810        |                       |                   |
| Δb = 0.0"   Δl = 0.0" |                       |                   |

### Geocentric Libration (Optical + Physical)

I = 2.00°  
 b = -0.46°  
 c = -20.75°

Brown Lun. No. = 1253



F. Espenak, NASA's GSFC - Fri, Jul 2,  
[sunearth.gsfc.nasa.gov/eclipse/eclipse.html](http://sunearth.gsfc.nasa.gov/eclipse/eclipse.html)

Image credit and © Fred Espenak.

Source: <https://eclipse.gsfc.nasa.gov/SEplot/SEplot2001/SE2024Apr08T.GIF>

# Total Lunar Eclipse of 2025 Mar 14

Ecliptic Conjunction = 06:55:48.0 TD (= 06:54:33.5 UT)

Greatest Eclipse = 06:59:56.2 TD (= 06:58:41.7 UT)

Penumbral Magnitude = 2.2595 P. Radius = 1.1899° Gamma = 0.3484

Umbral Magnitude = 1.1784 U. Radius = 0.6537° Axis = 0.3171°

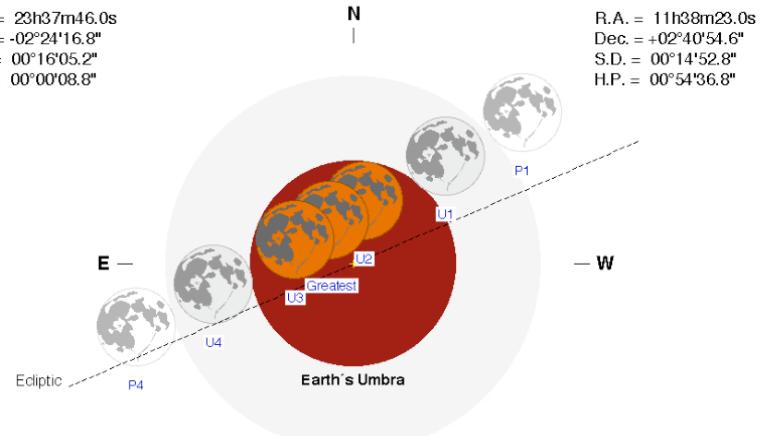
Saros Series = 123 Member = 53 of 73

**Sun at Greatest Eclipse**  
(Geocentric Coordinates)

R.A. = 23h37m46.0s  
Dec. = -02°24'16.8"  
S.D. = 00°16'05.2"  
H.P. = 00°00'08.8"

**Moon at Greatest Eclipse**  
(Geocentric Coordinates)

R.A. = 11h38m23.0s  
Dec. = +02°40'54.6"  
S.D. = 00°14'52.8"  
H.P. = 00°54'36.8"



## Eclipse Durations

Penumbral = 06h02m37s  
Umbral = 03h38m15s  
Total = 01h05m24s

ΔT = 75 s

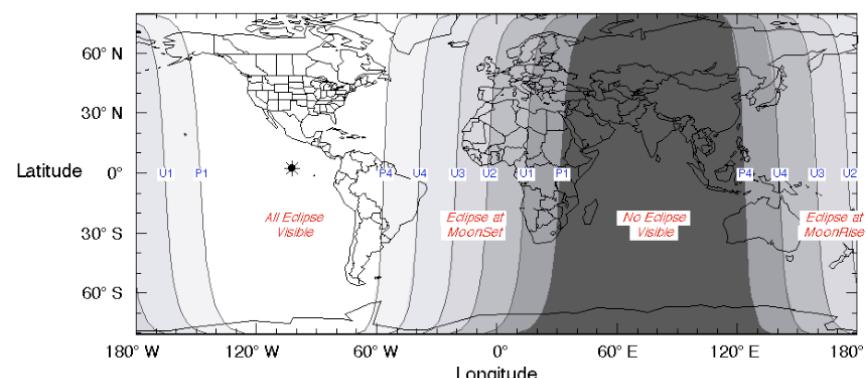
Rule = CdT (Danjon)  
Eph. = VSOP87/ELP2000-85

## Earth's Penumbra



## Eclipse Contacts

P1 = 03:57:24 UT  
U1 = 05:09:33 UT  
U2 = 06:25:59 UT  
U3 = 07:31:23 UT  
U4 = 08:47:48 UT  
P4 = 10:00:01 UT



Source: <https://eclipse.gsfc.nasa.gov/LEplot/LEplot2001/LE2025Mar14T.pdf>

# Question...

- How large would Earth's shadow be on the Moon for a lunar eclipse?

# Lunar Eclipse of November 19, 2021



*Image credit and © Zoltan Levay*

*Source: <https://skyandtelescope.org/observing/solar-and-lunar-eclipses-in-2022/>*

*Source: <https://www.flickr.com/photos/zoltlevay/51693464621>*



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## Questions...

- Am I in eclipse during night? Aren't I in Earth's shadow at night?
- Am I in eclipse if I am in the ISS and in Earth's shadow looking down on the night side of the Earth?

# Gibbous Moon vs. Lunar Eclipse



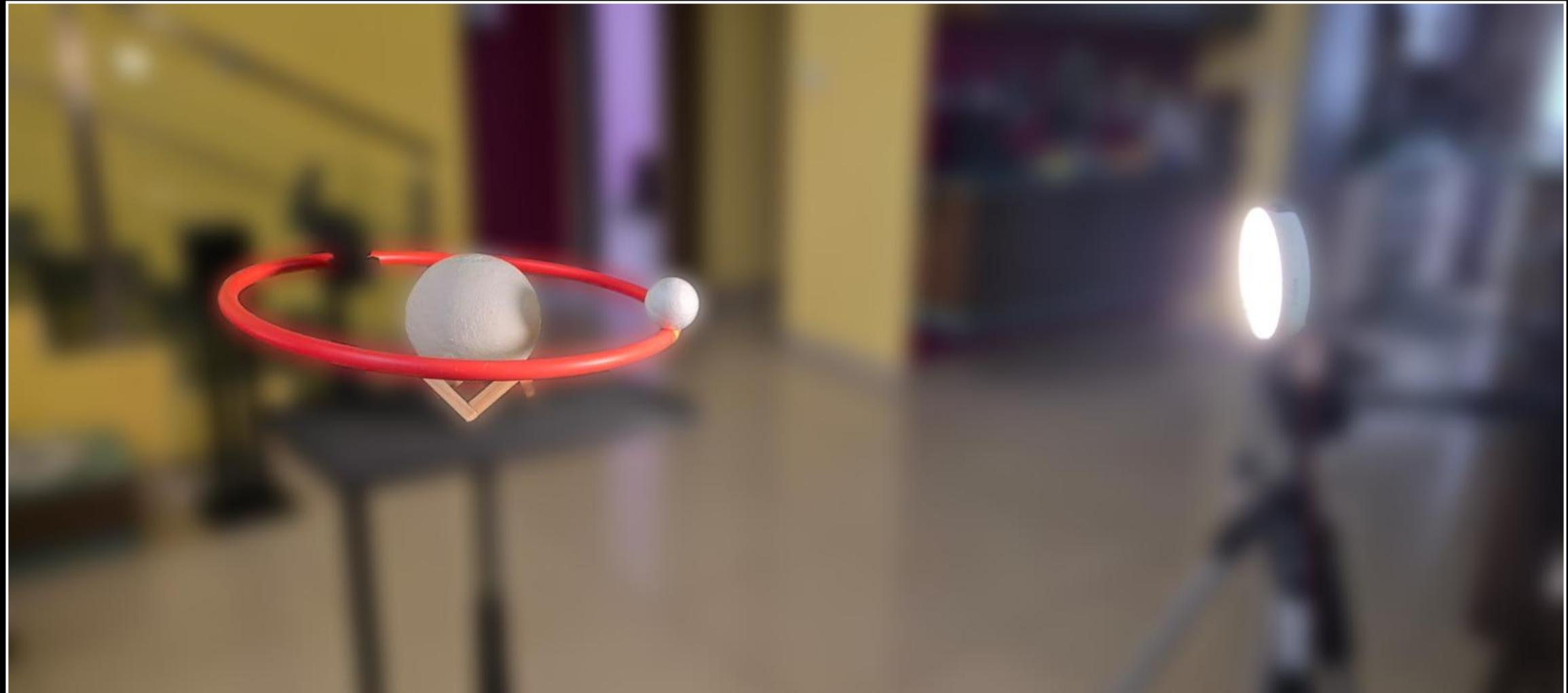
Gibbous Moon Source: [https://en.wikipedia.org/wiki/Lunar\\_phase#/media/File:2013-01-02\\_00-00-55-Waning-gibbous-moon.jpg](https://en.wikipedia.org/wiki/Lunar_phase#/media/File:2013-01-02_00-00-55-Waning-gibbous-moon.jpg)  
Eclipsed Moon Source: [https://commons.wikimedia.org/wiki/File:Partial\\_Moon\\_Eclipse.jpg](https://commons.wikimedia.org/wiki/File:Partial_Moon_Eclipse.jpg)

# Solar vs. Lunar Eclipses: A Recap

| Feature                      | Solar Eclipse   | Lunar Eclipse   |
|------------------------------|---|---|
| Definition                   | Occurs when the Moon passes between the Sun and the Earth, casting a shadow on Earth.<br> | Occurs when the Earth passes between the Sun and the Moon, casting a shadow on the Moon.<br> |
| Visibility                   | Visible only from a <a href="#">narrow path</a> on Earth.   | Visible from anywhere on the night side of Earth.   |
| Frequency                    | <a href="#">More frequent</a> than total lunar eclipses, but totality is rare at any given location.  | Total lunar eclipses are less frequent than total solar eclipses.   |
| Types                        | Total, Annular, Partial, <a href="#">Hybrid</a>   | Total, Partial, Penumbral   |
| Umbral and penumbral shadows | Umbral shadow is 100-160km wide near equator. Shadows near poles can be 1000km+. Penumbral shadow is ~6400km.   | Umbra is about 2.7 Moon diameters. Penumbra is about 4.7 Moon diameters.  |
| Duration                     | Totality can last up to 7.5 minutes for solar eclipses.   | Totality can last up to 1 hour and 40 minutes for lunar eclipses.   |
| Appearance                   | During totality, the <a href="#">solar corona</a> is visible.   | During totality, the <a href="#">Moon appears reddish</a> due to scattered sunlight from Earth's atmosphere.  |
| Safety                       | Never look directly at the Sun during a solar eclipse without proper eye protection.  | Safe to view with the naked eye.  |

# Predicting Eclipses





## Experiment #3



# Eclipse Geometry Patterns

- Sun-Earth-Moon in near linear alignment
  - Necessary conditions
    - Close to new moon (solar eclipse) or full moon (lunar eclipse)
    - Sun and Moon close to either of the lunar nodes
  - Conditions for kinds of solar eclipses
    - Annular – closer to earth (e.g., closer to perigee)
    - Total – farther from earth (e.g., closer to apogee)
  - Time cycles
    - Draconic month (node to node) – 27.2122 days
    - Sidereal month (revolution against stars) – 27.3217 days
    - Anomalistic month (perigee to perigee) – 27.5545 days
    - Synodic month (new moon to new moon) – 29.5306 days
  - Eclipse year
    - 346.62 days (beat period of synodic and draconic months)
    - $EY = N \times SM = (N+1) \times DM$
    - $N = SM * DM / (SM - DM)$

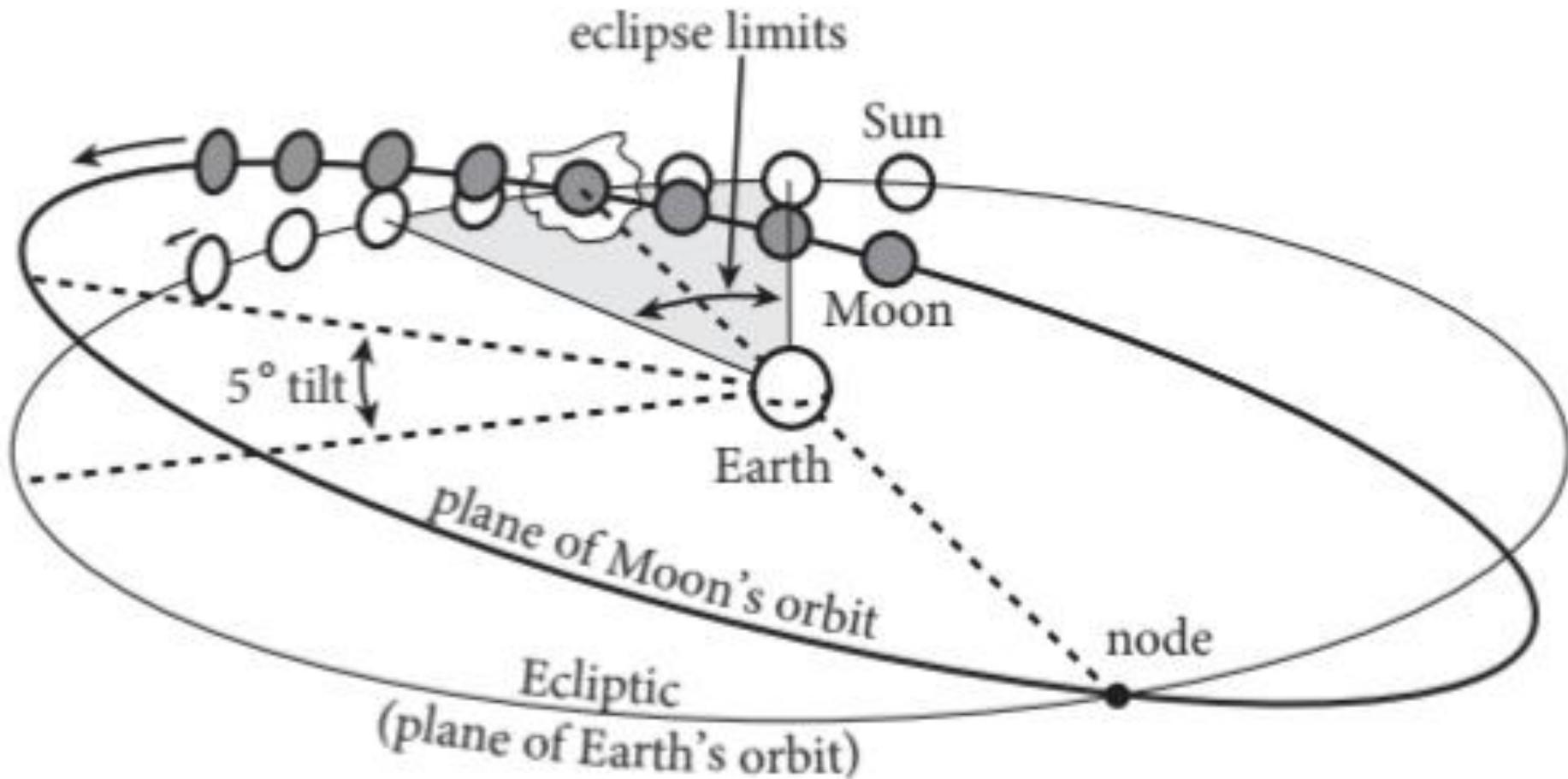
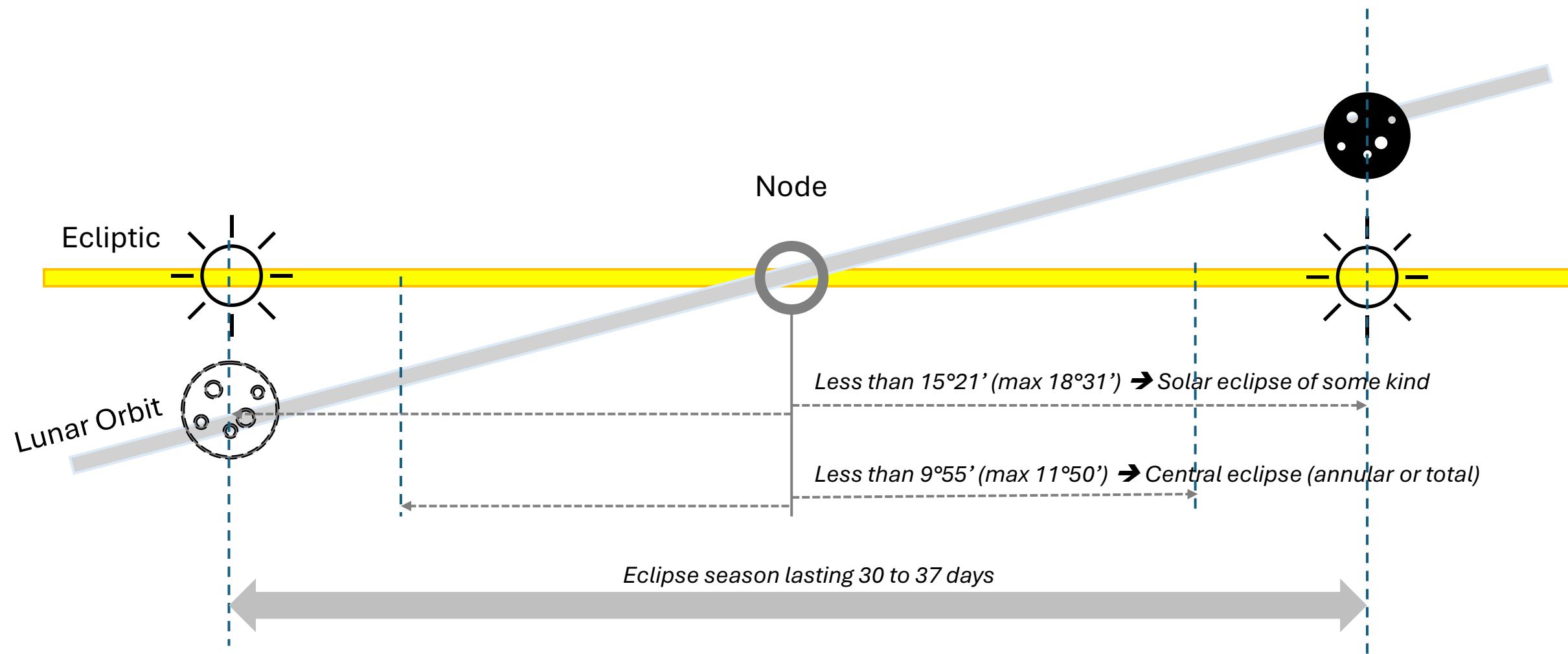
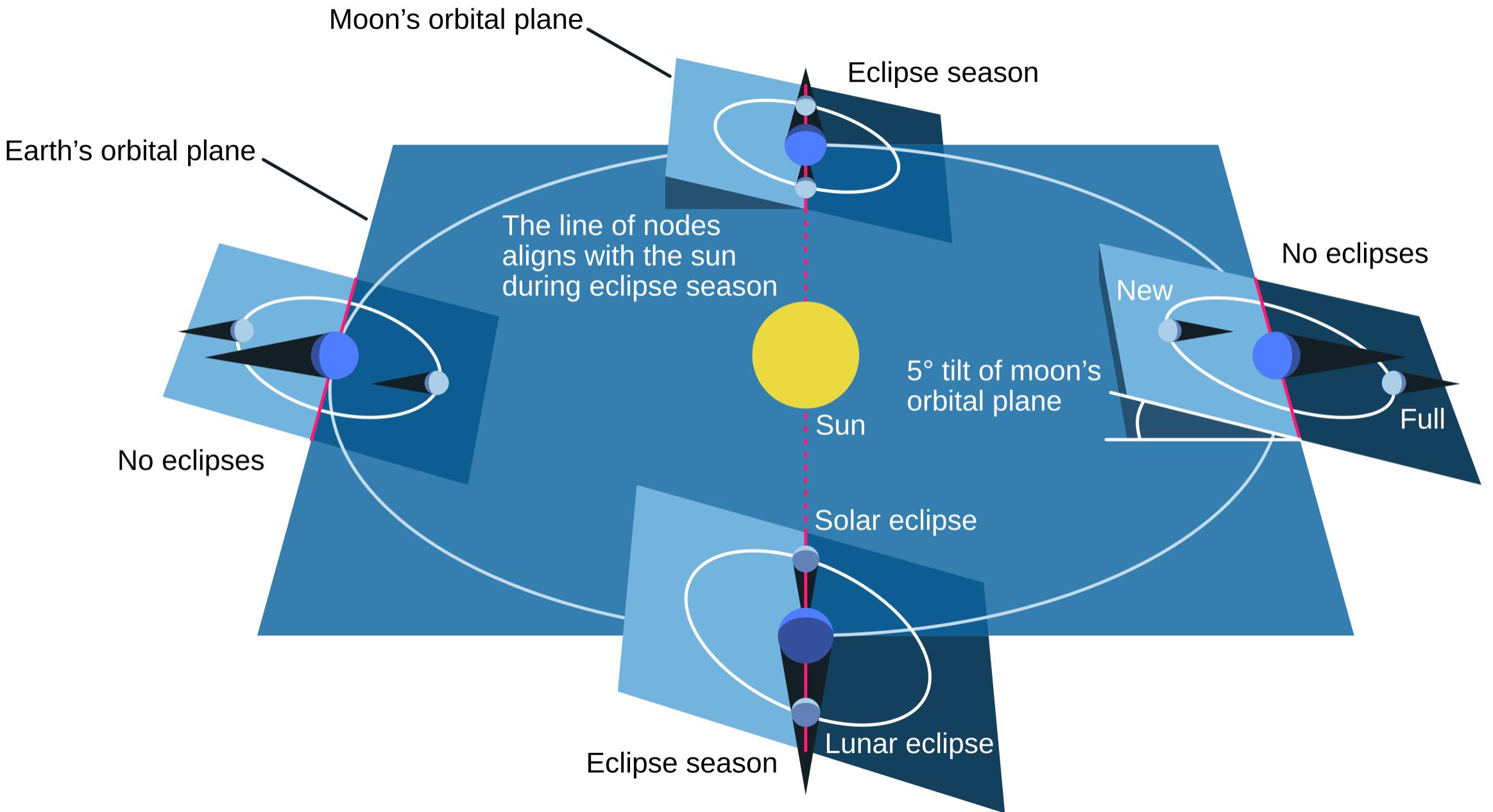


Image credit and © Mark Littman and Fred Espenak: Totality, The Great North American Eclipse of 2024.

New Moon

Ecliptic longitude of Moon = Ecliptic longitude of Sun





Source: [https://en.wikipedia.org/wiki/Eclipse\\_season#/media/File:Eclipse\\_vs\\_new\\_or\\_full\\_moons,\\_annotated.svg](https://en.wikipedia.org/wiki/Eclipse_season#/media/File:Eclipse_vs_new_or_full_moons,_annotated.svg)

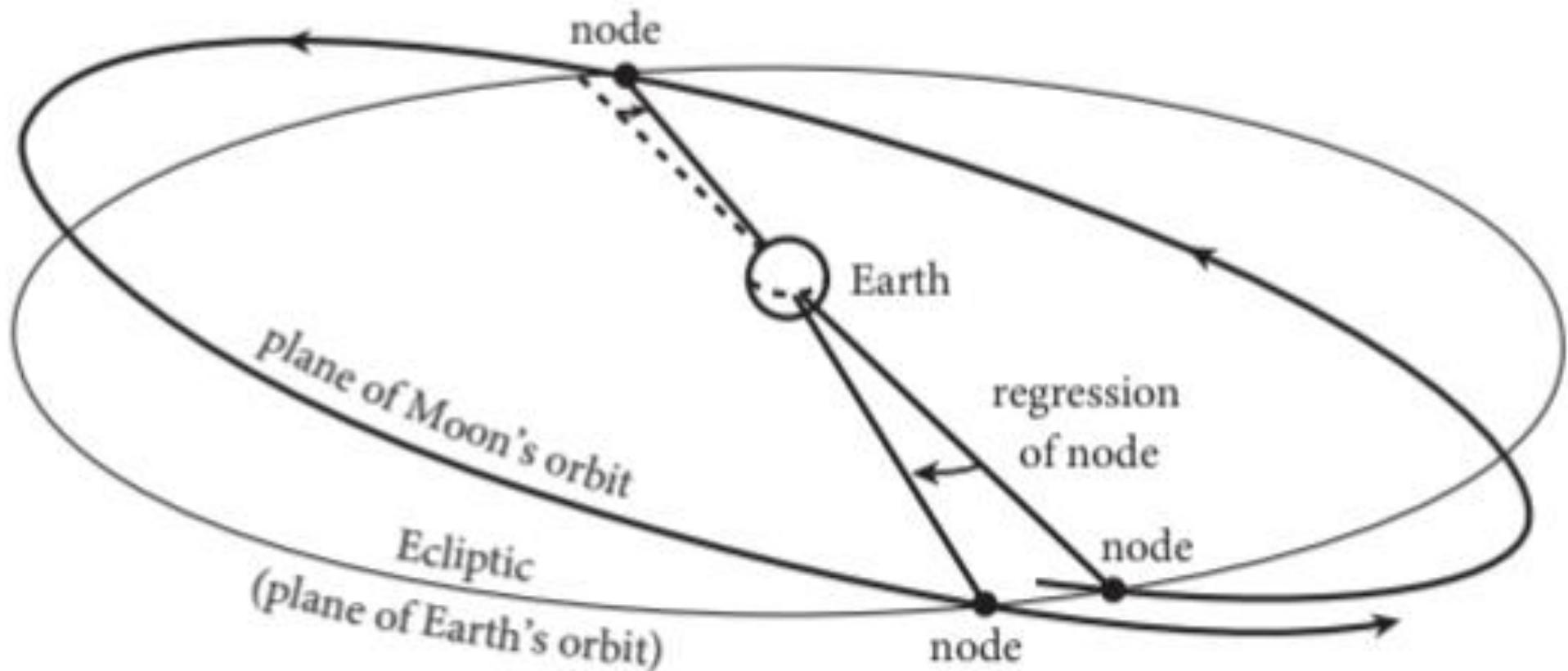
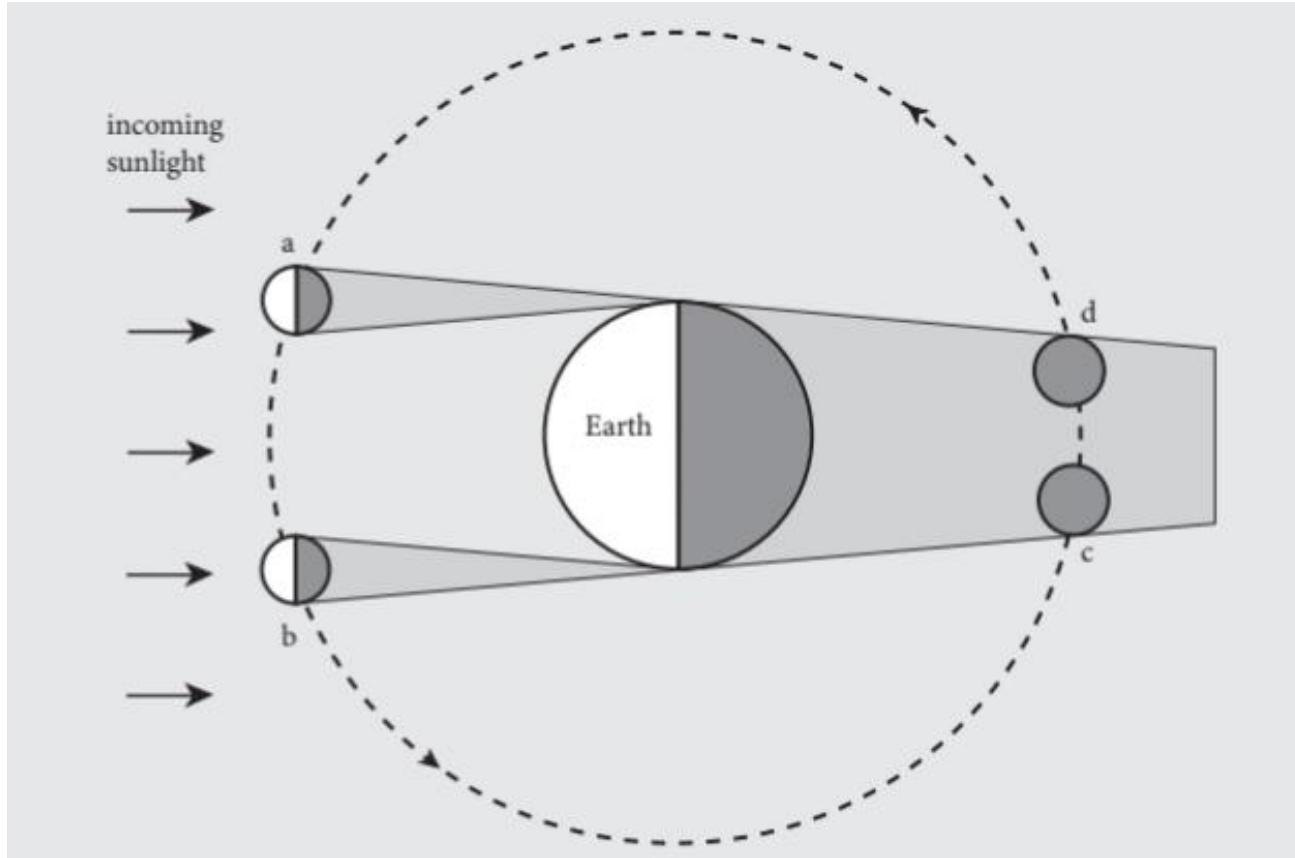


Image credit and © Mark Littman and Fred Espenak: Totality, The Great North American Eclipse of 2024.

# Frequency of Solar Eclipses

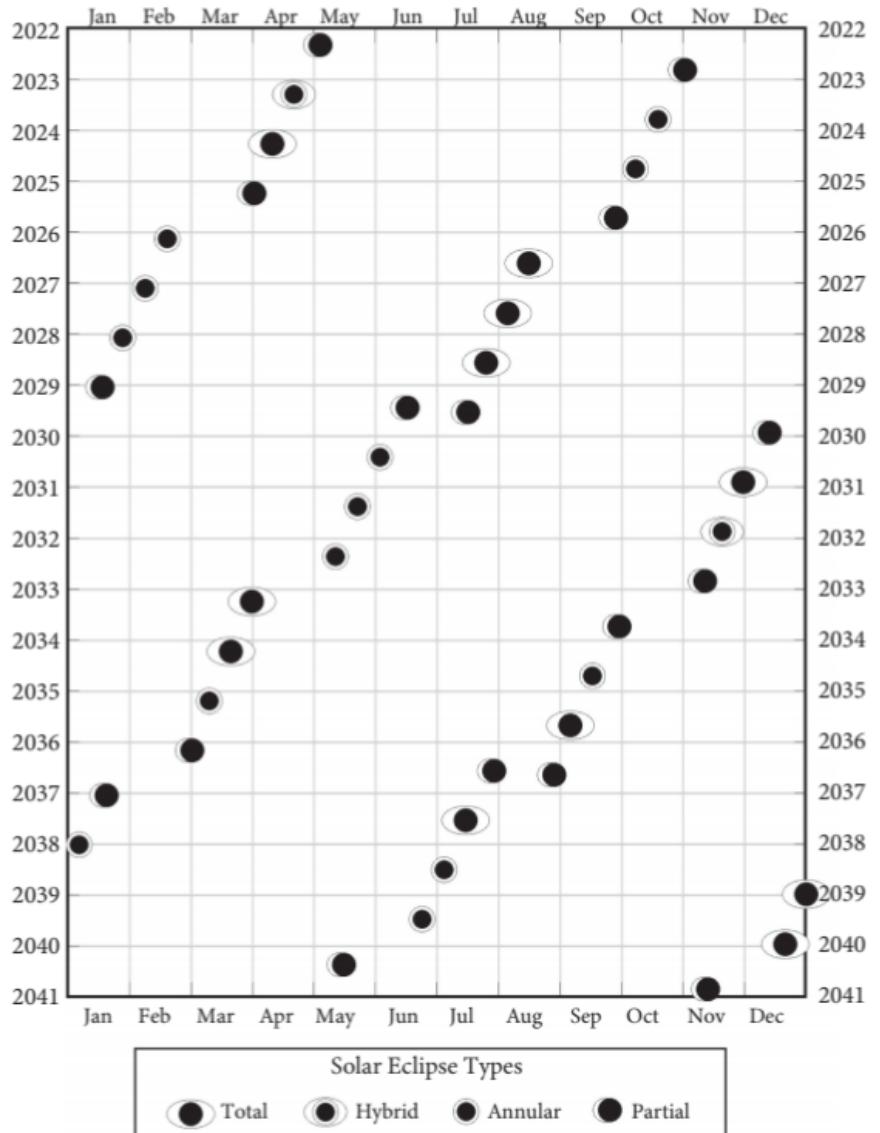
- At least one solar eclipse each eclipse season
  - At least one each eclipse season; at most two
  - At least two in an eclipse year of 346.22 days
  - At least two in a calendar year
  - Usually a max of four in a calendar year; occasionally five
  - In this century, 224 eclipses of which 144 are central
- Two lunar eclipses in most years
  - None in a few
  - At most three in a few



*Image credit and © Mark Littman and Fred Espenak: Totality, The Great North American Eclipse of 2024. Diagram is **not** to scale.*

## Why do solar eclipses occur more often?

## Calendar of Solar Eclipses: 2022 –2041



*Image credit and © Mark Littman and Fred Espenak: Totality, The Great North American Eclipse of 2024.*

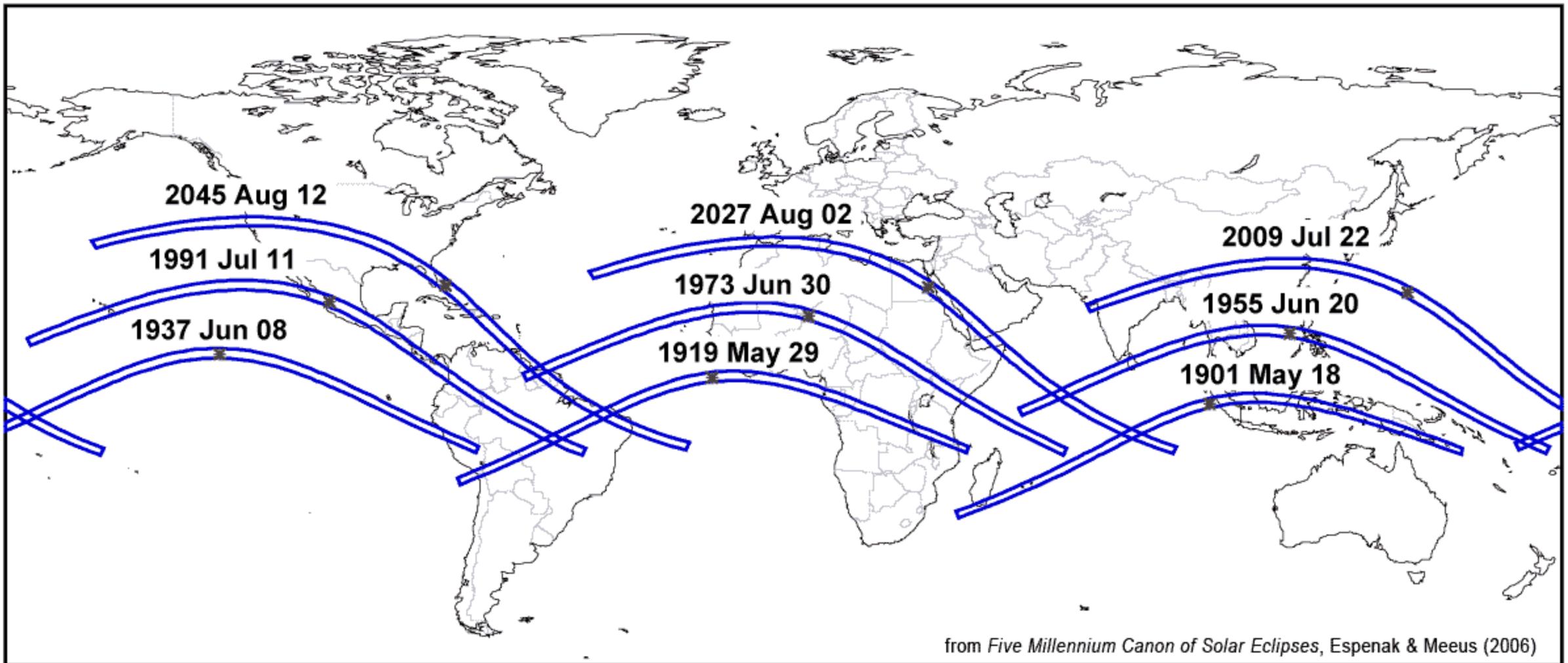
# Saros Cycle



| Draconic Months          | Anomalistic Months       | Synodic Months           |
|--------------------------|--------------------------|--------------------------|
| 241.999                  | 238.992                  | 223.000                  |
| 6585.32 days             | 6585.32 days             | 6585.32 days             |
| 18 years + 10/11/12 days | 18 years + 10/11/12 days | 18 years + 10/11/12 days |

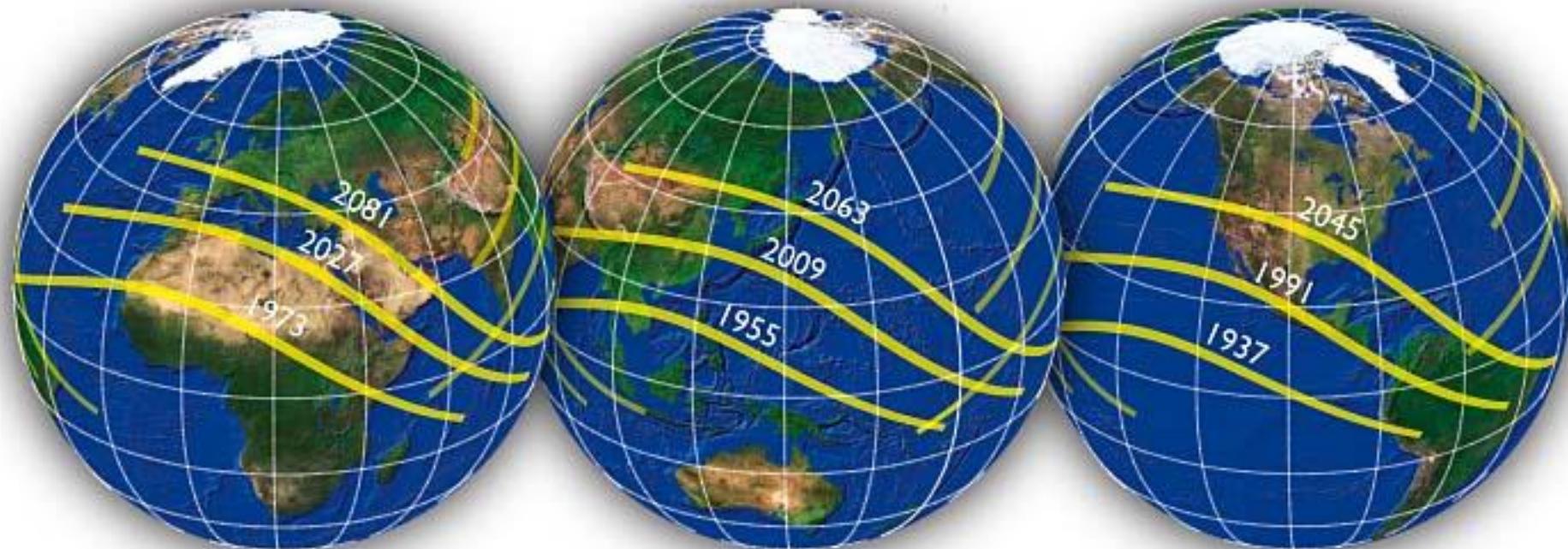
*One saros period after an eclipse, the Sun, Earth, and Moon return to approximately the same relative geometry, a near straight line, and a nearly identical eclipse will occur, in what is referred to as an eclipse cycle. A sar is one half of a saros.*

## Eclipses from Saros 136: 1901 to 2045



Source: <https://skyandtelescope.org/astronomy-news/how-did-the-ancients-predicted-eclipses-the-saros-cycle/>

## Saros 136



Each eclipse path shifts ~120° west of the previous one.

Orthographic projection centered  
at 26° North, 22° East

Map illustration by Michael Zeller

Orthographic projection centered  
at 26° North, 142° East

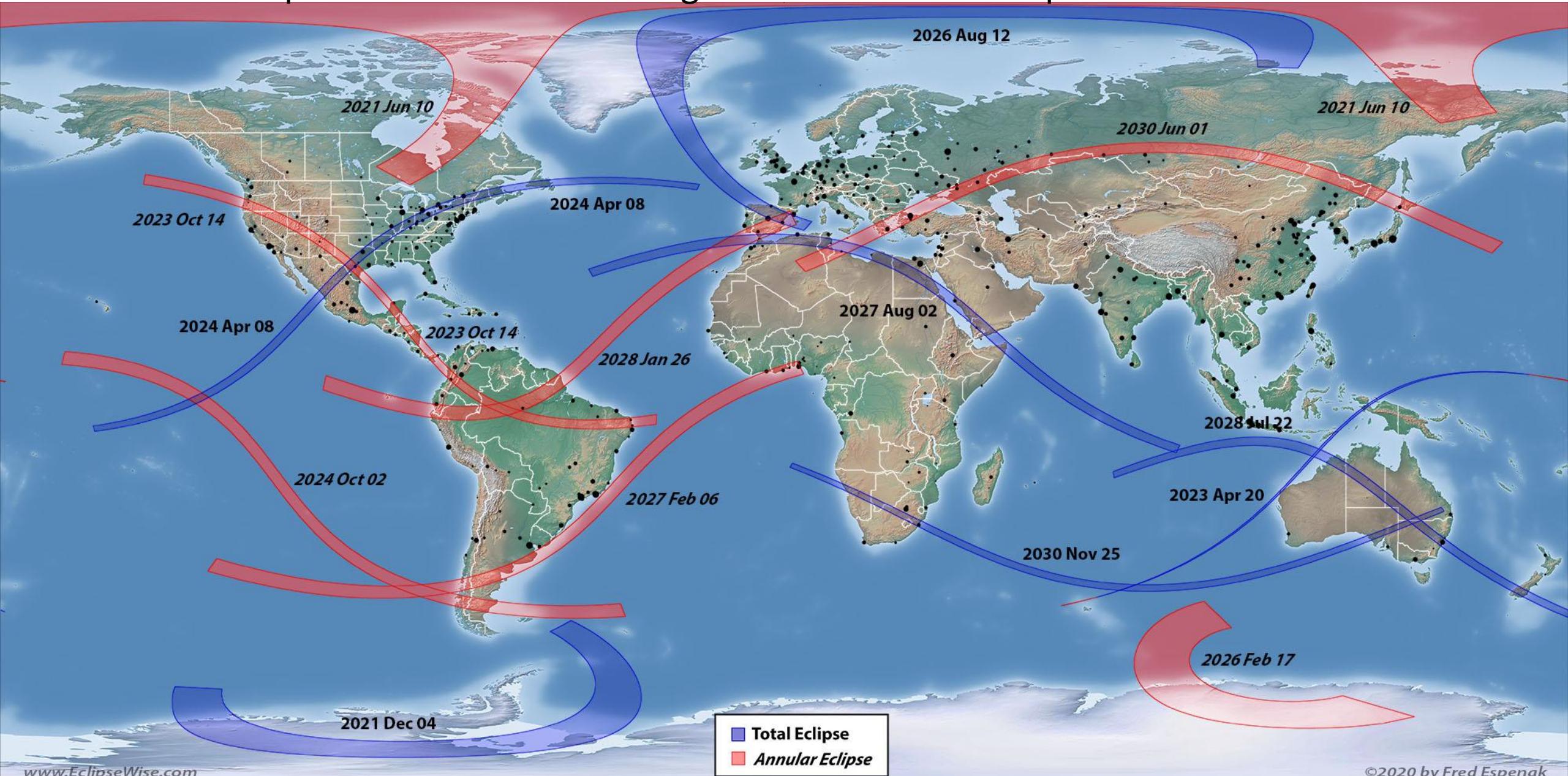
Eclipse predictions by Fred Espenak, NASA Goddard Space Flight Center

Orthographic projection centered  
at 26° North, 98° West

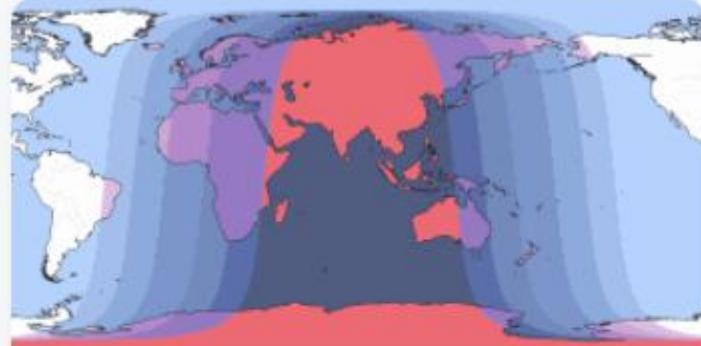
Paths of totality from eclipse calculator by Xavier Jubier

Source: <https://eclipse.gsfc.nasa.gov/SEsaros/SEsaros.html>

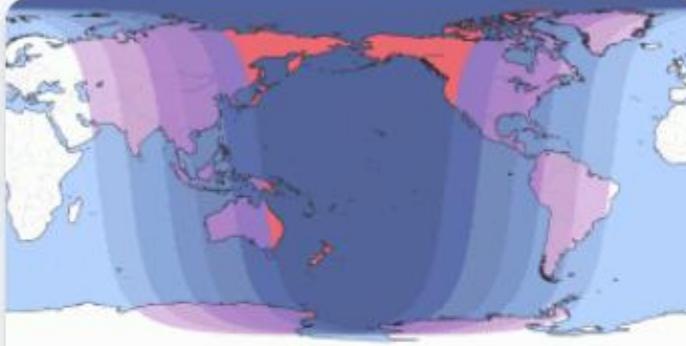
# Central Solar Eclipses: 2021 to 2030 – Image credit and © Fred Espenak



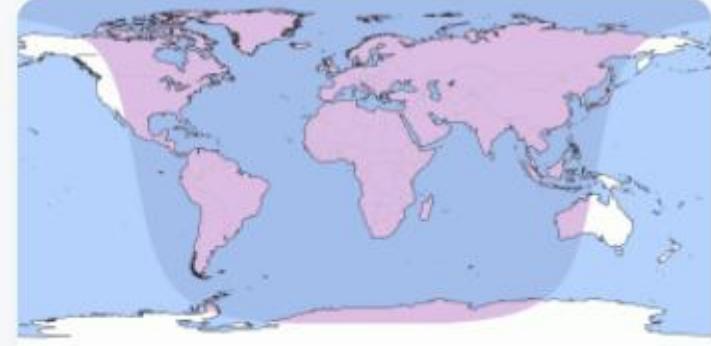
# Upcoming Eclipses for Bangalore



**Total Lunar Eclipse**  
7 Sep 2025



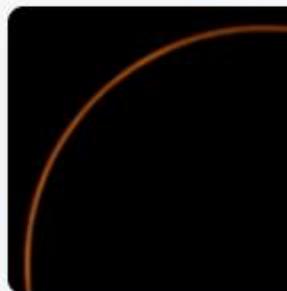
**Partial Lunar Eclipse**  
3 Mar 2026



**Penumbral Lunar Eclipse**  
20 Feb 2027



**Next Total Lunar Eclipse**  
7 Sep 2025  
0 years 290 days



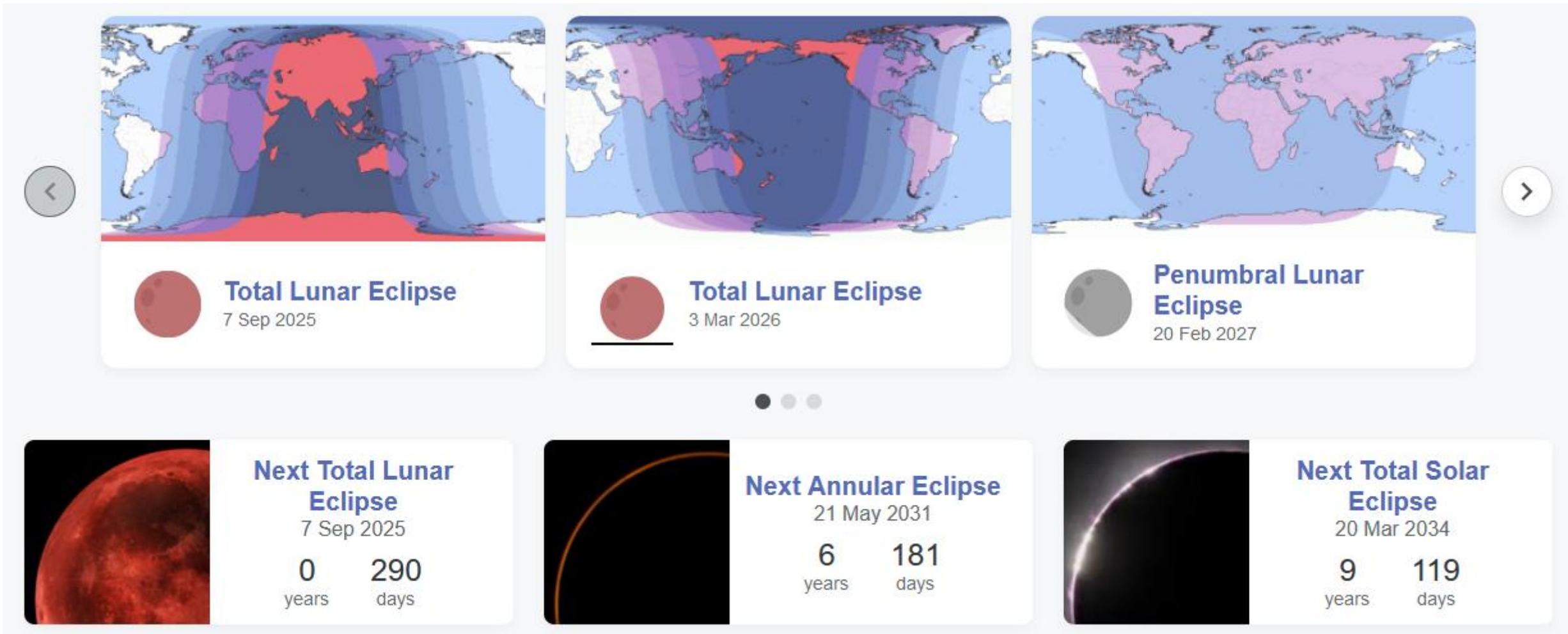
**Next Annular Eclipse**  
22 Jun 2085  
60 years 213 days



**Next Total Solar Eclipse**  
Not visible before the year 2200

Source: <https://www.timeanddate.com/eclipse/in/india/bengaluru>

# Upcoming Eclipses for India

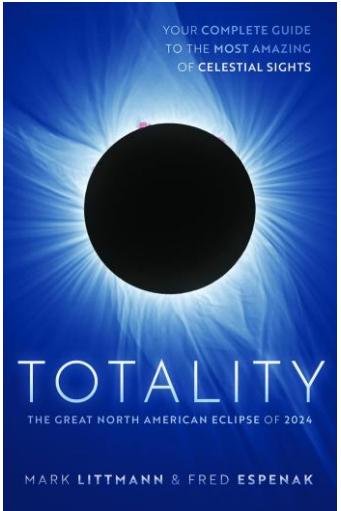


Source: <https://www.timeanddate.com/eclipse/in/india>

# Resources



# Books



**Totality: The Great North American Eclipse of 2024**  
Mark Littman and Fred Espenak

**In the Shadow of the Moon**  
Anthony Aveni



# Web Resources

- Key Resources
  - <https://science.nasa.gov/moon/eclipses/>
  - <https://eclipse.gsfc.nasa.gov/>
  - <https://www.eclipsewise.com/>
  - <https://en.wikipedia.org/wiki/Eclipse>
  - <https://www.britannica.com/science/eclipse>
  - <https://nationaleclipse.com/>
- Animations
  - <https://www.earthspacelab.com/app/eclipse/>
  - <https://svs.gsfc.nasa.gov/5093/>
  - <https://in-the-sky.org//newsindex.php?feed=eclipses>
  - <https://www.timeanddate.com/eclipse/>
- Educational Resources from NASA
  - <https://www.jpl.nasa.gov/edu/resources/lesson-plan/model-a-solar-eclipse/>
  - <https://www.jpl.nasa.gov/edu/resources/teachable-moment/how-to-watch-a-total-lunar-eclipse-and-get-students-observing-the-moon/>
  - <https://www.jpl.nasa.gov/edu/resources/lesson-plan/when-do-lunar-eclipses-happen/>
  - <https://www.jpl.nasa.gov/edu/resources/lesson-plan/modeling-the-earth-moon-system/>
- Miscellaneous Articles
  - <https://www.space.com/25644-total-solar-eclipses-frequency-explained.html>
  - <https://www.quantamagazine.org/how-the-ancient-art-of-eclipse-prediction-became-an-exact-science-20240405/>

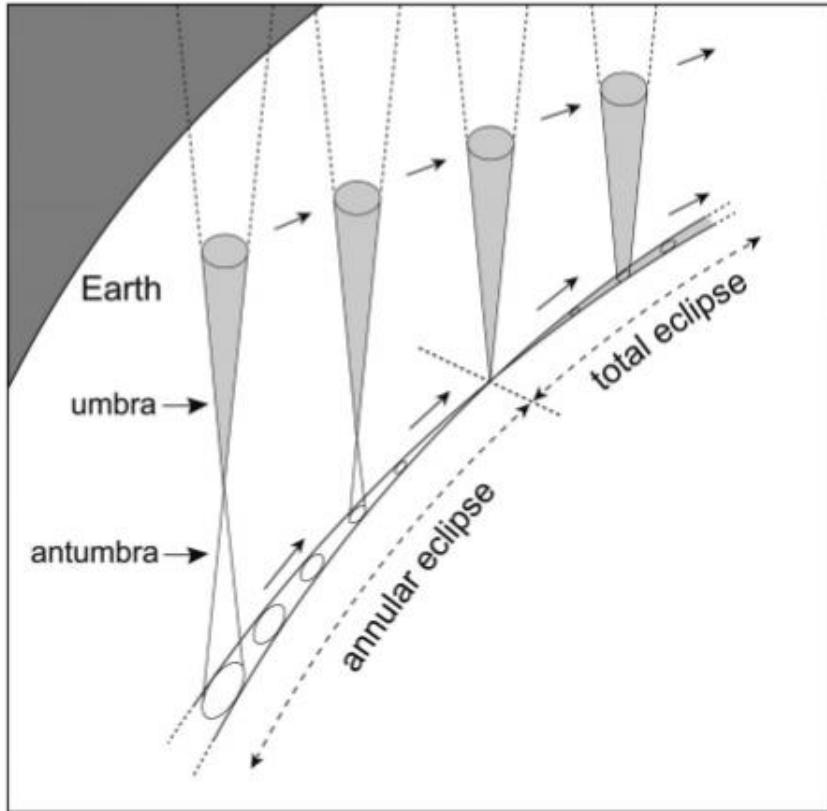
# Thank You!



*Image credit and © Sankar Viswanathan. Lunar eclipse of January 31, 2018 taken from California, US.*



# Backup Reference Slides



An occasional solar eclipse may start off annular but become total as the roundness of the Earth reaches up to intercept the shadow. The eclipse then returns to annular as the curvature of the Earth causes its surface to fall away from the shadow. These unusual eclipses are called hybrid or annular-total eclipses.

*Image credit and © Mark Littman and Fred Espenak: Totality, The Great North American Eclipse of 2024. Diagram is **not** to scale.*

## Hybrid Solar Eclipse