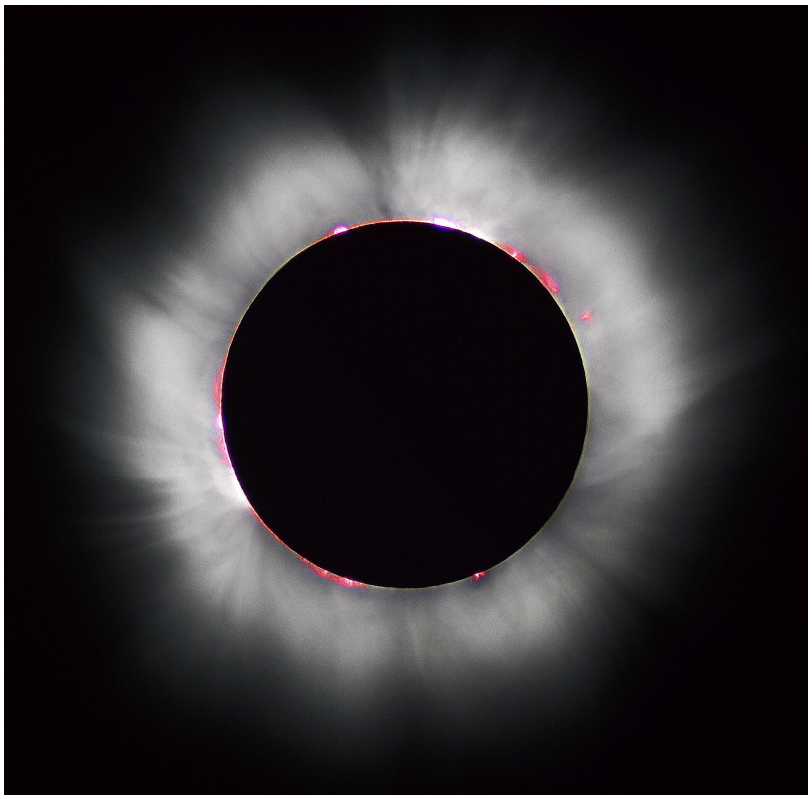
Eclipse 101 For Hosts and Teachers



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March 2024

Title Page image by Luc Viatour, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=60793

South Plains Astronomy Club: https://www.southplainsastronomy.org

Solar System Ambassadors: https://solarsystem.nasa.gov/solar-system-ambassadors/events/

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1. Introduction

A total solar eclipse is a relatively uncommon, unique, almost mystical event. For a few moments, the sun goes dark, the sky dims to dusk, birds roost, and briefly, we see the glory of the corona. An eclipse is unique enough to be memorialized in petroglyphs and other historical documents, helping historians date such records. It is my hope that you have the opportunity to see the April 8, 2024 eclipse or another total solar eclipse in your lifetime. It is something you'll remember for the rest of your life!

The oldest recorded solar eclipse was recorded on a clay tablet in modern day Syria in either 1375 BC or 1223 BC (the favored date)[1]. The eclipse of 763 BC is mentioned in an Assyrian text, which helps fix dating of Near East history[2]. It is told that Chinese king Zhong Kang supposedly had two astronomers beheaded for not predicting an eclipse 4,000 years ago[3] and Chinese records of eclipses begin around 720 BC.[4] By the 4th century BC, Shi Sen predicted eclipses using the positions of Sun and Moon.[5]

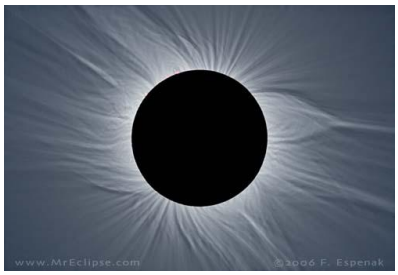

Figure 1: Figure 1 - Figure 2 - 2006 Total Solar Eclipse
by Fred Espenak[https://mreclipse.com/Special/SEprimer.html]

Total solar eclipses have even brought peace during war. The Greek historian Herodotus recorded that the Medes and Lydians put down their weapons and declared peace when an eclipse appeared over the battlefield, believed to be in 585 BC in Asia Minor.[6]

In the Americas, we have only petroglyphs with uncertain dating. Most famously, the petroglyph in Chaco Canyon.[7] Since the Chaco culture had many astronomical alignments in their buildings and cities, we know they timed the skies, likely for agricultural and ritual timings. When this petroglyph was found near the Una Vida ruin in what appears to be an ancient solar observing station marking the summer solstice. This petroglyph appears to be an image of the corona at the time of a total solar eclipse.

Figure 2 - Solar Eclipse petroglyph at the Una Vida ruin in Chaco Canyon

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[1] Smith, Kiona N. "People Recorded A Total Solar Eclipse For The First Time 3,241 Years Ago". Forbes.

[2] van Gent, Robert Harry. "Astronomical Chronology". University of Utrecht. Archived

[3] Harrington, Philip S. (1997). Eclipse! The What, Where, When, Why and How Guide to Watching Solar and Lunar Eclipses. New York: John Wiley and Sons. ISBN 0-471-12795-7.

[4] Stephenson, F. Richard (1982). "Historical Eclipses". Scientific American. Vol. 247, no. 4. pp. 154–163. Bibcode:1982SciAm.247d.154S

[5] Needham, Joseph (1986). Science and Civilization in China: Volume 3. Taipei: Caves Books. pp. 411–413. OCLC 48999277.

[6] Le Conte, David (December 6, 1998). "Eclipse Quotations". MrEclipse.com. Archived

[7] https://www2.hao.ucar.edu/education/prehistoric-southwest/solar-eclipse-petroglyph

There were four total solar eclipses crossing the canyon during the time the Chaco culture was active - 13 April 804, 11 July 1097, 13 June 1257, and 17 October 1259. If this is an eclipse, then the round glyph to the upper left is likely Venus, which can appear in the daytime sky during a solar eclipse.

On April 8, 2024, Texas is blessed with a total eclipse covering many of our major population centers. Southern Texas has the best average cloud cover of the path[8], so we will host millions[9] from across North America and the world at large. In Texas, totality starts at roughly 1:30 pm at the border with Mexico and take just 10 minutes to sweep across Texas to the border with Oklahoma. The two cities closest to the north and south Texas borders and the center-line are Radar Base and Clarksville, a distance of 461 miles (563 miles driving)[10]. Totality at the center line will last about 4 minutes, 20 seconds[11], with a partial eclipse lasting roughly 1 hour, 15 minutes before and after totality.

This document is intended primarily for event hosts and teachers who need to answer questions about the upcoming total solar eclipse, but anyone wanting to learn about total eclipses should find this guide useful. We will include a list of web sources and extensive footnote sources for further reading. Diagrams and information are from sources that allow free distribution with attribution. If I missed any attributions, please let me know.

We hope this will feed your desire for knowledge!

2. Eclipse Safety

Figure 3 - Eclipse phases and safety[12]

Before we go into details about the solar eclipse, we must cover eye safety[13]. On a normal day, the ultraviolet and high-energy blue light can cause "solar retinopathy[14]" in seconds. Solar retinopathy, sometimes called "eclipse retinopathy" is basically a sunburn on your retina that permanently damages the rods and cones of your eye:

Remember that your retina is a fragile, sensitive tissue and that the lens of your eye concentrates sunlight to a small point. Staring at the sun without protection can easily cause permanent damage to the focus point of your retina, which will remain as a dark spot just where you see the most detail.

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[8] https://eclipsophile.com/2024tse/#Texas_to_Missouri

[9] https://www.greatamericaneclipse.com/visitation

[10] https://www.travelmath.com/distance/from/Radar+Base,+TX/to/Clarksville,+TX

[11] https://eclipse2024.org/eclipse_cities/states.php?type=total&state=Texas&country=USA

[12] https://mynasadata.larc.nasa.gov/sites/default/files/inline-images/Total%20Eclipse%20Images%20to%20crop.png

[13] https://www.aao.org/eye-health/tips-prevention/solar-eclipse-eye-safety

[14] https://www.allaboutvision.com/eye-injuries/solar-retinopathy/

Figure 4 Solar Retinopathy (www.aao.org)
https://www.aao.org/eyenet/article/blink-mystery-image-10

An eclipse greatly increases this danger. As the sun approaches totality it dims, yet it is still has more than enough ultraviolet energy to cause permanent retinal damage[15], especially if you're staring at the sun. Sunglasses are not a viable filter for this intense energy entering your eye.

To keep your eyes safe, experts recommend only a few safe ways to view the partial eclipse:

A. Certified Solar Glasses:

The most common way to safely view the eclipse is through ISO 12312-2 certified solar glasses from a reputable vendor. Beware of counterfeit glasses (often marked certified) that flood the market just before the eclipse. Your eyes matter, so it's safer to stick to known major vendors' glasses and avoid generic brands. (Our club sells certified solar glasses for $2 each. I've used mine many times to look at sunspots safely.) Such filters will show the Sun as a yellow, orange, or perhaps blue-white image, depending on the exact filter type. All good solar filters filter out more than 99% of visible, UV, and IR light.

NOTE: Do not use solar glasses with binoculars, telescopes, cameras, or spotting scopes! The density of these filters is meant only for unmagnified sunlight and will fail under intensified output of these devices.

B. #14 Welder's Glass

Another safe method of viewing is through a welder's glass rated at 14 or higher[16]. These filters are meant to block the intense UV light of the welding arc and are safe to use to observe the Sun. These filters often show the Sun in a green light. If it's embedded in a welder's mask, it has the advantage of both preventing sunburn and blocking reflections from behind the glass (better contrast).

Some authorities dispute using welder's glasses as a safe solar filter. As with solar glasses, choose reputable welder's glass that follows the OSHA standards fact sheet to be sure you are filtering all of the dangerous rays.

Just as with the solar glasses, it is not safe to use the welder's glass behind a pair of binoculars or camera!

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[15] https://mreclipse.com/Totality2017/Totality2017-Ch11.html

[16] https://mreclipse.com/Totality2017/Totality2017-Ch11.html

C. Projection

You can project the image through small holes, binoculars, your telescope or even between leaves of a tree. The simplest of these devices is a pair of paper plates, a colander, or even lacing your fingers together. You'll get larger images with pinhole projection boxes. If you project through binoculars and telescopes - **DO NOT LOOK THROUGH AN UNFILTERED TELESCOPE OR BINOCULARS!** - you'll be able to see surface features like sunspots.

Indirect Viewing Methods: Project images of the Sun using your hands or a colander.
Credit: Left Image: AAS; Right Image: NASA/Joy Ng.

Figure 5 Simple projection viewing
https://mynasadata.larc.nasa.gov/sites/default/files/inline-images/Indirect%20Viewing%20Methods.png

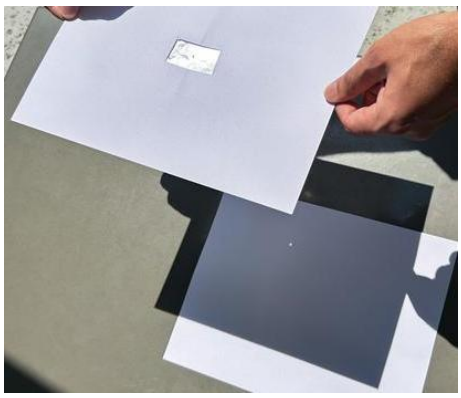

Figure 6 Simple foil projection project
https://www.jpl.nasa.gov/edu/learn/project/how-to-make-a-pinhole-camera

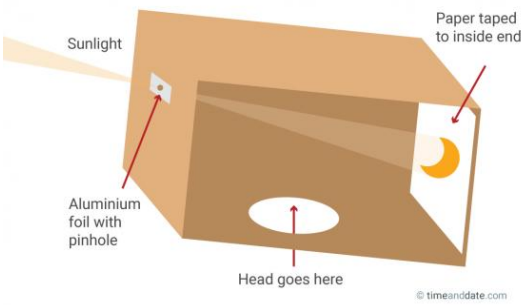

Figure 7 Projection Box that goes on your head
https://www.timeanddate.com/eclipse/box-pinhole-projector.html

You can use a 1/2” mirror (or a larger mirror masked to 1/2”) to project a larger image of the eclipse. The image will be somewhat blurrier than a pinhole projection, but it will be bigger and clearly show the eclipse progress:

Figure 8 Projection with a mirror
https://skyandtelescope.org/2017-total-solar-eclipse/low-tech-eclipse-viewing/

Telescopes or binoculars can project an image of the eclipse that includes surface features like sunspots, which is really neat. You’ll need to add a lightweight shade like the photos below or use a box with one side open. You can use cheap and small binoculars, finder scopes, or small telescopes to do the projection.

Figure 9 Telescope projection
https://astronomynow.com/2014/10/23/north-america-gets-ready-for-a-partial-solar-eclipse/

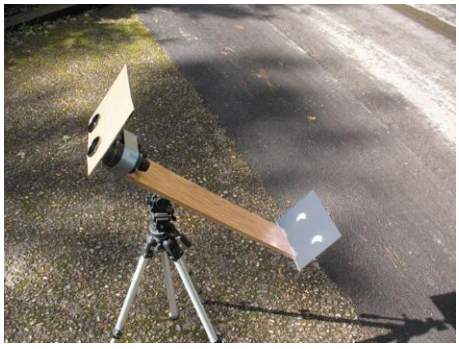

Figure 10 Simple binocular projection
https://skyandtelescope.org/2017-total-solar-eclipse/low-tech-eclipse-viewing/

NOTE: Telescopes and binoculars pointed at the Sun are easily capable of instantly starting fires or burning your flesh close to the eyepiece. Don’t put anything close to the eyepiece while tracking the Sun!

Some telescopes can be damaged if you allow the sun to track out of view while projecting. As the Sun tracks out of view, the magnified sunlight can touch the metal baffles in the telescope or the elements holding the lenses in your eyepiece. This can be enough to melt the thin metal or plastic elements!

D. Camera and Telescope Filters

Cameras and telescopes magnify the sunlight by an order of magnitude, so damage can occur before you can blink[17] and will burn your flesh instantly near the eyepiece. The only way to directly view the partial eclipse is to use a solar filter made for your equipment. See the extensive list of vendors at the American Astronomical Society. You can remove the filter to view totality, but you must put the filter back on before the diamond ring returns and the partial eclipse exposes the surface of the Sun. (More on the phases and timing below.)

3. What is an Eclipse?

An eclipse[18], also known as an occultation,[19] is one heavenly body, like a planet, moon, or asteroid, passing into the shadow of another. On Earth, we can see two basic types of an eclipse with the naked eye - lunar and solar. (With a telescope, can also see planets eclipse their moons and moons eclipsing their planets, but that's outside this discussion.) This Internet meme might help you remember which eclipse is which:

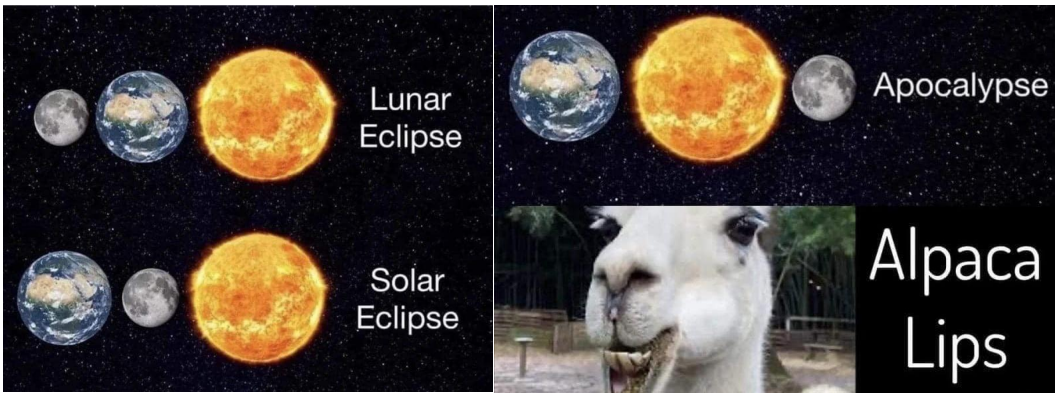

Figure 11: Yes, the two on the right are jokes.

You can remember which one is which by looking at what gets darker. A lunar eclipse darkens the Moon while a solar eclipse darkens the Sun:

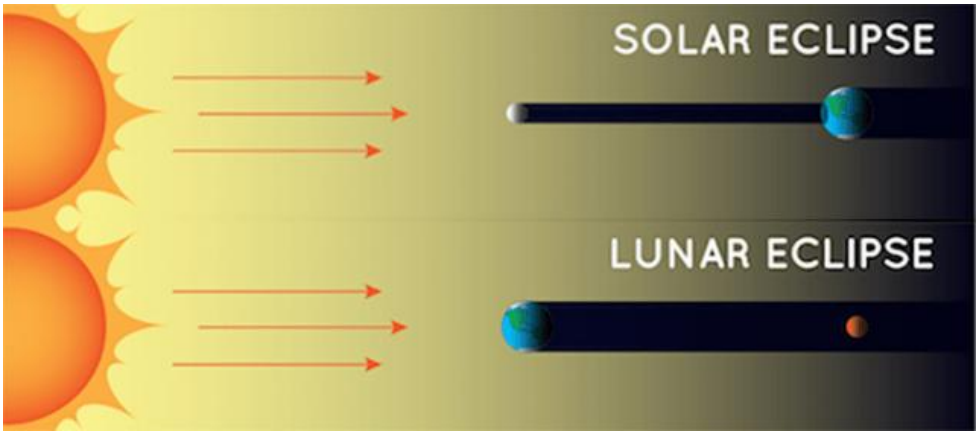

Figure 12 Basic Eclipse Diagram. NASA SpacePlace

[17] https://science.nasa.gov/eclipses/safety/

[18] https://en.wikipedia.org/wiki/Eclipse

[19] https://en.wikipedia.org/wiki/Occultation

To understand the types of eclipses, you'll need to know the three shadows that an eclipsing body throws.

- The **umbra** is the darkest shadow where the observer would not see the Sun, which is a total eclipse.
- The **penumbra** is a lighter shadow where the observer can see part of the Sun's surface, which is a partial eclipse.
- The **antumbra** is the lighter shadow beyond the farthest reach of the umbra,where the observer can see a ring of the Sun's surface, which is an annular eclipse.

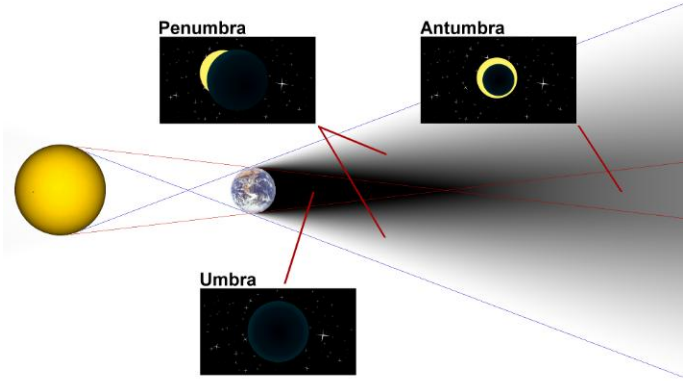

Figure 13: Eclipse Shadows[20]

A. Lunar Eclipse

A lunar eclipse[21] occurs when the Moon moves into the Earth's shadow and there are three types of lunar eclipses:

- **Total**, where the moon is fully inside the darkest part of the Earth's shadow, called the umbra.
- **Penumbral**, where the moon is fully inside the lighter part of the Earth's shadow, called the penumbra, and does not enter the umbra.
- **Partial**, where the moon is inside both the penumbra and umbra or partially in the penumbra.

Figure 14: Lunar Eclipse Diagram. NASA

Total lunar eclipses lasts roughly 90 minutes, are visible from a majority of the night side of the Earth, and can only occur during a full moon.

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[20] By Qarnos - Own work, Public Domain, https://commons.wikimedia.org/w/index.php?curid=3675853

[21] https://en.wikipedia.org/wiki/Lunar_eclipse#Types_of_lunar_eclipse

B. Solar Eclipses

In a solar eclipse[22], the moon is between the Sun and Earth so that it casts a shadow on the surface of the Earth. At this moment in time, the Moon is roughly the same angular size as the Sun, but elliptical orbits of both the Earth and Moon sometimes shift the Moon into a wider orbit so the Moon is smaller than the Sun.

Only a small portion of the Earth can see the eclipse along the shadow path.

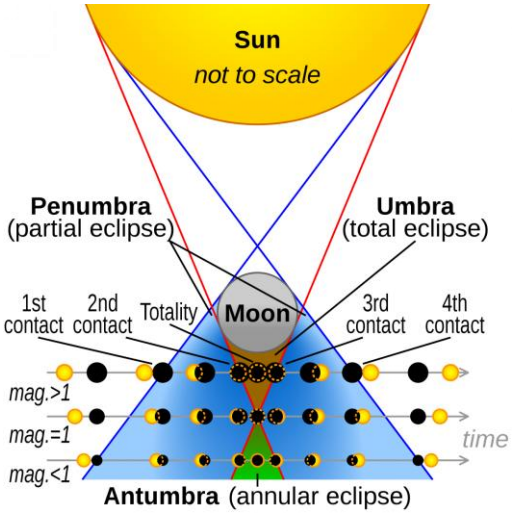

Figure 15: Solar Eclipse by Cmglee[23]

We see four types of solar eclipses[24]:

- **Partial** - The Moon covers only part of the Sun's surface, but is not an annular eclipse.
- **Total** - The Moon covers all of the Suns' surface.
- **Annular** - The Moon covers almost all of the Sun's surface, but is surrounded by a small ring of the Sun's surface.
- **Hybrid** - The eclipse transitions between total and annular eclipses.

1) Partial Solar Eclipse

If you are outside the central shadow of a total or annular solar eclipse, the Moon covers only a portion of the Sun's surface. On the eclipse shadow path, a partial eclipse precedes and follows a total, annular, or hybrid eclipse, lasting about an hour before and after the main event.

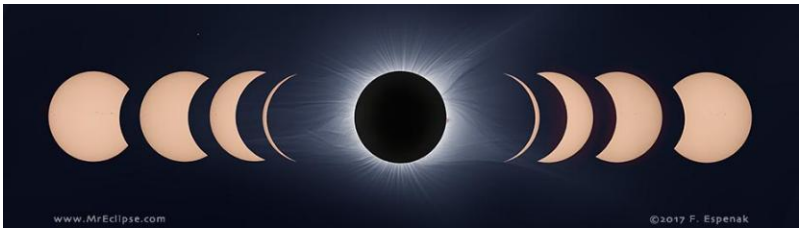

Figure 16: Eclipse of 2017 sequence
by Fred Espenak www.MrEclipse.com

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[22] https://science.nasa.gov/eclipses/types/

[23] Cmglee - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=39077179

[24] https://science.nasa.gov/eclipses/types/

Outside the path, the partial eclipse lasts a few minutes to two hours and will cover a maximum of 1% to 99% of the Sun's surface, depending on the distance from the eclipse path. The partial shadow path is much wider than North America. In 2024, all of Texas outside the eclipse path will see a partial eclipse covering 80% or more of the Sun's surface.

Figure 17: 2024 Eclipse Path Map
https://solarsystem.nasa.gov/eclipses/2024/apr-8-total/where-when/

2) Total Solar Eclipse

The Moon fully covers the Sun's surface, dramatically darkening the sky. Only a narrow path on the Earth sees the full eclipse and only for less than 7 minutes. The few minutes of totality are the ONLY time it is safe to view with the naked eye. In fact, the spectacle of totality is NOT visible through solar filters or eclipse glasses. So, put down your pinhole projectors and remove your filters and glasses during totality and just gaze upward in awe, **BUT BE SURE TO RESUME SAFE VIEWING JUST AS TOTALITY ENDS!**

A total solar eclipse is a marvelous, almost mystical event. Words can't do justice to the experience. A total eclipse has many events (solareclipse2015.org.uk) (Skyandtelescope.com) that are only visible at totality and never seen in annular or partial eclipses:

a) Crescent images & fuzzy shadows: Once a good portion the Sun is covered and it appears as a crescent, then trees and pinholes will have crescent-shaped images. Shadows will be fuzzy, too.

Figure 18 Fuzzy shadows by Ken Kroft

Figure 19 Crescent images from leaves by Mark Smith

b) Ambient light dims: Starting roughly 15 minutes before totality, the ambient light begins to dim. Even if the sky is overcast, the Moon's shadow will noticeably dim the sky.

c) Birds and insects think it's twilight: Starting roughly 10 minutes before totality, birds will flock to roost and evening insects will start to sing. The Eclipse Soundscapes project aims to measure this effect during the eclipse.

d) Your shadow sharpens: As the Sun is reduced to a thin sliver, your shadow sharpens. When you look at your shadow during a normal day, it's fuzzy because you're getting light beams from the full surface of the Sun. Just prior to totality, the spread of light is narrowed, so shadows look more solid and the edges are sharp.

e) The Moon's shadow sweeps across the land: A few minutes before totality, if you have a good view of the landscape, you'll be able to see the Moon's shadow sweep across the land. Remember that the shadow is more than 100 miles across, so it will look more like a curtain falling than a round shadow.

Figure 20 Eclipse seen from orbit (ISS 2006, Turkey and Cyprus) Credit: NASA

f) Shadow Bands: Close to totality, when the crescent is very thin, the air will refract the sunlight into ripples or shadow bands a few feet wide. They'll move faster than you can run and are easiest to see on a white sheet. They are very difficult to photograph, but your eye will see the light fluctuate oddly. Here is a video from Australia that shows the effect you'll see on a smooth white surface: https://youtu.be/f_XMnU7Ad40?si=epAhrf3tAVJ2DsHR&t=12
https://eclipse2017.nasa.gov/exploring-shadow-bands

g) Temperature drops: Without the bright sunlight heating the ground, the air and ground will experience a slight temperature drop.
https://www.nationalgeographic.com/science/article/120328-solar-eclipses-winds-weather-sun-earth-space-science

h) Eclipse Weather: It's not well-understood, but eclipses and the cooling effect of the Moon's shadow also changes the weather. The wind may slow, speed up, or change direction. Clouds may also change. The Globe Observer project aims to measure the changing clouds at many sites along the path. You can join the project by using their app.
https://earthsky.org/earth/solar-eclipses-have-an-effect-on-wind/
https://weather.com/science/weather-explainers/news/2024-03-08-total-solar-eclipse-weather

i) Bailey's Beads and Diamond Ring: As the Moon covers the Sun's surface, the last tiny fraction of the surface will shine brilliantly through the valleys at the limb of the Moon. You get a

Figure 21 Baily's Beads[25]

Figure 22 Diamond Ring effect[26] .

[25] By Tomruen - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=61897030

j) Prominences: Once the Moon fully covers the Sun's surface, you won't see anything through your solar glasses and it's safe to take them off. Around the edge of the Moon, you'll see spots or even flames of red. These are prominences, which are magnetic loops coming from lower levels of the Sun that also carry the energetic plasma (glowing red) high up into space. Each of these prominences will be at least several times the size of the Earth!

k) Corona: The most stunning sight of a total eclipse is the thin wisps of the corona, the Sun's outer atmosphere. We are fortunate in that the Sun is active right now, so the corona should extend in a wide disk similar to the photo below from 2015. The corona is dim enough that it is only visible when the Sun's surface is blocked.

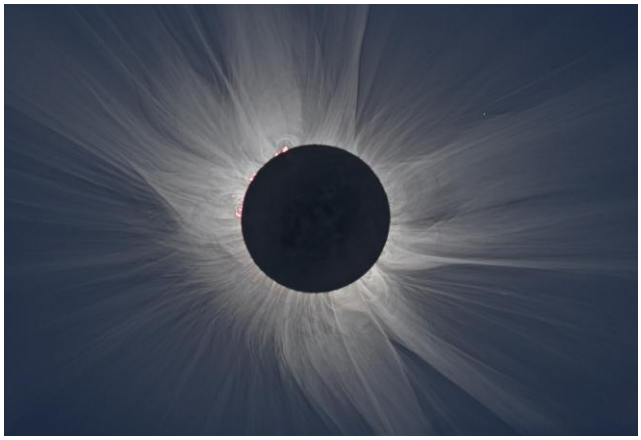

Figure 23 Sun's corona and prominences[27]

l) Bright stars and planets! Once the corona comes out, you'll see the brighter stars and planets in the sky. We are lucky to have Venus, Mars, Jupiter, and Saturn, which will be visible. Mercury, Neptune, and Uranus will also be up, but won't be visible to the naked eye. Comet 12P/Pons-Brooks will be near Jupiter, but will probably not be visible to the naked eye. Here's a simulated view I created in Stellarium:

[26] By Natarajanganesan - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=62022371

[27] https://www.jpl.nasa.gov/edu/news/2017/8/10/get-students-excited-about-science-during-this-months-total-solar-eclipse/

Figure 24 Stellarium simulation of eclipse view in April 8, 2024. Credit Tom Heisey

m) Everything repeats in reverse! Once totality ends, you'll see everything in reverse:

- Baily's Beads and the Diamond Ring
- Shadow bands
- The Moon's shadow sweeping across the land (from a high spot)
- The light brightens and the birds and insects revert to daytime habits.
- Your shadow go from sharp to fuzzy
- Crescent images through tree leaves and pinholes.

3) Annular Solar Eclipse

The Moon is centered on the Sun, but is smaller and leaves a ring of the Sun's surface on all edges. This type of eclipse is also called a "ring of fire" for good reason. Because some of the surface is visible, it is not safe to observe with the naked eye. The will dim slightly, but not as much as during totality.

Figure 25: 2005 Annular Solar Eclipse before, during, and after annularity. Credit Fred Espenak

4) Hybrid Solar Eclipse

In a rare occurrence, the eclipse path features both a total and annular eclipse. These occur along the limb or poles of the Earth to vary the distance from the surface to the Moon and are typically very short. At any site along the path, you'll either see a brief total eclipse or a very slight "ring of fire", but not both.

4. Why don't we have an eclipse every month?

Solar eclipses only happen at the **new moon phase** and lunar eclipses happen at **full moon**, so it seems that we should see one of each every month. However, the Moon's orbit is **tilted at 5.1°** to the plane of Earth's orbit[28] around the Sun, limiting our opportunity to have an eclipse.

The tilt of the Moons orbit means that we can have eclipses only twice a year, roughly six months apart, when the Moon crosses the plane of Earth's orbit. These locations are known as **eclipse seasons**[29], which extend roughly 17° either side of the crossing point. An eclipse season lasts for 34.5 days[30] and the lunar month is 29.5 days, so each eclipse season hosts a combination of one to three solar and lunar eclipses, with two being most common. Since 1582, only six years have had five eclipses in a year - 1693, 1758, 1805, 1823, 1879, 1935. The next occurrence will be in 2206.[31] Between 1600 and 2599,

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[28] https://spaceplace.nasa.gov/eclipses/en/

[29] https://eclipse.gsfc.nasa.gov/SEsaros/SEperiodicity.html#section101

[30] https://www.timeanddate.com/eclipse/eclipse-season.html

[31] Pogo, Alexander (1935). "Calendar years with five solar eclipses". *Popular Astronomy*. Vol. 43. p. 412.

there are 126 eclipse seasons featuring a total or annular solar eclipse and a total lunar eclipse, out of a total of 2108 eclipse seasons.[32]

Most seasons feature one lunar and one solar eclipse of some sort and usually, one of the eclipses will be a full (total lunar, total solar, or annular solar) eclipse followed by a partial lunar or solar eclipse. This makes sense if you think about the Moon passing through the narrow window for the eclipse season. It's likely that one eclipse will happen closer to the edge, giving a partial eclipse, while the other one happens closer to the center, giving a full eclipse.

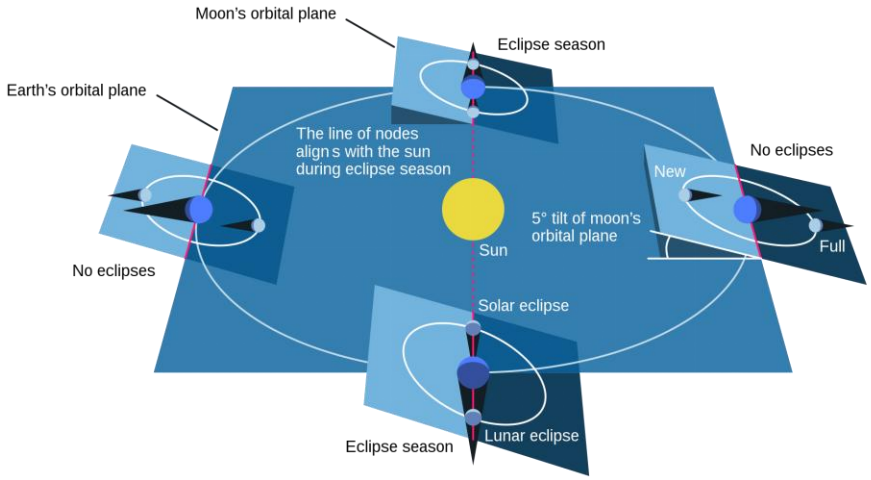

Figure 26: The tilt of the Moon's orbit By Nela (nyabla.net)[33]

Because the eclipse seasons are spaced 173.31 days (1/2 an eclipse year[34]) and the lunar half-year is 177 days (lunar month 29.5 days x 6 months), the eclipse seasons regularly shift to later months:

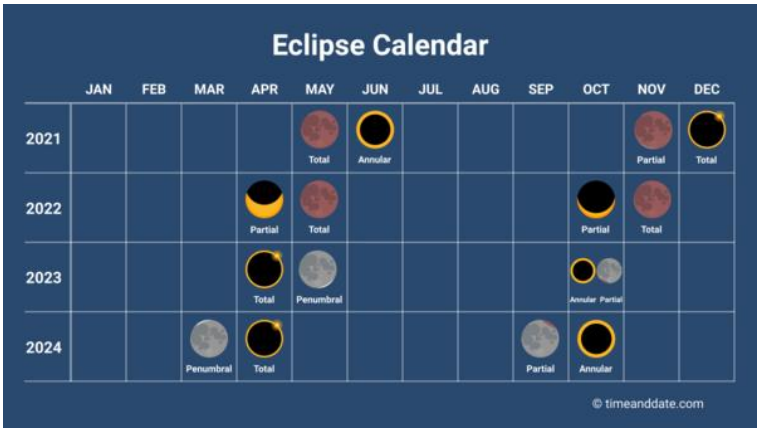

Figure 27: Eclipse Calendar. Credit timeanddate.com

5. History and future of solar eclipses

Eclipses are relatively rare and common at the same time. A solar eclipse occurs somewhere on Earth an average once every 18 months. However, it is very rare for a total eclipse to occur twice in the same location. On average, any location on Earth will experience a total eclipse roughly every 400 years. Continental USA was lucky enough to have the total eclipse

[32] https://www.timeanddate.com/eclipse/eclipse-season.html

[33] Nela (nyabla.net) - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=126239384

[34] https://en.wikipedia.org/wiki/Year#Draconic_year

of 2017 followed by the eclipse in 2024, but we won't see another total solar eclipse until 2045. The maps below show that the lower 48 states have had only eight total eclipses (blue paths) over 100 years - 1954, 1959 (barely), 1963 (only Maine), 1979, 2017, 2024, 2044, and 2045

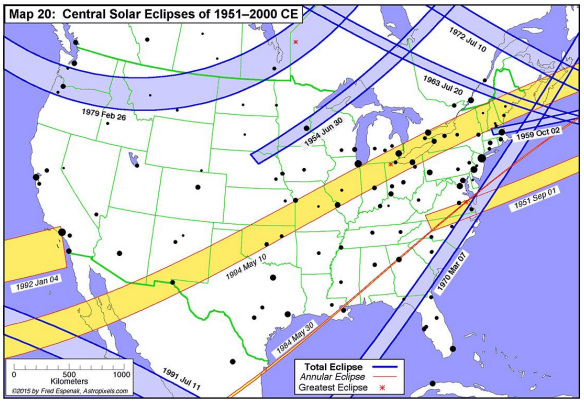

Figure 28: Solar Eclipses over the USA 1951-2000 by Fred Espenak

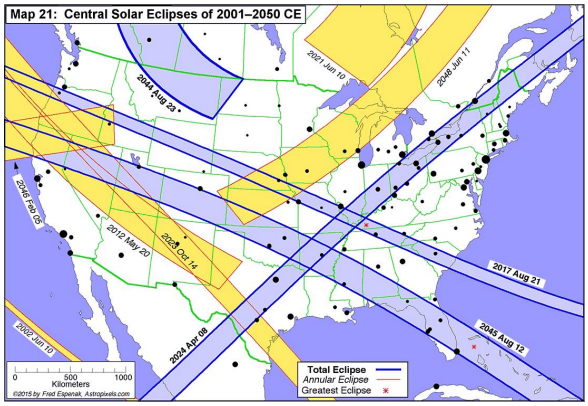

Figure 29: Solar Eclipses over the USA 2001-2050 by Fred Espenak

Even over 1,000 years, some large regions of the continental USA will not see a total eclipse:

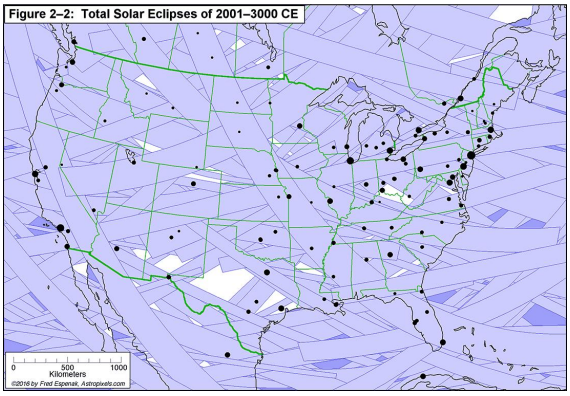

Figure 30: 1000 years of Eclipses over the USA by Fred Espenak, Astropoxels.com

6. Eclipse Season Math

The interval between successive eclipses and eclipse seasons is determined by several factors[35]

- Our year is 365.24 days, meaning on average, Earth travels 0.99° each day. Therefore, it takes an average of 173.3 days to travel between nodes.
- The Moon takes 29.53 days to orbit the Earth starting and ending in the Sun-Earth line.
- An eclipse can only occur within 15.39° to 18.59° (17°mean) of the nodes where the Moon crosses Earth's orbit. The variation is due to the eccentricity of both the Moon's and Earth's orbits. The Moon's shadow will miss Earth and Earth's shadow will miss the moon outside this region.
- The eclipse season is an average of 34.5 days (17° x 2 times the 0.99°/day movement), so there is time for one solar eclipse and one lunar eclipse each season. The variability is actually 30.5 to 36.8 days.

[35] https://eclipse.gsfc.nasa.gov/SEsaros/SEperiodicity.html#section101

- The lunar nodes are separated by 173.3 days, which is short of a half-year (182.5), so the lunar nodes regress westward by 19.3° per year. It would take almost 19 years for the node to rotate around the Sun once.

Taken together, this means solar eclipses are separated by 1 (same node), 5, or 6 (opposite node) lunar months. 65% of the eclipses from 2000 BC to 3000 CE are separated by 6 lunar months. Only 11.4% are separated by 1 month and 23.1% are separated by 5 months.[36]

7. Suggested activities during the eclipse

- Live Stream of the Eclipse: If you're not able to view the eclipse in person, NASA will provide a live stream on April 8 from 1:00-4:00 pm EDT on NASA and YouTube
  https://plus.nasa.gov/banner/2024-total-solar-eclipse-through-the-eyes-of-nasa/
  https://www.youtube.com/watch?v=2MJY_ptQW1o
- **Easy projection** of the partial phase through index cards with a hole punch. Paper plates, construction paper, and other stiff paper works well, too. A colander or grater is another great device to show a "herd" of crescents. Whatever you use, it should be pretty thin with a no more than a 1/4" hole. However, you can see the same thing through a tree's leaves.
  https://www.exploratorium.edu/eclipse/snacks/spot-the-sun
  https://eclipse.aas.org/eye-safety/projection
- **Pinhole projection** for a sharper image of the Sun. A fine pinhole will give you a much clearer image of the Sun. The three links step up from paper & foil, a cereal box & foil, and a box for your head. You should get a better image in the boxes, since they are shaded:
  https://www.jpl.nasa.gov/edu/learn/project/how-to-make-a-pinhole-camera
  https://science.nasa.gov/resource/eclipse-cereal-box-viewer/?category=total_eclipse_activities
  https://www.timeanddate.com/eclipse/box-pinhole-projector.html
  https://eclipse.aas.org/eye-safety/projection
- **Kid-friendly solar glasses:** Kids may have a bit of trouble using solar glasses, so you can glue the glasses into a cut paper plate to make it easier for them to shade their eyes and see a clearer image. It's also a bit safer than glasses that don't fit well. Just be sure that the glue doesn't touch the foil and that the foil remains undamaged.
  https://www.classicalhomemaking.com/2017/08/worry-less-eclipse-glasses-for-kids.html?m=1

- **Photograph the eclipse:** If you're good with a camera, take some photos to remember the event. However, be sure to look around and not spend all the time looking at your camera!
  https://eclipse.aas.org/imaging-video/images-videos
  http://www.mreclipse.com/SEphoto/SEphoto.html
  https://eclipse2017.nasa.gov/smartphone-photography-eclipse
- **Mirror Projected Eclipse image:** A mirror the size of a dime will project a larger image onto a shadowed wall. This image would be suitable for groups to view the progress without the need for solar glasses.
  https://www.nightwise.org/single-post/solar-eclipse-activities#viewer-6ploo
- **Sun Funnel:** If you don't have a solar filter for your telescope, you can use your telescope to project the Sun's image. Some use a white board, but a "Sun funnel" provides a bright and clear image.If you choose projection be sure your

[36] https://eclipse.gsfc.nasa.gov/SEsaros/SEperiodicity.html#section102

telescope is either centered on the Sun or pointed away from the Sun. If the Sun is just off to the side, there is the possibility that your telescope may be damaged by rays straying off to touch the edges of your equipment. https://eclipse.aas.org/sites/eclipse.aas.org/files/Build_a_Sun_Funnel_v3.5s.pdf

- **Shadow bands on white:** If you lay out a white sheet or paint a white square at least a meter in size, you should be able to see the shadow bands pass over. This is a subtle effect that's not completely understood, but it's fascinating https://eclipse2017.nasa.gov/exploring-shadow-bands https://www.strickling.net/shadowbands.htm
- **UV-Sensitive Beads** - Demonstrate the power of UV in sunlight by experimenting with UV beads. Test if your sunscreen and sunglasses block UV light. Add a safety lesson about the importance of safe viewing of the eclipse. https://science.nasa.gov/resource/experimenting-with-uv-sensitive-beads/?category=total_eclipse_activities
- **Eclipse Soundscapes** - Become a citizen scientist and use your phone to record the sounds and sights during the eclipse. https://eclipsesoundscapes.org/
- **GLOBE Eclipse** - Another citizen scientist initiative to record temperature and other observations. https://observer.globe.gov/de/do-globe-observer/eclipse

8. Solar Structure

The Sun is both a nuclear furnace and a twisted magnet. Both of these drive what we see on the Sun's surface. The Sun's core compresses helium into 600 million tonnes of hydrogen every second. This generates 15 million degrees Celsius or 27 million degrees Fahrenheit![37] This heat is what keeps the Earth warm and fertile as it spreads slowly through the Sun's layers to the surface, reaching the earth in the form of a solar wind.

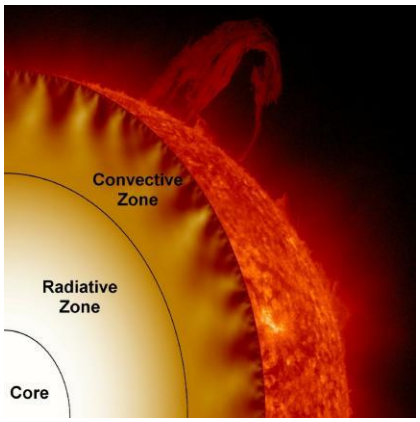

Figure 32 The Sun's interior. Credit NASA.gov

The Sun is also a magnet, with magnetic lines running from pole-to-pole. On Earth, these magnetic lines are fixed to the surface, but on the gaseous Sun, the equator rotates faster than the poles, so the magnetic lines twist with the surface. When the lines twist into knots, you get a variety of features you see on the solar surface (photosphere) and lower atmosphere (chromosphere).

[37] https://solarscience.msfc.nasa.gov/interior.shtml

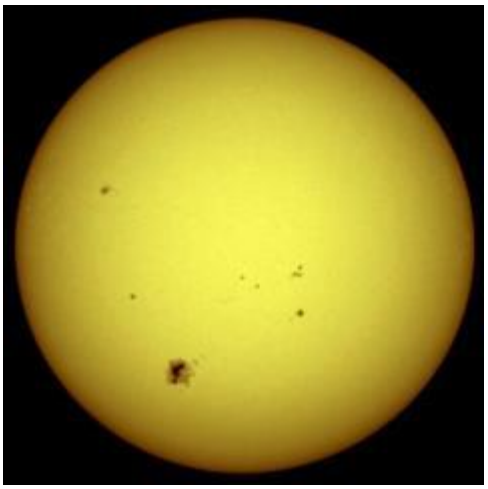

Figure 33 Solar Photosphere credit NASA

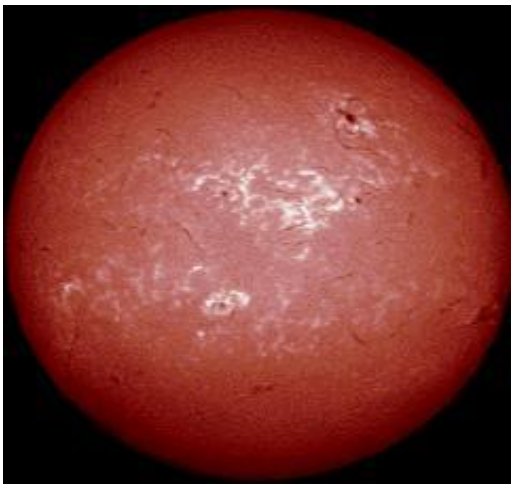

Figure 34: Solar Chromosphere credit NASA

So what can we see in each layer?

A. Photosphere

The photosphere is the boiling surface of the Sun. This would correspond to the bubbling water surface in a pot of boiling water. It is dense enough that we cannot see below it, so it's called the photosphere.

Solar glasses will only show the largest sunspots and maybe large bright regions. Telescopes will show more detail, perhaps including supergranules.

1) Sunspots

Sunspots are locations where magnetic lines twist together and force the plasma rising from the core to the side. They are much cooler (3,700 K) than the surface (5,700 K) and are slightly lower than the surface. The smallest sunspots visible in solar glasses will be 10 or more times the size of Earth (or the size of Jupiter). Telescopes will show sunspots well below the size of the Earth. (108 Earths fit across the equator of the Sun!) Sunspots include an umbra, which is black, and a penumbra, which is much lighter. The colors indicate the magnetic field strength, where darker equals stronger.

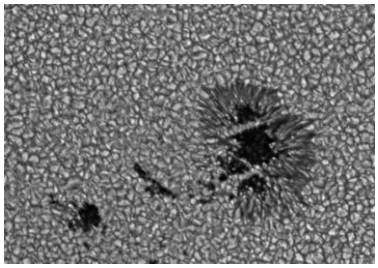

Figure 35: Sunspot credit NASA

2) Faculae, Active regions

Faculae are the opposite of sunspots. Here, the magnetic lines form a conveyor belt bringing the hot plasma from the interior to the surface. These regions are thought to be less dense than the surface, allowing the bright glow of lower layers through, brightening the area.

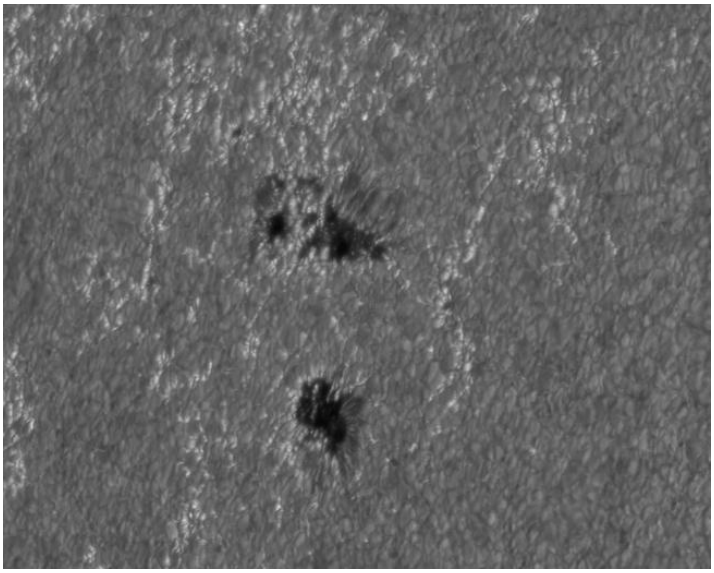

Figure 36: The light areas around the sunspots are faculae. Credit NASA

3) Granules and Supergranules

Granules and Supergranules are the tops of convection cells. Think of the boiling pot where water rises in columns, reaches the air and cools. It can't sink into the rising column, so it slides off to the side and sinks back down to be heated and repeat the cycle over and over. The granules are roughly 1,000 km across (roughly the size of Texas), while supergranules are 35,000 km (5 times larger than Earth!). These cells give the Sun an orange peel texture:

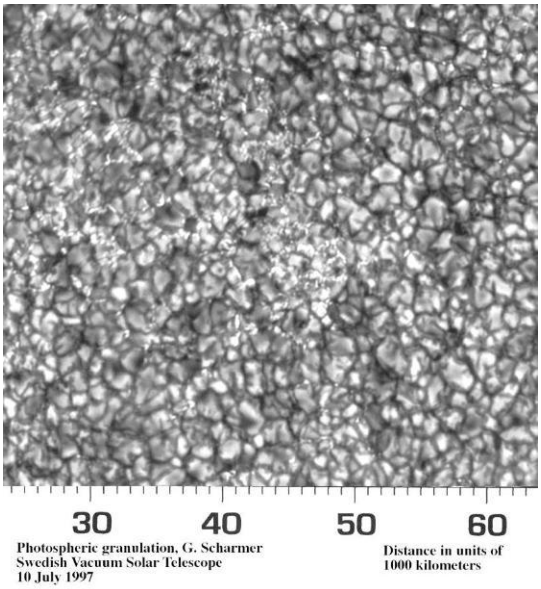

Figure 37: Photospheric Granulation credit NASA and SVST

4) Limb Darkening

The photosphere is gaseous enough that the center of the disk allows for a deeper and therefore brighter view of the rays coming to meet our eyes. On the limb, we're looking at a very shallow angle, so we see the cooler top of the layer, which appears darker. This is called limb darkening:

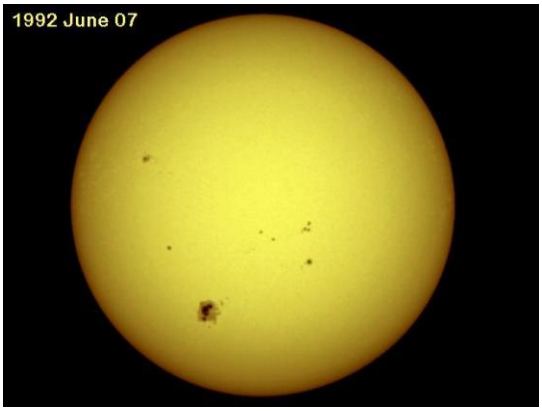

Figure 38: Limb darkening. Credit NASA

B. Chromosphere

The Chromosphere is where hydrogen gets heated from 6,000° C in the photosphere to 20,000° C. At this point, it glows at a specific wavelength of 656.46 nm, known as Hydrogen-alpha (hydrogen's strongest emission) or H-alpha for short. Spectroscopy works because each element gives off unique spikes within the rainbow spectrum of light. In this case, H-alpha telescopes are tuned to this wavelength and excludes all others, because the H-alpha glow is lost in all the other visible light.

H-Alpha telescopes like the one I'll have on the big screen TV can see the dimmer light of the chromosphere, which is the lower atmosphere of the Sun. If you think of a boiling pot of water, this would be the thin layer above the water that includes splashing water, bubbles, and steam. On the Sun, this layer is where temperatures rise high enough to make hydrogen glow and give off light. These telescopes have a very specialized filter that looks only at a very narrow band of red that corresponds to that hydrogen glow, excluding 99.9999% of other bands.

Many of the features of the chromosphere are a result of the activity in the photosphere:

1) Prominences and Filaments

Prominences and filaments are the same object, seen from different viewpoints. Magnetic lines that have twisted below the photosphere bring up plasma from below in beautiful arches. When seen near or on the limb of the Sun, they are known as prominences and have been know (though not always named) since ancient times. During a total eclipse, large prominences are visible, which is how this layer got its name. Prominences are usually several times the Earth's diameter high, but can extend into massive loops many times that length.

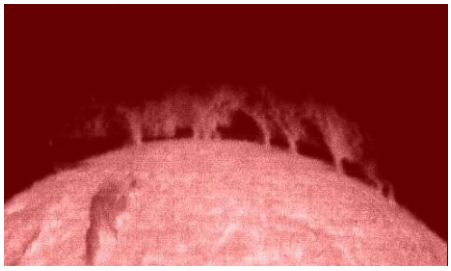

Figure 39: Prominences and Filaments. Credit NASA

Chromospheric Network and Plage

Chromospheric Networks and Plage (French for beach) are brighter, active areas. Like the faculae below, plage surround sunspots, suspended by a concentration of magnetic fields bringing brighter material to the foreground. The chromospheric networks surround the supergranule cells and are suspended by bundles of magnetic lines.

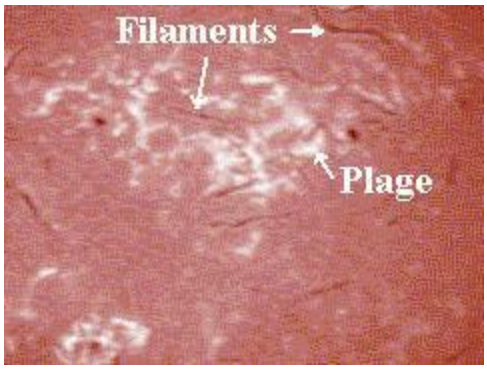

Figure 40: Plage and filaments. Credit NASA

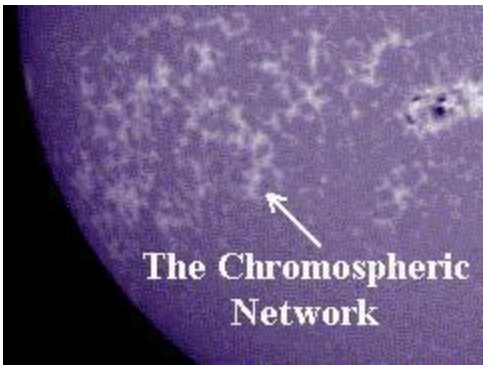

Figure 41: Chromospheric Network. Credit NASA

9. Lake Amistad NRA Notes

The Lake Amistad site is close to the eclipse shadow edge, so we'll see 2 minutes, 30 seconds of the eclipse. As of March 9, as I write this, the early forecast is for good viewing, which is in our favor! While we'll miss two minutes of the full eclipse, we'll see all of the events outlined under the total solar eclipse section.

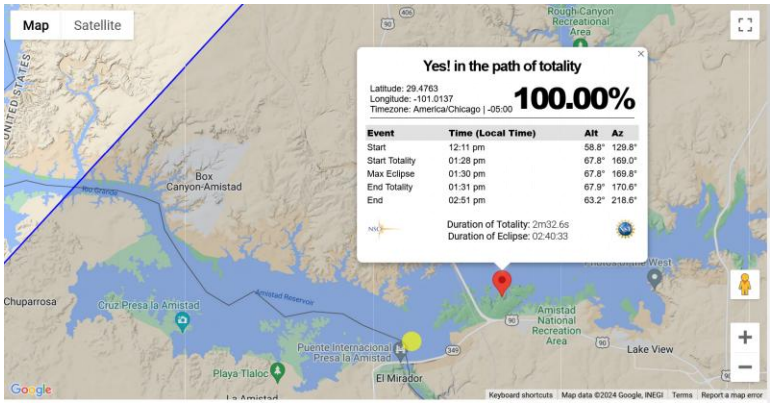

Figure 42: Interactive solar eclipse map, credit https://NSO.edu/for-public/eclipse-map-2024/

At the center line, the duration is 4 minutes 26 seconds.

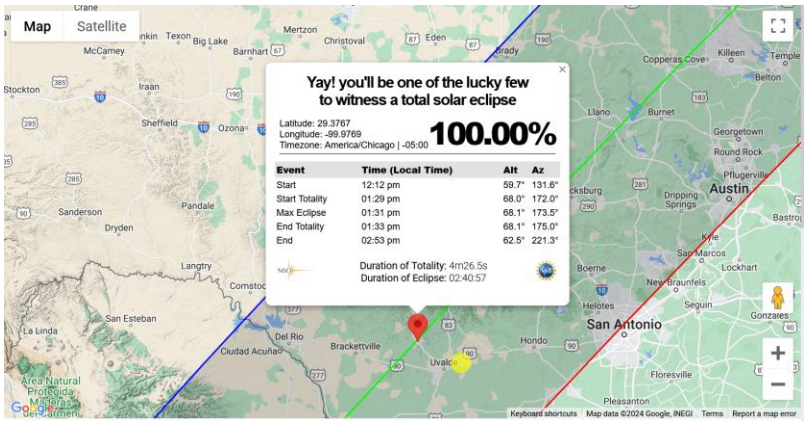

Figure 43: Interactive solar eclipse map, credit https://NSO.edu/for-public/eclipse-map-2024/

If we have the volunteers/staff, I would recommend several activities for families and kids of all ages:

- Projection projects - hole punches in index cards or paper plates. You can add markers or crayons for the kids to decorate their viewers:
  https://www.exploratorium.edu/eclipse/snacks/spot-the-sun
  https://eclipse.aas.org/eye-safety/projection
- A large white sheet or white board (even white paint on the parking lot surface) so people can see the shadow bands. (The larger, the better.) This might best be a 2x4 frame at a 45 degree angle towards the noon Sun. The angled surface should give the widest viewing possible for the crowd.
- Pinhole projection on a large scale. A large heavy tent or other structure with a dark interior could feature a pinhole in the roof to project a large image of the Sun. I have a 70mm lens projection system I'm building that could fit in this, though cheap binoculars would work, too. The crowd could file through to look at large sunspots. A pinhole wouldn't need tending and the Sun's image would just move across the floor, but the lens system would need to be aimed.
  https://www.timeanddate.com/eclipse/box-pinhole-projector.html
  https://eclipse.aas.org/eye-safety/projection
- Photography - I'll have my camera and will take shots of the crowd, plus I'll record the partial eclipse through my H-Alpha telescope, but the "money shot" would include the crowd with the total eclipse overhead. I'll be too close to get the shot with the Sun near the zenith, but someone standing on the top of the hill over the parking lot should be able to get the shot with a wide lens. It would be epic to include that shot in the history of the NRA.

10. Links

NASA eclipse site: https://science.nasa.gov/eclipses/

NASA Eclipse site: https://science.nasa.gov/eclipses

Old NASA Eclipse site: https://eclipse.gsfc.nasa.gov/solar.html

Time And Date https://www.timeanddate.com/eclipse/

Mr Eclipse: Solar eclipses for Beginners https://mreclipse.com/Special/SEprimer.html

Solar Astronomy in the Prehistoric Southwest: https://www2.hao.ucar.edu/education/prehistoric-southwest

Eclipse Myths and Misconceptions: https://eclipse2017.nasa.gov/eclipse-misconceptions

Eclipses through history: https://eclipse2017.nasa.gov/eclipse-history

April 8, 2024 Eclipse event info

NASA Science https://solarsystem.nasa.gov/eclipses/2024/apr-8-total/overview/
Eclipsewise https://www.eclipsewise.com/2024/2024.html

Eclipseophile https://eclipsophile.com/2024tse/

Time & Date https://www.timeanddate.com/eclipse/solar/2024-april-8

Great American Eclipse https://www.greatamericaneclipse.com/april-8-2024

Info for kids

NASA SpacePlace: https://spaceplace.nasa.gov/eclipses

NASA learning https://www.nasa.gov/learning-resources/for-kids-and-students/what-is-an-eclipse-grades-5-8/

Scientific American https://www.scientificamerican.com/article/how-to-explain-aprils-total-solar-eclipse-to-kids/

Teacher's Resources

NASA https://www.nasa.gov/learning-resources/nasa-releases-new-solar-eclipse-educational-materials/

Lesson Plan: How to safely observe a solar eclipse:
https://mynasadata.larc.nasa.gov/lesson-plans/how-safely-observe-solar-eclipse

2017 Eclipse Activity Guide for teachers:
https://eclipse2017.nasa.gov/static/img/eclipse-kit/NASA_Eclipse_Activity_Guide.pdf

STEM Learning Resources for Upcoming Eclipses:
https://www.nasa.gov/learning-resources/prepare-for-upcoming-eclipses/

Eye Safety and Viewing Methods

About ISO 12312-2 https://eclipse.aas.org/eye-safety/iso12312-2

ISO 12312-2 https://www.iso.org/standard/59289.html

American Academy of Ophthalmology Eye danger:

https://www.aao.org/eye-health/tips-prevention/how-sun-can-burn-your-retina-in-seconds

https://www.aao.org/eye-health/tips-prevention/solar-eclipse-eye-safety

https://eclipse.aas.org/eye-safety/iso-certification

Safe Viewing Methods

Solar Filters https://skyandtelescope.org/observing/solar-filter-safety/

Low-Tech Viewing https://skyandtelescope.org/2017-total-solar-eclipse/low-tech-eclipse-viewing/

Safe Solar viewer: https://richardsont.people.cofc.edu/safe_solar_folder/

Hardware store projection: https://www.instructables.com/Hardware-Store-Solar-Eclipse-Viewer/

DIY Solar filter for your camera: https://www.instructables.com/Cheap-and-effective-filters-solar/

Make Magazine viewing projects:
https://makezine.com/article/maker-news/an-eclectic-collection-of-projects-for-your-solar-eclipse/

Nightwise Activities: https://www.nightwise.org/single-post/solar-eclipse-activities#viewer-6ploo

Citizen Science Projects

NASA Master list of citizen science projects:
https://science.nasa.gov/eclipses/future-eclipses/eclipse-2024/eclipse-2024-citizen-science/

Eclipse Soundscapes (birds and insects reacting to the eclipse) https://eclipsesoundscapes.org/

GLOBE Eclipse (temperature and cloud changes) https://observer.globe.gov/eclipse

Eclipse Megamovie (DSLR images of the corona) https://science.nasa.gov/citizen-science/eclipse-megamovie-2024/

Appendix: Eclipse Saros

Eclipses come in series. This is not a common question, but some may find it interesting, so I've included it here.

The eclipses in a Saros share very similar geometries, which includes the Moon's distance from the Earth, the same node, and the same time of year - But is displaced 8 hours or 120° westward. A Saros series returns to roughly the same region every 3 Saroses, which is 54 years, 34 days.

The map of nine Saros 136 eclipses of the modern era shows the 120° movement westward, as well as the gradual northward movement of its solar eclipses:

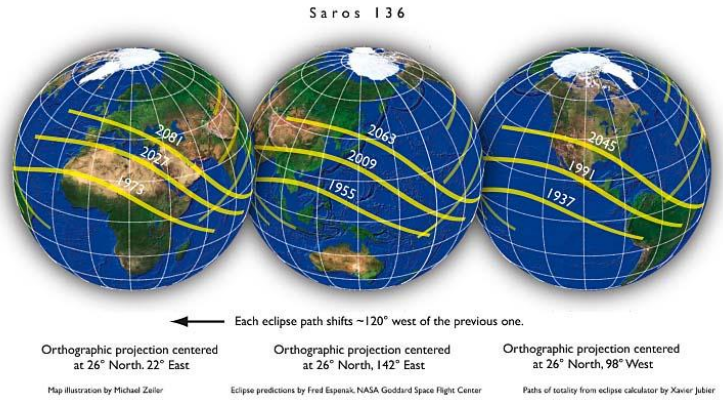

Figure 31: 9 modern eclipses from Saros 136
https://eclipse.gsfc.NASA.gov/SEsaros/SEsaros.html

NASA also has an animated graphic of all 71 eclipses of Saros 136 that shows the movement of the eclipses as well as the paths and types of eclipses. You can view it at https://eclipse.gsfc.nasa.gov/SEsarosanimate/136.gif

All Saros series start and end with a series of partial eclipses as the moon "walks" into the eclipse season. Here are some quick Saros statistics from NASA on the eclipses and Saros series from 2000 BCE to 3000 CE:[38]

- Those 5,000 years have 204 Saros series.
- There are 21 active Saros series in the current time period. (early 2000s)[39]
- 72% of those 204 Saros series contain 70 to 73 eclipses (range between 69 and 87 eclipses)
- The 5,000 years contain 11,898 eclipses[40]:
  - 4,200 partial eclipses
  - 3,956 annular eclipses
  - 3,173 total eclipses
  - 569 hybrid eclipses.
- A Saros series last for 1226 to 1551 years.

For a deeper dive into the timing and geometry of solar eclipses and Saros series, download NASA's Five Millennium Catalog of Solar Eclipses.

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[38] https://eclipse.gsfc.nasa.gov/SEsaros/SEperiodicity.html#section106

[39] https://eclipse.gsfc.nasa.gov/SEsaros/SEsaroscat.html

[40] https://eclipse.gsfc.nasa.gov/SEpubs/5MKSE.html