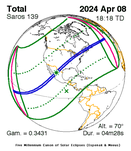
The Waltz of the Eclipses

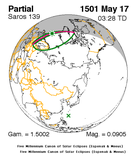
Saros 139

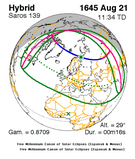
The Saros series that spawned the April 8, 2024 eclipse

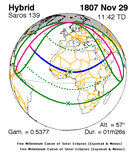
Left: My daughter Meg observing the April 8, 2024 total eclipse in Lake Shore Park, Ashtabula, Ohio.

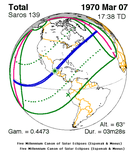
Below: My son Tim's picture of the eclipse from Lampasas, Texas.

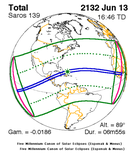


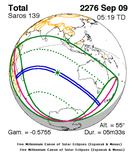


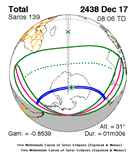


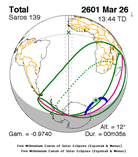


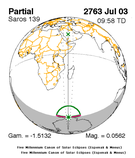












The April 8,

Saros Num	Date	Eclipse Type	Central Duration	Eclipse Mag	Path Width (km)
139	5/17/1501	P		0.0905	
139	5/28/1519	P		0.2342	
139	6/7/1537	P		0.3796	
139	6/19/1555	P		0.529	
139	6/29/1573	P		0.677	
139	7/20/1591	P		0.8249	
139	7/30/1609	P		0.9657	
139	8/11/1627	H	00m00s	1.0001	1
139	8/21/1645	H	00m16s	1.004	28
139	9/1/1663	H	00m29s	1.0065	38
139	9/12/1681	H	00m40s	1.0083	43
139	9/23/1699	H	00m49s	1.0095	46
139	10/4/1717	H	00m56s	1.0104	47
139	10/16/1735	H	01m02s	1.011	48
139	10/26/1753	H	01m08s	1.0115	49
139	11/6/1771	H	01m13s	1.012	50
139	11/17/1789	H	01m19s	1.0126	52
139	11/29/1807	H	01m26s	1.0135	55
139	12/9/1825	H	01m34s	1.0148	60
139	12/21/1843	T	01m43s	1.0165	66
139	12/31/1861	T	01m55s	1.0186	74
139	1/11/1880	T	02m07s	1.0212	84
139	1/22/1898	T	02m21s	1.0244	96
139	2/3/1916	T	02m36s	1.028	108
139	2/14/1934	T	02m53s	1.0321	123
139	2/25/1952	T	03m09s	1.0366	138
139	3/7/1970	T	03m28s	1.0414	153
139	3/18/1988	T	03m46s	1.0464	169
139	3/29/2006	T	04m07s	1.0515	184
139	4/8/2024	T	04m28s	1.0566	198
139	4/20/2042	T	04m51s	1.0614	210
139	4/30/2060	T	05m15s	1.066	222
139	5/11/2078	T	05m40s	1.0701	232
139	5/22/2096	T	06m06s	1.0737	241
139	6/3/2114	T	06m32s	1.0766	248
139	6/13/2132	T	06m55s	1.0788	255
139	6/25/2150	T	07m14s	1.0802	260
139	7/5/2168	T	07m26s	1.0807	264
139	7/16/2186	T	07m29s	1.0805	267
139	7/27/2204	T	07m22s	1.0793	269
139	8/8/2222	T	07m06s	1.0774	270
139	8/18/2240	T	06m40s	1.0746	270
139	8/29/2258	T	06m09s	1.0712	269
139	9/9/2276	T	05m33s	1.0671	266
139	9/20/2294	T	04m56s	1.0627	263
139	10/1/2312	T	04m20s	1.0578	258
139	10/13/2330	T	03m46s	1.0528	251
139	10/23/2348	T	03m14s	1.0476	242
139	11/3/2366	T	02m46s	1.0426	231
139	11/14/2384	T	02m22s	1.0377	217
139	11/25/2402	T	02m02s	1.0332	202
139	12/5/2420	T	01m44s	1.029	185
139	12/17/2438	T	01m30s	1.0254	168
139	12/27/2456	T	01m19s	1.0222	151
139	1/8/2475	T	01m09s	1.0196	136
139	1/18/2493	T	01m02s	1.0174	123
139	1/30/2511	T	00m57s	1.0157	114
139	2/10/2529	T	00m53s	1.0143	108
139	2/21/2547	T	00m50s	1.0132	106
139	3/3/2565	T	00m46s	1.0121	107
139	3/15/2583	T	00m42s	1.0109	115
139	3/26/2601	T	00m35s	1.0091	142
139	4/6/2619	P		0.9781	
139	4/17/2637	P		0.9013	
139	4/28/2655	P		0.8094	
139	5/8/2673	P		0.708	
139	5/20/2691	P		0.5922	
139	5/31/2709	P		0.4697	
139	6/11/2727	P		0.3372	
139	6/22/2745	P		0.1992	
139	7/3/2763	P		0.0562	

2024 eclipse map

Table 1: Lunar months between eclipses (Luna diff)

Date	Saros Num	Eclipse Type	Luna diff
9/9/1904	133	T	6
3/6/1905	138	A	6
8/30/1905	143	T	6
2/23/1906	148	P	6
7/21/1906	115	P	5
8/20/1906	153	P	1
1/14/1907	120	T	5
7/10/1907	125	A	6
1/3/1908	130	T	6
6/28/1908	135	A	6
12/23/1908	140	H	6
6/17/1909	145	H	6
12/12/1909	150	P	6
5/9/1910	117	T	5
11/2/1910	122	P	6
4/28/1911	127	T	6
10/22/1911	132	A	6
4/17/1912	137	H	6
10/10/1912	142	T	6
4/6/1913	147	P	6
8/31/1913	114	P	5
9/30/1913	152	P	1
2/25/1914	119	A	5
8/21/1914	124	T	6
2/14/1915	129	A	6
8/10/1915	134	A	6
2/3/1916	139	T	6
7/30/1916	144	A	6
12/24/1916	111	P	5
1/23/1917	149	P	1
6/19/1917	116	P	5
7/19/1917	154	Pb	1
12/14/1917	121	A	5
6/8/1918	126	T	6
12/3/1918	131	A	6
5/29/1919	136	T	6
11/22/1919	141	A	6
5/18/1920	146	P	6
11/10/1920	151	P	6
4/8/1921	118	A	5
10/1/1921	123	T	6
3/28/1922	128	A	6
9/21/1922	133	T	6
3/17/1923	138	A	6
9/10/1923	143	T	6
3/5/1924	148	P	6
7/31/1924	115	P	5
8/30/1924	153	P	1
1/24/1925	120	T	5
7/20/1925	125	A	6
1/14/1926	130	T	6
7/9/1926	135	A	6
1/3/1927	140	A	6
6/29/1927	145	T	6
12/24/1927	150	P	6
5/19/1928	117	T	5
6/17/1928	155	Pb	1
11/12/1928	122	P	5
5/9/1929	127	T	6
11/1/1929	132	A	6
4/28/1930	137	H	6
10/21/1930	142	T	6
4/18/1931	147	P	6
9/12/1931	114	Pe	5
10/11/1931	152	P	1
3/7/1932	119	A	5
8/31/1932	124	T	6
2/24/1933	129	A	6
8/21/1933	134	A	6
2/14/1934	139	T	6
8/10/1934	144	A	6
1/5/1935	111	Pe	5
2/3/1935	149	P	1
6/30/1935	116	P	5
7/30/1935	154	P	1
12/25/1935	121	A	5
6/19/1936	126	T	6
12/13/1936	131	A	6
6/8/1937	136	T	6
12/2/1937	141	A	6
5/29/1938	146	T	6
11/21/1938	151	P	6
4/19/1939	118	A	5
10/12/1939	123	T	6
4/7/1940	128	A	6
10/1/1940	133	T	6
3/27/1941	138	A	6
9/21/1941	143	T	6
3/16/1942	148	P	6
8/12/1942	115	Pe	5
9/10/1942	153	P	1
2/4/1943	120	T	5
8/1/1943	125	A	6
1/25/1944	130	T	6
7/20/1944	135	A	6
1/14/1945	140	A	6
7/9/1945	145	T	6
1/3/1946	150	P	6
5/30/1946	117	P	5
6/29/1946	155	P	1
11/23/1946	122	P	5
5/20/1947	127	T	6
11/12/1947	132	A	6
5/9/1948	137	A	6
11/1/1948	142	T	6
4/28/1949	147	P	6
10/21/1949	152	P	6
3/18/1950	119	A	5
9/12/1950	124	T	6
3/7/1951	129	A	6
9/1/1951	134	A	6
2/25/1952	139	T	6
8/20/1952	144	A	6
2/14/1953	149	P	6
7/11/1953	116	P	5
8/9/1953	154	P	1
1/5/1954	121	A	5
6/30/1954	126	T	6
12/25/1954	131	A	6
6/20/1955	136	T	6
12/14/1955	141	A	6
6/8/1956	146	T	6
12/2/1956	151	P	6
4/30/1957	118	A	5
10/23/1957	123	T	6
4/19/1958	128	A	6
10/12/1958	133	T	6

Introduction

(If you want to predict an eclipse, you must first understand the dance)

Eclipses are a terrible sight to those who do not understand them. One of the two dominant features in the sky suddenly, and without warning, goes dark. Lunar eclipses would probably be less terrifying because they are visible from half the earth, they last several hours so their appearance is not as dramatic, and they may not be noticed because most people would be asleep at night. The sun, however, is the source of heat and light for the earth. During a solar eclipse, not only does the sun go dark, but also the temperature of the air typically drops by 5 to 14 degrees Fahrenheit. It is little wonder that eclipses were considered to be evil omens and thus worthy of study by the rulers of ancient cultures.

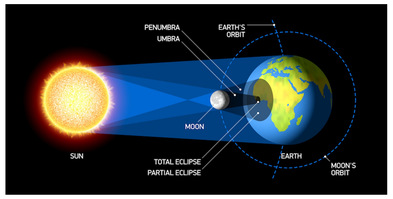
By keeping records, people noticed that the appearance of eclipses was not totally random, they came in various patterns. By studying these patterns, ancient cultures, such as the Chaldeans and Babylonians, were able to predict lunar eclipses, however, predictions of solar eclipses had to wait until the invention of modern astrometry. Then, in 1715, Edmond Halley (of comet fame) correctly predicted, to within four minutes and 20 miles, a total solar eclipse which happened to pass over his own house in London.

Halley's map of the 1715 eclipse over London

Ancient people noticed that two consecutive lunar eclipses were separated by either 6, 5, or 1 lunar months (which occurred at 74%, 19%, and 7% of the time, respectively, see Table 1 to left). However, these consecutive eclipses were usually quite dissimilar. Then someone realized that after 18 years the pattern of eclipses repeated. This formed the basis of the Saros cycle, which is a valuable tool in investigating the periodicity and recurrence of eclipses.

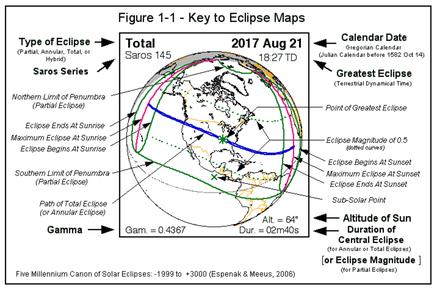
What Makes an Eclipse?

Solar eclipses occur whenever the moon passes between the earth and the sun. If the orbit of the moon around the earth and the orbit of the earth around the sun were perfect circles, and if the moon's orbit around the earth was not tilted with respect to the earth's orbit around the sun, then eclipses would occur once a month at every new moon, which occurs approximately every 29.5 days.



However, orbits are not circular, the moon's orbit around the earth is tilted about 5.1 degrees with respect to the earth's orbit around the sun and, the distance that the moon is from the earth varies from 362,600 to 405,000 km. This all makes the dance of the eclipses a bit more complicated.

One major factor is that, because of the tilt of the moon's orbit around the earth with respect to the orbit of the earth around the sun, an eclipse can only occur when the moon is close to the earth-sun plane and the earth, moon, and sun are aligned. This happens only twice in the earth's journey around the sun, and so eclipses can only occur at approximately 6 month intervals. However, because this alignment does not have to be exact, the window of opportunity for an eclipse to occur is 34.5-days long. This window is called an eclipse season There is actually enough time for two Solar eclipses (and one total lunar eclipse) to occur during a particular eclipse season, although they will always be partial eclipses. This explains why there may be 3, 4, or even (very rarely) 5 solar eclipses in a year. This happens on average every 200 years. See the table to the left for the last time that it happened, which was in 1935.



Explanation of Solar Eclipse Maps

Each eclipse is represented on an orthographic projection map of Earth that shows the path of the Moon's penumbral (partial) and umbral/antumbral (total, hybrid, or annular) shadows with respect to the continental coastlines, political boundaries and the Equator. North is to the top and the daylight terminator is drawn for the instant of greatest eclipse. An "x" symbol marks the sub-solar point or geographic location where the Sun appears directly overhead (zenith) at that time.

The limits of the Moon's penumbral shadow (green lines) delineate the region of visibility of a partial solar eclipse. This irregular or saddle shaped region often covers more than half the daylight hemisphere of Earth.

The eclipse magnitude is defined as the fraction of the Sun's diameter occulted by the Moon. The curves of eclipse magnitude 0.5 (dotted green lines) delineate the locus of all points where the local magnitude at maximum eclipse is equal to 0.5. The northern and southern limits of the penumbra may be thought of as curves of eclipse magnitude of 0.0. For total eclipses, the northern and southern limits of the umbra (blue lines) are curves of eclipse magnitude of 1.0.

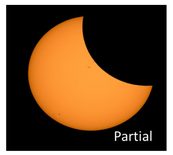
Greatest eclipse is the instant when the axis of the Moon's shadow cone passes closest to Earth's center. The point on Earth's surface intersected by the axis of the Moon's shadow cone at greatest eclipse is marked by an asterisk symbol "*". For partial eclipses, the shadow axis misses Earth entirely, so the point of greatest eclipse lies on the day/night terminator and the Sun appears on the horizon.

Types of Eclipses

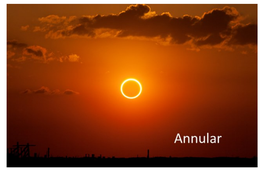
Depending upon the configuration of the earth-moon-sun system, four types of solar eclipses can occur: total, partial, annular, and hybrid.

A **total eclipse** occurs when the moon is close enough to the earth to completely cover the sun. In this situation, the central part of the moon's shadow, the umbra, touches the earth. The width of the moon's shadow on the earth can be up to 1000 km wide, and it can take up to 7.5 minutes for the shadow to pass over a particular location on the earth.

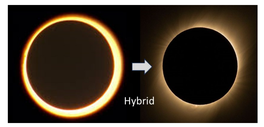
A **partial eclipse** occurs when the moon only partially covers the sun as seen from the earth. This can occur in conjunction with a total eclipse or by itself. The width of a partial eclipse is typically over 6400 km (or about the distance from New York to Rome, Italy). The moon has to cover more than 90% of the sun before there is a noticeable dimming of the sun.



An **annular eclipse** occurs when the moon is too far from Earth to completely cover the Sun, and thus the Moon's antumbral shadow crosses the Earth. The term "annular" comes from the Latin word anulus, meaning "ring". The antumbra (from the Latin *ante* "before" and *umbra* "shadow") is the region where the blocking body (the moon) appears entirely within the disc of the light source (the sun).



A **hybrid eclipse** occurs when the Moon's umbral and antumbral shadows traverse Earth. In this case the eclipse is total along the central portion of its path and annular along the rest of its path.



Saros Cycles

The periodicity and recurrence of eclipses is predicted by the Saros cycle, a period of approximately 6,585.3 days (18 years 11 days 8 hours). It was known to the Chaldeans as a period when lunar eclipses repeated themselves, but the cycle can also be applied to solar eclipses as well.

The Saros is the result of a natural harmony between three of the Moon's orbital periods:

Synodic Month (New Moon to New Moon)	= 29.530589 days	= 29d 12h 44m 03s
Anomalistic Month (perigee to perigee)	= 27.554550 days	= 27d 13h 18m 33s
Draconic Month (node to node)	= 27.212221 days	= 27d 05h 05m 36s

The perigee is the point in the orbit of the moon when it is nearest to the earth. A node is one of the two points where the moon's orbit around the earth crosses the plane of the earth's orbit around the sun. The Moon moves from south to north of Earth's orbit at the ascending node, and from north to south at the descending node.

One Saros is equal to 223 synodic months. However, 239 anomalistic months and 242 draconic months are also equal to this same period (to within a couple hours).

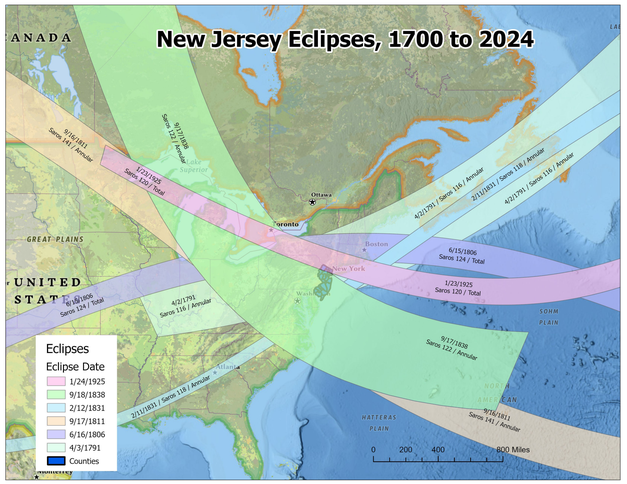
223 Synodic Months	= 6585.3223 days	= 6585d 07h 43m
239 Anomalistic Months	= 6585.5375 days	= 6585d 12h 54m
242 Draconic Months	= 6585.3575 days	= 6585d 08h 35m

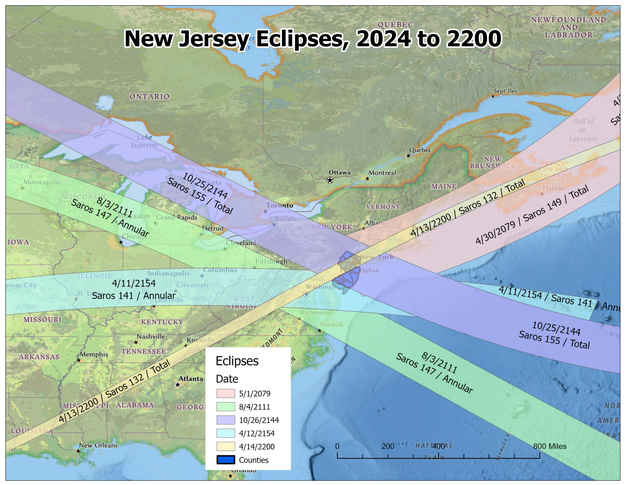
Any two eclipses separated by one Saros cycle share very similar geometries. They occur at the same node with the Moon at nearly the same distance from Earth and at the same time of year. Because the Saros period is not equal to a whole number of days, its biggest drawback is that subsequent eclipses are visible from different parts of the globe. The extra 1/3 day displacement means that Earth must rotate an additional ~8 hours or ~120º with each cycle. For solar eclipses, this results in the shifting of each successive eclipse path by ~120º westward. Thus, a Saros series returns to about the same geographic region every 3 saroses (54 years and 34 days). (See the maps for Saros 139 to the right.)

A Saros series doesn't last indefinitely because the three lunar months are not perfectly commensurate with one another. In particular, the Moon's node shifts eastward by about 0.5º with each cycle. A typical Saros series for a solar eclipse begins when new Moon occurs ~18° east of a node. If the first eclipse occurs at the Moon's descending node, the Moon's umbral shadow will pass ~3500 km below Earth and a partial eclipse will be visible from the south polar region. On the following return, the umbra will pass ~300 km closer to Earth and a partial eclipse of slightly larger magnitude will result. After ten or eleven Saros cycles (about 200 years), the first central eclipse will occur near the south pole of Earth. Over the course of the next 950 years, a central eclipse occurs every 18.031 years (= Saros) but will be displaced northward by an average of ~300 km. Halfway through this period, eclipses of long duration will occur near the equator. The last central eclipse of the series occurs near the north pole. The next approximately ten eclipses will be partial with successively smaller magnitudes. Finally, the Saros series will end a dozen or more centuries after it began at the opposite pole. Due to the ellipticity of the orbits of Earth and the Moon, the exact duration and number of eclipses in a complete Saros is not constant. A series may last 1226 to 1550 years and is comprised of 69 to 87 eclipses, of which about 40 to 60 are central (i.e., total, hybrid or annular). The lower map shows the first 32 eclipses of the Saros 139 series.

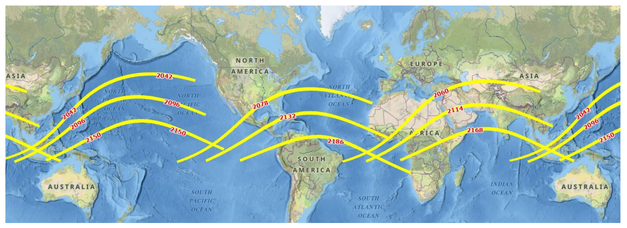
Solar eclipses that take place near the Moon's ascending node have *odd* Saros numbers. Each succeeding eclipse in a series shifts progressively southward with respect to the center of Earth. On the other hand, solar eclipses occurring near the Moon's descending node have *even* Saros numbers. Each succeeding eclipse in a series shifts progressively northward with respect to the center of Earth.

See: https://eclipse.gsfc.nasa.gov/SEsaros/SEsaros.html

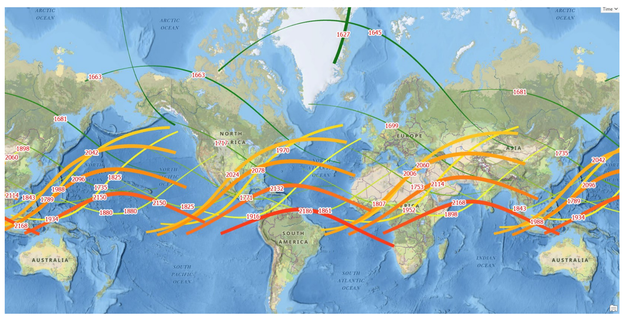




Saros 139, 2042 to 2186



Saros 139, 1627 to 2186, eclipse path colored by year



Acknowledgements

- FIVE MILLENNIUM CANON OF SOLAR ECLIPSES: -1999 TO +3000, NASA Technical Publication TP-2006-214141
- Solar Eclipse paths were prepared by Michael Zeiler from data courtesy of Xavier Jubier. The data contains 905 solar eclipses from 1601 to 2200.
- Close, Frank (2017). Eclipse: Journeys to the Dark Side of the Moon. Oxford University Press.
- Wikipedia

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