



NUS

National University
of Singapore

GEK1506

Heavenly Mathematics: Cultural Astronomy

Eclipse



Submitted by Group: 21
AY 2005/2006

Heng Shi Hui Valerie	U050749N
Lau Minyi	U052659B
Leong Jieying	U042868J
Lim Yi Hua	U052367E
Wu Xinni	U052663A

A Full Moon Eclipse

by **William Bonilla**

Thursday, November 13, 2003

The full moon, was eclipsing
I felt no inspiration
Something or spirits
Were darkening my moon.

As I treaten and waved
My war club, Towards the heavens
To wart away, the evil spirits
Approaching from the left.

Evil clouds, surrounded her
In a haze, of mystic formations
They seem to change shapes
Before my observation.

I saw a cat
The moon was his eye
The creatures, I saw
High up, in the brilliant sky.

Each used the moon, as their eye
A dragon, flying upside down
A sea turtle, looking back
She wore a crown.

The serpent, had no eye
But the moon
Was his glowing head
As, she just drifted slowly
And obviously dead.

The night stood still
Very dark, accompany by a chill
The moon was ashen
I thought her dead.

I lower my war club,
I lower my head
Sadly I walked away
Towards my cave.

To narrate
This unfolding story
To my cowering clan
Babbling away, their heads

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What is an Eclipse?

An Eclipse refers to occasions in which the 3 heavenly bodies- the Sun, the Moon and the Earth are exactly aligned on the same plane. The Moon can be between the Sun and the Earth or the Earth can be in between the Sun and the Moon. Therefore, there are a few types of eclipses, namely, the Solar eclipse and the lunar eclipse, each subdivided into some more other types.

Eclipses occur only either at the full or new phase of the Moon and it must be at the nodes. Nodes are the intersection points between the ecliptic pathway and the Moon's orbit. The 2 paths are at a separation angle of 5° . Hence, if either one of the conditions is unfulfilled, an eclipse will not happen. These nodes are not stationary points. They move backwards with respect to the Earth due to precession. Hence, the predicting of Eclipses will no longer be as simple as it seems. The frequency and characteristics will change. This prediction will be discussed later on. Now, we shall look at the sub-groups of the Solar and Lunar eclipse.

The Solar eclipse

The Solar eclipse occurs when a new Moon is in between the Earth and the Sun on the same plane (on the nodes). With the Moon in between, the Sun shines on the Moon, casting a shadow of cone shape. This shadow may or may not reach the Earth, depending on whether the Moon in its orbit, is near enough to the surface of the Earth. This distance between the Moon and the Earth plays an important part in determining what kind of solar eclipse we will see.

Totality

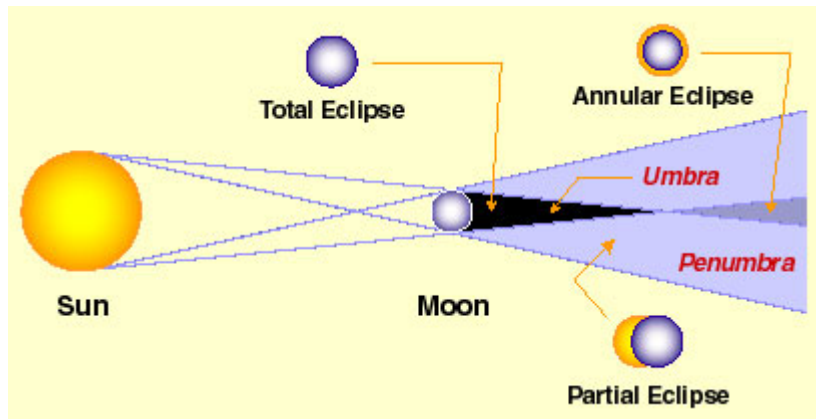
At totality, the Moon is at a distance which when viewed from the Earth, its size will be bigger or the same as the Sun. Hence, the Moon will fully cover the whole area of the Sun and this causes a full Solar eclipse which we named it as totality. A special case will happen as the Moon moves to cover the Sun completely. Before totality, we will see a “diamond ring” and follow by Baily’s beads forming. Baily’s beads are tiny sunrays streaming from the crescent of the Sun as the Moon moves in to cover the Sun. As soon as the Moon covers the Sun, these Baily’s beads disappear and a corona-sunrays spreading out from the eclipse will be observed.

The distance of the Moon and Earth determines what kind of eclipse we will see. If the distance is small, this means that the Moon’s shadow will be able to reach the Earth’s surface. Thus, an annular eclipse will be observed. This will be discussed later below. The shadow has 2 parts-the umbra and the penumbra. The umbra is the darker part of the shadow and penumbra, the lighter part of the shadow. If the shadow reached the Earth’s surface, the region of the Earth where the umbra touches will experience totality and the region where the penumbra touches will experience a partial solar eclipse.

Hence, only at a small region of the Earth will we see a full solar eclipse, totality.

Annular eclipse

Annular eclipse occurs when the new Moon is farthest away from the Earth at its orbit. Therefore, it appears smaller and will not be able to cover the full area of the Sun. When such a case happens, the Moon will appear to be a dark circle in the Sun, making a ring shape. We call this an annular eclipse. At annular eclipse, the sky does not turn dark and we do not experience total darkness like what solar eclipse will result. The sunrays are still able to pass through the Moon and the Moon’s shadow does not touch the Earth’s surface.



The shadow cast by the Moon can be divided by geometry into the completely shadowed *umbra* and the partially shadowed *penumbra*.

Partial eclipse

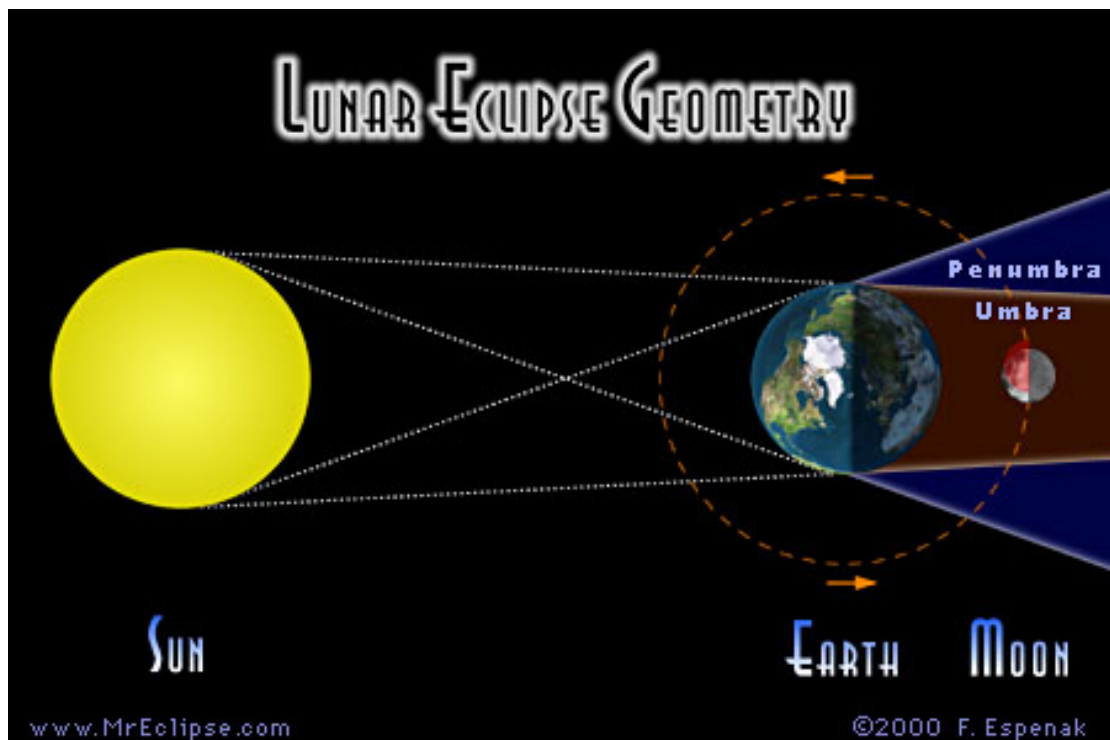
There are 2 cases in which such an eclipse can happen. Firstly, it occurs on the region where the penumbra shines. The closer this region is to the umbra region, the greater the area of the Moon blocks the Sun. Hence, at a farther part, one will observe only a small partial eclipse of the Sun. Secondly, a partial eclipse happens when the new Moon is actually not in the same plane as the Sun and the Earth, that is, the new Moon is not at the nodes and it is just passing through a small part of the Sun.

Lunar eclipse

The Lunar eclipse occurs longer than the Solar eclipse. More than half the area of the Earth which is facing the full moon will have a chance to catch this eclipse. A lunar eclipse is when the full moon moves into the Earth's shadow. The Earth is now in between the Sun and the Moon. When the Sun shines on the Earth, the shadow will intercept with the Moon's orbit. As the full Moon follows its orbit, it soon moves into the shadow of the Earth. Hence, it will change from a creamy white full Moon to a dull, reddish brown full Moon. This Moon does not become dark because the sunrays are still able to reach the Moon. These sunrays are refracted through the Earth's atmosphere and only the red colour is able to reach the Moon because it has the greatest wavelength of 700nm.

Partial lunar eclipse

A partial lunar eclipse happens just like the solar eclipse: when the full moon is not at the nodes and it passes through its orbit, moving just into a small part of the Earth's shadow. Therefore, one will see a convex part of the moon being 'eaten up' instead of a full one getting 'devoured'. At such an occasion, only can we see a gibbous crescent Moon.



History of Eclipses

Eclipses were often linked with superstitions. They were once perceived as augurs of ill and harbingers of good fortune. Whether it is good or bad luck, there seemed to have a relationship with them.

For the ancient Chinese, many thought that the lunar eclipse was a phenomenon, “Black dog swallowing the Moon”. Black represents bad luck for the Chinese, hence, it was meant as a black omen to them. Even the solar eclipse was considered as an unlucky sign. It was known as the “Dragon swallowing the Sun”.

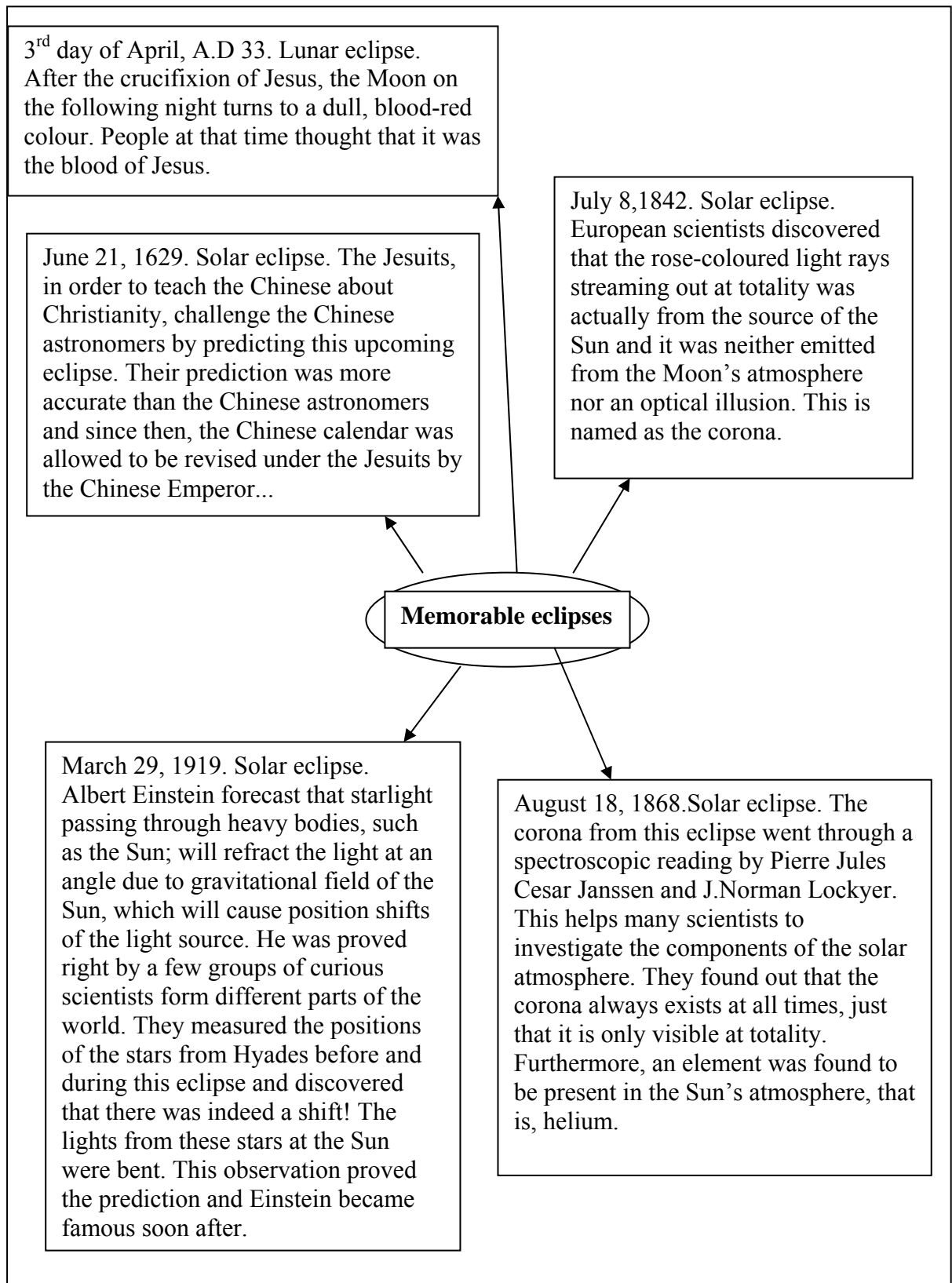
At war times, eclipses may determine its outcome. A solar eclipse occurs in bright daylight, the sudden darkness may be interpreted as a bad omen. Those who planned to attack on the day of the eclipse will interpret this sudden darkness of the sky as a god-sent aid, attacking enemies in the midst of darkness. Enemies even thought that the evil forces were on their side; hence, the loss of morale makes the loss of the battle. The same goes for the lunar eclipse, which the Moon turns blood-red.

After more scientific researches in later centuries, many get to know how eclipses are formed and became less superstitious about eclipses. Many people soon became interested and enthusiastic about all types of eclipses. It was made known to be a hard to come-by event so they chased after eclipses by moving to different parts of the Earth where eclipses are predicted to occur. Cameras, telescopes, binoculars and other optical instruments were then invented and used to view and analyze eclipses. The importance of not looking directly at solar eclipses was made known and optical devices help to project the images on screens.

Soon, these fervent astronomers record eclipses so as to predict its cycle for later decades. Calendars are formed based on previous record of eclipses too. The cycle was done by looking up to old records up to past few centuries on available information such as the dates, time, and location of those eclipses, mostly recorded by ancient astronomers, the Babylonians and the Greeks. It was a tedious job but nothing seems impossible for these astronomers.

Research and discoveries over the centuries now give us almost full information on eclipses. Advances in knowledge enable the modern world to predict eclipses by computer software calculations. When, where and what questions of the prediction of eclipses could be calculated almost right away.

Memorable Eclipses

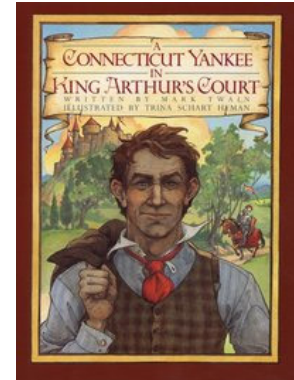


Myths and Legends

There are many myths and legends related to eclipse and in the olden days where people have little or no knowledge on eclipse. People fear eclipse and thought the Moon or the Sun was eaten up by some monster and some believed that it is a premonition of bad omen and pray intensively during an eclipse. Eclipses are blame for if anything bad happens. We will share some stories related to eclipse in this section.

Stories related to eclipse

The novel “A Connecticut Yankee in King Arthur’s Court” written by Mark Twain is about this man who is transported back through time to England and ended up in jail in one of his many encounters. In order to find a way out of jail, he came up with the idea to cheat his captors that he will steal the sun if he was not released. Since he knows about the solar eclipse that is coming, the captors were deceived when the solar eclipse took place and release him immediately.



A true accident that happened to Christopher Columbus on his fourth voyage to America in 1503 when he was trapped on an island as his ship was damaged. His crew and he depend largely on the natives on that island for food. Eventually they were no longer willing to supply them with food. Knowing that a lunar eclipse is approaching, Columbus deceived the locals and they were horrified and pleaded with him to bring the moon back in exchange for food. Columbus and his crew lived on that white lie till they were rescued.

Moral of the story: Know your astronomy well to cheat your way through a crisis ☺

China in the older days especially the King believed that during a solar eclipse the giant dragon will eat up their precious Sun so all astronomers back then were required to accurately predict the solar eclipse. This will give ample time for the King and his people to create a ceremony by beating drums and shooting arrows into the sky to scare off the poor dragon. Two astronomers, Hsi and Ho did not fulfill their duty as they forgot to warn the King about the fore coming solar eclipse, as they were drunk. However the King managed to “scare off” the dragon but these two astronomers was punished severely. In this legend, the King chopped off their heads and threw it high into the sky and they became stars between the constellations of Perseus and Cassiopeia.

Misconceptions

Misconception 1: Looking at the Sun causes Blindness? Do you agree?

Have you heard the common story that looking at the Sun even briefly will cause the eyes to be blind? I bet most of you did hear of this before but is it true?

It is far more dangerous to view the Sun during a solar eclipse as compared to viewing the Sun when it is not eclipsed with the naked eye! This is totally true as the mechanisms in our eyes prevents overexposure to the Sun and little or no long term damage actually results from looking at the uneclipsed Sun. Thus the common idea that looking at the Sun actually causes blindness is not exactly true after all. According to Andrew Young, an adjunct faculty member of the San Diego State University's Department of Astronomy, under normal circumstances, glancing at the Sun will not permanently damage your eyes. The pupils of the eyes will constrict immensely when overexposed to very bright light and this will efficiently reduce the majority of light entering the eyes and prevent damage to the retina. Thus a 4 degrees rise in temperature of the tissue is insufficient to cause permanent damage. However, the amount of pupil constriction varies among people thus some people's retina get damaged by viewing the Sun (solar retinopathy) but they only belong to the minority of the population.

Physicians from Moors fields Eye Hospital, London, England also confirmed that observing the Sun can result in damage to the eye but not total blindness. They reported that 50% of their patients suffering from eye injury recover completely and only 10% suffers from permanent vision loss but no one had a total loss of vision from solar retinopathy.

However during a total eclipse, all the rays of the Sun are blocked by the Moon. At this point, the sky turns dark and your pupils dilate to allow us to see clearly. But when this phase of the eclipse end, part of the Sun's rays will suddenly be exposed. This sudden exposure to the Sun's ray when your pupils are dilated cause severe damage to the retina as all the light get through to your eyes which might result in blindness.

Misconception 2: X-rays emitted from Sun's Corona can damage your eyes

Everyone knows x-rays are harmful to us and assumes that the x-ray from the corona during an eclipse will damage the eyes. But this is not **TRUE!** The Earth's atmosphere prevents any x-ray from any source in the sky from penetrating the Earth as they absorb every x-ray photon coming from space. Also, the corona is too faint to hurt our eyes and the corona is around no matter if the sun is eclipsed or not. Thus, the corona could hurt you at any time but since is too faint the corona can never damage your eyes!

Misconception 3: Galileo's went blind by viewing the Sun through his telescope



Galileo did go blind but it is due to glaucoma and cataract in the later part of his life and not from telescope observations. Galileo soon realized the sharp pain in his eyes after viewing the Sun through his telescope so he projected the image of the Sun onto the wall or observed the Sun just before sunset where it is dimmer and safer to see. Although viewing the Sun through the telescope can cause severe damage to the eyes but this kind of damage occurs rapidly after solar observation and Galileo eyes were perfectly fine till he was 70.

Predicting Eclipses

The Saros Cycle

To predict eclipses, we first need to understand 3 terms: Synodic month, Anomalistic month and Eclipse year. The Synodic month is the period of time from a new moon to the next new moon and on average, it is 29.530588 days. The period between successive perigees is defined as the Anomalistic month, which has an average of 27.55455 days. Lastly, the period for the Sun (as seen from the Earth) to complete one revolution with respect to the same Moon's node is known as the Eclipse year. The duration is about 346.62005 days. Coincidentally, these three cycles repeat nearly exactly every 18+ years:

223 Synodic months (29.530588 days) = 6585.321124 days

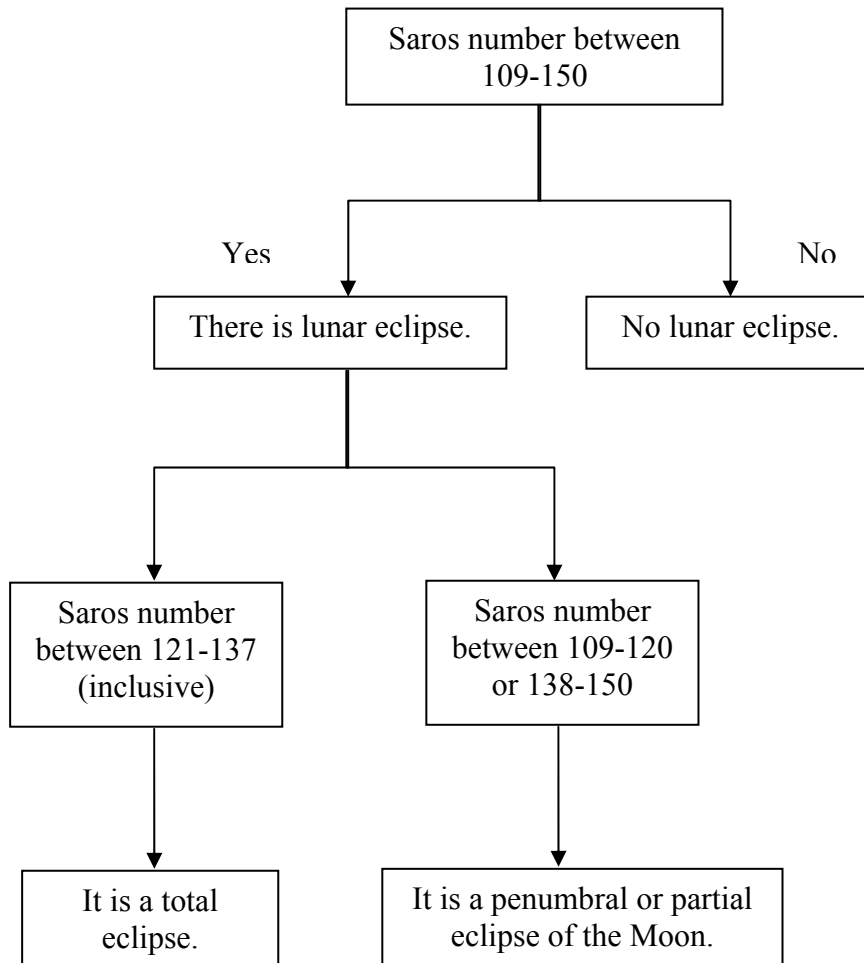
239 Anomalistic months (27.55455 days) = 6585.53745 days

19 Eclipse years (346.62005 days) = 6585.78095 days

This period of 223 Synodic months is known as the Saros cycle. The interval of the Saros cycle is about 18years and $11\frac{1}{3}$ days (18years, 11days and 8hours). Therefore, if there is an eclipse now, after one saros cycle, another eclipse will occur with very similar geometrical configuration of the Sun, Moon and Earth. It will occur at the same node with the Moon at nearly the same distance from Earth and at the same time of year. However, subsequent eclipses are seen at different parts of the world due to the fact that the saros cycle is not a whole number in terms of days. The extra $\frac{1}{3}$ day means that the Earth must rotate an additional ~ 8 hours or $\sim 120^\circ$ with each cycle. For solar eclipses, this results in the shifting of each successive eclipse path by $\sim 120^\circ$ westward. As a result, a saros series returns to about the same geographic region every 3 saroses (54 years and 34 days).

Predicting Lunar Eclipses

There are 223 independent series of Full Moons in which each next Full Moon comes one saros after the previous one. All Full Moons in such a series are given the same saros number, which is between 1 and 223 (inclusive). According to Astronomical Institute/Utrecht University, during the coming years, lunar eclipses can be predicted using the flowchart shown below:



The saros number of the Full Moon can be calculated as follows:

1. Given the first Full Moon of 2003 (on 17 January) has the saros number 192. 192 fall outside the 109-150 range. Thus, there is no lunar eclipse.
2. Add 38 to the saros number for each next Full Moon.
3. Subtract 223 from the saros number if it gets greater than 223.

For example, the saros number for the second Full Moon of 2003 is $38 + 192 = 230$. This is bigger than 223. Hence, the resultant saros number for the second Full Moon of 2003 is $230 - 223 = 7$. Saros number 7 is not within the range of 109-150 so there is no lunar eclipse. The saros number for the third Full Moon is $7 + 38 = 45$. Again it is out of range, so there is no eclipse. This series of steps is continued until the fifth Full Moon, where the saros number is 121. 121 fall in the interval of 121-137. Therefore, the fifth Full Moon of 2003 has a total lunar eclipse. For the sixth Full Moon the saros number is $121 + 38 = 159$ which is too high for a lunar eclipse.

Below is a table that shows the dates and saros numbers of the first Full Moon of the years 2003-2010. The column "FM" gives the ordinal number of the first Full Moon of that year in a series that starts with number 1 for the first Full Moon of the year 2000. The column "Jan" gives the date in January which has the first Full Moon of the year. The column "Saros" lists the corresponding saros number.

Year	FM	Jan	Saros
2003	38	17	192
2004	50	7	202
2005	63	25	27
2006	75	14	37
2007	87	3	47
2008	100	22	95
2009	112	11	105
2010	125	30	153

Once a lunar eclipse is found, another method can be used to predict the next eclipse. In this method, it is stated that the next eclipse will occur 1, 5, or 6 Full Moons later, and its saros number will be 38 greater, 33 less, or 5 greater, respectively, than the saros number of the previous eclipse. More information on this method can be found in the website.

Predicting Solar Eclipses

The method described above can also be used to predict solar eclipses. But, the intervals range is different from the lunar eclipses. A point to note is that a solar eclipse with a certain saros number is not related to a lunar eclipse with the same saros number. In the near future, if the saros number falls between 117-156, there is solar eclipse. If the saros number falls between 126-140, only total or annular solar eclipses occur. However, there are also a few such eclipses outside of that range.

The saros number of a New Moon can be calculated as follows:

1. Given the first New Moon of 2003 (on 3 January) has saros number 180. 180 fall outside the 117 – 156 range. Thus, there is no solar eclipse.
2. Add 38 to the saros number for each next New Moon.
3. Subtract 223 from the saros number if it gets greater than 223.

Using this method, the saros numbers of the first seven New Moons of 2003 are 180, 218, 33, 71, 109, 147, and 185 respectively. The saros numbers 109 and 147 are inside the 117-156 range, so there are solar eclipses during the fifth and sixth New Moons of 2003.

Below is a table showing the dates and saros numbers of the first New Moon of the years 2003-2021. The column "NM" gives the ordinal number of the first New Moon of the year in a series that starts with number 1 for the first New Moon of the year 2000. The column "Jan" gives the date in January of the first New Moon of the year. The column "Saros" provides the corresponding saros number.

Year	NM	Jan	Saros
2003	37	4	180
2004	50	23	5
2005	62	11	15
2006	75	30	63
2007	87	20	73
2008	99	9	83
2009	112	27	131
2010	124	16	141
2011	136	6	151
2012	149	25	199
2013	161	13	209
2014	173	2	219
2015	186	21	44
2016	198	11	54
2017	211	29	102
2018	223	18	112
2019	235	7	122
2020	248	26	170
2021	260	15	180

Once a solar eclipse is found, another method can be used to predict the next eclipse. In this method, it is stated that the next eclipse will occur 1, 5, or 6 New Moons later, and its saros number will be 38 greater, 33 less, or 5 greater, respectively, than the saros number of the previous solar eclipse. More information on this method can be found in the website.

The method described above uses saros numbers to predict whether there will be a solar (or lunar) eclipse. However, it cannot predict where each eclipse will be seen. To find out the visibility of a particular eclipse, we can visit Fred Espenak's website <http://sunearth.gsfc.nasa.gov/eclipse/eclipse.html>. In this website, Fred Espenak provides detailed information about past, present and future eclipses.

How an Eclipse Looks from Different Parts of the World

Duration of eclipse and eclipse visibility at different parts of the world are affected by many factors.

Duration of Eclipse

What is totality? It is the total phase of an eclipse. It is the period during a solar eclipse when the Sun is completely blocked by the Moon or for totality for a lunar eclipse is the period when the Moon is in the complete shadow of the Earth.

Factors influencing totality duration

- Shadow diameter
- Ground speed

The larger the shadow cast on the ground and the slower the speed of this shadow moving across the ground results in longer totality duration.

Moon's umbra is the complete shadow of the Moon within which the source of light Sun is totally hidden from view. Diameter of the Moon's umbra changes with the distance between the Moon and Earth. Since the Earth's surface is curved, the shortest distance occurs near the midpoint of the shadow's path across Earth's surface (refer to diagram below).

Factors affecting speed of shadow on ground

Earth's curvature and rotation

The Earth's rotation occurs in identical angular direction with the orbital movement of the Moon. Thus, this slows down the speed of the shadow moving across the ground. The speed becomes slowest when the movement of moon and shadow on Earth's surface is almost parallel which occurs near the midpoint of the shadow's path across Earth's surface.

Diagram shows the shortest distance, which occurs near the midpoint of the shadow's path across Earth's surface. Speed is also slowest at this point.



Eclipse visibility

In order to calculate the visibility at a specific location, we need the:

- Moon's altitude during each phase of the eclipse
- Latitude and longitude of the location
- Celestial coordinates of the Moon
- Greenwich Sidereal Time at 00:00 UT

Lunar Eclipse

The visibility of the lunar eclipse at different parts of the world from 1951 to 2050 can be computed by an Excel program designed by “Eclipse Predictions by Fred Espenak, NASA/GSFC” by inputting the longitude and latitude of the desired location. We will use Singapore as an example and analyze the table produced.

The program is located at <http://sunearth.gsfc.nasa.gov/eclipse/LEvis/LEvis.html>

Singapore latitude and longitude converted to decimals degrees:

Latitude: $1^{\circ}, 22 \text{ min North} = 1.366667^{\circ}$

Longitude: $103^{\circ}, 55 \text{ min East} = 103.916667^{\circ}$

														Singapore							
Universal Time of Each Contact														Altitude of Moon at Each Contact							
Date	Type	Pen. Mag	Umb. Mag	Pen.E. Begins P1	Partial Begins U1	Total Begins U2	Great. Eclipse	Total Ends U3	Partial Ends U4	Pen.Ec. Ends P4	Moon RA	Moon Dec	GST (0 UT)	P1	U1	U2	Great	U3	U4	P4	
2001 Jan 09	T	2.187	1.194	17:44	18:42	19:50	20:21	20:52	21:59	22:58	7.419	22.38	7.296	68	60	46	39	33	17	4	
2001 Jul 05	P	1.573	0.499	12:11	13:35	-	14:55	-	16:15	17:40	18.988	-23.41	18.911	14	32	-	49	-	62	64	
2001 Dec 30	N	0.919	-0.110	08:26	-	-	10:29	-	-	12:33	6.635	24.21	6.596	35	-	-	8	-	-	20	
2002 May 26	N	0.714	-0.283	10:13	-	-	12:03	-	-	13:54	16.231	-20.03	16.259	42	-	-	14	-	-	39	
2002 Jun 24	N	0.235	-0.787	20:19	-	-	21:27	-	-	22:36	18.224	-24.78	18.191	37	-	-	22	-	-	6	
2002 Nov 20	N	0.886	-0.222	23:32	-	-	01:47	-	-	04:01	3.708	18.65	3.928	9	-	-	41	-	-	66	
2003 May 16	T	2.100	1.134	01:05	02:03	03:14	03:40	04:07	05:17	06:15	15.512	-18.59	15.563	30	43	59	64	68	72	65	
2003 Nov 09	T	2.140	1.022	22:15	23:33	01:06	01:19	01:31	03:05	04:22	2.927	16.33	3.188	8	10	32	35	38	59	71	
2004 May 04	T	2.288	1.309	17:51	18:48	19:52	20:30	21:08	22:12	23:10	14.807	-16.54	14.871	68	58	44	35	26	11	3	
2004 Oct 28	T	2.390	1.313	00:06	01:14	02:23	03:04	03:45	04:54	06:03	2.176	13.44	2.454	19	35	51	60	69	75	66	
2005 Apr 24	N	0.890	-0.138	07:50	-	-	09:55	-	-	12:00	14.106	-13.91	14.169	46	-	-	16	-	-	14	
2005 Oct 17	P	1.004	0.068	09:51	11:34	-	12:03	-	12:32	14:15	1.465	10.25	1.739	1	12	-	19	-	26	51	
2006 Mar 14	N	1.056	-0.056	21:22	-	-	23:48	-	-	02:14	11.678	3.09	11.497	28	-	-	8	-	-	45	
2006 Sep 07	P	1.158	0.190	16:42	18:05	-	18:51	-	19:38	21:00	23.110	-6.74	23.114	80	73	-	62	-	51	31	
2007 Mar 03	T	2.345	1.238	20:16	21:30	22:44	23:21	23:58	01:12	02:25	10.964	6.93	10.757	45	27	8	1	10	28	46	
2007 Aug 28	T*	2.478	1.481	07:52	08:51	09:52	10:37	11:23	12:24	13:22	22.447	-9.96	22.418	48	33	18	7	4	19	33	
2008 Feb 21	T	2.171	1.111	00:35	01:43	03:01	03:26	03:52	05:09	06:17	10.247	10.47	10.029	19	35	54	60	66	78	71	
2008 Aug 16	P	1.862	0.812	18:23	19:36	-	21:10	-	22:45	23:57	21.762	-12.92	21.708	66	51	-	28	-	5	12	
2009 Feb 09	N	0.924	-0.093	12:37	-	-	14:38	-	-	16:40	9.528	13.53	9.321	20	-	-	49	-	-	75	
2009 Jul 07	N	0.182	-0.908	08:33	-	-	09:39	-	-	10:44	19.136	-23.86	19.033	36	-	-	21	-	-	7	
2009 Aug 06	N	0.428	-0.662	23:01	-	-	00:39	-	-	02:17	21.046	-15.58	20.979	1	-	-	22	-	-	45	
2009 Dec 31	P	1.081	0.082	17:15	18:52	-	19:23	-	19:54	21:30	6.756	24.02	6.690	67	56	-	50	-	44	23	
2010 Jun 26	P	1.603	0.542	08:56	10:16	-	11:38	-	13:00	14:21	18.353	-24.00	18.299	30	12	-	6	-	25	42	
2010 Dec 21	T	2.306	1.261	05:28	06:32	07:40	08:17	08:54	10:02	11:06	5.955	23.75	5.986	64	57	44	37	28	13	1	
2011 Jun 15	T	2.712	1.705	17:23	18:23	19:22	20:13	21:03	22:03	23:02	17.592	-23.23	17.584	65	59	49	38	27	14	0	
2011 Dec 10	T	2.212	1.111	11:32	12:45	14:06	14:32	14:58	16:18	17:32	5.143	22.55	5.265	9	25	43	49	54	67	67	
2012 Jun 04	P	1.343	0.376	08:47	09:59	-	11:03	-	12:07	13:20	16.860	-21.67	16.886	32	15	-	0	-	14	31	
2012 Nov 28	N	0.942	-0.183	12:13	-	-	14:33	-	-	16:53	4.334	20.46	4.526	19	-	-	51	-	-	71	
2013 Apr 25	P	1.012	0.021	18:02	19:52	-	20:07	-	20:24	22:13	14.214	-14.43	14.266	68	45	-	41	-	37	11	
2013 May 25	Nb	0.040	-0.928	03:43	-	-	04:10	-	-	04:37	16.153	-19.41	16.194	64	-	-	68	-	-	71	
2013 Oct 18	N	0.791	-0.267	21:48	-	-	23:50	-	-	01:52	1.572	11.00	1.842	15	-	-	15	-	-	45	
2014 Apr 15	T	2.344	1.296	04:52	05:58	07:06	07:46	08:25	09:33	10:39	13.556	-10.05	13.560	81	74	58	49	39	23	6	
2014 Oct 08	T	2.171	1.172	08:14	09:14	10:25	10:55	11:24	12:35	13:35	0.919	6.31	1.133	39	24	6	1	8	26	41	
2015 Apr 04	T	2.105	1.005	09:00	10:15	11:54	12:00	12:06	13:45	15:01	12.892	-5.29	12.833	32	13	11	13	14	39	58	
2015 Sep 28	T	2.254	1.282	00:10	01:07	02:11	02:47	03:23	04:27	05:24	0.293	1.53	0.438	19	33	49	58	67	82	82	
2016 Mar 23	N	0.801	-0.308	09:37	-	-	11:47	-	-	13:57	12.222	-0.31	12.093	24	-	-	9	-	-	41	
2016 Aug 18	Nb	0.017	-0.993	09:24	-	-	09:42	-	-	10:01	21.849	-11.42	21.813	25	-	-	21	-	-	16	
2016 Sep 16	N	0.933	-0.058	16:53	-	-	18:54	-	-	20:56	23.674	-3.26	23.743	85	-	-	61	-	-	31	
2017 Feb 11	N	1.014	-0.030	22:32	-	-	00:44	-	-	02:55	9.640	13.05	9.419	11	-	-	21	-	-	52	
2017 Aug 07	P	1.315	0.251	15:48	17:22	-	18:20	-	19:19	20:53	21.181	-15.42	21.097	64	73	-	66	-	54	32	
2018 Jan 31	T	2.320	1.321	10:50	11:48	12:51	13:30	14:08	15:11	16:10	8.935	17.00	8.715	6	8	23	32	41	55	67	
2018 Jul 27	T	2.706	1.614	17:13	18:24	19:30	20:22	21:13	22:19	23:30	20.472	-18.97	20.364	70	63	50	39	27	12	5	
2019 Jan 21	T	2.193	1.201	02:35	03:33	04:41	05:12	05:44	06:51	07:49	8.208	20.34	8.019	45	57	67	68	67	58	47	
2019 Jul 16	P	1.729	0.658	18:42	20:01	-	21:31	-	23:00	00:19	19.733	-21.88	19.629	58	42	-	22	-	2	16	
2020 Jan 10	N	0.921	-0.111	17:06	-	-	19:10	-	-	21:14	7.446	23.00	7.319	68	-	-	54	-	-	28	
2020 Jun 05	N	0.594	-0.399	17:43	-	-	19:25	-	-	21:06	16.974	-21.45	16.979	65	-	-	49	-	-	27	
2020 Jul 05	N	0.380	-0.638	03:04	-	-	04:30	-	-	05:55	18.987	-24.05	18.909	52	-	-	65	-	-	65	
2020 Nov 30	N	0.855	-0.257	07:30	-	-	09:43	-	-	11:56	4.480	20.75	4.648	46	-	-	16	-	-	15	
2021 May 26	T	1.979	1.016	08:46	09:44	11:09	11:19	11:28	12:53	13:51	16.244	-20.74	16.283	32	19	1	3	6	25	38	
2021 Nov 19	P	2.098	0.979	06:00	07:18	-	09:03	-	10:47	12:05	3.674	19.15	3.908	63	48	-	25	-	0	18	
2022 May 16	T*	2.397	1.419	01:30	02:27	03:29	04:11	04:54	05:55	06:52	15.524	-19.33	15.591	36	48	61	68	72	68	57	
2022 Nov 08	T	2.440	1.363	08:00	09:09	10:16	10:59	11:42	12:49	13:58	2.897	16.85	3.174	39	23	7	3	13	29	45	
2023 May 05	N	0.989	-0.041	15:12	-	-	17:23	-	-	19:34	14.807	-17.24	14.888	58	-	-	71	-	-	48	
2023 Oct 28	P	1.143	0.127	18:00	19:34	-	20:14	-	20:53	22:28	2.163	14.08	2.461	68	47	-	37	-	28	5	
2024 Mar 25	N	0.982	-0.128	04:51	-	-	07:13	-	-	09:35	12.345	-1.20	12.216	85	-	-	60	-	-	24	
2024 Sep 18	P	1.062	0.091	00:39	02:12	-	02:44	-	03:17	04:49	23.768	-2.59	23.835	25	48	-	56	-	64	87	
2025 Mar 14	T	2.286	1.183	03:55	05:09	06:25	06:59	07:32	08:48	10:02	11.640	2.68	11.477	70	86	72	63	55	36	18	
2025 Sep 07	T	2.369	1.368	15:27	16:27	17:30	18:12	18:53	19:57	20:56	23.111	-6.00	23.138	65	78	80	71	62	46	31	

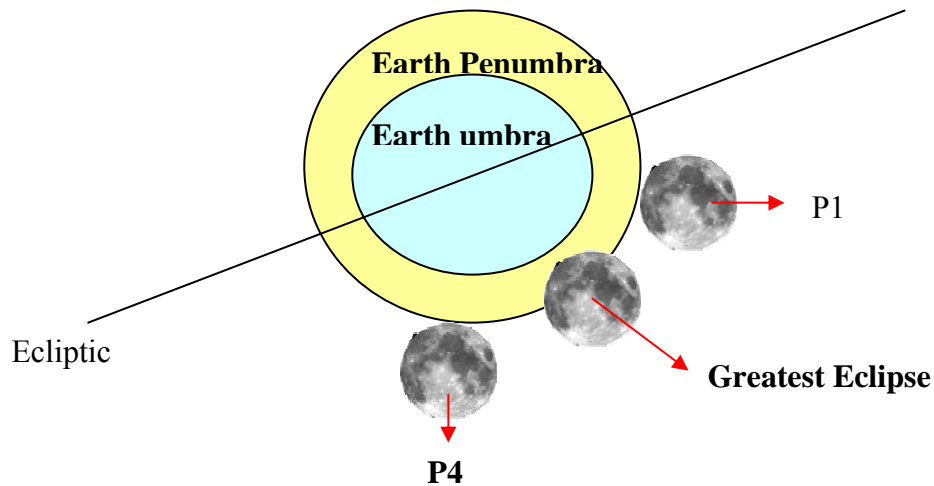
* If the phase occurs before moonrise then you will not see it. However, if that phase occurs after moonrise then it can be seen if weather permits.

Altitude Colour Key
Yellow = Moon above horizon
Grey = Moon below horizon

Key to Eclipse Visibility Map	
P1	Penumbral eclipse begins (not visible to the eye)
U1	Partial eclipse begins
U2	Total eclipse begins
U3	Total eclipse ends
U4	Partial eclipse ends
P4	Penumbral eclipse ends (not visible to the eye)

Column	Heading	Description/Definition
1	Date	Calendar Date(Gregorian) at instant of Greatest Eclipse (Julian calendar is used before 1582 Oct 15)
2	Greatest Eclipse	Universal Time (UT) of Greatest Eclipse, which is Eclipse defined as the instant when Moon passes closest to the axis of Earth's shadows
3	Type	Type of lunar eclipse where: N = Penumbral Eclipse. P = Partial (Umbra) Eclipse. T = Total (Umbra) Eclipse. Tc = central total eclipse) If the Type ends with: "m" = Middle eclipse of Saros series "+" = Central eclipse (Moon north of axis) "- " = Central eclipse (Moon south of axis) "b" = Saros series begins (first eclipse in series) "e" = Saros series ends (last eclipse in series)
4	Saros	Saros series of eclipse. (Each eclipse in a Saros is separated by an interval of 18 years 11.3 days.)
5	Gamma	Distance of the Moon from the axis of Earth's shadow cone (units of equatorial radii) at the instant of greatest eclipse.
6	Pen. Mag.	Penumbral eclipse magnitude is the fraction of the Moon's diameter obscured by the penumbra
7	Umb. Mag.	Umbra eclipse magnitude is the fraction of the Moon's diameter obscured by the umbra
8	S.D. Par	Semi-duration of partial (umbra) eclipse (minutes)
9	S.D. Tot	Semi-duration of total (umbra) eclipse (minutes).
10	GSTO	Greenwich Sidereal Time at 00:00 U.T.
11	Moon RA	Geocentric Right Ascension of the Moon at greatest eclipse (hours)
12	Moon Des	Geocentric Declination of the Moon at greatest eclipse (degrees)

In the Year 2005 in Singapore, we can deduce from the table that we will see a partial lunar eclipse on 17 October 2005. We will be able to see the beginning of partial eclipse(U1), **great eclipse**, end of partial eclipse(U4) and end of penumbral eclipse (**P4**--not visible).

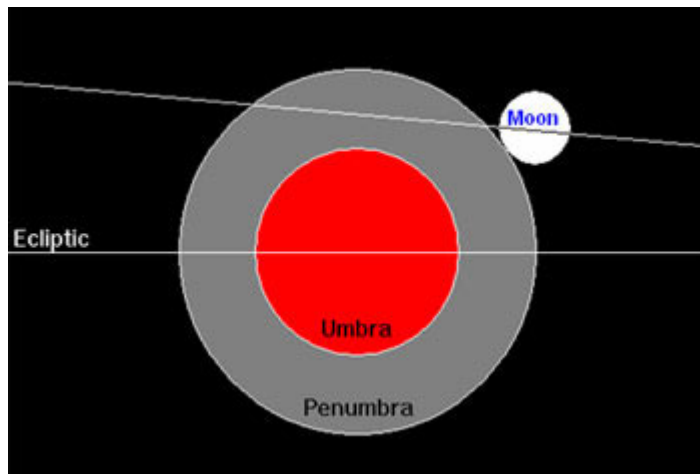


From the table, the (umb. mag. = 0.068) which means that 6.8% of the Earth side facing the Moon will be covered by the Earth's umbra during the middle of the eclipse.

Information from the table above coincides with the data below provided by Singapore Science Centre.

Partial Lunar Eclipse of the Moon, 17 October 2005

Circumstances of the eclipse	Singapore local time
Moon enters penumbra (not visible)	17 51 h
Moon Rises	18 45 h
Middle of eclipse	20 03 h
Moon leaves penumbra (not visible)	22 15 h



Penumbral eclipse is not visible to naked eyes as the brightness of the moon will not vary much when the moon enters the Earth's penumbra. Thus the difference will be hard to notice.

Other factors affecting visibility of eclipse

- Clouds
- Umbra size at the earth's surface
- Solar elevation angle and azimuth relative to path of totality (for solar eclipse)
- Local weather conditions such as haze
- Altitude of scattering elements in the upper troposphere and lower stratosphere
- Site elevation
- Lunar limb profile (significant only for short eclipses)

Solar Eclipse

Solar eclipses are fairly numerous, generally two to five per year. However, the area on the ground covered by totality is only a few kilometres wide. Hence, it is rare to be in the path of a total solar eclipse. In addition, in any given location on Earth, a total solar eclipse happens only once every 360 years. Below is a basic geometry of the Sun, Moon and Earth during an eclipse of the sun.

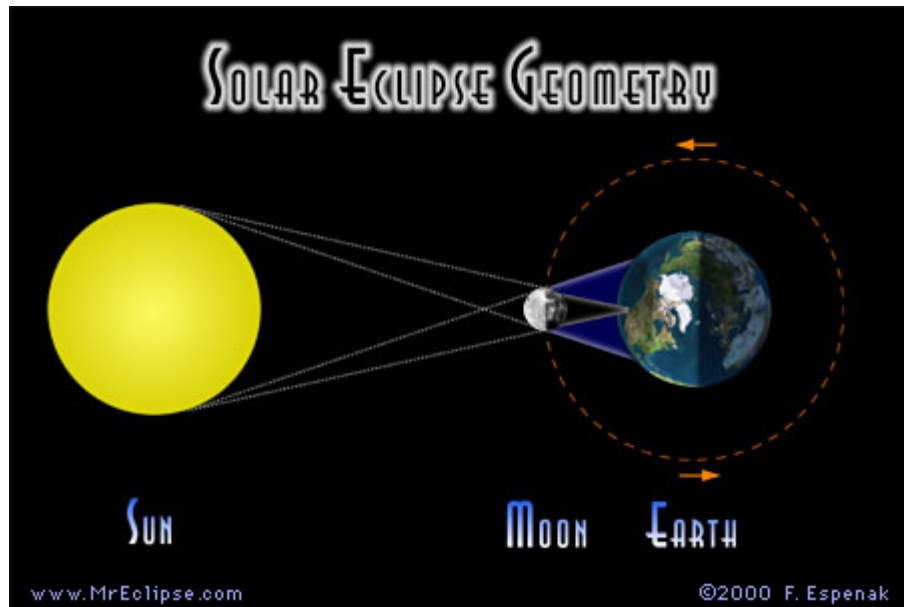


Diagram: basic geometry of the Sun, Moon and Earth during an eclipse of the sun

An eclipse of the Sun (or solar eclipse) can only occur at New Moon when the Moon passes between Earth and Sun. If the Moon's shadow happens to fall upon Earth's surface at that time, we see some portion of the Sun's disk covered or 'eclipsed' by the Moon. This is known as the solar eclipse. Since New Moon occurs every 29.5 days, we will expect to see solar eclipse about once a month. Unfortunately, this does not happen as the Moon's orbit around Earth is tilted 5 degrees to Earth's orbit around the Sun. As a result, the Moon's shadow usually misses Earth as it passes above or below our planet at New Moon. The geometry must line just right at the right place so that some part of the Moon's shadow falls on Earth's surface and an eclipse of the Sun is seen from that region. This occurs at least twice a year.

The Moon's shadow actually has two parts:

Penumbra	Faint outer shadow; partial eclipses are seen from within this shadow.
Umbra	Dark inner shadow; total eclipses are seen from within this shadow

When the Moon's penumbral shadow strikes Earth, partial eclipse of the Sun from that region will then be able to observe. On the other hand, if the Moon's dark umbra shadow sweeps across Earth's surface, this results in a total eclipse of the Sun (see Diagram below). The track of the Moon's shadow across Earth's surface is called the Path of Totality. The path of totality is usually very narrow; typically 10,000 miles long and only 100 miles or so wide. This is due to the relative size of the Moon and Sun and their relative distances from Earth. Hence, in order to see the Sun total eclipse, one must be in the path of totality as shown in the diagram.

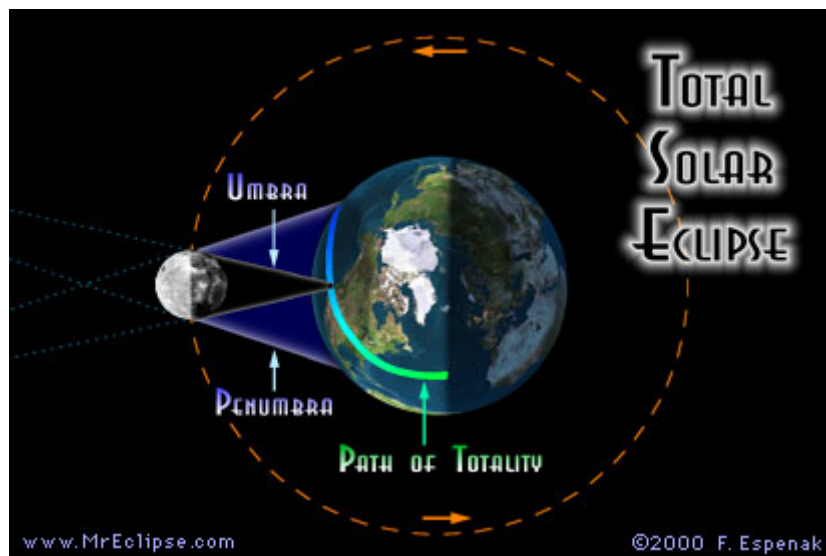


Diagram on Total Solar Eclipse and the Path of Totality

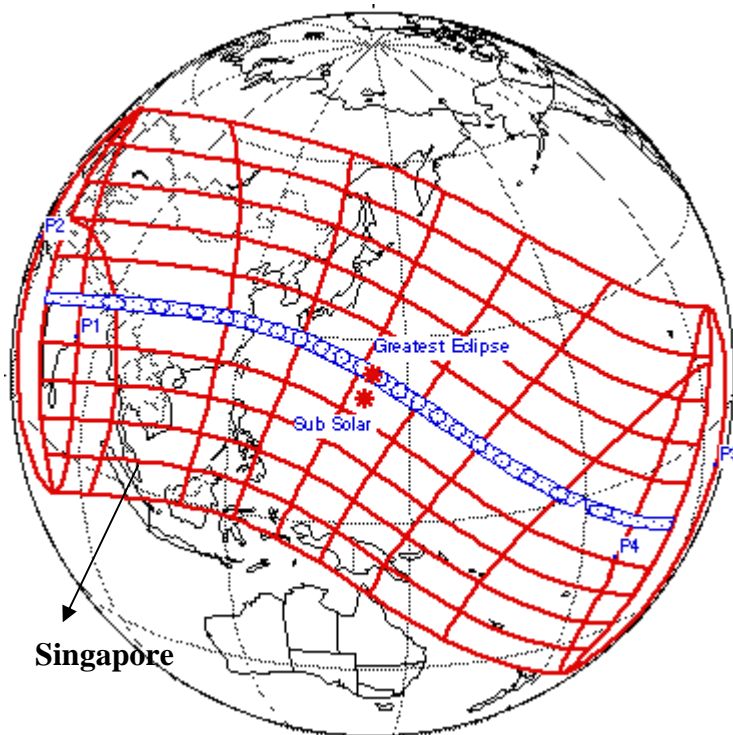
An example of a total solar eclipse occurred on August 11, 1999, was visible from Europe and the Middle East. Below are the nine images captured by Fred Espenak in sequence at Lake Hazar, Turkey. This information is provided by Mreclipse homepage.



Photo of the Total Solar Eclipse of 1999 Aug 11 (Lake Hazar, Turkey)

In Singapore, the next coming total eclipse is being predicted. It will occur on 29 March 2006 as provided by Singapore Science Centre. This is the longest eclipse of the 21st century.

For each eclipse, a map of the path of totality (in blue) and the accompanying partial region (in red) is shown below. The general locations where the eclipse is total are also listed. The maximum width of the path of totality and the maximum duration of the total phase are also being deduced.



22 July 2009

General location:

India at sunrise, China, Pacific Ocean.

Maximum path width: 258 km

Maximum duration of totality: 6m 39s

In Singapore, the mid-eclipse local time is at 09h 17m and the magnitude (fraction of the Sun's diameter covered by the disc of the Moon at middle eclipse) is 0.06.

How Eclipse Prove that our Earth is Round

How do we determine the shape of the Earth? Is it generally round or is the Earth flat? Ancient people tried to view the shaped of the Earth from a mountaintop to prove that it was curve. However there were many arguments about the validity of the claim. Fret not because there has been a better way of determining if the Earth is round.

Pythagoras and Aristotle, along with other Greek philosophers debated on the question. Eclipses took the limelight of the debate. They came up with the thesis that if the moon were eclipsed when it is in the shadow of the Earth (Lunar Eclipse), then the shape of that shadow must represent the shape of the Earth.

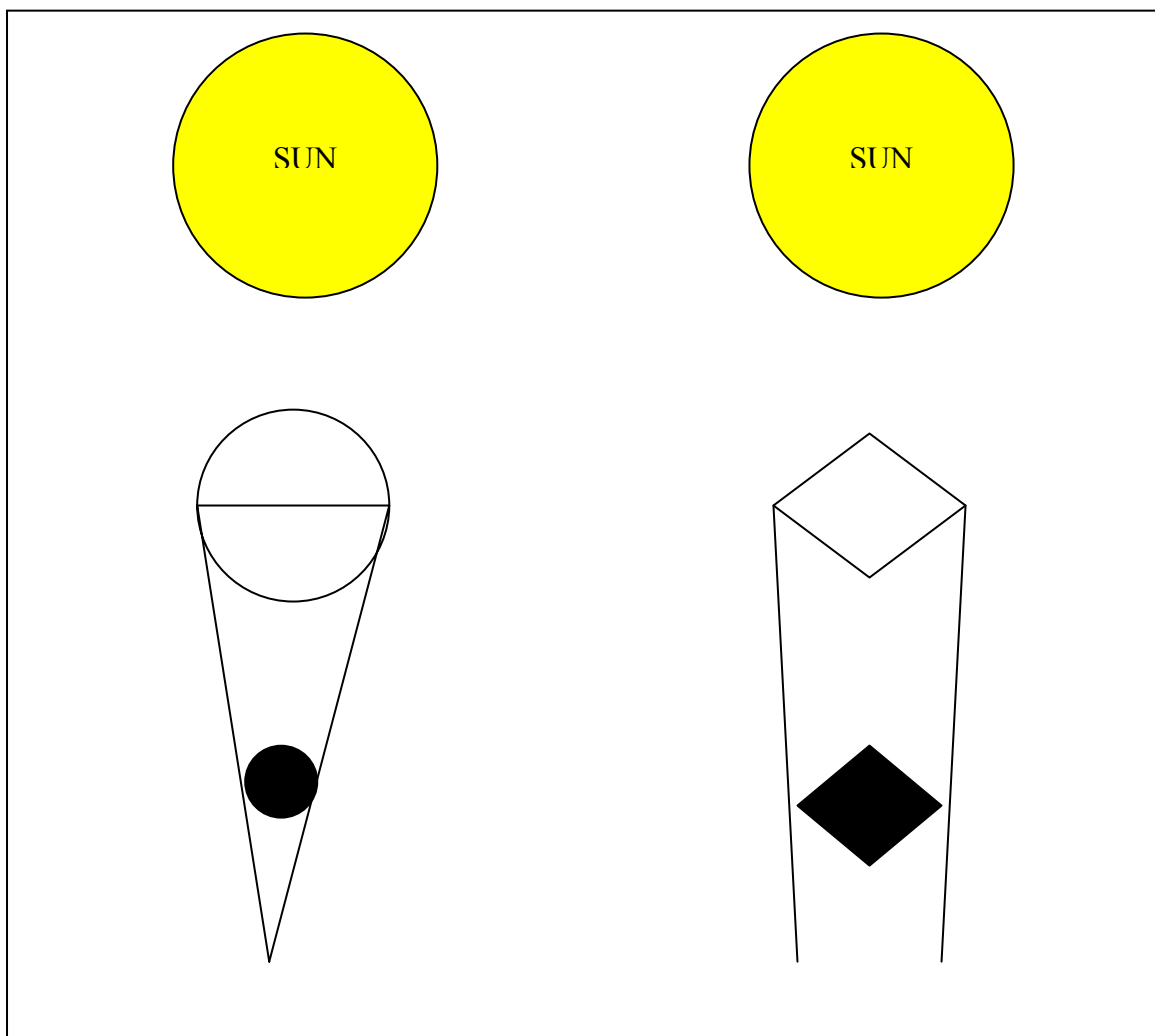


Diagram: Lunar Eclipse

From observation, the shadow cast onto the Moon's surface is a circle. Thus Lunar Eclipses prove that the Earth is indeed round. This is because if the Earth is of another shape (example: square), the shadow cast onto the Moon's surface would be that of the shape (example: square).

Newspaper Articles (Past 10 Years) on Eclipses in Singapore

(Original articles are attached at the back)

The Sunday Times, October 15, 1995

Solar eclipse: Darkness at noon on Oct 24

This article gives information on the solar eclipse that would happen on 24 Oct 1995. It had included the time of the total solar eclipse, the eclipse path and the period of the totality. It was stated that the eclipse path would stretch from the Caspian Sea across India and South-east Asia to the Pacific. However, only partial eclipse could be seen in Singapore. Thus, a group of 20 Singaporeans from the Astronomical Society of Singapore traveled to Lopburi in Thailand in order to catch the eclipse in its totality. This spectacular event also attracted large number of tourists. Other than tourists, astronomers and other academics were also excited as they could make use of this rare chance to conduct studies of the Sun. In addition, viewing tips were included in this article to guide and teach the public the correct way to view solar eclipses.

The Straits Times, 24 October, 1995

Poly student will not let his exams outshine today's eclipse

This article shows how a Polytechnic student was prepared to be late for his exams rather than to miss catching the partial solar eclipse. It was mentioned that only 60 percent of the eclipse was visible in Singapore and it would look like a big black cloud had covered the Sun. The article also included the explanation for the 'disappearing' of Sun and why direct viewing of the Sun was not advisable.

The Straits Times, 25 October, 1995

Catching last total solar eclipse this century

This article shows the power of the solar eclipse phenomenon which made people queued for a look through telescopes, swelter and sweat. It was mentioned that there are at least two eclipses in a year but to see it, one has to chase them. Pictures on the safest way to view solar eclipse and the full eclipse seen in central Thailand were included.

The Straits Times, 25 October, 1995

Many risked eye damage by staring at eclipse

This is the continuation of the previous article. It was stated that around 3000 people had gathered at Jurong to see the crescent sun but most of them did not have the right protection on. Pictures on the right and wrong way to view a solar eclipse were included. In addition, the ways on how people from Thailand, India, Philippines and Bangladesh watched the solar eclipse were also featured.

The Straits Times, 16 September, 1997

Mid-Autumn lunar eclipse tonight

This article features on the Chinese legends related to lunar eclipse and gave an explanation, together with illustration, on how lunar eclipse occurred. It was also mentioned that lunar eclipses are rarer than solar eclipses but lunar eclipses are visible to half of the people on earth. In addition, it was stated that there would be a solar eclipse in August 1998.

The Straits Times, 23 August, 1998

Sun over S'pore plays hide and seek

This article shows how people in different parts of Singapore got excited and disappointed by the annular eclipse. The crowd at Nanyang had a spectacular view on the annular eclipse whereas the crowd at Science Centre was left disappointed due to the bad weather. It also mentioned that a special prayer session, called Gerhana, will be conducted whenever there is an eclipse as Muslims believe that it is a sign from God that he can do anything.

The Straits Times, 18 February, 1999

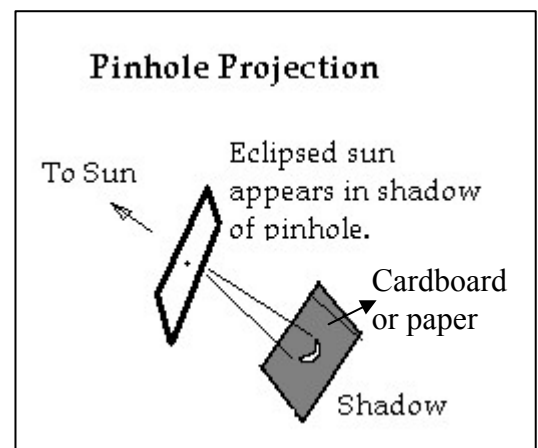
Last eclipse of the century leaves many disappointed

This article explains why many people were disappointed by the last eclipse of the century. This was because only 8 percent of the Sun was covered. Therefore, it was not as spectacular compared to the previous eclipses in Singapore, where large portion of the Sun was covered. It was mentioned that on the next solar eclipse, which will be in January 2009, 85 percent of the Sun will be covered and it will happen in the evening, which is very rare.

Methods to View Eclipse Safely

Lunar eclipse is perfectly safe to look at with naked eyes. The moon illuminated by reflected sunlight, just as the Earth's surface is during the day; gazing at it directly will never damage you vision. Unlike, the total solar eclipse, it poses some danger if viewed incorrectly. Hence, proper precautions are required to take into consideration when viewing solar eclipses. Several ways of viewing solar eclipses are discuss below.

Pinhole projection is the safest and most inexpensive way to view the sun. It projects its image onto the screen, such as white paper or cardboard. Projection works equally well with or without a telescope or binoculars. With telescope or binocular, it helps to project a magnified image of the Sun onto a white screen. The main advantage of the projection methods is that no one needs to look at the Sun directly and yet able to enjoy viewing the



eclipse. On the other hand, there is disadvantage to this method. The pinhole method is that the screen must be placed at least a metre behind the opening to get a solar image that is large enough to see easily.

Solar filter is the only way to observe the sun with a telescope directly. Not any filter will be sufficed for this sort of viewing. A right filter is required for the telescope. A solar filter deflects (or rejects), a significant amount of the energy from the Sun is released. To overcome this, one way is to use a mirror like substance to reflect the light energy and let only a small amount to pass through. The other way is to use a dark filter that absorbs the energy, thus allowing only a small amount to get through for viewing. Solar observers generally prefer a reflection filter since they will not heat up as much as absorption filters. The solar filter should be located at the front of the optics and not in between the main objective and the eyepiece. Below is a diagram that illustrates the correct way of using solar filter.

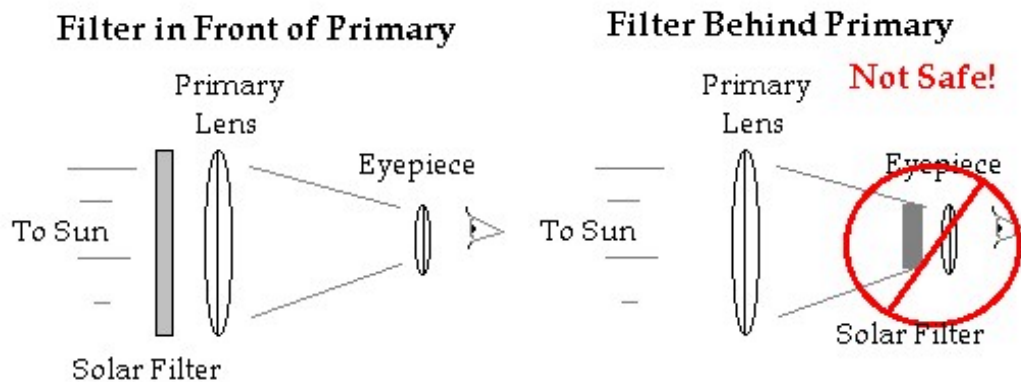


Diagram that illustrates the correct way of using solar filter

Did You Know

Once in a *blue moon*?

DID YOU KNOW...? There is really such a thing as a *blue moon*? Believe it or not, scientists say blue-coloured moons are real.

What is a *blue moon*?

A *blue moon* is the second full moon in a calendar month.



How is this so?

Usually, months have only one full moon as full moons are separated by 29 days. However occasionally, a *blue moon* can be sighted because most months are 30 or 31 days long. Thus it is possible to have 2 full moons in a month. This accounts for the phrase 'Once in a *blue moon*' as *blue moons* are rare. On average, a *blue moon* can be sighted once every two and a half years.

The normal bluish-white moon has turned *reddish-brown*?

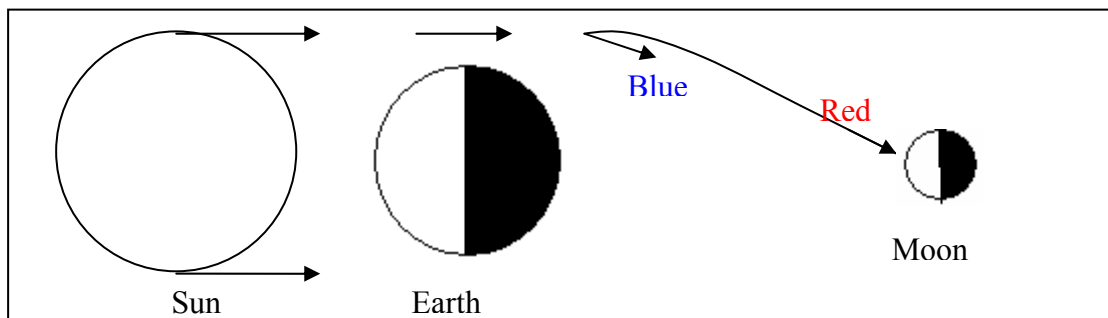
DID YOU KNOW...? During an eclipse, the normal bluish-white moon appears reddish-brown? This is because our planet, Earth, has a



Lunar Eclipse on 21st January 2000 (0301GMT)

considerable atmosphere which makes its perimeters somewhat obscure. Due

to the unequal atmospheric transmission of different wavelengths of light, the air molecules between your eyes and the Sun scatter light at the blue end of the spectrum more than at the red end. Thus the blue end of the light spectrum gets refracted outwards making the sky blue and the red end of the light spectrum gets refracted towards the moon. The moon appears reddish-brown.



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