Title:

Regularities and irregularities in the eclipses

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Abstract

On June 6, 2011 we had the opportunity to observe a total lunar eclipse and started to ask ourselves some questions:

- Why doesn't a lunar eclipse occur whenever there is full moon?
- Why doesn't a solar eclipse occur whenever there is a new moon?
- How can be known when an eclipse will happen?

With this study we have analyzed the complexity inherent in celestial mechanics and we have found that, despite this complexity, it may be understandable and predictable. The correct answers appeared only when the delicate geometric conditions that lead to the occurrence of these phenomena are well-understood.

In addition to the conclusions reached after this study, we show the techniques we used to go all the way. The graphs that we have made by investing in them many hours of work are very numerous and animation sequences we have also made are very important to understand the phenomenology side throw-in.

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Developement

Introduction

During the primary and secondary studies, sometimes we have addressed issues related to our solar system, and in particular solar eclipses and lunar eclipses.

We have learned well that a solar eclipse occurs when the moon comes between the Earth and the Sun and that lunar eclipses occur when the Earth is between the Sun and the Moon. We have also learned that the shadow of a body, when illuminated by an extensive source of light, it always produces an area of umbra and penumbra, as we can see in Figure 1.

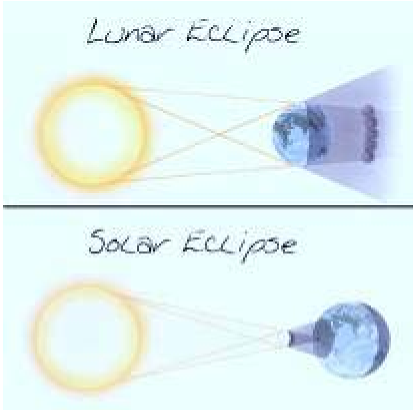


Figure 1. Umbra and penumbra in the eclipses

On June 6, 2011 we had the opportunity to observe a total lunar eclipse and we began to ask ourselves some questions:

- Why doesn't a lunar eclipse occur whenever there is full moon?
- Why doesn't a solar eclipse occur whenever there is a new moon?
- How can be known when an eclipse will happen?

Truth is, these questions haven't been always explained clearly enough to us.

We look for appropriate information sources: books, specific Astronomy books, we ask our teachers and search online... And we begin getting answers.

Basic geometrical aspects

The Earth moves around the sun in a nearly circular orbit that is contained in a plane. This plane is called the ecliptic plane. Is called so because, when the moon is somewhere in that plane and currently being in New Moon or Full Moon, is when eclipses occur.

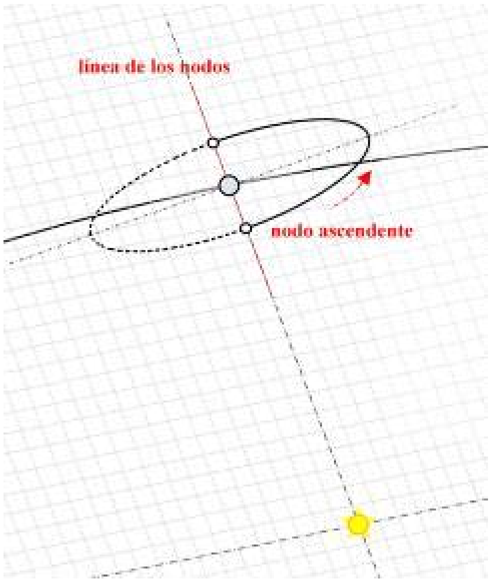


Figure 2
Plane of the ecliptic and Moon's orbit

We discovered that the Moon moves around the Earth in an almost circular orbit too, but is tilted about 5 ° to the plane of the ecliptic. Due to this inclination, the orbit of the Moon crosses the ecliptic plane and is located sometimes above it and sometimes below it.

The intersection of the Moon's orbit with the plane of the ecliptic happens in two points that are known as nodes: descending node when the moon falls down to the bottom of the ecliptic and ascending node when it emerges at the top.

The imaginary line that joins the two nodes is called line of the nodes and, if there isn't a cause that requires him to do so, the orientation of this line in space should remain constant all the time. Right now, this consideration is not very important, but we will see later that in fact this is not true and that it does have important consequences.

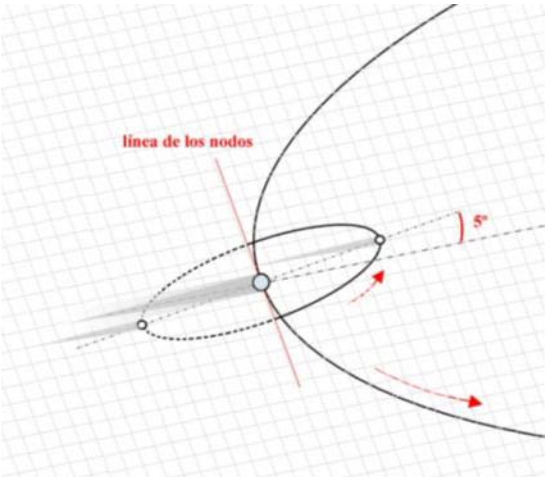


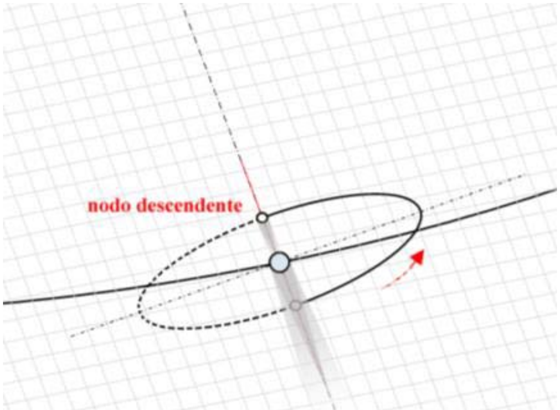
Figure 3. Lost shadows

If the line of the nodes is not aligned with the rays of the Sun (as seen in this image) the shadows of the Earth and the Moon are lost in space and have no effect on the other body.

The Moon (opposed to the Sun) is outside the shadow cone of the Earth and is for us a full moon to which we are well used to seeing normal.

Figure 4. New Moon

By the same way, if the shadow of the Moon, when New Moon, does not touch the Earth, we won't observe anything extraordinary: the Moon becomes invisible between the intense rays of the Sun and seems to be absent for a few days. We simply say there is New Moon, which is one of the most common situations throughout the months.



But what happens when the line of nodes matches the direction of the Sun's rays?

We now see that the shadows projected by the two bodies can fall one upon the other. This is the moment when the eclipses occur.

Figure 5
Condition for eclipses to occur

Different kinds of Moon eclipses

The first case that can occur is that the Moon enters the penumbra cone of the Earth and only passes through this area.

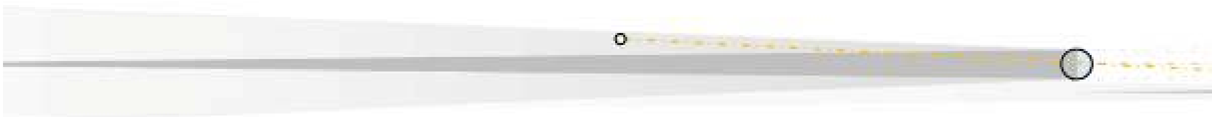


Figure 6. The Moon passing the penumbra area

This is a penumbral eclipse of Moon. Full Moon loses some of its normal brightness for a few hours, althoughmost people never see this brightness decline. Penumbral eclipses often remain completely unnoticed by the general public.

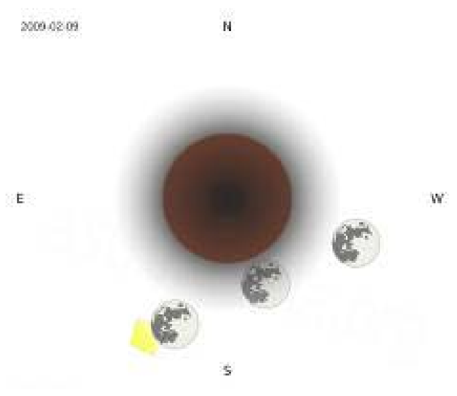


Figure 7. Penumbral eclipse

Figure 8. Little brightness variation during a penumbral eclipse.

As a result of our study, we have learned that it is important to record this type of eclipses as they will allow us to make future predictions, because they are part of eclipses families that would otherwise be incomplete.

A second kind of eclipse occurs when the Moon enters the shadow cone of the Earth but not completely.

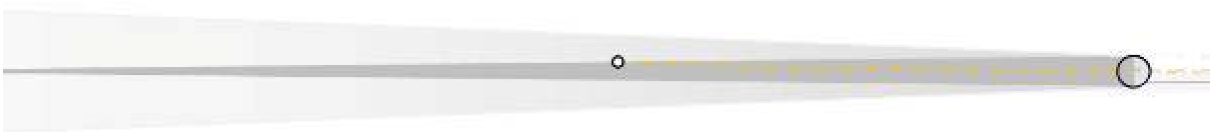


Figure 9. The Moon grazes the Earth's umbra area

In this kind of eclipses, the Moon passes through the penumbra and enters the umbra, but not completely: there is always an illuminated part. This is a partial lunar eclipse.

Partial lunar eclipses make us observe very graphically (as we see in this montage) that the shadow of the Earth is circular, a direct evidence of the Earth's sphericity and a discovery ancient Greeks already made.

Figure 10
Earth's sphericity

When the Moon is completely immersed in the umbra cone of the Earth there is a total lunar eclipse. For an hour or two the moon is dark, sometimes almost to disappear from view, but the most common is that of a red jock off.

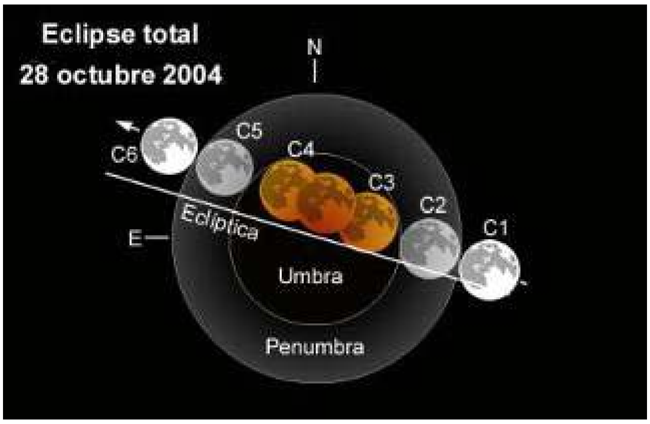


Figura 11. The Moon passing the umbra area

Why this reddish color in the eclipses of this class?

White light (a mixture of all colors) that comes from the sun passes through the Earth´s atmosphere and experience two optical phenomena: refraction and dispersion of light into colors.

Cool colors (violet, blue and green) are the most commonly diverted and are quickly absorbed by the atmosphere; the warm colors (yellow and orange) deviate less but also fail to get through and is the red color the only thing that gets their way into the shadows.

So, only the red color reaches the Moon dyeing it with blood.

The presence of varying amounts of dust in the atmospheric layers, make that this reddish color sometimes is darker than others. Truth is, there are never two Moon´s eclipses with the same tonality.

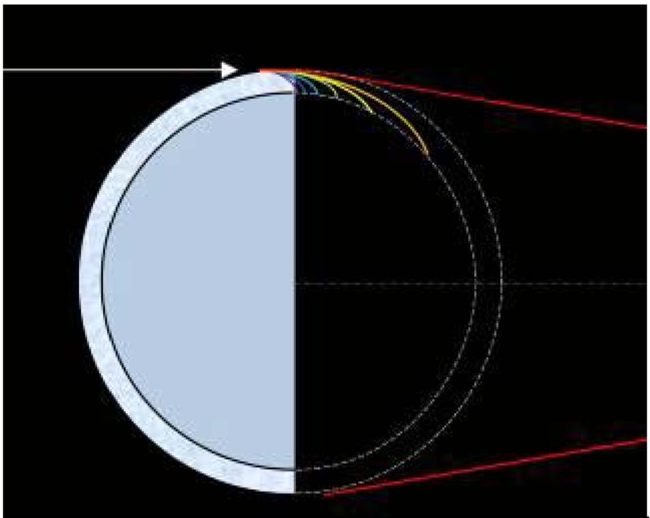


Figure 12. Refraction, scattering and absorption of light

Different solar eclipses

It is now up to the moon come between the Earth and the sun projecting its shadow on the surface of the Earth.

Figure 13. The umbra and penumbra incident on Earth during a solar eclipse

From those places on Earth by passing the disc from the shadow (which is usually not more than 200 km), we can see a total solar eclipse.

For a total solar eclipse the temperature drops significantly the stars and animals begin t appear in general, somewhat bewildered, seek shelter and prepare for sleep.

Figure 14.
Shadow and umbra of the Moon photographed from the ISS during a solar eclipse

The total solar eclipses also have a great attraction, and a great scientific interest, is that during the same we can see:

- The Solar Corona: ionized gas extending to millions of kilometers and are guided by the magnetic field of the Sun.
- The Solar Chromosphere, in which appear, with some frequency, huge gas explosions that are larger than our Earth: The Solar Bumps.
- Pearls of Bailey: small portions of the Chromosphere that are seen between the valleys and mountains of the Moon in its rough outline.

Figure 15. The Solar Corona

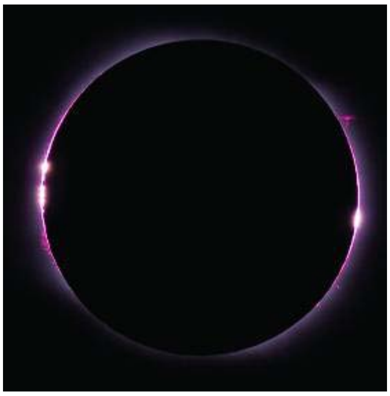


Figure 16.
The Solar Bumps and Pearls of Bailey

Further north or just south of the zone of totality, will see a partial solar eclipse. In this kind of eclipse only part of the Sun is covered by the Moon. The more we move away from that area, the less important the partial eclipse: smaller proportion of the solar disk is hidden.

If we are away from the whole area, or the cone of shadow or penumbra cone touch and we will not see any eclipse.

Figure 17. Partial Solar Eclipse

It is important to point out that total eclipses longer occur when the Moon coincides with perigee (the closest approach of the Moon to the Earth in its orbit nearly circular but in reality an ellipse).

When the eclipse of the Sun occurs at the apogee of the lunar orbit, it is too far from Earth and ends not completely hide the sun. In the moment of maximum eclipse, a glowing ring of light surrounding the moon so no total darkness occurs. This is an annular eclipse of the Sun

Figure 18. Annular Solar Eclipse

Delving into our research

So far, everything we have discussed and planned, somehow, in our textbooks plus some expansion on our part. But we have found that things really are not so simple...

We have found that the Moon takes to make one revolution around the Earth in an interval of time that lasts 27 days, 7 hours, 43 minutes and 11 seconds. It is a complete revolution which is taken as a reference point to the stars. This period is called the sidereal month.

And we found that, during those 27 days, the Earth moves (along with the Moon) considerable space around the Sun After this time, the sun's rays reach us now at another address so that must pass two days, 4 hours, 17 minutes and 52 seconds to re-occur, again, new moon**.**

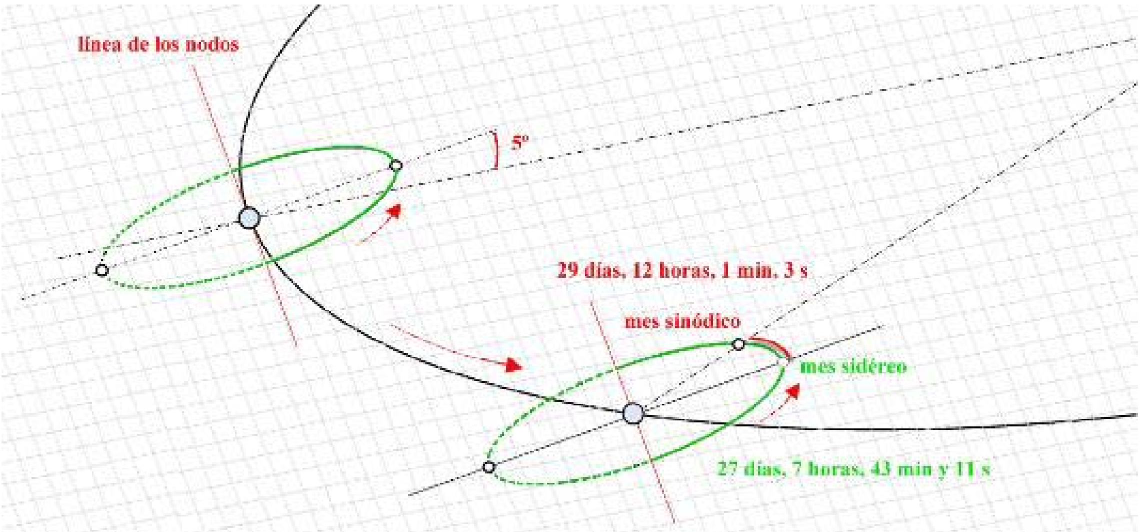
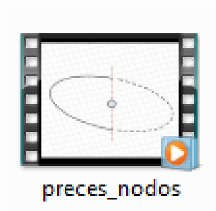


Figure 19. Sidereal and synodic Month

To happen again another New Moon should, therefore, spend 29 days, 12 hours, 1 minute and 3 seconds. This new period is called the synodic month and is very important for the prediction of eclipses.

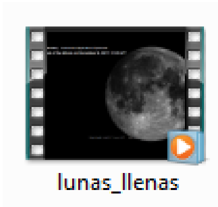
On the other hand, as we announced earlier, the line of nodes does not remain constant over time.



Due to the disturbances caused by the Sun and the Earth, the inclined orbit of the Moon is "wobbling" slowly over a period of about 18.6 years (period draconítico)

(Click to see the animation)

This movement is called precession of the line of nodes and has the consequence that the Moon is again located at a new node, not next month, but a little earlier: to 27.2122 days. This period is called draconítico month and it is also very important for the prediction of eclipses. El origen de este nombre se remonta a la antigüedad: los antiguos chinos creían que en los nodos vivía un dragón capaz de devorar al Sol o a la Luna.



On the other hand, we went to the Astronomical Applications Department of the U.S. Naval Observatory and took 256 photographs of all the Full Moons occurred between 1990 and 2011. With these 256 photographs we setted up a video sequence which allowed us to observe how the Moon shows moments when it is closer to the Earth and others when is away from it. These are, respectively, the lunar perigee and apogee. We clearly observe that the full Moon does not have to coincide with the lunar perigee or apogee. In fact, we can see that this happens in all the intermediate positions.

(Click to see the animation)

Closer observation of this sequence of images showed us, too, that the apogee and perigee change of position slowly ;is the movement of precession of the apsides line (the line joining the perigee position of the peak) , which this time takes place in the forward direction and cycling in 18.03 years. Thus, the Moon will be positioned at its perigee (or at its peak) each 27.5545, a period called the anomalistic month.

(Click to see the animation)

We consult Astronomy specialized books which inform us that eclipses are happening in an orderly and every so often (about 18 years) return to repeat again in the same order and very accurate.

But which was the reason behind this strange repetition of eclipses types?

We could see that to happen a solar eclipse or a lunar eclipse again they have to occur simultaneously:

- An integer N of draconitic months (the nodes are back again in the same position),
- An integer M of synodic months (the Moon is again in full phase or New Moon) and
- An integer number of anomalistic months T (so the New Moon coincides again with its perigee or apogee in an eclipse).

Giving values to N, M and T we find a first value which in the three circumstances occur at the same time, and, if not exactly, at least very roughly:

- 242 draconitic months are **6585,357482** days
- 223 synodic months are **6585,321347** days
- 239 anomalistic months are **6585,537450** days

So after 223 synodic months, or what it’s the same: 18 years, 11 days and about 8 hours, the Moon will be back in full phase (or New) and also repeated almost exactly the same geometrical conditions 18 years ago.

Every 18 years, 11 days and almost eight hours the Moon, Earth and Sun are, again, in very similar positions and distances, so that eclipses begin to repeat in the same order as in the previous period. This period is called the Saros period and was known by the ancient Babylonians and the ancient Greeks.

Every 18 years, 11 days and almost eight hours the Moon, Earth and Sun are, again, in very similar positions and distances, so that eclipses begin to repeat in the same order as in the previous period. This period is called the Saros period and was known by the ancient Babylonians and the ancient Greeks.

In order to check these time periods, we note the data of all lunar eclipses that occurred between 1940 and 1957 in an Excel spreadsheet and next all lunar eclipses that occurred between 1958 and 1975. In this way we could compare Saros eclipses of two successive periods.

We got all this information from the letters of F. Espenak of NASA's GSFC.

Subtracting the dates and times of each pair of eclipses belonging to both periods, we see that differences always threw the same result: 18 years, 11 days and 8 hours, with some minor differences. We could also observe that in some cases the difference was 10 days instead of 11, a fact which is due to the absence of one of leap years between two dates compared.

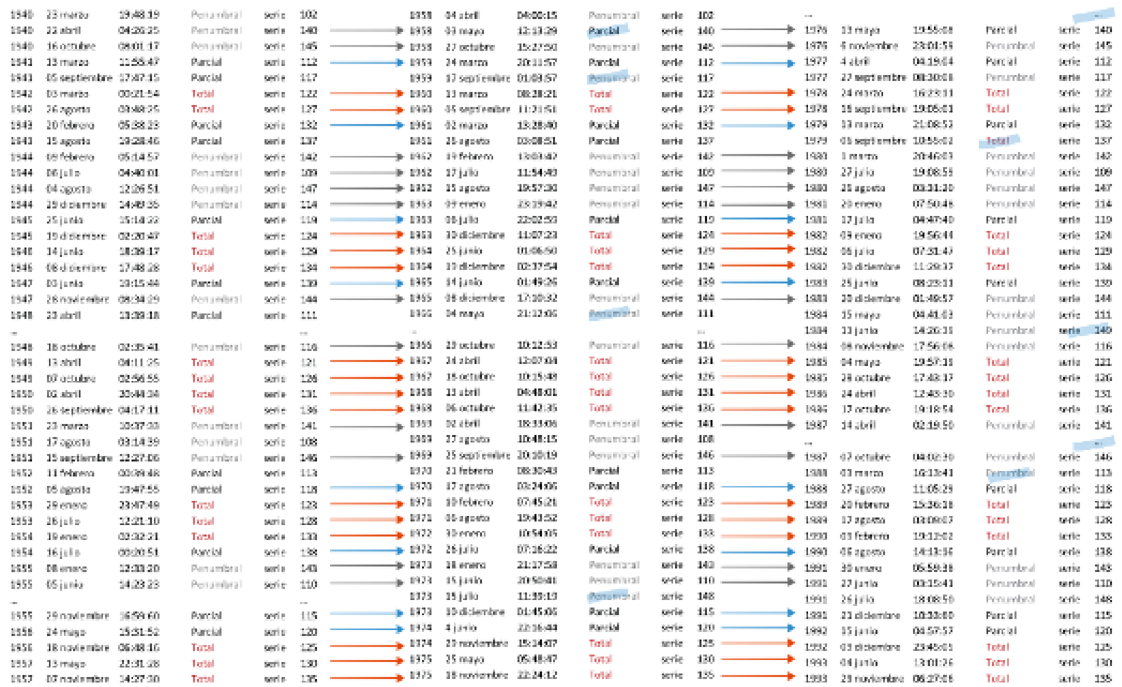
(See Figure 20)

Eclipses de Luna								
Período Saros de 1940 a 1957		Período Saros de 1958 a 1975		días		años	días	horas
23/03/1940	19:48:19	04/04/1958	4:00:15	6585	18,0410959	18	11	8:11
22/04/1940	4:26:25	03/05/1958	12:13:29	6584	18,0383562	18	10	7:47
16/10/1940	8:01:17	27/10/1958	15:27:50	6584	18,0383562	18	10	7:26
13/03/1941	11:55:47	24/03/1959	20:11:57	6584	18,0383562	18	10	8:16
05/09/1941	17:47:15	17/09/1959	1:03:57	6585	18,0410959	18	11	7:16
03/03/1942	0:21:54	13/03/1960	8:28:21	6584	18,0383562	18	10	8:06
26/08/1942	3:48:25	05/09/1960	11:21:51	6584	18,0383562	18	10	7:33
20/02/1943	5:38:23	02/03/1961	13:28:40	6584	18,0383562	18	10	7:50
15/08/1943	19:28:46	26/08/1961	3:08:51	6585	18,0410959	18	11	7:40
09/02/1944	5:14:57	19/02/1962	13:03:42	6584	18,0383562	18	10	7:48
06/07/1944	4:40:01	17/07/1962	11:54:49	6584	18,0383562	18	10	7:14
04/08/1944	12:26:51	15/08/1962	19:57:30	6584	18,0383562	18	10	7:30
29/12/1944	14:49:35	09/01/1963	23:19:42	6584	18,0383562	18	10	8:30
25/06/1945	15:14:22	06/07/1963	22:02:59	6584	18,0383562	18	10	6:48
19/12/1945	2:20:47	30/12/1963	11:07:23	6584	18,0383562	18	10	8:46
14/06/1946	18:39:17	25/06/1964	1:06:50	6585	18,0410959	18	11	6:27
08/12/1946	17:48:28	19/12/1964	2:37:54	6585	18,0410959	18	11	8:49
03/06/1947	19:15:44	14/06/1965	1:49:26	6585	18,0410959	18	11	6:33
28/11/1947	8:34:29	08/12/1965	17:10:32	6584	18,0383562	18	10	8:36
23/04/1948	13:39:18	04/05/1966	21:12:06	6584	18,0383562	18	10	7:32
18/10/1948	2:35:41	29/10/1966	10:12:53	6584	18,0383562	18	10	7:37
13/04/1949	4:11:25	24/04/1967	12:07:04	6584	18,0383562	18	10	7:55
07/10/1949	2:56:55	18/10/1967	10:15:48	6584	18,0383562	18	10	7:18
02/04/1950	20:44:34	13/04/1968	4:48:01	6585	18,0410959	18	11	8:03
26/09/1950	4:17:11	06/10/1968	11:42:35	6584	18,0383562	18	10	7:25
23/03/1951	10:37:33	02/04/1969	18:33:06	6584	18,0383562	18	10	7:55
17/08/1951	3:14:39	27/08/1969	10:48:15	6584	18,0383562	18	10	7:33
15/09/1951	12:27:06	25/09/1969	20:10:19	6584	18,0383562	18	10	7:43
11/02/1952	0:39:48	21/02/1970	8:30:43	6584	18,0383562	18	10	7:50
05/08/1952	19:47:55	17/08/1970	3:24:06	6585	18,0410959	18	11	7:36
29/01/1953	23:47:49	10/02/1971	7:45:21	6585	18,0410959	18	11	7:57
26/07/1953	12:21:10	06/08/1971	19:43:52	6584	18,0383562	18	10	7:22
19/01/1954	2:32:21	30/01/1972	10:54:05	6584	18,0383562	18	10	8:21
16/07/1954	0:20:51	26/07/1972	7:16:22	6584	18,0383562	18	10	6:55
08/01/1955	12:33:20	18/01/1973	21:17:58	6584	18,0383562	18	10	8:44
05/06/1955	14:23:23	15/06/1973	20:50:41	6584	18,0383562	18	10	6:27
		15/07/1973	11:39:19					
29/11/1955	17:00:00	10/12/1973	1:45:06	6585	18,0410959	18	11	8:45
24/05/1956	15:31:52	04/06/1974	22:16:44	6584	18,0383562	18	10	6:44
18/11/1956	6:48:16	29/11/1974	15:14:07	6584	18,0383562	18	10	8:25
13/05/1957	22:31:28	25/05/1975	5:48:47	6585	18,0410959	18	11	7:17
07/11/1957	14:27:30	18/11/1975	22:24:12	6584	18,0383562	18	10	7:56

Figure 20.
Time differences between lunar eclipses of two successive Saros

In the next stage of our study we note the data of all lunar eclipses occurred between 1940 and 1993. Again, the letters or F.Espenak of NASA's GSFC were now our source of information.

In the chart below we can see the data from three consecutive Saros cycles.



1940	23 marzo	19:48:19	Penumbral	serie	102	1958	04 abril	04:00:15	Penumbral	serie	102	...					...
1940	22 abril	04:26:25	Penumbral	serie	140	1958	03 mayo	12:13:29	Parcial	serie	140	1976	13 mayo	19:55:08	Parcial	serie	140
1940	16 octubre	08:01:17	Penumbral	serie	145	1958	27 octubre	15:27:50	Penumbral	serie	145	1976	6 noviembre	23:01:59	Penumbral	serie	145
1941	13 marzo	11:58:47	Parcial	serie	112	1959	24 marzo	20:11:57	Parcial	serie	112	1977	4 abril	04:19:04	Parcial	serie	112
1941	05 septiembre	17:47:15	Parcial	serie	117	1959	17 septiembre	01:08:57	Penumbral	serie	117	1977	27 septiembre	08:30:08	Penumbral	serie	117
1942	03 marzo	00:21:54	Total	serie	122	1960	13 marzo	08:28:21	Total	serie	122	1978	24 marzo	16:23:11	Total	serie	122
1942	26 agosto	03:48:25	Total	serie	127	1960	05 septiembre	11:21:51	Total	serie	127	1978	16 septiembre	19:05:03	Total	serie	127
1943	20 febrero	05:38:23	Parcial	serie	132	1961	02 marzo	13:28:40	Parcial	serie	132	1979	13 marzo	21:08:53	Parcial	serie	132
1943	15 agosto	19:28:46	Parcial	serie	137	1961	26 agosto	03:08:51	Parcial	serie	137	1979	06 septiembre	10:55:02	Total	serie	137
1944	09 febrero	05:14:57	Penumbral	serie	142	1962	19 febrero	13:03:42	Penumbral	serie	142	1980	1 marzo	20:46:03	Penumbral	serie	142
1944	06 julio	04:40:01	Penumbral	serie	109	1962	17 julio	11:54:40	Penumbral	serie	109	1980	27 julio	19:08:55	Penumbral	serie	109
1944	04 agosto	12:26:51	Penumbral	serie	147	1962	15 agosto	19:57:30	Penumbral	serie	147	1980	26 agosto	03:31:20	Penumbral	serie	147
1944	29 diciembre	14:48:35	Penumbral	serie	114	1963	09 enero	23:19:42	Penumbral	serie	114	1981	20 enero	07:50:46	Penumbral	serie	114
1945	25 junio	15:14:22	Parcial	serie	119	1963	06 julio	22:02:53	Parcial	serie	119	1981	17 julio	04:47:40	Parcial	serie	119
1945	19 diciembre	02:20:47	Total	serie	124	1963	30 diciembre	11:07:23	Total	serie	124	1982	09 enero	19:56:44	Total	serie	124
1946	14 junio	18:39:17	Total	serie	129	1964	25 junio	01:06:50	Total	serie	129	1982	06 julio	07:31:47	Total	serie	129
1946	08 diciembre	17:48:28	Total	serie	134	1964	19 diciembre	02:37:54	Total	serie	134	1982	30 diciembre	11:29:37	Total	serie	134
1947	03 junio	20:15:44	Parcial	serie	139	1965	14 junio	01:49:26	Parcial	serie	139	1983	25 junio	08:23:11	Parcial	serie	139
1947	28 noviembre	08:34:29	Penumbral	serie	144	1965	08 diciembre	17:10:32	Penumbral	serie	144	1983	20 diciembre	01:49:57	Penumbral	serie	144
1948	23 abril	13:39:18	Parcial	serie	111	1966	04 mayo	21:12:06	Penumbral	serie	111	1984	15 mayo	04:41:03	Penumbral	serie	111
...					...	...					...	1984	13 junio	14:26:31	Penumbral	serie	140
1948	18 octubre	02:35:41	Penumbral	serie	116	1966	29 octubre	10:12:53	Penumbral	serie	116	1984	08 noviembre	17:56:06	Penumbral	serie	116
1949	13 abril	04:11:25	Total	serie	121	1967	24 abril	12:07:04	Total	serie	121	1985	04 mayo	19:57:11	Total	serie	121
1949	07 octubre	02:56:55	Total	serie	126	1967	18 octubre	10:15:48	Total	serie	126	1985	28 octubre	17:42:17	Total	serie	126
1950	02 abril	20:44:34	Total	serie	131	1968	13 abril	04:48:01	Total	serie	131	1986	24 abril	12:43:30	Total	serie	131
1950	26 septiembre	04:17:11	Total	serie	136	1968	06 octubre	11:42:35	Total	serie	136	1986	17 octubre	19:18:54	Total	serie	136
1951	23 marzo	10:37:30	Penumbral	serie	141	1969	02 abril	18:33:06	Penumbral	serie	141	1987	14 abril	02:19:50	Penumbral	serie	141
1951	17 agosto	03:14:39	Penumbral	serie	108	1969	27 agosto	10:48:15	Penumbral	serie	108	...					...
1951	15 septiembre	12:27:06	Penumbral	serie	146	1969	25 septiembre	20:10:19	Penumbral	serie	146	1987	07 octubre	04:02:30	Penumbral	serie	146
1952	11 febrero	00:39:48	Parcial	serie	113	1970	21 febrero	08:30:43	Parcial	serie	113	1988	03 marzo	16:13:41	Penumbral	serie	113
1952	05 agosto	19:47:55	Parcial	serie	118	1970	17 agosto	03:24:06	Parcial	serie	118	1988	27 agosto	11:05:29	Parcial	serie	118
1953	29 enero	23:47:49	Total	serie	123	1971	10 febrero	07:45:21	Total	serie	123	1989	20 febrero	15:36:18	Total	serie	123
1953	26 julio	12:21:10	Total	serie	128	1971	06 agosto	19:43:52	Total	serie	128	1989	17 agosto	03:09:07	Total	serie	128
1954	19 enero	02:32:21	Total	serie	133	1972	30 enero	10:54:05	Total	serie	133	1990	09 febrero	19:12:02	Total	serie	133
1954	16 julio	00:20:51	Parcial	serie	138	1972	26 julio	07:16:22	Parcial	serie	138	1990	06 agosto	14:13:16	Parcial	serie	138
1955	08 enero	12:33:20	Penumbral	serie	143	1973	18 enero	21:17:58	Penumbral	serie	143	1991	30 enero	05:59:18	Penumbral	serie	143
1955	05 junio	14:23:23	Penumbral	serie	110	1973	15 junio	20:50:41	Penumbral	serie	110	1991	27 junio	03:15:41	Penumbral	serie	110
...					...	1973	15 julio	11:39:13	Penumbral	serie	148	1991	26 julio	18:08:50	Penumbral	serie	148
1955	29 noviembre	16:59:60	Parcial	serie	115	1973	10 diciembre	01:45:06	Parcial	serie	115	1991	21 diciembre	10:33:00	Parcial	serie	115
1956	24 mayo	15:31:52	Parcial	serie	120	1974	4 junio	22:16:44	Parcial	serie	120	1992	15 junio	04:57:57	Parcial	serie	120
1956	18 noviembre	06:48:16	Total	serie	125	1974	29 noviembre	15:14:07	Total	serie	125	1992	09 diciembre	23:45:01	Total	serie	125
1957	13 mayo	22:31:28	Total	serie	130	1975	25 mayo	05:48:47	Total	serie	130	1993	04 junio	13:01:26	Total	serie	130
1957	07 noviembre	14:27:30	Total	serie	135	1975	18 noviembre	22:24:12	Total	serie	135	1993	29 noviembre	06:27:06	Total	serie	135

Picture 21
Matching eclipses of three Saros consecutive periods

By grouping three cycles and comparing rates, we realize that the succession of eclipses repeats of one another. We have marked with gray arrows penumbral eclipses repeat with blue and red total eclipses.

Unexpected findings

But we also saw some differences. That is why we have left out of arrows some possible correspondences. We will comment on some of these exceptions.

At the beginning of each of the three cycles that we were analyzing, we saw that the penumbral eclipse Series 102 occurred in March 1940 and was repeated in April 1958 but did not appear in the third cycle (in 1976).

What would have happened?

We wanted to know what consists the Series 102 and found out that this series began with a penumbral eclipse in October 461 (1551 years ago!).

We look at other irregularities over our comparison chart and investigate in their respective series (Series 117, 137 and 140).


serie_102

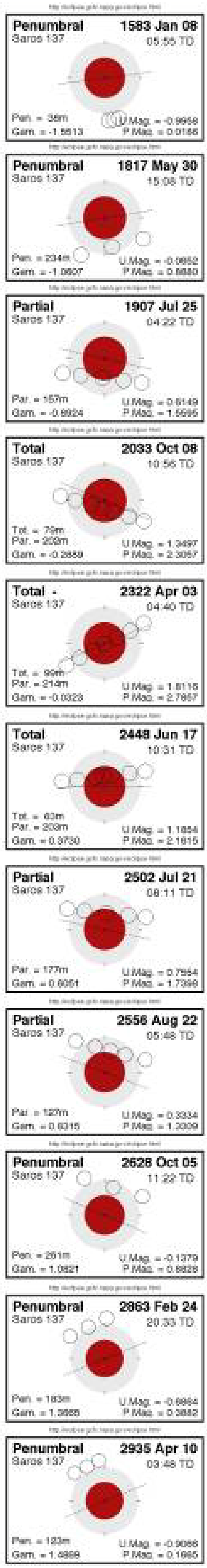

serie_117


serie_137


serie_140

We found that each of the series consisted of about 80 eclipses. We obtained their graphic cards of "Five Millennium Canon of Lunar Eclipses (Espenak & Meus)".

Armed with patience and with the help of image editing programs were cut imagery of these graphics and letters and we assemble various video-clips which can check what was actually happening.



Discovery

Each of the series whose main character is a single eclipse whose geometric conditions are changing slowly over time. Each of the series whose main character is a single eclipse whose geometric conditions are changing slowly over time. See how:

All series begin always with a penumbral eclipse which begins to graze the twilight zone of the Earth. So for some hundreds of years, the Saros cycles repeated a penumbral eclipse. In each Saros period, the geometric conditions are gradually changing so that each of the following eclipses goes into a little deeper into the gloom.

There comes a time when the Moon has deepened so much that the gloom now beginning to graze the umbra area, and become partial eclipses instead of penumbral. And a few hundred years pass more repeated, now cycle after cycle, partial eclipses.

The geometric conditions continue to change and partial eclipses become to total, now entering the moon fully in the umbra. There are other several hundred more years of total eclipses.

And conditions are invariably changing until the Moon starts to leave the area of umbra. It is the turn again now, a long period of partial eclipses. Finally, after nearly a thousand years of evolution, penumbral eclipses return to be, again, as before.

The end of each series is the total loss of geometry that makes possible the eclipse and this eclipses ceases to exist in the following Saros cycles.

(Click to see animation)

Picture 22
Summary chart showing some of the 80 lunar eclipses of Saros series 137.

This series began in January 1583 and end in April 2935

Regarding solar eclipses

We analyze, on the other hand, the Saros Series 136 solar eclipses, from 1937-2081. We found that the time differences found are similar to those of lunar eclipses (18 years, 10 to 11 days and 8 hours).

We note, moreover, that the difference of about 8 hours, typical of Saros periode translated into the repetition of the same eclipse but in a place on Earth located about 120º further west.

On the other hand, as we saw in our computer animations made with the computer, the geometry of these phenomena will gradually ascending from Saros period and the next, so that the trajectory of the Moon's shadow passes after three eclipses again, for the same area of the globe, although a little higher each time.

Eclipses de Sol

Serie Saros 136 (desde 1937 a 2081)				días		años	días	horas
08/06/1937	20:41:02	20/06/1955	4:10:42	6585	18,0410959	18	11	7:29
20/06/1955	4:10:42	30/06/1973	11:38:41	6584	18,0383562	18	10	7:27
30/06/1973	11:38:41	11/07/1991	19:07:01	6584	18,0383562	18	10	7:28
11/07/1991	19:07:01	22/07/2009	2:36:25	6585	18,0410959	18	11	7:29
22/07/2009	2:36:25	02/08/2027	10:07:50	6584	18,0383562	18	10	7:31
02/08/2027	10:07:50	12/08/2045	17:42:39	6584	18,0383562	18	10	7:34
12/08/2045	17:42:39	24/08/2063	1:22:11	6585	18,0410959	18	11	7:39
24/08/2063	1:22:11	03/09/2081	9:07:31	6584	18,0383562	18	10	7:45
03/09/2081	9:07:31	14/09/2099	16:57:53	6584	18,0383562	18	10	7:50

Picture 23
Time differences between solar eclipses of 2 successive Saros.
In each Saros cycle of eclipses observed 120 more to the west and a little north or south (depending on the series to which it belongs).

(Click to see animation)

Conclusions

With these studies and experiences we have analyzed the complexity inherent in celestial mechanics and we have verified that, despite this complexity, it may be understandable and predictable.

Eclipses are grouped into families that are repeated over time every 18 years, 11 days and 8 hours (*Saros period*).

For example: "to three total lunar eclipses always follow two sets and two penumbral, then happen two totals and three partial ...". After 18 years, 11 days and 8 hours again repeat the same orderly sequence types.

But each of these individual eclipses belongs to a series that evolves slowly over the course of about 1300 years (*Saros Series*).

Each *Saros series* corresponds to a unique eclipse penumbral always begins after several hundred years becomes partial and then in total. After about 800 years leaving the shadow cone of the Earth and will become partial, and later, again, in penumbral. When finally leaves the penumbra Earth, the series will end.

In short, know this periodicity of Saros cycles and if we investigate the Series to which each belongs eclipse, it is easy to predict, with high accuracy, when will a new eclipse and how it will be.

And finally:

This work has opened the doors to motivate us in conducting in others future research work based on the same line.

Incidence on teaching practice

It is advisable that, throughout the entire the proceedings, our students can think and speak for itself all theoretical and practical aspects of these methods of calculation, not forgetting the preparation of clear graphics.

Once the techniques were mastered, begin to address the digital processing of images and video sequences. Although laborious, all these tasks were highly motivating and (why not?) also fun.

When designing and develop this project were well assured of having built an excellent interdisciplinary work favoring the dialogue between different departments and being, at the same time contributing to the acquisition of basic skills by our students.

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