THE ROSETTE OF SPIRAL DIAGRAMS AS PRODUCED BY THE SAROS SERIES OF SOLAR ECLIPSES

DIMITRIE OLENICI[1,2]

[1]*Astronomical Observatory, Stefan cel Mare University, Suceava*
[2]*The Romanian Society for Cultural Astronomy, Timisoara*

Abstract. This article presents a new concept to illustrate the chain of solar eclipses in accordance with the Saros cycle. Eclipses in a Saros cycle are placed in a circle depending on the calendar date. By concentrically placing several Saros circles in chronological order, we notice that the Saros series appear in the form of spirals that resemble a rosette. In an entire Saros series we can easily notice where it begins and ends. By analyzing within the rosette representation the chain of eclipses – circular, radial, and spiral – we can highlight several cycles of eclipses. A correlation between the Saros cycle and the Maya cycles of repeating eclipses is also illustrated.

Key words: Astronomy – Solar system – Eclipses – Saros.

1. BACKGROUND

The Rosette of spiral diagrams of Saros series of solar eclipse was elaborated by the author in the 1990's as a prelude to the total solar eclipse of August 11, 1999 which had the center in Romania near the town of Râmnicu Valcea.

With this occasion the author has published a book (in Romanian) about eclipses entitled *The eclipse since the Sun the Moon and the World exists* (*Eclipsele de când lumea Soarele şi Luna*, Editura Casei Corpului Didactic, Suceava, 1999 – in Romanian). The book was reedited in 2015 when the spiral diagrams of Saros series of solar eclipse was added to the text (Olenici, 1999).

In 2007, a poster entitled The spiral diagrams of Saros series of solar eclipse was presented at the Solar Eclipse Conference SEC2007, held at Griffith Observatory in Los Angeles, USA. The results were well received and a total of 75 posters were distributed to participants.

A similar poster was presented by us for the lunar eclipses at the Solar Eclipse Conference (SEC 2011) held in New Delhi India.

In this article a novel representation of the Saros series as a rosette of spirals is proposed. It creates an overview of the eclipses occurring over a long timespan, helping in better understanding the notions of Saros cycle and Saros series. At the same time, we notice the use of spirals throughout history as a solar symbol.

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2. ABOUT SAROS CYCLES AND SERIES

It is well known that the Chaldeans, a tribe near the ancient city of Ur, discovered that, the eclipses were repeated almost in identical conditions after an interval of 18 years and 11 days. The cycle discovered by the Chaldeans was named Saros by Halley in 1691 (Neugebauer, 1975). It may derive from the word šāru (meaning 3,600), a term wrongly identified with a period of 18 1/2 years. Instead, the word *sara*, a period of 6585 1/3 days (223 lunations), well-known by Babylonians, may be better suited as original term (Yeates (1820) and Picke (1837) on page 471). The cycle was improved by the Greek astronomer Meton in the 5^{th} century BCE. It is widely known that Babylonian astronomy influenced Greek astronomy and that by Alexander the Great's conquest of Babylon in the 4^{th} century BCE more than 1,903 years of astronomical observation made by Babylonians were transmitted to the Greeks, some at the request of Aristotle. Ptolemy cites for instance ten Babylonian observations of lunar eclipses ranging between 721–382 BCE. The Chaldean astronomers attributed to the possible discovery and later improvement of this cycle are Kidinnu (Cidenas) in the 4^{th} century BCE and Naburiannu (Naburianos) at the end of the 6^{th} century BCE (Fotheringham, 1928) both influencing the work of Hipparchus in the 2^{nd} century BCE.

The cycle discovered by the Chaldeans attracted the attention of modern astronomers to discover the causes that produce this periodicity.

It is known that when a solar eclipse occurs, the Moon is in the lunar phase New Moon or conjunction, and a lunar eclipse occurs when the Moon is in the Full Moon phase. that is, at the opposition. The time interval after which the Moon returns to the same phase is called the synodic month and has the duration S = 29.5305881 days.

If eclipses depended only on the **synodic period**, then in each synodic month there would be a lunar eclipse and a solar eclipse. Through observations it was found that not every time the Moon is at the conjunction or in opposition there is an eclipse. This is partly due to the lunar orbit being tilted by $5.145\deg$ with respect to the ecliptic and to the precession of the lunar nodes taking 18.6 years to complete a full orbit.

In fact, total solar eclipses are quite difficult to predict over a certain location based on repeatable cycles since it requires both a precision of under 1/20 degrees of arc and a discernible pattern of occurrences (Odenwald) since the shadow of the Moon on Earth is only 300km across. Lunar eclipses on the other hand are quite the opposite, with the shadow of the Earth being 12,000 km across. In addition, following a record of 1,000 years of possible total solar eclipses between 1,207 BCE to 1 BCE over Ancient Egypt, no discernible pattern can be noticed. On contrast, lunar eclipses seem to repeat every 135 and 223 synodic months.

Over a large time span, by looking closely and improving their methods for determining the position of the Moon and planets, ancient astronomers found that the Moon intersects the ecliptic in two points called nodes: the ascending node that the Moon crosses when it passes over the ecliptic, and the descending node, that the Moon crosses when it passes under the ecliptic. Ancient astronomers probably noticed that eclipses occur only when the Moon is near one of these nodes.

The time interval between two consecutive Moon passes through one of the two nodes received the name of **draconian period** and has the value M = 27.21221780 days. Interestingly, the term draconian has a mystical origin and is related to the ancestry conception of which, at eclipses, the Sun or Moon are swallowed by dragons placed at the respective points. As in Latin, the dragon is called draco, the respective drones or called draconian, and the time required by the Moon to return to the same draconian point, draconian period. In Hindu mythology there are two demons Rahu, when the Moon transit ascending node, and Ketu, when the Moon transit descending node. In the Romanian mythology, guilty of the disappearance of the Sun and the Moon, there are werewolves, three-headed demons that appear if the women purr at night without light (Olenici).

Through visual observations, it has been found that eclipses do not occur every time the Moon passes through the draconian points. It has been observed that eclipses only occur if both conditions are met at once, that is, the Moon is at the conjunction or opposition and crosses or is very close to one of the orbital nodes.

Therefore, the period after which the eclipses can be repeated will have to be a period in which S and M are encompassed several times. Calculations show that 242·M = 6,585.45670 days and 223·M = 6,585.32115 days.

If we make the transition from days to years, that is to divide the period above to 365.25 (the number of days in a calendar year) we obtain a duration of 18 years and 11 days, and 8 hours which represents exactly the duration of the **Saros cycle** discovered by the Chaldeans (Todoran, 1977).

In ancient times the values of the synodic and draconian periods did not have the current accuracy, but this does not greatly influence the duration of the Saros cycle established at 18 years.

By observing the eclipses within a Saros cycle, the Chaldeans could predict with satisfactory accuracy how the eclipses of the next Saros cycle would succeed.

Since the orbit of the Moon is inclined to the ecliptic, the eclipses take place only if the position of the nodes of the lunar orbit is below 16.5deg from the Sun on the ecliptic. When this angular distance falls below 10.5deg the eclipse becomes total (Olenici). In Figure 1(a) we can see the necessary position of the Moon in its orbit and of the Sun on the ecliptic when a solar eclipse occurs. Similarly, in Figure 1(b), we can see the position of the Moon in its orbit and the shadow of the Earth on the ecliptic when a lunar eclipse occurs (N-nodes, S-Sun, M-Moon, E- Earth, U-umbra, P- penumbra).

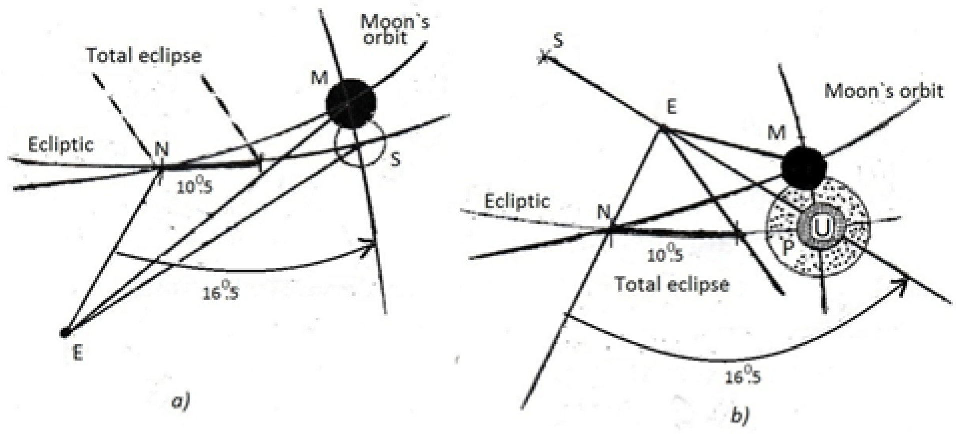

Fig. 1 – The position of the Sun, the Moon, and the Earth necessary to produce a solar eclipse (a) and a lunar eclipse(b). Olenici (1999)

These situations are repeated after half a year. These positions are called **eclipse seasons** and last between 31 and 37 days. During this time, the Moon can partially or totally cover the Sun.

Currently, researchers believe that the Chaldean astronomers could have predicted lunar eclipses based on the 223 synodic month cycle (Nickiforov, 2011). Considering that in most cases eclipses occur in pairs, a Sun eclipse paired a Moon eclipse at 14 days intervals, the Saros cycle discovered by the Chaldeans and used to predict the lunar eclipses, is also valid for the provision of the solar eclipses.

We should note that the points on Earth that see the repetition of a solar eclipse are displaced from the previous ones about 120deg westward. The cause, the duration of a Saros contains a fractional part, equal to about a third of the day (8 hours). Because of this, a solar eclipse recurs in a place on the Earth's Surface, in roughly similar conditions, after a series of three Saros cycles, that is, after 54 years and 34 days, but moved further north if the Moon passes through the ascending node and moving further south if the Moon passes through the ascending node. This interval of three Saros cycles is named triple Saros or *exeligmos* (Greek for "turn of the wheel").

All eclipses that are chained by a Saros cycle form a Saros series which lasts between 1200–1500 years and contains 68–75 Saros cycles, after which the Sun rises from the range of 33deg near the nodes of the lunar orbit (eclipse season) and thus eclipses can no longer occur. The term of Saros series was introduced by the Dutch astronomer G. van den Bergh (FlatEarth.ws).

3. ECLIPSES INSIDE A SAROS CYCLE AS A TEMPORAL CIRCLE: THE SAROS YEAR

Considering that the eclipses are repeated cyclically, we represented a Saros cycle in the form of a single circle (Figure 2) that presents the months and days of a calendar year named temporal circle or **Saros year**. The symbols of solar eclipses are as follow: total eclipses are represented by dots, partial eclipses by crescents, annular eclipses by two concentric circles and hybrid eclipses by stars.

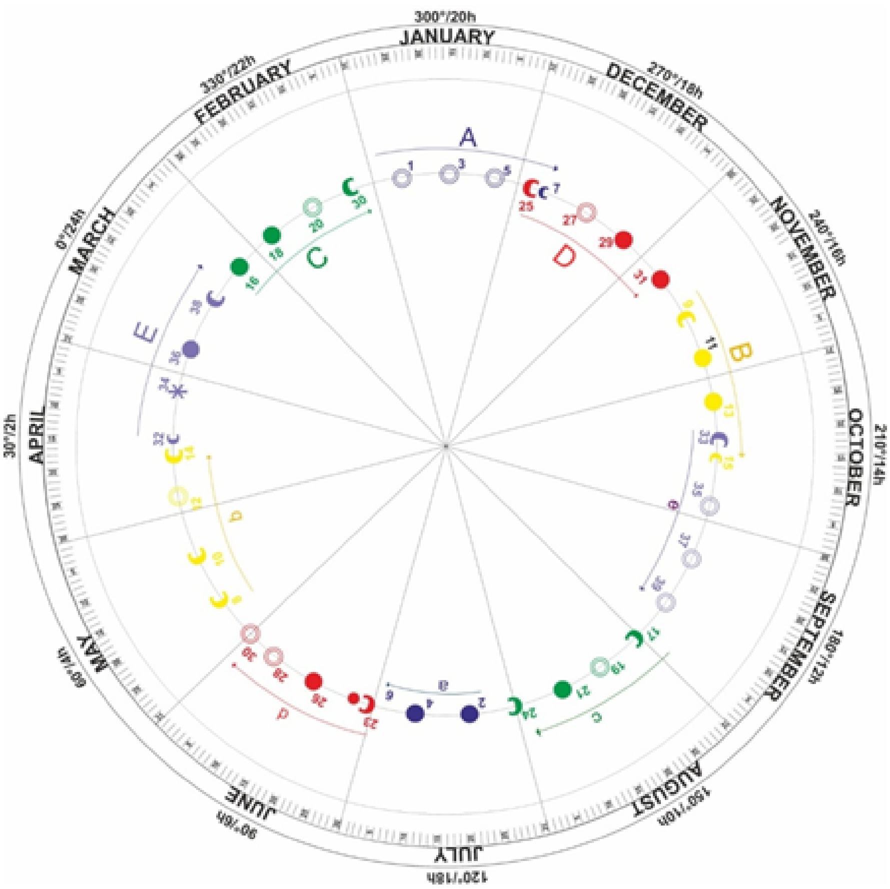

Fig. 2 – The order of the eclipses in the eclipse temporary circle of Saros cycle between January 26, 1990 – September 11, 2007.

For example, let us consider the Saros cycle between January 26, 1990, and September 11, 2007. We choose this cycle because it includes the total solar eclipse of August 11, 1999, whose bandwidth crossed Romania. We give every eclipse a serial number as follows: **1**–26.01, 1990; **2**–22.07, 1990; **3** – 15.0,1991 . . . **19**–11.08,1999 . . . **39**– 11.09, 2007. The solar eclipse of August 11, 1999 has in this temporal circle the number 19. It must be noted that eclipses within this cycle are not part of the same Saros series since series is formed by eclipses repeated every 18 years, over 12–15 hundred years.

In our proposed depiction we chose the place of the month of the year on the circle from right to left, to be in agreement with the direction of the Sun on the ecliptic, as we observe in nature with the sky above our head. When we put each eclipse on the day of the month, we see it alternating every six months in agreement with the seasons of eclipse. Their layout (Figure 2) is not done in a calendar order, but we notice that there are five pairs of families, *i.e.* A-a, B-b, C-c, D-d, E-e.

It appears like an imaginary force is ensuring that each circle should be covered by 39 eclipses. Given this fact we propose that the temporary circle defined by eclipses occurring within a single Saros cycle to be named also "Saros Year" by analogy with the civil year, the Platonic year, the galactic year, etc.

4. THE SPIRAL DIAGRAM. THE ROSETTE OF SOLAR ECLIPSES AND SAROS SERIES

Next, we present a novel illustration of the succession of eclipses of Saros series into spirals diagrams who look like a rosette. This is a different approach from den Bergh's matrix approach (van den Bergh, 1955) and has the advantage of better outlying the major eclipse cycles as depicted next. The creation of the spirals proceeds as follows:

First, we trace several concentric temporary circles, each divided in twelve parts for the twelve months of the year and the days. Next, we mark on circles the position of all the eclipses in a Saros cycle by starting from the inner circle. Having completed all the eclipses inside one cycle, we proceed to add the eclipses of the next Saros cycle. As we mark the position of each eclipse on these circles, we observe, in agreement with the idea that eclipses succeed one another at intervals of about six months, that through two consecutive years, approximately in and after the same period of the year, the period of appearance of the eclipses changes.

In our presentation (Figure 3), we began by illustrating the eclipse of January 16, 1972, and ended with the eclipse of October 24, 2079. For each eclipse we used data from the Five Millennium Catalog of Solar Eclipse (Espenak and Meeus, 2006). After displaying on the first circle the position of the 39 eclipses within the first Saros cycle, we start again on the second circle, and mark the fortieth eclipse as the first one of the second Saros cycle, which starts on 26 January 1990. Then the first eclipse of the third Saros cycle starts on February 2008, etc.

Each eclipse is represented by two numbers: inside the temporary circle is the date of the month and the outside marked with an apostrophe there are the two last digits of the year. For instance, 16/'72 means the 16th day of January 1972, and

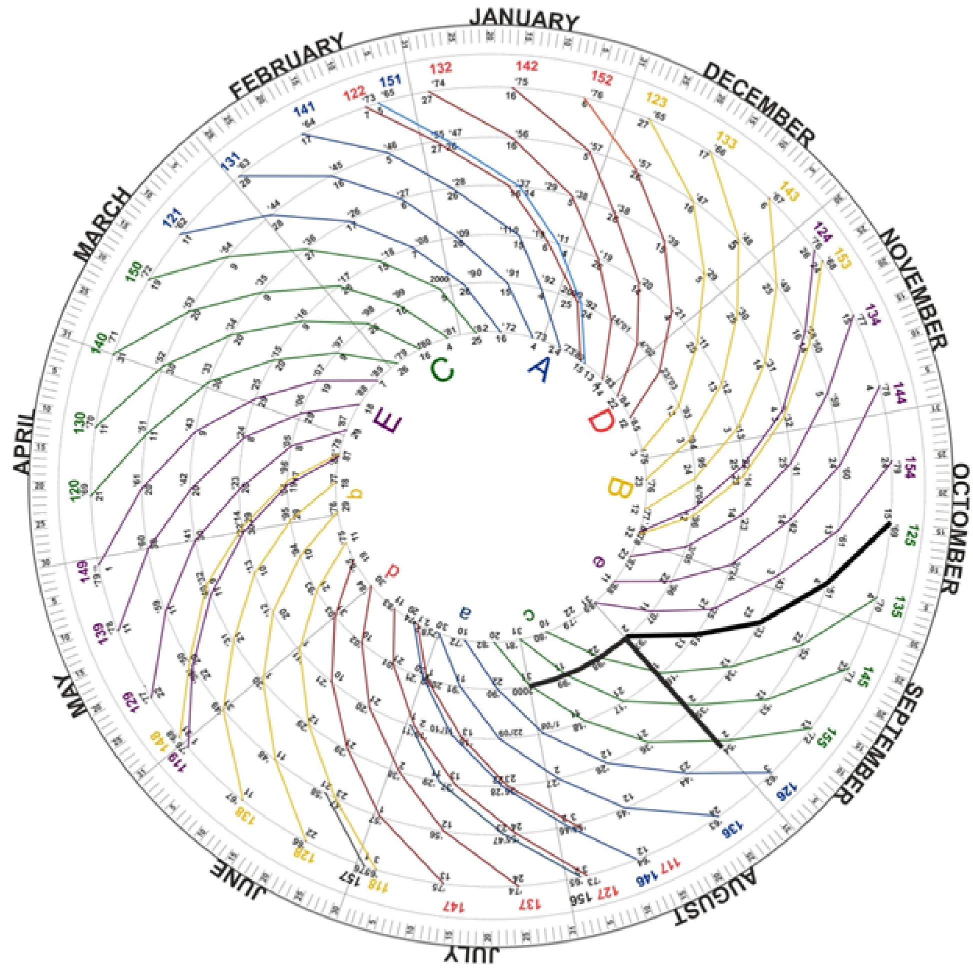

Fig. 3 – The Rosette of spiral diagrams of Saros series of solar eclipse between January 16, 1972 – May 1, 2079.

11/’99 means August 11, 1999, where the month is visible in the figure.

For the four eclipses of 2000, February 5, July 1, July, 31 and December 25 we wrote the full year 2000. For the eclipses of the XXI century we used the notation /’ 01, /’ 02 . . . /’ 79.

It is interesting to observe that, the eclipses of the same Saros series are arranged into a spiral. This is because each eclipse in a Saros cycle is 11 days late every 18 years.

Finally, all these spiral diagrams look like a rosette. On the outer edge of the rosette are marked the serial numbers of the Saros series; 117, 118, 119 … 155.

As we already mentioned, the Saros series groups itself in five pair of families: A-a, B-b, C-c, D-d, and E-e, of which the components are "born" in successive diametrical positions during the Saros cycle. We realize that in the time range we use (January 16, 1972 – May 1, 2079) nine of these families have four members, and that the tenth, the family "a" has only three members.

The Saros series in each family is as follows:

- A (121, 131, 141, 151); a (126, 136, 146)
- B (123, 133, 143, 153); b (118, 128, 138, 148)
- C (120, 130, 140, 150); c (125, 135, 145, 155)
- D (122, 132, 142, 152); d (117, 127, 137, 147)
- E (119, 129, 139, 149); e (124, 134, 144, 154)

It is interesting to note that in each family the interval between two successive Saros series is 10, for example: 121–131–141–151 etc. Very interesting is the fact that, the rosette is a solar symbol. In ethnography, the rosette with curved arms represent the moving Sun (Olenici).

5. THREE TYPES OF SERIES OF SOLAR ECLIPSES FOUND IN THE ECLIPSE ROSETTE

By carefully analyzing the arrangement of the eclipses within the rosette we find that we can distinguish three types of eclipse series (Figure 4):

- I-Spiral series (succession according to Saros cycles);
- II-Radial series (succession according to Metonic cycle);
- III-Circular series (succession according to the lunar year of 354 days).

Here, we mention the fact that over time, 82 types of eclipse cycles have been highlighted. They have various timespans and names such as: the Saros (18.0 years), Sar (Half Saros, 9.015 years) Metonic Cycle (19.0 years), Hipparchos Cycle (345 years) Exeglimos (54.1 years), Babilonian Period (441.3 years), Hexon (2.83 years), Hepton (3,315 years), Tzolkinex (7,115 years) etc. (FlatEarth.ws)

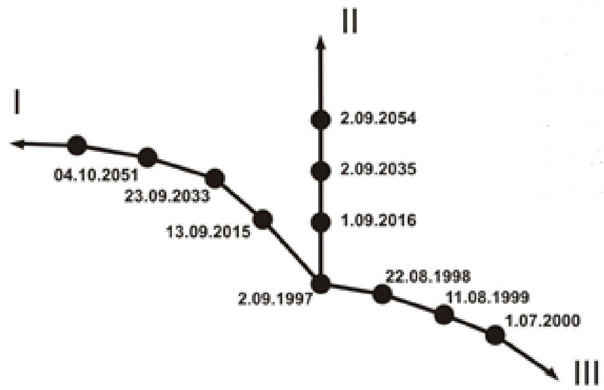

Fig. 4 – Example of the spiral, radial, and circular series into the rosette of spiral diagrams of Saros series of solar eclipse.

6. CORRELATION BETWEEN THE SAROS CYCLE AND MAYA INTERVALS

A careful analysis shows us, that, this interval of 354 days is double the duration of the Maya cycle of succession of eclipses at interval of 177 days. This interval was deciphered in The *Codex of Dresden*, and there was also a shorter interval of 148 days (Innvista). These are average values, in practice there are also values of 176 and 179 days as well as 145, 146, 147, and 149 days.

As it can be noticed in Figure 5, these values are repeated according to the Saros cycle. We notice the chaining, after the Mayan cycles (vertically), of the solar eclipses for a period of five years 1981–1985 and their repetition, after the Saros cycle (horizontally), in the years 1999–2003, 2017–2021, and 2035–2039.

If we correlate the Maya intervals and the Saros series, we find a shorter Maya cycle of 29 or 30 days.

The two intervals of 148 and 29 days (or 147 and 30) together form the interval of 177 days and follow a complete Saros cycle.

The calculations show that six lunar months are exactly 177 days, $6 \times 29.5 = 177$. In fact, every year there are at least two separate solar eclipses of 177 days apart. Therefore, the Maya may have used this fact to chain the seasons of the eclipses.

Another interesting aspect is that the Maya intervals of 29 or 30 days are accompanied by intervals of 148 days as seen in Fig. 6.

Maya intervals	Saros cycles →				Saros series
	1981.02-04	1999.02.16	2017.02.26	2035.03.09	140
176.5	*177 days*	*176 days*	176 days	177 days	
	1981.07.31	1999.08.11	2017.08.21	2035.09.02	145
177,75	177 days	178 days	178 days	178 days	
	1982.01.25	2000.02.05	2018.02.15	2036.02.27	150
147.25	**147 days**	**147 days**	**148 days**	**147 days**	
	1982.06.21	2000.07.01	2018.07.13	2036.07.23	117
29,25	**29 days**	**30 days**	**29 days**	**29 days**	
	1982.07.20	2000.07.31	2018.08.11	2036.08.21	155
147.75	**148 days**	**147 days**	**148 days**	**148 days**	
	1982.12.15	2000.12.25	2019.0106	2037.01.16	122
177.75	178 days	178 days	177 days	178 days	
	1983.06.11	2001.06.21	2019.07.02	2037.07.13	127
176.25	176 days	176 days	177 days	176 days	
	1983.12.04	2001.12.14	2019.12.26	2038.01.05	132
178.0	178 days	178 days	178 days	178 days	
	1984.05.30	2002.06.10	2020.06.21	2038.07.02	137
176.5	176 days	177 days	176 days	177 days	
	1984.11.22	2002.12.4	2020.12.14	2038.12.26	142
177.75	178 days	178 days	178 days	177 days	
	1985.05.19	2003.05.31	2021.06.10	2039.06.21	147
177.75 ↓	177 days	176 days	177 days	177 days	
	1985.11.12	2003.11.23	2021.12.4	2039.12.15	152

Fig. 5 – The correlation between Saros cycle (horizontally) and Maya intervals (vertically) for the period between February 5, 1981 and December 15, 2039.

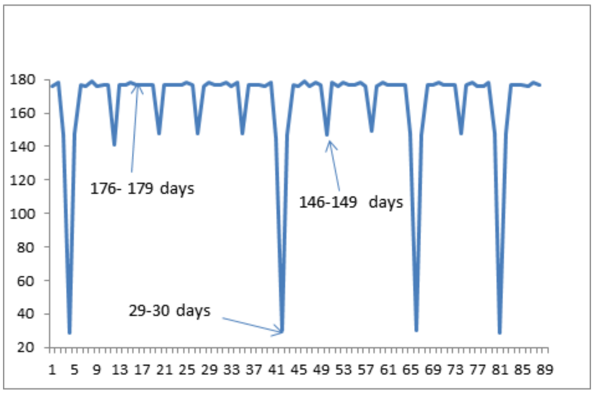

Fig. 6 – The Maya eclipse intervals between February 15, 1981 – December 15, 2039.

7. THE SPIRAL DIAGRAM OF SAROS SERIES NUMBER 145 AND THE CYCLE OF 595 YEARS

Another advantage of the representation of the Saros series as a rosette is that when we implement a representation of many eclipses, we can observe the start and the end of a Saros series. In Fig. 7 is illustrated the spiral of eclipses of Saros series number 145. This Saros begins on January 4, 1639 and ends on April 17, 3009 and includes the total solar eclipse of August 11, 1999 centered in Romania.

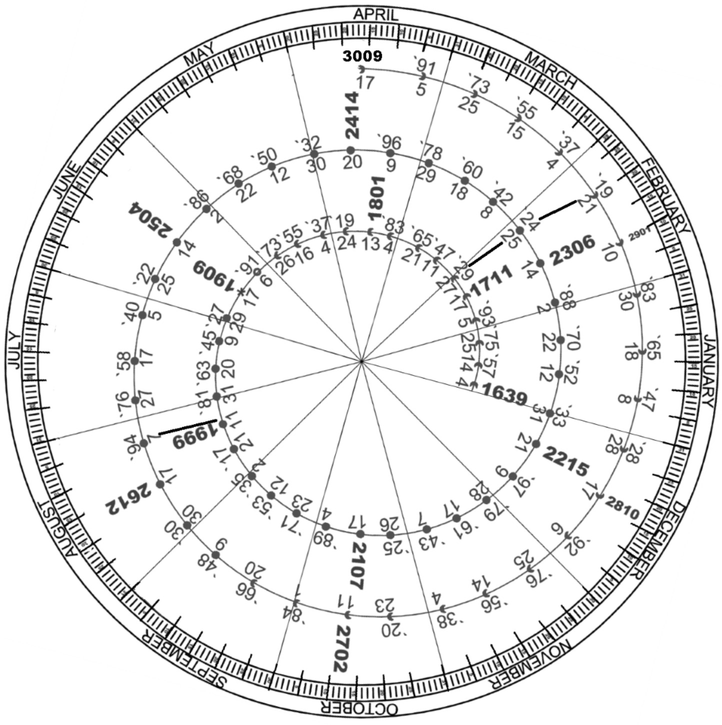

Fig. 7 – The spiral representation of the solar eclipses of Saros series number 145.

If we cross the spiral radially, joining the adjacent spirals, we identify the 595 year cycle of repeating eclipses (exactly 594.99 years or 217315.6 days) around the same calendar date. For instance, after the solar eclipse of February 27, 1729, at the age of 595, the solar eclipse of February 25, 2324 follows, and after another 595 years, the solar eclipse of February 21, 2919 takes place.

This cycle of 595 years, is a multiple of 33 Saros cycles and is mentioned as "Unnamed (595) 33 S" in (van Gent). Interestingly, if we divide 365.25 days by 11.3 days, we find 32.32. If we count the eclipses in a Saros spiral we find the number 32, *e.g.*between January 4, 1639 and December 21, 2215. In other words, expressing in units of time the step in the spirals of the Saros series is 595 years, and the angular velocity is 11 days and 8 hours.

8. CONCLUSION

In this article we presented for the first time the concept of temporary succession of eclipses in form a rosette of Saros series. By marking the position of eclipses of Saros cycle on a circle on which the months and calendar data are presented, we find that their arrangement is made alternately at intervals of six months in five pairs of families of series of eclipses. The resulting rosette created by a succession of Saros series of eclipses gives us an overview of the occurrence of Saros cycles and series. Within the rosette we can distinguish the arrangement of three cycles of eclipses: spiral (Saros cycle), radial (Metonic cycle) and circular (lunar year). By viewing an entire Saros series, we can easily notice where it begins and ends. Based on this representation we can also identify a cycle of 595 years for the repetition on nearly the same calendar date of the same eclipse in a Saros series.

The shared analysis of the Saros cycle and the Maya intervals of repeating eclipses of 148 and 177 days suggests the idea that there are two more Maya intervals of 29 or 30 days and that the Mayans may have included eclipses in their calendar.

In the methodology of teaching astronomy, the rosette of the Saros series helps to create a better overview of the time arrangement of Saros cycles and series.

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