THE COLUMN OF SAROS SERIES AND THE 8 AND 10 YEARS CYCLE OF SOLAR ECLIPSES

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Abstract. This article shows that the rosette of the Saros series of solar eclipses can be arranged in space in the form of a column. We previously described the three types of cycles of solar eclipses represented in the plane in the rosette: spiral series, radial series and circular series. Within the columnar representation these are arranged obliquely, vertically and horizontally. By analyzing the succession of eclipses from the Saros series we found a cycle of 8 years and 2 days and a cycle of 10 years and 10 days after which the solar eclipses are repeated. These cycles has not been known until now.

Key words: History of the Astronomy – Astronomy in culture.

1. INTRODUCTION

As we showed in a previous article (Olenici, 2020), the Saros series of solar eclipses can be arranged in the form of a rosette.

To build the rosette we draw several concentric circles. On each circle we place the eclipses of a Saros cycle.The last circle is divided into 12 sectors which represent the 12 months of the year. On each sector are divided divisions that indicate the days of the respective months. With their help we can correctly indicate the position of the eclipses in each Saros cycle. We chose the lunar order to be from right to left in order to be in agreement with the increasing direction of the longitudes of the astronomic coordinates. When we mark the positions of eclipses on these circles we find that they are not arranged in calendar order, this is due to the fact that alternatively one eclipse is visible from the northern hemisphere and the next is seen after six months in the southern hemisphere. For example, Saros cycle eclipses from January 16, 1972 to July 22, 1990 (the first rosette made by us) are arranged in the following order:

1972 (01.16, 07.10), **1973** (01.04, 06.30, 12.24), **1974** (06.20, 12.13), **1975** (05.11, 11.03), **1976** (04.29, 10.23), **1977** (04.18, 10.12), **1978** (04.07, 10.02), **1979** (02.26, 08.22), **1980** (02.16, 08.10), **1981** (02.04, 07.31), **1982** (01.25, 06.21, 07.20, 12.15), **1983** (06.11, 12.04), **1984** (05.30, 11.22), **1985** (05.19, 11.12), **1986** (04.09, 10.03), **1987** (03.29, 09.23), **1988** (03.18, 09.11), **1989** (03.07, 08.31), **1990** (01.26).

The next Saros cycle is played on the second circle and begins with the solar eclipse on January 26, 1990, the third Saros cycle is played on the third circle and begins on February 7, 2008, the fourth Saros cycle is on the fourth circle and begins on February 17, 2026, the fifth Saros cycle is on the fifth circle and begins on March 11, 2062. Because all these eclipses occur after 18 years with a delay of 10 days are arranged further to the left and by joining them with a line we obtain a spiral. Moreover, eclipses in the same spiral, are part of the same Saros series. In third case Saros series 121. All 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 in accord with season of eclipse.

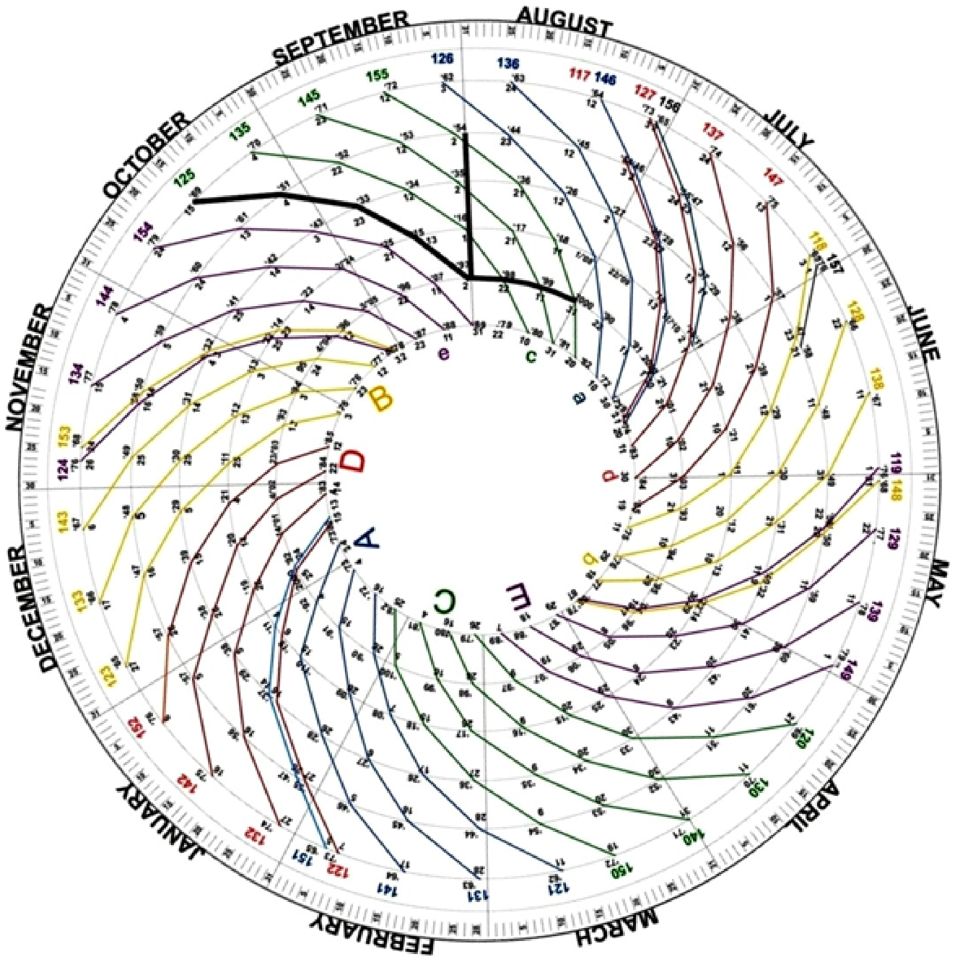

Fig. 1 – : The rosette of Saros series of solar eclipses between Jan 16, 1972 and May 1, 2079.

To distinguish each family of Saros series they are colored differently in Fig. 1. This two-dimensional representation of eclipses in the form of a rosette gives us the opportunity to have an overview of the arrangement of all the eclipses in a chosen period of time. If the chosen time interval is very long, between 1300 and 1600 years we have the possibility to see the complete spiral of a Saros series, where it starts and when it ends (*e.g.* see Fig. 7 in our previous article Olenici, 2020).

In what follows we define a three-dimensional representation of the Saros series of solar eclipses. This gives us the opportunity to discover two new cycles of solar eclipses.

2. TRANSFORMING THE ROSETTE INTO A COLUMN

The process of transforming the rosettes into a columnar representation consists of dividing the rosette into six sectors, each comprising two calendar months, and representing the eclipses in a quadrilateral matrix. Total eclipses are represented by polka dots, annular eclipses by circles, partial eclipses by crescents and hybrid eclipses by stars. Next to each symbol, at the bottom left is the calendar date and at the top right is the year. On the left and top are indicated the numbers of Saros series 121–157 (Espenak and Meeus, 2006a).

In Figs. 2 we present the six matrix corresponding to (January, February) - (November, December), between January 16, 1972 and December 08, 2151.

We note that each Saros series family has four members, but when a series ends and a new one begins, in the representation in the form of a rosette (or matrix) there may be five members in the same family. For example, in Fig. 2d we see that there are five Saros series together (117, 127, 137,147,157). This is because the 117 series ends in 2054 and the 157 series begins in 2058. The duration of the Saros series in this family is between the years: 117 (792–2054), 127 (991–2452), 137 (1389–2633), 147 (1624–3049), 157 (2058–3302) (Espenak and Meeus, 2006a).

If we chain in order the six matrices, in calendar order from right to left, we obtain a single one in the shape of a cylindrical column. In this columnar representation the Saros cycles are arranged in horizontal parallel rings, the Saros series are oblique spirals and, on the vertical are the Meton cycles (Fig. 3).

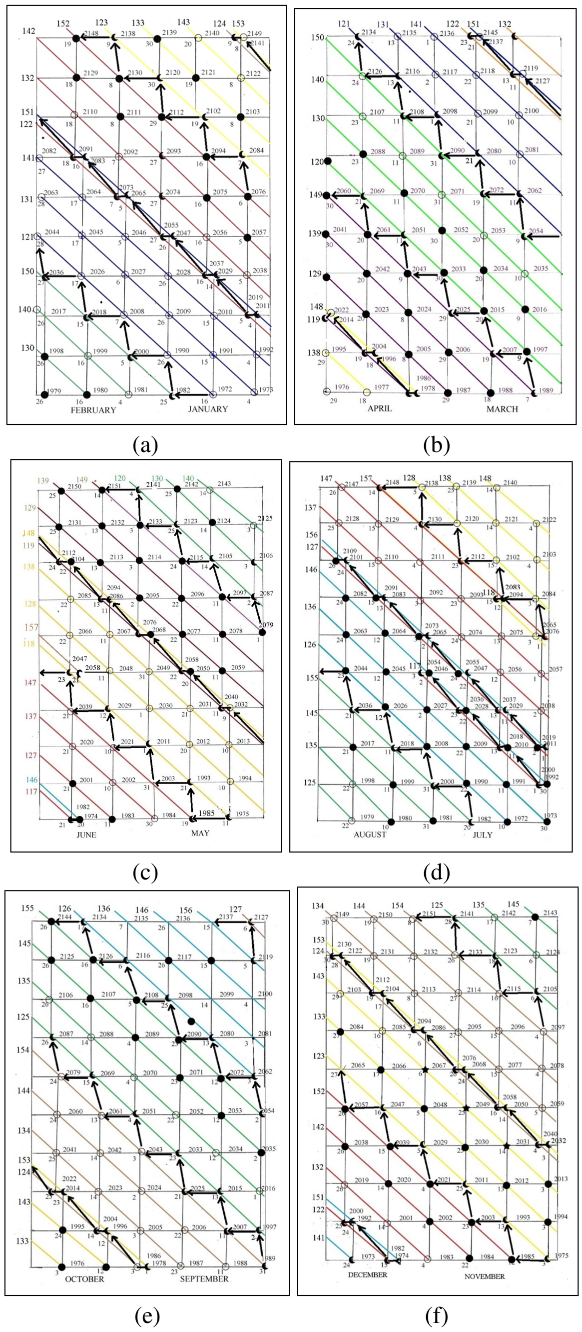

Fig. 2 – : The matrix of solar eclipses:
(a) January 16, 1972 (Saros 121) - January 9, 2149 (Saros 124); (b) April 18, 1977 (Saros 138) - March 23, 2145 (Saros 151); (c) May 20, 1974 (Saros 146) - June 14, 2151 (Saros 149); (d) July 10, 1972 (Saros 126) - August 14, 2148 (Saros 157); (e) October 3, 1976 (Saros 133) – October 26, 2144 (Saros 155); (f) December 24, 1973 (Saros141) - December 8, 2151 (Saros 154).

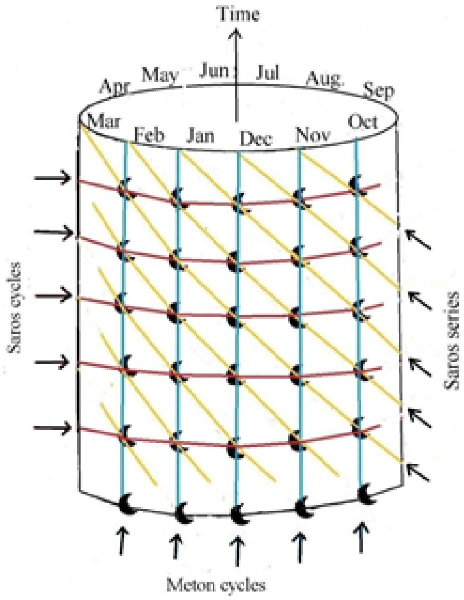

Fig. 3 – : The columnar representation of Saros series.

3. THE DISCOVERY OF THE CYCLES OF SOLAR ECLIPSE OF 8 AND 10 YEARS

We recall that by analyzing the arrangement of the eclipses within the rosette, we find that on the spiral direction they are arranged after the Saros cycle -I, on the radial direction after Meton Cycle –II, and finally circular according to the monthly year of 354 days III (cf. Fig. 4 Olenici, 2020).

By carefully analyzing the matrices of solar eclipses presented above, we find that the connection between two families of Saros series together is zigzagged at intervals of 8 years and 2 days alternately with intervals of 10 years and 10 days. These are two new cycles of solar eclipse. The coupling between these eclipses is represented in the matrix by thick arrows. We also found that these eclipses have the γ parameter around $| \pm 1 |$. The γ of a solar eclipse is a numerical value (a number) that describes the position of the Moon's shadow relative to the center of the Earth during the maximum of eclipse (McGlaun). As is well known, the shadow of the Moon, illuminated by the Sun, forms a cone. Then the γ of an eclipse is defined as the ratio between the distance D, from the axis of the cone of the Moon's shadow to the center of the Earth, and the equatorial radius of the Earth, $Re = 6,378.137$ km.

By convention, the values of the range γ are considered positive in the northern hemisphere and negative in the southern hemisphere In practice, we encounter several distinct situations. If the axis of the shadow cone is tangent to the terrestrial North Pole then the range has the value 0.9972 because the polar radius of the Earth is

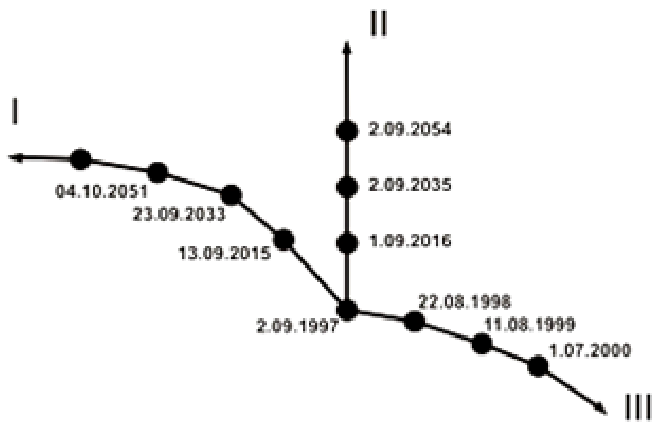

Fig. 4 – : Example of the spiral, radial, and circular series into the rosette of spiral diagrams of Saros series of solar eclipse.

$Rp = 6356.8$ km and $\gamma = 6356.8/6378.1$. If the axis of the shadow cone is directed towards the center of the Earth through the terrestrial equator then $\gamma = 0$. If the axis of the shadow cone is tangent to the terrestrial equator at the cardinal east or west points then $\gamma = \pm 1$. If the axis of the cone of the Moon‘s shadow passes at a distance $D = 4943$ km from the center C of the Earth then the range will have value 0.75. In the same way the value of the γ is calculated and if the axis of the shadow cone passes through the outside of the Earth and an eclipse occurs. In Fig. 5 we can see illustrated these particular cases.

On the other hand, the surface of the Earth is very close to that of a spheroid, S, with a large half-axis equal to the equatorial radius of the Earth and with a small half-axis equal to the polar radius of the Earth. The axes of the shadow cones of eclipses with a range less than 0.9972, (with values greater than -0.9972 in the southern hemisphere) intersect with the distances to the center of the Earth inside an inner tangent sphere Si with the spheroid S in the terrestrial poles. Similarly, the axes of the shadow cones of eclipses with a range greater than 1 (with values smaller as -1 in south hemisphere) are outside a sphere So, tangent to the outer equator. In the space between these two spheres we meet the axes of the shadow cones of eclipses with γ values between 0.9972 and 1 in the northern hemisphere and -0.9972 and -1 in the southern hemisphere.

Next in Figs. 6 and 7 we present the values of the γ parameter and the geographical coordinates of the maximum of the eclipses from the January–February matrix, for the eclipse which make the connection between the Saros 1–150, 122–151 and 123–152 series (Espenak and Meeus, 2006b). In the table of Fig. 6, we

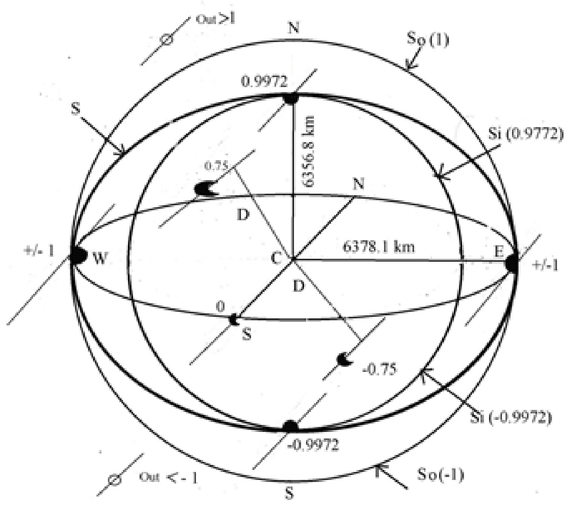

Fig. 5 – : The connection between the position of the axis of the shadow cone of an eclipse and the γ parameter.

present for the eclipses from the January–February matrix between which there is a time interval of 8 years and 2 days, the values of the Range parameter as well as the geographical coordinates of the maximum eclipse. In the middle of the table the numbers 150, 151 and 152 represent the Saros series which include eclipses on the left and the numbers 121, 122 and 123 represent the Saros series which include eclipses on the right, which are repeated after 8 years

In the same way, in the table in Fig. 7 we can see the parameters of eclipses that are repeated at intervals of 10 years and 10 days between the Saros series 121–150, 122–151 and 123–152.

From the analysis of these data we find two interesting things:

1. The γ parameter of these eclipses has values around ± 1. Therefore the axis of the shadow cone does not touch the Earth and is outside the spheroid S (see Fig. 5).

2. The points on the Earth's surface where the maximum eclipses occur have a latitude greater than 61°. Therefore, these eclipses occur in the polar areas of the globe.

We can see this very easily with the *FInspector* program developed by Robert Nufer (Nufer, 2011). Given the fact that, in the polar areas the population is very small in number, no systematic observations were made on eclipses. From our point

Year	Date	Gama	Lat.	Lon.	Saros	Year	Date	Gama	Lat.	Lon
					150-121					
1982	01.25	**-1.2311**	69.35N	91.7W		1990	01.26	**-0.9457**	71.0S	22.20N
2000	02.05	**-1.2233**	70.2S	134.1E		2008	02.07	**-0.9570**	67.58S	150.5N
2018	02.15	**-1.2116**	70.1N	0.6E		2026	02.17	**-0.9743**	64.71S	86.8E
2036	02.27	**-1.1942**	71.6S	131.4W		2044	02.28	**-0.9954**	62.19S	25.56W
					151-122					
2011	01.04	**1.0627**	64.7N	20.8E		2019	01.06	**1.1418**	67.4N	153.6E
2029	01.14	**1.0553**	63.7N	114.2W		2037	02.16	**1.1447**	68.5N	20.8E
2047	01.26	**1.0450**	62.9N	111 E		2055	01.27	**1.1550**	69.5N	112.2W
2065	02.05	**1.0336**	62.2N	21.9W		2073	02.07	**1.1651**	70.5N	114.9E
2083	02.16	**1.0170**	61.6N	154.1W		2091	02.18	**1.1779**	71.2N	17.8W
					152-123					
2076	01.06	**-0.9373**	87.18S	173.4W		2084	01.07	**-1.0715**	64.4S	142.9W
2094	01.16	**-0.9334**	84.77S	10.55W		2102	01.19	**-1.0741**	63.5S	73.6W
2112	01.29	**-0.9212**	80.63S	163.8W		2120	01.30	**-1.0792**	62.7S	145.3E
2130	02.08	**-0.9212**	75.94S	51.82E		2138	02.09	**-1.0872**	62.1S	5.1E

Fig. 6 – : The table of parameters of solar eclipses of matrix January–February 1982–2138 at interval of 8 years.

Year	Date	Gama	Lat.	Lon.	Saros	Year	Date	Gama	Lat.	Lon.
					121-150					
1972	16.01	**-0.9365**	74.95 S	107.7E		1982	25.01	**-1.2311**	69.3 S	91.7 W
1990	26.01	**-0.9457**	71 S	22.2 W		2000	05.02	**-1.2233**	70.2 S	134.1 E
2008	07.02	**-0.957**	67.6 S	150.5 W		2018	15.02	**-1.2116**	71 S	0.6 E
2026	17.02	**-0.9743**	64.7 S	86.8 E		2036	27.02	**-1.1942**	71.6 S	131.4 W
					122-151					
2019	06.01	**1.1417**	67.4N	153.6 E		2029	14.01	**1.0553**	63.7 N	114.2 W
2037	16.01	**1.1477**	68.5 N	20.8 E		2047	26.01	**1.045**	62.9 N	111.7 E
2055	27.01	**1.155**	69.5 N	112.2 W		2065	05.02	**1.0336**	62.2 N	21.9 W
2073	07.02	**1.1651**	70.5 N	114.9 E		2083	16.02	**1.017**	61.6 N	154.1 W
2091	18.02	**1.1779**	71.2 N	17.8 W		2101	28.02	**0.9964**	60.5 N	80 E
					123-152					
2084	07.01	**-1.0715**	64.4 S	68.5 E		2094	16.01	**-0.9333**	84.8 S	10.6 W
2102	29.01	**-1.0715**	63.5 S	73.6 W		2192	29.01	**-0.9292**	80.6 S	163.8 W
2120	30.01	**-1.0792**	62.7 S	145.3 E		2130	08.02	**-0.9212**	75.9 S	51.8 E
2138	09.02	**-1.0872**	62.1 S	5.1 E		2148	19.02	**-0.9111**	70.9 S	88.3 W

Fig. 7 – : The table of parameters of solar eclipses of matrix January–February 1972–2148 at interval of 10 years.

of view, this is the reason why these 8 and 10 years cycles of solar eclipses has not been highlighted so far. Similarly, we find the same difference for eclipses in the other matrices. We mention the fact that these cycles of 8 years and 2 days (8.0055 years), and 10 years and 10 days (10.0274 years) are not presented in Van den Berg's catalog of eclipse cycles (van Gent). In Van den Berg's list there are 82 cycles of solar eclipses arranged in the order of the period between 0.0809 years — Sinodic month (shortest possible interval between two lunar o solar eclipse) – and 3310.2

years — Horologia (Same week day, approximately). The 8.0055 years cycle should be interspersed in Van den Berg's catalog between the 7,115 years Tzolkinex cycle and the 8,975 year Hibbardina cycle. The 10.027 years cycle should be interspersed in Van den Berg's catalog between the Sarf (Half Saros) cycle 9.015 years and the Tritos (Saroid) cycle 10.915 years.

Given that eclipses are formed by oppositions and conjunctions which are astronomical phenomena in the solar system that depend on the position of the Sun on the ecliptic, their chronology must be related to the ecliptic coordinate system and the tropical year.

As the tropical year gives the periodicity of the seasons, we consider that in the tropical year the periodicity of the eclipse seasons also takes place after six months, more precisely every 177 days (see the Fig. 5 of our previous article Olenici, 2020), and therefore we prefer to use the tropical year, respectively the tropical day in the calculations of the cycles of eclipses.

A simple mathematical calculation shows that in 8 years and 2 days (2923,9368 tropical days) there are 99,0158 synodic periods (29.53 days) or 107,0216 sidereal periods (27,321 days) or 107,4503 draconian periods (27,212 days). Also in 10 years and 10 days (3662.421 tropical days) there are 124.0238 synodic periods, 133.9535 sidereal periods and 134.5885 draconic periods.

In our opinion, even the Chaldean astronomers who discovered the Saros cycle made observations in accordance with the tropical year. The notion of leap year appeared much later. On the other hand, nature did not operate considering leap years. Consequently our coordinate and calendar systems and their use involves various corrections.

4. CONCLUSION

In conclusion we can say that:

1. The rosette of the Saros series of eclipses can be transformed into a cylindrical matrix, as a column that gives us a much more suggestive overview of the succession of eclipses.

2. The matrix representation in the cylindrical column of eclipses is similar to the representation of chemical elements in the periodic table.

3. The connection between closely related series families is made at intervals of 8 years and 2 days and alternately with intervals of 10 years and 10 days.

4. The intervals of 8 years and 2 days and 10 years and 10 days are new two cycles of solar eclipses hitherto unknown.

5. Because the combined duration of these two cycles is 18 years they can be considered subcycles of a compound Saros cycle that connects the Saros series families.

6. One of the advantages of the Saros series column (or the cylindrical matrix of eclipses) is didactic, because it allows a better understanding of the notions of Saros cycle and Saros series and the connection between them. Consequently, such columns could be made at planetariums and popular astronomical observatories. The reader can reproduce the six matrices and make a column of solar eclipses.

7. Because these 8-year and 10 years cycles occurs in polar areas, we propose to call it *the Polar Cycles* of 8 and 10 days cycles of solar eclipses.

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