There is no dark side of the Moon really, as a matter of fact it is all dark,

- Pink Floyd ("The Dark Side of the Moon").

1. THE PLANETARY GAMBLING MACHINE.

Everybody living on this planet must have heard here or there about eclipses of the Moon and the Sun. It does not matter if she/he is interested in astronomy, or is completely ignorant. Eclipses are facts, they take place in our sky, either we like it or not. From time to time there is something more about eclipses in newspapers and TV. Typically, if the eclipse takes place in the given country, local newspapers are filled in with details. Typically trivial facts about eclipses are presented to the public. In the year 1999 there was a total eclipse of the Sun visible from Europe, and a few countries were lucky to host the eclipse on their own soil.

What is so interesting about eclipses in the first place ? The answer probably would be , that they are very rare, and this is why it is so loudly pronounced about them, when they happen. This is not true, eclipses are not rare on the planet Earth. There are eclipses of the Sun and Moon, and there can be total, annular (only for solar eclipses), and partial eclipses. Every year, on average there are around four eclipses visible in our sky. Eclipses of the Moon are less spectacular "shows" than eclipses of the Sun, and they can be seen more often. The main difference between the eclipse of the Sun, and the eclipse of the Moon, is that the first one is visible from the small area, while the other can be seen from the big portion of Earth. As a result, it is easier to see the total eclipse of the Moon, than the total eclipse of the Sun. In spite of the fact, that total eclipses of the Sun happen on average two times for every three years, the requirement of specific geographical location makes them hard to observe. It is said that the total eclipse of the Sun happens one time for every hundred years. This is true for the given point on Earth, on average. Everybody moves a bit here and there, so in reality for the average person, it is a once in a lifetime event. Of course, clouds can be the reason for the "show cancelation", unfortunately. Let us concentrate on eclipses of the Sun, since they are closely related to the subject of the book. Why do eclipses of the Sun happen ? By coincidence, the apparent size of the Sun happens to be more or less equal to the size of the Moon in our sky.

(This coincidence fascinated me from my early childhood, and already long time ago, I had a gut feeling that sizes of the Sun and the Moon in the sky are the same for a reason, and not just by accident. Years were suppose to pass, before my proof could have been formulated, and this is also what this book is partially about.)

Unfortunately I must say a few words about the theory, in order to make it easier to understand events described in the book. Four factors are responsible for the eclipse of the Sun.

1. The distance of the Moon from the observer (the closer the better).
2. The distance of the Earth from the Sun (the farther the better).
3. Timing of the eclipse (the closer to the local noon the better).
4. Geographical position of the eclipse on the globe (the closer to the equator the better).

All listed above factors, close to their extreme values, are needed for the eclipse to be a very long one. Please imagine a gambling machine with four rotating disks. If you happen to have four times '7', you win. For eclipses , the maximum win is a very long total eclipse (maximum possible time is equal seven minutes and thirty seconds). On the other hand, loosing would be no total eclipse of the Sun, the so called annular eclipse of the Sun, when the Moon is smaller than the Sun. The Sun is still shining in such a case, and the total effect is not achieved. The remaining rim-like edge of the Sun, is so bright that the day is still a day. For the total eclipse it is opposite, the day turns into night for a few minutes..

The total eclipse, indeed looks like a win in our imaginary gambling machine (big machine, the size of the distance between the Sun and Earth) . The prize is incomparable to anything else, a few minutes of night during the day. From all listed factors that are responsible for the eclipse, two are related to the position of the Earth and the Moon on their orbits, and two are related to the position of the Moon's shadow on the globe.

The last one from our list of four factors, the distance from the equator, is a very important one. The fact that the Earth rotates, and the observer on the equator is in a sense following the escaping Moon's shadow, gives us the first '7'. A big factor, it can contribute as much as 3.5 minutes to the total time of the eclipse (which is theoretically equal 7.5 minutes for the perfect "7777"). It is the main reason, why it is said that the best eclipses are observed close to the equator. However this is true only on condition, that the observer is on the equator around the local noon. If the observer is on the equator during the sunrise or sunset, and the eclipse happens to take place at this time, the rotation of the Earth moves the observer in the wrong direction. In this case, the rotation of the Earth does not help the observer to follow the escaping shadow of the Moon. It is almost as bad, as if the observer was positioned on the north or the south pole. From what was said, a conclusion can be formulated, that timing of the eclipse is also very important.

From our four factors, the third one was about timing. The closer to the local noon the better. Of course I am talking here about the location of the observer within the zone of totality. For every eclipse there is only one point on the globe where the eclipse is the longest, called the greatest eclipse point. Typically for the greatest eclipse point the eclipse takes place during the local noon.

The second '7' in our "gambling machine" is the one for timing then. Wrong timing, like for example close to sunrise or sunset (or in other words location of the observer far from the greatest eclipse point) can cancel everything that is gained by positioning of the eclipse close to the equator. The 3.5 minutes gain in the total time of the eclipse, can be achieved only on condition of the perfect timing. Of course the closer to the pole the eclipse takes place, the less important the timing is. On the pole it does not matter at all. The maximum possible duration for the eclipse is around four minutes there, and no gain thanks to timing can be achieved. On the pole then, it does not matter if the eclipse is at noon, sunrise, sunset, the duration of the eclipse will be similar in all cases. Well, that is obvious, on the pole there is either polar day or night, and the Sun is visible all the time (polar day) or not (during the six months long night). In both cases, there are no sunrises and there are no sunsets. Well, we have just discovered that our globe is round; that is good.

The positioning of the eclipse close to the equator, during the local noon (greatest eclipse point) can add as much as 3.5 minutes. The maximum was said to be 7.5 minutes. What about the remaining four minutes then ?

The first two factors that I listed are, the distance from the observer to the Moon and the distance from the Earth to the Sun. They are the remaining two 7s in our gambling machine. The distance from the observer to the Moon is listed first, and this is done for reason. It is simply more important than the distance from the Earth to the Sun. Why ? The Earth goes around the Sun on the elliptical orbit. The Moon goes around the Earth on elliptical orbit also. Let us not go too far to numbers, just the absolute necessity. Here are some facts first. It takes one year for the Earth to complete one rotation around the Sun. It takes one month for the Moon to complete one rotation around the Earth. So far so good. Now the hard stuff. Since the Moon is on elliptical orbit, the distance from the Earth to the Moon changes, as a result the size of the apparent Moon in the Earth's sky changes also. The apparent changes of the size of the Moon in Earth's sky are close to 10%, of the size of the Moon's disk diameter in the sky.

A similar story takes place for the Sun.

In spite of the fact, that it is the Earth that goes around the Sun, the Sun's disk moves in Earth's sky. It takes one year for the Sun's disk to complete one full circle in the sky. The Sun on its journey in the sky, for example eclipses some stars, and the brightest of the stars from the stars that the Sun can eclipse is DELTA GEMINORUM (this star helped me to write this book, more about this later in the book).

So the disk of the Sun moves in the sky, and in fact it is the Earth that goes around the Sun on the elliptical orbit. As a consequence the Sun's disk in the sky can have a different size every day. The changes of the Sun's disk, are not as drastic as in the case of the Moon. It is more or less three times less, around 3% of the size of Sun's diameter, is the maximum change of the size of the Sun in the sky. It is a fact, that the orbit of the Moon around the Earth, is more elliptical than the orbit of the Earth around the Sun. To be more precise, the orbit of the Moon is three times more elliptical than the Earth's orbit around the Sun.

The remaining four minutes (7.5 -3.5 = 4) of the maximum theoretical eclipse time, are dependant on the position of the Moon and the Earth on its orbits. The Moon's influence is three times more important. So, it can be said that the maximum possible size of the apparent Moon can contribute three minutes, while the minimum possible size of the disk of the Sun can add only one minute (since the total is equal four minutes and 3 + 1 = 4)

The distance from the observer to the Moon, is additionally dependant on the position of the observer on the Earth. The closer to the Moon the better, and that means that the best position for the eclipse, is very high above our heads. This point is called zenith. It is the highest possible point in the sky. When the Moon is positioned in zenith, the distance to the Moon is shorter by one Earth's radii, and this is approximately equal 2%. Of course during the eclipse, the positions of the Sun and the Moon are the same, so the Sun is also at zenith. The farther from the Sun the better (smaller size of the apparent Sun) , and in zenith the distance to the Sun is shorter. This is a contradiction, however not a big one. The distance to the Sun is shorter for the Sun at zenith, than for the Sun at sunrise or sunset only by 0.004 %, and this is almost nothing. Simply the Sun is this far from the Earth, that the size of the Earth is relatively small. For the Moon, which is closer to the Earth it is a different story. The difference between the position of the Moon at zenith, and the Moon close to the horizon adds 2% to the eclipse time, that the Moon is responsible for (this was estimated to three minutes for the maximum eclipse). So the position of the Moon at zenith adds a few additional seconds to the total eclipse time.

The Sun can be observed in zenith from the Earth only in certain areas. North from the tropic of Cancer, and south from the tropic of Capricorn, the Sun is never in zenith. The Moon can be observed in zenith farther to the north than the tropic of Cancer, and farther to the south than the tropic of Capricorn (five degrees farther for both tropics to be exact). Since we are talking about the eclipse however, it does not matter. The Moon must be where the Sun is, and the conclusion in these circumstances must be, that the best area for eclipses of the Sun is located between tropics of Cancer and Capricorn, on very low latitudes.

SUMMARIZING, IN ORDER TO HAVE A VERY LONG TOTAL ECLIPSE OF THE SUN :

1. THE MINIMUM DISTANCE OF THE MOON FROM THE EARTH IS THE MOST IMPORTANT FACTOR.

2. THE SECOND MOST IMPORTANT FACTOR IS THE POSITION OF THE ECLIPSE ON THE GLOBE, AND THE CLOSER TO THE EQUATOR THE BETTER .

3. TIMING OF THE ECLIPSE IS THE THIRD IMPORTANT FACTOR. THE CLOSER TO THE LOCAL NOON TIME THE BETTER. IN OTHER WORDS THE OBSERVER MUST BE LOCATED AS CLOSE TO THE GREATEST ECLIPSE POINT AS POSSIBLE.

4. THE DISTANCE OF THE EARTH FROM THE SUN IS THE LAST FACTOR FROM THE POINT OF VIEW OF THE INFLUENCE ON THE DURATION OF THE ECLIPSE. THE FARTHER TO THE SUN THE BETTER.

A few words should be said here, about the area of the eclipse on Earth. The zone of totality is the area, where the total eclipse can be observed. Typically the area is around 100 km across, but very long, up to many thousands kilometers. The zone of totality can be close to 300 km in width for the very deep eclipse (however for eclipses close to the pole the area of totality can be wide because of the projection on the globe). Within the zone of totality the eclipse is called central, on the very axis of the zone of totality. The farther from the line of the central eclipse, the shorter the eclipse, however it is still a total one. Outside of the area of totality the eclipse also takes place, however it is a partial eclipse. The partial eclipse is visible in quite a large area on the globe. Unfortunately there is a big difference between the total eclipse and the partial one. During the partial eclipse, only a part of the Sun is eclipsed, and visually it looks like nothing, when compared to the total eclipse.

Some eclipses are called partial, for the simple reason that the area of totality is outside of the globe, and no matter where on Earth , only partial eclipse can be observed.

For the annular eclipse (mentioned earlier) the situation is similar to the total eclipse. There is a special zone of annularity, and from this area the disk of the Moon, can be seen with the disk of the Sun in the background. Of course there is no zone of totality in such a case. Same as in the case of the total eclipse there is a central eclipse, on the very axis of the zone of annularity, and the farther from the axis (inside the zone of annularity) the shorter the annular eclipse is. Outside the zone of annularity only partial eclipse can be observed, the same like outside of the totality zone.

The last type of the eclipse is the so called hybrid one (4% of all total and annular eclipses). In this case we have a mixture of the total eclipse and the annular one. Typically the middle zone of the eclipse, is the total eclipse zone, while on both sides of a few thousand kilometers long area there are zones of annularity. This type of eclipse is very interesting, since the size of the apparent Moon is almost exactly equal to the size of the apparent Sun, and Sun rays shining through mountains on the edge of the Moon can be observed. On the other hand such an eclipse is a very short one, and also does not happen very often. This type of eclipse took place two days after the sinking of “Titanic” on 17th of April 1912, I will say a few more words about that in the next chapter.

Eclipses of the Sun, and also eclipses of the Moon can be predicted based on the mathematical theory of the eclipses. This looks like a contradiction to the title of this chapter, which suggests that they are random. There is no contradiction. In the case of the gambling machine, the result can be predicted also. All we need to know is the interior of the machine, and the physical rules that govern the rotating disks. As long as we do not know that, it looks like with every “draw” we have a random result. The same is true for eclipses. There are rotating “disks” like the Moon (around the Earth), the Earth (around the Sun), the Earth around its own axis of rotation. Additionally we have the observer that can be placed randomly anywhere on the globe. The result of our “draw” looks random for the observer, as long as the observer is not a knowledgable astronomer equipped with the tools of the modern world. Of course every theory has its limits, and the same applies to the theory of eclipses. The farther backwards in time we calculate eclipses, the bigger is the probability of the error, and the same applies for predictions of eclipses in future.

The longest period covered with eclipse data that I have heard about, covers the period from 4000 B.C. to 3000 A.D.. This is 7000 years long period, and I will use it later in the book. Even in such a short period (in astronomical terms) of time, there are changes impacting the predictability of eclipses. Below I dedicated a few words to show how complicated the Sun-Earth-Moon system is in reality. The simplified model that I presented so far is sufficient enough, in order to understand my book. The less curious reader can go now to the next chapter.

So far I was talking about four rotating disks in our imaginary gambling machine. In reality there are more “rotating discs”, and the machine is in a sense more random. I will try to describe them briefly.

The first one is precession of the lunar orbit. The Moon rotates around the Earth, but the Sun has also something to say here. It is pulling the orbit of the Moon, trying to force it to be in the same plane as the rotating around the Sun Earth. As a result the orbit of the Moon rotates around the pole. It takes 18 years 11 days and one third of a day for one rotation. After this time the cycle of eclipses more or less repeats itself. It does not mean that eclipses will be repeated in the same place on the globe. The one third of a day that I mentioned will cause the eclipse to be shifted 120 degrees on the globe (1/3 of the arc of the circle). For the eclipse that took place close to the equator, the one from the next cycle will be more or less 1/3 of the size of the equator (40 000 km) farther. This is more or less 13 000 km, or more or less the distance between America and Asia. The cycle that I described is called Saros, and it was first observed by Babylonian astronomers. Even today astronomers group eclipses together based on saros numbers. My book is about the eclipse of 11th of July 1991. This eclipse belongs to saros #136. The matching one from the same saros took place on June 30th 1973 and it was visible on Atlantic Ocean, Central Africa and Indian Ocean.

The rotating Earth is perturbed by combined forces of the Moon and the Sun. This is the famous precession that is causing the movement of the pole in the sky. The influence of the Moon is more or less twice as big as the one from the Sun. It takes 26 thousand years for one rotation. Only a few thousand years ago the star Polaris was far from the pole in the sky. Another star was called “polar star” for example in ancient Egypt.

Associated with precession is nutation. Its period is equal 18.6 years, and it is forcing the movement of the poles. As we know at the moment the pole in the sky is located very close to the Star Polaris. It is located less than one degree from this star. Nutation moves the real pole in the sky close to nine arcseconds from its average location (one degree contains 3 600 seconds), so it is very minimal effect.

The speed of the Moon on its orbit goes through cyclical variations, and the average period is equal approximately thirty years. At the moment we are in the area of increasing speed.

Another interesting fact is the escaping from the Earth Moon. Yes, this is correct, the Moon is escaping form the Earth, but fortunately very, very slowly. As a result the average distance to the Moon is being increased by 3.8 centimeters (around 1.5 inches) for every year. The reason for that is the export of the energy from rotating Earth to the Moon. This is done with help of tides on Earth. The other part of this process, is the fact of slowing down of the rotation of the Earth. Yes, the day is getting longer and longer, and the average speed is equal around 16 seconds for every million years. This means that the dinosaurs had the day shorter by more or less one hour.

There are also periodic changes in eccentricity of Earth’s orbit. Sometimes the orbit is more circular, sometimes less. The influence of other planets is one of the reasons for this process. The average value of 0.017 of the eccentricity is changed with the amplitude of 5%, during the period of 100 000 years, and is believed to be one of the factors responsible for passed ice ages on Earth.

The obliquity of the Earth is equal 23.5 degrees. This value is also periodically changed with the amplitude equal 1.5 degrees. It takes 41 000 years for one full cycle. Since the existence of the obliquity is responsible for seasons on Earth in the first place, it is easy to imagine that the higher the value the more heat is the Earth receiving from the Sun (melting of polar caps), as a result it is directly impacting the ice ages.

The north and the south poles are not still in the same place. They move on the Earth with the amplitude of 3 -15 meters, and a period from 12 to 14 months. This is due to weather changes on the globe. Melting of snow, and internal movements of mass inside the Earth are the factors here, but probably not the only factors.

Random events, like say the Moon being hit by a small asteroid, or the Earth being hit by a comet or asteroid are much harder to take into account. It is easy to imagine potential influence of these events in a long run.

I hope that the curious reader that decided to read this chapter to the very end, now has the overall picture of how complex the Earth-Moon-Sun system is. Considering all factors that I described so far, I would not risk personally prediction of eclipses for say one hundred thousand years. As far as I know so far nobody tried to calculate eclipses for such a long period. For the seven thousand years long period (the data that I use in my book) probably we can say that the error in predictions is small with the high degree of confidence.

Seven thousand years of calculated eclipses is the longest period that the author of this book knows about (year 1999).