Through the looking glass, and what Alice found there,

- L. Carroll.

3. THE ECLIPSE OF ECLIPSES.

Why do eclipses happen ? I guess the reader knows that now, from the previous chapters of this book. The Sun's size in the Earth's sky is more or less equal the Moon's size. More or less, that is on average the difference in sizes is around 2% of the size of the Moon's disk . To be more exact the Sun is typically bigger. Because of that, more often we have annular eclipses, than the total ones. The annular eclipse is not very spectacular, the remaining narrow rim like edge of the Sun is enough bright, so that the day light is almost not impacted. I was lucky to observe such an eclipse on May 10th 1994 in downtown Toronto. It was interesting but not exciting.

The real eclipse show is the total eclipse of the Sun. Against all odds, I was lucky enough to experience such a show in Mexico, one hundred kilometers south from La Paz on Baja California. The eclipse called then the big eclipse took place on July 11th 1991. For sure it was worth the money, that I paid for the plane ticket and accommodation down there. Indeed the night-like seven minutes, took place around the local noon. It was possible to see bright stars, and the brightest planets at noontime. However the most striking experience that I will never forget was this applause, and people clapping after the "show". Hearing that, it was very difficult not to think that there is an author of the show behind the scene, and that the author will come to the stage soon, to say a few words of explanation and interpretation. This did not happen, the show was over, and people went home. Among these people was also the author of the book. The feeling that somebody was indeed behind the scenes, stayed with me for years. Is there really an author of the show ? If the answer is yes, what is the intention of the "show" ? As I said earlier, a few years were supposed to pass before the answer could have been formulated.

Why the eclipse was called big ? The answer would be, because of two different reasons. First of all the eclipse was long. The theoretical maximum for the length of the eclipse is around 7 minutes and 30 seconds. This of course, as typically with all similar theoretical things never happens. In reality eclipses with the duration of around seven minutes are considered big, since they are very rare. How rare ? The next eclipse longer than the eclipse that took place in Mexico, will take place in the year 2132. Probably 141 years of waiting time for the next longer one, is partly the justification for this book. The second reason for naming the eclipse big, is its depth (1.080). The so called ratio factor tells us how deep the eclipse is. The factor describes how big is the apparent Moon in the sky in comparison to the apparent Sun. For example 1.000 means that the sizes are exactly matching each other, while the maximum possible 1.082 tells us that the diameter of the Moon in the sky is by 8.2% bigger than the Sun's diameter. Why the depth or in other words high value of the ratio factor is important ? It is easy to imagine that the more the Sun is hidden behind the Moon the darker it is during the eclipse, and that is what the eclipse is about. It is supposed to be very dark, like during the night. Another important factor is, how fast the "night" falls during the eclipse. It is also easy to imagine that the deeper the eclipse the faster the "short night effect" will be reached. Also the deeper the eclipse the more people can see it, since the zone of the total eclipse on the globe is bigger. The conclusion is that depth of the eclipse is very important. What is more important the depth or the total time ? I would say that both things are important for the "show" to be a good one.

There is also one more factor that describes the quality of the eclipse. It is called GAMMA, and tells us how symmetric is the placement of the eclipse on the globe. The value of this factor equal zero means that the symmetry is absolute, so the geometric center of the Sun, the center of the Moon and the center of Earth are placed in one line during the moment of the greatest eclipse.

THE COMPLETE LIST OF VERY LONG TOTAL SOLAR ECLIPSES
(DURATION LONGER THAN 6 MINUTES AND 52 SECONDS)
FROM 3000 B.C. TO 4000 A.D.

YEAR	LOC.	DU.	DEP.	GAM.	YEAR	LOC.	DU.	DEP.	GAM.	YEAR	LOC.	DU.	DEP.	GAM.
-2602	12.5S	7.03	1.079	0.452	-425	2.5 N	7.12	1.078	0.244	1937	9.9 N	7.04	1.075	0.225
- 2584	4.8S	7.17	1.079	0.378	-407	9.6 N	7.13	1.078	0.170	1955	4.8N	7.08	1.078	0.153
-2566	2.1N	7.20	1.079	0.307	-389	16.1N	7.04	1.077	0.095	1973	18.8N	7.04	1.079	0.079
- 2548	8.3 N	7.14	1.078	0.238	114	4.7 N	7.06	1.075	0.266	**1991**	**22.0N**	6 53	**1.080**	**0.004**
- 2530	3.4N	6.58	1.075	0.175	132	11.1N	7.14	1.077	0.191	**2132***	**22.3N**	6.55	1.079	0.018
- 2266*	7.4 S	7.10	**1.082**	0.242	150	16.6N	7.12	1.079	0.117	**2150***	8.3 N	7.14	**1.080**	0.091
- 2248*	0.7N	7.20	**1.082**	0.168	168	21.4N	7.02	1.079	0.042	**2168***	13.2N	7.26	**1.081**	0.166
- 2230*	8.7N	7.21	**1.082**	0.092	**327** *	20.4N	7.03	**1.081**	0.044	**2186***	7.4N	7.29	**1.081**	0.239
- 2212*	16.1N	7.12	**1.081**	0.019	**345** *	16.9N	7.17	**1.081**	0.118	2204	1.0N	7.22	1.079	0.313
- 2194*	**23.1N**	6.55	1.079	0.055	**363** *	12.6N	7.24	**1.080**	0.192	2222	6.0 S	7.06	1.077	0.383
-1478	12.8N	6.57	1.078	0.160	381	7.5 N	7.22	1.079	0.263	2486	1.8 N	6.59	1.076	0.358
-1460	0.1N	7.04	1.078	0.232	399	1.9 N	7.11	1.076	0.331	2504	1.8 S	7.10	1.077	0.427
-1442	6.6 N	7.05	1.076	0.299	468	20.3 N	6.56	1.079	0.049	2522	6.6 S	7.12	1.077	0.498
-1424	2.5 N	6.57	1.074	0.362	**486 ***	**27.1 N**	6.54	**1.081**	0.121	2540	12.4 S	7.04	1.076	0.572
-1355	16.0N	6.53	1.079	0.080	663	3.3 N	6.56	1.079	0.284	2849	9.1 S	7.00	1.075	0.532
- 1142*	4.0 S	6.56	**1.081**	0.380	**681 ***	1.1 N	7.09	**1.080**	0.356	2867	4.1 S	7.10	1.077	0.463
- 1124*	6.1 S	7.03	**1.080**	0.454	699	2.3 N	7.16	1.079	0.431	2885	0.0 S	7.11	1.078	0.391
-1106	9.3 S	7.03	1.079	0.529	717	6.6 S	7.15	1.078	0.792	2903	3.3 N	7.04	1.078	0.319
-1088	13.3 S	6.55	1.076	0.602	735	12.0 S	7.02	1.076	0.505	3655	11.6 N	6.55	1.077	0.033
- 779	13.6 S	7.12	1.079	0.544	1044	11.0 S	7.12	1.077	0.552	3673	4.0 N	6.55	1.077	0.105
- 761 *	6.6 S	7.26	**1.080**	0.470	1062	5.2 S	7.20	1.078	0.478	3955	12.9 N	6.58	1.075	0.169
- 743	0.4 S	7.28	1.079	0.397	1080	0.1 S	7.18	1.078	0.404	3973	7.5 N	7.12	1.077	0.240
- 725	4.8 N	7.18	1.078	0.325	1098	3.8 N	7.05	1.077	0.331	3991	1.2 N	7.18	1.078	0.310
- 707	8.9 N	7.00	1.075	0.257	1398	7.8 N	6.59	1.074	0.229	*extracted from data calculated*				
- 443	4.9 S	7.01	1.077	0.316	1416	13.5N	6.56	1.074	0.158	**by Fred Espenak NASA/GSFC.**				

LOC. - LOCATION (LATITUDE), **DU.** - DURATION OF THE ECLIPSE,
DEP. - DEPTH OF THE ECLIPSE, **GAM.** - GAMMA FACTOR (SYMMETRY).

The list shows all eclipses longer or equal to the eclipse 1991.07.11. The list contains 73 eclipses for a 7000 years long period of time. It is easy to observe that this long eclipses happen one time in a century on average. Eclipses are concentrated in groups from one to six in every group. In every group intervals between eclipses are equal 18 years. Every group represents a few longest eclipses from the same Saros. Saros is related to precession of the lunar orbit (I explained that briefly in the first chapter). There are nineteen groups of different Saroses. Intervals between groups look irregular ranging from 69 years to 752 years. Only three eclipses from the list, took place farther from the equator than the eclipse of 1991. These eclipses are marked (''). 15 eclipses that are deeper or equal in depth to the eclipse of 1991 are* also marked. *Majority of eclipses concentrate very close to the equator (low value of geographical latitude, either south - 'S' or north 'N'), since the higher the latitude, the lower the probability of the long eclipse (it was explained in the first chapter of the book). Please observe all record holders (max. latitude 27.1N - 486, max. depth 1.082 - -2266,-2248,-2230, max. duration 7.29 - 2186, min. GAMMA 0.004 -* ***1991 (!)*** *).*

GAMMA equal one or more would mean that the line "center of the Sun-center of the Moon" would pass outside of the Earth's globe. In other words this tells us how far from the center of the Earth the axis of the eclipse is positioned (measured in radii of the Earth). One can say that it tells us how precisely the Earth was hit by the shadow of the Moon. For example value 0.1 would mean around 670 km from the center of the Earth (0.1 * 6700 km). GAMMA has also a sign ('+' or '-') indicating the direction, but for the purposes of the book it is not important, so I ignored it.

In the table I listed data for all eclipses longer than the 1991 eclipse. I will try to convince the reader now, that in spite of the fact that from the table it looks that this long eclipse happens once every 100 years on average, the 1991 eclipse was much more unique and precise. Please look at the table and read the description of details. We want somehow to measure the quality of the eclipse. I mentioned a few factors that must be taken into account. We can analyze every factor separately, and then create a total score that would be an average score for all factors. It is like in sport. Say triathlon, where the total score is a combination of three different scores from three different fields (swimming, biking and running). Let us analyze the factors one by one then.

First of all one can see that in 20th century we had three other eclipses that were longer than the "eclipse of eclipses" (1937, 1955, 1973). All three eclipses however, were very close to the equator, and that is the only reason why they were longer. I explained earlier in the book, that the closer to the equator the more the rotating Earth is "helping" the eclipse. The observer on the rotating Earth is following the escaping shadow of the Moon, and the closer to the equator the bigger the speed. As a result the observer stays in the shadow of the Moon longer. All three eclipses were longer but shallower that the 1991 one (depths : 1.075, 1078, 1079 while 1991 one is equal 1.080). Please observe that the eclipse longer and at least as deep as the EE (eclipse of eclipses) did not take place for the last 1310 years (!). The eclipse of 681 A.D. is the one that I am talking about. Longer and deeper eclipse took place last time in the year 486 A.D. (1505 years ago). The future looks brighter. The eclipse longer and equal in depth will take place in the year 2150 (159 years), and deeper and longer one in the year 2168 (177 years). There are a total of 10 eclipses longer and deeper than EE (depth 1.081 or 1.082) . In addition there are a total of 5 eclipses that are as deep as my eclipse and longer (depth 1.080). So 15 eclipses during the 7000 years are longer and deeper or equally deep to the eclipse of 1991. Our 1991 eclipse is positioned as #16 (for the total of 73 "competitors " that qualified to the final in the preliminary contest "very long duration").

The theoretical maximum for the eclipse is seven and a half minute; however this is for the equator. If we go closer to the pole (either south or north pole), the maximum time limit is shorter. On the pole it is only around four minutes, and for every geographical location on the globe between the equator and the pole, it is more than four minutes, and less than seven and a half. The fair judgement of the eclipse greatness, should be also related to the position of the eclipse, since it is almost as rare to have a four minute eclipse on the pole, as it is for the seven and a half minute long one to take place on the equator. How big was the 1991 eclipse, from this point of view ? The eclipse for the geographical latitude 22 degrees north, where the very center of the EE was located, was extremely rare, with its 6m 53 sec. of duration time. I find it hard to believe, but longer eclipses farther from the equator than 22 degrees (north or south) , happened during the last 5000 years only two times ! There was an eclipse in the year -2194, and there was an eclipse in the year 486 A.D.. The same thing for the next 2000 years, only one time in the year 2132 the eclipse will be longer, and will take place on 22.3 degrees north from the equator. So in the "sport" called difficult geographical location our eclipse is positioned as #4 (again for the total of 73).
(Please note that there is only one eclipse (!) in the table that is farther from the equator, longer and deeper than the '91 EE. I am talking about the eclipse of 486 A.D.).

The last “sport” is the symmetry of the eclipse (GAMMA factor). This is important because the more symmetric the eclipse the longer the zone of totality, and theoretically more people can see it. It has also a symbolic meaning, please think about it, it tells us how precisely the Sun, the Moon and the Earth are in one line (!). Let us look at the table. The lower the value of GAMMA the better. What do we see ? There is not a single eclipse with GAMMA lower than 0.004, and the winner is ... the eclipse of 1991! In this “sport” our eclipse “outclassed” other eclipses. The second “competitor” (eclipse of 2132) has a value of 0.018, and that is almost five times more ! This is a “knockout in the first round” ! Let me calculate it. GAMMA equal 0.004 means that the center of the Earth was only 27 km from the line “center of the Sun- center of the Moon” during the greatest eclipse. Our eclipse is NUMERO UNO (this means number one) in this “sport”. The global map of the eclipses that I present in the book looks so perfectly symmetrical thanks to GAMMA equal 0.004. Let us go back to the main question. How rare was the eclipse ? As I described it above everything depends on how we look at the eclipse. Our eclipse in three different “sports” was classified as # 16, #4 and finally #1. The average score is #7, for seven thousand years of eclipses.

THE ECLIPSE THAT TOOK PLACE ON JULY 11th 1991 WAS VERY LONG, VERY DEEP AND VERY, VERY SYMMETRICAL. ON AVERAGE IT IS ONLY ONE TIME FOR EVERY THOUSAND YEARS FOR SUCH A LONG, DEEP AND SYMMETRICAL ECLIPSE TO TAKE PLACE FOR THE LATITUDE CLOSE TO THE TROPIC (NORTH OR SOUTH).

It is nothing special mathematics shows that this can happen, however there is much more to come, so please be patient. Typically the area where the total eclipse can be observed is a few thousands kilometers long, but only one or two hundred kilometers wide. The bigger the eclipse the wider is the area of the so called zone of totality. For the 11th of July eclipse, the maximum width of the eclipse was equal approximately 250 km. The most shocking thing for me, was the way the eclipse path was placed on the globe. Typically eclipses are placed randomly on the globe. They can happen everywhere where the Sun is able to shine. Some areas are more lucky, some are less, however in a long run it is just random. The eclipse of eclipses does not look random at all. It started on the Pacific Ocean, passing later over the Hawaii Island, and here is the thing that makes it not random. The very axis of the eclipse, that is the middle line of the zone of totality, passed almost precisely over the peak of the Mauna Kea dormant volcano. Nothing special one can say, the eclipse can pass on top of any mountain, anywhere. True, however Mauna Kea is the biggest mountain on Earth, that is more than 10 km from the bottom to the top. Of course it is not the highest, it is even not very high compared to other peaks. The peak is only 4205 meters high, and that is not much. It is enough however for the purpose of astronomy. The exceptionally good “seeing conditions” on top of the mountain, are the reason why many huge telescopes are located there. This high, most of the water vapor is below, on average 60 percent of the water is below, and only 40 % above. Water is the enemy of so called infrared astronomy, and this is why the higher the telescope is located the better. Many infrared telescopes found their home on the top of Mauna Kea. At the moment Mauna Kea is the biggest concentration of astronomical telescopes on Earth. Still the biggest telescope in the world, the Keck Telescope is located there. Now there are two Keck Telescopes, it is the so called twin telescope. On July 11th 1991, there was only one Keck Telescope there, and it was the biggest in the world at that time. The eclipse passed over the biggest telescope in the world. That must have happened before, there is always somewhere in the world the biggest telescope, and since the eclipse can happen anywhere, it can also happen above the biggest telescope

Total Solar Eclipse of 1991 Jul 11

Geocentric Conjunction = 19:06:11.3 UT J.D. = 2448449.295964
Greatest Eclipse = 19:06:04.7 UT J.D. = 2448449.295887

Eclipse Magnitude = 1.07997 Gamma = -0.00444

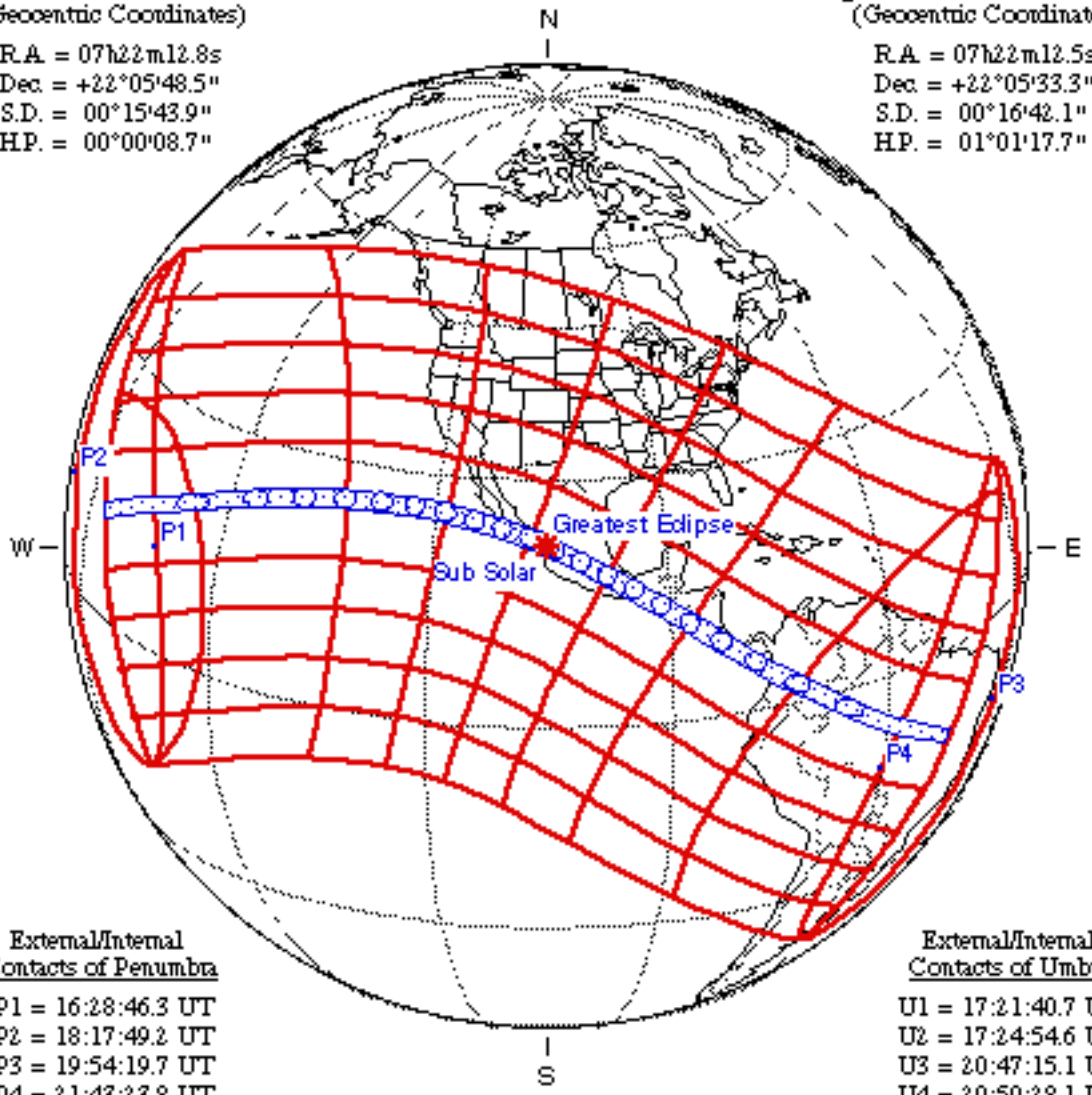
Saros Series = 136 Member = 36 of 71

Sun at Greatest Eclipse (Geocentric Coordinates)

R.A. = 07h22m12.8s
Dec. = +22°05'48.5"
S.D. = 00°15'43.9"
H.P. = 00°00'08.7"

Moon at Greatest Eclipse (Geocentric Coordinates)

R.A. = 07h22m12.5s
Dec. = +22°05'33.3"
S.D. = 00°16'42.1"
H.P. = 01°01'17.7"



External/Internal Contacts of Penumbra

P1 = 16:28:46.3 UT
P2 = 18:17:49.2 UT
P3 = 19:54:19.7 UT
P4 = 21:43:23.8 UT

External/Internal Contacts of Umbra

U1 = 17:21:40.7 UT
U2 = 17:24:54.6 UT
U3 = 20:47:15.1 UT
U4 = 20:50:28.1 UT

Local Circumstances at Greatest Eclipse

Lat. = 21°59.0'N Sun Alt. = 89.9°
Long. = 105°13.1'W Sun Azm. = 27.6°
Path Width = 258.0 km Duration = 06m53.1s

Ephemeris & Constants

Eph. = Newcomb/ILE
ΔT = 58.0 s
k1 = 0.2724880
k2 = 0.2722810
Δb = -0.6" Δl = 0.0"

Geocentric Libration (Optical + Physical)

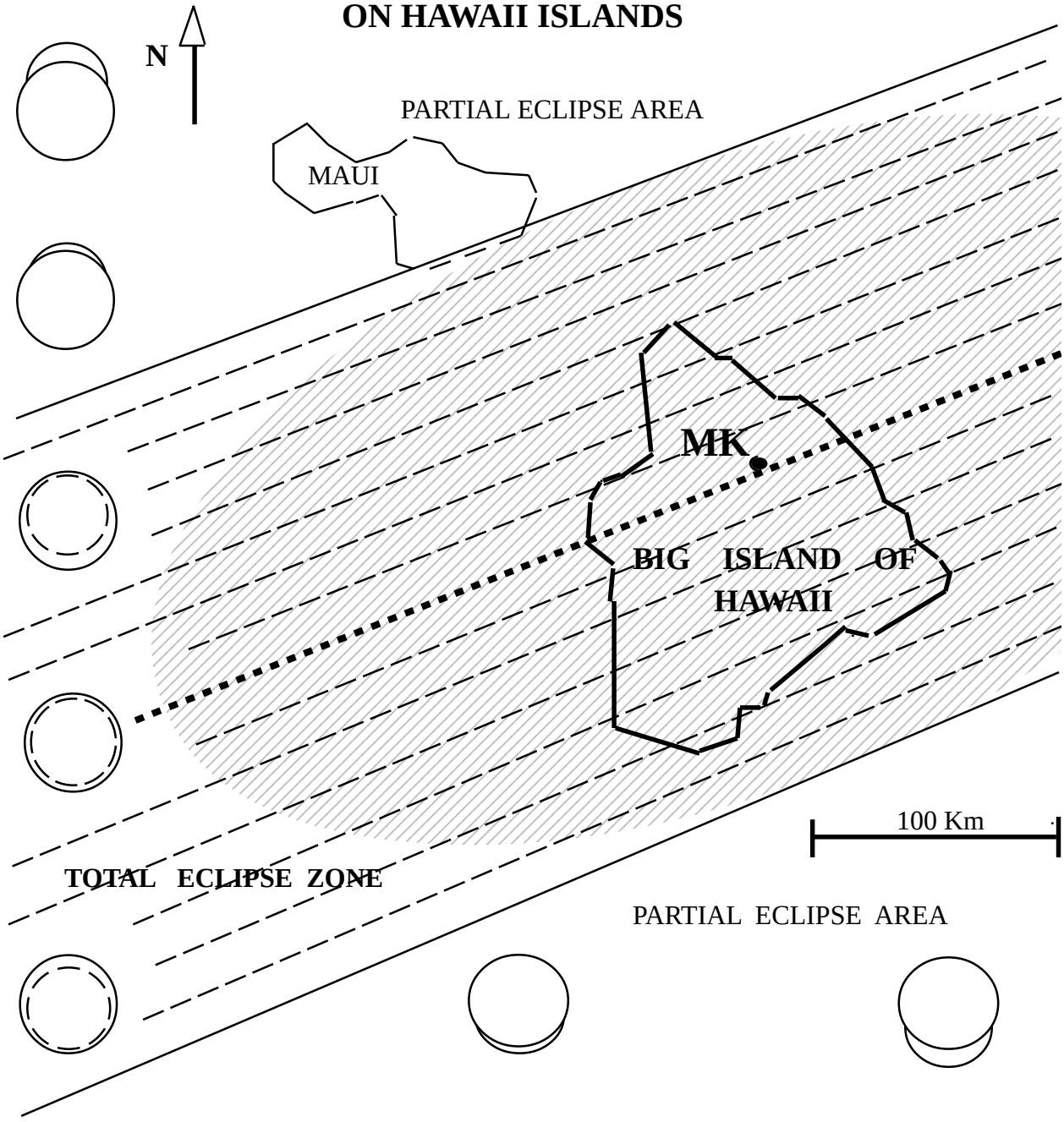
l = 0.88°
b = 0.01°
c = 6.52°

Brown Lun. No. = 848

F. Espenak, NASA/GSFC - Thu, 1999 Jun 03

empty

THE TOTAL ECLIPSE OF THE SUN 11th OF JULY 1991 ON HAWAII ISLANDS



The drawing shows schematically the eclipse on the Big Island of Hawaii. As you can see the eclipse passed on top of the Mauna Kea (MK) mountain, where the biggest concentration of astronomical observatories in the world is located. The center line passed a few kilometers south from the observatories. The eclipse was also visible, from the southern portion of the Maui Island, however it was only seconds long. The big ellipse in the zone of totality, shows the shadow of the Moon on Earth, at around 7.31 in the morning local time on 11th of July 1991.

Small circles on the left side and at the bottom of the drawing, show relative positions of the Moon and the Sun, as visible from the given area at the maximum local eclipse time.

As I said before the area is sometimes 200 km wide and a few thousands kilometers long. On average the total eclipse of the Sun on a given point on Earth, takes place approximately once every hundred years (I take this high value, other sources say that it is as rare as one time in 360 years !) The hit was very precise, though. The very center of the eclipse zone, that is the axis of the zone of totality passed directly over the top, only around three to four kilometers south from the biggest observatory in the world. What are the odds ? Once every hundred years the eclipse passes over a given point on Earth on average. The average width of the zone of totality I would estimate to around 100 km. The minimum is zero and the maximum is more than 200 kilometers, so on average the typical zone of totality is 100 km in width. The hit was very precise, only three to four kilometers, say it was only four. Since it could have been north or south from the center line, say it fits in the zone only 8 kilometers across. Say it is as much as 10 kilometers to make the calculations easier, and to be away from speculation with facts. Still, 10 divided by 100 is one tenth, looks like such a precise hit, happens once every thousand years. The fact is that the eclipse passed over the biggest telescope on Earth. One thousand years ago there was no telescopes, agreed ? The conclusion is that this happened only one time so far, probably.

THE ECLIPSE OF ECLIPSES PASSED PRECISELY OVER THE BIGGEST TELESCOPE ON EARTH (LOCATED ON THE LARGEST MOUNTAIN ON EARTH AND ALSO THE HIGHEST MOUNTAIN ON PACIFIC OCEAN), AND THE ODDS FOR THAT TO HAPPEN ARE ONE TIME IN THOUSAND YEARS.

Let us multiply, thousand (from the greatness of the eclipse) and thousand (from the precise location hit) that is ONE TIME IN A MILLION YEARS. Just the coincidence you would say , but your conscious mind at this stage probably noticed the first “wave of doubts”, either the guy is lying you say, or this is too far going speculation on facts. I am afraid that none of these is true. There is still more to come, actually the best part is yet to come, so please be patient.

The biggest observatory on Earth, the brightest astronomers working there you would say. Is it possible that the fellows up there could have missed something ? No way you would say, they have the best equipment in the world, they are “today’s priests at the altar of science”, very high at the top of the mountain, almost like gods on Olympus Mountain. The fact is, that there is not enough oxygen in the air at the top of Mauna Kea, and some people experience hallucinations there. I was never there, I hope one day I will go. The name Mauna Kea means white mountain, simply due to the fact that the peak is snow covered for a few months in the year. Even skiing is possible on the very top. During the last few years a few new technology telescopes were constructed there. Among them the SUBARU telescope (Japanese name for Pleiades), the Gemini telescope, and the second Keck (twin) telescope. All telescopes that I listed here, were added there after the eclipse in 1991. At the time of the eclipse, the original Keck telescope was the ruler of the mountain. There were also other telescopes on the top, but not as big as the Keck telescope. There was and still is United Kingdom infrared telescope, the Canada-French-Hawaii telescope, the University of Hawaii telescope, and NASA telescope (total of 8 big telescopes - world record !). Astronomers in the PBS TV series “The Astronomers” , named the Keck telescope “the king of the mountain”.

In order to say more about the “eclipse of eclipses” we must go back in time. We must go to the year 1930. Astronomy in the year 1930 was a different kind of astronomy. The “king of the mountain” was 100 inch telescope on top of Mt. Wilson in California. In the year 1930 there was not a single big telescope on top of Mauna Kea, construction of the first big astronomical observatory on top of the white mountain on Big Island of Hawaii started around 1970. Of course there were no computers and CCDs (CCD stands for charged coupled device used for the electronic way of taking pictures), and the astronomical research was being done using photography.