Reliability of the totality of the eclipse in AD628 in the Nihongi

Kiyotaka TANIKAWA and Mitsuru SÔMA
National Astronomical Observatory
Mitaka, Tokyo, 181-8588, Japan

Abstract

It is generally accepted that the solar eclipse on April 10, AD628 (the reign of Empress Suiko, 36th year, 3rd month, second day) recorded in the Nihongi is not total but partial though it is written as a total eclipse. We argue for the record appealing to the total or near total eclipses in Chinese history books and a Japanese occultation observation. If the value of the tidal term in the lunar longitude(the coefficient of T^2 term) is different from the present value by about $-2''/\mathrm{cy}^{-2}$, then there disappears an apparent contradiction of ΔT around AD600 derived from lunar and solar eclipses. Grazing occultation data are found to be useful.

1. Introduction

(推古三十六年) 三月丁未朔戊申, 日有蝕盡之
(The reign of Empress Suiko, 36th year,) 3rd month starting at *Dingwei*, second day *Wushen*, there was a total eclipse of the Sun.

We find this record in the Nihongi, the oldest history book in Japan. Though the expression is a little out of the Chinese rule of recording solar eclipses, this clearly shows that there was a total eclipse on that day. Indeed, usually the expression total(既) is used. Here, 'exhausted'(盡) is used. We find this expression in case of lunar eclipses. For example, we find 'exhauted lunar eclipse'(月蝕盡) in the record of (Beishu)Taihe, 12th year, 9th month, day *guisi*(AD488). According to calculation[1], there actually was a total eclipse on the Earth. This was April 10, AD627 in the Western Julian calendar. Our problem is whether the zone of totality passed the Japanese Islands or not.

1.1. Importance of the Eclipse

1.1.1 The first astronomical record in the Nihongi

This is the first formal record of solar eclipse in the Japanese history. We have a famous record in the mythological age of the Nihongi which is usually interpreted as implying the observation of the total solar eclipse: 'At this time, the DayGoddess ... went into a rocky cave and shutting herself up'(是時, 天照大神..., 入于天石窟, 閉磐戸而幽居焉).

1.1.2 An important epoch in the Japanese History

We see the rise and evolution of Japan in Chinese chronicles. Japan has been described in WèiZhiWoRenZhuan(魏志倭人伝) in the third century, in SongShuWoGuoZhuan(宋書倭国伝) in the fifth century, and in SuiShuTuoGuoZhuan(隋書倭国伝) in the seventh century. We understand that Japan grew gradually and apparently in these centuries. Finally, Woguo(i.e., ancient Japan) declared independence in the sovereign message(国書) in third year of Daye(大業三年, AD607)[2].

The King Tarishihoko sent messengers to greet the (Chinese) Emperor. ...
The sovereign message said that the son of heaven at the rising Sun
sends a letter to the son of heaven at the sinking Sun with compliments.
The Emperor said “this barbarian letter is impertinent.
Never bring this kind of letter to me.”
其王多利思北孤, 遣使朝貢. ...
其国書曰, 日出処天子致書日没処天子無恙.
帝覧之不悦, ..., 蛮夷書, 有無禮者. 勿復以聞.

What is the meaning of independence from China? To mimic the political system of China. It seems to the authors that the independent nation must do the following things:
(1) to make laws;
(2) to standardize the units of weight, length, time;
(3) To make a calendar system;
(4) To record important events.

The first three items are indispensable for a nation to keep its integrity. We everyday talk about future, contracts, etc. The fourth item symbolizes the integrity of a nation toward the time axis. A nation becoming independent first adopt chinese systems and then adapt these to its own. Sometime in China, there were more than one empires. In this case, the system introduced to a newly independent nation may depend upon power politics surrounding China.

China, from its really ancient past, recorded solar and lunar eclipses and various other astronomical phenomena in its history books. These records were important in view of items (3) and (4) above. The first day of the month should be the new moon in the calendar system which adopted Dingshuo(定朔). If this does not the case, the calendar system had to be changed. To change the system, we need a long-term accumulation of observational data. The independence requires this accumulation. Did Wōguo(倭国) already have this in 607? We do not know. Did Woguo have an intention to have this? Yes. Woguo started various kind of observations sooner or later[3]: comet(AD634), meteorite(AD637), lunar eclipse(AD643), mutual phenomea of the moon and stars(AD640), planetary pehnomena(AD692), stars in the daylight(AD702).

Japanese original calendar system started as late as 1685 when Shunkai Shibukawa introduced the European idea. Until this Japan constantly used the Chinense calendar adapted to Japan[4].

1.1.3. Long-term variations of Earth’s spin and Moon’s orbital motion

At present, the moon is known to recede from us at a rate several(3.8) cm/year. We do not know whether or not this rate has been constant. Similarly, the spin rate of the Earth has been changed in the past several decades. However we do not know its change rate in the past few thousand years.

We do not have an appropriate theory to answer above questions. More precisely, to follow the rotational motion of the Earth for one thousand years, taking into account the existence of the sea, atmosphere, mantle, liquid core under the influence of the Moon, Sun and other planets, is a tremendous task. Even at present this is one of the most difficult scientific problems to solve.

Ancient astronimcal records give us unique opportunity to determine the Earth’s spin and the orbital motion of the Moon.

1.2. Conventional views to the eclipse

According to Conventional views, the total eclipse record in the Nihongi of Empress Suiko is an exaggeration[1,8,9]. Let us cite the comment of Uchida[8] as a representative: “There is an assertion that the calendar systen was already adopted at that epoch because of this record. I do not agree with this opinion. In this eclipse, the deepest eclipse took place at Asuka just before nine thirty in the morning. The largest magnitude was more than 0.9 but less than one. Although the eclipse was not total, if magnitude became greater than 0.9, then the temperature went down and the surrounding atmosphere became unfamiliar. This is a conspicuous phenomenon without any public prediction. So the record might have been the actual record of observation of amateur. Then the record is not related to the adoption of a calendar system[8, p.525].

This view has strong support. It is generally accepted that $\Delta T = 4000$sec at around AD600. In this case, The zone of totality the Suiko eclipse passes through the pacific Ocean. Another support is the unreliability of the ancient eclipse records. Indeed, Some of the the records in Chinese Chronicles are not reliable. This is the case especially in the total eclipse records. We will later come back to this point.

There are comments from over sea.

Stephenson[10, p.267]: 'The recorded date proves to be in accurate accord with that of a computed solar eclipse. Although the obscuration of the Sun was said to be total, further description is lacking, so that I have included the observation in the lowest category. It is noteworthy that event does not seem to be linked in any way with the Empress' death by the chronicler(unlike several similar occurrences in China – see above)'.

Steele[11], 'In common with all of the other observations in the Nihongi, this record is not very detailed. No times are ever recorded for any of the eclipse records in this work.'

1.3. Reliability of eclipse records in ancient chinese books

Saito & Ozawa[12] checked the reliabilty of Chinese astronomical records from Chunqiu(8 century BC) to Wedai(10th century AD). The method of the check is to calculate these phenomena using the present value and judge whether these actually occured or not. Here we extract solar eclipse data from their books and make some comments.

Table I. Eclipse records and reality in Chinese chronicles[12, p.17].

Era	Number of records	Real	Probability	NE・OB	OE
Chunqiu(春秋)	37	35	95	1	1
Shiji(史記)	10	4	40	6	0
Hanshu(漢書)	61	42	69	1	18
HouHanShu(後漢書)	88	65	74	7	16
Sanguozhi(三国志)	12	11	92	0	1
Jinshu(晉書)	82	49	60	16	17
Songshu(宋書)	83	60	72	16	7
Weishu(魏書)	61	41	67	16	4
Nanqishu(南斉書)	5	4	(80)	1	0
Liangshu(梁書) } Chenshu(陳書)	10	7	70	10	0
Nanshi(南史)	35	23	66	10	2
Beiqishu(北斉書)	2	2	(100)	0	0
Zhoushu(周書)	22	7	32	15	0
Beishi(北史)	82	46	56	34	2
Suishu(隋書)・Liang(梁)	3	2	(67)	1	0
Suishu(隋書)・Chen(陳)	1	0	0	1	0
Suishu(隋書)・Qi(斉)	1	1	(100)	0	0
Suishu(隋書)・Zhou(周)	10	2	20	8	0
Suishu(隋書)・Sui(隋)	8	3	(37)	5	0
Jiutangshu(旧唐書)	99	69	70	25	5
Xintangshu(新唐書)	93	66	71	25	2
Jiuwudaishi(旧五代史)	20	15	75	5	0
Xinwudaishi(新五代史)	18	14	78	4	0

Saito & Ozawa[12] compiled all the solar eclipse records in Chinese chronicles starting from Chunqiu to Wudai and calculated the rate of reliability of the records. They give Table I[12, p.17]. In their Table, the third column shows the percentage of the real solar eclipses among the predicted or recorded.

The first thought looking at this table is that the probability of success of prediction does not go up with time. There, of course, is a reason. Before explaining the reason, let us define the terminology. We have three different terms: NE(night eclipse), OB(out of Eclipse zone), and OE(the eclipse zone is Out of the Earth).

Table II. Total and near total eclipses in China:
5th – 9th centuries
The third column represents the comment of Saito & Ozawa[12] and their calculation of eclipse maginitude adopting $\Delta T = 4000$ sec. The fourth column represents ours adopting $\Delta T = 2000$ without correction to the tidal term.

Year(AD) (Empire)	date phenomena	magnitude $\Delta T \simeq 4000$	$\Delta T = 2000$
453.08.20 (Song)	Yuan-jia, 30th year, 7th month, first day *Xinchou*, Solar eclipse, total, stars appeared	OB	OB
454.08.10 (Song)	Xiao-jian, first year, 7th month, first day *Bingshe*, Solar eclipse, total	0.96	0.97
516.04.18 (Liang)	Tian-jian, 15th year, 3rd month, Solar eclipse, total	0.97	0.94
522.06.10 (Liang)	Pu-tong, 3rd year, 5th month, first day *Renchen*, Solar eclipse, total	horizontal	0.97, non-horizontal
562.10.14 (Beizhou)	Bao-ding, 2nd year, 9th month, first day *Wechen*, Solar eclipse, total (Zhoushu) non-total	0.35	0.225
616.05.21 (Sui)	Da-ye, 12th year, 5th month, first day *Bingxu*, solar eclipse, total	0.90, 'total' is irrelevant	0.967
702.09.26 (Zezhou)	Chang-an, 2nd year, 9th month, first day *Yichou*, Solar eclipse, nearly total At one degree of Jiao (Jiutangshu)Solar eclipse, like a hook, seen from the capital and its vicinity	0.99	1.016
754.06.25 (Tang)	Tian-bao, 13th year, 6th month, first day *Yichou*, Solar eclipse, nearly total at 19 degrees of Dongjing, 京師分也 (Jiutangshu)Solar eclipse, like a hook	0.87	0.854
756.10.28 (Tang)	Zhi-de, first year, 10th month, first day *Xinsi*, Solar eclipse, total, At 10 degrees of Di (Jiutangshu) non-total	0.96	0.886
761.08.05 (Tang)	Shang-yuan, 2nd year, 7th month, first day *Guiwei*, Solar eclipse, total, all the bright stars appeared, at 4 degrees of Zhang (Jiutangshu)total eclipse, all the bright stars appeared	0.99	1.011
846.12.22 (Tang)	Hui-chang, 6th year, 12th month, first day *Wechen*, Solar eclipse, at 14 degrees of Nandou. (Jiutangshu) total	0.85	0.818
879.04.25 (Tang)	Gan-fu, 6th year, 4th month, first day *Gengshe*, Solar eclipse, total, at 8 degrees of Wei (Jiutanshu)No description	OE	OE

In China, from ancient times, astronomical phenomena are predicted using calendar system. Predictions sometimes hit but other times did not hit. Some predicted solar eclipse took place in the nightside of the Earth(NE), others were in the polar regions(OB) so that people in middle latitudes could not observe. Sometime eclipse shadow was out of the Earth(OE). The predictions seem to start in Qianhan era. This is a surprise to the authors.

From above observations, we can conclude that to examine the reliability of individual eclipse records is a dangerous task. We can calculate a particular historical eclipse. So at first glance, if the corresponding records are found in a history book, we are apt to believe that this was really observed. But we need to be careful. We do not know that the astronomers at that time actually observed the eclipse. It might have been cloudy. It may have been that the prediction hit. Moreover, we are not sure that our parameters are correct.

The situation is more subtle for total or near total eclipses. For almost all cases, the corresponding eclipses are real. But did the astronomers in the capital of the empire see the totality? Saito & Ozawa[12] answered to this qustion(see Table II). According to their calculations, no total eclipses in the Chinese history book from 5th to 9th century were total. "We can interpret that the eclipse was judged to be total if the magnitude is greater than about 0.5. We cannot believe the ancient records of total eclipse as total."[1]

The authors wonder: Did people in Changan or Luoyang not see any total solar eclipse during 5th and 9th century? This is one of the motivations of this work. We know an example in which the zone of totality runs parallel to latitude lines, so shifting the zone to the west or to the east does not bring the capital into the eclipse zone. The eclipse on June 25, 754 was this kind of eclipse. In this case, the record surely is an exaggeration. When the zone of totality runs transverse to the latitude lines, there is a chance to have a total eclipse in a desired place. (See section 2.1 for the reasoning of the parallel shift of the eclipse zone.)

1.4. Investigations of Stephenson[10]

Stephenson and Morrison[13] and Stephenson[10] compiled the ancient solar and lunar eclipse records of Babilon, China, Greece, Europe, and Arab and analysed each records. They fitted ΔT curves with spline curves with several nodes.

Stephenson[10, p.508] obtained $\Delta T = \mathrm{TT} - \mathrm{UT} = 5000$ sec for the period around AD600 from lunar and solar eclipses. On the other hand, solar eclipses at around AD680 give us $\Delta T = \mathrm{TT} - \mathrm{UT} = 2000$ sec as is seen in Stepenson's graph. Solar eclipses are out of the fitted spline curve. This fitted line seems to adjust to the lunar eclipses. The Japanese eclipse in AD628 is in a similar situation.

Our important question is: what is the reason for the inconsistency between solar and lunar eclipses?

2. Solar and lunar eclipses and the secular change of Earth's spin

As is well-known, solar and lunar eclispes take place when the Sun, Earth, and moon align in a line. If the orbital motion of the Earth round the Sun, the orbital motion of the Moon round the Earth, and revolution of the Earth round its spin axis are all constant, then these phenomea take place regularly or quasi-periodically. If one or more of the above motions change secularly, then the phenomena occur non-regularly.

In what follows, we study qualitative nature of the occurrence change of solar eclipses during thousands of years assuming the constancy of the orbital motion of the center of gravity of the Earth-Moon system and allowing the secular change of the orbital motion of the moon and the spin rate of the Earth.

It is to be noted here that using the modern techniques like atomic clocks and lunar laser ranging, our knowledge on the secular changes of the motion is less than 50 years for rotation and less than 40 years for the motion of the Moon. These represent instantaneous values compared with long-term trend in two or three thousand years. We cannot say that the value changed or not.

2.1. The consequence of the slowing down of the motion of the Earth and Moon

The contents of this section may be known. We add the section for completeness sake and also for the expository purpose.

It is well-known that both the spin rate of the earth and the orbital motion of the moon around the Earth slow down as time goes on. The slowing down of the spin rate is expressed as ΔT, whereas the slowing down of the orbital motion of the moon is expressed as the coefficient of T^2 in the longitude of the moon where T is the time in centuries. This term is called a tidal term.

2.1.1 No secular change

In this case, we can calculate the place, time, and duration of any eclipse in any past. This situation is not a historical fact. Anyway, if this is the case, historical astronomical data are almost useless.

2.1.2 The spin rate of the Earth slows down

We assume that the spin rate of the Earth is larger in the past and it gradually slowed down. We assume on the other hand that the orbital motion of the moon did not change. For simplicity of consideration, we assume that the spin axis of the Earth is perpendicular to its orbital plane. We sit on the north pole of the earth and wind back the time and see what happens.

We fix the past time, say to 1000 years ago and suppose there was a total solar eclipse at some place. By assumption, the orbital motion of the Sun and Moon around the Earth can be traced back theoretically. This means we know exactly at particular time of the eclipse day the Sun, Moon, and the Earth come on a line in a uniform time. The remaining problem is which part the Earth's surface is in the shadow of the Moon. This depends on the slowing down of the spin.

The spin was faster in the past. Then we need to wind the Earth more to the west than the case of constant spin. This implies that the place of the eclipse is shifted to the east compared with the prediction from constant spin.

Let TT be the uniform time and UT be the time measured by the rotation of the Earth as unit. Define

$$\Delta T = \mathrm{TT} - \mathrm{UT}$$

We adjust the clock at some time in the modern era. Then, before this epoch, UT proceeds faster than TT, that is, the value UT is smaller in the past. Consequently, we have $\Delta T < 0$ in the past. The difference of two kinds of times can be transformed to the longitude difference of the eclipse place. The Earth rotates 15° in an hour. Roughly speaking, $\Delta T = 3600$ sec is equivalent to the shift 15° in longitude.

The procedure to determine ΔT using the historical solar eclipse is as follows. Fixing the motion of the Moon to some model, one free parameter is ΔT. We adjust so as to place the observed point (usually the capital) at the west and east bounaries of the zone of totality. Then the range of ΔT is given. Additional information such as duration of the eclipse or the starting or ending time of the eclipse yields narrow range of ΔT.

2.1.3. The case when the orbital motion of the moon slows down

Suppose that the orbital motion of the moon was faster in the past and it gradually slowed down. For simplicity, we assume that the spin rate of the Earth did not change. We look at the Earth-moon system as in the former subsection. The first prediction(to the past) is to assume the constancy of the moon's orbital motion. Suppose that the Sun, Earth, and Moon are on a line in this case and place A is in a shadow. Now remember that the moon's motion is faster in the past. Then, winding back the time, the Moon is to the west of place A. The shift is very small if we go back only few thousand years. The Moon is in the parallel light rays of the Sun. As a result, the shadow of the Moon is to the west of place A and the distance is almost exactly the difference of the positions of the Moon on its orbit. It turns out that the fast slow down of the orbital motion of the moon has the opposite effect to the slow down of the Earth's spin.

2.1.4. Combined effects

The position of the eclipse is shifted to the east by the slow down of the Earth's spin and shifted to the west by the slow down of the orbital motion of the Moon both compared with predictions without these effects. To know the combined effects, we need to know the relation between the change rate both of motions. Let us see qualitatively how the angular momentum is redistributed to the Earth's spin and Lunar orbital motion.

The total angular momentum of the Earth–Moon system is the sum of the orbital angular momentum of each body around their center of gravity and spin angular momentum of each of the body. Their magnitude is ordered as

$$\{\text{Orbital angular momentum}\}_{\text{moon}} > \{\text{spin angular momentum}\}_{\oplus} >$$
$$\{\text{Orbital angular momentum}\}_{\oplus} > \{\text{spin angular momentum}\}_{\text{moon}}$$

To the first approximation, we can neglect the smaller two. Then the total angular momentum of the Earth–Moon system is reduced to the sum of the orbital angular momentum of the Moon and the spin angular momentum of the Earth. This angular momentum is regarded as constant in time. The slow down of the Earth's spin represents the loss of the spin angular momentum. This reflects on the increase of the lunar orbital angular momentum, which in turn impies the increase of the semi-major axis of the Moon's orbit and increase of the orbital period of the Moon. In other word, the slow down of the Earth's spin and the slow down of the Moon's motion are related uniquely in the first approximation. We here do not go into a mathematical detail.

2.2. ΔT and the tidal term

We find in section 2.1.4, under a simple approximation, a relationship between the rate of change of the Earth's spin velocity and the orbital mean motion of the Moon.

Suppose we have a single ΔT data at some past, say 1000 years ago. Is it possible to know the orbital velocity of the Moon at that time? Or equivalently, is it possible to know the Earth's spin rate? The answer is no. We need more than one ΔT data to obtain the long-term Earth rotation.

We now know that the slow down of the Earth's spin, and slow down (with a larger rate compared with the present) of the orbital motion of the moon have opposite effects. Let us obtain the equivalent effects of spin down and slow down of revolution.

The moon can be regarded as moving in the parallel light from the Sun. Then the distance the moon sweeps on its orbit is exactly the distance its shadow sweeps on the Earth's surface neglecting the curvature of the surface. One second of arc on the Moon's orbit corresponds to 1.86 km on the ground. The speed of the rotation of the Earth is 0.463km/sec, that is, $\Delta T = 1$sec is equivalent with 0.463 km on the equator. $1''$ on the Moon's orbit is equvalent with $\Delta T = 4$sec. So roughly speeking, $\Delta T = 1000$ sec is equivalent with $250''$ on the Moon's orbit.

2.3. Inconsistency of solar and lunar eclipses

$\Delta T = \mathrm{TT} - \mathrm{UT}$ obtained from lunar eclipses are determined by the comparison between the starting or ending timing and the calculated starting or ending timing. The reduction method of ancient solar eclipses is not precisely described in Stephenson[10] and Stephenson and Morrison[13]. We guess these are not the time observation. It fixes the place of observation and estimate the value ΔT. The position of the moon at the solar eclipses should be taken into account. The accuracy of the time observation needs be checked. Here we take into the uncertainty of the theory of the lunar motion for a few thousand years, we introduce a different coefficient in the tidal term of the lunar motion.

Historically, the tidal term changed as in Table III. In the table T is measured in units of 100 years.

Table III. History of the Moon's tidal term

Spencer Jones (1939)	$-11''.22T^2$	(Moon vs planets)
Van Flandern (1970)	$(-28'' \pm 8'')T^2$	(Moon vs Brown)
Morrison (1973)	$(-21'' \pm 3'')T^2$	(Moon vs Brown)
Van Flandern (1975)	$(-32''.5 \pm 9'')T^2$	(Moon vs Num. Int.)
Morrison & Ward (1975)	$(-13'' \pm 1'')T^2$	(Moon vs Mercury Transits)
Calame & Mulholland (1978)	$(-12''.3 \pm 2''.5)T^2$	(LLR)
Williams et al. (1978)	$(-11''.9 \pm 2''.0)T^2$	(LLR)
Ferrari et al. (1980)	$(-11''.9 \pm 1''.3)T^2$	(LLR)
Dickey et al. (1982)	$(-11''.9 \pm 0''.8)T^2$	(LLR)
Dickey et al. (1994)	$(-12''.94 \pm 0''.25)T^2$	(LLR)

The adopted vale at present is $-13''T^2$. We here show as an example the positional difference of the Moon according to the difference of ephemerides DE200 and DE405. The period is from AD1600 to AD2000. The frequency is every 50 years.

Table IV. Difference of the positions of the Moon coming from the difference of ephemerides(DE200 and DE405): DE405 − DE200

date	long	lat	dist	d-long	d-lat	d-dist
	o	o	au	”	”	km
1600 1 1	104.77143	+1.41719	0.002561	-40.91810	+3.67448	-3.48105
1650 1 0	245.58877	-0.85420	0.002415	-25.18135	+2.29119	+0.83199
1700 1 0	26.53991	-3.28175	0.002557	-10.42751	+0.71961	+1.42244
1750 1 0	180.28823	-5.20741	0.002703	-4.47492	+0.09208	+0.07907
1800 1 0	335.71660	-4.33024	0.002589	-2.98036	-0.17168	-0.37561
1850 1 0	119.43714	-2.18999	0.002395	-1.80050	-0.15803	-0.09627
1900 1 0	258.26803	-0.18464	0.002492	-0.61495	-0.06873	+0.05555
1950 1 0	49.31906	+3.00530	0.002689	-0.06852	-0.01840	-0.00134
2000 1 0	205.08024	+5.17687	0.002655	-0.04320	+0.01766	-0.00966

If we adopt $-2''.0T^2$ for the correction to the tidal term in DE406, the time of lunar occultation changes only 10 minutes from the nominal value in the 7th century. This value is negligible when we consider the timing of ancient lunar eclipses. On the other hand, the difference of position of the moon on its orbit affects the position of total solar eclipse. Thus, for example, we need to increase ΔT from 2000 sec to 3000 sec to have a total solar eclipse of AD628 in Japan.

By adopting our parameters, the inconsistency of ΔT obtained from solar and lunar eclipses is resolved.

The correction $-2.''0T^2$ is incompatible with the LLR data. This suggests that the tidal term may have changed in the past one thousand and few hundred years.

3. Examination

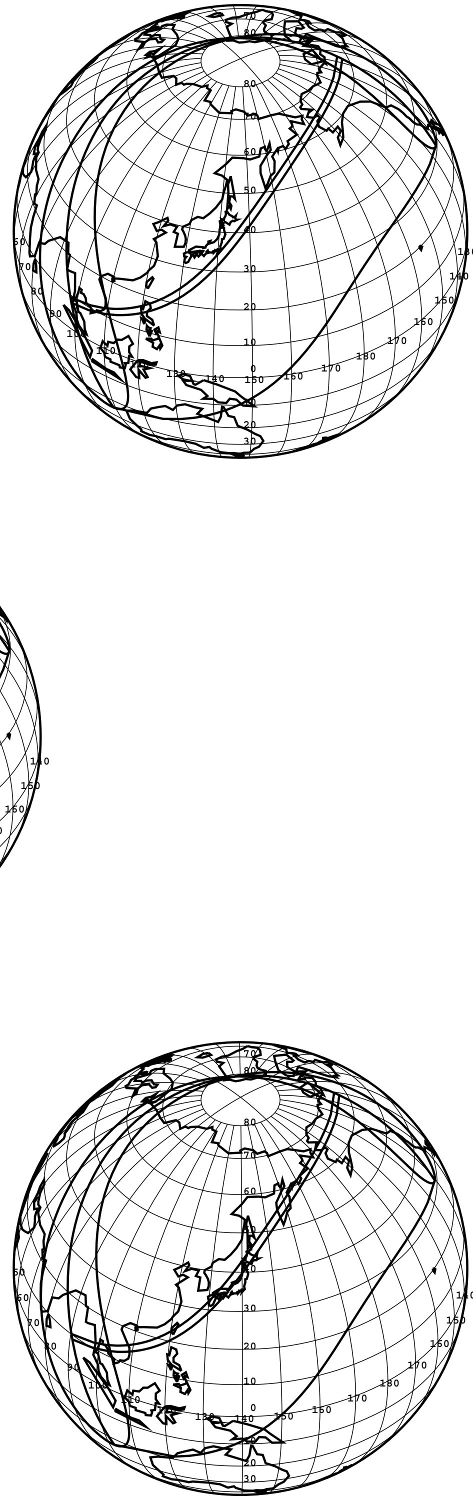
3.1. Solar eclipses

If we take $\Delta T = 4000$ sec at around AD600 as Stephenson[10] derived(?), then the zone of totality passes through the Pacific Ocean on April 10, 628. This implies that the Suiko Eclipse would have been partial. If we take $\Delta T = 2000$ sec, then the eclipse becomes total in Japanese Islands. But in this latter case, there are inconsistency between ΔT's derived from solar and lunar eclipses.

In order to resolve the inconsistency, we add $-2''.0T^2$ to the tidal term of the lunar ephemerides. As we already pointed out, this correction does not affect the lunar ephemerides. As for solar eclipses, the effect is large. Indeed, The eclipse of Suiko becomes total if we adopt $\Delta T = 3000$ sec. This resolves the inconsistency. The result is shown in Fig.1.

3.2 Grazing occultations

Ancient astronomical records contain occulation observations. As in the case of partial solar eclipses, the site from which stellar occultations is visible covers a wide range. This means most of occultation data are useless for determining our parameters. Only grazing type of occultations are useful. Fortunately, we have this kind of observation in the 7th century. The Mars occultation by the Moon on November 3, 681 is this.



a

Figure 1: The solar eclipse on Arpil 10, 628(The second day, the third month, the thirty sixth year of Empress Suiko). Shown are the zones of totality. From the top, $\Delta T = \mathrm{TT} - \mathrm{UT} = 4000\mathrm{s}$, Corr. to tidal term $= 0''T^2$; $\Delta T = 2000\mathrm{s}$, Corr. to tidal term $= 0''T^2$; $\Delta T = 3000\mathrm{s}$, Corr. to tidal term $= -2''T^2$.

a

Figure 2: Occultation of Mars by the Moon on November 3, 681. Shown are the bands of partial eclipse. The total occultation took place to the south of the band. From the top, $\Delta T = \mathrm{TT} - \mathrm{UT} = 4000\mathrm{s}$, Corr. to tidal term $= 0\text{"}T^2$; $\Delta T = 2000\mathrm{s}$, Corr. to tidal term $= 0\text{"}T^2$; $\Delta T = 3000\mathrm{s}$, Corr. to tidal term $= -2\text{"}T^2$.

The Nihongi says that the reign of Emperor Temmu, 10th year, 9th month, day *Guichou*, the Mars(熒或) went into the Moon. Saito[9a, p.14] states that "The magnitude of this planet in the night was -1.3, the Moon age was 17.3, the apparent radius of the moon was $0^\circ.28$. According to the calculation, at 2 am, November 4 in Julian calendar, Mars passed by the northern edge of the Moon $0^\circ.04$ apart. The Nihongi says that it entered the Moon. But the truth is that it was a passing-by(Fan, 犯). Supposedly, the observer lost Mars in the glaring Moon of age 17.3." Our opinion is different. Even the Moon is bright, after two days from the full Moon, it is unnatural that the observer lost Mars of $-1^{\mathrm{m}}.3$ at $0^\circ.04$ degree from the edge. It is true that there were no occultation except the southern part of the Kyushu Island if we adopt the present tidal value and $\Delta T = 4000$ sec. But if we adopt $\Delta T = 2000$ sec, then the occultation could have been observed in the southern part of Kinki area. Further, if we add correction $-2''/\mathrm{cy}^2$ to the tidal term and adopt $\Delta T = 3000$ sec, then the occultation was able to be observed at Asuka area.

Summarizingly, this record of the Nihongi supports our paprameter values (see Figures1 and 2).

4. Discussions

We point out that the record of the total eclipse in 628 is not an exaggeration. The reasonings for this are:

1. If we take $\Delta T = \mathrm{TT} - \mathrm{UT} = 2000.0$ sec, the eclipse was total in the western Japan. This value of ΔT is not so unreasonable.

2. If we take $\Delta T = 3000.0$ sec and introduce a correction $-2''.0T^2$ to the adopted value of the coefficient of T^2 of the lunar longitude, the lunar occultation of Mars in November 3, 681 is also explainable as in the record.

3. Wo(Old Japanese Empire) sent a declaration of independence in AD607, which implies that the official astronomer existed[14]. Evidence is that the record of other astronomical phenomena started nearly the same epoch: comet(AD634), meteorite(AD637), approach of stars and the moon(AD640), lunar eclipse(AD643).

4. Wo was using the calendar[15].

Acknowledgments

The authors express their thanks to Drs. Hiromitsu Yokoo(Kyorin University) and Tsuko Nakamura(NAOJ) for information on reference meterials. The authors thank Professor K. Kawabata for discussions and Dr. Shen Zhiqiang for reading the manuscript.

References

[1] Watanabe, Toshio: *Canon of solar end lunar eclipses*(日食月食宝典), Yusankaku Press, Tokyo, 1979(in Japanese).

[2] Nishijima, Sadao: *Yamatai and Wo*(邪馬台国と倭国), Yoshikawa-Kobunkan Press, Tokyo, 1994(in Japanese)

[3] Kanda, Shigeru: *Astronomical data of Japan*(日本天文史料), Hara Press, Tokyo, 1978(in Japanese).

[4] Yabuuchi, Kiyoshi: *Chinese Method of Calendar*(中国の天文暦法), Heibon-Sha Press, Tokyo, 1969(in Japanese).

[5] Chenshou(陳寿)(ed.), *Sanguozhi*, Chinese Press Buraeu, 1959.

[6] Liyanshou(李延寿)(ed.), *Nanshi*, Chinese Press Buraeu, 1975.

[7] Yanshigu et al.(顔師古 他), *Suishu*, Chinese Press Buraeu.

[8] Uchida, Masao(ed.): *Source Book of Japanese Calendar*(日本暦日原典), Yusankaku Press, Tokyo, 1975(in Japanese).

[9] Saito, Kuniji: *Ancient Records of Stars*(星の古記録)(Iwanami Press, Tokyo, 1982a), *Astronomy in Asuka Era*(飛鳥時代の天文学)(Kawade Shobou Press, Tokyo, 1982b)(in Japanese).

[10] F.R. Stephenson, *Historical eclipses and earth's rotation*, Cambridge University Press, 1997.

[11] J.M. Steele, *Observation and Predictions of Eclipse Times by Early Astronomers*, Kluwer Academic Press, 2000.

[12] Saito, Kuniji and Ozawa, kenji: *Examination of Chinese Ancient Astronomical Records*(中国古代の天文記録の検証), Yusankaku Press, Tokyo, 1992(in Japanese).

[13] F.R. Stephenson and L.V. Morrison, Long-term fluctuations in the Earth's rotation: 700BC to AD1990 Phil. Trans. R. astr. Soc. London A 351, 163-202, 1995.

[14] Kawabata, Kin-aki, Private communication, 2001.

[15] Ogawa, Kiyohiko, On the calendar dates in the Nihongi (日本書紀の暦日について), in 日本書紀暦日原典 (ed. UCHIDA, M.), 1946(in Japanese).

Appendix. Japan as appeared in the Chinese history

The third century(魏志倭人伝 [5]) – 卑弥呼

- 倭人在帯方東南大海之中. 依山島為国邑. 舊百余国. 漢時有朝見者, 今使譯所通三十国. ...
- 景初二年六月 (AD238), 倭女王遣大夫難升米等詣郡, 求天子朝献. ...
- 其年十二月詔書報倭女王曰, "... 汝之忠孝我甚哀汝今以為親魏倭王..."

The fifth century(宋書倭国伝 [6]) – 倭五王

- 倭国在高驪東南大海中. 世々修貢職.
- 高祖の永初二年 (AD421), 詔曰, "倭讃修万里貢遠宣執可賜除授"
- 太祖元嘉二年 (AD425), . .. 讃死弟珍立遣使貢献. ... 詔除安東将軍倭国王.
- (元嘉) 二十年 (AD443), 倭国王済, 遣使奉献. 復以為安東将軍倭国王.
- (元嘉) 二十八年 (AD451), ... 済死世子興, 遣使貢献.
- 世祖の大明六年 (AD462), 詔曰, "倭王世子興奕世戴忠作藩外海..., 宜爵号可安東将軍倭国王". 興死弟武立, 自稱... 安東大将軍倭国王.
- 順帝昇明二年 (AD478), 遣使上表. 曰, "封国偏遠, ... 窃自假開府儀同三司, ..." 詔除... 安東大将軍倭王.

The seventh century(隋書倭国伝 [7]) – 日出処天子致書日没処天子無恙

- 倭国在百済新羅東南. ... 魏志所謂邪靡堆者也.
- 開皇二十年 (AD600), 倭王姓阿毎字多利思北孤...
- 大業三年 (AD607), 其王多利思北孤, 遣使朝貢. ... 其国書曰, 日出処天子致書日没処天子無恙. 帝覧之不悦, ..., 夷蛮の書, 有無禮者. 勿復以聞.
- 大業四年 (AD608), 遣文林郎裴清使倭国.
- 此後遂絶.