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A Solar Eclipse Versified in the Shijing

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Abstract

A solar eclipse versified in an ode called 'At the conjunction in the 10th month' in the Shijing 詩経 has been analyzed under the light of the present astronomy. We have shown that the solar eclipse on 735 BC November 30 is a unique candidate of the eclipse in 801–720 BC satisfying the following three requirements: (1) the sexagenary cyclic day of the eclipse was *xin-mao*, (2) the sun became faint in the capital, and (3) the moon was eclipsed not long before the solar eclipse. The eclipse was at least very close to annular in Hao 鎬 (the Capital of Western Zhou). The maximum magnitude of every eclipse between 794 BC and 764 BC was too small to say 'the sun became faint' like in the ode. These results strongly support the dating of the eclipse by Hirayama and Ogura (1915, Tokyo Sugaku-Buturigakkwai Kizi, Ser.2, 8, 2) and reject any dating in 794–764 BC.

Key words: eclipse — ephemerides — history and philosophy of astronomy

1. Introduction

For calculations of the time and magnitude of solar eclipses, we have to use two parameters: the lunar tidal acceleration, $\dot{n}$, and clock corrections of the time defined by earth rotations, $\Delta T = \mathrm{TT} - \mathrm{UT}$. Here, TT and UT mean the terrestrial dynamical time and the universal time, respectively. According to the conservation of angular momentum of the earth–moon system, the recession of the moon results from a tidal reduction of the spin angular momentum of the earth. The lunar tidal acceleration, $\dot{n}$, is due to the recession of the moon. The clock correction, ΔT, is partly due to a decrease of the rotation speed resulting from the tidal decrease of the spin angular momentum of the earth. The remaining part of ΔT is due to variations of the moment of inertia of the earth.

The lunar tidal acceleration, $\dot{n}$, has already been obtained by Calame and Mulholland (1978), Dickey et al. (1994), Chapront, Chapront-Touzé, and Francou (2002), and others by LLR (the lunar laser ranging method). The recent value obtained by Chapront, Chapront-Touzé, and Francou (2002) is $\dot{n} = (-25.858 \pm 0.003)'' \mathrm{cy}^{-2}$. Though such a small uncertainty in $\dot{n}$ is still open to a question, their value is very close to $-25.''7\,\mathrm{cy}^{-2}$ adopted in DE403 and DE336 ephemerides (Williams, Dickey 2003). We cannot expect a significant change of the lunar tidal acceleration and the rate of tidal decrease of the earth's rotation speed on the historical time scale, but the moment of inertia of the earth may change significantly with time scales of several centuries. The variation of the moment of inertia of the earth of this time scale would be due to the variation of the sea level resulting from melting and growth of polar glaciers.

The solar eclipse in the ode called 'At the conjunction in the 10th month' in the Chinese classics Shijing 詩経 was said to be an eclipse in the reign period of King You 幽王 in the Western Zhou 西周 era since the dynasty of Western Han 漢. In the dynasty of Liang 梁, Astronomer Royal Yu-Guang 虞劆 pointed out that the eclipse occurred the during the King You reign period, 6th year, epochal year Taisui 太歳 *yi-chou* 乙丑, day *xin-mao* 辛卯, 1st day of the 10th month [776 BC September 6]. His proposal was believed until the 19th century. In 1896,[1] Chambers (1912) reported in his book 'The story of eclipses' that Rev. Johnson pointed out the eclipse was seen mainly in the circumpolar region, but not in the territory of Zhou 周, and that proposed the solar eclipse on the 781 BC June 4, because none else occurred during the reign period of King You.

Instead of 781 BC June 4 eclipse, Hirayama and Ogura (1914) have proposed the 735 BC November 30 eclipse during King Ping 平王 reign period, the 36th year, because of such a small magnitude of the 781 BC eclipse. Their proposals have been confirmed by Hartner (1935) and Nōda (1943). However, some historians are still insisting that the eclipse on 781 BC June 4 in King You 1st year is supported by astronomical evidence. In the present article, we present additional evidence supporting the proposals by Hirayama and Ogura (1914), and rejecting the proposals by Johnson. The present study shows that the solar eclipse on 735 BC November 30 satisfies all of the requirements described in the ode, and that no other eclipse from 801 BC through 720 BC was in accord with the ode.

In the present study, we employed JPL's DE406 distributed along DE405 (Standish 1998) to calculate the positions and motions of the sun and moon. For the earth's precession and the sidereal time we employed formulae by Williams (1994).

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[1] The first edition of Chambers' book was published this year.

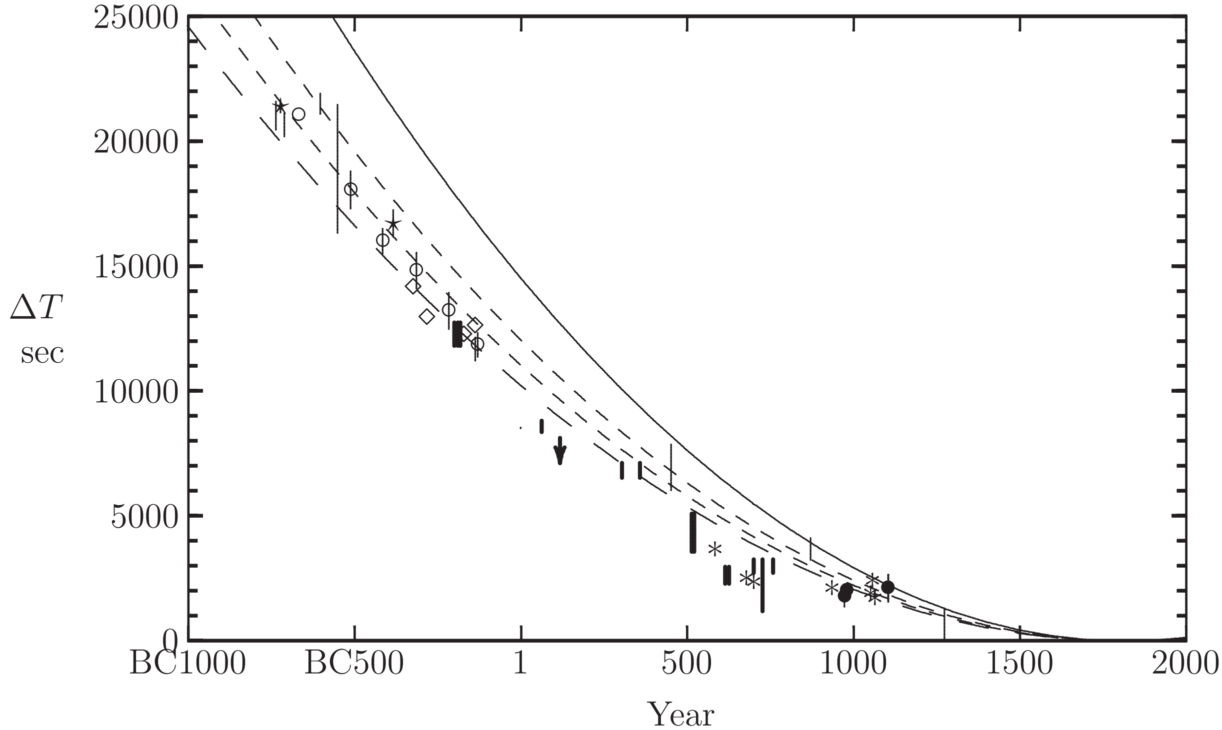

Fig. 1. Long-term variation of ΔT. Solid line, tidal effect; long dashed line, parabolic fitting (Stephenson 1997); short dashed lines, effect of a sea-level change (upper and lower limits, respectively) assuming a constant rate of height change; vertical lines, total/annular eclipses (including nearly ones); ⋄, Babylonian timed solar eclipses; ∗, Chinese timed solar eclipses; •, Japanese timed solar eclipses; ⋆, Babylonian lunar eclipses in Almagest; ○, Babylonian timed lunar eclipses. Babylonian lunar eclipses are grouped and averaged. ΔT values from Babylonian records and timed Chinese records are from Stephenson (1997).

Figure 1 illustrates the long-term variations of ΔT derived from ancient and medieval records of solar and lunar eclipses. The ΔT values in the figure are mainly from Kawabata, Tanikawa, and Sôma (2004), Sôma, Tanikawa, and Kawabata (2004a, 2004b). ΔT values from Babylonian and timed Chinese records in the Suishu and the Yuanshi obtained by Stephenson (1997) are also included.

2. The Ode

The followings are the first two sections and 6th section in the original and the translation by Legge (1865–1895) of the ode ‘At the conjunction in the 10th month’ in Shijing. The numerals at the beginning of each item are the section number of the ode, and are added for convenience of correspondence between the original ones and the translations. Since Legge used a rather archaic form of translation, equivalent pinyin is added in square brackets.

1. 十月之交。朔日辛卯。日有食之。亦孔之醜。彼月而微。此日而微。今此下民。亦孔之哀。
2. 日月告凶。不用其行。四國無政。不用其良。彼月而食。則維其常。此日而食。于何不臧。
6. 皇父孔聖。作都于向。擇三有事。亶侯多藏。不憖遺一老。俾守我王。擇有車馬。以居徂向。

1. At the conjunction (of the sun and moon), in the tenth month.
   On the first day of the moon, which was sin-maou [xin-mao],
   The sun was eclipsed,
   A thing of very evil omen.[2]
   Then the moon became faint[3],
   And now the sun became faint[3].
   Henceforth the lower people
   Will be in a very deplorable case.
2. The sun and moon announce evil,
   Not keeping to their proper paths.
   All through the kingdom there is no (proper) government,
   Because the good are not employed.
   For the moon to be eclipsed
   Is but an ordinary matter.
   Now that the sun has been eclipsed, —
   How bad it is!
6. Hwang-foo [Huang-fu] is very wise;
   He has built a great city for himself in Hëang [Xiang].
   He choose three men as his ministers,
   All of them indeed of great wealth.
   He could not bring himself to leave a single minister,
   Who might guard our king.

[2] According to Shirakawa (2002), the sentence implies that the eclipse is central.

[3] ‘small’ in Legge but we have changed to ‘faint’ in accordance with the opinion of Hirayama and Ogura (1914).

He also selected those who had chariots and horses,
To go and reside in Hëang [Xiang].

According to the Zuozhuan 左傳, Huang-fu is the father of the queen of king You and is the grandfather of king Ping 平王. The king left in Hao without even a guard is king Xie 携王. The history of Zhou in this era becomes recently much more clear than before from studies of records on metallic ornaments unearthed after 1956 (e.g. Hirase 1995, 1996). King You was killed in 772 BC. King Ping succeeded in Luoyang in 770 BC and king Xie succeeded in Hao in 772 BC. We can trace records of king Xie until 762 BC on ornaments. Records on ornaments indicate that king Xie was still in good condition until 762 BC, and then the ode tells us that the eclipse was after 762 BC.

3. Earlier Investigations of the Solar Eclipse

According to Nōda (1943), the ode

> At the conjunction in the 10th month, on the first day of the moon, which was xin-mao, the Sun was eclipsed. ……

in the canto '10th month' 十月篇 of the Shi Xiaoya 詩小雅 is a sole record of solar eclipses in the Chinese classic Shijing 詩経. Since the Shijing is said to have been compiled by Confucius 孔子 (551 – 479 BC), and is believed to describe stories in the Zhou dynasty, the epoch of the story in the ode should be from the beginning of the Zhou dynasty (c 1045 BC) through 479 BC. The most probable period of stories in Shijing is said to be from the reign period Gong-he 共和 1st year (841 BC) through 722 BC, the beginning of the Chunqiu 春秋 era. The reason for putting the 1st year of Gong-he as the beginning of the probable period is that the chronological table in the Shiji 史記 starts from this year. The reason for starting the table at this year is written in the Shiji chapter 13 that the chronology of China until this year was not in the hands of the author of Shiji, Sima Qian 司馬遷. Though the Chinese sexagenary cyclic day is written in the ode, the year of the eclipse recorded in Chinese classics was described by scholars after Western Han dynasty, and these are all based on speculations.

According to Nōda (1943), Duke Mao 毛公 in the Western Han dynasty said that 'At the conjunction in the 10th month' 十月之交, Yu-wu-zheng 雨無正, Xiao-min 小旻, and Xiao-yuan 小宛 in Canto of '10th month' of Shi Xiaoya 詩小雅 were odes of affairs in the period of King You 幽王 (781–771 BC). On the other hand, Zheng Xuan 鄭玄 in the Eastern Han dynasty said that these were odes of affairs in the reign period of King Li 厲王 (878–828 BC).

The ode 'the 7th month' 七月 in Bin-feng 豳風 of the Guo-feng 国風 describes calendars for farming. According to Iijima (1930), descriptions from the 4th month through the 10th month agree with the actual phenomena, if the month is given in the Xia system 夏正. In the Xia system, the winter solstice is in the 11th month of the year, and then the 1st month of the year becomes at the beginning of the spring in the central part of China at that time.

The first astronomical study of this ode was carried out by Wang Ji 王基 in the San-guo era. He insisted that none of conjunctions of the sun and moon on day *xin-mao* in the 10th month in the Zhou system 周正 or the 8th month in the Xia system 夏正 could be expected during a period from Gong-he 共和 (841–828 BC) through the era of King You. For this reason, he concluded that the eclipse should be before Gong-he.

In the Suishu chapter 17 Zhi 12 Lu-li 2 (隋書巻十七 志第十二 律暦中), it was written that the solar eclipse could be justified by calculations due to the Jia-zi-yuan-li 甲子元暦, though the year of the eclipse was not written. The year of this eclipse was probably assumed to be King You 6th year, epochal year *yi-chou* [776 BC], because it was already assumed in the Liang dynasty, as is described in the paragraph of descriptions in the Yuanshi. Descriptions on the Jia-zi yuan li can be found in the Jin shu chapter 18 Zhi 8 Lu-li 3 晋書巻十八 志八 律暦下.

The next astronomical study appeared in the section of Li Chungfeng 李淳風 of the Jiu-Tangshu chapter 79 舊唐書巻七十九 and reported that the year of the eclipse was the 6th year of King You and that the eclipse could be justified by the Lin-de-li 麟徳暦. In the Xin-Tangshu chapter 27 Zhi 17 No. 2, Li-zhi 新唐書巻二十七 志十七下暦志, it was also written that the year of the eclipse was the 6th year of King You and the eclipse was in the daytime according to the Kai-yuan-li 開元暦 (the Da-yan-li 大衍暦).

The followings are described in the Yuanshi chapter 53 Zhi 5, Li 2 Shou-shi-li 元史巻五十三 志第五 暦二 授時暦議下.

> Astronomer Royal Yu-Guang 虞劆 of Liang 梁 dated the eclipse versified in the ode 'At the conjunction in the 10th month' to King You 6th year, epochal year *yi-chou* [776 BC], 1st day of the 10th month, day *xin-mao*. Da-yan-li predicts the eclipse on this day. According to the Shou-shi-li, the argument of the lunar ecliptic latitude was 14.5709 days ($P \approx 8.^{\circ}8$) and then the moon was located inside the eclipsing range on King You 6th year, epochal year *yi-chou*, day *xin-mao*, 1st day of the month.

Incidentally, King You 6th year, epochal year *yi-chou*, the 10th month in the Zhou system, day *xin-mao*, the 1st day of the month is 776 BC September 6 (Julian day: 1438238). The Oppolzer number of the eclipse on this day is 1013. The track of the range of the central eclipse and the area of partial eclipses are shown in figure 2. As can be seen in the figure, the solar eclipse could not be observed in the territory of Zhou. The argument of the lunar latitude given in Oppolzer's table was $P = 9.^{\circ}70$. The argument of the lunar latitude given in Yuanshi is very close to that given in Oppolzer's table. These values of P imply that the solar eclipse could have been observed somewhere at the latitude of Hao (roughly 35°N). Failures of predictions by Shou-shi-li, Da-yan-li, Lin-de-li, and Jia-zi-yuan-li would be due to lack of knowledge on the shape of the earth at that time, and not due to insufficient accuracy of the lunar position.

According to Chambers (1912), Rev. Johnson[4] doubted this, and then proposed the eclipse (Oppolzer number 1000) on 781 BC June 4. In this case the month in the Chinese luni–solar

[4] Reference of this article is not written in Chambers and then we can not read the original article.

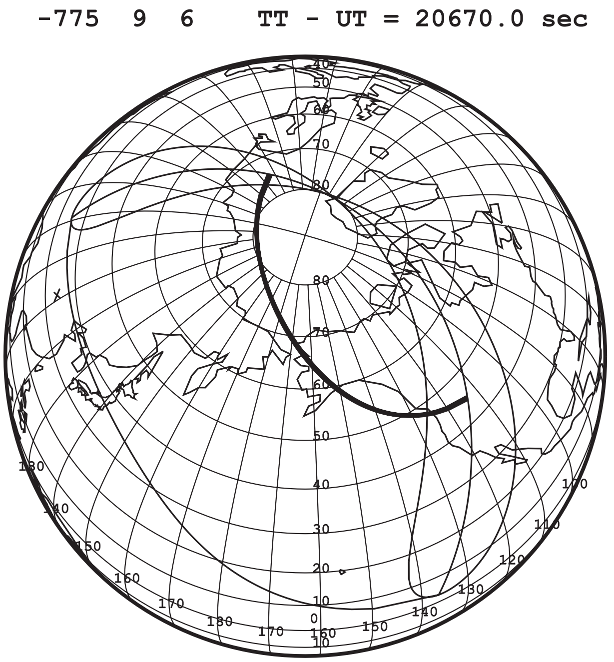

Fig. 2. Zone of central eclipse (shown by thick lines) and the range of the partial eclipse on 776 BC September 6. The location of Hao is indicated by ×.

calendar is not the 10th month in either the Zhou nor Xia system. The sexagenary cyclic day of this eclipse is also *xin-mao*, but the month corresponding to 781 BC June 4 is the 4th month in the Xia system and the 6th month in the Zhou system according to Nōda (1943). The magnitude of this eclipse was only 0.45 in Hao. According to Watanabe (1979), Ginzel has shown from statistical investigations of eclipse records that solar eclipses can be recognized without any a priori knowledge only if the magnitude is larger than 0.75. Therefore, people in Hao would not recognize the eclipse. Even if they recognized the eclipse, the sun was not so faint, as is described in the ode.

Hirayama and Ogura (1914) have calculated the southern limit for the 776 BC eclipse by a differential method taking the system of constants by Hansen (1857), Oppolzer (1887, 1962), Ginzel (1899), Newcomb (1909), and Radau (1911). These border lines distribute nearly parallel around the southern limit in figure 2 near Hao with differences in the latitude of about 7° in peak to peak. The southern limit, employing the constants by Oppolzer, Ginzel, Newcomb, and Radau, are close to the line in figure 2. In this way, they have confirmed the conclusion concerning the 776 BC eclipse by Johnson. They have, however, opposed the proposal concerning the 781 BC June 4 eclipse by Johnson, because Johnson searched an eclipse in the reign period of King You only. Hirayama and Ogura can find no reason why it should be confined to the reign of King You.

They then searched for eclipses on day *xin-mao* 1st day of the 10th month from 1000 BC through 1 BC. Thus, they found that two eclipses, 735 BC November 30 and 492 BC November 14, satisfy these requirements. They concluded that the solar eclipse on 735 BC November 30 is a unique candidate of the eclipse corresponding to the ode, because solar eclipses written in Shijing should be in 841–722 BC.

According to Nōda (1943), the winter solstice in 735 BC was the last day of the 10th month, if we put the Chinese date of the eclipse as the 1st day of the 10th month. Therefore, the month of the winter solstice was not the 11th month, as it should be in the Xia system. Nōda gave a comment that the 1 day difference in the calendar in the Zhou dynasty is quite common. He thus concluded that the 1 day difference on the date of the winter solstice does not matter. In section 4, we show that $\Delta T = 20670\,\mathrm{s}$ is a good reasonable estimate of ΔT in the latter half of the 8th century BC from records of solar and lunar eclipses in China and Babylon. When we adopt $\Delta T = 20670\,\mathrm{s}$, the time in the Julian calendar of the winter solstice in 735 BC is 735 BC December 28 09:10 UT. The conjunction of the sun and moon next to the eclipse is 735 BC December 29 22:49 UT. Therefore, the conclusion on the month by Nōda is justified in the present astronomical system.

Because some monographs cite incorrectly these earlier astronomical studies without consulting the originals, we cite whole descriptions related to the ode in Chambers (1912) and those related to Johnson's paper in Hirayama and Ogura (1914) in the following. The description in Chambers is as follows:

> Confucius relates that during the reign of the Emperor Yew Wang an eclipse took place. This Emperor reigned between 781 B.C. and 771 B.C., and it has been generally thought that the eclipse of 776 B.C.[5] is the one referred to, but Johnson doubts this on the ground that this eclipse was chiefly visible in the circumpolar regions, and if seen at all in China must have been of very small dimensions. He leans to the eclipse of June 4, 781 B.C.[6] as the only large one which happened within the limits of time stated above.

The description in Hirayama and Ogura (1914) is as follows:

> With regard to the epoch of this poem, there are two different opinions: one puts it in the reign of Yu Wang [幽王] (781–771 B.C.), and the other in the reign of Li Wang [厲王] (878–828 B.C.). The former is generally adopted. Indeed, in the sixth year of Yu Wang an eclipse occurred on the day hsin mao (*xin-mao*) (*sin maou* in Legge) of the tenth month by the Chou calendar, *i.e.*, on −775 IX 6 of the Julian calendar. It has been generally believed that this eclipse was visible in China. But the Rev. S. J. Johnson [According to 'The Story of Eclipses' by G. F. Chambers. We were unable to see Johnson's original paper.] doubts this on the ground that it was chiefly visible in the circumpolar regions, and if seen at all in China must have been of very small magnitude.
> Our results confirm Johnson's (*fig*. 2)[7]. The limits of the eclipse may be displaced slightly by a small correction of the lunar or solar elements; but it is quite impossible to make the eclipse sufficiently large in China, so as to justify the verse "And now the Sun became small". [The word wei 微, should be translated "faint" rather than

5 In Chambers (1912), the year was written as 775 BC by mistake.
6 In Chambers (1912), the year was written as 780 BC by mistake.
7 A figure showing southern limits of eclipsing area for the 776 BC eclipse in Hirayama and Ogura (1914).

> "small".] Consequently, as long as the text of the Shih Ching (Shijing) may be trusted, there must be another eclipse agreeing with it. Johnson takes the eclipse of −780 VI 4, putting so much weight on the epoch that he has not taken care about the month. We can find no reason why it should be confined to the reign of Yu Wang.

Here descriptions in brackets [and] are written as footnotes in their original paper.

According to Nōda (1943), Hartner (Chinese name 郝威烈, 1935) also confirmed that the solar eclipse on 776 BC September 6 could not be observed in Hao, and found that 7 solar eclipses occurred in Hao on day *xin-mao* until 441 BC in Oppolzer's table of solar eclipses. These are the following eclipses:

1. 1117 BC June 28,
2. 1096 BC May 9,
3. 781 BC June 4,
4. 735 BC November 30,
5. 729 BC March 3,
6. 636 BC February 23,
7. 492 BC November 14.

Among these, the month of both of 735 BC November 30 and 492 BC November 14 is the 10th in the Xia system. Thus, he also proposed the solar eclipse on 735 BC November 30 as a unique candidate of the eclipse corresponding to the ode.

4. Solar Eclipses in the 8th Century BC

From the requirement of totality of the solar eclipse on 709 BC July 17 (a total eclipses recorded in the Chunqiu) in Qu-fu 曲阜, the capital of Lu 魯, the inequality

$$20201\ \mathrm{s} < \Delta T < 21143\ \mathrm{s} \quad (1)$$

was obtained, when we inserted $\dot{n} = -26'' \mathrm{cy}^{-2}$.

We then assumed

$$\Delta T = 20670\ \mathrm{s} \quad (2)$$

in following calculations, inserting a rounded middle value.

According to Stephenson (1997), the records of lunar eclipses in Almagest give

$$\Delta T = 21650\ \mathrm{s} \quad (3)$$

from the 721 BC March 19/20 eclipse (started at 1.5 hr after moonrise) and

$$\Delta T < 21400\ \mathrm{s} \quad (4)$$

from the 720 BC September 1/2 eclipse (started after moonrise). By comparing ΔT from Chinese and Babylonian records, we can estimate $\Delta T = 20670 \pm 1000\,\mathrm{s}$ in the latter half of the 8th century BC. The error in ΔT is equivalent to the error in longitudes of $\pm 5°$ in maps of the eclipsing area.

In 1940–1945, Watanabe (1979) compiled the total/annular solar eclipses that occurred in the region 100°E–150°E, 10°N–50°N from 801 BC through AD 1900 for studies of solar eclipses in Japan, Korea, and China. Table 1 lists of all solar eclipses until 720 BC from his table and the time of the maximum phase, and the maximum magnitude of each eclipse in Hao has been added. Figure 3 shows plots of the magnitudes of these eclipses versus the year. From table 1 and figure 3, we can see that no total eclipse is expected in Hao during the period from 801 BC through 720 BC. However, we can find that an annular eclipse was visible on 735 BC November 30 in Hao.

Solar eclipses with relatively large magnitude were visible on the following dates. Here, the numeral in the first column of each line indicates the serial number of an eclipse in the table by Watanabe (1979). The date for the eclipse of Watanabe's serial no. 24 in his table is 729 BC March 3. The difference is due to the definition of the cited date and the difference of the astronomical ephemeris employed. The table by Watanabe (1979) gives the day of the conjunction of the sun and moon in his system. Our table gives the day of the time of maximum magnitude for each eclipse in our system.

3. 795 BC September 6 in King Xuan 33rd year,
14. 758 BC September 17 in King Ping 13th year,
15. 756 BC January 31 in King Ping 15th year,
16. 755 BC July 16 in King Ping 16th year,
19. 749 BC September 7 in King Ping 23rd year,
20. 742 BC April 25 in King Ping 29th year,
22. 735 BC November 30 in King Ping 36th year,
24. 729 BC March 2 in King Ping 42nd year,
25. 727 BC July 6 in King Ping 44th year.

Weather permitting, all of these eclipses should have been noticed at this time. We can easily see that solar eclipses with large magnitudes distribute in the latter half of this period. If we suppose that the eclipse in the ode was in the era of King You 幽王, we can not understand the description

> 日月告凶。不用其行。
>
> The sun and moon announce evil,
> Not keeping to their proper paths.

in the ode. When we suppose that the eclipse in the ode is in the era of King Ping 平王, the meaning becomes quite clear.

When we search for solar eclipses that occurred on day *xin-mao* from table 1, we can find three: 781 BC June 4, 735 BC November 30, and 729 BC March 3 (the date is in the local time in China). Among these three eclipses, only one, on 735 BC November 30, occurred in the 10th month in the Xia system, and the others occurred not in the 10th month in any system. As already stated, because the eclipse on 735 BC November 30 was at least very close to annular in Hao, it clearly satisfies the requirement of the phrase 'the sun became faint'.

The eclipse on 729 BC March 3 was a partial but the magnitude was fairly large in Hao. When we adopt $\Delta T = 20670\,\mathrm{s}$, the winter solstice in 730 BC is on December 28 in Chinese time (at 22:14 Chinese Standard Time). New moons following to this winter solstice are 729 BC January 4, February 3, and March 3, and then 729 BC March 3 is the 1st day of the 2nd month in the Xia system. Because the magnitude of the eclipse on 781 BC June 4 was very small, people at that time probably did not notice it. When we adopt $\Delta T = 20670\,\mathrm{s}$, the winter solstice in 782 BC is on December 29 in Chinese time (at 06:56 Chinese Standard Time). New moons following to this winter

Table 1. Solar eclipses in Hao 鎬 from 801 BC through 720 BC selected from the table in Watanabe (1979).*

Number		Julian calendar			J.D.	Cyclic day		UT	ST	Mag	Chinese year			
W.	Opp.	y	m	d	d			h	h		King		y	
1	961	798 BC	Nov	7	1430264	*ding-you*	丁酉	9.96^{s}	17.21	0.625	Xuan	宣	30	p
2	966	796 BC	Mar	24	1430767	*geng-shen*	庚申	3.08	10.33	0.658	Xuan	宣	32	p
3	969	795 BC	Sep	6	1431298	*xin-hai*	辛亥	1.89	9.14	0.833	Xuan	宣	33	p
4	983	789 BC	Oct	28	1433542	*yi-hai*	乙亥	2.08	9.33	0.572	Xuan	宣	39	p
5	984	788 BC	Apr	24	1433720	*gui-you*	癸酉	2.82	10.07	0.060	Xuan	宣	40	p
6	993	784 BC	Feb	9	1435107	*geng-chen*	庚辰	···	···	···	Xuan	宣	44	
7	995	783 BC	Jan	29	1435461	*yi-hai*	乙亥	23.93^{r}	7.18	0.094	Xuan	宣	45	p
8	1000	781 BC	Jun	3	1436317	*xin-mao*	辛卯	23.85	7.10	0.450	You	幽	1	p
9	1016	774 BC	Jan	20	1438739	*gui-chou*	癸丑	···	···	···	You	幽	8	
10	1019	773 BC	Jul	4	1439270	*jia-chen*	甲辰	···	···	···	You	幽	9	
11	1026	770 BC	May	5	1440305	*wu-wu*	戊午	11.33^{s}	18.58	0.356	Ping	平	1	p
12	1042	763 BC	Jun	15	1442903	*bing-zi*	丙子	9.76	17.01	0.720	Ping	平	8	p
13	1043	763 BC	Dec	10	1443081	*jia-xu*	甲戌	0.20	7.45	0.379	Ping	平	8	p
14	1055	758 BC	Sep	17	1444823	*bing-zi*	丙子	10.52	17.77	0.857	Ping	平	13	p
15	1059	756 BC	Jan	31	1445325	*wu-xu*	戊戌	9.48	16.73	0.840	Ping	平	15	p
16	1062	755 BC	Jul	16	1445856	*ji-chou*	己丑	4.98	12.23	0.906	Ping	平	16	p
17	1069	752 BC	Nov	7	1447066	*geng-zi*	庚子	23.19	6.44	0.455	Ping	平	19	p
18	1070	751 BC	May	5	1447245	*wu-xu*	戊戌	2.32	9.57	0.668	Ping	平	20	p
19	1077	749 BC	Sep	7	1448101	*jia-yin*	甲寅	7.71	14.96	0.764	Ping	平	23	p
20	1093	742 BC	Apr	25	1450522	*bing-zi*	丙子	22.60	5.85	0.897	Ping	平	29	p
21	1096	741 BC	Oct	8	1451054	*ding-mao*	丁卯	3.48	10.73	0.268	Ping	平	30	p
22	1110	735 BC	Nov	30	1453298	*xin-mao*	辛卯	2.65	9.90	0.942	Ping	平	36	a
23	1121	730 BC	Mar	14	1454863	*bing-shen*	丙申	10.77^{s}	18.02	0.578	Ping	平	41	p
24	1123	729 BC	Mar	2	1455217	*xin-mao*	辛卯	23.96	7.21	0.921	Ping	平	42	p
25	1130	727 BC	Jul	6	1456073	*ding-wei*	丁未	21.69	4.94	0.889	Ping	平	44	p
26	1140	723 BC	Apr	25	1457462	*yi-mao*	乙卯	9.31	16.56	0.577	Ping	平	48	p
27	1147	720 BC	Feb	21	1458495	*ji-si*	己巳	23.60^{r}	6.85	0.483	Ping	平	51	p

* The numerals in the 1st and 2nd columns are serial solar eclipse numbers given in Watanabe (1979) and Oppolzer (1962), respectively. UT and ST mean the universal time and the mean solar time in Hao, respectively. The Julian calendar and Julian days are given in UT. ST and Chinese sexagenary cycle are given in the local solar time in China. Lines with a mark — in the column of UT, ST, and Mag indicate that the sun was not eclipsed in Hao. The solar eclipse in 784 BC started after the sunset in Hao. The solar eclipses in 774 BC and 773 BC ended before the sunrise in Hao on January 21 LT and July 5 LT, respectively. Here, LT means the local time. The characters in the last column indicate the type of eclipse in Hao: 'a' indicates an annular eclipse and 'p' indicates a partial eclipse, respectively. ^{r} and ^{s} in the column of UT indicate that the cited time is the time of sunrise and the time of sunset, respectively.

Table 2. Annular eclipse on 735 BC November 30 in Hao.*

	UT			*P*	*V*	Mag	Azimuth	Altitude
	h	m	s	deg	deg		deg	deg
Start	1	10	42	300.96	343.88	0.00	130.19	16.81
Annular start	2	36	1	264.62	292.94	0.93	147.57	27.97
Maximum	2	38	46	212.81	240.59	0.94	148.20	28.26
Annular end	2	41	31	161.06	188.30	0.93	148.84	28.55
End	4	19	55	123.44	128.41	0.00	174.39	34.64

* *P* and *V* denote the position angle of the radial vector from the center of the solar disk to the center of the lunar disk reckoned from the direction of the north pole and the vertex, respectively. The azimuth is measured from the north through east.

solstice were 781 BC January 9, February 8, March 8, April 6, May 6, and June 4. Thus, 781 BC June 4 is the 1st day of the 5th month in the Xia system.

We examine the eclipse that occurred on 735 BC November 30 (the reign period of King Ping 平王) at first. Figure 4 shows the eclipsed area for the value of ΔT = TT − UT given at the top of the figure. Tables 2 and 3 give the position of the lunar disk center and the magnitude of the eclipse at the starting time

Table 3. Annular eclipse on BC 735 November 30 in Luo-yi.*

	UT			P	V	Mag	Azimuth	Altitude
	h	m	s	deg	deg		deg	deg
Start	1	14	16	297.06	336.31	0.00	133.81	19.22
Maximum	2	44	36	212.60	235.75	0.87	153.41	29.80
End	4	27	33	126.75	126.04	0.00	180.80	34.21

* Notations are the same as table 2.

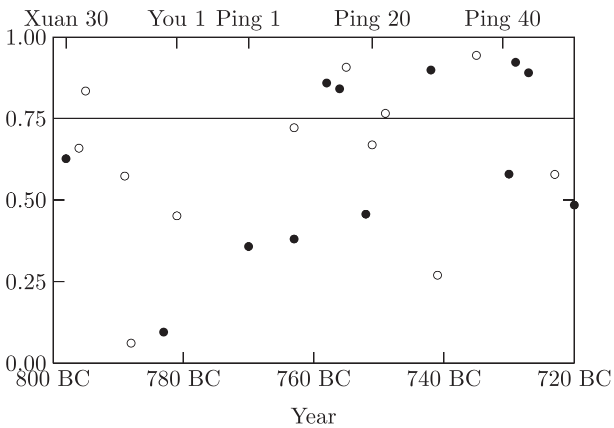

Fig. 3. Magnitudes of solar eclipses between 801 BC and 720 BC in Hao. The ordinate is the magnitude and the line at 0.75 indicates the border line given by Ginzel as a limiting magnitude of eclipses that can be recognized without any knowledge about the occurrence of the eclipse on that day. Solar eclipses below the line could be observed only if eclipses were observed near the horizon. Solar eclipses plotted by ● started before sunrise or ended after sunset. Eclipses plotted by ● could be observed near the horizon, even if the magnitudes were less than 0.75.

of the eclipse, the starting time of the annular eclipse, the time of maximum phase, the end of the annular eclipse, and the end of the eclipse in Hao and Luo-yi, respectively. The eclipse was annular in Hao (the capital of the Western Zhou) but partial in Luo-yi 洛邑 (the capital of the Eastern Zhou), when we put $\Delta T = 20670\,\mathrm{s}$. The columns of P and V give the position angle of the center of the lunar disk reckoned from the north pole and the vertex, respectively. The columns of Azimuth and Altitude give the azimuth angle and altitude of the sun at the respective times. The column Mag gives the magnitude of the eclipse. The maximum magnitude was 0.94, and thus the sun became clearly faint, as is described in the ode.

When we put a requirement that the eclipse on 735 BC November 30 is annular in Hao, we obtain

$$20457\ \mathrm{s} < \Delta T < 21587\ \mathrm{s}. \qquad (5)$$

The range of ΔT given by inequality (5) almost overlaps with the range of ΔT given by inequality (6).

The inequality

$$20457\ \mathrm{s} < \Delta T < 21143\ \mathrm{s} \qquad (6)$$

satisfies a requirement that the 709 BC July 17 eclipse is total in Qu-fu and the 735 BC November 30 eclipse is annular in Hao.

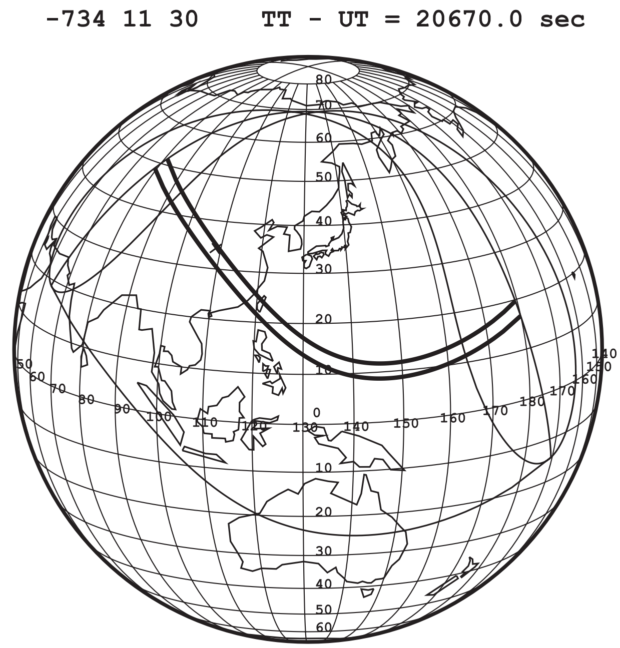

Fig. 4. Zone of the central eclipse (shown by thick lines) and the range of partial eclipse on 735 BC November 30. The location of Hao is indicated by ×.

When

$$20201\ \mathrm{s} < \Delta T < 20457\ \mathrm{s}, \qquad (7)$$

the 709 BC July 17 eclipse was total in Qu-fu, but the 735 BC November 30 eclipse was partial in Hao though the eclipse was very close to annular.

For the solar eclipse on 781 BC June 4 (in the local time in Hao), the time of the maximum phase was around 7 hr and the maximum magnitude was only around 0.45. Since the lower limit of the magnitude for detections of solar eclipse is 0.75, the eclipse was probably not recognized by people in Hao at that time. Even if they recognized the eclipse, the sun did not become faint, as is written in the ode.

5. Lunar Eclipses

The followings

彼月而微。此日而微。

Then the moon became faint,

Table 4. Lunar eclipses visible in Hao during a period from 10 years before the 735 BC November 30 solar eclipse until the solar eclipse.*

Julian calendar			UT	Mag	Duration		Moon	
			h		Part	Tot	λ	ϕ
743 BC	May	20	14.8	1.48	110	46	+135	+19
743 BC	Nov	14	13.0	1.53	110	48	+161	−18
742 BC	Nov	3	17.2	0.18	48	···	+97	+12
739 BC	Mar	9	11.8	1.46	109	45	−174	+9
739 BC	Sep	1	16.5	1.73	112	51	+112	−12
738 BC	Feb	26	14.3	0.06	28	···	+149	+12
736 BC	Jul	1	20.8	1.14	103	28	+49	−24
736 BC	Dec	25	20.0	1.55	110	48	+63	+24
735 BC	Jun	20	21.9	1.13	103	27	+32	−23

* Part and Tot in the header of the 4th and 5th columns indicate Partial and Total, respectively. The units of durations are minutes. The columns of λ and ϕ give the longitude and latitude in degrees of the location where the moon was located at the zenith. + sign in the longitude implies that the longitude was measured eastword from Greenwich.

And now the sun became faint.

are written in the first line of the ode, and the followings

彼月而食。則維其常。此日而食。于何不臧。

For the moon to be eclipsed
Is but an ordinary matter.
Now that the sun has been eclipsed, —
How bad it is!

are written in the second line of the ode. We then give a list of lunar eclipses in table 4. The table is a list of lunar eclipses that occurred during a 10-year period advanced to the 735 BC November 30 solar eclipse. We can find from this table that the last lunar eclipse in advance to the solar eclipse on 735 BC November 30 was the total lunar eclipse on 735 BC June 20. The following 5 total lunar eclipse given in table 4 were visible within 5 years before the annular solar eclipse on 735 BC November 30:

1. 739 BC March 9,
2. 739 BC September 1,
3. 736 BC July 1,
4. 736 BC December 25,
5. 735 BC June 20.

Any of these lunar eclipses would probably satisfy the description in the ode cited above.

6. Discussions and Conclusions

In the present paper, we have confirmed that the solar eclipse on 735 BC November 30 satisfies following conditions described in the ode:

1. Chinese cyclical day was *xin-mao*.
2. The sun became faint.
3. The moon was totally eclipsed not long before the solar eclipse.

When we adopt the date of the eclipse in the luni–solar calendar to the 10th month, the winter solstice in this year was the last day of the 10th month. Since 1 day difference of the date of the winter solstice from true date was quite common in that era, we may conclude that the Chinese date of the eclipse at that time was the 1st day of the 10th month in the Xia system. The results confirm the opinion of Hirayama and Ogura (1914) concerning the date of the solar eclipse in the ode 'at the conjunction in the 10th month' in Shijing. No other eclipse in the period from 801 BC through 720 BC satisfies these requirements described above, and thus does not match with the verse.

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References

Calame, O., & Mulholland, J. D. 1978, Science, 199, 977
Chambers, G. F. 1912, The Story of Eclipses (New York: D. Appleton and Company)
Chapront, J., Chapront-Touzé, M., & Francou, G. 2002, A&A, 387, 700
Dickey, J. O., et al. 1994, Science, 265, 482
Ginzel, F. K. 1899, Spezielle Kanon der Sonnen- und Mondfinsternisse für das Ländergebiet der klassischen Altertumswissenschaften und der Zeitraum von 900 v. Chr. bis 600 n. Chr. (Berlin: Mayer & Muller)
Hansen, P. A. 1857, Tables de la Lune (London: G. Edward Eyre)
Hartner, W. 1935, T'oung Pao, 31, 3
Hirase, T. 1995, Revised edition of the Chronology of the Eastern *Zhou* in the *Shiji* 新編 史記東周年表 (Tokyo: Tokyo Univ. Press 東京大学出版会) (in Japanese)

Hirase, T. 1996, Studies of Ancient Chinese Chronology 中国古代紀年の研究 (Tokyo: Kyuko-Shoin Co. Ltd. 汲古書院) (in Japanese)

Hirayama, K., & Ogura, S. 1915, Tokyo Sugaku-Buturigakkwai Kizi, Ser. 2, 8, 2

Iijima, T. 飯島忠夫, 1930, The Origin of Chinese Astronomical Ephemeris 支那暦法起源考 (Tokyo: Daiichishobo 第一書房) (in Japanese)

Kawabata, K., Tanikawa, K., & Sôma, M. 2004, in Proc. 35th Symp. on Celestial Mechanics of N bodies (Tokyo: NAOJ), 283 (in Japanese but with English extended abstract)

Legge, J. 1865–1895, The Chinese Classics, Vol. 4, Part II, 320 (London, Oxford: Clarendon Press)

Newcomb, S. 1909, MNRAS, 69, 164

Nōda, C. 能田忠亮, 1943, History of Astronomy in Far-East 東洋天文学史論叢 (Tokyo: Koseisha 恒星社) (in Japanese)

Oppolzer, Th. Ritter von 1962, Canon of Eclipses, translated by O. Gingerich (New York: Dover Publications INC.), originally published as vol. 52 of the Memoirs, Mathematics Natural Sciences Class of the Imperial Academy of Sciences in Vienna (1887)

Oppolzer, Th. Ritter von 1881, Syzygien-tafeln für den Mond (Leipzig: Wilhelm Engelmann)

Radau, R. 1911, Tables de la Lune, Ann. du Bureau des Longitudes, t. VII

Shirakawa, S. 白川 静, 2002, Shijing 詩経 (Tokyo: Chuokouron Shinsha 中央公論新社) (in Japanese)

Sôma, M., Tanikawa, K., & Kawabata, K. 2004a, in Proc. 35th Symp. on Celestial Mechanics of N bodies (Tokyo: NAOJ), 267 (in Japanese but with English extended abstract)

Sôma, M., Tanikawa, K., & Kawabata, K., 2004b, in Proc. JOURNÉES 2003: Astronomy Geodynamics and Solar System Dynamics (St Petrosburg: Inst. Appl. and Russian Acad. Sci.) in press

Standish, E. M. 1998, JPL Planetary and Lunar Ephemerides DE405/LE405, JPL Interoffice Memorandum 312.F-98-048

Stephenson, F. R. 1997, Historical Eclipses and Earth's Rotation (Cambridge: Cambridge University Press)

Stephenson, F. R. 2003, Astronomy and Geophysics, 44, 222

Watanabe, T. 渡邊敏夫, 1979, Solar and Lunar Eclipses Recorded in Japan, Korea, and China 日本・朝鮮・中国 日食月食宝典 (Tokyo: Yuzankaku 雄山閣) (in Japanese).

Williams, J. G. 1994, AJ, 108, 711

Williams, J. G., & Dickey, J. O. 2003, in Proc. of 13th International Laser Ranging Workshop, Oct. 7–11 2002, Washington DC, USA[8]

[8] ⟨http://cddisa.gsfc.nasa.gov/lw13/lw_proceedings.html⟩.

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