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Solar Eclipses and SHIBUKAWA Harumi (澁川春海)

(A preliminary study)

Yukio Ôhashi (大橋由紀夫)
3-5-26, Hiroo, Shibuya-ku, Tokyo 150-0012, Japan
e-mail: yukio-ohashi@dk.pdx.ne.jp

1. Introduction

(1.1.) Solar Eclipse as a test of traditional calendars

For traditional calendars, a solar eclipse was a kind of test of the accueacy of a particular calendar.

In the early stage of Chinese traditional calendars, when solar eclipses could not be predicted, a solar eclipse was a test of the accuracy of the length of synodic month or its epoch, because a solar eclipse, which occurs at the time of new moon, should occur in the first day of a month in traditional Chinese luni-solar calendars if it is accurate. In China, a cycle, which corresponds to the present half eclipse year, was found empirically at the time of Former (Western) Han (前漢(西漢)) dynasty (206 BC ~ AD 23), and the prediction of lunar eclipses was started from the *Santong-li* (三統暦) of Liu Xin (劉歆) which was made at the end of the Former (Western) Han dynasty. However, solar eclipses could not be predicted at that time.

By the 1st century AD in the Later (Eastern) Han (後漢(東漢)) dynasty (AD 25 ~ 220), the armillary sphere with the ecliptic ring was established, and, then, the equation of centre of the lunar orbit, and also the fact that the lunar orbit is inclined to the ecliptic were recognised. So, the prediction of solar eclipses using lunar nodes became possible by the end of the Later (Eastern) Han dynasty. The *Jingchu-li* (景初暦) (AD 237) of the Three kingdoms (三國) period started the prediction of solar eclipses officially. Since then, solar eclipses were used to test the accuracy of the length of nodical (draconic) month, anomalistic month etc. and their epoch. Later, equation of centre of the solar orbit was discovered by Zhang Zixin (張子信) in the 6th century, most probably independently of Hipparchus (2nd century BC) etc. in the ancient Mediterranean world, and it was also considered in the prediction of eclipses later.

What I am going to discuss in this paper is one episode concerning the development of the prediction solar eclipses in East Asia, more specifically in the Edo (江戸) period (AD 1603 ~ 1867) of Japan.

After the establishment of the modern celestial mechanics, eclipses have been predicted fairly accurately. Now, the historical records of solar eclipses are used to estimate the long term fluctuation of the rotation of the earth, which is, of course, beyond the scope of the present paper.

(1.2.) SHIBUKAWA Harumi and his *Jōkyō-reki*

There were five systems of Chinese calendar which were officially used in pre-Edo period of Japan. Among them, the last Chinese calendrical system used in Japan was the *Xuanming-li* (宣明暦, *Senmyō-reki* in Japanese, where Chinese *li* or Japanese *reki* stands for "calendar" (or ephemeris)), which was used from AD 862 to 1684 in Japan.

By the beginning of the Edo (江戸) period (AD 1603 ~ 1867), some Japanese scholars noticed the inaccuracy of the old *Xuanming-li*, and tried to study the more accurate *Shoushi-li* (授時暦, *Juji-reki* in Japanese), an excellent Chinese traditional calendrical system which was made by GUO Shoujing (郭守敬) etc. at the time of the Yuan (元) dynasty of China, and was used in China from AD 1281 (but has never been used officially in Japan).

In AD 1683, SHIBUKAWA Harumi (澁川春海, AD 1639 – 1715), who studied the *Shoushi-li*, proposed a new calendrical system, which was named *Jōkyō-reki* (貞享暦) in the next year, and was officially used in Japan from AD 1685. It was the first theory of calendrical system produced in Japan. [For an overview of Japanese traditional calendars in Japanese, see ŌHASHI (2005).]

(1.3.) SHIBUKAWA Harumi and solar eclipses

Before SHIBUKAWA Harumi made his own calendrical system, he firstly proposed to use the *Shoushi-li*. However, in AD 1675, the *Shoushi-li* failed to predict a solar eclipse when the outdated *Xuanming-li* succeeded to predict the solar eclipse. Since then, SHIBUKAWA Harumi recognised that he should make his own calendrical system.

In this paper, I would like to discuss the role of solar eclipses when SHIBUKAWA Harumi was making his calendrical system. We should investigate the reson why the outdated *Xuanming-li* could make better result. And also, we would like to know how SHIBUKAWA Harumi settled the defect of the *Shoushi-li*.

2. The *Xuanming-li* and the *Shoushi-li*

(2.1.) The *Xuanming-li*

The *Xuanming-li* (宣明暦, *Senmyō-reki* in Japanese) is a calendrical system compiled by a Chinese astronomer XU Ang (徐昂) at the time of Tang (唐) Dynasty (AD 618 ~ 907) of China, and was used from AD 822 to 892 in China. It was also used from the end of the Silla (新羅) Dynasty to the Koryo (高麗) Dynasty in Korea, and was also used in

Japan from AD 862 to 1684.

The *Xuanming-li* is recorded in a Chinese official dynastic history *Xin-tang-shu* (新唐書, New [official] history of the Tang dynasty) (AD 1060), but its description is too brief. More detailed description is recorded in a Korean official history *Koryo-sa* (高麗史, [Official] history of the Koryo dynasty) (AD 1451) (Vol.50). And also, there is a detailed monograph entitled *Senmyō-reki* (宣明暦), published in AD 1644 in Japan. There is also a detailed exposition published in Japan, that is the *Chōkei Senmyō-reki Sanpō* (長慶宣明暦算法, Method of calculation of the *Xuanming-li* [originally compiled] in Changqing era) (AD 1676) written by ANDŌ Yūeki (安藤有益).

(2.2.) The *Shoushi-li*

The *Shoushi-li* (授時暦, *Juji-reki* in Japanese) is a calendrical system compiled by a Chinese astronomer GUO shoujing (郭守敬) (AD 1231 – 1316) and his colleagues at the time of Yuan (元) Dynasty (AD 1271 ~ 1368) of China, and was used from AD 1281 to 1367 (and, after that, its emendation *Datong-li* (大統暦) was continued to be used) in China. The *Shoushi-li* (or its emendations or revisions) was also used from the end of the Koryo (高麗) Dynasty to the middle of the Choson (朝鮮) Dynasty in Korea, but has never been used officially in Japan.

GUO shoujing and his colleagues compiled the *Shoushi-li* in AD 1280, which is the most excellent Chinese inherent calendar. They incorporated several superior devices of their predecessors. Besides the accurate astronomical constants, there is certain significance in this calendar as follows.

Almost all Chinese classical calendars used grand epoch when the sun, moon, and planets are assumed to be in conjunction. One exception is the *Futian-li* (符天暦) of CAO Shiwei (曹士蔿), a privately made calendar in the 8th century, which did not use grand epoch. The *Shoushi-li* also abandoned the artificial grand epoch, and used contemporary epoch with certain initial condition obtained by observations.

Almost all Chinese classical calendars used fraction with different denominators. One exception is the *Futian-li* which used 10,000 as the denominator. The *Shoushi-li* also used 10,000 as the denominator. Although it was not the first calendar to use this denominator, it was certainly a method approaching decimal fraction.

The *Shoushi-li* succeeded the method of the *Tongtian-li* (統天暦) (AD 1198) of YANG Zhongfu (楊忠輔) that the length of a tropical year gradually diminishes. This method is called *"xiaozhang-fa"* (消長法). According to the modern astronomy, it is true that the length of a tropical year diminishes, but its amount is very small, and it must not have been detected by the inaccurate observations at that time. The theory of

Tongtian-li and *Shoushi-li* must have been misguided by the inaccurate ancient records, and the rate of diminishment used in the *Tongtian-li* and the *Shoushi-li* are too large. This idea that the length diminishes was abandoned in AD 1385 in the *Datong-li* (大統曆) (AD 1368) of the Ming (明) dynasty (AD 1368 ~ 1644) which almost completely followed the *Shoushi-li* otherwise.

The *Shoushi-li* also used some new mathematical devices, such as the third order interpolation, and a mathematical method of transforming spherical coordinates, where the method devised by SHEN Kuo (沈括) (AD 1031-1095), an encyclopaedic scientist and thinker in the Northern Song (北宋) dynasty, was used.

The *Shoushi-li* is recorded in the chapter of calendar in the *Yuan-shi* (元史, [Official] history of the Yuan dynasty) (1370 AD) (Vols.52-55), and also in the *Xin-Yuanshi* (新元史, New [official] history of the Yuan dynasty) (1920 AD) (Vols.36-40).

It should be noted that GUO Shoujing and his colleagues created 17 new astronomical instruments, and made several accurate observations in order to make their calendar. One of the most important observations is the determination of the time of winter solstice by a high gnomon called *"gaobiao"* (高表). The gnomon was used in China since ancient period to observe the sun's midday shadow, and determine the winter solstice, which is the fundamental point of time in Chinese classical calendars. GUO Shoujing improved it and made it five times higher than the previous traditional gnomons. A huge gnomon constructed by GUO Shoujing etc. exists in Dengfeng (登封) in Henan (河南) province, and is called Guanxingtai (观星台) (Observatory to watch stars). (See Fig.1.)

Fig.1: The Guanxingtai photographed by the author

The main difficulty of the observation of gnomon-shadow is that the sun is not a point source, and the shadow's penumbra produces ambiguity of shadow-length. GUO Shoujing overcame this difficulty by using *"jingfu"* (or possibly pronounced as *"yingfu"*, 景符), which is a device to use a pinhole. The image of the sun is projected through a pinhole, and the position of the *"jingfu"* is adjusted so that the shadow of the horizontal bar which is in the window at the top of the gnomon-wall exactly passes through the centre of the image of the sun. Then, the position of the shadow of the bar indicates the length of the exact gnomon-shadow when the height of the bar is considered to be the height of gnomon. (See Fig.2.) The *"jingfu"* was also used by SHIBUKAWA Harumi in Japan. (See Fig.5 also.)

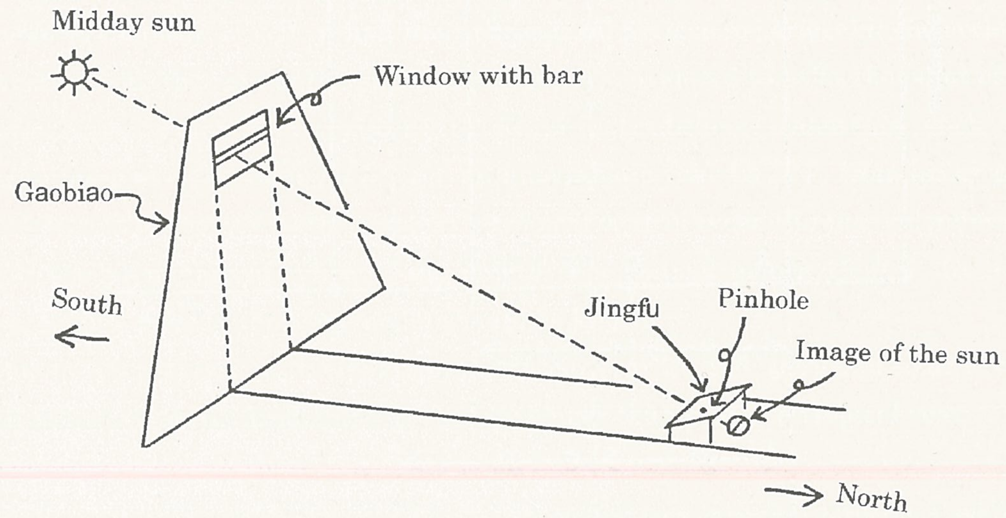

Fig.2: The principle of the *"jingfu"*

GUO Shoujing and his colleagues observed the gnomon-shadow by the *"gaobiao"* several times around the winter and summer solstices, and determined the time of solstices by the method devised by ZU Chongzhi (祖冲之) (AD 429-500). This determination led them to use the fairly accurate length of a tropical year 365.2425 days in the *Shoushi-li*. Actually, this value had already been used in the *Tongtian-li* (AD 1198), and it was confirmed by GUO Shoujing. GUO Shoujing and his colleagues also determined the point of the winter solstice on the celestial sphere, the time when the moon passes its perigee, the time when the moon passes its nodes, the right ascensional distances of lunar mansions, the time of sunrise and sunset at Dadu (大都) (present-day Beijing), etc. They also conducted astronomical observations at 27 different places, and observed the altitude of the celestial North Pole, the length of gnomon-shadow at solstices, the length of daytime and nighttime, etc.

The method devised by ZU Chongzhi, which was also used by SHIBUKAWA Harumi in Japan, is as follows. (See Fig.3.)

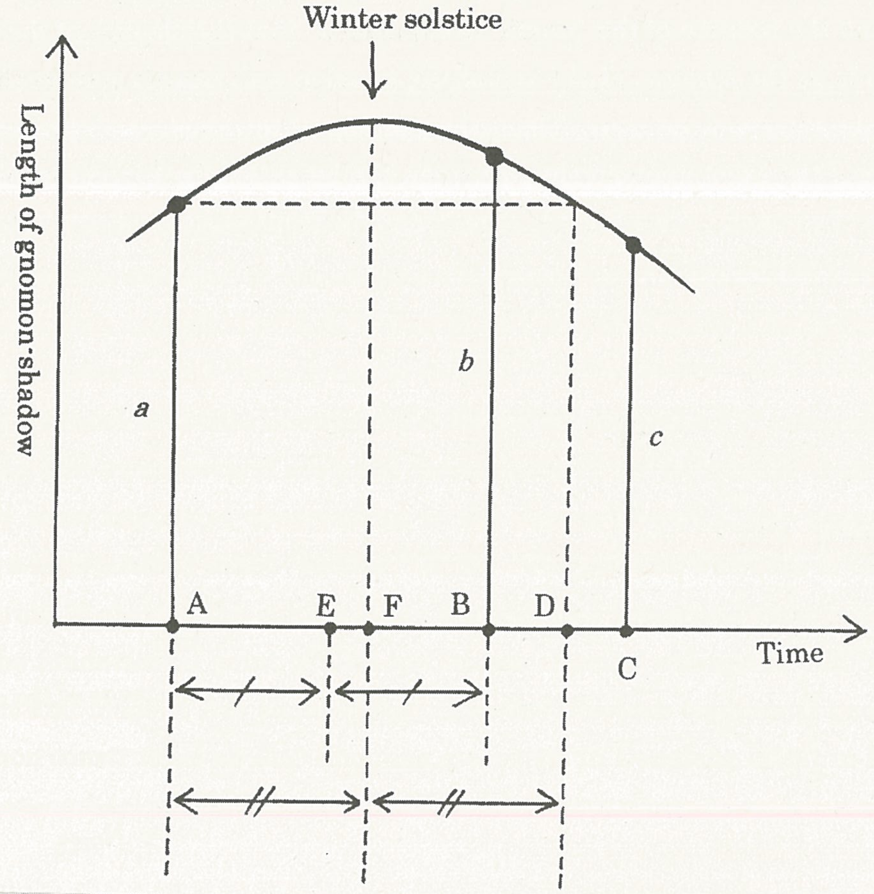

Fig.3: ZU Chongzhi's method

For the determination of the time of winter solstice, three observations (A, B, and C in the figure) of the midday gnomon-shadow (a, b, and c) are used. Here, $b > a > c$, and the period BC is one day. In ancient China, one day was divided into 100 *"ke"* (刻). Let an imaginary gnomon-length at D (between B and C) be equal to a. The point E is the midpoint of AB, and F the midpoint of AD, that is the time of winter solstice. Then, EF is a half of BD. Now, by linear interpolation:

$$BD = \frac{100 \times (b-a)}{b-c}\ ke, \quad \text{hence } EF = \frac{100 \times (b-a)}{2 \times (b-c)}\ ke.$$

As the time E is already known, the time F of winter solstice is obtained from this equation.

(2.3.) Accuracy of the *Xuanming-li* and the *Shoushi-li*

(2.3.1) Introduction

Chinese traditional calendars treated several astronomical phenomena, such as the movement of the sun, moon and five planets, the prediction of eclipses, etc. In this paper, I would like to discuss the movement of the sun and moon, which is also used to predict eclipses.

In solar and lunar theories, the most fundamental constants are the length of a tropical year (回帰年, from winter solstice to winter solstice) and of a synodic month (朔望月, from new moon to new moon).

As the solar motion and the lunar motions are not uniform, their inequalities (which correspond to the modern "equation of centre") are applied. In the case of the moon, an anomalistic month (近点月, from [lunar passage of] perigee to perigee) is the cycle of this correction. In the case of the sun, the perigee is considered to be at the point of winter solstice (first point of Capricorn) in Chinese traditional calendars such as the *Xuanming-li* and the *Shoushi-li*. So, an anomalistic year (近点年, from [solar passage of] perigee to perigee) was the same as a tropical year in these Chinese calendars.

For the prediction of eclipses, the length of a nodical month (交点月, from [lunar passage of] a node to the same node) should be known.

Due to the precession, the length of a sidereal year (恒星年, period of solar revolution with reference to the fixed stars) is slightly longer than that of a tropical year.

The exact value of these constants is as follows [Seidelmann (1992), p.698. I have rounded the solar constants in seven digits, because more exact value is not necessary here, and also solar constants slightly change with time.].

Lunar constants:

Synodic month ≈ 29.53059 days

Anomalistic month ≈ 27.55455 days

Nodical month ≈ 27.21222 days

Solar constants:

Tropical year ≈ 365.2422 days

Anomalistic year ≈ 365.2596 days

Sidereal year ≈ 365.2564 days

(2.3.2) Accuracy of the lunar theory

In the *Xuanming-li*, one day is divided into 8400 parts, and some of the constants are expressed by fraction whose denominator is 8400.

The lunar constants in the *Xuanming-li* and their error in a century are as follows.

$$\text{Synodic month} = \frac{248057}{8400}\ \text{days} \approx 29.53060\ \text{day},$$ (Error: about +0.01 day in a century.).

$$\text{Anomalistic month} = \frac{231458\frac{19}{100}}{8400}\ \text{days} \approx 27.55455\ \text{days},$$ (Almost exact.).

$$\text{Nodical month} = \frac{228582\frac{6512}{10000}}{8400}\ \text{days} \approx 27.21222\ \text{days},$$ (Almost exact.).

In the *Shoushi-li*, one day is divided by the powers of ten, and the expression is practically similar to the decimal fraction system.

The lunar constants in the *Shoushi-li* and their error in a century are as follows.

Synodic month = 29.530593 days, (Almost exact.).

Anomalistic month = 27.5546 days, (Error: about +0.07 day in a century.).

Nodical month = 27.212224 days, (Almost exact.).

From the above data, it is clear that these constants are enough accurate, and these calendars can be used for centuries.

(2.3.3) Accuracy of the solar theory

The solar constants in the *Xuanming-li* and their error in a century are as follows.

$$\text{Tropical year} = \frac{3068055}{8400} \approx 365.2446\ \text{days},$$ (Error: about +0.24 day in a century.).

$$\text{Sidereal year} = \frac{920446199}{2520000} \approx 365.2564\ \text{days},$$ (Almost exact.).

The solar constants in the *Shoushi-li* and their error in a century are as follows.

Tropical year = 365.2425 days, (Error cannot be expressed in simple way.).

Sidereal year = 365.2575 days, (Error: about +0.11 day in a century.).

In the *Shoushi-li*, the length of a tropical year diminishes by 0.0002 day in a century by its *"xiaozhang-fa"* (消長法). Fortunately, the length of a tropical year in the *Shoushi-li* is slightly longer than the exact value (365.2422 days), and the effect of the *"xiaozhang-fa"* did not produce much error for a few centuries, but the Edo period was already the time when the *"xiaozhang-fa"* had been producing certain error, of which SHIBUKAWA Harumi was not aware. SHIBUKAWA Harumi succeeded the *"xiaozhang-fa"* in his *Jōkyō-reki*.

(2.3.4) Solar perigee

Now let us discuss the problem of the solar perigee (which corresponds to the modern perihelion of the Earth in the opposite direction in the space). In Chinese classical calendars including the *Xuanming-li* and the *Shoushi-li*, the solar perigee was fixed to the point of the winter solstice.

The longitude of the solar perigee (observed from the Earth) in the year t, according to the modern astronomy, is as follows [Goldstine (1973), p.vi. I have omitted the terms above squared t.].

$$279^\circ 30' 12''.30 + 61''.8026\, t + \cdots,$$ (epoch Gregorian 1800 January 0, noon).

So, the solar perigee can roughly be expressed as follows.

$$279^\circ.5 + 1^\circ.7\ T, \quad [T = (t - 1800)/100].$$

From this expression, we know that the solar perigee was at the point of winter solstice (first point of Capricorn) in mid 13th century, that is the time of the preparation of the *Shoushi-li*. The *Shoushi-li* considered that the solar perigee was fixed to the point of winter solstice. It was right at the time of the *Shoushi-li*. However, in mid 17th century when SHIBUKAWA Harumi was studying calendar, the true longitude of solar perigee was about 7°.5 from the point of winter solstice. So, the *Shoushi-li* was quite innacurate in this respect. (As the point of the winter solstice was the initial point in East Asian astronomy, I shall measure the longitude of solar perigee from the point of winter solstice in the following discussion.)

In the case of the *Xuanming-li*, the true longitude of the solar perigee was about −7° from the point of winter solstice when it was made in the 9th century. As the *Xuanming-li* also considered that the solar perigee is at the point of winter solstice, its inaccuracy diminished for 5 centuries or so, and then started to increase. In this respect, the *Xuanming-li* was quite fortunate. What was more fortunate is that the length of a tropical year in the *Xuanming-li* was too long. If the length of a tropical year in the calendar is too long, the solar perigee in the calendar, which is fixed to the point of calendrical winter solstice, advances among the actual sky, and this inaccuracy produces an effect that the longitude of the solar perigee in the calculation of eclipses etc. practically increases. As the time of the winter solstice according to the *Xuanming-li* was about 2 days later than the correct time at the time of SHIBUKAWA, we can consider that the practical longitude of the solar perigee in the *Xuanming-li* was about 2° from the true point of winter solstice at that time. As the correct longitude was about 7°.5 from the point of winter solstice, the amount 2° is much better than the amount 0° in the *Shoushi-li* which was quite accurate otherwise.

We should note that the inaccuracy of the time of winter solstice cannot be noticed by common people, while the inaccuracy of the position of solar perigee produces a direct effect on the prediction of eclipses whose failure is easily noticed.

So, at the beginning of Edo period, the *Xuanming-li* sometimes could produce better result than the *Shoushi-li* thanks to the inaccuracy of the length of a tropical year in the *Xuanming-li*. This must be one reason why SHIBUKAWA recognized that even the *Shoushi-li* was not enough accurate.

In order to show this fact clearly, I have graphed the true longitude of the solar perigee measured from the point of winter solstice (which can also be considered to be the time of the solar passage of the perigee since the time of winter solstice), the calendrical winter solstice according to the *Xuanming-li*, and the calendrical winter solstice according to the *Shoushi-li* (which is fairly exact, and it almost coincides with the straight line of 0 day (or 0°) in the graph for centuries since its establishment). (See Fig.4.)

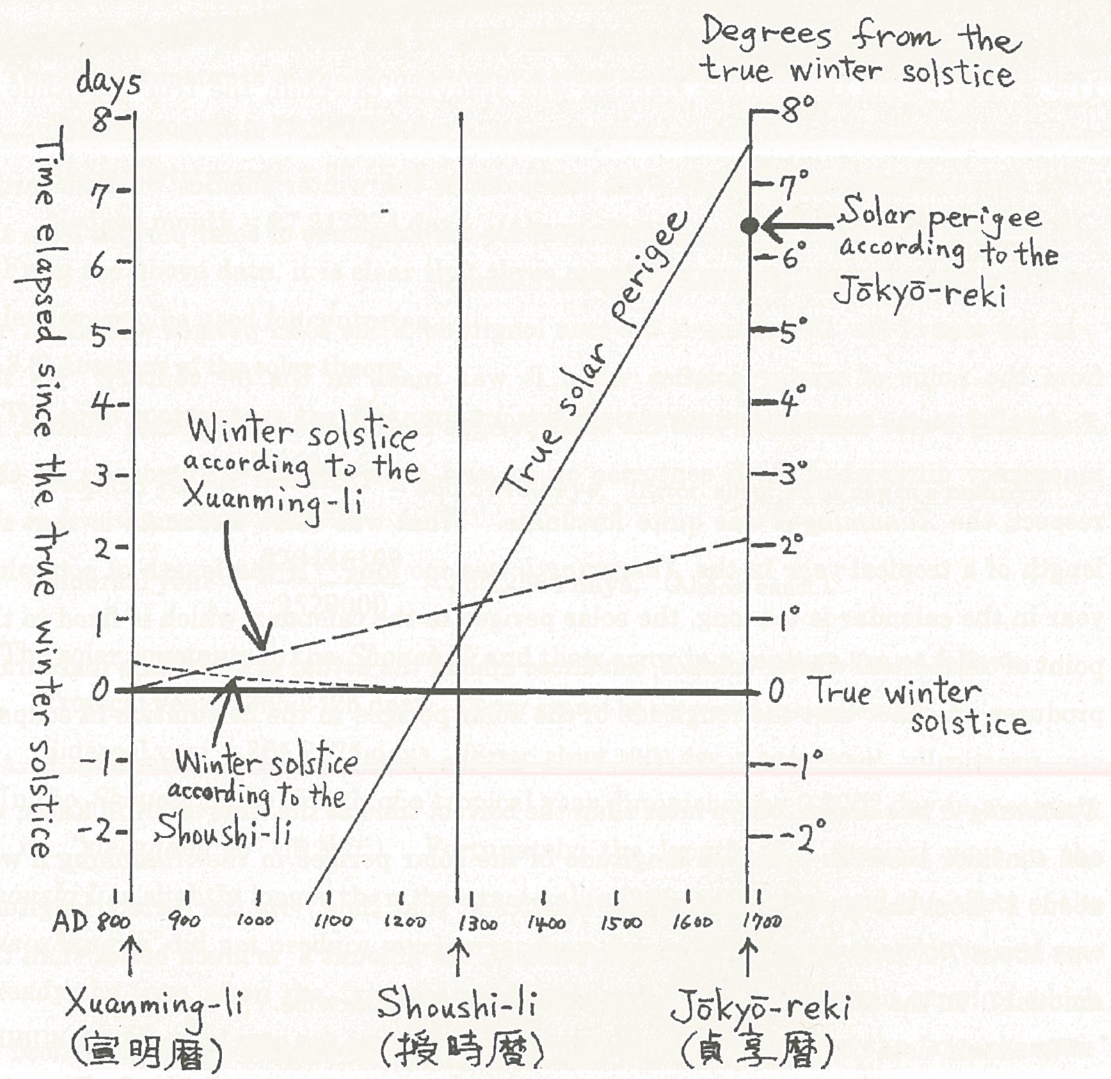

Fig.4: The winter solstice and the solar perigee according to three calendars

From Fig.4, we can understand that the inaccuracy of the solar perigee of the *Shoushi-li* at the time of SHIBUKAWA was worse than that of the *Xuanming-li* due to the accuracy of the time of winter solstice of the *Shoushi-li*, and that the decision of SHIBUKAWA to differentiate the solar perigee and the winter solstice was indispensable to make an accurate calendar at his time. Of course, the error of the solar perigee directly affects the prediction of eclipses.

3. SHIBUKAWA Harumi the Astronomer

SHIBUKAWA Harumi (澁川春海, AD 1639 – 1715), who was originally a "go" (碁, a kind of Japanese game) player, was interested in astronomy, and studied the *Shoushi-li*. Besides the information through the books from China, certain informathion about the *Shoushi-li* was also brought to Japan through a traveller from Korea, as the *Shoushi-li* was well studied in Korea at that time. SHIBUKAWA noticed the innacuracy of the *Xuanming-li*, and tried to substitute the *Shoushi-li* for the *Xuanming-li*. However, it was found that even the *Shoushi-li* was not enough accurate.

In AD 1683, SHIBUKAWA Harumi proposed a new calendrical system, which was named *Jōkyō-reki* (貞享暦) in the next year, and was officially used in Japan from AD 1685. It was the first theory of calendrical system produced in Japan. It mainly besed on the *Shoushi-li*, but it considered the time difference between China and Japan, and also the change of the position of the apogee or perigee of the sun since the time of the *Shoushi-li*. In AD 1684, a new post "tenmon-kata" (天文方, [shogunate] astronomer) was created, and SHIBUKAWA Harumi was appointed to be the first "tenmon-kata".

SHIBUKAWA Harumi made several astronomical observations, and used the *"jingfu"* (*"keifu"* in Japanese) devised by GUO Shoujing. It is mentioned in SHIBUKAWA's theoretical work which is also entitled *Jōkyō-reki*. (See Fig.5.)

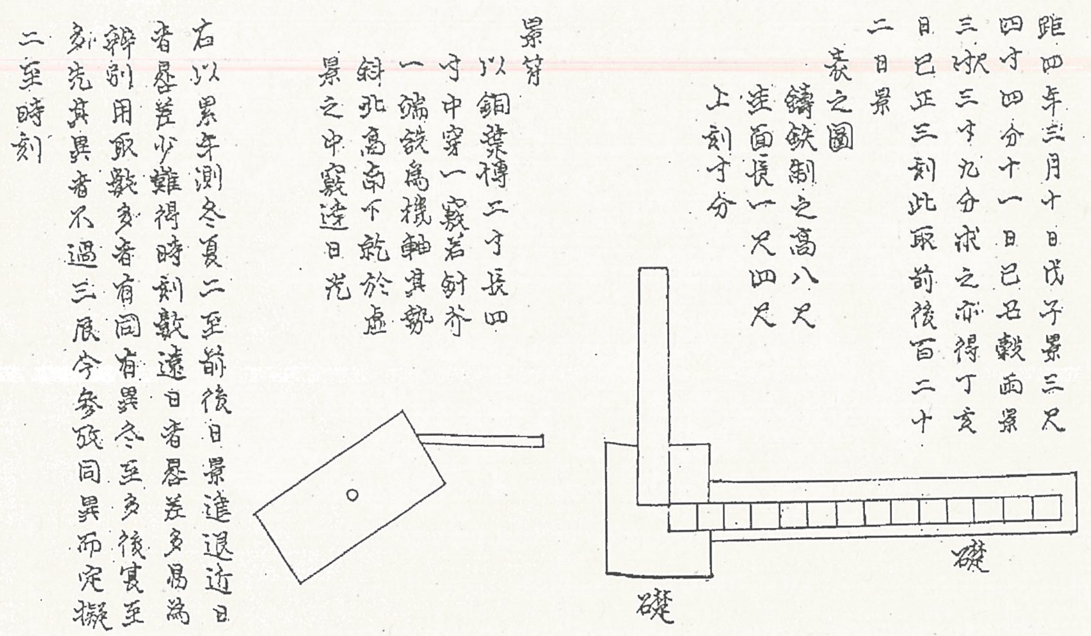

Fig.5: SHIBUKAWA's *"keifu"* in his *Jōkyō-reki* (manuscript) (vol.1)
(Courtesy: Wasan Institute, Shimodaira collection no.032)

SHIBUKAWA recognized that the earth is round through a Chinese popular astronomical book entitled *Tianjing-huowen* (天經或問, *Tenkei-wakumon* in Japanese) of YOU Yi (游藝, or YOU Ziliu (游子六)), which was imported to Japan sometime around AD 1670's, and some other Western information brought by Jesuits to East Asia. Although books contain Western culture (particularly Christianity) were basically prohibited to import at that time in Japan, the *Tianjing-huowen* was fortunately allowed to import. So, SHIBUKAWA could estimate the time difference between China and Japan using the comparison of the predicted time of eclipses by Chinese calendars and the actually observed time in Japan. That the earth is round had been informed to some Japanese people by Jesuits in the late 16th century, but it was not so widely known. SHIBUKAWA's *Jōkyō-reki* is the first Japanese official document in which the round earth theory is explicitly assumed.

Later, the *Tianjing-huowen* became quite popular in Japan thanks to NISHIKAWA Masayasu (西川正休)'s edition. Fig.6 is a world map printed in the *Tenkei-wakumon* (天經或問) edited by NISHIKAWA Masayasu (published in AD 1730). Although this is a later edition, we can suppose that SHIBUKAWA must have seen a similar map.

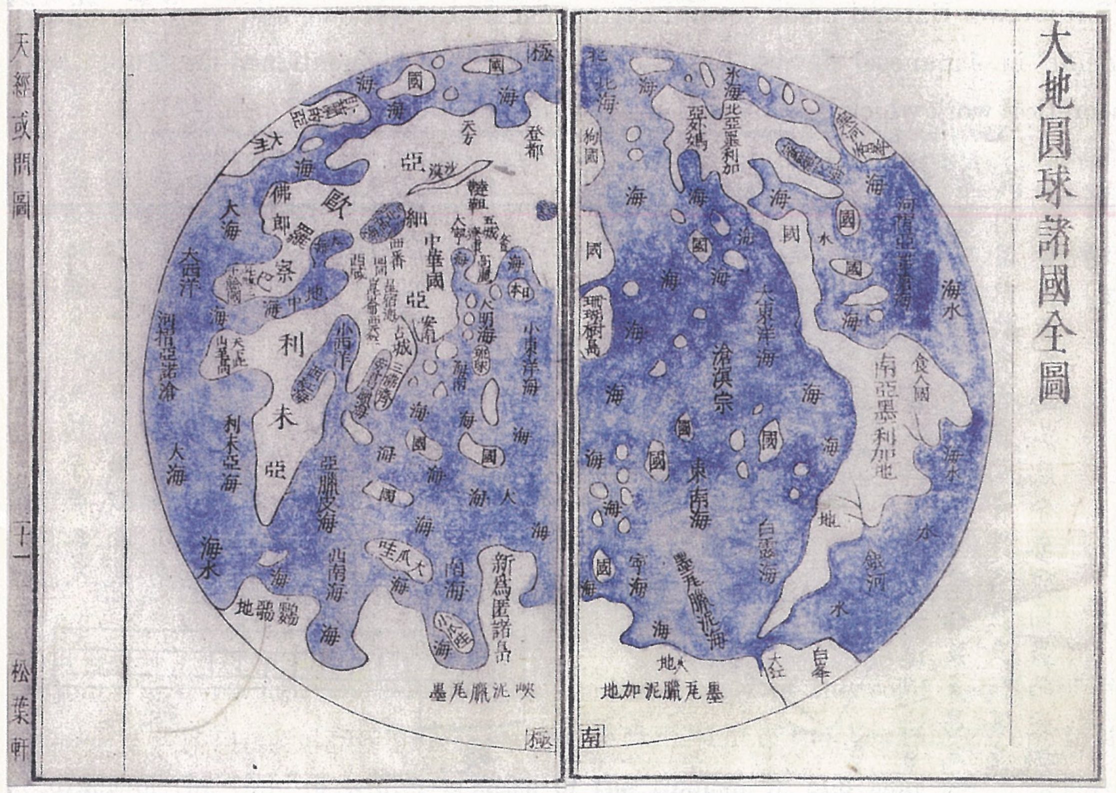

Fig.6: A world map in NISHIKAWA's edition of the *Tenkei-wakumon* (reprinted: AD 1794)
(Author(ÔHASHI)'s copy)

SHIBUKAWA also obtained the knowledge of the change of the position of the apogee or perigee of the sun through an information of Western astronomy mentioned in the *Tianjing-huowen*. So, SHIBUKAWA incorporated this knowledge in his calendar.

The *Tianjing-huowen* tells that the longitude of the solar perigee is 6° from the point of winter solstice. SHIBUKAWA used "6 *do* (度) 44 *fun* (分) and a half" as the longitude of the solar perigee from the point of winter solstice. One *do* is the arc on the celestial sphere which the mean sun moves in a day (that is about 1/365.25 of a circle), and one *fun* is 1/100 *do*. So, SHIBUKAWA's value is about 6°.4. As the correct longitude of the solar perigee at that time according to the modern astronomy was about 7°.5 from the point of winter solstice, SHIBUKAWA's value was fairly good.

Although SHIBUKAWA Harumi could not understand the mathematical rational of the *Shoushi-li* perfectly, his adoption of the western knowledge of the change of the longitude of the solar perigee made his *Jōkyō-reki* more accurate than the *Shoushi-li*. Actually, at that time, China had already accepted much information of Western geocentric astronomy, and had used more accurate *Shixian-li* (時憲暦) since AD 1645.

When SHIBUKAWA Harumi overcame the inaccuracy of the *Shoushi-li*, Chinese astronomy had developed further. This does not mean that SHIBUKAWA's effort was in vain. The office of "tenmon-kata (天文方)" started by SHIBUKAWA later became a centre of the study of Western astronomy. More systematic adoption of Western elements in Japanese traditional calendar was done by TAKAHASHI Yoshitoki (高橋至時, AD 1764 – 1804), who became a "tenmon-kata", and his colleague HAZAMA Shigetomi (間重富, AD 1756 – 1816), and they made the calendrical system *Kansei-reki* (寛政暦). Western astronomy was more fully adopted by SHIBUKAWA Kagesuke (渋川景佑, AD 1787 – 1856), the second son of TAKAHASHI Yoshitoki. SHIBUKAWA Kagesuke became an adopted son of the SHIBUKAWA family, became a "tenmon-kata", and made the calendrical system *Tenpō-reki* (天保暦), which is the last traditional calendar in Japan. SHIBUKAWA Harumi was a predecessor of these later development.

4. Conclusion

When SHIBUKAWA Harumi was studying astronomy, his contemporary SEKI Takakazu (關孝和, ca.AD 1640 – 1708), who was a famous mathematician, was also interested in astronomy. It is sometimes said by modern historians of mathematics that SHIBUKAWA's ability of mathematics was inferior to SEKI. It may be true, but SHIBUKAWA was a practician. His new devices, including the adoption of the new data of the longitude of the solar perigee, could lead his new calendar to success. SHIBUKAWA must have recognised the defect of the *Shoushi-li*, such as the inaccuracy of the solar perigee. The ability of SHIBUKAWA as a practical astronomer made firm ground for the further development of astronomy in the Edo period of Japan.

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Japanese Summary:

「日食と渋川春海」(大橋由紀夫)

要旨：日本では、平安時代以来、江戸初期まで、「宣明暦」が使われていたが、それは回帰年の長さとして、約 365.2446 日という、やや長すぎる値を使っており、江戸時代初期には冬至の日時に約 2 日の誤差を生じていた。そこで、江戸時代初期には、もっと精密な「授時暦」(回帰年を約 365.2425 日とする) が研究され、「授時暦」に改暦しようとする動きもあった。しかし、当時、「宣明暦」が予報に成功した日食について、「授時暦」が予報に失敗する、という現象が起こってしまった。

日食予報について、時代遅れだったはずの「宣明暦」のほうが、良い結果を出した主要な原因は、「宣明暦」も「授時暦」も、太陽の近地点を冬至点に固定していたが、実際の近地点は移動している、ということである。真の近地点は、「授時暦」の時代には、ほぼ冬至点に一致していたが、江戸時代初期には冬至点から 7°あまり先に進んでいた。そこで、「宣明暦」は冬至の日時の誤差のおかげで近地点が約 2°進んだのと同じ結果を生じ、このため、怪我の功名で、江戸時代初期には日食予報の精度が「授時暦」よりも良かったのである。

渋川春海は、『天経或問』に記載されている西洋天文学の知識によって、近地点が冬至点から離れていることを知り、自身の「貞享暦」において、近地点は冬至点から 6.445 中国度 (≒6°.4) のところにあるとした。このように、新しい情報を柔軟に取り入れて、近地点の位置を改定したことが、「貞享暦」を成功に導いた重要な要素である。「貞享暦」は、中国暦の単なる模倣ではなく、独自の見識によって作られたものだったのである。

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編集者　相馬　充・谷川清隆

発行者　国立天文台
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