Formation of Chinese Classical Mathematical Astronomy

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ABSTRACT

After the creation of several astronomical ideas in the Chunqiu-Zhanguo period or its preceding periods, Chinese Classical Mathematical Astronomy was well systematized in the Han period (206 BC – 220 AD). In this period, calendrical astronomy, including the prediction of eclipses, observational astronomy, cosmology etc., were rapidly developed. And also, according to my study, some fragmental information of Indian astronomy reached China in this period.

1. INTRODUCTION

It can be said that the foundation of the Chinese classical astronomy was formed in the Han period (Former (Western) Han dynasty (206 BC – 8 AD) and Later (Eastern) Han dynasty (25–220 AD)). The preceding Chunqiu-Zhanguo ("Spring and autumn" and "Warring states") period (770–221 BC) can be considered to be the period of the preparation of some fundamental ideas.

In this paper, I would like to present my view regarding the process of the formation of the mathematical astronomy in the Han period and the subsequent Sanguo (Three kingdoms) period (220–265 AD), and also a bibliographical guide to this field.

2. ASTRONOMY BEFORE THE HAN PERIOD

Chinese classical calendars, which is the nucleus of the Chinese mathematical astronomy, are luni-solar calendars, which can be traced to the Shang dynasty (=Yin dynasty) (16^{th}-11^{th} century BC).This fact is inferred from the oracle bone inscriptions (ca.13^{th}-11^{th} century BC).The development of the calendrical science in the Western Zhou dynasty (11^{th} century BC – 771 BC) and the Chunqiu (Spring and autumn) period (770-476

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BC) is still awaiting further research. By the end of the Zhanguo (Warring states) period (475-221 BC), the 19-year cycle of intercalation, in which 7 intercalary months are added, was already in use, and the length of a year was considered to be $365\frac{1}{4}$ days. This type of calendar is called *Sifen* calendar ("Quarter" calendar) named after the fraction of the length of a year. And also, the divisions of a year, which finally became the 24 divisions at (or before) the early Former Han dynasty, were being formed in the Chunqiu-Zhanguo period.

As regards the descriptive astronomy, in the Chunqiu-Zhanguo period (770-221 BC), 28 lunar mansions were established. The naïve cosmology in this period was the "*tian-yuan-di-fang*" theory, which means that the round heaven is over the square earth. This model developed into the *gaitian* theory in the Former Han dynasty, in which the upper heaven and the lower earth are considered to be flat and parallel.

3. DEVELOPMENT OF THE CALENDRICAL SCIENCE

3.1 Calendar reformation of the Taichu era in the Former Han dynasty

At the beginning of the Former (Western) Han dynasty (206 BC – 8 AD), the *Zhuanxu* calendar, a kind of *Sifen* calendar, of the previous Qin dynasty (221-206 BC) was still used. In this calendar, an intercalary month was put at the end of the relevant year. A fragment of the calendar for the year 134 BC was excavated in 1972 in Shandong province, and the calendar's actual use was proved.

As the exact calendar was considered to be a symbol of the dynasty's authority, calendar reform was proposed in 104 BC under the reign of Wu-di (Emperor Wu)(reign 141-87 BC). The emperor ordered to make this year the first year of the new era "*Taichu*", and several intellectuals discussed about calendar reformation. After the proposal of several calendars, the calendar made by DENG Ping, which was the same as the calendar made by LUOXIA Hong, was finally adopted. It was used from the fifth month of the first year of "*Taichu*" (104 BC) as the *Taichu* calendar. At that time, the celebrated historian SIMA Qian was the "director of the Institute of chronology (and astronomy)" (*taishi-ling*), and DENG Ping was appointed to be the deputy director. Another contributor LUOXIA Hong is said to be the inventor of the armillary sphere (*huntian-yi* or *hun-yi*). At that time, only right ascension must have been measured. (The north polar distance, which must have been absent at that time, might have been added sometime later.)

In the *Taichu* calendar, the 19-year cycle of intercalation was used as before, but the length a year was changed into $365\frac{385}{1539}$ days, and that of a synodic month $29\frac{43}{81}$ days. Here, the denominator 81 was specially selected as it was the same as the volume of the fundamental pitch pipe. At that time, several Chinese astronomers tried to relate the tuning system with calendar, although it may appear to be farfetched for modern people. The accuracy of the length of a year and a month of the *Taichu* calendar is almost the same as that of the *Sifen* calendar.

One merit of the *Taichu* calendar is the new method of intercalation. By the beginning of the Former Han dynasty, one year from the winter solstice to the next winter solstice was divided into 24 equal periods, and 24 points of time called *jieqi* were established. It may be noted here that the *jieqi* in the modern East Asian classical calendars is the point of time when the sun passes through the point whose longitude is the multiple of 15°. In the *Taichu* calendar, alternative 12 points called *zhongqi* were selected from the 24 *jieqi*, and the name (serial number) of a month was determined by the *zhongqi* which was included in the month. As the length of a synodic month is a little shorter than the interval of the *zhongqi*, sometimes a month without *zhongqi* is produced, and this month becomes an intercalary month. This method of intercalation was followed by later Chinese classical calendars.

At the end of the Former Han dynasty, LIU Xin (d.23 AD) added a kind of method of the prediction of lunar eclipses, a method to calculate the position of five planets, and the concept of grand epoch etc. This enlarged calendar is known as *Santong* calendar, and is recorded in the chapter of calendar in the *Han-shu* (Official history of the Former (Western) Han dynasty)(ca.78 AD) of BAN Gu (32 AD-92 AD).

There is one curious matter in SIMA Qian's masterpiece *Shiji* (Record of history). At the end of the chapter of calendar in the *Shiji*, SIMA Qian described a system of calendar called *"Lishu-jiazi-pian"*.Curiously, it is not the *Taichu* calendar, but a kind of *Sifen* calendar. It may be that it is one of the rejected calendars proposed at the time of the calendar reformation. I suspect that SIMA Qian tried to oppose the farfetched denominator used in the *Taichu* calendar. Let us compare the length of a year and a month converted into decimal fraction of these calendars, which are almost identical and equally inaccurate.

Sifen calendar:

1 year = 365.25 days, 1 month ≈ 29.53085 days.

Taichu calendar:

1 year ≈ 365.2502 days, 1 month ≈ 29.53086 days.

From the above comparison, it is clear that the fraction used in the *Taichu* calendar was only artificially selected for metaphysical purpose only referring to the well-established value of the *Sifen* calendar, without any attempt to revise them by observations. This artificial fraction might have been opposed by SIMA Qian. As far as the length of a year and a month is concerned, that of the *Sifen* calendar was the single authority recognized even by the compilers of the *Taichu* calendar. Although the *Han-shu* tells that several astronomical observations were made at the time of the calendar reformation, they were for the determination of the better epoch of the calendar of the same accuracy, and not for the revision of the length of a year and a month. The inaccuracy of the *Sifen* calendar was noticed in the Later (Eastern) Han dynasty, and some astronomers attempted to revise the value.

3.2 Development of the calendrical astronomy in the Later Han dynasty

Chinese classical astronomy further developed in the Later (Eastern) Han dynasty (25 AD – 220 AD). A new calendar *Hou-Han Sifen* calendar was made in 85 AD. And also the armillary sphere was further developed. Previously, the armillary sphere in the Former Han dynasty was only used to measure equatorial coordinates, and at that time, GENG Shouchang noticed that the right ascensional movement of the sun and the moon is not uniform. This inequality corresponds to the reduction to the equator. At the beginning of the Later Han dynasty, a non-government astronomer FU An started to observe the movement of the sun and moon along the ecliptic, probably for the first time in China. Then, LI Fan and SU Tong discovered that the movement of the moon is not uniform even if it is measured along the ecliptic. JIA Kui (30 AD – 101 AD) analyzed their discovery, and concluded in his report (92 AD) that it is the real inequality of lunar motion due to the change of the distance of the moon, and that the point on the lunar orbit where the moon's speed is fastest revolves once in nine years. This inequality evidently corresponds to the equation of centre of the moon. The instrument with an ecliptic circle was originally used by non-government astronomers. The official instrument with an ecliptic circle is said to have been made in 103 AD. ZHANG Heng, a very famous astronomer of ancient China, also made an armillary sphere and a celestial globe as we shall see later.

The obliquity of the lunar orbit to the ecliptic was also found in the Later Han dynasty. This fact and the inequality of lunar motion were considered in the *Qianxiang* calendar composed by LIU Hong in 206 AD.

4. BEGINNING OF THE PREDICTION OF ECLIPSES

4.1 Eclipses in ancient China

In Ancient China, unusual heavenly phenomena were considered to be warnings to the king (or emperor) by the Heaven. If phenomena can be predicted, it is not "unusual" any longer.

So, Ancient Chinese scholars tried to make exact ephemeris with which several heavenly phenomena could be predicted more precisely than the requirement of usual daily life. Of course, the exact ephemeris was indispensable to agricultural activities etc., and was a symbol of the authority of the emperor over the agricultural society.

After determining the cycles of tropical year and synodic month, Ancient Chinese scholars tried to predict the movement of five planets and eclipses. LIU Xin, who made the *Santong* calendar at the end of the Former (Western) Han dynasty, was one of them, and started to predict the movement of five planets and lunar eclipses.

Since then, the method to predict eclipses developed in China.

4.2 Before the *Santong* calendar

The earliest Chinese literature which mentions the cycle of lunar eclipses is the treatise of constellations of the *Shiji* of SIMA Qian in the Former (Western) Han dynasty. However, the description in its present text contains a contradiction, and does not give correct cycle.

4.3 Prediction of lunar eclipses in the *Santong* calendar

The first Chinese text which gives the correct cycle of lunar eclipses is the *Santong* calendar of LIU Xin recorded in the *Hanshu*. It considers that there are 23 lunar eclipses at the time of full moon in 135 synodic months. This cycle (135/23 synodic months) corresponds to a half of modern "eclipse year".

Actually, lunar eclipses do not necessarily occur with this cycle, but do fit the cycle when they occur. Ancient Chinese people found this cycle experimentally. This kind of experimental law could not be proved at this stage, but had a possibility to become an important hint for the next development. One may suspect that the experimental law can be disproved by the absence of eclipses with this cycle. However, it is quite difficult to ascertain the absence, and the law cannot be disproved so easily. We should also note that basically no lunar eclipse occurred without prediction, if the calendrical cycle was adjusted to the actual cycle. So, the prediction must have been useful to ease people's mind at that time.

4.4 Cosmological interpretation of the eclipses

Some people in Ancient China also made cosmological consideration of eclipses. LIU Xiang (the father of LIU Xin) in the Former (Western) Han dynasty wrote that the solar eclipse is that the moon moves and covers the sun.

ZHANG Heng in the Later (Eastern) Han dynasty wrote that the lunar eclipse occurs when the moon enters the shadow of the earth.

They must have found their theory by a kind of intuition. An intuition is not necessarily true, but sometimes contributes to the development of theory.

4.5 Development of lunar theory

At the time of the Later (Eastern) Han dynasty, the theory of lunar motion also developed much. The equation of centre of the moon was found. And also the inclination of the lunar orbit to the ecliptic was found.

The discovery of the inclination of the lunar orbit made possible to make full-fledged prediction of eclipses.

4.6 Prediction of eclipses in the *Qianxiang* calendar

The *Qianxiang* calendar of LIU Hong was made in AD 206 in the Later Han dynasty, and was officially used from AD 223 in the Wu dynasty of the Sanguo period. Its treatise is recorded in the calendrical chapter of the *Jinshu* (Official history of the Jin dynasty).

The *Qianxiang* calendar formally uses the half eclipse year to predict lunar eclipses. It says that there are 1882 lunar eclipses at the time of full moon in 893 years. However, the *Qianxiang* calendar also tells the method to calculate the moon's node distance. LIU Hong writes in his treatise that the moon moves on the ecliptic between two boundaries (*xian*) around the node, which correspond to the present ecliptic limits. So, it must have been possible to predict eclipses using the node distance. In fact, the *Jinshu* tells that LIU Hong predicted the direction and magnitude of solar eclipses, which must only be possible by using the node distance.

Why LIU Hong retained the old method to use the half eclipse year in his treatise, when he could use the node distance? I suspect that he could not ascertain the exact value of the ecliptic limits, and retained the old method for safety. In any case, LIU Hong knew the astronomical meaning of the half eclipse year and its relationship with the lunar nodes. He almost created a new theory, which is not a negation of the old theory, but a synthesis of the old theory and new ideas. The knowledge of the half eclipse year was utilized to determine the time of the moon's node passage.

4.7 Prediction of eclipses in the *Jinchu* calendar

The *Jingchu* calendar of YANG Wei in the Sanguo (Three kingdoms) period was officially used from AD 237 by the Wei dynasty of the Sanguo period. Its treatise is recorded in the calendrical chapter of the *Jinshu*. It officially started to predict solar and lunar eclipses using the node distance.

It uses two ecliptic limits. One is the limit of definite eclipses, and the other is the limit of small eclipses. YANG Wei must have found these limits experimentally, and these limits are enough good.

I suppose that YANG Wei could start to use this new method officially, because he could find enough accurate limits.

We should note that the new method to use node distance was a kind of dialectical synthesis of the old method and new ideas. We can study the process of the development of scientific theories from the history of the method of prediction of eclipses in Ancient China.

5. COSMOLOGY AND ASTRONOMICAL INSTRUMENTS

5.1 Cosmology

At the time of Han dynasty, there were three theories of cosmology, namely, the *gaitian* theory (where the heaven and earth are flat), the *huntian* theory (where the heaven is spherical), and the *xuanye* theory (where the heaven is infinite). Among them, the *huntian* theory became the orthodox theory. ZHANG Heng, a famous astronomer in the Later (Eastern) Han dynasty, fully developed the *huntian* theory, and composed cosmological works, the *Lingxian* (Delicate law) and the *Hunyi* (Armillary sphere). The latter is sometimes called *Huntianyi-zhu* etc.

In his *Hunyi*, ZHANG Heng wrote that the heaven is like the shell of a hen's egg, and the earth is at its centre like the egg's yolk. Probably, the earth was considered to be flat. As the heaven was considered to be spherical, spherical coordinates could be set up. Chinese equatorial coordinates consisted of the right ascension, for which the hour circles passing through the representative stars of 28 lunar mansions are used as datum lines, and the north polar distance. The angular distance was measured in terms of *du*, which is the angular distance on the celestial sphere through which the sun moves in one day. (It may be noted here that the term *du* is used to denote degree in modern Chinese.)

It may also be noted here that some Chinese astronomers also used the polar longitude, which is the longitude of the hour circle passing through the object on the ecliptic, for which datum lines are also the hour circles passing through the representative stars of 28 lunar mansions. The conversion of the polar longitude and the right ascension was graphically made on the celestial globe.

ZHANG Heng wrote a method to convert the right ascension of the sun into the longitude on the celestial globe in his *Hunyi*.

5.2 Astronomical instruments

According to his *Hunyi*, ZHANG Heng constructed an armillary sphere called *"tongyi"* (bronze instrument) for observation, and a celestial globe called *"xiaohun"* (small sphere) for demonstration and graphic calculation. According to a historical record (*Jin-shu*), ZHANG Heng's celestial globe was rotated by waterpower in a room, and coincided with the actual sky precisely. Its construction is not recorded, but it is evidently the beginning of the water-driven celestial globe in China.

The water clock is said to have already been used in Chunqiu-Zhanguo period (770-221 BC), but its construction is not recorded. The extant water clocks date back to the Former (Western) Han dynasty, which are simple outflow-type water clock. According to his fragmental work *Loushuizhuan-huntianyi-zhi* (Construction of water-driven armillary sphere), ZHANG Heng constructed an inflow-type water clock with double reservoir. The double reservoir is to make the water-flow constant. As water is supplied by the upper reservoir, the water level and water-flow of the lower reservoir do not decrease much. This is the first attempt to make the water-flow constant in China. Due to the difference of the length of day-time and night-time, two acceptors were used for day-time and night-time respectively. The technique to make the water-flow of the water clock constant further developed in China later.

ZHANG Heng also made a seismograph called *"houfeng-didong-yi"* in 132 AD.

6. CHINESE SYSTEM OF CONSTELLATIONS

Certain knowledge of stars must go back to remote ancient period. Systematization of constellations begins from the 28 lunar mansions ("*xiu*") in China. The lunar mansions already existed in the late 5th century BC in the early Zhanguo (Warring states) period, and a wooden box on which the name of each lunar mansion is written was excavated from a tomb of this period in Hebei province in 1978.

The first Chinese literature where several constellations over the visible sky are described is the treatise of constellations in the *Shiji* (Record of history)(ca.91 BC) of SIMA Qian. Here, a little more than 90 constellations or a little more than 500 stars are described.

CHEN Zhuo (fl. ca.265–317 AD), an astronomer of the Wu dynasty of the Sanguo (Three kingdoms) period and the subsequent Western Jin dynasty, further made a comprehensive survey of constellations, and recorded 283 constellations or 1465 (or 1464) stars. Constellations other than lunar mansions were divided into three groups, and were attributed to three ancient legendary astronomers, GAN De and SHI Shen of the "Warring states" period and WU Xian of Shang (= Yin) dynasty, respectively.

Although, CHEN Zhuo's own work is not extant, his system of constellations has become the standard system of Chinese traditional constellations, and is known from later works based on CHEN Zhuo's system, such as the *Butian-ge* (Poem "Walking the heaven"). The authorship of this poem is controversial, and sometimes attributed DAN Yuanzi of Sui dynasty (581-618 AD), sometimes to WANG Ximing of Tang dynasty (618-907 AD), and some people suspect that they are the identical person.

7. EARLY CONTACT WITH INDIAN ASTRONOMY IN THE LATER HAN DYNASTY—A HYPOTHESIS

Chinese astronomy and Indian astronomy are originally independent. Both of them already had developed when Indian astronomy was introduced into China along with Buddhism. The exact date of the introduction of Buddhism into China is not known, but it can be said that Buddhism was gradually being introduced into China at the beginning of the Later (Eastern) Han dynasty or so. According to my study, the earliest information of the Indian astronomy reached China at the time of the Later Han dynasty.

At the time of the Former (Western) Han dynasty, there was no apparent foreign influence on Chinese astronomy. As Buddhism was already known at the time of the Later Han dynasty, there was a possibility that certain Indian culture including astronomy was also introduced into China.

According to my study, some fragmental information about Indian calendar reached China at the time of the Later Han dynasty. There are three reasons of my view.

(a) When the *Hou-Han Sifen* calendar was compiled in AD 85, its first month was proposed to be large, although, it was finally rejected. In the Chinese traditional calendar, the first month should be small, because the first new moon occurs at the initial point of time, and the second new moon is included in the first day of the next month. On the contrary, the first month of the Indian traditional calendar is large, because the first new moon occurs at the initial point of time, and the second new moon is included in the last day of the same month. I suspect that the rejected proposal of the *Hou-Han Sifen* calendar might have been influenced by the Indian method.

(b) The *Hou-Han Sifen* calendar has special days called *"mori"* and *"mieri"*, which did not exist in the Former Han dynasty. If one year is divided into 360 parts and one day is included within a part, the day is called *"mori"*. If the end of a day coincides with the boundaries of the parts, the day is called *"mieri"*.These days are of no use in Chinese traditional calendars, but are similar to certain concept of Indian traditional calendars, such as the method of intercalation in the *Artha-śāstra*.

(c) In Chinese traditional calendars, the midnight is considered to be the beginning of a day. However, when the date of the half moon and full moon was calculated in the *Hou-Han Sifen* calendar, daybreak was considered to be the beginning of a day. In Indian traditional calendars, sunrise is usually the beginning of a day. Therefore, the Chinese use of daybreak might have connection with Indian method.

From these three reasons, I suspect that certain information of Indian calendar reached India. However, the information must have been fragmental, and did not influence Chinese calendar much.

At the time of Sanguo (Three Kingdoms) period (mid 3rd century AD), a Buddhist text called *Śārdūlakarṇa-avadāna* in Sanskrit was translated into Chinese by ZHU Lüyan and ZHI Qian as the *Madengqie-jing*. This is the first Chinese text where Indian astronomy and astrology are explicitly mentioned. This text explains the lunar mansions and astrology based on them at length, and also mentions some calendrical information.

The astronomical system of the *Śārdūlakarṇa-avadāna* belongs to the stage of the *Vedāṅga* astronomy, which is one of the six branches of the auxiliary learning for the *Veda*. According to my study, the *Vedāṅga* astronomy was produced in North India sometime during the 6th and the 4th centuries BC. The description of astrology in the *Śārdūlakarṇa-avadāna* is also based on Indian traditional system.

The original Sanskrit version of the *Śārdūlakarṇa-avadāna* has the description of the annual variation of the gnomon-shadow, which is similar to that of the *Vedāṅga* astronomy. The Chinese version *Madengqie-jing* also has the description of the annual variation of the gnomon-shadow, but it is different from the Sanskrit original. SHINJŌ Shinzō, a pioneer of the study of the history of Eastern astronomy in Japan, pointed out that the description of the *Madengqie-jing* is based on the data around 43°N, and that the data might have been incorporated in Central Asia.

The *Śārdūlakarṇa-avadāna* was also translated into Chinese as the *Shetoujian-taizi ershiba-xiu jing* by ZHU Fahu at the time of the Western Jin dynasty (AD 265 – 316).

8. HISTORIOGRAPHY OF CHINESE ASTRONOMY

Being an agricultural land, ancient China considered astronomy, which is indispensable to make calendar for cultivation, to be a fundamental discipline for a dynasty. The *Liji* (Record of rites) and the *Da-Dai-li* (Rites compiled by Elder Dai), confusianist classics formed during the Warring States period and early Former Han dynasty, have chapters *"Yueling"* (Rules for months) and *"Xia-xiaozheng"* (Small standard of the [alleged] Xia dynasty) respectively. They are the records of naïve non-mathematical calendar and schedules for a year. The *Lüshi-chunqiu* (Spring and autumn of Mr. Lü) of Lü Buwei (3rd century BC) has a similar record. An encyclopaedic work *Huainanzi* (Master Huainan's treatises) of Liu An, the Lord of Huainan, compiled in the 2nd century BC in the Former Han dynasty, has chapters *"Tianwen-xun"* (Teaching of astronomy) and *"Shize-xun"* (Teaching of the rule of time). This is the earliest Chinese work which has independent chapters of astronomy and calendar.

The monumental work *Shiji* (Record of history) of Sima Qian consists of *benji* (basic annals of the emperors' reign), *biao* (chronological tables), *shu* (treatises of cultural topics), *shijia* (hereditary houses), and *liezhuan* (biographies). It later became the first Chinese official dynastic history, and the model of later official dynastic histories. Among the eight treatises of cultural topics in the *Shiji*, there are the *"Lü-shu"* (Treatise of tuning system), where mathematical theory of musical tuning system, which was considered to be related to the calendar in ancient China, is described, the *"Li-shu"* (Treatise of calendar), and the *"Tianguan-shu"* (Treatise of constellations). In the "Treatise of constellations", Sima Qian described a little more than 90 constellations or a little more than 500 stars all over the visible sky.

Following the style of Sima Qian with a little modification, most of all later official dynastic histories included chapters of calendar and astronomy. That we can write several papers on Chinese classical astronomy without much difficulty largely owe to this tradition started by Sima Qian.

APPENDIX

Bibliographical guide to the history of Chinese astronomy

In this appendix, I shall try to introduce references written in English (and some other European languages) as far as possible, and also mention some very important works written in Chinese and Japanese. If a reader wants to study Chinese astronomy more deeply, I would like to advise him/her to study Chinese language first, because there are so many indispensable references written in Chinese.

The transliteration of Chinese words in my paper is based on the "Pinyin" system which is officially used in present China. The transliteration used in previous Western works may be different from this system.

REFERENCES

(1) General References

The early history of Chinese astronomy is discussed in some general histories of Chinese astronomy. Among them, the following works written in English may be consulted.

Needham, Joseph (with the collaboration of WANG Ling). *Science and Civilisation in China*, Volume 3, Mathematics and the Sciences of the Heavens and the Earth, Cambridge University Press, London, 1959.

Sivin, N. "Cosmos and computation in early Chinese mathematical astronomy", *T'oung Pao*, **55**, 1969, 1-73. (This paper was also published as an independent monograph by E. J. Brill, Leiden.)

SUN Xiaochun. "Crossing the Boundaries between Heaven and Man: Astronomy in Ancient China", in Selin, Helaine (Ed.). *Astronomy Across Cultures*, Kluwer Academic Publishers, Dordrecht, 2000, pp. 423-454.

Martzloff, Jean-Claude. "Chinese Mathematical Astronomy", in Selin, Helaine (Ed.): *Mathematics Across Cultures*, Kluwer Academic Publishers, Dordrecht, 2000, pp. 373-407.

The followings are some standard histories of Chinese astronomy written in Chinese.

Editorial committee (headed by BO Shuren): *Zhongguo tianwenxue-shi* (History of Chinese astronomy, in Chinese), Kexue-chubanshe (Science publishing house), Beijing, 1981.

CHEN Zungui. *Zhongguo tianwenxue-shi* (History of Chinese astronomy, in Chinese), 4 vols., Shanghai-renmin-chubanshe (People's publishing house of Shanghai), Shanghai, 1980-1989.

CHEN Meidong. *Zhongguo kexue-jishu-shi, Tianwenxue-juan* (A History of Science and Technology in China, Astronomy Volume, in Chinese), Kexue-chubanshe (Science publishing house), Beijing, 2003.

Most of the works of Chinese scholars are written in Chinese, but the following book contributed by renowned Chinese scholars is written in English, and may be a convenient introduction for non-Chinese readers.

The Institute of the History of Natural Sciences, Chinese Academy of Sciences. *Ancient China's Technology and Science*, Foreign Language Press, Beijing, 1983.

The following is a standard history of Chinese calendars written in Japanese.

YABUUTI Kiyosi (=YABUUCHI Kiyoshi): *Zōho-kaitei Chūgoku no tenmon rekihō* (Enlarged and revised edition of the History of astronomical calendars in China, in Japanese), Heibonsha, Tokyo, 1990.

(2) Sima Qian and his Shiji

There are several publications of the Chinese original text of the *Shiji*, and are fairly popular in East Asia. I shall not list them here. There is a partial English translation of the *Shiji* as follows.

Watson, Burton (tr.). *Records of the Grand Historian of China,* translated from the *Shih chi* of Ssu-ma Ch'ien, 2 vols., Columbia University Press, New York, 1961.

This is a good translation, but the astronomical treatises are unfortunately omitted. The astronomical treatises are included in the following French translation.

Chavannes, Édouard (tr.). *Les Mémoires historiques de Se-ma Ts'ien*, Tome troisiéme, Deuxiéme partie, Ernest Leroux, Paris, 1899.

There is a good biography of Sima Qian written in English as follows.

Watson, Burton. *Ssu-ma Ch'ien: Grand Historian of China*, Columbia University Press, New York, 1958.

There are so many works on Sima Qian written in Chinese and Japanese, which I shall not list here.

(3) Development of the calendrical science

The following work contains some important papers on the calendrical science in the Han period, written in German and English.

Eberhard, Wolfram. *Sternkunde und Weltbild im alten China*, Chinese Materials and Research Aids Service Center, Taipei, 1970.

For the social context of the calendar reformation of the Taichu era, the following paper may be consulted.

Cullen, Christopher. "Motivations for Scientific Change in Ancient China: Emperor Wu and the Grand Inception Astronomical Reforms of 104 BC", *Journal for the History of Astronomy,* **24**(3), 1993, 185-203.

The following paper of mine written in English may be consulted for the history of mathematical astronomy in the Later Han dynasty.

ÔHASHI, Yukio. "Historical Significance of Mathematical Astronomy in Later-Han China", in Yung Sik Kim and Francasca Bray (eds.). *Current Perspectives in the History of Science in East Asia*, Seoul National University Press, Seoul, 1999, pp. 259-263.

For the prediction of eclipses, I would like to mention the following paper of mine written in Japanese.

ÔHASHI Yukio. "Chūgoku ni okeru nichigesshoku yosokuhō no seiritsu katei" (On the Formation of the Method of Prediction of Eclipses in Ancient China, in Japanese), *Ikkyō-ronsō (The Hitotsubashi Review)*, Vol.122, No.2, 1999, pp. 67 – 86 (= Vol.122, pp.179 – 198)).

(4) Cosmology and instruments

The following is a work in French in which Chinese cosmologies etc. are discussed.

Maspero, Henri. "L'astronomie chinoise avant les Han", *T'oung Pao*, **26**, 1929, 267-356.

The three schools of cosmology are described in the chapter of astronomy (compiled by LI Chunfeng (602-670 AD)) in the *Jin-shu* (Official history of the Jin dynasty), which has been translated into English in the following work.

HO Peng Yoke. *The Astronomical Chapters of the Chin Shu*, Moulton & Co., Paris, 1966.

And also, the following work in English, in which the text of the *gaitian* theory of cosmology is discussed, may also be consulted.

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