"Double dawn" eclipse and the rotational variation of the earth

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Abstract A record of "double dawn" at State Zheng in the first year of the reign of King Yi in Western Zhou Dynasty in the chronicle "Bamboo Annals" (Zhushu Jinian) is discussed. We think that it may be a record of an annular solar eclipse happening in 899 BC. The record and the ΔT, which describes the secular variation of the earth's rotation, are analyzed and discussed.

Keywords: solar eclipse, earth's rotation.

"Bamboo Annals" is an ancient Chinese chronicle unearthed in the 3rd century from a tomb of State Wei in Ji Jun (a shire in ancient China, it is now in Henan Province) during the Warring States period, including a record that "during the first year of King Yi double dawn appeared at State Zheng". Before Gong He epoch (in Western Zhou period) there was not a certain chronology in ancient history of China. King Yi was the 4th king before Gong He epoch, the region of his reign has not been certainly identified yet. The identification with the celestial phenomenon is a reliable basis for determining historical annals. So this record attracts the related scholars' attention. "Dawn" means the sky is bright. Why was the phenomenon called "double dawn"? It was not clearly recorded, and thus makes people feel puzzled. In 1944, Liu Chaoyang first raised his viewpoint that "double dawn" is a phenomenon

formed by a total solar eclipse happening before sunrise. Some scholars approved Liu's hypothesis. Unfortunately, the twice solar eclipses appeared on Mar. 21, 926 BC and May 12, 966 BC, which were determined by Liu and Dong Zhuobin respectively, did not confirm Liu's judgment. According to Liu's idea and referring to Oppolzer's "Canon of Eclipse", Fang Shanzhu, a Korean scholar, demonstrated that the record of "double dawn" in "Bamboo Annals" was a record of an annular solar eclipse on Apr. 21, 899 BC[1]. After this, some other scholars also discussed this record. Pang et al. (1988) identified that the recorded eclipse was a solar annular eclipse happening in 899 BC, at Zheng (now located in Huaxian County of Shaanxi Province, λ=109.8° E, ϕ=34.5° N). The phenomenon of "double dawn" needed certain astronomical conditions. Pang et al. first made the theoretical analysis and calculation in detail. In addition, they assumed that the maximum of the eclipse happened at sunrise. Their computation gave a correspondent rotational variation of the earth (ΔT is about (5.8±0.15) h). The study on "double dawn" has thus been advanced one more step[2, 3].

What was the "double dawn"? Was it a solar eclipse? What kind of solar eclipse could cause "double dawn"? Did this kind of solar eclipse exist in years of King Yi's reign? When an annular eclipse happened, the sun looked like a golden ring, the sky could not become dark entirely. Was such solar eclipse able to form "dobule dawn"? These problems remain to be proved. The observation would help us to understand these problems, if the variation of the skylight could be observed during a solar eclipse happening before and after sunrise.

1 Practical observation of the "double dawn" phenomenon

A total solar eclipse occurred close to the sunrise in Xinjiang Uygur Autonomous Region of China on Mar. 9, 1997 (for short Xinjiang, the same below). This practical observation was designed and conducted by Liu Ciyuan and Zhou Xiaolu. It is helpful for understanding the above-mentioned problems. According to the news reported, the observation center was located at Tacheng City. There were more than 20 observational sites around Tacheng City. The overall observations' items included the different altitudes of the sun, the different magnitudes of the eclipse at the middle of eclipse and the various climatic situations in all observation sites. The focal point was the variation of the skylight in the course of the solar eclipse. The observation methods included subjective feeling by visual observation and the photometry with cameras.

Tacheng City is located in the northern part of Xinjiang (λ=82°58′E, ϕ=46°45′N). This solar eclipse seen at Tacheng City was a partial eclipse. Its first contact was at 7:45 (Beijing time, the same below), third contact (middle time of the eclipse) was at 8:39, and the magnitude was 0.97, the last contact (the end of the eclipse) was at 9:36. Sunrise was at 8:53. The civil beginning of the morning twilight was at 8:22.5 (the horizon altitude of the sun was at −6°), astronomical beginning of morning twilight was at 7:11.5 (the horizon altitude of the sun was −18°).

The observation of the solar eclipse in Xinjiang has confirmed that the near total eclipse before sunrise will cause the course of the skylight changing, not only for subjective feeling by visual observations but also photometry with instruments. The skylight turned bright and then dim, then it turned bright again. In this practical observation the magnitude of the eclipse in Tacheng City was 0.97, the middle time of the eclipse happened 14 min before sunrise. The situation suggested the following: i) The solar eclipse happening before or after sunrise could really be able to form the phenomenon of "double dawn". ii) Not only the total solar eclipse is able to cause "double dawn" feeling, but all of annular solar eclipses or the near total solar eclipses are also able to lead to the feeling of "double dawn". iii) There will be difference of subjective feelings, if there is different magnitudes of eclipse or the different time intervals between sunrise and middle of an eclipse. Therefore, the greater the magnitude of an eclipse at some site, the stronger the feeling of "double dawn" caused; and the closer the time interval between the maximum of the eclipse and the sunrise, the stronger the feeling of "double dawn" caused.

In addition, according to the practical experience of solar eclipse observations at Tacheng City and the photometry measurement with instruments, if the middle of an eclipse appeared one hour earlier or more, in the stage of the last contact the eclipse would not cause the feeling of "double dawn".

Now, both observation practice and theoretical analysis confirm that the total, annular and the almost near total solar eclipses are really able to cause "double dawn". So there is very much possibility that the record in "Bamboo Annals" be a solar eclipse. With the result, what was written in "Bamboo Annals" was very much posssibly a record of a solar eclipse. Among many statements about chronology of Western Zhou Dynasty, the earliest first year of King Yi was 966 BC, but the latest one was 895 BC. The difference was about 71 years. The authors have made an investigation. Among all the solar eclipses happening in this period, the annular solar eclipse appearing on Apr. 21, 899 BC indeed possessed the considerable possibility as identified by Fang and Pang, et al.

2 The solar eclipse in 899 BC and the secular variation of the earth's rotation

The discovery of the non-uniformity of the earth's rotation is an important achievement of astronomy development in the 20th century. At present for deriving solar and lunar eclipses recorded in the history, we have to know the value of the correction of universal time ΔT, which describes the secular variation of the earth's rotation quantitatively and shows the accumulated time difference between a kept uniform time and universal time correspondingly in the same period. We express $\Delta T = ET-UT$ where ET is ephemeris time, which is one of the uniform time, UT is universal time. Generally speaking, various values of ΔT in the history were obtained through the records of observation of eclipses. Such observations include timed solar and lunar eclipses, the total, annular and near total solar eclipses, and the eclipses at sunrise or sunset. At present, the materials used of the 8th century BC are the earliest one. If we can confirm "double dawn" at State Zheng really to be an observed solar annular eclipse phenomenon closed to the sunrise on Apr. 21, 899 BC, it practically means that we unearthed a piece of timed observing record about 3000 years ago. Observation in Xinjiang showed that only a total, annular or the near total solar eclipse would cause the feeling of "double dawn", so it could be inferred that Huaxian County certainly is located in the annular eclipse zone or on the boundary of the zone. Then we can use both methods, timed solar eclipse and central solar eclipse, to calculate the corresponding ΔT, which can extend the earlier age about 200 years forward. Thus, the situation reflecting the variation of earth's rotation will have very important significance for deriving solar and lunar eclipses in remote antiquity such as in Xia, Shang and Zhou dynasties.

(i) The ΔT value derived from the method of timed solar eclipse. According to Hansen's method and J-2 Ephemeris, we selected the lunar tidal acceleration $\dot{n} = -26.''0/cy^2$, where cy shows century (the same below). On the basis of computation, we obtained the visual magnitude of eclipse and the instants of ET at various phases of the annular solar eclipse appearing on Apr. 21, 899 BC at Huaxian County, Xi'an City and some other sites[4]. The observed magnitude of eclipse, the instant of 3rd constact at Huaxian County and Xi'an City in this solar eclipse are very similar to the situation of the total solar eclipse appearing in Tacheng City on Mar. 9, 1997. The observations of the latter have confirmed that all observers have already felt "double dawn" in the time passage of the third contact 15 min before sunrise. In this way we have obtained the value of ΔT. While the middle of eclipse happened at sunrise, ΔT =5.95 h; while the middle of eclipse happened 15 min before sunrise, ΔT = 6.20 h.

(ii) The ΔT value derived from the method of the central solar eclipse. The method using the records of total or annular solar eclipses in the ancient time for studying ΔT is called the central solar eclipse method, which is based on the limited width of central eclipse zone. Since such a zone only passes through the partial district on the earth's surface, there is a longitudinal difference $\Delta\lambda$. The value of $\Delta\lambda$ is the difference between the practical position of the central eclipse's zone on the earth's surface and the theoretical position derived from a uniform time system. $\Delta\lambda$ can be converted into a accumulated value ΔT to describe the variation of the earth's rotation, which will lead to the variation of UT. In this work, the theoretical position of the central line was obtained in the ET system, then ΔT can be shown as $\Delta T = \Delta\lambda / 1.002\ 738$, where $\Delta\lambda = \lambda_e - \lambda_o$, where λ_e describes the corresponding ephemeris longitude at a certain point in the theoretical central line of the eclipse, and λ_o describes the geography longitude of observational site. In the study, we stipulated that values of longitudes measured westward are the positive.

The method of observing the central solar eclipse is mainly applicable to the case where the phenomenon of the central solar eclipse is really observed and the observational site is recorded or the site can be identified through textual research. The error in the method mainly comes from the uncertainty of the width of the central eclipse zone in the longitudinal direction at observational site. The relative error in ΔT is less for solar eclipse that happened in ancient time. This method is also suitable for the near total eclipses (solar eclipse with greater magnitude). The more the magnitude of eclipse is, the less the error will be.

The solar eclipse causing "double dawn" for the observational site is probably a near total eclipse at least or possibly it is a central solar eclipse (total or annular eclipse). It can be studied by the method of central solar eclipse. The calculated ΔT is about 6.1 h. If the solar eclipse was a central one at Zheng, the uncertain range of the ΔT possibly is about 0.2 or 0.3 h. If the solar eclipse was a near total one, the uncertain range of ΔT may reach 0.5 h. This result is not in contradiction with Pang's. The result obtained by using timing method also dropped in this error range.

3 Summary and discussion

Usually, one can use a parabolic equation to show the variation of the ΔT values in a certain historical period approximately. That is $\Delta T=ct^2$, where t is Julian century number from AD1800.0. With timed solar eclipse method we have derived the value of ΔT from the middle of eclipse happening at sunrise or the middle of eclipse happening 15 min before sunrise. The corresponding c is 29.43s/cy^2 and 30.67s/cy^2, respectively. The value of c obtained with the method of central eclipse is about (30.17 ± 2.47) s/cy^2.

We selected 32 observing records of the timed solar eclipses in the period of 800 years from Western Han Dynasty to the end of Sui Dynasty and 5 records of total or near total solar eclipses in the period from Spring and Autumn Period to the beginning of Han Dynasty. We obtained the average of c are 32.30s/cy^2 and 33.26s/cy^2, respectively[5]. It is easy to see that the former (32.30s/cy^2) matched with the third contact of the annular eclipse happening 33 min by sunrise at Huaxian County on April 21, 899 BC. The latter (33.26s/cy^2) corresponded with the total eclipse happening 46 min before sunrise. Stephenson studied 33 definite records of solar eclipses in the period of corresponding Spring and Autumn Period in China, and obtained that c is 32.5s/cy^2 [6]. Stephenson's result is close to the author's one. At the same time, we have found that if "double dawn" really was a record of the annular eclipse in 899 BC, there was a deviation in the ΔT value between this eclipse and the records of solar eclipses in the period of Spring and Autumn and Warring States. The reasons may be as follows: i) the eclipse happening at Zheng was not a central solar eclipse but a near central solar eclipse, or there was a slightly greater difference between the middle of eclipse and sunrise; ii) there may be a certain difference of the earth's rotation rate between that time (899 BC) and in the period of Spring and Autumn and Warring States. The problems remanin to be deeply studied.

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