

The investigation of meteorite stream using the Chinese historical records

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ABSTRACT

A meteorite cataloguing, gathering report, based on Chinese historical records of “Song Shi”, “Yuan Shi”, and “Ming Shi” was constructed, which consists of 52 meteorites appearing between the years 960 A.D. to 1644 A.D. Several peaks over 1 σ level are found in the bar chart of meteorites with their moving average and emerge from February to July, which also has a good agreement with the window of the moving average of meteors. Therefore, the agreement suggests that the appearance of a meteorite stream could be found in astronomical records of the historical books in China.

1. INTRODUCTION

At the night sky, one has probably seen a streak of light in a fraction of a second and quickly fades. The small, solid body while in space and before it reaches the atmosphere, is called a meteoroid. When a meteoroid enters our atmosphere and heats up, the trail of luminous gas it leaves is called a meteor. When the body lands on the ground, it is called a meteorite (Army and Schneider 2014). When the apparent brightness of the meteor reaches a magnitude around -14 or brighter, it is generally called a fireball (Di Martino and Cellino 2004). Meteorites and fireballs are interesting natural events all the time, which could have a significant influence on human civilization as well (Beech 2002). Generally, meteorites and fireballs originate from meteoroids which are the fragments of comets or asteroids spread in outer space. The meteoroid streams, which are ejected from the parent body, are organized with orbits similar to their parent (Hughes and McBride 1989). They are perturbed by radiation pressure from Sun, the Poynting-Robertson effect, and the Yarkovsky effect (Brown 1999), and by the planets, in particular Jupiter (McNaught and Asher 1999). Every time the Earth passes through a meteor stream, it will be seen that meteors appear to come from the same general

direction in the sky. Meteors of this type are part of what is called a meteor shower (Army and Schneider 2014). As Leonids and Geminids, these two famous meteor showers are caused by the meteoroid stream from comet 55P/Tempel-Tuttle (Yeomans 1981) and asteroid 3200 Phaethon (Williams and Wu 1993). Because of the diversity of source and the size spectrum of meteoroid streams, they would bring meteor streams (Southworth and Hawkins 1963), fireball streams (Terentjeva 1990), and meteorite streams (Jones and Williams 2008) as Earth encounters.

In earlier studies, scientists (Southworth and Hawkins 1963) tried to recognize meteor stream, its orbital formation, its orbital evolution, and its parent bodies that associate with the meteor shower, such as Quadrantid (Williams et al. 1979; McIntosh 1990), Perseid (Lindblad and Porubčan 1994; Brown and Jones 1998), Draconid (Beech 1986; Wu and Williams 1995), Geminid (Plavec 1950; Fox et al. 1982; Williams and Wu 1993), Leonid (Yeomans 1981; Brown and Jones 1993; Asher 1999), Orionid and Eta Aquarid (Hajduk 1970; McIntosh and Hajduk 1983; Hughes 1988), Taurid (Jones 1986; Steel et al. 1991), and Giacobinid (Davies and Lovell 1955; Davies and Turski 1961). According to these studying, the existence of the meteor streams associated with meteor showers is confirmed. The meteor stream implies that all have similar heliocentric

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orbits, whose orbital elements can be determined, and this can give a strong indication of its parentage (Jopek and Williams 2013). Hence, the observation of a large number of fireballs or meteorites also will give the orbital and structural features of fireball or meteorite streams if they existed.

Existences of the fireball streams have been established and investigated (Terentjeva 1990; Porubčan and Gavajdová 1994). Some researches indicated that the association between fireball streams and asteroids (Gavajdová 1995; Porubčan et al. 2004) or cometoids (or comet like asteroids) (Terentjeva and Barabanov 2002). In contrast to meteor streams and fireball streams, there is a little literature (Spurný et al. 2003) to discuss meteorite streams, because of rare meteorite events. For some reason, a gap appears around the meteorite category from the historical records. Many historical records of various civilizations have been documenting meteorites for a long period of time. For instance, several types of research are worked on fireball cataloguing, gathering reports for the period of the last century (Denning 1912; Baggaley 1977; Terentjeva 1990; Beech 2006), or of these ten centuries (Astapovič and Terenteva 1968; Zamora et al. 2015), and the properties of fireball streams are studying through those efforts. By contrast, in each dynasty of ancient China, the official astronomical observation agency would be established. The official astronomical observation agency recorded and kept the celestial phenomena, which will be included in the history books. To find the possible existence of meteorite streams, the astronomical records in the historical books of “Song Shi” (960 A.D. - 1279 A.D.) (TuoTuo 1977), “Yuan Shi” (1271 A.D. - 1368 A.D.) (Song 1976), and “Ming Shi” (1368 A.D. - 1644 A.D.) (Zhang 1974) in China are catalogued, gathered, and analyzed.

2. METEORITE CATALOGUING AND COMPUTATIONAL ANALYSIS

The official historical record for China is named as the Twenty-Four Histories, which are the Chinese historical books covering a period from 3000 BC to the Ming dynasty in the 17th century. These Chinese historical books include many official records of meteorites. The reason why “Song Shi”, “Yuan Shi”, and “Ming Shi” were selected is that they are the last three historical books of the Twenty-Four Histories edited by the government. These historical books are introduced in Table 1. The draft history of Qing, also named “Qing Shi Gao”, is a draft of the official history of the Qing dynasty, which was quickly published in 1928. Owing to many factual or superficial errors “Qing Shi Gao” will not be taken into consideration. Generally, the official astronomical observation agency is named “Taishiju” in the Song dynasty, “Taishiyuan” in the Yuan dynasty, and “QinTianjian” in the Ming dynasty, and recorded the celestial phenomena including meteorites. These meteorite records in the historical books contain the date and location of the occurrence, as well as the description of the occurrence process and the appearance of the meteorite. For example, the meteorite’s historical record of “Song Shi” in 1235 A.D., a meteorite falls in Jintang, Huai’an (Chengdu, Sichuan now) with sound like thunder and becomes red gravel. However, most of these historical records contain date, but not accurate moment.

Since the meteorite records use the sexagenary of the Chinese calendar for time-keeping, it needs to be converted into a Gregorian calendar. Here a meteorite cataloguing (shown in Table 2), gathering report based on “Song Shi”, “Yuan Shi”, and “Ming Shi” was constructed, which

Table 1. The Introduction of historical books in this study.

| Name of historical book | History of dynasty | Publication process |
|-------------------------|--|--|
| “Song Shi” | Starting in 960, the first year of Emperor Taizu of Song’s Jianlong Era, and ended in 1276, the second year of Emperor Gong of Song’s Deyou Era. | Through the Yuan dynasty’s initial epoch, Kublai, the founding emperor commanded his followers to compile the history of the Song Dynasty. However, as a result of the style dispute, he didn’t finish it during his tenure. Then in the March of 1343, the third year of Emperor Huizong’s reign, under the order of that emperor, the courtiers started to edit the Song Shi, the history of the Song Dynasty. Only after two and a half years, in the October of 1345, they completed this task. |
| “Yuan Shi” | Starting in 1271, the eighth year of Emperor Shizu of Yuan’s Zhiyuan Era, and ended in 1368, the twenty-eighth year of Emperor Huizong of Yuan’s Zhizheng Era. | Yuan Shi, the recording of the Yuan Dynasty, was originally written under the command of Ming’s founding emperor Yuanzhang Zhu in 1369. Then in 1370, it was the Ming dynasty’s official historical institute guided by Song Lian which really complied with the content. Unfortunately, the courtiers found that they couldn’t gain enough materials of Yuan’s later period, they had to stop editing for a while and search for more historical data. In the same year, with more data, they successfully finished Yuan Shi in a second compilation. It merely took courtiers 331 days to complete the 210 chapters. |
| “Ming Shi” | Starting in 1368, the first year of Emperor Taizu of Ming’s Hongwu Era, and is ended in 1644, the seventeenth year of Emperor Sizong of Ming’s Chongzhen Era. | It was made up of 332 rolls, compiled by the Qing Dynasty’s courtiers who were under the leadership of Zhang Tingyu. From the second year of Emperor Shunzhi to the fourth year of Emperor Qianlong, it took nearly one century to finish Ming Shi. Actually, the essential sections were completed in Kangxi’s Era. |

Table 2. A meteorite cataloguing, gathering report based on “Song Shi”, “Yuan Shi”, and “Ming Shi”, have 52 meteorites between the years 960 A.D. to 1644 A.D.

| Gregorian calendar | | Chinese calendar | | | |
|--------------------|-------------|------------------|---|-----------------------------|--------------------|
| Year | day of year | dynasty | year | the month of the lunar year | Date in sexagenary |
| 1137 | 242 | Song | the seventh year of the Shaoxing's Era | the eighth month | Ren-Yin |
| 1189 | 89 | | the sixteenth year of the Chunxi's Era | the third month | Ren-Yin |
| 1196 | 201 | | the second year of the Qingyuan's Era | the sixth month | Xin-Wei |
| 1298 | 184 | Yuan | the second year of the Dade's Era | the fifth month | Ji-You |
| 1350 | 56 | | the tenth year of the Zhizheng's Era | the first month | Jia-Xu |
| 1356 | 298 | | the sixteenth year of the Zhizheng's Era | the tenth month | Ding-Wei |
| 1359 | 144 | | the nineteenth year of the Zhizheng's Era | the fourth month | Ji-Chou |
| 1363 | 204 | | the twenty-third year of the Zhizheng's Era | the sixth month | Geng-Xu |
| 1427 | 7 | Ming | the first year of the Xuande's Era | the twelfth month | Ji-Si |
| 1470 | 204 | | the sixth year of the Chenghua's Era | the sixth month | Ren-Shen |
| 1476 | 346 | | the twelfth year of the Chenghua's Era | the eleventh month | Yi-Chou |
| 1478 | 201 | | the fourteenth year of the Chenghua's Era | the sixth month | Xin-Hai |
| 1484 | 155 | | the twentieth year of the Chenghua's Era | the fifth month | Bing-Shen |
| 1487 | 145 | | the twenty-third year of the Chenghua's Era | the fifth month | Ren-Yin |
| 1491 | 319 | | the fourth year of the Hongji's Era | the tenth month | Ding-Si |
| 1497 | 42 | | the tenth year of the Hongji's Era | the first month | Ren-Zi |
| 1497 | 86 | | the tenth year of the Hongji's Era | the second month | Bing-Shen |
| 1497 | 275 | | the tenth year of the Hongji's Era | the ninth month | Yi-Si |
| 1498 | 48 | | the eleventh year of the Hongji's Era | the first month | Gui-Hai |
| 1499 | 178 | | the twelfth year of the Hongji's Era | the fifth month | Wu-Yin |
| 1501 | 230 | | the fourteenth year of the Hongji's Era | the leap seventh month | Xin-Si |
| 1506 | 245 | | the first year of the Zhengde's Era | the eighth month | Ren-Xu |
| 1507 | 8 | | the first year of the Zhengde's Era | the twelfth month | Geng-Wu |
| 1511 | 260 | | the sixth year of the Zhengde's Era | the eighth month | Gui-Mao |
| 1514 | 160 | | the ninth year of the Zhengde's Era | the fifth month | Ji-Mao |
| 1518 | 59 | | the thirteenth year of the Zhengde's Era | the first month | Ji-Wei |
| 1520 | 38 | | the fifteenth year of the Zhengde's Era | the first month | Ding-Wei |
| 1533 | 148 | | the twelfth year of the Jiajing's Era | the fifth month | Ding-Wei |
| 1540 | 166 | | the nineteenth year of the Jiajing's Era | the fifth month | Xin-Chou |
| 1563 | 107 | | the forty-second year of the Jiajing's Era | the third month | Gui-Mao |
| 1568 | 97 | | the second year of the Longqing's Era | the third month | Ji-Wei |
| 1575 | 183 | | the third year of the Wanli's Era | the fifth month | Gui-Hai |
| 1576 | 330 | | the fourth year of the Wanli's Era | the eleventh month | Jia-Wu |
| 1585 | 219 | | the thirteenth year of the Wanli's Era | the seventh month | Xin-Si |
| 1587 | 194 | | the fifteenth year of the Wanli's Era | the sixth month | Bing-Yin |
| 1587 | 195 | | the fifteenth year of the Wanli's Era | the sixth month | Ding-Mao |
| 1589 | 57 | | the seventeenth year of the Wanli's Era | the first month | Geng-Shen |
| 1589 | 295 | | the seventeenth year of the Wanli's Era | the ninth month | Wu-Wu |
| 1591 | 168 | | the nineteenth year of the Wanli's Era | the fourth month | Xin-You |
| 1594 | 87 | | the twenty-second year of the Wanli's Era | the second month | Bing-Chen |
| 1599 | 105 | | the twenty-seventh year of the Wanli's Era | the third month | Geng-Zi |
| 1605 | 301 | | the thirty-third year of the Wanli's Era | the ninth month | Wu-Zi |
| 1605 | 302 | | the thirty-third year of the Wanli's Era | the ninth month | Ji-Chou |
| 1607 | 356 | | the thirty-fifth year of the Wanli's Era | the eleventh month | Gui-Si |
| 1615 | 89 | | the forty-third year of the Wanli's Era | the third month | Wu-Shen |
| 1618 | 326 | | the forty-sixth year of the Wanli's Era | the tenth month | Xin-You |
| 1623 | 293 | | the third year of the Tianqi's Era | the ninth month | Jia-Yin |
| 1630 | 111 | | the third year of Chongzhen's Era | the third month | Ji-Chou |
| 1636 | 278 | | the ninth year of Chongzhen's Era | the ninth month | Ding-Wei |

consists of 52 meteorites between the years 960 A.D. to 1644 A.D. The bar chart for the situation of the annual rates is plotted in Fig. 1a. To inspect the meteorite streams, the graph of meteorites for the 960 A.D. - 1644 A.D. period with its moving average (black line) is shown in Fig. 1b. Using the method of moving average (Wold 1949), the average value $f(x)$ is obtained as

$$f(x) = \frac{1}{2n+1} \sum_{k=x-n}^{x+n} p_k \tag{1}$$

where p_k is the count number of events and $n = 15$, and the window is about one month. Furthermore, the data ranges from 960 A.D. to 1644 A.D., covering about 700 years. Considering the earth's precession period about 26000 years into account, a 10 degree or 10 days of axial precession exists. To choose a one-month window will avoid the problem of axial precession and no accurate momentum. Ultimately the relation to an average value of meteorite events and date is brought out. In Fig. 1b, the blue line is the average daily occurrence frequency. Then, the red and green lines are 1σ and 2σ levels. So, there are eight peaks over 1σ level. One of these eight peaks, which is about days 189 - 193, is over 2σ level, and one of these eight peaks, which is about days 96 - 101, is near 2σ level. The existence of the meteorite streams

was implied by these peaks. Especially, the peaks occurring at the days of 41, 96, and 166 appear that a meteorite stream would be passed by Earth orbit.

3. COMPARISON WITH METEORS AND FIREBALLS

To appear the computational results of meteor and fireball are required before the meteorite streams were analyzed. There have 208791 records of meteors in the range 2007 - 2015 from the SonotaCo database (Japan, <http://sonotaco.jp/doc/SNM>), which reduced from charge-coupled devices (CCDs) of the SonotaCo Network Members in Japan. According to the above database, their bar chart of the annual rates is plotted in Fig. 2a. Then, the database from the National Aeronautics and Space Administration (NASA, <http://cneos.jpl.nasa.gov/fireballs>), 388 records of the global fireball that provides a chronological data summary of fireball events provided by U.S. Government sensors in the period of 2005 - 2015 are aggregated. In Fig. 2b the bar chart of the annual rates of fireballs is shown. Figures 2a and b show that the trends in the quantity of meteors and fireballs are similar from 2007 to 2014, and the presentations of amounts between meteors and fireballs are similar.

In Fig. 3a the bar chart of meteors with 1-day bins every year are plotted in black curves and the date with red round



Fig. 1. (a) The bar chart for the annual rates of meteorites. (b) The graph of meteorites with their moving average. The blue line is the average daily occurrence frequency, and the red and green lines are 1σ and 2σ level.

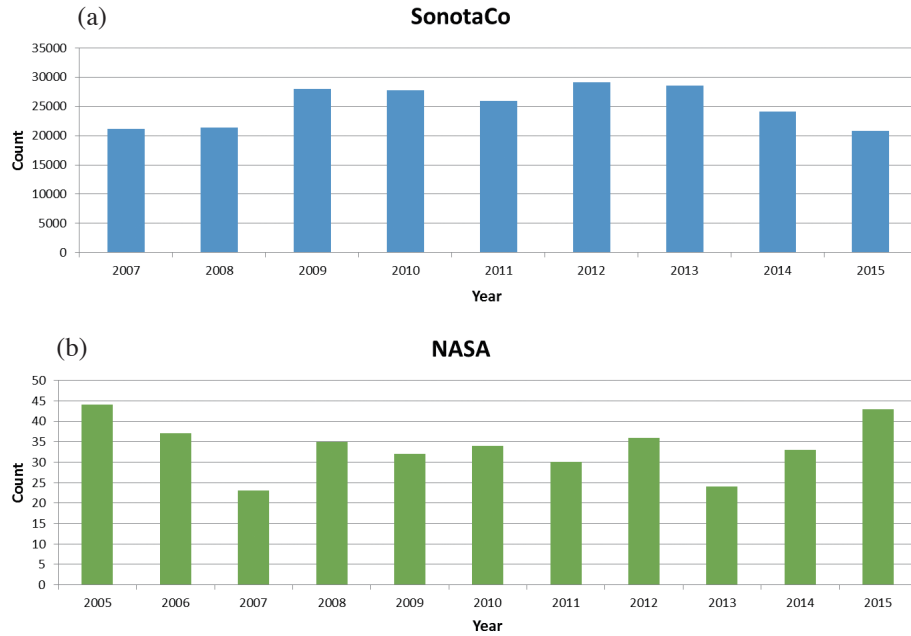


Fig. 2. (a) The bar chart for the annual rates of meteors. (b) The bar chart for the annual rates of fireballs.

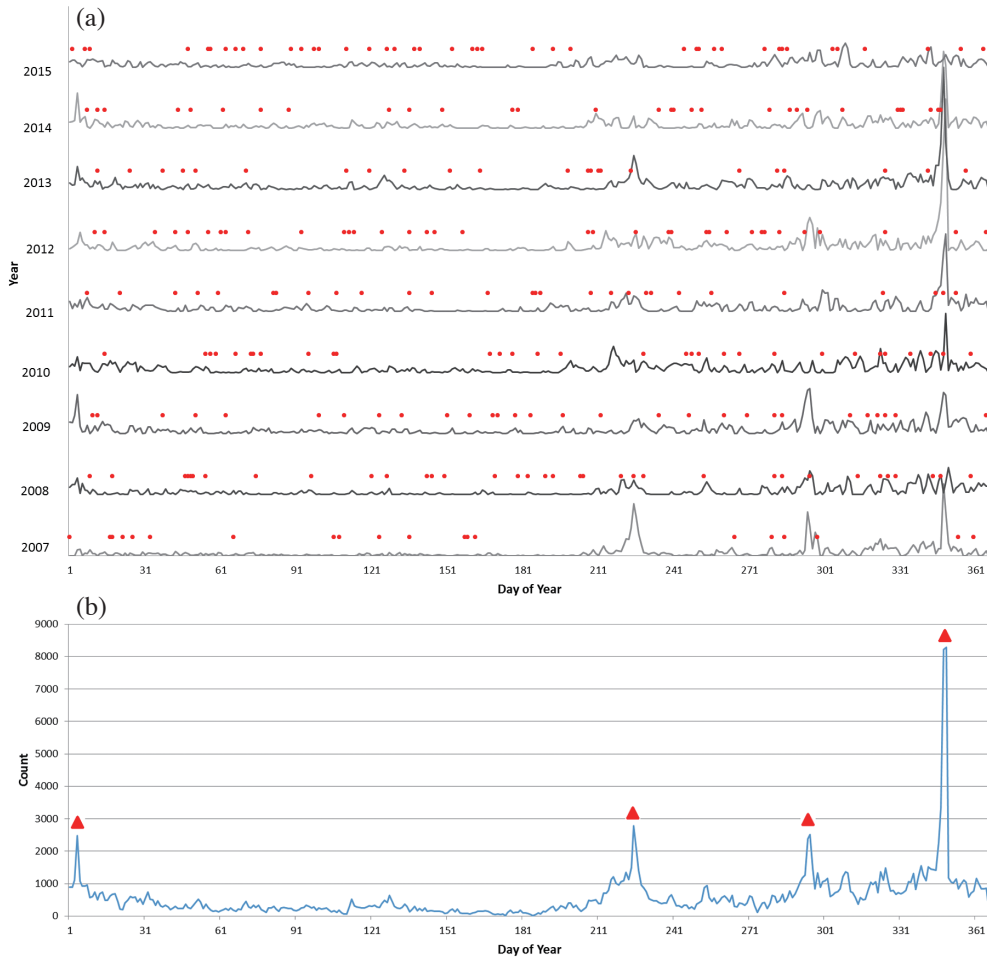


Fig. 3. (a) The bar chart of meteors with 1-day bins every year and the red round dot as fireball occurred. (b) The graph of meteors with 1-day bins. The red triangles are Quadrantids (0010 QUA), Perseids (007 PER), Draconids (009 DRA), and Geminids (004 GEM) sequentially.

dot as fireball occurred. Here it showed that the fireball that occurred does not overlap the meteor shower. These four main peaks, in Fig. 3b, that are marked by red triangle, are Quadrantids (0010 QUA), Perseides (007 PER), Draconids (009 DRA), and Geminids (004 GEM) sequentially. According to Fig. 3b, there is a window from day 31st to 181th in a year. This result is consistent with the article of Campbell-Brown (2007). For the reason the date that occurred between the fireballs and meteors, the source of fireballs is different from the meteors. The bar chart of fireballs with their moving average (orange line) is displayed in Fig. 4a, and the purple line is the average daily occurrence frequency in Fig. 4b. Then, the red and green lines are 1σ and 2σ levels. So, there are nine peaks over 1σ level. One of these nine peaks, which are about 63 days, is over 2σ level. Those peaks in Fig. 4b also mean the existence of a fireball stream, but this is not the focus of this article.

As a result of the peaks of the moving average of meteor in Fig. 4b denoting the existence of the meteor streams, the peaks of the moving average of meteorites in Fig. 1b will appear the existence of meteorite streams. However, the peaks over 1σ level emerge from days 41 - 200 for meteorites, and from days 210 - 365 for meteors. The peaks of the moving average of meteorites are different from the moving average of meteors. The peaks of the moving average of meteorites overlap with fireballs (Fig. 4a). Therefore, this implies that the source of meteorite streams similar to fireball streams, but not of the familiar meteor streams.

4. CONCLUSION

Besides Chinese historical records, modern scientists will explore meteorites also (Levin and Simonenko 1969). Therefore, some researchers raise the question of whether "meteorite streams" exist (Oberst and Nakamura 1987; Pauls and Gladman 2005; Jones and Williams 2008). In summary, according to the peaks of moving average of meteorite events in Fig. 1b, the appearance of meteorite stream could be found in this article, and these peaks over 1σ level emerge from February to July. On the other hand, the peaks of the moving average of meteors emerge from August to January and a window of the moving average of meteors from February to July. This window of the moving average of meteors can be considered as another evidence of the appearance of a meteorite stream. The model of a meteorite stream is shown in Fig. 5, and this meteorite stream could result in the window of the moving average of meteors in purifying meteor streams.

Unlike most of the existing researches, the orbital parameters of meteorite streams are not found, but some recent events support results of the current study. Chelyabinsk meteorite occurred on 15 February 2013 (Popova et al. 2013) and Che et al. (2016) observed the associated meteorite in Korea. They strongly suggested that the first range of peak

in Fig. 1b might correspond to a meteorite stream. Nevertheless, the source of meteorites would be the bigger size meteoroids which are unlikely to be possible coming from the fragments of comets or asteroids. It will be an open question as to the origin of the meteorite streams if they exist.

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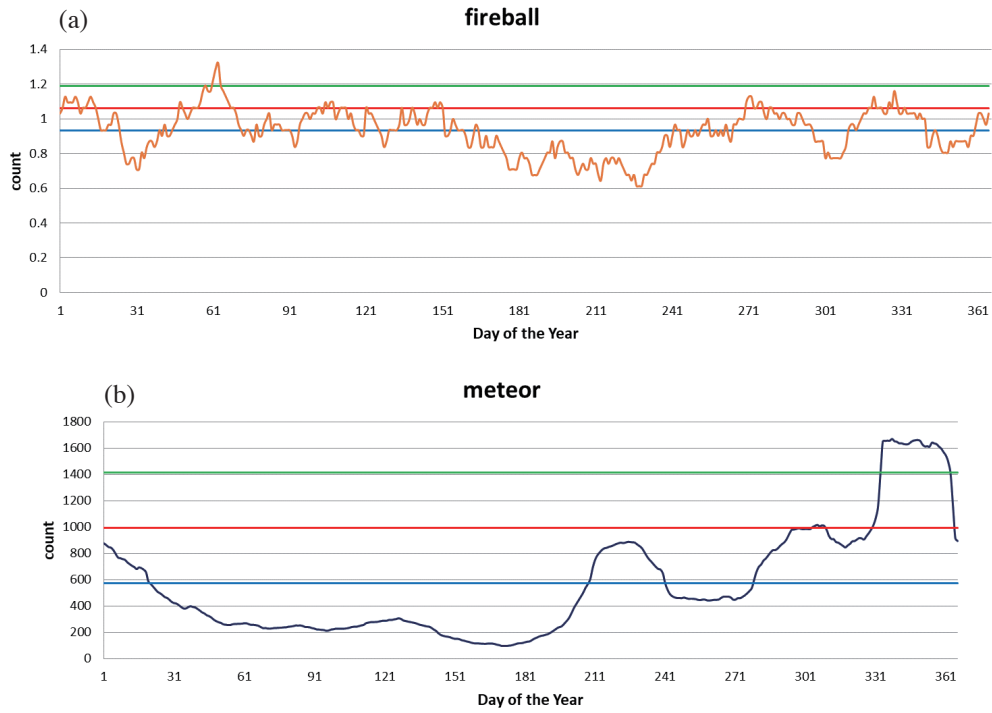


Fig. 4. (a) The graph of fireballs with their moving average. The blue line is the average daily occurrence frequency, and the red and green lines are 1σ and 2σ level. (b) The graph of meteors with their moving average. The blue line is the average daily occurrence frequency, and the red and green lines are 1σ and 2σ level.

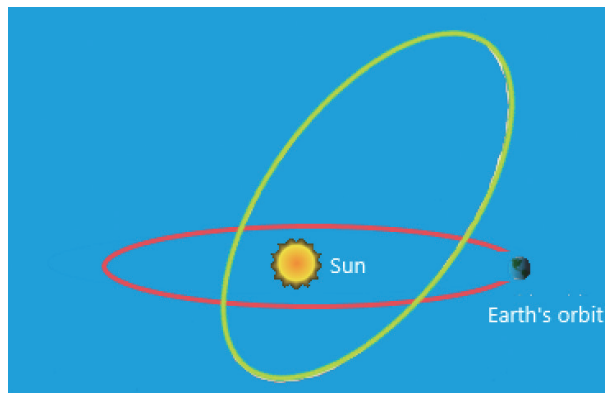


Fig. 5. The model of a meteorite stream. The red circle is Earth's orbit, and the green circle is the orbit of meteorite stream. Commonly the orbit of meteorite stream would be passed twice by Earth.

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