RAA 2015 Vol. **15** No. **9**, 1504–1512 doi: 10.1088/1674–4527/15/9/007
http://www.raa-journal.org *http://www.iop.org/journals/raa*

***R**esearch in*
***A**stronomy and*
***A**strophysics*

Searching for events in Chinese ancient records to explain the increase in ^{14}C from AD 774–775 and AD 993–994

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Received 2014 June 26; accepted 2014 December 11

Abstract According to analysis of the ^{14}C content in two Japanese trees, that grew over a period of approximately 3000 years, with high time resolution, Miyake et al. found a rapid increase at AD 774–775 and another one at AD 993–994. These increases correspond to high-energy events that happened within those years and radiated γ-ray energy of about 7×10^{24} erg toward the Earth. The origin of these events is a mystery. Such strong events should have an unusual optical counterpart, and have been recorded in historical literatures. We searched Chinese historical materials around AD 744–775 and AD 993–994, but no remarkable event was found except for a violent thunderstorm in AD 775. However, the possibility of a thunderstorm containing so much energy is unlikely. We conclude that the events, which caused the ^{14}C increase, are still unclear. These events most probably had no optical counterpart, and a short gamma-ray burst, giant flare of a soft gamma-ray repeater or a terrestrial γ-ray flash could all be candidates.

Key words: astroparticle — ^{14}C — gamma rays: general — astronomical history — astrobiology

1 INTRODUCTION

Two Japanese cedar trees recorded a significant increase of 1.2% in ^{14}C content in 774–775 (Miyake et al. 2012) (unless otherwise stated, all years in this article mean "AD"). This result is also consistent with IntCal98 (Miyake et al. 2012), which is derived from a diverse range of trees, such as Irish oak, German oak and pine (Stuiver et al. 1998). The ^{10}Be content also increased by 30%, which can be extracted from layers of ice or snow in Antarctica corresponding to around 775. According to a simulation of the temporal variations of ^{14}C content, the high energy event leading to this increase happened within one year. What kind of phenomenon radiated such a huge amount of energy toward Earth and caused the increase in ^{14}C and ^{10}Be is an interesting mystery.

Hambaryan & Neuhäuser (2013) and Pavlov et al. (2013) proposed that a Galactic short gamma-ray burst (GRB) led to the increase in ^{14}C content in 774–775. However, this short GRB was supposed to be located from 1 to 4 kpc away, and the rate (directed towards Earth) should be roughly once per 1300 years, which is much larger than the estimated rate – about 1000 Gpc^{-3} yr^{-1} (assuming a beaming factor of 25 and a typical luminosity of $L \sim 10^{49}$ erg s^{-1}) (Nakar 2007). On the other hand, there is no evidence of short GRBs located closer than 1 kpc in the last few million

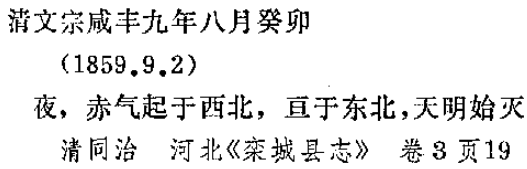


Fig. 1 The record of the aurora in 1859 from *The General Catalogue of Chinese Ancient Astronomical Records* (Beijing Astronomical Observatory 1988), which was transcribed from a historical book *Luancheng Xianzhi*. This aurora resulted from the Carrington event.

years, because such nearby GRBs could destroy life on Earth (Melott et al. 2004; Thomas et al. 2005). The inconsistency in the rate makes the short GRB scenario unlikely. Later, Miyake et al. (2013) found another ^{14}C increase event from 993–994 in a measurement from 822 to 1020. This discovery notably increases the event rate, which may make the GRB model even less likely.

Considering the Sun as a possible explanation, Melott & Thomas (2012) and Thomas et al. (2013) suggested a huge solar proton event might be the source, but the released energy should be 10 to 20 times stronger than the Carrington event (Thomas et al. 2007). However, Cliver et al. (2014) claimed that 775 is in an inactive interval of solar activity, which makes it hard to produce the required solar particle event. The Carrington event, which occurred around the beginning of September, 1859, is regarded as the strongest event associated with solar activity in the last 200 years. It greatly affected the geomagnetic field. As a result of that event, in the night, colorful polar auroras in the sky could be seen as far south as Cuba and Hawaii. These auroras were also recorded in the Chinese history book *The General Catalogue of Chinese Ancient Astronomical Records* (Beijing Astronomical Observatory 1988), as shown in Figure 1. Consequently, the solar event in 774–775 might have also produced an even stronger polar aurora. However, there is no record of such an event from that period, which will be described in Section 2.

As pointed out by Miyake et al. (2012), the event from 774–775 affected the whole world, and a huge amount of γ-ray energy ($\sim 10^{25}$ erg toward Earth) was radiated at that time. This kind of occurrence would most likely have produced some observable phenomena, which might be an astronomical event that could have been recorded. China has a long historical record found in various literature, which were mostly written by official organizations, assuring their reliability. We searched records provided by ancient literatures around 774–775 and 993–994, to investigate whether counterparts were recorded. Although we did not find any astronomical counterparts in the historical records, the details of the records for several years around 774–775 and 993–994 are listed in Section 2. In Section 3, we discuss a possible event found from the literatures, terrestrial γ-ray flashes (TGFs). We draw our conclusions in Section 4.

2 HISTORICAL RECORDS

Chinese historical literatures contain comprehensive descriptions of historical events and astronomical phenomena. The event leading to the significant increase in ^{14}C might also have produced other observable phenomena on the Earth. 775 was in the 10th year of the *Dali* era in the Tang dynasty of China. We then searched numerous Chinese historical literatures about that period. These books are: *Jiutangshu* (Liu 945), finished in the Later Jin Dynasty period, which is an officially edited history book about the Tang Dynasty for 618–907, where two issues (issue 35, 36) especially record astronomical phenomena; *Xintangshu* (Ouyang 1060), finished in the Song Dynasty, which is also an official history book about the Tang Dynasty, but contains more detailed materials, as well as a

description of astronomical phenomena; *Zizhitongjian* (Sima 1085), which is a comprehensive history book about the period 403 BC–AD 959; and several modern books and articles like *The General Catalogue of Chinese Ancient Astronomical Records* (Beijing Astronomical Observatory 1988); *A New Catalogue of Ancient Novae* (Hsi 1955); and *Chinese Astronomical History* (Chen 2006).

We list all the records during 770–780, and some other remarkable events around that period in the following. For each event, there may be duplicate records in different books. We just list a few representatives. *The General Catalogue of Chinese Ancient Astronomical Records* (Beijing Astronomical Observatory 1988) has the most comprehensive records, which are all collected from numerous ancient books. We preferentially chose records from this book. This book records more than 270 sunspots, 300 polar auroras, 300 meteorites, 1600 solar eclipses, 1100 lunar eclipses, 200 occurrences of lunar occultations of planets, 100 novae and supernovae, 1000 comets, 400 meteor showers, and 4900 meteors, from *the Spring and Autumn period* (BC 770–221) to AD 1991. However, during 770–780, except for a few comets and meteors that were recorded, there were no records of sunspots, auroras, meteorites, notable meteor showers, novae or supernovae. We also did not find records from other literatures.

All the dates are from the Western calendar. Here we list the few comets that are recorded. On 770 May 26 (Beijing Astronomical Observatory 1988, p. 408), "A comet from *Wuche*, (*Wuche*, or *Five chariots*, an ancient Chinese asterism, is in the same area as Auriga and Taurus), as long as five *Zhang* (1 *Zhang* = 3.3333 meters), disappeared on 770 July 25 (*Tanghuiyao*, vol. 43, p. 167). A comet from *Wuche* radiated brilliant light, as long as three *Zhang*. On June 15, in the north, it was white. On June 19, it gradually moved to the east, near the middle star of *Bagu* (*Bagu*, or *Eight kinds of crops*, is an ancient Chinese asterism, in the region of Auriga), then moved to *Sangong* (*Sangong*, or *Three excellencies*, is an ancient Chinese asterism, in the region of Canes Venatici) on July 9, and disappeared on July 25 (*Xintangshu.Tianwener*, vol. 32, p. 838)." There are also four other records in different books with a similar description, which are not listed here. There was another comet on 773 January 17 (Beijing Astronomical Observatory 1988, p. 408), "Long star from *Shen* (*Jiutangshu.Daizong*, vol. 11, p. 301, *Xintangshu.Daizong*, vol. 6, p. 176); there was a long star under the *Shen* (*Shen* is one of the lunar mansions which is in the region of Orion.), that extended over the whole sky. It was a long star, which is classified as a comet (*Xintangshu.Tianwener*, vol. 32, p. 838)." Other similar records are not listed here. However, comets are very unlikely to be the origin of the ^{14}C increase, and the time is not consistent with the ^{14}C event.

Several records of meteors are listed in the following: on 771 November 2 (Beijing Astronomical Observatory 1988, p. 642), "in the night, a meteor in the southwest, as big as a *Shengqi* (a container with volume about 1 liter), with a tail. The light illuminated the ground, like a shimmering pearl, longer than five *Zhang*. Starting from *Xunv* (*Xunv*, or *Girl*, is one of the lunar mansions, including four stars located in Aquarius) and disappeared in the south of *Tianshiyuan* (*Tianshiyuan* is one of three enclosures) (*Jiutangshu.Tianwenxia*, vol. 36, p. 1327)." On 18 July, 773, "There was a meteor as big as *Shengqi*, with a tail about three *Zhang*. Falling in *Taiwei* (*Taiwei*, also known as the Supreme Palace Enclosure, contains part of Virgo, Leo, Coma Berenices, Canes Venatici and Ursa Major) (*Jiutangshu.Tianwenxia*, vol. 36, p. 1327)." On 774 January 18, "a meteor as big as a *Shengqi*, with a tail, longer than two *Zhang* from *Ziwei* (*Ziwei*, or *Purple Forbidden Enclosure*, an ancient Chinese asterism, near Polaris), to *Zhuo* (Hyades) (*Xintangshu.Tianwener*, vol. 32, p. 843)." On 775 April 9, "a meteor from the west, as big as two *Shengqi*, with a tail, as long as two *Zhang*, to *Zhuo* (*Xintangshu.Tianwener*, vol. 32, p. 843). On 777 April 11, a meteor as big as a peach, with a tail as long as ten *Zhang*, from *Hugua* (*Hugua*, or *Good gourd*, an ancient Chinese asterism) to *Taiweiyuan* (*Taiweiyuan*, or *Supreme Palace Enclosure* is one of the *Sangong*) (*Xintangshu.Tianwen'er*)." In conclusion, during 774–775, the only observed astronomical events are two meteors, but they are common in other periods, and they cannot be that energetic.

It is possible that one of the literary sources is not complete and that some events might be recorded in other literatures. Therefore, we expanded the scope of time and literature that we

45	唐宝应元年建巳月壬子夜，西北方有赤光见，炎赫亘天，贯紫微，渐流于东，弥漫北方，照耀数十里，久之乃散	762	5	1	《旧唐书·天文下》
46	唐宝应元年八月庚午夜，有赤光亘天，贯紫微，渐移东北，弥漫半天	762	9	16	《新唐书·五行志》
47	唐贞元二年十一月壬午，日没，有赤气五，出于黑云中，亘天	786	12	21	《新唐书·五行志》

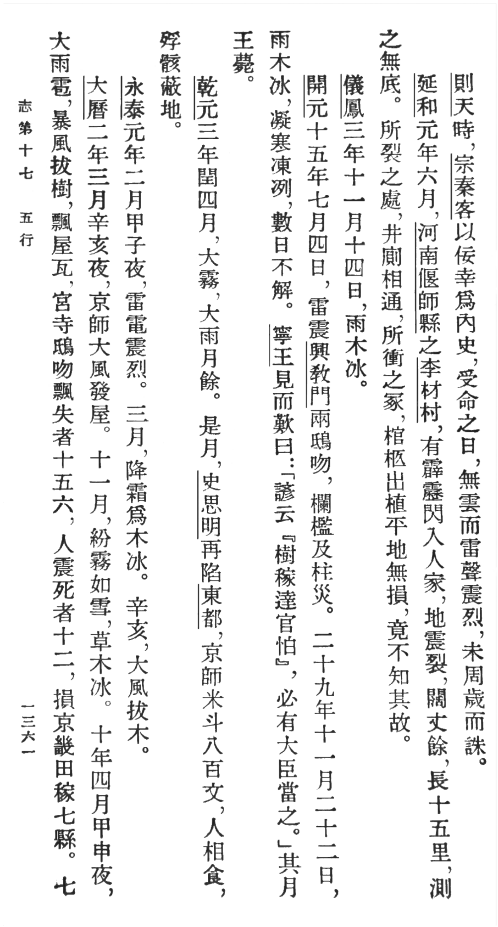
Fig. 2 The records on auroras around 774/5 in *Chinese Astronomical History* (Chen 2006, p. 951). It shows there was no remarkable aurora event from that period, which is consistent with the *The General Catalogue of Chinese Ancient Astronomical Records* (Beijing Astronomical Observatory 1988).

searched. We found in *A New Catalogue of Ancient Novae and Explorations in the History of Science* (Xi 2002, p. 113) that "there is a fireball in the sky on 745 January 8," and "in 827, the Arabic poet Haly and Babylonish astronomer Albumazar saw a nova as bright as a half moon lasting four months, in the tail of Scorpio." Xi (2002) concluded that there was no record of novae between 745 and 827. *Chinese Astronomical History* (Chen 2006, p. 866) recorded that there were only meteor events in 774–775, and the descriptions were the same as those given by *The General Catalogue of Chinese Ancient Astronomical Records* (Beijing Astronomical Observatory 1988). *Zizhitongjian* (Sima 1085) did not indicate that any special astronomical events happened during that time.

In conclusion, there was no notable astronomical event recorded in 774–775[1].

Then we turned our attention to the polar auroras, as Melott & Thomas (2012) pointed out that a solar flare might be the source of ^{14}C increase. If so, we may have records like the Carrington event (or even stronger) (Thomas et al. 2007). There are in fact records about the Carrington event in *The General Catalogue of Chinese Ancient Astronomical Records* (Beijing Astronomical Observatory 1988, p. 49): on 1859 September 2, "red light emerged from northwest, lay across northeast, disappeared till dawn (*records of Luancheng County, Hebei Province*), as shown in Figure 1. There were several other records of auroras from the same year, but for other years, the records are much rarer (as China is located at a relatively low latitude, only exceptionally strong auroras can be seen). This indicates the Sun was active during the whole year. Consequently, there must have been a much stronger polar aurora occurring in 774–775. However, there is no record included in that general catalog. The nearest two events were in 762 and in 786, as shown in Figure 2. On 762 September 16 (Beijing Astronomical Observatory 1988, p. 31), "at night, there was red light that emerged from the northwest extending to the sky and reaching *Ziwei*. It then moved slowly to the east, covering half of the sky (*Jiutangshu.Daizongji*, vol. 11, p. 270)." The next record about a polar aurora was on 786 December 21, "at sunset, the red light came from the black clouds, covered the sky (*Xintangshu.Wuxingzhi*, vol. 34, p. 894)." There was nothing recorded about a polar aurora between 762 and 786. On the other hand, solar activity is often accompanied by sunspots. However, there was also no ancient Chinese record about sunspots during that period (Beijing Astronomical Observatory 1988). Together with the lack of records about sunspots, this may indicate that a solar flare was not the source.

[1] One cannot conclude that there was no optical event in that period just because there is no record. However, considering the completeness of Chinese historical records and considering there were official astronomers in every dynasty, the assumption that no record means no notable event occurred is very likely.


則天時，宗秦客以佞幸爲內史，受命之日，無雲而雷聲震烈，未周歲而誅。

延和元年六月，河南偃師縣之李材村，有霹靂閃入人家，地震裂，闊丈餘，長十五里，測之無底。所裂之處，井廁相通，所衝之冢，棺柩出植平地無損，竟不知其故。

儀鳳三年十一月十四日，雨木冰。

開元十五年七月四日，雷震興教門兩鴟吻，欄檻及柱災。二十九年十一月二十二日，雨木冰，凝寒凍冽，數日不解。寧王見而歎曰：「諺云『樹稼達官怕』，必有大臣當之。」其月王薨。

乾元三年閏四月，大霧，大雨月餘。是月，史思明再陷東都，京師米斗八百文，人相食，殍餒蔽地。

永泰元年二月甲子夜，雷電震烈。三月，降霜爲木冰。辛亥，大風拔木。

大曆二年三月辛亥夜，京師大風發屋。十一月，紛霧如雪，草木冰。十年四月甲申夜，大雨雹，暴風拔樹，飄屋瓦，宮寺鴟吻飄失者十五六，人震死者十二，損京畿田稼七縣。七

志第十七　五行　一三六一

Fig. 3 Records about lightening from *Jiutangshu* (Liu 945). The left (*last*) two lines show the records in 775, while the other records (*on the right*) are much weaker than this year.

Considering other possible causes not related to astronomical events, we also searched different historical books describing that period. This brought our attention to the *Jiutangshu* (p. 1361) (Liu 945): “On 25 May, 775, there was extremely torrential rain in the night. The strong wind uprooted the trees. The tiles of houses were blown away. 50%–60% of *Chiwens* (a *Chiwen* is an ornament on the ridge of a roof, in the shape of a legendary animal, that was pinned to the wall by tile nails) were blown away. 20% of people died in the thunderstorm and the crops were destroyed in seven prefectures around the capital.” This record is shown in Figure 3. There were fifteen thunderstorm and lightning events that were recorded in the *Xintangshu*. To show the particularity of this thunderstorm event, we list all other records during that period (Ouyang 1060, p. 941):

On 637 May 9, “An ancient locust tree in front of the *Qianyuan* temple was struck.”

On 694 December 9, “Thundering. The sound of the thunder is *Yang*, and appeared at an inappropriate time, indicating a subordinate is attempting to usurp the throne.”[2]

On 704 June 9, “Thundering. Wind uprooted the tree, and some people were killed.”

[2] Notice that Chinese authors of historical books not only recorded records, but also occasionally made comments.

In July and August, 712, “Thunderstorm and lightning struck some villagers’ houses in Licai village, Yanshi prefecture, Henan province. The ground was split into a gap that was several meters wide and 7.5 km long, which was unfathomable. The gap made the outhouse connect to the well, or crossed the tomb, while the coffin went out of the ground without damage. The village was named Li, which is the surname of the emperor. Thunderstorm and lightning indicate cruel punishment. Ground indicates *Yin*.”

On 765 February 26, “Huge thunder in that night. There was no thunder any more until July.”

On 775 May 25, “Thunderstorm and lightning. The storm wind uprooted trees and blew away tiles. Some people were killed, and the crops were destroyed in seven prefectures around the capital.” (Descriptions of this event in the *Xintangshu* and the *Jiutangshu* are very similar.)

On 780 October 20, “Thunderstorm.”

783, “*Jiedushi Ge Shuzhai* (a commander) was assaulting *Jedushi Li Xilie*, when he led his army to *Yingqiao* (name of a place), heavy rain and thunderstorms came. 30%–40% of people could not speak, and some horses and donkeys died.”

On 798 June 18, “The 1st thunder of this year.”

In 816, “Thundering in the winter.”

On 822 June 28, “Strong wind, thunderstorm and lightning, a *Chiwei* (similar to a *Chiwen*, a decoration on the roof) dropped on the imperial ancestral temple, and broke a tree.”

On 834 April 22, “Heavy rain with an earthquake in *Dinglingtai* (a place). The ground was split with a width of twenty-six steps.”

On 843 June 7, “ Started to thunder.”

January to February in 864, “Thunderstorms.”

In January of 876, “Thunderstorms and hails.”

From these records, we find that the thunderstorm and lightning on 775 May 25 was really the strongest one, because in addition to the death of some people and the Chiwei blowing away just like in 704 and 822, crops were destroyed in seven prefectures around the capital in 775.

For the ^{14}C increase event in 993–994 (Miyake et al. 2013), we list all the records about sunspots, auroras and meteors (Beijing Astronomical Observatory 1988; Hsi 1955; Chen 2006) around 993–994, and events associated with that year.

Here we list the comet events that are nearest to the recorded times. On 990 February 2, “A star started from *Zhenxiu*, (*Zhenxiu*, also called *Chariot*, one of the lunar mansions in the region of Corvus), then had its retrograde motion and ended in *Zhang* (*Zhang*, also called *Extended net*, is one of the lunar mansions in the region of Leo). It lasted 70 days, and disappeared when it passed 40° (*Songshi.Tianwenjiu*, vol. 56, p. 1230).” On 998 February 12, “A comet from the north of *Yingshi* (*Yingshi*, also called *Encampment*, is one of the lunar mansions in the region of Aquarius), shined with a light whose length was about several *Chi* (1 *Chi* = 0.231 meters). It lasted 26 days (*Songhuiyaojigao*, vol. 52, p. 2085).”

Auroras are listed in the following: 988, “There was red light like a sunburst in the northwest at night, as long as two *Zhang* (*Songshi.Tianwenzhi*, vol. 60, p. 1308).” On 1003 July 14, “Red light lay across the sky (*Songshi.Tianwenzhi*, vol. 60, p. 1308).” There was no record of comets or auroras in 993–994.

All we can find are three meteor events (though meteors are very unlikely to be the origin of the ^{14}C increase):

On 993 May 31, “At dawn, a bluish white star from *Nandou* (*Nandou*, also called *Dipper*, is one of the lunar mansions in the region of Sagittarius) in the southeast moved to the northwest and disappeared (*Songshi.Tianwenshi*, vol. 57, p. 1235).”

On 994 October 7, “Stars were not seen, a meteor from the east, bluish white, moved slowly in the northeast, to *Zhuo* (Hyades). It was from around *Kui* (*Kui*, also called *Legs*, is one of the lunar mansions in the region of Andromeda and Pisces) and *Lou* (*Lou*, also called *Bond*, is one of the lunar mansions in the region of Aries) (*Songshi.Tianwenshi*, vol. 57, p. 1235).”

On 994 October 28, “Stars from the north of *Mao* (*Mao*, also called *Hairy head*, is one of the lunar mansions in the region of Taurus), moved slowly, crossing *Juanshe* (*Juanshe*, also called *Rolled tongue*, is a Chinese asterism in the region of *Hairy head*) and disappeared in *Lishi* (*Lishi*, also called *Whetstone*, is a Chinese asterism in the region of *Hairy head*) (*Songshi.Tianwenshi*, vol. 57, p. 1235).”

Here we also list the records of thunderstorms from 980 to 1000, to find out if there was a huge thunderstorm event in 993 or 994.

On 995 May 30, “Thundering and lightning in the capital city, and the water was several feet deep on the road.”

In July or August, 977, “Feng Yi, a businessman trading cattle, was killed by lightning in Jingcheng county.”

In September, 989, “Liu Zheng, a resident in Xinghuajun, was killed by lightning, and a sign ‘very unfilial’ was carved on his chest.”

In August, 992, “Blew hard and rained heavily in Sizhou. The column of the Sengjia tower was struck by thunder.”

People from this time thought that lightning and thunder always occurred together and that people could be killed and objects could be destroyed by thunder. On 995 April 30, “Thundering without sound. The emperor called in Zhao Zhao who was the official astronomer and asked the reason. Zhao Zhao said: ‘According to the augury books, thundering without sound is the sign of the policy of leniency’. In August, the wind blew hard and it rained heavily in Sizhou. The column of the Sengjia tower was struck and the belfry was destroyed by thunder.”

On 998 February 17, “Thunder and lightning in the northwest of the capital city.” In November or December, “Thundering located in Yingzhou county, Shunanjun county and the northwest part of of the capital city.”

From these records, we cannot find any thunderstorms or lightning in 993 or 994. This may reduce the possibility that thunderstorms and lightning caused the ^{14}C increase though it is possible that those events in 993–994 were not recorded.

3 TERRESTRIAL γ-RAY FLASH MODEL

From the description above on the details of thunderstorm and lightning events in the *Xintangshu*, we can infer that the thunderstorm and lightning event which occurred in 775 led to the heaviest damage. Though the literature just recorded the area next to the capital, considering that information could not be easily disseminated during this ancient time, it is possible that a much larger area was heavily destroyed by that event (or a series of thunderstorm and lightning events). We suppose that there could have been an extremely energetic thunderstorm and lightning event in 775, and the γ-ray counterpart might also be very energetic, which could have caused the ^{14}C increase.

Since the *Compton Gamma Ray Observatory* was launched in April 1991, it has recorded numerous γ-ray flashes from the Earth (Fishman et al. 1994). Researchers who study high-energy atmospheric physics have found that X-rays and γ-rays can be emitted by lightning. Thunderclouds are thought to be the source of TGFs (Dwyer et al. 2012). There are two characteristics associated with TGFs: one is that the spectra of TGFs are much harder than gamma-ray bursts, solar flares and other cosmic sources; the other is that their duration is short (Fishman et al. 1994). Fishman et al. (1994) estimated the energy of a typical TGF is on the order of 10^8 to 10^9 erg at a typical distance to the source of 500 km, supposing isotropic emission. Thunderstorms can also produce neutrons. Babich (2006) estimated that the number of neutrons generated from a common TGF would be 10^{15}. However, the energy of common TGFs is far less than the 7×10^{24} erg that is required for the ^{14}C content to increase by 1.2%. The effect of neutrons generated from a common TGF is negligible (Babich 2006). It is still possible considering that a significant increase in ^{14}C only occurred once in 3000 years. Fuschino et al. (2011) estimated the global rate of TGFs is 220–570 TGFs per day. If

we use the upper limit of 570 TGFs per day, there will be about 2×10^5 TGFs per year. Supposing the same amount of energy needed for lightning goes into generating high energy γ-rays, the total energy from TGFs in a normal year is about 10^{14} erg, which is much less than the energy required to produce the increased abundance.

Assuming the number of TGFs versus its energy obeys a power law relation, we can make a rough estimate of the rate of huge thunderstorms and lightning events. For a general thunderstorm and lightning event, the total energy is about 10^9 erg, and the rate is around 10^5 TGFs per year. We do not have the slope of the relation for energy. For an estimate, if one needs the ^{14}C increase that comes from the TGF, the rate of an event with 7×10^{24} erg should be $\sim 10^{-3}\,\mathrm{yr}^{-1}$ (in the past $\sim$2000 years from 774 until now, there were two ^{14}C increase events that have been discovered). Then the slope should be $\alpha \sim -0.5$, where α obeys $\frac{\mathrm{d}N(E)}{\mathrm{d}E} \propto E^{\alpha}$, and $N(E)$ is the rate of lightning with total energy E. This slope is too shallow and hence unlikely[3], even though the energy (7×10^{24} erg) might be the total energy of all the TGFs during that year. If we consider the absorption of the atmosphere, the real energy of a typical TGF might be much larger than 10^9 ergs, possibly adding credence to this scenario.

Though we did not find evidence of significant destruction by thunderstorm and lightning events in the year 993–994, this may not rule out the TGF model as the corresponding thunderstorm and lightning event that could have occurred in an area which has no historical records. Unlike astronomical events, which can be seen by official astronomers on any clear night, thunderstorm and lightning events are more local and very common. Only very special events may interest people enough to record them. Considering the widely dispersed population and the poor communication at that time, it is very likely that such an event occurred but was not recorded.

4 CONCLUSIONS AND DISCUSSION

The increase of 1.2% in ^{14}C within one year should have been an extremely energetic event with $\sim 7\times10^{24}$ erg in the form of γ-rays being radiated toward Earth. These events, occurring in 774–775 and in 993–994, should have had some observable counterparts, which could have been observed by the people in those eras. China has long and detailed historical records in ancient literatures. We searched for counterparts in that period. Unfortunately, except for a few meteors and comets, which are common phenomena, there are no notable astronomical records for 774–775 and 993–994. This means that neither a supernova, solar flare, meteorite nor comet is likely to be the source.

We found that thunderstorms and lightning were much more intense in 775, compared with other periods. The corresponding TGF might also be intense, which could cause the increase in ^{14}C. However, the rate of thunderstorms (accompanied by TGFs) extending to energy $\sim 7\times10^{24}$ erg is too low to be likely, and the special TGFs (correlated to the ^{14}C increase) do not originate from normal thunderstorms and lightning.

Regarding historical Chinese records, an event with a bright optical counterpart has been ruled out, which confirms Miyake et al. (2012)'s conclusion that a normal supernova is unlikely. Here we can conclude that the event which caused the ^{14}C increase very likely did not have an optical counterpart. A short gamma-ray burst and TGF are still candidates. According to Hambaryan & Neuhäuser (2013), a giant flare of a soft gamma-ray repeater located at 1 to 4 kpc is also possible, which may be a normal pulsar at present.

[3] The slope of population versus energy is often around –2 or even less, like a shock accelerated electron's distribution being around –2.2 (Bednarz & Ostrowski 1998), number of X-ray flares versus the total energy in many different astronomical objects being around –1.5 (Wang & Dai 2013), and spectral index of ultrahigh-energy cosmic rays being around –2 (Nagano & Watson 2000). This slope ($\alpha < -2$) guarantees the integral of the total population not going to infinity if there is no cutoff in the high end.

Although the records from Chinese literature are very rich, it would be worthwhile searching records from other countries. A similar analysis of the trees from other regions would also be very helpful to confirm the global nature of the ^{14}C increase.

Acknowledgements We would like to thank Bing Zhang, Ding-Xiong Wang, Qingwen Wu, Biping Gong, Weihua Lei, Zigao Dai and Fayin Wang for their helpful discussions, and the anonymous referee for his useful comments. This work was supported by the National Natural Science Foundation of China (Grant No. U1231101), and the National Basic Research Program of China (973 Program, Grant No. 2014CB845800).

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