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Possibility of the detection of past supernova explosion by radiocarbon measurement

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Gamma-ray emission from a supernova explosion, which occurred near the earth, can produce detectable amount of radiocarbon in the atmosphere of the earth. However, terrestrial radiocarbon content is modulated also by change of solar activity with 11-year periodicity. In order to investigate how the effect of supernova explosion is, we measured radiocarbon content of tree ring samples for the extended duration of AD 992 to 1072, which corresponds to an appearance of SN1006 and SN1054. Radiocarbon contents were determined with the precision of 0.28 % using an accelerator mass spectrometer in Nagoya University. Our results show increases of radiocarbon content in the years near supernova explosions. However, one can see the cyclic feature in the variation, which can be considered as the 11-year cycle variation by the solar activity change as to the cycle length and the amplitude. Therefore, most part of the increases is considered to be the variation caused by solar activity. Conditions for possible detection of supernova explosion are discussed.

1. Introduction

Radiocarbon (^{14}C) is usually produced by galactic cosmic rays through the nuclear interaction with atmospheric nuclei such as nitrogen and oxygen. Produced ^{14}C forms CO_2 and circulates in the carbon reservoirs within the global carbon cycle. In this way ^{14}C is taken to plants through photosynthesis and stays for some time inside it. Dead plants or tree rings keep the ^{14}C nuclei inside while ^{14}C decays radioactively with a half-life of 5730 years. We can know the cosmic ray intensity at the time when its metabolism stopped.

Also gamma rays can produce ^{14}C through photonuclear reaction in the atmosphere. If a large amount of gamma rays come to the earth, the production of ^{14}C will be recorded in terrestrial archives such as tree rings. One of most possible sources of intense gamma rays is supernova explosion, which occurs nearby the earth [1]. Damon et al. [2] claimed that they found the evidence of supernova explosion in ^{14}C content in tree rings around AD1006. However, the duration of their measurement is rather short and the structure of the variation curve was unclear. Therefore we have measured radiocarbon content for extended duration around AD1006 and even to more recent years. We report the results of our measurements and discuss on the possibility of supernova detection.

2. Supernovae

Some past observations of supernova explosion in the last millennium are listed in table 1 [3, 4]. These are based on written records of historical documentation mainly from East Asia. The supernova SN1006 is almost the nearest one with a distance of 2 kpc from the earth. By measuring ^{14}C content for SN1006, we will be able to compare our results with that of Damon et al. Moreover, this duration could be extended to the more recent side of time so that SN1054 is included in the data. SN1006 may be assigned to be a type Ia supernova, while the type was determined by the brightness found in the documentation. The type Ia supernova is considered to emit 10^{51} erg. SN1054 is the type II supernova and considered to emit more energy in the explosion than type Ia.

Table 1. Historical supernovae and remnants in the last millennium [3, 4]

Supernova	Year AD	Historical record	Remnant	Distance (kpc)[2]	Distance (kpc)[3]	Type
SN1006	1006	Japan, China	PKS 1459-41	1.4	2.0	Ia
SN1054	1054	Japan, China	Crab	2	2.2	II
SN1181	1181	Japan, China	3C 58	2.6	8.0	II
SN1572	1572	Tycho, China, Korea	Tycho	2.3	7.0	Ia
SN1604	1604	Kepler, China, Korea	Kepler	4.4	10.0	Ia
---	1680	---	Cas A	2.8	3.4	II

3. Sample preparation

Sample wood was taken from Yaku Island in southern Japan. The geographical location is 30°N, 130°E and 950 m asl. The tree was cut in 1956. It was dendrochronologically dated. We have measured ^{14}C content in the tree rings from AD992 to 1072, annually or every other year. This duration includes the dates of SN1006 and SN1054 (Crab) explosions. The single-year tree rings were carefully separated and washed with distilled water in ultrasonic bath. Then the samples were bleached in a $NaClO_2/HCl$ solution at 80°C to remove lignin. After the bleach the samples were washed with HCl solution. Then the samples were treated with NaOH solution at 55°C to obtain α-cellulose, then neutralized with HCl solution and finally rinsed with distilled hot water. The extracted cellulose was combusted with CuO in vacuum and converted to CO_2, which was successively purified with cold traps (-90°C and -130°C) to remove water and sulfide. The purified CO_2 was reduced with hydrogen gas under iron catalyst at the controlled temperature of 620°C to be converted to graphite as targets for the ion source of accelerator mass spectrometers (AMS). Standard reference samples (NIST SRM4990C, oxalic acid) and blank samples for determination of the background (commercial oxalic acid from Wako Pure Chemical Industries) were also converted to graphite in the same way. Measurements were done with AMS at Nagoya University. Typical precision of measurements was 0.28 %.

4. Results and discussion

4.1 Result on SN1006

Figure 1 shows the measured results of ^{14}C contents for the period from AD 992 to 1028. The data obtained by Damon et al. [2] are also shown for comparison. Both data are almost consistent with each other within the measurement errors. The shapes of the two curves are similar. An increase of ^{14}C content is seen around AD1010 to 1014, which is close to 1006, the year of SN1006 explosion. The magnitude of increase is about 5 permil.

4.2 ^{14}C increase by supernova

Here we consider the increase of ^{14}C due to supernova explosions. We assume that gamma rays are emitted within a few years from supernova explosion and the emission lasts for a few years at most, the emission of gamma rays is isotropic, and the energy spectrum of gamma ray emission from supernova is subject to a power law with an index of –2.5. When gamma rays enter the earth's atmosphere, they interact with atmospheric atoms and develop electromagnetic showers while competing with photonuclear interaction. We computed the neutron production yield of gamma ray with GEANT4 simulation code and photonuclear cross section data [5]. Result is shown in Figure2. The neutron yield has a maximum due to resonance absorption at gamma ray energy of 25 MeV and a constant value above 100 MeV. Using this result and assumptions above, we obtain a numerical value of ^{14}C production yield as 130 ^{14}C atoms per 1 erg of total gamma ray energy by integration with gamma ray energy over 10 MeV. Then, gamma ray energy necessary to make increase of 0.5 % of ^{14}C content in the atmosphere is estimated to be 5×10^{50} erg, which is smaller than expected total explosion energy of 10^{51} erg but rather too high because the explosion energy should be shared to several processes.

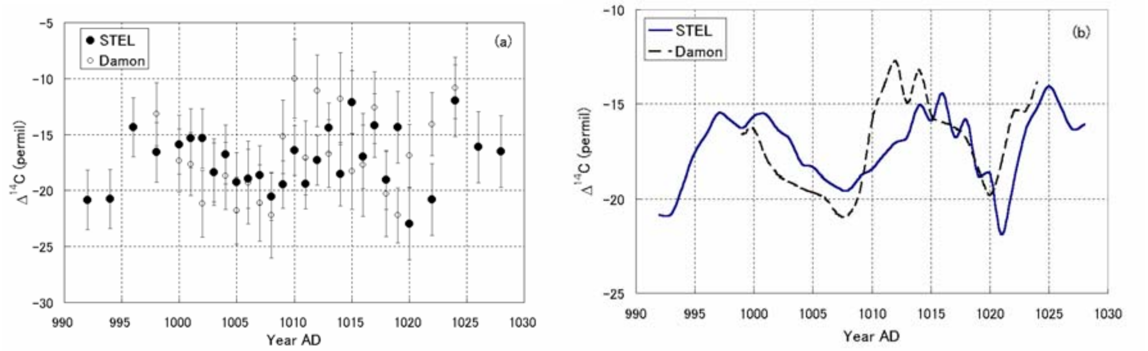

Figure1 Radiocarbon content in tree rings for the period from AD992 to 1028; (a) raw data and (b) 3-year moving average.

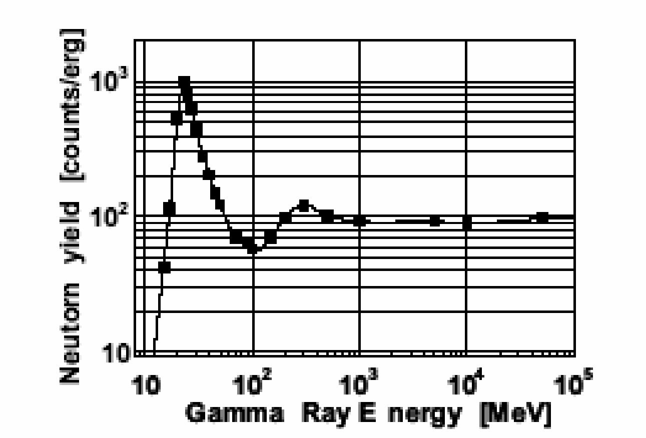

Figure2 Neutron yield by gamma rays in the atmosphere simulated with GEANT4

4.3 ^{14}C change by solar activity

^{14}C content in the atmosphere depends on solar activity change with 11-year periodicity. The amplitude of the variation is about 4 permil [6]. Variation of ^{14}C content in Figure1 shows a periodic structure. The period is 12-14 years and the amplitude is 5-6 permil. This is similar to those due to solar activity. Therefore, the variation of ^{14}C content measured in this experiment is consistent with that due to the solar activity. In order to detect an increase of ^{14}C due to supernova explosions, the total energy of gamma ray entering earth's atmosphere, which depends on source energy and distance from the earth, should be larger than that of SN1006.

4.4 SN1054

To search more energetic supernova explosion, we measured ^{14}C content in tree rings around AD1054, when SN1054 exploded and the Crab nebula was created. The distance of SN1054 from the earth is about 2kpc, which is almost same as that of SN1006. Figure 3 (a) shows the measured results together with that of Damon et al. [7]. Both data could be connected smoothly. Figure 3 (b) shows the data filtered by band-pass of 7-35 years. Also in this case we see periodic structure and no meaningful increase due to supernova around or later than AD1054. Therefore, gamma ray emission energy of SN1054 was less than 5×10^{50} erg.

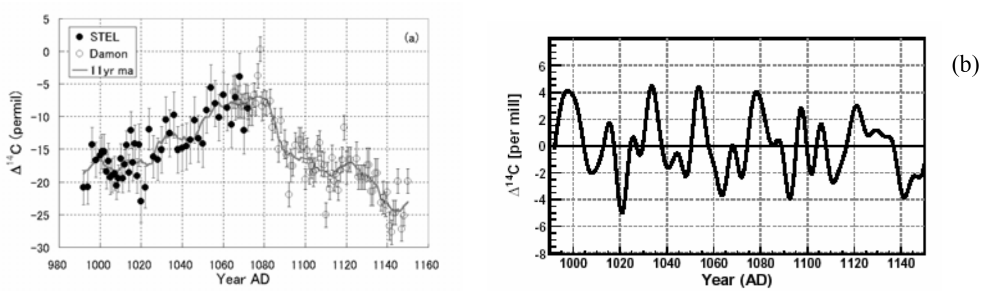

Figure 3 Radiocarbon content in tree rings for the period from AD992 to 1078 together with those from 1065 to 1150 by Damon et al. [7]; (a): raw data, (b): 7-35 year filtered data

5. Conclusion

We have measured ^{14}C content in tree rings during the years corresponding to the supernova explosions of SN1006 and SN1054. There is no evidence of explosions in the ^{14}C content. It is likely the variation of solar activity. The gamma rays emitted in supernova explosions around 2kpc from the earth are expected to create increase in atmospheric ^{14}C content only by a few permil at most according to the rough estimate. This is comparable to or less than the change of ^{14}C content due to solar activity. Therefore, nearer supernova explosion must occur to give increase of ^{14}C over solar activity.

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