Mysterious abrupt carbon-14 increase in coral contributed by a comet

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A large and sudden increase in radiocarbon (14C) around AD 773 are documented in coral skeletons from the South China Sea. The 14C increased by ~15% during winter, and remain elevated for more than 4 months, then increased and dropped down within two months, forming a spike of 45% high in late spring, followed by two smaller spikes. The 14C anomalies coincide with an historic comet collision with the Earth’s atmosphere on 17 January AD 773. Comas are known to have percent-levels of nitrogen by weight, and are exposed to cosmic radiation in space. Hence they may be expected to contain highly elevated 14C/12C ratios, as compared to the Earth’s atmosphere. The significant input of 14C by comets may have contributed to the fluctuation of 14C in the atmosphere throughout the Earth’s history, which should be considered carefully to better constrain the cosmic ray fluctuation.

Carbon-14 (14C) is a cosmogenic isotope of C formed on Earth primarily through radiation of atmospheric nitrogen by the reaction: 14N(n,p)14C (refs. 1–4). Its abundance in the atmosphere varies with time, which is generally attributed to variations in the earth’s magnetic field, solar activity and changes in the carbon cycle. A large and sudden increase in 14C of ~12% was reported from a tree ring study in Japan to have occurred between AD 774 and AD 775 (hereafter M12). Their modeling showed that the atmospheric level of 14C must have jumped over the course of no longer than a year, corresponding to an increase 10 times larger than the average production from Galactic cosmic rays and 20 times larger than that expected over 2 × 11 yr solar cycles. The measured values were shown to be too large for a solar flare or local supernova. Given that no detectable increase in 14C corresponding to supernovas SN 1006 and SN 1054 were observed, it is argued that much higher energies would be required for the M12 event, if it is related to a supernova. Alternative explanations for this mysterious 14C elevation include a highly energetic radiation burst, e.g., proton storms from giant solar flares3, a giant cometary impact upon the Sun4, or floods of γ-rays from supernova explosions5. Such high levels of radiation however, might also cause mass extinctions6, which are absent following the M12 event. Moreover, it has been argued, based on historical records, that no superflares have occurred in the Sun during the last two millennia7.

A simulated carbon cycle model10 suggested that the strength of the M12 event was significantly overestimated by the previous study2. One key issue is the duration of the 14C input. Based on modeling, it has been proposed that a tree ring record of the event could be explained by a spike in 14C production that lasted less than 1 year. However, owing in part to the annual resolution of the 14C data, they could not assess the duration in more detail. Porites coral with an annual growth rate ≥ 10 mm/yr has now provided a high temporal-resolution 14C record15.

One 1.2-m fossil Porites coral, XDH, was drilled from the Xiaodonghai Reef (18°12.46’N, 109°29.93’E) from the northern South China Sea in 1997. We analysed 14C contents for half-annual-resolution subsamples at depths of 1.04–42.65 cm and ~2-year biweekly-resolution subsamples at depths of 12.25–17.19 cm (Fig. 1, Table S2 and S3).

Results

The 14C increased by ~15% in the winter of AD 773 and remained roughly constant for ~4 months, and then jumped up by another ~45% within four weeks and then dropped down in late spring, forming a spike...
of 45% high. This is followed by two smaller spikes of > 20% over the next 6 months until fall, and then maintained ~15% higher than normal values over the following several months (Fig. 1b). We obtained a 230Th date of AD 783 ± 14 (table S1) at a depth of 2.15 cm, which is 7 annual growth bands above the layer containing the onset of 14C anomalies at a depth of 16.11 cm and corresponding to an age of AD 776 ± 14. When the previously published tree ring spectrum7 was examined, the 14C content had actually started to climb in AD 773 (Fig. 1d). There are no other 14C increases until 200 yrs later16. Considering dating errors, the major 14C increases we observed are also likely to have occurred in AD 773 (Fig. 1a).

**Discussion**

The coral 14C spectrum shown in Fig. 1 is difficult to be explained using normal production pathways from Galactic cosmic rays. The abrupt 14C increase by ~45% within two weeks (Fig. 1b) requires a radiation intensity 100 times stronger than the previous estimation for M12. Since the residence time of carbon dioxide in the atmosphere is 5–15 years17,18, 14C spikes in coral suggest highly uneven distribution. It is well established that a comet collided with the Earth’s atmosphere from constellation Orion (or Shen in traditional Chinese astronomy) on 17 January AD 773, the 7th year of Emperor Dai Zong of the Tang Dynasty. The phenomenon (hereafter Dai7) lasted less than one day and had an accompanying coma that...
tonnes of materials would then be required to explain the 14C abundance of 10% in the comet, a total of $10^8$ tonnes. Assuming an average 14C/12C ratio of 1.

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The coincidence of Dai7 and the 14C,10Be spikes in tree rings and coral suggests that comets might also contributed significant amount of 14C to the Earth’s atmosphere episodically.

Figure 2 | A cartoon illustrating our proposed mechanism causing a 14C spike—the collision of the Dai7 “Comet” with high 14C and 10Be contents with the Earth’s atmosphere. As it descends, 14C and 10Be is released until the comet burns out. This spike of cosmogenic 14C is first added to the atmosphere with its originally very low 14C, and the additional carbon is then incorporated into coral from the South China Sea and Japanese trees. The original record of the Dai7 “Comet” event (in Chinese with translation) is also shown in the lower left corner of the cartoon. Photos are provided by Yi Liu.

It is quite possible that Dai7 resulted in the M12 global abrupt 14C increases recorded in tree rings and corals. Comas are known to have percent levels of nitrogen by weight (in the forms of NH3,NH2,NH,etc) and are heavily exposed, as compared to nitrogen within the earth’s atmosphere because of lacking a magnetic field protection. Considering that meteorite usually has 14C and 10Be about two orders of magnitude higher than those of rocks from the Earth’s surface, it is reasonable to propose that coma and comet may be expected to have 14C/12C ratios several orders of magnitude higher than that of the Earth’s atmosphere. Generally, 14C occurs in very low concentrations in the Earth’s atmosphere, i.e., no more than one part per trillion of the total carbon content of the atmosphere. The total amount of preindustrial 14C in the atmosphere was ~150 metric tonnes. Assuming an average 14C/12C ratio of 1 x 10^-3 in the Dai7 comet, ~150 million metric tonnes of C from the Dai7 event would double the 14C content of the Earth’s atmosphere. Assuming a C abundance of 10% in the comet, a total of ~30–150 million metric tonnes of materials would then be required to explain the 14C anomalies. This is only about 1–3% of the estimated total mass-loss of Haley’s Comet in 1910 (ref. 28). With the considerable uncertainties surrounding the dispersal of cometary material throughout the atmosphere and shallow oceans, such a process seems commensurate with the observed 14C increases (Fig. 1).

The coma 14C would have been dispersed into the Earth atmosphere heterogeneously (Fig. 2). Because the coma is far better exposed to cosmic radiations than the nucleus, it should have a much higher 14C/12C ratio. A considerable proportion of the coma with its higher 14C/12C content is probably scattered and absorbed into the outer atmosphere. The bulk of the cometary material with 14C/12C values that are much lower than that of the coma, but still considerably higher than the Earth’s atmosphere, may be expected to descend into the troposphere and become incorporated into corals and trees. Four months later, the high 14C/12C material captured in the outer atmosphere (stratosphere) mixes downward into the troposphere, a process facilitated by summer storms, and is absorbed by corals, resulting in their high and fluctuating 14C spikes in coral (Fig. 1b).

As an alternative, short radiation bursts, e.g., the merger of two magnetized neutron stars, can produce a spinning black hole and launch a relativistic energy jet as observed in short γ-ray bursts that might also explain the brief input of 10Be data in this study. Nevertheless, 10Be is another cosmogenic isotope formed through spallation of nitrogen12,14N(p,α)10Be, or oxygen, which often co-varies with 14C. The increase in 10Be can also be interpreted by the Dai7 event. The comet with abundant oxygen and nitrogen, could likewise produce high amounts of 10Be under exposure to cosmic radiation.

Consistent with the 14C increase, there was a 30% increase in the decadal 10Be flux record in Dome Fuji from AD 755 to 785 (refs. 7,16,29), which has been attributed to a burst of high energy γ-rays13. We were not able to obtain 10Be data in this study. Nevertheless, 10Be is another cosmogenic isotope formed through spallation of nitrogen12,14N(p,α)10Be, or oxygen, which often co-varies with 14C. The increase in 10Be, can also be interpreted by the Dai7 event. The comet with abundant oxygen and nitrogen, could likewise produce high amounts of 10Be under exposure to cosmic radiation.

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Methods

Coral core. A 1.2-m long core of fossil Porites XDH was drilled from Xiaodonghai Reef in the northern South China Sea in 1997. Slabs of 7 mm in thickness, were sectioned, washed with ultrapure water, and dried for X-ray images. X-ray diffraction analysis shows our coral samples are 100% aragonite and scanning electron microscopy image indicates the absence of secondary aragonite around the coral part having the C3 spike. The subsamples were crushed and homogenized one by one in an agate mortar.

Measurements. Sample XDH-2 at depth of 2.15 cm was dated by $^{14}$C technique and in the High-precision Mass Spectrometry and Environment Change Laboratory (HSPEC), at National Taiwan University, on a multi-collector inductively coupled plasma mass spectrometer (MC-ICP-MS) (Table S1).

Carbon-14 sample preparation was carried out in the State Key Laboratory of Isotope Geochemistry, Guangzhou Institute of Geochemistry. About 8–9 mg coral sample power was weighed and put in a special reaction quartz tube reacted with purified $\mathrm{H}_2\mathrm{PO}_4$ for more than 24 hours at room temperature after being kept continuously in a 1.0 $\times$ 10$^{-2}$ torr vacuum system for at least 4 hours. CO$_2$ from the reaction tube is purified and then transferred to a tube and graphitized [41]. The graphite samples were analyzed in the AMS laboratory at Peking University [42], the standards used during the analysis are NIST OXI and OXII, the analytical precision for our samples are better than 3% and 5% for half-annual and biweekly samples, respectively.

$^{14}$C measurements from the same biweekly subsamples were carried out using MAT-252 mass spectrometry equipped with Kiel II micro carbonate automatic sample power was weighed and put in a special reaction quartz tube reacted with purified $\mathrm{H}_2\mathrm{PO}_4$ for more than 24 hours at room temperature after being kept continuously in a 1.0 $\times$ 10$^{-2}$ torr vacuum system for at least 4 hours. CO$_2$ from the reaction tube is purified and then transferred to a tube and graphitized [41]. The graphite samples were analyzed in the AMS laboratory at Peking University [42], the standards used during the analysis are NIST OXI and OXII, the analytical precision for our samples are better than 3% and 5% for half-annual and biweekly samples, respectively.

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Additional information

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