A comet could not produce the carbon-14 spike in the 8th century

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Abstract

A mysterious increase of radiocarbon $^{14}$C ca. 775 AD in the Earth’s atmosphere has been recently found by Miyake et al. (Nature, 486, 240, 2012). A possible source of this event has been discussed widely, the most likely being an extreme solar energetic particle event. A new exotic hypothesis has been presented recently by Liu et al. (Nature Sci. Rep., 4, 3728, 2014) who proposed that the event was caused by a comet bringing additional $^{14}$C to Earth. Here we calculated a realistic mass and size of such a comet to show that it would have been huge ($\approx$ 100 km across and $10^{14} - 10^{15}$ ton of mass) and would have produced a disastrous impact on Earth. Such an impact could not remain unnoticed in the geological records and chronicles. The absence of an evidence for such a dramatic event makes this hypothesis invalid.

1. Introduction

Radiocarbon $^{14}$C is a primary cosmogenic radioisotope produced in the Earth’s atmosphere by galactic cosmic rays whose flux is a subject to solar and geomagnetic modulation. After production, radiocarbon is redistributed in the complicated terrestrial carbon cycle (Roth and Joos, 2013) and finally stored in a natural archive like tree trunks or corals, where it can be measured later to reconstruct the cosmic ray flux and respectively solar activity in the past (Beer et al., 2012; Usoskin, 2013). Occasionally however, sources other than galactic cosmic rays may contribute to the measured $^{14}$C. One such known event is related to a strong increase of $^{14}$C around year 774-775 AD, discovered first in a Japanese cedar tree rings (Miyake et al., 2012) and later confirmed by measurements in a German oak tree (Usoskin et al., 2013). A similar increase has been observed also in another cosmogenic radioisotope $^{10}$Be measured in Dom Fuji Antarctic ice core (Horiuchi et al., 2008; Usoskin and Kovaltsov, 2012). Different possible sources of this event have been discussed in the literature, from a gamma-ray burst (Hambaryan and Neuhäuser, 2013; Pavlov et al., 2013) to a cometary impact on the Sun (Eichler and Mordecai, 2012). The most boring and realistic source is yet an extreme flux of solar energetic particles accelerated in a giant solar flare or interplanetary shock (Melott and Thomas, 2012; Usoskin et al., 2013; Cliver et al., 2014).

A very recent development has been made by Liu et al. (2014) who provided a new measurements of $^{14}$C in coral skeletons of the South China Sea for the period of 770s AD. The measurements are very good and show a clear
increase of $\Delta^{14}$C occurred in 773 AD as resolved with a great temporal resolution. This confirms the earlier discovery of a 12 permill increase of $\Delta^{14}$C in tree rings in Japan (Miyake et al., 2012) and Europe (Usoskin et al., 2013) for 774-775 AD. In addition, Liu et al., (2014) reported a chronicle record of a comet observed on the sky on 17-Jan-773 AD. Accordingly, they proposed that this comet might have brought additional $^{14}$C and $^{10}$Be into the atmosphere which would explain the observed peak. This is a strong conclusion with potentially great scientific impact and thus requires a robust quantitative support. However, the estimates of the comet’s body offered by Liu et al., (2014) are too much uncertain. Here we revisited this idea and estimated the realistic size and mass of a comet needed to produce the observed increase in $^{14}$C.

2. Result and Discussion

All the measurements in tree rings (Miyake et al., 2012; Usoskin et al., 2013) and in corals (Liu et al., 2014) agree that the relative increase of $^{14}$C was 11–12 permill (1.1–1.2%), and considering the complementing information of $^{10}$Be deposition in Antarctic ice (Horiuchi et al., 2008), the effect was global. Such an increase of $\Delta^{14}$C requires an additional source of $S \approx 1.5 \times 10^8$ $^{14}$C atoms per cm$^2$ in the atmosphere (Usoskin et al., 2013; Pavlov et al., 2013). By applying the global distribution, one can easily obtain that $N = S \times 2\pi R_{\text{Earth}}^2 = 8 \times 10^{26}$ atoms (or about 18 kg) of $^{14}$C should be instantly injected into the atmosphere. Since the amount of radiocarbon in the comet’s body is a result of a balance between production $Q$ and radioactive decay (the life-time $\tau = 8266$ years) of $^{14}$C, $N = \tau \cdot Q$, one can calculate that $Q = 3 \times 10^{15}$ atoms of $^{14}$C should be produced in the comet’s body per second during its transport in space.

Radiocarbon is mostly produced from nitrogen by capture of a (epi)thermal neutron:

$$^{14}\text{N} + n \rightarrow ^{14}\text{C} + p.$$ (1)

Other channels have much lower cross-sections (Kovaltsov et al., 2012). Thus, the amount of nitrogen atoms in a thick target irradiated by cosmic rays is essential for its ability to produce $^{14}$C. In this sense, the Earth’s atmosphere containing 78% of nitrogen is a very effective target. Even if one assumes a comet consisting mostly of ammonium, it would be not more effective for producing $^{14}$C, than the Earth’s atmosphere.

According to numerical radiocarbon production models (Masarik and Beer, 2009; Kovaltsov et al., 2012), the average $^{14}$C production rate in the Earth’s atmosphere as produced by galactic cosmic rays in the absence of solar and geomagnetic shielding (as corresponding to an outer part of the solar system) is about 10 atoms/cm$^2$/s. Thus, in order to guarantee sufficient production of $^{14}$C in the comet’s body, its surface area (the body is assumed to be thick enough for the development of a cosmic-ray induced cascade to produce (epi)thermal neutrons for reaction$^{[1]}$) must be $3 \times 10^{14}$ cm$^2$. This corresponds to the mean radius of about $5 \times 10^6$ cm or 50 km (100 km across). We note that $^{14}$C is produced only in an upper layer of tens of meters thickness, while the bulk of the volume is unreachable for cosmic rays. With the mean comet density (Britt et al., 2006) of about 0.6 g/cm$^3$, it leads to the total mass of a $3 \times 10^{14}$ ton. A similar estimate can be found independently in Overholt and Melott (2013) based on direct numerical simulations. This would
be definitely the biggest comet observed. A body of such size and mass would necessarily produce a dramatic impact if falling on Earth. A simple estimate of such a body at 10 km/s velocity leads to the impact energy of $1.4 \times 10^{25}$ J or $3.3 \times 10^{9}$ megaton TNT. Such an impact would lead to dramatic geological/biospherical consequences and could not remain unnoticed.

We note that all the assumptions made here are one-sided and may lead only to underestimating the comet’s size. For example, any composition other than considered here (78% of nitrogen), of the comet would only lead to a less effective production of $^{14}$C and accordingly to the bigger size/mass required. Thus, the present estimate is a conservative lower bound.

A possibility still would exist that, while the very comet’s nucleus had missed the Earth, its coma deposited radiocarbon into the atmosphere. In such a case, only a small fraction of the entire $^{14}$C contained in the comet would had been deposited, about 1% or less, depending on the coma’s size and the comet’s trajectory. This would imply a much bigger, than evaluated above, comet to deposit the required amount of radiocarbon into the atmosphere, viz. it must be a thousand km across or even bigger. Such a huge comet traversing close to the Earth could not be unnoticed and undocumented in numerous chronicles in the late eighth century. Since we are not aware of any indication of such an event, one can conclude that it hadn’t take place.

Thus, the hypothesis of a comet bringing additional radiocarbon to the atmosphere in ca. 773 AD (Liu et al., 2014) is proven invalid, and the solar origin of the event (Usoskin et al., 2013; Cliver et al., 2014) remains the most plausible explanation.

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