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Yael Peleg
MSc Student
Ben Gurion University of the Negev
Israel

Jonathan Walg
PhD Student
Ben Gurion University of the Negev
Israel

Itzhak Orion
Professor
Ben Gurion University of the Negev
Israel

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Athens Institute for Education and Research
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Solar Flare Effect on Geological Radiometric Dating Methods Based on Thorium Decay

Yael Peleg
Jonathan Walg
Itzhak Orion

Over the past decade, an increasing number of studies have examined radioactive decay rate changes, a controversial topic that may affect many aspects of scientific research. Our previous studies found that the count-rate for an Am-241 alpha emitter altered due to changes in the neutrino flux from the sun. Gamma radiation measurements in these experimental setups were obtained using NaI(Tl) detectors. Our findings also indicated that the Rn-222 radioactive nuclide is affected by an order-of-magnitude neutrino flux change, from the sun. To track additional radiation count-rate responses due to solar flare events, we integrated an experimental detector system for gamma radiation count-rates measurements, facing a Th-232 radioactive source. Several geological radiometric dating methods, such as the U-235 chain, U-238 chain, Th-230, and Th-232 chain, which are used in geological dating, may be affected by the findings of this work. Our new findings question the reliability and accuracy of these dating methods. Indeed, solar activity varies over time because the sun has undergone an evolutionary process, changing the half-life duration of radioactive isotopes that are used for dating and defining the age of layers. A new formula was developed to evaluate the Th-232 decay constant changes resulting from relatively strong solar flares. This formula was used in a Monte Carlo simulation to determine the decay constant change over 200 Ma. Due to our methodical assessment calculations, the real age of a 200 Ma old layer should be 186 Ma, or even younger. Based on the simulation, and considering the effect of solar flare events, we conclude that geological radiometric dating should be altered, and that the unidirectional correction of dating is essential.

Keywords: *half-life, solar flare, dating, decay constant, radioactive*

Introduction

General Geological Dating

Dating is very important in understanding our earth, its aeons, and the changes that have occurred throughout the many years of its existence. The age of one fossil layer is determined by comparing it to another, and for this purpose we must date layers and minerals (Peppe and Deino 2013). Dating layers can also shed a great deal of light on evolution. There are various geological dating methods, among them relative dating, Fossil Index, absolute dating, and more. However, geologists favour radioactive dating, which is based on the decay rate of natural radioactive isotopes in nature.

Radioactive Dating

For a long time, traditional radioactive dating methods have been employed to determine and date the age of geological layers of materials such as organic substances, rocks, minerals, and other objects. To calculate and define the age of a layer, it is necessary to compare the abundance of the radioisotope "parent" with the products of its decay, "daughters," while using a known decay rate constant (Vértes et al. 1998). Using this calculation, we can date all materials anywhere around the globe at sea level, under sea level, volcanos, rocks, and more. Several radioactive geological dating methods are used, such as the Uranium Chain, U-238, U-234, Th-232, and Th-230. This Uranium chain and its derivatives emit Alpha radiation.

Our new findings reveal that the Neutrino flux interacts and affects the Alpha emitter, consequently affecting the half-life ($T^1/_2$). Therefore, the reliability and accuracy of these common dating methods must be questioned. Indeed, the solar activity raises the Neutrino flux and apparently changes Half-Life duration, which was until now considered a constant value (Walg et al. 2019).

In addition to the Uranium Chain method, which is called Uranium-Lead dating, there are also many other well-known radiometric dating methods such as Argon-Argon Dating and Potassium-Argon dating. All these can help to define the age of a layer. We can obtain a huge amount of data regarding fossil ages by using these Geological Radiometric dating methods. The above methods are considered accurate and useful, and each method is employed vis-a-vis a different material or location.

Thorium Dating

In this article we will discuss Uranium–Thorium dating, known as Th-230 Radiometric dating method. This method was established during the 1960s and is used to determine the age of materials that contain calcium carbonate, such as coral. This dating method, which is based on the U-series, is highly sensitive because it derives into many chemicals and many isotope fractions or "daughters."

The Uranium-Thorium radiometric dating process includes mass spectrometry detection of both the parent (U-234) and daughter product (Th-230) of decay and the emission of alpha radiation. The decay of U-234 to Th-230 is part of a very long decay chain of the Uranium-Lead decay chain that starts with U-238 and ends with Pb-206 (Simpson and Grün 1998).

It is very difficult to calculate an accurate or reliable age because the earth is constantly changing geologically, and simultaneously isotopic concentration changes occur. The initial radioactive isotopic ratio of Th-230/U-234 at the time the sample was formed must be known or calculated for Uranium-Thorium dating, because this will constitute part of the comparison rate. It should be noted that Th-230 is the parent of Ra-226 that decays to Rn-222. In our previous paper, we reported that the Rn-222 decay constant changes as well (Walg et al. 2020). Once the radioactive isotopes start to decay, they will accumulate in the sample over time. The sample age can be calculated based on the difference between the initial amount rate of Th-230/U-234 and the accumulated rate of the sample, assuming that this occurs in a closed, unchanged system. The Uranium-Thorium method is used for sediment samples, carbon samples, and bone and teeth samples with an estimated age of 1000–300,000 years (Vértes et al. 2010). When applying this Uranium-Thorium method to human fossil dating (bones and teeth), the closed system assumption is highly relevant. When we compare bones to fossils bones, the fossil can contain hundreds of times more Uranium, due to the high exposure to ground water. The fossil bone tends to behave like an absorbent sponge when it is buried in sediment, and it absorbs a great deal of Uranium – the "uptake" phenomenon. The Uranium can also leak out of the bone – the "leaching" phenomenon.

Many articles and studies emphasize the difficulty in identifying the U-series (U-234-U-238) and (Th-230-U-234) sources in sediments (Ivanovich and Harmon 1992). It is difficult to define coral ages older than 150,000–200,000 years (Villemant and Feuillet 2003).

Thorium is a naturally occurring radioactive material with some radioactive isotopes that are part of the uranium decay chain, and it is about three times more abundant than Uranium in nature. We find Thorium in sands and sediments because it is insoluble (Vértes et al. 2010). By contrast, we find Uranium in seawater because it is soluble. Thorium dating is a known, usable method that can employ both Thorium-232 and Thorium-230. Thorium-230, which is more radioactive, can be used for age dating in marine sediments. The half-life of Th-232 is 14.5 Giga years and the half-life of Thorium-230 is 75,200 years, making it useful for dating sediments of up to 400,000 years old when applying the Th-232/Th-230 rate (Vértes et al. 2010).

The Thorium dating method assumes that the initial Th-232/Th-230 rate stays constant, without any changes, assuming a closed system during the period of sediment layer formation. In addition, this method also assumes that the Th-232/Th-230 rate of leaching, precipitation out to the sediment, stays constant. If these two assumptions are correct, this dating method can produce accurate and reliable results (Vértes et al. 2010, Rafferty 2010).

During evolutionary processes and changes in the earth, the sedimentation processes also undergo massive changes. Consequently, in a closed system, the classical U-238-U-234-Th-230 dating system is not always sufficiently accurate and reliable. To make this method more accurate, calculations must use the initial rates of $(\text{U-234/U-238})_0$ and $(\text{Th-230/Th-232})_0$ and in so doing can achieve increased accuracy in determining the ages of corals and sediments.

In ash beds of zircon crystallization and deposition of the ash were sampled, data was often found to be out of sequence of U–Pb dates, leading to problematic age evaluation.

The sample data set demonstrates that the interpretation of U–Pb dates in terms of sediment deposition age is not necessarily straightforward. This requires a full control for any post-crystallization lead loss, which would result in a date younger than the previously supposed age. Post-crystallization Pb loss is therefore a serious problem that must be mitigated.

Such effects may explain the 1 Ma discrepancy of zircon 206Pb/238U dates of Ash Bed (Ovtcharova et al. 2015, Gradstein and Ogg 2004, Bergström et al. 2008, Gradstein et al. 2008, Leach et al. 2001).

Methods

Solar Flares Data Collection

Previous studies indicated that alpha emitters were affected as the decay rate decreased due to neutrino flux change from the sun's activity (Walg et al. 2019, Walg et al. 2020). Our new findings question the reliability of these dating methods. Solar activity changes impact the half-life duration of the isotopes that are used for dating and as a result the determined layer age is probably not accurate.

Solar x-ray flares occur when the sun’s activity intensifies during the active sun cycle, which is known to be around 11 years. During the active cycle there is a higher probability that solar flares will occur. The solar X-ray flare phenomenon produces an increased neutrino flux (Walg et al. 2019, Jenkins and Fischbach 2009). A series of GOES (Geostationary Operational Environmental Satellites) satellites operated by the Space Weather Prediction Center, National Oceanic and Atmospheric Administration provides daily measured solar x-ray flux data, which is reported in units of W/m^2 for each minute. This daily x-ray flux data is classified as A, B, C, M, or X according to peak flux magnitude, where class A, the lowest flux, is less than 10^{-7} W/m^2, X is above 10^{-4} W/m^2, and the difference from class to class is 10-fold.

Data concerning solar flares was collected for the years 2014-2020 for the purpose of analyzing its effects on radioactive sources. The database helped understand the changes in the radioactive material’s count rate, and how the characteristics of the solar flares (magnitude – size (B, C, M, X), frequency, and duration) affect the count rate. (www.spaceweatherlive.com)

Figure 1a shows the accumulated solar flares for each month over the past 5 years, with each color representing a different duration. For example, in January during the years 2015-2020 there were 8 solar flares with a duration of 30 to 60 minutes. Figure 1b shows the distribution of the solar flare duration as a function of the month. In March, for example, the duration of the solar flares was longer relative to the other months.

Figure 1. a) *Solar Flare Events Accumulated for Each Month Between the Years 2015-2020, with Each Color Representing a Different Duration* b) *The Duration Distribution by Month*

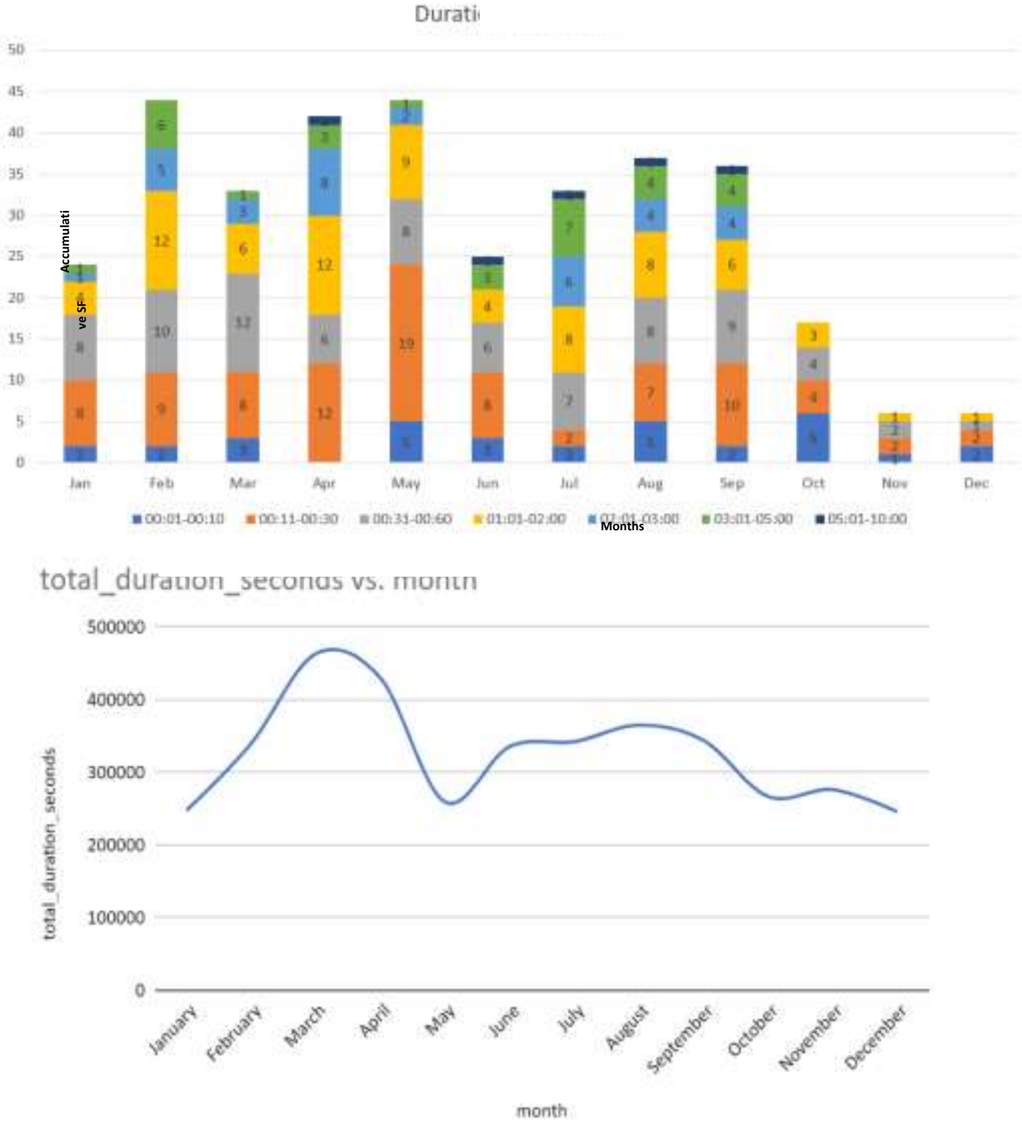


Figure 1a reveals that the months February, April, May, July, August, and September have greater solar flare activity: the cumulative number of events is higher than other months. In addition, events between 11 and 30 minutes occur with greater frequency, particularly in those specific months. Figure 1b demonstrates again the higher occurrences of solar flares in the months of February, April, May, July, August, and September.

Figure 2 shows how the magnitude of solar flares distributed over each month between 2015-2020. Figure 2a provides the size distribution per month, and figure 2b demonstrates the accumulated distribution.

Figure 2. *Solar Flares by Size (Magnitude) per Month*

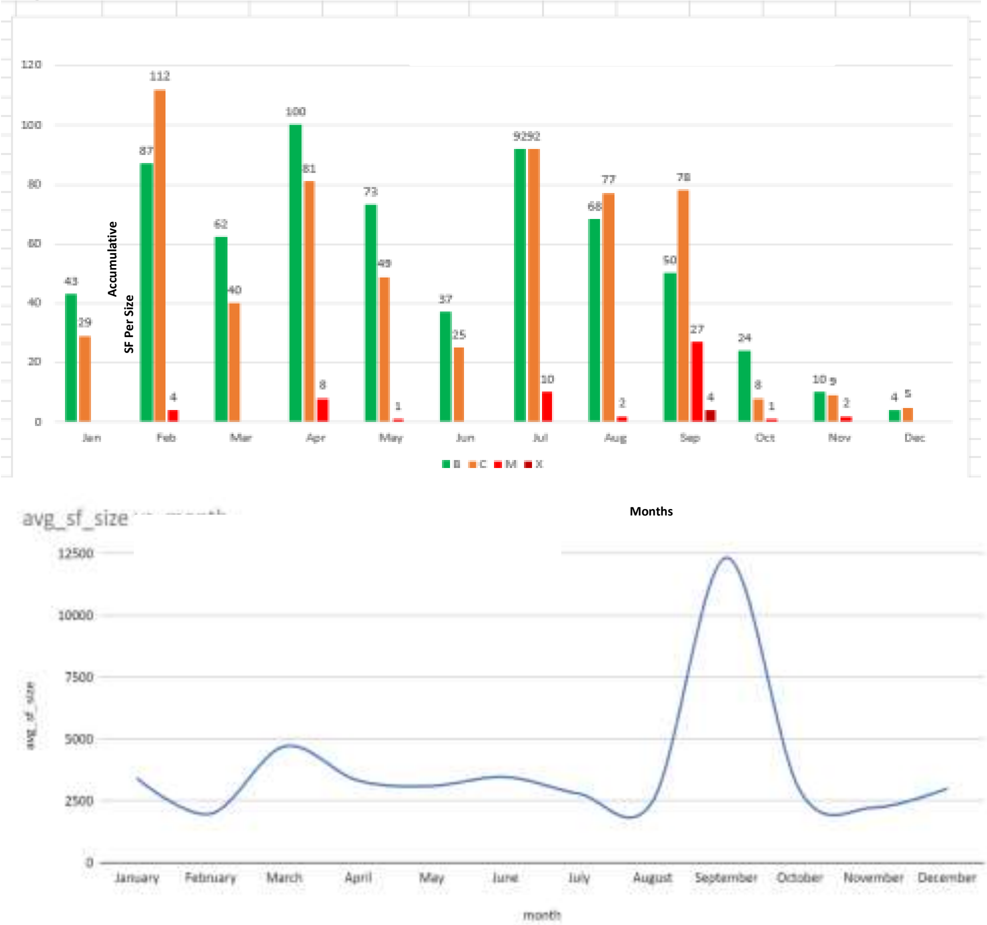


Figure 2a indicates that the magnitude of the solar flares is divided into 4 types, B, C, M, and X, and during months with a greater frequency of events, the magnitude also increased– there were more solar flares as well as more solar flares of higher magnitude.

Figure 2b demonstrates that when calculating the average size, higher magnitudes are evident during March and April, and much higher ones occur during September, October, and November.

Based on the graphs in Figures 1-2, we can understand that the sun's activity and solar flare behavior correspond with the sun's rotation period, which has a 30 day mean value; hence a monthly response should be evident. The months February, April, May, July, August, and September have greater solar flare activity, and the cumulative number of events is higher than other months. There are many solar flare events with different durations and magnitudes, however, solar flare events between 11 and 30 minutes occur at a high frequency, and, moreover, at a higher frequency in those specific months.

Data concerning the magnitude of solar flares was collected daily in the years 2015-2020. The magnitude of the solar flares is divided into 4 types, B, C, M, and X, and during those specific months with many events, there were more solar flares events as well as their magnitude was higher. When calculating the average size, higher magnitude is evident during March, April, and much higher magnitude is evident during September, October and November.

To summarize, certain months have greater solar flare activity, and those months also have solar flares of a higher magnitude.

Experimental

As part of this study, we performed count rate measurements for radioactive sources from August 2018, and these are still ongoing (Walg et al. 2019, Walg et al. 2020). The measurements were caried out in order to discover whether solar flares affect the decay of radioactive sources. We sought to discern whether this impacts the radioactive half-life of alpha emitters. Therefore, we checked the following radioactive sources: Am-241, Rn-222, and Th-232. Our measurements clearly demonstrate that count rates prior to the solar flares were relatively smooth and stable. Once a solar flare occurred, we detected significant decreases in the count rates of the radioactive sources.

NaI(Tl) gamma radiation detector system for count-rate measurements is used for each radioactive source (the system is described in our previous publication (Walg et al. 2019)). The NaI(Tl) detector faced a Th-232 source, 50 g of $Th(NO_3)_4 \cdot 5H_2O$, and total counts were scored every 15 minutes. The detector showed a significant change in its count rate once medium solar flare events occurred, with a delay of 9 days. In solar flare events the neutrino flux increased by 3-4 orders of magnitude. The detailed solar flare neutrino production process is reported by Ryazhskaya et al. (2002). A radioactive nucleus that captures a free neutrino into its system may possess it for a certain period until it will affect the count rate alteration (Walg et al. 2019, Walg et al. 2020). We found that in the alpha emitter radioactive sources, the half-life altered due to changes in neutrino flux from the sun. Due to our novel findings, all the radiometric dating methods need to be re-evaluated and re-calculated.

Results and Discussion

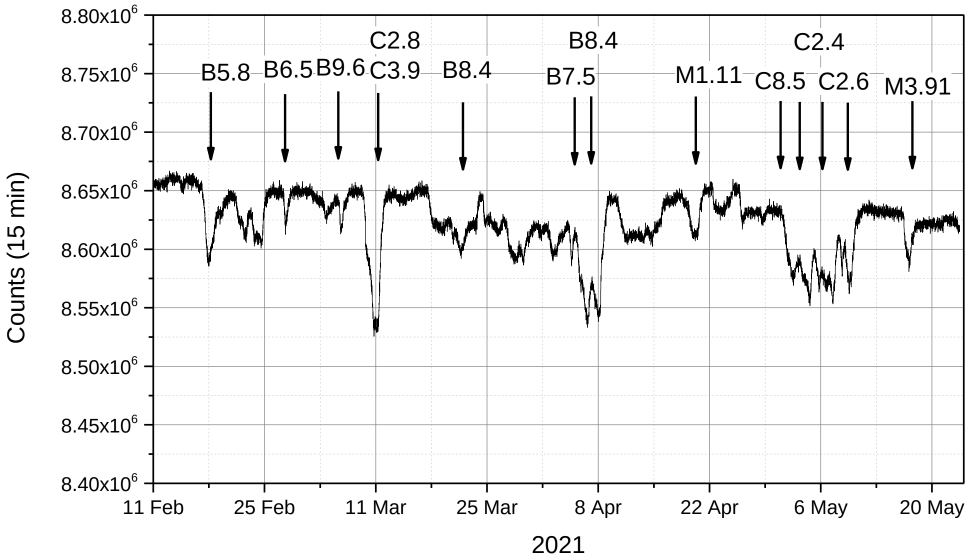
Experimental Results

Table 1 summarizes the measured count rate changes for Th-232 as scored in our system. Figure 3 presents the Th-232 count rates during the measurement period since January 2021. The changes due to solar flares are indicated.

Table 1. *Th-232 Count Rate Responses to Solar Flares (SF) During 2021: Left to Right: Solar Flare Occurrence Date; SF Type (Letter and Size in nW·m^{-2}; Dip in Count Rate Reading Date, and the Percentage of Count Rate Change)*

Date of SF	SF size - Type	Dip Date	% Change	Comments
10/02/2021	580 B	17/02/2021	-0.79%	
22/02/2021	650 B	27/02/2021	-0.37%	
26/02/2021	960 B	06/03/2021	-0.28%	
27/02/2021	2800 C	9-11/03/2021	-1.28%	13 hours difference between SF
28/02/2021	3900 C			
25/03/2021	840 B	06/04/2021	-1.01%	
30/03/2021	750 B	08/04/2021	-0.94%	
12/04/2021	840 B	20/04/2021	-0.50%	
20/04/2021	11100 M	02/05/2021	-0.81%	
22/04/2021	8560 C	04/05/2021	-1.16%	
24/04/2021	2470 C	07/05/2021	-1.10%	
25/04/2021	2650 C	09/05/2021	-1.03%	
07/05/2021	39100 M	17/05/2021	-0.57%	

Figure 3. *Gamma Radiation of Th-232 Count-Rates (in 15-min Intervals) During 2021*



Model Development

To implement the relationship between the solar flare characteristics and the effect on the radioactive source decay, we developed a new formula. The change in the radioactive Th-232 decay constant occurs due to solar flares and their intensity, causing the count rate to decrease. The decay constant can only decrease.

$$\lambda_{change} = \lambda \cdot \sum_{i \to date} (\Delta_i \cdot \Delta_{duration}) \cdot [\%]$$

Where:

λ_{change} – Modified Decay Constant caused by solar flares
λ – Decay Constant from the literature
Δ_i – Random variable to match between dip distribution to solar Flare Types
$\Delta_{duration}$ – Solar flare duration dependency (currently $\Delta_{\text{duration}} = 1$ was used)

Δ_i dependency was obtained corresponding to the dip range: for Type B the range was set to (-0.79%) – (-0.28%), and for Type C the range was set to (-1.1%)– (-0.6%). These ranges were obtained from a set of measured dip responses of Th-232, as presented in Table 1. The solar flare duration influence on the count rate change is yet to be investigated and analysed, therefore we set this parameter as equal to 1.

A Monte Carlo simulation was applied to this formula for estimations of Th-232 dating in a geological time scale. The decay constant change can only decrease, hence increasing the apparent half-life.

For example, if a geological layer has been sampled and the date obtained was 200 Ma, due to our methodical assessment calculations, the real age of this layer is 186 Ma or even younger.

Conclusions

Radioactive materials that are used for dating are influenced and impacted by the change in neutrino flux due to solar flares.

The Th-232 count-rate measurements showed several counting dips, indicating that the radioactive nuclide could be affected by neutrino flux change from the sun (Walg et al. 2019, Walg et al. 2020). In Table 1, we presented several relatively strong solar flare events and their responses, as collected in our database, and the dip size distribution is based on Th-232 count-rates changes, as shown in Figure 3.

In this study we developed a new formula that enables us to simulate the radiometric aging corrections. Considering the dip size of the readings, we can calculate the overall decay constant changes that indicate the implications of solar flare on radioactive source decay.

Based on the simulation we conducted with our new formula, we found that there is a significant delta change in time, a change of million of years between the measured age and the real age of radioactive matter.

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