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ScienceDirect
Advances in Space Research 41 (2008) 275–279
ADVANCES IN SPACE RESEARCH (a COSPAR publication)
www.elsevier.com/locate/asr

Mid 19th century minimum of galactic cosmic ray flux inferred from ^{44}Ti in Allegan meteorite

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Received 8 November 2006; received in revised form 21 June 2007; accepted 25 June 2007

Abstract

Measurements of ^{44}Ti activity in meteorites show that the galactic cosmic ray (GCR) intensity has been declining in the interplanetary space during the past three centuries and has a component of cyclic variation, with periodicity of about 87 years [Taricco, C., Bhandari, N., Cane, D., et al. Galactic cosmic ray flux decline and periodicities in the interplanetary space during the last 3 centuries revealed by ^{44}Ti in meteorites. J. Geophys. Res. 111, A08102, 2006.]. In order to verify these results, we have measured ^{44}Ti activity in Allegan meteorite which fell in 1899 and in some other meteorites with better precision. The measurements confirm low cosmic ray flux and consequently high solar activity near the middle of 19th century.

Keywords: Meteorites; Cosmic rays; Solar variability; Interplanetary magnetic field; Instruments and techniques

1. Introduction

Variations of the solar activity have been studied by direct measurements of solar parameters e.g., geomagnetic indices, neutron monitor data and solar irradiance. In view of the importance of the solar activity variations in understanding solar physics, cosmic ray modulation and its influence on Earth, attempts of reconstructing the past solar activity have been made by measuring cosmogenic isotopes produced in Earth's atmosphere and deposited in terrestrial archives (Beer et al., 1990; Lal et al., 2005; Solanki et al., 2004 and references therein). Based on these studies, some trends, periodicities and spikes in solar activity have been proposed. Lal et al. (2005) used ^{14}C in Greenland ice core to extend the solar activity reconstruction back to 32 Kyr and found epochs of low (8.5–9.5 and 27–32 Kyr) and high (12–16 Kyr) solar activity. Beer et al. (1990) used ^{10}Be concentrations in polar ice core for the study of solar activity variations and showed the imprint of the 11 yr solar cycle during the period 1783–1985.

Cosmogenic isotopes produced by GCR in meteorites offer the opportunity to understand the strength of solar modulation in the past, free of terrestrial interferences due to, e.g. geomagnetic field variations, exchange between various terrestrial reservoirs and terrestrial climate. In our study, we focus on the variations during the past three centuries, determined by measuring the activity of the cosmogenic isotope ^{44}Ti (half life 59.2 ± 0.6 yr) in meteorites. ^{44}Ti is mainly produced by spallation reactions between cosmic ray protons (>70 MeV) and meteoritic iron and nickel. We previously performed measurements of ^{44}Ti in 19 chondrites which fell since 1766 (Taricco et al., 2006); we have shown that cosmic ray intensity between 1 and 3 AU, the orbital space of meteorites, (i) has linearly decreased at about 18% per century and (ii) had a cyclic variation with amplitude of ~25% with periodicity of ~87 yr.

Considering the importance of these results, we are continuing with additional measurements. For this purpose,

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doi:10.1016/j.asr.2007.06.050

we have now measured Allegan meteorite which fell in 1899, allowing us to verify the GCR minimum around 1850. This measurement was performed using an improved gamma-ray spectrometer, with detectors of higher efficiency and resolution compared to the spectrometer used by our group earlier on which most of the meteorites were measured (Bonino et al., 1995). The measurement of Allegan meteorite is presented here together with three other chondrites, measured using this new spectrometer.

1.1. Half life of ^{44}Ti

Accurate value of half life of ^{44}Ti is essential in this study, because the measured activity has to be corrected for decay since the time of fall. Several attempts have been made to determine the half life of ^{44}Ti. The measured values are summarized in Table 1. Alburger and Harbottle (1990) used an end-window gas-flow proportional counter system, to measure the beta decay from two samples of ^{44}Ti. After 3 yr of counting, they obtained a value of 66.6 ± 1.6 yr (2σ). Subsequent measurements using different methods, such as gamma counting, gave lower values of half life (see Table 1). Because of absorption of beta rays, which require significant corrections, generally the gamma counting data are considered more reliable compared to beta counting. In order to determine the half life more accurately, our Laboratory of Monte dei Cappuccini in Torino (Italy), in collaboration with the Argonne National Laboratory (ANL) and the Hebrew University of Jerusalem, carried out independent measurements of three sets of sources prepared at Argonne National Laboratory from the same source material. The values obtained by the three laboratories were in excellent agreement with each other. The weighted mean gives the ^{44}Ti half life reported by Ahmad et al. (1998) as 59.0 ± 0.6 yr (1σ). At about the same time, Görres et al. (1998) reported a value of 60.3 ± 1.3 yr applying direct ion counting of a mixed radioactive ion beam containing ^{44}Ti as well as ^{22}Na ions. In view of the compatibility of the value of Ahmad et al. (1998) with the result of Görres et al. (1998) and due to the better precision, we use the weighted mean of these values, i.e. 59.2 ± 0.6 yr. More recently, following the decay of ^{44}Ti for a period of 20 yr using a set of four high resolution detectors, Wietfeldt et al. (1999) gave a value of 60.7 ± 1.2 yr. Even if this value is used in calculating the ^{44}Ti activity at time of meteorite fall, the observed trend and the centennial cycle remain substantially the same as reported by Taricco et al. (2006) and Usoskin et al. (2006).

Table 1
Reported measurements for ^{44}Ti half life

Author	Method	Half life (years)
Alburger and Harbottle (1990)	Beta counting	66.6 ± 1.6
Ahmad et al. (1998)	Gamma counting	59.0 ± 0.6
Görres et al. (1998)	Gamma counting + ion counting with respect to ^{22}Na	60.3 ± 1.3
Wietfeldt et al. (1999)	Gamma counting	60.7 ± 1.2

2. Experimental system

^{44}Ti decays to its radioactive daughter, ^{44}Sc ($T_{1/2} = 3.93$ h), which emits a positron in coincidence with a 1157 keV gamma-ray. Our gamma-ray spectrometer, tailored to suit the decay scheme of ^{44}Sc, allows a highly sensitive and selective measurement of 1157 keV gamma-ray, by detection of one (511 keV) or two (1022 keV) annihilation photons, emitted in coincidence with the positron. The 3 kg HPGe detector, used in the new system, has a relative efficiency of 147%, a resolution of 1.85 keV and a peak-to-Compton ratio of 104 for the 1332.5 keV ^{60}Co gamma-rays. It is surrounded by a NaI(Tl) annular single crystal and a NaI(Tl) cylindrical plug at the top (total mass ~90 kg). The scintillator is coupled to seven photomultipliers for better optical efficiency. The assembly is housed in a 20 cm thick high-purity lead shield, internally lined with 1 mm of Cd, 5 cm OFHC copper and the empty space surrounding the detector is filled with polyethylene to reduce the amount of ambient air radon. To shield off penetrating cosmic rays, the spectrometer is located underground (70 m water equivalent of overburden) in the Research Station of Monte dei Cappuccini in Torino, Italy. ^{44}Sc(^{44}Ti) can thus be efficiently counted, mainly because the interference due to the environmental 1155 keV gamma-ray from the ambient ^{214}Bi is minimized. A detailed description of this system is given in Taricco et al. (2007).

Allegan meteorite shower fell on 10th July 1899 in Michigan, USA. The total weight of fragments recovered was 42 kg. It has been classified as H5 chondrite containing 30.2% Fe and 1.69% Ni (Easton and Elliott, 1977). One of the fragments from Vatican observatory museum, Rome, weighing 0.296 kg, was available to us for this measurement.

3. Results and discussions

The main source of background in the immediate adjacent bins towards lower energy of ^{44}Ti peak (1157 keV) is that due to the environmental ^{214}Bi at 1155.19 keV. On the higher energy side there is no interference and the Compton background is smooth and featureless. ^{214}Bi is the decay product of radon, which is produced by decay of uranium and is present everywhere. This peak is partially superimposed on the ^{44}Ti peak, and although unimportant for fresh meteorite falls where ^{44}Ti activity is high, becomes increasingly important for older falls, where ^{44}Ti has decayed. This interference is reduced significantly by our selective channel coincidence set up as described before. Because of such coincidence, not only the ^{214}Bi peak is strongly reduced but the Compton level also reduces by a factor greater than 20, without much loss in the counting efficiency. Moreover in the coincidence