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A multiparametric HPGe-NaI acquisition system for low gamma activity measurements of meteorites

C. Taricco[1,2], N. Bhandari[3], P. Colombetti[1,2], I. Mariani[1], N. Verma[4], and G. Vivaldo[1,2]

[1] Dipartimento di Fisica Generale, Università di Torino, Via Pietro Giuria 1, I-10125 Torino, Italy, e-mail: `taricco@ph.unito.it`
[2] Istituto di Fisica dello Spazio Interplanetario di Torino (IFSI–INAF), Corso Fiume 4, I-10133 Torino, Italy
[3] Basic Sciences Research Institute, Navrangpura, 380 009 Ahmedabad, India
[4] Indian Institute of Astrophysics, Bangalore 560 034, India

Abstract The study of long-term solar activity variations in the past requires the use of radioisotopic data planetary reservoirs. At the Laboratory of Monte dei Cappuccini in Torino (IFSI-Torino, INAF) for many years we have been studying radioisotopes in meteorites, because their production, which is related to galactic cosmic ray flux in the heliosphere, is anticorrelated with the heliospheric magnetic field variations. We have developed very sensitive gamma detection techniques, in particular to measure ^{44}Ti activity in meteorites; due to its half-life ($t_{1/2}$ = 59.2 years), this radioisotope is an ideal index to reveal the imprint of solar activity variations on the centennial scale. Recently we have improved the spectrometer by a new multiparametric acquisition system, which allows to extract efficiently the ^{44}Ti peak from the natural background.

Key words. Sun: activity – Meteoroids – Cosmic rays – Sun: magnetic fields – Techniques: gamma spectroscopy – Sunspots – Interplanetary medium – Solar-terrestrial relations

1. Introduction

Reconstructions of solar activity in the past centuries are based on cosmogenic radionuclides produced by interaction of cosmic rays with terrestrial atmosphere, planetary surfaces and meteorites. However, the concentration of radionuclides, such as ^{14}C in tree rings or ^{10}Be in ice cores, is also influenced by terrestrial phenomena, such as variations of deposition rates and terrestrial magnetic field. In order to avoid these influences, our group started to study cosmogenic radionuclides produced in meteorites. In particular, in order to investigate centennial and multicentennial solar variations, we identified ^{44}Ti as an ideal index tracer due its half-life of 59.2 years. ^{44}Ti is produced in meteoroids by spallation reactions between galactic cosmic rays (GCR) and meteoritic iron and nickel; its activity gives information about cosmic ray flux (and solar activity) roughly over a mean life before the meteorite falls on the Earth.

The results obtained by the measurement of 21 chondrites are described in detail in Taricco et al. (2006) and Taricco et al. (2008); ^{44}Ti activity reveals a decreasing trend of GCR flux of $\sim 43\%$ in the last 235 years and, superimposed on it, a centennial oscillation with period of ~ 87 y and amplitude (peak to trough) $\sim 20\%$. We have used these measurements also to validate some models of solar activity variations in the past (Usoskin et al. 2006).

Meteorites were measured at the underground Laboratory of Monte dei Cappuccini in Torino (70 m.w.e.), using γ spectrometry. ^{44}Ti activity in meteorites is very low (~ 1 dpm/kg) and there is a strong interference due to ^{214}Bi, from the naturally occurring ^{238}U. In order to minimize this interference, we have set up a coincidence Ge-NaI system, which measures 1157 keV γ's from ^{44}Sc (in secular equilibrium with parent ^{44}Ti) and the contemporaneous β^+-annihilation γ's from ^{44}Sc decay. The hyperpure germanium detector (coaxial p-type crystal, mass ~ 3 kg) is surrounded by a NaI(Tl) umbrella (mass ~ 90 kg). These detectors are housed in a Pb-Cd-Cu passive shield, with empty spaces filled with polyethylene to minimize radon from ambient air. The measuring cavity can accomodate a rock of mass up to ~ 1 kg.

2. The new multiparametric system: ^{44}Ti in Dergaon chondrite

We have developed and installed a new multiparametric acquisition system which allows to optimize the coincidence windows in order to reduce ^{214}Bi interference. This system (Colombetti et al. 2008) allows to obtain a spectroscopic information also from NaI, very useful to optimize the selection of concidence NaI windows.

We have tested the new system measuring Dhajala (fell in 1976) and Dergaon (2001) meteorites. Here we show some results obtained with the Dergaon measurement. The accuracy of the multiparametric system has been verified by comparison with the contemporary acquisition with the multichannel analyser previously used.

Figure 1 shows the 2-dimensional spectrum of Dergaon meteorite: we can clearly see the coincidence between the ^{26}Al 1808.6 keV peak detected by Ge and the contemporaneous β^+-annihilation γ peaks detected by NaI.

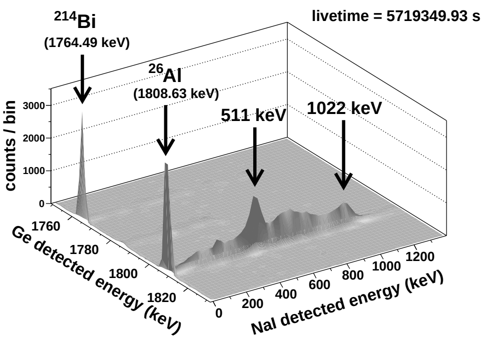

Figure 1. Dergaon meteorite Ge-NaI 2-dimensional spectrum in the Ge energy region around ^{26}Al 1808.63 keV peak, for which corresponding NaI detection of β^+-annihilation γ's is visible. The mostly single-γ ^{214}Bi 1764.49 keV peak is also shown.

In Fig. 2 the spectrum obtained in *normal* mode is shown: we notice the strong interference of ^{44}Ti and ^{214}Bi peaks. In *coincidence* mode this interference is strongly reduced (see Fig. 3).

In order to reliably extract the ^{44}Ti peak, we have also developed a fitting procedure, based on work of Simonits et al. (2003). Following

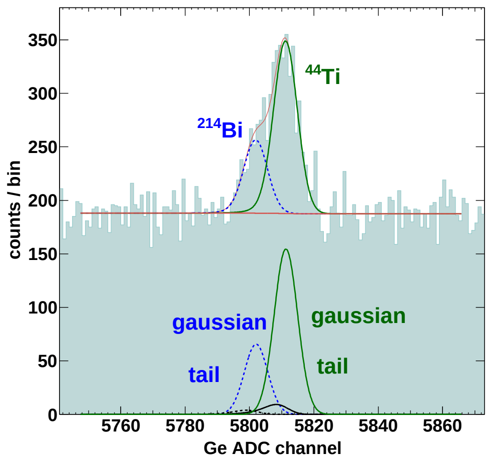

Figure 2. Detail of Dergaon spectrum in ^{44}Ti region in *normal* mode. The fit of ^{44}Ti and ^{214}Bi (dotted line) overlapping peaks using a gaussian and a tail is shown.

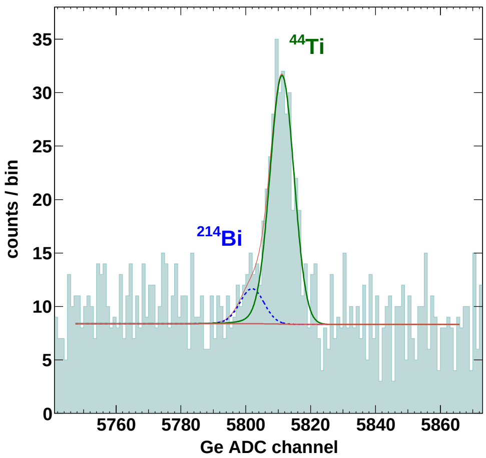

Figure 3. Detail of Dergaon spectrum in ^{44}Ti region in *coincidence* mode, obtained using NaI coincidence window at 1022 keV. As before, the dotted line represents the ^{214}Bi peak.

this procedure, we fit a γ peak by a curve consisting of a gaussian, a smoothed step and a low energy tail. By analysing several well-defined peaks in the spectrum, we have fixed the peak energy and resolution (it is particularly useful for poor statistics peaks). In *normal* mode spectrum, the double peak fitting curve, together with its gaussian and tail components, is shown in Fig. 2, superimposed on the raw data.

The same fitting procedure is applied to the peaks acquired in *coincidence* mode.

One of the main advantages of the new acquisition system is the possibility to select the NaI coincidence windows after the conclusion of the measurement. Exploiting this feature, we have deduced the ^{44}Ti counts using different coincidence windows.

The counts obtained in normal mode and in the coincidence modes (using NaI windows at 511 keV, 1022 keV and both energy intervals) are compatible within the errors (see Table 1). These demonstrate the reliability of the ^{44}Ti activity detection by the new system.

The error is smaller in normal mode and this is due to the fact we do not have to correct by C/N factor. Even if in recent meteorites,

Table 1. Comparison of ^{44}Ti peak intensities as obtained with different NaI coincidence windows (at 511 keV, 1022 keV and both energy intervals). ^{44}Ti counts obtained taking into account the C/N (coincidence to normal ratio).

Dergaon meteorite	^{44}Ti counts	C/N corrected counts
Normal (N)	1508 ± 68	1508 ± 68
Coinc. 511 keV	189 ± 17	1499 ± 134
Coinc. 1022 keV	218 ± 19	1405 ± 124
Coinc. 511+1022	401 ± 27	1421 ± 95

such as Dergaon, it seems better to consider the value deduced by normal mode (which is more precise), while for more ancient meteorites the ^{44}Ti low activity would make it less precise and the coincidence mode preferable. Using the 1022 keV *coincidence* window we obtain the ^{44}Ti counting rate per day of 3.3 ± 0.3, in agreement with Dergaon meteorite measurements performed using the previous acquisition system (Taricco et al. 2008; Taricco et al. 2006).

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