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The COMPTEL instrumental-line background

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Abstract. The instrumental-line background of the Compton telescope COMPTEL onboard the Compton Gamma-Ray Observatory is due to the activation and/or decay of a number of different isotopes. The major components of the COMPTEL instrumental-line background can be attributed to eight individual isotopes, namely ^{2}D, ^{22}Na, ^{24}Na, ^{28}Al, ^{40}K, ^{52}Mn, ^{57}Ni, and ^{208}Tl. In addition, evidence for the presence of ^{27}Mg has been obtained in the search for gamma-ray lines from supernovae. The identification of the instrumental lines with specific isotopes is based on the line energies as well as on the variation of the activity with time, cosmic-ray intensity and deposited radiation dose during passages through the South-Atlantic Anomaly. The characteristic variation of the activity due to an individual isotope depends on its life-time, orbital parameters, and the solar cycle.

INTRODUCTION

Gamma-ray experiments in low-Earth orbit, such as the Compton telescope COMPTEL, are operated in an intense and variable radiation environment. The main constituents of the ambient radiation fields are primary cosmic-ray particles, geomagnetically trapped radiation-belt particles, and albedo neutrons as well as γ-ray photons emanating from the Earth's atmosphere. These particles interact with the spacecraft and detector materials through a multitude of processes, resulting in the emission of instrumental-background photons. A detailed qualitative and quantitative understanding of the intense and complex COMPTEL instrumental background is crucial for many astrophysical analyses.

The Compton telescope COMPTEL, sensitive to γ-ray photons from 0.8–30 MeV, consists of two planes of detector arrays, D1 and D2, separated by about 1.5 m [8]. The D1 detector consists of seven modules filled with organic liquid scintillator, the D2 detector consists of 14 NaI(Tl) crystals. Each of the two detector arrays

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is completely surrounded by anti-coincidence domes to reject charged-particle triggers of the telescope. The COMPTEL instrument accepts and registers coincident triggers in a single D1 and D2 detector module in the absence of a veto signal as valid events. Among other parameters the time-of-flight (ToF) value and a so-called pulse-shape discriminator (PSD) value in D1 are recorded for each event. The ToF is a measure for the time difference between the triggers in the D1 and D2 detector. The PSD is a measure for the shape of the scintillation-light pulse in the D1 detector and is used to reject neutron-induced events. The total energy of the incident photon, E_{tot}, is measured by the summed energy deposits in the two detectors, E_1 and E_2.

The instrumental background experienced by COMPTEL can be subdivided into two major components according to their signature in energy space: first, a continuum background discussed in [7]; second, the instrumental-line background which is the focus of this paper.

IDENTIFIED ISOTOPES

The major components of the COMPTEL instrumental-line background can be attributed to eight individual isotopes, namely ^{2}D, ^{22}Na, ^{24}Na, ^{28}Al, ^{40}K, ^{52}Mn, ^{57}Ni, and ^{208}Tl (e.g. [5,12,14]). Identification of these isotopes was achieved in an iterative process, starting from the most prominent lines in E_{tot} and E_2 spectra. Viable isotope identifications were required to account self-consistently for spectral features in selected regions of the E_1-E_2 dataspace, as well as for their variation with time and/or incident cosmic-ray intensity. The telescope response to individual isotopes was modelled in Monte Carlo simulations. In addition, evidence for the presence of ^{27}Mg has been obtained from fits of E_{tot} spectra and excess counts in E_{tot} and E_2 following South-Atlantic Anomaly (SAA) transits [4]. The isotopes, their half-lifes, most important decay channels, and main production channels are summarized in Table 1.

The different radioactive isotopes result from activation of the instrument material (^{22}Na, ^{24}Na, ^{52}Mn, and ^{57}Ni), from thermal-neutron absorption (^{2}D and ^{28}Al), and from primordial radioactivity (^{40}K and ^{208}Tl). The majority of the instrumental-line background arises from the D1-detector material. The material composition of the D1-detector system therefore provides important clues as to which radioactive isotopes can effectively be produced.

LONG-TERM VARIATION

The activity of long-lived isotopes such as ^{22}Na, ^{24}Na, ^{52}Mn, and ^{57}Ni varies over long timescales due to the competing processes of activation/production and decay. In contrast, the activity of the primordial radio-nuclides ^{40}K and ^{208}Tl does not noticeably change with time over the duration of the COMPTEL mission of several years. Also, the activity of short-lived nuclei such as ^{28}Al, averaged over

TABLE 1. A summary of the isotopes identified in the COMPTEL instrumental-line background. For simplicity, only the photon energies of the most frequent decay modes are listed. If β-decays are involved, the β-particles have been included in the response simulations. The identification of ^{208}Tl has to be considered tentative. The evidence for the presence of ^{27}Mg in the instrumental background still is not unambiguous.

Isotope	Half-Life	Decay Modes and Photon Energies [MeV]	Main Production Channels
^{2}D	prompt	2.224	^{1}H(n_{ther},γ)
^{22}Na	2.6 y	β^+ (91%): 0.511, 1.275 EC (9%) : 1.275	^{27}Al(p,3p3n), Si(p,4pxn)
^{24}Na	14.96 h	β^-: 1.37, 2.75	^{27}Al(n,α), ^{27}Al(p,3pn)
^{27}Mg ?	9.5 min	β^- (28%): 1.014 β^- (71%): 0.844	^{27}Al(n,p)
^{28}Al	2.2 min	β^-: 1.779	^{27}Al(n_{ther},γ)
^{40}K	1.28×10^9 y	EC (10.7%): 1.461	primordial
^{52}Mn	5.6 d	EC (64%): 0.744, 0.935, 1.434 β^+ (27%): 0.511, 0.744, 0.935, 1.434	Fe(p,x), Cr(p,x), Ni(p,x)
^{57}Ni	35.6 h	β^+ (35%): 0.511, 1.377 EC (30%): 1.377	Ni(p,x), Cu(p,x)
^{208}Tl	1.4×10^{10} y (^{232}Th)	β^- (50%): 0.583, 2.614 β^- (25%): 0.511, 0.583, 2.614	primordial

time-scales long compared to the orbital period of about 90 min, is fairly constant because the isotopes' half-lifes are much shorter than the orbital period, which precludes a build-up of their radioactivity. Therefore, the study of the long-term variation of the activity of a background component provides valuable information concerning the half-life of the responsible decay.

It is expected that the long-term variation of the activity of long-lived radionuclides mostly arises from the combined effects of the isotopes' decay and the time history of the activation episodes during SAA passages, with activation outside the SAA by cosmic-ray particles being negligible (see e.g. [3]). Based on this assumption, a model for the activity of long-lived isotopes as a function of time (the "activity model") was developed [10]. The activity model describes the activity of a specific isotope as a function of six parameters: orbit altitude, geographic longitude and latitude, time since launch (to include variations due to the solar cycle), and the orientation (azimuth and zenith) of the satellite relative to its velocity vector.

A comparison of the measured activities of the long-lived isotopes ^{22}Na and ^{24}Na with the predictions of the normalized activity model over a time period of more than 6 years (May 1991 through July 1997) is depicted in Fig. 1. The activity

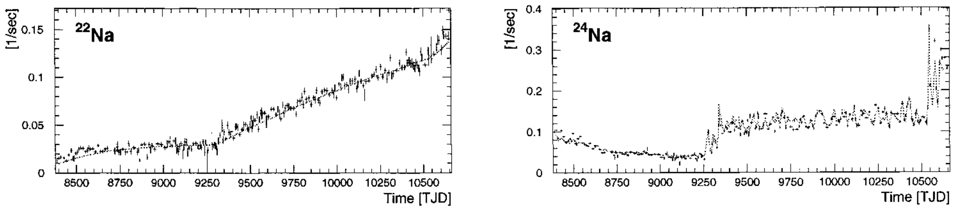

FIGURE 1. The long-term variation of the activity from ^{22}Na and ^{24}Na, compared to the activity model.

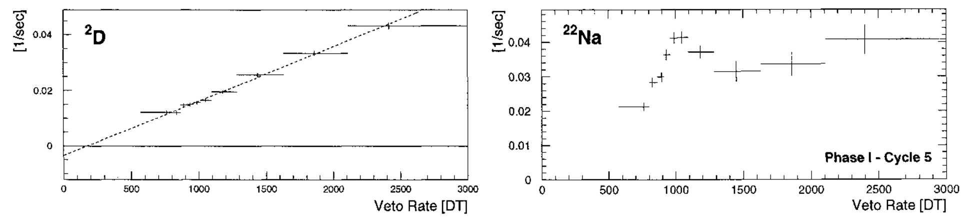

FIGURE 2. The variation of the ^{2}D and ^{22}Na activity with veto rate (DT $\equiv$ veto deadtime-clock counts/2.048 sec). The dashed line in the left panel represents a linear fit to the ^{2}D count rate.

model can accurately reproduce the long-term activity-variation for these two isotopes, confirming the correctness of the basic model assumptions, in particular that activation predominantly occurs during transits through the SAA. In addition, the comparison of model and data provides a valuable verification of the isotope identifications, as the activity of an isotope depends, among other parameters, on its half-life.

VARIATION WITH COSMIC-RAY INTENSITY

The prompt (i.e. instantaneous) instrumental background closely follows the local cosmic-ray intensity, which can, e.g., be parameterized by a geomagnetic cut-off rigidity. Another way of parameterizing the incident cosmic-ray intensity is to use the count rate of the anti-coincidence domes of the COMPTEL instrument, referred to as "veto rate" in the following. To a good approximation, the prompt background varies linearly with the incident cosmic-ray intensity as monitored by the veto rate and can be eliminated from the data by an extrapolation technique in analyses of the cosmic diffuse gamma-ray background (CDG) [1]. As an example, the linear dependence of the event rate in the instrumental 2.2 MeV ^{2}D-line due to thermal-neutron capture on hydrogen in the organic scintillator of the D1 modules [11] is depicted in Fig. 2.

In contrast to prompt background components, the activity of the primordial isotopes ^{40}K and ^{208}Tl is independent of the incident cosmic-ray intensity and hence does not vary with cosmic-ray intensity or veto rate.

The variation of the activity of long-lived isotopes such as ^{22}Na with veto rate is complex and – in general – non-linear (as exemplified in Fig. 2), and depends on the isotopes' half-life as well as on the encountered geophysical environment and its time-variation (e.g. [12,14]). Similar to the study of the long-term variation, the study of the variation of the activity of a background component with cosmic-ray intensity can therefore provide valuable information concerning the half-life of the responsible decay.

SUMMARY AND DISCUSSION

The major components of the COMPTEL instrumental-line background can be attributed to eight different radioactive isotopes. Identification of the instrumental lines with specific isotopes is based on the line energies as well as on the long-term variation of the activity and its dependence on incident cosmic-ray intensity. The activity of long-lived isotopes can be described well by our activity model [10], implying that activation occurs predominantly during transits through the SAA, with the deposited radiation dose depending on orbital parameters such as the height of the satellite above Earth and the solar cycle. Considering the material composition of different γ-ray detectors, the isotopes identified in the COMPTEL line background were expected to be present based on experience from the SMM [9] and HEAO 3 instruments [15]. The different detection principles employed, however, result in significant differences in the count rates related to specific isotopes. Detailed understanding of the instrumental-line background and its variation is crucial for many astrophysical analyses, such as that of the CDG (e.g. [2,12,13]) or that of the galactic ^{26}Al 1.8 MeV line emission (e.g. [5,6]).

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