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The Preliminary Cosmic Diffuse γ-Ray Spectrum from 800 keV to 30 MeV Measured with COMPTEL

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Abstract. We report a preliminary Cosmic Diffuse γ-ray (CDG) spectrum from 800 keV to 30 MeV obtained with the COMPTEL instrument, the Imaging Compton Telescope on-board the Compton Gamma Ray Observatory. The spectrum is constructed by measuring the count rate of γ rays from high galactic latitudes and first extrapolating the rate to a zero cosmic-ray flux environment to eliminate the prompt background. The prompt background is produced primarily by the interactions of protons and neutrons with the spacecraft. Second, this rate is then corrected for the effects of delayed internal radioactivity to arrive at the γ-ray count rate due to the CDG radiation. The preliminary measurements of the CDG flux in the 2–10 MeV range is 5–10 times lower than earlier reports. The 2–30 MeV flux is consistent with power-law extrapolations from lower and higher energies. The preliminary measurements show no evidence of a 'MeV bump' above 2 MeV. The bump, if present, is restricted to energies less than $\sim$ 2 MeV.

Key words: gamma rays – diffuse extragalactic gamma-radiation – Compton telescope – COMPTEL

1. Introduction

The measurement of the Cosmic Diffuse γ-radiation (CDG) is of fundamental importance because it is a unique probe of the Universe. The origin of the CDG radiation has been discussed in the literature in the context of either the superposition of sources or a truly diffuse process. The measured diffuse radiation spans several orders of magnitude in energy from 0.1 keV up to 10 GeV and may well be a composite of different components with different origins. The different components may dominate the diffuse radiation in specific energy ranges. The properties of the CDG radiation are less well measured than those of the X-ray diffuse radiation. The difficulties in measuring the CDG radiation vary with energy. At the lower energies (0.5–10 MeV), the major difficulty is the instrumental background, while at the higher energies (>100 MeV) it is important to accurately subtract the Galactic diffuse radiation. To solve the question of the origin of the CDG radiation, it will be necessary to obtain an accurate measurement of its energy spectrum and its granularity. The CDG radiation in the 0.5–30 MeV range has been measured with satellite-borne spectrometers (e.g., Trombka *et al.* 1977; Mazets *et al.* 1975) and balloon-borne Compton-telescopes (e.g., Schönfelder *et al.* 1980; White *et al.* 1977). The COMPTEL instrument is ideally suited to measure with greater precision and accuracy the CDG flux because of its large detection area, low background, wide field-of-view ($\sim$ 1 sr) and long exposure time. We report preliminary results of COMPTEL measurements of the CDG energy spectrum from 0.8–30 MeV.

2. Instrumentation

A detailed description of the COMPTEL instrument was presented by Schönfelder *et al.* 1993. The analysis was performed on 'Telescope data' of COMPTEL that have the advantage of a high signal-to-noise ratio. Each 'telescope' event is defined by a coincident signal in the upper (D1) and lower (D2) detectors with the proper time-of-flight and with no signal from any of the charged-particle shields. For each event, COMPTEL measures the following: the energy deposit in D1, the energy deposit in D2, the interaction position in D1, the interaction position in

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D2, the pulse-shape of the signal in D1 (to discriminate between γ-ray and neutron-induced events), the time-of-flight (TOF) between D1 and D2 and the absolute time of the event. The energy deposits in D1 and D2 are in turn used to compute the total energy and the photon scatter angle via the Compton scatter kinematics. These data are supplemented by the spacecraft orbit and attitude data.

3. Observation

The data used in this analysis are from the Phase III observations of the Virgo region ($l \sim 270^o$, $b \sim 65^o$), totalling about 60 days. The high-latitude observations minimize the contribution from the Galaxy. The data were accumulated during the periods when the Earth was outside the COMPTEL field-of-view. This eliminates any contamination from atmospheric γ rays.

4. Data Analysis

The CDG radiation is considered to be isotropic in space and constant in time. Hence, we expect no unique spatial or temporal variations to distinguish the CDG radiation from the background radiation. Background radiation refers here to all non-cosmic sources of gamma radiation. The CDG measurement is made by first subtracting every instrumental background source, correcting for identifiable cosmic sources and then attributing the residual flux to the CDG radiation.

Telescope events are produced by cosmic (external) γ rays and background (internal) γ rays. The background γ rays are produced primarily by the interaction of protons and neutrons with the spacecraft and hence are internal in origin. The ideal event occurs when a cosmic γ-ray scatters from D1 to D2 with a complete energy measurement of the electron in D1 and a completely absorbed scattered photon in D2. The scattered photons have a TOF of $\sim$ 5 nsec ($\sim$ 1.5 meter between the two detectors). The background events are comprised of accidental events, local-multiple-γ events and internal photons that scatter from D1 to D2. Accidental events are produced by two independent and uncorrelated γ rays interacting in each of the detectors within the TOF window. These events are distributed uniformly in TOF. The local-multiple-γ events are produced by multiple-nuclear-deexcitation γ rays that scatter individually in D1 and D2. The γ rays originate from the excited nuclei around COMPTEL and form a continuum in TOF space because of the distribution of the mass around COMPTEL. Most single-photon-scattered events from excited nuclei are suppressed because they have large scatter angles. Hence, the unscattered γ rays generally exhibit a different TOF behaviour from the scattered γ rays. The TOF spectrum can be accurately described by a Gaussian peak, respesenting the scattered cosmic γ-ray events, superimposed over a smooth continuum produced by the local-multiple γ-ray events. A typical TOF spectrum is shown in Figure 1. The TOF-peak events are due to cosmic γ rays (the desired signal) and some local-multiple and single-scatter γ events that originate in the upper part of the instrument (i.e. D1 platform). It is merely the geometrical positon of the D1 platform that places these background events within the TOF peak. The TOF spectra are fitted with the above mentioned components in each energy range to derive the TOF-peak event rates. However, the peak rates include some background events. These background event rates must be estimated to derive the CDG count rates. The prompt background present in these fitted rates is estimated by extrapolating the TOF-peak rates to a zero cosmic-ray flux environment.

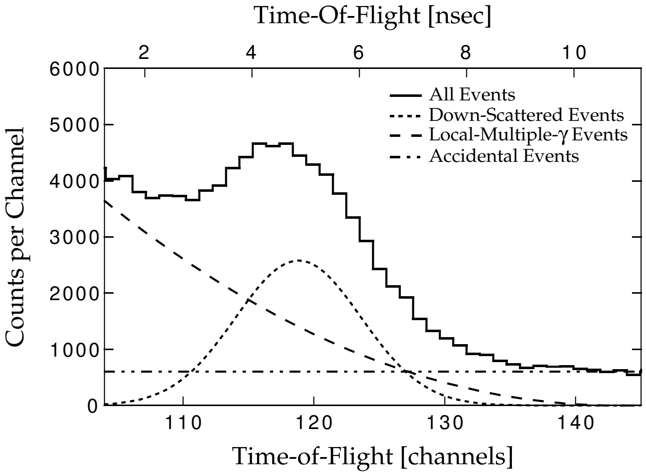

Fig. 1. A typical Time-of-Flight spectrum.

Neutrons interact inelastically through (n, n' γ) or (n, x γ) type reactions with the carbon in the D1 scintillators. When the n' or x produces a signal in D1 and the γ-ray produces a signal in D2 a telescope event is produced. Such background events are suppressed by selections on the pulse-shape of the signal in the D1 detector. Thermal neutron-capture by hydrogen produces 2.223 MeV photons that are not affected by selections on the pulse-shape.

The prompt background component ($\tau_{1/2} < 1$ minute) in the downward-scattered TOF peak can be calculated by ordering the fitted TOF-peak rates by the local geomagnetic vertical cutoff rigidity. The typical behavior of the fitted rates with rigidity is shown in Figure 2. The fitted TOF-peak event rates are extrapolated to infinite rigidity to estimate the steady-state event rate. The steady-state events are due to cosmic γ rays and quasi-steady-state background γ rays (i.e. beta decays). The 2.223 MeV line flux is prompt ($\tau_{1/2} \sim 100\mu$s) and rigidity dependent and hence its contribution is eliminated in the infinite rigidity extrapolation. The prompt background is seen to be negligible compared to the steady-state background for energies below 2 MeV.

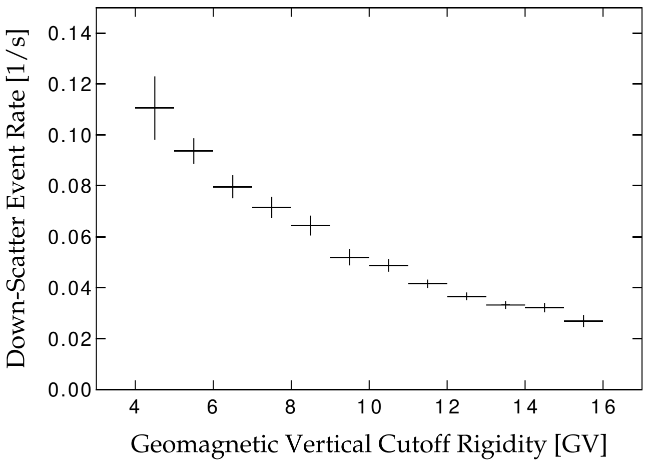

Fig. 2. Downward-Scattered event rate from 4–10 MeV versus the vertical cutoff rigidity.

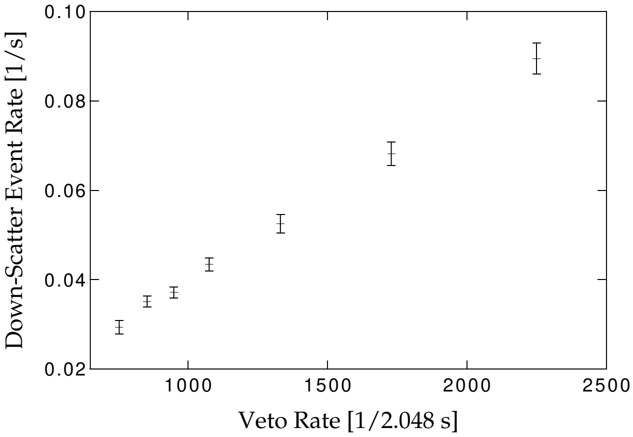

Fig. 3. Downward-Scattered event rate from 4–10 MeV versus the Veto scaler rate.

The motivation for using rigidity as a background scaling parameter is that rigidity is an indicator of the cosmic-ray flux incident on COMPTEL. Another indicator of the cosmic-ray flux incident on COMPTEL is the charged-particle shield rates. The veto rates scale with the instantaneous, solid-angle integrated cosmic-ray flux incident on COMPTEL. We find that the fitted TOF-peak rates vary linearly with the veto rates while they vary non-linearly (exponential or power-law) with rigidity. Hence, veto rate scaling is a superior background scaling parameter. Hence, the prompt background component ($\tau_{1/2} < 1$ minute) in the downward-scattered TOF peak can also be *independently* calculated by ordering the fitted TOF peak rates by the veto scalar rates. The typical behavior of the fitted rates with veto rates is shown in Figure 3. The fitted TOF-peak event rates are then extrapolated to zero veto rates (corresponding to infinite rigidity) to estimate the steady-state event rate. The steady-state rates derived using veto scaling are consistent with those derived using infinite rigidity extrapolation, implying that the extrapolated steady-state rates are accurate and free of any large systematic errors.

As stated above, the scatter-angle selections (rejection of events with large scatter-angles) eliminate most of the single-photon-scatter background events. Hence, the steady-state background γ rays are primarily due to multiple-photon decays from long-lived radioactive isotopes. These long-lived beta sources can often be identified by characteristic decay γ-ray lines measured in the individual detector spectra. Above 4 MeV there is no evidence of any steady-state γ-ray background of this type. Below 4 MeV, we have identified the ^{24}Na isotope to be the dominant source of quasi-steady background γ rays. ^{24}Na events in the TOF peak are produced by fast neutron interactions with ^{27}Al in the D1 structure. ^{24}Na decays ($\tau_{1/2} \simeq 15$ hours) emit two simultaneous photons (1.368 and 2.754 MeV). When one photon hits D1 and the other hits D2 a telescope event is registered. We measure directly the ^{24}Na activity by measuring the intensity of the lines with the D2 detector and through simulations predict the full telescope response. At least two other unidentified sources of steady state background are seen below 2 MeV. One of these is eliminated through tighter event selections on the scatter-angle while the other remains. We are working to identify and estimate these background sources.

5. Results

The CDG flux (Figure 4) was determined by deconvolving the resultant count spectrum with the computed instrument response for an $E^{-2.5}$ power-law diffuse source. Only upper-limits are plotted for energies < 2 MeV due to the presence of uncorrected background events. The errors are statistical and do not include systematic errors of the ^{24}Na event corrections and effective area calculations. It is important to note that although the results are high latitude measurements, they do *include* flux contributions from the Galactic diffuse γ-radiation ($< 5\%$ at 1 MeV to $< 35\%$ at 15 MeV) (A. Strong, private communication; Strong *et al.* 1995) and γ-ray point sources in the field-of-view, specifically 3C 273 and 3C 279 ($< 1\%$ at 1 MeV to $< 4\%$ at 15 MeV) (Hermsen *et al.* 1993).

6. Discussion

The preliminary COMPTEL measurements of the CDG flux in the 2–10 MeV range are a factor of 5–10 lower than previous measurements. The 10–30 MeV flux is in agreement with the measurements reported by White *et al.* 1977. The observed 2–30 MeV flux is compatible with the extrapolated power-law spectra from lower energies (Mazets *et al.* 1975) and higher energies (Kniffen *et al.* 1995; Osborne *et al.* 1994). The preliminary COMPTEL measurements show no evidence of a 'MeV bump' for energies above ~ 2 MeV. We have plotted *conservative*

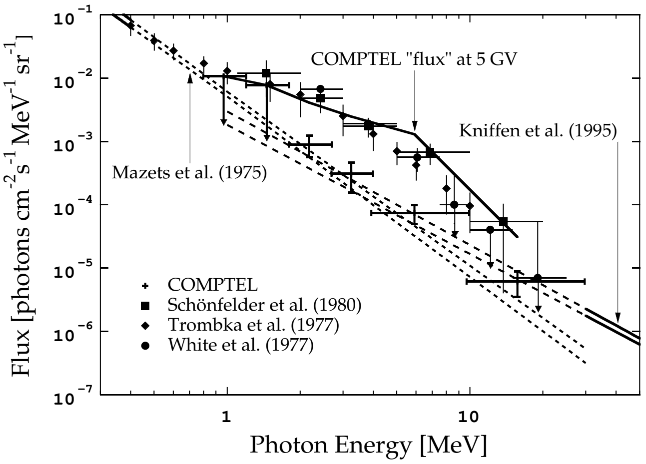

Fig. 4. The Cosmic Diffuse γ-ray spectrum. COMPTEL measurements are shown with other experiments and the power-law extrapolations from spectral fits at lower and higher energies.

upper-limits in the 0.8–1.8 MeV range due to the remaining uncorrected background. The 1.2–1.8 MeV flux must be reduced by $\sim$ 75% and the 0.8–1.2 MeV flux by $\sim$ 30% if they are to lie on the extrapolated power-law. The 'MeV bump', if present, is confined to the 0.8–2 MeV energy range. Adding the CDG flux reported here to the 5 GV (typical balloon environment) rigidity dependent background measured with COMPTEL yields "flux" values (COMPTEL "flux" at 5 GV, Figure 4) that agree with earlier measurements (Schönfelder *et al.* 1980; White *et al.* 1977). We believe that this is the basis of the high values reported earlier. Hence, the ability to extrapolate COMPTEL data to a zero cosmic-ray environment via extrapolation to infinite rigidity or zero charged-particle shield rate and correct for cosmic-ray and neutron-induced prompt background lowers the COMPTEL CDG flux values with respect to earlier measurements.

A variety of explanations have been proposed with regard to the possible origin of the radiation (see e.g., Gehrels & Cheung 1993; Fichtel & Trombka 1981). Since the 'MeV bump' is in question, all theories that explain the bump are challenged, including the model of primordial matter-antimatter annihilation radiation integrated over redshift (Stecker *et al.* 1971). The integrated γ-ray spectrum of Type Ia Supernovae (SN Ia's) could also contribute significantly to the diffuse radiation in the 0.1–1 MeV range (The *et al.* 1993). Note that this SN Ia model contributes significantly only below 1.3 MeV and hence is not in conflict with the data. At X-ray energies, around a few keV, the results of the Einstein Deep Survey (Giacconi *et al.* 1979) and Rosat Deep Observations (Hasinger *et al.* 1993; Shanks *et al.* 1991) show that a significant fraction of the diffuse radiation is due to unresolved sources. AGNs (Seyferts in the 2-500 keV range) could contribute up to 100% of the diffuse radiation by assuming luminosity evolution and integrating over redshift (Zdziarski *et al.* 1995; Schwartz & Tucker 1988). Above 100 MeV, blazar type AGNs as observed by EGRET (Montigny *et al.* 1995), could contribute a significant fraction of the diffuse radiation, again assuming a γ-ray luminosity function and integrating over redshift (Chiang *et al.* 1995; Setti & Woljter 1994; Padovani *et al.* 1993; Stecker *et al.* 1993).

In conclusion, the preliminary COMPTEL measurements in the 2–10 MeV range is 5–10 times lower than earlier reports. The 2–30 MeV flux is consistent with power-law extrapolations from lower and higher energies. The preliminary measurements show no evidence of a 'MeV bump' above 2 MeV. The bump, if present, is restricted to energies less than $\sim$ 2 MeV. The CDG spectrum in the 60 keV to 10 GeV range, except for perhaps the range 0.8–2 MeV, can be well described by a broken power-law that evolves from soft to hard with increasing energy. The break energy seems to occur in the 1–10 MeV range.

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