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THE RESPONSE OF THE BATSE LADS TO RADIATION FROM THE CRAB NEBULA AND PLANS FOR RADIOACTIVITY STUDIES ON SPACE STATION

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I. Response of BATSE Large Area Detectors

Introduction

The Burst And Transient Source Experiment (BATSE) onboard the Compton Gamma-Ray Observatory (CGRO) was designed to measure X-rays and gamma rays with energies from about 50 keV to above 2 MeV. As with many scientific investigations, the success of the original experiment lead to additional areas of research interest. In the case of BATSE the ability to observe the radiation from sources down to about 20 keV became readily apparent. This lead to a continuing program of measuring the spectrum of radiation from stellar objects at these lower energies. One of these, the Crab Nebula, has a very steady radiation flux and, thus, has become a "standard candle" for such measurements.

The Large Area Detectors (LADs) on BATSE contain a 1.27-cm thick, 25.4-cm radius NaI(Tl) detector behind a 6.35-mm thick polystyrene Charged Particle Detector (CPD) (Pendleton95) used to "veto" charged particles signals. The detectors have been calibrated with a series of gamma and X-ray sources and the results carefully simulated with a Monte Carlo code. In the calibration process the computer simulation accounts for scattering from material in the counting room as well as the BATSE structure. For an orbiting detector, scattering from the entire spacecraft must be modeled as well as for all covering material over the detectors.

Five years after CGRO was launched on April 5, 1991, a large body of observational data has been taken of the Crab Nebula. The technique used for these observation, and for many other X-ray sources, is Earth occultation. From the perspective of the spacecraft, the Earth occults most stellar objects once an orbit, i.e., the signal is lost as the source sets and is regained as the source rises. A careful analysis of the continuing signals from all sources measured allows for an accurate measurement of the spectrum of a given source. An analysis of this data from the Crab has indicated that the LADs are very responsive at energies as low as 20 keV—at energies below the range of calibration. While the model accounts for many of the interactions of the photons with the detectors, the observation of nonstatistical deviations at low energy and at small angles has suggested a need to recalibrate at energies where the attenuation effects are increasing exponentially(Pendleton94).

Spectral Shape

To a good approximation at low energy the count rates measured by the LADs can be approximated as

$$C(E) = A(E)\cos(\theta)\exp(-B/\cos(\theta)) \qquad (1)$$

where $A(E)$ is the product of the flux of photons $\Phi(E)$, the intrinsic efficiency of the detector $\varepsilon(E)$ and the area of the detector, θ is the angle between the incident beam and the normal to the detector, B is the absorption factor. The absorption factor is given by

$$B = \sum_i \mu_i \rho_i t_i \tag{2}$$

where μ_i is the mass absorption coefficient, t_i is the thickness and ρ_i is the density of the covering material.

The spectrum of radiation from the Crab Nebula as observed by BATSE has been studied using this simple model. A χ^2 minimization procedure has been used to obtain the A and B coefficients giving the best fit to this data. The quality of a typical fit is shown for LAD 3 in Figure (1) while the trend of these coefficients is give in Figures (2) and (3). This behavior of B is that expected for a rapidly decreasing mass absorption coefficient.

However, although a very good fit to the data can be obtained using Eq. (1), there is a tendency for the model to fall below the data below about 30°. This is most pronounced in channel 1. Since the energy window spanned by this channel is roughly 20-30 keV, the simulation of the covering material may not have been done with sufficient accuracy to properly reproduce the detector response. In particular, the hexel shape of the honeycombed aluminum covering the CPDs may be the cause, or part of the cause, for this problem.

A Model of the Honeycombed Aluminum Sheet

The structure covering the CPDs contains two 10 mil aluminum sheets glued with epoxy to a hexel aluminum structure. This structure appears to be made by stamping three-sided "troughs" into ¼" wide, 2 mil aluminum strips and placing them together to form a hexel pattern. The distance between opposite sides is 0.49 cm. Incident photons entering the hexel region at 0° encounter the ¼" aluminum hexel covering 2% of the surface area. As the angle increases photons entering the hexel region in a plane of incidence normal to one wall pass through less material although the effective area increases. At 38° photons begin to pass though a second wall and at 57° a third wall.

The adjacent hexel walls are at 30° to the incident plane. The thickness through which the photons pass are greater than the first wall and the opposing walls are much closer. These photons are more greatly attenuated. Rotating the incident beam about the normal to the LADs produces a changing effective area and attenuation for a given angle θ. Modeling such a structure requires a complex mathematical statement.

A simple model of the hexel structure has been chosen as a series of long parallel sheets placed perpendicular to the plane of incidence. For such a structure the effective sheet thickness varies as $t / \sin(\theta)$ until the angle of 38°. An introduction of this model into Eq. (1) gives

$$C(E) = A(E)\cos(\theta)\exp(-B / \cos(\theta) + C / \sin(\theta + D)) \qquad (4)$$

where D is introduced to keep the argument of the exponential finite at 0°. The results of a χ^2 fit of this function to the count rates is shown in Fig. (4) for LAD 3. The χ^2 values are comparable to those for Eq. (1), but the quality of fit for small angles in channel 1 for all LADs is much better. However, the parameter C is positive, not negative as expected for an attenuation, and D is typically about 30°, not about 0.5° as might be expected from the 2 mil by ¼" hexel cell.

Although this seems non-physical, a physical interpretation can be made. At higher angles there are a greater number of data points than at small angles. This "forces" the B parameter to represent an effective thickness which includes several hexel walls and the increased effective thickness of the planar material. At smaller angles the C coefficient must "decrease" the attenuation factor to properly reduce the attenuation. At higher energy, higher channels, the rapidly decreasing absorption coefficients reduce the effect of the hexels. Therefore, C coefficients consistent with zero are usually found in Channel 2 and higher channels where Eq. (1) adequately fits the data.

Energy Recalibration

The energy calibration of the BATSE detectors was performed preflight and may have changed during orbital insertion or because of thermal gradients in orbit. This will cause the preflight model of the detector responses to be incorrect. The count rates for Channel 1 in the LADs indicate sufficient differences to suggest that this has occurred. The variations in the A coefficients from Eq. (1) can be used to adjust the energy widths of the low energy channels. In addition, the values of the B coefficients give the average attenuation factor for several channels of each LAD. This is directly related to the energy range covered by a given channel. By varying the energy range to give a better fit to the data the energy calibration can be adjusted. While the small angle deviation from the model is still present, the resultant fits properly reproduce the spectra at larger angles. Corrections to other detectors can be obtained in a similar manner.

II. Induced Radioactivity

The Long Duration Exposure Facility (LDEF) was orbited for a period of 68 months beginning in April, 1984. Nearly 400 samples taken from that mission have been studied to study the induced activity encountered while in orbit. A review of the results found in an article submitted for publication(Harmon96) shows significant scientific information on total activation and on the directionality of the proton flux encountered by LDEF. However, the delay between retrieval and sample counting resulted in only a few long-lived radioisotopes being found. This precluded attempts to determine the proton energy flux by analysis of production of radioisotopes with differing activation thresholds. For the same reason, the possibility of measuring high energy neutron fluxes with reactions having small cross sections and short half lives was negated.

Despite this, these results indicated the potential for significant new scientific investigations. For example, similar passive experiment can be undertaken on the Space Station. A set of 1/16" samples of aluminum, vanadium, cobalt, nickel, indium, tantalum, and tungsten and another set of the same samples sandwiched between moderating material could study proton and neutron activation in orbit. Differences in the activities from the two sets would allow separation of fast and slow neutron effects.

These samples should be placed behind the racks in the first Space Station module orbited. After six months in orbit a moderated set and an unmoderated set of samples would be replaced and returned on a shuttle mission. After landing the samples would be immediately transported to a counting facility. This will allow for the determination of the abundance of the activated isotopes with half-lives of 3-4 days or less rather than the 70 day half life material typically measured on LDEF. These samples could be replaced and returned to Earth on a monthly basis, or as often as the availability of shuttle missions. This study would result in a better understanding of the flux of particles encountered by the Space Station and the onboard experiments.

An active experiment to measure the high energy neutrons could be flown on the Space Station or in an external experiment rack. A detector such as a fission fragment detector should be investigated as a possible active system. This system measures the energy of neutrons which interact with a thin sheet of uranium. Fission in the uranium produces recoiling fragments which interact with a particle detector. The signals produce by these interactions can be analyzed to determine the number and energy of the high energy neutrons.

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(Harmon96) Harmon, B. A., et al., Induced Radioactivity of LDEF Materials and Structural Components, accepted for publication by Radiation Tracks.

Figure 1. Crab_LAD3_Chan 1

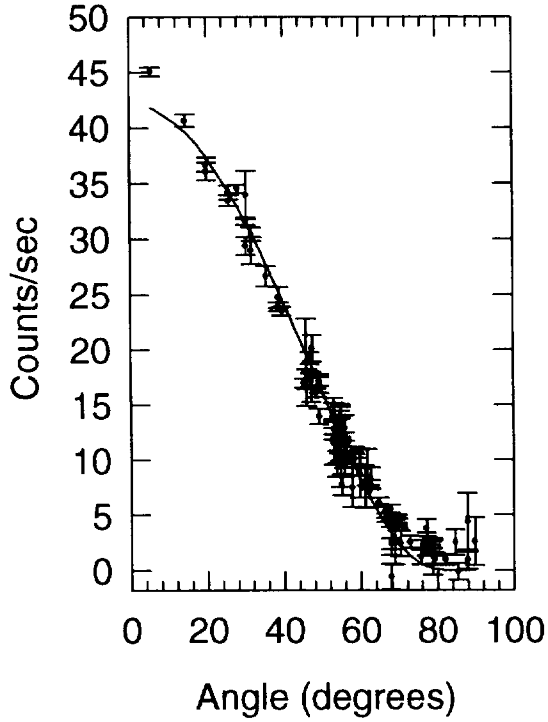

Figure 2. A Coefficients for LAD 3

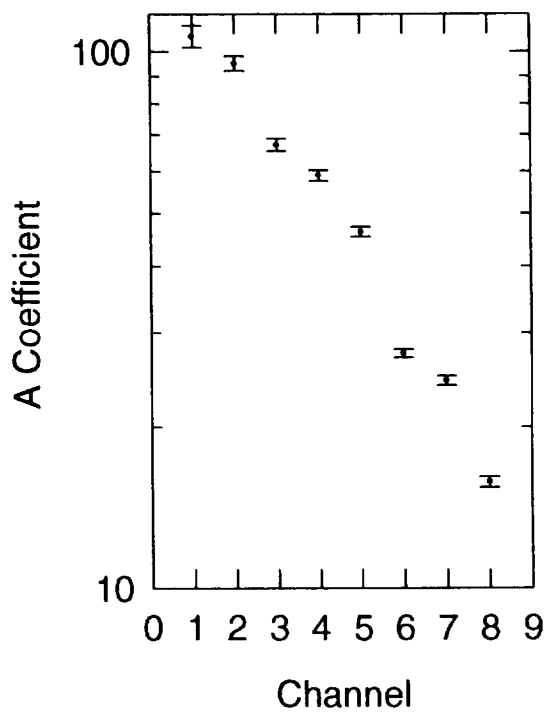

Figure 3. B Coefficients for LAD 3

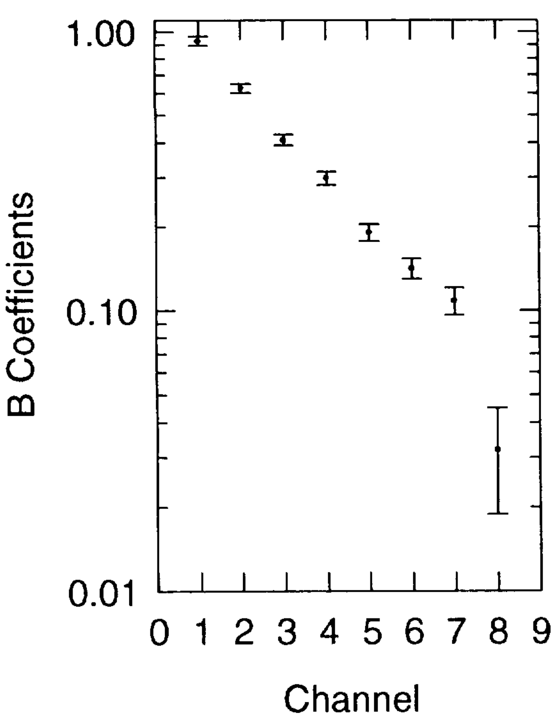

Figure 4. Crab_LAD3_Chan 1