SPECTRAL ANALYSIS OF GAMMA RAYS WITH THE COS-B SATELLITE

The Caravane Collaboration

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Abstract. The ESRO satellite COS-B carries one single experiment aiming at the measurement of arrival direction and energy of celestial gamma rays with energies between 25 MeV and 10 GeV. The experiment is conventional in design and consists of a veto counter, a wire spark chamber, a telescope and an energy calorimeter.

The energy measurement is obtained by a CsI scintillation crystal of 4.7 radiation length thickness. The expected energy resolution at 100 MeV is 50% FWHM. The other detector elements are designed as to cause the least possible degradation of the energy measurement.

The possibilities for the detection of a small contribution of π^0-origin gamma rays in the presence of a power-law type background spectrum will be discussed.

1. Introduction

The COS-B is an ESRO satellite entirely devoted to gamma-ray astronomy, scheduled for launch in 1974.

Given the opportunity of the prolonged observation time available with satellites a detailed study of gamma-ray origin is possible. Such a study should include energy measurement to the extent that the gamma-ray production mechanisms may be recognized and that the energy spectra of those particles giving rise to gamma rays will be determined.

For this reason a substantial part of the payload of COS-B is reserved for energy measurement.

The sensitivity of the instrument is limited by the available weight (~120 kg). It

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will be shown that within this boundary condition detailed spectral and structural information will be obtained on the emission from the galactic plane. Also the isotropic radiation may be analysed in detail as well as the spectra from point sources with a strength in excess of 10^{-6} γ/cm^2 s.

Of special interest among the candidate point sources are pulsars. A search for pulsed emission for sources 50 times weaker than NP 0532 (in the keV region) may be made, while for strong pulsars a detailed spectral analysis and pulse profile measurement seems feasible.

2. The Satellite

A schematic representation of the satellite is given in Figure 1. It is a spinning satellite with a diameter of approximately 150 cm, a height of 110 cm and a total weight around 260 kg. The viewing direction of the detector is parallel to the spin axis. All satellite sub-systems are mounted well outside the forward or backward sensitive cone, thereby reducing local background to a minimum. The sub-systems include a buffer memory capable of transferring the data smoothly to the real-time telemetry.

The spin stabilisation keeps the detector oriented to any given position (accurate to within 1°) on the celestial sphere. The only restriction comes from the requirement to keep the spin axis perpendicular to the solar vector plus or minus 30 deg.

In contrast to other gamma-ray satellites, a highly eccentric orbit is chosen. The apogee is typically 100000 km. The main advantage is, that gamma-ray albedo from the Earth will not affect the experiment and almost no time is lost by occultation of sources by the earth.

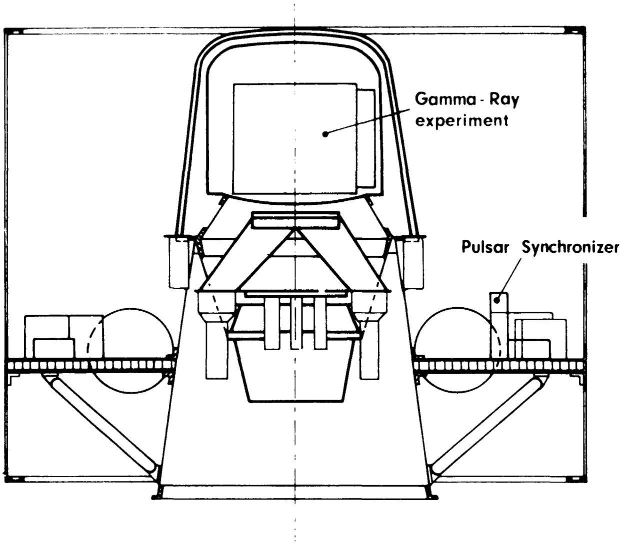

Fig. 1. Satellite configuration. The gamma-ray experiment and the pulsar synchronizer are shown.

3. The Gamma-Ray Experiment

The experiment is conventional and consists of a digitized wire spark chamber, a telescope, a veto counter and an energy calorimeter. The sensitive area is about 500 cm^2. Of the total weight of approximately 120 kg, 30 kg is allocated to the energy spectrometer. A sketch of the entire experiment is shown in Figure 2.

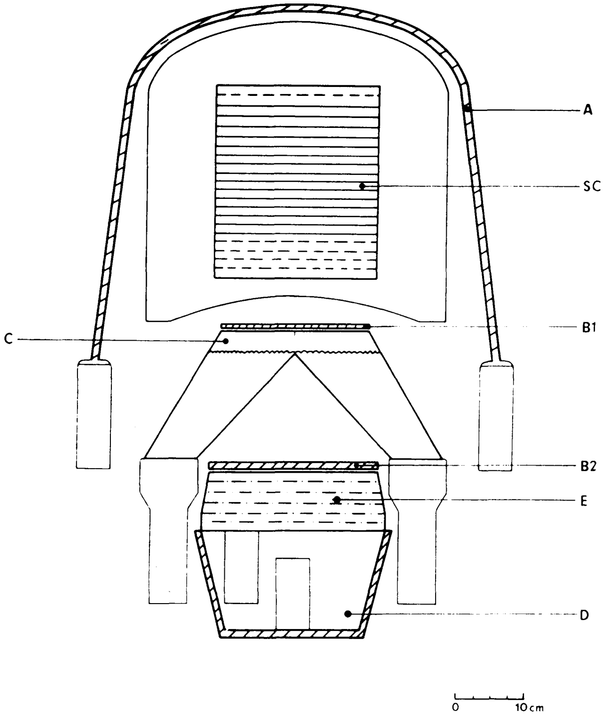

Fig. 2. A schematic view of the COS-B gamma-ray experiment.

Before describing the energy measurement we will review some points of interest of the other detector units.

The digitized wire spark chamber has a sensitive area of 576 cm^2. A total of 1 radiation length converter material is distributed non-uniformly over 20 layers. Monte Carlo calculations indicated that the efficiency at energies around 50 MeV did not increase appreciably with a converter thickness exceeding 0.3 radiation lengths. Therefore, it is advantageous to reduce the thickness of the lower plates while keeping a high efficiency at high energies by increasing the thickness of the upper plates. This solution also guarantees the best possible angular resolution throughout the entire energy range. Data to be obtained from tests in accelerator gamma-ray beams will yield information to determine the optimum matter distribution in the spark chamber.

The telescope consists of three elements. Two scintillation counters, B_1 and B_2 and a directional Čerenkov counter (C). The telescope is designed as to minimize the amount of material between the point of conversion and the energy calorimeter, since otherwise the energy measurement would be seriously degraded. Therefore the PM-tubes of the Čerenkov counter have been removed from the particle beam. Laboratory tests have shown that the performance, efficiency and forward-backward ratio, is quite adequate in this configuration. The Čerenkov counter and the B_2 counter are segmented to allow for an inflight variation of the acceptance cone of the events. In addition, a choice of triggering at one or two particles exists.

The pulse heights of B_1 and B_2 are analysed for each event. This provides a check on the identification of gamma rays (specifically important for the diffuse radiation) and it also contributes to the determination of energy.

The veto counter (A) consists of plastic scintillator. It has a thickness of 1 cm and is viewed by 9 PM tubes which will provide an adequate efficiency.

We aim to measure gamma-ray energies from 25 MeV up to about 10 GeV. This is not possible with the passive method employing the multiple scattering of the created electrons in the spark chamber, but requires an active calorimeter in which a significant part of the electromagnetic cascade is absorbed.

We tested spectrometers consisting of lead-glass, lead-plastic sandwich and CsI at accelerator electron beams. Application of CsI gives a marked improvement in energy resolution below 100 MeV. As a compromise between resolution and weight a crystal of 4.7 radiation length thickness was selected.

The crystal is coated with a highly reflective white paint (Harshaw) and viewed by four RCA 7151-Q photomultipliers, directly coupled with Dow Corning 51 dielectric gel. The light yield corresponds to approximately 150 photo-electrons/MeV. Application of the diffuse reflecting white paint also provides an excellent uniformity.

Because of the exposure of the crystal to the environment of an eccentric orbit care must be taken to prevent the pulse height analysis electronics and the photomultipliers from overload. The tube gain will be set at about 3×10^4 and delay-line clipped amplifiers with base-line restoration will be employed. Photomultiplier currents are limited at 10 μÅ and in addition the high-voltage will be switched off during passage of the radiation belts.

Induced radioactivity in the crystal will not interfere with the energy measurement because the associated energy levels are below 5 MeV. The temporary increase in output current will not be excessive.

At low energies (<100 MeV) a correction must be applied on the energy measurement to allow for the energy loss of the pair electrons between the point of conversion and the energy calorimeter. In this respect the pulse height measurement on B_1 and B_2 supplies vital information. Energy which is radiated along the path of the electrons is absorbed, with a high probability, in the spectrometer.

A plastic scintillation counter (D) is added below E for two reasons:

(1) At energies beyond 500 MeV its pulse height provides additional information on the energy.

(2) For low energy events it serves as an extension of the veto counter, thereby reducing background due to cosmic rays interacting in the spectrometer.

The overall energy resolution is expected to be about 50% FWHM, except maybe at the very low and very high energies.

4. Anticipated Results

One of the gamma-ray emitting regions of prime interest in this mission will be the galactic plane. Estimates of counting rates have been derived from the revised intensities observed by OSO-3 as reported by G. Clark at this symposium.

Table I summarizes the number of counts above 100 MeV expected for a one month observation period.

TABLE I

Number of observed gamma rays with energies above 100 MeV over a period of 1 month

Galactic centre:	5 interval in l^{II}	2900
Galactic disk:	5 interval in l^{II}	1100
Galactic pole:		1400

The number of counts observed within the galactic plane for typical intervals of 5° longitude are sufficient for a detailed determination of the spectral shape. Figure 3 illustrates this. In this figure we show the expected spectra resulting from one month observation in the galactic plane outside the centre region integrated over a 5° interval in longitude. Two types of input spectra were taken as an example (π^0-decay and E^{-2}) each normalized to the same integral flux above 100 MeV (4×10^{-5}/cm^2 s rad). These spectra were folded with the estimated detector response and the resultant spectra were devided into arbitrary energy bins. Statistical errors are indicated. It is apparent that these two types of spectra can be distinguished clearly.

In reality one may expect to observe a π^0-spectrum on a power law type background. It turns out that in the previous example a 20% π^0-component on a power law background will be resolved at a 3 σ confidence level. This limit is a factor three below the expected contribution, inferred from the known cosmic-ray spectrum and hydrogen column densities.

The high energy tails of these spectra allow for an accurate determination of the spectral slope, namely

$$\mathrm{d}N/\mathrm{d}E = kE^{-\alpha} \qquad \alpha = x \pm 0.05\,.$$

This accuracy allows for a significant correlation with the spectra of cosmic-ray particles responsible for the production of gamma rays. Point sources in excess of 10^{-6} γ/cm^2 s and the 'isotropic' component may be investigated to a similar detail. Weaker sources can be discovered but only crude spectral information is obtained. A search for a knee in the extragalactic radiation between 5 and 10 GeV may be made.

Pulsars are intriguing phenomena of universe. We aim to measure the pulse shape and the energy spectra of pulsars if their gamma-ray intensity is strong enough. A search for emission of gamma radiation from pulsars require a very accurate timing over long periodes. Because of the apparent drift of the pulsar frequency due to the satellite motion it is not possible, in general, to accomplish this timing by a stable clock onboard or on the ground. A simpler and much more reliable method is to determine the local frequency and phase by observing the pulsar simultaneously at much longer wavelength. This will be accomplished by an X-ray detector (called pulsar synchronizer) of approximately 10 cm^2. The onboard telemetry clock is then calibrated on a typical time scale of one hour in terms of pulsar-time, to an accuracy of 0.25 ms. Of course one must know the approximate period (e.g. from radio observations) and one must assume a continuous-emission spectrum from radio wavelengths up to gamma-ray energies.

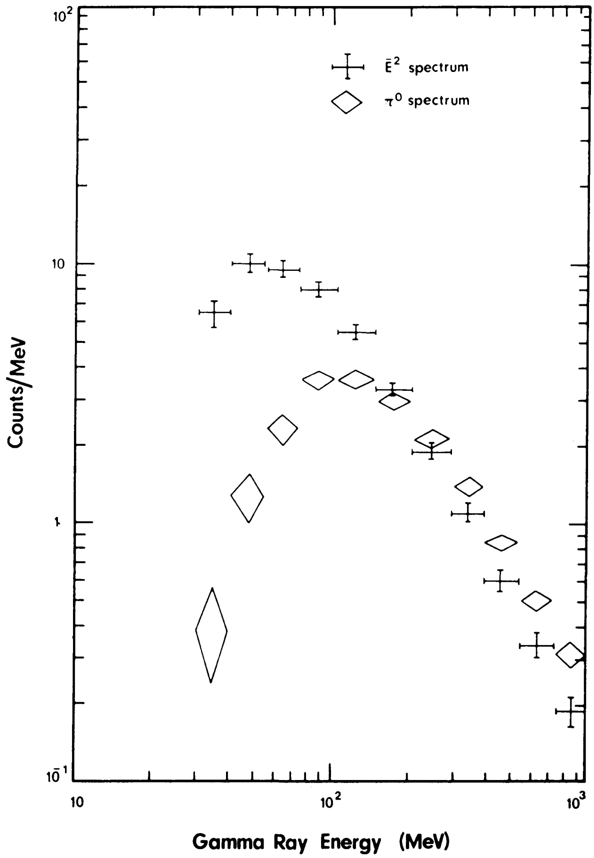

Fig. 3. Accuracy of energy spectra of galactic radiation as may be obtained over a one month observation period while pointing towards the galactic disc in a region outside the galactic centre. The estimated intensities are integrated over a 5° interval in l^{II}.

Following this method pulsed sources may be detected down to lower intensities than continuous sources, because of the apparent reduction of background counts by virtue of the knowledge of the pulsar phase.

Acknowledgements

We greatly appreciate the valuable information supplied by Dr. L. E. Peterson on the application of large CsI crystals in satellites. The authors are very much indebted to the valuable advice and support given to this project by G. Occhialini and R. Lüst.

DISCUSSION

J. E. Grindlay: With regard to your 'pulsar synchronizer', it would seem your pulsar observations would be restricted, at least for the present to the Crab Nebula from which an X-ray component has been detected. Do you therefore plan extended X-ray observations of other pulsars?

B. N. Swanenburg: The X-ray detector is a device to simplify the timing problems for pulsar measurements. It was first suggested for reference timing for the Crab pulsar, but it may be sensitive enough for other pulsars.