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ENERGY SPECTRA OF COSMIC GAMMA-RAY BURSTS

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ABSTRACT

We report spectral measurements of six cosmic gamma-ray bursts in the energy region of 0.1 to 1.2 MeV, made using a semi-omnidirectional x-ray detector on IMP-6.   These measurements confirm the hard X-ray or gamma-ray nature of the bursts, as inferred from the original observations by Klebesadel et al., (1973), and show that their maximum energy release is in this several hundred keV region.   Each burst consists of several 1 or 2-second pulses each with the characteristic spectrum of a $\approx$ 150-keV exponential, followed by a softer decay.   There is no evidence of line structure in this energy region, or for a marked change in the energy spectrum within a given pulse.   Event size spectra are estimated for galactic and extragalactic models; the total emission is consistent with present measurements of the diffuse background, and unlikely to account for any spectral feature in the few-MeV region.

I.   INTRODUCTION

The occurrence of intense, several-second duration bursts of 0.1 to 1.2-MeV cosmic gamma rays, recently found using multiple Vela satellites (Klebesadel et al., 1973), has been confirmed with measurements from the IMP-6 satellite.   Observations regarding times of occurrence, photon flux,

and temporal and spectral characteristics of the bursts are entirely

consistent. In particular, since the IMP-6 instrument incorporates

a hard X-ray detector with active particle rejection and full-time

omnidirectional particle intensity monitoring, the results fully

confirm and establish the hard X-ray or gamma-ray nature of the inci-

dent flux.

Detailed differential energy spectra were obtained with the IMP-6

for six of the eight known events occurring during the March 1971 to

September 1972 lifetime of the instrument. All of these are multiple-

pulse events, with several seconds separation between distinct pulses

of one or two seconds duration. The pulse spectra do not obey single-

index power laws in energy, but can be simply represented by exponentials

in photon flux throughout the 100 to 1200 keV region. The character-

istic energies at maximum intensity appear to cluster near 150 keV, with

indications that departures from this value can be interpreted as

circumstantial, due to attenuation when the source is at great angles

from the detector axis. These burst pulses appear to ride on a softer

component that exhibits a longer decay time constant, and has a character-

istic exponent near 75 keV. There is no evidence for monoenergetic line

structure in the several hundred keV region, or for marked changes in

the spectrum with time during a single pulse. Size spectra can be estimated

to predict the frequences of occurrence of smaller events for both a

galactic model, e.g., a new class of gamma-ray flare star, and an extra-

galactic model, e.g., supernovae. In either case the total emission is

below the value currently obtained for the diffuse celestial X-ray background, and unlikely to account for any of its spectral features.

II. INSTRUMENTATION

The IMP-6 satellite was launched on 14 March 71 into an elliptic orbit with an initial apogee of over 200,000 km. Gamma-ray monitoring was provided on a nearly continuous basis, except for passes every 4.14 days through the magnetosphere, lasting several hours each. The detector was in operation from launch until 2 May 1971, and again for the period from 9 June 71 to 27 September 72. The instrument used consisted of a 2.25-inch diameter by 1.5-inch thick CsI(Tℓ) crystal, entirely surrounded by a thin plastic scintillator for particle rejection, viewed by a single PM tube. In addition to full-time monitoring of the rates of total intensity, particle intensity and gamma ray intensity, energy spectra of incident gamma rays were measured by a 14-channel analyzer with simultaneous storage in all channels. The spectra were accumulated for one half of the time, for each $\approx$ 6.3 second period from sun rise to sunset on the detector, determined by the optical aspect. This 50-percent duty cycle resulted in missing several of the very brief gamma-ray bursts. The spectral accumulation times were fixed at $\approx$ 5.1 seconds so that the $\approx$ 6.3-second life times were asynchronously split into 2 or 3 intervals of shorter durations, making possible more than one spectral determination during some of the pulses. The gain of the system was cycled through 4 positions with changes at $\approx$ one-week intervals for purposes of in-flight calibration, so that some of the bursts happened to be observed with a 69 to 1150-keV dynamic range and some with a 53 to

880-keV range. The primary purpose of this gamma-ray detector was

use as a coincident annihilation spectrometer incorporated in a

positron detector. The secondary objective was that of a solar flare

monitor, and it was in this mode of operation that these unexpected

gamma ray bursts were observed.

III. DATA OBSERVATION AND ANALYSIS

The times of occurrence of gamma ray bursts observed with multiple

Vela satellite coincidences were used to identify coincident increases

in the IMP-6 gamma-ray intensity. Six of the eight Vela events were

observed well above the omnidirectional background, the others being

missed because of the 50-percent detector duty cycle. It is possible

that other events, of intensity too low to exceed the Vela threshold

triggers, may also be observable with the IMP-6 instrument. Figure 1 shows

the response of the IMP gamma-ray detector to the event of 30 June 1971.

During a several second interval, the counts in the plastic scintillator

(P) surrounding the gamma ray crystal increased by about 50, while the

neutral counts in the crystal $(\gamma \overline{P})$ simultaneously increased by about 18,000.

Pulses satisfying the gamma-ray logic are fed to a multichannel analyzer,

from which the outputs of three channels, added to provide the flux of

140 to 475 keV photons, indicate an increase during one $\approx$ 5-second interval

of nearly 5000 counts from a total omnidirectional and secondary back-

ground of about 400 counts. This illustrates the remarkable intensity

of the bursts, and shows that the response is entirely consistent with that

of hard x-rays or gamma rays.

The times of occurrence and various properties of all Vela-IMP events

(Wheaton et al., 1973), contain too much emission in the X-ray region
to fit $\approx$ 150 keV black body spectra, and yet too little emission in
the lower energies to be compared to the typical, steep X-ray spectra,
having index of $\approx$ -3 or more, of most hard solar flares and many
celestial X-ray sources. For those pulses which were observed with
sufficient temporal resolution to obtain more than one spectrum per
pulse, there is no evidence for changes in the characteristic energy
during its extent (not illustrated). Further, there is no evidence
for line structure in this energy region. It is possible, however, that
great improvements in energy and time resolution might show fine-scale
spectral variability with a variety of monochromatic lines, which average
out over 2-second summations.

An integral size spectrum can be constructed, assuming a power law
with index -1.5, normalized to 6 or 8 events per 1.5 years with sizes
greater than 10^{-4} erg cm^{-2} for the energy region above 100 keV. Since
the 18 known events have source directions compatible with isotropy (Strong
and Klebesadel, 1973) rather than with, e.g., galactic plane clustering,
the source objects must either have distances in the tens to hundreds
of pc if galactic, or, if extragalactic in nature, have distances of >
several Mpc. Thus, this size spectrum can be normalized for these two
models in order to obtain predictions of the frequencies of occurrence of
smaller events. In the case of extragalactic sources, e.g., gamma-ray
rich and optically poor supernovae or other large collapsing objects,
a summation of all emissions up to cosmological distances produces a total
isotropic background intensity which is below the presently observed

diffuse cosmic background in this energy interval. Thus an extra-galactic origin cannot be ruled out. Further, if all sources have spectra with $\approx$ 150-keV exponentials, then the total cosmic spectrum will not extend into the several MeV region with sufficient intensity to explain the bump in the diffuse cosmic background observed (Trombka et al., 1973) at those energies.

References

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EVENT	BURST	I_0	E_0	LOOK ANGLE
15 Mar 71	Second Max	1.9	156	Includes Source ($\alpha \approx 50°$, $\delta = -30 \pm 10°$)
18 Mar 71	Decay of 1st	1.8	74	Spins through Source
30 Jun 71	First Max	0.7	276	Source below satellite horizon
30 Jun 71	Second Max	5.5	142	Spins through Source
30 Jun 71	Decay of 2nd	0.7	110	Spins through Source
17 Jan 72	Decay of 1st	0.10	138	Source position undetermined
17 Jan 72	Second Max	0.35	184	Source position undetermined
17 Jan 72	Decay	0.11	170	Source position undetermined
28 Mar 72	First Max	0.50	238	Source near or below horizon
28 Mar 72	Second Max	0.55	176	Source position undetermined
14 May 72	First Max	0.8	166	Includes Source ($\alpha \approx 175°$, $\delta \approx +77°$)
14 May 72	Second Max	0.8	152	Includes Source

Table 1. Characteristics of gamma-ray burst spectra.

Exponential fits in dn/dE provide I_0 in units of photons cm^{-2} keV^{-1}, and E_0 in units of keV, both of which have systematic uncertainties depending on relative look angle.

Figure Captions

Figure 1.   The response of the detector to a gamma ray burst,
as indicated by the plastic anticoincidence (P),
the CsI gamma ray detector ($\gamma\bar{P}$) and several channels
added to give the 140 to 475 keV photon rate, where
the gamma-ray energy response is maximized. Each
point samples two differential energy spectra.

Figure 2a.   Number spectra dn/dE, of several bursts, selected for
the greatest variety of responses. The harder spectra
are interpreted as due to attenuation of the incident
beam by the satellite material in cases where the source
was below the detector horizon. Fig. 2b (insert). The
energy spectrum, E dn/dE, of a directly observed event.

IMP-6 EVENT OF 30 JUNE 1971