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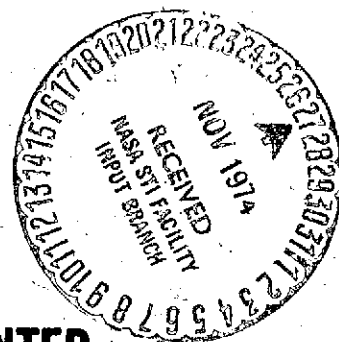
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T. L. CLINE
U. D. DESAI

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Observations of Cosmic Gamma-Ray Bursts with IMP-7:
Evidence for a Single Spectrum*

T. L. Cline and U. D. Desai
NASA/Goddard Space Flight Center
Greenbelt, Maryland 20771

ABSTRACT

Spectral observations of nine recent cosmic gamma-ray bursts are reported. The average photon number spectra of all nine events are each consistent with a 150-keV exponential from 100 keV to about 400 keV, and a power law of index -2.5 from 400 keV to 1100 keV. The observations also indicate an event rate of 16 in 1972 and 1973, or 8 ± 2 per year, higher than the 5 ± 1 per year initially reported. This corresponds to an approximately 40-percent lower effective intensity threshold, attained by using more sensitive detectors in multiple-satellite coincidence.

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I. INTRODUCTION

We report spectral observations of nine of the eleven known cosmic gamma-ray bursts (GRB) detected from late 1972 to the end of 1973. These events, seven of which are previously unreported, were observed during the fourteen months following the launch of the IMP-7 satellite. All nine events were found to have event-average photon number spectra from 100 to 1100 keV that are statistically consistent with each having the same shape. In two of these events, departures from a good fit can be reconciled as instrumental, due to effects of an eclipsing scan mode. The hypothesis of a single >100 -keV spectrum for all gamma-ray bursts, when averaged over each event duration, was inferred from IMP-6 observations of the intensity maxima of five earlier events (Cline et al., 1973), and is hereby considerably strengthened. In addition to the mutual consistency of these five IMP-6 and nine IMP-7 events, all other independently reported GRB events are also consistent with the same event-average spectral shape; these include an Apollo-16 event (Metzger et al., 1974), and several OSO events (Wheaton et al., 1973, and Palumbo et al., 1974).

The observed lack of variability of the event-average spectrum, despite the indication of some spectral variation with time during one of these events (Imhof et al., 1974), suggests that the production mechanism is tied to more rigidly fixed source parameters than most celestial or solar hard x-ray phenomena. Other characteristics of GRB events, suggested by these observations, include a >400 -keV spectral tail with power-law index -2.5 , a rate of occurrence of observed events up

from $5 \pm 1 \text{ yr}^{-1}$ to $8 \pm 2 \text{ yr}^{-1}$, with a 40% increase in experiment sensitivity, and a hint of clustering of event occurrence in time.

II. INSTRUMENTATION

The IMP-7 satellite was placed into an approximately circular earth orbit with a $\approx 200,000$ -km apogee in October 1972, where interplanetary data are obtained, free from interference by encounters with trapped radiation, on a nearly continuous basis. Data collection for our electron and gamma-ray detector was initiated on 14 October 1972, and this instrument is still operating properly. The IMP-7 detector's instrumental configuration and spectral analysis scheme are identical to those on IMP-6 (Cline et al., 1973), but the spin rates, data collection times and duty cycles differ. The consequent dissimilarities between the IMP-7 and IMP-6 data collection modes warrant some discussion here, since the IMP-7 detector is more effectively omnidirectional than IMP-6, and thereby provides less biased and also less ambiguously interpreted spectra.

The IMP-7 gamma-ray data were collected in two modes; six of the nine GRB events detected (see Table 1) were observed in the mode which consists of the continuous accumulation of data for 40.9 seconds into a 14-channel differential analyzer. During this time there are approximately thirty rotations of the satellite of about 1.3 seconds each. The time duration of each of these six events, due to their brevity at energies over 100 keV, happened to lie entirely within a single 40.9-second summation. The celestial directions of origin of nearly all of the IMP-7 events are unknown, so that the effective collection areas and aspects

are not calculable. However, the fact that each event has a >100 -keV duration long compared with the IMP-7 spin period (Klebesadel, pri. comm.) means that each IMP-7 spectral accumulation takes place as the satellite rotates through the incident flux at least several times during the duration of each burst. Since the detector has a better than semi-omnidirectional view angle, a fair representation of the average spectrum of each event is obtained if the spectral character is constant or changes slowly during an event. This collection mode is in contrast to that on IMP-6, in which the spin period was about 10.5 seconds, long compared to the duration of a typical intensity variation; also, on IMP-6, the individual spectral storage times were much shorter, averaging 2 or 3 seconds, and the data collection had a 0.5 duty cycle, accumulating only during the sunward half of each satellite rotation. Consequently, the several-second wide intensity maxima of the GRB events were asynchronously observed on IMP-6 at differing and usually unknown relative azimuths. By contrast, these six events observed with IMP-7 were effectively averaged over in a manner relatively independent of source direction.

The other three of the IMP-7 events were observed in an alternate 40.9-second collection mode, which, as on IMP-6, consisted of storage during only the half of each rotation in which the satellite faced the sun, but which, unlike IMP-6, summed the data for about 30 spins. Thus, depending on the azimuth direction of each of these three GRB sources relative to the sun, their spectra could be obtained in an eclipsing manner thereby introducing attenuation effects at the lower energies.

In all nine events, independent of azimuth, some spectral distortion must be present due to the fact that the rotation of the satellite systematically introduces a somewhat wider effective sensitive angle for high-energy photons than for lower-energy quanta. On the average, however, this effect will be the same for all of the IMP-7 events having spectral time constants long compared with one spin period, and will not alter the conclusion that these events are spectrally similar.

III. OBSERVATIONS

Table 1 lists the known gamma-ray burst events from the launch of IMP-7 to the end of 1973, giving the satellite observations in the order of detection and confirmation. Work is still in progress to search for events in all the available data, and it is possible that other events during this time interval may yet be found. The total number of known bursts in calendar years 1972 and 1973 is now sixteen (Table 1 and Strong et al., 1974), increasing the earlier rate of detection from four or five per year (Klebesadel et al., 1973) to nearly double that number. This increase in efficiency is due to the lowering of the effective detection threshold by requiring only one Vela trigger in coincidence with any IMP or other satellite observation, such as SAS-II (C. Fichtel, to be published) or Apollo-16 (Metzger et al., 1974). It should be noted that all GRB events that have been spectrally observed are of relatively long duration and are structured in their time histories; none of the very fast, ≈ 100 -millisecond, events detected by the Vela satellites as comprising about one-tenth of the total population (Strong et al., 1974) have been observed spectrally. These

very fast events are sufficiently different in their time histories from the slow events that their other characteristics, and even origin mechanism, may also be distinct.

The energy windows of the 14-channel analyzer on IMP-7 for all nine events were approximately the same as those used in one of the two gain modes on IMP-6, in which the 30 June 1971, 17 January 1972 and 28 March 1972 events were observed (Cline et al., 1973); the data were accordingly treated in same manner regarding the corrections for efficiency and energy-dependent geometric factors. The resulting differential photon number spectra of all nine of these IMP-7 events are plotted in Figure 1. Minor statistical differences are seen, but the similarity is striking, considering the usual variations in the spectra of most astrophysical or solar x-ray phenomena. A comparison spectrum was arbitrarily created by the construct of a 150-keV exponential tangent to a power-law of index -2.5 at the higher-energy end. This spectrum is shown as a dashed curve, plotted for comparison against each event spectrum in Figure 1. Normalization was chosen to provide the best visual fit in each case. It is noted that two of the three eclipsing scan-mode events are deficient at the low-energy end; this is exactly what one would expect from attenuation in the satellite material if the sources were near or below the detector horizon. Thus, the conclusion that these nine events are consistent with having the same spectrum is easily reached by inspection. Since they were all obtained with the same detector, the absolute calibration would not effect this conclusion, but comparison with events observed with other detectors would of course be subject to relative calibration errors.

The IMP-6 events were previously shown to be consistent with 150-keV exponentials, when sampled through their intensity maxima (Cline et al., 1973); their lack of an obvious power-law tail may result from the more intensive spectral corrections that were, of necessity, applied to the IMP-6 data due to electronic imperfections that did not exist on IMP-7. Not only the various IMP results, but all spectral observations (including Palumbo et al., 1974, Wheaton et al., 1973, Imhof et al., 1974 and Metzger et al., 1974) of sixteen different event-average spectra are mutually consistent. The GRB event of 27 April 1972, detected with Apollo 16 (Metzger et al., 1974) and one Vela (Strong et al., 1974) was measured with greater differential accuracy than any other, and yet agrees in detail with our spectral model, including the existence and shape of the power-law tail. Finally, the event of 18 December 1972 has been found to have a certain amount of spectral variation in time (Imhof et al., 1974); yet this event is also one which, on the average, was observed with IMP-7 to fit the standard spectrum. The equivalent event-average spectrum cannot be produced from the results of Imhof et al. since their observations cover only a portion of the burst duration. The fact that at least one of the IMP events spectrally varies thus suggests that variations may be present in the other events, yet with a pattern that reproduces the same average result.

IV. DISCUSSION

The similarity of all known GRB event spectra should provide information regarding the nature of the production mechanism. It certainly implies that the parameters of the source process should have narrow limits as to their variability. Thus, a model such as stellar collapse, for example, might be more likely than that of stellar superflares, since it would seem that collapse would occur in a situation where more critical limits are attained. On a different scale, the iron-grain model (Grindley and Fazio, 1974) may also be capable of producing a relatively fixed gamma-ray spectrum, but in that case it is not immediately apparent why the fast-time spectral samples would not be representative of the average spectrum. Extensive theoretical investigation of the models proposed may provide arguments as to their compatibility with this observation; the cooling blackbody model (Ramaty and Cohen, 1973), for example, is one in which the instantaneous spectra undergo extreme variability, but the average spectrum of the bursts is a constant.

Another implication of these results is the existence of a hard or high-energy x-ray tail on the photon number spectrum. [If the earlier indication of a pure 150-keV exponential (Cline et al., 1973) were extrapolated, there would be very little flux above a few MeV.] This picture of a power law with index -2.5 above a few hundred keV thus allows for the possibility of observing a measurable flux in the $>$ several-MeV range. Of course, considering the lack of a large number of observations of the soft x-ray component, one may prefer to view the spectrum as composed of two power laws, of index ≈ -1 and one of index Δ steeper than -2 . In this interpretation, the spectral bend always occurs at the same energy.

Another result is that the occurrence rate of GRB observations is increasing as the data from a variety of satellites are more extensively examined for coincident event detection. However, comparing the IMP and Vela measurements to provide event confirmation has lowered the integral size spectrum by only 40 percent, assuming a -1.5 power law. Thus, considerably greater sensitivity will be required to improve the measurement of the size distribution, sufficient to establish any structural details, as would occur if the source objects are all within our galaxy. Finally, it is worth mentioning that the evidence hints at clustering of event occurrence; e.g., there are now six occasions of event-to-event intervals of less than 4 days, including two occasions of two bursts on the same day. An analysis of compatibility with a Poisson distribution in time intervals gives a result some three standard deviations away from randomness. Thus, it cannot be established whether multiple GRB events clustered within a few days interval, are produced by the same source object.

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Table 1

KNOWN COSMIC GAMMA RAY-EVENTS OCCURRING AFTER THE LAUNCH OF IMP-7

DATE YEAR MN. DY.	SECS (UT)	KNOWN SATELLITE OBS.	IMP-7 ANALYSIS TIME (SECS)	IMP-7 MODE*
1972 11 01	68206	Velas ⁺	(no data**)	180°
1972 12 18	73695	Velas ⁺⁺ , IMP-7 1972-076B***	73634-73675	360°
1973 03 02	84478	Velas ⁺⁺ , SAS-2 ⁺⁺⁺ , IMP-7	84474-84515	360°
1973 05 07	29072	Velas ⁺	(no telemetry)	---
1973 06 06	25648	IMP-7, SAS-2 ⁺⁺⁺ , Vela ⁺⁺	25638-25679	360°
1973 06 06	67634	SAS-2 ⁺⁺⁺ , IMP-7, Vela ⁺⁺	67611-67652	360°
1973 06 10#	75582	Velas ⁺ , IMP-7	75551-75592	360°
1973 07 21	32118	Velas ⁺⁺ , IMP-7	32096-32137	180°
1973 07 25	61677	Velas ⁺⁺ , IMP-7	61636-61677	180°
1973 12 17	29348	IMP-7, Vela ⁺⁺	29343-29384	360°
1973 12 23	02387	IMP-7, Vela ⁺⁺	02385-02426	180°

* 180° mode consists of solar hemisphere turn-on only of 0.65 second of each 1.3 second spin; see text.

** It is likely that this event was missed by IMP-7 due to its unusual 0.1-second brevity (Strong et al., 1974) and to the 0.65-second gaps in the data collection cycle in the 180° scan mode of IMP-7 (See text).

*** Imhof et al. (1974), using the 1972-076B satellite, found the direction of this event to be approximately r.a. = 70° to 120° and decl. = 0° to 20°, along or up to 20 degrees from the ecliptic plane, in which the IMP-7 instrument rotates.

⁺(Strong et al., 1974).

⁺⁺(R. Klebasedel, private communication).

⁺⁺⁺(C. Fichtel, private communication).

#Directional information (Strong et al., 1974) and some solar activity suggest that a flare origin here cannot be completely ruled out.

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FIGURE CAPTION

Figure 1. The nine event spectra of gamma-ray bursts observed with IMP-7. The three at the right were taken in the eclipsing scan mode, in which, depending on the azimuths of the source objects, the spectra could be attenuated at the low-energy ends due to absorption of photons by spacecraft material. Such an effect appears to have occurred in two of these observations, if one assumes that all event spectra fit the same typical shape. A comparison spectrum is shown for each event by a dashed curve, which was arbitrarily created by the combination of a 150-keV exponential and tangent power law of index -2.5. This curve appears to provide a reasonable fit in all nine events, taking into account the eclipsing effect discussed. (The daggers in all cases represent statistical errors, with only a small contribution of systematic errors from the uncertainty in the amount of background subtraction.)

Figure 1.

