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A 2.2 SECOND PERIOD IN THE 1984 AUGUST 5 GAMMA-RAY BURST

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ABSTRACT

We present the time history and the associated Fourier power spectrum of 1984 August 5 gamma-ray burst (GRB) observed with the Hard X-ray Burst Spectrometer (HXRBS) on the *Solar Maximum Mission* (*SMM*) and the *Pioneer Venus Orbiter* (*PVO*) spacecraft. A significant complex feature of the event is identifiable in both data sets: a gradual ripple with a well-defined 2.2 s period lasting for seven cycles, with a series of narrow spikes, which appear always on the ascending phase of the sinusoidal ripple. This event is unusual in both its temporal and spectral attributes: it exhibits coexistence of periodic and nonperiodic features; it was also reported as the most intense GRB event observed with the Gamma-Ray Spectrometer (GRS) on *SMM* extending up to 100 MeV.

Subject heading: gamma-rays: bursts

I. INTRODUCTION

The evidence for the existence of periodicities in cosmic gamma-ray bursts (GRBs) has always been a controversial issue, the controversy arising mainly from the difficulty of quantitatively determining a suspected period out of the few cycles contained in these short, transient phenomena. In order to satisfy the criterion of a truly periodic phenomenon, an event ideally should exhibit long-lasting statistically significant variations which would produce well-defined narrow peaks in the power spectrum. The 1979 March 5b GRB is the unique example fulfilling such a requirement; in fact, this event, still remains the only universally accepted example of GRB periodicity with a period of 8 s for more than 20 cycles over 170 s (Mazets *et al.* 1979; Barat *et al.* 1979; Cline *et al.* 1980; Terrell *et al.* 1980). A few other events have been reported as having suggestions of periodicity in the range 1–10 s (Barat *et al.* 1984), intriguing patterns (Evans *et al.* 1980), or a 4.2 s period (Wood *et al.* 1981). The ambiguity expressed above results from the fact that most events contain too few cycles to be clearly revealed by a Fourier analysis method or they have several slightly out-of-phase pulses which result in the distribution of power over a range of frequencies. In view of these natural constraints a more general approach to the analysis of time structures of transient events has been developed. It consists of first identifying the statistically significant features in an event, then measuring the time intervals between successive and alternate peaks, and finally evaluating the probability of occurrence of such an interval distribution. Studies using this technique have suggested repetition times of the order of 1–6 s (Desai 1981).

In spite of this paucity of observational evidence for periodicities, and given that no other studies, such as the search at optical, radio, and ultraviolet wavelengths, have yet revealed any identifiable point source candidates, the study of the detailed GRB time profiles today still provides unique information for theoretical modeling. Wood *et al.* (1981) have already tested whether any populations of neutron stars with known distribution are consistent with the GRB observations. They obtain best agreement with the time scales of the presently detected GRB periods or modulations by using the period distribution of old neutron stars in binary systems. However, further well-established periodicities are needed to provide support for a possible association of GRB sources with this particular neutron star population.

We analyze in this letter the 1984 August 5 GRB as recorded with the Hard X-Ray Burst Spectrometer (HXRBS) on the *Solar Maximum Mission* (*SMM*) satellite and with the GRB detector on the *Pioneer Venus Orbiter* (*PVO*). Observations with two different spacecraft provide independent spectral information and time profiles for comparative study of the repetitive structures. Detailed descriptions of these instruments have been given by Orwig, Frost, and Dennis (1980) and Klebesadel *et al.* (1980). Here we present count rate data from the HXRBS central CsI(Na) detector and from the cylindrical well-type CsI(Na) crystal used as an active anticoincidence shield and collimator for the central detector. This shield scintillator is viewed by four photomultiplier tubes and has an energy-loss threshold of about 150 keV.

In both data sets shown in Figure 1, we distinguish a significant complex feature of the event: a sinusoidal ripple of 2.2 s period with a series of narrow pulses (<0.5 s) riding on the ascending phase of the sinusoid. Although the ripple structure does not lend itself to detailed spectral analysis in either set, we believe that the good statistics in the four energy channels of PVO during some of the spikes will facilitate a future study of their spectral evolution.

II. OBSERVATIONS

Figure 1 shows the count rate time profiles of the event on 1984 August 5 for the HXRBS shield and central crystal and the *PVO* detector. Due to the limited memory capacity of the *PVO* instrument, only the first 24 s of the event were recorded.

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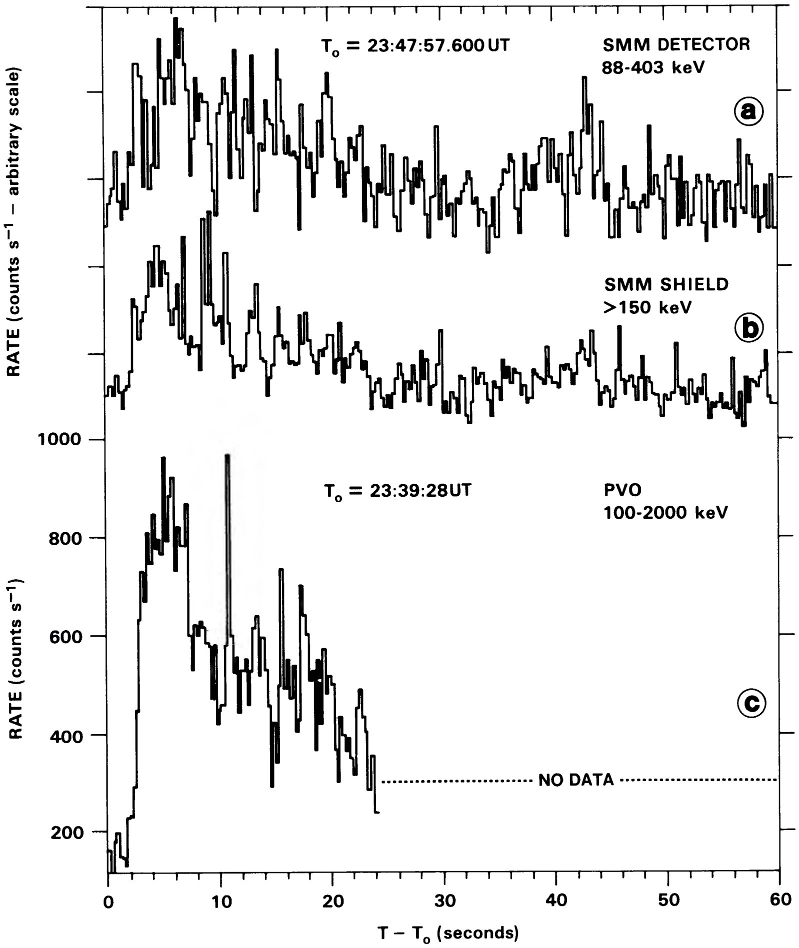

FIG. 1.—Time profiles of the 1984 August 5 gamma-ray burst plotted with 250 ms time resolution: (*a*) the count rates from the high-energy channels (90–400 keV) of the HXRBS central crystal, (*b*) the HXRBS shield crystal integral count rates above ~150 keV, and (*c*) the *PVO* count rates integrated over all energy channels (0.1–2.0 MeV). The start times T_0 have been adjusted for best visual fit between the HXBRS and *PVO* data sets, and the *Y*-axis scale is arbitrary for Figs. 1*a* and 1*b* to accomodate all profiles.

The *SMM*-HXRBS count rates are continuously recorded with 128 and 64 ms time resolution for the central crystal and the shield, respectively. Thus the total duration of the event was determined unambiguously as ~43 s starting at 23:47:59 UT.

The burst wavefront arrived 8.5 minutes later at *SMM* than at *PVO*. Tentative triangulation results identify the source location to be in the Hydra constellation, about 60° from the direction to the Sun (Share *et al.* 1986). Since the *SMM* instruments were pointed at the Sun during the observations and the HXRBS shield gives a 40° FWHM open field of view, the rates in the HXRBS central crystal low-energy channels (25–88 keV) were significantly reduced by absorption in the shield. Consequently, these rates are not included in Figure 1*a*. The high count rate in the shield from this event, when compared to the low count rate in the central crystal, also independently confirms that the source of the event was not in the field of view of the central detector.

The part of the event observed in common with *SMM* and *PVO* is shown on an expanded time scale in Figure 2. The time resolution in Figures 2*a* and 2*b* is 128 ms (2 times the highest available for the shield) and 117.19 ms in Figures 2*d* and 2*e* (10 times the highest resolution for *PVO*). We use the *SMM* shield rates here because of the better statistics compared with the central detector data. Since the shield data set has not been introduced up to this time and care must be taken for its interpretation, a brief description of its attributes and limitations is justified here.

The shield count rates always show statistically significant variations that are greater than those expected from Poisson statistics. On top of these background fluctuations, we see large spikes lasting from one to several 64 ms observing intervals, resulting from the passage of charged cosmic particles undergoing large energy losses in the shield. We were able to identify and discard the two most intense of these that occurred during the GRB by comparison with the *PVO* data set, and by checking the duration and structure of these spikes in the HXRBS central crystal memory data, which has 10 ms time resolution. In this way, we determined that the spikes at 23:48:06.5 UT ($T - T_0 = 8.9$ s) and 23:48:11.2 UT ($T - T_0 = 13.6$ s) are not related to the GRB; they are drawn, therefore, with dashed lines in Figures 2*a* and 2*b*. The spike at 23:48:07.0 UT ($T - T_0 = 9.4$ s), which does not appear in either the HXRBS central crystal or the *PVO* data, is most probably also a noise spike.

The remaining spiky structures were considered after the following criteria were satisfied: (1) simultaneous existence in both HXRBS shield and *PVO* data sets; (2) duration longer than 100 ms and shorter than 500 ms, as seen with the best

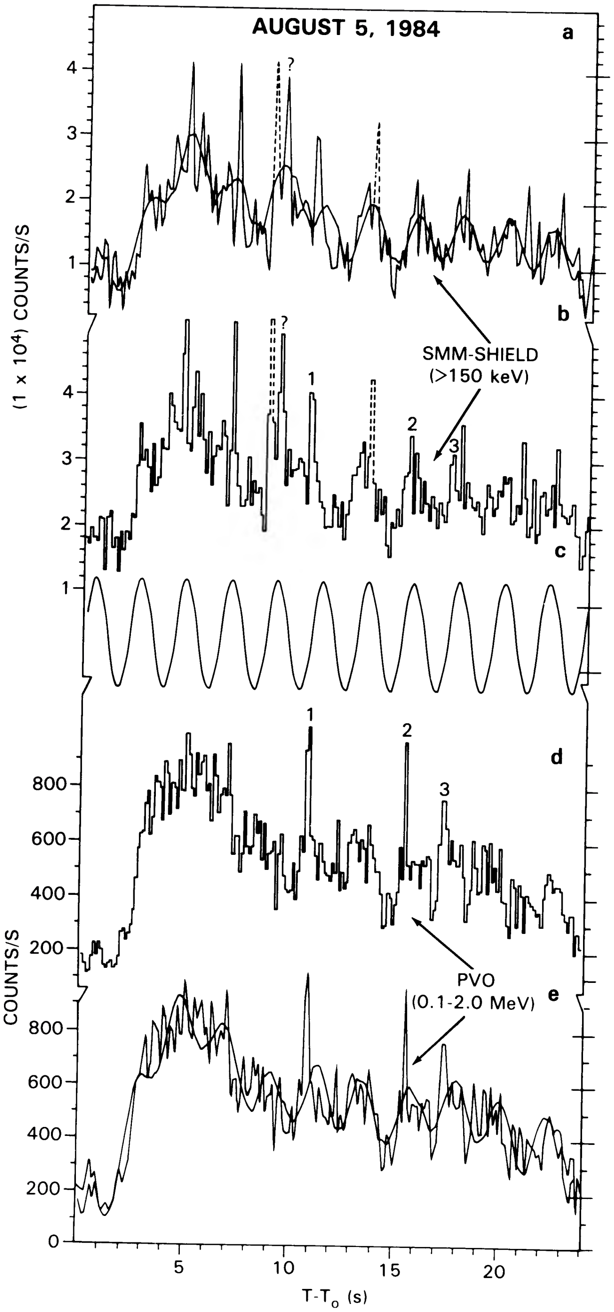

FIG. 2.—The first 24.161 s of the 1984 August 5, GRB. (*a*) and (*b*): the HXRBS shield data plotted with 128 ms time resolution. (*d*) and (*e*): the *PVO* time profile with 117.19 ms time resolution. (*c*): a sine wave of 0.45 Hz frequency positioned at the calculated phase for both time profiles but with arbitrary amplitude. As explained in the text, the broken lines and the question marks in Figs. 2*a* and 2*b* denote features attributed to charged particles and the numbers 1 to 3 in Figs. 2*b* and 2*d* indicate the position of the spikes that are believed to be part of the GRB. Figs. 2*b* and 2*d* show profiles of the raw data; Figs. 2*a* and 2*e* show a superposition of the raw data and the smoothened data with a sinusoid of 2.2 s period added as described in the text.

time resolution of the *PVO* data (11.719 ms); and (3) statistical significance higher than 3 σ estimated over the local background of the *PVO* data. This analysis yielded three significant spikes marked as 1, 2, and 3 on Figures 2*b* and 2*d*. All spikes ride on a broader pulsed structure and at approximately the same phase of the sinusoidal variation discussed below and shown in Figures 2*a* and 2*e*. They have similar temporal characteristics, the shortest of them (2) lasts 100 ms, while 1 and 3 have a FWHM of ~300 ms with indications of substructure which cannot be confirmed with the present statistics.

The period of the pulsed structure is obtained at a high level of significance by a Fourier transform of the HXRBS-shield data. Figure 3 shows the power spectrum of the first 24.16 s of the event obtained from these data using 128 ms time resolution. The technique used involves the substraction of a second-order polynomial fit to the data and division by the mean; the power spectrum is thus the relative power as a function of frequency. The data set was limited at the ends with a cosine-bell window to avoid spurious high-frequency power, and it was padded with zeros to the next power of 2. We present here the total frequency range up to the Nyquist value of 3.9 Hz in order to establish the white noise level, although there is no significant information at frequencies above 1 Hz. We clearly identify a well-defined, significant peak in the power spectrum at 0.45 Hz, which corresponds to a period of 2.2 s.

The uncertainty of the peak in the power spectrum is given by $N * \exp\,[-(P_{\text{peak}}/\langle P\rangle_{\text{peak}})]$, where N is the number of channels searched in the transform; P, and $\langle P\rangle$ are the peak power and the mean power at the peak, respectively. We can estimate $\langle P\rangle$ by extrapolating the exponential part of the spectrum, thus obtaining an upper limit for the probability of the 0.45 Hz peak accuracy in the absence of periodicity. For $\langle P\rangle \approx 0.05$, $P \approx 0.48$ and for 95 frequency channels we have 0.64% probability or a lower limit of a 99.36% confidence level for the periodicity. If we assume that the peak is riding on the white noise level of the spectrum where the mean power is ~0.025, we obtain a 99.99% confidence level as an upper limit. We wish to note here that the subtraction of the polynomial fit from the data has an effect only at the low-frequency part of the spectrum. The Fourier spectrum of the unsmoothened event is identical to the one shown in Figure 3 above 0.2 Hz.

A similar analysis of the *PVO* data also reveals the peak at 0.45 Hz but at a lower significance level. We believe that this is due to the suppression of the pulses by the higher number of low energy photons recorded by *PVO*, which has a threshold of 100 keV. We will expand this argument at the discussion section of this letter.

The existence of the periodic structure is also demonstrated clearly at Figures 2*a* and 2*e*, each a composite of two time series. On the raw data profiles we have superposed a curve obtained by first smoothing the raw data with a running mean of 2.2 s duration and then adding to them a sine wave of 0.45 Hz frequency. The phase and the amplitude of this sinusoid were calculated for both the HXRBS and the *PVO* data sets, and the sine wave itself is shown in Figure 2*c*, with the calculated phase but arbitrary amplitude. The results qualitatively show that the origin of the narrow peak in the power spectrum at 0.45 Hz is the rippling structure already quantitatively identified in the data, particularly the HXRBS shield time profile. Seven cycles with this period can be clearly resolved in the data during the first 24 s of the event. In the remaining 19 s of the event, the intensity level is too low to reveal any significant periodic features (see Fig. 1).

III. DISCUSSION

The 1984 August 5 event is unique in that it contains both a well-established periodic structure of 2.2 s period, as well as spikes that appear to be associated with the pulsation. These features have been confirmed by utilizing two independent

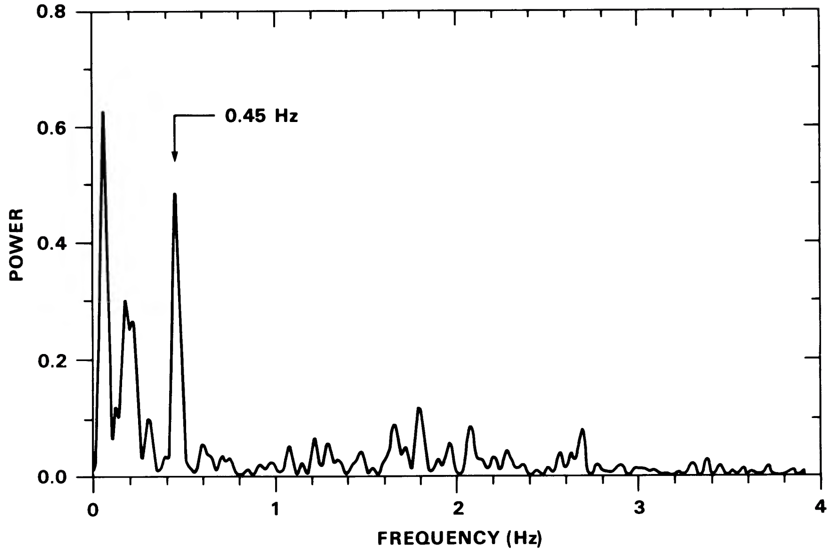

FIG. 3.—The power spectrum of the first 24.161 s of the event obtained from the HXRBS shield data with 128 ms time resolution.

data sets from instruments on *PVO* and *SMM*. Not only do the instruments on *SMM* and *PVO* differ in design, sensitivity, and response, but the two spacecraft were also separated by a large distance of ~14 lt-minutes during the observation. Thus, the existence of the common structures in the GRB time profiles can only be attributed to real structures in the GRB itself. The instrumental differences are reflected in the overall temporal shape and spectral information of the event. Hence, although the pulsation is evident throughout the event in the *SMM* data (Figs. 2*a*, 2*b*), it is less significant and even not observable at all in the *PVO* data during the initial 5 s hump (Figs. 2*d*, 2*e*). There is a twofold explanation for this discrepancy: (1) the lower energy threshold of the *PVO* GRB detector (100 keV) compared to the threshold of the HXRBS shield of $\gtrsim 150$ keV, which allows low-energy photons to suppress the modulation, and (2) the bigger collecting area of the *SMM* shield (~140 cm^2), as opposed to the ~23 cm^2 of the *PVO* detectors, which results in better count rate statistics.

The combination of these facts implies that the pulsation is due to the higher energy photons of the event. Unfortunately, as mentioned earlier in this *Letter*, several reasons prohibit us from supporting this conclusion in a more rigorous way. The *SMM* central crystal data are highly attenuated by the shield absorption, and the shield events are not pulse-height analyzed. The *PVO* energy channel equivalent to the HXRBS shield energy-loss threshold of >150 keV is Channel 2 with energy edges of 200–500 keV; this profile shows well-defined minima every ~2.2 s. In the *PVO* higher energy channels (0.5–2.0 MeV), the pulses (or the minima) are lost in the low statistics data, and there is hardly any modulation in the lowest channel (100–200 keV).

Evidence for similar behavior has been presented by Laros *et al.* (1985) for the 1984 December 15 GRB. In their presentation of the time profiles from two different spacecraft (*ICE* and *PVO*) they note that "peaks are sharper and the valleys are broader and deeper" in the higher energy time histories.

The 1984 August 5 GRB has another unique attribute. It is the hardest GRB recorded so far extending up to 100 MeV (Share *et al.* 1986). Thus, its duration and spectrum clearly place it in the "classical" GRB population. The requirements of the geometric modulation and the period of the pulsation would favor the binary neutron star population indicated by other studies (Wood *et al.* 1981). The dual nature (ripple-spike) temporal profile of GRB 840805 also raises the question: could the ripple be the result of emission from an extended region surrounding the location where the spike emission originated? In that case the energy spectrum of the gradually varying component should be softer than that of the spikes. Preliminary results of the spectral study point to that answer since the spikes clearly extend into the 1–2 MeV *PVO* channel, but a complete study is still underway.

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