Gamma-Ray Burst Variability Above 4 MeV

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1. Introduction. We explore the relationship between the hard X-ray and gamma-ray emissions during four bursts using the anti-coincidence shields of the High Energy Astronomy Observatory 3 (HEAO 3) Gamma-Ray Spectrometer. Recent observations of gamma-ray bursts by the Solar Maximum Mission Gamma-Ray Spectrometer (GRS) have shown that high energy emission above 1 MeV is a common and energetically important feature (Matz et al. 1985). Time histories of four gamma-ray bursts in 3 energy bands (>100 keV, around 511 keV, and >4 MeV) with 10.24 s resolution show that the >4 MeV flux is only weakly coupled to the spectrum below $\sim$ 600 keV.

2. Instrumentation. The HEAO 3 detections were made using the CsI anti-coincidence shield which is a right cylinder in five independent segments (see Mahoney et al. 1980 for a complete description). The spectrometer aperture is defined by the disclike collimator shield while the remaining well is equally divided into four segments. The crystal is 6.62 cm thick with a roughly isotropic response, and approximately 1000 cm^2 effective area ($\sim$ 600 cm^2 at 4 MeV) in directions not blocked by the Earth or spacecraft structure. Events are accumulated for each shield piece in three energy bands, a lower level discriminator (LLD) above 100 keV every 1.28s, a 150 keV window (WIN) centered at 511 keV every 10.24 s and an upper level discriminator (ULD) above 4 MeV every 10.24 s. Also, the logical sum of the LLD and logical sum of the ULD are accumulated in separate OR'D LLD and ULD rates.

3. Observations. We selected the bursts of 1980 13 FEB, 19 APR, 2 JUN, and 20 DEC which were four of the most intense bursts detected by HEAO 3. All four bursts were also detected by the Pioneer Venus Orbiter and the last three were also detected above 5 MeV by the GRS (Share et al. 1982, Share et al. 1981, Nolan et al. 1984). The rates shown in Figure 1 are uncorrected for any instrumental effects. The best HEAO 3 shield time resolution of 1.28 s is shown by the OR'D LLD rate as well as its 10.24 s average. In the lowest panel for each burst a 10.24 s average of the LLD rate and the WIN rate are shown for the side shield closest to the burst direction. The relative shield rates indicate that all four bursts were located in the forward 2π steradians facilitating comparisons between the bursts.

In Table 1 we give three numbers for each 10.24 s interval indicated at the top of Figure 1. The LLD rate is the sum of 10.24 s averages of the above background burst LLD rate in the collimator shield and the two side shields which subtend the direct burst flux. In the next column we show the ratio of this summed LLD rate to a similarly formed WIN rate. The next column gives the approximate variance of this ratio. The error is almost entirely due to large non-Poisson fluctuations in the background (also discussed in Wheaton et al 1982). A smaller ratio crudely indicates a harder spectrum below ~ 600 keV. The LLD/ULD ratio using the OR'D rates is a measure of the gamma-ray hardness followed by the percent error in the ULD rate.

4. Results. Both the LLD/WIN ratio in Table 1 and the bottom panel of Figure 1 show that the LLD and WIN rates track each other closely throughout any given burst. Also, for each burst the interval with the highest LLD rate has a hard LLD/WIN ratio. This effect is particularly pronounced for 20 DEC during interval 2 and for 2 JUN during interval 3 (low LLD and soft LLD/WIN). The only significant exception is interval 1 for 2 JUN which is harder than interval 2 which has a higher LLD rate. However, the 1.28 s time history shows an intense spike during the first 10.24 s interval. Comparing bursts, three of the bursts have LLD/WIN ratios clustered from ~ 7-8.5 but the 2 JUN burst is clearly the softest overall below ~ 600 keV and its interval 3 is the softest interval overall.

At first glance the LLD/ULD ratio seems much more variable, however we must assess the importance of the poorer signal-to-noise ratio in the ULD. Examining the burst of 13 FEB in Figure 1 and Table 1, there is a large ULD spike in interval 1 and a LLD/ULD ratio of 70. Interval 2 is as impulsive in the 1.28 s LLD rate as interval 1, but with a little more than half the LLD and WIN intensity. But, the ULD rate does not show any significant increase over background. Summing the OR'D ULD and OR'D LLD rates over all of the 13 intervals (except interval 4 for 13 FEB) obtains an overall LLD/ULD ratio of 135. We use that ratio to compute a reduced chi-squared statistic from

$$\chi^2_{12} = \frac{1}{12} \Sigma \frac{(ULD_i - LLD_i\ (\Sigma ULD/\Sigma LLD))^2}{\sigma_i^2}.$$

σ_i is the ULD variance for each interval with a LLD rate. Thus, χ^2_{12} = 7.5. Using a similar technique over the 13 FEB burst we obtain an average LLD/ULD of 122 and χ^2_4 = 8.8. The large value of the reduced chi-square statistic clearly shows a large variability in the gamma-ray to hard X-ray ratio within a burst and from burst to burst. Note that the 19 APR burst is the hardest burst overall in the MeV range.

The spectral hardness in the below 600 keV range is not directly related to the burst intensity above 4 MeV. The 19 APR burst has the hardest LLD/ULD ratio of 43 and a median LLD/WIN ratio of 8.4. In contrast interval 2 of 20 DEC has the hardest LLD/WIN ratio of 6.8 but its LLD/ULD ratio is 220 ± 50 which is the softest interval having a significant ULD flux.

5. Conclusions. Over the 10.24 s intervals used here, the highest rates over 4 MeV occur during the highest rates above 100 keV. However, throughout a given burst the > 4 MeV flux is not a constant fraction of the >100 keV flux. Also, spectral hardness below 600 keV is not a reliable indicator of gamma-ray hardness. Finally, the below 600 keV hardness correlates with the >100 keV intensity, although hardness within a burst changes less than from burst to burst.

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TABLE I

Net Burst Rates

Burst	Interval	LLD	(LLD/WIN)	σ	(LLD/ULD)	σ (ULD)
13 FEB	1	21500	7.7	.1	70	10%
	2	11200	7.6	.1	>200	-
	3	7000	8.0	.2	160	70%
	4	-	-	-	-	-
	5	10900	8.1	.1	190	45%
	6	9600	8.4	.1	110	30%
	Average	10000	7.7		123	13%
19 APR	1	3900	8.4	.1	43	14%
	2	1500	8.4	.2	70	60%
	Average	2700	8.4		50	20%
02 JUN	1	4200	10.4	.1	-	-
	2	12200	11.1	.05	110	11%
	3	1700	14.7	.4	-	-
	Average	6000	11.2		172	20%
20 DEC	1	3400	7.8	.1	170	50%
	2	12700	6.8	.05	220	19%
	3	3400	8.2	.1	-	-
	Average	6500	7.2		253	24%

Table 1. LLD and LLD/WIN are computed using the summed rates of three shield pieces. LLD/ULD is obtained from the OR'D rates.

HEAO 3 Burst Time Histories

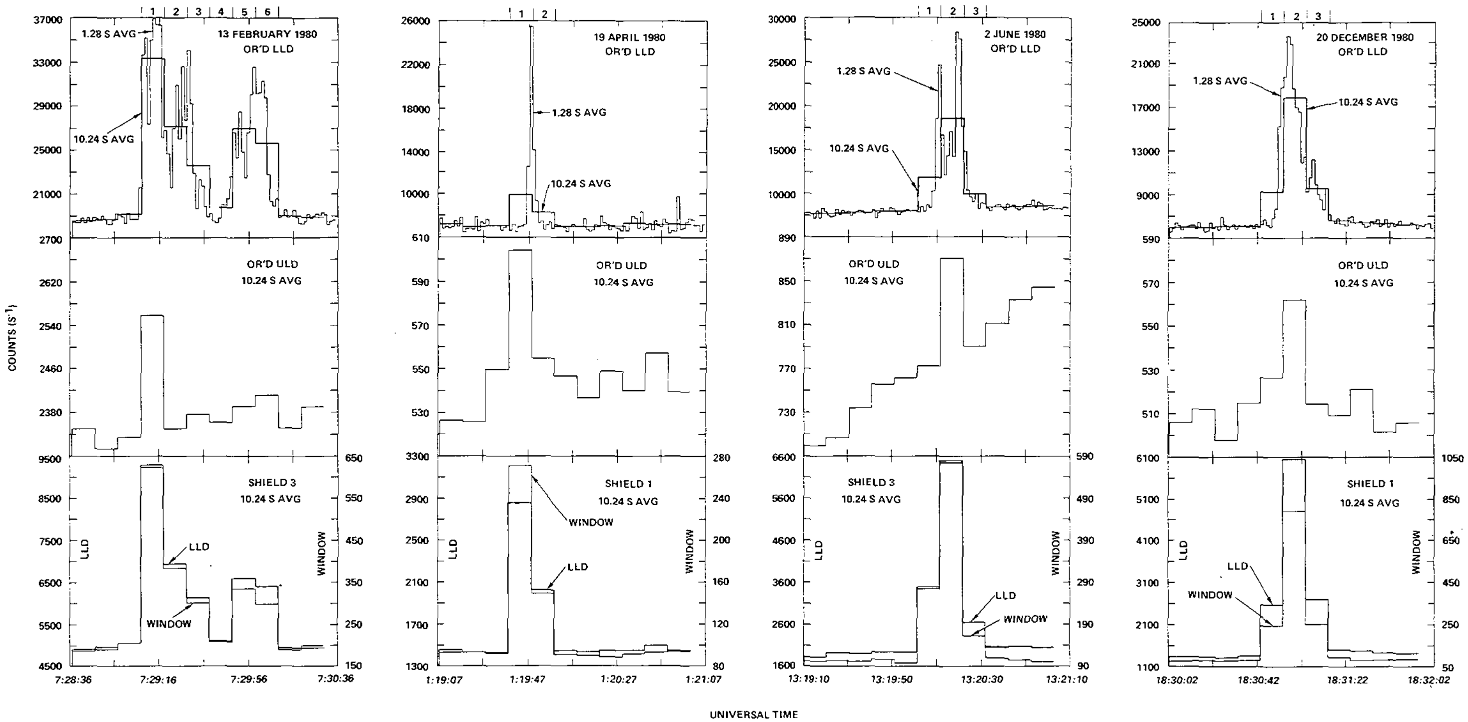

Figure 1. Selected rates of four bursts detected by the anti-coincidence shield. LLD events > 100 keV, WINDOW events within 75 keV of 511 keV, and ULD events > 4 MeV.