On the Bimodal Distribution of Gamma-Ray Bursts

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ABSTRACT

Kouveliotou et al. (1993) recently confirmed that gamma-ray bursts are bimodal in duration. In this paper we compute the statistical properties of the short ($\leq 2\text{ s}$) and long ($> 2\text{ s}$) bursts using a method of analysis that makes no assumption regarding the location of the bursts, whether in the Galaxy or at a cosmological distance. We find the 64 ms channel on BATSE to be more sensitive to short bursts and the 1024 ms channel is more sensitive to long bursts. We show that all the currently available data are consistent with the simple hypothesis that both short and long bursts have the same spatial distribution and that within each population the sources are standard candles. The rate of short bursts is $\sim 0.4$ of the rate of long bursts. Although the durations of short and long gamma-ray bursts span several orders of magnitude and the total energy of a typical short burst is smaller than that of a typical long burst by a factor of $\sim 20$, surprisingly the peak luminosities of the two kinds of bursts are equal to within a factor of $\sim 2$. 
1 Introduction

The Burst and Transient Source Experiment (BATSE) on board the Compton Gamma-Ray Observatory has demonstrated that the distribution of gamma-ray bursts is isotropic over the sky and bound in the radial direction (Meegan et al. 1992). This strongly indicates that the sources of the bursts are located either at cosmological distances (Paczyński 1991, Dermer 1992, Mao & Paczyński 1992, Piran 1992) or in an extended Galactic halo (Li & Dermer 1992, Duncan, Li, & Thompson 1992). Many models have been proposed for the cosmological scenario (e.g., Eichler, et al., 1989, Piran, Narayan, & Shemi, 1992, Narayan, Paczyński, & Piran 1992, Rees & Mészáros 1992, Usov 1992, Woosley 1993) as well as for the extended halo scenario (Fabian & Potsaidowski 1993). For a recent review on gamma-ray bursts, see Paczyński (1992).

Recently Kouveliotou et al. (1993) showed that the distribution of durations of gamma-ray bursts is bimodal. In terms of the parameter $\Delta t_{90}$, which is the time interval during which the integrated counts of a burst go from 5% to 95% of the total integrated counts, the bursts seem to separate cleanly into two distinct groups, with the transition occurring around $\Delta t_{90} \approx 2$ s. This confirms similar indications from earlier experiments (Cline & Desai 1974, Norris et al. 1984, Dezalay et al. 1992, Hurley 1992), and is the first compelling evidence for distinct sub-classes of gamma-ray bursts. (We refer here to classical gamma-ray bursts, which represent the bulk of the bursts, and do not discuss the class of soft repeaters.)

An obvious and natural question that arises from this result is: what is the relation between the two kinds of bursts? One possibility is that they represent two distinct types of sources. For instance, it is even conceivable that one class of sources is cosmological and that the other is in the Galactic halo. Alternatively, both types of bursts may come from a common source, and the differences may arise merely from variations in the initial conditions of the sources prior to the bursts, or changes in the environment or the viewing angle. We attempt to shed some light on this question by carrying out a statistical comparison of the properties of the two kinds of bursts. We describe the detector channels on BATSE and some selection effects in §2, present the main data analysis in §3, and discuss the implications of the results in §4.
2 Detector Channels and Selection Effects

The burst catalog available in the public domain contains a list of all gamma-ray bursts that triggered the BATSE detectors between April 1991 and March 1992 (Fishman et al. 1993). The catalog provides the angular positions for 260 bursts, the ratio $C_{\text{max}}/C_{\text{min}}$ for 241 bursts, where $C_{\text{max}}$ is the maximum count rate and $C_{\text{min}}$ is the detection threshold, the fluences and peak count rates for 260 bursts, and durations for 220 bursts.

The trigger mechanism and various selection effects of BATSE have been explained in detail in Fishman (1992). We will repeat the essentials here. The BATSE on-board software tests for bursts by comparing count rates on eight large-area detectors to the threshold levels corresponding to three separate time intervals: 64 ms, 256 ms, and 1024 ms. A burst trigger occurs if the count rate is above the threshold in two or more detectors simultaneously. The thresholds are set by command to a specified number of standard deviations above the background (nominally 5.5 $\sigma$), and the average background rate is computed every 17 s. Due to an unknown technical reason, many bursts have “undetermined” $C_{\text{max}}/C_{\text{min}}$ in the 256 ms channel. We therefore ignore this channel in what follows.

For a variety of reasons, BATSE has a variable background as a function of time, so that the detection threshold $C_{\text{min}}$ does not remain constant. Moreover, there are periods corresponding to “overwrites” when the sensitivity of the detectors is greatly reduced. These effects make an analysis of the $C_{\text{max}}/C_{\text{min}}$ data somewhat difficult. In order to have a more uniform sample to work with, we select a constant threshold $C_{\text{cut}}$, and prune the data so as to include only those bursts which satisfy both of the following criteria:

1. $C_{\text{min}} \leq C_{\text{cut}}$,
2. $C_{\text{max}} \geq C_{\text{cut}}$.

The resulting database corresponds to those bursts which would have been found by a detector that (i) had a constant threshold of $C_{\text{cut}}$, and (ii) was turned on at those times when the real detectors on BATSE had $C_{\text{min}} \leq C_{\text{cut}}$, and was turned off whenever the BATSE sensitivity was poorer than $C_{\text{cut}}$. By cutting the data in this fashion, we are guaranteed to have a sample of bursts with a constant detection threshold and a uniform selection bias. Of course, in the process we lose a few bursts, which causes loss of statistical accuracy. To minimize this, we select $C_{\text{cut}}$ such that the number of bursts retained in the database is maximized. This leads to the choice $C_{\text{cut}} = 71$ counts for the 64 ms channel and $C_{\text{cut}} = 286$ counts for the 1024 ms channel. Fortunately,
only a few bursts are eliminated for these choices of \( C_\text{cut} \); moreover, the excluded bursts are mostly those that are labeled “overwrites”, and would have been eliminated in any case.

Following Kouveliotou et al. (1993) we define “short bursts” as having \( \Delta t_{90} \leq 2 \) s, and “long bursts” as having \( \Delta t_{90} > 2 \) s. Before going into the main analysis, which we discuss in the next section, we explain first some selection effects associated with the different sensitivities of the 64 ms and 1024 ms channels to the two kinds of bursts. Fig. 1 shows \( \left( \frac{C_{\max}}{C_{\text{cut}}} \right)_{1024} \) in the 1024 ms channel vs. \( \left( \frac{C_{\max}}{C_{\text{cut}}} \right)_{64} \) in the 64 ms channel for the short and long bursts. It is apparent that the 1024 ms channel is more sensitive to long bursts, while the 64 ms channel is more sensitive to short bursts. Both of these effects are quite natural, as we now show.

The noise in the background counts increases, generally, as the square root of the integration time. Therefore the noise is expected to be 4 times greater in the 1024 ms channel than in the 64 ms channel. Now, if a burst has a broad luminosity maximum extending over a time interval greater than 1024 ms then there will be 16 times more signal counts in the 1024 ms channel than in the 64 ms channel, and the signal-to-noise ratio will be 4 times greater. Long bursts are likely to display this behavior. On the other hand, if a burst is extremely narrow, with a duration less than 64 ms, then the number of signal counts will be the same in both channels. The most extreme short bursts will correspond to this limit. Based on this argument, we see that the ratio \( \left( \frac{C_{\max}}{C_{\text{cut}}} \right)_{1024} \) to \( \left( \frac{C_{\max}}{C_{\text{cut}}} \right)_{64} \) for the two channels must satisfy

\[
\frac{1}{4} < \frac{\left( \frac{C_{\max}}{C_{\text{cut}}} \right)_{1024} \left( \frac{C_{\max}}{C_{\text{cut}}} \right)_{64}}{< 4,} \tag{1}
\]

with short and long bursts tending towards the lower and upper limit respectively.

Comparing the ratio in eq (1) for the long burst bursts, we find

\[
R_1 = \frac{\left( \frac{C_{\max}}{C_{\text{cut}}} \right)_{1024}}{\left( \frac{C_{\max}}{C_{\text{cut}}} \right)_{64}}_{\text{long}} = 2.5 \pm 0.64, \tag{2}
\]

where the error estimate reflects the width of the distribution. Since \( R_1 \) is not very different from the maximum value of 4, we conclude that, to a first approximation, the long bursts tend to have broad nearly constant luminosity profiles. For a more detailed description of the intensity statistics, we note that the maximum luminosity in the 64 ms channel is greater by a factor \( \sim 4/2.5 = 1.6 \) than the luminosity in the 1024 channel. This may be interpreted as evidence for a “fractal” behavior in the burst luminosity,

\[
\bar{L}(\Delta t) \propto \Delta t^{-0.2}, \tag{3}
\]
where \( L(\Delta t) \) represents the maximum luminosity of a burst as measured with a time constant of \( \Delta t \).

In the case of the short bursts we find

\[
R_2 = \left\langle \left( \frac{C_{\text{max}}}{C_{\text{cut}}} \right)_{1024} \right\rangle_{\text{short}} = 0.76 \pm 0.48,
\]

which shows that the 64 ms channel is more sensitive than the 1024 ms channel. This is almost entirely because the longer channel dilutes the signal. As clear evidence of this effect we note that there is a strong correlation between the widths \( \Delta t_{90} \) of the short bursts and the quantity \( \left( \frac{C_{\text{max}}}{C_{\text{cut}}} \right)_{1024}/\left( \frac{C_{\text{max}}}{C_{\text{cut}}} \right)_{64} \) (the correlation coefficient is 0.49).

### 3 Data Analysis

In this section we carry out a comparison among various samples of bursts. We work primarily with three samples:

- sample \( s_{64} \) consisting of 40 short bursts which were detected in the 64 ms channel,
- sample \( l_{1024} \) consisting of 113 long bursts detected in the 1024 ms channel, and
- sample \( l_{1024,64} \) consisting of 71 long bursts detected in both the 1024 ms and 64 ms channels.

In comparing different samples, the key observational data we use are the distributions of \( V/V_{\text{max}} \) of the samples, where \( V/V_{\text{max}} = (C_{\text{max}}/C_{\text{cut}})^{-3/2} \) (Schmidt et al. 1988). Our analysis is based on a simple hypothesis, namely that all three populations of bursts have the same underlying spatial distribution, and that within each population the sources are standard candles. On this hypothesis, any apparent differences between the samples are just because they are viewed to different distances (or depths) on account of differences in the source luminosity and/or detector sensitivity. Our main result is that all the available data are consistent with this idea.

In our analysis, we make use of the fact that the brighter bursts agree with a homogeneous Euclidean distribution, which is characterized by cumulative counts varying linearly as \( V/V_{\text{max}} \) and a mean \( \langle V/V_{\text{max}} \rangle \) equal to 0.5. In
contrast, the fainter bursts deviate significantly from such a distribution. Based on this observation, we make the following reasonable assumptions:

(1) We assume that \( \langle V/V_{\text{max}} \rangle \) decreases monotonically with increasing depth of a sample. Therefore, if we compare two samples of bursts (with the same spatial distribution by hypothesis), we can say that the sample with the smaller value of \( \langle V/V_{\text{max}} \rangle \) corresponds to a greater depth or distance. Conversely, if two samples have the same value of \( \langle V/V_{\text{max}} \rangle \) we say that they correspond to the same distance. As a further check, when \( \langle V/V_{\text{max}} \rangle \) of two samples agree, we compare their full \( V/V_{\text{max}} \) distributions by means of the Kolmogorov-Smirnov test (K-S test), and thus investigate whether or not the two populations do indeed have a common spatial distribution.

(2) If two samples have different \( V/V_{\text{max}} \) distributions and different mean \( \langle V/V_{\text{max}} \rangle \), but we suspect that they have intrinsically the same spatial distribution, then we can bring the two samples into agreement by increasing \( C_{\text{cut}} \) for the deeper population. In effect, we artificially reduce the sensitivity of the detector corresponding to the deeper sample so that its sensitivity becomes equal to that of the shallower sample. We can think of this operation equivalently as reducing the luminosity of all bursts in the deep sample by a constant factor. Of course the procedure is meaningful only if it leads to agreement in the mean \( \langle V/V_{\text{max}} \rangle \) and also in the shapes of the \( V/V_{\text{max}} \) distributions, as discussed in (1) above.

A point that we would emphasize is that our method of analysis is virtually model-free and applies regardless of whether bursts are Galactic or cosmological.

To illustrate the method we consider the two samples of long bursts, \( l_{1024} \) and \( l_{1024,64} \). The discussion in §2 showed that the 1024 ms channel is more sensitive to long bursts than the 64 ms channel by a factor of 2.5 (eq 2). We therefore expect \( l_{1024} \) to correspond to a deeper sample than \( l_{1024,64} \). This is confirmed by the mean \( \langle V/V_{\text{max}} \rangle \) values, which are 0.29 ± 0.027 for \( l_{1024} \) and 0.38 ± 0.034 for \( l_{1024,64} \). Both groups deviate significantly from a uniform distribution in Euclidean space, but the deviation is much larger for \( l_{1024} \). We can now artificially bring the two populations to the same distance by increasing \( C_{\text{cut}} \) for the \( l_{1024} \) sample by a factor of 2.5. On doing this we find that the value of \( \langle V/V_{\text{max}} \rangle \) for \( l_{1024} \) becomes 0.37 ± 0.035, which is nearly equal to the \( \langle V/V_{\text{max}} \rangle \) of the \( l_{1024,64} \) sample, exactly as expected. Furthermore, the two cumulative \( V/V_{\text{max}} \) distributions agree very well with each other after this distance correction has been done. The K-S probability (for a worse fit than the one obtained) is 86%, which is excellent. These calculations show that the \( l_{1024} \) and \( l_{1024,64} \) samples do have the same spatial distribution, with
the former being a deeper sample than the latter by a factor of $\sqrt{2.5}$ in luminosity distance. This is no surprise since the two samples have a large number of bursts in common, and moreover we know that there is a good correlation between the signals in the 1024 ms and 64 ms channels for long bursts (cf Fig. 1). The test however demonstrates the validity of the method.

We next proceed to the more interesting test of comparing the short and long bursts. The average $\langle \frac{V}{V_{\text{max}}} \rangle$ of the $s_{64}$ sample is 0.31 ± 0.042, as compared to 0.29 ± 0.027 for $l_{1024}$, which indicates that the two samples correspond to nearly the same distance. We now vary $C_{\text{cut}}$ of the $l_{1024}$ sample and $s_{64}$ sample individually so as to find the range of values over which the $\langle \frac{V}{V_{\text{max}}} \rangle$ values of the two samples agree to within ±1σ (see Fig. 2). We find that

$$R_3 = \left( \frac{C'_{\text{cut}}}{C_{\text{cut}}} \right)_{l_{1024}} \left( \frac{C_{\text{cut}}}{C'_{\text{cut}}} \right)_{s_{64}} = 1.4^{+1.3}_{-0.6},$$

where the value $R_3 = 1.4$ corresponds to the case when the two $\langle \frac{V}{V_{\text{max}}} \rangle$ values are exactly equal. As defined here, $\sqrt{R_3}$ represents the ratio of the limiting distances of the $l_{1024}$ and $s_{64}$ samples. We should mention in passing that there is a second region of good fit around $R_3 \sim 6$, but the number of bursts that survive the cut for this comparison is so small that we do not find the solution convincing. Even the primary solution given in eq (5) suffers to some extent from the limited number of bursts in the two samples.

We now test whether or not the $s_{64}$ and $l_{1024}$ populations are really consistent with the same spatial distribution. For this we do a K-S test to compare the two distributions of $\frac{V}{V_{\text{max}}}$ (see Fig. 2). We see that the test indicates fairly convincingly that the two populations do have the same spatial distribution. For instance, the K-S probability is 42% if we keep the two $C_{\text{cut}}$ values unchanged ($R_3 = 1$) and 50% if we multiply $C_{\text{cut}}$ for the 1024 ms channel by the optimum factor of 1.4 to obtain equality of $\langle \frac{V}{V_{\text{max}}} \rangle$. To illustrate the quality of the agreement, we show in Fig. 3 the $\frac{V}{V_{\text{max}}}$ distributions corresponding to the case when $R_3 = 1$. Note how much better the two distributions agree with each other than with the diagonal line which represents the homogeneous Euclidean model. The probability that either of the observed samples is drawn from the Euclidean distribution, is vanishingly small, $< 10^{-4}$ according to the K-S test.

Finally, we compare the $s_{64}$ and $l_{1024,64}$ samples. In analogy with eq (5) we define a corresponding ratio $R_4$ for this comparison,

$$R_4 \equiv \left( \frac{C'_{\text{cut}}}{C_{\text{cut}}} \right)_{s_{64}} \left( \frac{C_{\text{cut}}}{C'_{\text{cut}}} \right)_{l_{1024,64}}.$$
For consistency with the two previous comparisons, we expect

$$R_4 = \frac{R_1}{R_3} = 1.8^{+2}_{-1}. \quad (7)$$

To check this, we change $C_{\text{cut}}$ for the $s_{64}$ sample from 71 counts to $C'_{\text{cut}} = 1.8 \times 71$ counts and compare the modified $s_{64}$ sample with $l_{1024,64}$. The mean $\langle V/V_{\text{max}} \rangle$ values of the two samples are $0.41 \pm 0.047$ for $s_{64}$ and $0.38 \pm 0.034$ for $l_{1024,64}$, showing excellent agreement. Further, the K-S test gives a high probability of 46%, again in good agreement. We thus conclude that the $s_{64}$ and $l_{1024,64}$ samples are consistent with a common spatial distribution, and that the former is deeper than the latter by about $\sqrt{1.8}$ in luminosity distance. (As an aside we mention that, corresponding to the second solution $R_3 \sim 6$ mentioned earlier, there is an indication of a solution at $R_4 \sim 0.5$, but the reduction in counts in these comparisons is somewhat severe and we are inclined not to take these solutions seriously.)

A very interesting feature of the comparison discussed in the previous paragraph is that $R_4$ directly represents the ratio of the luminosities of the long and the short bursts in the same detector, viz. the 64 ms channel. Since the 64 ms channel corresponds to the shortest time interval used in the triggers, it provides the closest approximation to the instantaneous luminosity of a burst. We thus conclude that the maximum instantaneous luminosities of the short and long bursts are nearly equal, to within a factor $\sim 2$. In fact, the difference in the luminosities may be even less than the value indicated in (7). This is because, in the cosmological scenario, the K-correction (cf. Piran 1992; Mao & Paczyński 1992) depends on the spectral index of the gamma-ray bursts. Although the spectral indices of bursts have large variations, there is some indication that the short bursts are systematically harder than the long ones (Dezalay et al. 1992; Kouveliotou et al. 1993). The effects of this will be to bring the luminosity ratio even closer to unity. Utilizing the fact that we have $C_{\text{min}} = 71$ counts in the 64ms channel, we can roughly estimate the peak luminosity of bursts by assuming a power law spectrum (see eq 10 below):

$$L_{\text{peak}} \sim 2 \times 10^{43} (D_{\text{max}}/\text{Mpc})^2 \text{ erg s}^{-1}, \quad (8)$$

where $D_{\text{max}}$ is the maximum distance to which the bursts can be detected in the 64 ms channel.

An important consequence of the comparisons carried out above is that we obtain the relative depths of the short and long burst samples. We can therefore estimate the relative number densities in space of the two kinds of bursts. We find

$$\frac{n_S}{n_L} \sim 0.4^{+0.4}_{-0.2}. \quad (9)$$
We should however mention one caveat, namely that BATSE may have missed some very short bursts with durations smaller than 64 ms because of dilution. If this is a substantial effect, then the above ratio may be higher, possibly closer to unity.

We now estimate the ratio of the total energy outputs in the short and long bursts. We first define an effective duration $\Delta t_{\text{eff}}$ as the duration of a burst would have if it had a constant count rate $C_{\text{max}}$ and the same fluence, i.e.,

$$\Delta t_{\text{eff}} = \frac{S}{\langle E \rangle C_{\text{max}}}, \quad \langle E \rangle \equiv \frac{\int_{E_1}^{E_2} E^{-\alpha+1} dE}{\int_{E_1}^{E_2} E^{-\alpha} dE},$$

(10)

where $S$ is the fluence in units of erg cm$^{-2}$ in the energy range 50–300 keV (which coincides with the trigger energy range), $\langle E \rangle$ is the mean energy in the energy range of 50-300 keV, $C_{\text{max}}$ is the maximum count rate in units of photons cm$^{-2}$ s$^{-1}$, and we assume a power law photon number distribution $n(E) dE \propto E^{-\alpha} dE$. Adopting $\alpha = 2$ (Schaefer et al. 1992), we find that $\langle \Delta t_{\text{eff}} \rangle \approx 0.4$ s, 12.5 s for the short and long bursts respectively. Combining this with the luminosity ratio $R_4$, we find the total energy ratio is $E_L/E_S \approx 20$. It is quite remarkable that the short and long bursts differ by such large factors in their durations and total energy outputs, but yet are so similar in their maximum luminosities. Finally, for completeness, we mention that the short and long bursts are both individually consistent with perfect isotropy.

4 Discussion

This paper has been motivated by the recent discovery of Kouveliotou et al. (1993) that gamma-ray bursts consist of two distinct subclasses, namely short and long bursts. The main aim of our investigation is to test the simple hypothesis that both populations of bursts have the same underlying space distribution and that within each population the sources are standard candles. Our conclusion is that all the available data are consistent with this hypothesis. Even though the distributions of $C_{\text{max}}/C_{\text{cut}}$ for the short and long bursts sometimes appear to be different in certain detector channels, we are always able to bring the two populations into agreement by modifying the detector sensitivity in one or the other sample so as to reduce the two samples to the same depth or distance. When we do this, not only do the mean $\langle V/V_{\text{max}} \rangle$ values agree, but also the full distributions of $V/V_{\text{max}}$ agree when compared by means of the K-S test. Of course, these calculations do not prove our basic hypothesis, particularly since we are hampered by the small number of bursts in the samples but they make the idea quite
plausible. We therefore feel that it is unlikely that one type of bursts (say long) is cosmological while the other arises in the halo, or that one is in the halo and the other in the disk (Smith & Lamb 1993). It would be too much of an accident for the two populations to have the same $V/V_{\text{max}}$ distributions. Instead, we favor models where the two kinds of bursts arise in the same source. In this case, the large difference in durations between the short and long bursts may be caused by variations in the initial conditions or in the environment of the source or due to differences in the viewing angle.

Once we accept that the two kinds of bursts arise from a common source population, we are able to estimate the relative luminosities and number densities of the two populations. Surprisingly, we find that both the short and long bursts have the same peak luminosity, $L_{\text{peak}} \sim 2 \times 10^{43} (D_{\text{max}}/\text{Mpc})^2 \text{erg s}^{-1}$, to within a factor of two. The equality of the two peak luminosities is quite remarkable when we consider that the durations of the short and long bursts differ by $\sim 50$ and their total energy outputs differ by $\sim 20$. Incidentally, our estimate of $L_{\text{peak}}$ corresponds to the 64 ms channel. On smaller timescales, the peak luminosity will be larger, though not by a significant factor (see eq 3). Further, we estimate the number density of the short bursts to be $\sim 0.4$ times that of the long bursts. If the difference between short and long bursts is due to viewing angle, this ratio gives an estimate of the relative solid angles associated with the two kinds of bursts.

An important point that we would stress is that these results are obtained in an essentially model-independent way. For instance, we do not need to make any assumption on whether the sources are at cosmological distances or in the Galaxy.

The constancy of luminosity in two classes of bursts which differ so much in their other properties might provide a clue to the physical origin of the bursts. Unfortunately, it is virtually impossible to explain the result using the most widely used limiting luminosity in astrophysics, namely the Eddington limit. If we assume that the sources are not dynamically expanding (but see Piran and Shemi, 1993) and take a fixed opacity (e.g. electron scattering), the Eddington limit is proportional to the mass of the source, which in turn is limited by the variability timescale, $\delta t$, i.e., $L_{\text{Edd}} < 1.3 \times 10^{40} (\delta t/\text{ms}) \text{erg s}^{-1}$. Taking $\delta t \sim 10$ ms, the characteristic burst luminosity $L_{\text{peak}}$ that we have obtained is marginally consistent with the Eddington luminosity limit for sources of mass $\sim 10^3 M_\odot$ located at distances $\sim 100$ kpc in the Galactic halo. Smaller masses are ruled out by the observed isotropy of the bursts, while larger masses are ruled out by the variability argument. In fact, Bhat et al. (1993) claim to see variability down to 200 $\mu$s, which rules out even the $10^3 M_\odot$ scenario.
Another robust limiting luminosity is \( L_{\text{max}} = c^5/G = 4 \times 10^{59} \text{ erg s}^{-1} \), which is an absolute upper limit for any source, corresponding to the emission of the entire rest mass within a gravitational light crossing time. If we identify \( L_{\text{peak}} \) with this limit, then we obtain the luminosity distance to the sources to be \( \sim 10^8 \text{ Mpc} \), corresponding to a redshift of \( \sim 10^4 \), in an \( \Omega = 1 \) Friedmann universe. This is far too large for any known model.

The fact that it is not easy to come up with a physical explanation for the existence of a characteristic peak luminosity for gamma-ray bursts implies that, if the effect is real, it may provide an important and vital clue for understanding the origin of the bursts. Unfortunately, as we have tried to stress, the results have only modest statistical significance at this point. It would be very interesting to repeat the analysis with the complete database of bursts detected by BATSE.

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6 Figure Captions

Fig. 1: $C_{\text{max}}/C_{\text{min}}$ for the 1024 ms channel vs. that for the 64 ms channel. All bursts with $C_{\text{max}}/C_{\text{min}}$ available in both the 64 ms and 1024 ms channels are plotted. Open and filled circles correspond to bursts with durations shorter and longer than 2s respectively. Note that $C_{\text{max}}/C_{\text{min}}$ in the 1024 ms channel is larger than $C_{\text{max}}/C_{\text{min}}$ in the 64 ms channel for almost all the long bursts, while the short bursts tend to have larger $C_{\text{max}}/C_{\text{min}}$ in the 64 ms channel.

Fig. 2: The thick line shows the probability values $p_{K-S}$ obtained with the Kolmogorov-Smirnov (K-S) test when the $l_{1024}$ and $s_{64}$ samples are compared versus the quantity $\log R_3$ (see eq 5). Also shown as a thin line is $\Delta/\sigma$ vs. $\log R_3$, where $\Delta$ is defined as the absolute difference of $\langle V/V_{\text{max}} \rangle$ between the two samples, and $\sigma$ is the expected standard deviation. The dotted line corresponds to a $1\sigma$ deviation.

Fig. 3: $V/V_{\text{max}}$ for each burst is shown versus the burst’s intensity rank normalized by the total number. The thick and thin lines correspond to the 113 long bursts in the 1024 ms channel (sample $l_{1024}$) and the 40 short bursts in the 64 ms channel (sample $s_{64}$). The K-S probability that these two samples are drawn from the same distribution is 42%. The probabilities that these two samples are drawn from a uniform distribution in a Euclidean space (indicated as a dashed diagonal line) is $< 10^{-4}$. 

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