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No New Limit on The
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Gamma-Ray Bursts

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No New Limit on the Size Distribution of Gamma-Ray Bursts

Carter et al.[1] have recently published the results of their search for small gamma-ray bursts with a long-duration balloon exposure, from which they have concluded that the size spectrum extrapolates to a power law with index from -1. to -0.5. They draw the firm conclusion that gamma-ray bursts are therefore of galactic origin. When assessing their data we did not find a sound basis for their arguments; in fact, we claim in what follows that their data are consistent with an upper limit that is over 100 times above their results. There is therefore no conclusion regarding the nature or origin of gamma-ray bursts that can be drawn from their measurements. The resulting upper limit to the rate of occurrence of small bursts lies above the -1.5 index power-law extrapolation of the size spectrum of known events, i.e., greater than the rate expected from an infinitely extended source region.

A number of basic considerations in the treatment of the data apparently were either ignored or inappropriately minimized by the authors, each of which independently pushes their upper limit upwards. Our treatment of these issues is indicated in Figure 1, in which the claimed results of Carter et al.[1] are shown, adjusted by the following six individual considerations.

(1) Their selection criterion for finding statistically significant bursts in the gamma-ray count rate was that of seeking three successive increases in 0.6-second accumulations. This requirement will ignore most known gamma-ray bursts due to their varying temporal nature - - some are only 0.1 second or less in duration and most consist of 0.1-sec to

0.3-sec increases occurring randomly throughout durations up to 30 seconds in extent[2,3,4]. It is fair to estimate that, at most, 20% of 25% of the known events could be found using this single criterion. If, instead, one searches typical scintillation counter data for 0.1-sec increases, the number found is always too great to be of value, a result which necessarily dictates an undesirably high upper limit to the gamma-ray burst occurrence rate. A thorough treatment of the data must either evaluate the upper limits for all known types of burst time histories, or normalize to the subset of selected types --- either method would certainly increase their upper limit by a factor of at least 4. (The data selection interpretation of Carter et al. may not be the only one in print suffering from this problem since, in the absence of a comprehensive, published study of gamma-ray burst time histories, a full appreciation of their variability may not be widespread. However, it has been known since the beginning that bursts are not usually one or two seconds in duration.)

(2) The total photon energy measured in the given three successive 0.6-sec intervals, or in whatever selection requirement used, does not represent the entire energy emitted in that burst, again, because of the varying temporal nature of gamma-ray bursts. To take into account missing energy due to fluctuations requires reassigning the magnitude of the event size under consideration by an undetermined factor, which can be estimated to be usually over a factor of two.

(3) A related consideration is that satellite gamma-ray burst size spectra are customarily plotted after the measured flux of each event

is multiplied by another factor of two,[3,4] in order to include the missing energy below the usual threshold of 100 to 150 keV. This has been done with knowledge of only a few low-energy spectra[5,6] as an admittedly arbitrary treatment which supposes that all events have the same spectrum below 100 keV, on the basis of the fact that all known spectra are similar above 100 keV[7]. Thus, for purposes of comparison, balloon data with similar energy thresholds must include the same or equivalent normalization.

(4) The authors knowingly plotted a one-standard deviation upper limit. We plead that small-number statistics demand the more commonly employed and firmer confidence limit of 95%. This is recognized by Carter et al.[1] in their text but ignored, and raises the upper limit by another factor of three.

(5) The fraction of the sky observed from their balloon-borne detector was apparently taken to be one half, which we infer from estimating their results, given the raw data and using their stated methods of analysis. However, since the atmosphere presents a great absorption to photons of these energies at large zenith angles, the equivalent fraction of the sky viewed in an unobscured manner is about 0.25 to 0.3, a consideration which raises their limit by another factor of 1.7 to 2.

(6) The response of a flat, horizontally-positioned detector to a distribution of gamma-ray bursts distorts the measurement of the size spectrum of the bursts, even from an isotropic distribution. A consideration of this point can be condensed as follows: Given an

intrinsic burst size spectrum $N(S)\,dS = kS^{-\gamma}\,dS$ with isotropic arrival directions, an ideal, flat, totally absorbing detector above the atmosphere would observe events of apparent size $Z = S\cos\theta$ such that the size spectrum would be

$$N(Z)dZ = \frac{1}{4\pi}\int_0^{2\pi}\int_0^{\theta_o} N(S)dS\,\sin\theta\,d\theta\,d\phi = kZ^{-\gamma}dZ\int_0^{\theta_o}\frac{1}{2}\sin\theta\cos^{\gamma-1}\theta\,d\theta$$

$$\equiv kZ^{-\gamma}dZ\int_0^{\theta_o} g(\theta)d\theta\,.$$

The smallest detectable event of size Z is not equal to the expected smallest detectable burst size S. A more meaningful estimate of the smallest detectable S would be the average burst size $\overline{S}$ that would contribute to the smallest Z. Thus,

$$\frac{\overline{S}}{Z} = \int_0^{\theta_o}\frac{S}{Z}\,g(\theta)d\theta\Big/\int_0^{\theta_o} g(\theta)d\theta = \frac{\gamma-1}{\gamma-2}\cdot\frac{1-\cos^{(\gamma-2)}\theta_o}{1-\cos^{(\gamma-1)}\theta_o}$$

which is the average of the relative size S/Z that contributes to Z. Testing the hypothesis of a -2.5 index power law differential spectrum with an ideal detector and with $\theta_o = 90°$, results in a shift on the vertical, N(S), axis of 1/0.4 = 2.5 upwards, from the first equation, and a horizontal shift of 1.67 towards larger size, from the second, i.e., when converting from Z to S coordinates. Using a real detector, with the photon energy spectrum of E^{-2} considered by Carter et al.,[1] folded with the response of their 1-cm thick NaI(Tℓ) detector, an approximate fit to a totally absorbing disk for 70 percent of counts above 100 keV and to a zenith-independent detector for 30 percent is found. We approximate the atmospheric effect using a simple cutoff at $\theta = 70°$. The result gives a vertical shift of 1/0.45 = 2.2 and a horizontal shift of 1.3, not as severe as for the ideal, disk-shaped detector, because the real one has a finite volume and some of the radiation is penetrating. This incorporates the zenith angle effect in our fifth point above and is independent of the other four considerations.

The combined effect of points (1) to (6) is that the upper limit derived from the data of Carter et al.[1] is actually above the -1.5 index power law extrapolation of the size spectrum of known events. Even if we assume, somewhat arbitrarily, a combined error for all considerations (1) to (6) of 50%, the conclusion of this letter remains that no inference regarding either the small-event size spectrum or the origin of cosmic gamma-ray bursts can be drawn from all the balloon data published up to the present time.

As a post script, we add the following remark: Even if, on the basis of the lack of observation of a single event, an upper limit well below -1.5 index power law extrapolation were found, it would be misleading to assume that this result alone would necessarily prove either the burst size spectrum model or the origin hypothesis suggested by Carter et al.[1] A metagalactic origin with a cosmological cutoff or one of a variety of other models could also fit. The ultimate choice between these would require an independent measurement, such as an anisotropy or a spectral dependence on size. If such a size cutoff is ever found, it would be by itself imply only that the source distribution is not infinite in extent, assuming that the average absolute magnitude of emitters is independent of distance.

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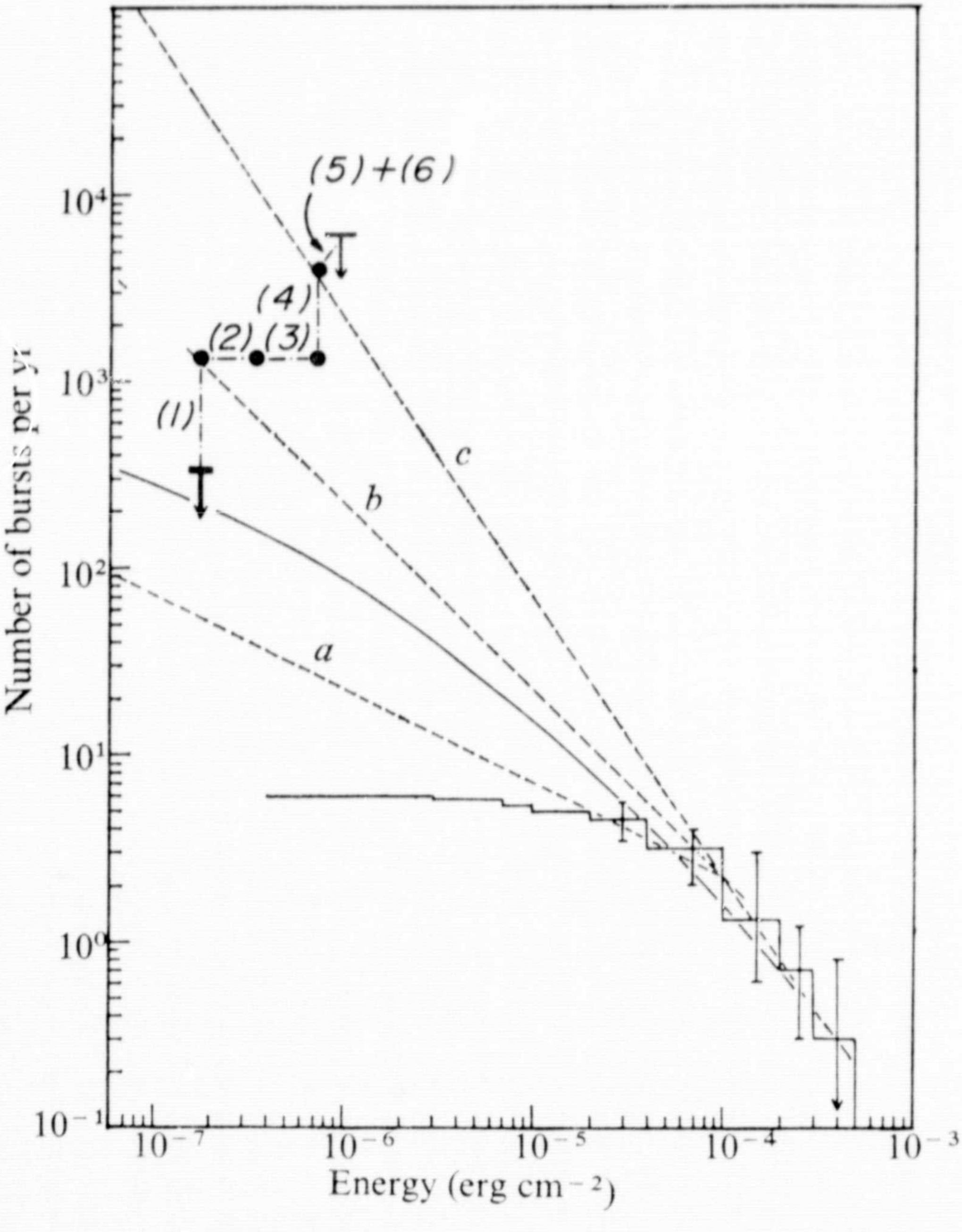
Figure Caption

Fig. 1. The results of Carter et al.[1], adjusted by the six factors considered in this letter, numbered accordingly. The observed burst size spectrum of Vela events and comparison models, as incorporated in Figure 1 of Carter et al.,[1] are included.


Number of bursts per yr
Energy (erg cm^{-2})
10^4
10^3
10^2
10^1
10^0
10^{-1}
10^{-7}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
(5)+(6)
(4)
(2) (3)
(1)
c
b
a