GAMMA RAY BURST SIZE-FREQUENCY DISTRIBUTIONS: SPECTRAL SELECTION EFFECTS

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ABSTRACT

We have investigated the effects of spectral variation on the detection of gamma ray bursts. We find that selection biases resulting from these effects can account for the reported deviation of the observed size-frequency distribution in peak energy flux from that expected for a simple uniform distribution of sources. Thus these observations as yet provide no clear evidence for structure in the burst source distribution. We also show that because of selection biases the intrinsic average temperature of the bursts is much harder (kT ~ MeV) than the observed average (~ 200 KeV).

INTRODUCTION

Size-frequency distributions of gamma ray bursts, i.e. the number of bursts greater than some fluence or some peak energy flux as a function of fluence or flux, have been extensively studied[1] in an attempt to determine the spacial distribution of the burst sources. Of particular interest is the flattening at low fluxes and fluences of the observed size-frequency distributions below that of a simple -3/2 power-law in flux or fluence expected from a uniform source distribution. This flattening has been generally interpreted as evidence for a spacially limited source distribution that is confined to the galactic disk or halo.

Such an interpretation, however, is inconsistent with the distribution of measured[2] burst positions on the sky, which fail to show any anistropy even at low fluences.

We have recently shown,[3] moreover, that the flattening of the fluence distributions at low fluence can, in fact, result solely from observational selection effects due to variations in burst duration. We now show here that the flattening of the peak energy flux distribution is also the result of observational selection effects, due, in this case, to variations in the energy spectra of the bursts.

BURST IDENTIFICATION

To understand the selection effects, we must briefly review how gamma ray bursts are identified. The identification depends on the detection of a burst signal above the instrumental background, usually in two or more detectors so as to exclude local phenomena.

The possibility of distinguishing between a gamma ray burst and a random fluctuation in the detector background depends on the signal-to-noise ratio of the event in the detector—the greater this ratio, the greater the probability that the event is not a random background fluctuation. The signal of an event is the number of photons measured or counted above the mean detector background in some energy band, ΔE. For an event of duration, t_d, the number of counts in a possible $n\sigma$ fluctuation in the background is $n(Bt_d)^{1/2}$, with a mean background counting rate B, assuming Poisson statistics. The number of photons detected in an energy range E to $E + \Delta E$ depends on the burst intensity $\phi(E,t)$ as a function of energy and time as well as the detector characteristics: area, A; integration time t_i; and efficiency, e, assumed for

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simplicity to be a constant over the energy range ΔE. Thus the number of photons detected in the energy range ΔE in a time t_i is

$$Ae \int_{E}^{E+\Delta E} dE \int_{t_o}^{t_o+t_i} dt\, \phi(E,t) = Ae<\phi> t_i \Delta E \tag{1}$$

where $<\phi>$ is the mean intensity of the burst during time t_i. A signal-to-noise ratio of n thus requires that

$$n = Ae<\phi> t_i \Delta E / (Bt_i)^{1/2}. \tag{2}$$

The limiting burst fluence, S_o, greater than some energy, E_o, that a detector system can measure to a statistical significance of $n\sigma$ is

$$S_o = n\epsilon (Bt_d)^{1/2}/eA, \tag{3}$$

where the effective photon energy

$$\epsilon \equiv \int_{E_o}^{\infty} \phi(E) E dE / \int_{E}^{E+\Delta E} \phi(E) dE. \tag{4}$$

Similarly the limiting peak energy flux, P_o, that can be measured in an integration time t_i, shorter than the duration t_d, is

$$P_o = n\epsilon (B/t_i)^{1/2}/eA. \tag{5}$$

Thus the fluence threshold increases with increasing spectral hardness and duration of the bursts, while the peak energy flux threshold increases only with spectral hardness. These are unavoidable selection biases against harder spectra and longer duration bursts that must be considered when interpreting not only the size frequency distributions but the observed distributions of spectra and durations which can be strongly biased as well.

These selection effects are a general problem affecting all burst detectors. But in the discussion that follows we confine our analysis to Venera data because it is not only the most extensive data set, but also the only one for which sufficient information has been published[2,4,5,6] to permit an analysis.

SPECTRAL EFFECTS

To investigate the spectral variation biases on the peak energy flux distribution, we calculate the limiting peak energy flux, P_o, from equations (4) and (5) using energy spectra $\phi(E)$ of the form $E^{-1}\exp(-E/T)$ which Mazets et al.[6] used to fit the observed spectra. They found a range of effective temperatures T with a distribution shown by the data in Figure 1. The intrinsic temperature distribution of the sources differs from this, however, because of spectral biases. But if we assume an intrinsic temperature distribution, $n(T)$, we can then calculate the distributions of both T and peak flux for observed bursts expected from a uniform spacial distribution of such sources. Specifically the expected peak flux distribution

$$N(>P) = \int_{0}^{\infty} n(T) f(P) dT, \tag{6}$$

where $f(P) = CP_o(T)^{-3/2}$ for $P \leqslant P_o(T)$ and $f(P) = CP^{-3/2}$ for $P > P_o(T)$. The normalization constant C is determined by comparison with the observed distribution of $N(>P)$ measured by Mazets et al.[2] (Figure 2). Similarly the expected distribution of observed temperatures

$$N(T)\Delta T = \int_{T}^{T+\Delta T} n(T) P_o(T)^{-3/2} dT / \int_{0}^{\infty} n(T) P_o(T)^{-3/2} dT. \tag{7}$$

Here we have assumed that $n(T)$ has the form $\exp(-T/T_o)$, shown by dashed lines in Figure 1, in order to calculate the expected flux and temperature distributions to be observed from a uniform spacial distribution.

Comparisons of these calculated distributions for various values of T_0 with the observed distributions of Mazets et al.[6] gave a best fit to both distributions for an effective temperature T_0=1.1 MeV, shown by the solid lines in Figures 1 and 2.

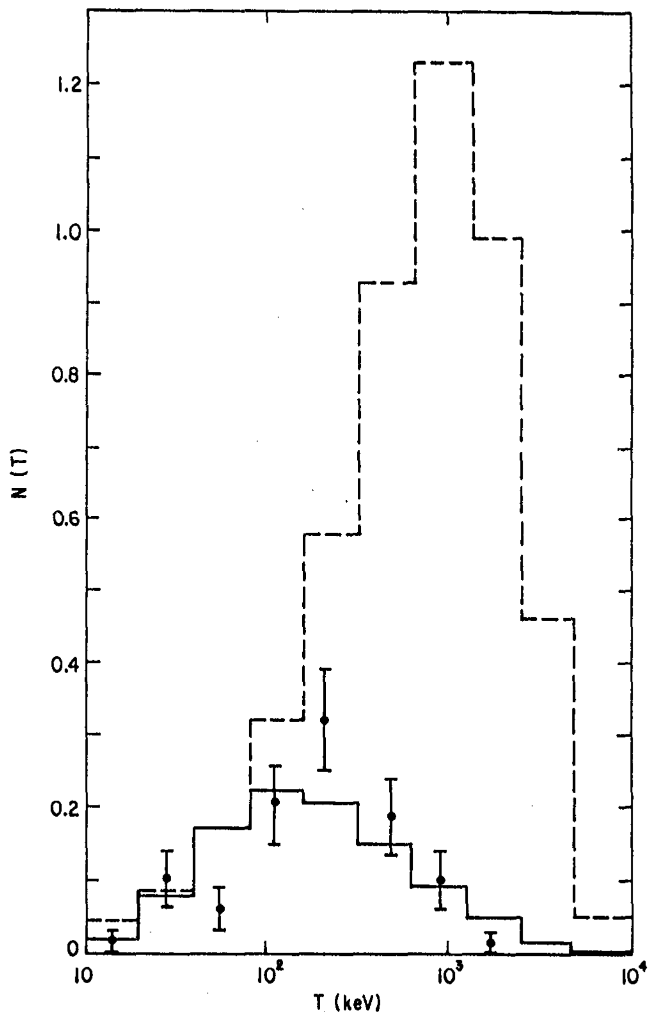

Fig. 1. Distribution of burst temperatures observed by Mazets et al.[6], compared with the calculated distribution (equation (7), solid line) expected from the assumed intrinsic distribution n(T) (dashed line arbitrarily normalized), showing the strong selection bias against bursts with harder spectra.

SUMMARY

As can be seen, such a simple distribution of burst spectra can account for both the observed distribution of effective burst temperatures and for the observed flattening of the peak energy flux distribution. In particular these calculations show that the observed N(>P) *vs* P distribution is quite consistent with a uniform spacial distribution of sources, since the flattening at low fluxes can be due entirely to spectral selection effects. Moreover, the observed distribution of effective burst temperatures is also strongly biased by selection effects, such that the mean temperature (~200 KeV) of the observed bursts is almost an order of magnitude lower than the intrinsic mean temperature (~1 MeV), as can also be seen in Figure 1. Thus gamma ray bursts are truly gamma ray, not hard X-ray, phenomena with the bulk of their emitted power at MeV energies, an order of magnitude above that of typical detector triggers.

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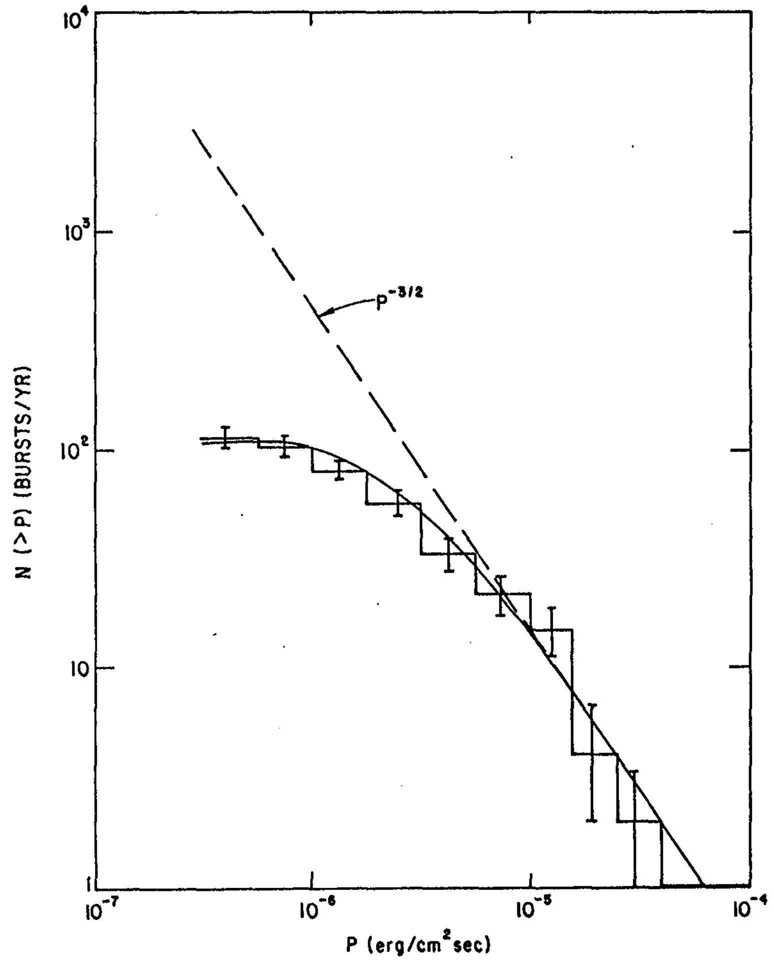

Fig. 2. Size-frequency distribution of peak energy flux, N(>P) *vs* P, for bursts observed by Mazets et al.[2], compared with that expected (solid curve) from a uniform distribution of sources with the intrinsic temperature distribution shown in Figure 1. As can be seen spectral selection biases can account for the observed deviation from a simple -3/2 power law distribution.

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