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Reclassification of Gamma Ray Bursts based on their brightness distributions

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Abstract : A reclassification of the cosmic gamma-ray bursts has been done into two distinct classes on the basis of their brightness distributions. While one (majority) class is found to be compatible with a homogeneous and mono-luminosity source population with simple cosmological effects folded into the brightness distribution function, the other, smaller population is not consistent with such a scenario and may need a consideration of source evolutionary effects.

1. Introduction

Even though gamma-ray bursts (GRB) continue to confound astrophysicists today, nearly 3 decades after their discovery, our perception of this enigmatic phenomenon has improved considerably (Piran, 2001) after the recent detection of afterglow emissions from the directions of some of the bursts, spanning the wavelength range from x-ray to radio. Around 20 bursts with inferred redshifts between 0.008 to 3.4 or more for the host galaxy have been detected, suggesting a cosmological origin for the associated bursts (Metzger et al 1997; Djorgvski et al 1998; Kulkarni et al 1997, 1999; Vreeswijk et al 1999). However, as the number of events with reliable counterparts is still small at present, it is not possible yet to globally characterize the GRB with respect to the nature of their sources or their origin, using this otherwise, direct identification procedure. Hence, our understanding of gamma-ray bursts has still to rely largely on various statistical studies of their properties.

2. Data analysis and discussion

We have used the 4B catalog of the BATSE events in our analysis. The main parameters of our interest are (a) Time duration T_{90}, which is the duration in which the observed counts accumulate from 5% to 95% of the total counts and (b) Hardness ratio (HR), which is the ratio of the fluence recorded by the BATSE in the third energy channel (100-300 keV) to that in the second energy channel (50-100 keV). Since the ranges of values for the variables in question are quite wide, we have used logarithms of the variables, namely, $T = \log(T_{90})$, $H = \log(HR)$, for the analysis here.

The frequency distribution of 1233 events of the 4B catalog with respect to the duration parameter T, shows the well-known bimodal distribution with broad peaks at $T_{90} \sim 0.32$ and ~ 32s, separated by a minimum at ~ 2s. When these events are plotted in the H-T plane, again, two well divided populations are seen, as is evident from Fig. 1. The straight line fit to the data, shown in this figure, is obtained from the linear regression coefficients computed using the OLS Bisector method (Feigelson and Babu 1992)

We now examine these two populations separately for underlying signatures of possible anisotropy and/or inhomogeneity. To test for the anisotropy, we calculate the dipole moment (d) and the quadrupole moment (q) for the two populations , while for checking the inhomogeneity, we

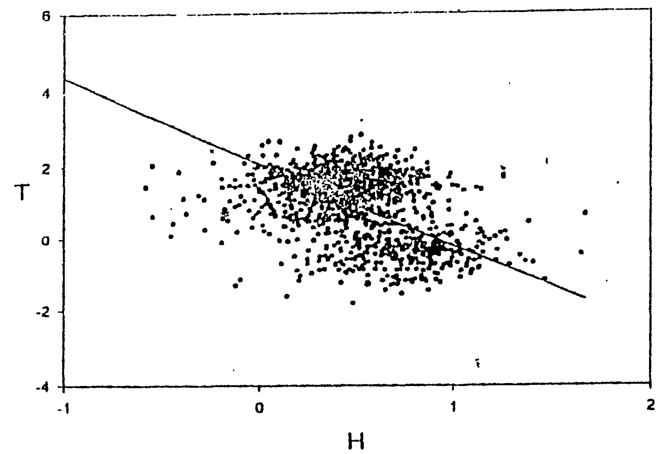

Fig.1. GRB distribution in the T-H plane along with the best fit regression line. Here T is log (T_{90}) in seconds and H is log (HR) which is the logarithm of the ratio between the burst fluence in the BATSE, (100-300 keV) energy channel to that in the (50-100 keV) channel.

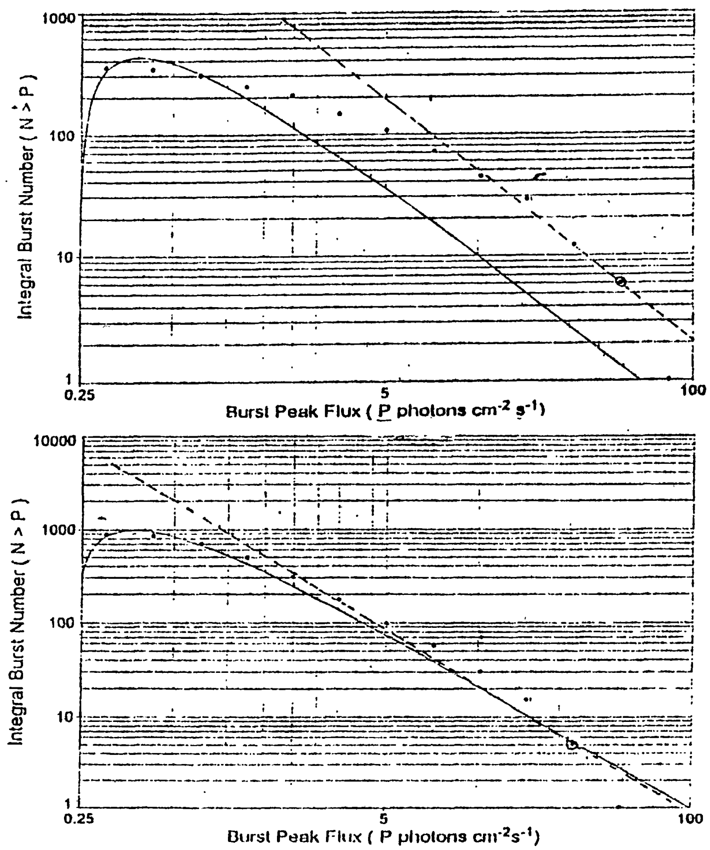

Fig. 2 . a) Log N – log P distribution for Type A bursts. Here, N represents the number of bursts exceeding 256 ms BATSE trigger threshold with peak flux > P photons cm^{-2} s^{-1}. Dashed line : - 3/2 slope normalized at P = 32 photons cm^{-2} s^{-1}.Solid line : best-fit for simple cosmological model of Eqn. (1).

b) Same as above for Type B bursts (T_{90} > 2.5s and HR> 3 GRB of population (II)

Dashed line : -3/2 slope normalized at P = 50 photons cm^{-2} s^{-1}.

examine their peak flux distributions (log N – log P) separately. The resulting d and q for population I events are – 0.049 ± 0.03 and – 0.001 ± 0.01 respectively whereas for population II events, d = - 0.01 ± 0.01 and q = 0.001 ± 0.009. As there is no significant indication an of anisotropy for either population, it can be concluded that perhaps most of the GRB are be coming from cosmological distances, in line with the observational evidence obtained so far (see section I).

Recently, Tavani (1998) has divided the GRB into four classes according to their different hardness ratios and durations. Based on an examination of log N – log P distributions of these classes, he has pointed out that only the sub-class of long and very hard bursts, with $T_{90} > 2.5$s and HR > 3, show a strong deviation from the Euclidean distribution, whereas the other 3 classes are in good agreement with the –3/2 slope, expected for a homogeneous spatial distribution. Taking a lead from this recent work, we have divided the event shown in Fig.1 into two different hardness ratio/duration classes of HR < 3 and duration < 2.5s (population A) and HR > 3 and duration > 2.5s (population B). According to Tavani (1998), the critical value HR = 3, is chosen for distinguishing GRBs with typical photon energies below or above 800 keV, which is ~ 4 times the average photon energy E_r detected by the BATSE (~ 200 keV) and outside the optimal energy range of BATSE detection (50-300 keV).

Assuming that the bursts are of a cosmological origin with no creation, destruction or evolution of the sources, we investigate whether a simple cosmological model can provide proper fits to the log N – log P distributions derived for these two populations of events. According to this model, the number of sources with a peak flux greater than P is given by (Berry 1991)

$$N(> P) = (4\pi\, n(t_0) / 3)\ (L / 4\pi P)^{3/2}\ (1-3 H_0 / c (L / 4\pi P)^{1/2}) \qquad (1)$$

Where n (t_0) is the present number density of bursts in Mpc^{-3} and L is the luminosity in ergs s^{-1}. The Hubble's constant H_0 is taken to be 75 km s^{-1} Mc^{-1}. The results are shown in Fig.2.

It is evident from Fig. 2a that Equation (1) fits the experimental results quite well in the case of population A events (solid line). The resulting number density of the GRB sources, n (t_0) turns out to be ~ 3.62 x 10^{-7} Mpc^{-3} and the source luminosity L ~ 1.6 x 10^{49} ergs s^{-1}. On the contrary, as is apparent from Fig. 2b, the 'simple' cosmological fit of Equation (1) is found to deviate pronouncedly from the actual population B distribution and significantly underestimates the number of brighter bursts of this genre.

There can be two possible reasons for Type B events (long and very hard bursts) to deviate strongly from the homogeneous distribution and not being compatible with Eqn (1) : One, Type B bursts could be a different class of objects experiencing strong evolutionary effects. The second possibility is that this deviation may be an artifact of selection effects due to the inefficient BATSE triggering for Type B bursts with longer duration and photon energies outside the BATSE optimal detection range, corresponding to 1 < HR < 2.5. While future investigations should help to unequivocally settle between these two possibilities, it will be in order at this stage to make the following observations in relation to the first possibility : We have confirmed that the deviation from the expected shape cannot be accounted for in terms of a higher source-density n(t_0) and would instead require invoking source luminosity, density and/ or spectral evolution, a conclusion also arrived at by Tavani (1998). As argued by him, the Type B burst sources would have to be located in remote regions of space (z ≥ 1) where a relative decrease of their spatial density would make them strongly non-Euclidean. On the other hand, they would have to be relatively much brighter and harder vis-à-vis Type A events to be consistent with the observed log N – log P distribution. Noting that the density of star forming galaxies (SFG) peaks at z ~ 1 and decreases for larger z, one can draw attention to the possible role of the GRB mechanism linked to these galaxies in the generation of Type B events. One interesting thing to note in the present context is that out of the 9 GRB detected by BATSE and for which optical counterparts have been detected, all of them have $T_{90} > 2.5$s and qualify for classification as Type B events from the duration point of view. Further, 6 out of 9 events also meet HR > 3 criterion of the Type B events, and the rest of 3 bursts with HR ~3. Also all the 9 GRBs referred above have z ≥ 0.8 and all belong to Type B category. This perhaps suggests that type

B bursts generally favour larger z and may as such be subject to evolutionary effects.

3. Conclusions

Using an extended data-base of 1233 events from the BATSE 4B catalogue, we propose here a valid justification for reorganising the GRB into Type A and Type B as suggested in this work. In this case the majority of GRB belonging to Type A class represent a homologous population where the log N – log P distribution is consistent with a simple cosmological model, whileas a smaller population Type B represents an intrinsically different population, perhaps subject to some significant evolutionary effects.

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