29th International Cosmic Ray Conference Pune (2005) **4**, 439–442

Galactic and Extragalactic components in Gamma ray bursts

R. K. Manchanda

Dept. of Astronomy Astrophysics, Tata Institute of Fundamental Research
Homi Bhabha Road, Mumbai 400 005, India
Presenter: R. K. Manchanda (ravi@tifr.res.in), ind-manchanda-R-abs1-og24-oral

The origin of the Gamma ray bursts is still an unresolved issue even after 32 years since the discovery of the first event. From the recent data from the HETE satellite, it has become obvious that some of these events are definitely associated with Supernova explosions and some of these have cosmological distances. However, no simple classification scheme fit the data. We present an analysis of the $\log \mathrm{N} - \log \mathrm{S}$ distribution of the GRBs and argue that data suggest the presence of two components which may be associated with galactic and extragalactic origin.

Introduction

Gamma ray bursts are the most energetic explosions known in the Universe since the Big Bang. GRBs are unpredictable flashes of electromagnetic radiation in the X- and γ-ray energy region around 100 keV, coming from any direction, their time durations range from few millisec to seconds and during the time they last, they outshine all other celestial sources combined. The mean rate of detected GRBs is around one per day. If the sky exposure time and the actual solid angle of the detectors are taken into account, this mean rate typically raises to a few (2-3) per day. Since its discovery in 1973, the gamma ray burst astronomy has gone through many revolutions. The first radical change was brought about by the BATSE detectors on board CGRO satellite which was launched on 1991. In its 9 years operation, the BATSE team cataloged 2704 events of different shapes, sizes and peak fluences (see fig 1). Statistical studies show that about 80% of all GRB last less than one minute, and that there is a class of short-duration GRB which last less than a few seconds and that the distribution is well described by a bimodal function, with the two peaks around 0.3s and 30s, respectively. A breakthrough in the understanding of GRB came with the discovery of GRB afterglow in the X-ray [1], optical [2], and radio [3] bands. The detection of the host galaxies and the measurement of their redshifts showed that some of the long duration GRB events are related to the final stage in the evolution of massive stars, taking place at cosmological distances. High Energy Explorer Satellite 2 (HETE-2) has dramatically changed our understanding of GRB phenomena. Apart from the discovery of short-hard bursts, X-ray rich bursts, optical dark bursts, it confirmed the GRB-SN connection and that some of the long bursts are associated with Type 1c core collapse supernovae. It has provided evidence that the isotropic-equivalent energies and luminosities of GRBs are correlated with the redshift, implying that GRBs and their progenitors evolve strongly with redshift. Both of these results have profound implications for the nature of GRB progenitors and for the use of GRBs as a probe of cosmology and the early universe [4]. However, 8 years after the discovery of the first afterglow, spectroscopic redshifts have been determined only for 40 bursts among 263 localized GRBs of which about 100 have an optical, X-ray or radio afterglow. The spectral data too does not provide clue to the origin of gamma ray bursts. Although GRBs release their energy mostly in the 50-1000 keV band, photons down to a few keV and up to 18 GeV have been detected in some events. The non-thermal spectra are well described by the Band law (5], that is a smoothed broken power law. This functional form fits the burst spectra satisfactorily in the energy range from 10 keV to 100 MeV and the break energy typically ranges from 100 keV up to some MeV. The properties derived from the afterglow observations also reveal only limited information about the distribution of GRB sources. Though the temporal nature of the afterglow can be explained globally, within the framework of the relativistic fireball models, first proposed by [6] [7] [8], the extreme characteristics of GRBs seem to lead to a paradox called "the compactness problem" and also the re-brightening of the afterglow is not yet understood. The gamma rays in a GRB are believed to be produced by internal shocks taking place in a collimated jet directed close to the line of sight, while the afterglow would result from the interaction of the jet with the surrounding medium. However, the energy release of about $10^{50} - 10^{54}$ ergs cm^{-2}, the time duration of 10^{-1} to 10^{4} sec and temporal structures of millisec duration within the time history, remain some of the nagging problems still to be resolved. The successful phenomenological models too, can only produce global picture and a composite understanding of all observed parameters and the uniqueness and individual nature of each of these events depends on the nature of the progenitors and their distribution in the universe.

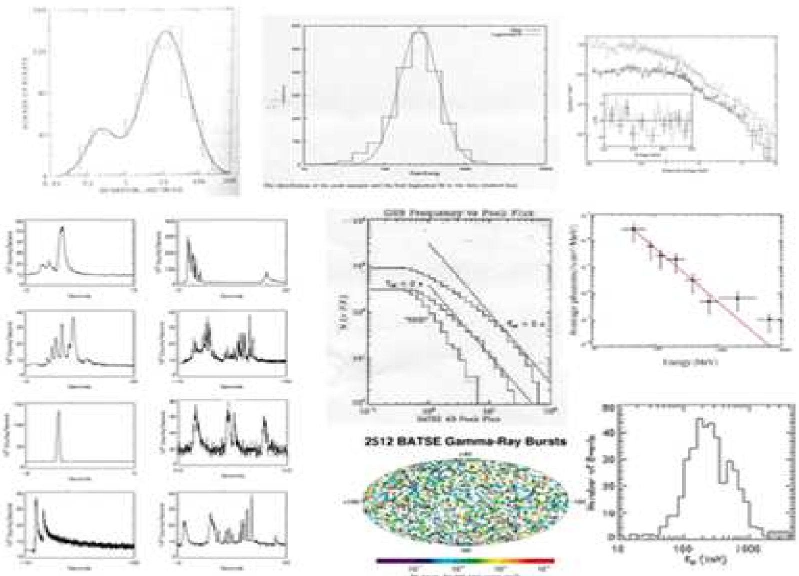

Figure 1. A collage of the Spatial, Temporal and Spectral properties of GRBs *(top)* time duration, fluence distribution, *(bottom)* typical energy spectrum, variety in pulse shapes, angular distribution and log N-log S for T_{90} events,

Source distribution of GRBs

The angular distribution of the 2704 bursts from BATSE catalog as seen in Fig 1 suggests an apparent isotropic distribution [9], although earlier data did indicate concentration near the galactic plane [10] [11]. The observed dipole and quadrupole relative to the galaxy are perfectly consistent with null values, i.e. with an isotropic distribution. This property clearly supports an extragalactic origin or, at least, from an extended dark halo surrounding our Galaxy. However, the number of faint bursts in the BATSE GRB sample are fewer than expected for a homogeneous distribution if one supposes that GRBs are standard candles. Taking that all bursts have the same luminosity L in a Euclidean geometry and if S is the peak flux, V the volume of the sphere whose radius R is the distance to the GRB source; then for a minimum detectable flux S_{min} for a given detector, there is the maximum volume V_{max} , whose radius can be obtained from $S_{\rm min} = L/4\pi R^2$ and under these assumptions,

$$V/V_{\rm max} = (S_{\rm min}/S)^{-3/2}$$

The ratio expressed by above equation can be used for testing the spatial distribution of a GRB events for a homogeneous distribution within a Euclidean space. The V/V_{max} distribution is uniform in the allowed range $0 \leq \mathrm{V/V_{max}} \leq 1$ with a mean value $\mathrm{V/V_{max}} = 0.5$. However, in the case of BATSE bursts the corresponding mean value is $\mathrm{V/V_{max}} = 0.33 \pm 0.01$ [12]. Similarly, the hypothesis for isotropic or a disk distribution of the GRBs can be tested with the log N-log S curve by considering the cumulative distribution N(>S) representing the number of bursts, whose flux intensity is greater than S and which in the case of a homogeneous distribution is characterized by the N(>S) = $\mathrm{S}^{-3/2}$. The best fit parameters for a large sample of BATSE bursts, clearly show that the spatial distribution of GRBs is not consistent with the homogeneous case since there are fewer faint bursts than expected on this hypothesis. The distribution of short duration bursts in the BATSE data is consistent with the homogeneous distribution and the short bursts also show more symmetrical profiles than the long ones. Similarly, the observed time durations of the events in the BATSE sample, there is some evidence for the existence of two classes. The $\mathrm{T_{90}}$ (calculated by taking the interval going from the time at which the total fluence is at 5% to the time at which it is at 95% of the overall burst fluence) distribution shows a bimodal behaviour, i.e. short bursts $\mathrm{T_{90}} < 3s$ and long ones with $\mathrm{T_{90}} > 30s$ [13].

The significant deviation from the homogeneous distribution of sources therefore requires a fresh look to explain the observed data. The fundamental questions to be answered are whether, the present sensitivity of the instruments has been sufficient to detect true GRB frequency and if there is a class of events which have defied detection. For example, some of the weak burst events reported in literature have no correspondence in the BATSE data. Second, whether observed transient events are a mixture of completely independent phenomena only related in their transient nature or third, if the log N-log S curve consists of a mixture of different populations having different spatial distribution.

Two component model

We propose that GRB sample indeed consists of two populations namely, extragalactic and galactic. The contribution from the galactic component is small, such that observed angular distribution has an apparent isotropy. In figure 2, I have plotted the GRB frequency distribution of peak fluxes for the events published in 4B BATSE catalog. It is seen from the figure that a simple 3/2 scaling law does not fit the data. The solid line in the figure is the best fit for a mixture of two populations, one of which follows a 3/2 scaling law and the second, a Gaussian distribution with a peak flux at 28 counts and a relative number density of 7.5% of the first component. The composite functional form is given by;

$$\mathrm{N(> S) = 950\ S^{-1.5} + \Sigma\ 70\ e^{-[(S-2.8)/19]^2}}$$

It is seen from Fig. 2 that a mixed population functional form fits the data quite well. A cumulative Gaussian distribution of galactic component simply reflects the radial distribution of matter in the galaxy and is similar to the distribution of galactic supernovae. In addition, a small spread in the absolute luminosity of GRB events will further broaden the source distribution [14]. Assuming that the peak in the gaussian distribution corresponding to 28 BATSE counts represents an average GRB luminosity of $\sim 10^{51}$ ergs, similar to the energy release in type II supernovae and that the bursts are located at an average galactic distance of 6 kpc, then the observed $\log \mathrm{N} - \log \mathrm{S}$ distribution of the GRB peak fluxes corresponds to an absolute luminosity scale between $\sim 3 \times 10^{49}$ to $\sim 3 \times 10^{52}$ ergs. The average distance for the weakest burst thus corresponds to ~ 35 kpc, thereby, favouring a halo model for the source distribution.

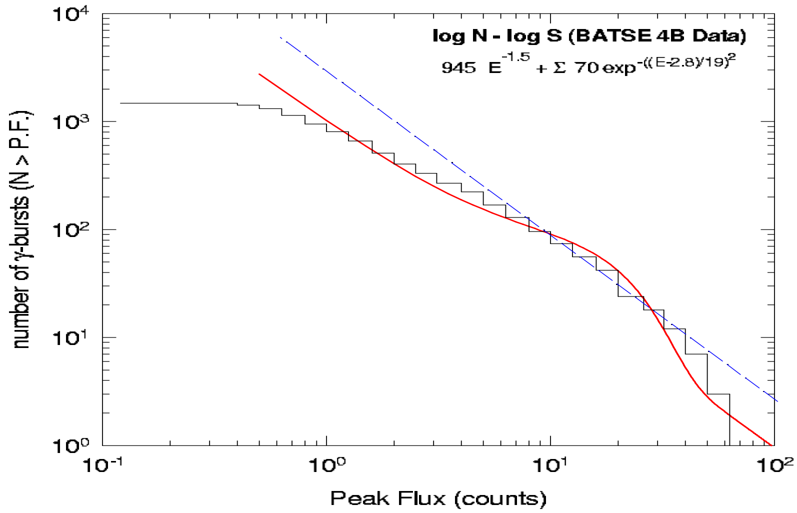

Figure 2. Log N-Log S curve for the gamma ray bursts, The dotted line represent the -3/2 distribution while the solid line gives the composite fit.

In conclusion, irrespective of the fact that some of the long bursts are associated with the supernovae in other galaxies and may be at cosmological distance, the statistical analysis of the observed burst parameters clearly suggest that the observed sample consists of both galactic and extragalactic components.

Acknowledgements

It is a pleasure to thank BATSE team for making the archival data available on the WEB. I also than the members of the SIX team who provide a continuous support for research activities.

References

[1] E. Costa, F. Frontera, J. Heise et al., Nature, 387, 783 (1997).
[2] J. van Paradijs, P. J. Groot, T. Galama et al., Nature 386, 686 (2003).
[3] D. A. Frail, S. L. Kulkarni, S. R. Nicastro et al., Nature, 389, 261 (1997).
[4] D. Q. Lamb et al., Nuclear Physics B (Proc. Suppl.) 132, 279, (2004).
[5] D. Band, J. Matteson, L. Ford et al., Ap. J., 413, 281 (1983).
[6] G. Cavallo & M. Rees, MNRAS, 183, 359 (1978).
[7] J. Goodman, Ap. J., 308, L43 (1986).
[8] B. Paczynski, Ap. J., 308, L43 (1986).
[9] W. S. Paciesas, Baltic Astronomy, vol. 13 pp. 187-192 (2004)
[10] E. P. Mazets et al., Ap & SS, 80, 3 (1981).
[11] J-L Attia et al., Ap. J., 320, L105 (1987).
[12] C. Kouveliotou et al., Ap. J., 413, L101 (1993).
[13] T. Cline et al., Ap. J., 527, 827 (1999).
[14] R. K. Manchanda & D. Ramsden, Nature, 266, 425 (1977).