Populations of High Energy Sources in Galaxies
Proceedings IAU Symposium No. 230, 2005
E. J. A. Meurs & G. Fabbiano, eds.

doi:10.1017/S1743921306008362

Using jet breaks to estimate GRB distances

P. Ward, E. J. A. Meurs and C. del Burgo
Dunsink Observatory, Castleknock, Dublin 15, Ireland

Abstract. Recent observations have suggested that the true energy release of GRBs is potentially far less than previously thought. This is due to beaming, a signature of which is a broadband break in the power-law decay of the afterglow emission. Taking these results we have constructed a basic distance estimator, which may be useful as a diagnostic tool for the large amount of GRBs without a spectroscopically measured redshift.

Keywords. gamma rays: bursts, cosmology: distance scale.

The value for the isotropic equivalent energy output of a GRB, E_{iso}, in a given bandpass is found by $E_{iso} = S_\gamma \frac{4\pi D_l^2}{(1+z)} k$ where S_γ is the fluence received in the observed band pass and D_l is the luminosity distance at redshift z. The quantity k is the k-correction. However, it has been shown that true energy release, E_γ, of a GRB is in fact much less than this when the burst is beamed into a collimated jet of half opening angle θ_j. E_γ will therefore be less than E_{iso} by a factor $(1 - \cos\theta_j)$. The beaming fraction can also be described as the ratio of the true energy release and isotropic equivalent energy; $\frac{E_\gamma}{E_{iso}} \approx \frac{\theta_j^2}{2}$.

One signature of such a jet is a broadband break in the power-law decay of the afterglow emission which occurs at a time t_j when the bulk Lorentz factor of the blast wave (Γ) has slowed down to $\Gamma < \theta_j^{-1}$. According to the formulation made by Sari *et al.* (1999) the spherical adiabatic evolution of the Lorentz factor is $\gamma(t) \approx 6(\frac{E_{iso}}{n_1})^{1/8} t_j^{-3/8}$. Subsequently if the break occurs when $\gamma \approx \theta_j^{-1}$, we find that $(\frac{2E_\gamma}{E_{iso}})^{-1/2} \approx 6(\frac{E_{iso}}{n_1})^{1/8} t_j^{-3/8}$ which can be rearranged to give $E_{iso} = 119(2E_\gamma)^{4/3}(n)^{-1/3}(t_j)^{-1}$, giving us an alternative approach for determining E_{iso}.

If GRBs are in fact standard candles the value for E_γ is a constant. Using this presumption we can use the two equations for E_{iso} to construct the following relationship between intrinsic burst parameters and the redshift,

$$\mathbf{D_T(z) = Q_T(t_j, S_\gamma, n, k) E_\gamma^{4/3}}$$

We can separate the relationship into a distance quantity D_T, which is a function of redshift z, and a burst quantity Q_T, which is a function of the burst properties t_j, S_γ, n and k; we define Q_T and D_T as $Q_T \equiv \frac{238.7}{t_j n^{(1/3)} S_\gamma k}$ and $D_T \equiv [\frac{2c}{H_0}(1 + z - \sqrt{(1+z)})]^2 \times \frac{1}{1+z} pc$.

We can now test this relationship using existing data for 12 bursts which have well established values for z, n, t_j, S_γ and k. Subsequently, for each burst, we derive a value for Q_T (Table 1). Figure 1 shows a plot of Q_T vs. z (logarithmic scale). The dotted line represents the observed trend; the value for Q_T appears to increase with redshift. Amati *et al.* (2002) previously noticed a trend of E_{iso} to increase with z.

The derived relationship is $\mathbf{Q_T} = \mathbf{A} \times \mathbf{z}^\beta$, where A $\sim 0.1\,\mathrm{cm}^3\,\mathrm{erg}^{-1}\,\mathrm{s}^{-1}$ and β=1.5 (see Figure 1). We therefore have a method for determining z*, the estimated redshift, according to the relationship derived from the plot in Figure 1: $\mathbf{z* = (\frac{Q_T}{0.1})^{2/3}}$.

Table 1. The parameters used for the 12 bursts in our sample

GRB	z	n $[cm^{-3}]$	t_j [days]	S_γ $[10^{-6}$ erg $cm^{-2}]$	k	Q_T $[10cm^3\ erg^{-1}\ s^{-1}]$
GRB970508	0.8349±0.0003	1 ±0.5	25 ±5	1.8 ±0.3	1.55 ±0.08	0.3420 ±0.3140
GRB980329	2.95 ±0.95	29 ±10	0.29 ±0.2	65 ±5	0.97±0.09	0.4250 ±0.5120
GRB980703	0.9662±0.0002	28 ±10	3.4 ±0.5	22.6 ±2.26	0.94±0.08	0.1090 ±0.0751
GRB990510	1.6187±0.0015	0.29±0.15	1.57 ±0.03	19±2	1.29±0.03	0.9370 ±0.6548
GRB991208	0.7055±0.0	18 ±22	< 2.1	100 ±10	1.09±0.03	0.0398 ±0.0537
GRB991216	1.02 ±0.02	4.7 ±6.8	1.2 ±0.4	194 ±19.4	0.88±0.09	0.0696 ±0.1379
GRB000301	2.0335±0.0003	26 ±12	7.3 ±0.5	2 ±0.6	1.37±0.36	0.4028 ±0.4402
GRB000418	1.1182±0.0001	27 ±256	25.7 ±5.1	20.00±2	1.00±0.02	0.0155 ±0.1519
GRB000926	2.0369±0.0007	27 ±3	1.8 ±0.1	6.20 ±0.62	3.91 ±1.33	0.1823 ±0.0548
GRB010222	1.4769	1.7 ±0.85	0.93 ±0.15	120.00 ±3	1.03±0.04	0.1740 ±0.1261
GRB021004	2.3351	30 ±270	6.5 ±0.2	2.55 ±0.69	1.04 ±0.06	0.4456 ±4.1707
GRB030329	0.1685	5.5 ±2.75	0.48 ±0.03	163.00±1.4	1.01±0.03	0.1711 ±0.1028

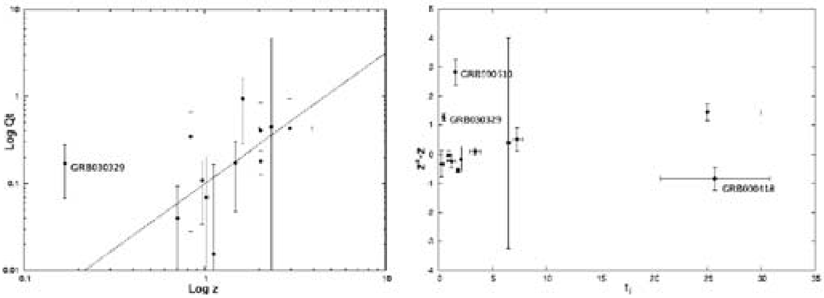

Figure 1. (left) A plot of $logQ_T$ vs. $logz$. We observe one main outlier to the relationship, GRB030329. This is the only GRB in our sample associated with a supernova, it has the highest fluence and is also the closest at z=0.1685. (right) The dispersion of t_j around z*-z.

If the observed trends are indeed due to some intrinsic characteristic of the bursts, then the above method would be extremely useful not only as a redshift estimator but would also be a useful tool to fill in the many gaps in the current set of GRB results. It is clear however that more data is required to understand fully both the nature of GRBs and their potential as probes of the high redshift universe. Continued research should include data mining of bursts with well established values for S_γ, n, t_j, and z. This would better provide a costraint to the relationship found from Figure 1. Also a more complete treatment involving D_T is necessary. If this relationship is true then a plot of D_T vs. Q_T should give a linear relationship with a slope equal to the value for $E_\gamma^{4/3}$.

References

Amati, *et al.* 2002, *A&A* 390, 81
Berger, Kulkarni and Frail 2003, *ApJ* 590, 379
Bloom, *et al.* 2001, *AJ* 121, 2879
Bloom, *et al.* 2003, *ApJ* 594, 674
Frail, D. A., Waxman, E., and Kulkarni, S. R. 2000, *ApJ* 537, 191
Frail, D. A. *et al.* 2001, *ApJ* 562, L55
Ghirlanda, *et al.* 2004, *ApJ* 616, 331
Rees and Mezsaros 1994, *ApJ* 430, 93
Rhoads, J. E. 1999, *ApJ* 525, 737
Sari and Piran 1999, *A&A* 138, 537
Sari, R. 1999, *ApJ* 524, L43
Sari, R., Piran, T., and Halpern, J. P. 1999, *ApJ* 519, L17
Wei and Lu 1997, *A&A* 323, 312

https://doi.org/10.1017/S1743921306008362 Published online by Cambridge University Press