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What Causes GRB Time Dilation?

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Abstract. That groups of apparently faint GRBs are detected as having longer durations than groups of apparently bright GRBs is well known, and is sometimes referred to as "time dilation." Reasons for GRB time-dilation remain ambiguous, and likely convolve intrinsic effects, cosmological effects, and even detector threshold effects. With redshifts of a significant number of GRBs now in hand, attempts at an accurate deconvolution are now possible, and carry interesting cosmological implications. Toward this goal, we use redshift estimates of a large subset of BATSE GRBs obtained by Band et al. (2004) from the lag-luminosity relation of Norris et al. (2000). Inspection of different sets of GRBs separated in estimated redshift appear to qualitatively show the expected time-dilation effect, indicating that cosmological information was and is convolved in GRB BATSE data.

Keywords: GRB, time dilation.
PACS: 98.70.Rz

HISTORICAL CLAIMS

Over a decade ago, perhaps the most prominent disagreement among GRB researchers was whether GRBs occurred in or near the Milky Way Galaxy or at cosmological distances. In 1995, an actual debate occurred on this topic (for details please see Paczynski 1995, Lamb 1995, and Nemiroff 1995). One line of evidence that GRBs occurred at cosmological distances was that faint GRBs appeared to have longer durations, on the average, than bright GRBs. Such an effect would be expected were GRBs to occur at cosmological distances. Elaborate analyses detailed in papers such as Norris et al. (1994) and Norris et al. (1995) showed that such an effect existed in the BATSE data. The effect was dubbed "time dilation." Was time dilation real? If so, was its origin cosmological? A preliminary attempt to answer these questions in the light of more modern data is given here.

IS DURATION A GOOD STANDARD CLOCK?

That time dilation could possibly be evidence for cosmology is predicated on several assumptions. One assumption is that GRB duration can act as a good standard clock. Now a standard clock runs at a predictable speed in its own frame, so that observing how this clock runs from across the universe could be a measure of relative conditions that are cosmological in origin.

In practice, the time dilation effect measured by Norris et al. (1994), Norris et al. (1995) and others endeavored to divide the universe into near and far groups and compare a standard clock for both of them. Several candidate measures for a standard clock were used, most of them tied to the duration of the entire GRB event as measured by BATSE.

At first blush, using any measure of GRB duration seems foolhardy since GRBs durations have such a large dynamic range -- from milliseconds to hours. Still, GRB durations were clear GRB attributes and might well be averaged over to reduce variance.

Next, one must be careful about how one measures GRB duration. Although known in the mid-1990s, it is perhaps even better understood today that GRBs dominated by a single pulse have relatively large intrinsic differences between energy bands that makes them less useful than multiple-pulse GRBs for time-dilation analyses.

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It is well known empirically that, inside a single GRB, pulses typically have significantly lower temporal durations at higher energies (see, for example, Fenimore et al. 1995).

Therefore, to use GRB duration as a standard clock, one must choose a GRB duration measure that is relatively less influenced by pulse-energy correlations and relatively likely to include multiple pulses over single pulses. Now of the established GRB duration measures, T0.45 (Reichart et al. 2001) appears to pick out single pulses in GRBs more readily than T50, and T50 appears to pick out single pulses more readily than T90. Therefore, in this analysis we will focus on T90 and previous claims made involving T90.

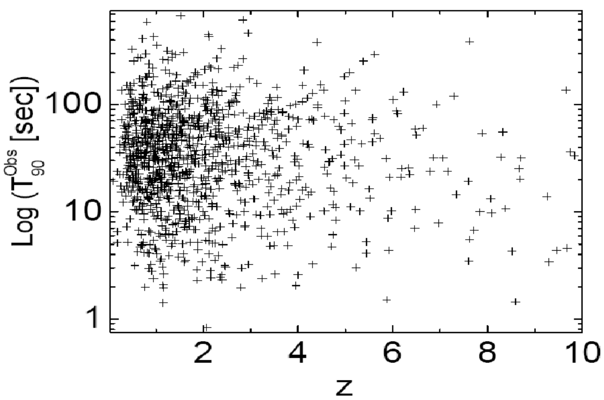

FIGURE 1. Shown above is a plot of T90 as recorded in the BATSE 4B catalog versus redshift z as determined from a lag-luminosity analysis of Band (2004). 1134 GRBs are included in the plot. Inspection of this plot shows nothing obvious to the authors.

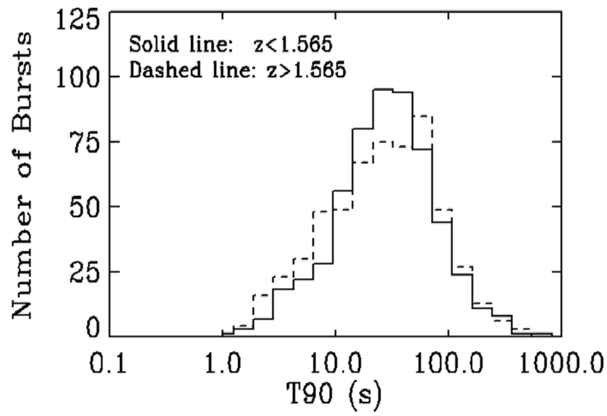

FIGURE 2. Shown above is a histogram of T90s for the 1134 GRBs depicted in Figure 1. The solid line indicates GRBs with an estimated redshift (Band et al. 2004) of less than 1.565, while the dotted line depicts GRBs with estimated redshift of greater than 1.565. The dividing redshift (z = 1.565) was chosen to make these two subsets relatively equal in number.

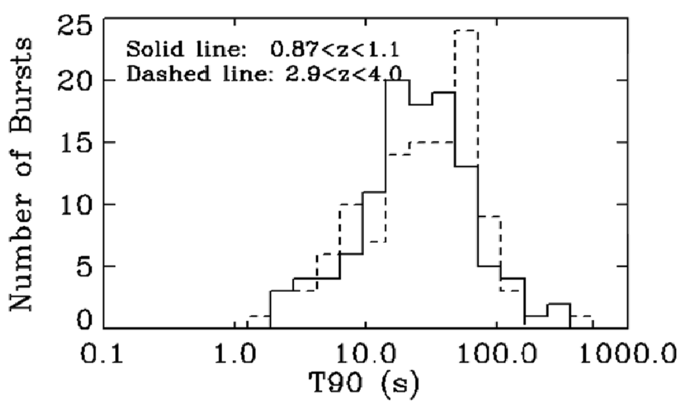

FIGURE 3. Shown above is a histogram of T90s that mimics the analysis of Norris et al. (1995). Here two subsets of T90 well separated in estimated redshift are depicted. The solid line indicates GRBs with an estimated redshift between 0.87 and 1.1, while the dashed line indicates GRBs with an estimated redshift between 2.9 and 4.0. Here again it is clear that the higher redshift subset of GRBs has its median shifted toward longer durations that the lower redshift subset. This sample incorporated 121 BATSE GRBs in total.

At the first glance, no signature of time dilation could be seen in the plot of T90s for 1134 BATSE GRBs vs. the derived redshifts from lag-luminosity relation (Band, 2004) in figure (1). However, inspection of the frequency histograms of T90s in figure (2) for two redshift subsets of $z < 1.565$ & $z > 1.565$ does show that the higher redshift same appears to be skewed toward longer T90 durations. The discrepancy is bolstered when two subsets of T90 well separated in estimated redshift are considered (figure 3). Together, these plots seem to indicate that GRB duration, at least T90 duration as measured from BATSE data, does indeed have usable attributes of a standard clock, and could in theory be used to find a cosmological time dilation signal in BATSE GRB data.

IS PEAK FLUX A GOOD STANDARD CANDLE?

To measure GRB time dilation one must not only have a standard clock, but one must be able to divide GRBs into subsets based on distance. This distance measure must be independent from the standard clock. Redshift is one parameter that is directly convolved with distance, but no redshifts were available in the mid-1990s. Norris et al. (1995) and others used peak flux under the common assumption that "faintness means farness." Low peak flux GRBs were assumed to be further out than high peak flux GRBs. Inherently, peak flux is then assumed to have attributes as a standard candle. Like a standard clock, a standard candle occurs at a predictable brightness in its own frame, so that observing how bright this candle appears from afar is a measure of relative conditions that could be cosmological in origin. Was (Is) peak flux a good choice for a standard candle?

Now whereas no obvious correlation appeared from a casual inspection of Figure 1, inspection of Figure 4 does show a marked correlation between the peak fluxes of the bursts and their estimated redshifts. In particular, there is a dramatic lack of high redshift GRBs with a large P256 peak flux. There is a strong indication that standard candle attributes are indeed present in P256. Inspection of the peak flux frequency histogram of figure (5) also indicates that many more ‘low redshift’ GRBs have high P256 when compared the high redshift group.

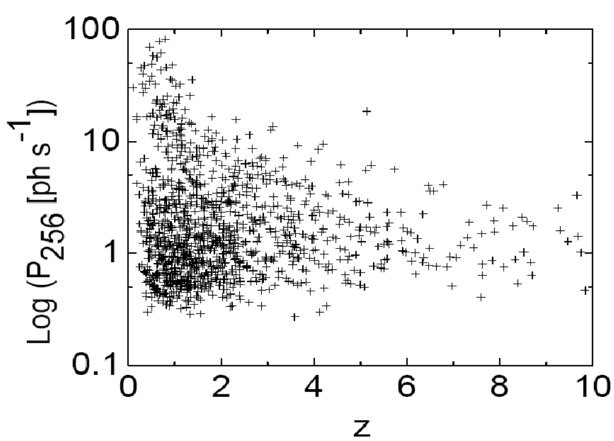

FIGURE 4. Shown above shows a plot of P256, a measure of peak flux, versus estimated redshift z (Band, 2004).

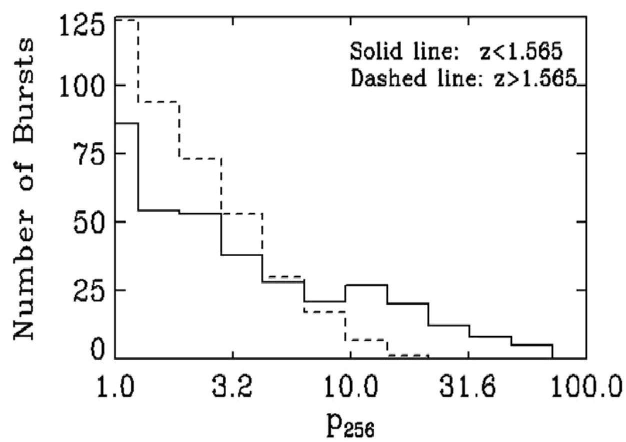

FIGURE 5. Shown above is a histogram of 751 BATSE GRBs with a redshift estimated from Band et al. (2004) is plotted as a function of P256. The solid line denotes GRBs with an estimated redshift less than 1.565, while the dashed line denotes GRBs with a redshift higher than 1.565.

DISCUSSION AND CONCLUSIONS

Present redshift estimates of GRBs indicate that, indeed, the time dilation claims of Norris et al. (1994) and Norris, et al. (1995) were evidence that GRBs were cosmological in origin. Note that also the isotropy of the GRB distribution and the curvature of the brightness distribution were also early evidences of the vast distances to GRBs. Figures (6) & (7) depict T90 frequency histograms of BATSE GRBs in two subsamples, representing dim and bright populations of BATSE bursts. Inspection of the plots clearly indicates that the dim GRBs are shifted toward longer T90 durations than the bright GRB group and that the bright BATSE groups have a lower median T90 than the dim BATSE groups.

It is interesting to wonder whether time dilation is still a useful attribute to measure for GRBs. Theoretically: yes. A plot of standard candle versus standard clock attributes are at the heart of the Hubble diagrams that are so useful for supernovae calibrations of cosmology. Recent attempts have been made to do the same using GRBs (see, for example, Schaefer 2007). Although high redshift GRBs do not occur in dark energy dominated regions of the universe, their primarily dark matter surroundings will not erase the dark energy-caused brightness divergence on the Hubble diagram (Schaefer 2007), and the GRB light will need to travel through more dark energy than nearer supernovae.

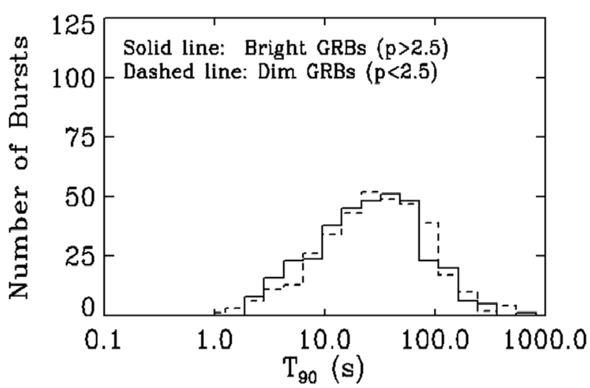

FIGURE 6. Shown above is a histogram of T90 durations divided into two groups according to peak flux. The solid line depicts GRBs with P256 less than 2.5 photons / sec/ cm2, while the dotted line depicts GRBs with P256 greater than 2.5 photons / sec / cm2. These results are similar in parameters to the analysis of Norris et al. (1995). 713 BATSE GRBs were used for this plot.

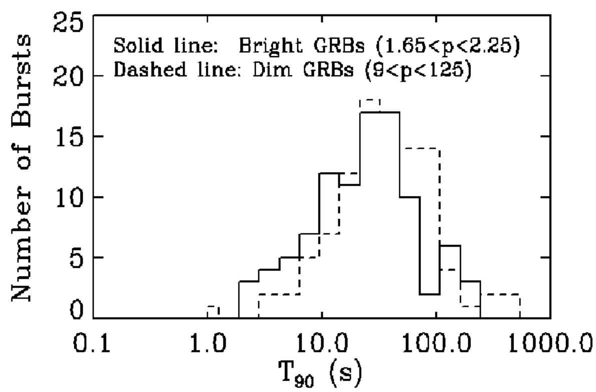

FIGURE 7. Shown above is the plot most similar to those in Norris et al. (1995), using groups of GRBs with more widely separated p256 peak flux. The solid line indicates GRB with a P256 between 1.65 and 2.25, while the dashed line indicates GRBs with a P25 between 9 and 125. 198 GRBs fall into these brightness samples.

Practically, however, the situation is less clear. Peak flux appears to be a sufficiently useful standard candle, although confounding factors remain including the (unknown) luminosity function and the spectral diversity function. Duration estimate T90, however, is not a very compelling standard clock: actual redshifts are much better. This presents a challenge of whether any other simply measured, ubiquitous, lag-independent BATSE parameter could act as a significantly better standard clock than T90.

ACKNOWLEDGMENTS

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