Time-Dilation, Log N - Log P, and Cosmology

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We investigate whether a simple cosmology can fit GRB results in both time dilation and Log N - Log P simultaneously. Simplifying assumptions include: all GRBs are spectrally identical to BATSE trigger 143, Ω = 1 universe, and no luminosity and number density evolution. Observational data used includes: the BATSE 3B peak brightness distribution (64-ms time scale), the Pioneer Venus Orbiter (PVO) brightness distribution, and the Norris et al. time dilation results for peak aligned profiles presented at this meeting. We find acceptable cosmological fits to the brightness distributions when placing BATSE trigger 143 at a redshift of $0.15 \pm 0.10$. This translates into a $(1 + z_{\text{dim}})/(1 + z_{\text{bright}})$ factor of about $1.50 \pm 0.50$ between selected brightness extremes of the Norris et al. sample. Norris et al. estimate, however, that $(1 + z_{\text{dim}})/(1 + z_{\text{bright}}) \approx 2.0 \pm 0.5$ when considering duration tests. The difference is marginal and could be accounted for by evolution. We therefore find that evolution of GRBs is preferred but not demanded.

INTRODUCTION

There are two main results evident with BATSE data which, when taken together, appear consistent with a cosmological origin [1, 2]. The first is the isotropic nature of the BATSE GRB distribution, and the second is the apparently confined nature of the peak brightness distribution [3, 4]. Cosmological fits to the brightness distribution have been made by several research teams [5, 6, 7]. An independent third result is now claimed to be consistent with a cosmological origin of GRBs: time dilation [8, 9, 10, 11, 12]. In this paper we investigate whether the most recent time dilation results of Norris et al. [13] and Bonnell et al. [14] are consistent with the 3B peak brightness distribution. Fenimore & Bloom [15] imply that the two might not be consistent with a single cosmological setting, as the redshifts they derived from the Norris et al. [8] time dilations are much greater than those find implied by the brightness distribution and uniformity assumptions.

Data from the BATSE 3B catalog was accessed from the Compton GRO
FIG. 1. The combined BATSE - PVO brightness distribution fit to an $\Omega = 1$ cosmology. The solid histogram steps show BATSE 3B data. The asterisks show PVO data normalized to the BATSE rate. The dotted line represents a canonical uniform distribution with -1.5 slope line. The dot-dashed line shows a Monte Carlo fit to an $\Omega = 1$ cosmology of standard candle GRBs with no evolution. The best fit had BATSE trigger 143 placed at a redshift of 0.15, and statistically acceptable fits placed 143 within a redshift of 0.1 of this value.

Science Support Center. BATSE bursts with T90 durations greater than 2 seconds and peak fluxes greater than 1.827 photons cm$^{-2}$ sec$^{-1}$ were included. BATSE is at least 95% complete to this peak flux, according to the published BATSE 2B trigger efficiency table.

PVO brightness distribution data was taken from Table 1 of Fenimore and Bloom [15]. The conversion from PVO rate to equivalent BATSE rate was found by demanding that the rates be equivalent at the dimmest complete PVO peak flux bin. The conversion factor of 1.25 between peak flux in the PVO energy band 100 - 500 keV and peak flux in the BATSE energy band 50 - 300 keV was given by Fenimore in a private communication.

To test for consistency we created Monte Carlo simulations. We first generated theoretical log N - log P (here P stands for peak flux in photons cm$^{-2}$ sec$^{-1}$ on the 64-ms time scale) by considering BATSE trigger 143 a burst with a canonical spectrum. BATSE trigger 143 is one of the brightest and best studied GRBs: its spectrum is well known because of good counting statistics and because it was also seen by the EGRET and COMPTEL instruments on board CGRO; its time series is well studied because of good counting statistics and because it was only the 10th cosmic GRB detected by BATSE. We use only the spectrum at the peak - more specifically for 1 second
FIG. 2. Comparison of the time-dilation results implied by the brightness distribution plots with the time-dilation results measured by Norris et al. for a simple cosmological model. The triangles represent the expected time-dilation from fits to the Log N - Log P for the simple cosmology described and for BATSE trigger 143 placed at a redshift of 0.15. The diamond with the error bars is the time-dilation result extracted from Norris et al. measured by the peak alignment technique.

centered on the bin of peak counts.

We quantified 143’s photon spectrum and generated a theoretical cosmology by throwing it randomly in an Ω = 1 universe. In the subsequent Monte-Carlo simulation, we then re-measured each new “143” burst being careful to consider all cosmological dimming, time-dilating, and reddening factors on the actual 143 spectrum and burst rate. No evolution was considered, however.

We then numerically compared the theoretical brightness distributions generated with a combined BATSE - PVO brightness distribution. The comparison was done using the two-distribution KS test. The test is sensitive to not just the shape of the two distributions but their dynamic range in peak flux. The only parameter varied to maximize the goodness of fit was the actual redshift of the measured 143 spectrum itself.

RESULTS

First, ignoring time dilation, we found it quite possible to fit the combined BATSE - PVO brightness distribution with this simple cosmological paradigm. Such a fit is shown in Figure 1. In this fit BATSE trigger 143 was placed at a redshift of 0.15. Acceptable fits at the 1 σ level were found for redshifts
between 0.05 and 0.25.

Next, we wished to test whether these fits were consistent with the most recent Norris et al. (13) measurement of time-dilation. Figure 2 shows effective time dilations from the best fit to the cosmology implied by Figure 1, along with the recent time dilation result for the peak alignment method (13). Only one redshift-corrected time-dilation point can be used to date.

Figure 2 shows that the time-dilation factor between the brightness groups in question is about 2.0, while the time-dilation factor implied by the brightness distribution fit in the above cosmology is about 1.5. There is some uncertainty in the Norris et al. (13) factor however, which is about 0.50 in redshift based on the quoted uncertainties and the jitter of the time dilation points. This places the two time-dilation factors about one $\sigma$ apart. One may note that the time dilation in this bin is only about two $\sigma$ away from no time-dilation at all - but the inference that time-dilation itself has only marginal statistical significance would be deceiving. This is because neighboring unrelated data points also stray in the same sense from the line, so that the cumulative probability of all the points straying is greater (10) (13). As the full time-dilation redshift-decomposition has only been estimated for a single point as yet, we can only estimate that the statistical probability would be at least a factor of a few higher, were points from all brightness classes accounted for.

We also note that were a $1-\sigma$ higher fit redshift used for 143 in the brightness distribution, a much better agreement would be found between the time-dilation factor implied by the brightness distribution and that measured by the Norris et al. (13) time dilation analysis.

**CONCLUSIONS**

In general we find the cosmologies implied by the Log N - Log P and the time-dilation are only in good agreement for some methods of time-dilation determination. For peak alignment and auto-correlation measures there is a disagreement in the sense that the burst redshifts implied by the Norris et al. (8) (14) (13) time dilations are greater than those implied by the combined BATSE - PVO brightness distributions. Since the measured errors are large, however, even this simple non-evolutionary cosmology is not rigorously excluded - to greater than about $2\sigma$ - from explaining both results simultaneously. We therefore conclude that evolution is preferred but not demanded.

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