Towards a More Standardized Candle Using GRB Energetics & Spectra

Andrew S. Friedman[1] and Joshua S. Bloom[1,2] **(astro-ph/0408413)**

1: Harvard-Smithsonian Center for Astrophysics, 2: UC Berkeley (On leave)

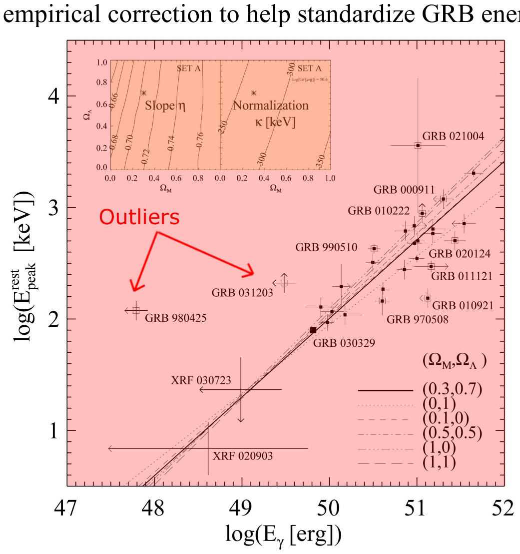
afriedman@cfa.harvard.edu, jbloom@cfa.harvard.edu, **www.cosmicbooms.net**

Abstract

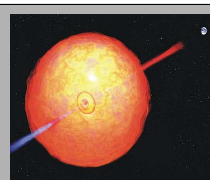
The use of γ-ray bursts (GRBs) energetics for cosmography has long been advanced as a means to probe to redshifts beyond those possible with Type Ia SNe, to the epoch of deceleration. However, though relatively immune to systematic effects of dust extinction, the prompt energy release in GRBs, even when corrected for jetting geometry, is far from being a standard candle. Recently, two groups (Dai et al. and Ghirlanda et al.) have claimed that by using the newly discovered relation between the apparent geometry-corrected energies (E_γ) and the peak in the rest frame prompt burst spectrum ($E_p = [1+z]E^{obs}_p$), GRBs now provide meaningful constraints on Ω_M, Ω_Λ, and the equation of state parameter w. In presenting the first self-consistent formalism for correcting GRB energies with a thorough accounting for observational uncertainties, we demonstrate that the **current sample** of 19 GRBs is simply **inadequate for cosmography** when compared to results from Type Ia supernovae, large-scale structure, and the microwave background. **The proper use of the relation clearly brings GRBs an impressive step closer toward a standardizable candle**, but until the physical origin of the E_p-E_γ relation is understood, additional corrections are discovered, and a larger and homogeneous determination of prompt-burst and afterglow observables exists (e.g., from *Swift*), bold claims about the utility of GRBs for cosmography will have to wait.

The E_p-E_γ relation

Although the E_p-E_γ relation is a highly significant correlation (Spearman ρ = 0.89, null probability = 2.3 x 10^{-7}), **the correlation is not well fit by a power law: $E_p = \kappa(E_\gamma/E_o)^\eta$** (where $E_o = 10^{50.6}$ erg is chosen to minimize the covariance between η and κ) across a range of cosmologies, with a reduced χ^2_ν = 3.05 (17 dof) in the standard cosmology (Ω_M, Ω_Λ, h_{70}) = (0.3,0.7,1) and a minimum χ^2_ν = 3.04. The correlation, however, does provide a simple empirical correction to help standardize GRB energetics.



The (weak) cosmological dependence of the E_p-E_γ relation. The best fit power-law relations for a representative set of cosmologies are shown above as a series of lines. Only the data for a standard cosmology (Ω_M,Ω_Λ,h_{70})=(0.3,0.7,1) is shown for clarity with upper/lower limits indicated with arrows. **Notable outliers** are indicated with a large square surrounding the data points. The best fit values of the slope (η) and normalization (κ) are shown inset (standard cosmology = *). Note that the data for a standard cosmology with best fit η = 0.70 ± 0.07, essentially brackets the fits across all cosmologies in the range: Ω_M, Ω_Λ ∈ [0,1].



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A clearinghouse for GRB and afterglow observables and energetics. Here you will find a compilation of observables (jet break time, density, fluence, etc.) useful in determining GRB energies, constraining the Ghirlanda and Amati relations, and beyond. All of the data contained therein are public.

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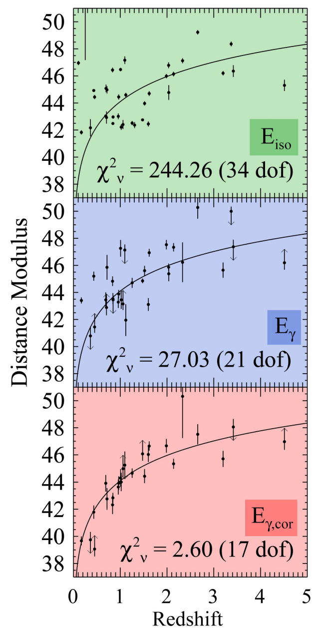
The GRB Hubble Diagram

A GRB standard candle is some function of prompt burst and afterglow observables and the luminosity distance (or distance modulus) which does not evolve with z and is roughly constant from burst to burst.



Are GRBs really useful for cosmology? The left figure shows the improvement of GRB Hubble diagrams for (Ω_M, Ω_Λ, h_{70}) = (0.3,0.7,1) constructed using different standard candle assumptions: E_{iso}, E_γ, or $E_{\gamma,cor}$ = constant, where E_{iso} is the isotropic equivalent prompt γ-ray energy release, $E_\gamma = E_{iso} f_b$ is the geometry-corrected energy where f_b is the beaming fraction inferred from the afterglow jet break time, and $E_{\gamma,cor} = E_\gamma(\kappa/E_p)^{1/\eta}$ is a further correction, making use the E_p-E_γ relation. From top to bottom there is a continual reduction in scatter (improved χ^2_ν) after applying empirical corrections to the energetics. **However, more data and new empirical correlations, perhaps to be found in *Swift* data, will be necessary for GRB standard candles to be competitive with Type Ia SNe (χ^2_ν=1.06, Riess et. al 2004) as cosmological distance indicators.**

Cosmological Parameter Determination

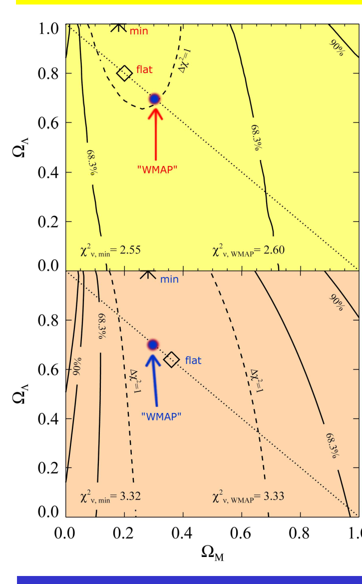


Figure (left) shows χ^2 contours over (Ω_M,Ω_Λ) for the GRB Hubble diagram constructed using the corrected energy $E_{\gamma,cor}$ for the current sample of 19 bursts. Indicated on plot are: surface minima (asterisk), minima assuming flatness (diamond), and the location of the standard "WMAP" cosmology (blue circle). **Top panel** includes errors on correlation slope η and intercept κ. Although the fit seems to favor a (Ω_M,Ω_Λ) = (0.2,0.8) cosmology (assuming flatness), **the fit is only marginally acceptable**: minimum χ^2_ν=2.55 (17 dof). **Bottom panel** assumes η and κ are known *a priori*. Although Ω_M~0.3 appears to be favored, **the fit is unacceptable**: minimum χ^2_ν=3.32 (17 dof). With the current, small sample, and few low z bursts, Ω_Λ is essentially unconstrained in both cases. Although not shown here, **the shape of the χ^2 surfaces and hence the best fit values and uncertainties for Ω_M and Ω_Λ are highly sensitive to outliers in the E_p-E_γ relation.**

Conclusion

Although cautious optimism is warranted with the addition of an order of magnitude more data and possible new empirical corrections to GRB energetics in the *Swift* era, **GRBs are currently not useful for cosmography as compared, for example, to Type Ia supernovae.**

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