Towards a More Standardized Candle Using GRB Energetics & Spectra

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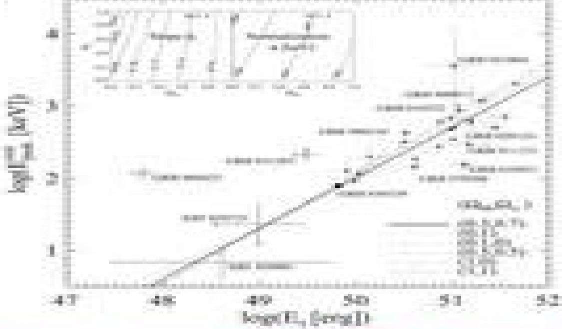
Abstract

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 (Eγ) and the peak in the rest frame prompt burst spectrum (Ep), GRBs now provide meaningful constraints on Ω_M, Ω_Λ and the quintessence 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 18 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 Ep-Eγ 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 Ep-Eγ relation

Although the E_p-E_γ relation is a highly significant correlation (Spearman $\rho = 0.88$, null probability = 1.1×10^{-6}), **the relation itself is not well fit by a power law** [$E_p = \kappa(E_\gamma/10^{51}\,\mathrm{erg})^\eta$] across a range of cosmologies, with a reduced $\chi^2_\nu = 3.22$ (16 dof) in the standard cosmology (Ω_M, Ω_Λ, h_{70}) = (0.3,0.7,1) and a minimum $\chi^2_\nu = 3.20$. 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 relation for a representative set of cosmologies are shown as a series of lines. Only the data for a standard cosmology of (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. Note that the data for a standard cosmology (with best fit η = 0.70 ± 0.07) essentially brackets the fits across all cosmologies, excepting only the extreme cosmologies with $\Omega_M = 0$ and $\Omega_\Lambda = 1$.

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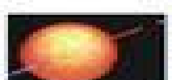
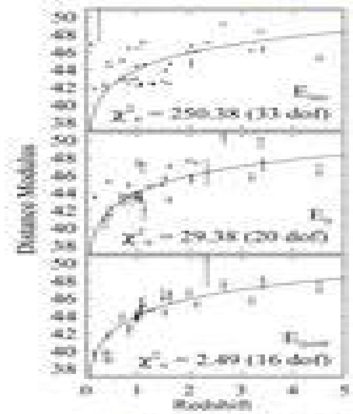


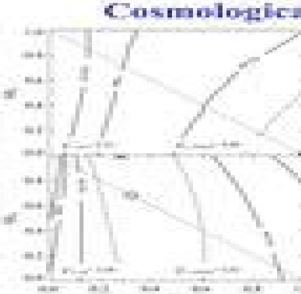
www.cosmicbooms.net: A Clearinghouse for GRB and Afterglow Observables and Energetics. Here you will find a compilation of observables (jet break time, density, fluence, etc.) useful in determining GRB energies, constraining the Ghirlanda and Amati relations, and beyond. All of the data contained herein are public.

The GRB Hubble Diagram



Are GRBs really useful for cosmology? Shown is the improvement of GRB Hubble diagrams for (Ω_M, Ω_Λ, h_{70}) = (0.3,0.7,1). From top to bottom there is a continual reduction in scatter after applying corrections to the energetics (i.e. different standard candle assumptions). Eiso is the isotropic equivalent prompt γ-ray energy release, Eγ= Eiso·fb is the geometry-corrected energy where fb=1-cos(θ) is the beaming fraction, and Eγ,cor= $E_\gamma(\kappa/E_p)^{1/\eta}$ is a further correction, making use the E_p-E_γ relation. **Future empirical correlations, perhaps to be found in *Swift* data, will be necessary for GRB standard candles to be competitive with Type Ia SNe as cosmological distance indicators.**

Cosmological Parameter Determination



χ^2 contours for the GRB Hubble diagram constructed using the corrected energy Eγ,cor. Top panel includes errors on correlation slope η and intercept κ. Bottom panel assumes fit parameters are known *a priori*. Although the fits are marginally acceptable (minimum χ^2_ν = 2.2, [top]), **the shape in the χ^2 surface and hence the best fit values and uncertainties for Ω_M and Ω_Λ are dominated by outliers in the E_p-E_γ relation, and thus not yet meaningful.**

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.**

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