The Present and Future of GRB Cosmography

Andrew S. Friedman (Harvard-CfA) & Joshua S. Bloom (Harvard-CfA / UC Berkeley)


www.cosmicbooms.net
Motivations

• GRBs: brightest explosions in universe
• Detectable out to high z > 5 (easy), $z_{\text{max}} \sim 10-20$ (?)
• Gamma-rays penetrate dust
• Any evolution likely orthogonal to Type Ia SNe
• Swift satellite in space! SNAP in 2010? ($z_{\text{max}} \sim 1.7$)

A GRB standard candle could serve as an independent probe of the geometry & expansion history of the universe, complementary to SNe Ia
Improvement in the GRB Hubble Diagram

Panels use different combinations of GRB observables as “standard candles”

1. $E_{iso}$
   - $\chi^2_v = 343.30$ (36 dof)

2. $E_\gamma$
   - $\chi^2_v = 19.27$ (21 dof)

3. $E_{\gamma, cor}$
   - $(\Omega_M, \Omega_\Lambda, h_{70}) = (0.3, 0.7, 1)$
   - $\chi^2_v = 3.42$ (17 dof)
The $E_p$-$E_\gamma$ relation

$E_p$: peak energy of rest frame prompt $\gamma$-ray spectrum

$E_\gamma$: total $\gamma$-ray energy, corrected for beaming

Power Law Fit

$$E_p = \kappa \left( \frac{E_\gamma}{E_0} \right)^\eta$$

To determine $E_\gamma$ one needs to **assume a cosmology**, pick a model for the jet structure, and “measure” the following:

1. Fluence in observed bandpass ($S_\gamma$) **VERY EASY**
2. Peak of prompt-burst spectrum ($E_p$) **EASY**
3. Spectroscopic redshift ($z$) **HARD**
4. Time of afterglow jet-break ($t_{jet}$) **HARD**
5. Ambient Density ($n=10 \text{ cm}^{-3}$?) **VERY HARD**
6. $\gamma$-ray conversion efficiency ($\eta_\gamma=20\%$) **UNKNOWN**
Constructing A GRB Hubble Diagram

For self-consistency, one must re-fit for the slope ($\eta$) and intercept ($\kappa$) of the $E_p$-$E_\gamma$ relation in each cosmology.

Don’t want to assume the right answer!

Apparent GRB Distance Modulus [mag]

$$DM_\gamma \approx -2.5 \log \left( \frac{4\pi S_\gamma k t_{\text{jet}} (n\eta_\gamma)^{1/3}}{(1 + z)^2} \right) + C_\gamma + zp$$

Empirical Correction From $E_p$-$E_\gamma$ relation [mag]

$$C_\gamma = \frac{10}{3\eta} \log \left( \frac{E_p^{\text{obs}} (1 + z)}{\kappa} \right)$$

$$zp = \left( \frac{10}{3} \right) \log \left( \frac{2E_0}{B^2} \right) - 5 \log (3.085 \times 10^{19} \text{ cm}) + 5 \log (h_{70})$$
Goodness of fit ($\chi^2$/dof) for distance modulus-relation computed for each cosmology in grid. $(\chi^2$/dof)$_{\text{min}}$ gives favored $(\Omega_M, \Omega_\Lambda)$ cosmology. But $\chi^2$/dof > 3 under our assumptions.

So is $\chi^2$/dof acceptable for any $(\Omega_M, \Omega_\Lambda)$?
Sensitivity to Input Assumptions

An acceptable fit for the cosmology requires an acceptable fit for the $E_p - E_\gamma$ relation which is highly sensitive to assumptions for:

1. Density ($n$)
2. Fractional error ($\sigma n / n$)
3. Data references for individual bursts (small # statistics)

There exist assumptions + data subsets that yield good fits (Dai et. al 2004, Ghirlanda et. al 2004b), but these are not necessarily favored a priori.
Conclusions

• The cosmographic utility of a GRB standard candle constructed from the $E_p - E_\gamma$ relation is **highly sensitive to input assumptions**

• Need **better constraints on the density** ($n$) from broadband afterglow modeling

• Need **more data** from *Swift* to combat small # statistics
  ($\sim20$ $E_p - E_\gamma$ bursts, $\sim40$ with measured $z$)

**Cosmography with GRBs is still *possible*, but is not yet competitive with Type Ia SNe**

References

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