Gamma-ray bursts: cosmic rulers for the high-redshift universe?

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The desire to extend the Hubble Diagram to higher redshifts than the range of current
Type 1a Supernovae observations has prompted investigation into spectral correlations
in gamma-ray bursts (GBRs), in the hope that standard candle-like properties can be
identified. In this paper, we discuss the potential of these new ‘cosmic rulers’ and
highlight their limitations by investigating the constraints that current data can place on
an alternative Cosmological model in the form of Conformal Gravity. By fitting current
Type 1a Supernovae and GRB data to the predicted luminosity distance redshift relation
of both the standard Concordance Model and the Conformal Gravity, we show that
currently neither model is strongly favoured at high redshift. The scatter in the current
GRB data testifies to the further work required if GRBs are to cement their place as
effective probes of the cosmological distance scale.

Keywords: cosmology; gamma-ray bursts; supernovae; concordance model;
conformal gravity

1. The Ghirlanda relation as a cosmic ruler

Recently a number of authors have highlighted the potential of long-duration
gamma-ray bursts (GRBs) as distance indicators. The most promising indicator
appears to be the so-called ‘Ghirlanda Relation’ (Ghirlanda et al. 2004); the tight
correlation between the isotropic equivalent energy and the peak energy of the
GRB integrated spectrum.

However, several authors (e.g. Friedman & Bloom 2005) have pointed out
potential sources of systematic error which may undermine the application of the
Ghirlanda Relation as a distance indicator, for example, Dai et al. (2004) assume
a cosmology when calibrating the relation, which presents a circularity issue
when using it to fit cosmological parameter values.

Friedman & Bloom conclude that the Ghirlanda Relation provides no
significant improvement in the constraints on $\Omega_M$ and $\Omega_A$. In their view, this
is mainly due to the currently small number of GRB calibrators, including the

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One contribution of 35 to a Discussion Meeting Issue ‘Gamma-ray bursts’.
lack of low-redshift GRBs. Contributions to the uncertainty also arise from the sensitivity to data selection choices and to the values, and ranges assumed for the number density of the surrounding medium and the efficiency of each event.

Notwithstanding the caveats of Friedman & Bloom, we have recently considered their application to test the viability of Conformal Gravity theories (Mannheim 2003). Mannheim’s theory makes a specific, and very strong, prediction; the expansion of the Universe has always been accelerating. However, the Hubble Diagram for this model does not diverge from the corresponding Friedman model until $z > 1$.

In Mannheim’s Conformal Gravity theory, the luminosity distance redshift relation is given by

$$d_L = -\frac{c(1+z)^2}{H_0 q_0} \left[ 1 - \left( 1 + q_0 - \frac{q_0}{(1+z)^2} \right)^{1/2} \right],$$

(1.1)

where $z$ is the redshift of the source, $H_0$ is the Hubble parameter, $c$ is the speed of light and $q_0$ is the model deceleration parameter, related to the Concordance Model parameters by $q_0 = \frac{\Omega_M}{2} - \Omega_A$.

2. Results and conclusions

We have used data on 150 Gold Sample Type 1a Supernovae from Riess et al. (2004), 71 SN from the first year results of the Supernova Legacy Survey (Astier et al. 2006) and 19 GRBs compiled by Friedman & Bloom (2005), employing a cut at $cz<5000$ km $s^{-1}$ to remove the effect of peculiar velocities from the SN data. The Hubble diagram for these datasets can be seen in figure 1. We have compared these data with distance moduli predicted for the Standard Model with

Figure 1. The $\log(z)-\mu$ Hubble diagram for standard model and conformal gravity, with SN and GRB data sets.
(Ω_M=0.3, Ω_A=0.7) and the corresponding Conformal Gravity model with q_0=−0.55. Values for σ_{obs} for our SN were taken from the published data source, while for the GRBs they were calculated following Dai et al. (2004). These fit gives χ^2/d.f. = 4.91 and 5.65, respectively.

From our results, we see that—with current SN+GRB data—the specific prediction of Mannheim’s Conformal Gravity that the universe did not undergo a deceleration phase remains viable. However, the large χ^2 per degree of freedom for both the Conformal Gravity and the Friedman models shown in figure 1 should sound an important note of caution regarding the efficacy of GRBs as distance indicators. The GRB data do not yet appear good enough to discriminate reliably between models which accelerate and decelerate above z=1.

References


Phil. Trans. R. Soc. A (2007)