Gamma Ray Bursts: Cosmic Rulers for the High-Redshift Universe?

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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 2004) 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 $\Omega_\Lambda$. In their view, this is mainly due to the currently small number of GRB calibrators, including the 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 Friedmann model until $z > 1$.

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

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

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 $q_0 = \frac{\Omega_M}{2} - \Omega_\Lambda$. 

Article submitted to Royal Society
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 and Bloom (2004), employing a cut at \( cz < 5000\text{km}s^{-1} \) to remove the effect of peculiar velocities from the SN data. The Hubble diagram for these data sets can be seen in Fig. 1. We have compared these data with distance moduli predicted for the Standard Model with \( \Omega_M = 0.3, \Omega_\Lambda = 0.7 \) and the corresponding Conformal Gravity model with \( q_0 = -0.55 \). Values for \( \sigma_{\mu_{\text{obs}}} \) for our SN were taken from the published data source, while for the GRBs they were calculated following Dai et al. (2004). These fits give \( \chi^2_{/d.o.f} = 4.91 \) 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 \( \chi^2 \) per degree of freedom for both the Conformal Gravity and Friedmann models shown in Fig. 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 reliably discriminate between models which accelerate and decelerate above \( z = 1 \).

References

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Article submitted to Royal Society