Gamma-Ray Bursts and the Cosmological Constant

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Abstract

We study the hardness distribution of long-duration gamma ray bursts (GRBs) to determine the red shift of the various populations. Our study suggests that GRBs could have progenitors at very high red-shift z out to $z \sim$ 5–6. In this case, GRBs could be sensitive to the cosmological parameters of the Universe and the evolution of the GRBs sources. We show how a cosmological constant with $\Omega_\Lambda \sim 0.7$ or 0.8 could be determined by future studies of GRBs.

1 Introduction:

The current understanding of the bulk of the gamma ray bursts (GRBs), is that the sources are at cosmological distances (van Paradijs et al., 1997). Recent observation of counterparts with Beppo-SAX and other telescopes are fully consistent with this postulate (Costa et al., 1997). While GRBs are not known as standard candles (as we now understand them), the associated frequency distributions can be sensitive to the spatial nature of the Universe at the z value of the source. We show in this note that the faintest long–soft GRB may indicate that the high-z Universe is actually spatially flat or quasi Euclidean and that this could indicate a significant cosmological constant in a low density Universe (Filippenko & Riess, 1998).

In a solution to the general theory of relativity, one finds that the scale factor of the Universe is $a(t) = (1+z)^{-1}$. The deceleration of the Universe is given by $\dot{a}$(t). It can be shown that the Friedman equation can be used to relate $\dot{z}$ = - $(1+z)^2\dot{a}$ to the matter density of the Universe [Eq. (1)],

$$\dot{z} = -H_0(1+z)\sqrt{\Omega_M(1+z)^3 + \Omega_R(1+z)^2 + \Omega_\Lambda} \;\; , \tag{1}$$

where Ω_R = 1 - Ω_Λ - Ω_M, Ω_M is the ratio of the matter density to the critical density $3H_0^2/8\pi G$ and Ω_Λ is the density associated with the vacuum energy in the Universe. We note that for Ω_M = Ω_Λ = 0 and Ω_M = 0.3, Ω_Λ = 0.7, the result on $\dot{z}$ is very similar for $z \leq 3$. We note that this was known before (Peebles, 1984; G-Yi, 1994). The Universe is quasi Euclidean for the same values of Ω_Λ, Ω_M for the $z \leq 3$ range as shown in Table 1.

Table 1. Values $\sim \dot{z}$.

z	Ω_M=1	Ω_M=0.4,Ω_Λ=0.6	Ω_M=0.3,Ω_Λ=0.7	Ω_M=Ω_Λ=0
0	-1	-1	-1	-1
0.5	-1.84	-1.40	-1.31	-1.5
1	-2.83	-1.95	-1.76	-2
2	-5.20	-3.38	-2.97	-3
3	-8.00	-5.12	-4.46	-4

Recently, there has been growing evidence that Ω_M = 0.3, Ω_Λ = 0.7 fits many data, most notably the recent SNIa data from two groups (Filippenko & Riess, 1998; Goldhaber & Perlmutter, 1998) (see also Table 2). While these are very important results they are not free from some questions and, in Table 2, we suggest some of the possible problems with these results).

Table 2. - Tests for a cosmological constant.

Gravitational Lens Excess (Kochanek, 1996; Myungshi et al., 1997):
- Very sensitive to models of galactic halos, etc. – low statistics.
- However, quasars are at $z \sim 2$–3 giving sensitivity $\Omega_\Lambda \leq 0.7$;
SNIa (Filippenko & Riess, 1998; Goldhaber & Perlmutter, 1998):
- An open universe $(\Omega_M \sim 0.4) q_0 \sim 0.2$ and dust could fake a $\Omega_\Lambda \neq 0$ Universe;
- However, data (at high *z*) collection increases rapidly.
Age vs H_0 (Sandage et al., 1998):
- Need precision measurements.
CMBR (Lineweaver & Barbosa, 1998):
- Data is poor - but it favours a $\Omega_M < 1$;
- MAP + Plank will help resolve the issue in the future.

There is growing evidence for the cosmological nature of the long-duration GRBs from time dilation studies (Meegan et al, 1992), hardness studies and, more recently, direct evaluation for the distance of GRB970508 and GRB971214 from observation of the X-ray and optical counterparts in the associated galaxy (Metzger et al., 1997; Kulkarni et al., 1998).

In this note we focus on the use of the hardness distribution to select a relatively bias-free high-*z* sample of GRBs to study. Fig. 1 shows the hardness distribution for all GRBs from the BATSE 4B Catalogue.

Currently the only sample for which there is clear cosmological evidence is for the long duration burst (all Beppo-SAX events are in this sample). We therefore choose events with condition: $\tau_{\rm duration} > 1$ s to study. We divide these events into four hardness classes $H_1 - H_4$ for future study (Fig. 1).

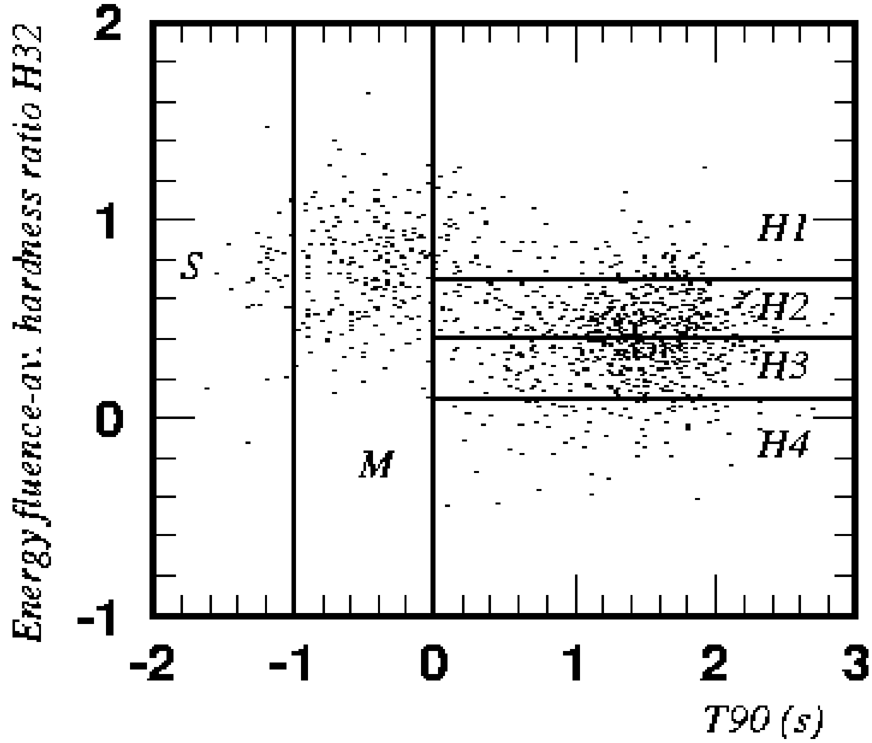

Figure 1: The hardness scatter plot.

It is generally considered that the study of the ln *N* - ln *S* distribution or the integral distribution of *N* $(> c_p)$ of the number of sources with a peak count greater than c_p provides valuable information about the spatial distribution and luminosity distribution of the source.

In the case of N $(> c_p) \propto {c_p}^{-3/2}$, one expects that the simplest Euclidean spac for the source will provide the simplest explanation (G-Yi, 1994; Meszaros & Meszaros, 1996). We have therefore studied the ln N $(> c_p)$ vs ln c_p distribution for the hardness cuts

$H_1 - H_4$. The hardness of the GRB should decrease as the γ of the Galaxy increases. Since $(1+z) \sim 2\gamma_G$ (where $\gamma_G = 1/\sqrt{1-\beta_G^2}$ we expect the hardness to decrease as 1/(1+z). The choice of the softest events (or H_4) should correspond to the highest z data. If this selection increases the z of the sample, we expect these GRBs to be dimmer, which provides a cross check on the assumption.

2 Results:

In Fig. 2 we show the results of a determination of $< v/v_{\max} >$ as a function of $< z >$, deduced from the hardness and ln N - ln S distributions. We compare this with the expectation of different cosmological modes. Note that at the highest $< z >$ there is a strong evidence for source evolution.

We note that even through an empty universe and a flat universe with Ω_Λ = 0.7, Ω_M = 0.3 are nearly undistinguished, in itself this does not lead to an ln N - ln S distribution with a slope of -3/2 [**?**]. However, the observable of a slope -3/2 for the ln N - ln S distribution will be easier to produce for a system with galactic source evolution and the flat Ω_Λ = 0.7, Ω_M = 0.3 case (G-Yi, 1994).

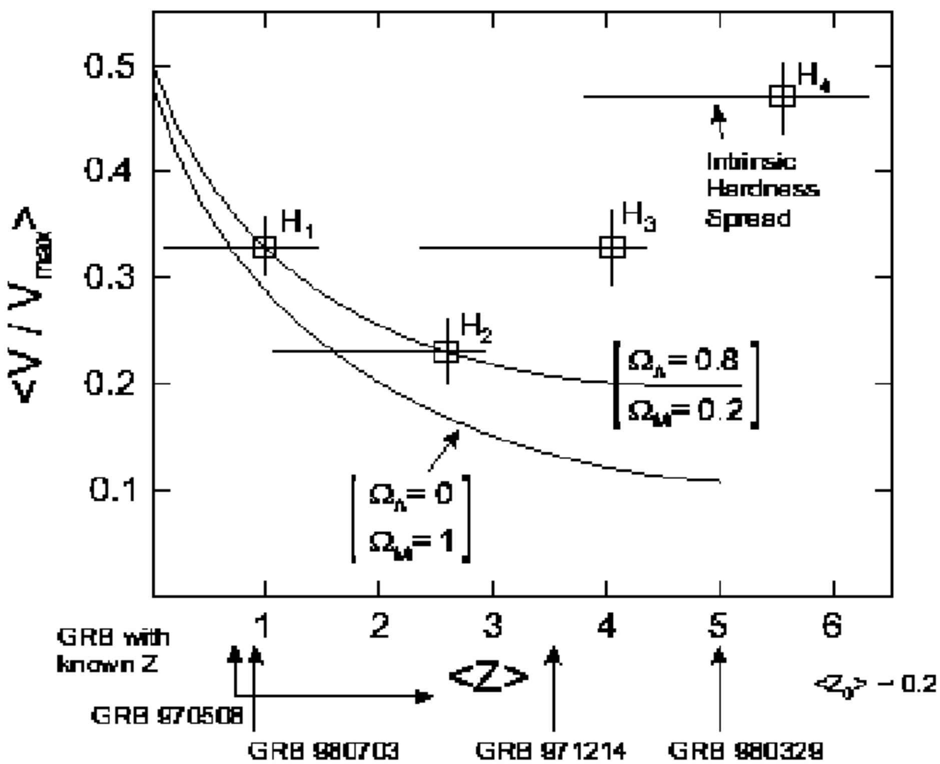

Figure 2: The $< v/v_{max} >$ vs $< z >$ for four regions (H1–H4).

3 Conclusions:

While the results reported here are consistent with a quasi-Euclidean space–time in the Universe at $< z > \sim$ 3, the explanation of the hard event ln N - ln c_p distribution could come from a power-law luminosity function that gives the $\mathcal{L}^{-\beta}$ (Meszaros 1996), which results in a ln N - ln S distribution slope for small c_p of $c_p^{1-\beta}$ and $\beta \sim 2$ would be consisted with the data. For the soft or high *z* data it is possible that a strong evolution in the source that goes like $(1+z)^6$ combined with a cosmological constant can give rise to a quasi-Euclidean ${c_p}^{-3/2}$ distribution (G-Yi, 1994; Meszaros & Meszaros, 1996).

A more plausible form of evolution has been proposed by Totani et al. (1997). They have shown that the value of Ω_Λ is a key input to a reasonable evolution model and is very sensitive. In essence if $\Omega_\Lambda \sim 0.7$ the amount of evolution needed fits the experimental data (Totani et al., 1997). In turn this constant evolution combined with Ω_Λ may then explain the quasi Euclidean nature of the ln N - ln S distribution observed in our analysis. In this sense, the GRB data lead to an expectation that $\Omega_\Lambda \sim 0.7$ as shown in Fig. 2, given the constraints from Table 2.

References

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