ARE SWIFT LONG-LAG GAMMA-RAY BURSTS IN THE LOCAL SUPERCLUSTER?

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ABSTRACT

A sample of 18 long-lag (τ_{lag} > 1 s) gamma-ray bursts (GRBs) has been drawn from our catalog of all Swift long GRBs. Four different tests were done on this sample to test the prediction that a large fraction of long-lag GRBs are from our Local Supercluster. The results of these four tests reveal that: (1) the distribution of these GRBs shows no tendency toward the Supergalactic plane; (2) the distribution shows no tendency toward the Virgo or Coma Cluster; (3) no associated bright host galaxies (m < 15) in the Local Supercluster are found for any of the 18 GRBs; (4) 17 of these 18 GRBs have redshifts of z > 0.5, which are too far to be in the Local Supercluster. All these results disproved the hypothesis that any significant fraction of long-lag GRBs are from Local Supercluster. Hence these long-lag GRBs cannot be counted in the calculation of LIGO detection rates. An explanation of why we can detect long-lag GRBs at high redshift is presented.

Key words: gamma rays: bursts

1. INTRODUCTION

Gamma-ray bursts (GRBs) are bursts of gamma radiations that are isotropically distributed in the sky. Their time duration \(T_{90}\) ranges from \(~0.1\) s up to \(~1000\) s, and their measured spectroscopic redshifts range is \(0.008 < z < 6.7\). Based on the time duration, they are divided into two different groups: GRBs with \(T_{90} < 2\) s are classified as short-duration bursts, and those with \(T_{90} > 2\) s as long-duration GRBs. The spectral lag (τ_{lag}) of a GRB is a parameter that measures the delay time between the soft and hard light curves of the GRB. The global hard-to-soft spectral evolution of GRB pulses was found by Norris et al. (1986) in analysis of SMM (Solar Maximum Mission satellite) GRB data, and a cross-correlation analysis between different channels of data for calculating τ_{lag} values was performed by Band (1997). A power-law function between the τ_{lag} value and the peak luminosity (L) was well fitted for six BATSE and BeppoSAX long GRBs with measured redshifts (Norris et al. 2000). In the power-law function, the τ_{lag} is corrected for the cosmological time dilation effect by dividing a factor of (1 + z). It was also pointed out in the same paper that GRB980425 with a long τ_{lag} value (τ_{lag} = 2.8 s) falls far below the power-law fitting curve by a factor of several hundred. The empirical τ_{lag}-L relation can be simply explained as a consequence of radiative cooling of the shocked material in the jet (Schaefer 2004). High-luminosity bursts will have fast radiative cooling and hence short lags, while low-luminosity bursts will have slow radiative cooling and hence long lags. This general result predicts that the burst luminosity should be proportional to τ_{lag}^{-1} and that is exactly what is observed.

The τ_{lag} analysis on BATSE and INTEGRAL samples shows a distribution from \(~0–10\) s for long GRBs (Norris 2002; Foley et al. 2008), with most of these τ_{lag} concentrated in the 0–1 s region. According to the τ_{lag}-L relation, a long τ_{lag} corresponds to a low luminosity, and for a low-luminosity GRB to be detected by our instruments, it should be relatively nearby. Norris (2002) pointed out that GRB980425 might represent a subclass of long GRBs that have long τ_{lag}, soft spectrum, ultralow luminosity, and that are nearby. In this case, a possible break might exist in the τ_{lag}-L relation in the long τ_{lag} region, which would indicate that these long τ_{lag} GRBs are even closer than what is predicted by the \(L \propto \tau_{lag}^{-1}\) relation. Indeed, two long τ_{lag} bursts are confidently known to be at distances close enough to be inside the Local Supercluster. GRB980425, with τ_{lag} = 2.8 s, has an ultralow luminosity, and lies in a galaxy only \(~38\) Mpc away (Galama et al. 1998). GRB830801 is the all-time brightest GRB yet has a long τ_{lag} (2.2 ± 0.2 s), so a very low redshift of z ∼ 0.01 is calculated from the τ_{lag}-L relation (Schaefer et al. 2001). GRB830801 also happens to be from a direction close to the Virgo Cluster.

Given that these long τ_{lag} GRBs might be nearby, is there any local structure of galaxies to host these GRBs? The Local Supercluster was proposed by de Vaucouleurs (1953), from an investigation of spatial distribution of galaxies. It was first named “Supergalaxy,” which was later changed to “Local Supercluster” (de Vaucouleurs 1958). More detailed studies show that the main body of the Local Supercluster is a filamentary structure extending over \(~40\) h^{-1} Mpc, and is centered on the Virgo Cluster (Karachentsev & Makarov 1996; Lahav et al. 2000). Around 60% of the luminous galaxies in the volume of Local Supercluster are within the structure that defines the plane of the Supercluster (20% in Virgo Cluster and 40% in Virgo II Cloud and Canes Venatici Cloud), and most of the remaining 40% lie within five clouds off the plane, which is called a “halo” (Tully 1982). Our Local Group is in the outskirts of this region.

Norris (2002) presented a catalog of τ_{lag} values for 1429 BATSE long GRBs, from which a sample of 64 long τ_{lag} GRBs (with τ_{lag} > 2 s) was selected. These τ_{lag} values were calculated in the observer’s rest frame, without making the time dilation correction (which should be small for local bursts). By plotting these long τ_{lag} bursts on a sky map in Supergalactic coordinates, a concentration toward the Supergalactic plane was found, with three-fourth of these bursts located in the half of the sky between −30° and 30° of Supergalactic latitude. Quantitatively, the quadrupole moment of these GRBs is roughly −0.10 ± 0.04, which shows a 2.5σ deviation from isotropy. This result implies that a long τ_{lag} value will be an indicator for local GRBs. From the solid long GRB–SN connection (e.g., GRB980425 & SN1998bw, GRB030329 & SN2003dh) and the model of massive SN (from the collapsing in highly nonaxisymmetric modes), strong gravitational waves can be
produced at a rate of $\sim 4$ yr$^{-1}$, and these gravitational waves might be possible to be detected by LIGO (Norris 2003).

An independent catalog of long $\tau_{\text{lag}}$ bursts discovered by INTEGRAL has been created by Foley et al. (2008), with 11 long $\tau_{\text{lag}}$ ($\tau_{\text{lag}} > 0.75$ s) GRBs being pulled out from the whole INTEGRAL sample. They found that 10 of the 11 long $\tau_{\text{lag}}$ bursts were located within the $-30^\circ$ to $30^\circ$ Supergalactic latitude region. The quadrupole moment of the 11 GRBs is $-0.225 \pm 0.090$. This result has been confirmed by Vianello et al. (2009), who, also taking into account the variations of GRB triggering efficiency, obtained a quadrupole moment $Q = -0.271 \pm 0.089$ for long lag GRBs and $Q = -0.007 \pm 0.042$ for the whole sample. The INTEGRAL result is broadly consistent with the conclusion of Norris (2002); however, in Norris (2002), the quadrupole moments for the samples of $\tau_{\text{lag}} > 0.5$ s and $\tau_{\text{lag}} > 1$ s have a substantially lower significance ($Q = -0.022 \pm 0.020$ for the $\tau_{\text{lag}} > 0.5$ s sample and $Q = -0.043 \pm 0.026$ for the $\tau_{\text{lag}} > 1$ s sample). With three results on two independent samples (pointing to a concentration toward the Supergalactic plane), another sample is needed to test the Local Supercluster hypothesis.

Swift, the multiwavelength GRB detection satellite, was launched in 2004 November (Gehrels et al. 2004). It has three instruments on board. The wide-field Burst Alert Telescope (BAT), which covers a 15–150 keV energy band, can position a burst to $1^\circ$–$4^\circ$ accuracy. The narrow X-ray telescope (XRT) and UV/Optical telescope (UVOT) will start observing the GRB within $\sim 100$ s after it is triggered and position it within $5^\circ$ and $0.3^\prime$, respectively. Within $\sim 100$ s, this accurate position of the GRB will be measured and distributed to the community through GRB Coordinate Network (GCN), and large ground telescopes will be able to follow-up and make their own observations. During its four years of operation, Swift has been triggered by more than 350 GRBs, $\sim 300$ of which have been confirmed as long-duration GRBs, and of $\sim 30\%$ the spectroscopic or photometric redshift has been measured. The accurate localizations of Swift GRBs make possible the search for hosts of long $\tau_{\text{lag}}$ bursts in Local Supercluster galaxies. The GRB redshift will also directly tell us the distances of these GRBs.

In this paper, we will use Swift data to test the hypothesis that most long $\tau_{\text{lag}}$ GRBs are in the Local Supercluster. The tests are made of four parts: (1) Is there any tendency of concentration toward the Supergalactic plane? (2) Is there any tendency of concentration toward the Virgo Cluster? (3) Can we find bright host galaxies for these long $\tau_{\text{lag}}$ GRBs? (4) Do any of these long $\tau_{\text{lag}}$ GRBs have a redshift of $z < 0.013$?

2. SWIFT DATA

All Swift GRB data are available on the Legacy ftp site,$^1$ along with the software published by the Swift team. BAT light curves for GRBs within any possible energy bands (15–150 keV) at any possible time bins ($> 0.064$ s) can be generated. Conventionally, for the calculation of $\tau_{\text{lag}}$, we use the light curves with 0.064 s time bins and energy bands of 25–50 keV and 100–150 keV. By applying a cross-correlation function (CCF) method on the light curves, and fitting the CCF plot with an automatically selected polynomial function, we calculated the $\tau_{\text{lag}}$ values for all Swift long GRBs. Details of our conventional calculation are presented in Xiao & Schaefer (2008).

Figure 1. Sky distribution of the 18 long $\tau_{\text{lag}}$ Swift GRBs, the Virgo Cluster, and the Coma Cluster. The GRBs are marked as filled triangles and the Virgo and Coma Clusters are marked as empty squares (upper: Coma; lower: Virgo).

From our Swift GRB redshift and luminosity indicators catalog (ranging from 2004 December (GRB041220) to 2008 July (GRB080723A)), we pulled out 18 GRBs with long $\tau_{\text{lag}}$ values ($\tau_{\text{lag}} > 1$ s). Data for these 18 GRBs are listed in Table 1. Column 1 gives the six-digit identification numbers of each GRB. Column 2 listed our measured $\tau_{\text{lag}}$ values with their $1\sigma$ uncertainties. Column 3 gives the spectroscopic redshifts for six of these GRBs and our calculated redshifts $z_{\text{ind}}$ with $1\sigma$ uncertainties for the remaining 12. The references for these redshifts are listed in Column 4. The celestial right ascension and declination of these GRBs from BAT localizations are listed in Columns 5 and 6, and the corresponding latitude and longitude in Supergalactic coordinate systems are listed in Columns 7 and 8. The conversion from celestial coordinate system to the Supergalactic coordinate system is done by using the online tools provided on a NASA Web site.$^2$ Column 9 lists the galaxy information within the field of the GRBs, with all the references given in Column 10. All information of the galaxies are drawn from the reports on GCN Circulars and the Digital Sky Survey.$^3$

The sky distribution of these long $\tau_{\text{lag}}$ GRBs in Supergalactic coordinates are plotted in Figure 1. At first glance, there is no tendency of concentration either toward the Supergalactic plane or toward the Virgo or Coma Cluster. More detailed analyses are presented in the next section.

3. FOUR TESTS

3.1. Concentration Toward Supergalactic Plane

Our Local Supercluster has a flattened distribution, with 60% of its luminous galaxies being in the structure which is called the plane of the Local Supercluster, and the other 40% lying in five clouds off the plane, called the “halo.” If long $\tau_{\text{lag}}$ GRBs

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1 http://legacy.gsfc.nasa.gov/swift/
2 http://lambda.gsfc.nasa.gov/toolbox/tb_coordconv.cfm
3 http://archive.stsci.edu/cgi-bin/dss_form
reside in galaxies in our Local Supercluster, they will show a tendency of concentration toward the Supergalactic plane.

To quantitatively measure the tendency of the concentration, a quadrupole moment of the distribution can be calculated, with $Q = (\sin^2 b - 1/3)$ and $\sigma_Q = \sqrt{4/(45N_{\text{GRB}})}$ (Briggs et al. 1996), where $b$ is the latitude of GRBs in Supergalactic coordinate and $N_{\text{GRB}}$ is the number of GRBs. A significant concentration toward the plane will result in a negative $Q$ value, while an isotropic distribution will result in a near-zero $Q$ value. The quadrupole moments of both Norris (2002) ($Q \sim -0.10 \pm 0.04$) and Foley et al. (2008) ($Q = -0.225 \pm 0.090$) show high significance (with $|Q| \gtrsim 2.5\sigma_Q$) of a concentration toward the Supergalactic plane.

For our long $\tau_{\text{lag}}$ burst sample from Swift, by simply counting the number of GRBs, we get only 8 of a total of 18 (44%) lying between $-30^\circ$ and $30^\circ$ in Supergalactic latitude, which is in agreement with the area coverage percentage within the usual uncertainties. The calculated quadrupole moment of this distribution is $Q = -0.02 \pm 0.07$. It is not significantly negative. Instead, the $Q$ value equals zero within $1\sigma$ uncertainty and this is an indication of a homogeneous distribution. We also raised the lower limit of the "long $\tau_{\text{lag}}$" criterion to $\tau_{\text{lag}} > 1.5$ s and $\tau_{\text{lag}} > 2$ s, and calculated the quadrupole moment for these subsamples. The results of $Q = -0.02 \pm 0.08$ for $\tau_{\text{lag}} > 1.5$ s and $Q = -0.06 \pm 0.09$ for $\tau_{\text{lag}} > 2$ s also show no tendency toward the Supergalactic plane. The samples and our results are shown in Table 2. A real-time sky map of Swift GRBs shows a nearly isotropic sky distribution for Swift bursts, and the quadrupole moment for all short $\tau_{\text{lag}}$ ($\tau_{\text{lag}} < 1$ s) long-duration GRBs ($Q = -0.03 \pm 0.02$) also shows an isotropic sky distribution, with no tendency either toward or away from the Supergalactic plane. With this, we see that Swift has a uniform sky coverage for the purpose of this paper, and so our quadrupole moment of the long $\tau_{\text{lag}}$ bursts needs no correction for sky coverage. As such, we find no concentration toward the Supergalactic plane, and the Supergalactic hypothesis fails our first test.

### 3.2. Concentration toward Virgo or Coma Cluster

The majority of the mass in our Local Supercluster is toward the Virgo Cluster and the Coma Cluster (which is in about the same direction as the Virgo Cluster, but with much larger distance from the Earth). So, if these long $\tau_{\text{lag}}$ GRBs are from the Local Supercluster, there should be a tendency of concentration toward the Virgo and Coma Clusters. A dipole moment can be calculated to quantitatively measure the concentration, with $D = (\cos \theta)$ and $\sigma_D = \sqrt{1/3N_{\text{GRB}}}$ (Briggs et al. 1996), in which $\theta$ is the angle between the Virgo and the Coma Cluster.
Cluster. A concentration toward the Virgo or Coma Cluster will result in a positive dipole moment, while an isotropic distribution would result in a near-zero dipole moment. D values for a majority of long Swift GRBs (331 bursts with $\tau_{\text{lag}} < 1$ s) show no tendency toward or away from Virgo and Coma Clusters, as shown in Table 2. The fact that the dipole for the $\tau_{\text{lag}} < 1$ s bursts is close to zero tells us that the Swift sky coverage is sufficiently uniform for the purpose of this paper and no correction to our measured D values is needed.

We calculated the dipole moment of our long $\tau_{\text{lag}}$ GRBs, toward both the Virgo and Coma Clusters. For the Virgo Cluster, the dipole moments are $-0.25 \pm 0.14$ for the $\tau_{\text{lag}} > 1$ s sample, $-0.30 \pm 0.15$ for the $\tau_{\text{lag}} > 1.5$ s sub-sample, and $-0.28 \pm 0.17$ for the $\tau_{\text{lag}} > 2$ s sub-sample, while for the Coma Cluster, the calculated dipole moments are respectively $-0.14 \pm 0.14$, $-0.20 \pm 0.15$, and $-0.18 \pm 0.17$ for the three cuts on $\tau_{\text{lag}}$. With the negative dipole moments, Swift long $\tau_{\text{lag}}$ bursts are showing a tendency away from the Virgo and Coma clusters. Hence, the hypothesis that these GRBs are from the Local Supercluster fails our second test. By checking Figure 5 in Norris (2002) and Figure 3 in Foley et al. (2008), we do not see any tendency toward the Virgo or Coma Cluster.

### 3.3. Host Galaxy of These GRBs

As long GRBs are formed by the collaping of fast-rotating massive stars, they should be located in the star-forming region of galaxies (e.g., in the spiral arms of the spiral galaxies), and these galaxies should appear within the small Swift-XRT 90% error circles. If these galaxies are members of the Local Supercluster, given the scale of the Local Supercluster ($\sim 40 h^{-1}$ Mpc), they should be rather nearby, and hence relatively bright. If we adopt the R-band Schechter luminosity function with $M = -21.2$ (for a Hubble constant of 65 km s$^{-1}$ Mpc$^{-1}$; Lin et al. 1996), a galaxy in our Local Supercluster with luminosity of $L^*/10$ will have its absolute magnitude of $M = -18.7$. This limit of $L^*/10$ is somewhat arbitrary, but it does include 90% of the mass in a standard luminosity function. Such a galaxy on the far edge of Local Supercluster (for which we adopt a distance of $\sim 56$ Mpc) will have an apparent magnitude of $m = 15.0$ or brighter. An increase in the Hubble constant from 65 to 72 km s$^{-1}$ Mpc$^{-1}$ will cause a slightly decreasing of the distance, and hence a brighter apparent magnitude for the threshold. As a result, if the long $\tau_{\text{lag}}$ GRBs reside in our Local Supercluster, we should be able to find their host galaxies with $m \leq 15$. That is, any GRB from our Local Supercluster should be immediately obvious by having its bright host galaxy in the Swift-XRT error circle.

We checked all the GCN reports regarding these long $\tau_{\text{lag}}$ GRBs, and all these 18 GRBs have follow-up observations reported except for GRB060607B (which was too close to the Sun). Possible host galaxies are found for GRB050126 and GRB060218, with redshifts of 1.29 and 0.033. With accurate positions reported by XRT, no galaxies were found to be within the XRT 90% error circles for the remaining 16 GRBs. We also searched through the Digital Sky Survey for the fields of these GRBs, and no galaxies are found to be within the XRT error circle for all of the 18 GRBs in POSS II-F archive, the limit magnitude of which is 20.8. Hence the Supergalactic hypothesis fails this test also.

GRB060218 is a very long and smooth burst with a very long lag (Liang et al. 2006). An optical transient was speedily discovered with UVOT (Marshall et al. 2006) and with ROTSE (Quimby et al. 2006). The burst position is coincident with a nearby galaxy at $z = 0.0331$ (Mirabal et al. 2006). Later, a supernova (SN2006aj) was found at the same position (Masetti et al. 2006; Soderberg et al. 2006). The position is on the edge of the constellation Taurus, with $\theta = 128^\circ$ to the Virgo Cluster and $\theta = 125^\circ$ to the Coma Cluster. For the redshift and a Hubble constant of $H_0 = 72$ km s$^{-1}$ Mpc$^{-1}$, the burst is $\sim 140$ Mpc distant from the Earth. This is close, but certainly outside our Local Supercluster. As such, this long $\tau_{\text{lag}}$ burst is an example of an extremely underluminous event, but is not associated with any concentration toward the Supergalactic plane.

### 3.4. Redshifts

Given that the distance of galaxies in Local Supercluster are less than 56 Mpc from the Earth (for the Hubble constant $H_0 = 72$ km s$^{-1}$ Mpc$^{-1}$), the corresponding upper limit on the redshift is $z < 0.013$. If the long $\tau_{\text{lag}}$ GRBs are from the Local Supercluster, they should be at redshift $z < 0.013$ or so.

Of our 18 long $\tau_{\text{lag}}$ GRBs, five have their spectroscopic redshift reported, ranging from 1.29 to 3.08 (as listed in Table 1). These bursts are certainly far outside the Local Supercluster. The redshift of GRB050126 is measured from the spectrum of its host galaxy, while the other four are all from multiple absorption lines in the optical afterglow spectra, hence these redshift values are with high confidence. The sixth GRB with a spectroscopic redshift is GRB060218, with $z = 0.0331$, which is also too far to be inside our Local Supercluster (see previous section). With six out of six long $\tau_{\text{lag}}$ GRBs having their spectroscopic redshift much larger than the upper-limit redshift of Local Supercluster (0.013), we are very confident to make the conclusion that the Supergalactic hypothesis fails this test also. While for the remaining 12 GRBs without spectroscopic redshifts, our redshift calculated from luminosity indicators, $z_{\text{ind}}$, are within the range of 0.6–5.0 (Xiao & Schaefer 2008), and the 1σ lower limit of redshifts for all these GRBs are $z > 0.5$. In summary, all these Swift long $\tau_{\text{lag}}$ bursts are certainly outside the Local Supercluster, with 17 out of 18 at $z > 0.5$. Hence, the Supergalactic hypothesis fails the fourth test for all of the 18 long $\tau_{\text{lag}}$ GRBs.

Moreover, if we check the whole Swift GRB catalog (with long and short $\tau_{\text{lag}}$ values), it is easy to see that only one of all the GRBs (GRB980425) with reported spectroscopic redshift is close enough to be in our Local Supercluster. The lack of low-redshift GRBs in the catalog also indicates that it is impossible to have a large fraction of long $\tau_{\text{lag}}$ GRBs in Local Supercluster.

### 4. IMPLICATIONS

The Local Supercluster hypothesis strongly failed all of our four tests. Although some small fraction of long $\tau_{\text{lag}}$ GRBs can still be local (e.g., GRB980425, GRB800801), our analysis on Swift data puts a limit of $< 5\%$ on the fraction of long $\tau_{\text{lag}}$ GRBs to be in Local Supercluster.

The results of both Norris (2002) and Foley et al. (2008) show a high significance (with $|Q| \geq 2.5\sigma_Q$) on the tendency of concentration toward the Supergalactic plane, which is not significantly high. Given that BATSE positions have had many selection of GRBs examined for anisotropies in many directions (Briggs et al. 1996), with this large number of trials, we can expect that some will be significant at this level.

From our analysis, it is evident that only a small fraction of long $\tau_{\text{lag}}$ GRBs (less than one out of 18 or so) could be in the Local Supercluster. Hence, the rate of long $\tau_{\text{lag}}$ GRBs in the Local Supercluster is greatly smaller than what has been
reported by Norris (2003), and should not be included in the calculation of LIGO’s detection rate.

From Table 1, we see that redshifts for these long \( \tau_{\text{lag}} \) GRBs \((z = 1.61)\) are not greatly lower than those for other GRBs \((z \sim 2.3)\). From the logic that long \( \tau_{\text{lag}} \) corresponds to low luminosity, one might be curious as to how we can detect a \( \tau_{\text{lag}} > 1 \) s GRB at redshift as high as \( z = 3 \). GRB980425 is an example of long \( \tau_{\text{lag}} \) and red-shift \((z \sim 0.008)\) GRB, and it is very underluminous (with its \( \gamma \)-ray peak luminosity \( L = (5.5 \pm 0.7) \times 10^{46} \) erg s\(^{-1}\)) according to Galama et al. (1998). Of course, if we put GRB980425 to the redshift of \( z = 3 \), its luminosity distance will be increasing by a factor of \( \sim 730 \), and its peak flux will be decreasing by a factor of \( 5.3 \times 10^{5} \). With such a low peak flux, we will definitely not be able to detect it. However, GRB980425 is not a typical GRB. Its energy is much lower than a “normal” GRB, and it falls far below the \( \tau_{\text{lag}}-L \) relation curve by a factor of several hundred. GRB980425 might represent a subclass of long GRBs with long \( \tau_{\text{lag}} \), soft spectrum, and low luminosity, as suggested by Norris (2002), but with only one example, it is unreasonable for us to take all long \( \tau_{\text{lag}} \) GRBs as ultralow-luminosity bursts.

Consider a “normal” long GRB that has \( \tau_{\text{lag}} = 1 \) s and redshift \( z = 3 \). Its \( \tau_{\text{lag-rest}} \) in the GRB rest frame would be \( 0.25 \) s. Assuming that it fits well with the \( \tau_{\text{lag}}-L \) relation from Xiao & Schaefer (2008),

\[
\log L = 51.31 - 1.02 \log [\tau_{\text{lag}}(1+z)^{-1}],
\]

(1)

its luminosity value \( L \) would be \( 8.40 \times 10^{51} \) erg s\(^{-1}\). From the concordance cosmological model, the luminosity distance \( d_L \) at a given redshift is calculated by

\[
d_L(z) = cH_0^{-1}(1+z) \int_0^z dz'[(1+z')^3\Omega_M + \Omega_\Lambda]^{-1/2},
\]

(2)

with \( H_0 = 72 \) km s\(^{-1}\) Mpc\(^{-1}\), \( c = 3 \times 10^{8} \) km s\(^{-1}\), \( \Omega_M = 0.27 \), and \( \Omega_\Lambda = 0.73 \). The luminosity distance for \( z = 3 \) is \( d_L \sim 2.5 \times 10^{4} \) Mpc. Then, from the inverse square law for light, \( P = L/(4\pi d_L^2) \), the bolometric peak flux would be \( P_{\text{bolo}} = 1.12 \times 10^{-7} \) erg cm\(^{-2}\) s\(^{-1}\). From the luminosity and the \( E_{\text{peak}}-L \) relation (Xiao & Schaefer 2008),

\[
\log L = 47.73 + 1.78 \log [E_{\text{peak}}(1+z)],
\]

(3)
a low \( E_{\text{peak}} \) value \( E_{\text{peak}} \sim 57 \) keV can be obtained. From the \( E_{\text{peak}} \) and average values of the low-energy power-law index \( \alpha = -1.1 \) and high-energy power-law index \( \beta = -2.2 \) (Band et al. 1993), the peak flux value in the energy range \( 15-150 \) keV can be calculated, with the result of \( P = 4.93 \times 10^{-8} \) erg cm\(^{-2}\) s\(^{-1}\), which is \( \sim 0.54 \) ph cm\(^{-2}\) s\(^{-1}\). This is significantly higher than the trigger threshold of \( \text{Swift} \). As a result, there is no doubt that we can detect long \( \tau_{\text{lag}} \) GRBs at a high redshift \((z = 3)\). Indeed, the long \( \tau_{\text{lag}} \) GRBs at \( z > 1 \) are consistent with the unbroken \( \tau_{\text{lag}}-L \) relation. Thus, it appears that the ultralow-luminosity “class” of bursts is quite rare (roughly fewer than one-in-eighteen), and the usual \( L \propto \tau_{\text{lag}}^{-1} \) relation should be used for normal long \( \tau_{\text{lag}} \) bursts with reasonable confidence.

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