Does the Redshift Distribution of *Swift* Long GRBs Trace the Star-Formation Rate?

Ali Hasan[1,2,*] and Walid Azzam[1]
[1]Department of Physics, College of Science, University of Bahrain, Sakhir, Bahrain.
[2]Physical Science and Engineering Division, King Abdullah University of Science and Technology, Thuwal, Saudi Arabia.
[*]Address: ali.hasan@kaust.edu.sa

INTRODUCTION

Gamma-Ray Bursts (GRBs) are traditionally classified into two classes: long GRBs (LGRBs) with an observed duration $T_{90} > 2$ s, and short GRBs (SGRBs) with an observed duration $T_{90} < 2$ s, where T_{90} is the observed duration during which 90% of the fluence is detected. It is theorized that SGRBs result from the merging of two compact objects, like neutron stars, while LGRBs are expected to emerge from the core-collapse of massive stars. Therefore, we expect the distribution of LGRBs through the universe to correlate with the star-formation history.

The aim of our study is to investigate the extent to which the redshift distribution of LGRBs traces the star-formation rate (SFR). To achieve that goal, we carry out Markov Chain Monte Carlo (MCMC) simulations to fit a sample of 370 *Swift* LGRBs with several proposed models.

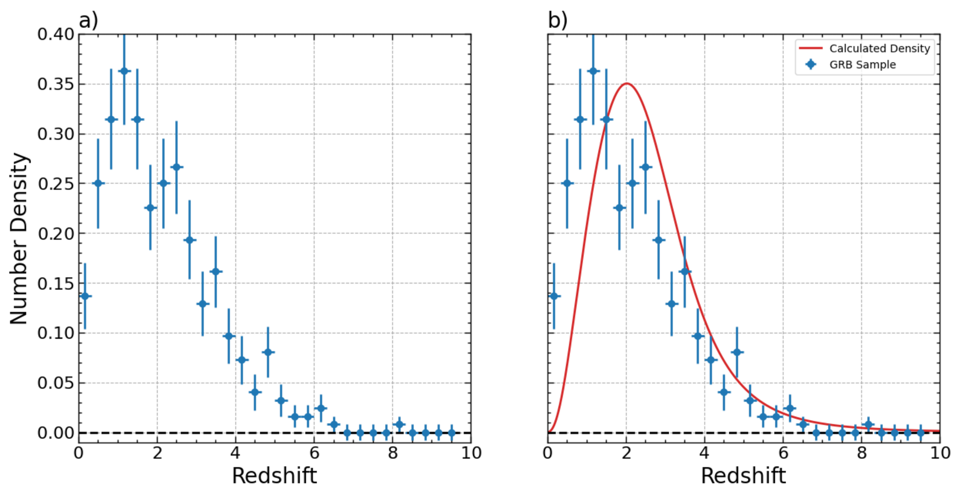

Figure 1. Shows (a) the redshift distribution of the GRB data set and (b) a comparison between the calculated number density using the star-formation rate and the redshift distribution.

THEORY

The number density of LGRBs can be calculated as follows:

$$\Phi(z) = \frac{dN}{dz} = \frac{dN}{dV}\frac{dV}{dN} = A\frac{\psi_*(z)}{1+z}\phi(z)\frac{dV(z)}{dz}$$

Where $\psi_*(z)$ is the star-formation rate density (SFRD), $\phi(z)$ is a term that contains all contributions to the distribution other than the SFRD, $\frac{dV}{dz}$ is the co-moving volume element and A is a normalization constant.

The SFRD used is given by:

$$\psi_*(z) = \frac{0.0157 + 0.118z}{1 + \left(\frac{z}{3.23}\right)^{4.66}}$$

Proposed Models	
SFRD-like function	$\psi_{\mathrm{GRB}}(z) = \frac{\alpha + \beta z}{1 + \left(\frac{z}{\gamma}\right)^{\delta}}$
Broken power law	$\phi(z) = \begin{cases} \frac{(1+z)^{\alpha}}{(1+r_1)^{\alpha}} & \text{for } z \le r_1 \\ \frac{(1+z)^{\beta}}{(1+r_1)^{\beta}} & \text{for } z > r_1 \end{cases}$
Triple power law	$\phi(z) = \begin{cases} \frac{(1+z)^{\alpha}}{(1+r_1)^{\alpha}} & \text{for } z \le r_1 \\ \frac{(1+z)^{\beta}}{(1+r_1)^{\beta}} & \text{for } r_1 < z \le r_2 \\ \frac{(1+r_2)^{\beta}}{(1+r_1)^{\beta}}\frac{(1+z)^{\gamma}}{(1+r_2)^{\gamma}} & \text{for } r_2 < z \end{cases}$
Exponential-power law	$\phi(z) = (1+z)^{\alpha}e^{\mu z}$

RESULTS

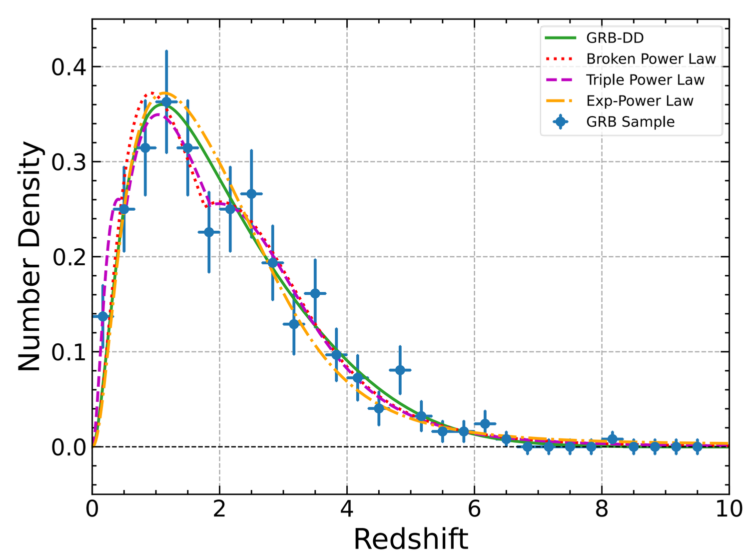

Figure 2. Shows number density vs redshift for all the models.

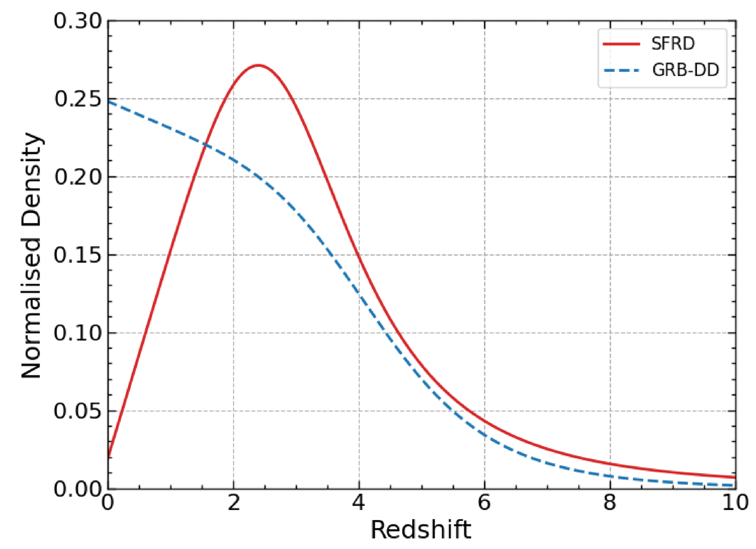

Figure 3. The SFRD compared to the SFRD-like function found by fitting.

Fitting Results		α	β	γ	δ	μ	r_1	r_2	χ^2	AIC
SFRD-like Function	Most Probable	$2.88^{+1.28}_{-1.37}$	$-0.20^{+0.16}_{-0.13}$	$4.74^{+0.69}_{-0.60}$	$4.94^{+1.26}_{-1.23}$	---	---	---	17.499	25.499
	Best Fit	3.190	−0.365	5.434	5.463	---	---	---		
Broken Power Law	Most Probable	$-2.56^{+0.41}_{-0.54}$	$0.00^{+0.30}_{-0.31}$	---	---	---	$1.71^{+0.23}_{-0.30}$	---	17.145	23.145
	Best Fit	−2.485	0.082	---	---	---	1.767	---		
Triple Power Law	Most Probable	$-5.36^{+2.60}_{-2.12}$	$-2.01^{+0.91}_{-0.50}$	$0.06^{+0.30}_{-0.29}$	---	---	$0.55^{+0.73}_{-0.19}$	$1.89^{+0.43}_{-0.22}$	10.657	20.657
	Best Fit	−6.280	−2.111	0.052	---	---	0.520	1.855		
Exponential-Power	Most Probable	$-3.23^{+0.48}_{-0.44}$	---	---	---	$0.67^{+0.12}_{-0.13}$	---	---	26.523	30.523
	Best Fit	−3.291	---	---	---	0.686	---	---		

CONCLUSIONS

- The best fitting model is the triple power law, followed by the broken power law and the SFRD-like function fit.
- The fitting functions indicate that there are two evolution regions, low redshift where there is significant contribution from $\phi(z)$ and high redshift where there is almost no contribution from $\phi(z)$. See Figure 3 for example.
- Results cooperate previous reports of high redshift LGRBs following the SFRD.
- Low redshift dilemma still proceeds.
- No indication about the physical nature of the "contribution term" $\phi(z)$.
- GRBs classification revision and investigation of possible contributions might be fruitful.

SUMMARY

- LGRBs are expected to be caused by the core-collapse of massive stars. This led researchers to investigate the correlation between the GRB distribution and the star formation rate (SFR).
- We sampled 370 GRBs observed by *Swift* observatory and used Monte Carlo simulations to fit the data with proposed models.
- The results indicate that the distribution of GRBs fits well with the SFR at high redshift but requires an evolution term at low redshifts. Previous works also concluded the same.
- A deeper look at GRB classifications, their physical origin and other possible contributors to the GRB distribution is necessary to draw stronger conclusions to this problem.

CONTACTS

Emails: ali.hasan@kaust.edu.sa | wjazzam@uob.edu.bh
LinkedIn: www.linkedin.com/in/ali-m-hasan-

REFRENCES

1. Hasan, A. and Azzam, W. (2024) Does the Redshift Distribution of Swift Long GRBs Trace the Star-Formation Rate?. International Journal of Astronomy and Astrophysics, 14, 20-44. doi: 10.4236/ijaa.2024.141002.