Estimation of long GRB rate at very high $(z > 8)$ redshift

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Abstract

We simulated the GRBs redshift distribution in the $z < 20$ range. The $z = 20$ limit was defined by shifting the Lyman break (912Å) out of the sensitivity range of THESEUS IRT. We pointed out the role of large fraction of intrinsic scatter of fluence in the simulations. We concluded that THESEUS could detect a remarkable fraction (about 25 %) of GRBs in the $z > 8$ range.

Introduction

It is an observational fact that long GRBs' fluency does not correlate significantly with redshift. This is mainly due to the fact that the standard deviation of fluency, measured in a co-moving frame, is several times greater than that of redshift. As the Lyman break is shifted out of the optical range at very large redshifts, an increasing proportion of faint GRBs do not have observed redshift. Assuming that the luminosity functions of long GRBs with and without redshifts are similar, we obtained an estimate of their rate in a range of redshifts that have so far been outside the optical range of giant telescopes.

Preparing data for further computations

Logarithms were taken to reduce the effect of outliers. In some cases, however, it was necessary to exclude them from further computations. Since they significantly distort the linear correlation between the variables we made a comprehensive outlier diagnostics using *boxplot()* procedure of *R* package. As a result of the diagnostic of this type we removed outliers from our further analysis.

Dependence of the observed variables on the redshift

On Fig. 1. we compared the density distribution of long GRBs. The figure demonstrated that the fraction of GRBs not having redshift is increasing towards fainter objects in Fluence and peak flux.

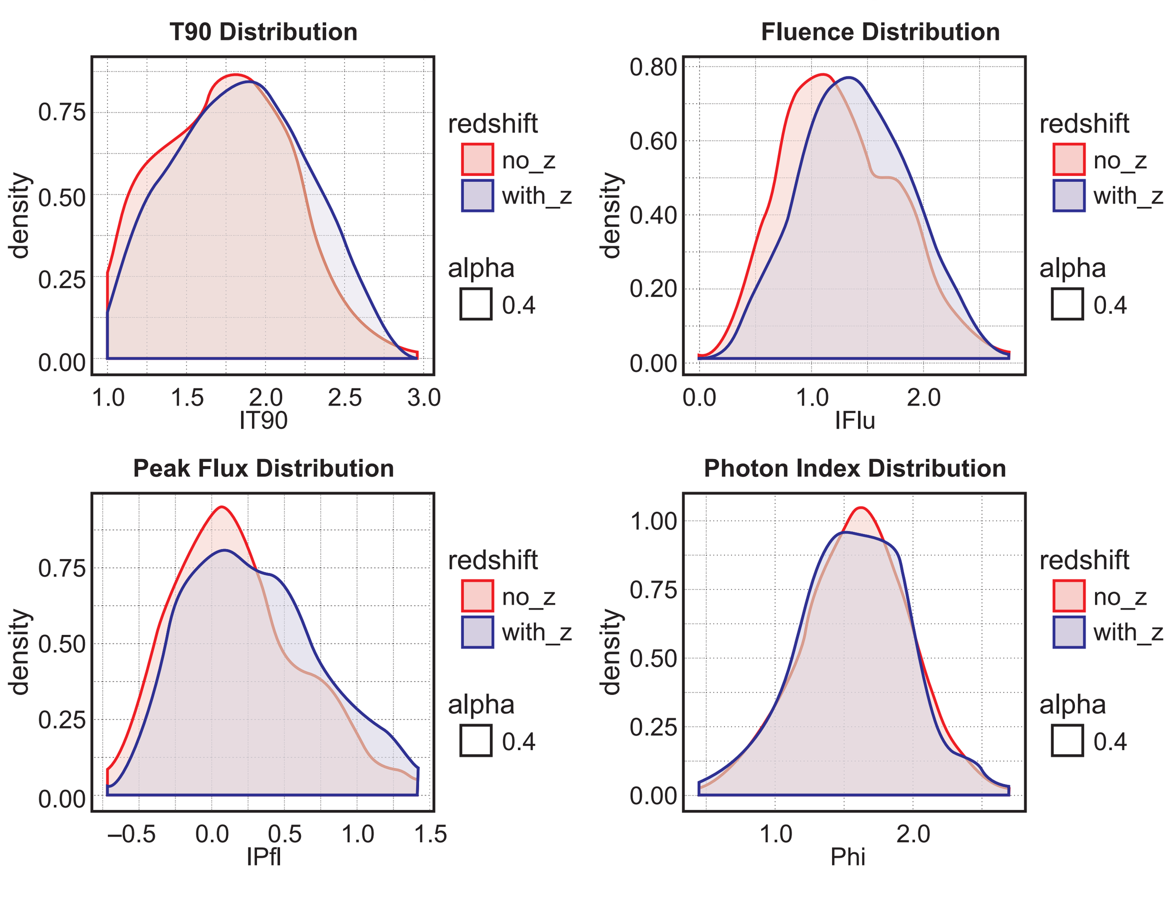

Fig. 1: Density distribution of Swift GRBs with and without redshift (the area under the curve is equal to 1). Note that the fraction of GRBs not having measured redshifts is greater at objects of fainter fluence and peak flux.

Fig 2. shows the observed quantities as a function of redshift. Due to the effect of the limiting sensitivity of the detector the figures of Fluence and Peak flux is truncated at a certain value. As a consequence, the measured correlation with redshift is much weaker than in the reality.

The low value of correlation with redshift also shows that the intrinsic standard deviation of the variables is larger than their observed values due to the redshift.

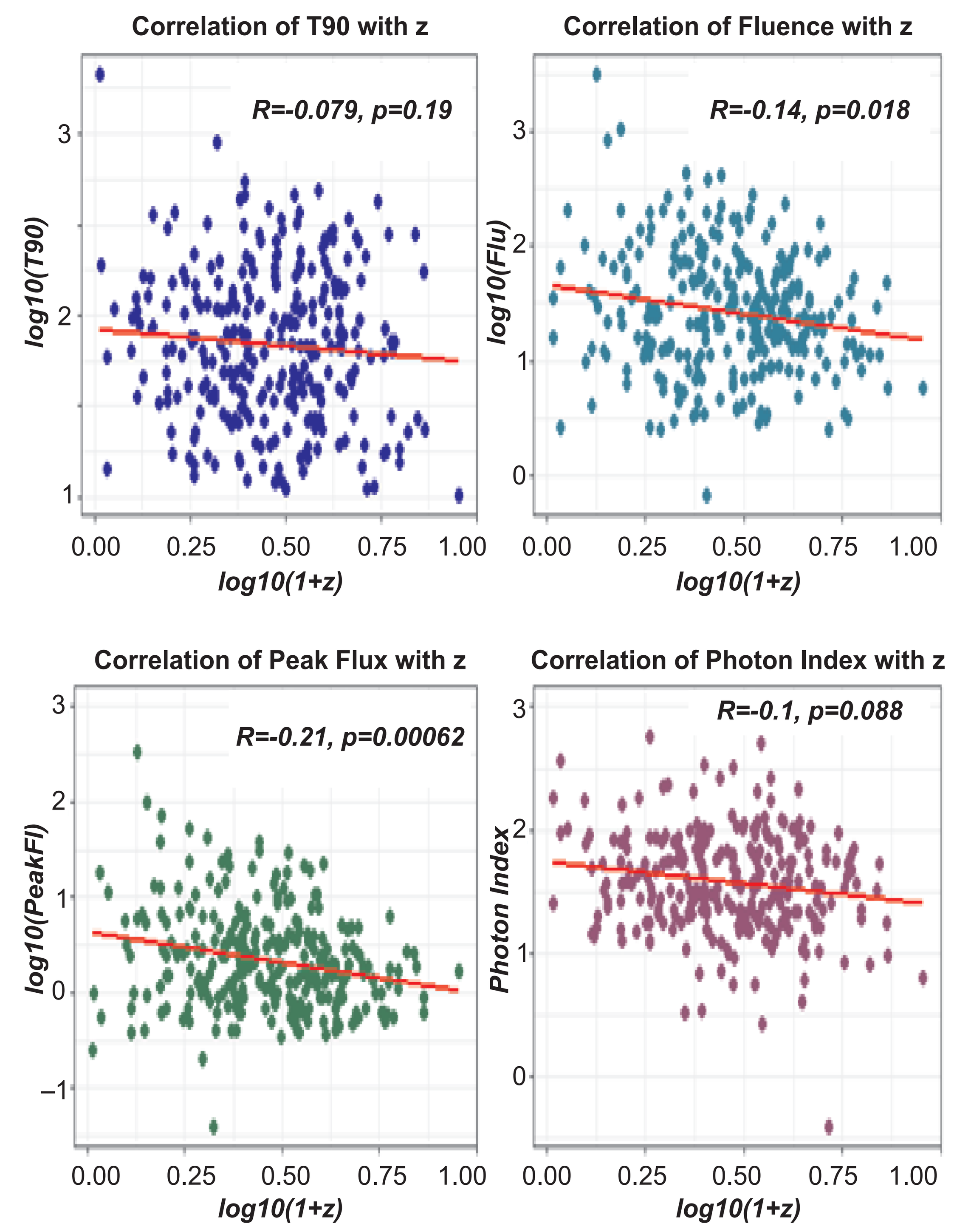

Fig. 2: Correlations of the observed quantities with the redshift. Note the low level of correlations of fluence and peak flux compared to what would be expected from the value of z. This is partly due to the fact that the figure is truncated by the detection limit and because most of the standard deviation is intrinsic.

Simulating z distribution

At $z = 20$ the Lyman break (912 Å) is shifted to 1.92 µm, which is just out of the THESEUS IRT sensitivity range (1.8 µm). Therefore we selected $Z_{max} = 20$ for our simulation. In the following we are using a simple model assuming a homogeneous GRB rate in the co-moving volume. In a ΛCDM flat cosmological model we computed numerically an *r(z)–r* co-moving distance – redshift relationship. Fitting this relationship using the *smooth.spline()* and *predict()* procedures in the *R* statistical package obtained a *z(r)* inverted relationship of *r(z)*. Using the assumed homogeneous distribution of GRBs in the co-moving volume, we determined the r co-moving distance of GRBs based on the relationship $r = (3/4\pi V)^{0.333}$, z from the $z(r)$ and $r_l = (1+z)r$ luminosity distance. Assuming a lognormal distribution for the the intrinsic value of the GRB fluence (see Balázs et al., 2003) we got a simulated value for the fluence. Since we neglected the *K*-correction, our approach is only a rough order of magnitude estimation of the true value of z frequency distribution at high redshifts.

Summary and conclusions

Assuming a homogeneous GRB rate in the co-moving volume we simulated the probability density of detecting GRBs in the $z < 20$ range. The used $z_{max} = 20$ limit of our simulation corresponds to shifting the Lyman break to the sensitivity limit of THESEUS IRT. In the simulation, we used our previous result that a significant part of the standard deviation of the observed parameters (duration, fluence, peak flux) of the GRBs are intrinsic. Due to its higher sensitivity the THESEUS experiment will detect about two times more GRBs of $z < 8$ as did Swift in the same observational time. Furthermore, for the THESEUS experiment, 25% of the detected GRBs could be in the $z > 8$ range.

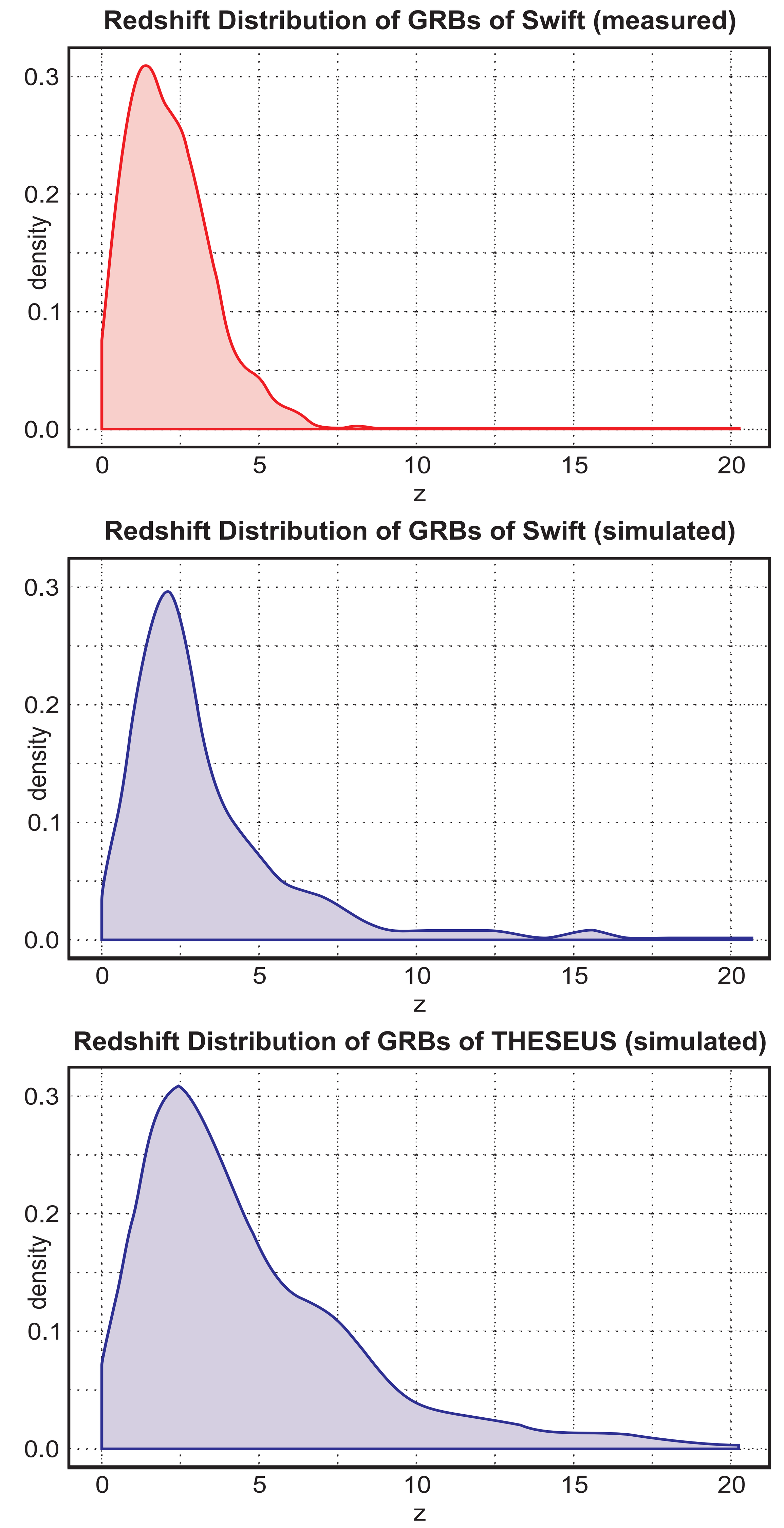

Fig. 3: Comparison of GRBs' density distributions. Top: Swift (measured), middle: Swift (simulated), and bottom: THESEUS (simulated). Note the remarkable increase of detection probability of THESEUS in the $z > 8$ range due to its about an order of magnitude higher sensitivity compared to Swift.

References

Amati, L.; O'Brien, P.; Götz, D., et al., 2018, AdSpR, 62, 191,The THESEUS space mission concept: science case, design and expected performances

Balázs, L. G.; Bagoly, Z.; Horváth, I. et al., 2003, A&A, 401..129, On the difference between the short and long gamma-ray bursts

Carroll, Sean M.; Press, William H.; Turner, Edwin L. , 1992, ARA&A, 30, 499, The cosmological constant

Swift GRB table (https://swift.gsfc.nasa.gov/archive/grb_table/)

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