The Swift Gamma-Ray Burst redshift distribution: rate evolution or selection effects?

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On behalf of 6 other authors
Gamma-Ray-Burst redshift distribution as a potential cosmological probe (the ideal World)

selection effects (the real World)

Astrophysical selection effects (dust extinction)

What can the “optically hidden” GRBs tell us about the SFR?
Measuring GRB redshifts

Swift -> XRT location X-ray light curves -> Robotic Telescopes: Transient optical source identified Photometry of early emissions -> Redshift obtained from spectroscopy of the host galaxy or directly from the OA

147 redshifts from OA used in this study + TOUGH subsample

Use the unbiased distribution to probe the SFR, host properties...

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From an ideal World to Reality

- About 50% of Swift triggered GRBs do not have an identifiable afterglow.
- Most Swift XRT localizations do not have an identifiable host galaxy: absorption redshifts from the optical afterglow.
- The Bottom line: about 67% of Swift GRBs do not have redshifts.
- The spatial distribution of 67% of GRBs is unknown!

**Key questions:**

- Why are most GRB redshifts missing?
- How is the “true” spatial distribution distorted to the observed one?
- Can the missing population be used to probe high-z star formation rates?
BAT + XRT \rightarrow \text{optical spectroscopy} \rightarrow \text{observed redshift distribution}

Selection function

Instrument sensitivities

GRB LF ?

Selection function

Telescopes sensitivities

OA LF ?

Astrophysical

• Host dust extinction
• Brightness evolution ?

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Known selection effects (~ 20% missing redshifts)

- Different redshift measurement techniques:
  - XRT localisation is required
  - Foreground Galactic extinction
  - Source angular distance from Sun
  - Source declination: geographical bias

Learning curve effect

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Historical attempts at reducing selection effects

- Select only those redshifts that satisfy optical observational criteria listed previously (e.g. TOUGH survey)

- Select only those redshifts triggered by Swift that have a peak flux well above the Swift triggering threshold. **Caution - this introduces another bias.**

- Remove photometric redshifts: the learning curve effect – first redshifts were biased towards relatively nearby bursts.

- Recently: TOUGH III survey – obtained spectroscopic redshifts of “dark” bursts by deep follow-up of XRT positions with the VLT.

- Howell and Coward use a redshift selection that excludes, emission, and most photometric redshifts.

The HC sample has 3 times as many bursts, and is a very similar distribution to that of TOUGH: PKS = 94%. Alternatively the S sample, with a peak flux cut-off of 2.6 phs$^{-1}$, is biased against high-z redshifts.
Dust extinction: Growing evidence that “dark bursts” (25-40)% are often obscured in their host galaxies.

1) Locally
2) From host galaxy line of sight

Decrease in dust content in host galaxies at very high redshifts?

Reason: Deficit of large dusty star forming galaxies at high-z.

Optically obscured GRBs following SFR of dusty galaxies!

Figure 4 from Exploring Dust Extinction at the Edge of Reionization: Tayyaba Zafar et al. 2011 ApJ 735 2 doi:10.1088/0004-637X/735/1/2
Using this model for the fraction of missed GRB OAs from host galaxy dust extinction, we obtain a missing GRB OA fraction of 30-35%, which is comparable to recent estimates based on spectroscopy of GRB host galaxies.

Assuming that GRB rate evolution tracks the SFR, i.e. Reddy & Steidel (2009)
high energy bursts are preferentially seen at large-z.

These bursts are more optically luminous, so that redshift measurement will be more probable.

This could have the affect of “reducing” the optical Malmquist bias at high-z.

This could (partially) explain an excess of high-z bursts not accounted for in current modeling.
Based on SNe dropouts from host dust extinction, redshift desert and Malmquist bias

Success rate of 85% for spectroscopic redshift measurement in the desert.

Optical Malmquist bias with and without a possible correction from the high energy and optical correlation.
Results

GRB redshift distributions for models with and without optical selection effects, and the relative distribution of 147 absorption spectroscopic redshifts.

Top – HC data selection

Bottom – TOUGH data selection

• Correlation between high energy and bright optical bursts will boost the fraction of redshifts measurable at high-z

• Astrophysical selection effects (mainly evolving dust extinction) should be included to make sense of the observed distribution.
Summary

The optimal model assumes significant fraction of GRBs are dust obscured by their hosts and only a few percent missed because of optical faintness at high-z.

Optical selection affects strongly influence the ability to acquire redshifts – in particular
- Malmquist bias
- Host galaxy dust extinction

The correlation between high energy and optical?
- GRB OAs are relatively brighter at high-z so that redshifts are easier to measure.
- This can be at least partially explained by the correlation between high-energy and optical luminosities.

Ironically, the optically missing bursts without redshifts maybe a strong indicator of the star formation rate (of massive stars)!
THE END

Thanks to the Moriond organizers

You are most welcome to visit and collaborate with UWA on a broad range of astronomy related research.
Other redshift dependant selection effects

- **Malmquist Bias:** This is the most fundamental bias that encompasses all peak flux limited detection and is the basis for modeling a selection function for OA/redshift measurement.

- **Redshift desert:** The so-called redshift desert is a region in redshift (1.3 < z < 2.5) where it is difficult to measure absorption and emission spectra. This becomes more significant for faint sources (small signal to noise ratio spectra).

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**L-alpha dropout:** Optical sources at z > 5 are strongly suppressed. NIR follow-up is optimal for GRB afterglows at high-z.
The Bottom figure shows the affect on the HC data after selecting only those z with peak fluxes above 2.6 ph/s.

The plot shows that this selection is compatible with Salvaterra et al. (2012), but not with the optical based selection of Hjorthet al. (2012) –TOUGH.
The redshift distribution of 147 Swift GRBs (up Aug 2012) acquired by absorption spectroscopy of the optical afterglow (normalized bars), but including six $z > 6$ NIR spectroscopic and photometric redshifts, along with a number density curve.