Luminosity function of long Gamma Ray Bursts

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GRBs: Prompt to Afterglow, NCRA (Pune)

The 'Luminosity function'

$$N = N(L_1, L_2; z_1, z_2) \equiv T\,\Delta\Omega \int_{z_1}^{z_2} \dot{R}\,(z)\,dV \int_{L_1}^{L_2} \Phi_z\,(L)\,dL\,, \tag{1}$$

$\Phi_z(L) \equiv$ "Luminosity function (LF)."

Fundamental quantity independent of the GRB-detector.

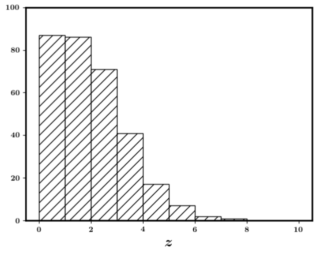
Also studied for a variety of other objects.

$$\dot{R}\,(z) = f_B\,C\,\dot{\rho_\star}(z)\,. \tag{2}$$

Q. Is $f_B\,C = f_B\,C\,(z)$ as well?

Limitations: I

- $L = L(z)$.
- Optical follow-ups and/or identification of host galaxy necessary.
- BATSE provided redshifts ~ 20 GRBs out of 2704.
- *Swift*-BAT provides redshifts for $\frac{1}{3}^{\mathrm{rd}}$ of the detected GRBs, ~ 300 GRBs till date.



Limitations: II

- Definition of L itself not clear (*variability*, *beaming*).
- To measure L, we also need the spectrum:

$$L = P.4\pi d_L(z)^2 \times k(z; \text{spectrum}), \tag{3}$$

$$k(z) = \frac{\int_{1\,\text{keV}}^{10^4\,\text{keV}} E.S(E)dE}{\int_{(1+z)E_{min}}^{(1+z)E_{max}} E.S(E)dE} \tag{4}$$

- GRB spectra usually described by Band function (Band et al., 1993).
- E_p uncertainties due to coverage of *Swift*-BAT: 15 to 150 keV.

Previous studies: BATSE

- Hand-picked redshift measurement. $\therefore$ other methods used...
- **General conclusion**: $\dot{\rho}_{\star}(z)$ shows significant cosmological evolution.
- Limitation: Suffers from poor understanding of detector-thresholds.

Previous studies: *Swift*

- A lot many authors have studied the LF.
- Complete confusion.
- **General conclusion**: constant & simple power-law models can be ruled out.
- Limitation: Suffers from observational biases; poor statistics.

What about *Fermi* ?

- Large energy coverage of GBM: 8 keV to 30 MeV.
  E_p is measured accurately.
- **2070** GRBs, **1729** have spectral parameters (till 2017-05-14).
- Why don't we use this database?
  No z.

Yonetoku correlation

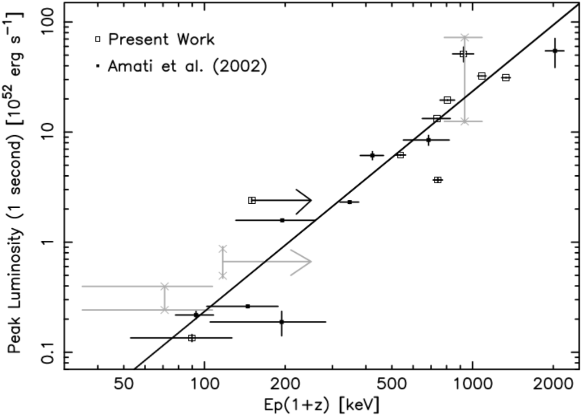


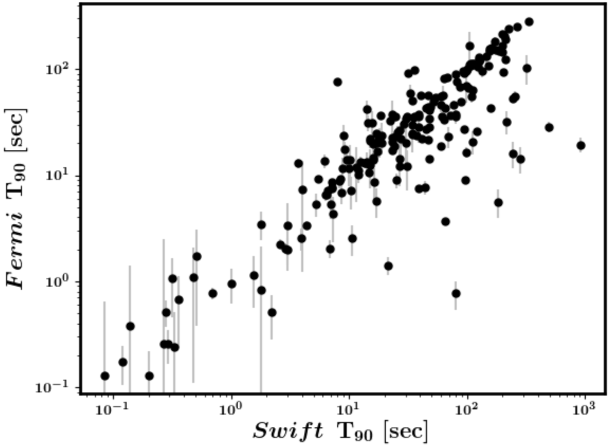
Figure : Yonetoku et al., 2004

Club *Fermi* and *Swift* databases

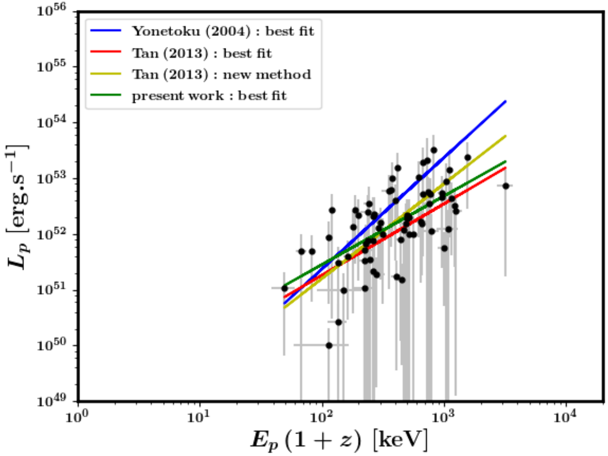
type	redshift measured	number	modeled as
both *Fermi* and *Swift*	yes	66	*Fermi*
only *Fermi*, or both	no	1278	
only *Swift*	no	499	*Swift*
only *Swift*	yes	224	

Table : The type of *Fermi* and *Swift* long GRBs used for modeling, and how they are referred. The total number is 2067. **No public database available** : clarification credits – Eric Burns.

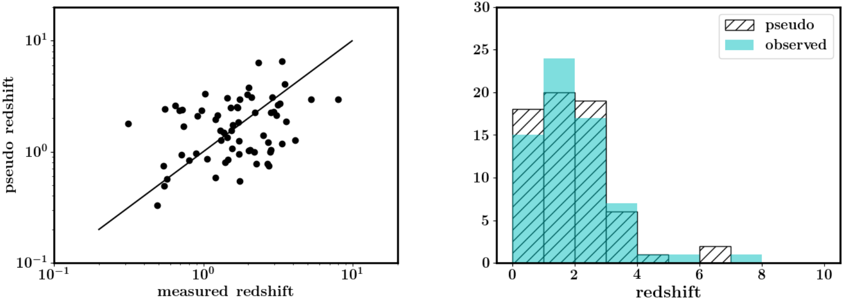
Fermi & *Swift* T_{90}s



Testing the Yonetoku correlation with ‘known’ GRBs

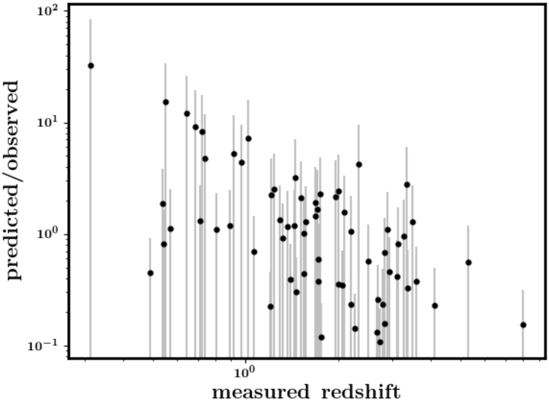


Redshift comparison



Systematics

Q. Is there any systematic effect that can be modeled away?
A. None. **This method does not allow GRBs to be used as standard candles**. However...



Swift

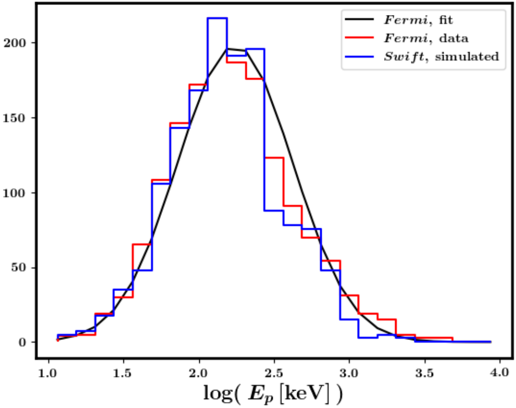
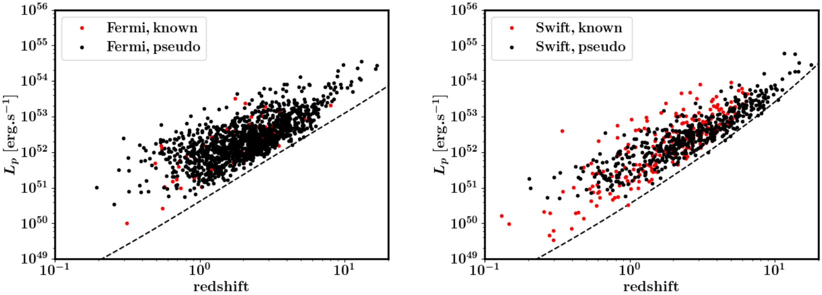


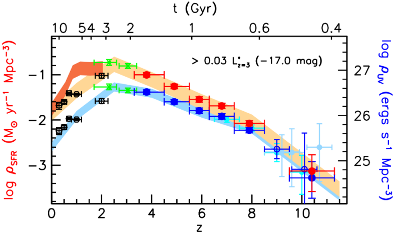
Figure : $< E_p >= 181.3$ keV, $< \alpha >= -0.566$, $< \beta >= -2.823$.

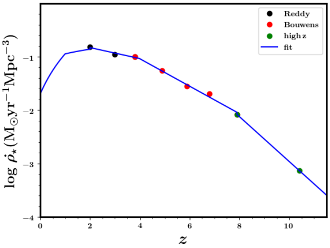
L vs z



$$N = T\,\Delta\Omega \int_{z_1}^{z_2} \dot{R}(z)\, dV \int_{max[L_1,\, \mathbf{L_c(z)}]}^{L_2} \Phi(L)\, dL\,. \quad (5)$$

Cosmic Star Formation Rate: Bouwens et al., 2015





Compiled data and fits from various papers referenced within.

Model : binned

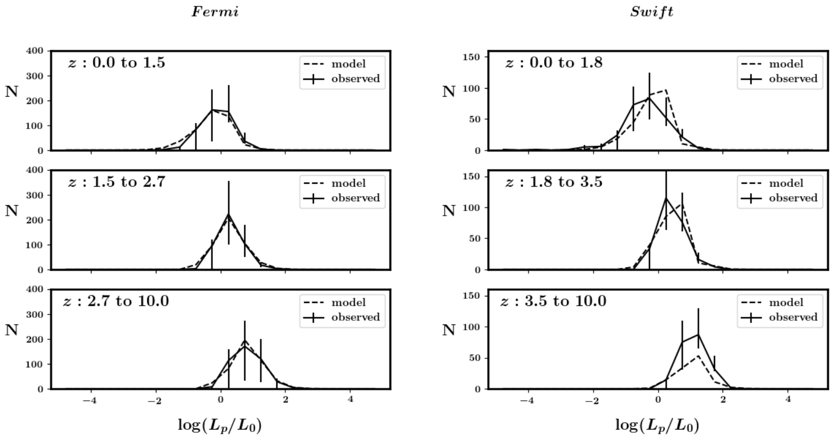


Figure : $L_b \propto (1+z)^{\delta}, \quad f_B C(z) \propto (1+z)^{\epsilon}$.

Other numerical details in D. Paul (2017), submitted to MNRAS.

Model : total

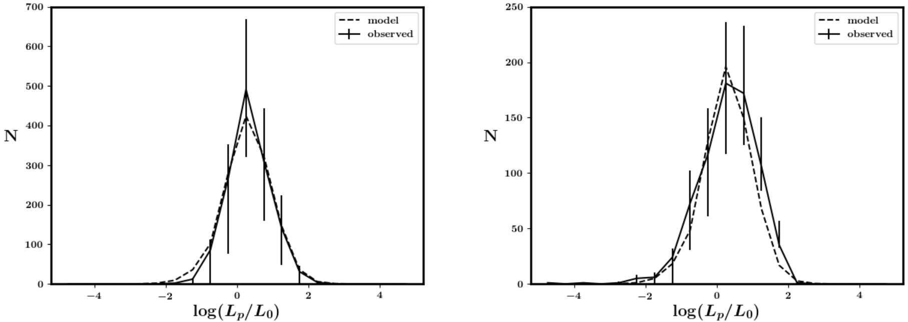


Figure : $\chi^2_{red,Fermi} = 0.362$, $\chi^2_{red,Swift} = 0.364$.

Model : comparison : I

parameter	present work	AR+'17	Tan+'13
ν_1	0.65	0.69 ± 0.09	0.8
ν_2	3.10	1.88 ± 0.25	2.0
$L_{b,0}$	0.30	$0.15^{+0.20}_{-0.09}$	0.12
δ	2.90	2.04 ± 0.45	2.0
ϵ	-0.80	-	-1.0

Table : The best-fit model parameters, as found by extensive search in the 5-dimensional space. The convergence of the parameters are tested thoroughly.

Model : comparison : II

$f_B C(0)$ is not known a priori – hence calculated via the model.

- We know: for *Fermi*, $T \sim 8.5$ yr; for *Swift*, $T \sim 12$ yr.
- Assume $\frac{\Delta\Omega}{4\pi} \sim \frac{1}{3}$ for *Fermi*; $\frac{1}{10}$ for *Swift*.
- Retrieve ratios of the observed and modeled, to get

$$f_B C(0) = \begin{cases} 7.498 \times 10^{-8}\,\mathrm{M}_{\odot}^{-1}, & \textit{Fermi} \\ 8.200 \times 10^{-8}\,\mathrm{M}_{\odot}^{-1}, & \textit{Swift}. \end{cases} \quad (6)$$

Self-consistent, and of the same orders as quoted by Tan et al. (2013).

A template for CZTI

Sensitivity of CZTI $\sim 0.1\times$ *Swift*-BAT sensitivity (GRB160417A)
$\sim$ *Fermi*-GBM sensitivity.
GBM detection-rate $\sim 3\times$ BAT detection-rate.
Assumption: CZTI detection-rate $\gtrsim 1.0$ BAT detection-rate.

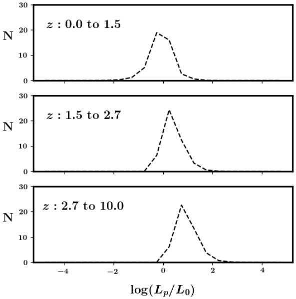


Figure : CZTI combines **spectral measurements** with **localization capabilities**.

Conclusions

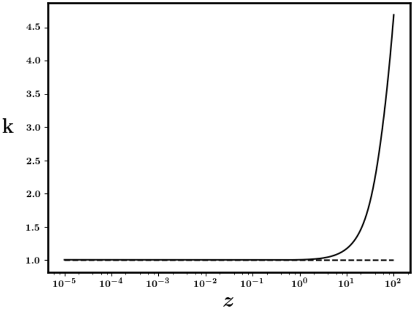
- Yonetoku correlation is intrinsically weak: cannot be used to standardized GRBs as candles.
- However, it statistically predicts pseudo redshifts reasonably.
- There is at least one model that simultaneously fits a large number of *Fermi* and *Swift* bursts reasonably.

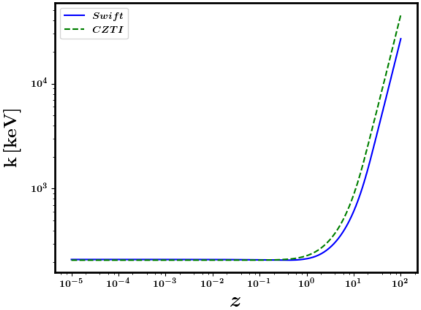
Limitations & Outlook

1. Empirical
   - To understand the detection thresholds in the respective instruments.
   - Bayesian parameter estimation from simultaneous fits.
2. Theoretical
   - To explain the systematics in the Yonetoku correlation.
   - To explain the model from a physical perspective.

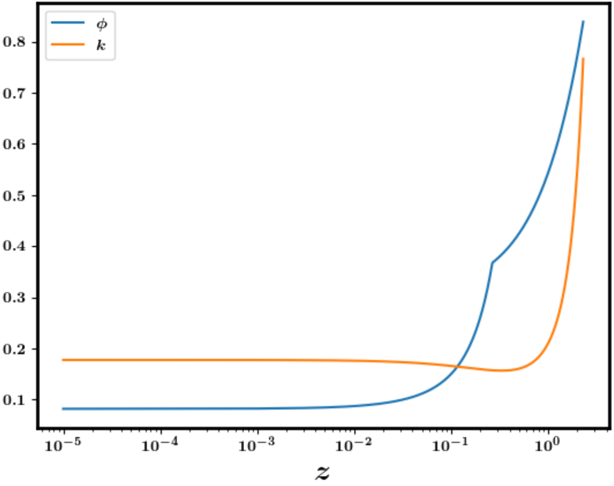
Backup slides

$k(z)$


4.5
4.0
3.5
k
3.0
2.5
2.0
1.5
1.0
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
z


$Swift$
$CZTI$
10^{4}
k [keV]
10^{3}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
z

Detection probabilities



Tan et al., 2013: premise

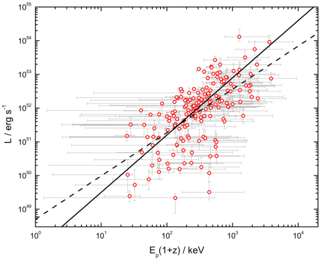


Figure 1. L–E_p relationship of the 172 redshift-known *Swift* GRBs (open circles). The dashed line represents the least-squares fit, while the solid line is obtained by reconciling the distributions of pseudo- and real redshifts.

(A color version of this figure is available in the online journal.)

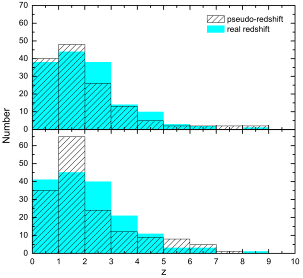


Figure 2. Comparisons between the number distributions of pseudo- and real redshifts of the redshift-known GRBs. The top panel shows the case where two distributions are closest to each other, while the bottom panel is obtained with the least-squares fit to the L–E_p relationship.

(A color version of this figure is available in the online journal.)

- Butler et al. (2007) catalog is used. Huge errors.
- *Sub-sample* the distribution but do not show the discrepancy!
- Parameters based on comparing distributions rather than understanding the issue.

Tan et al., 2013: Conclusions, Limitations

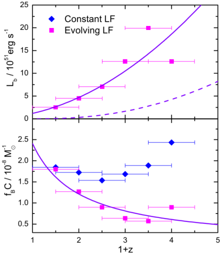


Figure 5. Redshift dependences of parameters L_b and $f_B C$ in both constant and evolving LF cases, where the horizon error bars represent the width of the redshift intervals. The errors of the parameter values could be very large but are not displayed due to the difficulty of the error estimation. In the evolving LF case, two empirical power-law fittings are provided by the solid lines. The adopted lower cutoff luminosity is presented by the dashed line in the top panel for a comparison.

(A color version of this figure is available in the online journal.)

- $\nu_1 = 0.8$, $\nu_2 = 2.0$.
- Errors not considered throughout the study.
- Unclear energy-flux is calculated, consistency of k not demonstrated– don't respond to email.

References

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Butler, N. R., Kocevski, D., Bloom, J. S., & Curtis, J. L. 2007, ApJ, 671, 656

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