Overviews of GRB observed by MAXI

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MAXI's observations for GRB

- Observation period of MAXI: 8/15/2009 –
  - MAXI detected 157 GRBs
    - simultaneously with MAXI and other detectors: 82 events
    - only MAXI: 75 events

- MAXI's observational properties
  - MAXI can observe about 80% of the entire X-ray sky as it moves in the orbit of ISS every 92 minutes.
  - MAXI has the soft X-ray energy range in 2–20 keV.

unique!

→MAXI observes GRBs in the soft X-ray range (2–20 keV) using unique observing methods not employed by other detectors.

→ MAXI is one of the most useful detectors for studying GRBs, which may occur at any time and any location.

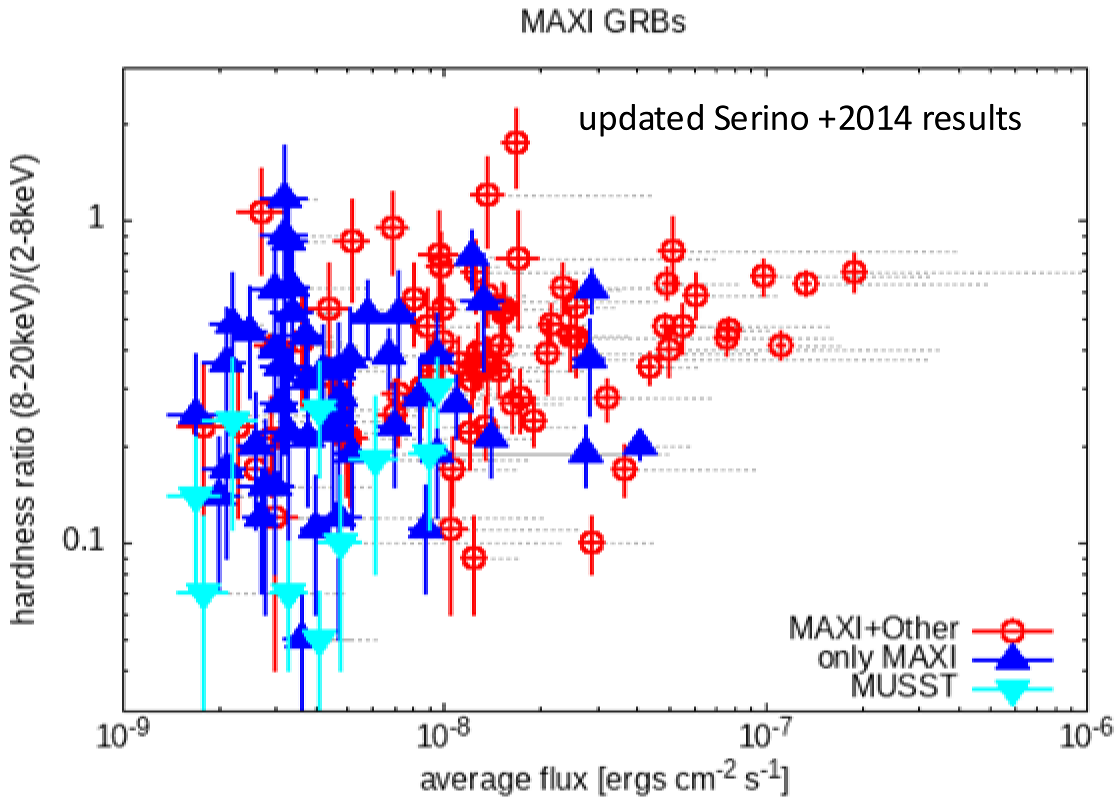
Motivations

Previous reports indicated that MAXI GRBs are low flux and soft spectra. (Serino +2014)
In particular, only MAXI events distribute to low flux and soft spectra.

These events would be unique GRBs that are not detected by other detectors.

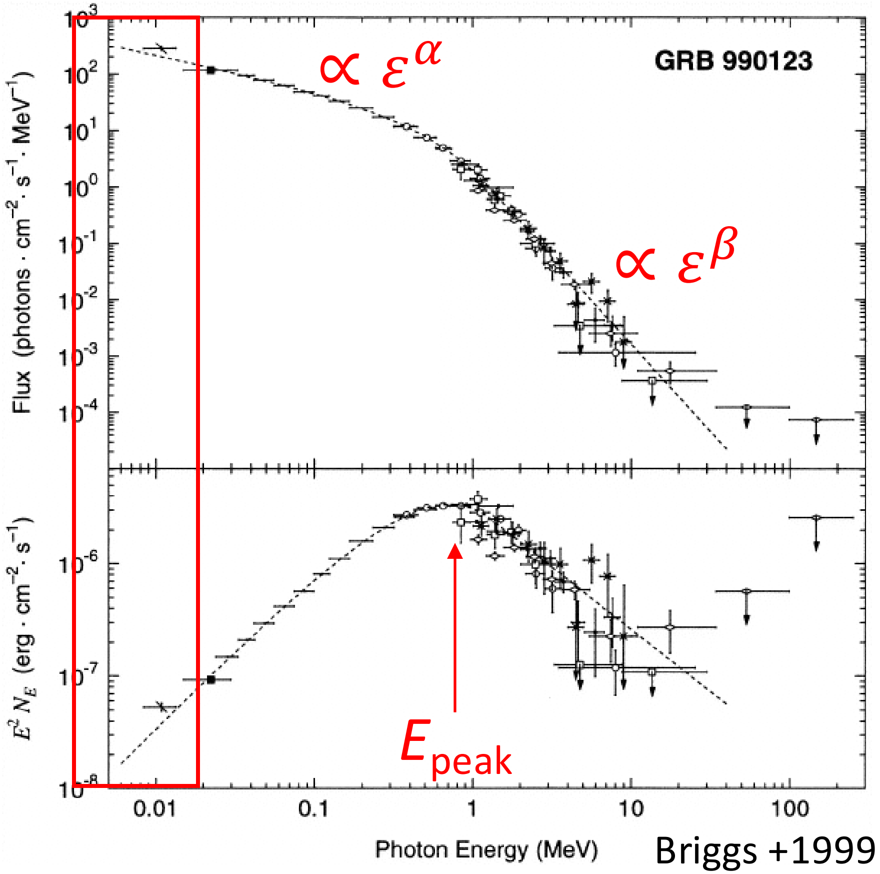
Previous studies performed the hardness ration analysis.
It cannot directly compare to the results by other detectors.

→We performed the spectral analysis.



http://maxi.riken.jp/grbs/

Spectral analysis



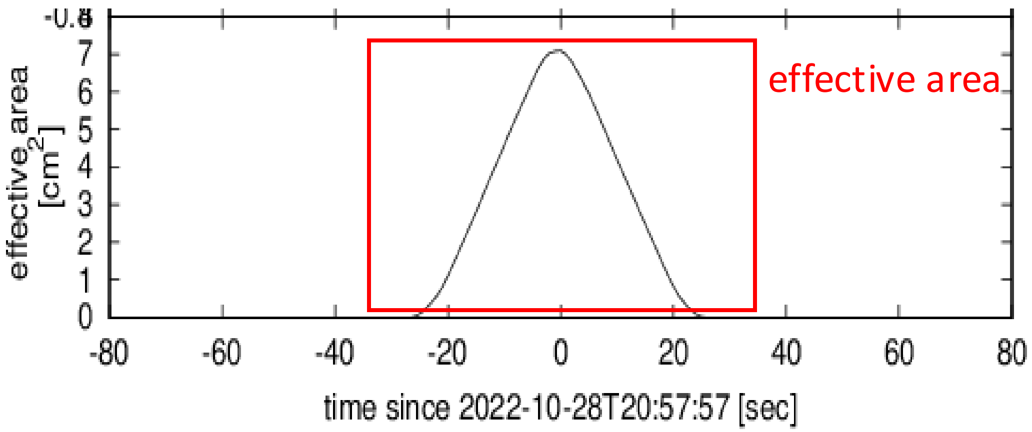
Briggs +1999

Energy range of MAXI

Technique of spectral analysis for MAXI GRBs

- You must take the changing effective area into account when making light curves and spectra, due to its scanning observation
- MAXI/GSC has sensitivity with energy range in the 2 – 20 keV

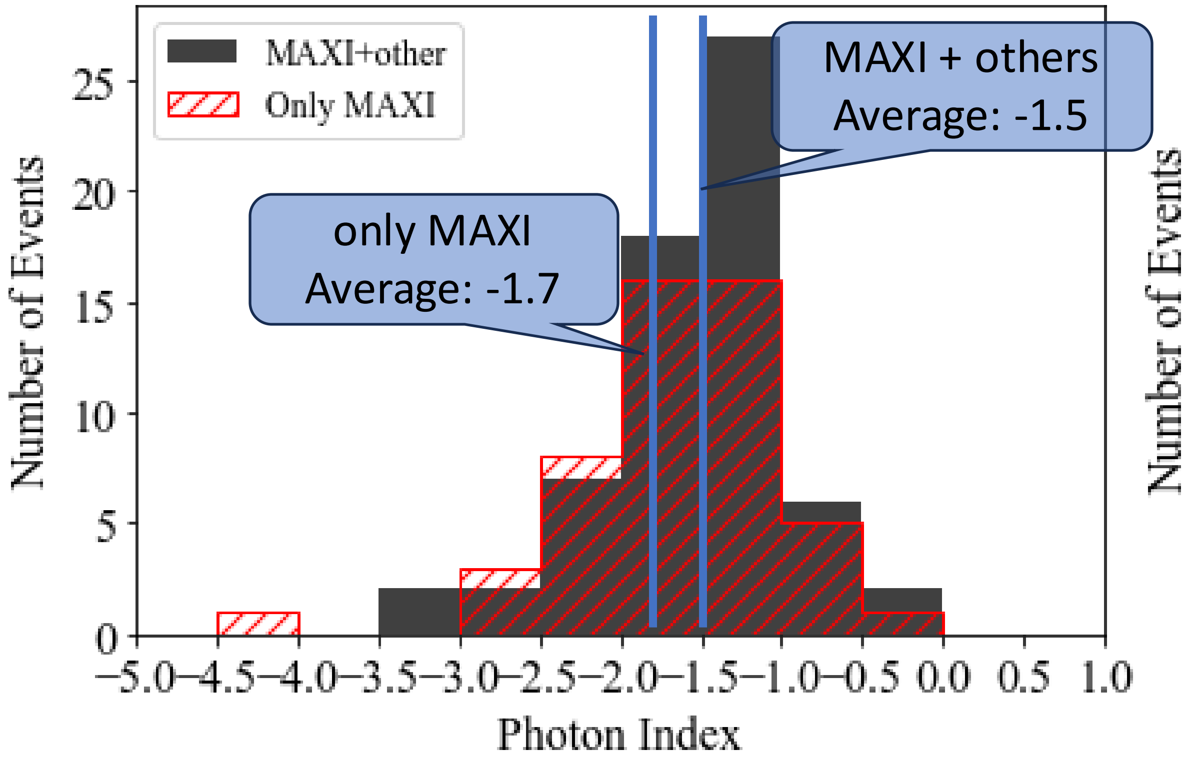
  →We fitted the single power law model

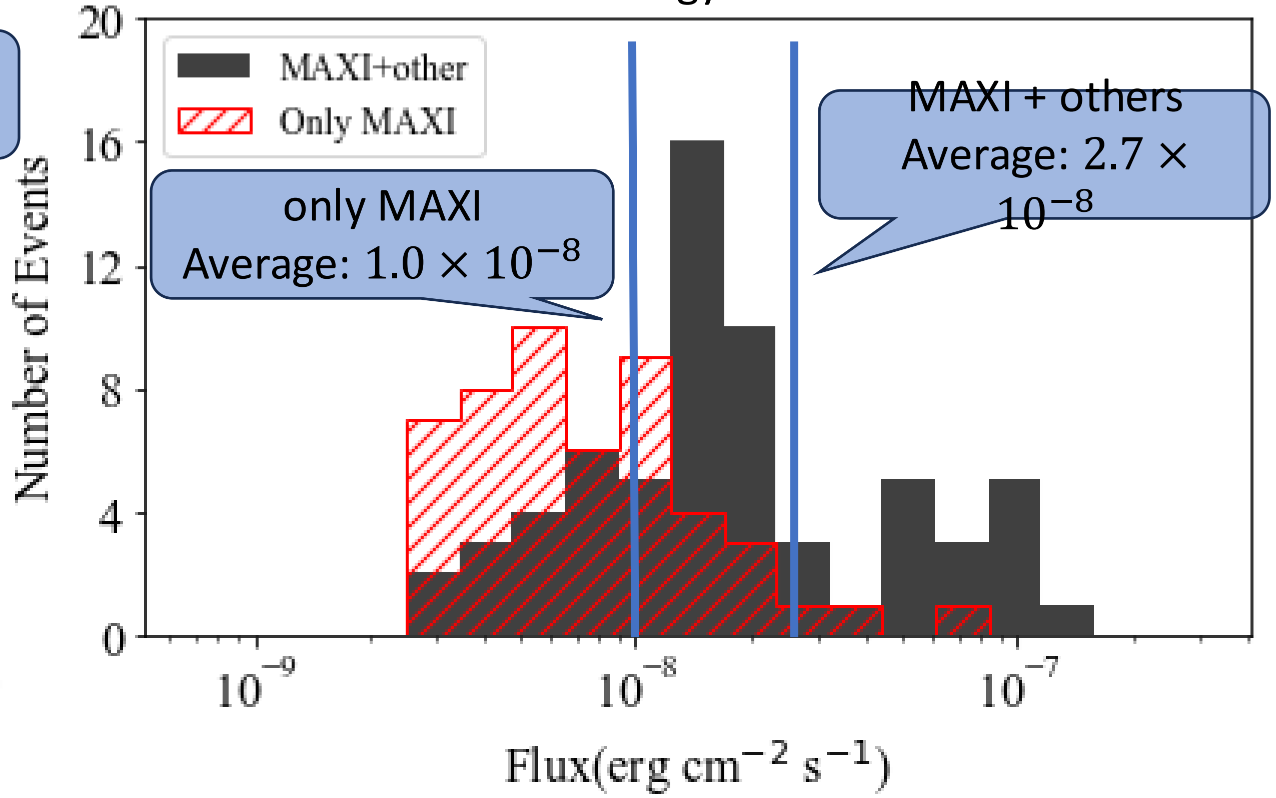


Histogram of photon index and flux

number of events: 114 events
- MAXI + other detectors: 64 events
- Only MAXI: 50 events

model: single power law
energy band: 2 – 20 keV





Compared to MAXI + others,
Only MAXI events possibly have the softer spectrum (< -1.7)
and distribute in the lower flux region ($< 10^{-8}$ erg cm^{-2} s^{-1})

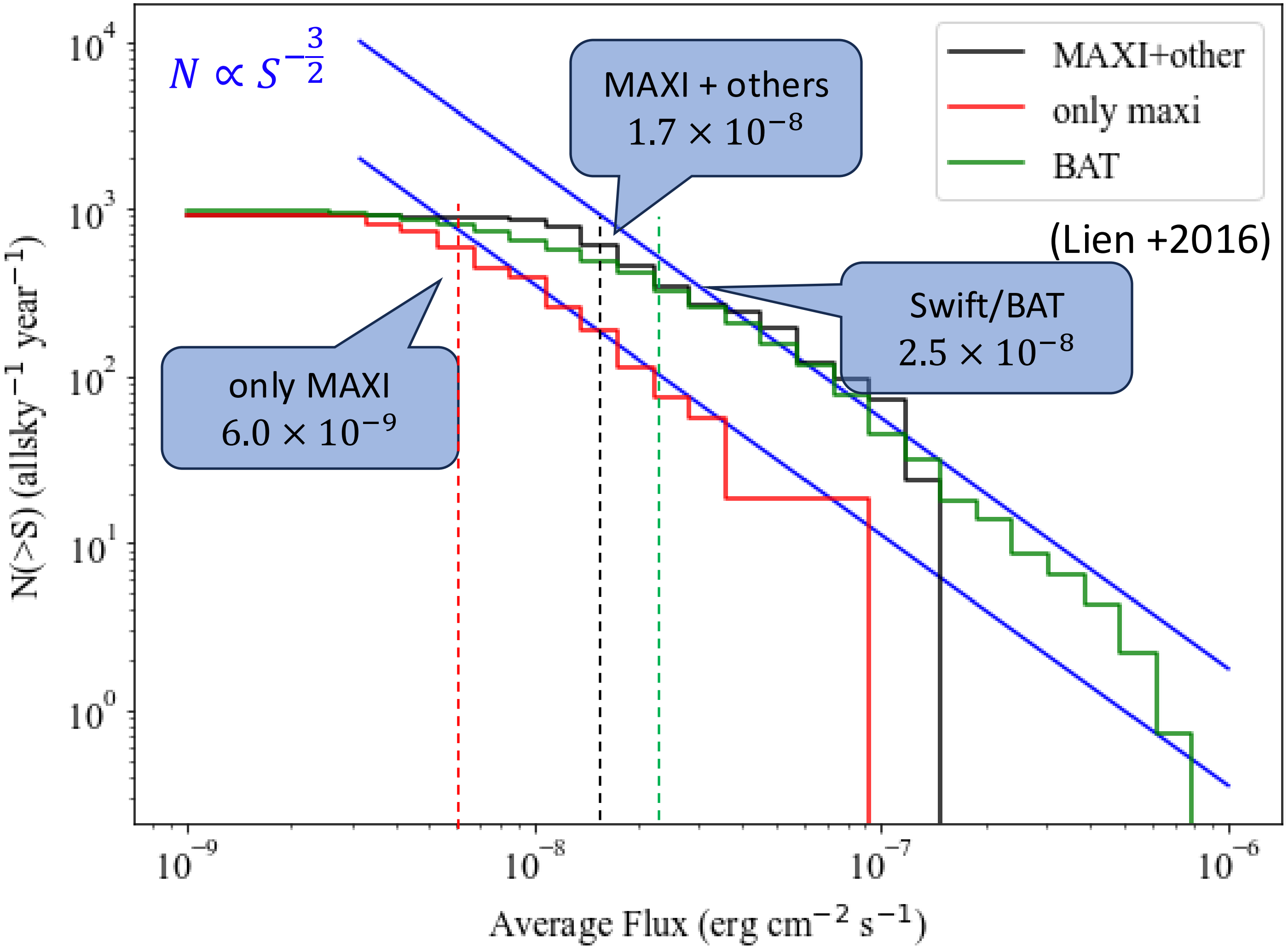
logN–logS distribution

MAXI + others: 1.7×10^{-8} erg cm^{-2} s^{-1}
Swift/BAT: 2.5×10^{-8} erg cm^{-2} s^{-1}

Only MAXI events follow a straight line with slope of -3/2 down to about 6×10^{-9} erg cm^{-2} s^{-1}

only MAXI events may indicate nearby and Low-Luminosity GRBs (LLGRBs) that are not influenced by cosmological effects

MAXI is capable of detecting LLGRBs



From here,

Spectral analysis

↓

Estimation of Luminosity Function for GRB

Luminosity Function

From spectral analysis, MAXI GRBs may be nearby and LLGRBs.

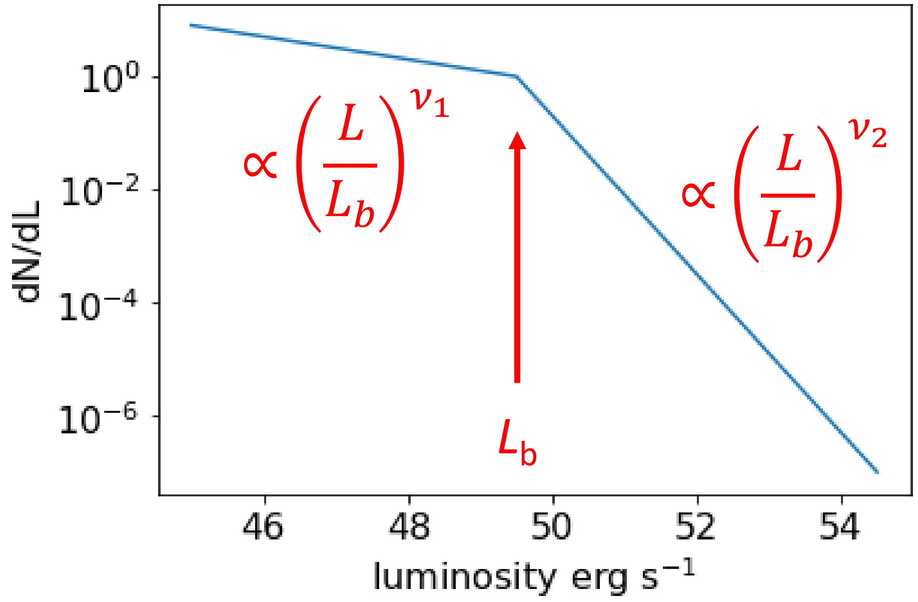
→ We want to know about luminosity distribution for MAXI GRBs

Luminosity Function (LF)

- defined as the number of bursts per unit interval luminosity

$$\frac{dN}{dL} = \begin{cases} \left(\frac{L}{L_b}\right)^{\nu_1} & , L \le L_b \\ \left(\frac{L}{L_b}\right)^{\nu_2} & , L > L_b \end{cases}$$

L_b: luminosity at the break of the power law



Estimating the LF for GRB

- understanding the distribution of GRBs as a function of luminosity and redshift z
- infer the GRB rate R_{GRB} $(\mathrm{Gpc^{-3}yr^{-1}})$

Methods of estimating LF

A LF for GRB is conventionally plotted using observed data with known z
But MAXI has a limited number of GRBs with known z
→It is challenging to estimate LF directly

To deal with this limitation,
we conducted a Monte Carlo (MC) simulation to generate many artificial GRB samples.

(Wanderman & Piran 2010)

$$\frac{dN}{dL} = \begin{cases} \left(\frac{L}{L_b}\right)^{\nu_1}, L \le L_b \\ \left(\frac{L}{L_b}\right)^{\nu_2}, L > L_b \end{cases} \quad \nu_1 = -0.2, \ \nu_2 = -1.4, \ L_b = 10^{49.5}\ \mathrm{erg\ s^{-1}}$$

(Porciani & Madau 2001) $\rho_0 = 1$

$$R_{GRB}(z) = 23\rho_0 \frac{e^{3.4z}}{e^{3.4z}+22.0}\ (\mathrm{Gpc^{-3}yr^{-1}})$$

- Determine the LF form parameters: ν_1, ν_2, L_b
- Assume the R_{GRB}

→

- Generate luminosity and z samples
- Determine the spectrum (Band function: Band +1993)
- Calculate the flux (2 – 20 keV)

→

- Plotted the logN-logS
- Compare simulation samples with observation samples

Creation of luminosity and z samples

Performing the MC simulation, we can create the luminosity and z samples

- ***z* sample**

$$dN = \frac{R_{GRB}(z)}{1+z}\frac{dV}{dz}dz$$ ①

dV/dz: variation of the volume of the universe as a function of the z (Zitouni +2021)

GRB rate of long GRB is proportional to the star formation rate (SFR) ②

- $SFR(z) = A\frac{e^{3.4z}}{e^{3.4z}+22.0}$
- $R_{GRB} = B \times SFR(z)$

A, B: constant factor

$$R_{GRB}(z) = C\frac{e^{3.4z}}{e^{3.4z}+22.0}$$

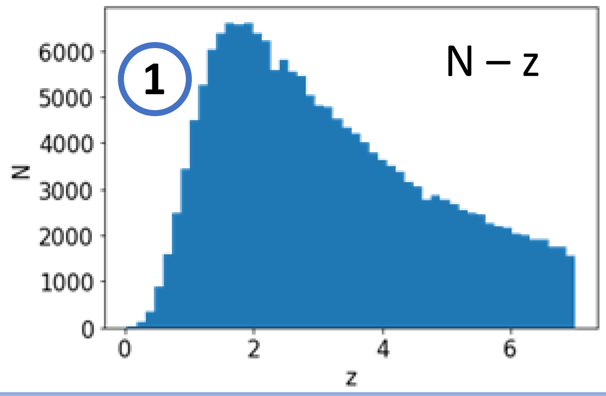
$C = A \times B$ (Porciani & Madau +2001)

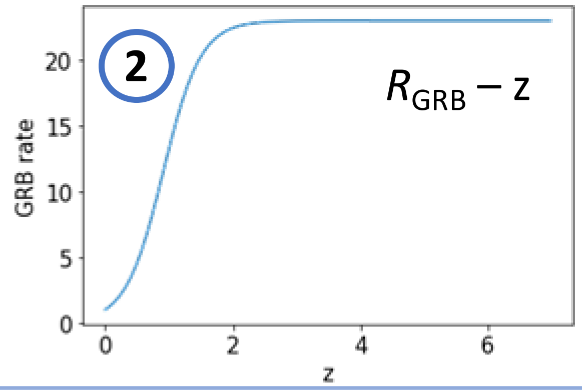
- **Luminosity sample**

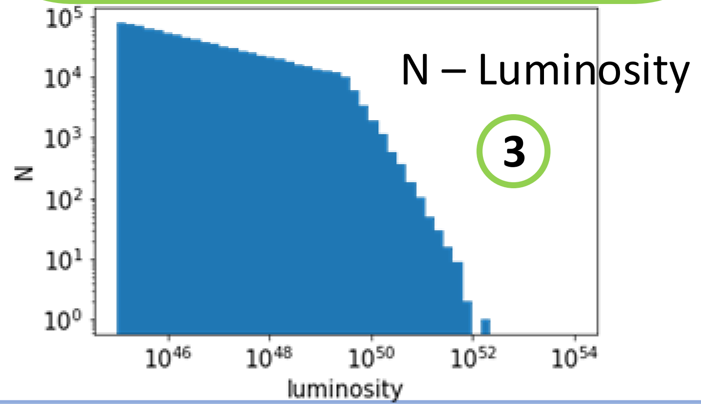
cannot estimate the LF directly
→LF form is need to determine ③

$$\frac{dN}{dL} = \begin{cases} \left(\frac{L}{L_b}\right)^{\nu_1}, L \le L_b \\ \left(\frac{L}{L_b}\right)^{\nu_2}, L > L_b \end{cases}$$

$\nu_1 = -0.2, \nu_2 = -1.4,$
$L_b = 10^{49.5}$ erg s^{-1} (Wanderman & Piran 2010)

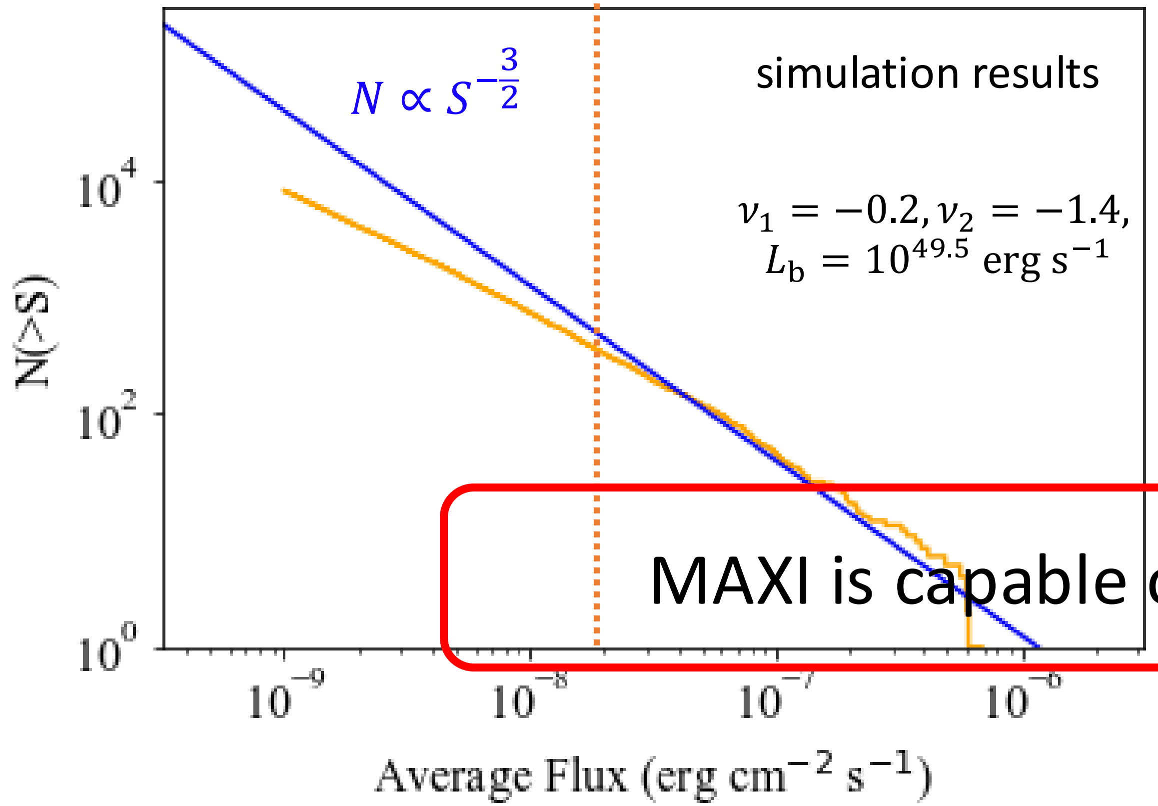


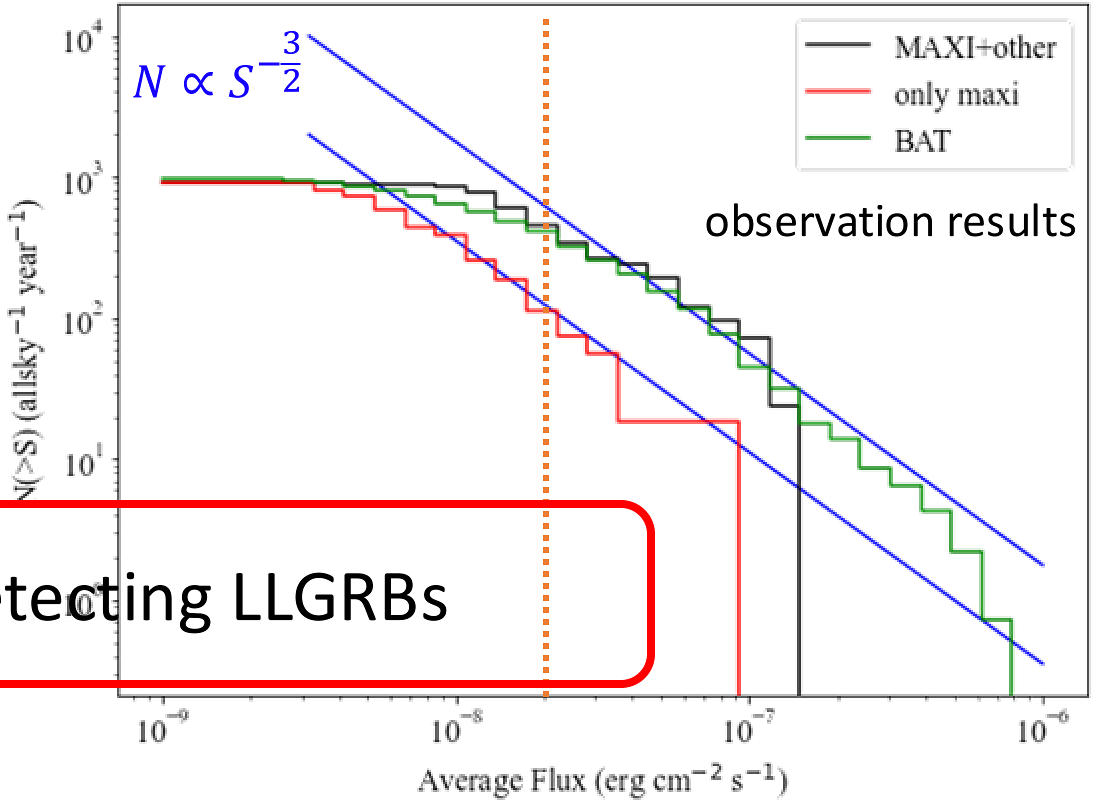




Comparison of simulation results and observation results

Detection limit of MAXI: flux$> 10^{-9}$ erg cm^{-2} s^{-1}
Energy band: 2 – 20 keV





MAXI is capable of detecting LLGRBs

For L_b= $10^{49.5}$ erg s^{-1}, simulation results are consistent with observation results
For $L_b > 10^{49.5}$ erg s^{-1}, they are not consistent

MAXI GRBs would distribute in the low-luminosity region ($L < 10^{49.5}$ erg s^{-1})

Future work

On-orbit Hookup of MAXI and NICER: OHMAN

This project is the collaboration between MAXI and NICER
→NICER can follow-up a GRB ~5 mins after MAXI detects it

https://global.jaxa.jp/press/2022/10/20221017-2_e.html

MAXI/GSC
Energy band: 2 – 20 keV
Effective area: ~10 cm^2 @4 – 10 keV
FoV: $160° \times 1.5° \times 2$

NICER
Energy band: 0.2 – 12 keV
Effective area: ~1700 cm^2 @1.5 keV
FoV: 5 arcmin

OHMAN can perform prompt and follow-up observations in the soft X-ray region, similar to Swift (hard X-ray region)

Future works for GRB

- investigation of MUSST
- observation early afterglow (typical long GRB, LLGRB)

(Serino-san's poster)
MUSST: MAXI Unidentified Short Soft Transient
The afterglow cannot be detected by follow-up observation

Summary

Spectral analysis

- MAXI GRBs distribute lower fluxes ($< 10^{-8}\ \mathrm{erg\ cm^{-2}\ s^{-1}}$) and softer spectra ($< -1.7$)
- From logN–logS distribution, MAXI GRBs may distribute nearby and LLGRB

Luminosity Function

- We performed a MC simulation to generate luminosity and z samples of GRB
- Plotted the logN–logS of simulation samples to compare with observation samples
- For $L_\mathrm{b} = 10^{49.5}\ \mathrm{erg\ s^{-1}}$, simulation results are consistent with observation results

→MAXI GRBs would distribute in the low–luminosity region ($L < 10^{49.5}\ \mathrm{erg\ s^{-1}}$)

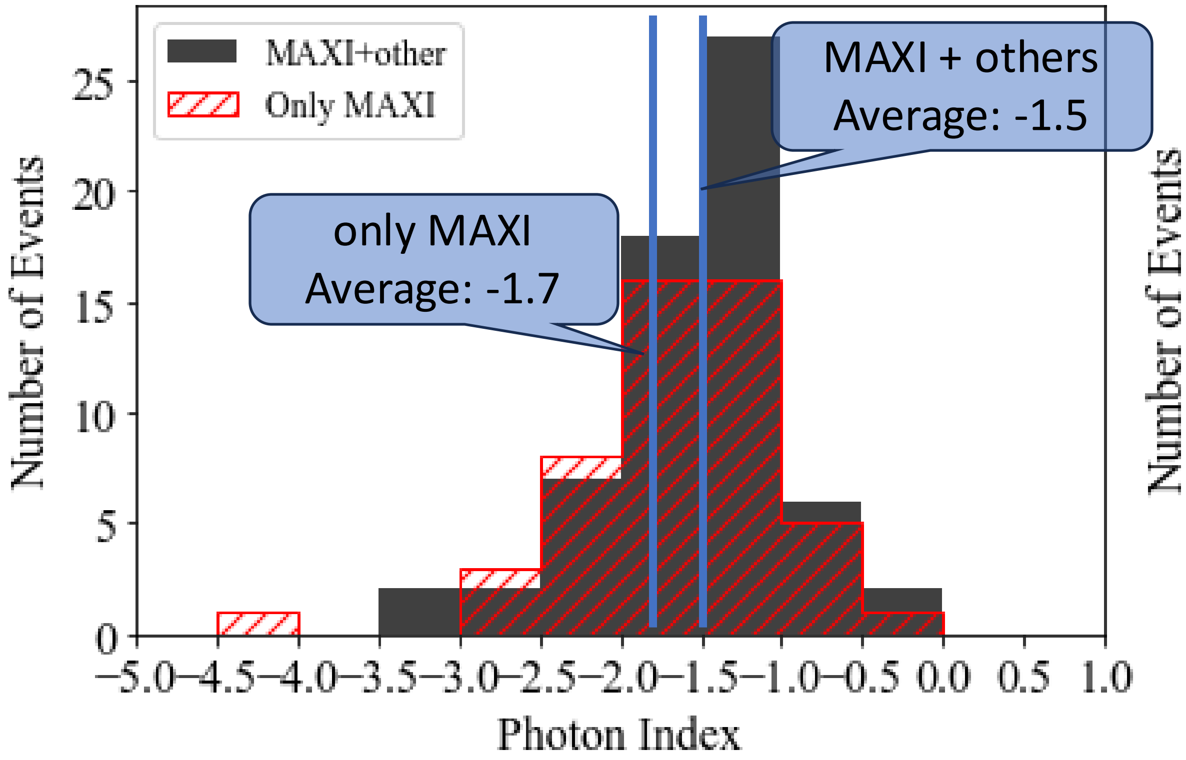
→MAXI is capable of detecting LLGRBs

Histogram of photon index and flux

number of events: 114 events

MAXI + other detectors: 64 events

Only MAXI: 50 events



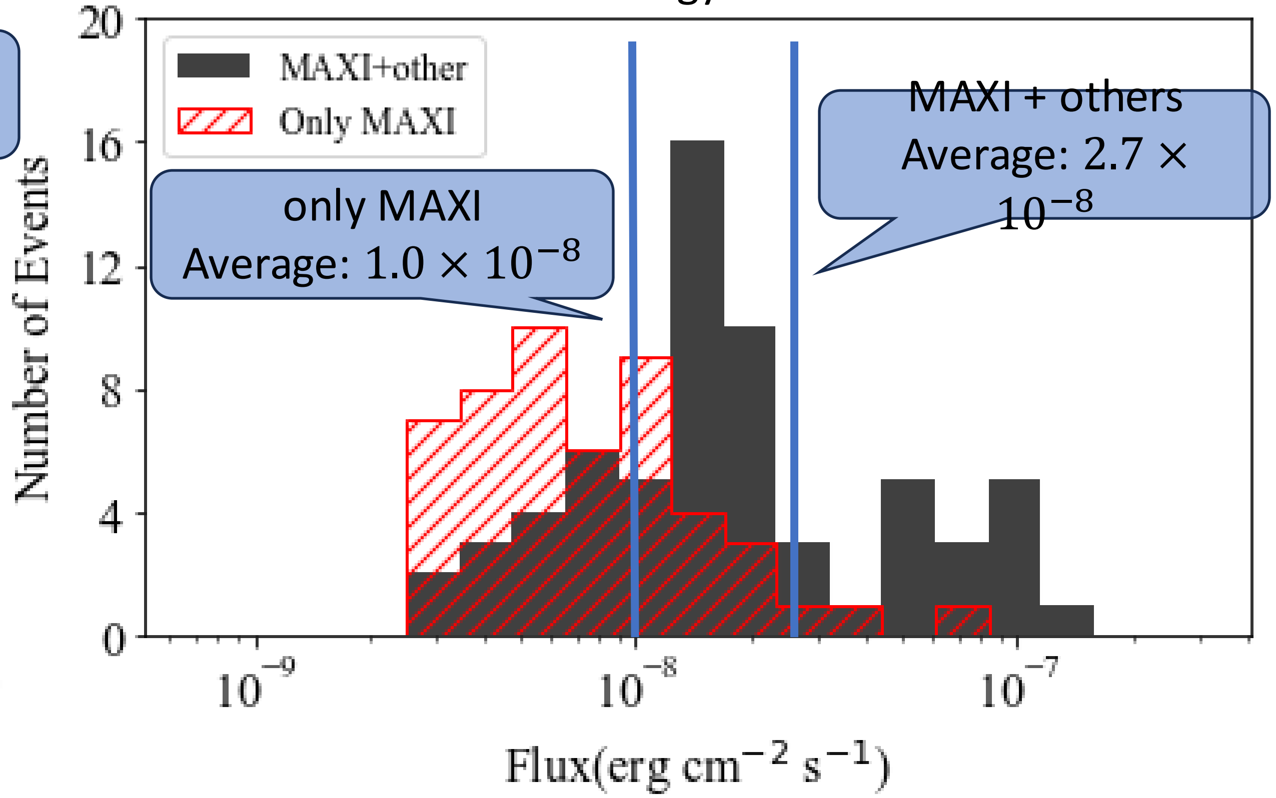
KS test

statistic: 0.161

p-value: 0.405

model: single power law

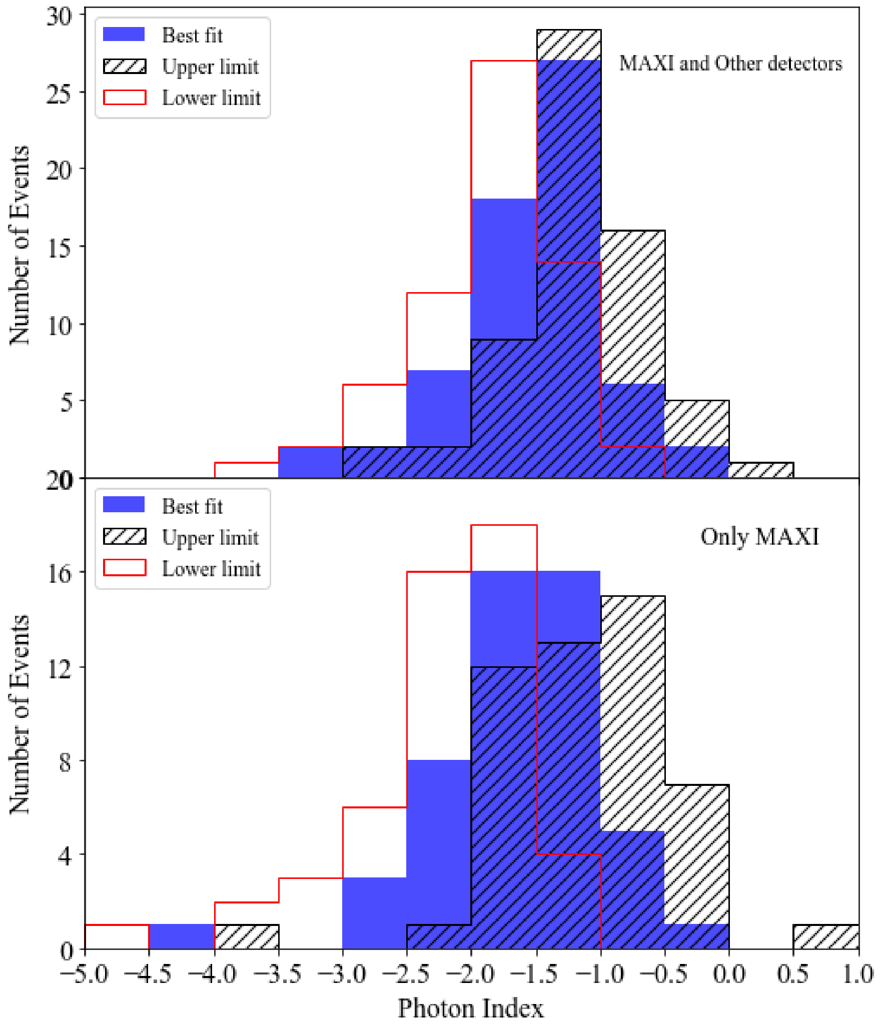
energy band: 2 – 20 keV

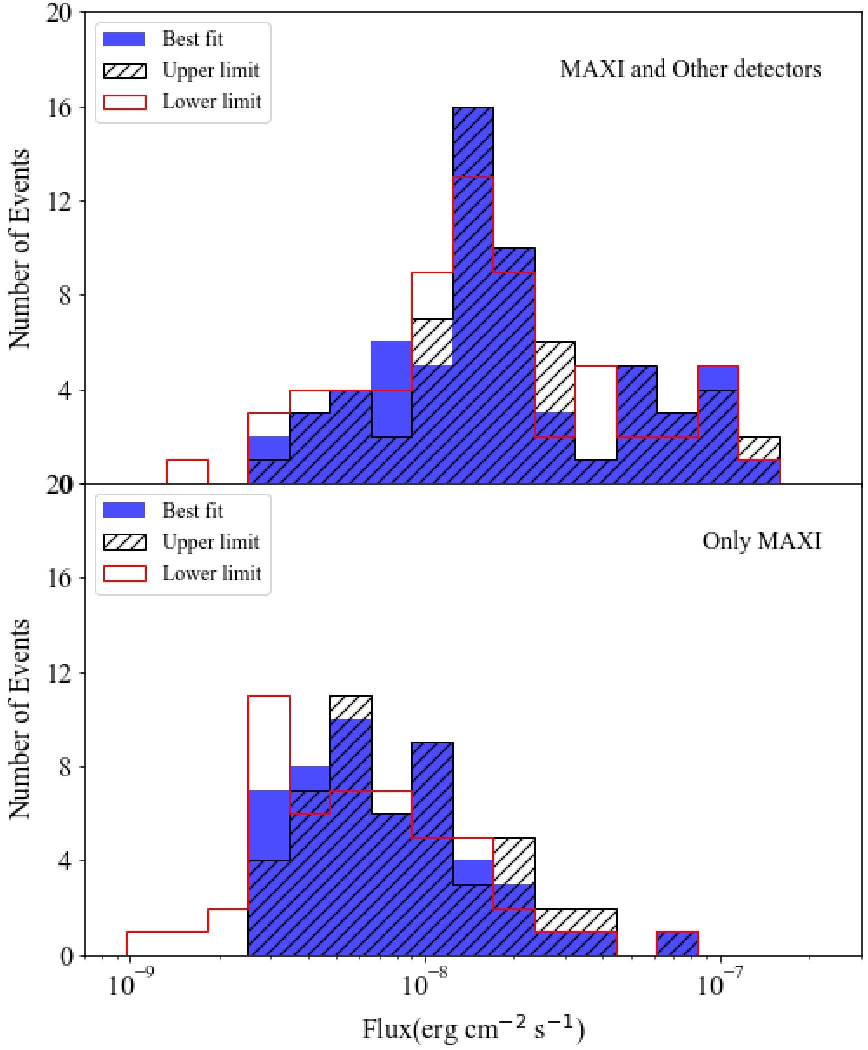


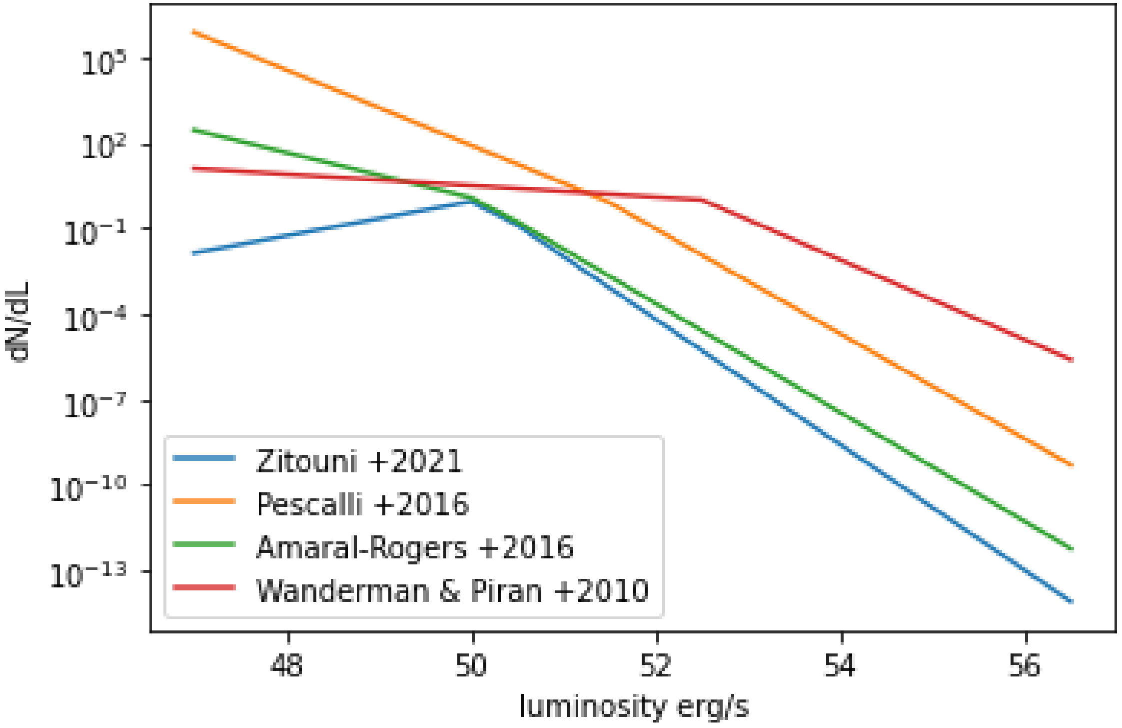
KS test

statistic: 0.503

p-value: 5.2×10^{-7}


Best fit
Upper limit
Lower limit
MAXI and Other detectors
Only MAXI
Number of Events
Photon Index


Best fit
Upper limit
Lower limit
MAXI and Other detectors
Only MAXI
Number of Events
Flux(erg cm^{-2} s^{-1})



	ν_1	ν_2	Log L_b erg s^{-1}
Zitouni +2021	$+0.60^{+0.08}_{-0.08}$	$-2.2^{+0.1}_{-0.2}$	$50.1^{+0.1}_{-0.3}$
Pescalli +2016	$-1.32^{+0.21}_{-0.21}$	$-1.84^{+0.24}_{-0.24}$	$51.45^{+0.15}_{-0.15}$
Yu +2015	$-0.14^{+0.02}_{-0.02}$	$-0.70^{+0.03}_{-0.03}$	51.5
Amaral-Rogers +2016	$-0.79^{+0.04}_{-0.04}$	$-1.91^{-2.04}_{-2.04}$	$52.22^{+0.08}_{-0.23}$
Lan +2019	$-0.36^{+0.16}_{-0.16}$	$-1.28^{+0.09}_{-0.09}$	$52.17^{+0.18}_{-0.14}$
Wanderman & Piran +2010	$-0.20^{+0.2}_{-0.1}$	$-1.4^{+0.3}_{-0.6}$	$52.5^{+0.2}_{-0.2}$

Luminosity evolution

Several author‘s have reported that luminosity is proportional to redshift z

$$L = L_0(1+z)^k$$

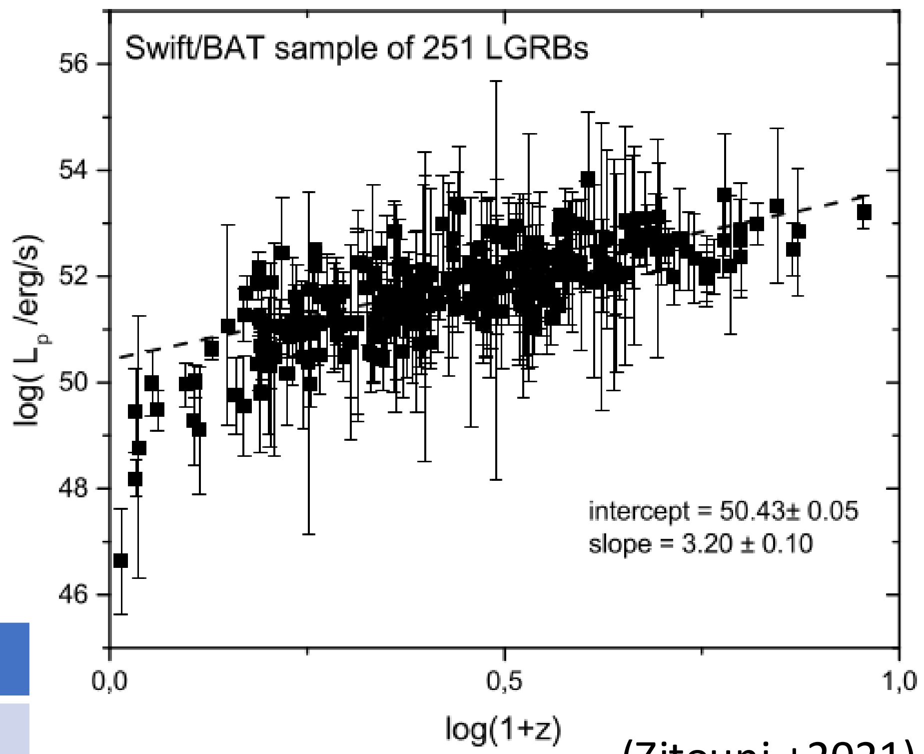
For apply to LF, the function is shown as

$$L_b = L_0(1+z)^k$$

k: slope
L_0: intercept

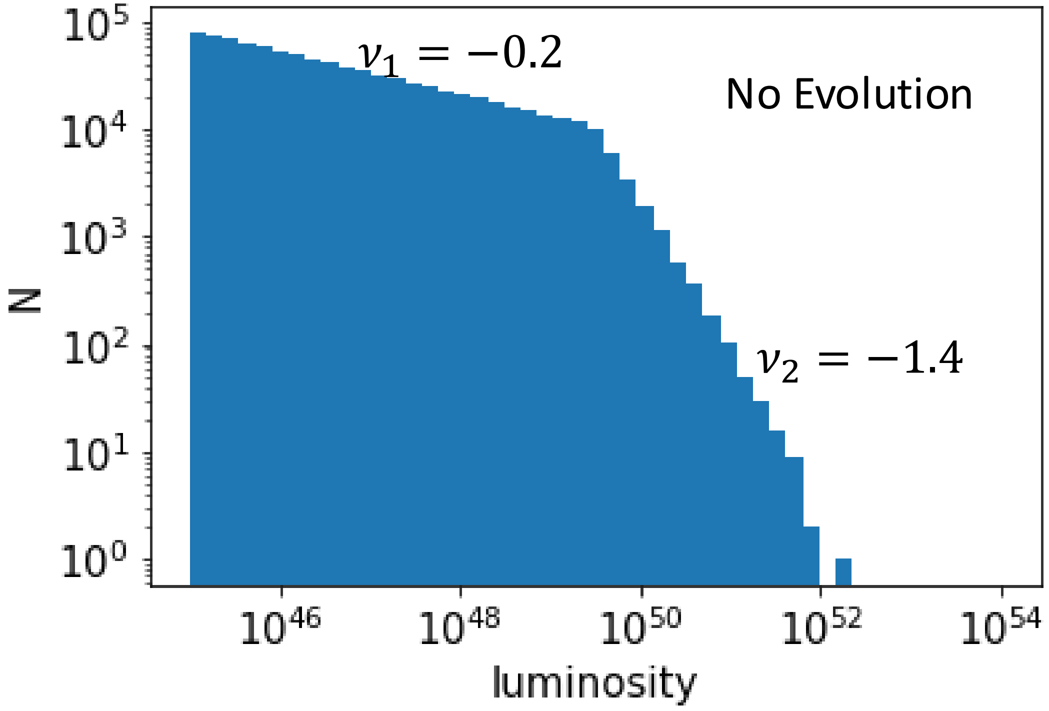
GRBs are distributed with high-luminosity at high z

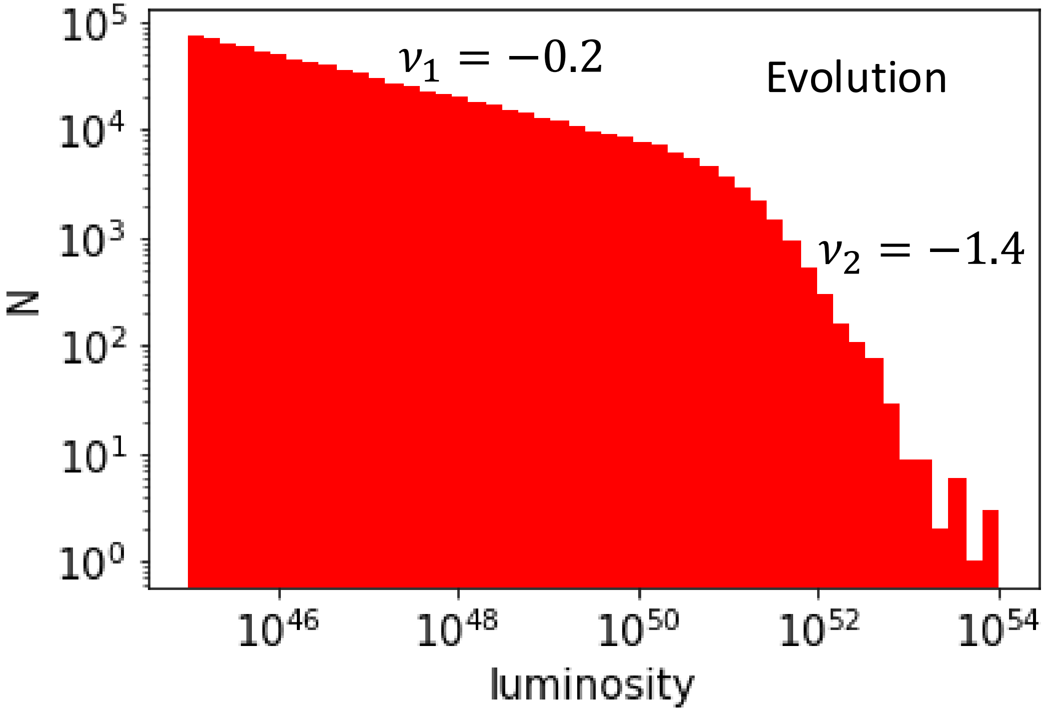
	L_0 erg s^{-1}	k
Zitouni +2021(Swift)	$50.33^{+0.05}_{-0.05}$	$3.40^{+0.10}_{-0.10}$
Zitouni +2021(Fermi)	$50.4^{+0.3}_{-0.3}$	$3.8^{+0.7}_{-0.7}$
Deng +2016	$49.98^{+0.09}_{-0.09}$	$2.95^{+0.19}_{-0.19}$
Pescalli +2016		2.5



(Zitouni +2021)

Luminosity sample





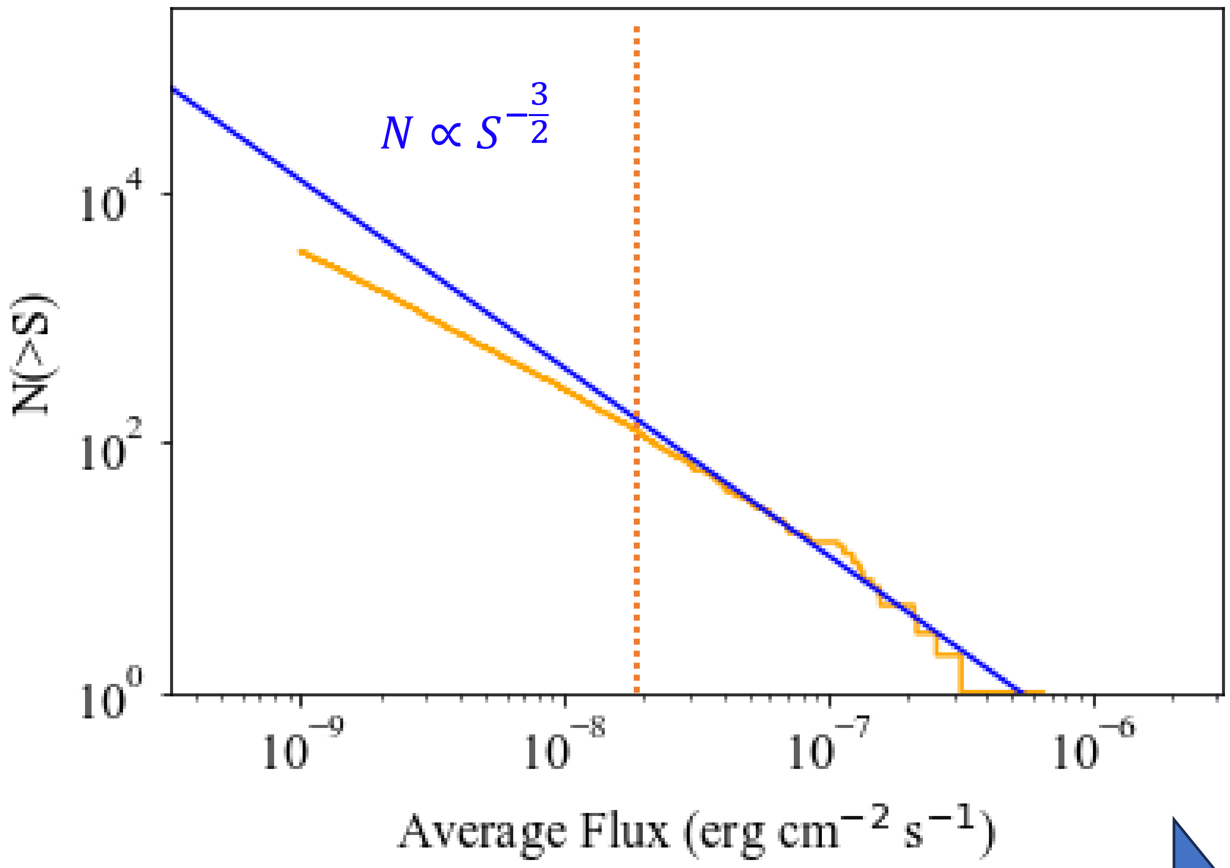
Parameters

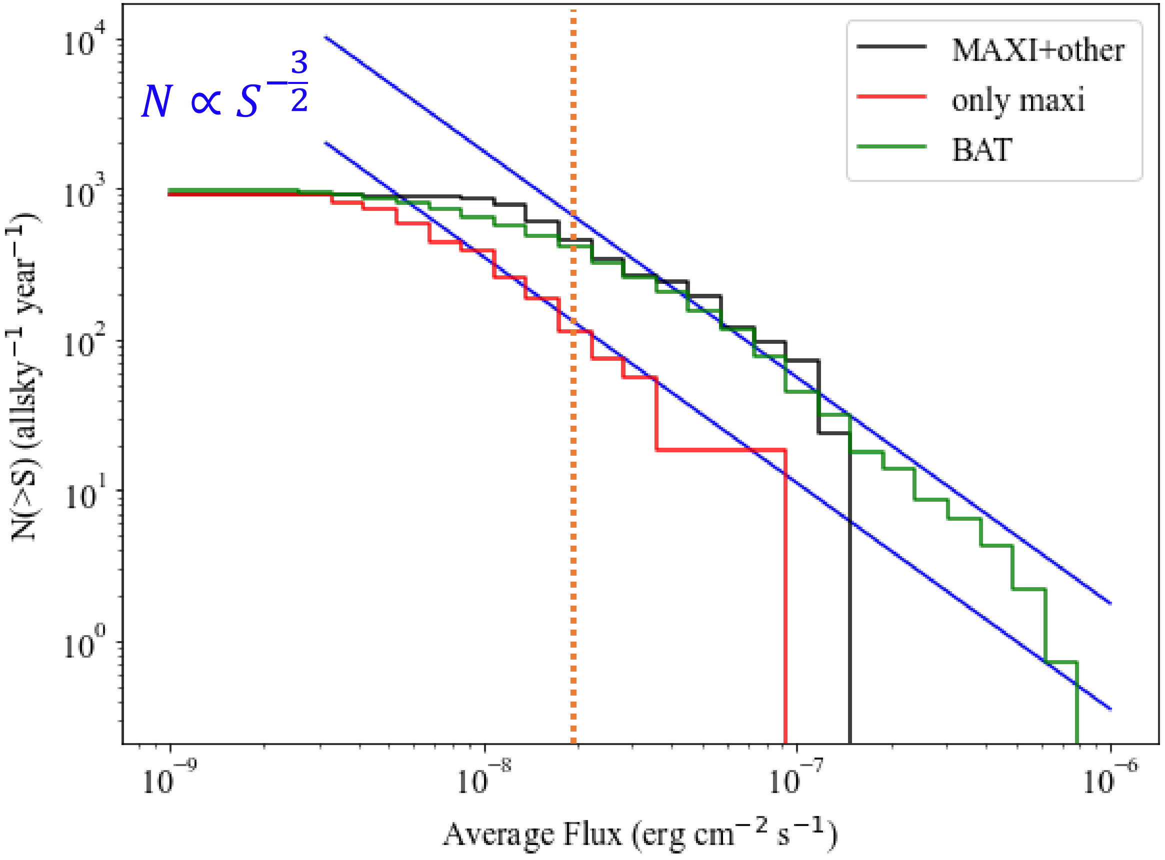
$\nu_1 = -0.2, \nu_2 = -1.4, L_\mathrm{b} = 10^{49.5}\ \mathrm{erg\ s^{-1}}$

Parameters

$\nu_1 = -0.2, \nu_2 = -1.4, L_0 = 10^{49.5}\ \mathrm{erg\ s^{-1}},$
$k = 2.5, \text{average } L_b = 10^{51}$

Comparison simulation results and observation results with luminosity evolution

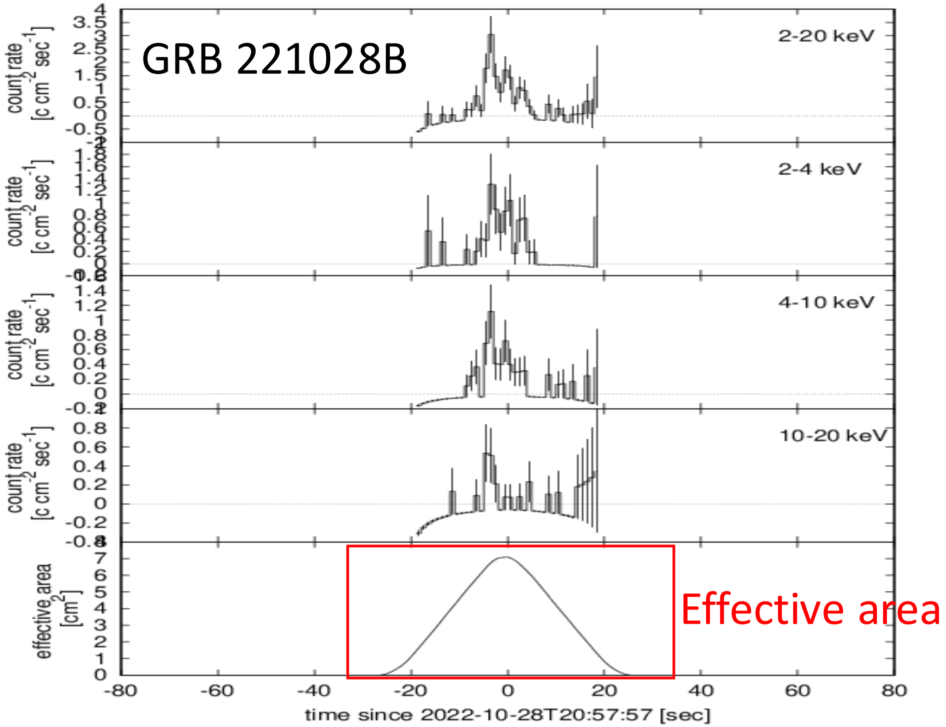


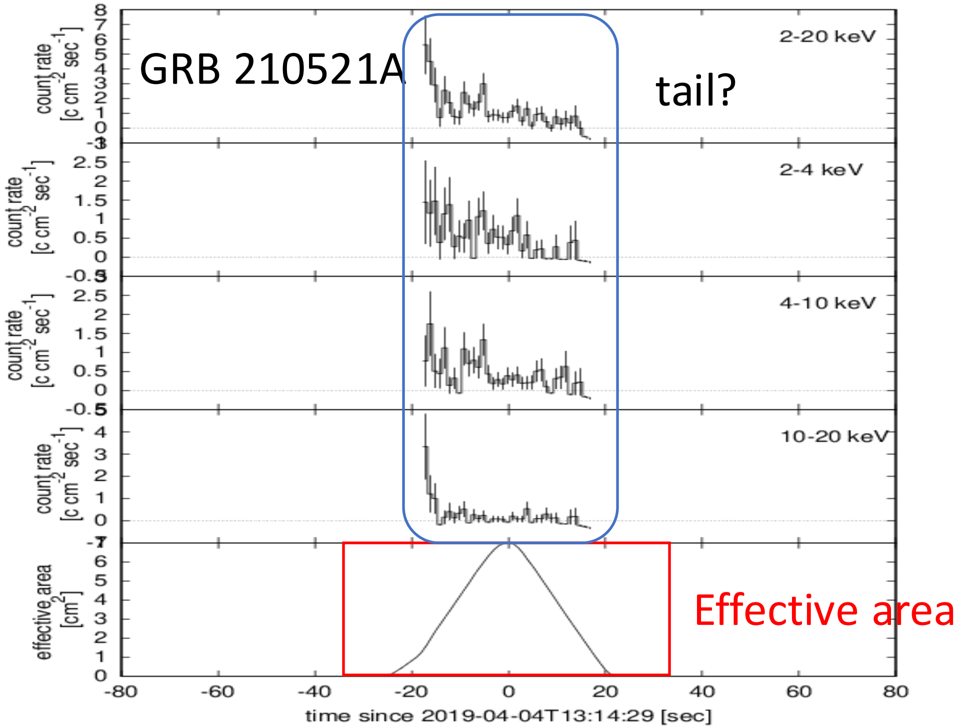


Parameters
$\nu_1 = -0.2, \nu_2 = -1.4, L_0 = 10^{49.5}\ \mathrm{erg\,s^{-1}}, k = 2.5$

Even with evolution, L_b and L_0 are about an order of magnitude smaller than in other studies

MAXI light curve





Effective area changing in time due to scanning of MAXI

It must consider varying effective area to analyze. We analyzed all MAXI GRBs taking the varying effective area into account.

Field of View is changing during the burst due to scanning.
We may observe out of the peak of prompt emission.
It’s difficult to estimate where to start or end with GRB only based on MAXI observations (prompt emission or tail).