Exploring Short Gamma-Ray Bursts: afterglow insights from the S-BAT4 extended sample

Celebrating 20 years of *Swift* discoveries, Firenze – 24-28/03/2025

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INAF, Osservatorio Astronomico di Brera – Merate (LC)

In collaboration with the INAF-OAB Swift team: Stefano Covino, Paolo D'Avanzo, Matteo Ferro, Maria Grazia Bernardini, Sergio Campana, Chiara Salvaggio, Tullia Sbarrato, Boris Sbarufatti, Giampiero Tagliaferri

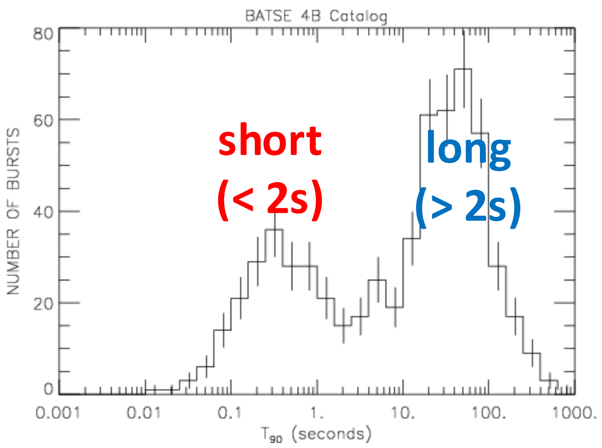
GRBs – a recap | SGRBs SAMPLE | PROMPT | AFTERGLOWS | CONCLUSIONS

Introduction – Gamma-ray bursts

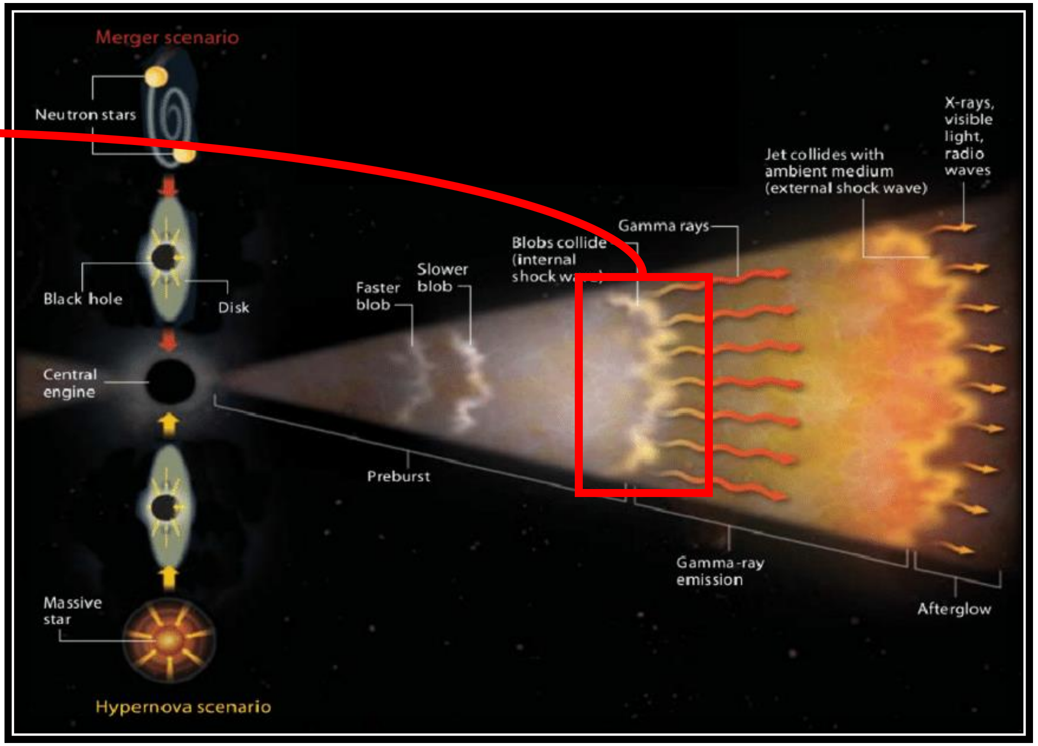
$E_{ISO} \sim 10^{50} - 10^{54}$ erg
Flux: $10^{-8} - 10^{-4}$ erg/cm²/s
<z> ~ 2.1

GAMMA-RAY BURSTS (**GRBs**)

PROMPT PHASE
(~msec to ~1000 sec)



From Kouveliotou et al (1993)



From Gehrels et al. (2002)

Introduction – Gamma-ray bursts

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Flux: $10^{-8} - 10^{-4}$ erg/cm²/s
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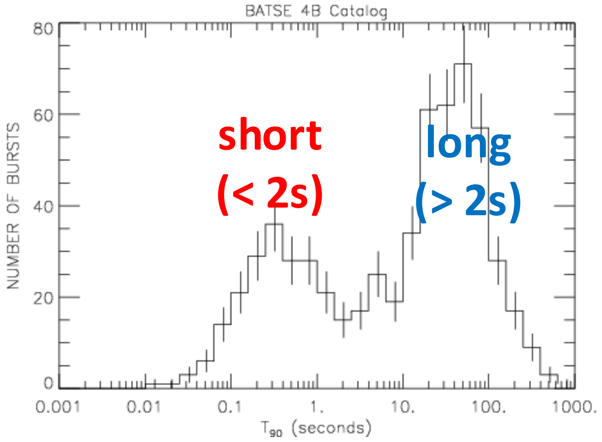
GAMMA-RAY BURSTS (**GRBs**)

PROMPT PHASE
(~msec to ~1000 sec)

AFTERGLOW PHASE
(hours to days to weeks)



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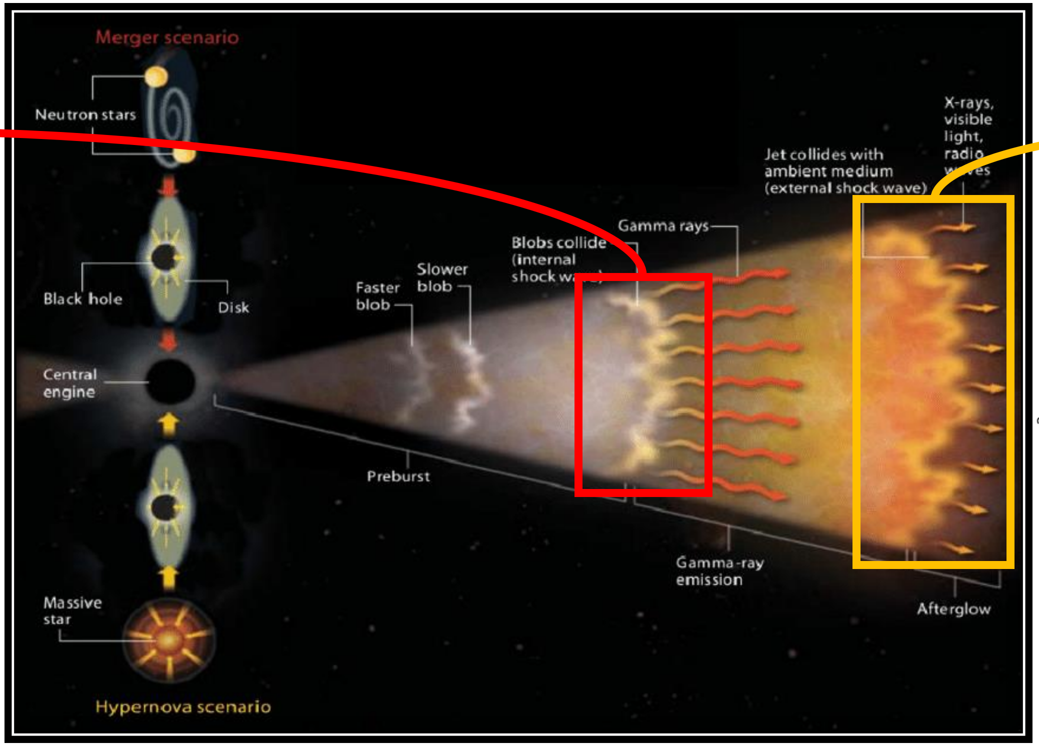

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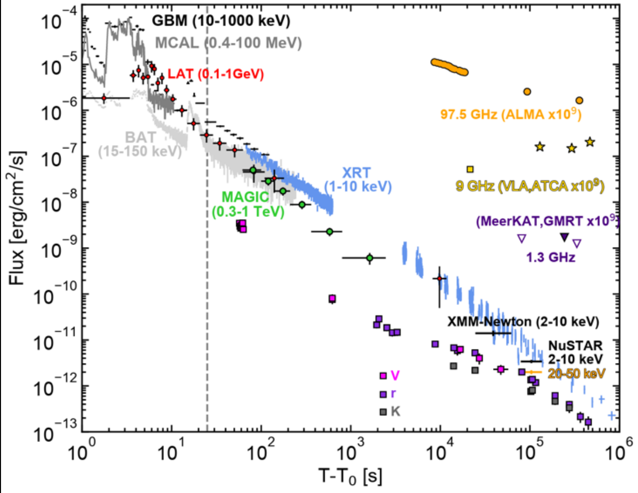
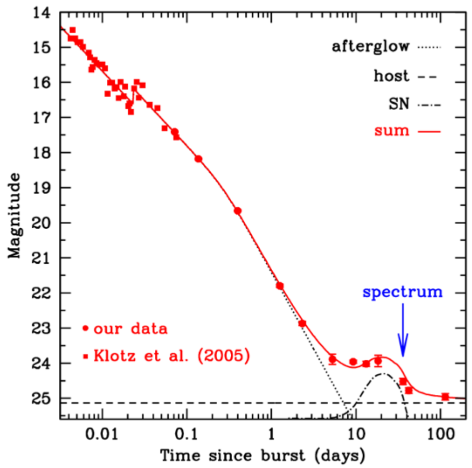


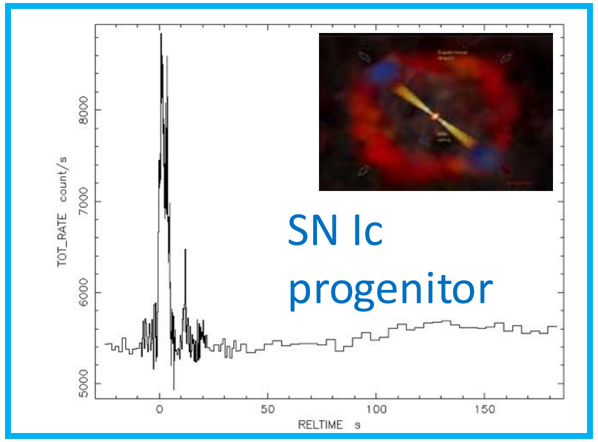
X-RAYS
UV
OPTICAL
IR
RADIO
TeV

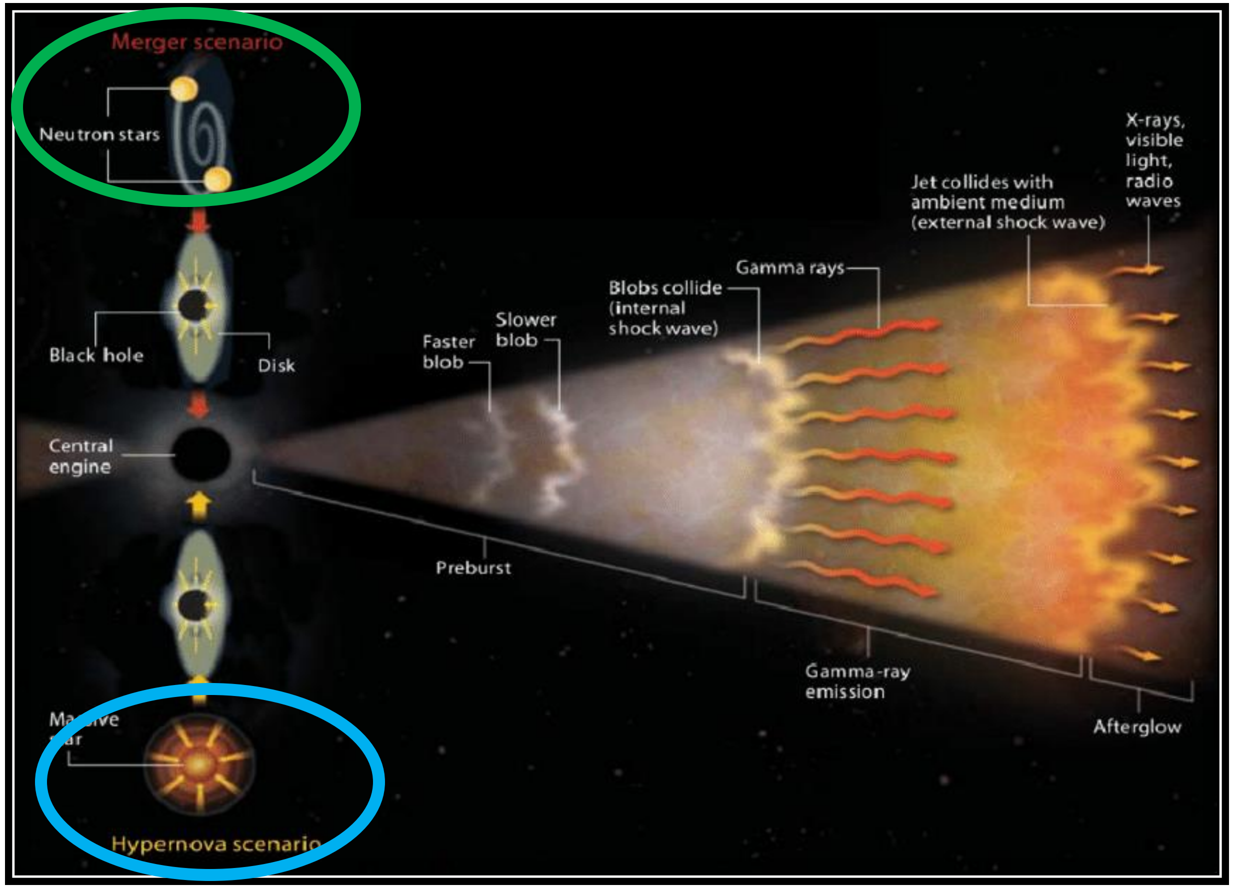
From MAGIC coll.+20

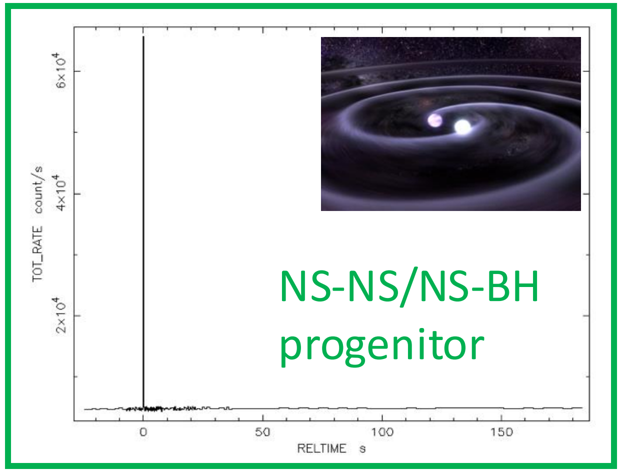
Introduction – Gamma-ray bursts

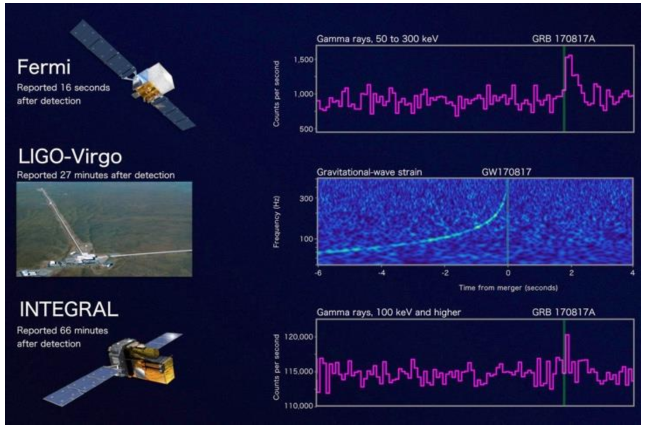


From Della Valle et al. (2006)





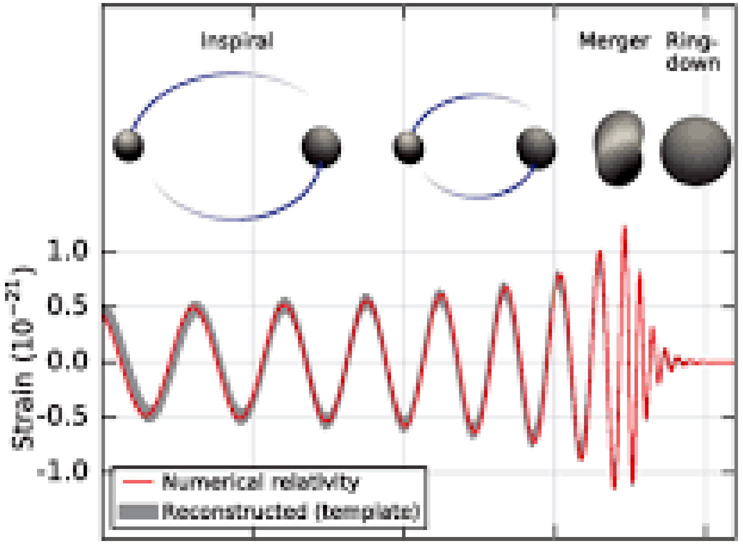


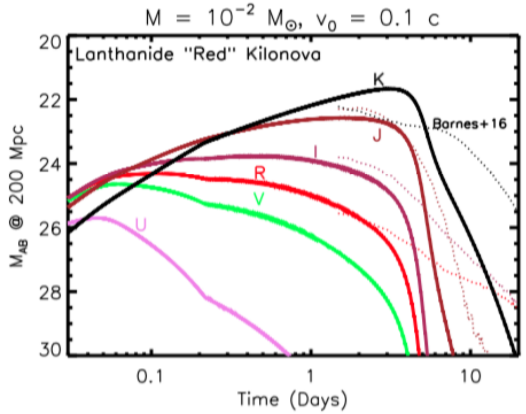


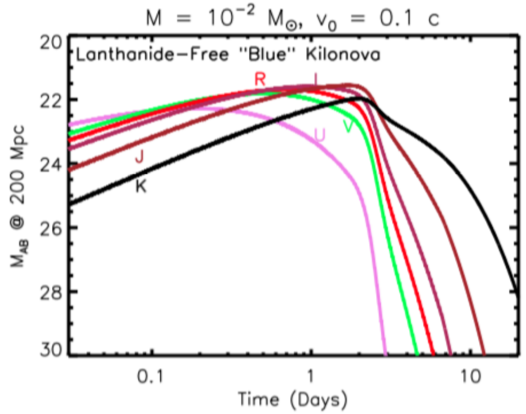
From Gehrels et al. (2002)

Introduction – Short GRBs

- $T_{90} < 2$ s , compact binary origin
- Hard spectra, negligible lag
- $E_{ISO} \sim 10^{50} - 10^{52}$erg
- Fainter emission → challenging to detect!!!



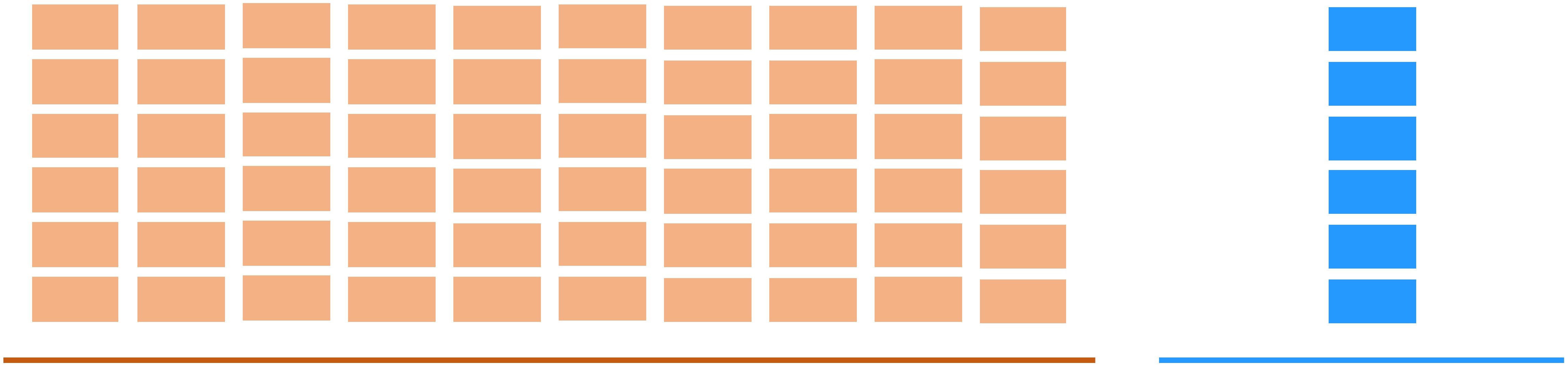




From Metzger (2020)

Introduction – Short GRBs

With the advent of the ***Swift*** satellite in **2005**, the discovery of SGRB **afterglows** and the identification of their **host galaxies** made possible **distance** measurements and the study of their energy scales and **environments**.



Swift long GRBs

Swift short GRBs

(~10 % of Swift GRBs)

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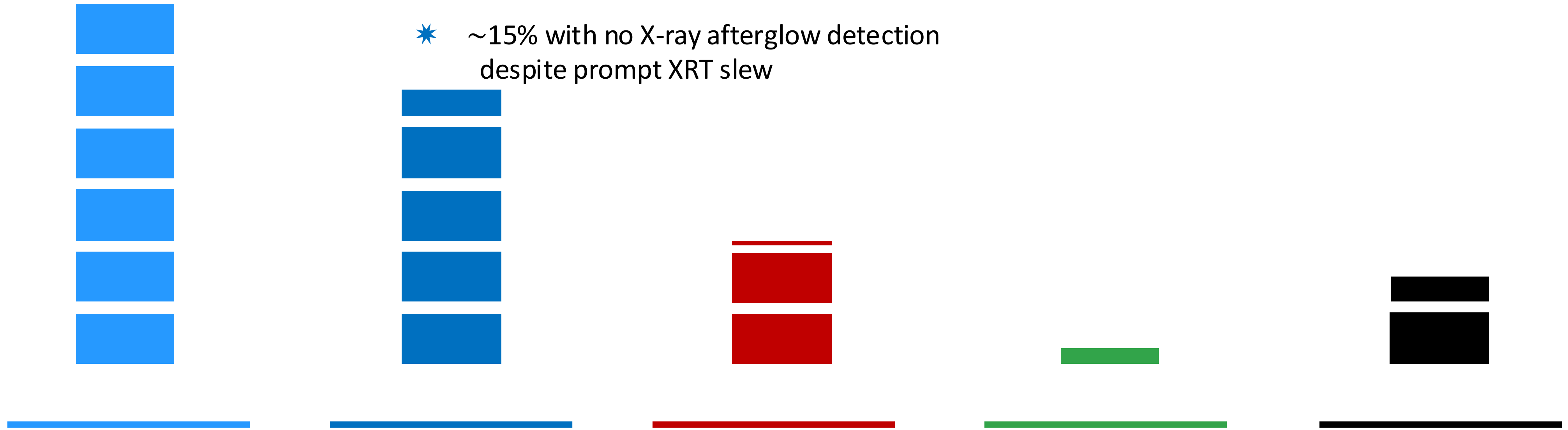

~180 SGRBs

~75 % X-ray afterglows

~35 % optical afterglows

~5 % radio afterglows

~50 % redshift measured

Introduction – Short GRBs

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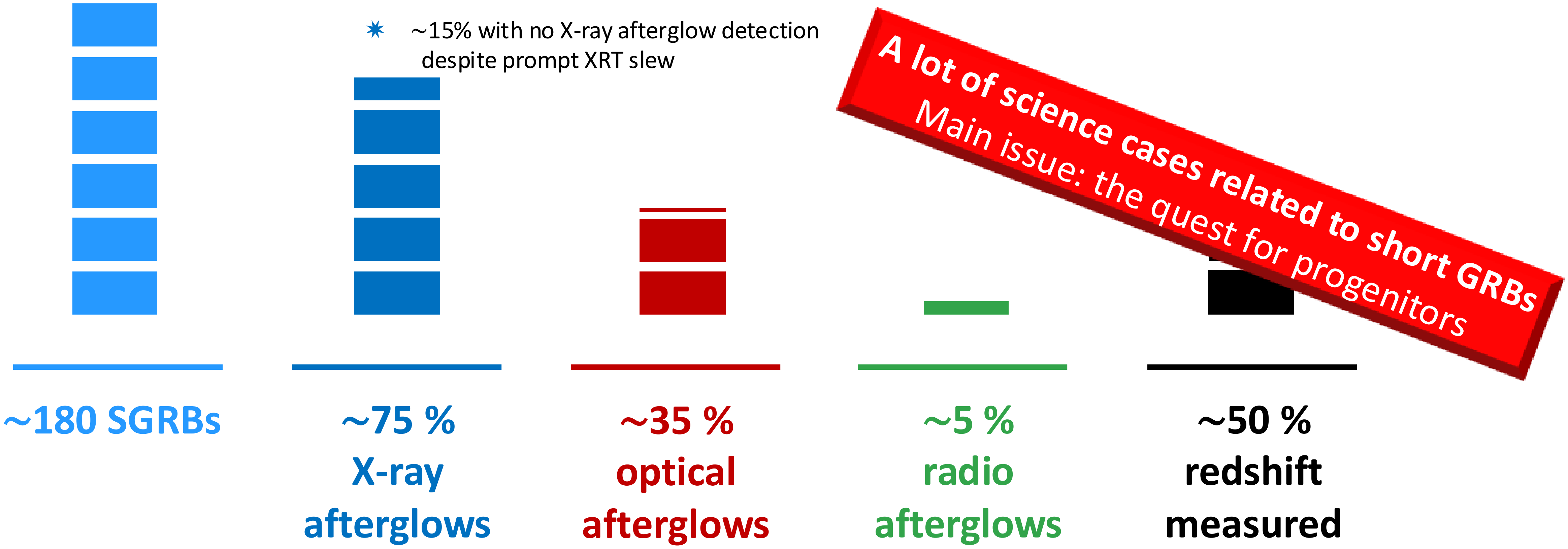

Building the sample

GOAL:

Put the observed quantities in the GRBs rest frame to obtain their intrinsic properties

Swift Short Gamma-Ray Bursts:
T_{90}< 2 sec +
extended emission (EE) bursts

Low Galactic extinction:
A_V < 0.5 mag

Flux-limited
complete sample

Peak photon flux
in 15-150 keV band:
P_{64} > 3.5 ph/s/cm^2

We avoid
selection effects

Prompt *Swift*-XRT
observation: < 120 sec
(no need for detection)

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BAT6 for Long GRBs

S-BAT4 for Short GRBs

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Peak photon flux
in 15-150 keV band:
P_{64} > 3.5 ph/s/cm²

Prompt *Swift*-XRT
observation: < 120 sec
(no need for detection)

The S-BAT4 extended sample

Swift Short Gamma-Ray Bursts:
T_{90}< 2 sec +
extended emission (EE) bursts

Low Galactic extinction:
A_V < 1.2 mag

- 16 SGRBs selected from Nov 2004 to Jun 2013
- 31 SGRBs selected from July 2013 to Dec 2022
- 5 new SGRBs added from Nov 2004 to Jun 2013
- 1 GRB re-classified as long GRB (GRB 090426)

Peak photon flux
in 15-150 keV band:
P_{64} > 3.5 ph/s/cm^2

Prompt *Swift*-XRT
observation: < 120 sec
(no need for detection)

The S-BAT4 extended sample

Swift Short Gamma-Ray Bursts: T_{90}< 2 sec + extended emission (EE) bursts

Low Galactic extinction: A_V < 1.2 mag

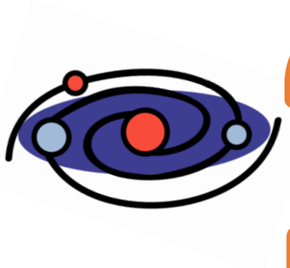
- 51 SGRBs selected from Nov 2004 to Dec 2022
- 31 spectroscopic redshift (61 %)
- 9 photometric redshift: 40 in total (78 %)

Peak photon flux in 15-150 keV band: P_{64} > 3.5 ph/s/cm^2

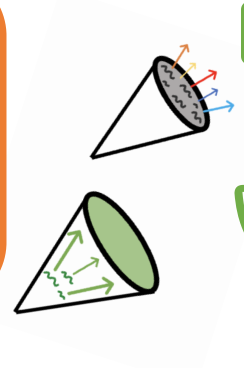
Prompt *Swift*-XRT observation: < 120 sec (no need for detection)

What can we do with the S-BAT4 sample?

1. Prompt phase properties & correlations



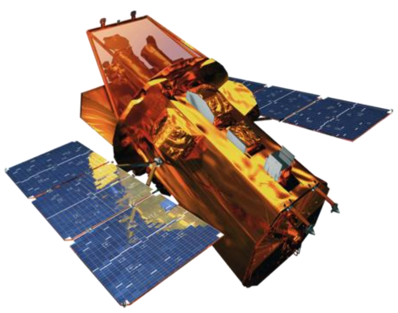
2. Rest-frame afterglow light curves analysis



3. Host galaxy determination

4. Extension: SGRBs with extended emission

5. Comparison with the BAT6 LGRBs sample



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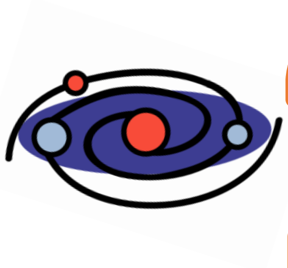


2 Rest-frame afterglow light curves analysis

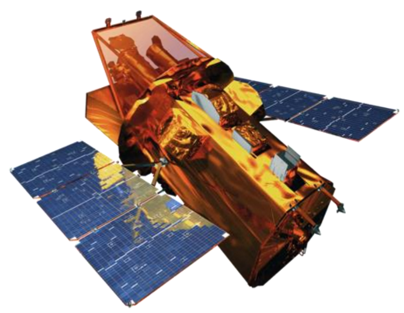
3 ...mination

See Matteo Ferro's talk!

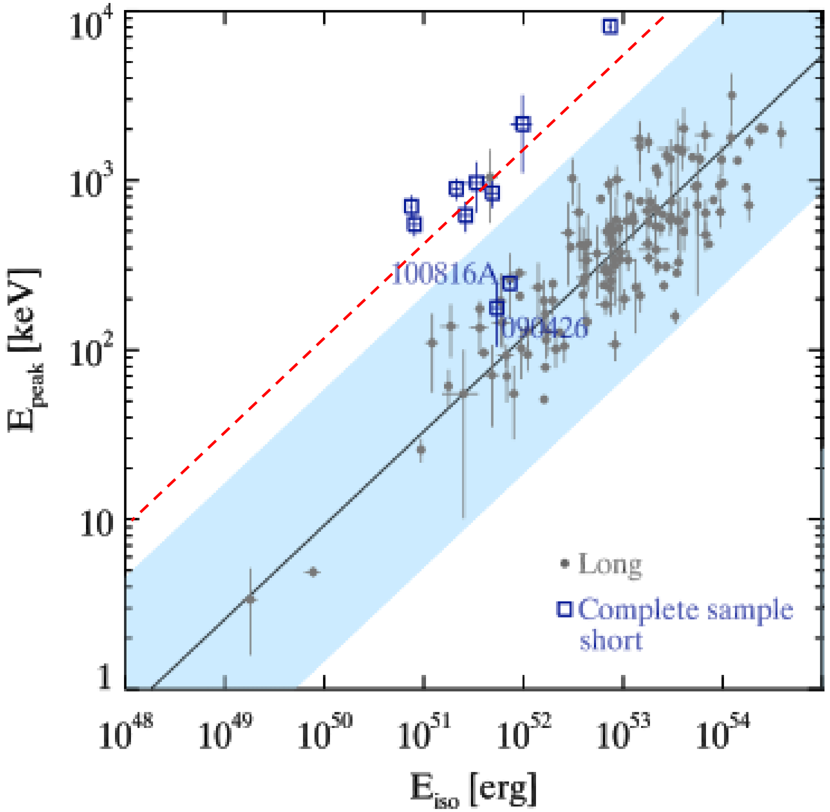
4 Exten... ...s ...tended emission

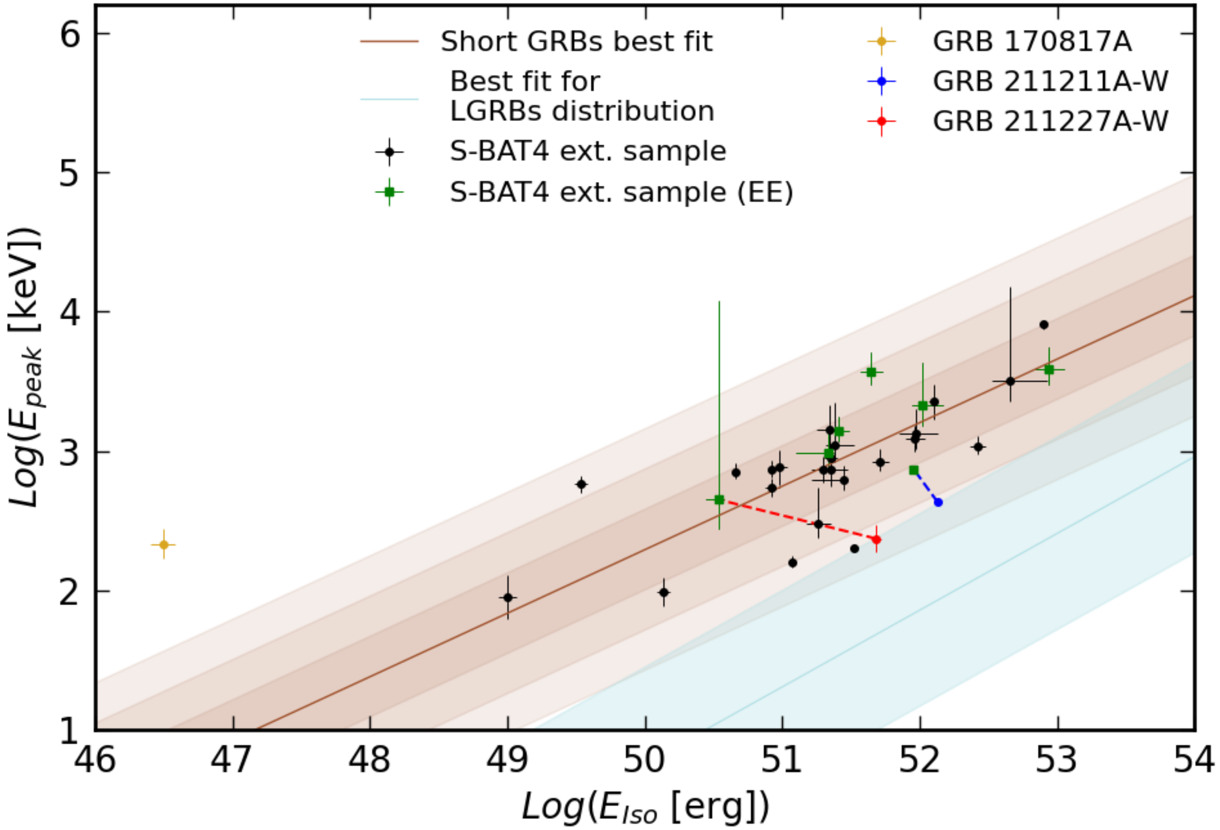
See Michela Dinatolo's poster!

5 Comparison with the BAT6 LGRBs sample



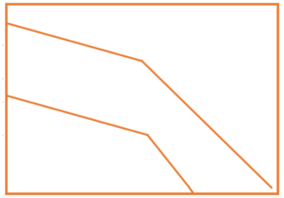
Prompt phase properties – Amati relation





Amati et al. 2002; Younetoku et al. 2004; Ghirlanda et al. 2009; Zhang et al. 2012; D'Avanzo et al. 2014

S-BAT4 extended sample – Afterglows



X-rays

- 49/51 detection
- 9 SGRBs with no redshift
- 5 GRBs with 1 point only

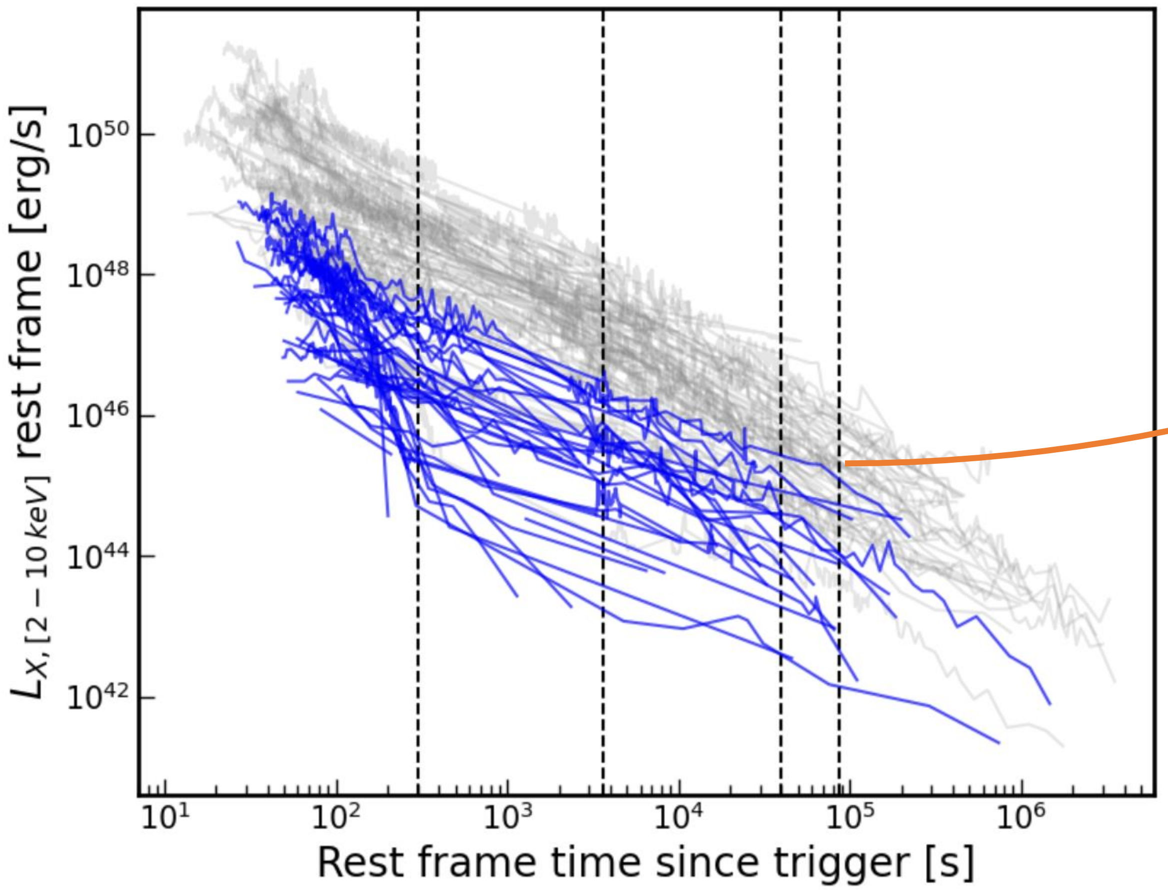
35 rest frame X-ray light curves

Optical

- 29/51 detection
- 8 SGRBs with no redshift
- 8 GRBs with < 3 points

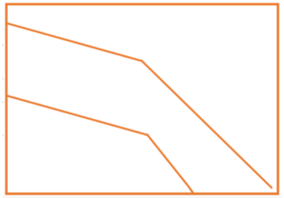
13 rest frame optical light curves

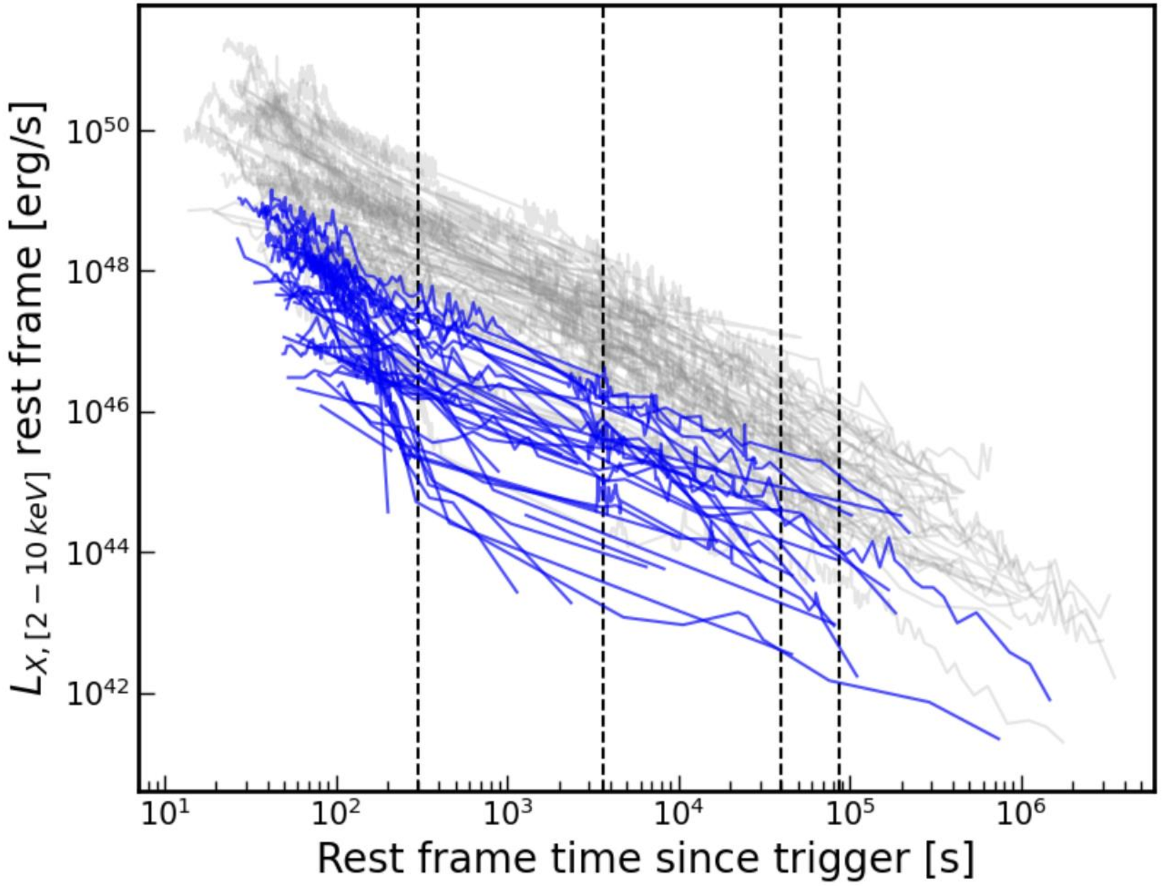
X-ray afterglow light curves

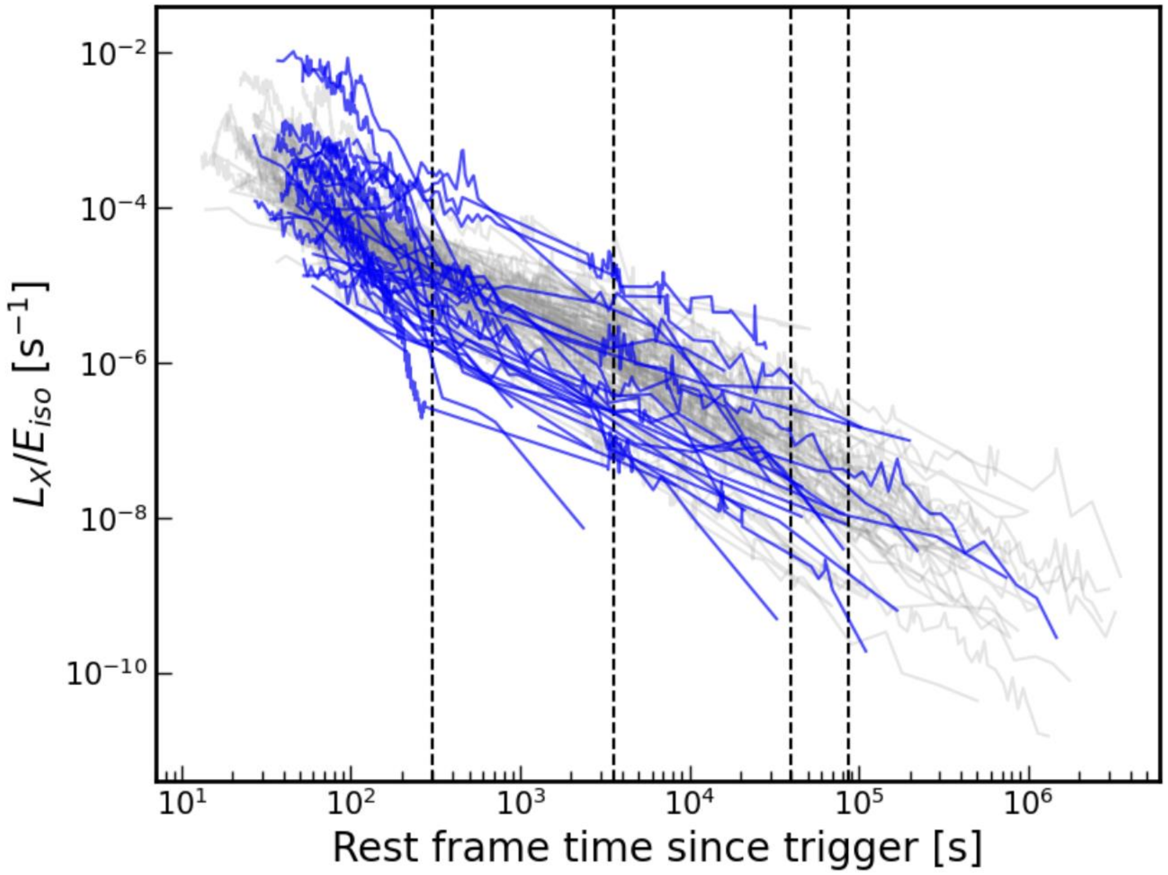


Clear separation between long & short GRBs

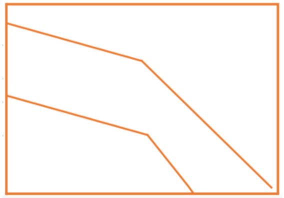
X-ray afterglow light curves

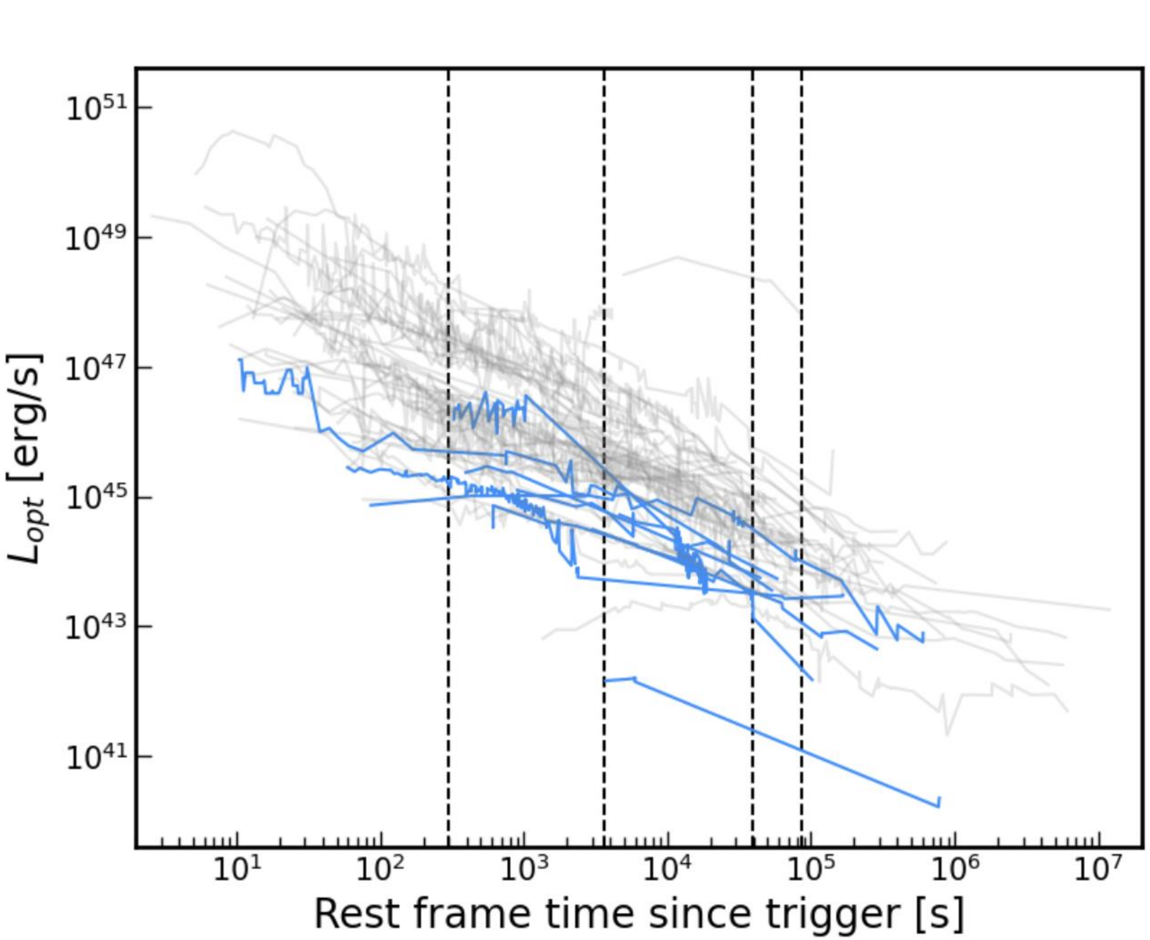


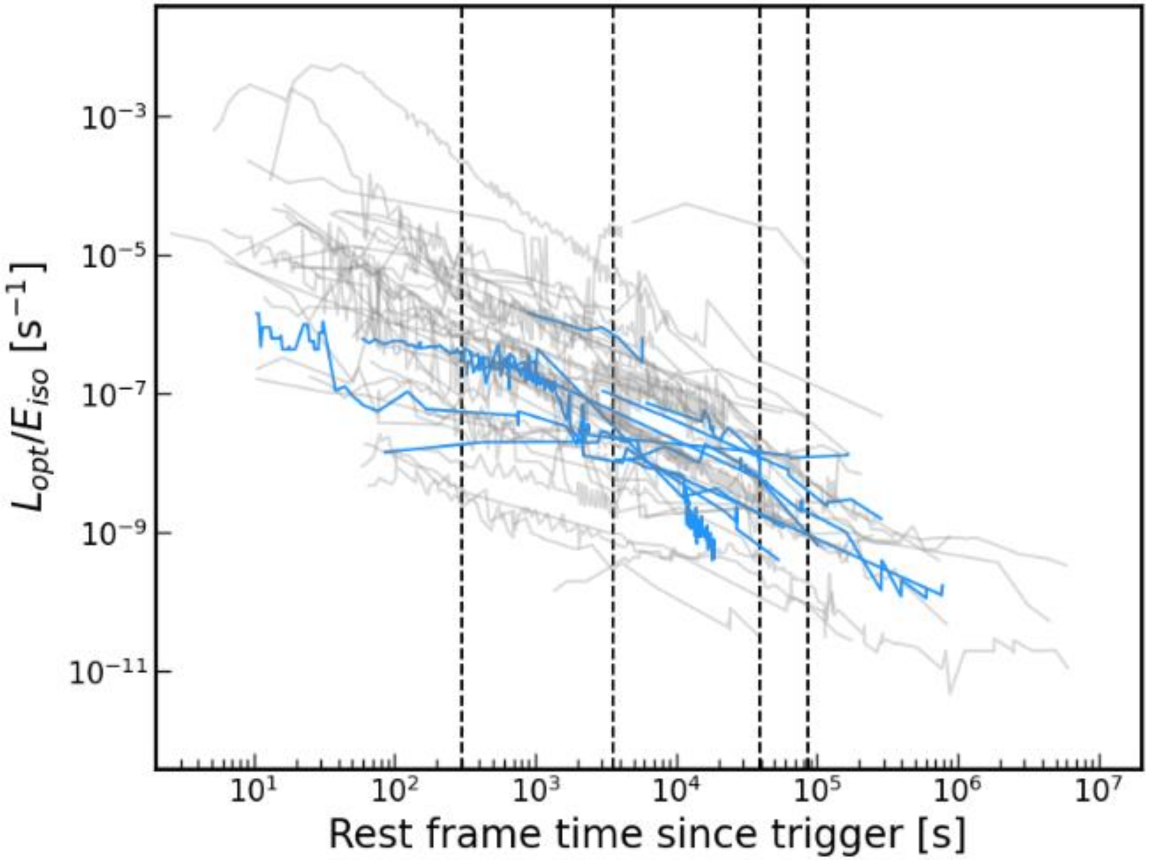




Optical-NIR afterglow light curves



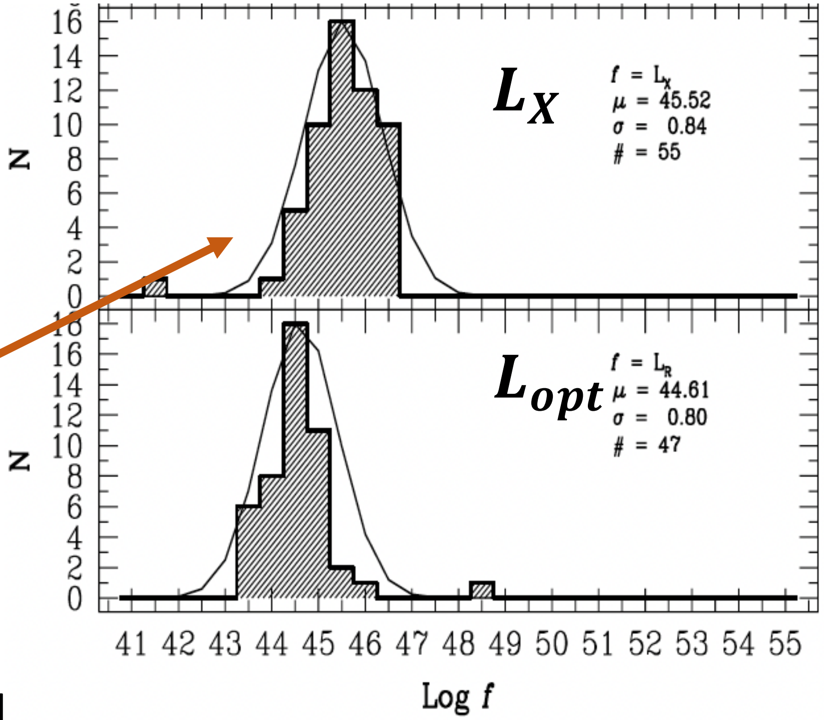


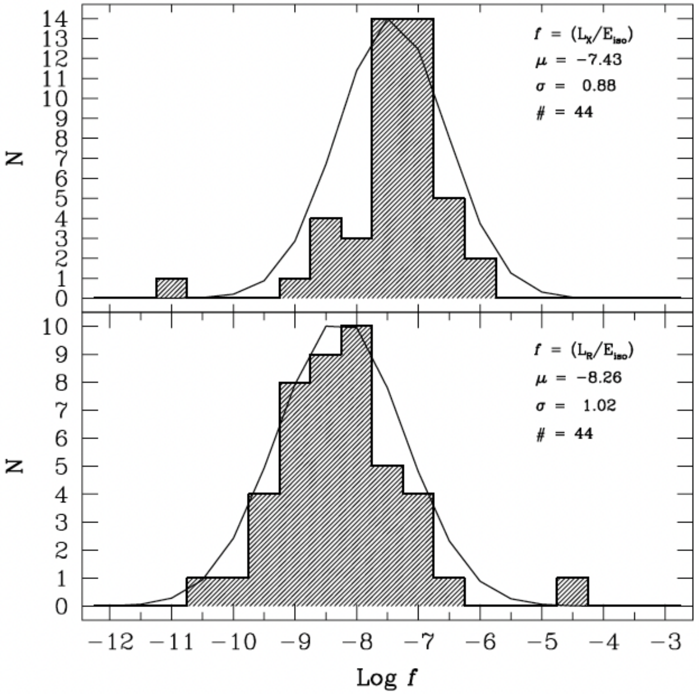


S-BAT4 – BAT6 afterglow comparison

<u>*RESULTS FOR LONG GRBs – BAT6 SAMPLE*</u>*:*

- Different decays between X-rays and optical in most cases → different physical origin;
- X-ray luminosity distribution broader and brighter with respect to the optical;
- X-ray E_{iso}-normalized luminosity distribution tighter with respect to optical E_{iso}-normalized.

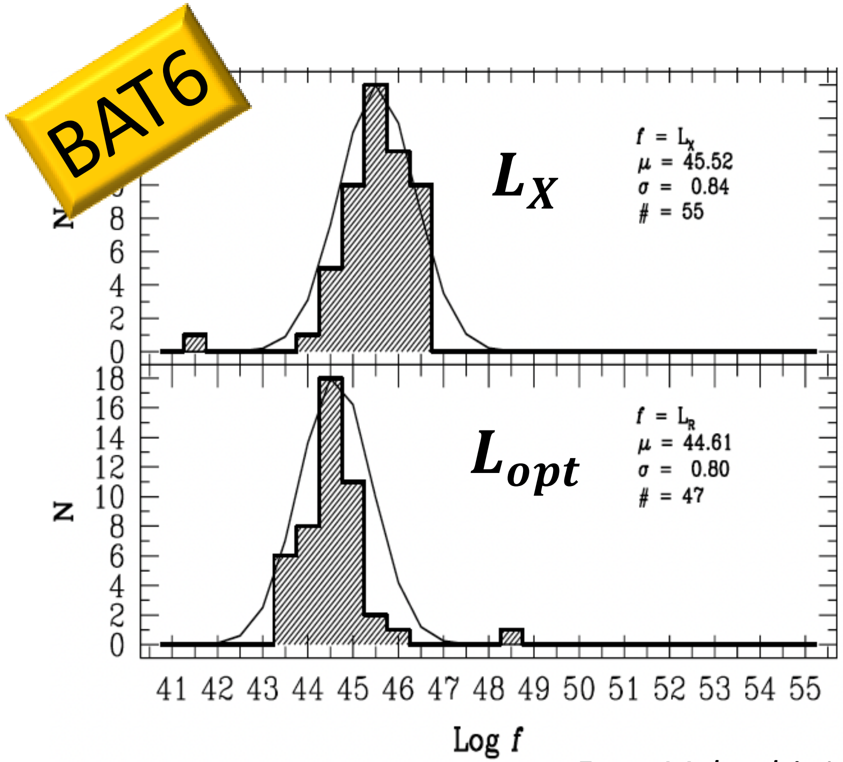




From Melandri+14

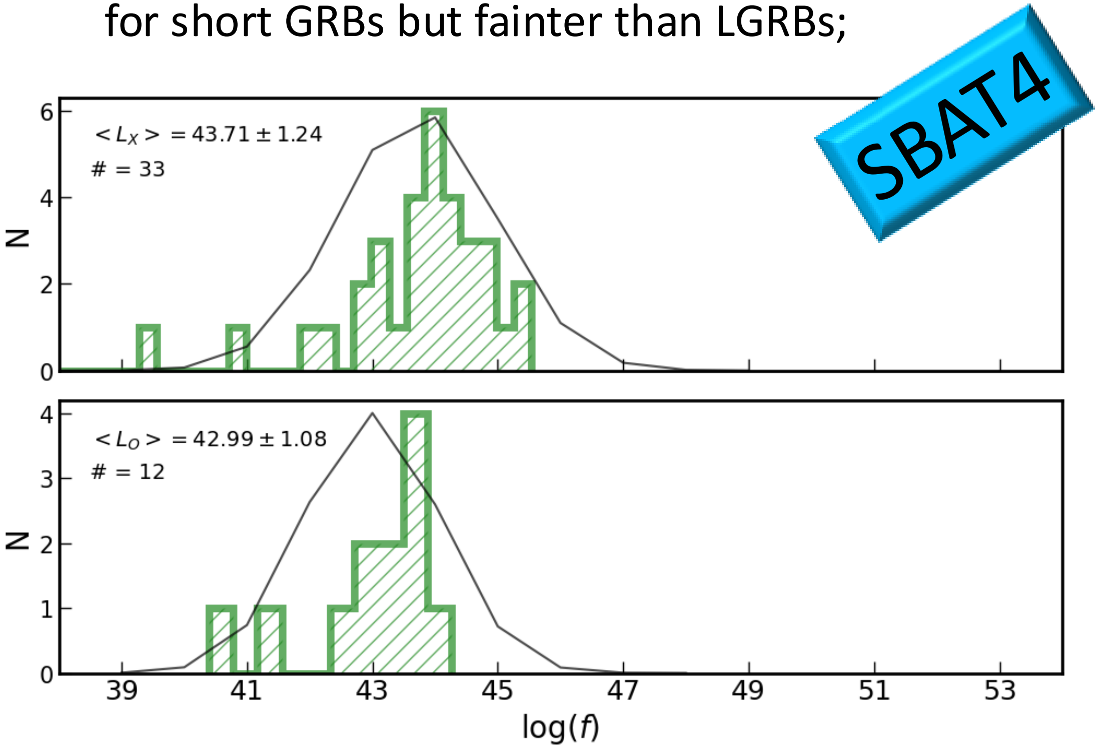
S-BAT4 – BAT6 afterglow comparison

- X-ray luminosity distribution broader and brighter with respect to the optical for LGRBs;



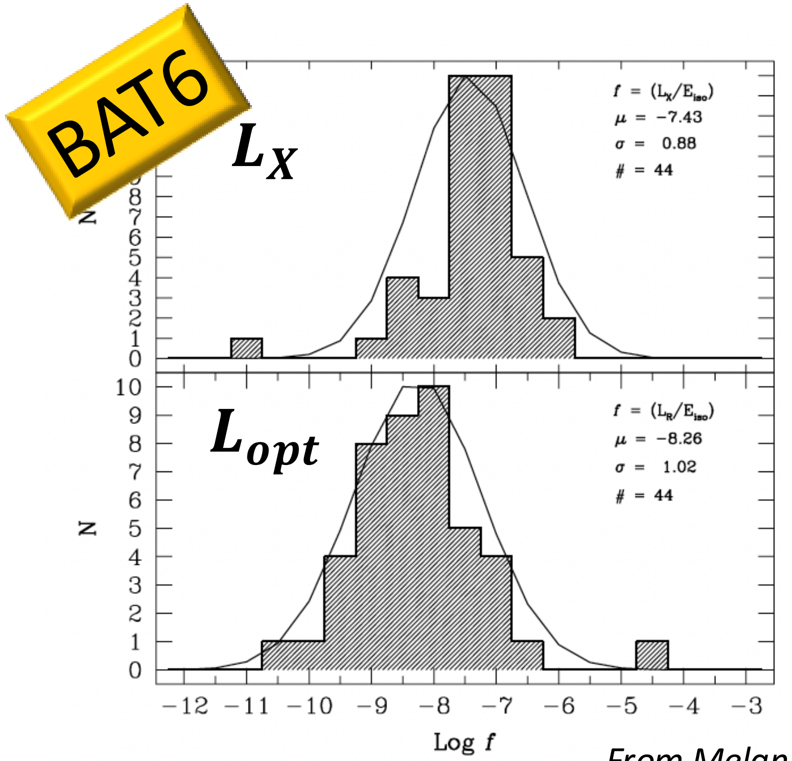
From Melandri+14

- X-ray luminosity distribution broader and brighter with respect to the optical for short GRBs but fainter than LGRBs;



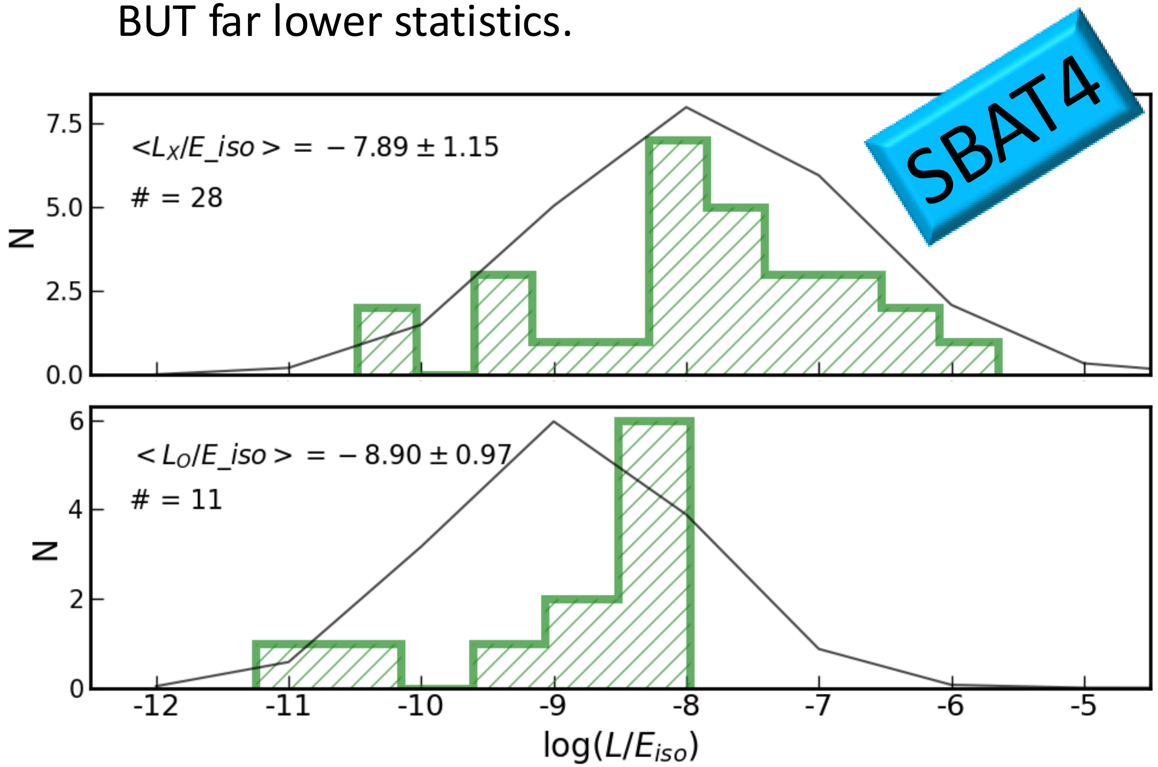
S-BAT4 – BAT6 afterglow comparison

- X-ray E_{iso}-normalized luminosity distribution tighter with respect to optical E_{iso}-normalized.



From Melandri+14

- X-ray E_{iso}-normalized luminosity distribution broader with respect to optical E_{iso}-normalized BUT far lower statistics.

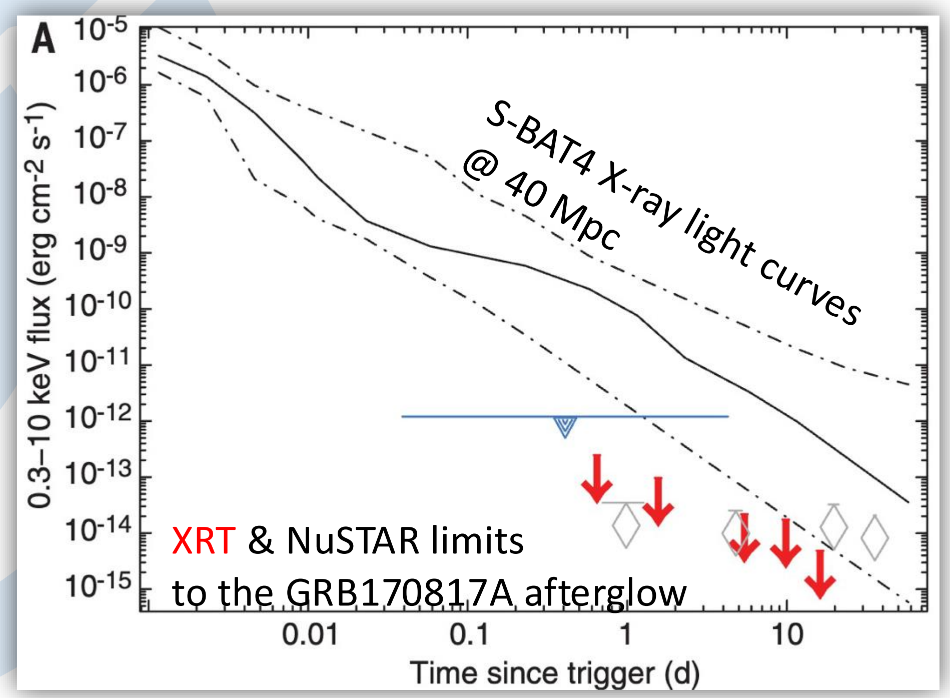


Conclusions

→ We have built a flux-limited, complete sample free of selection effects.
51 short GRBs detected by *Swift* match our criteria, 78% of which with a redshift measurement;

→ Multi-wavelength analysis of prompt and afterglow emission will enable a characterization of the intrinsic proprties of the short GRBs and investigation of their progenitors;

→ The knowledge of the population of short GRBs will allow us to properly characterize the next SGRB-GW joint event detected during O4(?), both in the X-rays and in the optical band.

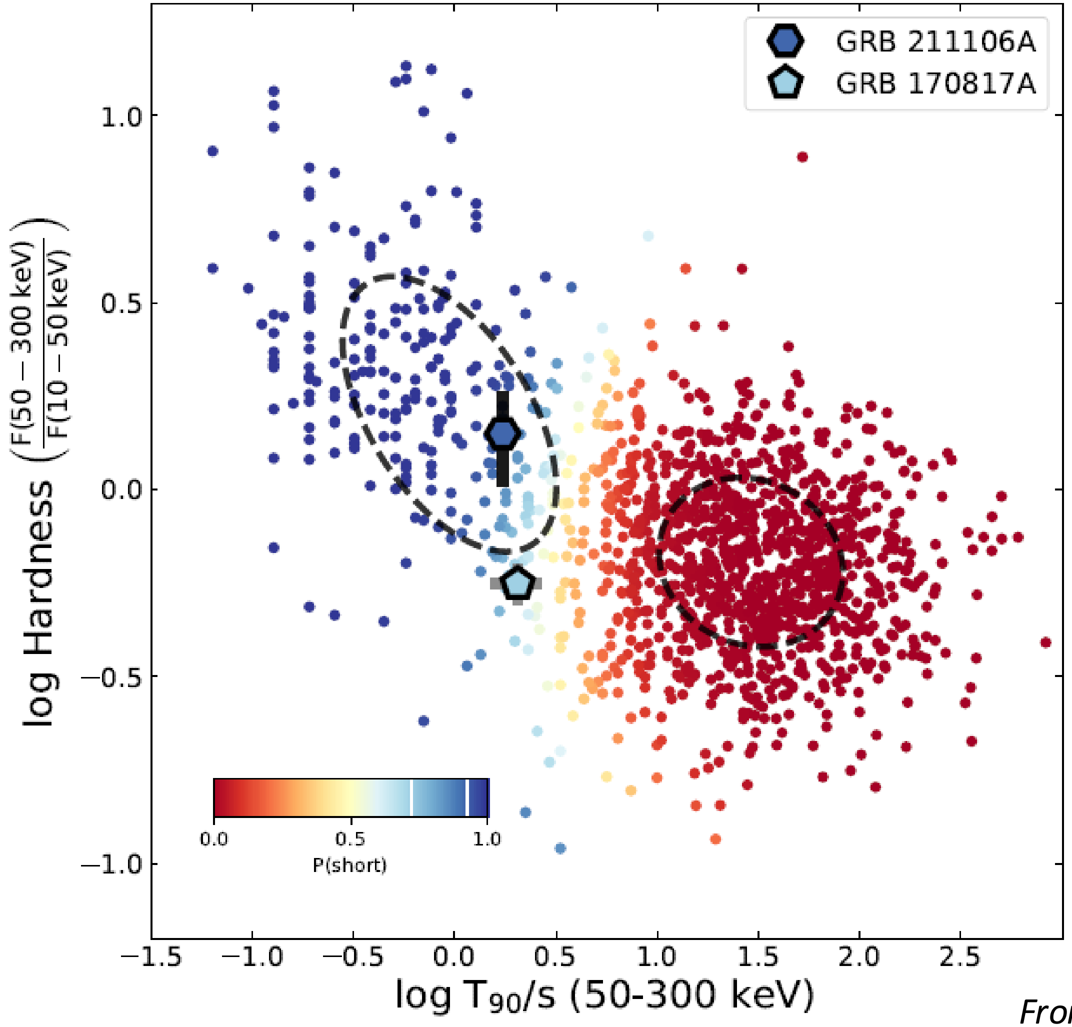


From Evans+17

Thank you for the attention!

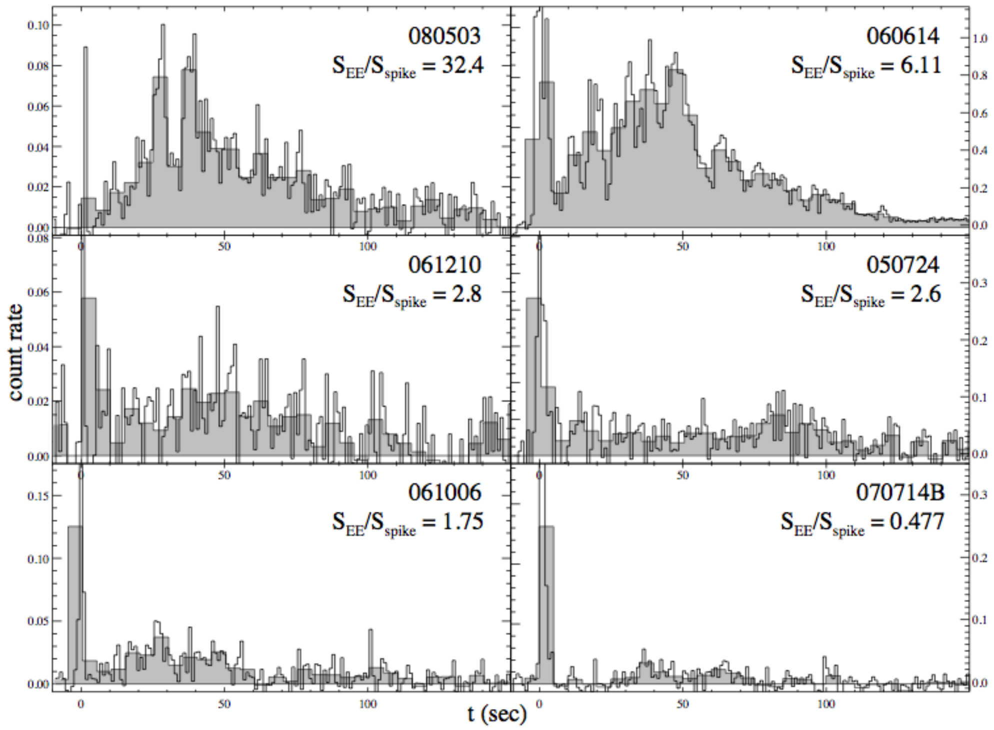
BACK-UP SLIDES

Gamma-ray bursts classification



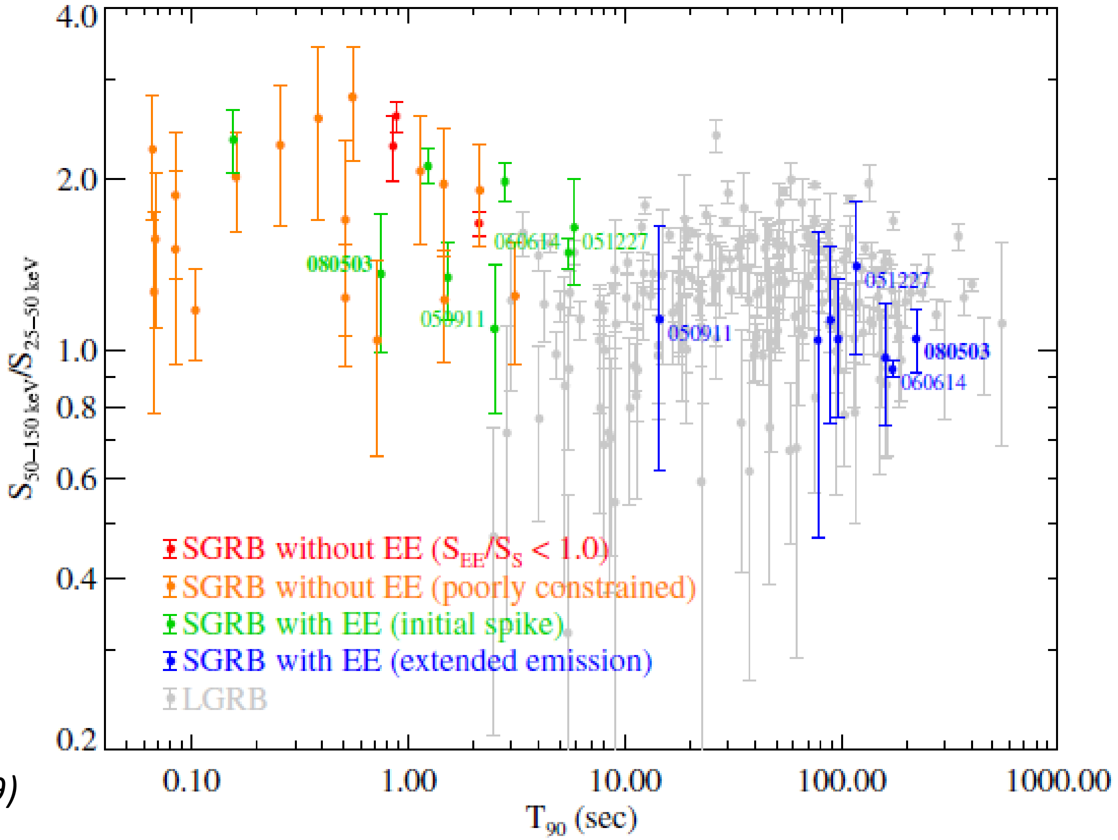
From Laskar et al. (2022)

Gamma-ray bursts classification



From Perley et al. (2009)

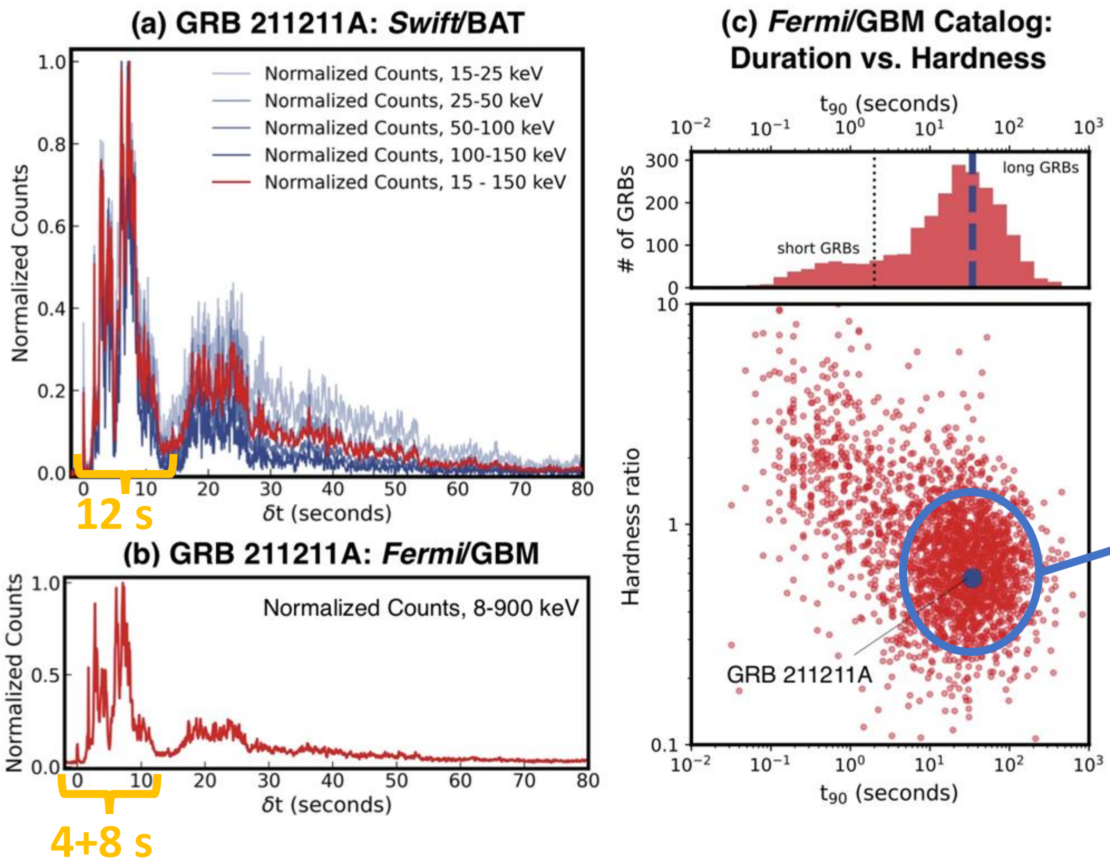
T_{90} >> 2 s



Short/hard spike + Long/soft tail

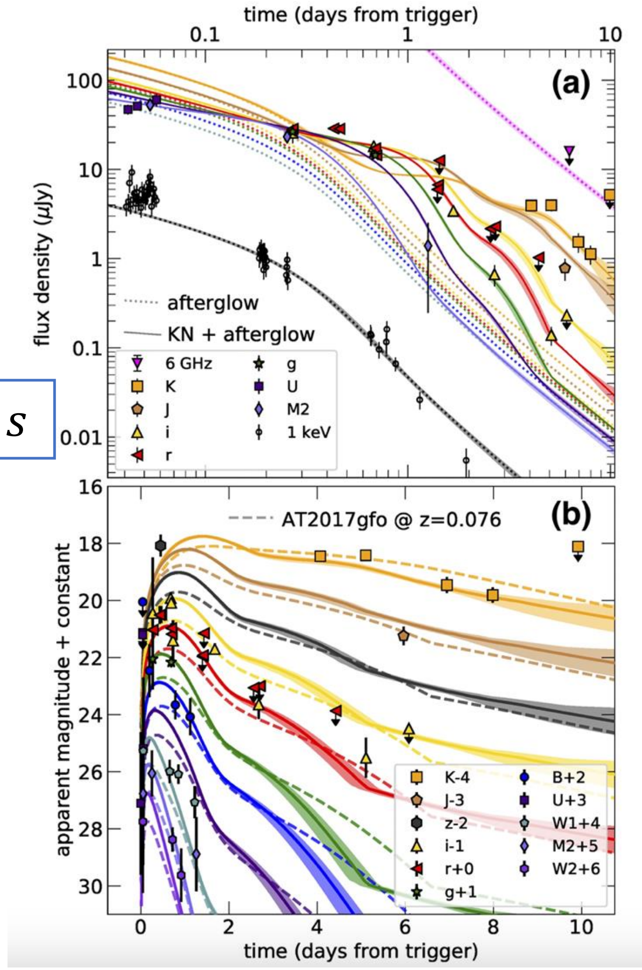
Gamma-ray bursts classification

GRB 211211A: a long gamma-ray burst with an associated kilonova?



$$t_{90} = 51.37 \pm 0.80 \;\; s$$

Consistent with long GRBs !



From Rastinejad et al. (2022)

The sample – original sample 2005-2013

Short Gamma-Ray Bursts:
T_{90}< 2 sec +
extended emission (EE) bursts

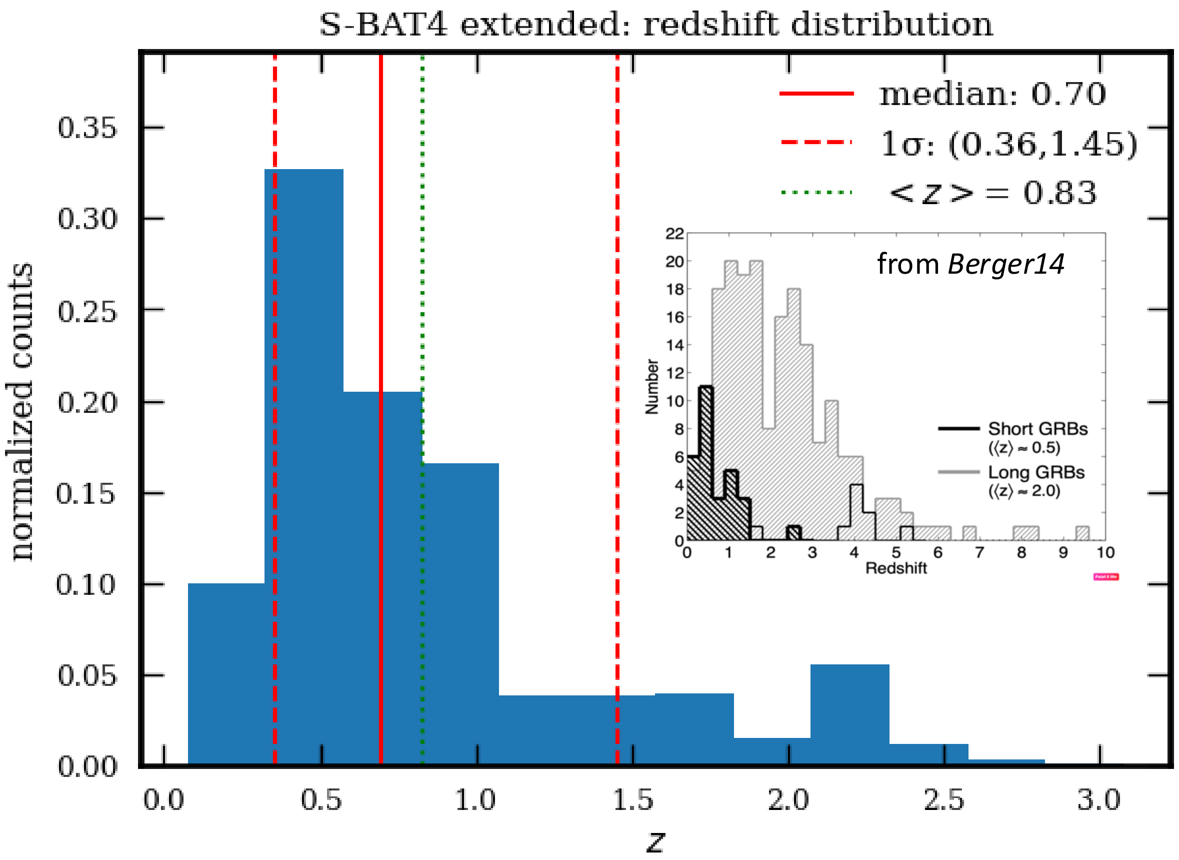
Prompt *Swift*-XRT
observation: < 120 sec
(no need for detection)

- 16 SGRBs selected from Nov 2004 to Jun 2013
- 11/16 measured redshift (71% completeness)
- 16/16 X-ray afterglow
- 12/16 optical afterglow

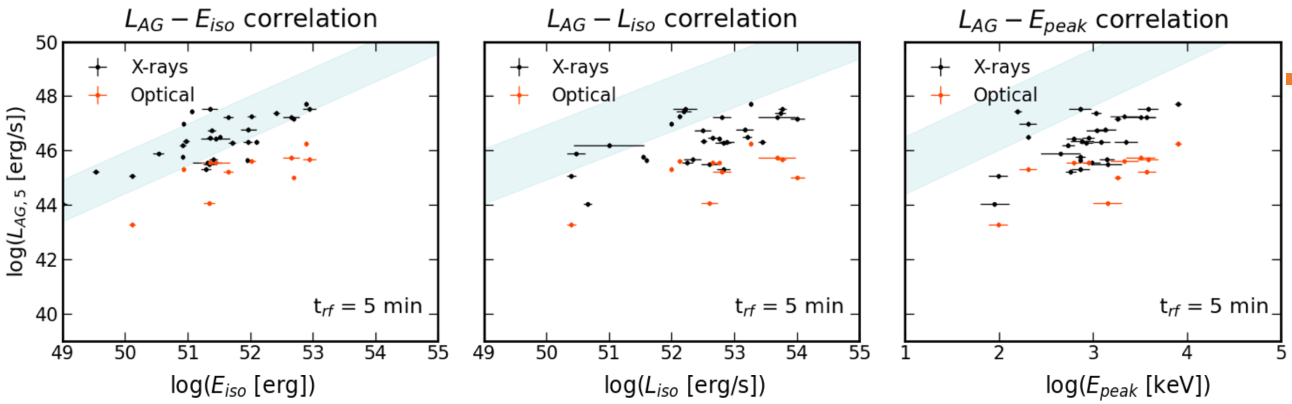
Low Galactic extinction:
A_V < 0.5 mag

Peak photon flux
in 15-150 keV band:
P_{64} > 3.5 ph/s/cm^2

Redshift distribution

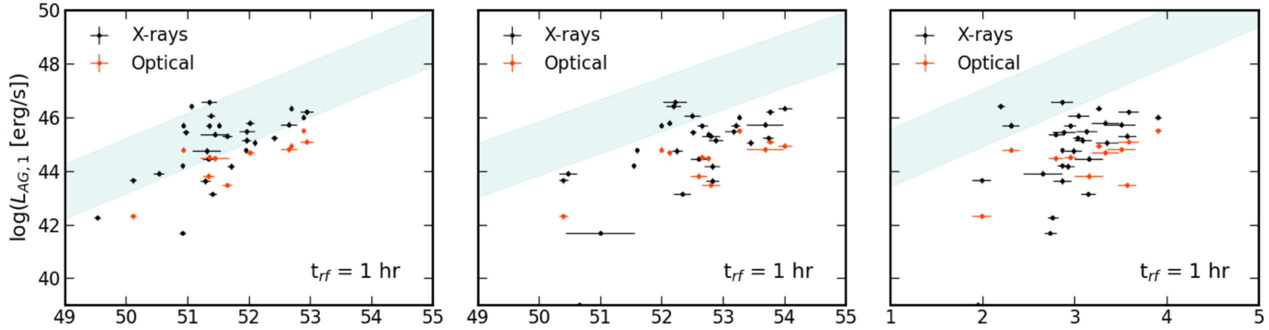


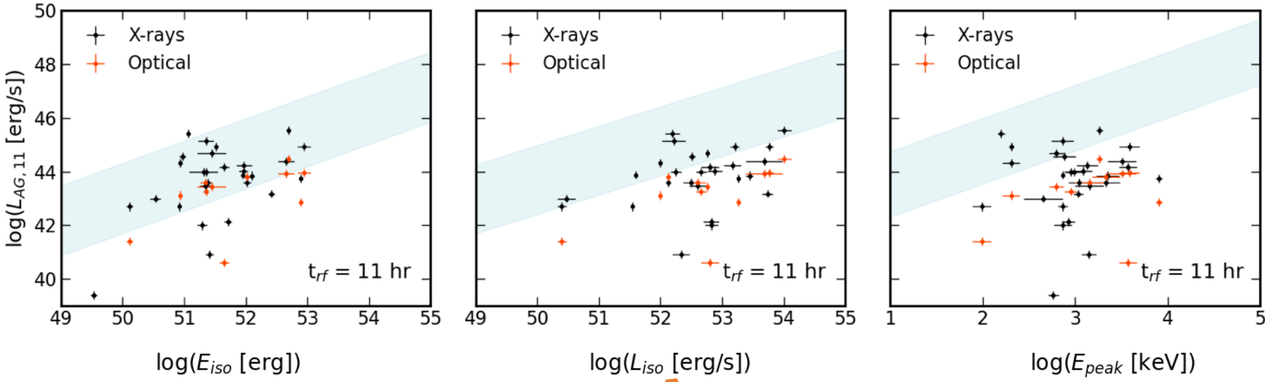
Prompt parameters-L_X correlation



$t_{rf} = 5\ min$

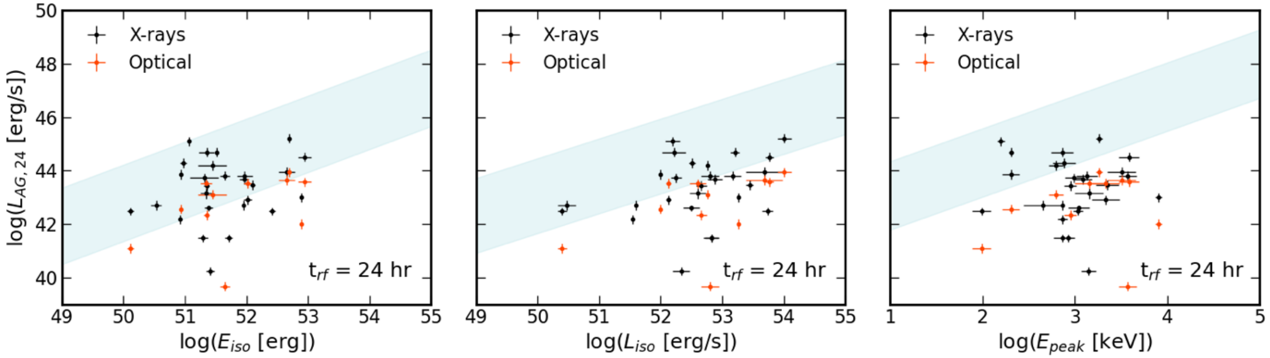
$t_{rf} = 1\ hr$



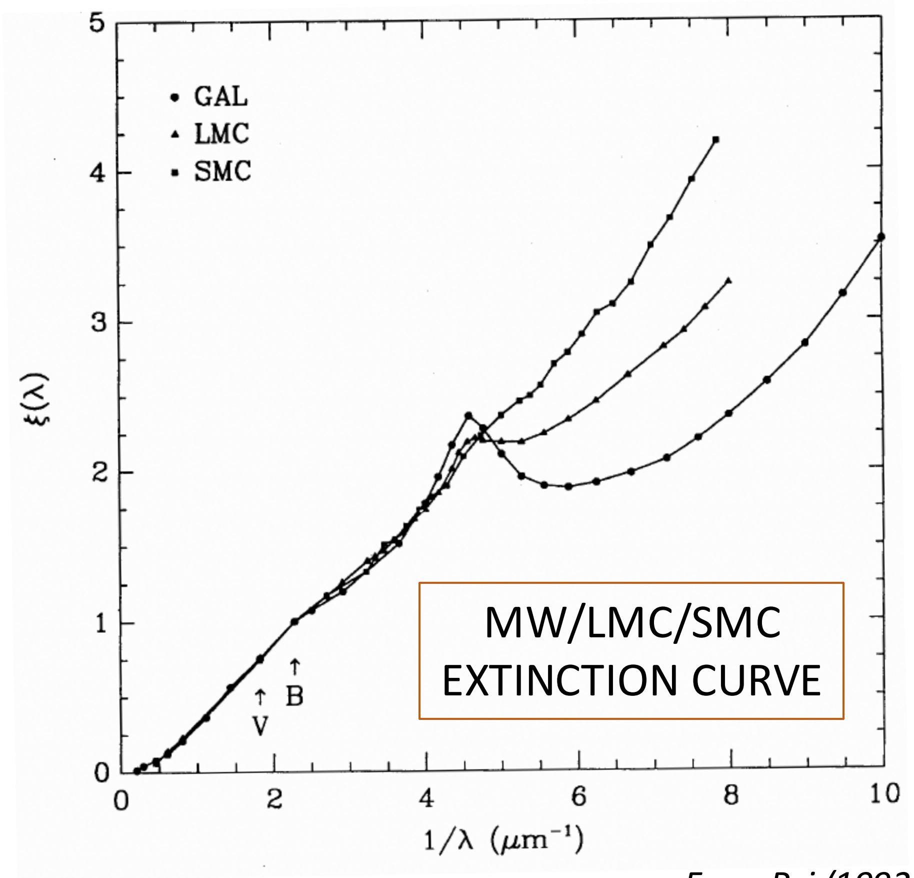


$t_{rf} = 11\ hrs$

$t_{rf} = 24\ hrs$



S-BAT4 extended sample – optical afterglows



MW/LMC/SMC EXTINCTION CURVE

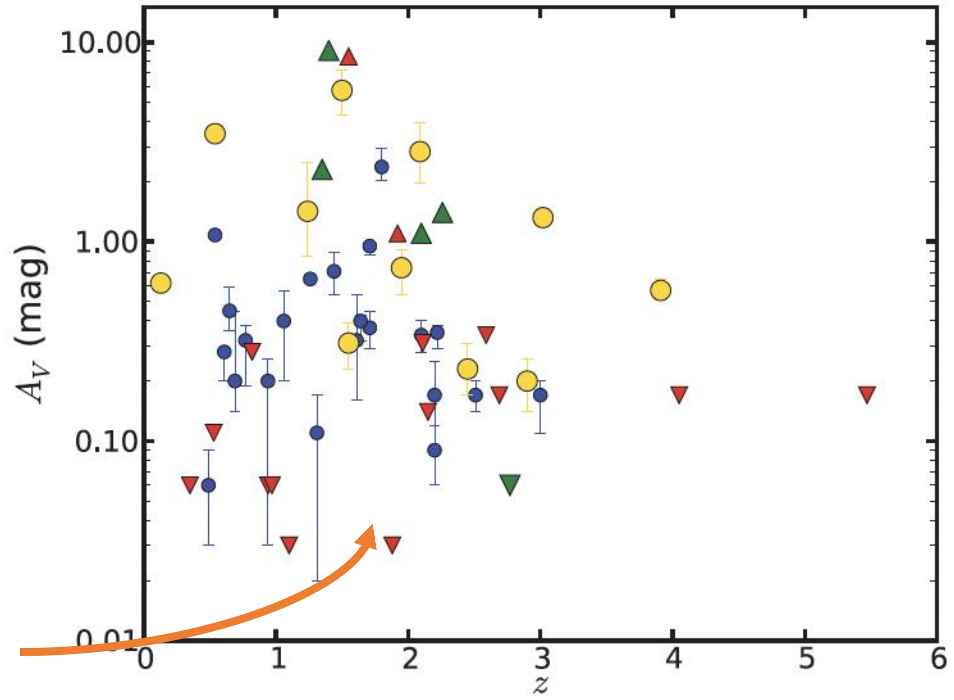
From Pei (1992)

GRB intrinsic optical extinction

⇩

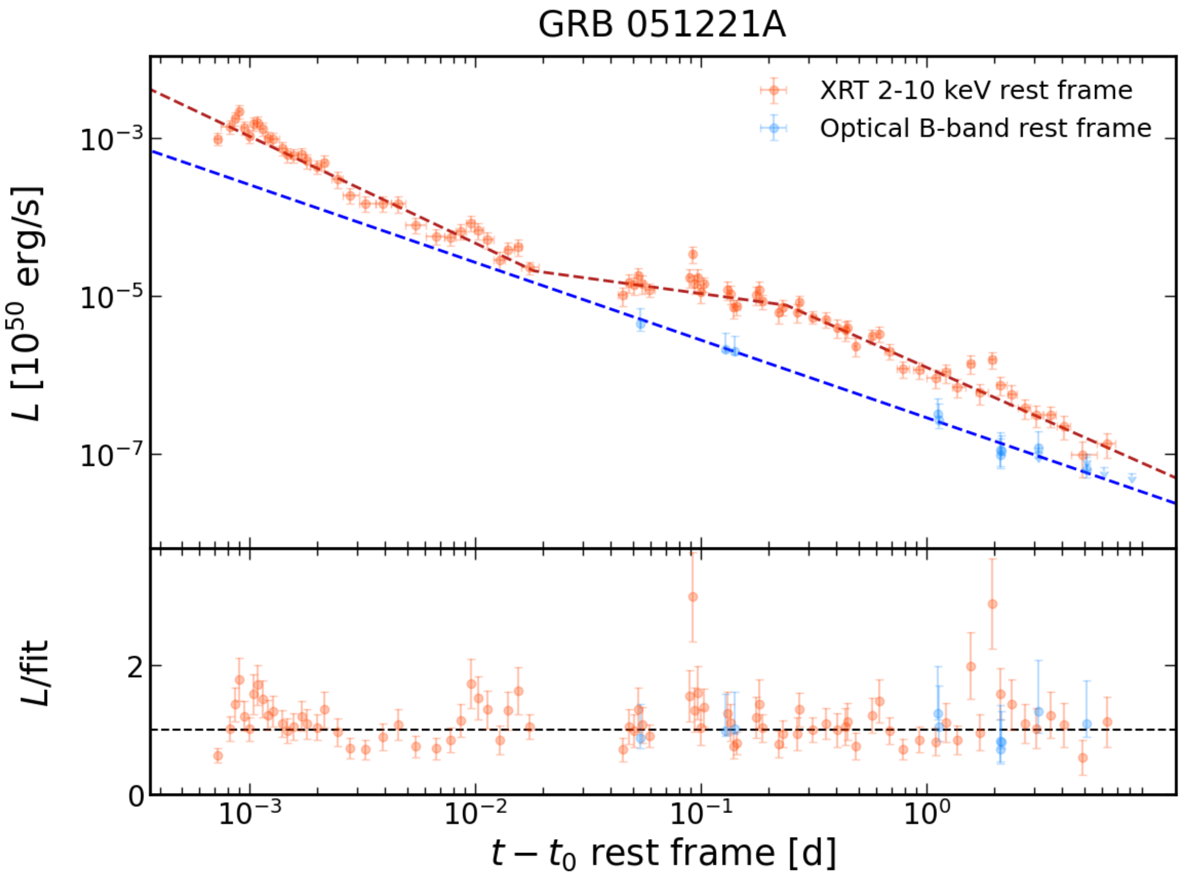
Environment density:
long/short different?

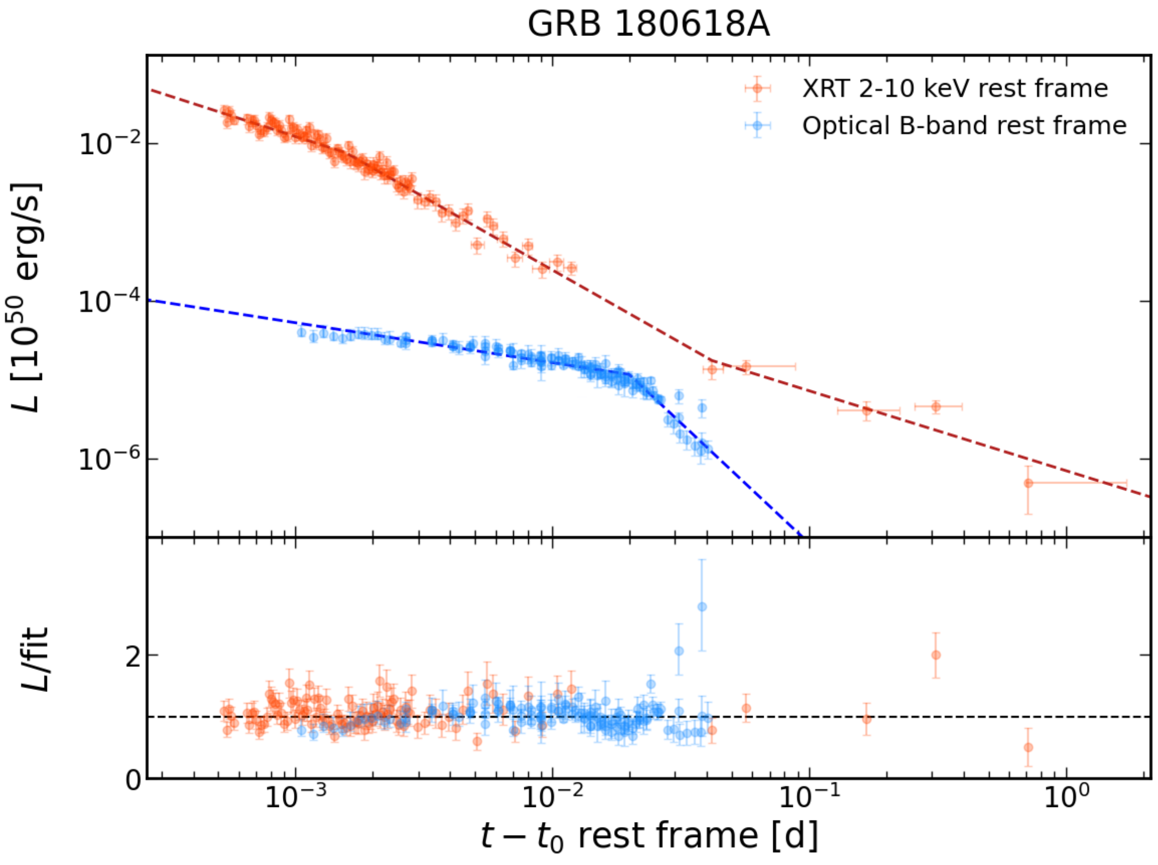
Results for Long GRBs(BAT6)



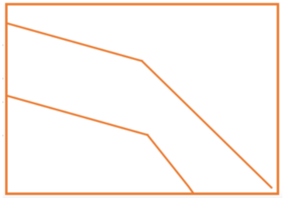
From Covino et al. (2013)

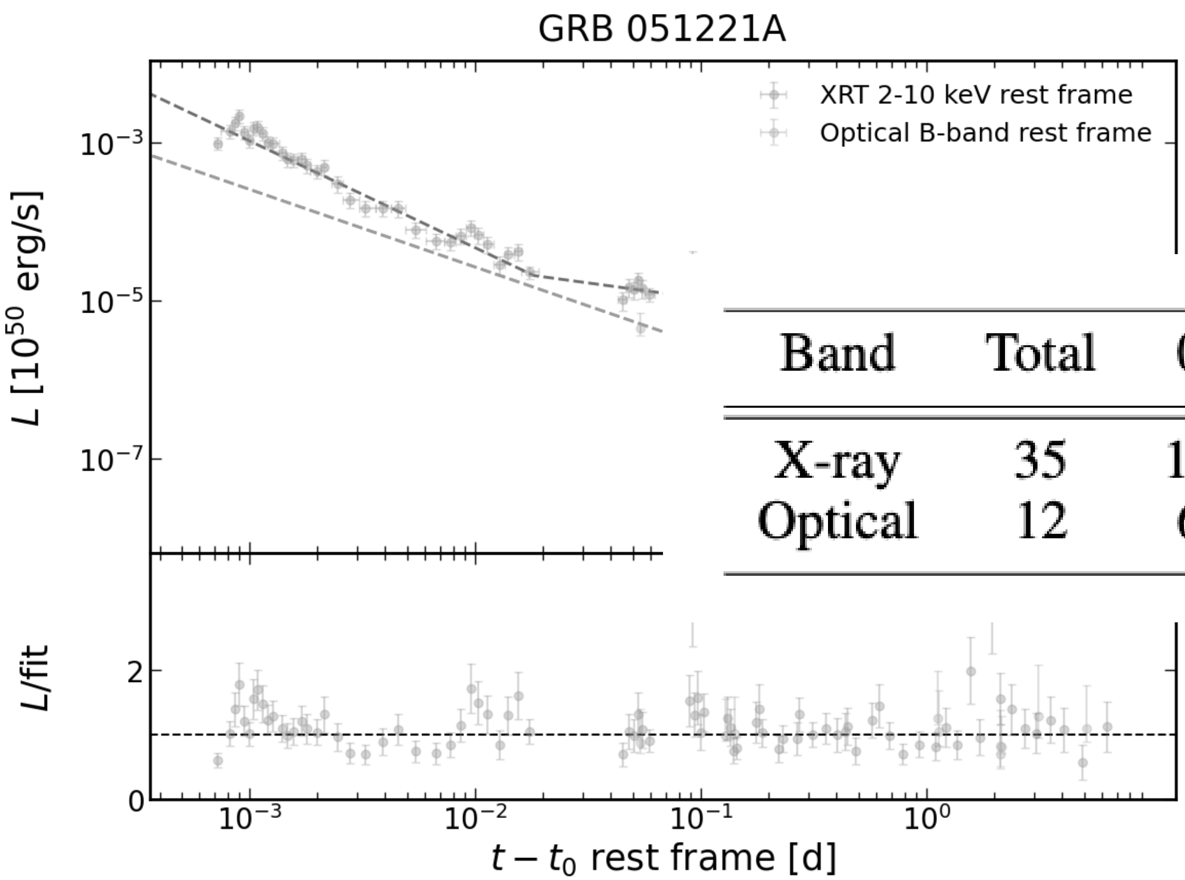
X-ray & optical-NIR light curves



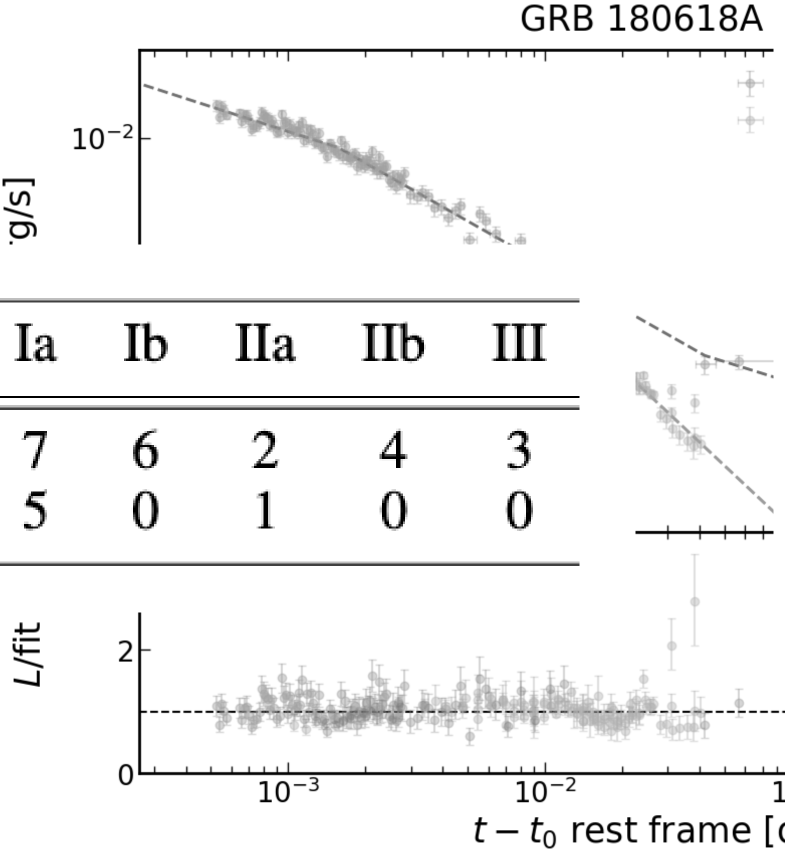


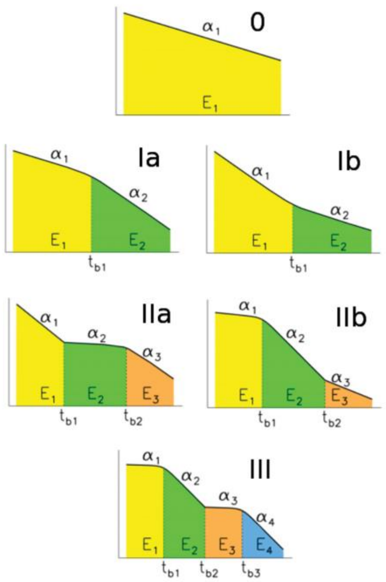
X-ray & optical-NIR light curves classification





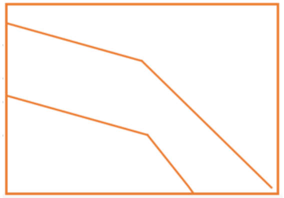
Band	Total	0	Ia	Ib	IIa	IIb	III
X-ray	35	13	7	6	2	4	3
Optical	12	6	5	0	1	0	0





From Margutti et al. (2013)

X-ray & optical-NIR light curves classification



BAT6

Band	Total	0	Ia	Ib	IIa	IIb	III
X-ray	35	13	7	6	2	4	3
Optical	12	6	5	0	1	0	0

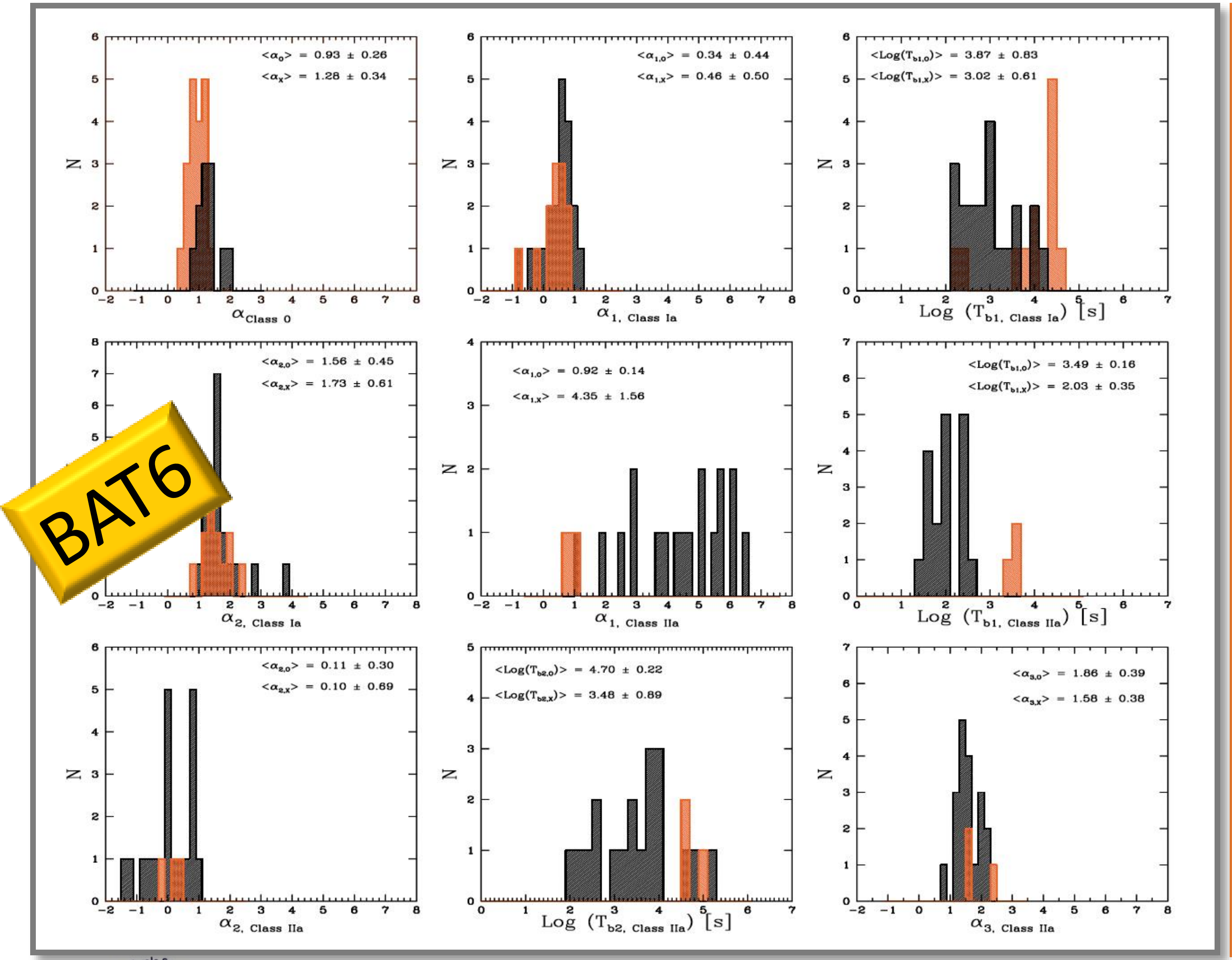
SBAT4

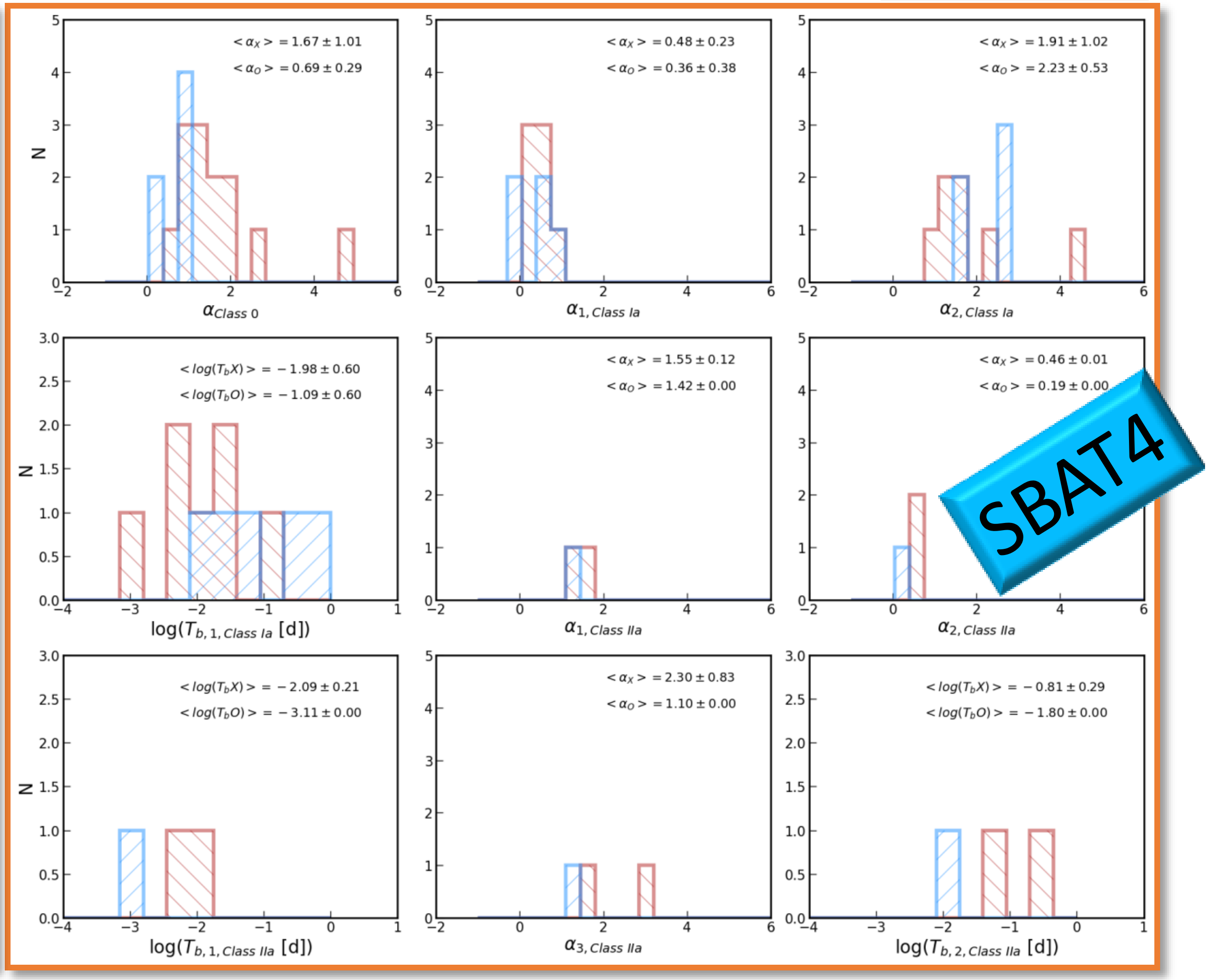
	Total	0	Ia	Ib	IIa	IIb
X-rays	55	11	20	3	20	1
Optical	47	27 (8)	13	4 (2)	3	0

From Melandri et al. (2014)

S-BAT4 – BAT6 afterglow comparison

From Melandri+14





Optical extinction properties