Probing the early X-ray emission of short Gamma-Ray Bursts in the Multi-Messenger Era

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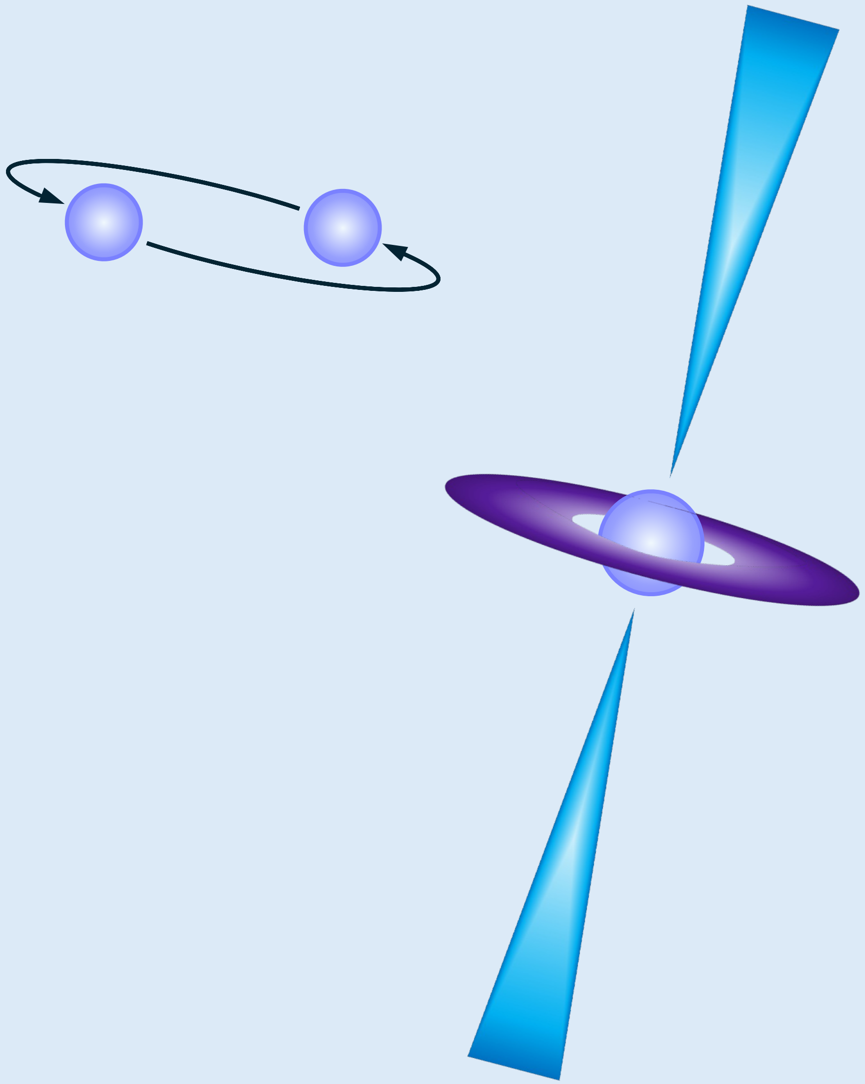
VIRGO

Short GRBs in the multi-messenger era

- Most of short GRBs originate from binary neutron star mergers

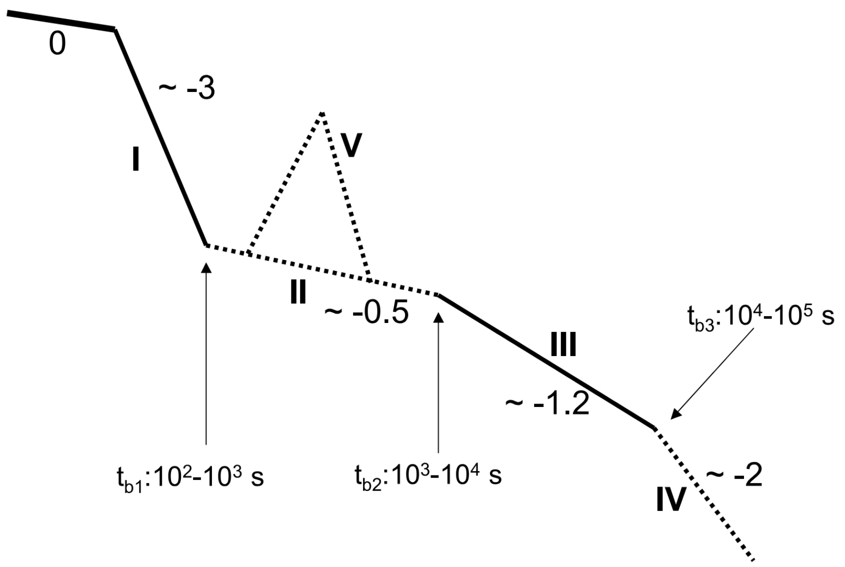
- Early X-ray emission of short GRBs can provide a precise localisation of multi-messenger events

- Newly launched wide-field X-ray monitors could detect these sources

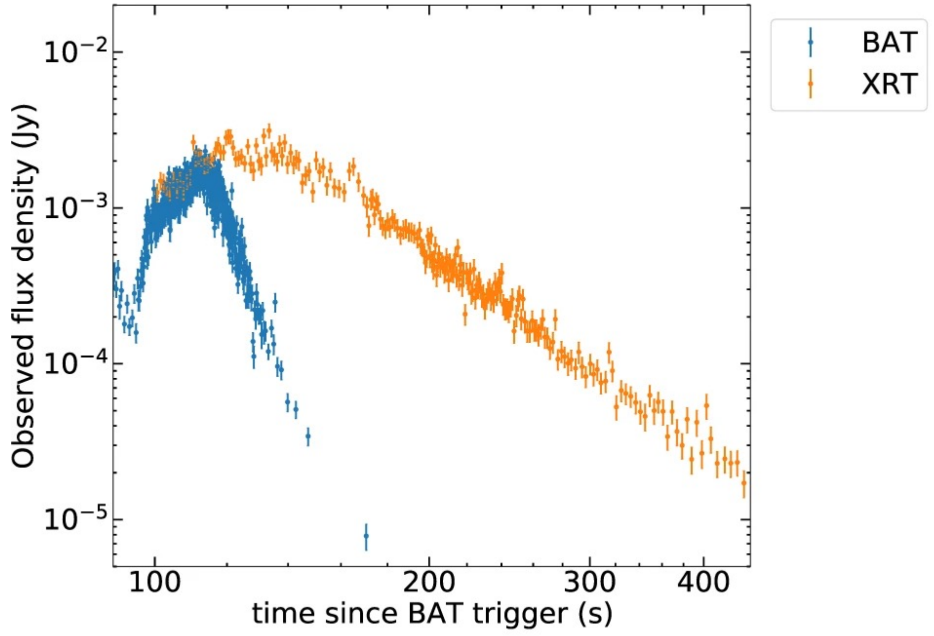


X-ray emission of GRBs

- The *Swift* satellite collected a vast archive of GRB X-ray observations over the last 20 years
- Steep decay in X-ray lightcurve is usually interpreted as the tail of prompt emission
  [Fenimore et al. 1996; Kumar & Painaitescu 2000]
- In long GRBs, we can observe the connection between pulses in hard X-rays and steep decline in soft X-rays



[Zhang et al. 2006]



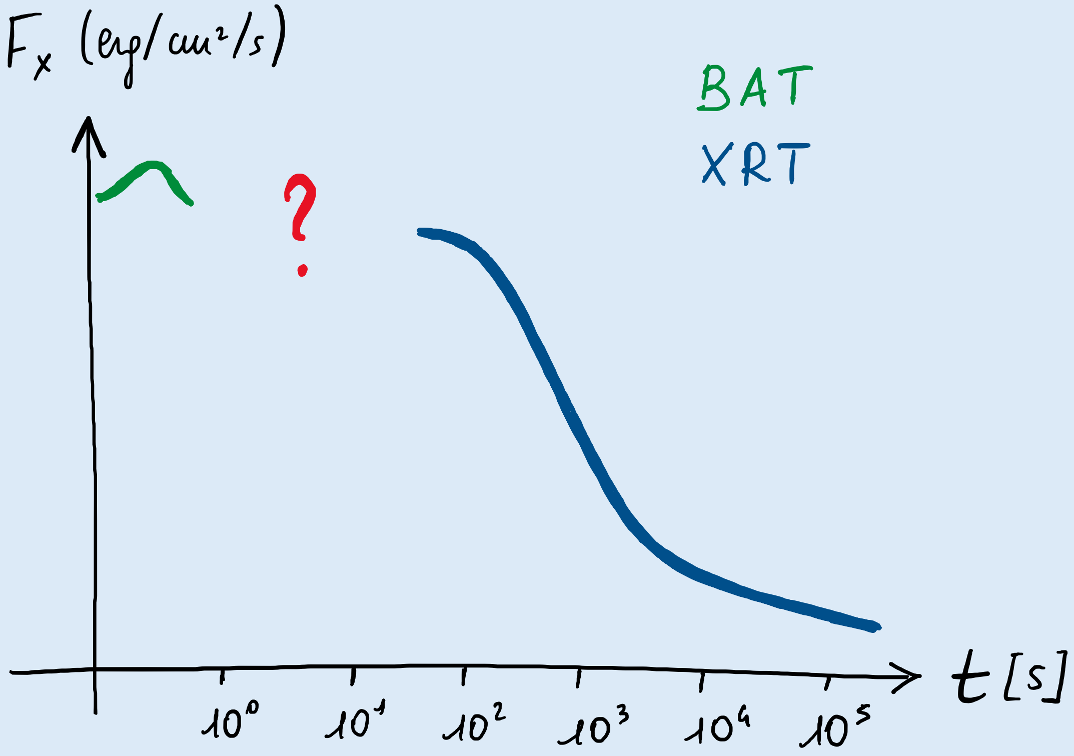
[Ronchini et al. 2021]

X-ray emission of short GRBs

- The prompt-to-afterglow transition is more difficult to study in short GRBs

- In short GRBs we can monitor steep decay for longer time (~15 minutes) compared to long GRBs (~2 minutes)

In this work, we systematically analyse the temporal and spectral evolution of early X-ray emission in short GRBs



1. Sample selection

Sample selection

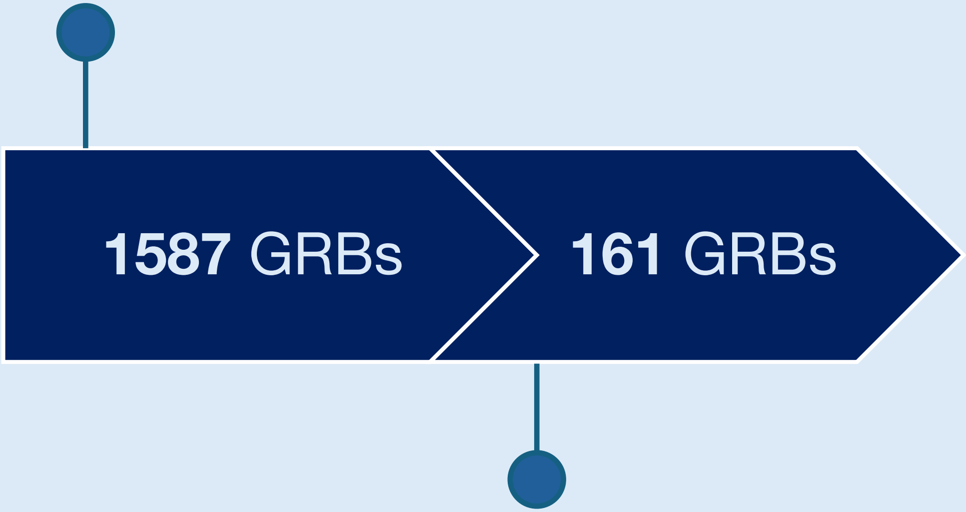
1. Swift BAT catalog

1587 GRBs

- **138** have $T_{90}^{BAT}(15\text{-}350\ \mathrm{keV}) < 2\ \mathrm{s}$
- **472** detected also by Fermi GBM

Sample selection

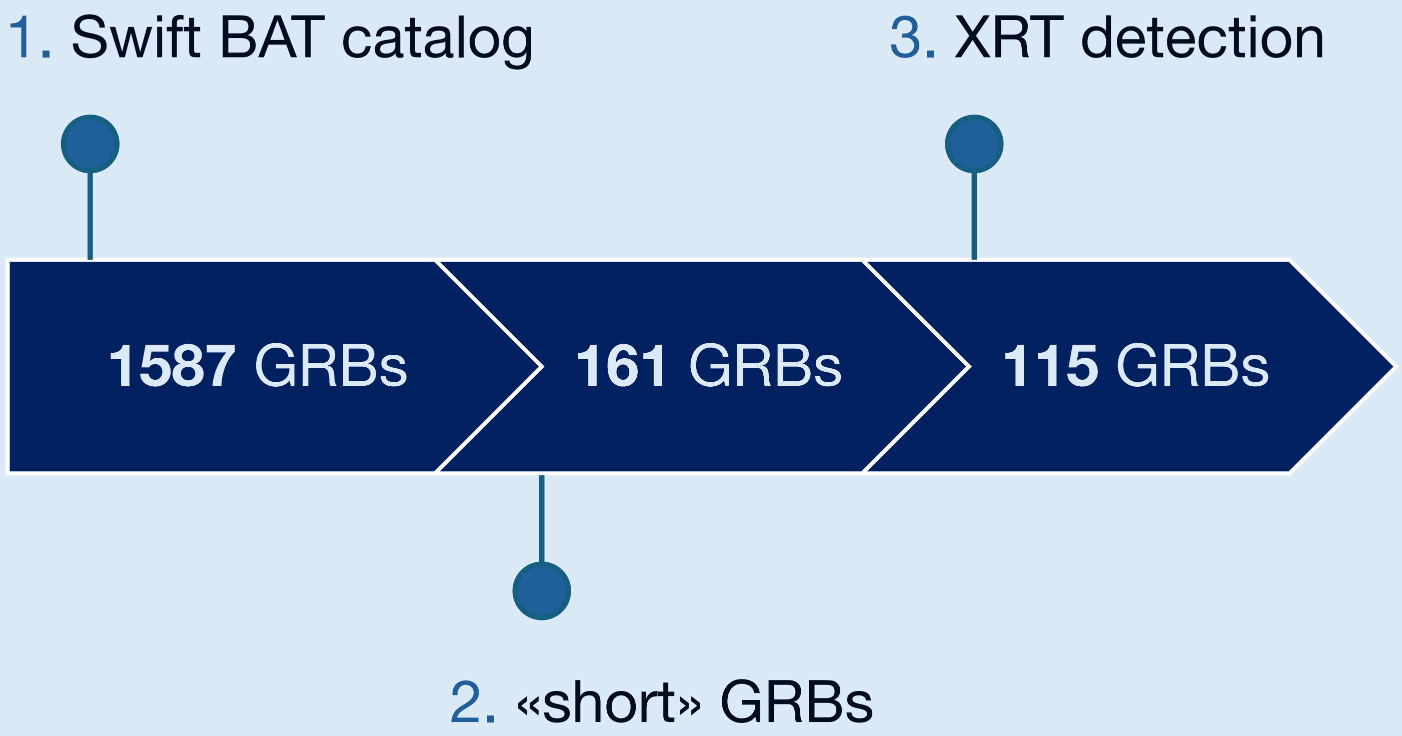
1. Swift BAT catalog



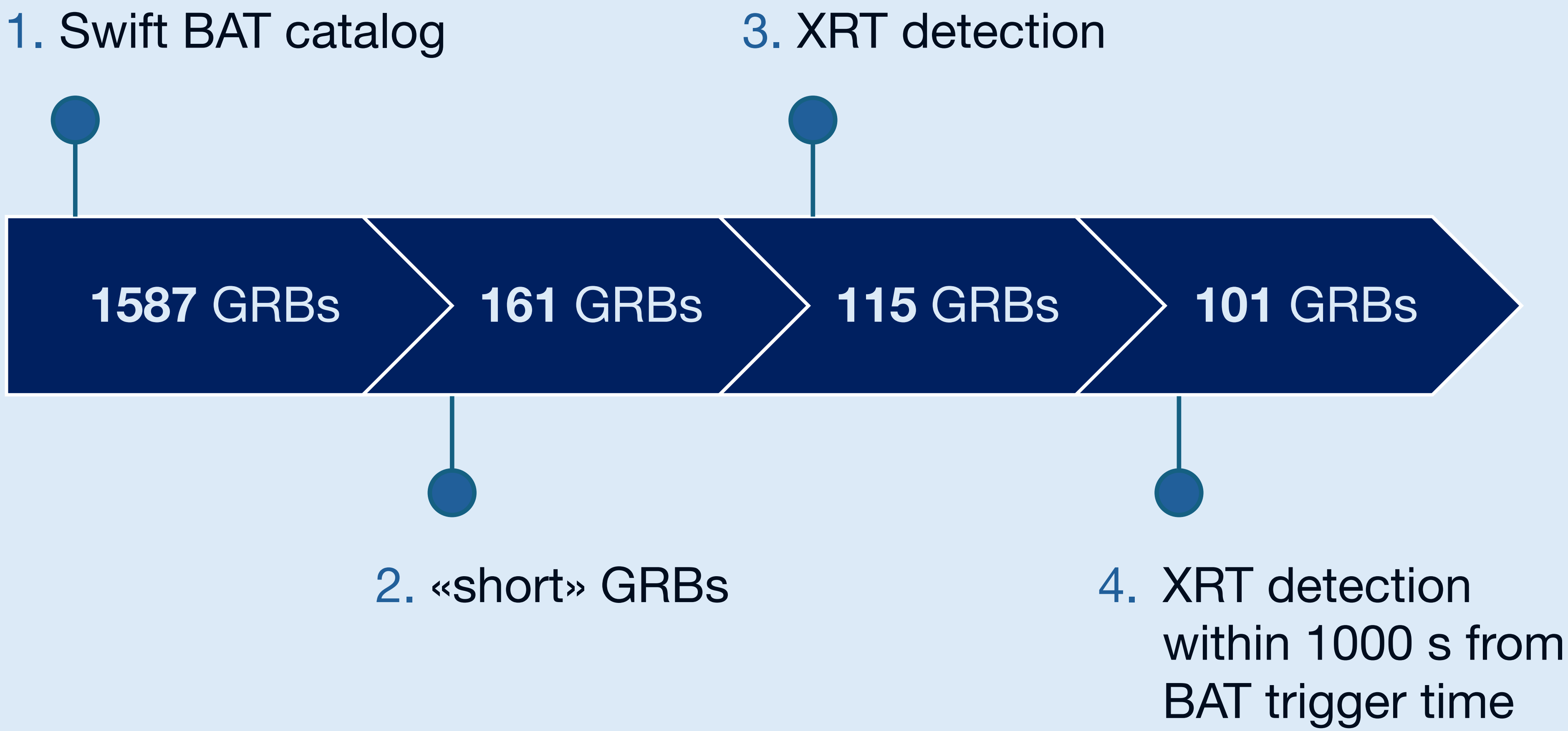
2. «short» GRBs

- BAT short GRBs (**138**)
- Short GRBs with extended emission (EE) in BAT catalog (**16**)
- GRBs long in BAT and short in GBM (**9**)

Sample selection



Sample selection



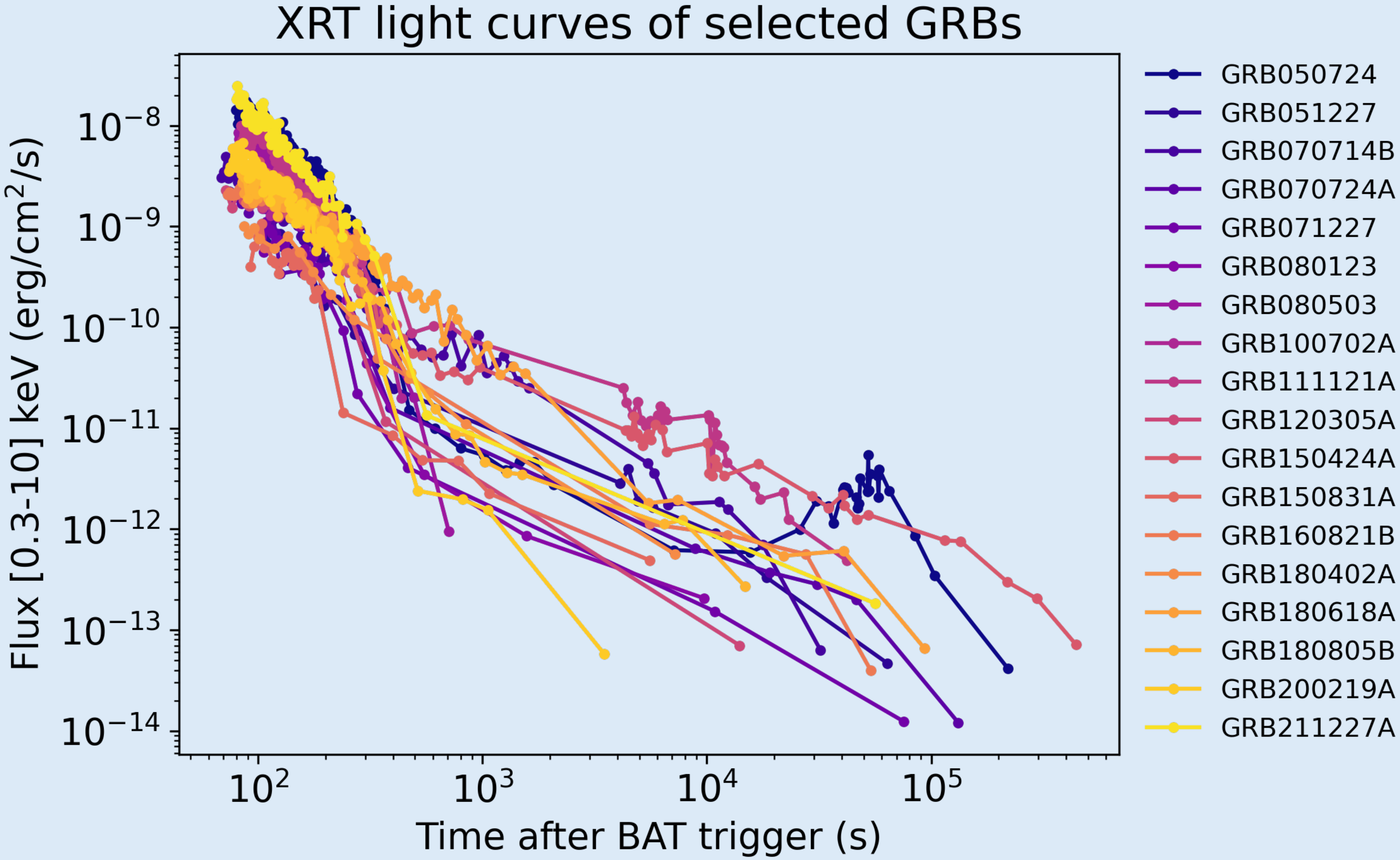
Sample selection

1. Swift BAT catalog
3. XRT detection
5. Spectral evolution

1587 GRBs → **161** GRBs → **115** GRBs → **101** GRBs → **18** GRBs

2. «short» GRBs
4. XRT detection within 1000 s from BAT trigger time

Final sample



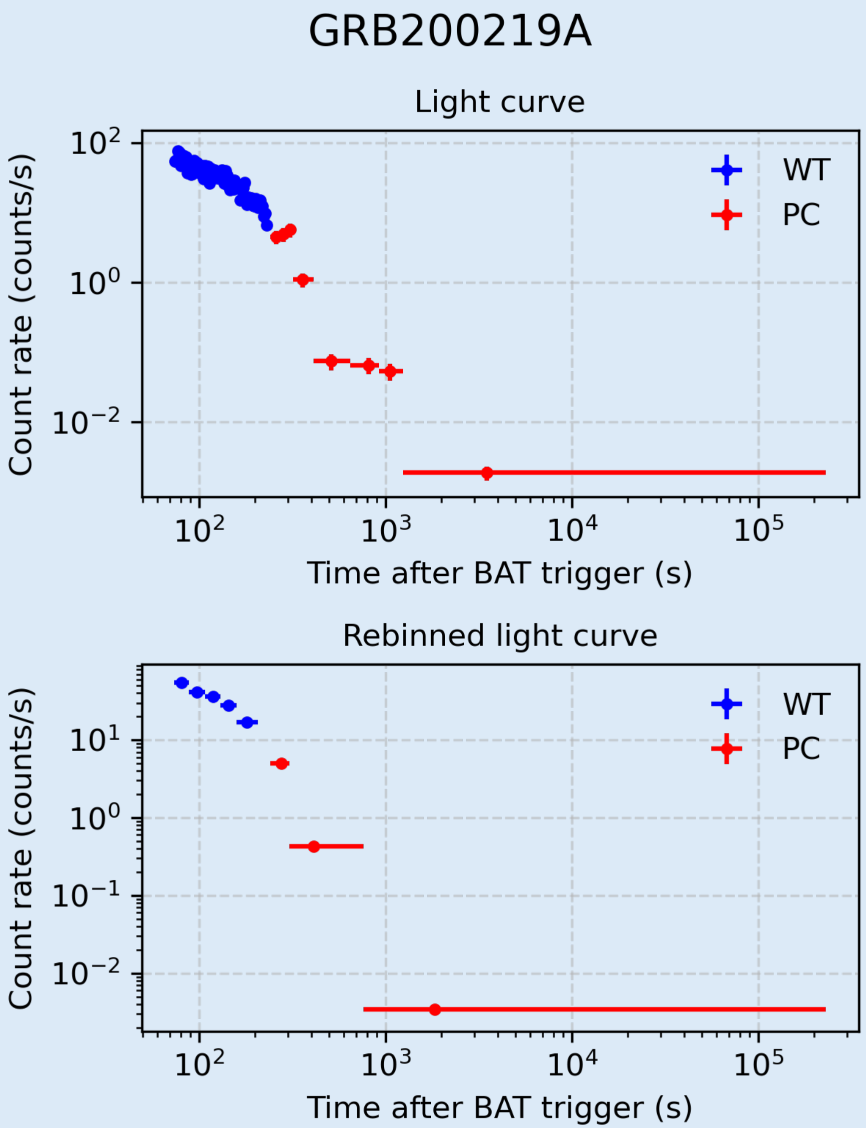
12 GRBs have EE detected by BAT

2. Data analysis

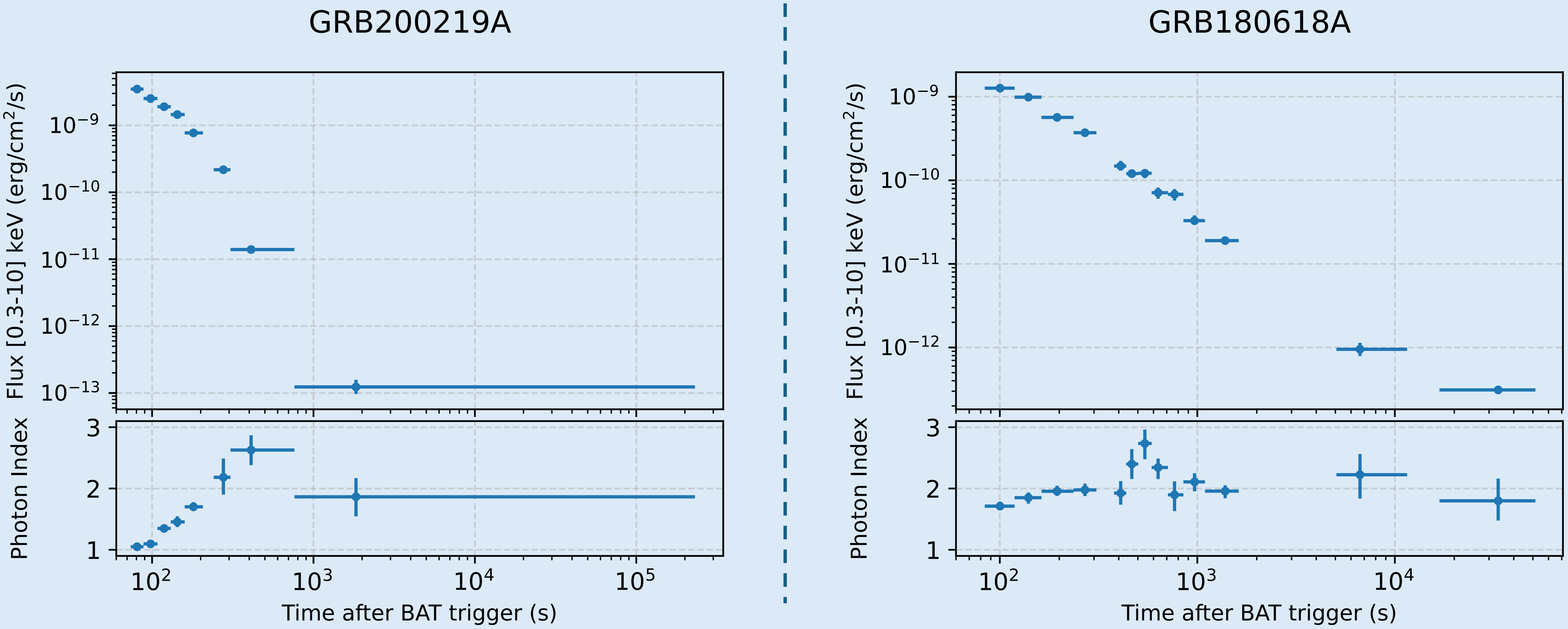
XRT data analysis

- Time-resolved spectral analysis of XRT data in [0.3 - 10] keV energy range
- Spectrum model: absorbed power-law
- The absorber column density N_H^z and the photon index are degenerate

To break this degeneracy, the spectra of the different temporal bins are fitted together, leaving N_H^z as free common parameter

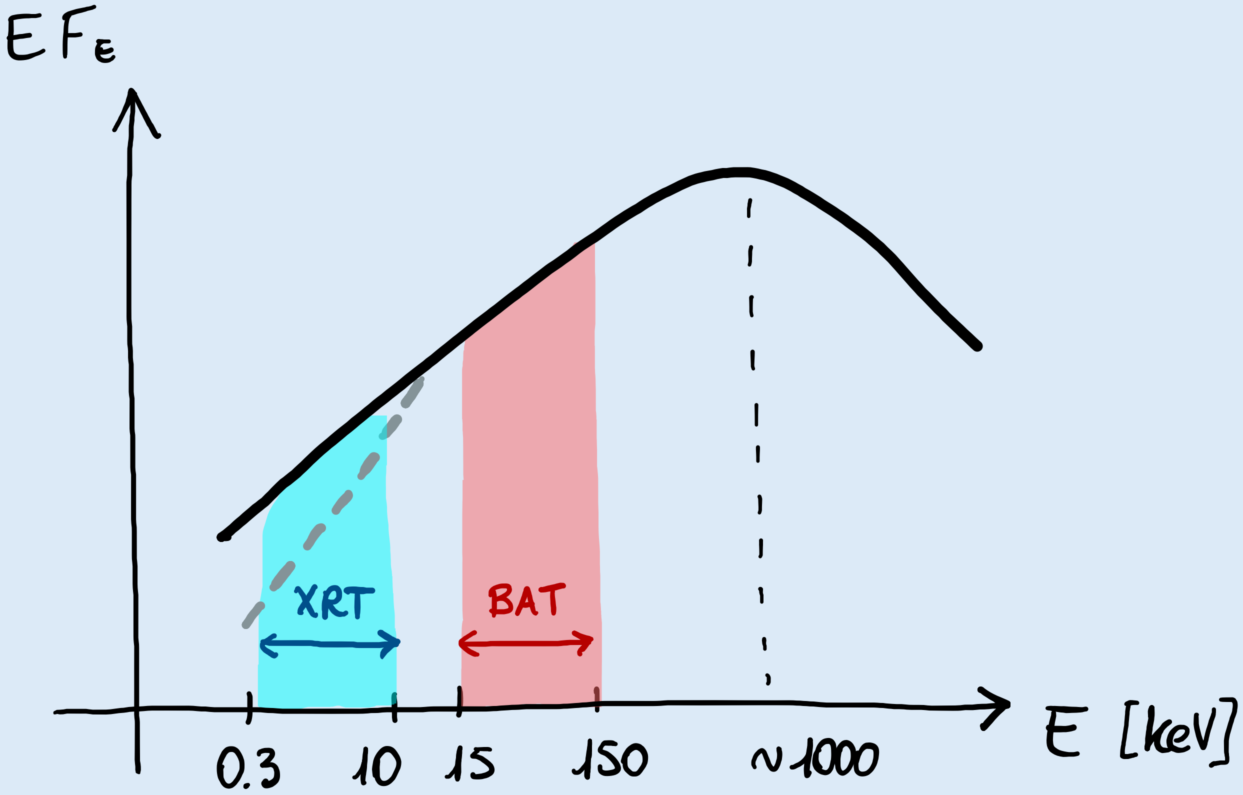


XRT spectral analysis

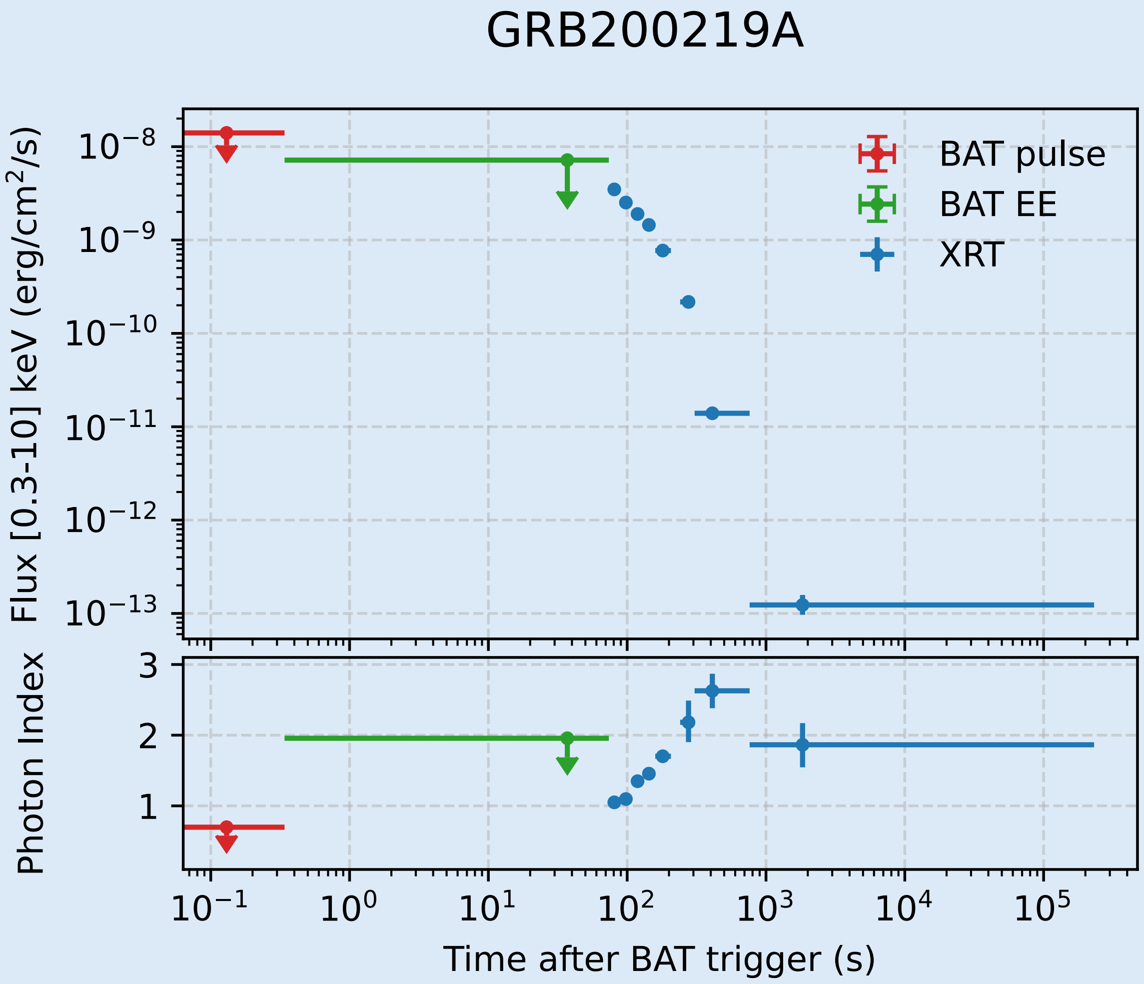


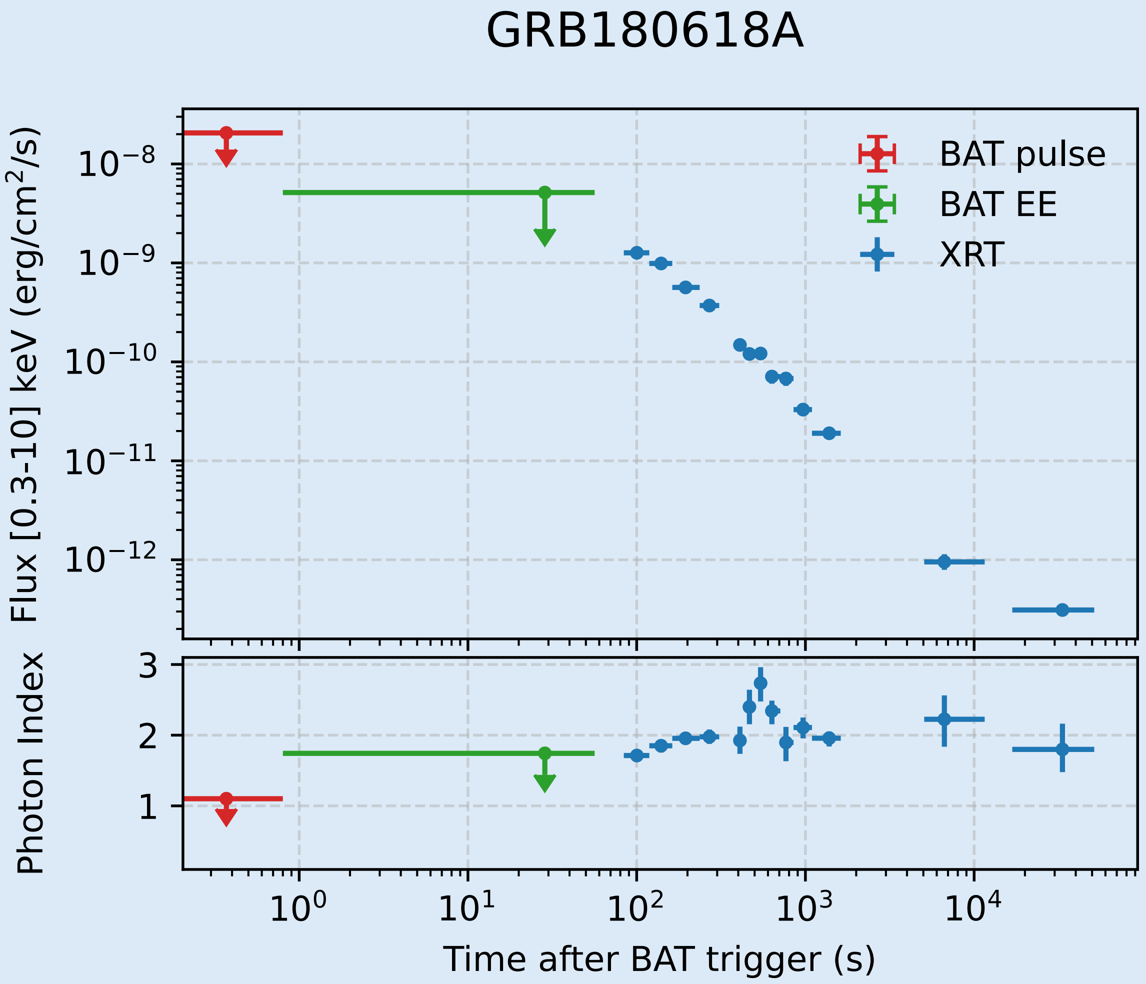
BAT data analysis

- Spectral analysis of BAT short pulse and EE (if any) in [15-150] keV energy range
- Spectrum model: power-law
- Extrapolation of BAT spectrum to XRT energy range
- Photon index and flux in [0.3-10] keV are interpreted as upper limits



BAT and XRT spectral analysis

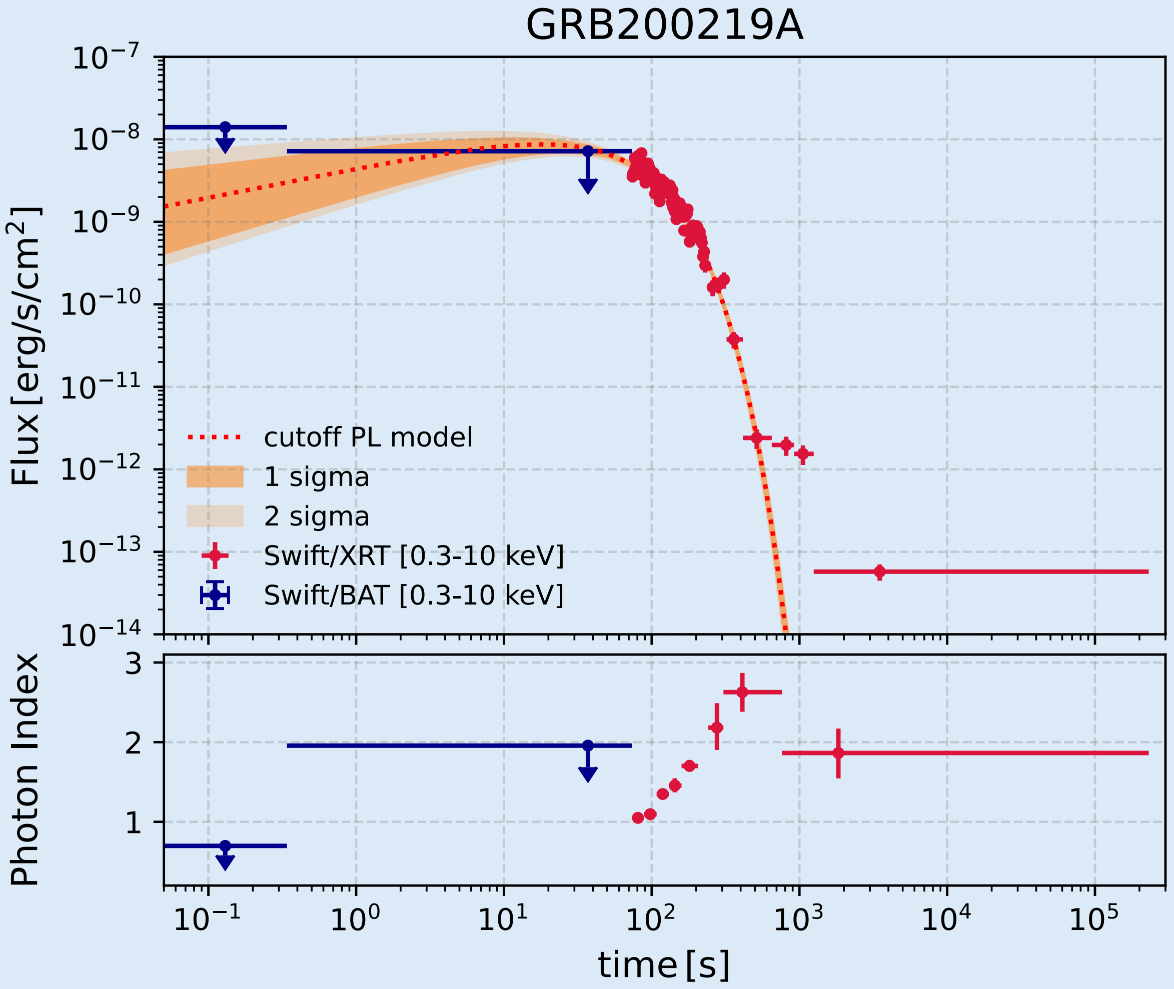


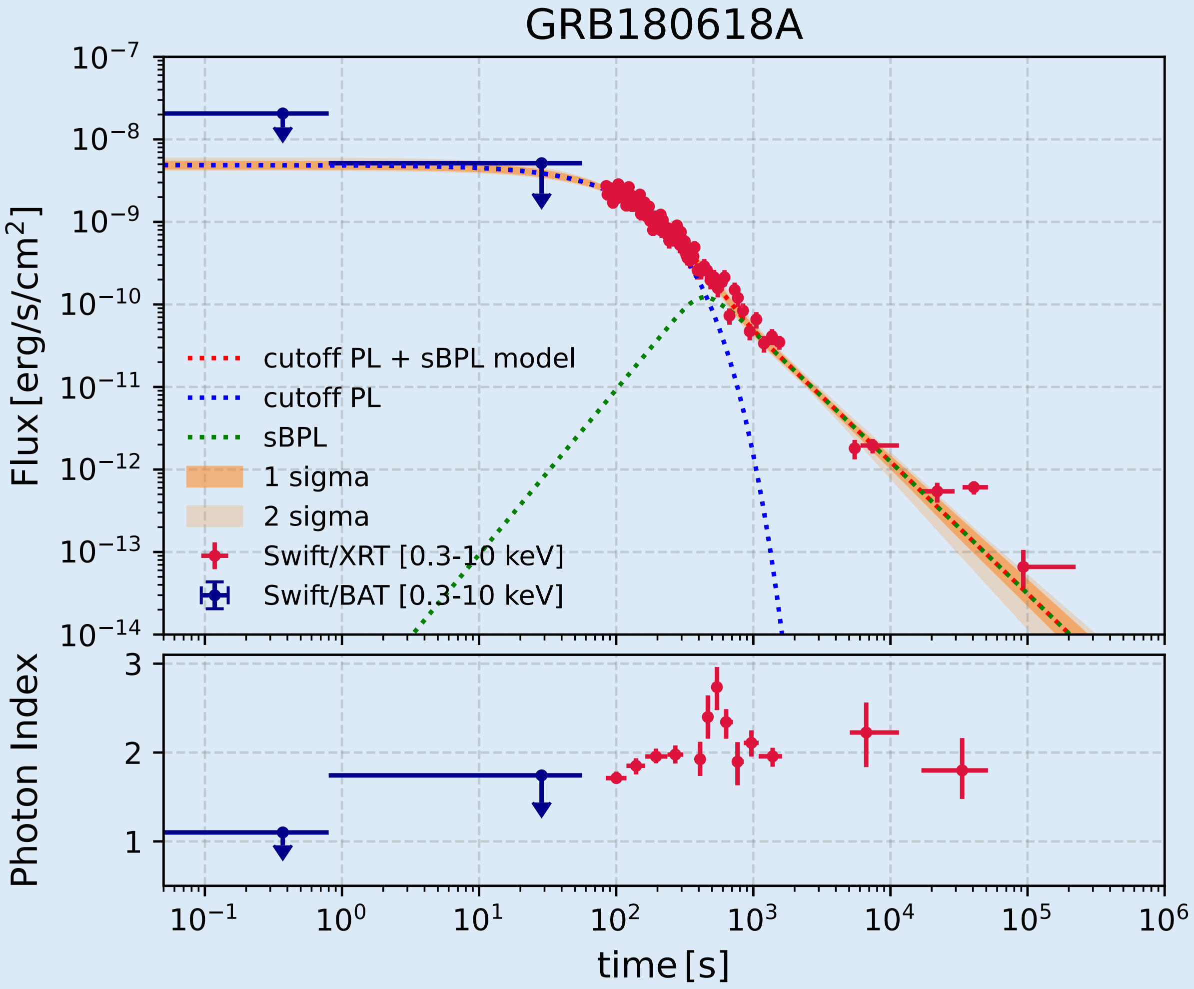


3. Temporal evolution

BAT+XRT lightcurve fit

Cutoff PL + sBPL (if needed) to model the BAT+XRT flux in [0.3-10] keV



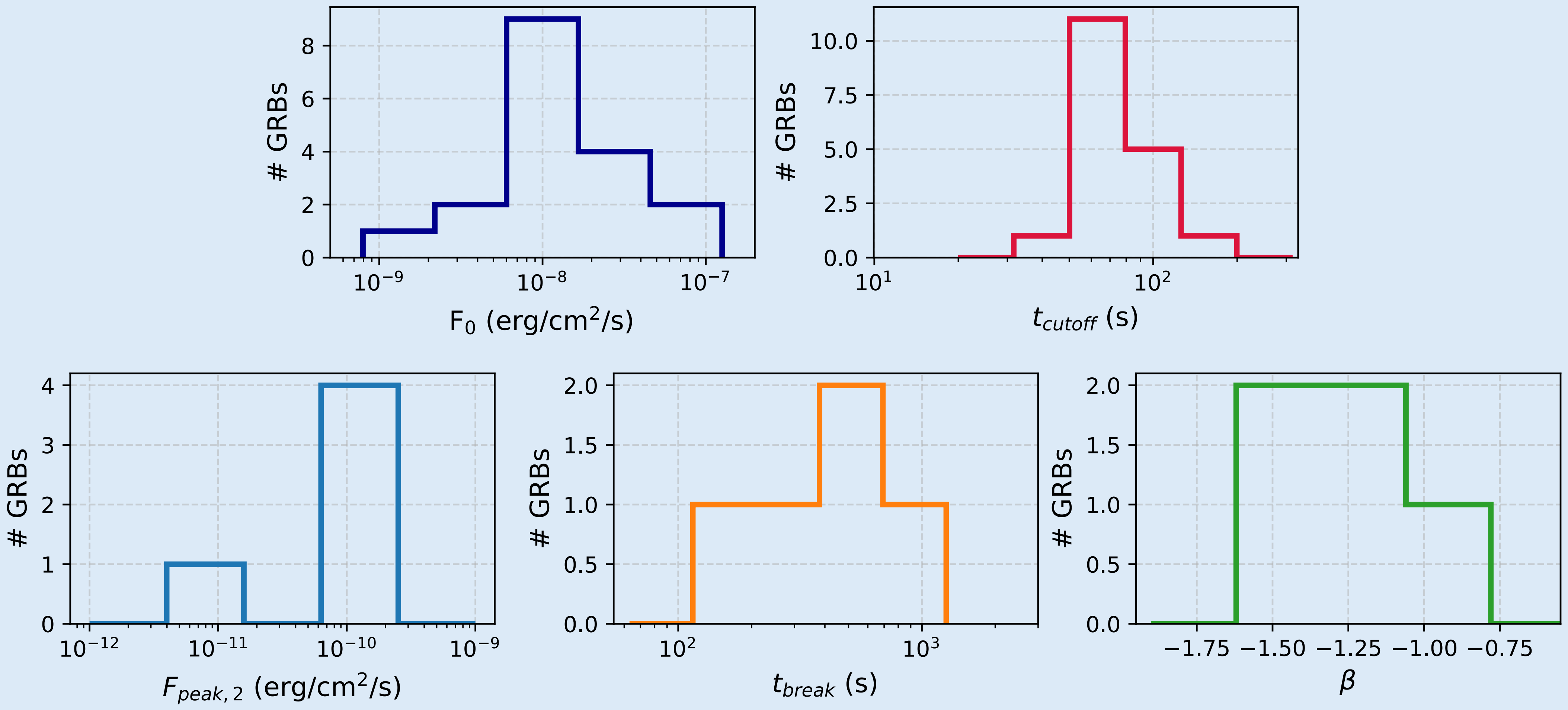


BAT+XRT lightcurve fit

Distribution of the best-fit parameters

Exp cutoff

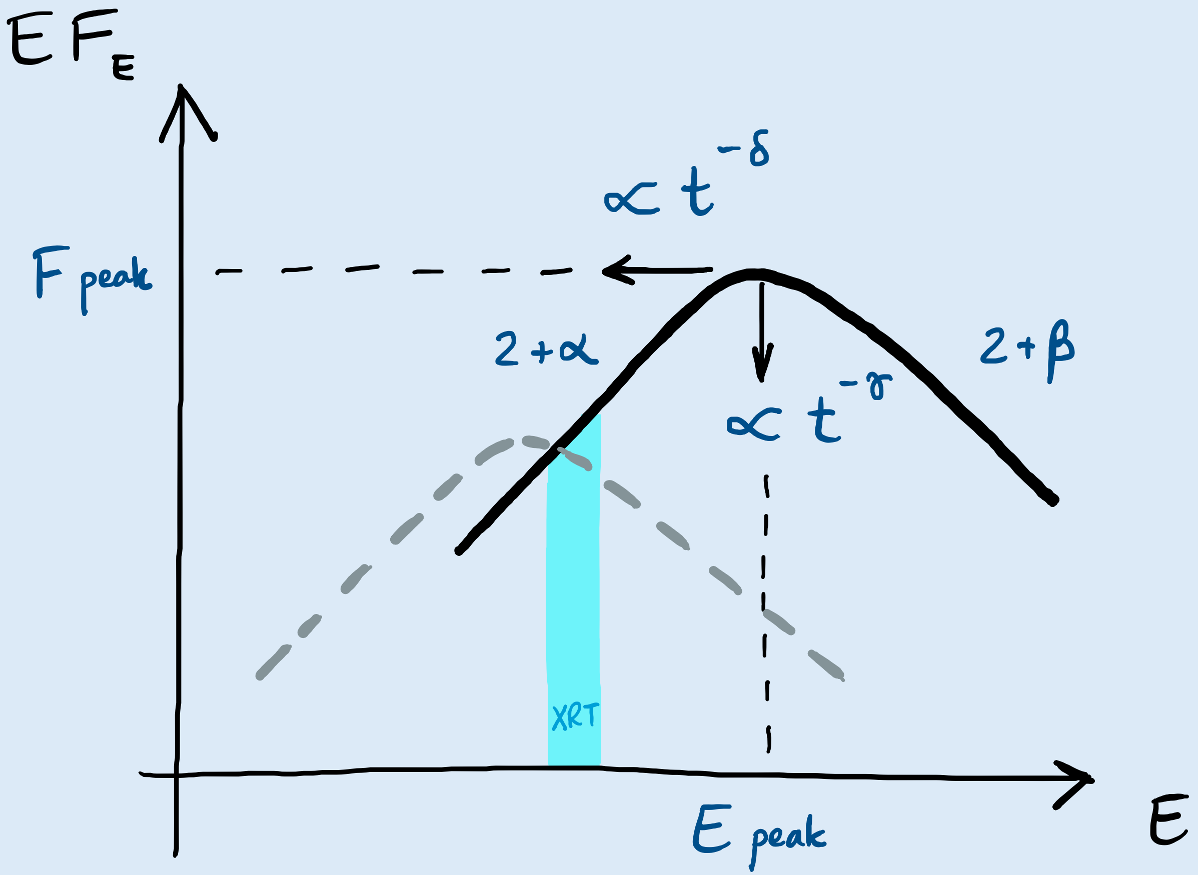
sBPL



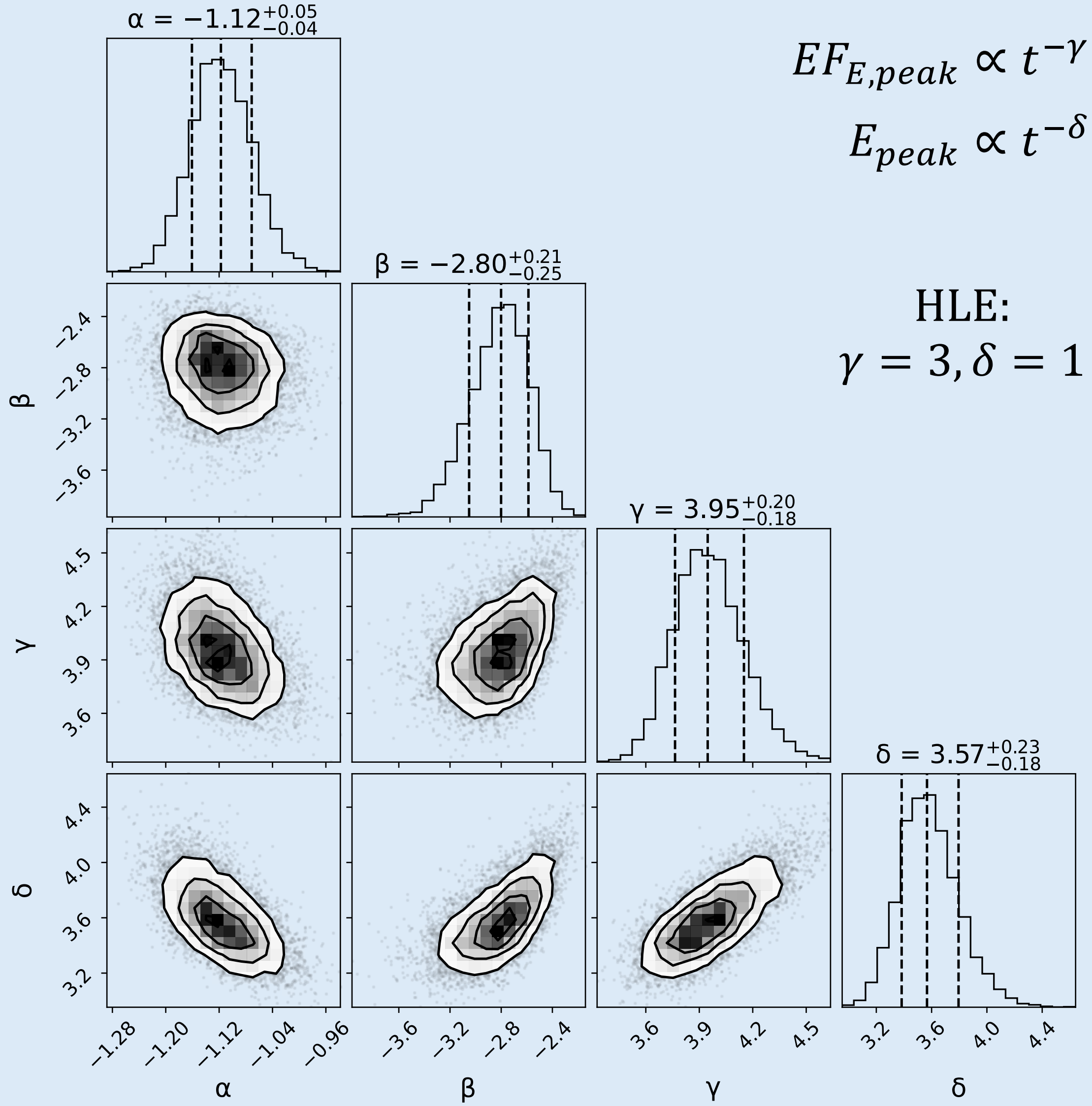
4. Modelling

Modelling

- Empirical modelling of early XRT flux and spectral evolution
- Generic non-thermal spectrum (Band function), whose peak is transiting across the XRT band
- Test if X-ray lightcurve and spectral evolution can be caused by fading of prompt emission
- Free parameters of the model: $E^0_{peak}, EF^0_{E,peak}, \alpha, \beta, \gamma, \delta$

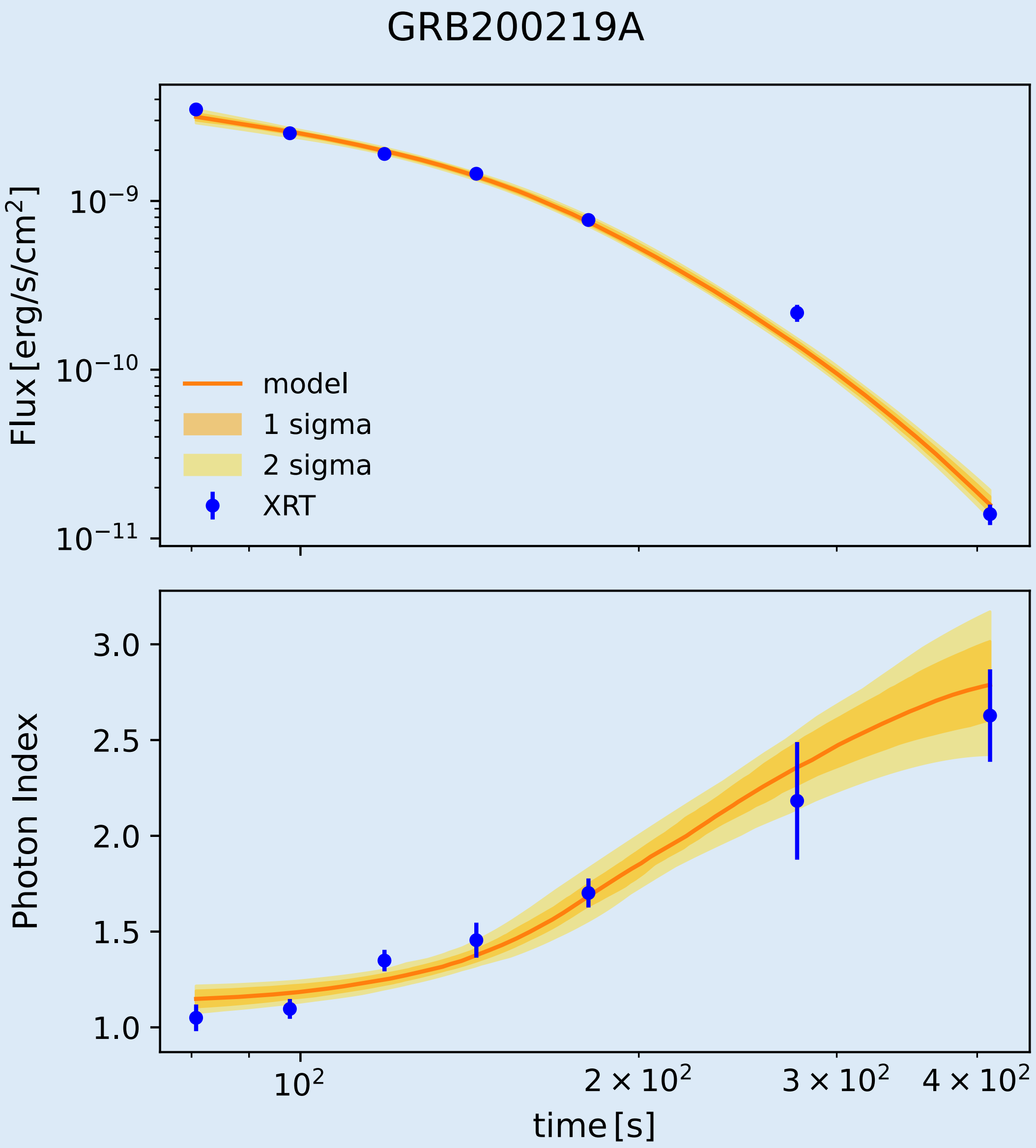


Modelling

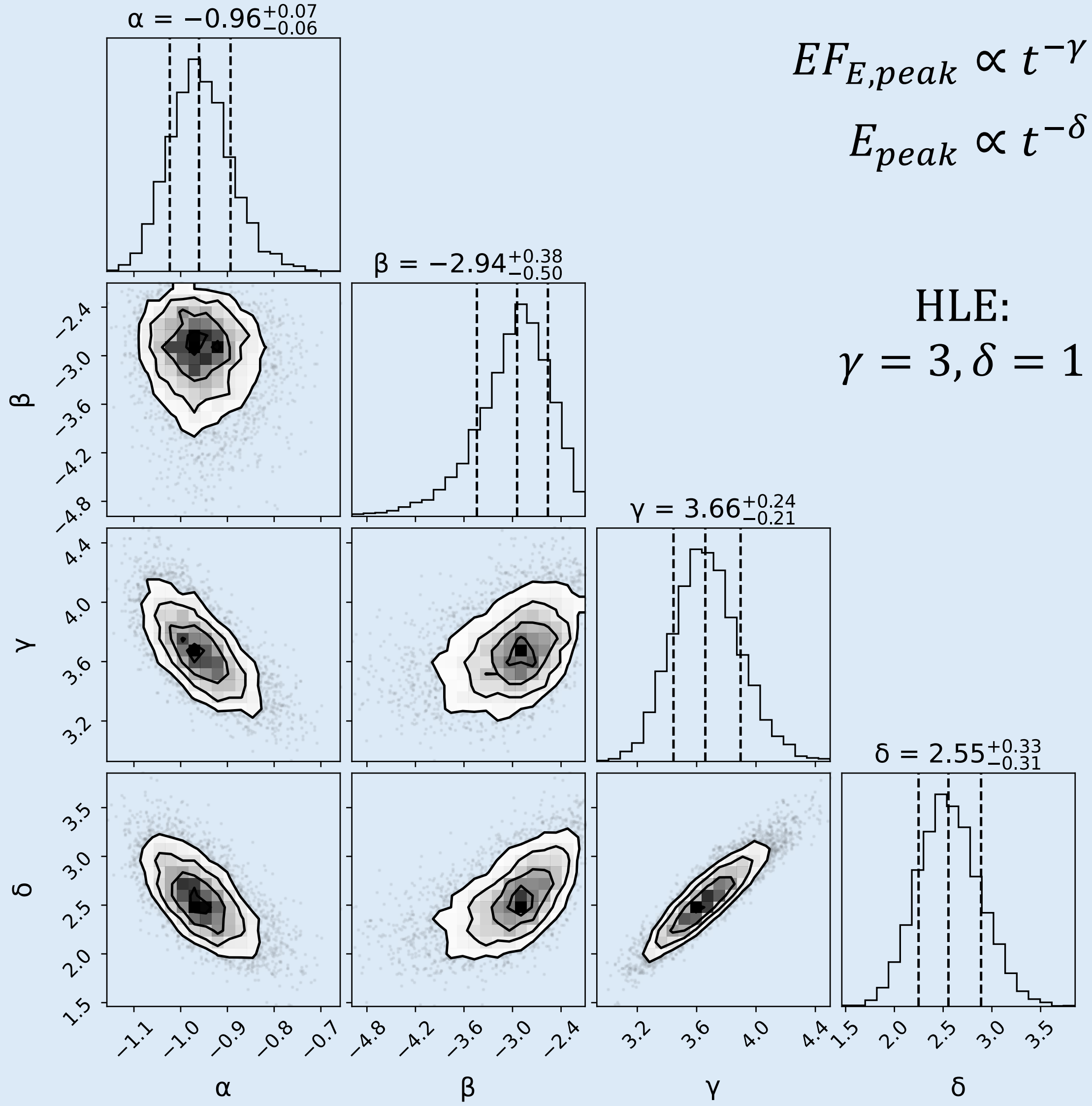


$$EF_{E,peak} \propto t^{-\gamma}$$
$$E_{peak} \propto t^{-\delta}$$

HLE:
$\gamma = 3, \delta = 1$



Modelling



$$EF_{E,peak} \propto t^{-\gamma}$$

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HLE:

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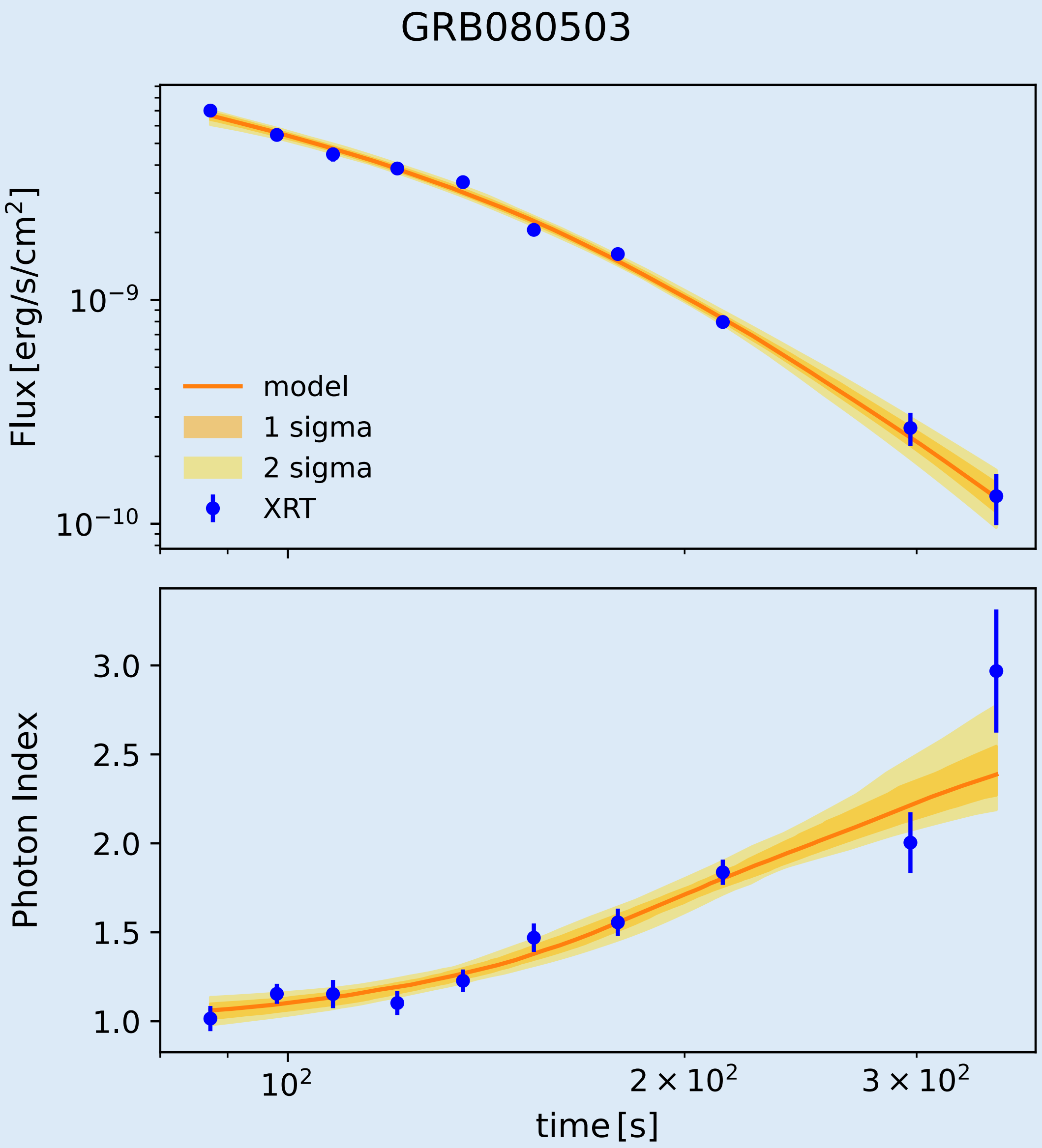
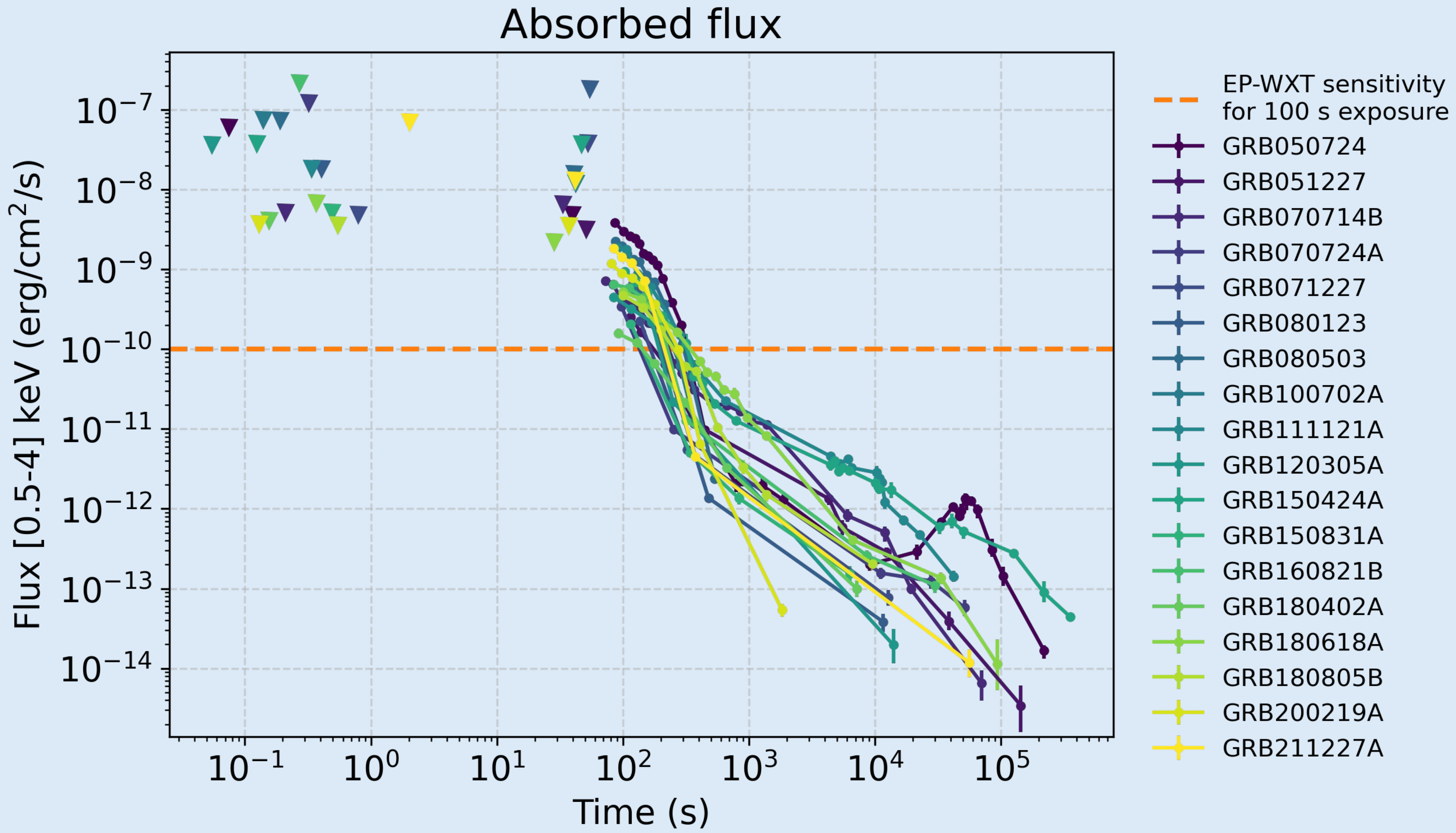


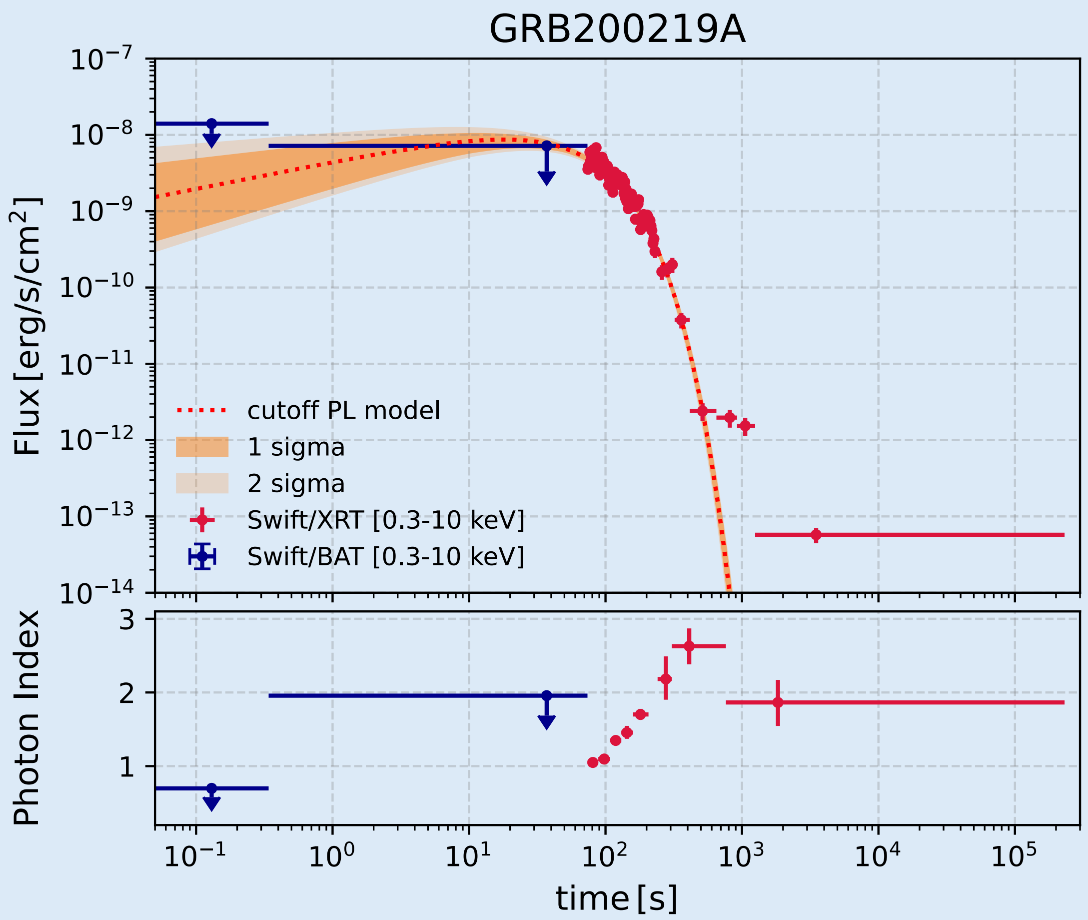
5. Detectability

Detectability with wide-field X-ray cameras



Summary

- All short GRBs in our sample show spectral softening in early X-ray emission
- Flux in soft X-rays can be modelled with two components
- We interpreted temporal and spectral evolution as the cooling of a non-thermal spectrum
- This category of short GRBs can be detected by current wide-field X-ray monitors



Backup

Sample selection

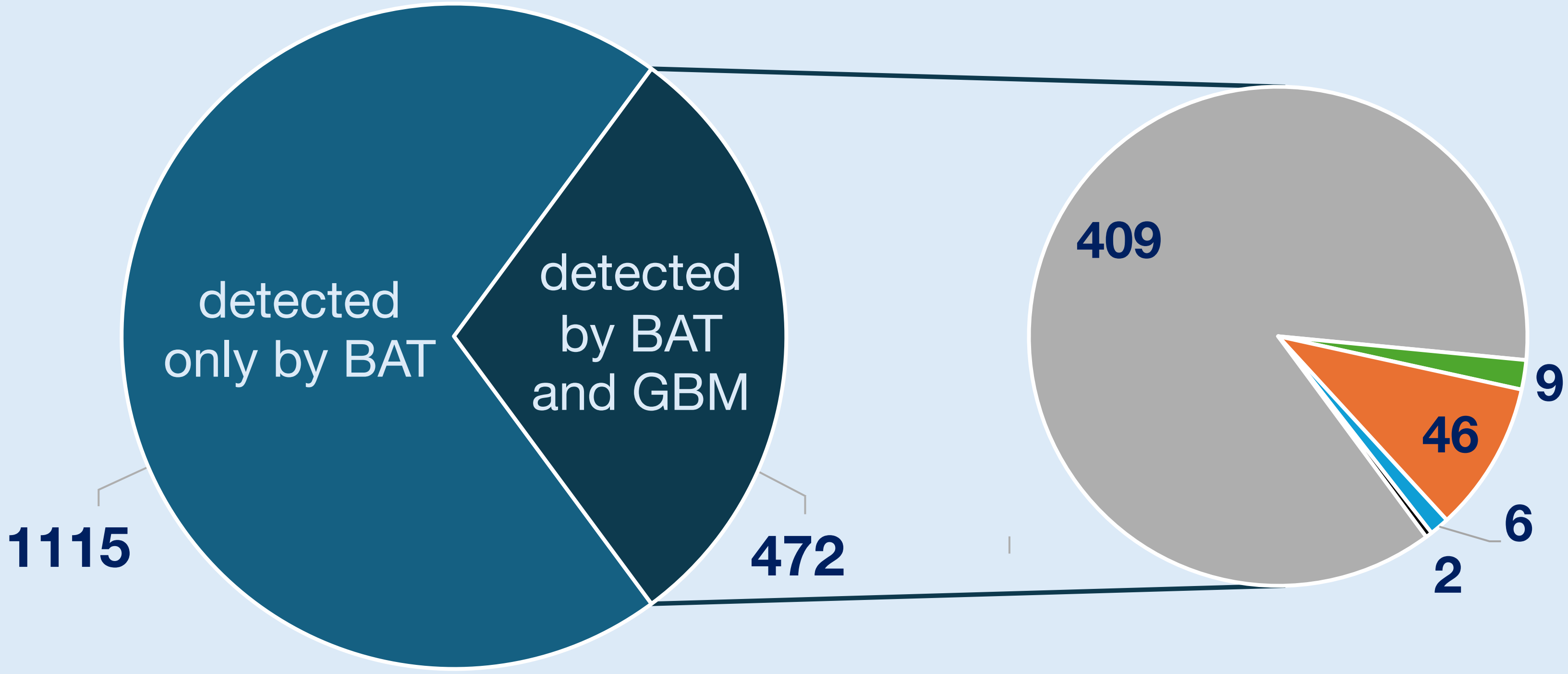
1. Swift BAT catalog

1587 GRBs

138 GRBs short in BAT

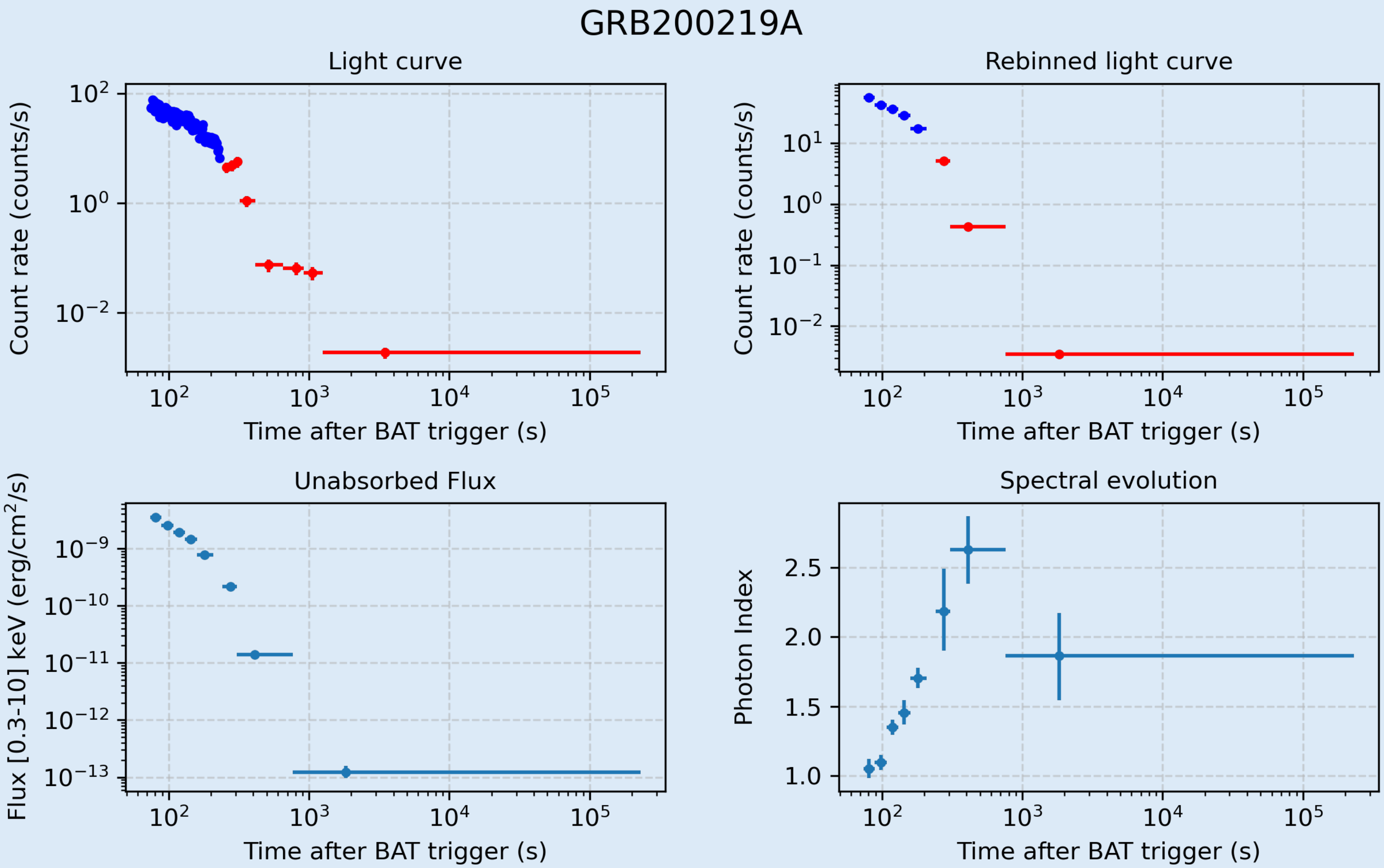
T_{90}^{BAT}(15-350 keV) < 2 s

GRBs in BAT catalog

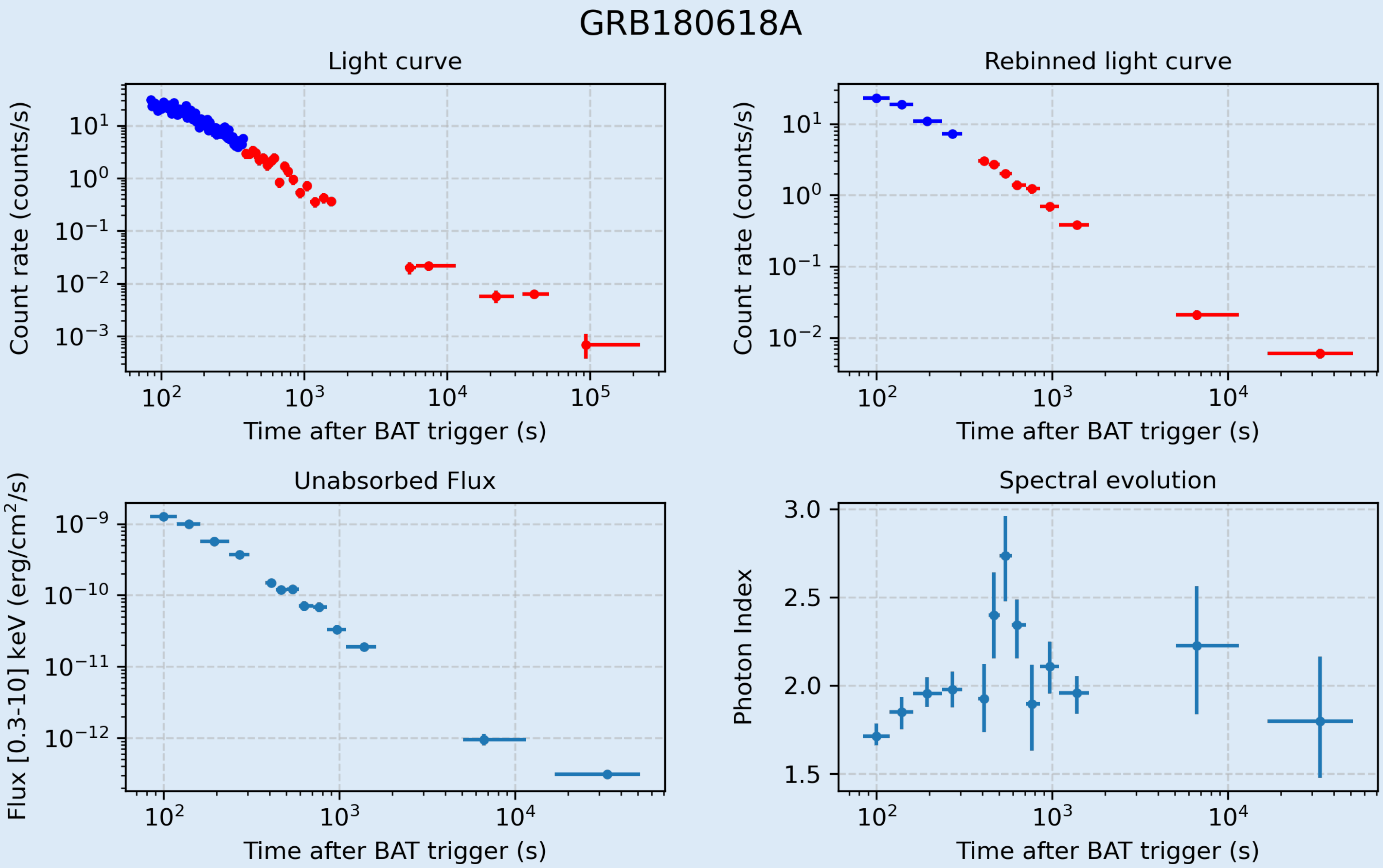


- long in BAT, long in GBM
- short in BAT, short in GBM
- BAT duration not available
- long in BAT, short in GBM
- short in BAT, long in GBM

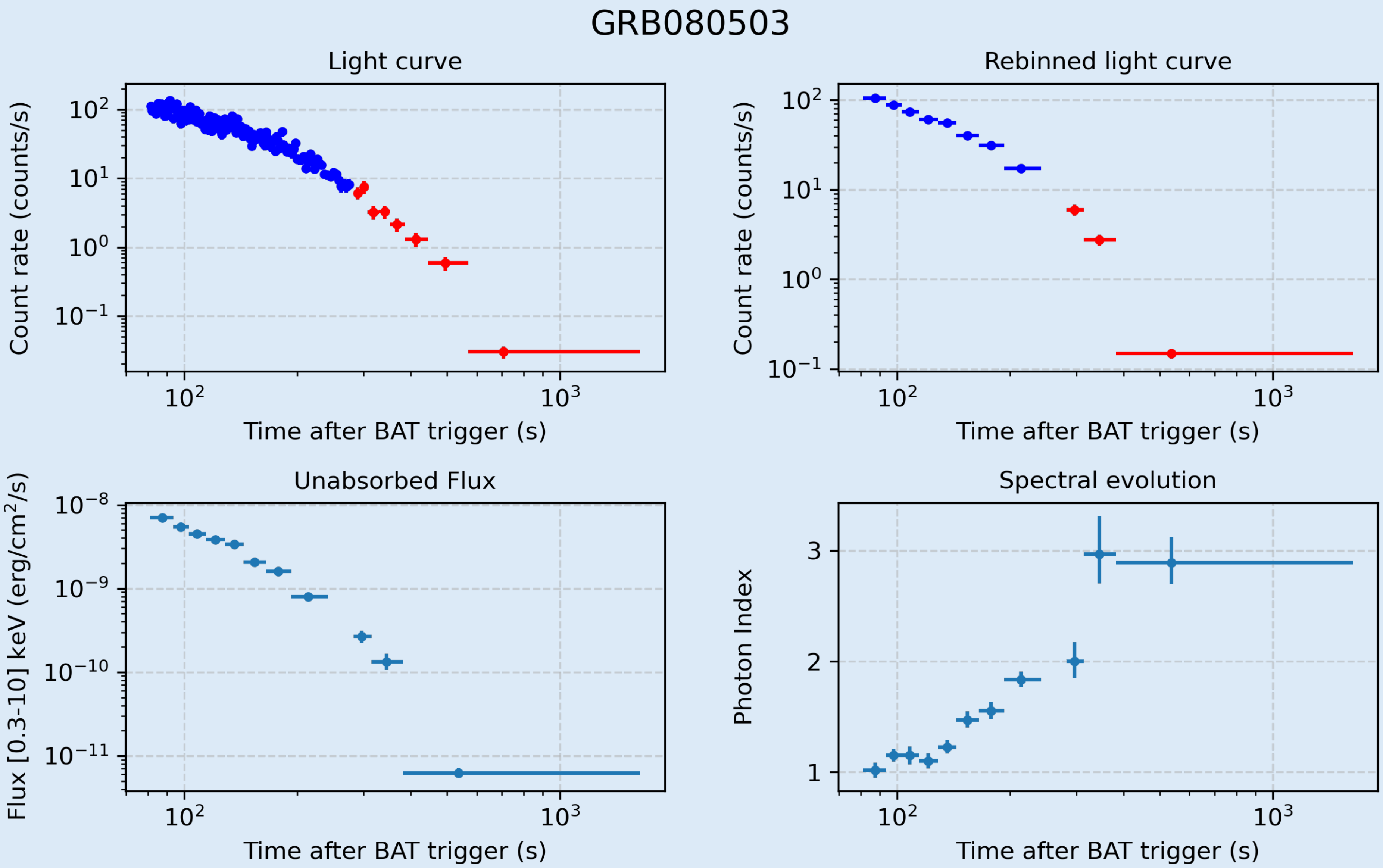
XRT spectral analysis



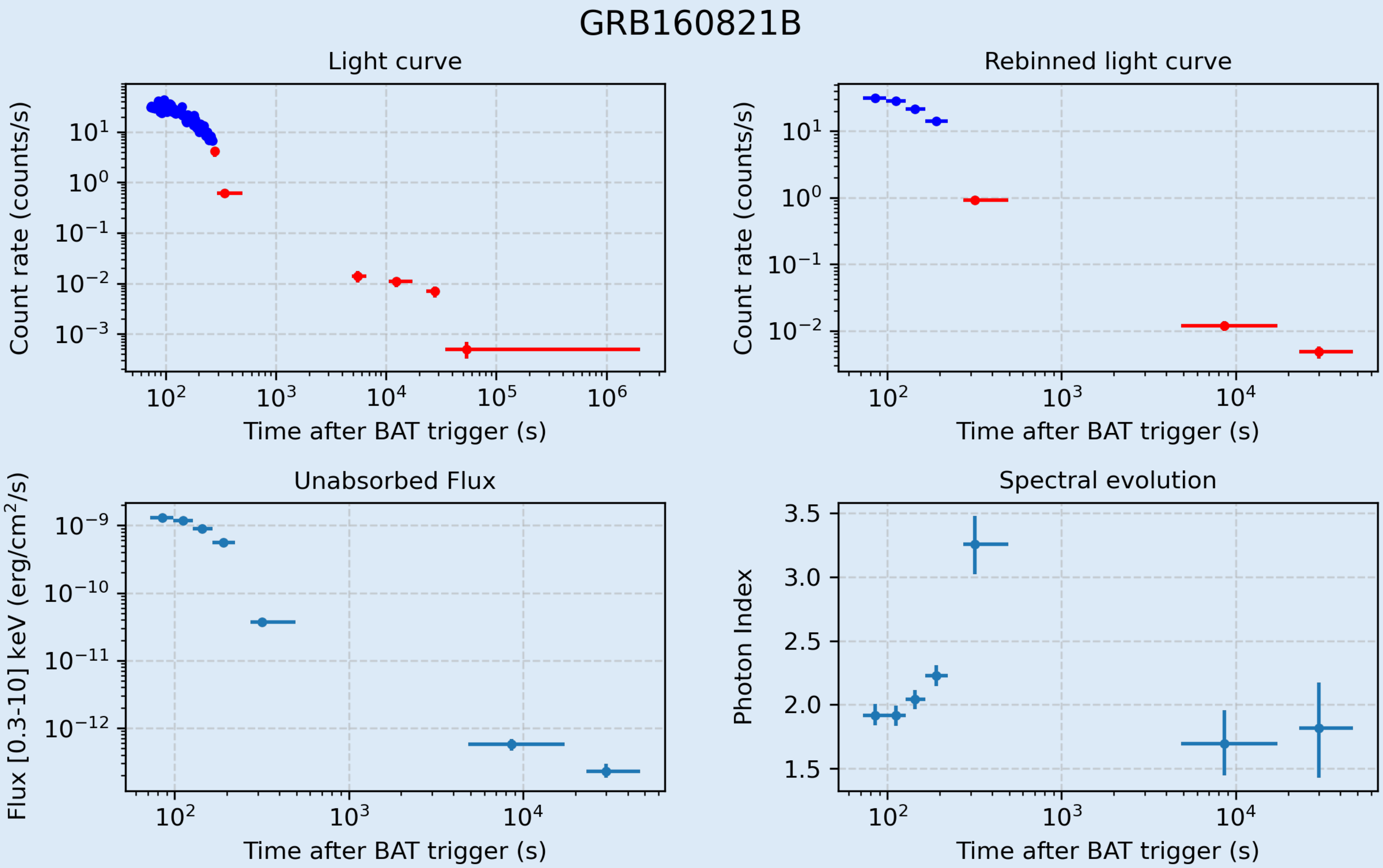
XRT spectral analysis



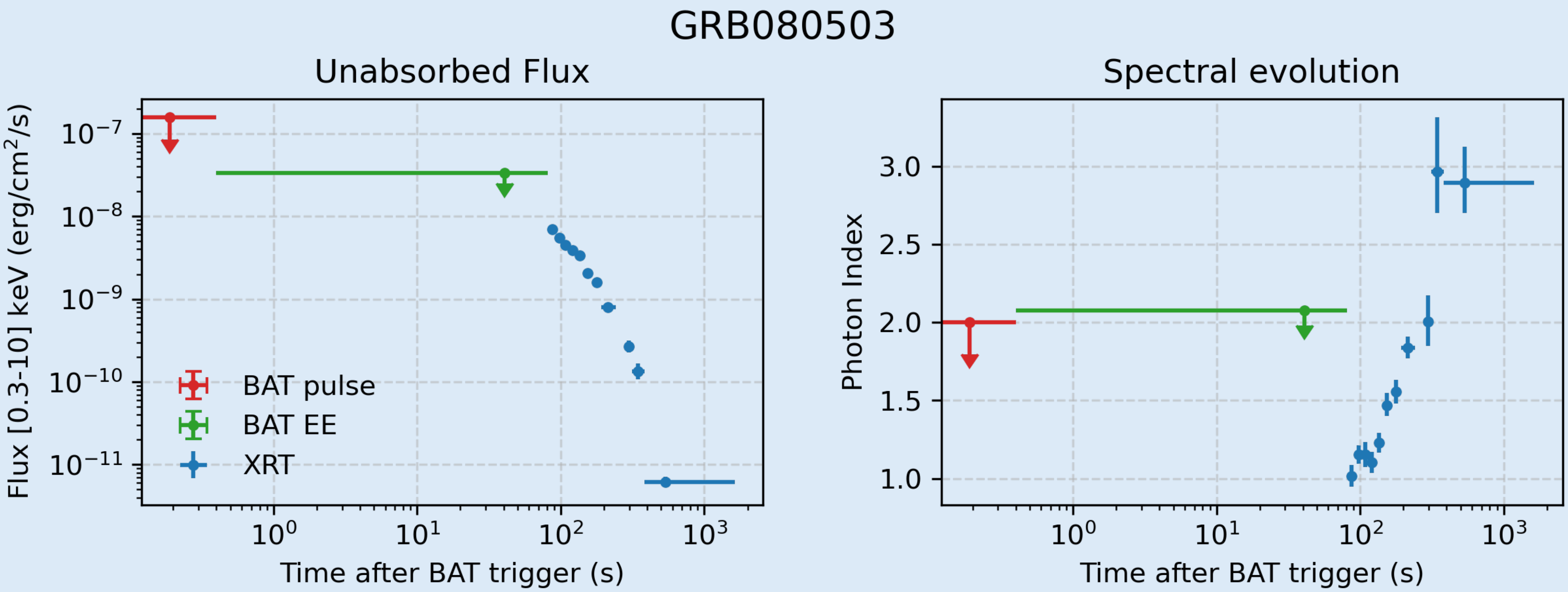
XRT spectral analysis



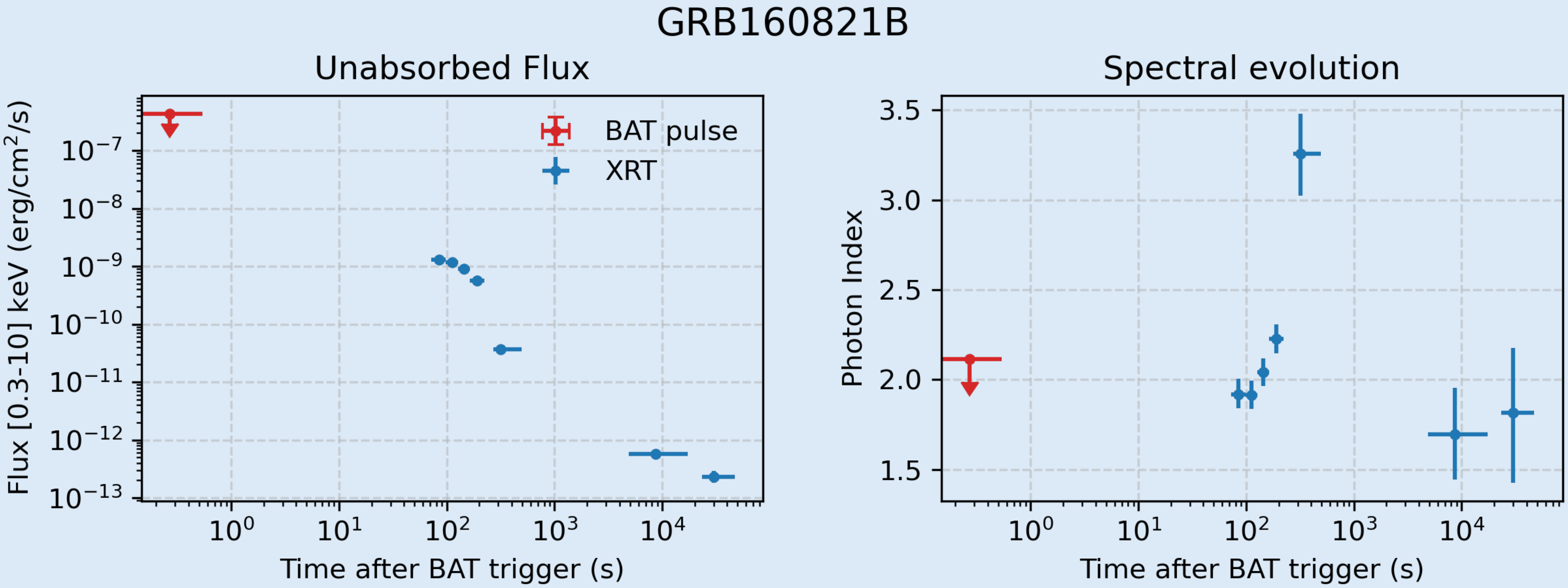
XRT spectral analysis



BAT and XRT spectral analysis

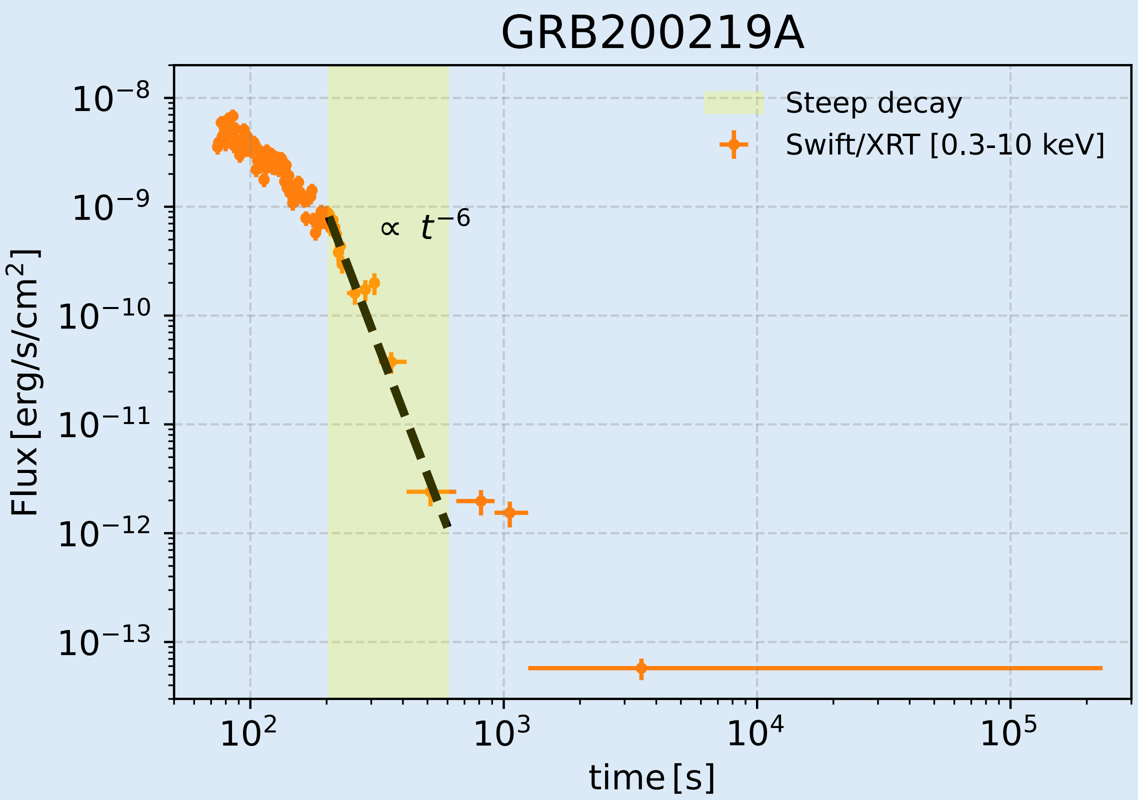


BAT and XRT spectral analysis



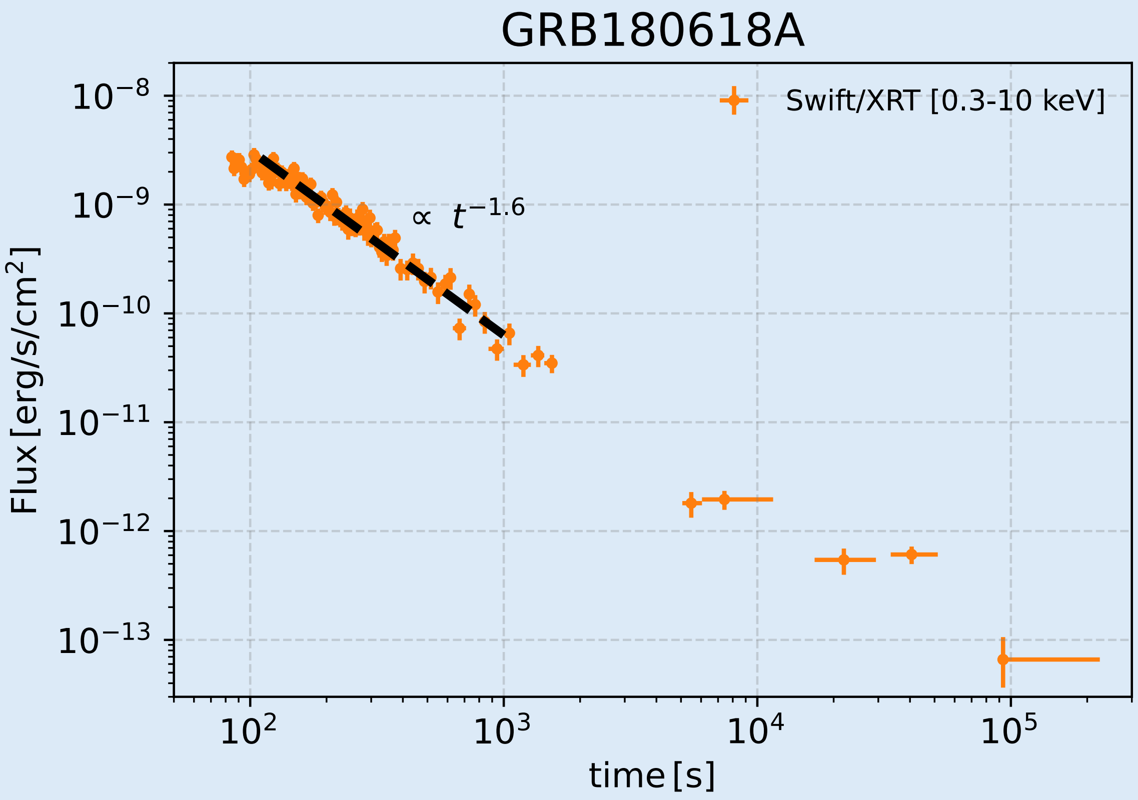
Temporal evolution

12 GRBs show a **steep decay** in the XRT lightcurve



8 of these GRBs have EE in BAT

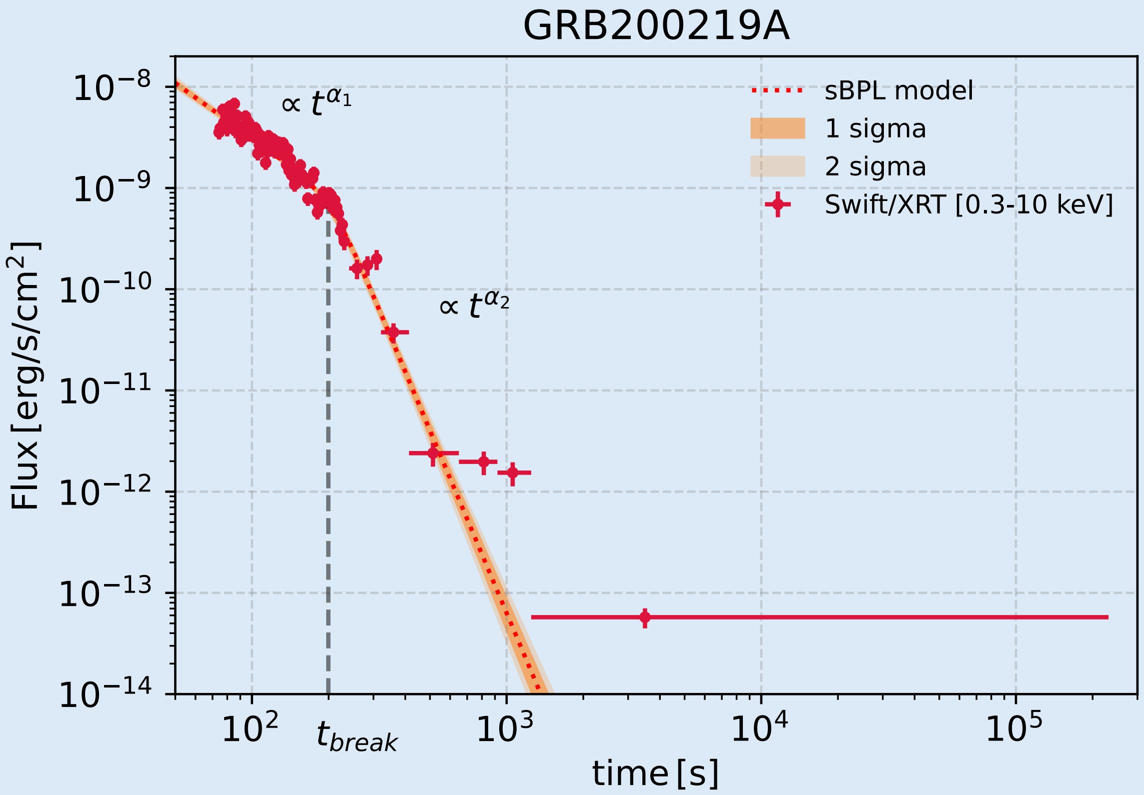
6 GRBs show a **standard decay** in the XRT lightcurve



4 of these GRBs have EE in BAT

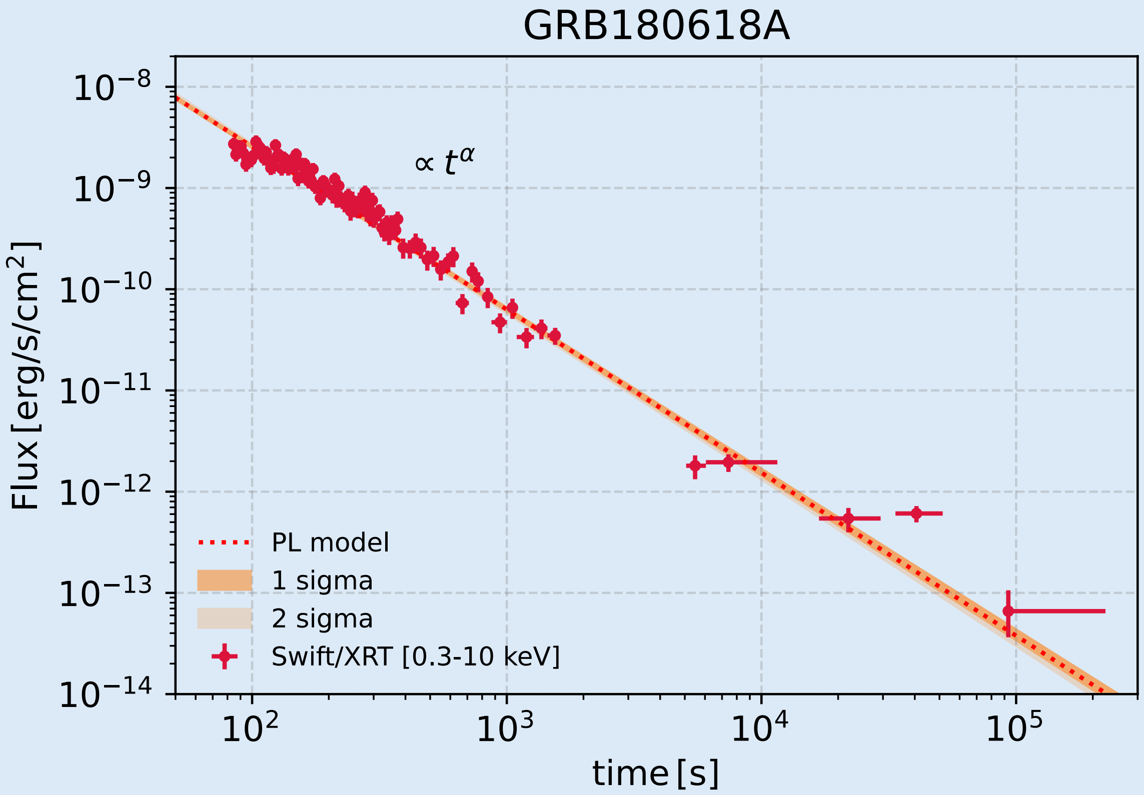
XRT lightcurve fit

Smoothly broken power-law (sBPL)
to model the early XRT lightcurve



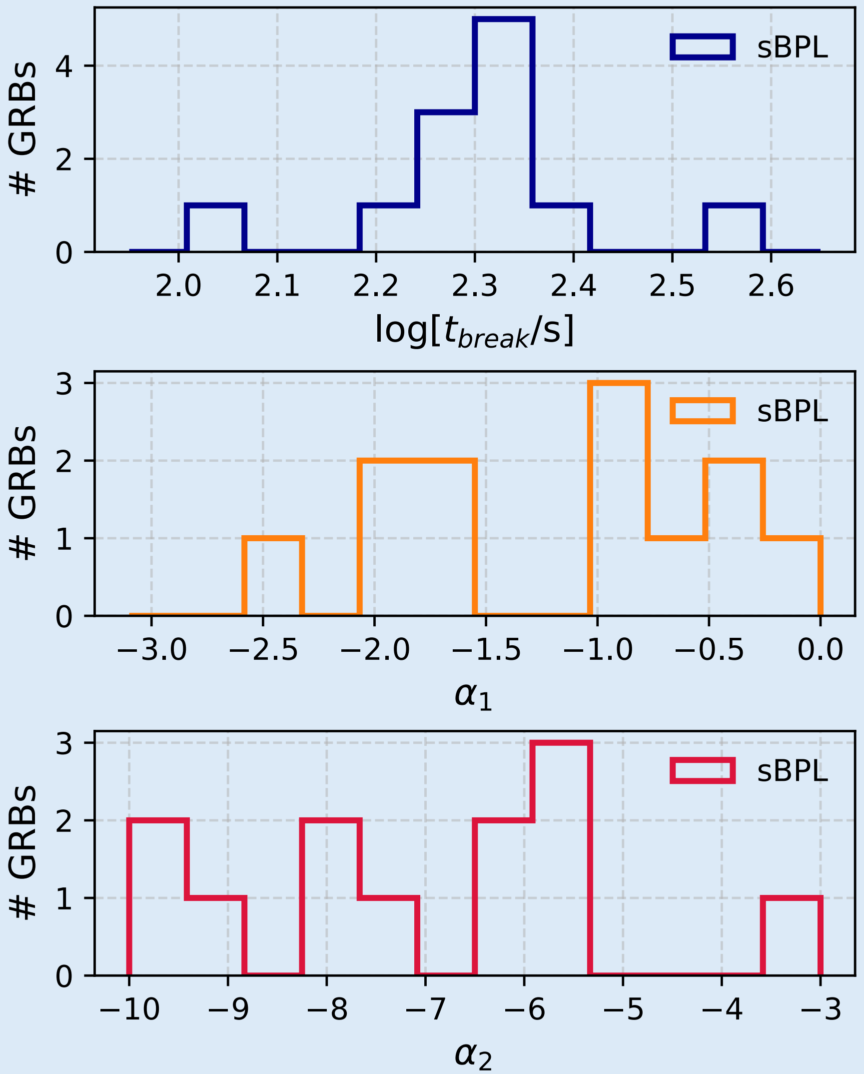
Steep decay duration: [200 – 800] s

Power-law (PL)
to model the early XRT lightcurve

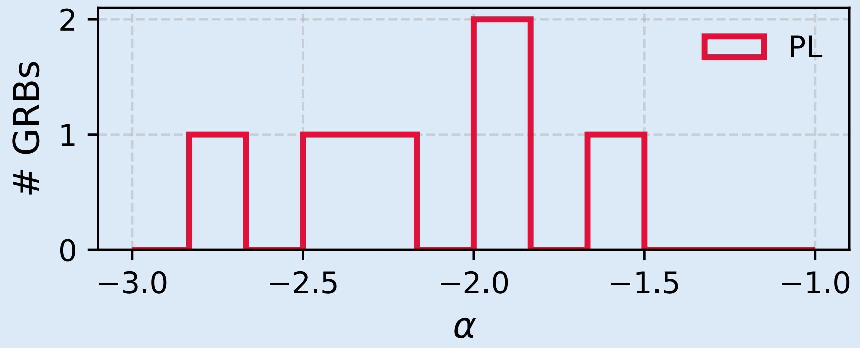


XRT lightcurve fit

Parameters of sBPL model

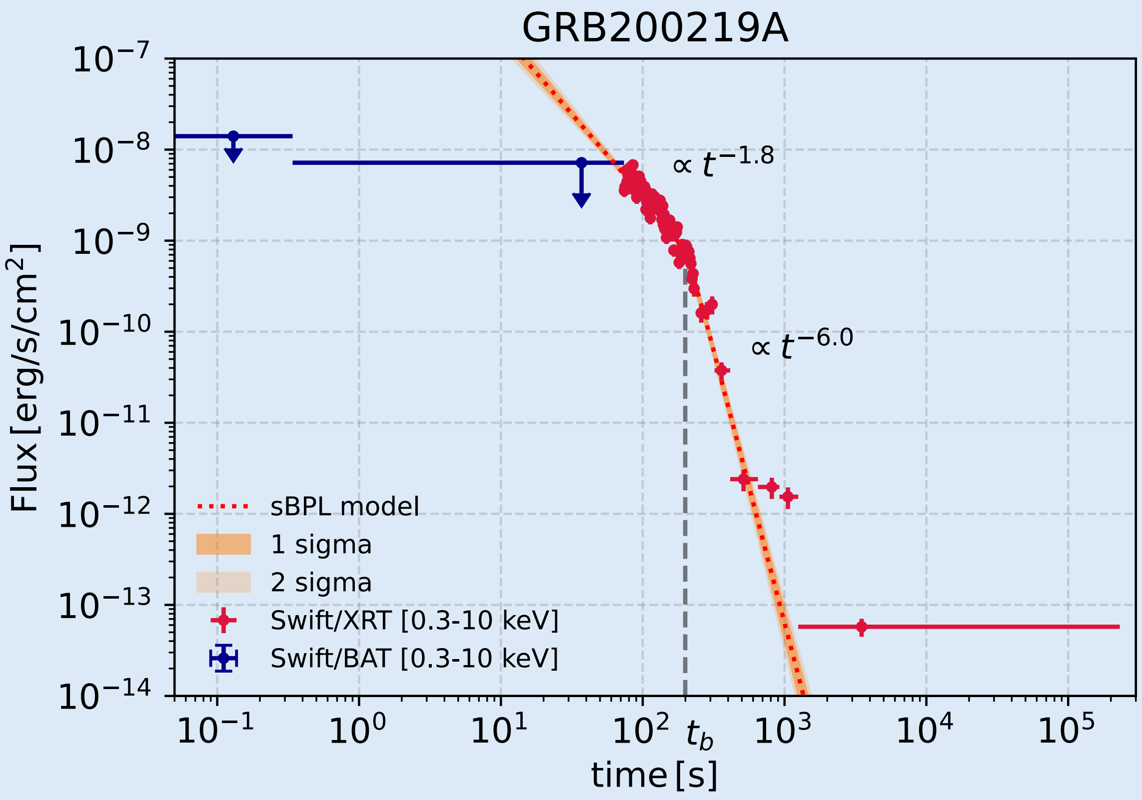


Parameters of PL model

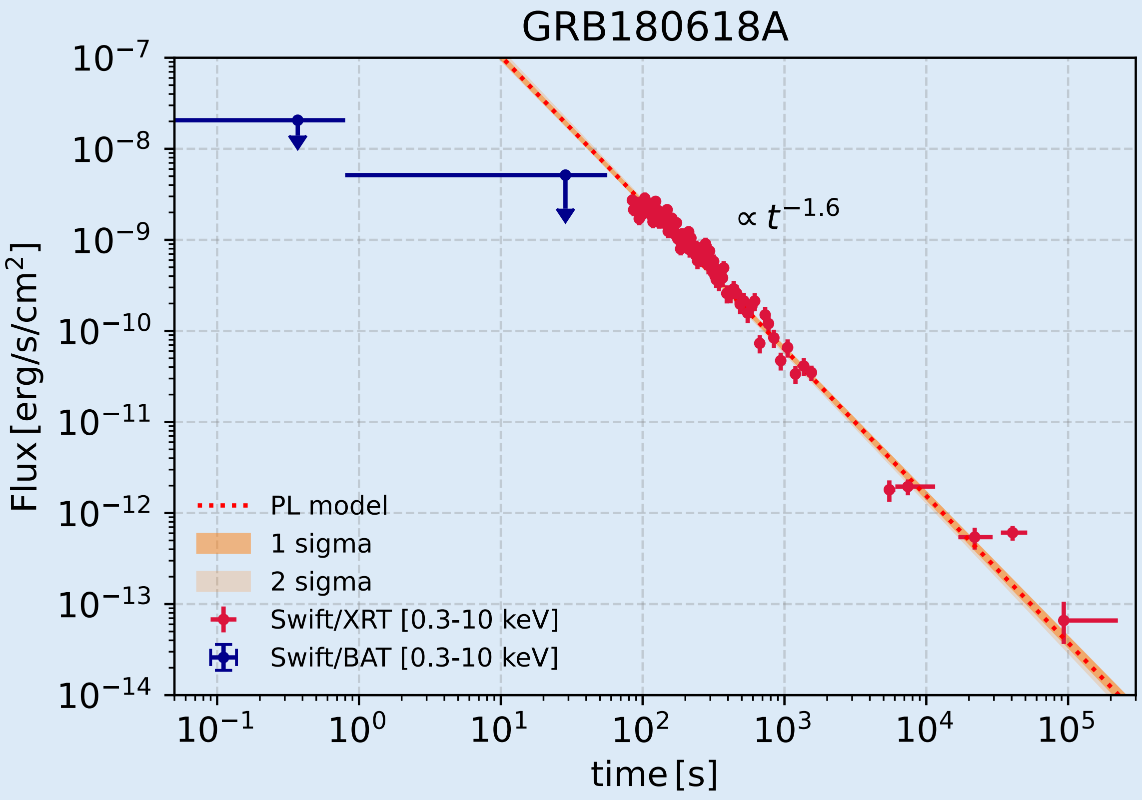


XRT lightcurve fit

12 GRBs show **steep decay** in XRT lightcurve

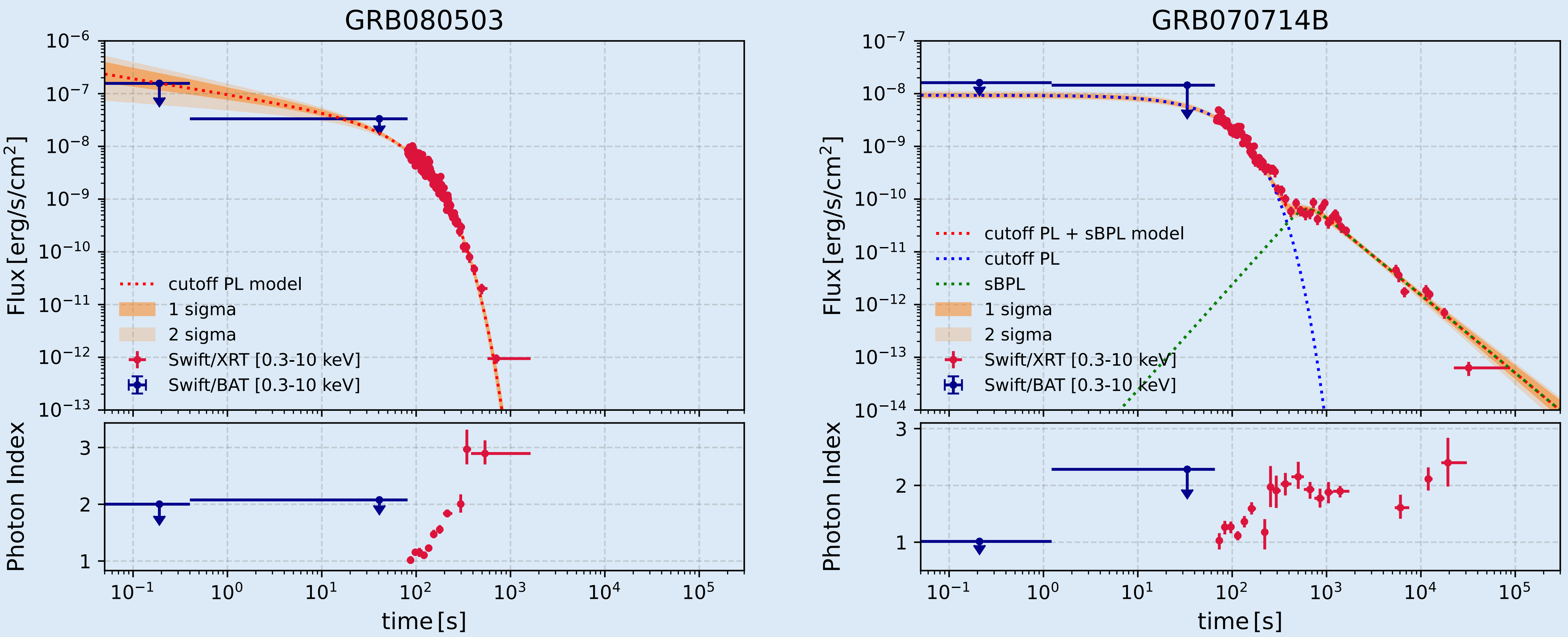


6 GRBs show **standard decay** in XRT lightcurve



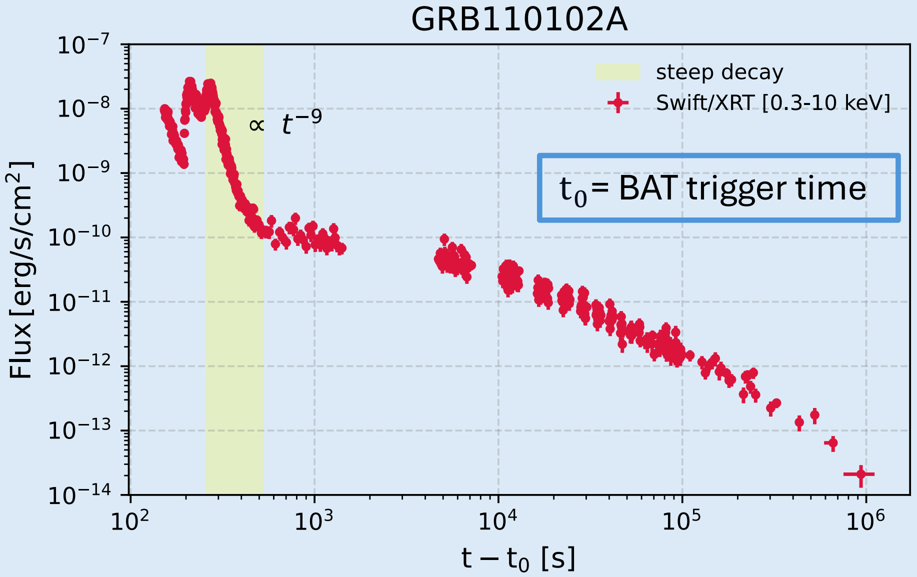
Both models overshine BAT upper limits!

BAT+XRT lightcurve fit

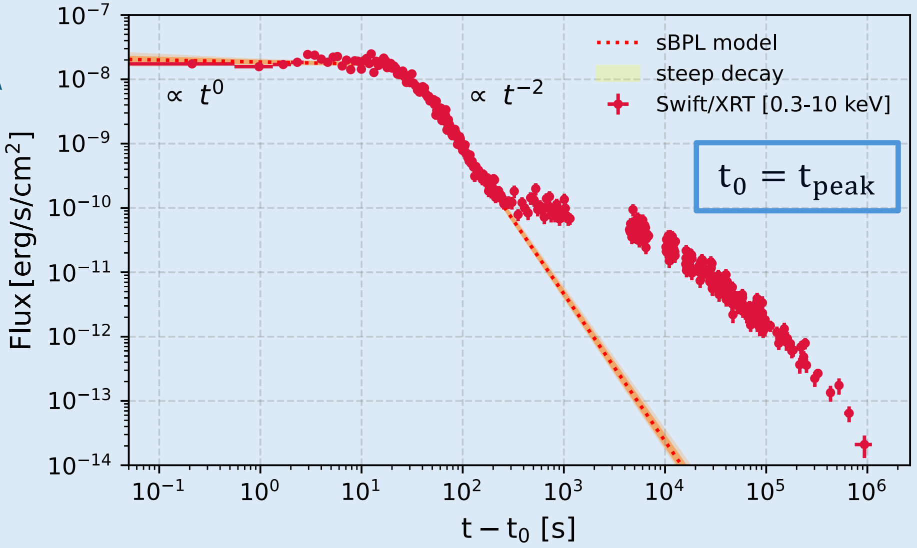


Long/short GRB comparison

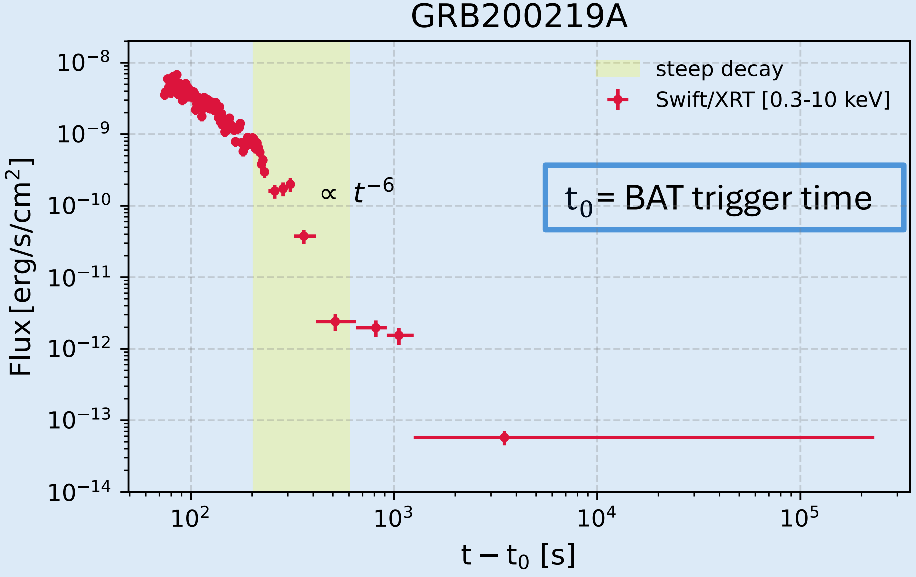
Long GRBs



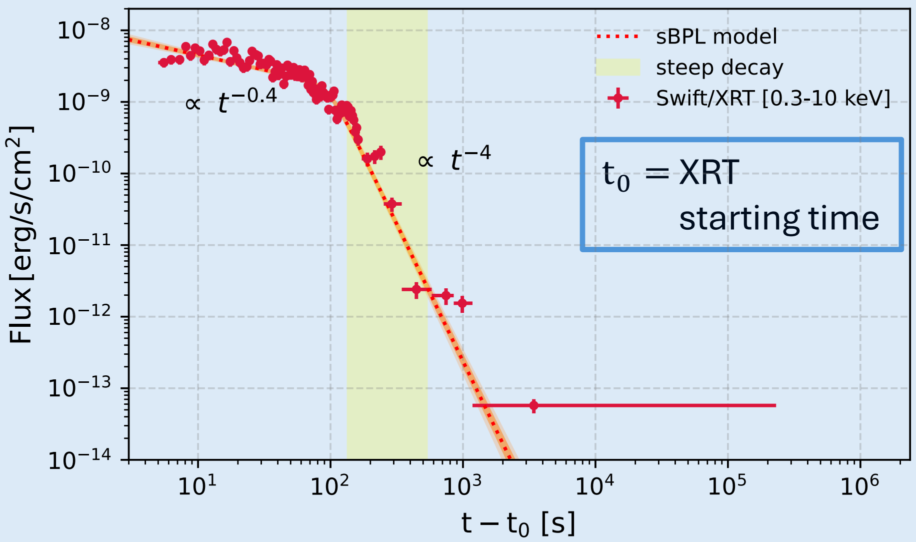
t_0 shift



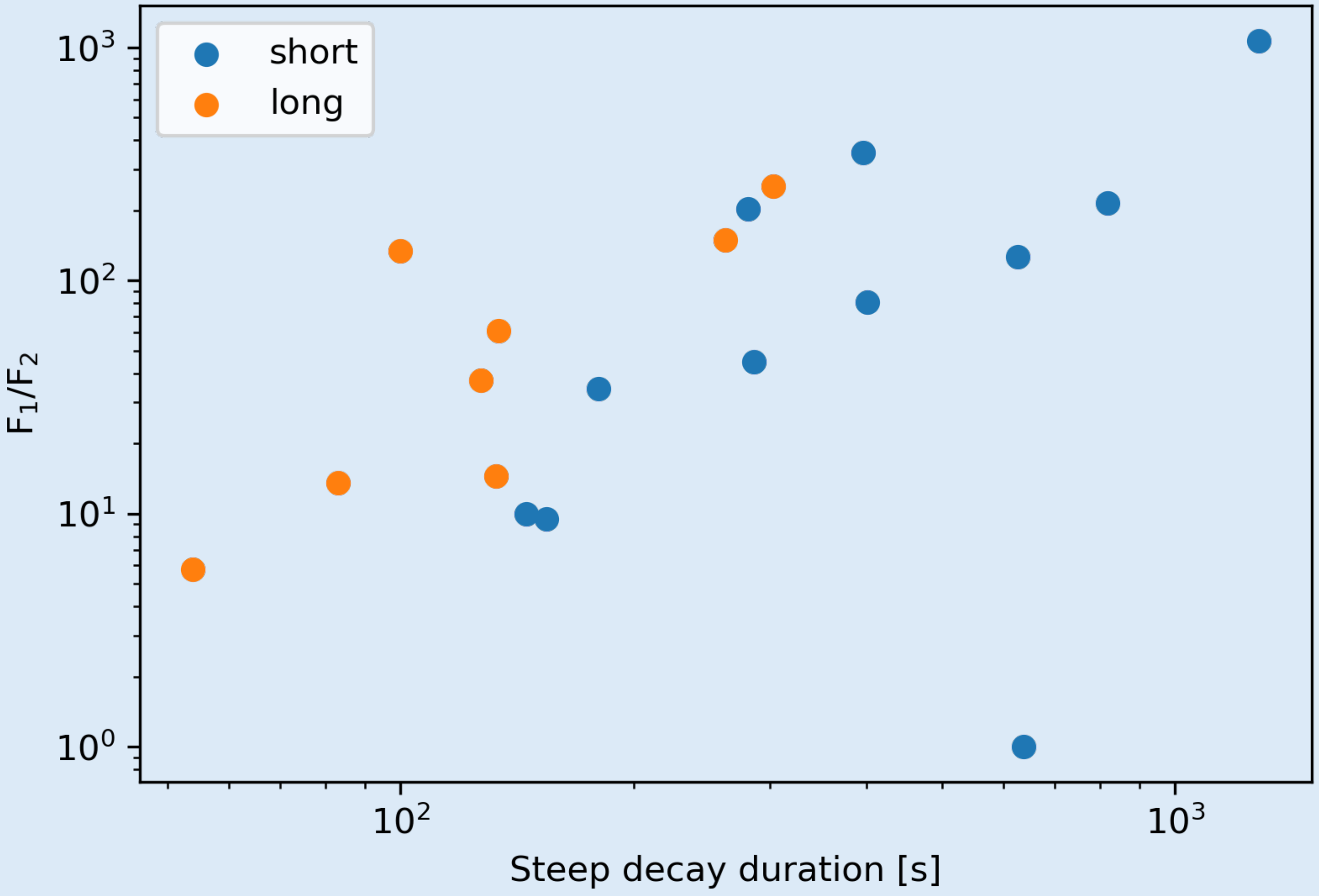
Short GRBs



t_0 shift

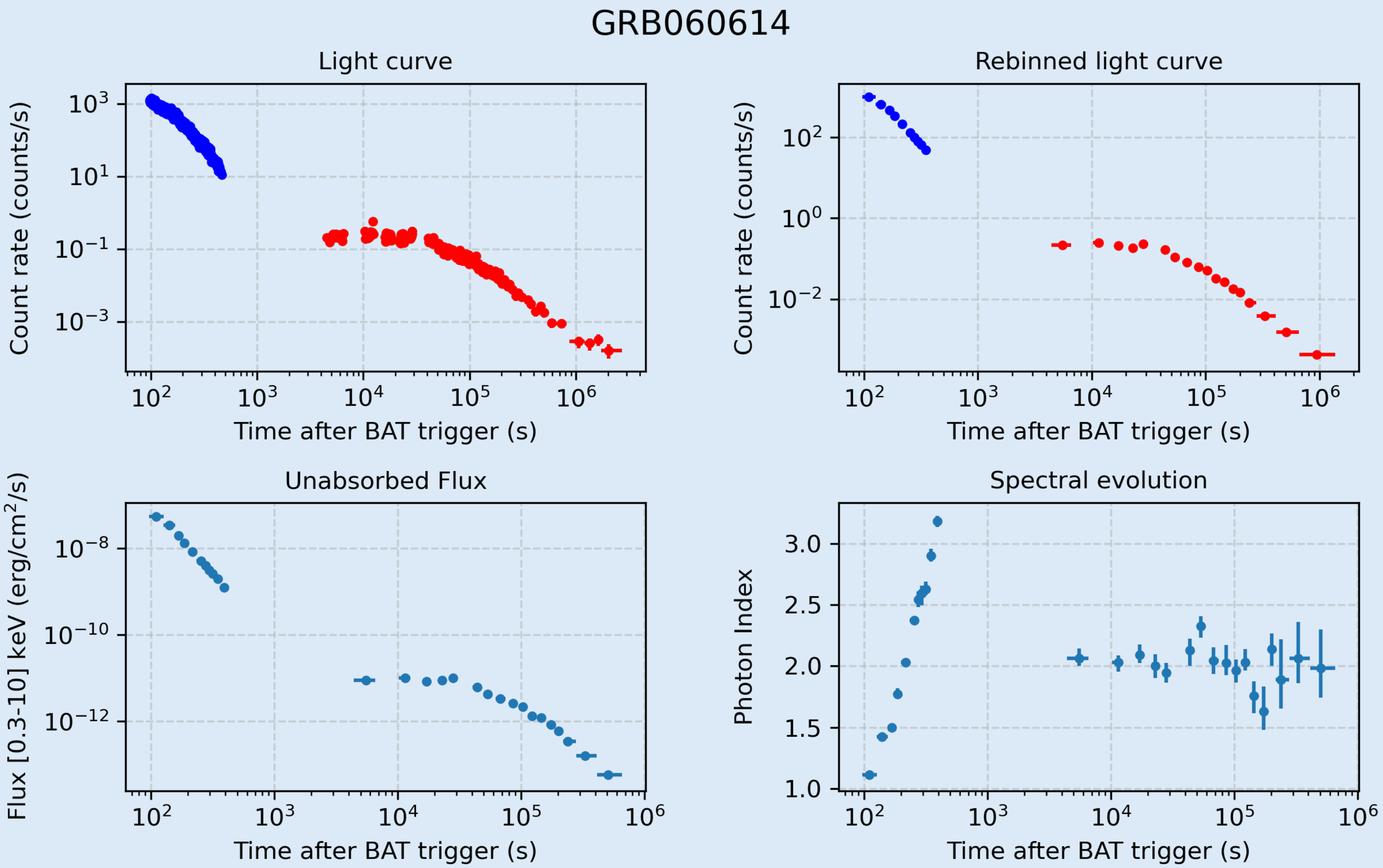


Long/short GRB comparison

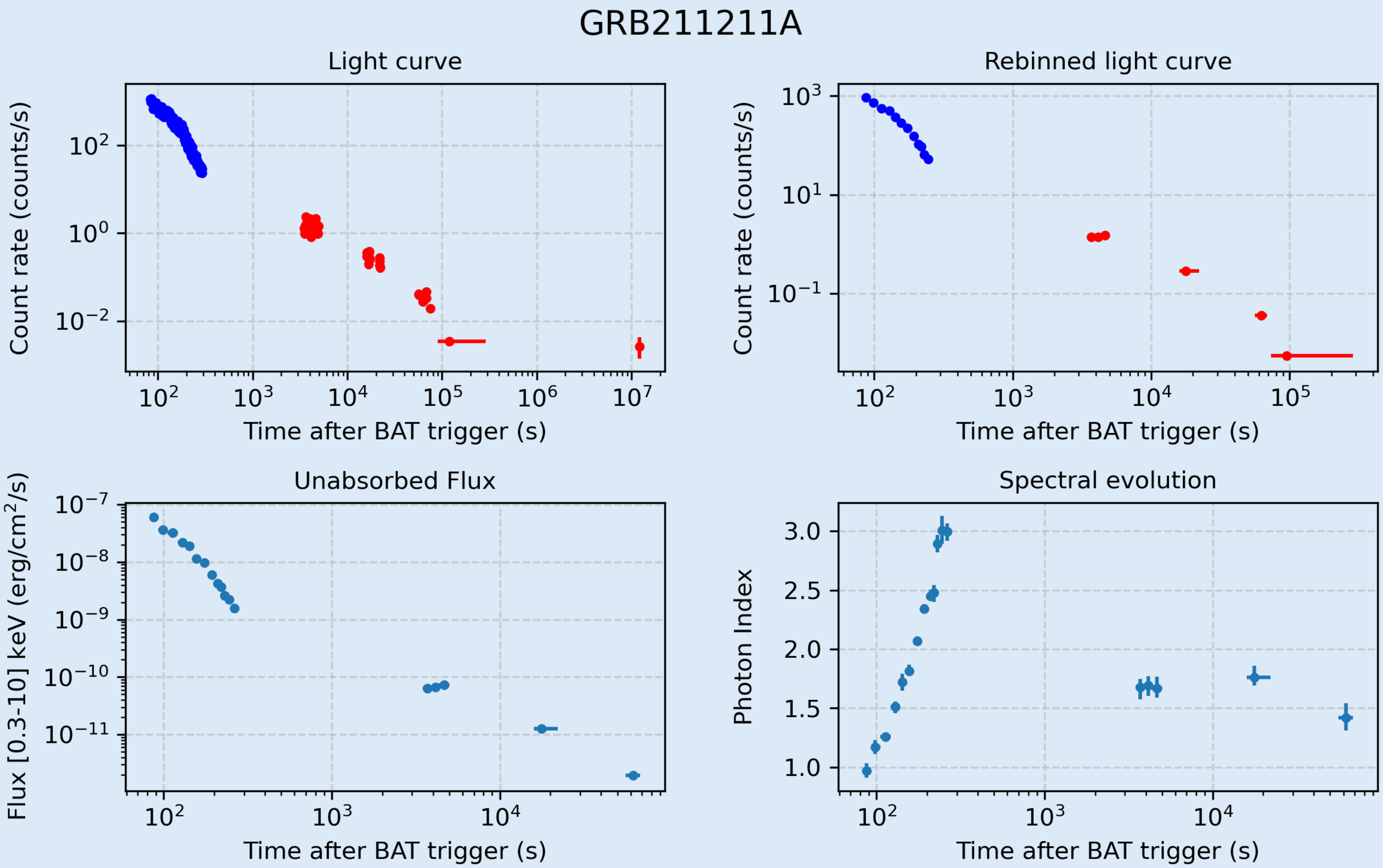


Peculiar GRBs

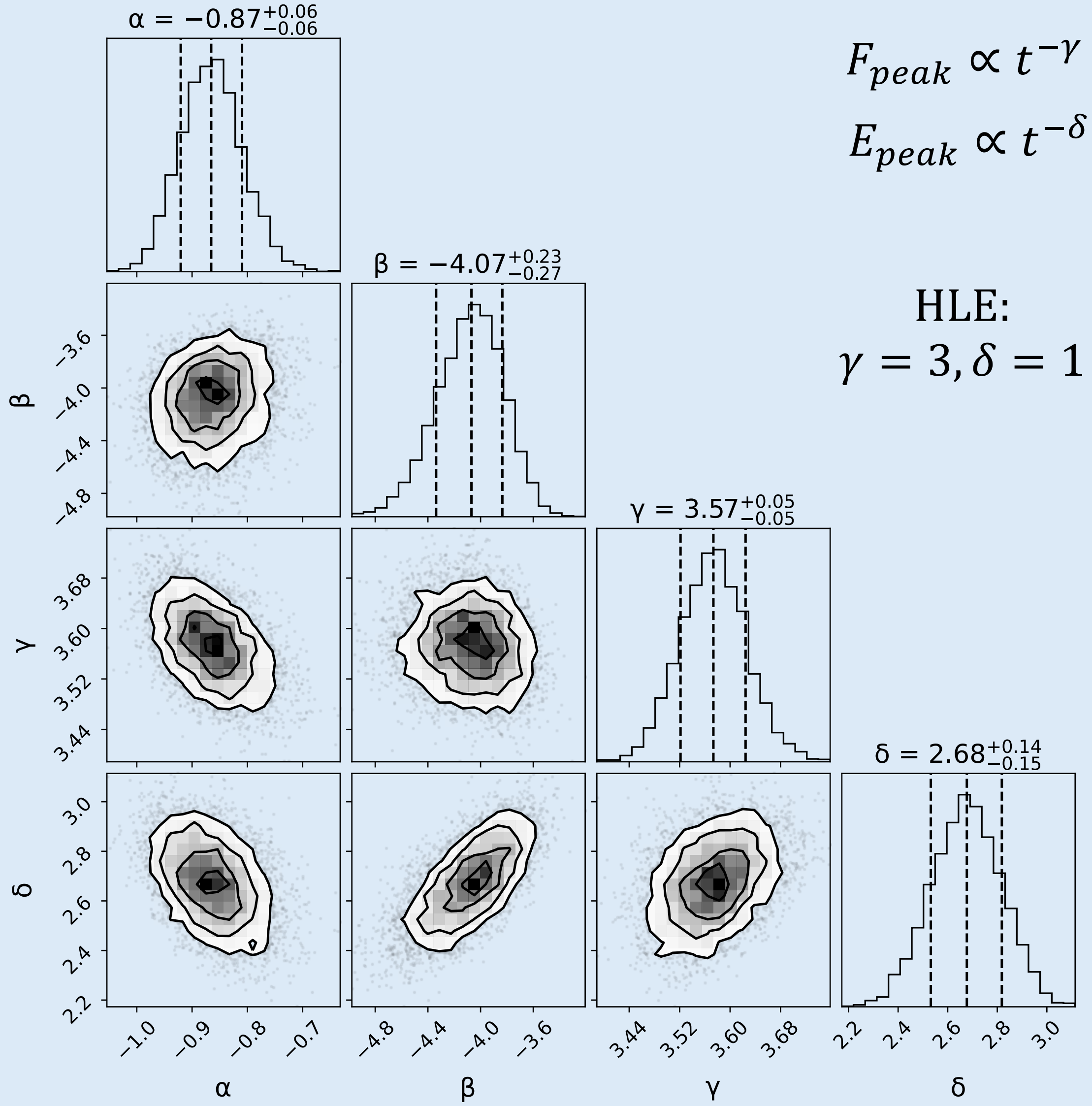
Supernova-less long GRB



Oddball


GRB211211A
Light curve
Rebinned light curve
Unabsorbed Flux
Spectral evolution
Count rate (counts/s)
Time after BAT trigger (s)
Flux [0.3-10] keV (erg/cm^2/s)
Photon Index

Oddball



$$F_{peak} \propto t^{-\gamma}$$

$$E_{peak} \propto t^{-\delta}$$

HLE:

$$\gamma = 3, \delta = 1$$