THE MAXIMUM ISOTROPIC ENERGY OF GAMMA-RAY BURSTS

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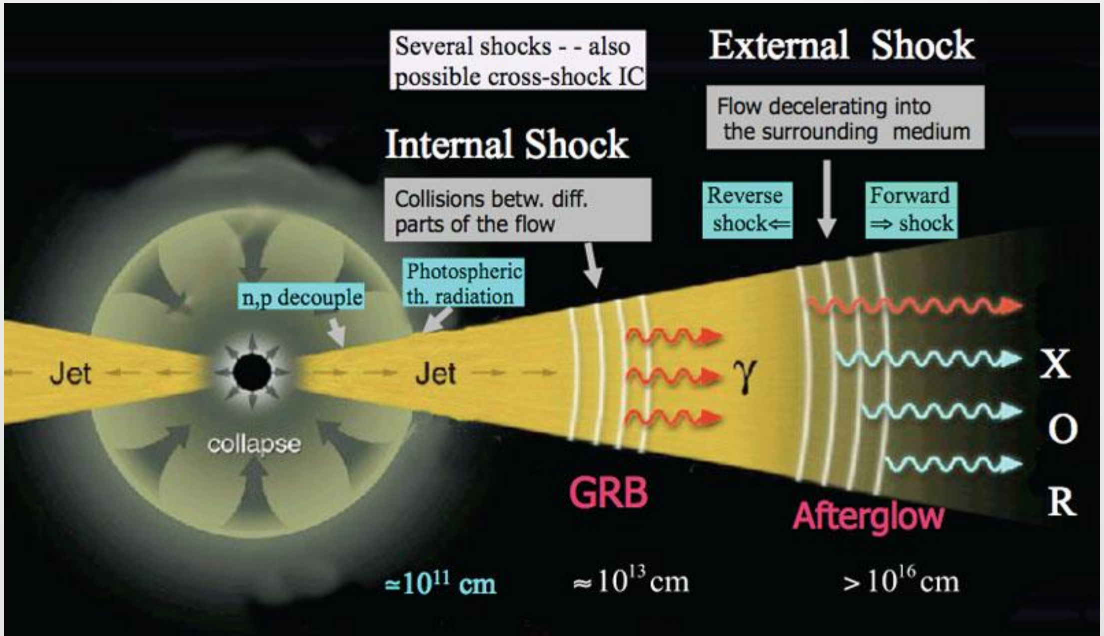
GRB jets

- GRBs are extremely efficient lighthouses!
  - The most luminous GRBs are visible up to $z \geq 8$.
  - However, GRBs require very special conditions:
    - Highly relativistic outflows: $\Gamma \sim 100$ → Doppler boost
    - Beamed outflows → The jet energy is radiated in a small solid angle
    - Radio calorimetry & afterglow jet breaks constrain the energy of the jet: $E_{jet} \leq 10^{51}$ erg



The isotropic equivalent energy E_{iso}

- Lacking information on the jet beaming for most GRBs, we cannot compute the energy radiated by the jet during the prompt emission, instead we compute the *isotropic equivalent energy* E_{iso}.

- E_{iso} is the energy released during the prompt phase assuming isotropic emission. E_{iso} is a proxy for the *energy radiated in our direction*. This is our imperfect view to GRB energetics!

- The true energy radiated in γ-rays is $E_{rad} = E_{iso}/f_b$

  $f_b = 4\pi/\Omega \approx 10^2$-$10^3$

We study the bright end of the E_{iso} distribution

Calculating E_{iso}

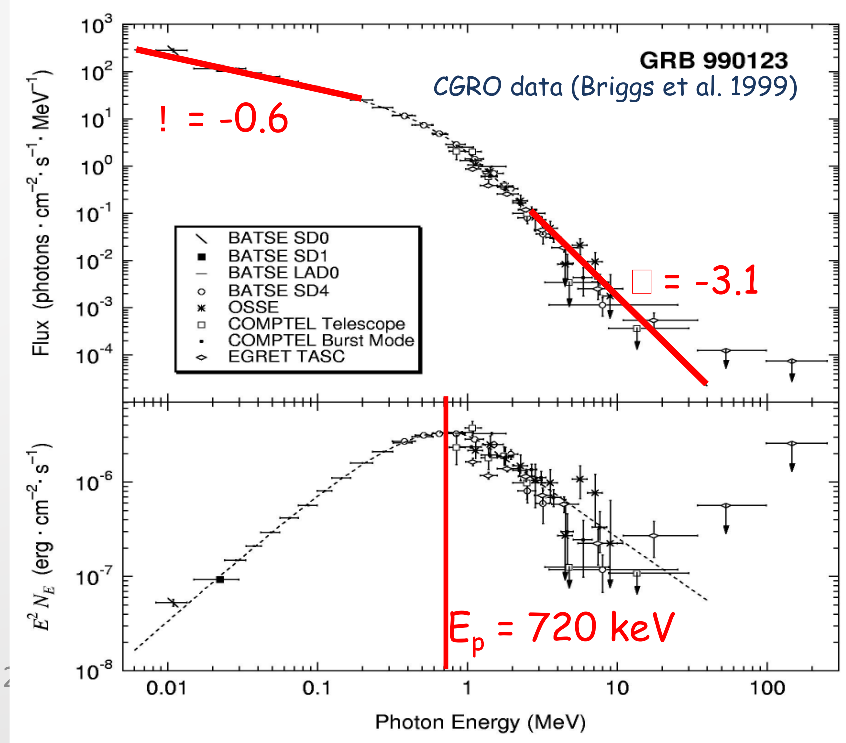
- E_{iso} is computed according to the formulae:

$$E_{\rm iso} = \frac{4\,\pi\,D_l^2\,S_{\rm bol}}{1+z} \qquad S_{\rm bol} = S_\gamma\,\frac{\int_{\frac{1}{1+z}}^{\frac{10^4}{1+z}} E\,N(E)\,dE}{\int_{E_{\rm min}}^{E_{\rm max}} E\,N(E)\,dE}$$

- S_γ is the fluence measured in the detector energy range, from E_{min} to E_{max}.

- N(E) describes the shape of the spectrum.

- E_{iso} is computed in the range $[1\text{-}10^4]$ keV *in source frame.*

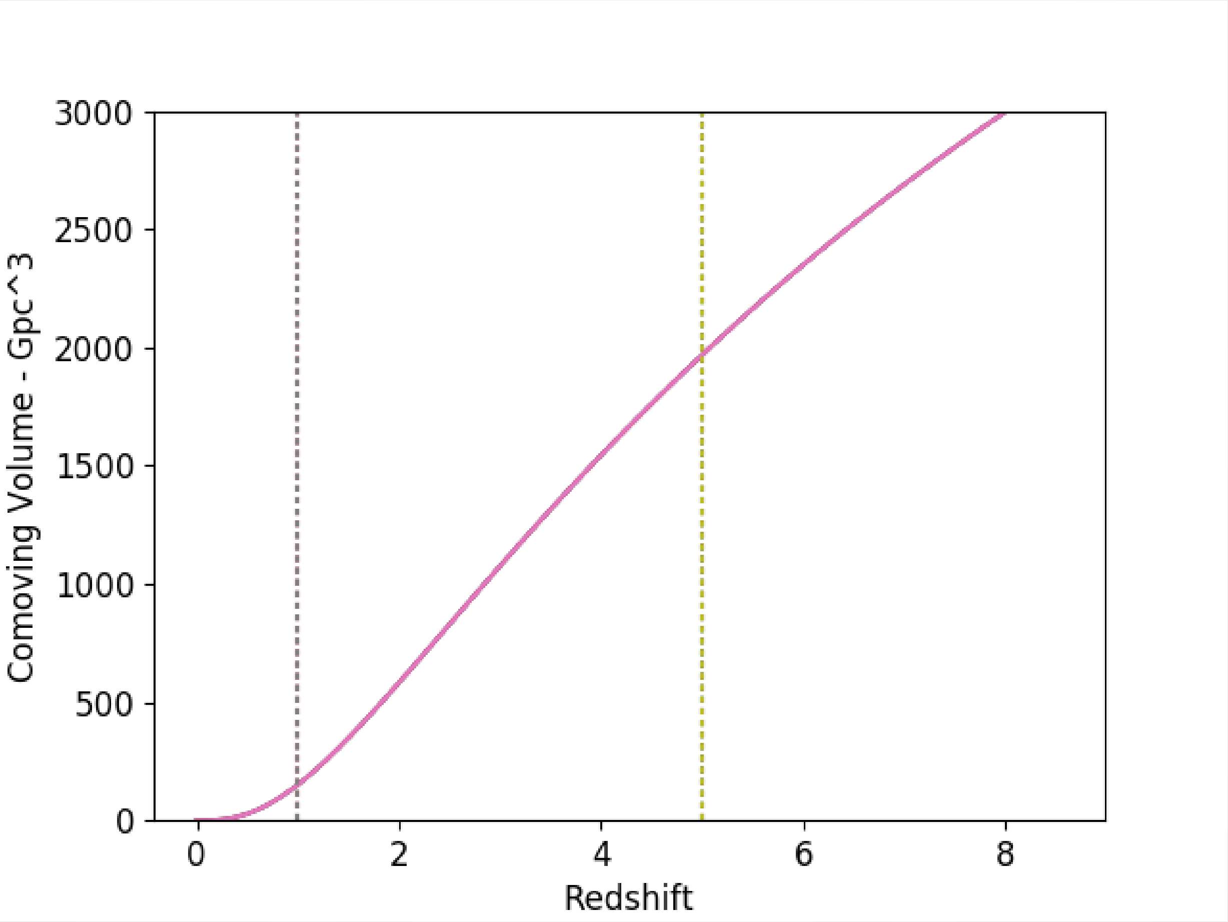


The sample

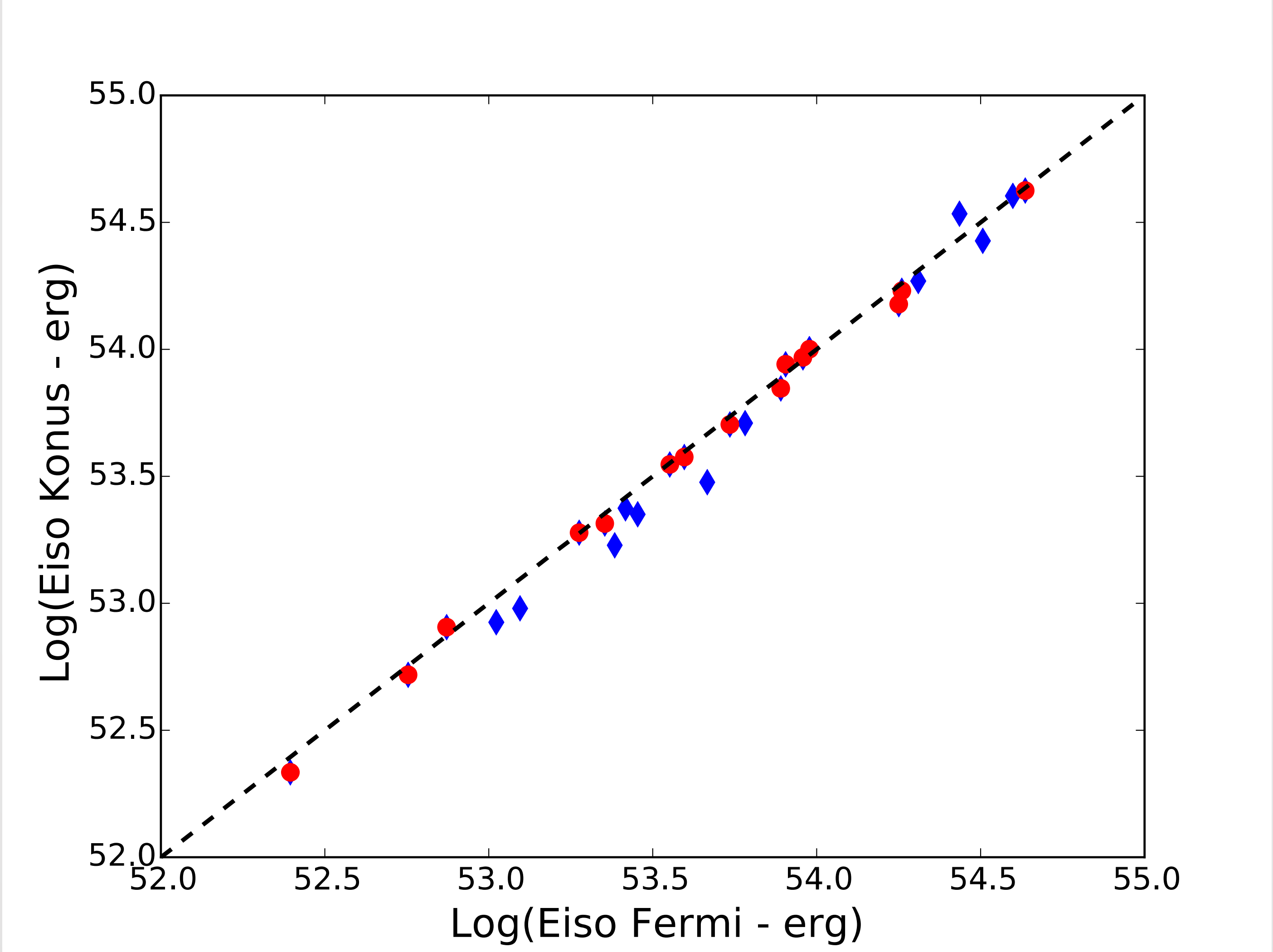
- To compute E_{iso}, we need GRBs with redshifts and reliable spectral parameters:
  - Spectra from *Fermi*/GBM (Gruber et al. 2014, von Kienlin et al. 2014) & *Wind*/Konus (Tsvetkova et al. 2017)
  - Redshifts from optical follow-up of *Swift* GRBs

- 95 GRBs with redshift $1 \leq z \leq 5$
  - 69 GRBs detected by *Wind*/Konus (K):
    - Sample threshold: $P_f \geq 3.5$ ph.cm^{-2}.s^{-1} in [50-200] keV
    - $P_{med} = 7.3$ ph.cm^{-2}.s^{-1} – $z_{med} = 1.77$
  - 52 GRBs detected by *Fermi*/GBM (G):
    - Sample threshold: $P_f \geq 1.05$ ph.cm^{-2}.s^{-1} in [50-300] keV
    - $P_{med} = 5.4$ ph.cm^{-2}.s – $z_{med} = 1.85$
  - 26 events in common

Sampled volume

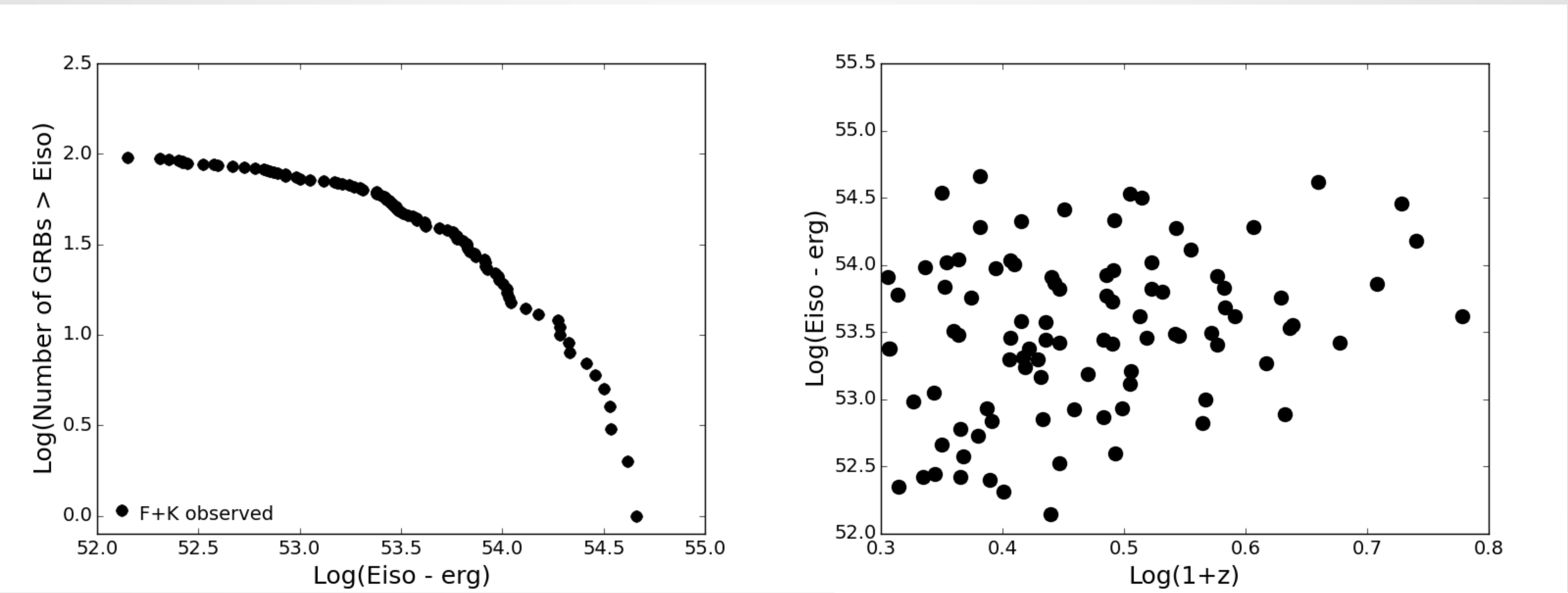


Konus vs GBM E_{iso}



The observed E_{iso} distribution

- Eiso is in the range [2 10^{52} – 4 10^{54}] erg



1	**Redshift**	**5**
150	**Volume (Gpc^3)**	**2000**

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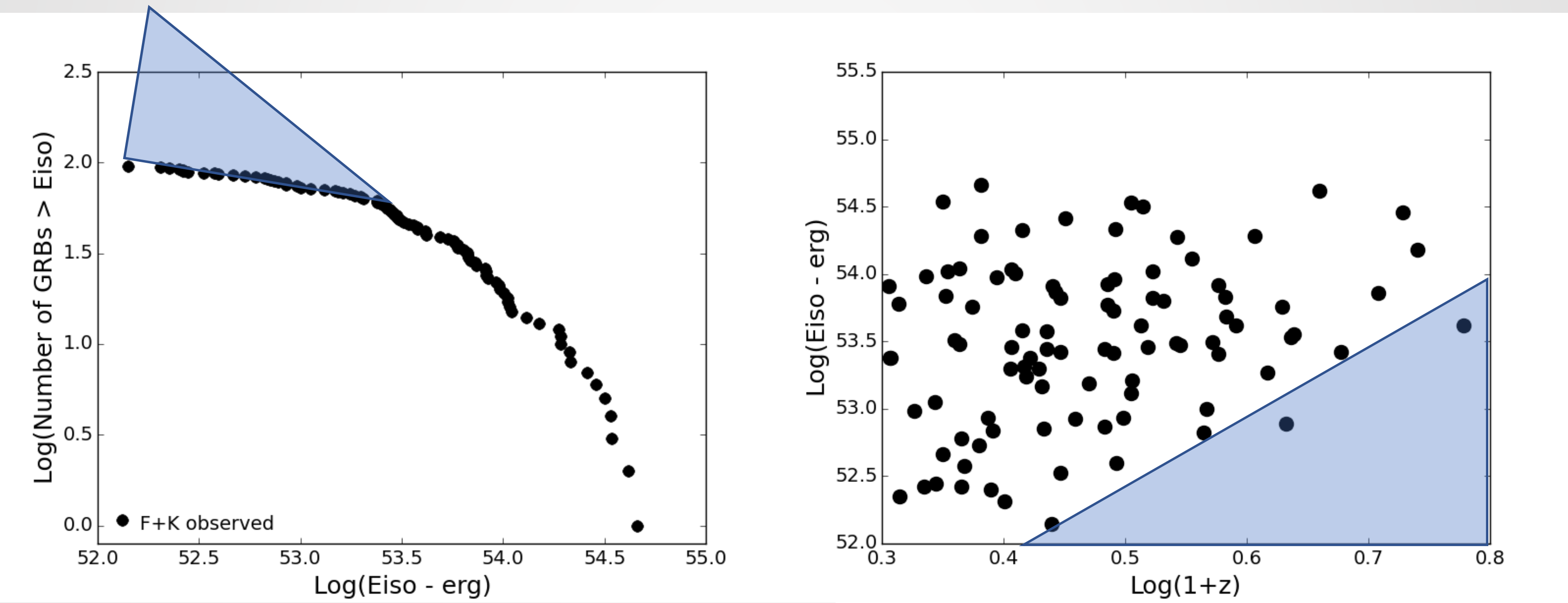


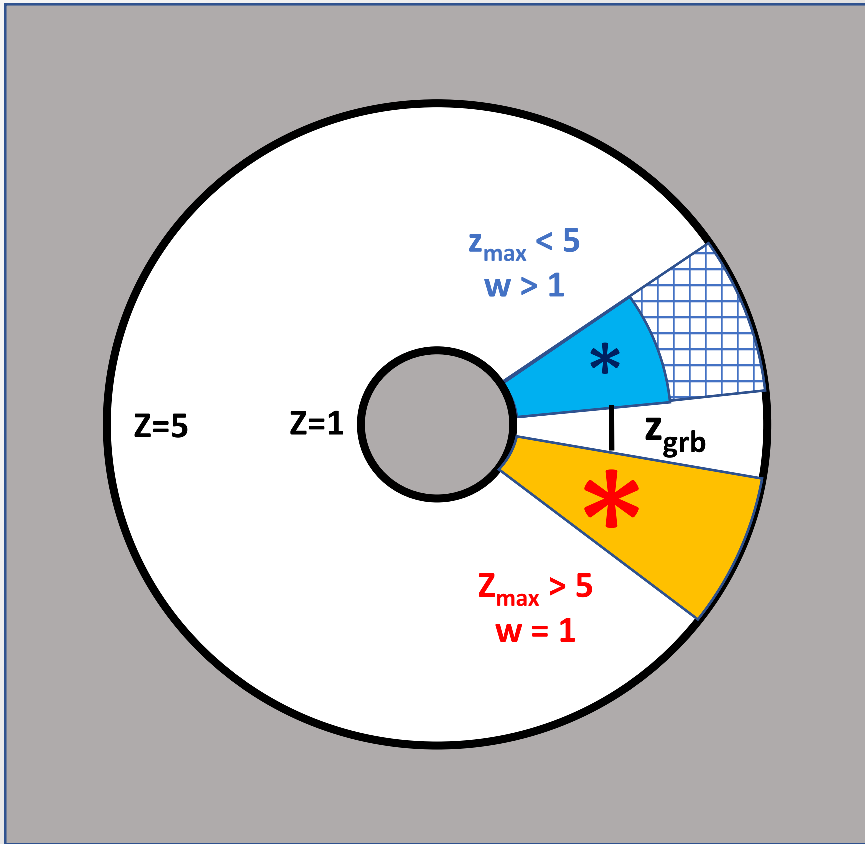
1	Redshift	5
150	Volume (Gpc^3)	2000

Correcting the Eiso distribution

1. For every GRB in our reference volume ($1 \leq z \leq 5$), we compute its *horizon* z_{max}, the redshift at which its peak flux becomes fainter than the sample limiting peak flux.

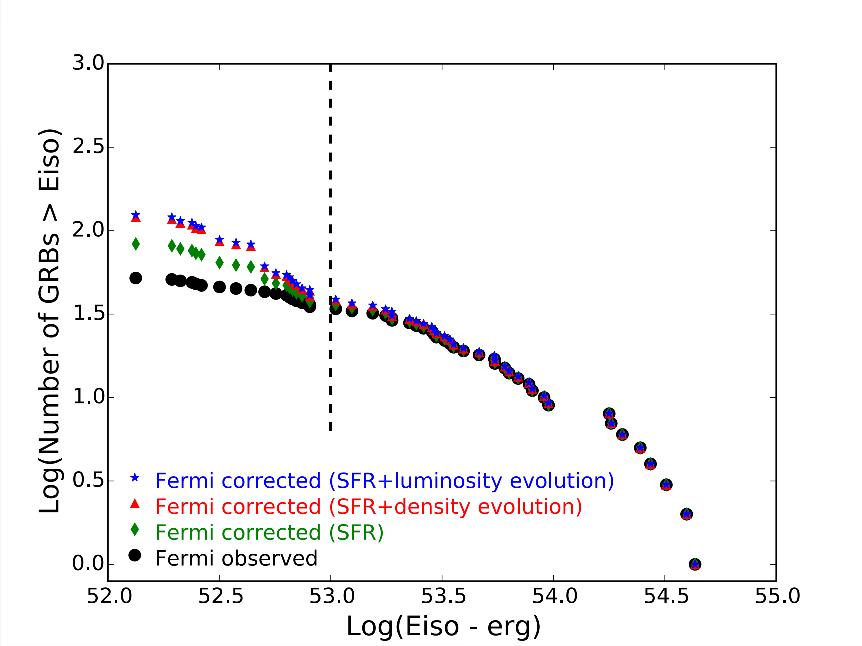
2. Assuming a *GRB world model*, we compute Nz_{max}, the number of GRBs in the volume $1 \leq z \leq z_{max}$ and N_5, the number of GRBs in the volume $1 \leq z \leq 5$.

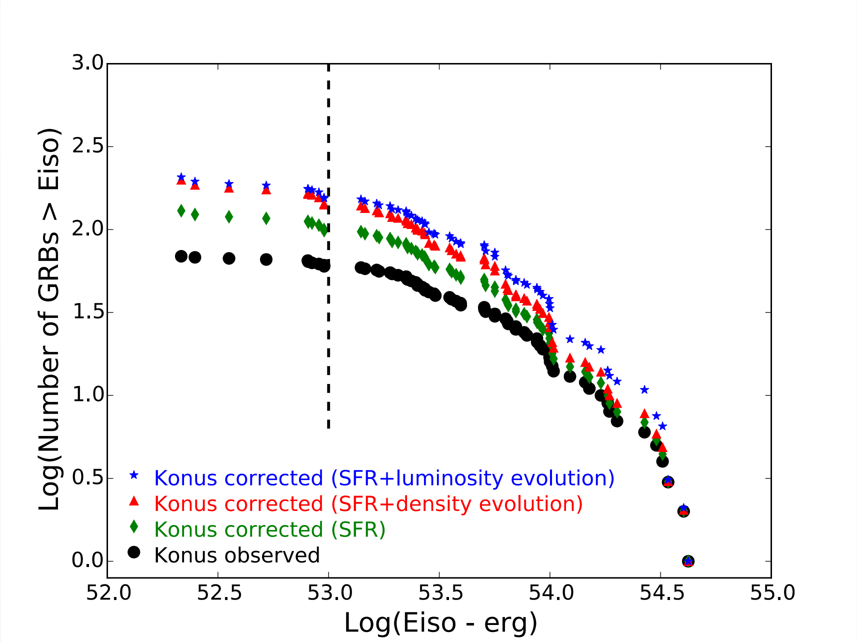
$w = N_5/Nz_{max}$ is the *weight* of this GRB, used to correct the E_{iso} distribution. If $z_{max} \geq 5$, $w = 1$.



The corrected E_{iso} distribution

- The correction does not change the bright end of the distribution (as expected).
  - The correction is stronger for Konus, which is less sensitive, with a closer horizon.
  - GBM detects GRBs with $E_{iso} \geq 10^{53}$ erg up to $z \geq 5$.





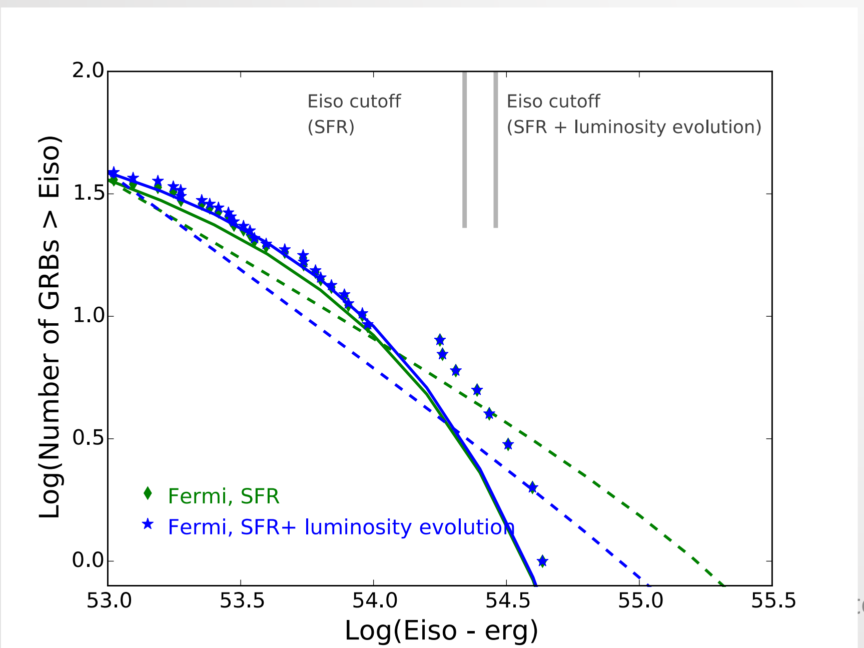
Existence of a cutoff E_{iso}

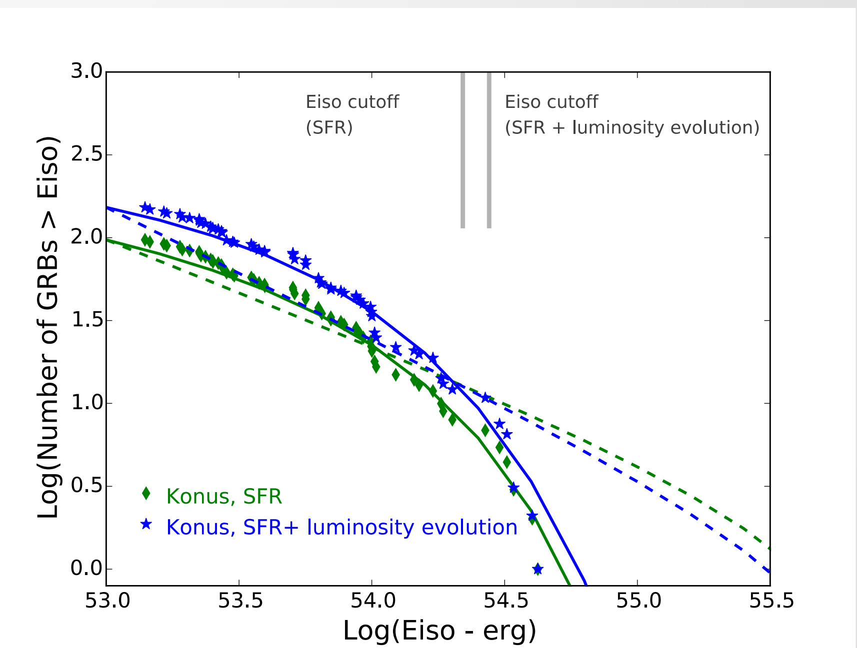
- We compare the data with various GRB models having different redshift distributions (SFR plus density or luminosity evolution).

We find that an energy cutoff around E_{iso} = 3 10^{54} erg is required at the level of 99.9%, for all models.

(more details in ApJ 2017, 837, 119 (arXiv:1711.06122)

- This energy cutoff must not be confused with the break of the luminosity function found by various authors in the range 10^{51} – 10^{52} erg.





Interpretation?

- There is no straightforward interpretation because the E_{iso} limit could be associated with the activity of the central engine (energy reservoir and energy extraction), with the beaming of the jet, or with the energy dissipation or radiation processes in the jet.

- Moreover, an upper limit on E_{iso} *does not* indicate a limit on the energy of GRB jets: the most energetic GRBs may not have the largest E_{iso}.
  - The geometry of the jet may change.
  - The energy may be radiated outside the keV/MeV energy range.
  - The energy may be emitted outside the electromagnetic spectrum.
  - …

Conclusions and perspectives

- The GRB isotropic energy shows a cutoff above $E_{iso} \approx 3\ 10^{54}$ erg, and there is no indication of a class of very energetic GRBs (e.g. Cenko et al. 2011).

- Energetic GRBs are rare, our study is based on 8 years of observation with Fermi/GBM and 22 years with Wind/Konus.
  - We estimate the rate of GRBs with $E_{iso} \geq 2\ 10^{54}$ to be ~5 yr^{-1}.
  - Most of them have no redshift!
  - Swift, Fermi and Wind are planned to operate for several more years.
  - In 2022+ SVOM will contribute ☺

- The E_{iso} limit may be associated with the activity of the central engine or with the physics of the jet.

- If we find a way to identify GRBs close to E_{iso} limit, we'll have very luminous standard candles, visible to $z \geq 10$!

Two additional GRBs

GRB 180914B:

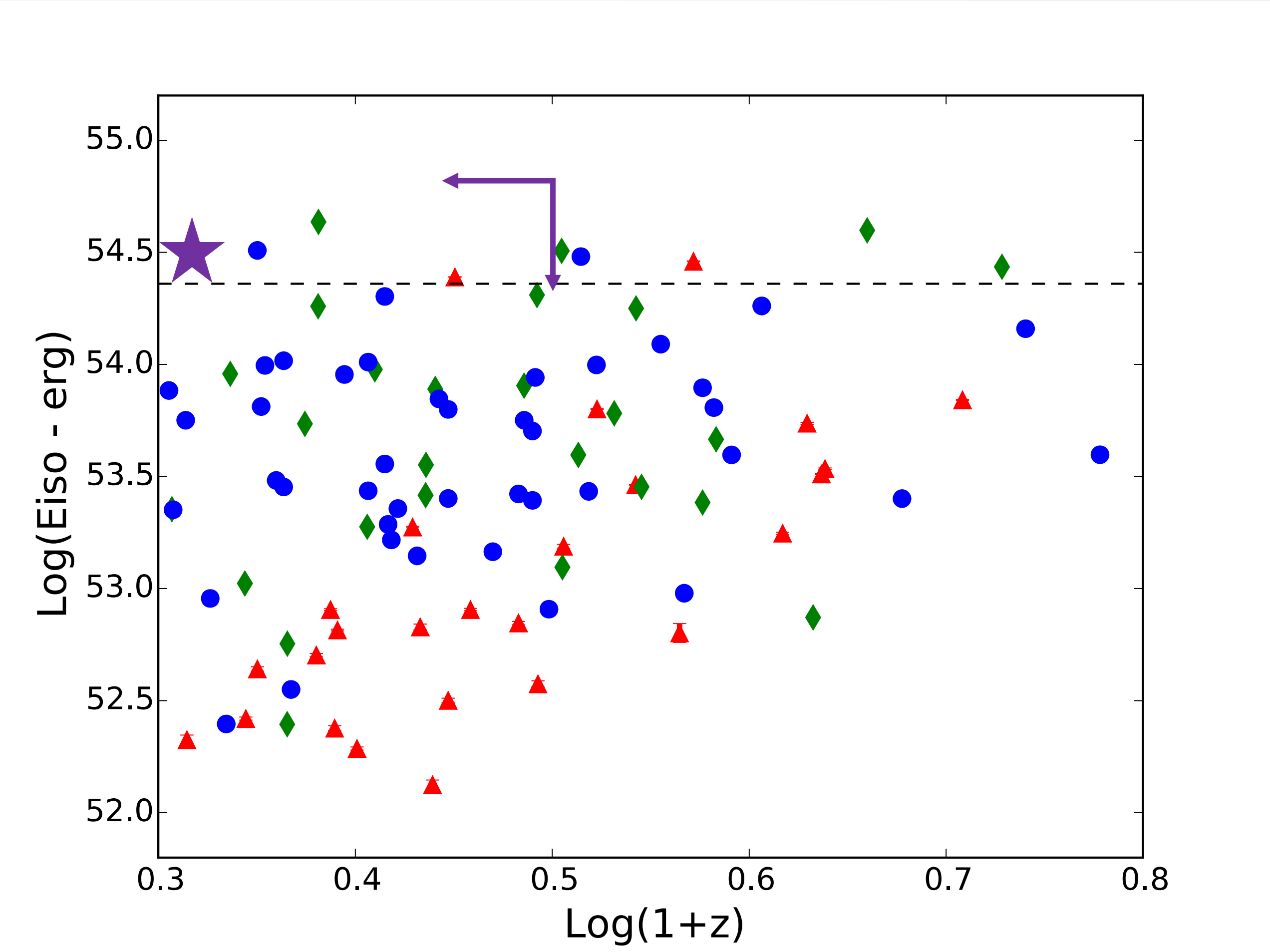
z = 1.096
(GCN 23246)

$E_{iso} \approx 3\ 10^{54}$ erg
(GCN 23240 and GCN 23246).

GRB 190530A:

z ≤ 2.2
(GCN 24715)

$E_{iso} \leq 6\ 10^{54}$ erg
(GCN 23240).



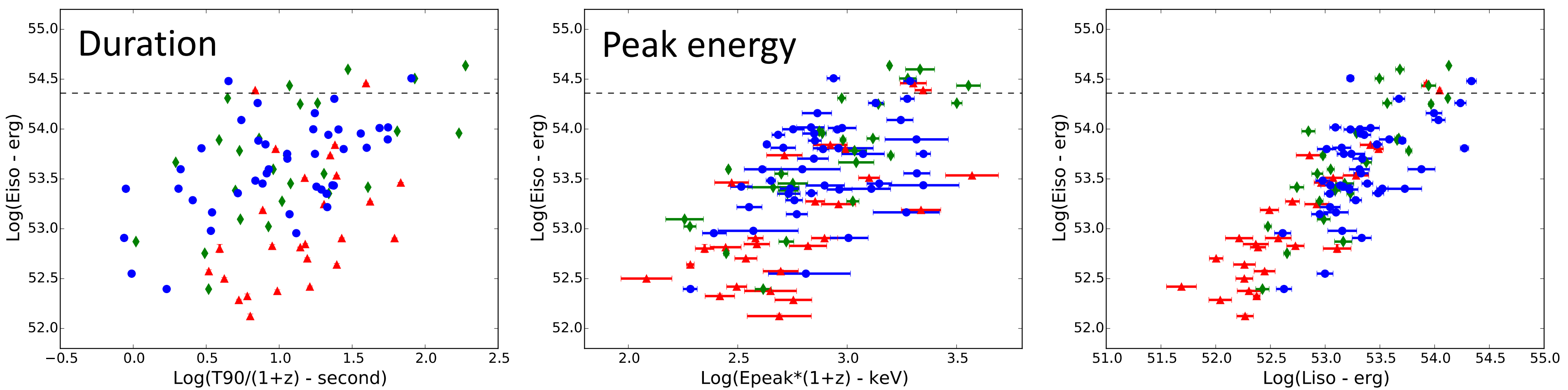
The most energetic GRBs

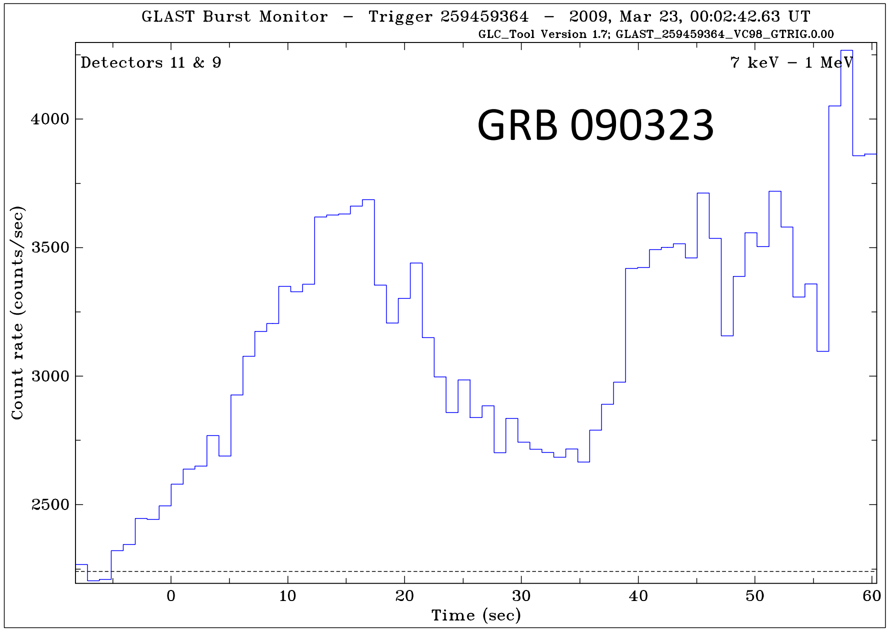
- Our sample contains 8 *energetic* GRBs with $E_{iso} \geq 2.3\ 10^{54}$ erg (arbitrary limit):
  - 080916C, 090323, 120624B, 160625B ➔ K+G (and *Fermi*/LAT)
  - 090902B, 140206A ➔ G only (and *Fermi*/LAT)
  - 130505A, 130907A ➔ K only

- These energetic GRBs are *not special*
  - z = 4.35, 3.60, 2.20, 1.41, 1.82, 2.73, 2.27,1.24

- Outside our redshift range, we found one energetic GRB:
  - GRB 110918A at z=0.984, with Eiso = 2.3 10^{54} erg detected by Konus
  - We found no energetic GRB beyond z=5, despite1500 Gpc^3 in 5<z ≤10

- We estimate the rate of energetic GRBs to be ~5/yr/sky.

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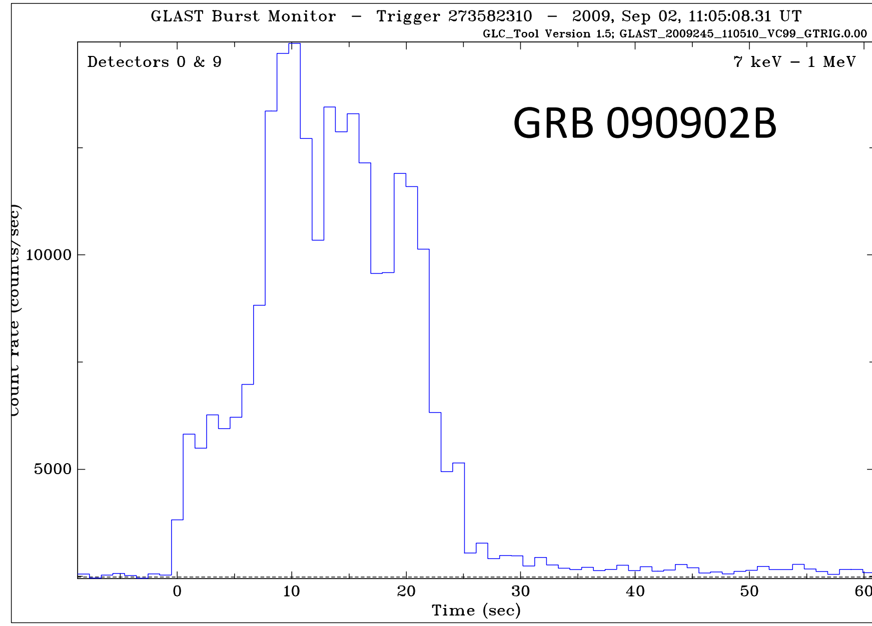
GLC_Tool Version 1.7; GLAST_259459364_VC98_GTRIG.0.00
Detectors 11 & 9
7 keV – 1 MeV
GRB 090323
Count rate (counts/sec)
Time (sec)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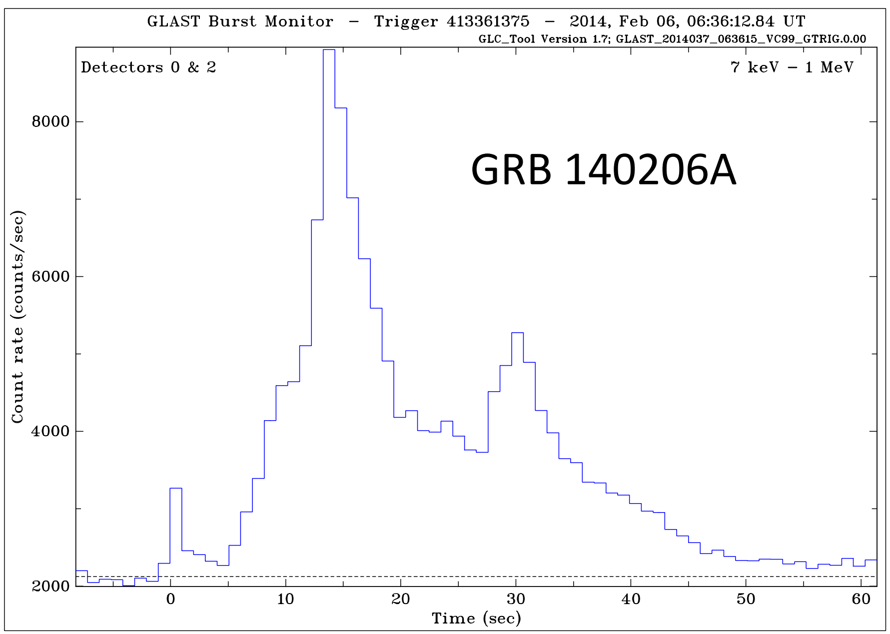
Detectors 0 & 9
7 keV – 1 MeV
GRB 090902B
Time (sec)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Detectors 0 & 2
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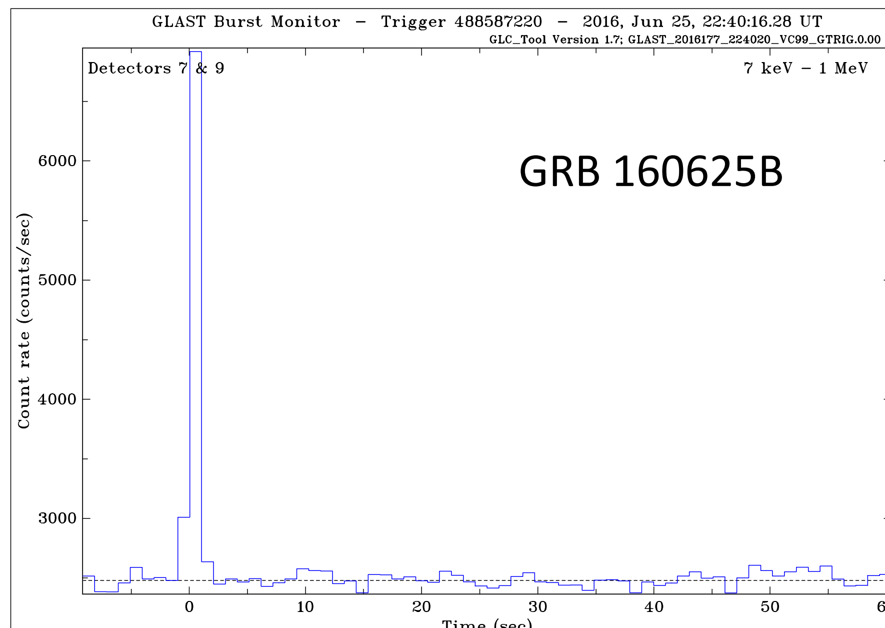
GRB 140206A
Count rate (counts/sec)
Time (sec)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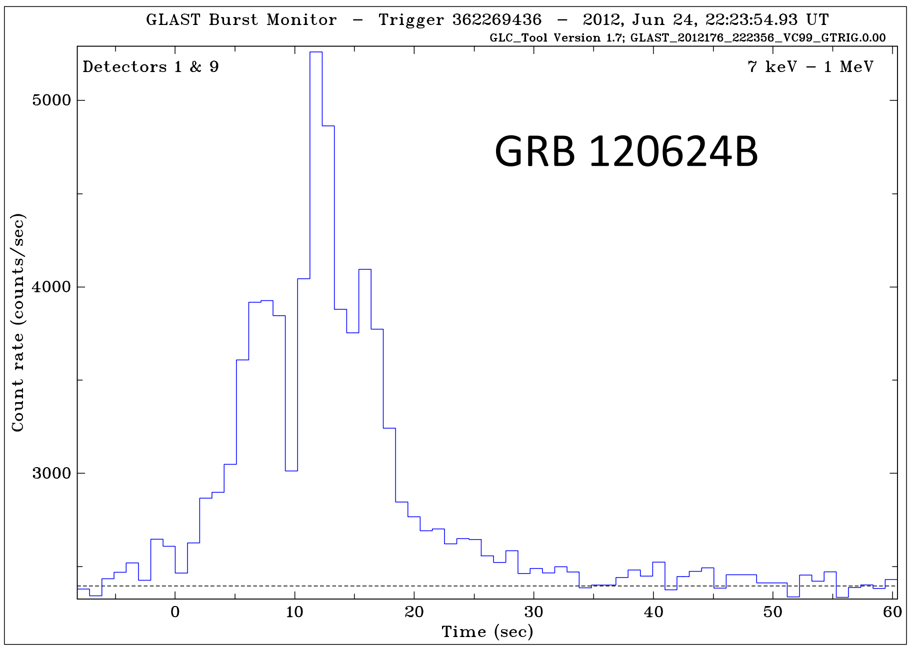
Detectors 7 & 9
7 keV – 1 MeV
GRB 160625B
Count rate (counts/sec)
Time (sec)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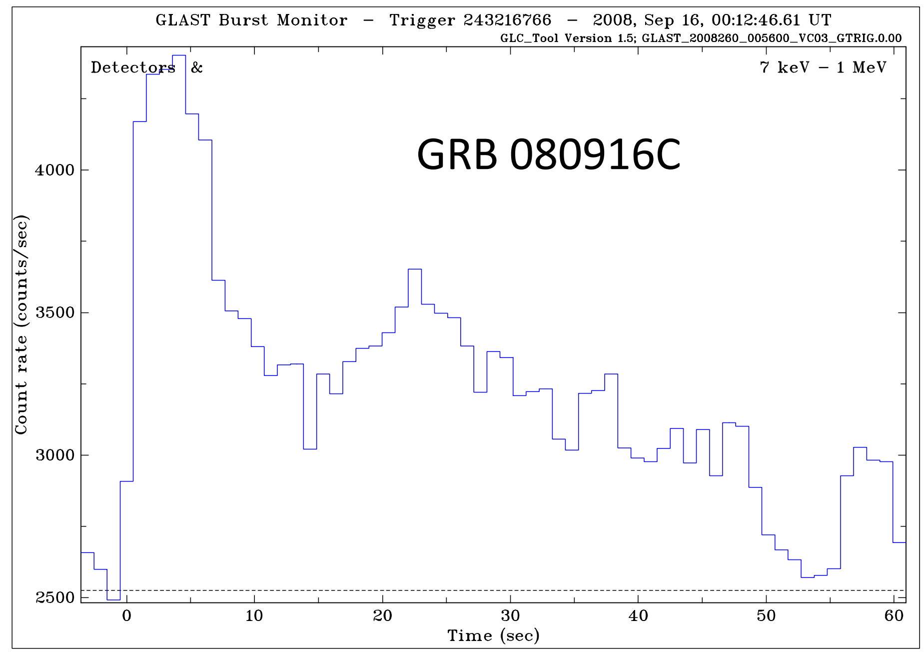
Detectors 1 & 9
7 keV – 1 MeV
GRB 120624B
Count rate (counts/sec)
5000
4000
3000
0
10
20
30
40
50
60
Time (sec)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Detectors &
7 keV – 1 MeV
GRB 080916C
Count rate (counts/sec)
4000
3500
3000
2500
0
10
20
30
40
50
60
Time (sec)