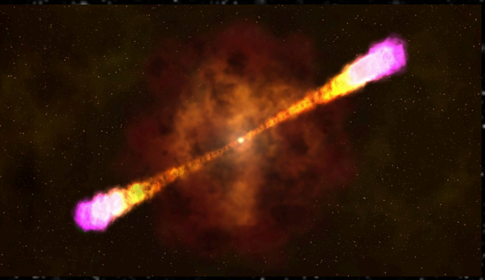
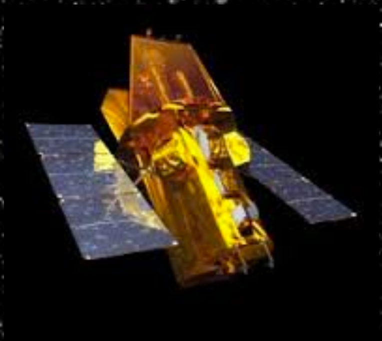




The Third Swift Burst Alert Telescope Gamma-Ray Burst Catalog:

Instrumental Sensitivity and Implication on the High-Redshift GRBs

Amy Lien (GSFC/UMBC)

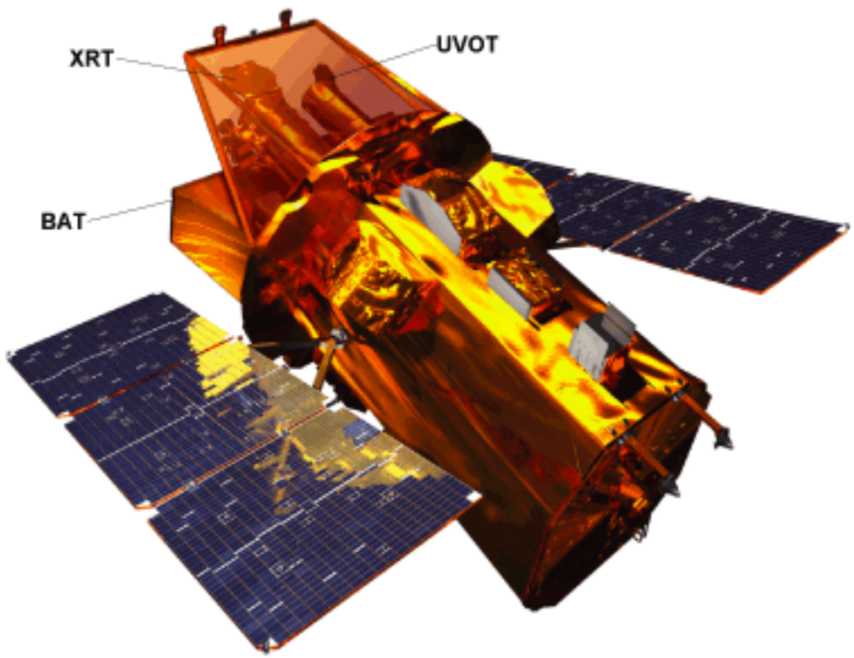
Takanori Sakamoto (Aoyama Gakuin Univ.)

and the BAT team

The 8th Huntsville GRB Symposium, Huntsville, AL, 2016/10/24

The Swift Burst Alert Telescope (BAT)

- Telescope that trigger GRBs
  - $\sim$ 90 burst per year ($\sim$ 2 per week)
- 15 - 150 keV
- Field-of-view: $\sim$ 2 sr ($\sim$ 1/6 of the sky)



The 3rd BAT GRB catalog

(Lien & Sakamoto et al. (2016) ApJ 829, 7)

- $\sim$ 1000 GRBs seen by BAT till GRB151027B
- Characteristics of prompt emission
  - Burst durations, spectral analysis
- GRB redshift list
- GRB trigger method, burst incident angles
- Discussions of instrumental sensitivity and their effects on GRB detections
- Search for extended emission beyond event data (survey data)

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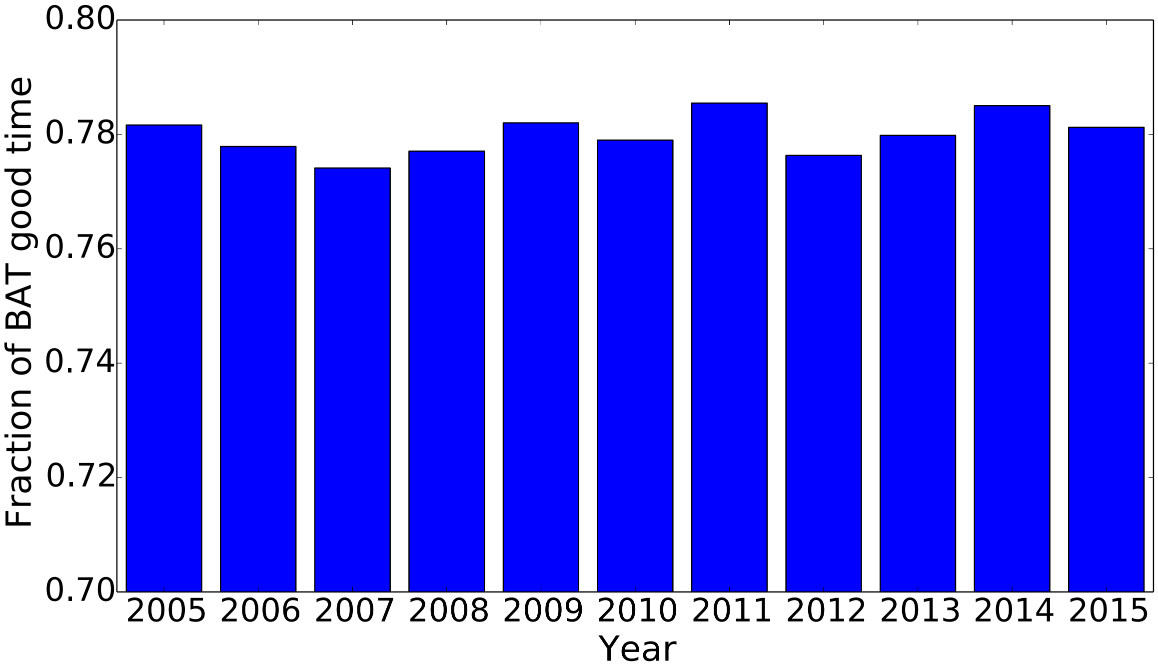
- GRB trigger method, burst incident angles
- Discussions of instrumental sensitivity and their effects on GRB detections
- Search for extended emission beyond event data (survey data)
- All results and data are public on:

  http://swift.gsfc.nasa.gov/results/batgrbcat/

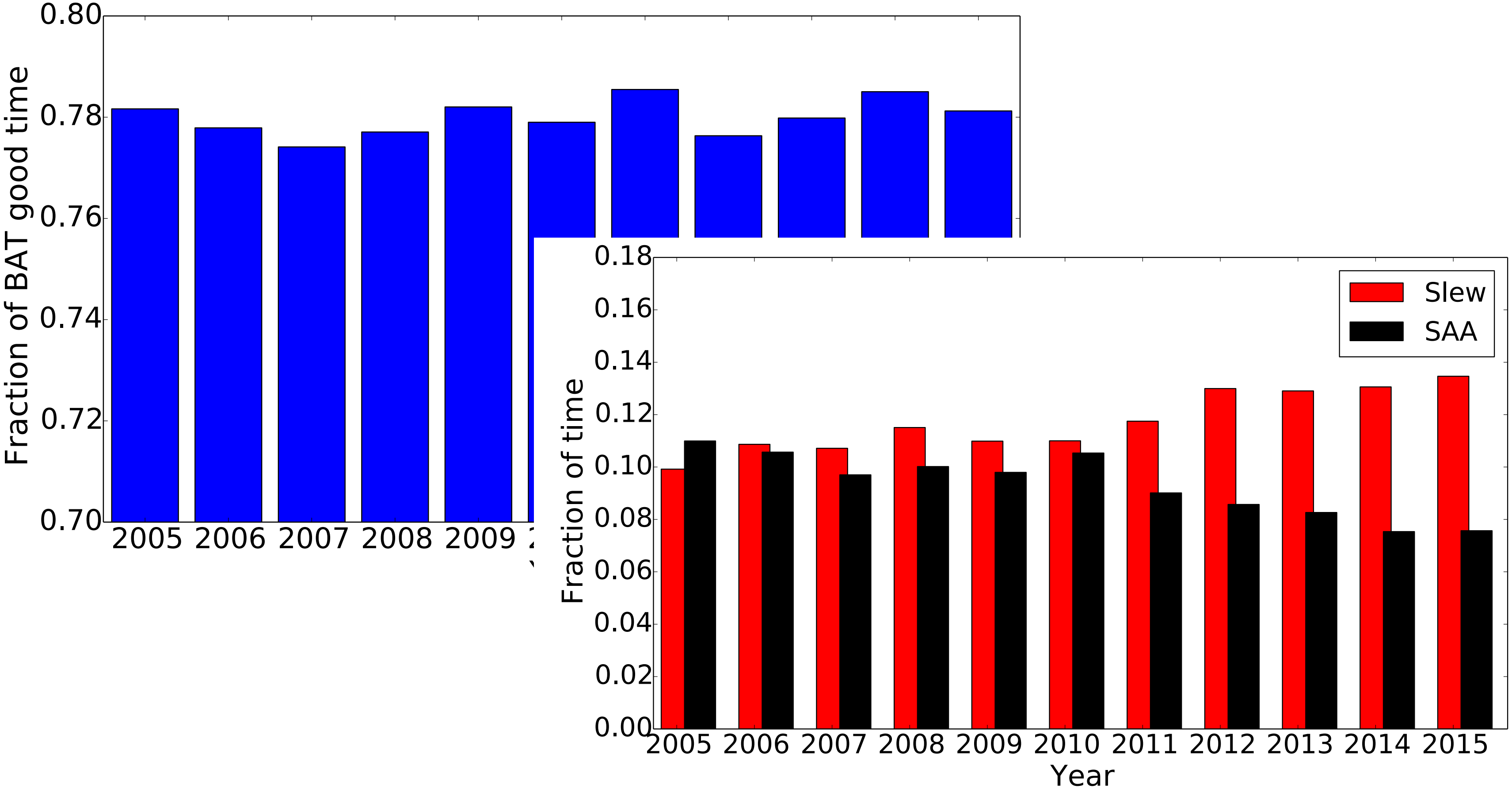
  Website will continue to be updated with recent bursts

BAT Observing Time



BAT Observing Time

- $\sim$ 11+-1% deadtime for the South Atlantic Anomaly (SAA)
- $\sim$ 11+-1% due to slewing

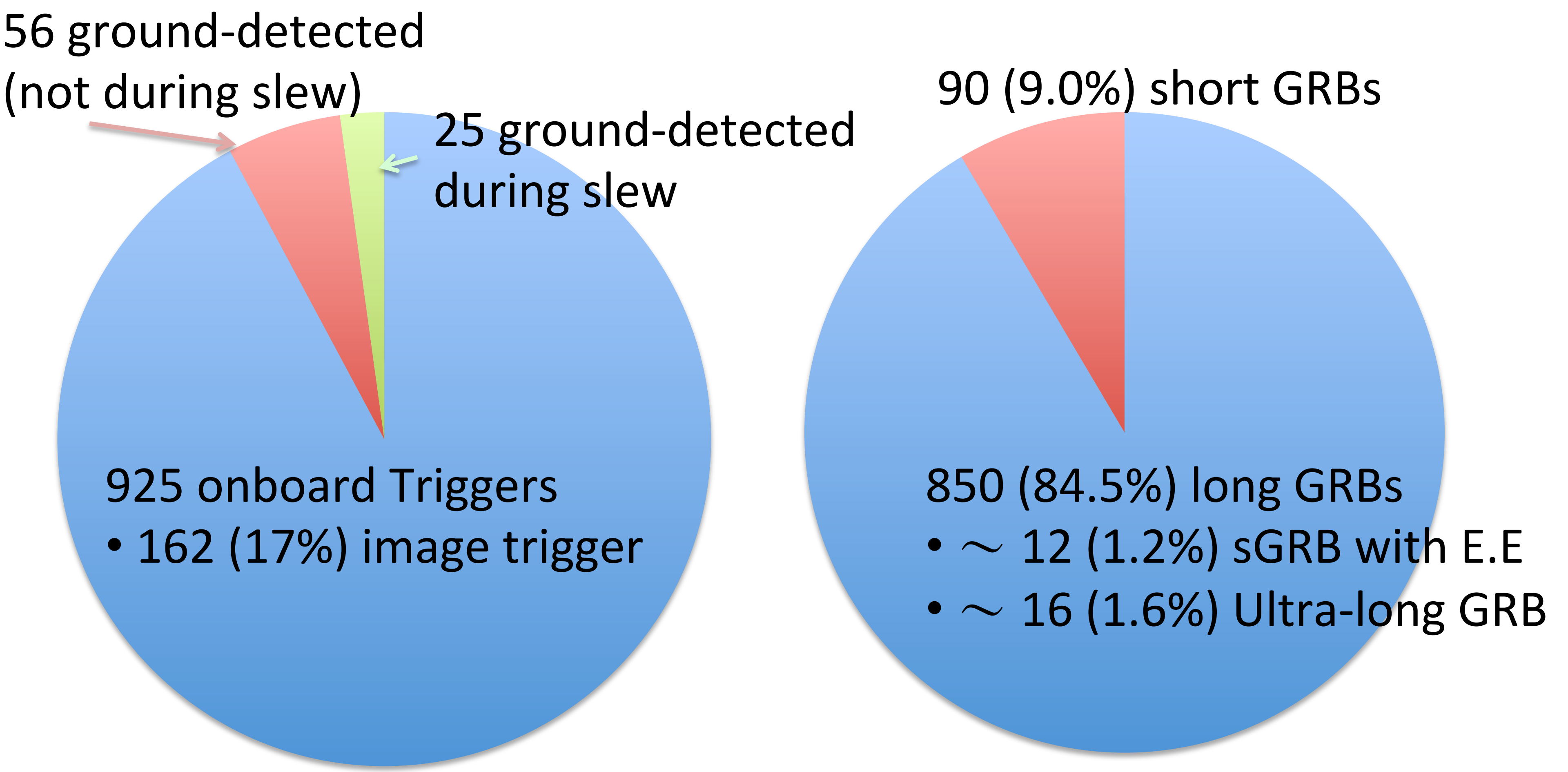


BAT Active Detectors

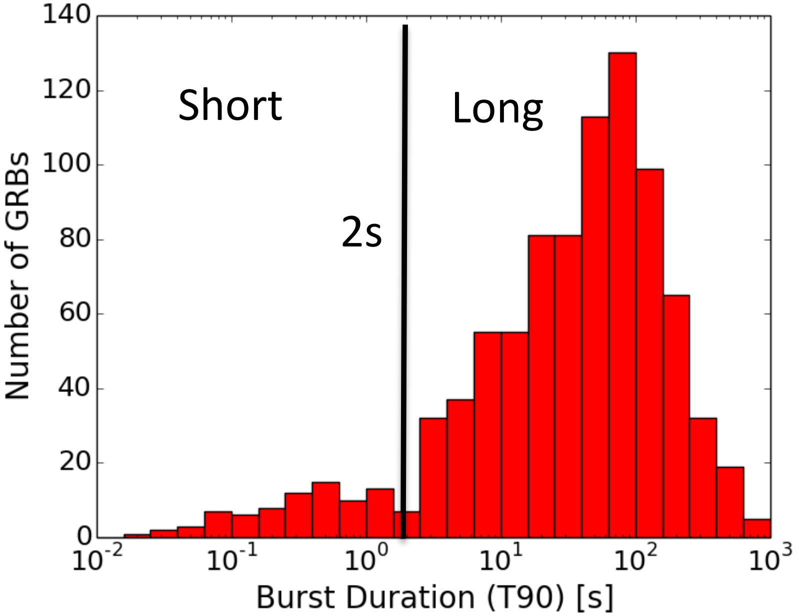
Year	Number of detections (with ground-detected GRBs)	Number of detections (no ground-detected GRBs)	Average number of active BAT detectors
2005	88	86	29413
2006	102	100	26997
2007	87	80	27147
2008	105	96	26478
2009	91	81	24387
2010	85	72	24050
2011	82	75	22817
2012	92	89	23017
2013	96	85	22053
2014	94	84	20413

Swift/BAT GRBs to date

- $\sim$ 1095 GRBs till now.
- In this presentation (3rd BAT GRB catalog): 1006 GRBs till GRB151027B



Burst Durations



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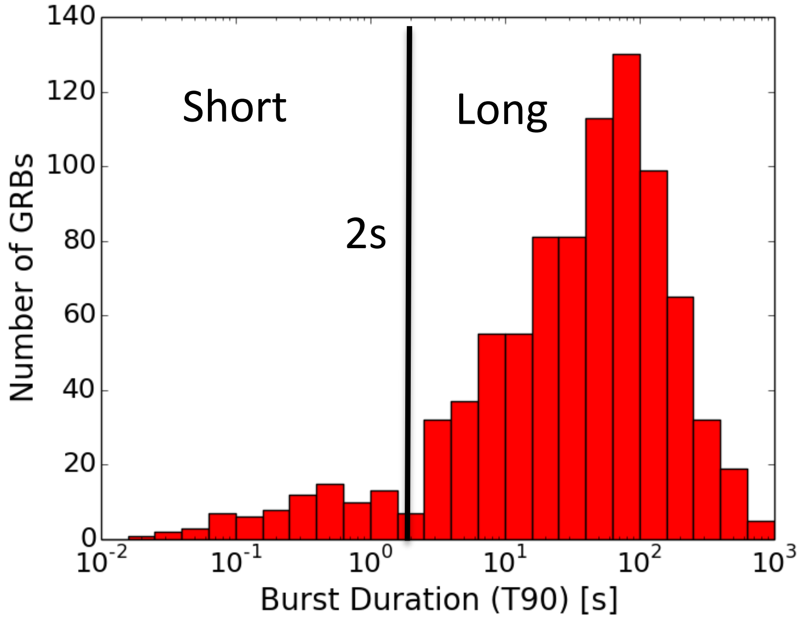


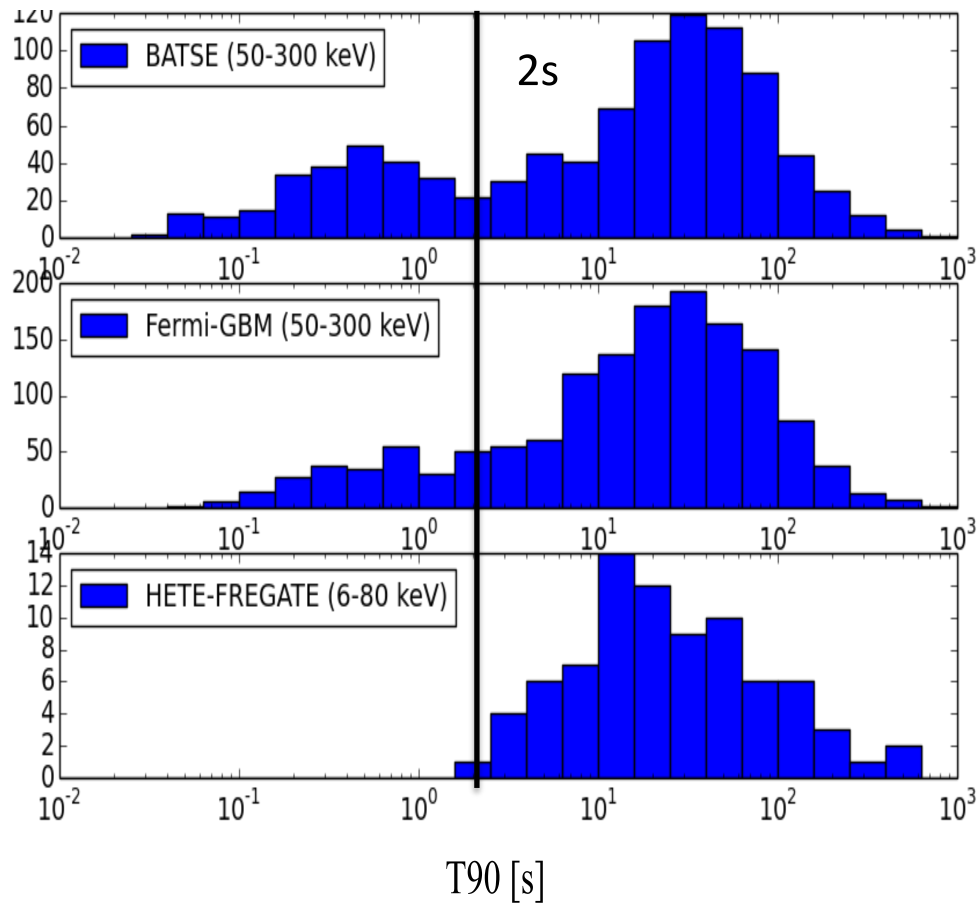
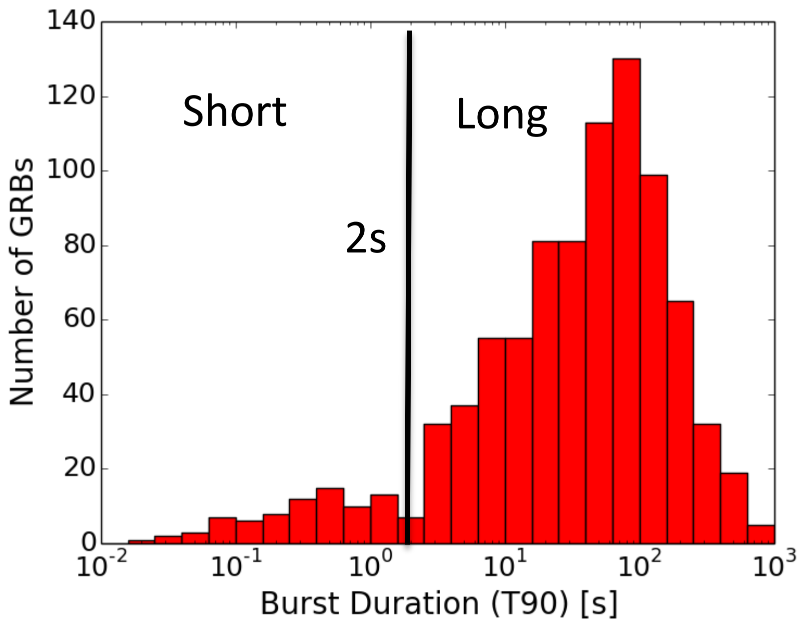
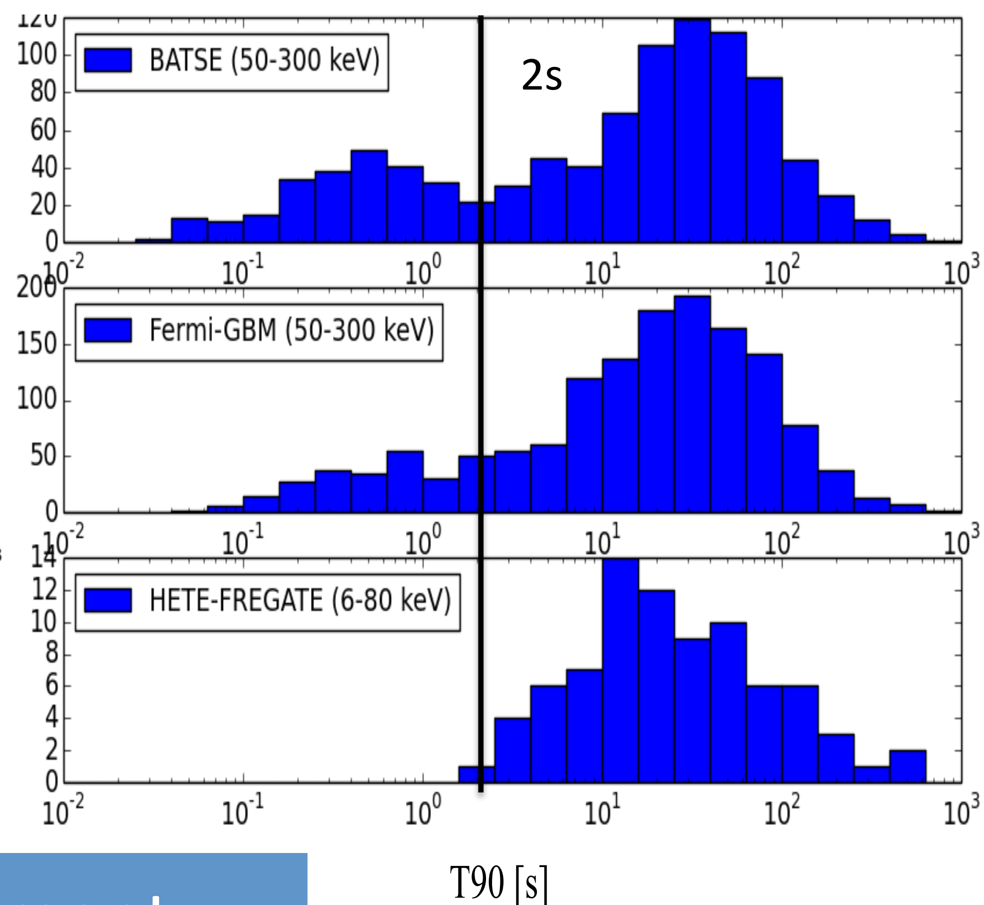


Fig credit: Taka's presentation

Burst Durations

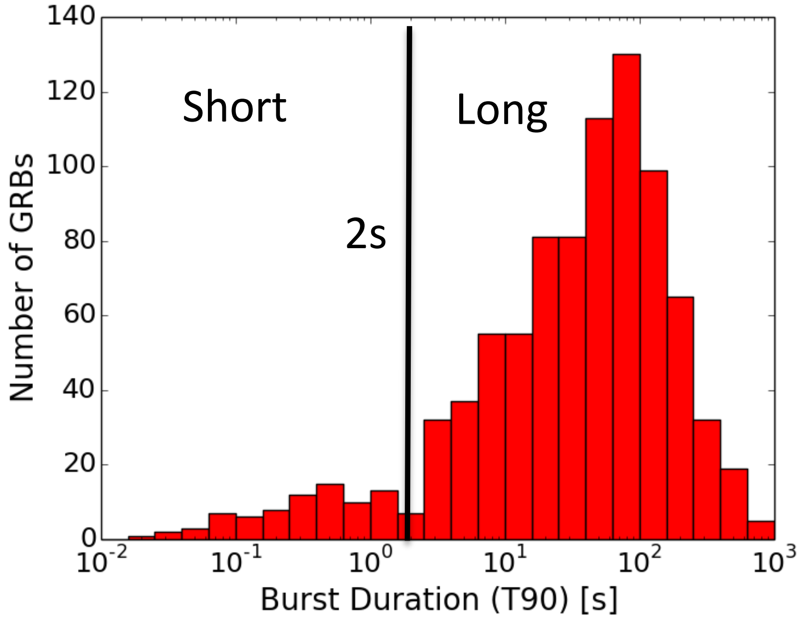


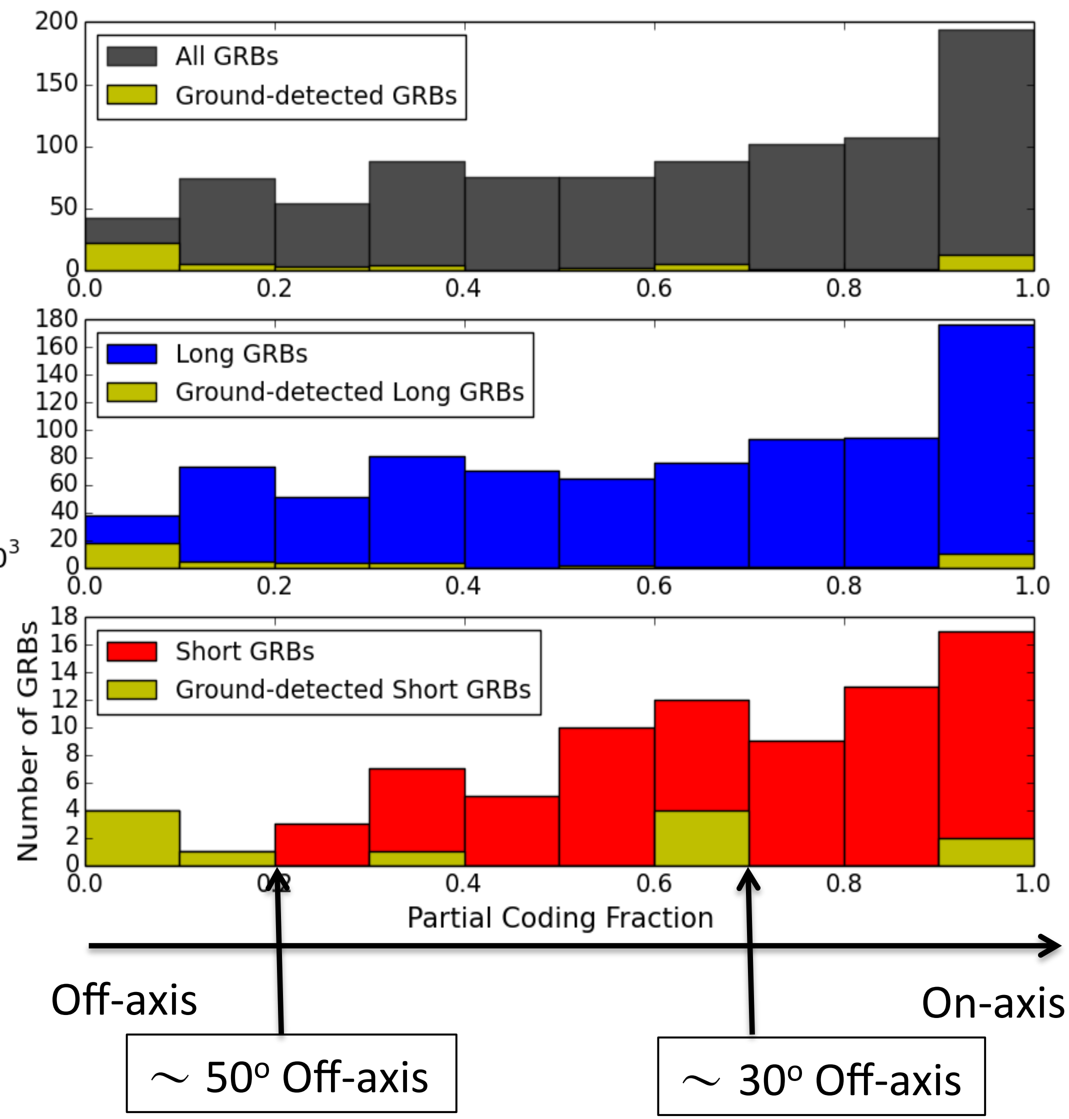


Distribution is instrument dependent

Fig credit: Taka's presentation

Burst Durations



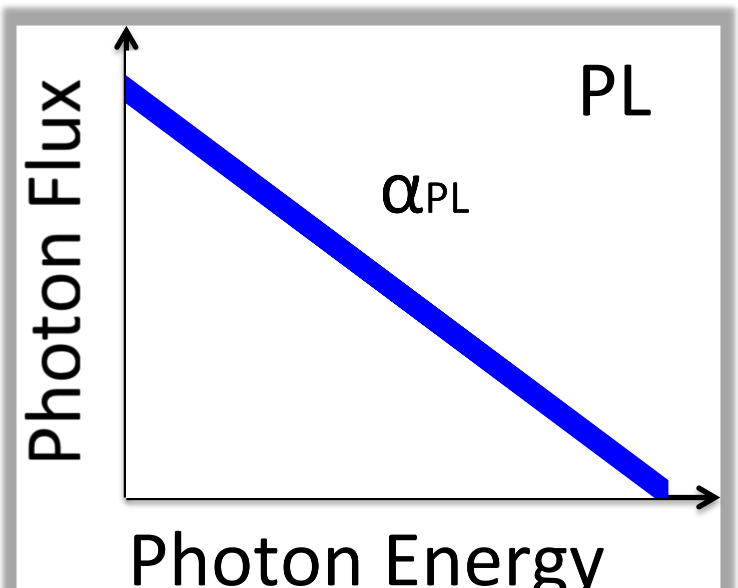


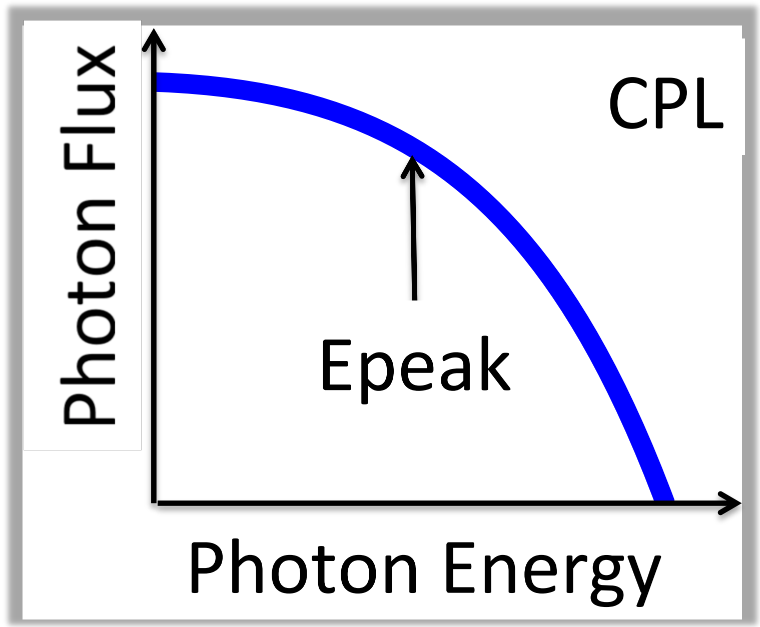
- Short GRBs are less-likely to be detected off-axis
- Some off-axis short GRBs are found in ground analyses

GRB Spectral Analysis

- Following the 2nd BAT GRB catalog (Sakamoto et al. 2011)
- (a) simple power law (PL)

  (b) cutoff power law (CPL)
- Choose CPL If $\Delta\chi^2 > 6$ (false-positive rate: 0.62%; Sakamoto et al. 2008))





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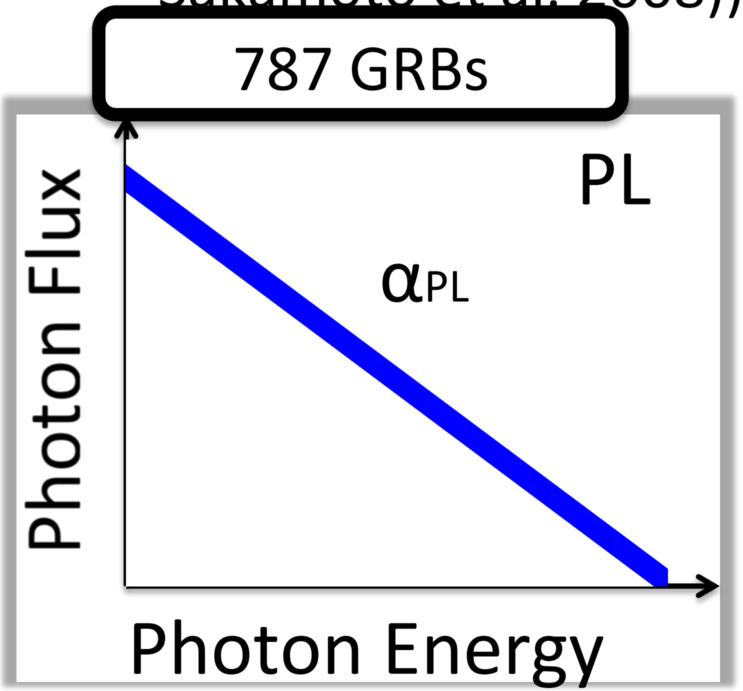

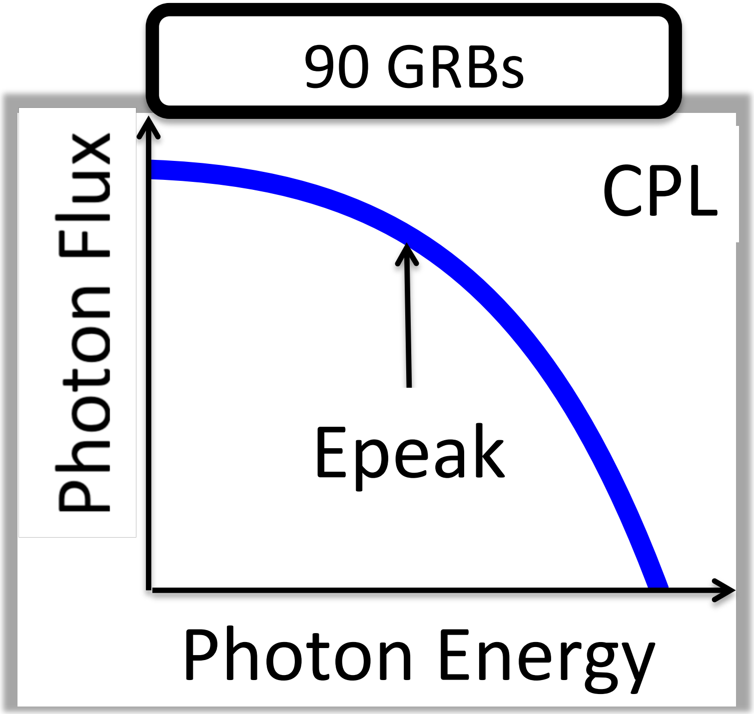

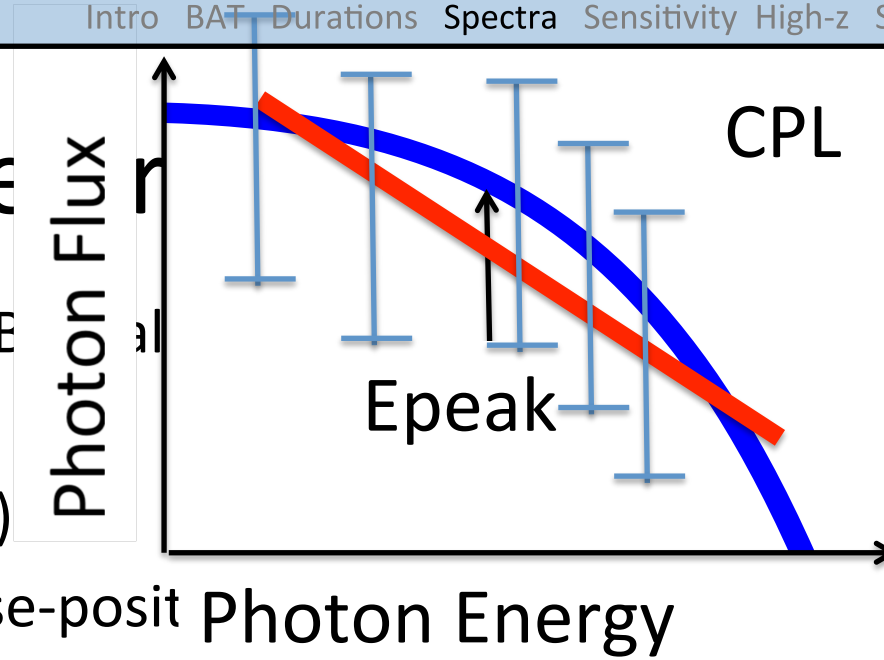

GRB Spe… r…

- Following the 2nd BAT GRB … al…
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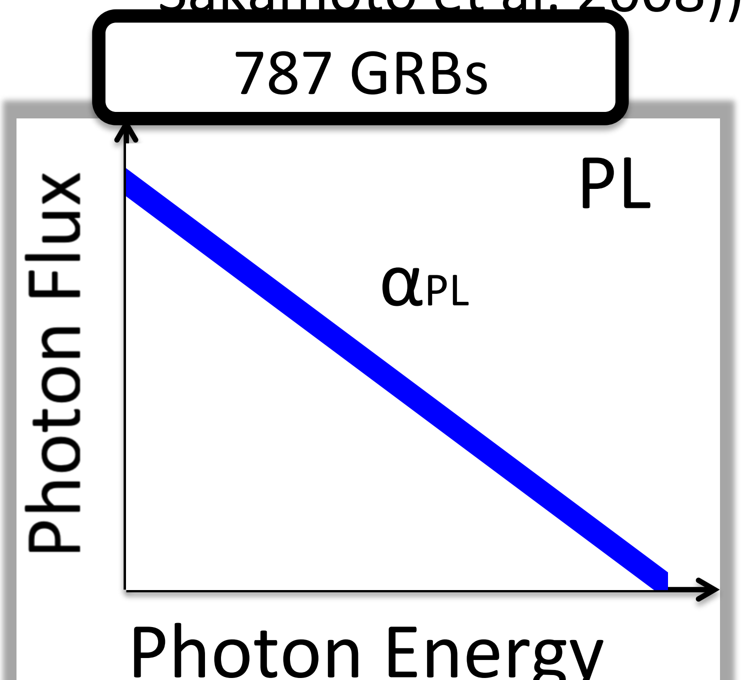
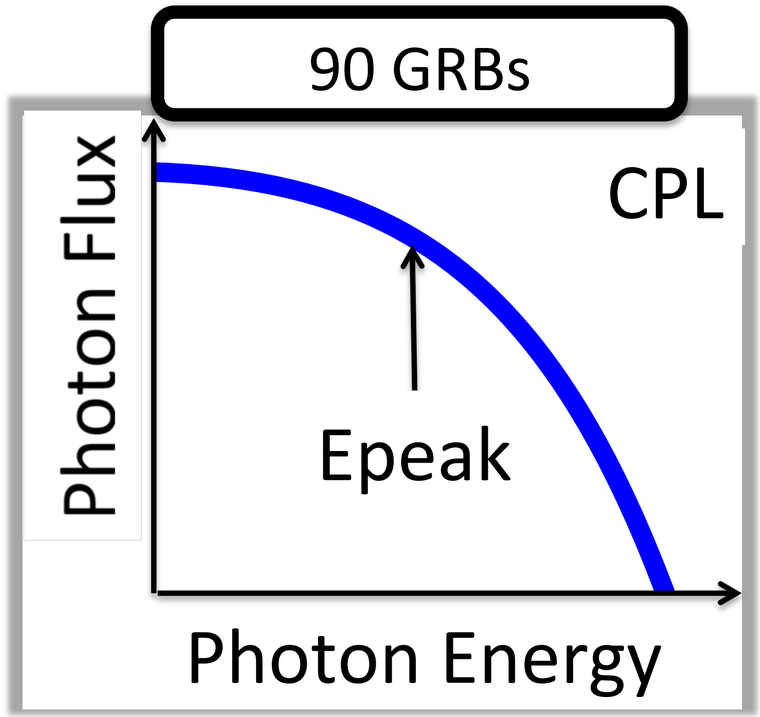
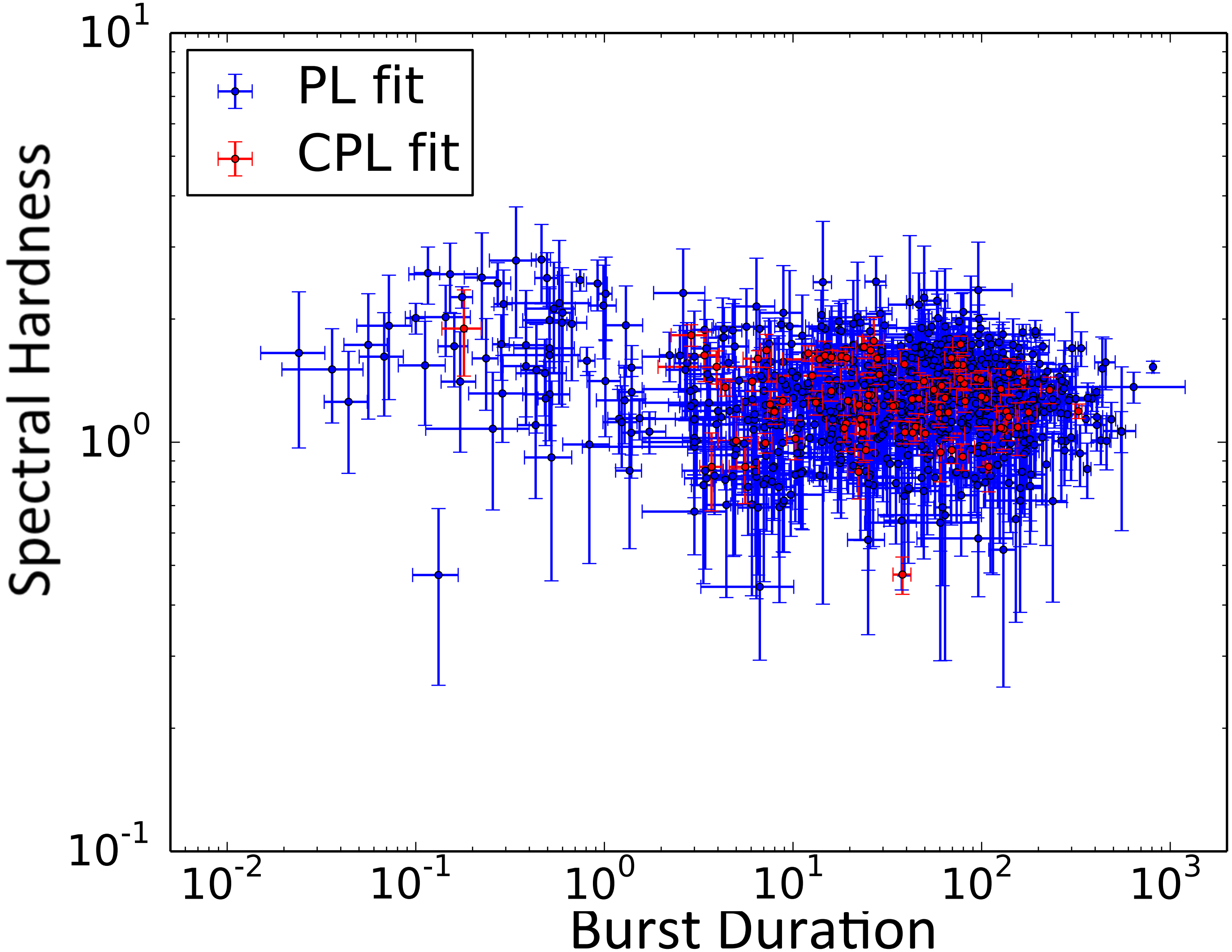


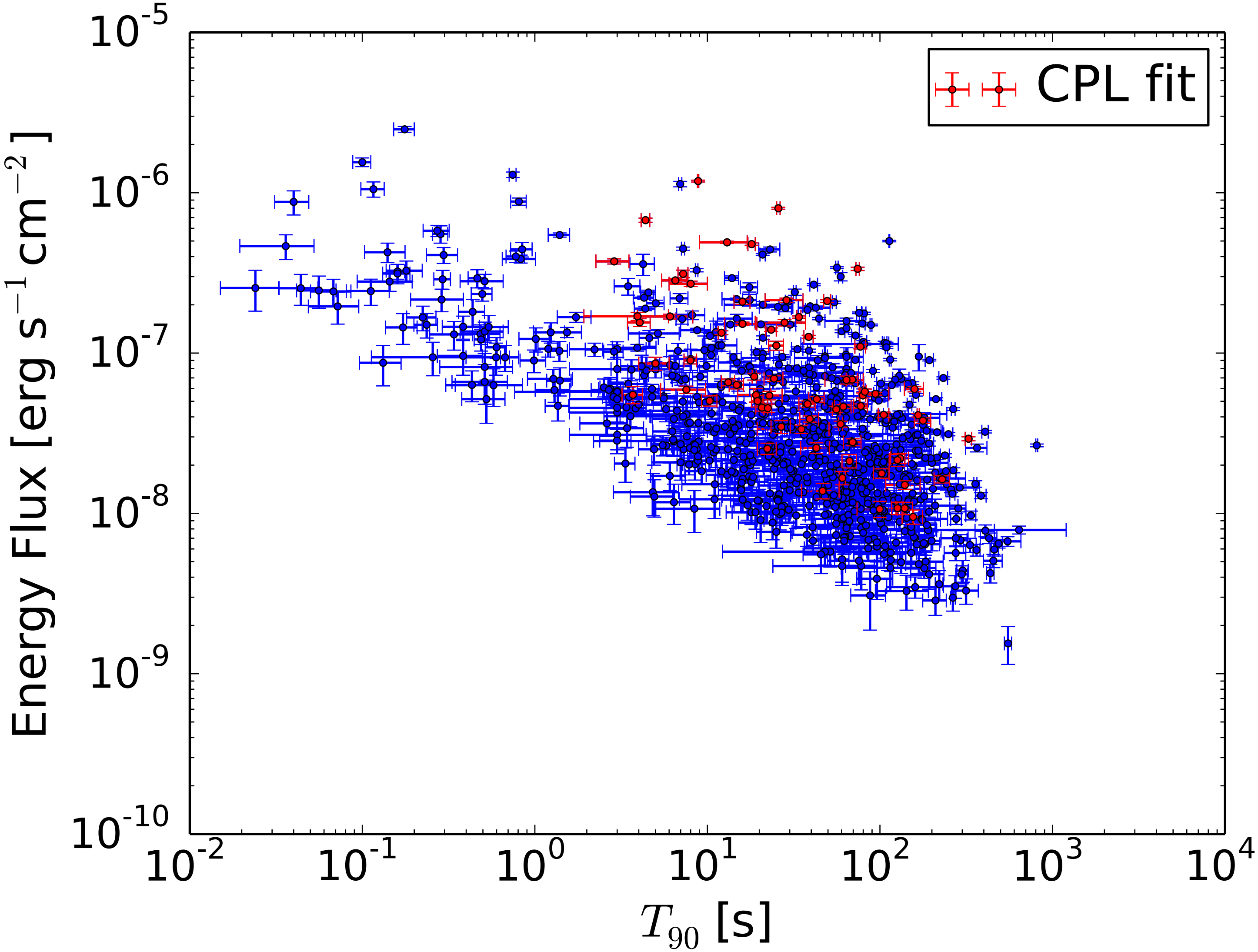


BAT GRB

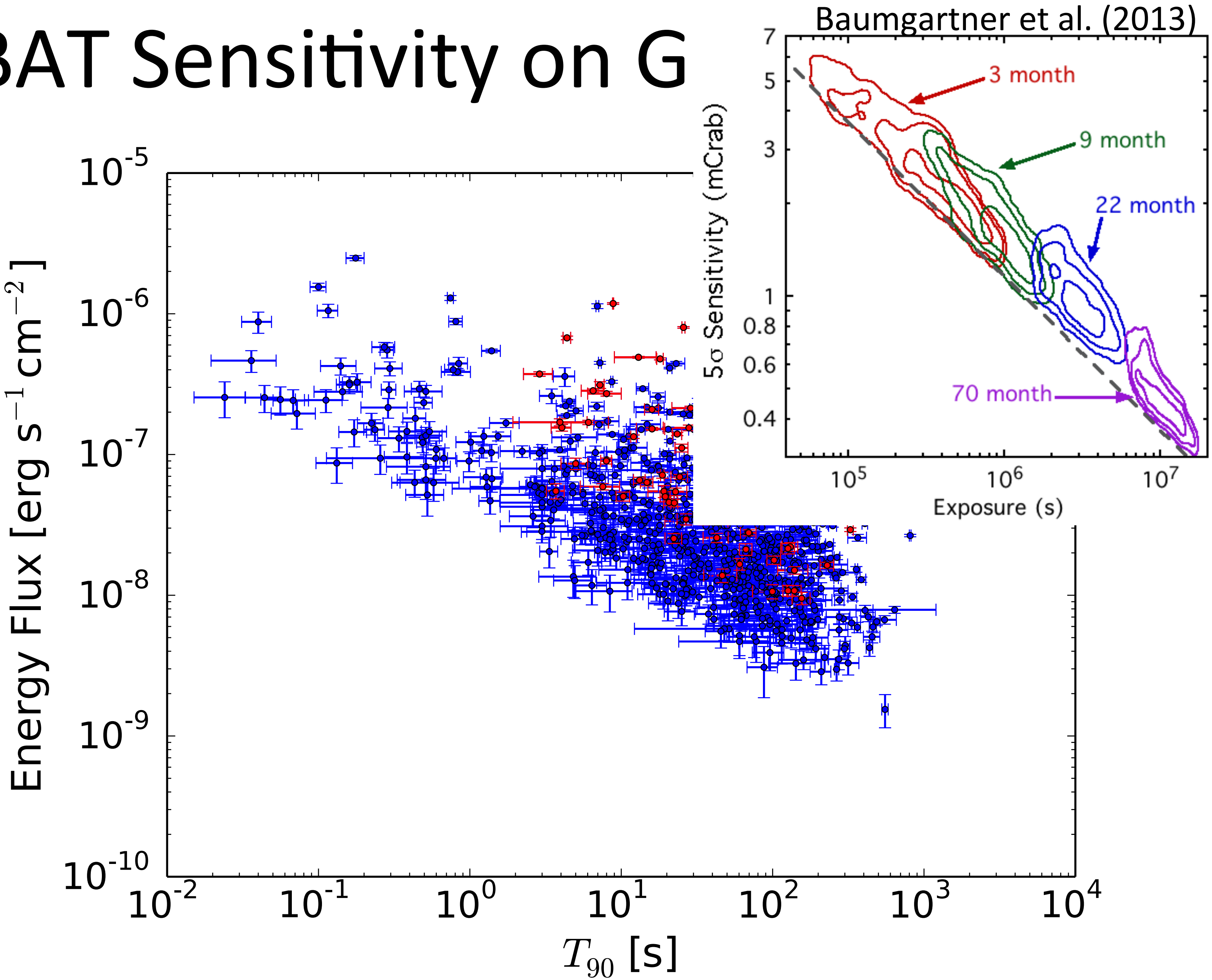
Spectral and Temporal Distributions



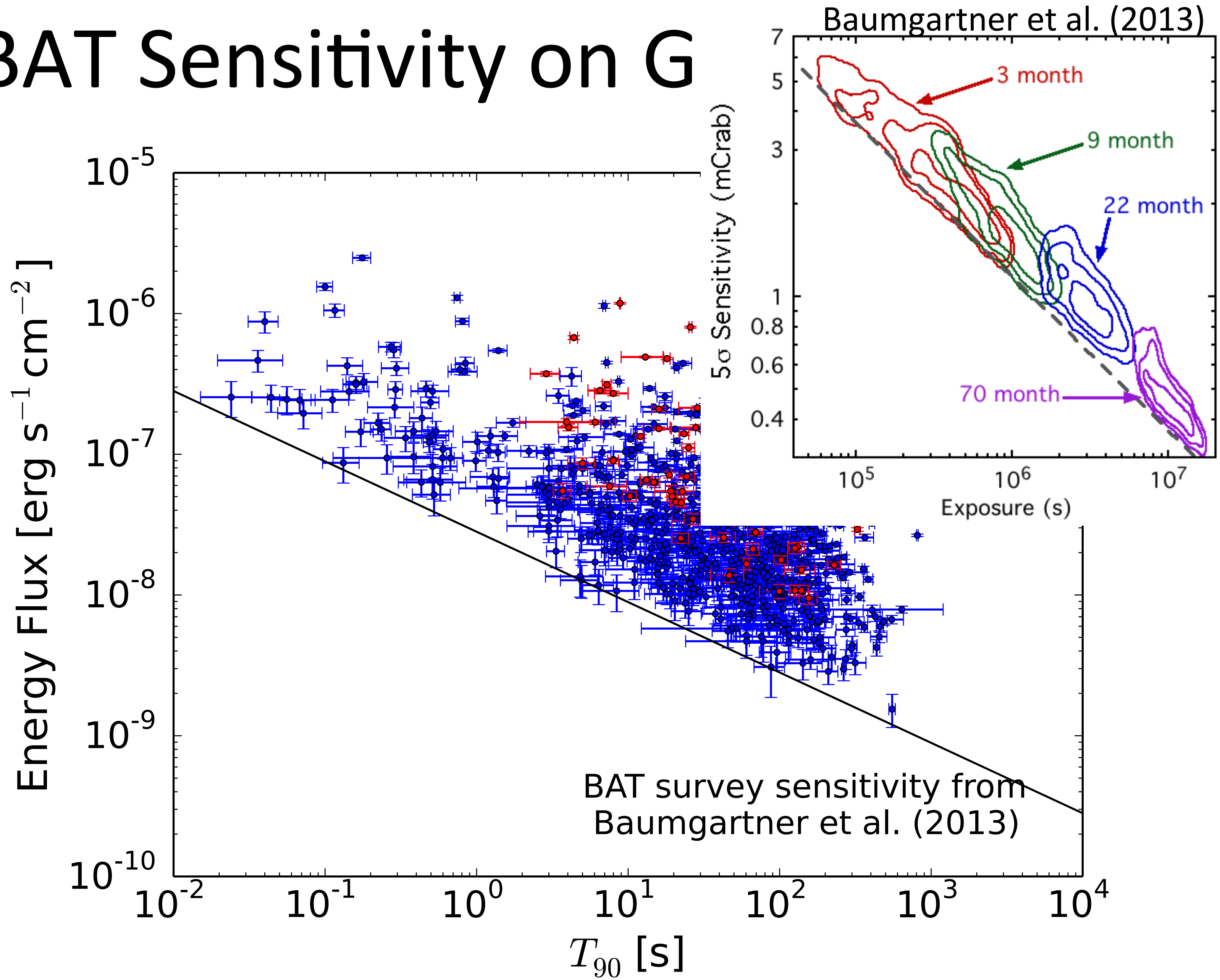
BAT Sensitivity on GRB Detections



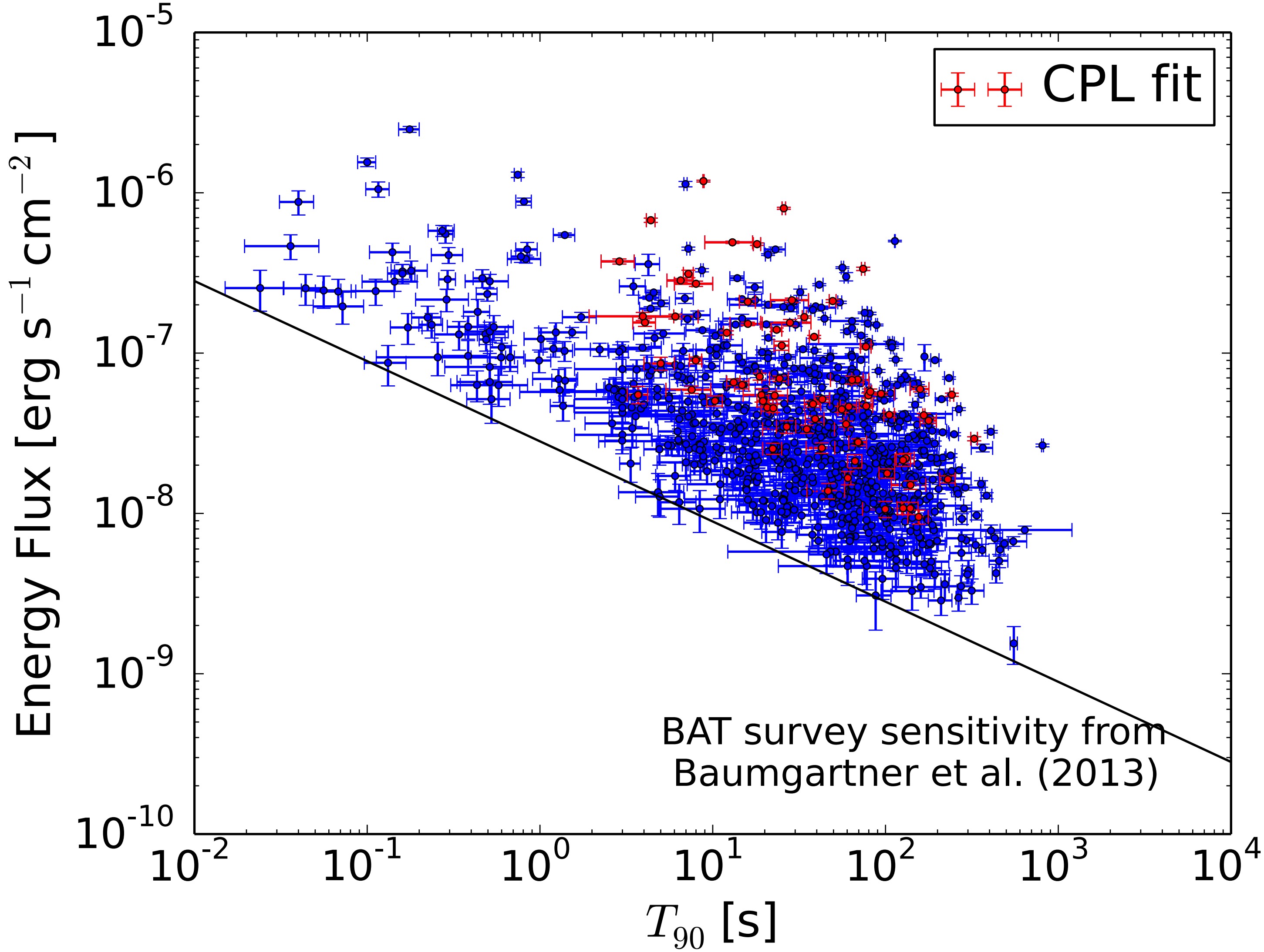
BAT Sensitivity on G



BAT Sensitivity on G

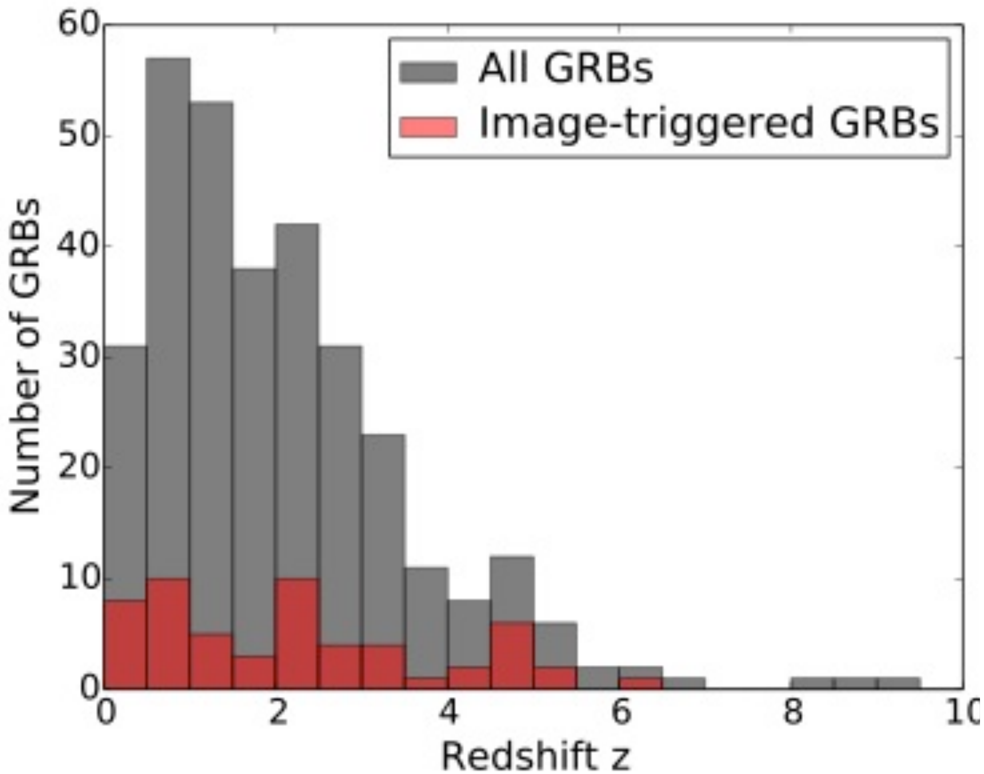


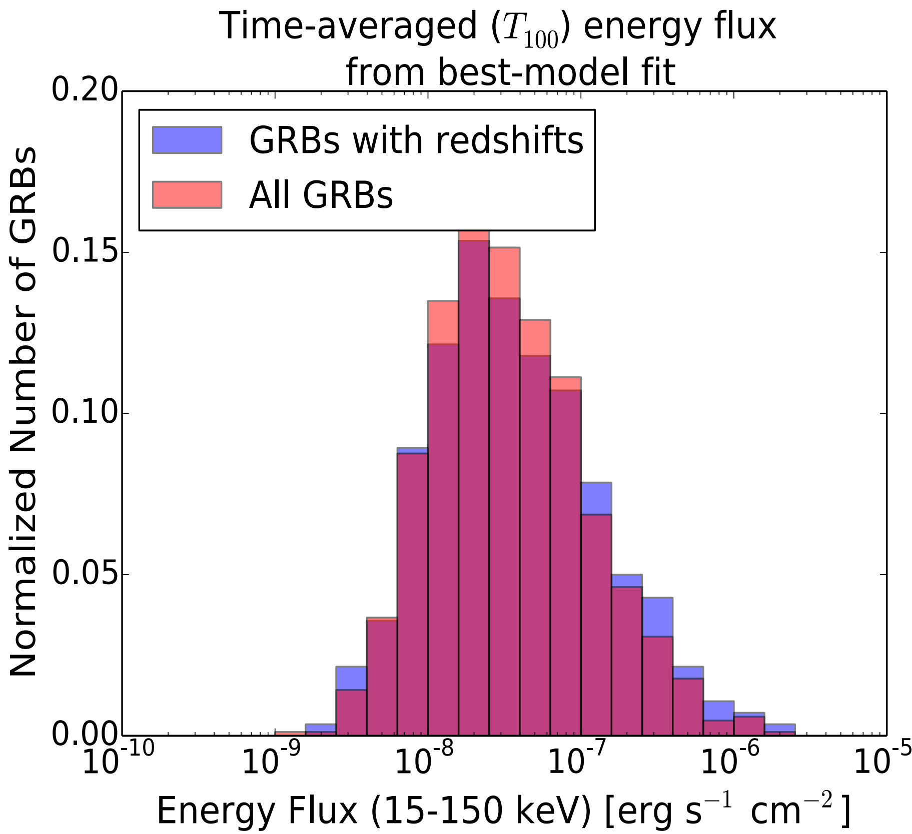
BAT Sensitivity on GRB Detections



Swift/BAT GRBs with Redshifts

- 378 ($\sim$ 1/3) GRBs have redshift measurements
  - Thanks to the ground-based follow-up campaign





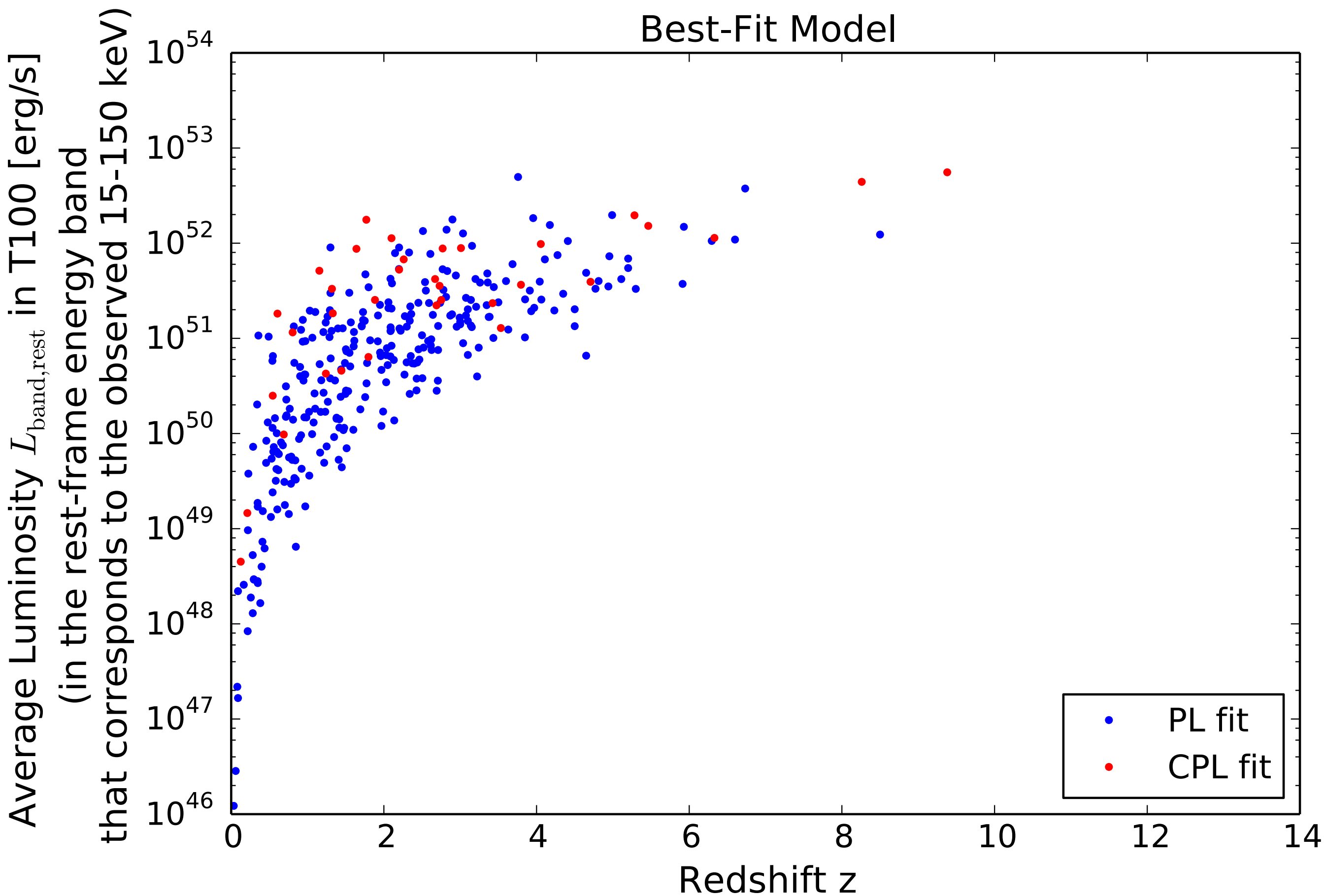
List of high-z (z > 5) GRBs to date

GRB name	Redshift	Method	Reference
GRB060522	5.11	ba	Cenko S.B. et al. GCN Circ. 5155
GRB071025	5.20	ba	Fynbo J.P.U. et al. ApJS 185 526 (2009)
GRB050502B	$5.20^{+0.3}_{-0.3}$	hp	Afonso P. et al. A&A 526 A154 (2011); *Schulze et al. ApJ 808 73 (2015)
GRB140304A	5.28	ba	de Ugarte Postigo A. et al. GCN Circ. 15924; *Jeong S. et al. GCN Circ. 15936
GRB050814	$5.30^{+0.3}_{-0.3}$	bp	Jakobsson P. et al. AIPC 836 552 (2006)
GRB060927	5.46	ba	Ruiz-Velasco A.E. et al. ApJ 669 1 (2007); *Fynbo J.P.U. et al. ApJS 185 526 (2009)
GRB130606A	5.91	ba	*Chornock R. et al. ApJ 774 26 (2013); Castro-Tirado A.J. et al. arXiv:1312.5631 (2013)
GRB120521C	$5.93^{+0.11}_{-0.14}$	bp	Tanvir N.R. et al. GCN Circ. 13348; *Laskar T. et al. ApJ 781 1 (2014)
GRB050904	6.29	ba	Kawai N. et al. Nature 440 184 (2006)
GRB140515A	6.33	ba	Chornock R. et al. GCN Circ. 16269; *Chornock R. et al. arXiv:1405.7400 (2014)
GRB060116	$6.60^{+0.15}_{-0.15}$	bp	Grazian A. et al. GCN Circ. 4545
GRB080913	6.73	ba	Greiner J. et al. ApJ 693 1610 (2009); *Patel M. et al. A&A 512 L3 (2010)
GRB090423	8.26	ba	*Tanvir N.R. et al. Nature 461 1254 (2009); Salvaterra R. et al. Nature 461 1258 (2009)
GRB120923A	8.50	bp	Tanvir N.R. arXiv:1307:6156 (2013); provisional; formal results yet to be released
GRB090429B	$9.38^{+0.14}_{-0.32}$	bp	Cucchiara A. et al. ApJ 736 7 (2011)

2005: 3
2006: 3
2007: 1
2008: 1
2009: 2
2010: 0
2011: 0
2012: 2
2013: 1
2014: 2
2015: 0
2016: 0

ba: burst absorption lines
bp: burst photo-z
hp: host photo-z

BAT detectability on high-z burst



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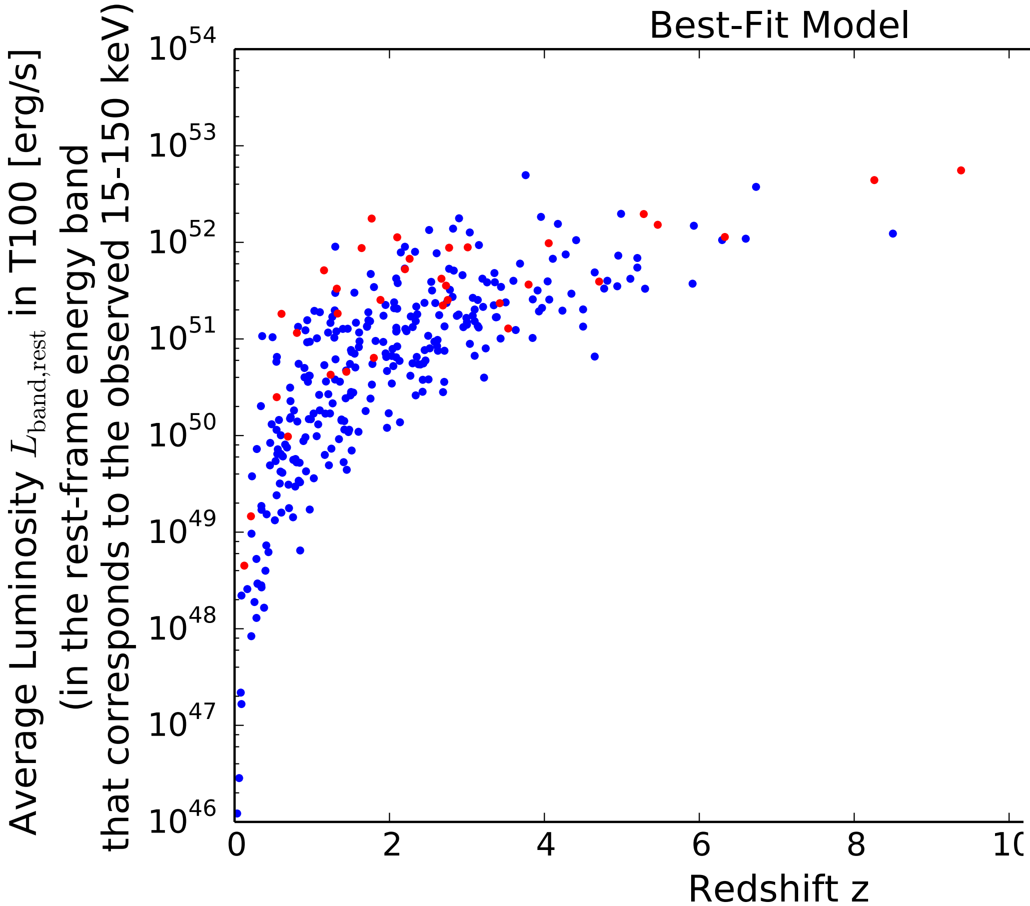
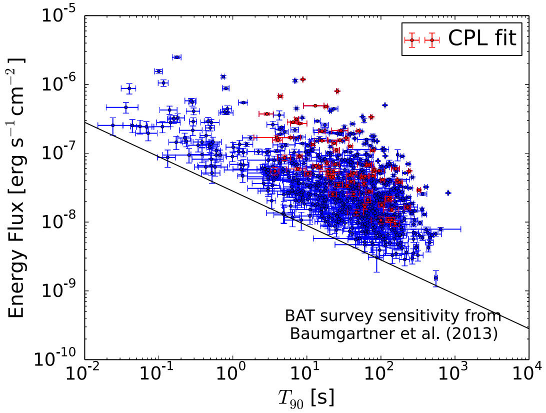
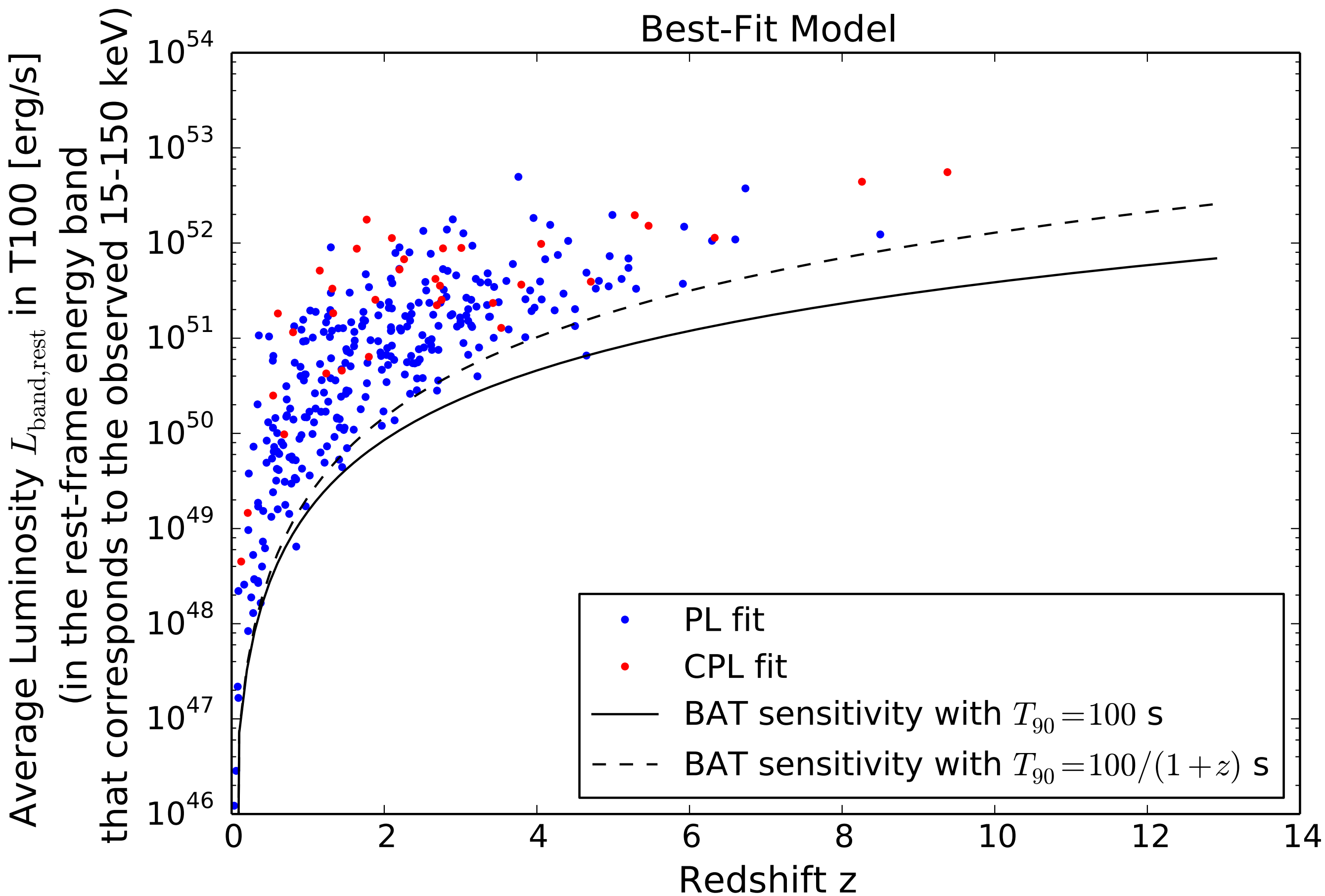




BAT detectability on high-z burst



BAT detectability on high-z burst: simulations

Peak Luminosity [erg/s]		Incident Angle [deg]	Highest Detectable Redshfit	
1-10000 keV	15-150 keV		ndet=20000	ndet=30000
1.00×10^{52}	1.52×10^{51}	56.29	0.70	0.90
		44.99	1.80	2.40
		26.56	2.50	3.00
		0.076	3.00	3.60

Peak Luminosity [erg/s]		Incident Angle [deg]	Highest Detectable Redshfit	
1-10000 keV	15-150 keV		ndet=20000	ndet=30000
5.00×10^{52}	7.62×10^{51}	56.29	1.50	1.80
		44.99	4.20	5.00
		26.56	5.40	6.90
		0.076	6.40	8.10

Peak Luminosity [erg/s]		Incident Angle [deg]	Highest Detectable Redshfit	
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		44.99	5.50	7.60
		26.56	8.10	9.90
		0.076	9.50	9.90

- Use light curve and spectra from GRB130427A
- Trigger simulator for determining the detectability

(Lien et al. (2014), http://userpages.umbc.edu/~alien/trigger_simulator/)

Incident angle	FOV [sr (deg^2)]	Fraction of Sky
56.29	2.11 (6926.72)	0.168
44.99	1.14 (3742.40)	0.091
26.56	0.41 (1345.95)	0.033
0.076	0.18 (590.91)	0.014

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		44.99	5.50	7.60
		26.56	8.10	9.90
		0.076	9.50	9.90

- BAT can generally detect burst with luminosity (obs 15-150 keV) > 10^{52} erg/s
- Incident angle is important

Incident angle	FOV [sr (deg^2)]	Fraction of Sky
56.29	2.11 (6926.72)	0.168
44.99	1.14 (3742.40)	0.091
26.56	0.41 (1345.95)	0.033
0.076	0.18 (590.91)	0.014

Comparison with real GRBs

- List of high-z burst detected to date

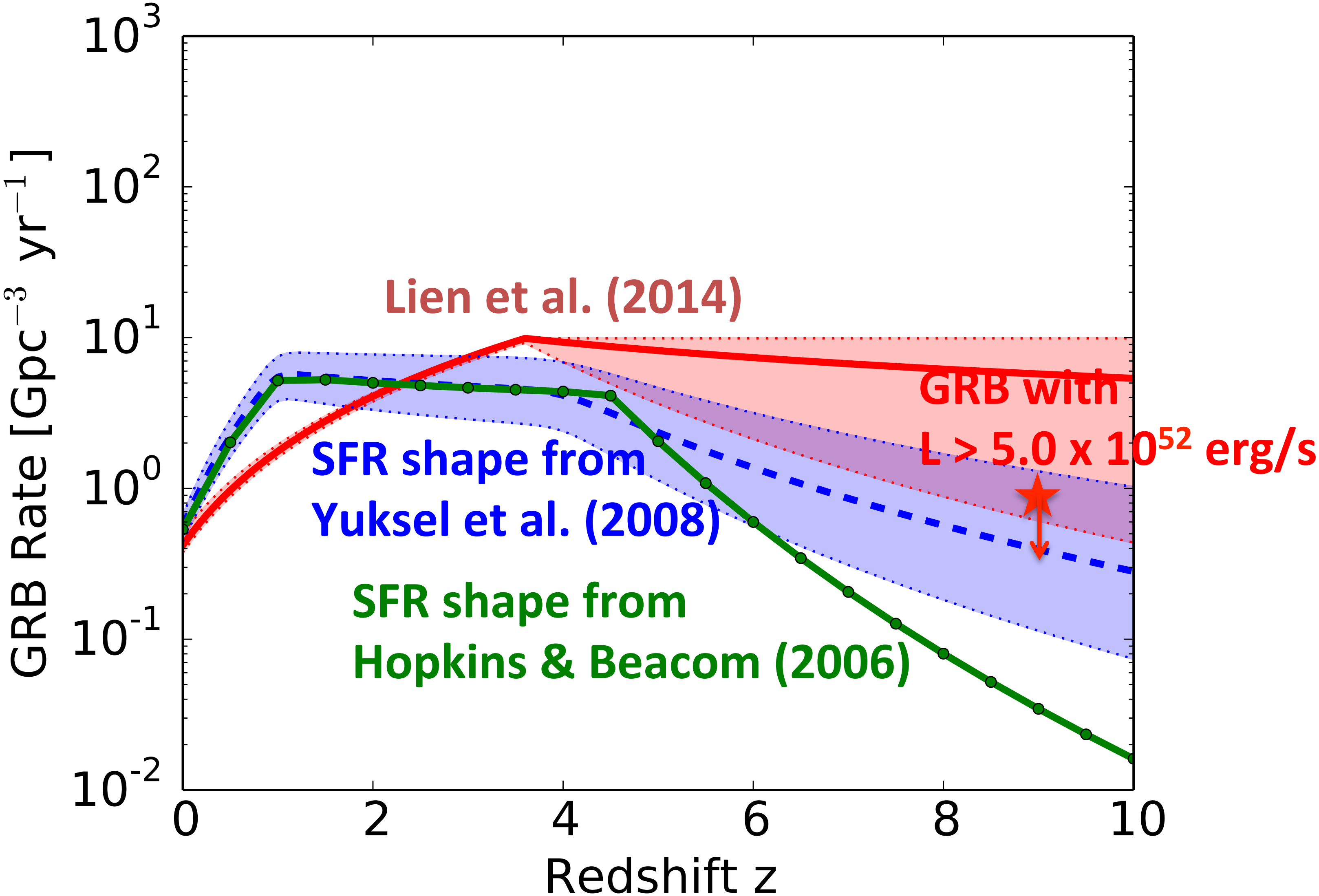
GRB name	Redshift	Avg lumnosity (obs 15-150 keV)	Incident angle	Partial coding fraction	
GRB060522	5.11	4.20×10^{51}	31.88	0.75	
GRB071025	5.20	5.48×10^{51}	30.56	0.49	< 5.40 - 6.90
GRB050502B	5.20	6.89×10^{51}	10.21	0.99	
GRB140304A	5.28	1.96×10^{52}	25.20	0.74	
GRB050814	5.30	3.31×10^{51}	39.66	0.26	
GRB060927	5.46	1.52×10^{52}	16.60	0.82	< 8.10 – 9.90
GRB130606A	5.91	3.73×10^{51}	22.74	0.97	
GRB120521C	5.93	1.49×10^{52}	19.15	0.68	
GRB050904	6.29	1.06×10^{52}	35.09	0.57	
GRB140515A	6.33	1.14×10^{52}	13.13	0.99	
GRB060116	6.60	1.09×10^{52}	37.93	0.21	< 5.5 – 7.60
GRB080913	6.73	3.75×10^{52}	46.33	0.39	
GRB090423	8.26	4.41×10^{52}	25.03	0.92	
GRB120923A	8.50	1.23×10^{52}	16.96	0.80	
GRB090429B	9.38	5.56×10^{52}	24.51	0.84	< 9.90

Can we constrain the high-z GRB rate?

GRB090429B

- Can be detected out to z > 9 if occurs fairly on-axis (within $\sim$ 26 deg)
- Assuming ground followup teams get all redshift
  → fz = 1
- Sky fraction = $\pi\,(26)^2/(4\pi(180/\mathrm{pi})^2) = 0.046$
- Number of detection = 1
- Obs year = 12
- All sky rate = (Number of detection)/(Sky fraction)/(Obs year)/fz = 1.6/fz yr^{-1}
- All sky comoving rate = 0.8/fz $\mathrm{Gpc}^{-3}\,\mathrm{yr}^{-1}$

The GRB Rate



Lien et al. (2014)

Summary

- 3rd BAT GRB catalog available on: http://swift.gsfc.nasa.gov/results/batgrbcat/

  Website will continue to be updated with recent bursts
  - Tables
  - Online webpages (quicklook plots)
  - Original data product
- Burst categories: Long, Short, Short with EE, Ultra-long (burst longer than 1000 s)
- Extended emission in survey data
- BAT can generally detect GRBs with 10^{52} erg/s (in the obs 15-150 keV) out to $z > 9$
  - Keep searching!

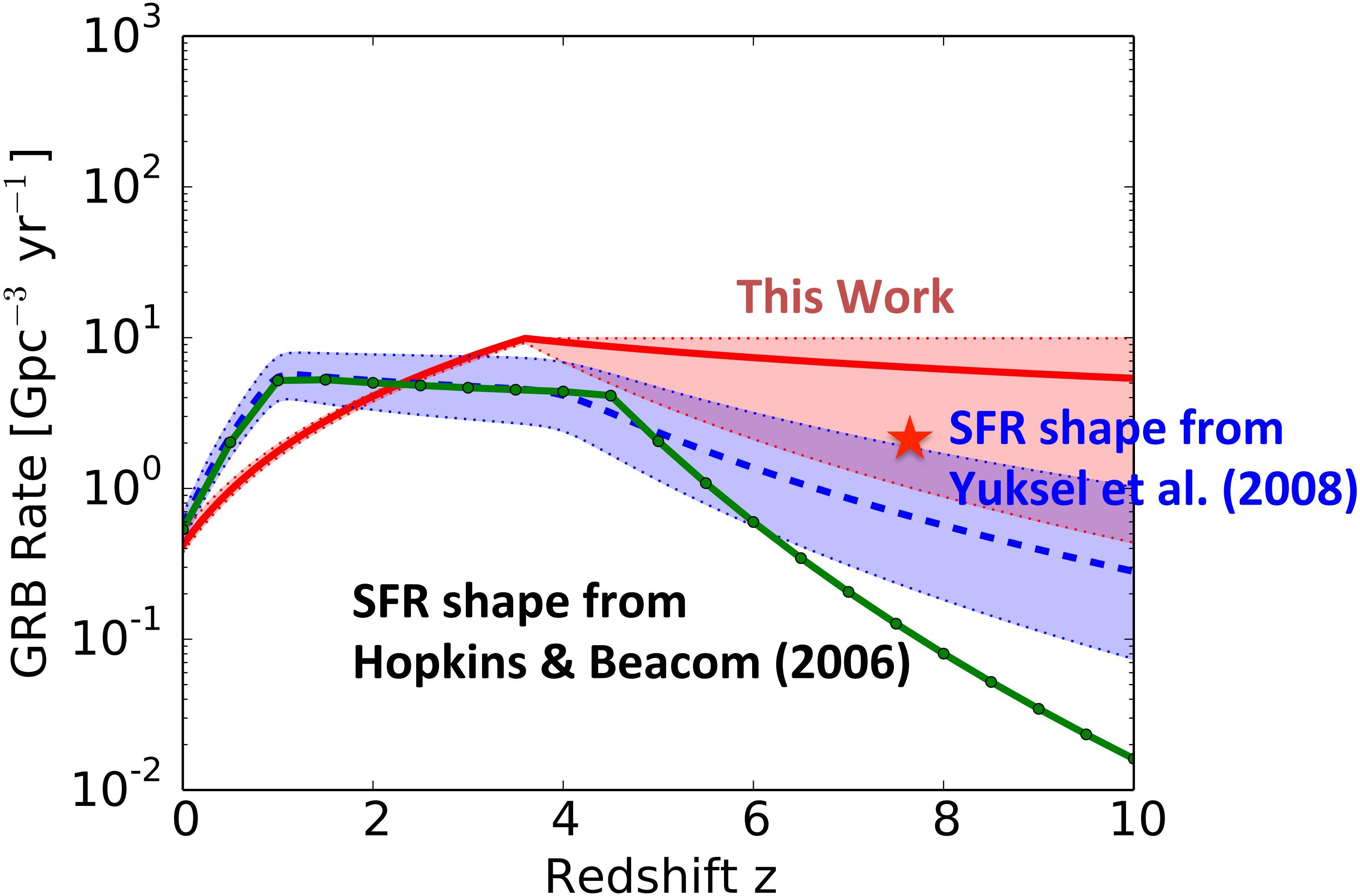
Thank You!

Back-up slides

GRB090429B

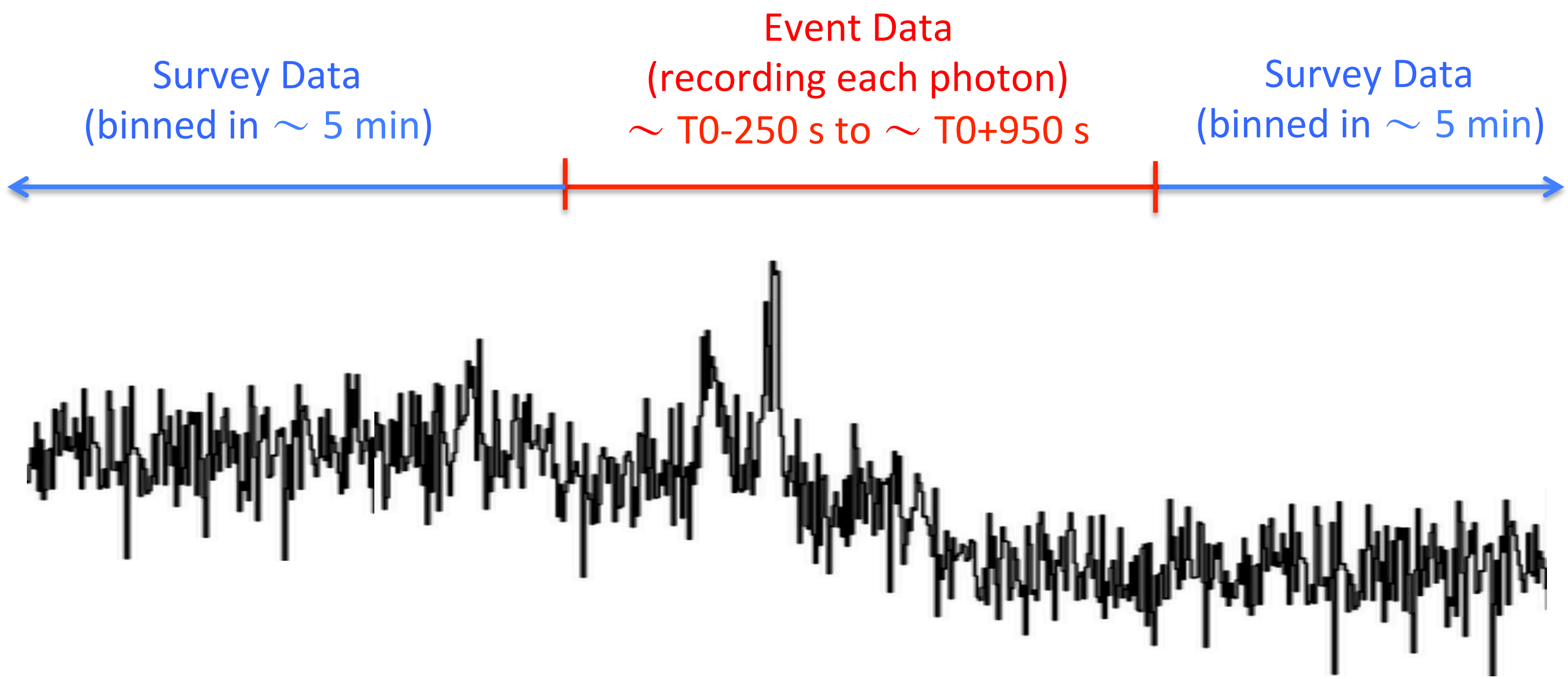
- Sky_fraction = 24.51*24.51*pi/(4*pi*(180/pi)^2) = 0.46
- Ndet = 1
- Obs_year = 10
- All_sky_Rate = Ndet/Sky_fraction/Obs_year = 1.82/yr
- All_sky_comov_Rate = 3.7

The GRB Rate



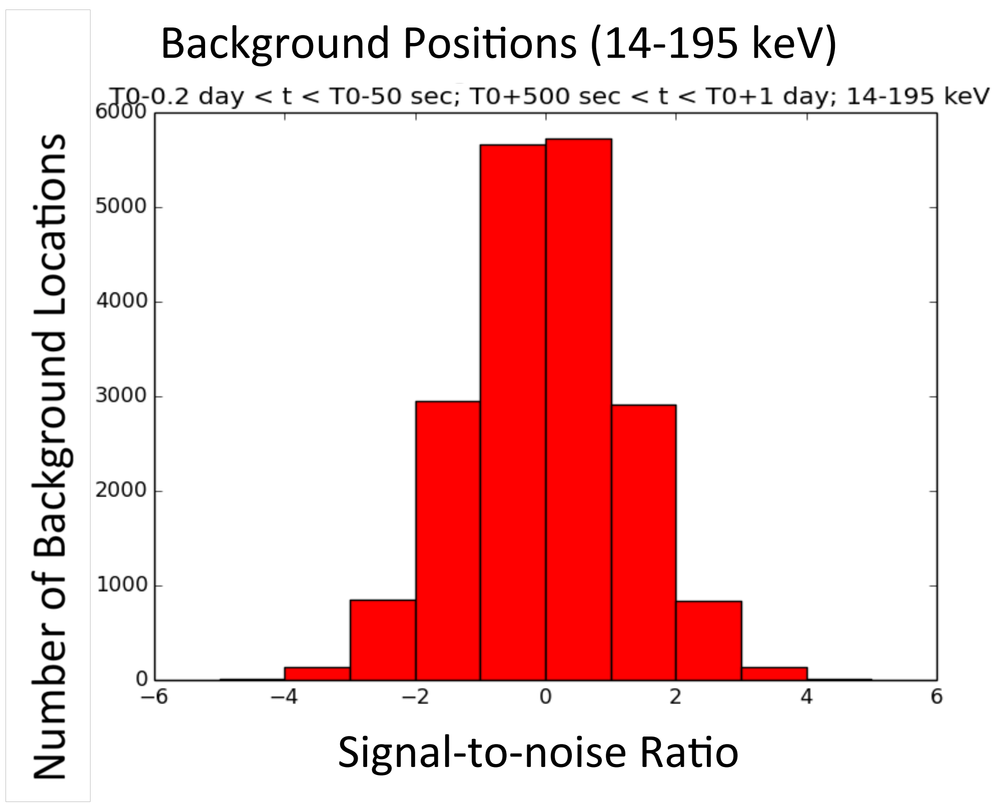
Lien et al. (2014)

Searching for extended emissions in the BAT survey data



Searching for extended emissions in the BAT survey data

- Method:
  - Searching for period of T0-0.2 day to T0+10 days
  - From 2004 to 2013/08 (e.g., Baumgartner et al. 2013)



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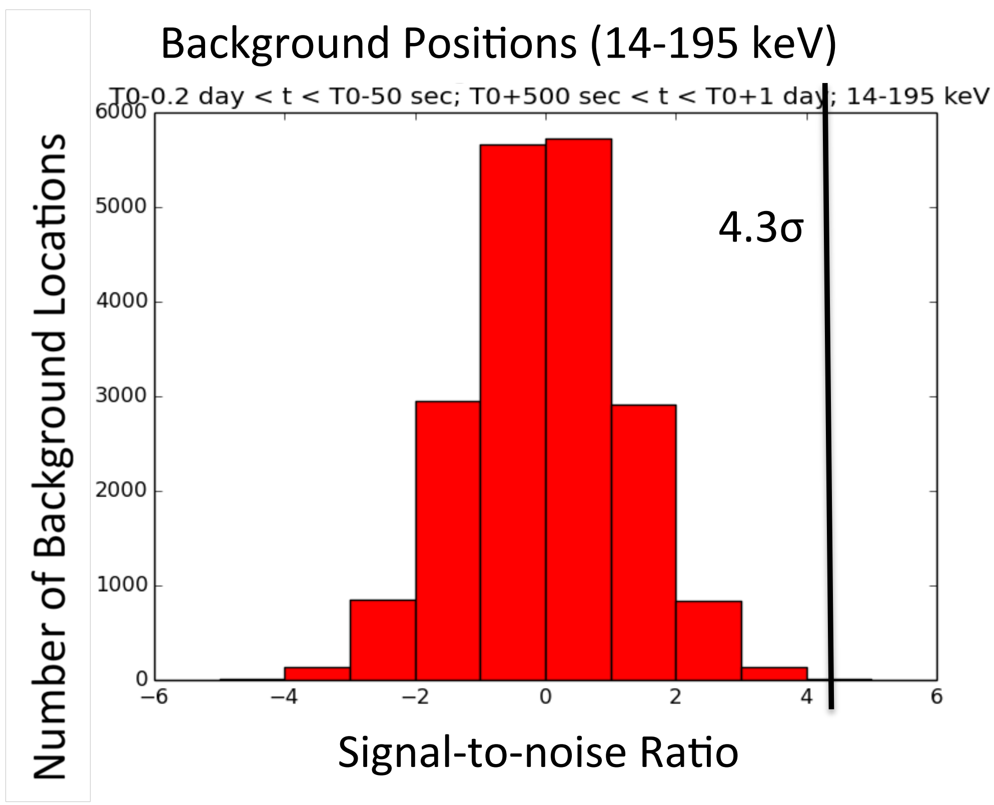

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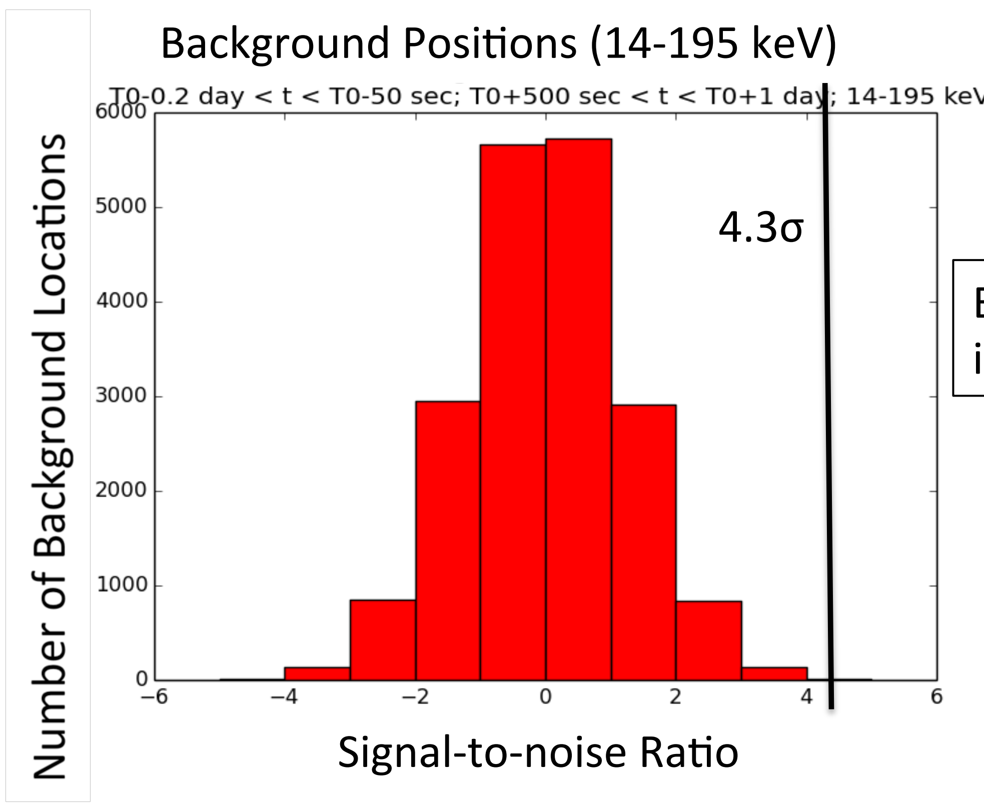

Expect ∼ 1 false-detection in our sample

Detections in BAT survey data

GRB name	detection time (since T0) [s]	image exposure time [s]	SNR in 14-195 keV
GRB121027A	1327.45	496.0	19.32
GRB121027A	5351.45	732.0	11.64
GRB111215A	703.0	840.0	12.27
GRB111209A	4814.0	2600.0	40.98
GRB111209A	10606.0	2584.0	14.08
GRB111209A	16427.0	2400.0	7.58
GRB111209A	565.0	630.0	92.73
GRB101225A	1372.0	300.0	10.28
GRB101225A	4936.0	2601.0	4.55
GRB101024A	-5252.13	779.0	4.73
GRB100728A	981.73	792.0	4.83
GRB100316D	-775.0	600.0	9.01
GRB091127	5192.90	409.0	4.36
GRB090417B	662.0	1140.0	23.51
GRB090404	44356.93	557.0	4.31
GRB090309	4075.176	2400.0	4.40
GRB080319B	938.1	799.0	11.26
GRB070518	57158.83	1381.0	4.92
GRB070419B	3724.13	2400.0	5.22
GRB060218	404.0	2327.0	19.20
GRB050730	356.2	390.0	8.53

Detections in BAT survey data

GRB name	detection time (since T0) [s]	image exposure time [s]	SNR in 14-195 keV
GRB121027A	1327.45	496.0	19.32
GRB121027A	5351.45	732.0	11.64
GRB111215A	703.0	840.0	12.27
GRB111209A	[illegible]	[illegible]	[illegible]
GRB111209A	[illegible]	[illegible]	[illegible]
GRB111209A	[illegible]	[illegible]	[illegible]
GRB111209A	565.0	630.0	92.73
GRB101225A	1372.0	300.0	10.28
GRB101225A	4936.0	2601.0	4.55
GRB101024A	-5252.13	779.0	4.73
GRB100728A	981.73	792.0	4.83
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Previously classified as ultra-long GRBs

Detections in BAT survey data

GRB name	detection time (since T0) [s]	image exposure time [s]	SNR in 14-195 keV
GRB121027A	1327.45	496.0	19.32
GRB121027A	5351.45	732.0	11.64
GRB111215A	703.0	840.0	12.27
GRB111209A	4[illegible]	[illegible]	[illegible].98
GRB111209A	1[illegible]	[illegible]	[illegible].08
GRB111209A	1[illegible]	[illegible]	[illegible].58
GRB111209A	565.0	630.0	92.73
GRB101225A	1[illegible]	[illegible]	[illegible].28
GRB101225A	4[illegible]	[illegible]	[illegible].55
GRB101024A	-5[illegible]	[illegible]	[illegible].73
GRB100728A	981.73	792.0	4.83
GRB100316D	-775.0	600.0	9.01
GRB091127	5192.90	409.0	4.36
GRB090417B	662.0	1140.0	23.51
GRB090404	44356.93	557.0	4.31
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GRB050730	356.2	390.0	8.53

Previously classified as ultra-long GRBs

Precursors

Detections in BAT survey data

GRB name	detection time (since T0) [s]	image exposure time [s]	SNR in 14-195 keV
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GRB121027A	5351.45	732.0	11.64
GRB111215A	703.0	840.0	12.27
GRB111209A	[illegible]	[illegible]	[illegible]
GRB111209A	[illegible]	[illegible]	[illegible]
GRB111209A	[illegible]	[illegible]	[illegible]
GRB111209A	565.0	630.0	92.73
GRB101225A	[illegible]	[illegible]	[illegible]
GRB101225A	[illegible]	[illegible]	[illegible]
GRB101024A	[illegible]	[illegible]	[illegible]
GRB100728A	981.73	792.0	4.83
GRB100316D	-775.0	600.0	9.01
GRB091127	[illegible]	[illegible]	[illegible]
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GRB090404	[illegible]	[illegible]	[illegible]
GRB090309	4075.176	2400.0	4.40
GRB080319B	938.1	799.0	11.26
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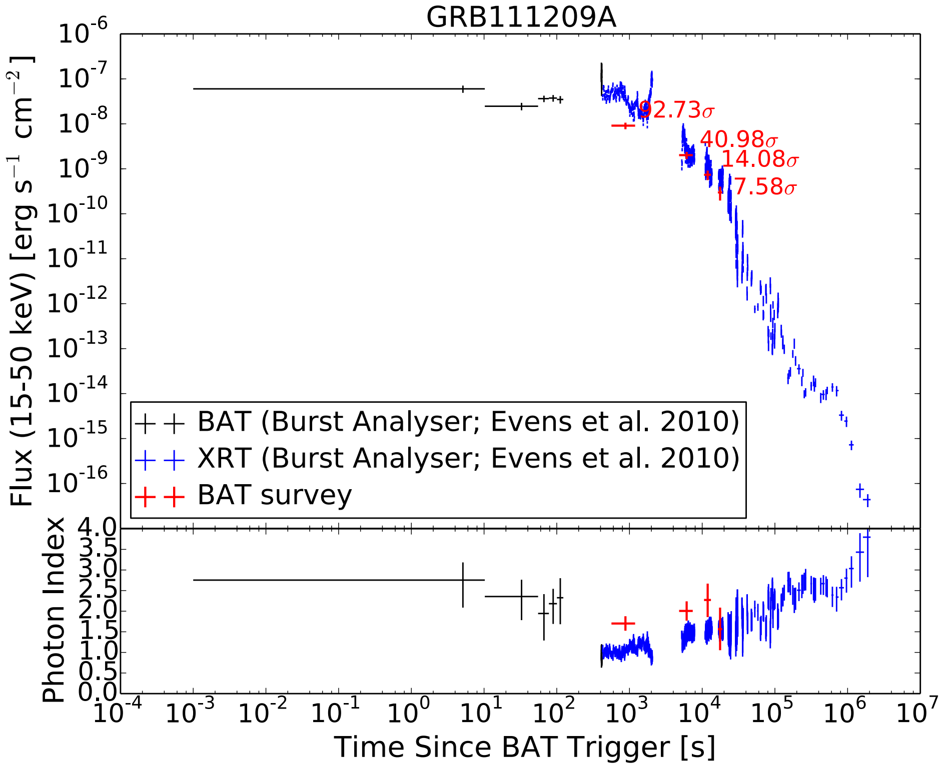
GRB060218	404.0	2327.0	19.20
GRB050730	356.2	390.0	8.53

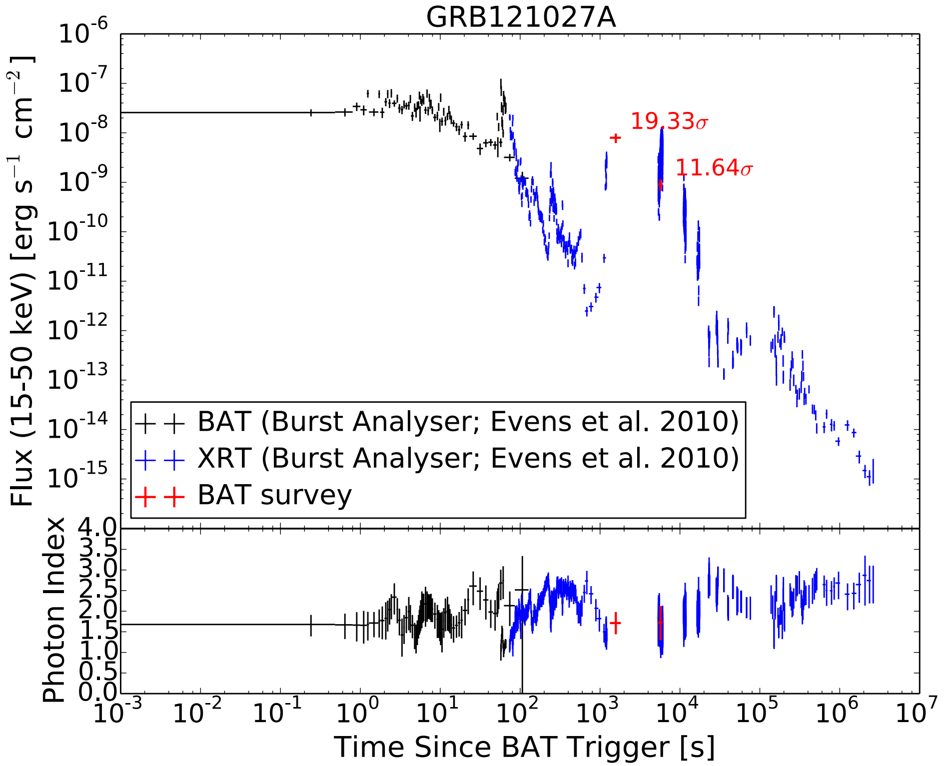
Previously classified as ultra-long GRBs

Precursors

Super-bright GRB

Comparison with XRT light curves



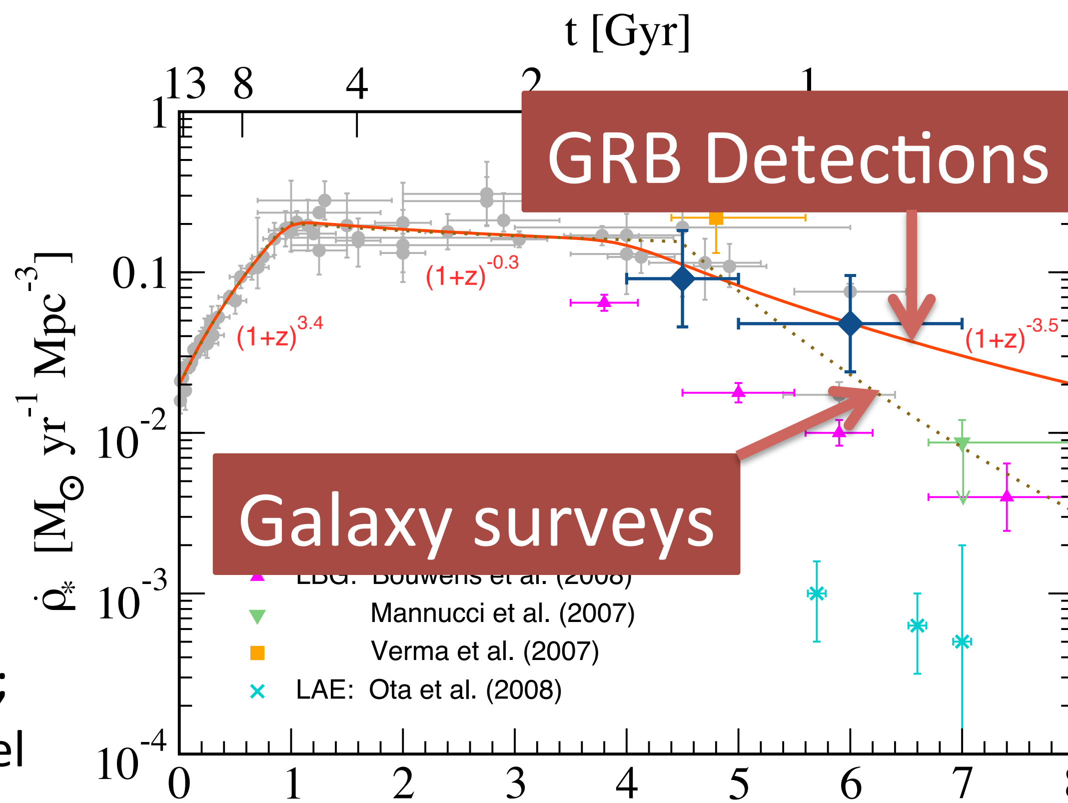


Swift/BAT GRB Detection Overlook

Year	Number of detections (with ground-detected GRBs)	Number of detections (no ground-detected GRBs)	Number of active BAT detector
2005	88	85	29413
2006	98	97	26997
2007	85	79	27147
2008	103	95	26478
2009	91	81	24387
2010	83	72	24050
2011	81	75	22817
2012	92	89	23017
2013	95	84	22053
2014	93	84	20413

GRBs, Supernovae, and Star Formation

- Long GRBs (T90 > 2 sec)
  - Related to core-collapse supernovae (Type Ibc)
  - Related to the death of massive stars
- Long GRBs as probes of star formation
  - Particularly crucial at high redshift (e.g., Ciardi & Leob 2000, Tanvir et al. 2012)
- Important to measure long GRB rate (e.g., Butler et al. 2010; Wanderman et al. 2010; Yuksel et al. 2008)

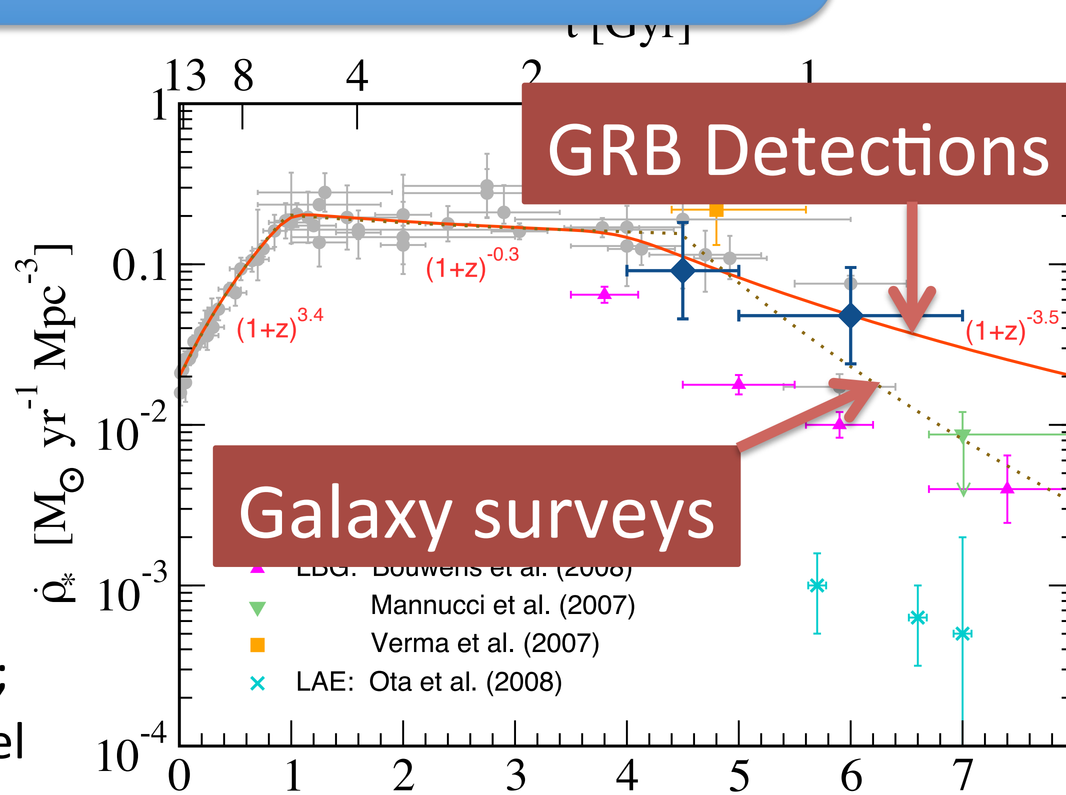


Yuksel et al. (2008)

GRBs, Supernovae, and Star Formation

- Long G
  - Rela
  - Rela
- Long G
  of star formation
  - Particularly crucial at high redshift (e.g., Ciardi & Leob 2000, Tanvir et al. 2012)
- Important to measure long GRB rate (e.g., Butler et al. 2010; Wanderman et al. 2010; Yuksel et al. 2008)

Do we have enough information?

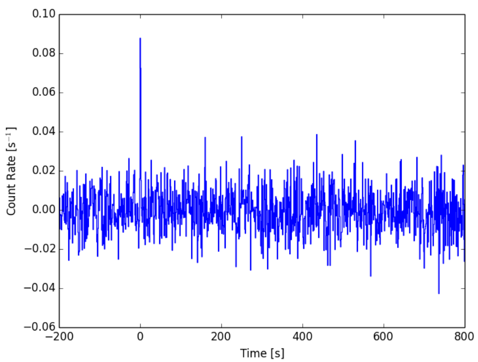


Yuksel et al. (2008)

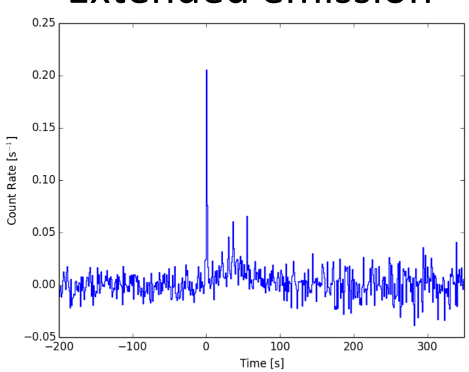
Swift GRBs to date

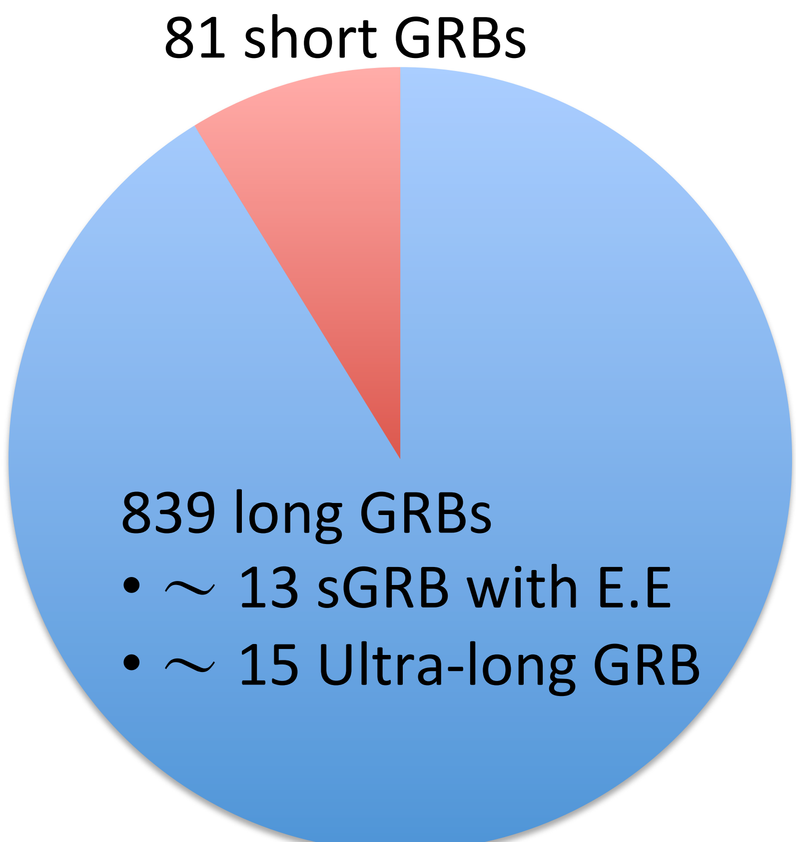
- 926 GRBs till now.
- In this presentation: 919 GRBs till GRB141109B
- 314 have redshift measurements

Short GRB

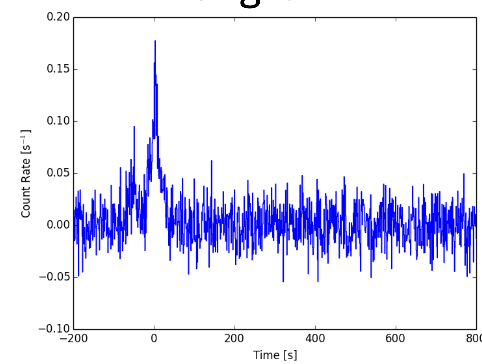


Short GRB with Extended emission

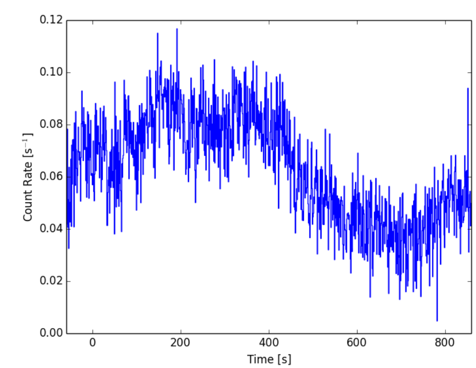




Long GRB

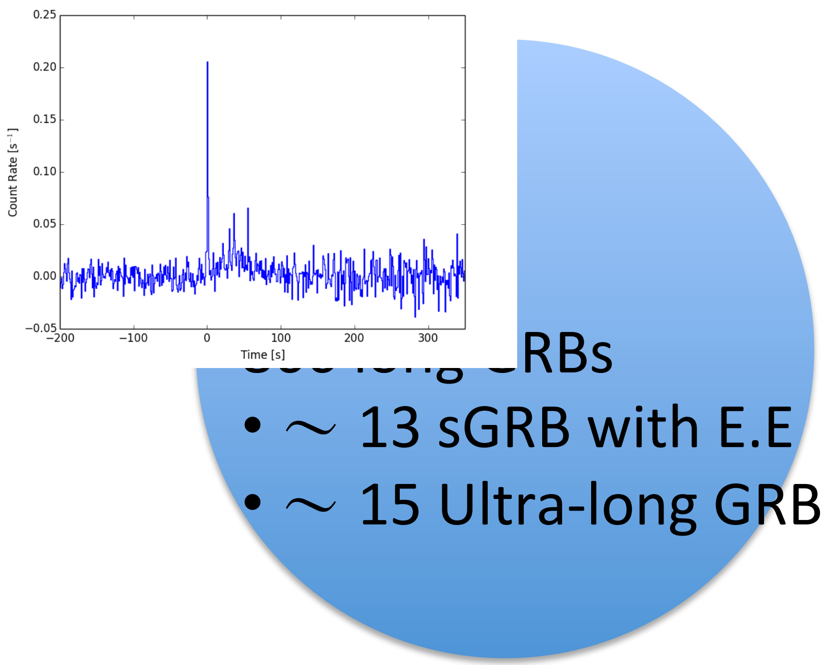


Ultra-Long GRB



Swift GRBs to date:
10 Years after Launch

- 926 GRBs till now
  - About 2 GRBs per weak
- 314 GRBs have redshift measurements
- Complete results will be in the 3rd BAT GRB catalog



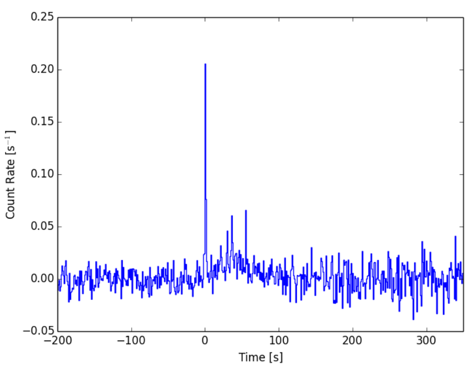
- ~ 13 sGRB with E.E
- ~ 15 Ultra-long GRB

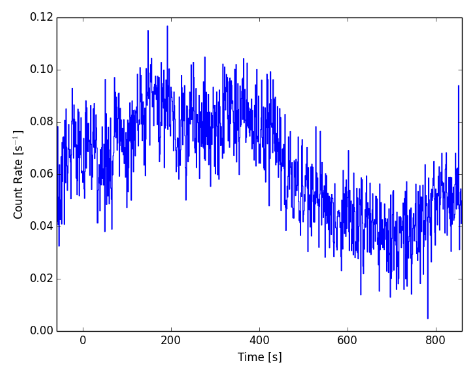
Figure credit: PSU webpage

Cake Credit: Judith Racusin

Swift GRBs to date: 10 Years after Launch

- 926 GRBs till now
  - About 2 GRBs per weak
- 314 GRBs have redshift measurements
- Complete results will be in the 3rd BAT GRB catalog



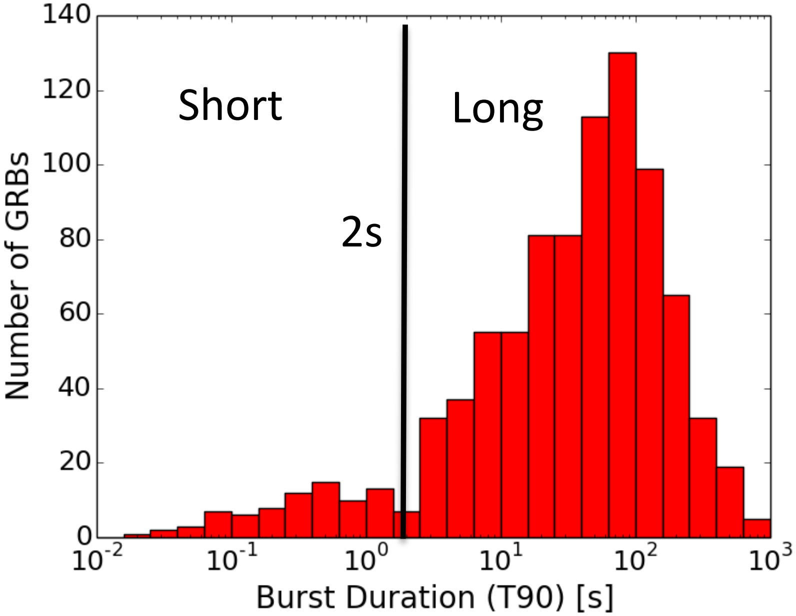


- ~ 13 sGRB with E.E
- ~ 15 Ultra-long GRB

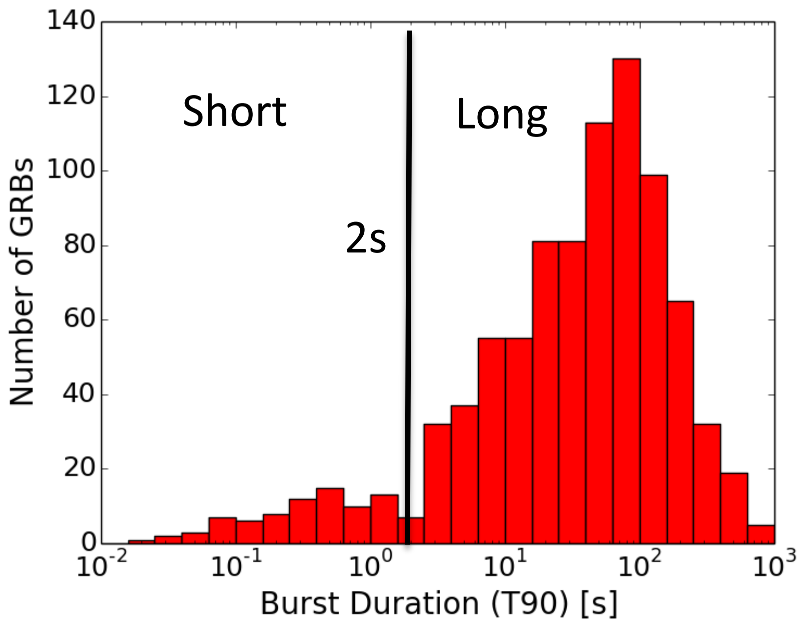
Figure credit: PSU webpage

Cake Credit: Judith Racusin

Burst Durations



Burst Durations



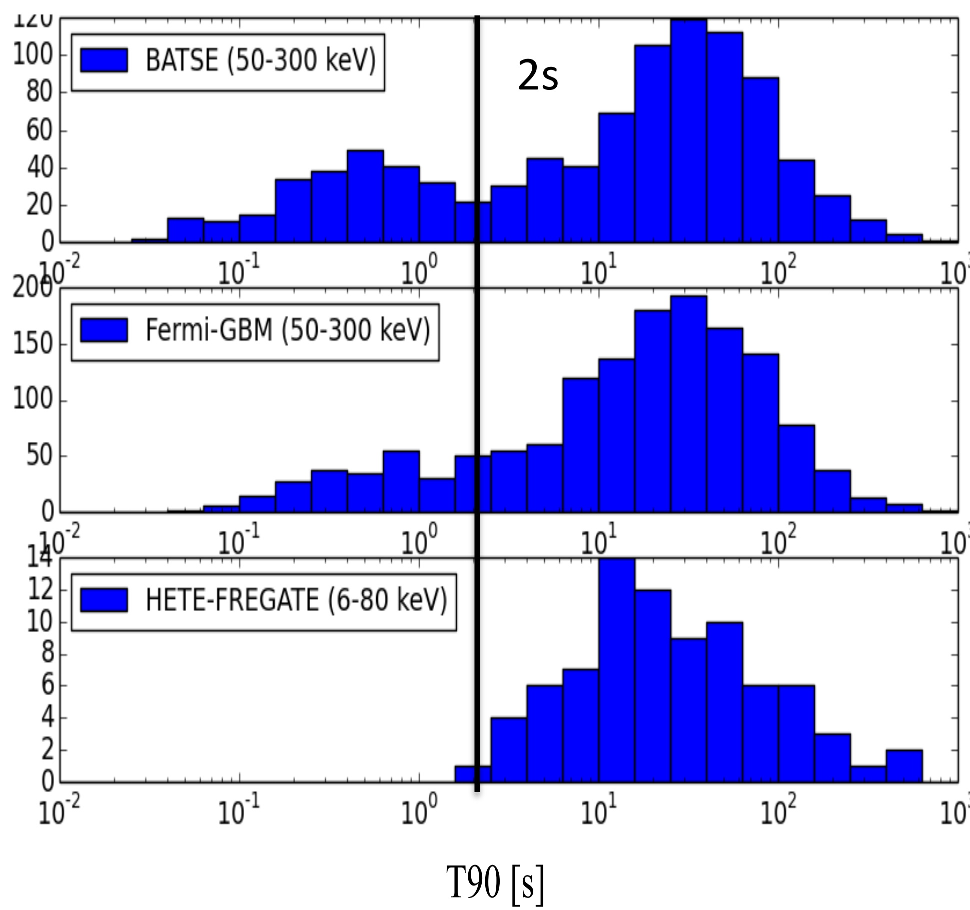
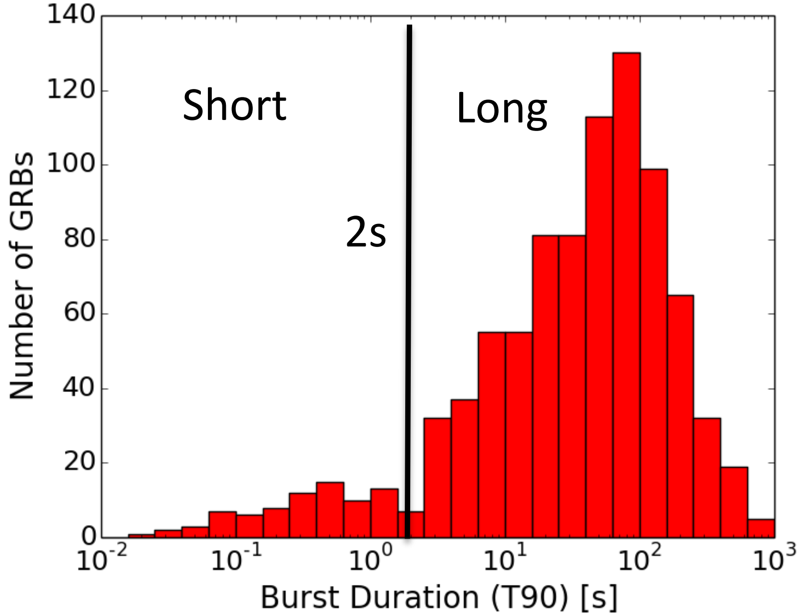


Fig credit: Taka's presentation

Burst Durations



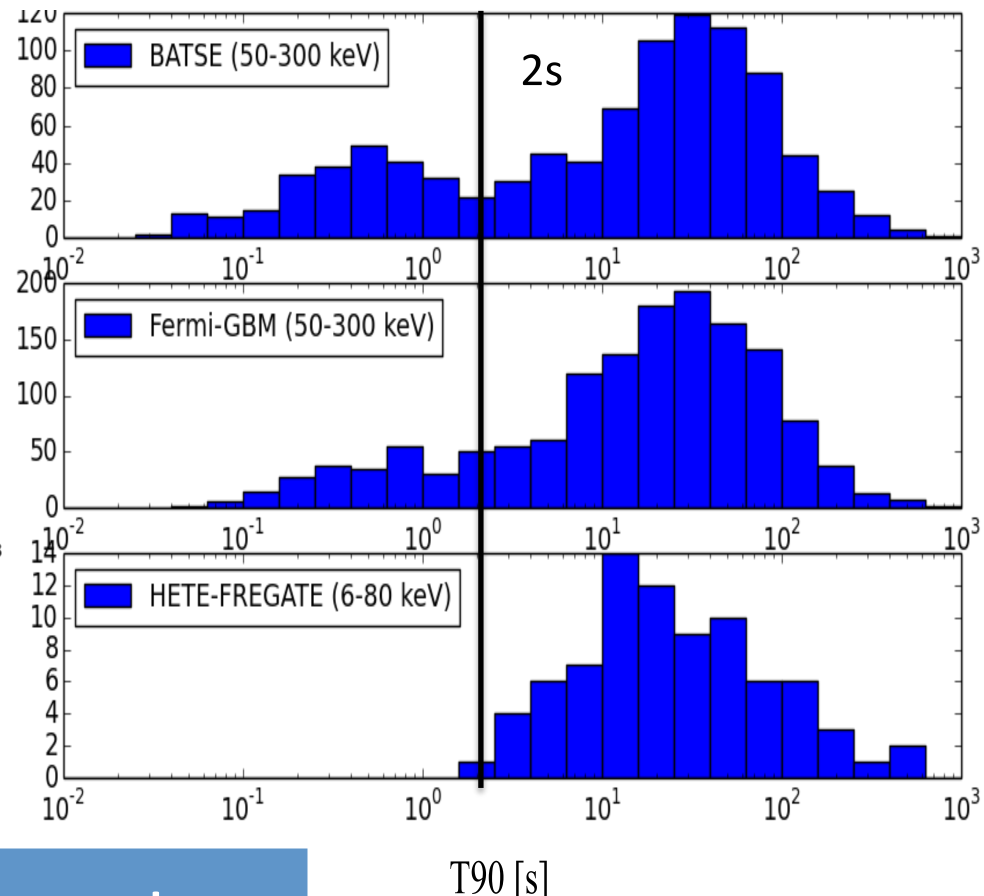
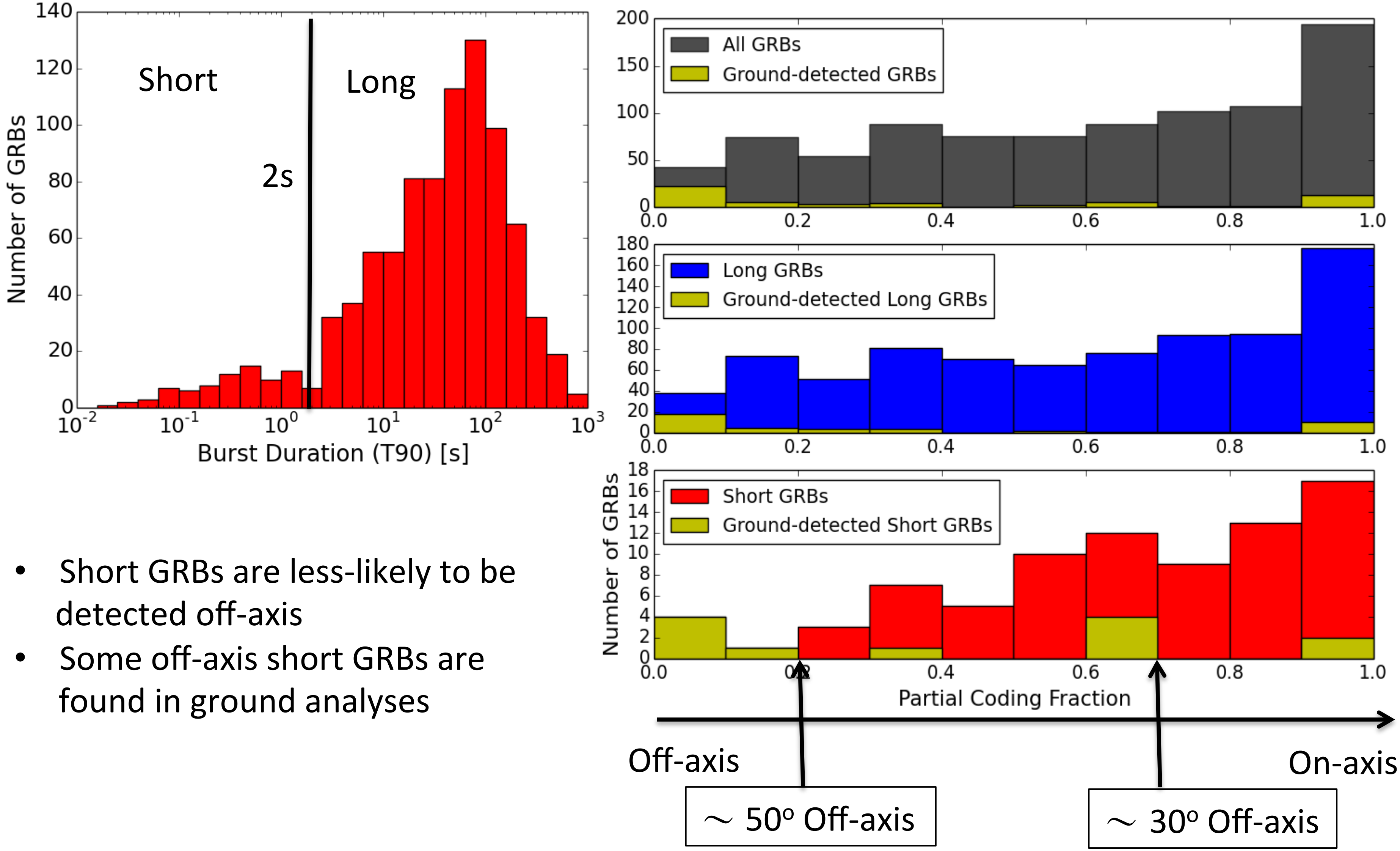


Fig credit: Taka's presentation

Distribution is instrument dependent

Burst Durations

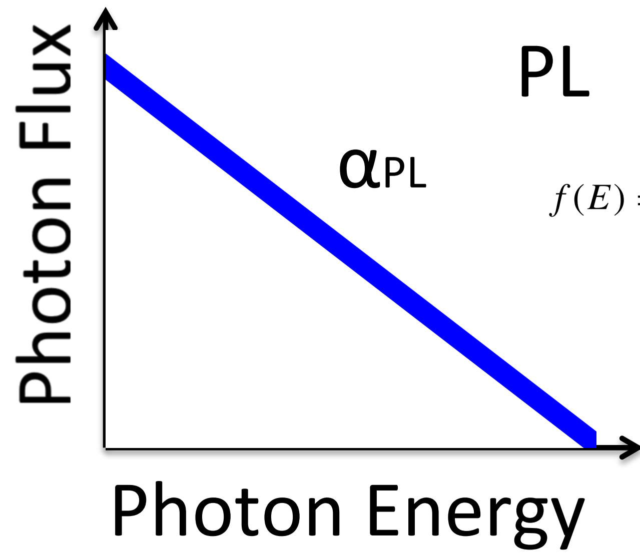


- Short GRBs are less-likely to be detected off-axis
- Some off-axis short GRBs are found in ground analyses

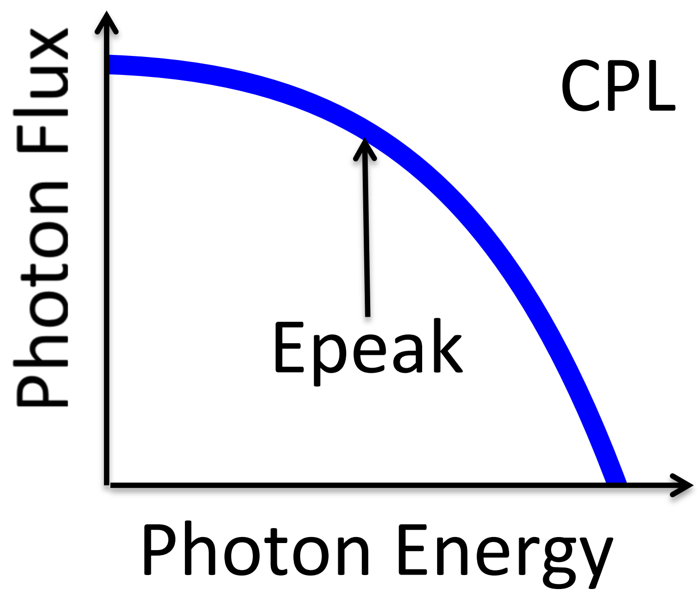
Spectral Fits

- Following the 2nd BAT GRB catalog (Sakamoto et al. 2011)
- (a) simple power law (PL)

  (b) cutoff power law (CPL)
- Choose CPL If $\Delta\chi^2 > 6$
- Additional criteria for an acceptable spectral fit



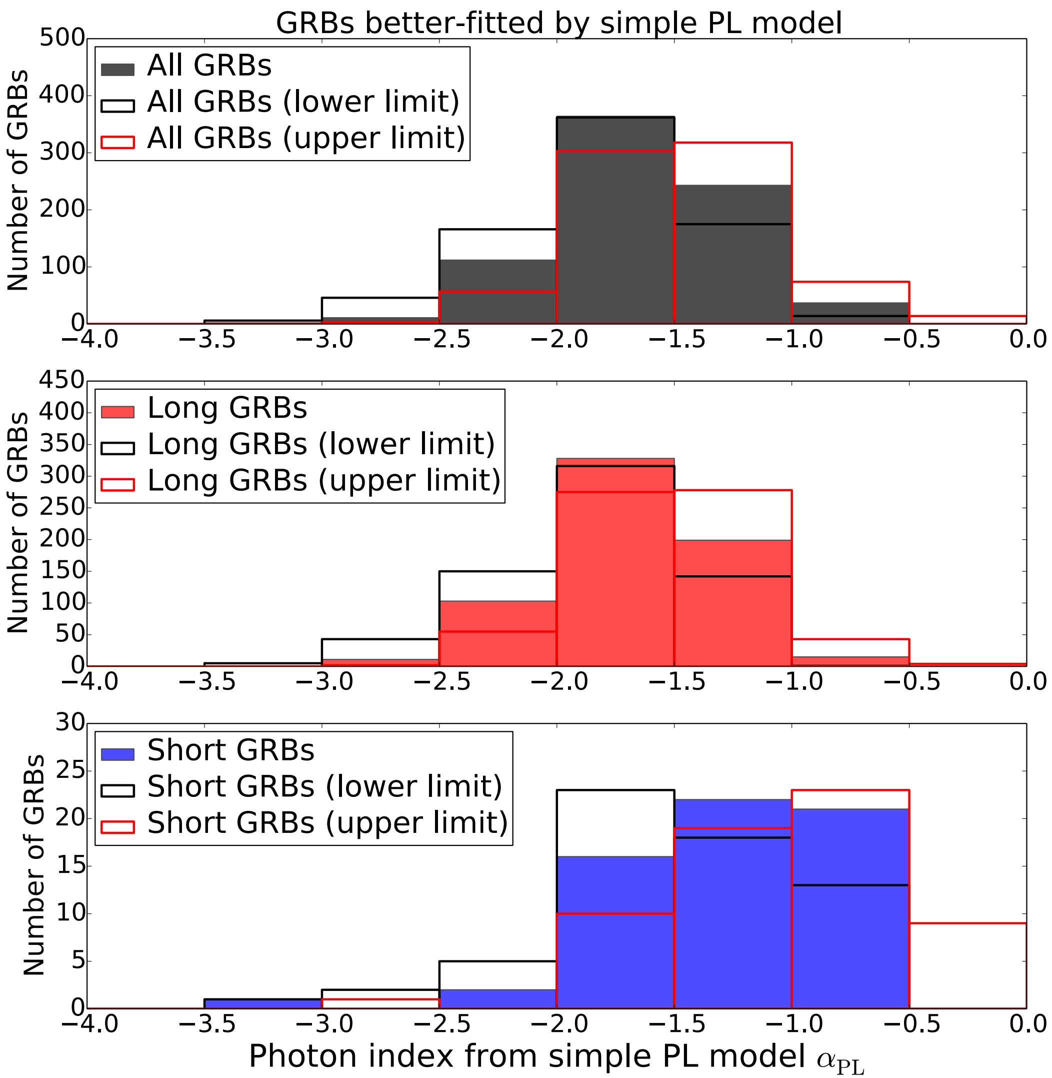
$$f(E) = K_{50}^{\mathrm{PL}} \left(\frac{E}{50\,\mathrm{keV}} \right)^{\alpha^{\mathrm{PL}}}$$



$$f(E) = K_{50}^{\mathrm{CPL}} \left(\frac{E}{50\,\mathrm{keV}} \right)^{\alpha^{\mathrm{CPL}}} \exp\left(\frac{-E(2+\alpha^{\mathrm{CPL}})}{E_{\mathrm{peak}}} \right)$$

Spectral Fits – Simple Power Law

- Following the 2nd BAT GRB catalog (Sakamoto et al. 2011)
- (a) simple power law (PL)
  (b) cutoff power law (CPL)
- Choose CPL If $\Delta\chi^2 > 6$
- Additional criteria for an acceptable spectral fit
- 767 GRBs are well-fitted with simple power law.



Spectral Fits – Simple Power Law

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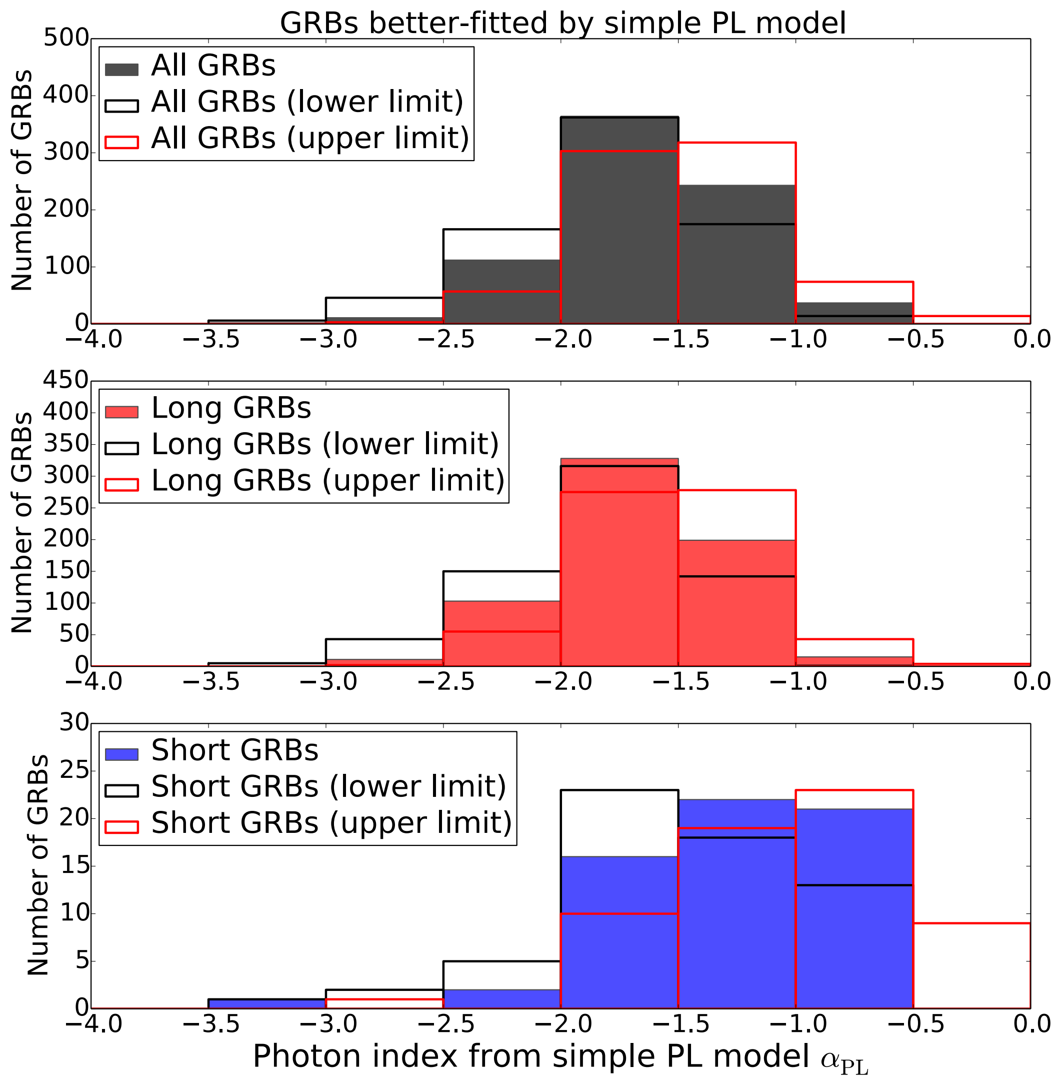
- Choose CPL If $\Delta\chi^2 > 6$
- Additional criteria for an acceptable spectral fit
- 767 GRBs are well-fitted with simple power law.

In BAT sample, short GRBs are only slightly harder than long GRBs.



Spectral Fits – Cutoff Power Law

- Following the 2nd BAT GRB catalog (Sakamoto et al. 2011)
- (a) simple power law (PL)

  (b) cutoff power law (CPL)
- Choose CPL If $\Delta\chi^2 > 6$
- Additional criteria for an acceptable spectrum
- 767 GRBs are well-fitted with simple power law.

Spectral Fits – Cutoff Power Law

- Following the 2nd BAT GRB catalog (Sakamoto et al. 2011)
- (a) simple power law (PL)

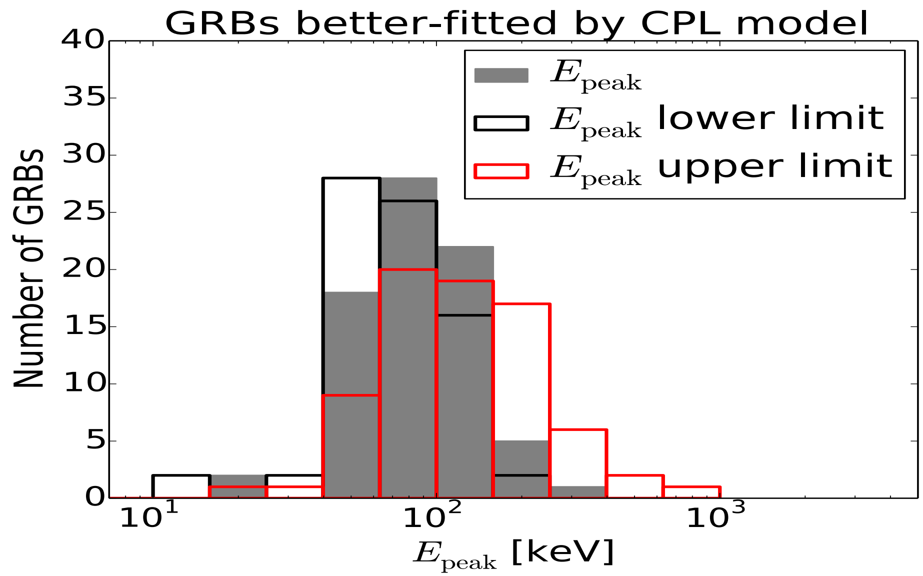
  (b) cutoff power law (CPL)
- Choose CPL If $\Delta\chi^2 > 6$
- Additional criteria for an acceptable spectrum
- 767 GRBs are well-fitted with simple power law.
- 76 GRBs are fitted better with cutoff power law

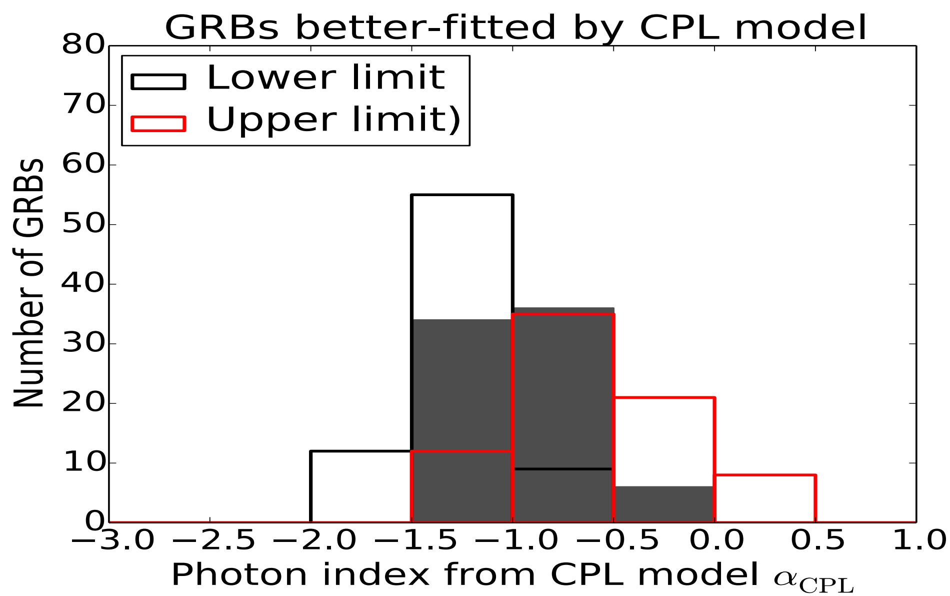
Spectral Fits – Cutoff Power Law

- Following the 2nd BAT GRB catalog (Sakamoto et al. 2011)
- (a) simple power law (PL)

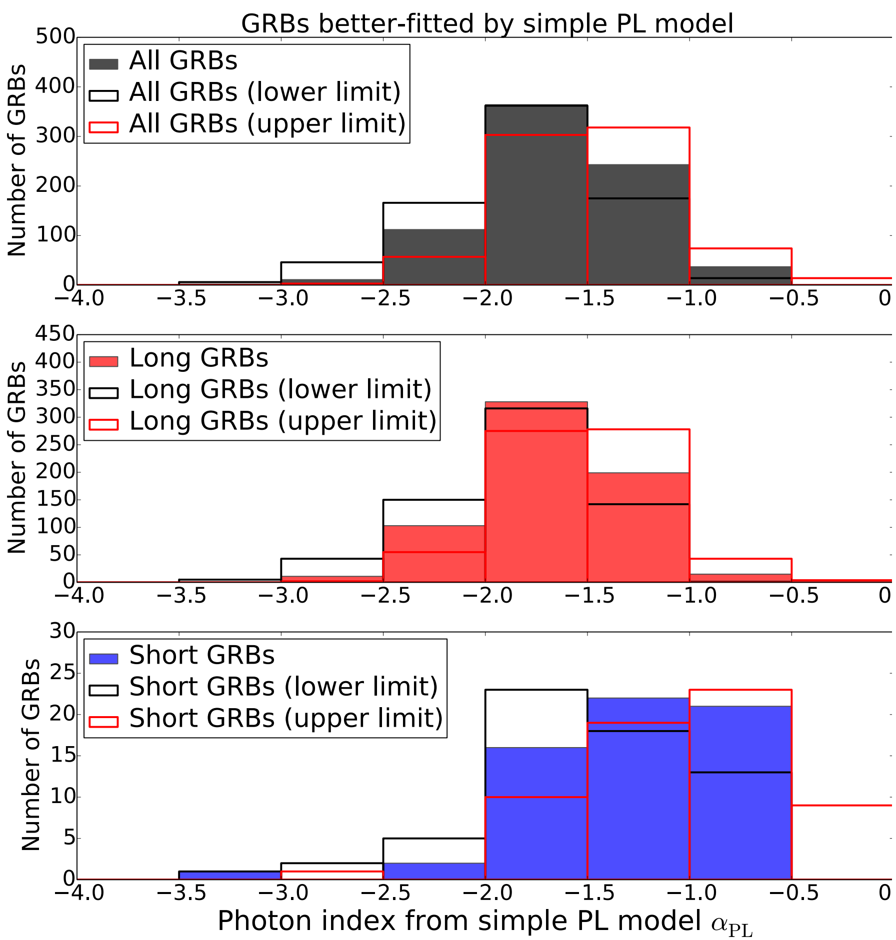
  (b) cutoff power law (CPL)
- Choose CPL If $\Delta\chi^2 > 6$
- Additional criteria for an acceptable spectrum
- 767 GRBs are well-fitted with simple power law.
- 76 GRBs are fitted better with cutoff power law

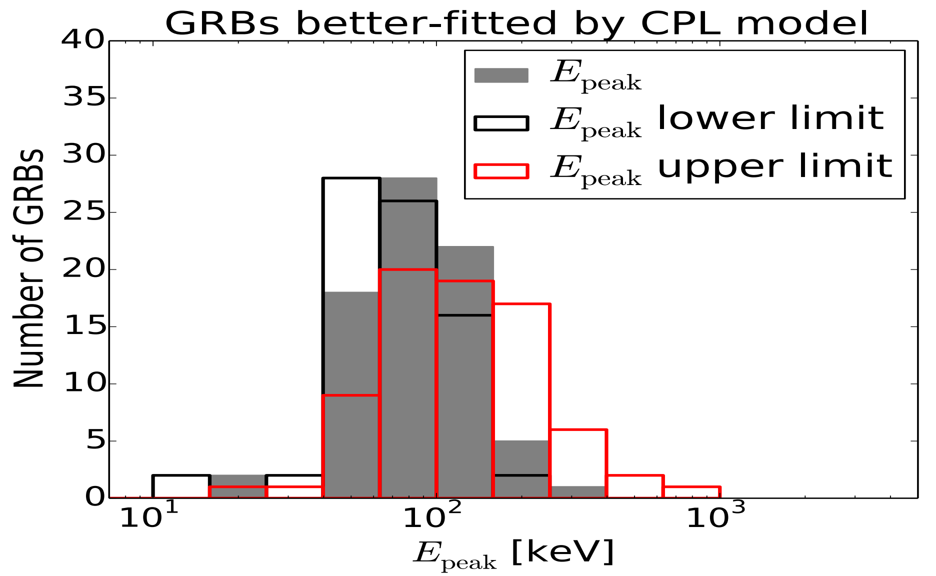
  (all long GRBs)

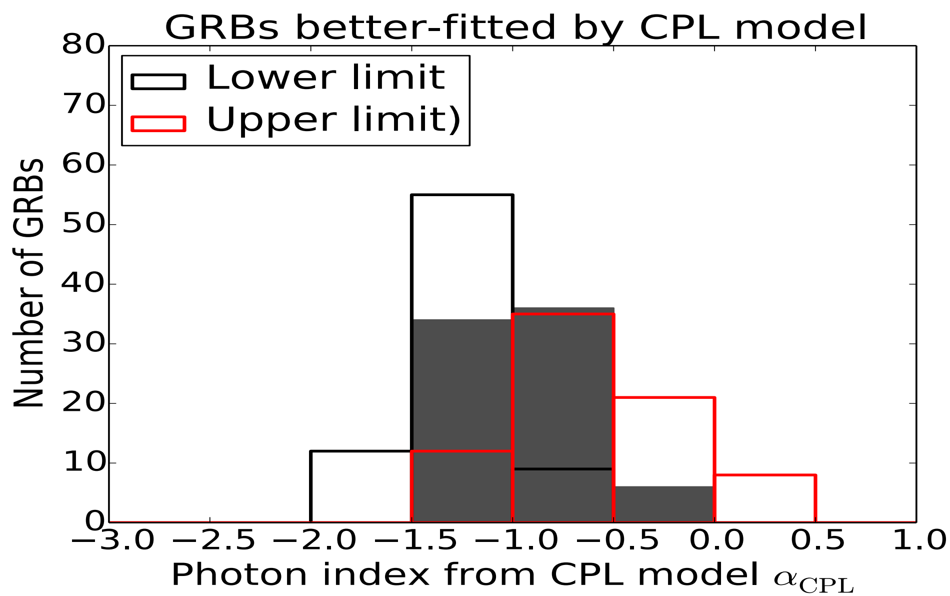




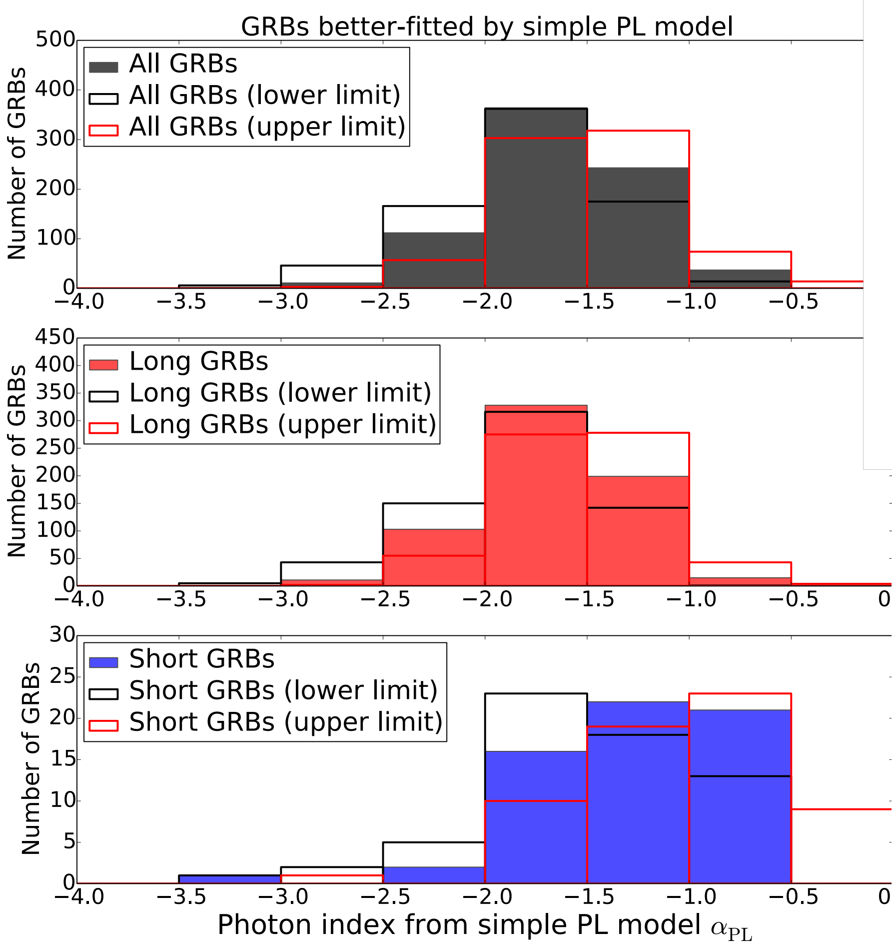
Spectral Fits – Cutoff Power Law

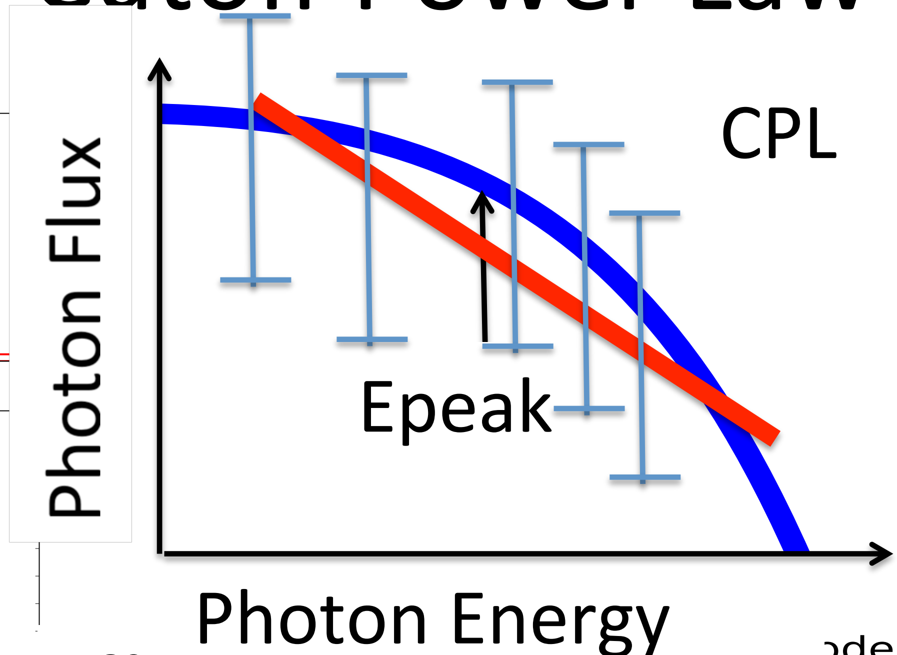


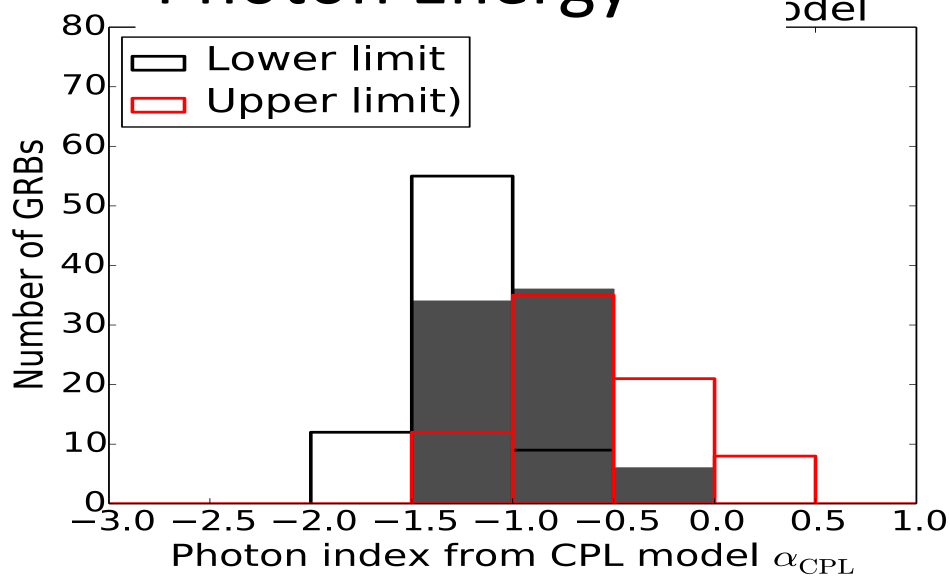




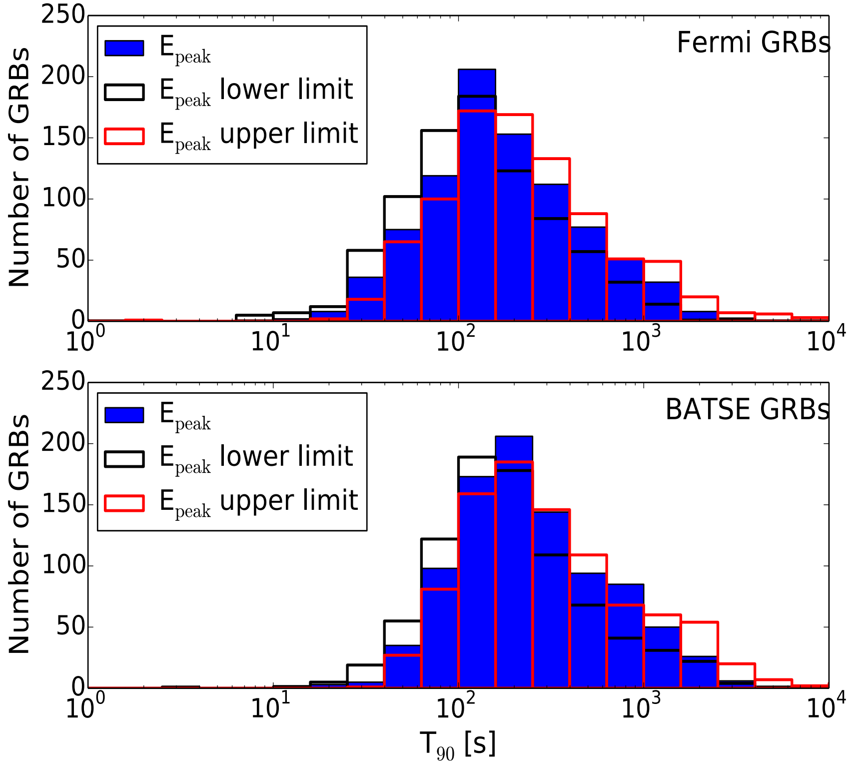
Spectral Fits – Cutoff Power Law

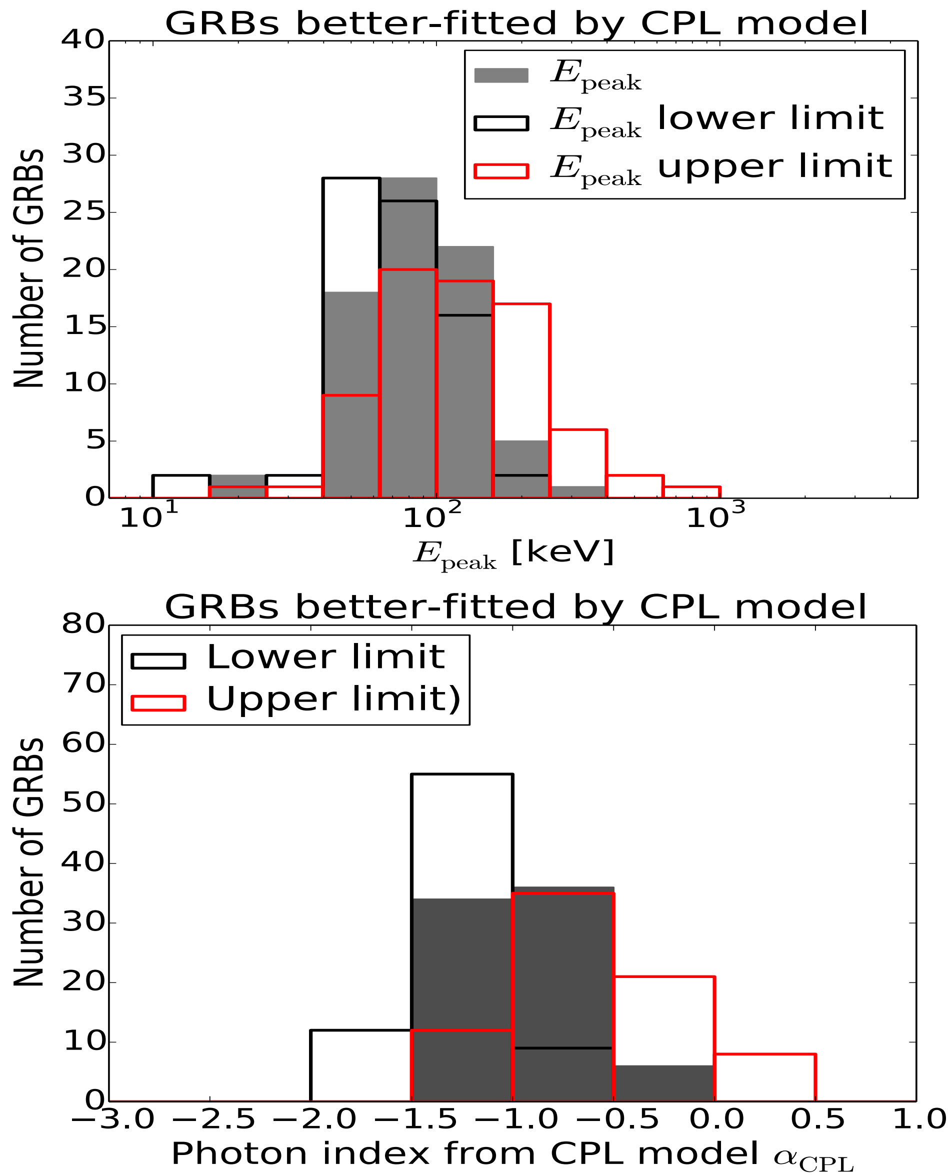






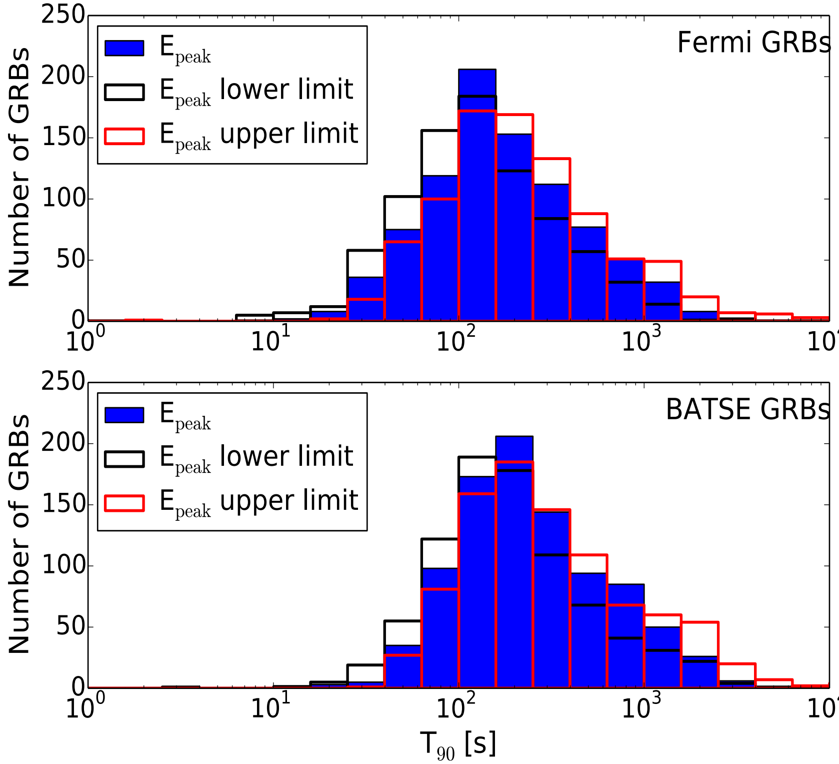
Spectral Fits – Cutoff Power Law

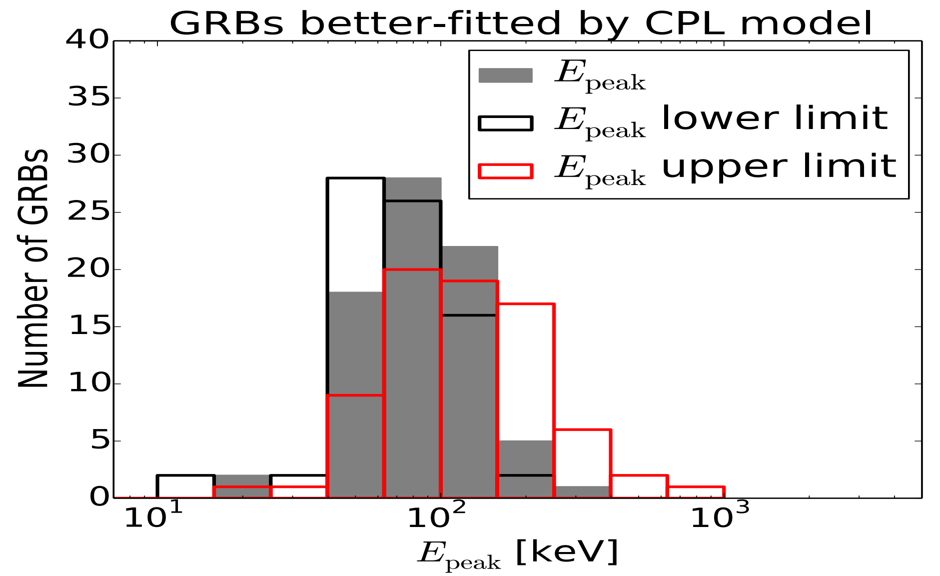


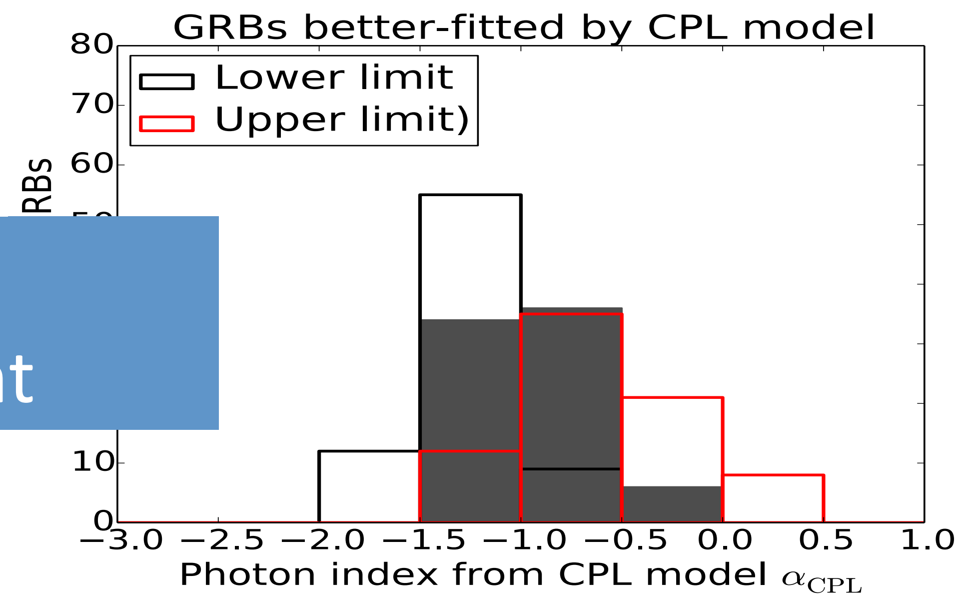


- 76 GRBs are fitted better with cutoff power law

Spectral Fits – Cutoff Power Law

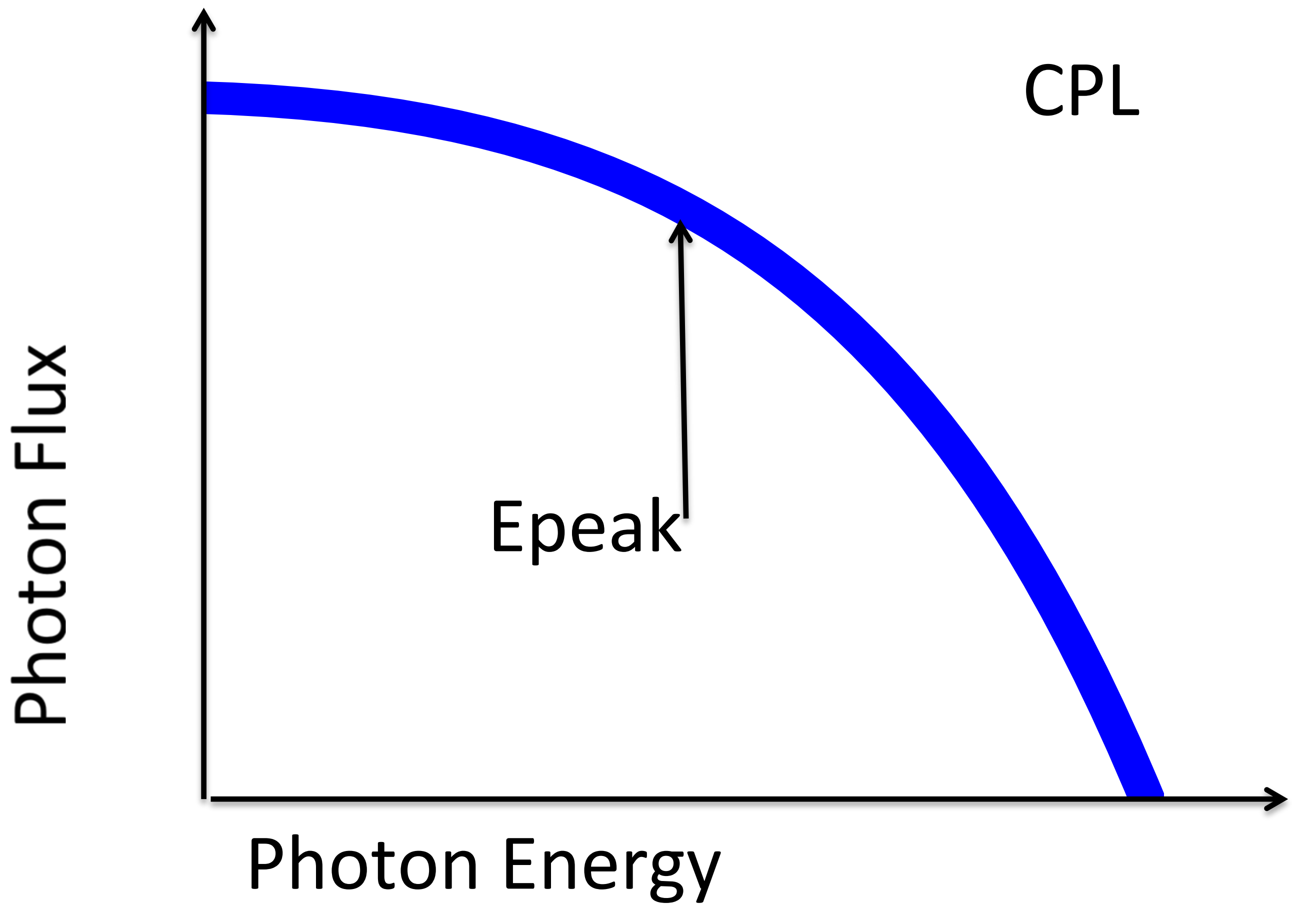




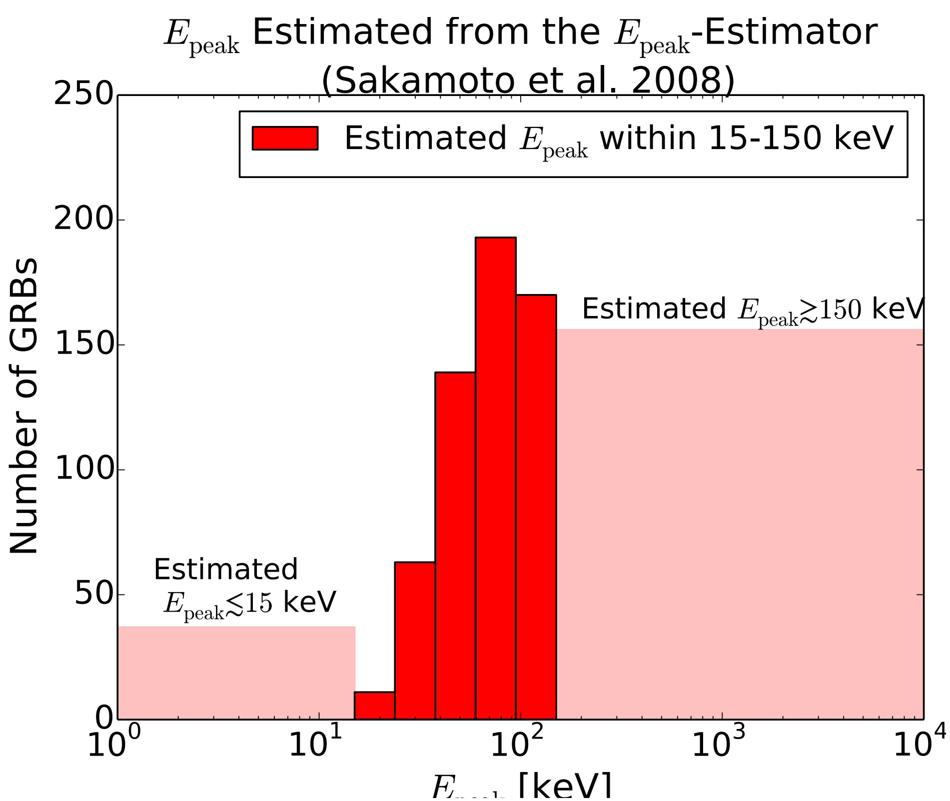


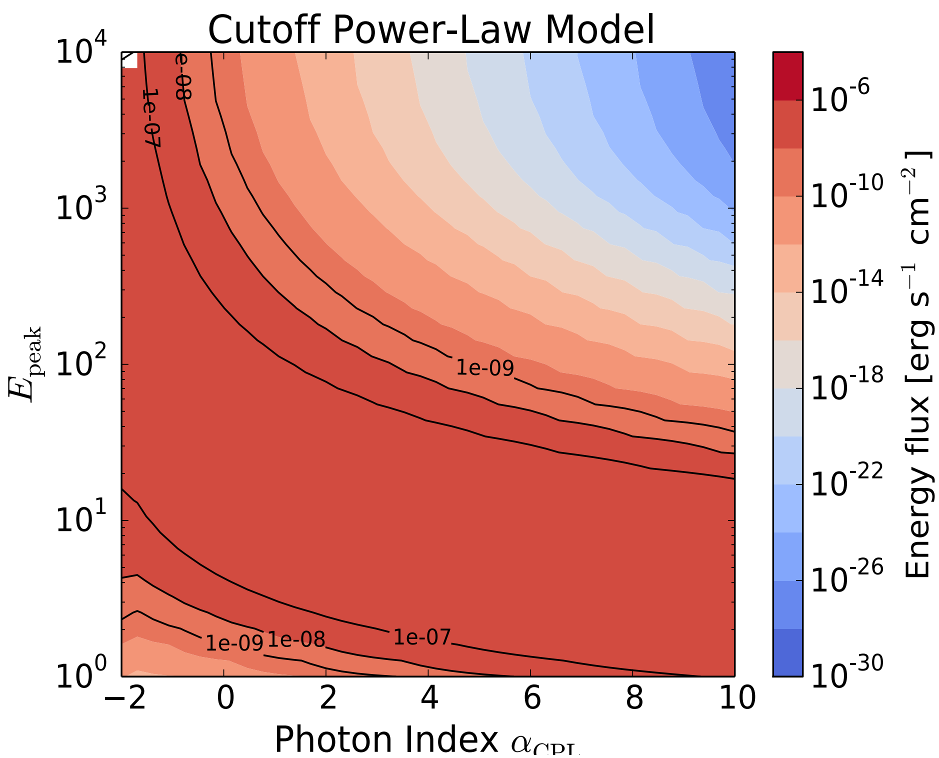
Epeak distribution is instrument dependent

BAT selection effect on GRB spectra

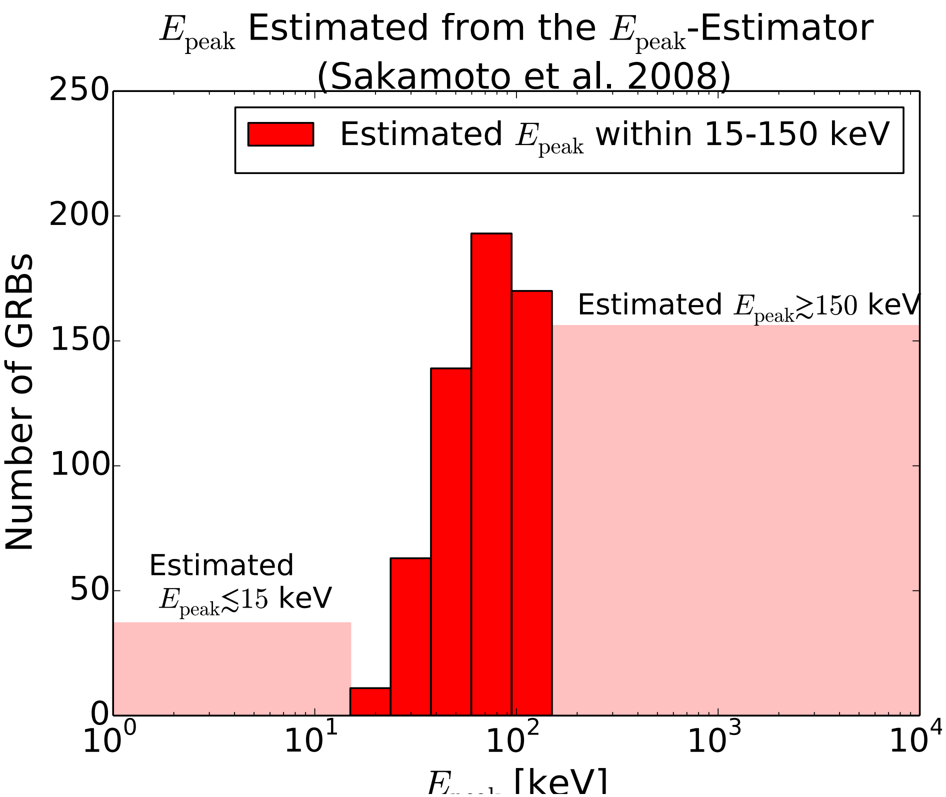


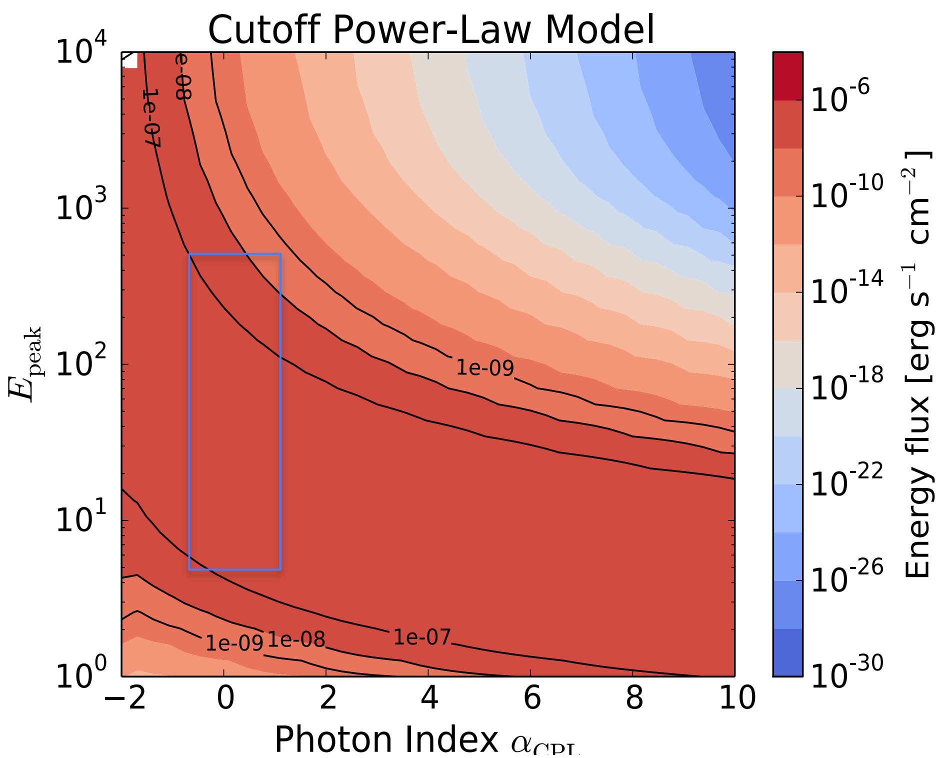
BAT selection effect on GRB spectra



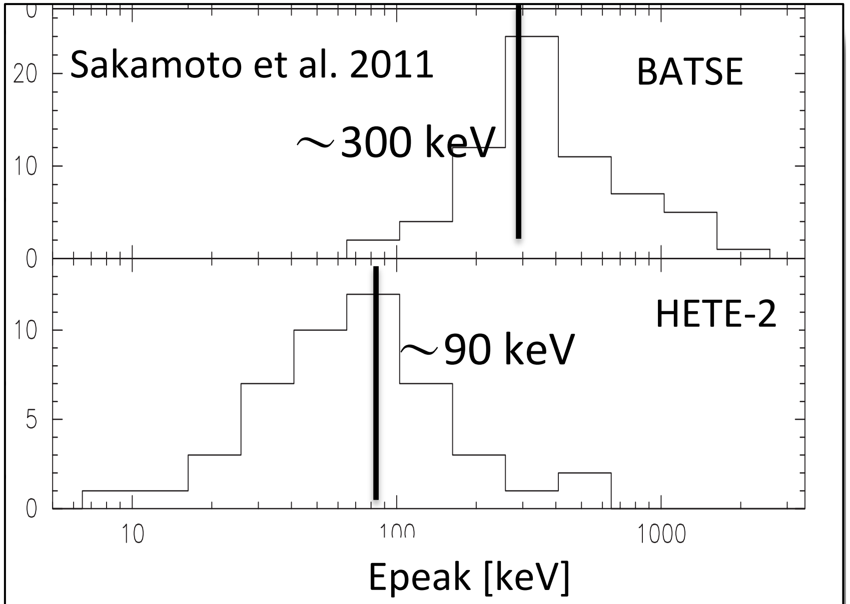


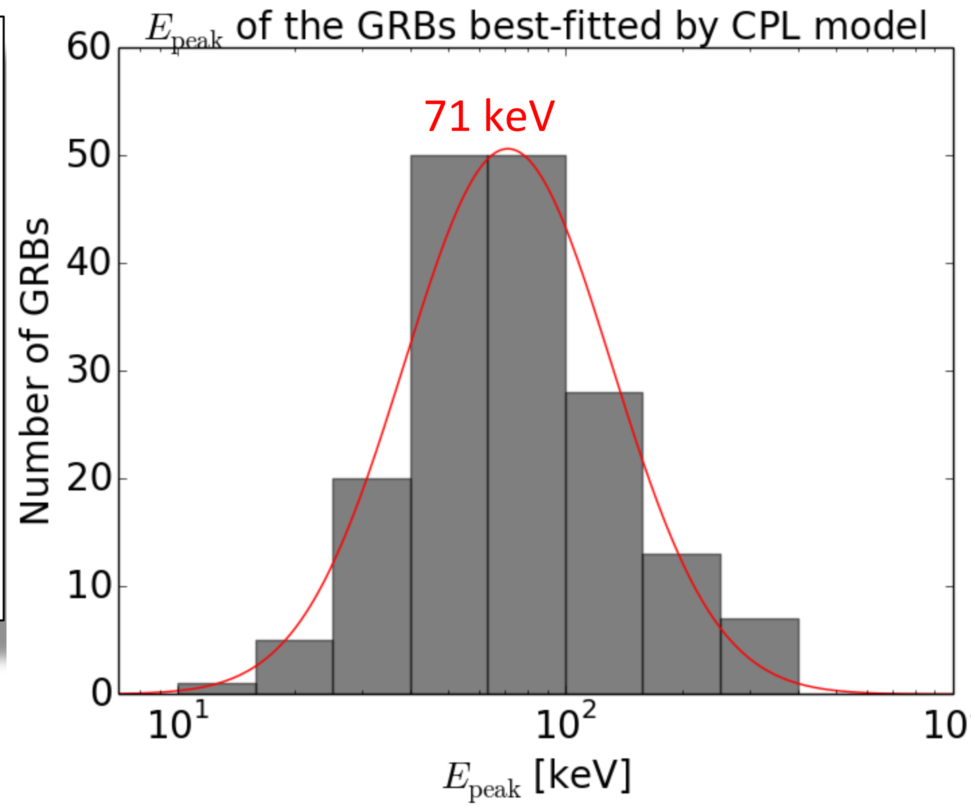
BAT selection effect on GRB spectra





Spectral Fits

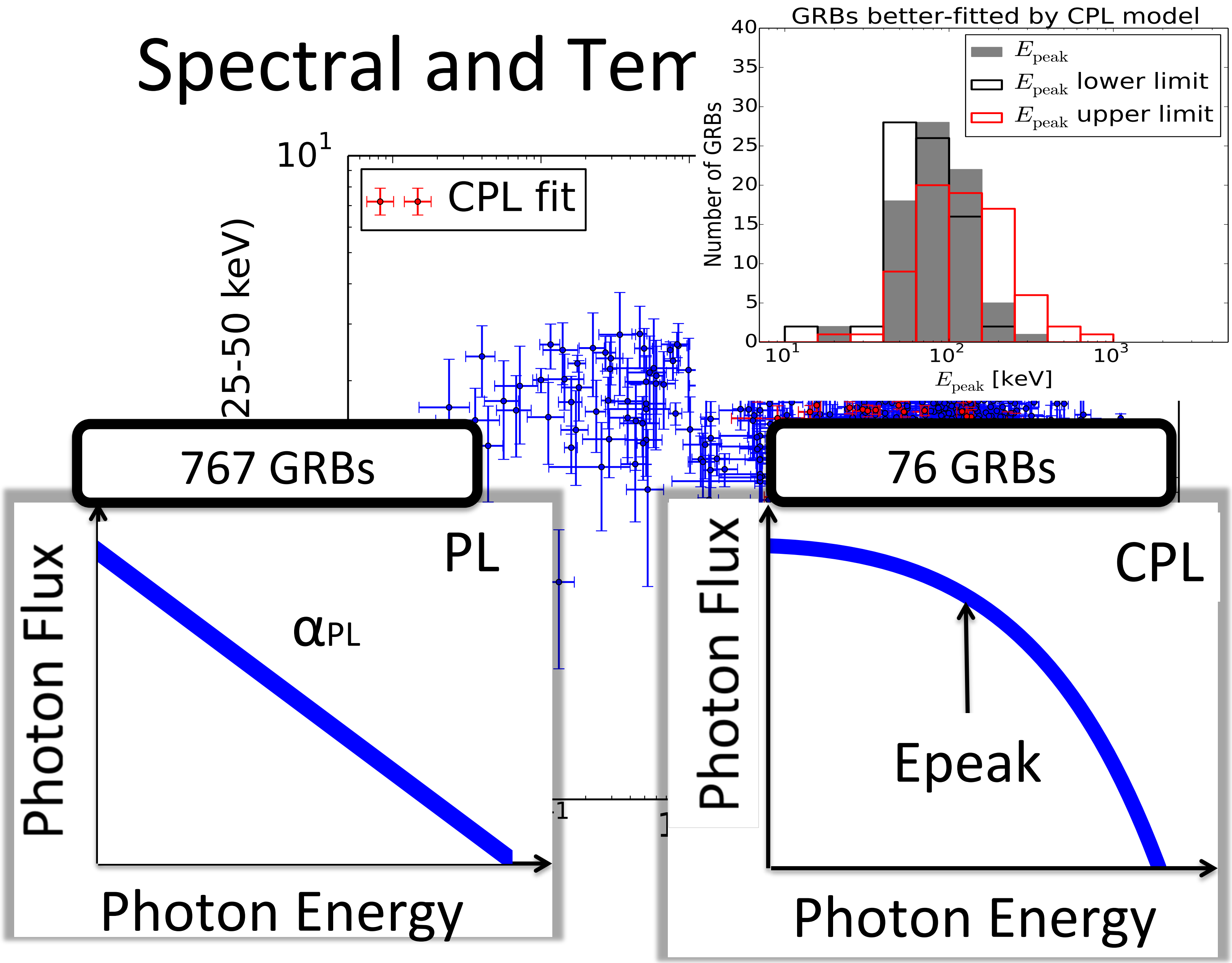




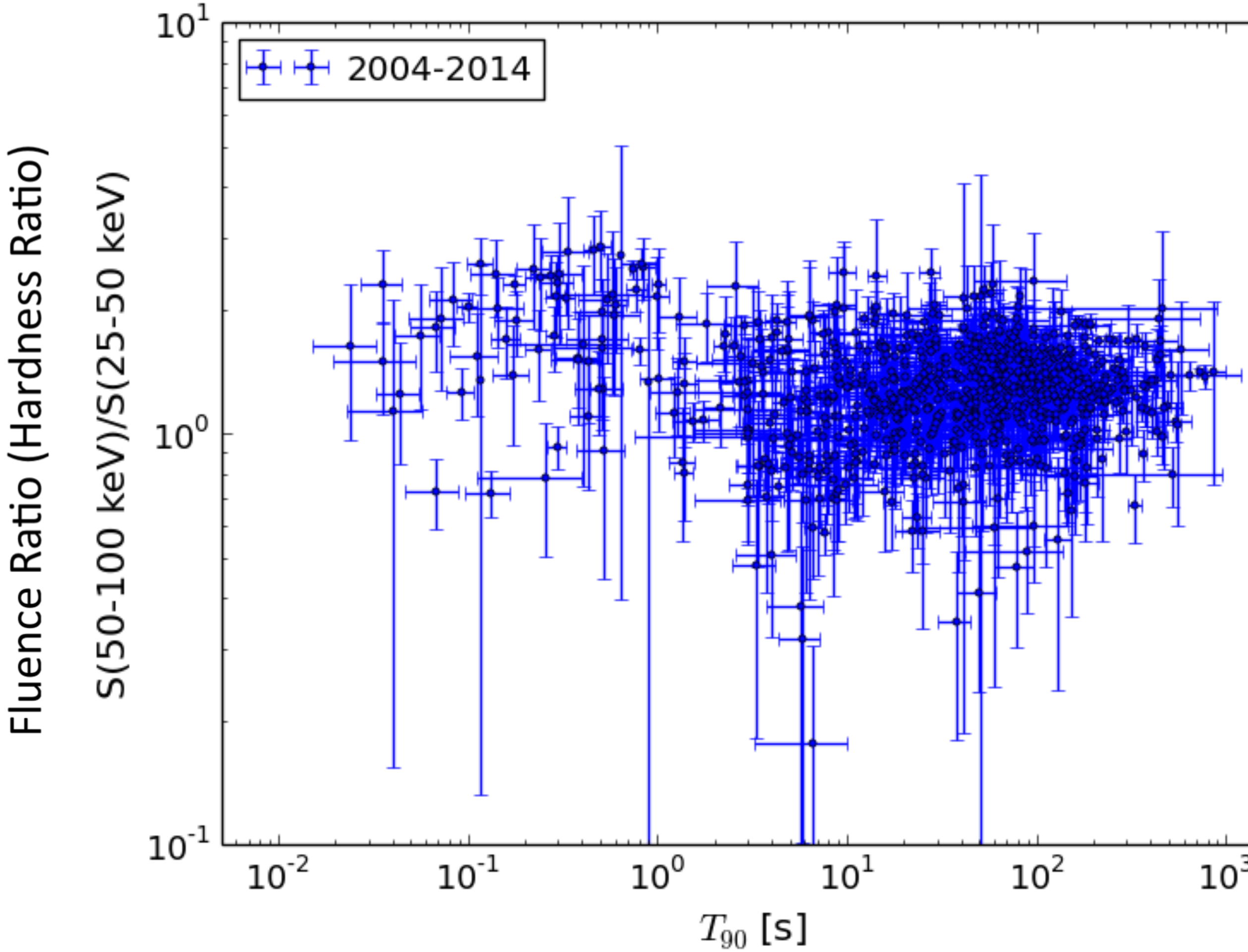
- 175 GRBs are fitted better with cutoff power law
  - Epeak are likely to be in the BAT-energy range.

BAT GRB

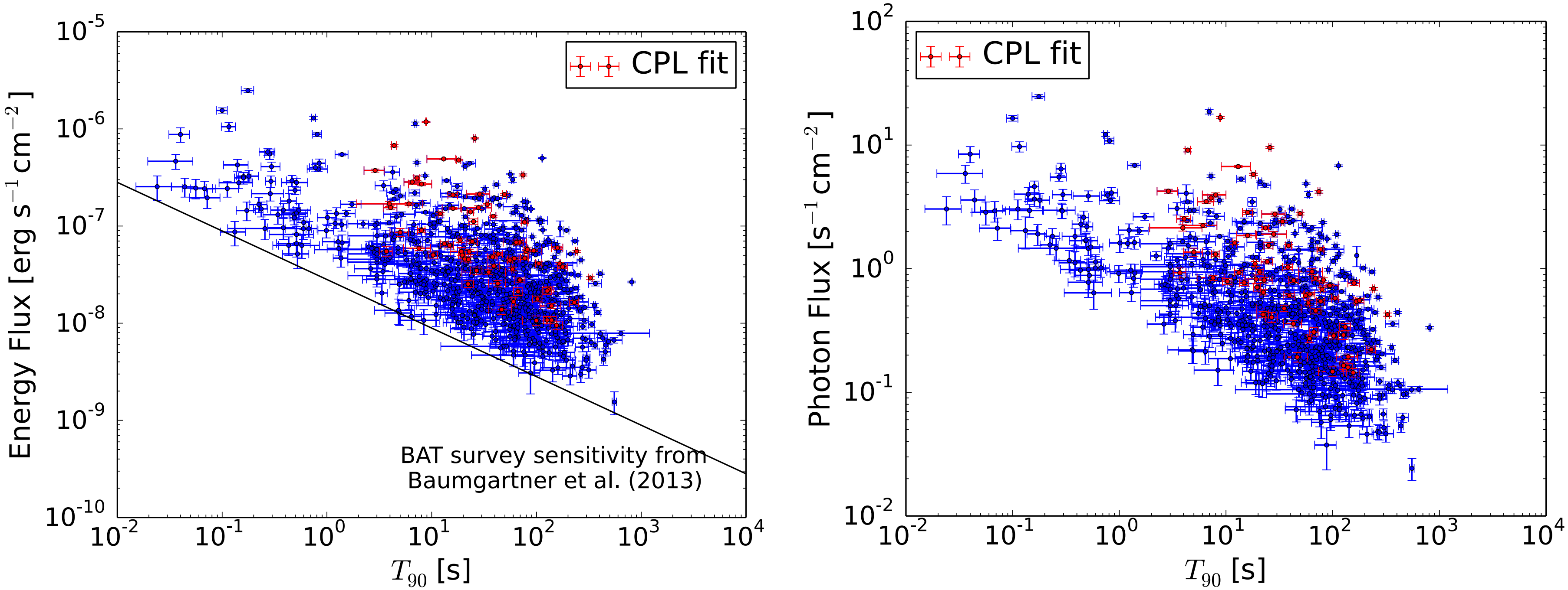
Spectral and Tem ons



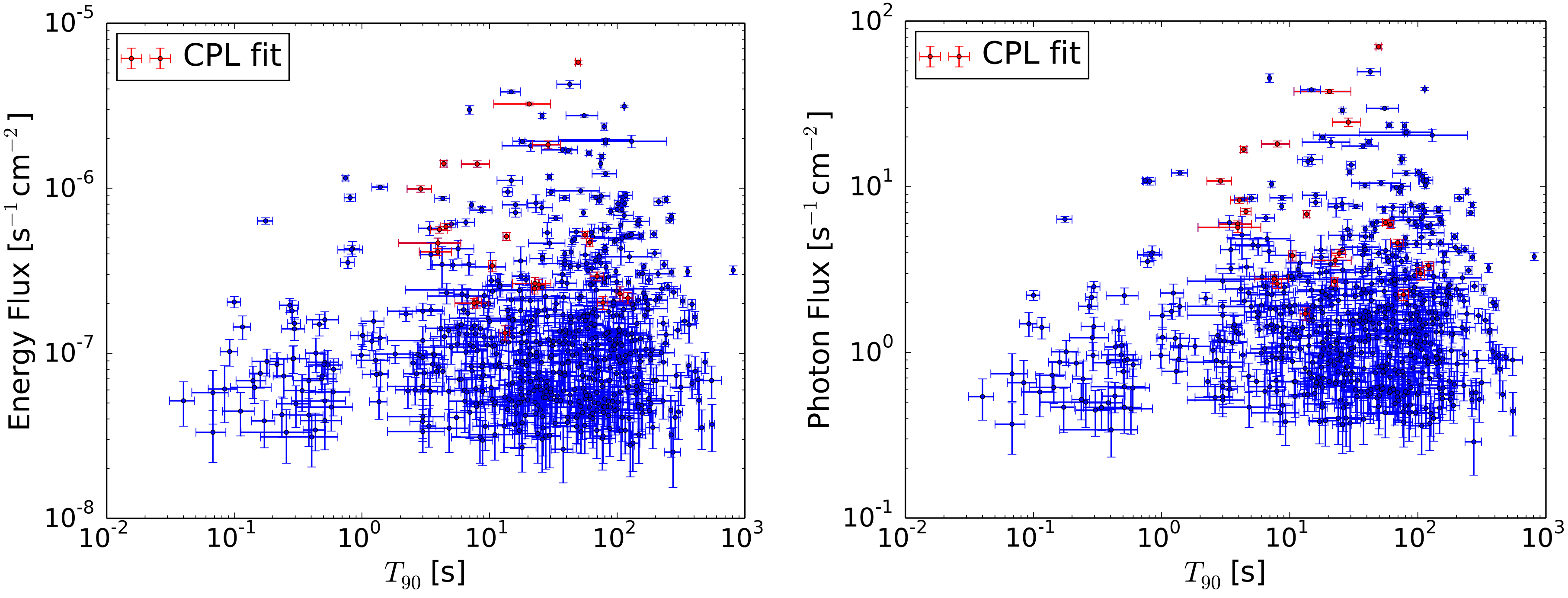
Burst Duration vs Spectrum



Burst Duration



CPL fit
Energy Flux [erg s^{-1} cm^{-2}]
T_{90} [s]
BAT survey sensitivity from
Baumgartner et al. (2013)
CPL fit
Photon Flux [s^{-1} cm^{-2}]
T_{90} [s]



CPL fit
Energy Flux [s^{-1} cm^{-2}]
T_{90} [s]
CPL fit
Photon Flux [s^{-1} cm^{-2}]
T_{90} [s]

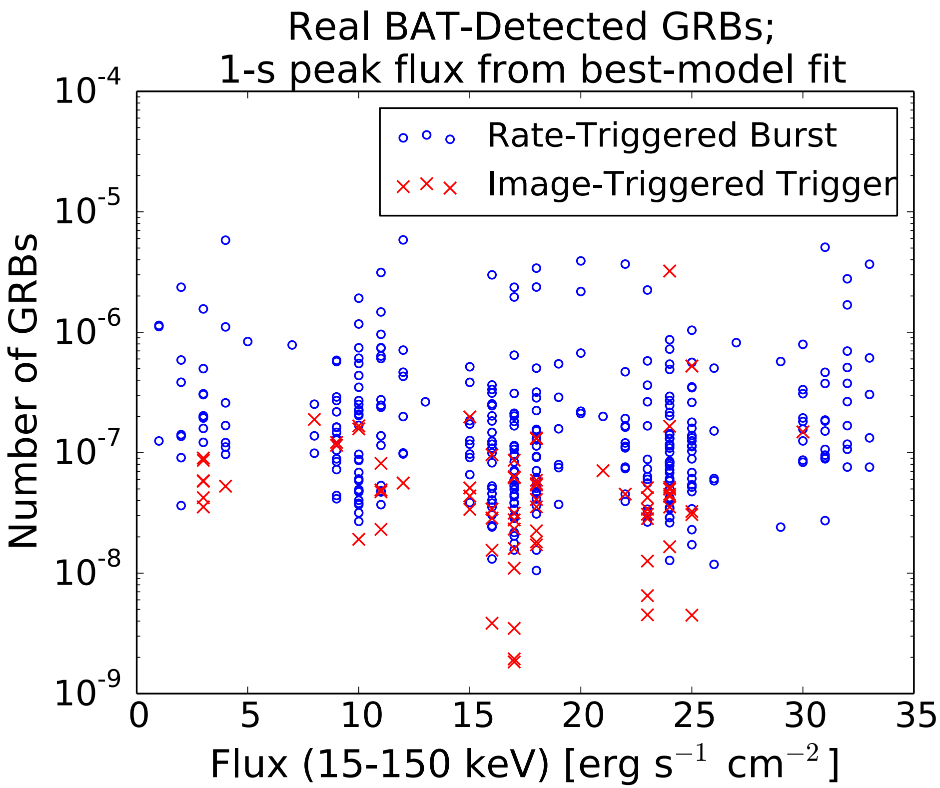
Ultra-Long GRBs

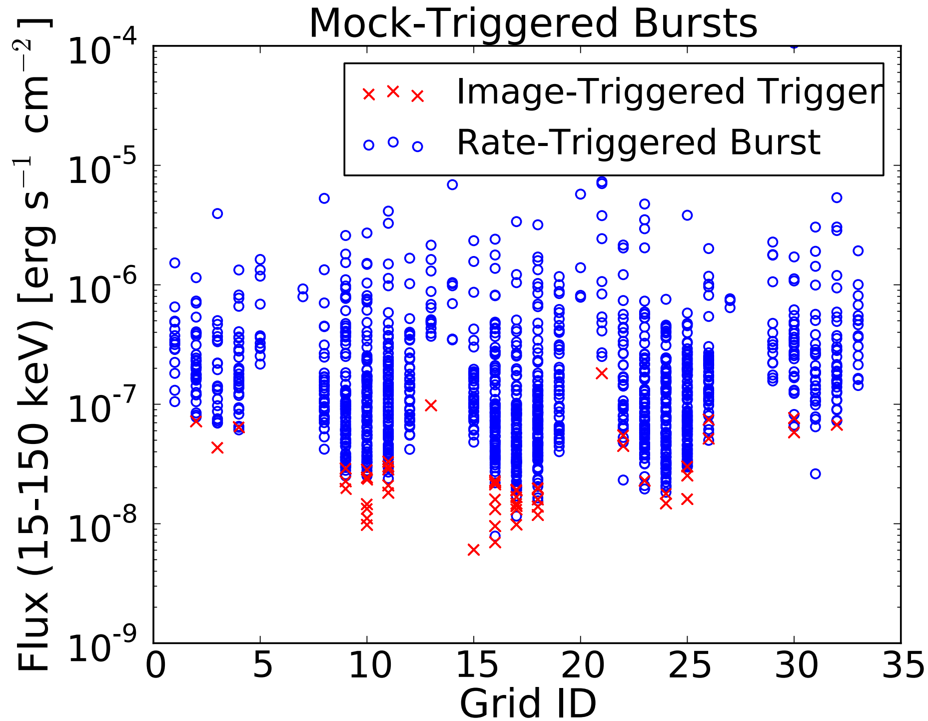
- $\sim$ 15 GRBs
- Burst duration > 1000 s (beyond event data)
- Burst durations here are very crude estimations

GRB Name	Burst Duration in BAT
GRB121027A	$\sim$ 5500 s
GRB111215A	$\sim$ 1123 s
GRB111209A	$\sim$ 17627 s
GRB101225A	$\sim$ 6237 s
GRB101024A	$\sim$ 5661 s
GRB100728A	$\sim$ 1378 s
GRB100316D	$\sim$ 2028 s
GRB091127	$\sim$ 5397 s
GRB090417B	$\sim$ 1232 s
GRB090404	$\sim$ 44635 s
GRB090309(?)	$\sim$ 5275 s
GRB080319B	$\sim$ 1338 s
GRB070518	$\sim$ 57849 s
GRB070419B	$\sim$ 4924 s
GRB060218	$\sim$ 1568 s

Sensitivity Comparisons

- Grid ID: ID name on the detector's plane, related to incoming angle





Real BAT-detected GRBs (2005-2009):
- Total triggered bursts: 409
- 338 rate trigger
- 71 image trigger

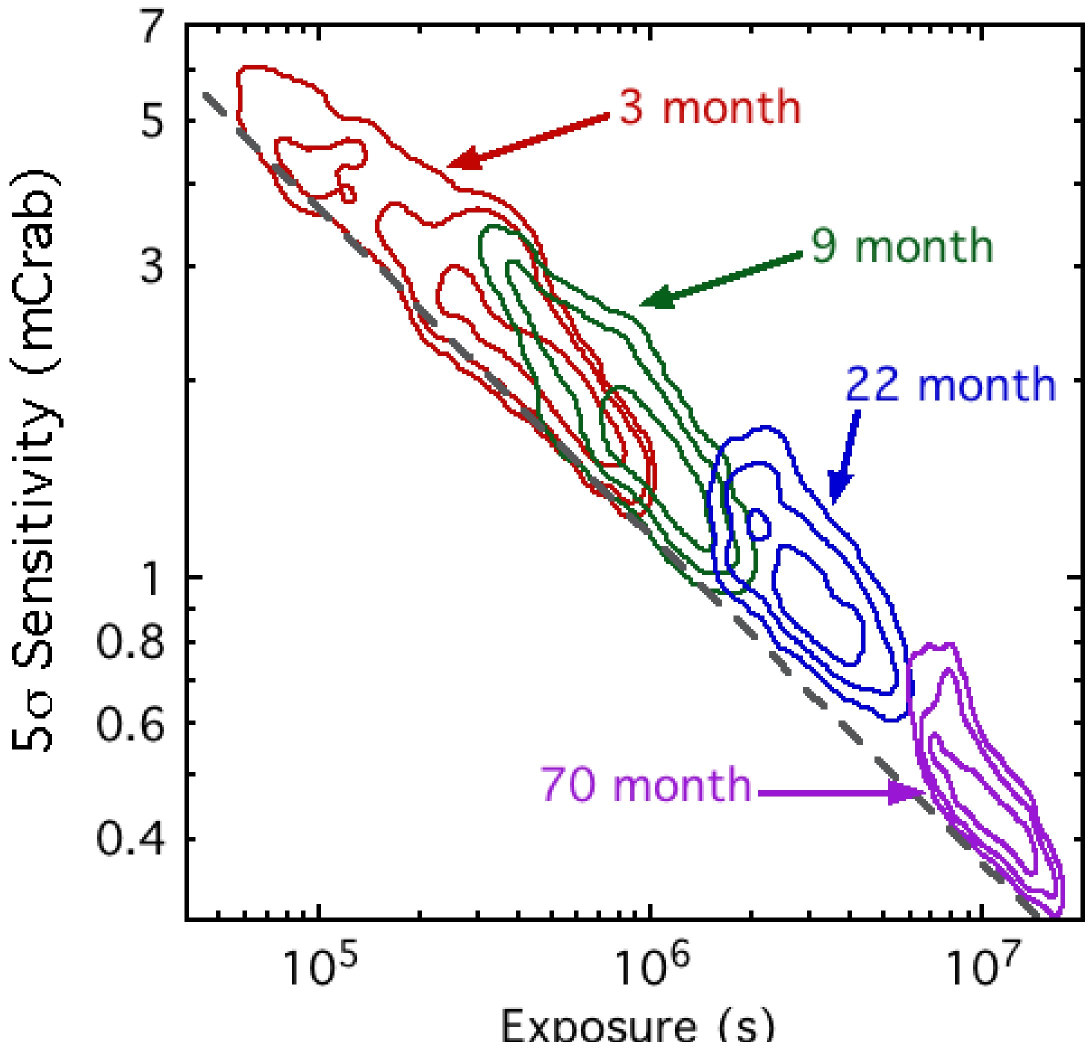
Our simulations:
- Total triggered bursts: 1400
- 1347 rate trigger
- 53 image trigger

Swift/BAT GRB Detection Overlook (old table)

Year	Number of detections (with ground-detected GRBs)	Number of detections (no ground-detected GRBs)	Number of active BAT detector
2005	88	86	29413
2006	101	100	26997
2007	86	80	27147
2008	102	94	26478
2009	91	82	24387
2010	85	72	24050
2011	80	75	22817
2012	92	89	23017
2013	96	85	22053
2014	91	83	20413

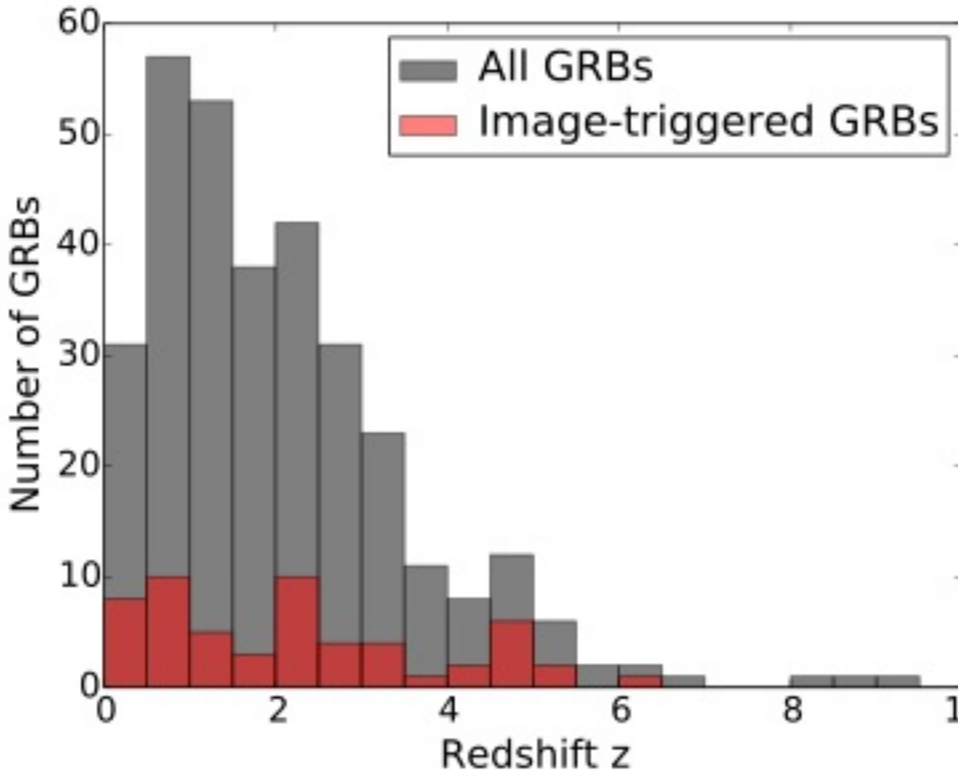
Summary

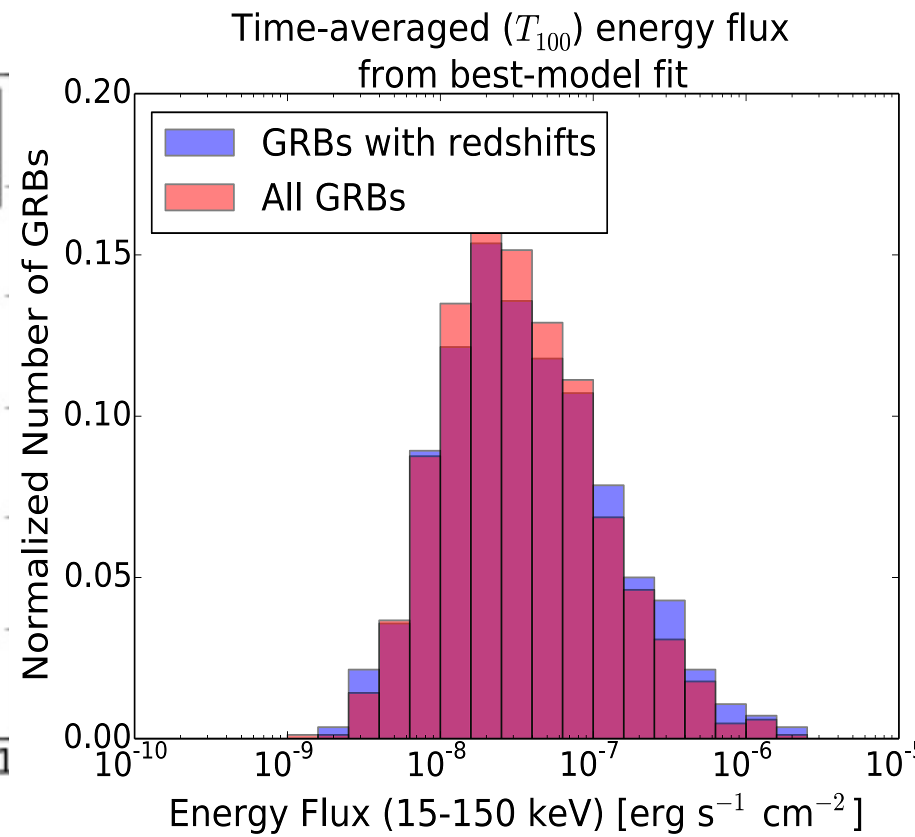
- Adopting the complex BAT-trigger algorithm improve the sensitivity and hence more dim (low-flux) bursts are needed in the intrinsic sample.
- Need more bursts from high redshift to create a good match with the observations.
- Very high GRB rate at large redshift, unless luminosity evolution is considered.
- It seems like some kind of relation between bursts' energy output (e.g., Lpeak) and spectral parameters (e.g., Epeak) is needed to generate good match with the observations.
- The 3rd BAT GRB catalog is coming soon! Suggestions welcome!


3 month
9 month
22 month
70 month
7
5
3
1
0.8
0.6
0.4
5σ Sensitivity (mCrab)
10^5
10^6
10^7
Exposure (s)

Redshift Distribution

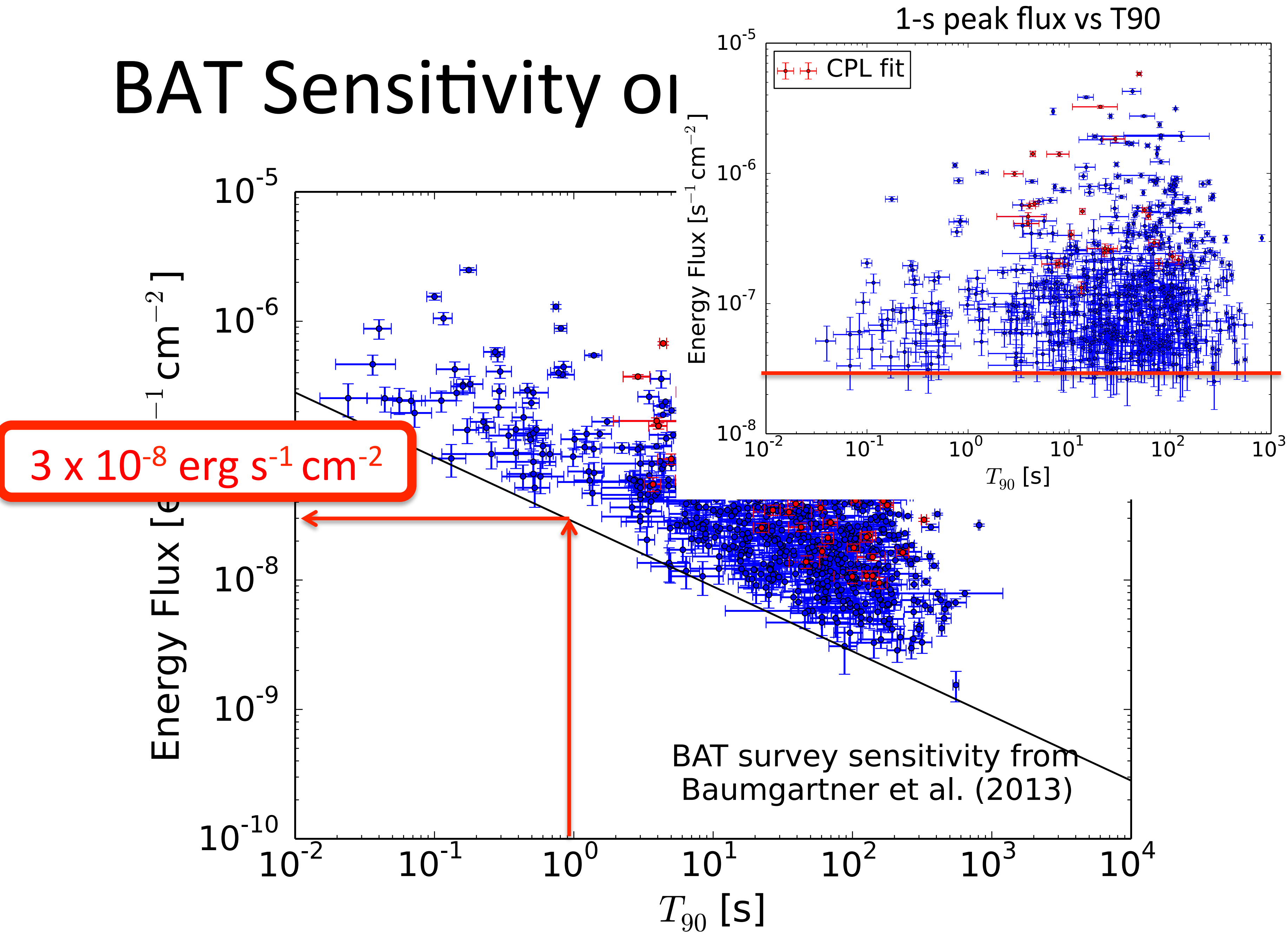
- Thanks to the ground-based follow-up campaign
- Redshift list compiled by Kevin Chen (U of California, Berkeley)
  - Info from papers, GCNs, online list (e.g., GRBOX by Dan Perley)





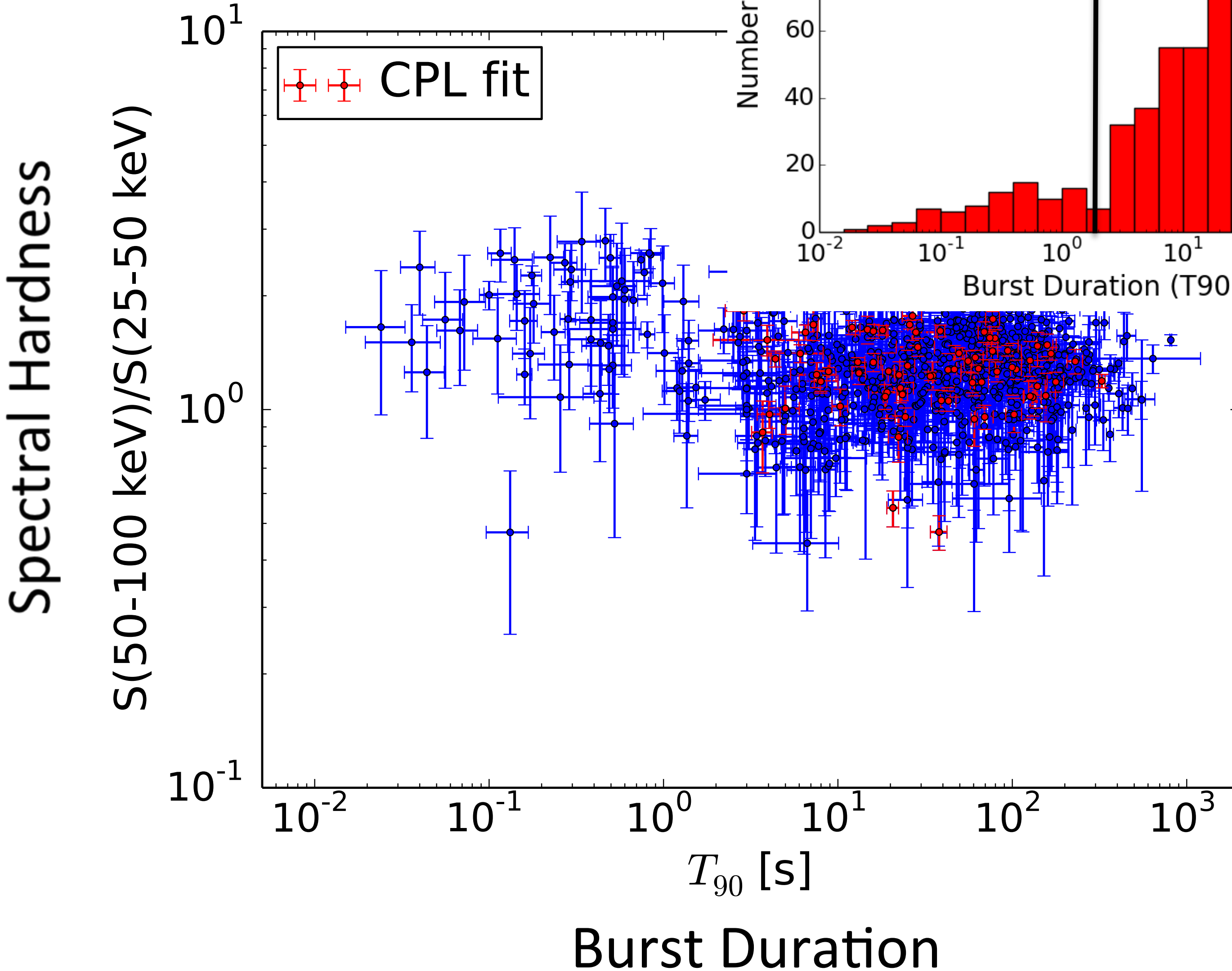
- Spectroscopic: 65%
- Photo-z: 9%
- Host galaxy spectrum: 28%
- Host galaxy photo-z: 3%

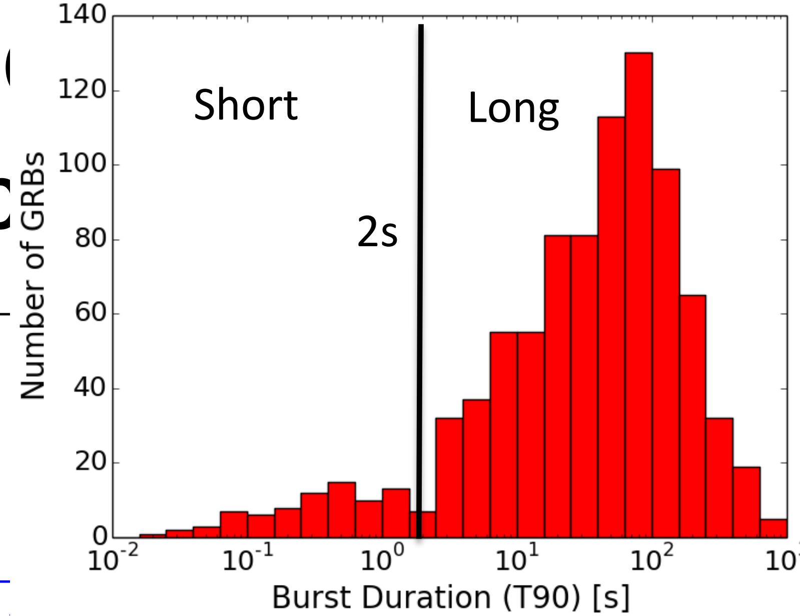
BAT Sensitivity on

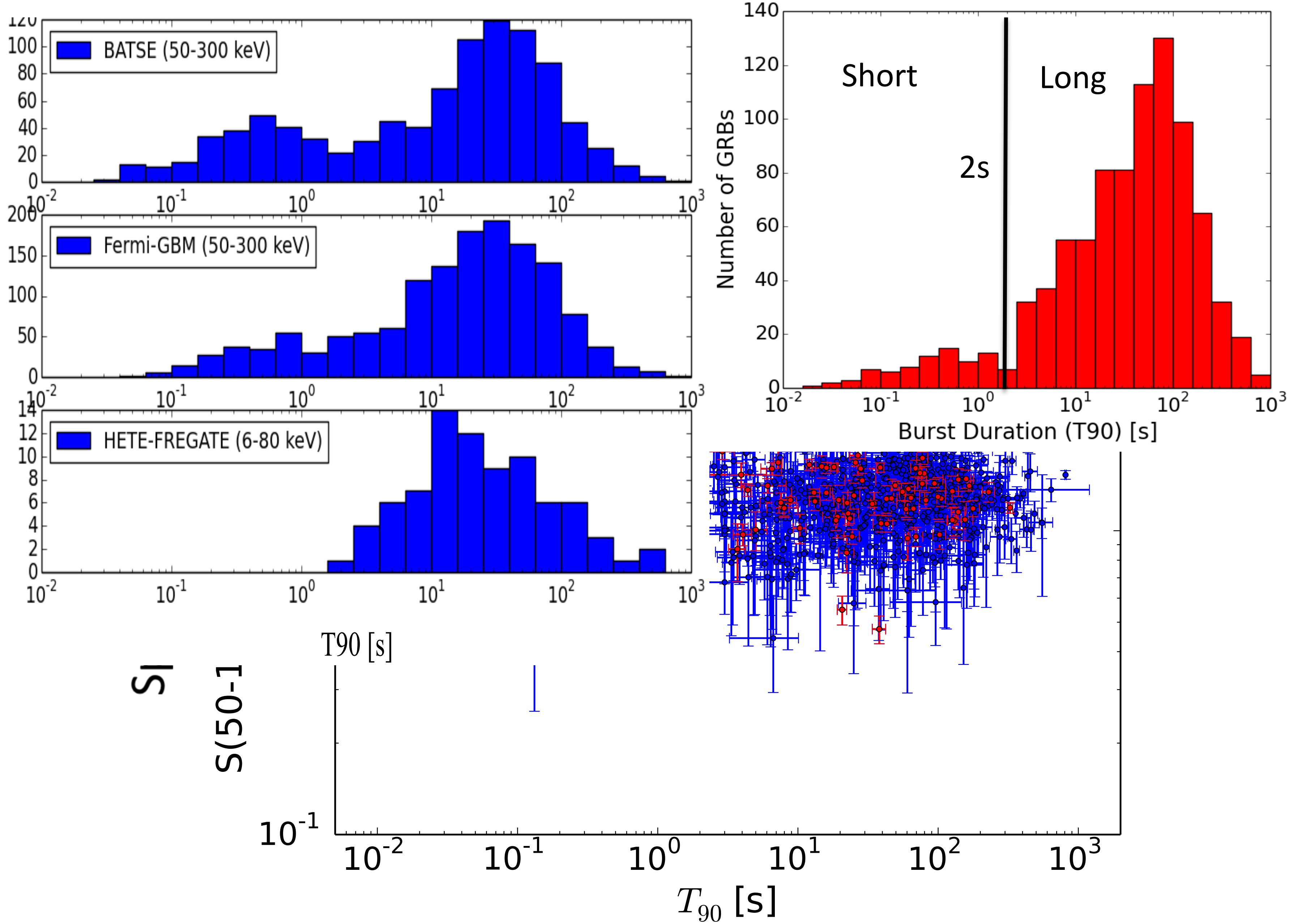


BAT (

Spectral and Temp



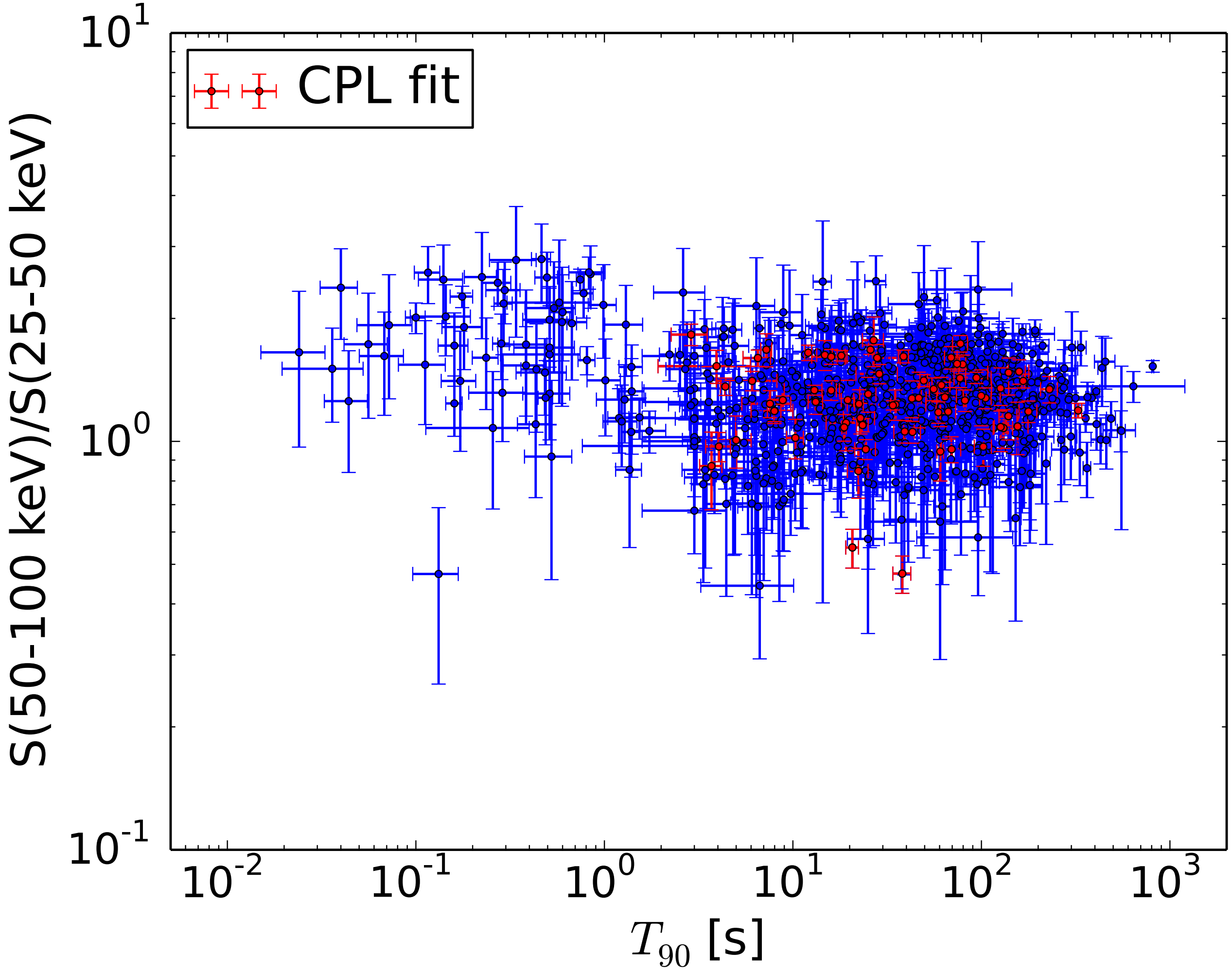




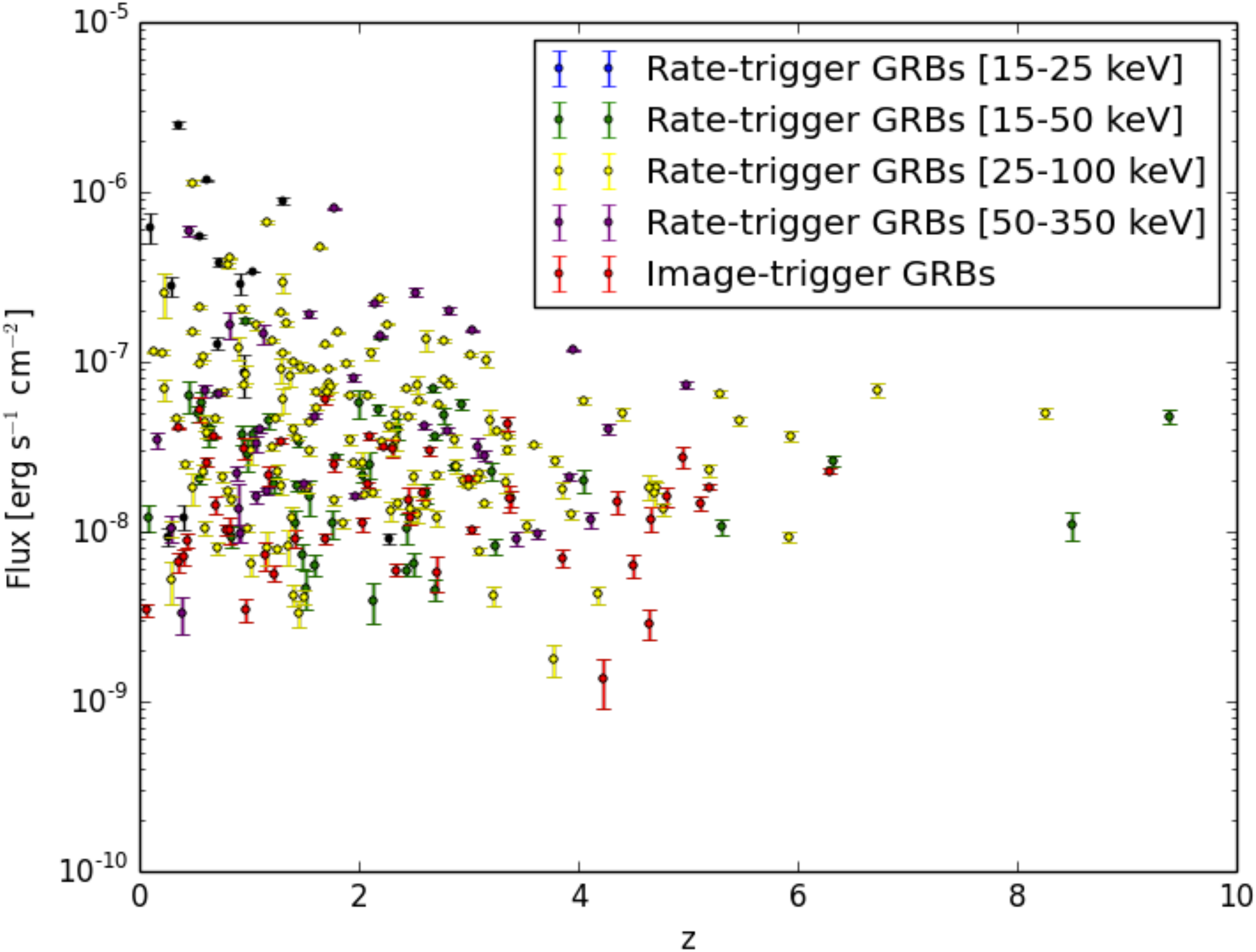
Burst Duration

BAT GRB
Spectral and Temporal Distributions

Spectral Hardness



Burst Duration


Rate-trigger GRBs [15-25 keV]
Rate-trigger GRBs [15-50 keV]
Rate-trigger GRBs [25-100 keV]
Rate-trigger GRBs [50-350 keV]
Image-trigger GRBs
Flux [erg s^{-1} cm^{-2}]
z
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
0
2
4
6
8
10

High-z rate estimation

- List of high-z burst detected to-date

GRB name	Redshift	Avg lumnosity (obs 15-150 keV)	Incident angle	Partial coding fraction	
GRB060522	5.11	4.20×10^{51}	31.88	0.75	
GRB071025	5.20	5.48×10^{51}	30.56	0.49	$\boxed{< 5.40 - 6.90}$
GRB050502B	5.20	6.89×10^{51}	10.21	0.99	< 6.40 - 8.10
GRB140304A	5.28	1.96×10^{52}	25.20	0.74	
GRB050814	5.30	3.31×10^{51}	39.66	0.26	
GRB060927	5.46	1.52×10^{52}	16.60	0.82	< 8.10 – 9.90
GRB130606A	5.91	3.73×10^{51}	22.74	0.97	
GRB120521C	5.93	1.49×10^{52}	19.15	0.68	< 8.10 – 9.90
GRB050904	6.29	1.06×10^{52}	35.09	0.57	
GRB140515A	6.33	1.14×10^{52}	13.13	0.99	
GRB060116	6.60	1.09×10^{52}	37.93	0.21	< 5.5 – 7.60
GRB080913	6.73	3.75×10^{52}	46.33	0.39	
GRB090423	8.26	4.41×10^{52}	25.03	0.92	
GRB120923A	8.50	1.23×10^{52}	16.96	0.80	< 8.10 – 9.90
GRB090429B	9.38	5.56×10^{52}	24.51	0.84	< 9.90