Fermi
Gamma-ray
Space Telescope

Fermi view of Gamma-ray bursts

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On behalf of the Fermi LAT/GBM collaboration

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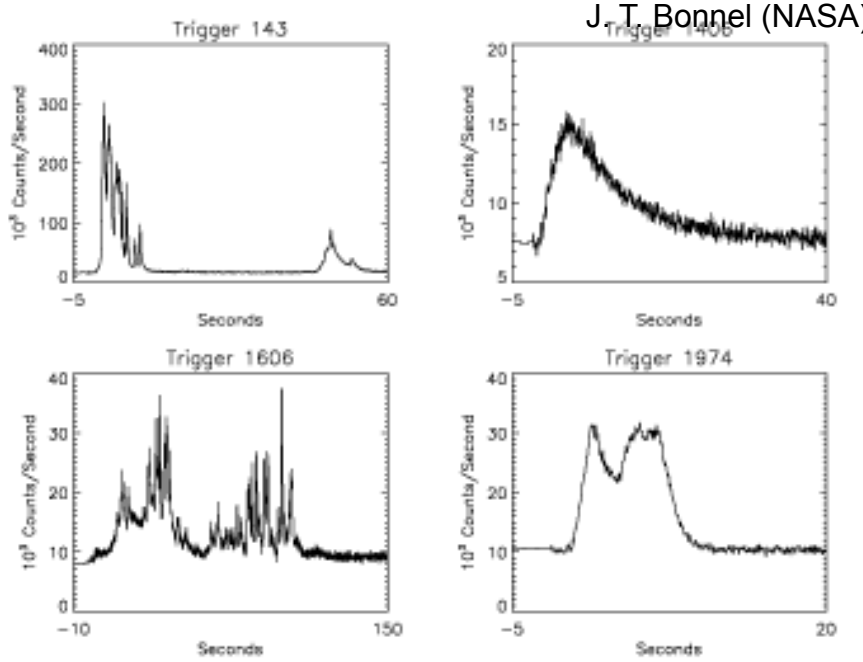
Gamma-ray Bursts: prompt emission

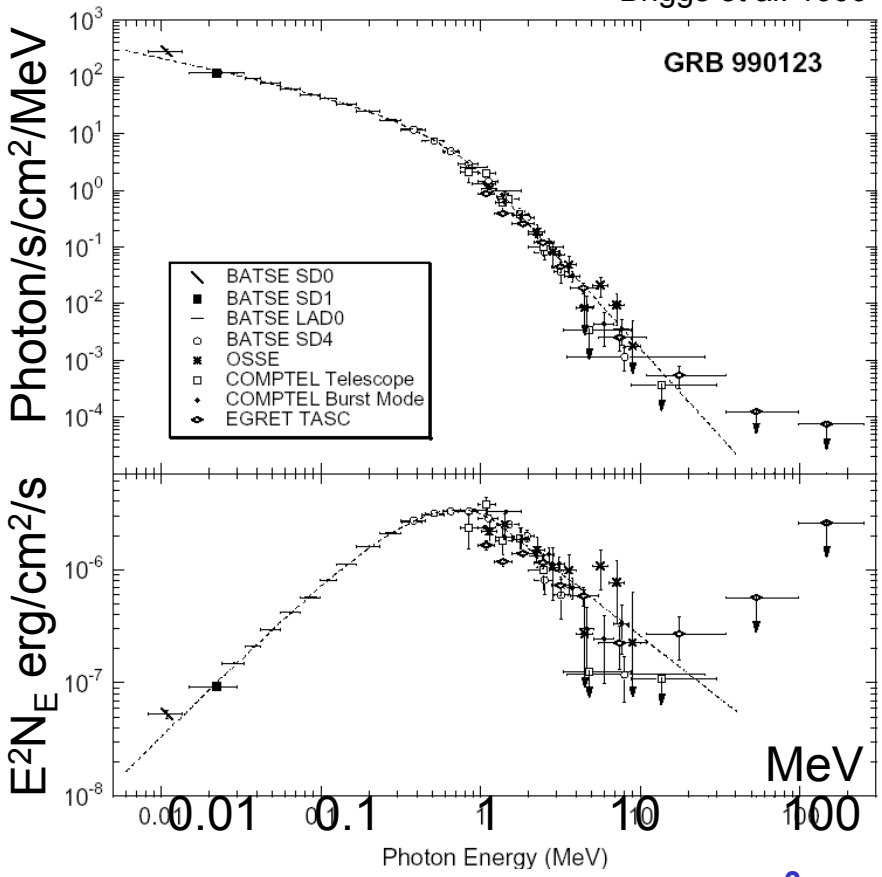
Intense hard X-ray to gamma-ray emission discovered at the 60's

- **Event rate : 1-2 per day**
- **Wide diversity in light curve (0.1-1000s duration)**
- **Cosmological distance (z~0.1-9)**
- **Bimodal duration distribution (short/long GRB)**
- **Non-thermal spectrum**

J. T. Bonnel (NASA)

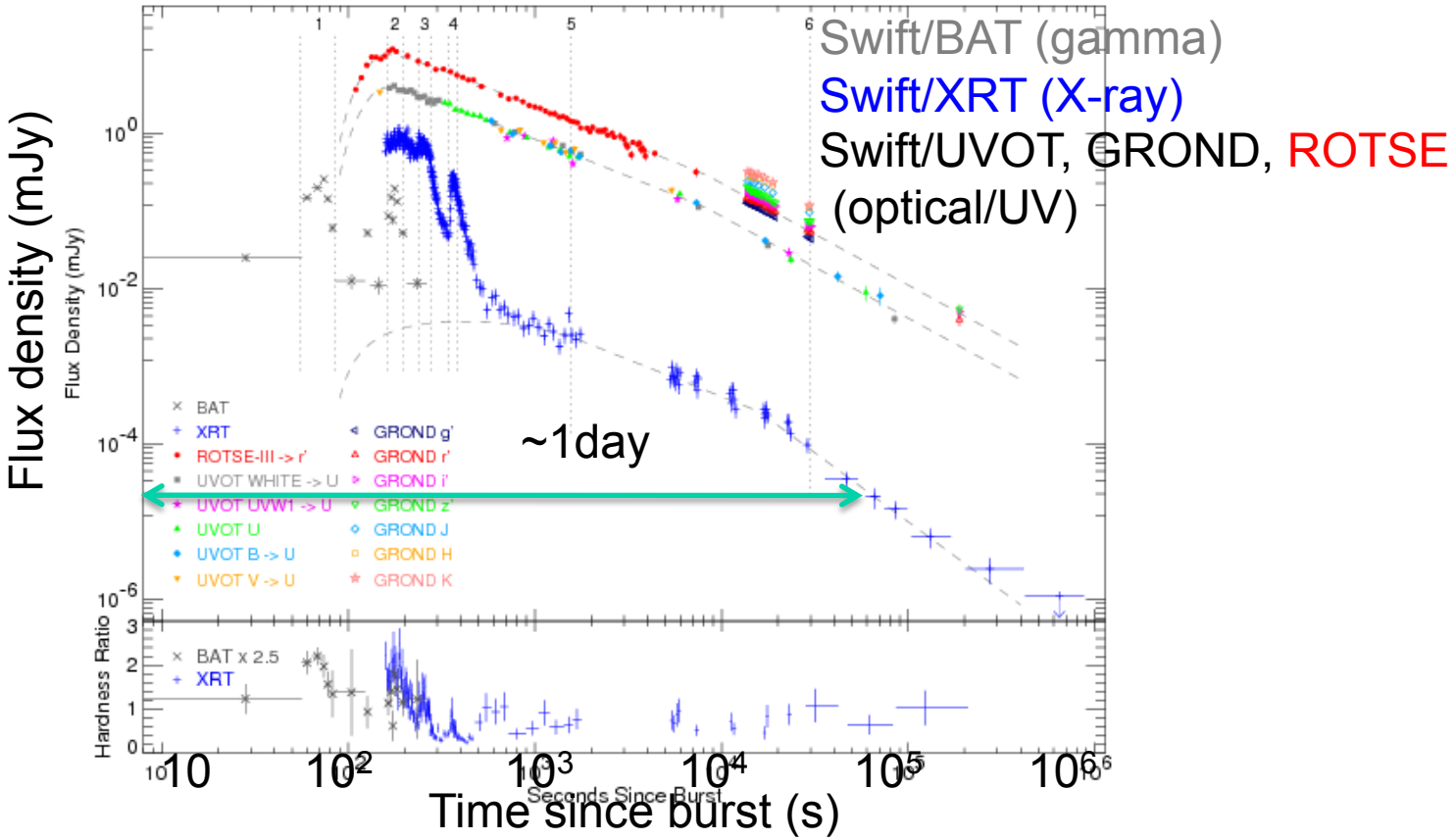


Briggs et al. 1999

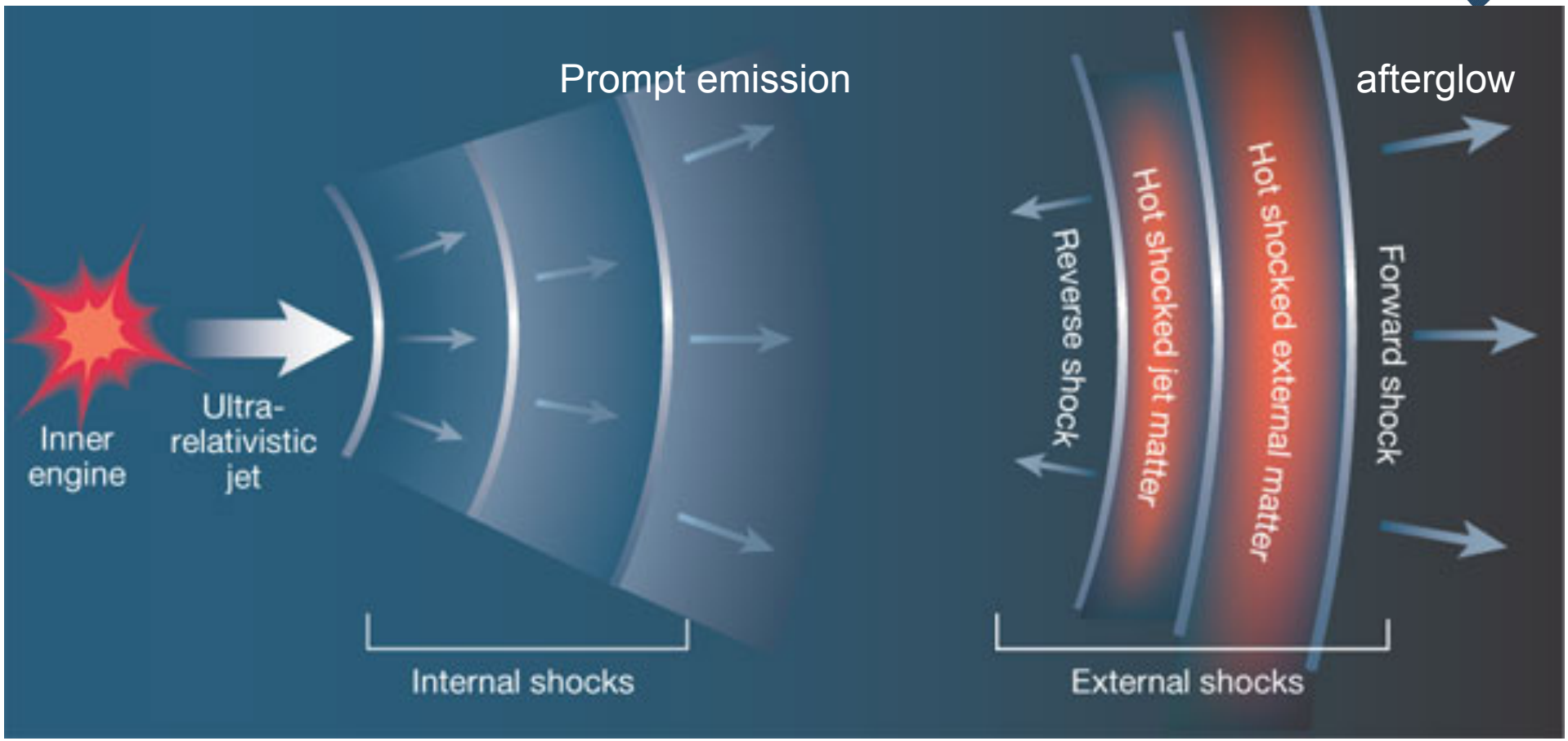


Gamma-ray bursts : afterglow

- **After the spiky prompt emission, there is long-lived (~day) afterglow from radio to X-rays**
- **Late phase afterglow shows smooth light curve**



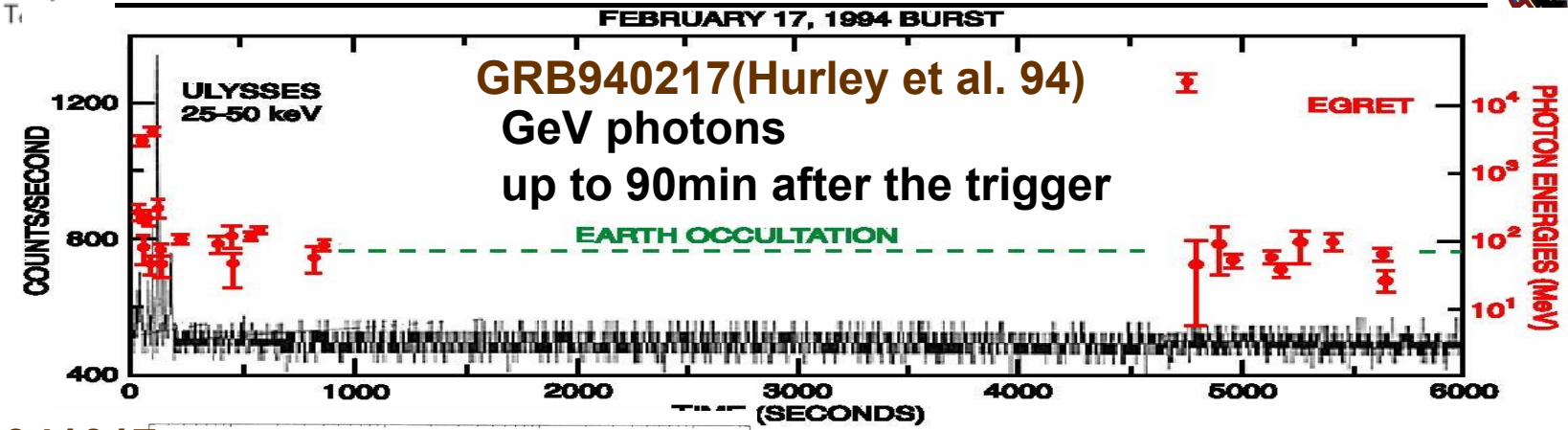
Standard model



- **Still many unknown, unclear…**
  emission mechanism of gamma-ray, jet formation, .. Etc
  key observation: high-energy gamma-ray emission

Piran 2003

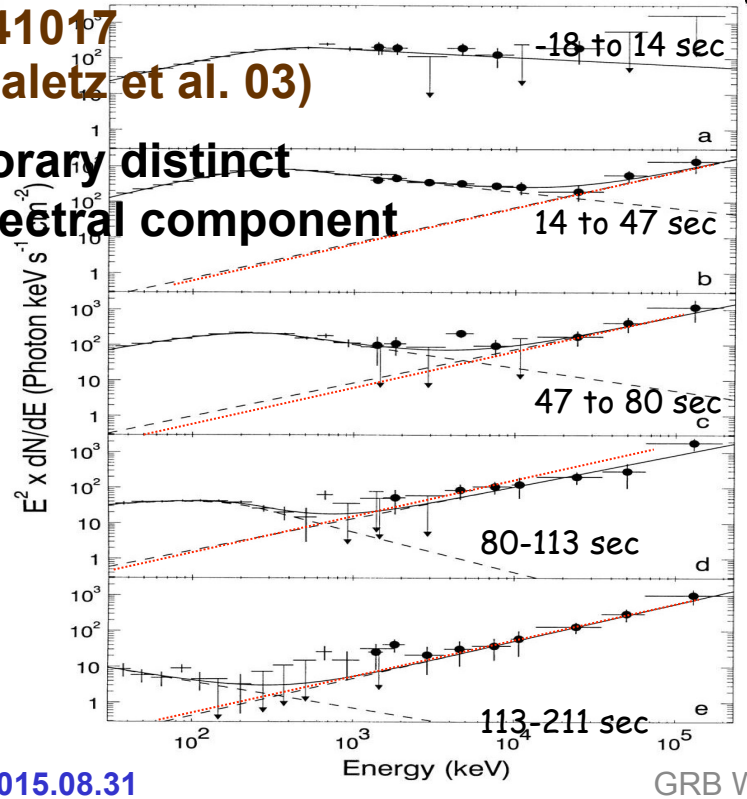
High energy emission from GRB : Pre Fermi Era



GRB940217(Hurley et al. 94)
GeV photons
up to 90min after the trigger

GRB941017
(Gonzaletz et al. 03)

Temporary distinct
HE spectral component



EGRET detected > 100 MeV photons from a few GRBs
Different behavior from <100 MeV photons

- ✓**Long-lived emission**
- ✓**Extra spectral component**
  - ➔ **constrain on emission mechanism**
- ✓**Highest energy photon**
  - ➔ **bulk Lorentz factor of jet**
- ✓**Cosmology, fundamental physics**
  - **Extra galactic background light**
  - **Lorentz invariance violation**

Need large FoV, high sensitivity

Fermi Gamma-ray Space Telescope

LAT

Silicon-Strip detectors
- Identification &direction measurement of γ-rays

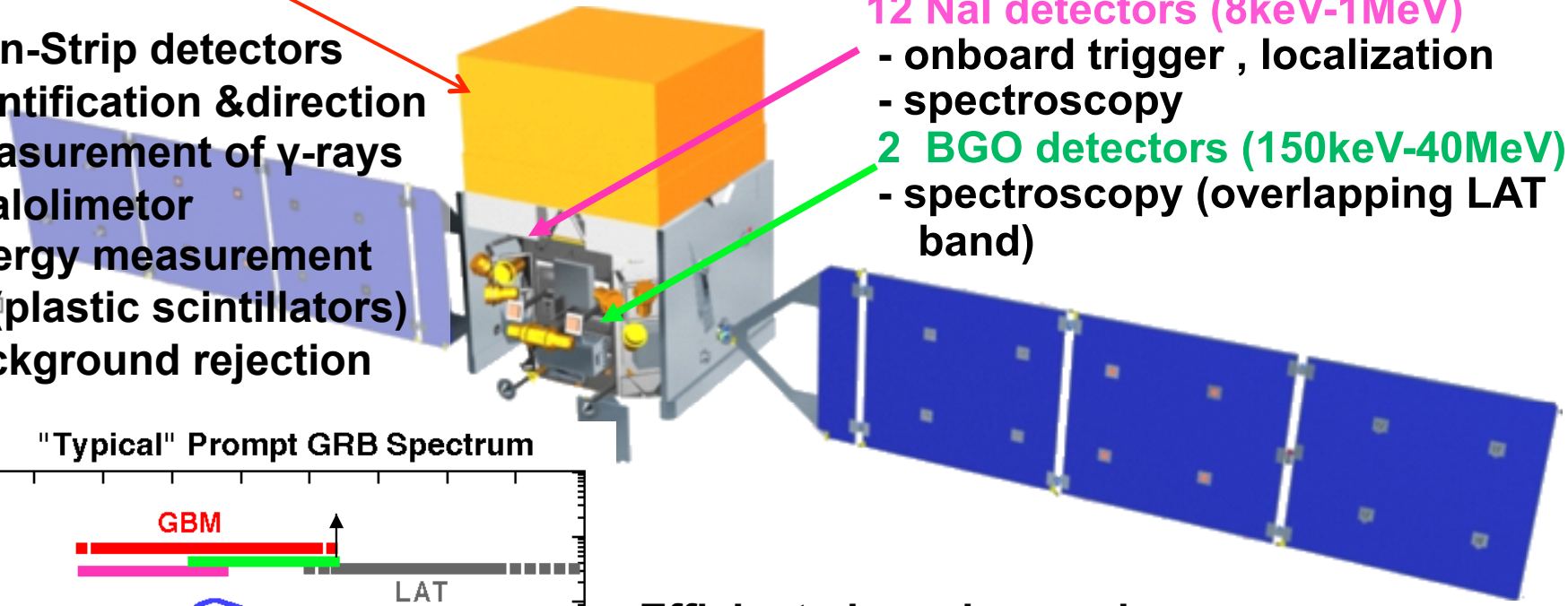
CsI calolimetor
- Energy measurement

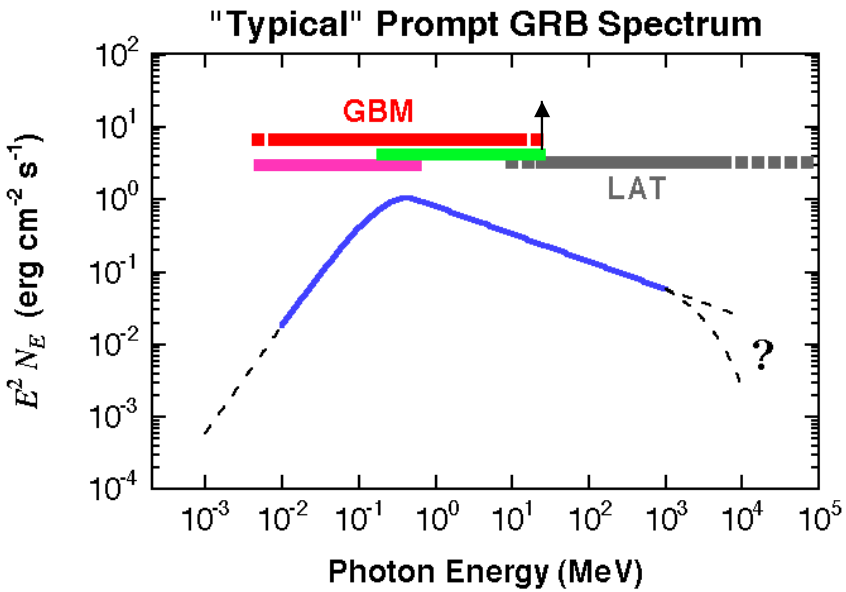
ACD (plastic scintillators)
- background rejection

Gamma-ray Burst Monitor (GBM)

12 NaI detectors (8keV-1MeV)
- onboard trigger , localization
- spectroscopy

2 BGO detectors (150keV-40MeV)
- spectroscopy (overlapping LAT band)

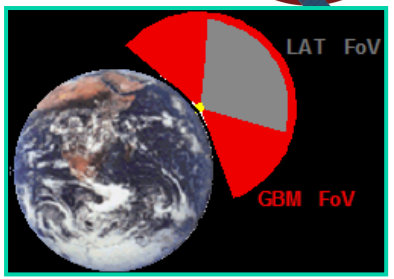




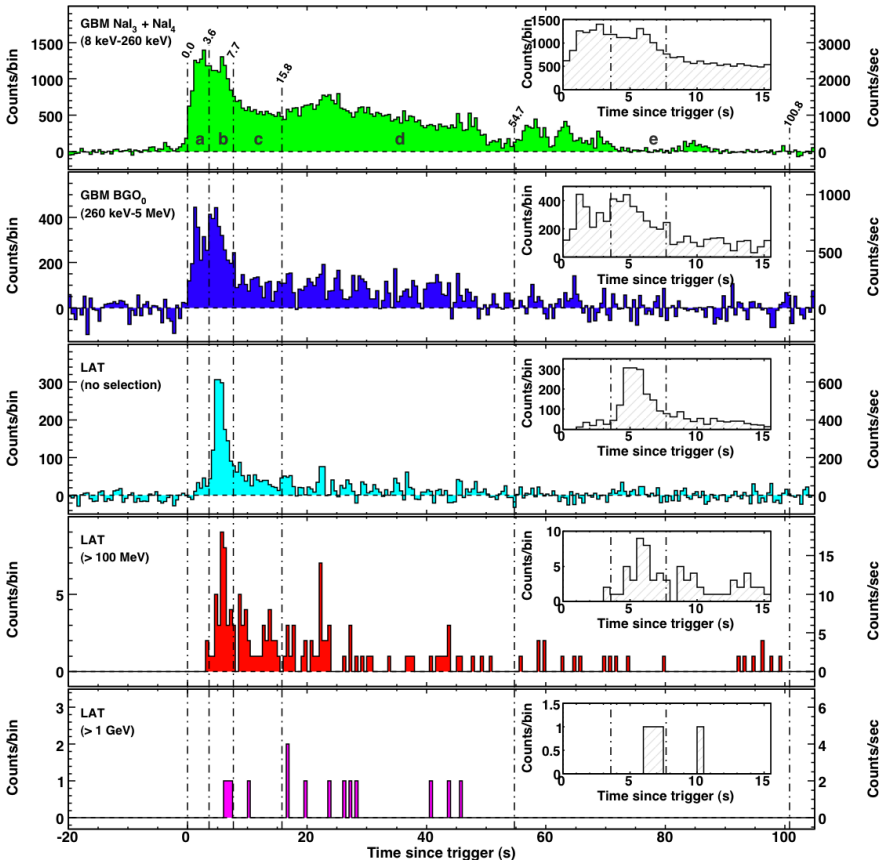
- Efficient observing mode
- Wide FoV
- Low deadtime
- Large effective area
- Good angular resolution
- Energy coverage

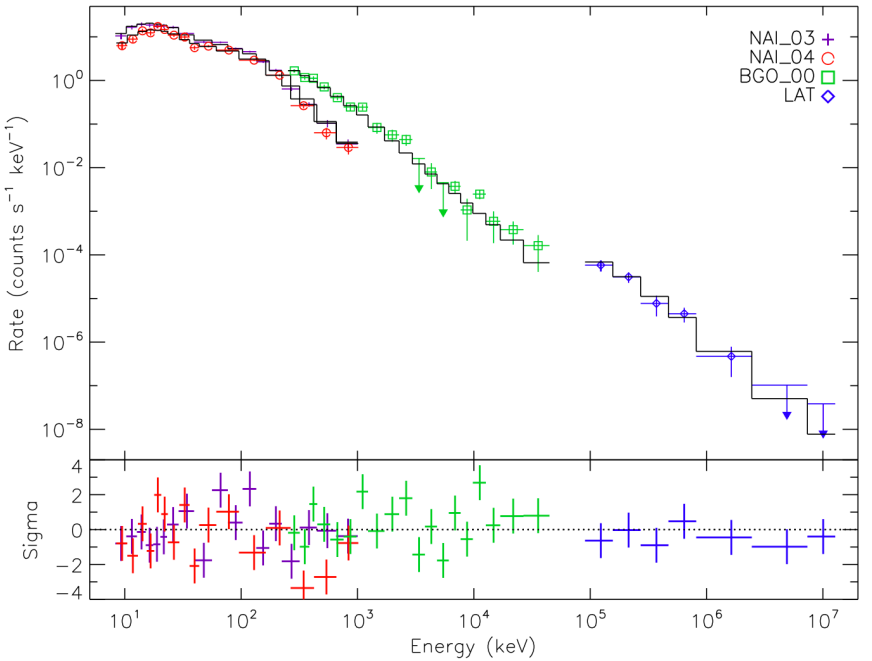
GRB observation by Fermi

- > 7 decades of energy range
- Large FoV(GBM:~4π,
  LAT: ~65deg (90deg for LLE)
- > 10 times sensitivity of EGRET

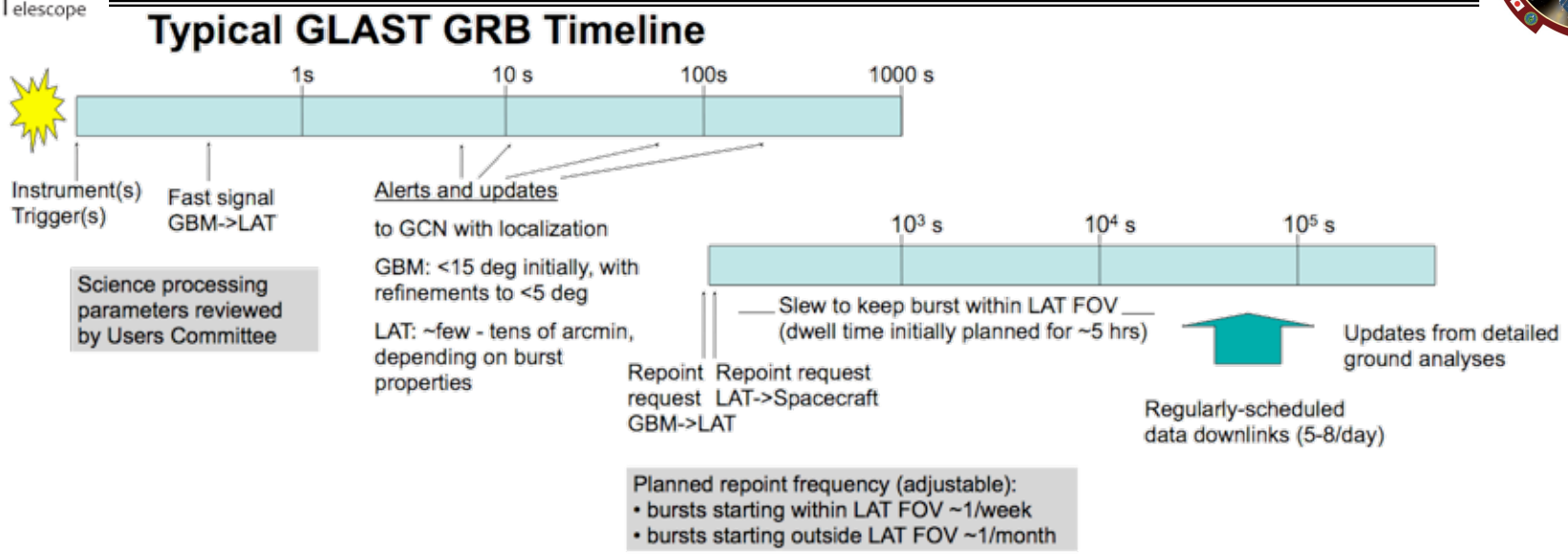


Example for bright GRB 080916C (Abdo+09)





Onboard alert and ground analysis



- GBM/LAT on-board processing (10—15 s):

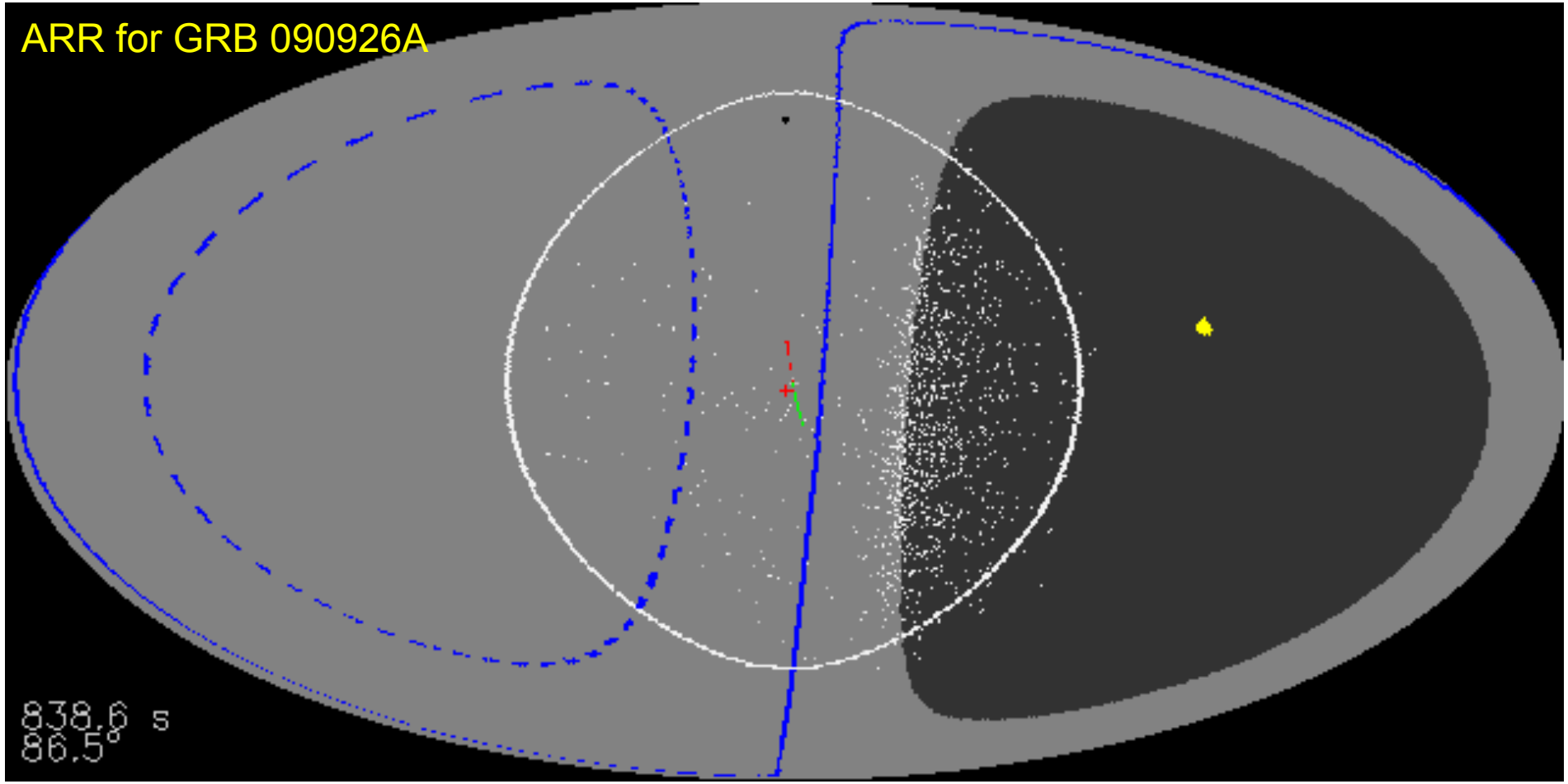
  GCN alert within 10—15 s from the trigger time through TDRSS (alert, location).
  Now 2 s~ 150s windows are also used for on-board search
  We have few onboard triggers (GRB 090510, GRB 131108A)

- LAT ground processing (a few hours after data downlink)

  Final location, spectrum (1st circular).
  Final location, high-energy flux and spectrum, afterglow search results (2nd circular).
  Data downlink may take > a half of day once ARR is triggered

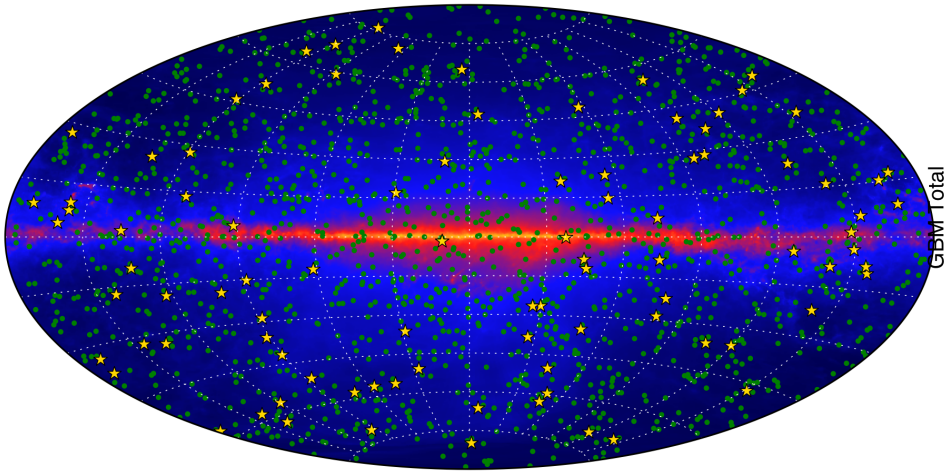
Autonomous Repoint Request (ARR)

GBM FSW triggers Autonomous Repoint Request (ARR)
S/C slew to the GBM position up to 2.5 hours subject to earth-limb constraint

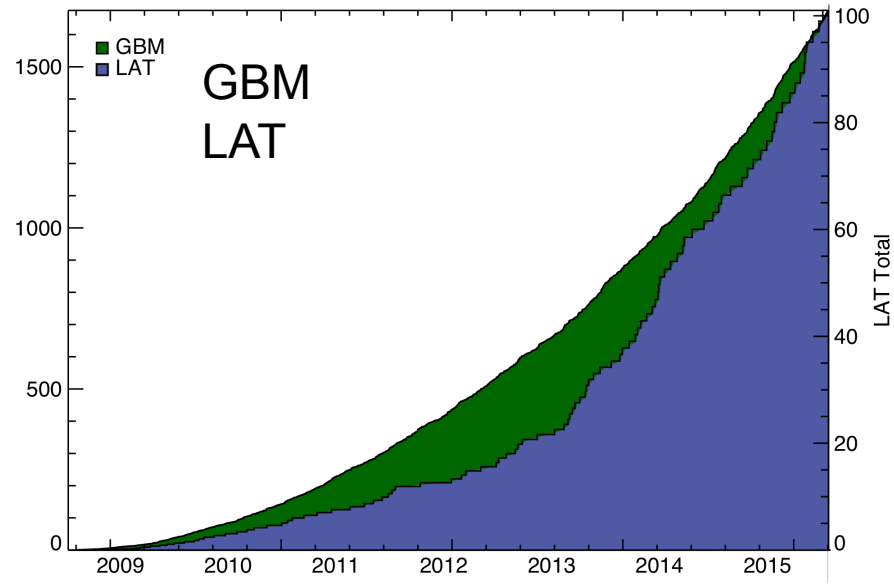


ARR triggered for almost a half of LAT events ➔ helpful for extended emission search

Fermi GRB statistics (up to Aug. 2015)



Cumulative GRB number

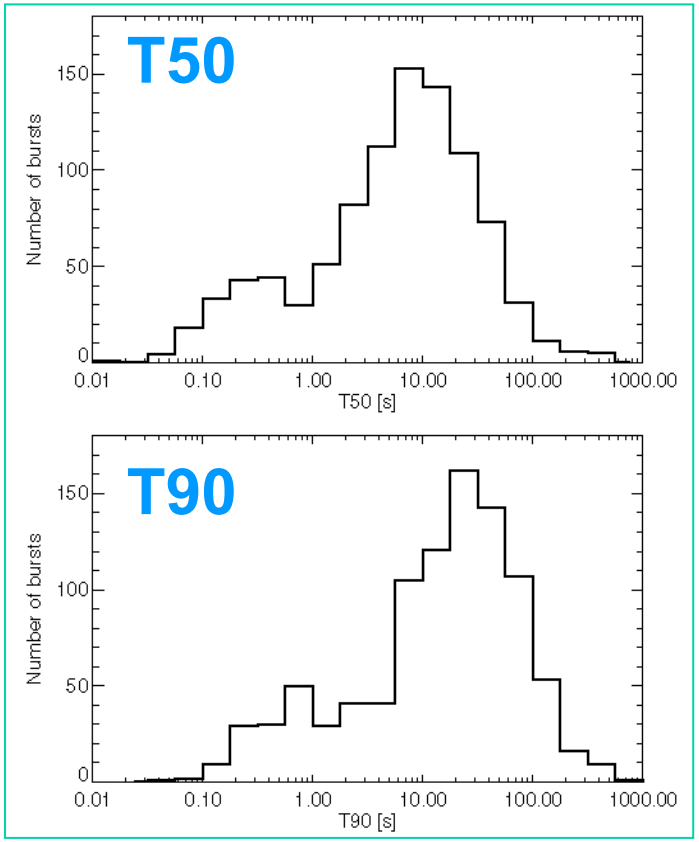


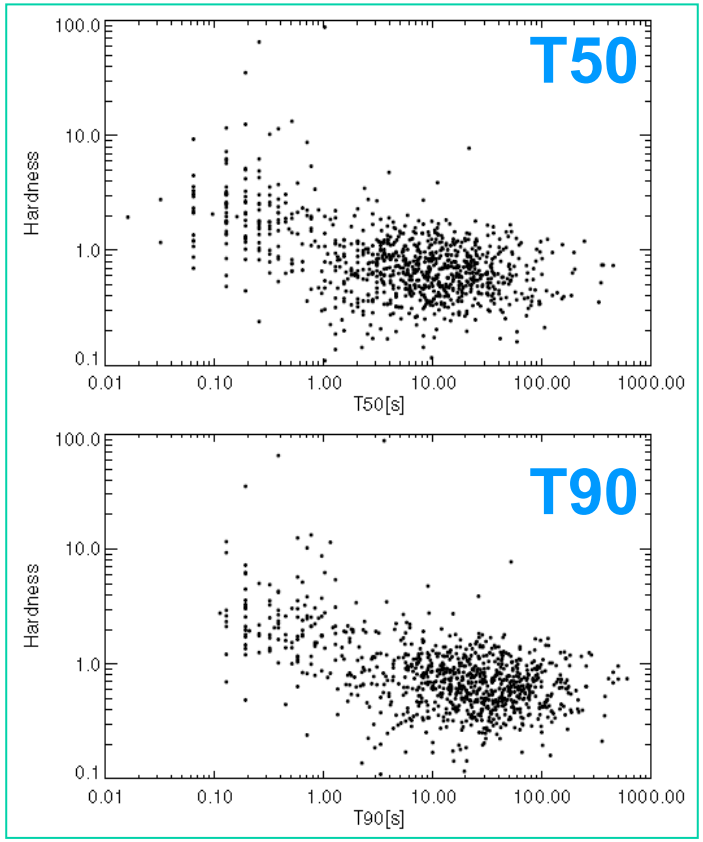
Green: GBM-detected GRBs
Gold : LAT-detected GRBs

- **GBM detections: ~250 GRBs / year (1700) , ~half in the LAT FoV**
- **LAT detections: ~15/year (102), ~8% of GBM detections**

Fermi-GBM highlights 1) duration

The second Fermi-GBM Gamma-ray Burst CATALOG: (von Kielin+14)

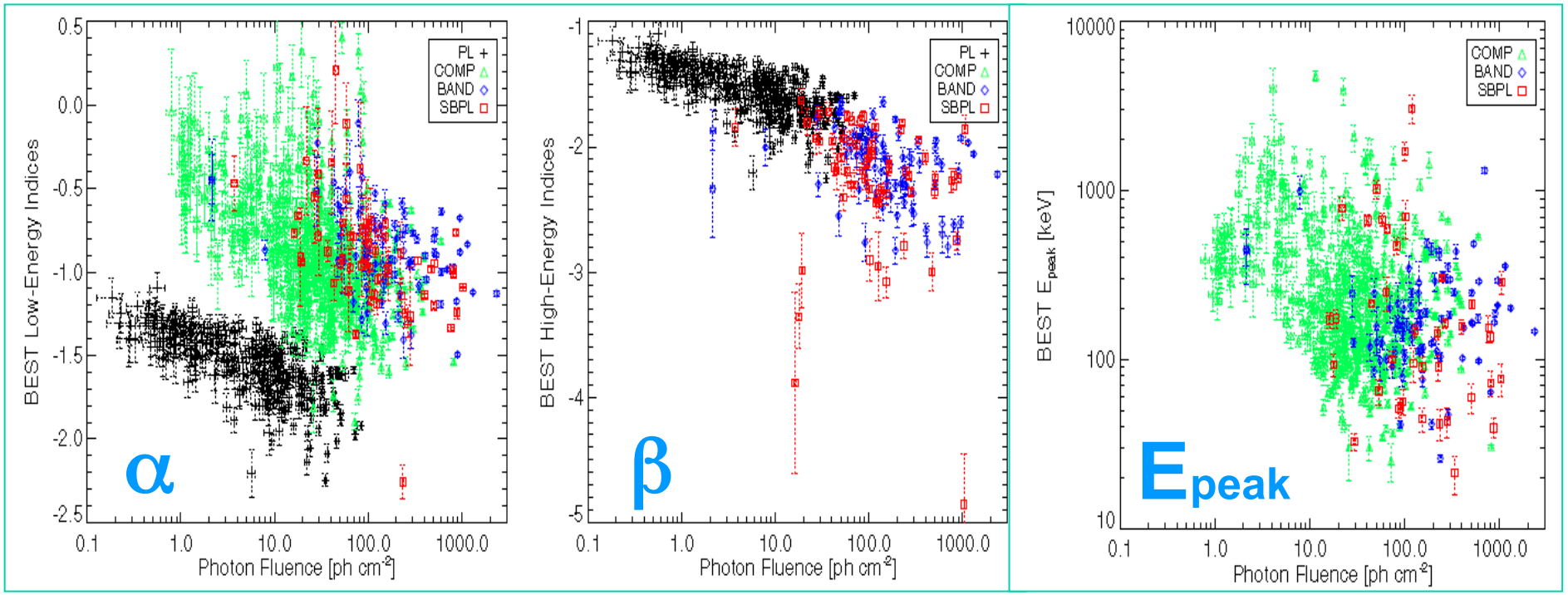




Differences can be seen between long/short GRBs

Fermi-GBM highlights 2) spectra

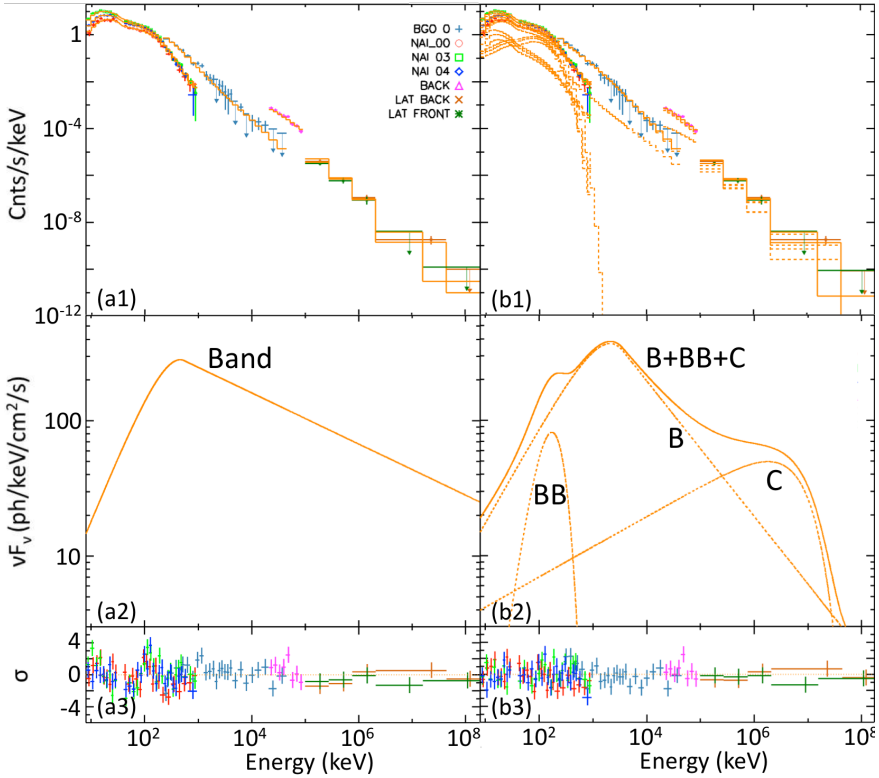
The second Fermi-GBM Gamma-ray Burst SPECTRAL CATALOG (Gruber+14)

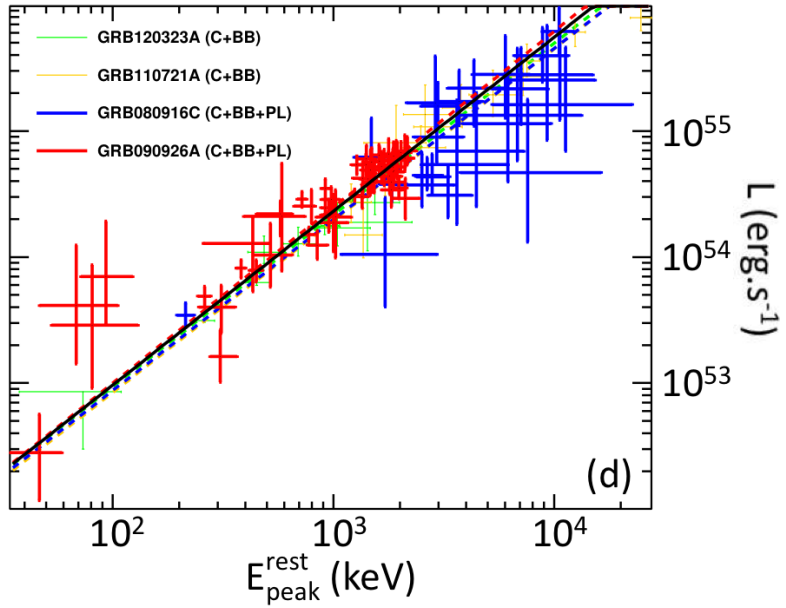


Systematic studies with large sample of Fermi-GBM detected GRBs

Fermi-GBM highlights 3) correlation

Non-thermal component gives an universal (e.g. short/long GRBs) E_{peak}-L_{iso} correlation (Guiriec+ 15)





$$L_i^{\rm NT} = (9.6 \pm 1.1)\,10^{52} \left(\frac{E_{{\rm peak},i}^{\rm rest,NT}}{100\ {\rm keV}} \right)^{1.38\pm0.04} \ {\rm erg\ s^{-1}}.$$

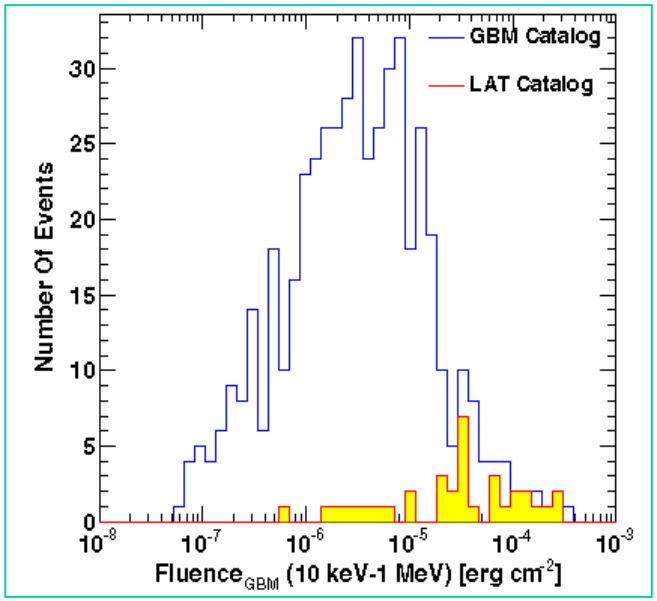
Fermi-LAT Catalog

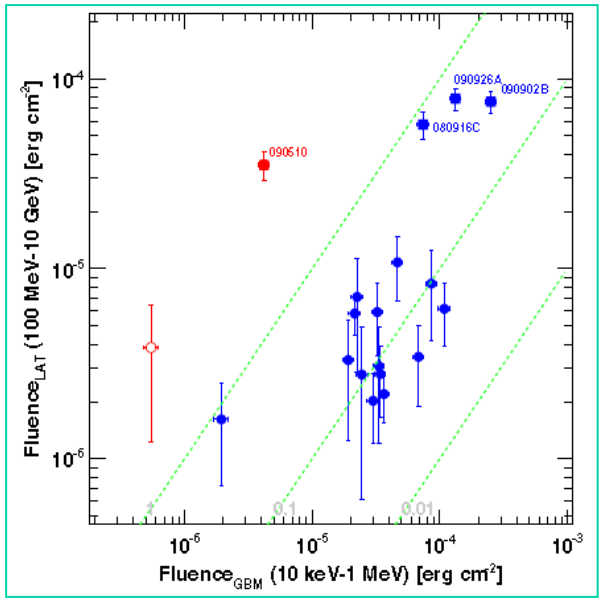
- **The FIRST Fermi-LAT Gamma-ray Burst CATALOG: (Ackermann+13)**
- **35 LAT-detected GRBs are listed and systematically studied.**

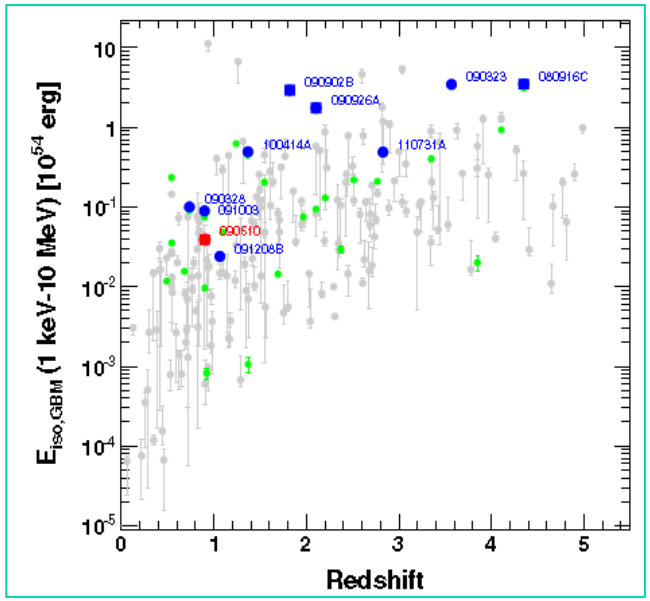
GRB Name	Date	GBM Trigger Time (MET[a])	R.A. Deg., J2000	Decl. Deg., J2000	θ Deg.	Loc. Err.[b]	Like.	LLE	Redshift	LAT GCN Number
080825C	2008 Aug 25 14:13:48.1	241366429.105	233.9	−4.5	60.3	0.°75[y]	1	0	...	8183
080916C	2008 Sep 16 00:12:45.6	243216766.614	119.85	−56.64	48.8	0.°36[*]	1	1	4.35	8246
081006	2008 Oct 6 14:29:34.1	244996175.173	136.32	−62.05	11.0	0.°52[y]	1	0	...	
081024B	2008 Oct 24 21:22:40.8	246576161.864	322.95	21.2	18.7	0.°22[y]	1	1	...	8407
090217	2009 Feb 17 04:56:42.5	256539404.560	204.83	−8.42	34.5	0.°35[y]	1	1	...	8903
090227B	2009 Feb 27 18:31:01.4	257452263.410	10.48	29.24	71.0	1.°00[Δ]	1	1	...	
090323	2009 Mar 23 00:02:42.6	259459364.630	190.71	17.053	57.2	0.′36[*]	1	1	3.57	9021
090328	2009 Mar 28 09:36:46.5	259925808.510	90.67	−41.715	64.6	0.′72[*]	1	1	0.74	9044, 9077
090510	2009 May 10 00:22:59.9	263607781.971	333.55	−26.583	13.6	1.′44[*]	1	1	0.90	9334, 9350
090531B	2009 May 31 18:35:56.4	265487758.490	252.07	−36.015	21.9	2.′10[*]	0	1	...	
090626	2009 Jun 26 04:32:08.8	267683530.880	170.03	−33.49	18.3	0.°22[y]	1	0	...	9584
090720B	2009 Jul 20 17:02:56.9	269802178.905	202.99	−54.21	56.1	0.°33[y]	1	0	...	
090902B	2009 Sep 2 11:05:08.3	273582310.313	264.94	27.324	50.8	3.′60[*]	1	1	1.82	9867, 9872
090926A	2009 Sep 26 04:20:26.9	275631628.990	353.4	−66.32	48.1	0.′60[*]	1	1	2.11	9934, 9972
091003	2009 Oct 3 04:35:45.5	276237347.585	251.52	36.625	12.3	1.′80[*]	1	0	0.90	9985
091031	2009 Oct 31 12:00:28.8	278683230.850	71.49	−57.65	23.9	0.°23[y]	1	1	...	10163
091208B	2009 Dec 8 09:49:57.9	281958599.956	29.392	16.89	55.6	1.′80[*]	1	0	1.06	
100116A	2010 Jan 16 21:31:00.2	285370262.240	305.01	14.43	26.6	0.°17[y]	1	1	...	10333
100225A	2010 Feb 25 02:45:31.1	288758733.147	310.3	−59.4	55.5	3.°13[†]	0	1	...	10450
100325A	2010 Mar 25 06:36:08.0	291191770.020	330.24	−26.45	7.1	0.°60[y]	1	0	...	10548
100414A	2010 Apr 14 02:20:21.9	292904423.990	192.11	8.693	69.0	1.′80[*]	1	0	1.37	10594
100620A	2010 Jun 20 02:51:29.1	298695091.100	86.9	−50.91	24.3	0.°71[y]	1	0	...	
100724B	2010 Jul 24 00:42:05.9	301624927.980	119.89	76.55	48.9	0.°88[y]	1	1	...	10978
100728A	2010 Jul 28 02:17:30.6	301976252.610	88.758	−15.255	59.9	0.′36[*]	1	0	...	
100826A	2010 Aug 26 22:58:22.8	304556304.898	279.593	−22.128	73.3	1.°20[Δ]	0	1	...	11155
101014A	2010 Oct 14 04:11:52.6	308722314.620	27.206	−50.819	54.0	1.°0[†]	0	1	...	11349
101123A	2010 Nov 23 22:51:34.9	312245496.973	135.16	1.91	78.2	3.°16[†]	0	1	...	
110120A	2011 Jan 20 15:59:39.2	317231981.230	61.5	−12.0	13.6	0.°36[y]	1	0	...	11597
110328B	2011 Mar 28 12:29:19.1	323008161.194	121.06	45.84	31.7	3.°23[†]	0	1	...	11835
110428A	2011 Apr 28 09:18:30.4	325675112.410	5.59	64.849	34.6	0.′04[*]	1	0	...	11982
110529A	2011 May 29 00:48:42.8	328322924.872	118.33	67.91	30.0	3.°35[†]	0	1	...	12044
110625A	2011 Jun 25 21:08:18.2	330728900.236	286.73	6.755	87.9	0.′36[*]	1	0	...	12097, 12100
110709A	2011 Jul 9 15:24:27.4	331917869.400	238.895	40.918	53.4	1.′08[*]	1	0	...	
110721A	2011 Jul 21 04:47:43.7	333291665.760	333.2	−38.5	40.7	0.°20[Δ]	1	1	...	12188
110731A	2011 Jul 31 11:09:29.9	333803371.954	280.504	−28.537	3.4	0.′36[*]	1	1	2.83	12218

Fermi-LAT highlights 1) energetics

- **The FIRST Fermi-LAT Gamma-ray Burst CATALOG: (Ackermann+13)**
- **35 LAT-detected GRBs are listed and systematically studied**





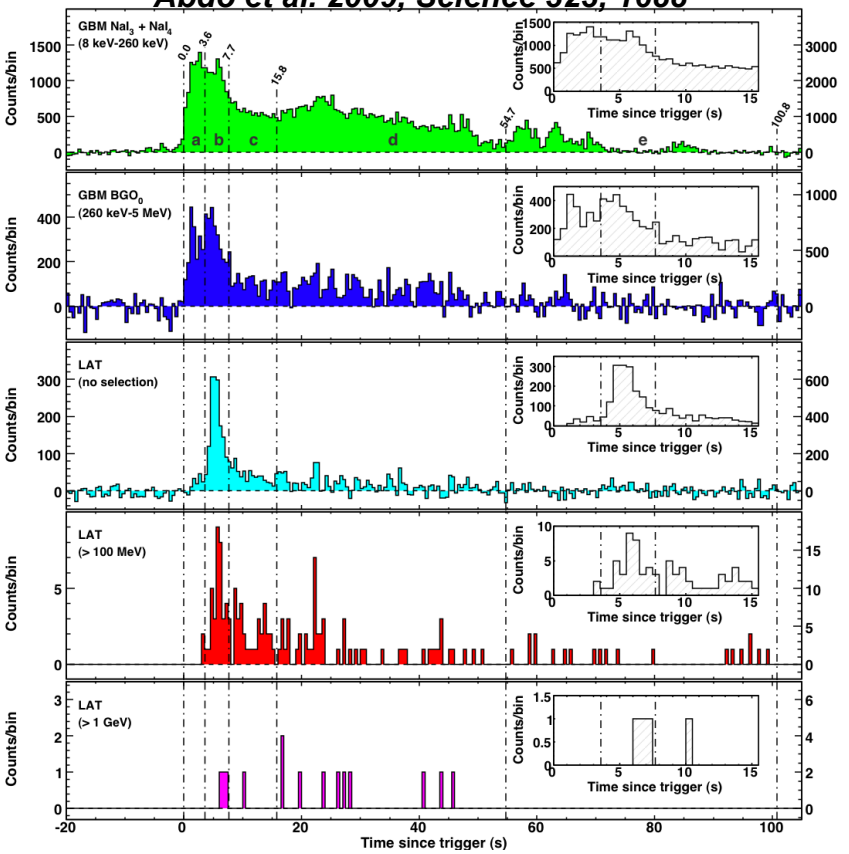


LAT-detected GRBs are typically brightest GBM bursts

Fermi-LAT highlights 2) delayed onset and extended emission

GRB 080916C (long)

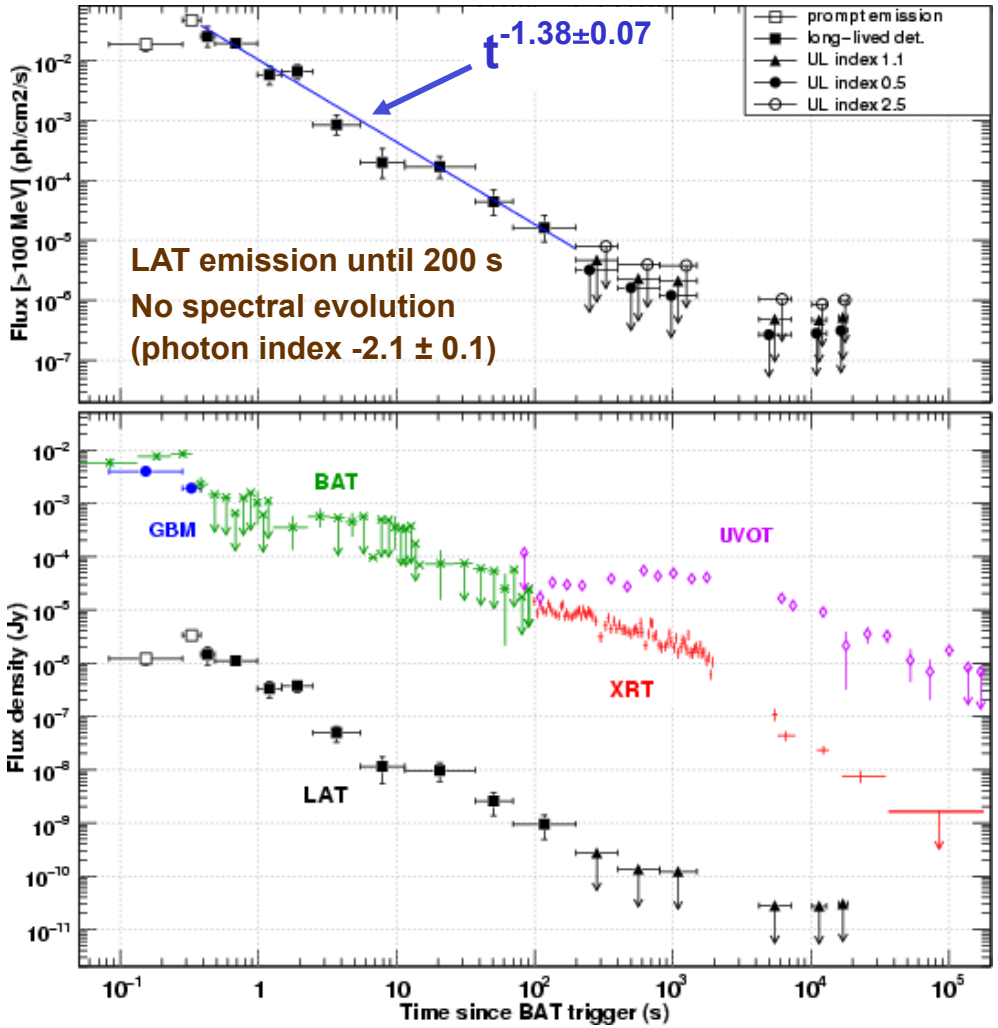
Abdo et al. 2009, Science 323, 1688



Delay in HE onset: ~4-5 s

GRB 090510 (short)

De Pasquale et al., ApJL 709, 146 (2010)



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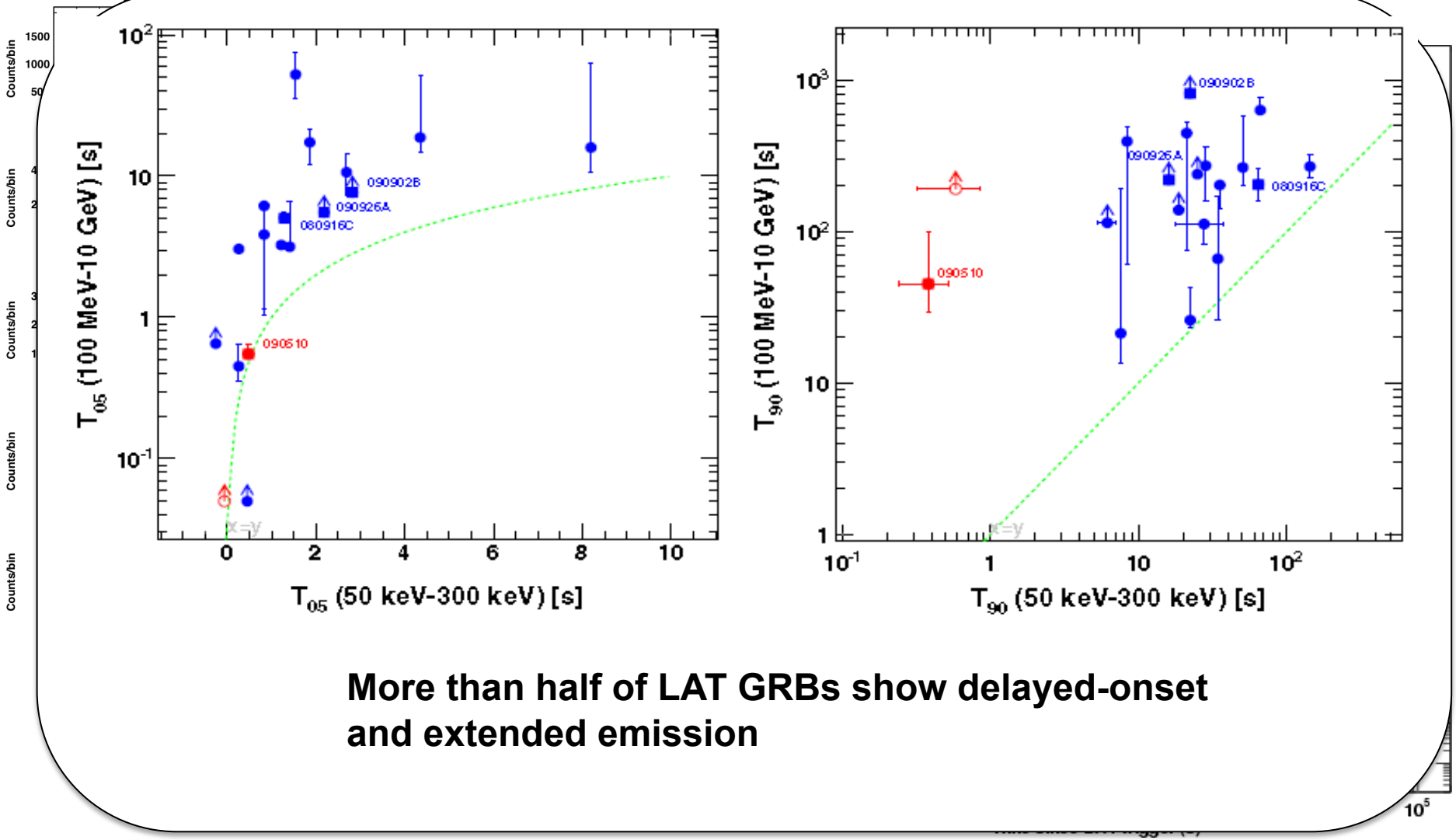


More than half of LAT GRBs show delayed-onset and extended emission

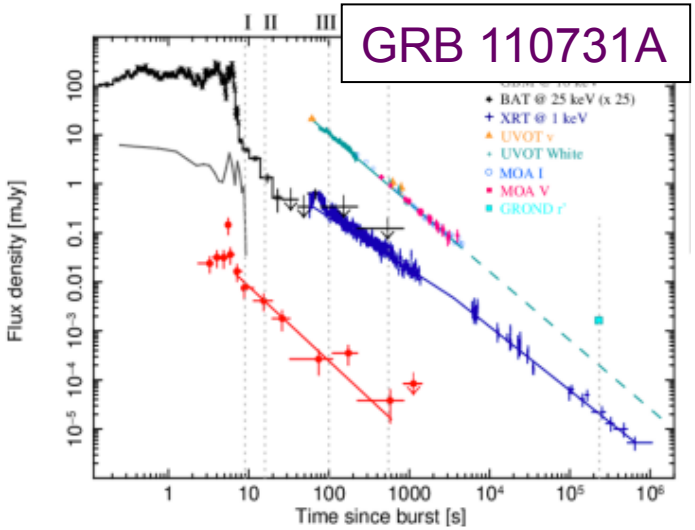
Origin of high-energy emission of LAT

Delayed and extended high-energy emission disfavors IC and SSC origin
But external shock origin is more likely (Kumar & Barniol Duran 2009)

GRB 110731A

Swift-XRT and many optical observations (Swift-UVOT, GROND, and MOA) are available

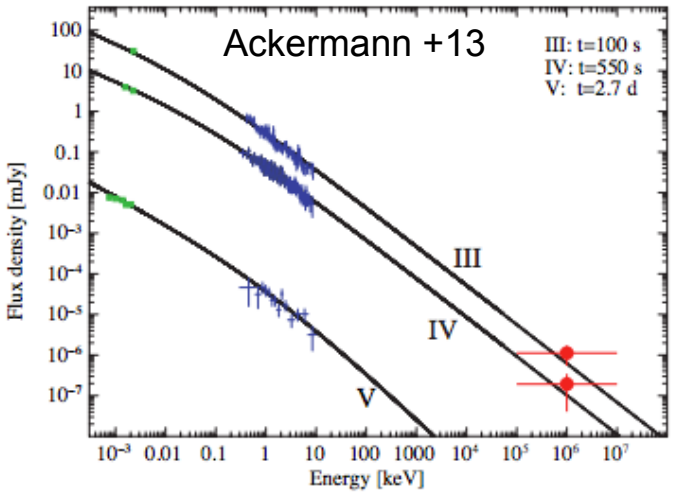
Broadband spectrum is well fit by a single power-law spanning 10 orders of magnitude in energy



GRB 130427A

Broadband spectrum is well fit by a broken power-law , still consistent with FS synchrotron emission (Granot & Sari 02, Perley +13)

95 GeV photon at T0+244s is problematic for modeling



Origin of high-energy emission of LAT

Delayed and extended high-energy emission disfavors IC and SSC origin
But external shock origin is more likely (Kumar & Barniol Duran 2009)

95 GeV photon
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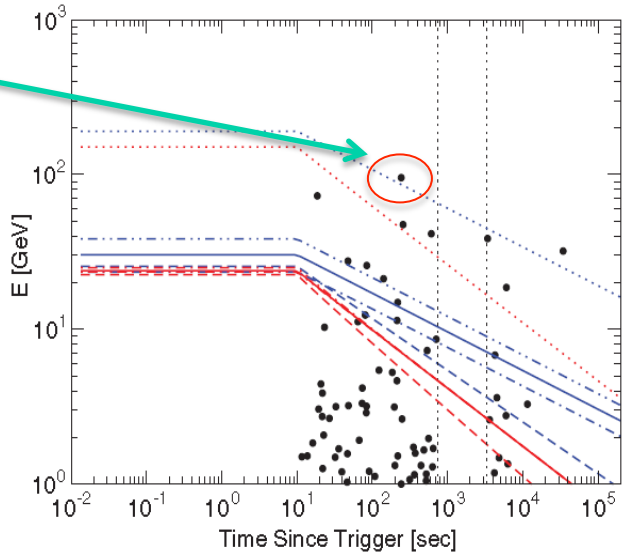
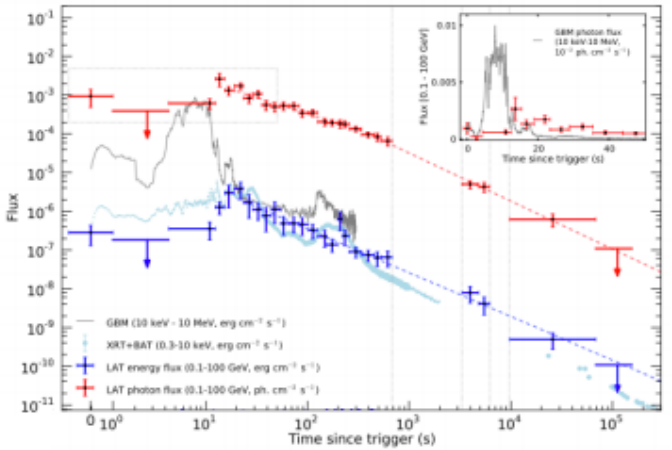


Ackermann +14

GRB 130427A



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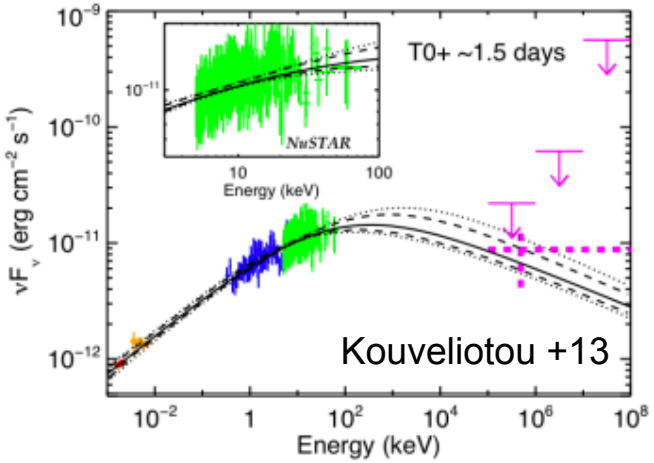
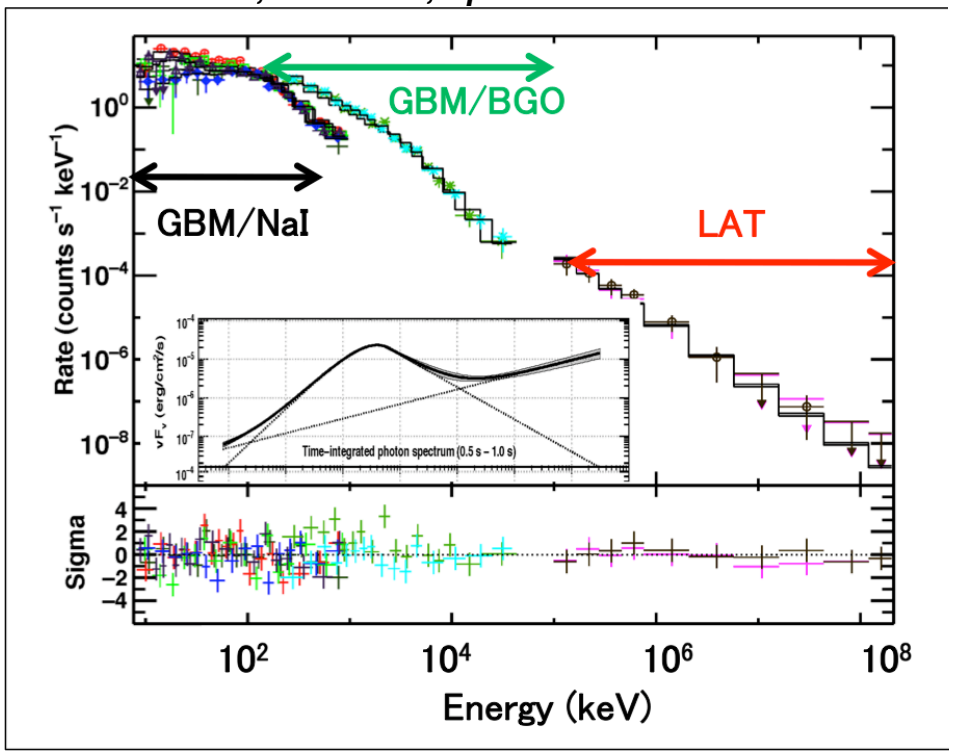


Fermi-LAT highlights 3) additional spectral component

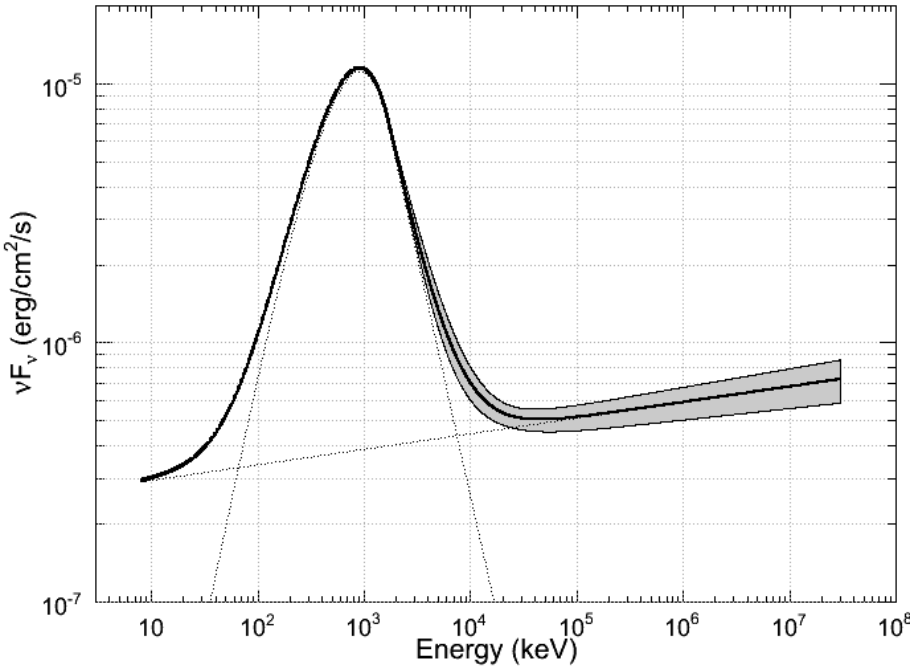
GRB 090510 (short)

Abdo, A. A. et al., ApJ submitted



GRB 090902B (long)

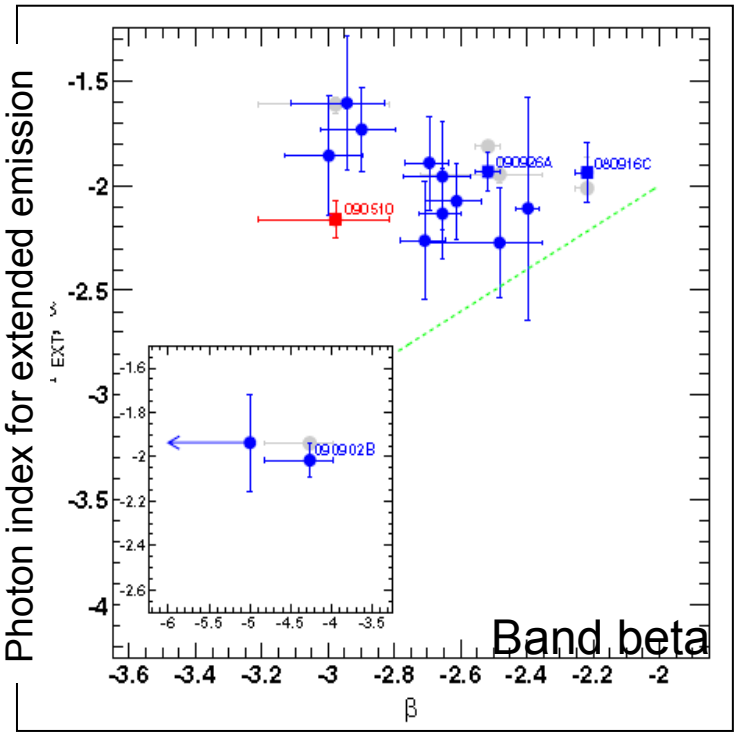
Abdo, A. A. et al., ApJL 706, 138 (2009)



Some bright LAT GRBs show deviations from typical Band function In high energy band

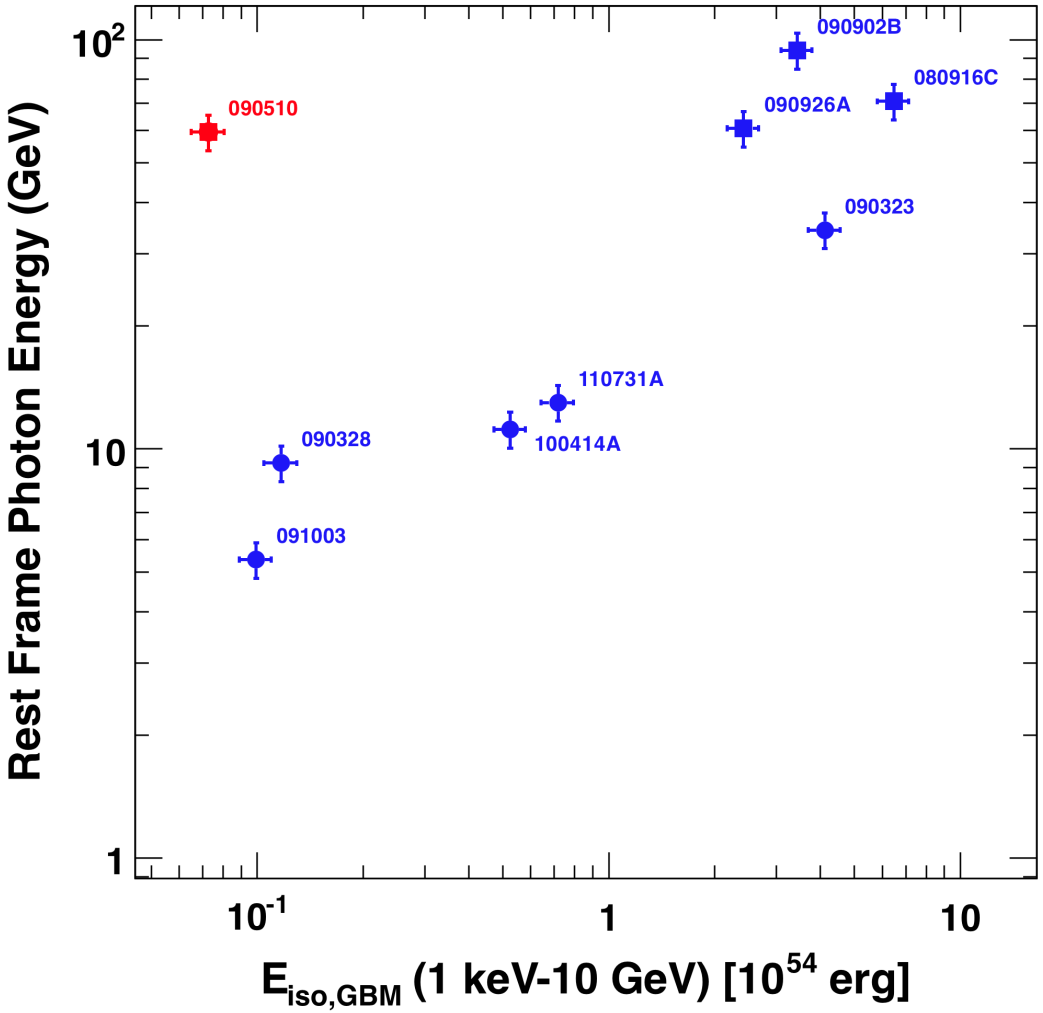
Fermi-LAT catalog –the Band crisis?

GRB Name	Fluence 10 keV–10 GeV (10^{-7} erg cm^{-2})	Best Model	θ (deg)
100724B	4665^{-76}_{+78}	Band with exponential cutoff	48.9
090902B	4058^{-24}_{+25}	Comptonized + power law	50.8
090926A	2225^{-48}_{+50}	Band + power law with exponential cutoff	48.1
080916C	1795^{-39}_{+41}	Band + power law	48.8
090323	1528^{-44}_{+44}	Band	57.2
100728A	1293^{-27}_{+28}	Comptonized	59.9
100414A	1098^{-27}_{+35}	Comptonized + power law	69.0
090626	927^{-16}_{+17}	Logarithmic parabola	18.3
110721A	876^{-28}_{+28}	Logarithmic parabola	40.3
090328	817^{-33}_{+34}	Band	64.6
100116A	638^{-25}_{+26}	Band	26.6
110709A	518^{-27}_{+28}	Band	53.4
080825C	517^{-20}_{+21}	Band	60.3
090217	512^{-15}_{+16}	Band	34.5
091003	461^{-14}_{+15}	Band	21.3
110120A	422^{-22}_{+23}	Band	13.6
110328B	417^{-37}_{+47}	Comptonized	31.7
110731A	379^{-21}_{+20}	Band + power law	3.4
090510	360^{-16}_{+18}	Band + power law	13.6
091031	288^{-10}_{+10}	Band	23.9
110428A	255^{-9}_{+10}	Band	
090720B	185^{-11}_{+13}	Band	
100225A	101^{-7}_{+7}	Band	
091208B	93^{-11}_{+13}	Band	
100620A	84^{-9}_{+9}	Band	
081006	56^{-9}_{+10}	Band	
110529A	49^{-6}_{+6}	Band	
100325A	46^{-4}_{+4}	Band	
090531B	38^{-5}_{+5}	Comptonized	
081024B	30^{-5}_{+6}	Band	



- **Some bright LAT GRBs show deviations from typical Band function in high energy band**
- **LAT high-energy photon is dominated by single PL component of extended emission phase**

Fermi-LAT highlights
4) highest energy photon



Several-tens-of-GeV photons In GRB frame

Possible correlation between E_{iso} and highest photon energy

Short GRB is outlier ? Need more sample !

Highest photon energy is useful for
-Limit on bulk Lorentz factor
-Constraint on synchrotron model
-EBL model
-Lorentz invariance violation (LIV)

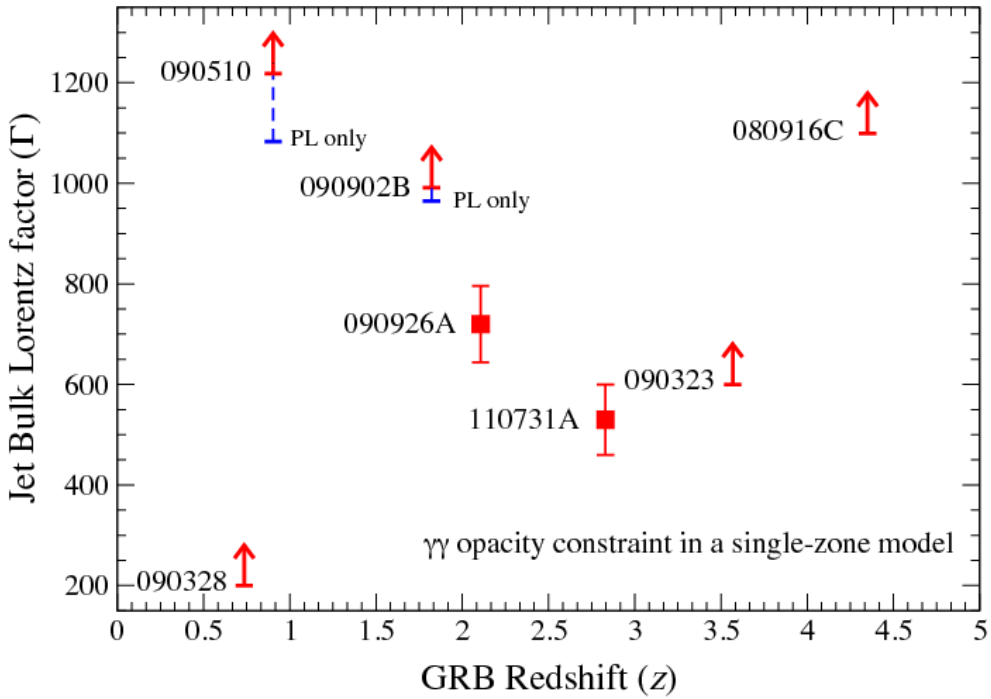
Fermi-LAT highlights
4) highest energy photon

Due to large luminosity and small emitting region, optical depth for the γ-γ -> e+e- pair production is too large to observe the non-thermal emission from GRB → compactness problem.

Relativistic motion (Γ>>1) could avoid this compactness problem

Γ_{min} can be derived using observed highest energy photon

Gehrels et al. arXiv1301.0840



Fermi-LAT highlights
4) highest energy photon

- **In the context of the early afterglow model, the delayed LAT onset is due to the transition between the coasting fireball and the self similar phase (Blandford & McKee 1976, Rees & Meszaros 1994)**
- **Peak-flux time of the LAT is of the order of the fireball deceleration time**

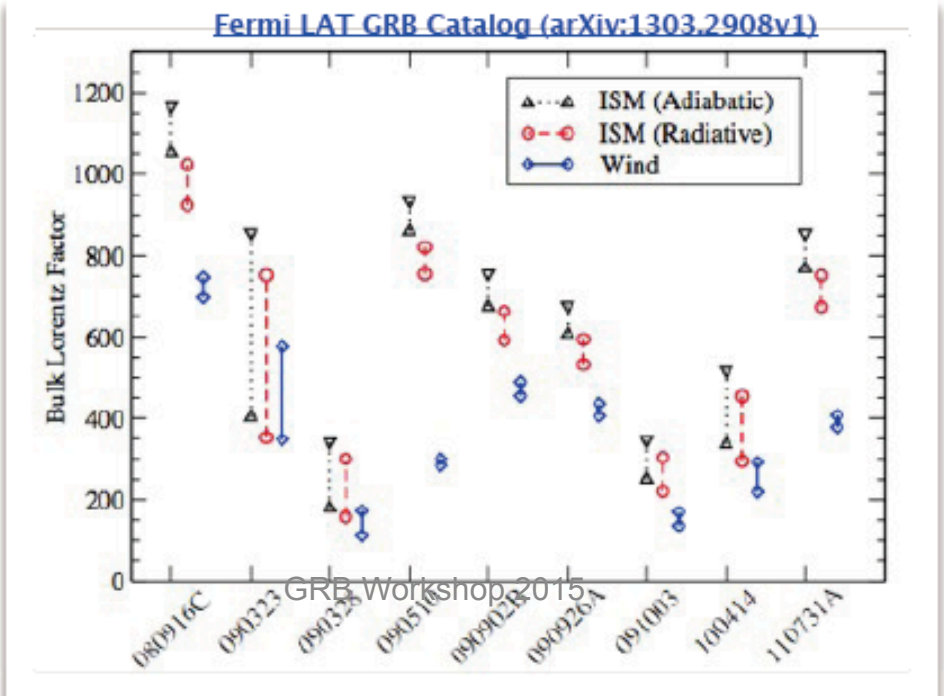
ISM [Blandford & McKee 1976; Sari et al. 1998; Ghisellini et al. 2010)]

$$\Gamma_0 = \left[\frac{3E_{k,\rm iso}(1+z)^3}{32\pi n m_p c^5 t_{\rm peak}^3}\right]^{1/8} \times \begin{cases} a^{-1/8}; & a = 4 \quad (adiabatic) \\ a^{-5/32}; & a = 7 \quad (radiative), \end{cases}$$

Wind environment [10^{-5} M⊙ yr^{-1} mass-loss rate, 10^3 km s^{-1} [Chevalier & Li 2000; Panaitescu & Kumar 2000]

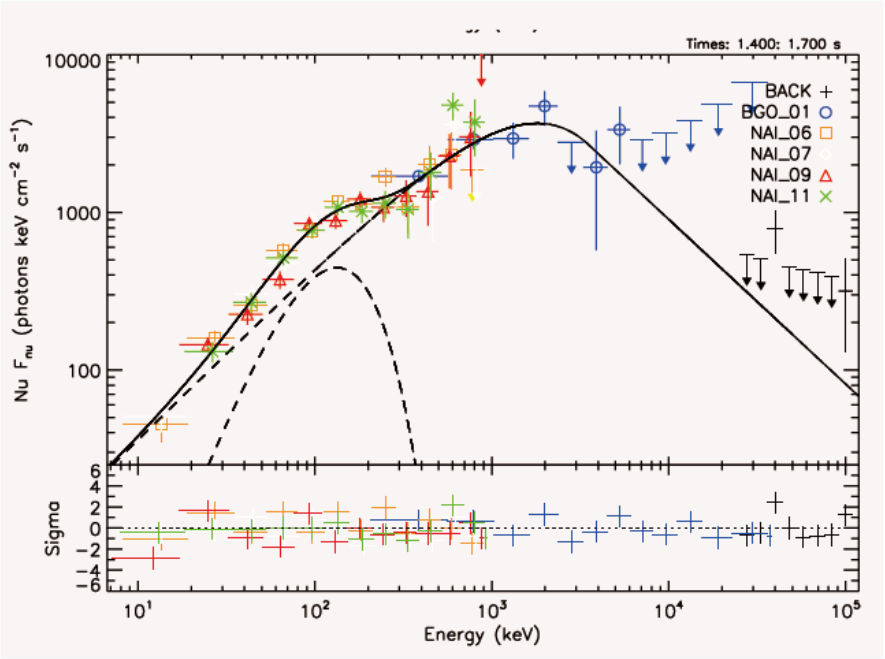
$$\Gamma_0 = \left[\frac{E_{k,\rm iso}(1+z)}{16\pi A m_p c^3 t_{\rm dec}}\right]^{1/4}$$

Similar result to γ-γ opacity limit

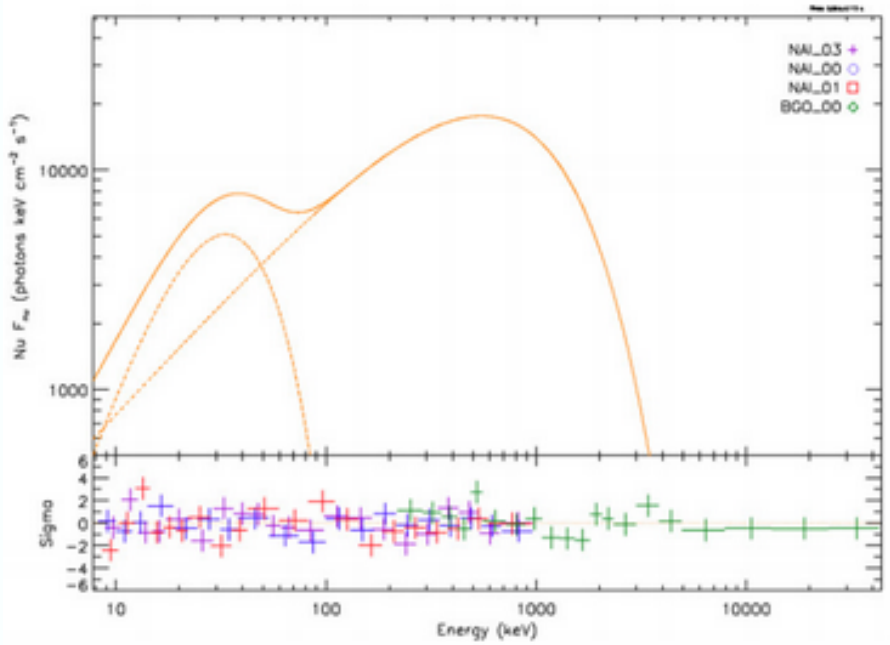


photospheric emission ?

GRB110721A Axelsson et al. (2012)



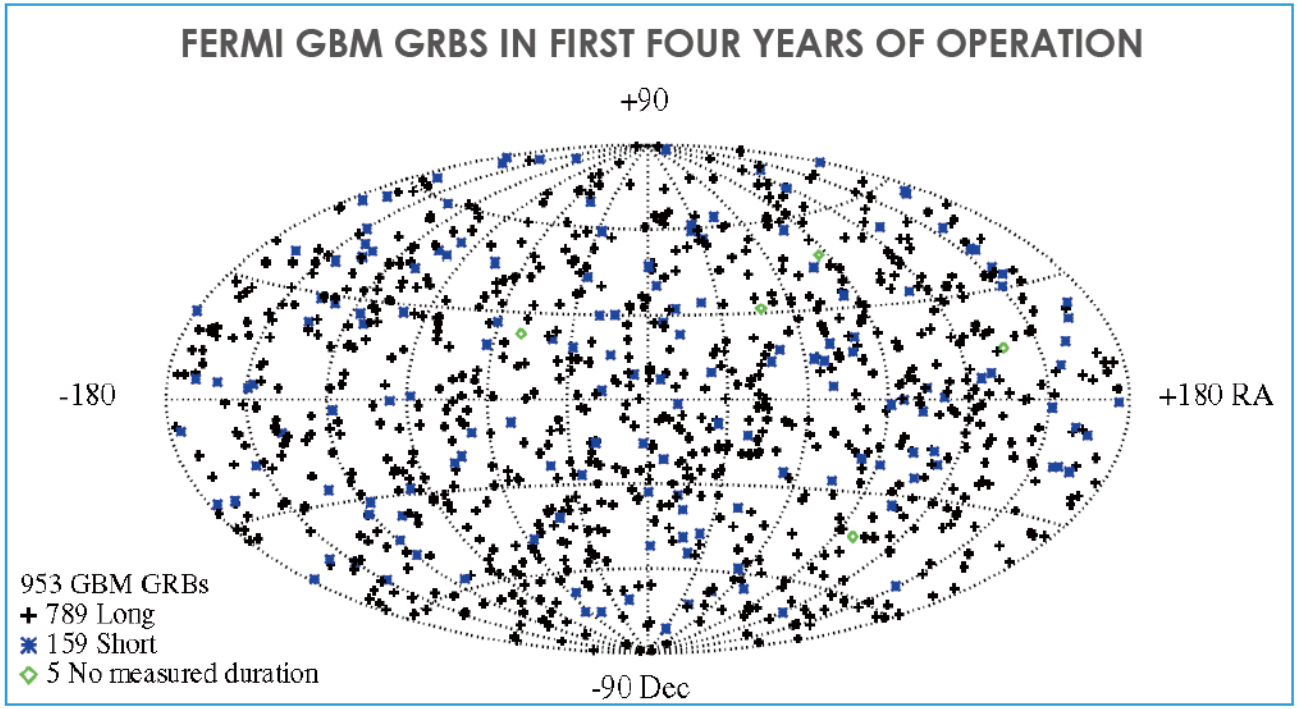
GRB120323A **Guiriec+13**



- **Several GRBs also show the evidence of an extra component at low energy (>3σ for GRB120323A, >5σ for GRB110721A)**
- **Signature of photospheric emission ?**
- **Artifact due to spectral evolution of single spectrum ? (Burgess & Ryde 2015)**
- **Further emission mechanism in addition to the BB is required ? (Burgess, Ryde & Yu 2015)**

The future of Fermi GRB observations

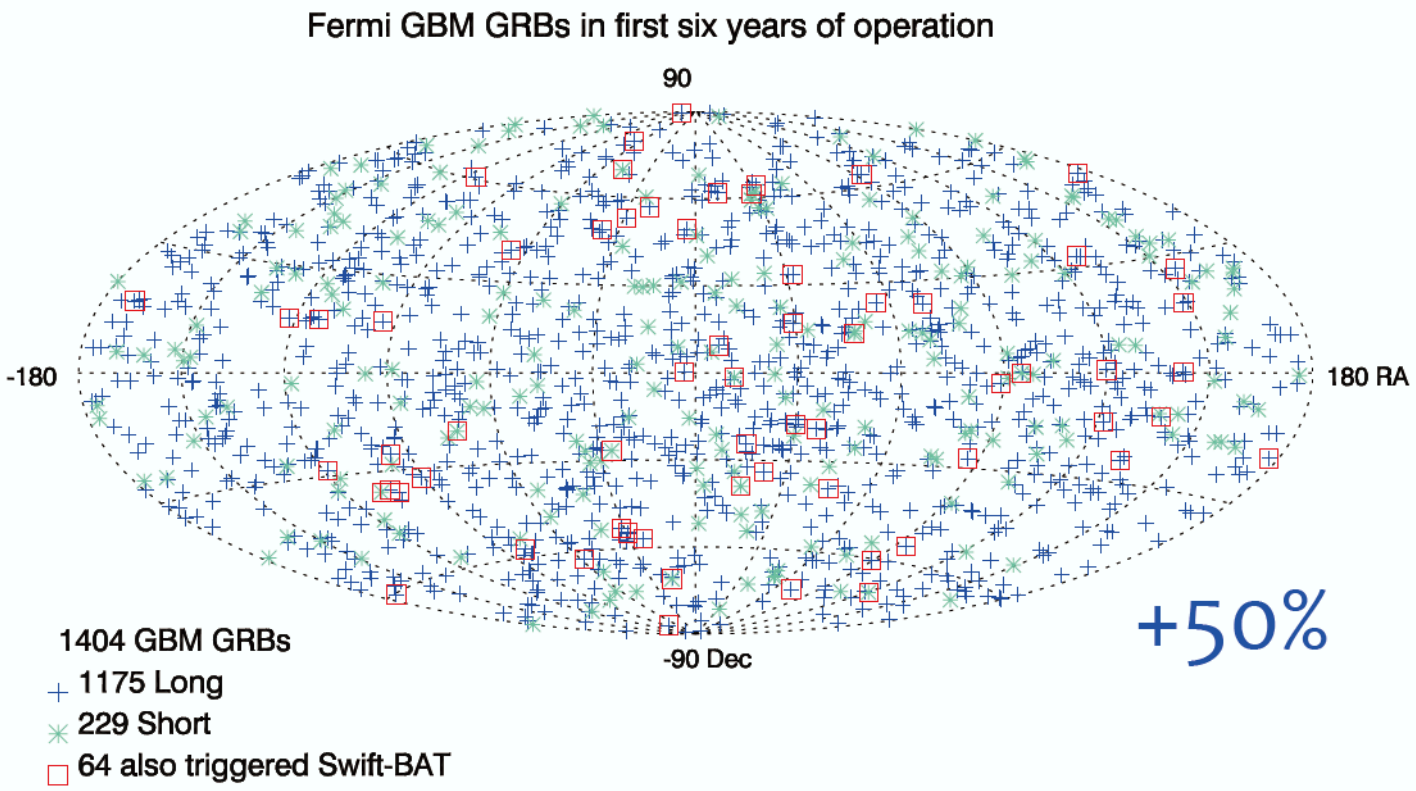
Towards to the Fermi-GBM 3rd Catalog



Will be completed within a few months.

The future of Fermi GRB observations

Towards to the Fermi-GBM 3rd Catalog



Will be completed within a few months.

The future of Fermi GRB observations

Towards to the Fermi-LAT 2nd Catalog

Pass8 **: A new low-level analysis and event reconstruction was developed during the past years. Data are available since June 24th**

- **improved effective area (100 % improvement below 100 MeV, 25% above 1GeV)**
- **better PSF and localization accuracy**
- **better background rejection**
- **reduction in systematic effect**

Fermi-LAT 2nd Catalog will contain more than 100 LAT-detected GRBs
(We have already >100 LAT bursts ! : Vianello & Omodei arXiv:1502.03122)

http://fermi.gsfc.nasa.gov/ssc/observations/types/grbs/lat_grbs/table.php

Fermi LAT GRBs

Important Table Information:

All analysis results presented here are preliminary and are not intended as an official catalog of Fermi-LAT detected GRBs. Please consult the table's caveat page for analysis details and other important informatic

Fermi SSC Home » LAT GRBs

GRB	GCN Name	MET	Date (UTC)	Time (UT)	RA (Degrees)	Dec (Degrees)	Error (Degrees)	Source	Theta (Degrees)	Zenith (Degrees)	LLE Detection	Likelihood Detection	LLE Significance	Likelihood TS
150724782	150724B	459456340.71	2015-07-24	18:45:36.71	351.92	3.67	0.3	Fermi-GBM	58.462	68.550	NO	YES	2.27	25.44
150702998	150702A	457574201.55	2015-07-02	23:56:37.55	52.78	-57.0	0.36	Fermi-LAT	117.60	88.222	NO	YES	--	31
150627183	150627A	457071806.0	2015-06-27	04:23:23	117.4706	-51.4900	9.72e-4	Fermi-GBM	74.373	97.351	YES	YES	8.48	174.67
150523396	150523A	454066191.08	2015-05-23	09:29:48.08	115.2859	-45.4209	0.001	Swift-XRT	25.741	55.489	YES	YES	6.78	207.83
150514774	150514A	453321308.35	2015-05-14	18:35:05.35	74.8750	-60.9691	1.1E-3	Swift-XRT	38.488	58.304	NO	YES	3.31	33.93
150513855	150513A	453241882.73	2015-05-13	20:31:19.73	49.044	-22.868	0.0167	Swift-BAT	50.679	11.149	YES	YES	4.72	29.83

Conclusion

- Fermi satellite is now observing GRBs normally
- Fermi-GBM detects more than 1000 GRBs
  - many statistical properties of GRBs have been studied
- Fermi-LAT detects more than 100 GRBs
- Discussed statistical properties of LAT GRBs in catalog paper
  - delayed onset/extended high-energy emission
  - additional spectral component
  - highest energy photons..etc
- Next catalog papers (GBM:3rd/LAT:2nd) is under production
  - large sample number of GBM-detected GRBs
  - >100 LAT-detected GRBs will be contained
  - new analysis result with PASS8 will be summarized