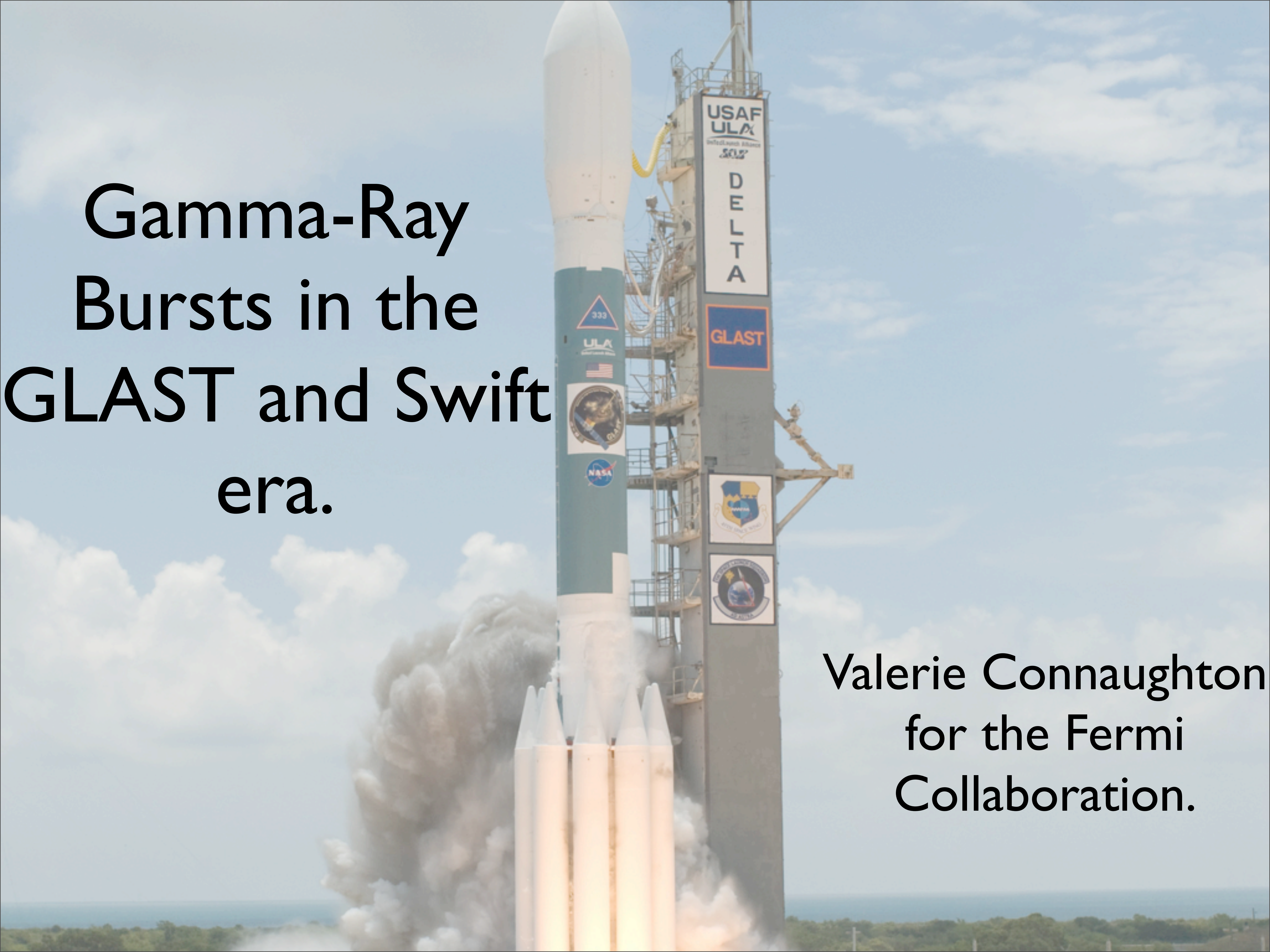
Gamma-Ray Bursts in the GLAST and Swift era.



Valerie Connaughton
for the Fermi
Collaboration.

Eras in GRB Astronomy

DISCOVERY & SPECULATION: 1967 -- 1991

POPULATION STUDIES, ENERGETICS & HEARTACHE: 1991 -- 1997

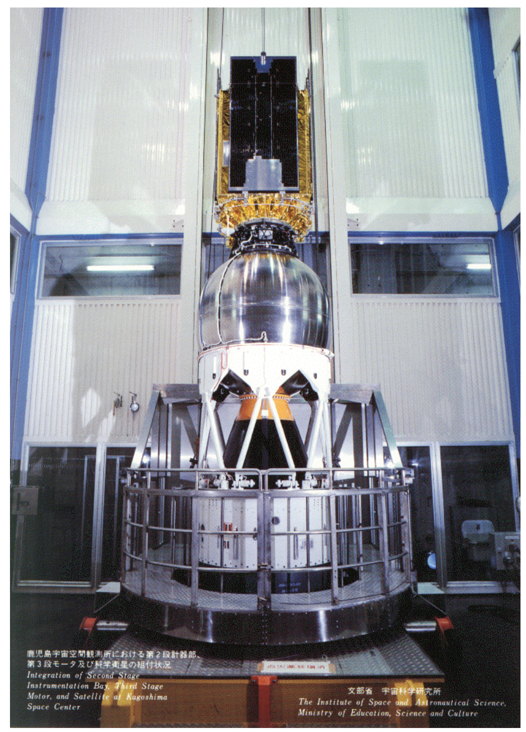
COUNTERPARTS! or THE *REAL* ASTRONOMERS GET INVOLVED... : 1997 -- 2006

GAMMA RAYS REDUX: 2006 -- ??

The Early Days....

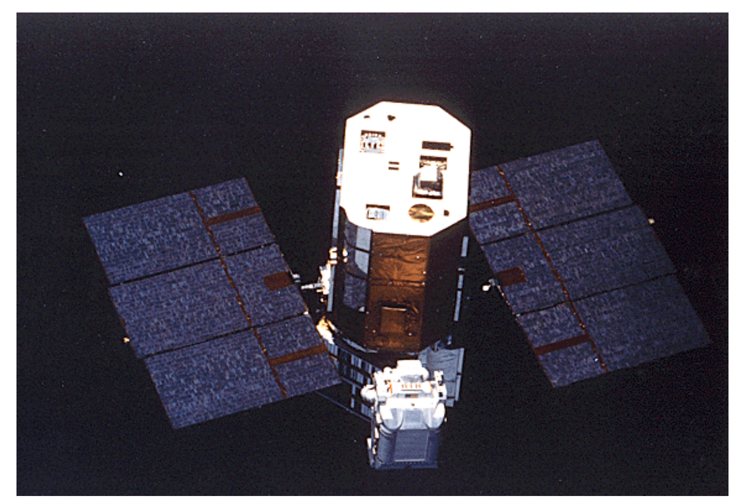
- What are these things? Disruptions on Neutron Stars? Are there lines in their spectra? Can we see anisotropies in their distribution? Can we see the edge of their distribution? Do they repeat?

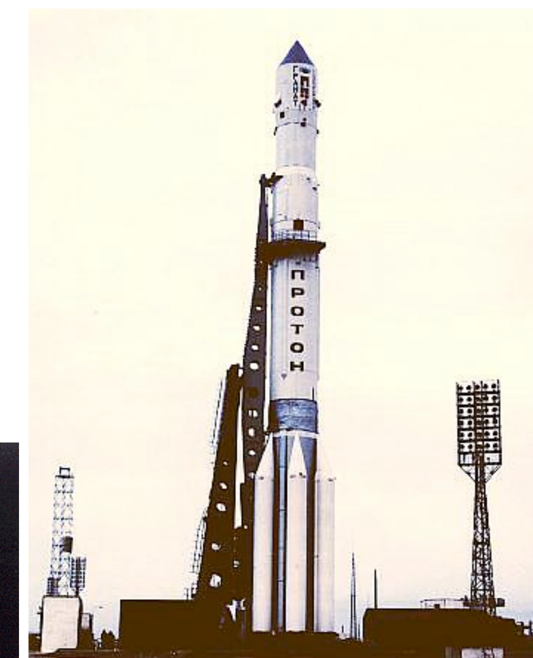
Vela series: discovery.



Ginga: lines?

SMM: High-energy. 75 GRB

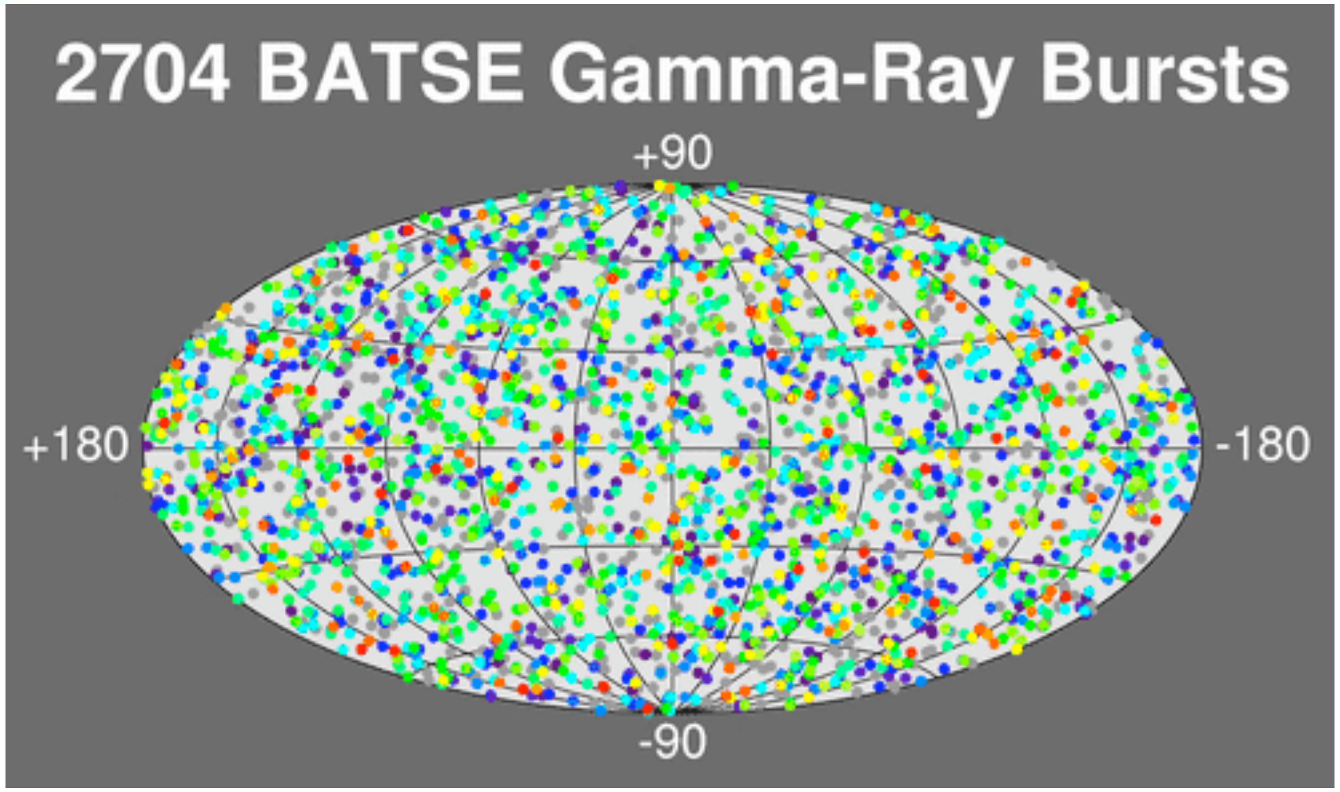




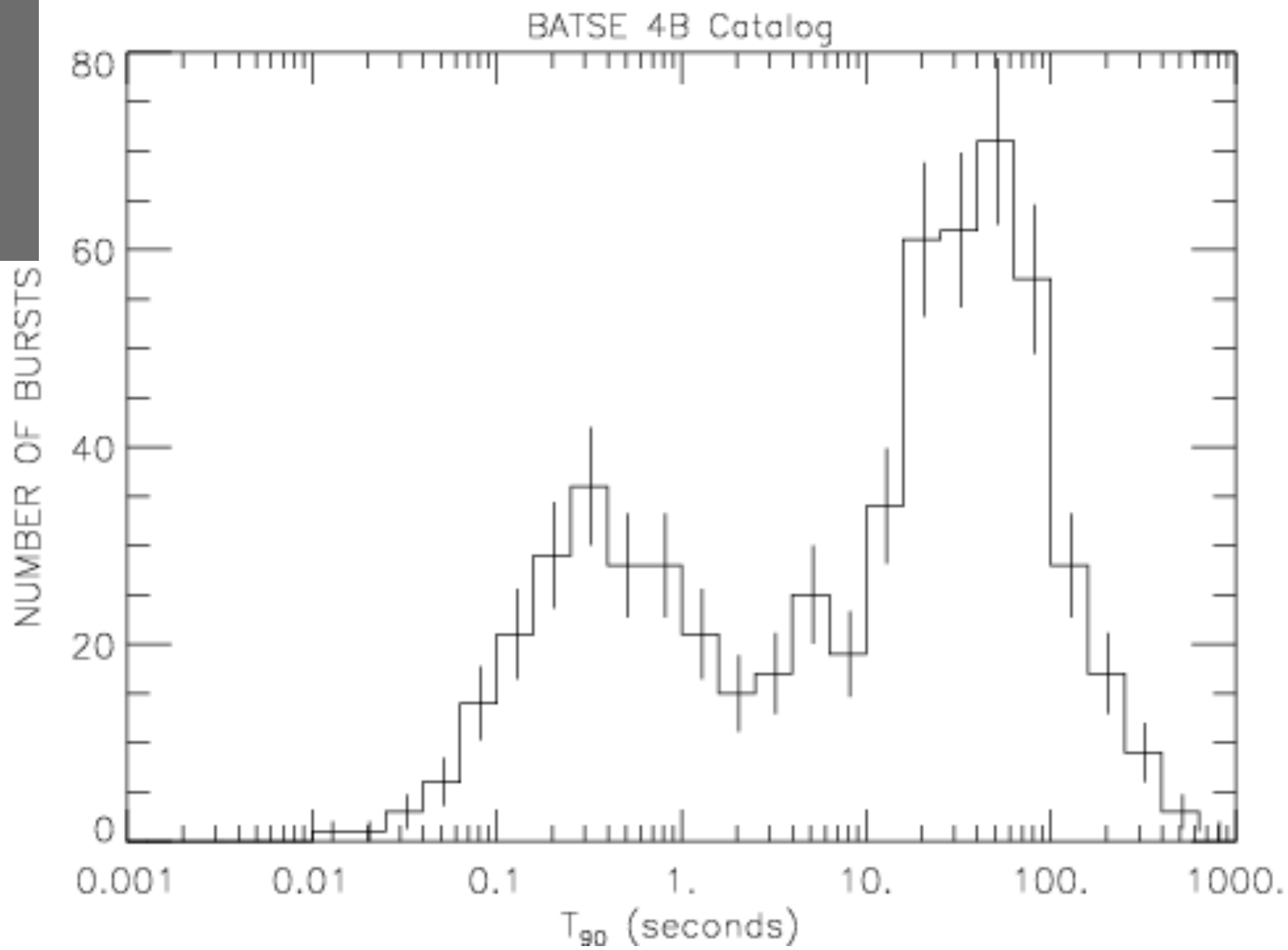
Granat: Phebus. 118 GRB

- Let's launch a huge big mass of all-sky-covering, scintillating material, with localization capabilities to find out!

The BATSE Days



...Not just about isotropy, homogeneity & duration bimodality...

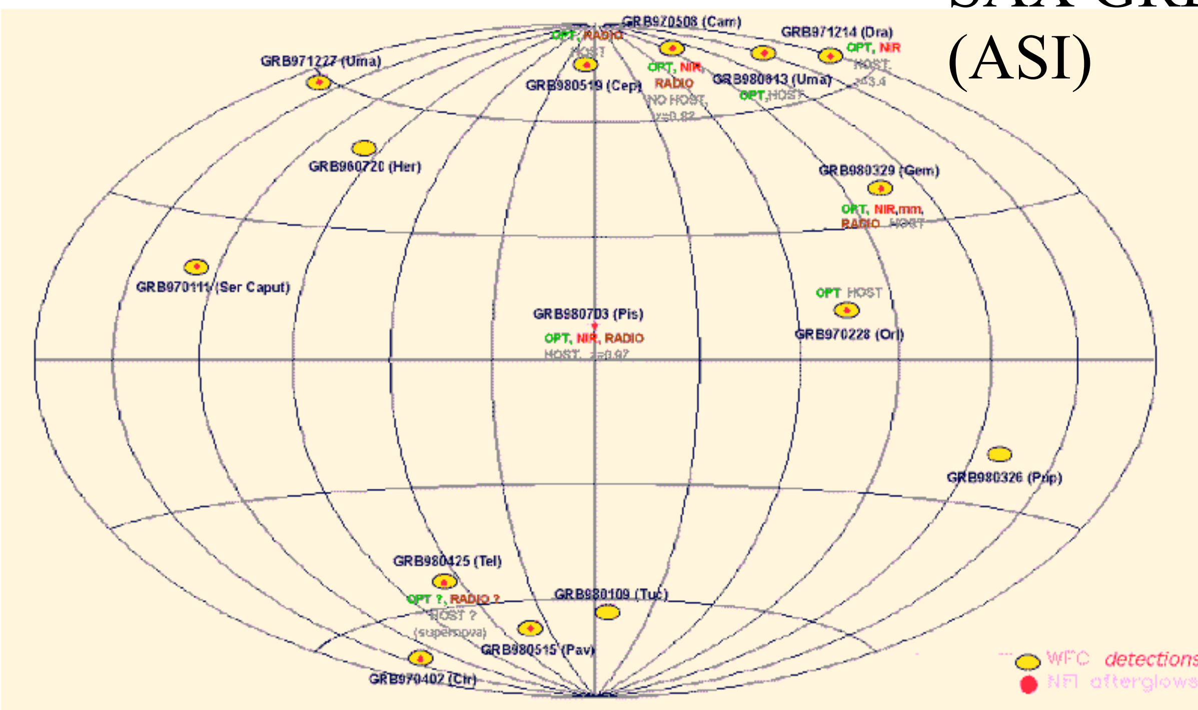


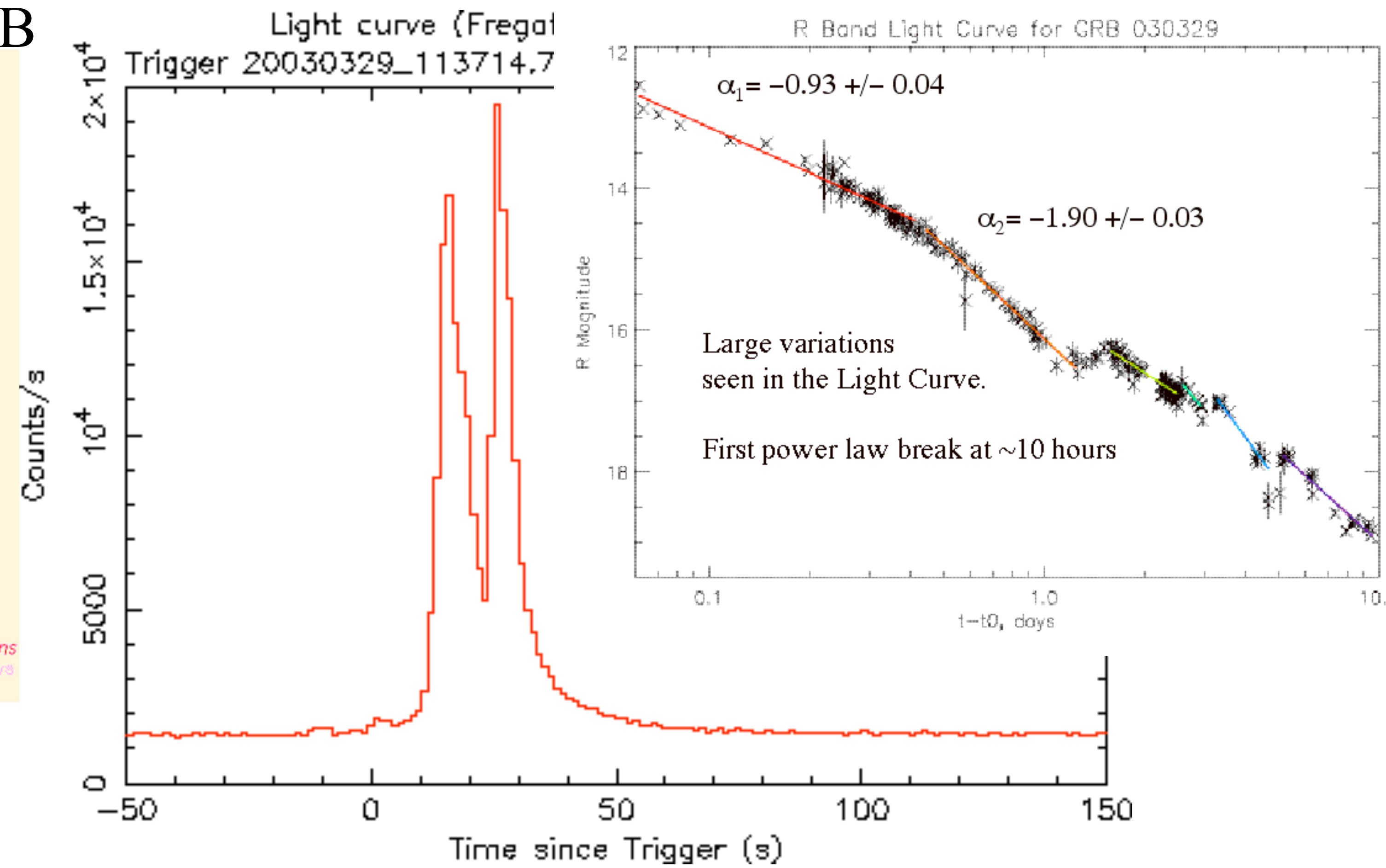
Paciesas et al. BATSE 4B Catalog

... BATSE's most enduring legacy is in the area of GRB spectroscopy...

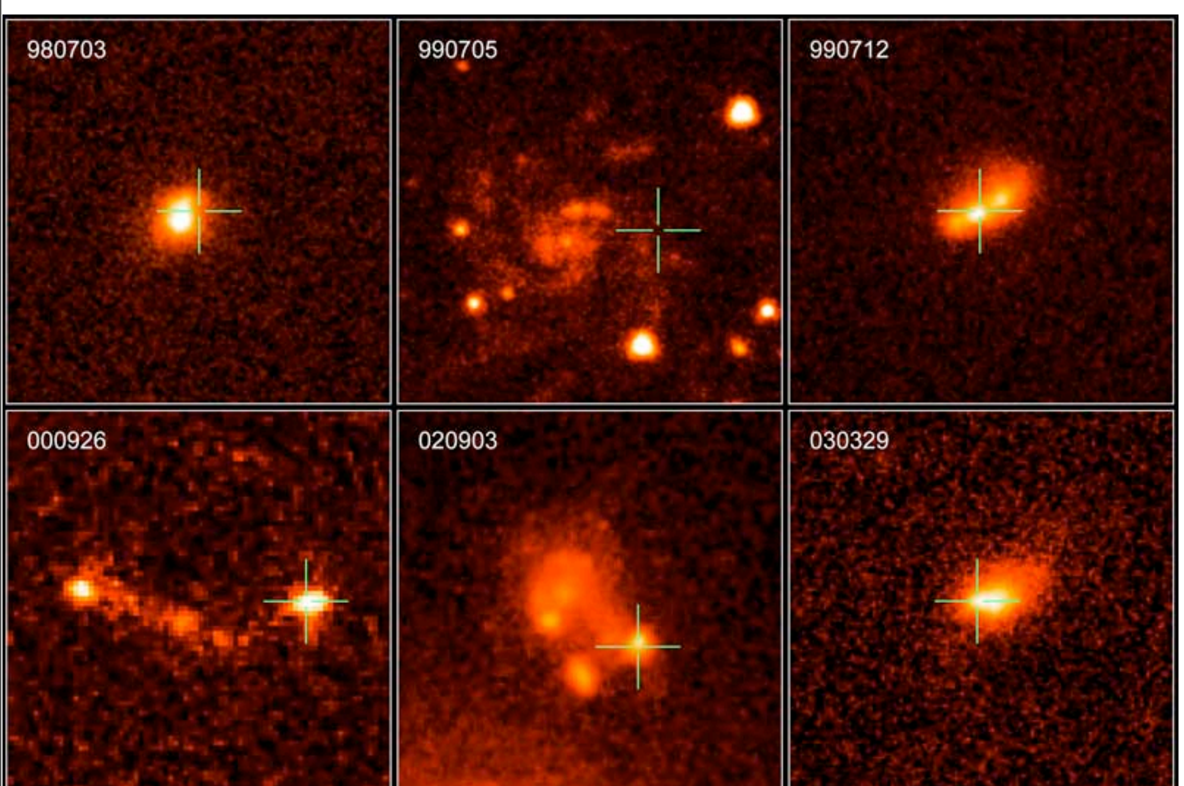
The Real Astronomers

SAX GRB (ASI)





HETE GRB 030329 (Vanderspek et al.) R Band data from GCNs.



APOD 060517 from HST.

BeppoSAX, HETE-2, Swift + multitude of optical, IR, radio observers.

Conclusions from the early Counterpart era

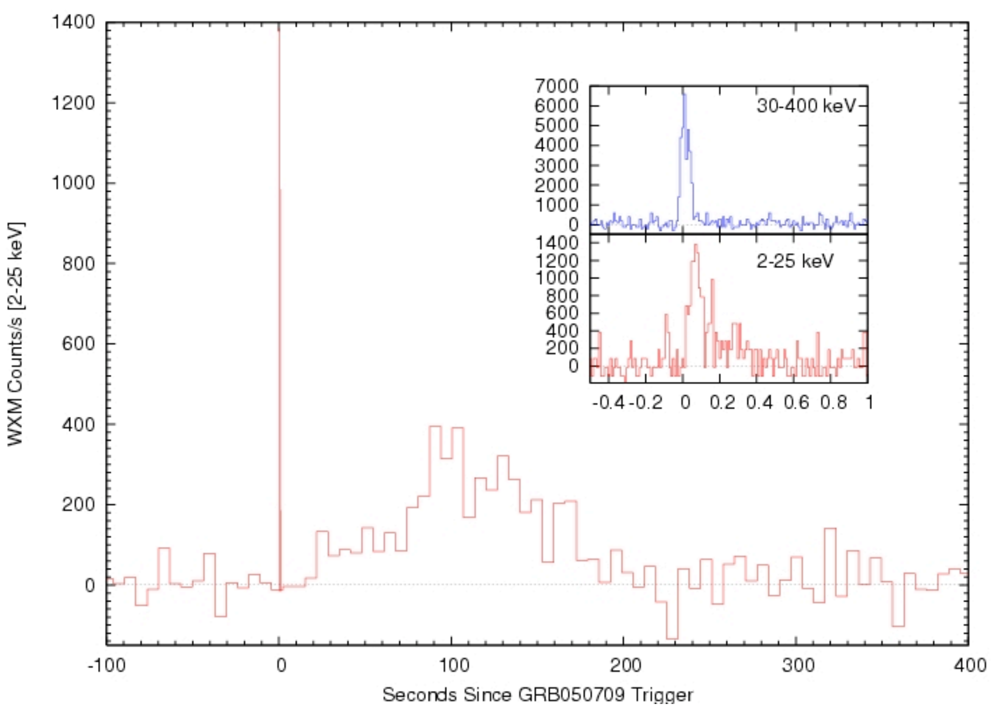
- The hypernova/collapsar model is consistent with both prompt and afterglow observations of GRB. Leptonic shock acceleration models (prompt = internal, afterglow = external) thrive.
- Expanding fireball consistent with radio scintillation in afterglow.
- Long bursts come from stellar collapse and their rate will follow the known SFR.
- If the sources are close enough, we will see a SN with the long GRB.
- The energy budget is decreased by collimation of the GRB emission. An achromatic jet break will allow the determination of the energetics (Possibility of GRB as standard candle for cosmology: Frail et al 2001).
- Short bursts come from binary mergers.
- They are close-by and come from elliptical galaxies with low SFR.
- Looking at energetics vs spectral parameters or pulse profiles at different energies in the gamma-ray regime provides interesting correlations (Amati, Ghirlanda, Firmani, Liang & Zhang, Norris).

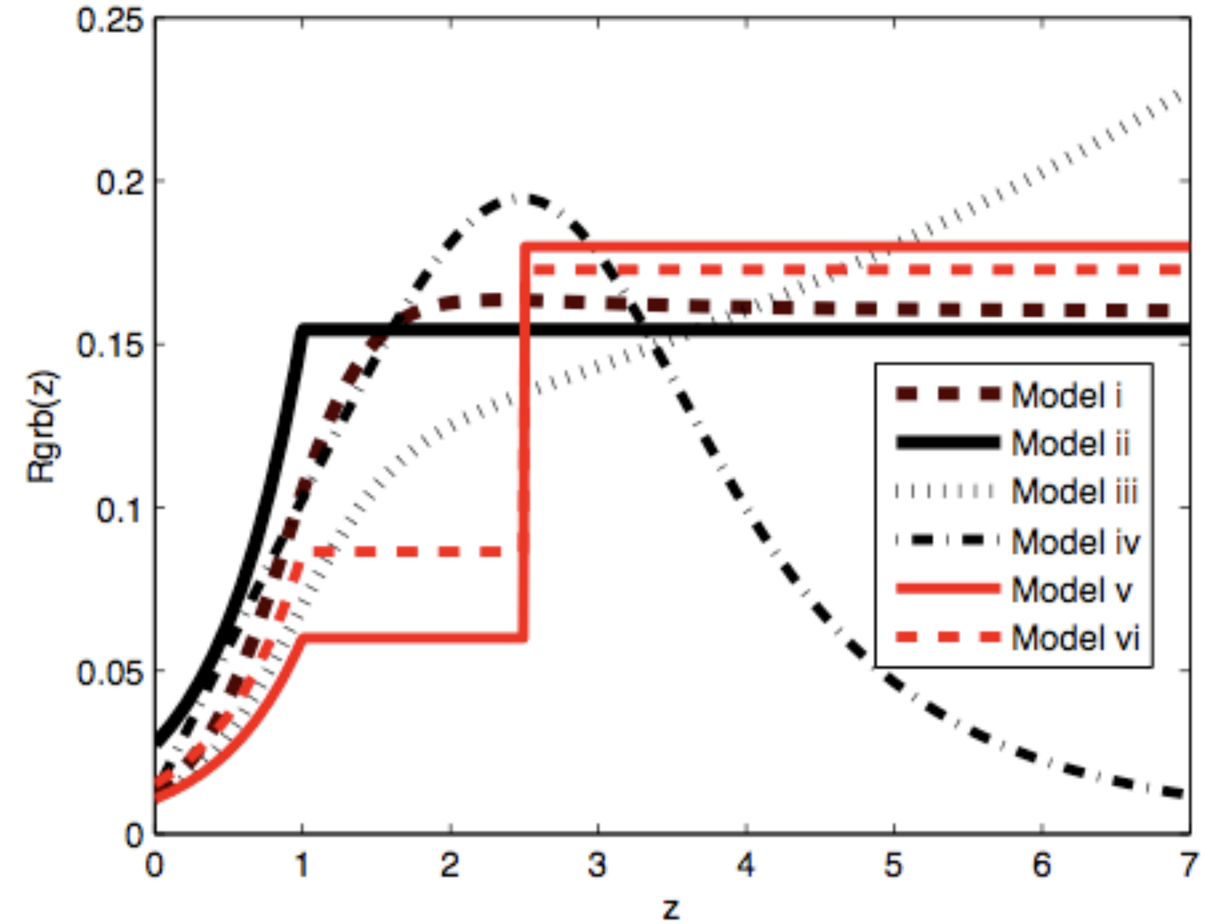
The Swift era progresses...

- ✤ Long bursts come from stellar collapse and their rate will follow the known SFR. ✖ (Swift high-z GRB imply higher rate in past e.g. Guetta & Piran 2007)
- ✤ If they are close enough, we will see a SN with long GRB. ✖ absence of SN in well-observed 060614 (Gehrels et al 2006)
- ✤ The energy budget is decreased by collimation of the GRB emission. An achromatic jet break will allow the determination of the energetics. ✖ breaks observed by Swift not achromatic (e.g. Willingale et al 2007).
- ✤ Short bursts come from binary mergers. Perhaps.. but sometimes long bursts are short, and short bursts long!
- ✤ They are close-by and in elliptical galaxies with low SFR. ✖
- ✤ X-ray flares! Central engine or afterglow?
- ✤ Steep and shallow phases of X-ray afterglow revealed by Swift.
- ✤ Looking at energetics vs spectral parameters in the gamma-rays provides interesting correlations ...

The Swift era continues...

HETE "short" GRB
050709.
Boer et al.





Guetta & Piran 07
SFR needs kick at high-z

... More Swift GRB needed with redshift and well-sampled afterglows, and more high-z bursts needed for cosmological studies of early universe.

The relationships

... relate spectral and temporal behavior in gamma rays with afterglow behavior either through overall relativistic kinematics or jet dynamics.

- **Amati (et al. 2002):** $E_{peak} \propto \varepsilon_{iso}^{1/2}$
- **Ghirlanda (et al. 2004):** $E_{peak} \propto \varepsilon_{abs}^{0.7}$
- **Firmani (et al. 2006):** bring T_{45} into E_{peak} and ε_{iso} relation.
  Need jet-breaks to measure equivalent isotropic energies.
  Need E_{peak} to see if relationships hold.

- **Fenimore & Ramirez-Ruiz (2000):** $\varepsilon_{iso} \propto$ variability in Υ-rays
- **Liang-Zhang (2005):** Does not assume break is jet break.
- **Norris (et al. 2000):** lag-luminosity relation. Short lag = luminous.
  Lags measured in observer frame i.e. not z-corrected.

Use these relationships to infer a pseudo-redshift from a measurement of spectral parameters or lags and luminosities in observer frame.... many more bursts without measured z than with.

These relationships have to reject the nearby, low-luminosity long bursts associated with supernovae... another class? Or do we need new relationships?

GRB Spectra

The Band Function:

$f(E) = A(E/100)^{\alpha}\ \exp(-E[2+\alpha]/E_{peak})$ if $E < E_c$

$f(E) = A([\alpha - \beta]\ E_{peak} / 100[2 + \alpha])^{\alpha-\beta}$ if $E \geq E_c$

where $E_c = (\alpha - \beta)\ E_{peak} / (2 + \alpha)$

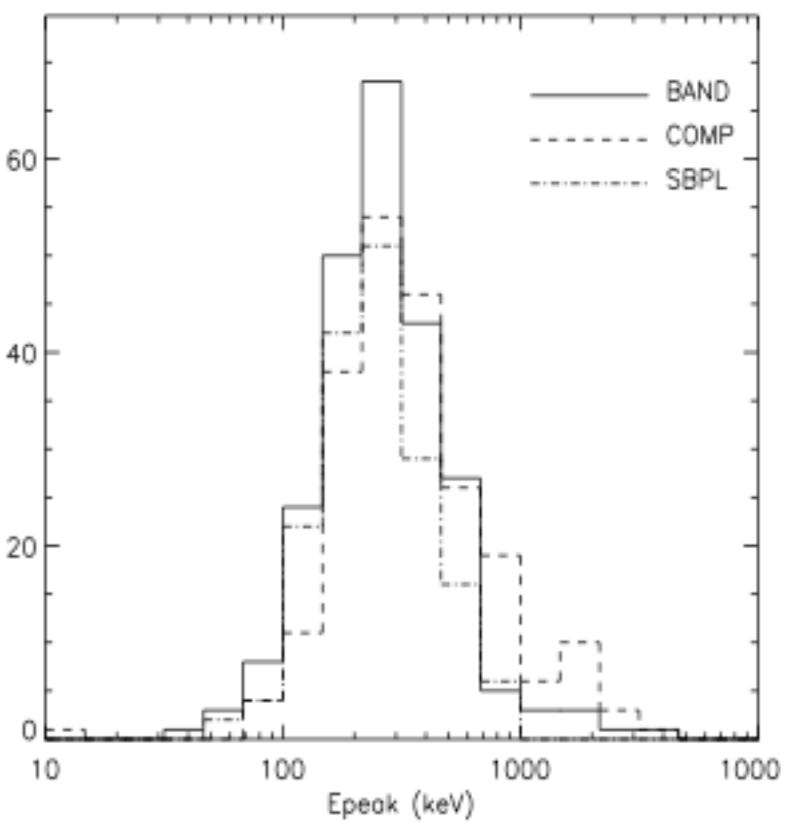
Comptonized Model: when HE PL ill-constrained i.e. too high E_{peak} or GRB is weak with too few HE photons. Use exponential cut-off instead of HE PL.

Single Power-Law: E_{peak} undetermined.

Swift is sensitive mainly between 15 and 150 keV... limited spectroscopy in traditional ϒ-ray range.

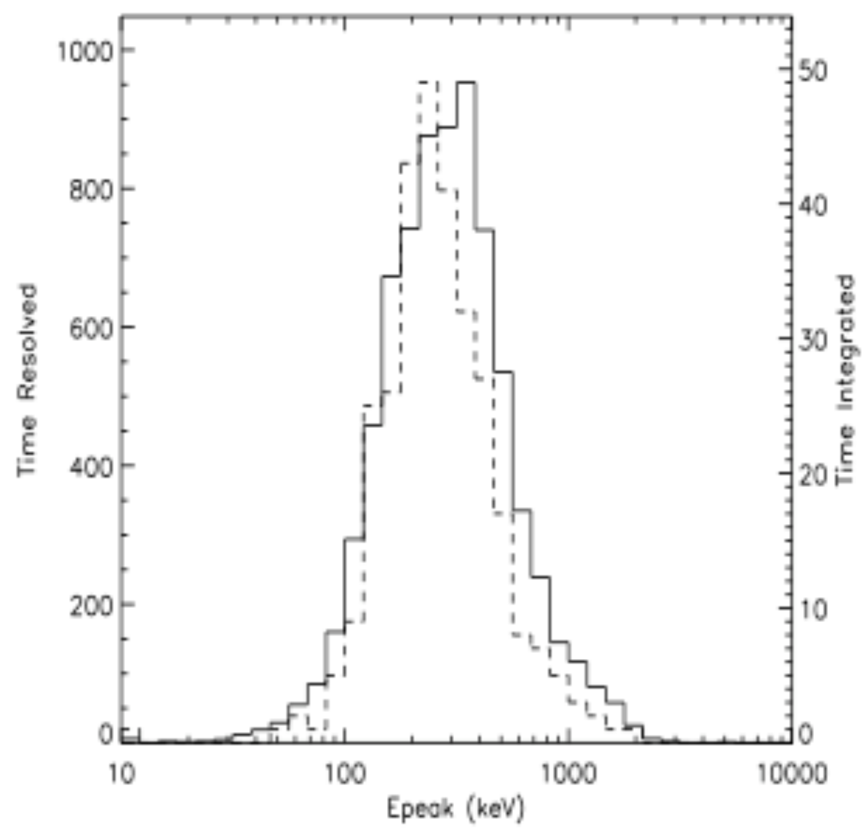
BATSE GRB Spectroscopy

Kaneko et al (2006) find some correlation between total fluence and E_{peak} but not consistent with Amati or Ghirlanda over their sample or over the entire BATSE spectral catalog.   Need to be careful in assigning single E_{peak} for a burst.
However - narrowness of E_{peak} in BATSE not seen elsewhere (XRR, XRF).



Band Time-integrated median
E_{peak} = 262 (+118 -80) keV

Comptonized Time-integrated
E_{peak} = 321 (+202 -105) keV



Best-fit Band
Time-resolved
E_{peak} = 273 (+112 -92) keV
Time-integrated
E_{peak} = 224 (+114 -66) keV

E_{peak} strongly correlated with α within a GRB in either Band or Comptonized models.

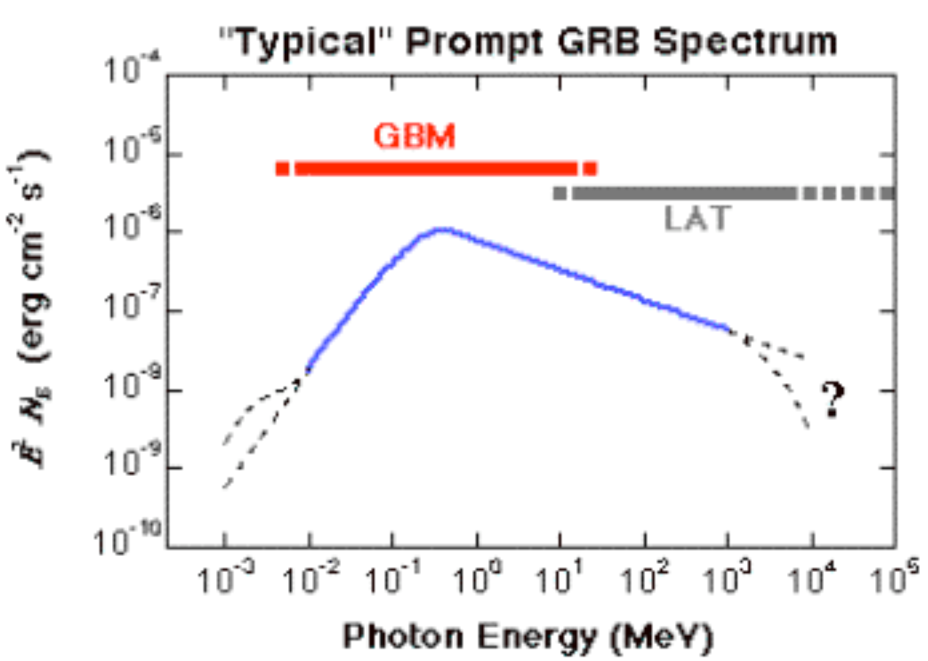
α and β are fundamental quantities in GRB emission models.   In simplest synchrotron shock models, the high index is related to the power-law spectrum of the accelerated electrons. Mean value of -2.3 favors fast-cooling over slow-cooling regime.

β should be constant throughout a burst. Kaneko et al. find this is not true 51% of time.   More seriously, α often not compatible with synchrotron scenarios of e shock acceleration.

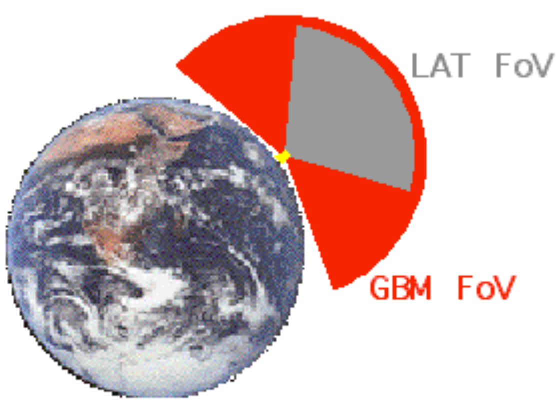
GBM and LAT usher in Swift & Fermi era!

If we have *known* z and a good handle on prompt spectrum, we can investigate these relationships... or find new ones.... the era of GLAST (Fermi) and Swift begins.

Fermi can help with GRB spectroscopy!
With or without the LAT, the GBM can pick up and enhance where BATSE left off.



9 decades of energy - extend low as well as high energy GRB spectra relative to CGRO



LAT

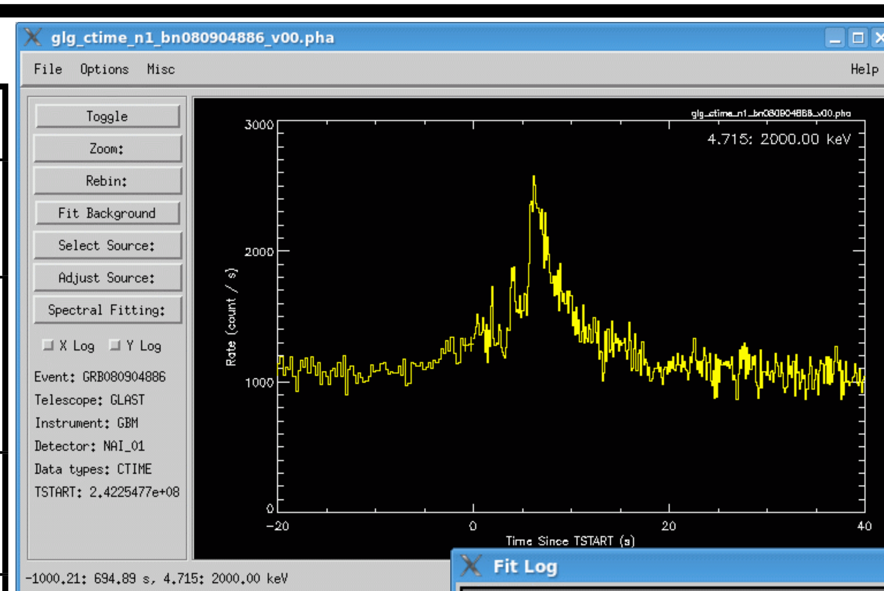
BGO

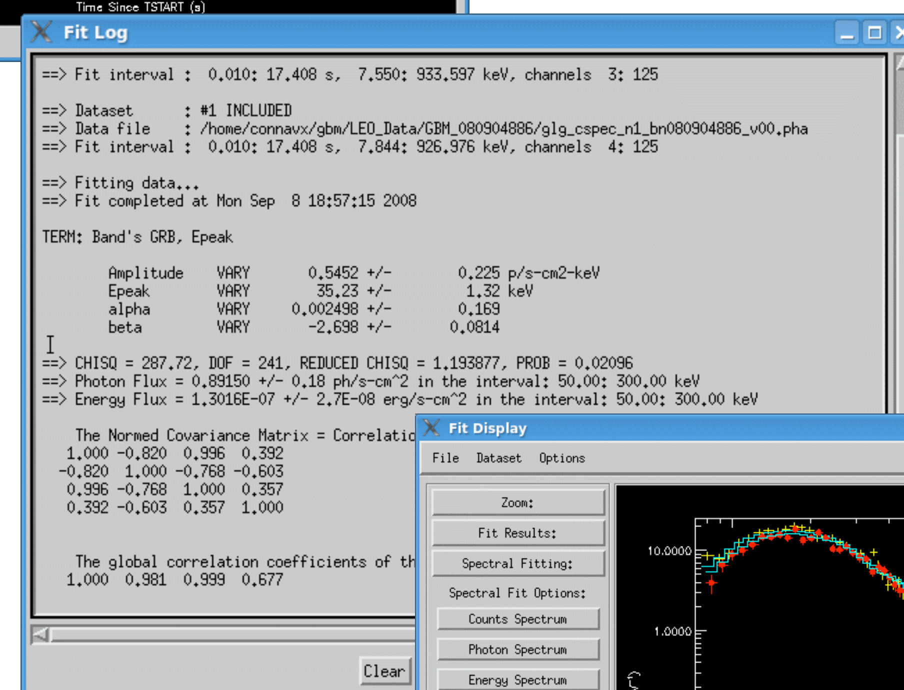
NaI

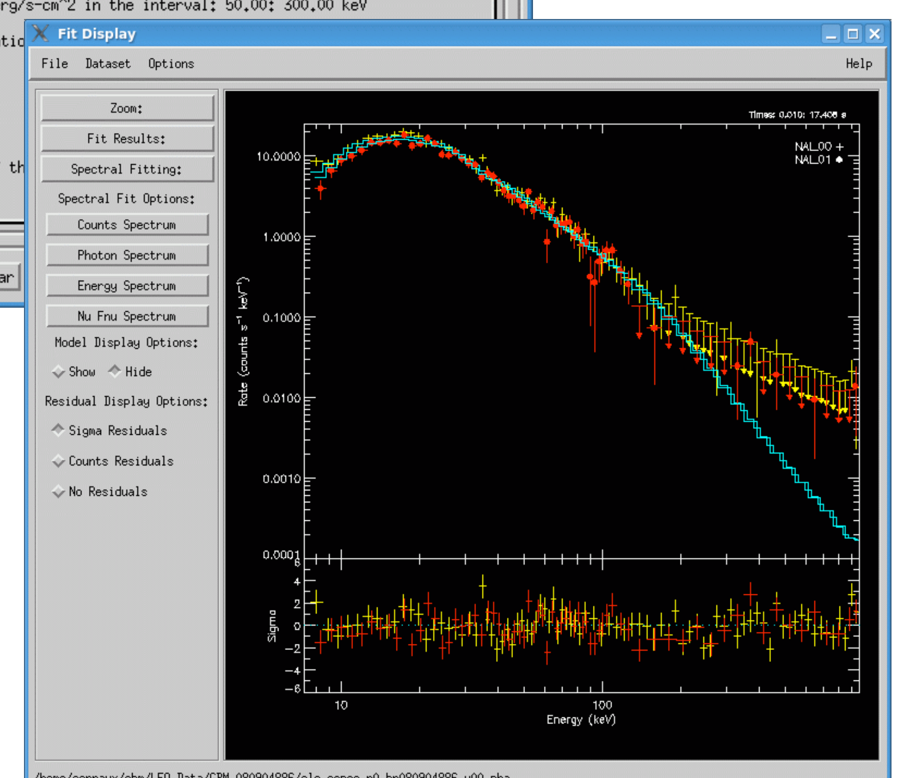
15% Swift GRB at z > 5... LAT EBL cutoffs?

GBM - Expected vs Early Observations

	GBM	BATSE
Energy range	8 keV – 1 MeV 150 keV – 30 MeV	20 keV – 1 MeV 30 keV – 10 MeV
Continuous Data (time, spec)	8 channel 0.256 s 128 channel 4 s	4 channel 1 s 16 channel 2 s 128 channel 300 s
Effective Area	12 x 126 cm^2 2 x 126 cm^2	8 x 2025 cm^2 8 x 126 cm^2
Trigger Threshold Ground	0.7 ph/s/ cm^2/ 0.4 ph/s/ cm^2/	0.2 ph/s/ cm^2/
Trigger Algorithms BURSTS/YR	Up to 120 over diff E ranges & Timescales & thresholds 200	1 energy range, 4 timescales, 1 threshold 300







GBM 080904 GCN 8206 = First GBM XRF.

⇑

Multitude of trigger algorithms ⇒ 58 GRB in ~2+ months ~300 GRB per year including XRF.

7Joint GBM/Swift GRBs (+ numerous SGR flares)

- 080725.435
  - ★ Swift: single PL index 1.5 +/- 0.1
  - ★ GBM: Band function, α = -1.1 +/- 0.1, β = -2.3 +/- 0.9, E_{peak} = 299 +/- 71 keV
- 080727.964
  - ★ Swift: Comptonized model, PL 0.87 +/- 0.20, E_{peak} = 143 +/- 50 keV
  - ★ GBM: Comptonized model, PL 0.90 +/- 0.10, E_{peak} = 149 +/- 13 keV
- 080804.972
  - ★ Swift: Single PL 1.19 +/- 0.10
  - ★ GBM: Comptonized, PL 0.63 +/- 0.06, E_{peak} = 277 +/- 21 keV [1.24 +/- 0.02 if forced to PL]
- 080810.549 -- both teams issued circulars.
  - ★ Swift: single PL index 1.34 +/- 0.06
  - ★ GBM: Comptonized model, PL 0.91 +/- 0.12, E_{peak}=313 +/- 74 keV
- 080905a (short)
  - ★ Swift: single PL index 0.85 +/- 0.24
  - ★ GBM: single PL index 0.96 +/- 0.05 (without BGO)
- 080905b
  - ★ Swift: single PL 1.78 +/- 0.15
  - ★ GBM: single PL 1.75 +/- 0.12 (no BGO)
- 080916.416
  - ★ Swift: Comptonized, PL 1.17 +/- 0.21, E_{peak} = 95 +/- 23 keV
  - ★ GBM: Comptonized, PL 0.90 +/- 0.10, E_{peak} = 109 +/- 9 keV

GBM - Current Status

- Spectral analysis of early events underway now that initial calibrations have been performed. Expect re-evaluation of many spectra in view of BGO calibration solution.
- GBM data starting 080811 now public through FSSC. Starting 080902 and going back to 080811 to fill archive. Operational upgrades will soon streamline data availability process.

TITLE: GCN CIRCULAR
NUMBER: 8269
SUBJECT: Fermi/GBM Data Now Available
DATE: 08/09/18 21:20:44 GMT
FROM: David L. Band at NASA/GSFC <David.L.Band@nasa.gov>

David Band (CRESST/GSFC/UMBC) reports on behalf of the Fermi SSC and the Fermi/GBM team:

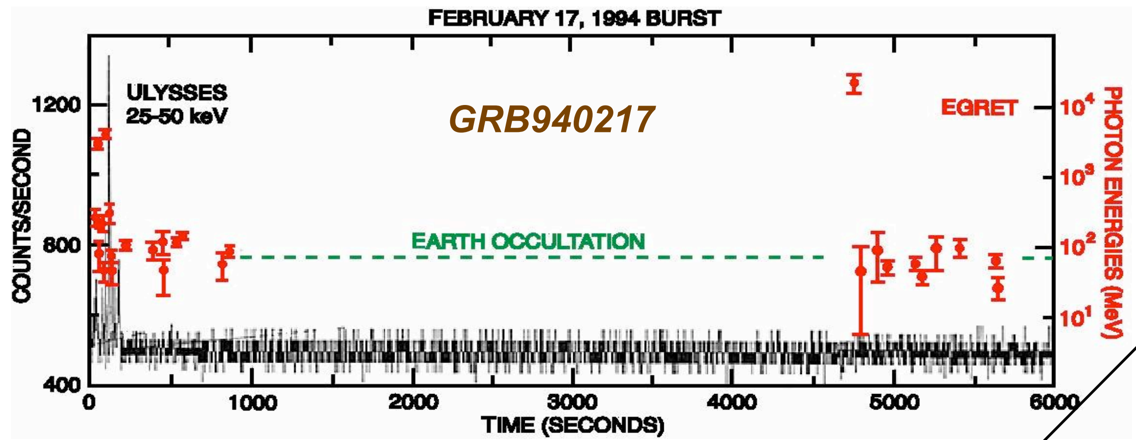
The Fermi/GBM burst catalog, burst data products and daily data products are now available. All data can be accessed through the HEASARC Browse interface at
http://heasarc.gsfc.nasa.gov/cgi-bin//W3Browse/w3table.pl?Action=Detailed%20Mission&Observatory=fermi,

while the data products can also be downloaded from the FTP site
ftp://legacy.gsfc.nasa.gov/fermi/. Tools and documentation for the analysis of the data products can be found at
http://fermi.gsfc.nasa.gov/ssc/data/analysis/. Please note the caveats at
http://fermi.gsfc.nasa.gov/ssc/data/analysis/software/caveats.html.

- GCN Circulars issued for all GRB after Burst Advocate performs initial localization (within 1 hour) and spectral analysis (can be up to 1+ days).
- Following FSW upgrade ~ start October, GCN Notices to be issued automatically with Trigger Alert, flight trigger classification, localization & updates, automated ground localization & updates.

LAT expectations & Early Observations

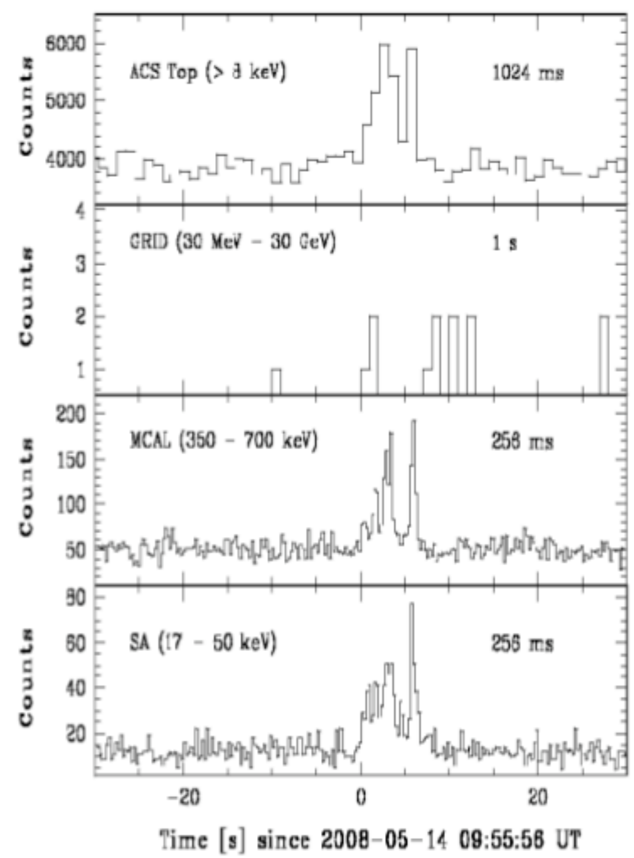
	LAT	EGRET
Energy range	**20 MeV to >300 GeV**	**20 MeV – 30 GeV**
Angular resolution (single photon, 10 GeV)	**<10%**	**10%**
Peak effective area	**9000 cm²**	**1500 cm²**
Energy resolution (on axis, 100 MeV – 10 GeV)	**0.15°**	**0.54°**
Field of view	**>2.2 sr**	**0.4 sr**
Deadtime per event	**27 us**	**100 ms**

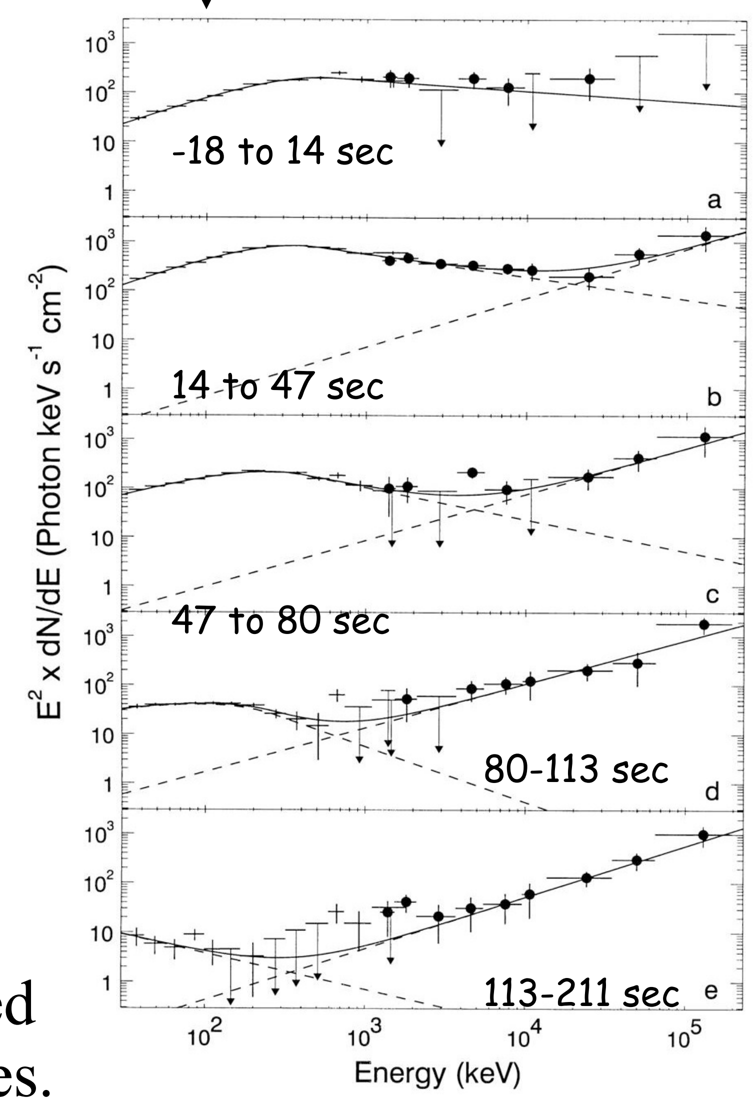


Hurley et al. 1994

Giuliani et al. 2008

Gonzalez et al. 2003

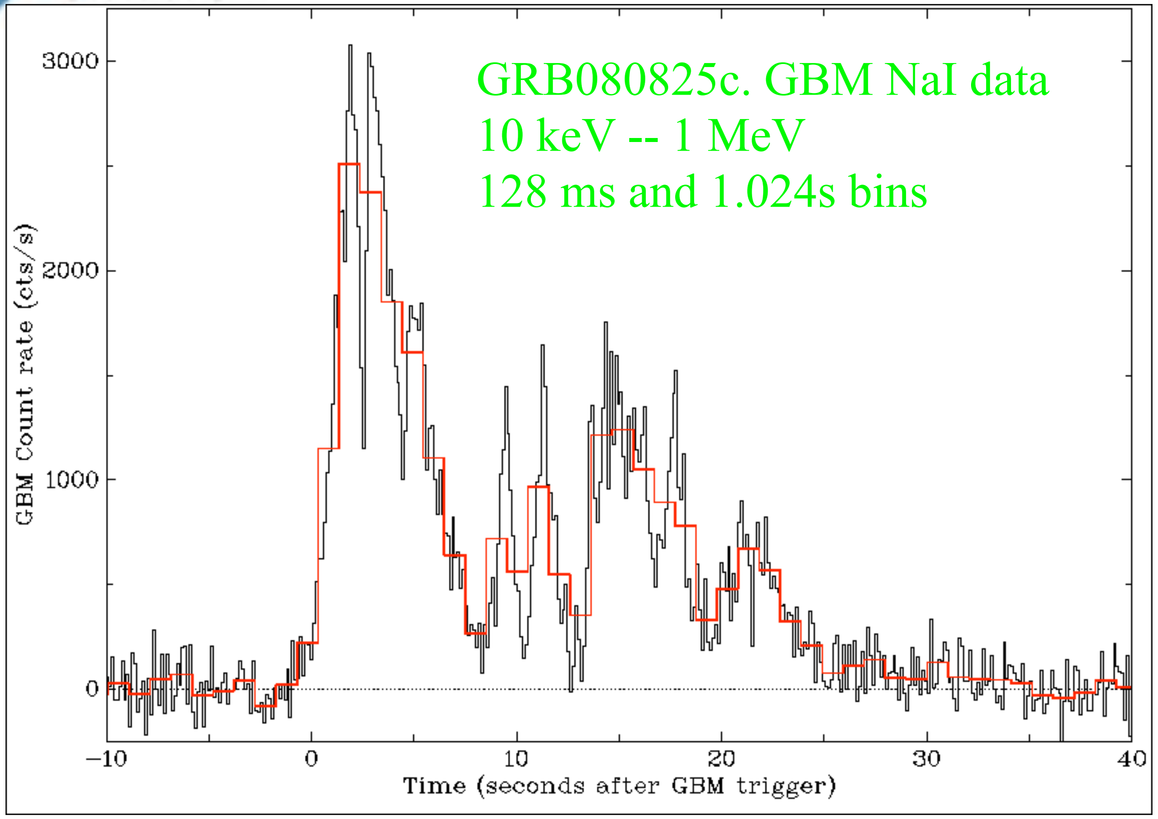




EGRET - 5 per year in spark chamber in 9 years. Difficult to (i) make predictions based on these low numbers (ii) extrapolate from BATSE based on possibility of distinct temporal and spectral components at high energies.

Early result: 1 GRB per month seen by LAT.

GBM GRB seen by the LAT: GRB080825c



TITLE: GCN CIRCULAR
NUMBER: 8183
SUBJECT: GRB080825C: Fermi-LAT observations
DATE: 08/09/05 17:45:46 GMT
FROM: Aurelien Bouvier at Stanford <bouvier@stanford.edu>

A. Bouvier (SLAC)... on behalf of the Fermi LAT team:

We report a detection by the Fermi Large Area Telescope (LAT) of emission from GRB080825C, which was triggered by the Fermi Gamma-ray Burst Monitor (GBM) at 14:13:48 UT on August 25th 2008 (GCN 8141 by Van der Horst et al.). The angle of the GBM best localization (ra, dec=232.2,-4.6) with the LAT boresight was 60 deg at the time of the trigger which is on the edge of our field of view.

The data from the Fermi LAT shows a significant increase in the event rate within 10 degree of the GBM localization and up to 35 seconds after the GBM trigger that is spatially and temporally correlated with the GBM emission with a significance of more than 5 sigma. All the LAT events detected during the GBM emission have energies below 1 GeV.

The best LAT on-ground localization is found to be RA,DEC=233.96,-4.72 deg with a 90% containment radius of 1.5 deg (statistical+systematics; 68% containment radius: 0.95 deg) which is consistent with the GBM localization...

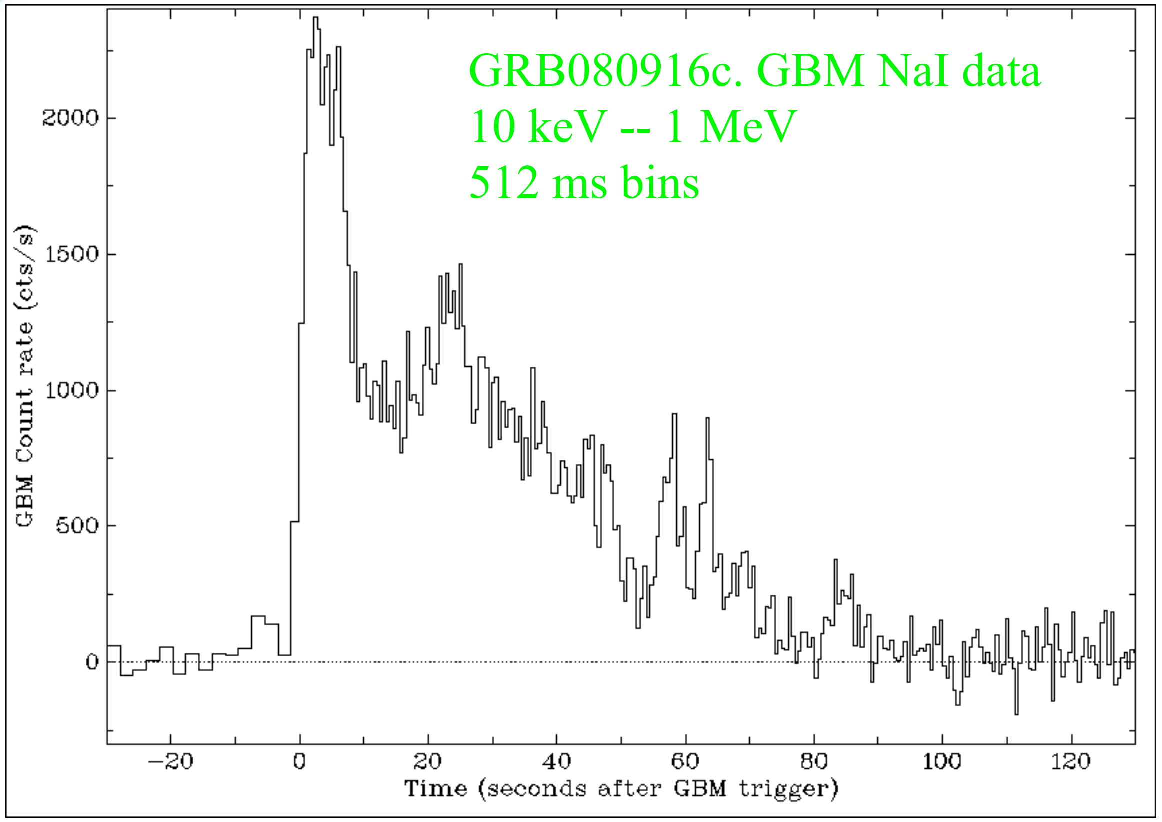
TITLE: GCN CIRCULAR
NUMBER: 8184
SUBJECT: GRB 080825C: Fermi GBM Spectral Analysis
DATE: 08/09/05 18:01:27 GMT
FROM: Alexander van der Horst at NASA/MSFC <avdhorst@science.uva.nl>

A.J. van der Horst (NASA/ORAU) ... on behalf of the Fermi GBM Team:

"We have performed time-resolved spectroscopy of GRB 080825C (GCN 8141, GCN 8183). The main emission up to 23 seconds is best fit by the Band function. Time-resolved spectra of this emission period display the commonly observed hard-to-soft spectral evolution, with Epeak decreasing from 170 to 110 keV, while the spectral indices remain roughly constant at alpha ~ -0.4 and beta ~ -2.4, consistent with the time-averaged spectral result (GCN 8141). Weaker emission following this period lasts a further 11 seconds and deviates from this spectral behaviour. The spectrum of this tail over the energy range 8-900 keV is best fit by a single power law with index -1.41 +/- 0.09.

- ✳ 13 +/- 2 photons with energies up to several hundred MeV.
- ✳ Photons over duration of GBM GRB.
- ✳ No follow-up possible owing to large error box of both instruments (not many LAT photons, none with E > 1 GeV).
- ✳ Joint spectral/temporal analyses in progress.

GBM GRB seen by LAT: GRB 080916c



TITLE: GCN CIRCULAR
NUMBER: 8246
SUBJECT: GRB 080916C: Fermi LAT observation
DATE: 08/09/16 18:25:23 GMT
FROM: Nicola Omodei at INFN(Pisa)/GLAST <nicola.omodei@pi.infn.it>

H. Tajima (SLAC)... on behalf of the Fermi LAT team:

We report a detection by the Fermi Large Area Telescope (LAT) of emission from the long GRB 080916C, which was triggered by the Fermi Gamma-ray Burst Monitor (GBM) at 00:12:45 UT on September 16th 2008 (GCN 8245). The angle of the GBM best position (RA, Dec=121.8,-61.3) with respect to the LAT boresight was 52 degrees at the time of the trigger, which is close to the edge of our field of view.

The data from the Fermi LAT shows a significant increase in the event rate within 10 degrees of the GBM location after the GBM trigger that is spatially and temporally correlated with the GBM emission with high significance. More than 10 photons are observed above 1 GeV during this time.

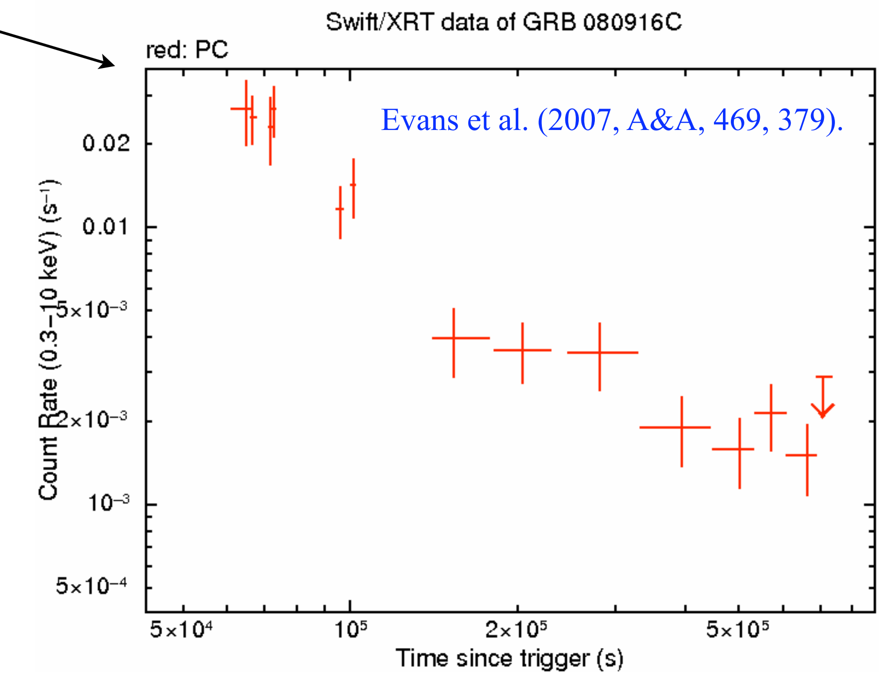
The best LAT on-ground localization is found to be (RA,Dec=119.88, -56.59) with a 90% containment radius of 0.13 deg (statistical; 68% containment radius: 0.09 deg, preliminary systematic error is less than 0.1 deg) which is consistent with the GBM localization...

TITLE: GCN CIRCULAR
NUMBER: 8278
SUBJECT: GRB 080916C: Fermi GBM Spectral Analysis
DATE: 08/09/20 23:41:31 GMT
FROM: Alexander van der Horst at NASA/MSFC <avdhorst@science.uva.nl>

Alexander van der Horst (NASA/ORAU) and Adam Goldstein (UAH) report on behalf of the Fermi Gamma-ray Burst Monitor Team:

"We have performed spectral analysis of GRB 080916C (GCN 8245, 8246). The time averaged spectrum, from 8 keV up to 30 MeV, of the main emission up to 66 seconds after the burst is best fit by a Band function with Epeak = 424 +/- 24 keV, alpha = -0.91 +/- 0.02, and beta = -2.08 +/- 0.06. The fluence (8 keV - 30 MeV) is 1.9e-4 erg/cm^2...

- ★ Good localization ⇒ Swift XRT.
- ★ Fading source.
- ★ GROND optical follow-up finds 21.7 magnitude fading source 32 hrs after Fermi GBM trigger (GCN 8257 Clemens et al. 2008).
- ★ No redshift.



- ✳ 200+ LAT photons with 3 ≥ 10 GeV.
- ✳ Photons over duration of GBM GRB.
- ✳ Joint spectral/temporal analyses in progress.

LAT - Current Status & future prospects

- LAT looks on ground for emission from all known GRB triggers.
- GBM and LAT see 2 bursts in common implying 1 burst in common with LE instruments per month. Magnitude of flux seen in LAT seems related to prompt emission GBM spectral index β.
- LAT ground processing also performs blind search for GRB.
- Currently no independent onboard LAT GRB trigger... October 2008. LAT trigger will operate both based on GBM trigger and independently based on clustering in time and space. Independent trigger would have found GRB 080916c, but not GRB 080825c.
- Also to be implemented - Automatic Repoint Recommendation to put bright/hard GBM bursts in LAT FoV for late prompt and afterglow emission ~ 1 per week [TBD] for 5 hours [TBD].
- Much analysis of common bursts in progress, both for prompt and afterglow emission (expected from several models e.g. Panaitescu 2008 or see Galli & Piro 2007 for predictions of GeV emission in coincidence with X-ray flares... or talks later this session).
- Quantum Gravity signatures in GRB emission with long lever arm of Fermi energy range.... studies and prospects ongoing.

Follow-up Observations in the GLAST/Swift Era

Swift BAT triggers on GRB → XRT/UVOT are on it. Small localization error bar → Easy follow-up. True also for Super-Agile or INTEGRAL IBIS/ISGRI triggers (but not numerous).

LAT triggers on GRB → HE photons get small localization error bar → XRT/UVOT can be on it → Easy follow-up.

GBM triggers on GRB and **LAT sees GRB in ground data**. HE photons mean small error bar → Easy but delayed follow-up.

GBM triggers on GRB and/or **LAT sees only LE photons** → can follow-up in real-time but need to cover large (several degs) error box.

IPN provides good localization → Potentially easy but delayed follow-up (Messenger, Suzaku, Konus, INTEGRAL ACS, AGILE MCal, GBM).

Key to follow-up on non-Swift BAT triggers = Good coordination and quick response from instrument teams and observers.

Key to continued progress of GRB science = Continued and cooperative operation of Fermi Gamma-ray Telescope & Swift.