

Fermi Observations of Gamma-ray Bursts

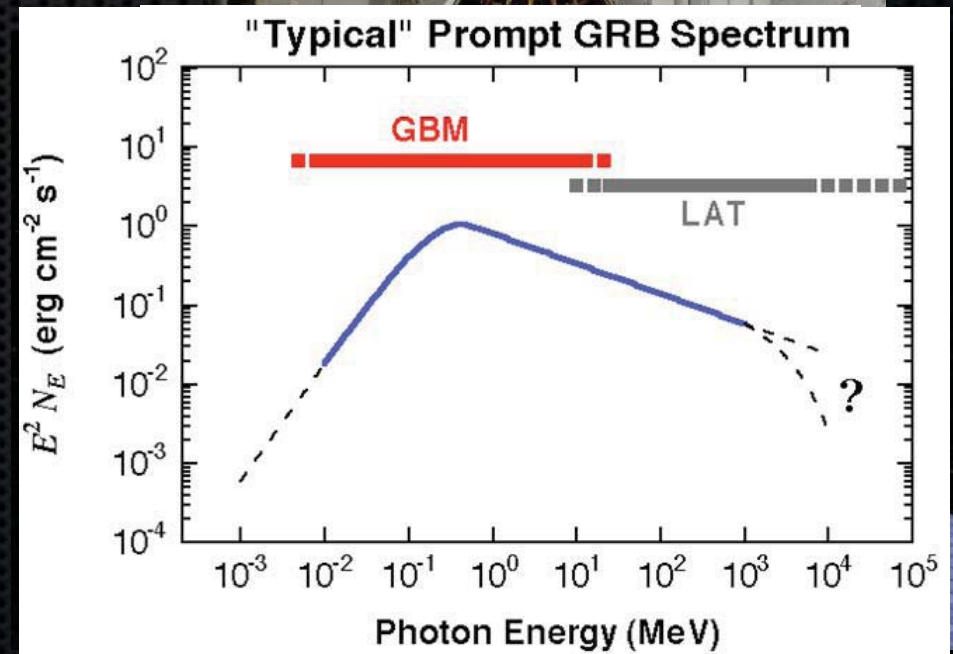
Daniel Kocevski

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Stanford University

On behalf of the Fermi collaboration

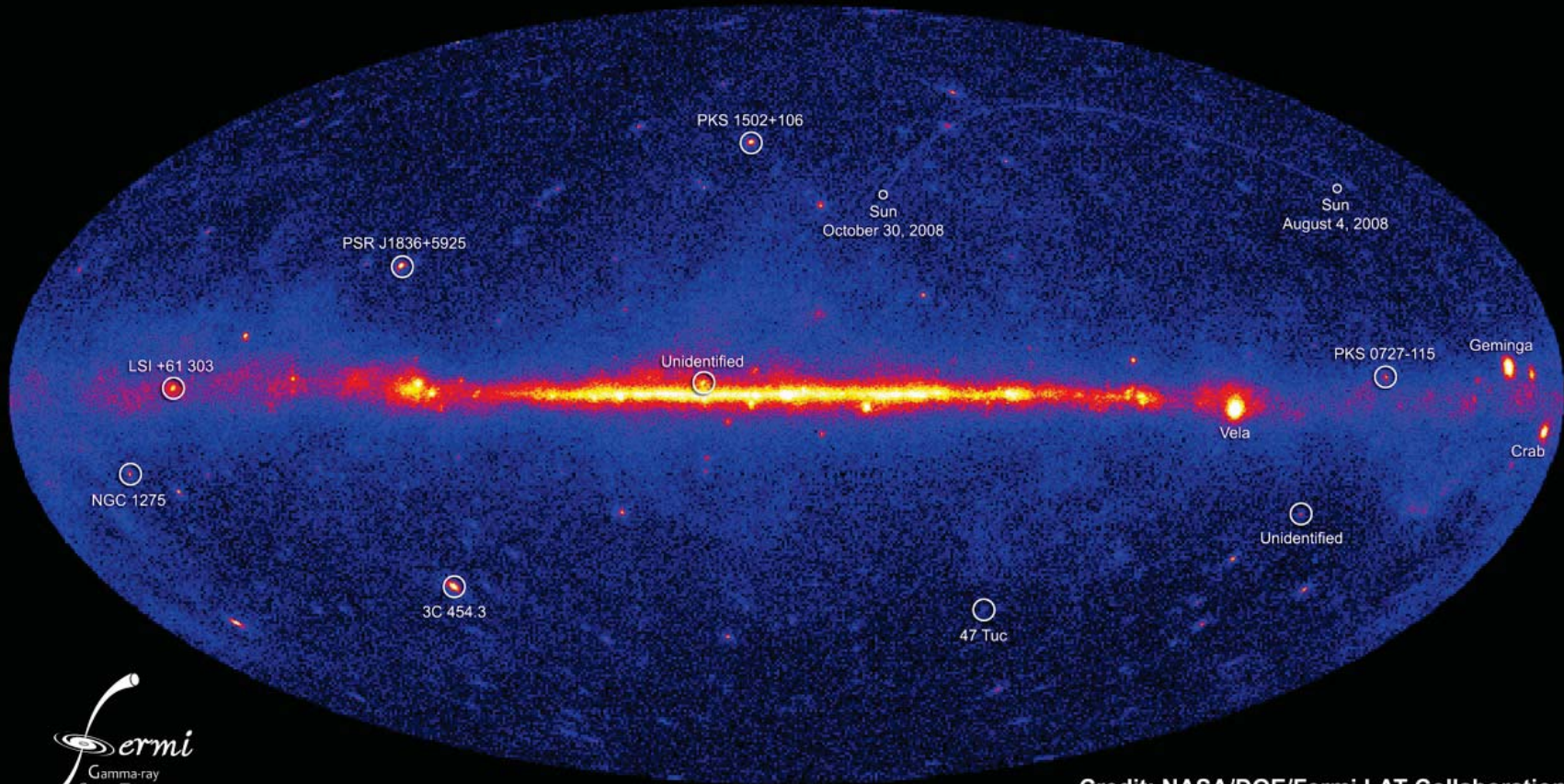
The Fermi Spacecraft

- Launched June 11th, 2008
- Triggering began Aug 7, 2008
- Fermi Gamma-ray Burst Monitor (GBM)
 - Scintillation detectors
 - 12 NaI: 8 keV - 1 MeV
 - 2 BGO: 200 keV - 40 MeV
- Fermi Large Area Telescope (LAT)
 - Pair conversion telescope
 - Energy coverage: 0.1 to >300 GeV



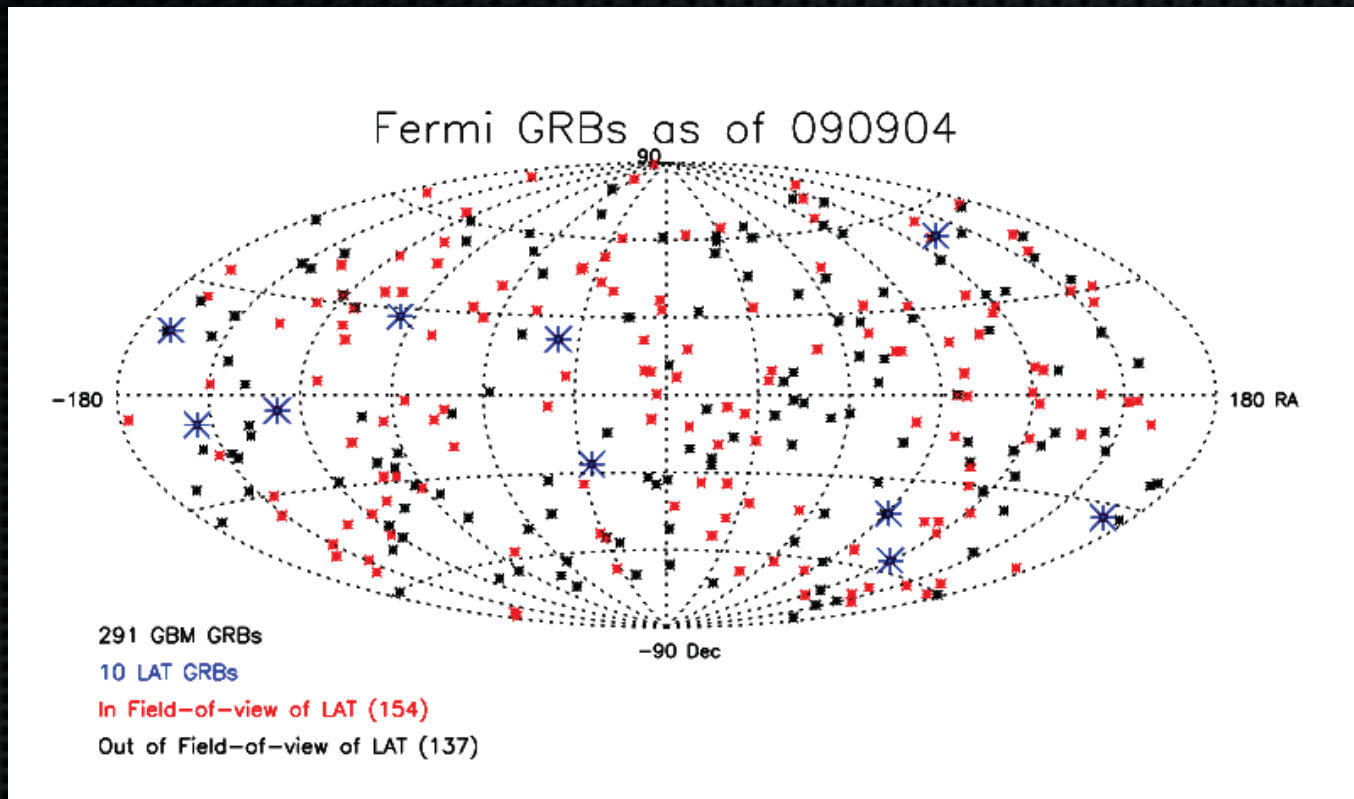
3 Month Sky Map - Top 10

NASA's Fermi telescope reveals best-ever view of the gamma-ray sky



Credit: NASA/DOE/Fermi LAT Collaboration

Fermi GRB Detections



- 291 GBM detections

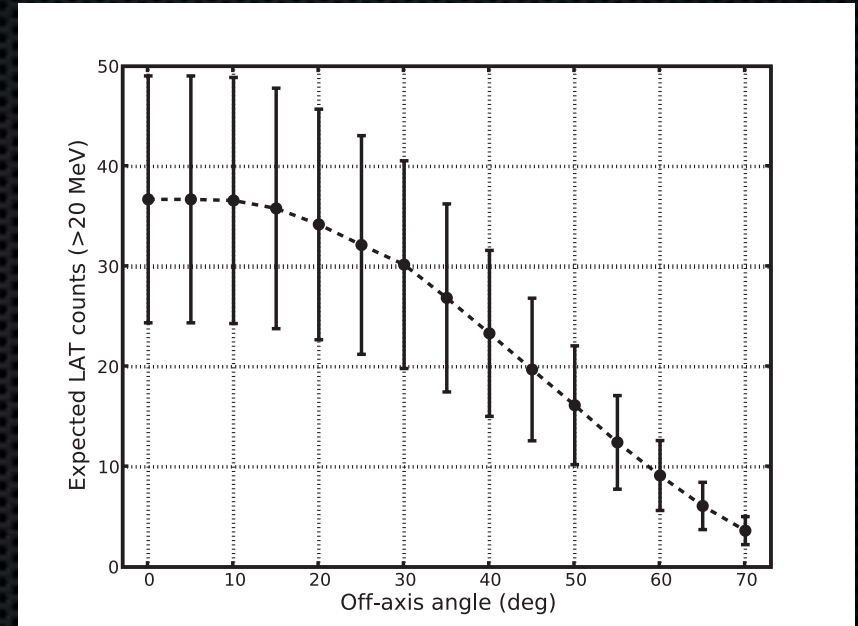
- Rate ~ 0.7 bursts/day

- 11 LAT detections

- Rate ~ 9 bursts/year

LAT Field of View (FOV)

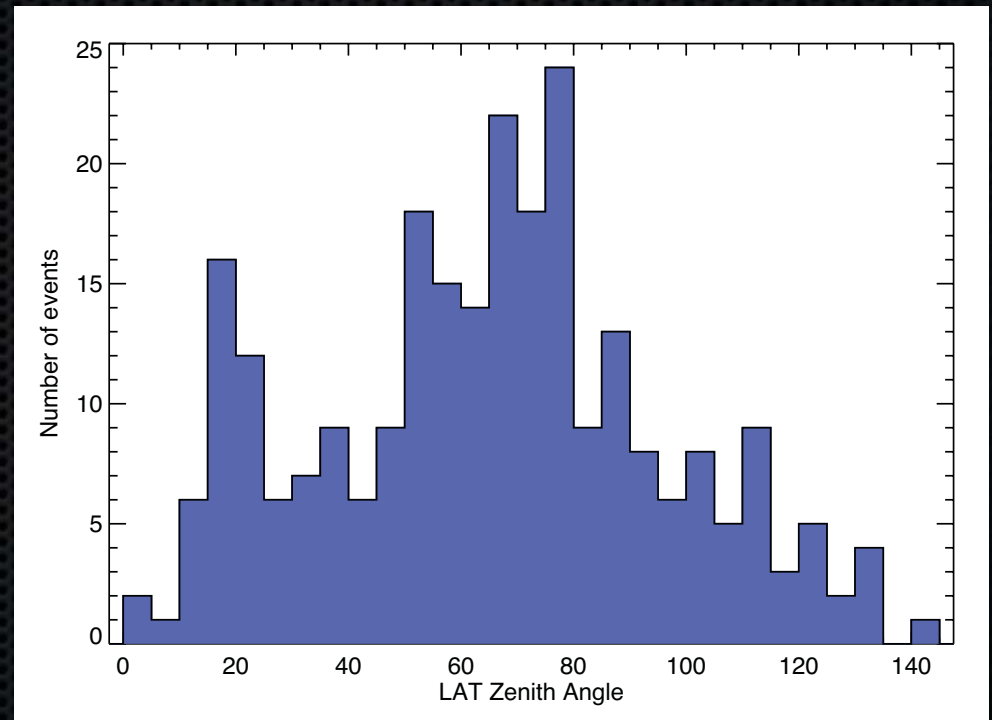
- ✦ Detector Fields of View
 - ✦ GBM: Full unocculted sky
 - ✦ LAT: ~ 2.4 Sr
 - ✦ LAT does not see all bursts
- ✦ Bursts in the LAT FOV
 - ✦ $< 65^\circ$ from the LAT Boresight
 - ✦ Sensitivity decreased rapidly above this



Expected counts vs. boresight angle

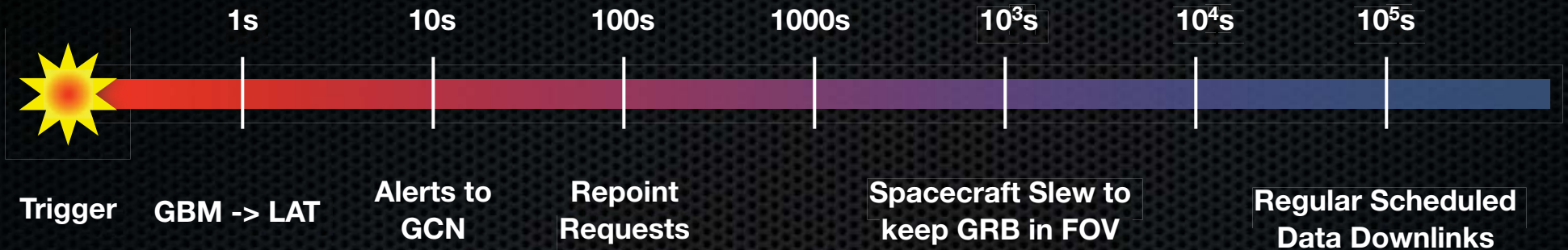
Burst Demographics

- ✦ GBM Detections
 - ✦ 291 events
- ✦ GBM Events in LAT FOV:
 - ✦ 154 events (52%)
- ✦ LAT Detections
 - ✦ 10 events was $\sim 3.4\%$
 - ✦ 10 events now $\sim 6.4\%$



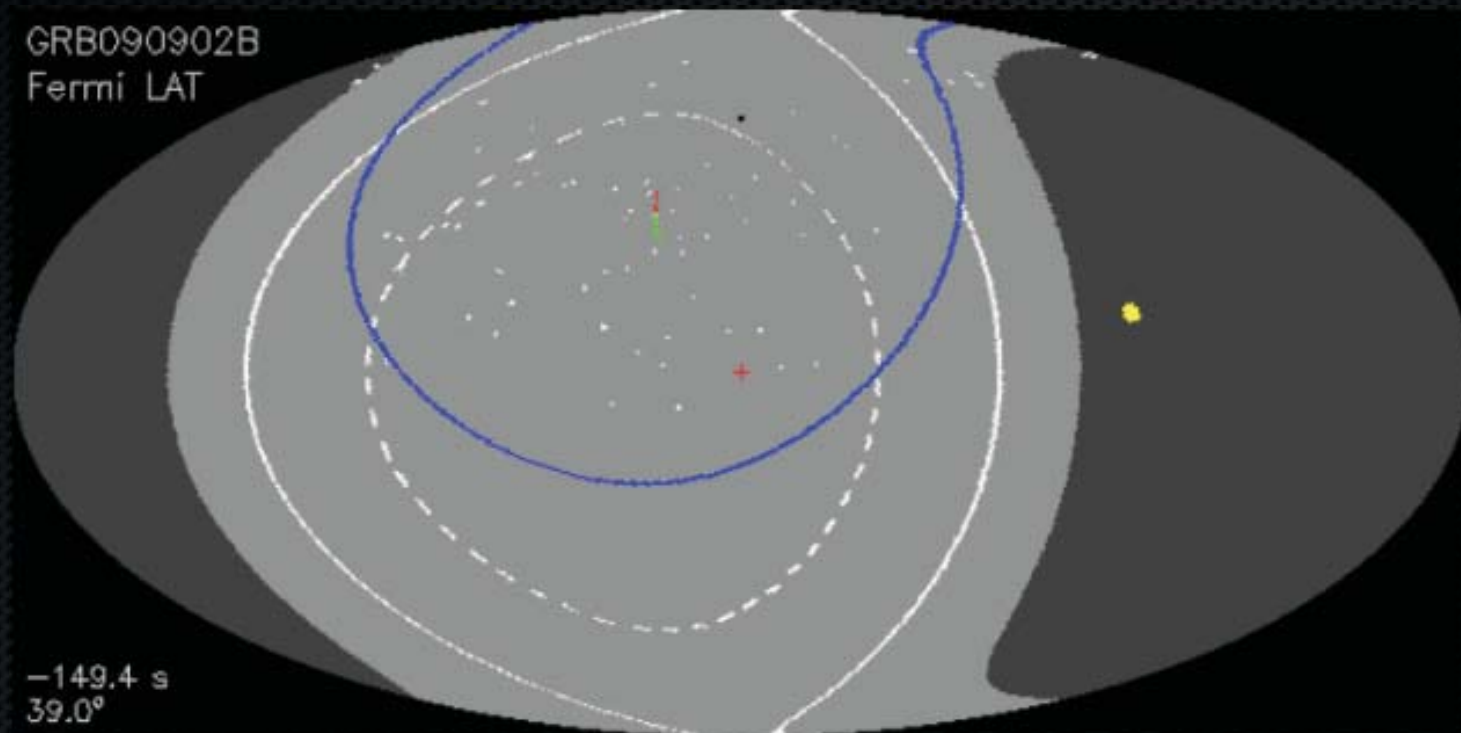
Angle of GRB to the LAT boresight at GBM trigger

Alerts and Data Flow



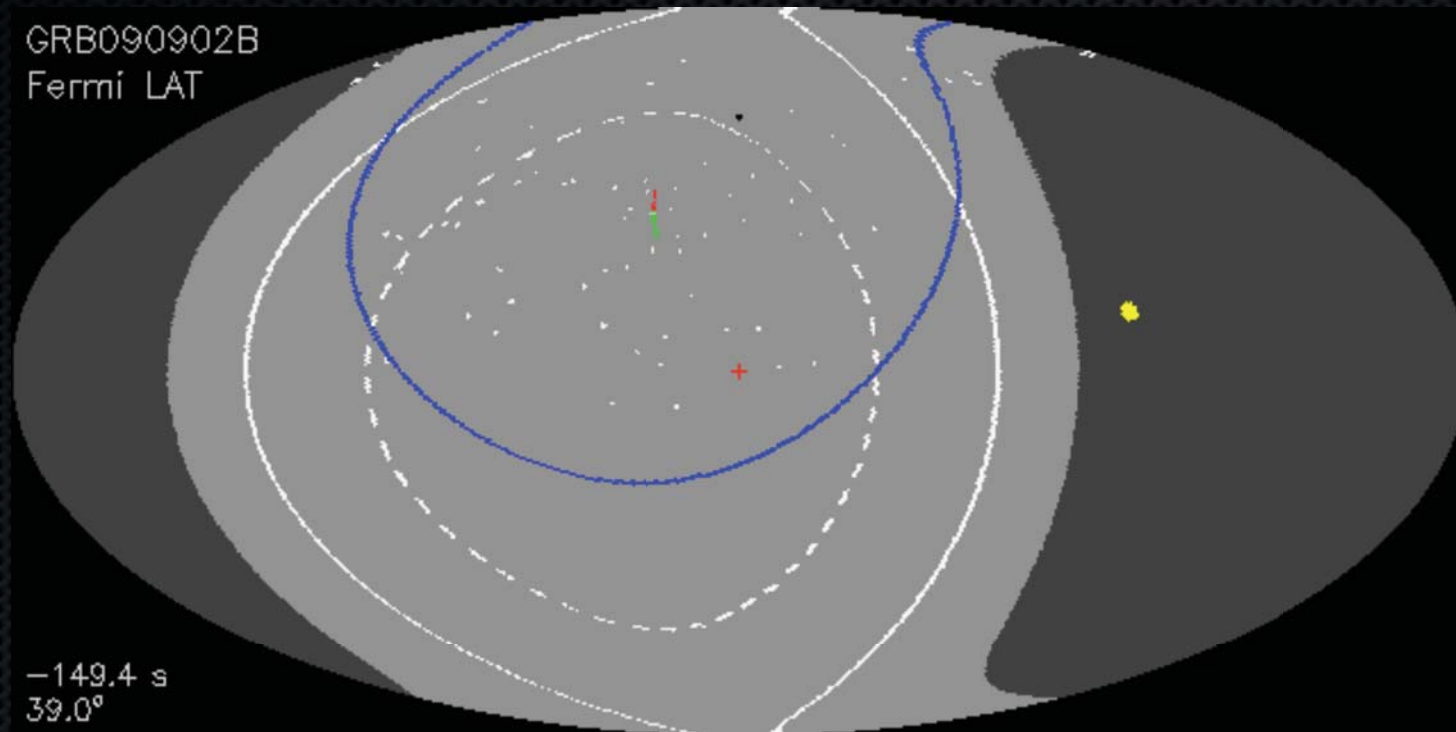
- **Onboard processing:** location, intensity, hardness ratio, classification...
- **LAT ground processing (5-12 hours):** Updated location, high energy spectrum, flux, afterglow search results
- **Final ground processing (24-48 hours):** Joint LAT-GBM model fits, fluence, raw GBM data online

Automated Repoint Request



- Red cross = GRB 09092B
- Blue lines = Earth avoidance angle
- Dark region = Occulted Earth
- White points = LAT transient events
- White Line = LAT field of view

Automated Repoint Request



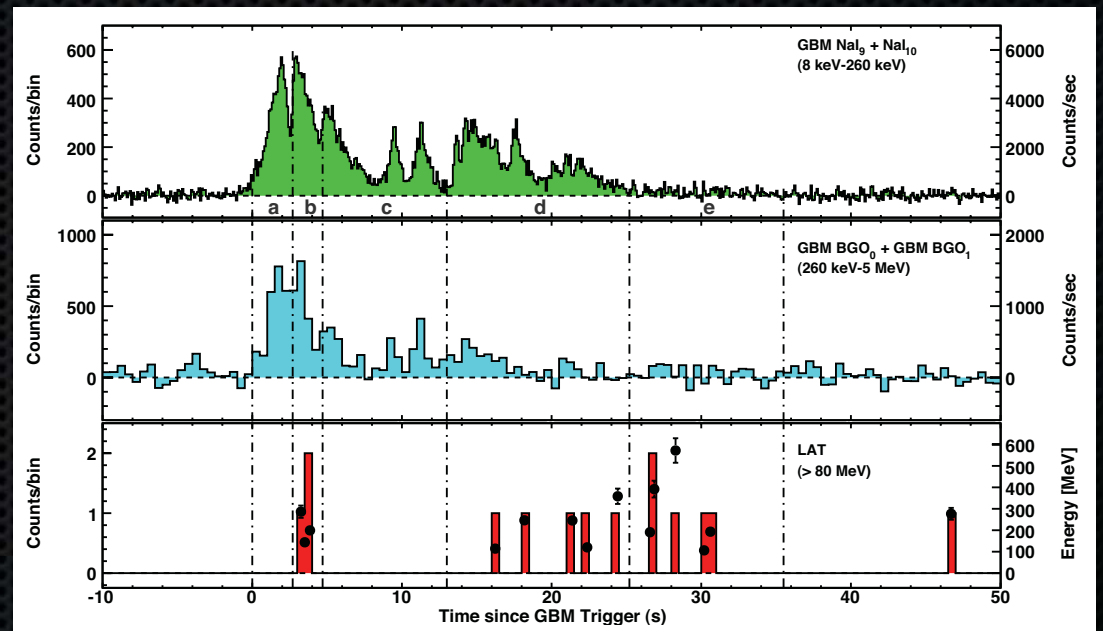
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Summary of LAT Bursts

GRB	duration	# of events > 100 MeV	# of events > 1 GeV	delayed HE onset	Long-lived HE	Highest Energy	Redshift
080825C	long	~10	0	✓	✓	~600 MeV	
080916C	long	>100	>10	✓	✓	~ 13.2 GeV	4.35
081024B	short	~10	2	✓	✓	3 GeV	
081215A	long	—	—	—	—	—	
090217	long	~10	0	x	—	~1 GeV	
090323	long	>10	>0	—	✓	—	3.57
090328	long	>10	—	—	✓	—	0.736
090510	short	>150	>20	✓	✓	~31 GeV	0.903
090626	long	—	—	—	✓	—	
090902B	long	>200	>30	✓	✓	~ 33 GeV	1.822

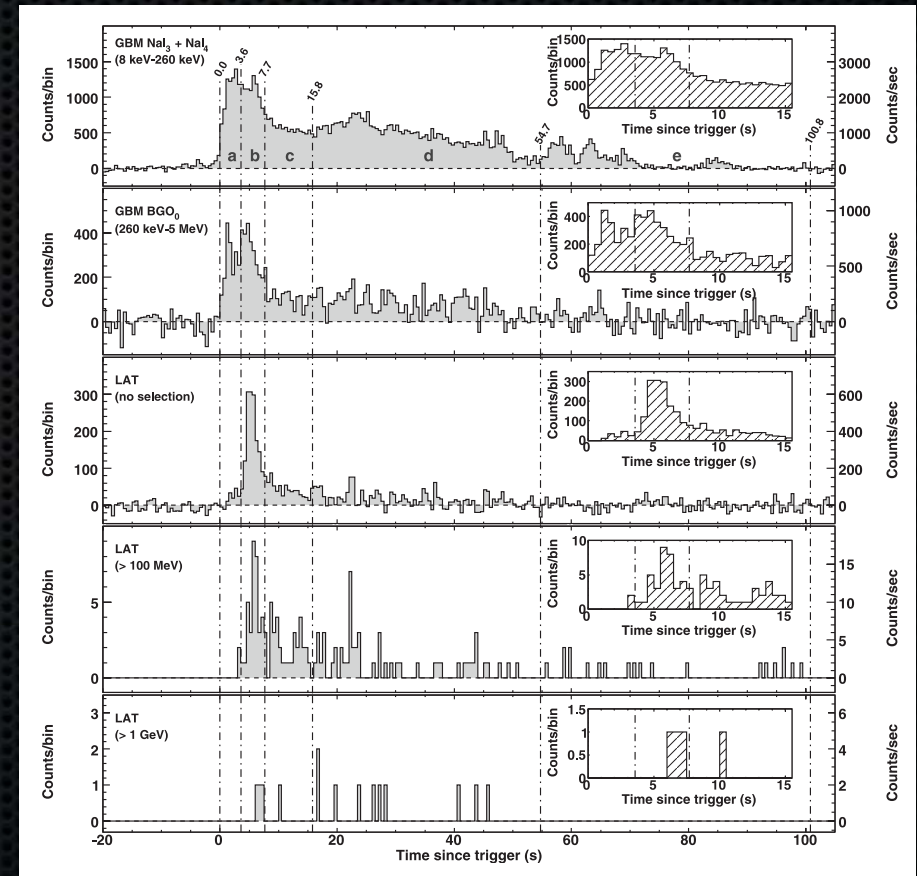
GRB 080825C

- ✦ First LAT GRB detection!
- ✦ Fluence = 2.4×10^{-5} erg cm^{-2}
- ✦ LAT Zenith Angle = 60°
 - ✦ Near edge of FOV
- ✦ 12 LAT Counts > 100 MeV
- ✦ No known redshift
- ✦ Evidence of long lived HE
- ✦ Delayed onset of LAT emission



GRB 080916C

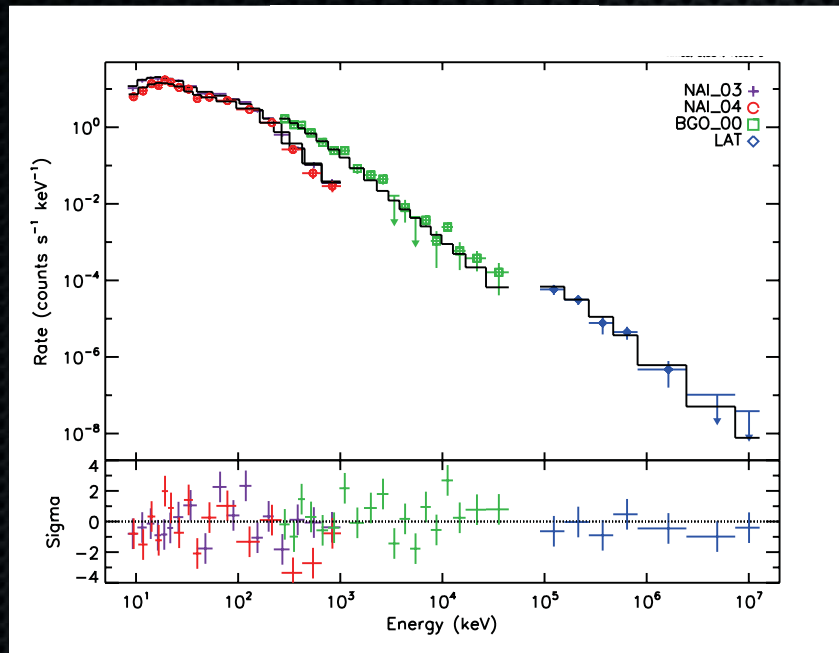
- Fluence $\sim 2.4 \times 10^{-4}$ erg cm $^{-2}$
- $Z_{\text{phot}} \sim 4.2$
- Eiso $\sim 8.8 \times 10^{54}$ ergs
- 145 LAT Counts > 100 MeV
- $E_{\text{max}} = 13.22$ GeV
- Delayed onset
 - Spectrum hardens, then softens
 - Opacity? Proton acceleration?



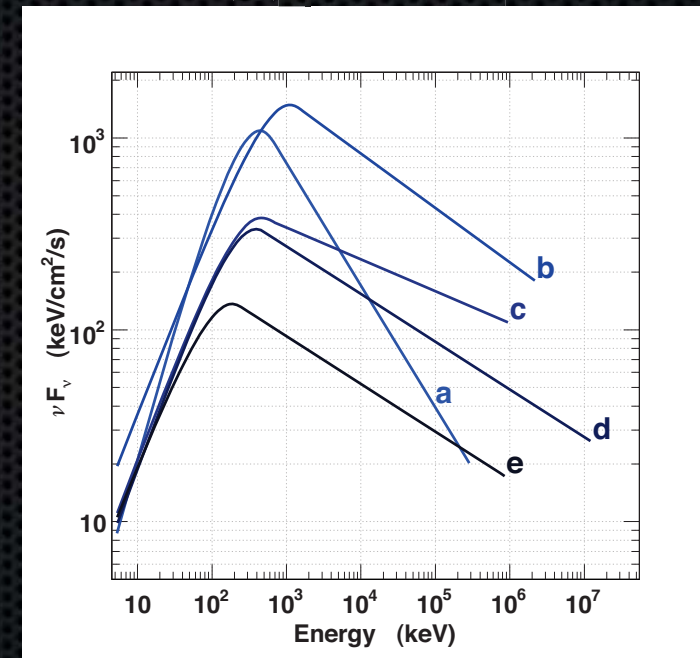
Abdo et al. 2009

GRB 080916C

Count Spectrum



νF_ν Spectrum

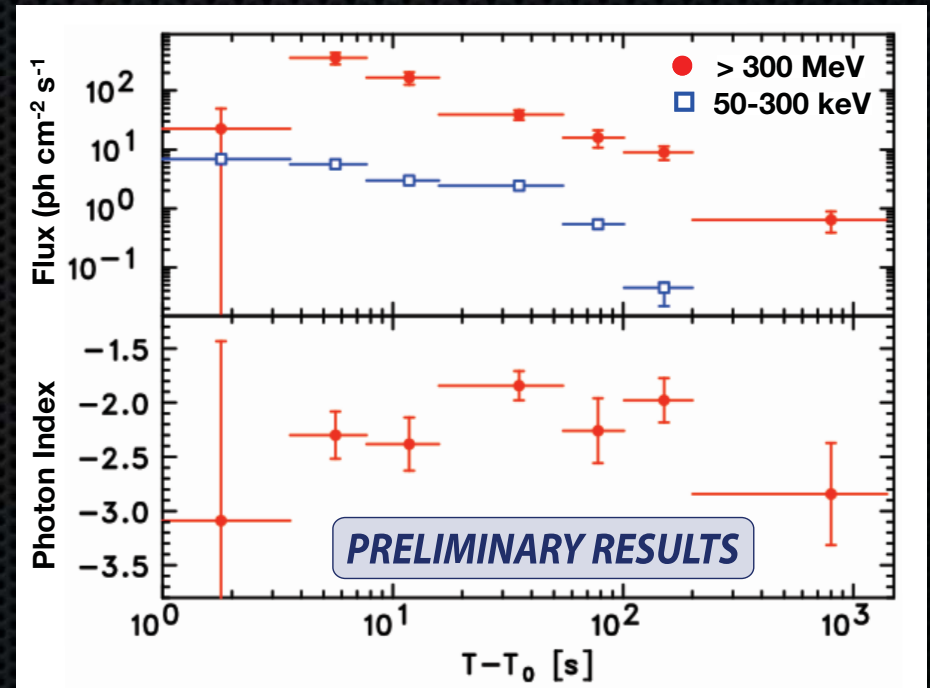


Abdo et al. 2009

- ❖ No additional spectral components needed
- ❖ No evidence for curvature due to $\gamma\gamma$ or EBL attenuation

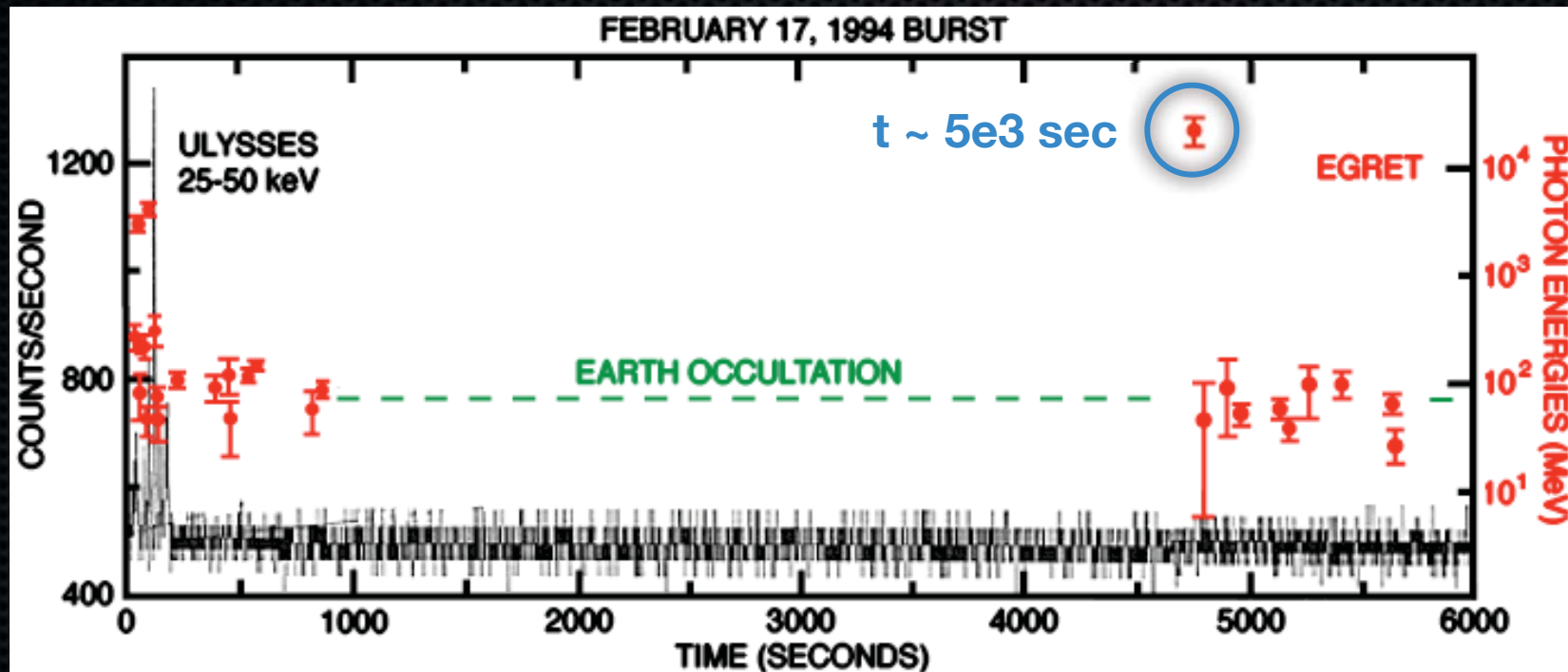
LAT Long Lived HE Emission

- ✦ GRB 080916C
 - ✦ Break in 50-300 keV emission
 - ✦ No break in > 300 MeV emission
- ✦ GRB 090232/090328
 - ✦ Similar long lived HE emission
 - ✦ Several kiloseconds in duration



HE emission from GRB 080916C

Long Lived HE Emission

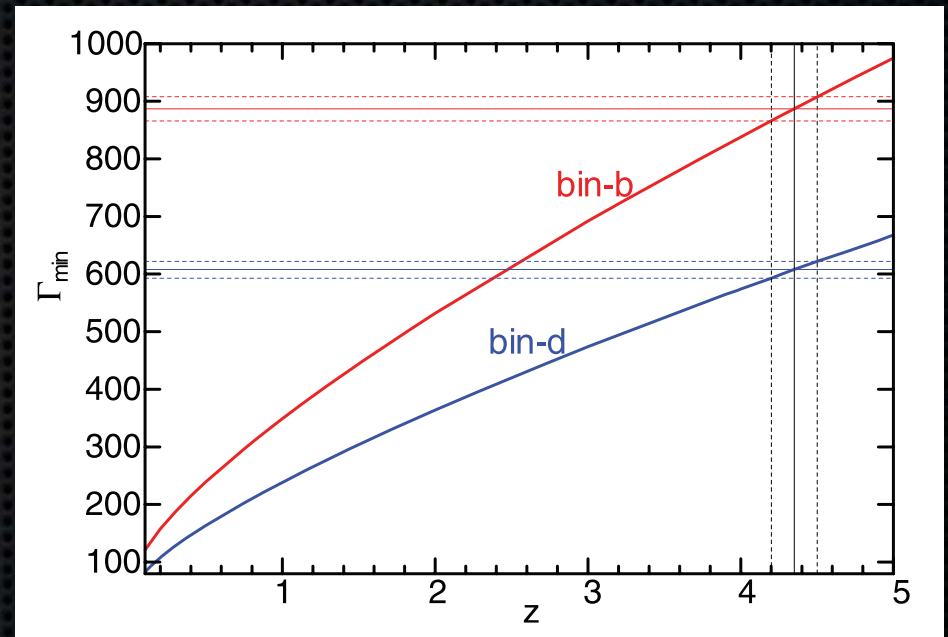


Hurley et al. 1994

- EGRET detected very long lived emission

Minimum Lorentz Factor

- ✦ No spectral rollover
 - ✦ $E_{\max} = 13.22 \text{ GeV}$
 - ✦ No $\gamma\gamma$ - attenuation
- ✦ $\Delta t \sim 2 \text{ sec}$ ($\sim R/c$)
- ✦ $z_{\text{phot}} \sim 4.2$
- ✦ $\tau_{\gamma\gamma}(E_{\max}, z, \Delta t, \Gamma, \beta) < 1$
- ✦ $\Gamma_{\min} \sim 870$



Abdo et al. 2009

Quantum Gravity Limits

- ✦ Lorentz invariance violations
- ✦ Frequency dependent c
- ✦ Delayed arrival time of γ s

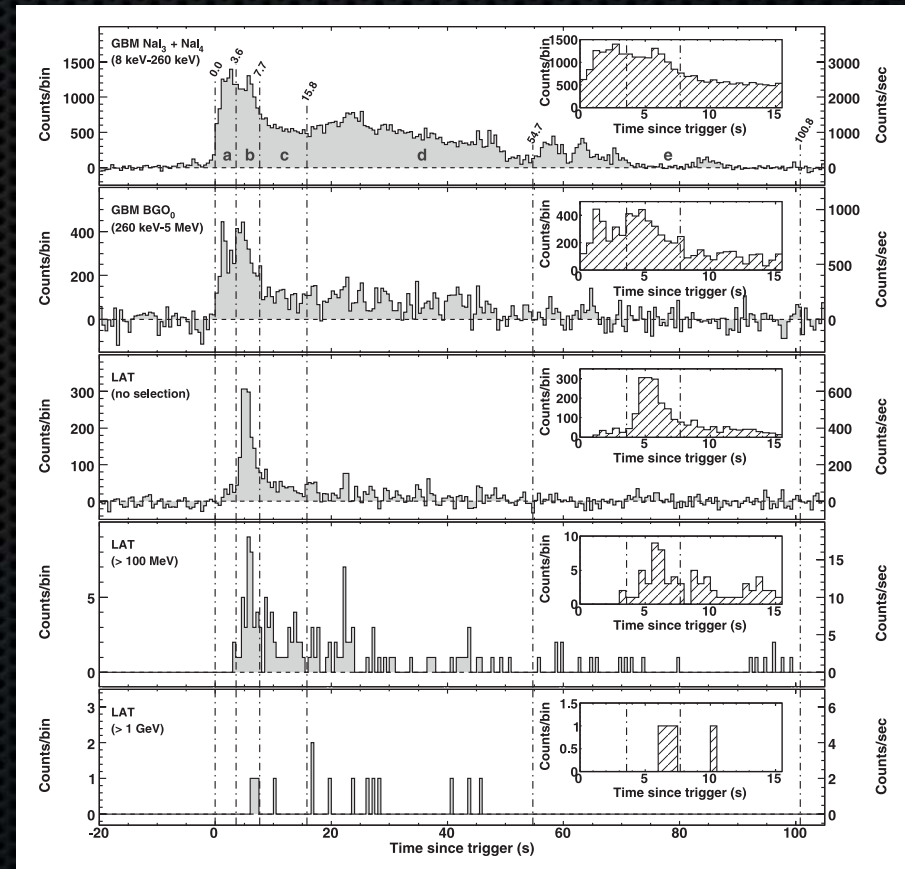
$$\Delta t \approx \frac{(1+n)}{2H_0} \frac{(E_h^n - E_l^n)}{(M_{QG,n} c^2)^n} \int_0^z \frac{(1+z')^n}{\sqrt{\Omega_M (1+z')^3 + \Omega_\Lambda}} dz'$$

Ellis et al. 2003

- ✦ $E_h = 13.22 \text{ GeV}$ and $0 < \Delta t < 16.54 \text{ s}$

- ✦ $M_{QG} > 1.3 \times 10^{18} \text{ GeV}/c^2$

- ✦ $M_{\text{planck}} = 1.22 \times 10^{19} \text{ GeV}/c^2$

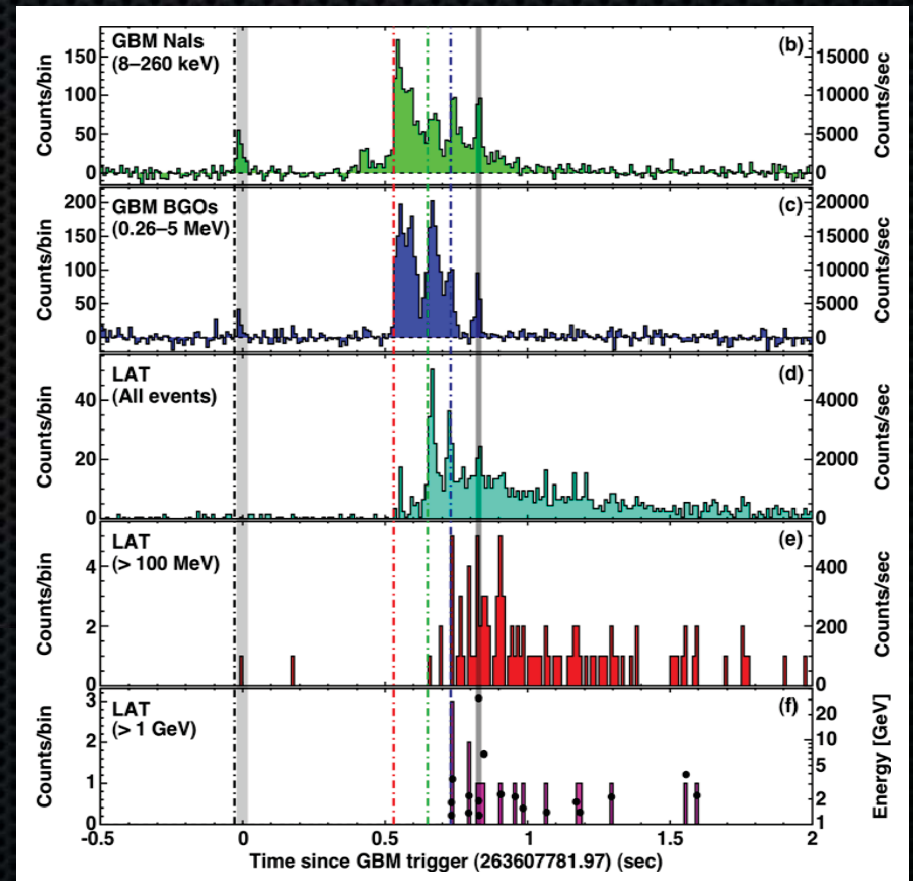


Abdo et al. 2009

Assumes the LAT emission wasn't emitted before t_0 !

GRB 090510

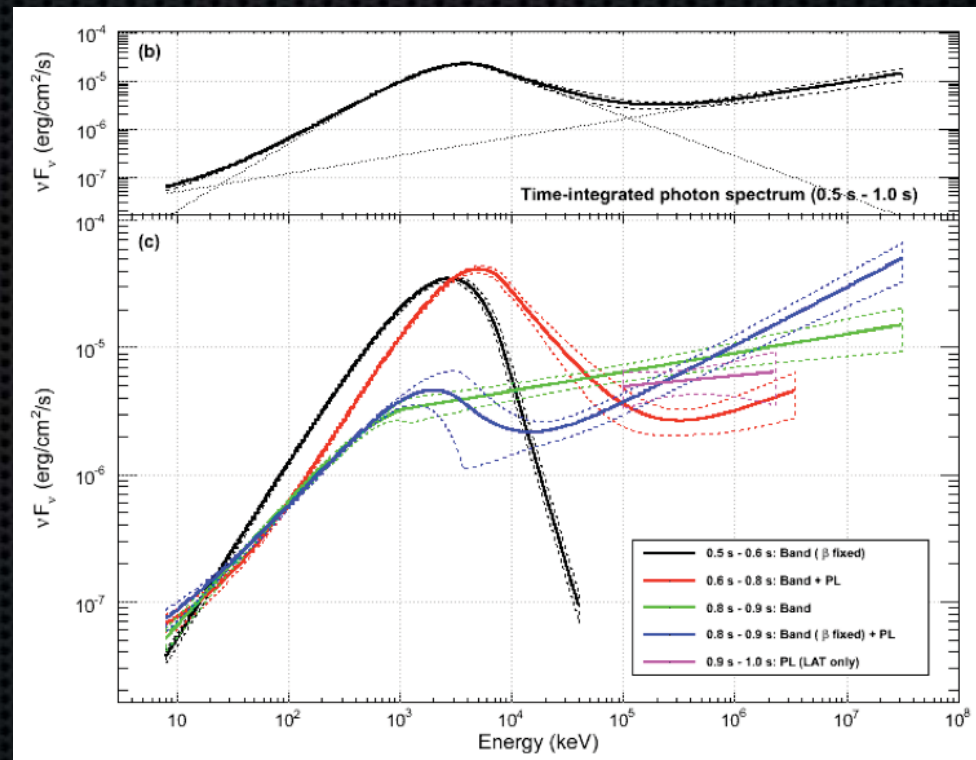
- Short GRB ($T_{90} \sim 2$ sec)
- $Z_{\text{phot}} \sim 0.903$
- $E_{\text{max}} = 31$ GeV
- $\Gamma_{\text{min}} \sim 1200$
- $M_{\text{QG}} / M_{\text{planck}} > 5.63$
- Delayed LAT emission
 - > 100 MeV begins $T_0 + 0.63$ s
- Extended LAT emission
 - 0.1 GeV detected to $T_0 + 200$ s



Abdo et al. Nature 2009

Extra Component in 090510

- Spectral Evolution
- Band + Power Law
 - $> 5 \sigma$ fit improvement
 - Delayed onset
- $E_{pk} \sim 3.9 \pm 0.3$ MeV
 - Highest Recorded
- PL Photon Index = -1.62
- No evidence of power law at low energies!

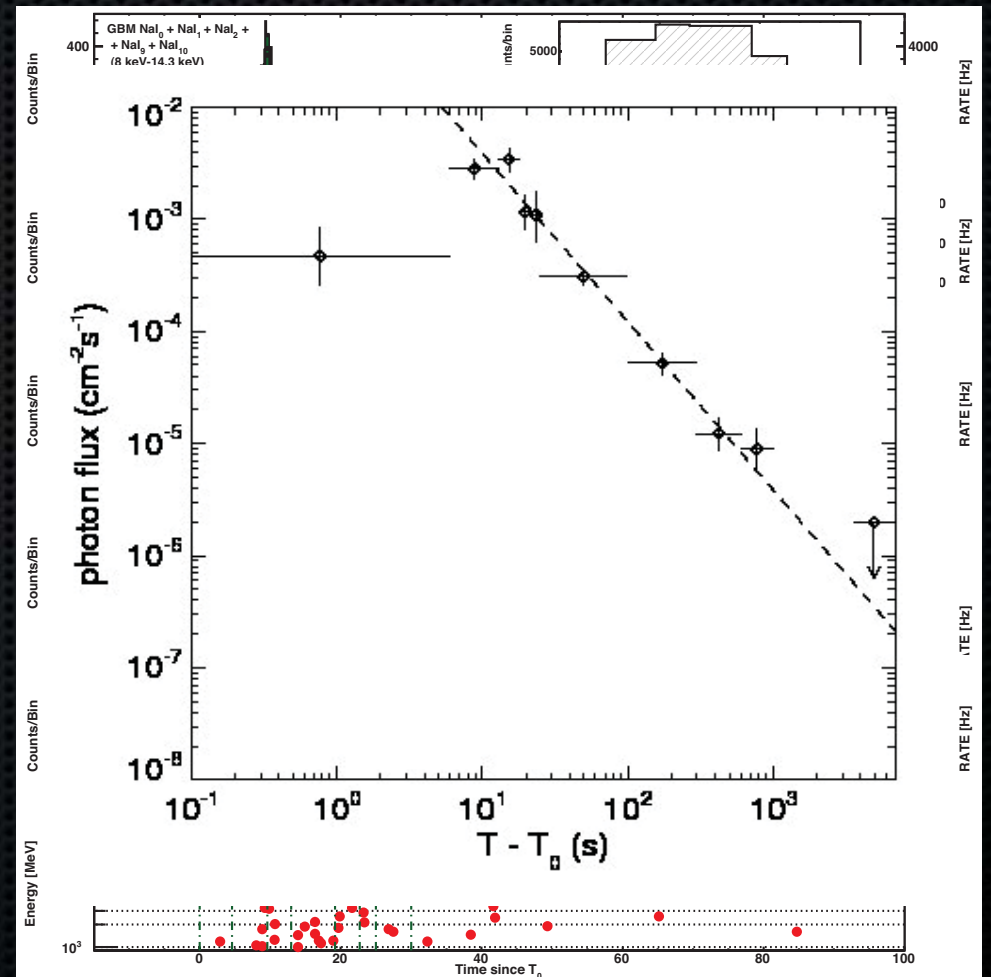


Abdo et al. Nature 2009

Raises all kinds of questions!

GRB 090902B

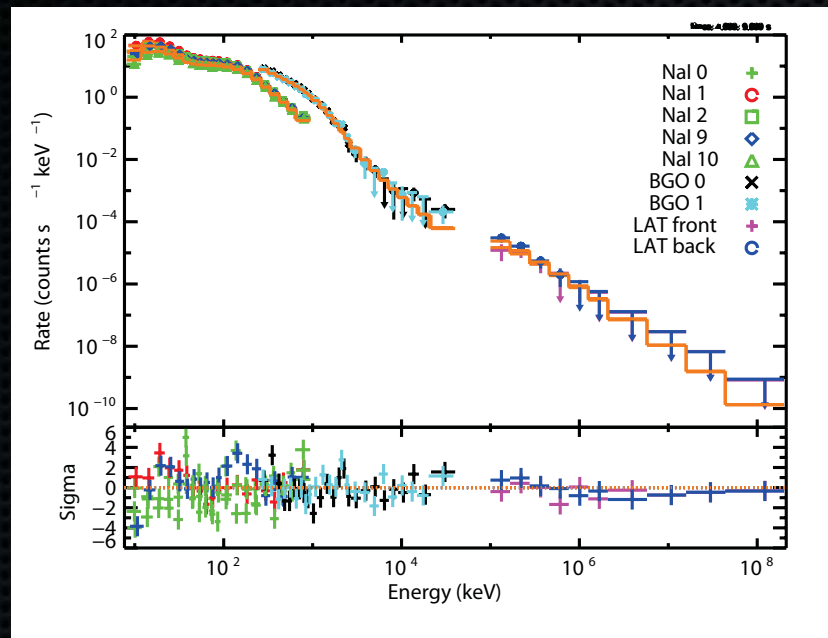
- ✦ Extremely bright long GRB
- ✦ Delayed LAT emission
 - ✦ > 100 MeV begins $T_0 + 10$ s
- ✦ Extended LAT emission
 - ✦ 0.1 GeV detected to $T_0 + 200$ s
 - ✦ Flux $\sim t^{-1.5}$
- ✦ Extra spectral component
 - ✦ Band + Power Law
 - ✦ Photon Index = -1.9



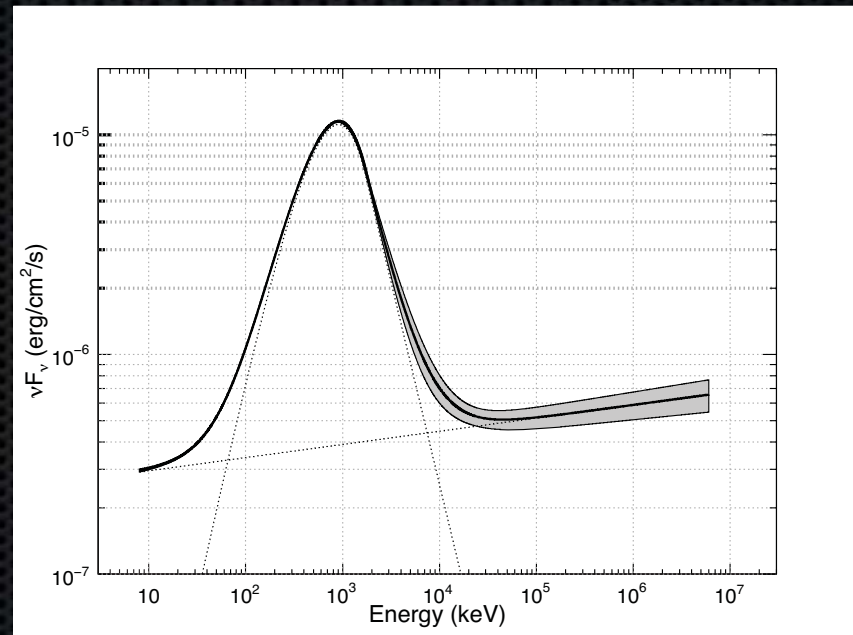
Abdo et al. 2009

Extra Components in 090902B

Abdo et al. 2009



Abdo et al. 2009



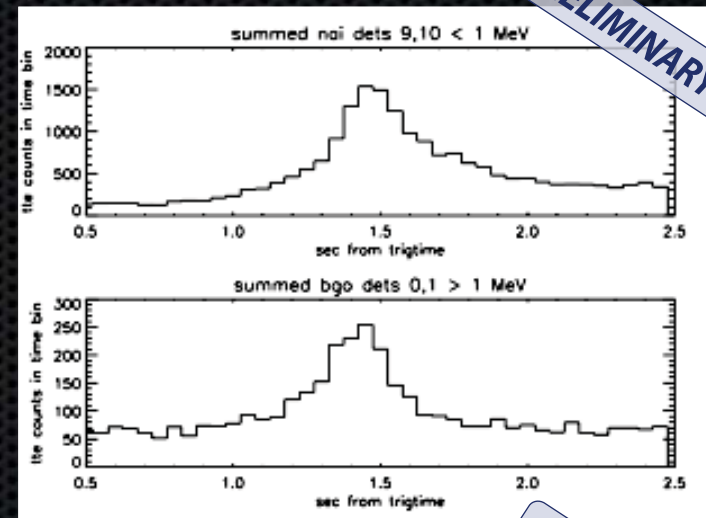
- Extra component at low and high energy!
- Low energy component consistent with extrapolation of HE power law
- Power law component = 24% of the total fluence

Summary of LAT Bursts

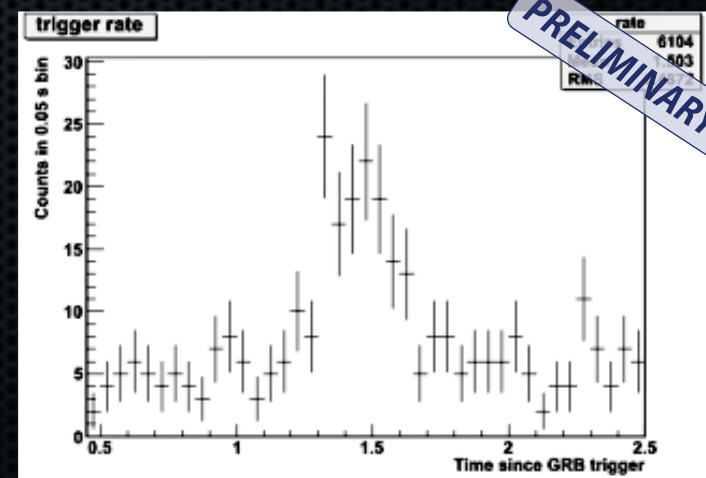
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090328	long	>10	—	—	✓	—	0.736
090510	short	>150	>20	✓	✓	~31 GeV	0.903
090626	long	—	—	—	✓	—	
090902B	long	>200	>30	✓	✓	~ 33 GeV	1.822

GRB 081215A

- GBM light curve:
 - Very hard, narrow pulse on top of broad emission episode
 - T90 ~ 7.7 sec
- LAT Light curve
 - Narrow, similar T90
- No delay in high energy emission!



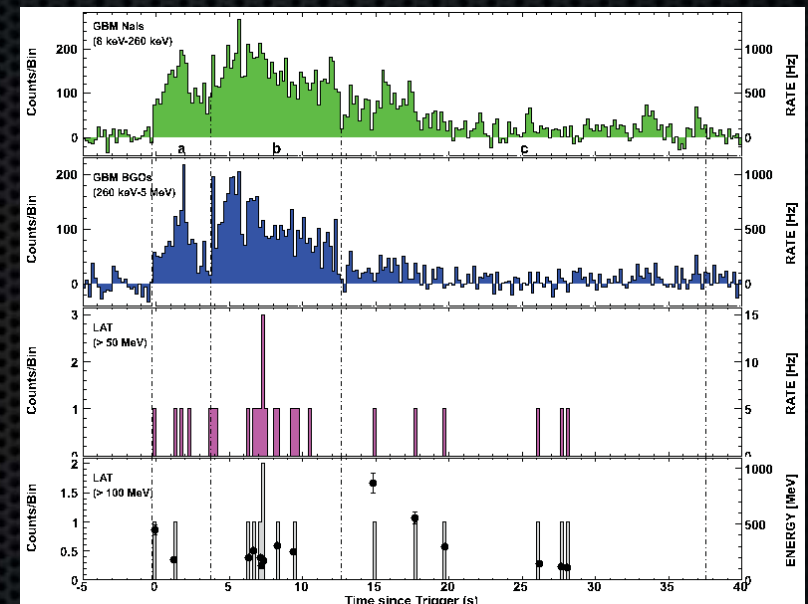
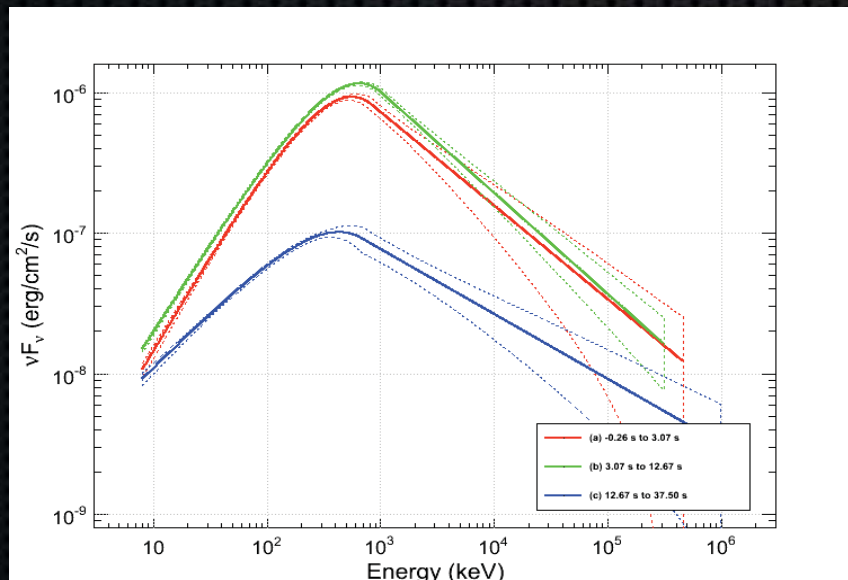
PRELIMINARY RESULTS



PRELIMINARY RESULTS

GRB 090217

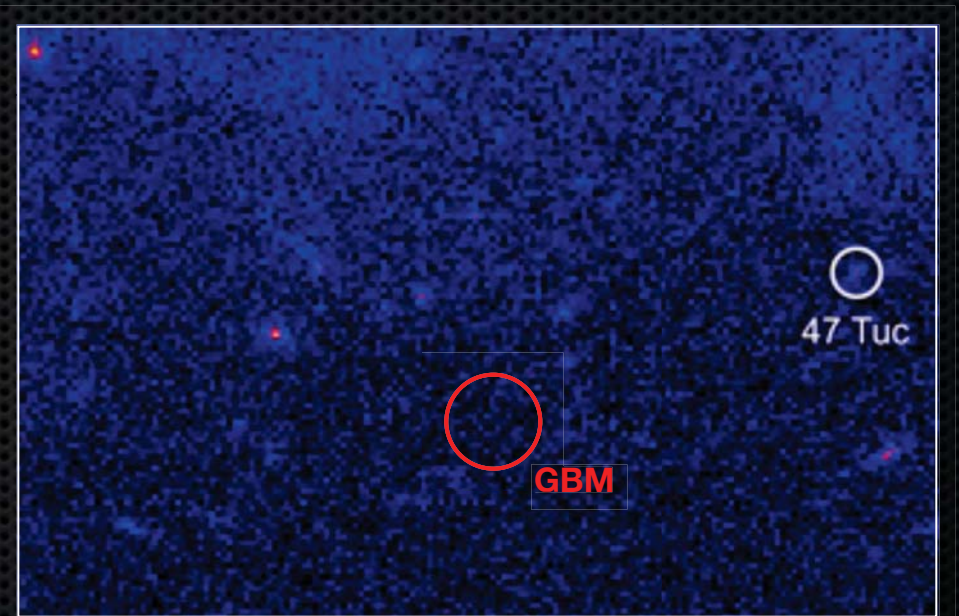
- ❖ No delay in HE emission
- ❖ > 100 MeV events detected from trigger
- ❖ Band model with no spectral evolution
- ❖ No extended emission



Delayed HE and extended emission trends to not extend to all LAT detected events!

LAT Upper Limits

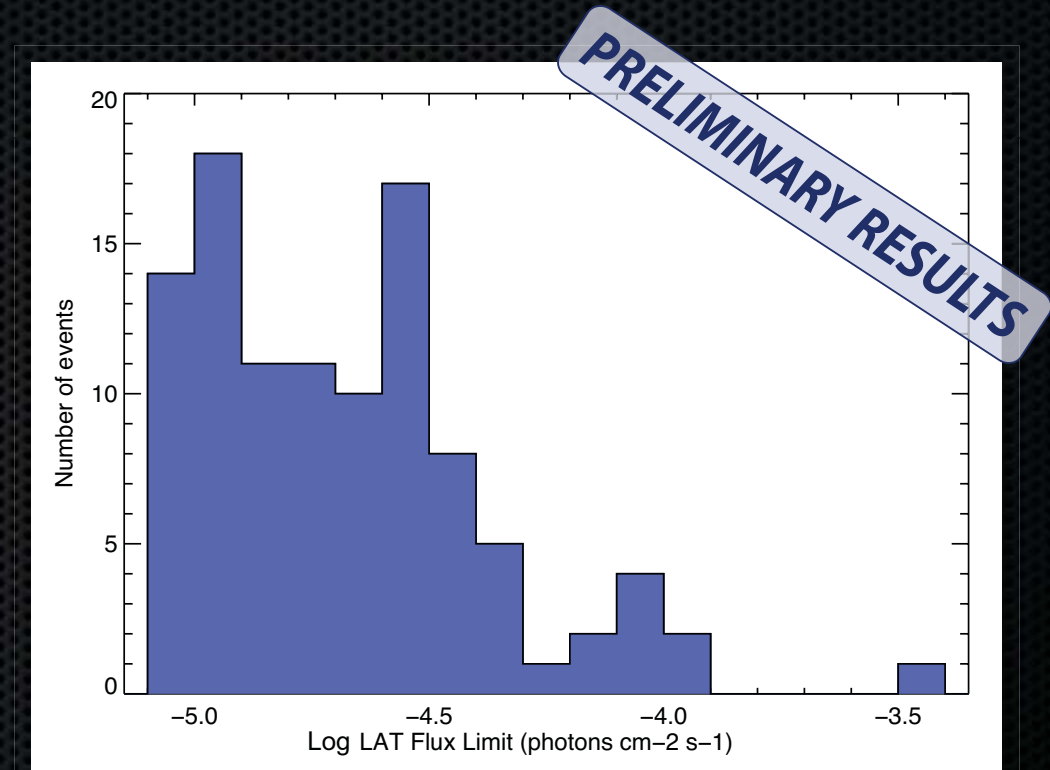
- What are the upper limits to the 0.1-300 GeV flux for GBM only bursts?
- Can we rule out high energy emission for these events?
- How do these upper limits compare to the expected flux?
- Could point to interesting physics
 - Intrinsic spectral breaks?
 - EBL or $\gamma - \gamma$ absorption?



LAT Count Map of hypothetical GRB Position

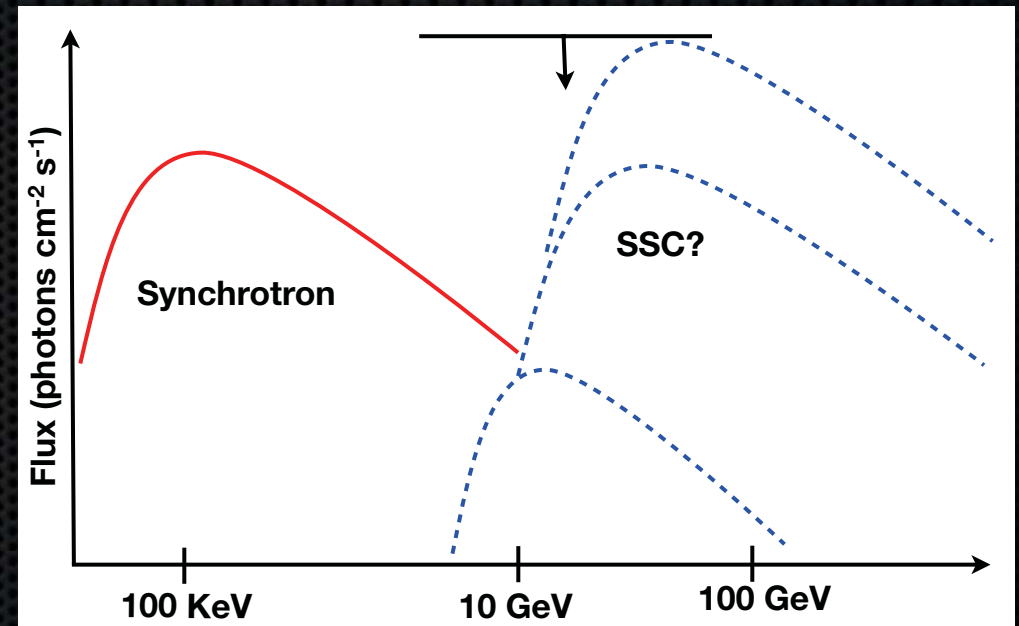
LAT Upper Limits (Year 1)

- GBM events in LAT FOV:
 - 121 events (47%)
- Events with flux upper limits
 - 104 events (40%)
 - Assume beta = -2.2
- Median flux limit (0.1 to 300 GeV)
 - $\sim 2.6 \times 10^{-5}$ photons $\text{cm}^{-2} \text{s}^{-1}$
 - Over T90 duration
- Implications for extra components?



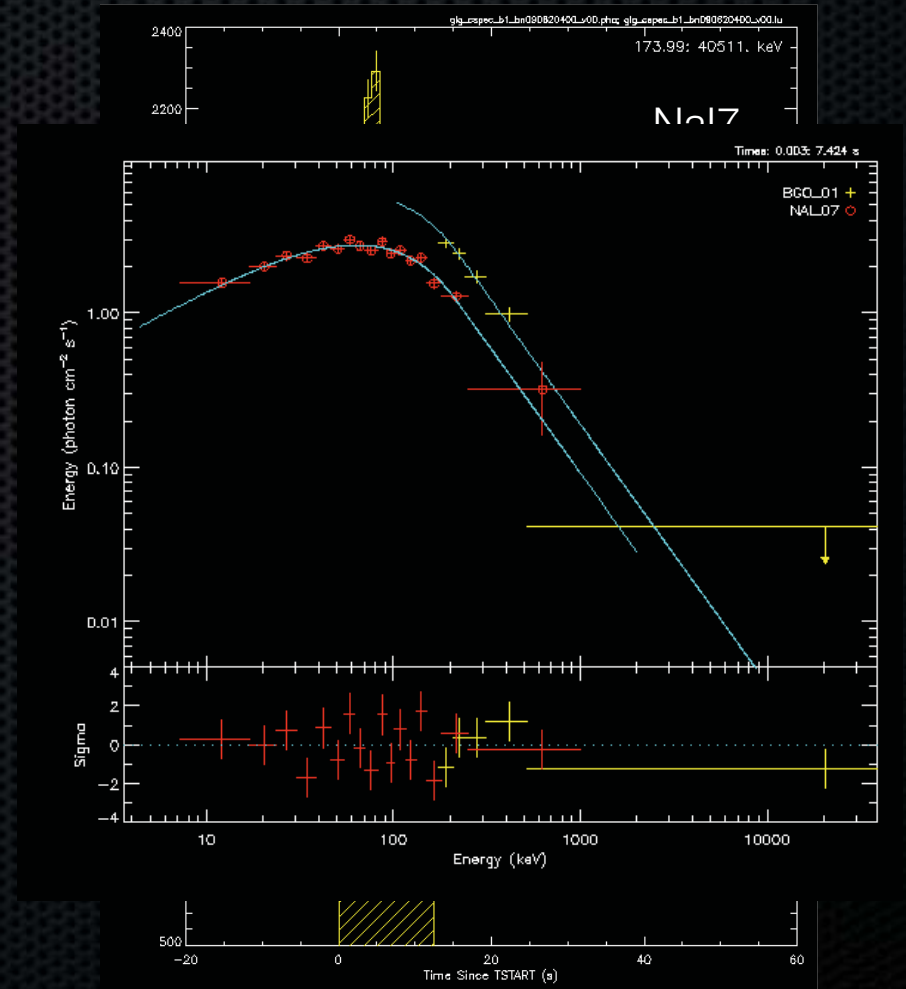
Extra Components

- SSC & pion decay components
 - No obvious evidence
 - Unless significantly delayed
- Implications of flux limits
 - $\gamma < 1, \epsilon_B > \epsilon_e$
 - $\gamma \gg 100, E_{pk_{SSC}} \gg 10 \text{ GeV}$
 - EBL attenuation?
- No evidence for EBL in any LAT event



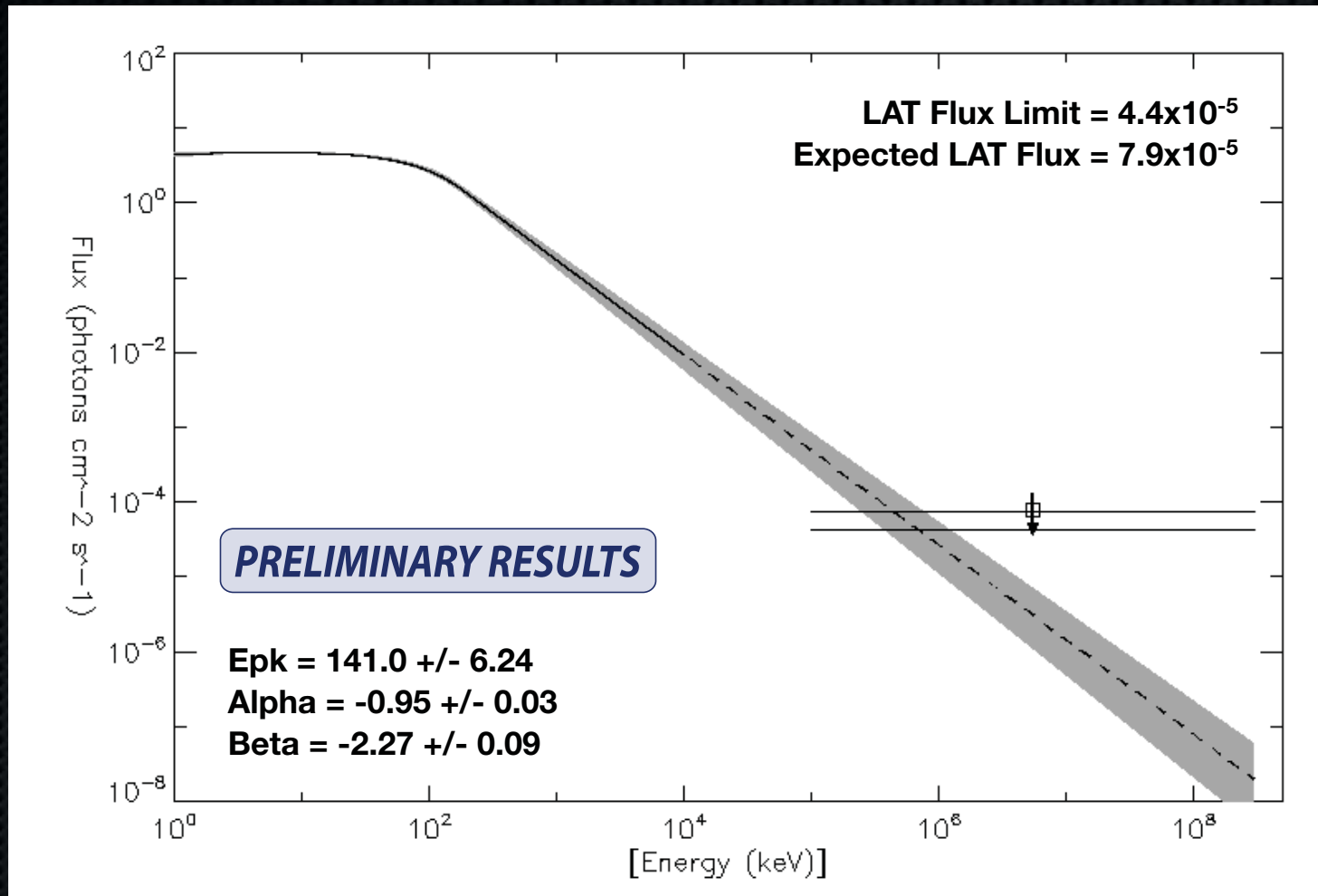
GBM Extrapolation

- Bright BGO Sample
 - GBM events with > 70 BGO cts
 - But no LAT detections
- 79 events
 - 33 in LAT FOV
- Performed spec fits with rffit
 - 15 events in “Gold” sample
 - Median beta ~ -2.3



GRB 090620.400

GRB 080925.775



- ✦ Spectral cutoff required to explain LAT non-detection!

Current Problems

- Power law index to GeV energies with no evidence of SSC
 - $\Upsilon < 1, \epsilon_B > \epsilon_e$
 - $\gamma \gg 100, E_{pk,SSC} \gg 10 \text{ GeV}$
- Delayed onset of high energy emission
 - Internal shocks with varying physical conditions?
 - Somewhat ad hoc
 - τ_{γ} - attenuation due to compactness?
 - No evidence for spectral cutoff in bursts seen with LAT
 - Proton synchrotron or photo-meson cascade?
 - Requires a very high energy budget

Current Problems (continued)

- Long lived high energy emission
 - Angle dependent scattering effects?
 - Synchrotron self-Compton from the forward shock?
 - Photo-meson cascade?
- Extra spectral component at high energies
 - Synchrotron self-Compton emission
 - Hard to produce delay unless microphysical parameters vary rapidly
 - Hadronic component (proton synchrotron or photo-meson processes)?
 - Proton synchrotron requires much higher energy budget!

Current Problems (continued)

- Extra spectral component at high & low energies
 - Cannot be synchrotron self-Compton emission
 - Proton synchrotron or photo-meson with secondary pairs at low energies
 - Taxing the overall energy budget of the system!
 - Photospheric model (thermal & non-thermal emission)
 - Fits show no improvement over Band + Power Law
- Evidence for spectral cutoffs in some GBM only bursts
 - Lower end of the Lorentz distribution?
 - Is the Lorentz distribution continuous, bimodal?

Conclusions

- ✦ 291 GBM detections, 11 LAT detections
- ✦ Power law index to GeV energies with no evidence of SSC in at least one burst
- ✦ Very high Lorentz factors in all LAT detected bursts
- ✦ Strong limits on the effects of quantum gravity in several burst
- ✦ Delayed onset of high energy emission in some bursts while not in others
- ✦ Long lived high energy emission in most LAT burst
- ✦ Extra spectral component at high & low energies in 1 burst
- ✦ Evidence for spectral cutoff on some GBM only events
- ✦ Lots of interesting problems in need of clever ideas!