Fermi LAT Gamma-ray Burst Highlights

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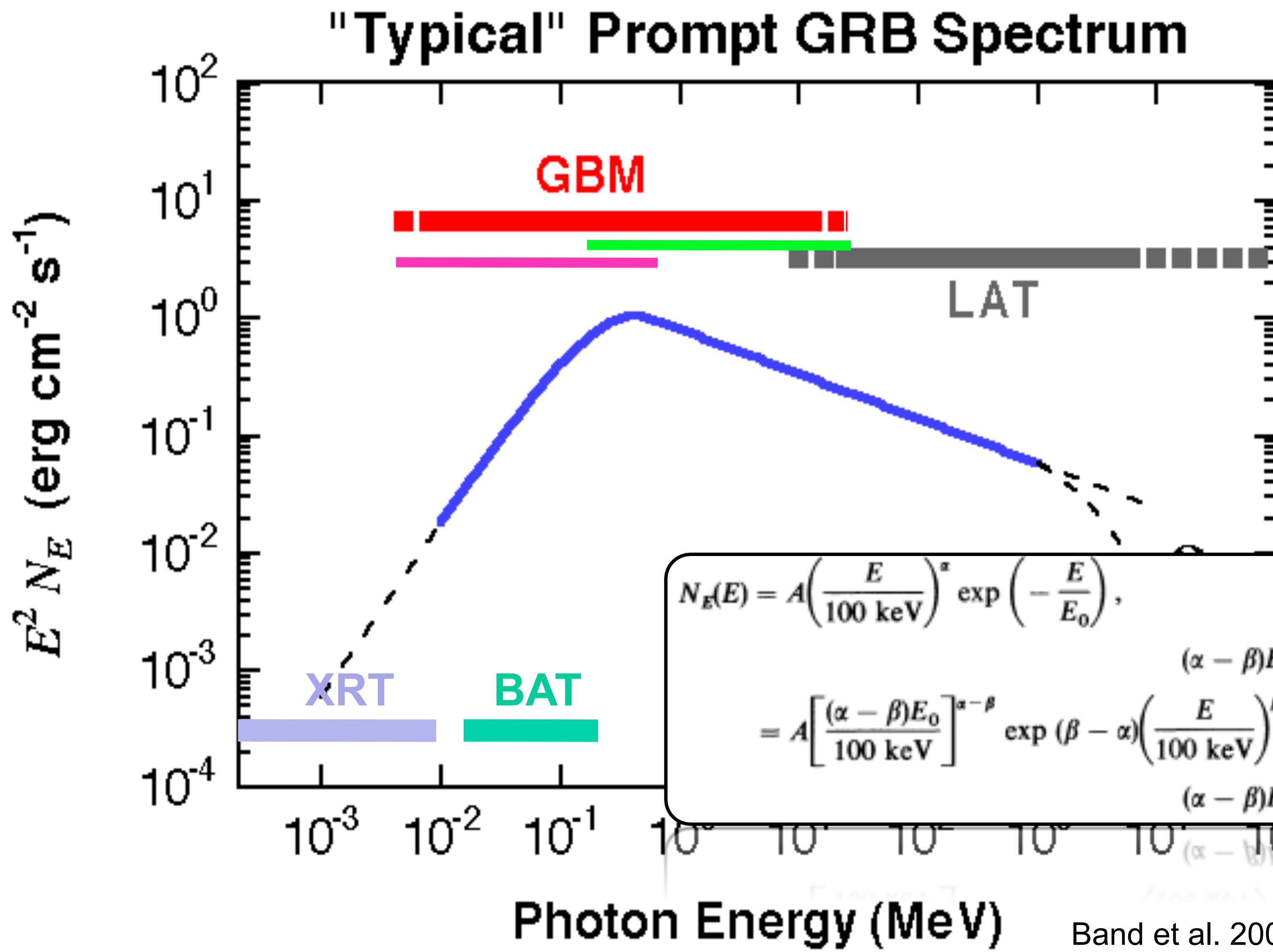
(NASA/GSFC)

Fermi Summer School 2014

How does Fermi add to our understanding of GRBs?



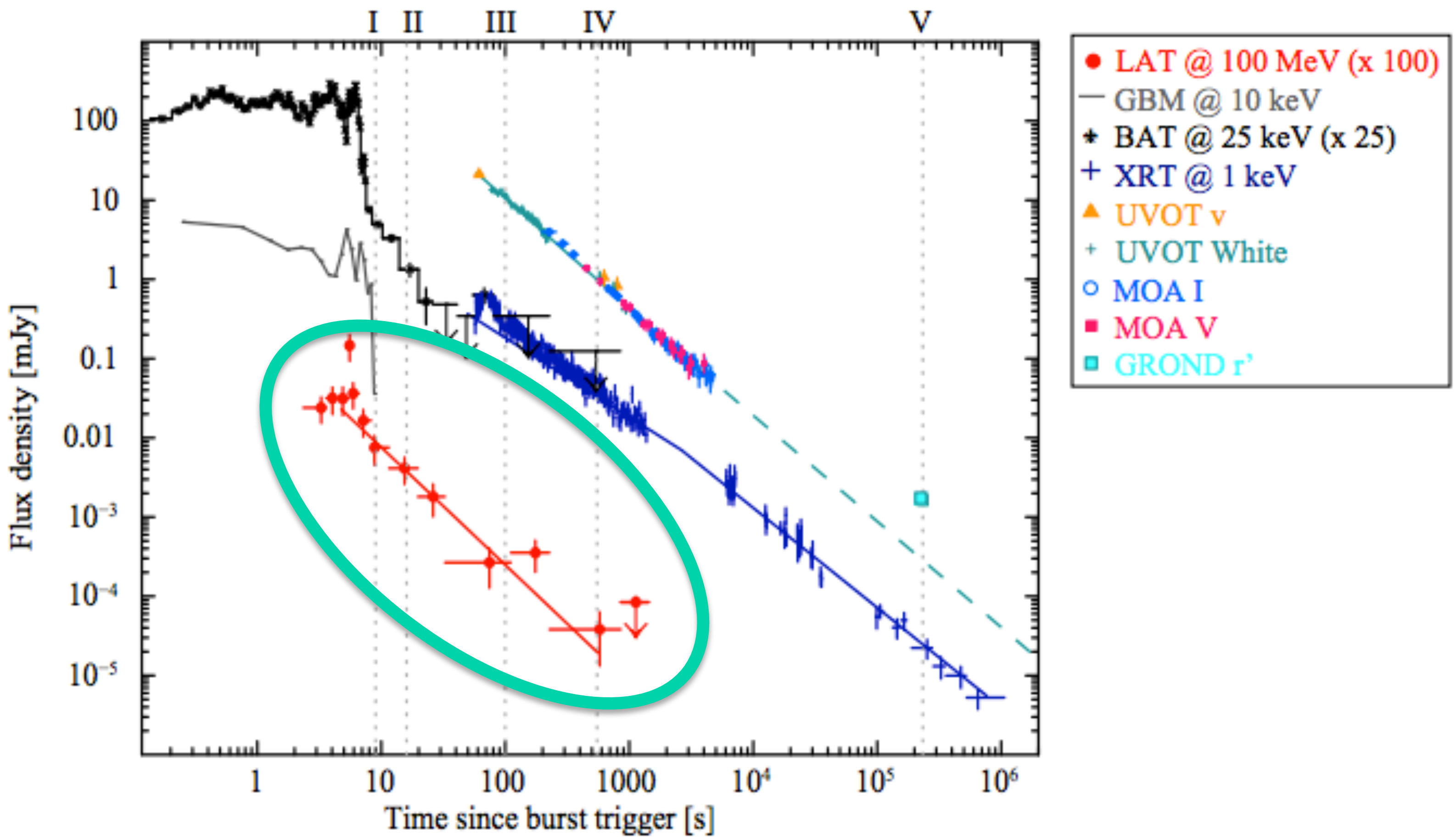
$$N_E(E) = A\left(\frac{E}{100\ \mathrm{keV}}\right)^{\alpha} \exp\left(-\frac{E}{E_0}\right), \quad (\alpha-\beta)E_0 \geq E,$$

$$= A\left[\frac{(\alpha-\beta)E_0}{100\ \mathrm{keV}}\right]^{\alpha-\beta} \exp(\beta-\alpha)\left(\frac{E}{100\ \mathrm{keV}}\right)^{\beta}, \quad (\alpha-\beta)E_0 \leq E, \quad (1)$$

Band et al. 2009

How does LAT add to our understanding of GRBs?

GRB 110731A

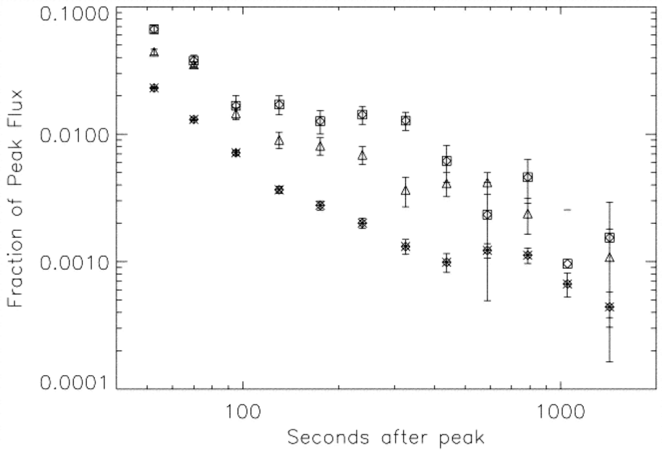


Ackermann et al 2012

What did we know about high energy GRB emission before Fermi?

- Band Functions worked most of the time
  - Power laws and cutoff power laws were sometimes all that could be constrained (especially with narrower coverage – e.g. BAT)
  - Hints from BATSE of low energy excesses
- A couple of BATSE and EGRET GRBs showed some long-lasting emission
- One case of extra power-law component in an EGRET burst

Emission tails in BATSE GRBs

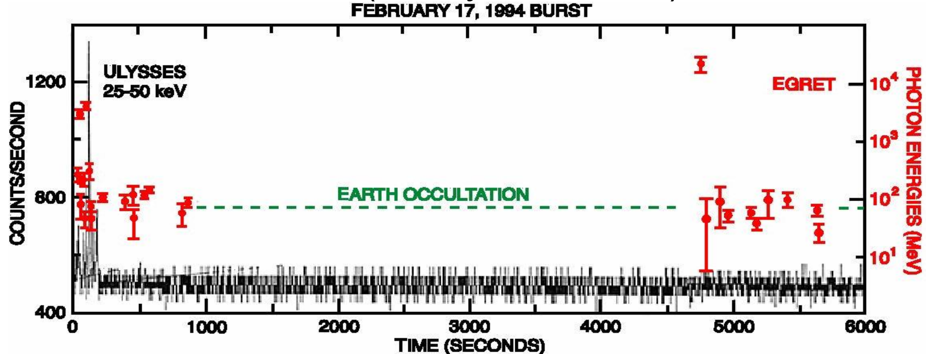


Connaughton et al. 2002

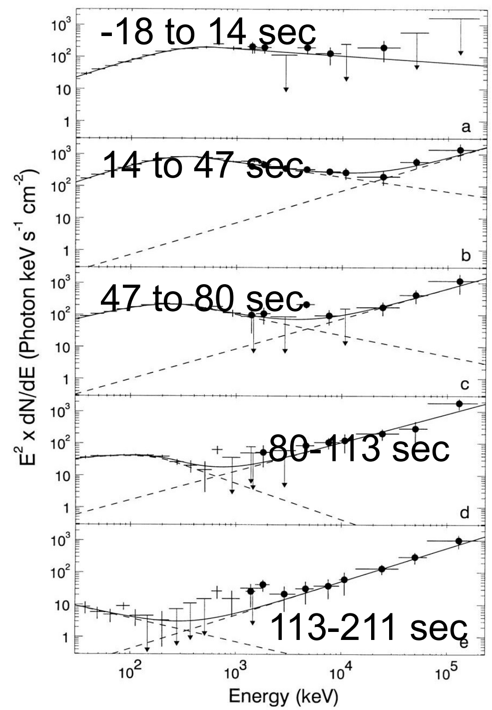
High energy emission from GRBs: Pre-Fermi era

- **Little known about GRB emission above ~100 MeV**
- **EGRET detected only 5 (long) GRBs, most notably:**
  - **GRB 940217: GeV photons were detected up to 90 minutes after the GRB trigger**
  - **GRB 941017: distinct high-energy spectral component (up to 200 MeV), with a different temporal evolution & > 3 times more energy**

GRB 940217 (Hurley et al. 1994)



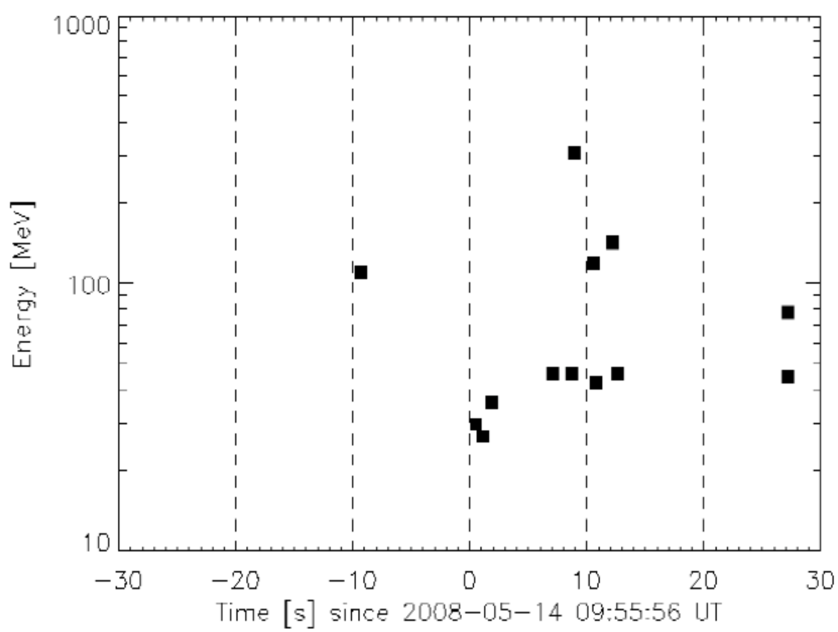
GRB 941017 (Gonzalez et al. 2003)

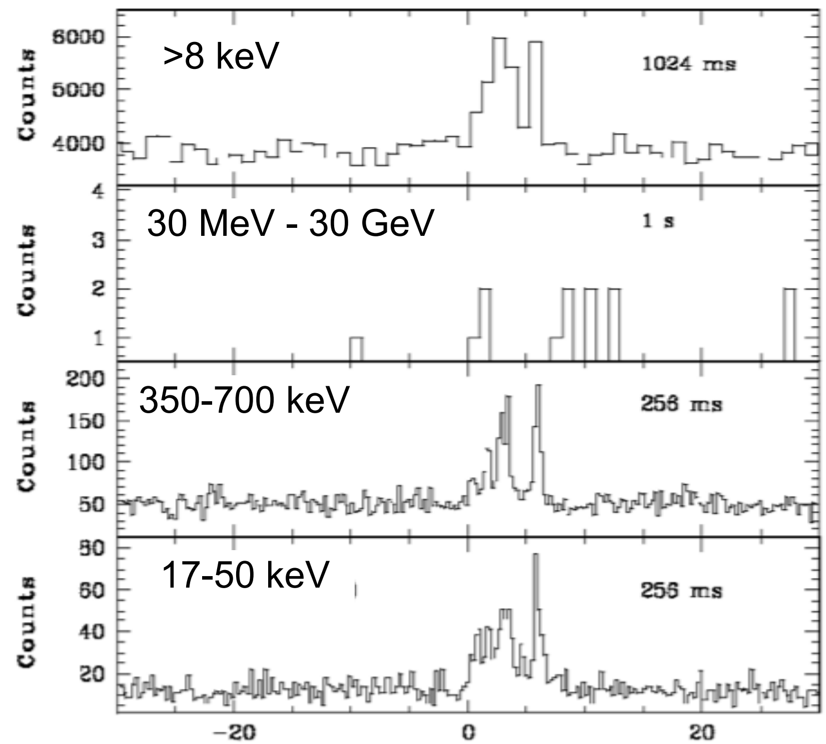


BATSE EGRET

High energy emission from GRBs: Pre-Fermi era

- **AGILE observed GRB 080514B and detected photons up to a few 100 MeV lasting somewhat longer than the soft gamma-rays**

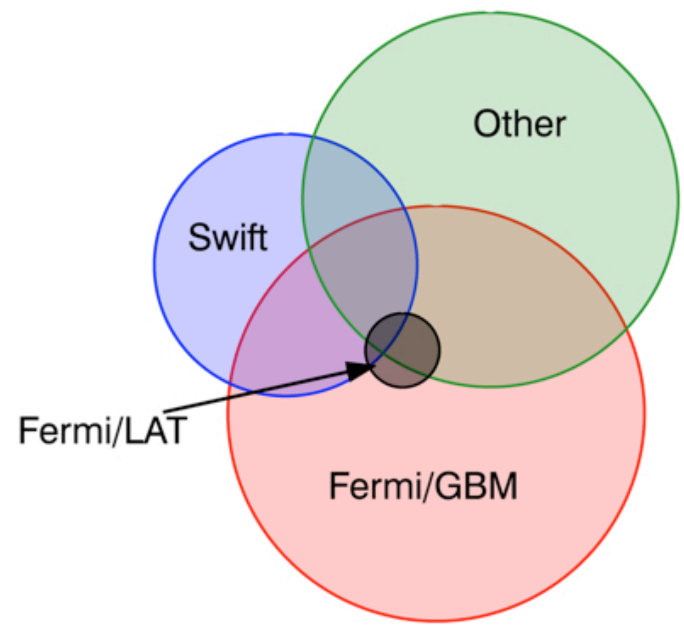




Giuliani et al. 2008

Fermi GRB Observations

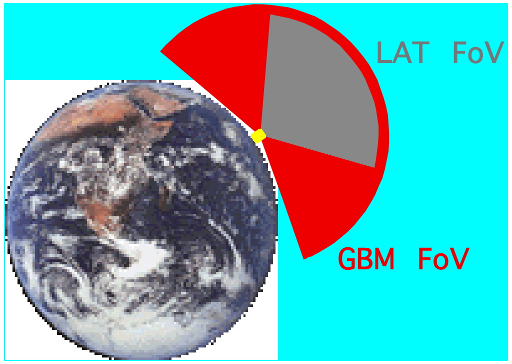
- Including bursts from Aug 2008-May 2014
  - ~550 Swift GRBs
  - ~1400 Fermi-GBM GRBs
  - ~80 Fermi-LAT GRBs
  - ~1000 Other (AGILE, Suzaku, Konus, INTEGRAL, etc.)
- Limitations
  - ~300 Swift GRBs with no high energy (>150 keV) observations
  - ~1200 poorly localized GRBs without afterglow observations
- Best Observed Subset
  - Those with both high and low energy coverage



Credit: A. Goldstein

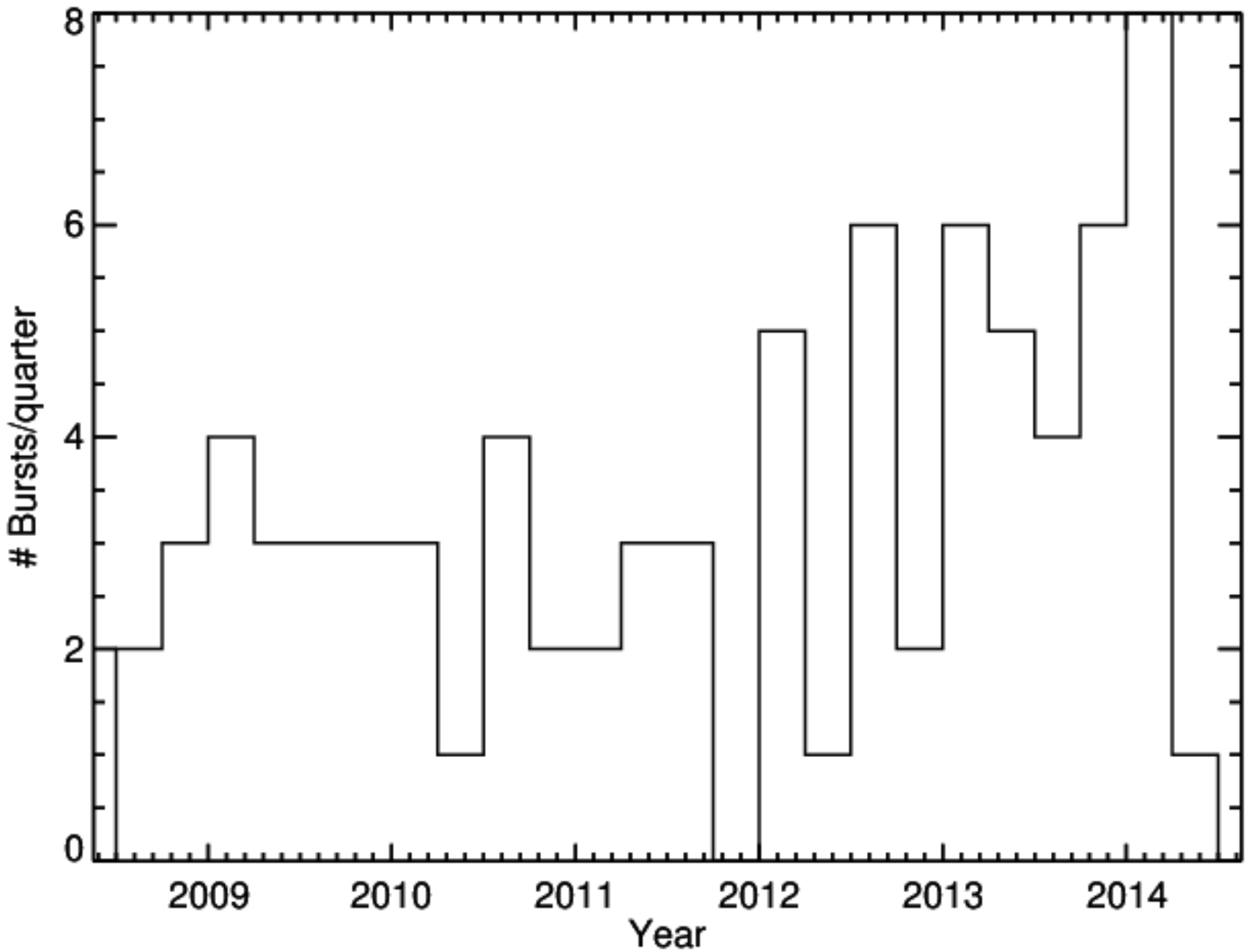
Fermi GRB Observations

- GBM triggers
  - Onboard localization (5-10 deg radius)
    - Followed by automatic ground localization (3-5 deg radius)
    - Human in the loop position (taking into account subjective decisions like interval and energy range)
    - (Adam already discussed a lot of this)



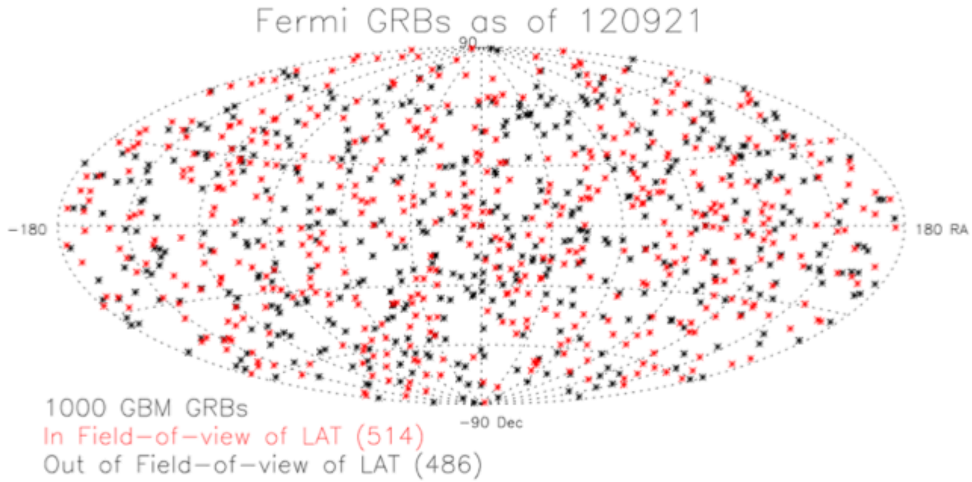
  - If high peak flux, or high fluence criteria are met -> ARR
    - triggers Autonomous Repoint Request (ARR)
    - LAT centers GRB in FoV for 2.5 hours (except when occulted)
    - Better effective area by bring burst into central area of detector
    - Improves temporal coverage for light curve to compare to broadband measurements
    - Background in GBM & LLE can be problematic due to slew
    - Occur with rate of ~1/month

LAT GRB Detections

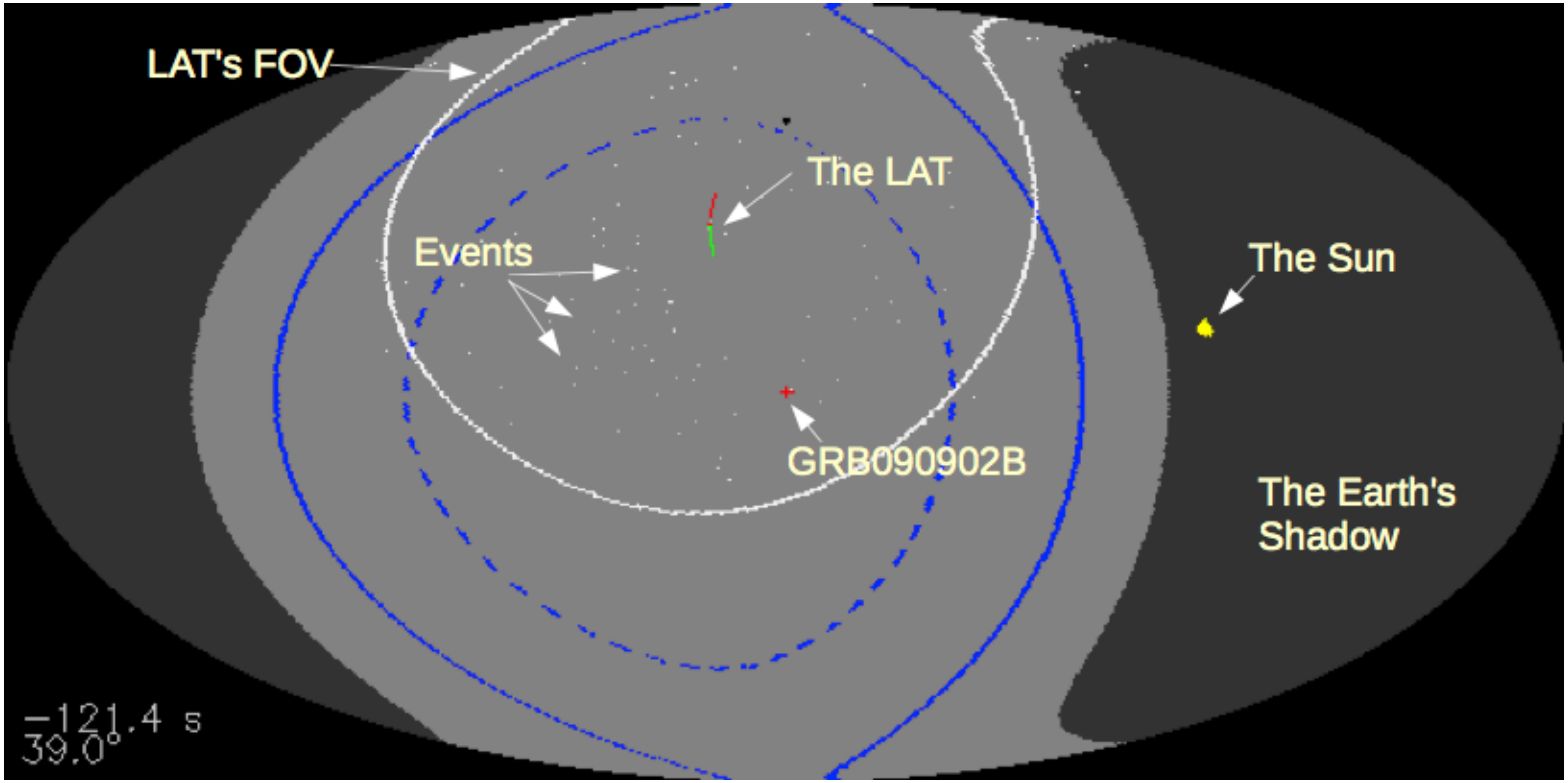


Fermi GRB Observations

- LAT observations begin
  - Onboard trigger (has occurred twice GRB 090510, 131108A, but algorithm has been improved over time)
  - Data comes to ground and is processed in ~8-12 hours
  - Ground analysis finds positions (automated scripts + humans)
  - LAT position disseminated to world (errors ~0.1-1 deg radius)
- Swift Follow-up (ideally)
  - Tiled or single pointing observations with XRT/UVOT
  - Arcsec position sent to world via GCN (gamma-ray coordinates network)
  - Ground-based telescopes find afterglow, get spectrum and redshift

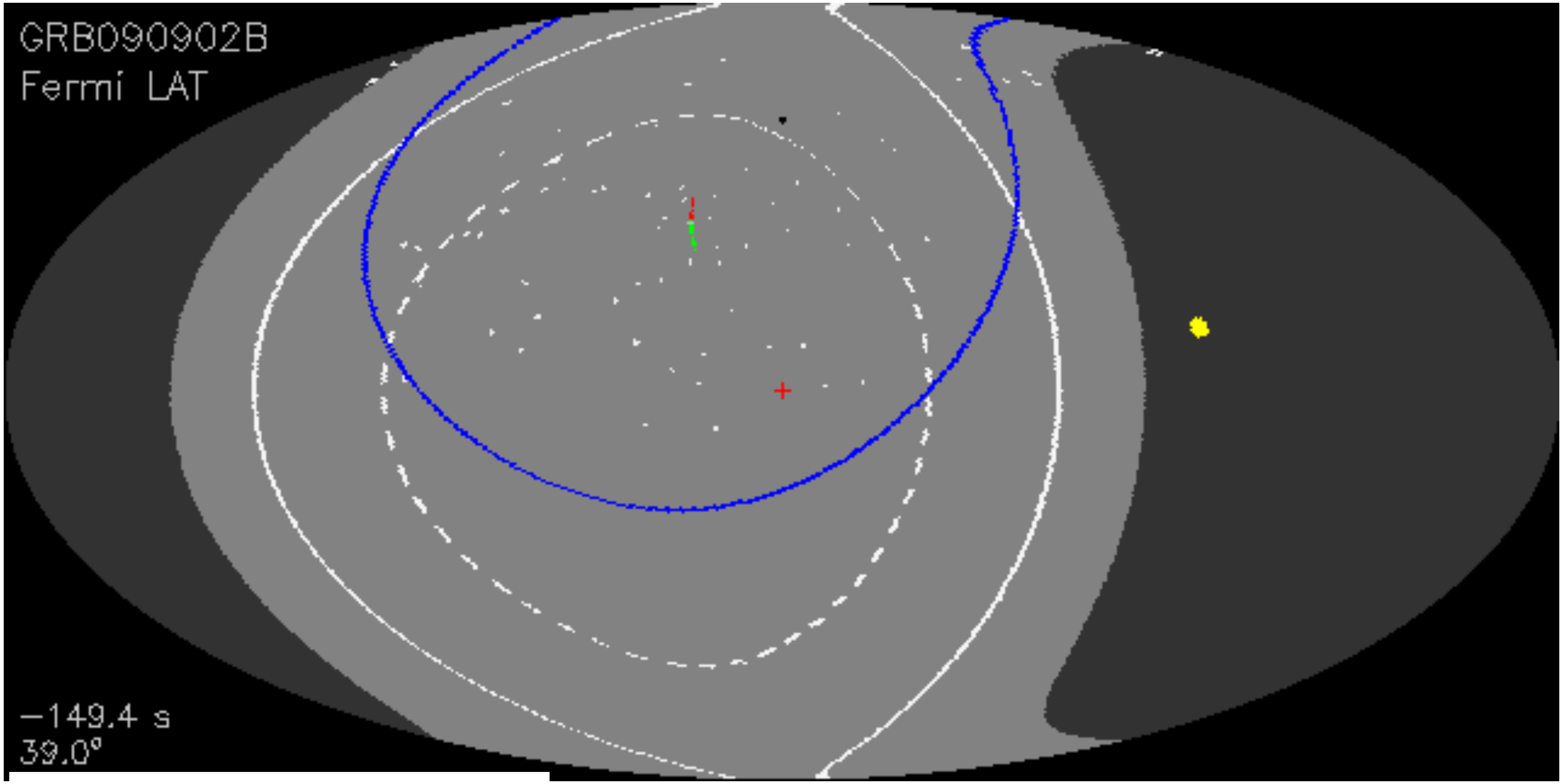


Autonomous Repoint Towards a GRB



- Red cross → GRB090902B
- Red/Green lines → The LAT
- White points → Detected events
- White circle → LAT Field of View
- Dark gray region → Earth's shadow
- Yellow dot → Sun

Autonomous Repoint Towards a GRB



- Red cross → GRB090902B
- Red/Green lines → The LAT
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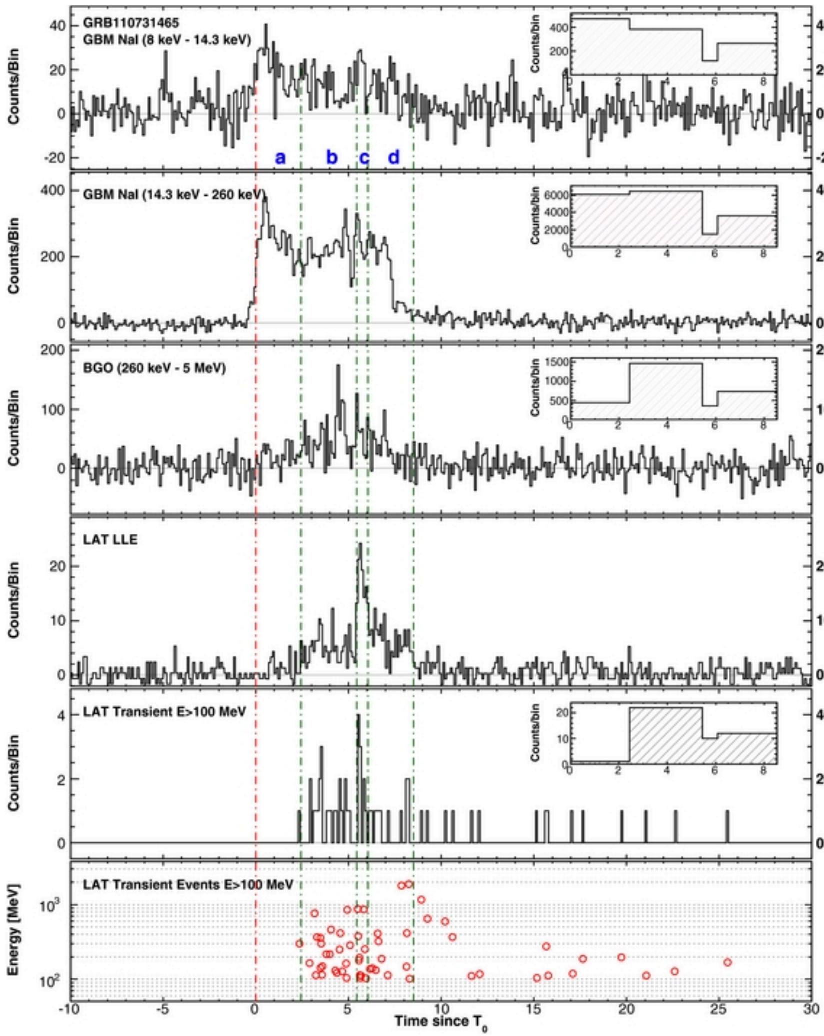
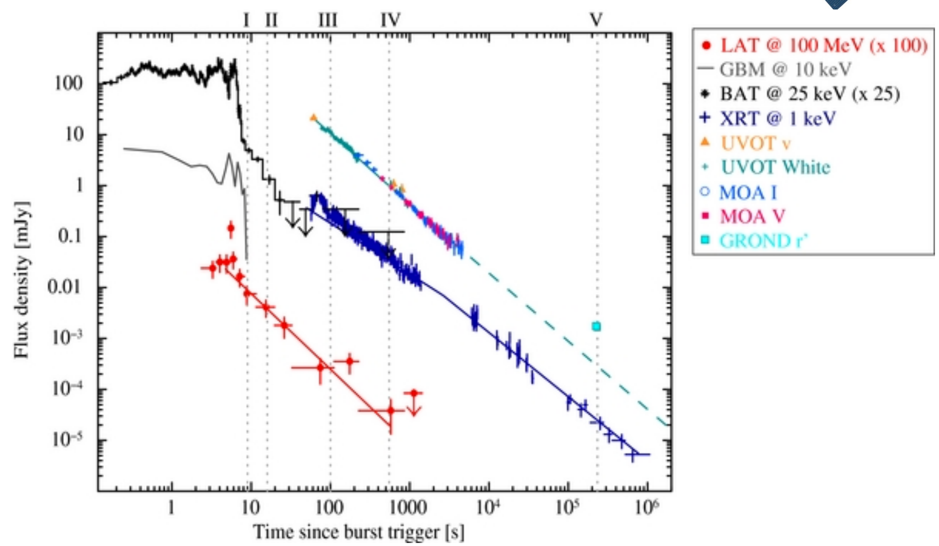
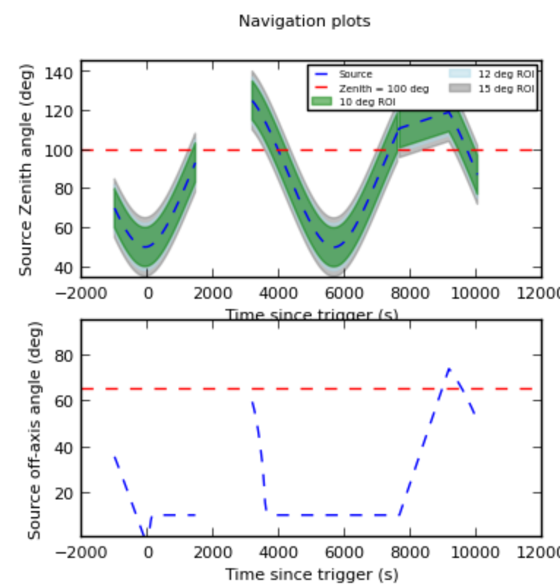
Fermi Observations of a GRB

GRB 110731A



Ackermann et al. 2012

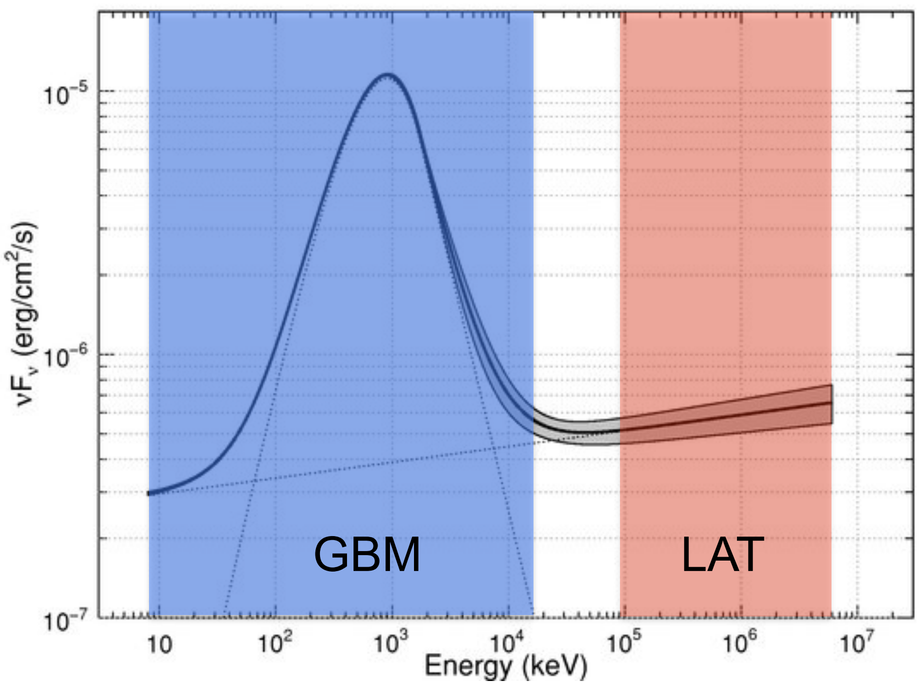




Common New Features in Bright Fermi GRBs

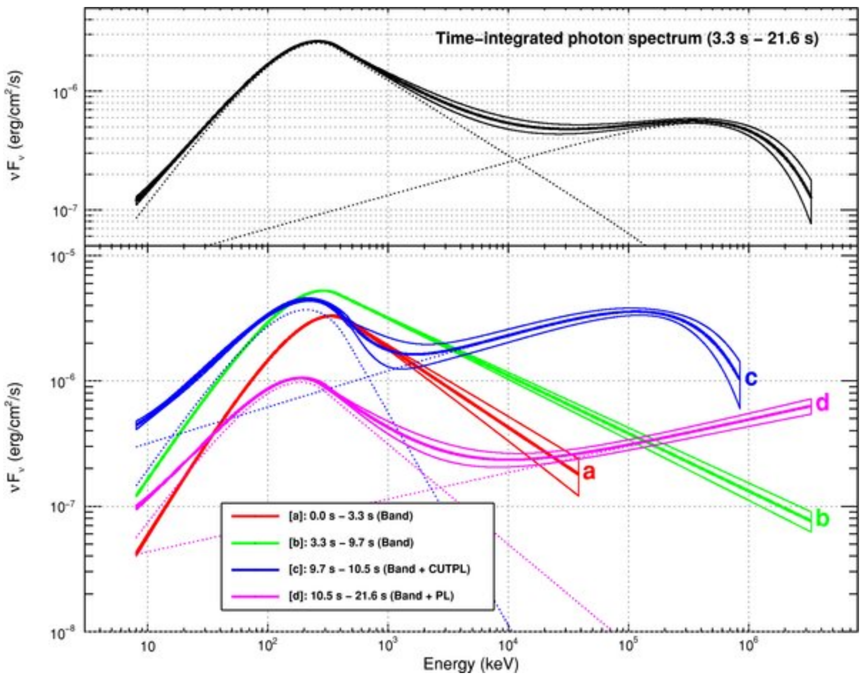
- **GRB spectra deviate from Band functions**
  - **Low energy deviation**
  - **Additional power law at high energies**
  - **High energy cut-offs is some cases**

GRB 090902B



Abdo et al. 2009, ApJ, 706L, 138A

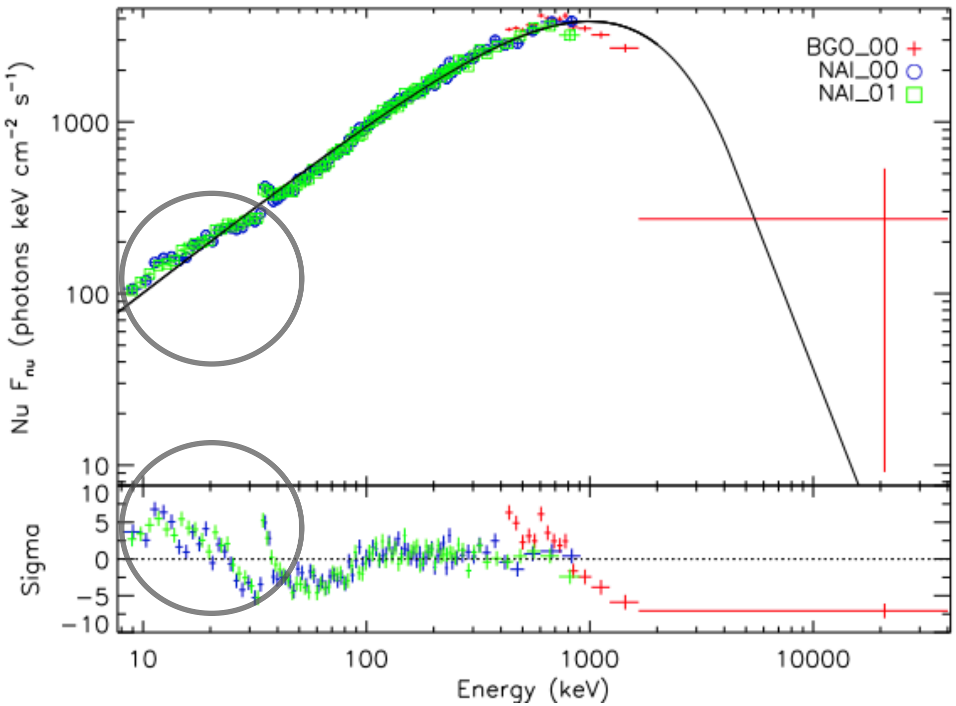
GRB 090926A



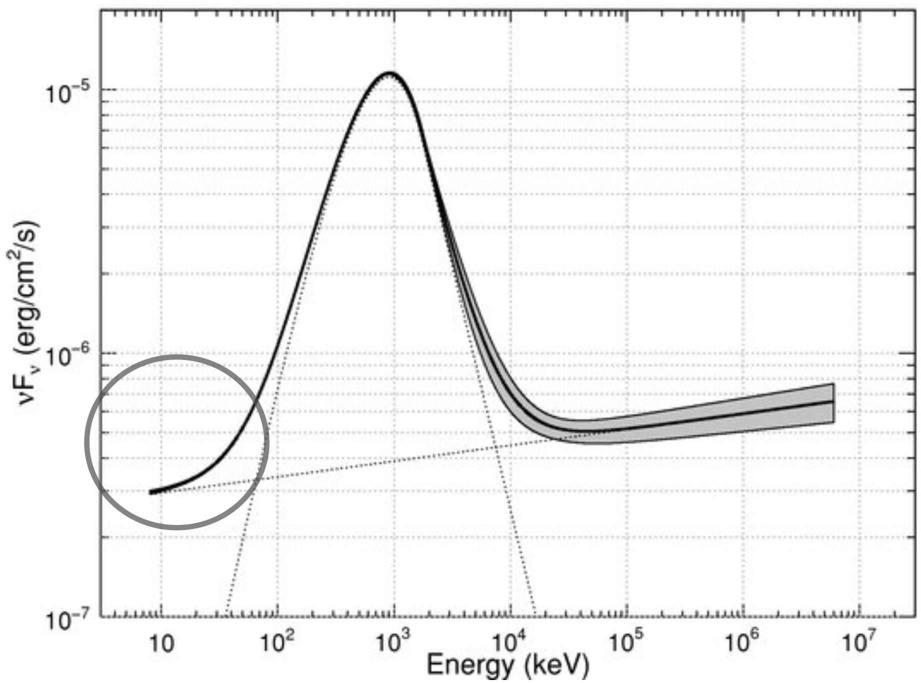
Ackermann et al. 2011, ApJ, 729, 114

Low-Energy Excess

GRB 090902B



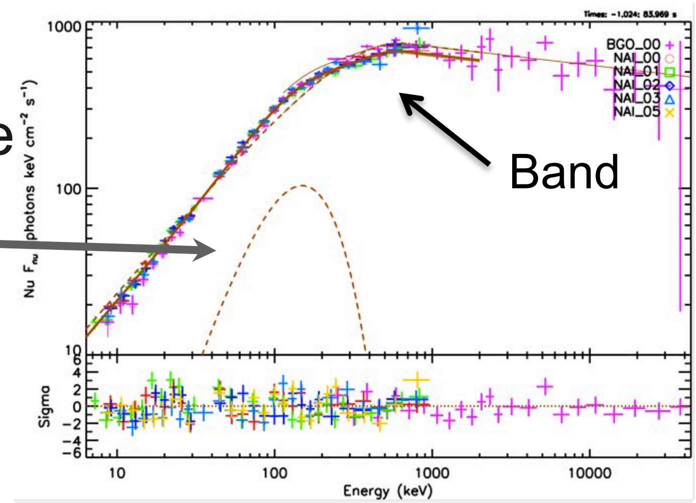
Tierney et al. 2013



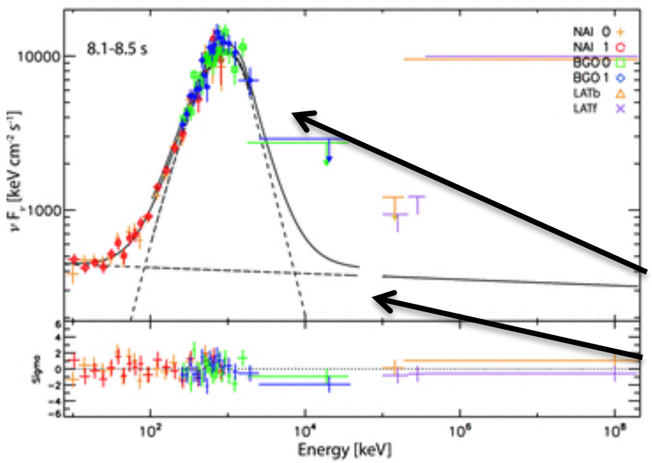
Abdo et al. 2009, ApJL 706, 138

Thermal Emission - Photospheric?

GRB 100724B



GRB 090902B

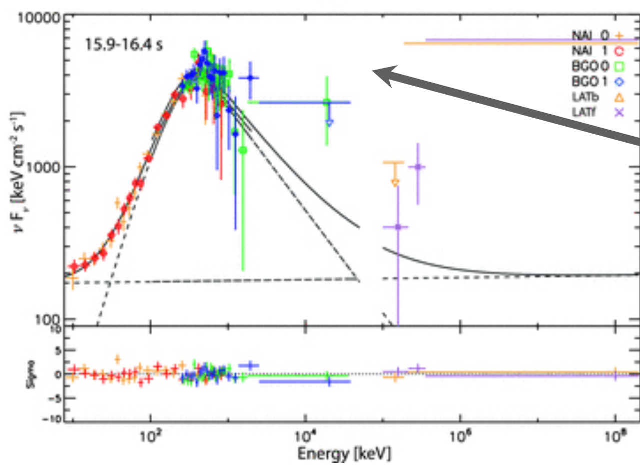


Sub-dominate Blackbody

Band

Dominate Blackbody + power law

Guiriec et al. 2011, ApJL 727, L33



Broadening not consistent with Band function

Ryde et al. 2011, MNRAS 415, 3693

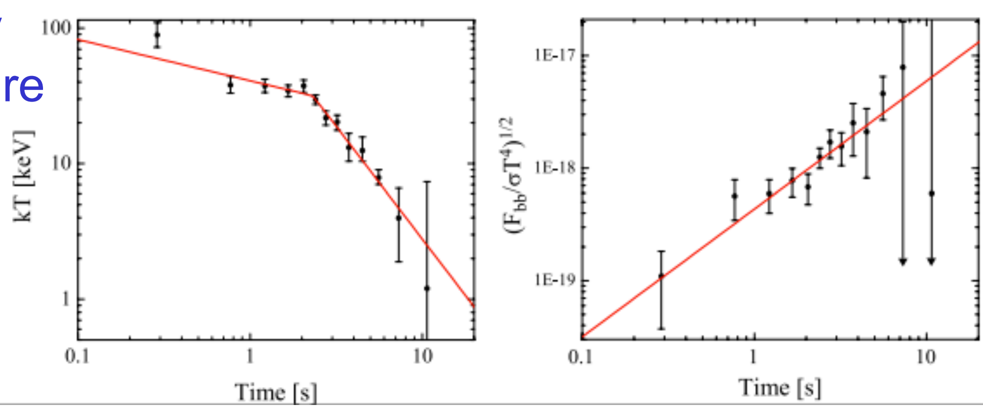
Photospheric Emission

- **Blackbody emission from turbulent relativistic outflow**
- **Deviations from Band function**
- **Thermal photosphere does not have to emit as a perfect blackbody – smeared by multiple temperatures, evolution, different emission regions**
- **However, GRB 090902B is best fit by a dominant blackbody component + power law**
- **Low energy excess in many other bursts fit by a sub-dominant blackbody**

GRB 110721A

Evolving blackbody temperature

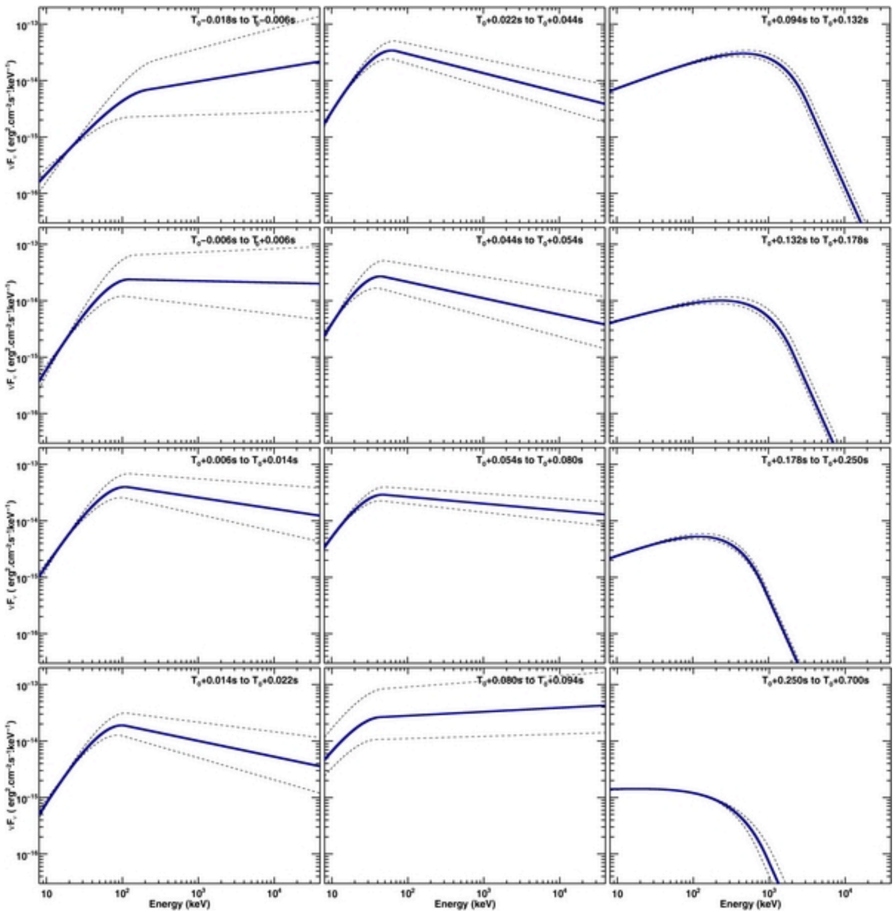
Evolving blackbody normalization



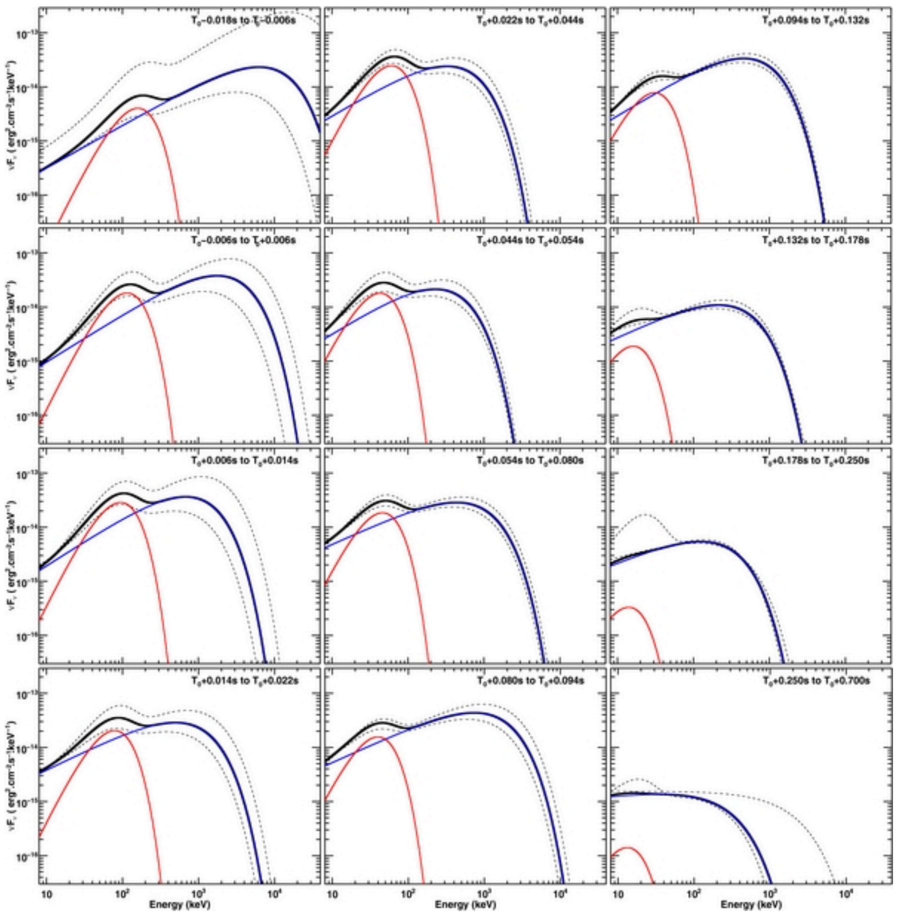
Axelsson et al. 2012

Photospheric Emission

Band only fits



Band+BB fits



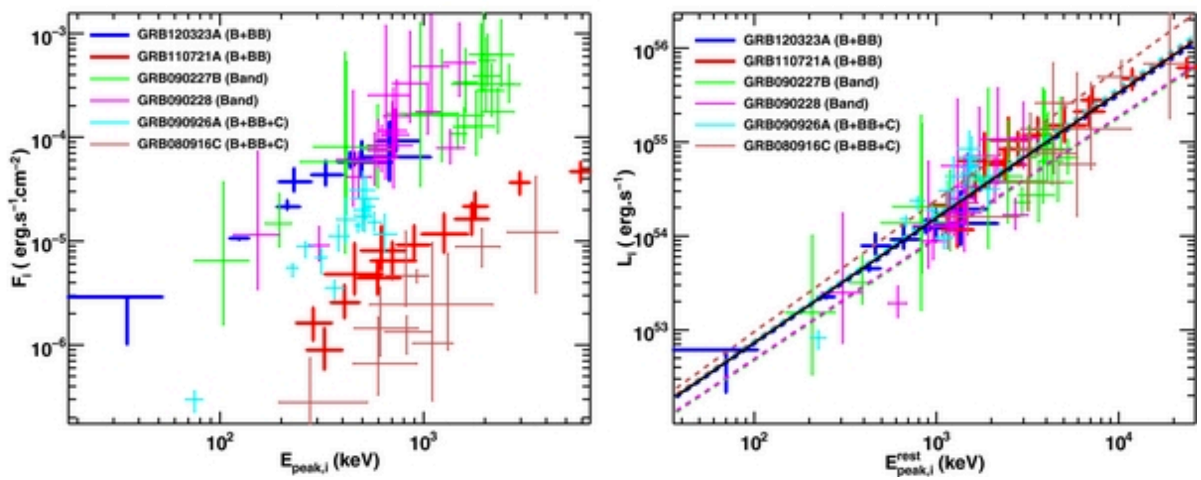
Guiriec et al. 2013

Photospheric Emission

- **Correlation between Luminosity and Epeak within a burst that is much cleaner when using Band+blackbody for bursts with evidence for sub-dominant blackbody**
- **Correlation among bursts converges when accounting for redshift**

Observed Frame

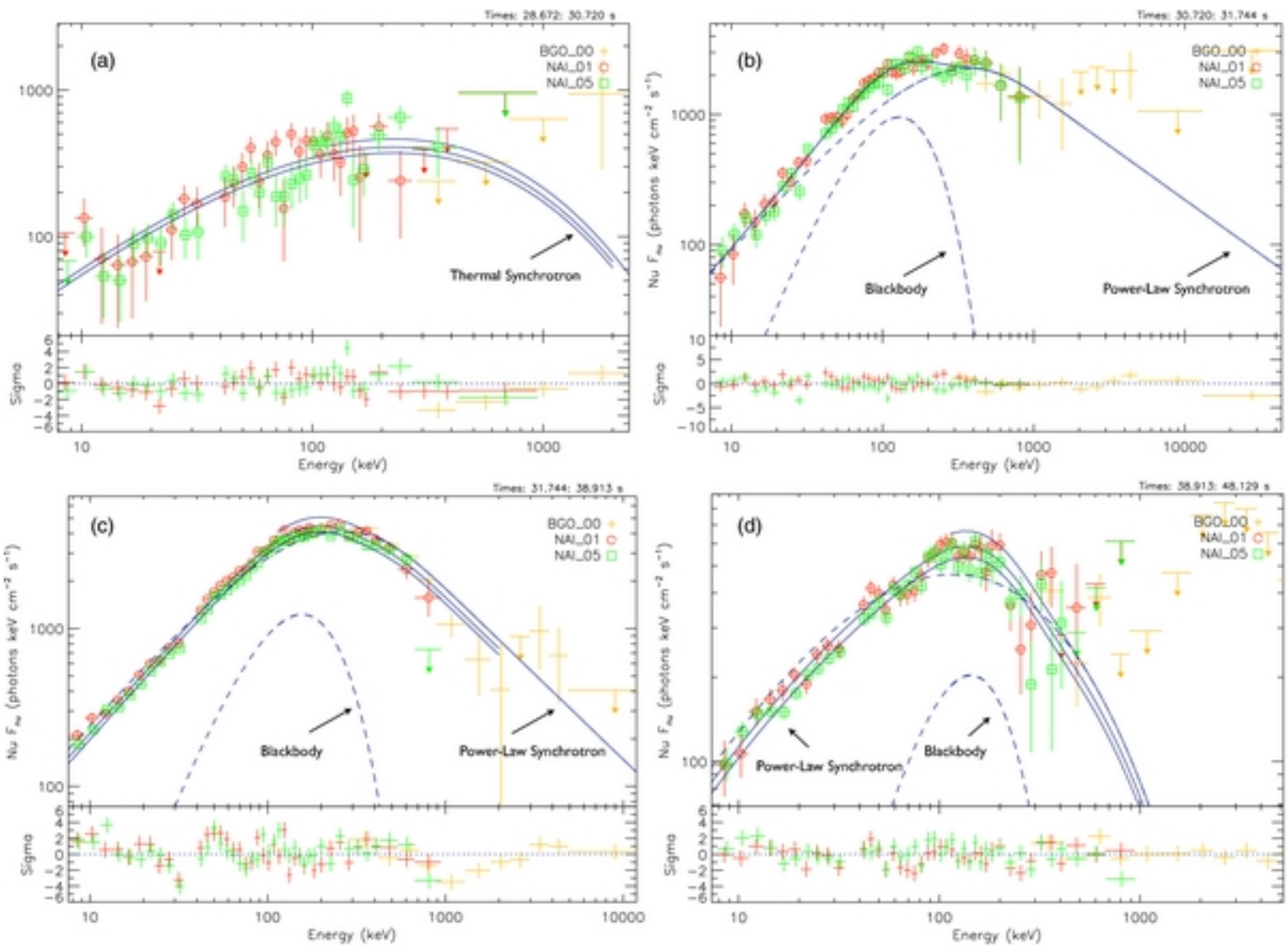
Rest Frame



Guiriec et al. 2013

Synchrotron + Blackbody

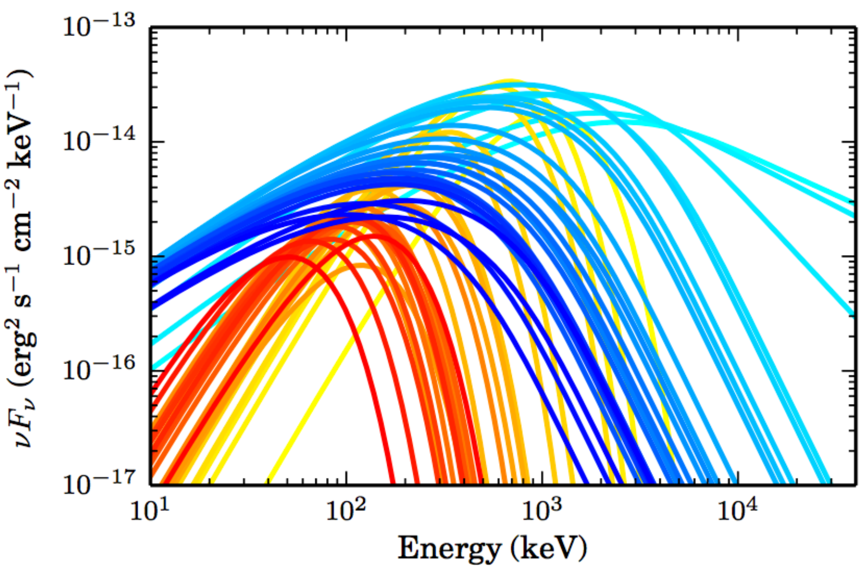
GRB 090820A

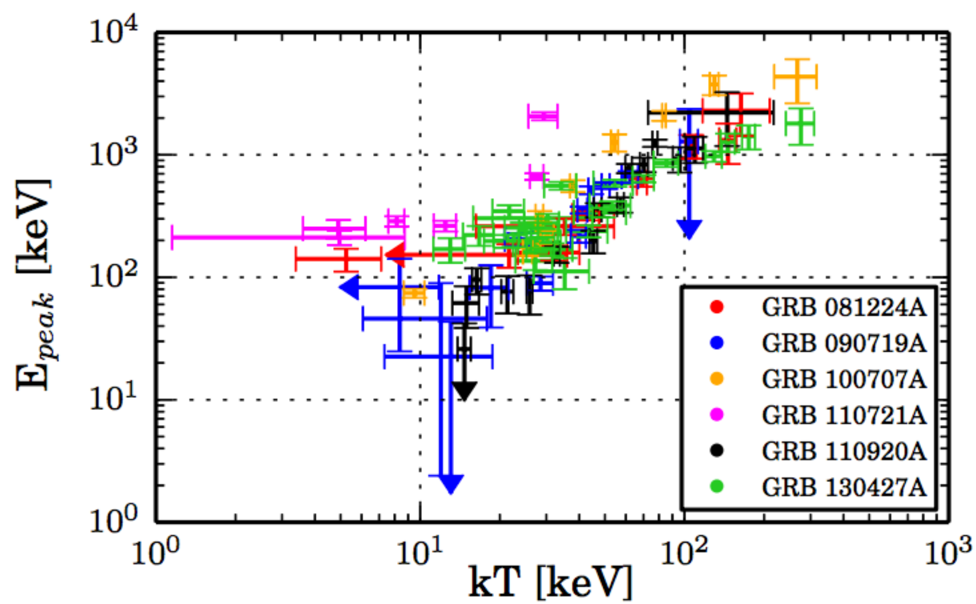


Burgess et al. 2011, ApJ 741, 24

Synchrotron + Blackbody

- **Synchrotron fits to the prompt emission work well with addition of blackbody in some cases**
  - **Find correlation between kT and Epeak**

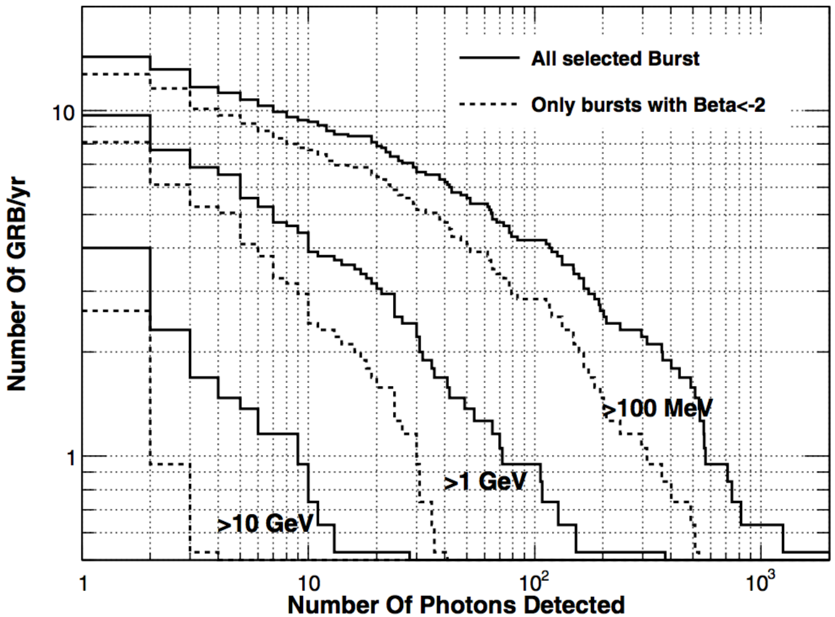




Burgess et al. 2014

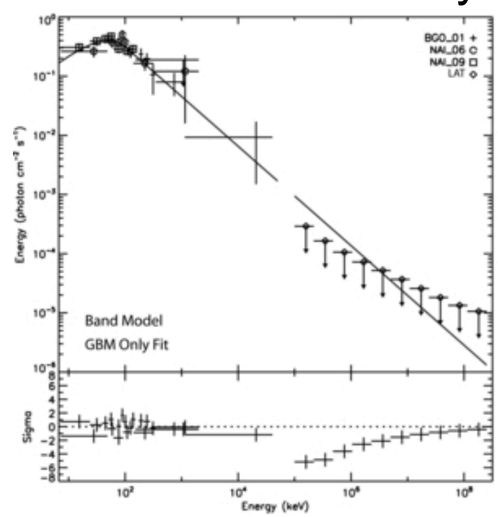
Understanding LAT Non-Detections

Pre-launch Predictions

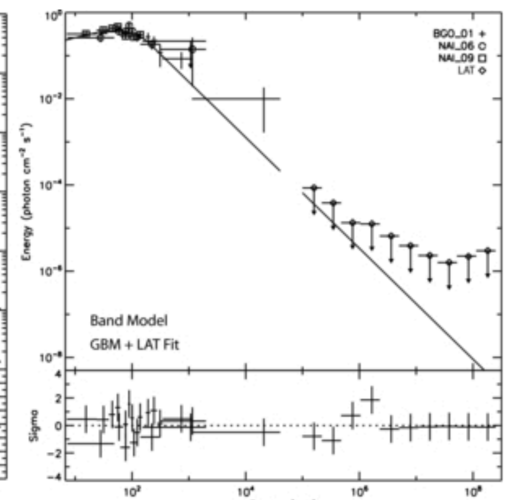


Band et al. 2009

Band fit to GBM only

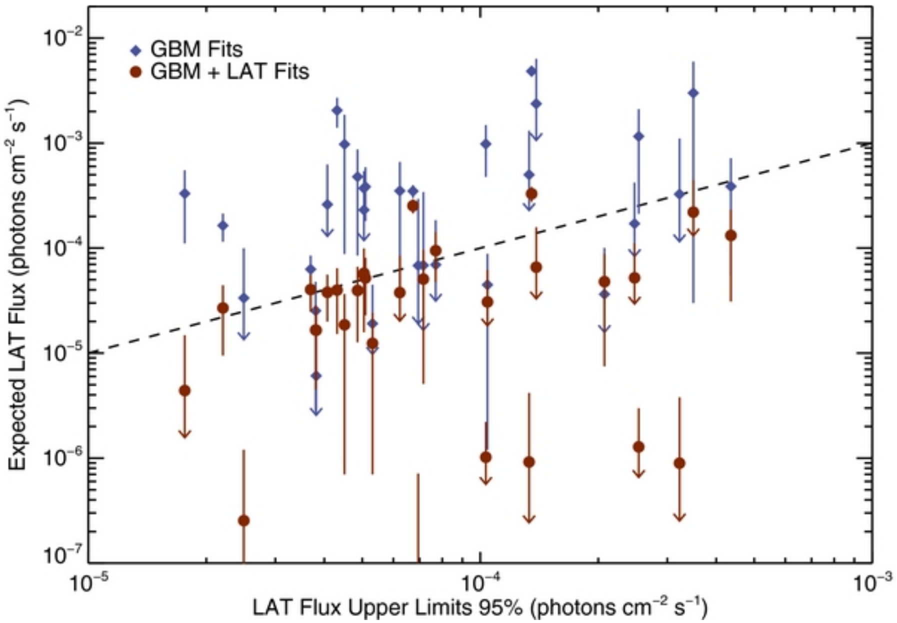


Band fit to GBM + LAT

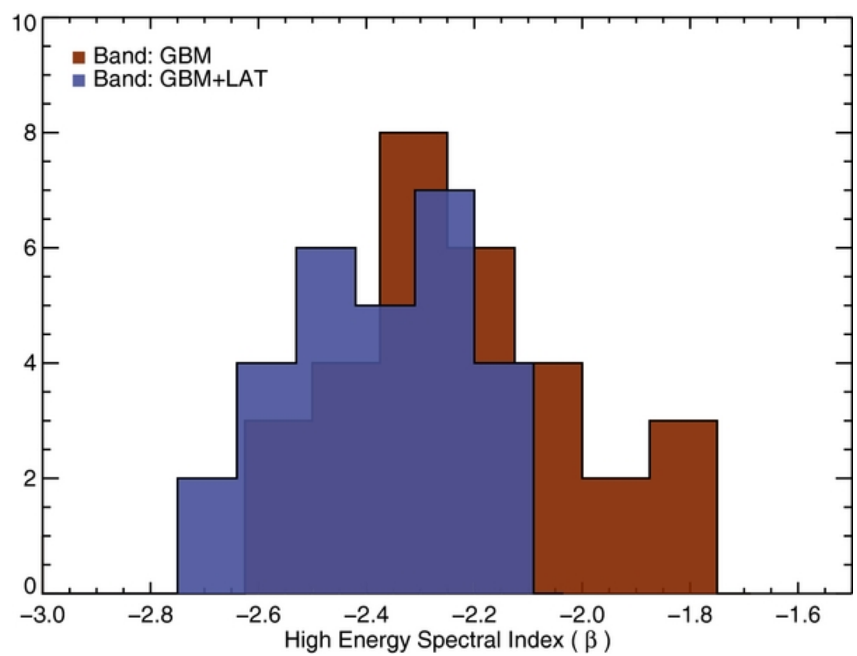


Ackermann et al., 2012, ApJ 754, 121

Cutoffs in the Spectra – constraints from upper limits



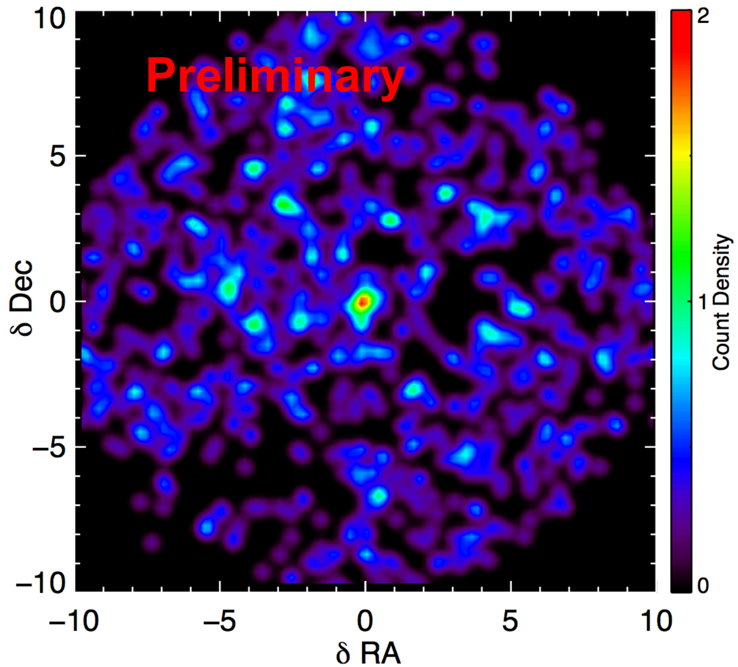
- Inclusion of higher energy -> steeper beta
- Extrapolation of flux to higher energies over-predicts the actual flux

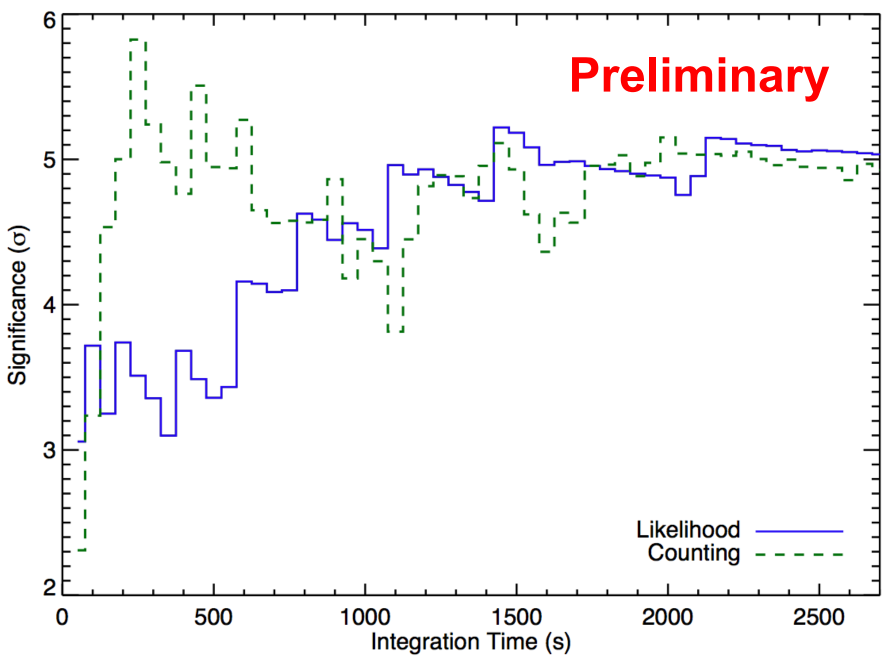


- ~50% of sample have expected fluxes > 95% CL upper limit when using low-energy data only
- Cutoffs likely between 40 & 100 MeV

Ackermann et al., 2012, ApJ 754, 121

Stacking Non-Detections



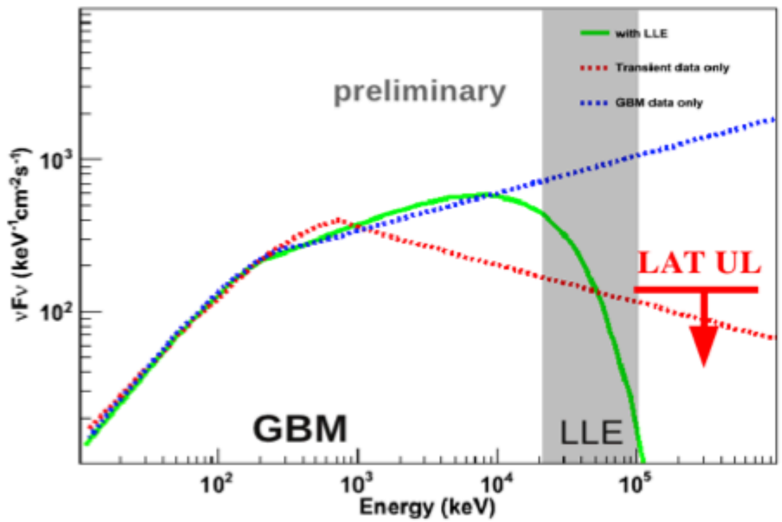


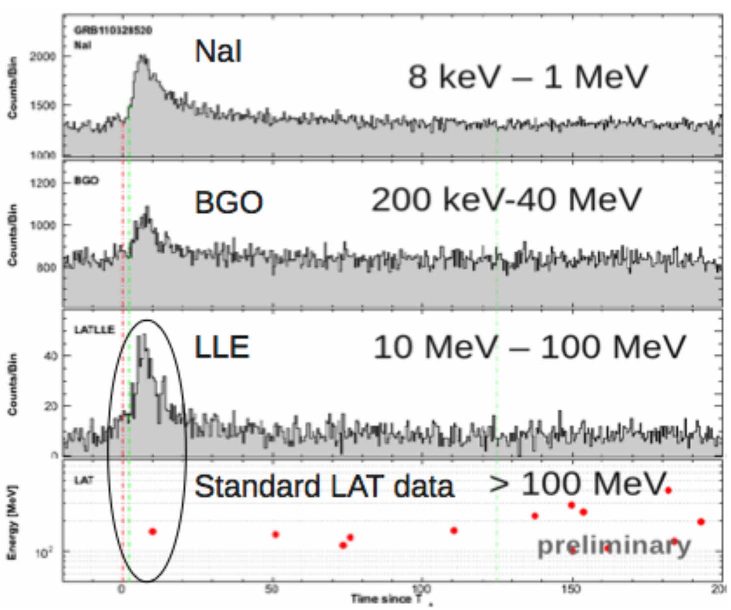
Kocevski et al., in-prep

Spectral Cutoffs and the LLE Event Class

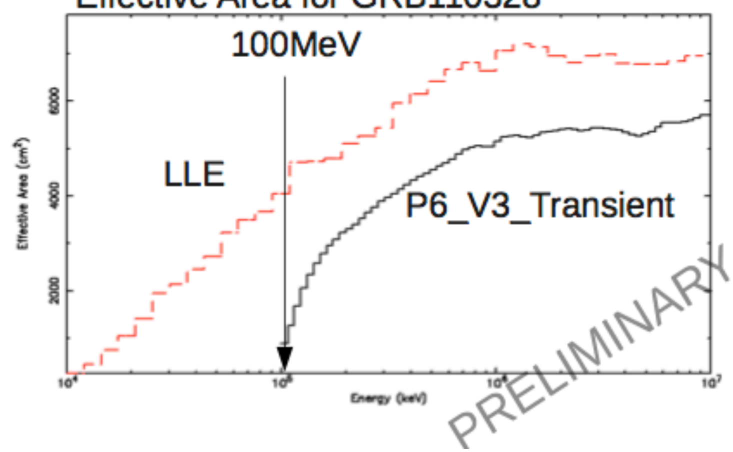
- **Standard LAT event selections (“Transient” class) run out of effective area at E<100MeV.**
- **“LAT Low Energy” (LLE) event selection → Very relaxed set of cuts → plenty of statistics in the tens-of-MeV-energy gap to probe GRB spectral cutoffs.**

To access LLE data:
http://heasarc.gsfc.nasa.gov/W3Browse/fermi/fermille.html





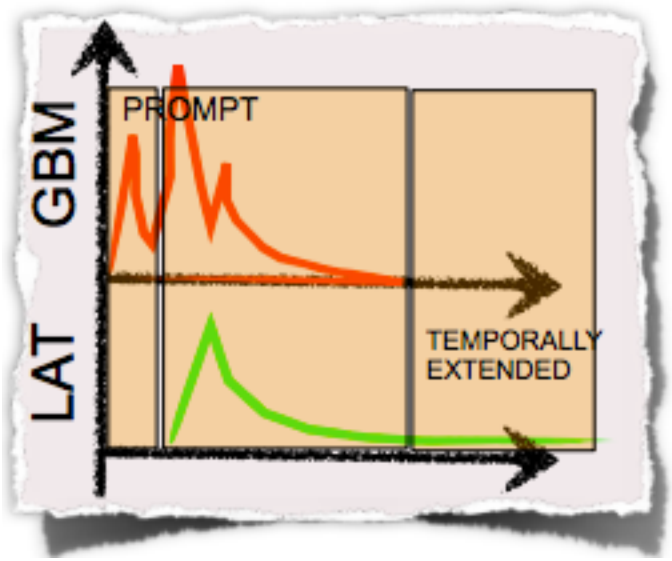
Effective Area for GRB110328



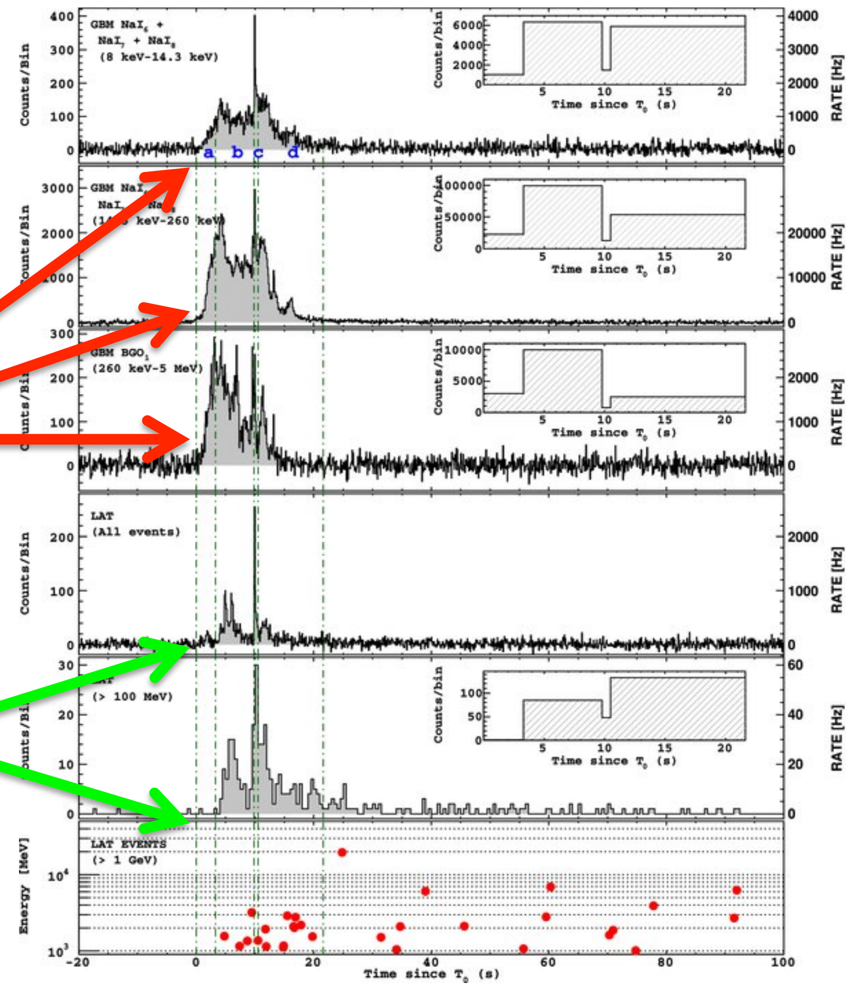
Credit: Vlasios Vasileiou

Common New Features in Fermi GRBs

- **LAT High-energy emission sometimes starts later the GBM low-energy emission**



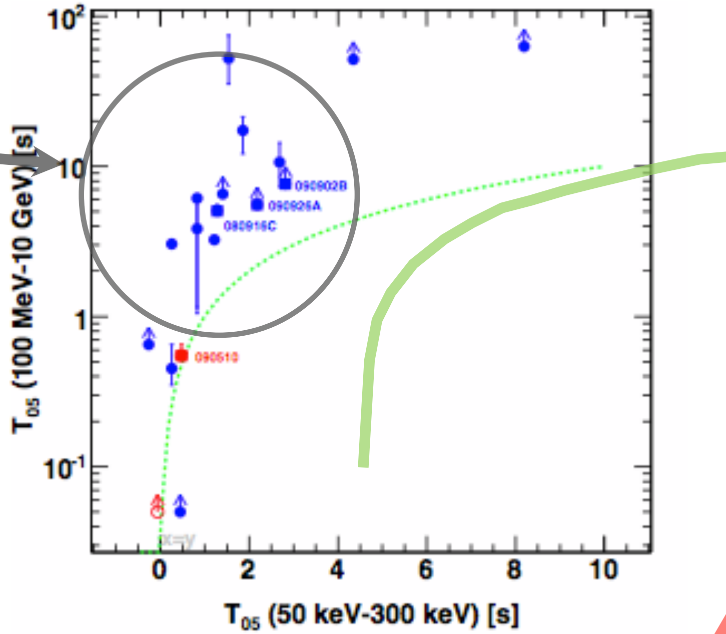
Credit: Nicola Omodei

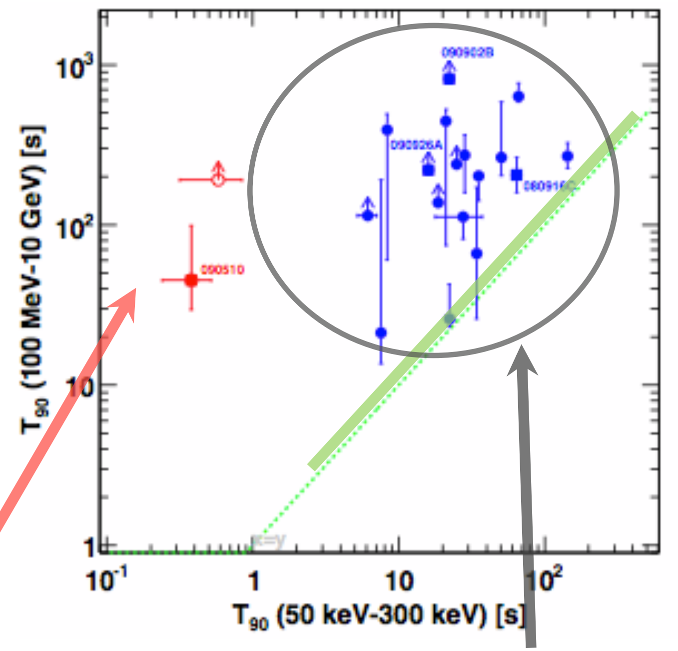


Ackermann et al. 2011, ApJ, 729, 114

Delayed High-Energy Emission

High-energy emission in the LAT is delayed from the emission in the GBM





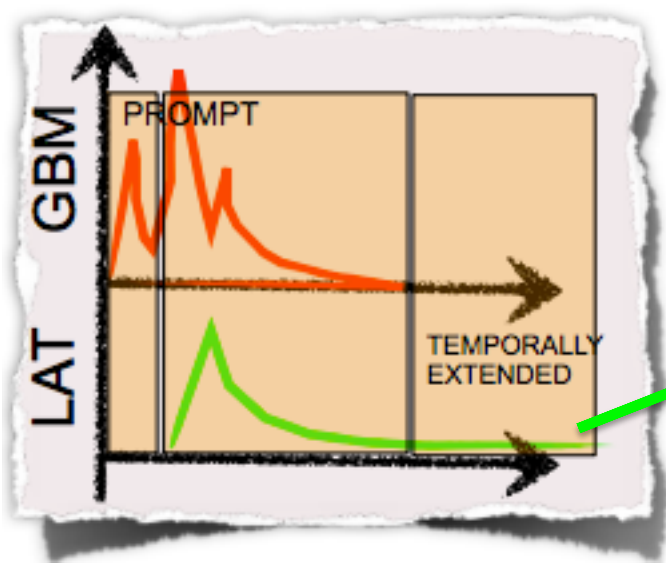
LAT Team et al., 2013, arXiv: 1303.2908

High-energy emission in the LAT also extends beyond the duration of the emission in the GBM

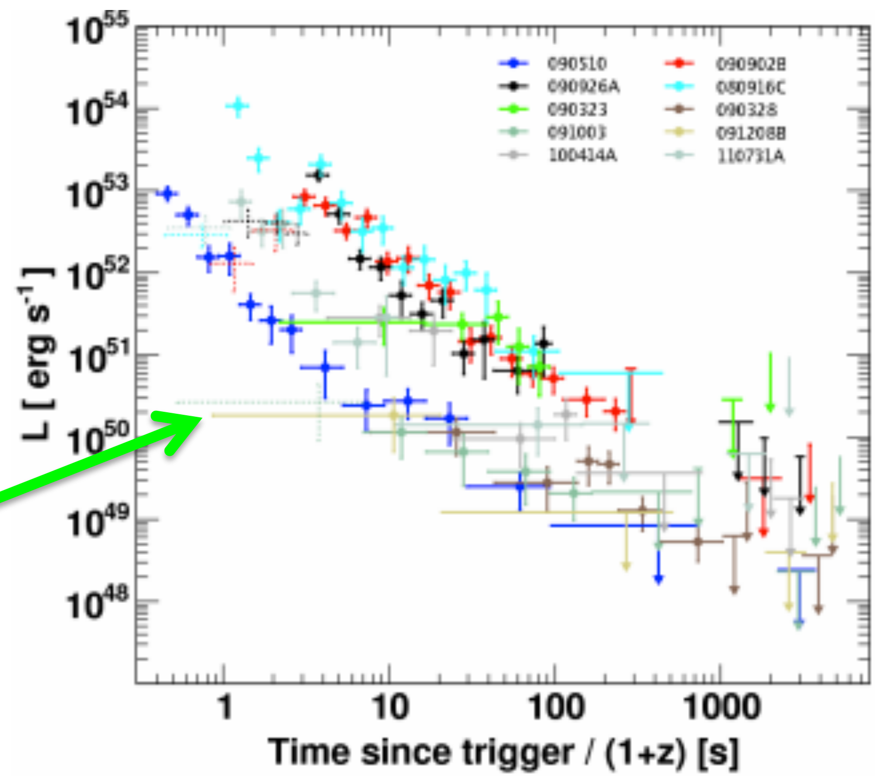
Short and Long GRBs show same extended emission behavior

Common New Features in Fermi GRBs

- **LAT High-energy emission sometimes lasts significantly longer then the GBM low-energy emission**



Credit: Nicola Omodei

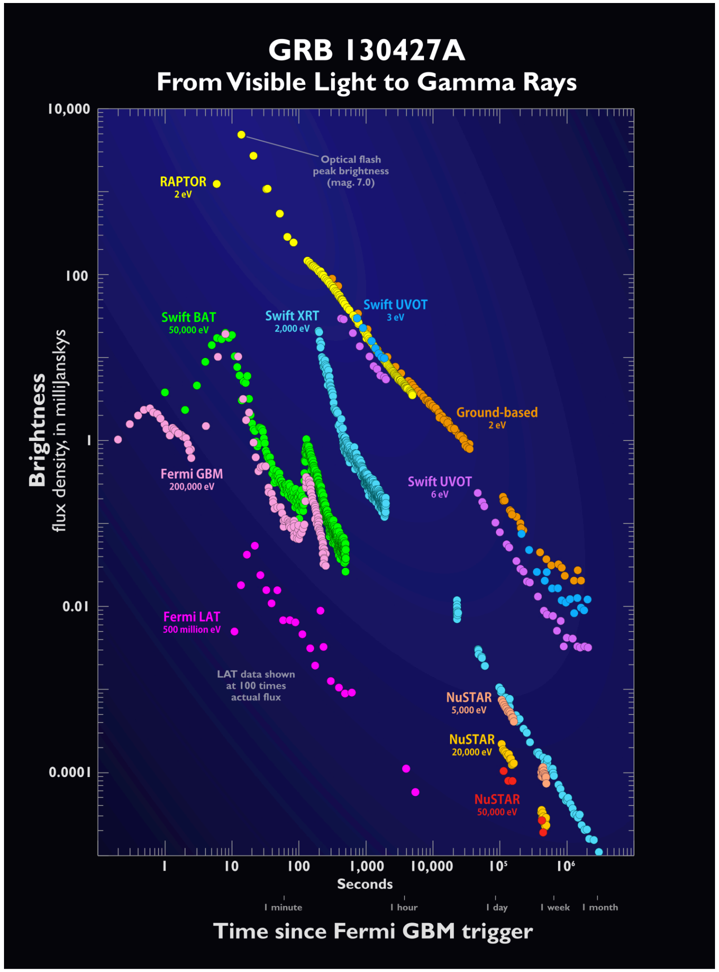


Ackermann et al. 2013, ApJS

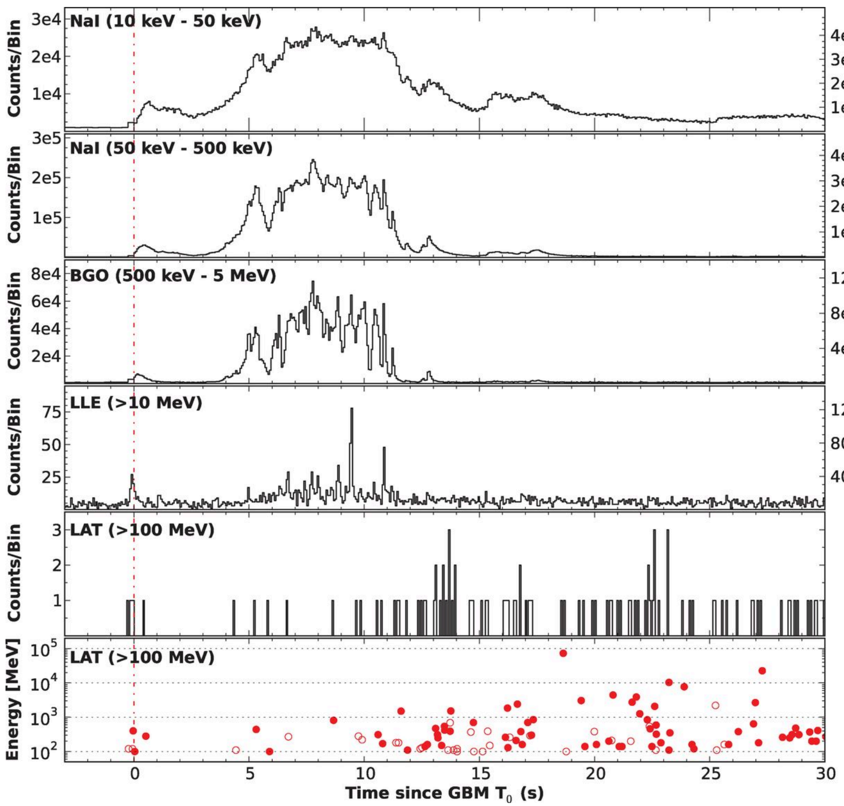
Origin of Extended Emission

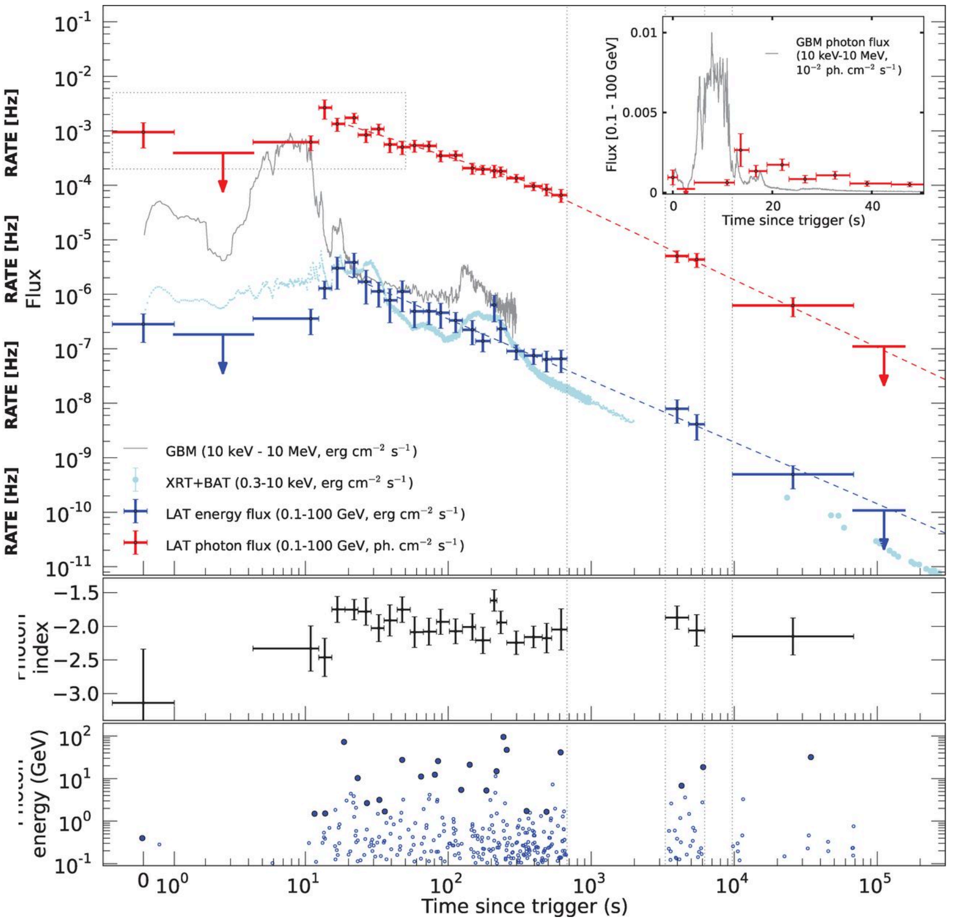
GRB 130427A

- Highest fluence GRB ever detected
- LAT emission lasted 20 hours
- Coincident trigger with Swift
- Bright (7.4 mag) optical flash
- Relative low redshift of 0.34
- Late-time afterglow emission consistent with single synchrotron spectrum
- Highest energy photon with 95 GeV at T0+244 s
- “Nearby Ordinary Monster”
- Really bright, but just normal burst like at cosmological distances, only nearby
- Lots of detailed observations, tons of papers



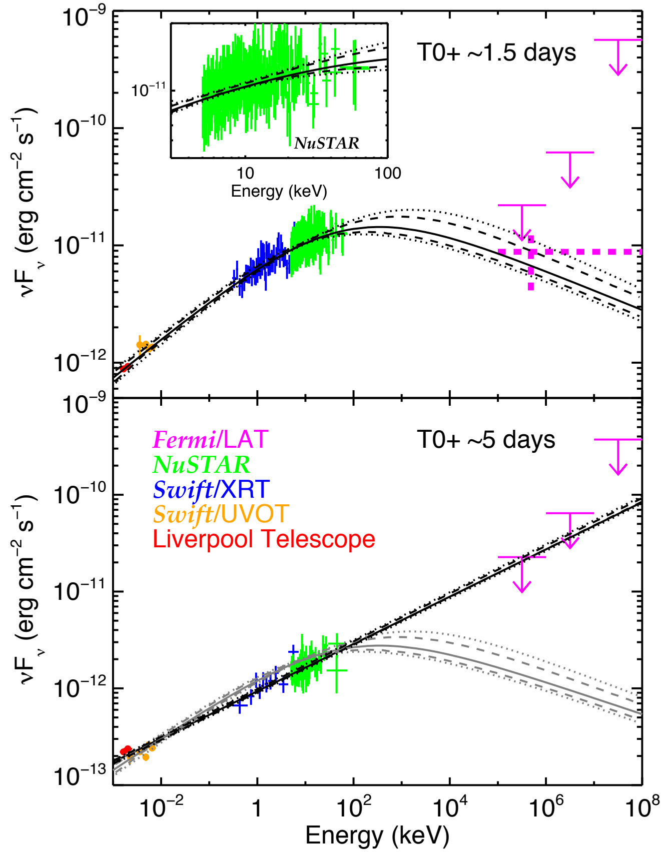
GRB 130427A



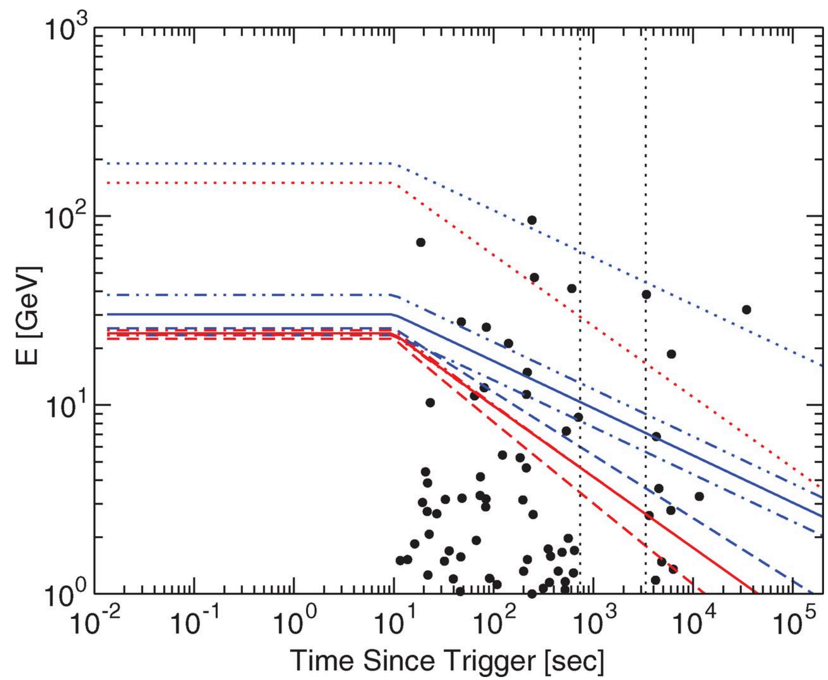


Ackermann et al. 2013, Science

GRB 130427A



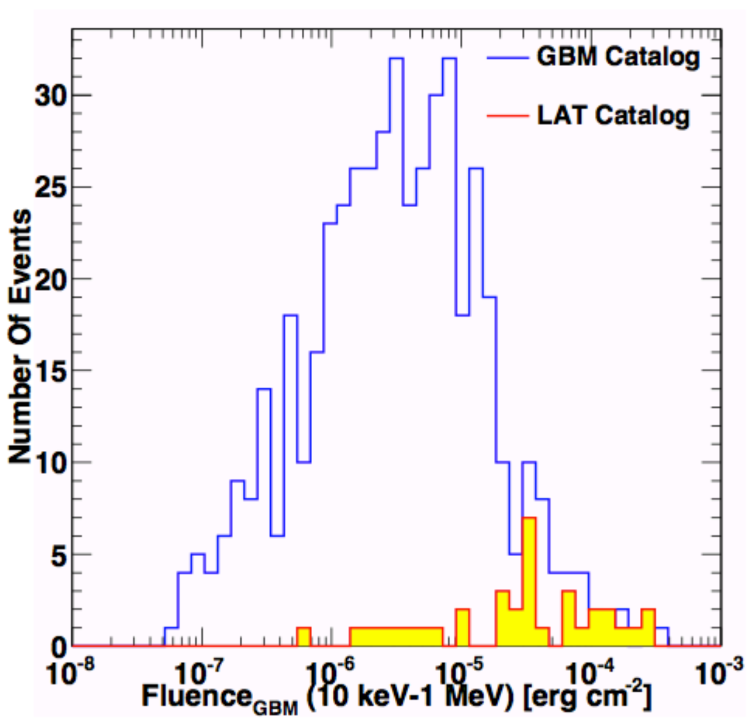
Kouvelioutou et al. 2013

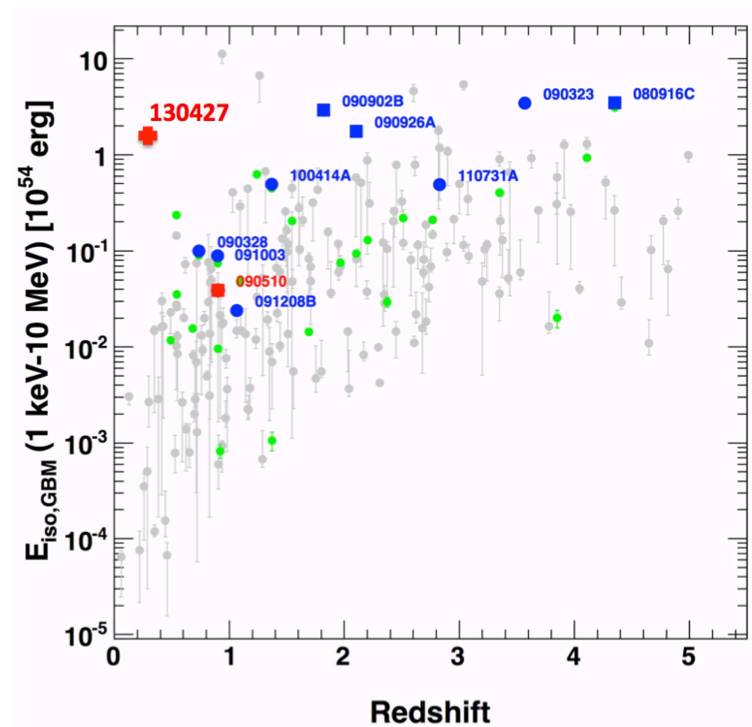


Ackermann et al. 2013, Science

Energetics

- **LAT GRBs are among the highest fluence and highest intrinsic isotropic energy of all GRB bursts**

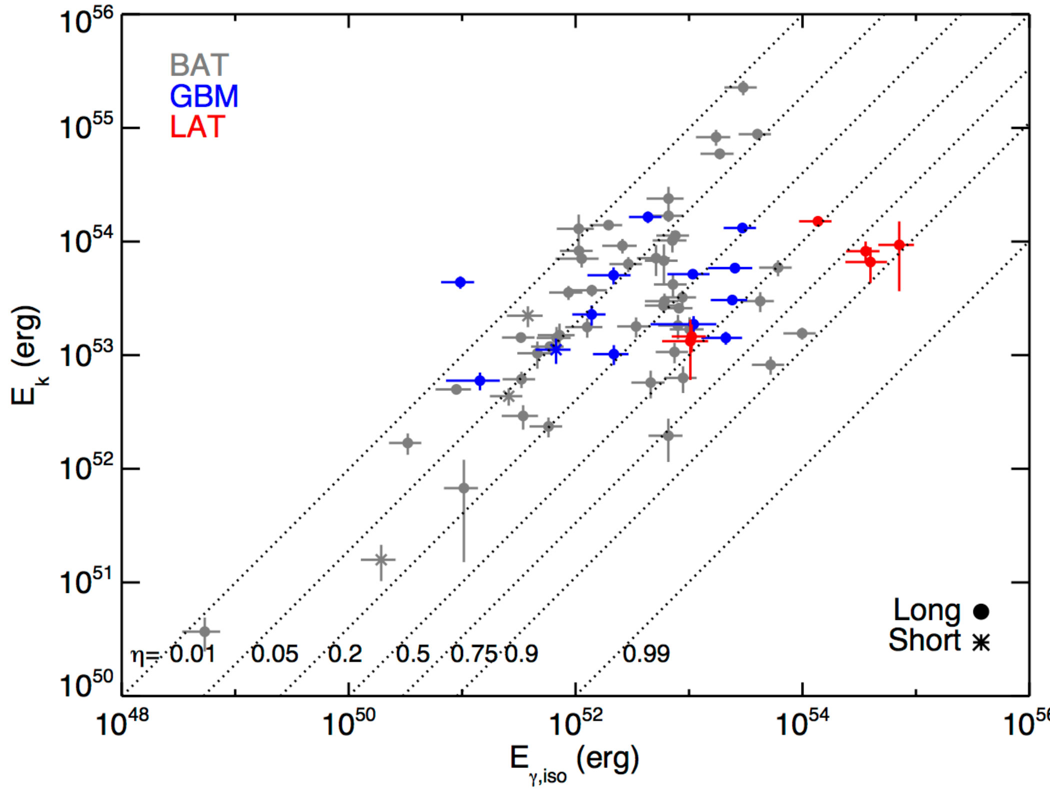




Ackermann et al. 2013, ApJS

Radiative Efficency

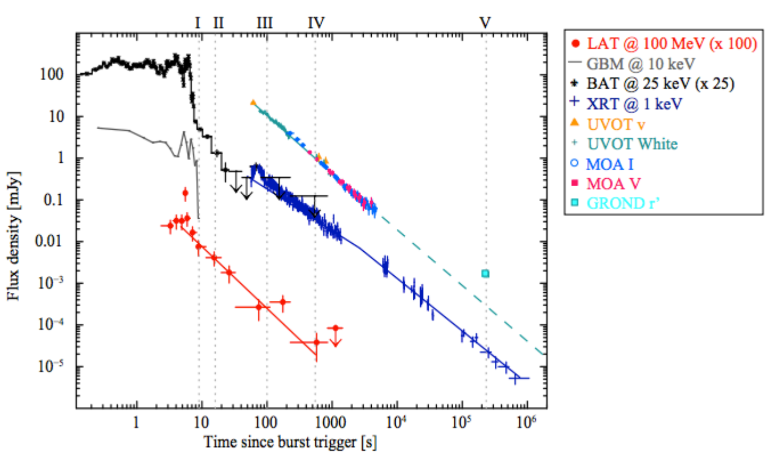
- **LAT GRBs have higher radiative efficiencies compared to those that don't produce high energy emission**
- **Derived from both gamma-ray and X-ray properties (model dependencies)**



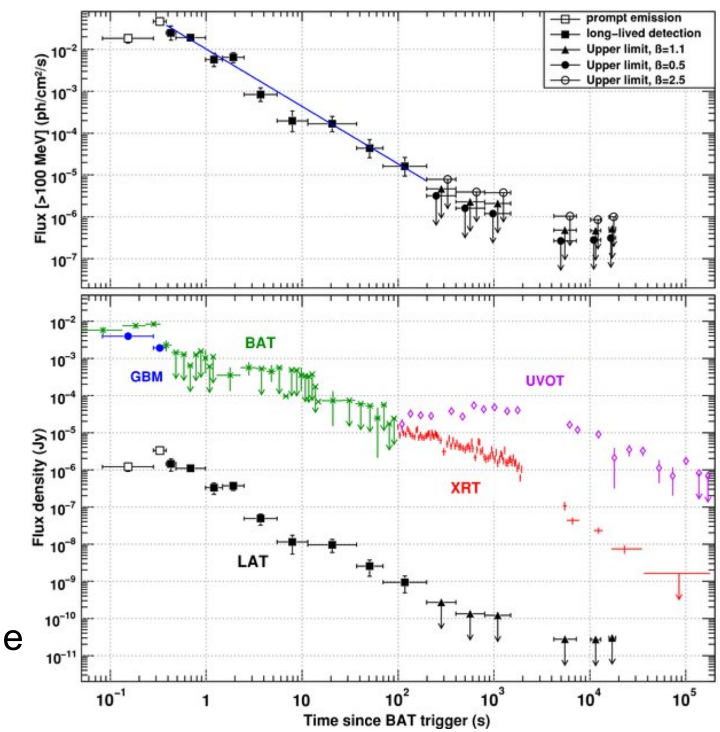
Racusin et al. 2011

Simultaneous Swift+Fermi Detections

- 15 GRBs have been simultaneously detected by Swift and Fermi-LAT
  - GRB 090510 (de Pasquale et al 2010)
  - GRB 090720B, 091208B (LAT GRB Catalog)
  - GRB100728A (Abdo et al ApJ 2011)
  - GRB110625A (Tam, Kong and Fan, ApJ 2012)
  - GRB 110709A
  - GRB110731A (Ackermann et al 2013)
  - GRB 120624B
  - GRB 121011A, 130206A, 130305A
  - GRB 130427A (lots of papers)
  - GRB 130907A, 140102A, 140323A

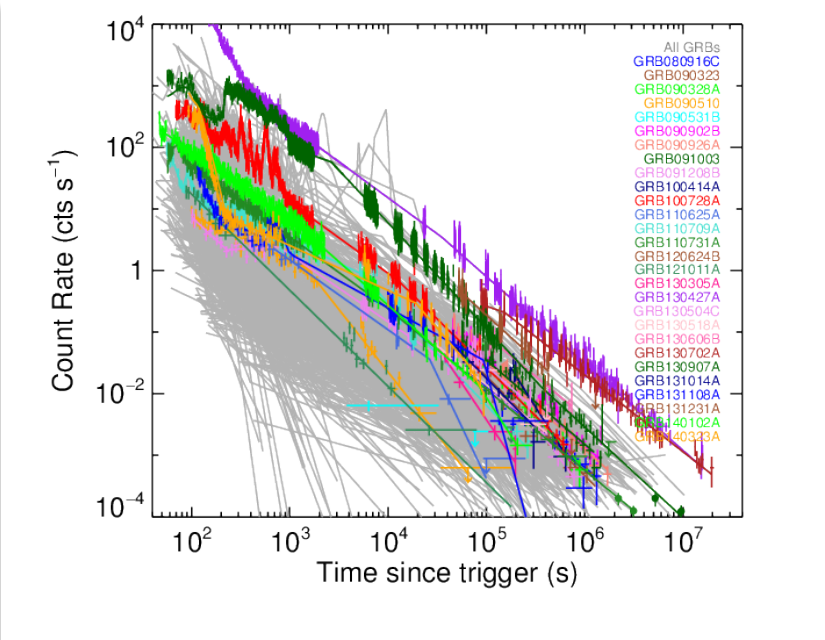


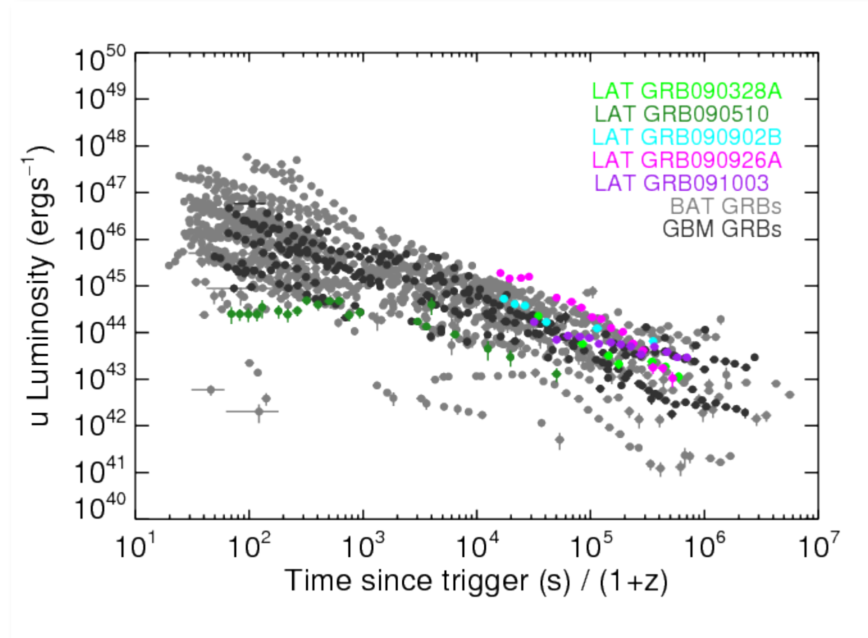
Ackermann et al 2012



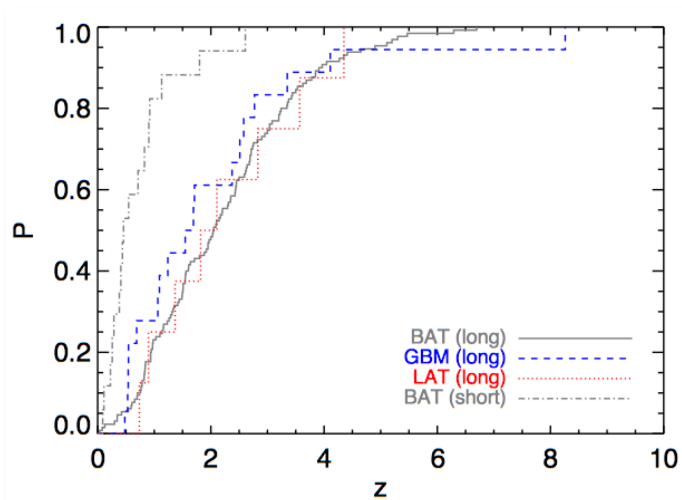
De Pasquale et al. 2010

Swift Follow-up of Fermi GRB Afterglows





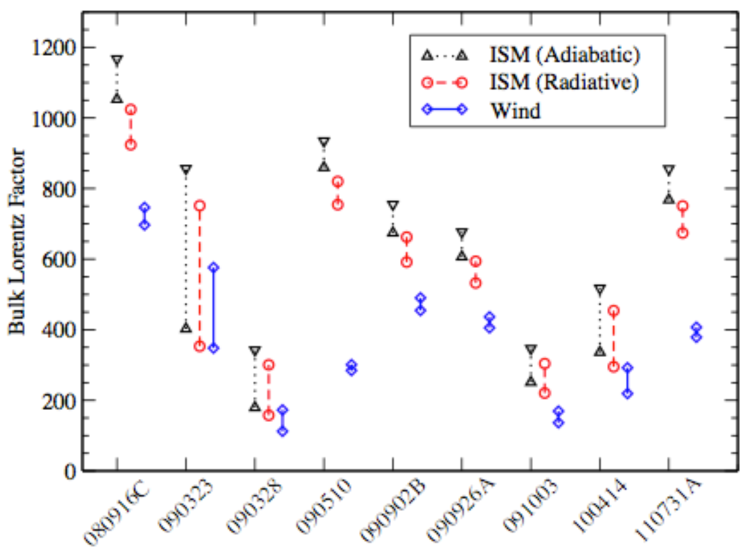
Updated more recently



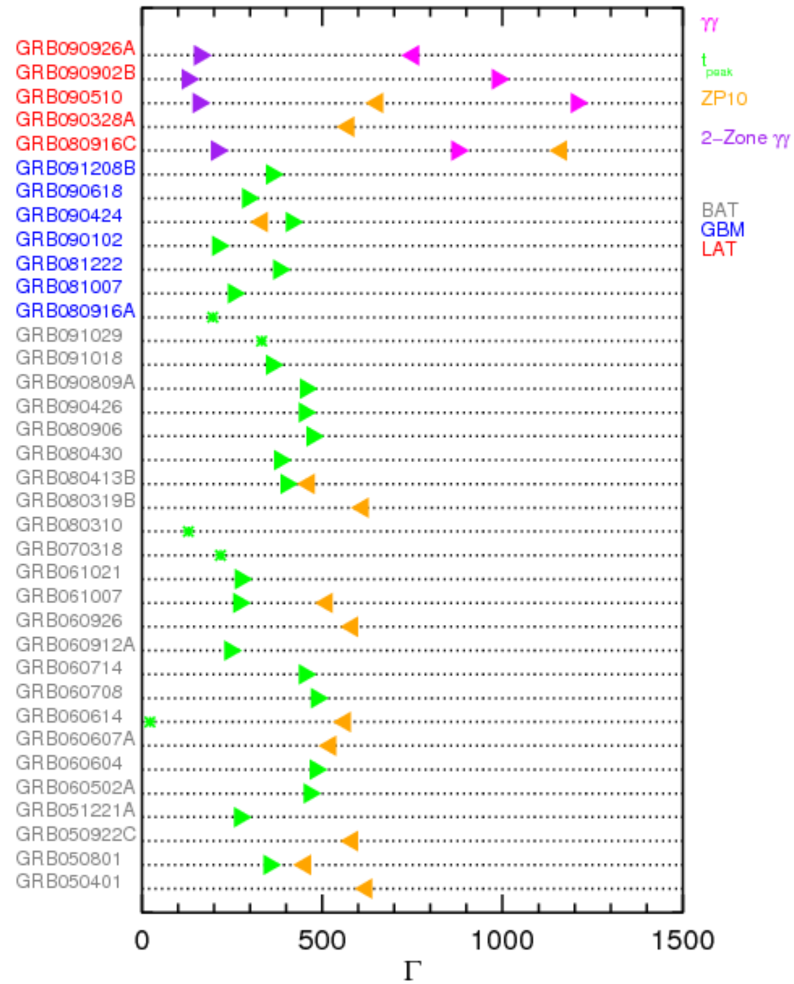
Racusin et al. 2011

Bulk Lorentz Factors

- **Measure from early peak of afterglow**
  - LAT?
  - Optical
- **γγ pair opacity**
  - Depends on multiple emission zones
  - Uses cutoffs or limits from high-E photns in LAT spectra



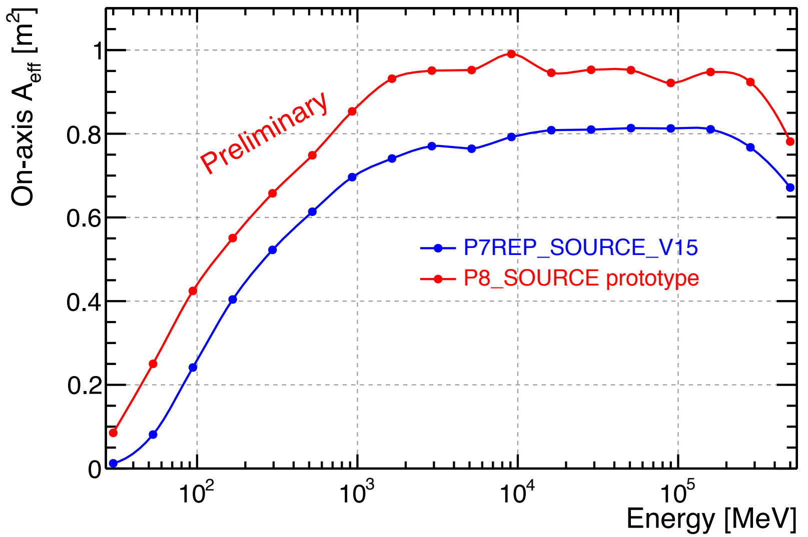
Ackermann et al. 2012

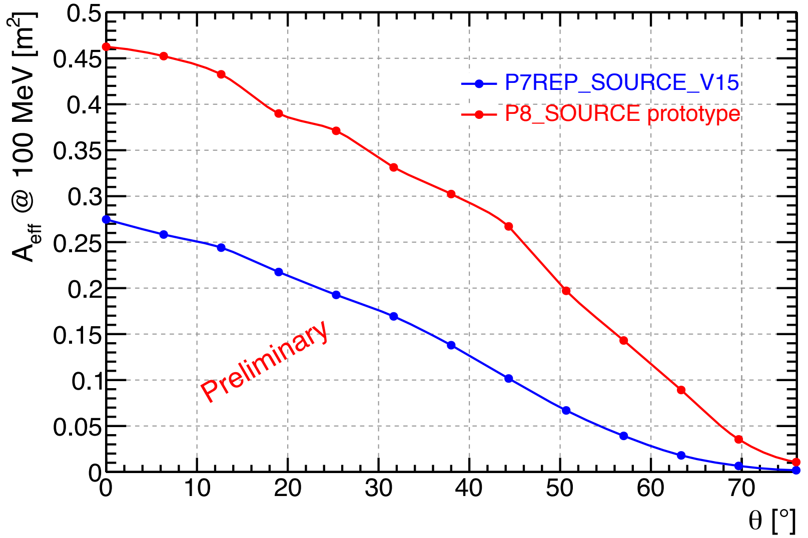


Racusin et al. 2011

Future of LAT GRB Studies with Pass 8

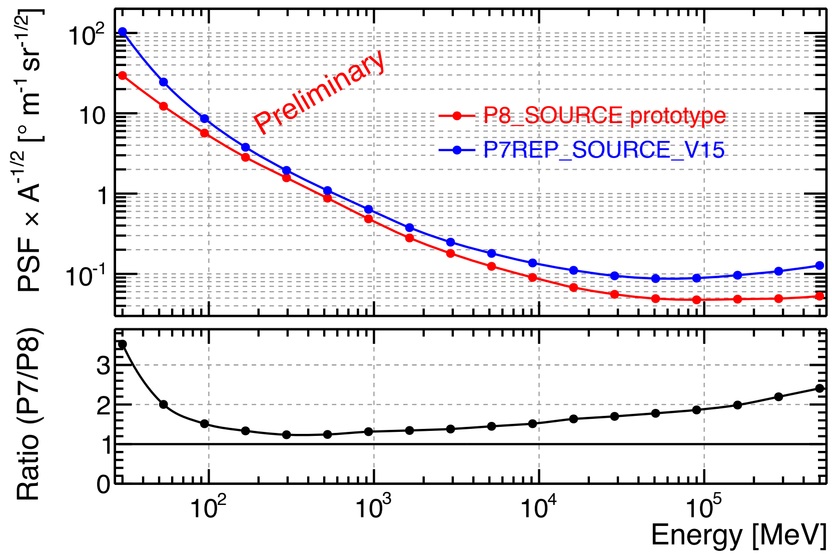
- **Improved effective area**
  - As a function of energy
    - Better characterization of spectrum, especially low energy
  - As a function of angle from boresight
    - Better measurements further off axis

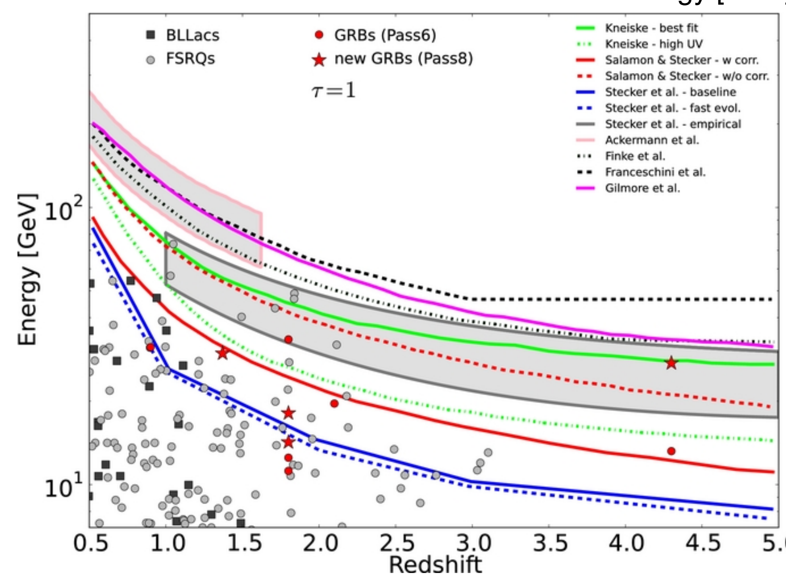




Future of LAT GRB Studies with Pass 8

- **Better event reconstruction/ background rejection**
  - **Better localizations (really important for follow-up)**
  - **Photons that were LLE only will be transient in P8**
    - **Localizations of more bursts (archival and future)**
  - **New high energy photons in Pass 8 provide new physics**
    - **Atwood, W., et al., ApJ, 774, 76 (2013)**





Conclusions

- Fermi provides a unique view of GRBs that is providing insight into the physics of GRBs, their environments, and as probes of the Universe
- As we collect more data, we are finding more unusual bursts, that have excellent broadband and maybe even multi-messenger observations
- We hope that both Fermi and Swift can continue operating for many years, providing broad observations, and triggers to other facilities