



Fermi  
Gamma-ray Space Telescope

# *Fermi*-LAT observations of GRB 130427A

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on behalf of the *Fermi*-LAT collaboration

Workshop on GRBs in the multi-messenger era  
(Paris, June 16, 2014)



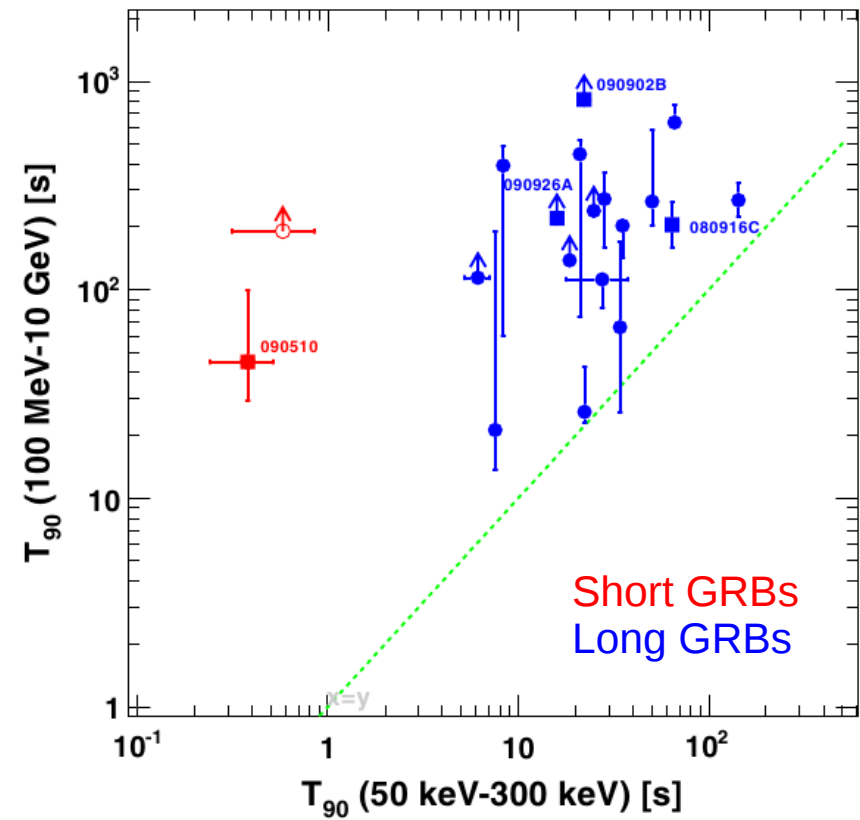
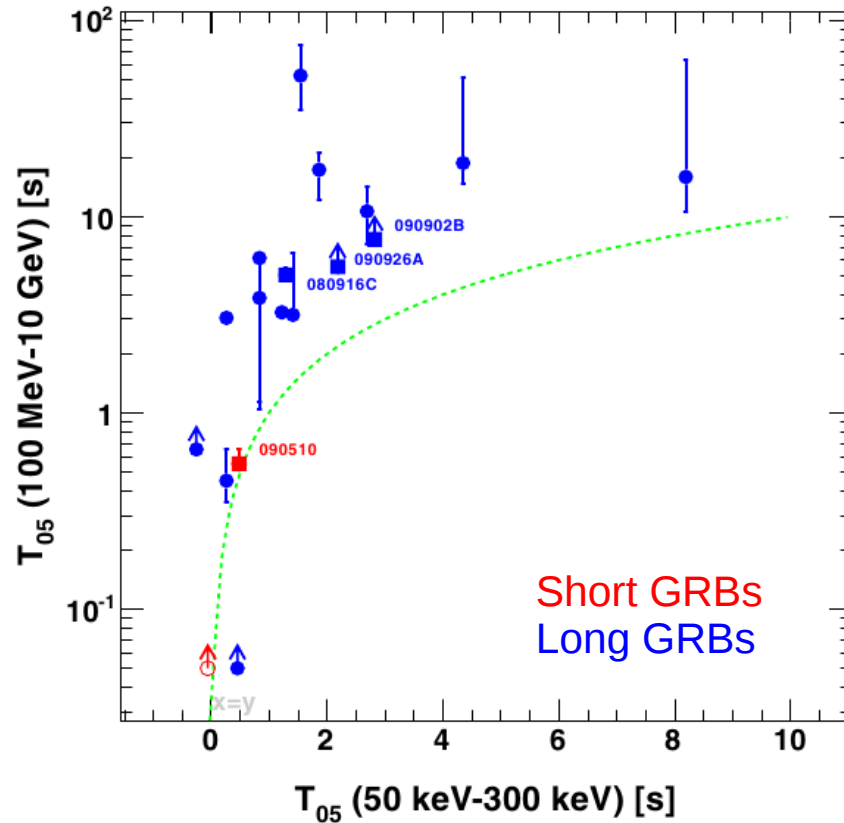
- **Reminder of GRB properties at GeV energies**
- **LAT observations of GRB 130427A**
- **GRB 130427A in the context of LAT-detected GRBs**



# The first LAT GRB catalog (1/2)



*Ackermann et al. 2013, ApJS 209, 11*

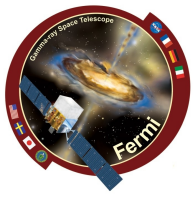


- **GeV emission onset is delayed and temporally extended**

- Most (but not all) of this emission likely comes from early afterglow: external shock  $\rightarrow$  synchrotron emission from accelerated electrons
- Confirmed by individual broad-band (visible to GeV domains) analyses (GRBs 090510, 110731A)
- Late internal shocks (inverse Compton scattering) or hadronic emission (proton synchrotron and/or photopion-induced cascades) still possible

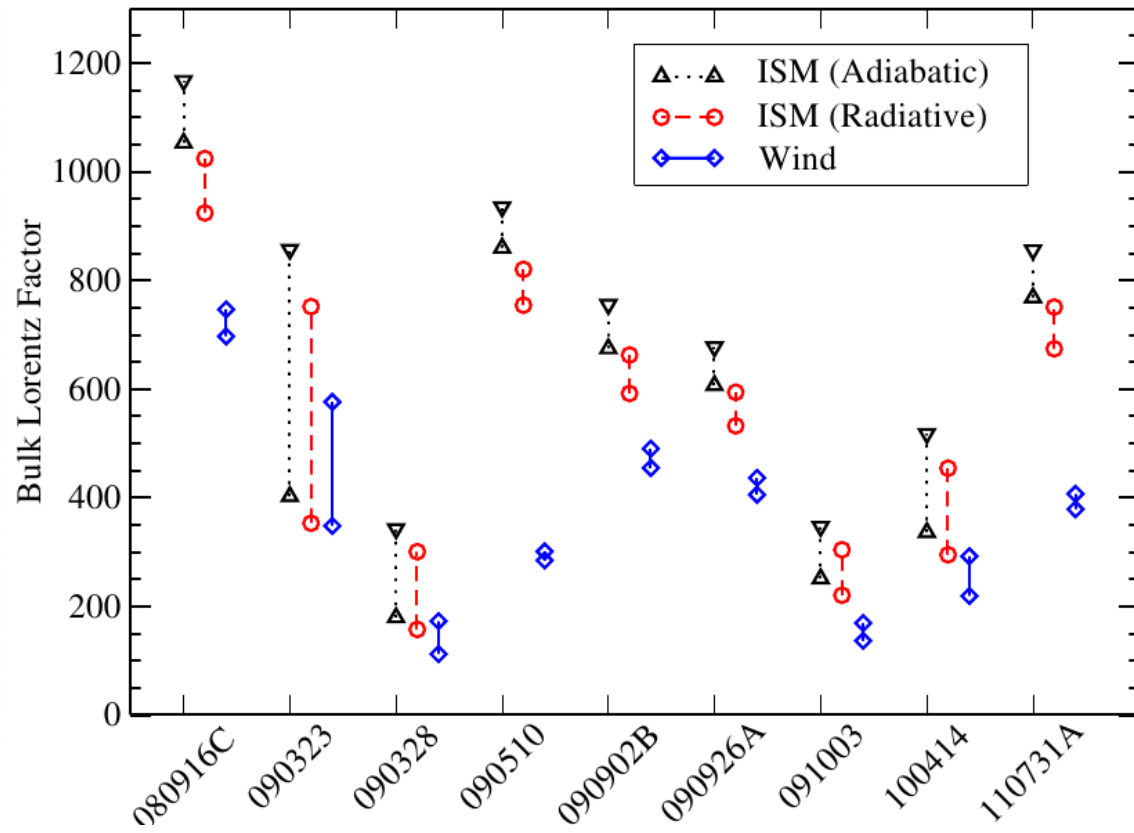
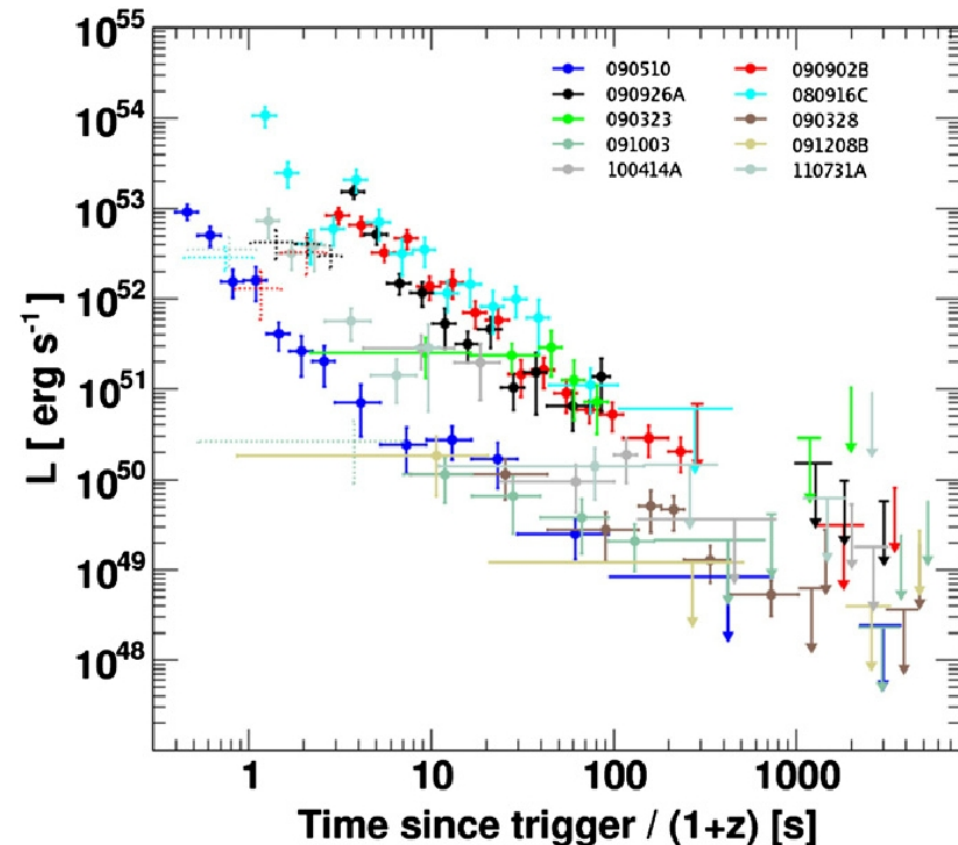


# The first LAT GRB catalog (2/2)



- **Long-lasting GeV emission consistent with the canonical afterglow model**
  - No strong spectro-temporal variability
  - Emission decays as  $t^{-1}$  (sometimes with a preceding steeper phase) with a photon spectral index of -2 at late times
- → **blast wave in adiabatic expansion**

- **Consequence: GRB jet Lorentz factors**
  - Inferred from the fireball energetics and from the blast wave deceleration time (taken as the LAT peak-flux time)
    - For 9 GRBs with measured  $z$
  - $\Gamma$  between  $\sim 200$  and  $\sim 1000$
- → **highly relativistic speeds**



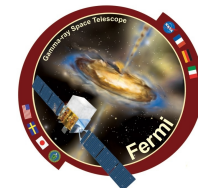
*Ackermann et al. 2013, ApJS 209, 11*

# Observations of GRB 130427A (GCN circulars)

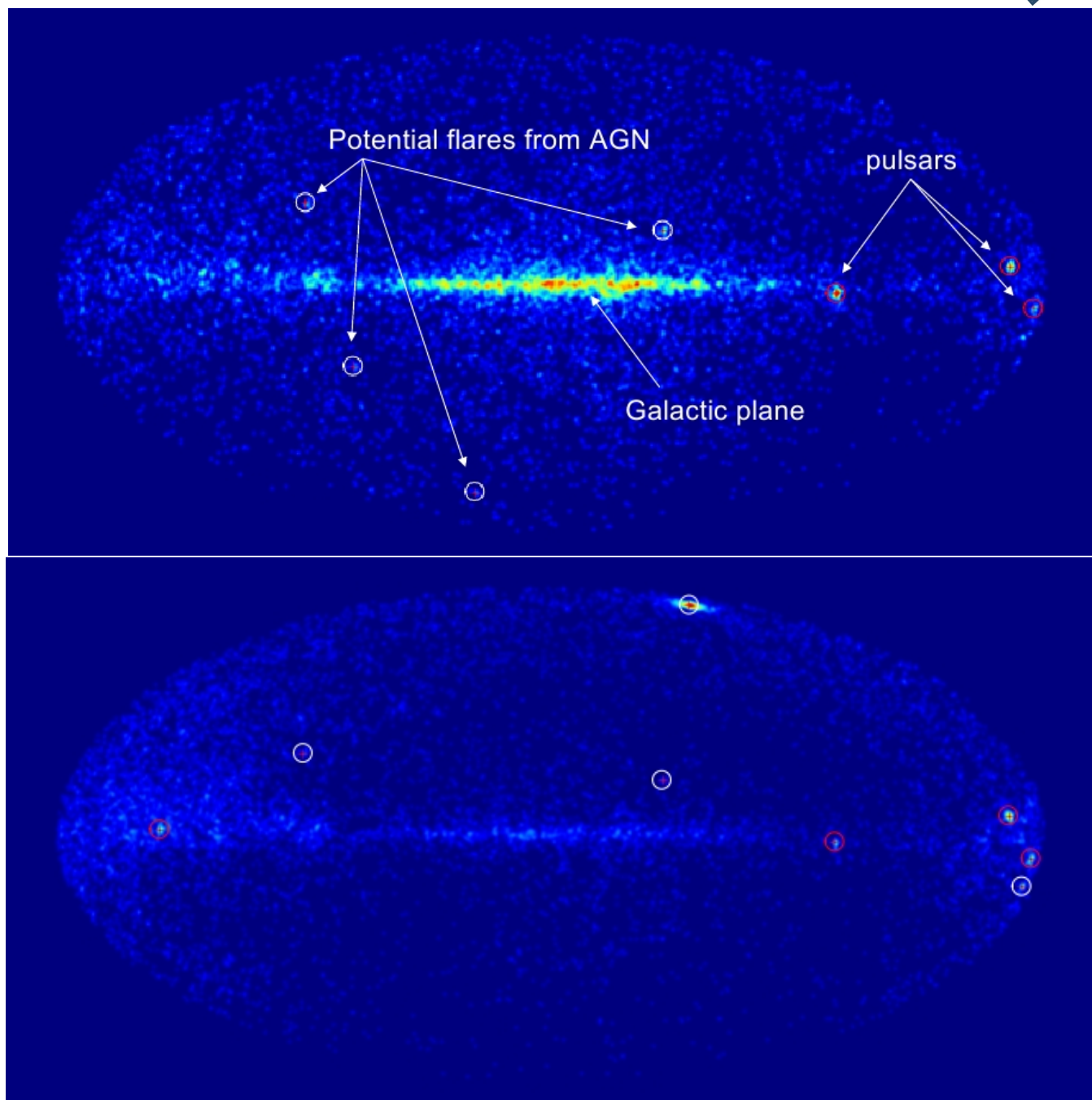


- [14686](#) GRB 130427A / SN 2013cq: Hubble Space Telescope Observations
- [14673](#) VLT observations of GRB 130427A
- [14672](#) GRB 130427A: Konkoly optical observations
- [14669](#) GRB 130427A: BTA spectroscopic observations on May 10/11.
- [14666](#) GRB 130427A: Continued RATIR Optical and NIR Observations - Photometric Evidence for a New Component
- [14662](#) GRB 130427A: Skynet detections of a possible supernova
- [14646](#) GRB 130427A: Spectroscopic detection of the SN from the 10.4m GTC
- [14645](#) GRB 130427A: optical observations
- [14631](#) GRB 130427A: Tautenburg 2nd epoch: No break, no clear SN
- [14617](#) GRB 130427A: host galaxy observations
- [14615](#) GRB 130427A: Keck/LRIS Observations
- [14608](#) GRB 130427A: Ten nights of Skynet/PROMPT/GORT observations
- [14606](#) GRB 130427A: Continued RATIR Optical and NIR Observations
- [14605](#) GRB 130427A, LBT optical spectrum
- [14598](#) GRB 130427A, Watcher afterglow detection
- [14597](#) GRB 130427A: Excess optical emission consistent with an emerging supernova
- [14596](#) GRB 130427A: Amateur observations from Sweden
- [14592](#) GRB 130427A: Tautenburg afterglow observations
- [14590](#) GRB 130427A: RHESSI observations
- [14582](#) GRB 130427A: optical observations in CrAO
- [14579](#) GRB 130427A: correction to GCN 14487
- [14549](#) GRB 130427A: Non-observation of VHE emission with HAWC
- [14538](#) GRB 130427A: Pan-STARRS 1 optical observations
- [14534](#) GRB 130427A: MITSuME Ishigakijima Optical Observation after 5 days
- [14526](#) GRB 130427A: Predictions about the occurrence of a supernova
- [14525](#) GRB 130427A: KAIT optical observations
- [14523](#) GRB 130427A: SARA-N optical observations
- [14522](#) GRB 130427A: VLA 20 GHz detection
- [14521](#) GRB 130427A: ABT optical observations
- [14520](#) GRB 130427A: High-energy neutrino search
- [14519](#) GRB 130427A: GMRT radio detection
- [14518](#) GRB 130427A: Continued GMG optical observations
- [14517](#) GRB 130427A: Nishi-Harima Optical Spectroscopic Observations
- [14516](#) GRB 130427A: photo-z of possible SDSS host galaxy
- [14515](#) GRB 130427A: high energy gamma-ray detection by AGILE
- [14514](#) GRB 130427A: Continued RATIR Optical and NIR Observations
- [14513](#) GRB 130427A: MITSuME Ishigakijima Optical Observation after 2 days
- [14511](#) GRB 130427A: Challis Observatory optical observations
- [14510](#) GRB 130427A: Continued Skynet/PROMPT Observations
- [14509](#) GRB 130427A: further GMG observations
- [14508](#) GRB 130427A: Fermi-LAT refined analysis
- [14507](#) GRB 130427A: SARA-N detection
- [14506](#) GRB 130427A: Continued RATIR Optical and NIR Observations
- [14505](#) GRB 130427A: CrAO RT-22 36 GHz observation
- [14503](#) GRB 130427A in the Ep,i - Eiso plane
- [14502](#) GRB 130427A: Improved Swift-XRT analysis
- [14498](#) GRB 130427A: MITSuME Okayama and Ishigakijima Optical Observation after 1 day
- [14497](#) GRB 130427A: Skynet/PROMPT Observations
- [14495](#) GRB 130427A: Nishi-Harima NIR Observations
- [14494](#) GRB 130427A: CARMA 3mm observations
- [14492](#) GRB 130427A : Xinglong TNT optical observation
- [14491](#) GRB 130427A: VLT/X-shooter redshift confirmation
- [14490](#) GRB 130427A optical time series
- [14489](#) GRB 130427A, Optical Observations
- [14488](#) GRB 130427A: Continued iTelescope T21 optical observations
- [14487](#) Konus-Wind observation of GRB 130427A
- [14486](#) GRB 130427A: Kanata/HOWPol optical imaging polarimetry
- [14485](#) GRB 130427A: Swift-XRT refined Analysis
- [14484](#) GRB 130427A: SPI-ACS/INTEGRAL observations
- [14483](#) GRB 130427A: Continued RATIR Optical and NIR Observations
- [14482](#) GRB 130427A: CARMA 85 GHz detection
- [14481](#) GRB 130427A: SNUO/SOAO/BOAO Observation
- [14480](#) GRB 130427A: VLA 5 GHz detection
- [14478](#) GRB 130427A: NOT optical photometry and redshift
- [14476](#) GRB 130427A: RAPTOR Bright Counterpart Before Swift Trigger
- [14475](#) GRB 130427A: T100 observations
- [14474](#) GRB 130427A: optical observations in CrAO
- [14473](#) GRB 130427A: Fermi GBM observation
- [14472](#) GRB 130427A: Swift/UVOT followup observations of an Optical Afterglow
- [14471](#) GRB 130427A: Fermi-LAT detection of a burst
- [14470](#) GRB 130427A: Swift-BAT refined analysis
- [14468](#) GRB 130427A: Zadko observatory - Gingin optical observations
- [14466](#) GRB 130427A: GMG optical observation
- [14465](#) GRB 130427A: MITSuME Okayama Optical Observation
- [14464](#) GRB 130427A: Optical Observations
- [14462](#) GRB 130427A: MAXI/GSC detection
- [14459](#) GRB 130427A: RATIR Optical and NIR Observations
- [14458](#) GRB 130427A: Weihai optical observations
- [14457](#) GRB 130427A: iTelescope T11 optical observations
- [14456](#) GRB 130427A: Continued P60 follow-up of an extremely bright optical afterglow
- [14455](#) GRB 130427A: Gemini-North redshift
- [14454](#) GRB 130427A: MITSuME Akeno Optical observation(T0+8000s~)
- [14453](#) GRB 130427A: PAIRITEL NIR Detections
- [14452](#) GRB 130427A: Faulkes Telescope North detection
- [14451](#) GRB 130427A: P60 early detection
- [14450](#) GRB 130427A: early optical observations
- [14449](#) GRB 130427A: P60 early nondetection
- [14448](#) GRB 130427A: Swift detection of a very bright burst with a likely bright optical counterpart

# How bright was GRB 130427A in the LAT?

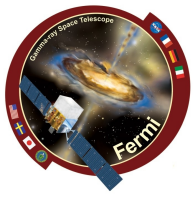


- **Maps from automated software which searches for transient on 6-hour time scale, in galactic coordinates**
- **Map before GRB 130427A occurred**
- **Map which includes GRB 130427A**

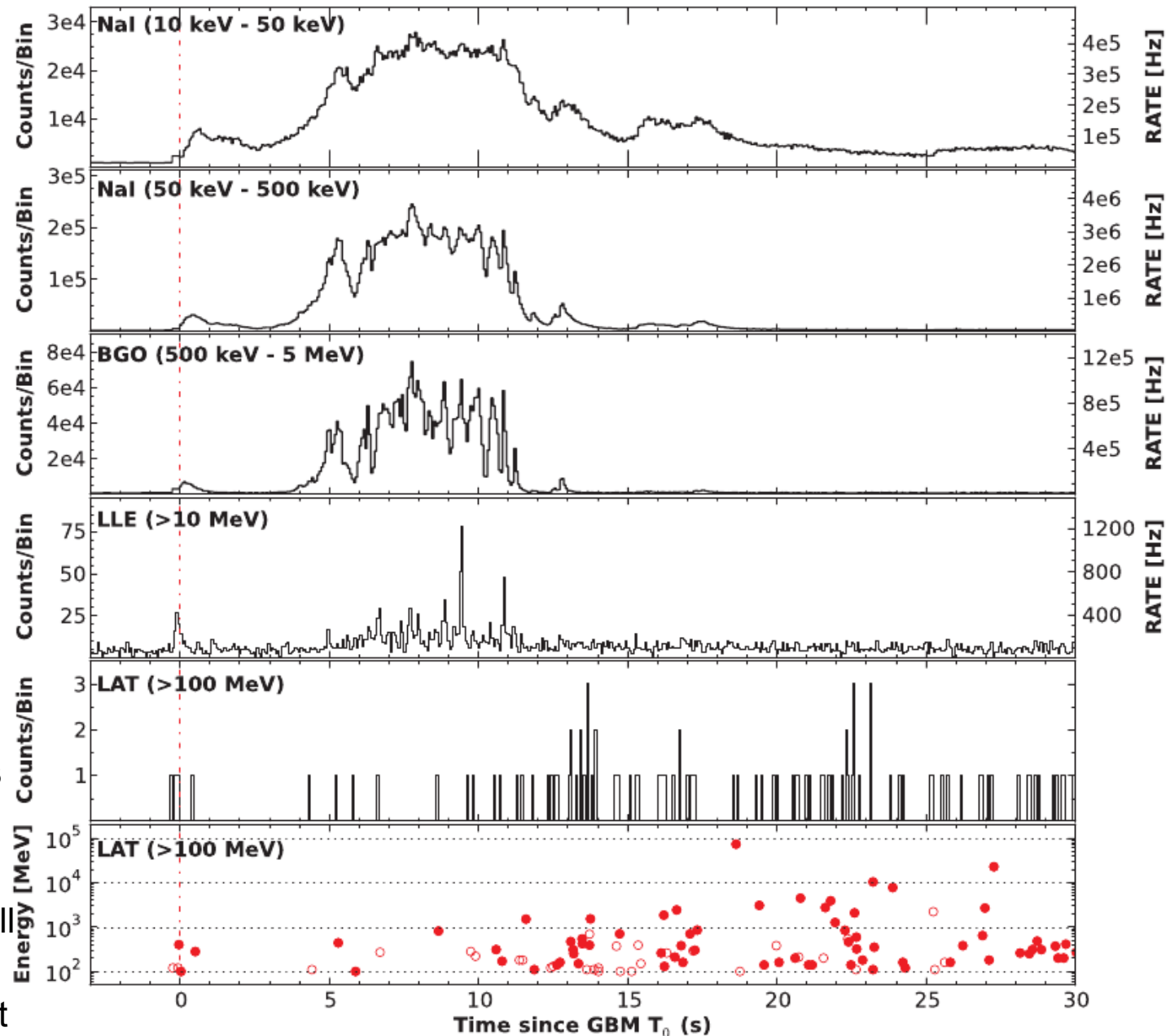




# GRB 130427A composite light curve

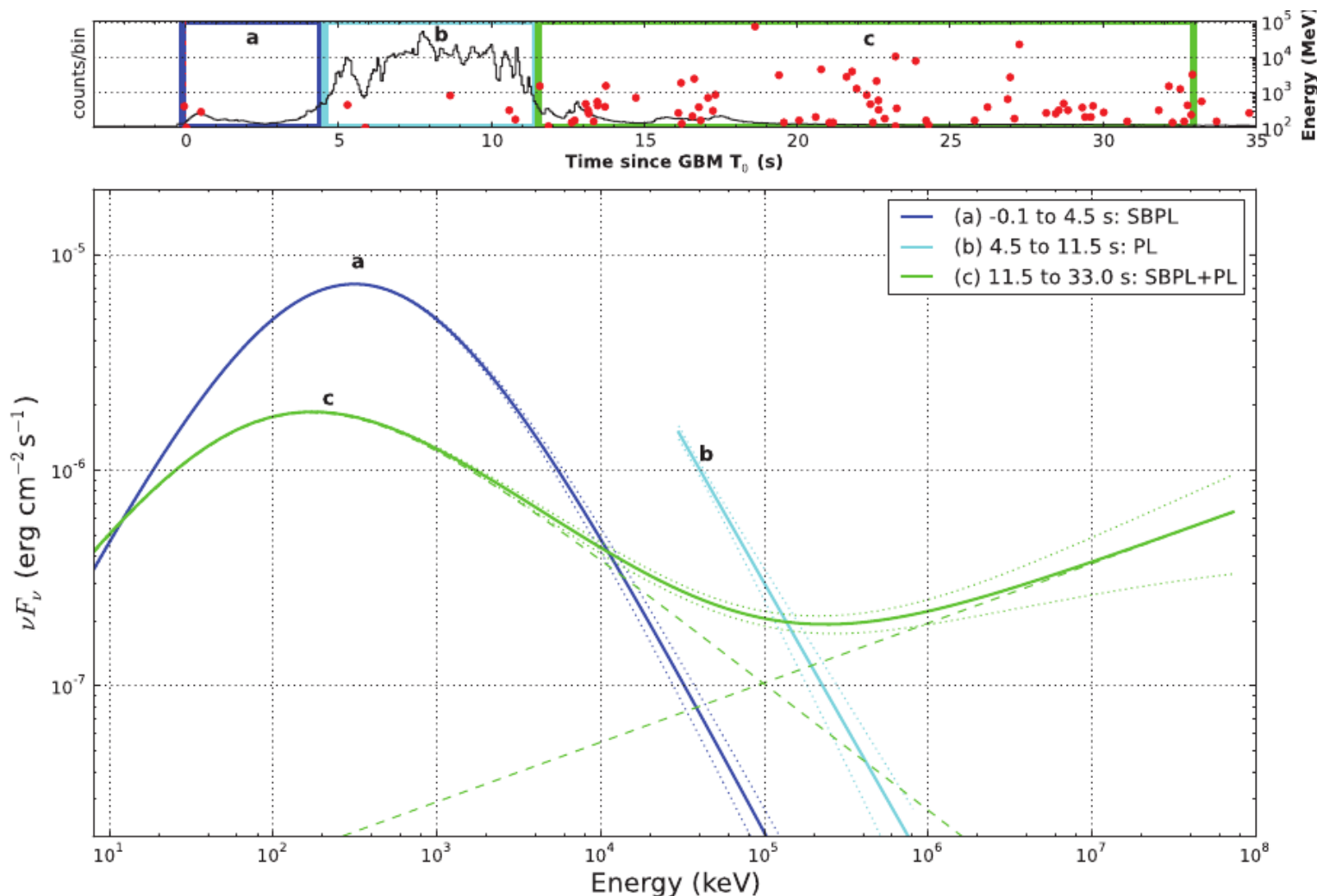
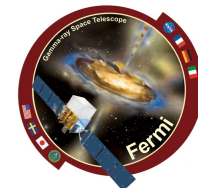


- Redshift  $z=0.34$
- Energy released in  $\gamma$  rays  
 $E_{\text{iso}} = 1.4 \cdot 10^{54}$  erg
- Brightest LAT GRB
  - >500 photons >100 MeV
  - 15 photons >10 GeV
- Unlike other bright LAT GRBs, the LAT >100 MeV emission is temporally distinct from the GBM emission
- LAT >100 MeV emission is delayed and temporally extended
  - Delay  $\sim 10$  s, continues well after the prompt phase
  - 73 GeV photon detected at  $T_0 + 19$  s



*Ackermann et al. 2014, Science 343, 42*

# Spectral Energy Distributions



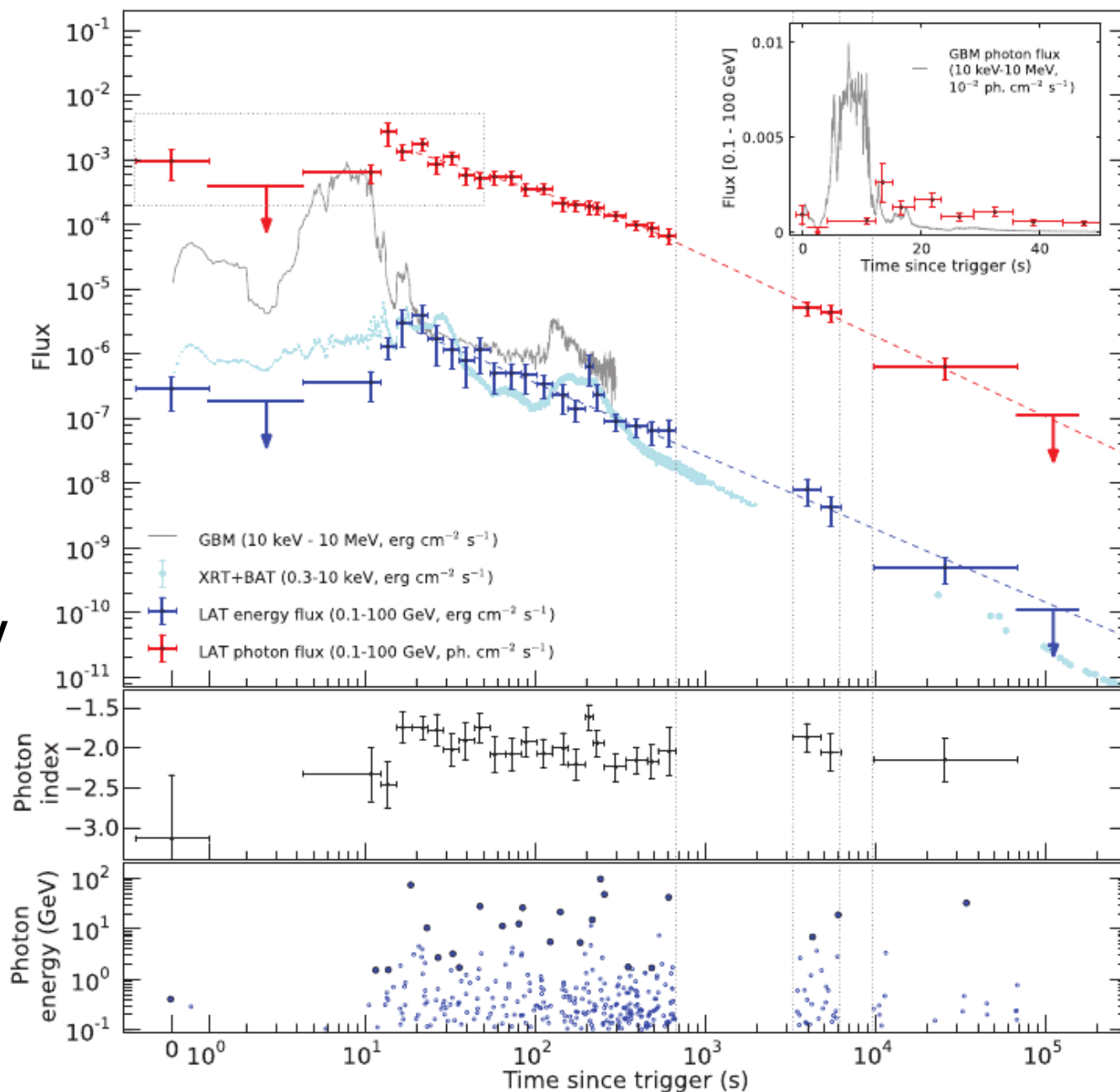
- **Unlike other bright LAT-detected GRBs, the extral PL component becomes significant only after the GBM-detected emission has faded. This suggests that:**
  - The GBM-detected emission is prompt emission (produced by internal shocks)
  - The LAT-detected emission is afterglow emission (produced by external shock)



# GRB 130427A afterglow in X-rays and $\gamma$ -rays



- **Brightest X-ray afterglow ever detected**
- **Longest-lived gamma-ray emission: LAT emission detected for 19 hours**
- **LAT light curve is  $\sim$ smooth**
  - Photon flux:  $t_{\text{break}} \sim 300\text{s}$
  - Energy flux temporal index:  $-1.17 \pm 0.06$
- **LAT spectrum described by a power law at all times**
  - Late spectral index  $\sim -2$
- **Some common features between LAT and lower energy light curves**
- **Record breaking 95 GeV photon at  $T_0 + 244\text{s}$**



*Ackermann et al. 2014, Science 343, 42*

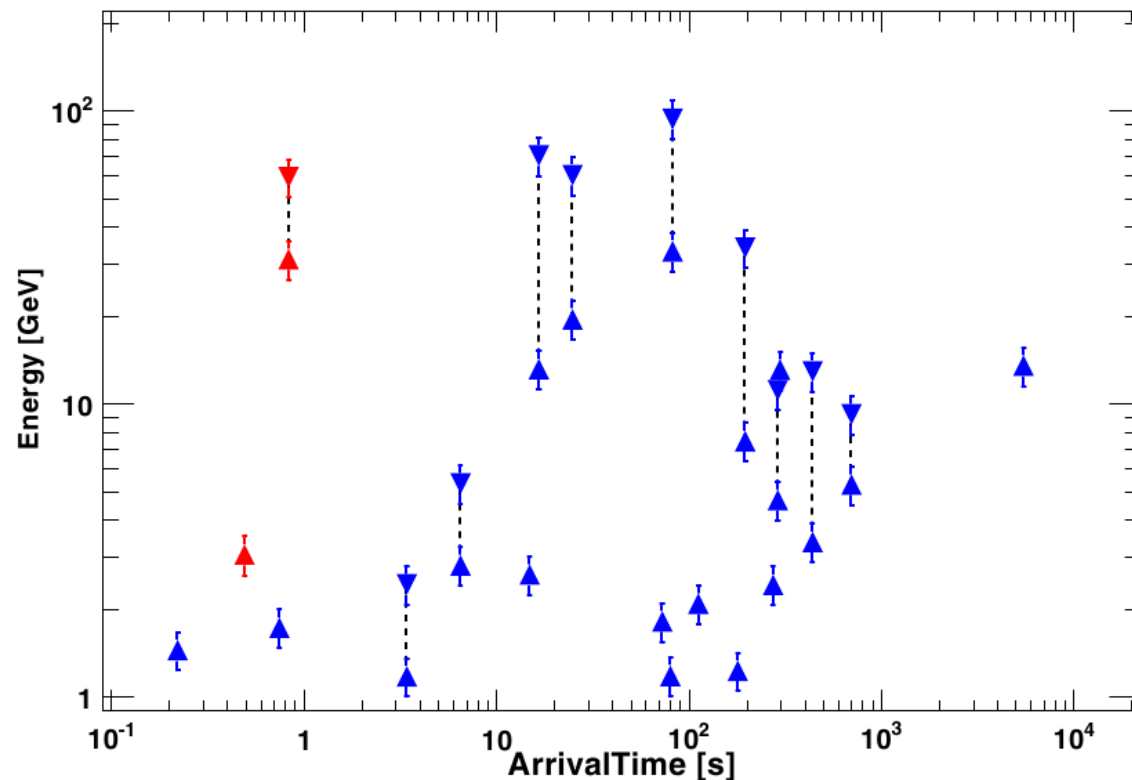


- 10 highest-energy LAT photons

*Ackermann et al. 2013, ApJS 209, 11*

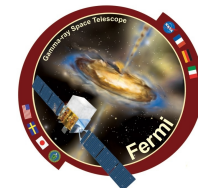
$E$	$E_{\text{rf}}$	$T - T_0$
95	128	243.55
73	97	19.06
47	63	256.70
41	55	611.01
39	52	3410.26
32	43	34366.58
28	37	48.01
26	35	85.16
21	21	141.53
15	20	217.89

*Ackermann et al. 2014, Science 343, 42*

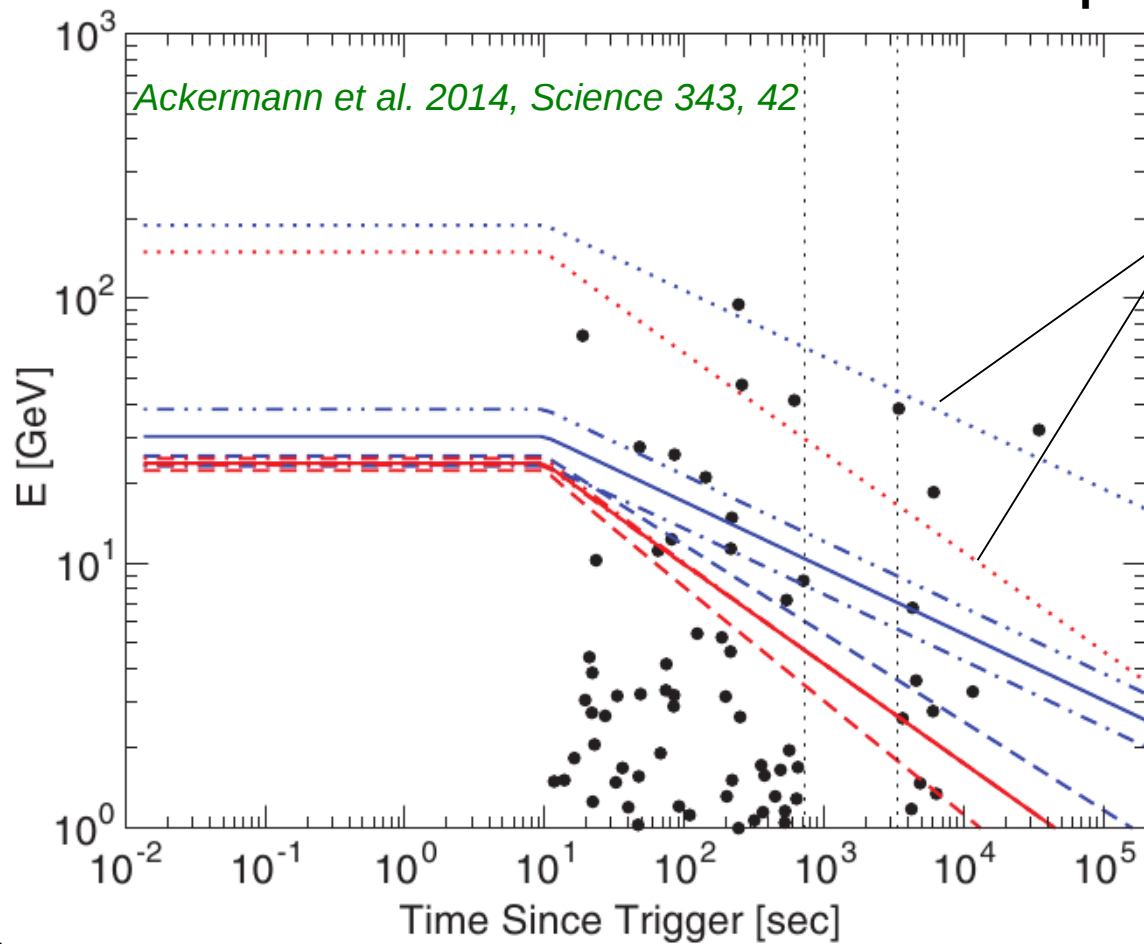


- GRB 090902B: 33.4 GeV photon at  $T_0 + 81.8$  s
- GRB 080916C: 27.5 GeV photon at  $T_0 + 40.5$  s  
(~150 GeV rest frame,  $z=4.35$ ) in Pass 8 data

# A challenge for synchrotron models



- **Synchrotron radiation models predict a maximum synchrotron energy, derived by equating the electron acceleration and synchrotron radiative cooling timescales**
  - Assuming a single acceleration and emission region
  - $E_{\text{max}} \sim 79\Gamma(t)$  MeV, with  $\Gamma(t)$  given by Blandford & McKee (1976) in the adiabatic limit
- **The LAT highest energy photons are incompatible with having a synchrotron origin**
- **Acceleration mechanism faster than the Fermi process?**



Extremely fast acceleration (less realistic):  
acceleration taking place on the inverse of  
the Larmor angular frequency  $t_{\text{acc}} \sim t_{\text{Larmor}} / 2\pi$

$$t_{\text{acc}} \sim t_{\text{Larmor}}$$

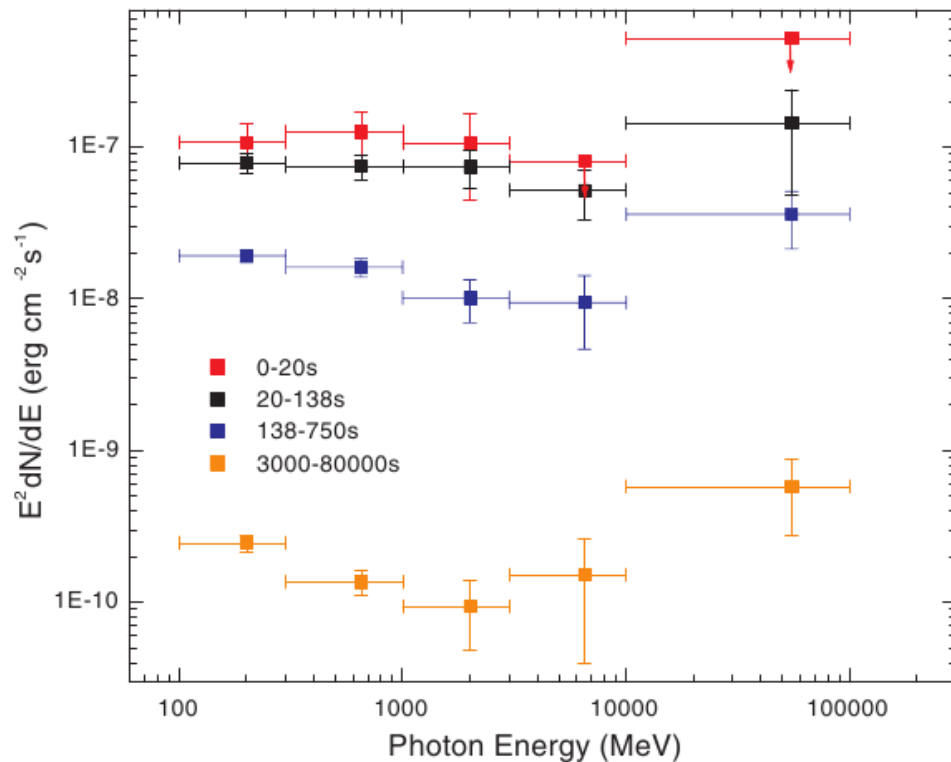
wind, adiabatic,  $\Gamma_0 = 2000$   
wind, adiabatic,  $\Gamma_0 = 1000$   
wind, adiabatic,  $\Gamma_0 = 500$   
  
wind, radiative,  $\Gamma_0 = 1000$   
ISM, adiabatic,  $\Gamma_0 = 1000$   
ISM, radiative,  $\Gamma_0 = 1000$



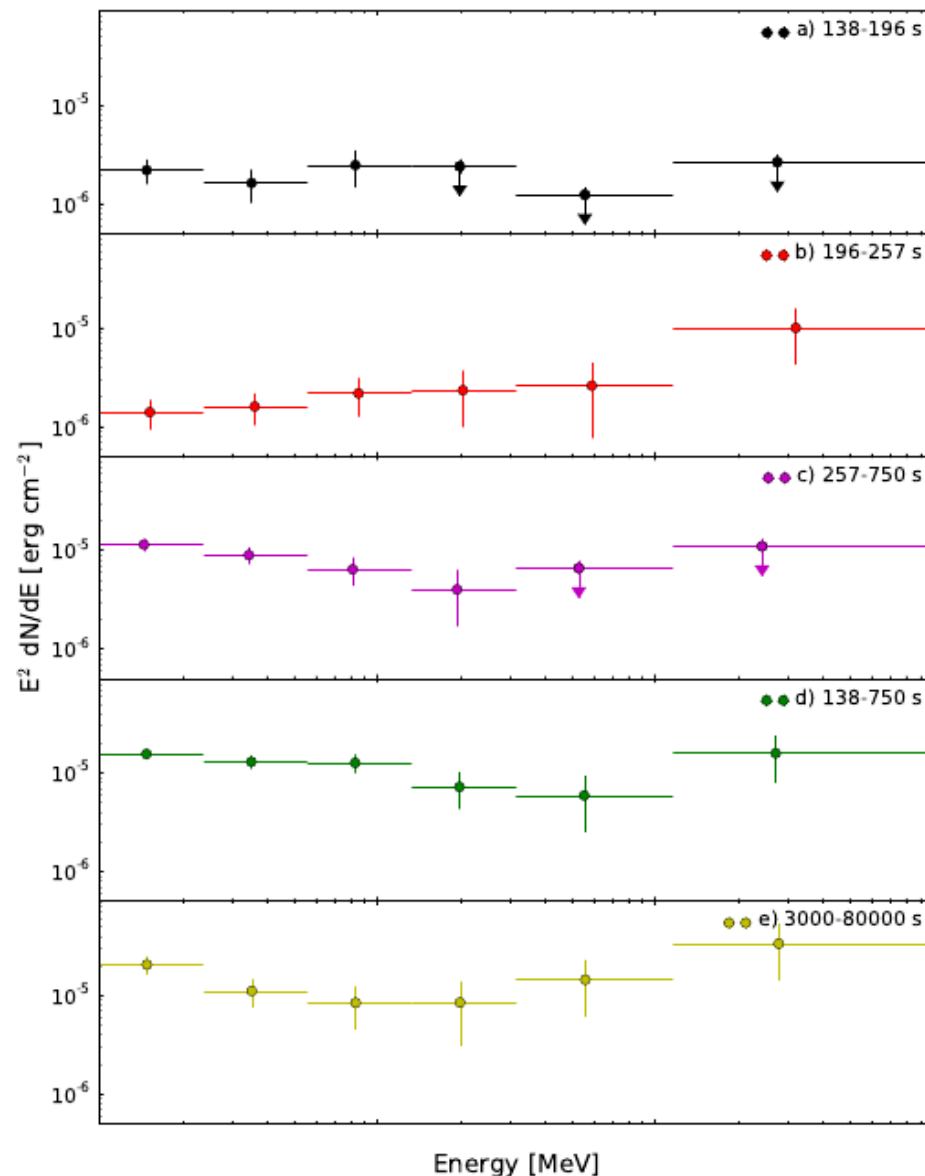
# No strong evidence for an SSC component



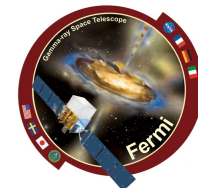
*Tam et al. 2013, ApJ 771, L13*



*Ackermann et al. 2014, Science 343, 42*

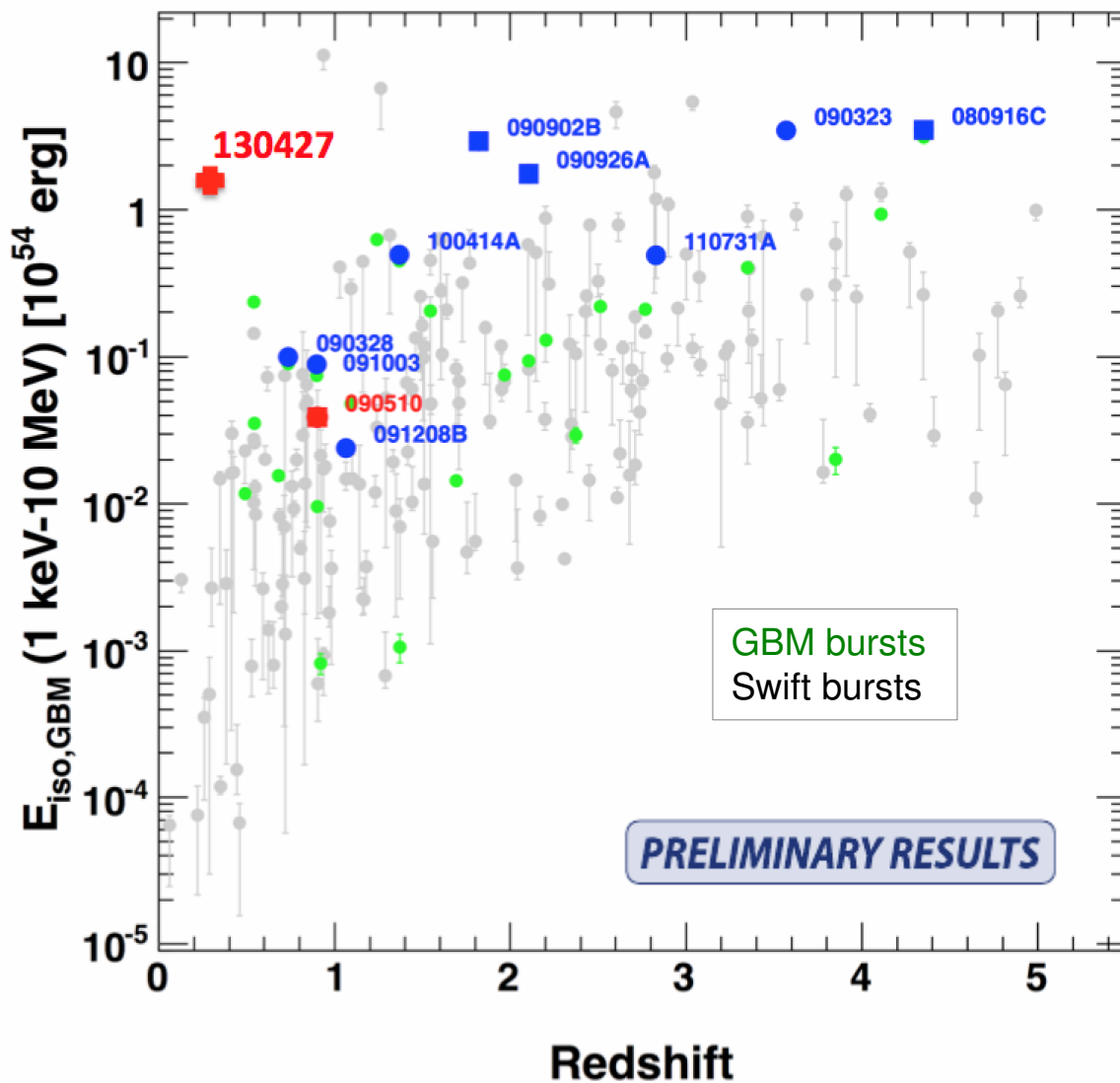


- **Tam et al. findings not confirmed by Ackermann et al. 2014**
- **Likelihood analysis in various time bins**
  - Simple PL model better describes the data, BPL model is not required
  - SED in d ~ sum of SEDs in a+c (soft) and b (hard)



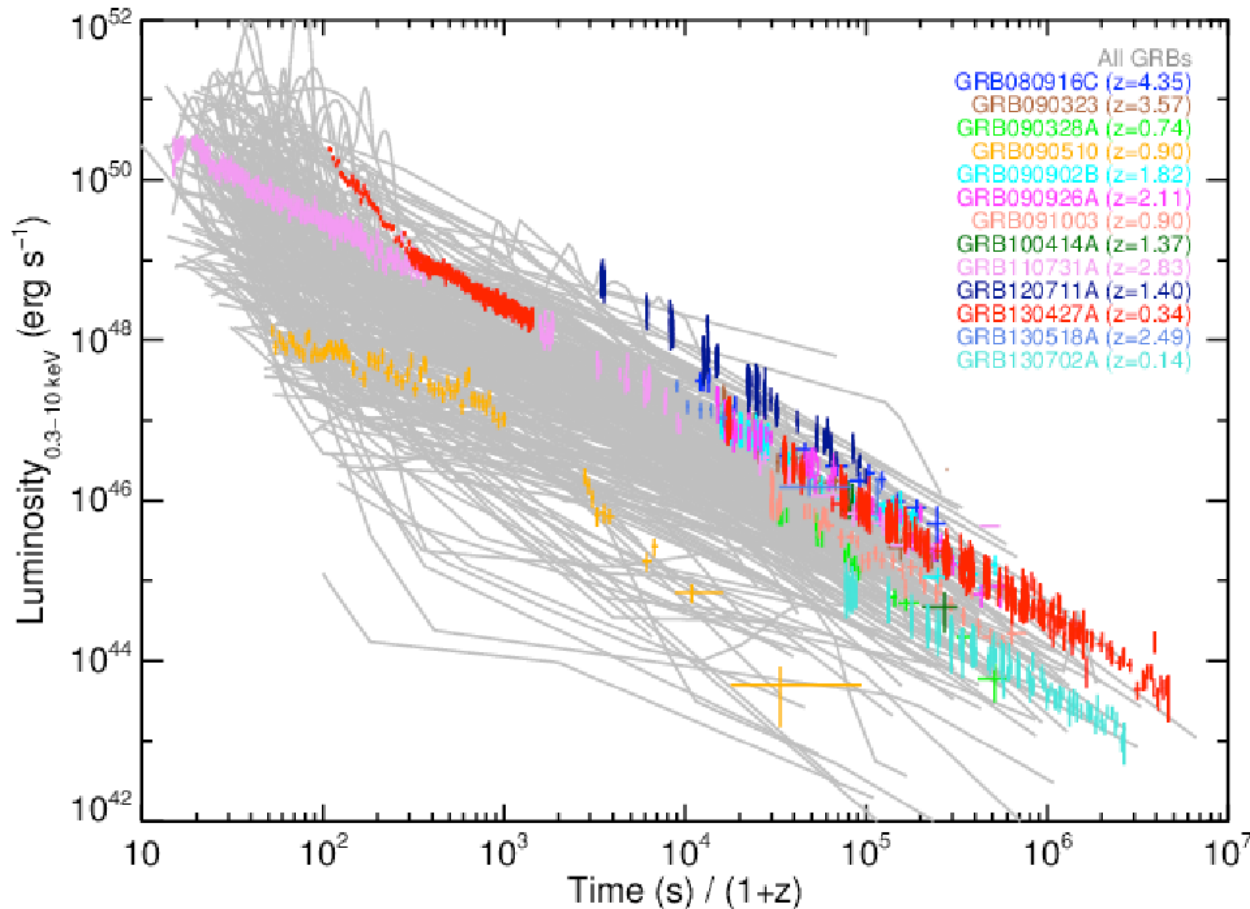
- **Comparing *Swift* and *Fermi* GRB samples:**

- *Butler et al. 2007, ApJ 671, 656 (see also Sakamoto et al. 2011, ApJS 195, 2)*
- *Goldstein et al. 2012, ApJS 199, 19*
- *Ackermann et al. 2013, ApJS 209, 11*



- **GRB 130427A is among the most energetic GRBs ever detected**
  - Comparable to the 4 most energetic LAT detected bursts
- **At first glance, GRB 130427A supports the idea that LAT bursts may represent a unique subpopulation of GRBs**
  - Hyper-energetic GRBs?
  - High Lorentz factors?

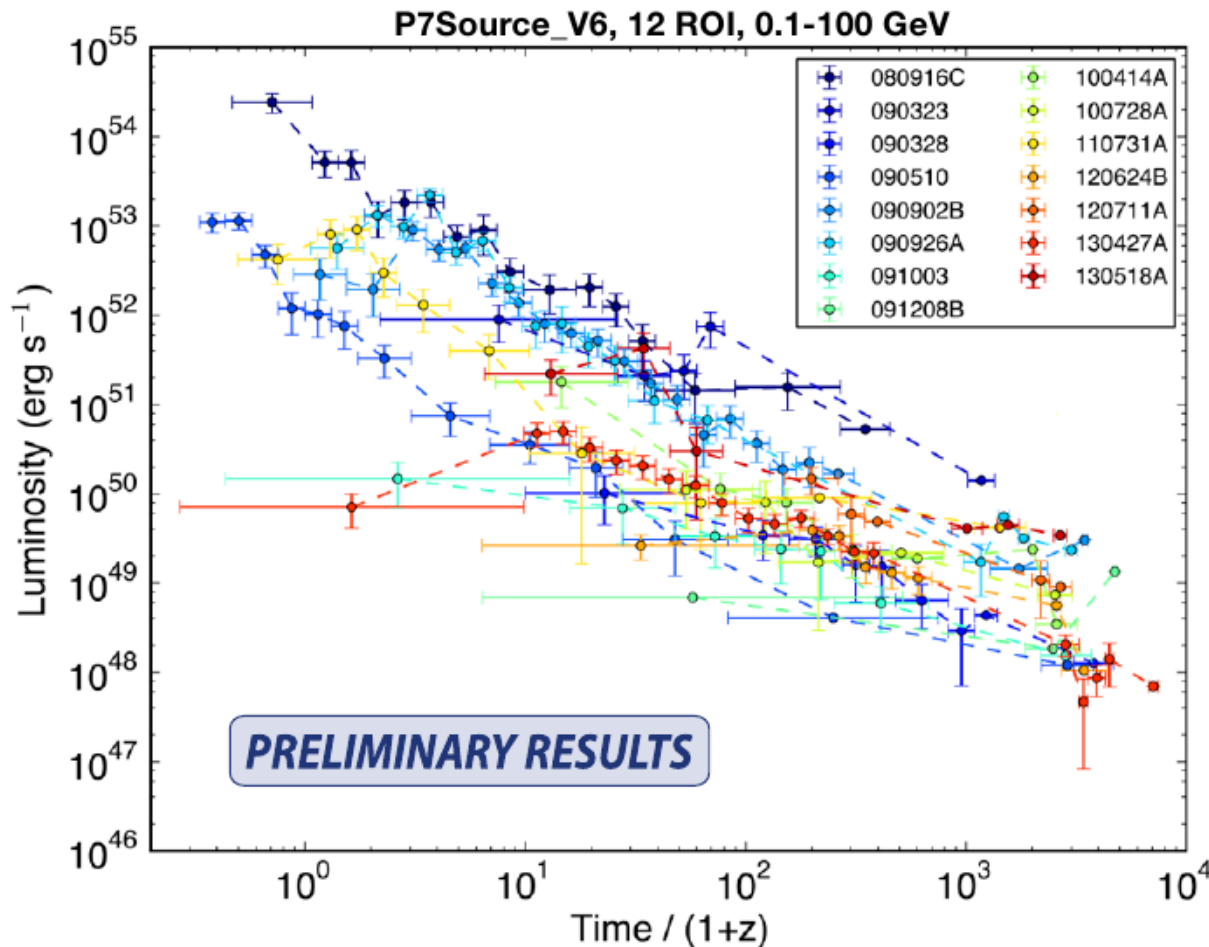
# X-ray afterglow properties



- **LAT-detected GRBs are on the high end of the XRT distribution**
  - The spread in LAT afterglows light curves has begun to widen as the sample increases
- **Source frame X-ray light curve for GRB 130427A is not extraordinary**
  - GRB 130427A is similar to other LAT detected bursts
  - Consistent with being drawn from the general population

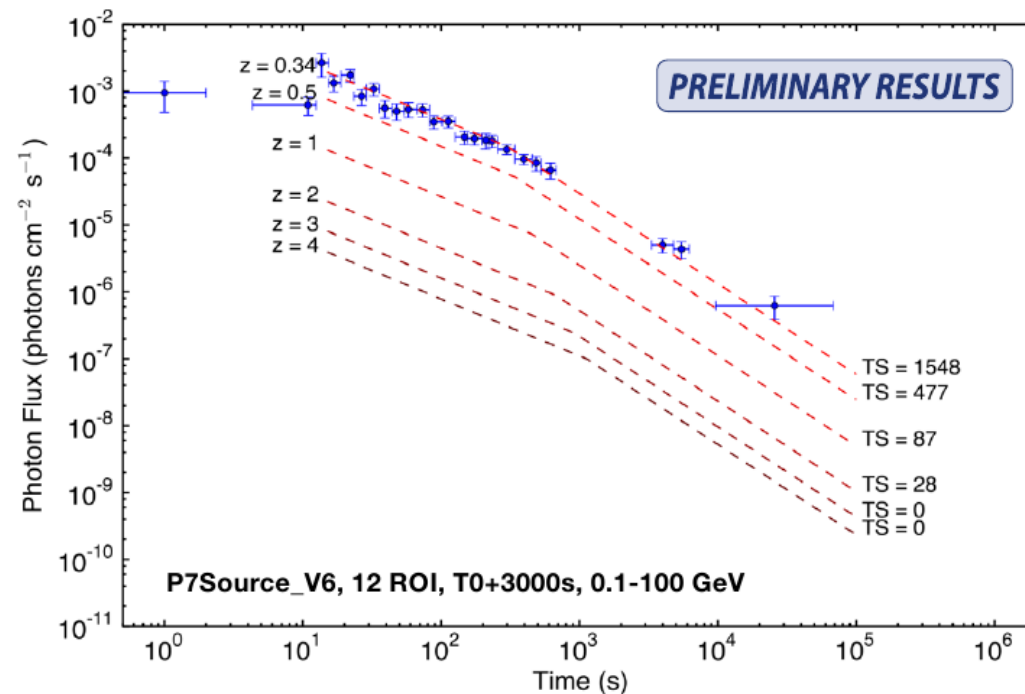
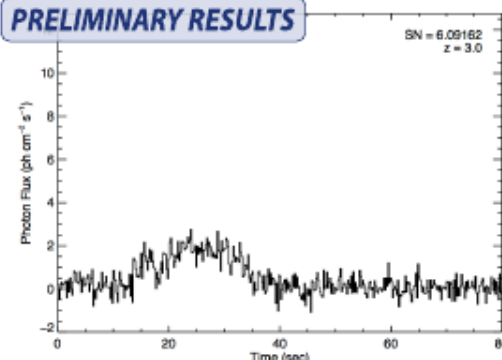
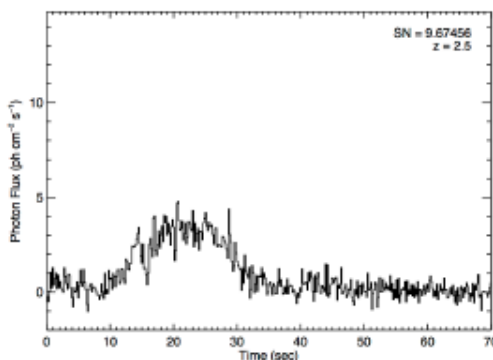
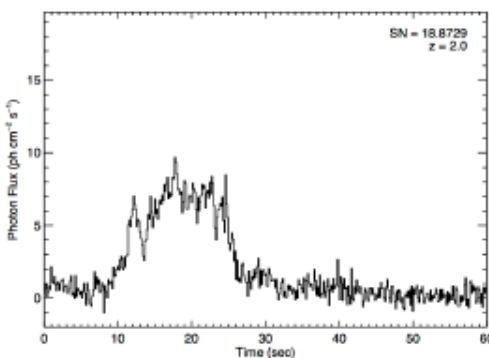
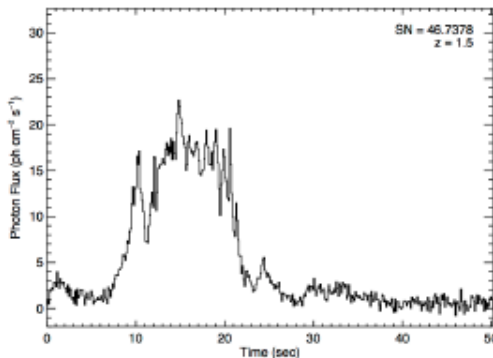
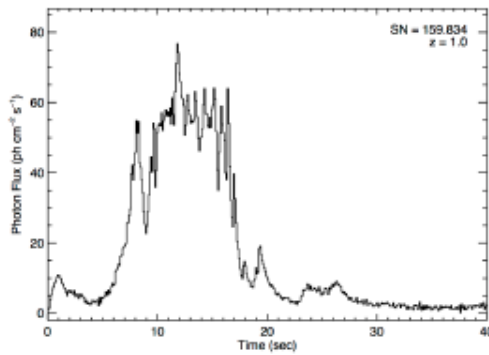
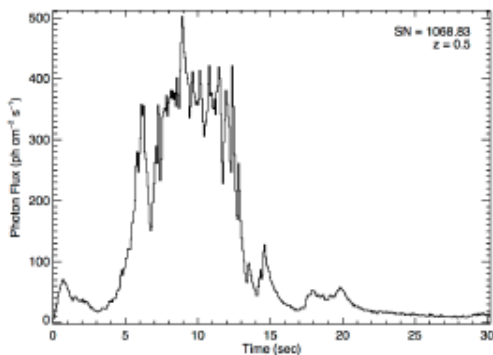
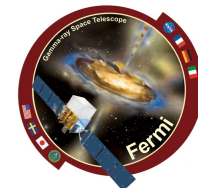


# LAT source frame light curve



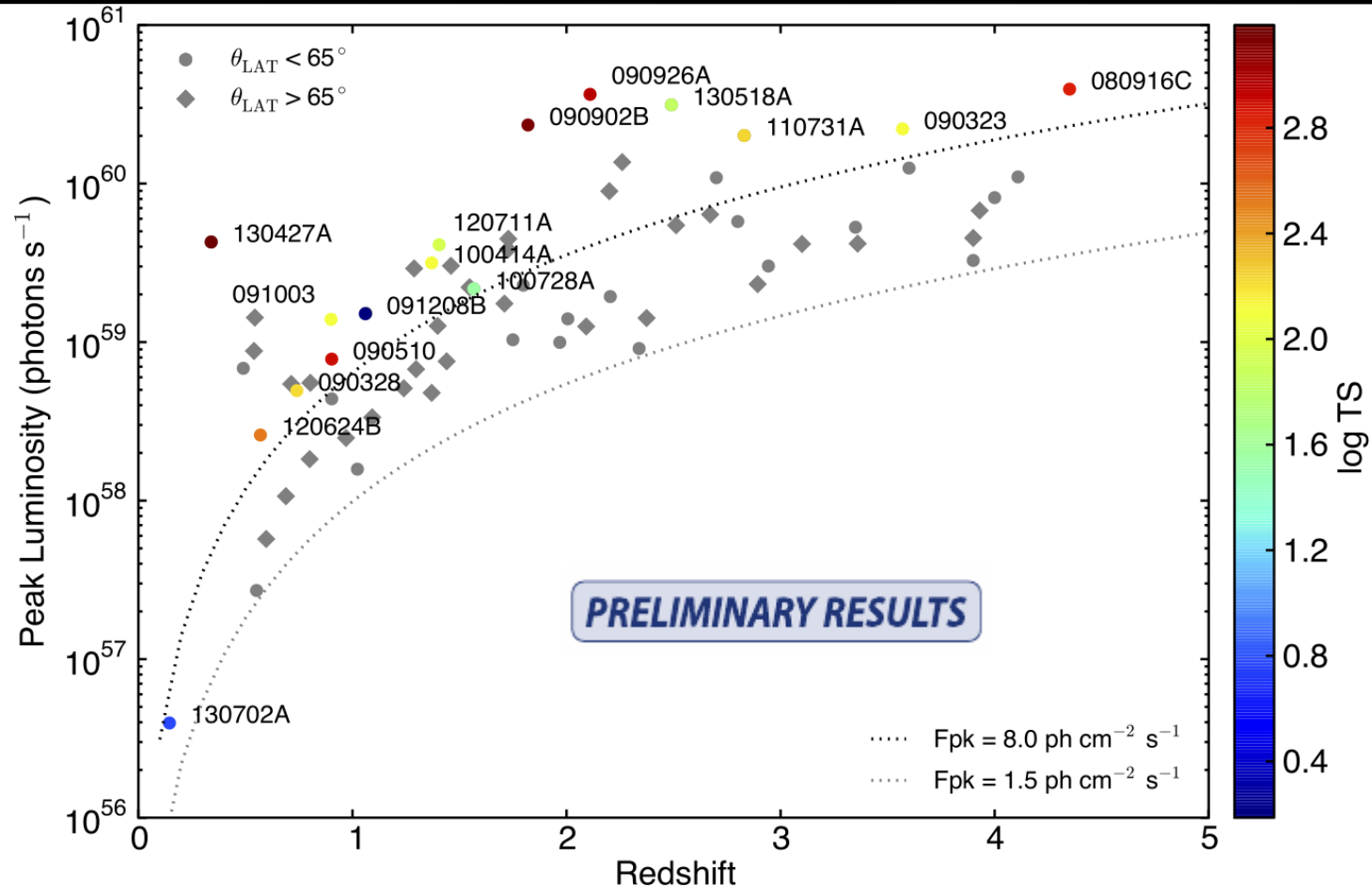
- **Source frame GeV light curve for GRB 130427A is also not extraordinary**
  - GRBs 080916C, 090902B, & 090926A are much brighter at early times
- **How far would we have seen GRB 130427A?**
  - What does this tell us about the nature of LAT non-detected GRBs?

# Detectability (1/2)



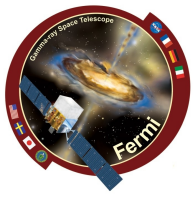
- **Simulation of GBM detectability vs. redshift**
  - The burst would have been detected out to  $z \sim 4.5$
- **Simulation of LAT detectability vs. redshift**
  - TS drops quickly as a function of redshift, barely detectable at  $z = 2$

# Detectability (2/2)



- **Large redshift range ( $2 < z < 5$ ) where GRB 130427A would have been GeV quiet**
  - LAT detectability closely traces the GBM peak flux threshold
- **LAT-detected bursts not necessarily a unique population of GRBs**
  - Appear instead to be a flux limited sub-sample of the normal GRB population





- **GRB 130427A was exceptionally unique in the observer frame**
  - Rare event, considering the co-moving volume at  $z \sim 0.34$  (within closest 5% of GRBs)
  - The  $\gamma$ -ray records broken
    - Highest  $\gamma$ -ray fluence ( $>10^{-3}$  erg/cm<sup>2</sup>)
    - $\gamma$ -ray photon w/ the highest observed energy (95 GeV)
    - Longest-lasting GeV emission (19 hours)
  - One of the largest isotropic energy releases ever observed from a GRB
  - GBM and LAT emissions arise from different emission mechanisms and/or regions
  - LAT observations put severe constraints on the FS synchrotron model
- **GRB 130427A is characteristic of long GRBs at high redshifts**
  - High end of the GRB luminosity function observed at low  $z$
  - Would have appeared as a GeV quiet burst starting at a moderate  $z$
- **Selection effects play an important role in our understanding of the ubiquity of GeV emission**
  - LAT bursts do not necessarily trace a unique hyper-energetic population of GRBs
  - As we accumulate more LAT detections, we'll be able to perform more refined population demographics analysis