# High-energy emission from Gamma-Ray Bursts

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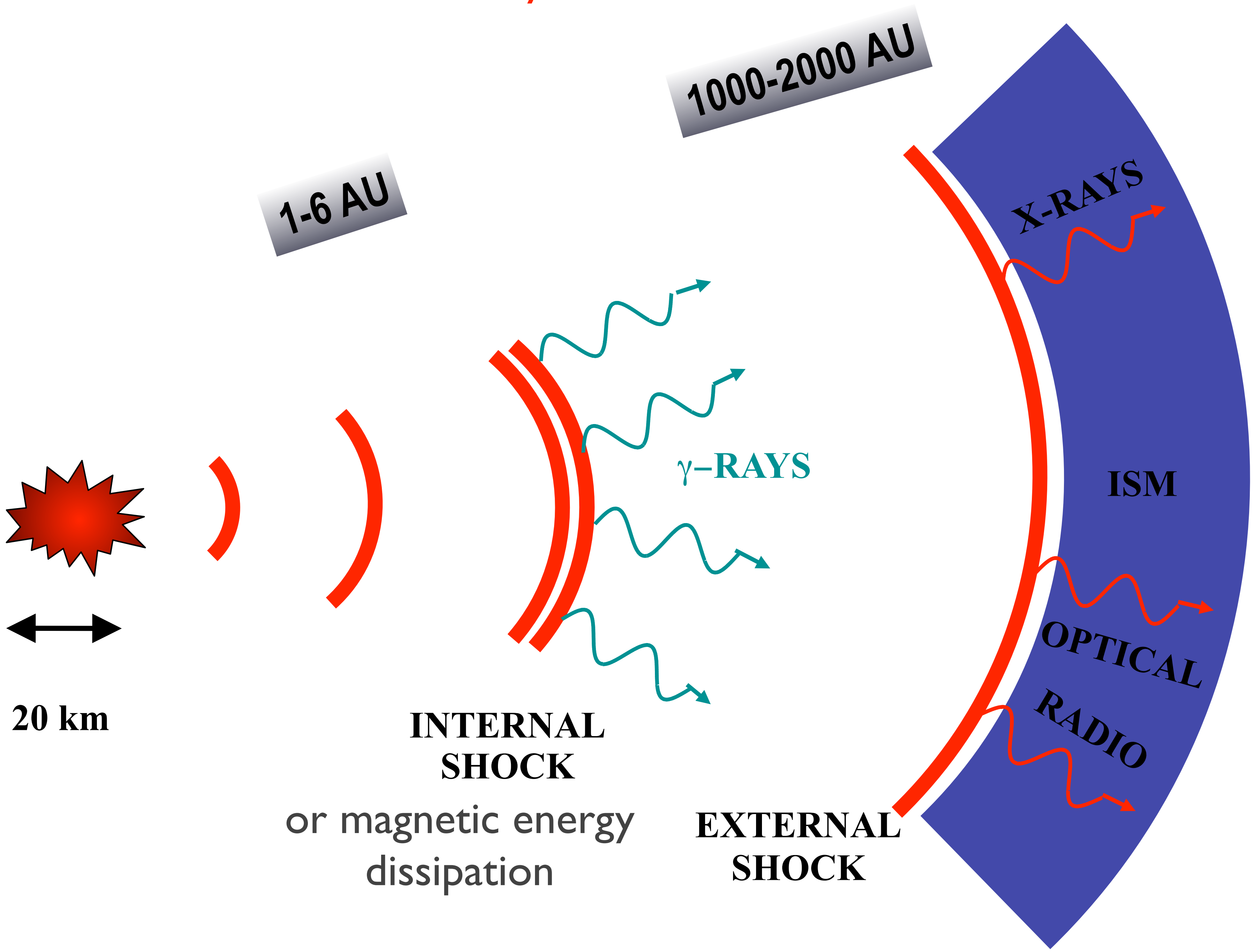
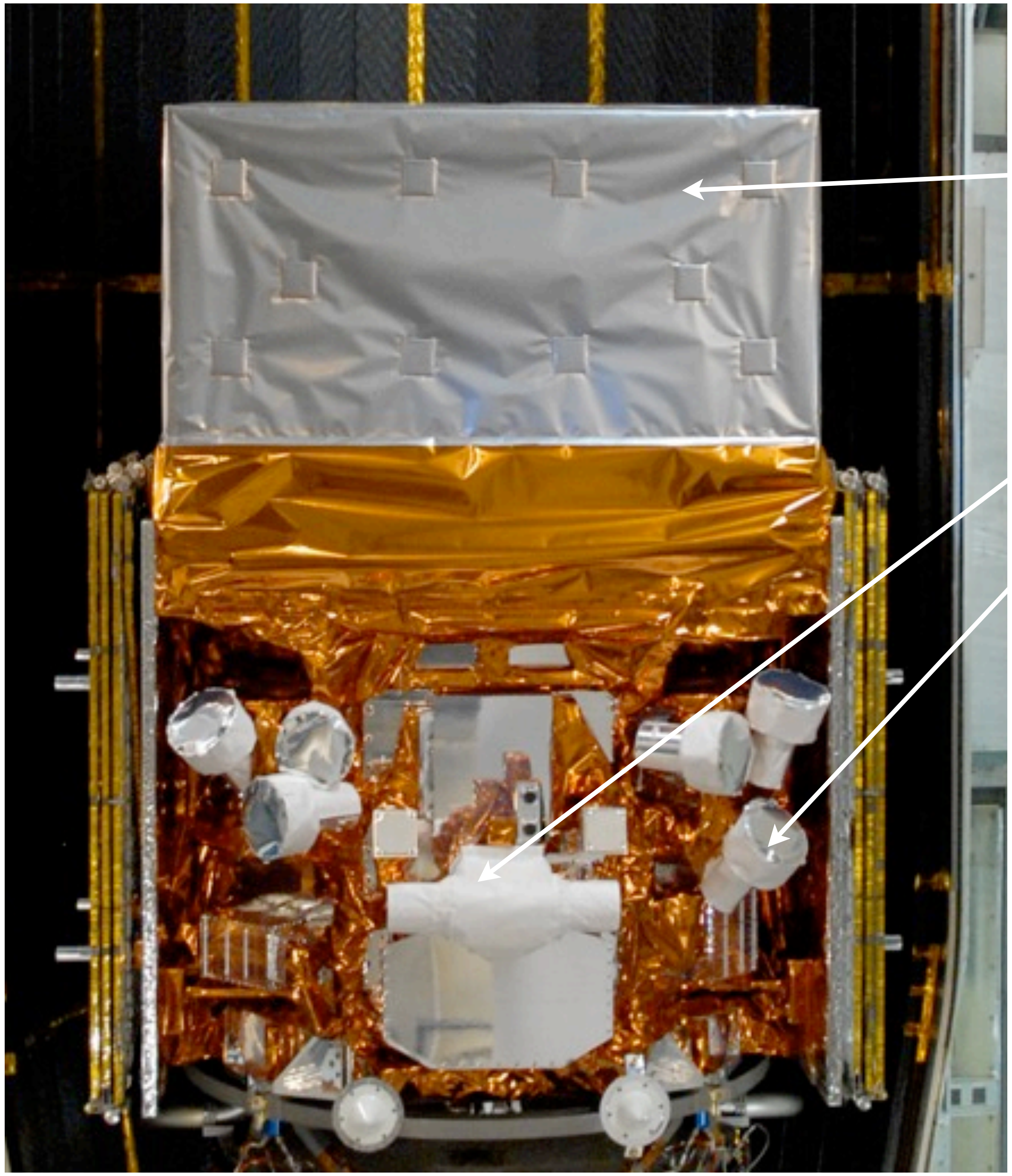
Prompt emission: dominated by gamma rays. Short-lived. Variability reflects central engine activity.

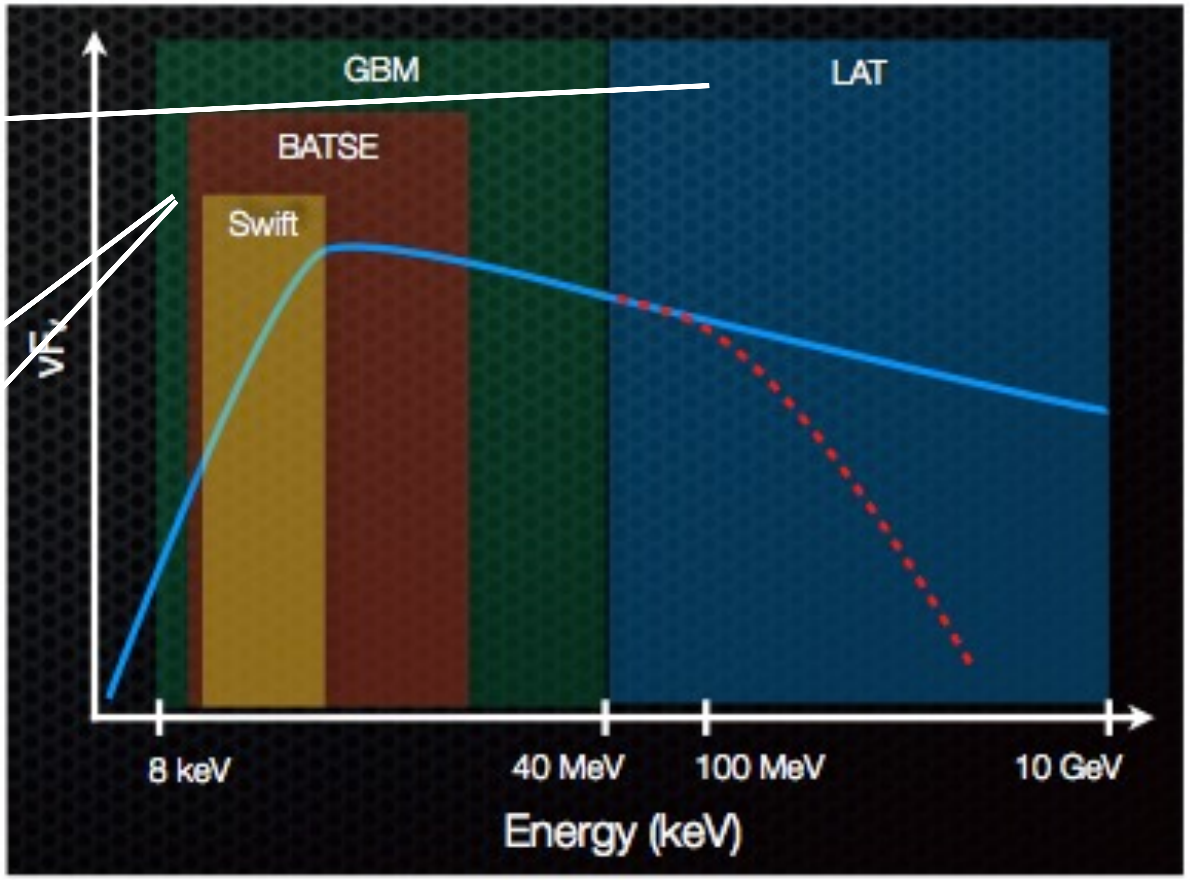
Afterglow emission: low energies. Long-lived. Smooth(ish) decay.

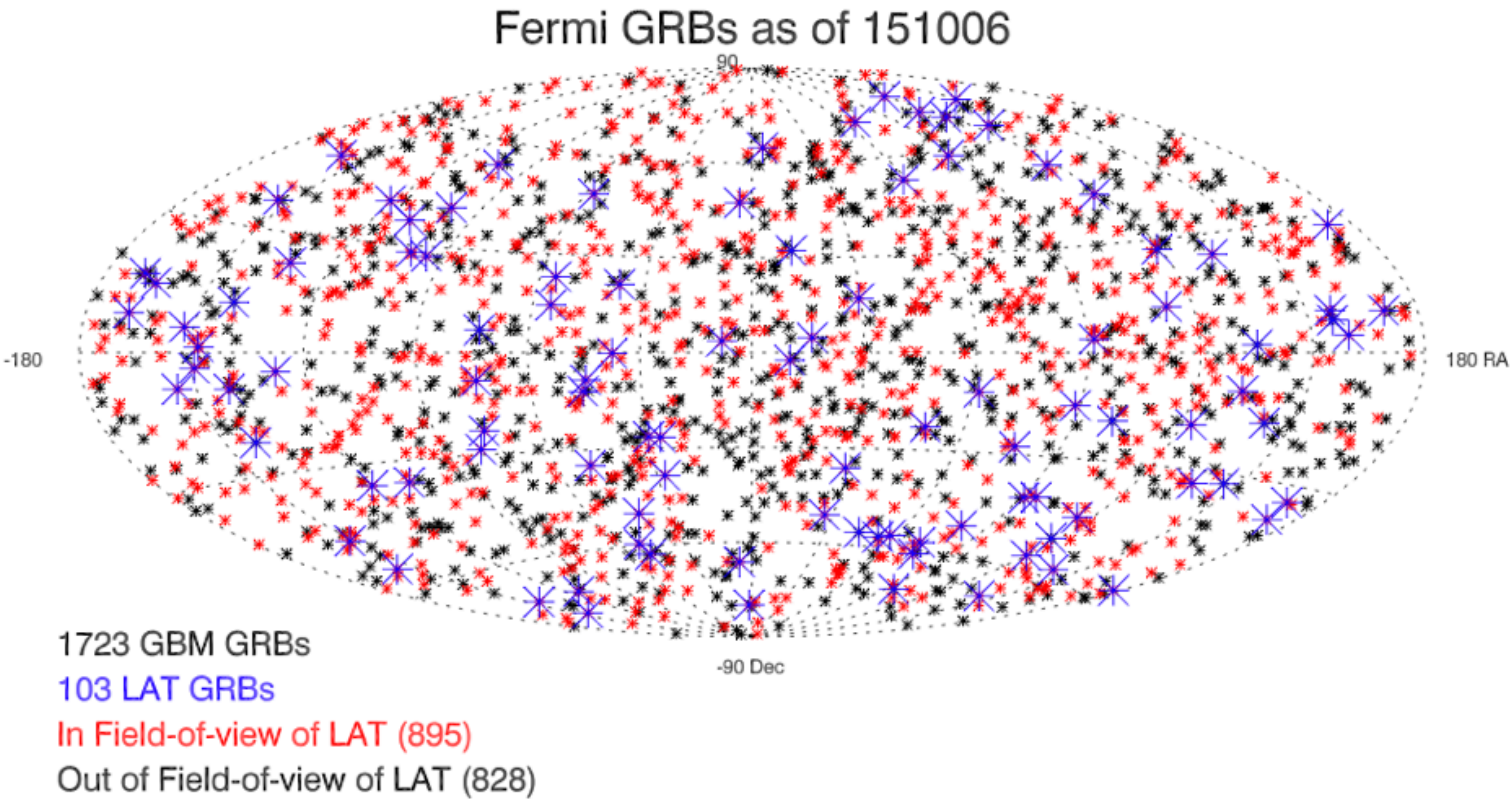



From Chuck Dermer

Fermi provides an unprecedented view of high-energy emission from GRBs:

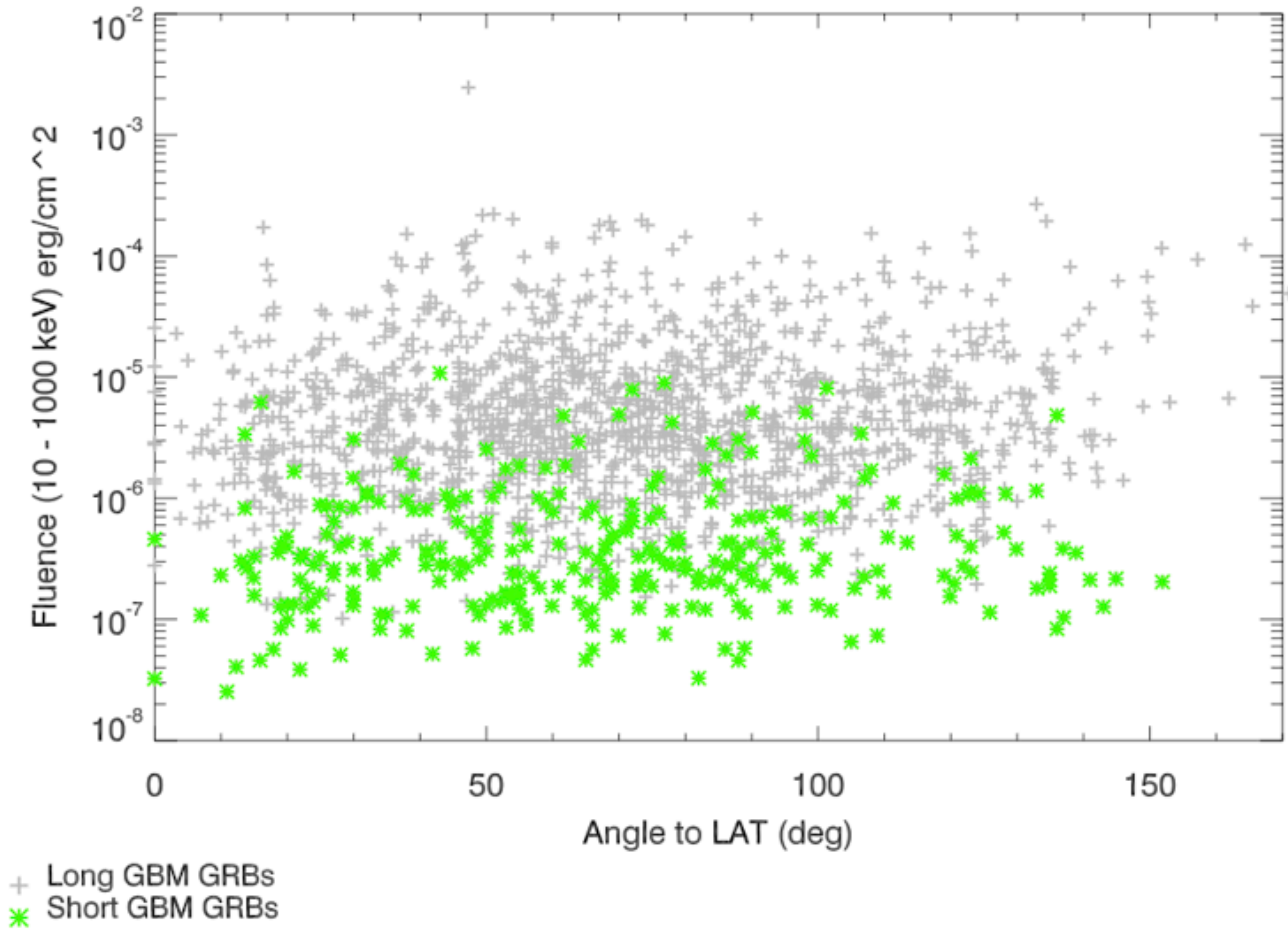




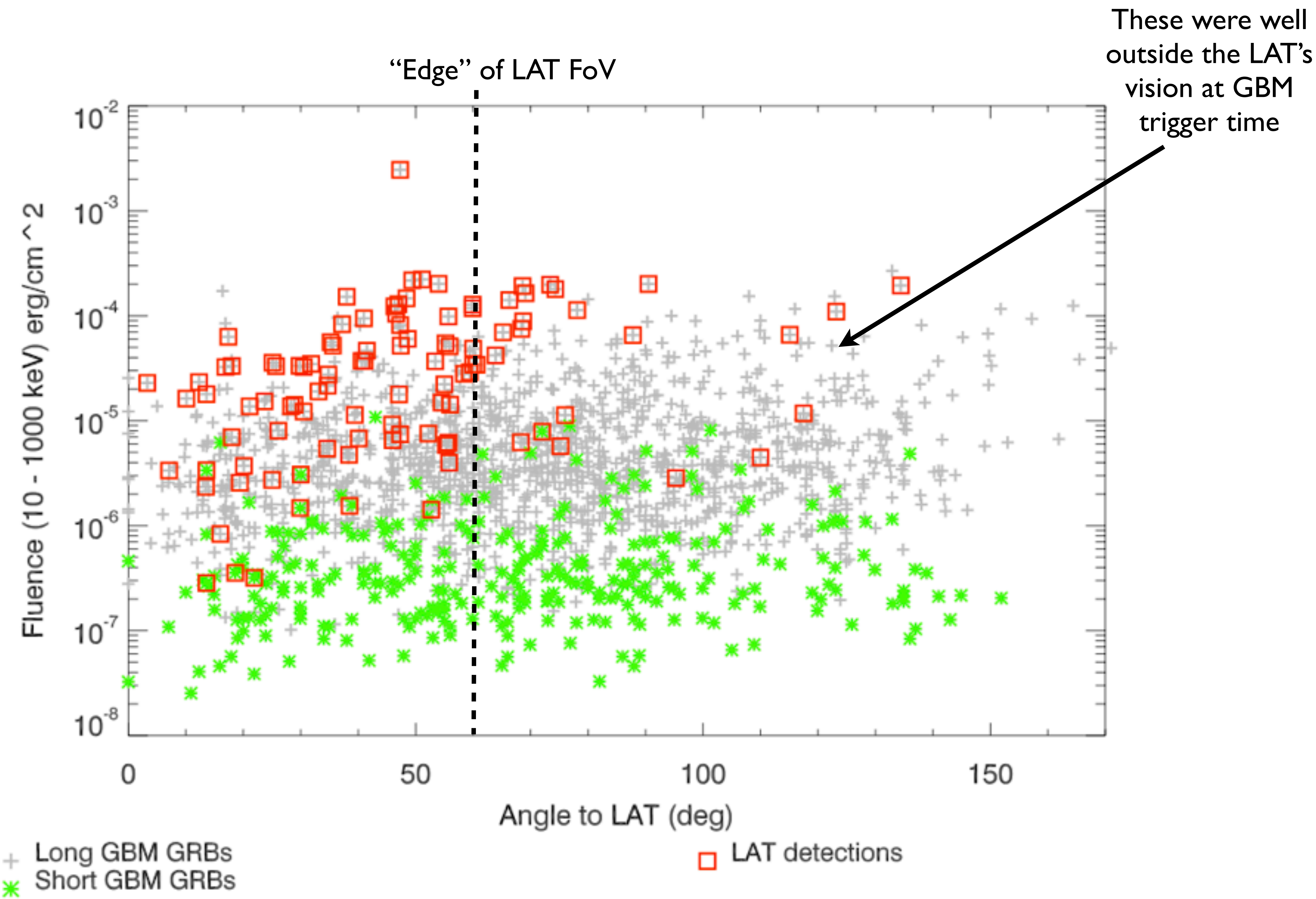



http://fermi.gsfc.nasa.gov/ssc/data/access/gbm/

# GBM Fluence < 1 MeV as a function of angle to LAT at GBM trigger time

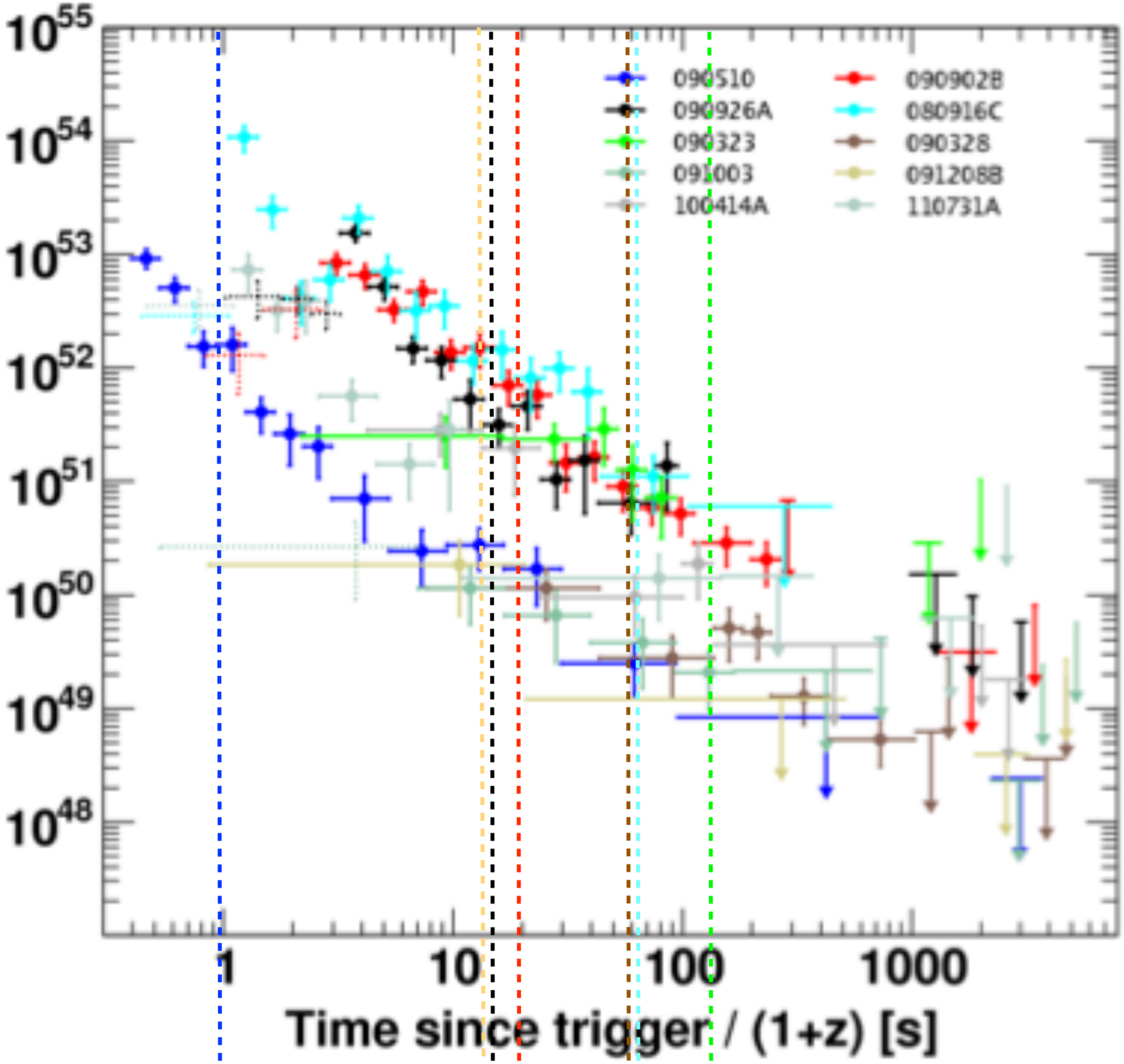


LAT detects the GRBs that are brighter (more fluent) at low energies and sees dimmer GRBs where it is most sensitive.

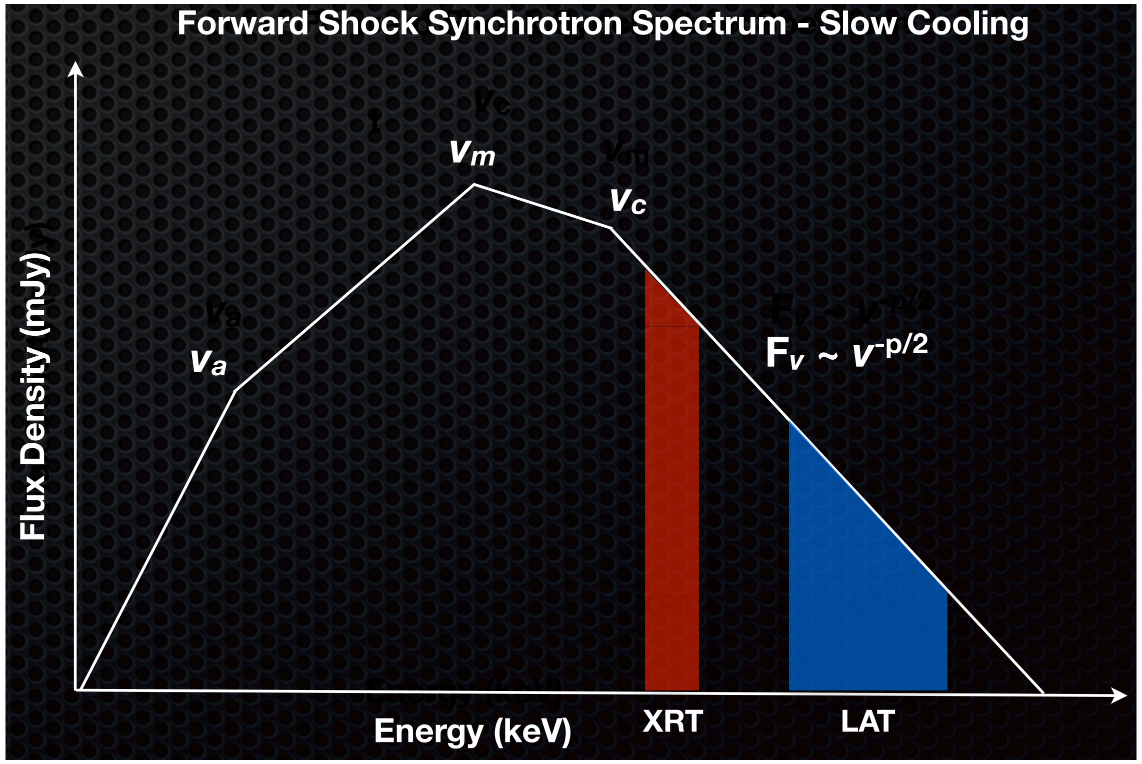


# Emission detected by the LAT > 100 MeV is extended in time relative to lower energies

LAT GRB Catalog
Ackermann et al. 2013



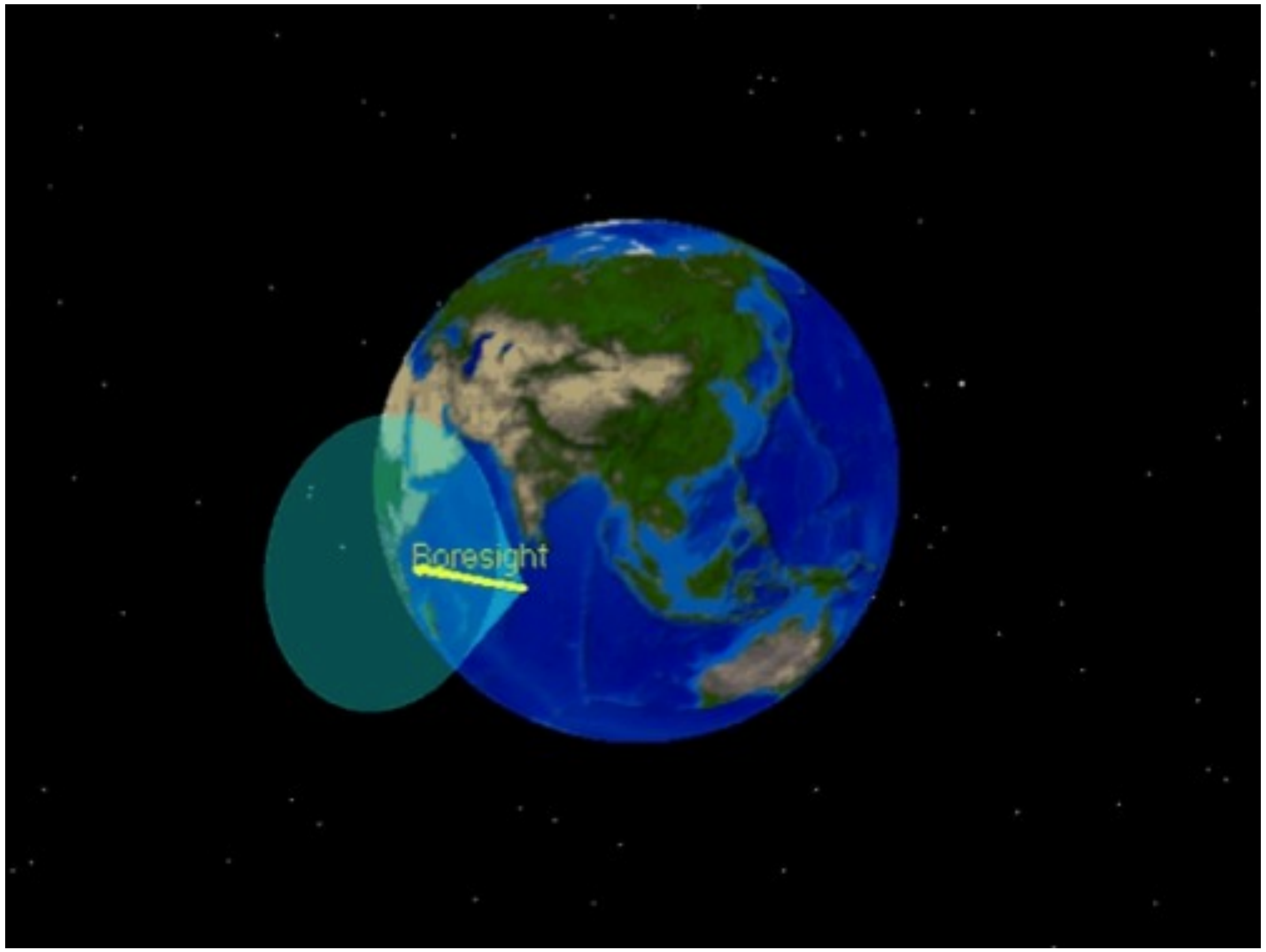

dashed lines are 50-300 keV t90s




?

How common is extended high-energy emission?
Is high-energy emission related to the afterglow?

Sensitivity of LAT to prompt emission is determined by angle to GRB position at GBM trigger time. Sensitivity to extended emission depends on which direction LAT boresight is headed after trigger time...



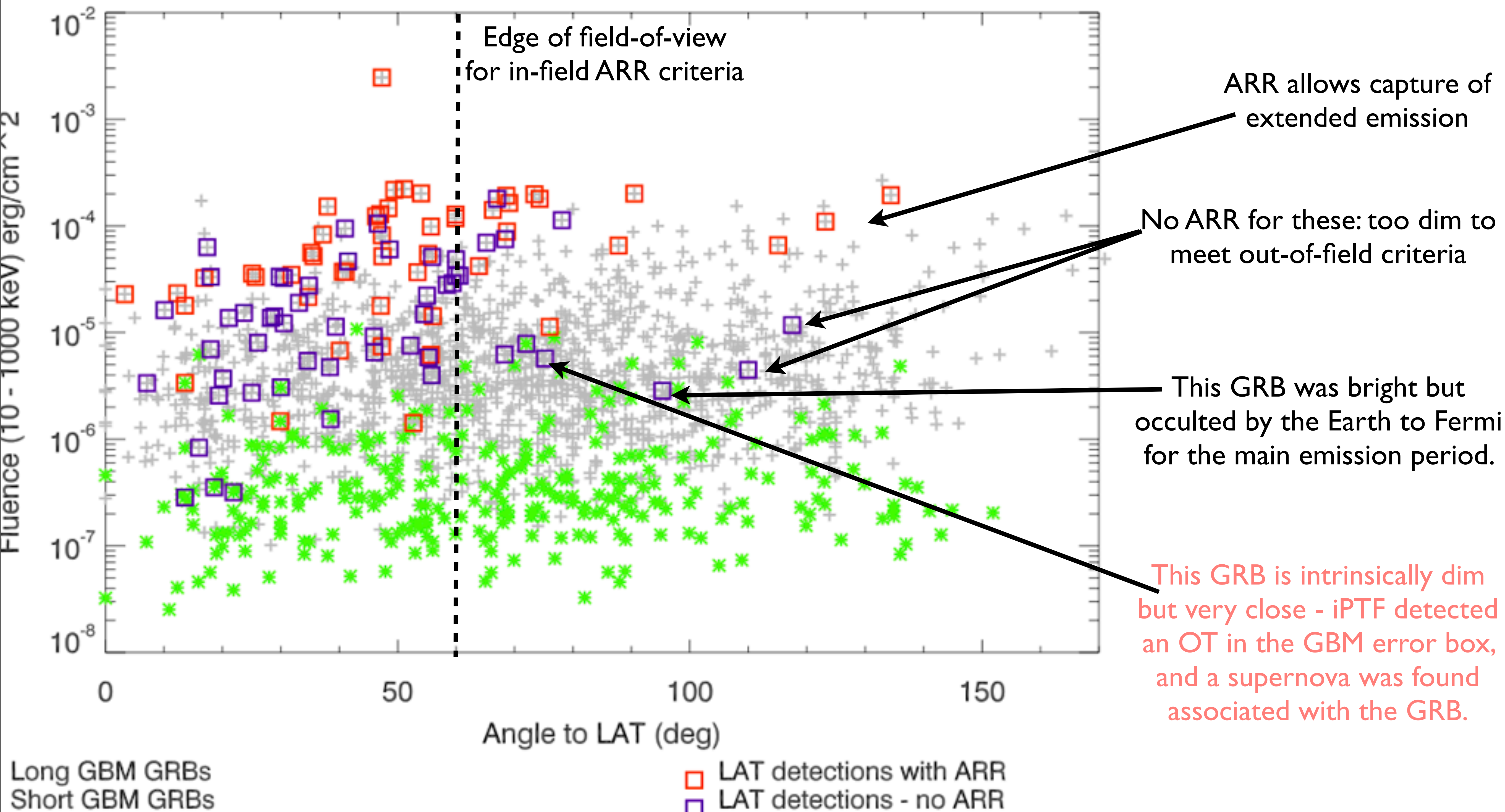

In survey mode the LAT rocks (now) 50 deg off the zenith north or south on alternate orbits. GRB placement in drifting of FoV affects sensitivity to GRB -> chance.

An Automatic Repoint Request (ARR) from the GBM Flight Software places the GBM on-board position for BRIGHT (peak flux or fluence) GRBs close to the LAT boresight for 2.5 hours (subject to constraints).

Over 140 times since enabling in 2009

Nearly 50% of LAT detections come from GRBs for which GBM issues ARRs.

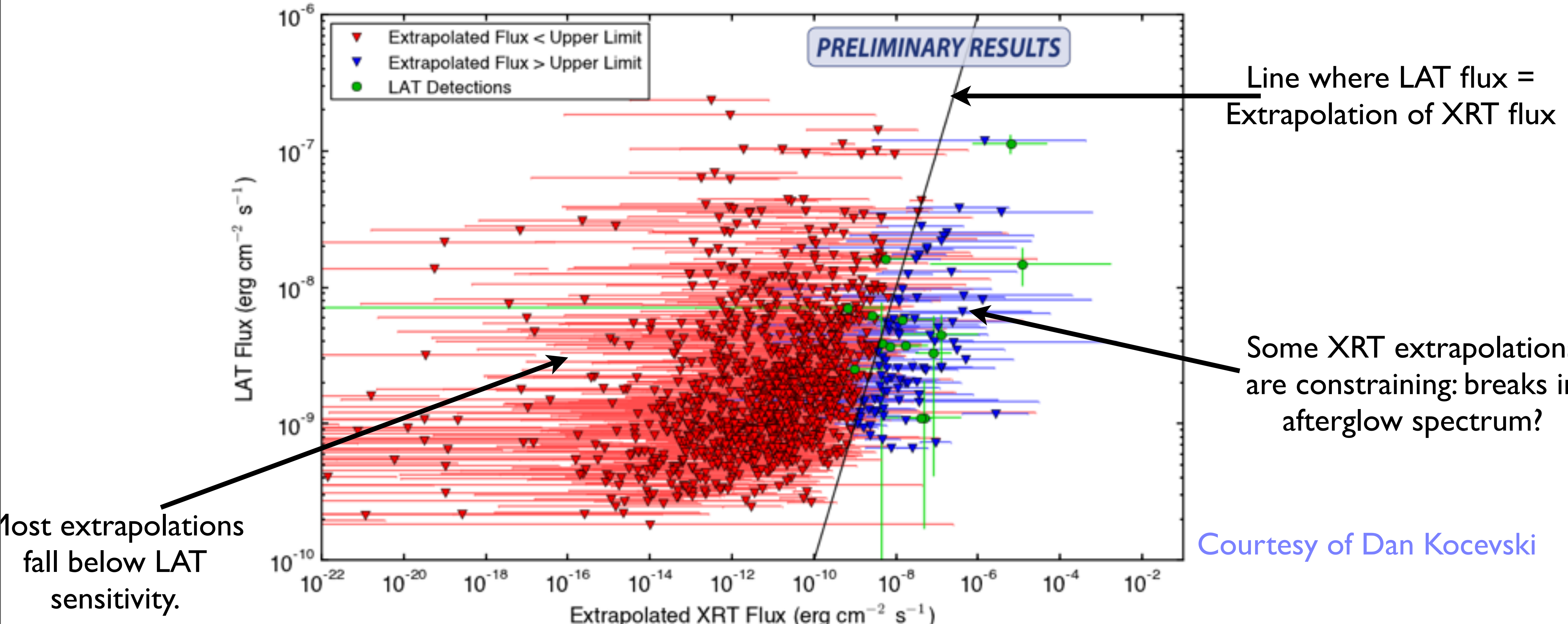
# Repointing the LAT to bright GBM GRBs enables the LAT detection of extended emission for GRBs outside its view at trigger time and/or over a longer period






Monday, October 26, 15

LAT flux and upper limits as a function of XRT flux extrapolated into the LAT energy range for 386 GRBs with exposure during XRT observations (1156 time intervals).

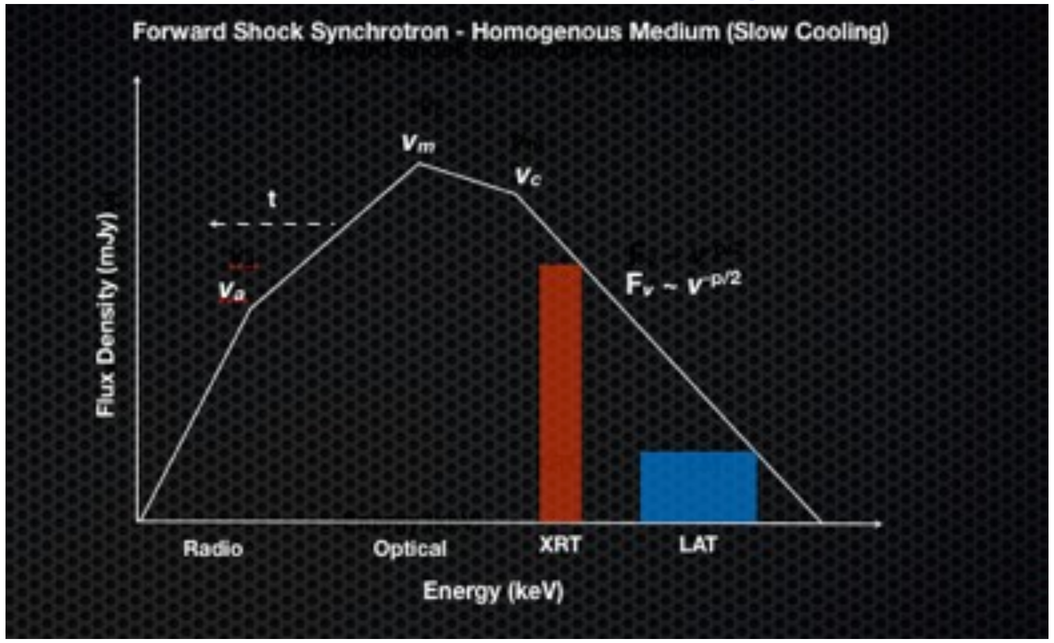



Courtesy of Dan Kocevski

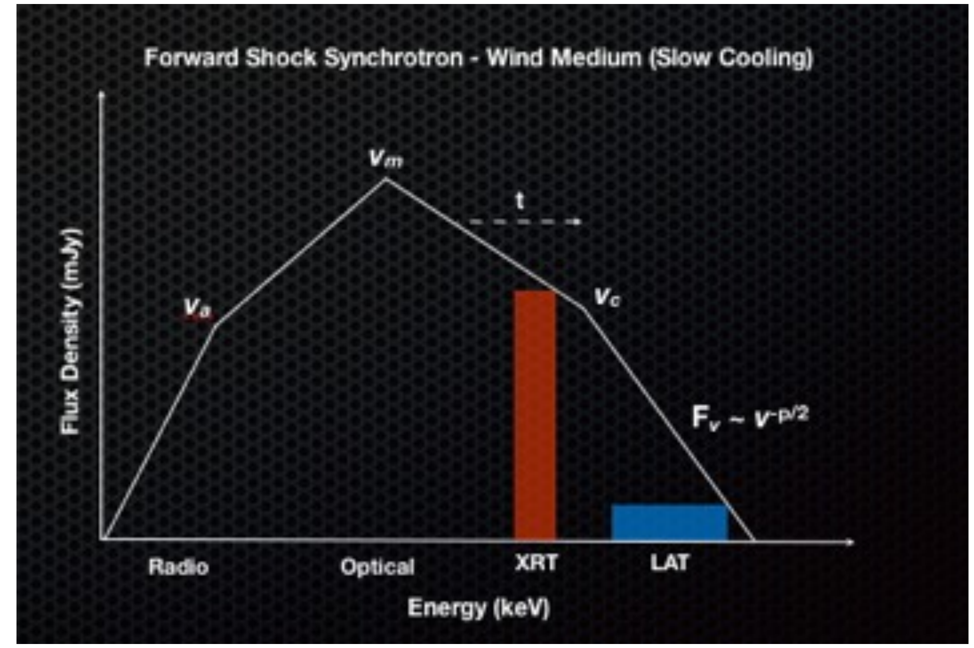
The Green points are detections (11 GRBs, 14 time intervals) - no separation of "prompt" from "afterglow" LAT flux: assumption is that all LAT emission is afterglow.

# Comparing expected vs measured LAT flux may provide probe of surrounding medium: wind versus homogeneous.

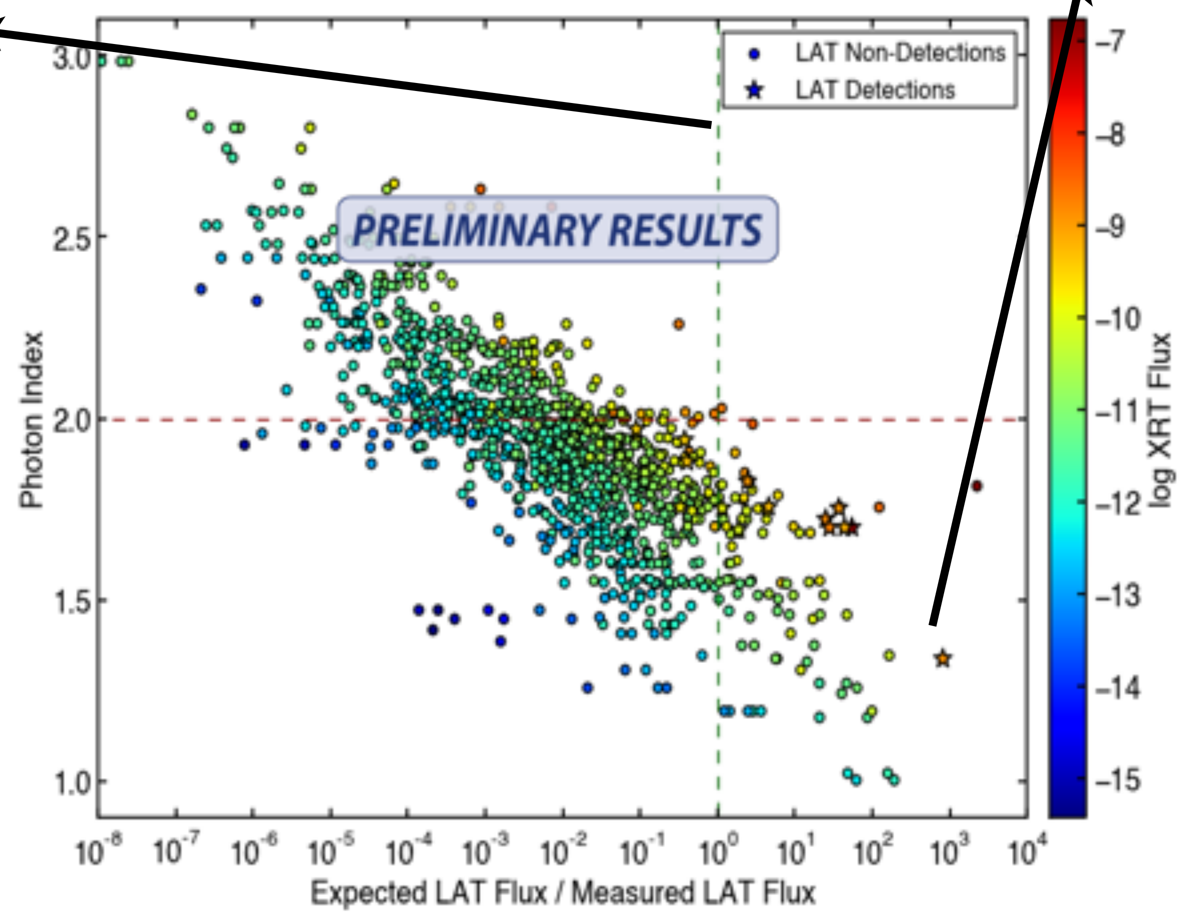
Homogeneous ISM




Wind medium




Along line of equality: LAT flux matches expectations.

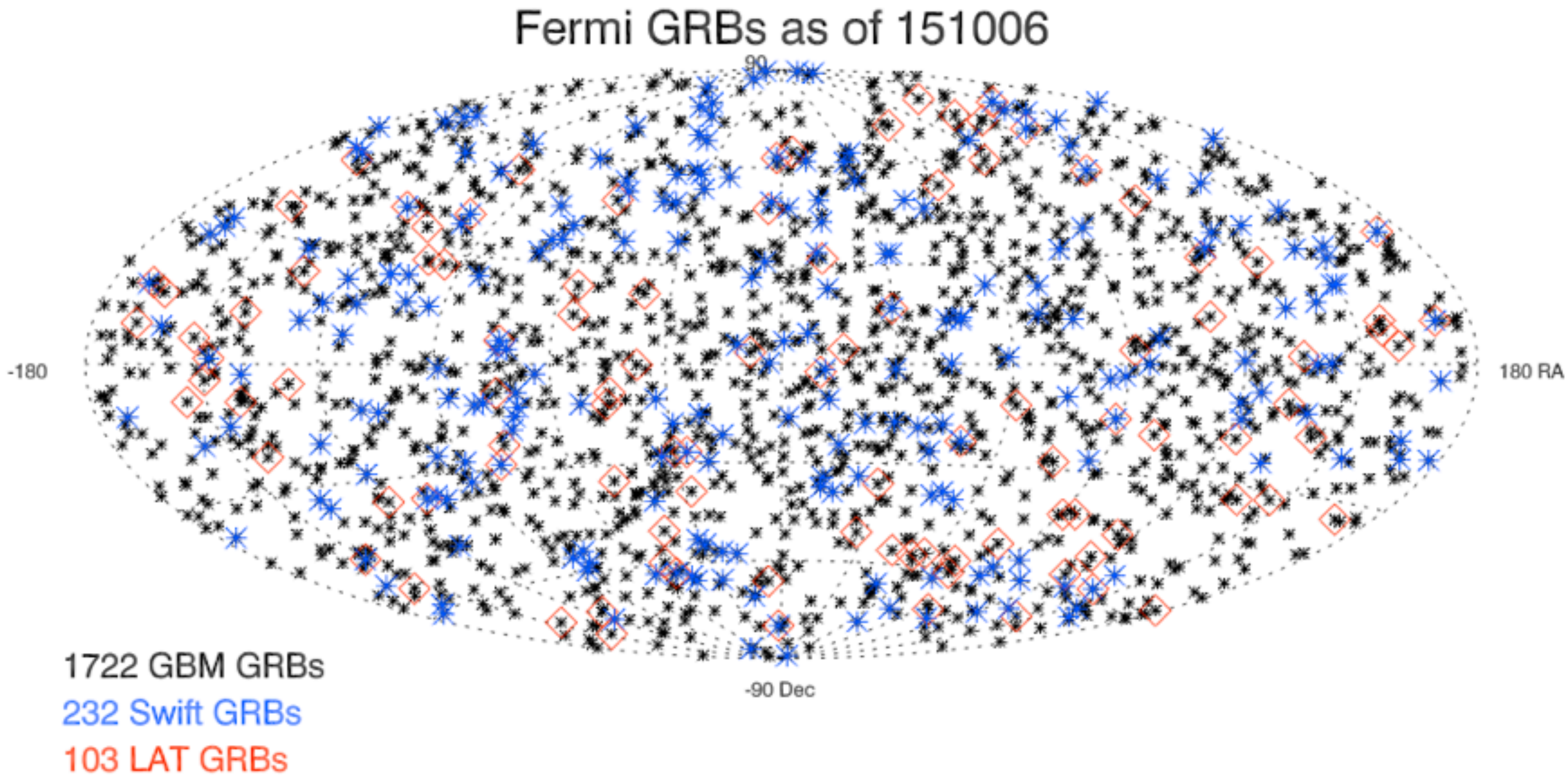



To the right of line: LAT flux is less than expected, implying cooling break between XRT and LAT

XRT photon index vs expected LAT flux: XRT spectra of GRBs LAT detectd fall here (hard spectra: photon index <2)

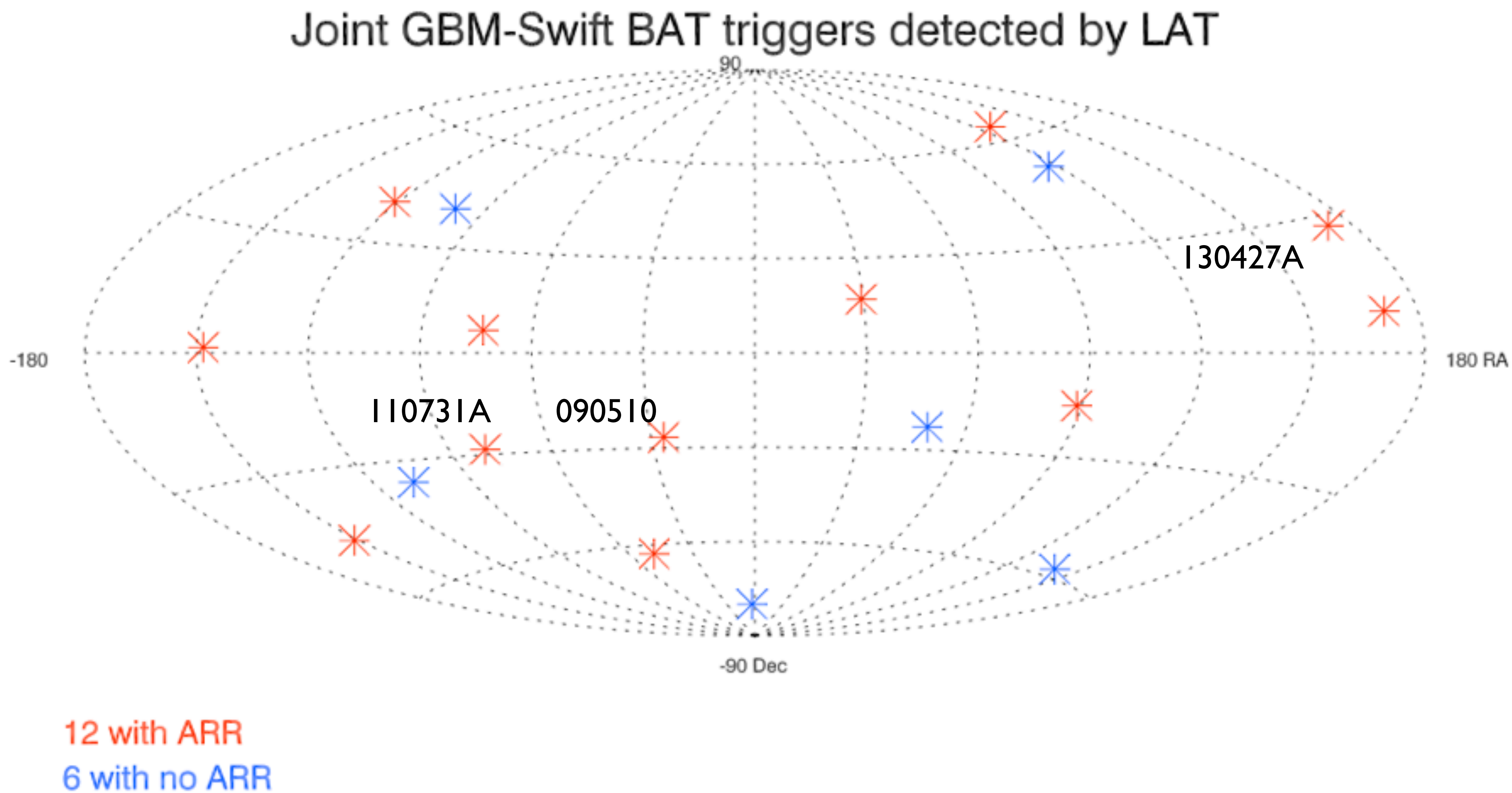
Courtesy of Dan Kocevski

One in ~7.5 GBM GRBs also triggers the Swift BAT - broad spectral coverage from Fermi and redshifts/energetics from Swift follow-ups.



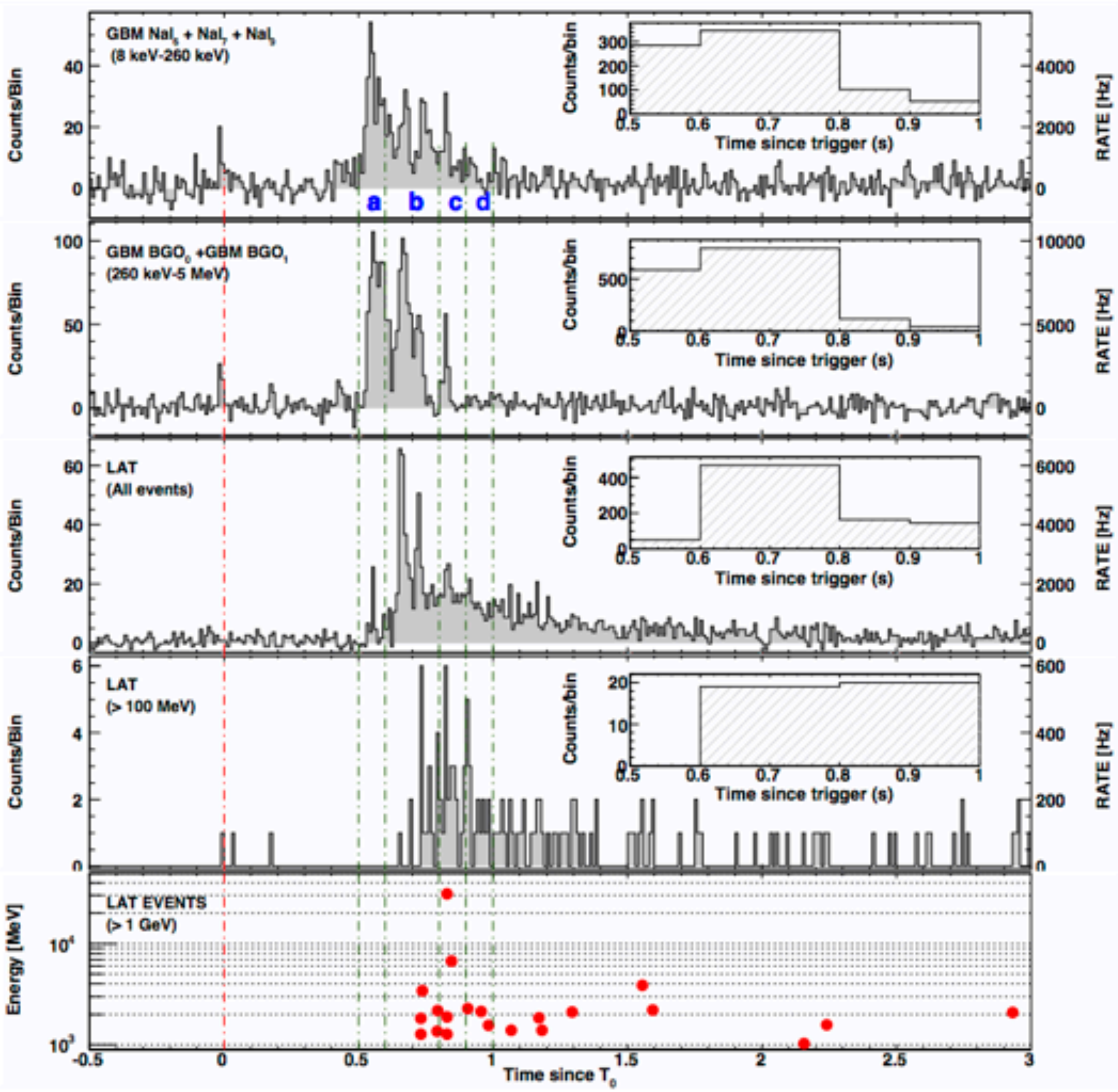

- In addition to those GRBs triggering the BAT, Swift detects Fermi GRBs by observing LAT-detected GRBs with the X-Ray Telescope - hours after the GBM trigger.

The overlapping sample of GBM-Swift BAT triggers and LAT detections contains GRBs observed contemporaneously over the prompt and early afterglow phase from keV -> GeV



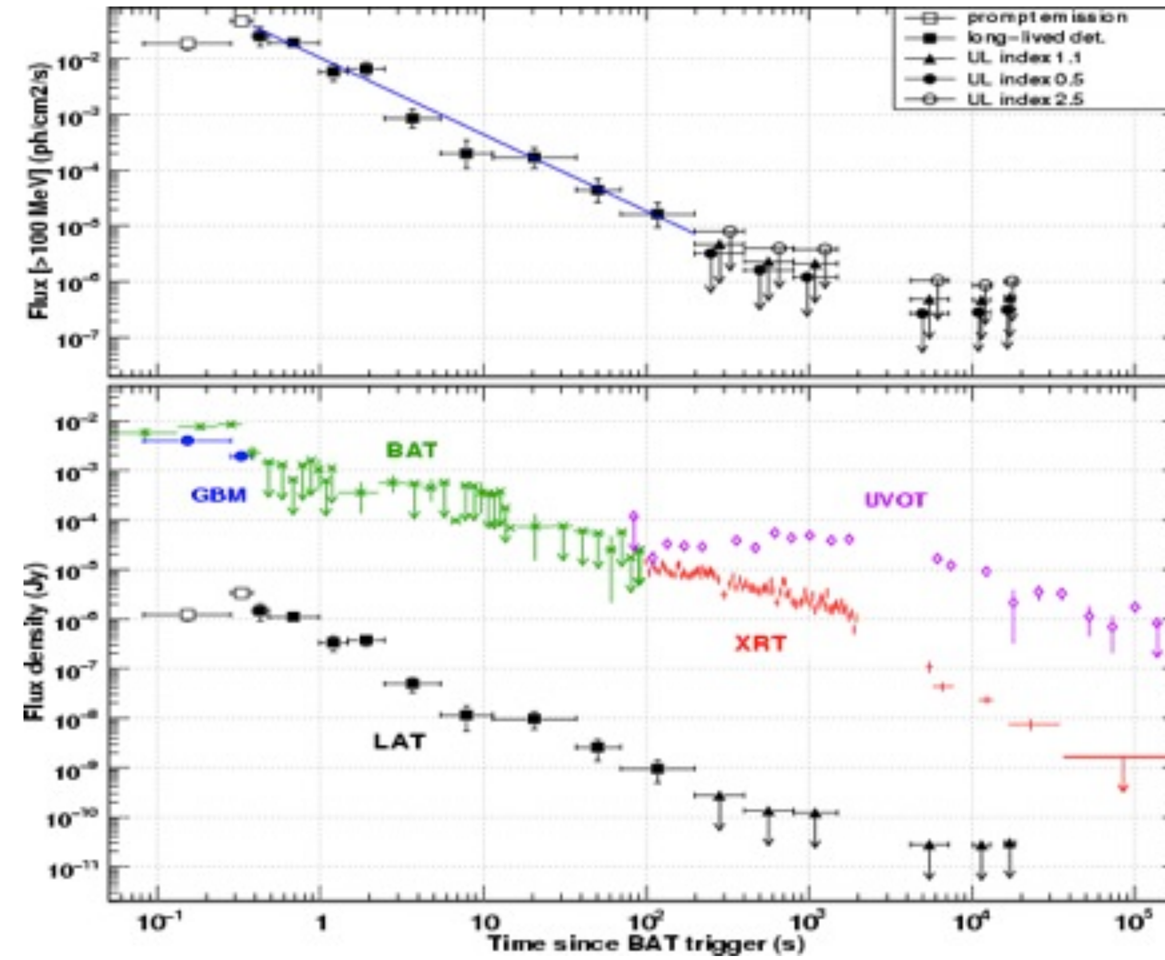
# GRB 090510 shows variable, spiky "prompt" emission with delayed onset of >100 MeV component, and smoothly decaying "afterglow" emission

Abdo et al. 2009




Delayed onset of >100 MeV emission: signature of proton synchrotron? Proton-induced cascades?

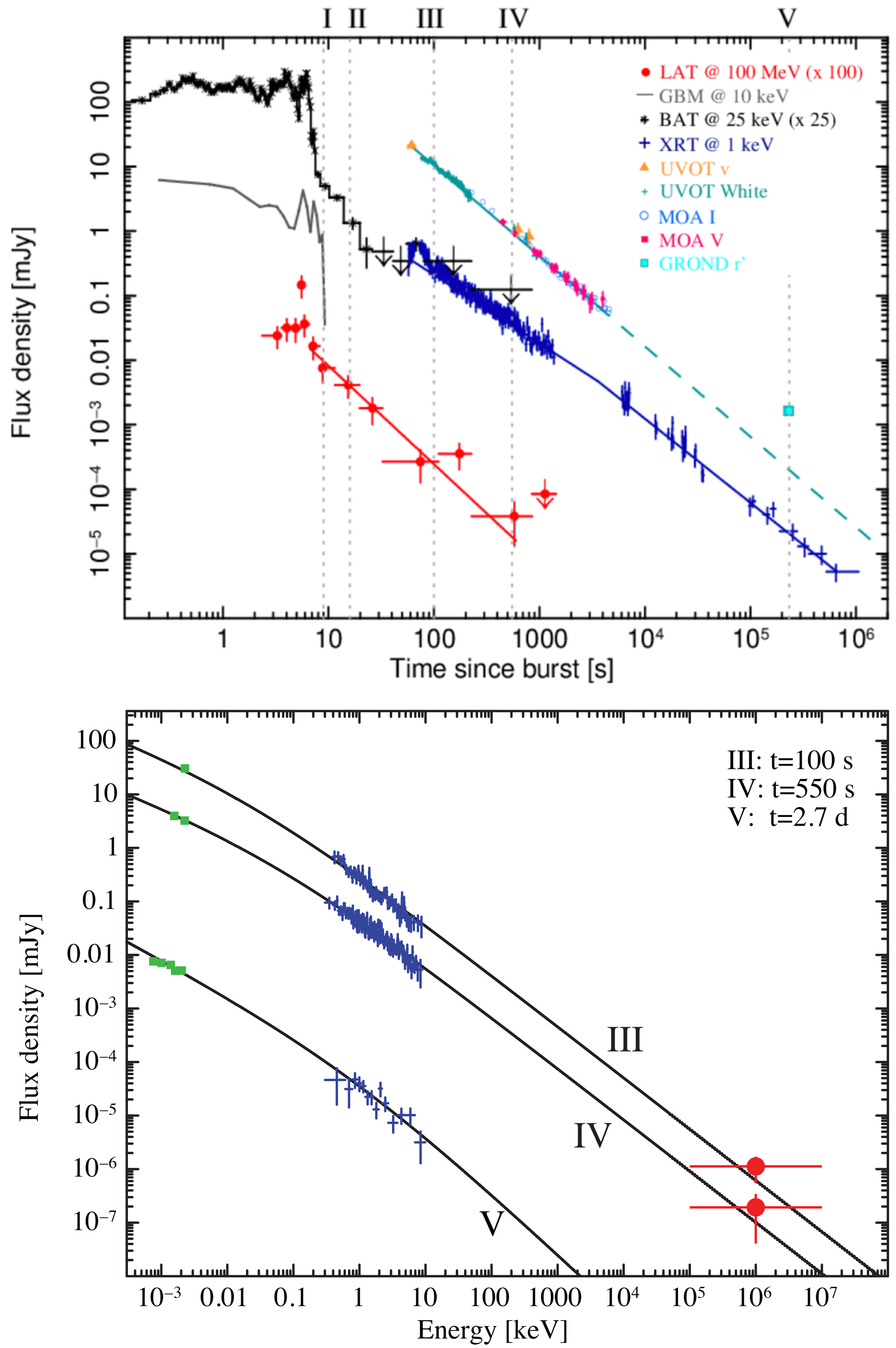
de Pasquale et al. 2010




Extended emission suggestive of afterglow

# GRB 110731A was observed long enough and over a broad enough energy range to test consistency of LAT with afterglow at lower energies.

But prompt high-energy emission is really spiky!

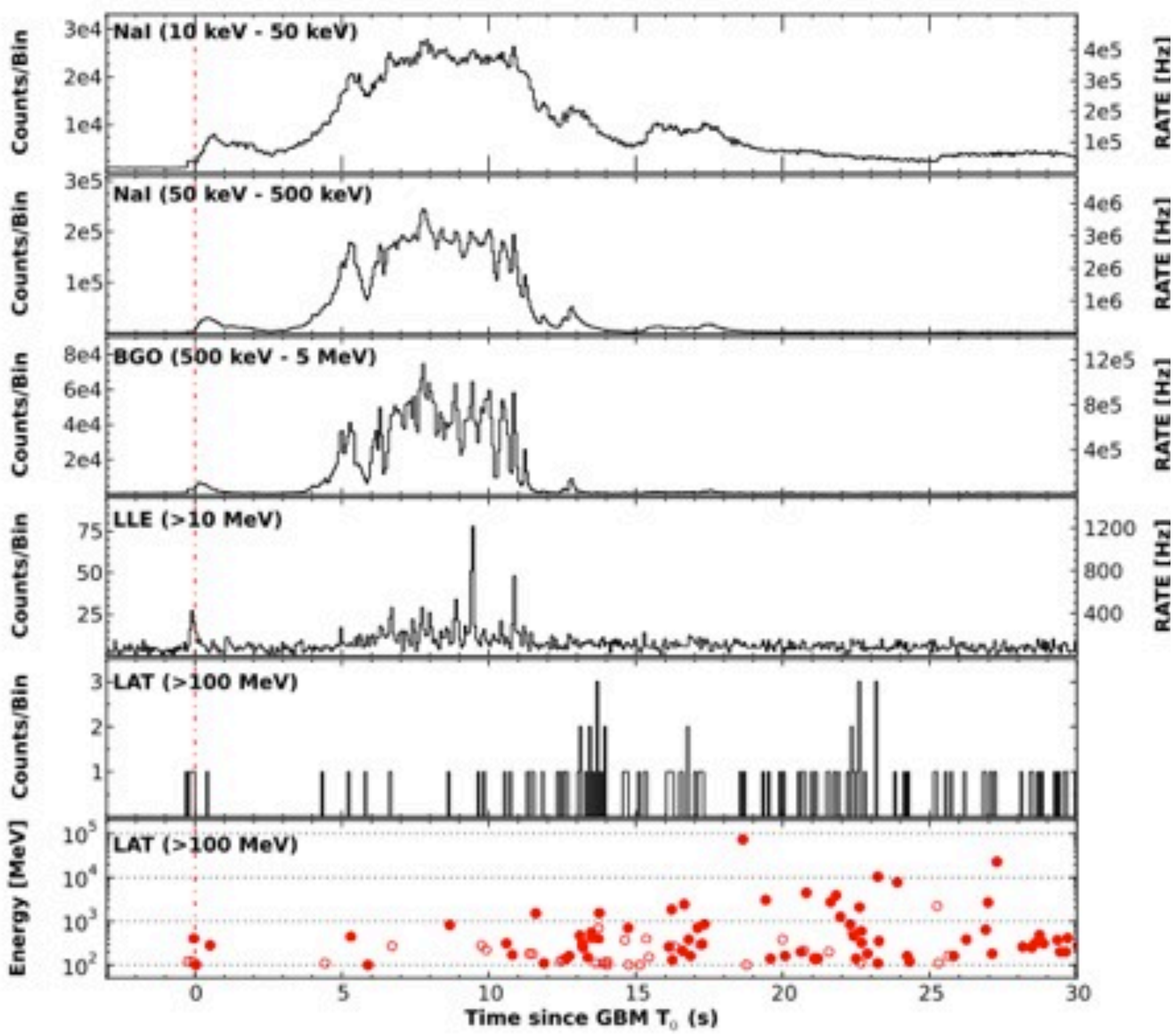



Ackermann et al. 2013

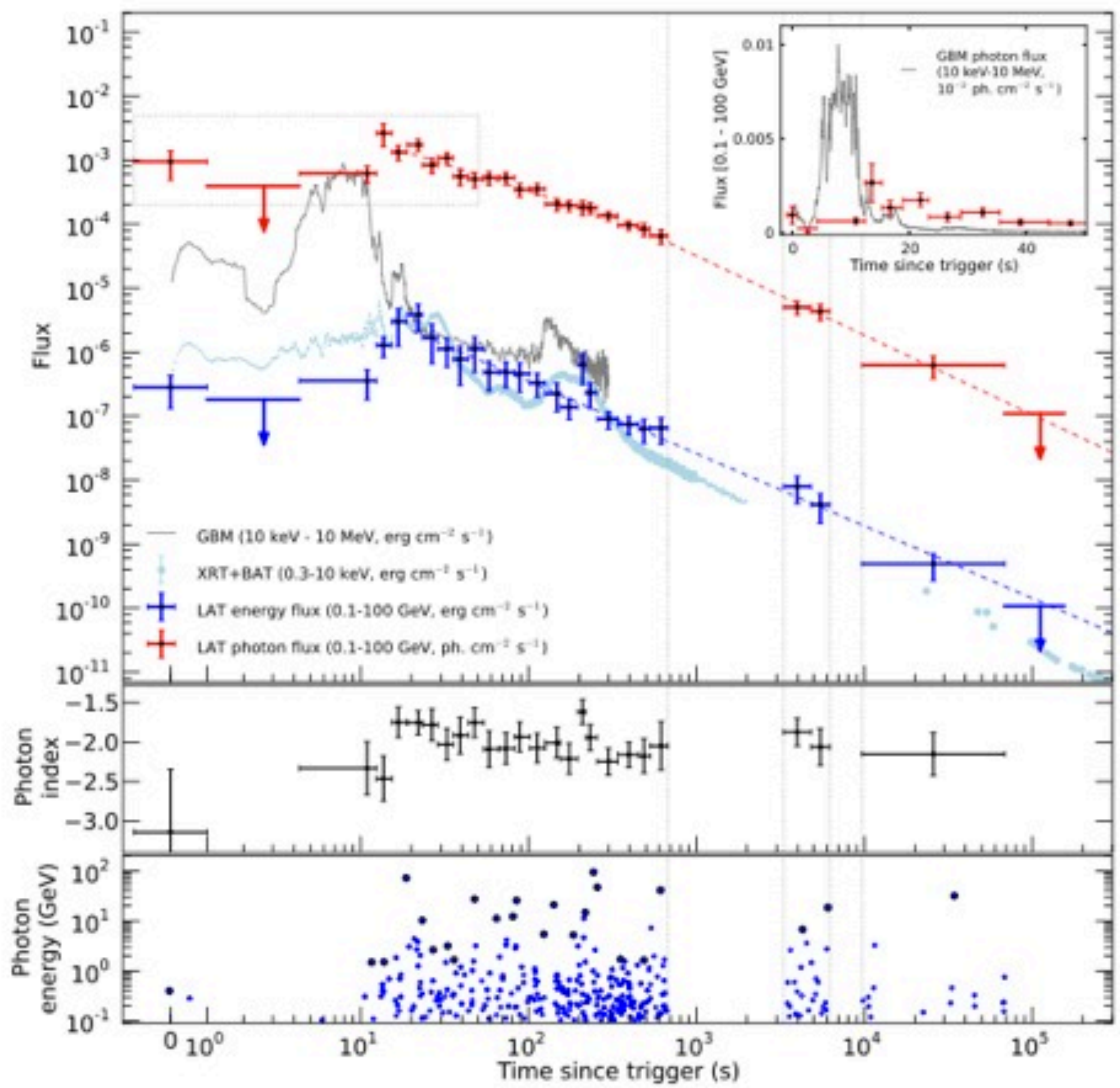
Broadband spectrum over 10 decades of energy consistent with a single power-law compatible with external-shock synchrotron.

# GRB 130427: the "ordinary monster" shows variable prompt emission and extended emission out to 70 ks later.

Prompt

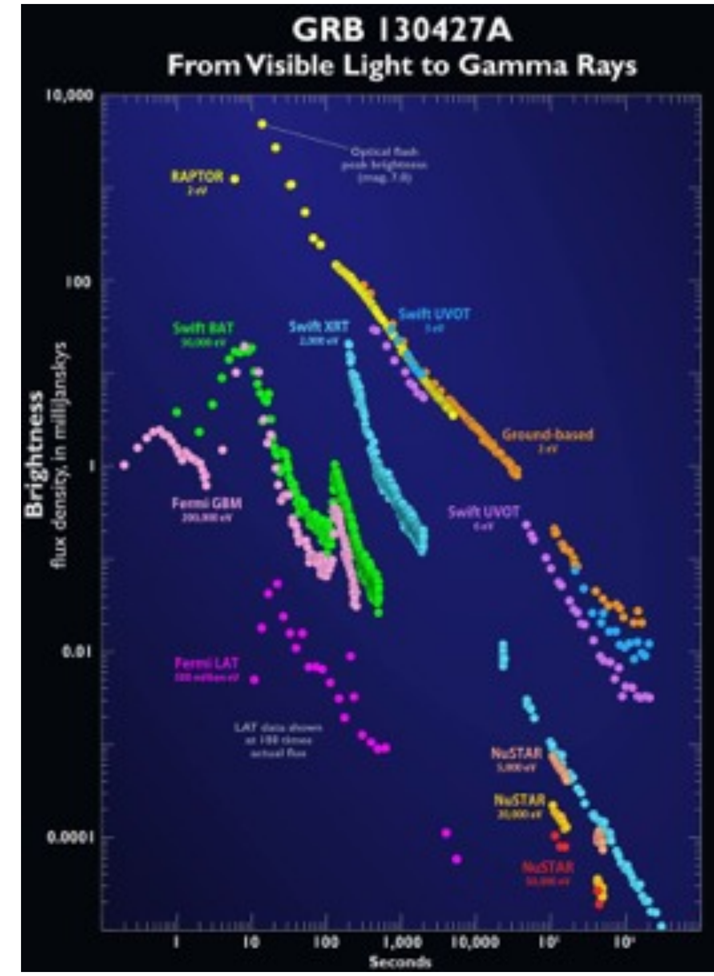



1 Day's observations

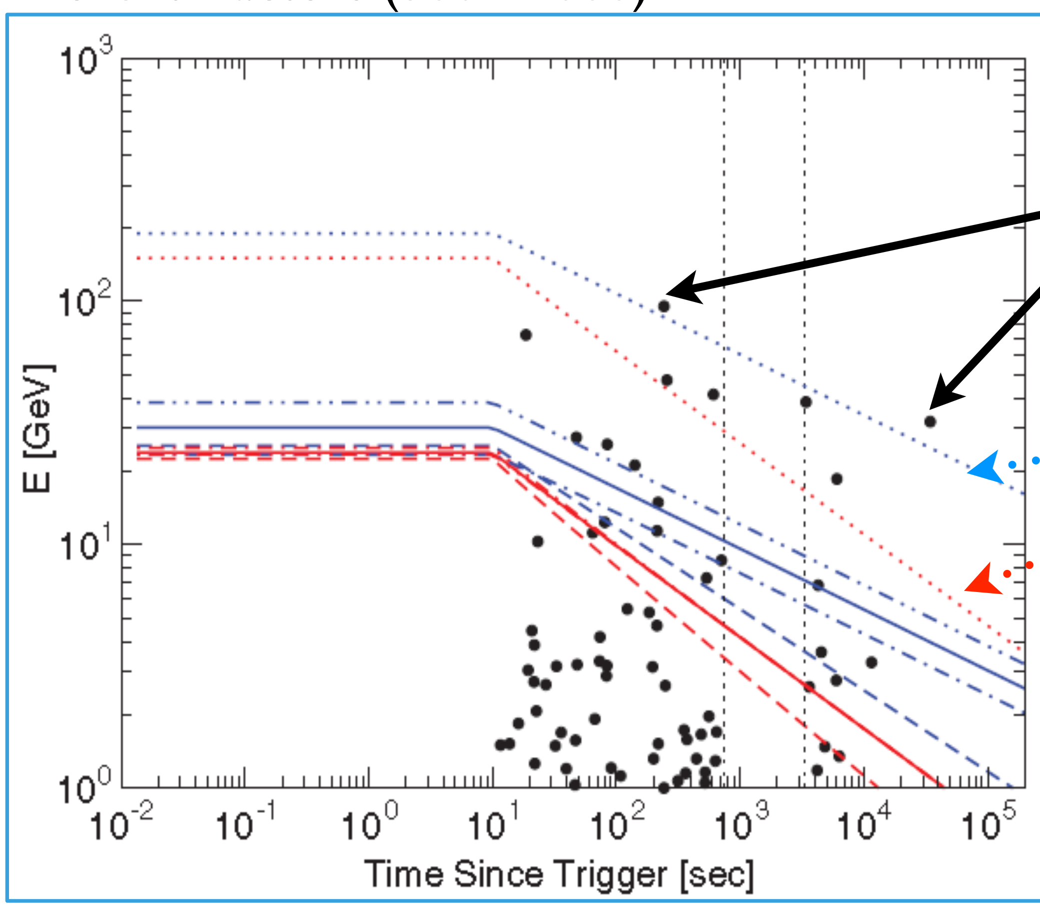



Ackermann et al. 2013

# GRB 130427A provides 70 ks of HE data to explore afterglow models: standard afterglow models challenged by GeV photons 100s s after trigger




Solid: Adiabatic
Dashed: Radiative
Dot-dashed: bracketing
Lorentz factors (500 - 2000)




Even with extreme conditions, observations of these HE photons challenge afterglow models

Extreme acceleration conditions

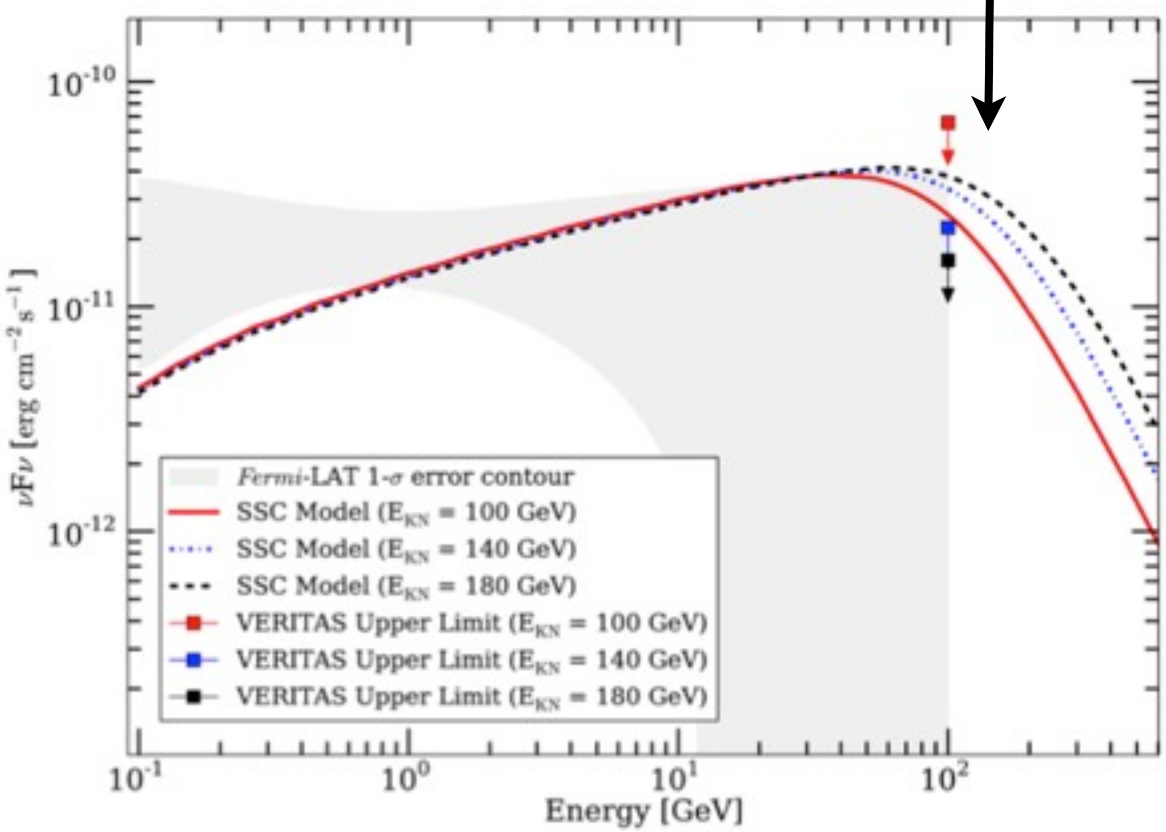
Wind medium

Homogeneous ISM

Ackermann et al. 2013

# NuStar observations and VERITAS upper limits provide additional evidence against SSC nature of extended HE emission

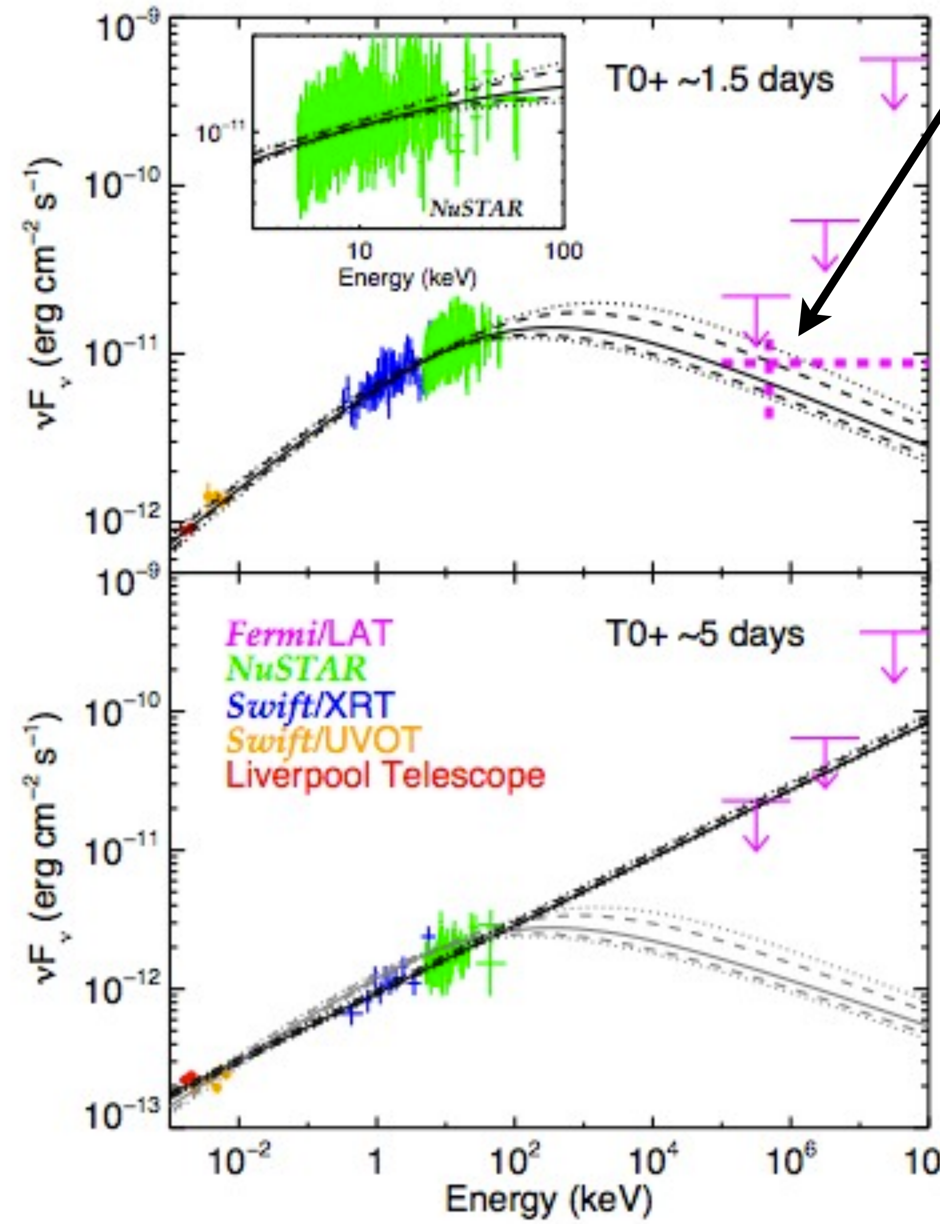
UL would require cut-off at 100 GeV




These observations are not contemporaneous with the final detected LAT data point.

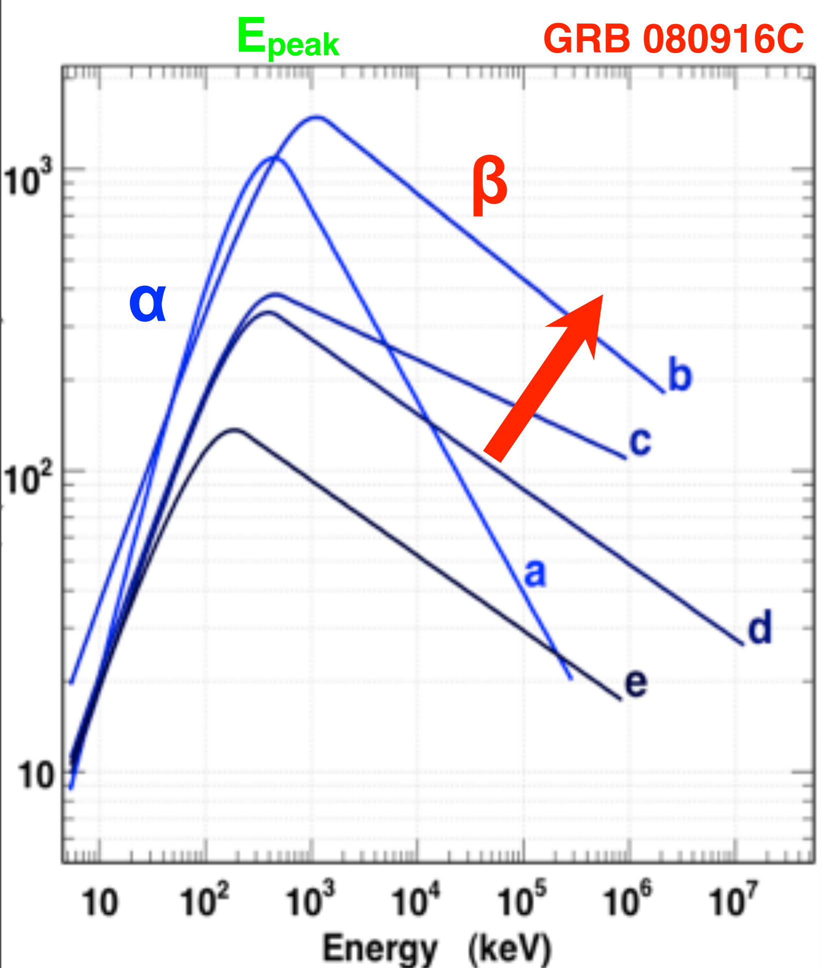
Aliu et al. 2014

UL to synchrotron PL compatible with extension of LAT PL in time.

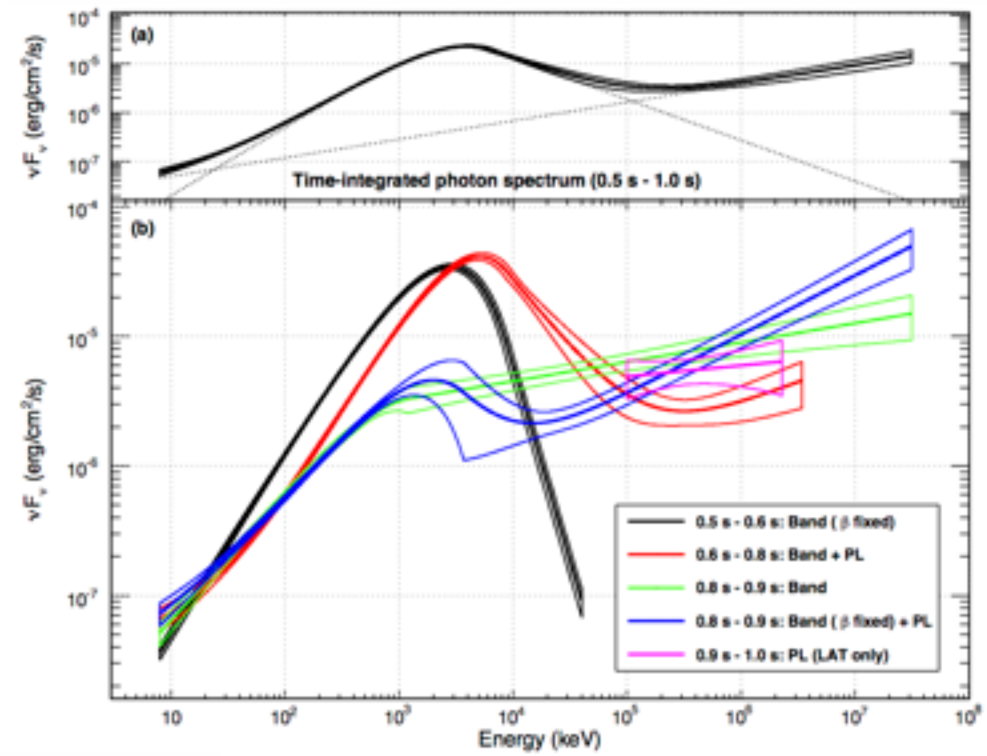



Kouveliotou et al. 2013

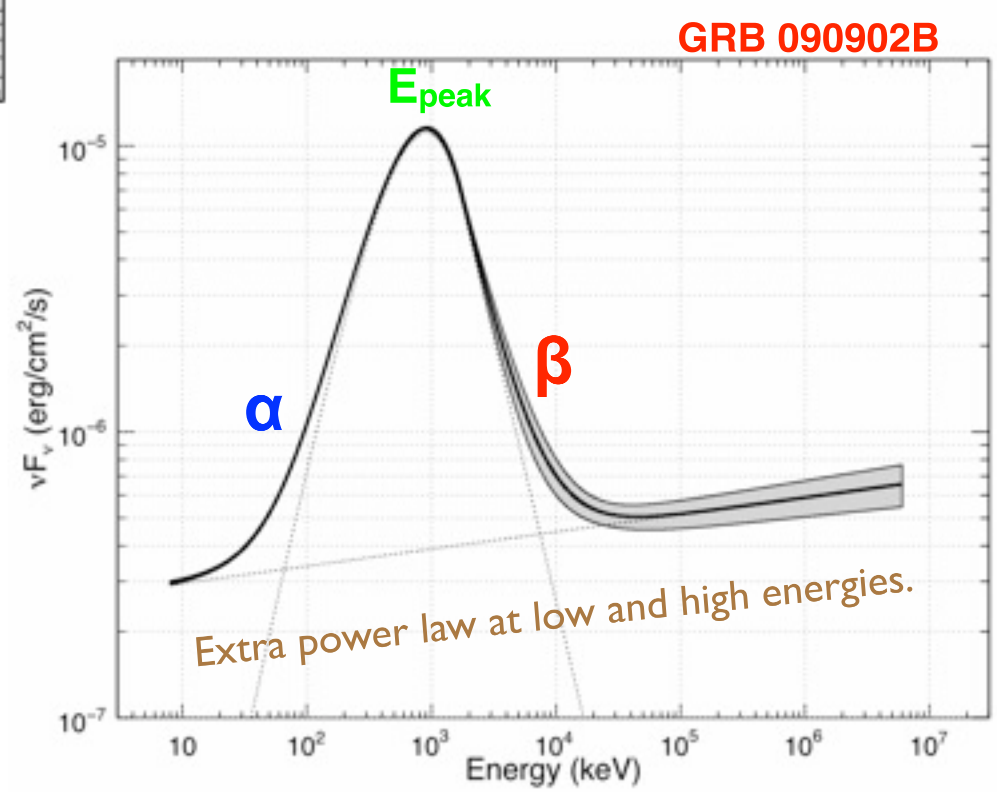
# Spectral shapes > 100 MeV exhibit varied relationships to the spectral shapes inferred from GBM observations




GRB 080916C
Abdo et al. 2009

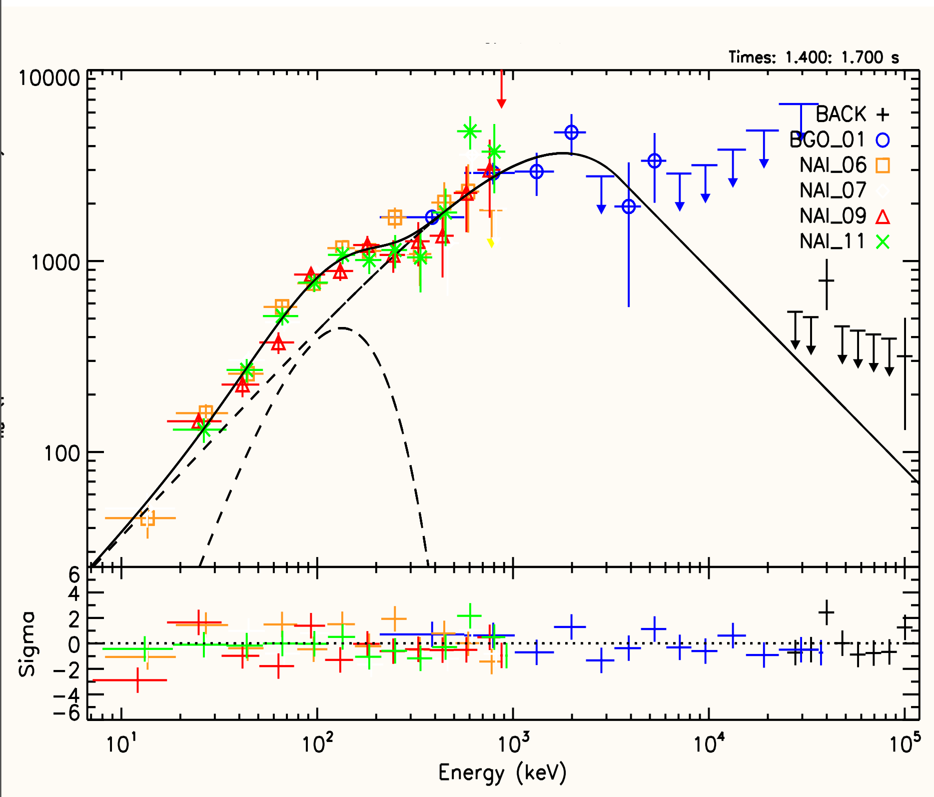



GRB 090510
Ackermann et al. 2010



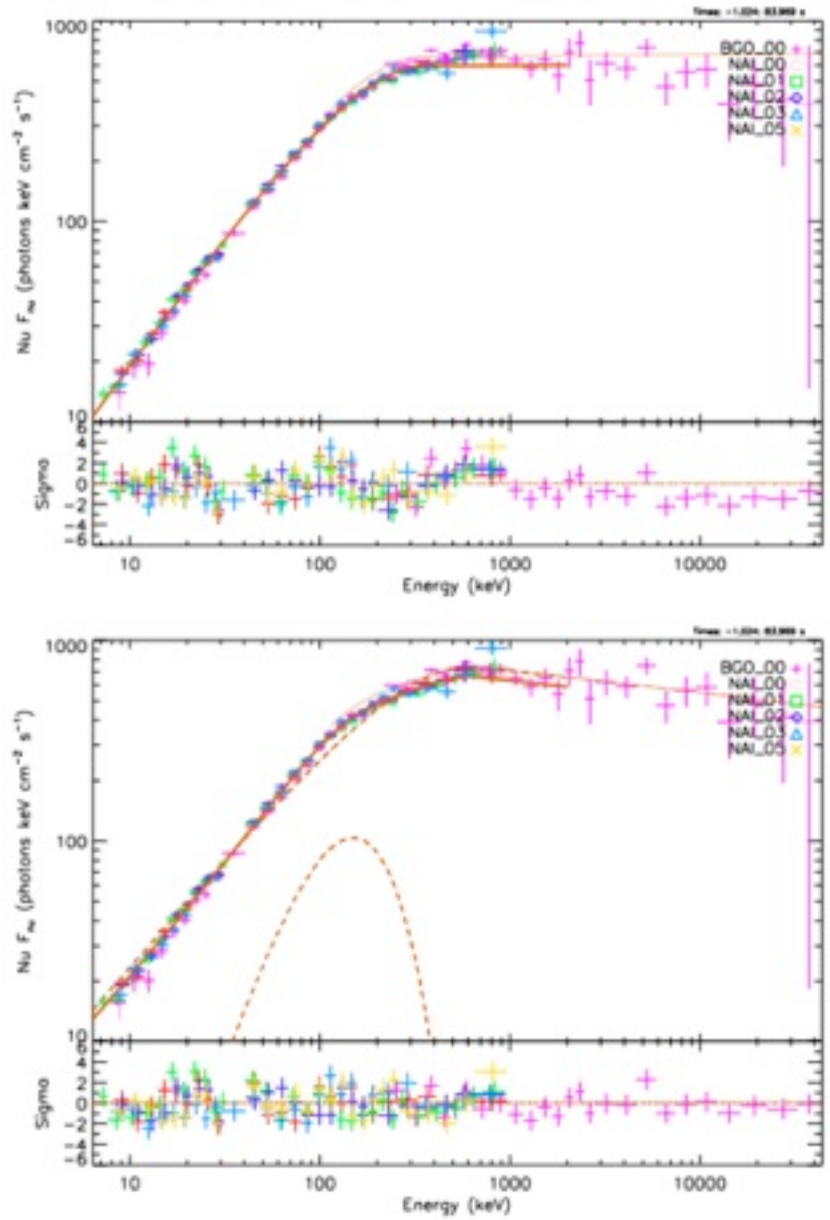

GRB 090902B
Abdo et al. 2009

The Band function may not represent some GRB spectra over the energy range sampled by GBM - extrapolations to LAT energies may not be reliable.




GRB 110721A

Axelsson et al. 2012




The thermal component steepens alpha & beta

| Models | Standard Model | | | |
|---|---|---|---|---|
| | Band | | | BB |
| Parameters | $E_{peak}$ | $\alpha$ | $\beta$ | kT |
| Band | 352 | −0.67 | −1.99 | |
| | ±6 | ±0.01 | ±0.01 | |
| Band+BB | 615 | −0.90 | −2.11 | 38.14 |
| | ±29 | ±0.02 | ±0.02 | ±0.87 |

GRB 100724B

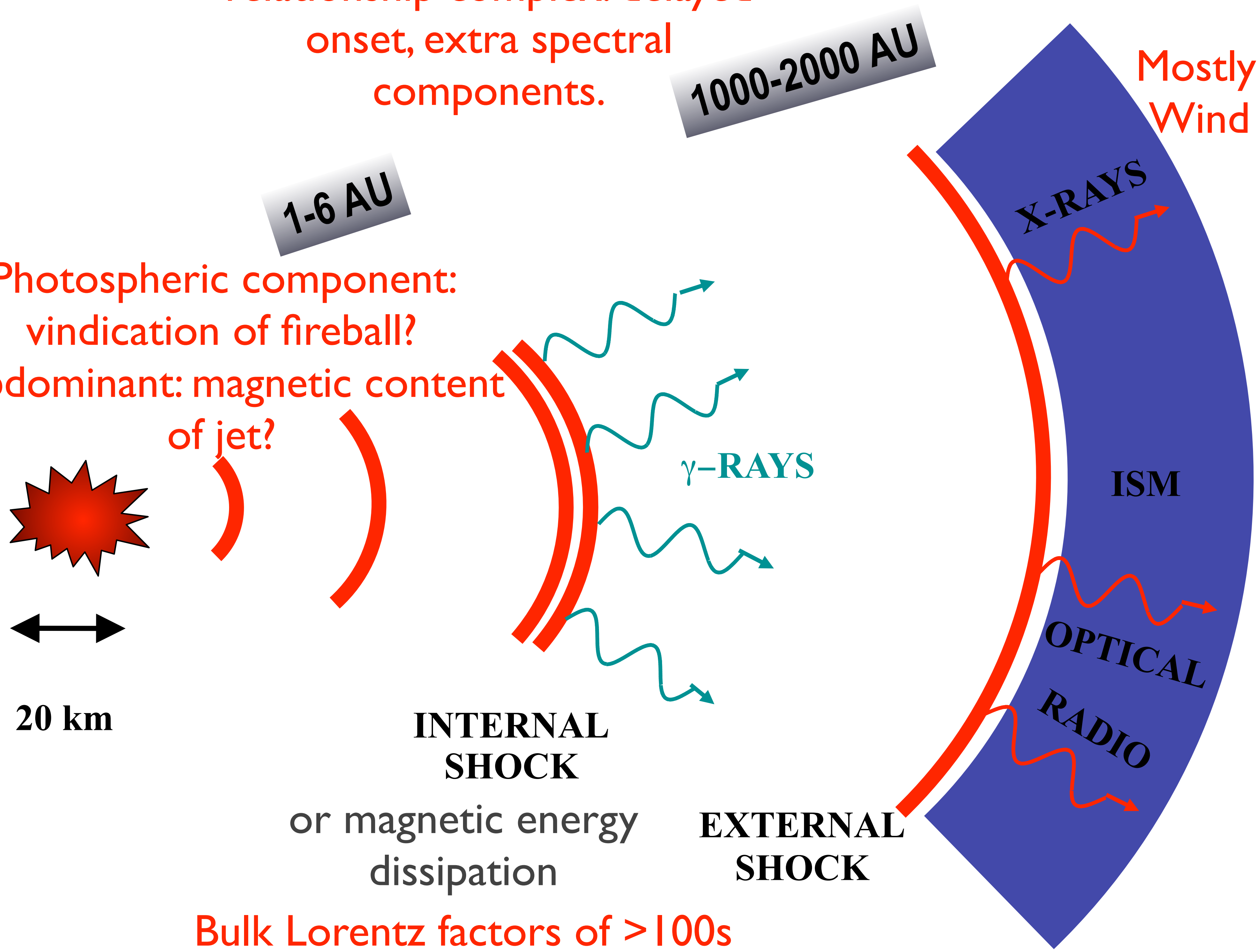
Guiriec et al. 2011

In addition, pure Band functions are broader than photospheric and narrower than synchrotron predictions e.g., Axelsson et al. 2014, Yu et al. 2015. Physical modeling (synchrotron, photospheric, combinations) is moderately successful e.g., Ryde et al. 2010, Burgess et al. 2013, Zhang et al., 2015.

Prompt emission: LAT component scales with GBM fluence but often with delayed onset. Temporal and spectral relationship complex: delayed onset, extra spectral components.

Afterglow emission: LAT component is common and scales with X-ray afterglow brightness/hardness.

Mostly adiabatic expansion
Wind medium sometimes favored.

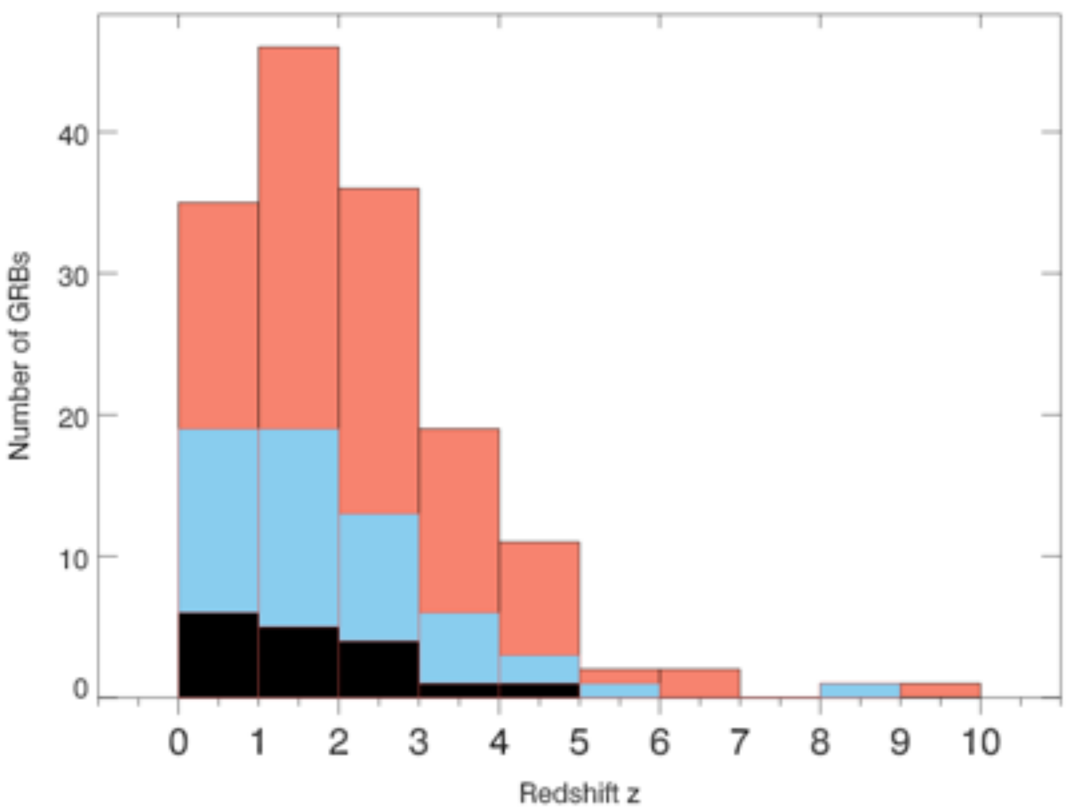



Photospheric component: vindication of fireball?
Subdominant: magnetic content of jet?

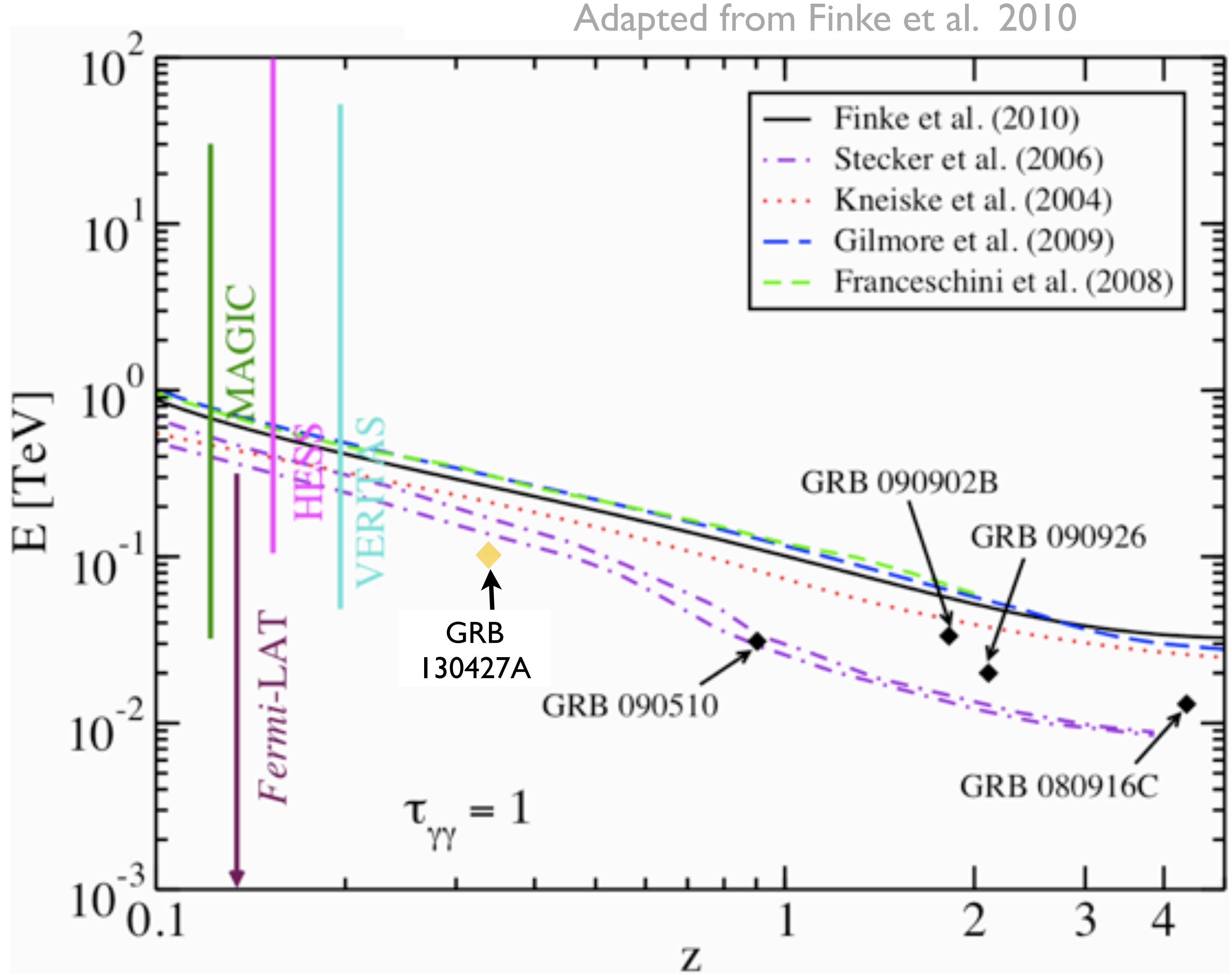
Bulk Lorentz factors of >100s implied by escape of GeV photons & variability timescales. Lorentz invariance.

Bulk Lorentz factors of 100s implied if peak LAT emission represents transition from coasting phase.

GRBs are detected to high redshifts: constraints on EBL absorption at distances that can't be probed by blazars.



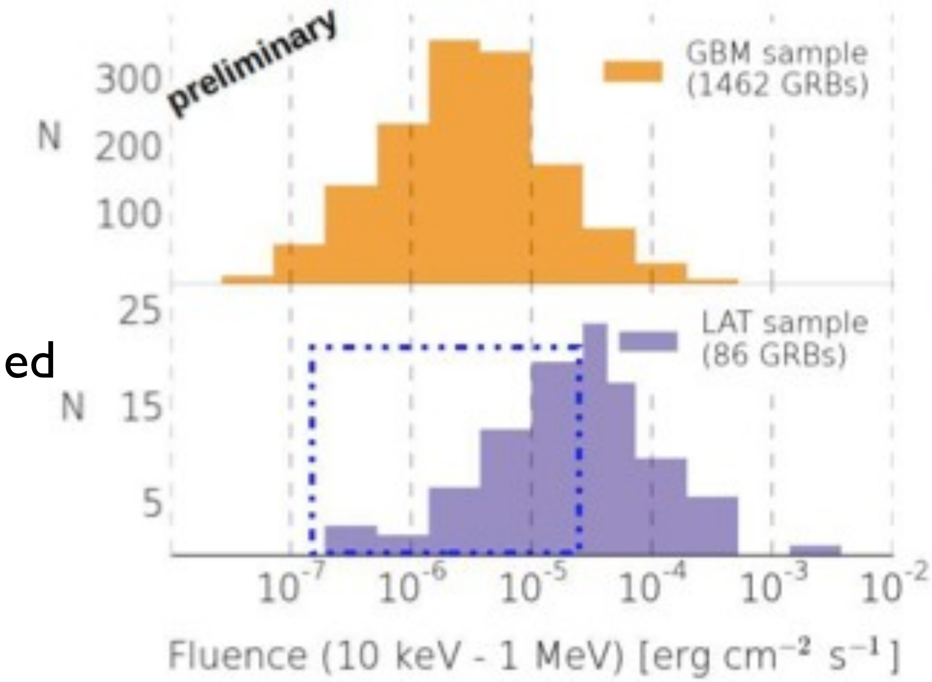

Adapted from Finke et al. 2010

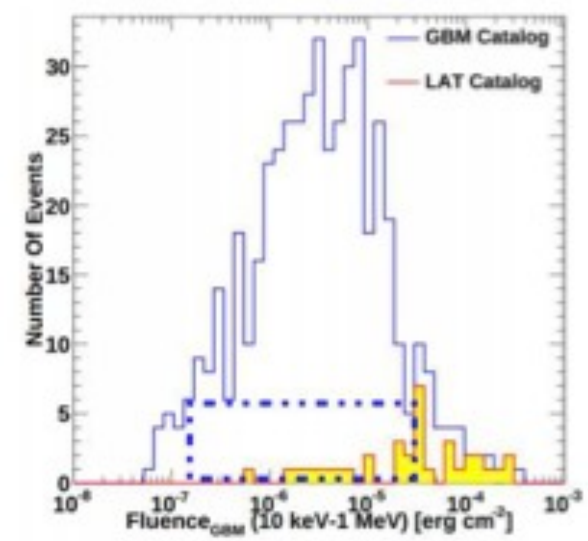


# New LAT catalog will have many new detections over 4 years of old catalog + 2 extra years

Vianello et al. 2015

Second LAT catalog:
the fluence gap is being filled




First LAT catalog: LAT saw only the brightest GBM GRBs

- Pass 8: A new low-level analysis and event reconstruction was developed during the past years. Data are available since June 24th, giving
    - improved effective area (100% improvement below 100 MeV, 25% above 1 GeV)
    - better PSF and localization accuracy
    - better background rejection
    - reduction in systematic effects

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

## 8th Huntsville GRB symposium

- Huntsville, Alabama. 24 - 28 October 2016.