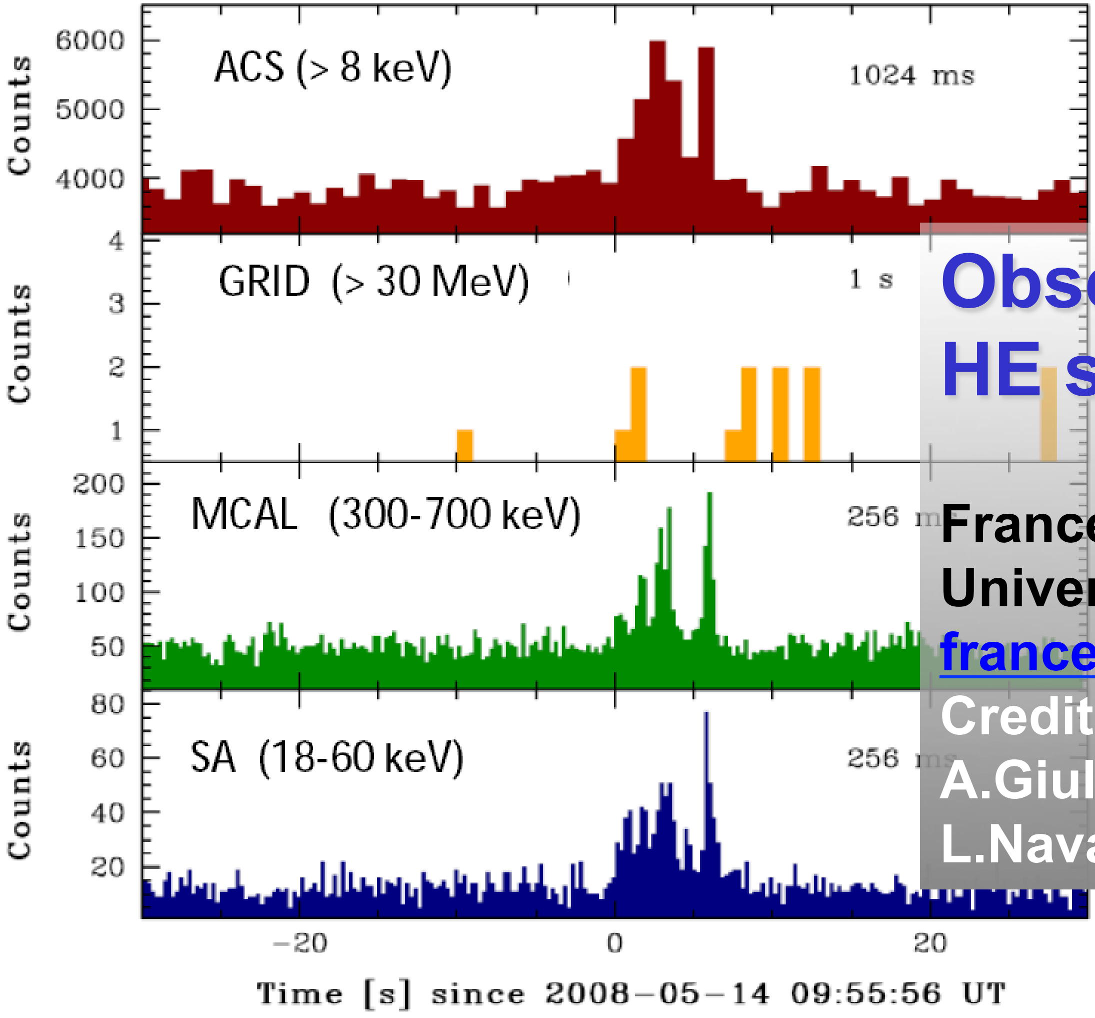

Observation of GRB with HE satellites

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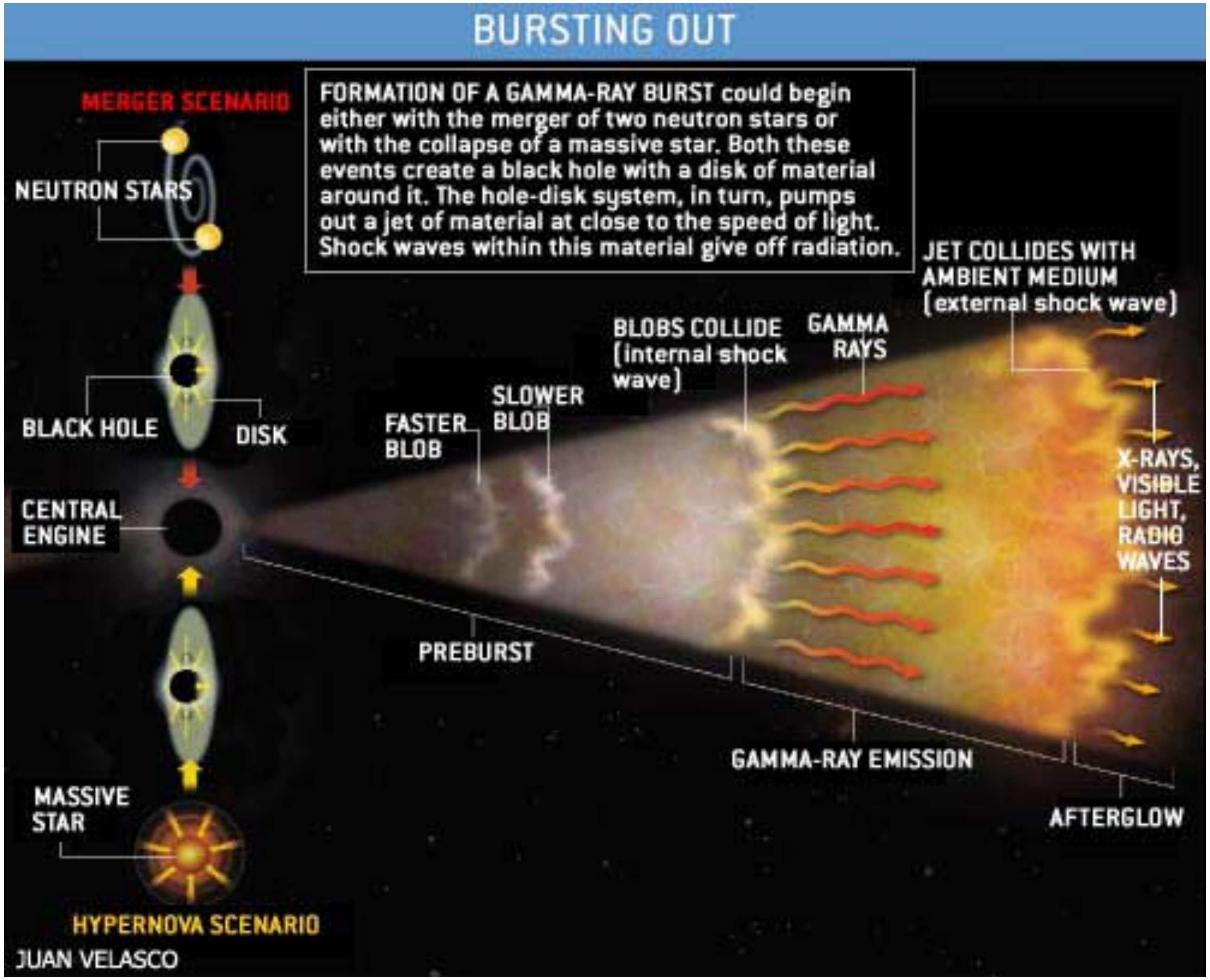
Credits to E.DelMonte, F.Verrecchia, A.Giuliani, N.Omodei, G.Vianello, L.Nava



FORMATION OF A GAMMA-RAY BURST could begin either with the merger of two neutron stars or with the collapse of a massive star. Both these events create a black hole with a disk of material around it. The hole-disk system, in turn, pumps out a jet of material at close to the speed of light. Shock waves within this material give off radiation.

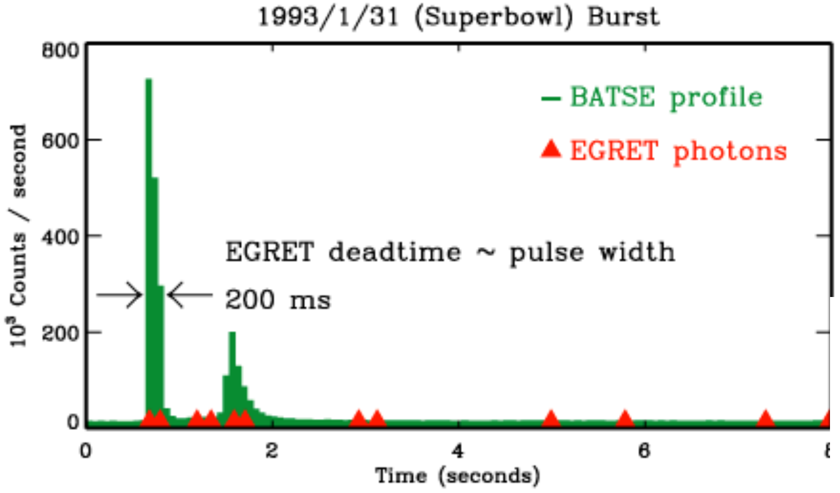
JUAN VELASCO

High Energy Emission from GRB
“The EGRET heritage”

The EGRET heritage on GRBs

- Need fast timing for gamma-ray detection (improving EGRET deadtime, 100 msec → 100 microsec or less).
- Need long exposure to get delayed emission

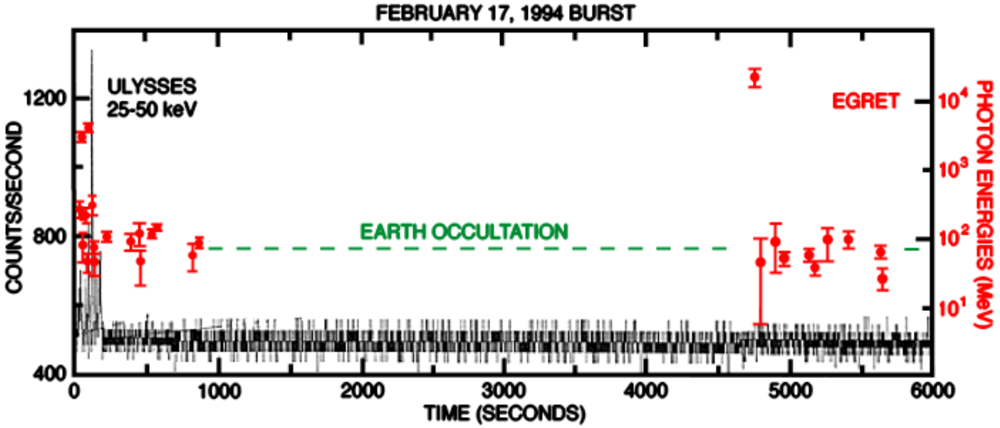
Prompt Emission (GRB 930131)



Kouveliotou et al 1994
Sommer et al. 1994

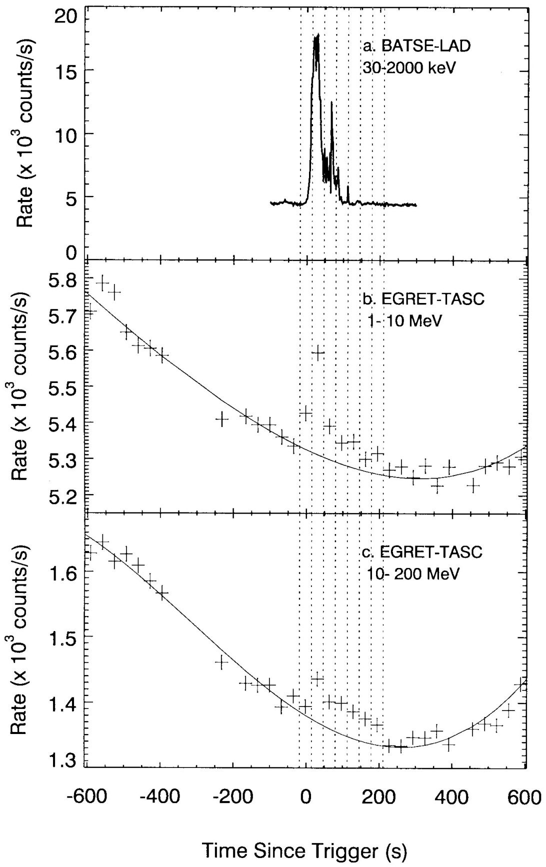
Delayed Emission (GRB 940217)

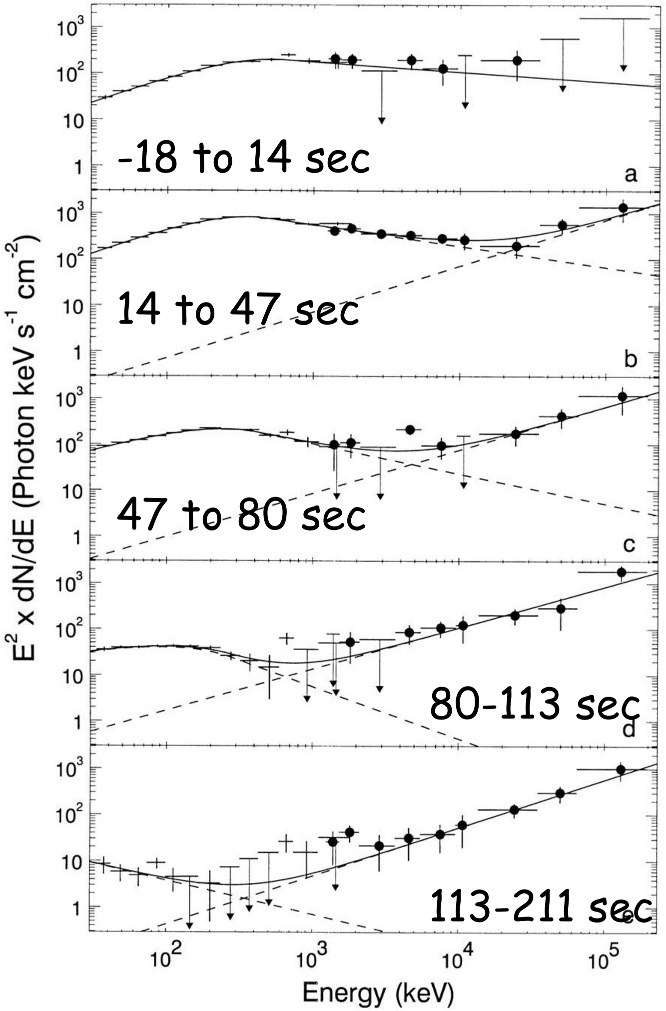
Hurley et al. 1994



The EGRET heritage on GRB

Gonzalez, et al. 2003



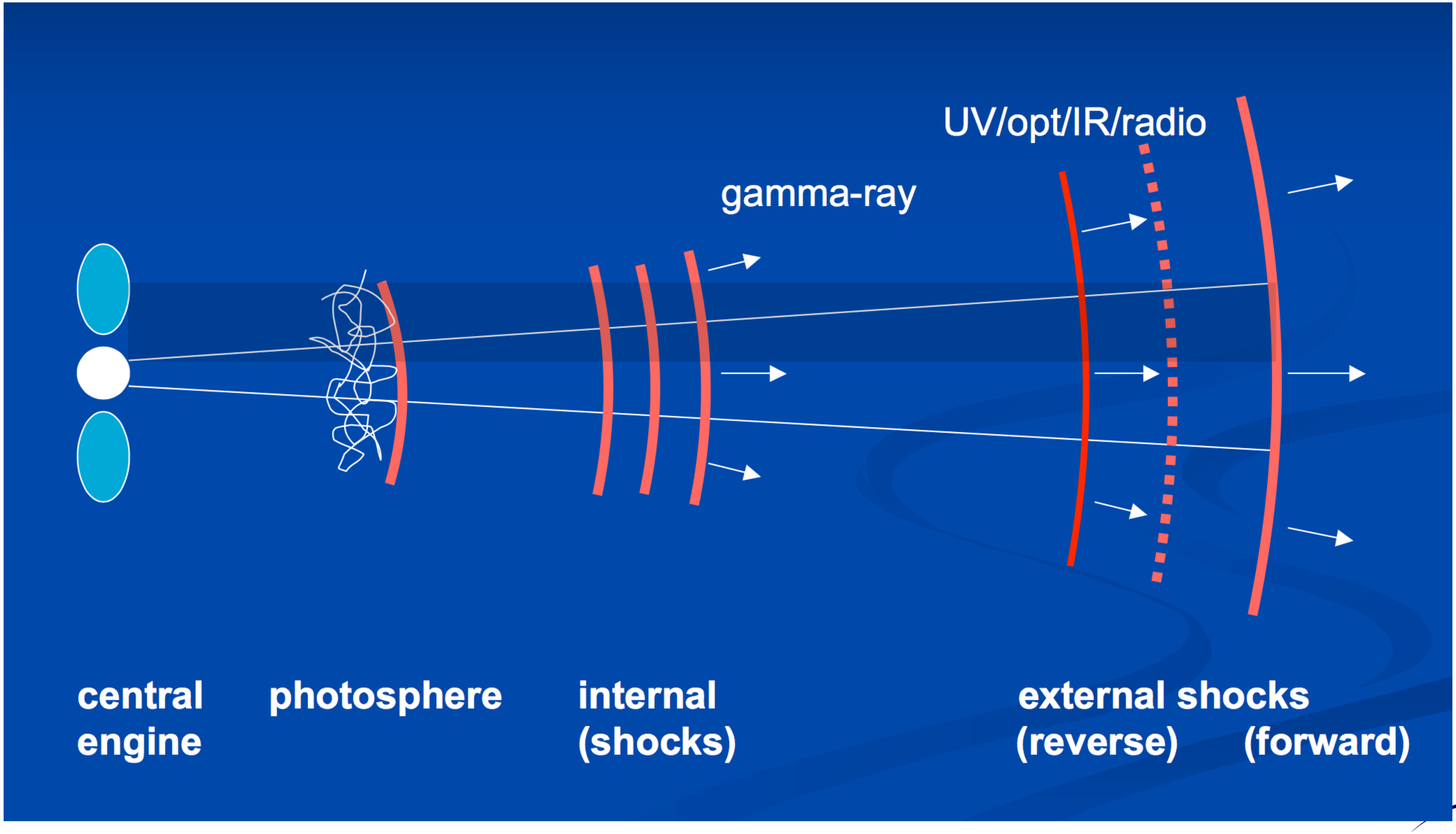


The EGRET heritage on GRBs

- Extended emission?
- Prompt emission?
- Spectral Components?
- Ubiquity of HE emission?

- Need of optimal timing and broad band fast detectors

GeV emission sites



Theoretical expectations (Zhang 2007)

- For nearby (z ~ 0.1) neutron-loaded GRBs of merger origin, GLAST may be able to detect prompt 100 MeV and 100 GeV photon signatures from proton-neutron inelastic processes
- In internal shocks, if the sub-MeV emission that triggers gamma-ray detectors is due to synchrotron emission, then a synchrotron self-Compton (SSC) component naturally extends to high energies. High energy photons are likely attenuated with low energy photons to produce pairs, whose secondary emission also contribute to the observed
- In internal shocks, protons are also accelerated. Their synchrotron emission or photon-meson interaction would also lead to high energy photon emissions.
- In the external reverse shock SSC would produce high energy photons in the GeV range
- In the external forward shock, SSC at early times also produces significant GeV emission that is detectable by GLAST

Theoretical expectations (Zhang 2007)

- Photons from the forward and reverse shock regions could be inverse Compton scattered by electrons in the other regions. These cross IC processes are important high energy emission contributors. The prompt sub-MeV photon bath may overlap the external shock region if the burst duration is long enough. The electrons in the shocked region would cool by scattering these prompt gamma-rays and produce high energy photons. The effect is especially important in a wind medium where the deceleration radius is small.
- Protons in the external shock region would produce high energy photons through synchrotron emission and photo-meson interaction
- Photons from X-ray flares and probably unobserved UV flares would be upscattered by the external shock electrons to produce GeV-TeV photons

Theoretical expectactions (Zhang 2007)

- SSC within the X-ray flares would produce high energy photons (Wang et al. 2006b).
- If additional soft photons are available from the GRB progenitor, external IC processes would boost soft photons to high energies.
- TeV photons escaping from GRB fireballs would be attenuated by intergalactic infrared background and produce pairs, if the GRB source is not too close to earth (say z < 0.5). These pairs would upscatter the cosmic microwave background and produce GeV photons, which would be detectable by GLAST if the IGM magnetic field is weak enough.
-

Theoretical expectactions (Zhang 2007)

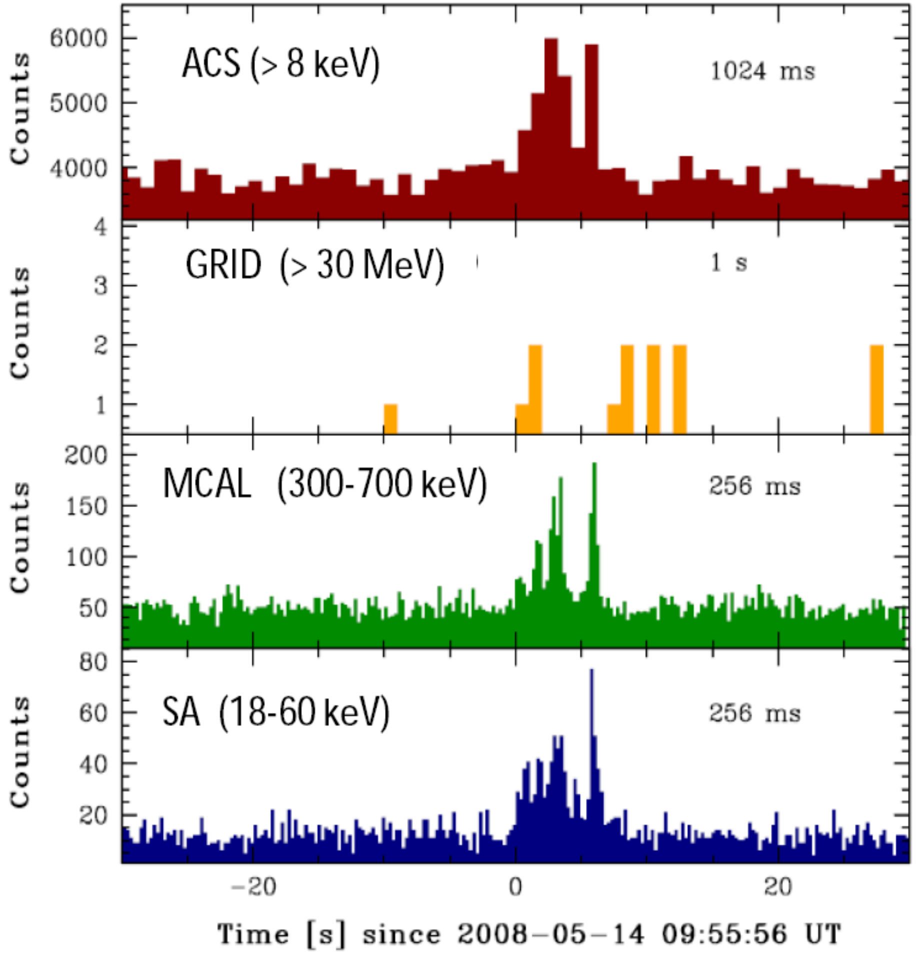
- A prospect of GLAST observation is to constrain the bulk Lorentz factor of GRBs. Due to internal photon-photon productions, it is expected that there would be a (sharp) spectral cutoff in the prompt GRB spectrum, which has not been clearly detected
- It is almost guaranteed to detect prompt emission in the GLAST band, with a possible spectral cut-off. The exact location of the cut-off depends on the properties of the burst.
- High energy emission typically lasts longer than the sub-MeV prompt emission The spectrum would have a temporal evolution. Harder photons tend to be detected at later times when the fireball becomes less compact for photons.

Theoretical expectactions (Zhang 2007)

- At the low energy regime in the GLAST band, the prompt emission light curves would have narrower spikes than the the sub-MeV light curves. However, at higher energies when the putative IC component takes over, the light curves would be more smeared out with less sharp spikes due to the non-linear IC processes involved.
- It is possible that GLAST would detect bursts for thousand of seconds. The long-lasting emission may have a broad temporal bump with flares overlapping on top of it. The rising and falling indices of the flares would be less steep (again due to the non-linear IC processes), and the flare amplitudes would be smaller than those of X-ray flares.

High Energy Emission from GRB
“AGILE and GRBs”

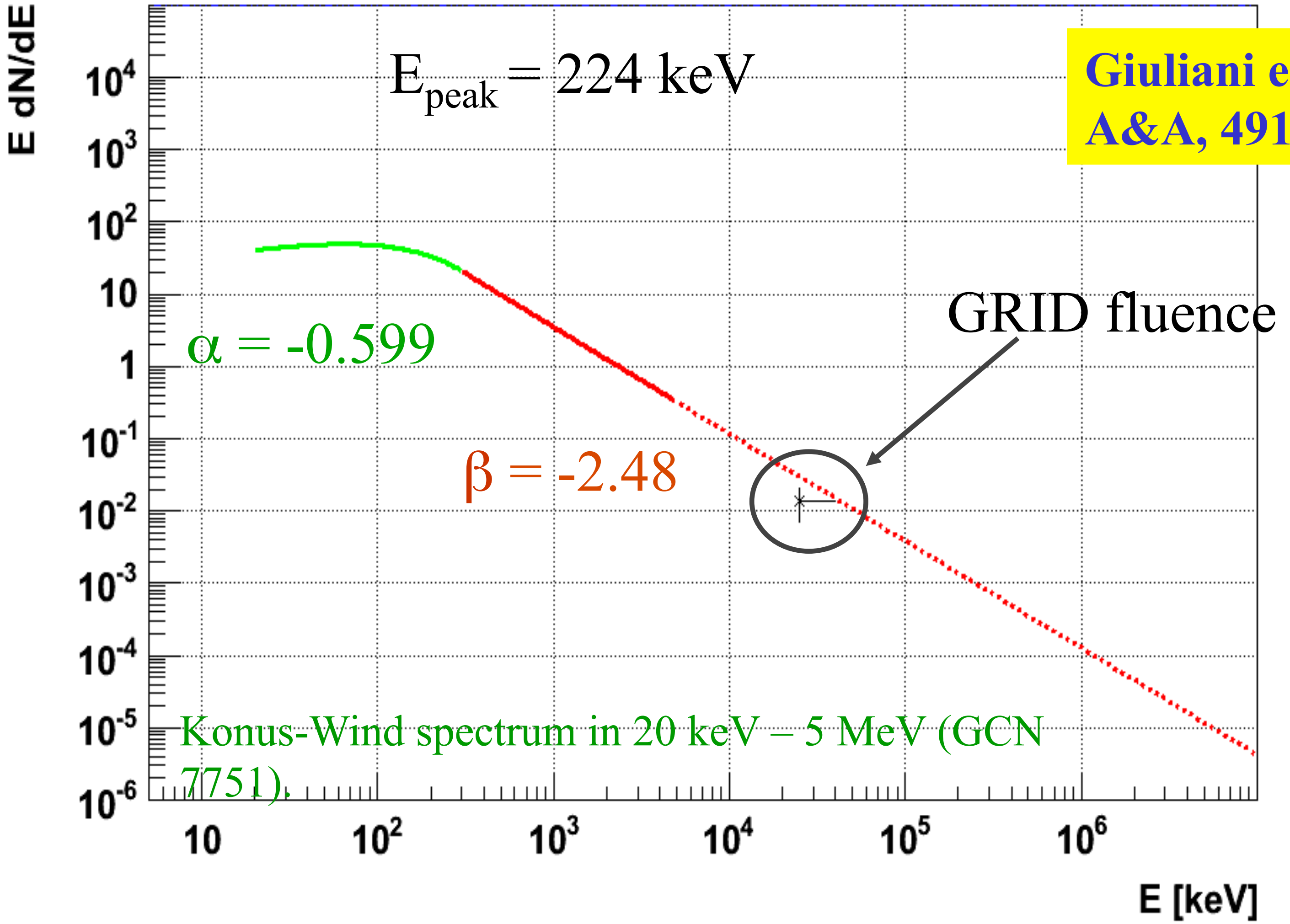
Gamma-ray extended emission in GRB 080514B



Giuliani et al., 2009, A&A, 491, L25 – L28

GRB 080514B is the first GeV-bright GRB after EGRET and it is also associated to an afterglow and a photometric redshift measure of 1.8 (A. Rossi et al., 2009, A&A).

A single spectral model for the whole spectrum of GRB 080514B

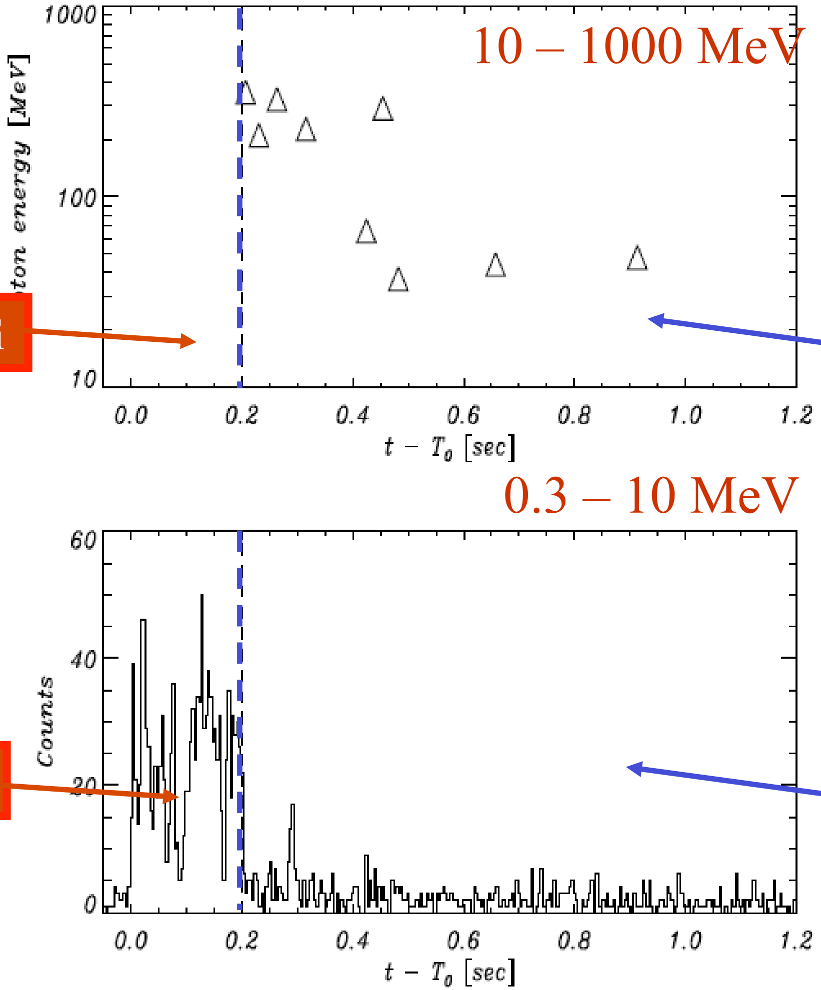


Giuliani et al., 2009, A&A, 491, L25 – L28

The same Band model fits the spectrum from 20 keV up to 50 MeV.

GRB 090510: the delayed emission

Giuliani et al. 2010, ApJ, 708, L84 – L88



10 – 1000 MeV

prompt emission interval

delayed emission interval

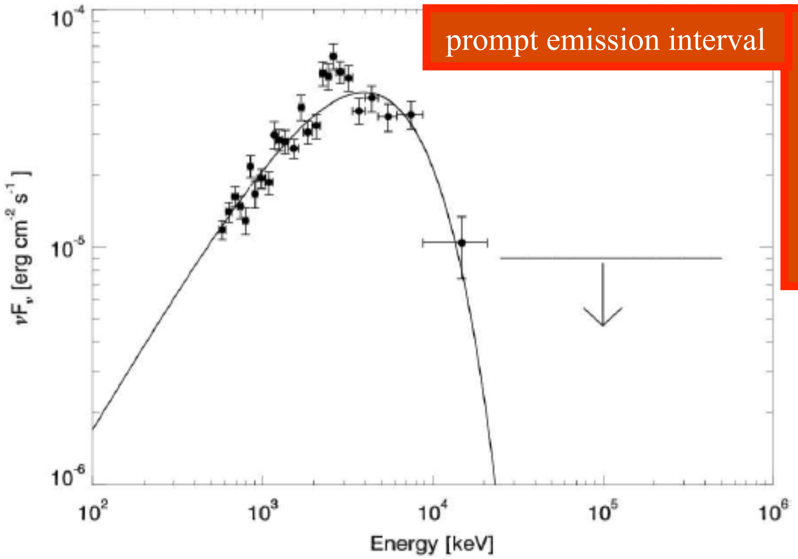
0.3 – 10 MeV

prompt emission interval

delayed emission interval

GRB 090510 has been localized by Swift and detected also by Fermi/LAT (Ackermann et al. 2010) and AGILE (Giuliani et al. 2010). The redshift is 0.903 (De Pasquale et al. 2010).

GRB 090510: spectral evolution in a short GRB

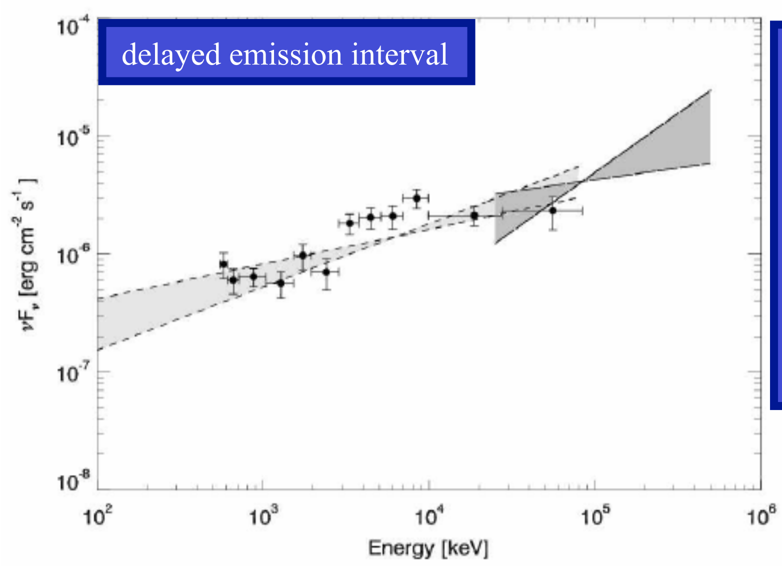


prompt emission interval

Powerlaw with cutoff

$\alpha_1 = 0.6 \pm 0.3$
Ec = 2.8 ± 0.9 MeV
1.8×10^{-5} erg/cm^2 (0.5 – 10 MeV)

Giuliani et al. 2010, ApJ, 708, L84 – L88



delayed emission interval

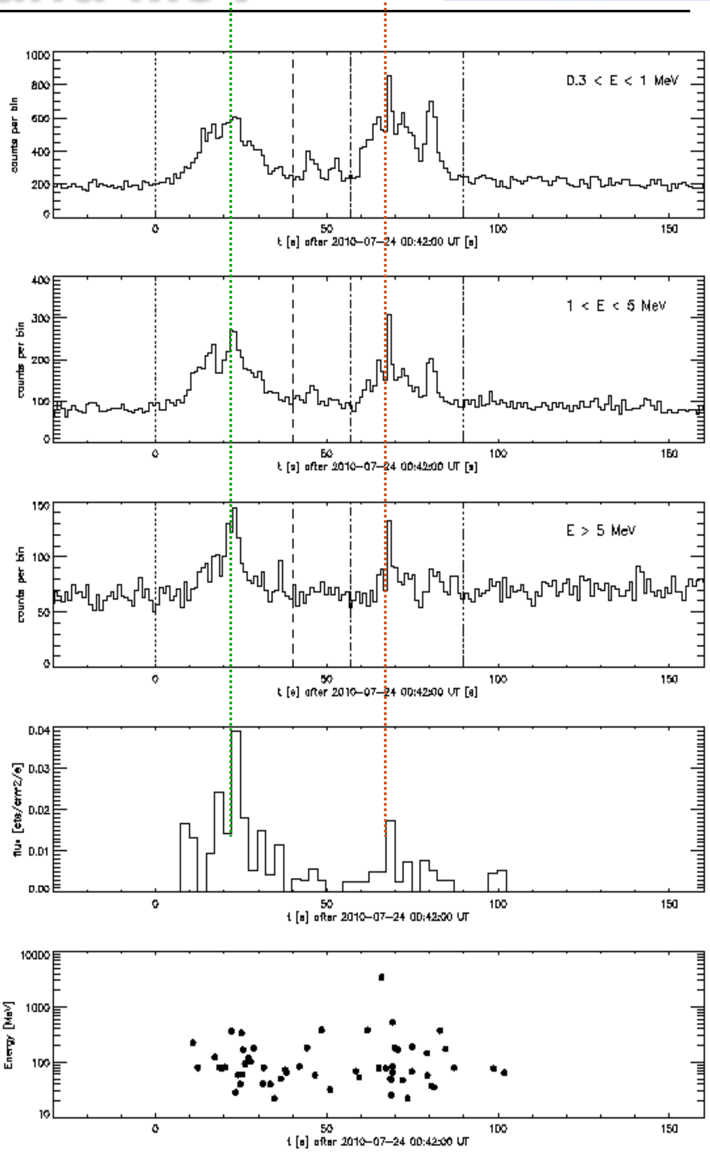
Powerlaw without cutoff

$\alpha_2 = 1.6 \pm 0.1$
3.1×10^{-6} erg/cm^2 (0.5 – 10 MeV)

$\alpha_3 = 1.4 \pm 0.4$
2.9×10^{-5} erg/cm^2 (25 – 500 MeV)

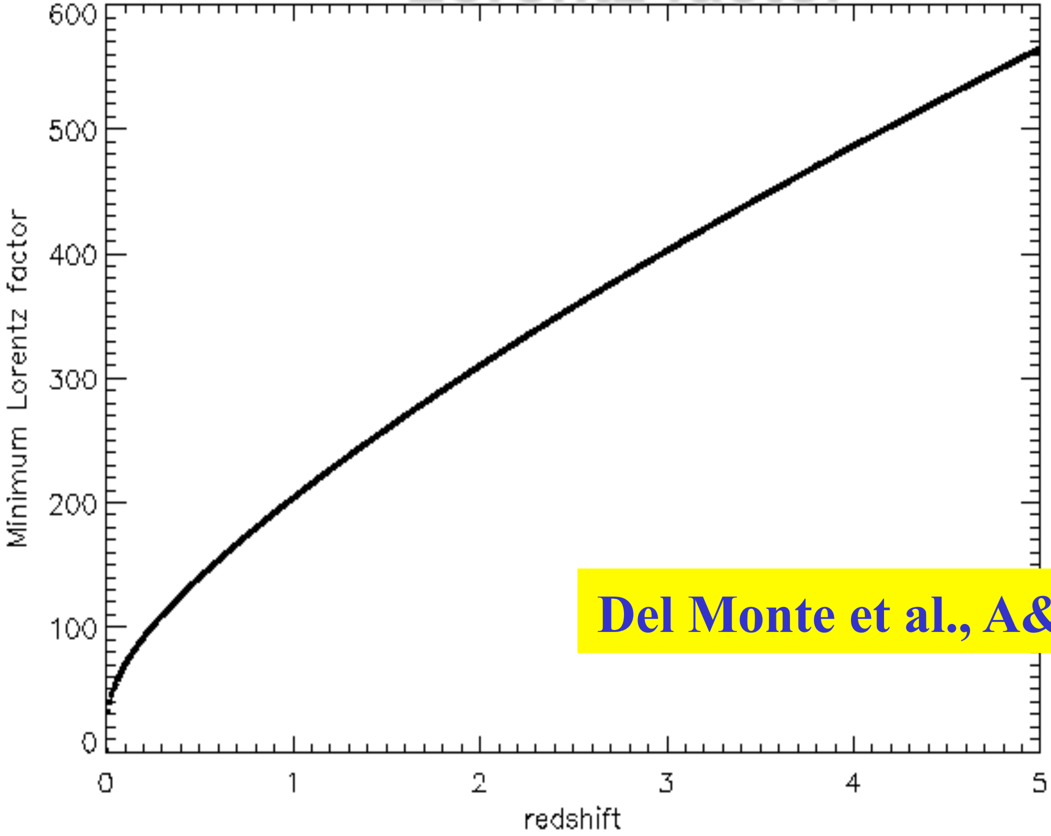
GRB 100724B: simultaneous onset of GeV and MeV

- No time lag is found between the MeV and GeV emission. The two main bumps in the lightcurve show a remarkably similar shape at MeV and GeV.
- Due to the spinning operative mode, GRB 100724B remained within the AGILE/GRID FoV between t_0+6s and t_0+125 s.
- The GRB is not detected during the next “transit” in the FoV (t_0 + 410 s , t_0 + 529 s).
- SuperAGILE was not collecting data for telemetry sharing reasons.



Del Monte et al., A&A, 535, 120, (2011)

GRB 100724B: minimum bulk Lorentz factor

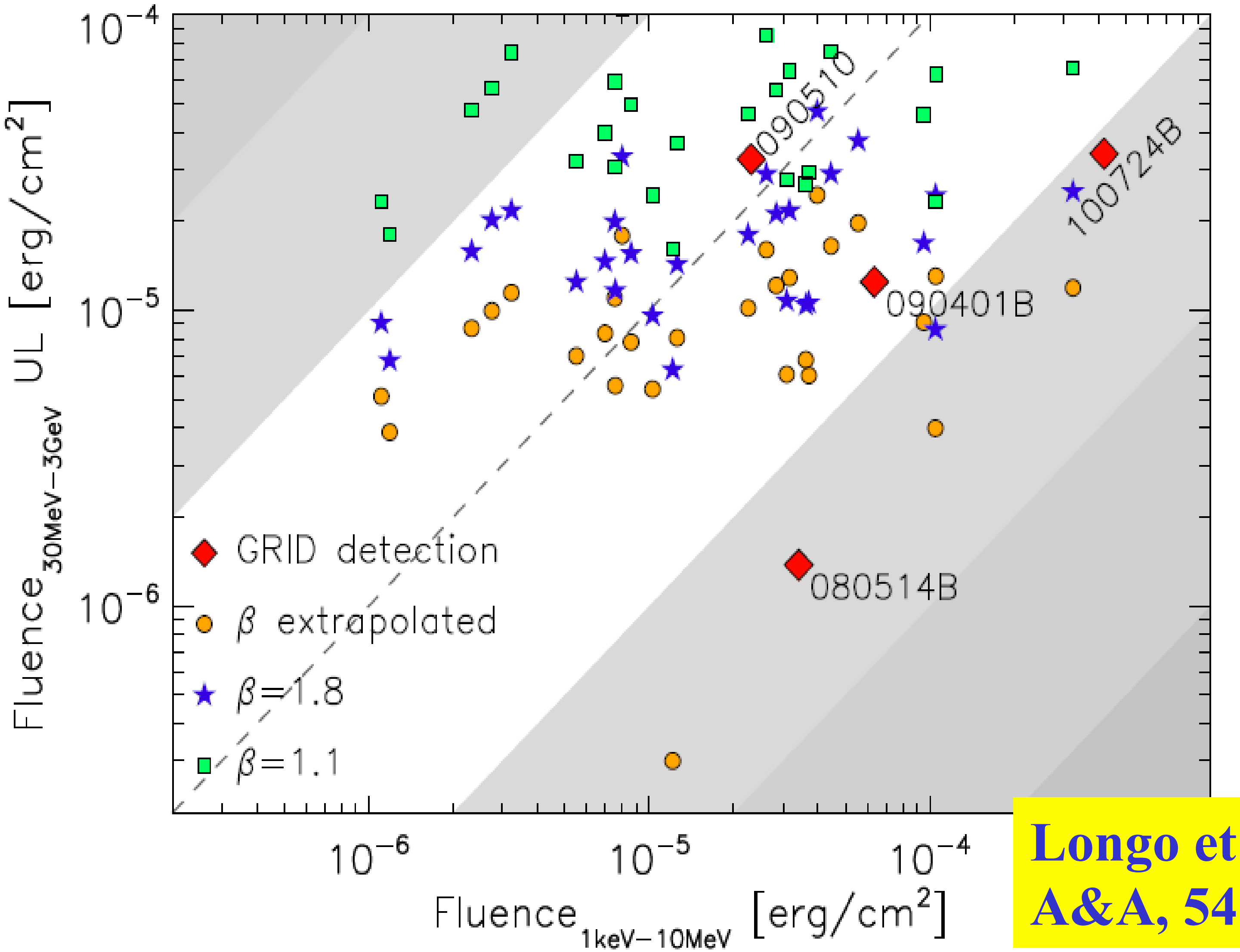


Del Monte et al., A&A, 535, A120 (2011)

Following the method reported in the Supporting Online Material of the paper about GRB 080916C (Abdo et al 2009, Science, 323, 1688), $\Gamma_{min} = \Gamma_{min}$ (z, Δt, E_{max}, β).

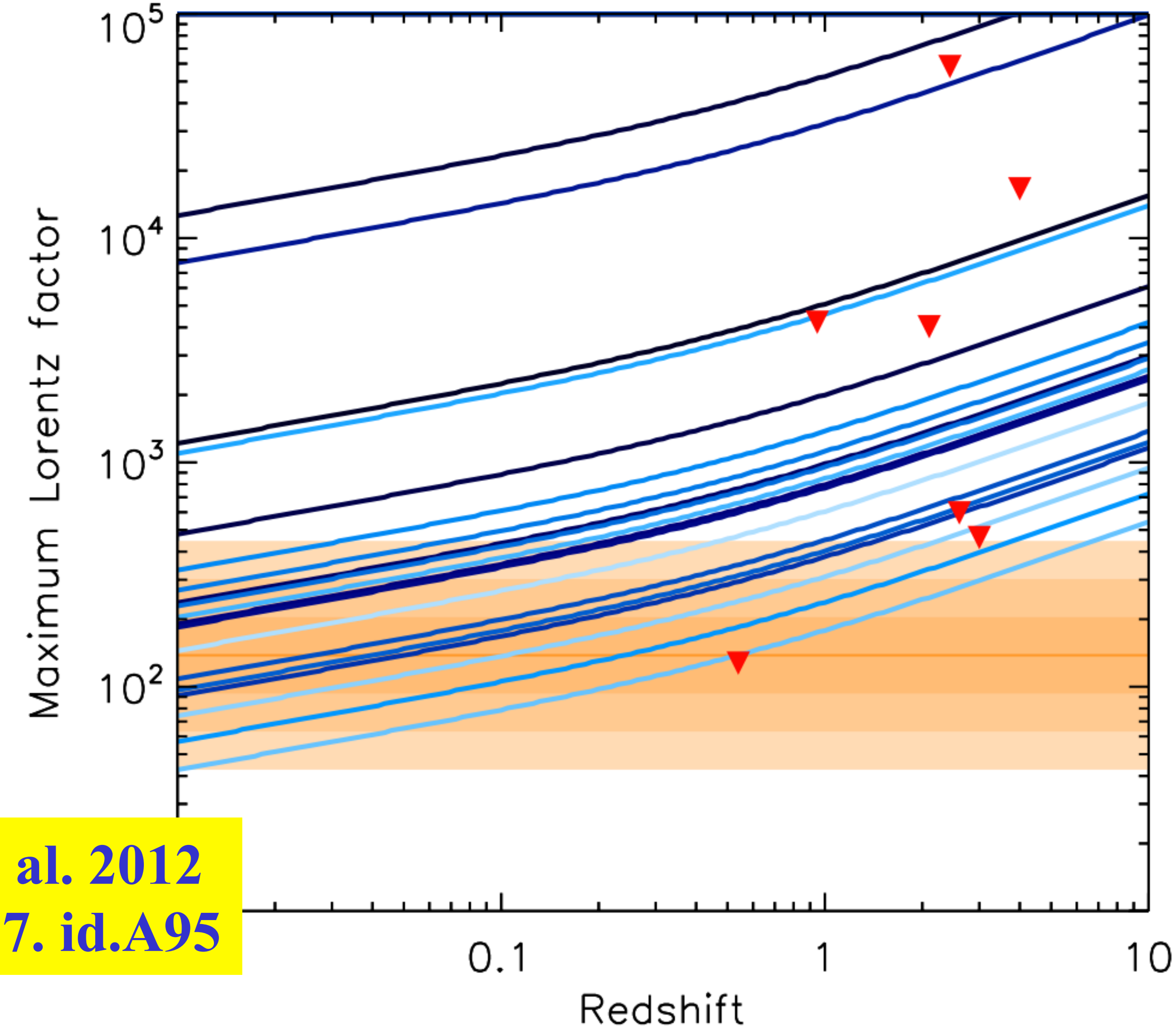
The estimated Lorentz factor is similar to other GeV-bright GRBs (e. g. GRB 080916C, GRB 090902B and GRB 090510).

GeV emitting GRBs as high fluence events



Longo et al. 2012, A&A, 547. id.A95

Upper limits on GeV emission



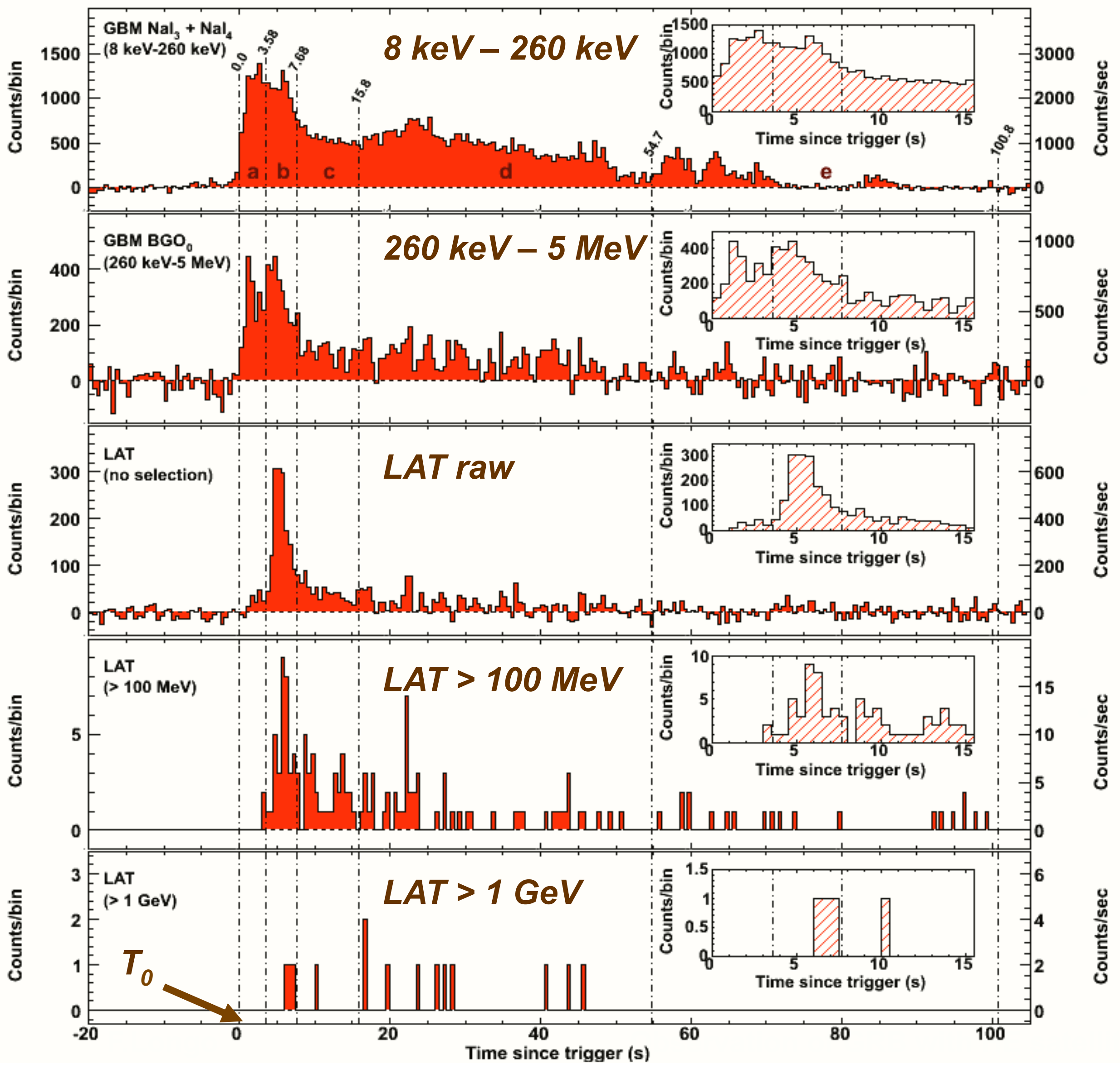
Longo et al. 2012
A&A, 547. id.A95

The AGILE view on GRBs

- Extended emission?
  - HE emission lasts longer …
- Prompt emission?
  - He emission could start later ..
- Spectral Components?
  - Several components observed
- Ubiquity of HE emission?
  - Not a common feature
  - Lack of bright GRBs

High Energy Emission from GRB
“Fermi/LAT and GRBs”

GRB080916C - Multiple detector light curve



es

Abdo et al. 2009, Science, 323, 1688

First 3 light curves are background subtracted

The LAT can be used as a counter to maximize the rate and to study time structures above tens of MeV

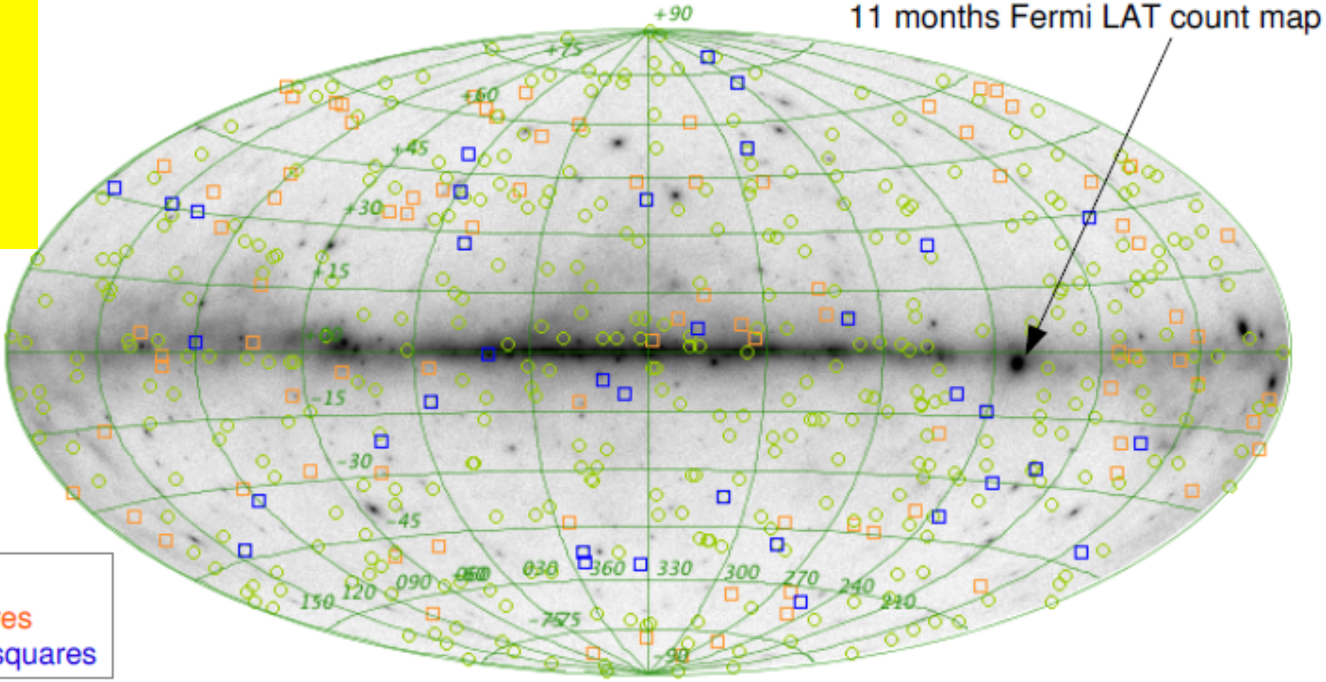
- The first low-energy peak is not observed at LAT energies

Spectroscopy needs LAT event selection (>100 MeV)

- 5 intervals for time-resolved spectral analysis: 0 – 3.6 – 7.7 – 16 – 55 – 100 s
- 14 events above 1 GeV

The 1st GRB catalog

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



11 months Fermi LAT count map

GBM LGRB: green circles
GBM SGRB: orange squares
LAT detections (35): blue squares

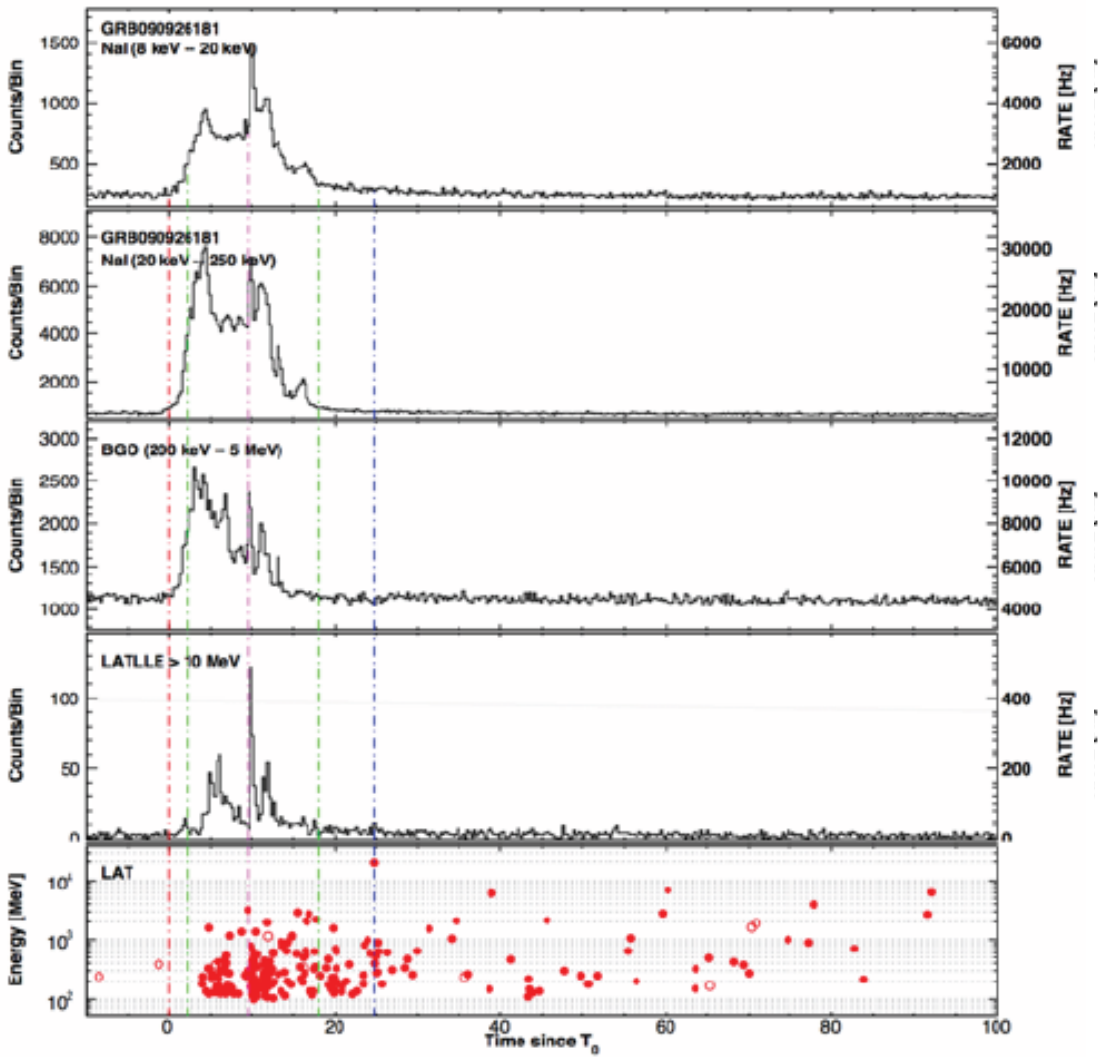
- The GBM detects ~250 GRBs / year, ~half in the LAT FoV

  Paciesas et al. 2012, ApJS 199, 18; Goldstein et al. 2012, ApJS 199, 19

- The LAT detected 35 GRBs in 3 years (30 long, 5 short), including 7 “LLE-only” GRBs
  - Bright LAT bursts with good localizations are all followed-up by Swift
  - 10 redshift measurements, from z=0.74 (GRB 090328) to z=4.35 (GRB 080916C)
  - 4 joint BAT-GBM-LAT detections: GRBs 090510, 100728A, 110625A, 110731A

A “typical” bright GRB in Fermi

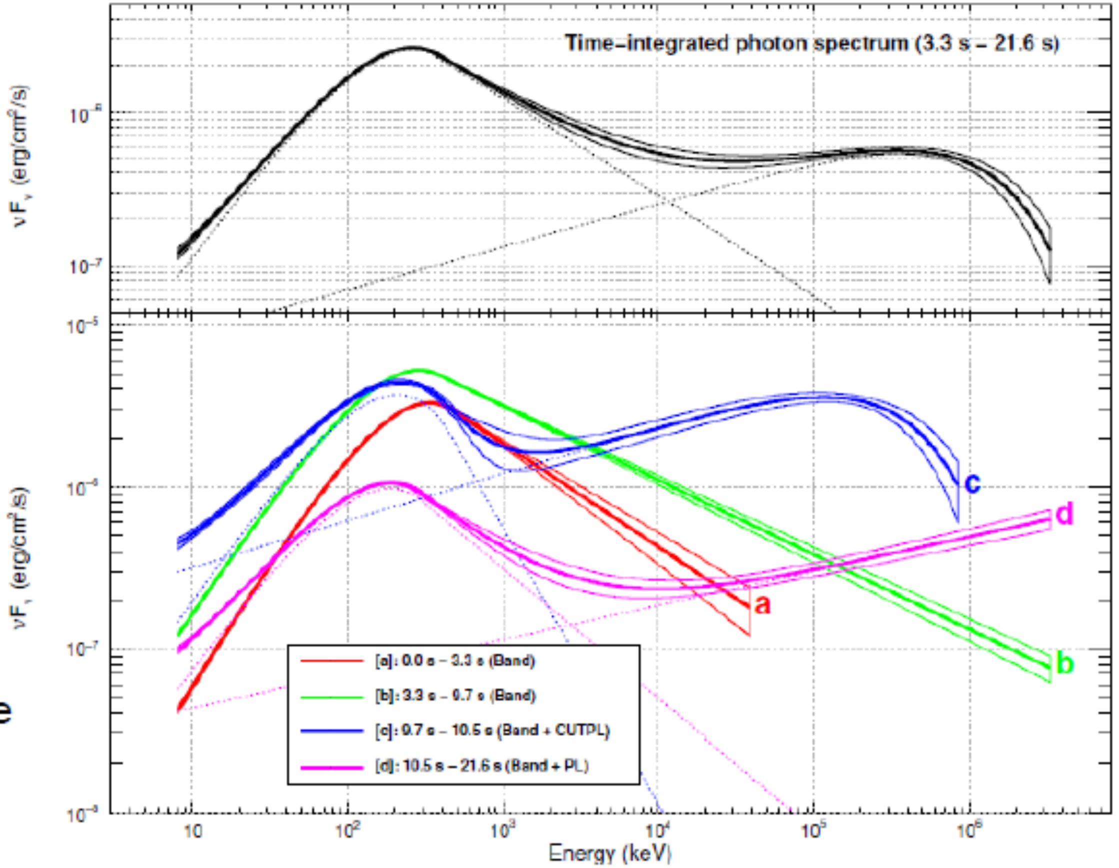
- Ackerman+11: correlated variability in various bands, with a sharp spike at T_0+10 s
  - All energy ranges synchronized (<50 ms)
  - Low and high energies are co-located or even causally correlated
- LAT >100 MeV emission is delayed (~4 s)
  - Delay > spike widths
- LAT >100 MeV emission is temporally extended, well after the GBM prompt phase
  - 19.6 GeV photon detected at T_0+24.8 s



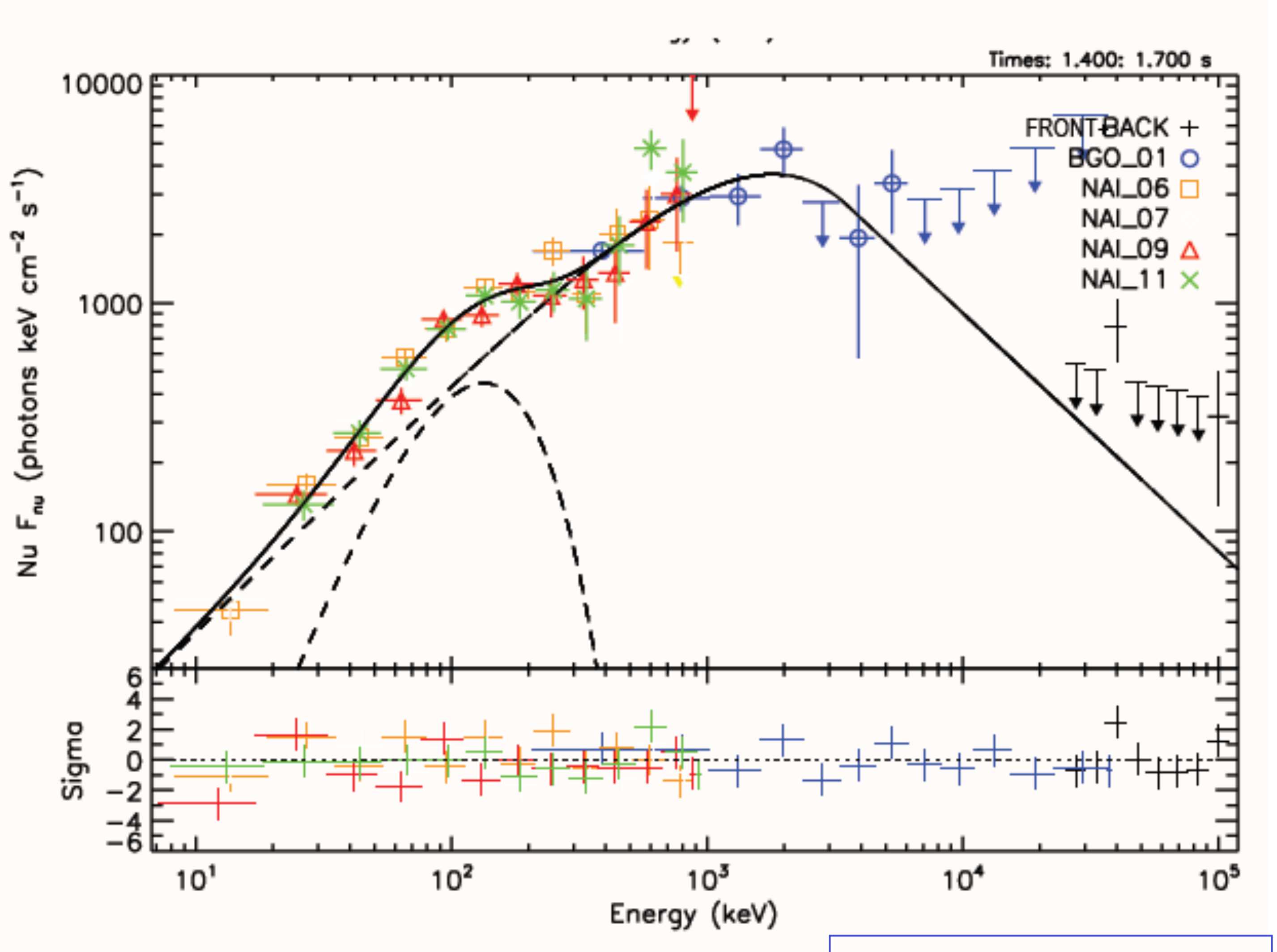
A “typical” bright GRB in Fermi

- Fluence = 2.2 x 10^{-4} erg cm^{-2} (10 keV - 10 GeV)
- E_{iso} = 2.2 x 10^{54} erg
- Extra component (power law)
  - Starts delayed (~9 s)
  - Persists at longer times
  - Dominates > 10 MeV
- Spectral cutoff
  - Significant in bin c, marginally in bin d
  - Shape not constrained
- First direct measurement of the jet Lorentz factor: $\Gamma \sim 200\text{-}700$
  - If cutoff due to $\gamma\gamma$ absorption
  - Model dependent

Ackermann et al. 2011, ApJ 729, 114

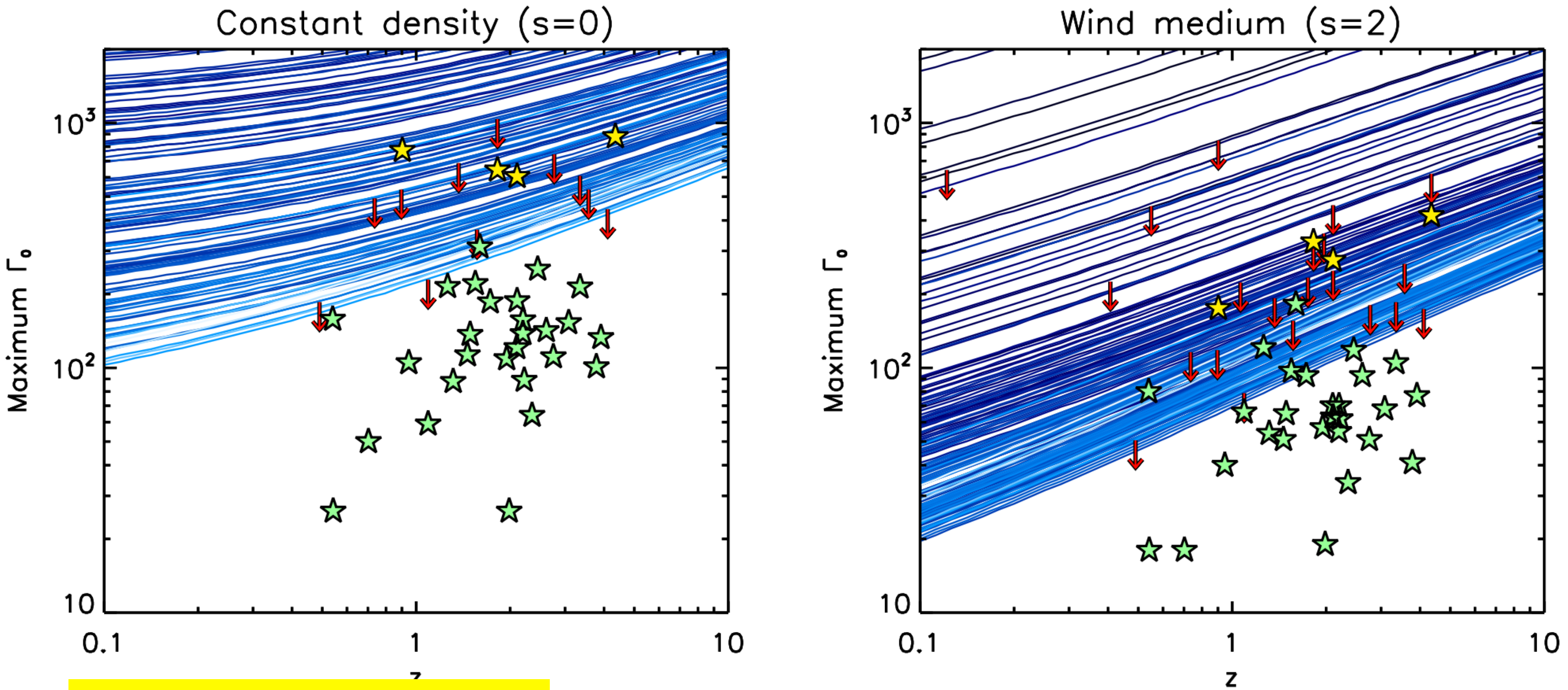


Multicomponent spectra



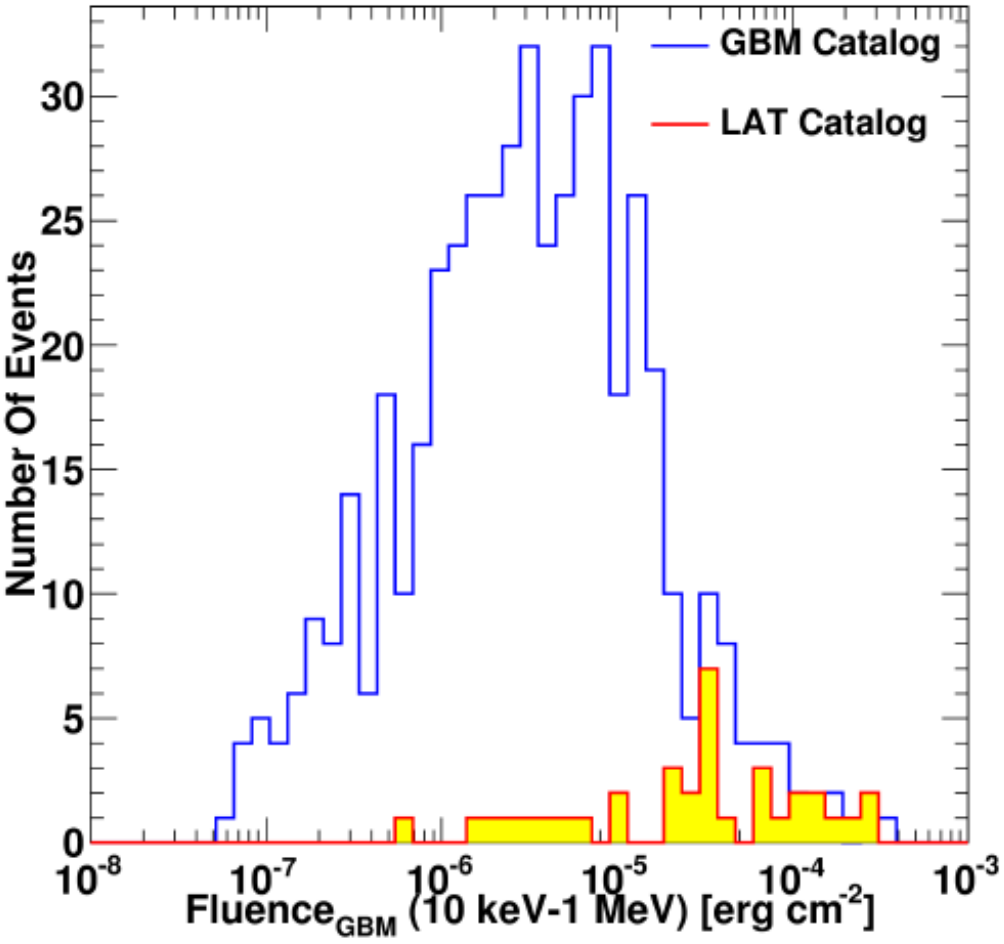
Axelsson et al. 2012

Estimate on Bulk Lorentz Factor



Nava, L. et al. 2016 MNRAS

Fluence of LAT GRB



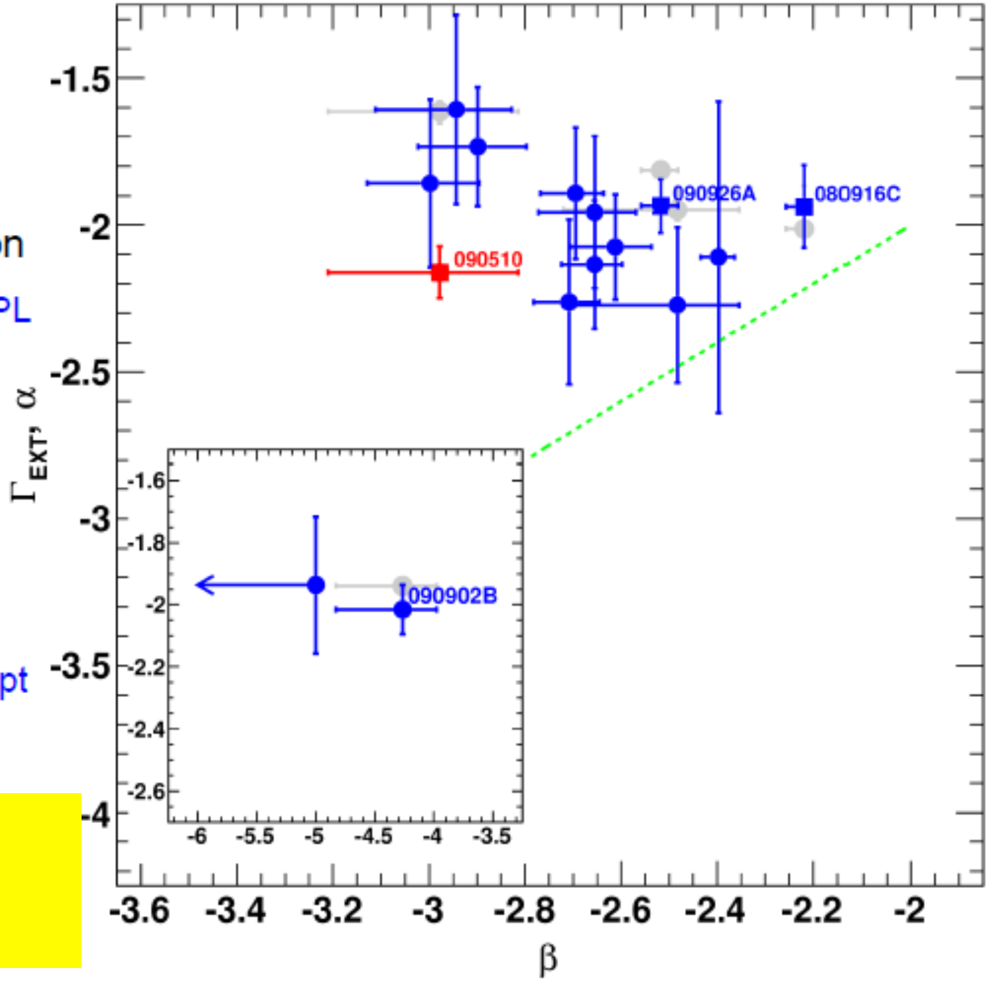
- Fluence in GBM energy range and "GBM" time window
  - LAT bursts vs. entire sample in GBM spectral catalog (Goldstein et al. 2012)
- Not surprisingly, LAT bursts are among the brightest GBM bursts
  - Selection effects (autonomous repointings) are possible though

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

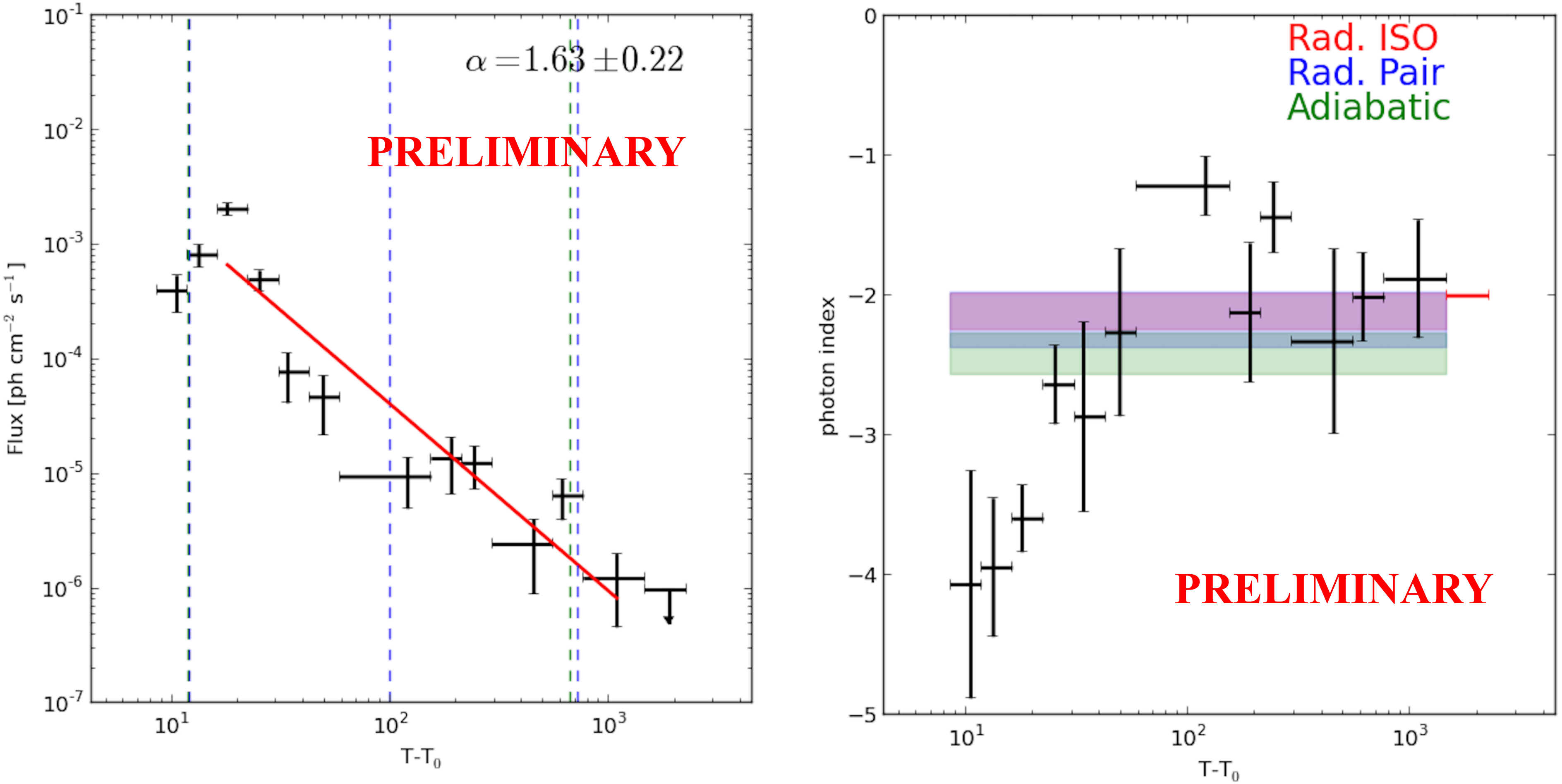
Extended and Prompt Spectra

- $\beta=\beta_{BAND}$ here: spectral index of Band function in the prompt phase
- Γ_{EXT} : spectral index of extended emission
  - α (grey points): spectral index of extra PL from GBM-LAT joint fit in the prompt phase
- Prompt and extended phase spectra not correlated
  - Stronger spectral variability in the prompt phase

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

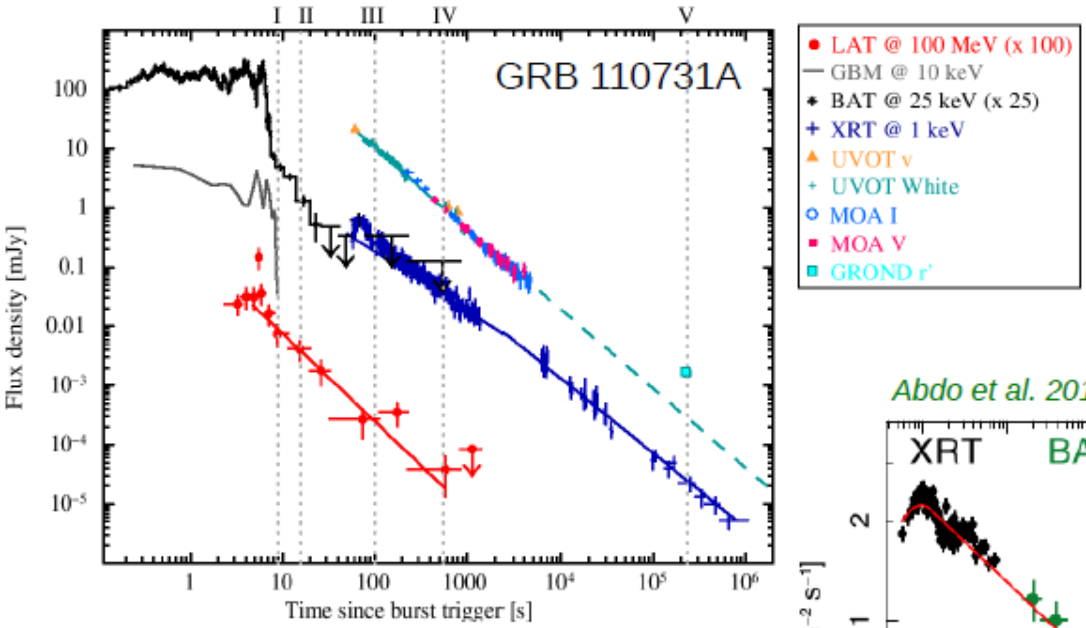


The case of GRB 160509A



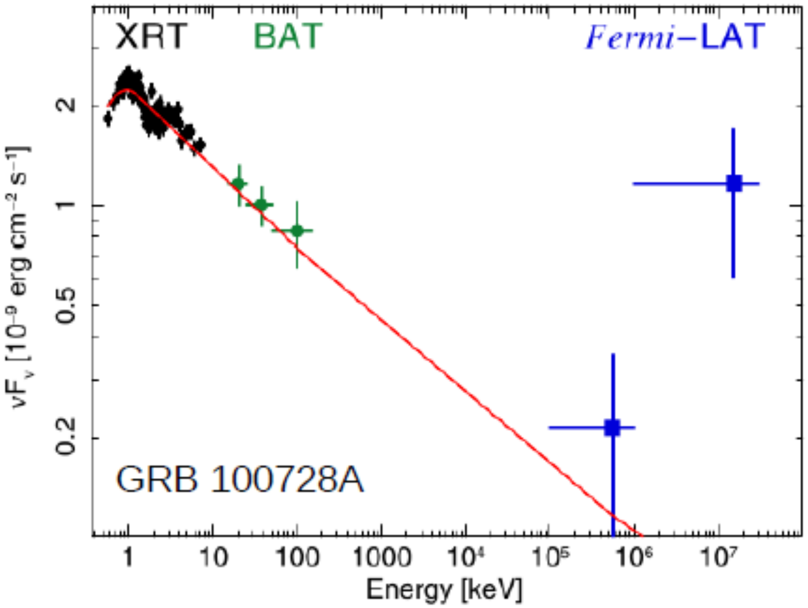
Swift and Fermi GRB

Ackermann et al. 2013, ApJ 763, 71



- GRB 110731A long-lived GeV emission from forward shock
  - Onset time <T_0+8 s (possible contamination from IS)
  - Γ~500 compatible with the value derived from the cutoff seen in the prompt emission spectrum (P~3x10^{-4})

Abdo et al. 2011, ApJ 734, L27

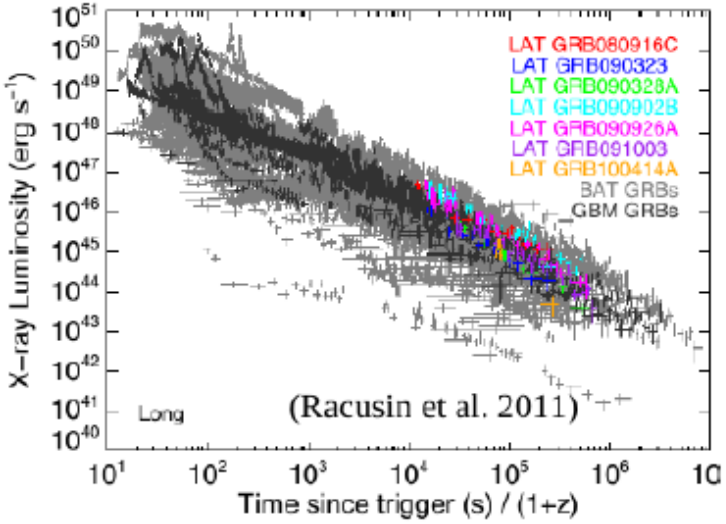


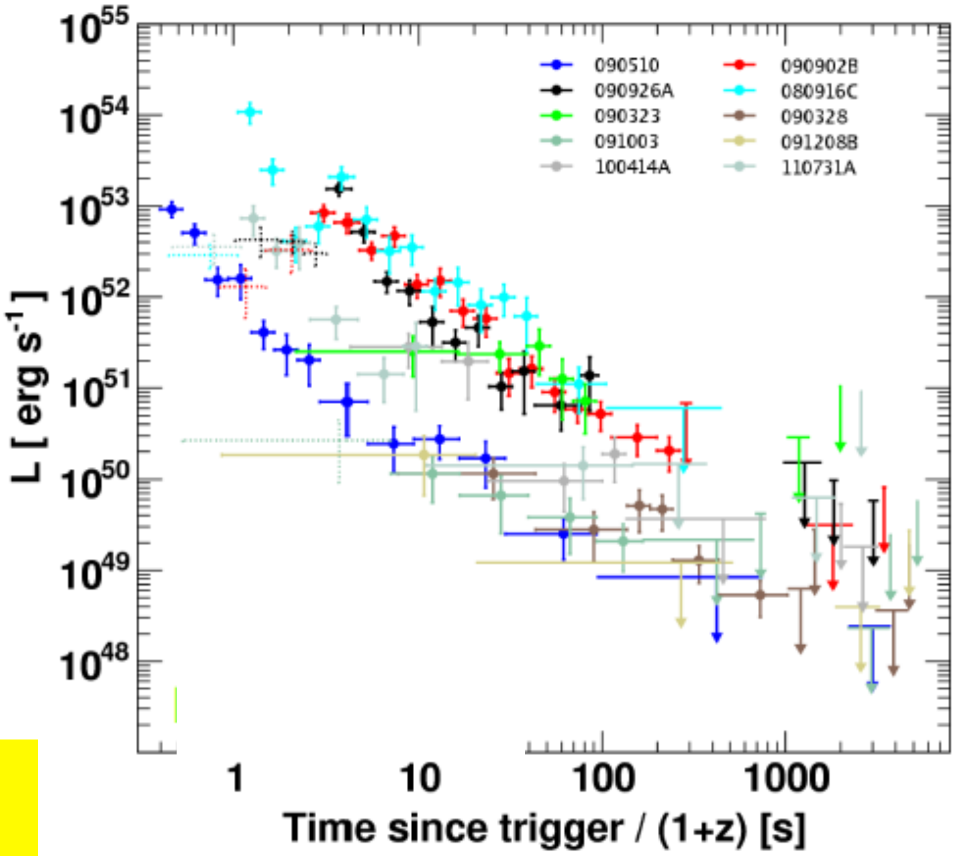
- GRB 100728A was detected during X-ray flaring activity only
  - Spectrum compatible with same PL from X rays to gamma rays, modeled with internal shocks

Afterglow of LAT GRB

- Photon spectral index is constant and typically averages around $\Gamma_{EXT} \sim -2$ (previous slide)
- Rest-frame luminosity (100 MeV – 10 GeV) in the afterglow phase: $L(E,t) \sim t^{-\alpha}E^{-\beta}$

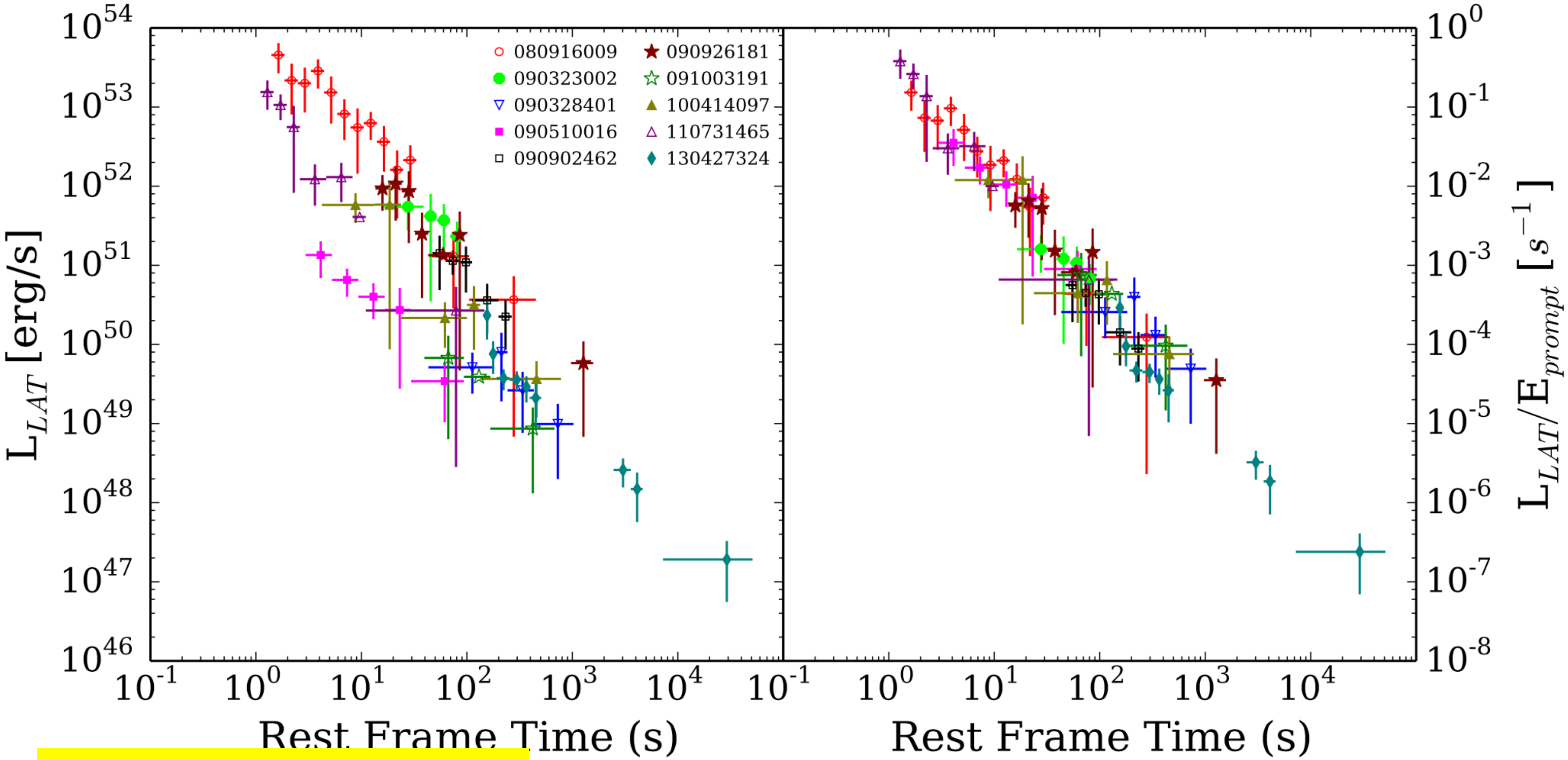
  $\beta=-\Gamma_{EXT}-1=1$, $\alpha=1$ for an adiabatic fireball in a constant density environment (10/7 if radiative)





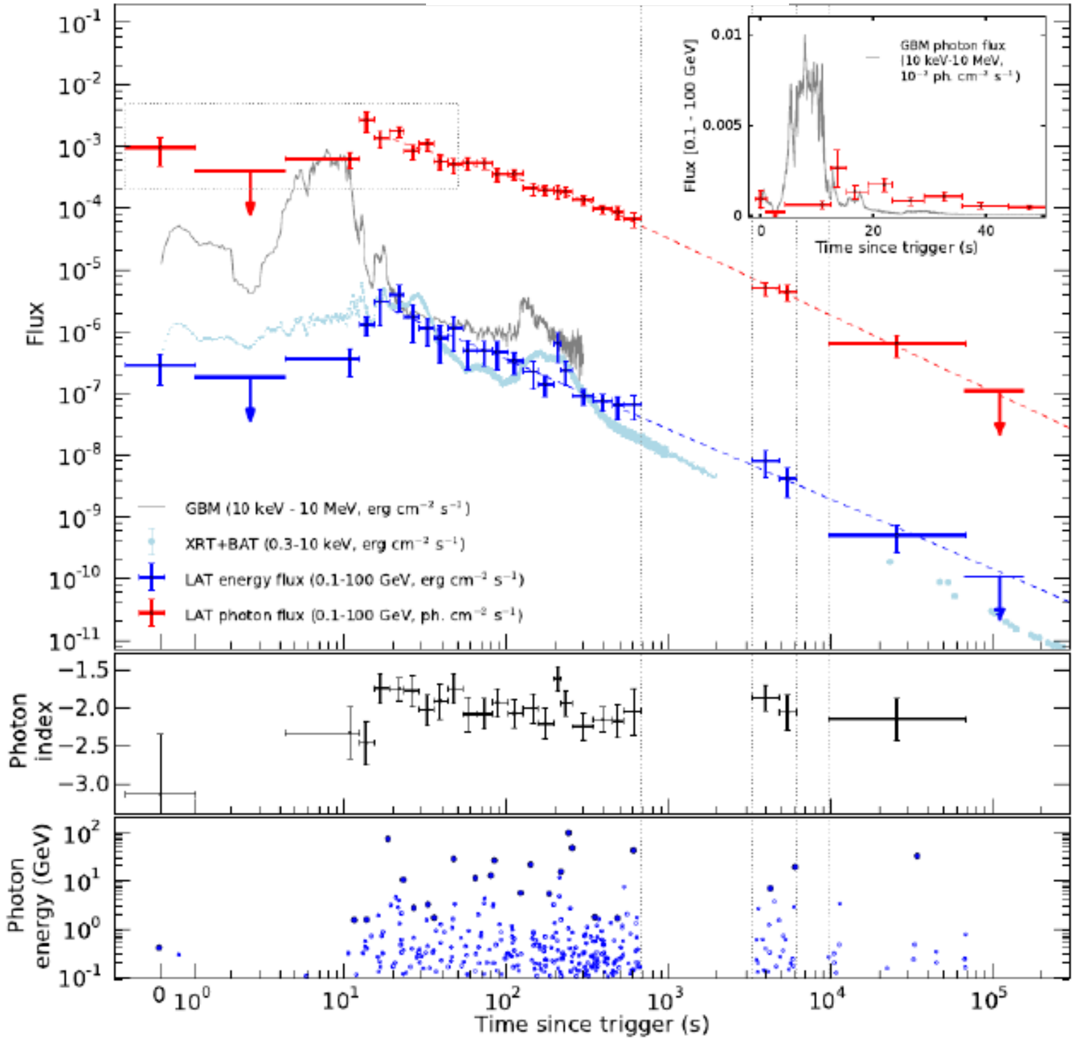
Ackermann, M. et al. 2013
ApJS, 209, 11

Clustering of LAT light curve



Nava, L. et al. 2014
MNRAS 443, 3578

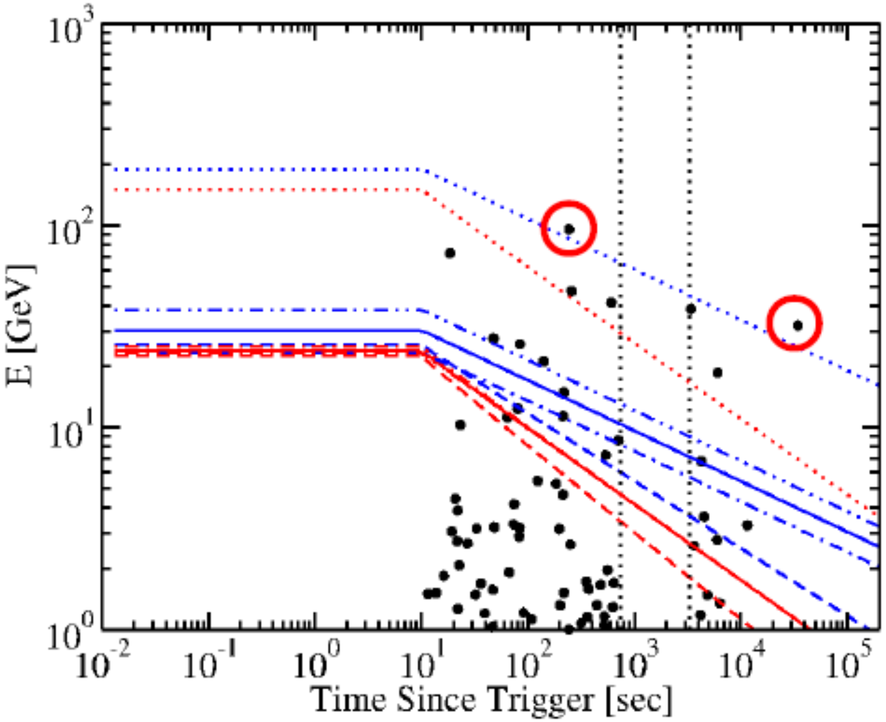
GRB 130427A



(Ackermann et al.,
Science, Vol. 343 no. 6166
pp. 42-47)

GRB 130427A

- Jet interacts with circumburst medium.
  - Charged particles are accelerated.
  - These particles then emit photons via synchrotron emission.
- This prescribes a maximum synchrotron photon energy.



Curves of **maximum** synchrotron photon energy from external shocks, for various conditions

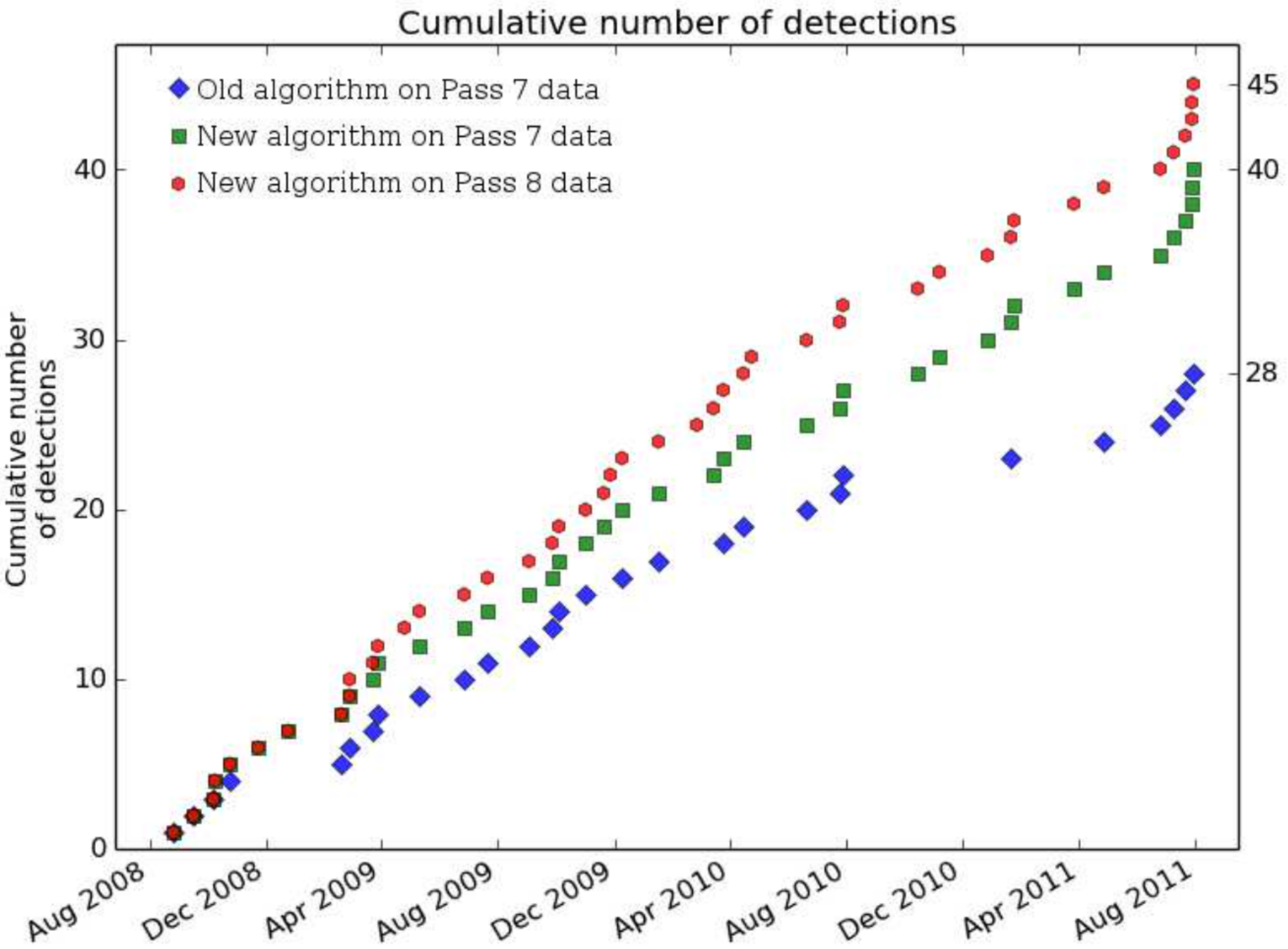
Black dots: LAT photons

Circumburst medium:
Red → constant density
Blue → density ~ r^{-2}

Dotted lines: more "extreme" (i.e., unrealistic) scenarios
→ LAT photons *still* lie above these lines

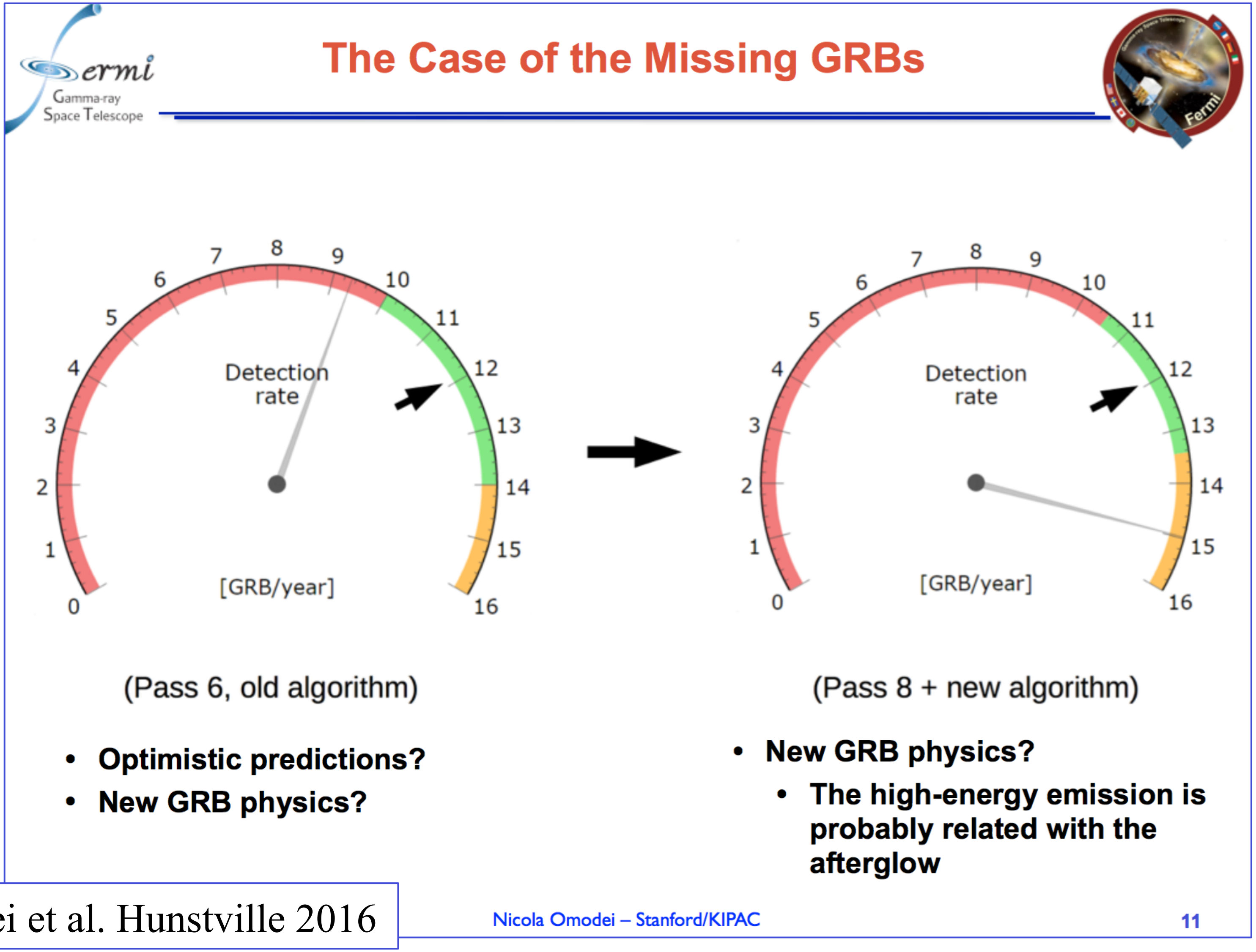
Ackermann, M. et al. 2014, Science, 343, 42S

The new Pass8 data



Vianello & Omodei

Towards the 2nd LAT catalog



The Case of the Missing GRBs

(Pass 6, old algorithm)

- **Optimistic predictions?**
- **New GRB physics?**

(Pass 8 + new algorithm)

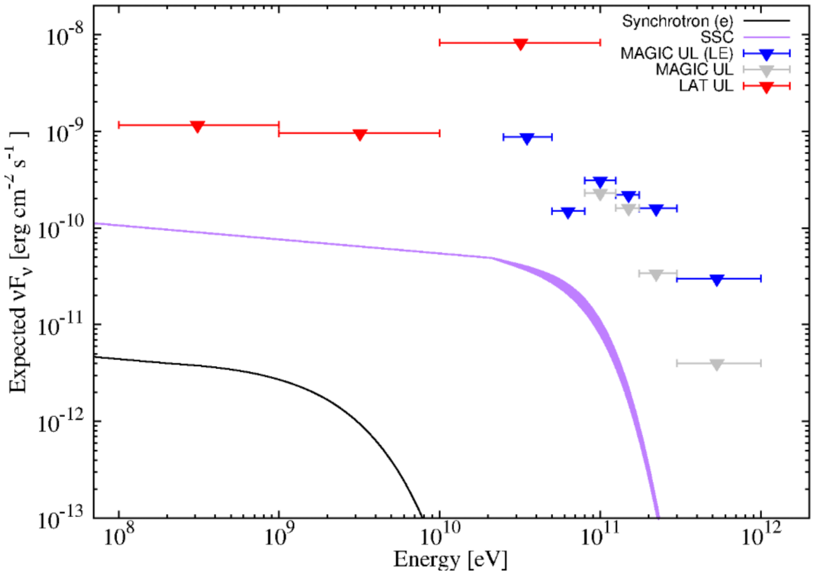
- **New GRB physics?**
  - **The high-energy emission is probably related with the afterglow**

Nicola Omodei – Stanford/KIPAC

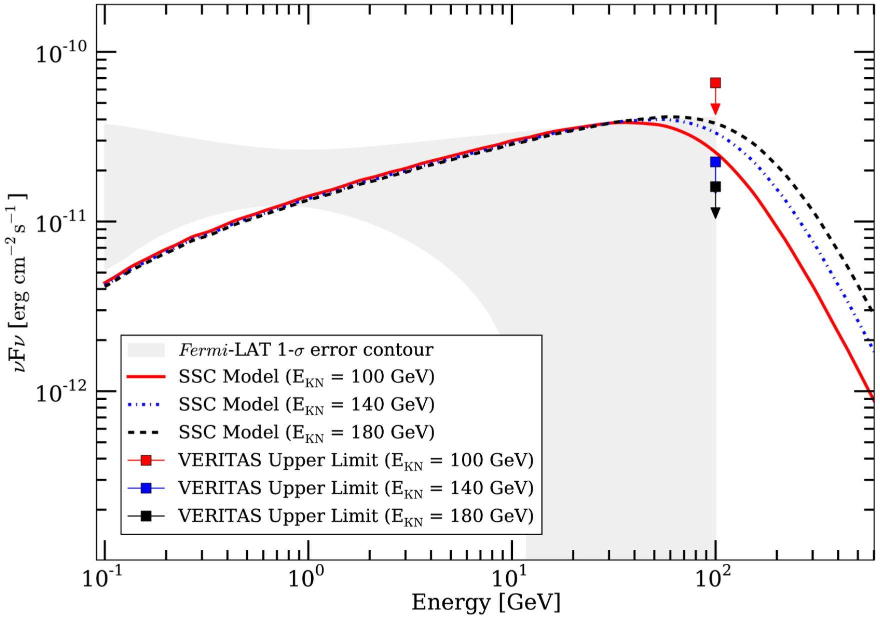
11

Omodei et al. Hunstville 2016

IACT upper limits



Inoue et al AstroParticlePhysics 2013
J. Aleksic et al., MNRAS 2014



Aliu et al. ApJ 2014

AGILE and Fermi view on the HE Emission from GRBs

- Extended emission
  - Extra long GRBs
- Prompt emission
  - Delayed onset
  - Emission mechanism
- SpectralComponents
  - Extra components
  - Multiple components
- Ubiquity of HE emission
  - Upper Limits in the > 100 MeV regime
- Population of HE emitting GRBs
  - Mission in the 10 MeV – 1 GeV
- Population of VHE emitting GRB
  - IACT detection ?