Fermi Observations of GRB 090902B: Spectral and Temporal Complexity During the Prompt and Extended Emission Phases

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On behalf of the Fermi GBM and LAT Collaborations

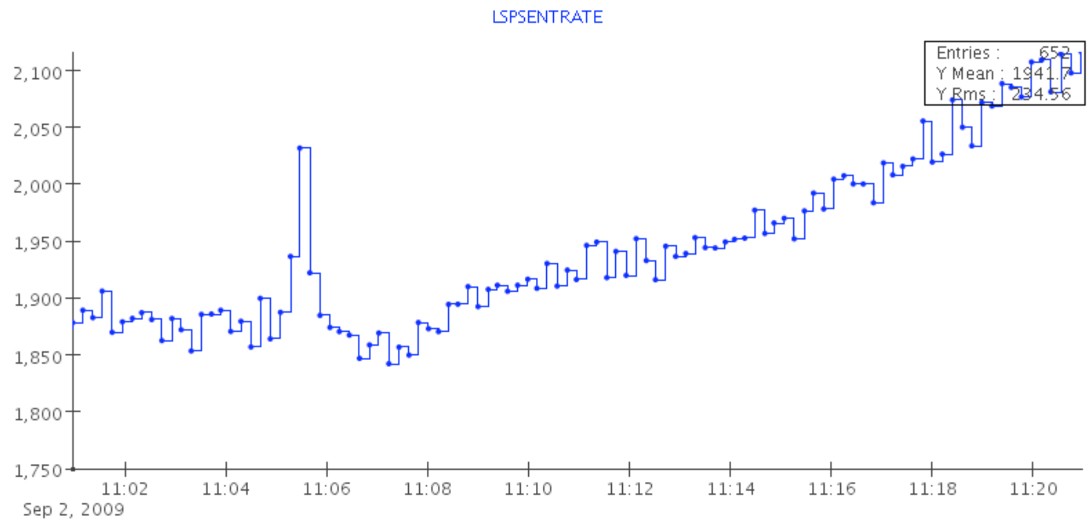
Abdo et al. 2009, ApJ, 706, L138 (arXiv:0909.2470v2)

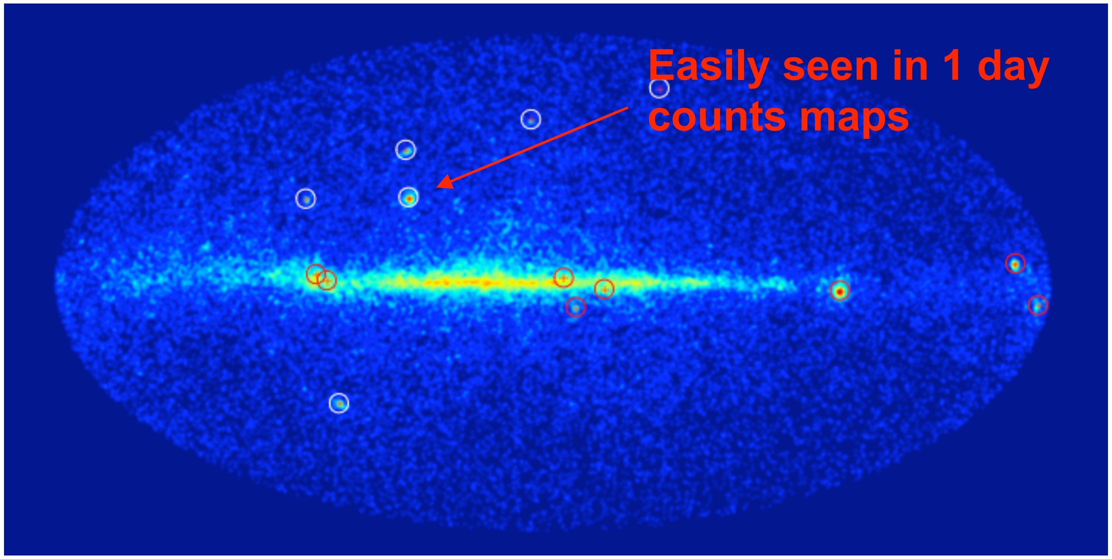
The Second LAT Collaboration Burst

- GBM Trigger at 11:05:08.31 UT, 2 September 2009
- ARR initiated
- GBM loc: RA, Dec = 264.5, 26.5, 51° from LAT boresight

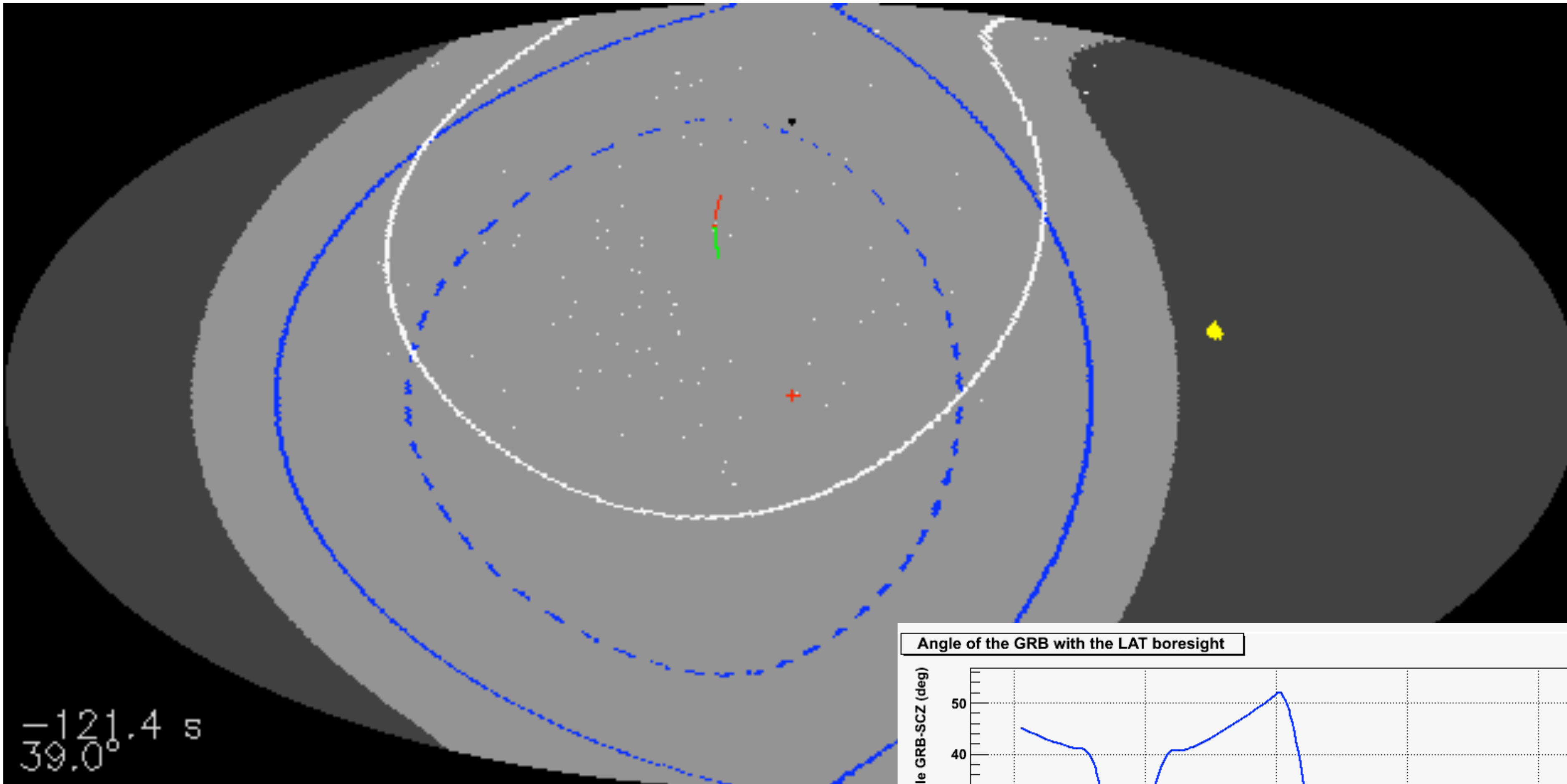
- 200 counts > 100 MeV, 39 > 1 GeV in 100 s
- LAT location: 265.00, 27.33

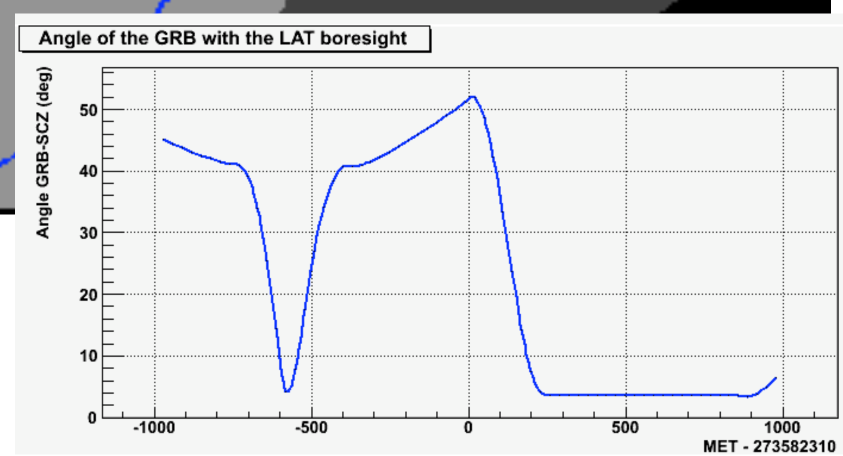
- Swift XRT afterglow/loc.
- GROND localization 3.3 arcmin from LAT location
- Gemini-N redshift: z = 1.822





Autonomous Repoint





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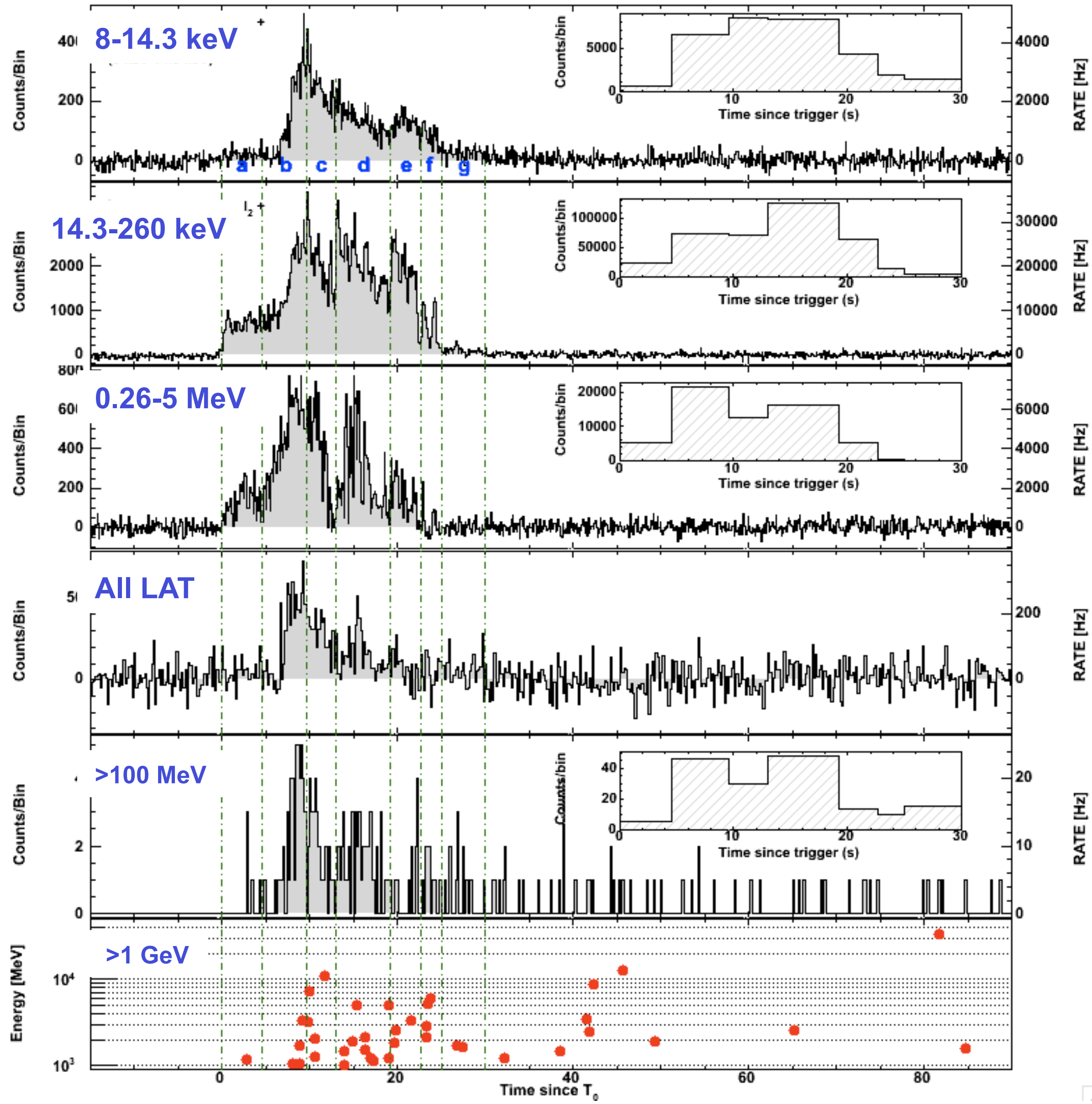
Properties and Light Curves

More vitae:

- T90 = 21.9 s, 50-300 keV
- Fluence = 4.4×10^{-4} erg cm^{-2} (10 keV – 10 GeV)
- $E_{iso} = 3.6\times10^{54}$ erg (cf. GRB 080916C, 9×10^{54} erg)
- LAT emission extends well beyond GBM prompt phase
- Highest energy photon measured from a burst: $33.4^{+2.7}_{-3.5}$ GeV, arriving 82 s after the GBM trigger

- Study correlated variability in various bands,
- Possible delayed onset of >100 MeV emission



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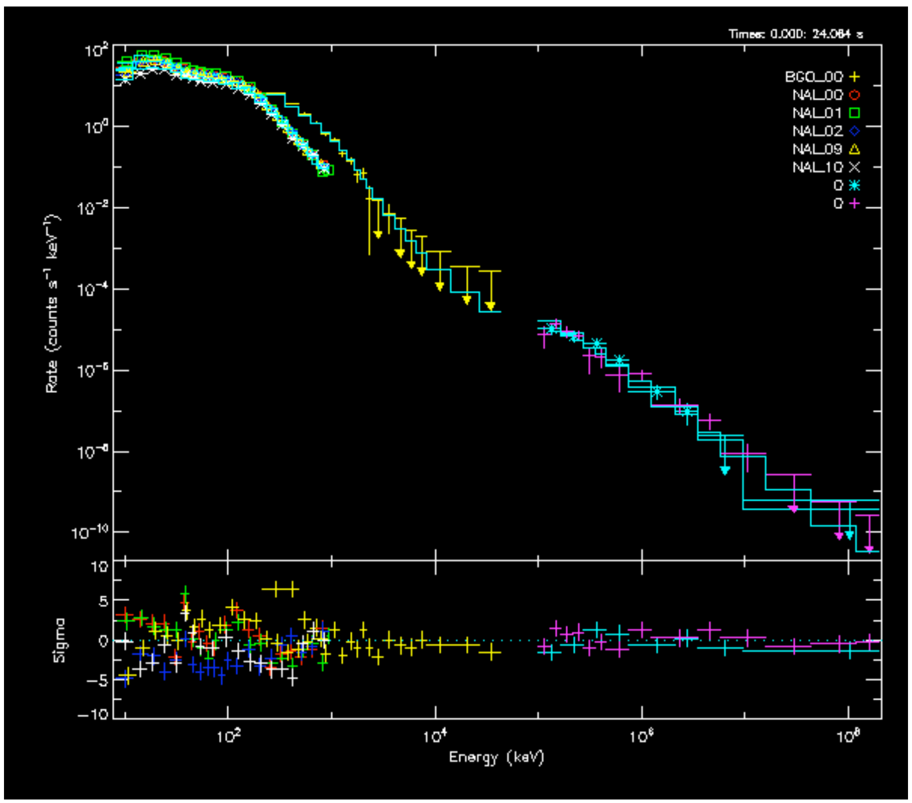
Time-integrated Spectrum

- Evidence for a hard power-law component, Γ = -1.93
- Band + PL $\Rightarrow$ ΔCSTAT = 2000 (2 dof)
- PL / (Band+PL) fluence ratio = 24%, 10 keV– 10 GeV

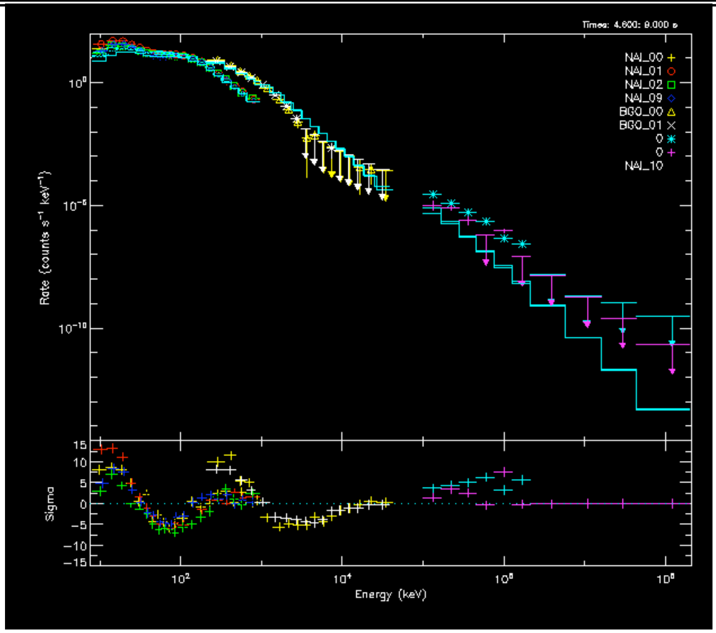


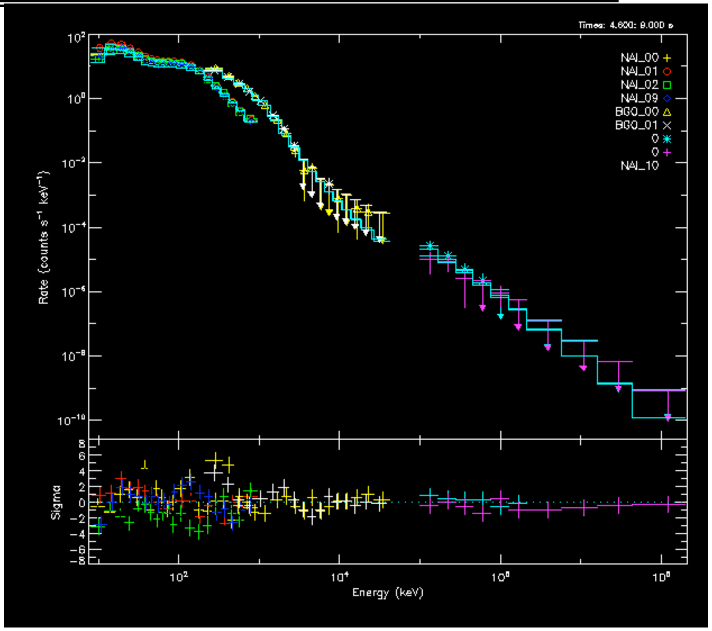
Low energy extension of PL component

Interval b,
T0 + 4.6 to 9.6 s

ΔCSTAT = 3165,
(≥ 1000 for GBM only)

This is the first time a low energy extension of the power-law component has been definitively seen.





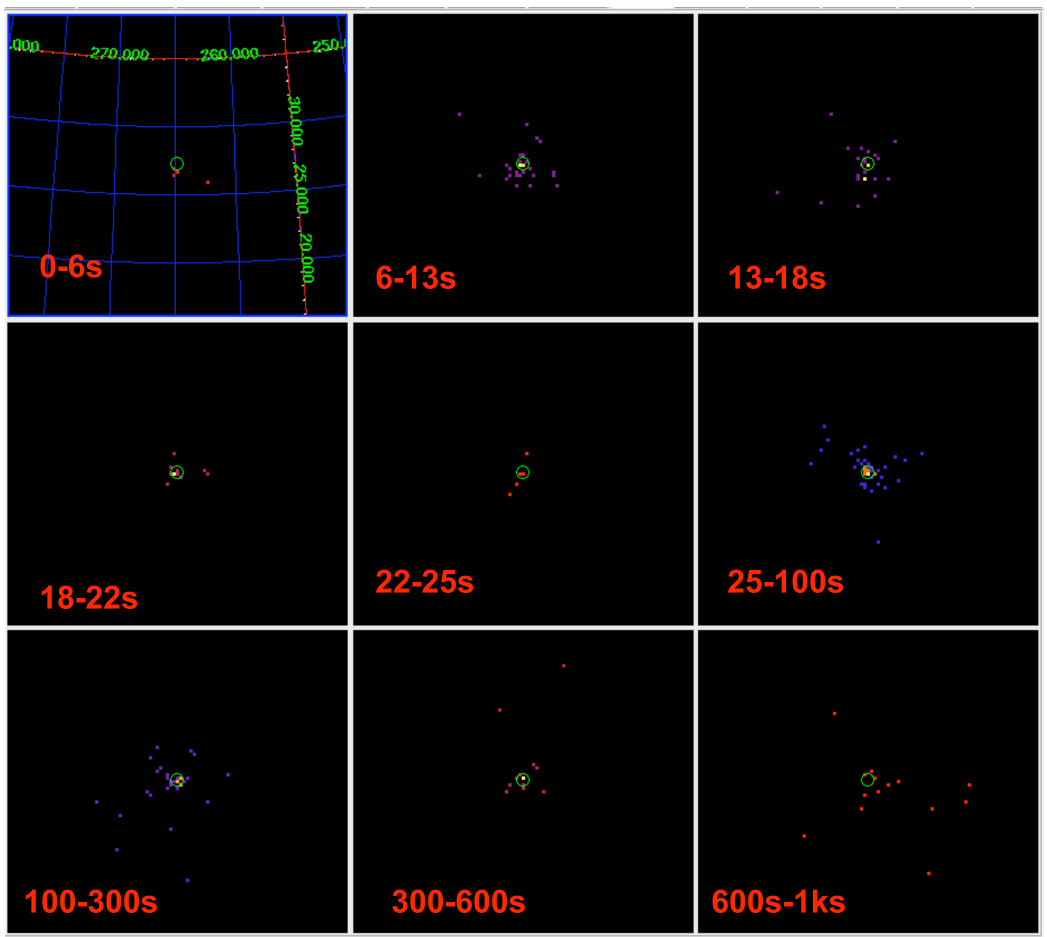
Time-resolved Spectral Fits

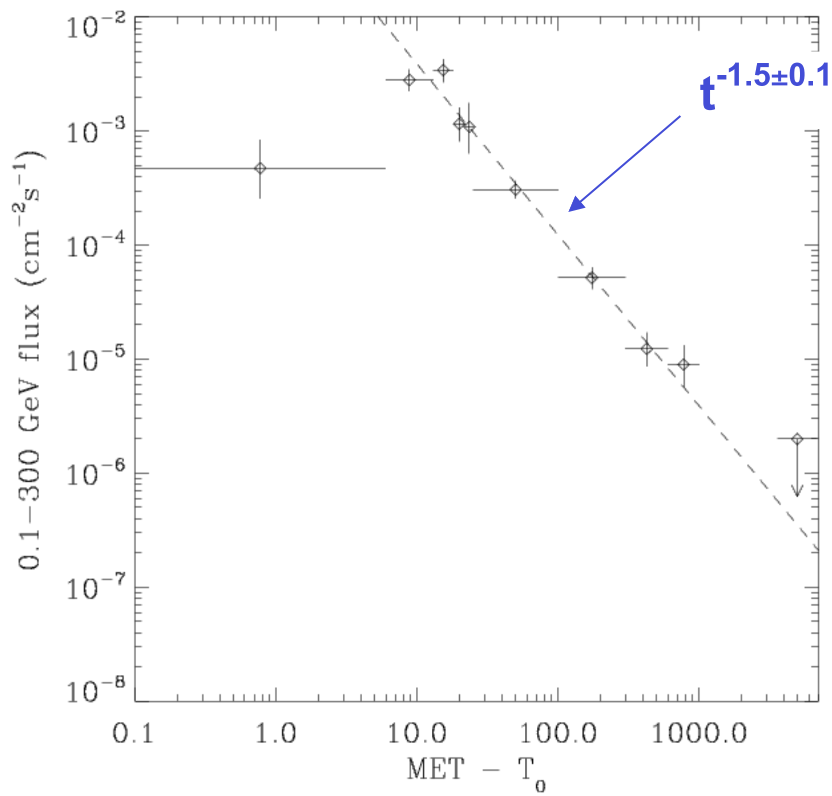
Table 1. Band function + power-law fit parameters for the time-resolved spectral fits.

Interval	Time Range (s)	E_{peak} (kev)	α	β	Γ	CSTAT/DOF	ΔCSTAT	Energy fluence ($\mathrm{erg\,cm^{-2}}$, 8 keV–30 GeV)
...	0.0–30.0	726 (±8)	-0.61 (±0.01)	-3.8 $(^{+0.2}_{-0.3})$	-1.93$(^{+0.01}_{-0.01})$	2562/963	2005	$(4.59 \pm 0.05)\times10^{-4}$
a.	0.0–4.6	526 (±12)	-0.09 (±0.04)	-3.7 $(^{+0.3}_{-0.6})$	-1.87$(^{+0.04}_{-0.05})$	901/963	43	$(3.72 \pm 0.13)\times10^{-5}$
b.	4.6– 9.6	908 $(^{+15}_{-14})$	0.07 (±0.03)	-3.9 $(^{+0.2}_{-0.3})$	-1.94 (±0.02)	1250/963	3165	$(1.44 \pm 0.03)\times10^{-4}$
c.	9.6–13.0	821 (±16)	-0.26 (±0.03)	-5.0$(^{+0.8}_{-\infty})$	-1.98 (±0.02)	1310/963	2109	$(9.42 \pm 0.24)\times10^{-5}$
d.	13.0–19.2	529 (±9)	-0.65 (±-0.02)	-3.2 $(^{+0.1}_{-0.2})$	-1.86 (± 0.02)	1418/963	199	$(1.29 \pm 0.03)\times10^{-4}$
e.	19.2–22.7	317 (±8)	-0.78 (±-0.02)	-2.4 (±0.1)	...	1117/965	...	$(4.8 \pm 0.2)\times10^{-5}$
f.	22.7–25.0	236 $(^{+25}_{-33})$	-1.30 $(^{+0.04}_{-0.03})$	-2.2 (±0.1)	...	1077/965	...	$(1.0 \pm 0.1)\times10^{-5}$
e.+f.	19.2–25.0	327 (±8)	-0.91 (±0.02)	-2.6 (±0.1)	-1.59 (±0.20)	1219/963	16	$(6.1 \pm 0.4)\times10^{-5}$
g.	25.0–30.0	...	...	...	-1.93 $(^{+0.25}_{-0.26})$	1209/967	...	$(6.8 \pm 0.8)\times10^{-6}$

- **Band component has an initial hardening then softens over course of prompt phase**
- **Power-law component index is roughly constant (Γ~1.9) through T0+19.2s, then hardens in last 6 s (Γ~1.6)**

Extended emission in LAT band

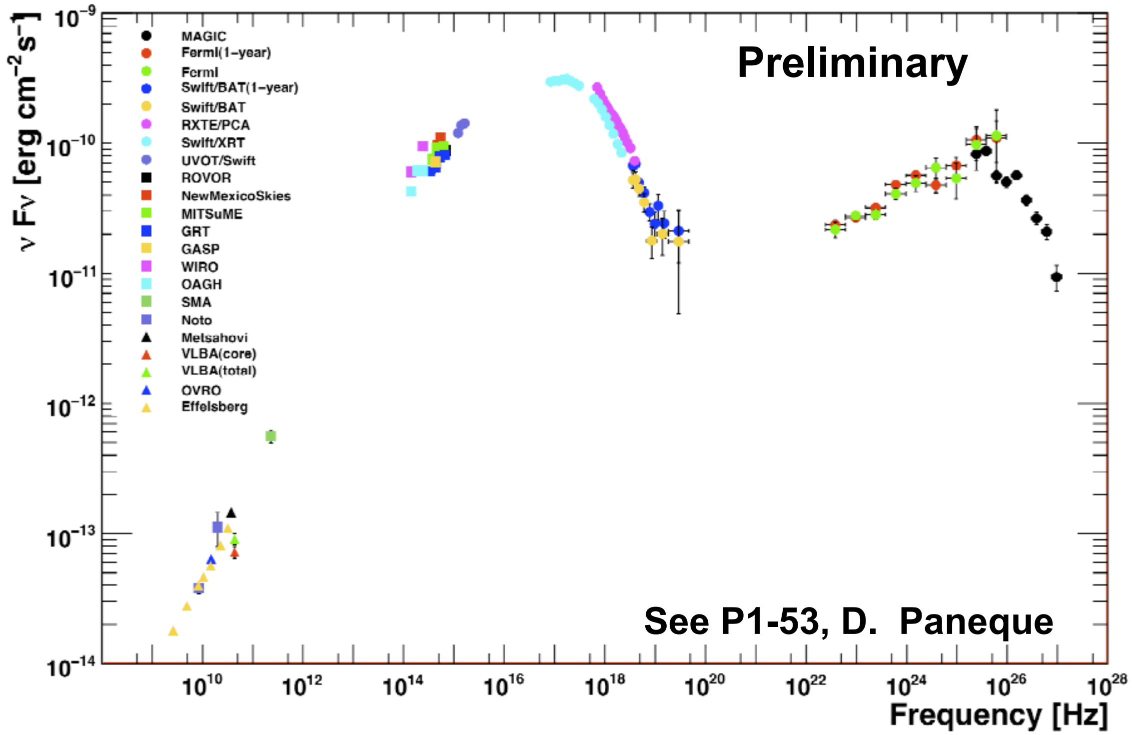




Photon index essentially constant after T0 + 25 s with Γ = -2.1

Implications for Models

- Conventional synchrotron-SSC models have difficulties producing <50 MeV power-law excess
- Syn-SSC blazar example: Mrk 421



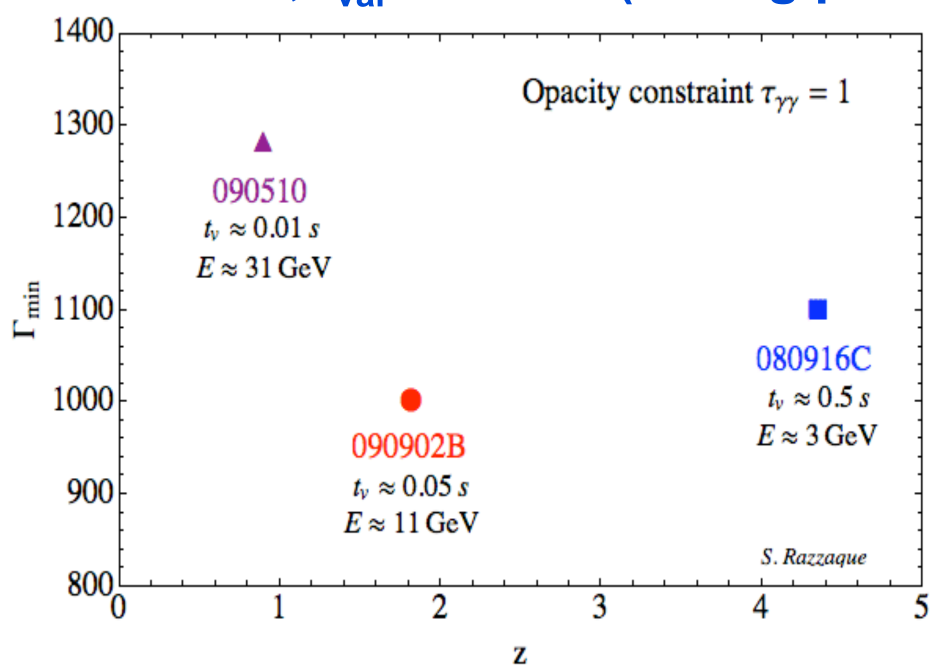
Implications for Models*

- **Alternatives to syn-SSC:**
  - **Hadronic models:**
    - **Proton synchrotron radiation (requires large B-fields)**
    - **Synchrotron by secondary pairs produced via photohadron interactions**
    - **Both scenarios require substantially more energy (1—2 orders of magnitude) than observed E_{iso} (=3.6×10^{54} erg).**
    - **Possible source of UHE cosmic rays**
  - **Early Afterglow (e+e- synchrotron from external shock)**
    - **Can also account for possible delayed (~9s) onset of power-law component**
    - **Variability time scale of 90 ms in LAT data argues against external shock**

***See P3-152 by Soeb Razzaque for more details**

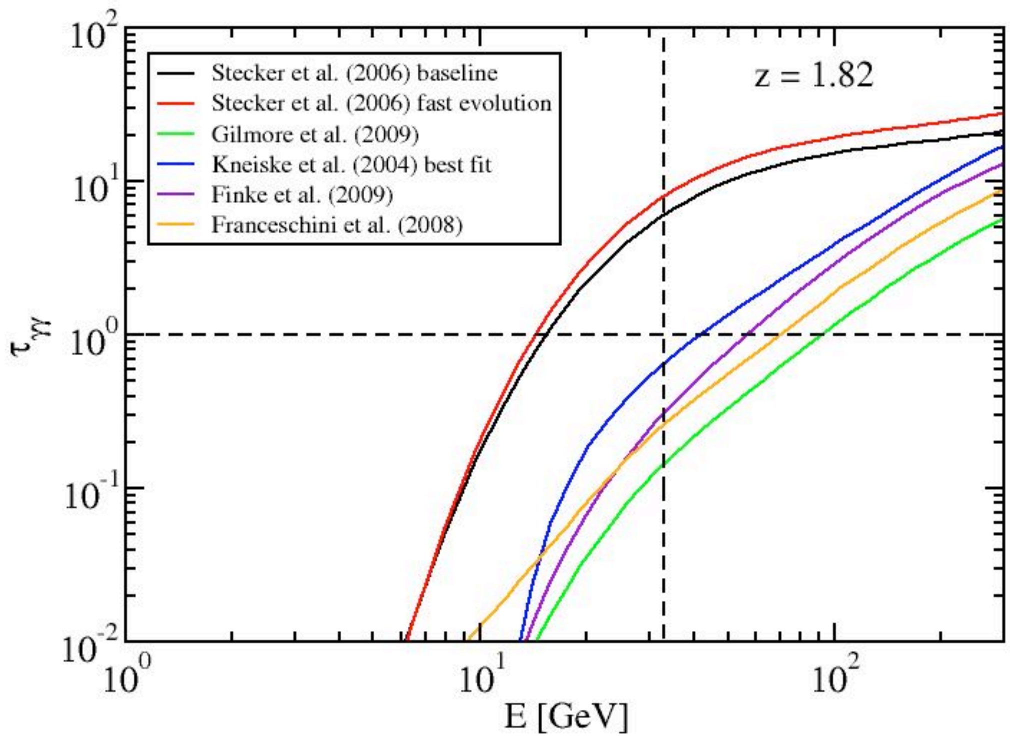
Implications for Models

- **Extended Emission (after T_0 + 30s):**
  - Afterglow synchrotron interpretation has difficulty explaining 33.4 GeV photon at T_0 + 82s
  - Photon index of -2.1 may pose difficulties for afterglow SSC emission
- **Constraints on Γ_{min}:**
  - E_{max} = 11.16 GeV, t_{var} = 51 ms (during prompt phase)

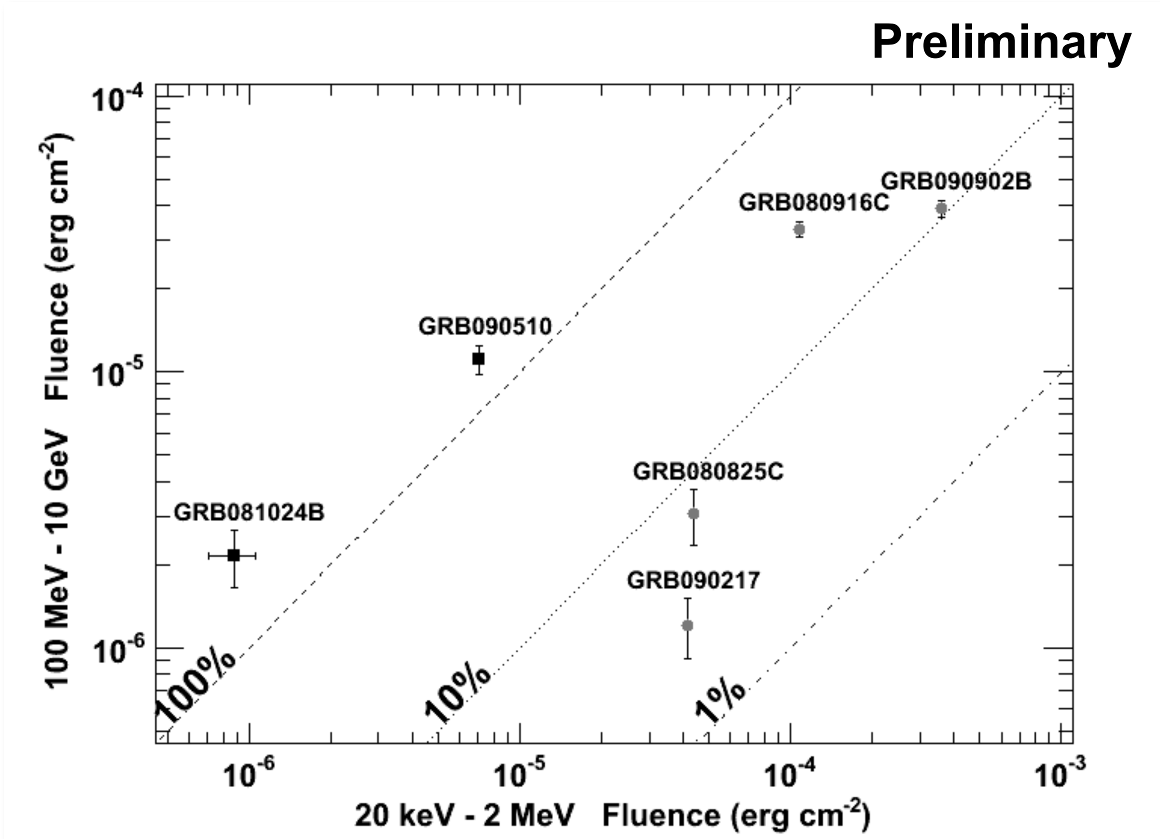


Implications for Models

- **EBL constraints: most models optically thin except "baseline" and "fast-evolution" models of Stecker et al 2006**
- **From analyses of MC sims, extrapolating the lower energy power-law, with and without absorption, these models are disfavored at >3σ level**



LAT Fluence vs GBM Fluence



- **Suggests that short and long could have different efficiencies for emitting gamma rays**

Summary

- One of the most luminous bursts seen by the LAT: $E_{iso}=3.6\times10^{54}$ erg
- Hard additional power-law component in the LAT band that extrapolates down to < 50 keV
  - Poses serious challenges for syn-SSC models
- PL/(Band + PL) fluence ratio: 24%
- Highest photon energy from a GRB: 33.4 GeV
- Extended emission out to 1ks, $\sim t^{-1.5}$ decline
- Γ_{min} = 1000
- z = 1.822 and E_{max} = 33.4 GeV constrains EBL models