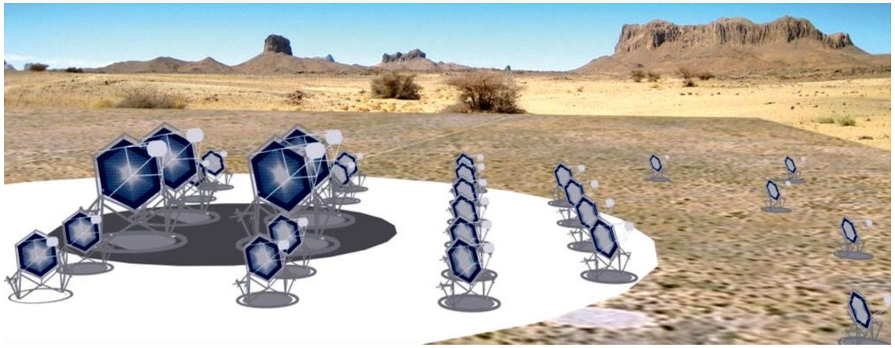
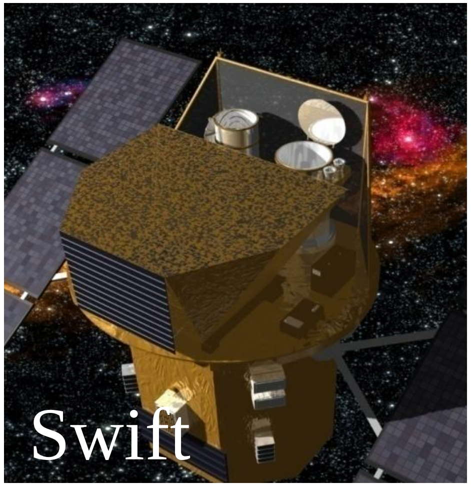
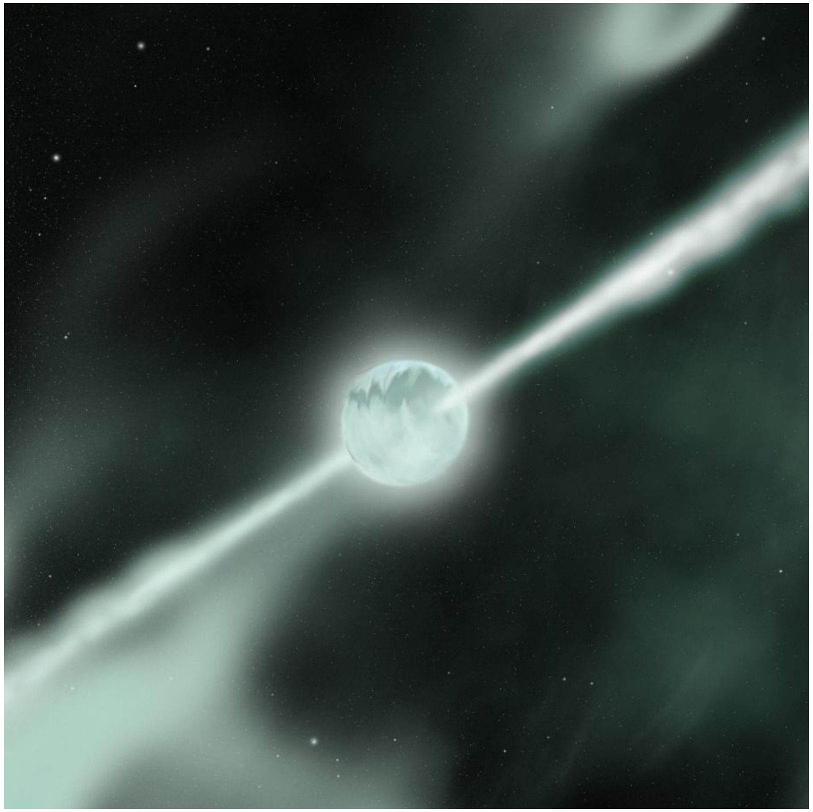
Studies of Gamma-Ray Bursts



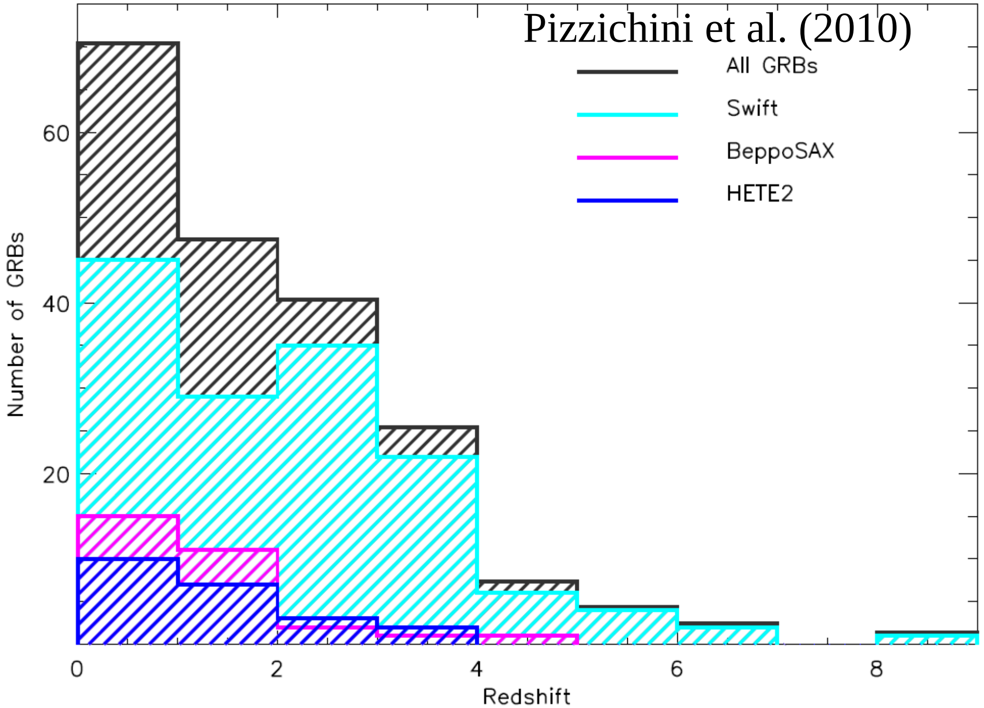




Paul O'Brien

(with thanks to Abe Falcone, Andreas von Kienlin and Jim Hinton)

GRB redshift and luminosity



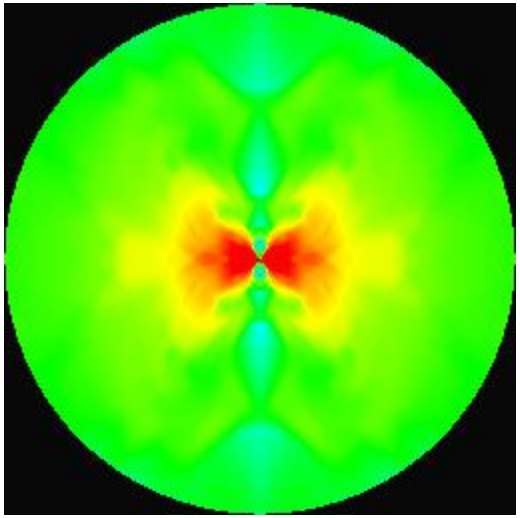
Average Redshift
- Pre-Swift: z ~ 1.2
- Swift: z ~ 2.3
- Highest z = 8.2

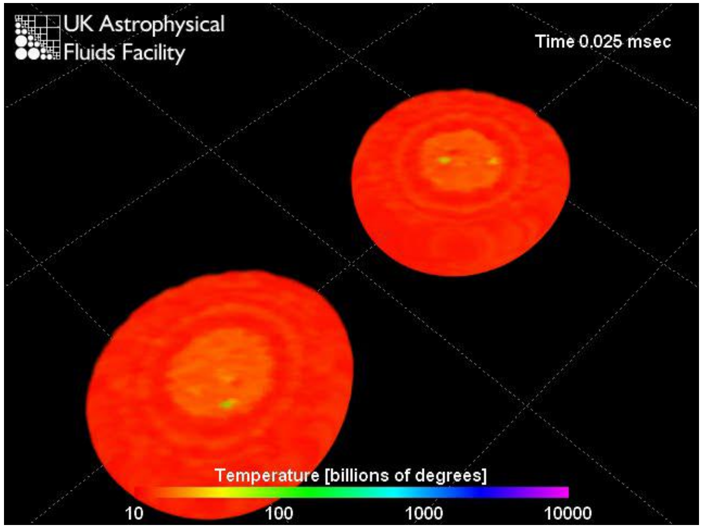
Isotropic Luminosity up to 10^{54} erg

Beaming corrected (?) ~$10^{51\text{-}52}$ erg

(N.B. this is only the radiation – more energy in neutrinos and gravity waves)

Long and short GRB models (plus others)





- Long GRBs (T_{90} >2s)
- Massive WR star (>30 $M_\odot$)
- Star-forming galaxy (young)
- Get Supernova + feeding Black Hole (accertion rate ~ 0.1 $M_\odot$ s^{-1})

- Short GRBs (T_{90} <2s)
- NS-NS merger (msec) $\Rightarrow$ BH
- Can occur in any type of galaxy
- Dynamical "kick" may cause merger to occur far from the original location

The Fireball-shock model

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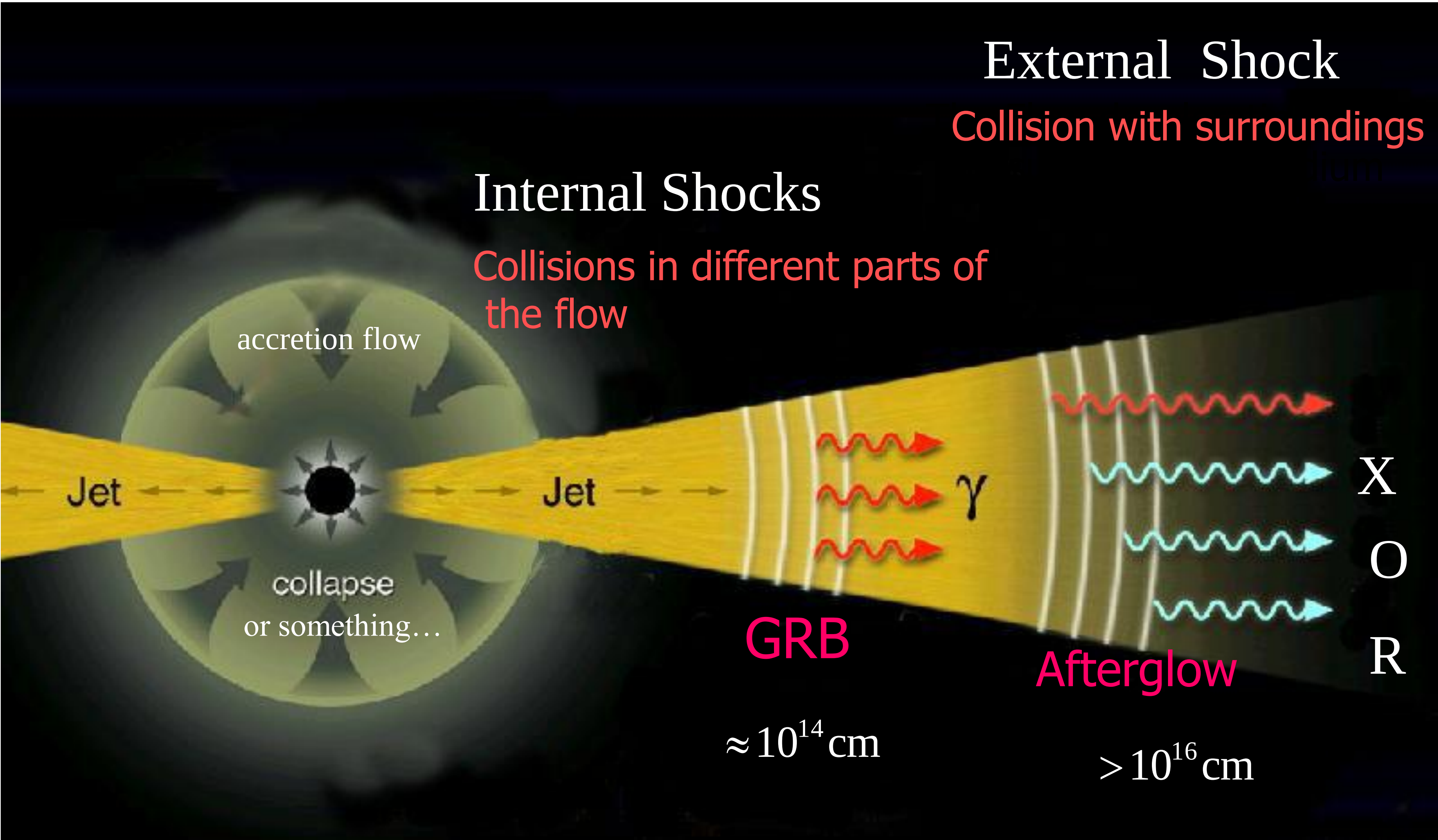
Ultra-relativistic expanding fireball-shock model ➔ evolving synchrotron spectrum



Swift era X-ray light curves

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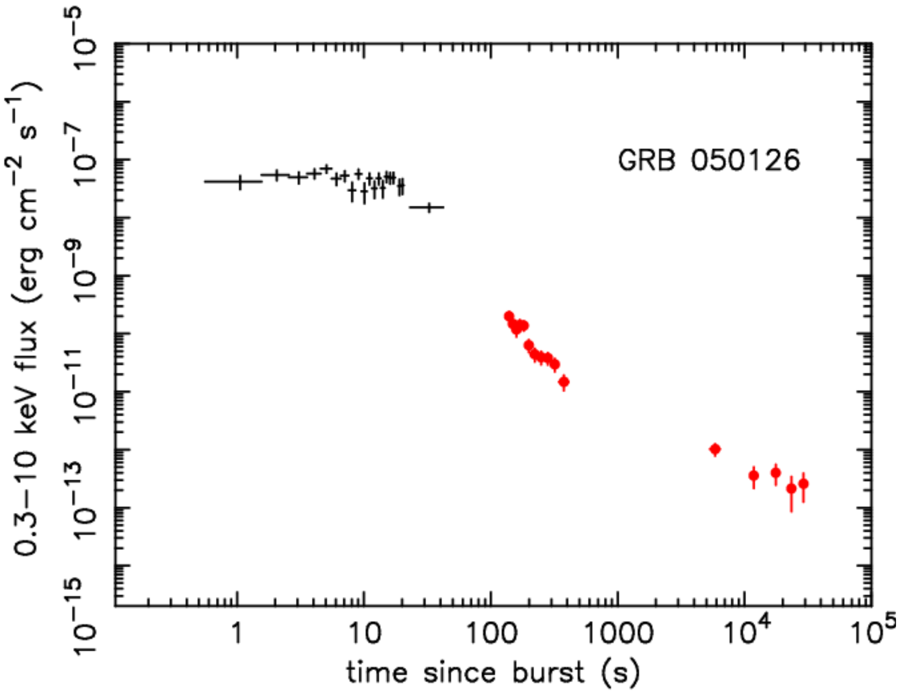

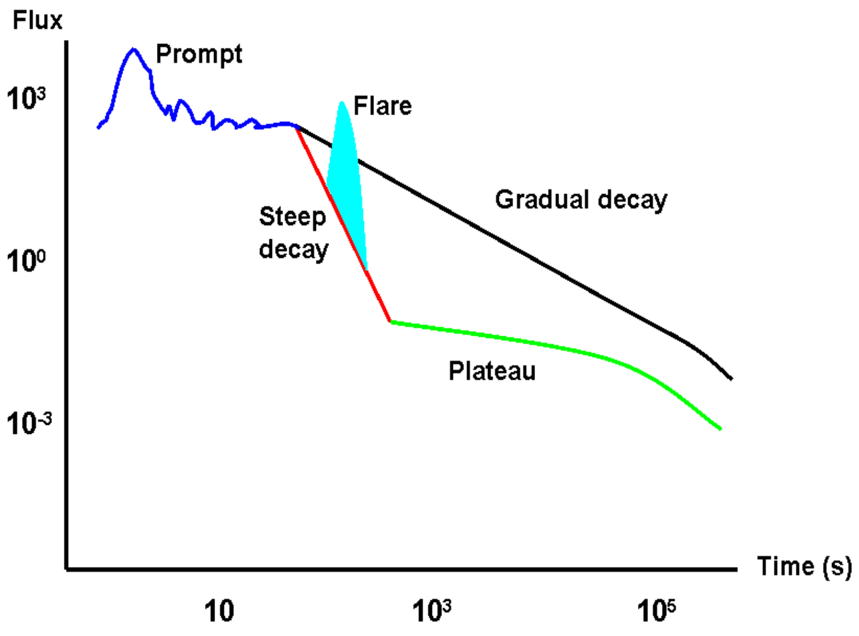

Complex light curve shapes imply we are observing a mixture of several “internal” and “external” processes (Nousek et al. 2006; O’Brien et al. 2006…)

- Fast decay and flares appear internal – engine dominated (lifetime unclear)
- Slow decays and plateau external – afterglow dominated (late engine activity?)

Why Study GRBs at VHE?

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- Luminous high-energy sources – prompt spectra peak up to several MeV
- VHE seen (e.g. EGRET detections and Fermi/LAT (GeV) from 100s – 1000s)
- Need to understand acceleration mechanisms in jets: energetics, bulk Γ, emission radius, hence constrain accretion, progenitors, environment…
- VHE and neutrinos can distinguish between:
  - Hadronic process (protons/ions radiate or produce pions that decay to give pair cascades and emission by secondary particles) – dominates if $\varepsilon_e << 1$
  - Leptonic process (mainly synchrotron, IC and SSC emission)
- Ultra high energy cosmic rays (UHECR) – proton energies up to ~10^{20} eV
- Probe extragalactic IR background via attentuation of VHE (pair production)
- Constrain Lorentz violations (but complicated by intrinsic energy lags)

Example: afterglow vs. prompt

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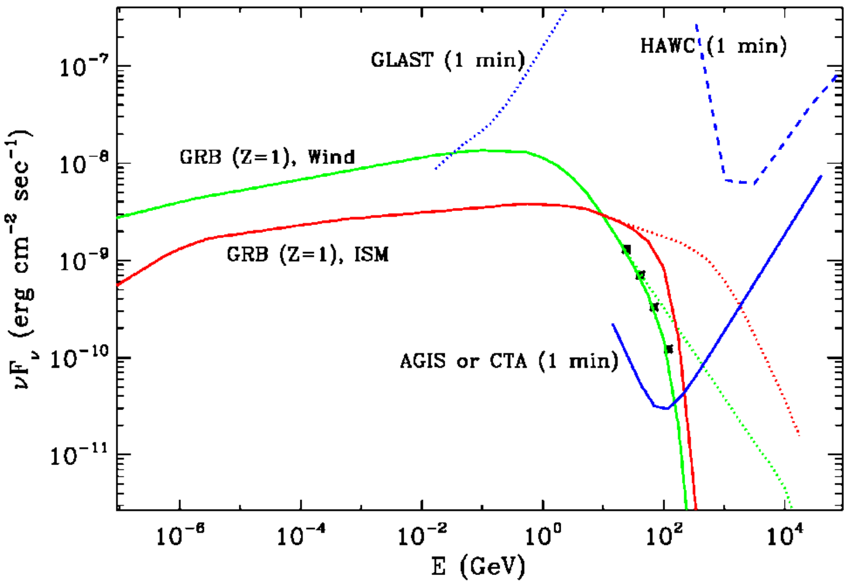

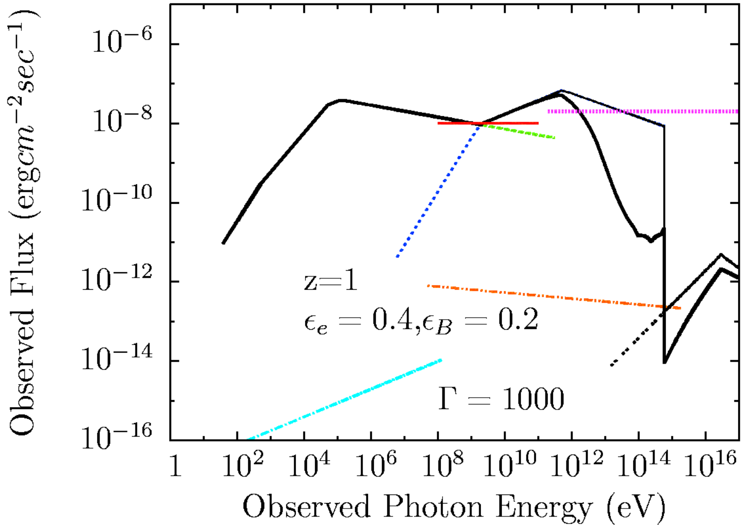

Taken from Falcone et al. (2009), using re-scaled forward shock model from Pe′er & Waxman (2005). Black boxes are CTA simulated independent spectral points.

Gupta and Zhang (2007) prompt emission model for a 10^{51} erg GRB at z=1.

Afterglow Emission

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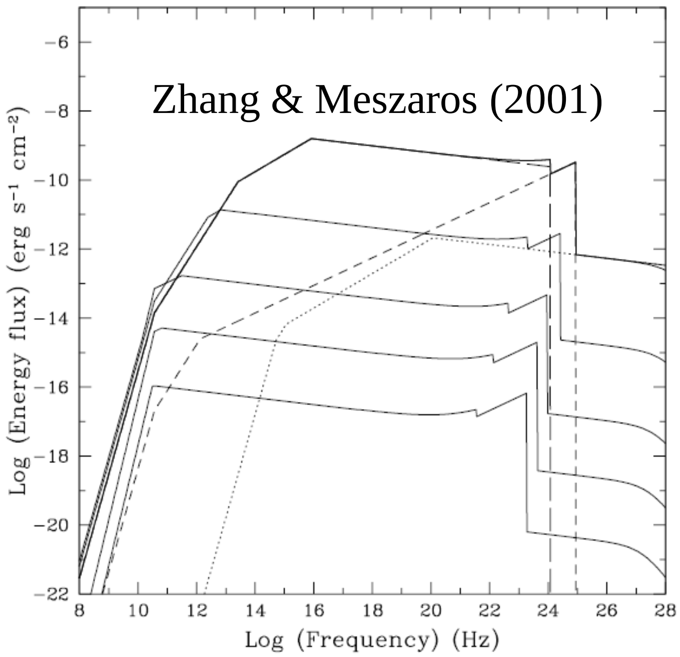
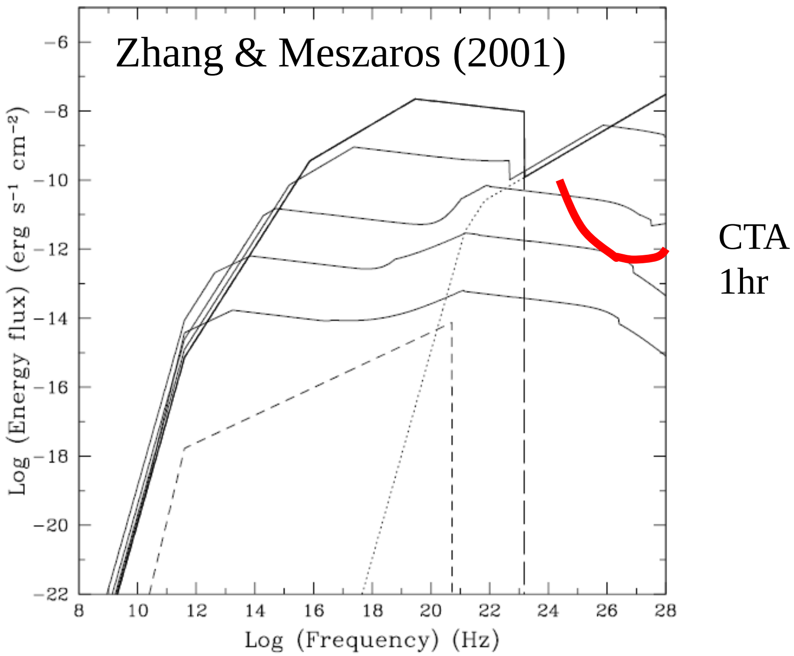
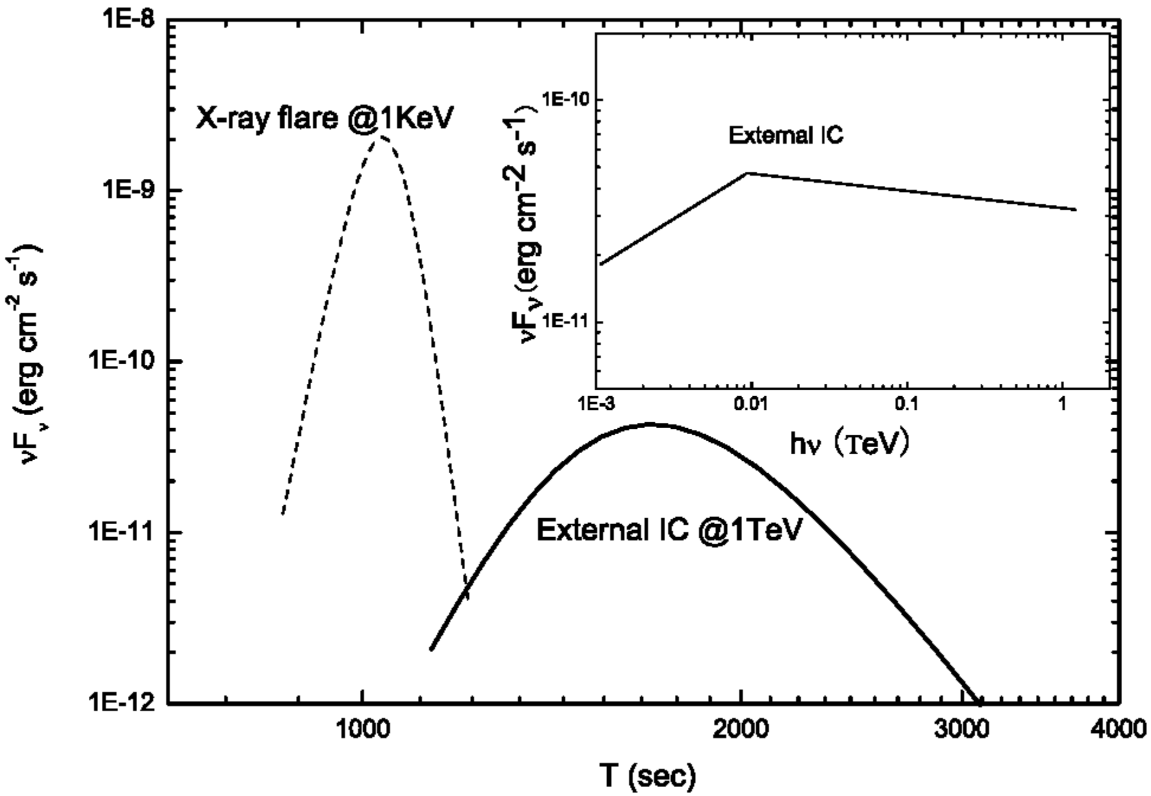




Comparison of two afterglow models (solid curves: prompt, 1min, 1hr, 1d, 1month):

Left: Proton-synchrotron (short dash) overcomes e-synchrotron (long dash).
Right E-synchrotron (long dashed) and e-IC (dotted) with latter dominating .

Example: Flares



Brightest X-ray flares have as much fluence as prompt GRB. [typically ~10%]

CTA limit ~8x10^{-13} erg cm^{-2} s^{-1} at 1TeV in 1hr.

Taken from Falcone et al. (2009, APS White paper). Luminous flare (E_{iso} =10^{53} erg) assumed to arise ~10$^{28.5}$cm from source)

1 Year+ of Fermi GRBs

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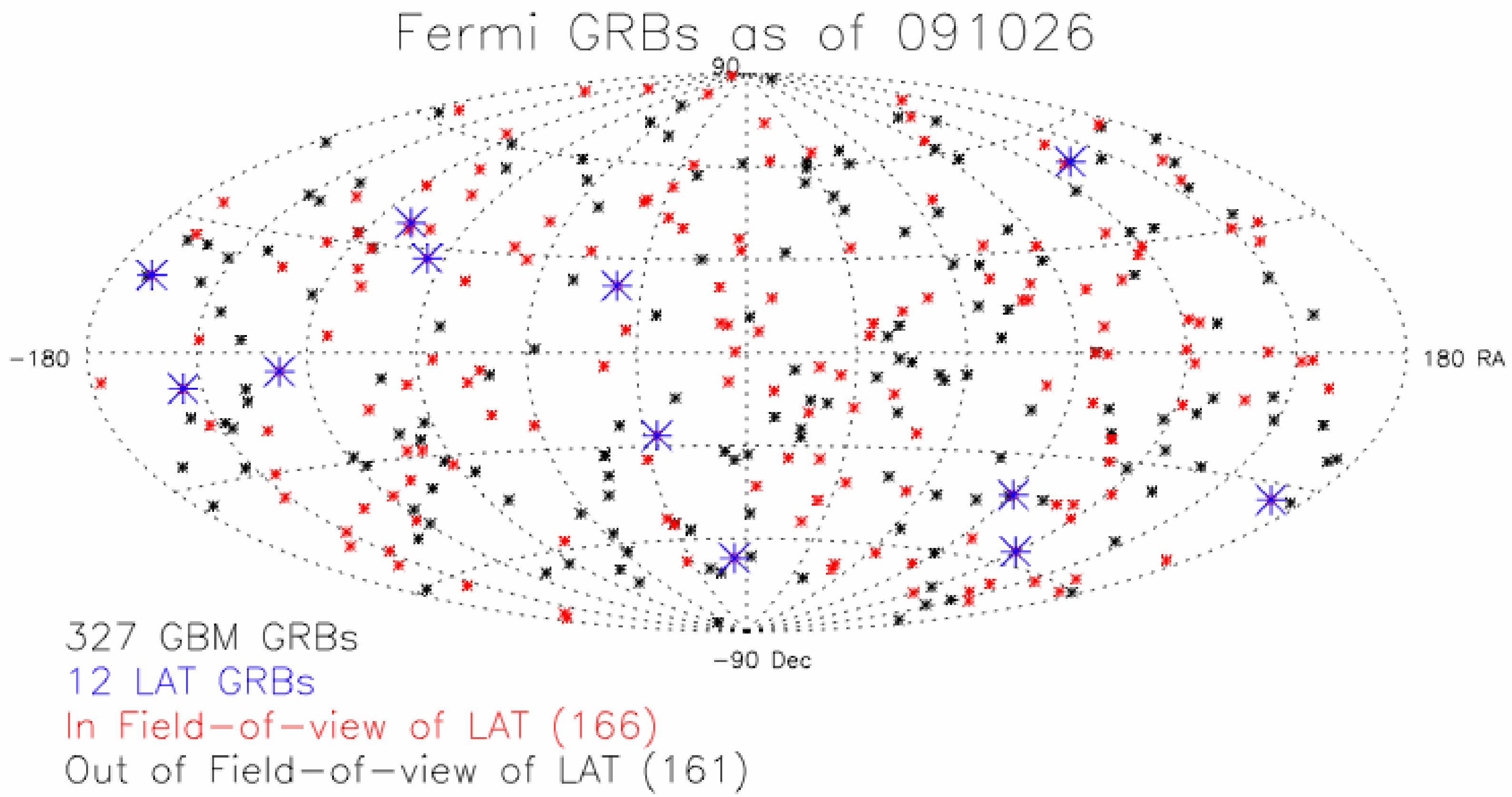

V. Connaughton

Today: 387 GBM GRBs
14 LAT GRBs

Abdo et al., (2009)

GRB 080916C

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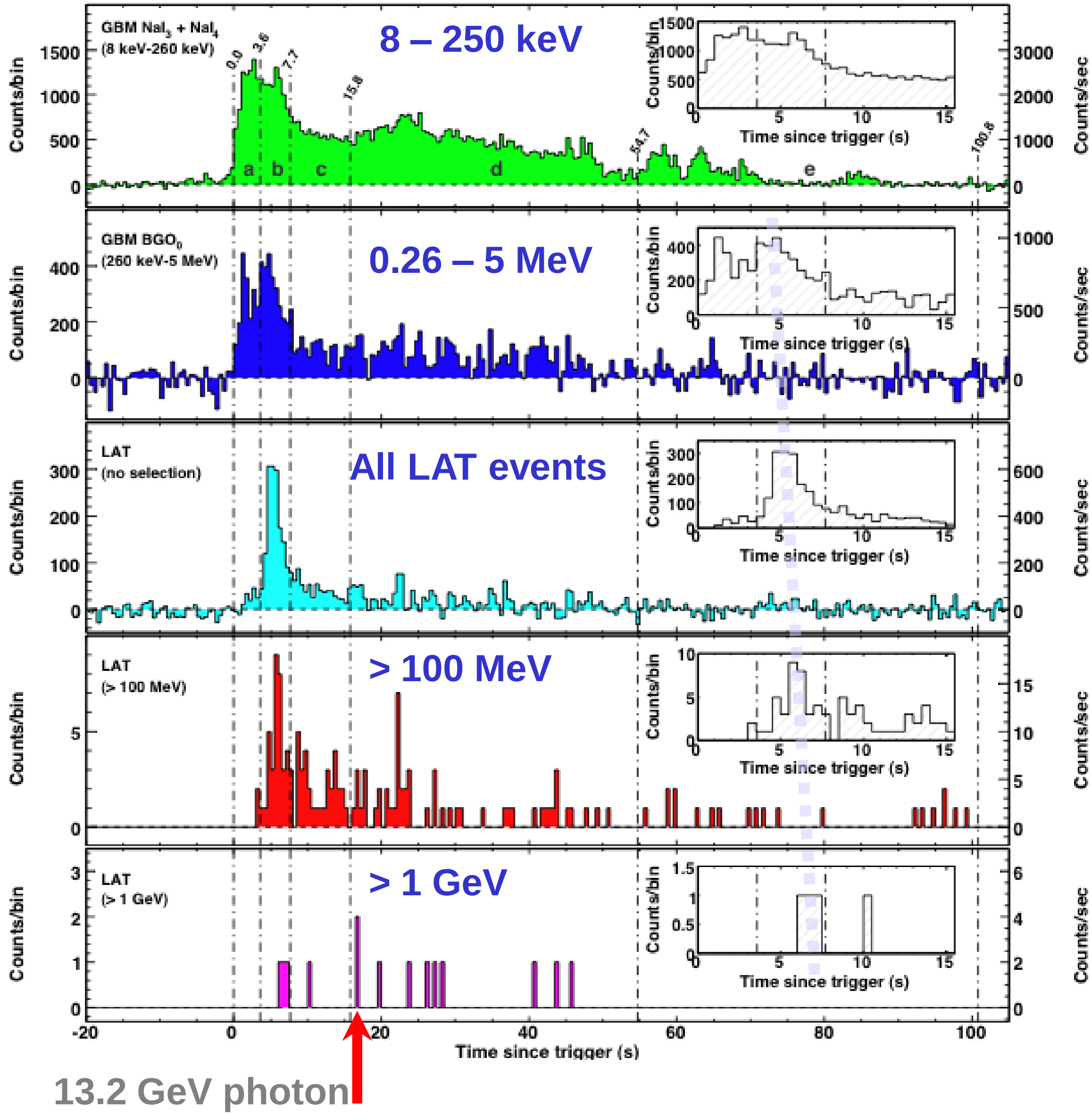
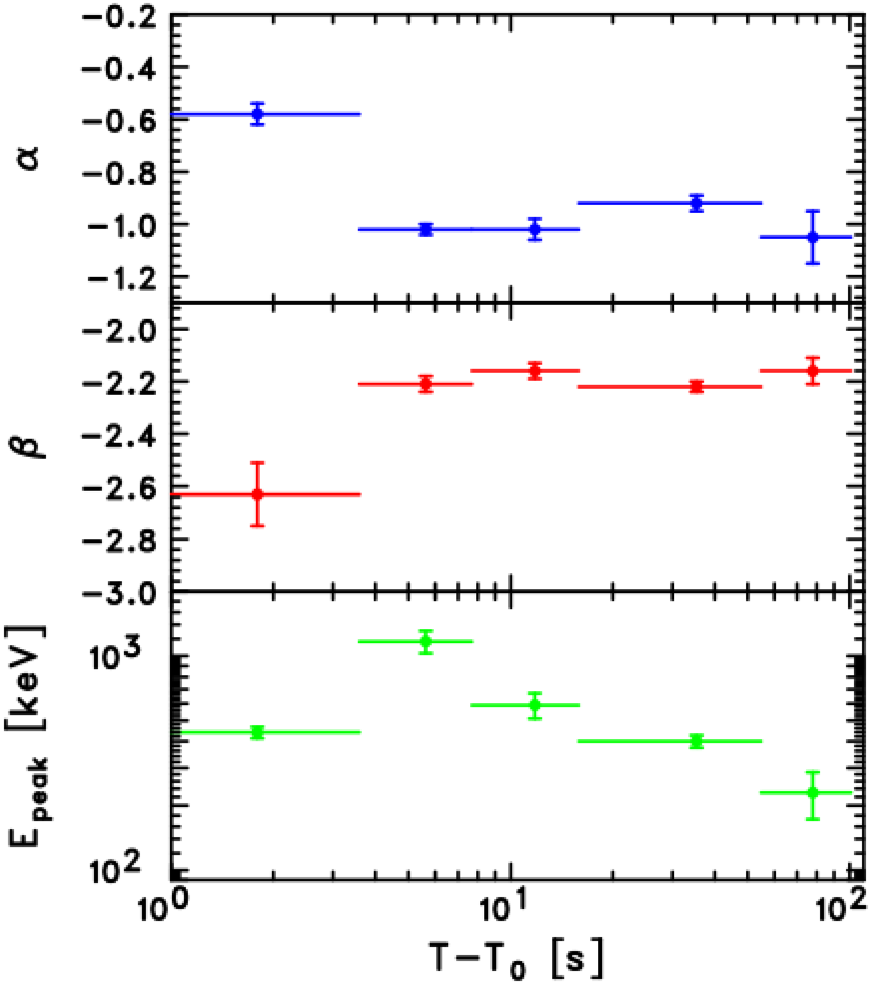
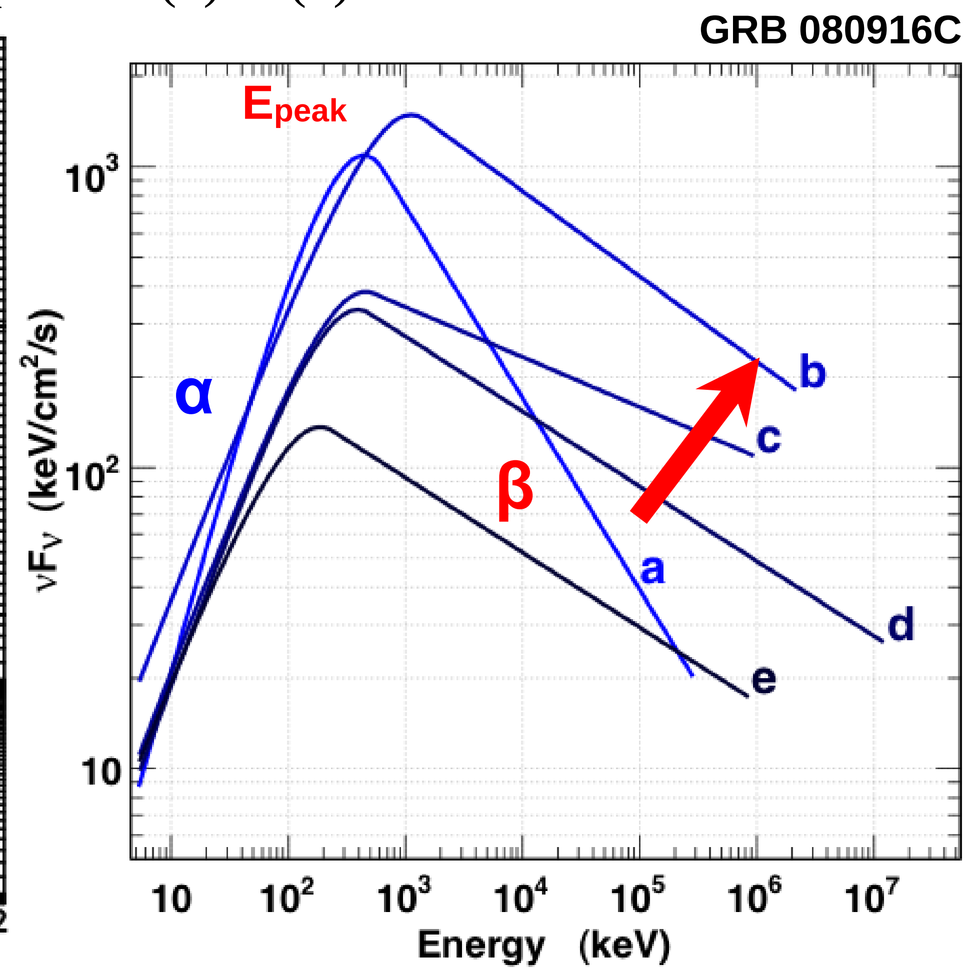
- z=4.35 GRB
- Start of HE emission delayed relative but detected for longer.
- Simple spectrum (Band function) but evolves.
- No spectral cutoff or extra components (SSC or thermal)
- Derive bulk Γ~4-900) (assuming low-energy seed ,expand region to prevent pair production)



Spectral Evolution of GRB 080916C

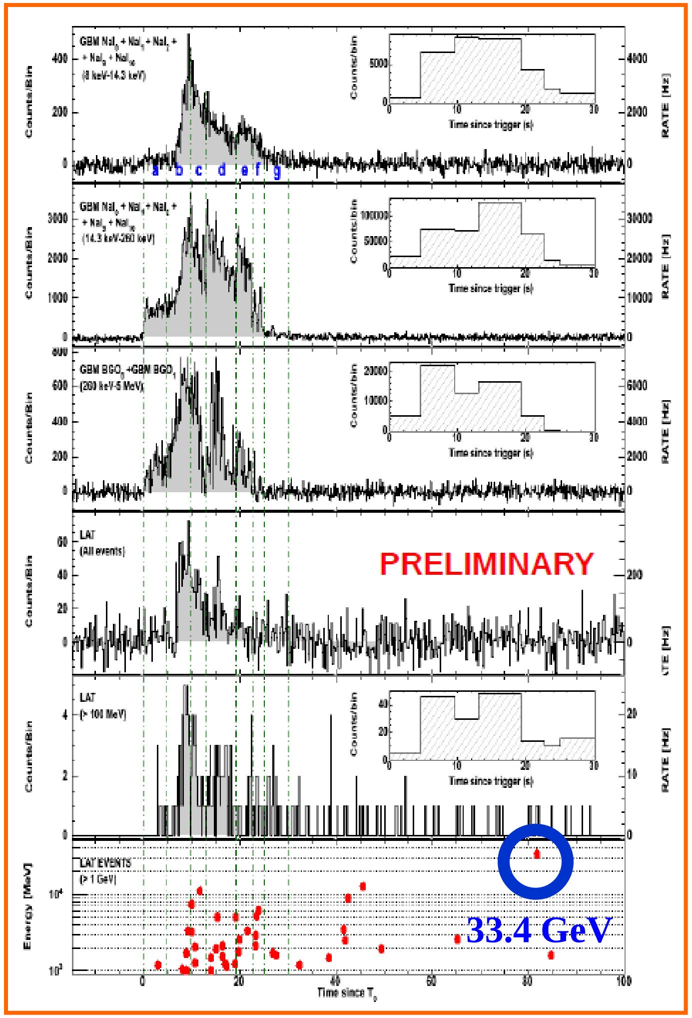
- Rapid soft to hard evolution in periods (a) to (b)
- Gradual decrease of E_{peak} from periods (b) to (d)

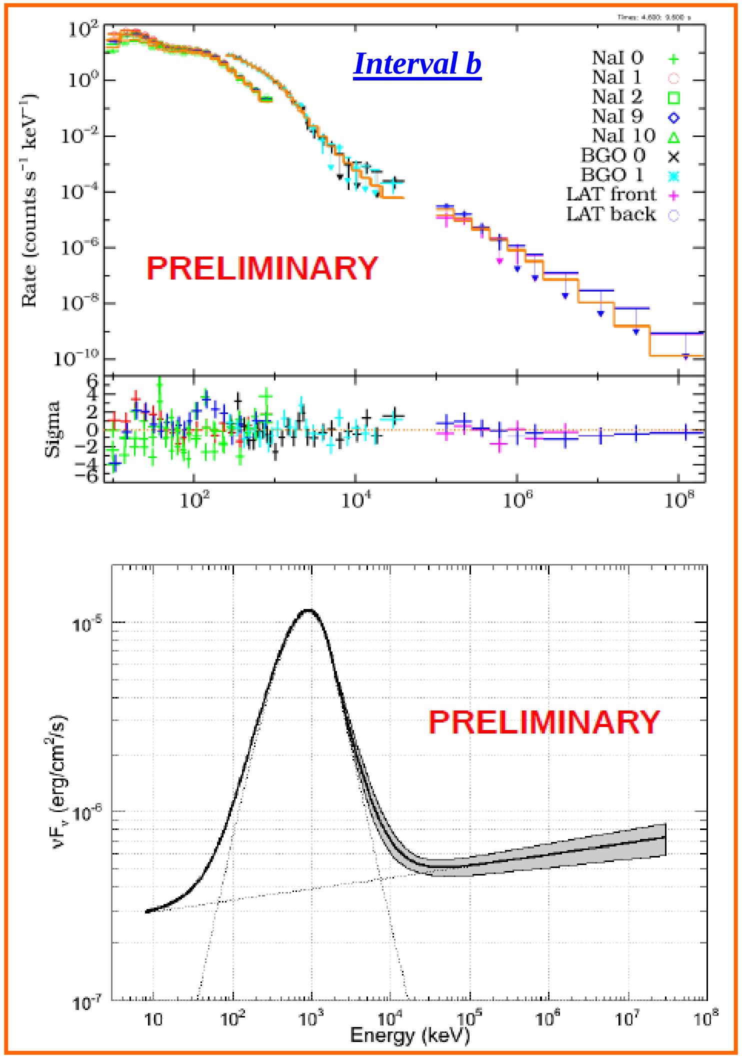




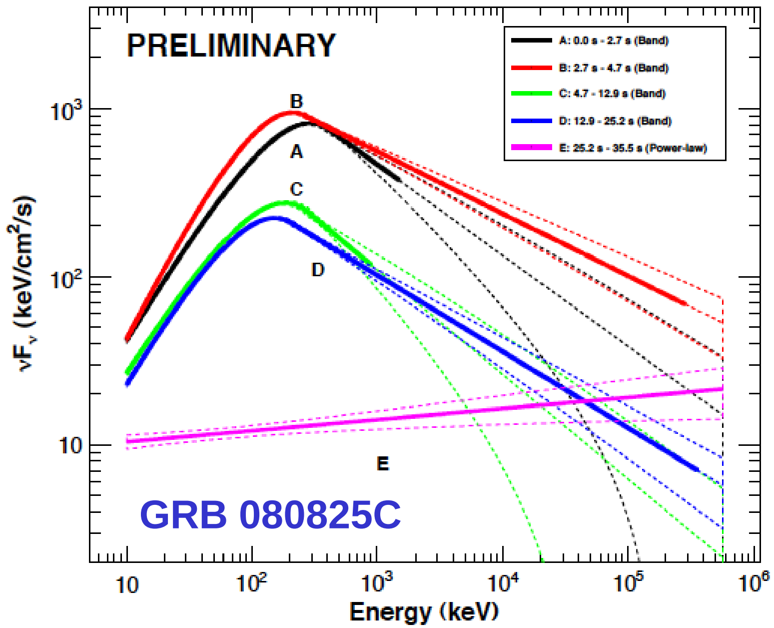
Fermi Observations of GRB 090902B (z=1.822)

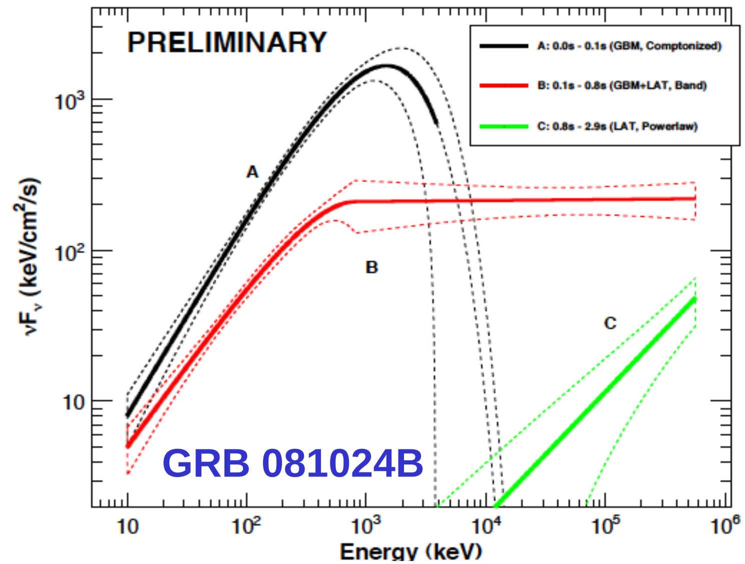
Bissaldi et al (2009)

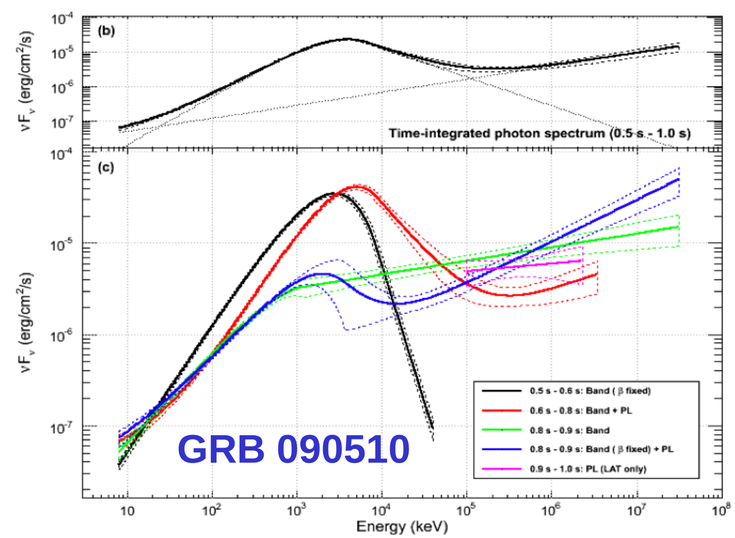




Spectral Evolution of Other LAT GRBs







- Some trends
  - Soft to hard evolution
  - Long-lived HE emission
  - “Extra component” @ HE
    - GRB090510, GRB090902B

Long-Lived HE Emission in Other LAT GRBs

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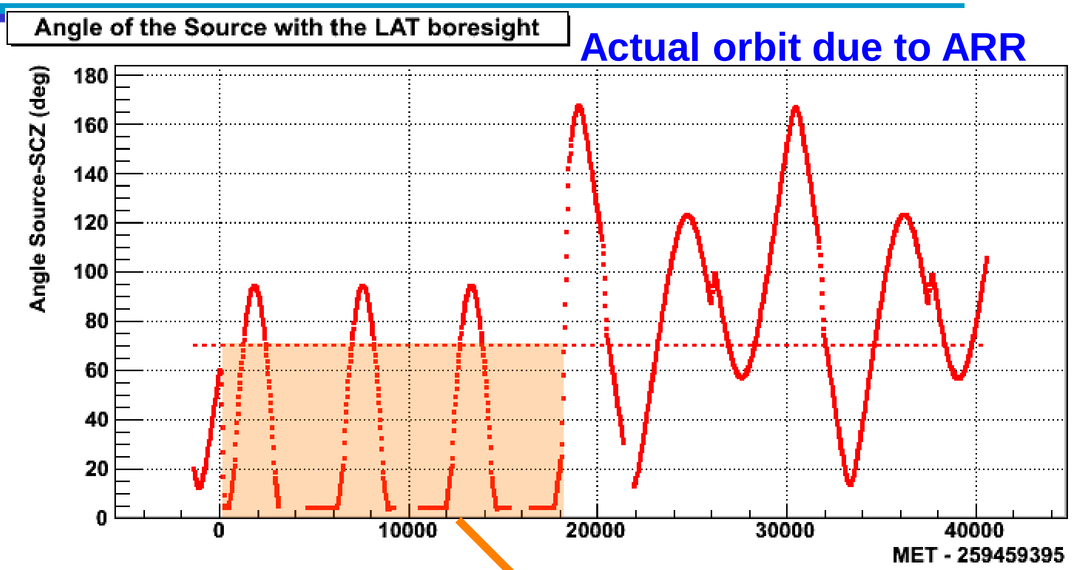
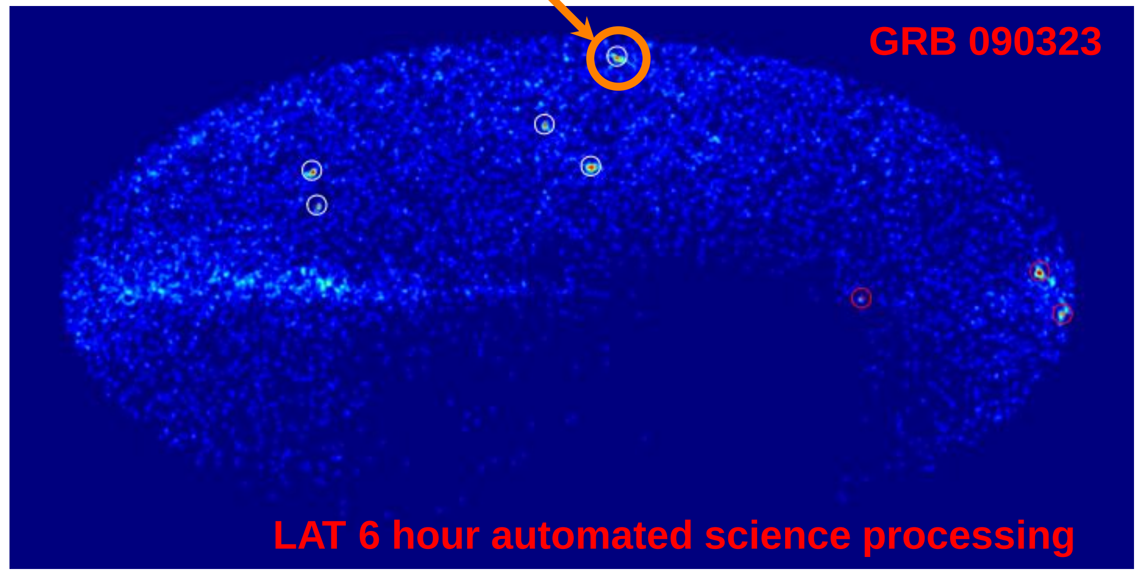
- GRB 090323
  - HE emission up to a few GeV lasted ~2000 s.
  - Made possible by ARR (autonomous repoint recommendation) by GBM
    - Otherwise GRB would have been out of FOV
- GRB 090328
  - HE emission lasted ~900 s
  - ARR was also issued





Summary of LAT Bursts

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GRB	duration	# of events > 100 MeV	# of events > 1 GeV	delayed HE onset	Long-lived HE emission	Redshift
080825C	long	~10	0	✔	✔	
080916C	long	~150	>10	✔	✔	4.35
081024B	short	~10	2	✔	✔	
081215A	long	—	—	—	—	
090217	long	~10	—	—	—	
090323	long	~20	>0	—	✔	3.57
090328	long	~20	—	—	✔	0.736
090510	short	>50	>10	—	✔	0.903
090626	long	~20	—	—	✔	
090902B	long	>200	>30	✔	✔	1.822

Does CTA need accurate GRB locations for blind pointing?

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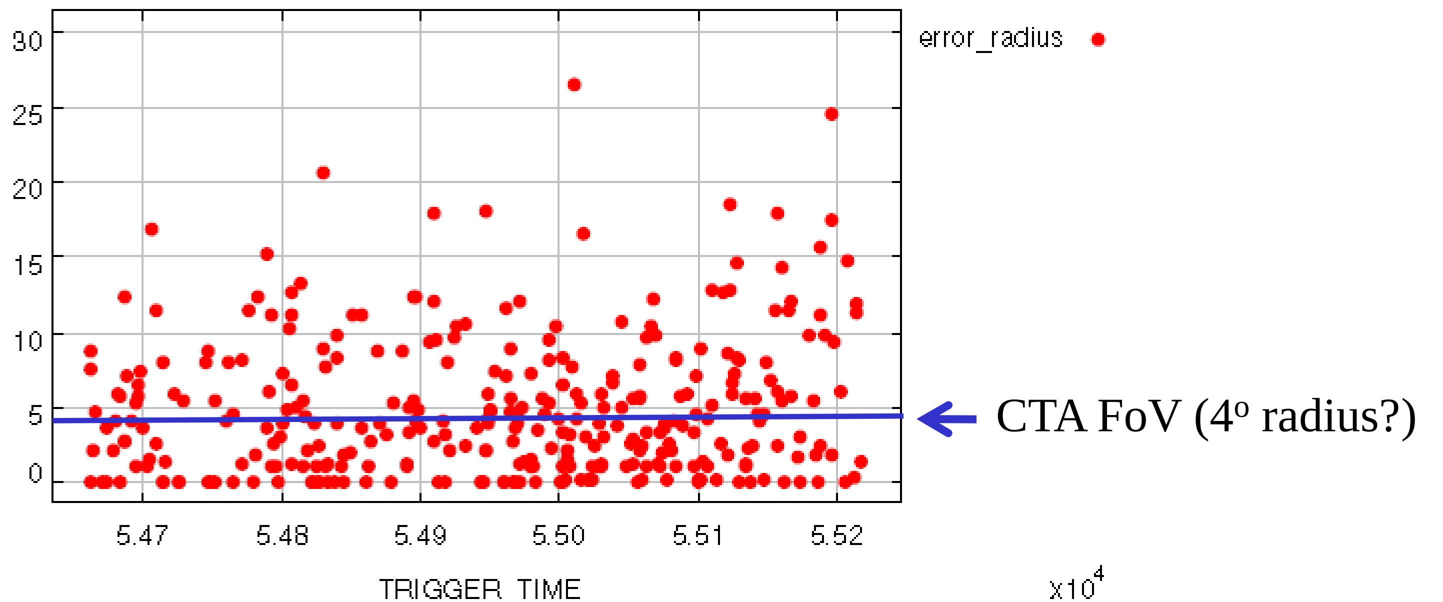
Swift BAT errors <3 arcmin radius so can blind point at all of them

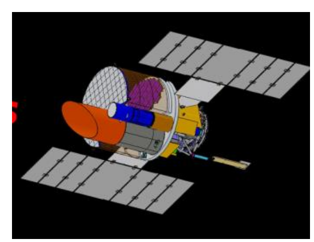
What about Fermi/GBM? Using Fermi GBM Burst catalog for GRBs with reliability >80% all sky. [error radius assumed to be 90%]

- 324/326 GRBs plotted
- 194 GRBs have error radius <5 deg. (~60%)
- 277 GRBs have error radius <10 deg. (~85%)

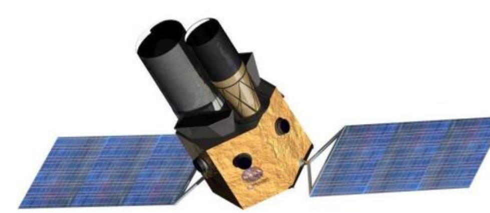


Conclusions

- Detection of VHE emission from GRB prompt or afterglow emission would constrain GRB prompt and afterglow models
- Given the low duty cycle and sky coverage, it will be important to point at every available GRB – you will get lucky!
- What prompt response time is required? Answer: as fast as possible (>slew speed of several degrees per second)
- Late time observations also valuable (more potential targets and perhaps filter on best chance cases)
- Future GRB missions...(i.e. there will be targets to look at)



EXIST



XENIA