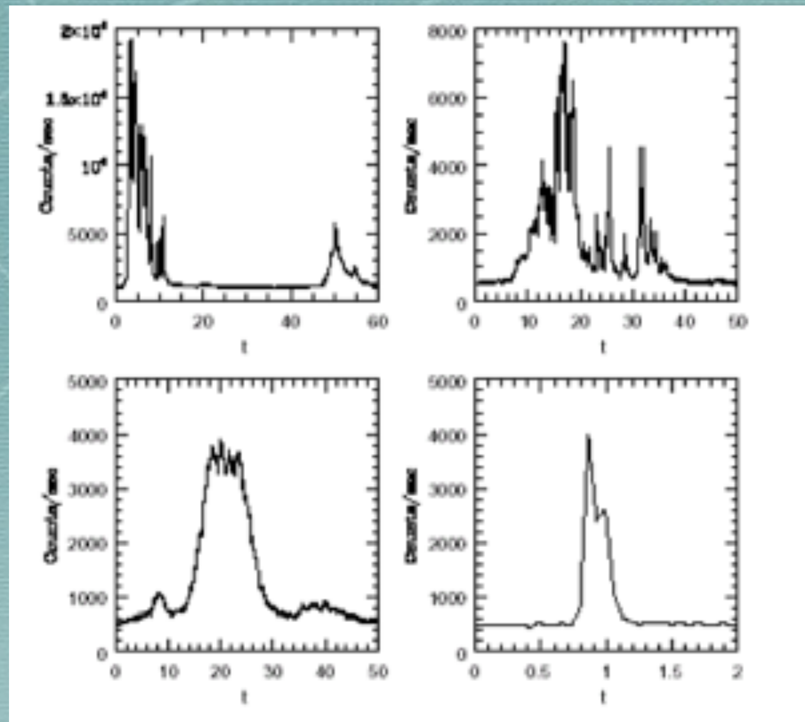
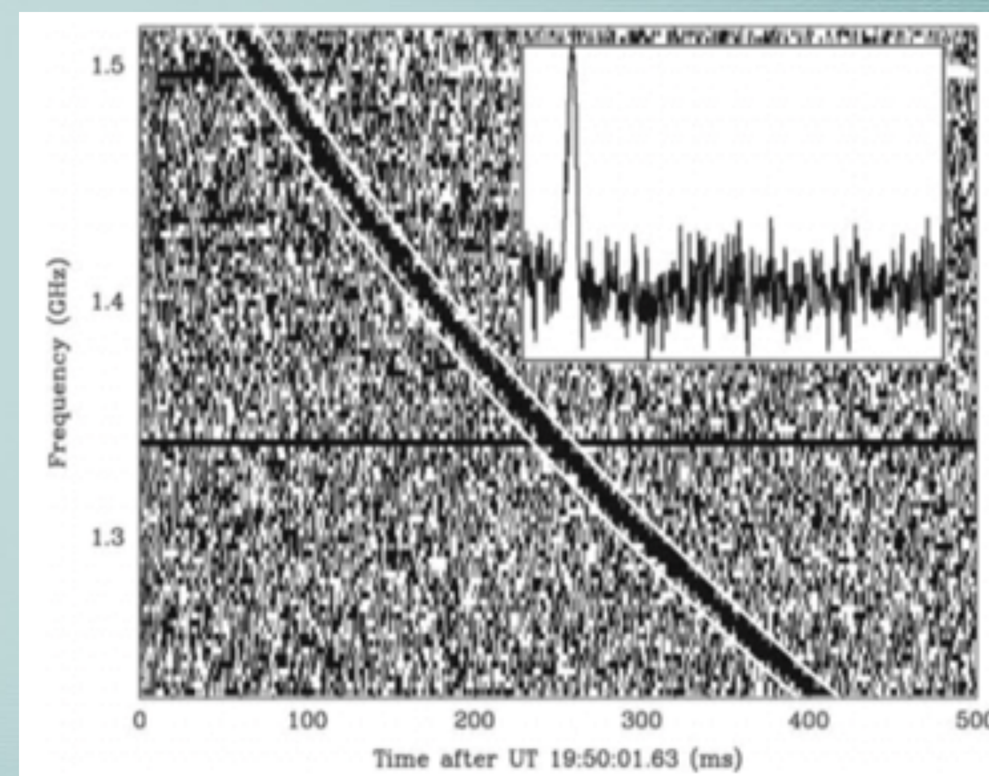


1. GAMMA-RAY BURSTS
&
2. FAST RADIO BURSTS



WITH

CTA

TAM, Pak Hin
(Sun Yat-sen University/ICRR)

GAMMA-RAY BURST OBSERVATIONS WITH CTA

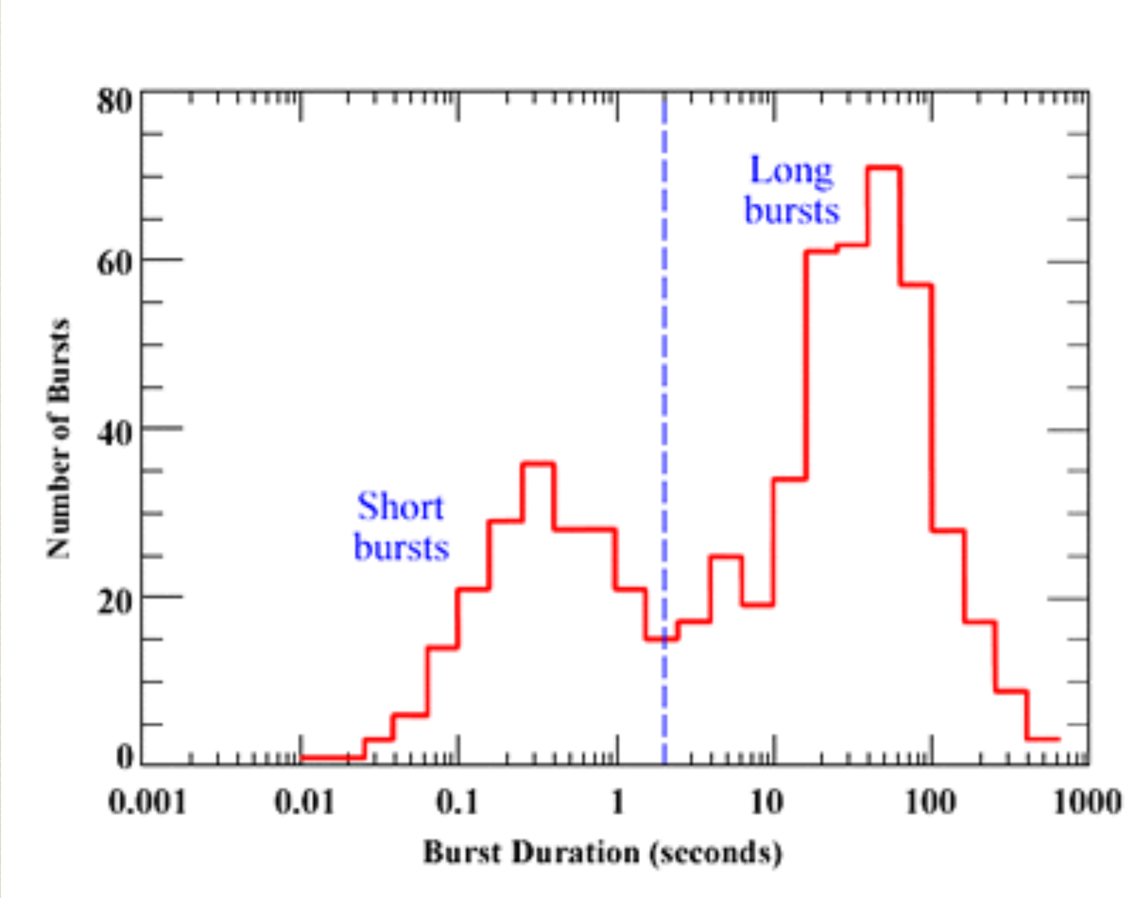
LESSONS LEARNT FROM FERMI/LAT

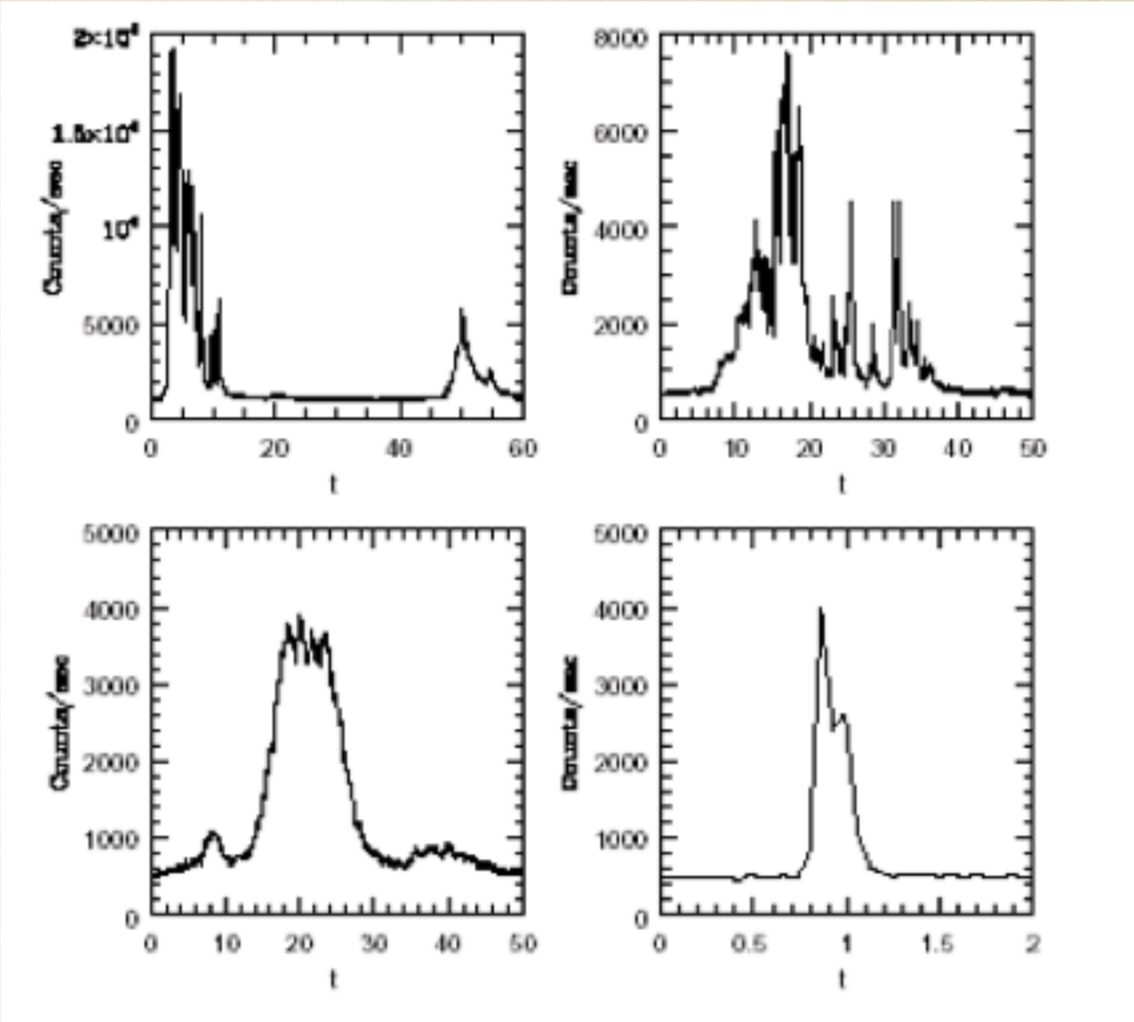
TAM, Pak Hin (Sun Yat-sen University/ICRR, U Tokyo)

Kashiwanoha, ICRR
15/12/2016

What are GRBs?

* Intense bursts of gamma-rays
* Duration: ~10ms - hundreds of seconds
* happen at a random position on the sky
never repeat





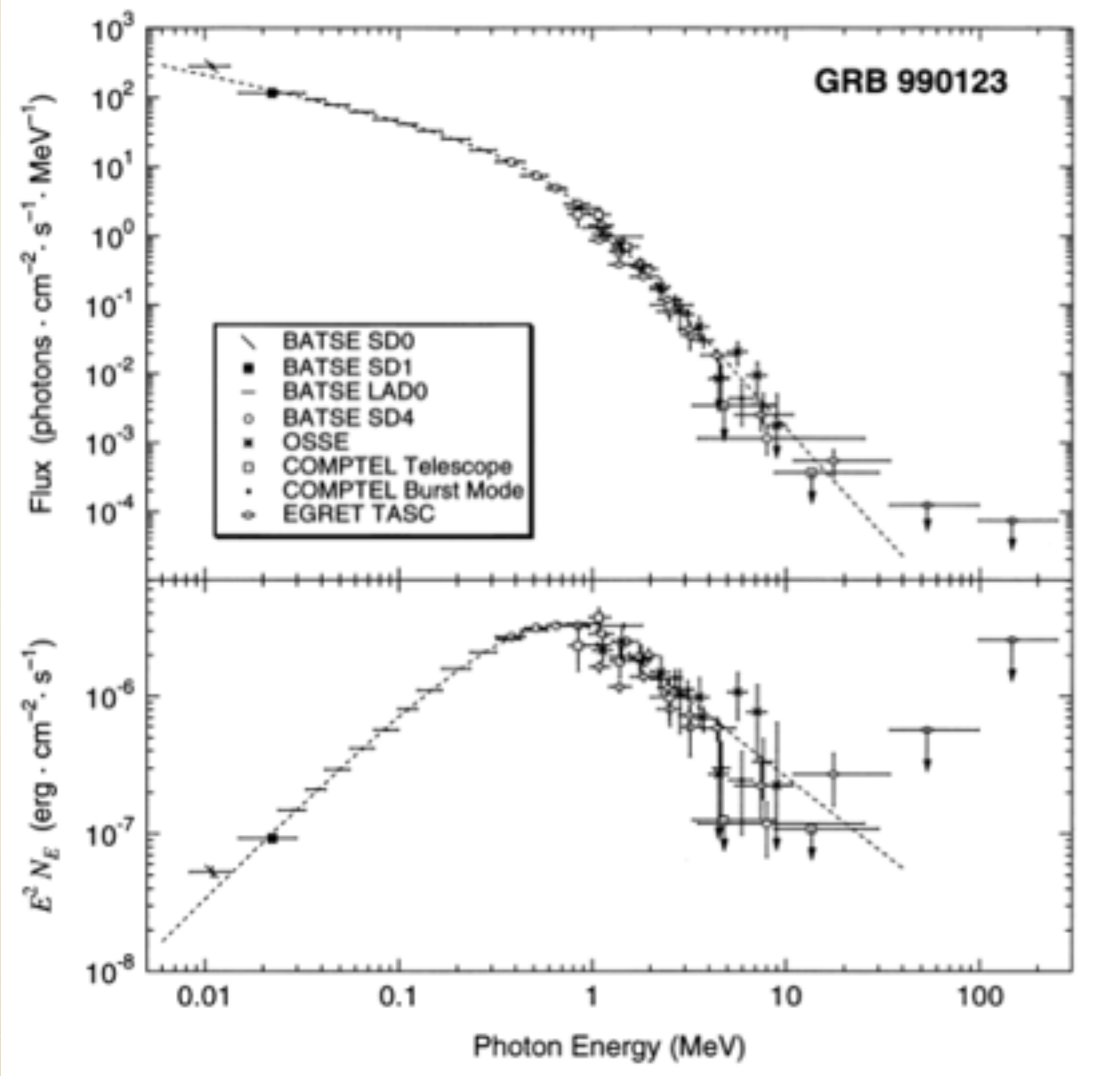
Burst spectra: “Band” function

* Most GRB spectra can be fit by the Band (1993) function

$$N_E(E) = A\left(\frac{E}{100\ \mathrm{keV}}\right)^{\alpha} \exp\left(-\frac{E}{E_0}\right), \qquad (\alpha-\beta)E_0 \geq E\,,$$

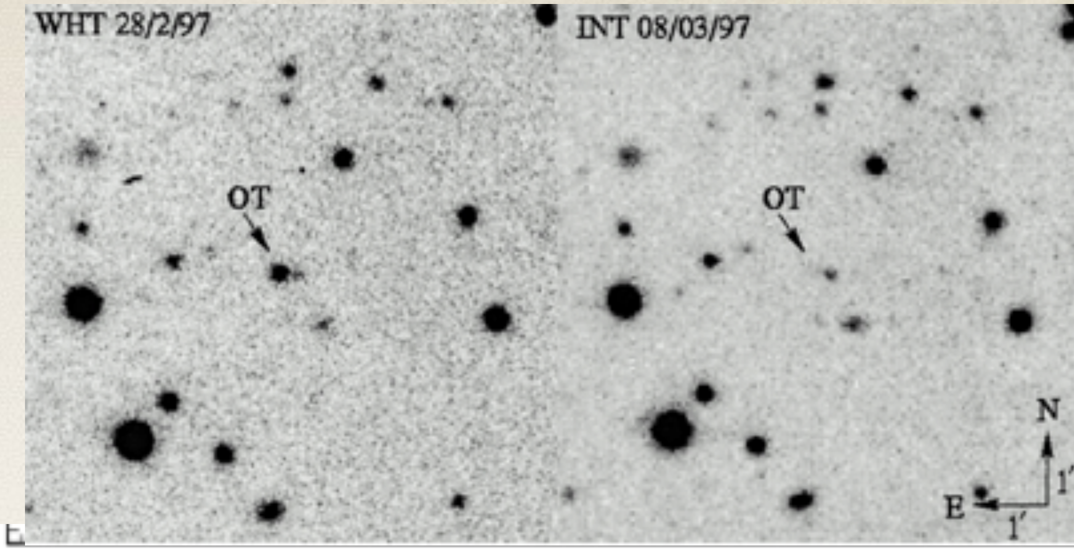
$$= A\left[\frac{(\alpha-\beta)E_0}{100\ \mathrm{keV}}\right]^{\alpha-\beta} \exp(\beta-\alpha)\left(\frac{E}{100\ \mathrm{keV}}\right)^{\beta}, \qquad (\alpha-\beta)E_0 \leq E\,,$$

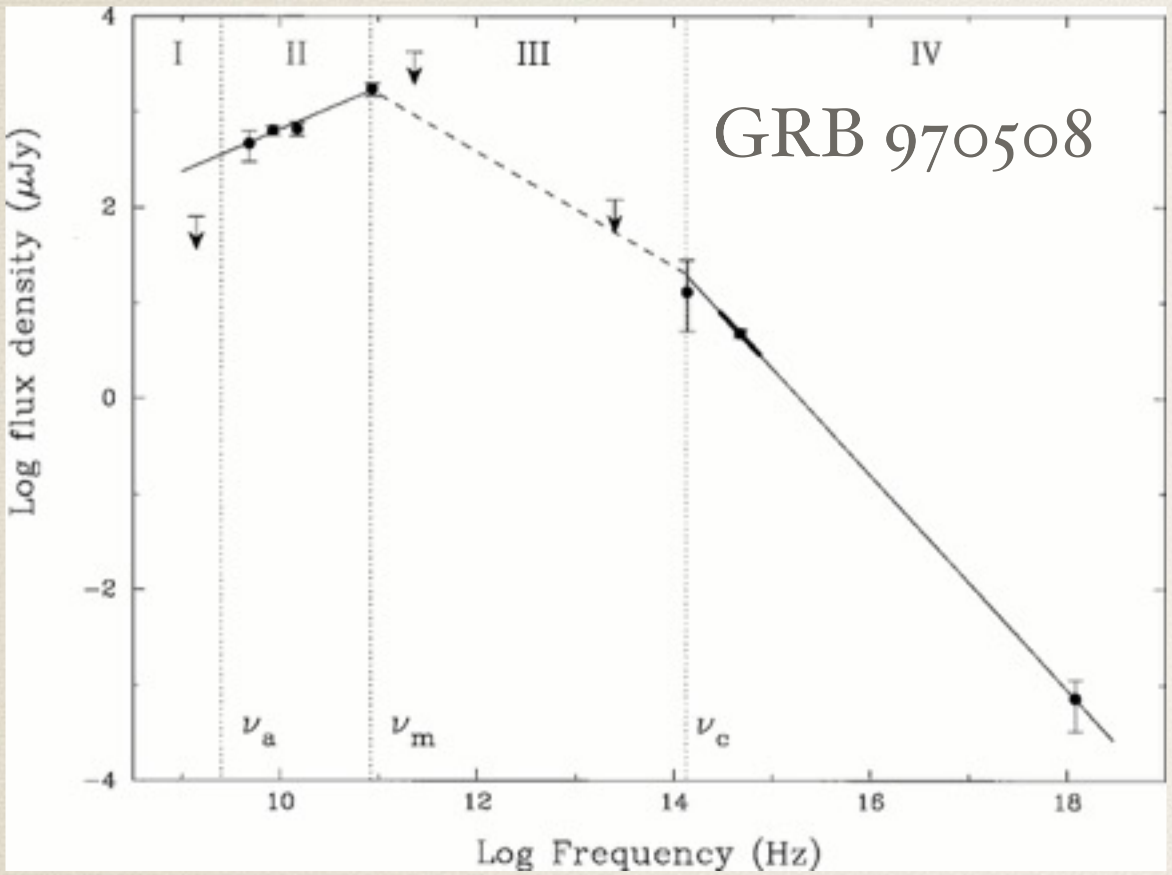
* which is a phenomenological function without being motivated by any theory.



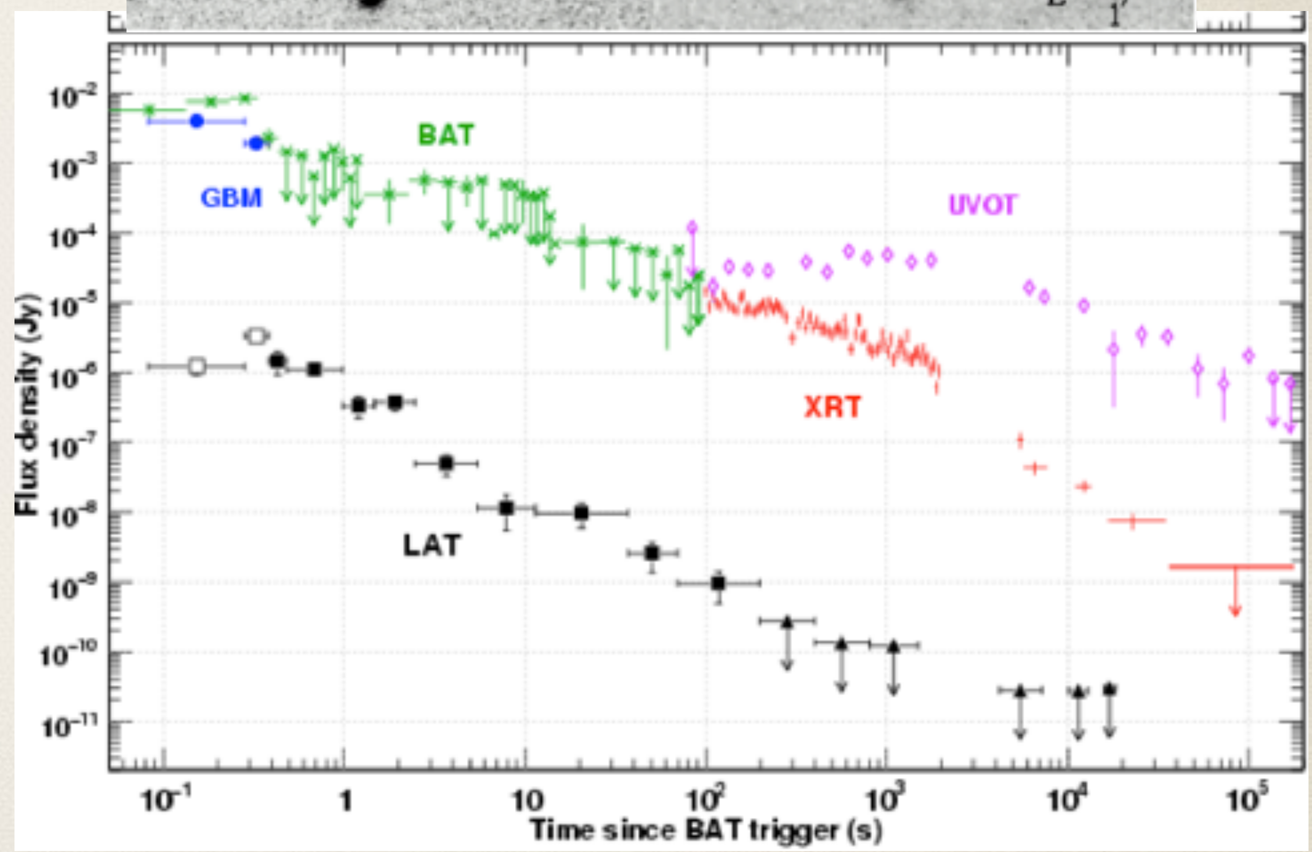
Afterglow

GRB 970228, van Paradijs et al. (1997)



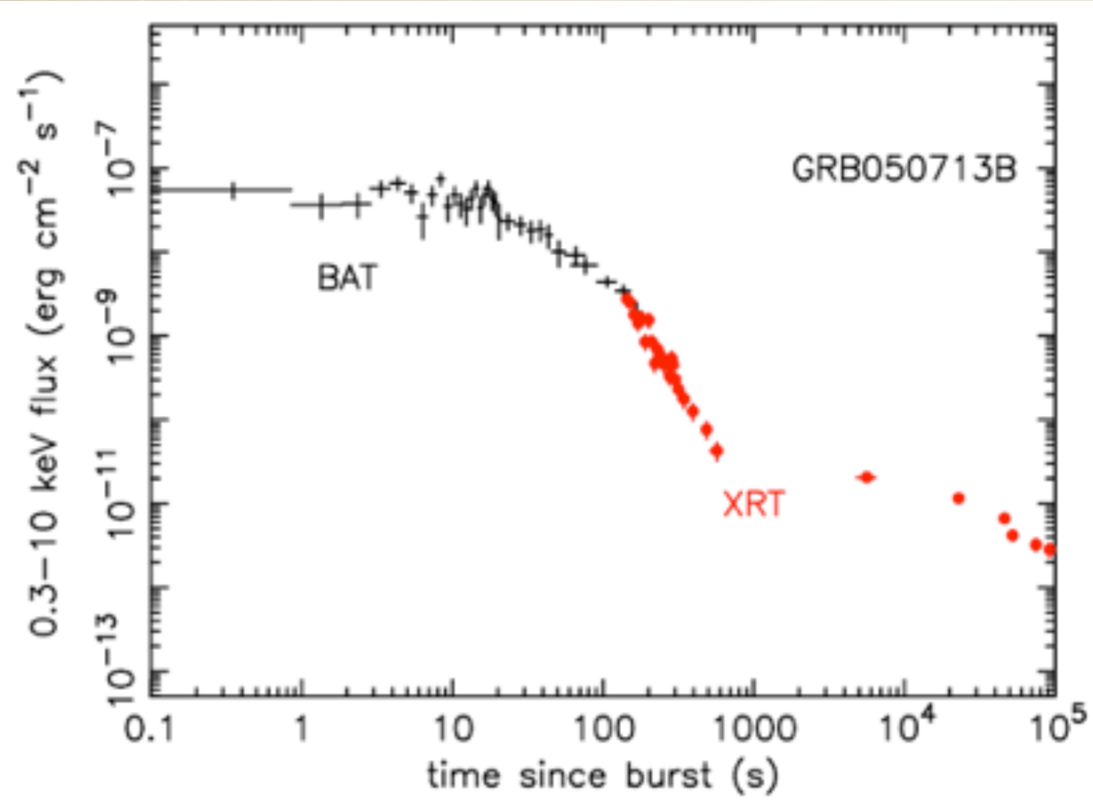


synchrotron spectrum

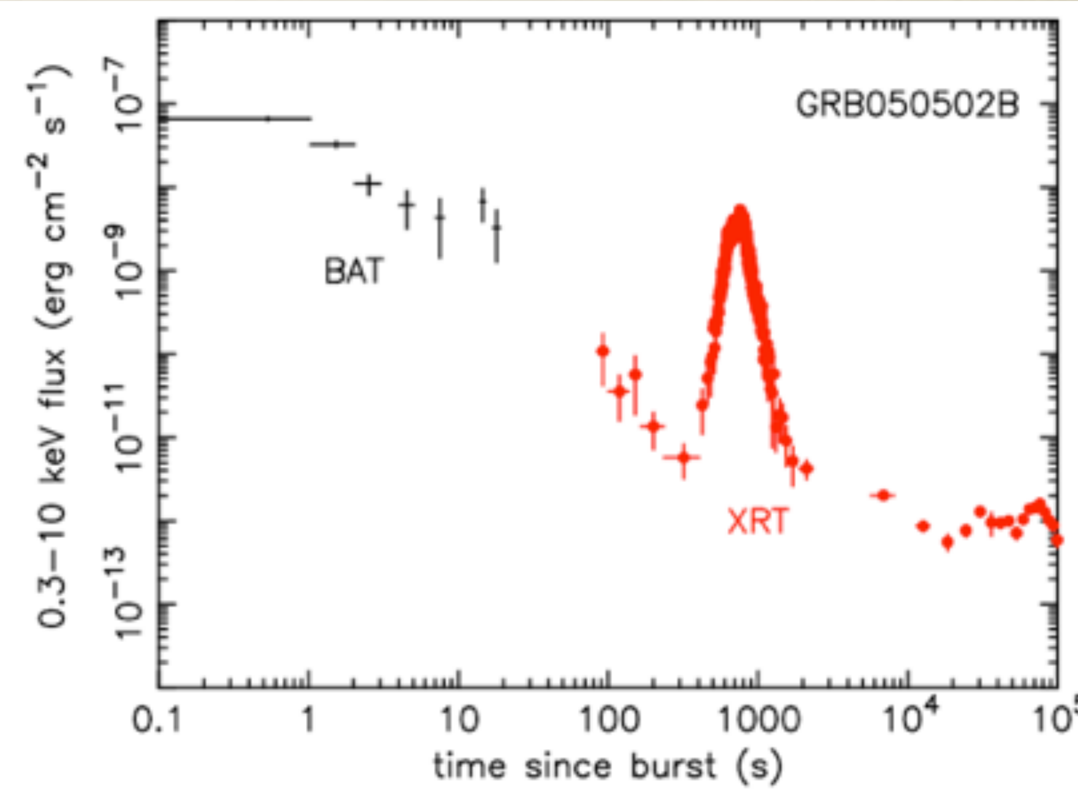


Decays connected by PLs, from optical, X-rays to GeV, GRB 090510

XRT afterglow light curves



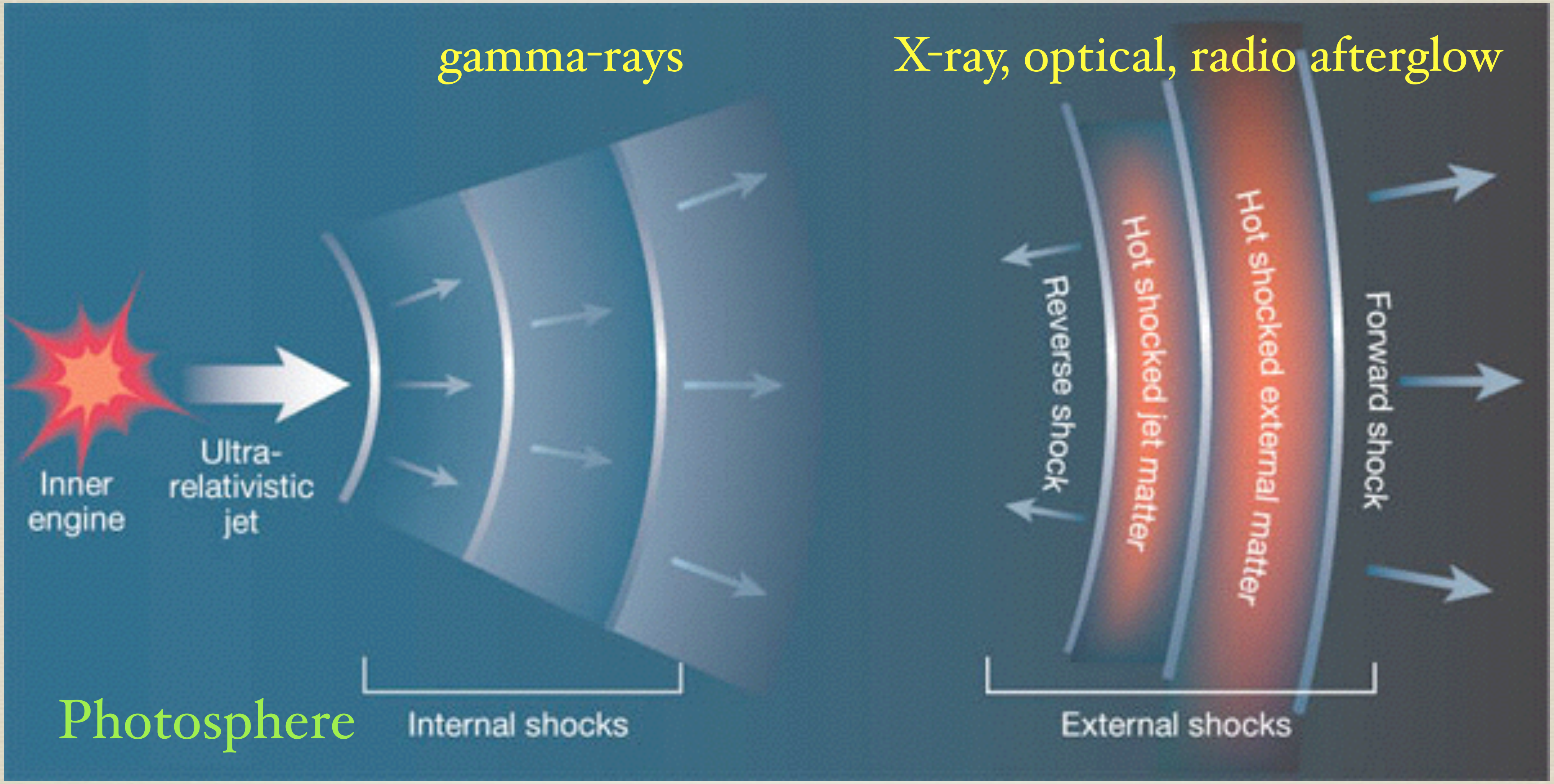
A "canonical" X-ray decay light curve without flares



Strong late-time activities, thought to be central engine

X-ray flares can be IC up-scattered to very high energy gamma-rays

The Fireball Model

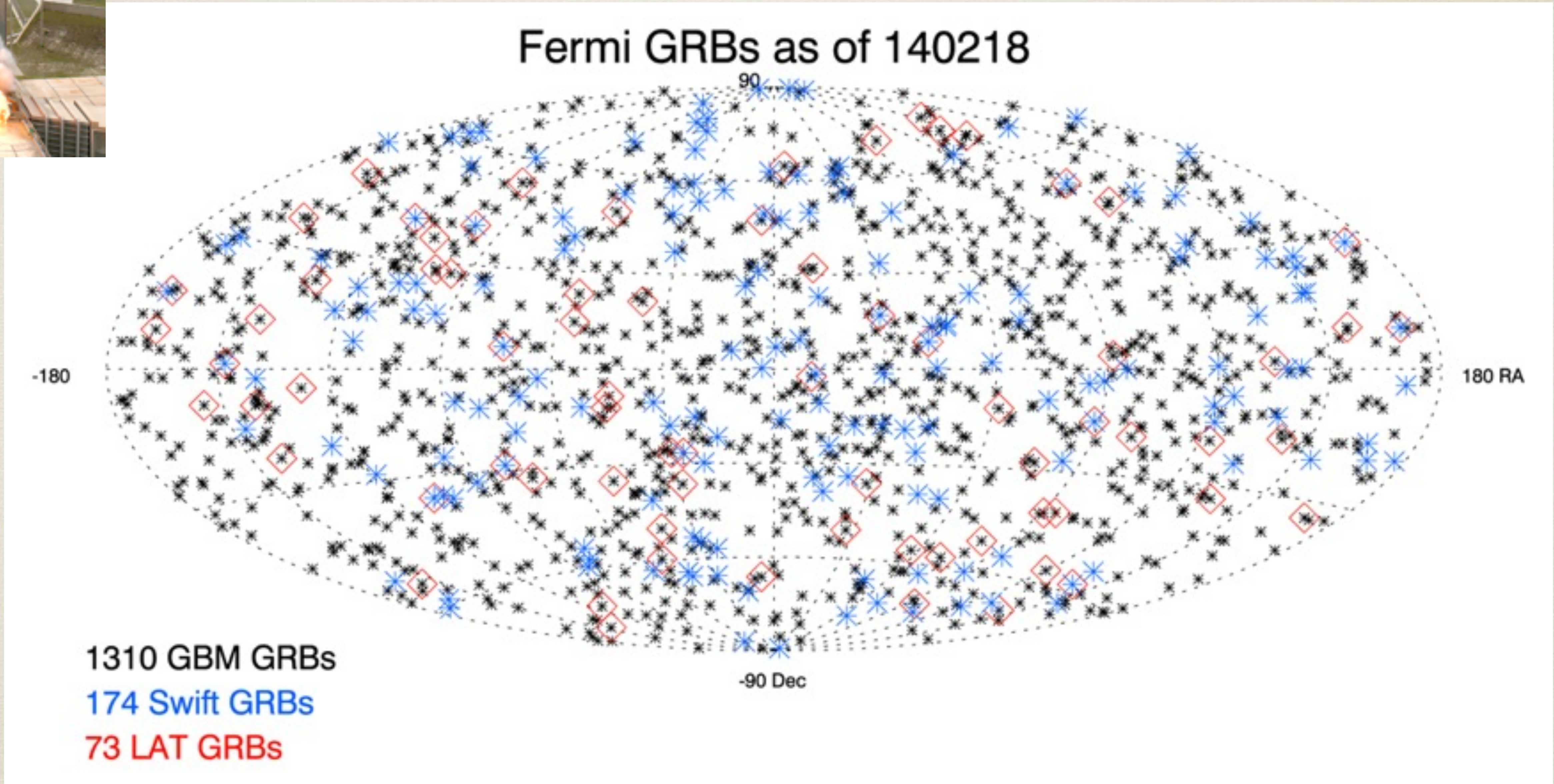


Prompt emission (short-lived, seconds)

Afterglow emission (long-lasting, up to days to weeks)

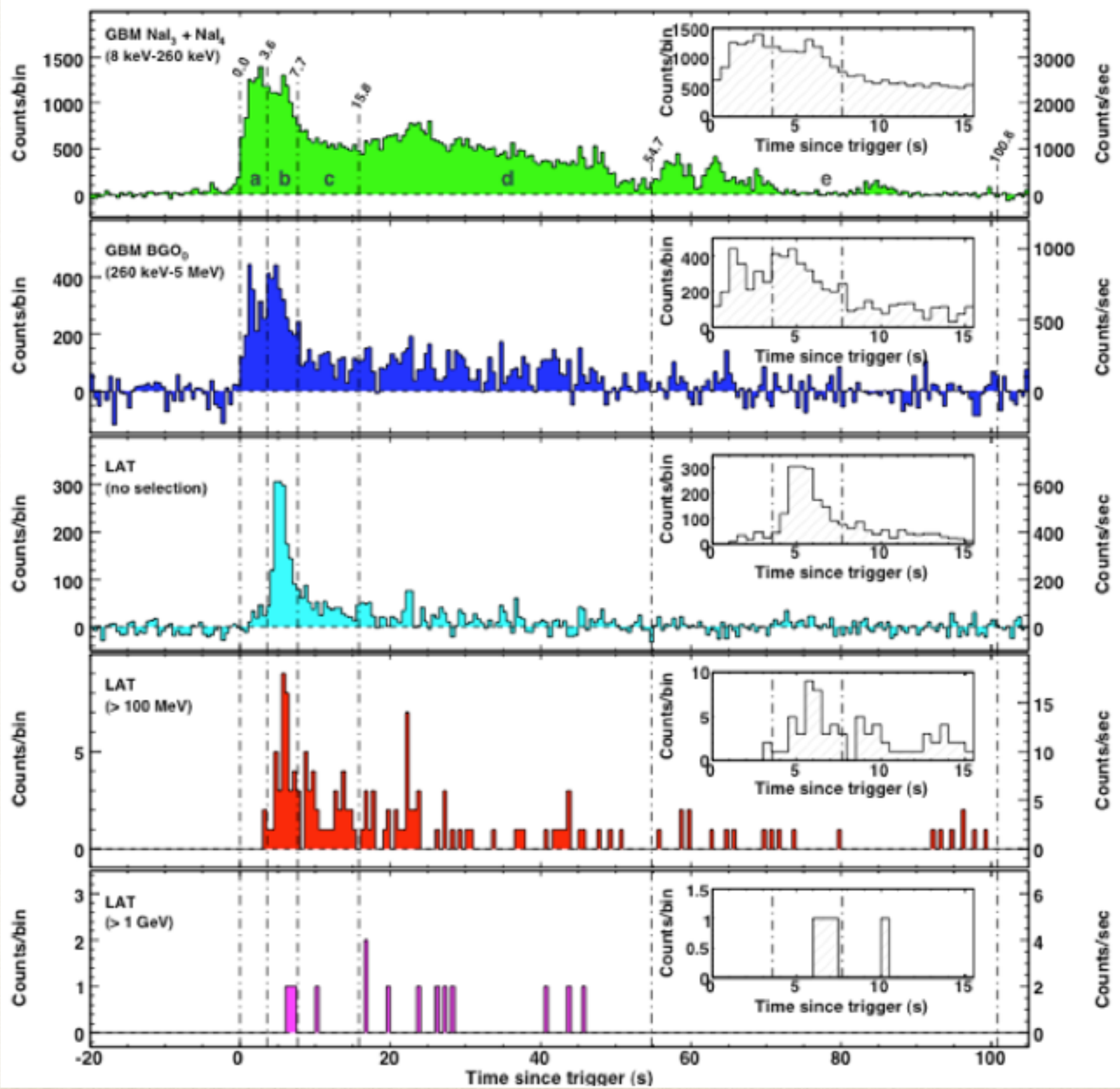
c.f. Piran (2004)

What does Fermi see?

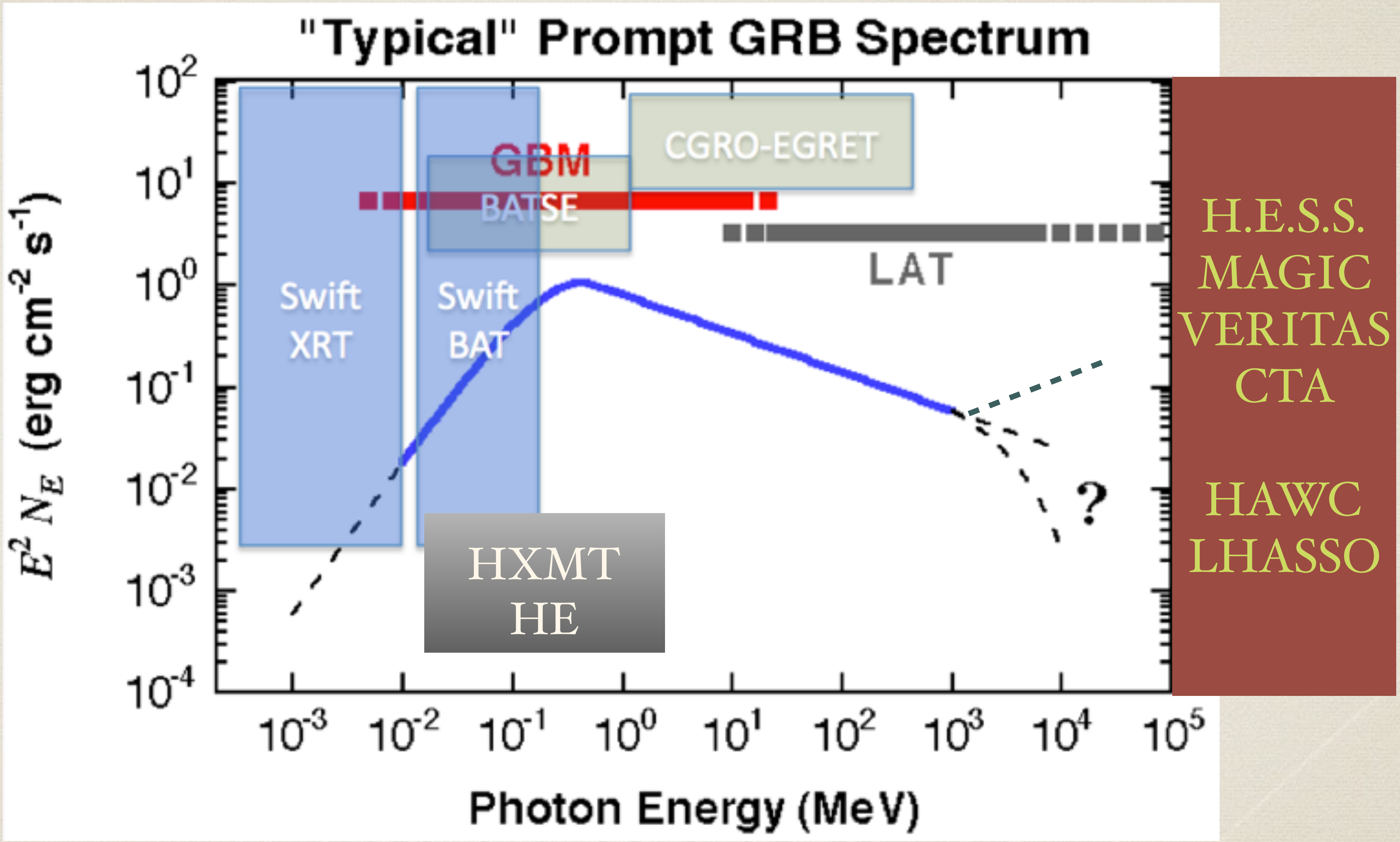


LAT does not see GeV emission from most GRBs
(see, e.g., Ackermann et al., 2012)

GRB 080916C

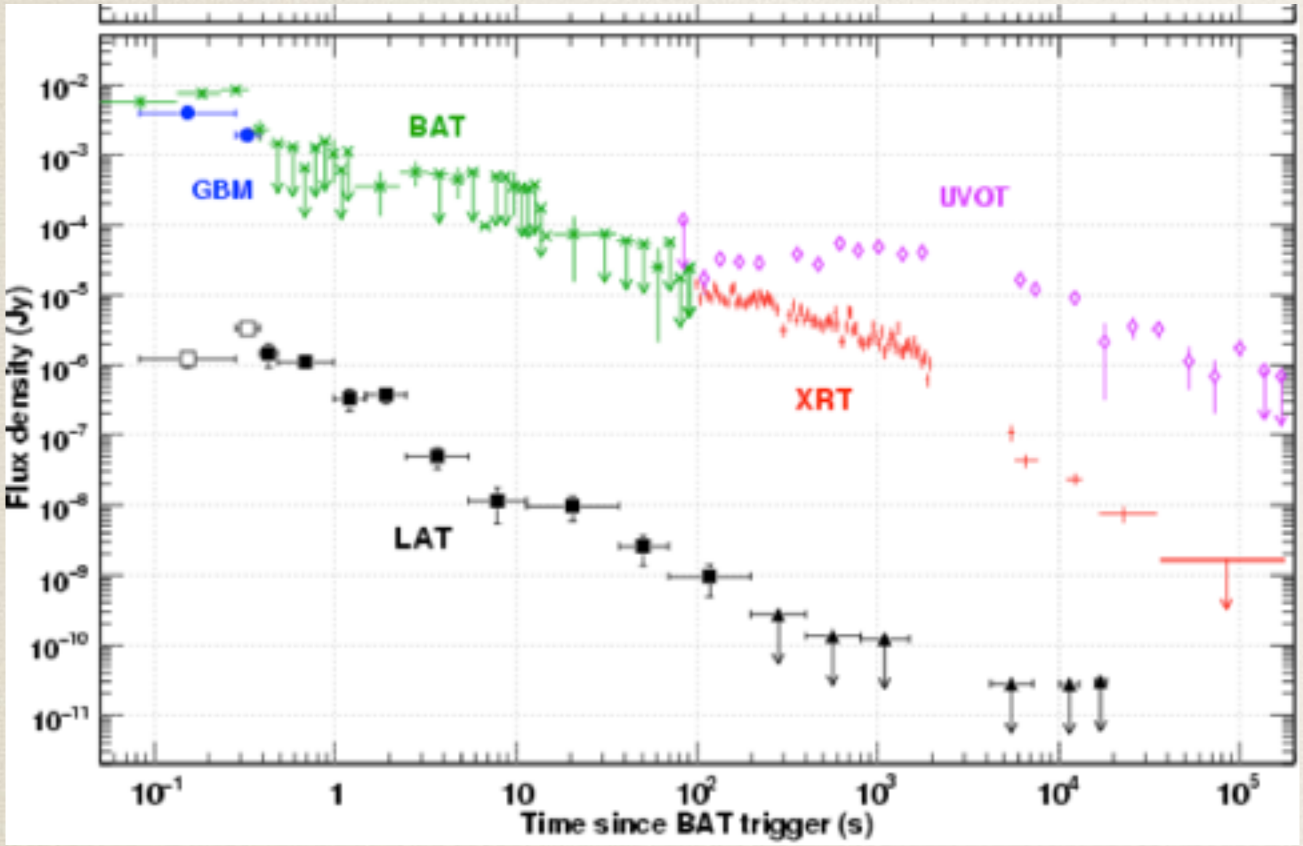


GBM NaI3 + NaI4
(8 keV-260 keV)
GBM BGO0
(260 keV-5 MeV)
LAT
(no selection)
LAT
(> 100 MeV)
LAT
(> 1 GeV)
0.0
3.6
7.7
15.8
54.7
100.8
a
b
c
d
e
Counts/bin
Counts/sec
Time since trigger (s)


"Typical" Prompt GRB Spectrum
$E^2 N_E$ (erg cm^{-2} s^{-1})
Photon Energy (MeV)
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^0
10^1
10^2
10^3
10^4
10^5
Swift XRT
Swift BAT
GBM
BATSE
CGRO-EGRET
LAT
?
HXMT HE
H.E.S.S.
MAGIC
VERITAS
CTA
HAWC
LHASSO

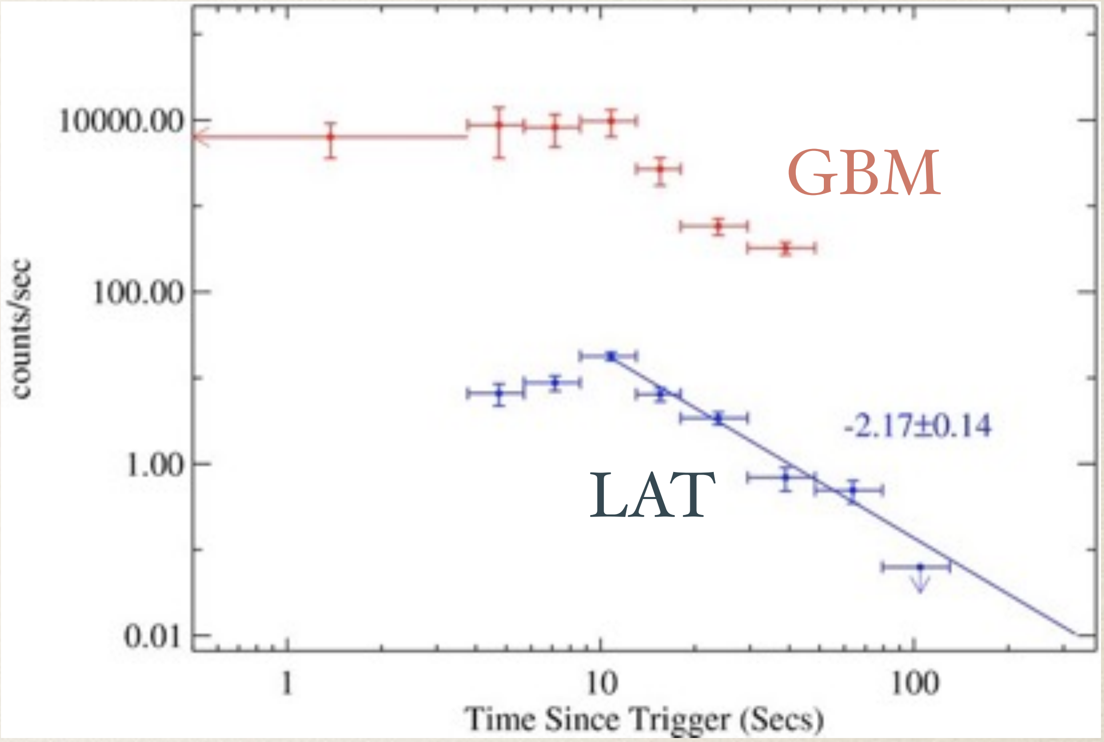
MWL/GeV photons during GRB afterglow

GRB 090510



Abdo et al. (2010)

GRB 090926A



Swenson et al. (2010)

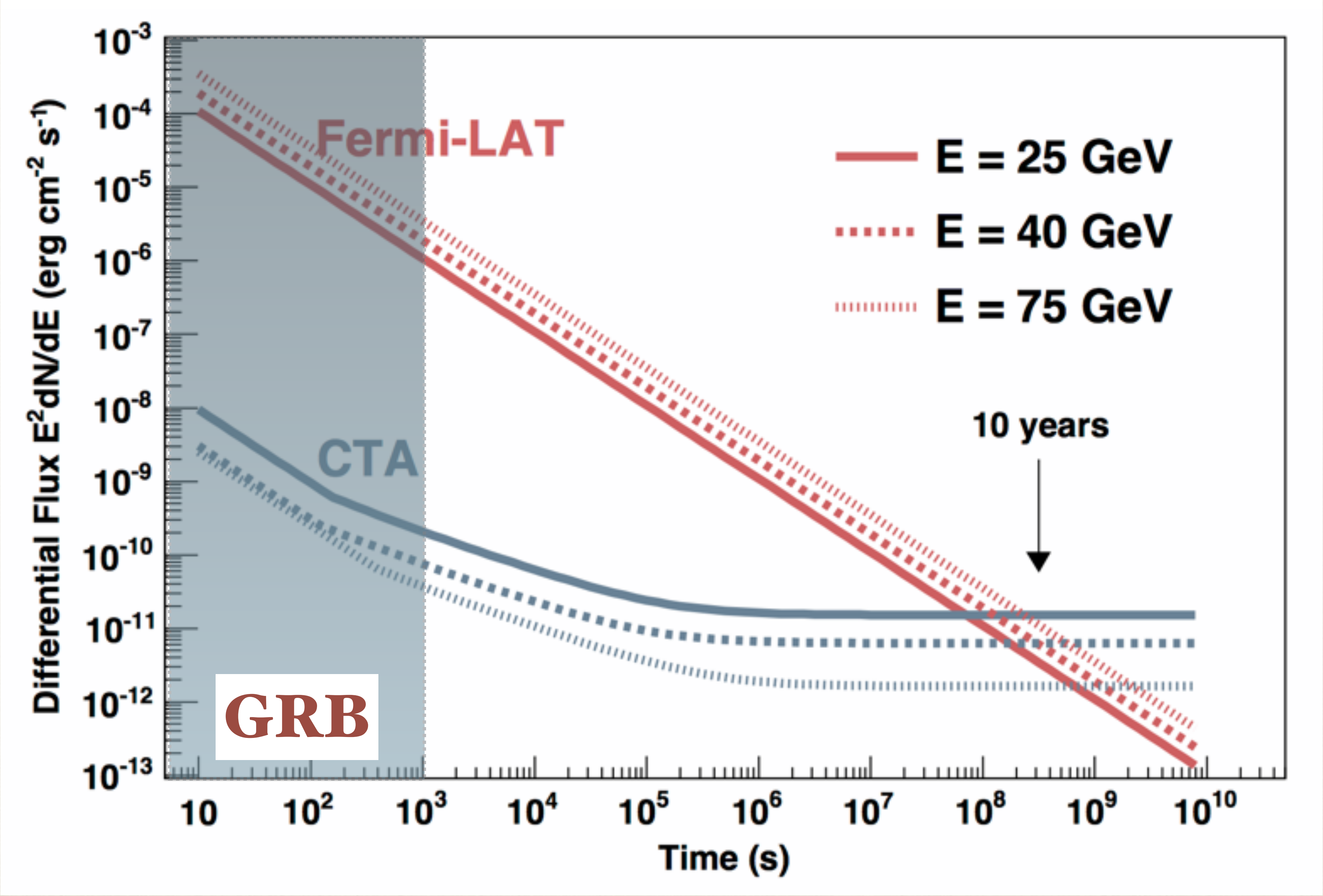
LAT (Fermi): 100 MeV-100 GeV

CTA: >10 GeV

Fermi vs ground-based tels

* Fermi-LAT is able to, and did see photons above 10 GeV, most notably a 27.4 GeV photon from GRB 080916C (at z=4.35, it is a 147 GeV one at origin), and a 95 GeV photon from GRB 130427A
* As time passes, Fermi-LAT will see more of them, but will find it hard to obtain good photon number statistics for spectral and light curve construction.
* Ground-based gamma-ray detectors have much larger effective collection area.

Fermi-CTA sensitivity

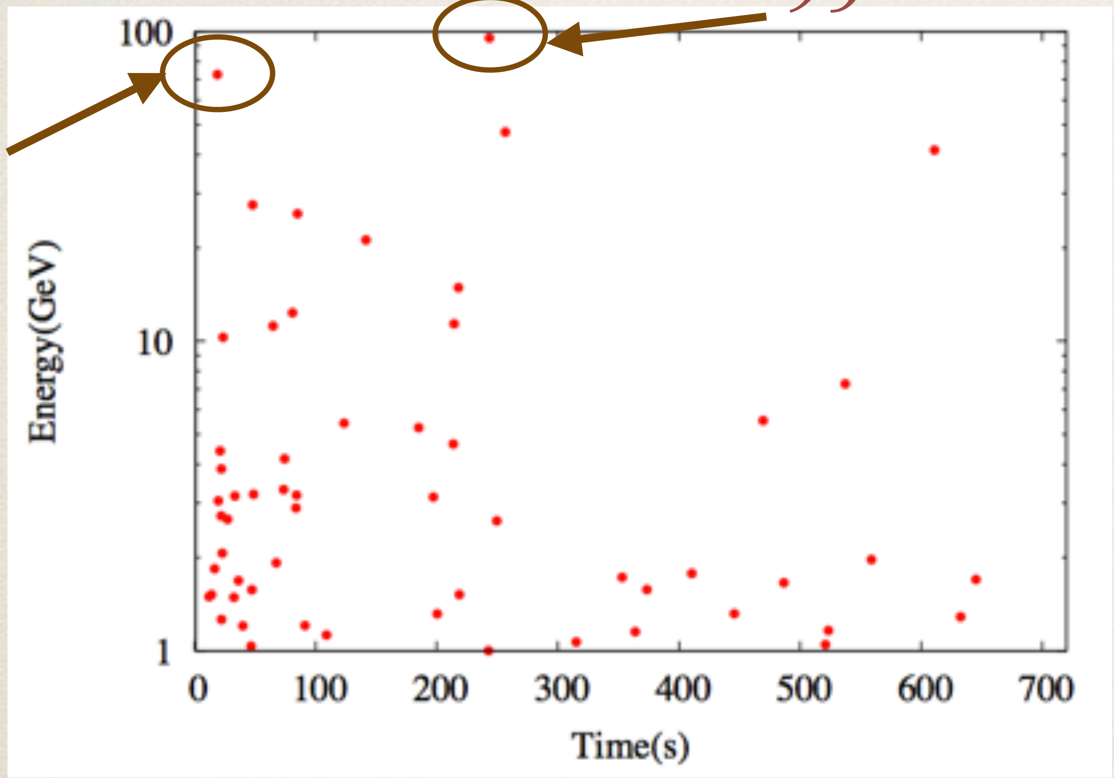


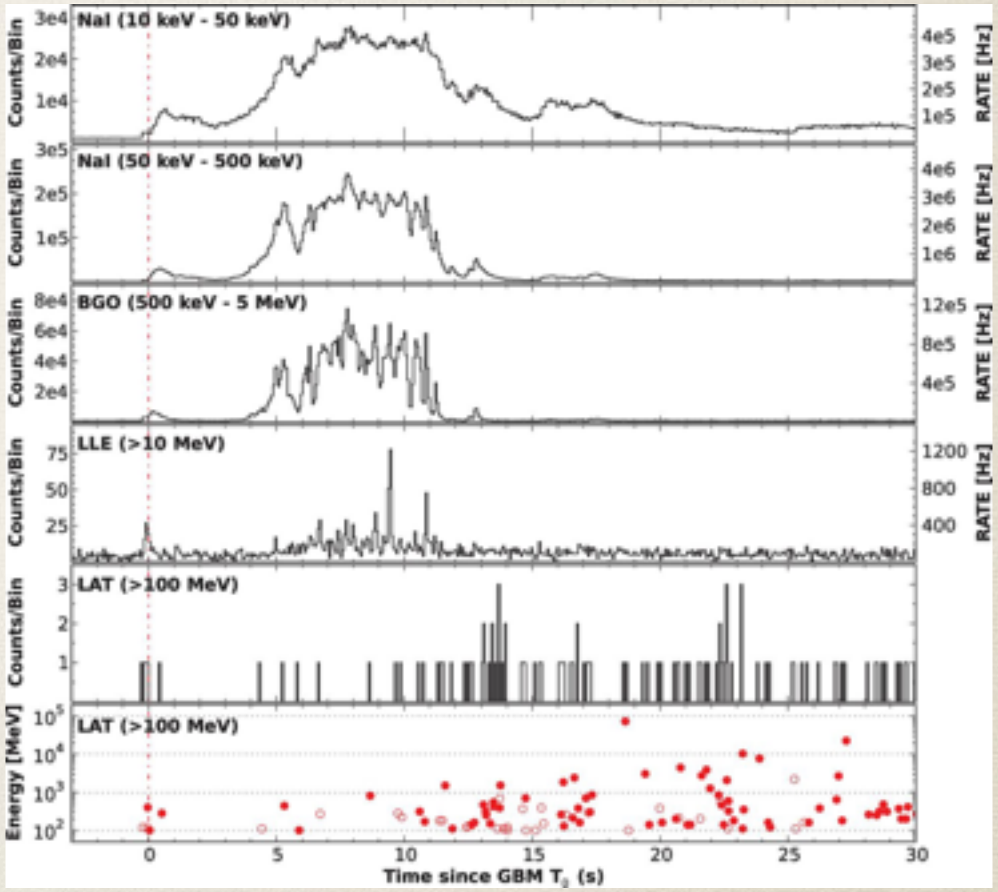
Very bright GRB 130427A

GRB 130427A emits many high-energy gamma-rays during the prompt & afterglow period, T_{90}~138s

95 GeV

73 GeV



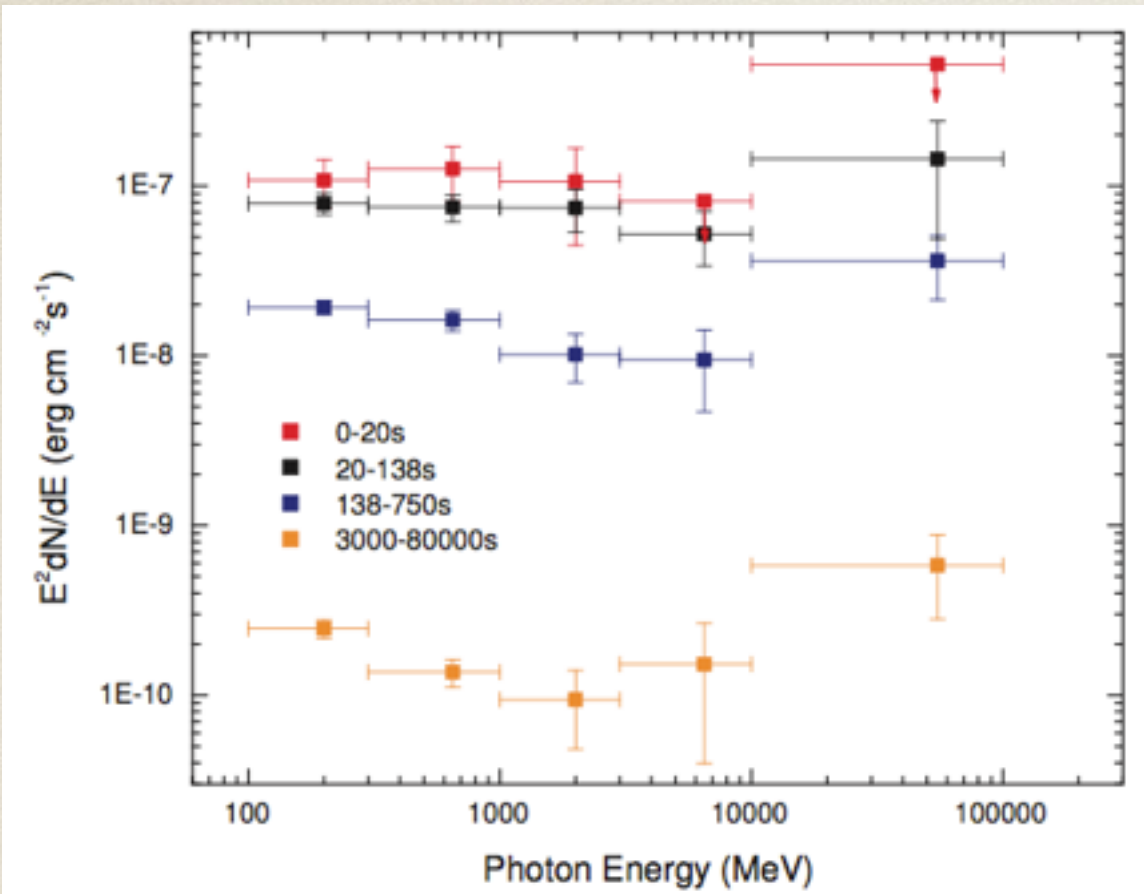


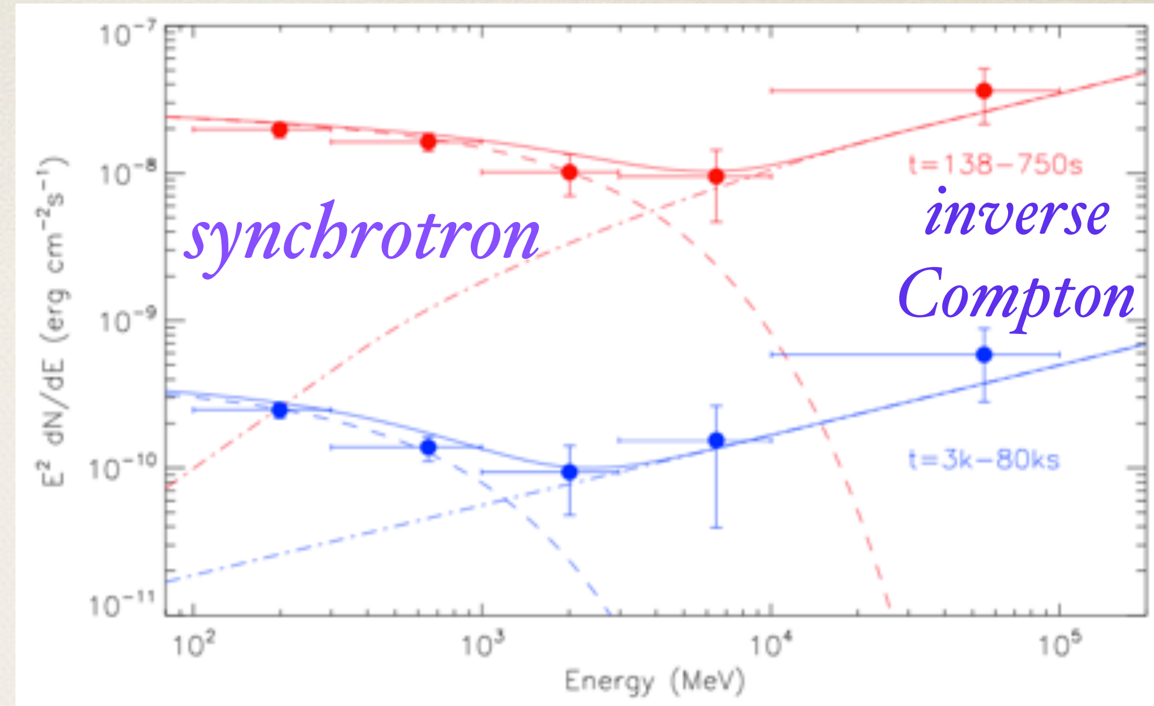
a 95 GeV photon arrived at T0 + 243s, corresponding to an intrinsic photon energy 128 GeV at z=0.34

Fan, Tam et al. (2013)

Ackermann et al. (2014)

Spectral evolution





Liu et al. (2013)

$t - T_0$ (sec)	Power Law (PL) Γ	Broken Power Law (BPL) Γ_1 $(E < E_b)$	Γ_2 $(E > E_b)$	E_b (GeV)	Improvement of BPL over PL[a] (σ)
0–20	−2.0±0.2		...		...
20–138	−1.9±0.1		...		...
138–750	−2.1±0.1	−2.2±0.1	−1.4±0.2	4.3±2.0	2.5
3000–80,000	−2.1±0.1	−2.6±0.7	−1.4±0.2	1.1±0.9	2.9
138–80,000	−2.1±0.1	−2.3±0.2	−1.4±0.1	2.5±1.1	3.5

[a] calculated as $\sqrt{2 \times [\log(\mathcal{L}_{\rm BPL}) - \log(\mathcal{L}_{\rm PL})]}$

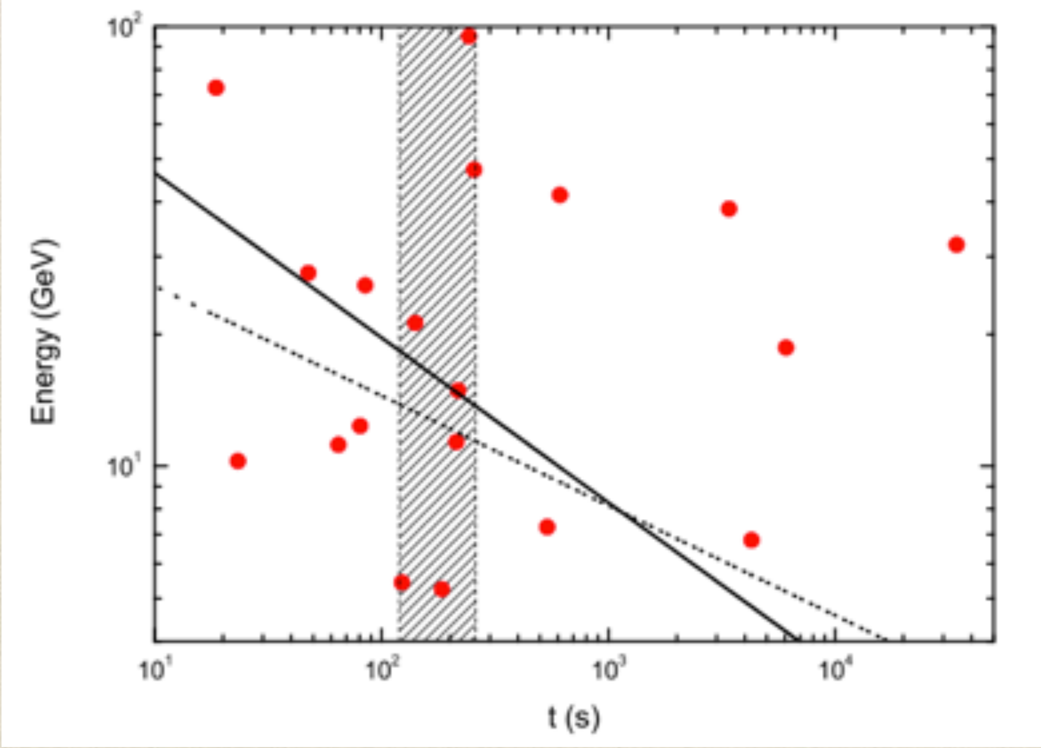
Significance of broken power law over power law

Power law index doesn't change!

Tam et al. (2013)

>10 GeV afterglow emission mechanism

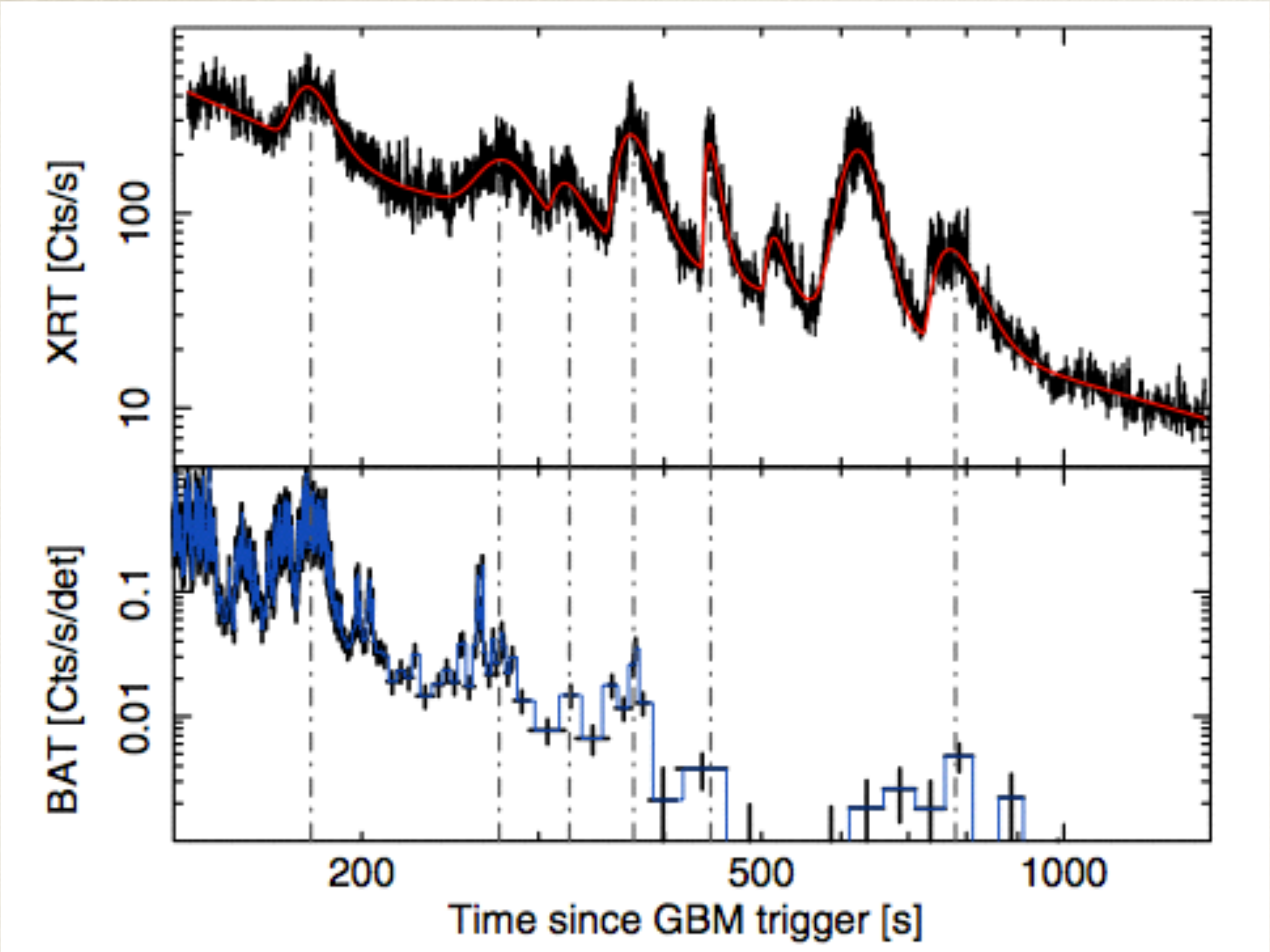
- Synchrotron emission (e.g., Kumar & Barniol 2009, Ghisellini et al. 2010)
- but there exists a maximum synchrotron energy, it is hard to explain the >10 GeV photons

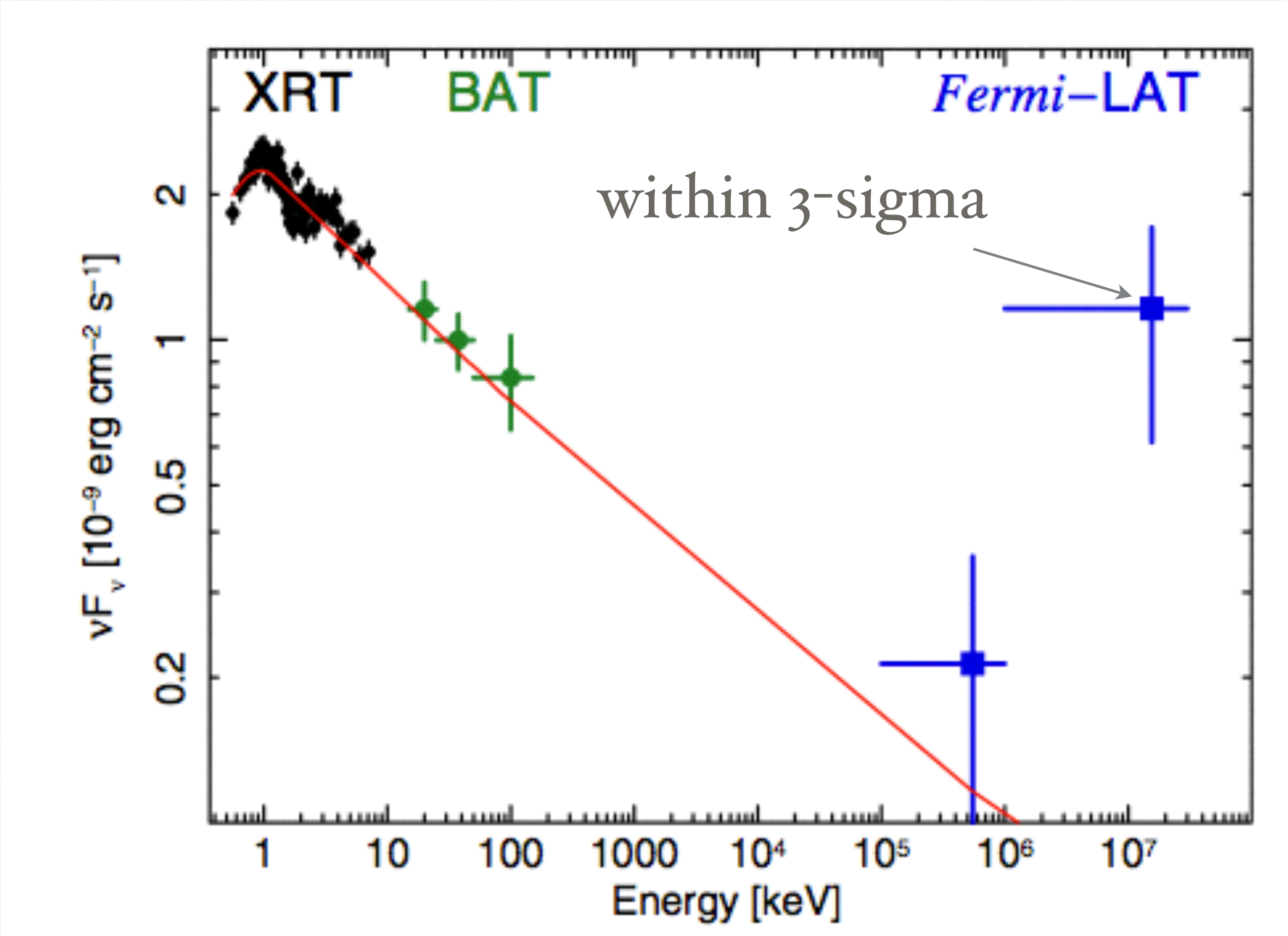


$$\epsilon_{\rm syn,M} \sim 100\ {\rm MeV}\ \Gamma(1+z)^{-1} \sim \begin{cases} 20\ {\rm GeV}\ E_{\rm k,54}^{1/8} n_{-2}^{-1/8} t_2^{-3/8} (\frac{1+z}{1.34})^{-5/8}, {\rm ISM}; \\ 15\ {\rm GeV}\ E_{\rm k,54}^{1/4} A_{*,-2}^{-1/4} t_2^{-1/4} (\frac{1+z}{1.34})^{1/4},\ \ {\rm wind}; \end{cases}$$

Fan, Tam, et al. (2013)
also see Ackermann et al. (2013)

Contemporaneous X-ray/ GeV flares?





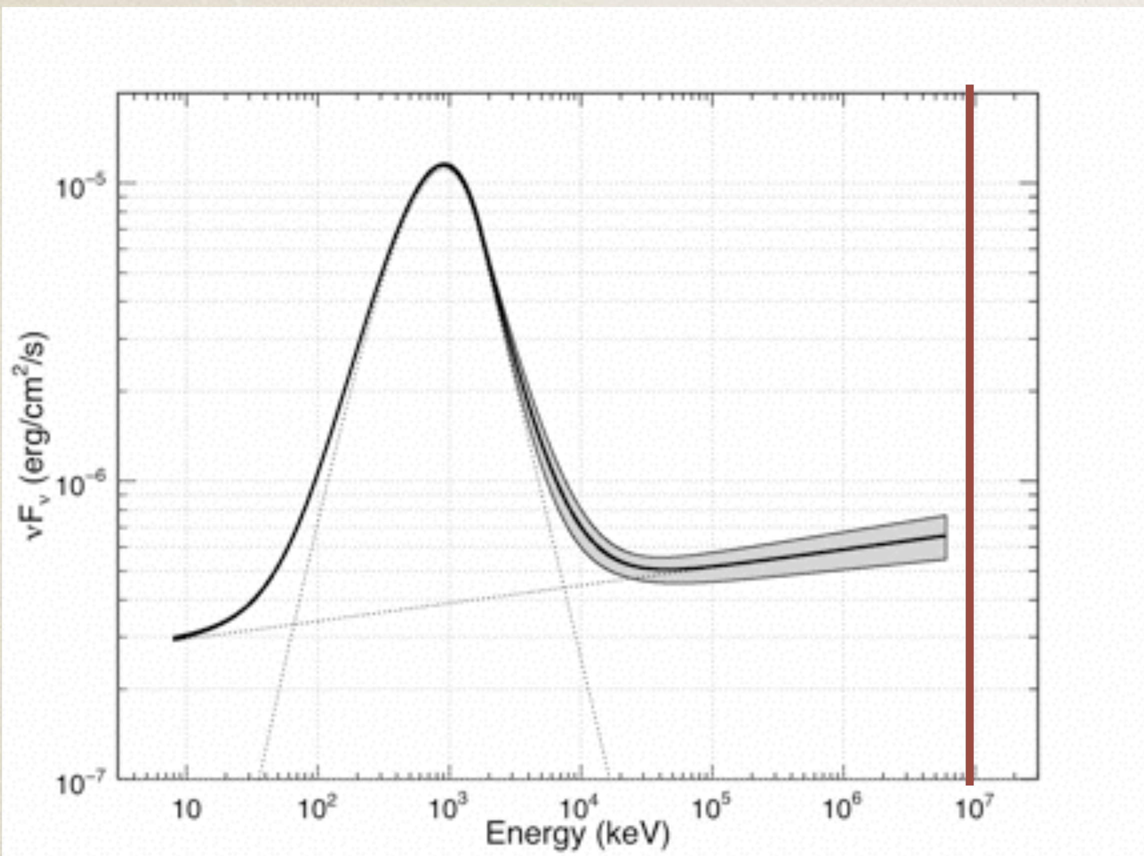
LAT detection: TS=32

Abdo et al. (2011)

GRB 100728A: LAT detection during X-ray flares

Power-law component during prompt phase

GRB 090902B

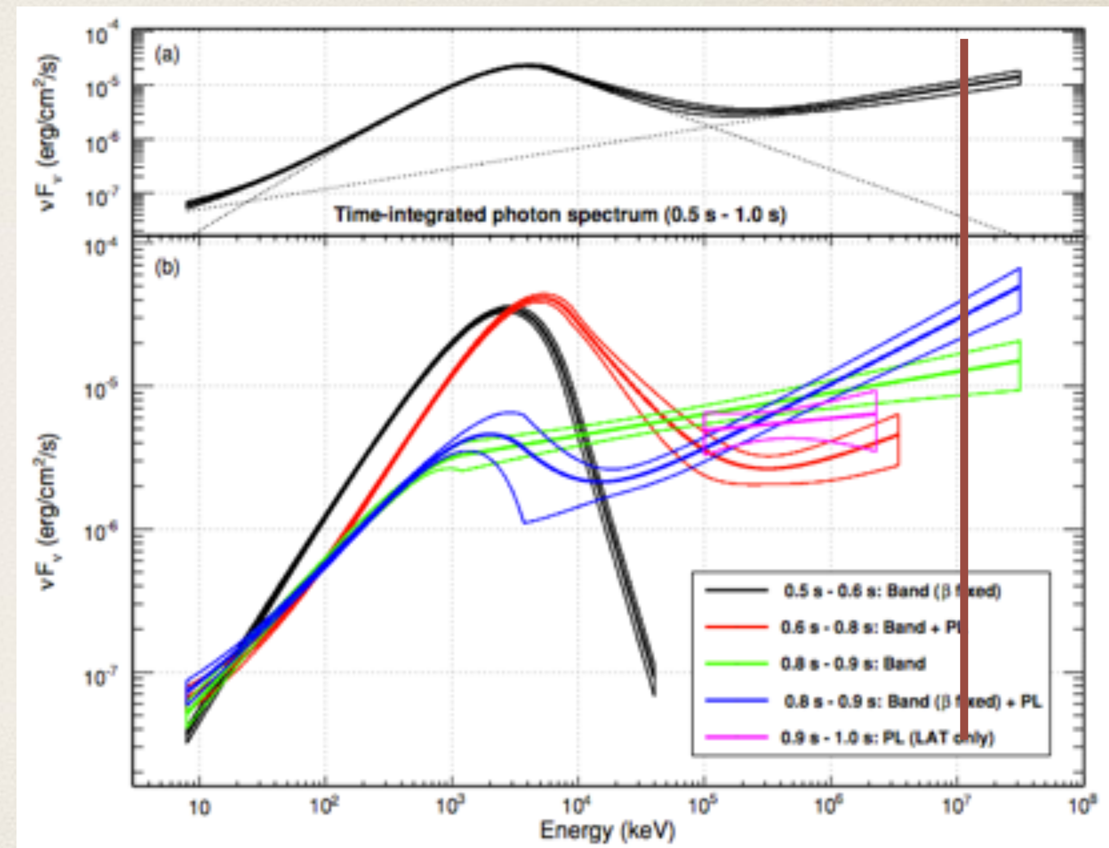


~10 GeV

Abdo et al. (2009)

~10 sec after trigger

GRB 090510

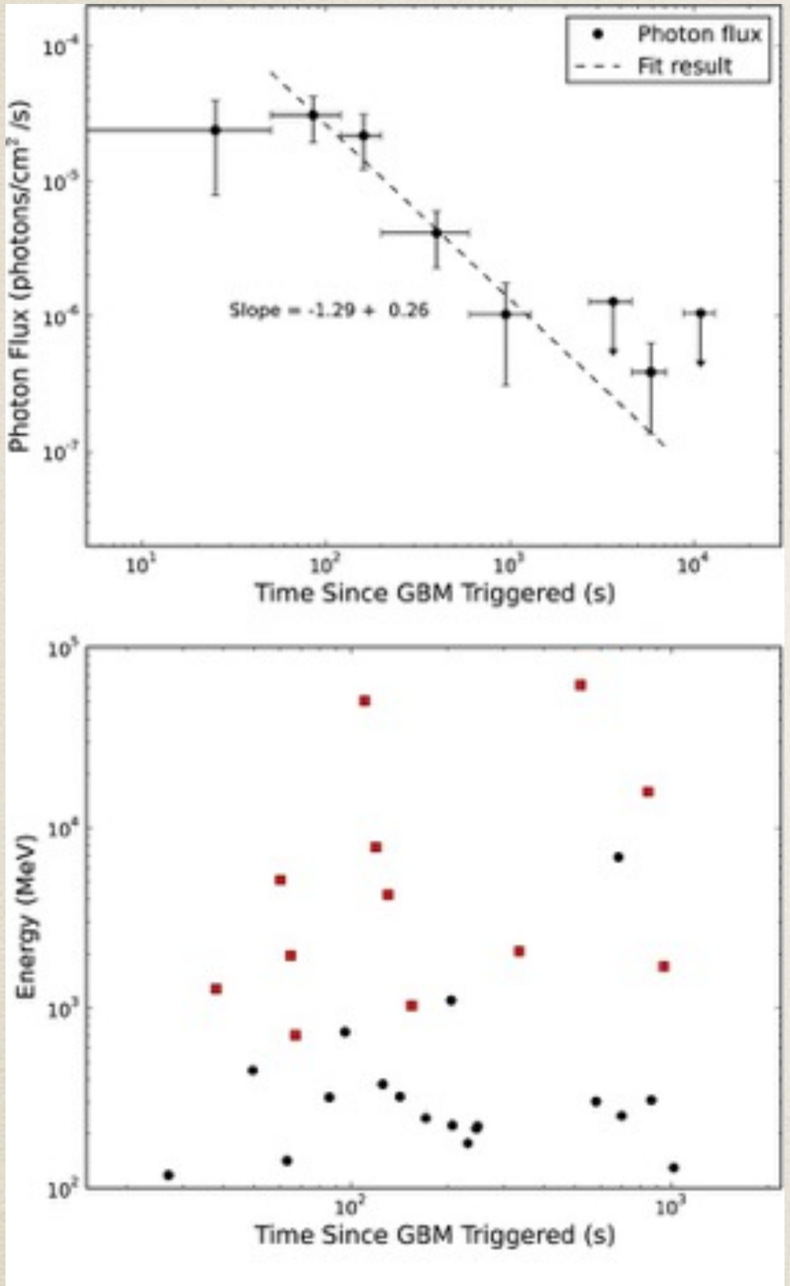


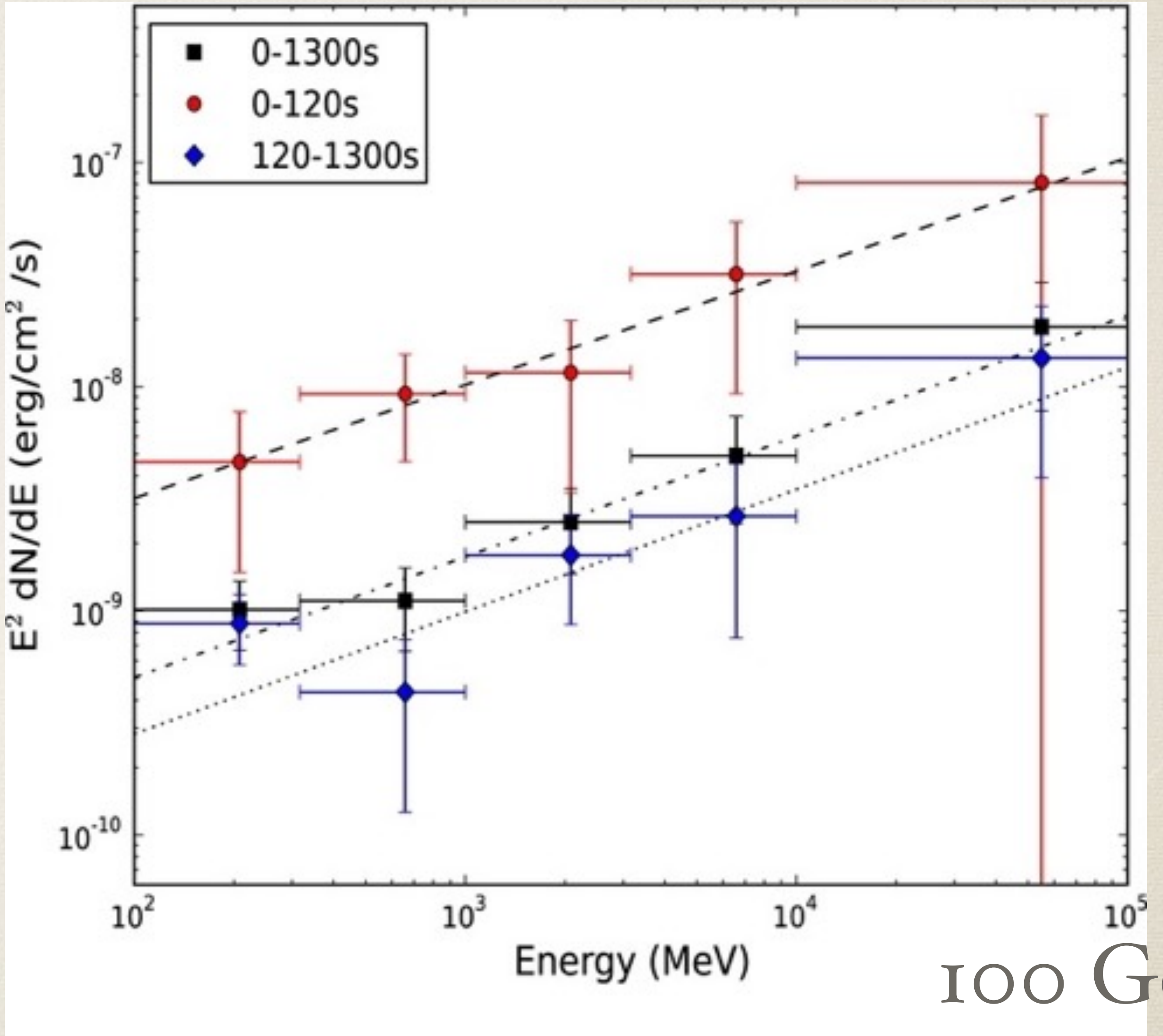
10 GeV

Ackermann, et al. 2010

~1 sec after trigger

GRB 131231A: showing very hard 0.1-100 GeV spectrum since T_0





100 GeV

Liu, B. et al. (2014)

Probably the strongest case for IC emission, besides 130427A

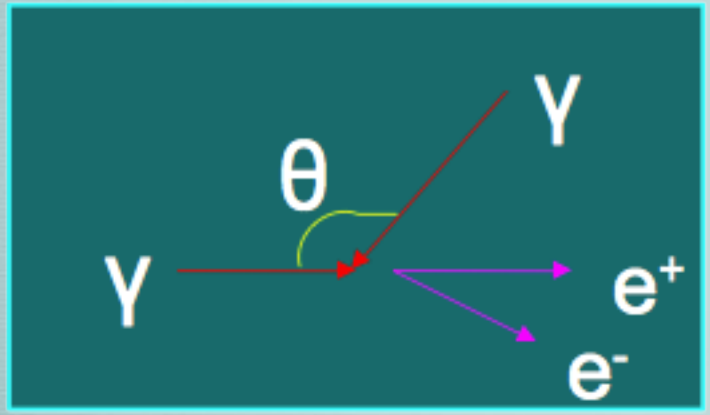
Why bother the very high-energy photons of GRBs?

* 10-100 GeV is the last observing window of GRBs
* The radiation mechanism at >GeV energies, both in prompt or afterglow phase, is still under debate
* The energy band where extragalactic background light (EBL) attenuation starts to modify the intrinsic spectra of the sources (e.g., AGN, GRBs)
* GRBs are more distant than AGNs, but a few nearby GRBs will be good ..

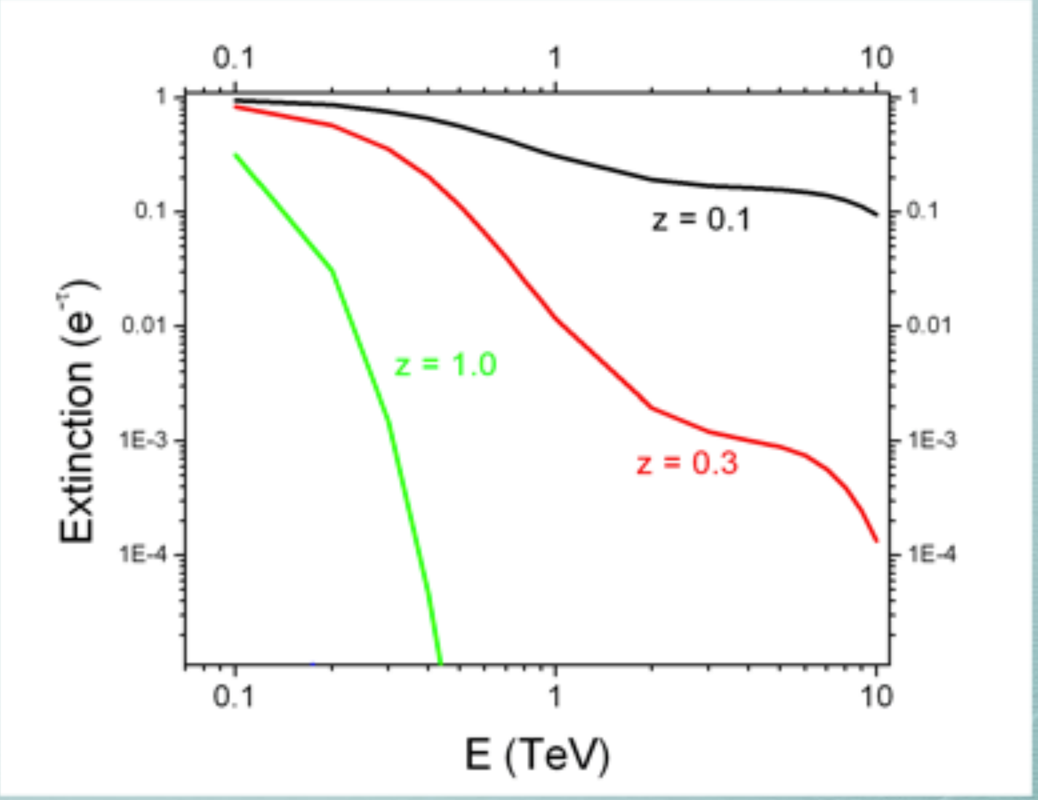
Extragalactic background Light

γ-γ interaction

high-energy photons will suffer absorption by EBL



$$F_{\rm obs}(E) = F_{\rm int}(E) \cdot e^{-\tau(E)}$$



early redshift information crucial !
Detection --> UL of z

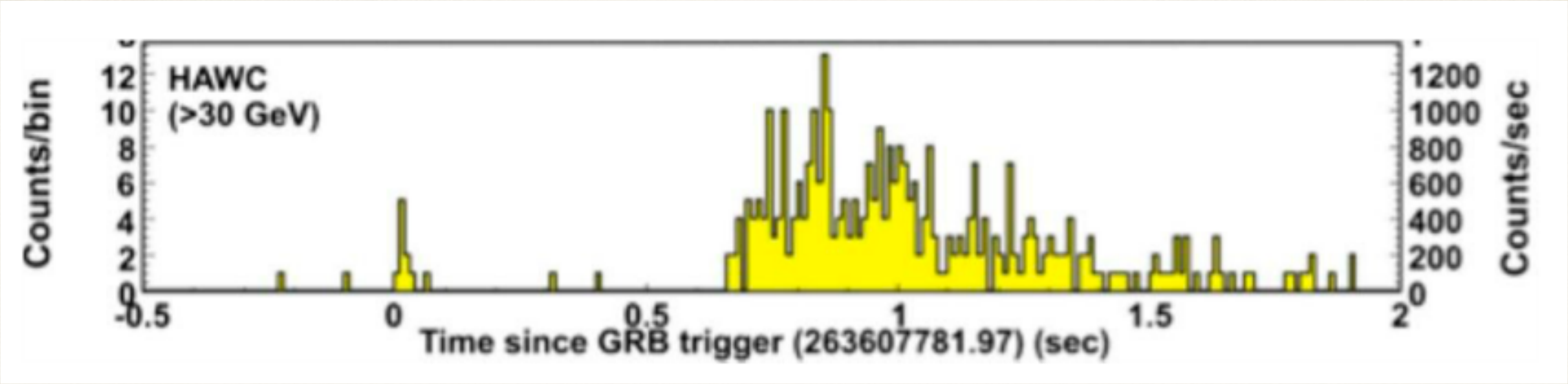
Aharonian et al. (HESS), Nature, 2006

Historical observations of GRBs

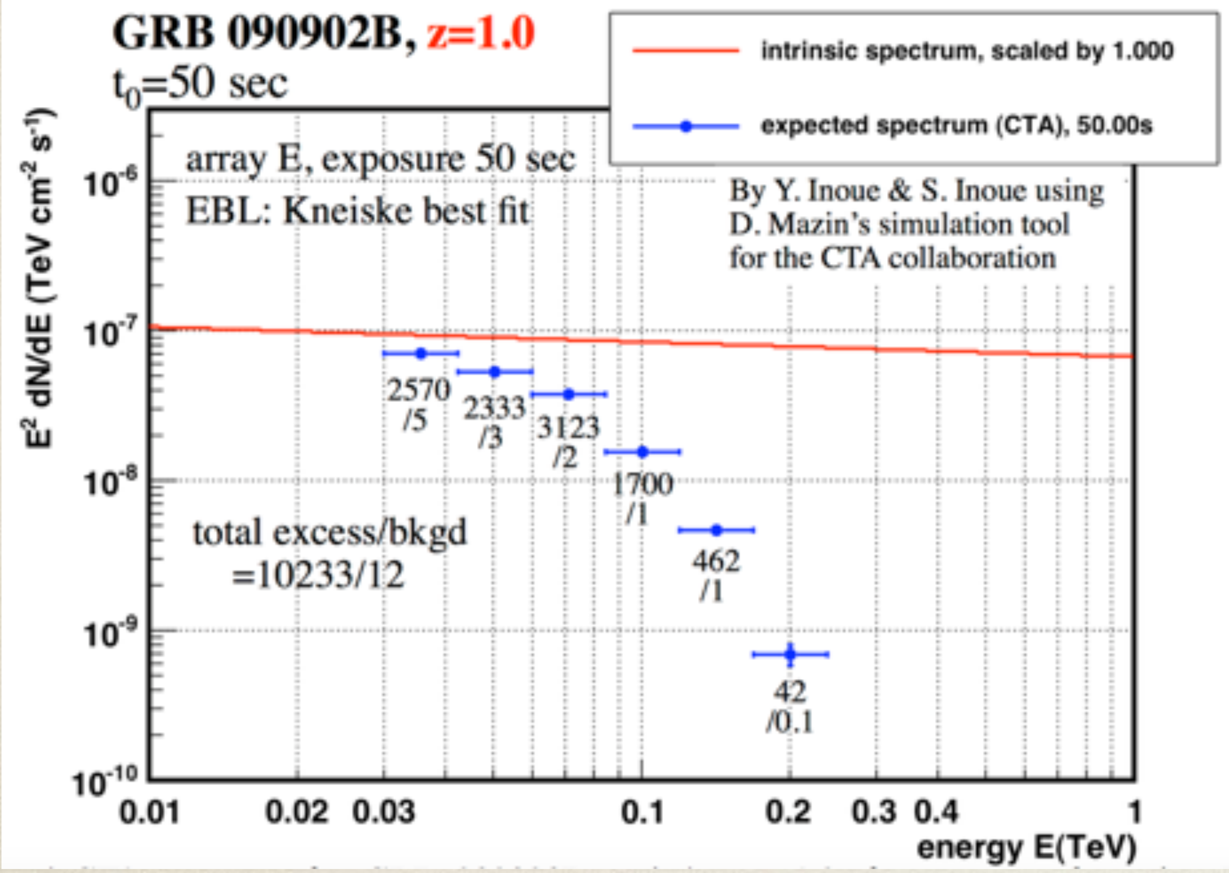
- Over the last twenty years or so, ground-based telescopes have not detected GRBs at significantly high confidence
- Some early claims:
  GRB 970417A by MILAGRITO （2.7σ），
  GRB 991208 by Tibet-ASγ （1.88σ, z=0.706）steep fall-off of optical flash like GRB 990123 was also seen
- Not even MAGIC II/H.E.S.S. II/VERITAS/HAWC (yet)
- Some evidence for Tupi detected photo-muons associated with several GRBs (Augusto et al. 2016)
- High energy threshold (thus absorbed by the EBL) is a major reason, other reasons include low sensitivity, time delay, etc. (see, e.g., Xue, Tam, et al., 2009).

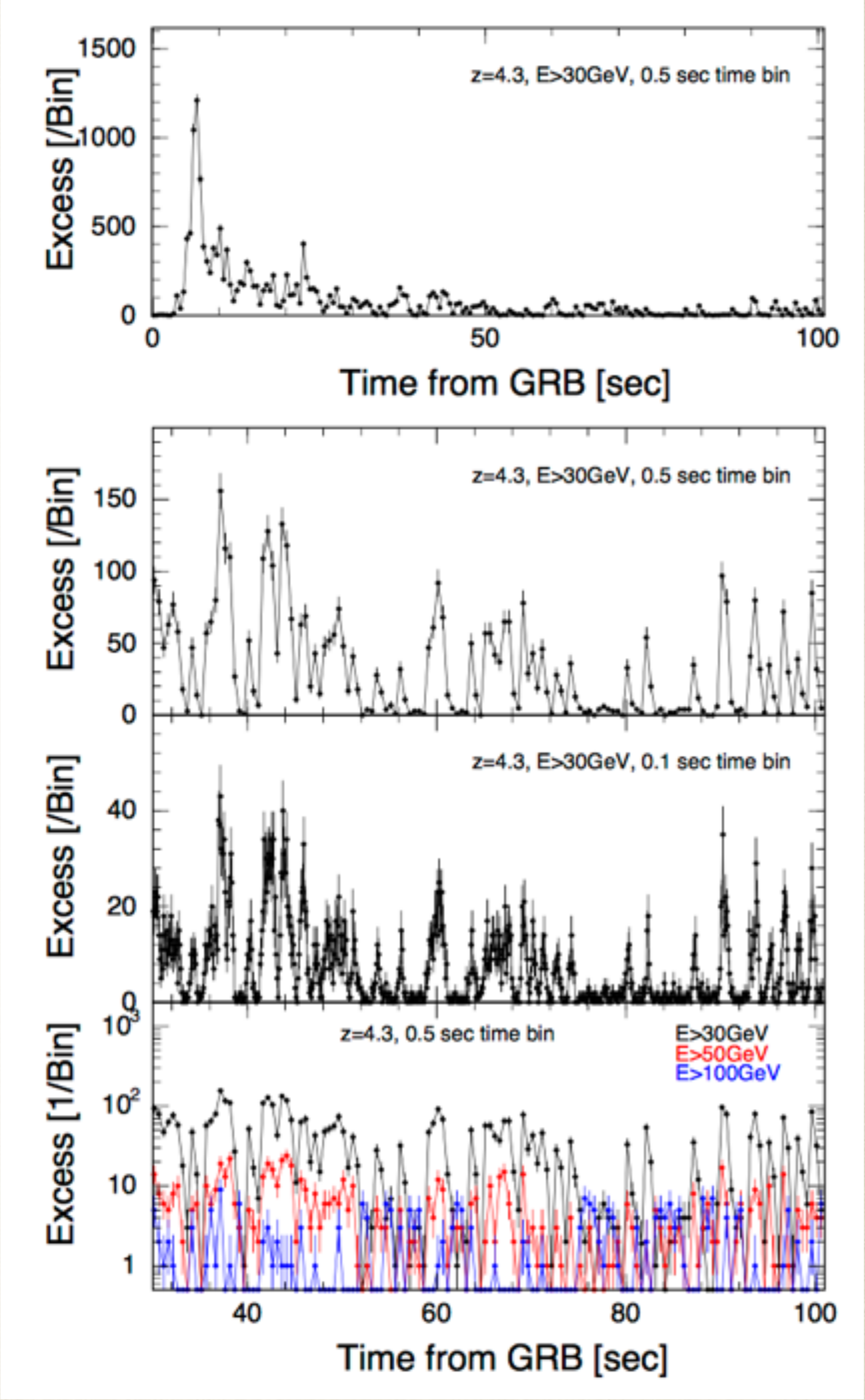
HAWC is observing GRBs

* With less than 1/3 of the array active, the HAWC observatory obtained limits for GRB 130702A, which is at a close redshift of z = 0.145, and a limit for GRB 130427A
* Simulated HAWC light curve of GRB 090510



CTA simulation





Inoue et al. (2013)

FAST RADIO BURSTS & CTA

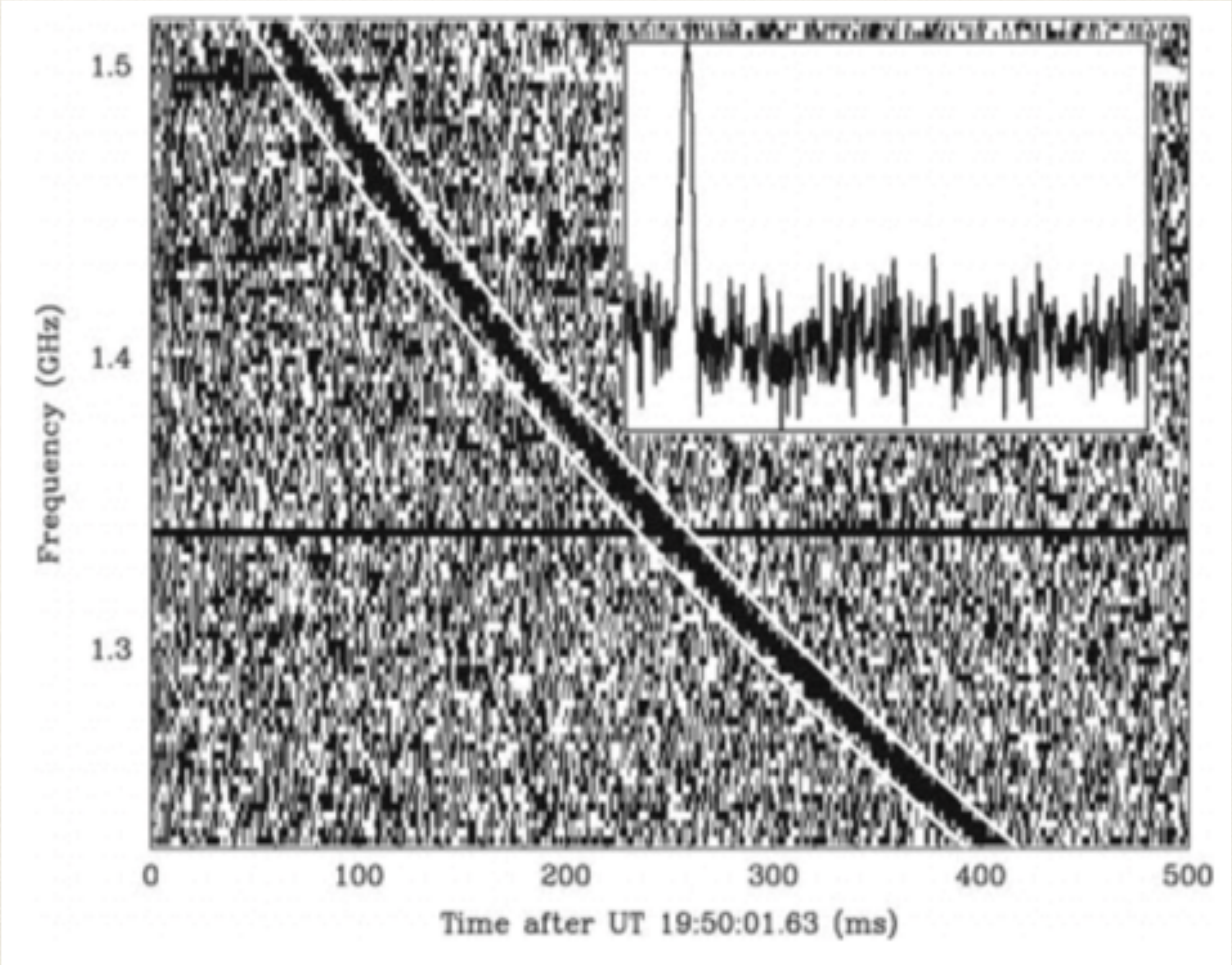
THE LOW & THE HIGH

TAM, Pak Hin (Sun Yat-sen University/ICRR)

Kashiwanoha, ICRR
15/12/2016

Fast Radio Bursts

* Discovered in 2007 (Lorimer et al.)
* ms-duration
* Large dispersion measure (DM), about 10 times the Milky Way contribution



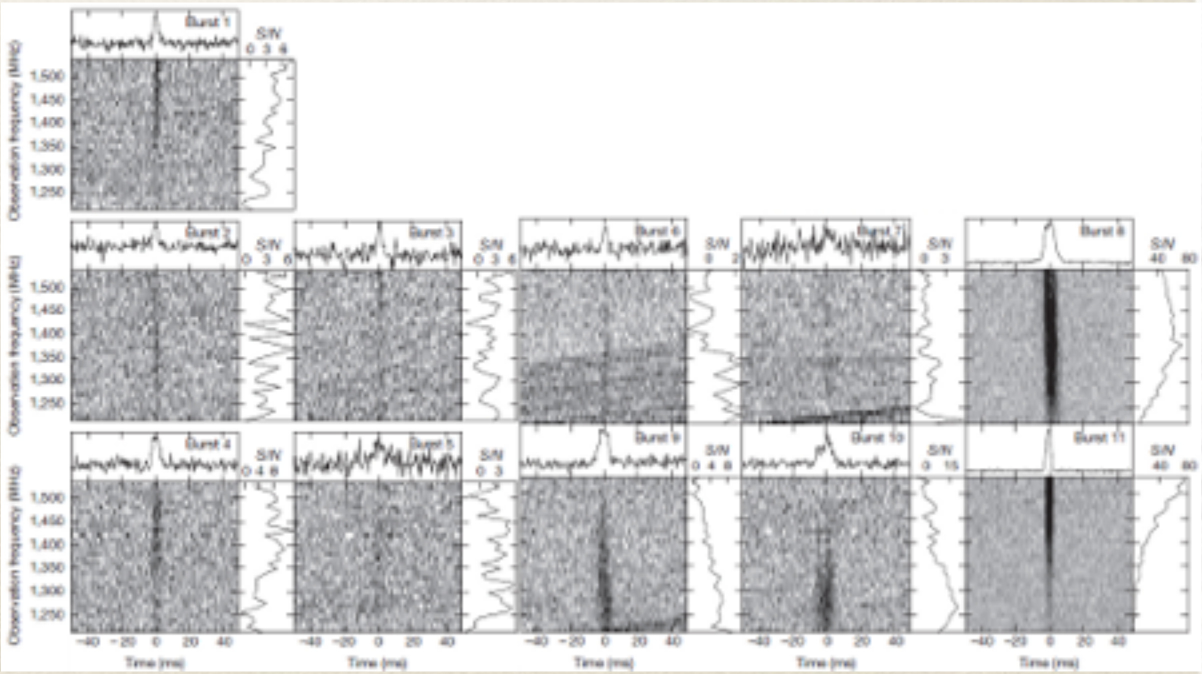
Lorime+ (2007)

Fast Radio Bursts

- Some or all excess DM may come from IGM Sources outside the Galaxy. Are they cosmological?
- Rate ~ 5,000 sky^{-1} day^{-1}
- Without EM signals in other wavelengths, our current knowledge of FRBs are pretty much like that of GRBs in the 1980s
- Many models proposed: some more discussed ones are: magnetar flares, neutron star collapse, binary mergers. Number of models > number of FRBs!

Recent developments (2016)

* A possibly fading radio afterglow & host galaxy (Keane+ 2016) of FRB 150418; this might be an AGN-like activity, though (Williams & Berger 2016)
* the first repeating FRB 121102 (Spitler+ 2016)
* No counterpart in any other wavelengths (Scholz+ 2016)



FRB 131104/ SwJ0644.5-5111

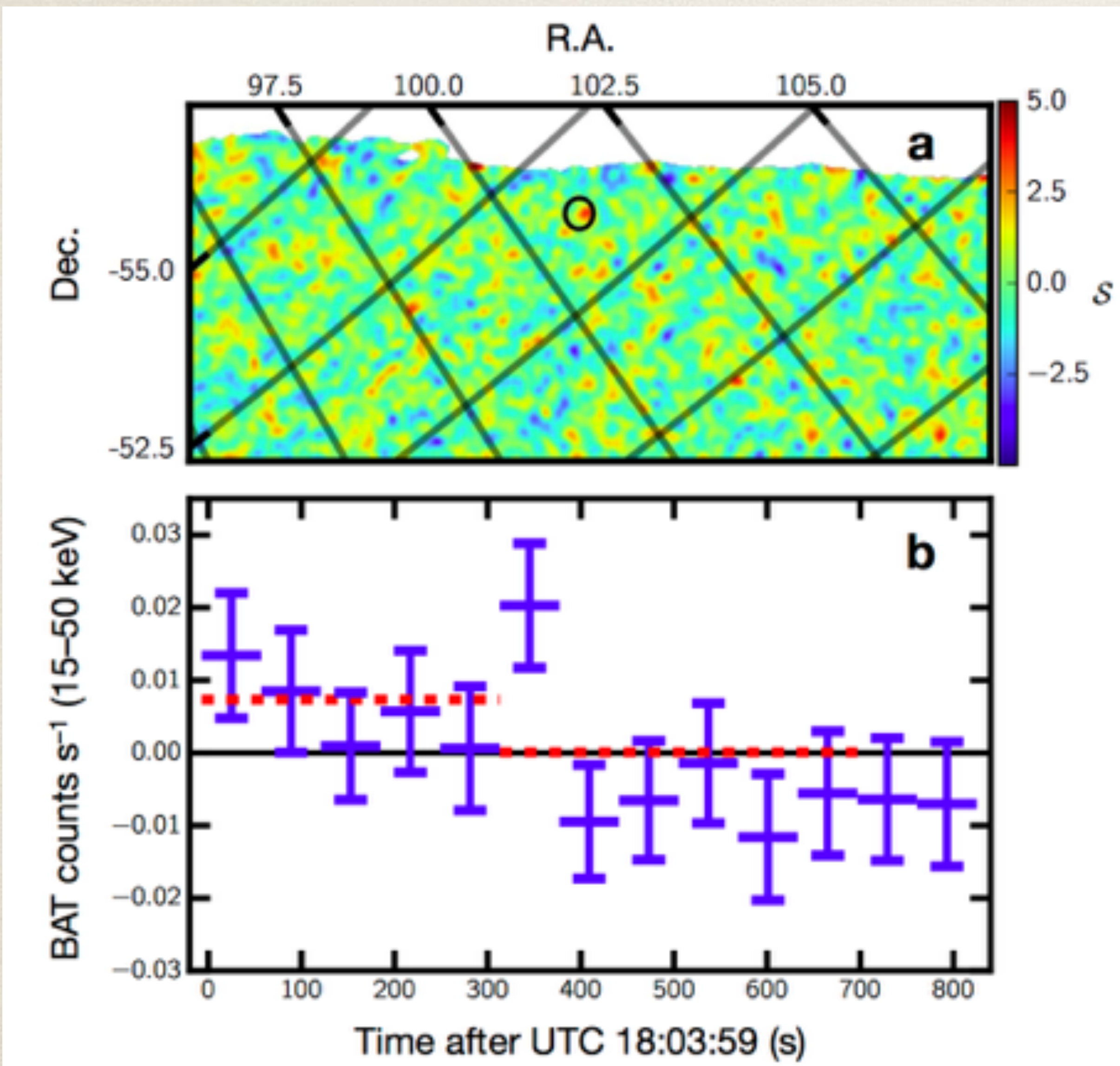


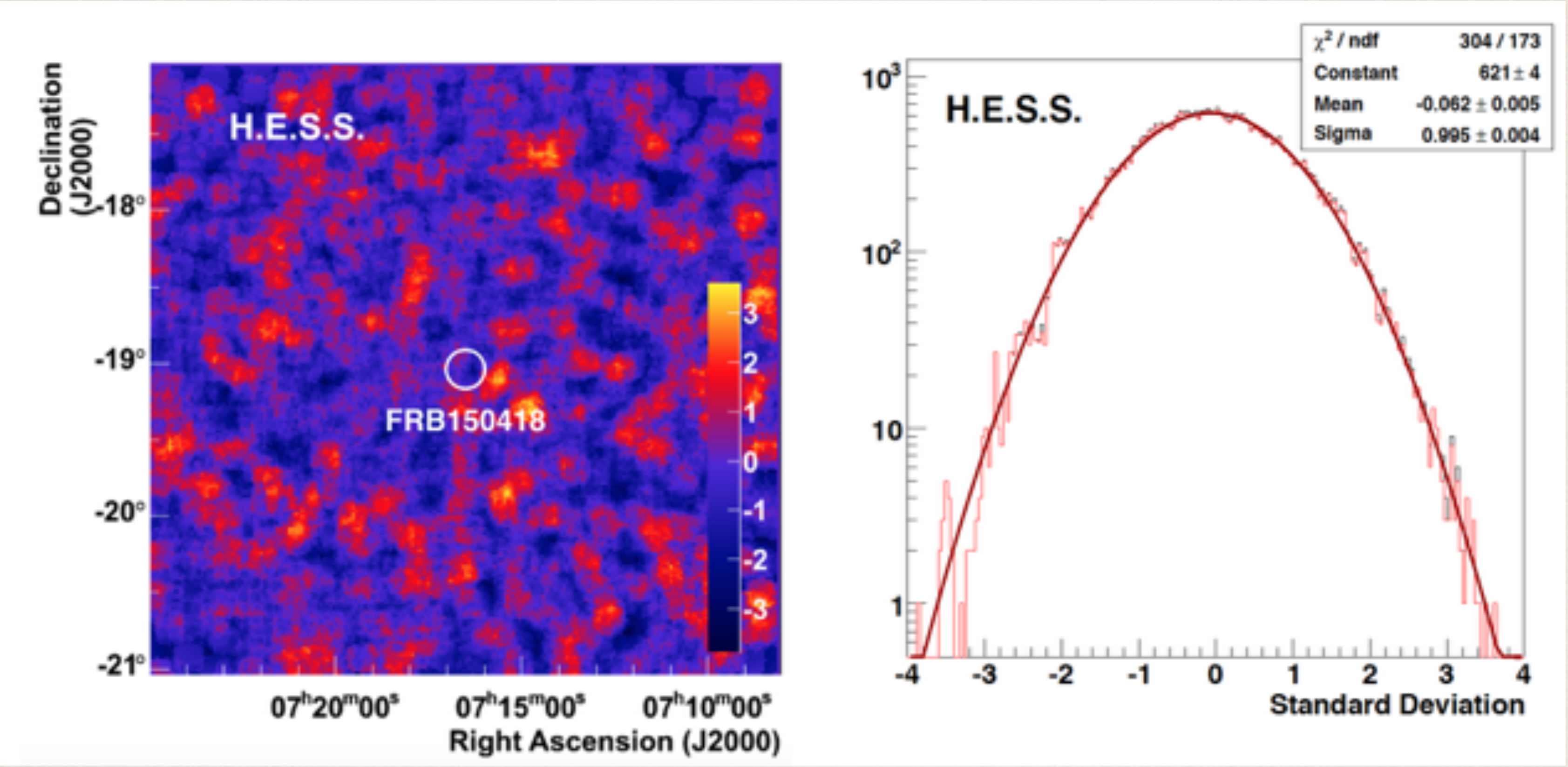
Table 2. Properties of FRB 131104

Joint	R.A.	$06^{h}\ 44^{m}\ 27\overset{s}{.}06$
	Dec.	$-51°\ 12'\ 54\overset{''}{.}0$
	r_{90}	$5\overset{'}{.}78$
Radio	UTC	18:03:59
	S_{GHz}	2.33 Jy ms
	DM	779 ± 1 pc cm^{-3}
	z_{max}	0.55
γ-ray	T_{90}	377 ± 24 s (1σ)
		>100 s (90%-c.l.)
PL	Γ	$1.16^{+0.68}_{-0.78}$
	$S_{\gamma,-6}$	4.0 ± 1.8
TB	kT	$200^{+\infty}_{-125}$ keV
	$S_{\gamma,-6}$	3.4 ± 1.5

Significance of association~3.2 sigma

DeLaunay+ (2016)

TeV observation of FRB150418



* Observations started 14.5 hr after the FRB, lasting for 1.1 hr
* No detection

CTA prospects?

* Prompt follow-up observations need coordination with radio facilities
* Pointed observations of repeating FRBs?
* Compared to GRBs, FRBs are more nearby, reducing the effect of EBL.
* Gamma-rays are less absorbed by FRB local environment
* Crucial: whether FRBs emit gamma-rays (or any counterpart at all) is an open question

Summary

- **GRBs**: 10-100 GeV is probably the last observing window which is still missing *(apart from a few photons seen by Fermi/LAT)*. It contains important clues on GRBs, EBL and related astrophysics.
- **Fast Radio Bursts**: origin unknown, but they are energetic and probably related to compact objects (see also talk by T. Totani tomorrow)