GAMMA-RAY BURSTS 在100 GEV 的輻射

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H.E.S.S. collaboration, FAN

南开大学
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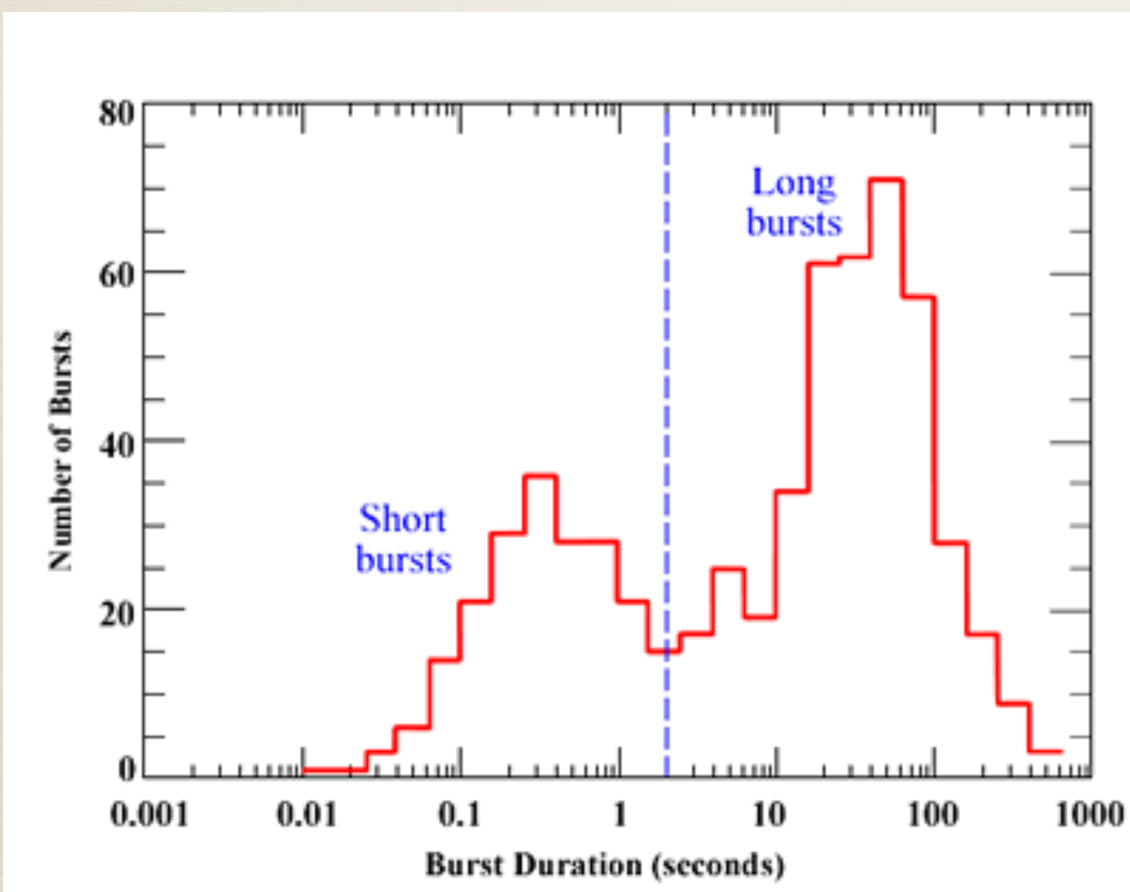
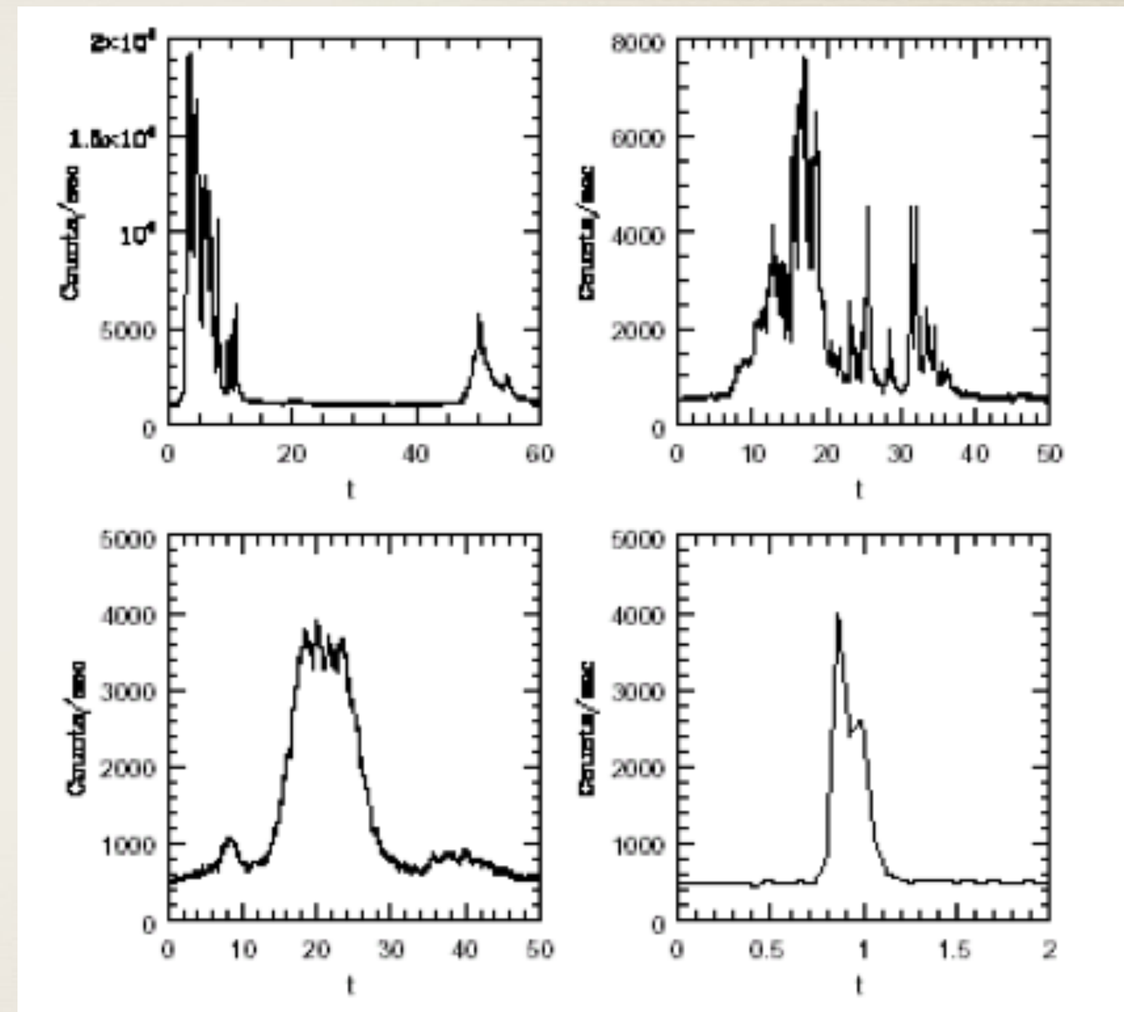
Contents

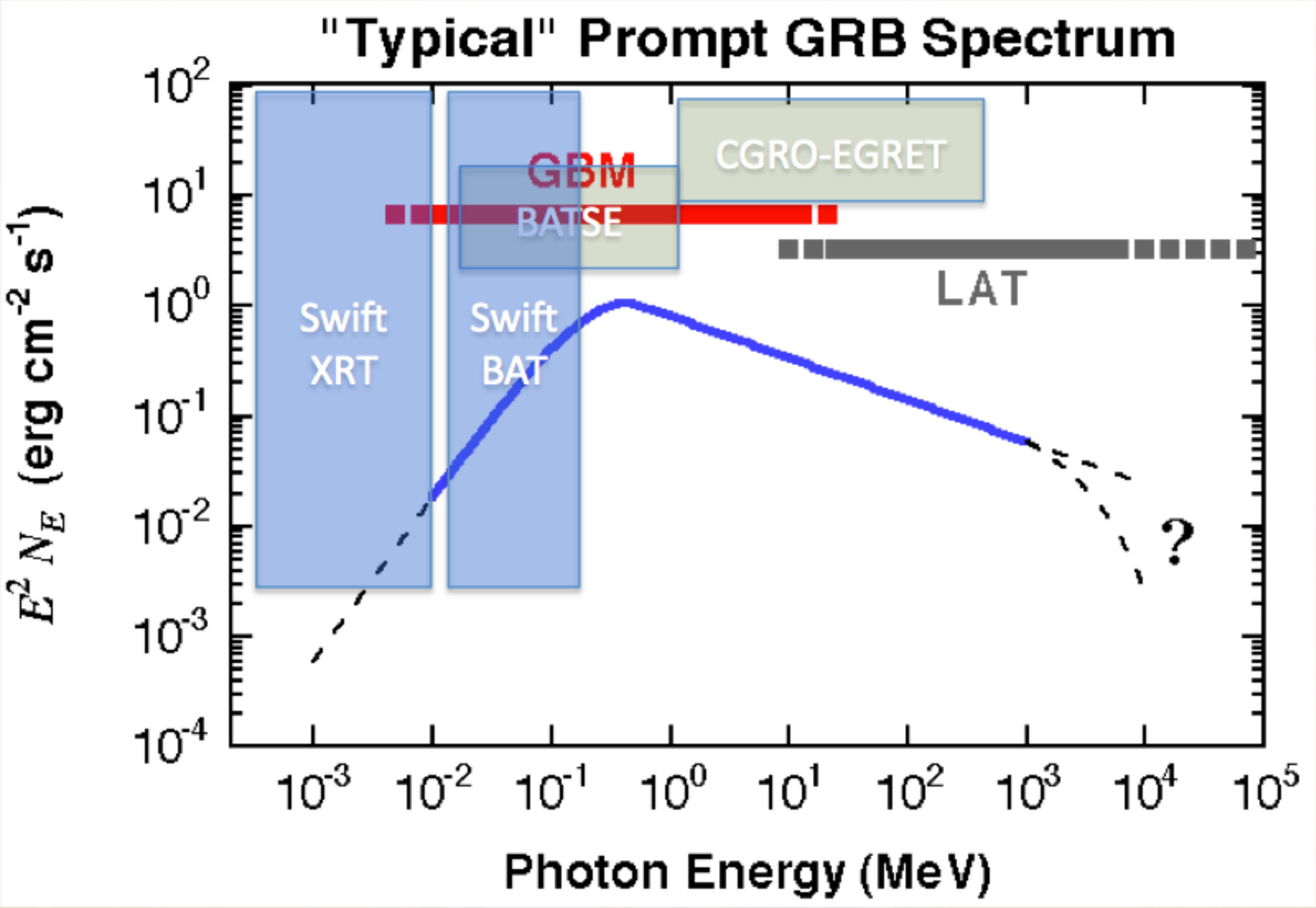
* Fermi-LAT Observations of GRBs
* Photons with the highest energy (~100 GeV) from GRBs
* Ground-based observations of GRBs
* LHAASO opportunities of GRBs

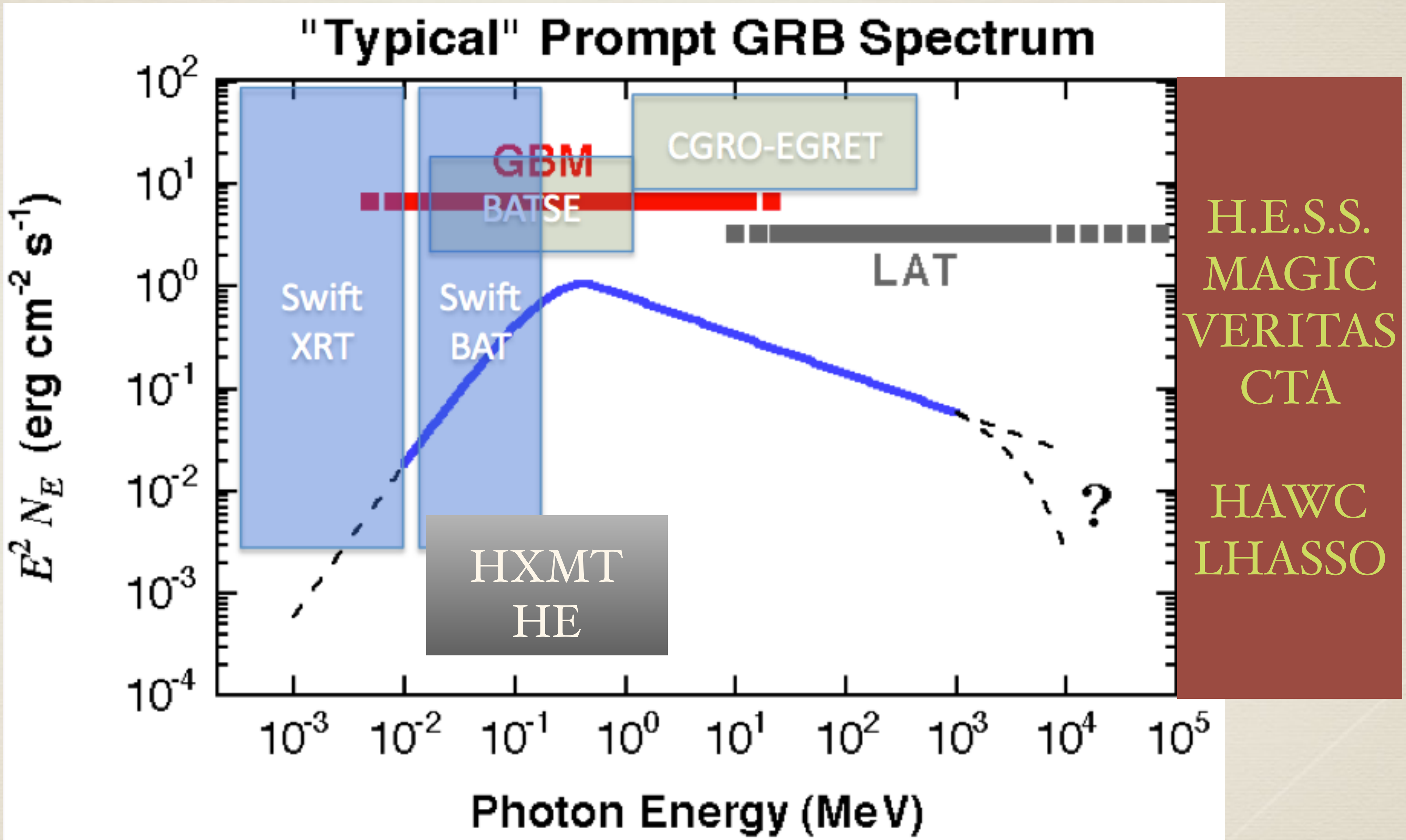
What are GRBs?

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






"Typical" Prompt GRB Spectrum
$E^2 N_E$ (erg cm^{-2} s^{-1})
Photon Energy (MeV)
Swift XRT
Swift BAT
GBM
BATSE
CGRO-EGRET
LAT
?
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



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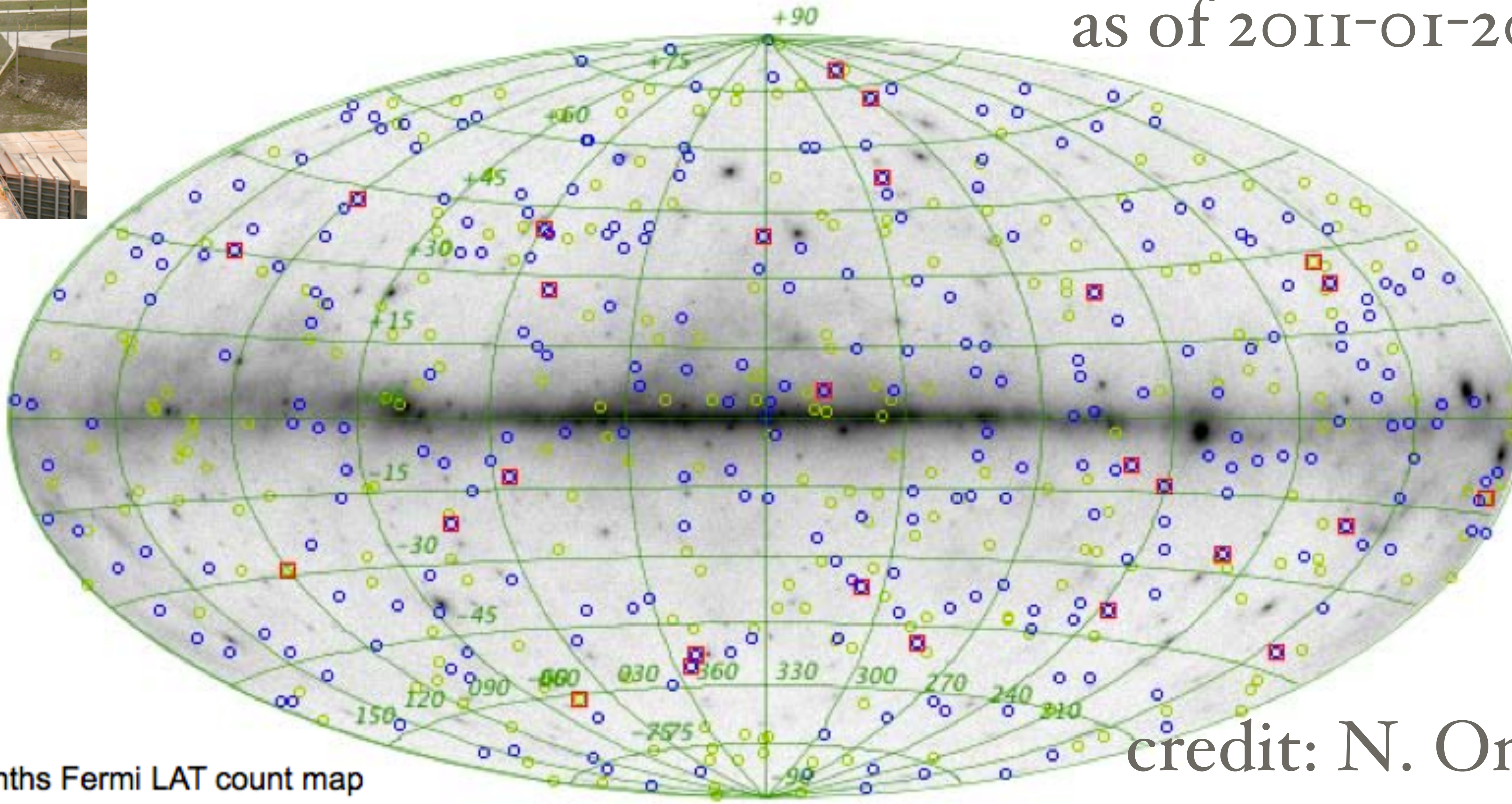
10^{-3} 10^{-2} 10^{-1} 10^{0} 10^{1} 10^{2} 10^{3} 10^{4} 10^{5}
Swift XRT
Swift BAT
GBM
BATSE
CGRO-EGRET
LAT
HXMT HE
?
H.E.S.S.
MAGIC
VERITAS
CTA
HAWC
LHASSO

What does Fermi see?

as of 2011-01-20



11 months Fermi LAT count map

Circles:
- In Field-of-view of LAT (<70˚): 275
- Out of the FOV

Squares:
- LAT detections

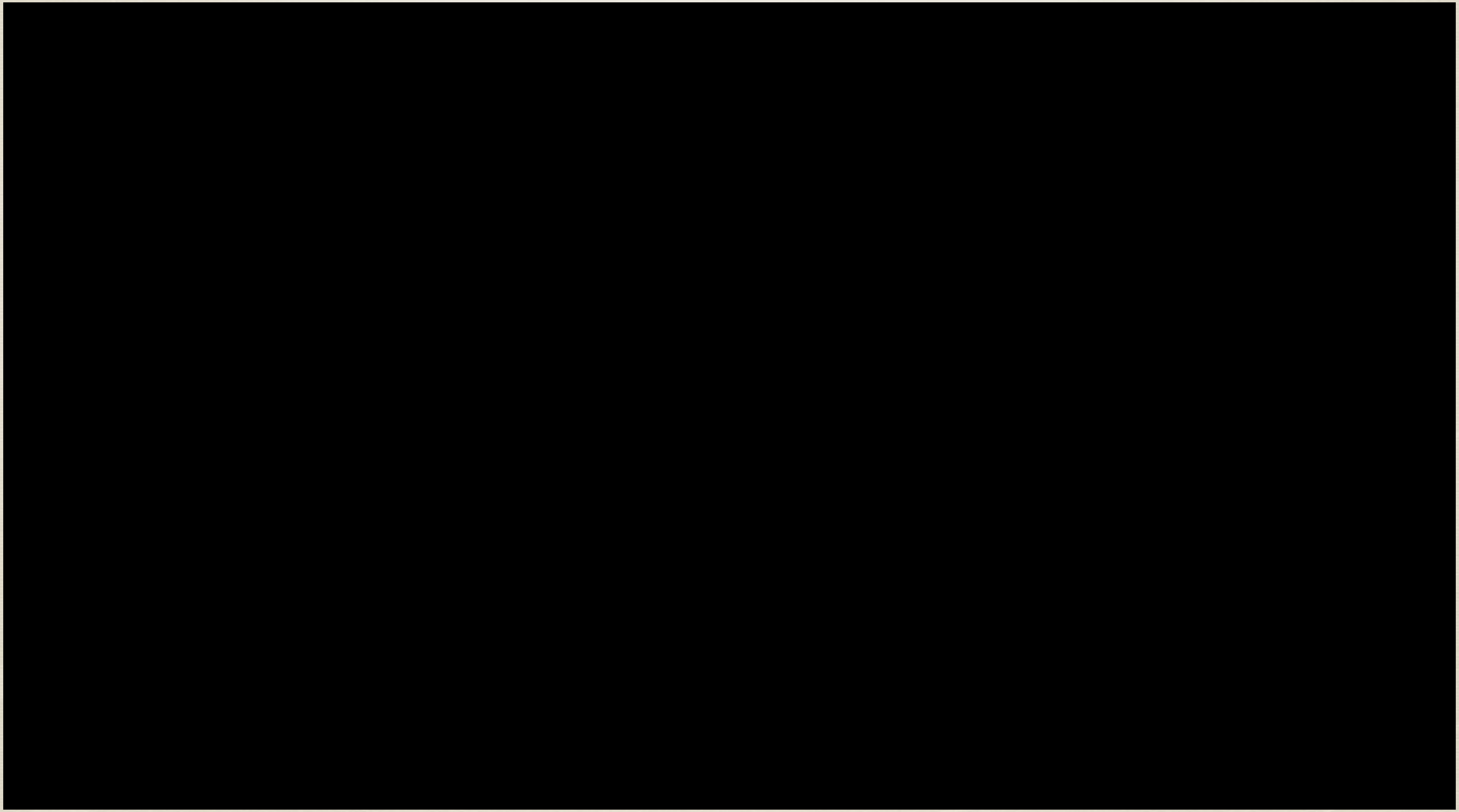
~550 GBM GRB (since Aug 2008)

27 LAT GRB (7 LAT LLE-only GRB)

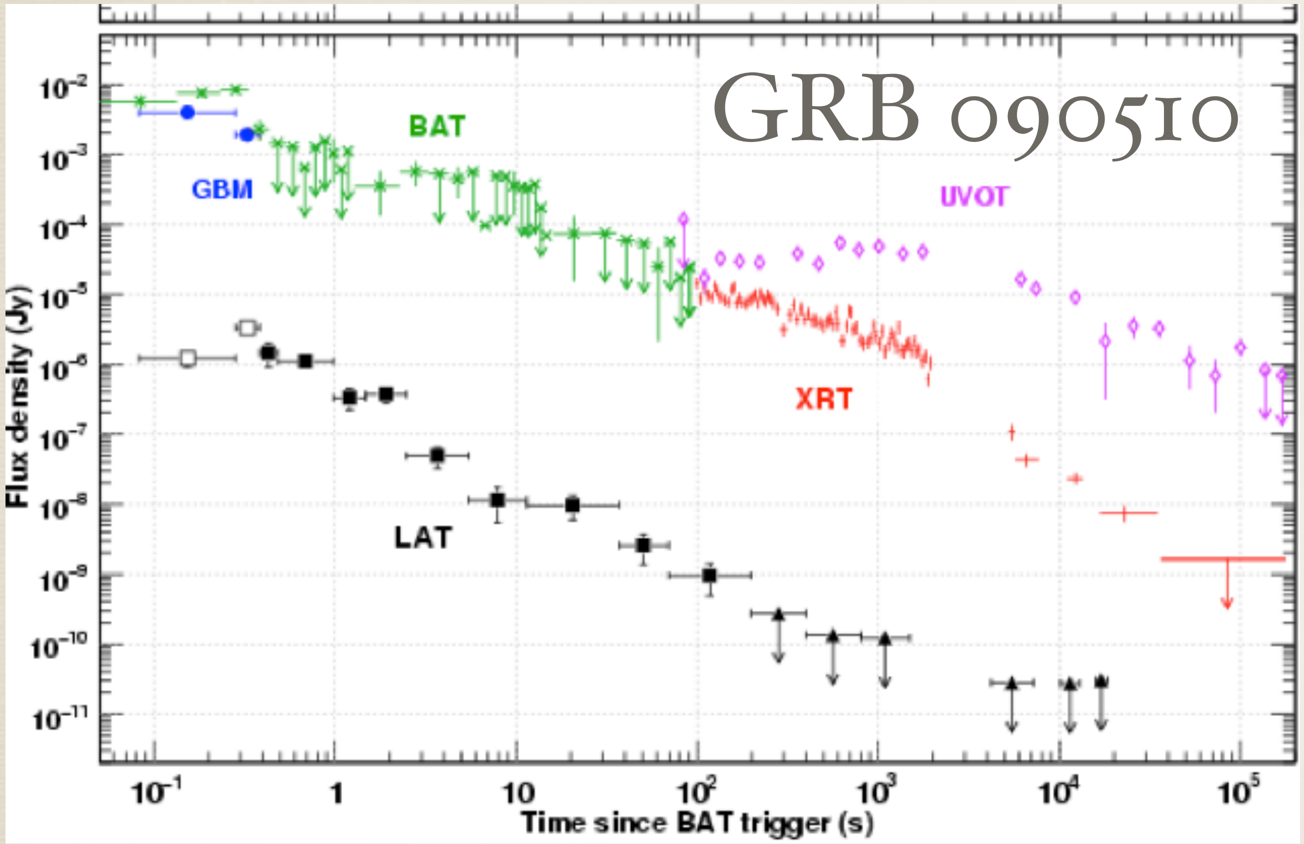
credit: N. Omodei

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

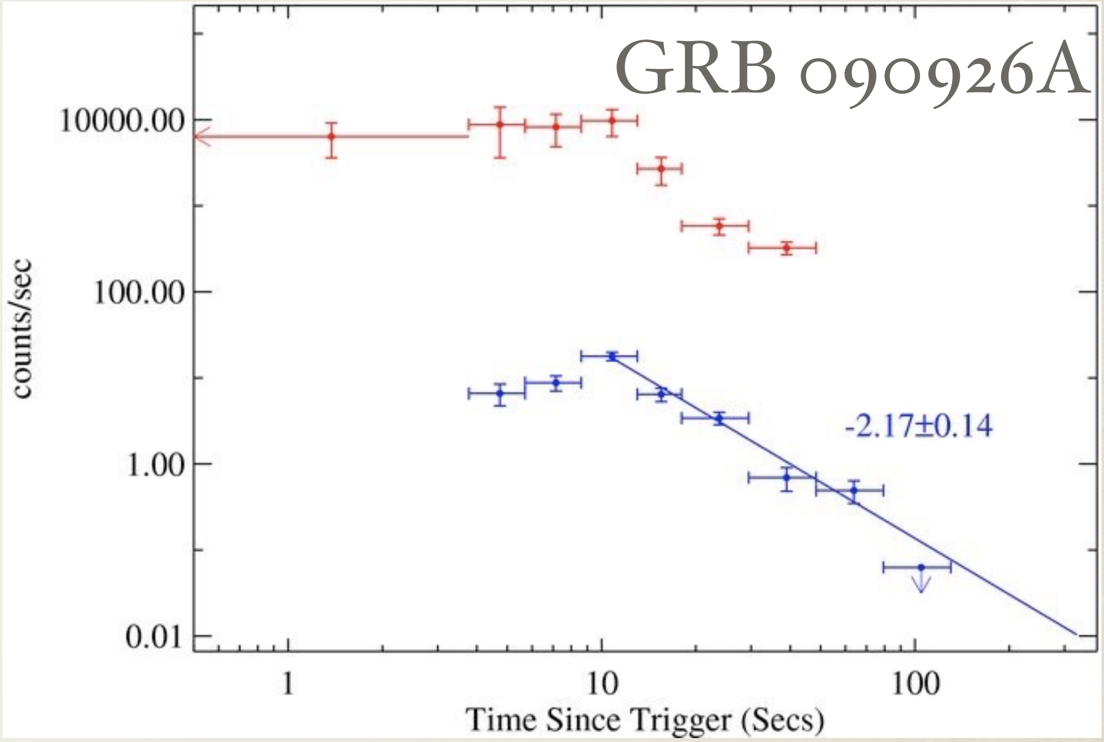
What have H.E.S.S./MAGIC/ VERITAS/HAWC seen?



GeV emission during afterglow

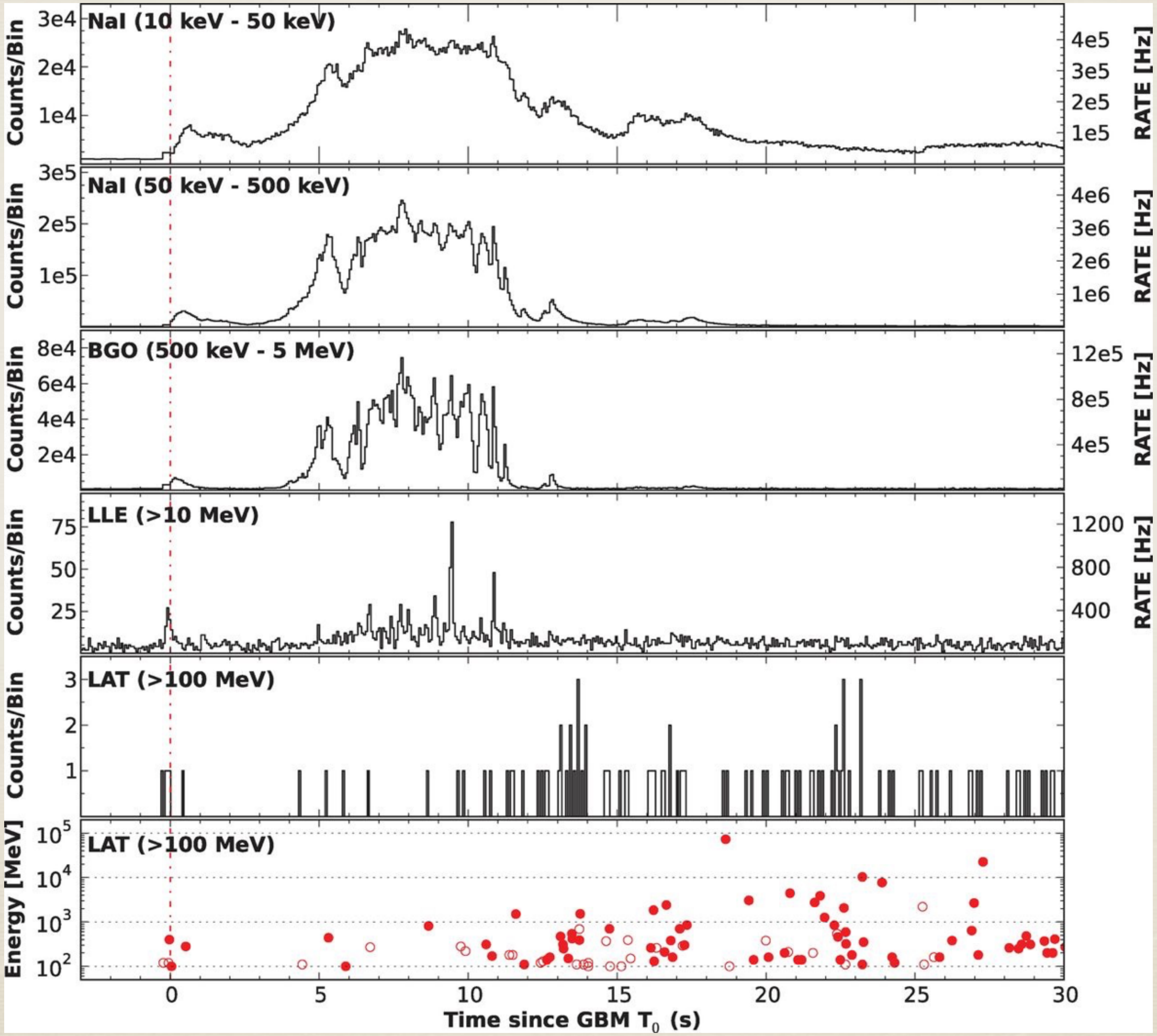


Abdo et al. (2010)



Swenson et al. (2010)

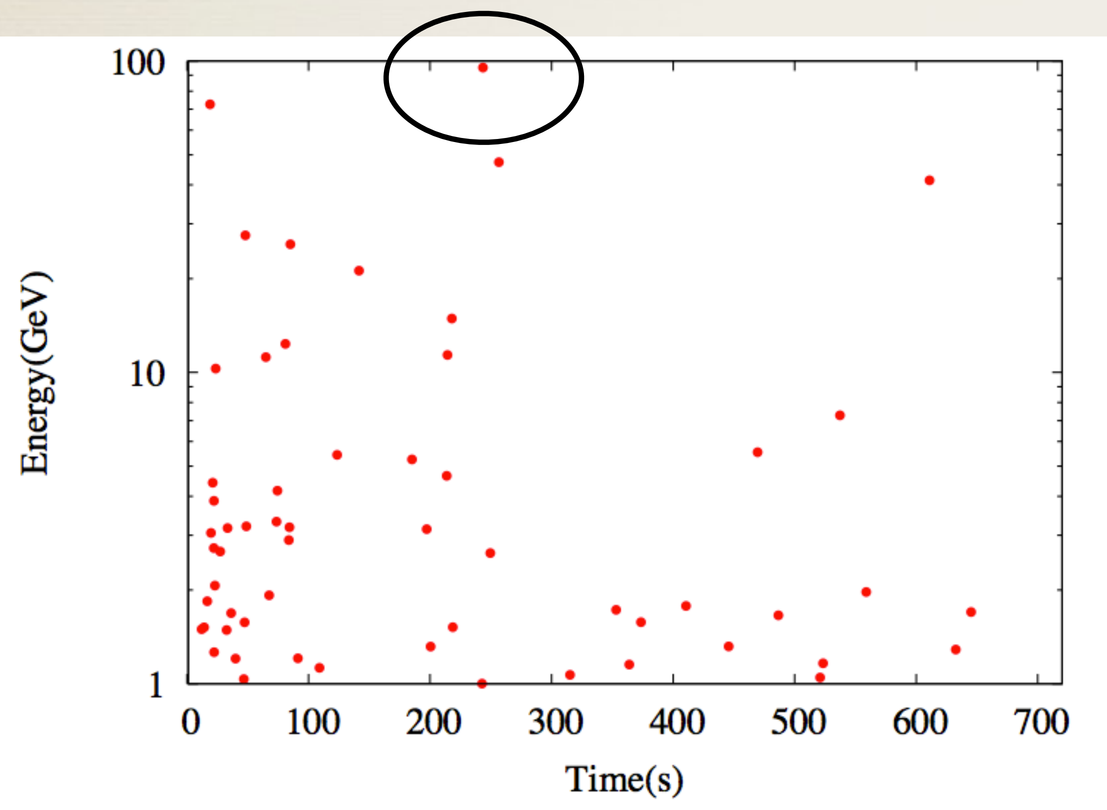
Very bright GRB 130427A



10-100 GeV photons

GRB 130427A emits many high-energy gamma-rays during the prompt & afterglow period

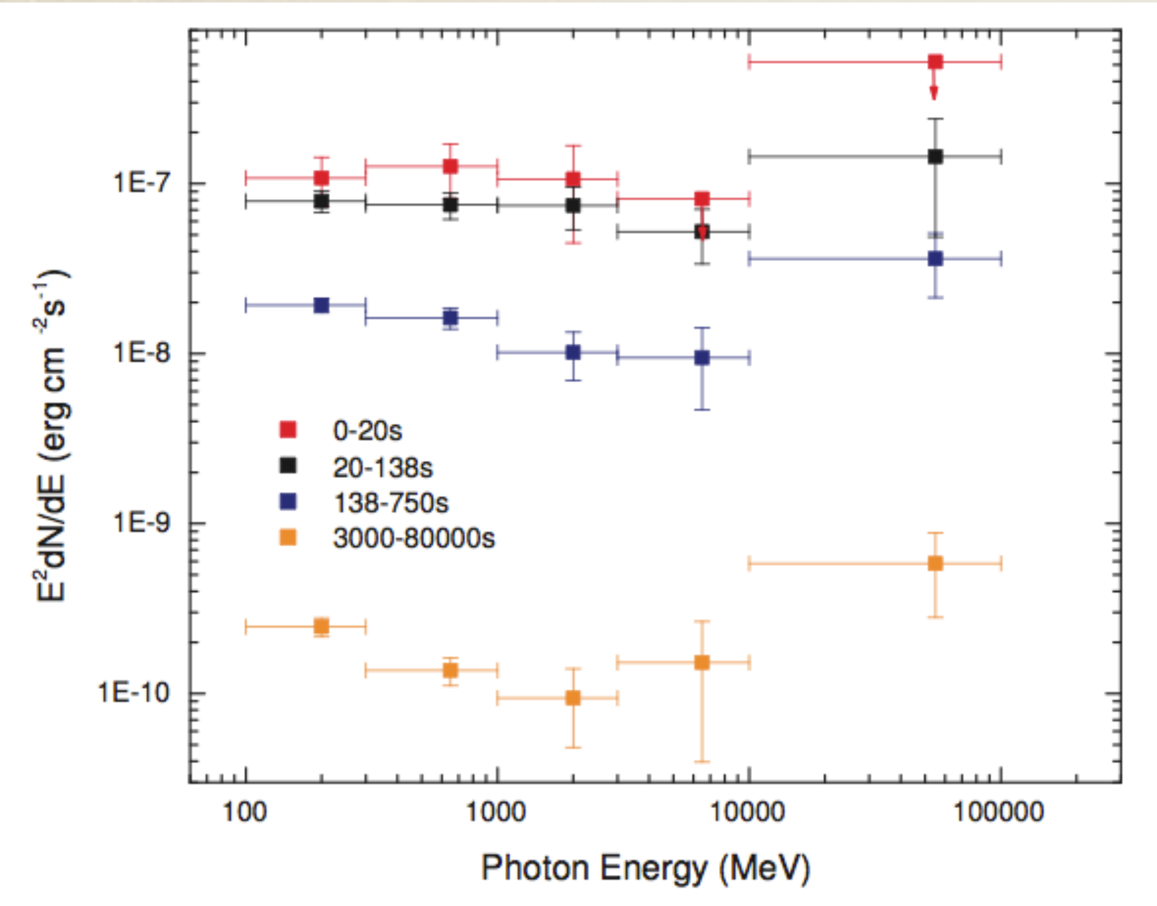
95 GeV

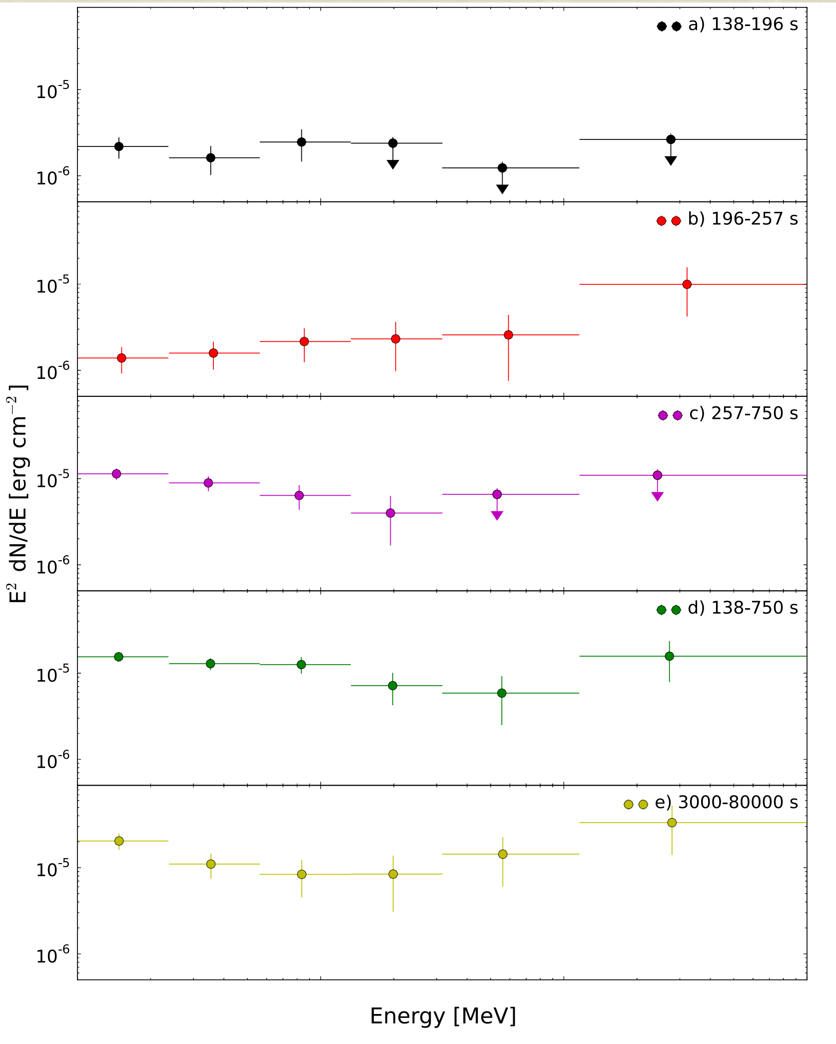


Fan, Tam, et al. (2013)

- a 95 GeV photon arrived at T_0 + 243s, corresponding to an intrinsic photon energy 128 GeV at z=0.34

Spectral evolution





Ackermann et al. (2014)

$t - T_0$ (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 $\sqrt{2 \times [\log(\mathcal{L}_{BPL}) - \log(\mathcal{L}_{PL})]}$

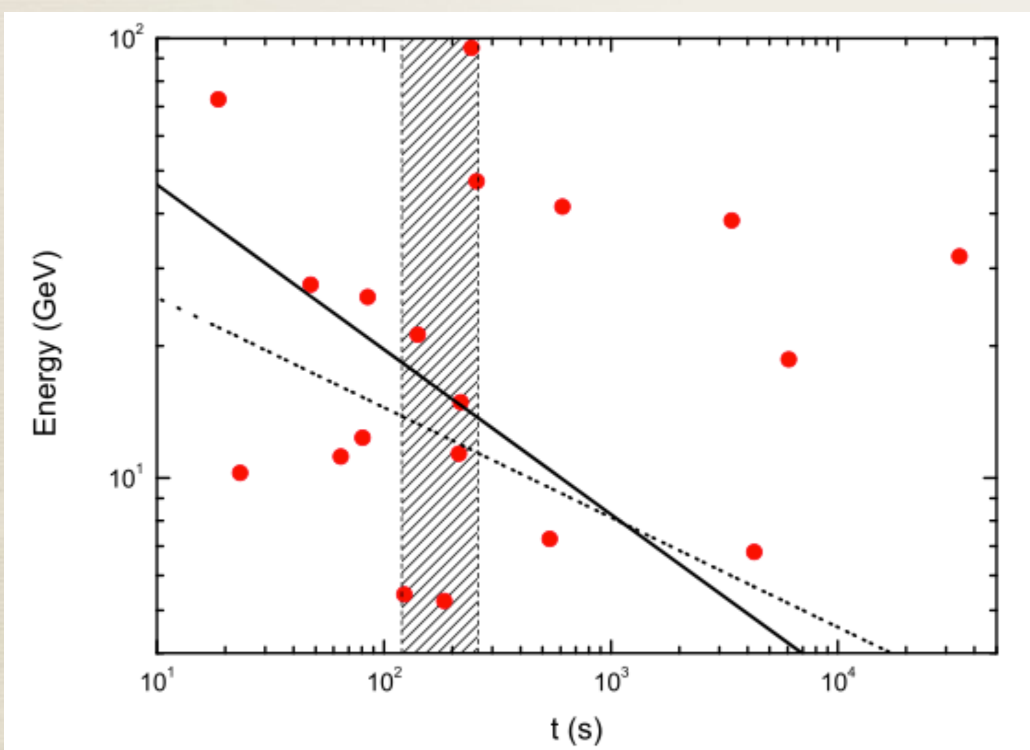
Power law index doesn't change!

Tam et al. (2013)

Significance of broken power law over power law

extended emission mechanism

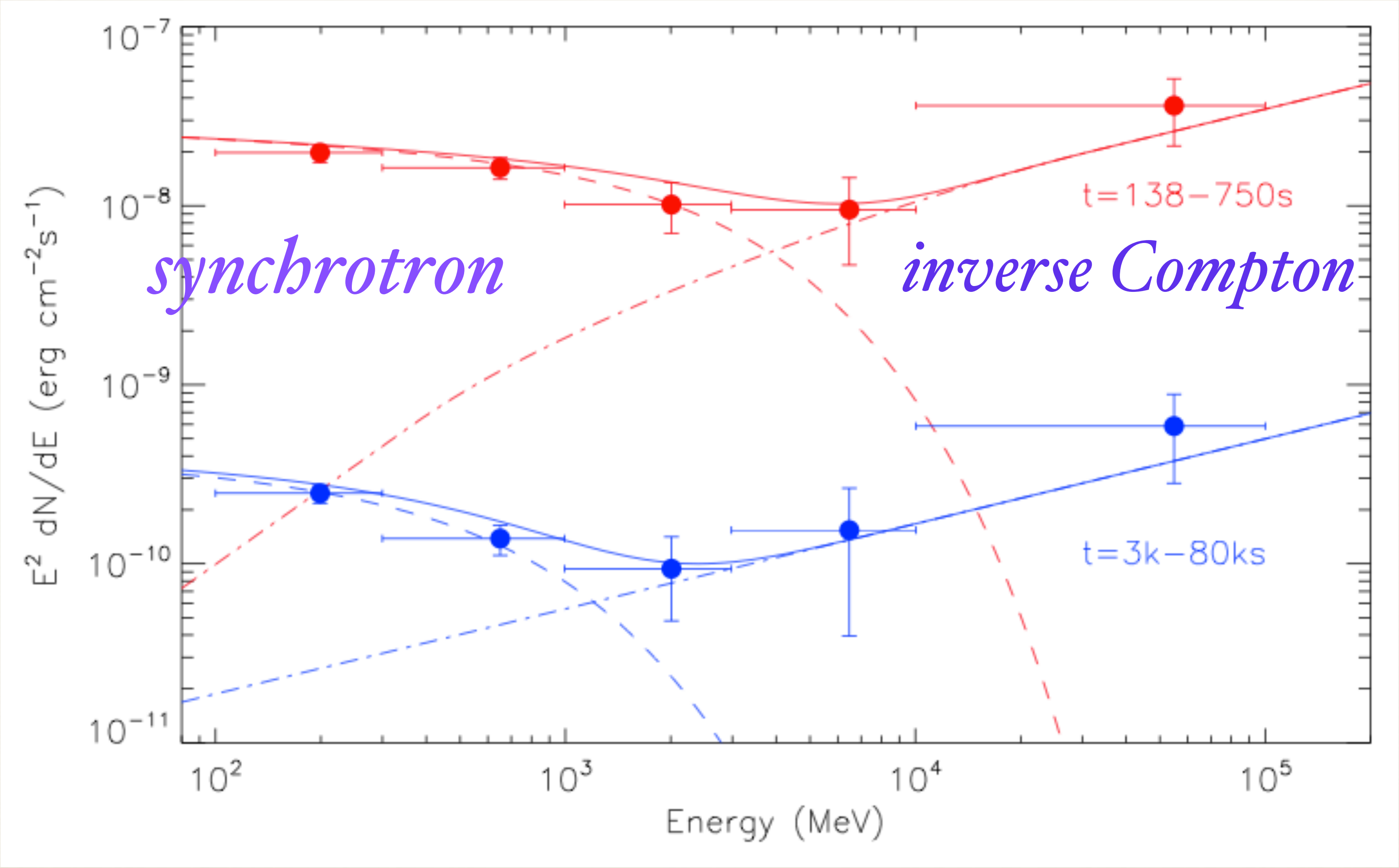
* Synchrotron emission (e.g., Kumar & Barniol 2009, Ghisellini et al. 2010)
* but there exists a maximum synchrotron energy, it is hard to explain the >10 GeV photons



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

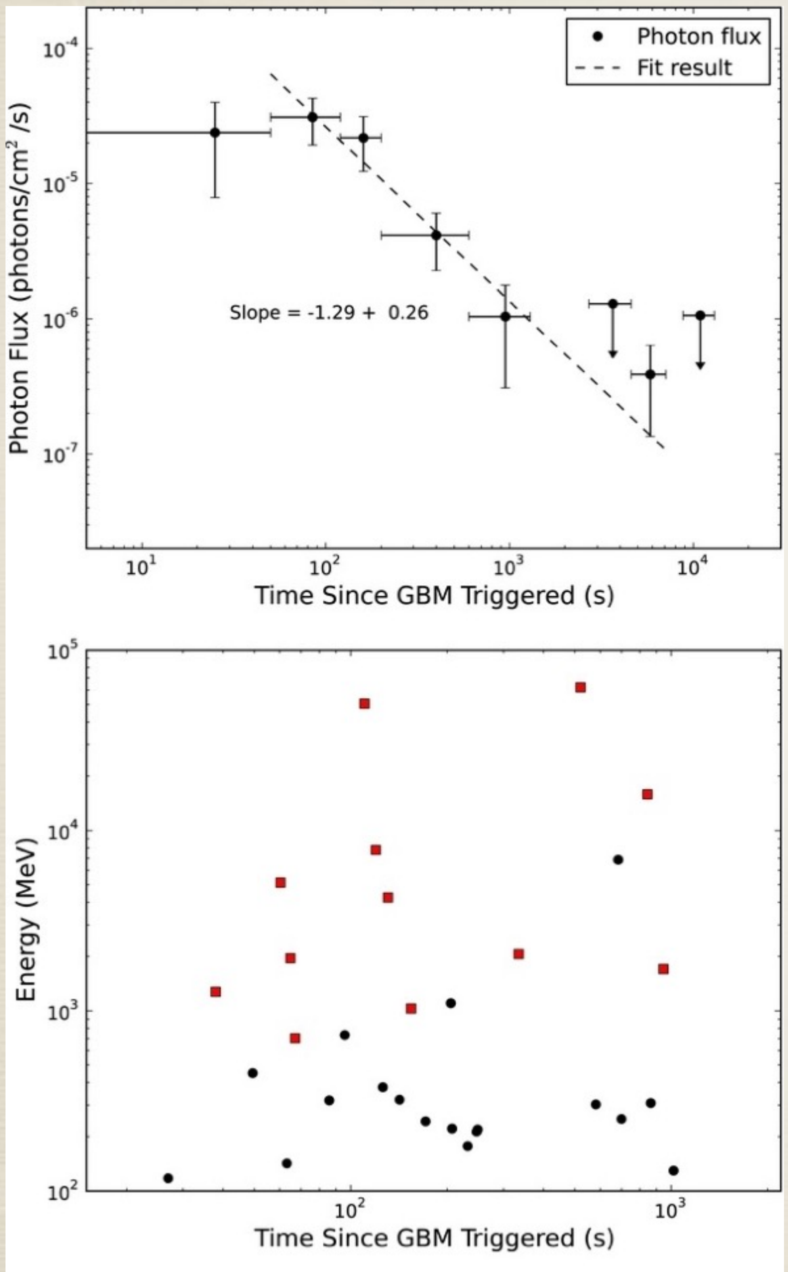
Fan, Tam, et al. (2013)
also see Ackermann et al. (2013)

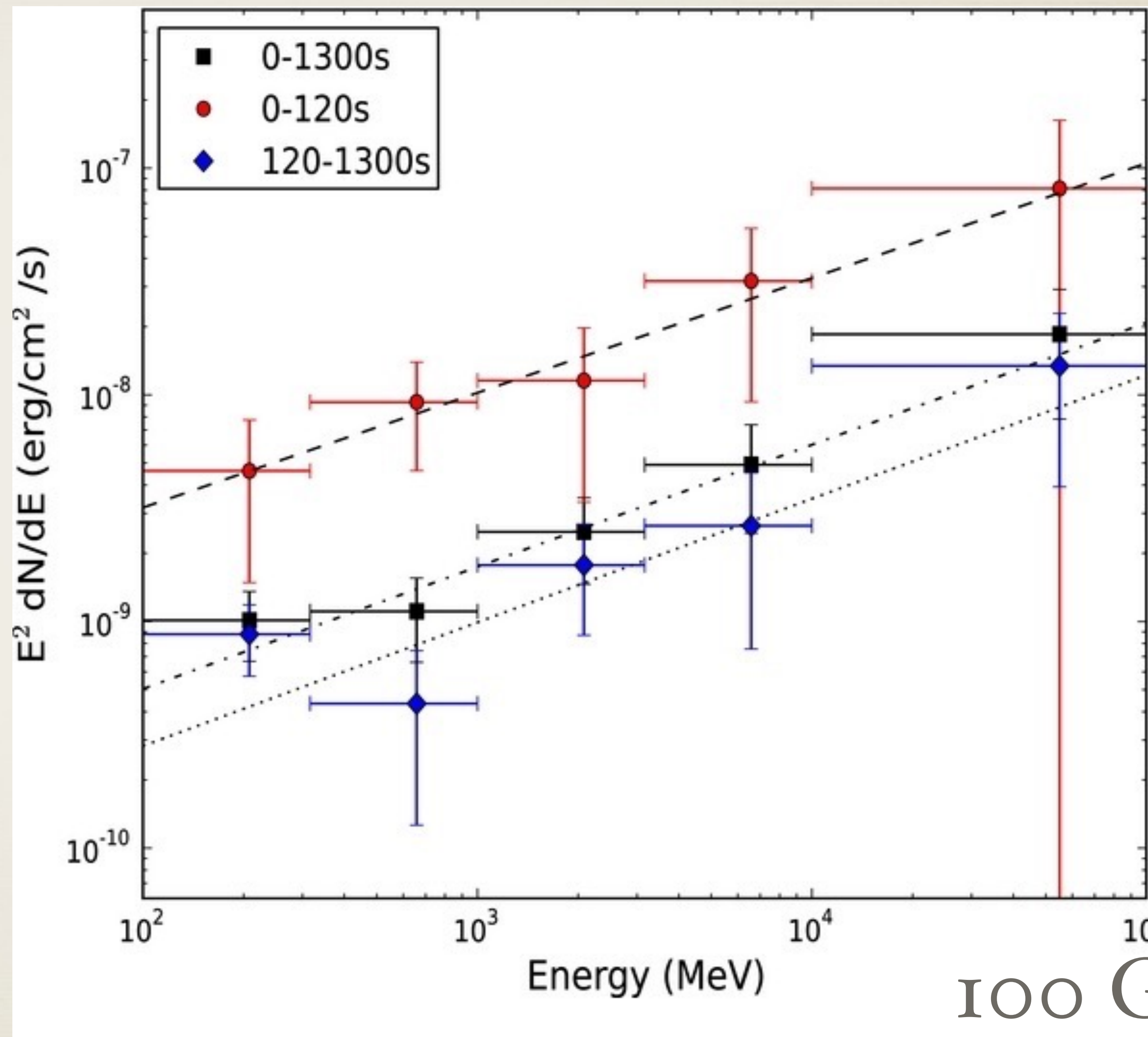
Inverse Compton emission can explain the extra hard component



Liu et al. (2013)

GRB 131231A





100 GeV

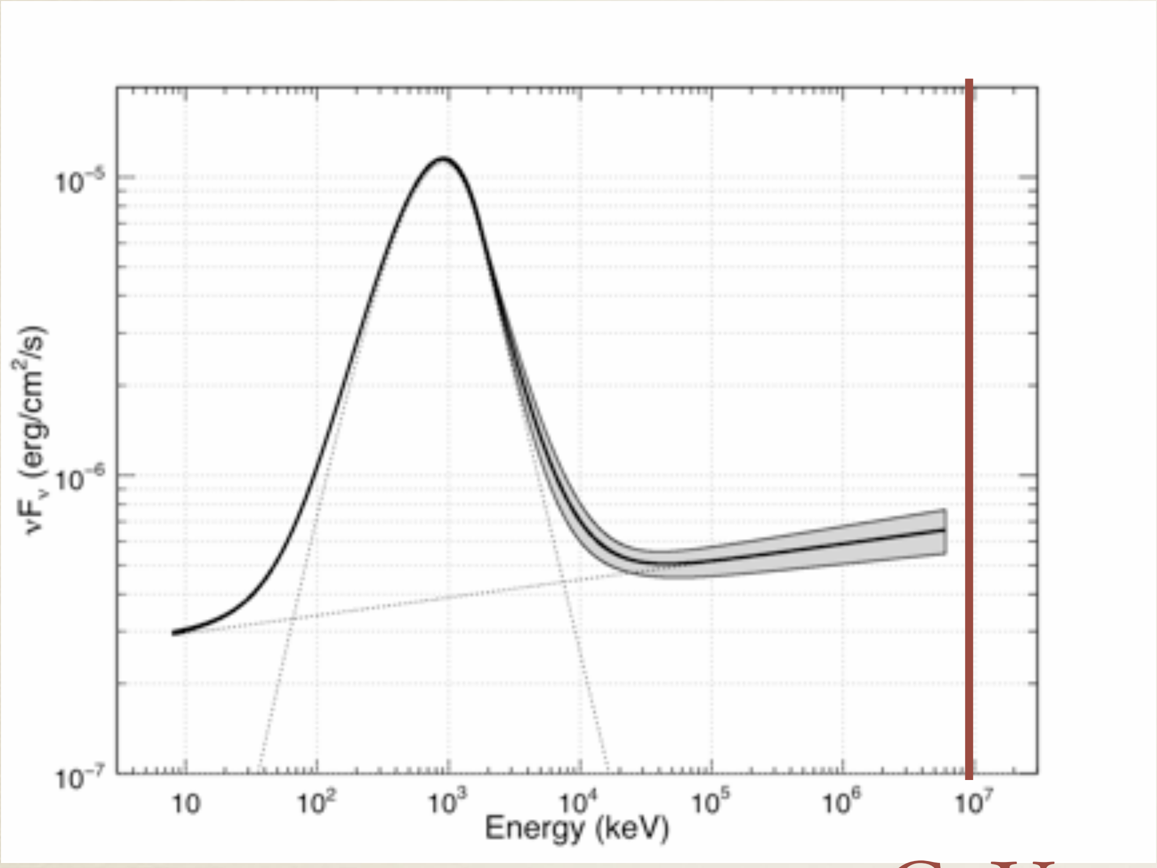
Liu, B. et al. (2014)

Probably the strongest case for IC emission, besides 130427A

* But the very high-energy photons come from the afterglow phase,
* and the 95 GeV photon was detected at 243s after the trigger
* **Is there any ~100 GeV during the prompt emission?**

Second component during prompt phase

GRB 090902B

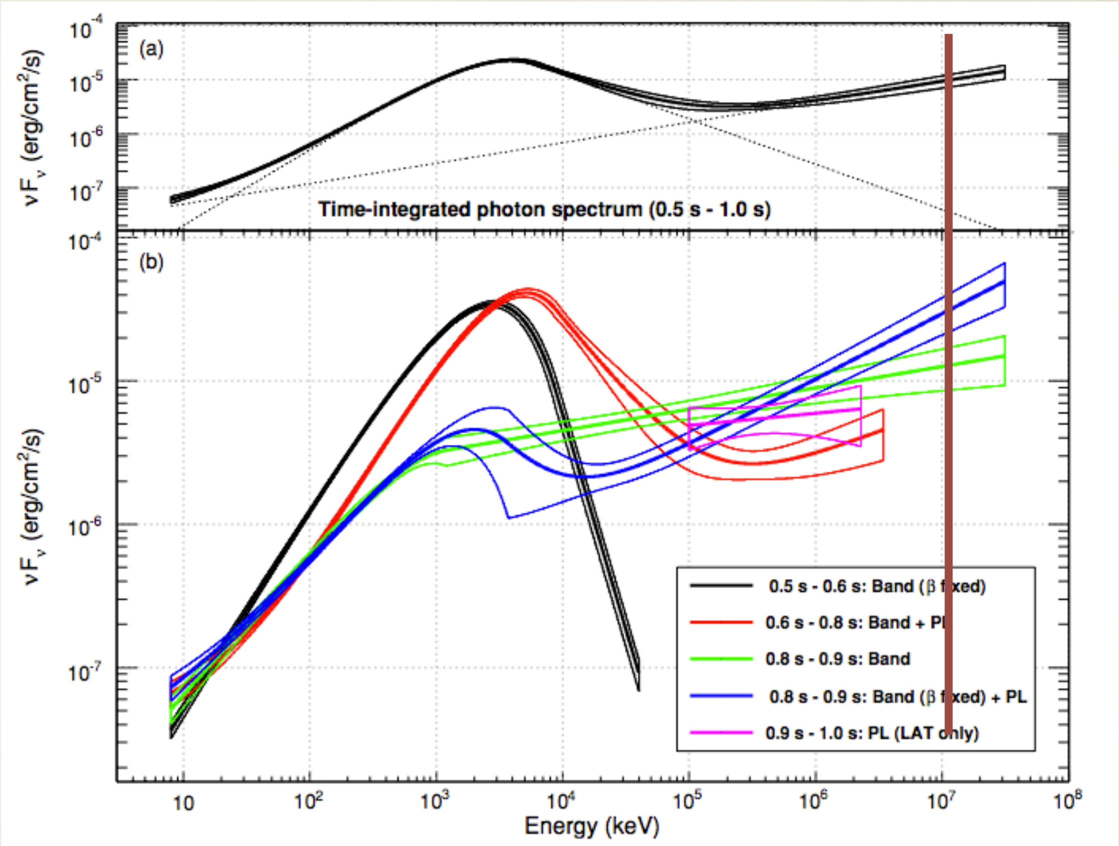


~10 GeV

Abdo et al. (2009)

~10 sec after trigger

GRB 090510



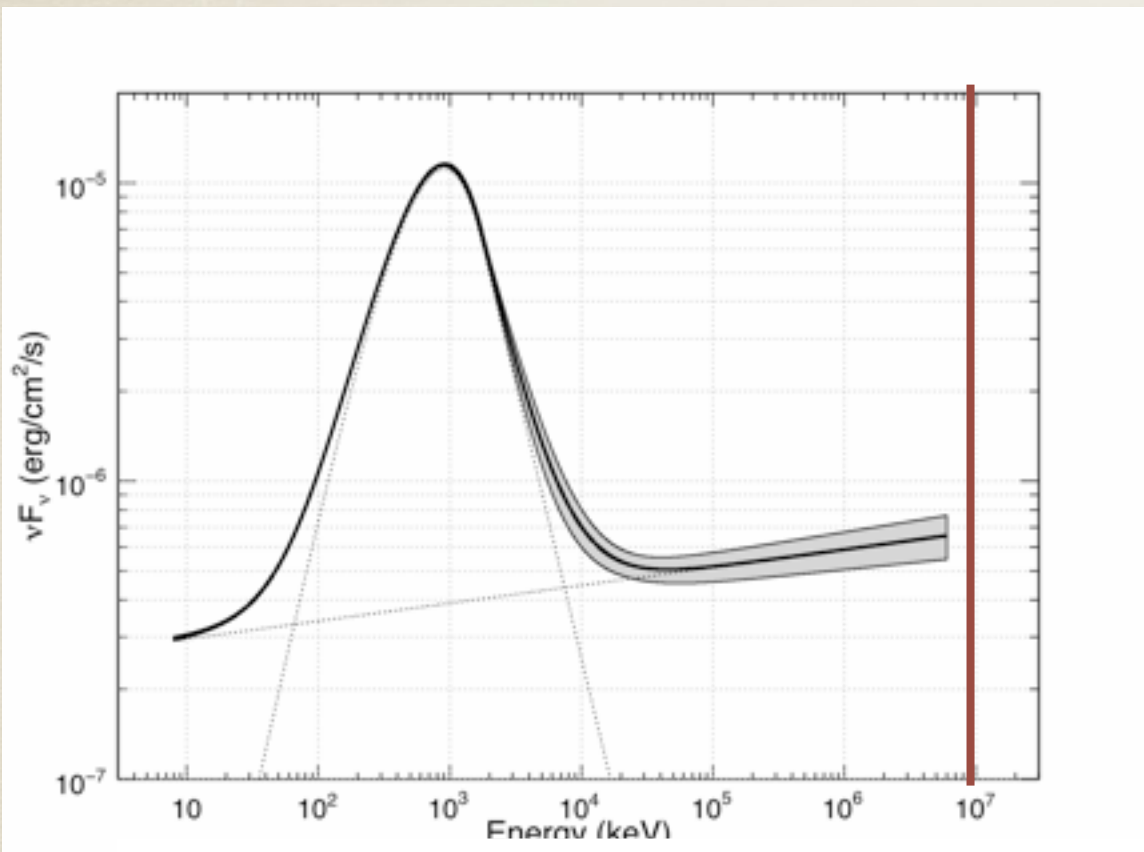
10 GeV

Ackermann, et al. 2010

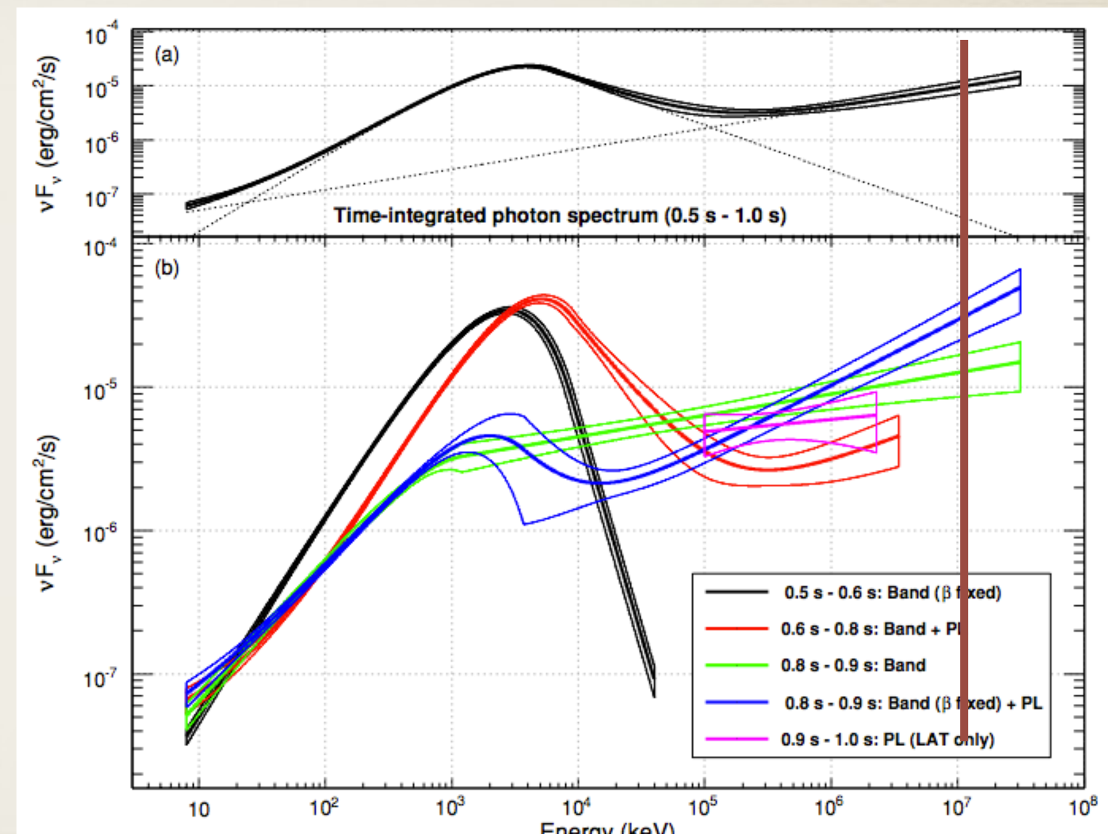
~1 sec after trigger

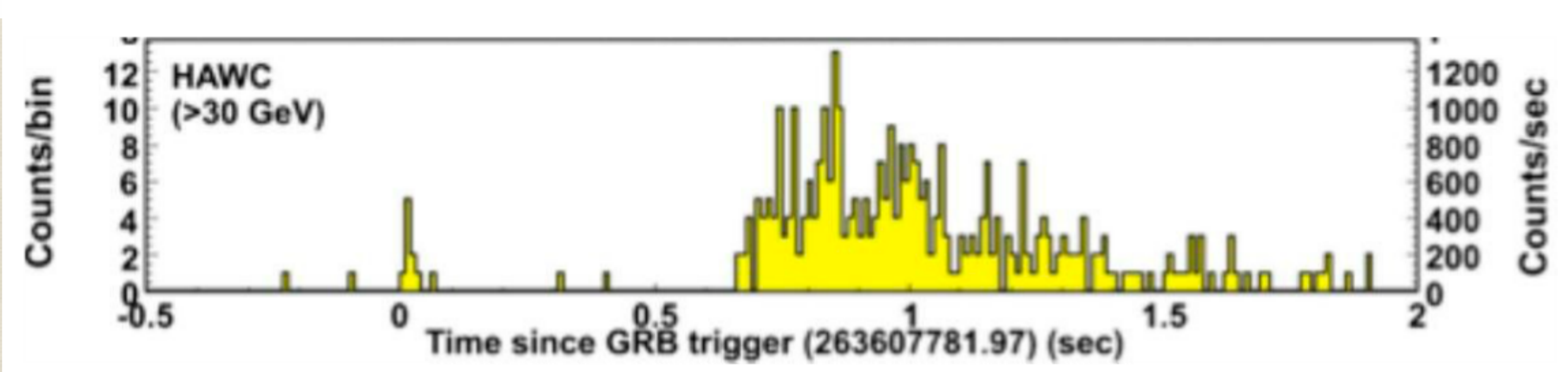
Second component during prompt phase

GRB 090902B



GRB 090510





Fermi的限制

* 在10 GeV以上，Fermi-LAT已经看到了与伽玛暴相关的约十个光子，包括一个来自GRB 080916C(z=4.35)的27.4 GeV光子（从源出发时是147 GeV），和GRB 130427A的一个95 GeV的光子，证明伽玛暴能产生约100 GeV的极高能伽玛光子！
* 随着时间的推移，Fermi-LAT将在未来几年看到更多10 GeV以上光子。但Fermi-LAT受制于有限的可接收面积(约0.8平方米)，将来也始终无法很好的得到10 GeV以上的伽玛辐射谱和光变。
* 要大幅提升可探测的极高能的伽玛光子数，就必须仰赖地面伽玛射线探测器。

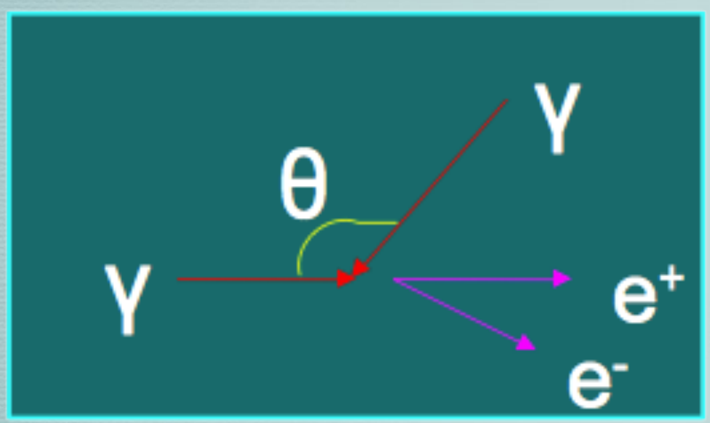
Why bother the very high-energy photons of GRBs?

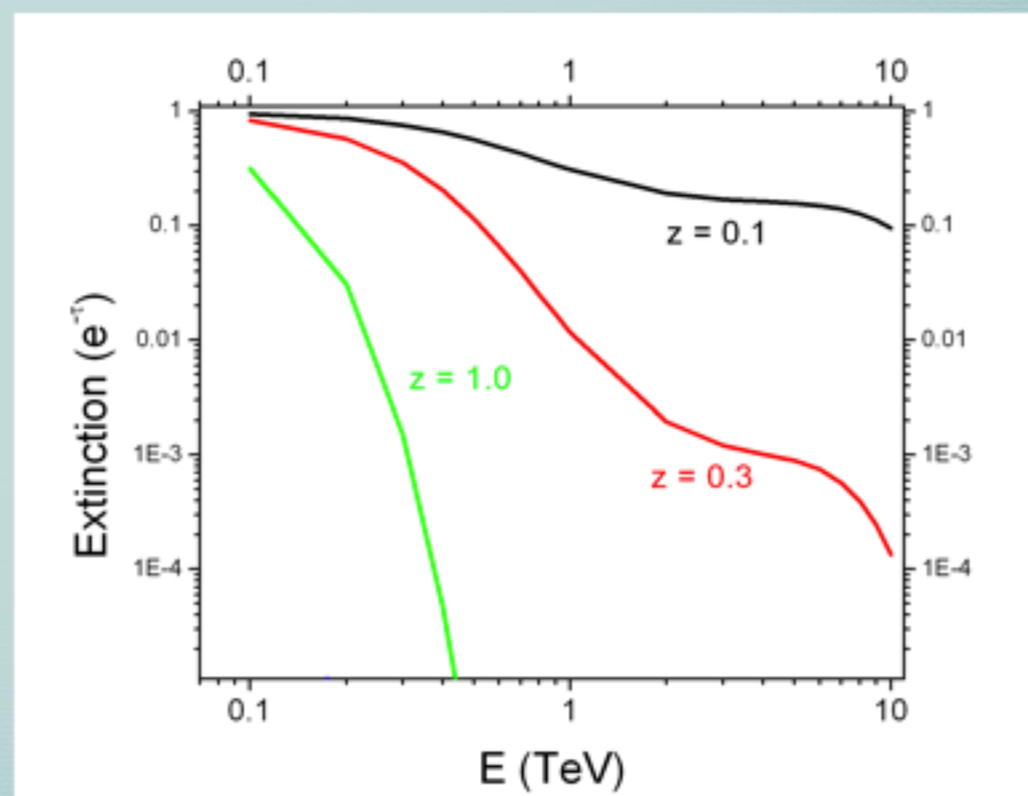
* Because LHAASO is upcoming!
* The radiation mechanism is still under debate
* The energy band where extragalactic background light (EBL) attenuation starts to modify the intrinsic spectra of the sources (e.g., AGN, GRBs)
* At these energies, GRBs can be seen at distances further than those of AGN, because of the EBL

Extragalactic background Light

γ-γ interaction

high-energy photons will suffer absorption by EBL





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

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

Aharonian et al. (HESS), Nature, 2006

一點回顧……

* 对于伽玛暴及其馀辉，地面伽玛射线探测器已经从事了约二十年的观测，还没实现首次显着性足够高的伽玛暴探测。
* 比较着名的有：
  MILAGRITO对于970417A的观测（2.7σ），
  国内的则有羊八井ASγ对于991208的观测，后者还被看到类似GRB 990123的可见光馀辉幂律陡降，红移0.706（1.88σ）
* Not even H.E.S.S. II/VERITAS/HAWC
* 原因包括灵敏度不够、观测延迟时间太长，伽玛射线被河外背景光(Extragalactic Background Light)吸收等(Xue, Tam, et al., 2009).

H.E.S.S.
(High-energy stereoscopic system)

A system of 4 air Cherenkov telescopes situated in *Namibia*, southern Africa

(23°16’ S, 16°30’ E)
1800 m above sea level

energy range > 100 GeV

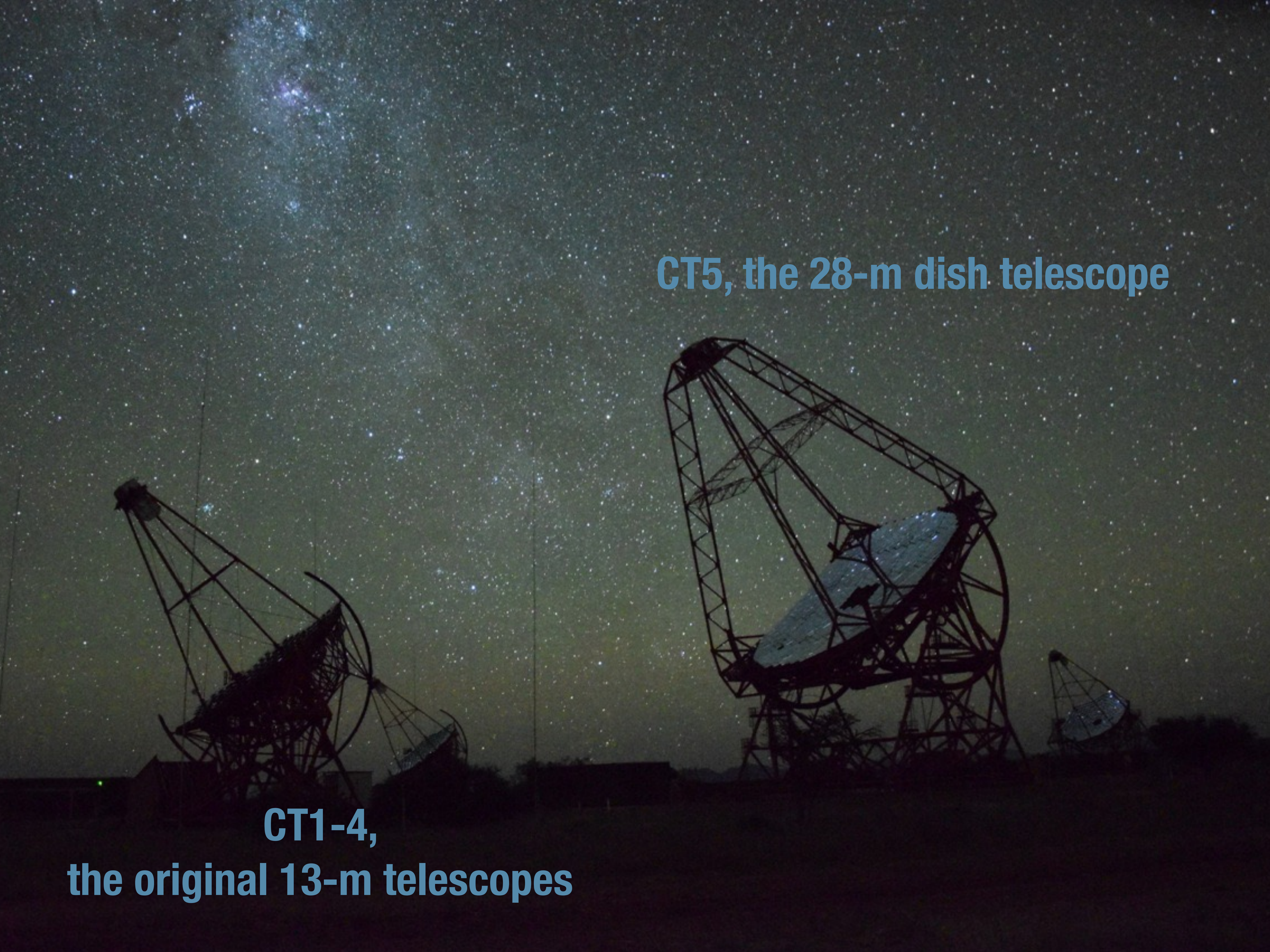
complete array operating since early 2004

HESS-observed GRBs

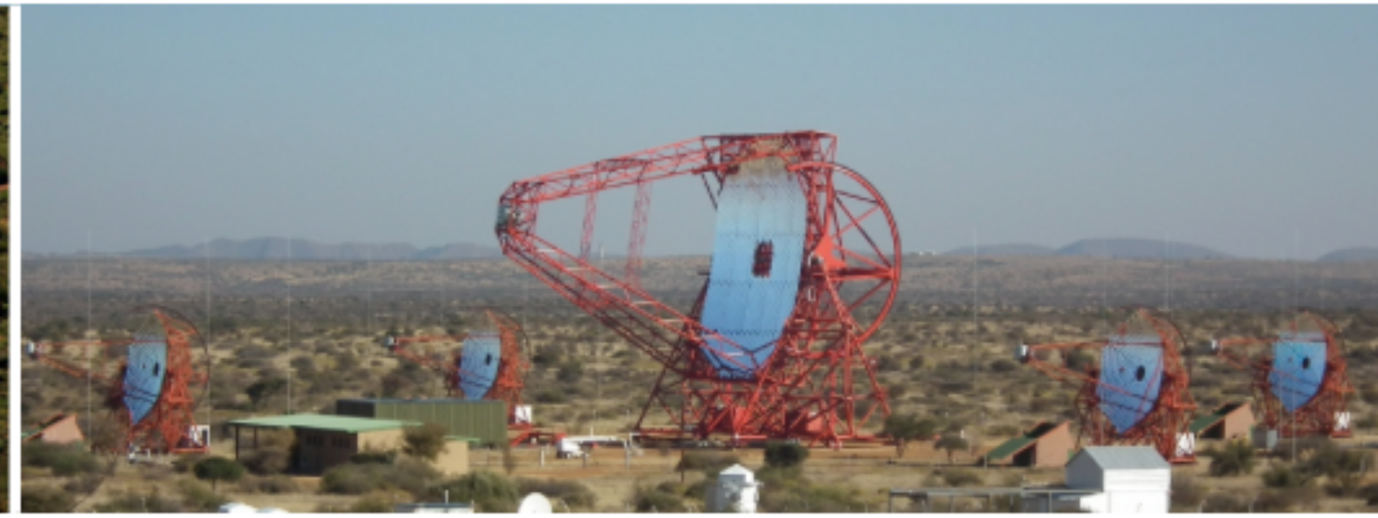
Table 1. Properties of GRBs observed with H.E.S.S. from March 2003 to October 2007.

GRB	Satellite	Trigger number	R.A.[a]	Decl.[a]	Error[a] ($''$)	Energy band (keV)	Fluence[b] (10^{-8} erg cm^{-2})	T_{90}[b] (s)	X[c]O[c]R[c]	z
071003	*Swift*	292934	$20^h07^m24^s.25$	$+10^{\circ}56'48''.8$	5.7	15–150	830	~150	√ √ √	1.604[e]
070808	*Swift*	287260	$00^h27^m03^s.36$	$+01^{\circ}10'34''.8$	1.9	15–150	120	~32	√ √ .	···
070724A	*Swift*	285948	$01^h51^m13^s.96$	$-18^{\circ}35'40''.1$	2.2	15–150	3	~0.4	√ × ×	0.457[f]
070721B	*Swift*	285654	$02^h12^m32^s.95$	$-02^{\circ}11'40''.6$	0.9	15–150	360	~340	√ √ ×	3.626[g]
070721A	*Swift*	285653	$00^h12^m39^s.24$	$-28^{\circ}22'00''.6$	2.3	15–150	7.1	3.868	√ √ .	···
070621	*Swift*	282808	$21^h35^m10^s.14$	$-24^{\circ}49'03''.1$	2	15–150	430	33	√ × .	···
070612B	*Swift*	282073	$17^h26^m54^s.4$	$-08^{\circ}45'08''.7$	4.7	15–150	168	13.5	√ × .	···
070429A	*Swift*	277571	$19^h50^m48^s.8$	$-32^{\circ}24'17''.9$	2.4	15–150	91	163.3	√ √ .	···
070419B	*Swift*	276212	$21^h02^m49^s.57$	$-31^{\circ}15'49''.7$	3.5	15–150	736	236.4	√ √ .	···
070209	*Swift*	259803	$03^h04^m50^s$	$-47^{\circ}22'30''$	168	15–150	2.2	0.09	× × .	0.314?[h]
061110A	*Swift*	238108	$22^h25^m09^s.9$	$-02^{\circ}15'30''.7$	3.7	15–150	106	40.7	√ √ .	0.758[i]
060526	*Swift*	211957	$15^h31^m18^s.4$	$+00^{\circ}17'11''.0$	6.8	15–150	126	298.2	√ √ .	3.21[j]
060505	*Swift*	208654	$22^h07^m04^s.50$	$-27^{\circ}49'57''.8$	4.7	15–150	94.4	~4	√ √ .	0.0889[k]
060403	*Swift*	203755	$18^h49^m21^s.80$	$+08^{\circ}19'45''.3$	5.5	15–150	135	30.1	√ × .	···
050801	*Swift*	148522	$13^h36^m35^s$	$-21^{\circ}55'41''$	1	15–150	31	19.4	√ √ ×	1.56[l]
050726	*Swift*	147788	$13^h20^m12^s.30$	$-32^{\circ}03'50''.8$	6	15–150	194	49.9	√ √ .	···
050509C	*HETE-II*	H3751	$12^h52^m53^s.94$	$-44^{\circ}50'04''.1$	1	2–30	60	25	√ √ √	···
050209	*HETE-II*	U11568	08^h26^m	$+19^{\circ}41'$	420	30–400	200	46	. × .	···
041211B[m]	*HETE-II*	H3622	$06^h43^m12^s$	$+20^{\circ}23'42''$	80	30–400	1000	>100	. × .	···
041006	*HETE-II*	H3570	$00^h54^m50^s.23$	$+01^{\circ}14'04''.9$	0.1	30–400	713	~20	√ √ √	0.716[n]
030821	*HETE-II*	H2814	21^h42^m	$-44^{\circ}52$	[o]	30–400	280	23	. . .	···
030329	*HETE-II*	H2652	$10^h44^m49^s.96$	$+21^{\circ}31'17''.44$	10^{-3}	30–400	10760	33	√ √ √	0.1687[p]

Aharonian…Tam…(2009)


CT5, the 28-m dish telescope
CT1-4,
the original 13-m telescopes

Lower the energy threshold



- H.E.S.S. phase I
  - four 12m telescopes
  - FoV 5 deg
  - energy threshold 100 GeV
  - angular resolution < 0.1 deg

- H.E.S.S. phase II
  - four 12m telescopes
  - one 28m telescope (FoV 3.5 deg)
  - energy threshold O(30 GeV)
  - angular resolution from 0.4 deg to less than 0.1 deg

H.E.S.S. phase I — 2002-2012

H.E.S.S. phase II — 2012-now

H.E.S.S. II Rapid Repointing System

* Fully automatic, no human-in-loop
* In order to minimise this delay, 2 major improvements have been made for CT5 over the original 4 telescope array

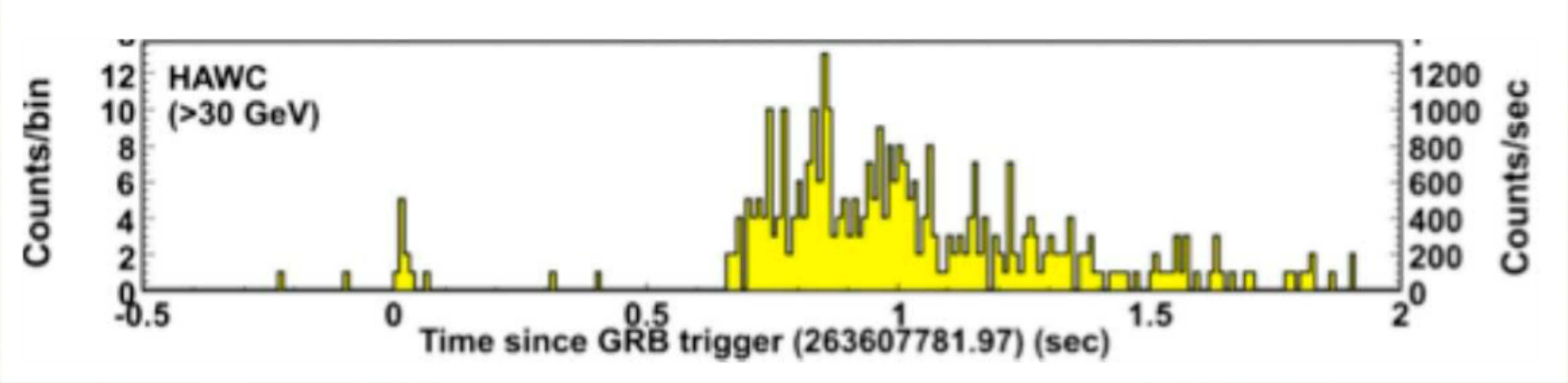
  1. the telescope drive system of CT5 is significantly updated over that of the original H.E.S.S. system, allowing a full rotation of the telescope (360 in azimuth) in 3.5 minutes

  2. CT5 is able to point in reverse-mode, allowing the telescope to slew through zenith, resulting in significantly faster repointing for some GRBs, where otherwise a large azimuthal slew would be required

HAWC simulated light curve

* With less than 1/3 of the array active, the HAWC observatory limits for GRB 130702A, which is at a close redshift of z = 0.145

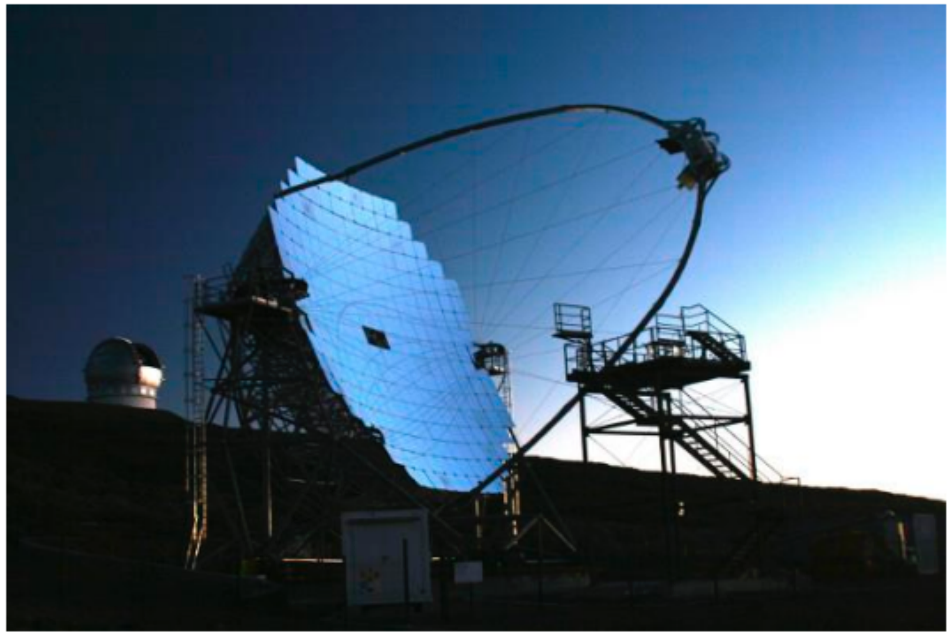
* Simulated HAWC light curve of GRB 090510



What have H.E.S.S./MAGIC/VERITAS/HAWC seen?

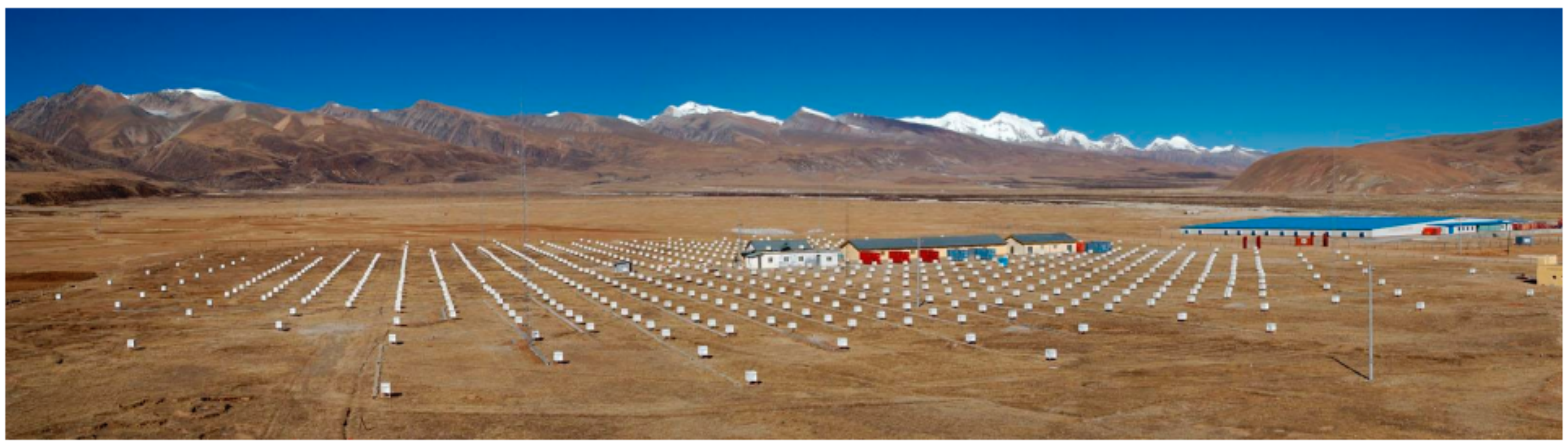
Short GRBs and gravitational wave

* NS-NS mergers are progenitors of short GRBs
* NS-NS mergers produce gravitational wave bursts, detectable by LIGO/Virgo, etc., before GRBs
* Only wide-field detectors can observe this g-wave precursor before GRBs
* LHAASO's has a irreplaceable role here!



- IACTs: H.E.S.S., VERITAS, MAGIC, ...
  - Good angular resolution (~0.1°);
  - Fair background rejection power;
  - Short duty cycle (~10%);
  - Narrow FOV (<5°);
  - Low energy threshold (~100 GeV);

➔ Mainly focused on deep observation.

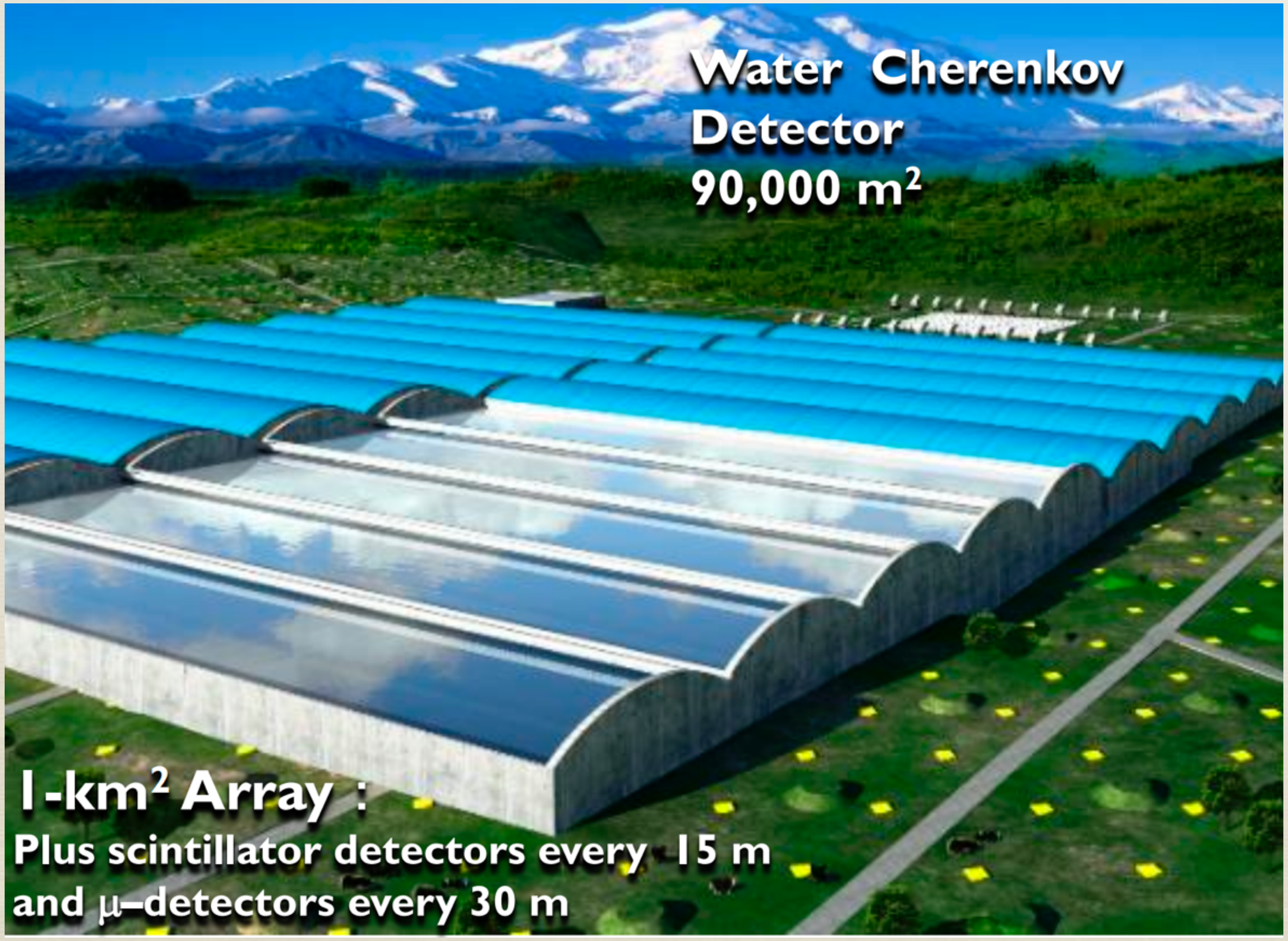


- Ground particle array: ASγ, ARGO-YBJ, Milagro, HAWC, ...
  - Not-so-good angular resolution (~0.5°);
  - Poor background rejection power (but much elaborated in water Cherenkov);
  - Full duty cycle (>95%, ~10× IACT);
  - Wide FOV (>2/3π, ~150× IACT);
  - High energy threshold ➔ improved by construction at high altitude (~1 TeV);

➔ Good at sky survey, extended sources and flares.

LHAASO opportunities

* Best instrument to observe GRB prompt emission (and before)



Maybe a good early science project