GAMMA-RAY BURSTS IN THE LAST FRONTIER: THE 10-100 GEV ENERGY BAND AND BEYOND

P. H. Thomas Tam (譚栢軒, School of Physics and Astronomy, Sun Yat-sen University)

collaborators: DaMing Wei, YiZhong Fan (PMO), XiangYu Wang (NJU), Qingwen Tang (NCU), H.E.S.S. collaboration

KIAA

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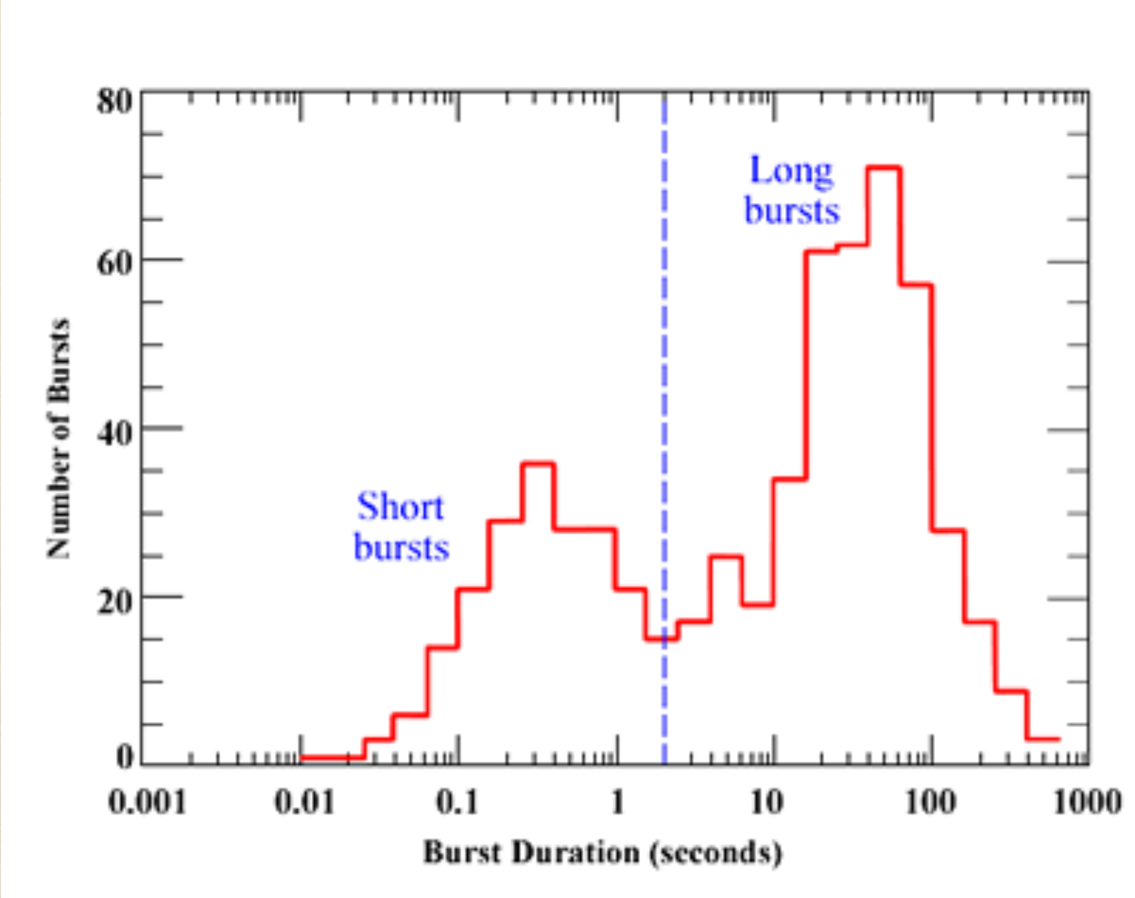
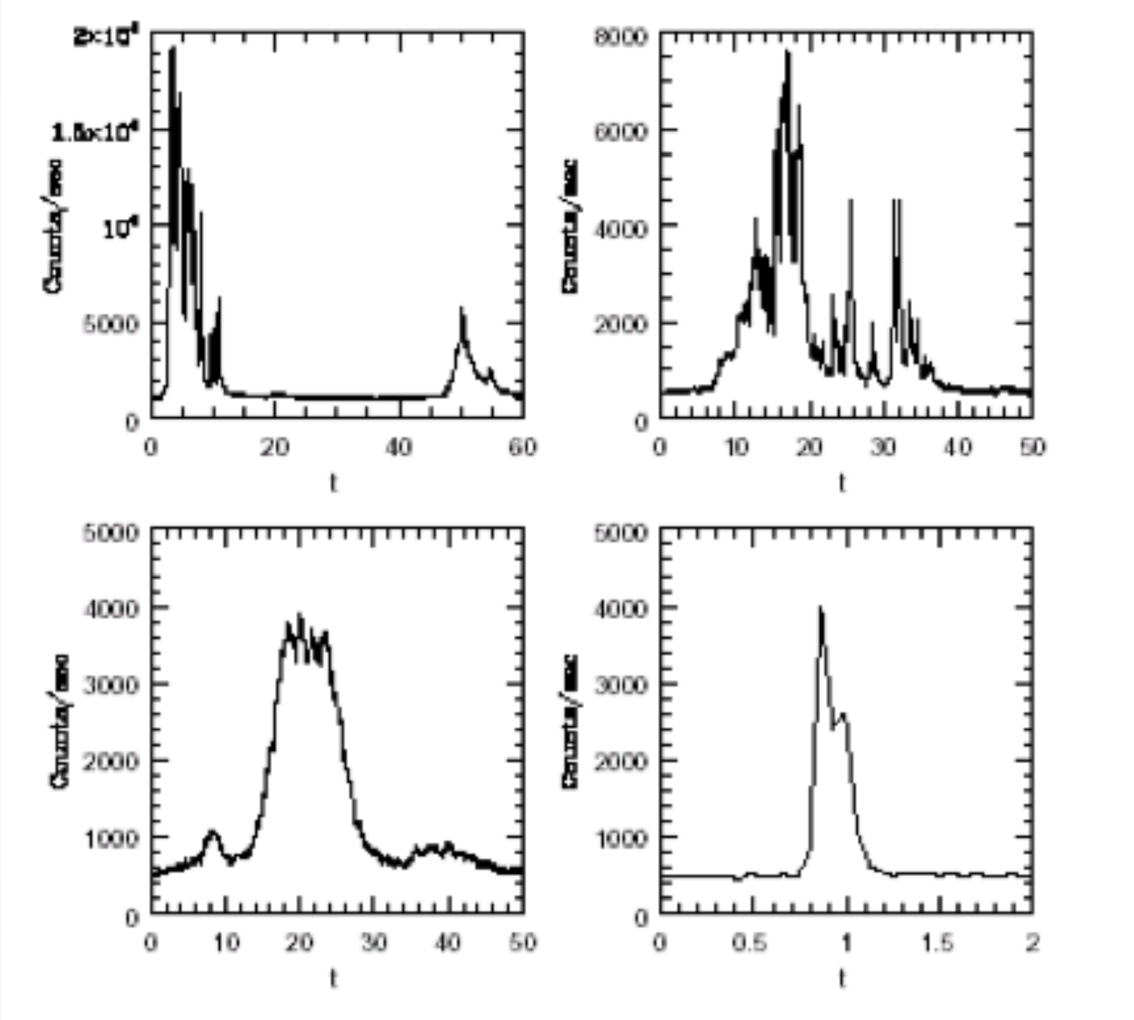
- Gamma-ray bursts
- LAT Observations of GRBs
- Photons with the highest energy from GRB afterglows
- H.E.S.S. array and previous GRB results
- Status of the H.E.S.S. II GRB program

What are GRBs?

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





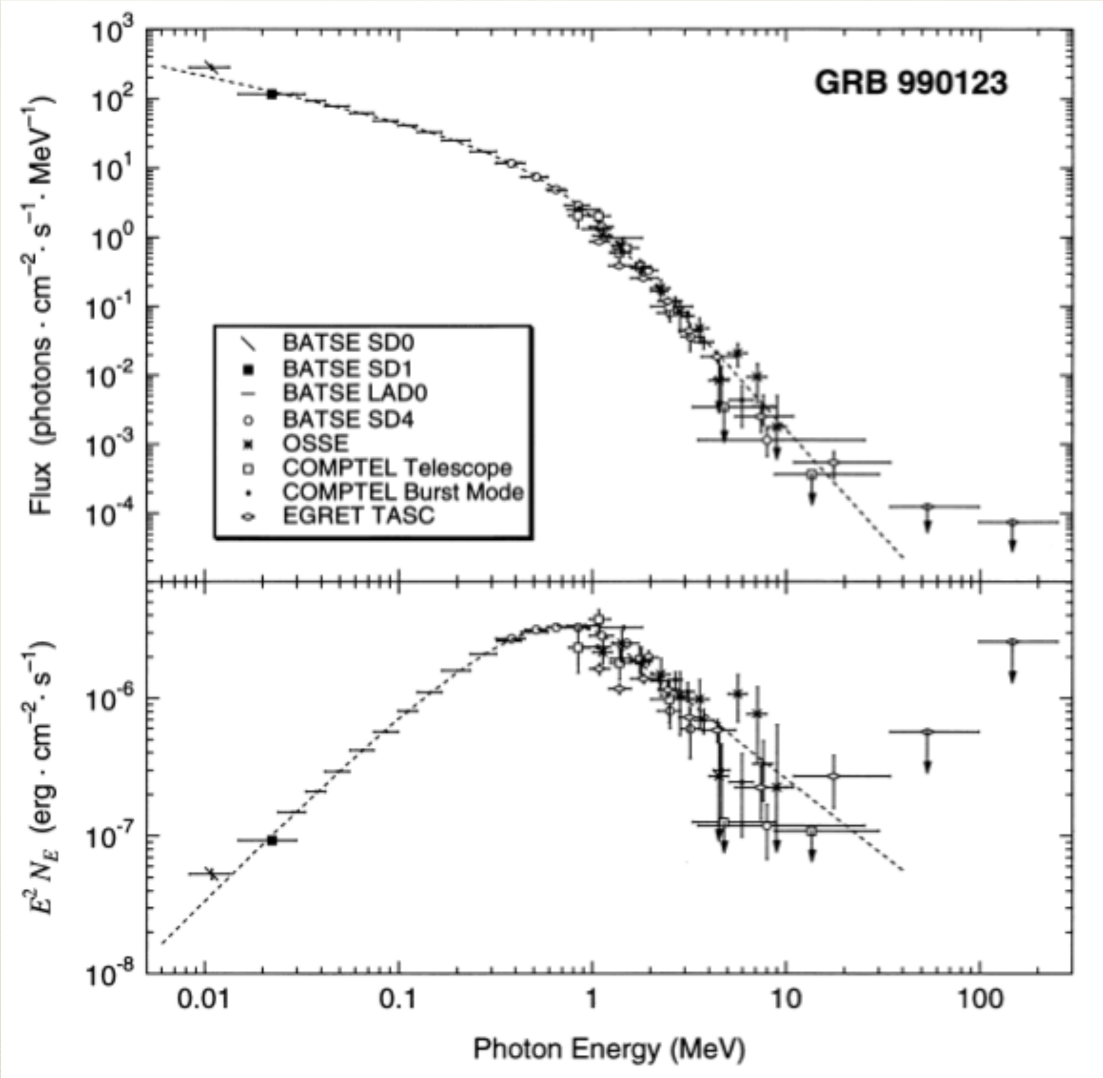
Burst spectra: "Band" function

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

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

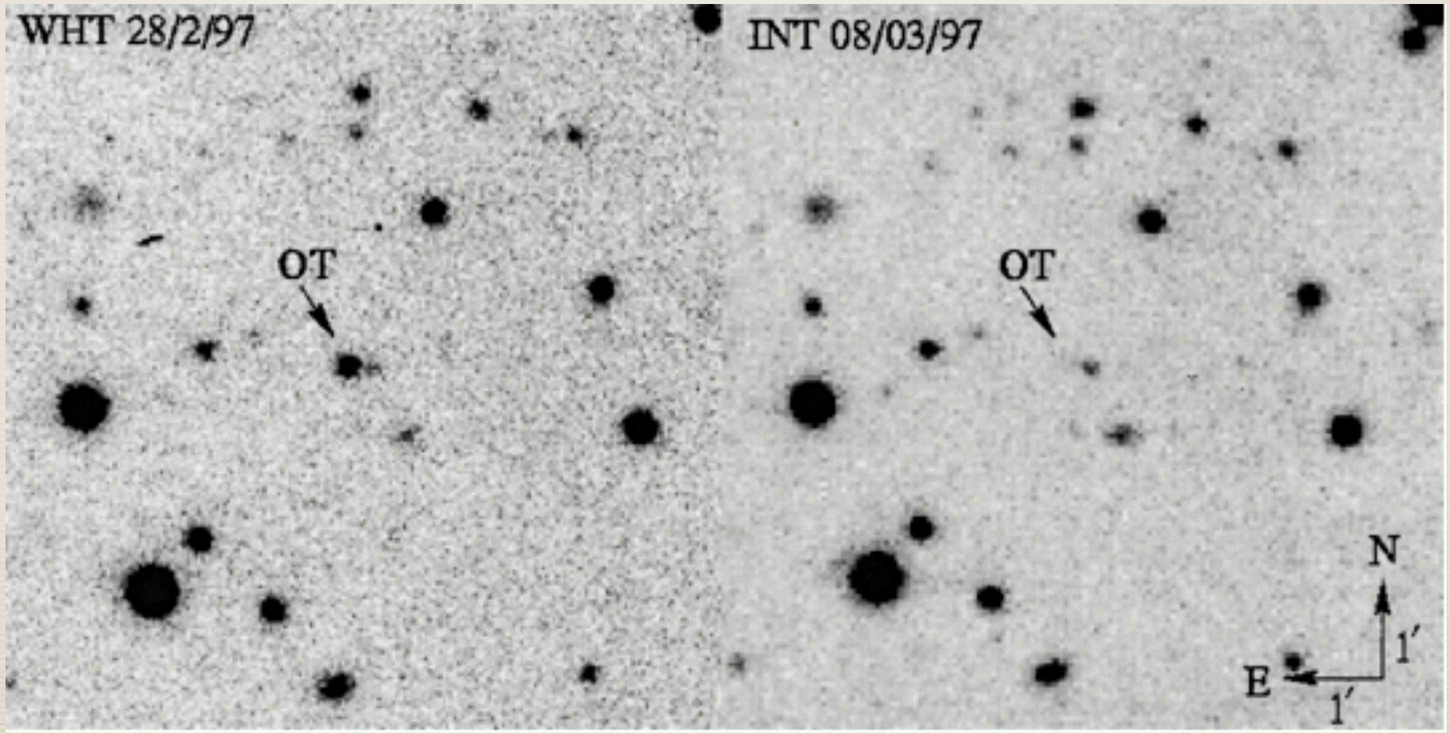
$$= A\left[\frac{(\alpha-\beta)E_0}{100\ \mathrm{keV}}\right]^{\alpha-\beta} \exp(\beta-\alpha)\left(\frac{E}{100\ \mathrm{keV}}\right)^{\beta}, \quad (\alpha-\beta)E_0 \leq E,$$

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



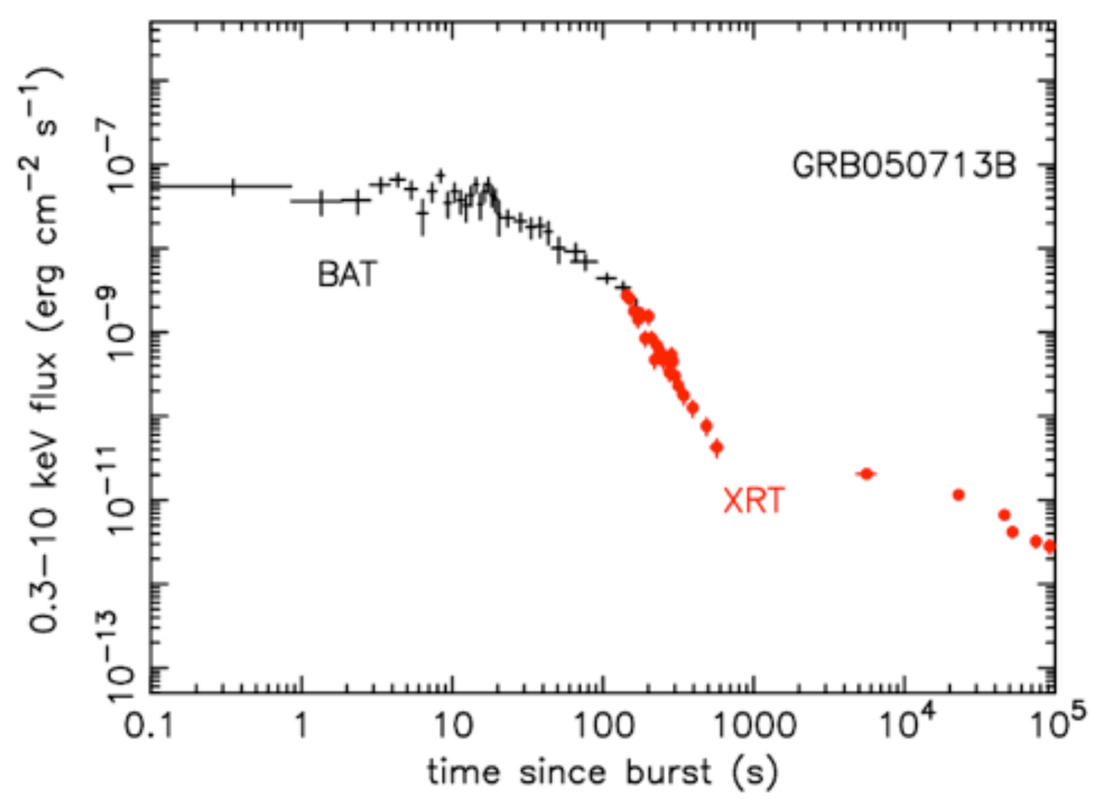
Optical/X-ray afterglows

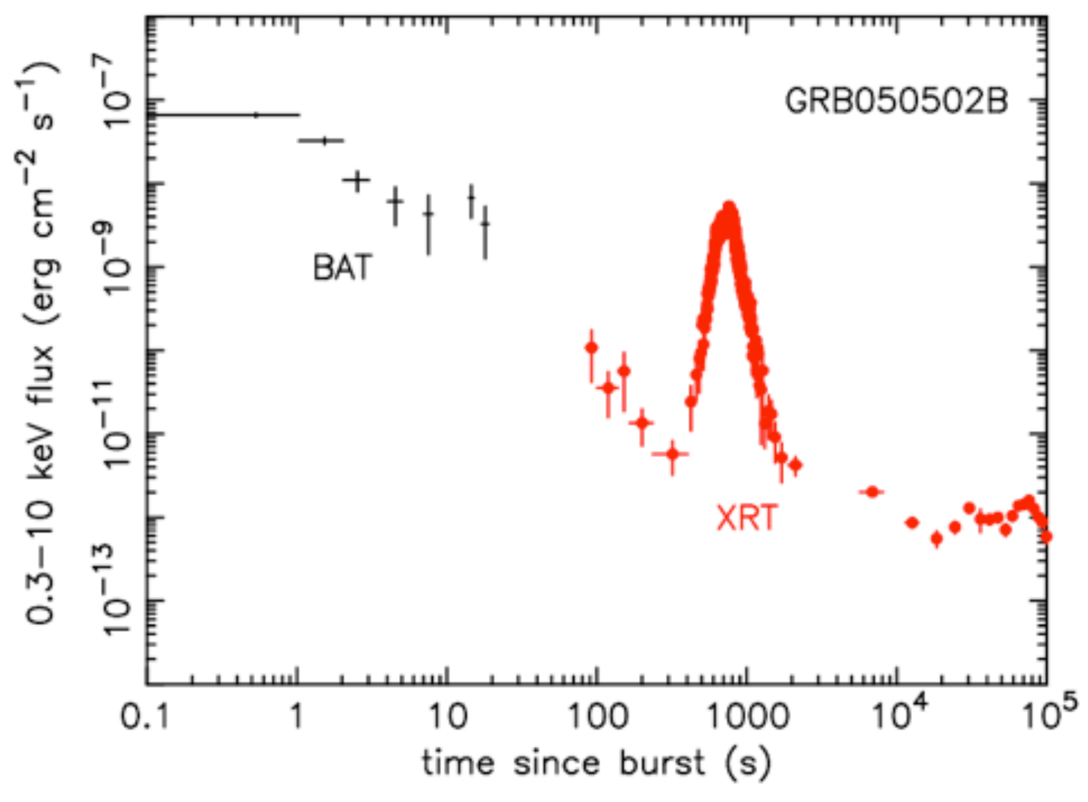
* Discovery of optical & X-ray afterglows in 1997
* Cosmological origin



van Paradijs et al. (1997)

XRT afterglow light curves

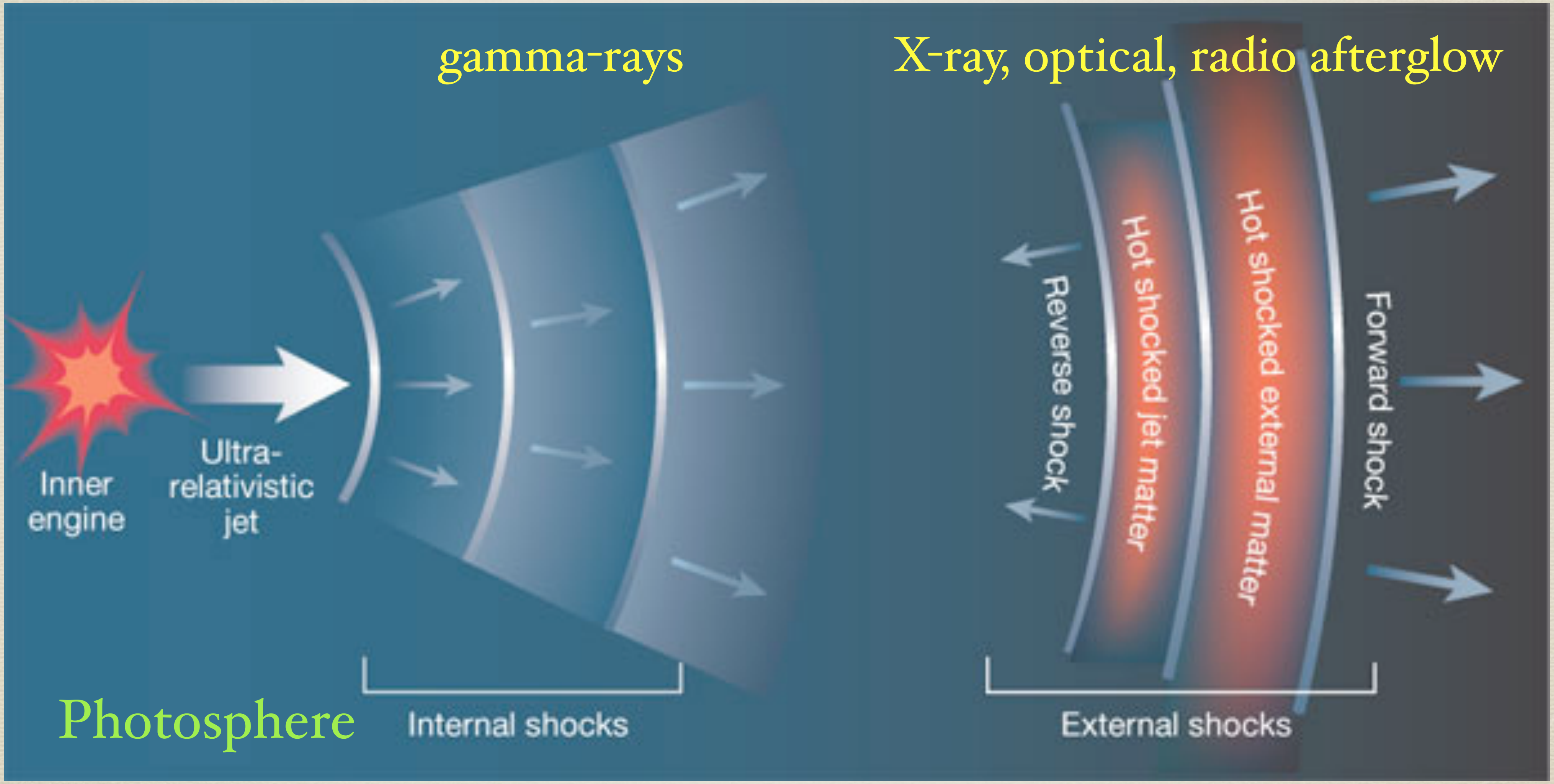




A “canonical” X-ray decay light curve without flares

Strong late-time activities

The Fireball Model



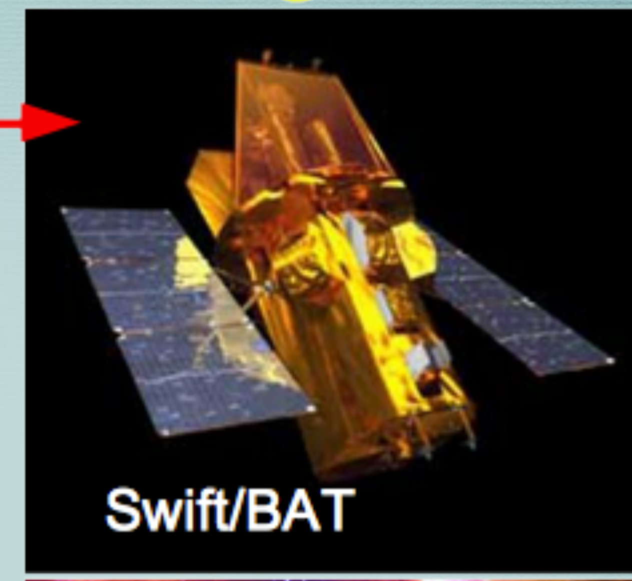
c.f. Piran (2004)

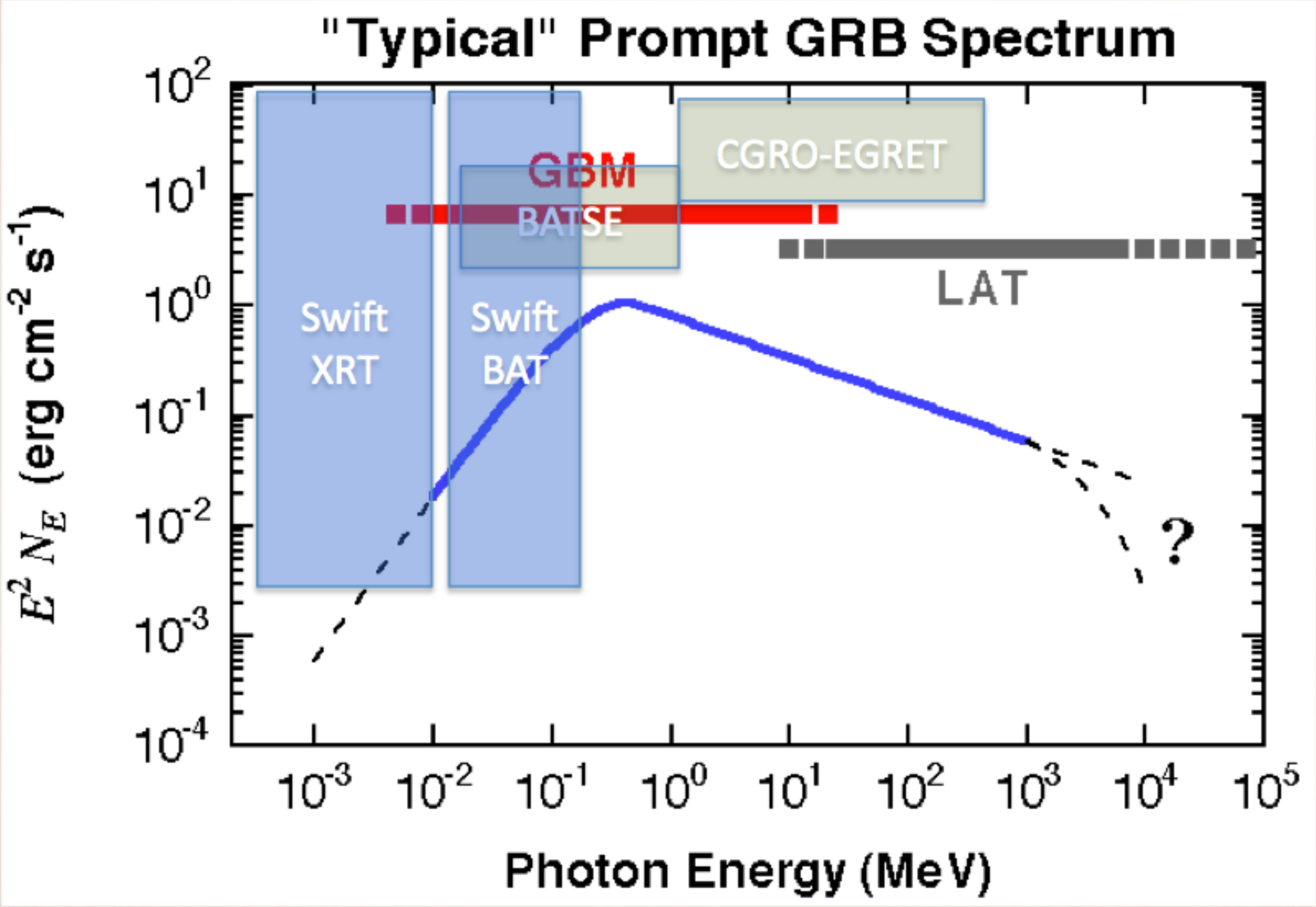
Gamma-rays at different energies

Low-energy gamma-rays:
~100 keV to ~100 MeV

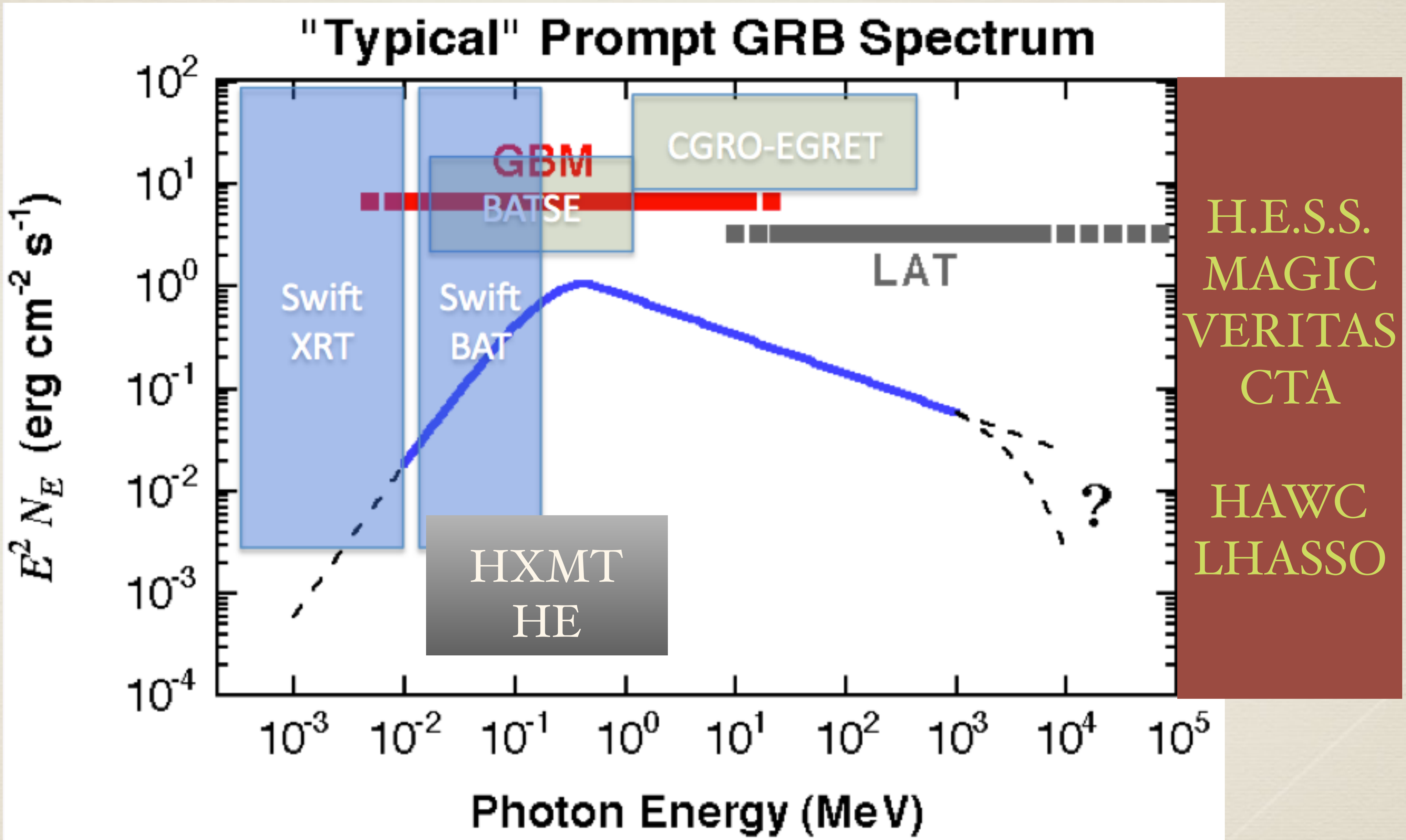
high-energy gamma-rays:
~100 MeV to ~100 GeV

Very high-energy gamma-rays:
> 100 GeV

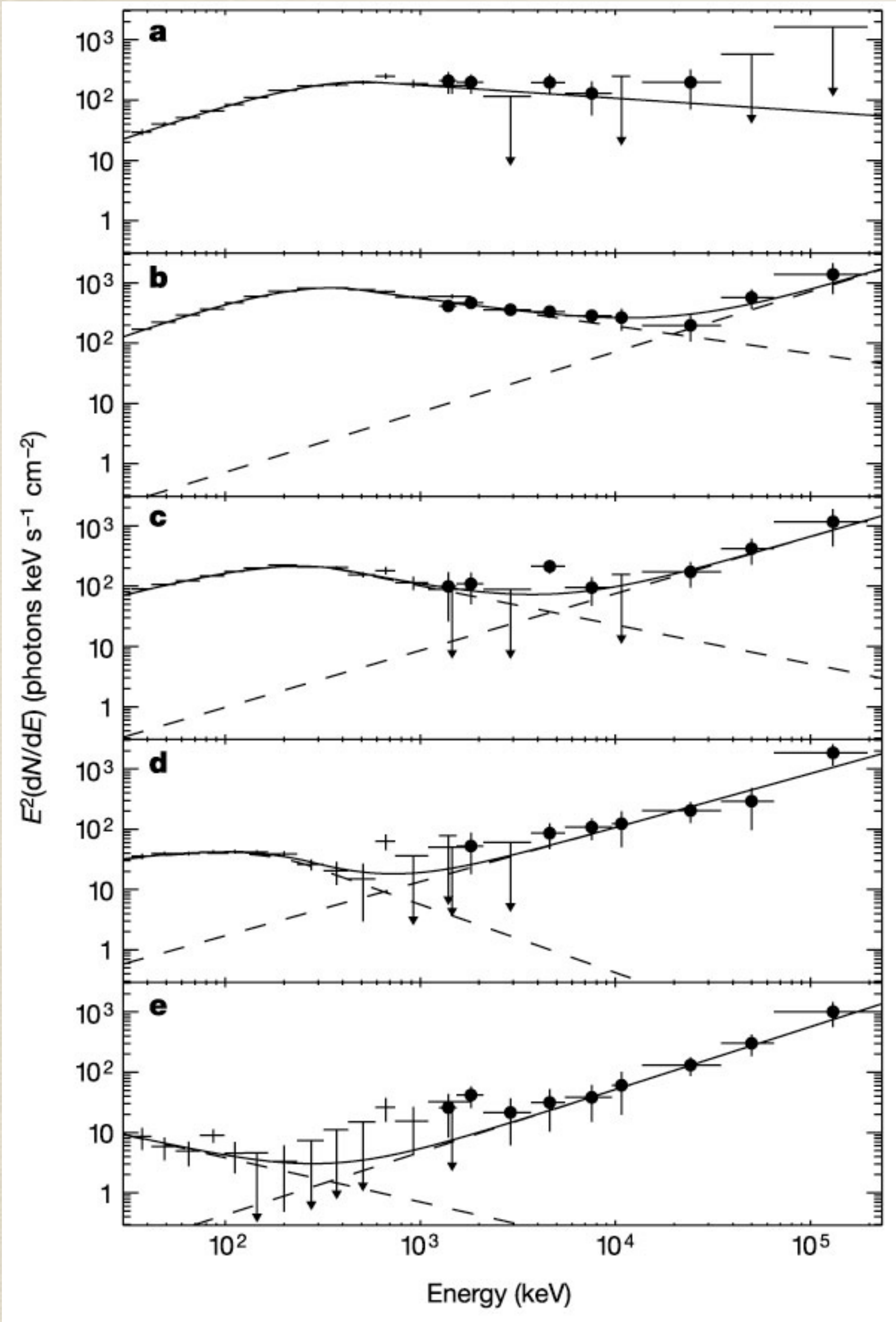


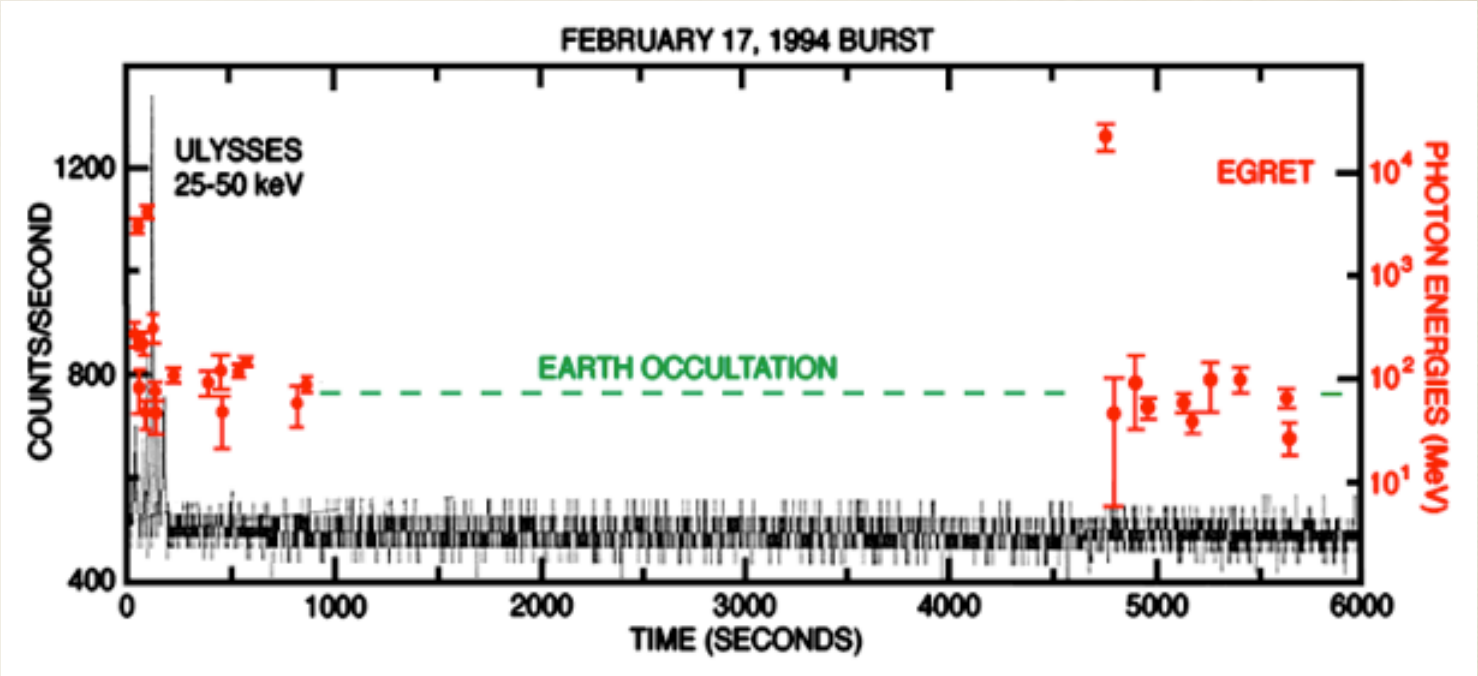


"Typical" Prompt GRB Spectrum
$E^2 N_E$ (erg cm^{-2} s^{-1})
Photon Energy (MeV)
Swift XRT
Swift BAT
GBM
BATSE
CGRO-EGRET
LAT
?


"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
HXMT HE
?
H.E.S.S.
MAGIC
VERITAS
CTA
HAWC
LHASSO

EGRET observations of GRBs





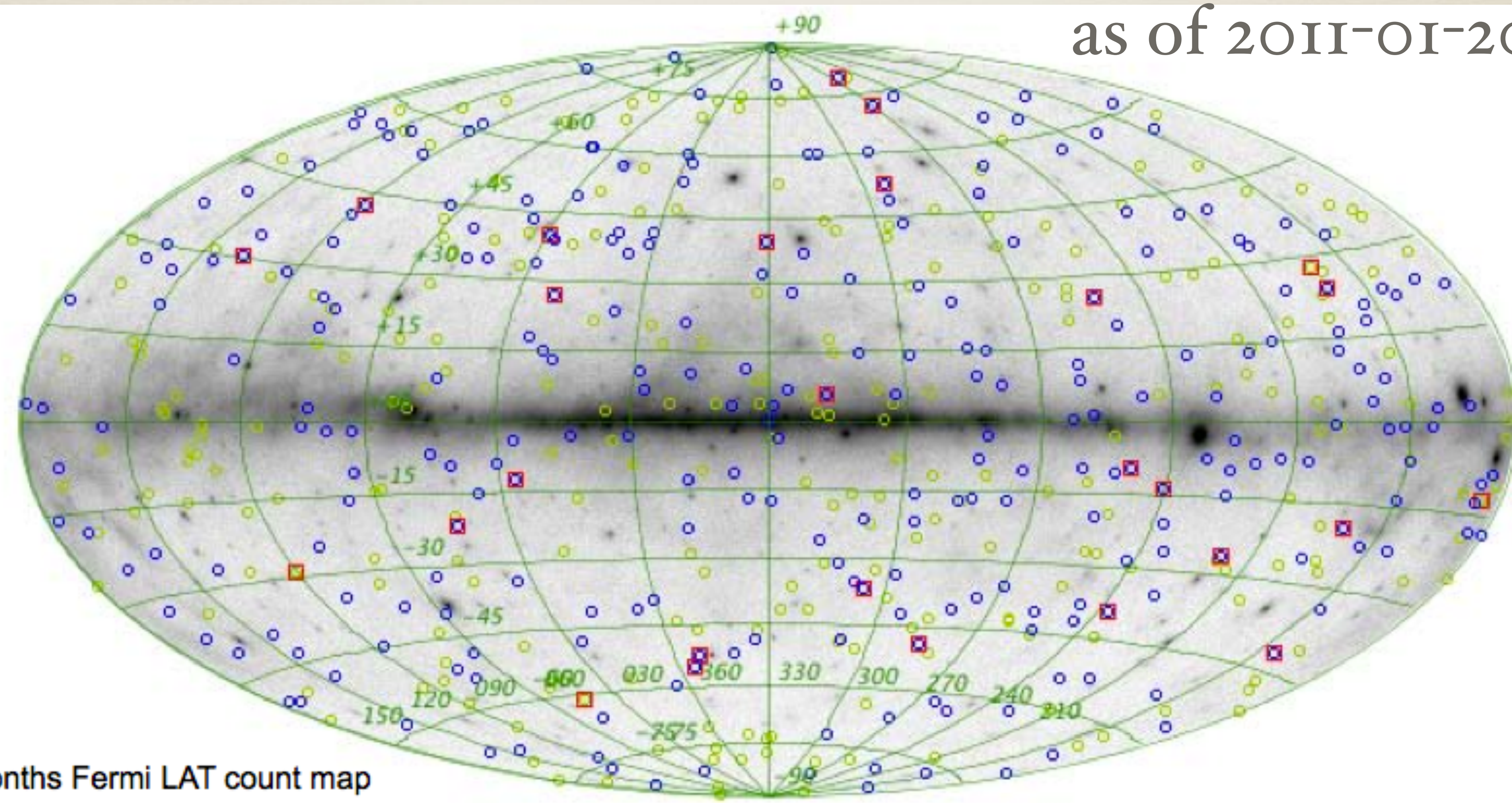
GRB 940217

GRB 941017

Fermi era

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

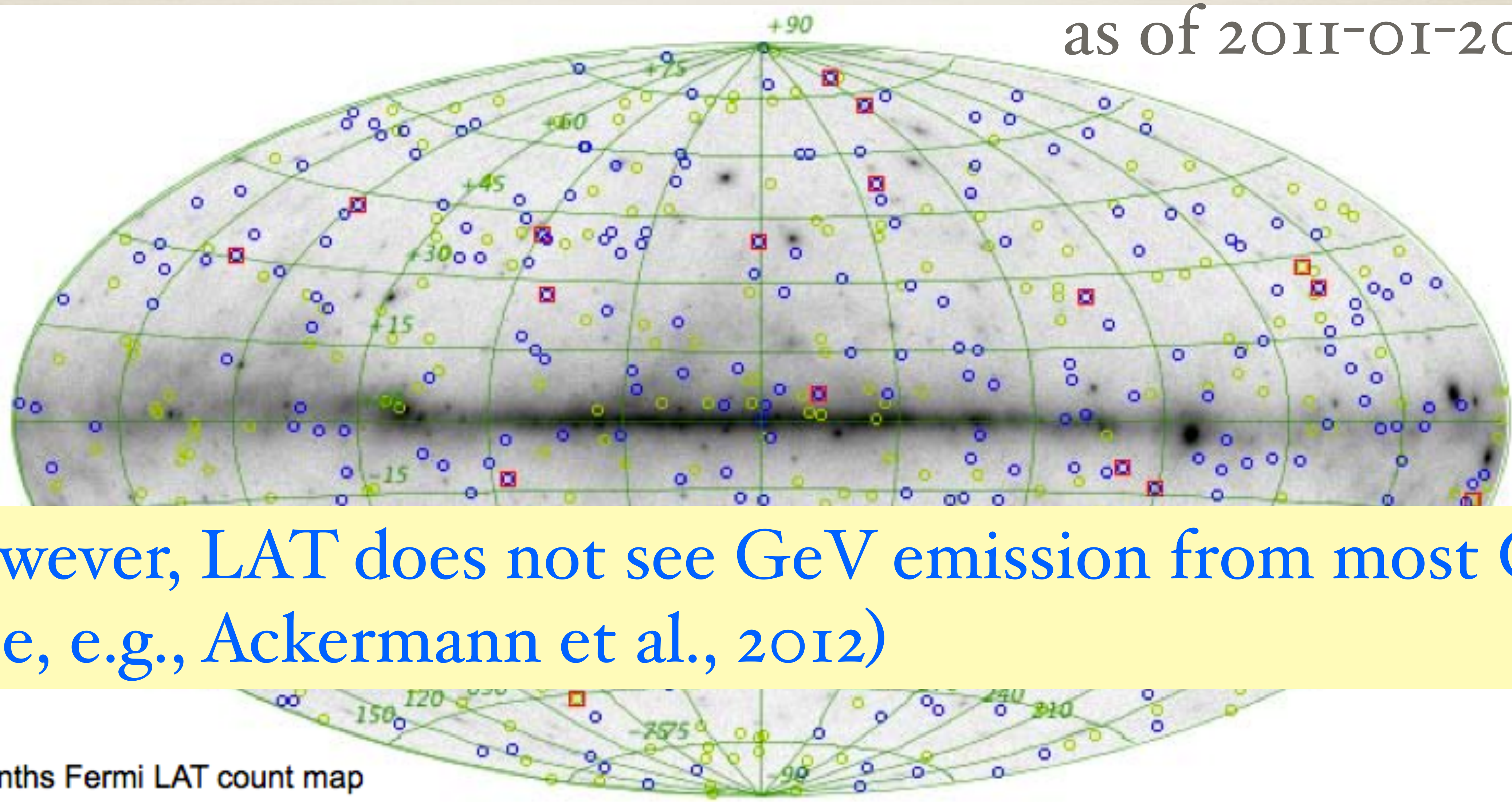
~550 GBM GRB (since Aug 2008)

27 LAT GRB (7 LAT LLE-only GRB)

from N. Omodei

What does Fermi see?

as of 2011-01-20



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

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)

from N. Omodei

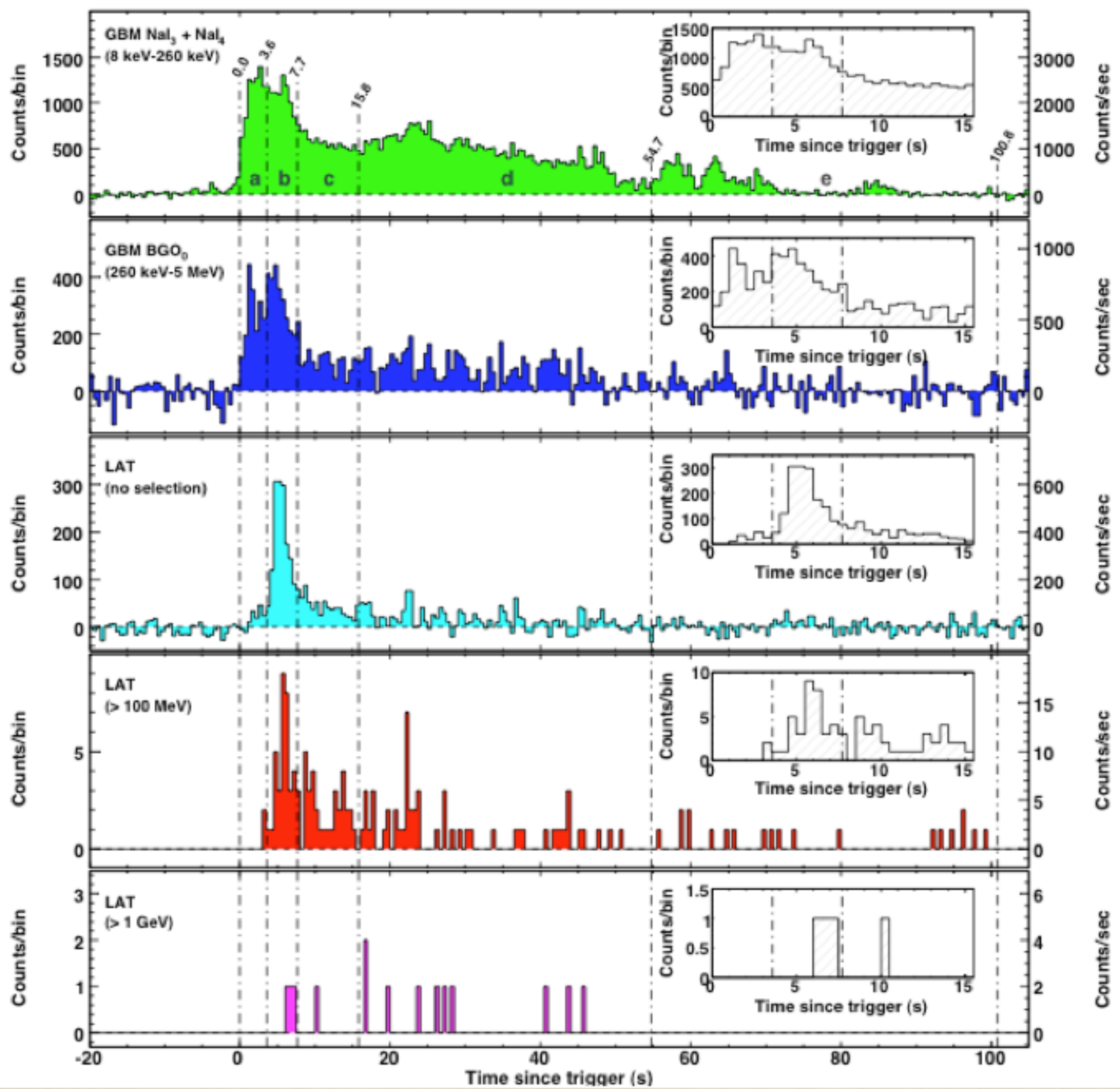
GRB Name	Likelihood Detection >100 MeV	LLE Detection	LAT off axis angle at T_0 (degrees)	GBM T_{90}	N Pred. Events (>100MeV, Trans.)	HE Delayed Onset?	Long Lived HE Emission?	Maximum Energy (GeV) meas. during the LAT detection	Arrival time of the highest events (seconds since trigger)	Redshift
GRB080825C	√	√	60.3	21	10	√	√	0.6	28.3	-
GRB080916C	√	√	48.8	63	211	√	√	13.2	16.5	4.35
GRB081006	√	x	10.7	6.4	13	-	√	0.6	1.8	-
GRB081024B	√	√	18.6	0.6	11	√	√	3.1	0.6	-
GRB081215	x	√	97.1	5.6	-	-	-	-	-	-
GRB081224	x	√	17	16.4	-	√	√	-	-	-
GRB090217	√	√	34.5	33.3	17	√	√	0.9	14.8	-
GRB090227B	√	√	70.1	1.3	3	-	-	-	-	-
GRB090323	√	√	57.2	135.2	39	√	√	7.5	195.4	3.57
GRB090328	√	√	64.6	61.7	58	√	√	5.3	698.3	0.736
GRB090510	√	√	13.6	1	183	√	√	31.3	0.8	0.903
GRB090531B	x	√	21.9	0.8	-	-	-	-	-	-
GRB090626	√	√	18.2	48.9	30	√	√	2.1	111.6	-
GRB090902B	√	√	50.8	19.3	323	√	√	33.4	81.7	1.822
GRB090926	√	√	48.1	13.8	252	√	√	19.6	24.8	2.106
GRB091003	√	√	12.3	20.2	33	√	√	2.8	6.5	0.897
GRB091031	√	√	23.8	33.9	16	√	√	1.2	79.7	-
GRB100116A	√	√	26.6	102.5	21	-	√	2.2	105.7	-
GRB100225A	x	√	54.9	13	-	-	-	-	-	-
GRB100325A	√	x	7.4	7.1	5	-	√	0.8	0.4	-
GRB100414A	√	√	69	26.5	28	√	√	4.3	39.3	1.368
GRB100707A	x	√	90.3	81.8	-	-	-	-	-	-
GRB100724B	√	√	48.8	87	24	-	-	0.1	15.4	-
GRB100728A	√	x	59.9	162.9	17	-	√	1.7	709	-
GRB101014A	x	√	54.1	450.9	-	-	-	-	-	-
GRB101123A	x	√	84.2	~160	-	-	-	-	-	-
GRB110120A	√	x	13.7	~20	9	-	√	1.8	72.5	-

from Nicola Omodei

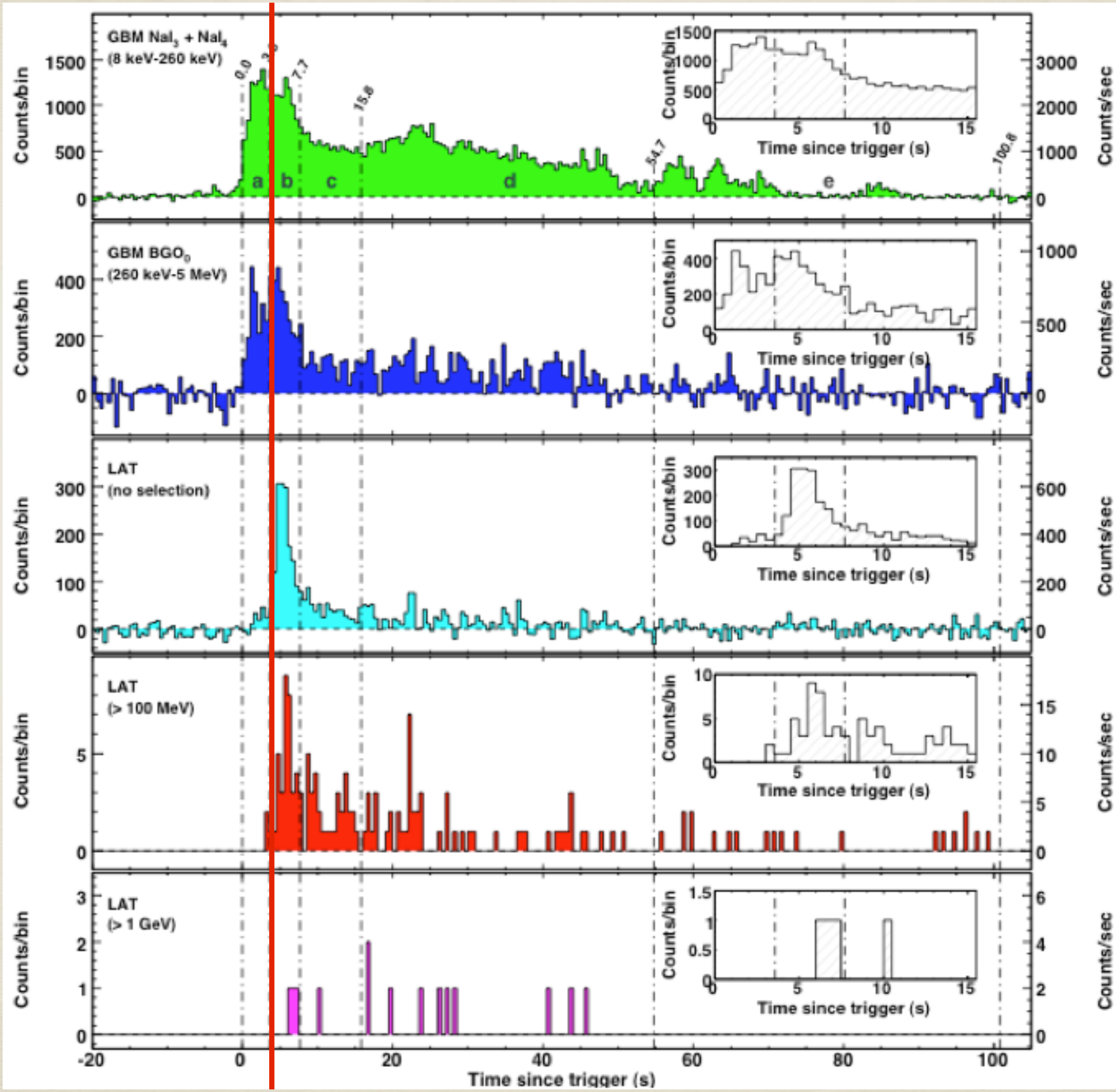
LAT observations of GRBs

* Delayed onset of high-energy emission *(prompt phase)*
* extra spectral components *(prompt phase)*
* extended GeV emission

GRB 080916C

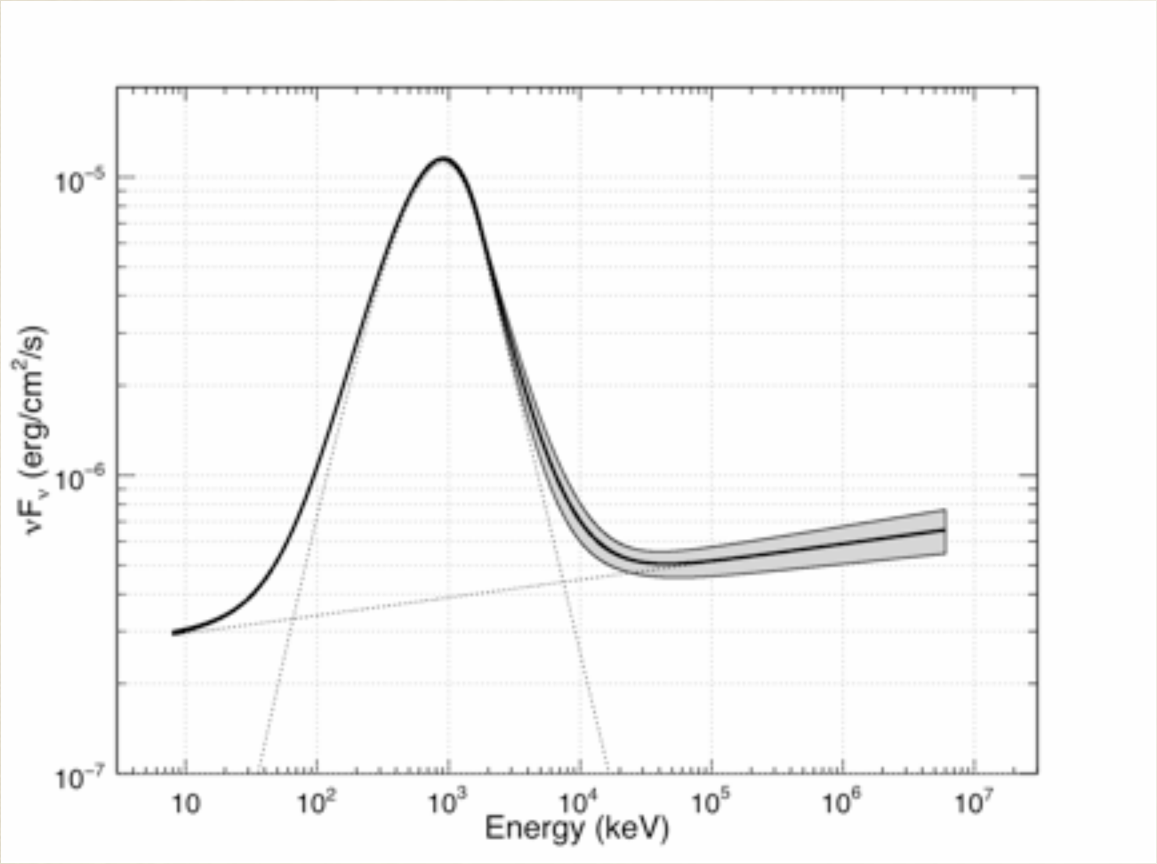

GBM NaI3 + NaI4 (8 keV-260 keV)
GBM BGO0 (260 keV-5 MeV)
LAT (no selection)
LAT (> 100 MeV)
LAT (> 1 GeV)
Counts/bin
Counts/sec
Time since trigger (s)
a b c d e
0.0 3.6 7.7 15.8 54.7 100.8

GRB 080916C


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

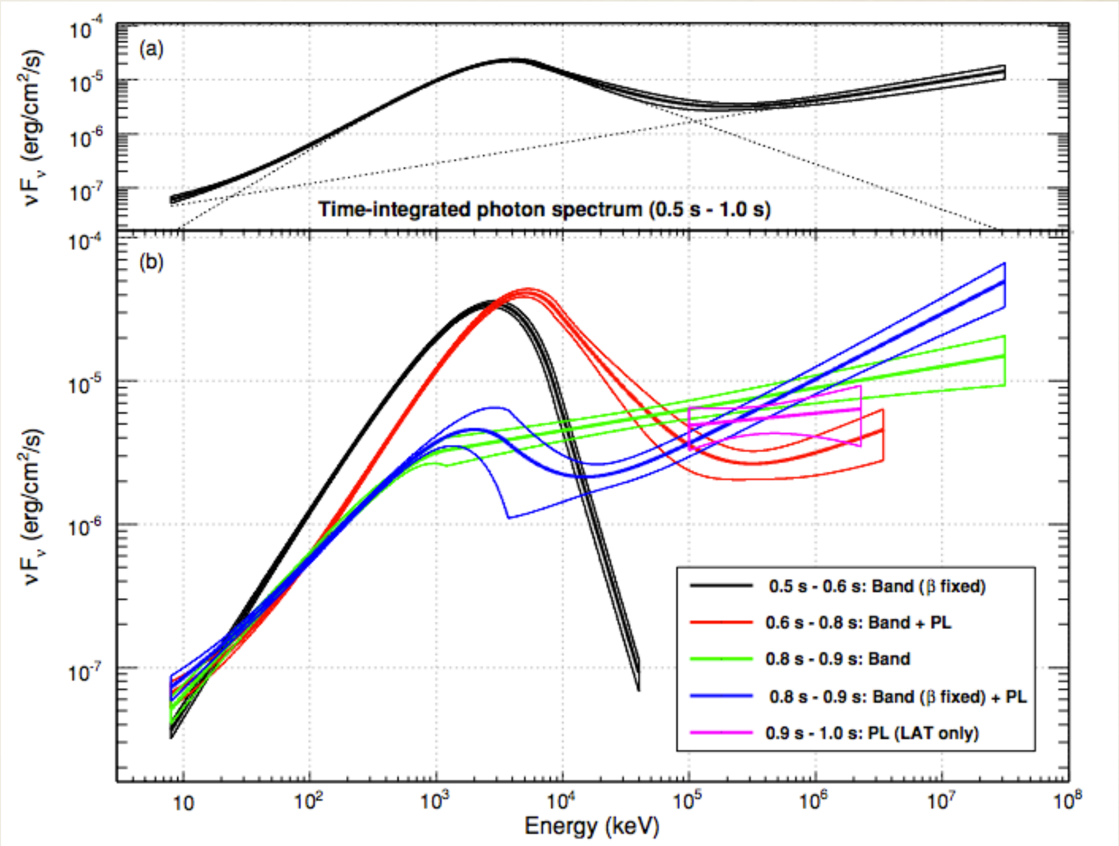
Second component during prompt phase

GRB 090902B



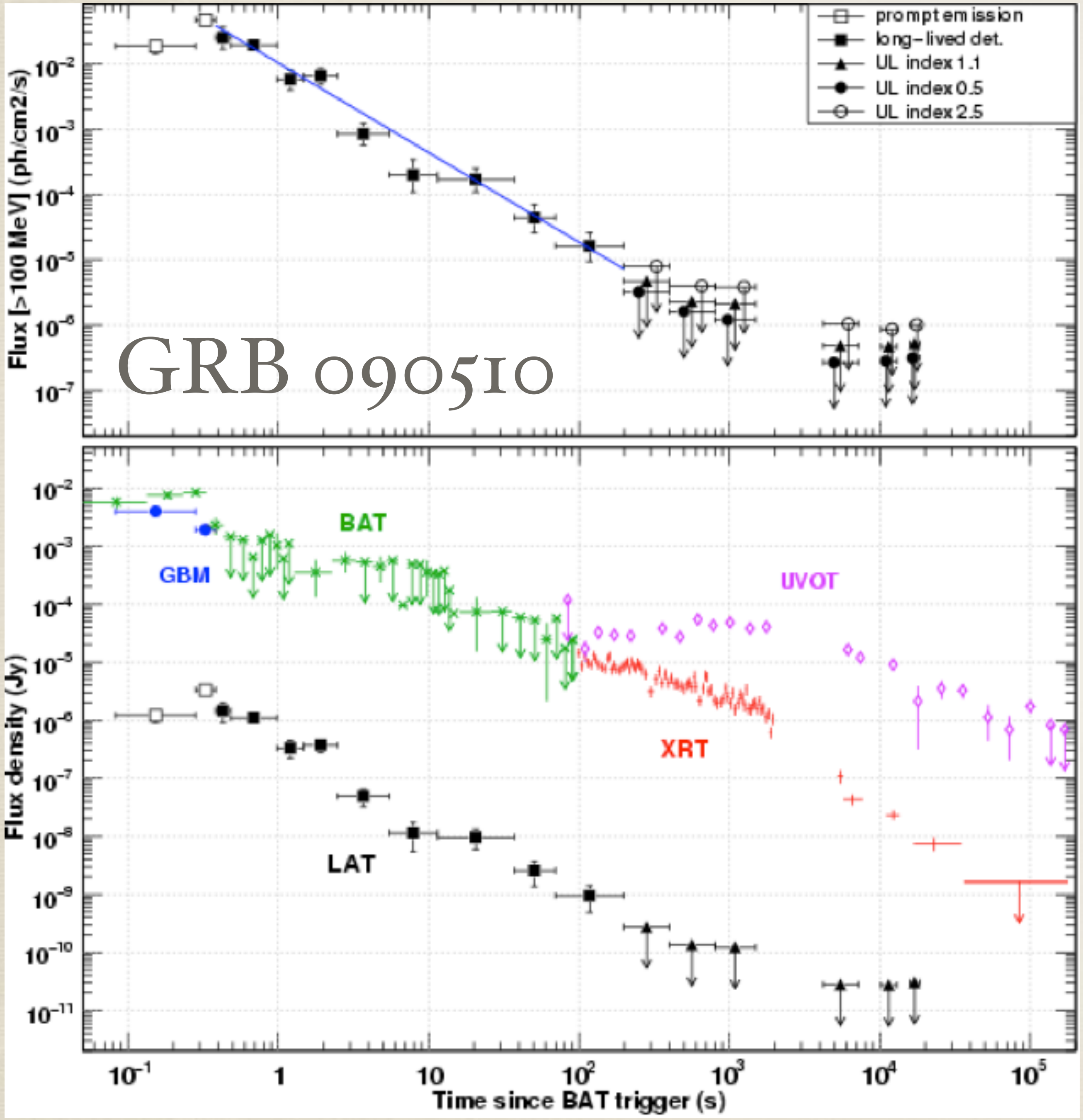
Abdo et al. (2009)

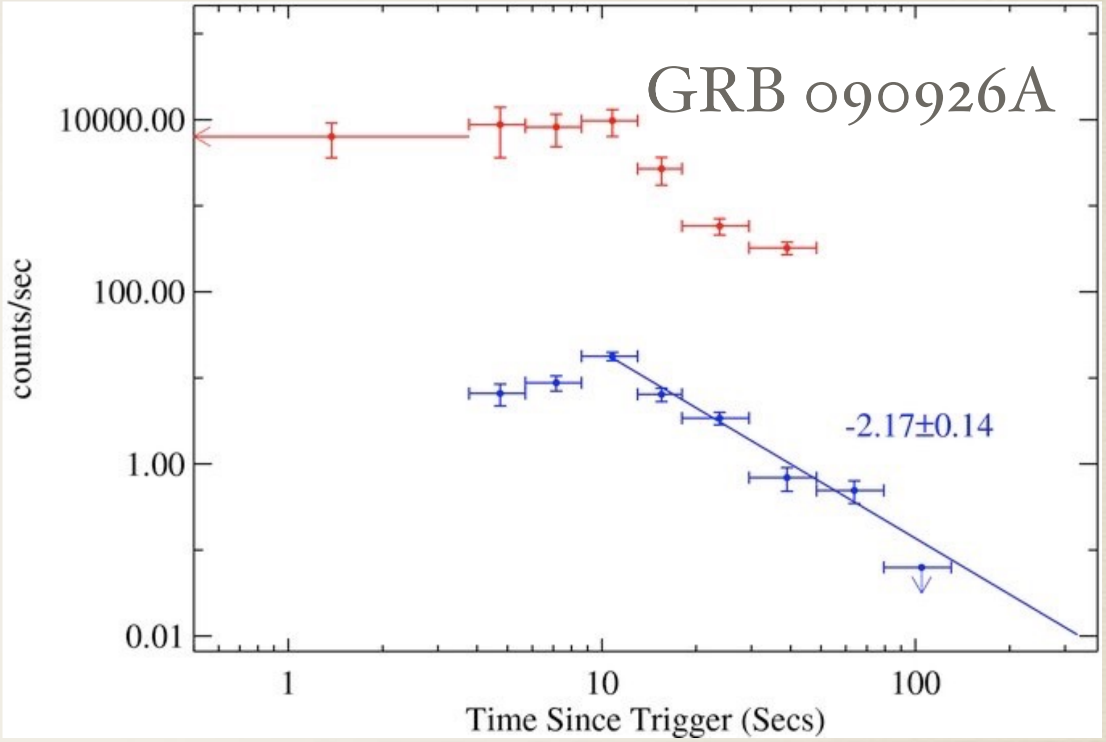
GRB 090510



Ackermann, et al. 2010

Power-law decay index



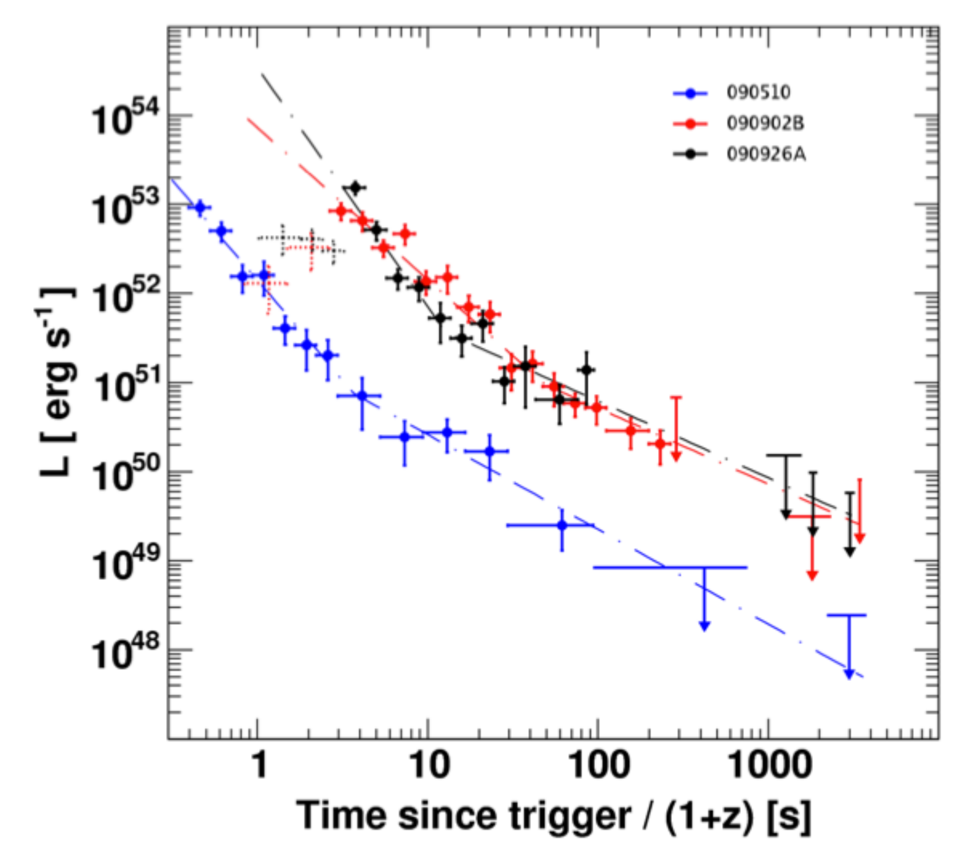


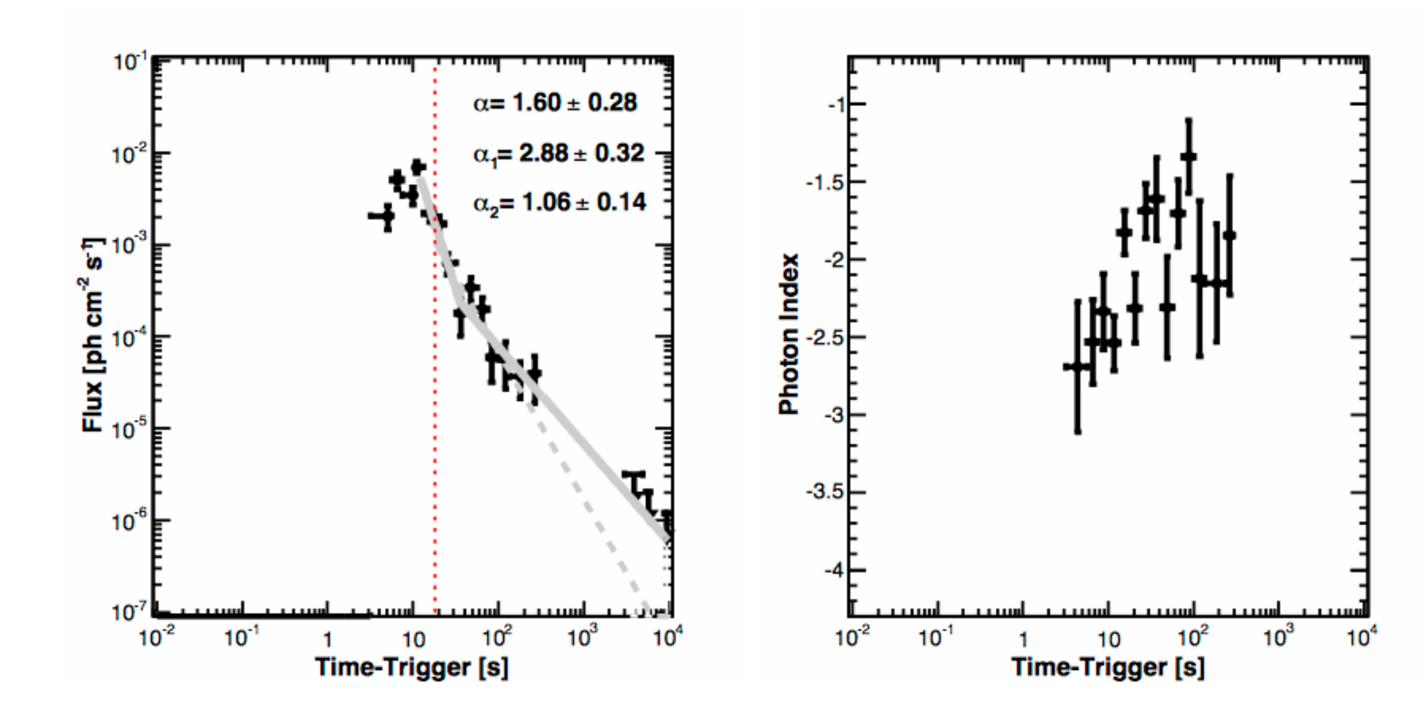
Swenson et al. (2010)

Abdo et al. (2010)

Catalog light curves

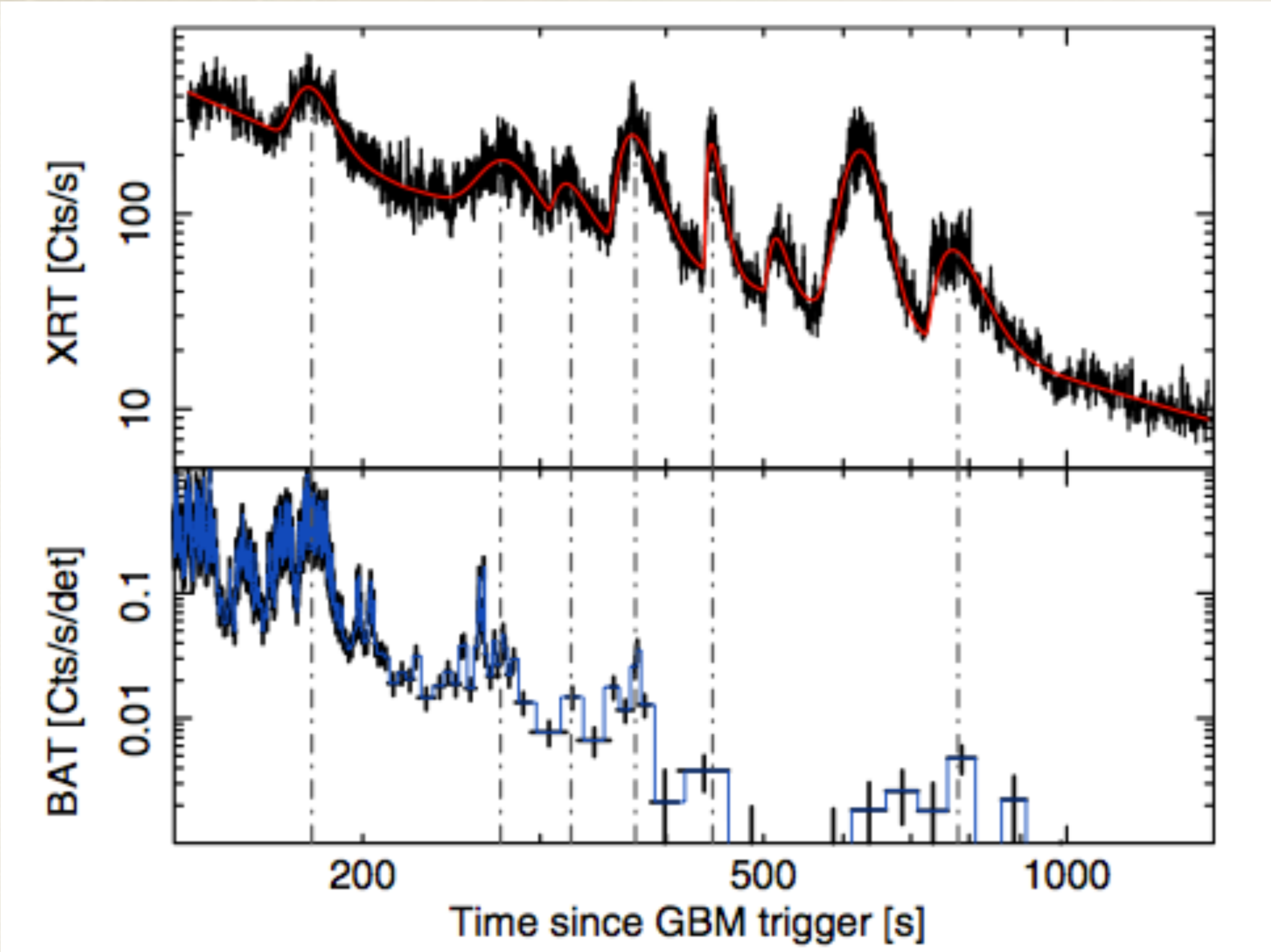
GRB 090926A

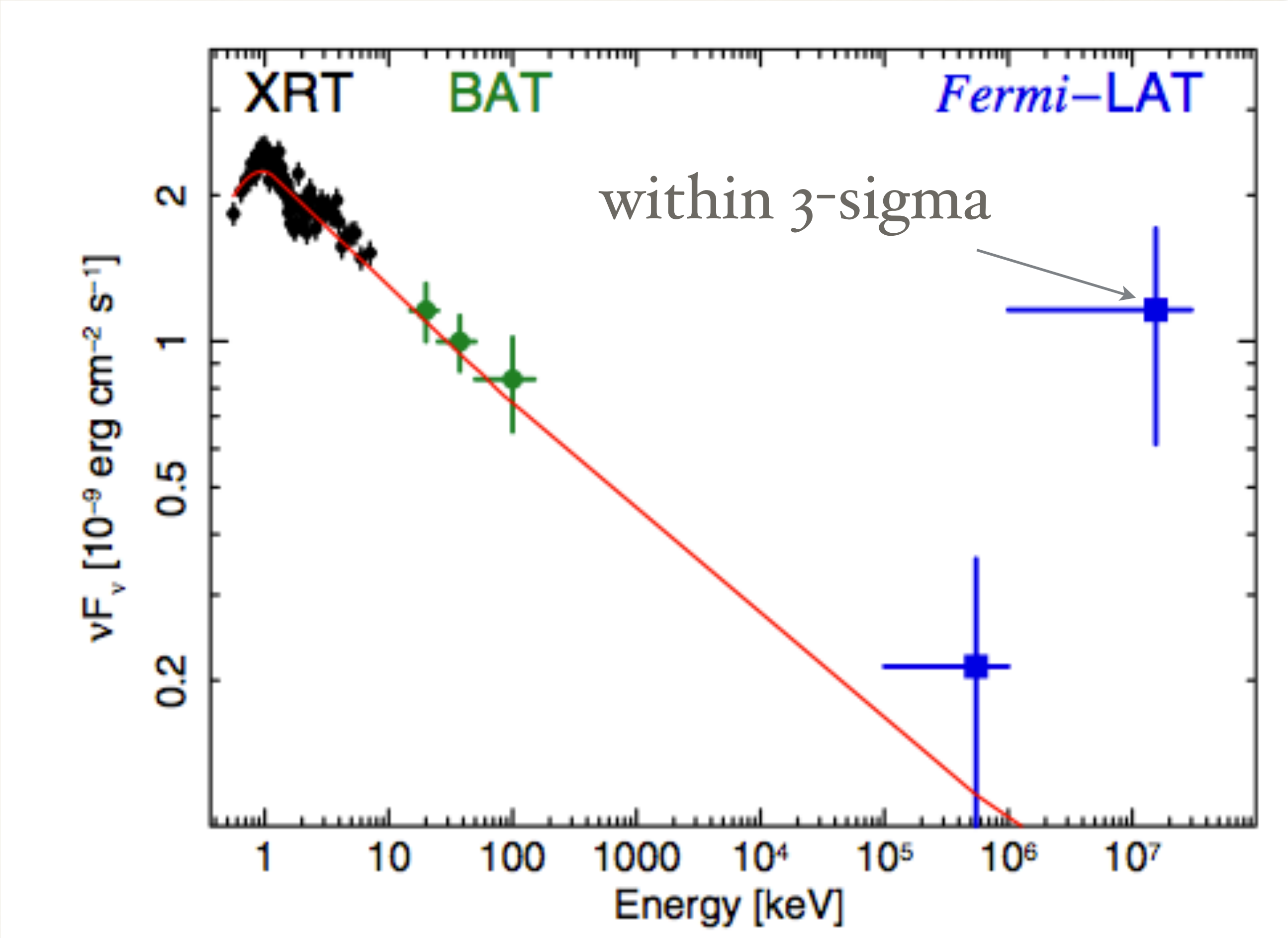




LAT Collaboration (first Fermi-LAT GRB catalog, 2013)

Contemporaneous X-ray/ GeV flares?



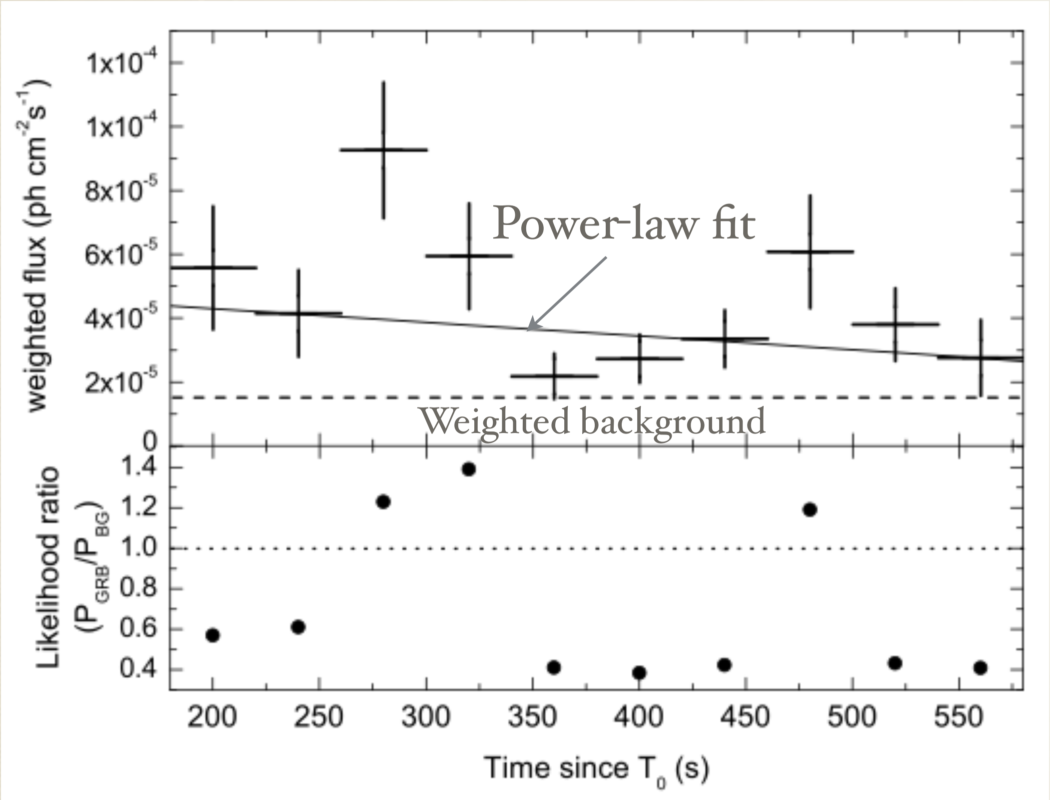


LAT detection: TS=32

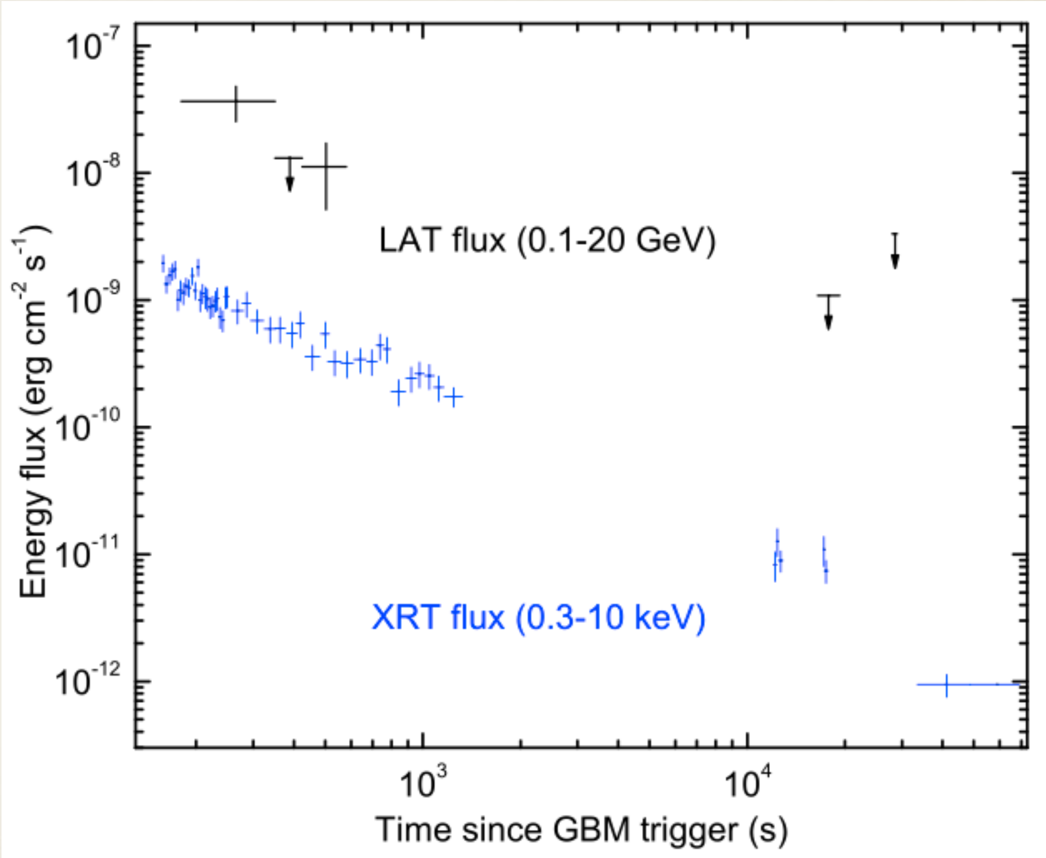
Abdo et al. (2011)

GRB 100728A: LAT detection during X-ray flares

GRB 110625A: LAT detection without X-ray flares

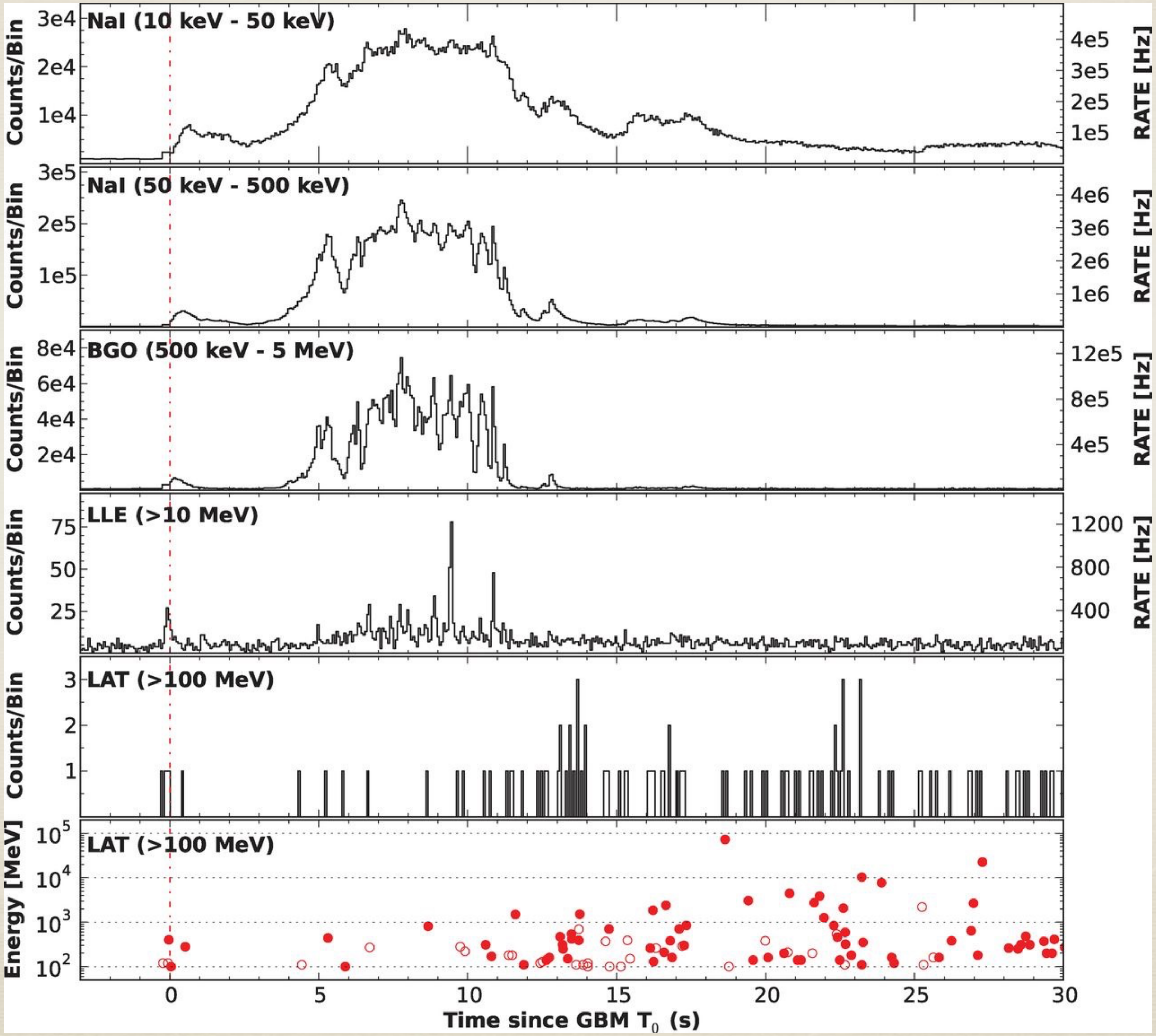


deviates from PL
at 96.77%



Tam et al. (2012)

GRB 130427A

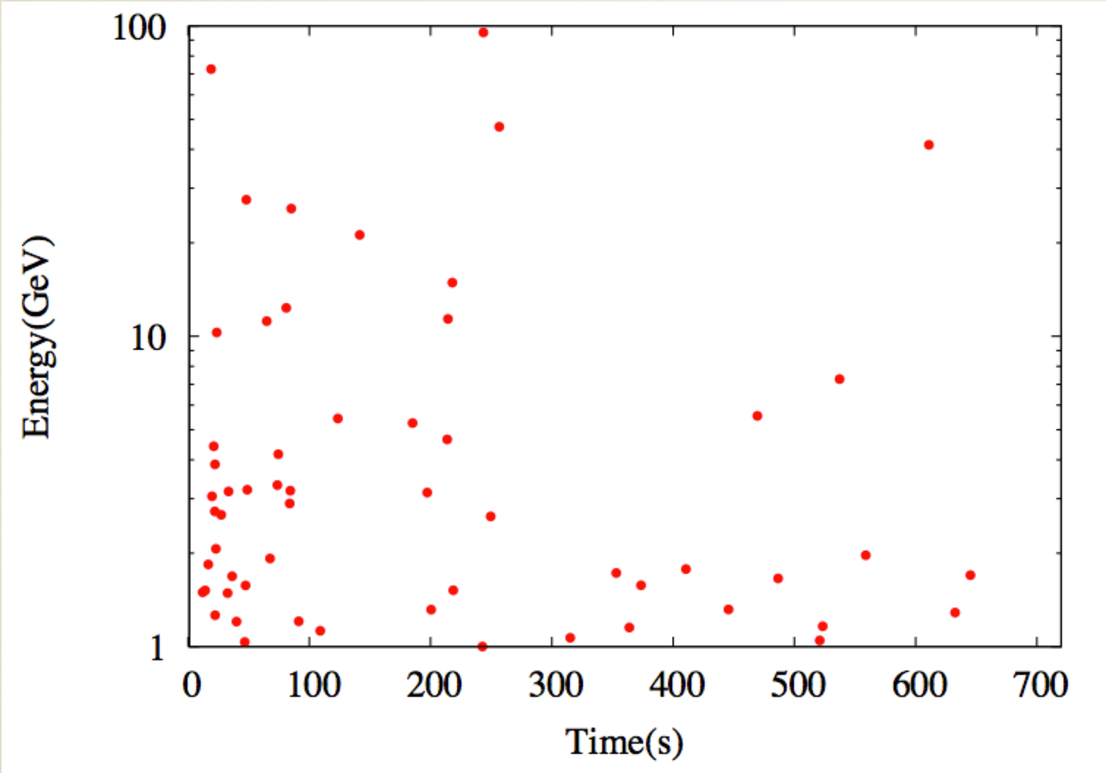

NaI (10 keV - 50 keV)
NaI (50 keV - 500 keV)
BGO (500 keV - 5 MeV)
LLE (>10 MeV)
LAT (>100 MeV)
LAT (>100 MeV)
Counts/Bin
RATE [Hz]
Energy [MeV]
Time since GBM T0 (s)

GRB 130427A

- T_{90} ~ 138s
- Fluence~2x 10^{-3} erg cm^{-2}, putting it as the GRB with the *highest fluence* in GBM and Konus-Wind mission lives
- Also highest fluence in LAT energy range, and the most luminous GRB at $z<0.5$
- Twelve >10 GeV photons were detected in the first 700s after the burst onset
- a 95 GeV photon arrived at T_0 + 243s, corresponding to an intrinsic photon energy 128 GeV at $z=0.34$, breaking the records

10-100 GeV photons

GRB 130427A is peculiar, that it emits many high-energy gamma-rays during the afterglow period

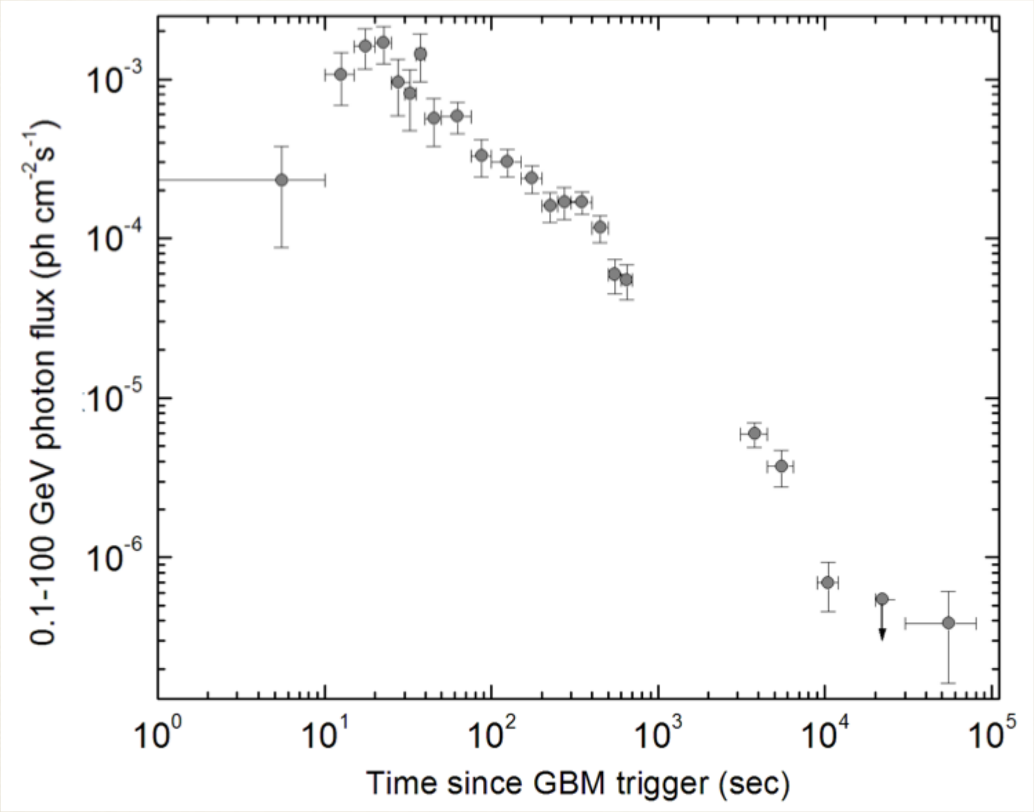


Fan, Tam, et al. (2013)

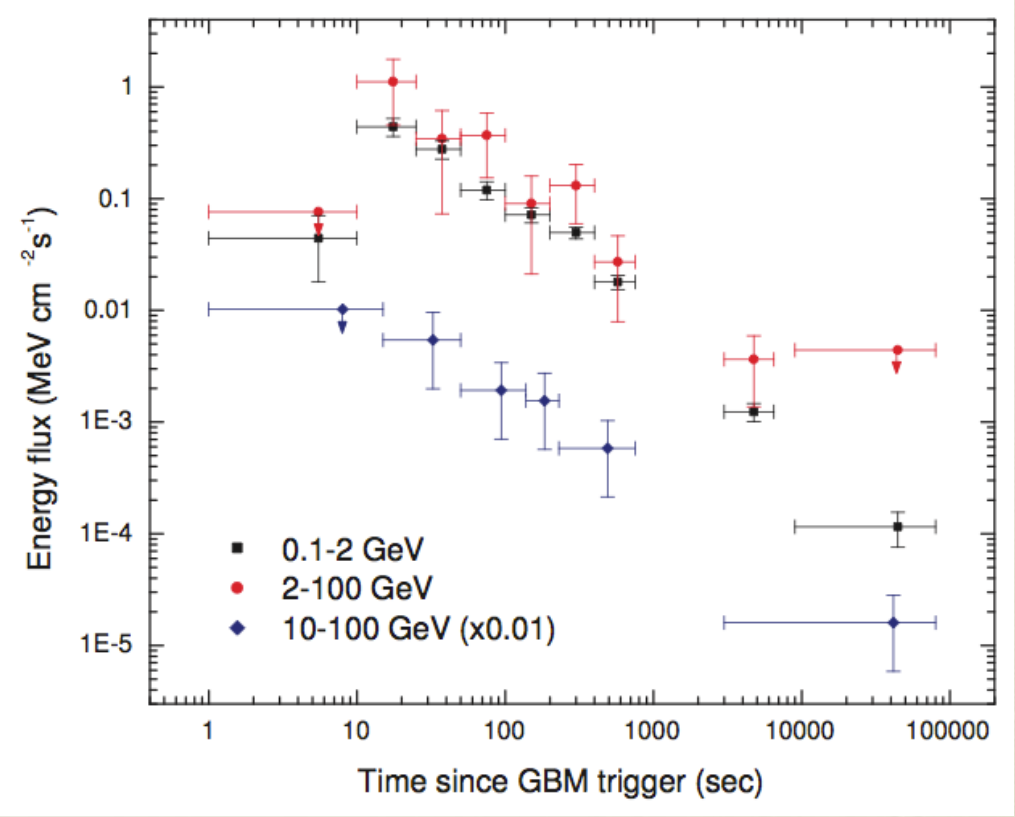
arrival time (since T_0, in sec)	energy (GeV)
18.4	72.6
22.9	10.3
47.3	27.5
64.2	11.2
80.2	12.3
84.5	25.8
140.8	21.2
213.7	11.4
217.2	14.9
242.8	95.3
256.0	47.3
610.3	41.4
3409.6	38.5
6062.3	18.6
34365.9	32.0

Tam et al. (2013)

Light curves

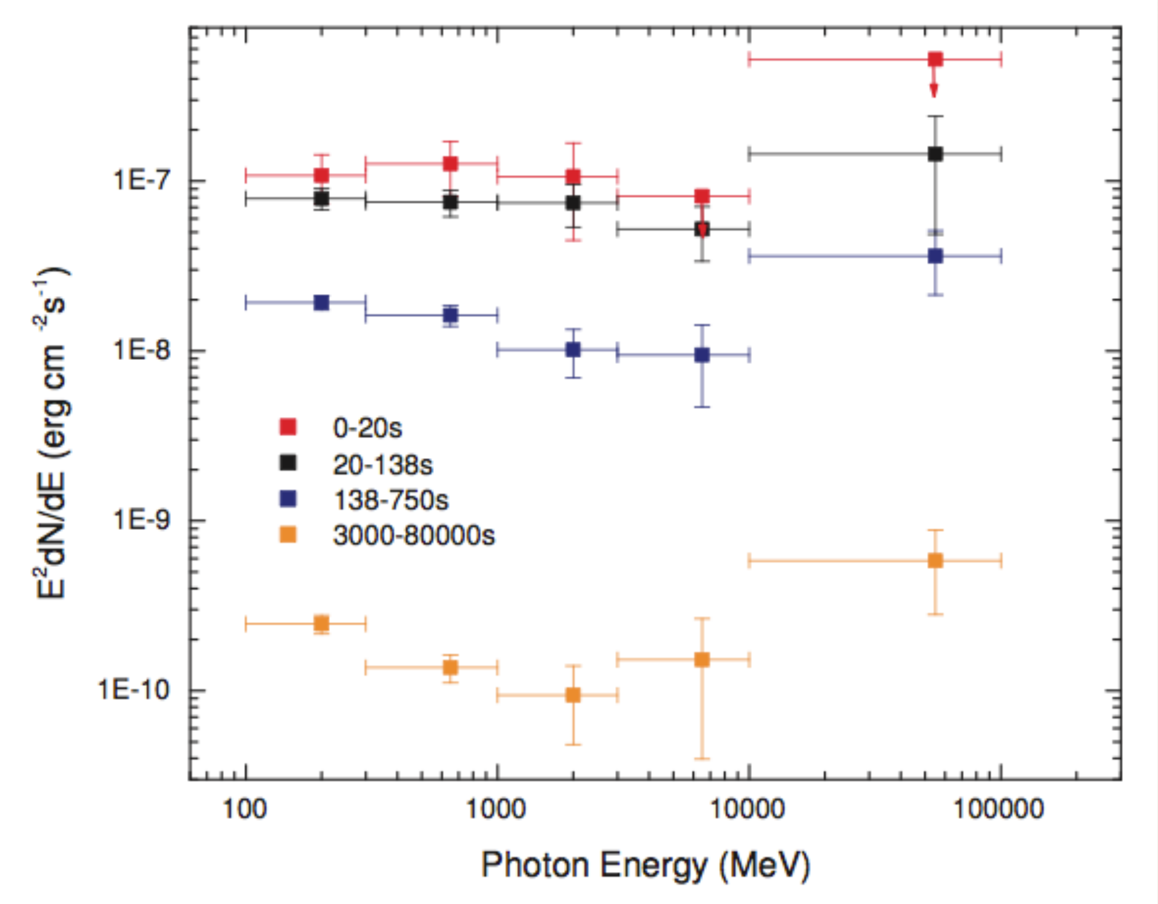


Fan, Tam, et al. (2013)



Tam et al. (2013)

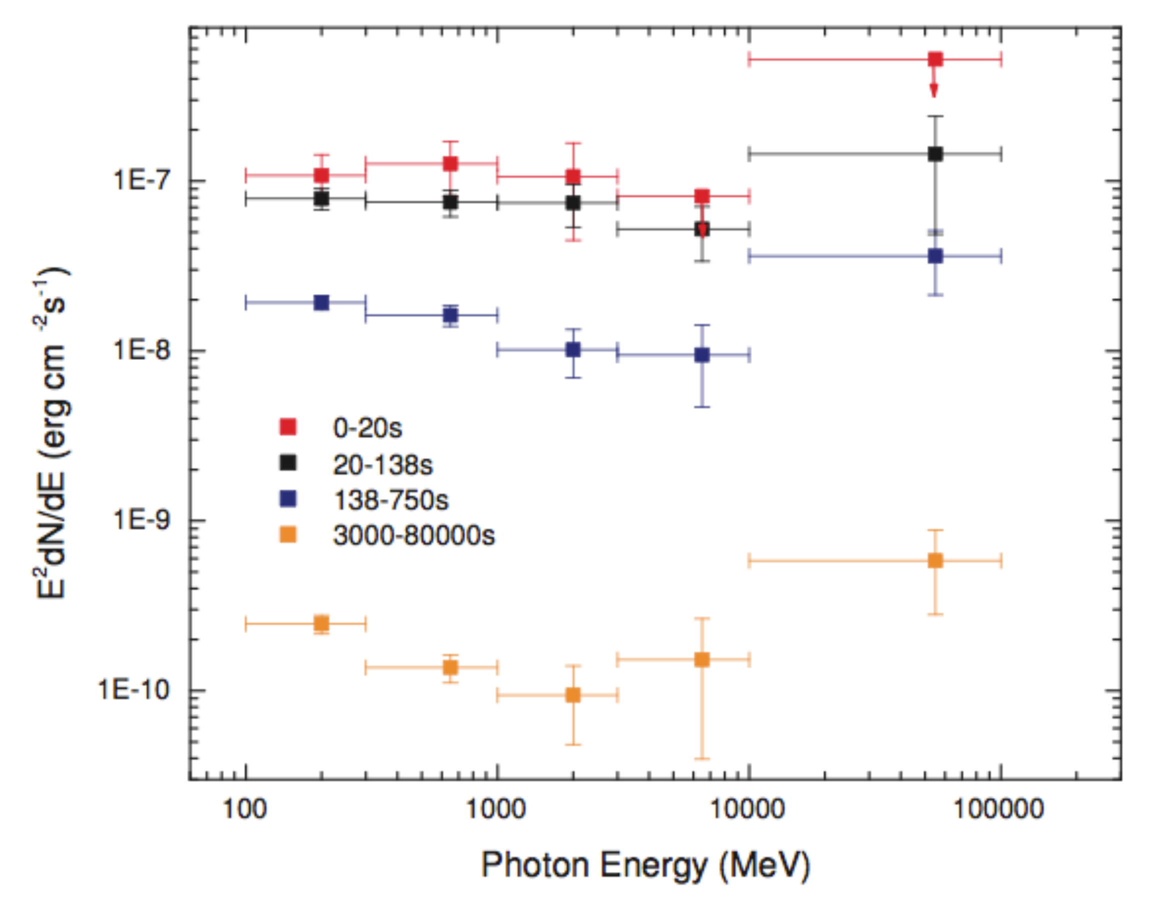
Spectral evolution

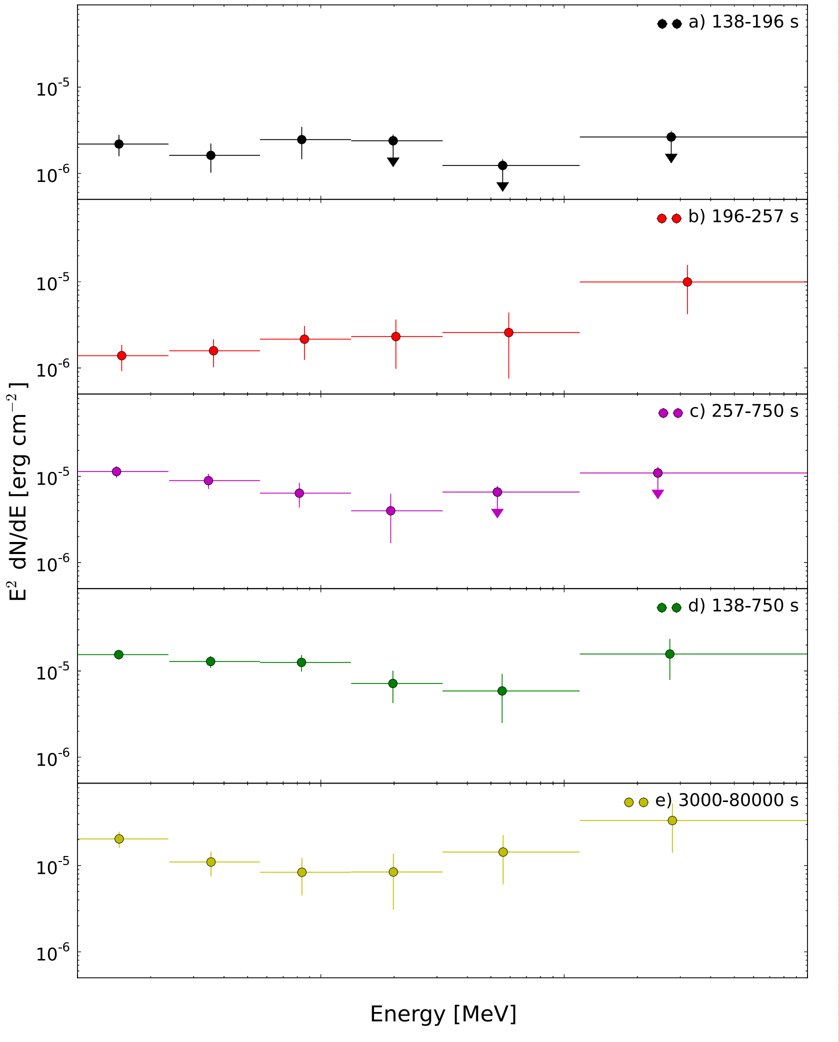


Two spectral components are found to co-evolve

Tam et al. (2013)

Spectral evolution





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

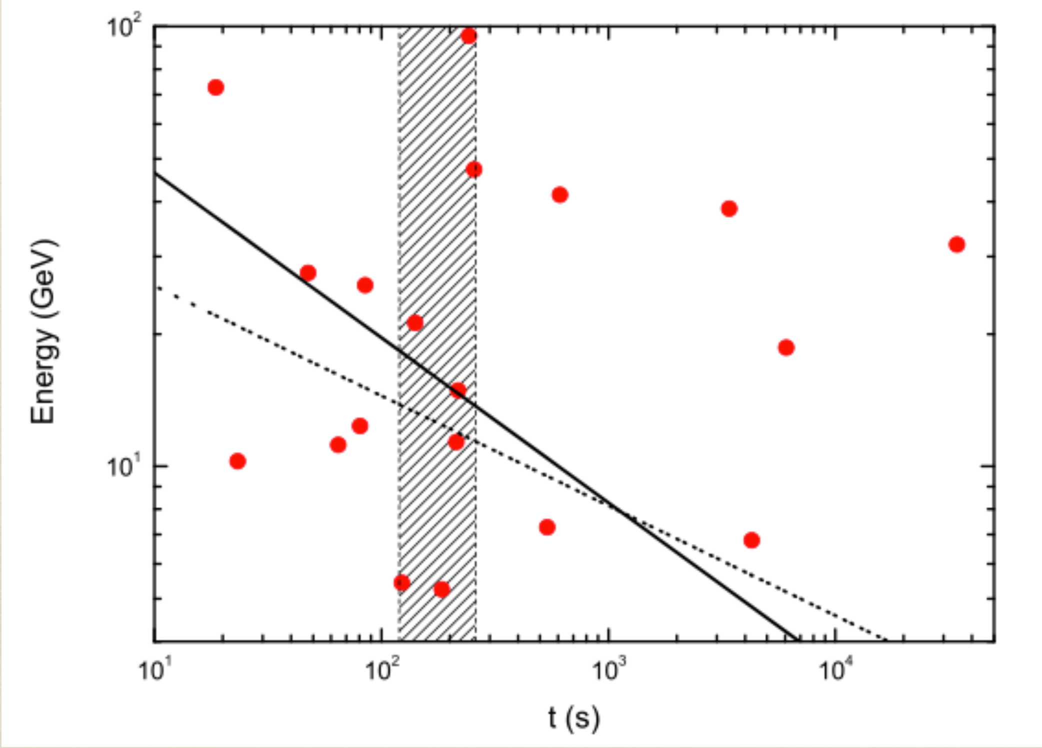
Power law index doesn't change!

Significance of broken power law over power law

Tam et al. (2013)

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



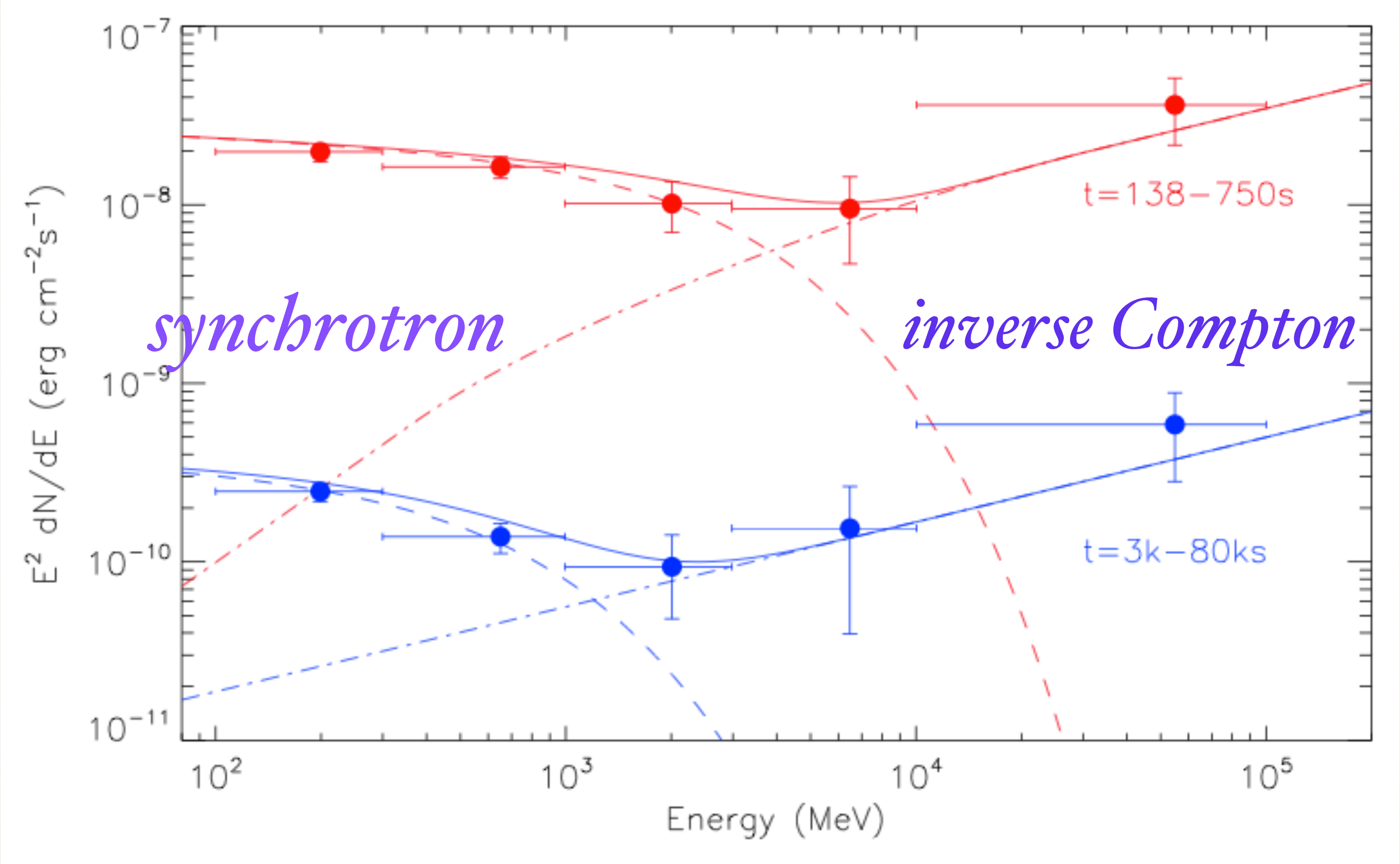
$$\epsilon_{\rm syn,M} \sim 100\ {\rm MeV}\ \Gamma(1+z)^{-1} \sim \begin{cases} 20\ {\rm GeV}\ E_{\rm k,54}^{1/8} n_{-2}^{-1/8} t_2^{-3/8} (\frac{1+z}{1.34})^{-5/8}, {\rm ISM}; \\ 15\ {\rm GeV}\ E_{\rm k,54}^{1/4} A_{*,-2}^{-1/4} t_2^{-1/4} (\frac{1+z}{1.34})^{1/4}, \ {\rm wind}; \end{cases}$$

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

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
* Inverse-Compton emission, long suspected, provides a natural explanation for the extra hard component at >10 GeV energies (Fan et al. 2013, Liu et al. 2013, also see Ackermann et al. 2013)

Are we seeing two mechanisms?

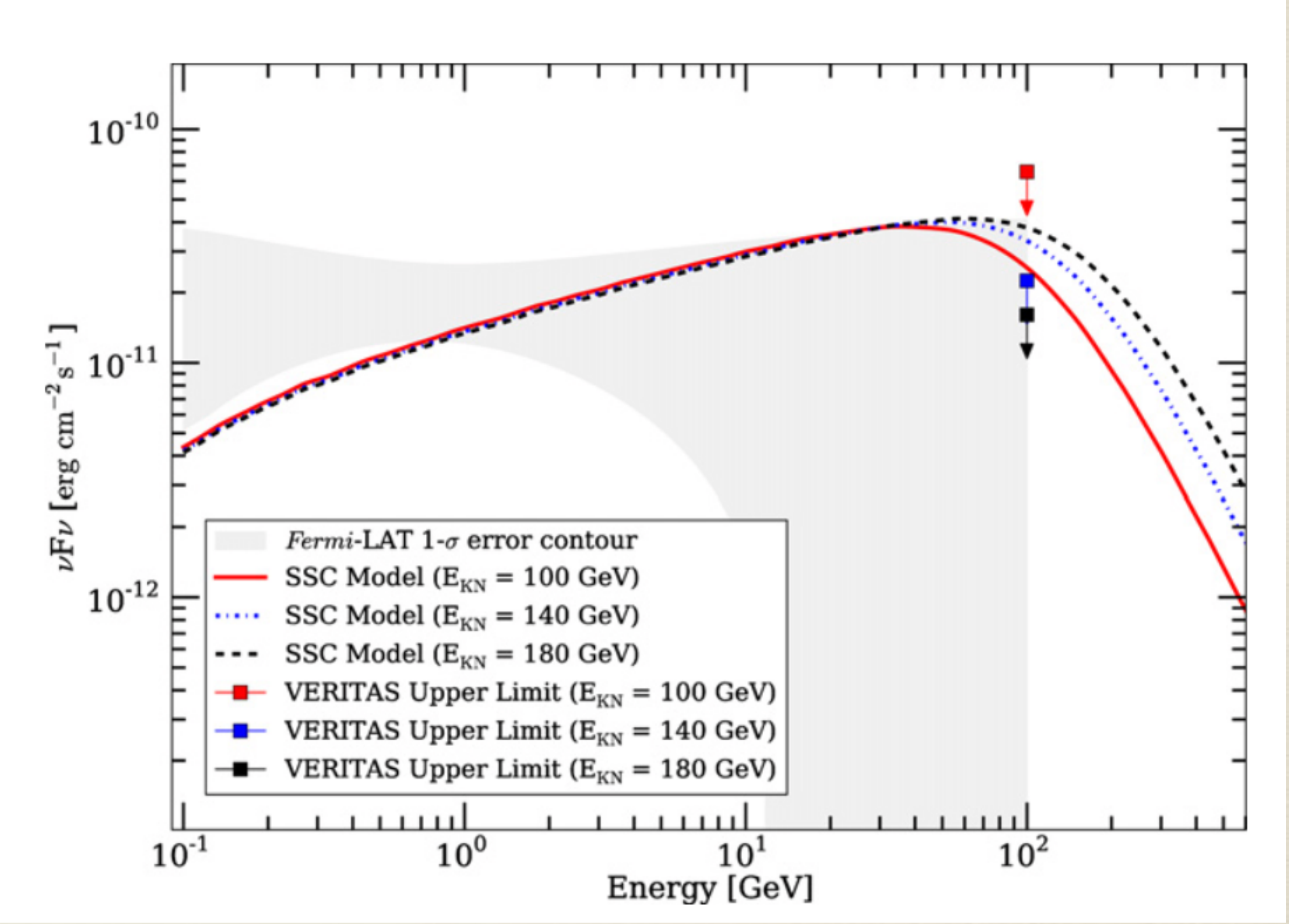


Liu et al. (2013)

VERITAS non-detection

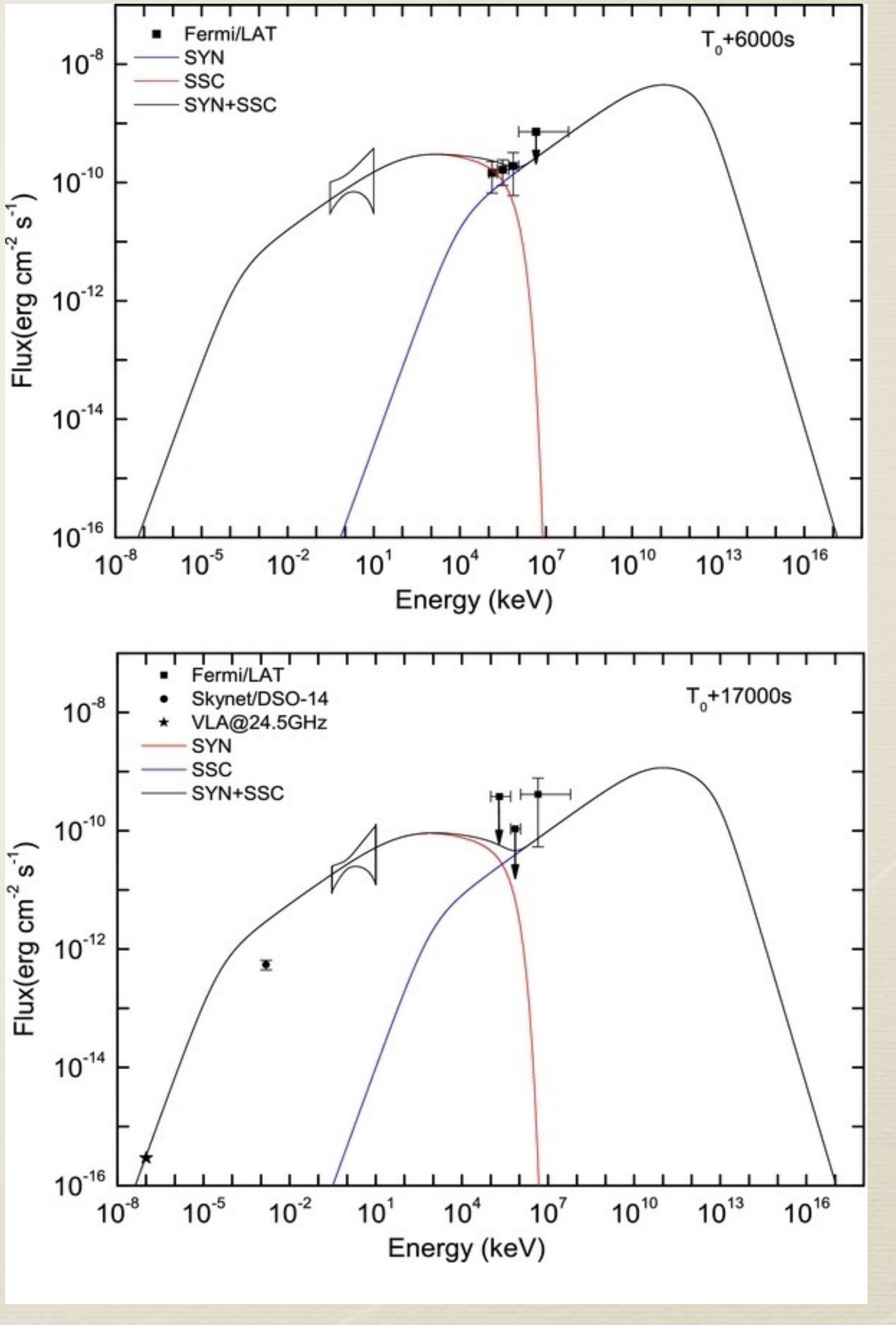
* VERITAS observations were initiated the following night, 71.128 ks after the Fermi-GBM trigger.
* Observations lasted for 59 minutes until moonrise.

Aliu et al. (2014)



GRB 130907A

- A 55 GeV photon was found about 5 hr after the prompt phase
- The energy of this photon (55 GeV) exceeds the maximum synchrotron photon energy at this time
- SSC emission of the afterglow? (Tang, Tam & Wang, 2014)



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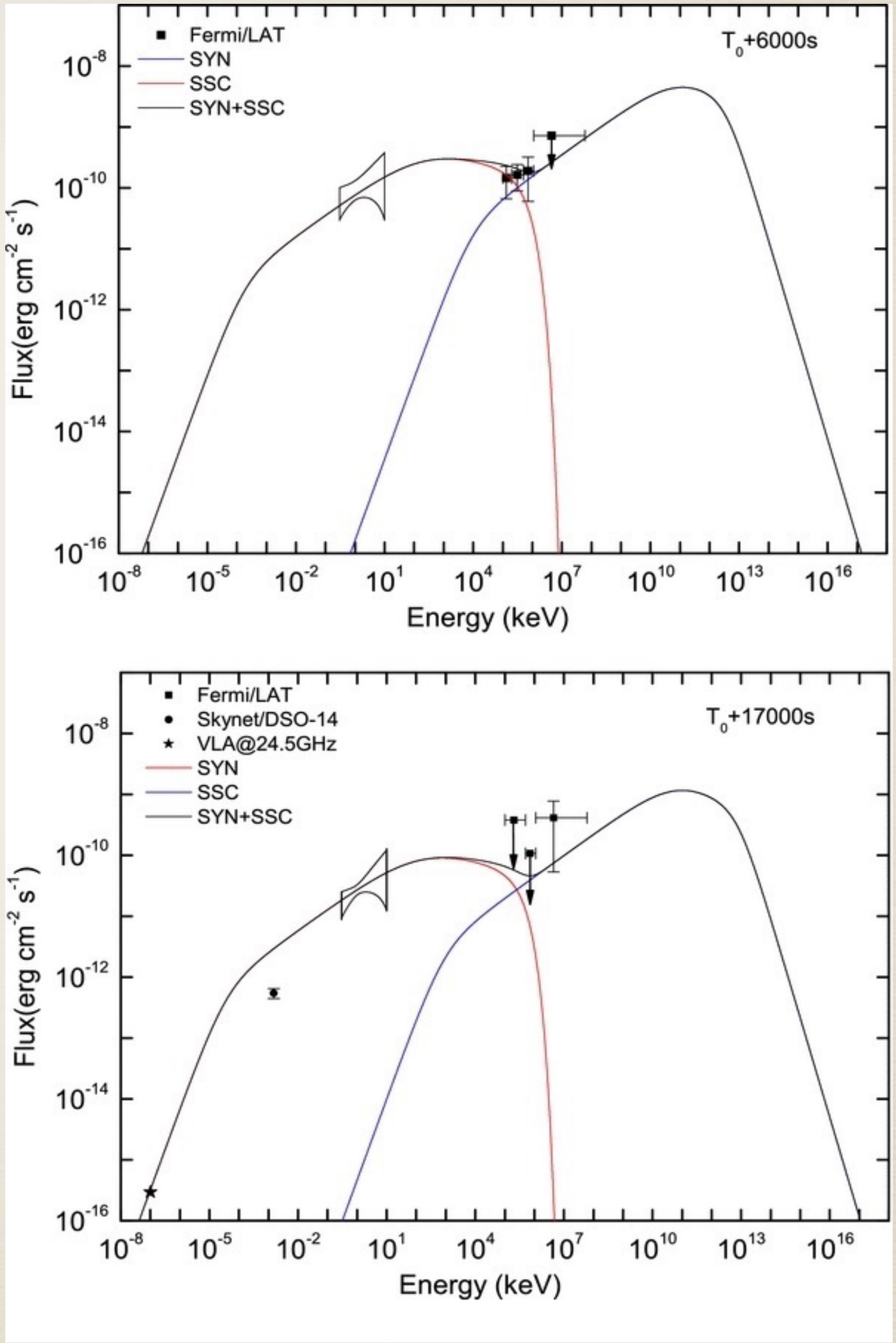
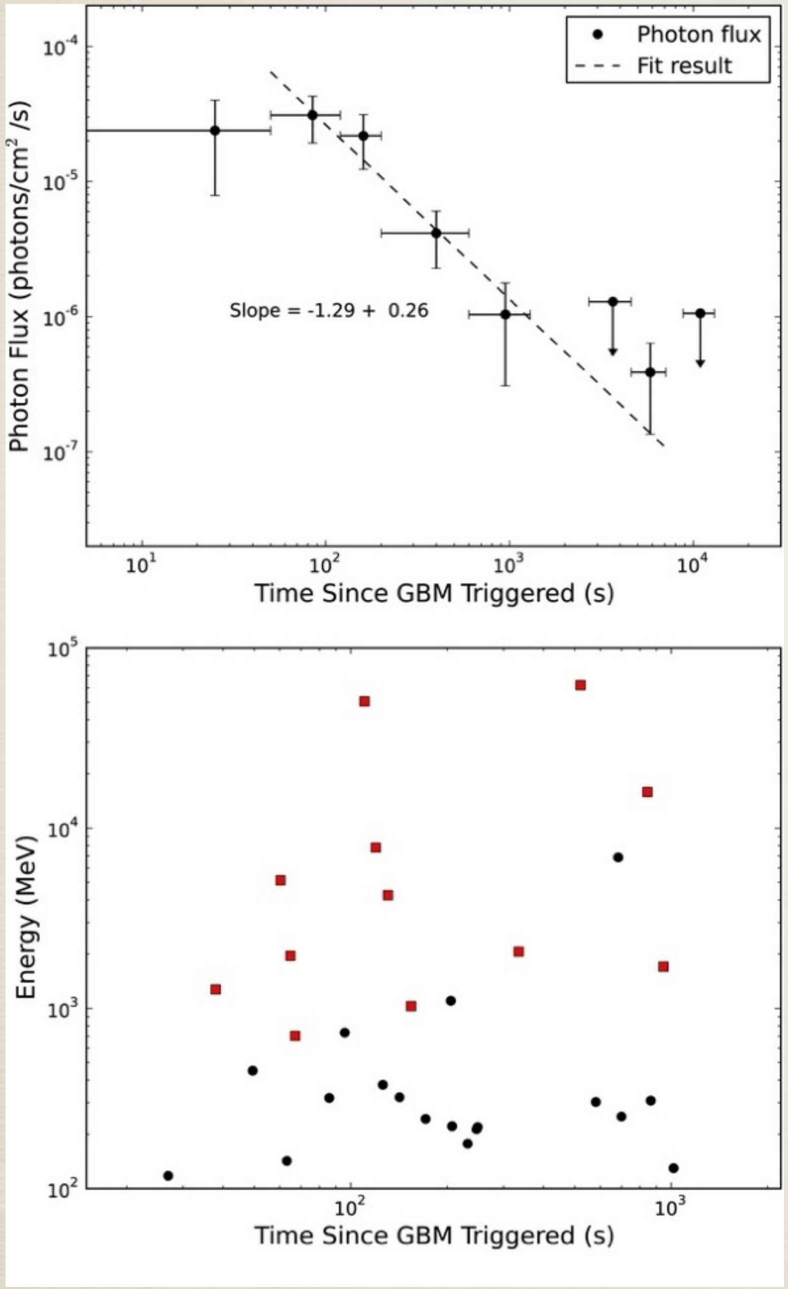
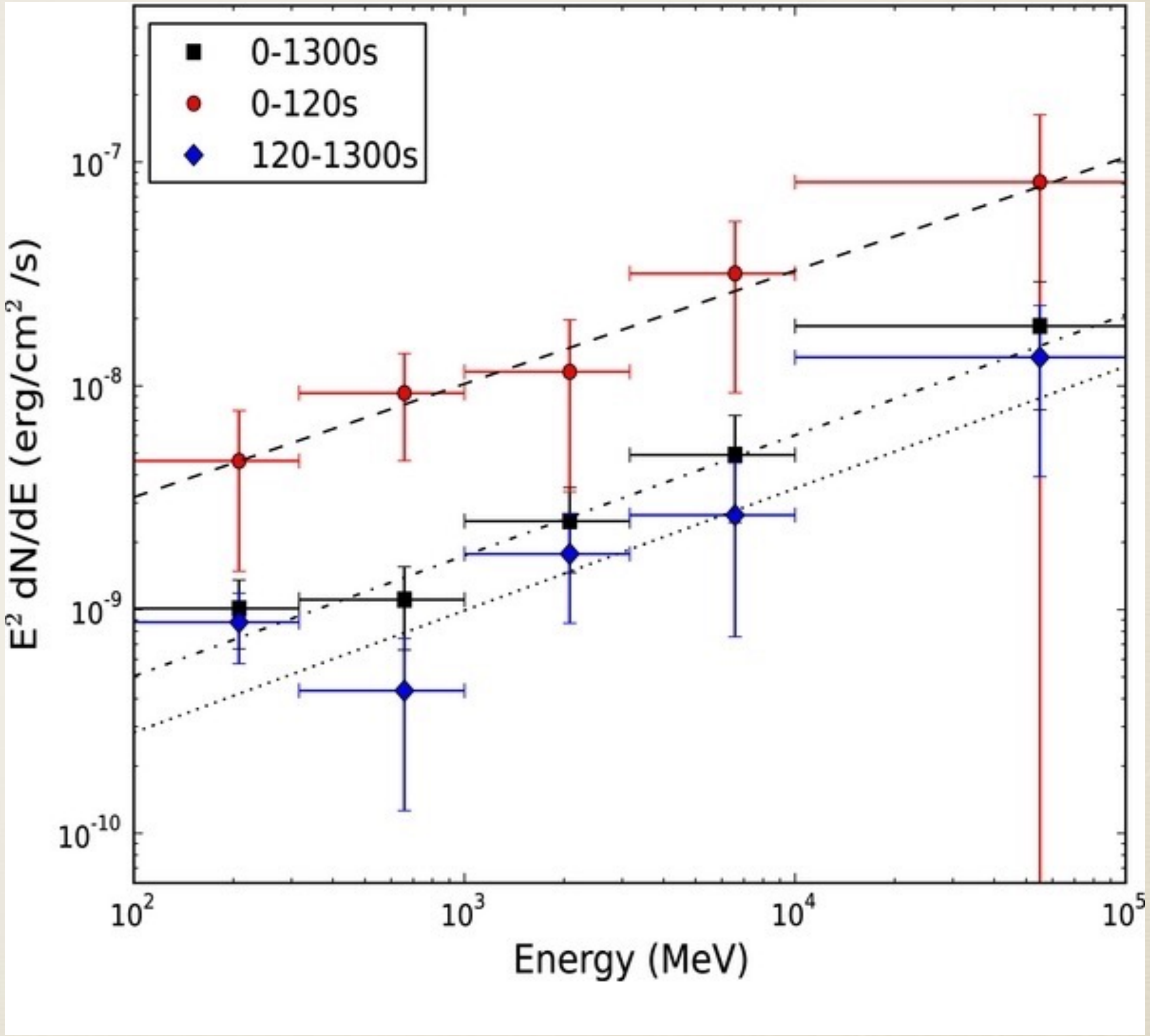
- The energy of this photon (55 GeV) exceeds the maximum synchrotron photon energy at this time
- SSC emission of the afterglow? (Tang, Tam & Wang, 2014)

Yet another GRB 160310A
1.36 GeV@100s; 27 GeV@5800s
GRB-940217-like bursts



GRB 131231A





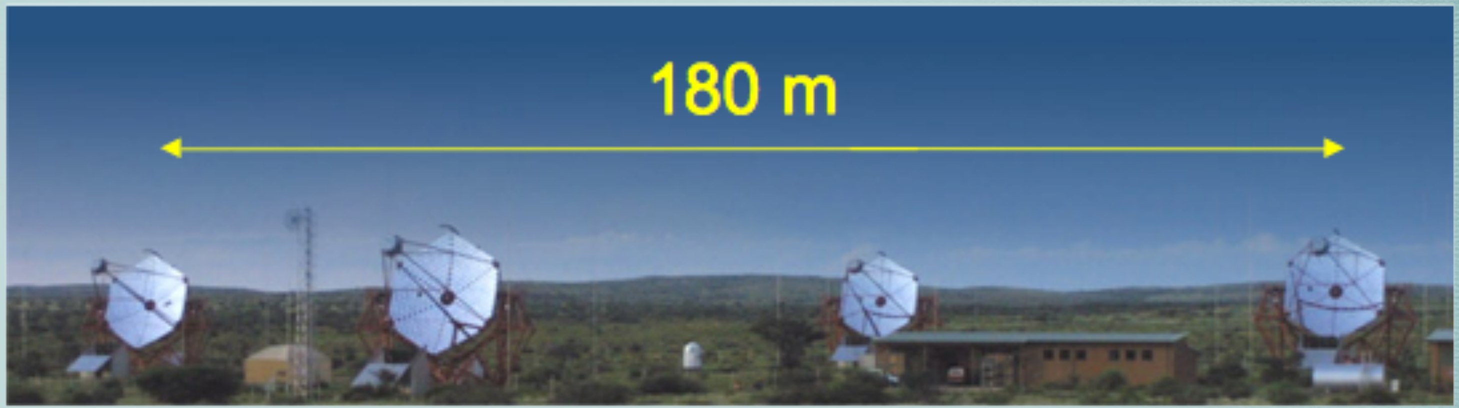
Liu, B. et al. (2014)

Probably the strongest case for IC emission, besides 130427A

GRB 160509A

- 0-1 hr, Γ ~-2.1
- 1-4 hr , Γ ~ -1.6
- 1-24hr, Γ ~ 1.0
- One 28.9 GeV photon seen by the LAT at 70 ks! (Tam et al. in preparation)
- VERITAS only obtained an upper limit (David William), observations should be within one day after the burst
- cut-off at 30-100 GeV (EBL attenuation)? (z=1.17)

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



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

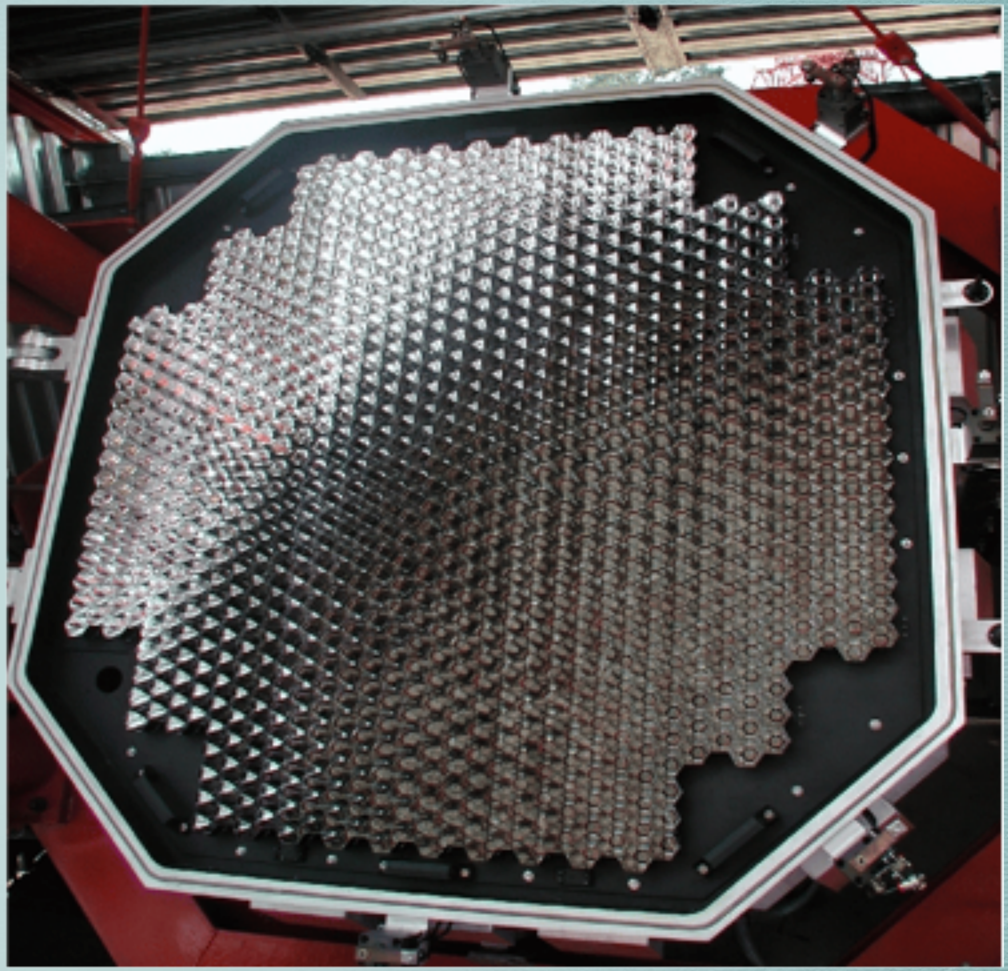
($23^{\circ}16'$ S, $16^{\circ}30'$ E)
1800 m above sea level

energy range > 100 GeV

complete array operating since early 2004

H.E.S.S. telescopes

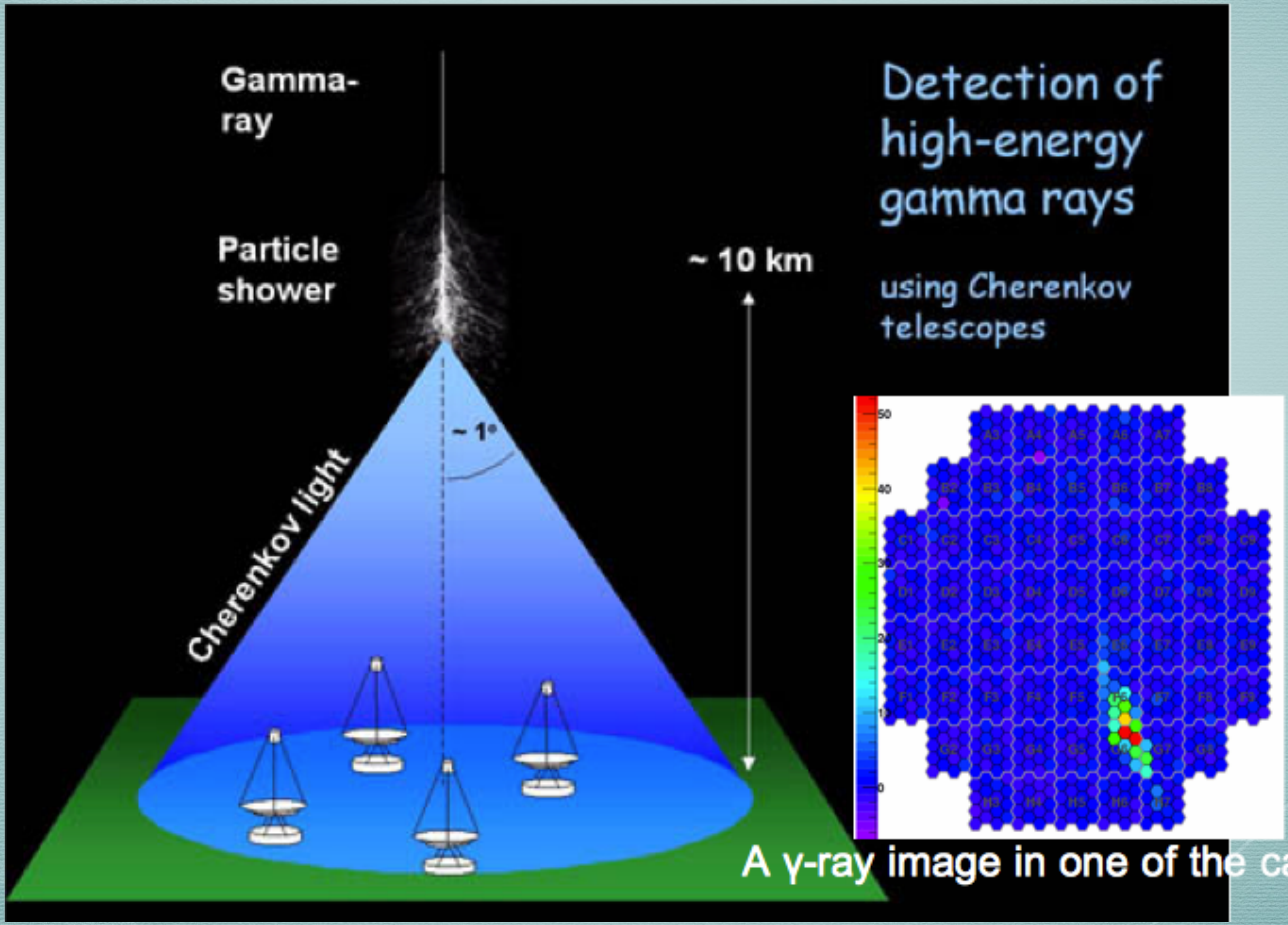
380 mirrors



Cameras

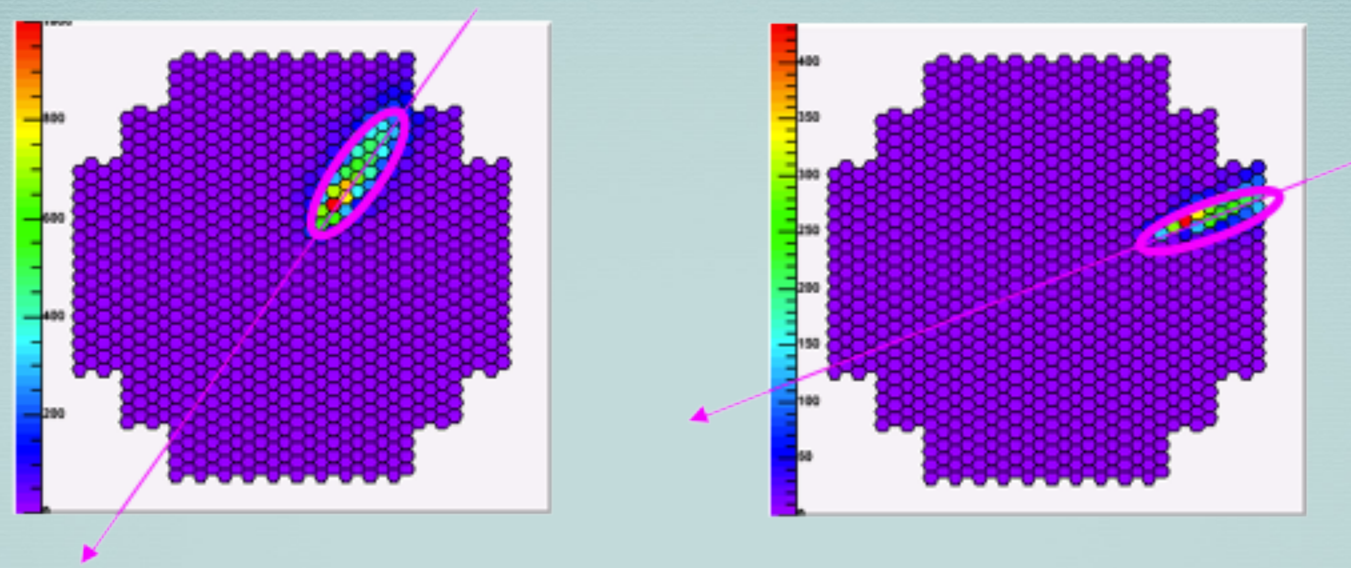
960 photomultiplier tubes
each of 0.16°
field of view ~5°

Observation principle

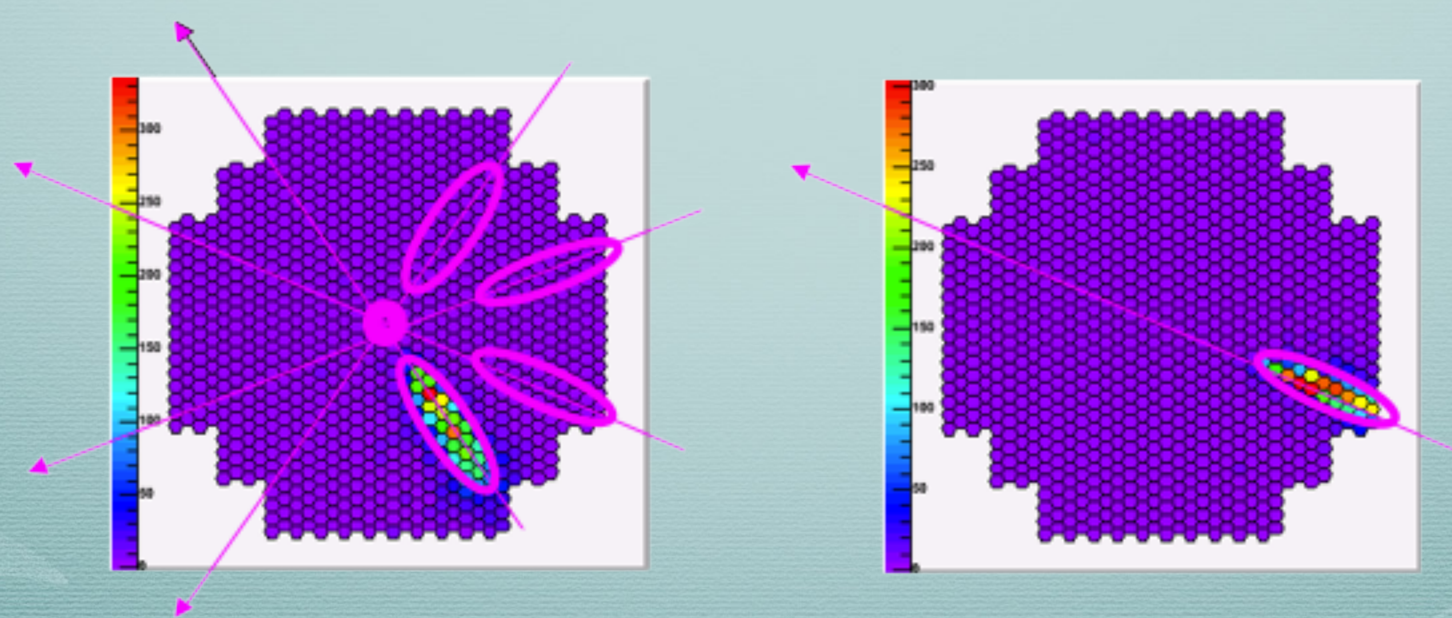


A γ-ray image in one of the cameras

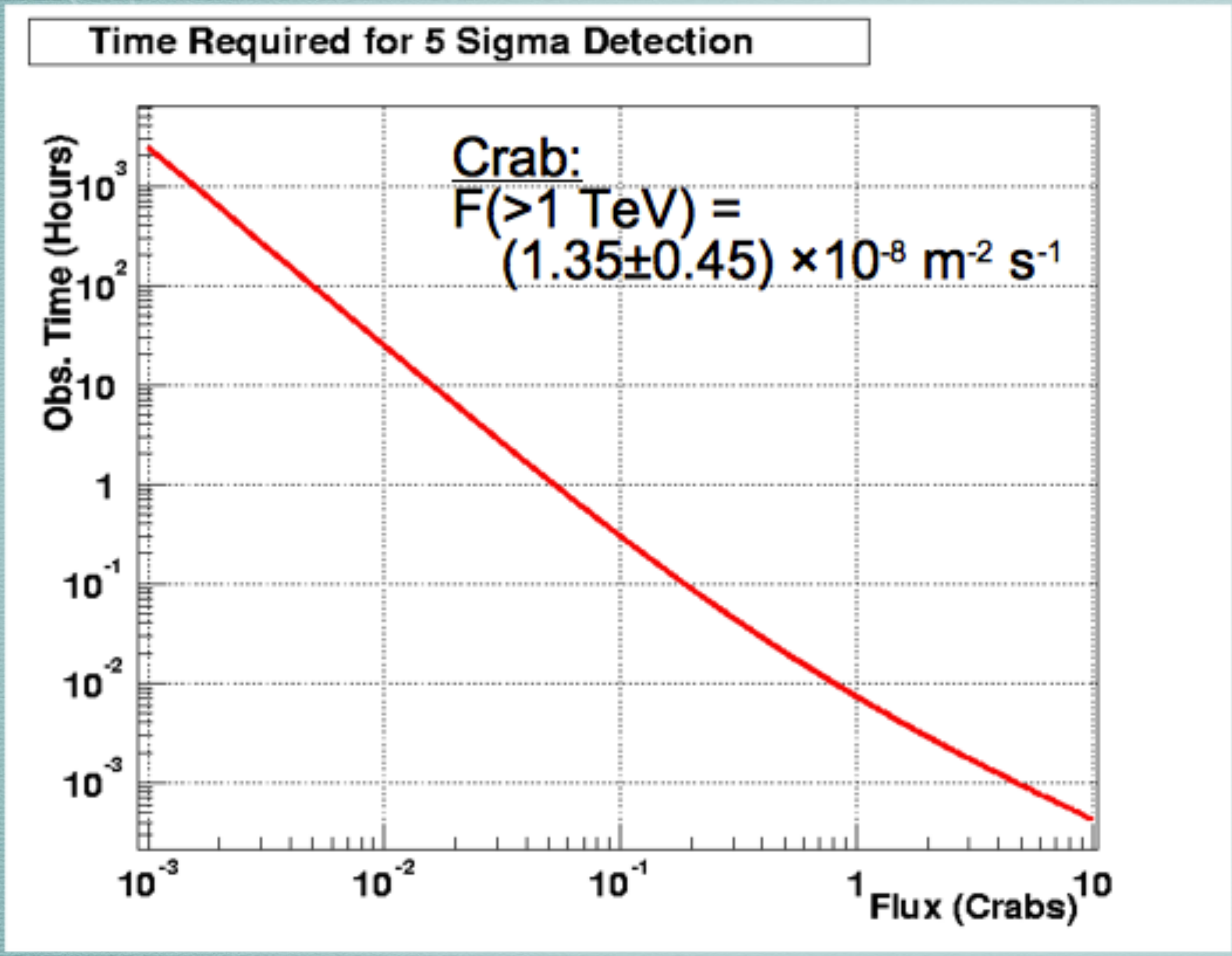
Stereo technique



Reconstruct the source position in the camera



H.E.S.S. sensitivity



Sensitivity::

- 0.01 Crab in ≈25 hrs
- 0.10 Crab in ≈20 min
- 1.00 Crab in ≈30 sec

Threshold (trigger, selected):

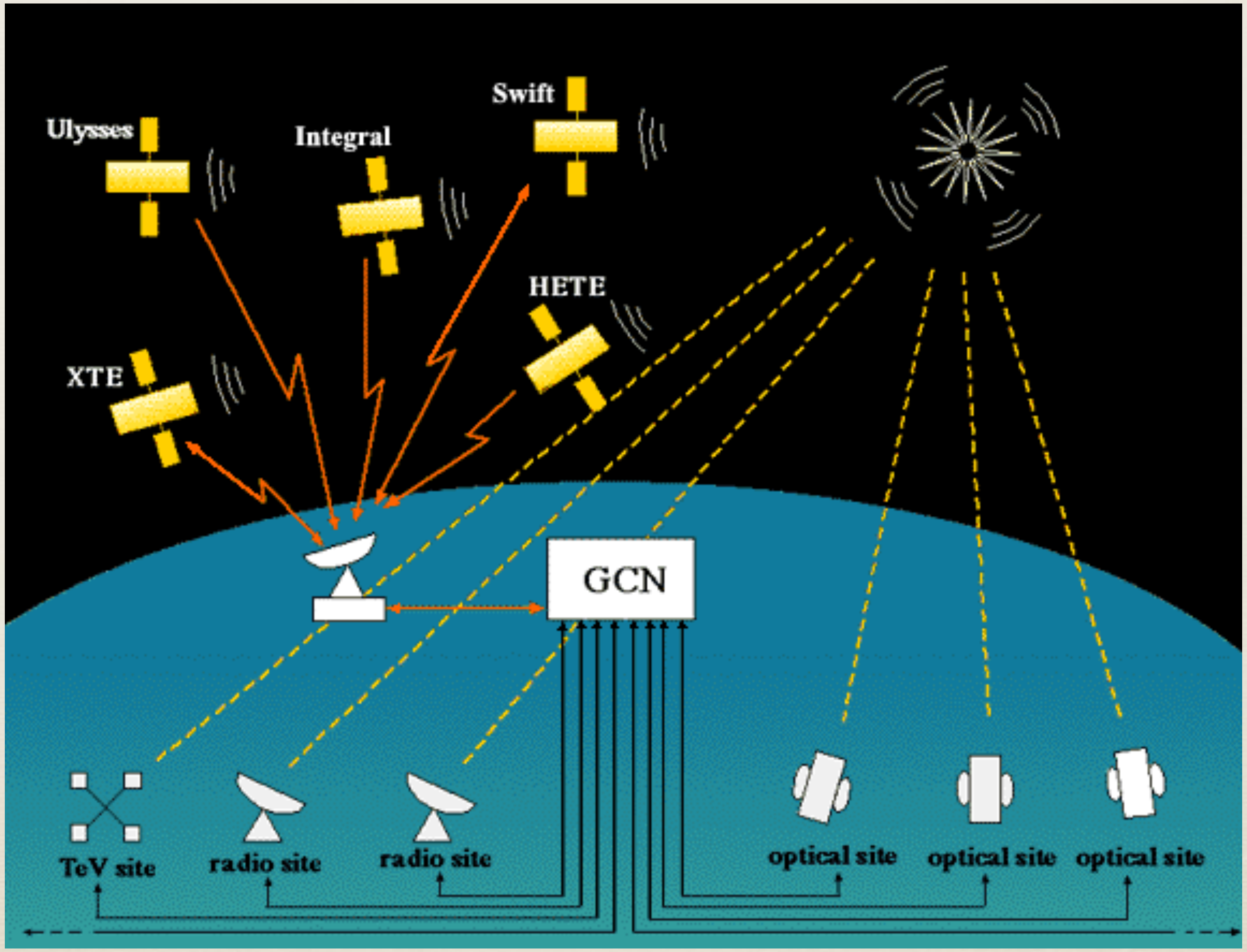
- (115,145) GeV at 20º ZA
- (265,305) GeV at 45º ZA

using standard analysis

At 20º zenith angle (ZA) after selection cuts

H.E.S.S. GRB observing program

- Receiving GRB Coordinates network (GCN) Notices



H.E.S.S. GRB observing program

* Receiving GRB Coordinates network (GCN) Notices
* Upon reception and filtering of a GCN Notice, we will observe the burst position as soon as possible (while interrupting the on-going/planned observations), limited to:

  - H.E.S.S. dark time (no moon)
  - Zenith angle < 45 deg

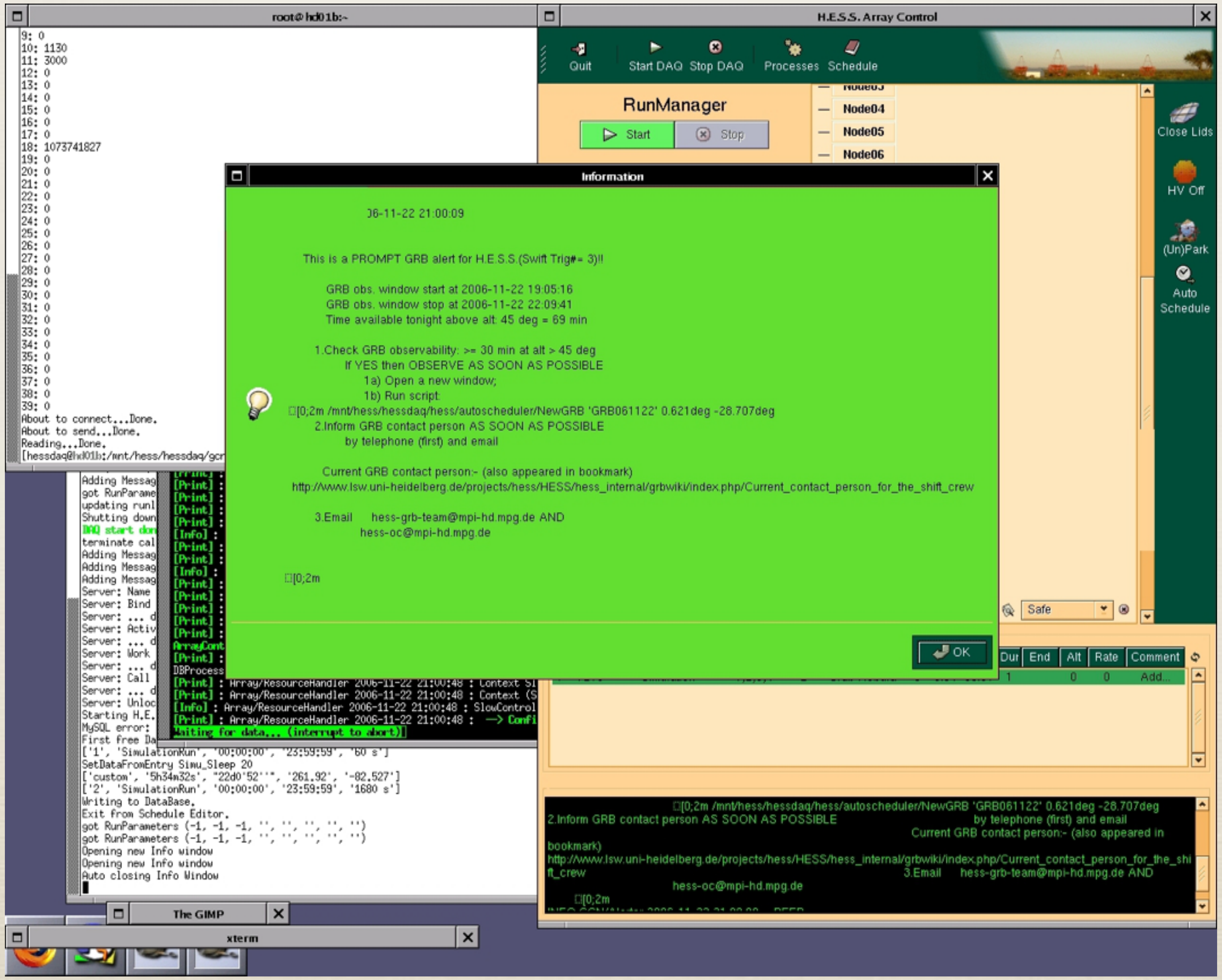
H.E.S.S. GRB observing program

* Receiving GRB Coordinates network (GCN) Notices
* Upon reception and filtering of a GCN Notice, we will observe the burst position as soon as possible (while interrupting the on-going/planned observations), limited to:

  - H.E.S.S. dark time (no moon)
  - Zenith angle < 45 deg
* We start GRB observations up to ~24 hours after onset
* Invest more time for more promising sources (i.e. low-redshift, short delay)

GRB observing strategies

* Pop-up window: shows up when an alert arrives



GRB observing strategies

* Invest more time for more promising sources (i.e. low-redshift, short delay)
* To observe a corresponding GRB position up to
  - 24h after trigger if $z<0.1$ is reported
  - 12h after trigger if $z<0.3$ is reported
  - 6h after trigger if $z<1.0$ is reported
  - 4h after trigger if z is unknown.

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

Aharonian…Tam…(2009)

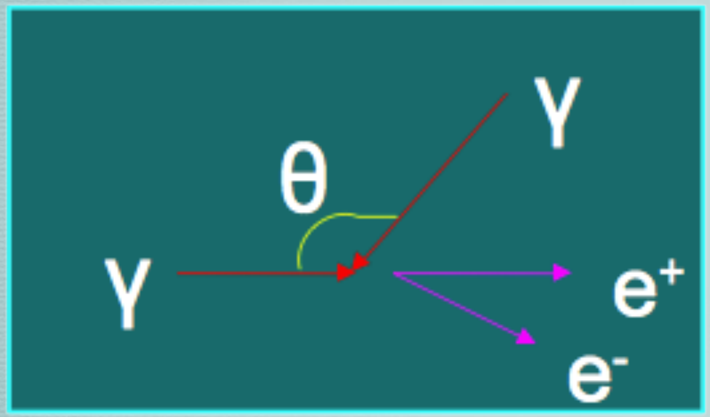
Summary of HESS-observed GRBs

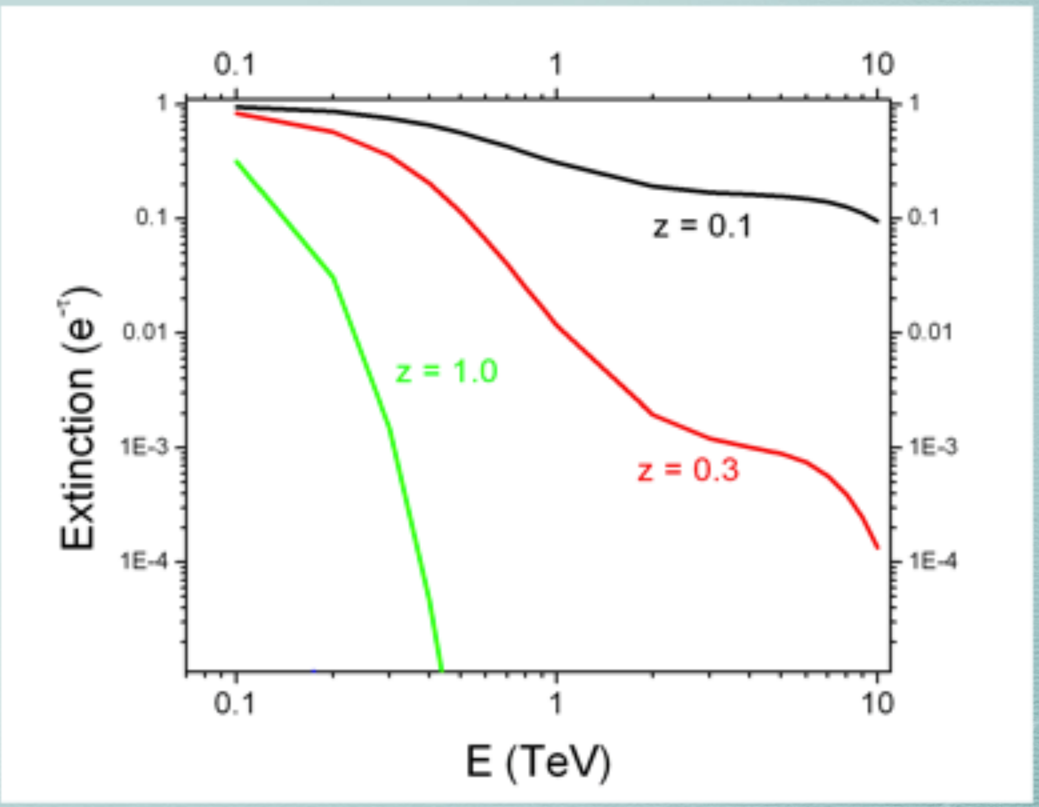
* 22 GRBs with good data published
* Brightest one (seen by satellite): GRB 030329
* Nearest: GRB 060505 ($z=0.089$)
* Shortest delay: GRB 070621 (~ 6 min)
* The largest published sample of GRB afterglow observations using an air Cherenkov instrument (>20 GRBs and observation hours ~32h)

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

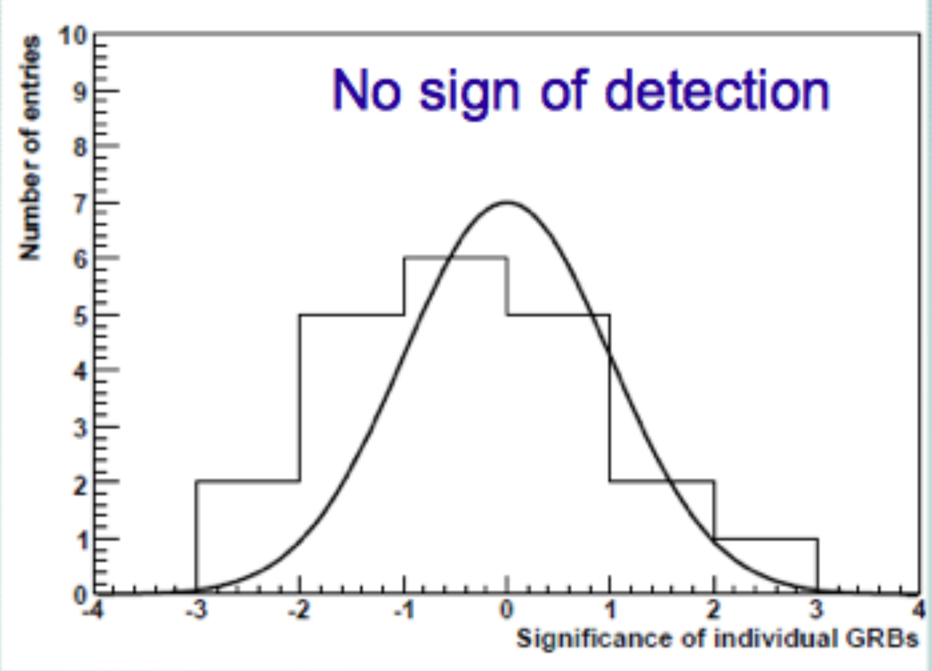
Aharonian et al. (HESS), Nature, 2006

GRB	Redshift	E_{th} (GeV)	F_{UL} [a]	$F_{corrected}$ [a]
060505	0.0889	400	3.9×10^{-14}	5.8×10^{-14}
030329	0.1687	1360	7.6×10^{-15}	9.7×10^{-14}
070209	0.314	370	1.2×10^{-13}	8.7×10^{-13}
070724A	0.457	200	2.1×10^{-13}	1.0×10^{-12}
041006	0.716	150	1.8×10^{-12}	2.7×10^{-11}
061110A	0.758	200	1.7×10^{-13}	1.7×10^{-11}
050801	1.56	310	2.1×10^{-13}	[b]
071003[c]	1.604	280	2.0×10^{-13}	[b]
060526	3.21	220	1.7×10^{-13}	[b]
070721B	3.626	320	1.1×10^{-13}	[b]

10 of them have redshift information; 6 have z < 1

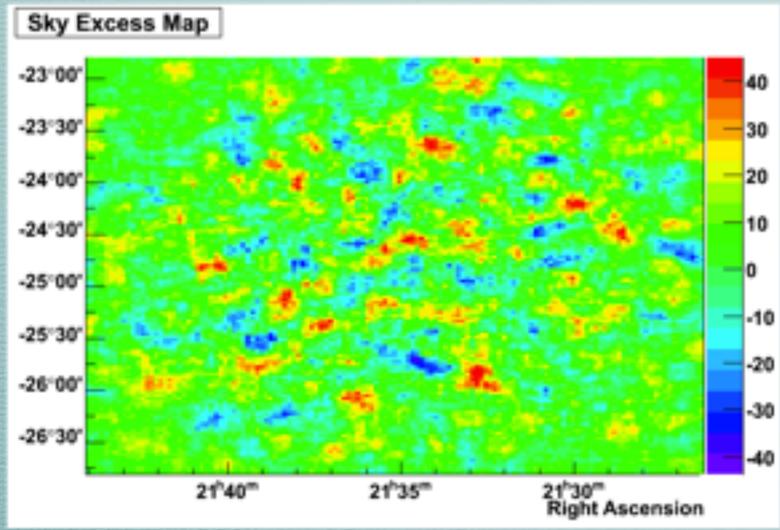
Aharonian...Tam...(2009)

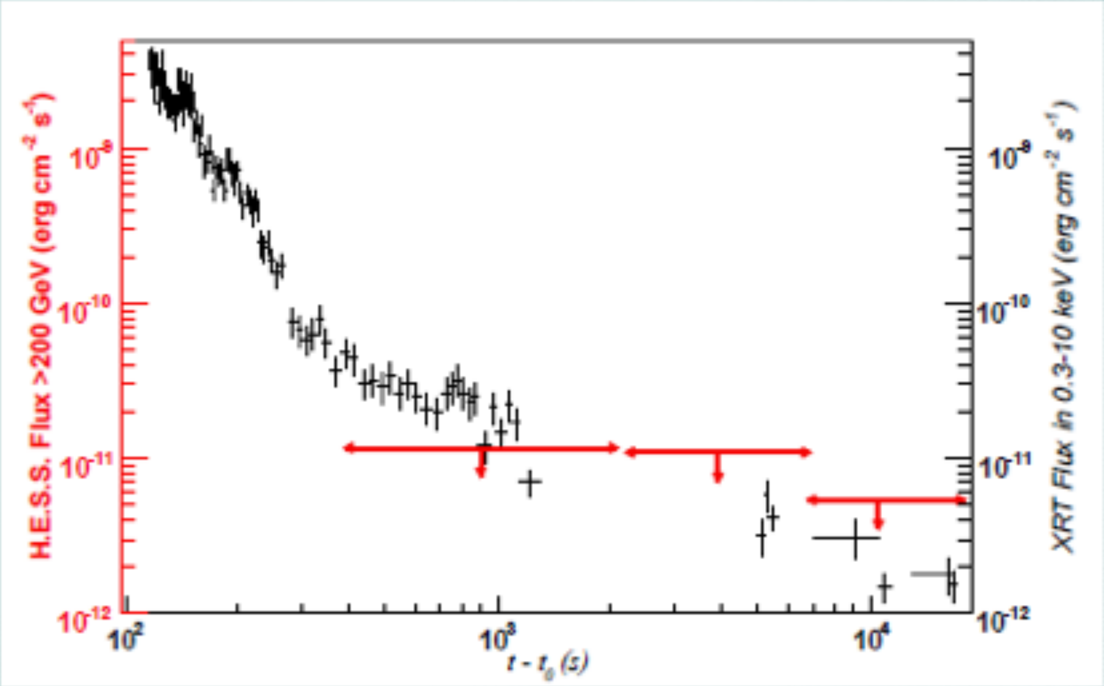
Results: no detection



Distribution of the statistical significance of the GRB positions

Long GRB 070621
Duration: 40 s
Fluence (15-150 keV)
4.3×10^{-6} erg cm^{-2}





"lightcurve"
(F_{UL} over time)

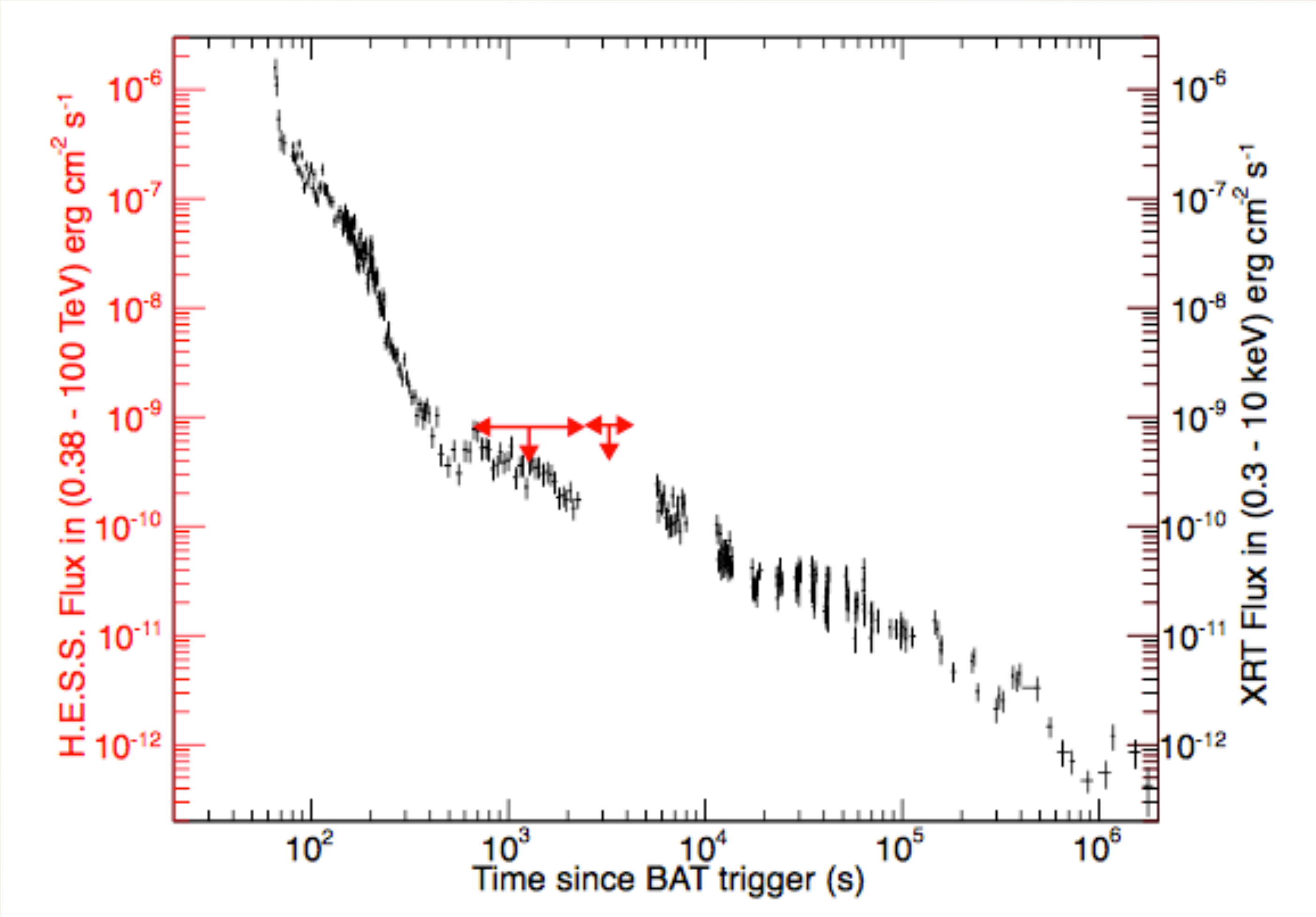
Δt = 6.5 min, ***unknown z***
exposure 4 hours, longest for H.E.S.S. GRB observations

No detection!

(Aharonian et al. 2009, A&A)

GRB 100621A

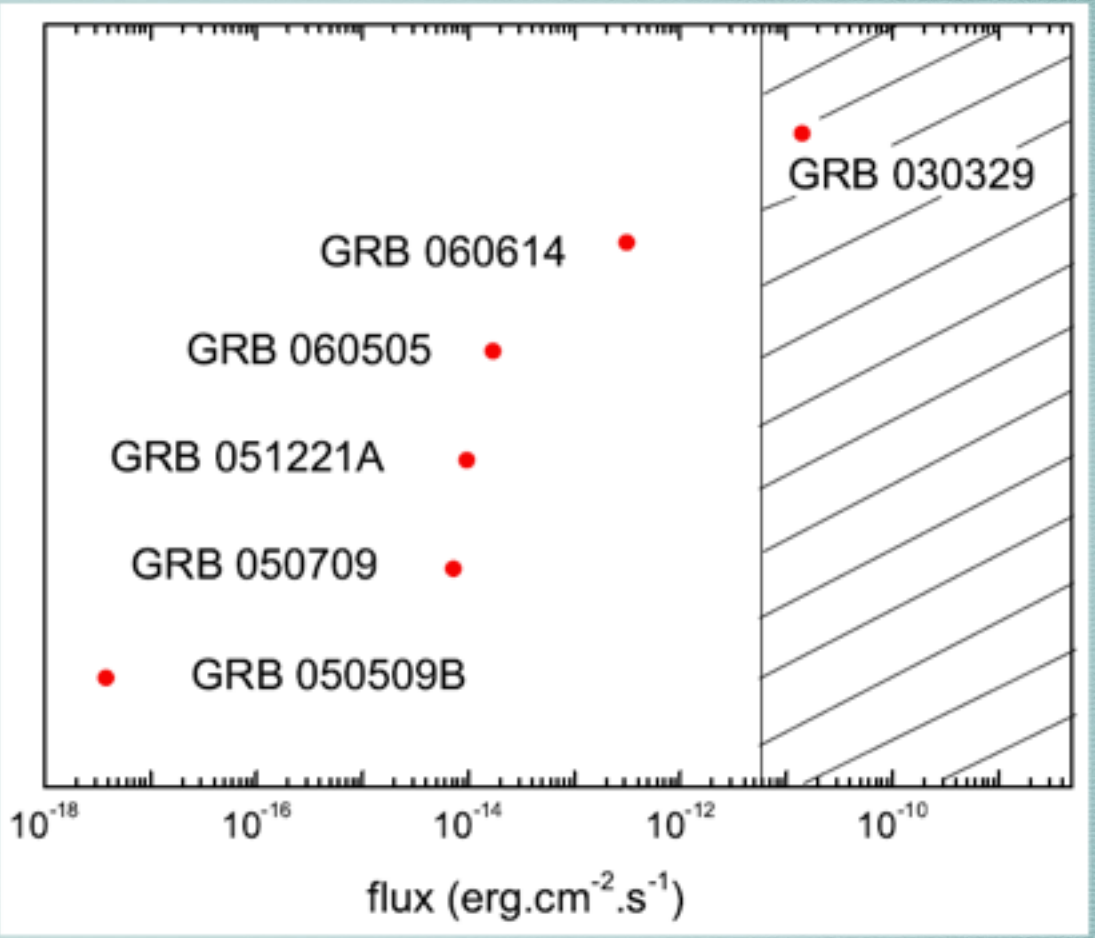
- Brightest XRT burst *before 130427A*
- *z=0.542*



H.E.S.S. collaboration (2014)

Modeled VHE flux compared with H.E.S.S. sensitivity

Red dots: Modeled VHE flux 10 h after the burst



H.E.S.S. 2-h sensitivity above 200 GeV

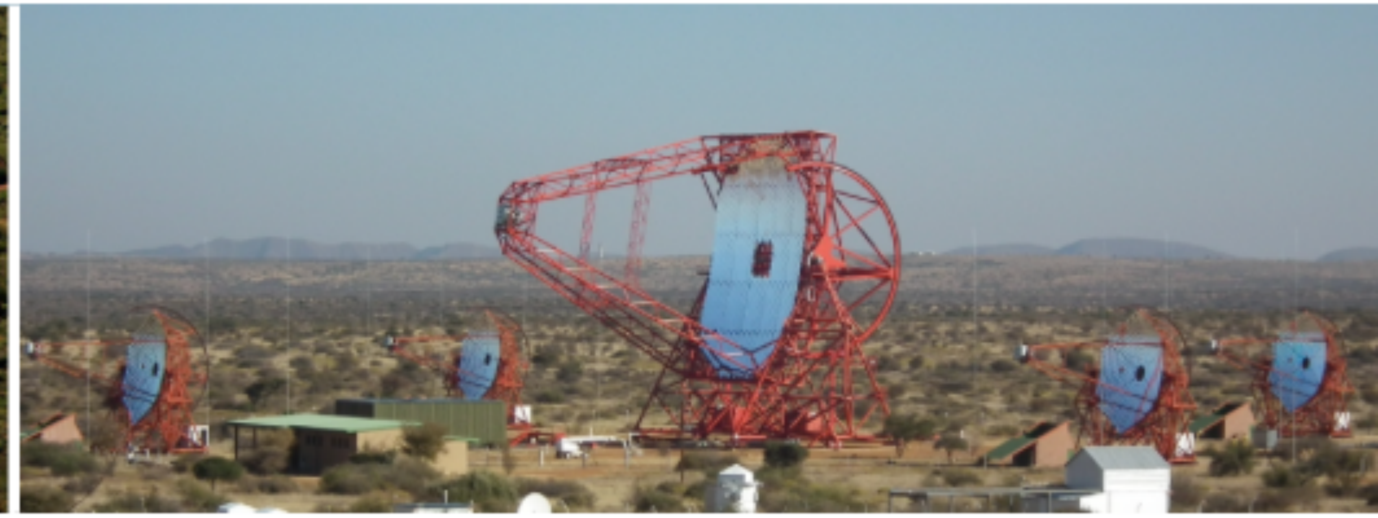
H.E.S.S. is sensitive to bright GRBs even with 10-h delay!

(Xue, Tam, et al., 2009)

What's next?

* Lower the energy threshold, to O(30 GeV)
* shorten the time delay

Lower the energy threshold

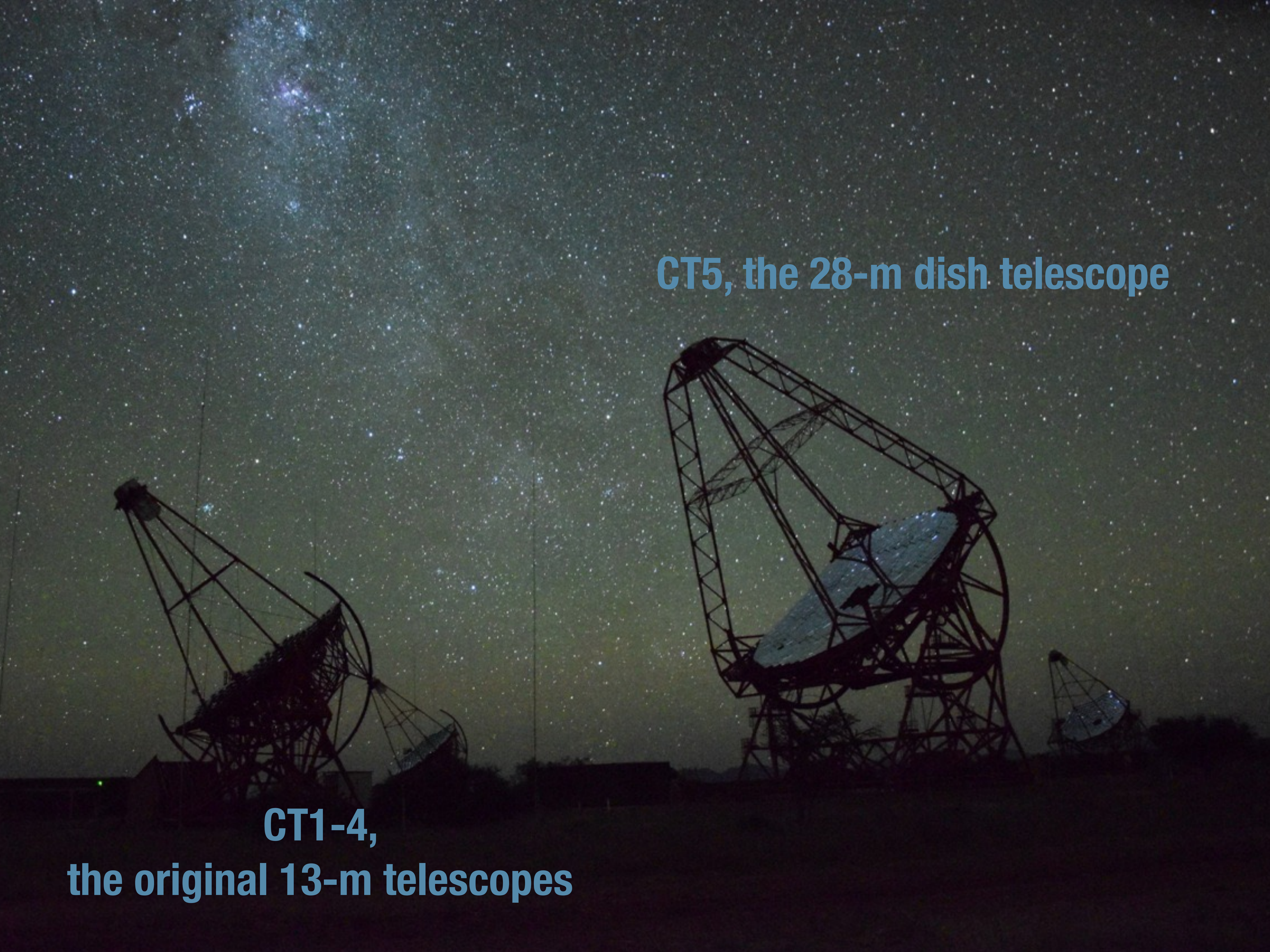


- H.E.S.S. phase I
  - four 12m telescopes
  - FoV 5 deg
  - energy threshold 100 GeV
  - angular resolution < 0.1 deg

- 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

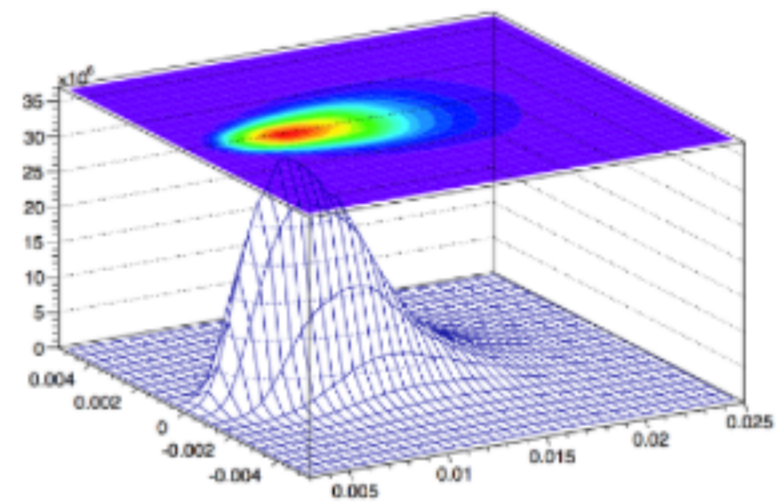
H.E.S.S. phase I — 2002-2012

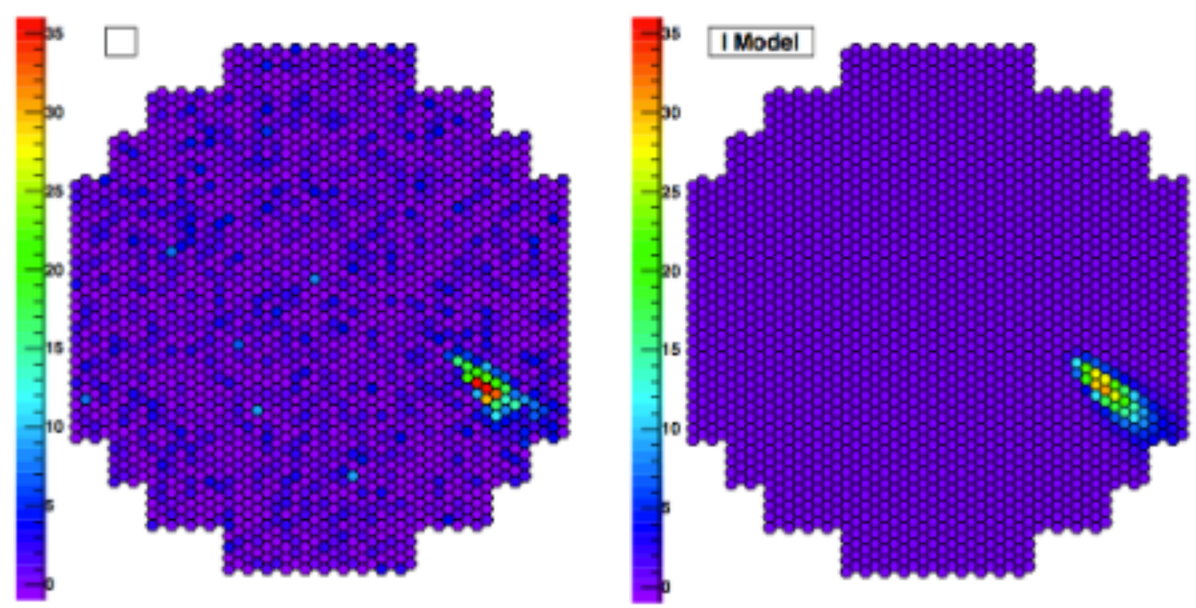
H.E.S.S. phase II — 2012-now


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

Single telescope reconstruction

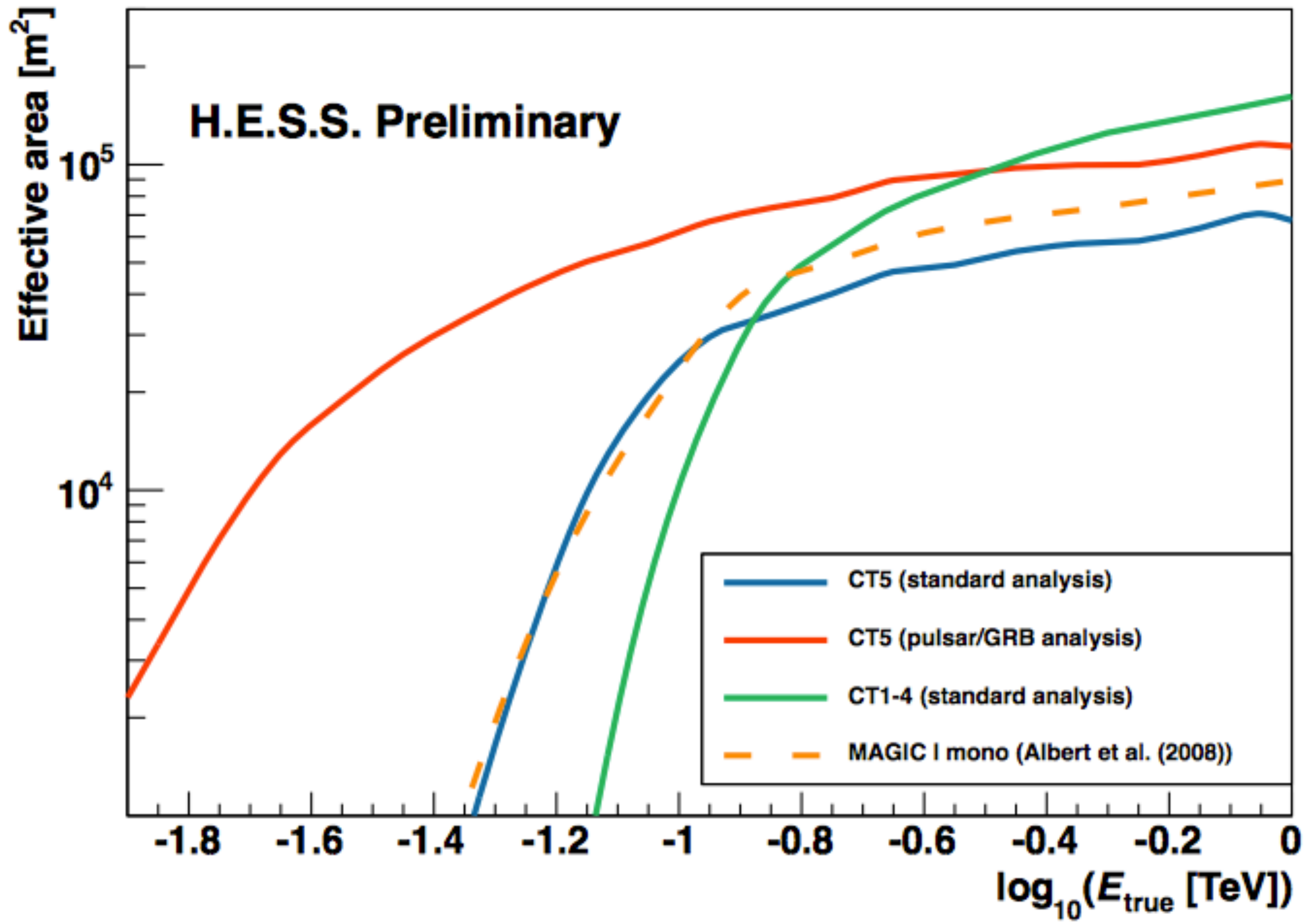
- Template (model) based photon reconstruction
  - Adapted from de Naurois et al APh 32, 231 (2009)
- Standard analysis
  - optimized for source observations
- PSR/GRB analysis
  - optimized for low E detections
- Template (MC) based photon reconstruction
  - ImPACT, Dan Parsons, ID215





camera event fit

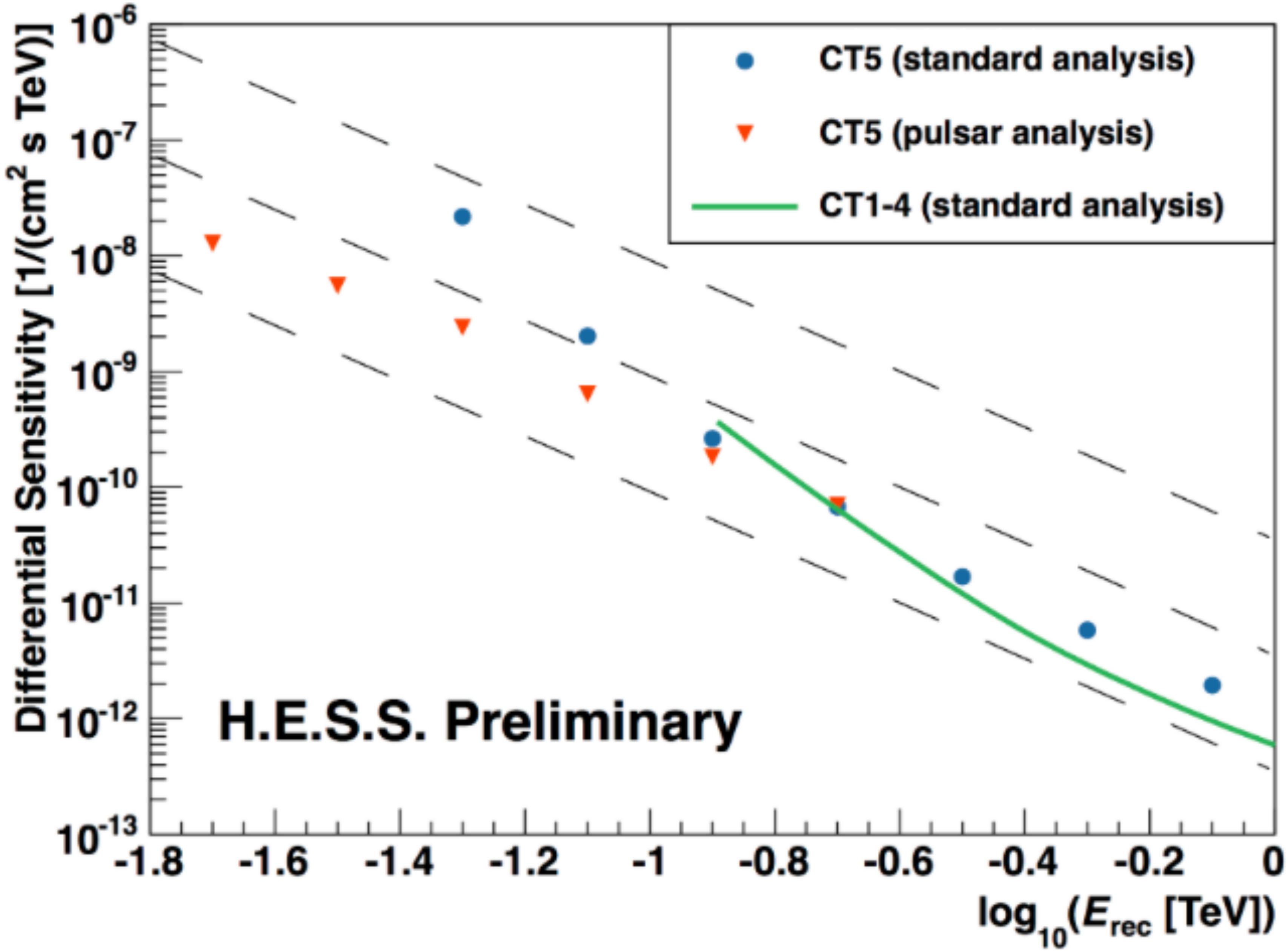
Collection area



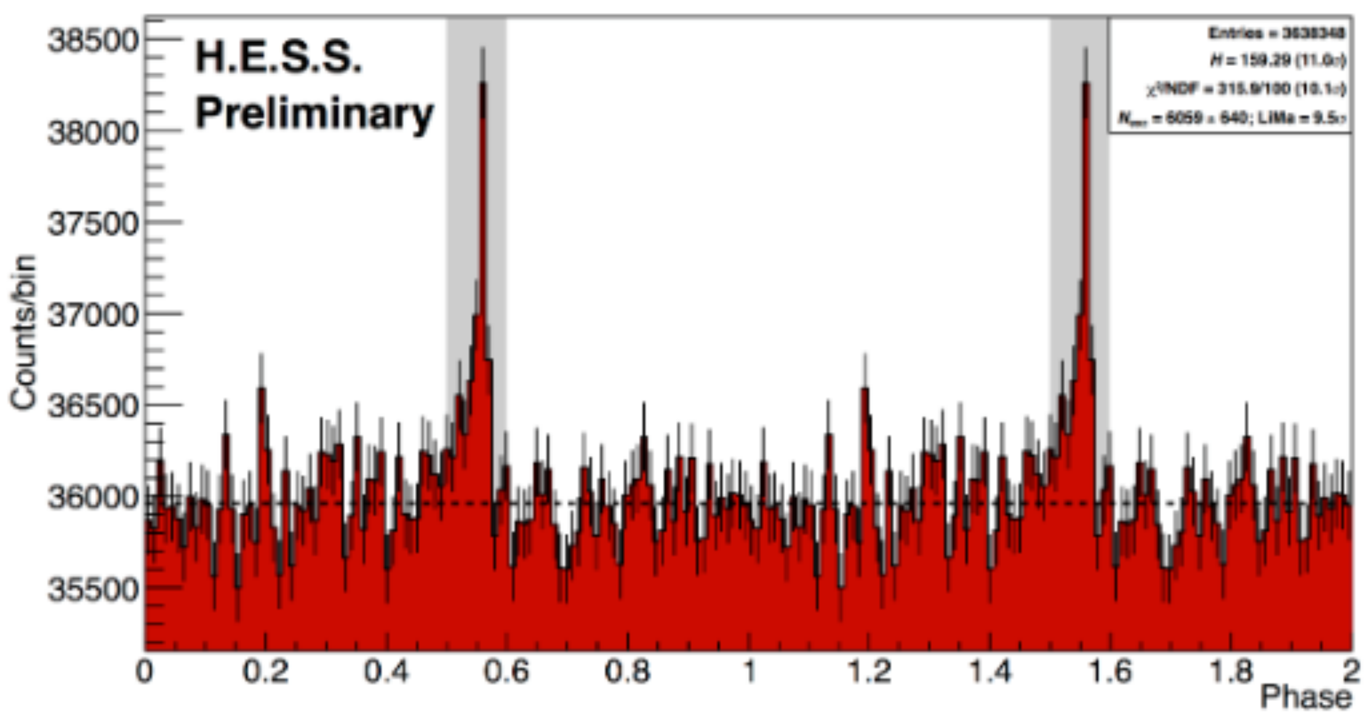
- Systematics at low energies under study

Sensitivity

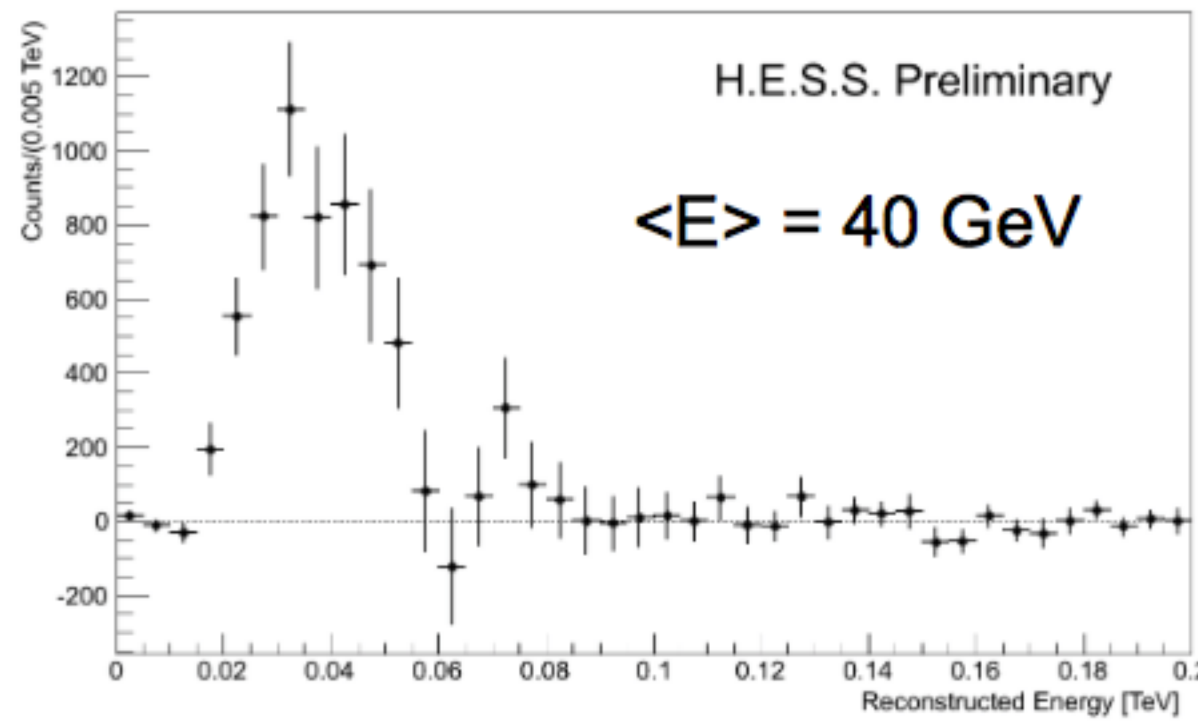
- Standard analysis
  - 5σ in 100 h
  - 5% background systematics
- Pulsar analysis
  - 5σ in 100 h
  - no background systematics



The Vela pulsar seen with CT5



Energy distribution



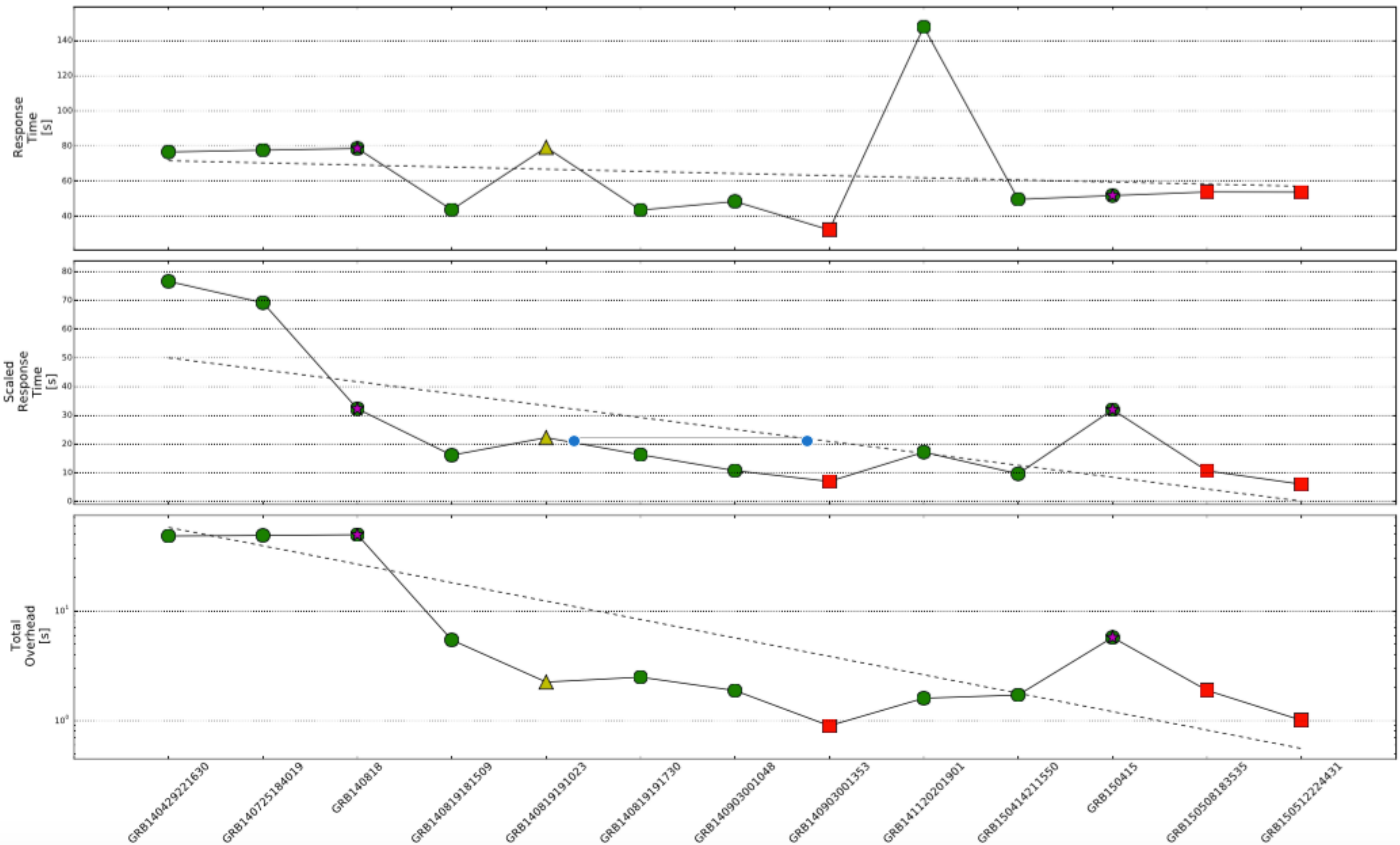
Shortening the time delay

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


Response Time [s]
140
120
100
80
60
40
Scaled Response Time [s]
80
70
60
50
40
30
20
10
0
Total Overhead [s]
GRB140429221630
GRB140725184019
GRB140818
GRB140819181509
GRB140819191023
GRB140819191730
GRB140903001048
GRB140903001353
GRB141120201901
GRB150414211550
GRB150415
GRB150508183535
GRB150512224431

Summary

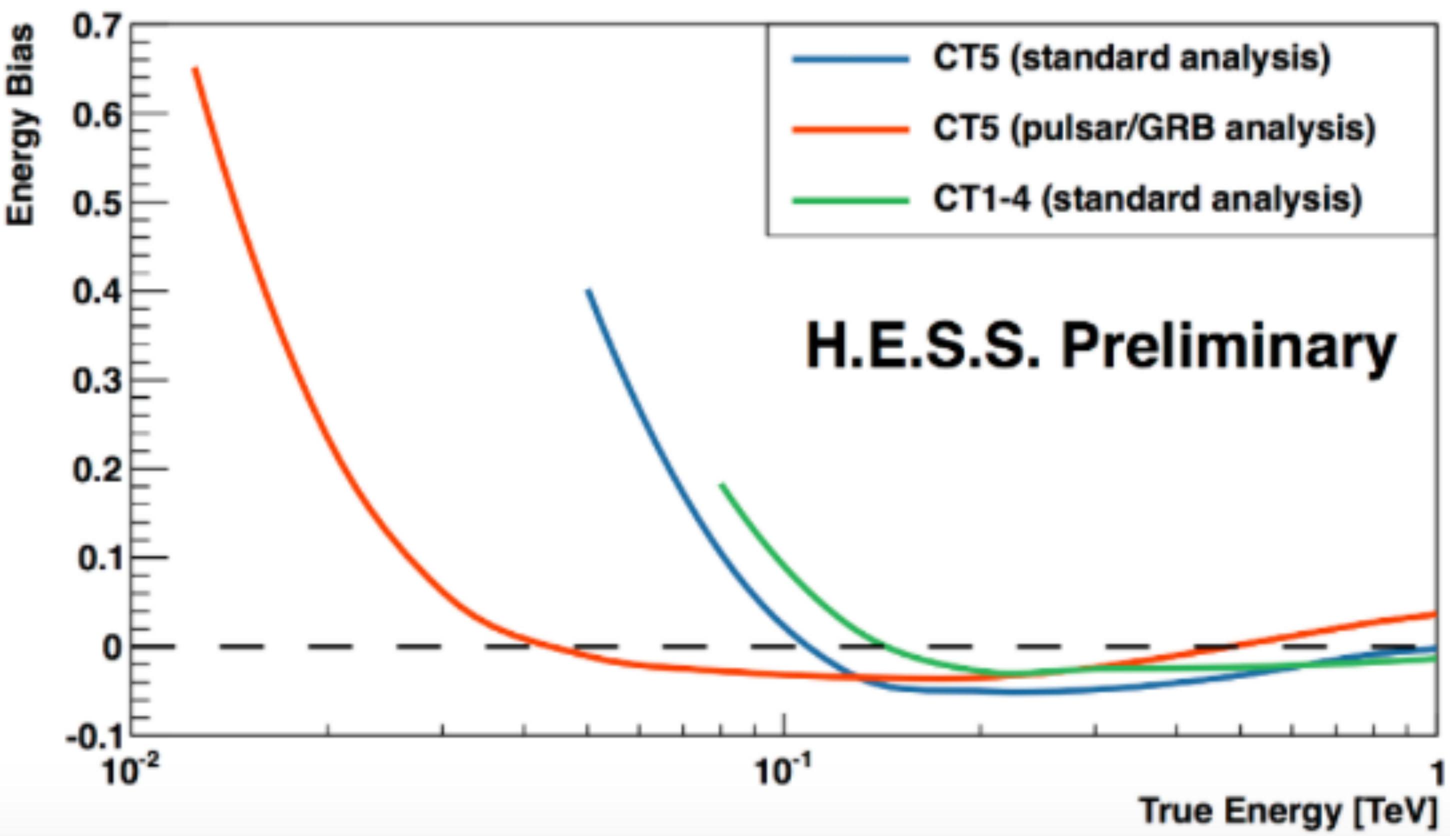
- Evidence for a hard spectral component at >GeV energies during the late afterglow is accumulating
- LAT GRBs are rare, but each individual burst is rather special!
- H.E.S.S. phase II is ready. Automatic re-pointing and the large telescope has been updated to shorten the delay time as much as possible
- Stay tuned, for the first >30 GeV light curve and spectrum from a nearby GRB using both *ground-based* and *space* telescopes

Spare slides

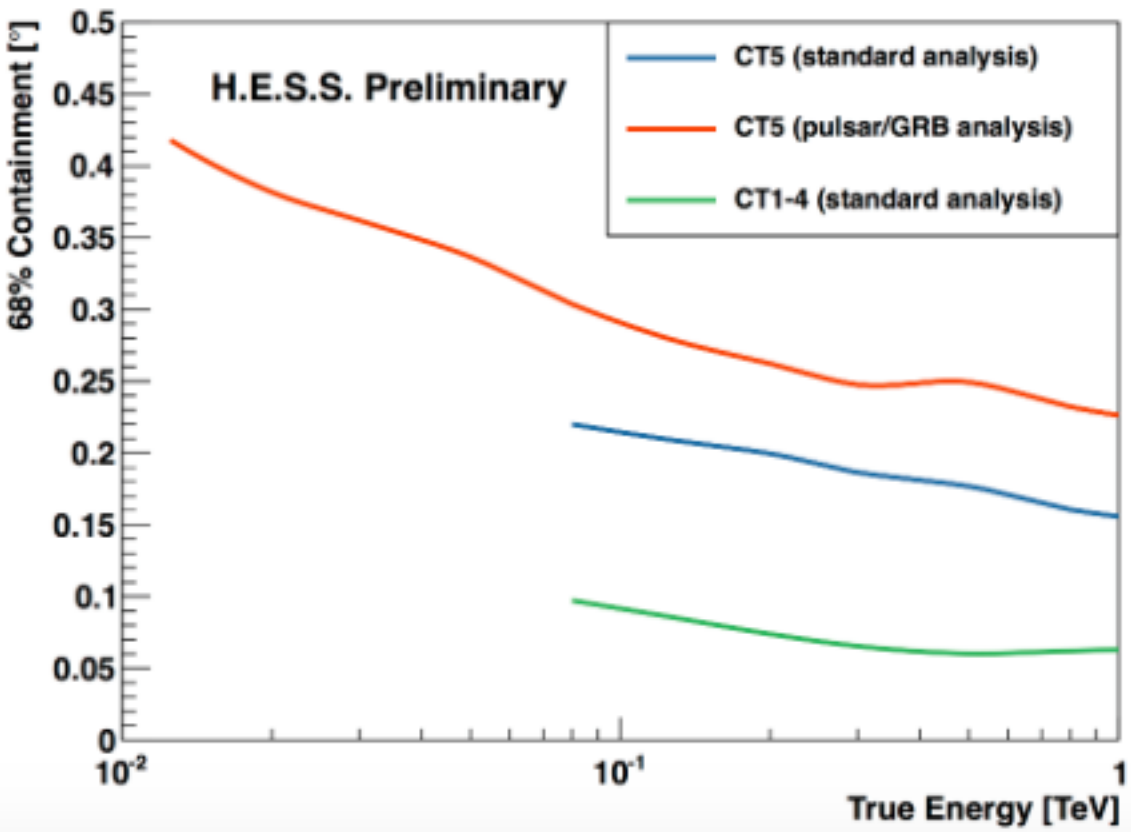
Energy and angular resolution

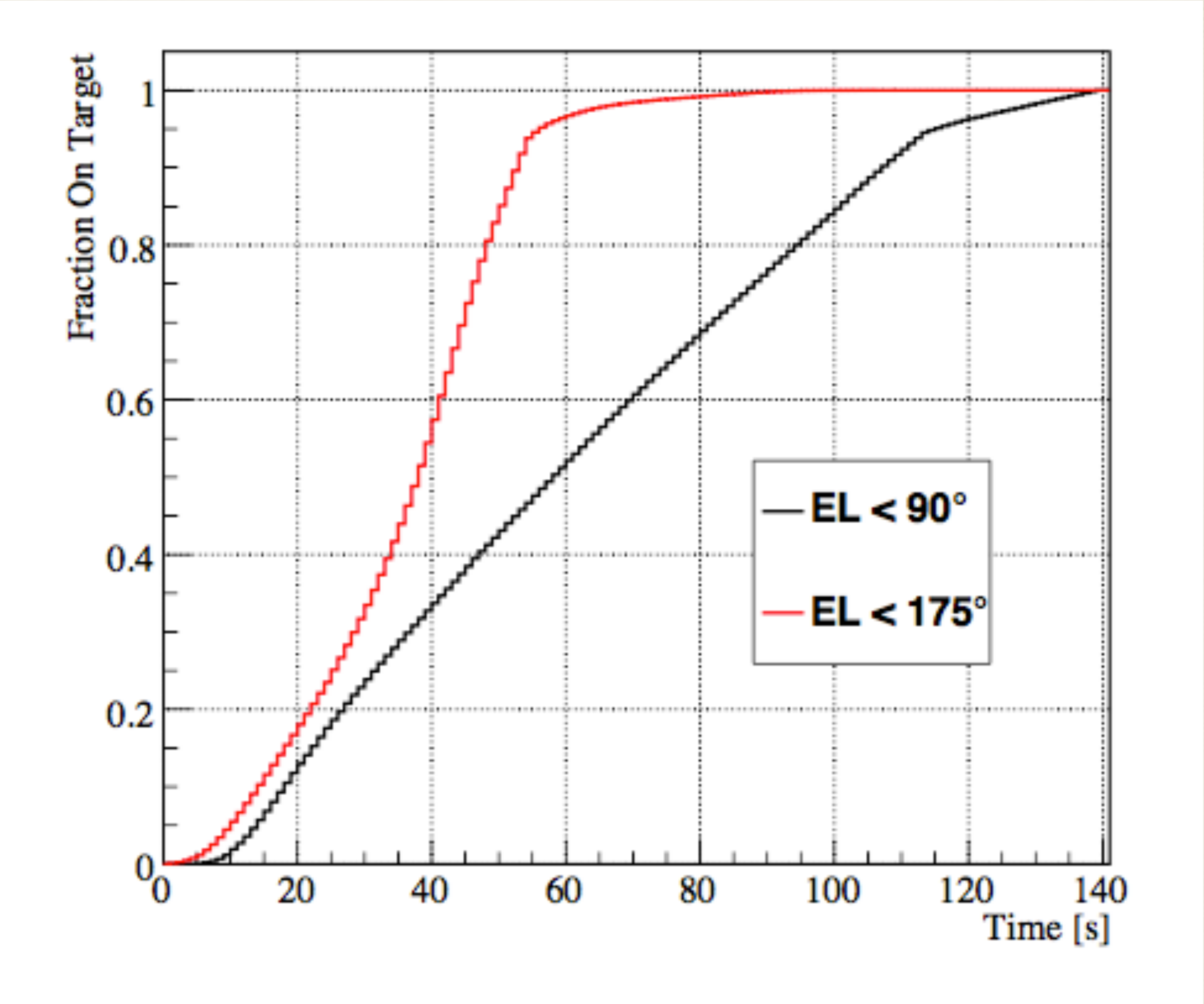
	Energy resolution	Angular resolution
Standard analysis	30%	0.2 deg
Pulsar/GRB analysis	30% - 40%	0.3 - 0.4 deg

Energy bias



Angular resolution





Fraction of times within which the CT5 telescope is able to arrive at it's target position random position on the sky versus the time after the issue of the repointing command. This fraction is shown for the systems with (EL<175, red line) and without (EL<90, black line) reverse observations enabled.