OBSERVATIONS OF GRBs IN VERY HIGH ENERGY REGIME

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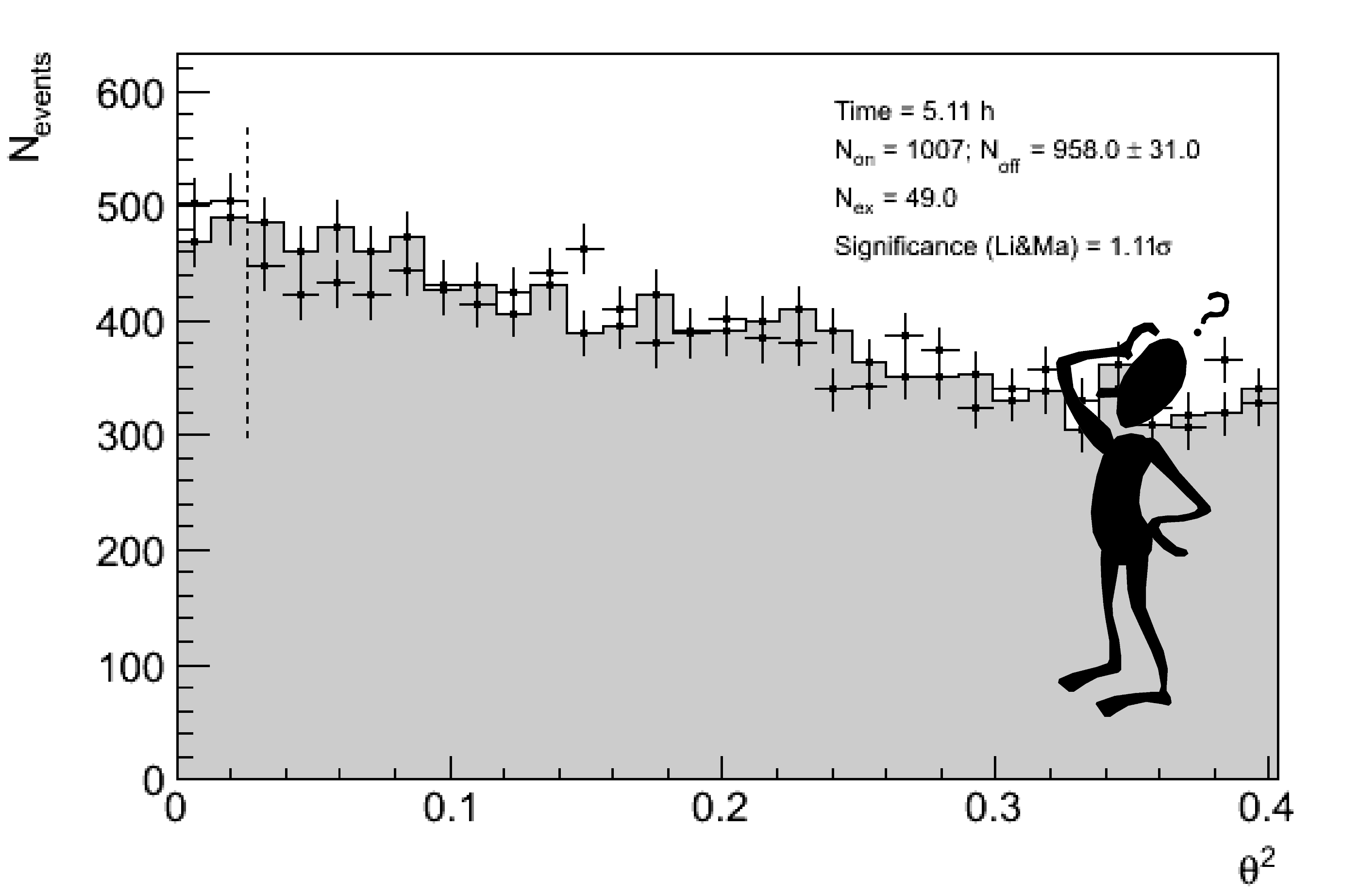
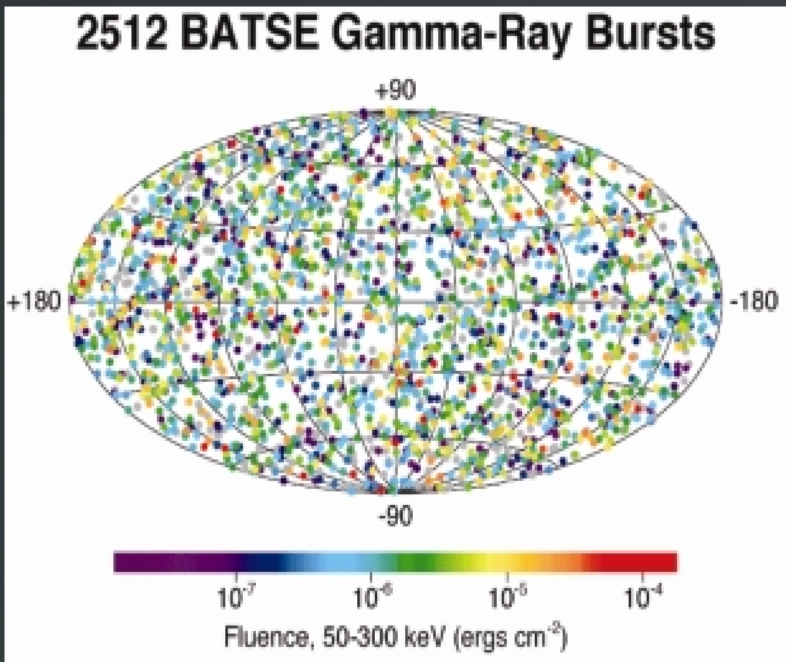


FENOMENOLOGY OF GRB:

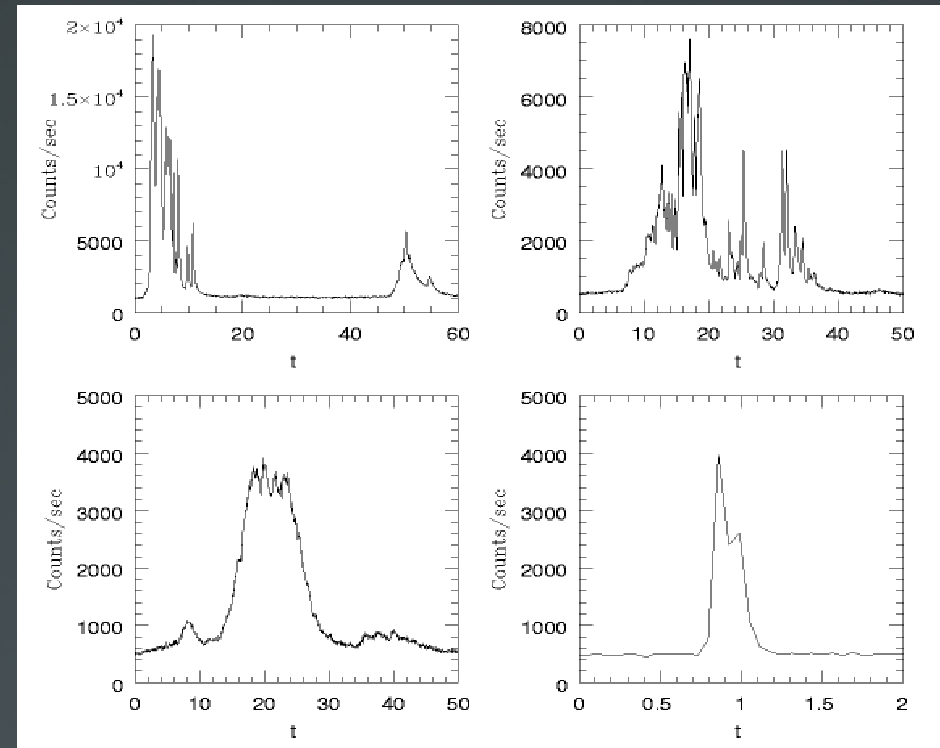
Disovered in 1973 by Vela satellites: 12 GRB in the keV-MeV energy range

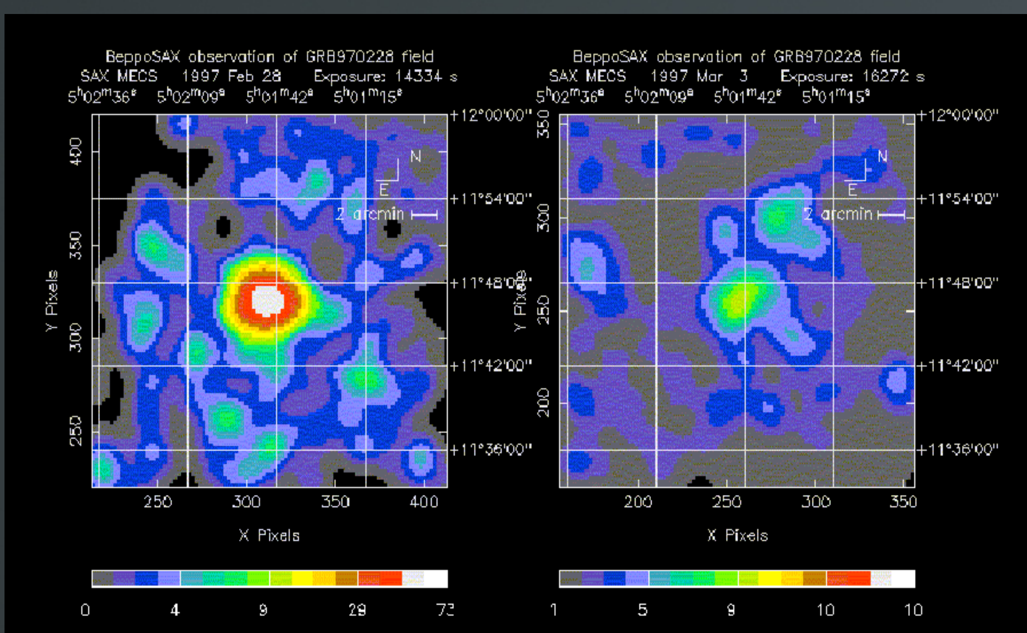
First systematic studies from the '90s.



BATSE
(25 KeV-10 MeV)
EGRET
(20 MeV-30 GeV)

- **Isotropy GRB**
- **Long and short GRB**
- **Temporal variability**





SAX (1996)
(0.1-300 KeV)

- **Accurate localization**
- **Discovery of the afterglow**
- **Confirmation of the cosmological scenario**

SWIFT (2004)
(BAT 15-150 KeV
XRT 0.3-10 KeV)

- **New structures in the afterglow**
- **Afterglow of short GRB**
- **Discovery of flares**

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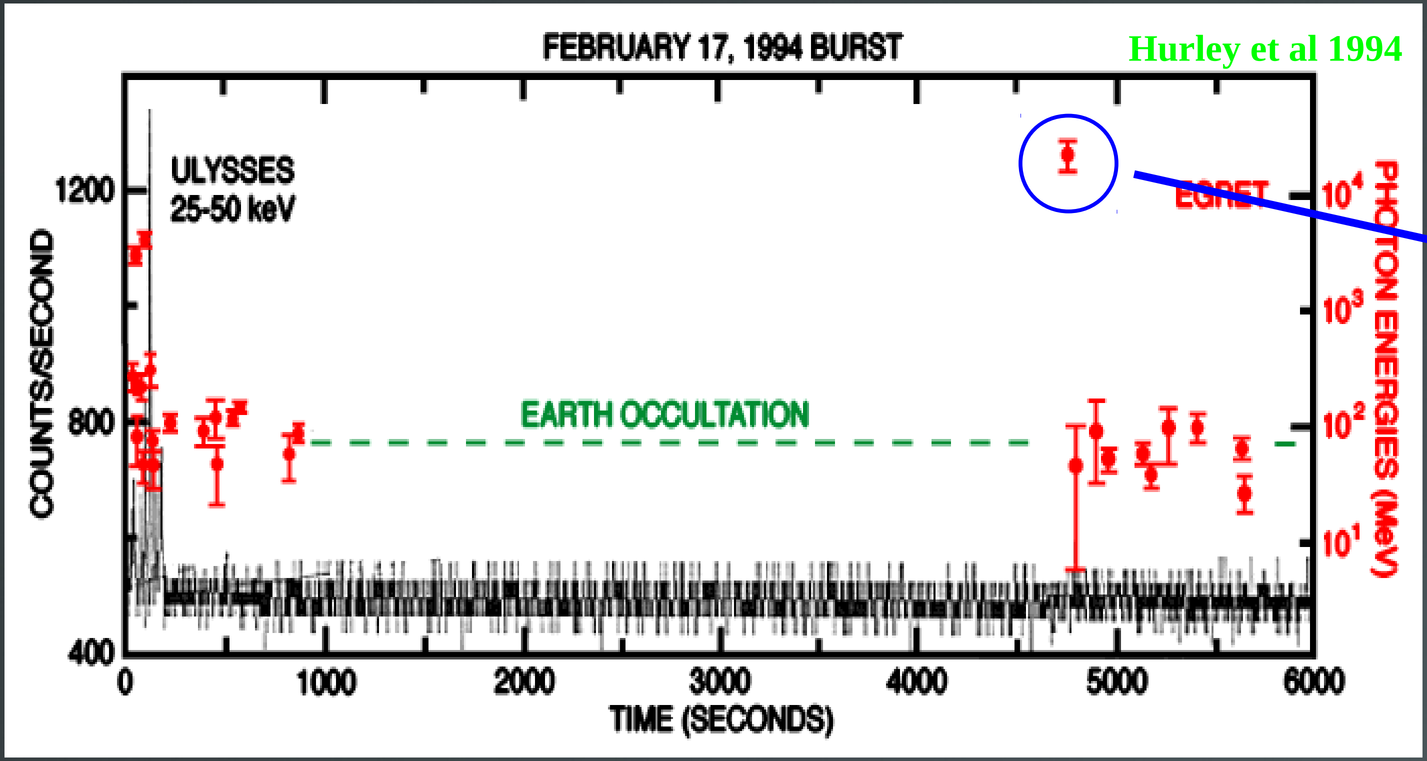
GRB IN THE VHE REGIME: HYSTORICAL HINTS

EGRET (20 Mev-30 GeV) : GRB940217



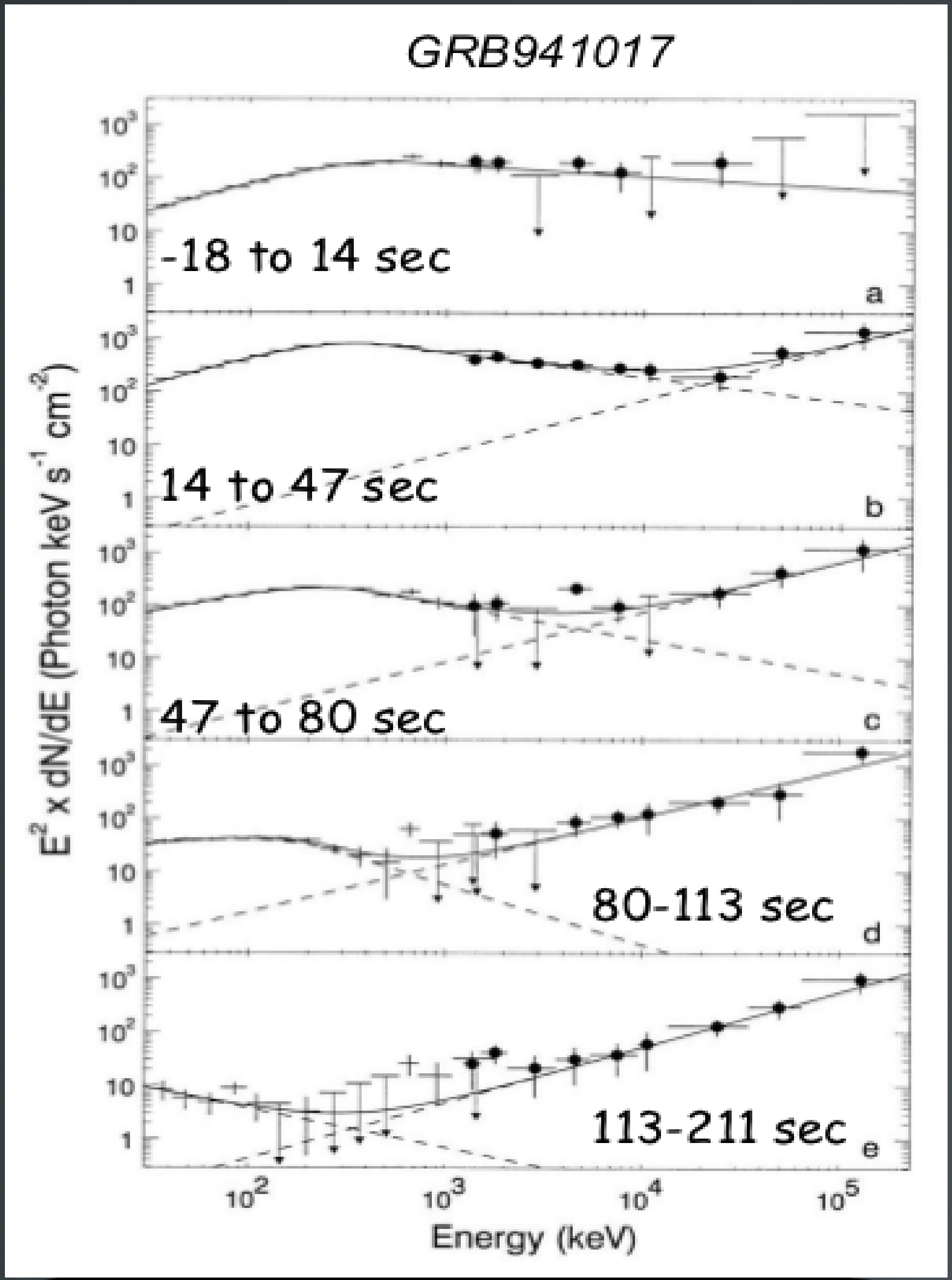
18 GeV photon was observed

EGRET observed emission above 30 MeV for more than an hour after the prompt emission.

Unlike optical/X-ray afterglows, gamma-ray luminosity did not decrease with time: additional processes contributing to high energy emission?

GRB IN THE VHE REGIME: HYSTORICAL HINTS

EGRET (20 Mev-30 GeV) : GRB941017



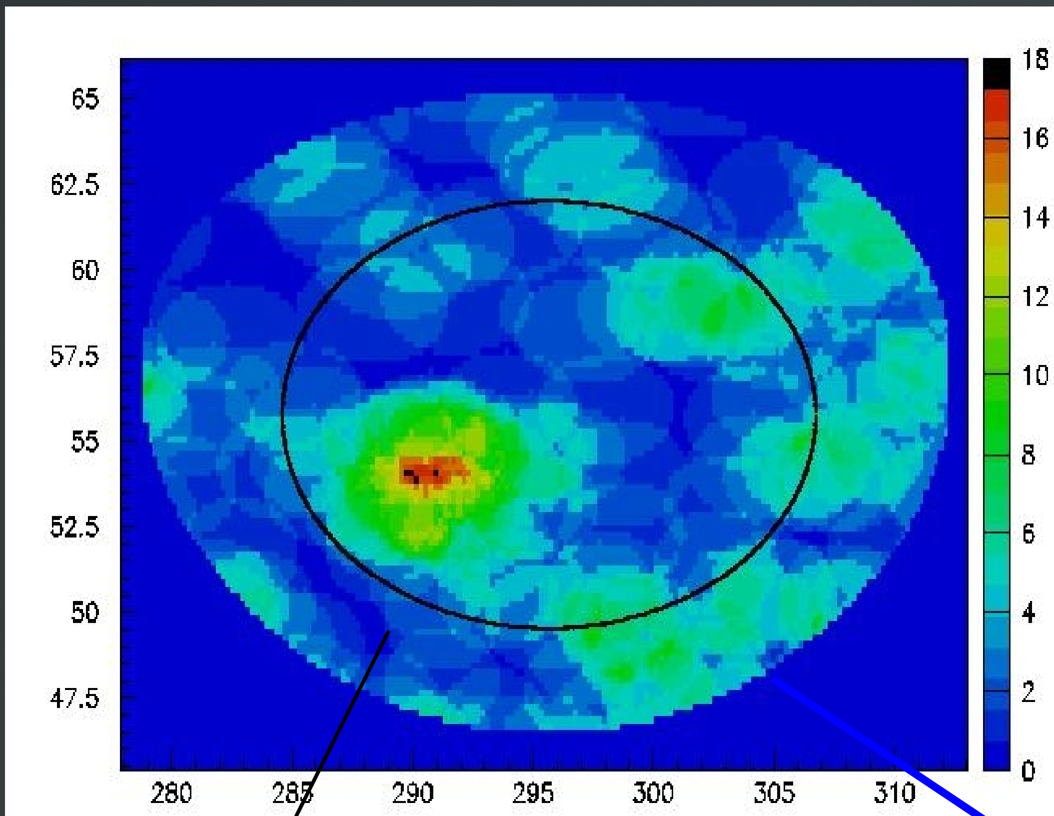
Classic sub-MeV component observed in BATSE

Second Higher Energy component has been observed within 14-47 seconds by EGRET and at later times by both BATSE and EGRET.

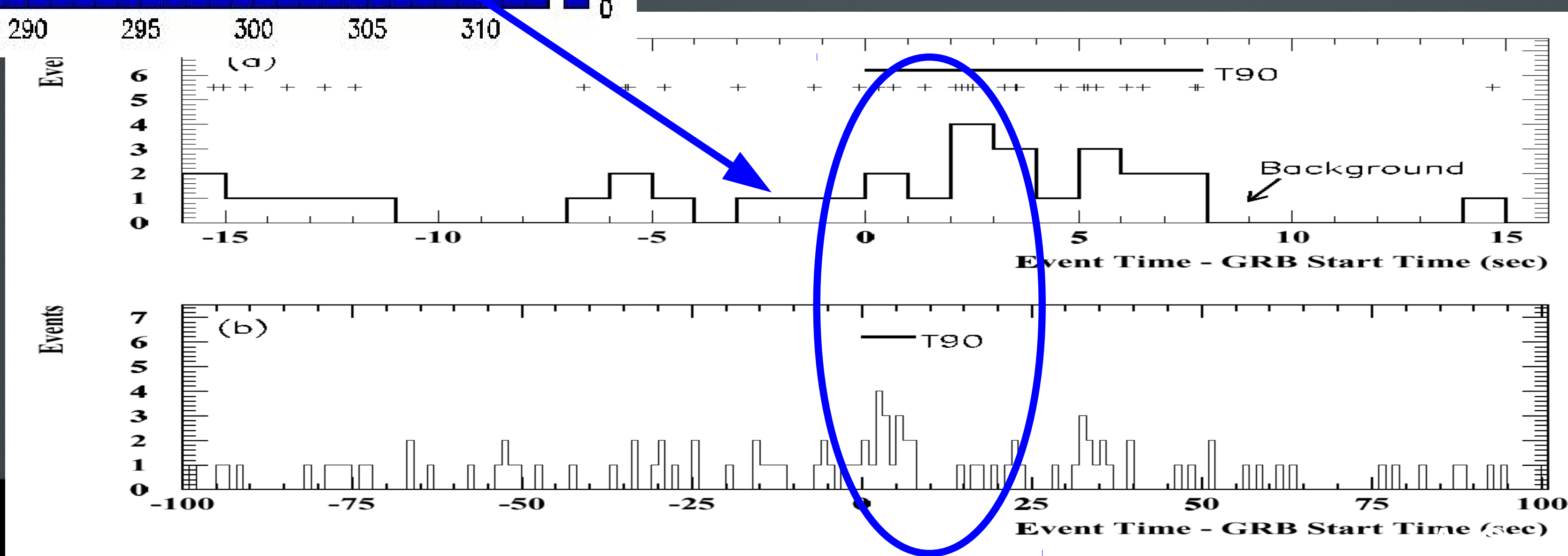
The second emission component lasts ~200sec. And it increases the total energy flux by factor of ~3

GRB IN THE VHE REGIME: HYSTORICAL HINTS

MILAGRITO (500 GeV-20 TeV) GRB970417a



- Searching 54 Batse bursts (T90)
- One burst 970417a showed 18 events w/background of 3.46
- This has a prob< 2.9×10^{-8}
- Accounting for all search trials – combined accidental chance 1/150
- This could mean TeV emission from GRBs?

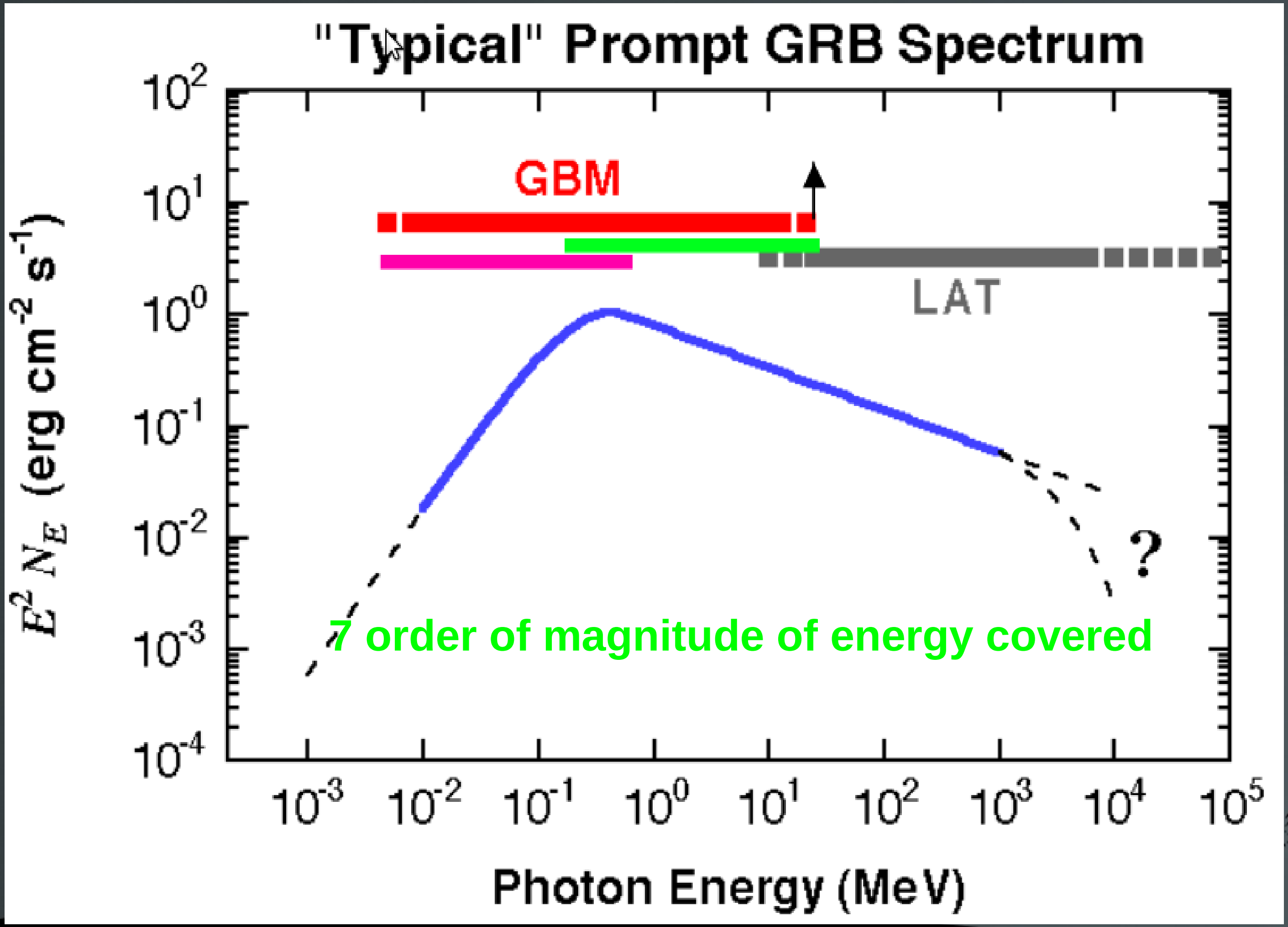


BATSE 1σ error circle

GRB IN THE VHE REGIME: FERMI

EGRET observations triggered new questions in GRB field:

- *Is there a second emission components? What is its origin?*
- *How the observed HE photons are linked to the prompt emission?*
- *How common are these HE events?*



FERMI

GBM (8 keV – 1 MeV)

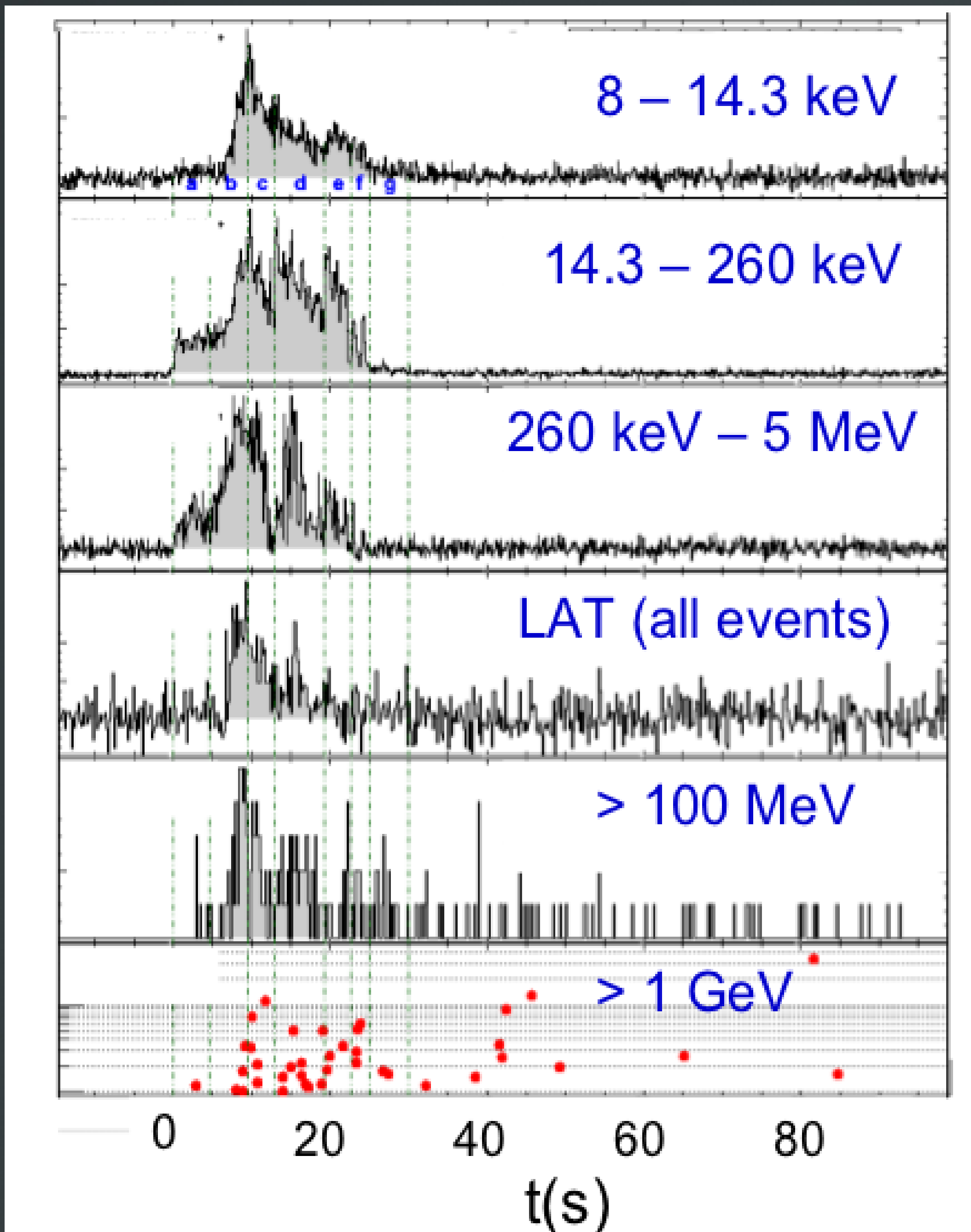
- Onboard trigger and localization
- Spectroscopy

LAT (20 MeV – 300 GeV)

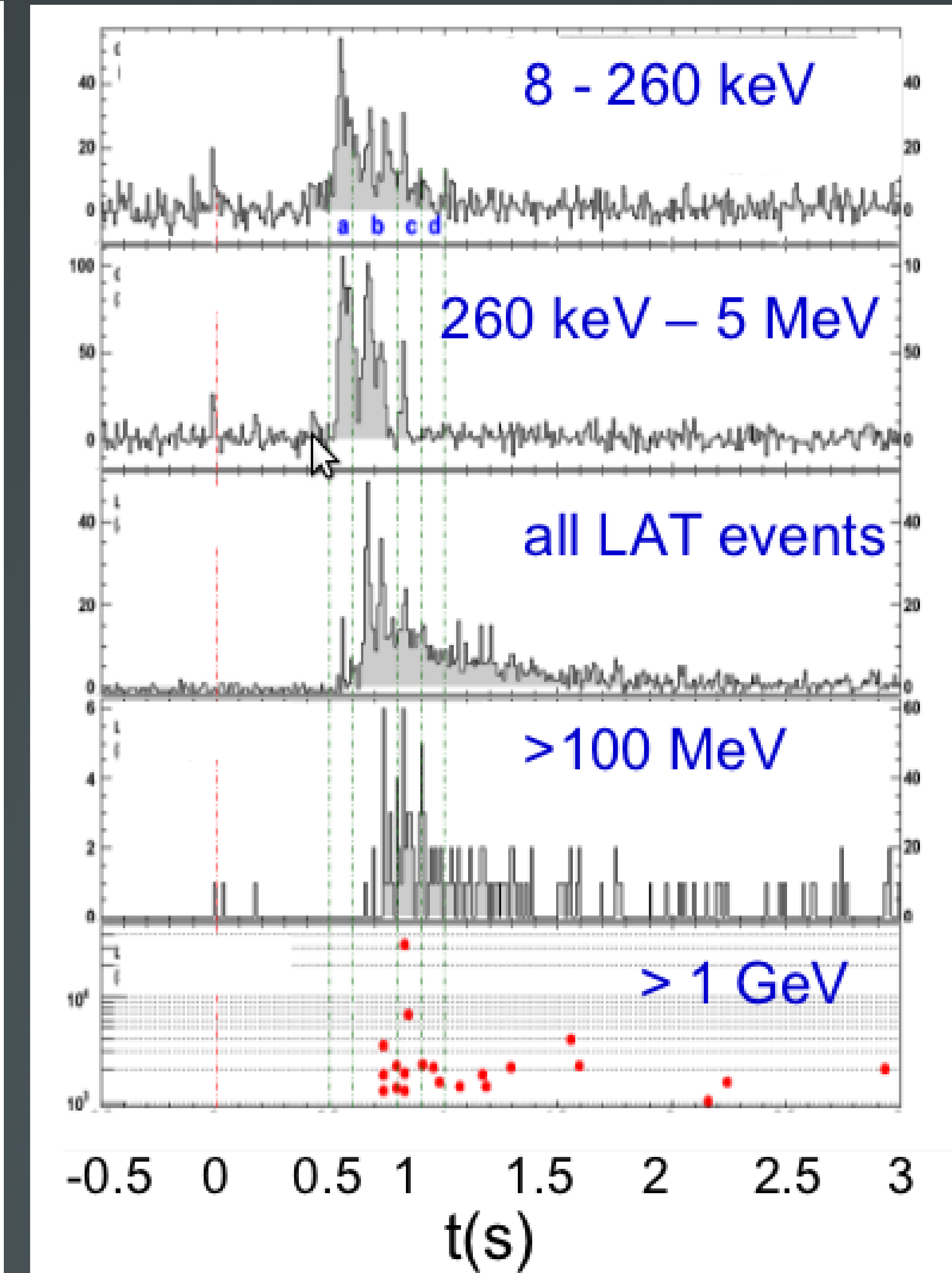
- Pair-production telescope for HE emission
- Onboard and ground trigger

GRB IN THE VHE REGIME: FERMI

GRB090902B (long)



GRB090510 (short)



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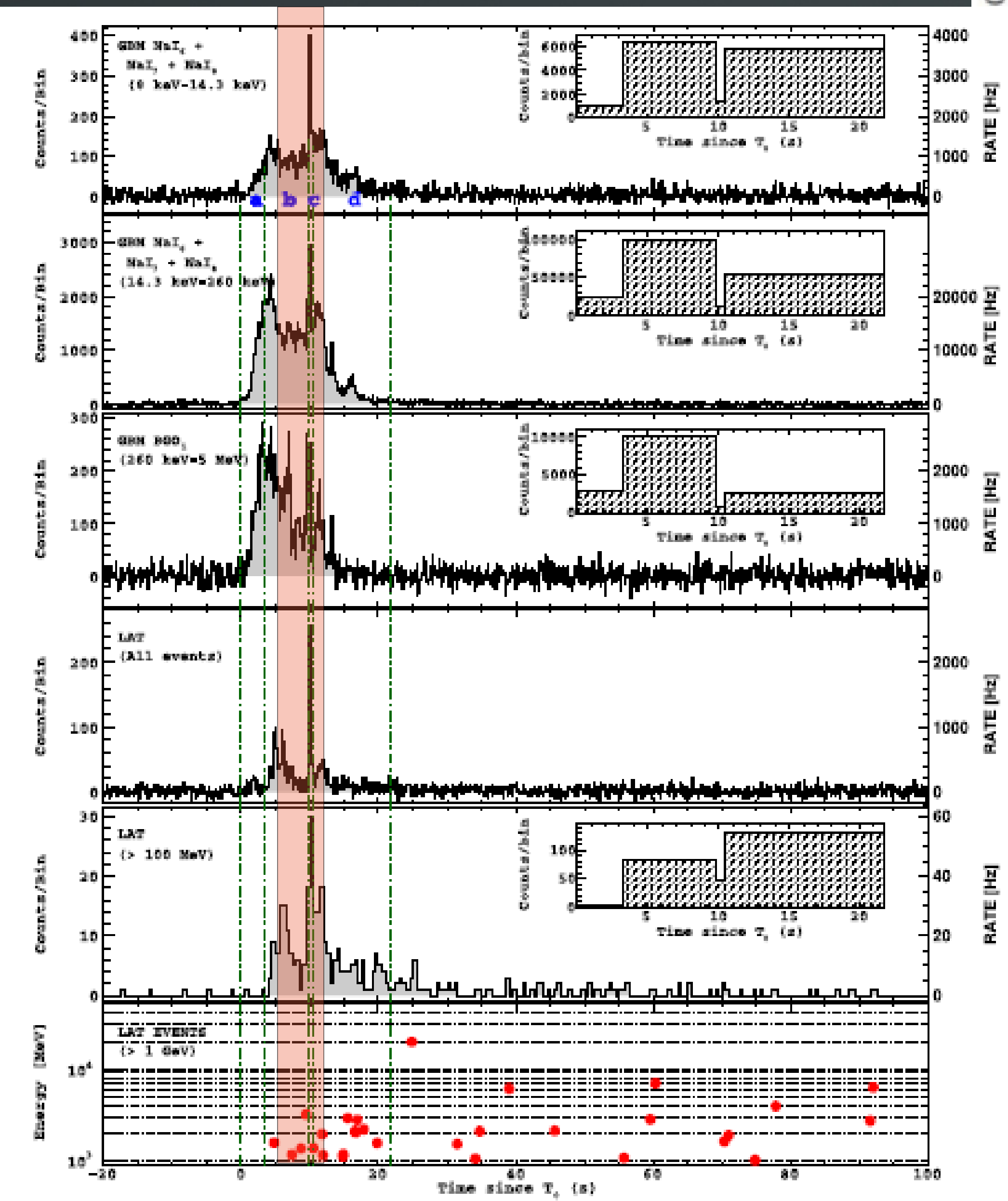
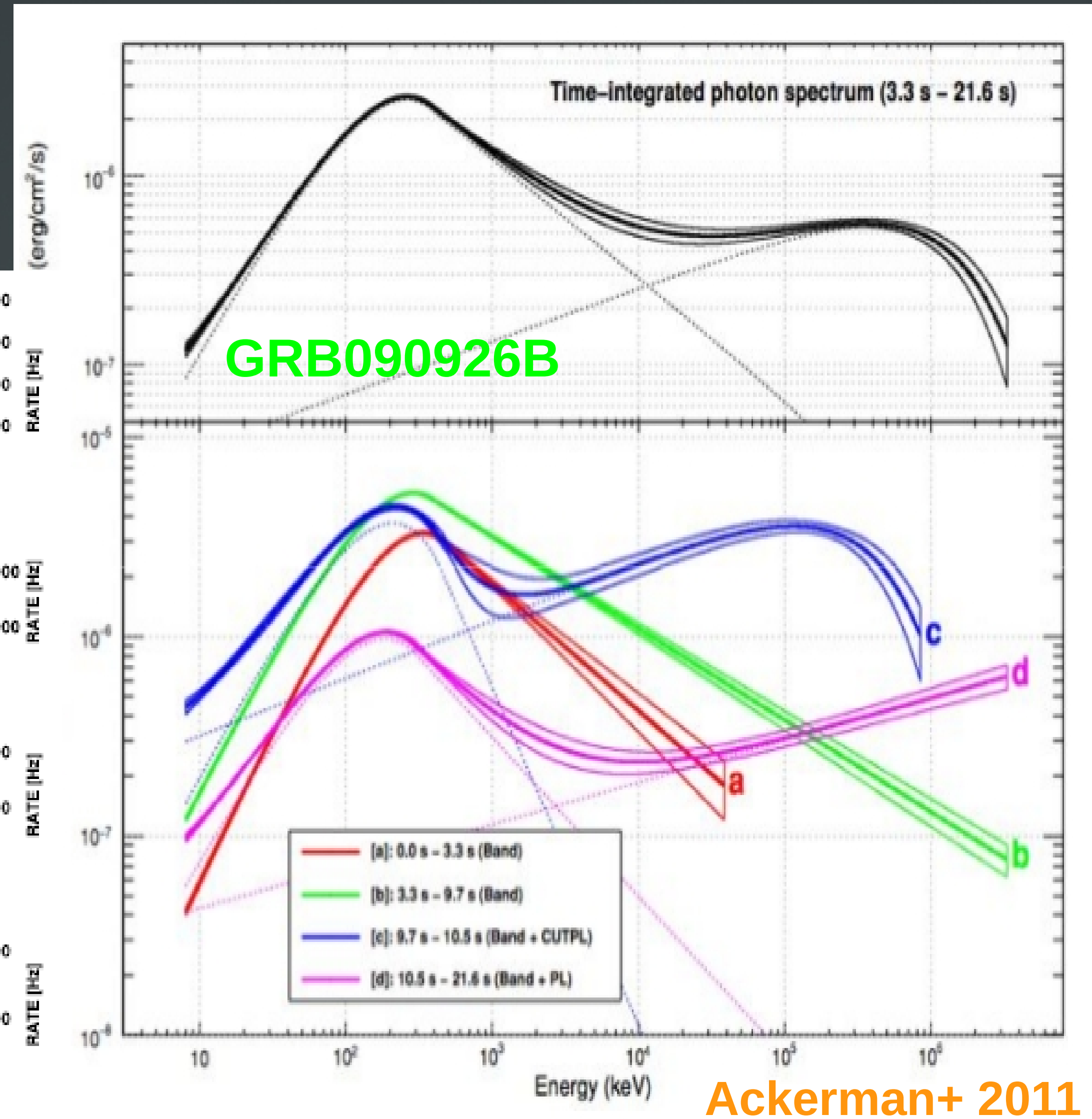
GRB IN THE VHE REGIME: FERMI

Spike at all energies

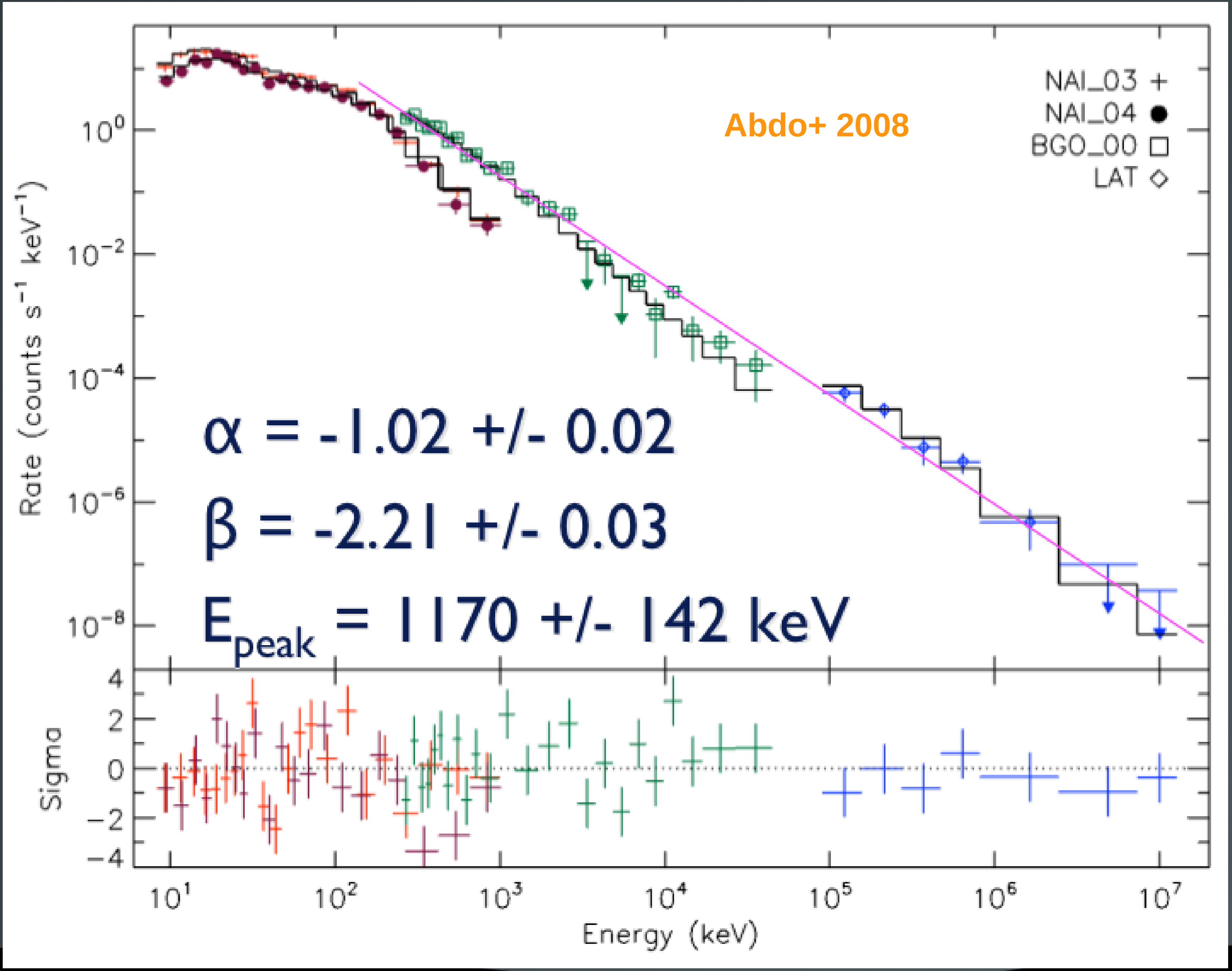




Evidence of an extra component Inconsistent with the Band function

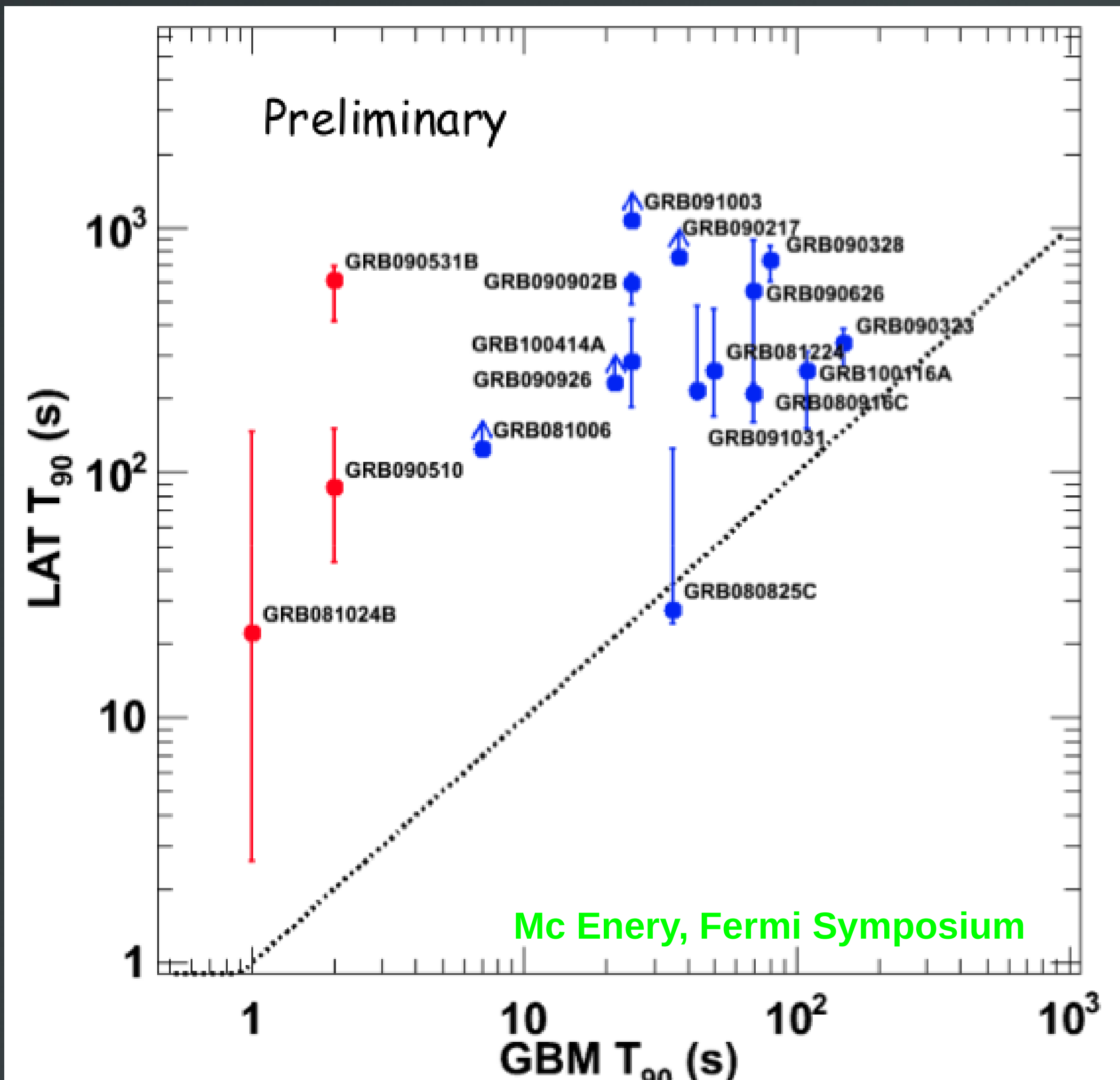
GRB IN THE VHE REGIME: FERMI

But GRB 080916C



GRB IN THE VHE REGIME: FERMI

DURATION DISTRIBUTION



Systematically longer duration In LAT

- Different component ?
- Experimental bias ?

(GBM background dominated)

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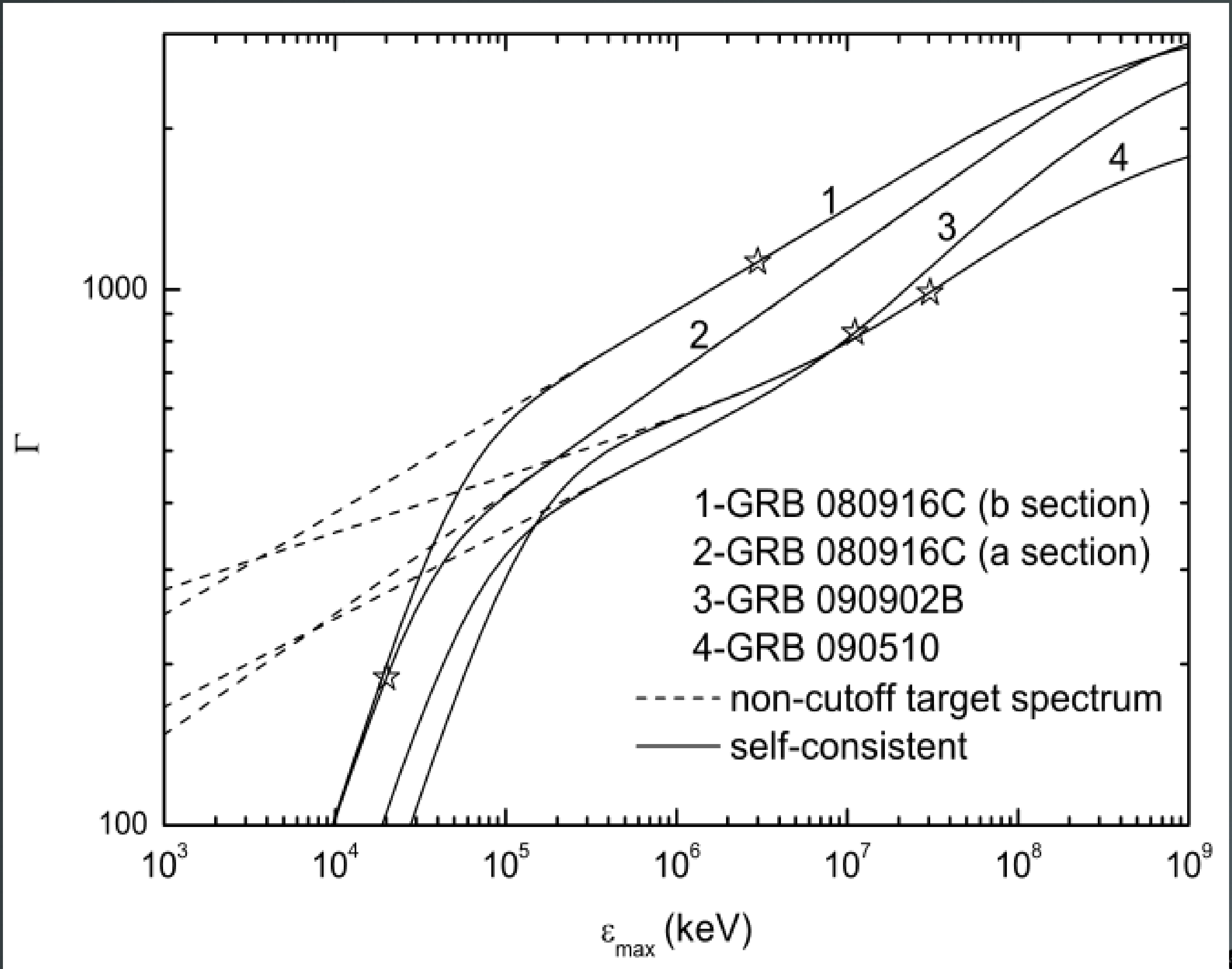
GRB IN THE VHE REGIME: FERMI

The bulk Lorentz factor of GRBs can be constrained by observations in the HE:



The compactness problem implies that the bulk Lorentz factor must be large

(if GeV emission is originated in the same zone of sub-MeV photons)

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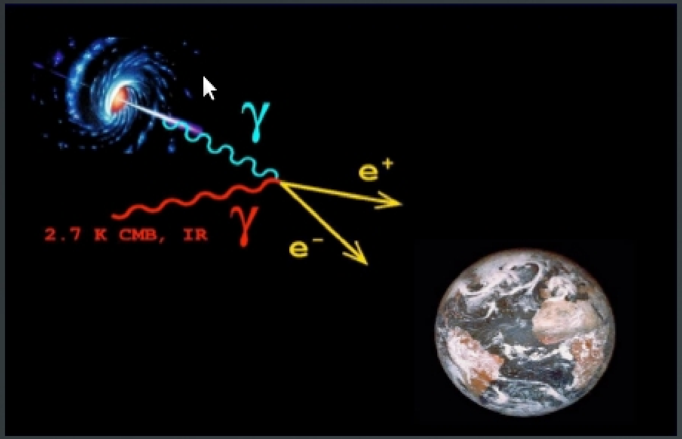
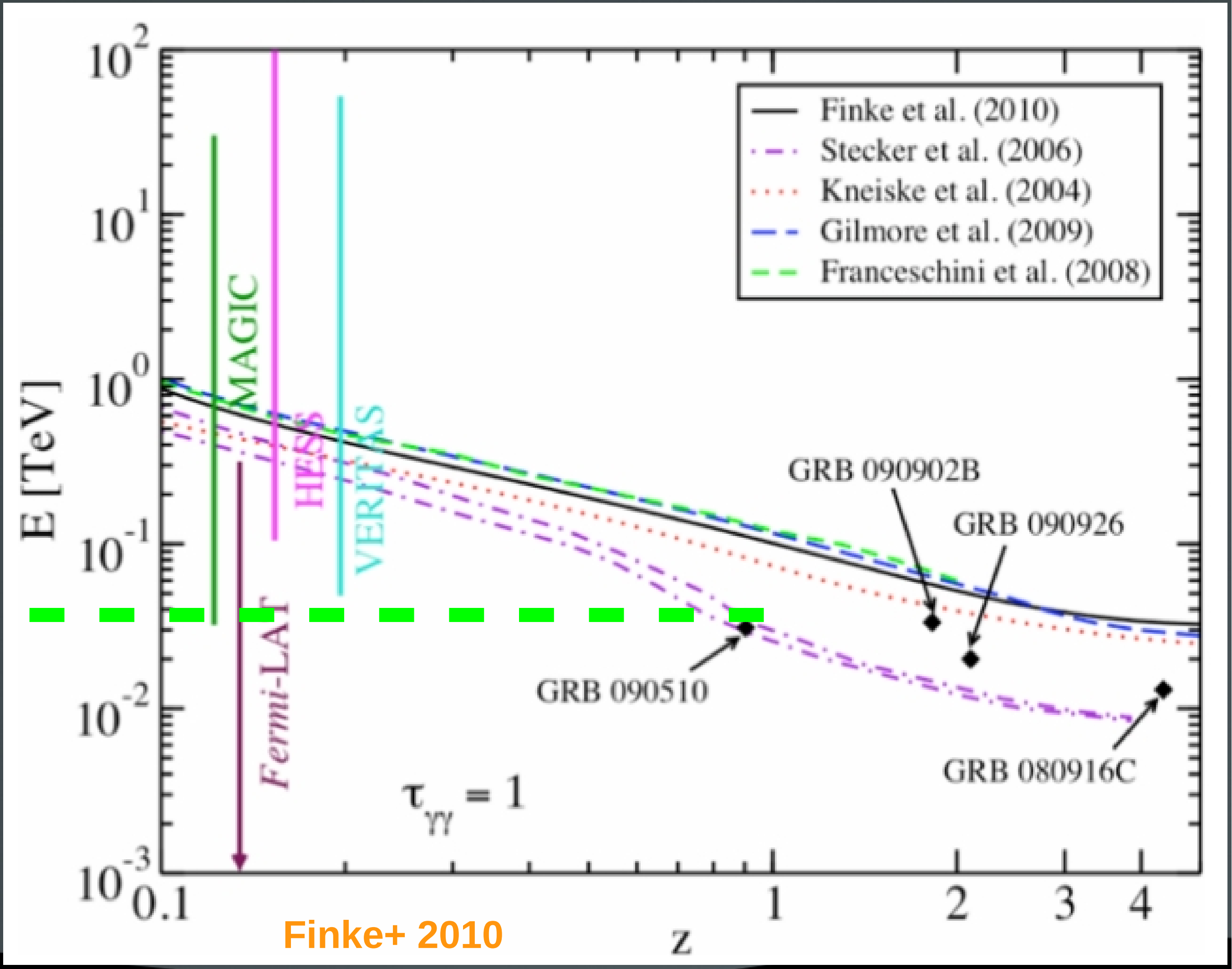
GRB IN THE VHE REGIME: FERMI



Observations of GRBs can discriminate between different EBL models

MAGIC limit



Finke+ 2010

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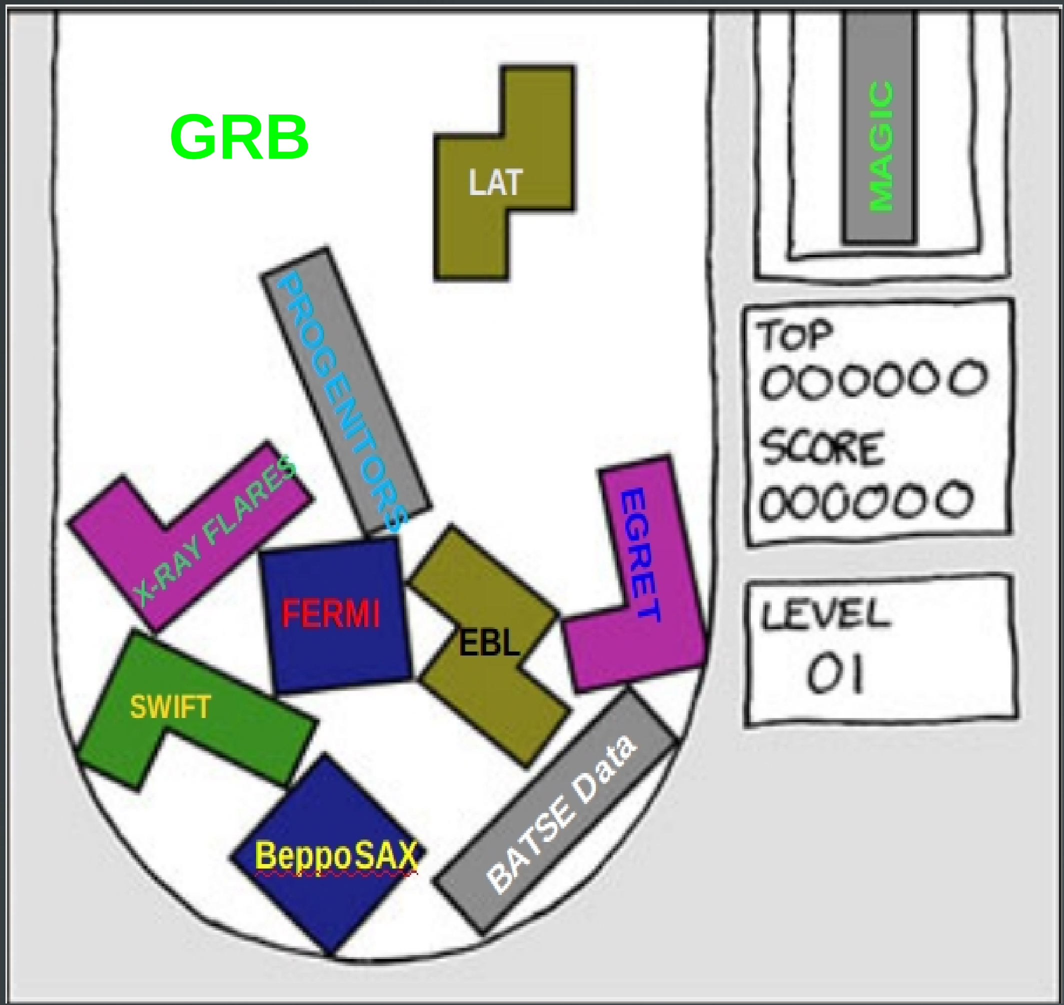
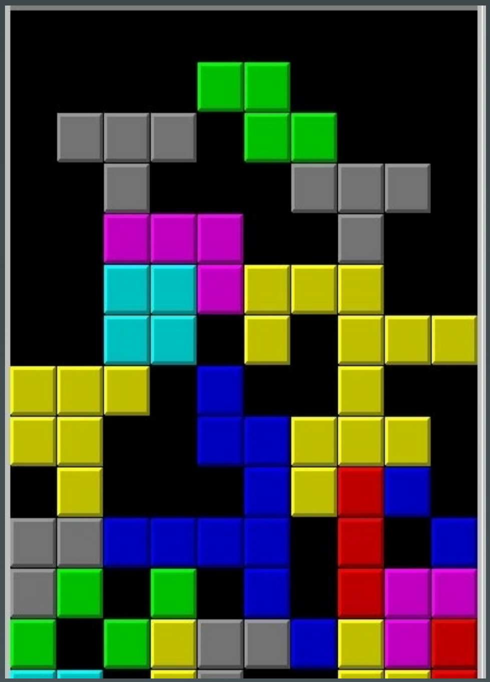
TETRIS SCENARIO FOR VHE ASTROPHYSICS:





- High energy emission is often extended in time, even for short GRBs
- Delayed onset of the high energy emission
- LAT and GBM spectral slopes are different (but one case)

- Common temporal decay law for LAT GRBs (Ghisellini+2010)
- LAT fluence < GBM fluence

- Bulk Lorentz factor
- EBL models
- Lorentz invariance

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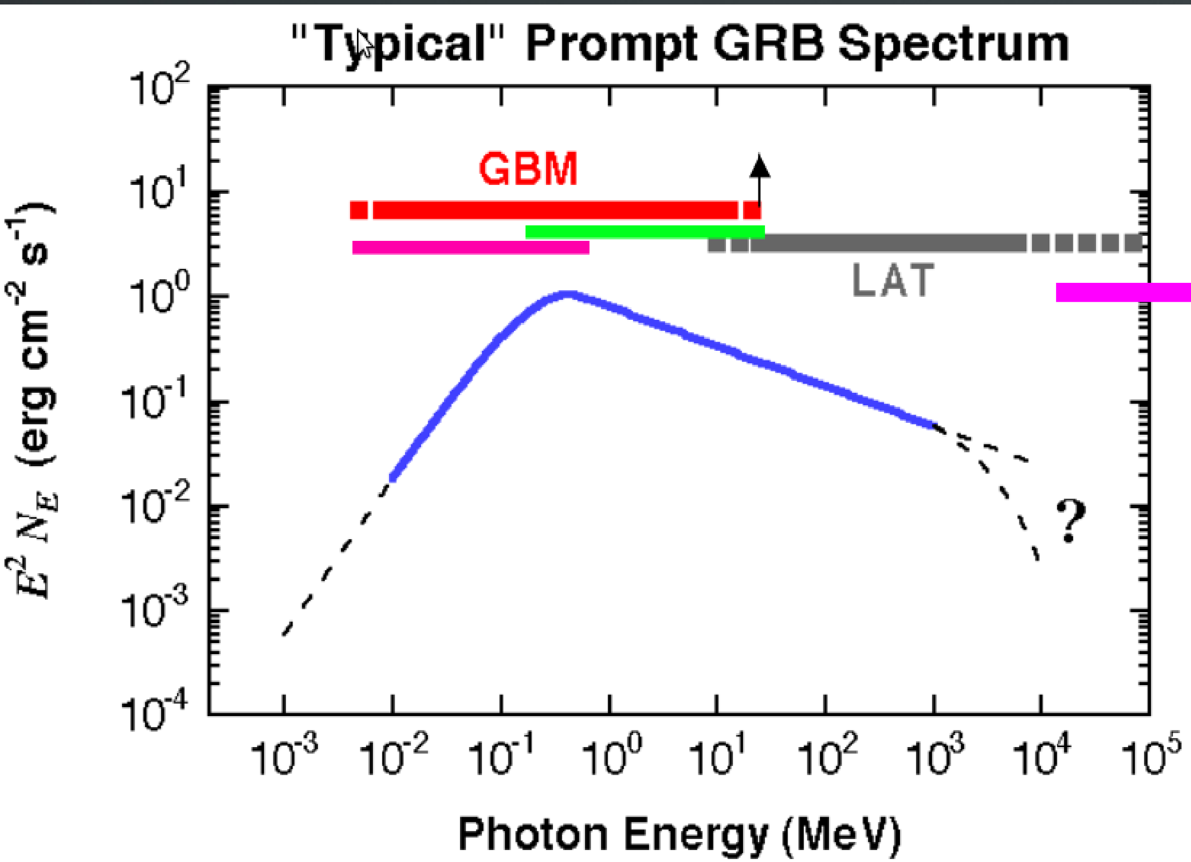
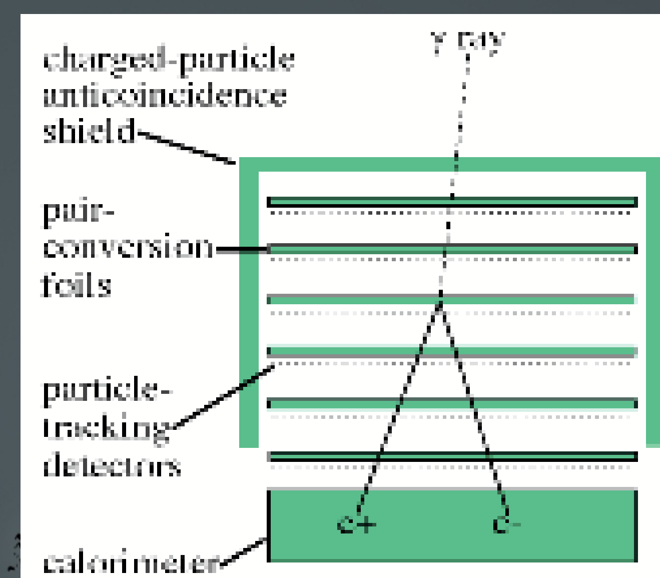
GAMMA RAY ASTRONOMY EXPERIMENTAL TECHNIQUE:



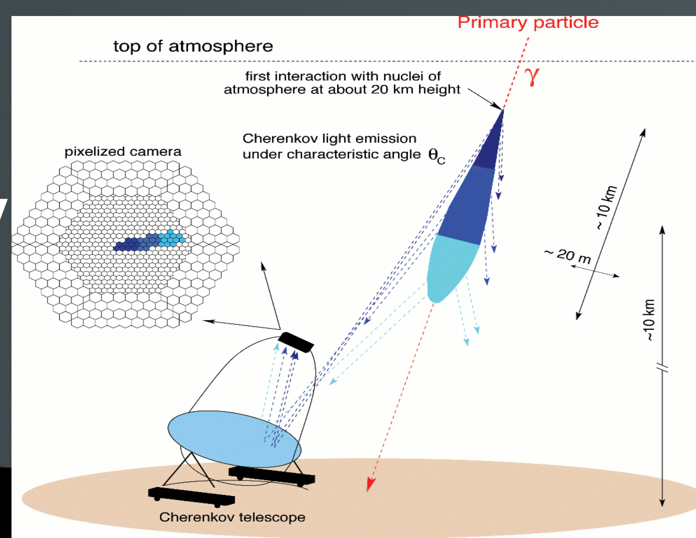
Space based instruments
(pair production telescopes)

Detection of the "primary" gamma
Energy range < 100 GeV
Eff. Area= ~ m^2
Duty cycle 100%
FOV: ~ 1 sr
High economic costs



Ground based instruments
(detector Cherenkov)

Secondary detection
Energy range > 60-100 GeV
Eff. Area: ~10^4 /10^5 m
Duty cycle 10%
FOV: ~ 0.01 sr
Low economic costs



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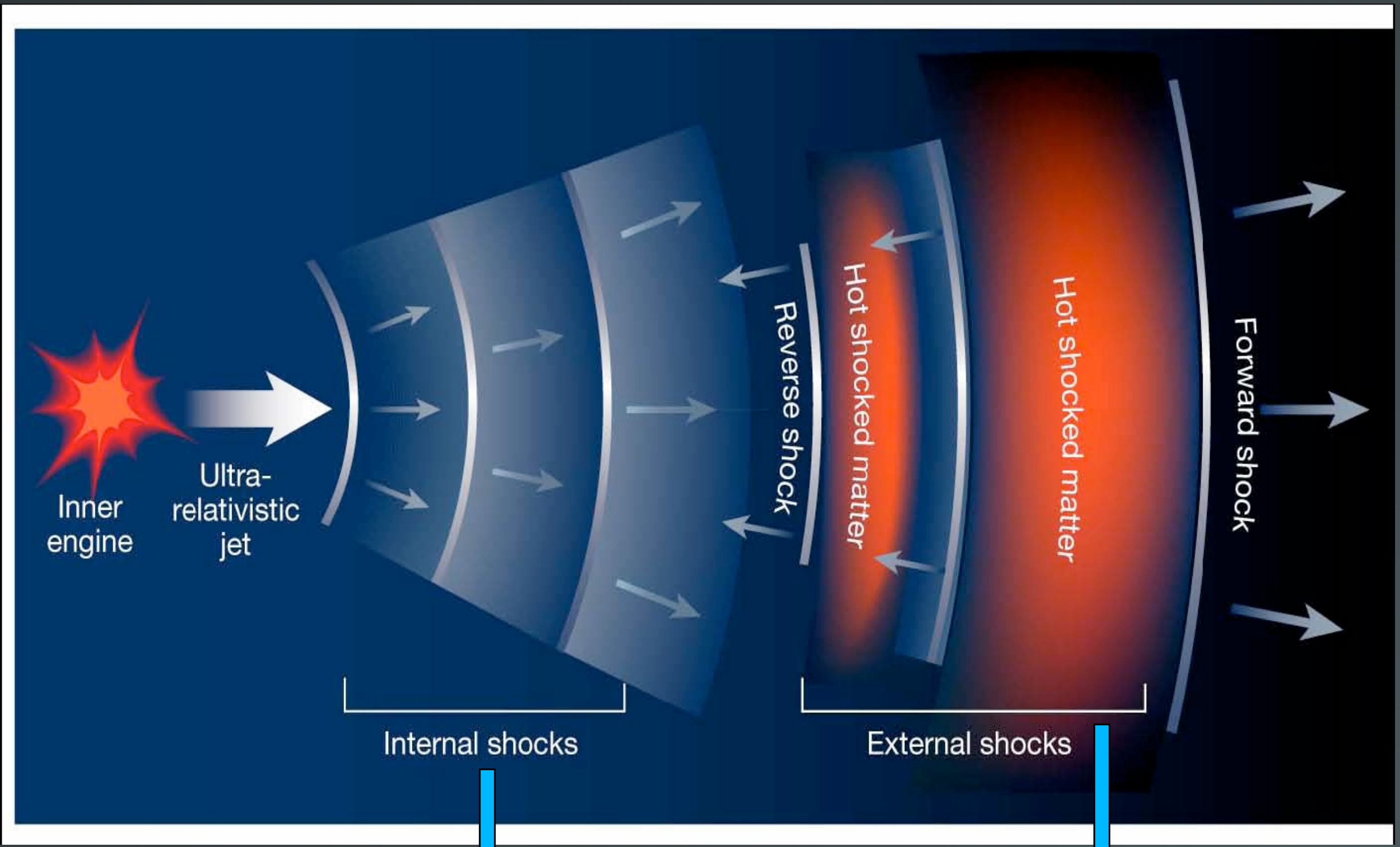
THE THEORETICAL PICTURE

Many models have been suggested for HE emission justification:



Internal/external shocks

Fermi Mechanism

Power law distribution for particle

Leptonic component
- Synchrotron emission (dominant process in th sub-Mev range)
- Inverse Compton

Hadronic component
- Proton syncrothron
- π_0 decay

SSC in internal shock: 1-50/100 GeV (Guetta&Granot 2003; Galli&Guetta 2007; Zhang & Meszaros 2007)

P-□ interactions: MeV- TeV (Gupta & Zhang 2007)

SSC in RS, keV-GeV (Granot & Guetta 2003, Kobayashi et al. 2007)

SSC in FS, MeV-TeV (Galli & Piro 2007)

Syncrothron in FS, GeV (Ghisellini+ 2009, Kumar+ 2009)

p-γ interaction in FS, GeV – TeV

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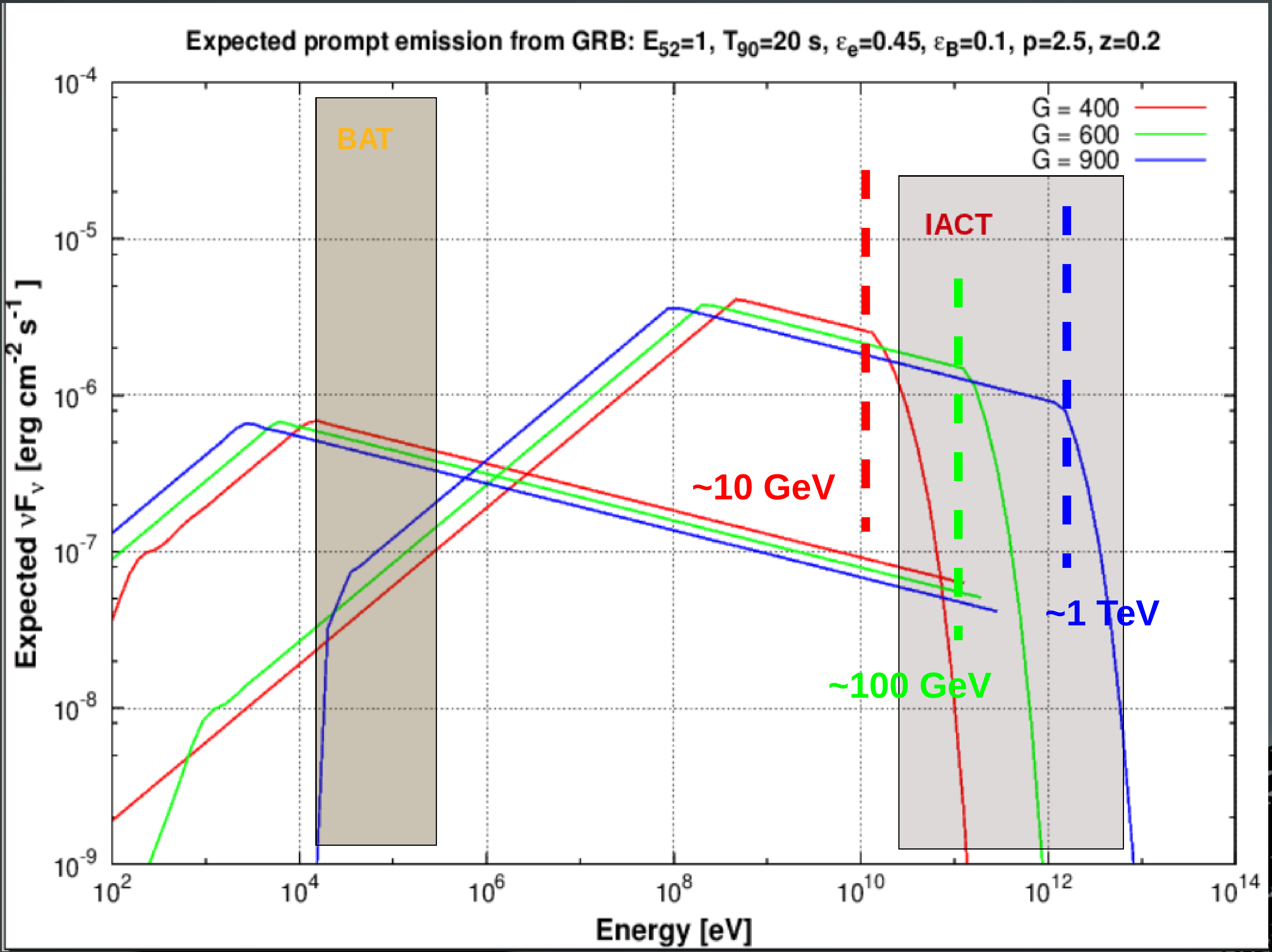
THE VHE REGIME:
A GOOD OBSERVATIONAL PROOF

A SCREENSHOT OF THE PROMPT EMISSION



Internal pair-production absorption makes difficult observation in the VHE range

Most probably candidates for high energy emission: (XRF) (Γ > 500)

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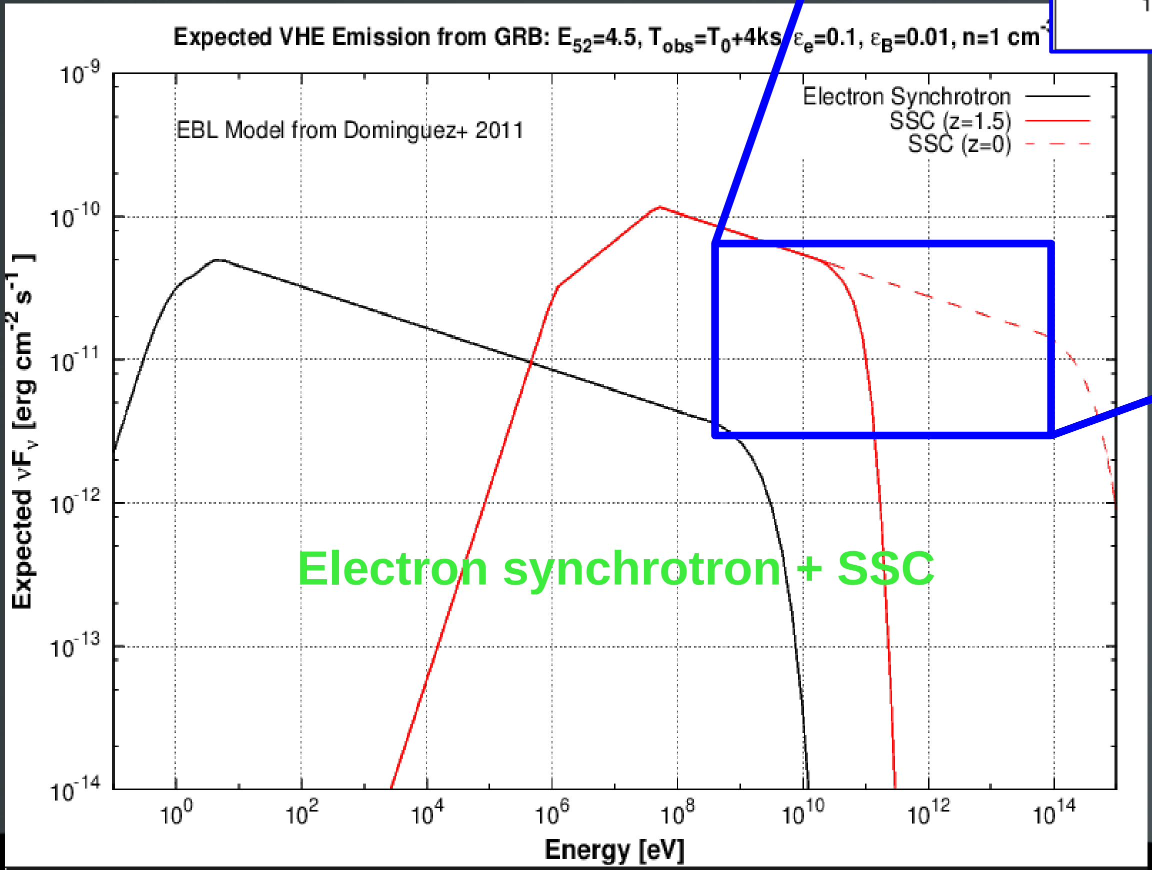
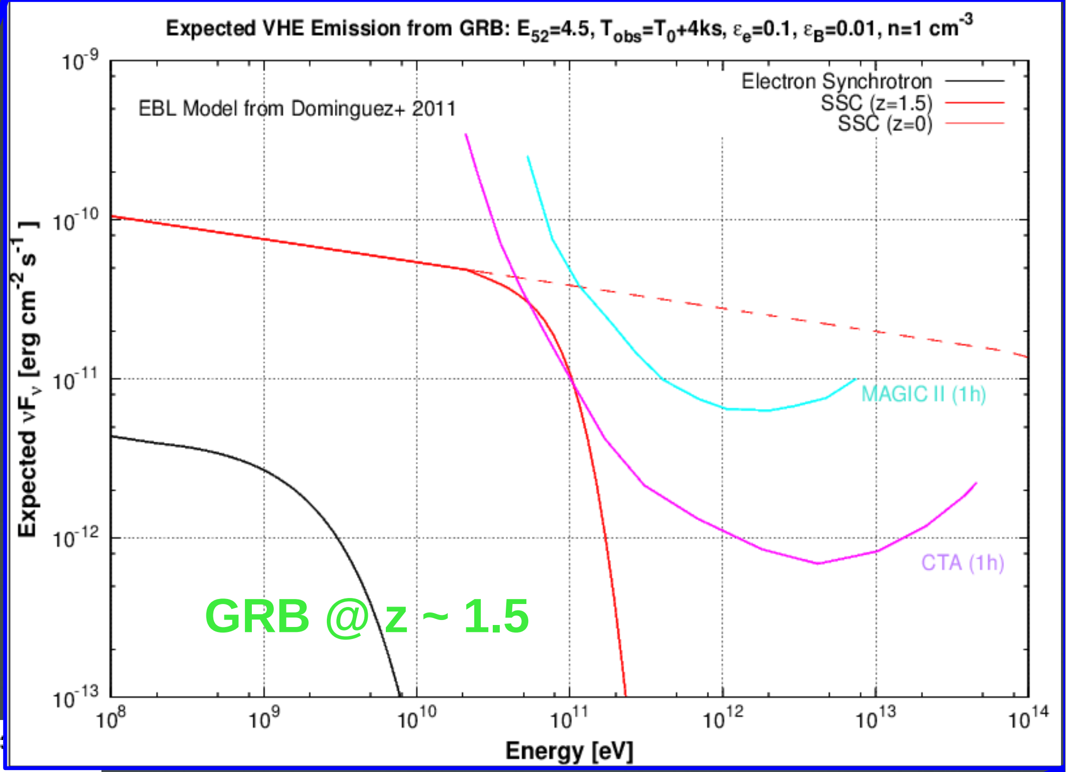
THE VHE REGIME:
A GOOD OBSERVATIONAL PROOF

Observation in GeV-TeV energy range is a powerful diagnostics tool for the emission processes and physical conditions of GRBs

"Standard Afterglow " leptonic scenario





- **Discriminating between different emission models**
- **EBL at "high" redshift**

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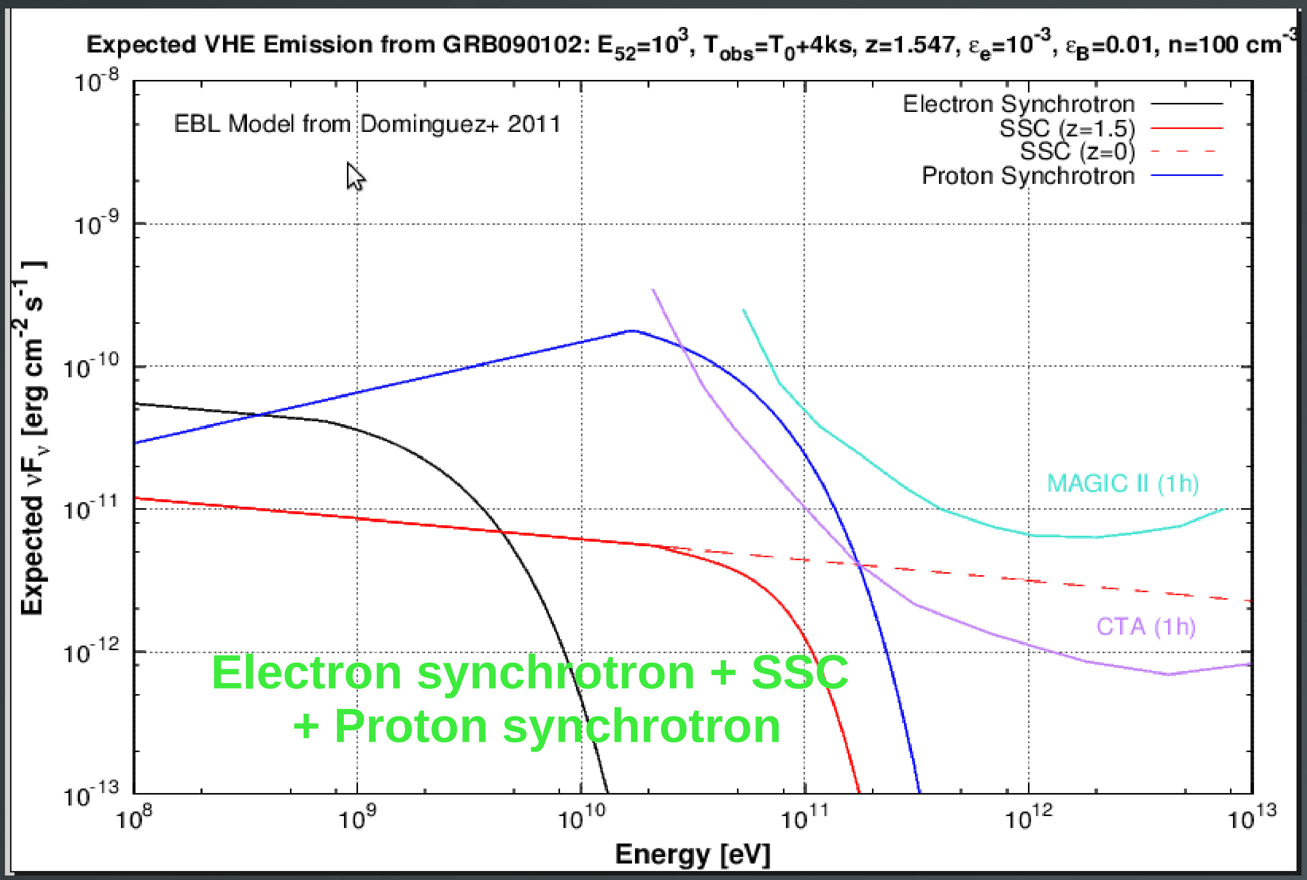
THE VHE REGIME:
A GOOD OBSERVATIONALS PROOF



The cooling frequency for protons can easily reach the GeV regime.

strong and prevalent proton synchrotron component in the GeV range is possible.

Afterglow in hadronic scenario

- Discriminating between hadronic and leptonic emission model
- Constraining space parameters

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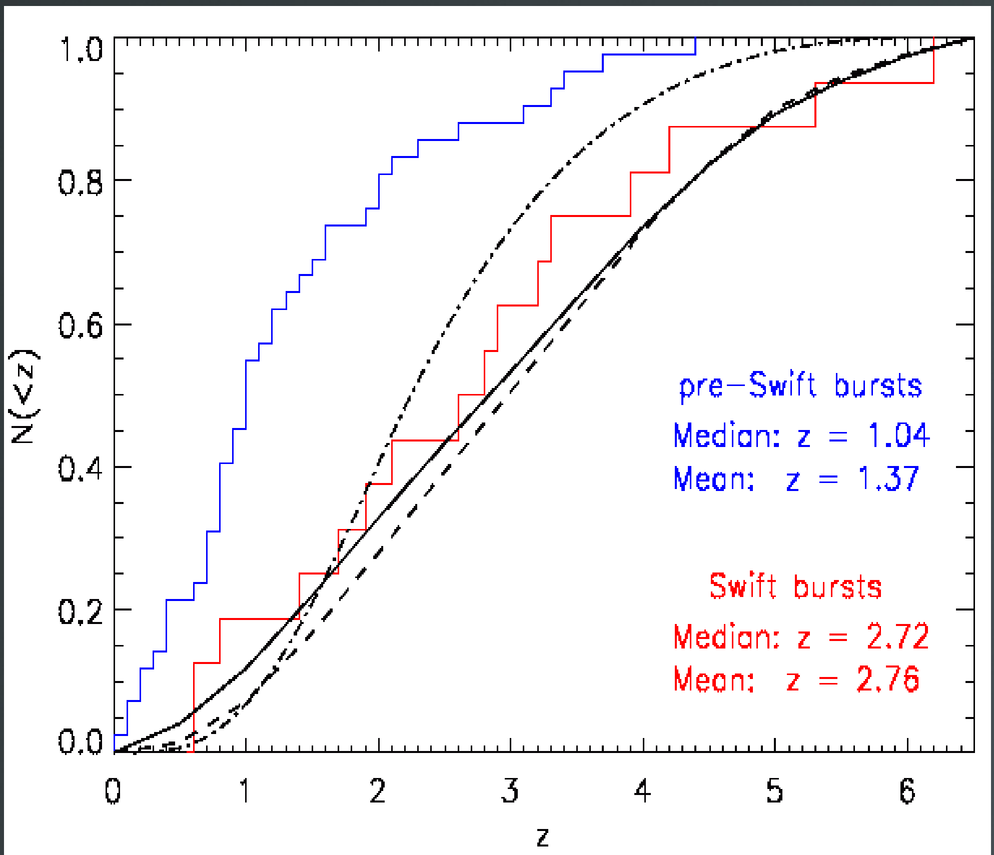
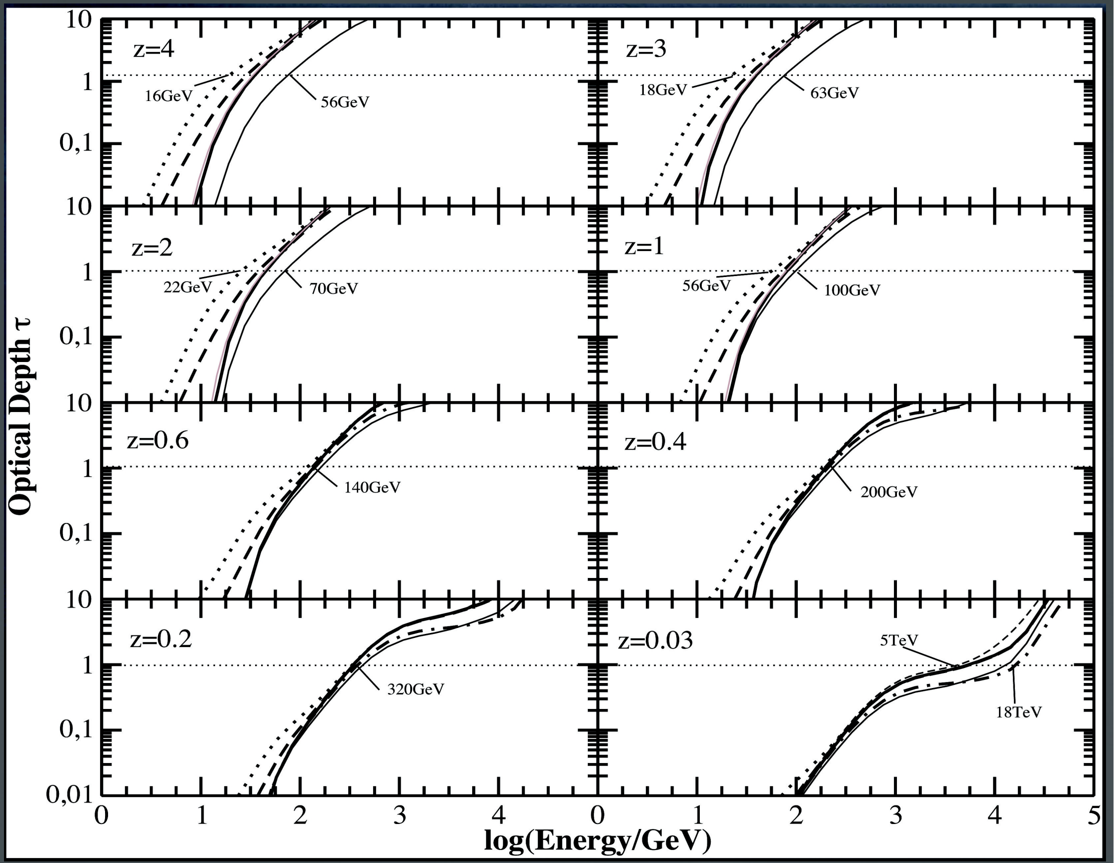
IACT OBSERVATION:

Difficult task for cherenkov telescopes:

- **Low duty cycle (10%)**
- **Gamma opacity due to EBL absorption**

$$\phi^{\rm obs}(E) = \phi(E) \cdot \exp(-\tau(E, z))$$





Z_{max} = 1 for an energy threshold of about 60 GeV

IACT observation possible if :

- **Low energy threshold**
- **Fast repointing**
- **High C – factor : Near (but not too much!) GRB**

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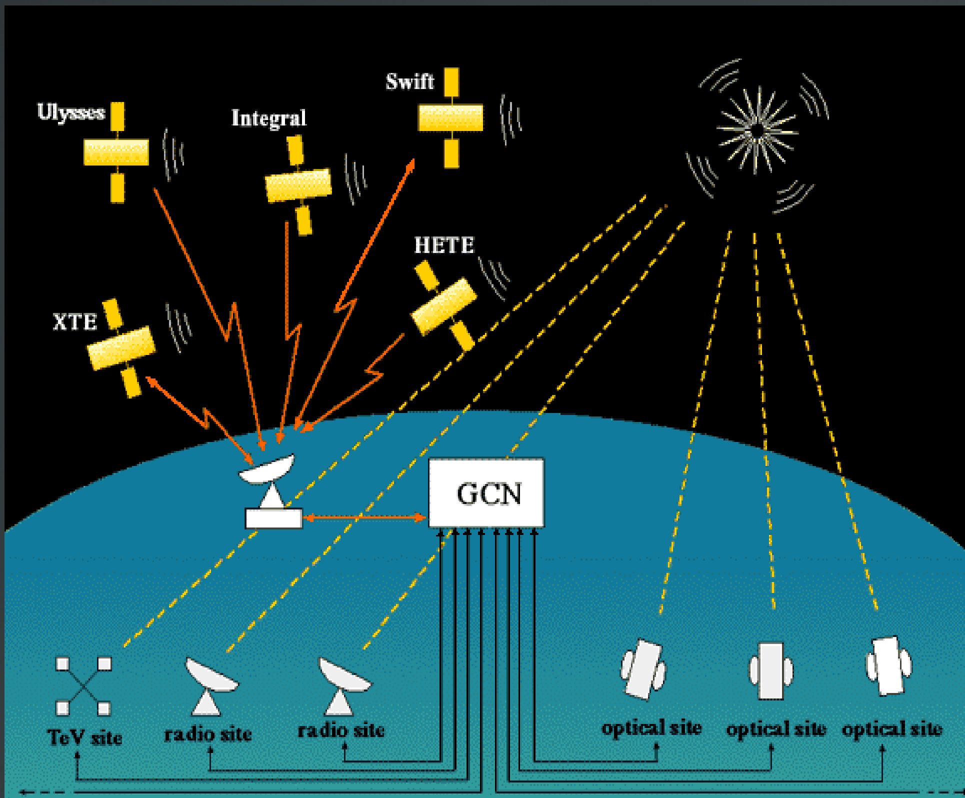
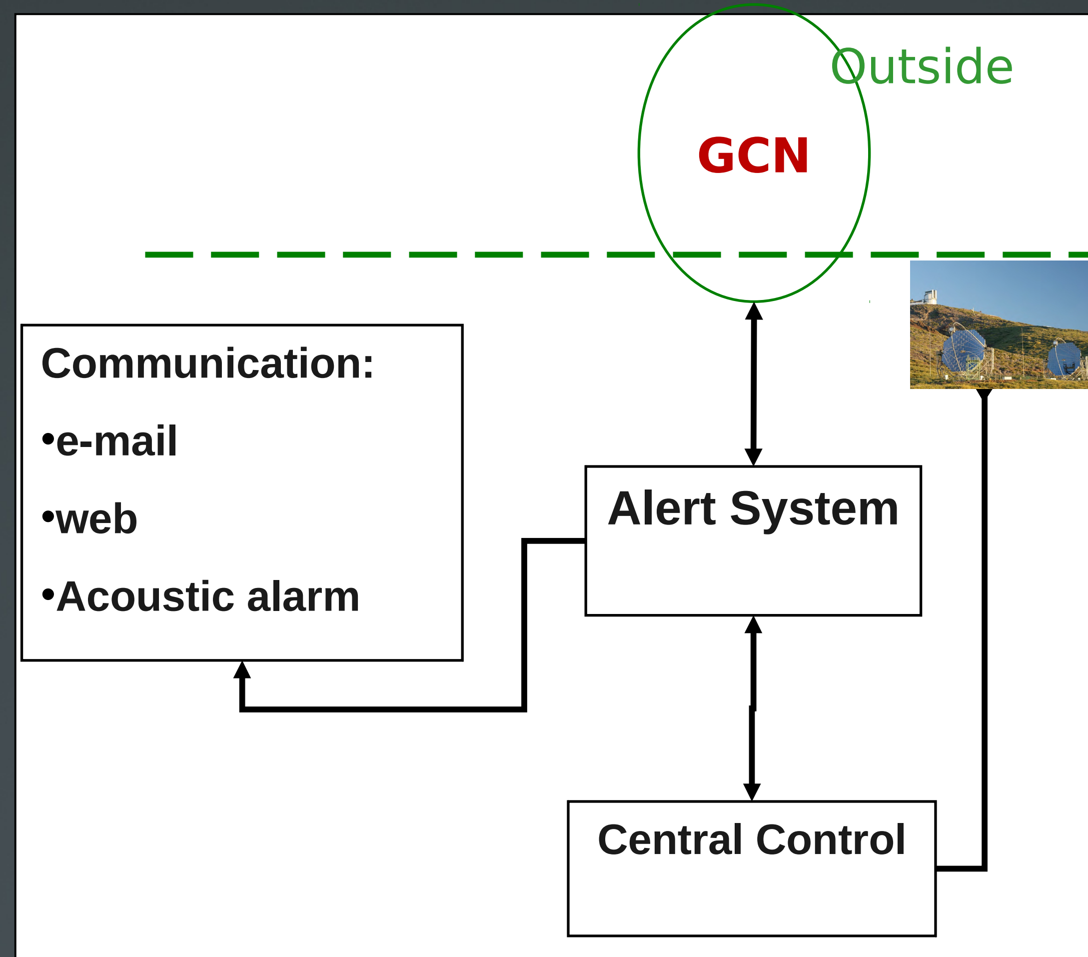
VHE COMMUNITY
MILAGRO
STACEE
CACTUS
VERITAS
MAGIC
TIBET
ARGO-YBJ
TACTIC
PACT
HESS
CANGAROO III

MAGIC DUTY CYCLE FOR GRB:





Sun below the horizon
ZA>103 degree

Zd < 60deg

Humidity <90% & wind
Speed <10 m/s

Angle from the moon <30 degree

+

Dedicated filter for GBM packets → **About 1 GRB/month is observed**

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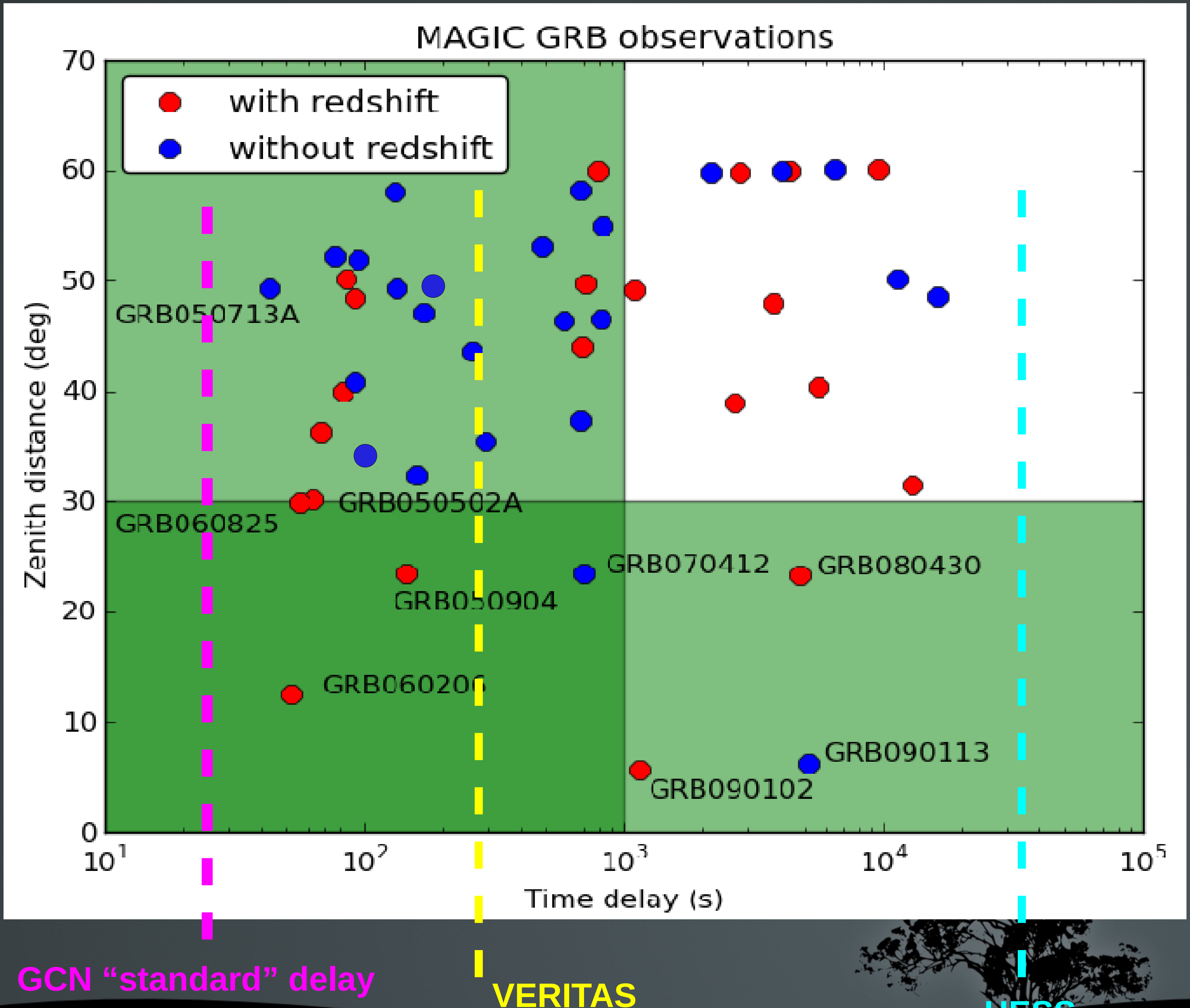
MAGIC IN ACTION!

MAGIC STATISTICS:



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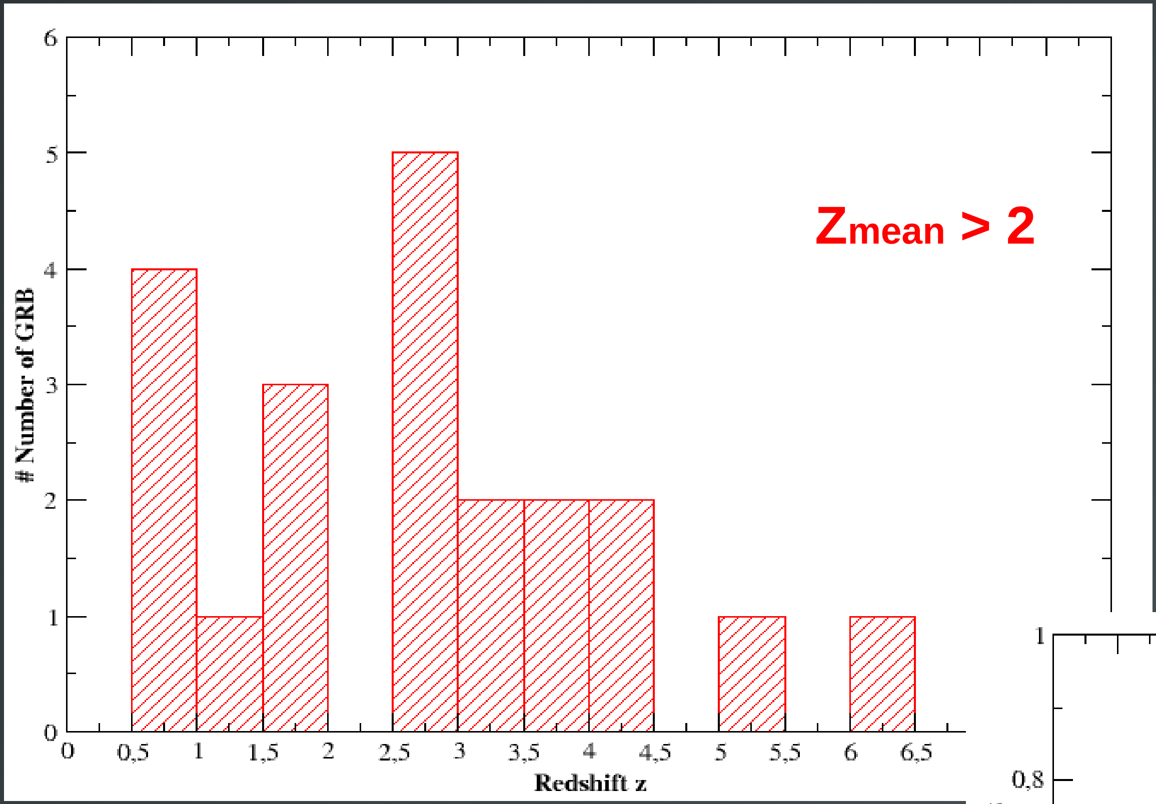
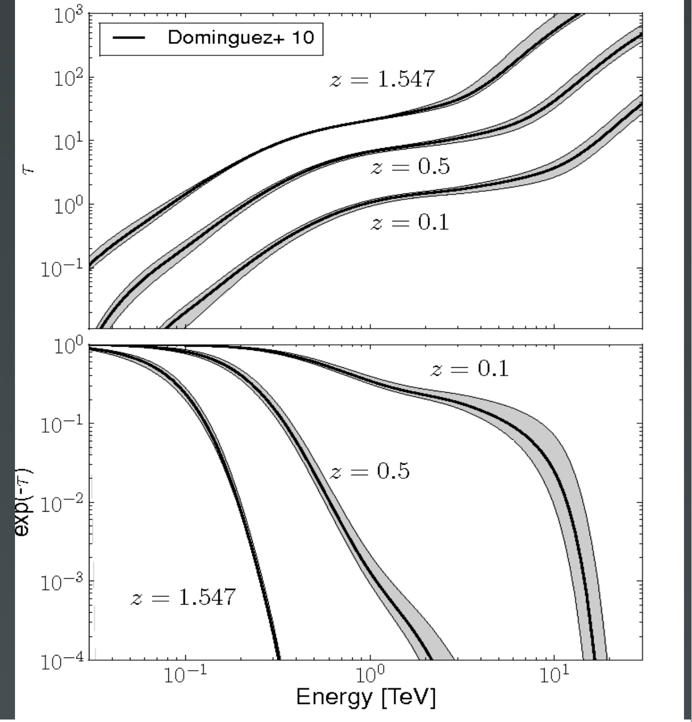
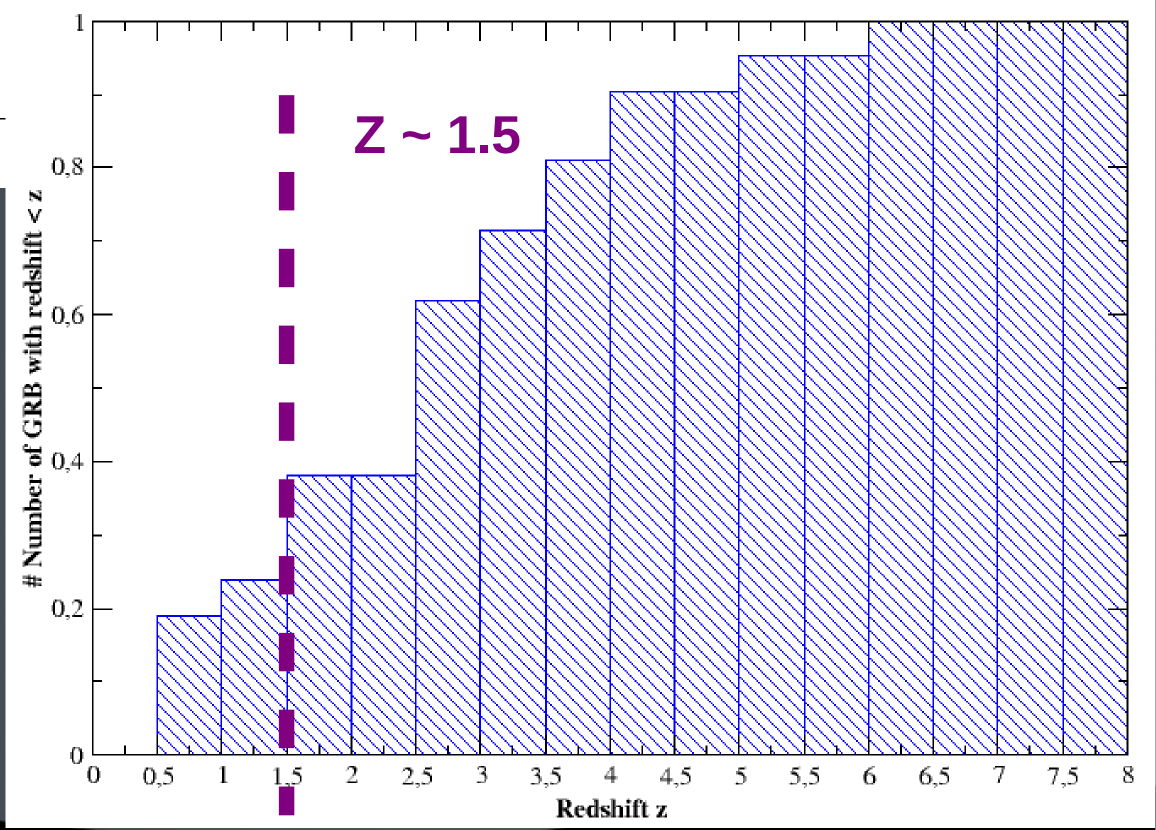
MAGIC STATISTICS: From 2005 MAGIC observed 68 GRBs





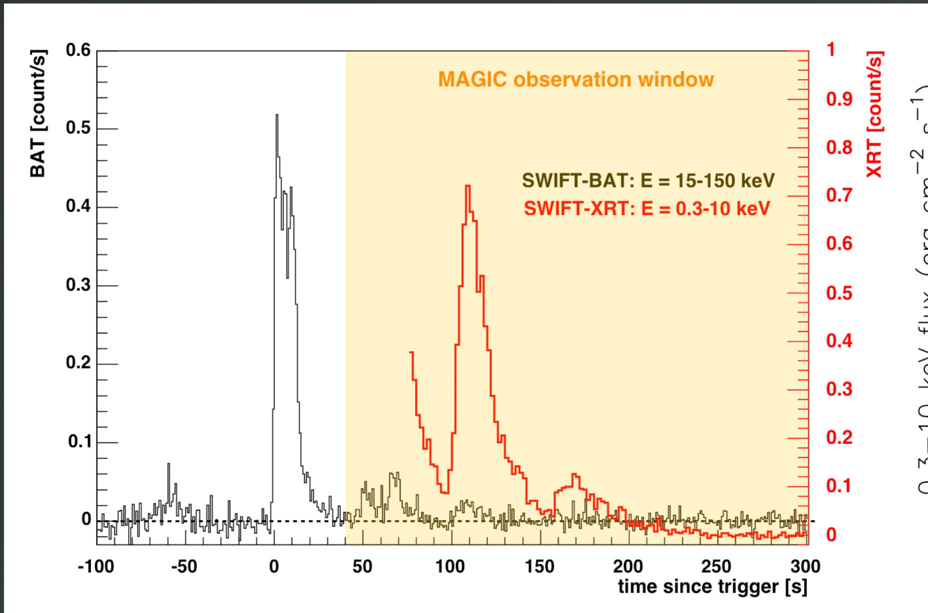
Only ~ 20% of the observed GRBs
Stay in the useful redshift range

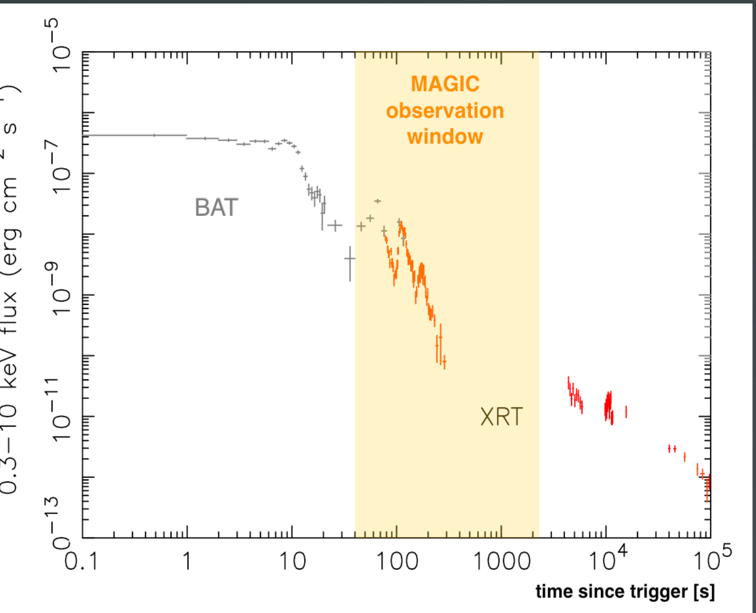


We need more statistics

MAGIC STATISTICS:

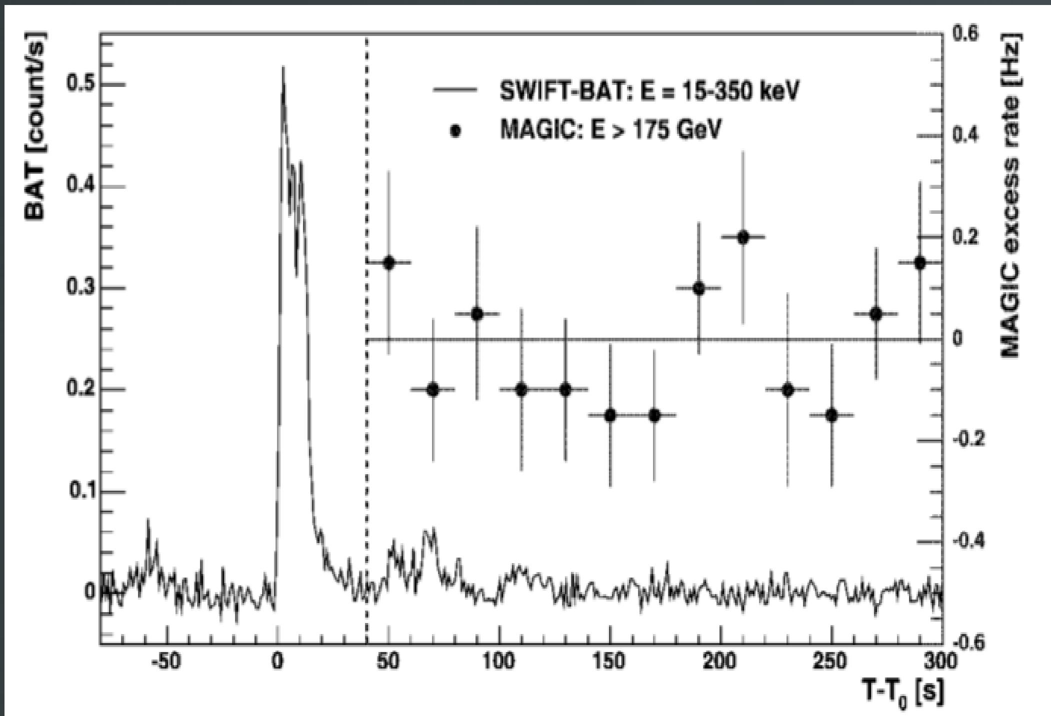
Two prompt emission

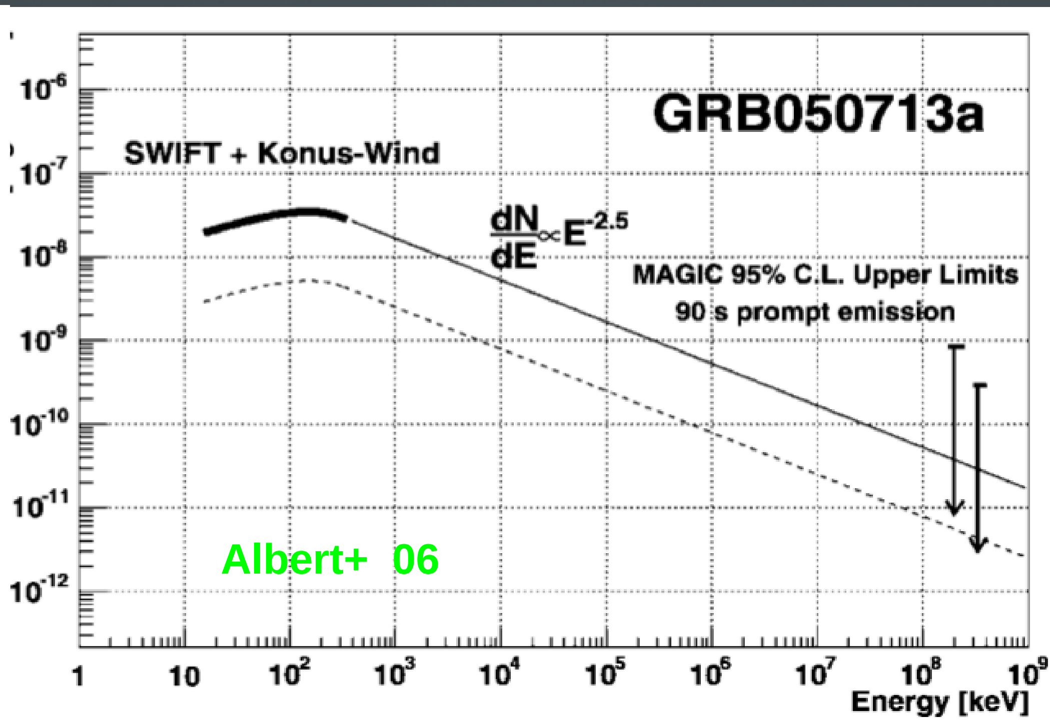




GRB 050713a

(And GRB 050904...)





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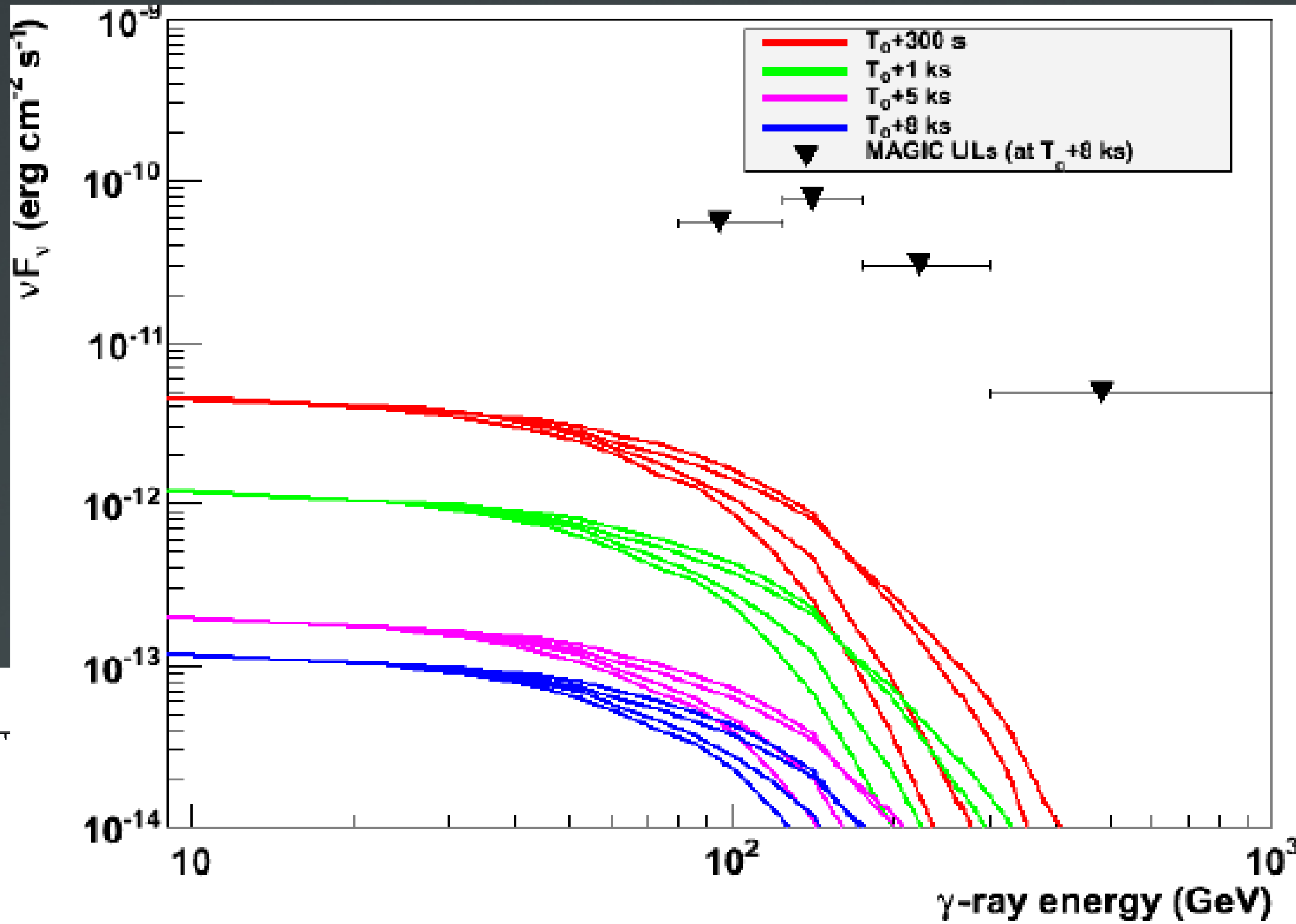
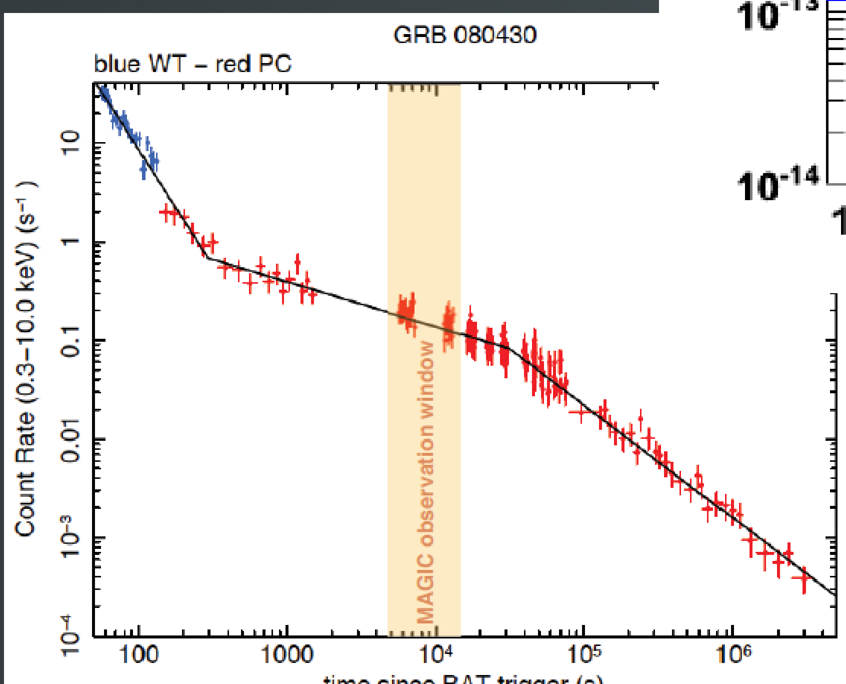
THE CASE OF GRB080430:

Published on A&A (Aleksic J. et al. 2010)

- Zenith angle: 22°-30°
- Delay: 1h 19m
- Redshift: 0.767

Follow up observation start about 4000s after the prompt emission due to bad weather conditions at the MAGIC site





Threshold energy ~ 80 GeV

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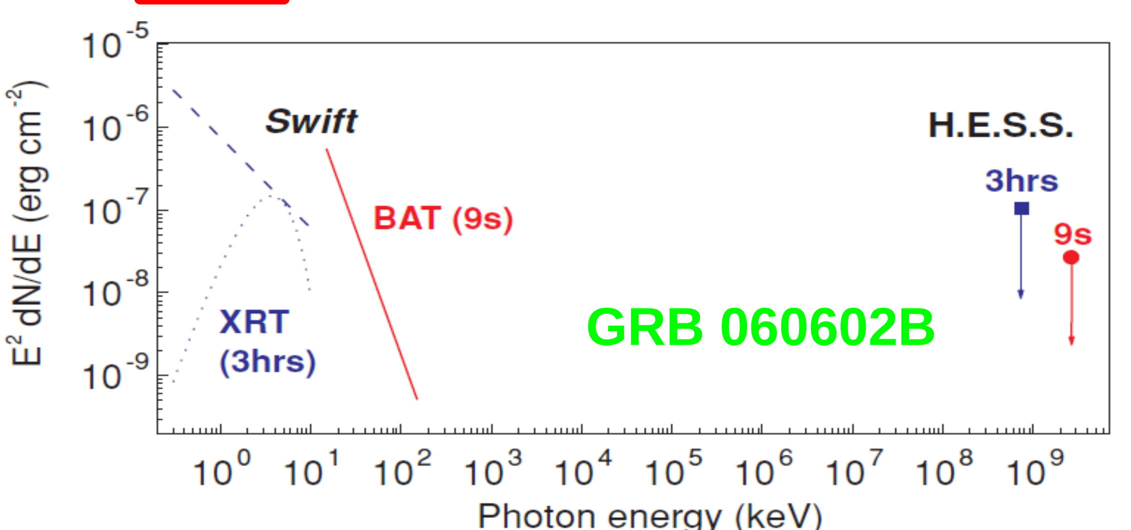
AND THE OTHER IACT

Table 2. H.E.S.S. observations of GRBs from March 2003 to October 2007.

F.Aharonian et al. A&A 2009

GRB[a]	T_{start} (min)	Exposure (min)	N_{tel}	Z.A. (°)	N_{ON}	N_{OFF}	α	Excess	Significance	E_{th} (GeV)	Flux ULs ($cm^{-2}\ s^{-1}$)	N_{ON}	N_{OFF}	α	Excess	Significance	E_{th} (GeV)	Flux ULs ($cm^{-2}\ s^{-1}$)	χ^2/d.o.f.	P(χ^2)
					Standard-cut analysis							Soft-cut analysis							Temporal analysis	
070621	6.5	234.6	4	16	204	2273	0.091	-2.6	-0.18	250	2.8×10^{-12}	731	5903	0.13	-6.9	-0.24	190	5.6×10^{-12}	19.2/28	0.89
050801	15.0	28.2	4	43	13	173	0.091	-2.7	-0.68	400	3.2×10^{-12}	46	442	0.13	-9.3	-1.2	310	1.6×10^{-11}	0.168/3	0.98
070429A	64	28.2	4	23	4	78	0.091	-3.1	-1.2	290	2.4×10^{-12}	20	203	0.13	-5.4	-1.0	220	1.0×10^{-11}	6.39/3	0.094
041211B[a]	567.1	14.2	3	64	9	87	0.11	-0.67	-0.21	1850	6.8×10^{-12}	27	236	0.17	-12	-1.9	1360	2.6×10^{-11}	14.6/14	0.40
	742.3	112.3	4	44	76	1247	0.063	-1.9	-0.21	380	3.7×10^{-12}	317	4353	0.083	-46	-2.4	280	1.8×10^{-11}		
071003[b]	623.3	56.2	4	35	16	272	0.10	-11	-2.2	390	1.0×10^{-12}	97	785	0.14	-15	-1.4	280	1.4×10^{-11}	32.3/12	0.0012
	691.1	56.2	3	41	25	204	0.10	4.6	0.93	480	5.6×10^{-12}	79	547	0.14	0.86	0.091	340	1.5×10^{-11}		
041006	626.1	81.9	4	27	80	770	0.10	3	0.32	200	1.1×10^{-11}	302	1974	0.14	20	1.1	150	6.8×10^{-11}	8.89/9	0.45
070419B	907	56.4	4	47	28	391	0.091	-7.5	-1.3	700	2.4×10^{-12}	121	1069	0.13	-13	-1.0	520	7.5×10^{-12}	11.9/6	0.064
060526	284.2	112.8	4	25	93	1068	0.10	-13.8	-1.3	280	2.9×10^{-12}	492	3711	0.14	-38	-1.6	220	9.2×10^{-12}	19.8/12	0.072
070808	306.2	112.8	4	34	49	659	0.091	-11	-1.4	310	3.2×10^{-12}	209	1733	0.13	-7.6	-0.49	260	7.5×10^{-12}	15.8/12	0.20
070721B	925.7	103.8	4	40	59	984	0.063	-2.5	-0.31	440	1.4×10^{-12}	237	2676	0.083	14	0.89	320	8.8×10^{-12}	15.5/11	0.16
061110A	407.68	112.8	4	25	76	838	0.093	-1.9	-0.21	280	4.3×10^{-12}	314	2671	0.13	-20	-1.0	200	8.4×10^{-12}	4.66/11	0.95
030329[c]	16493.5	28.0	2	60	4	26	0.14	0.27	0.13	1360	2.6×10^{-12}					…			5.93/3	0.12
050726	772.7	112.8	4	40	107	1031	0.083	21	2.1	320	7.1×10^{-12}	333	2619	0.11	42	2.3	260	3.4×10^{-11}	14.7/12	0.26
050209	1208.5	168.6	4	48	104	1096	0.11	-18	-1.6	480	4.4×10^{-12}	528	4204	0.14	-73	-2.8	340	1.5×10^{-11}	36.3/18	0.0065
070612B	901.7	112.8	4	18	104	1190	0.091	-4.2	-0.39	240	4.1×10^{-12}	415	3233	0.13	11	0.51	180	1.5×10^{-11}	4.87/12	0.96
060403	820.4	52.8	4	39	33	252	0.091	10	1.9	440	4.8×10^{-12}	128	875	0.13	19	1.6	320	1.3×10^{-11}	10.4/6	0.11
060505	1163	111	4	42	99	837	0.091	23	2.4	520	5.6×10^{-12}	339	2740	0.13	-3.5	-0.18	400	3.9×10^{-12}	22.1/12	0.036
050509C	1289	28.2	4	22	31	344	0.083	2.3	0.41	200	1.7×10^{-11}	112	965	0.11	4.8	0.43	150	1.5×10^{-10}	0.301/3	0.96
070721A	893.5	112.8	4	30	90	1436	0.059	5.5	0.58	320	6.5×10^{-12}	280	3837	0.077	-15	-0.86	260	1.3×10^{-11}	6.78/12	0.87
070724A	927.5	84.6	4	23	73	720	0.091	7.5	0.88	260	7.3×10^{-12}	246	2042	0.13	-9.3	-0.55	200	1.0×10^{-11}	14.3/9	0.11
070209	926.7	56.4	4	41	37	444	0.091	-3.4	-0.51	480	2.3×10^{-12}	185	1442	0.13	4.8	0.33	370	1.1×10^{-11}	5.35/6	0.50



- Huge Tdelay (~10 hr)
- High energy threshold

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AND THE OTHER IACT

VERITAS Observations of Gamma-Ray Bursts

				Standard Source Analysis			Soft Source Analysis		
GRB	T_{delay} (s)$^{\alpha}$	T_{obs} (min)$^{\beta}$	Elev. Range (°)$^{\gamma}$	E_{th} (GeV)$^{\delta}$	σ^{ζ}	Upper Limit	E_{th} (GeV)$^{\delta}$	σ^{ζ}	Upper Limit
070223	1.7×10^4	74.1	67–78	220	1.3	9.5×10^{-12}	150	0.8	2.0×10^{-11}
070419A	295	37.7	32–36	610	−0.1	8.1×10^{-12}	420	−1.0	1.0×10^{-11}
070521	1118	75.4	63–88	190	0.1	4.6×10^{-12}	120	−0.3	9.6×10^{-11}
070612B	201	131.9	46–50	380	0.6	2.5×10^{-12}	230	0.6	7.1×10^{-12}
071020	5259	73.5	30–43	570	1.8	1.7×10^{-11}	330	0.5	2.6×10^{-11}
080129	1456	31.4	47–50	370	1.2	7.7×10^{-12}	220	1.4	1.2×10^{-11}
080310	342	198.0	48–58	270	0.2	2.2×10^{-12}	170	1.8	7.3×10^{-12}
080330	156	107.8	64–88	180	0.2	4.0×10^{-12}	120	−0.7	6.3×10^{-12}
080409	6829	19.0	31–35	1300	0.1	5.3×10^{-11}	720	−0.7	3.8×10^{-11}
080604	281	151.8	33–70	250	1.1	4.7×10^{-12}	160	0.9	1.2×10^{-11}
080607	184	56.0	32–46	400	1.5	1.6×10^{-11}	310	1.1	2.4×10^{-11}
081024A	150	161.2	55–60	310	−1.5	1.5×10^{-12}	190	−2.0	2.2×10^{-12}
090102	5344	83.1	33–48	400	−0.1	8.4×10^{-12}	230	−0.3	1.8×10^{-11}
090418A	261	30.4	86–88	190	1.0	1.0×10^{-11}	120	1.7	3.0×10^{-11}
090429B	141	158.8	70–88	180	1.1	3.9×10^{-12}	120	1.0	9.6×10^{-12}
090515	356	78.8	37–57	340	0.1	6.3×10^{-12}	220	1.2	2.5×10^{-11}

Upper limits are given at the 99% confidence level in terms of νF_{ν} at E_{th}, assuming the spectral indices of 2.5 and 3.5 for the standard source and soft source analysis, respectively, in units of erg cm^{-2} s^{-1}. $^{\alpha}$Time between the GRB trigger time (T_{trig}) and the beginning of VERITAS GRB observation. $^{\beta}$Duration of VERITAS observation. $^{\gamma}$Elevation range of the VERITAS observation. $^{\delta}$The VERITAS energy threshold. $^{\zeta}$Statistical significance (standard deviations) of signal counts observed by VERITAS at the GRB position.

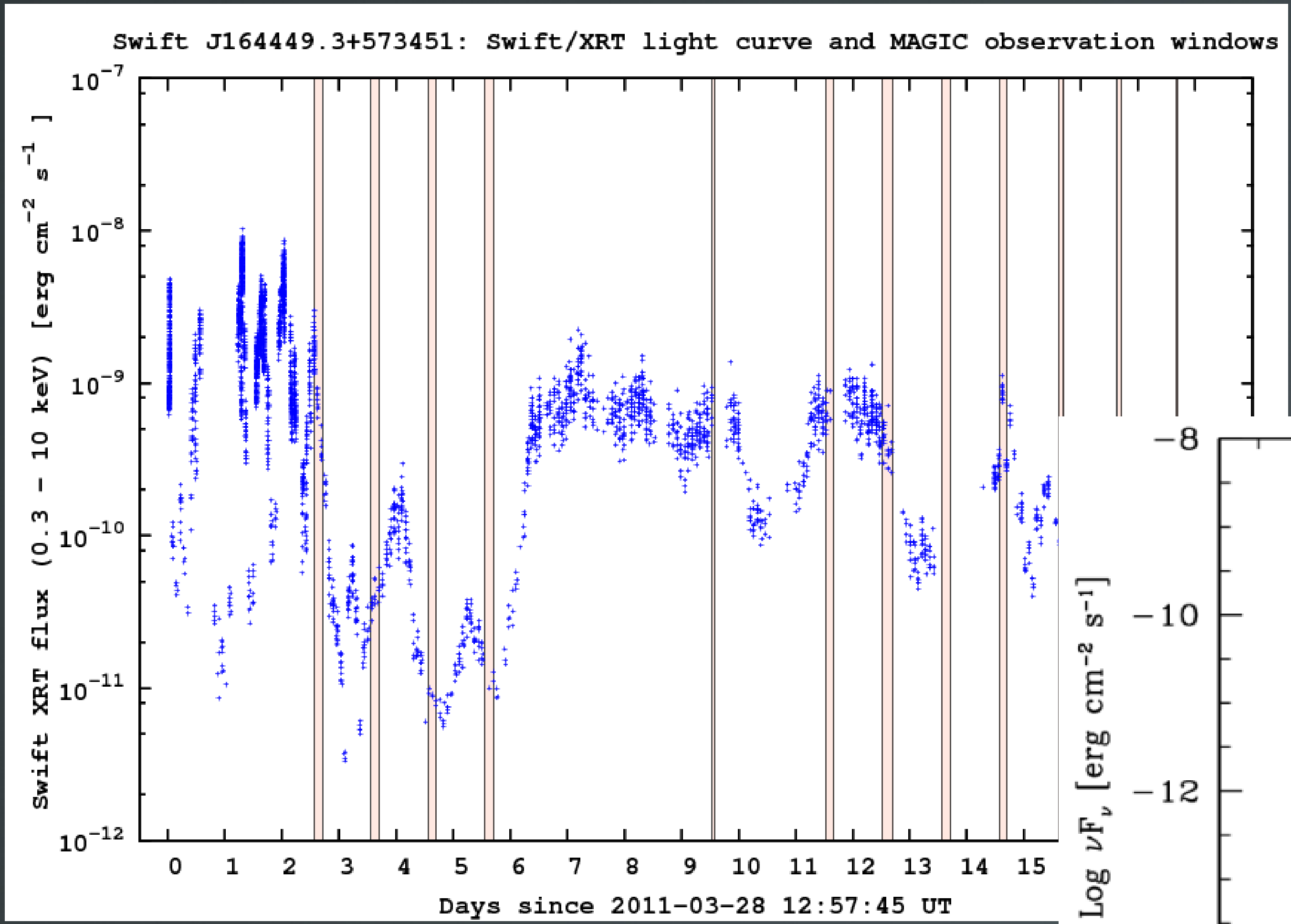
- More similar to MAGIC but higher threshold

The case of the *Swift J64449.3+573451* transient

Detected by Swift/BAT on 2011/03/28 at 12:57:45 UT

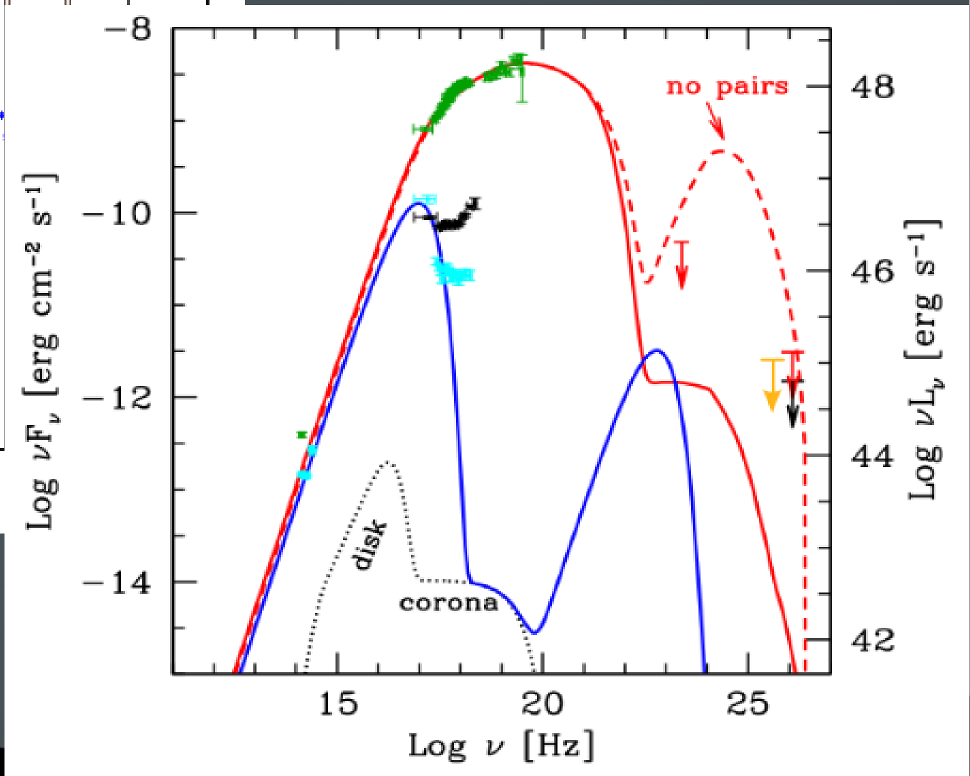
Dedicated observation by MAGIC started on 2011/03/31 at 02:22 UT (~2.5 days after the trigger)

The GRB nature of the source has been rapidly ruled out by the Unusual long lasting flaring activity detected by Swift



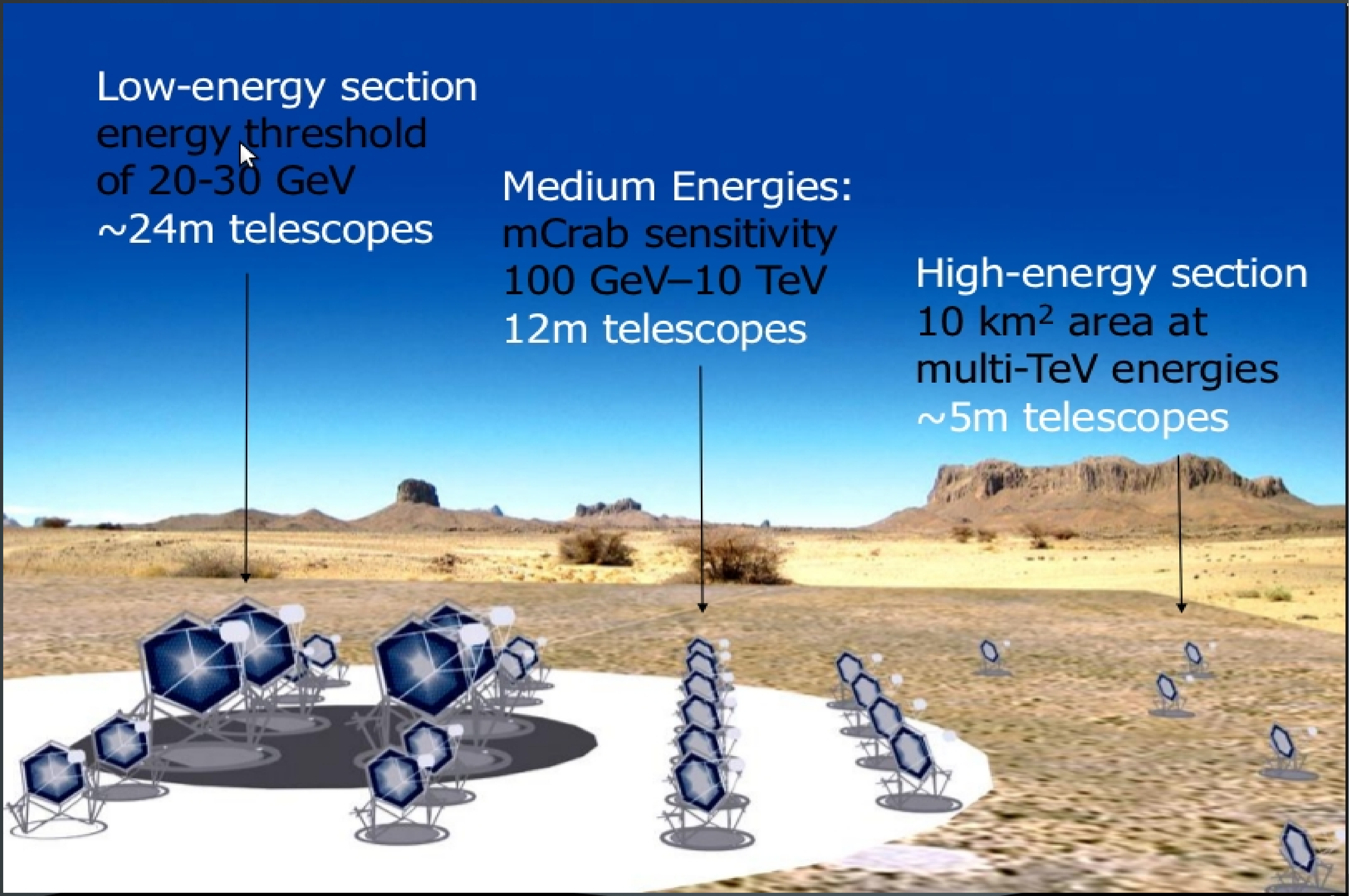
Ethr ~ 150 GeV

12 nights observed
~ 27 h of data
27° < Zd < 47°
Good quality data



MAGIC(100-300 GeV), LAT & VERITAS(~500 GeV) UL
(picture from Burrow+ 2011)

TOWARD THE NEXT GENERATION



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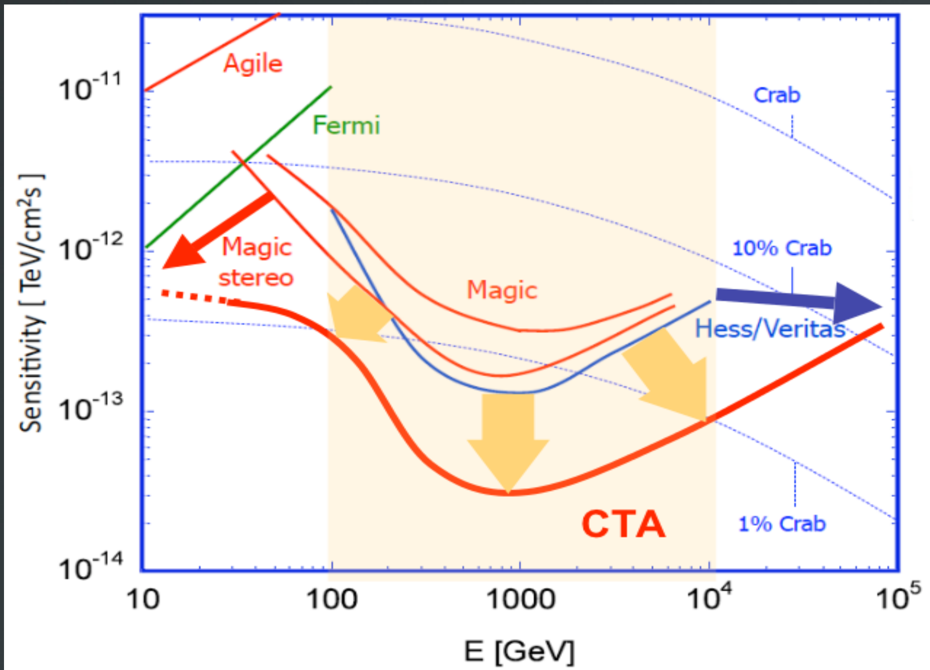
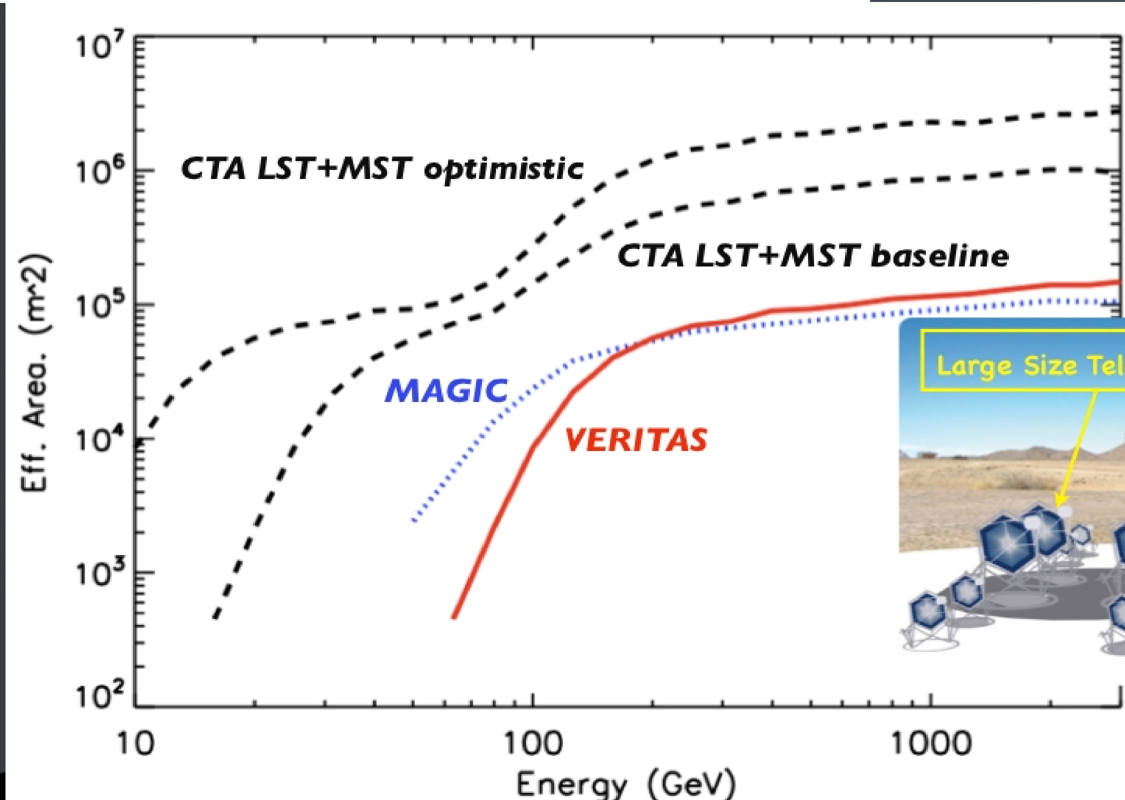
TOWARD THE NEXT GENERATION

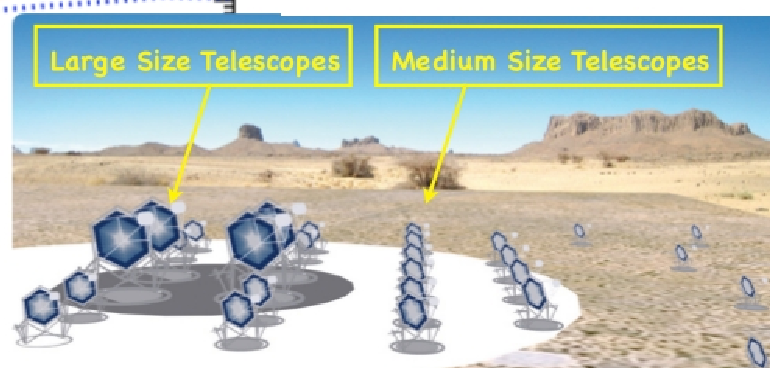


Simulated CTA performance:

Optimistic: 4 LST (Eth=10 GeV) + 75 MST
Baseline: 4 LST (Eth=25 GeV) + 25 MST



Bouvier+ ICRC 2011



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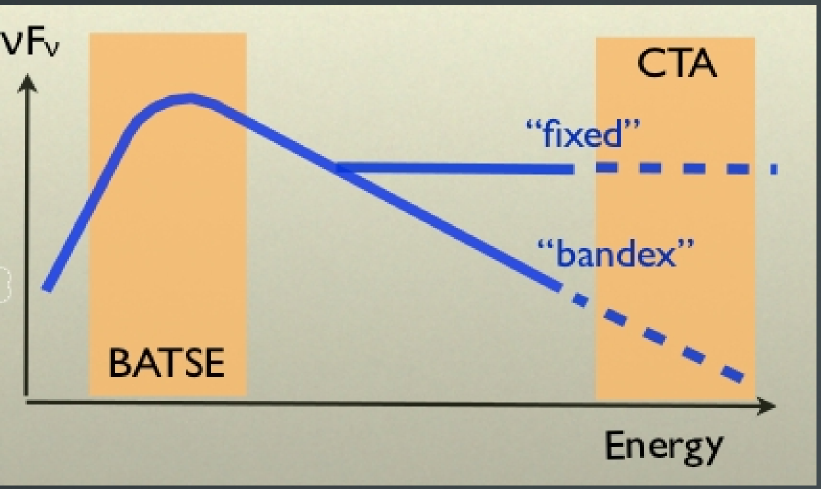
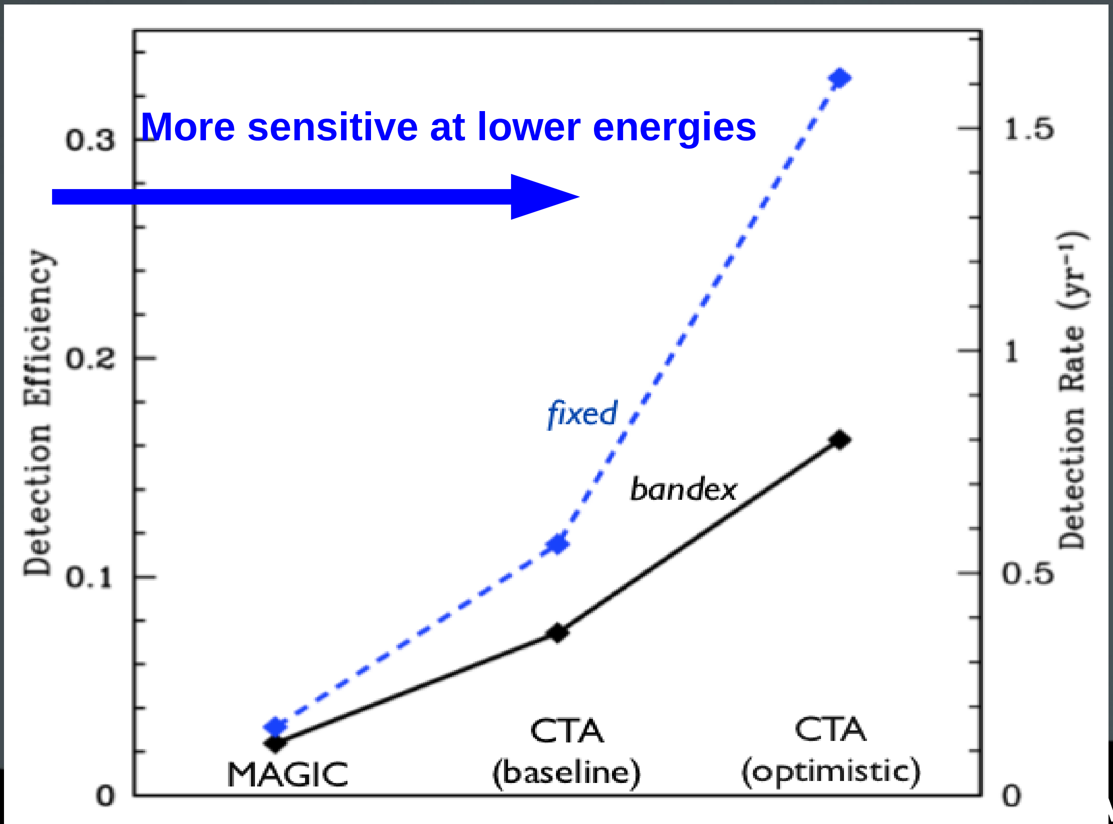
TOWARD THE NEXT GENERATION

Simulated GRB population:

- 2 spectral "type"
  - Extrpolation of the Band function to GeV energies
  - Power law component added on top of the Band function with an index -2.0



- Redshift distribution from Swift
- EBL model from Gilmore, Somerville, Dominguez and Primack



But CTA performance is still largely uncertain

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CONCLUSIONS:

- High energy component is expected for several competing emission processes during both prompt and afterglow in GRBs. Still no clear theoretical picture is really able to describe all the new features observed with Fermi/LAT.

- All the IACTs, and in particular the MAGIC telescope, are currently performing GRB follow up observations

- Until today, no evidence of VHE photons has been obtained in this energy regime. In some special case also the evaluated UL could be important to discriminate the emission processes or constrain the EBL models.

- CTA will probably open new era in VHE astrophysics and GRB field