Gamma-Ray Burst (GRB) Science with LST

Kunihito Ioka (KEK)

on behalf of the GRB subtask

CTA LST meeting 2010@RAL

- GRB science with LST
  - Lower limit on the bulk Lorentz factor
    - G>1000 is important, usually not exp cutoff, not necessarily the same region
  - Emission mechanism: afterglow/prompt? Lepton(syn?/ IC?)/hadron?
    - Spec: max synchro, IC component, Tempral: time-resolved
    - Long obs: early afterglow, Early obs: GeV onset delay (w/ precursor)
  - Probing EBL, High-z: LIV? Axion?, First star, ISM B
  - LIV (with CTA only)
- Best scenario: Energy is dominated by TeV, no cutoff

Lorentz factor>10000, Violate EBL + LIV! + ICECUBE&GW!

GRB Subtask

inaugurated Mar. 18, 2010

Asano, Katsuaki
Falcone, Abe
Granot, Jonathan (Yoni)
Hinton, Jim
Horns, Dieter
Inoue, Susumu
Inoue, Yoshiyuki
Ioka, Kunihito
Kakuwa, Jun
Lamanna, Giovanni
Markoff, Sera
Murase, Kohta
O'Brien, Paul
Raue, Martin
Ryde, Felix
Tam, P. H. Thomas
Teshima, Masahiro
Toma, Kenji
Torres, Diego
Wagner, Stefan
Wijers, Ralph
Yamazaki, Ryo
Zech, Andreas

You are welcome to join us

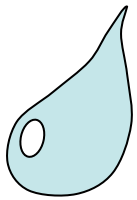
j.granot@herts.ac.uk
inoue@tap.scphys.kyoto-u.ac.jp
pto@star.le.ac.uk

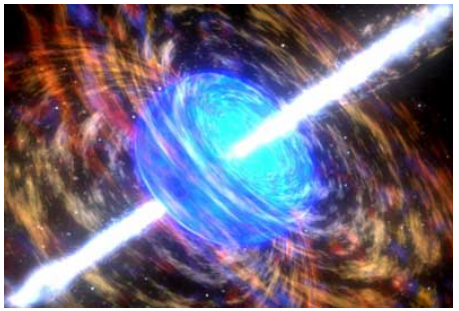
Red: Leaders

GRB: Brightest Explosion

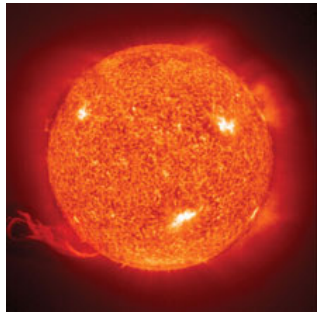
$E=mc^2$ (by Einstein)

=





=

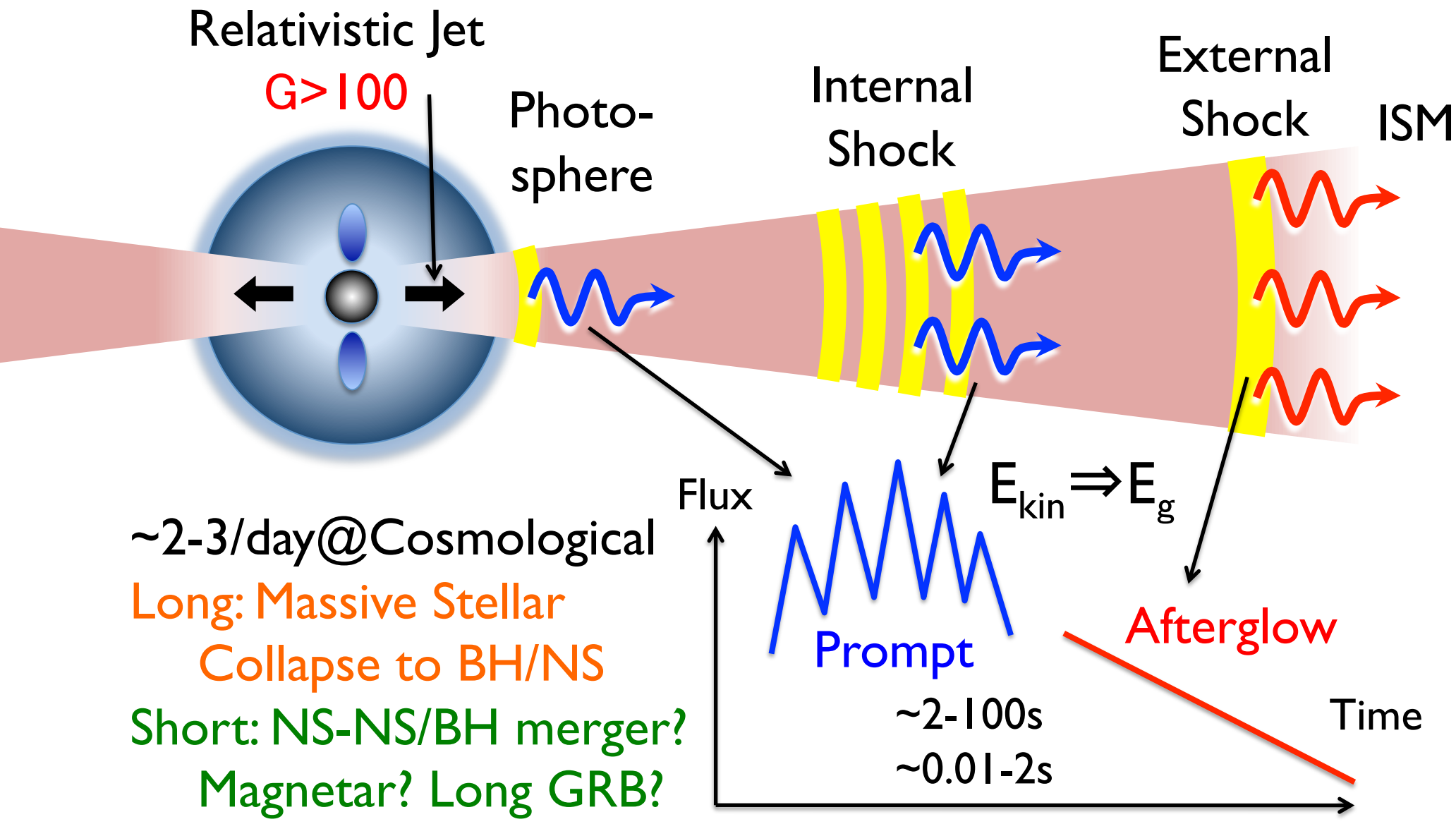


Atomic bomb	~1kg	GRB ~10^{52}erg	Sun ~10^{33}g

In ~sec, GRB release energy Sun emit over lifetime

GRB is the most luminous object

GRB in a Nutshell



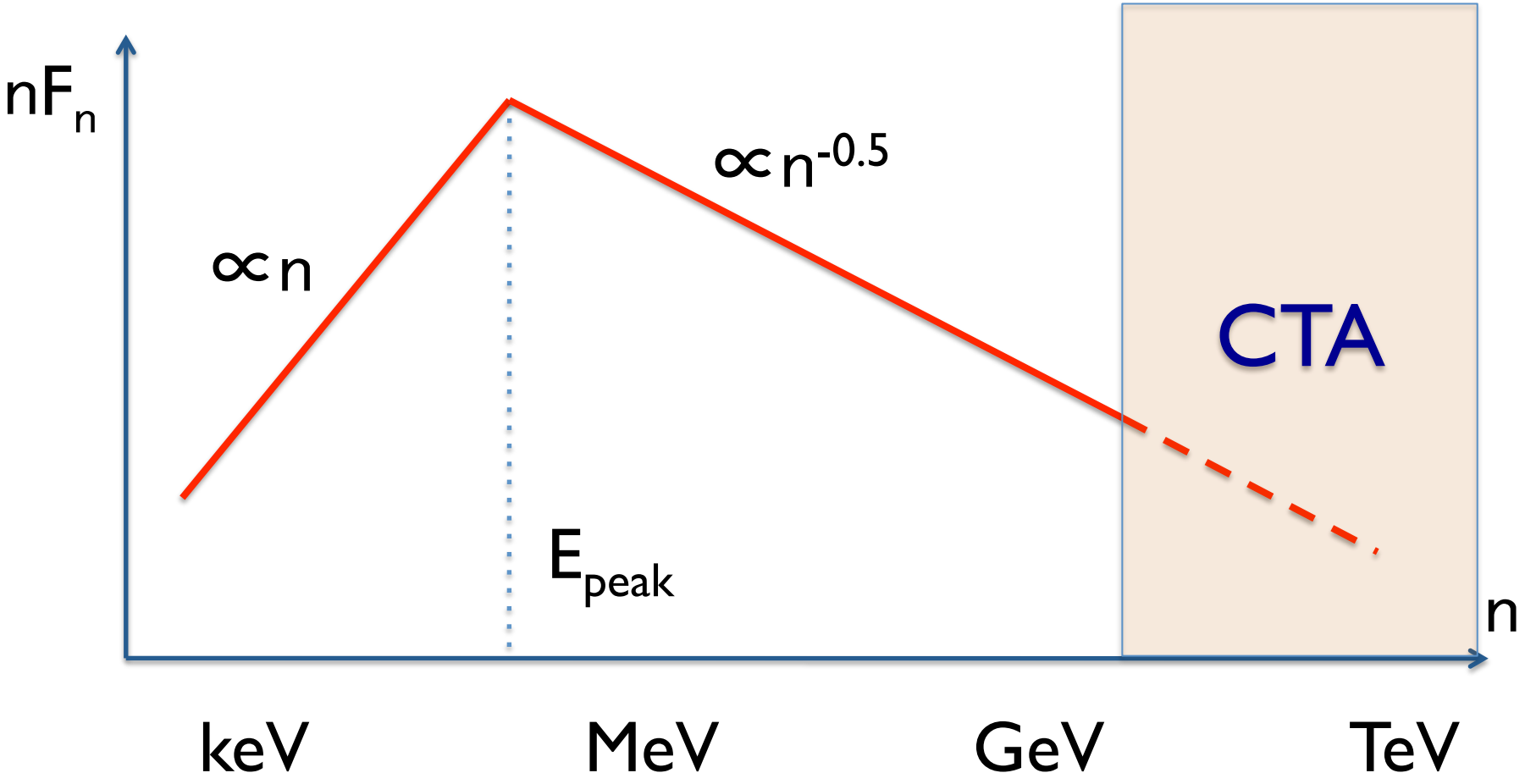
~2-3/day@Cosmological

Long: Massive Stellar Collapse to BH/NS

Short: NS-NS/BH merger? Magnetar? Long GRB?

GRB Spectrum

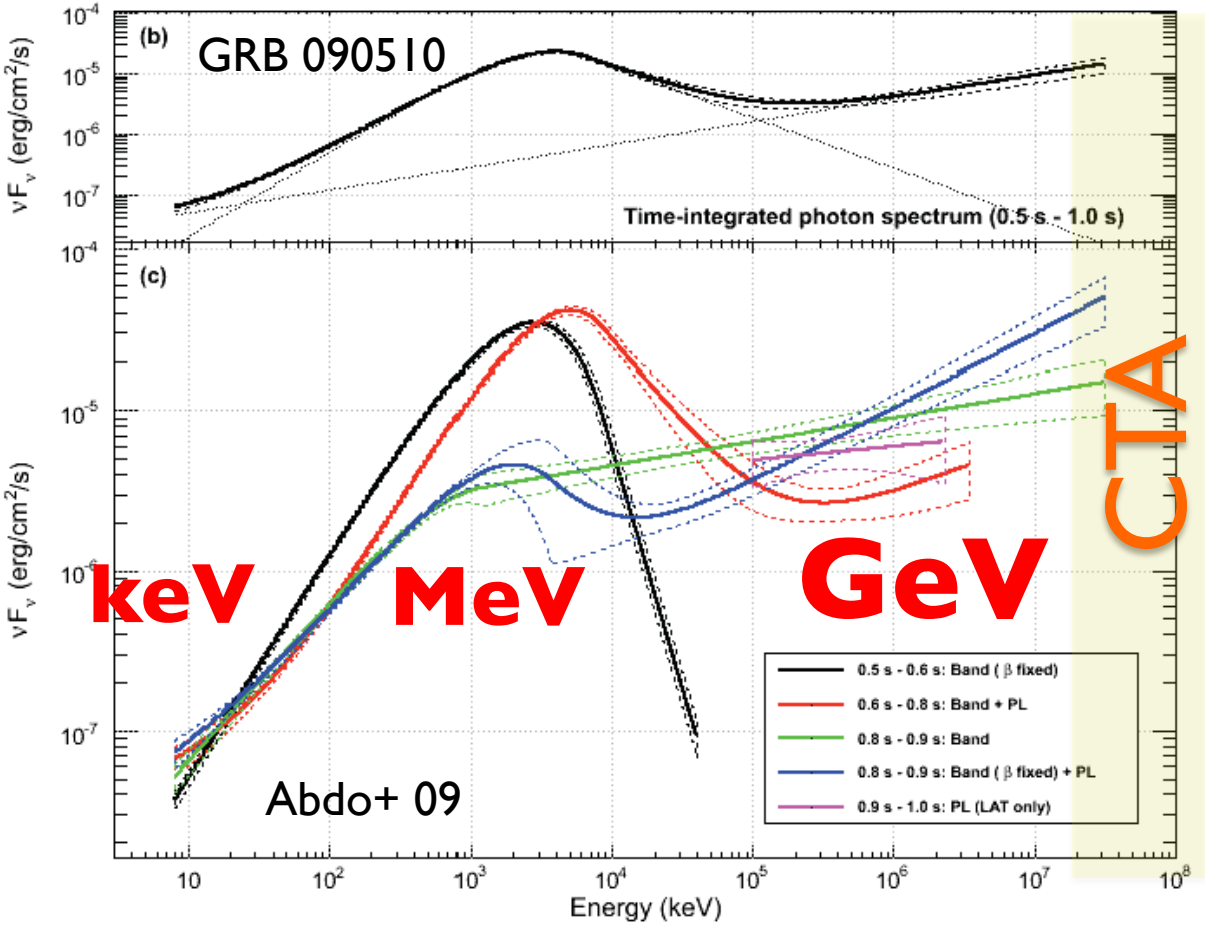
- Band spectrum



Fermi Revolution

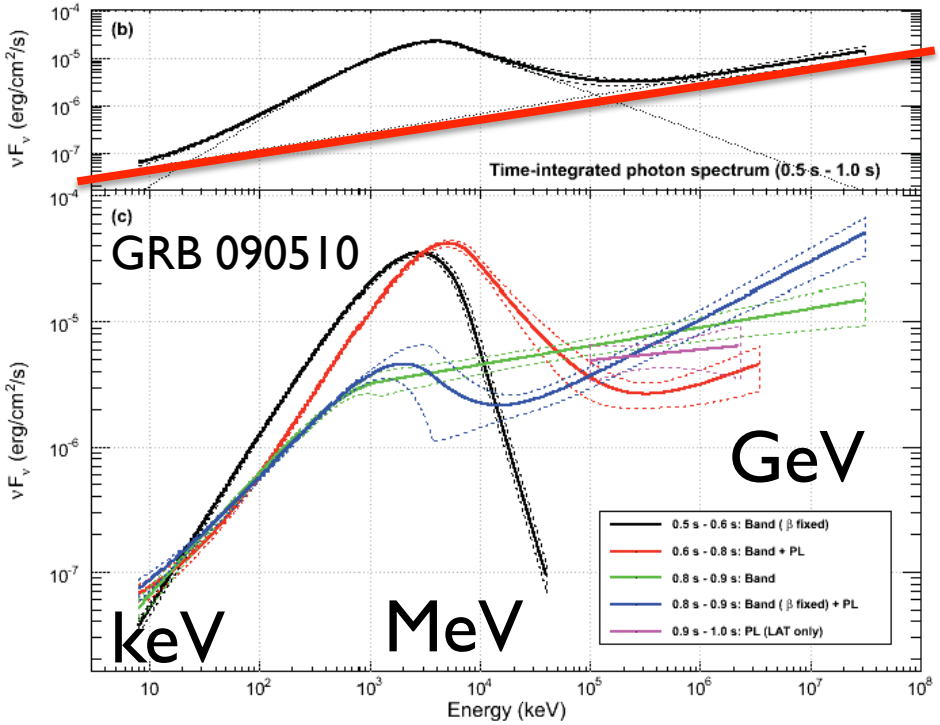
~30 GeV g from GRBs ⇒

Guaranteed source for CTA



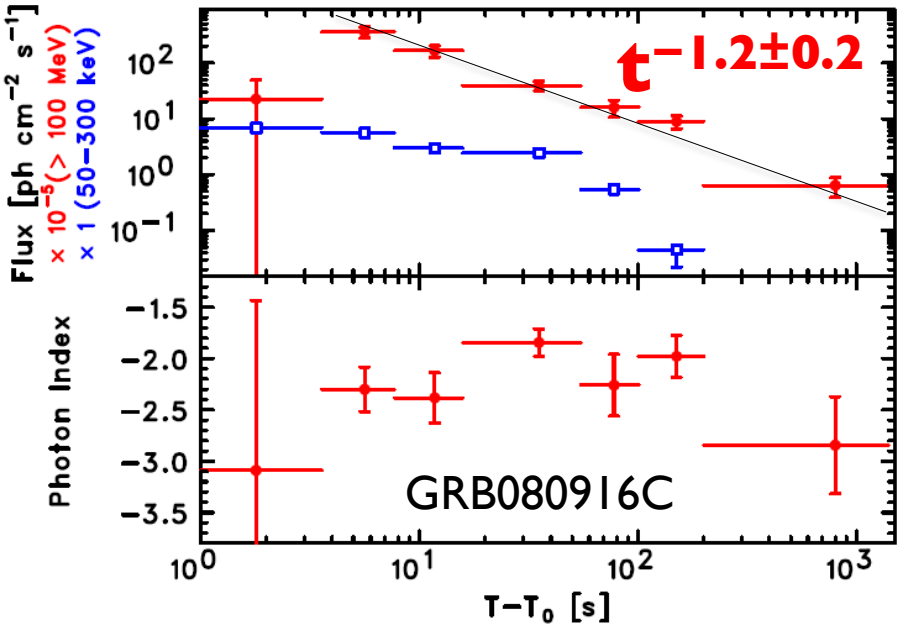
Fermi GRB Features

1. Extra spectral component



(But minor; majority is Band)

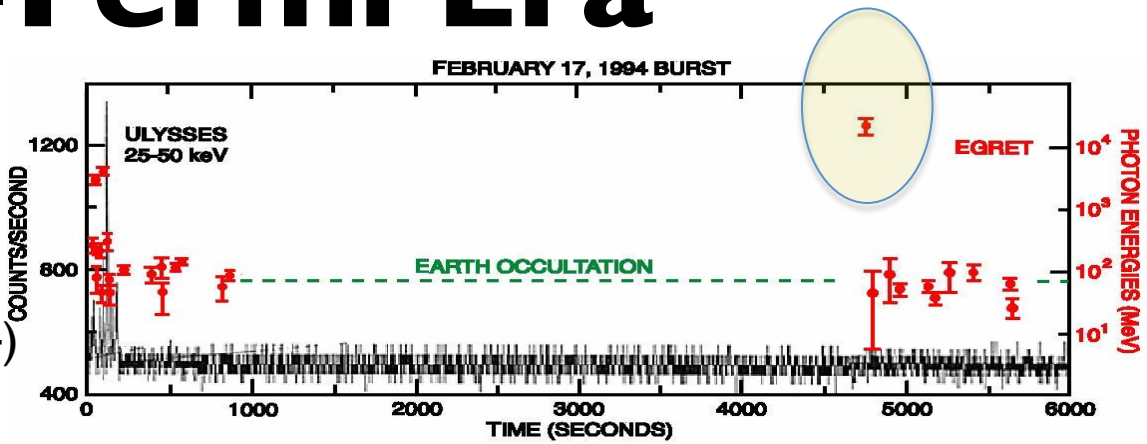
2. Temporally Extended Emission

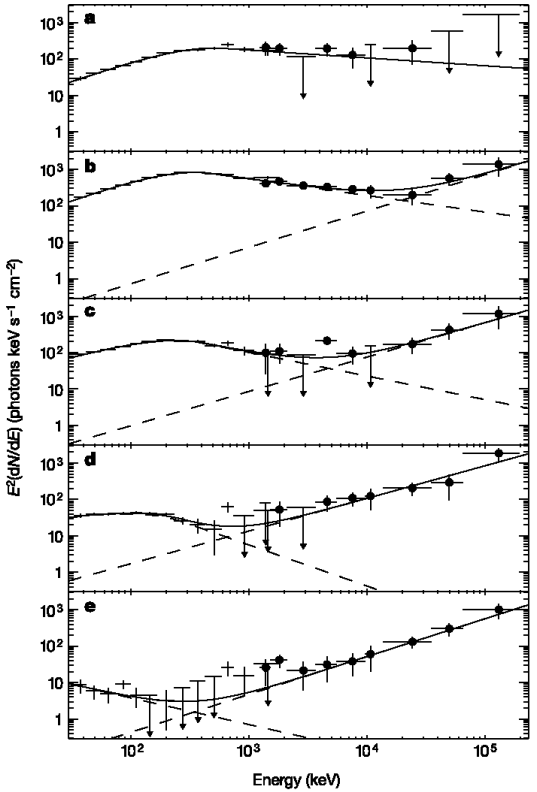


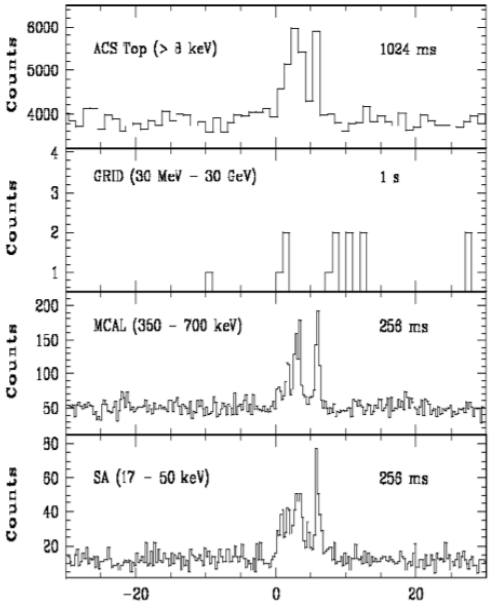
up to >1000sec

Pre-Fermi Era

- **EGRET**
  - GRB940217 (Hurley+94)
    - 18GeV to 90min
  - GRB941017 (Gonzalez+03)
    - Temporary distinct HE
- **AGILE**
  - GRB080514B (Giuliani+08)
    - Long-lived HE

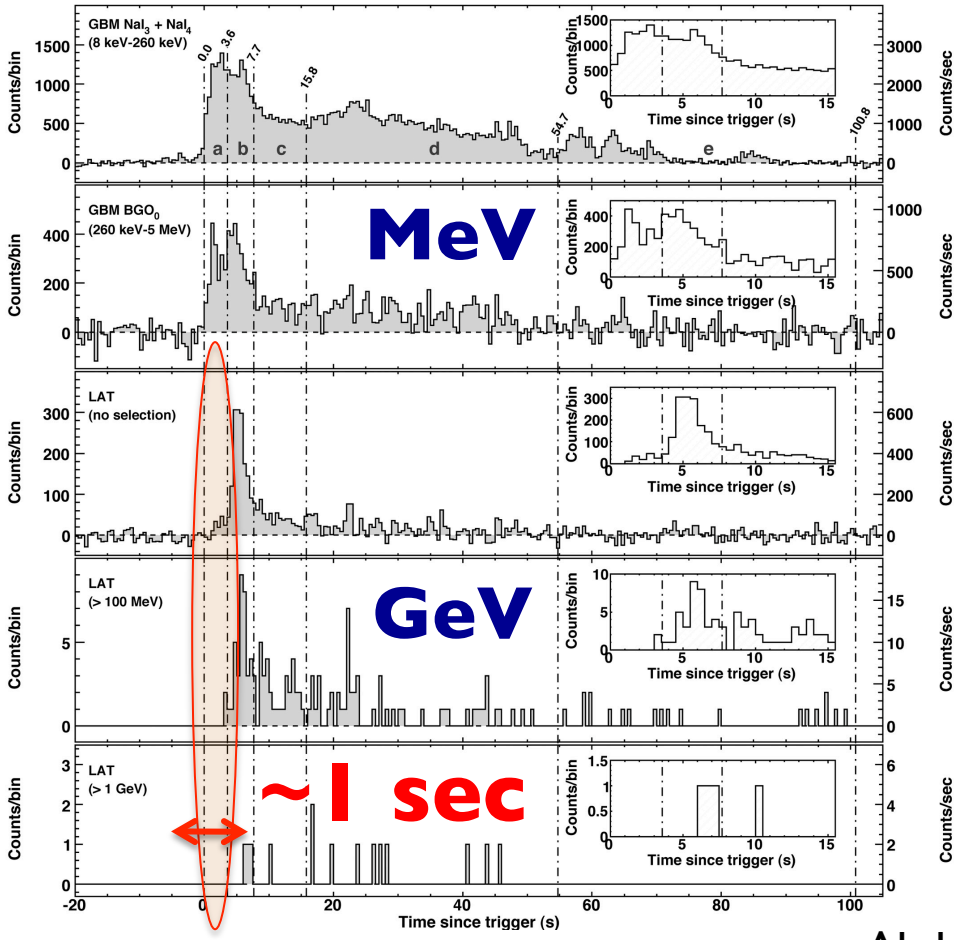




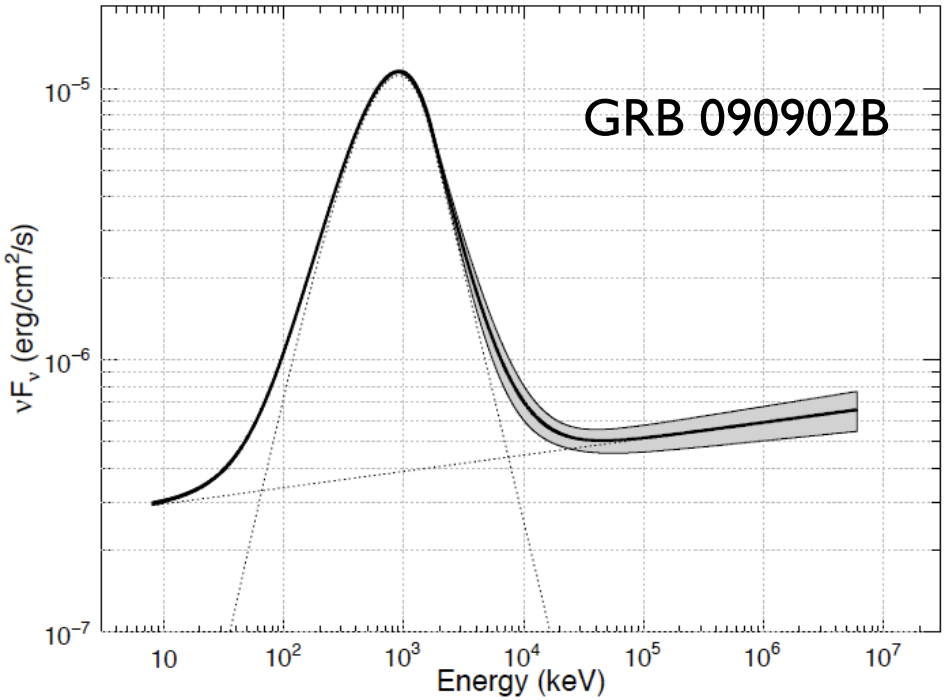


New Features

3. GeV onset delay 4. Photosphere-like



Abdo+ 09

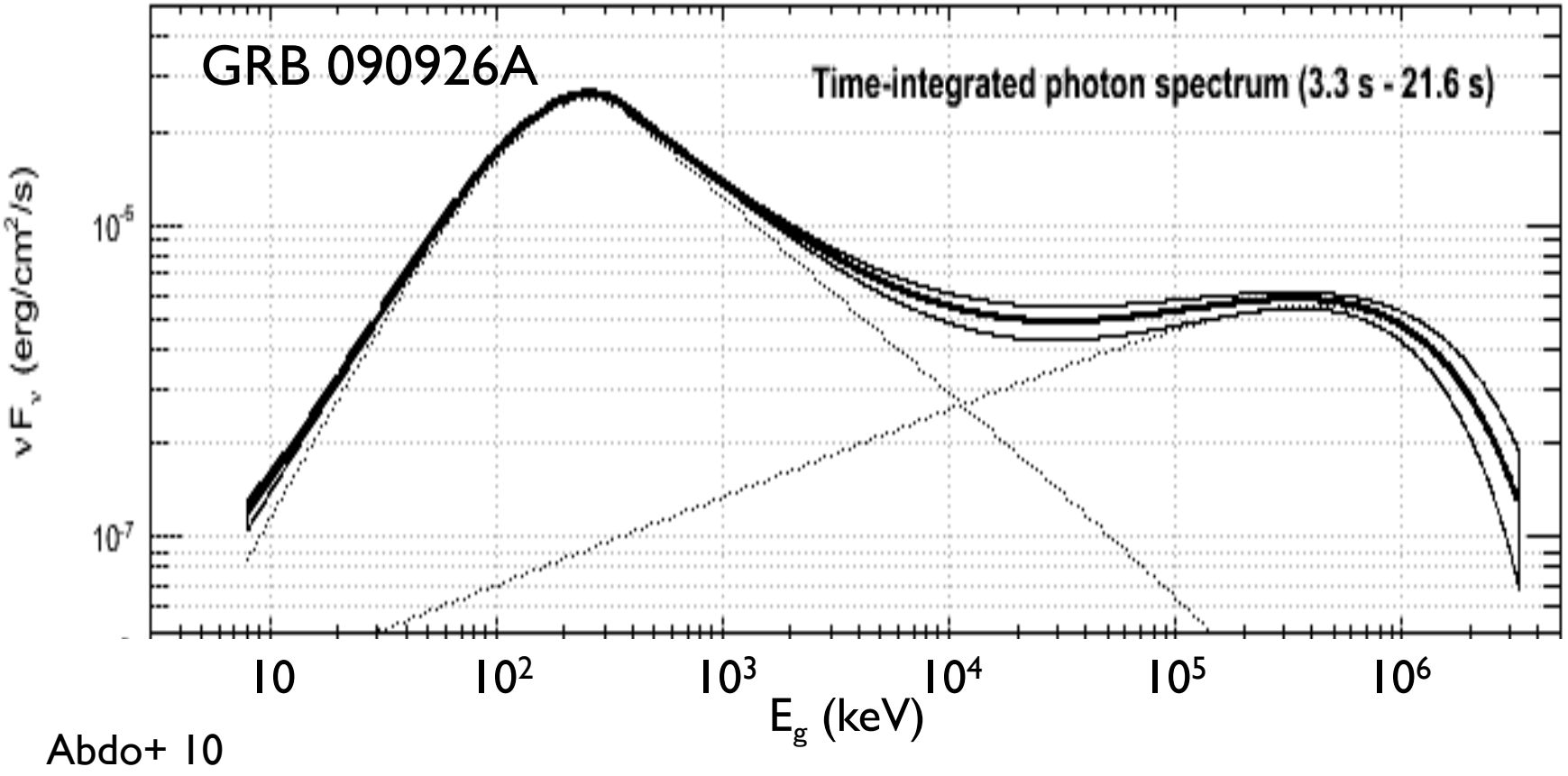


~ Black Body
(But minor)

GRB	Angle from LAT	Duration (or class)	# of events > 100 MeV	# of events > 1 GeV	Delayed HE onset	Long-lived HE emission	Extra spectral comp.	Highest photon Energy	Redshift
080825C	~ 60°	long	~ 10	0	?	✔	X	~ 600 MeV	
080916C	49°	long	145	14	✔	✔	?	~ 13.2 GeV	~ 4.35
081024B	21°	short	~ 10	2	✔	✔	?	3 GeV	
081215A	~ 86°	long	—	—	—	—	--	—	
090217	~ 34°	long	~ 10	0	X	X	X	~ 1 GeV	
090323	~ 55°	long	~ 20	> 0	?	✔	?		3.57
090328	~ 64°	long	~ 20	> 0	?	✔	?		0.736
090510	~ 14°	short	> 150	> 20	✔	✔	✔	~ 31 GeV	0.903
090626	~ 15°	long	~ 20	> 0	?	✔	?		
090902B	51°	long	> 200	> 30	✔	✔	✔	~ 33 GeV	1.822
090926	~ 52°	long	> 150	> 50	✔	✔	✔	~ 20 GeV	2.1062
091003A	~ 13°	long	~ 20	> 0	?	?	?		0.8969
091031	~ 22°	long	~ 20	> 0	?	?	?	~ 1.2 GeV	
100116A	~ 29°	long	~ 10	3	?	?	?	~ 2.2 GeV	©Ohno

~18 LAT+GMB (as of Jul 2010): **No HE cutoff**

Exception

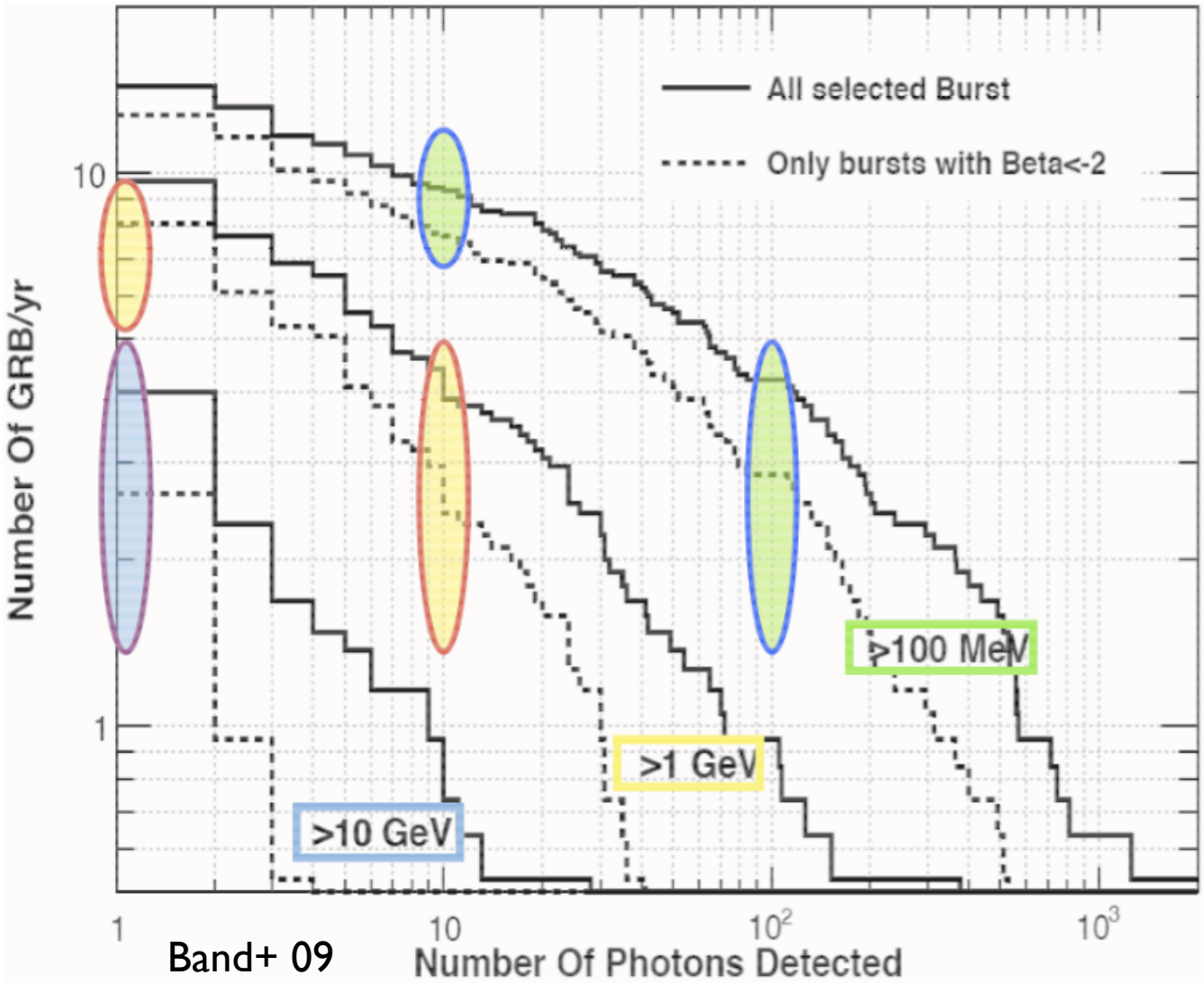


Abdo+ 10

Spectral break @~1.4GeV

G~200-700 if break is due to gg

Implication of LAT Rate



Band+ 09

Comparable to estimates based on extrapolated BATSE GRBs

no HE excess nor deficit (But, D. Kocevski @GRB2010)

Band is OK

Extra com. is rare

MAGIC

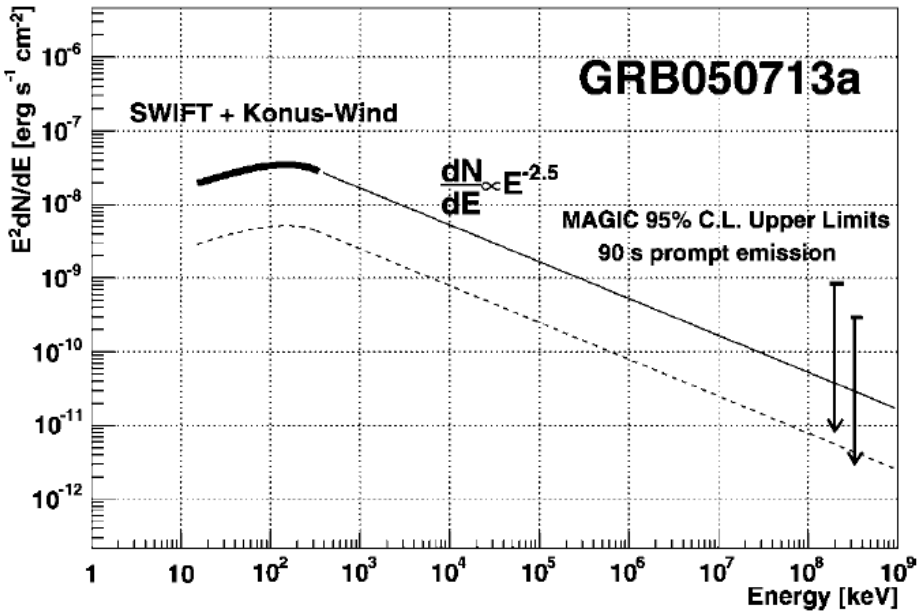


FIG. 4.—Upper limits set by MAGIC on GRB 050713a with no redshift correction applied (see text). The solid line is the flux measured by *Swift* averaged over the burst T_{90}, and the energy break is estimated using Konus/*Wind* data. The dashed line represents the fraction of the flux emitted between $T_0 + 40$ s and $T_0 + 130$ s.

Albert+ 06

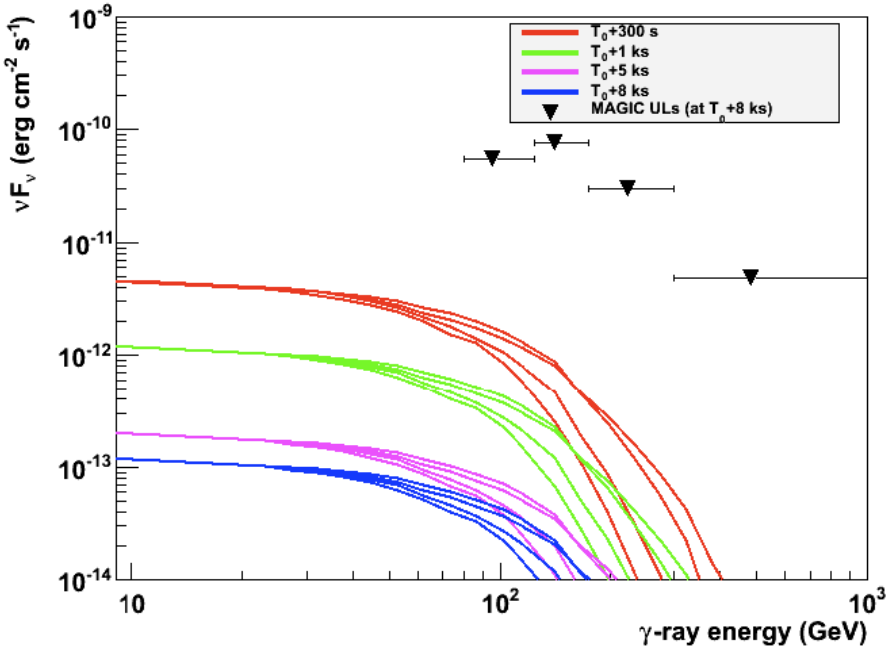


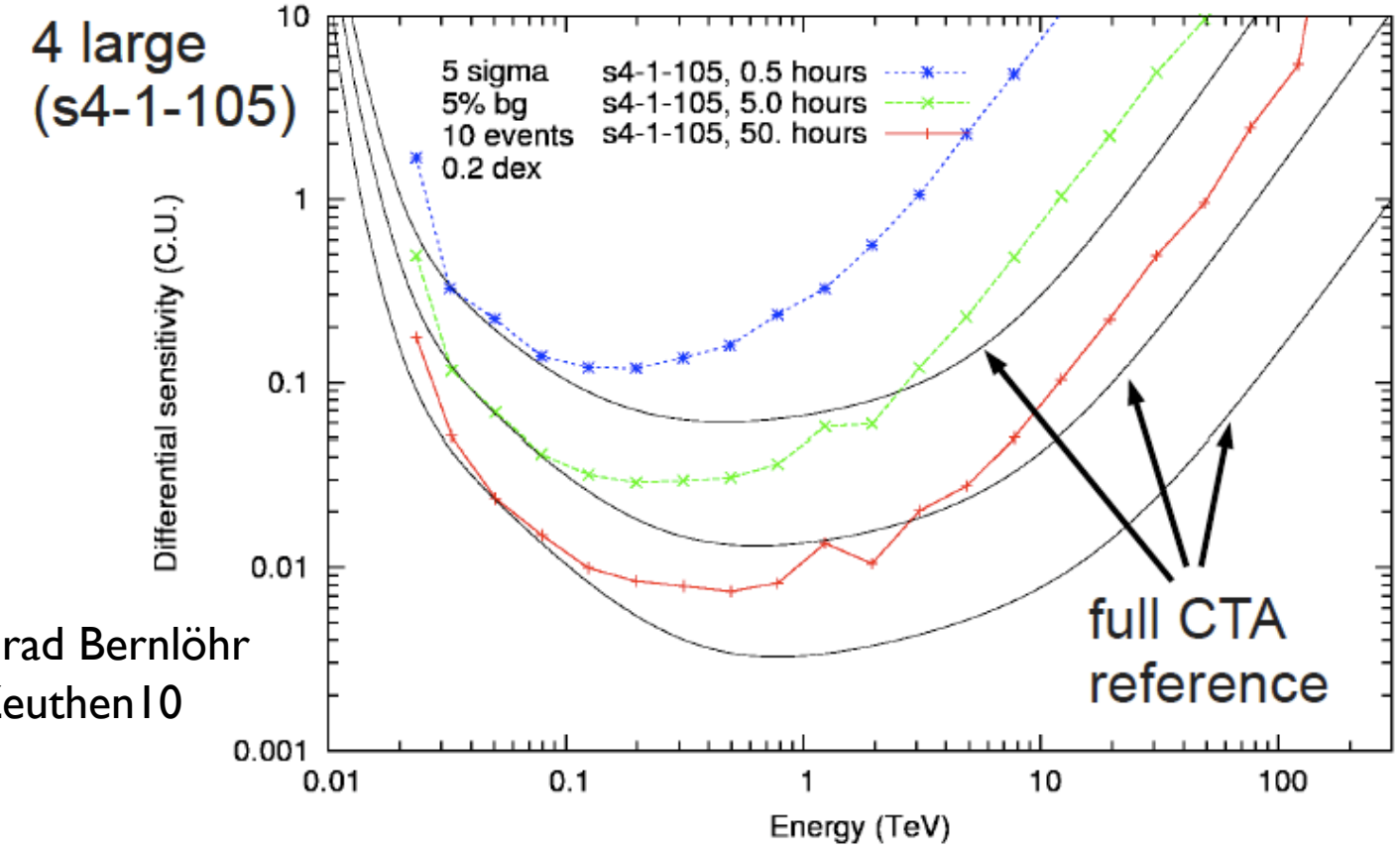
Fig. 1. Predictions at different time delays from the high-energy event for the SSC emission during the afterglow of GRB 080430. Black triangles are 95% CL upper limits derived by MAGIC at various energies. Lines of a same color show the same SSC model, but a different absorption model of the gamma-rays by the EBL. The blue lines correspond to the MAGIC observation window.

Aleksic+ 10

MAGIC is consistent with the Band extrapolation

LST sensitivity

A subset of 4 large telescopes

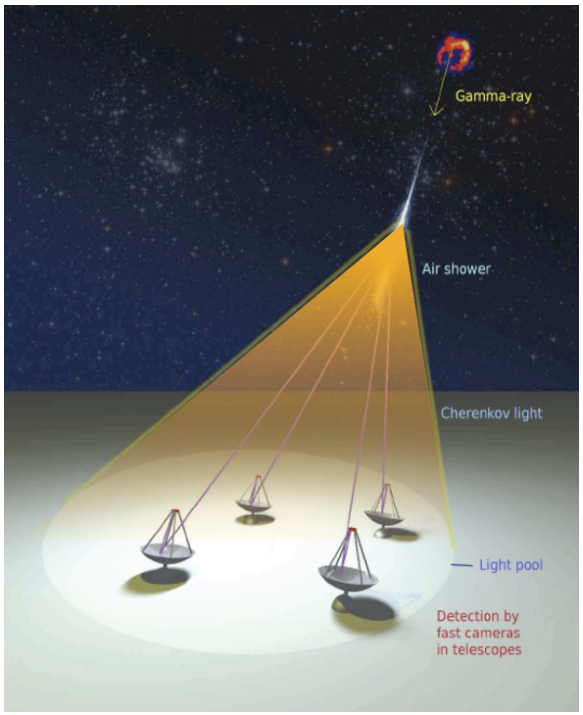


Konrad Bernlöhr
@Zeuthen10

Low energy (<200GeV) sensitivity is determined by LST

More g than Fermi

- Huge Effective Area
  - Fermi ~1m^2 @>10GeV
  - CTA ~10^{4}m^2 @30GeV
- Expected # of g
  - (0.1-1)g x (10^{4}m^2/1m^2)



~ 10^3-10^4 g per GRB!

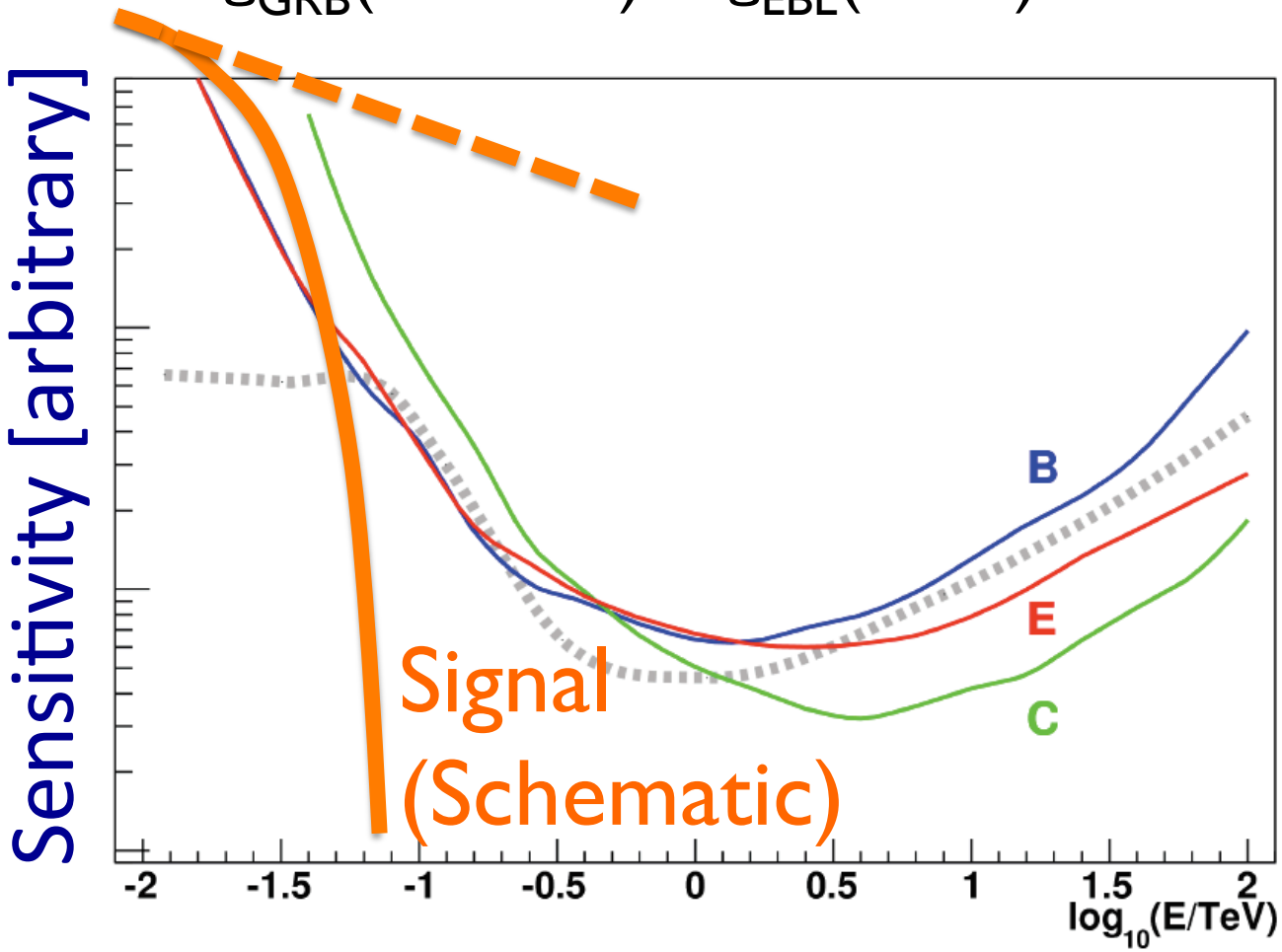
: Great Advantage of CTA

~Background (but >30s CL)

~10kHz data taking is necessary

Energy Threshold

- Extragalactic Background Light + Sensitivity
  - $g_{GRB}(100GeV) + g_{EBL}(10eV) \rightarrow e^+ + e^-$



Low Energy Sensitivity is CRUCIAL

S. Inoue's talk
in this CTA meeting

Rough Event Rate

- Fermi LAT(GeV)/GBM(MeV) ~ 0.1
  - ~1000/yr x (LAT/GBM) ~ 100/yr (Conservative)

1. **GRB in the FOV**

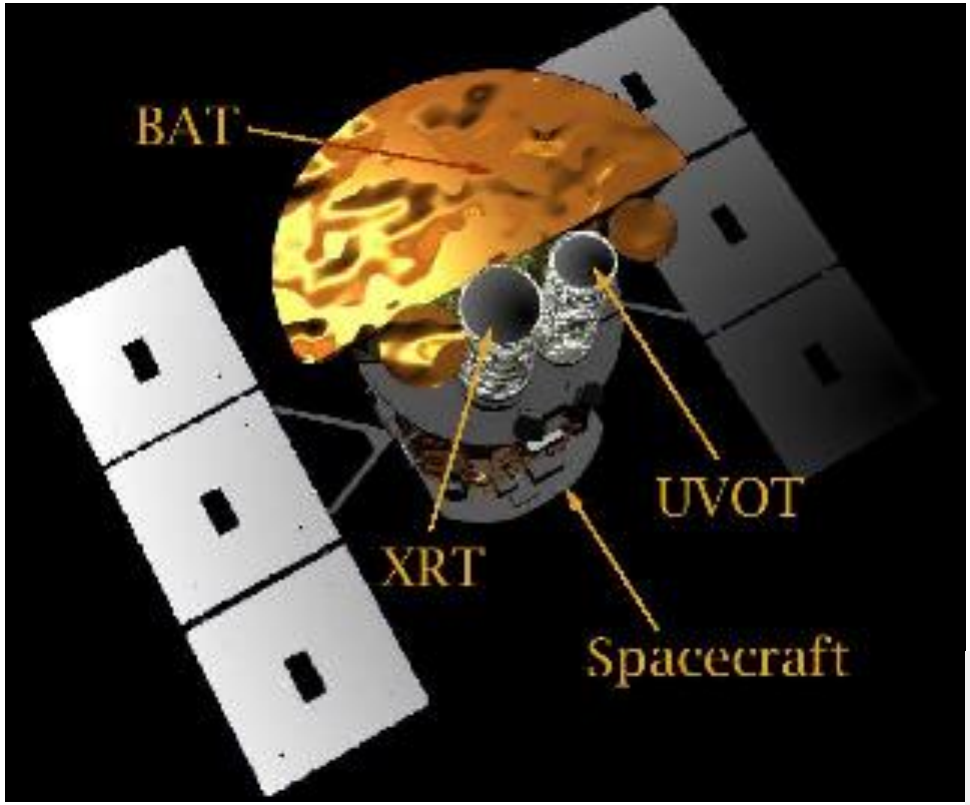
   ~100/yr x (Duty 0.1) x (FOV 5deg^2) ~ **0.03/yr**

2. **Follow-up**
   - Extended GeV emission lasts for >1000 sec
   - ~20 sec slews are enough

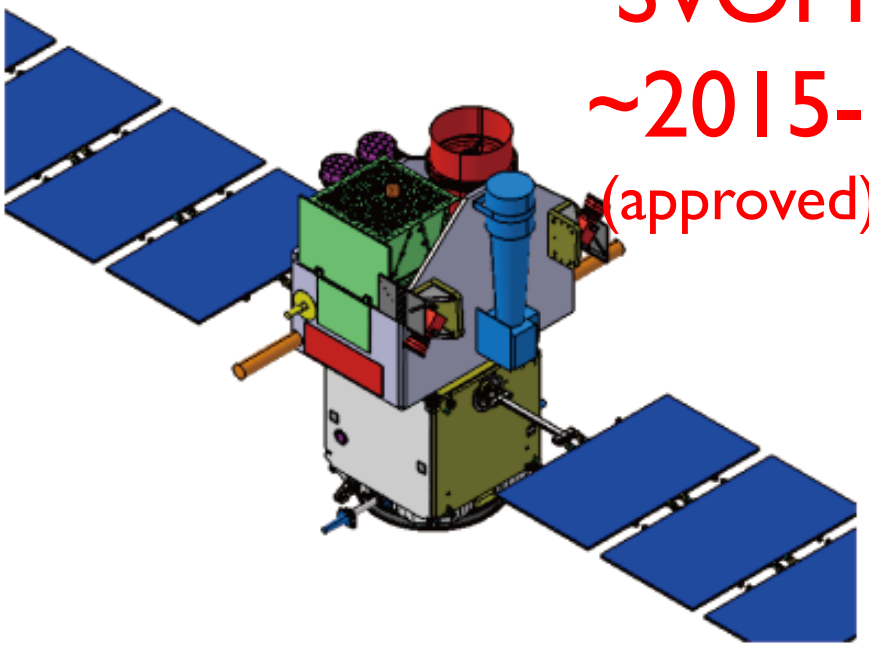
   ~100/yr x (Duty 0.1) x (Zenith 0.1) ~ **1/yr**

GRB subtask (J. Kakuwa) is refining the estimate

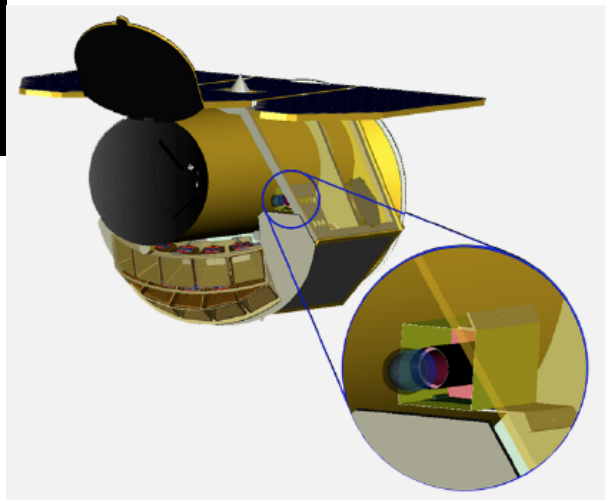
Alert for Follow-up



Swift
up to ~2015?



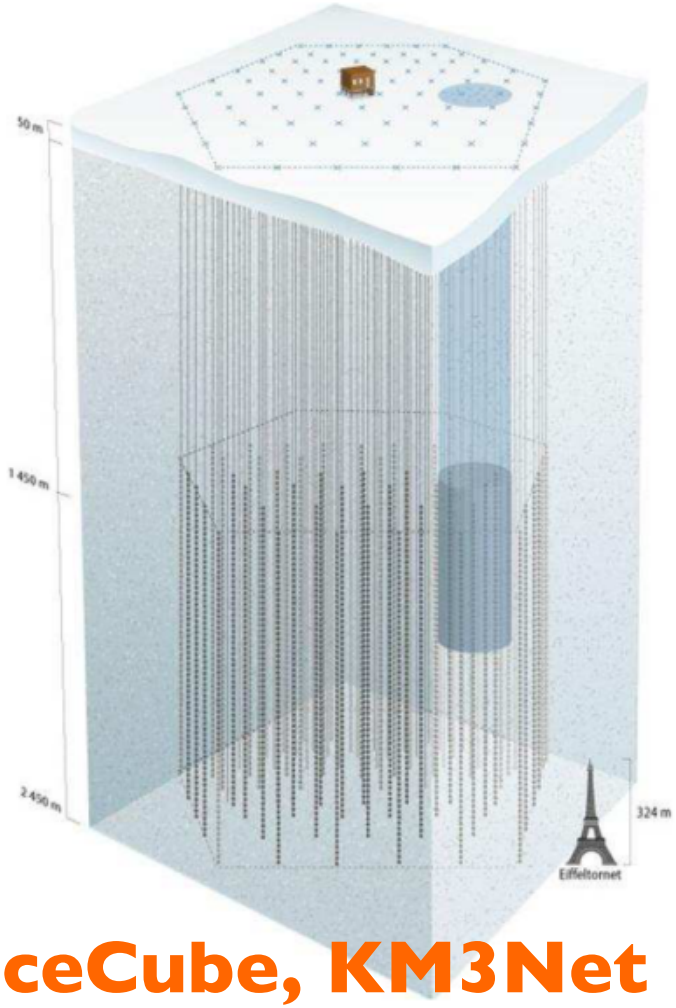
SVOM
~2015-?
(approved)



JANUS
~2016-?

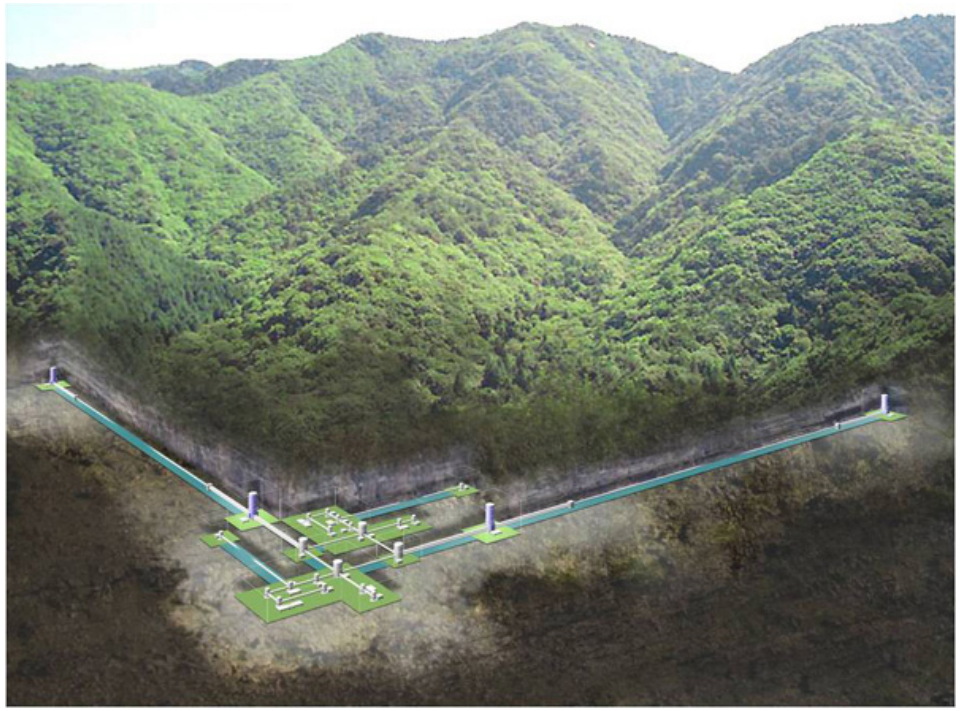
Upcoming New Windows

High Energy n



IceCube, KM3Net

Gravitational Wave



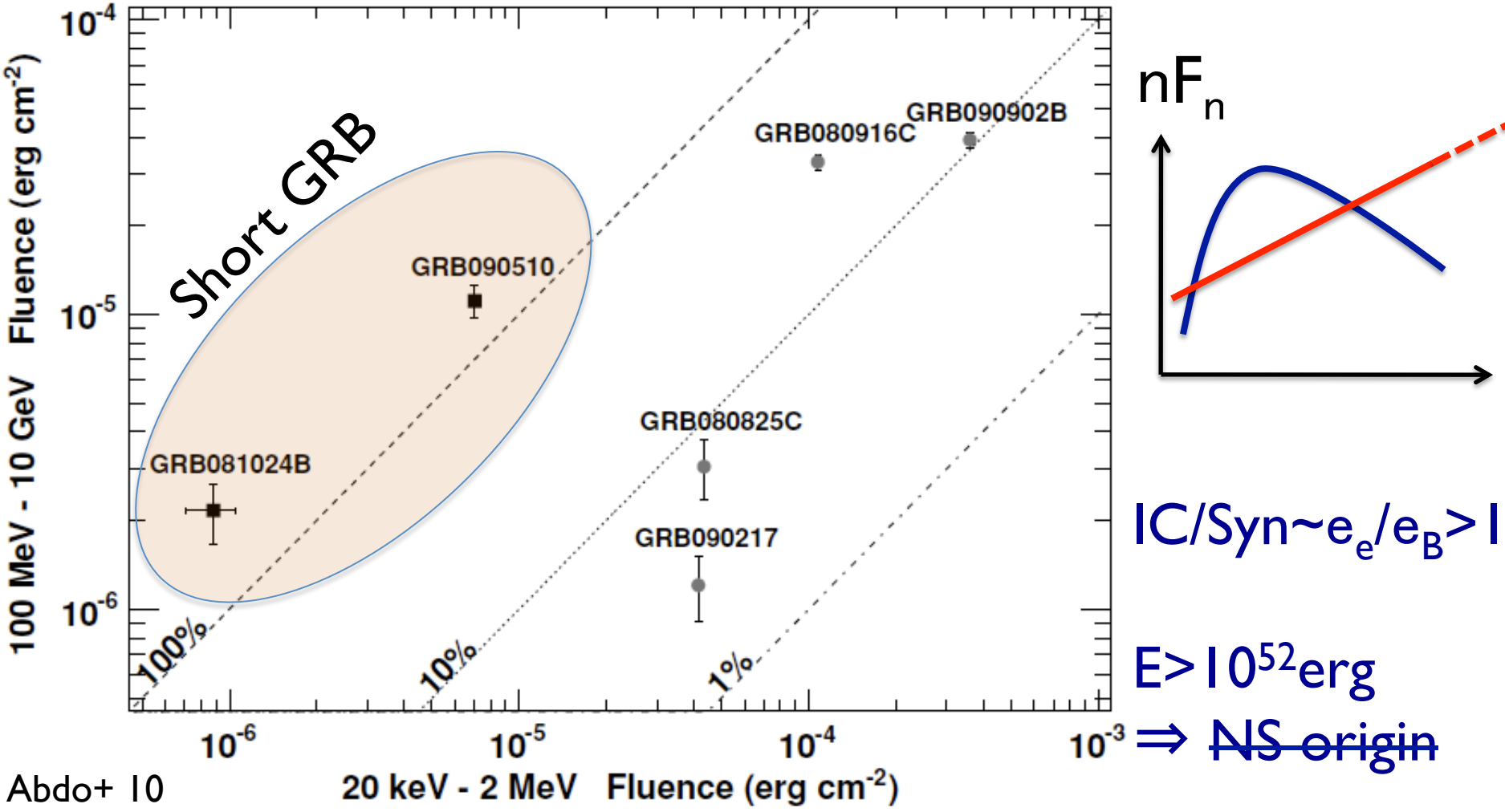
LIGO, Virgo, GEO, LCGT, AIGO, LISA, DECIGO/BBO

GRB Science with CTA

1. TeV calorimetry
2. Lower limit on the bulk Lorentz factor
3. Emission mechanism
   - Site? Leptonic(syn?/IC?)/Hadronic?
4. Cosmology
   - Probing EBL, B
5. Lorentz Invariance Violation (w/ CTA only)
6. …

1. TeV Calorimetry

Energetics may be determined by TeV g



Abdo+ 10

IC/Syn~e_e/e_B>1

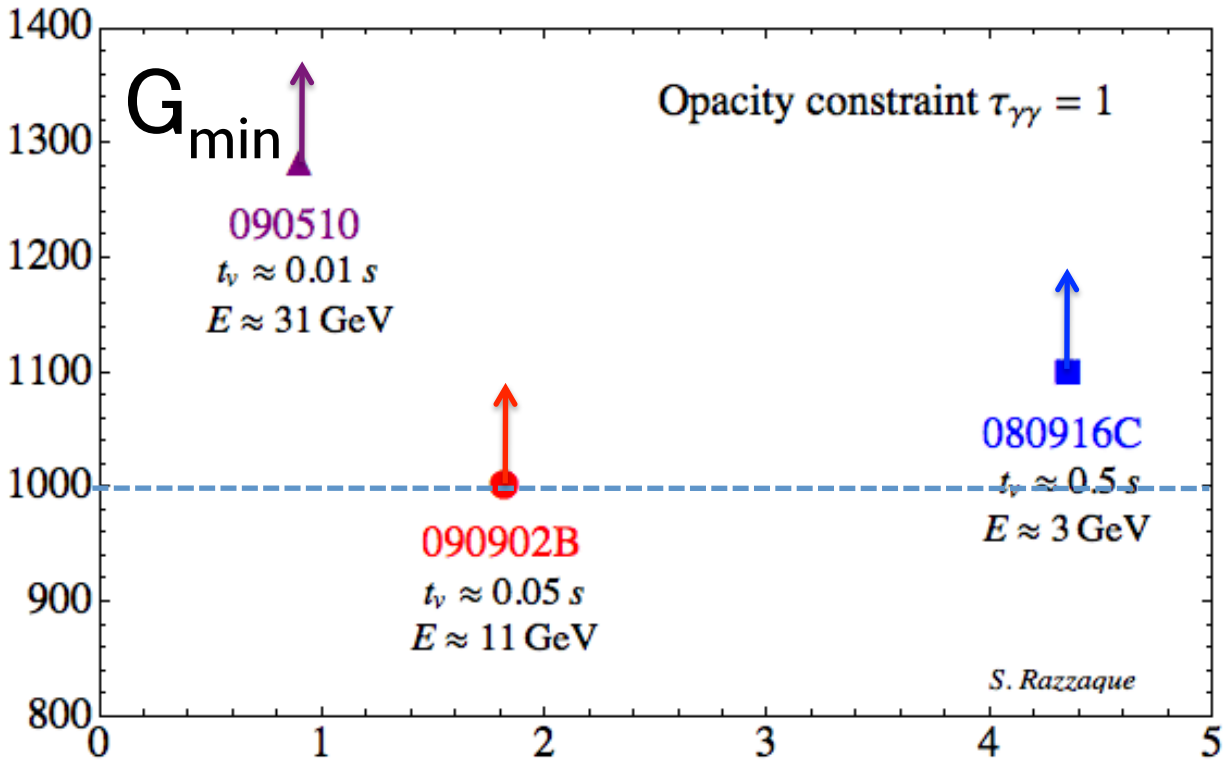
E>10^{52}erg

⇒ ~~NS origin~~

2. Lower limit on bulk G

- **$gg \rightarrow e^+e^-$** (e_{th}~MeV)
  - R~cDt ⇒ t~$s_T N_g / 4pR^2 \gg 1$ (g-ray cannot escape)
- **Relativistic**
  - R~G^2cDt
  - Blueshift
  - t~G^{2b-2}~G^{-6}
- **$G > 10^3$!**

v>0.999999×c



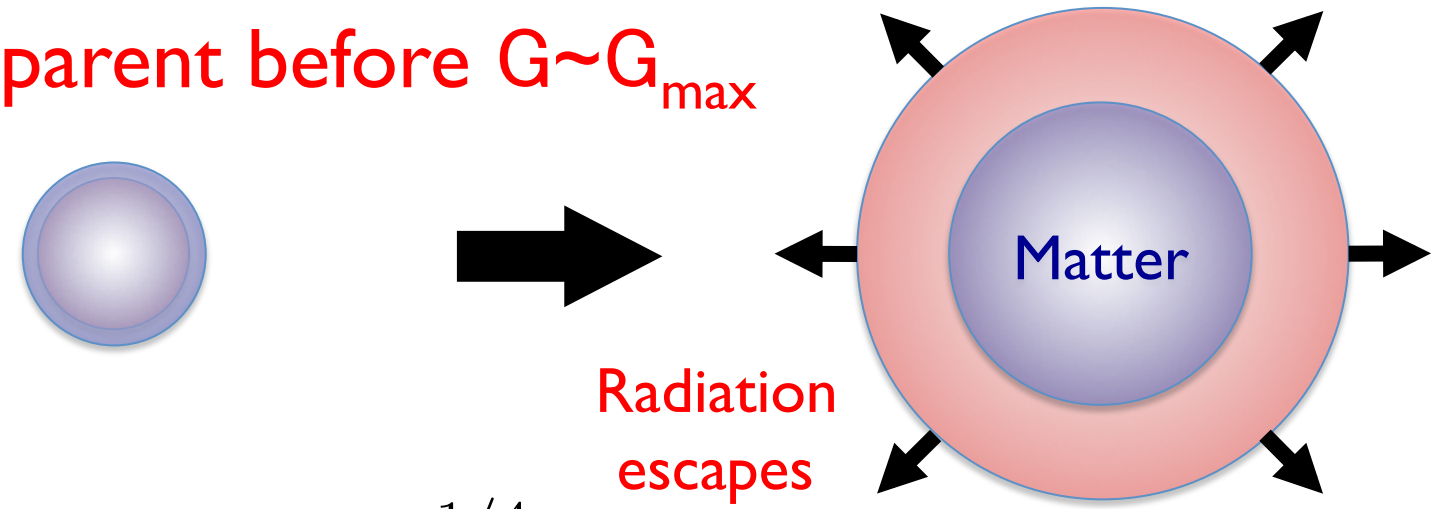
But see also Li 08, Granot+08, Bosnjak+09, Aoi+KI 10, Zou+10

Conventional G_{max}

- Fireball expands by radiation pressure
- In principle, G_{max} ~ Energy / Mass
- Mass ↓ G_{max} ↑ … However,

⇒ Transparent before $G \sim G_{max}$

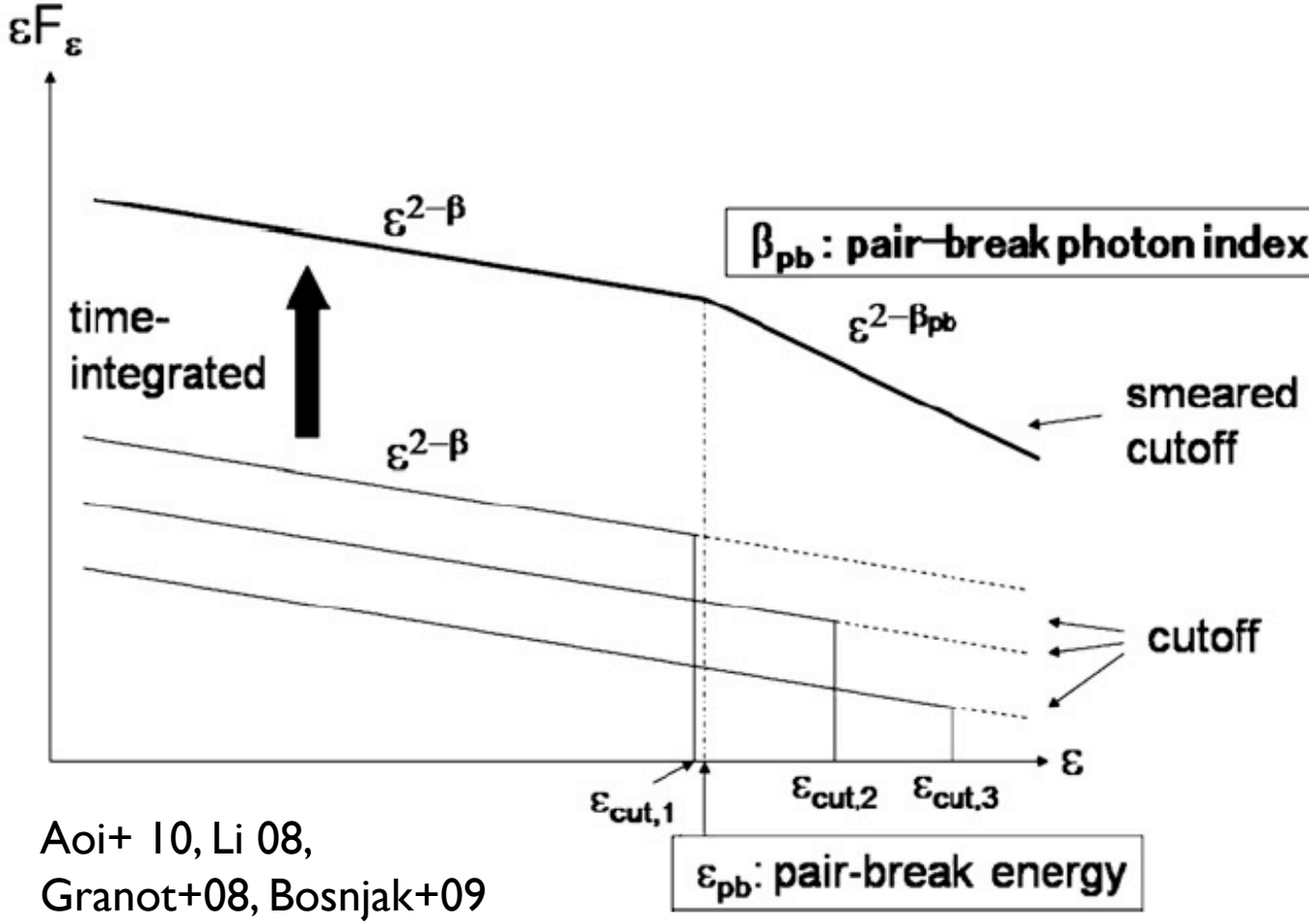
Paczynski 86
Goodman 86
Shemi & Piran 90
Meszaros & Rees



$$\Gamma_{\max} = \left(\frac{L\sigma_T}{4\pi m_p c^3 r_0} \right)^{1/4} \sim 10^3 L_{53}^{1/4} r_{0,7}^{-1/4}$$

$gg \rightarrow e^+e^-$ Annhilation Break

- Most likely Break (not Cutoff)

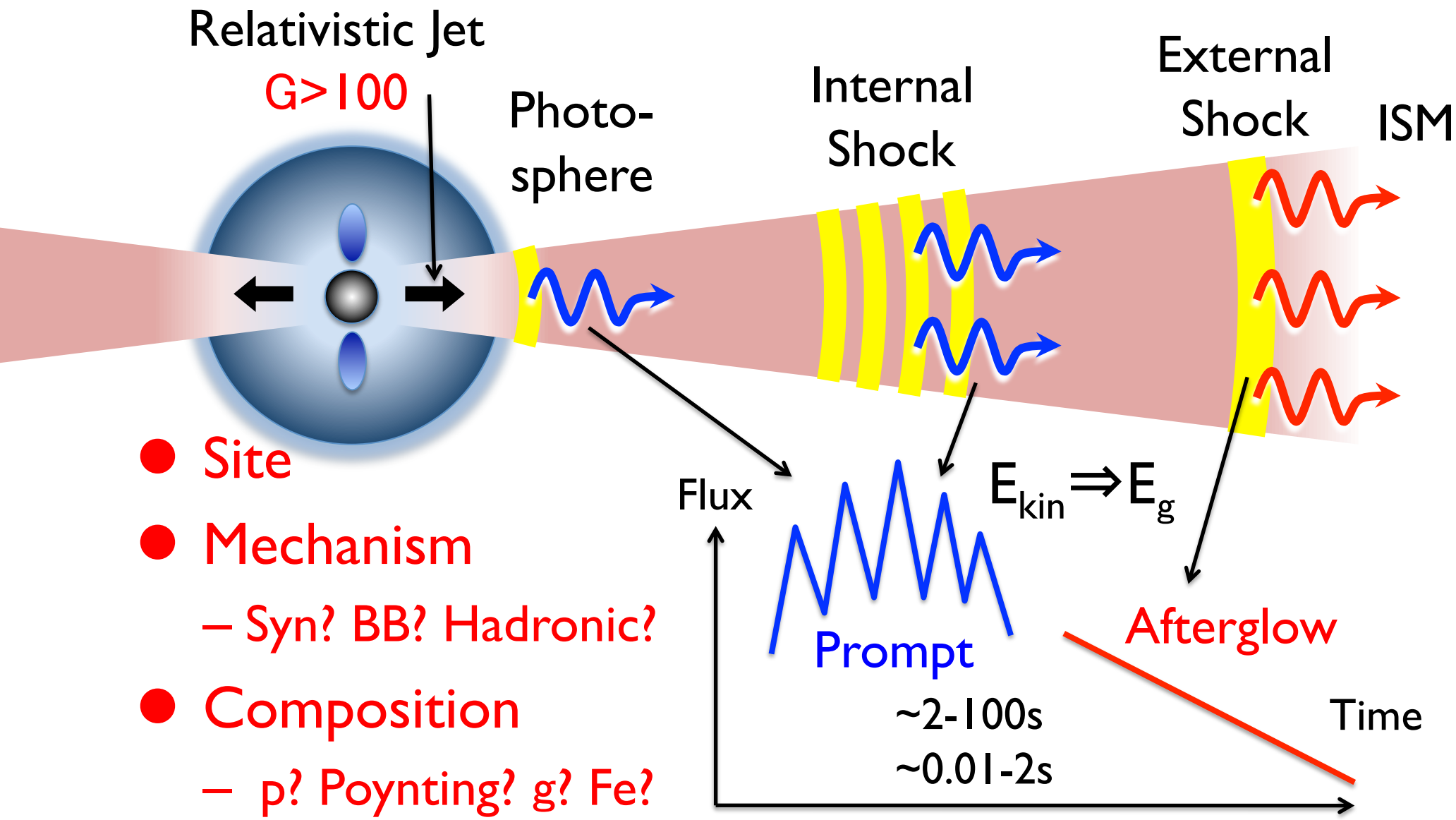


Aoi+ 10, Li 08,
Granot+08, Bosnjak+09

Time/Space integration smears the cutoff

High-statistical data or Time-resolved spectrum is important

3. Emission Mechanism



- Site
- Mechanism
  - Syn? BB? Hadronic?
- Composition
  - p? Poynting? g? Fe?

GeV Models

- External shock – long-lived, but not variable
  - Synchrotron (adiabatic/radiative shock)
  - SSC
  - External Compton of prompt g
- Internal shock
  - Synchrotron (peak at MeV) – not extra comp.
  - SSC – no low energy excess
  - Hadronic – proton luminosity is too large
  - External Compton of cocoon/photospheric g – May need fine tuning
  - Synchrotron (peak at GeV-TeV) w/ High G

Possible TeV Features

- $gg \rightarrow e^+e^-$ annhilation break

$$\nu_{\gamma\gamma} \sim 20\ \mathrm{GeV} \left(\frac{\Gamma}{10^3}\right)^{\frac{2+2\beta}{\beta-1}}$$

- IC component
- Max. Synchrotron Energy ($t_{acc}=t_{cool}$)

$$\nu_{\max}^{cool} = \frac{m_e c^2}{\alpha}\Gamma \sim 500\ \mathrm{GeV} \left(\frac{\Gamma}{10^4}\right)$$

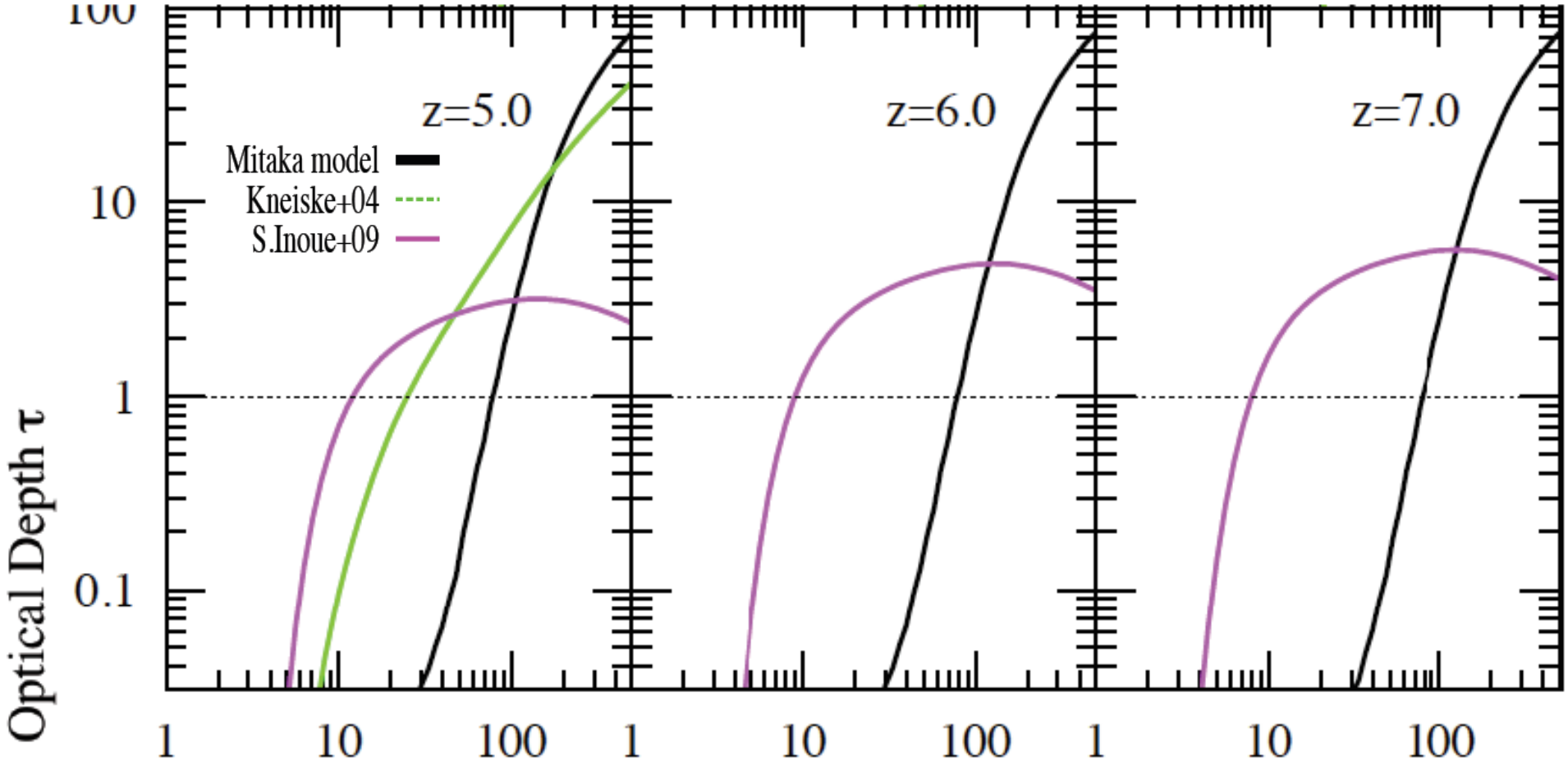
- Max. Synchrotron Energy ($t_{acc}=t_{dyn}$)

$$\nu_{\max}^{dyn} \sim 1\ \mathrm{GeV} \left(\frac{\Gamma}{6\times10^4}\right)^{-6}$$

How to separate these from EBL abs.?

EBL

Y. Inoue+ 10



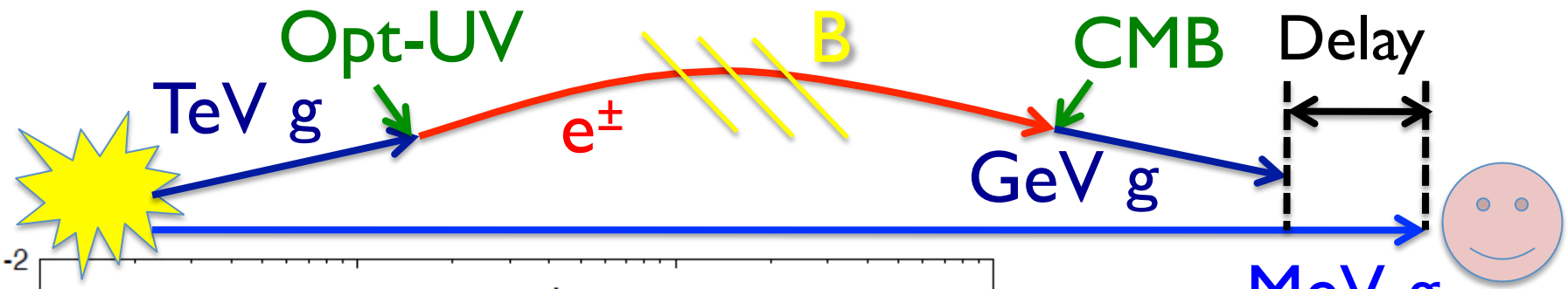
EBL has a large uncertainty

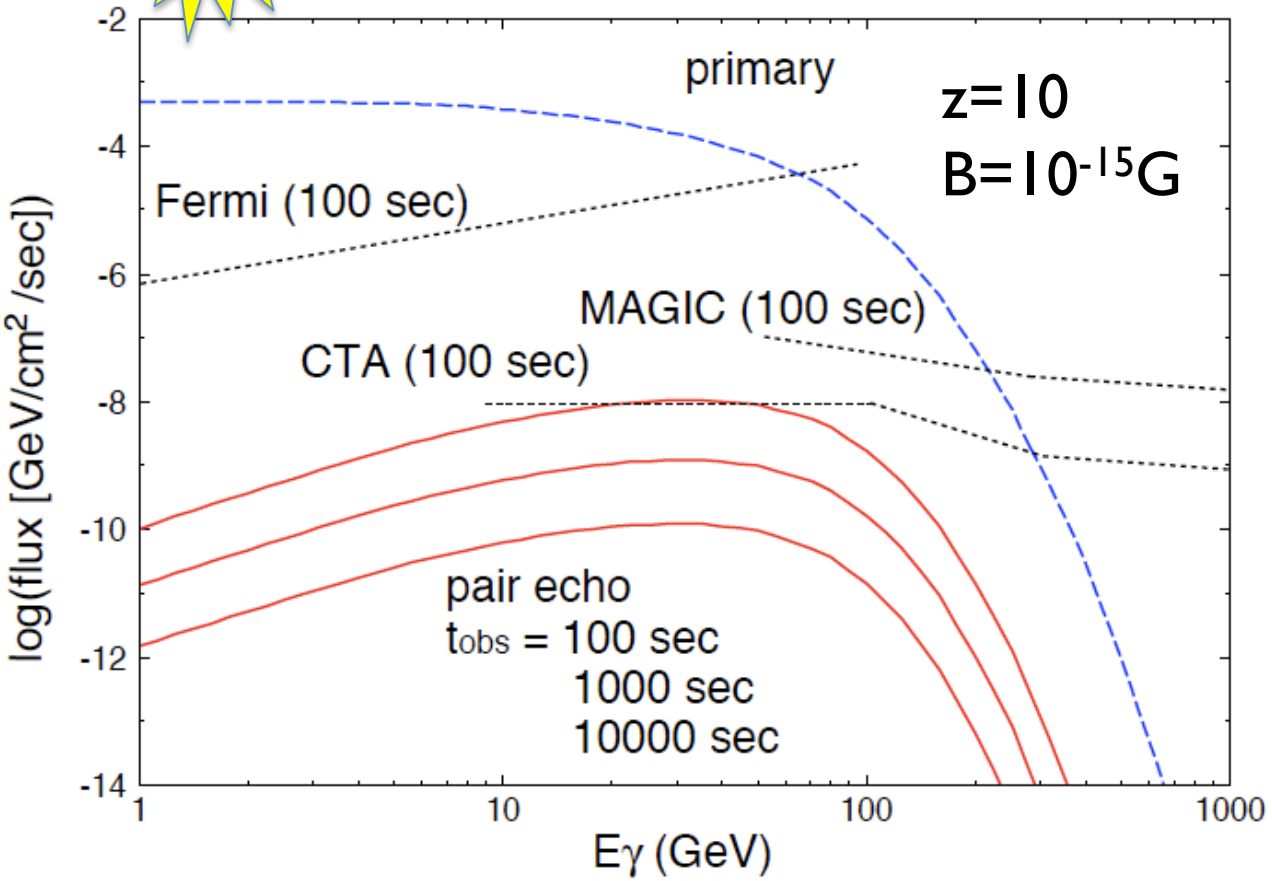
Probe of early star/galaxy formation

GRB 090423

@ z~8.2

Intergalactic B





Delay time
⇒ B

But, could be contaminated by afterglow

Proga 95
Takahashi+ 10

LIV

Summary

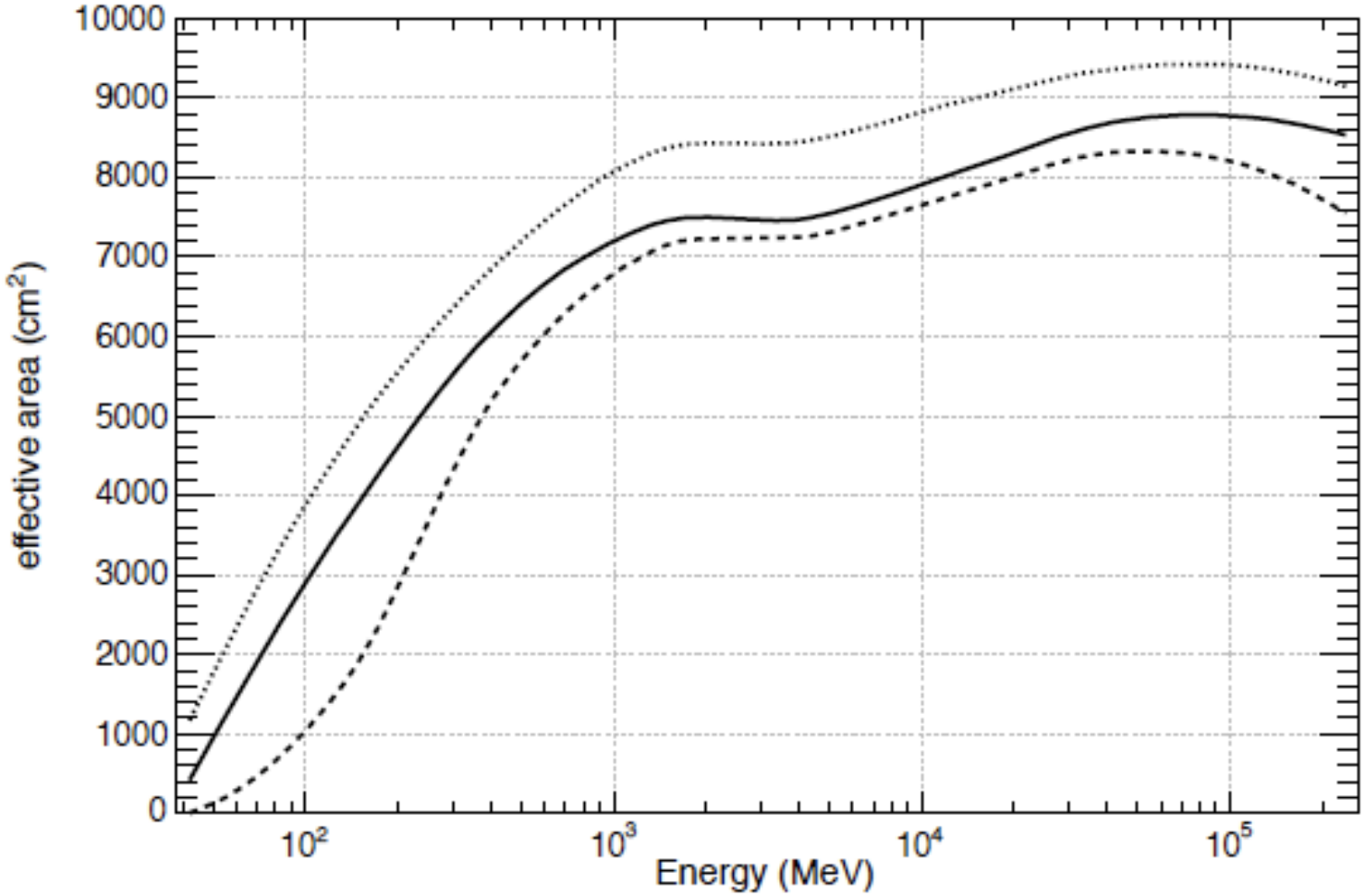


Fig. 2. Effective area versus energy at normal incidence for Diffuse (dashed), Source (solid) and Transient (dotted) P6_V3 event classes.

Rondo+ arXiv:0907.0626

Table 1. The GRBs co-detected by *Fermi* LAT and GBM since *Fermi* science operation and until May, 2010

Zhang+ 10

GRB	z	dur. [sec]	E_p [keV]	$E_{\gamma,\rm iso}$ [erg]	Fluence ($1-10^4$ keV)	Spectral Type	Onset Delay	$E_{\rm max}$
080825C	-	22	192 ± 15	-	$4.84^{+0.59}_{-0.57} \times 10^{-5}$	BAND	Y	~ 600 MeV
080916C	4.35	66	1443^{+433}_{-303}	$5.7^{+0.54}_{-0.41} \times 10^{54}$	$1.55^{+0.15}_{-0.11} \times 10^{-4}$	BAND	Y	~ 13.2 GeV
081024B	-	0.8	1258^{+2405}_{-522}	-	$(1,61 \pm 3.8) \times 10^{-6}$	BAND	Y	~ 3 GeV
081215A	-	7.7	1014^{+140}_{-123}	-	$8.74^{+1.21}_{-0.99} \times 10^{-5}$	BAND	-	-
090217	-	32.8	552^{+85}_{-71}	-	$4.48^{+0.69}_{-0.56} \times 10^{-5}$	BAND	N	~ 1 GeV
090323	3.57	150	812^{+181}_{-143}	$> 2.89^{+6.56}_{-0.69} \times 10^{54}$	$> 1.07^{+0.24}_{-0.26} \times 10^{-5}$	BAND	N	~ 1 GeV
090328	0.736	80	756^{+85}_{-72}	$1.02^{+0.087}_{-0.083} \times 10^{53}$	$7.14^{+0.61}_{-0.58} \times 10^{-5}$	BAND	?	> 100 MeV
090510	0.903	0.3	6010^{+2524}_{-1690}	$4.47^{+4.06}_{-3.77} \times 10^{52}$	$2.06^{+1.88}_{-1.74} \times 10^{-5}$	CPL+PL	Y	~ 31 GeV
090626	-	70	362^{+47}_{-41}	-	$7.81^{+0.44}_{-0.38} \times 10^{-5}$	BAND	?	~ 30 GeV
090902B	1.822	21	207 ± 6 [BB]	$(1.77 \pm 0.01) \times 10^{52}$	$(2.10 \pm 0.02) \pm 10^{-4}$	BB+PL	Y	$33.4^{+2.7}_{-3.5}$ GeV
090926A	2.1062	~ 20	412 ± 20	$2.10^{+0.09}_{-0.08} \times 10^{54}$	$1.93^{+0.08}_{-0.07} \times 10^{-4}$	BAND	Y	$\sim$20 GeV
091003	0.8969	21.1	409^{+34}_{-31}	$7.85^{+0.73}_{-0.57} \times 10^{52}$	$3.68^{+0.34}_{-0.27} \times 10^{-5}$	BAND	N	> 150 MeV
091031	-	~ 40	567^{+197}_{-135}	-	$3.17^{+0.64}_{-0.51} \times 10^{-5}$	BAND	N	1.2 GeV
100116A	-	~ 110	1463^{+163}_{-122}	-	$7.34^{+1.42}_{-1.26} \times 10^{-5}$	BAND	N	~ 2.2 GeV
100225A	-	13 ± 3	540^{+381}_{-204}	-	$1.21^{+1.07}_{-0.57} \times 10^{-5}$	BAND	Y	~ 300 MeV
100325A	-	8.3 ± 1.9	198^{+44}_{-37}	-	$6.15^{+2.85}_{-1.81} \times 10^{-6}$	BAND	N	~ 800 MeV
100414A	1.368	26.4 ± 1.6	520^{+42}_{-39}	$5.88^{+0.69}_{-0.65} \times 10^{53}$	$1.20^{+0.12}_{-0.10} \times 10^{-5}$	BAND	N	~ 2.6 GeV

Note. — References: (1) GRB080825C: z, T_{90} – van der Horst & Connaughton (2008); (2) GRB090916C: z – Greiner et al. (2009), T_{90} – Goldstein & van der Horst (2008), $E_{\gamma,\rm iso}$ – Abdo et al. (2009a); (3) GRB081024B: T_{90} – Abdo et al. (2010); (4) GRB081215A
:009); (7) GRB090902B
ara et al. (2009b); (10)

~18 LAT+GMB GRBs (as of Jul 2010)

No HE cutoff within the sensitivity

090902B

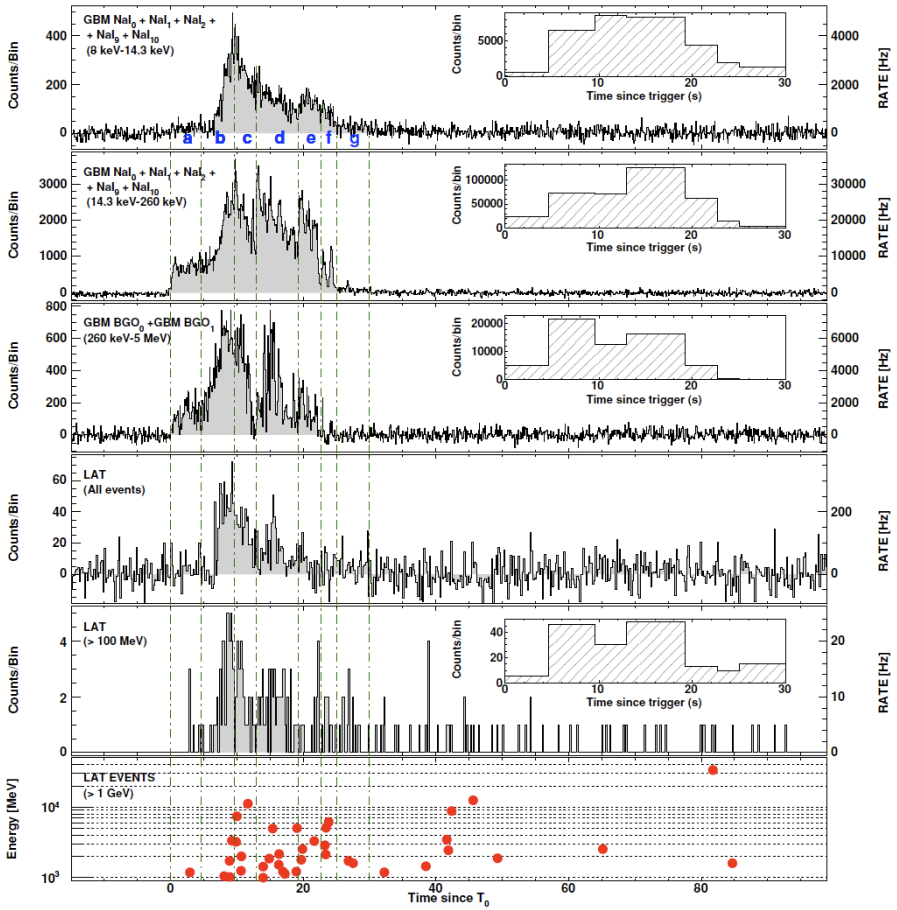


Figure 1. GBM and LAT light curves for the gamma-ray emission of GRB 090902B. The data from the GBM NaI detectors were divided into soft (8–14.3 keV) and hard (14.3–260 keV) bands in order to reveal any obvious similarities between the light curve at the lowest energies and that of the LAT data. The fourth panel shows all LAT events that pass the on-board gamma filter, while the fifth and sixth panels show data for the "transient" class event selection for energies >100 MeV and >1 GeV, respectively. The vertical lines indicate the boundaries of the intervals used for the time-resolved spectral analysis. Those time boundaries are at T_0 + (0, 4.6, 9.6, 13.0, 19.2, 22.7, 25.0, 30.0) s. The insets show the counts for the corresponding data set binned using these intervals in order to illustrate the relative numbers of counts considered in each spectral fit.

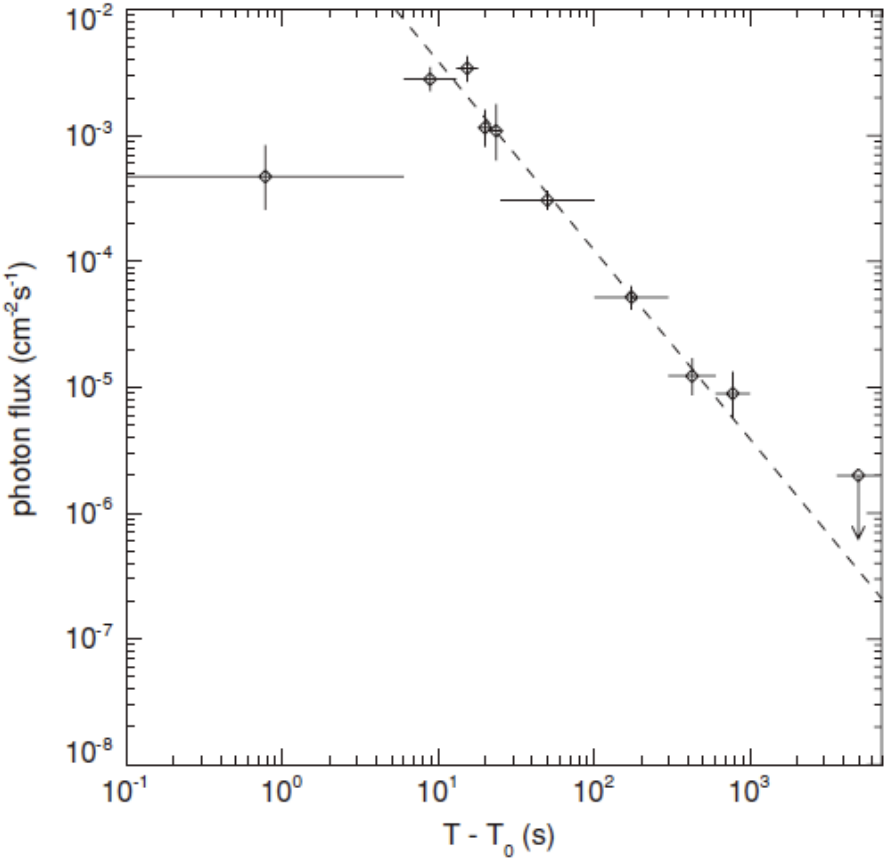


Figure 2. Light curve of GRB 090902B for energies 0.1–300 GeV from unbinned likelihood fits to the LAT data. After the prompt phase, extended or afterglow emission consistent with a temporal profile $\propto t^{-1.5}$ (dashed line) lasts until $\sim T_0 + 1000$ s. The upper limit at times $> T_0 + 3600$ s was derived from the data collected after the source emerged from occultation by the Earth.

Abdo+ 09