VHE γ Emission from GRB

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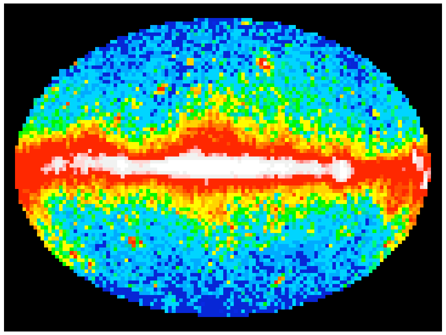
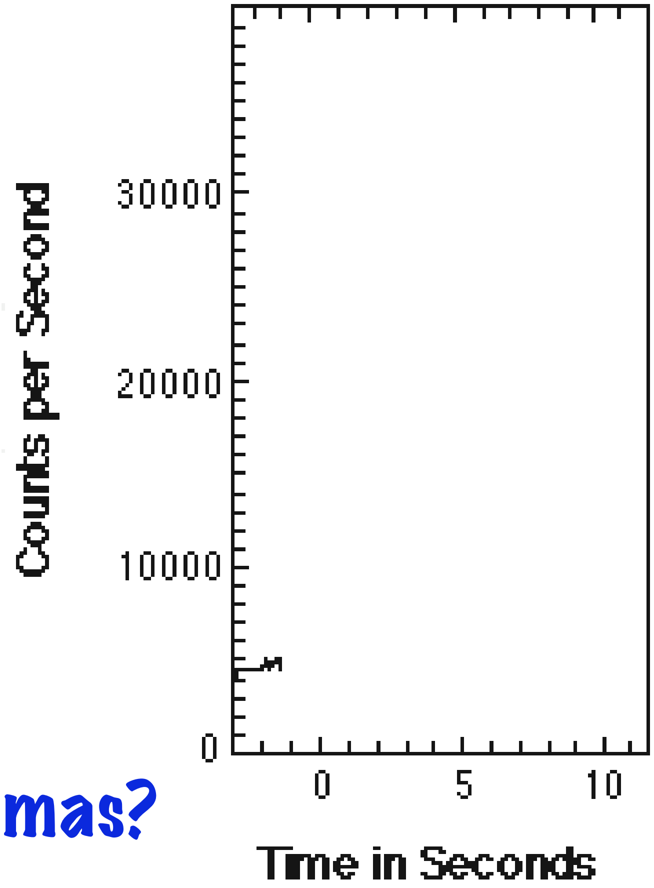
GRB @ MeV photon energies

For seconds, they dominate the γ-ray brightness of the *entire* Universe ... may also imply ***CR luminous***

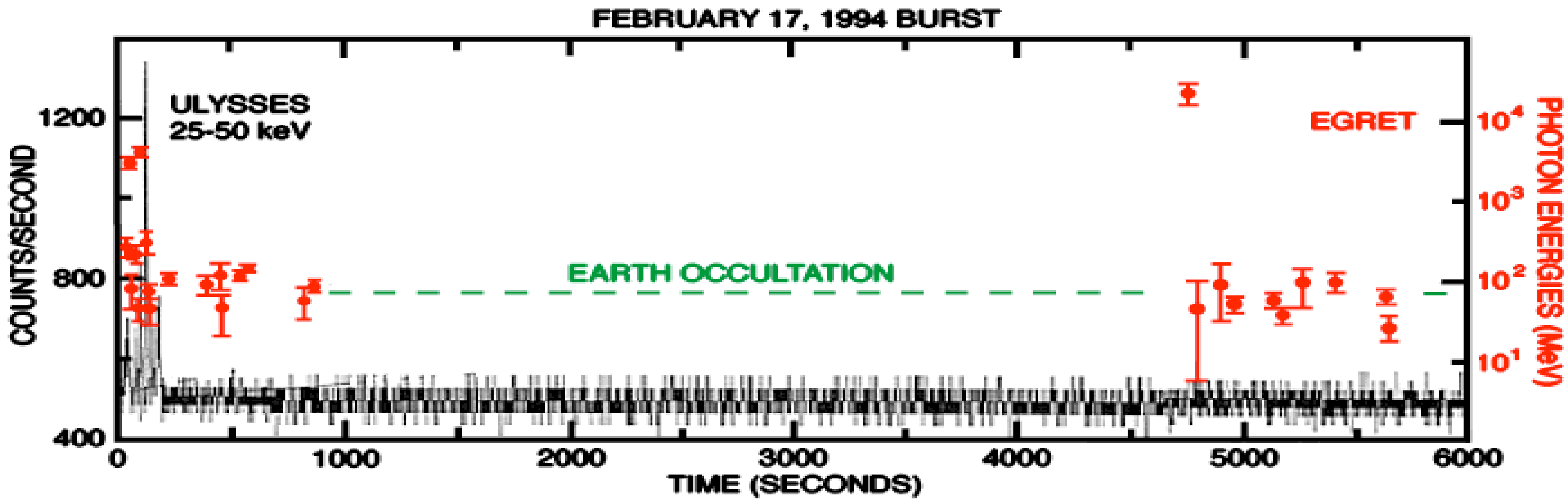


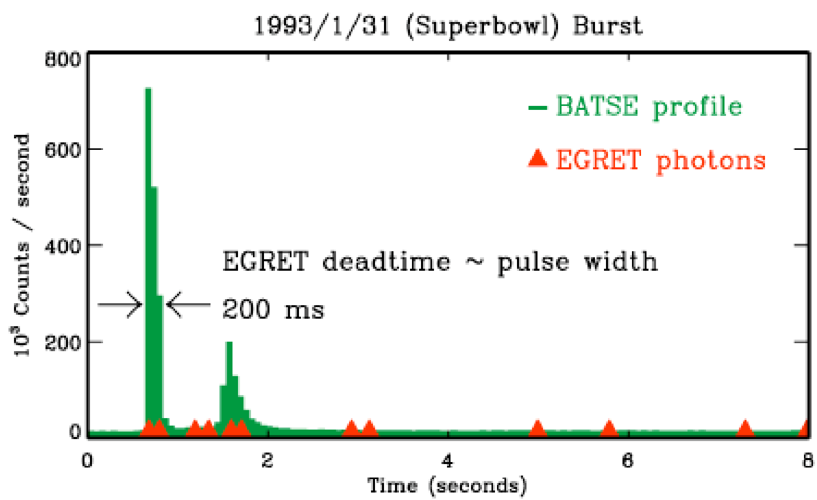


So, what about GeV-TeV gammas?

(T. DeYoung)

Two EGRET (~10 GeV) Bursts





- >10 GeV photons can last for > 1 hr,

  start w. MeV trigger
- Considerable energy

  at 100 MeV-10 GeV

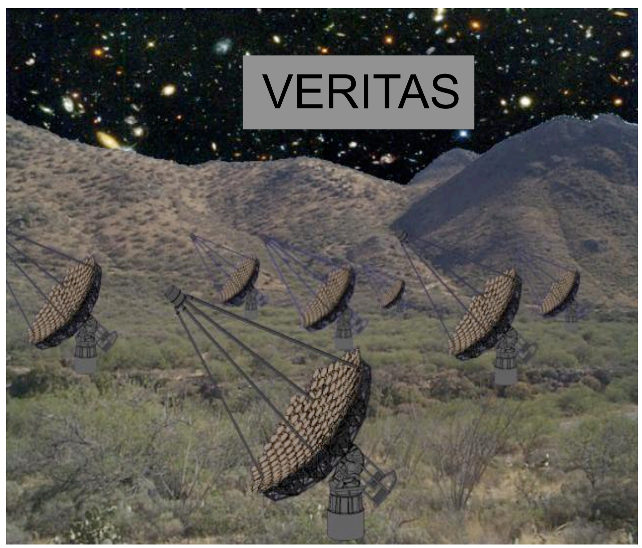
GeV-TeV γ experiments underway

Cherenkov Telescopes

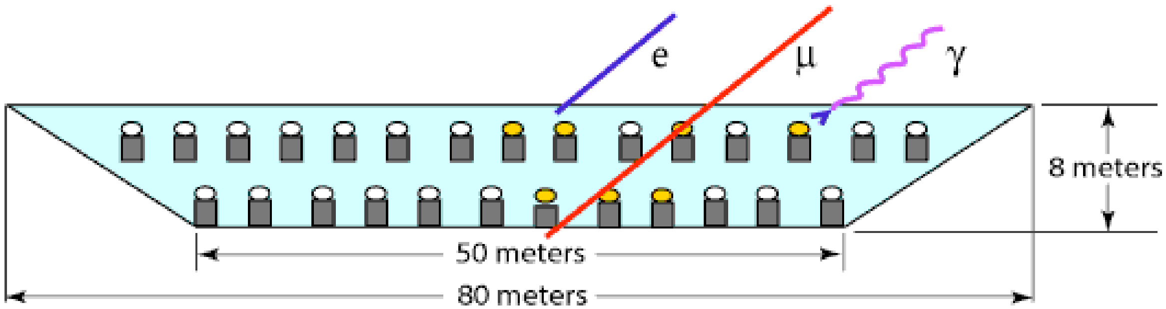
← **Water**

Air →

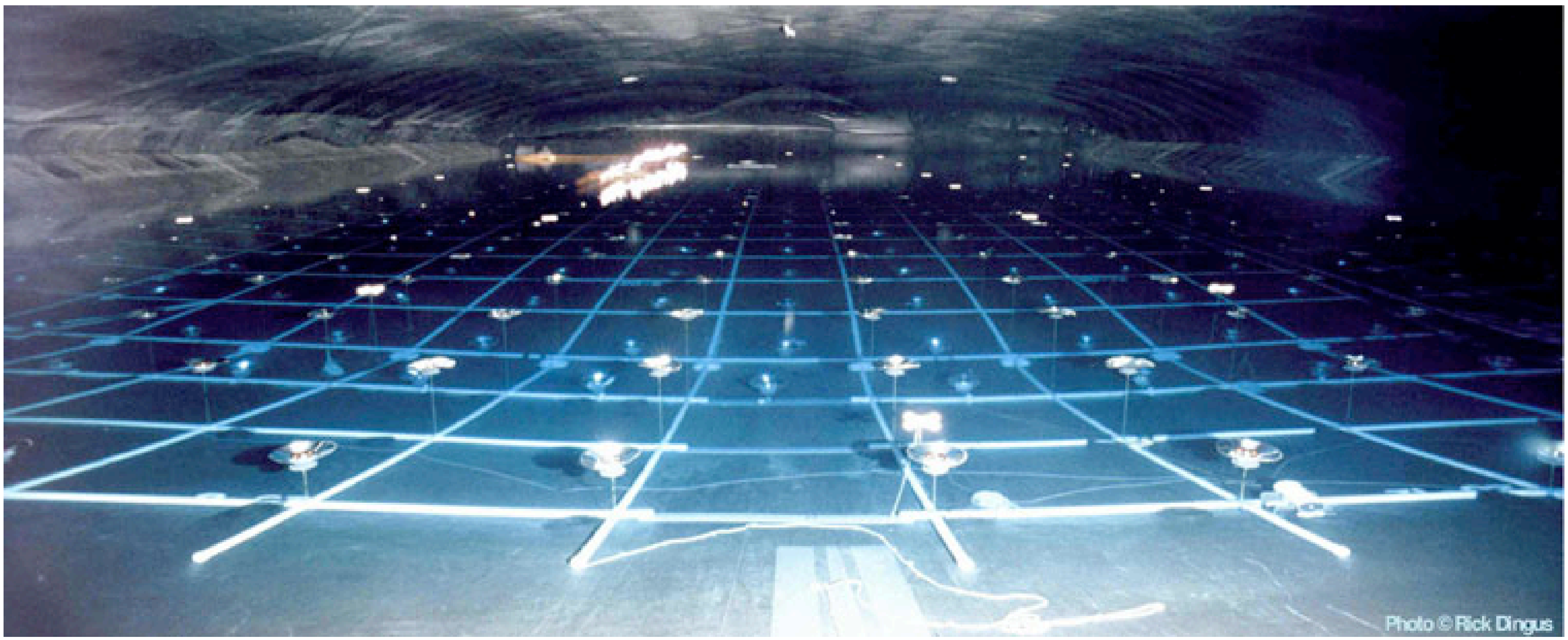
↓ ↓ ↓

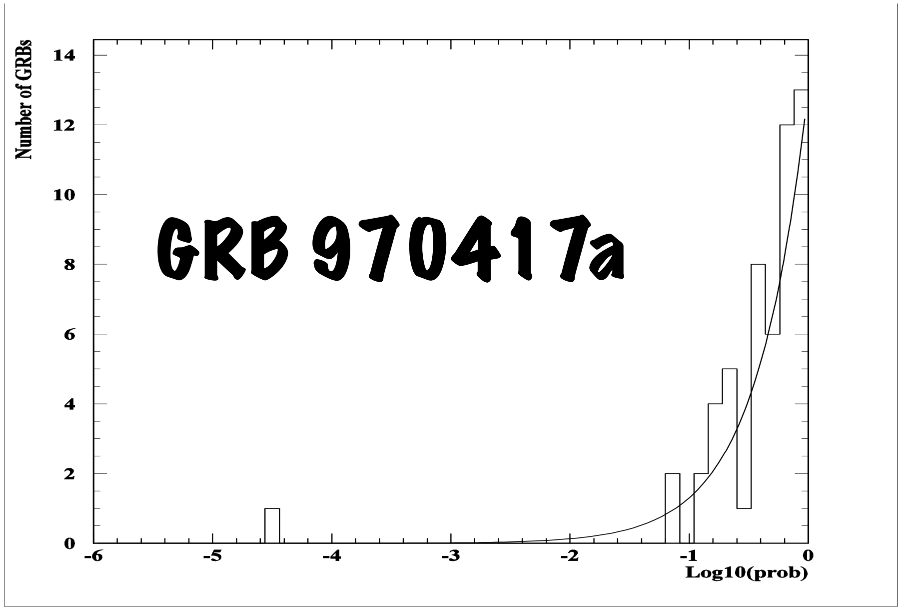


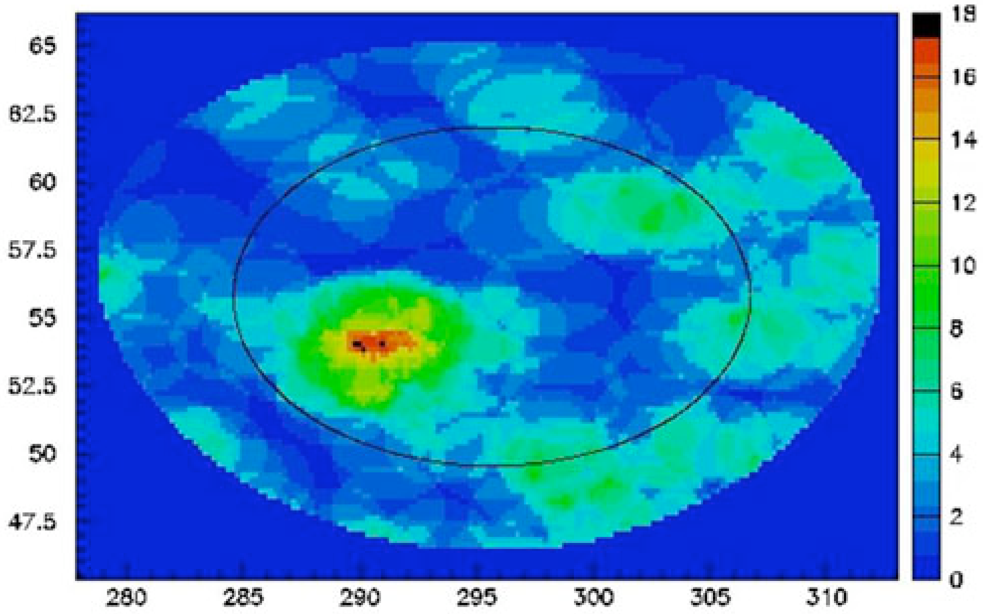
MILAGRO



Water Cherenkov
LANL





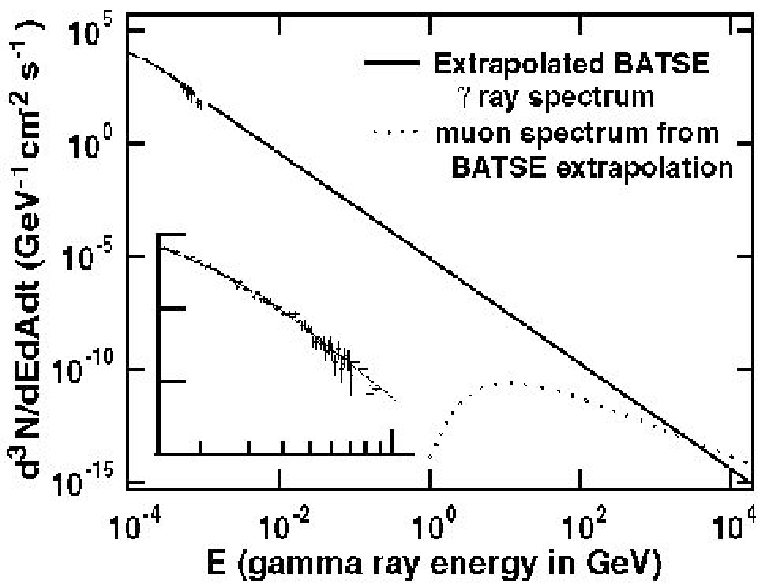


TeV GRB Detection Status

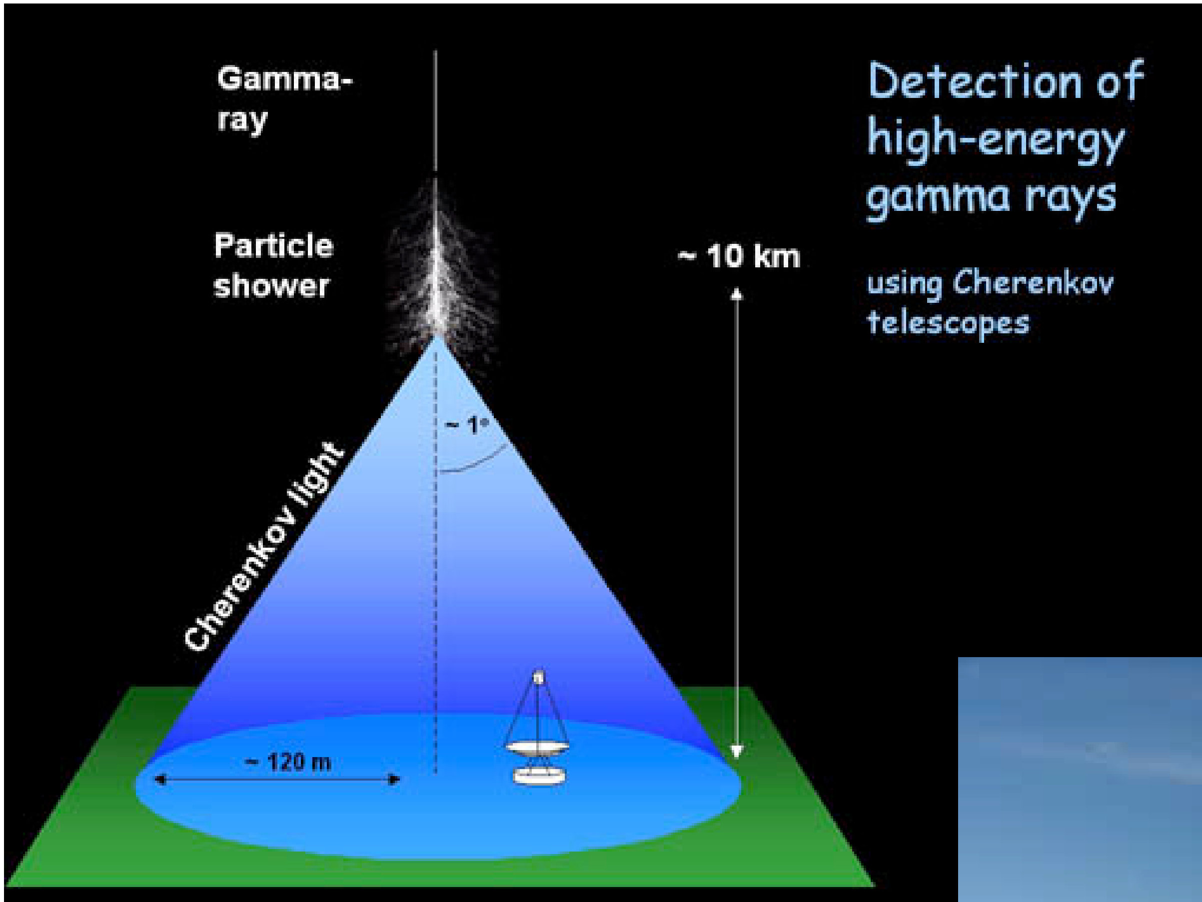
- **Milagrito** : Tentative (**3σ**) TeV detection ; $F_{TeV} \sim 10\ F_{MeV}$; but no redshift (no absorption: D < 100 Mpc?)

Atkins etal, 00, ApJL..

TeV GRB detection status (cont.)



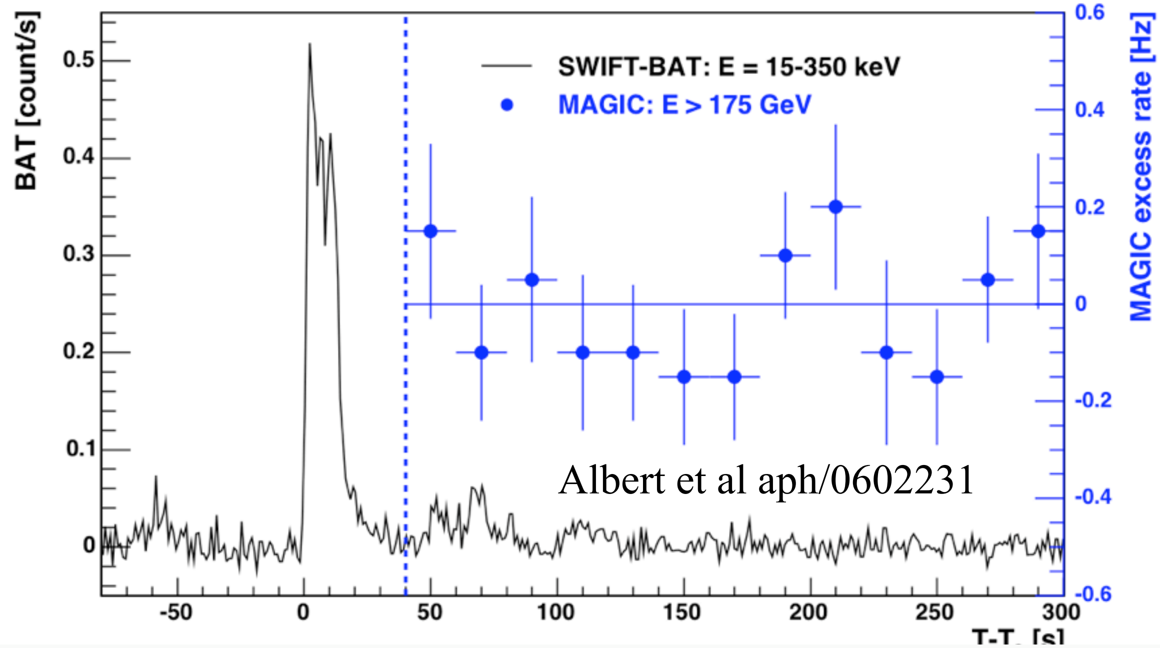
- **GRAND**: GRB 971110
  - reported det. at **2.7 σ** (Poirier et al PRD 03, aph/0004379)
  - modeling requires various assumptions, some severe (Fragile etal 03):
- **Tibet** array: superpose 50-60 bursts in coincid. w. MeV: joint significance **7σ ?** (Amenomori et al 01)
- **ARGO-YBJ a**rray (Tibet), 6700 m^2 area, 4.3 km alt., $E_{thresh:}$~ 1 GeV ; resistive plate chambers (RPC); observed 16 GRB Dec 04-May 06 in coincid. w. Swift; ***no detection,*** fluence upper limit $F<10^{-4}$ erg cm^{-2} (1-100 GeV) (Di Sciascio, et al aph/0609317)

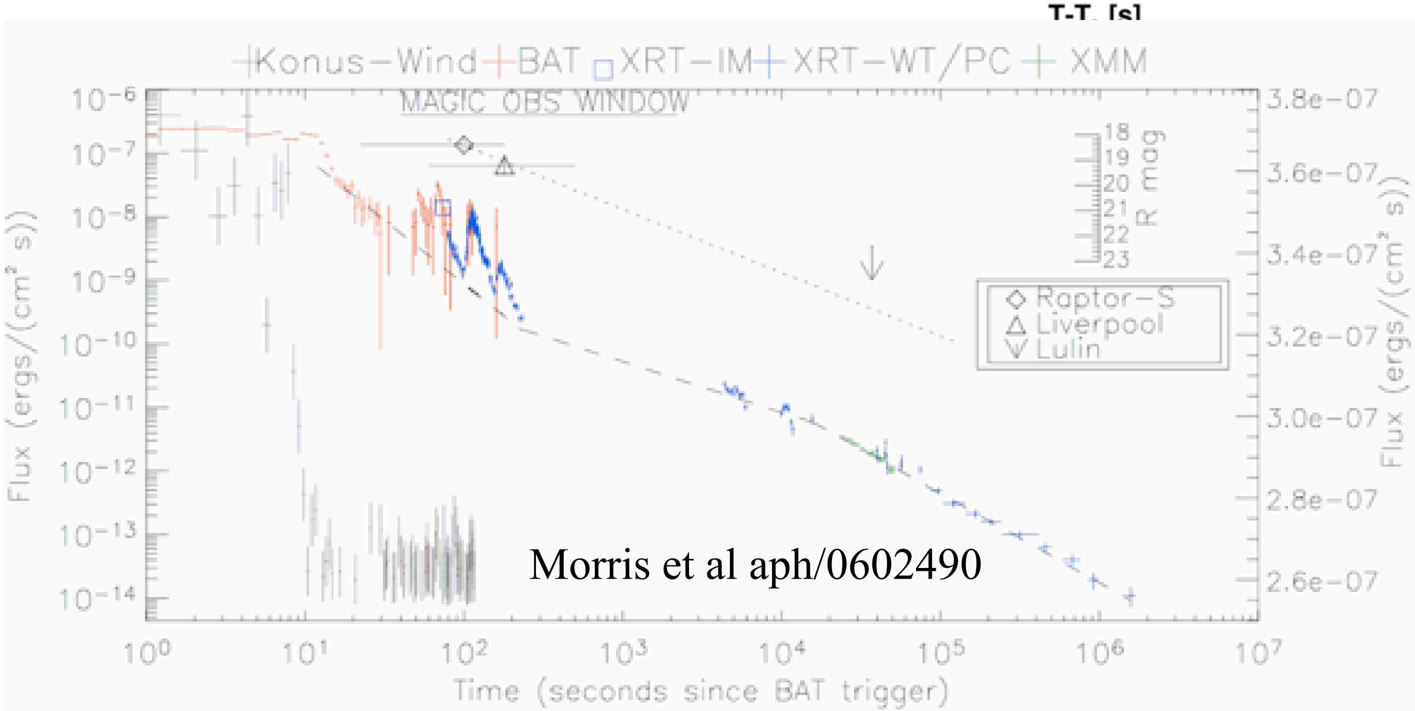


ACT

Air Cherenkov
Telescopes

- **MAGIC** :
- single 17m dish, slew time <35 s !, threshold E>50 GeV (..)

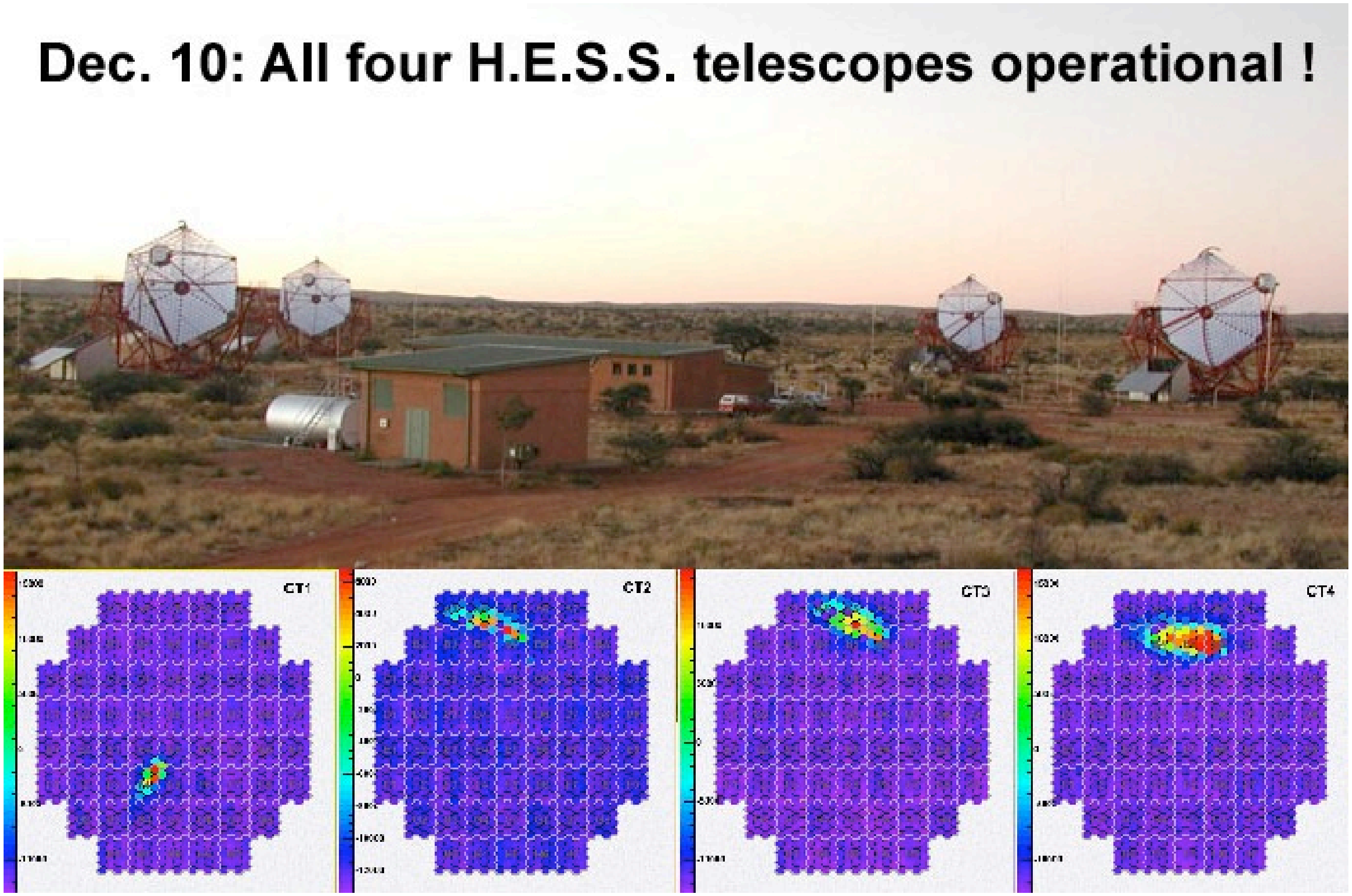




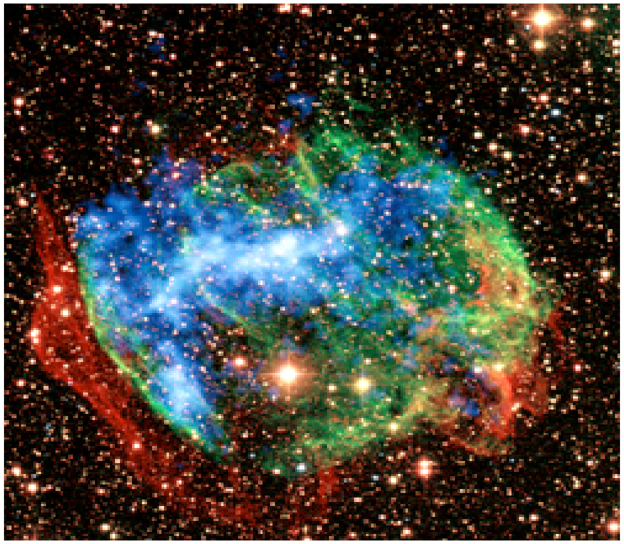
050713a MAGIC

- Observed @ T_0+40s , while MeV still detected, and during flaring X-ray afterglow
- >175 GeV flux upper limits
- Redshift unkown

HESS : Stereo Imaging



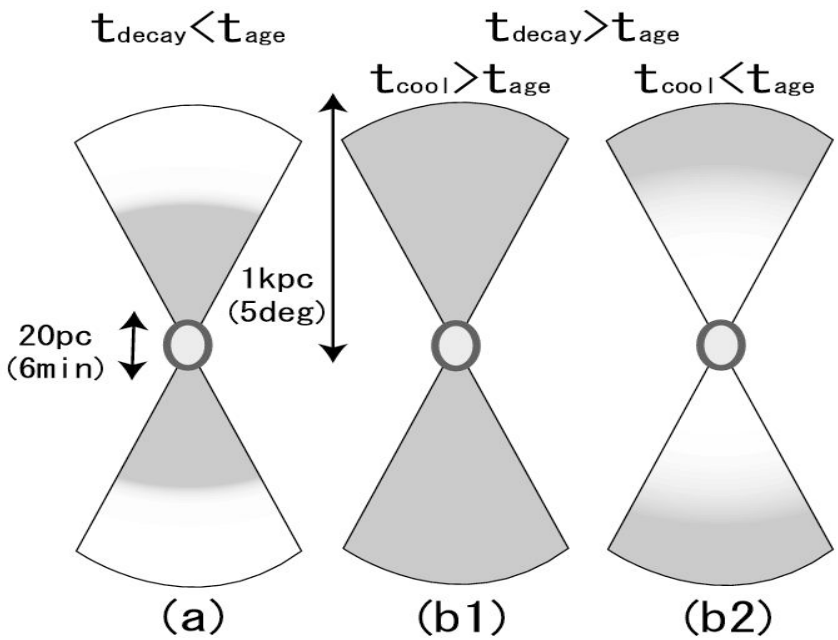
- Detected AGNs, PSRs, SNRs, un-IDs etc
- So far, ***no*** "fresh" GRB, but some possible **GRBR**



W49B:

a GRB remnant detected through its UHECR → γ luminosity?

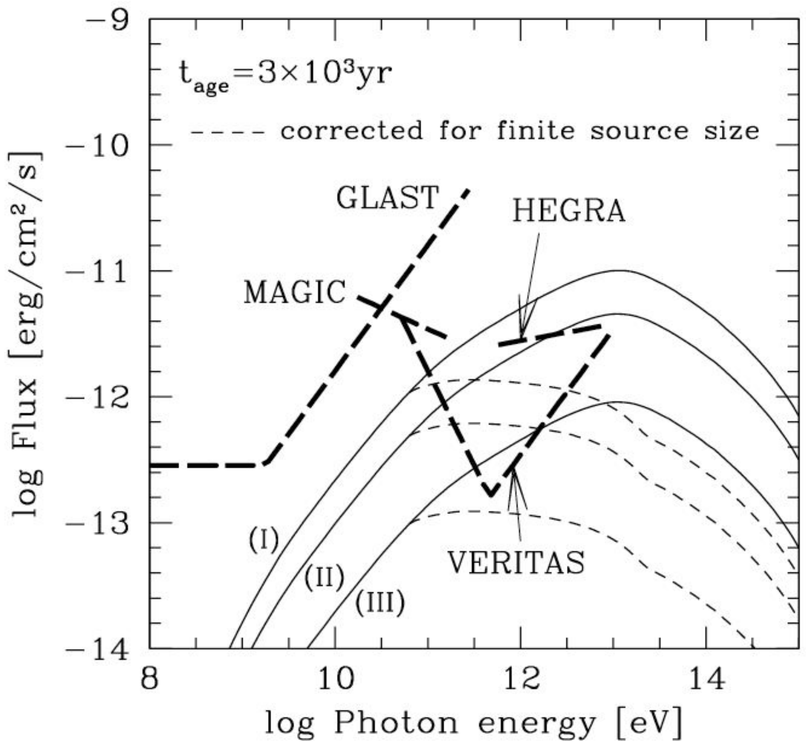
← CXC/Spitzer obs: two jets, rich in Fe (~ GRB remnant ?) (Clavin, Roy, Watzke '04)



- ~3000 yr old SNR: **any UHE signatures ?**
- ***If GRB = CR accelerator***
  → CR neutrons escape ejecta
- β decay e^- → synchrotron + IC in B_{gal} , CMB → ***GeV-TeV γ***
- Geometry dep. on t_{dec}, t_{cool} , t_{age}
- ⇒ may be detectable at GeV

(Ioka, Kobayashi,Mészáros 04 ApJ 613, L17)

W49 as a smouldering GRB remnant at GeV



- $\varepsilon_{ic,cmb}$ ~ 50 TeV
- $\varepsilon F_{\varepsilon}$ ~ 10^{-11} erg/s/cm^2

$\varepsilon F_{\varepsilon}/\Omega$ ~ 5 10^{-9} erg/s/cm^2/sr

(dep. on **n/CR** to γ−ray norm)

→ *possibly detectable w.*

VERITAS, MAGIC, HEGRA

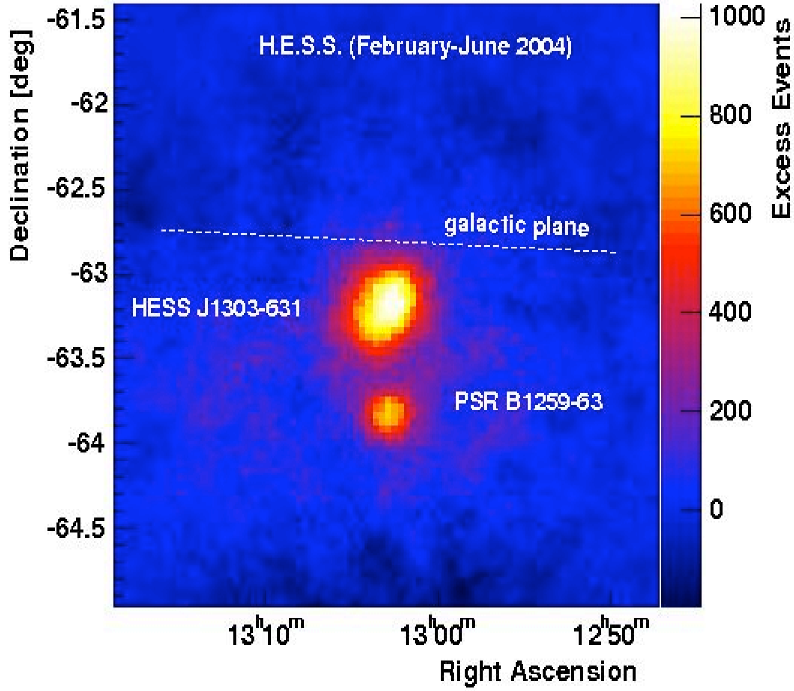
(northern → not for HESS, CANGAROO

too faint for GLAST;)

[Since neutrons escape SNR, imaging allows distinguishing n-decay outside SNR from π^0 decay due to proton acceleration in the SNR shock]

Ioka, Kobayashi, Mészáros 04, ApJL 613, L17

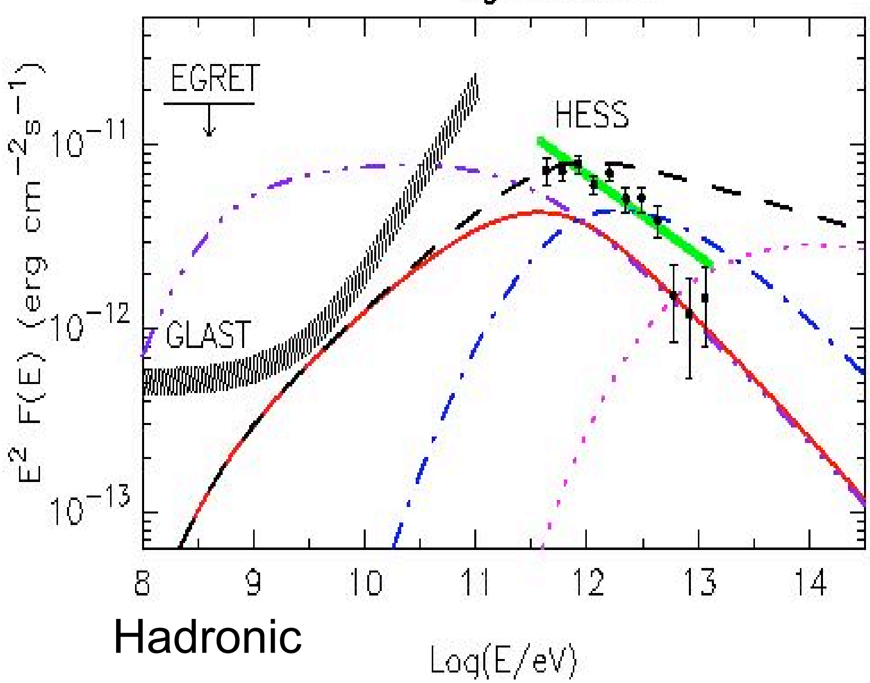
Un-ID TeV source: **HESS J1303-631** a GRB remnant?



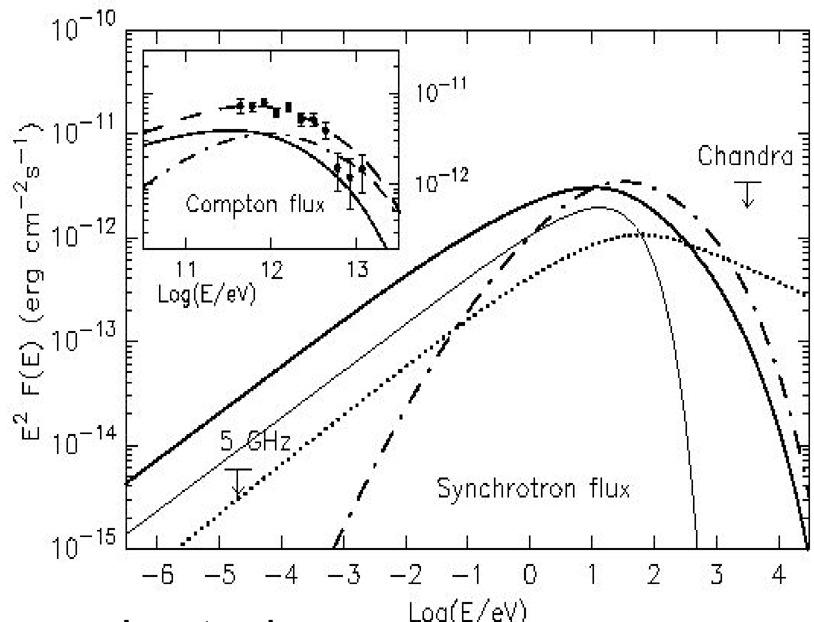
Emission absent at energies < TeV .

⇒ GRBR, d=12 kpc, $t=1.5\times10^4$ yr, $n_H=1$ cm^{-3} ?

Atoyan, Buckley, Krawczynski, ApJL-astro-ph/0509615

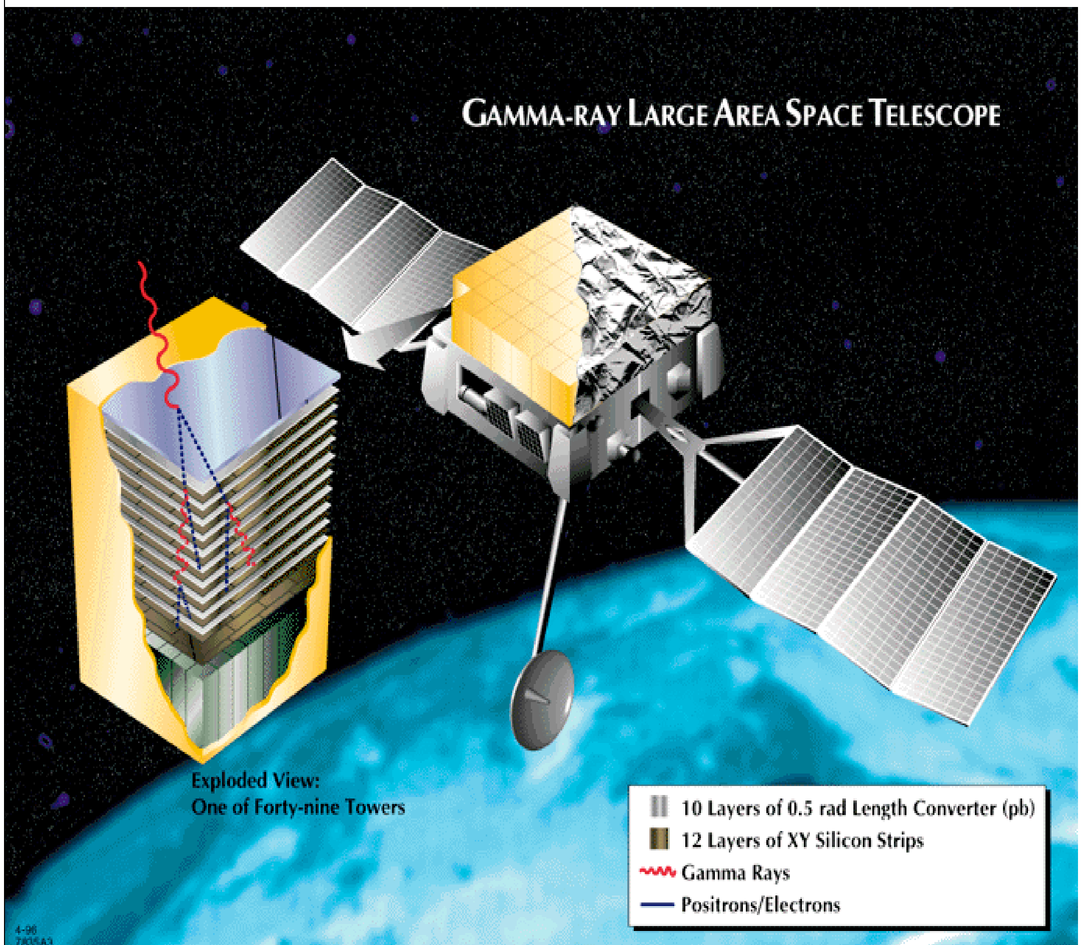


Hadronic



Leptonic

GLAST : LAT (Stanford +)



- LAT: launch exp '07, Delta II, 2-300 GRB/2yr
- Pair-conv.mod+calor.
- 20 MeV-300 GeV, $\Delta E/E \sim 10\%$@1 GeV
- fov=2.5 sr (2xEgret), θ~30"-5' (10 GeV)
- Sens ~2.10^{-9}ph/cm^2/s (2 yr; > 50xEgret)
- 2.5 ton, 518 W
- expect det/loc ~200 GRB/yr

Also on GLAST: GBM (~BATSE range) ; 12 NaI 10keV-3 MeV; 2 BGO 150 keV-30 MeV

AGILE

Launch early '07
(Indian Space
Res. Org. rocket)

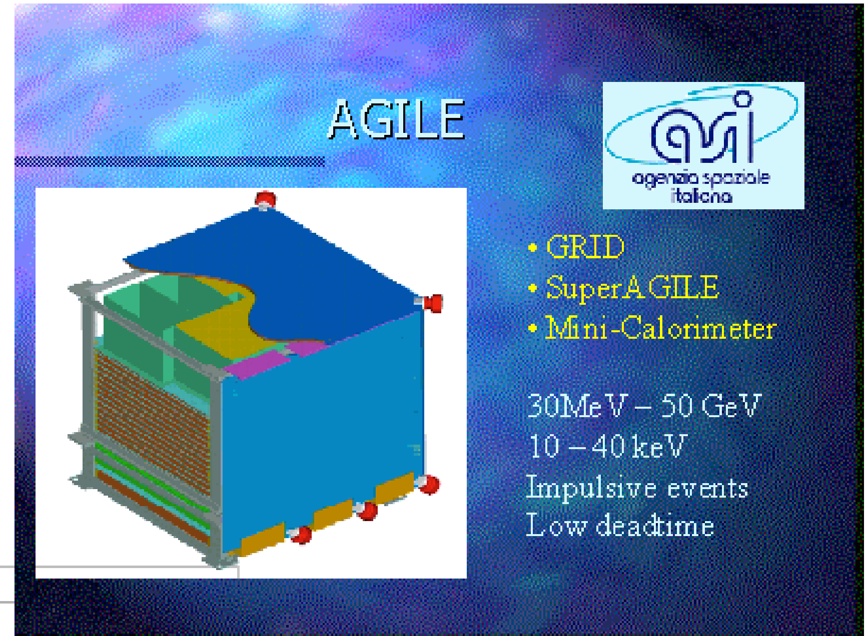


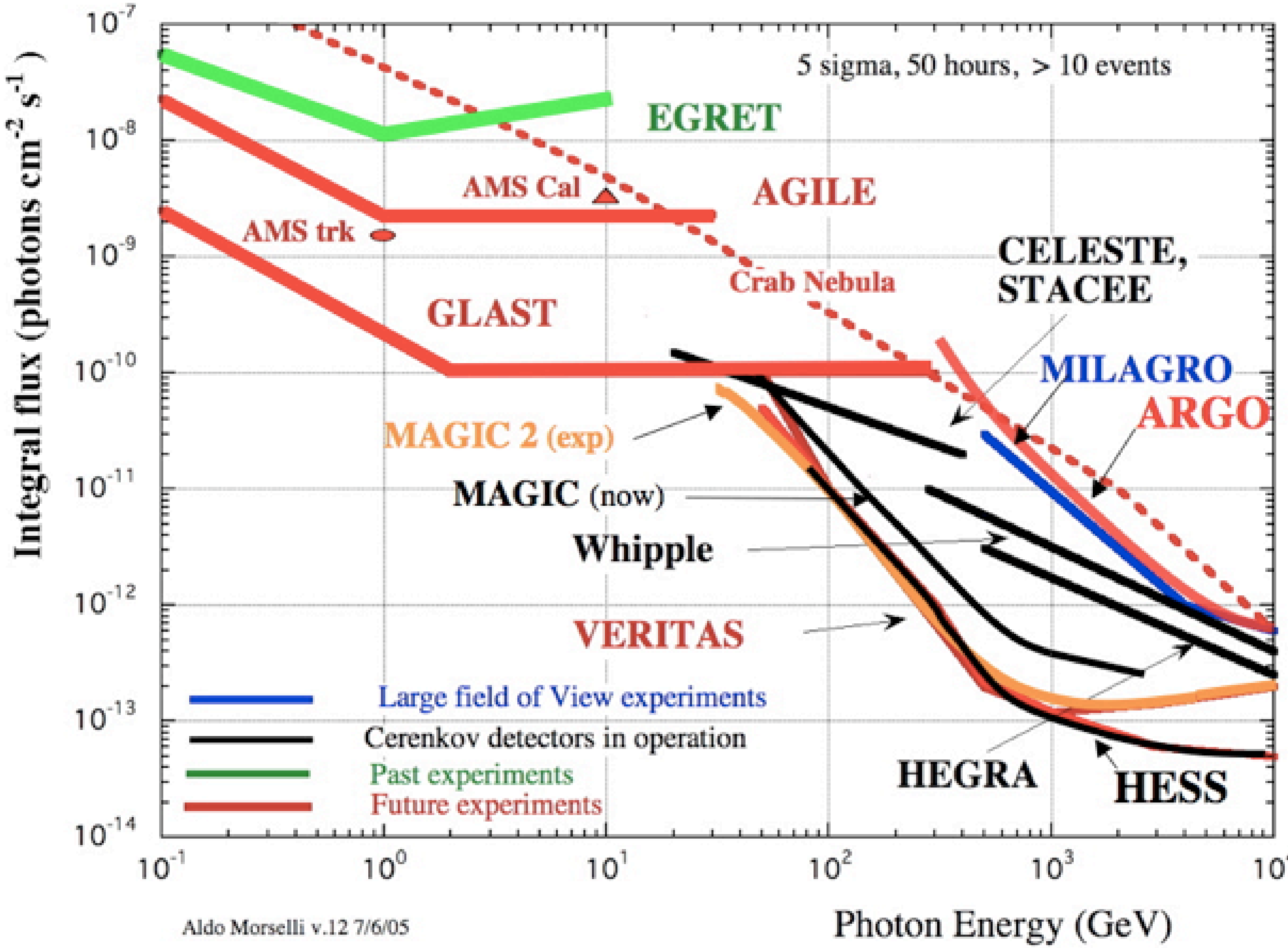
Table 3: **AGILE Scientific Performance**

Gamma-ray Imaging Detector (GRID)		
Energy Range	30 MeV – 50 GeV	
Field of view	∼ 3 sr	
Sensitivity at 100 MeV (ph cm^{-2} s^{-1} MeV^{-1})	6×10^{-9}	(5σ in 10^6 s)
Sensitivity at 1 GeV (ph cm^{-2} s^{-1} MeV^{-1})	4×10^{-11}	(5σ in 10^6 s)
Angular Resolution at 1 GeV	36 arcmin	(68% cont. radius)
Source Location Accuracy	∼5–20 arcmin	S/N∼10
Energy Resolution	ΔE/E∼1	at 300 MeV
Absolute Time Resolution	∼ 1 μs	
Deadtime	∼ 200 μs	
Hard X–ray Imaging Detector (Super-AGILE)		
Energy Range	10 – 40 keV	
Field of view	$107°\times68°$	FW at Zero Sens.
Sensitivity (at 15 keV)	∼5 mCrab	(5σ in 1 day)
Angular Resolution (pixel size)	∼ 6 arcmin	
Source Location Accuracy	∼2-3 arcmin	S/N∼10
Energy Resolution	ΔE<4 keV	
Absolute Time Resolution	∼ 4 μs	
Deadtime (for each of the 16 readout units)	∼ 4 μs	
Mini-Calorimeter		
Energy Range	0.3 – 200 MeV	
Energy Resolution	∼ 1 MeV	above 1 MeV
Absolute Time Resolution	∼ 3 μs	
Deadtime (for each of the 30 CsI bars)	∼ 20 μs	

FoV : 1/5 sky
10-12 GRB/yr

X-ray detector
Super-Agile:
localize to
Δθ ~ few arcmin

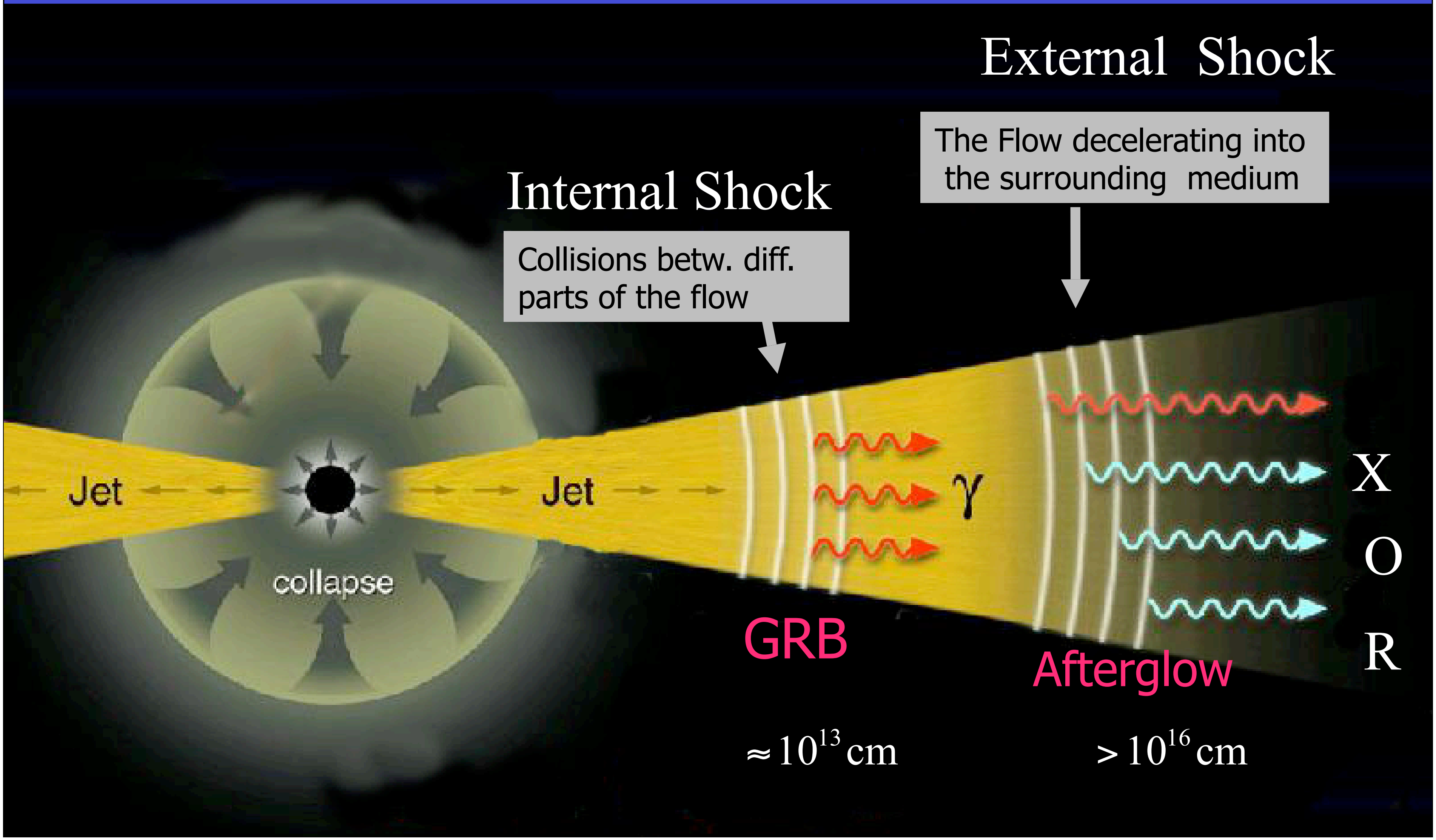
Gamma Ray Sensitivities



-glast06

Fireball Model: long GRBs

E.g., recent review on ***GRB-Swift results & implications***:
Mészáros, 2006, Rev.Prog.Phys 69:2259 (astro-ph/0605208)



Simplest "delayed" GeV γ mechanism ?

A purely leptonic interpretation:

GeV γ emission seen, start ~ same time as MeV γ trigger, but lasting ~ 1 hr:

→ could be

a) **internal** shock synchrotron

→ normal duration **MeV** to ~GeV

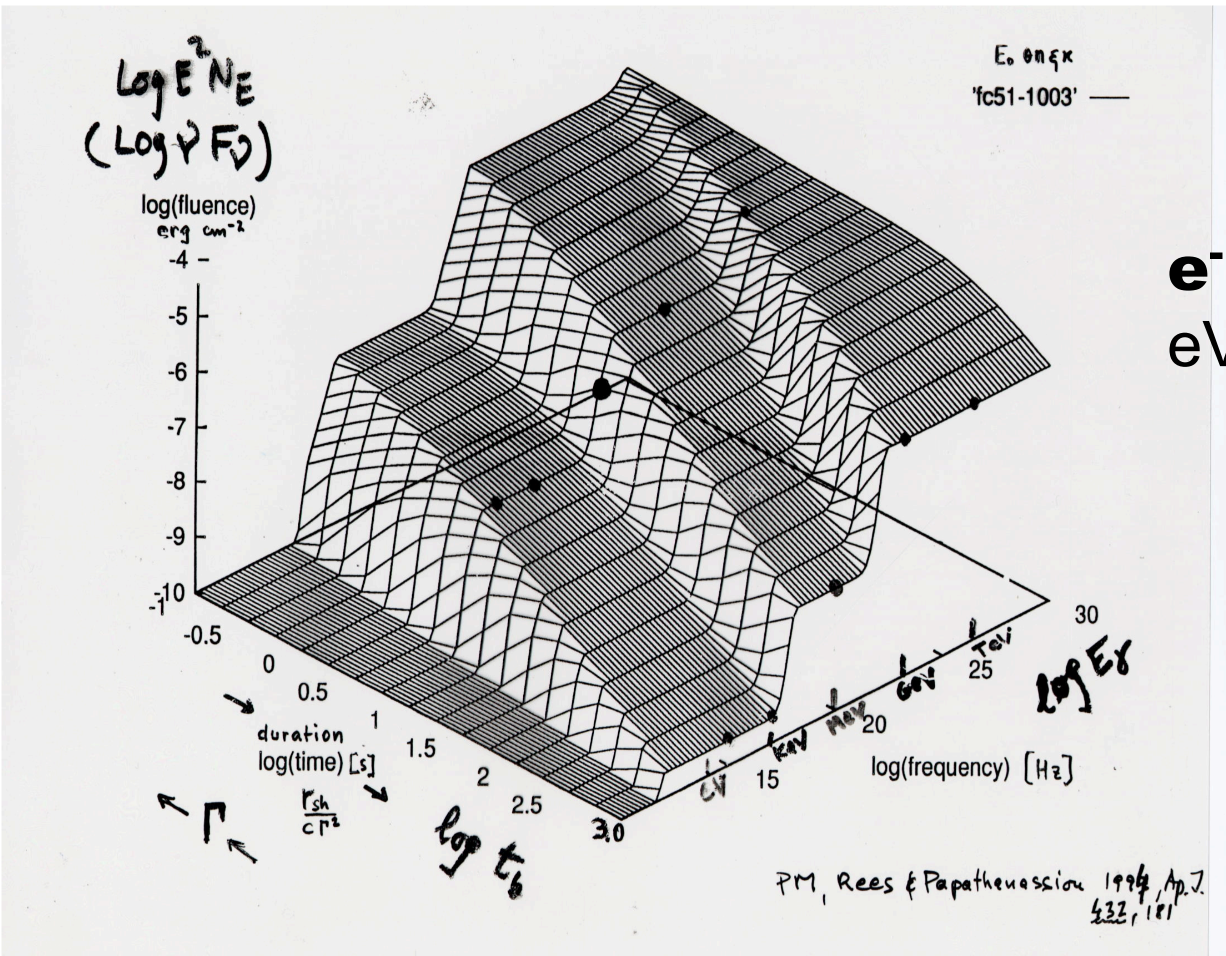
b) **external** shock (moder. Γ, low n_{ext})

IC → ~ **GeV** to TeV, lasts ~mins-hr

(Meszaros & Rees 1994 MNRAS 269, L41)

- Other possib (Katz 94) : proton impact on bin. comp.* pp → pγ

External Forw. & Rev. Shock Synchroton & IC spectrum

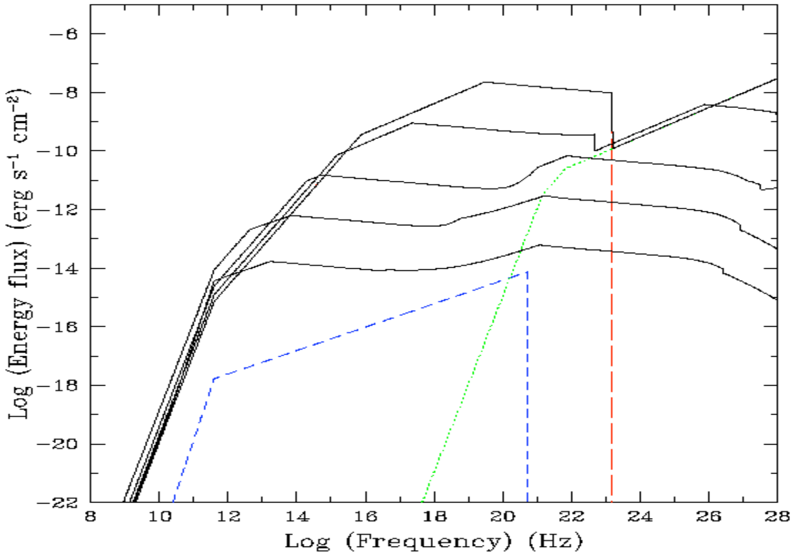


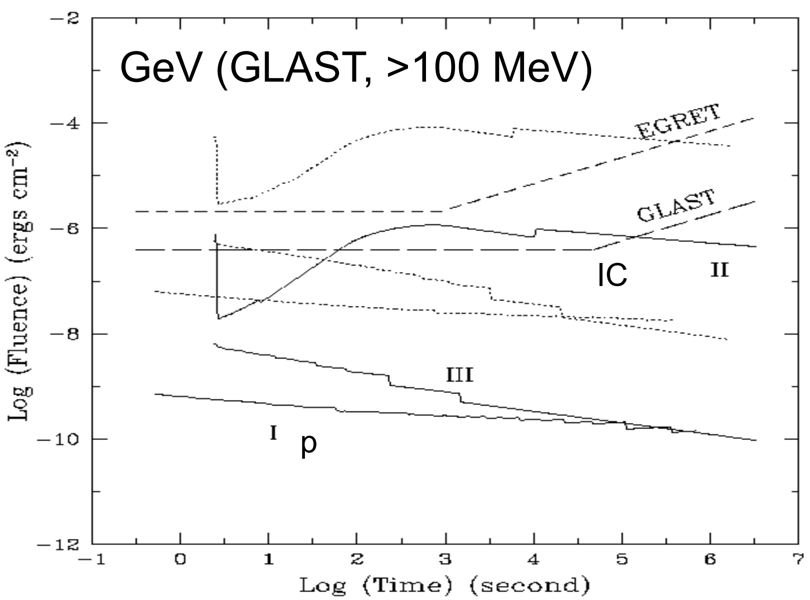
e⁻ energy losses:

eV< E <MeV : Synch

E >GeV : IC

GRB GeV emission: Leptonic - IC



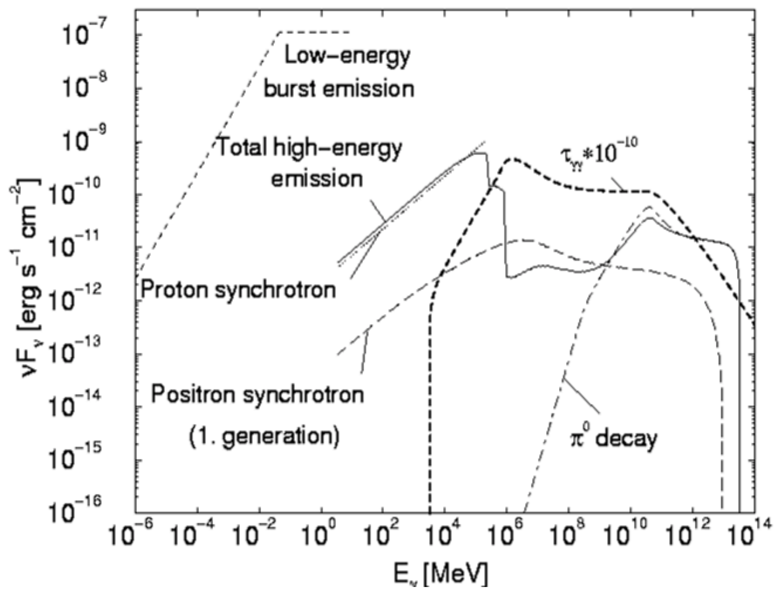


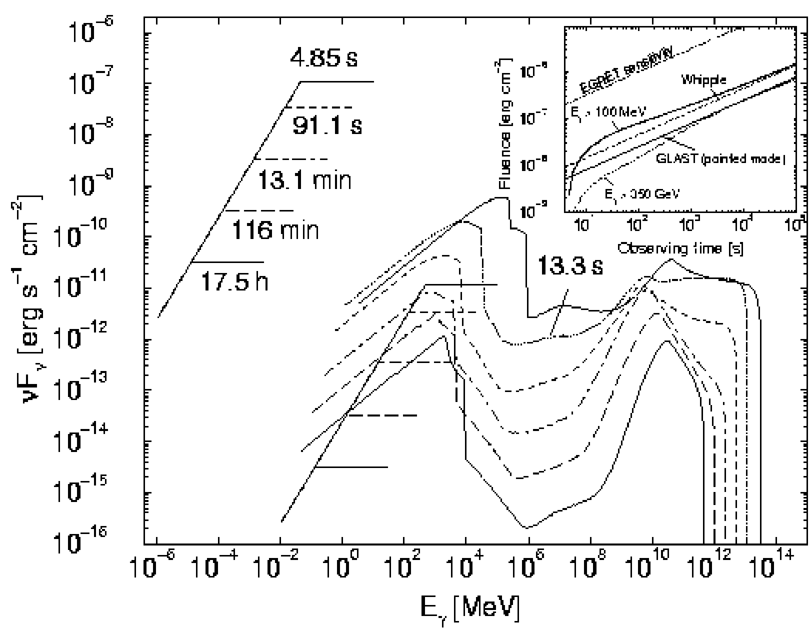
- Lightcurves start at t_{dec}, until reach Γ~2.
- IC of sync. ext. shock
- Full lines: z=1, flat U
  Dotted: z=0.1
- Model **IC** : recognize from **late GeV** peak 10-20 min after MeV), and
  from **late XR** hump (day)

- Long-dash lc: e-sy radn component
  short-dash lc: p-sy(pg), radn
  dotted lc : e-IC radn

Zhang & Mészáros 01 ApJ 559, 110

But:





GRB GeV γ :
pγ EM cascade?

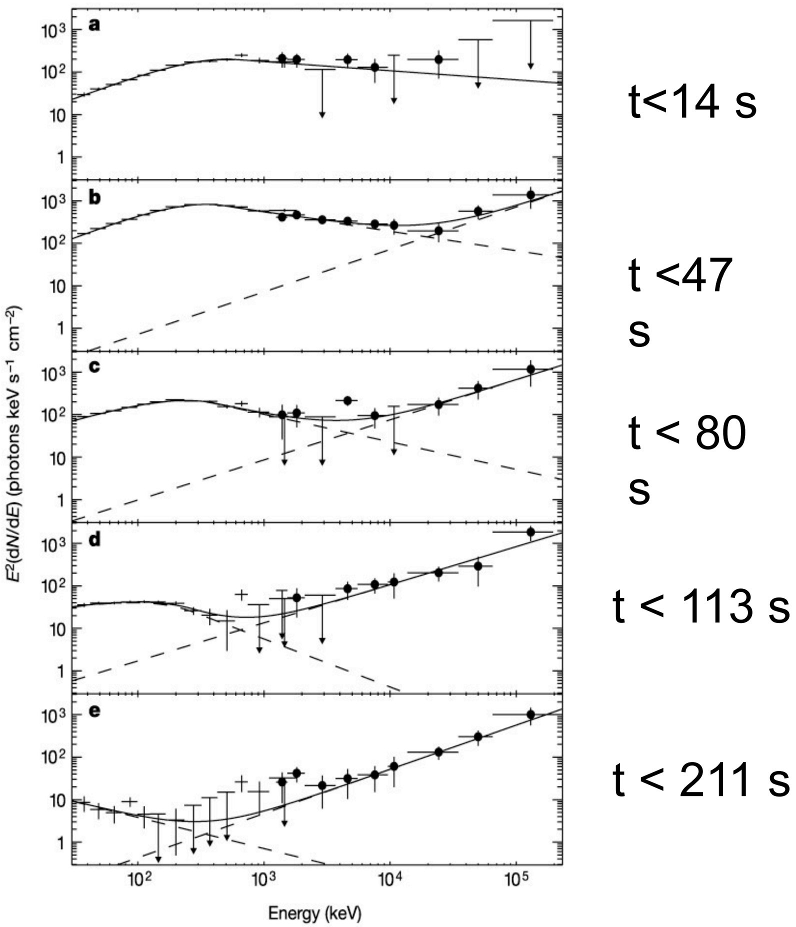
- Low energy: normalize to GRB 970508 (z=.83)
- Ext. forw. shock → MeV γs
- Proton index -2, $U_p \sim U_e$,

  p -sy & pγ cascades,

  e^+ sync, π^0 dec.
- Time decay of cascade rad, slower than a'glow decay (p's have less rad. losses) → GLAST

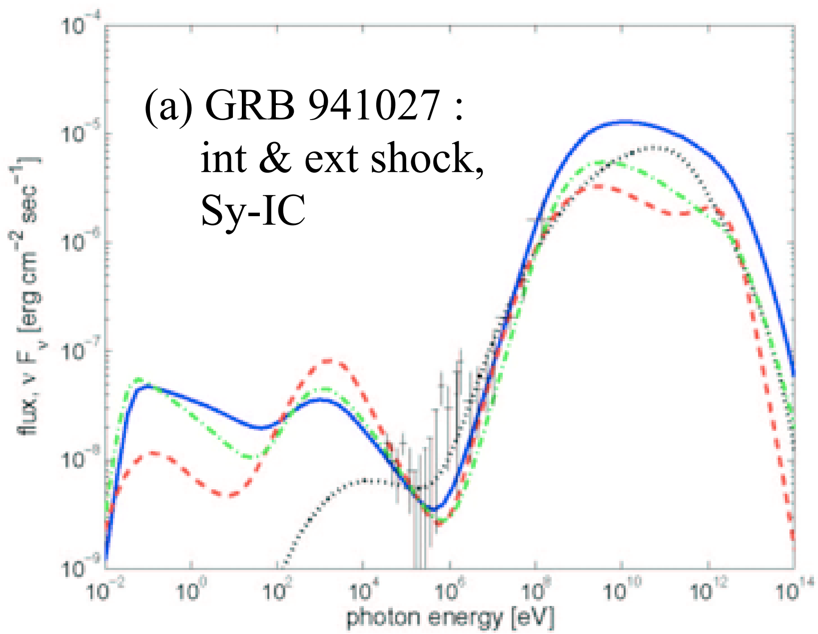
Boettcher & Dermer 98 ApJ 499, L131 ;
Dermer, Atoyan 03, PRL 91, 1102;
Dermer, Atoyan 04, AA418, L5

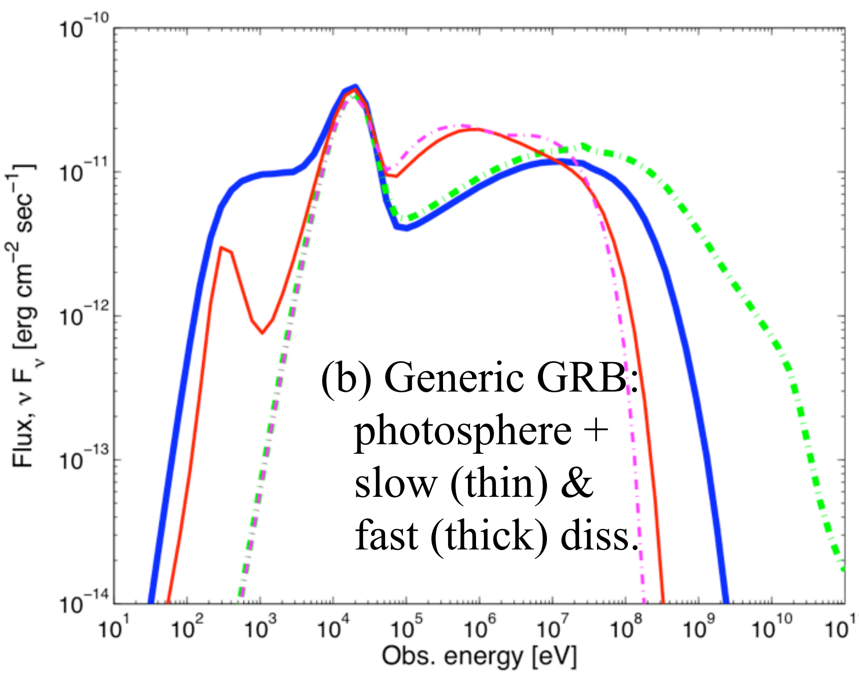
GRB 941017 : pγ signature?



Gonzalez, Dingus et al, 03, Nature 424, 749

- Hard **(10-200 MeV)** comp. in EGRET TASC calorimeter **not** compatible w. BATSE MeV fit
  (but in 26 other bursts a single BATSE/TASC fit works well)
- Hard comp. more prominent in time → **pγ signature?**
  might explain delay, hardness
  (also Dermer, Atoyan 04 AIPC 727, 557)
- **Alternative: could be IC**, in regime where IC sp is harder than sync PL ; e.g. scatt. of lower energy synch. asymptote; or observe IC region where electrons with a range of energies scatter off a range of photon energies (Granot,Guetta, astroph/0309231; Pe'er, Waxman, 04)

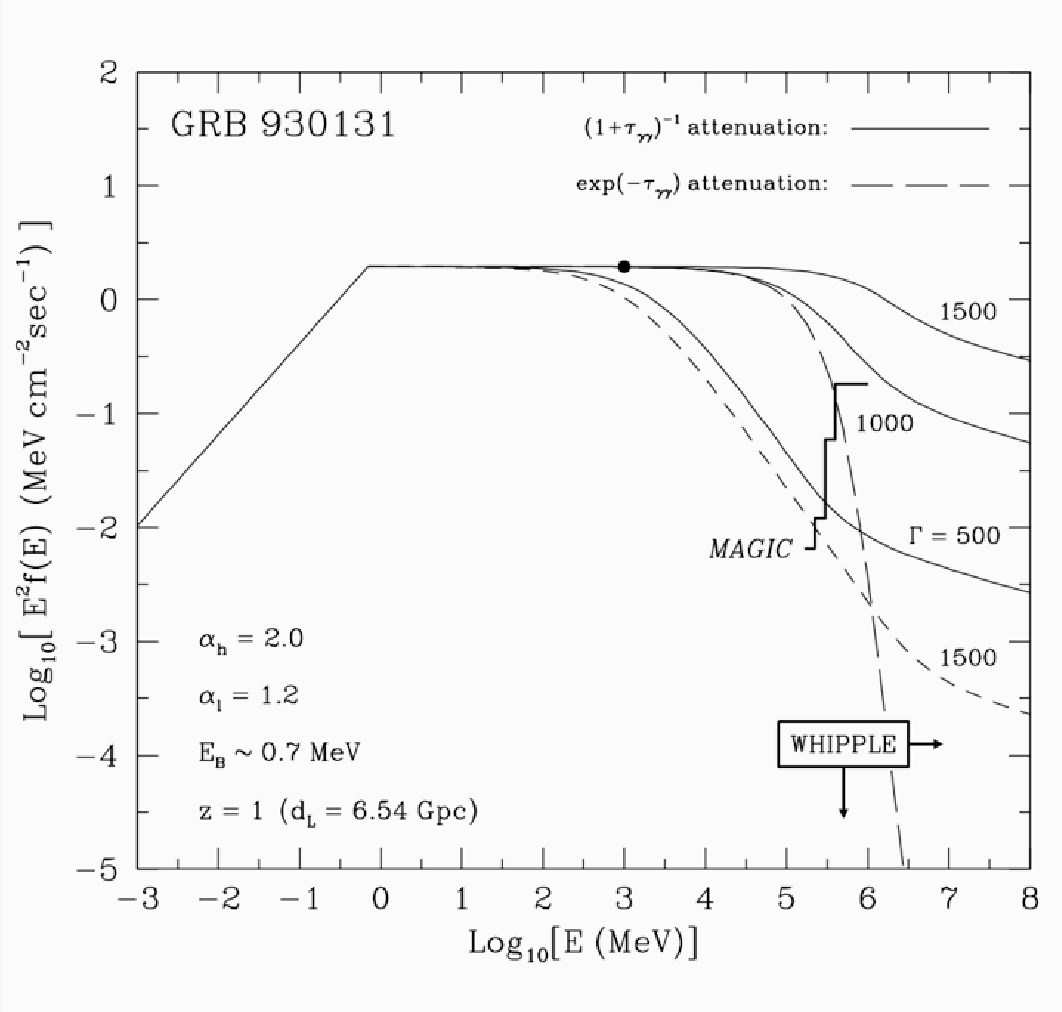




Leptonic GeV GRB emission

- ← (a) Sy-IC, pair formation in internal & external shock: 941027 need not be hadronic (Pe'er & Waxman 04)
- ← (b) Sy-IC, pair formation in slow dissipation or fast (shock) dissipation in or near jet photosphere (Pe'er, Mészáros, Rees 05) - preferred peak energy near MeV, and VHE photons from IC for modest scatt opt depth

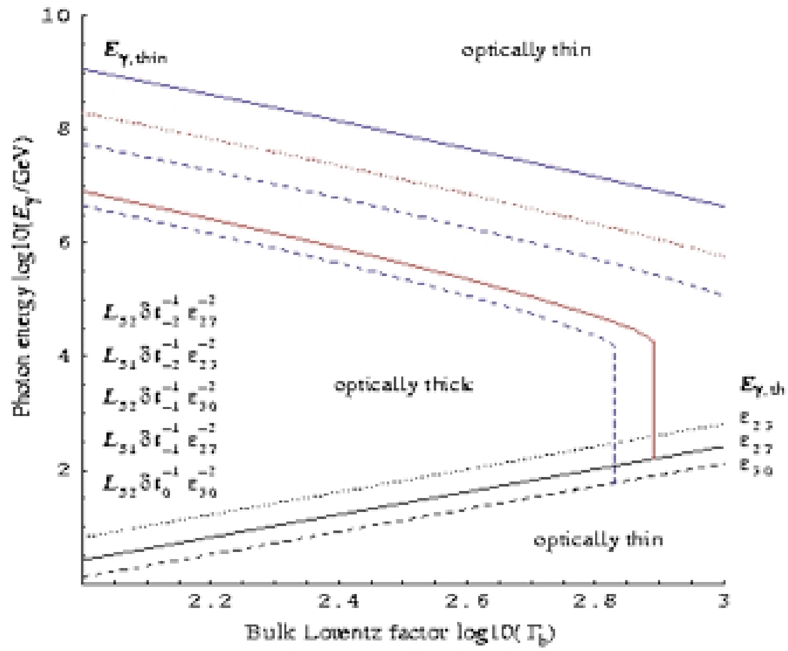
Physical clues from GeV-TeV photons in GRB



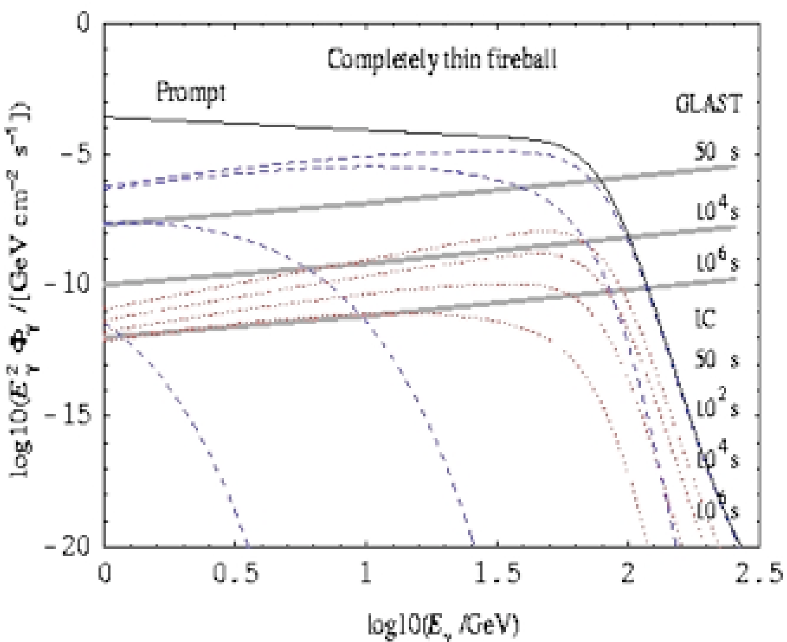
Baring 06, ApJ, aph/0606425

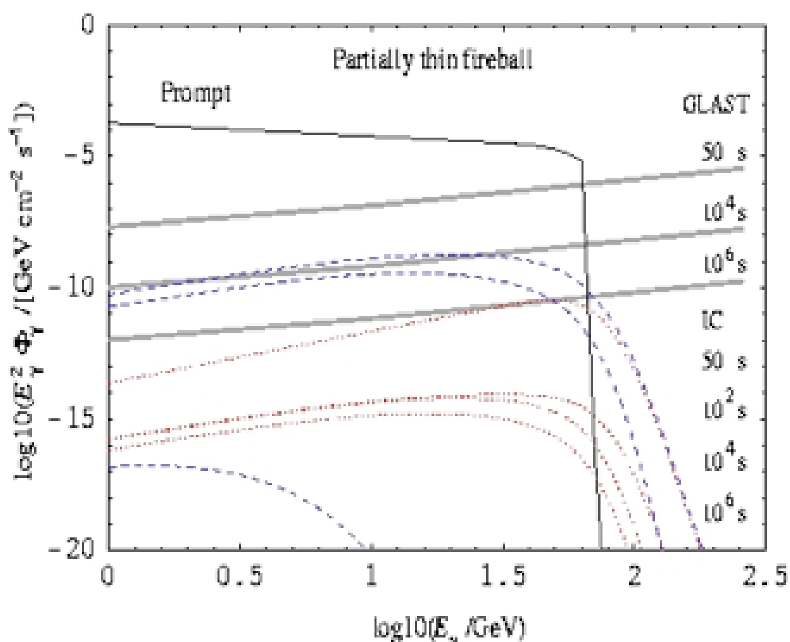
- Internal shocks: $\gamma\gamma \to e^{\pm}$, $\tau_{\gamma\gamma} \sim 1$ @ $E_\gamma \sim \Gamma^2_{300}$ GeV
  → pair cutoff in spectr
  → get info about r_{sh} (compactness,$t_{\gamma\gamma}$)
- In ext.shock, $\tau_{\gamma\gamma} < 1$ on GRB target γ ;
- test if shock is int. or ext;
  test bulk Lorentz factor, shock accel efficiency, magnetic field in shock (max. $e^{\pm}$ energy? →size of accel region)

How high in energy, and how late?



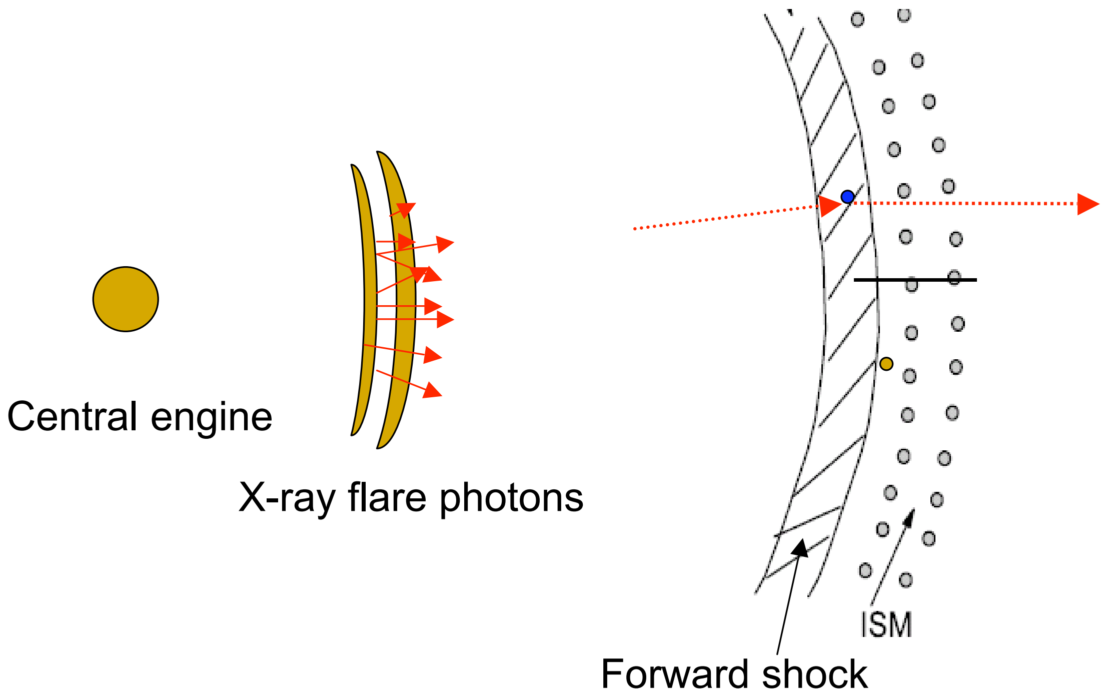
- Very high Γ →low compactness, high e± cut-off
- Higher cut-off for (late) afterglow than for prompt
- External IGM reprocessing: late, depends on B_{IGM}





Razzaque, Mészáros, Zhang 04, ApJ 613:1072

XR Flares ⇒ GeV Flares?



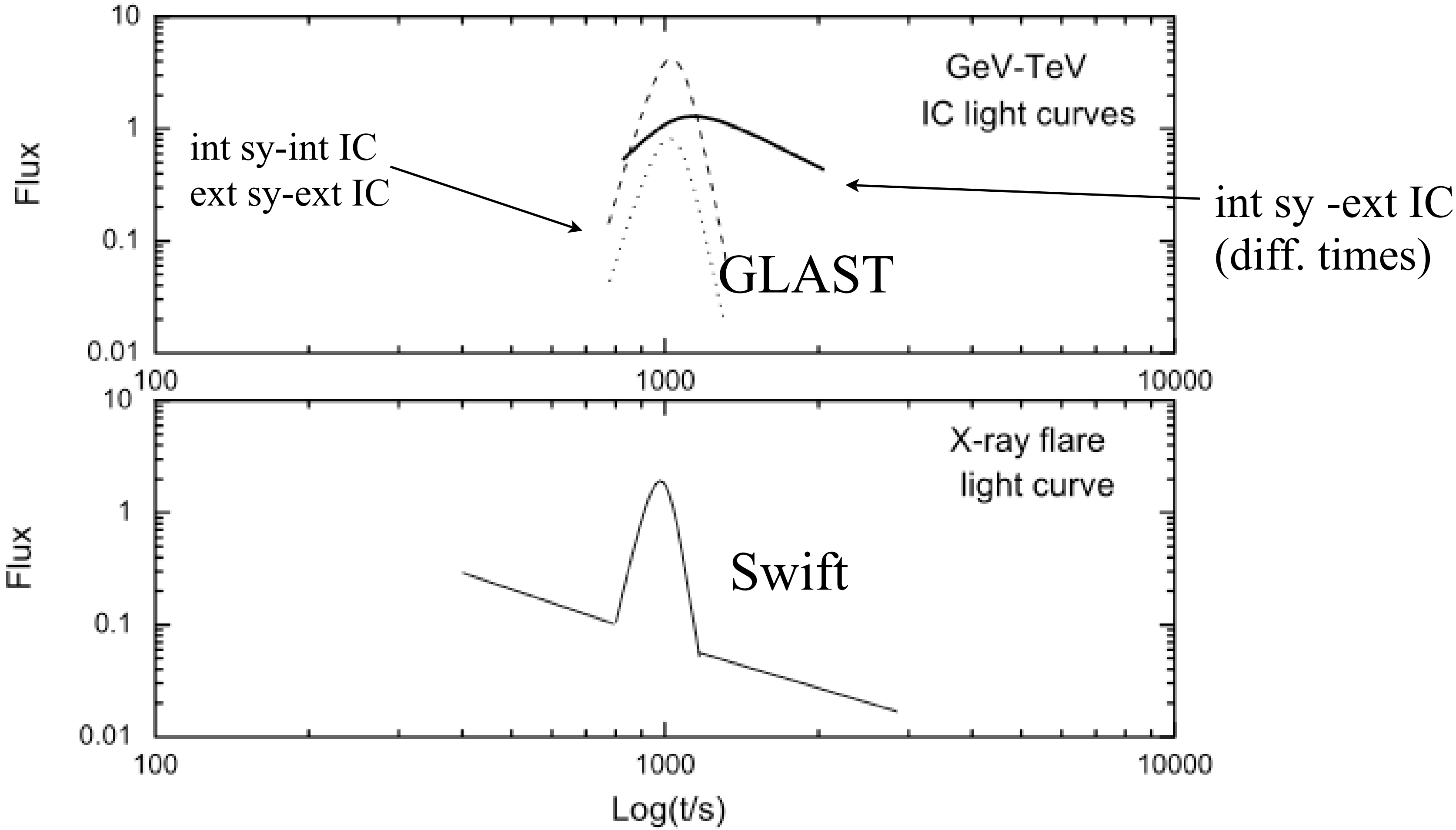
XR flares ubiquitous in Swift XR ; thought to be late internal shocks (or mag diss)

If so,
→ XR emission is inside the external shock

→ IC upscatter XR photons by ext shock e^-
→ GeV flares
→ GLAST det

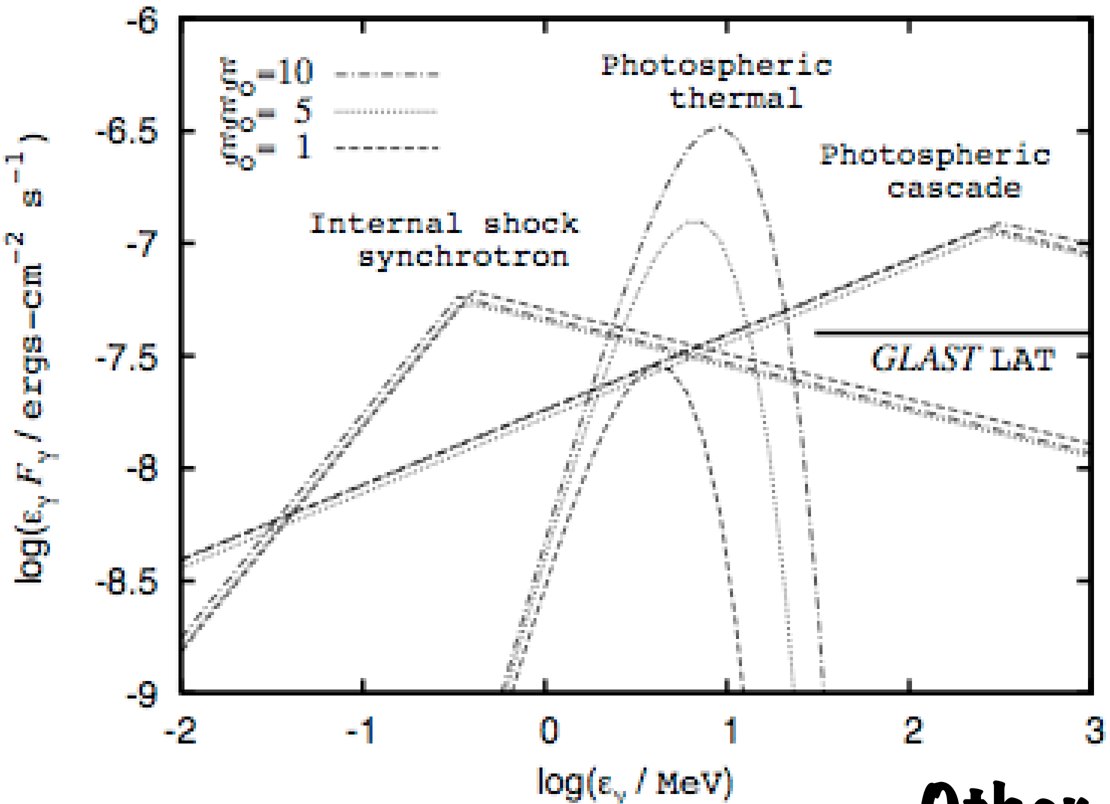
X.Y. Wang, Li, Mészáros 06 ApJ 641:L89

XR → GeV Flares



X.Y. Wang, Li, Mészáros 06 ApJ 641:L89
(c.f. Galli, Piro et al 06: same shock self-SSC)

Short GRB as DNS: pn dec



- DNS or BHNS merger: n-rich outflow → np decoupling
- → ($\pi^{\pm}$, π^0)
- → γ_{phot} γ_{π} cascade
- SGRB @ z ≲ 0.1 → GLAST det.

Razzaque & Mészáros, aph/0601652

Other DNS/NSBH GeV emission: ***neutron β-decay*** → e^- , p → inner bremss, **GeV photons** → GLAST det (Razzaque & Mészáros, 06, JCAP 06:006

Conclusions: GLAST impact on GRB science

- Will provide radically new info about GRB
- Energetics: will resolve the VHE γ contribution to total calorimetry
- Constrain hadronic contribution and quantify potential as UHECR and UHENU sources
- Provide unique info about compactness, emission region size, dynamics (Γ, etc)
- Indirect info about IGM properties (B, etc)