VHE $\gamma$ Emission from GRB

*Peter Mészáros*

*Pennsylvania State University*
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

Mészáros grb-glast06
GeV-TeV $\gamma$ experiments underway

MILAGRO

Cherenkov Telescopes

← Water

Air →

↓ ↓ ↓

Cangaroo

VERITAS

HESS

MAGIC & HEGRA

Meszaros grb-glast06
MILAGRO

Water Cherenkov
LANL
TeV GRB Detection Status

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

Atkins et al., 00, ApJL.
TeV GRB detection status (cont.)

- **GRAND**: GRB 971110
  - reported det. at $2.7 \sigma$
  (Poirier et al PRD 03, aph/0004379)
  - modeling requires various assumptions, some severe (Fragile et al 03).

- **Tibet** array: superpose 50-60 bursts in coincid. w. MeV: joint significance $7\sigma$? (Amenomori et al 01)

- **ARGO-YBJ** array (Tibet), 6700 m$^2$ area, 4.3 km alt., $E_{\text{thresh}} \sim 1$ 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)
• **MAGIC**:
  
  • single 17m dish, slew time <35 s!, threshold E>50 GeV (..)
• Observed @ $T_0+40s$, while MeV still detected, and during flaring X-ray afterglow
• $>175$ GeV flux upper limits
• Redshift unkown
HESS : Stereo Imaging

Dec. 10: All four H.E.S.S. telescopes operational!

- 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 \( B_{\text{gal}}, \ CMB \) → **GeV-TeV γ**
- Geometry dep. on \( t_{\text{dec}}, t_{\text{cool}}, t_{\text{age}}\)
- ⇒ may be detectable at GeV

(Ioka, Kobayashi, Mészáros 04 ApJ 613, L17)
W49 as a smouldering GRB remnant at GeV

- $\epsilon_{\text{ic,cmb}} \sim 50$ TeV
- $\epsilon F_\epsilon \sim 10^{-11}$ erg/s/cm²
  - $\epsilon F_\epsilon / \Omega \sim 5 \times 10^{-9}$ erg/s/cm²/sr
    - (dep. on n/CR to $\gamma$-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 $\pi^0$ decay due to proton acceleration in the SNR shock]
Un-ID TeV source: HESS J1303-631 a GRB remnant?

Emission absent at energies < TeV.

⇒ GRBR, d=12 kpc, t=1.5x10^4 yr, n_H=1 cm^{-3} ?

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), $\theta \sim 30^\prime - 5^\prime$ (10 GeV)
- Sens $\sim 2.10^{-9}$ ph/cm$^2$/s (2 yr; > 50xEgret)
- 2.5 ton, 518 W
- expect det/loc $\sim 200$ GRB/yr

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

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

<table>
<thead>
<tr>
<th>Table 3: AGILE Scientific Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gamma-ray Imaging Detector (GRID)</strong></td>
</tr>
<tr>
<td>Energy Range</td>
</tr>
<tr>
<td>Field of view</td>
</tr>
<tr>
<td>Sensitivity at 100 MeV (ph cm(^{-2}) s(^{-1}) MeV(^{-1}))</td>
</tr>
<tr>
<td>Sensitivity at 1 GeV (ph cm(^{-2}) s(^{-1}) MeV(^{-1}))</td>
</tr>
<tr>
<td>Angular Resolution at 1 GeV</td>
</tr>
<tr>
<td>Source Location Accuracy</td>
</tr>
<tr>
<td>Energy Resolution</td>
</tr>
<tr>
<td>Absolute Time Resolution</td>
</tr>
<tr>
<td>Deadtime</td>
</tr>
<tr>
<td><strong>Hard X-ray Imaging Detector (Super-AGILE)</strong></td>
</tr>
<tr>
<td>Energy Range</td>
</tr>
<tr>
<td>Field of view</td>
</tr>
<tr>
<td>Sensitivity (at 15 keV)</td>
</tr>
<tr>
<td>Angular Resolution (pixel size)</td>
</tr>
<tr>
<td>Source Location Accuracy</td>
</tr>
<tr>
<td>Energy Resolution</td>
</tr>
<tr>
<td>Absolute Time Resolution</td>
</tr>
<tr>
<td>Deadtime (for each of the 16 readout units)</td>
</tr>
<tr>
<td><strong>Mini-Calorimeter</strong></td>
</tr>
<tr>
<td>Energy Range</td>
</tr>
<tr>
<td>Energy Resolution</td>
</tr>
<tr>
<td>Absolute Time Resolution</td>
</tr>
<tr>
<td>Deadtime (for each of the 30 CsI bars)</td>
</tr>
</tbody>
</table>

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

X-ray detector
Super-Agile:
localize to
Δθ ~ few arcmin
Gamma Ray Sensitivities
Fireball Model: long GRBs

E.g., recent review on *GRB-Swift results & implications*:

---

**Internal Shock**

Collisions between different parts of the flow.

---

**External Shock**

The flow decelerating into the surrounding medium.

---

**GRB**

$\approx 10^{13} \text{ cm}$

---

**Afterglow**

$> 10^{16} \text{ cm}$
Simplest “delayed” GeV $\gamma$ mechanism?

A purely leptonic interpretation:

GeV $\gamma$ emission seen, start $\sim$ same time as MeV $\gamma$ trigger, but lasting $\sim$ 1 hr:

$\rightarrow$ could be

a) internal shock synchrotron

$\rightarrow$ normal duration MeV to $\sim$GeV

b) external shock (moder. $\Gamma$, low $n_{\text{ext}}$)

IC $\rightarrow$ $\sim$ GeV to TeV, lasts $\sim$mins-hr

(Meszaros & Rees 1994 MNRAS 269, L41)

• Other possib (Katz 94) : proton impact on bin. comp.* pp $\rightarrow$ p$\gamma$

Katz 94
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 $t_{\text{dec}}$, until reach $\Gamma \sim 2$.
- 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:**

- **py 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, π⁰ dec.
- Time decay of cascade rad, slower than a’glow decay (p’s have less rad. losses) → GLAST

Dermer, Atoyan 03, PRL 91, 1102;
Dermer, Atoyan 04, AA418, L5
GRB 941017: $p\gamma$ signature?

- 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 → $p\gamma$ 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)

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

- Internal shocks: $\gamma\gamma \rightarrow e^\pm$, $\tau_{\gamma\gamma} \sim 1$ @ $E_\gamma \sim \Gamma^2_{300}$ GeV
  $\rightarrow$ pair cutoff in spectr
  $\rightarrow$ get info about $r_{sh}$ (compactness, $t_{\gamma\gamma}$)

- In ext.shock, $\tau_{\gamma\gamma} < 1$ on GRB target $\gamma$;

- test if shock is int. or ext; test bulk Lorentz factor, shock accel efficiency, magnetic field in shock (max. $e^\pm$ energy? $\rightarrow$ size of accel region)

How high in energy, and how late?

- Very high $\Gamma \rightarrow$ low compactness, high $e^\pm$ cut-off
- Higher cut-off for (late) afterglow than for prompt
- External IGM reprocessing: late, depends on $B_{\mathrm{IGM}}$

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
XR $\rightarrow$ 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 $\rightarrow$ np decoupling
  - $\rightarrow (\pi^\pm, \pi^0)$
  - $\rightarrow \gamma_{\text{phot}} \gamma_\pi$ cascade
- SGRB @ $z \approx 0.1 \rightarrow$
  GLAST det.
  Razzaque & Mészáros, aph/0601652

Other DNS/NSBH GeV emission:
- neutron $\beta$-decay $\rightarrow e^-, p \rightarrow$ inner bremsstrahlung, GeV photons $\gamma_{\pi} \rightarrow$ 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)