GRB

Prompt and High Energy Emission

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Fireball Model of GRBs

Internal Shock
Collisions between different parts of the flow

External Shock
The Flow decelerating into the surrounding medium

Jet
Jet

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

Afterglow
$> 10^{16}\text{ cm}$
Prompt Optical Flashes: 3 models

(1994-1997)

- **GRB 990123** → bright (9th mag)
  - prompt opt. transient (Akerlof et al. 99).
  - 1st 10 min: decay steeper than forw.sh.
- → Interpreted as reverse external shock

Mészáros & Rees '97
Optical Flash : GRB 990123

Different time dep. of $\gamma$, opt. l.c.:
$\rightarrow$ infer opt is reverse shock

(Akerlof et al. 1999; Meszaros & Rees 1997; Sari & Piran 1999; Kobayashi 2000)
But: other prompt $\gamma, \text{opt}$?

*Sometimes same origin, sometime not?*  
(Vestrand et al, 06)
GRB 080319B

“naked eye” optical GRB

Racusin et al, 2008 Nature 455:183

$z=0.937$

$\gamma_{\text{opt}}$ l.c. similar $\rightarrow$ same emiss. region, but mechanism?

Interpret prompt as:

i) optical synchrotron

ii) 0.1-1 MeV IC (SSC) (and)

iii) predict 2nd order IC @ $\sim$100 GeV

Mészáros
Figure 2 | Composite Light Curve. Broadband light curve of GRB 080318B, including radio, NIR, optical, UV, X-ray and $\gamma$-ray flux densities. The UV/optical/NIR data are normalized to the UVOT $v$-band in the interval between $T_0 + 500$ s and $T_0 + 500$ ks. The Swift-BAT data are extrapolated down into the XRT bandpass (0.3-10 keV) for direct comparison with the XRT data. The combined X-ray and BAT data are scaled up by a factor of 45, and the Konus-Wind data are scaled up by a factor of $10^4$ for comparison with the optical flux densities. This figure
Supplementary Figure 7 | Two-Component Jet Model fit to X-ray Afterglow.

The X-ray afterglow is best described by the superposition of two broken power-laws, which is consistent with the narrow and wide jets of a two-component jet expanding into a stratified wind environment. The narrow jet dominates the first ~40 ks of the afterglow as indicated by the blue line, which shows the fit to the narrow jet component. After the narrow jet break decays, the wide jet dominates as indicated by the green line fit to late afterglow. The red line shows the superposition of both components and the overall fit to the X-ray light curve.
Supplementary Figure 6 | Three-Spectral Component Fit to the Decaying Optical Transient  Following the peak of the prompt optical flash, the optical transient light curve displays three distinct components that dominate in the intervals t<50s, 50s<t<800s, and t>800s. The initial decay of the bright optical flash is a power-law with $\alpha_1=6.5\pm0.9$ (dotted line). This is superimposed on a power-law with decay index $\alpha_2=2.49\pm0.09$ (dashed line) that dominates in the middle time interval and a third power-law with $\alpha_3=1.25\pm0.02$ (dot-dashed line).
Figure 4 | Schematic of Two-Component Jet Model. Summary diagram showing spectral and temporal elements of our two-component jet model. The prompt $\gamma$-ray emission is due to the internal shocks in the narrow jet, and the afterglow is a result of the forward and reverse shocks from both the narrow and wide jets. The reverse shock from the narrow jet is too faint to detect compared to the bright wide jet reverse shock and the prompt emission. If X-ray observations had begun earlier, we would have detected X-ray emission during the prompt.
An unusually long, smooth burst, $T_{90} \approx 2100 \pm 100$ s

Low luminosity, low energy: $E_{\text{iso}} \approx 6 \times 10^{49}$ erg

$z=0.033$, second nearest GRB (138 Mpc)

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Campana et al. 2006
Subsequent evolution—SN emerges

Figure 1 | Spectra of SN 2006aj and synthetic fits. The observed spectra of

Campana et al., 06, Nat 442:1008
Mazzali et al. 2006
Pian et al., 2006
A closer look at the XRT spectrum

Contribution of a fitted black-body component to the 0.3-10KeV flux constitute 20% of the total XRT fluence
(1) BB XR Component:
GRB060218/SN2006aj


• Anisotropy is a crucial ingredient: timescale \( \sim 10^3 \) s is attributed to sideways pattern expansion speed, not to radial speed.

• Breakout when \( \tau_T \sim c/v_s \), occurring (in the wind) at \( R_{\text{ph}} \sim 7 \times 10^{12} (T/0.17 \text{ keV})^{-4/7} (E_{\text{th}}/10^{49} \text{ erg})^{3/7} \) cm, for mass loss \( \frac{dM}{dt} > 10^{-4} \) Msun/yr when \( v_w \sim 10^3 \) km/s

• Note: corresponds to mass loss within last day before explosion–no data on such winds

• Anisotropy of semi–relat. shell & wind compatible with & expected from rotation effects (e.g. Burrows et al, aph/0608033, Metzger et al, aph0608682, Burrows et al, aph/0702539, etc
Origin of non-thermal gamma, X-rays: 

**Bulk comptonization** of semi-relativ. shock thermal photons scattering against progenitor wind (i.e., do not need highly relativistic jet in low lum GRB/SN)

Wang, Li, Waxman, Meszaros 
aph/0608033
Other supernova-GRBs

1) Low-luminosity GRB (& often high luminosity SN..)
2) Smooth light curves
3) Spectrum: a simple power-law with a high energy cutoff

Shorter $T_{90}$ duration for GRB980425 and GRB031203: possibly shock breakout from the star envelope (i.e. no optically thick wind)

Table 1: The spectrum of three nearby low-luminosity GRBs

<table>
<thead>
<tr>
<th>GRB/SN</th>
<th>$z$</th>
<th>$E_{\gamma,iso}$(erg)</th>
<th>$\alpha$</th>
<th>$\varepsilon_c$(KeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GRB980425/SN1998bw</td>
<td>0.0085</td>
<td>$8.5 \pm 0.1 \times 10^{47}$</td>
<td>0.45 ± 0.22</td>
<td>~ 200</td>
</tr>
<tr>
<td>GRB031203/SN2003lw</td>
<td>0.105</td>
<td>$4 \pm 1 \times 10^{49}$</td>
<td>0.63 ± 0.06</td>
<td>&gt; 190</td>
</tr>
<tr>
<td>GRB060218/SN2006aj</td>
<td>0.0331</td>
<td>$6.2 \pm 0.3 \times 10^{49}$</td>
<td>0.45</td>
<td>~ 30$^8$</td>
</tr>
</tbody>
</table>
GRB prompt broadband emission (CGRO era)

- Internal shock standard leptonic emission (sy, IC)
- Details depend on \( \gamma_{e,\text{min}} = \varepsilon_e (m_p/m_e) \Gamma_{sh} \) and \( \varepsilon_B \) (i.e. Compton Y)
- \( \gamma\gamma \) cutoff @ GeV depends on \( t_{\text{var}} \) (i.e. \( r_{sh} \sim c t_{\text{var}} \Gamma^2 \))

Papathanassiou, PM 96

\[
\log \varepsilon_B = -3
\]
\[
\log \varepsilon_B = 0
\]
**But:**

**GRB GeV emission:** hadronic ?

$\gamma p$ EM cascades

- Ext. forw. shock synchrotron $\rightarrow$ MeV $\gamma$s
- Proton acceleration (Fermi), spectral index $-2$, $U_p \sim U_e$,
  $\Rightarrow$ p-synchr. & **$\gamma p$ cascades,**
  $\rightarrow$ $e^+$ sync, $\pi^0$ dec.
- Time decay of cascade radn, slower than afterglow decay (p’s have less rad. losses) $\rightarrow$ distinguish from leptonic, detect with GLAST

Dermer, Atoyan 03, PRL 91, 1102;
Dermer, Atoyan 04, AA418, L5
GRB: prompt GeV

**basic int. shock model:**

Spectrum depends on whether leptonic or hadronic; if e, cooling regime; also B, Γ, r, etc. (semi-analytical)

Gupta-Zhang 07 MN 380:78
Fig. 2. Synchrotron (dot-dashed lines) and SSC (dashed lines) prompt emission spectra for a burst at redshift $z = 1.0$. The fireball Lorentz factor is fixed to $\Gamma = 600$, and the other parameters are the same as in Fig. 1. We display the predicted spectra for three different values of the burst temporal variability $t_v$: 0.1 ms (red), 1.0 ms (blue) and 10 ms (purple). The solid lines and the dot-dot-dot-dashed lines represent AGILE and GLAST sensitivity for an integration time of 10 s (in grey) and 50 s (in black). The solid vertical lines refer to the Swift XRT (red) and BAT (black) energy ranges.
XR Flares $\Rightarrow$ GeV $\gamma$ Flares?

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

If so, $\rightarrow$ XR emission is inside the external shock

$\rightarrow$ IC upscatter XR photons by ext shock e$^-$

$\rightarrow$ GeV flares $\rightarrow$ GLAST det

X.Y. Wang, Li, Mészáros 06 ApJ 641:L89
XR $\rightarrow$ GeV Flares

\[ \text{int sy- int IC} \quad \text{ext sy-ext IC} \]

\[ \text{int. sy-ext IC} \]

Delay caused by anisotropic IC from higher lat.

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


Monte Carlo simulations: Photon signature of protons may be easier to find than neutrinos!
If GRB are UHECR sources, may need $\varepsilon_p/\varepsilon_e \gtrsim 10 \rightarrow$ tends to give photon peak at higher energies

**Prompt hadronic secondary photons (GeV)**

*Asano, Inoue & Mészáros arXiv:0807.0951*

Diagnostic for

↑: high $\varepsilon_p/\varepsilon_e$
←: high bulk $\Gamma$
→ : high $\varepsilon_B/\varepsilon_e$
Conclusions

• Will learn much from coordinated sub-MeV / GeV obs.
• GRB 0980916c is the first high quality GeV GRB... now need find others with simultaneous Swift/ground obs.
• Will be able to constrain electron and proton acceleration / shock parameters, compactness of emission region (dimension, magnetic field,...)
• Will constrain total energetics & fraction in UHECR, UHENU components
• Do GRB contribute significantly to UHECR? At what E?
• Geometry of jet(s): progenitor & total GRB spatial density needs will be better understood / constrained
• Are there VHE-bright, MeV-dark GRBs? Relation to un-ID TeV?