The radiation mechanism in Gamma-Ray Bursts and X-ray Flashes

*Davide Lazzati* (IoA, Cambridge)
Outline of the talk

1. Introducing GRBs & XRFs
3. Models
5. Linear polarization in relativistic fireballs
6. Can all GRBs and XRFs be dominated by synchrotron?
7. Summary & future prospects
A Gamma-Ray night sky
A GRB history

BeppoSAX discovers afterglows and allows for redshift measurements to set the distance scale and energetics

Cracow, 24 June 2003

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A GRB history

The vela satellites discover the first GRB ever in 1967 (published in 1973)
A GRB history

BATSE on board Compton
GRO observes 2704 GRB light curves and spectra

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GRB facts

1. Appear Randomly in the Sky
2. Last between 1ms and 1000s
3. Bimodal distribution (2 classes; Afterglow only for long GRBs)
4. Highly variable (record spike 200µs)
5. Isotropic energy $E_{\text{iso}} = 10^{52-54}$ erg
6. Beamed (real energy $\sim 10^{51}$ erg)
7. Non-thermal spectra (exponentially smoothed broken power-law)
8. Relativistic expanding ($\Gamma > 100$)
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2704 BATSE Gamma-Ray Bursts

Fluence, 50-300 keV (ergs cm$^{-2}$)
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X-ray flashes

Duration (Heise 2003)

Spectrum (Kippen 2003)
The internal-external shock scenario

- Inner engine releases unsteady flow of $\sim 10^{52}$ erg
- Shells with different $\Gamma$ catch up at $R \sim R_0 \Gamma^2 \sim 10^{13}$ cm
- Shock waves (internal) accelerate electrons and generate magnetic fields causing synchrotron emission
- At $R \sim 10^{16}$ cm an (external) shock is driven in the interstellar medium
- Again synchrotron emission but at lower – and decreasing - frequencies

Peak Energy Distribution
(Preece et al. 2000)

Power-law slopes

Low Energy

High Energy

\[ N(\nu) = A \nu^{\alpha(\beta)} \]

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Amati et al. 2003
Synchrotron internal shocks have problems

2) Spectrum

![Graph showing spectrum distribution](image-url)
Synchrotron internal shocks have problems

2) Spectrum

The distribution of \( \alpha \)

Non cooling synchrotron has \( \alpha > -2/3 \)

But if electrons cool, they produce a softer spectrum

\[ t_{\text{cool}} \sim 10^{-7} \nu_{\text{MeV}}^{-2} \text{ s (observed)} \]
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3) Alternatives

- **Comptonization**
  - Good for low energy index $a$
  - Bad for high energy power-law (optically thick)
  - Bad for peak frequency

- **Compton drag**
  - Good for high efficiency
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  - Requires ad-hoc assumptions for spectrum
  - Bad for time variability

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Observations (Dec. 2002)

RHESSI observations of GRB021206 reveals

\[ P_{\text{lin}} = 80 \pm 20 \% \]

(Coburn & Boggs 2003)
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Polarization ← Synchrotron
The maximum polarization of synchrotron

\[ \Pi = \frac{(p+1)}{(p+7/3)} \]

could in principle be achieved

\( n_e(\gamma) = A \gamma^{-p} \)

\( p=3 \) would give \( \Pi = 75\% \)
Relativistic effects

Lyutikov et al. 2003

For $p=3$

$\Pi = 56\%$
Where was $\Pi$ measured?

The classic equation holds for the power-law branch with $h_\nu > h_\nu^{\text{peak}}$.

$\Pi = \frac{p+1}{p+7/3}$

$\Pi$ was measured around the peak of the spectrum.
Consider $p=4$
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A mildly anisotropic distribution of the pitch angles is required to suppress the relativistic dilution of linear polarization, reconciling the RHESSI measurement with expectations.
What about the “line of death”? 

There is still a subset of GRB spectra that **cannot** be explained by **optically thin synchrotron**. Optically thick synchrotron requires too large $B_B$ components? They should be less polarized.
Summary & Discussion

- GRBs & XRFs have similar properties and we therefore expect them to be similar objects characterized by different typical frequencies.
- GRB photons supposed to be due to synchrotron, but many problems led to several alternative proposals.
- Detection of polarization washes out doubts: at least in one case synchrotron is the dominant mechanism.
- It is not at all easy to produce the observed polarization with relativistically boosted synchrotron.
- A mild collimation of pitch angles is required (tells us something about particle acceleration?)
Summary & Discussion

- Polarization measurement is still a single case, confirmation required
- To be explained why the typical low-energy slope is $F(\nu) = A \nu^0$
- A number of GRB spectra (especially at early times) cannot be due to optically thin synchrotron
- Correlations, yet to be understood, open a window between micro and macro-physics of jets