The structure and magnetization of GRB jets

Davide Lazzati - IoA, Cambridge
Evolution

$\log R$

$\gamma$-ray phase

Precursors

Afterglow

$\log \Gamma$

$\log R$
Afterglow phase

Since $\Gamma$ is small, best phase to study jet structure
Afterglow light curve
Polarization curve
Afterglow phase

Homogeneous jet  Gaussian jet  Structured jet
Afterglow light curve

Rossi et al. 2004

Flux (mJy, R Band)

- SJ $\theta_o=4^\circ$
- $H\alpha$ $\theta_o=0$, $\theta_{jet}=8^\circ$
- $H\alpha$ $\theta_o=0.87$, $\theta_{jet}=8^\circ$

t(days)
Afterglow light curve

Rossi et al. 2002

Flux density (arbitrary units)

$10^{0}$ $10^{-2}$ $10^{-4}$

$t(s)$

$10^{3}$ $10^{4}$ $10^{5}$ $10^{6}$ $10^{7}$

$\alpha_{\varepsilon} = 1$ $\alpha_{\varepsilon} = 2$ $\alpha_{\varepsilon} = 3$ $\alpha_{\varepsilon} = 4$
Afterglow light curve

GRB 021004

Time [days]

mag

t = 0.25

R GCN
I papers
R papers
V papers
B papers
(U+I) papers
K GCN

time [hours]
Afterglow polarization

If $B$ is stochastic then polarization curve tells us about the energy distribution of the jet.

If $B$ is coherent polarization signature is clear.
Afterglow polarization

Rossi et al. 2004

![Graph showing polarization degree over time](image)
Afterglow polarization

DL et al. 2004
Afterglow polarization

GRB 020813  DL et al. 2004

Time after GRB explosion (days)
Afterglow polarization

GRB 030329  Greiner et al.

2004
Is the phase in which we observe the fireball with the largest Lorentz factor. Emission samples a very local portion of the fireball. Information on overall structure can be gathered with statistical studies. Polarization measurements can constrain B structure.
Figure from Lamb et al. 2004; see also Frail et al. 2001; Panaitescu & Kumar 2001
Figure from Lamb et al. 2004; see also Amati et al. 2002; Lloyd-Ronning et al. 2000
\(\gamma\)-ray phase

Standard energy correlation between local and global implies a regular jet.

Amati correlation is local in both variables and gives no information on jet structure.

New correlation between \(\xi_{\text{peak}}\) and \(E_{\text{true}}\) (Ghirlanda et al. 2004) strengthens need for regular jets.
Evolution

\[ \text{Log } \Gamma \]

\[ \text{Log } R \]

\[ \gamma\text{-ray phase} \]

Precursors
Precursors

Predicted thermal precursors in all models

Spectrum of precursor gives constraints on baryon content of fireballs

Time of precursors give constraints on the origin of GRB variability
20% of bright long BATSE GRBs have precursor activity.
Precursors

We see precursors with $\Delta t \sim 50$ s

Predicted precursor delay

$$\Delta t = \frac{R_\gamma}{2c} \Gamma^2 = 0.02 \, R_{\gamma,13} \, \Gamma_2^2$$
Precursors

Consider now the minimum variability timescale, set by the fireball curvature:

\[ t_{\text{var}} > \Delta t_{\text{curv}} = \frac{R_\gamma}{2c} \Gamma^2 = \Delta t \]
Precursors: ways out

Are they really precursors?
Precursors: ways out

Softer than average GRB

But all precursors for which spectral information is available are NON THERMAL
Are they really precursors?
Curvature timescale does not apply: the fireball is fragmented or emission is beamed in different directions in the fireball comoving frame.
Precursors: ways out
Precursors: ways out

Are they really precursors?
Curvature timescale does not apply: the fireball is fragmented or emission is beamed in different directions in the fireball comoving frame
Jet properties evolve & jet is magnetic dominated
Non thermal character of precursor implies that B dominates by at least a factor of 10 over baryon energy for reasonable stellar radii.
Conclusions?

All radiative phases of GRBs give information on jet structure and content.
Afterglow requires either magnetic or inhomogeneous jet, in some cases may be non-regular.
Prompt sets statistical strong limits on non-regularity.
Precursors may call for non constant properties of the jet, necessarily implying a structured jet.
Afterglow polarization at early times in a smooth afterglow (!!!)
Statistical prompt emission studies will have to wait for a big sample of GRBs to be accumulated
Precursors are still to be understood before any firm conclusion can be drawn (work for theorists)