In Gamma-Ray Bursts, Timing (vs. Energy) Is Literally Everything*

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Timescales in GRBs:

(1) Bimodal Duration Distribution

(2) “Contiguous Emission Episodes” — Pulse Conglomerates

(3) Individual Pulses, organized in time and energy

* (almost: there’s also polarization)
GRB Duration Distribution

S/N equalized (Bonnell et al. 1997)

BATSE 4B

$N_{occ}$

$T_{90} (s)$

$10^{-2}$  $10^{-1}$  $10^{0}$  $10^{1}$  $10^{2}$  $10^{3}$
Quiescent times in gamma-ray bursts – I. An observed correlation between the durations of subsequent emission episodes

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Figure 3. Correlations between the temporal properties of the different emission periods. In panel (a) we plot the duration of an emission episode (pre-quiet burst time) against the duration of the following quiescent time. No clear correlation is found in this case. In panel (b) we plot the duration of an emission episode (after-quiet burst time) against the duration of the previous quiescent time. There is a clear trend: the longer the quiescent time, the longer the duration of the following emission period.
Overview. GRB time profiles are notoriously heterogeneous – chaotic and unpredictable in appearance – challenging to physical modeling attempts. The first quantitative indication of a global tendency was the “□” asymmetry parameter (Nemiroff et al. 1994): Bursts are asymmetric on all timescales. Even for bursts at one extreme (example at right), where the spike-like pulses are nearly symmetric at BATSE energies, the envelope is asymmetric.

The “Pulse Paradigm” (Norris et al. 1996) further elucidates burst behavior: Pulses range from narrow and nearly symmetric, to wide and asymmetric, with low energy lagging high energy (schematic at left).
> 300 keV : blue
100-300 keV : green
50-100 keV : yellow
25-50 keV : red
BATtrigger #6526: GRB 971208
Simplistic geometrical explanation of connection between temporal lag as function of energy:

\[ \Delta t \sim R \left(1 + z\right) / 2 \cdot c \cdot \Gamma^2 \]

\[ v_{\text{line-of-sight}} = 2 \Gamma v_{\text{source}} \]

\[ v_{\text{emission edge}} = \Gamma v_{\text{source}} \]

GRBs: \( L_{\text{peak}} \) vs.
GRB 970201: Locus of Flux(t) vs. $E_{\text{peak}}(t)$ in decay phase of pulse evolves faster than pure relativistic kinematics of colliding shells.

Measures such as off-axis shells, varying shell thicknesses could not reproduce the observed pulse decay profiles.

Only slow cooling timescales superposed on the kinematics effected sufficient pulse evolution to match pulse spectral behavior.

Left. Not observed: pulse peak is energy-independent, and pulse centroid only slightly later in time at low energy.

Right. Observed: pulse peak shifts to later times at lower energies, centroid shifts significant fraction of pulse width. (Slow cooling required to reproduce the Observed behavior.)
A Main Sequence “HR Diagram for Gamma-Ray Bursts”

\[ L_{53} \approx 1.1 \frac{\square}{(\text{lag}/0.01 \text{ s})^{-1.15}} \]
$\theta_{\text{jet}}$ varies, 
$\sim 2^\circ-20^\circ$.

$\theta_{\text{view}}$ varies, 
outside jet cone.

$\theta_{\text{view}}$ varies, 
inside profiled jet.

**Beaming Fraction**

$L \sim \text{const.}$

$\frac{L_d}{L} \sim \text{constant},$

$\mu \sim L^{-1}$.

**Viewing angle**

Special Relativity:

Lorentz contraction

& Doppler boost

$L(\theta)$ reflects $\theta(\theta)$:

$30 < \theta(\theta) < 1000$

(jet fastest on axis)

**Profiled jet**

All three models realize broad observed, but narrow actual Luminosity and Energy distributions.
$L < 10^{-2}L_{53}$ (sensitivity-limited)

Observed: $dN/dL \sim L^{-1.0}$

Viewing Angle: $dN/dL \sim L^{+1/6}$

$z < 2, L > 10^{-1.5}L_{53}$ (vol-limited)

Observed: $dN/dL \sim L^{-1.8}$

Viewing Angle: $dN/dL \sim L^{-2}$
$L < 10^{-2}L_{53}$ (sensitivity-limited)

**Beaming Fraction Scenario:**

\[
\frac{dN(W_{jet})}{dW_{jet}} \propto W_{jet}^{-0.2}
\]

$z < 2$, $L > 10^{-1.5}L_{53}$ (vol-limited)

**Beaming Fraction Scenario:**

\[
\frac{dN(W_{jet})}{dW_{jet}} \propto W_{jet}^{0.5}
\]
$L < 10^{-2}L_{53}$ (sensitivity-limited)

Profiled Jet Scenario:

$L_{\text{jet}}^{-5/2}$

$z < 2, L > 10^{-1.5}L_{53}$ (vol-limited)

Profiled Jet Scenario:

$L_{\text{jet}}^{-5/2}$
Conclusions/Predictions

High-luminosity GRBs:

- GRB Distribution in redshift continues to rise to $z \sim 10$. But, this result has large uncertainty, arising from extrapolated correction for redshift of the energy-dependent time profiles.

- In a volume-limited regime ($z < 2$), $dN_{\text{vol}}/dL \sim L^{-1.8}$. This dependence is easily producible in the profiled jet scenario. Whereas, in the pure viewing angle scenario no wiggle room is left for range of beaming fractions or viewing angle ($dN_{\text{vol}}/dL$ would be too steep). The variable beaming fraction scenario requires $dN(\theta_{\text{jet}})/d\theta_{\text{jet}} \propto \theta_{\text{jet}}^{-0.5}$, a rising dependence.

- For highly luminous GRBs ($L_{51} > 3-20$), the required fraction of participating SNe is: $R_{\text{GRB}} \sim 0.003-0.015 \div R_{\text{SNIb/c}}$. 
A Population of Long Spectral Lag

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Subsample (~ 7%) of soft-spectrum BATSE GRBs:
  - Very long pulses and spectral lags (>~ 1 s)
  - Tendency towards Supergalactic Plane
  - \( d < 100 \text{ Mpc} \)
  - Ultra-low luminosity (<~ \( 10^{48} \text{ ergs s}^{-1} \))
  - \( R_{GRB} \sim R_{SN \text{ Ib/c}} \)

Could be LIGO II sources (but probably not UHECR sources).
Figure 10. Three-dimensional isodensity contour plots of the local Universe. The density field (average mask model) has been smoothed with a 500 km s\(^{-1}\) Gaussian filter. Only features within 8000 km s\(^{-1}\) are shown. The Local Group lies at the centre of the plot (indicated by an 'x'), with the North Galactic Pole towards the top of the box (the Z-axis). The X-axis is towards the Galactic Centre and the Y-axis is in the direction of galactic rotation. Superclusters are labelled with the name of the nearest cluster or group. The isodensity contour is at \(\delta_L = 1.5\). (a) The viewpoint is from \(l = 35^\circ, b = 25^\circ\), nearly perpendicular to the Supergalactic Plane. (b) The viewpoint has been rotated by 90° in longitude so that it is almost aligned with the Supergalactic Plane; it is now from \(l = 125^\circ, b = 25^\circ\). Note the concentration of superclusters towards the Supergalactic Plane.
SNe Ib/Ic: 62 detected 1954-2001.75,
(> 2/3 since 1998.0)
With 85% at distances < 100 Mpc.

Only ~10% of “nearby” SNe are detected.
See ~ 90 GRB Sources w/in 100 Mpc: $R_{\text{GRB}} \sim 100/\text{yr} \sim _{-}\, R_{\text{SN Ib/c}}$

Grav. Wave Strain $h > 10^{-24}$  Possible LIGO II sources
Possible Confirmation Approaches

(1) Untriggered BATSE bursts: For $F_p < 0.25 \text{ ph cm}^{-2} \text{ s}^{-1}$ long-lag bursts predominate. But, larger localization errors; ID’ing as bona fide GRBs is problematic.

(2) ~ 400-500 additional triggered BATSE bursts.

(3) Cross-correlation of nearby matter distribution ($d < 100 \text{ Mpc}$) and GRB positions (M. Hudson).

(4) Extrapolation of SNe light curves to $T_0$, comparison with GRB times and positions (J. Bonnell).

(5) Swift
Conclusions/Predictions:

- Near BATSE trigger threshold: Long-lag (ultra low-Luminosity) GRBs become numerous (~ 50% of BATSE sample):
  - For Long-lag GRBs ($\Delta t_{ag} > 0.35$ s), $N(>F_p) \propto F_p^{-3/2}$
  - Long-lag GRBs have very soft spectra.
  - For $\Delta t_{ag} > 1.5$ s $\rightarrow >2 \rightarrow$ Quadrupole w.r.t. Super-G plane.
  - $R_{GRB} \sim 100/yr \sim R_{SNIb/c}$.
  - LIGO II sources?
  - Swift should see a larger fraction of “really long-lag” GRBs. Many chances to find the associated SNe. Untriggered BATSE bursts should be dominated by “really long-lag” GRBs.
Determined GRB Redshifts
Rock of Ages
Wit's End by Dave Barry

By Dave Barry
Sunday, February 17, 2002; Page W44

You can skip this column. I'm sure you have more important things to do. You don't need to waste your valuable time reading about how MILLIONS OF PEOPLE, POSSIBLY INCLUDING YOU, RECENTLY WERE ALMOST KILLED BY A GIANT SPACE ROCK. And there are more coming and nobody is doing anything about it. Excuse me for going into CAPS LOCK mode, but I am a little upset here. In case you didn't hear about it, which you probably didn't: On January 7, an asteroid 1,000 feet across -- nearly three times the current diameter of Marlon Brando -- barely missed Earth, which is most likely your planet of residence.

What do I mean by "barely"? I mean that this asteroid, traveling at 63,000 mph, came within 400,000 miles. In astronomical terms, that is nothing. To get an idea how close this thing came, imagine that your head is Earth. Now hold your right hand, representing the sun, at arm's length. Now take your left forefinger, representing the asteroid, and move it toward Earth at 68,000 mph until your pinkie is up to the knuckle in your left nostril. Now try to type a sentence. That is what I mean by "barely."

... As it happens, the American Astronomical Society was holding a conference in Washington at the very same time as the asteroid nearly hit Earth. I know this because the New York Times covered the heck out of the conference. Here's the scary part: The Times did not print one word about the asteroid. Instead, as this thing whizzed past, the Times printed the following exciting astronomy news:

JANUARY 8 -- Astronomers have discovered that certain gamma rays, which they used to think came from billions of light-years away, in fact came from only a few hundred million light-years away!

JANUARY 9 -- Having studied the far edges of the universe with the Hubble telescope, astronomers now believe that roughly 14 billion years ago, stars formed more quickly than was previously thought!

JANUARY 10 -- Astronomers "peering deep into the heart of the Milky Way" have discovered more than 1,000 sources of "powerful X-rays," far more than were previously known!