Explosion of Cosmic Explosions

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‘‘Reports that say that something that has not happened is always interesting to me...

The message is that there are known knowns, there are things we know that we know.

There are known unknowns, that is to say there are things that we now know we don’t know.

But there are also unknown unknowns, there are things we do not know we don’t know and each year we discover a few more of the unknown unknowns.’’

Mr. Donald Rumsfeld, Department of Defense new briefing
Two classes of GRBs

Short - Hard

Long - Soft

1676 BATSE Bursts
Long Duration Bursts:

Kulkarni et al.
Bloom et al.
Frail et al.
Berger et al.
Soderberg et al.

Collapsar Model: Woosley, Heger, MacFadyen
Collapsar: The Movie

A Hollywood-Bollywood Production

From Bogus Enterprise,

A Division of General Propaganda
Long Duration GRBs: Questions

• Core Collapse: Bimodal or Continuum
  – Bimodal: Engine dominated vs pure collapse
  – Continuum: an engine is always present

• Production of Radioactive Nickel:
  – Only one channel: spherical shock
  – Two channels: spherical shock & jets
A New Family of Cosmic Explosions:
SUMMARY: Peak SN magnitudes

(Soderberg et al. 2005b)
SHORT GAMMA-RAY BURSTS
The birth of a black hole seen in the stars

INFLUENZA PANDEMIC
Genome sequence of the 1918 virus

SEX PHEROMONES
A glint in the eye

EARTHQUAKES
Pulling the trigger
Toward the SHB Progenitor: Redux

- How far away are they?
- How much energy do they release?
  - is the energy release isotropic or collimated?
  - are the central engines long or short-lived?
  - Is there associated non-relativistic ejecta?
- What are the progenitors?
  - Clue (macro) = host galaxy + offset
  - Clue (micro) = circumburst environment

The key to answering these questions has been the precise positions enabled by the discovery of long-lived afterglows.
NSC J123610+285901
\[ z = 0.225 \]

Bloom et al. 2005

Wavdetect position of diffuse emission

GRB 050509b

Optical Cluster Center

1'

N

E
HST imaging & search for supernova explosion

Fox et al. 2005
GRB 050724: *Swift*

Berger et al. 2005
Keck Laser Guide Star AO
GRB 050724 Host Galaxy
Keck/LGSAO/Narrow Camera
K'-Band

Red elliptical
z=0.258
L=1.6 L_
SFR<0.03 M_ yr^{-1}
Toward the SHB Progenitor

• How far away are they?
  – At least some short bursts are $z \sim 0.2$
• How much energy do they release?
  – About $10^{49}$ to $10^{50}$ erg
  – Evidence for "jets"
• Is there an associated supernova explosion?
  – Supernova, if any, are faint ($M_v > -13$)
• What are they?
  – Both elliptical and star-forming host galaxies
Holy smokes, he is dead?!!
Coalescence of Neutron Stars (Shibata)
Macronova

- Is there a sub-relativistic explosion accompanying short hard bursts?

  Li & Paczynski 1998

- If so, (observationally)
  > Nova
  < Supernova

  => “Mini-supernova” or “Macronova”

  Kulkarni 2005
Black Hole-Neutron Star (Rupert, Janka)
Macronova Model

- Parameters: $M_{\text{ejecta}}$ & $v=\beta c$
- Composition
  - Free Neutrons
  - Radioactive Nickel
  - Neutron Rich Material (non-radioactive)
- Injection of energy essential for macronova to shine and be detectable
The total heat of the system is due to the electrons (density, \( n_e \)), ions (density, \( n_i \)) and photons:

\[
E/V = \frac{3}{2} n_i (Z + 1) kT + aT^4, \tag{2}
\]

where \( V = 4\pi/3 R^3 \), \( N_i = M_{ej}/(A m_H) \), \( n_i = N_i/V \), \( n_e = Z n_i \) and \( m_H \) is the mass of a hydrogen atom. For future reference, the total number of particles is \( N = N_i (Z + 1) \). This heat store has gains and losses described by

\[
\dot{E} = \varepsilon(t) - L(t) - 4\pi R(t)^2 P v(t) \tag{3}
\]

where \( L(t) \) is the luminosity radiated at the surface. \( P \) is the total (electron, ion and photon) pressure and is

\[
P = n_i (Z + 1) kT + aT^4/3. \tag{4}
\]

As explained earlier, the ejecta gain speed rapidly from expansion (the \( 4\pi R^2 P v_s \) work term). Thus, following the initial acceleration phase, the radius can be expected to increase linearly with time:

\[
R(t) = R_0 + v_s t; \tag{5}
\]

With this (reasonable) assumption of coasting we avoid solving the momentum equation.
Heating by Decay of Neutrons

Even though half life is 10 minutes, neutron heating results in detectable signals.

\[ \varepsilon(t) = 5.4 \times 10^{14} \text{ erg gm}^{-1} \text{ s}^{-1}. \]
Heating by Neutron Decay

Problem: Initial photons radiated away
GRB 050505B: Keck/Subaru

Error radius = 9.3 arcsec

Kulkarni et al. 2005
HST Imaging: No Supernova

Error radius = 9.3 arcsec
4 HST Epochs
May 14 to June 10

Giant elliptical Bloom et al
L=1.5L_
SFR<0.1 M_\odot yr^{-1}

Kulkarni et al. 2005
Comparison to Data (GRB 050509b)

\[ \beta = 0.5 \]

\[ \beta = 0.05 \]
Heating by Decay of Ni$^{56}$

- Nickel decay results in 1.72 MeV gamma-rays.
- A few scatterings are needed to transfer bulk of the energy to electrons.
- Unlike ordinary SN, the ejecta become transparent to gamma-rays before 6 days.
\[ \beta = 0.1 \]

\[ \beta = 0.05 \]
The Macronova as a reprocessor

• Long lived central source (e.g. magnetar)
• Long lived accretion disk

There are already indications of tremendous late time activity.
Barthelmy al. 2005
Caveat: assumes no funnel geometry

Figure 8.

angular frequency and $P$ is the rotation period. For $B = 10^{15}$ G, $R_n = 16$ km we obtain $dE/dt \sim 10^{42}(P/100\text{ms})^{-4}$ erg s$^{-1}$ and the characteristic age is $5 \times 10^4$ s (Fig. 8).
Bottom Line

- Neutron decay: Keck/Subaru data (2 hr-26 hr) constrain, over the velocity range 0.05c to 0.5c,
  - Kinetic energy of the macronova to be less than $10^{49}$ erg, comparable to $E_\gamma$(isotropic)
- Nickel decay: Keck+HST constrain Nickel mass to be $<10^{-2}\text{ M}_\odot$
- Continued activity/flares but constrained to be less than $10^{41}$ erg/s on timescales of hours to days
TRANSIENT UNIVERSE 2006:
the Popular, the not so Popular
and the Knowable Unknowns

Kavli Institute for Theoretical Physics
Santa Barbara 13-14 March 2006

Eds. A. Rau & E. O. Ofek

Los Alamos National Laboratory
Kavli Institute for Theoretical Physics
California Institute of Technology
Dolicho: long
Brachy: short
Finding Brachynova ain’t easy

THE DEEP LEN S SURVEY TRANSIENT SEARCH. I. SHORT TIMESCALE AND ASTROMETRIC VARIABILITY

A. C. Becker, 1,2,3 D. M. Wittman, 1,4 P. C. Boeshaar, 4,5 A. Clocchiatti, 6 I. P. Dell’Antonio, 7 D. A. Frail, 8 J. Halpern, 9 V. E. Margoniner, 1,4 D. Norman, 10 J. A. Tyson, 1,4 and R. A. Schommer 11

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A Foreground Fog of Flares

Kulkarni & Rau (2006)
Dolichonova?

• Stellar mergers are common
  – 51 Peg-B like companion
  – Stellar companion -> Common envelope

• What does a stellar merger look like?
  – Is it an explosive transient?
  – Is it a very long lived transient?
Mergers (aka common envelope) can be explosive
Dolichonova?
Finding Dolichonova is easy

- V838 Mon, V4332 Sgr and M31-RV -- found serendipitously
- Long life means that the survey can be done leisurely
- Super Eddington is the best criterion to filter out novae

=> A survey of nearby mass concentrations is likely to pay off

(as we go to press …)
“It’s somewhere between a nova and a supernova
... probably a pretty good nova.”