GRBs with Dim Supernovae

Aimee Hungerford and Chris Fryer w/ Patrick Young and Frank Timmes (LANL)

- A little bit on Collapsars
- Nucleosynthesis in Collapsars
- Calculating Light Curves
Gamma-Ray Burst Engines

The Black Hole Accretion Disk systems are the leading models for GRBs with collapsars (the collapse of a massive star) the favored model for long-duration bursts and neutron star mergers the favored model for short duration bursts.

Hyperaccreting Black Holes

- NS - NS merger
- BH - NS merger
- BH - WD merger
- NS/BH - He core merger after common envelope

S. Woosley, Ringberg, 1997
Why does BH formation open up a new type of explosion?

• Angular Momentum can move from a supporting role (possibly producing asymmetries) to the lead role (energy source) in the explosion. But this does not preclude NS accretion disks as an explosion mechanism - we just don’t understand rotation enough to say one way or the other.
Two Types of Collapsar: Direct Collapse (I) and Fallback (II)

Fryer 1999

Warning! Assumes no mass loss
Prediction - SN vs. Hypernovae

Nomoto et al. (2003)

13M⊙ ~ 15M⊙

Main Sequence Mass, (M⊙)

$E_K$ (Kinetic Energy ($10^{51}$ ergs))

Hypernova Branch

Faint SN Branch

Failed SN?

Jets!
Can we differentiate the two different GRB scenarios?

- Fallback BHs are likely to be more common, but
- Accretion rates on Fallback Black Holes are lower and such BHs may not produce strong GRBs
- Fallback BHs are formed after a weak supernova is launched - as we shall see, this can mean a different nucleosynthetic yield!
GRBs produce heavy elements in 2 ways.

I. In the accretion disk itself, ejected in a wind (e.g. Surman and collaborators; Pruet and collaborators)

II. “Explosive Nucleosynthesis” in the strong shock (Nomoto and collaborators)

Surman, Mclaughlin & Hix 2006
Nucleosynthesis with a Fallback BH

- The weak supernova pushes material outward. If the delay is long, the temperatures and densities from the shock will be lower than predicted by a single strong explosion.
- The longer the delay, the more fallback and less material ejected.

CF, Patrick Young, & AH
Explosive Nucleosynthesis Yields from Fallback GRBs (long delays produce little $^{56}\text{Ni}$):

- $^{56}\text{Fe}$ - solid line
- Titanium - dotted line
- Calcium - dashed line
We can not simply state that higher entropy means we will produce more of something and less of something else. Instead, we are trying the Brad Meyer approach of understanding the results over a grid.

AH, Timmes et al. 2007
Understanding Yields - sometimes it works, sometimes it doesn’t

$T_{\text{peak}}, \rho_{\text{peak}}$ studies alone can roughly estimate the yields, but not exactly.
Low Nickel Yields Imply Low Supernova Luminosities

Long-Duration (?) GRBs have been observed with no associated supernovae.

- Are these fallback black holes?
- Can the dim supernovae place limits on the nickel yields?

Fynbo et al. 2006
We can calculate these light-curves using RAGE

- RAGE - Radiation Adaptive Grid Eulerian
- Adaptive Mesh Refinement Scheme (more primitive hydro solver than FLASH)
- Multi-group flux-limited diffusion scheme (we show gray simulations here)
- Connected with LANL opacities and equations of state
- 1,2, and 3 dimensions (we show 1D spherical results here)
We ran a series of models, focusing on our long-delay 23 solar mass progenitor with its 2e-5 solar mass per year mass-loss rate.
With our fast 
$\left(10^{52} \text{ erg}\right)$
explosions and 
low nickel yields,
the light curve 
peaks early and 
drops suddenly 
(dominated by 
thermal energy 
and not $^{56}\text{Ni}$ 
decay). The 
strength of the 
wind plays the 
dominant role in 
producing the 
emission. Light 
curve estimates 
measure winds, 
not $^{56}\text{Ni}$.

CF, AH, and Patrick Young
Conclusions

• Nucleosynthesis for Fallback BH GRBs will be different (less heavy element production), but the exact yields sensitive to a lot of effects.
• Fallback BH GRBs can produce dim supernovae
• Measuring Supernovae may be a better indicator of the mass-loss and not the nickel yield.