Massive Stars as the Progenitors of (long) Gamma-Ray Bursts

Davide Lazzati (NCSU)
Outline

- Prehistory
- History
- Modern Age
- Future
Prehistory

- Woosley 1993 “Gamma-Ray Bursts from stellar mass accretion disks around black holes”

- Paczynski 1998 “Are Gamma-Ray Bursts in star forming regions?”
History: Middle Ages

Era of indirect evidence

• Host Galaxies
• Star forming environments
• Location of explosion
• Environment density & density profile
• Iron lines
• GRB980425 - SN1998bw
Host Galaxies
Environment density & density profile

Panaitescu & Kumar 2001
History: Middle Ages

- GRB98045 - SN1998bw

Holland et al. 2002
History: Renaissance
SN Bumps

Bloom et al. 1999
History: Renaissance

- GRB030329-SN2003dh

Hjorth et al. 2003
(also Stanek et al. 2003)
History: Renaissance

MacFadyen & Woosley (1999) and Aloy et al. (2000)
Modern Era
At least some long-duration GRBs are associated to the explosion of massive compact stars.
The two events are coeval to within less than 1 day.
If we release relativistic energy in the core of a massive compact star, we can get a relativistic jet outside of it.
Do all long GRBs have SNe?

• Every time we can see one we do see it
• But we cannot see SNe at \( z > 1 \), where most GRBs are observed
• At least two long durations GRBs with no SN, but probably misclassification or evidence that the long-short classification is not physical
• “No SN” does not necessarily implies “no stellar progenitor” \((^{56}\text{Ni} \text{ production issue, see next talk by S. Nagataki})\)
Nature of the central engine

• Two main candidates: Black Hole Accretion Disk system, Magnetar.
• All require rotation
• How to tell?

  - Associated NRO (Non-Relativistic Outflow) and implications on nucleosynthesis (better seen in No-GRB SNe)
  - Evidence of BH-Sne e.g. SN1979C, SN2009kf
  - Very energetic events
  - Pre-explosion progenitor properties and/or or late-time engine emission
Consequences on the GRB

• Some $10^{51}$ e
drilling the
• Opening an
• Variability
• Increased p
• X-ray flares
How many WR stars/type Ibc SNe produce GRBs? Why some do and some don’t?

- GRBs rate ~1% of type Ibc SNe, 0.2% of all CCSNe (Podsiadlowski et al. 2004, Soderberg et al. 2010)
- Special ingredient 1: rotation (for formation of BH)
- Special ingredient 2: low metallicity (to keep angular momentum)
- Special ingredient 3: binarity (?) (Controversial)

Best constraints from observations, still too many uncertainties on the theoretical side. Most models predict only a few per cent of SNe to be associated to a GRB
Massive stars & BROs

BROs = Bipolar Relativistic Outflows

Successful GRB
When engine lasts long enough (t>5 s)
~1% of Ibc

980425-like Faint GRB
When the engine barely makes it to breakout (4.5<t<5 s)
~1% of Ibc

Radio-Bright SN
When the engine barely fails to break out (4<t<4.5 s)
~1% of Ibc

Apparently Normal SN
Any time E<=10^{51} erg
10% of Ibc???

Rates from Podsiadlowski et al. 2004; Guetta & Della Valle 2007; Soderberg et al. 2010
BROs-induced SNe

Stalled jet simulation, time = 0.000s

ρ

V

cm (×10^10)

cm (×10^{11})
None of 5 simulations succeeded in reproducing SN2009bb

\[ E_{\text{inj}} = 10^{51} \text{ erg} \]
\[ t = 1, 3, 6 \text{ s} \]

\[ E_{\text{inj}} = 3 \times 10^{51} \text{ erg} \]
\[ t = 1, 3 \text{ s} \]
Producing a 2009bb-like SN requires fine tuning

All SNe with detectable BRO effects amount to ~3% of Ibc SNe

Models for the origin of BROs predict only a few per cent (<1%) Ibc with BROs

Are BROs SNe relevant cosmologically (e.g. for heavy elements inventory?)
Riddles

- Precursors
- Why are short and long GRBs so similar to each other?
- Where are the winds?
Conclusions

What are the BROs engines, how they come about, how many of them?

- Better stellar evolution models to explain high incidence of engines in stripped massive stars
- Better engine models (especially for the BH-AD case)
- Better observational features to select BROs SNe
The Prompt Activity of Gamma-Ray Bursts

Their Progenitors, Engines, and Radiation Mechanisms

NC State University
Department of Physics
5-7 March, 2011
Raleigh, NC

Scientific Organizing Committee:
Davide Lazzati (Chair, NCSU)
Yi-Zhong Fan (Purple Mountain Obs.)
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Pawan Kumar (UT Austin)
Milos Milosavljevic (UT Austin)
Rob Preece (UA Huntsville)
Alicia Soderberg (Harvard)
Bing Zhang (UN Las Vegas)

Invited Speakers:
Andrei Beloborodov (Columbia)
Edo Berger (Harvard)
Niccolò Bucciantini (Stockholm)
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Gabriele Ghisellini (Milan)
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Rob Preece (UA Huntsville)
Stephan Rosswog (TBC, Bremen)
Alicia Soderberg (Harvard)
Anatoly Spitkovski (Princeton)
Binbin Zhang (UN Las Vegas)
Star forming environments

Hogg & Fruchter 1999
History: Middle Ages

Iron lines

Piro et al. 2000
History: Middle Ages

- Location of explosion

Bloom et al. 2002