Star Bombers

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Tuesday, October 30, 12
Super Luminous SNe

Smith+ 2007

Absolute Magnitude

Days since explosion

Smith+ 2007
Super Luminous SNe

Smith+ 2007

SN Ia

(P)PSN
more massive, opaque (longer diffusion time)
ordinary core collapse supernovae

more massive, opaque (longer diffusion time)

type Ia

2005ap 2008es
cscp06f6

more energetic, larger radius

more massive (longer diffusion time)

ordinary core collapse supernovae

2006gy

2007bi

Light curve duration (days)

Peak luminosity (ergs/sec)
ordinary core collapse supernovae

- type Ia: 2006gy, 2007bi, 2005ap, 2008es, ptf09cnd, scp06f6
- more massive, opaque (longer diffusion time)
  - more massive (longer diffusion time)
  - more energetic, larger radius

Tuesday, October 30, 12
The Death of Massive Stars

Woosley, Heger, & Weaver (2002)

(Talk by Wise)

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Mass Unit: solar mass

(GrB Talks: Aloy, Matsumoto, Mizuta)
(CCSNe Talk by Suwa)
(Talk by Wise)

Tuesday, October 30, 12
### The Death of Massive Stars

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Mass Unit: solar mass

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Tuesday, October 30, 12
Physics of PPSN & PSN

Star > 80 M☉
Physics of PPSN & PSN

Star > 80 M⊙
Physics of PPSN & PSN

Star > 80 M☉
Physics of PPSN & PSN

Star > 80 M\(\odot\)
Physics of PPSN & PSN

Star > $80 \, M_\odot$

$\gamma < \frac{4}{3}$

C/O
Physics of PPSN & PSN

Star $> 80 \, M_{\odot}$
Physics of PPSN & PSN

Star > 80 M⊙
Physics of PPSN & PSN

Star > 80 M☉

? ⬛️

150 M☉ > Star > 80 M☉
Physics of PPSN & PSN

Star > 80 M☉

? →

150 M☉ > Star > 80 M☉

E ~ 10^{52+} erg

250 M☉ > Star > 150 M☉
How to Blow Up Multi-D Stars?

1D Models
- 80 - 150 M☉ Stars (Woosley+ 2007, priv. comm.)

CASTRO (DOE SciDAC Computational Astrophysics Team)
- Massive Parallel, Adaptive Mesh Refinement (AMR), Multi-D,
- Radiation, Hydro, +( Nuclear Burning, Mapping, Rotation, GR, ... )

Supercomputers
- Itasca
- Franklin
- Hopper
- Jaguar

Tuesday, October 30, 12
Scaling Performance

CASTRO Weak Scaling on Jaguarpf

Average Time per Time Step (seconds)

Number of Cores

768  12K  96K  211K
Central oxygen depletion

Pulses occur on a hydrodynamic time scale for the helium and heavy element core (~500 s).

Based on Woosley’s Models

For this mass, there are no especially violent single pulses before the star collapses.
Pulses commence again after central oxygen depletion, but become more violent. Two strong pulses send shock waves into the envelope. Two days later the iron core collapses.

The 90 M☉ star with Helium core 41.3 M☉

90+ M☉

The pulses become more violent and the intervals between them longer. Multiple supernovae occur but usually just one of them is very bright.
Core of 110 M☉ Star

(cm/s)
Core of 110 M☉ Star

Time=0 s

(cm/s)
Physical Properties of Colliding Shells
Chen + in prep
Physical Properties of Colliding Shells

Chen + in prep

3,000,000+ CPU Hours

4096x4096x4096 ~ 6.8 billion zones

Tuesday, October 30, 12
Explosive Burning of 150 M☉ Star

Tuesday, October 30, 12
Explosive Burning of 150 M⊙ Star

Time = 0.125779 s
Core of 150 M☉ Star
Core of 150 M⊙ Star
Exploding 200 $M_\odot$ Star (2007 bi)
Mixing
More Explosions!
(Chen+ in prep)

No Bang!!
form a black hole

Tuesday, October 30, 12
Mixing of Elements

Element Abundance

Mass Coordinate

BSG 150

BSG 200

BSG 250

RSG 150

RSG 200

RSG 250

Black Hole
No Yield
### Results

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<tr>
<th>Model</th>
<th>Mass [M$\odot$]</th>
<th>Core [M$\odot$]</th>
<th>$E$ [$10^{52}$ erg]</th>
<th>Ni [M$\odot$]</th>
<th>Instab.</th>
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Ni is only slightly mixed out.
The Gamma-Ray emission for PSNe is unlikely.
Conclusion

Fate  Very Bright  Sources  Observation

80 ~ 150 M☉

150 ~ 250 M☉

250+  M☉
## Conclusion

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The first stars are promising candidates (Abel+ 2002, Bromm+ 2009)
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The first stars are promising candidates (Abel+ 2002, Bromm+ 2009)

**Mixing can be important!**
Conclusion

150 ~ 250 \( M_\odot \)

250+ \( M_\odot \)

Very Bright

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YES

No

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PSN

BH(?)

Sources

Observation

Mixing can be important!

Multi-SN

Large Ni

GW

Pop I, II, III

Pop I(?), II, III

No

The first stars are promising candidates (Abel+ 2002, Bromm+ 2009)

Tuesday, October 30, 12
Super Explosions !!

Stars > 1,000M☉ may not die as black holes

An Explosion of 55,000 M☉ Star
(Heger, & Chen+ in prep., Whalen, Heger, & Chen+ to be submitted)
Super Explosions!!

Stars > 1,000M\⊙ may not die as black holes

An Explosion of 55,000 M\⊙ Star

(Chen+, highlighted in the Coalition for Academic Scientific Computation (CASC) 2012)

Tuesday, October 30, 12
Many thanks for your attention

This work has been strongly supported by:

[Logos of various institutions]