Astrophysics I: Stars and Stellar Evolution

AST 4001

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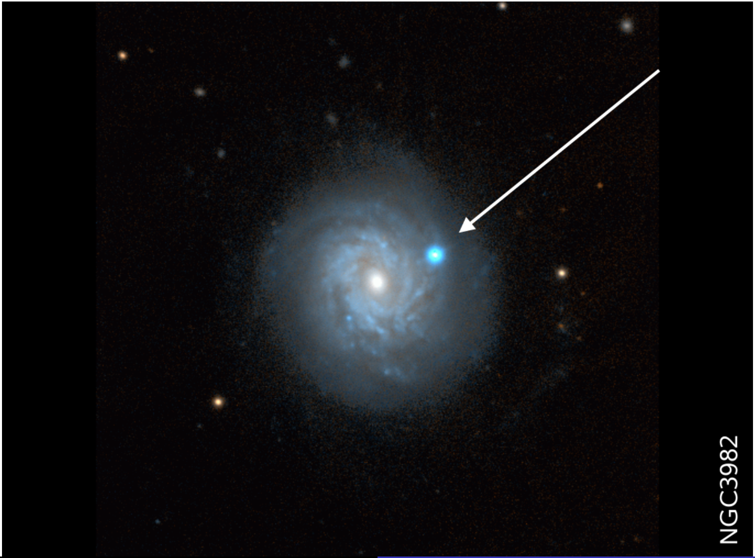
Stars and Stellar Evolution, Fall 2008

Overview

1. Recap
   - Things that blow up
2. Supernovae
   - (Pulsational) Pair-Instability Supernovae
   - Supernova Types
   - Core Collapse Supernovae

Supernovae



Supernovae - Overview

Things that blow up

supernovae from massive stars

1B=10^{51} erg

MASS

- CO white dwarf ➔ Type Ia SN, E≈1Bethe
- MgNeO WD, accretion ➔ AIC, faint SN
- “SAGB” star (AGB, then SN) ➔ EC SN
- “normal” SN (Fe core collapse) ➔ Type II SN
- WR star (Fe CC) ➔ Type Ib/c
- “Collapsar”, GRB ➔ broad line Ib/a SN, “hypernova”
- Pulsational pair SN ➔ multiple, nested Type I/II SN
- Very massive stars ➔ pair SN, $\lesssim$100B (1B=10^{51} erg)
- Very massive collapsar ➔ IMBH, SN, hard transient
- Supermassive stars ➔ $\gtrsim$100000 B SN or SMBH

Supernovae

Things that blow up

Neutron star-powered supernovae

- CO white dwarf ➔ Type Ia SN, E≈1Bethe
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Supernovae

Things that blow up

Thermonuclear supernovae (no *r*-process)

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Supernovae

Things that blow up

Black hole-powered supernovae ("Collapsars)

- CO white dwarf ➔ Type Ia SN, E≈1Bethe
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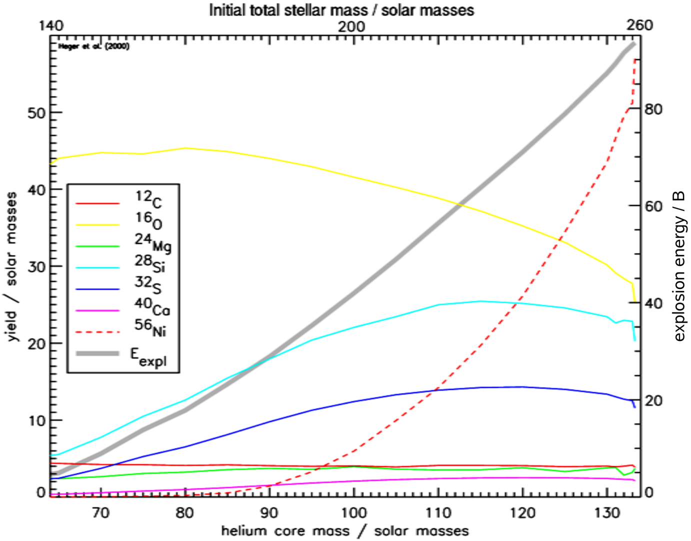
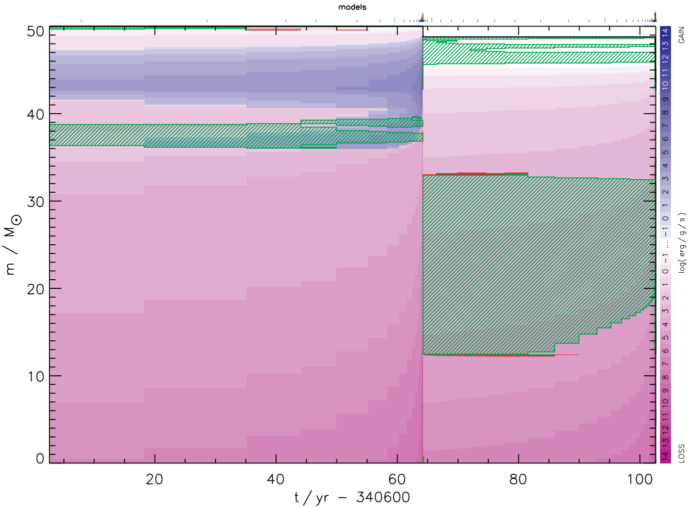
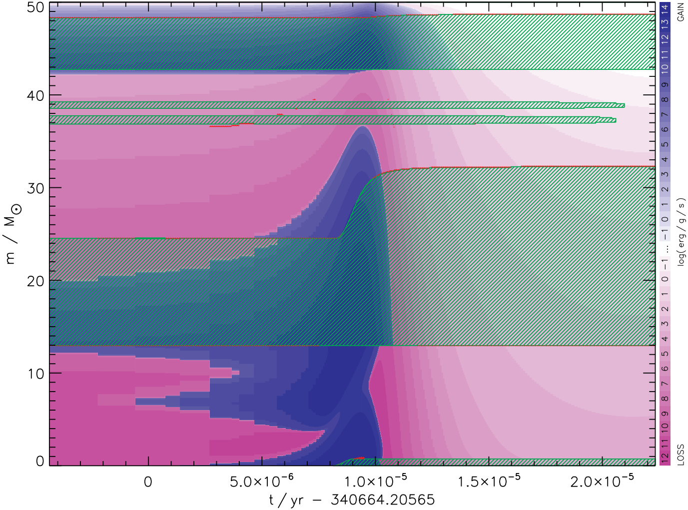
Pair-Instability Supernovae



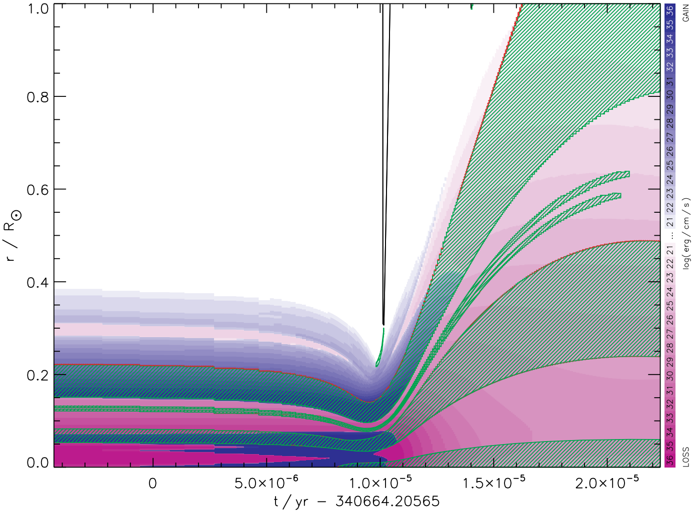
Pulsational Pair-Instability Supernovae



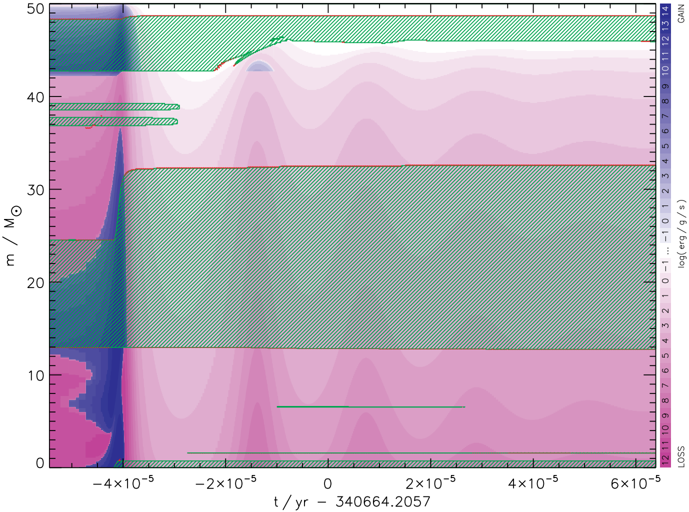
Pulsational Pair-Instability Supernovae - Pulse



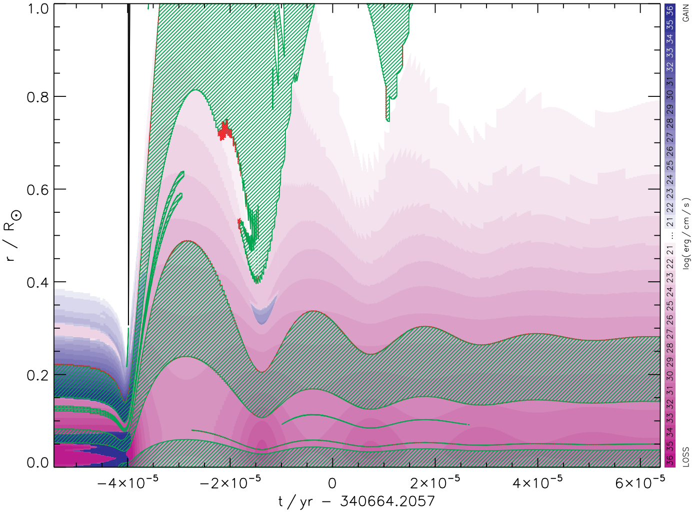
Pulsational Pair-Instability Supernovae - Pulse



Pulsational Pair-Instability Supernovae - Ringdown



Pulsational Pair-Instability Supernovae - Ringdown



Supermassive Supernovae

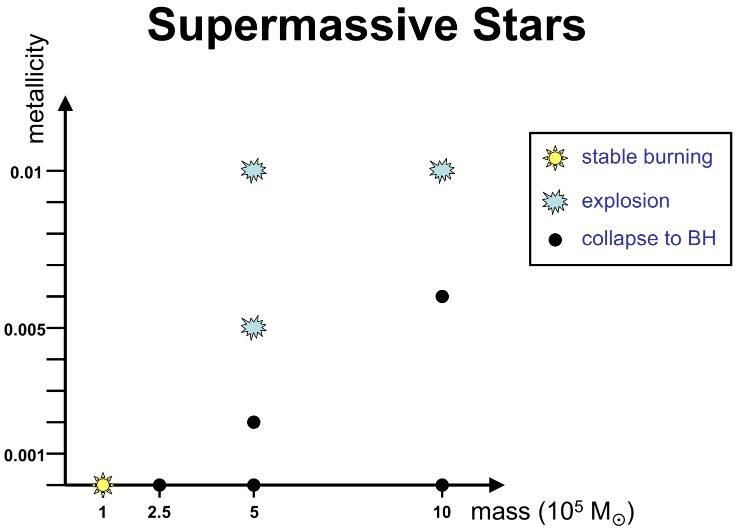
Supermassive Stars

RESULTS (Fuller, Woosley, & Weaver 1986)

Initial Mass $M/10^5\ M_\odot$ (1)	Initial Metallicity $Z_{\rm init}$ (2)	Fate (3)	Cumulative Time for $L > 10^{45}$ ergs s^{-1} [a] (4)
1	0	Stable	...
5	0	Black hole	...
5	2×10^{-3}	Black hole	...
5	5×10^{-3}	2.1×10^{56} ergs He: $0.249 \rightarrow 0.282$	$>3 \times 10^7$ s
5	1×10^{-2}	2×10^{56} ergs He: $0.247 \rightarrow 0.275$	$>2.6 \times 10^8$ s
2.5	0	Black hole	...
10	0	Black hole	...
10	6×10^{-3}	Black hole	...
10	1×10^{-2}	2.5×10^{57} ergs He: $0.25 \rightarrow 0.42$	$>10^8$ s

[a] The quantity L is the photon luminosity.

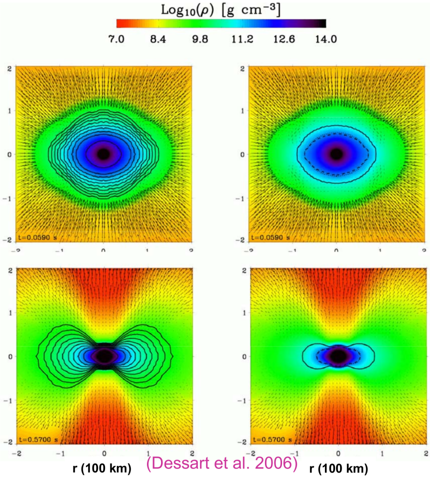
Supermassive Supernovae



(after Fuller, Woosley, & Weaver 1986)

Accretion Induced Collapse

Accretion Induced Collapse



(Dessart et al. 2006)

- NeMgO WD accretes from companion star
- When Chandrasekhar mass is approached, electron captures reduce electron degeneracy pressure support
- ◀ Rapid collapse and bounce (faint SN)

Supernovae

Supernova Types

as Function of Mass and Metallicity

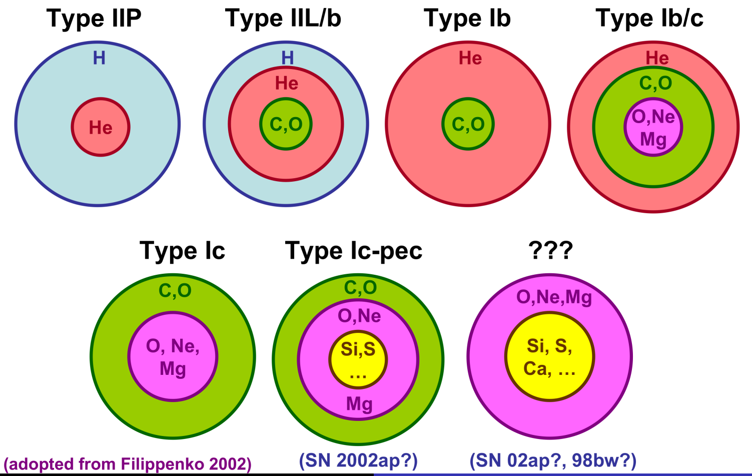
(single stars)

SN Type	pre-SN stellar structure
IIp	> 2 $M_\odot$ H envelope
IIL	< 2 $M_\odot$ H envelope
Ib/c	**no** H envelope

Type Ib/c He core mass at explosion	explosion energy	display
> 15 $M_\odot$	direct collapse	none
~15…8 $M_\odot$	weak	dim
~8…5 $M_\odot$	strong	dim
< 5 $M_\odot$	strong	bright

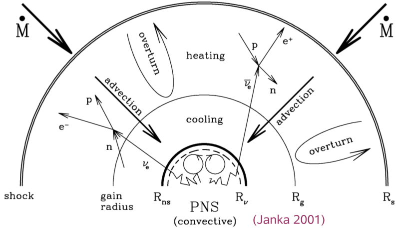
Supernovae

Sequence of increasingly stripped cc SNe

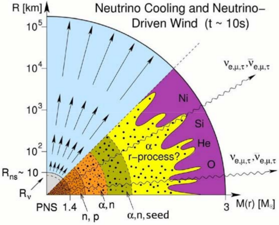


Supernovae

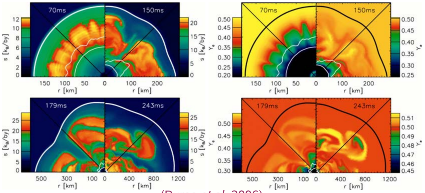
Core Collapse Supernovae



(Janka 2001)



(Woosley & Janka 2006)



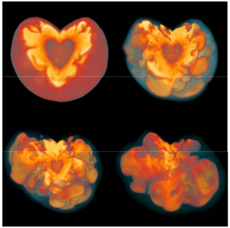
(Buras *et al.* 2006)

←Entropy and electron per baryon (Y_e) at different time snapshots in a core collapse supernova
(simulation: equatorial band)

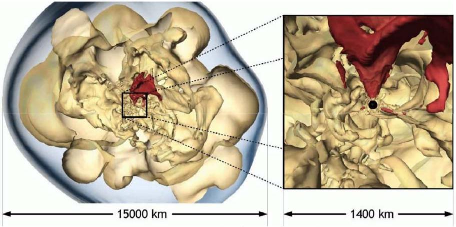
Supernovae

Core Collapse Supernovae – 3D

Cold inflow and **hot outflow** in 3D simulations ➔ similar to dipolar flow pattern observed in 2D rotationally symmetric simulations



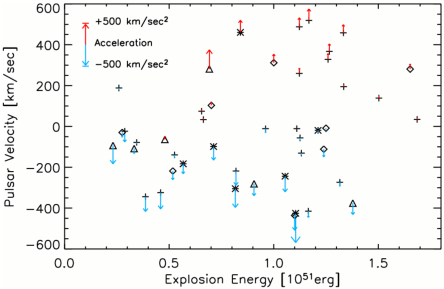
(Scheck, Janka, *et al.* 2006)

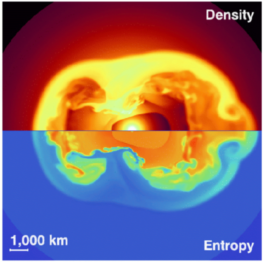


(Janka *et al.* 2005)

Supernovae

Neutron Star Kicks





(Janka 2004)

Dipolar oscillation may explain observed neutron star kicks of several 100 km/s.

Supernovae

Explosive Nucleosynthesis

in supernovae

Fuel	Main Product	Secondary Product	T (10^9 K)	Time (s)	Main Reaction
Innermost ejecta	*r*-process	-	>10 low Y_e	1	(n,γ), β^-
Si, O	^{56}Ni	iron group	>4	0.1	(α,γ)
O	Si, S	Cl, Ar, K, Ca	3 - 4	1	^{16}O + ^{16}O
O, Ne	O, Mg, Ne	Na, Al, P	2 - 3	5	(γ,α)
		p-process ^{11}B, ^{19}F, ^{138}La, ^{180}Ta	2 - 3	5	(γ,n)
		ν-process		5	(ν, ν'), (ν, e^-)