Astrophysics of gravitational wave sources

Lecture 5: White dwarfs, neutron stars, black holes

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Chandrasekhar mass

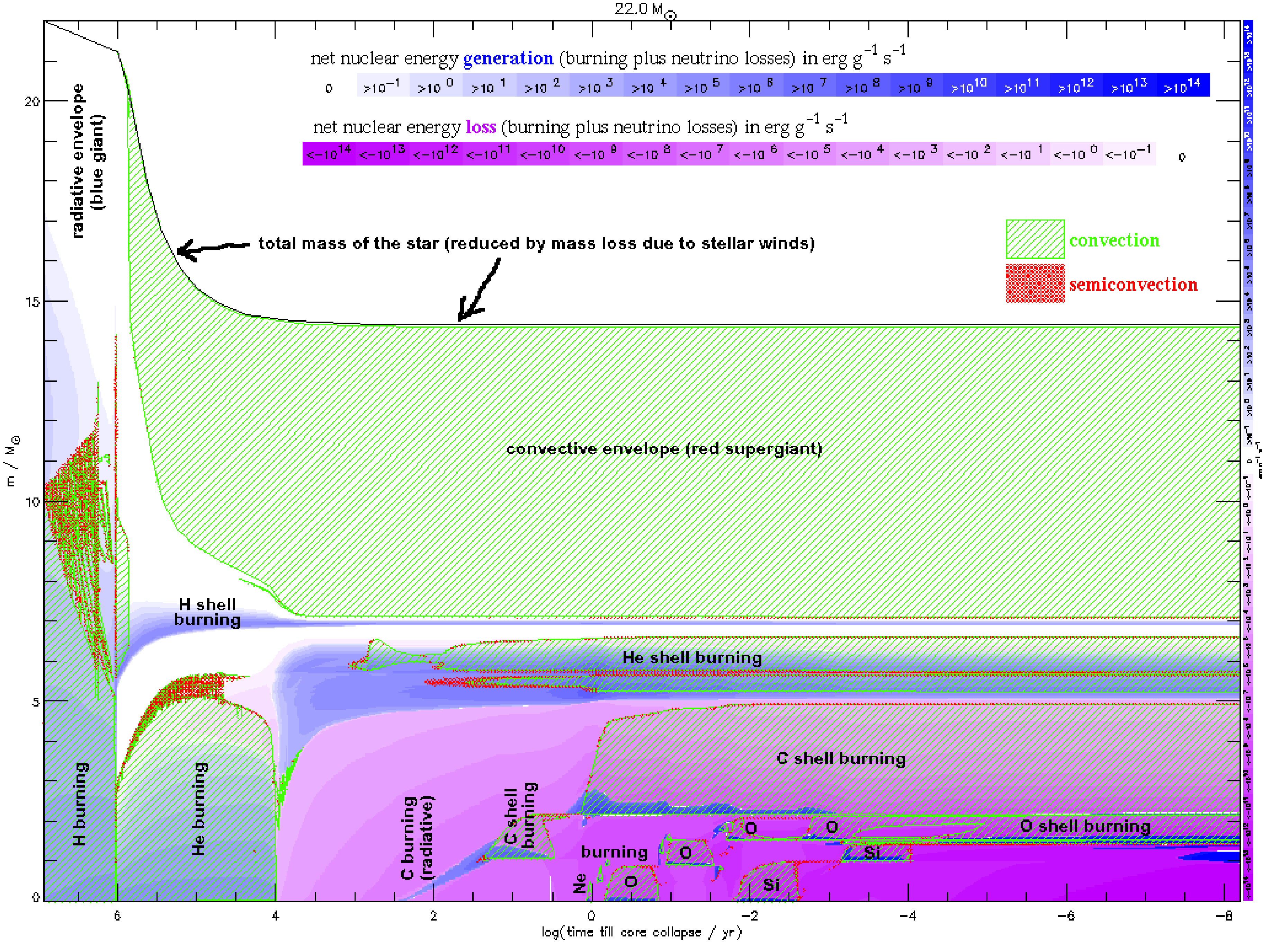
- [hbar] = erg s = g cm^2 s^-1
- [c] = cm/s
- [P] = cm^2/s^2 g/cm^3 = g s^-2 cm^-1
- For gamma=4/3 polytrope (P=K rho^gamma): M ~ (K/G)^1.5

- The units on K: we'll put in mp… mass of proton, combine with hbar and c (baryons contribute all of the mass)

- M_Chandrasekhar = (hbar c/G)^1.5 / (mu mp)^2 ~ m_planck^3/mp^2

- Electron mass does not appear in the equation!

ns.pdf

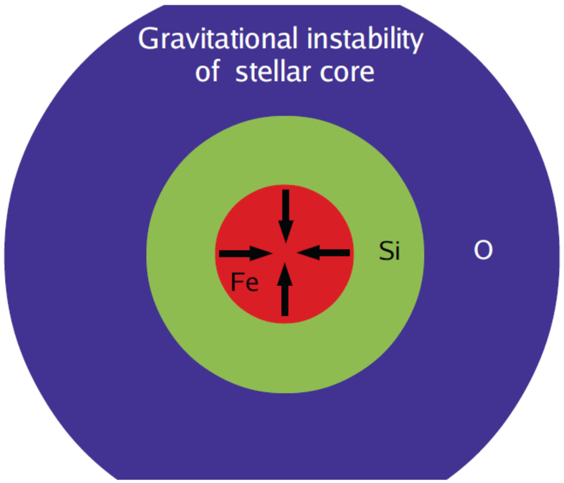


A. Heger website 2sn.org

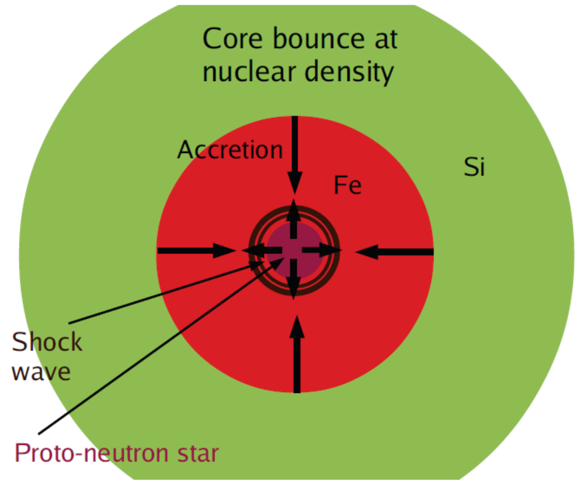
Massive star death

1 erg = 10^{-7} J

1 $L_\odot$ = 3.9 × 10^{33} ergs/s

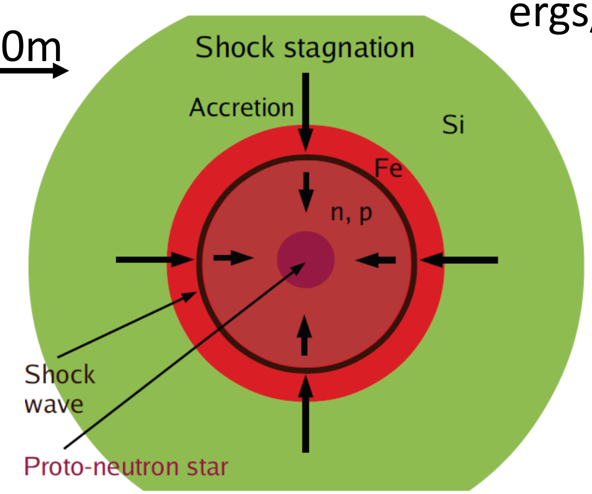


$M_{initial}$ > 8 $M_\odot$
Collapse from WD size ~0.3s



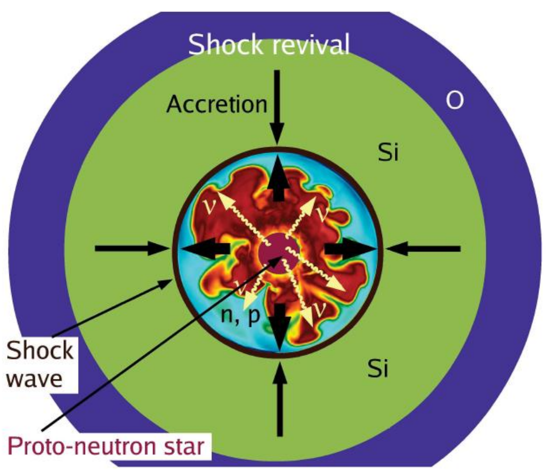
Proto-neutron star ~60 km
Binding energy ~ 3 × 10^{53} ergs

<10m
s

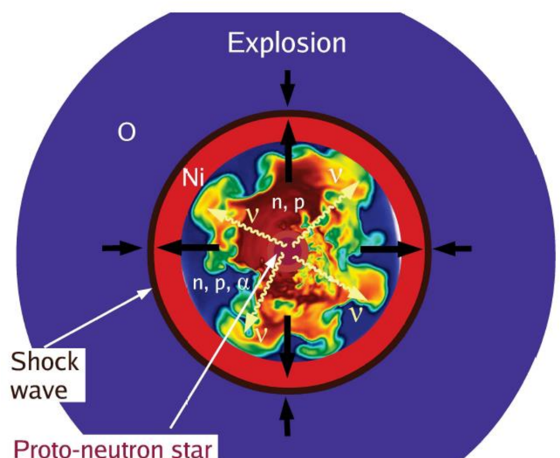


Stalled shock at 100-200 km
Neutrino cooling ~ 10^{52} ergs/s
Duration up to ~1 s

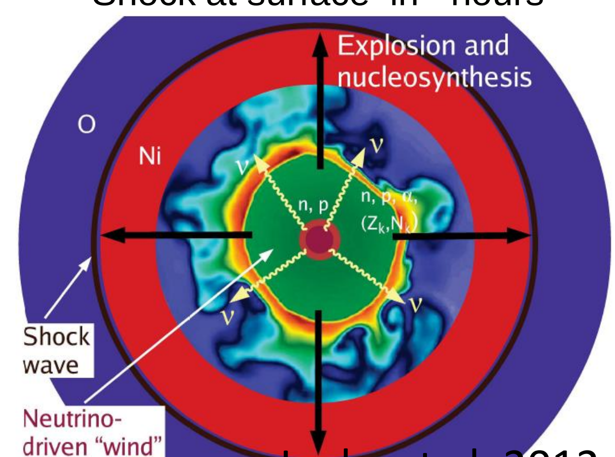
Reason not fully understood



All NS binding energy released
before 10-100s



Explosion energy ~10^{51} ergs
10^{-3} – 10^{-1} $M_\odot$ of Nickel-56
Shock at surface in ~hours



Janka et al. 2012

O'Connor & Ott (2011)
Ugliano et al. (2012)
Ertl et al. (2016)
N20
S19.8
W15
W18
W20
Sukhbold et al. (2016)
N20
S19.8
W15
W18
W20
Pejcha & Thompson (2015)
(a)
(b)
Müller et al. (2016)
Ebinger et al. (2019)
WH07
WHW02
10
15
20
25
30
35
40
Progenitor initial mass [$M_\odot$]

Collapse of the core

$$(A, Z) + e^- \rightarrow (A, Z-1) + \nu_e,$$

$$\epsilon_F \geq M(A, Z-1) - M(A, Z) \qquad \varepsilon_F = \sqrt{(p_F c)^2 + (m_e c^2)^2}$$

$$M(A', Z') \rightarrow M(A'-1, Z') + n \qquad \text{“neutron drip,”}$$

$$\rho_{\rm nuc} \approx 2.8 \times 10^{14}\,{\rm g\,cm^{-3}}$$