Two limits of supernovae: Electron capture supernova Pulsational pair-instability supernova

Shing-Chi Leung

Tapir, Caltech

In collaboration with
Ken'ichi Nomoto (IPMU)
Sergei Blinnikov (ITEP)
Koji Ishidoshiro (Tohoku)
Alexandre Kozlov (IPMU)
Elena Sorokina (Sternberg)
Petr Blaklanov (NRNU)
Alexey Tolstov (Open U*)
Toshio Suzuki (Nihon U.)
Shuai Zha (Stockholm)

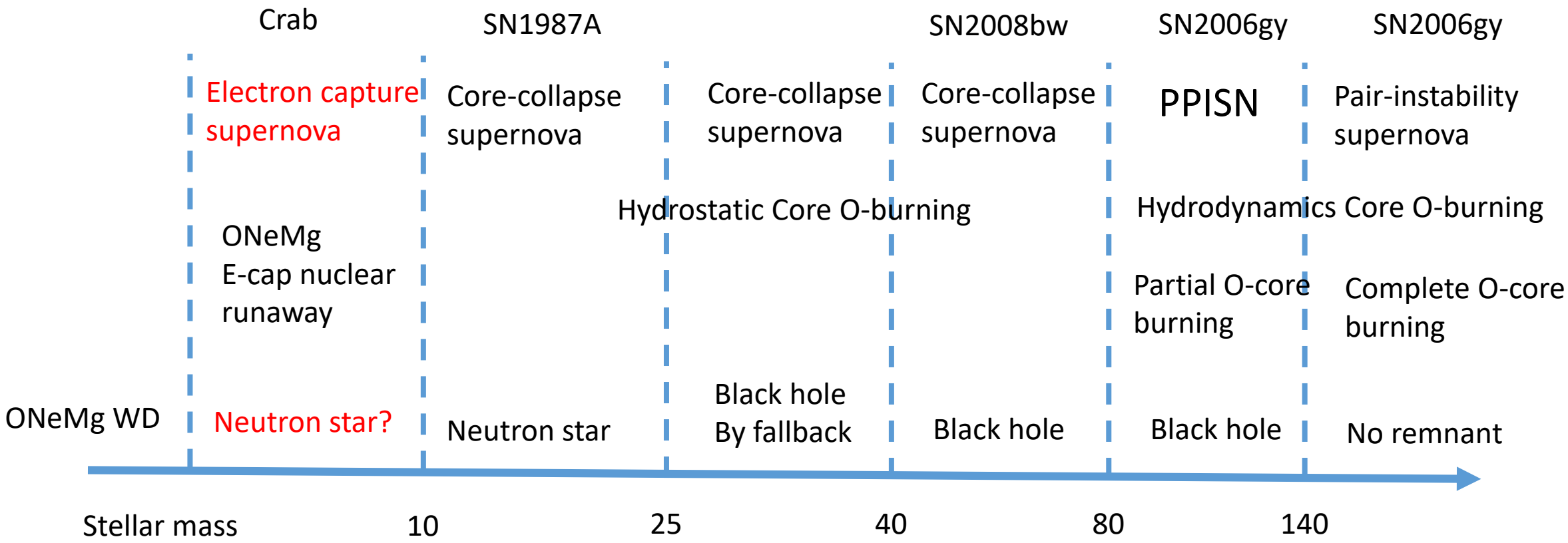
The low mass limit: ECSN

Based on our series of PPISN papers:

Suzuki+ ApJ 881, 64 (2019); Zha + ApJ 886, 12 (2019);

Leung+, PASA 36, e006 (2019); Leung+ ApJ 889, 34 (2020)

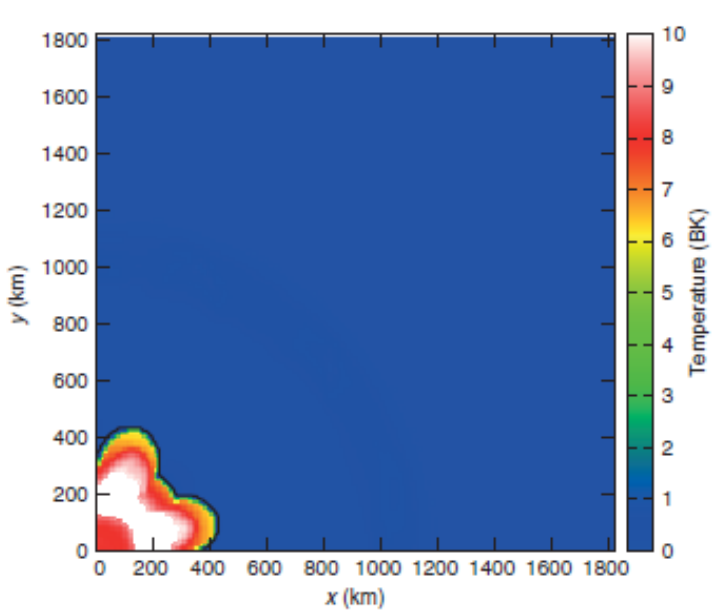
What is pulsational pair-instability?

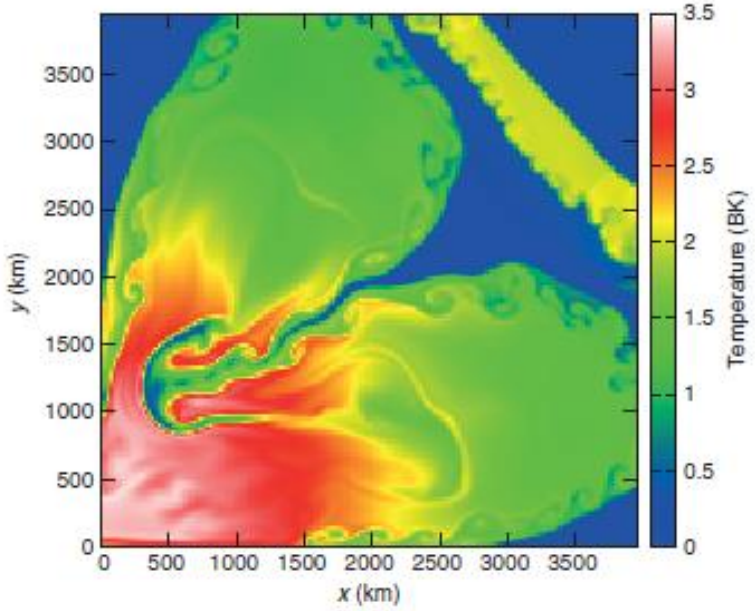


Note: exact mass depends on metallicity and mass-loss rate

Bifurcation of ECSN

- Collapse vs. Explode





- Electron capture → Suppress flame growth
- Nuclear reaction → Enhance flame growth

Leung, Nomoto, PASA 36, e006 (2019)

Where and how the nuclear runaway takes place?

What is the condition for the ECSN to collapse?

Published today!!

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Electron-capture Supernovae of Super-AGB Stars: Sensitivity on Input Physics

Shing-Chi Leung[1,2], Ken'ichi Nomoto[1], and Tomoharu Suzuki[3]

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Electron-capture Supernovae of Super-AGB Stars: Sensitivity on Input Physics

Shing-Chi Leung[1,2], Ken'ichi Nomoto[1], and Tomoharu Suzuki[3]

[1] Kavli Institute for the Physics and Mathematics of the Universe (WPI), UTIAS, The University of Tokyo, Kashiwa, Chiba 277-8583, Japan
shingchi.leung@ipmu.jp, nomoto@astron.s.u-tokyo.ac.jp

[2] TAPIR, Walter Burke Institute for Theoretical Physics, Mailcode 350-17, Caltech, Pasadena, CA 91125, USA

[3] College of Engineering, Chubu University, 1200 Matsumoto-cho, Kasugai, Aichi 487-8501, Japan; tsuzuki@isc.chubu.ac.jp

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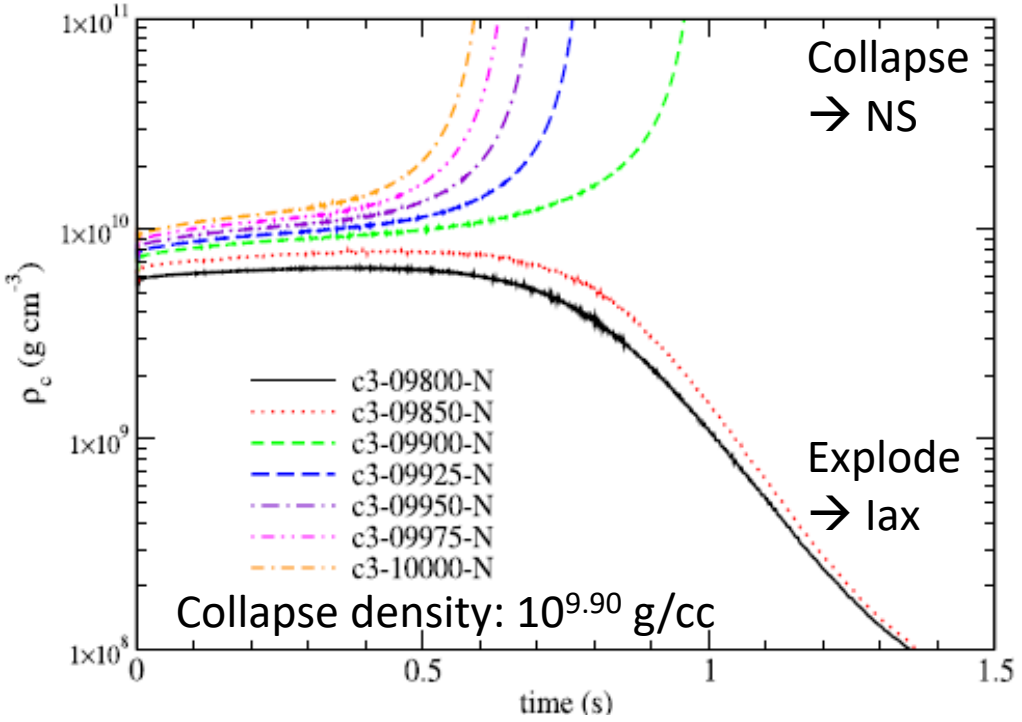
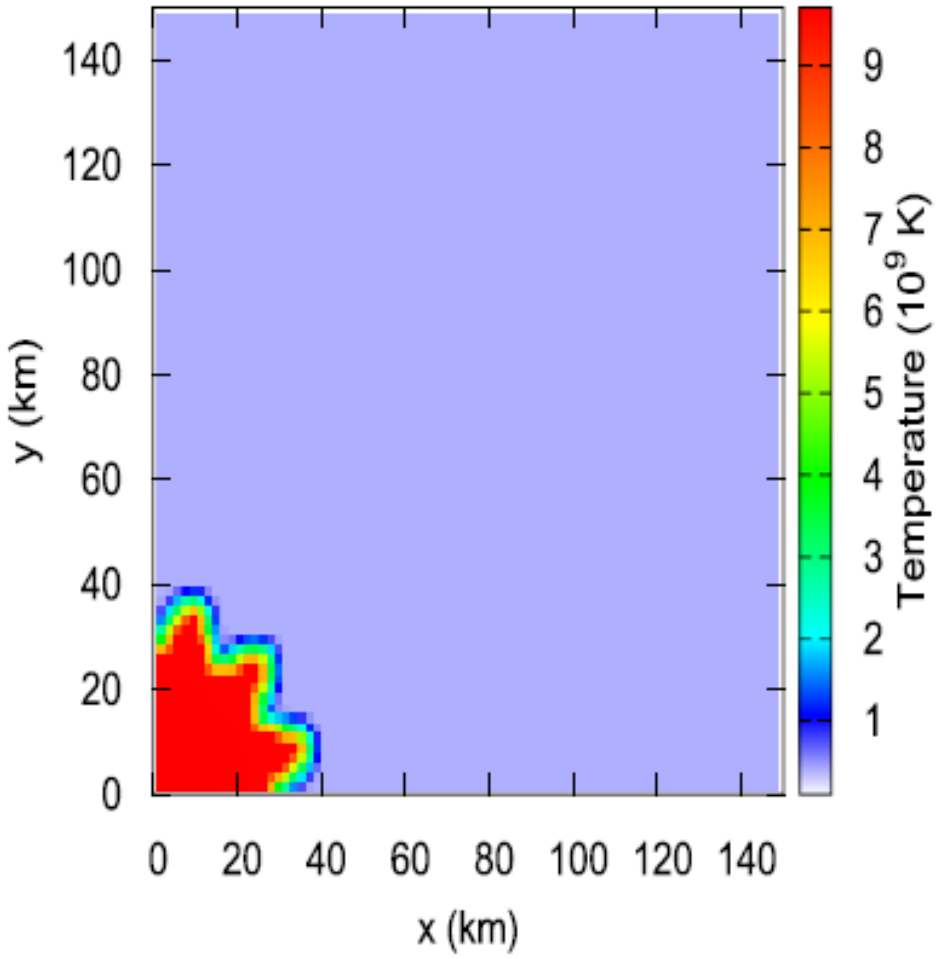
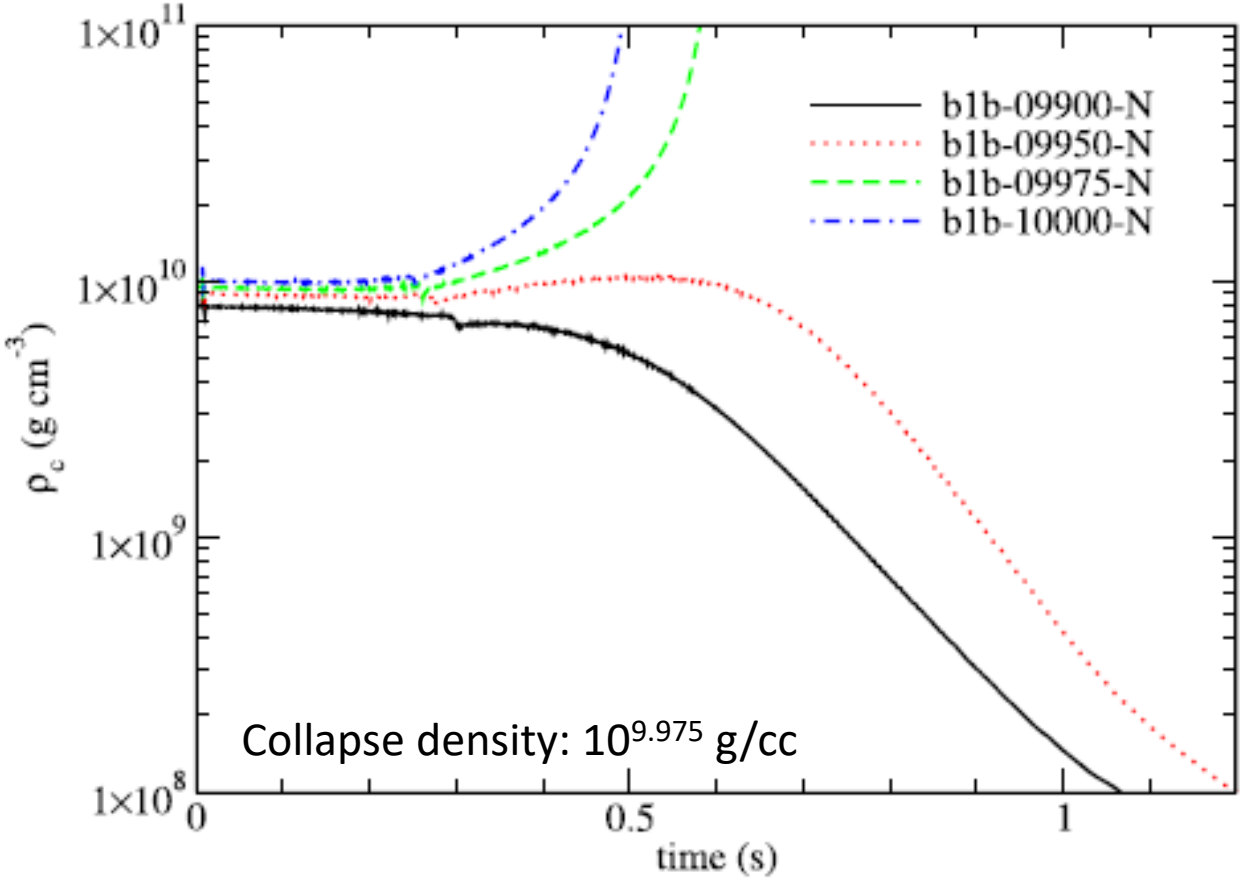
Sensitivity to Ignition density and position

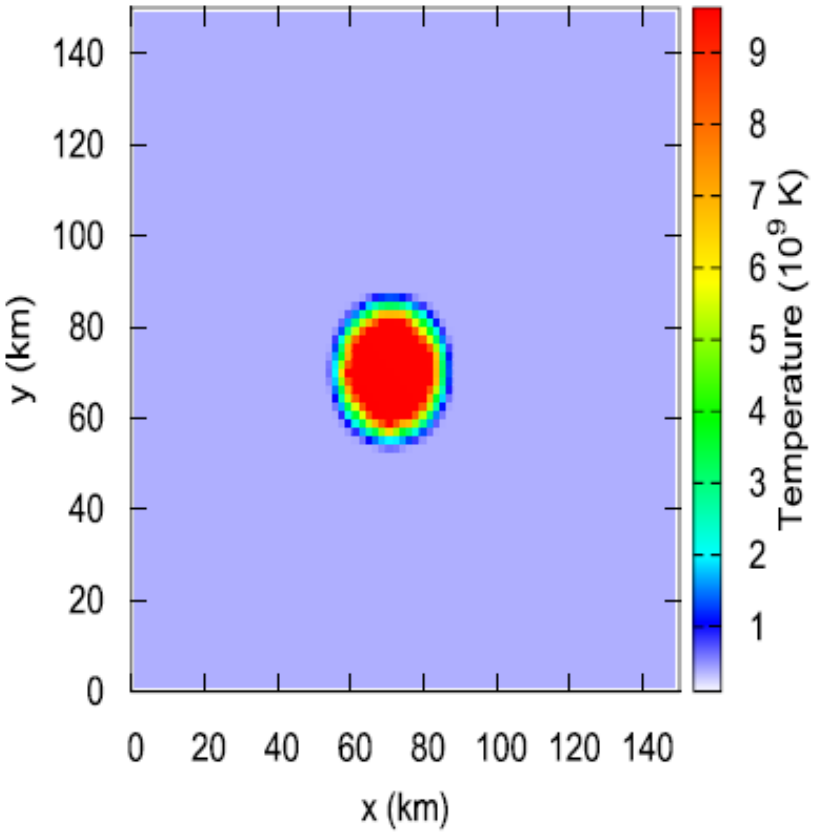




Leung, Nomoto, Suzuki ApJ 889, 34 (2020)

Sensitivity to Ignition density and position





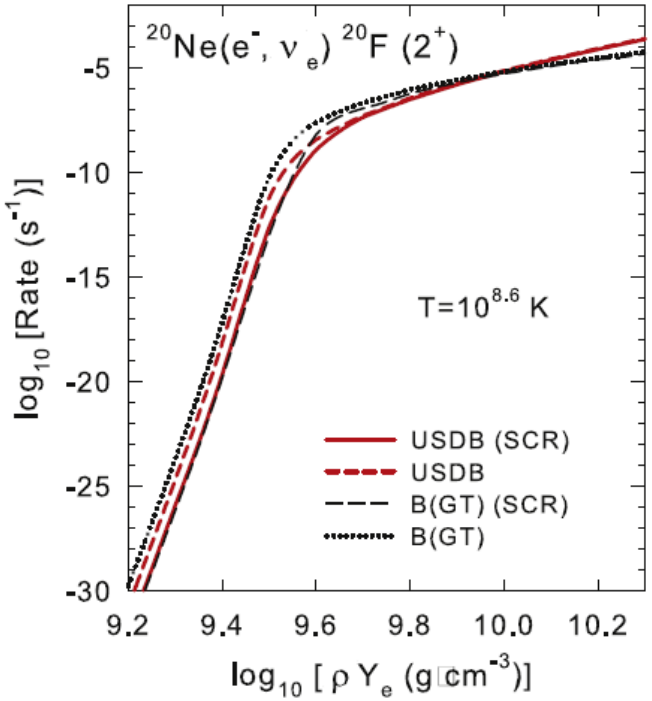
Leung, Nomoto, Suzuki ApJ 889, 34 (2020)

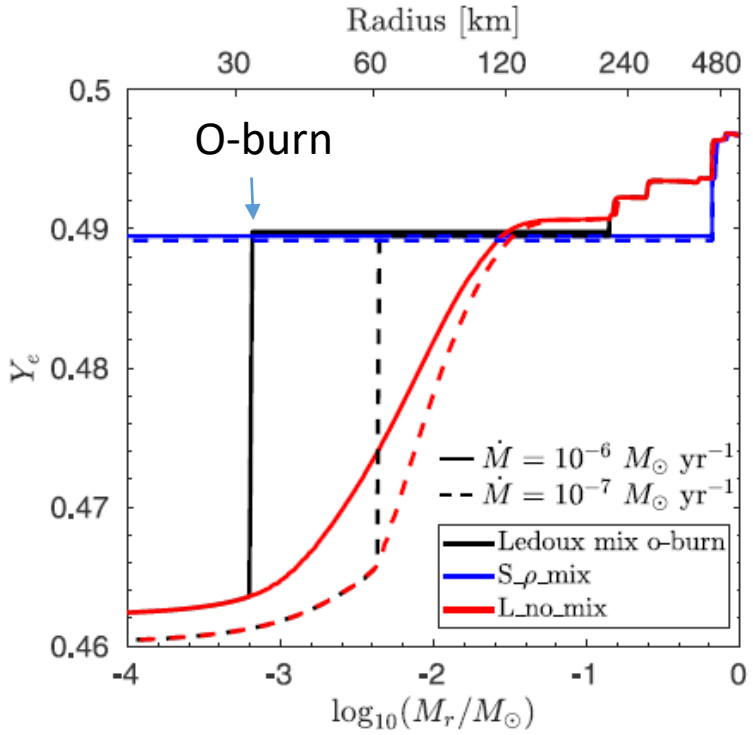
Recent motivations

A change in the e-cap rate translates to the ignition position and density

- New e-cap rate of ^{20}Ne
  - (Kirsebom+ 2018)

$$\log ft = 10.47 \pm 0.11$$

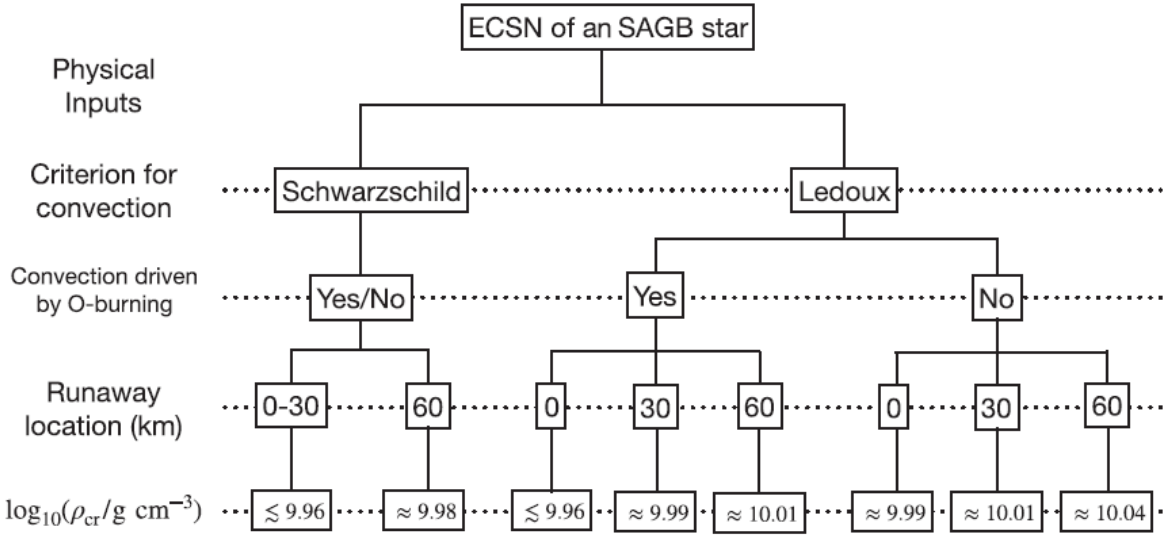




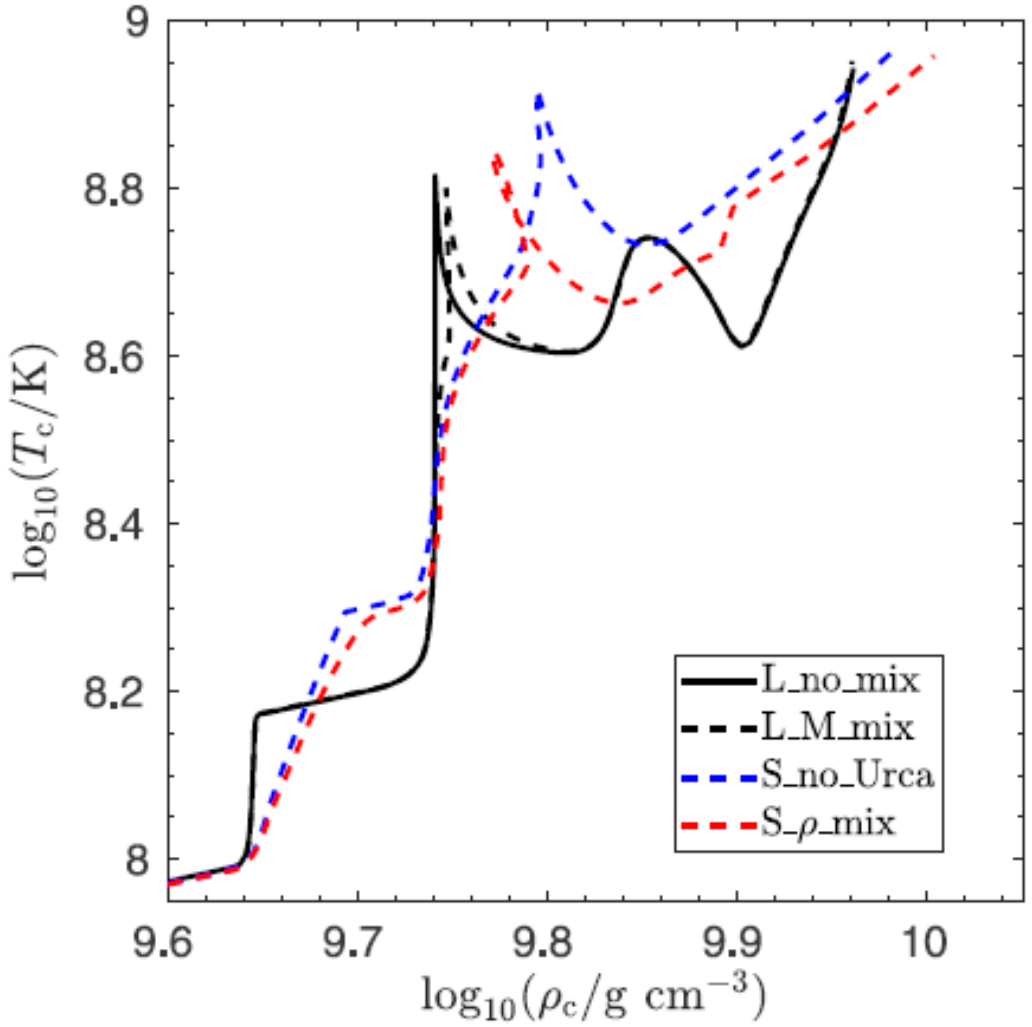
Suzuki, Zha, Leung, Nomoto, ApJ 881, 64 (2019)

Impact

- When does the star runaway?

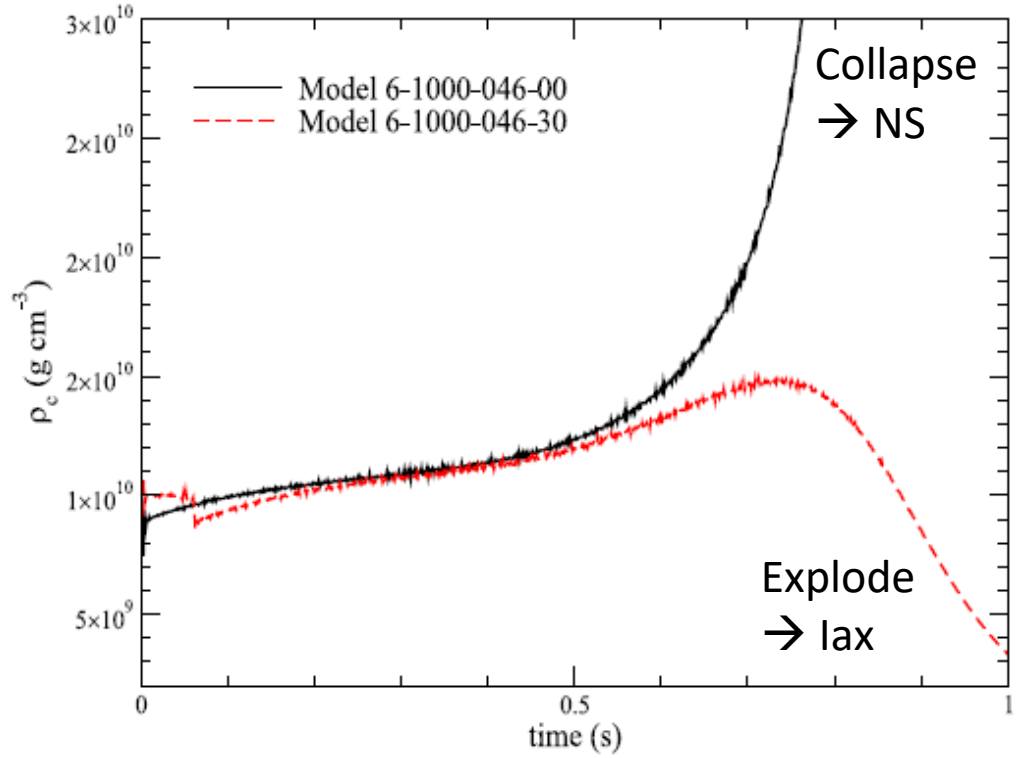


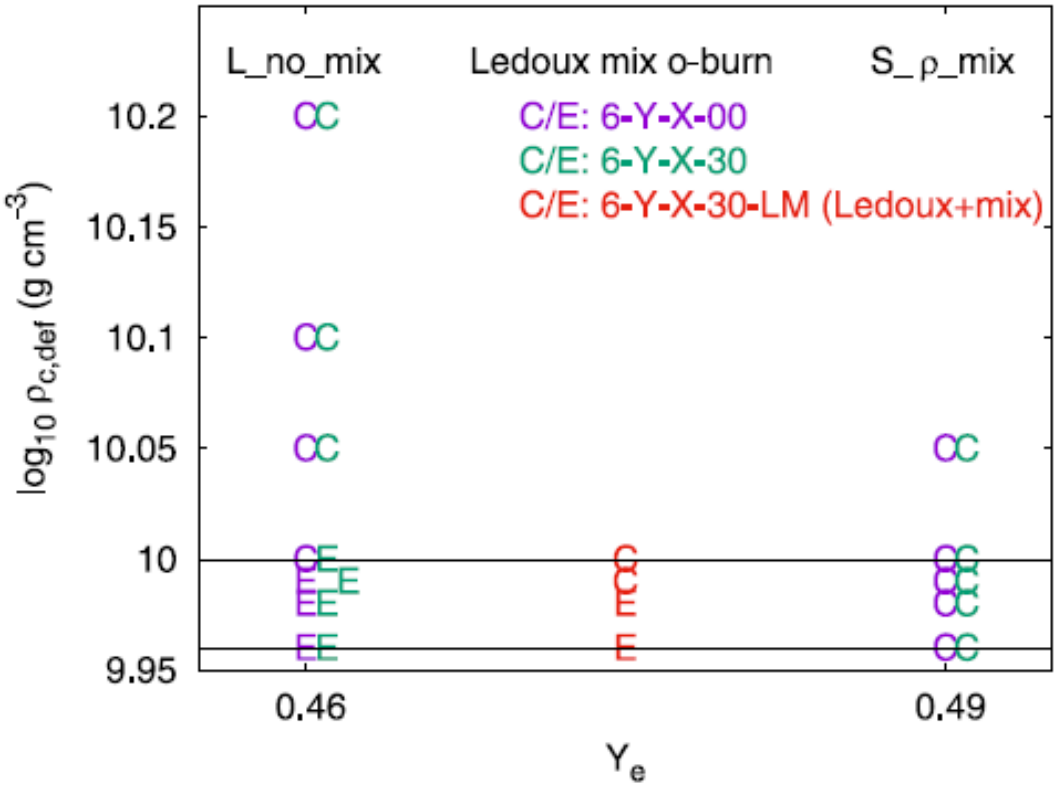
Stellar evolution of ONeMg core before nuclear runaway



Zha, Leung, Suzuki, Nomoto, ApJ 886, 22 (2019)

Most updated models





Most models tend to collapse to form a Low-mass neutron star.

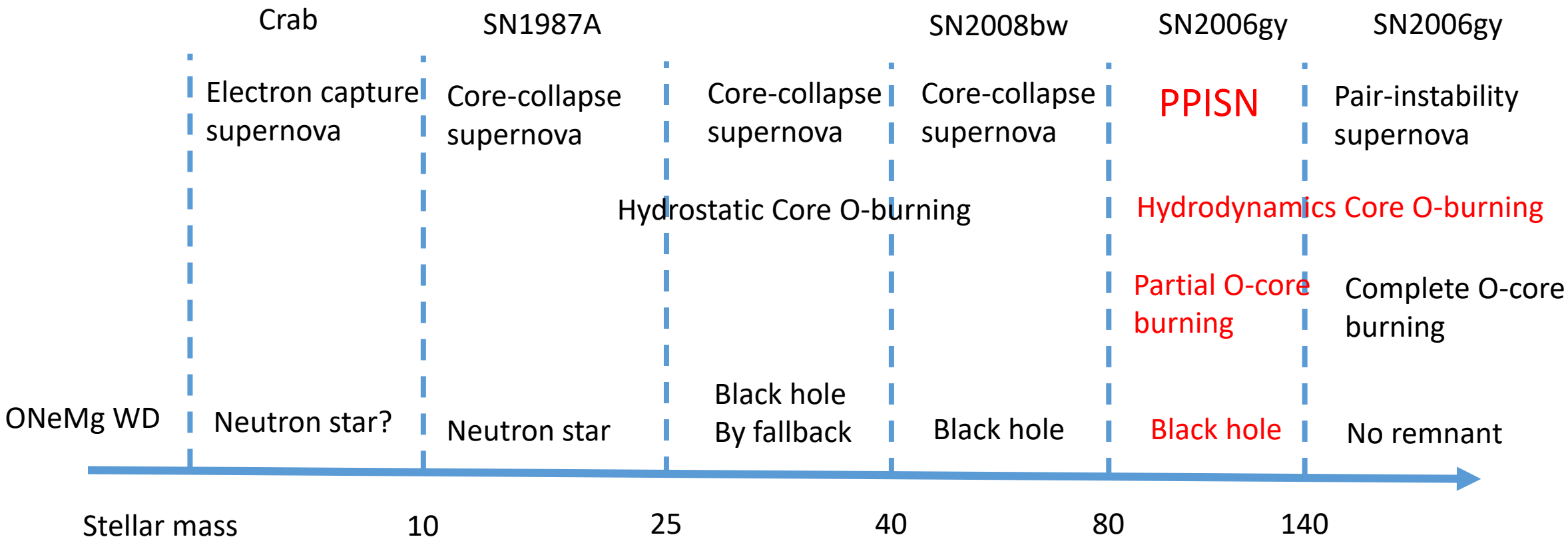
Zha, Leung, Suzuki, Nomoto, ApJ 886, 22 (2019)

The high mass limit

Based on our series of PPISN papers:

Leung+ ApJ 887, 72 (2019); Leung + ApJ accepted (2020); Leung+ in prep (2020)

What is pulsational pair-instability?

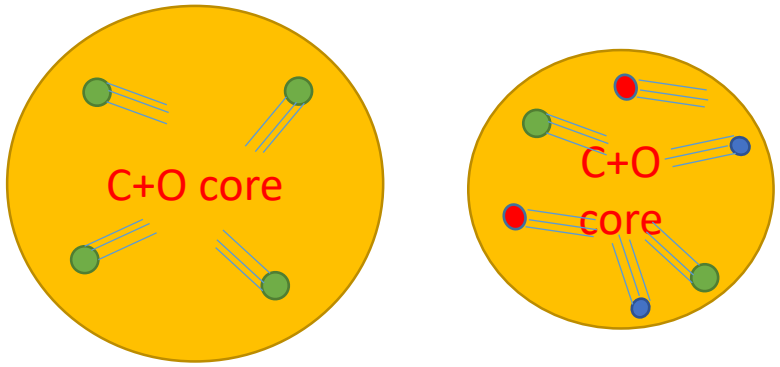


Note: exact mass depends on metallicity and mass-loss rate

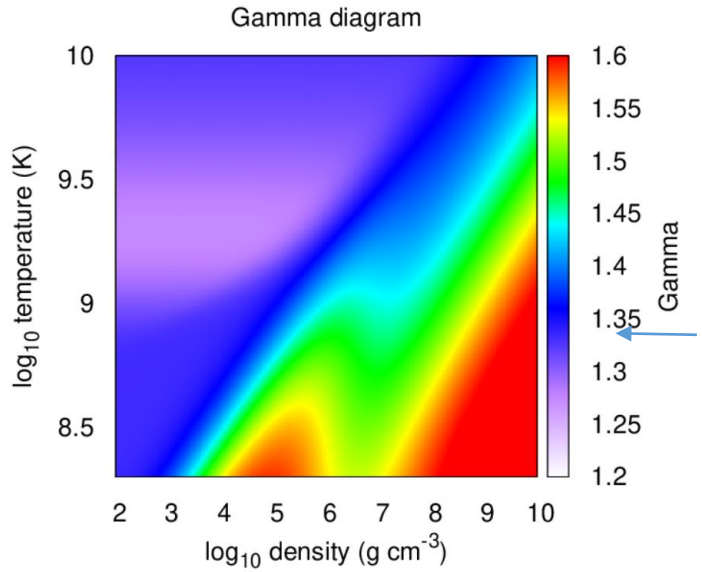
What is pair-instability?

Electron mass
511 keV

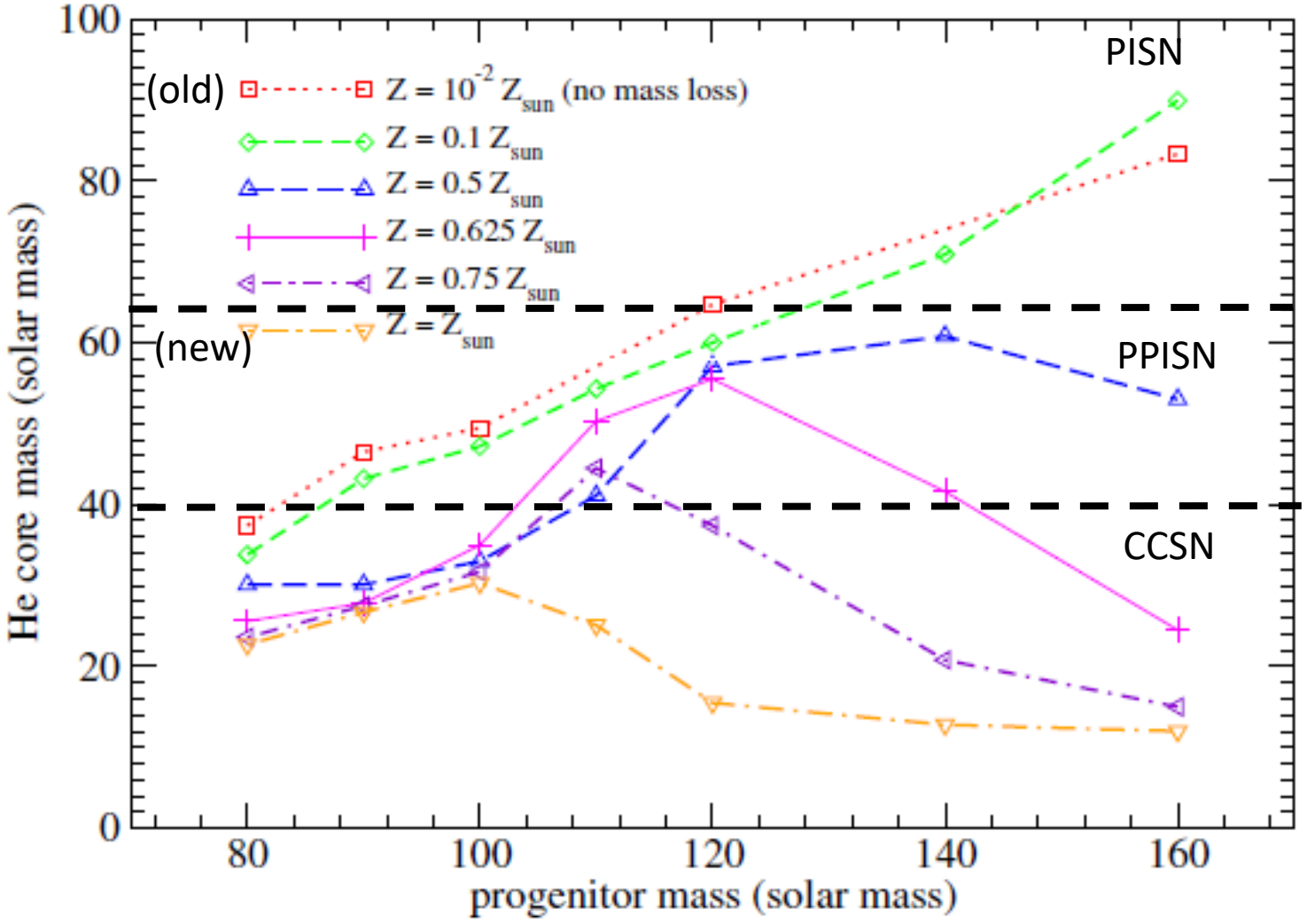
- In a very massive star, photon pressure is the main supporting force
  - High temperature (10^9 K), low density ($10^{2\text{-}6}$ g cm^{-3})
- After core He-burning, energetic photon → electron + positron pair
- Electron is non-degenerate → Low pressure support ($\Gamma < 4/3$)
- Faster contraction, more photons converted



Ultra-relativistic
Gamma = 4/3



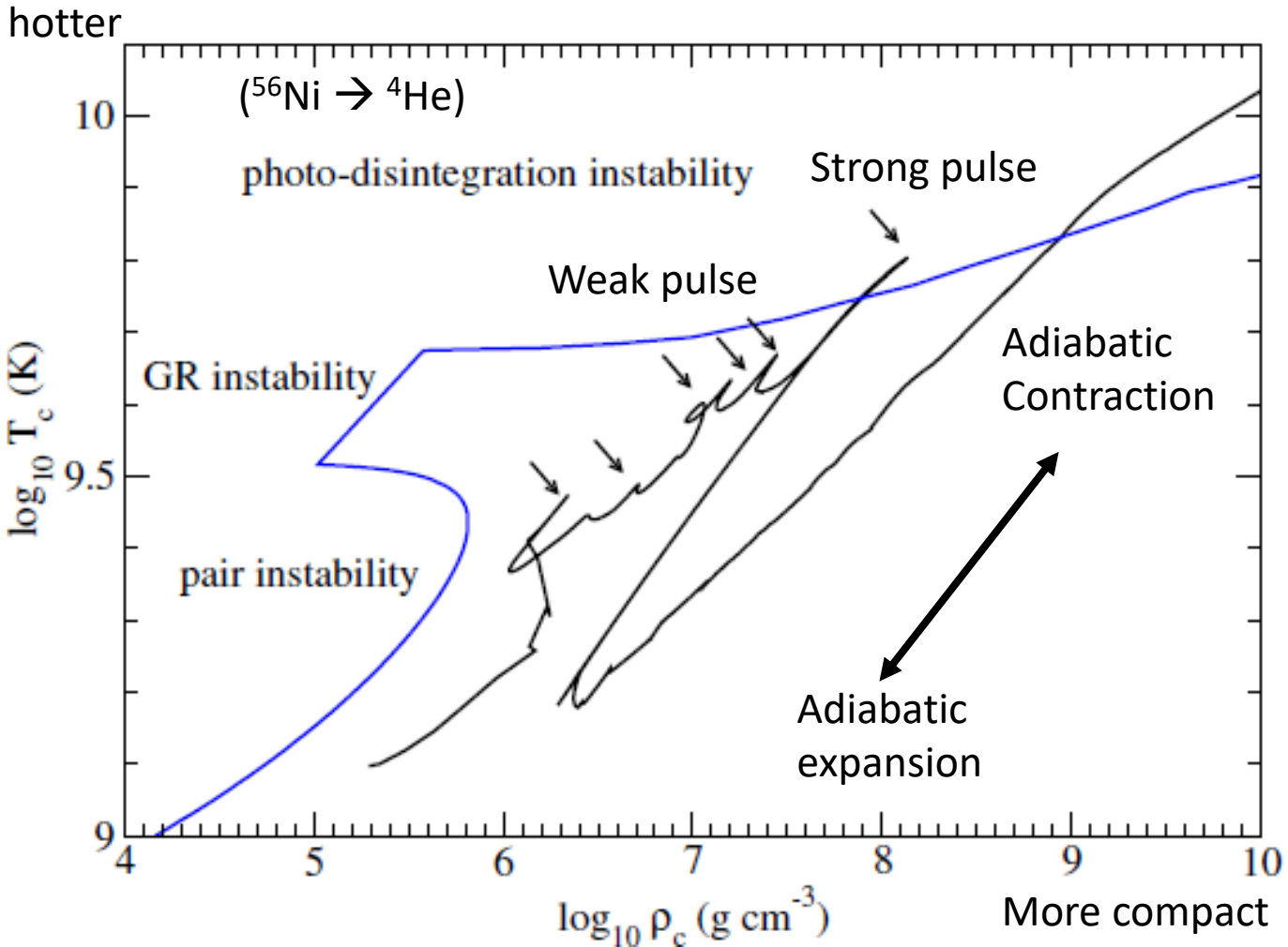
What metallicity range forms PPISN?



- $Z > 0.75\ Z_{sun}$
  - Only CCSN
- $0.5 < Z < 0.75\ Z_{sun}$:
  - CCSN
  - PPISN
- $Z < 0.5\ Z_{sun}$
  - CCSN
  - PPISN
  - PISN

Evolution and pulsation of 40 M_{sun} He core

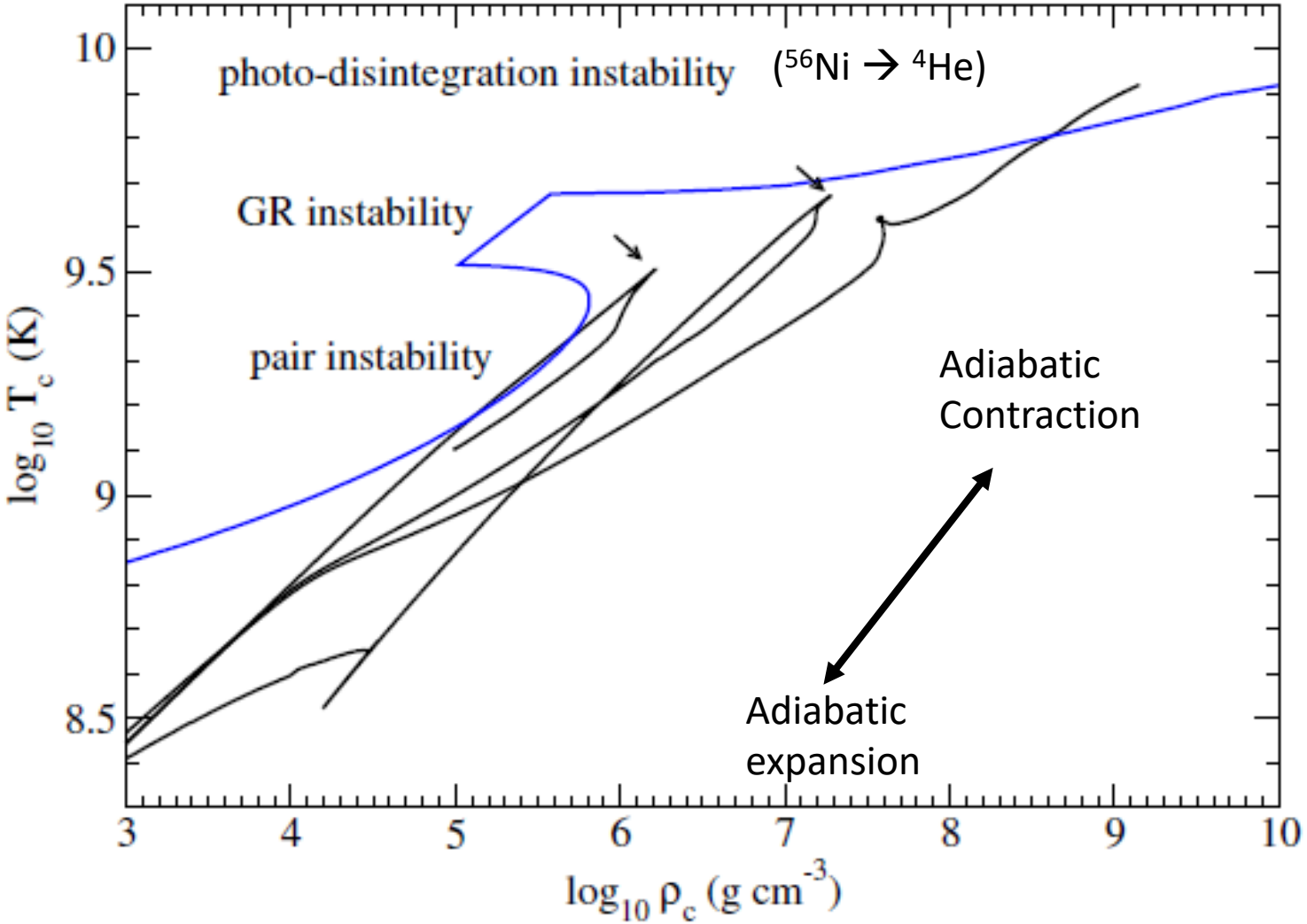
Below 40 M_{sun}, the He core does not pulse and eject mass



- Obtained from ~80 solar mass star
- 5 weak pulses
- 1 strong pulse
  - Ejected ~1 Msun mass

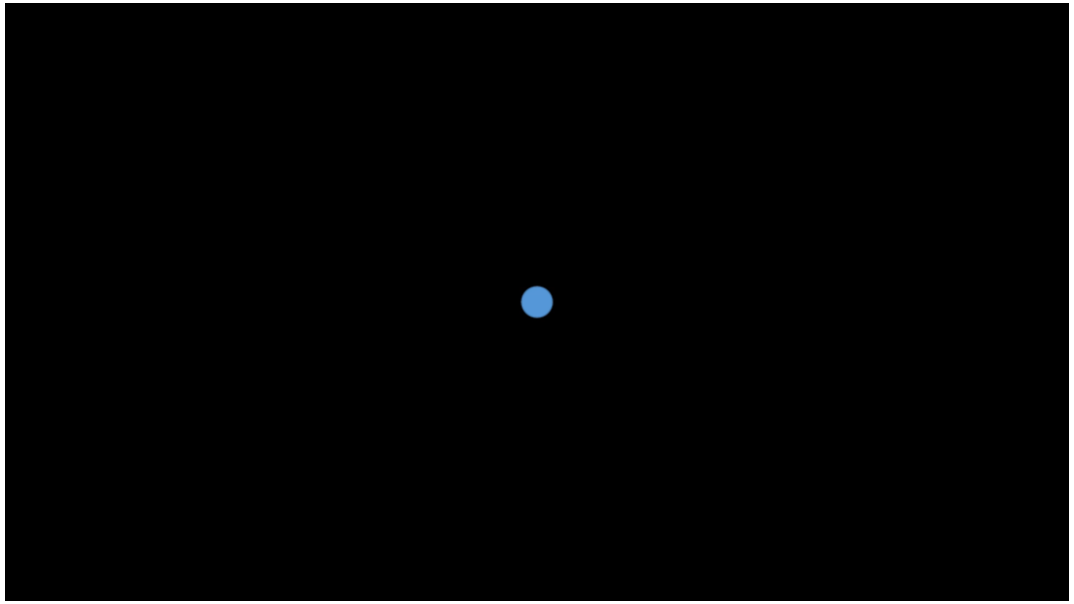
Evolution and pulsation of 62 M_{sun} He-core

Above 64 M_{sun}, the He core does not pulsate but explode directly

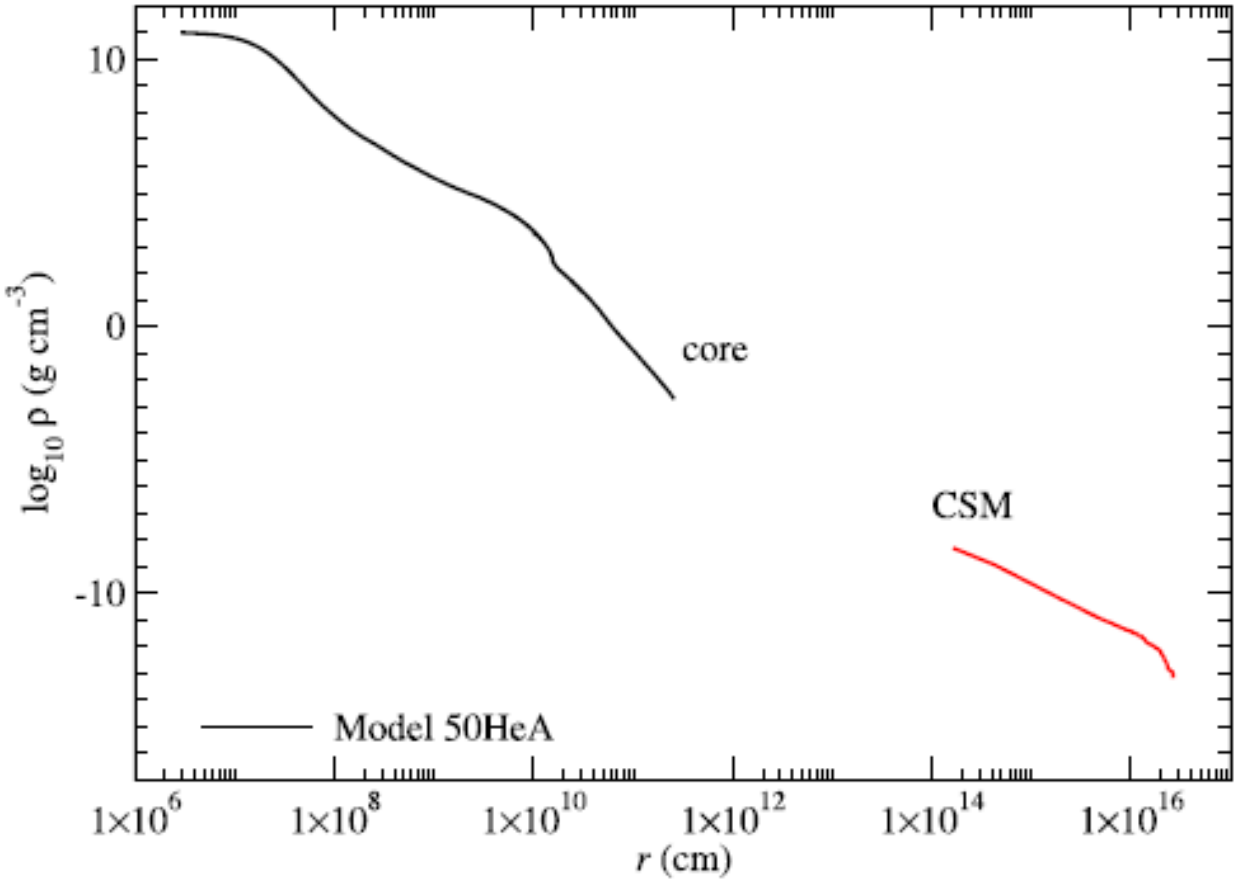


- Obtained from ~120 M_{sun} star
- 2 strong pulses
  - Ejected 10 M_{sun} mass

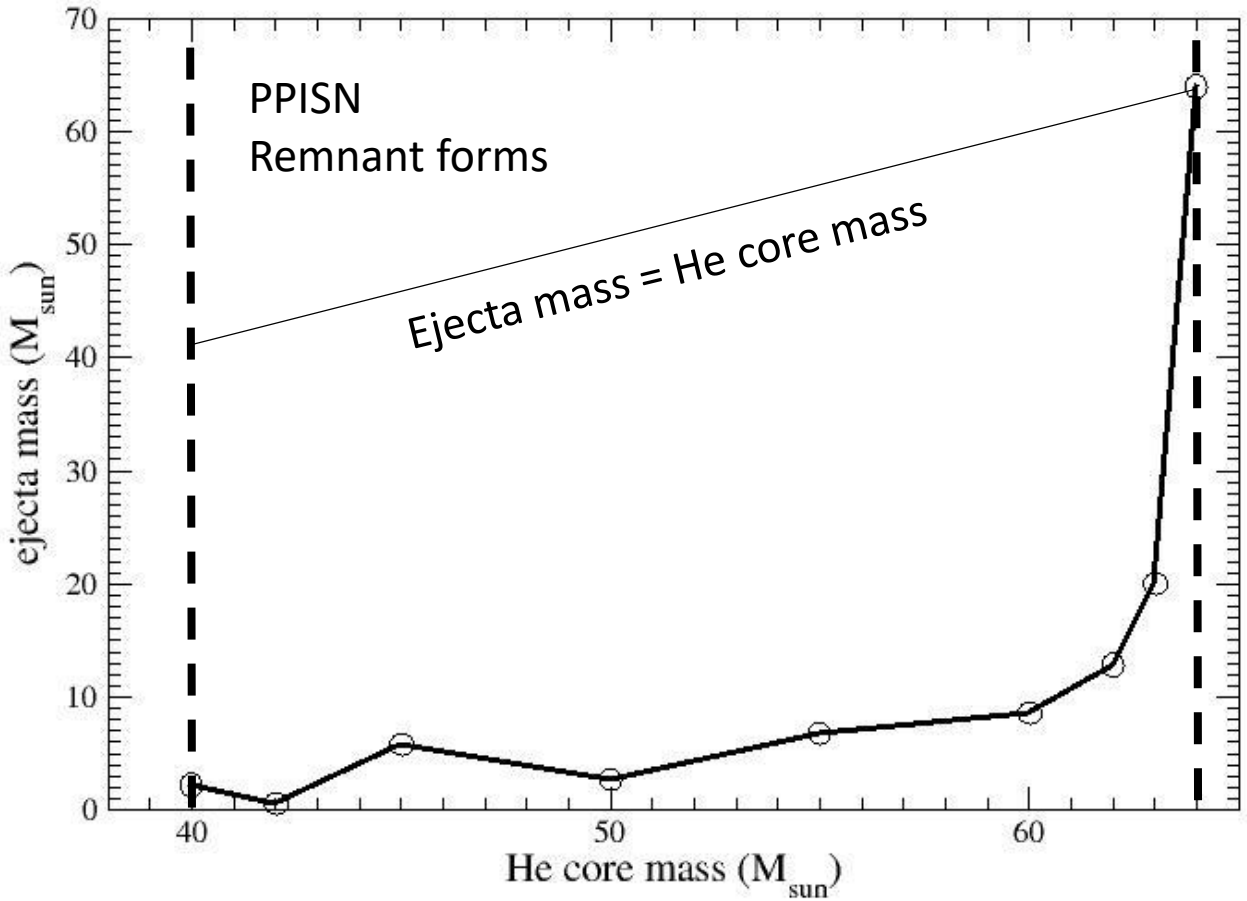
Ejecta mass and composition



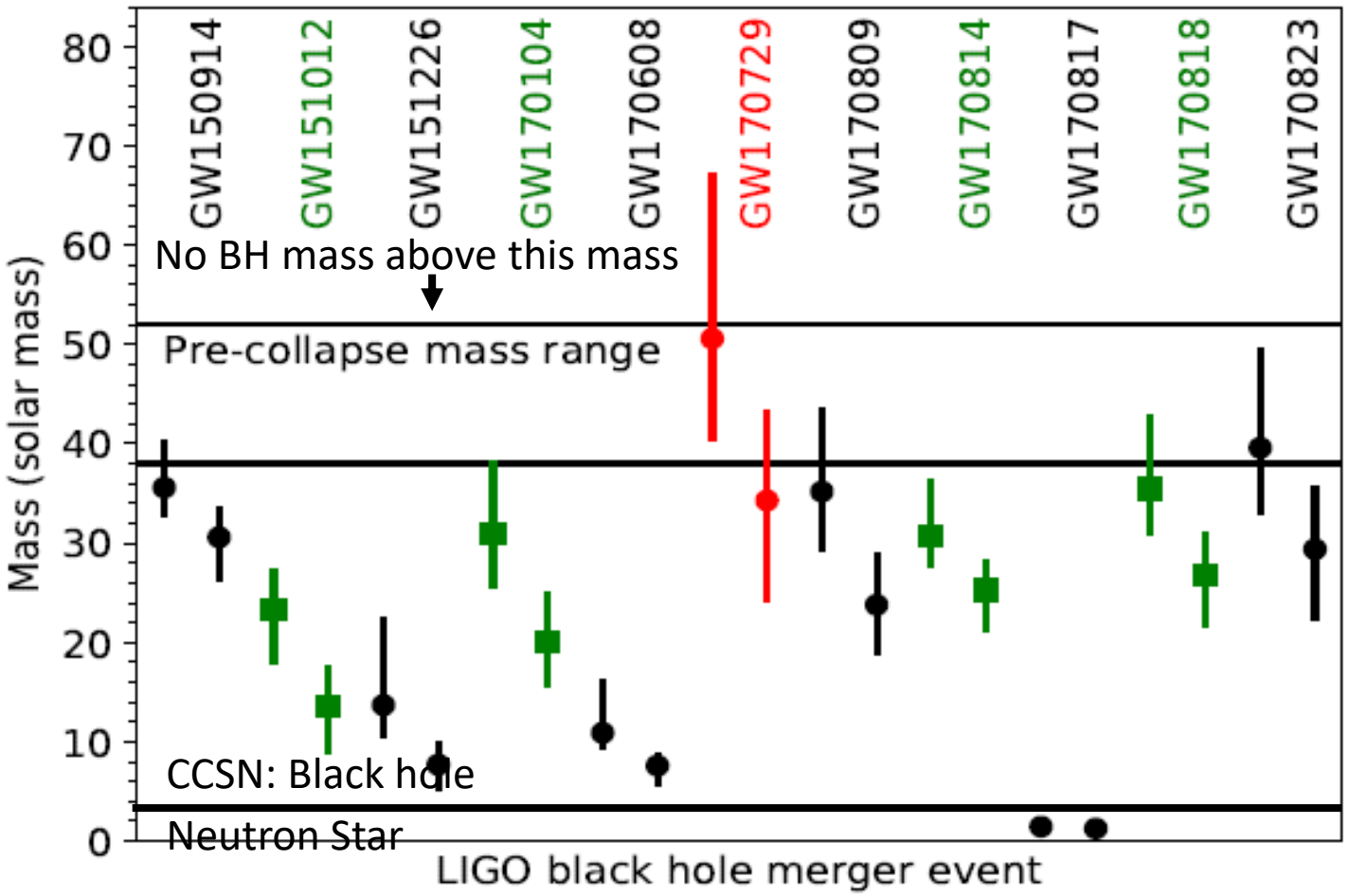
Schematic cartoon



How much mass is ejected?



PPISN Remnant vs. LIGO



- Most aLIGO black holes are formed by CCSN
- Black hole between 36 – 52 Msun by PPISN