# Astrophysics of gravitational wave sources

## Lecture 3: Late stages of stellar evolution

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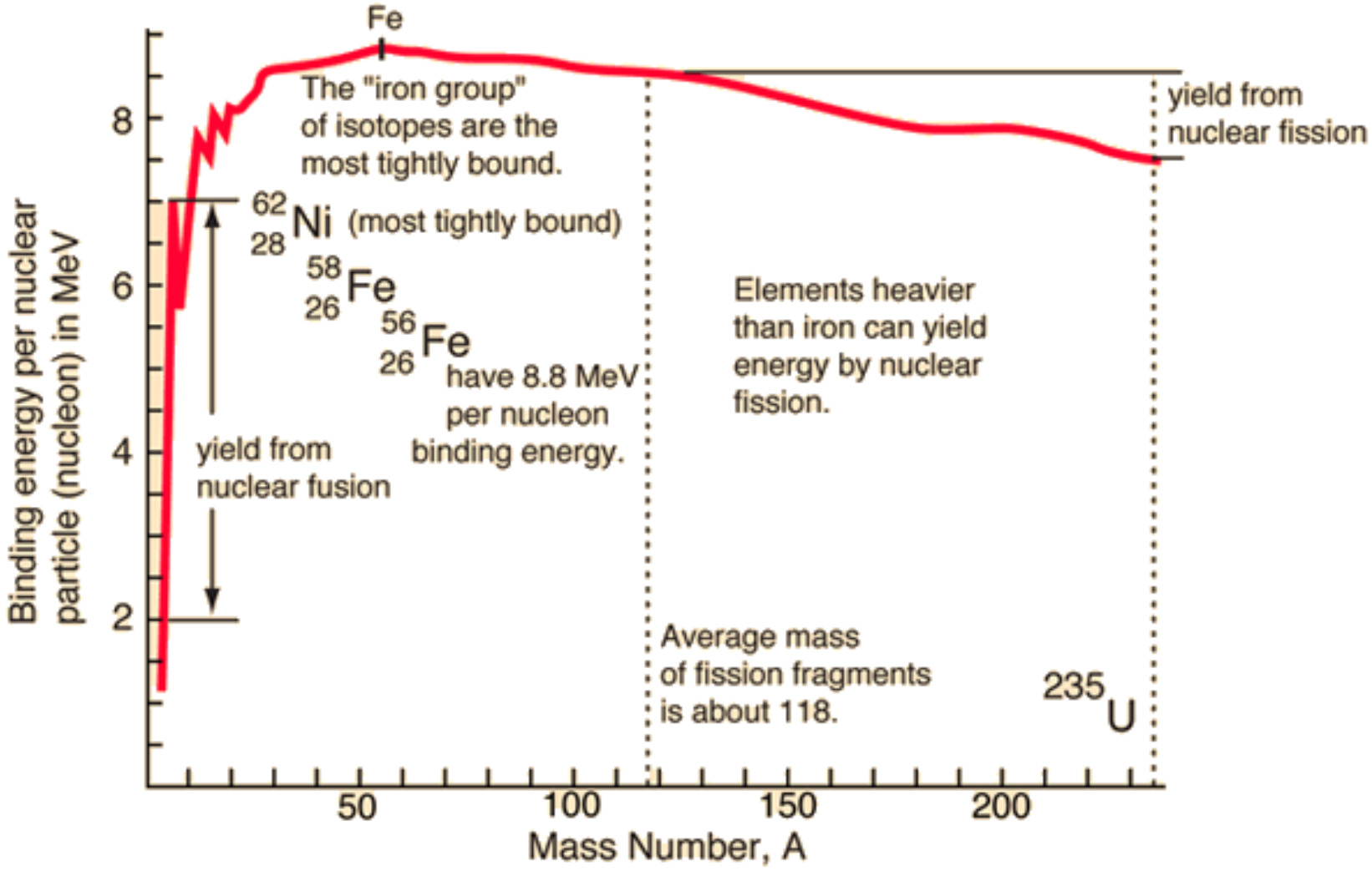
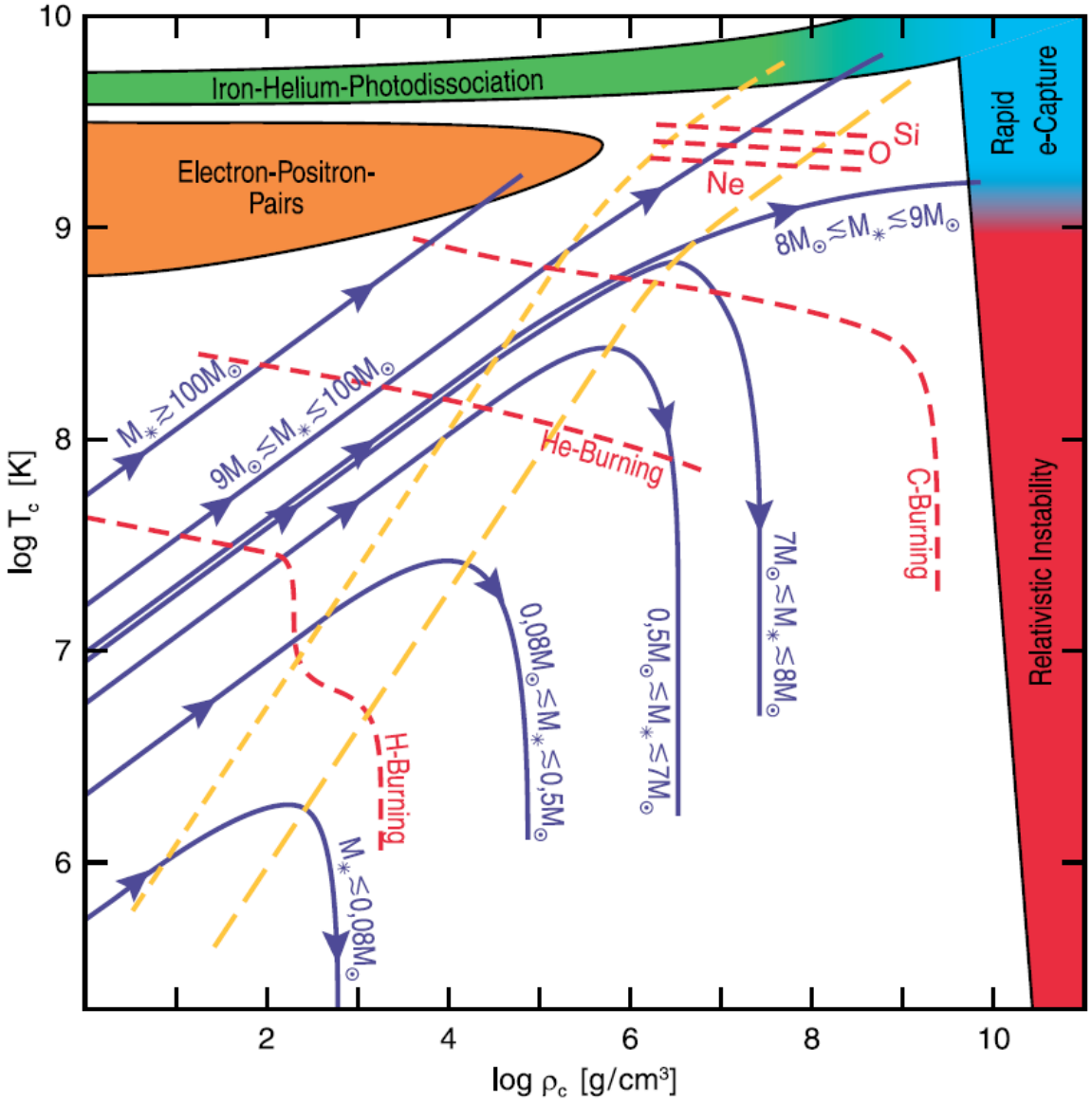
# Evolution of single (low-mass) star


Fe
The "iron group" of isotopes are the most tightly bound.
yield from nuclear fission
62 28 Ni (most tightly bound)
58 26 Fe
56 26 Fe have 8.8 MeV per nucleon binding energy.
Elements heavier than iron can yield energy by nuclear fission.
yield from nuclear fusion
Average mass of fission fragments is about 118.
235 U
Binding energy per nuclear particle (nucleon) in MeV
8
6
4
2
50
100
150
200
Mass Number, A

# Single star evolution before core-collapse

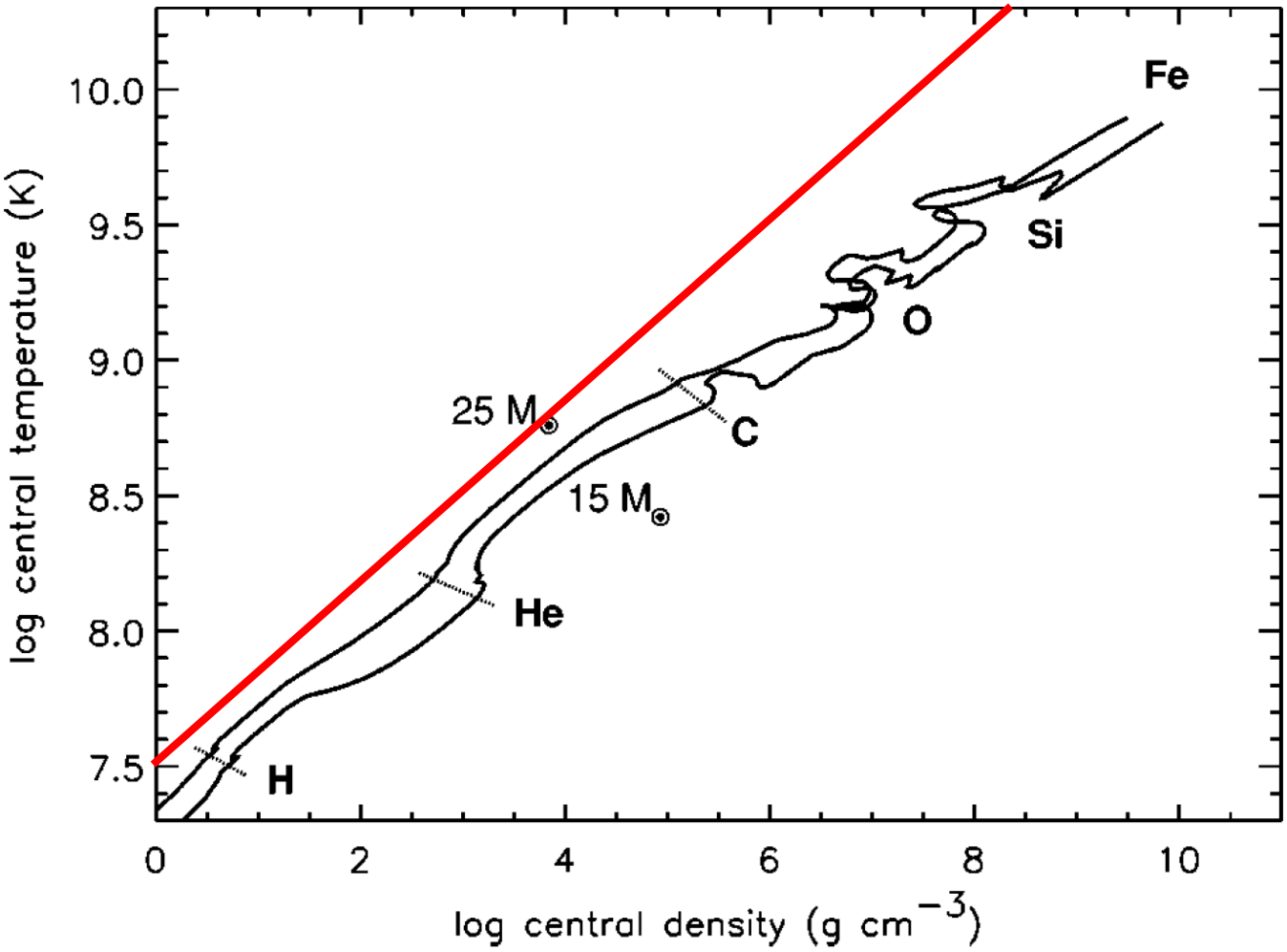
Central temperature and pressure



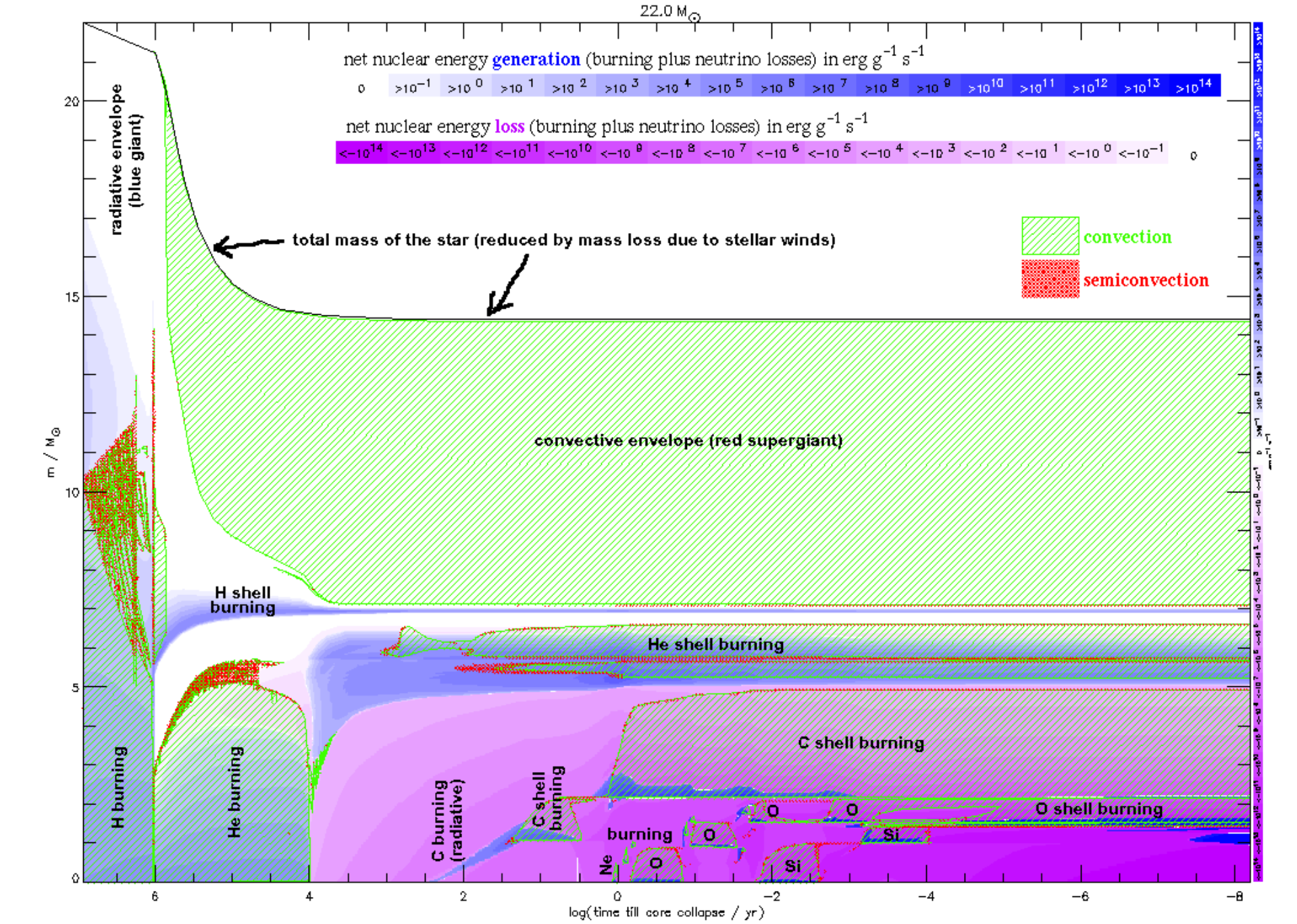

Janka (2012)

# Single star evolution before core-collapse

Central temperature and pressure




Woosley et al. (2002)




A. Heger website 2sn.org

# Physical processes inside massive star

- Neutrino losses
  - Mostly due to thermal processes (T^9), later due to neutronization (T^6)
  - Accelerates evolution (~day timescale for silicon)
- Convection
  - Mixing length theory, but convective and nuclear timescales comparable
  - Mixing as a diffusive process
- Semi-convection
  - Schwarzschild – instability only due to temperature/pressure gradients
  - Ledoux – also takes into account chemical composition
  - Unstable by Schwarzschild & stable by Ledoux = semi-convection
  - Diffusion coefficient uncertain
- Overshoot mixing
  - Modeled by diffusion
- Rotation & magnetic fields
  - Coupling of core to envelope – affected by mass loss
- Mass loss