Astrophysics of gravitational wave sources

Lecture 4: Single star evolution

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Why do stars shine?

(wrong answers only)

Two-point boundary value problem

$$\frac{dP}{dM_r} = -\frac{GM_r}{4\pi r^4},$$

$$\frac{dr}{dM_r} = \frac{1}{4\pi r^2 \rho},$$

$$\frac{dT}{dM_r} = -\frac{3\kappa L_r}{64\pi^2 acT^3 r^4},$$

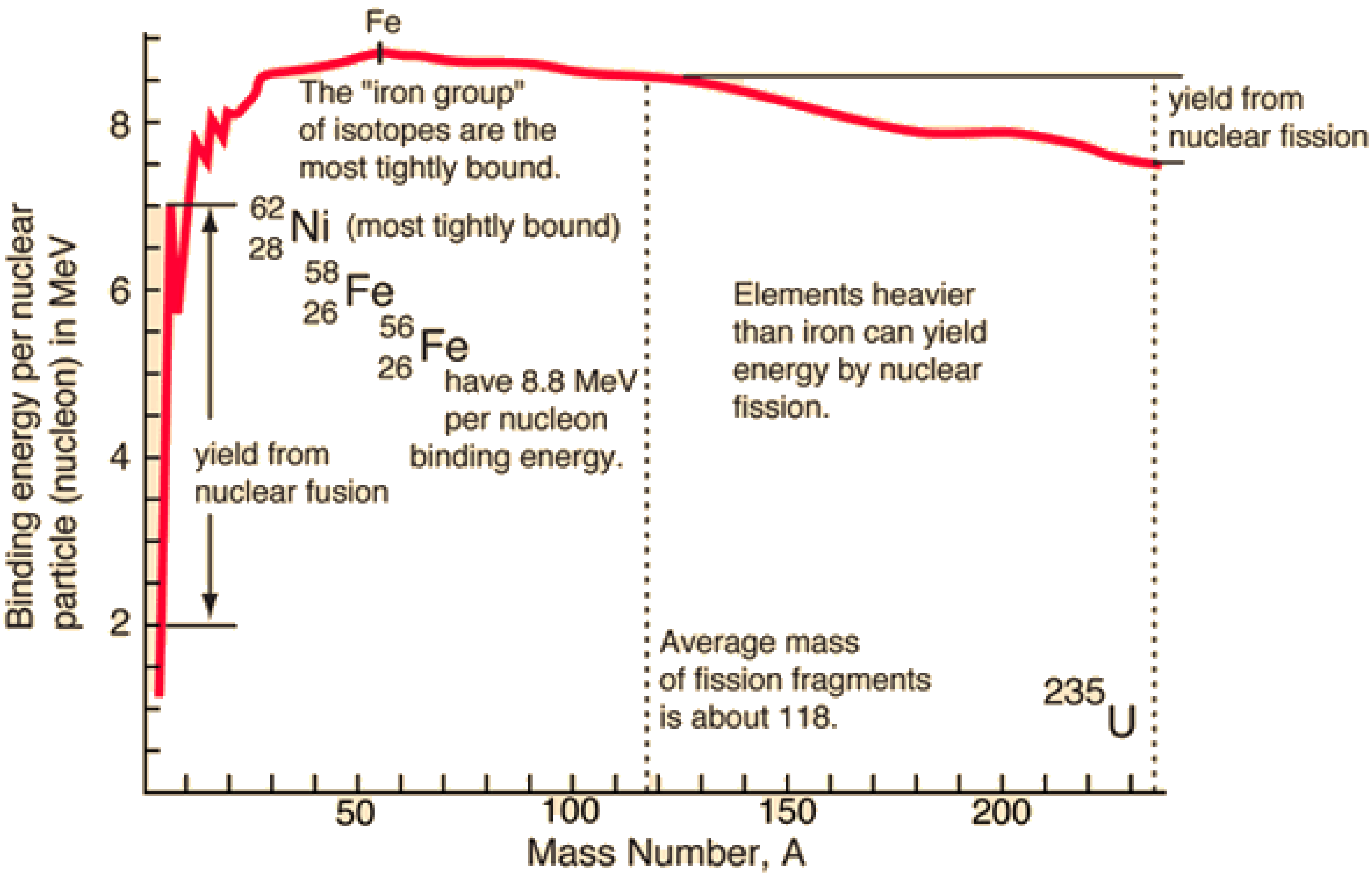
but convection!

$$\frac{dL_r}{dM_r} = \epsilon.$$

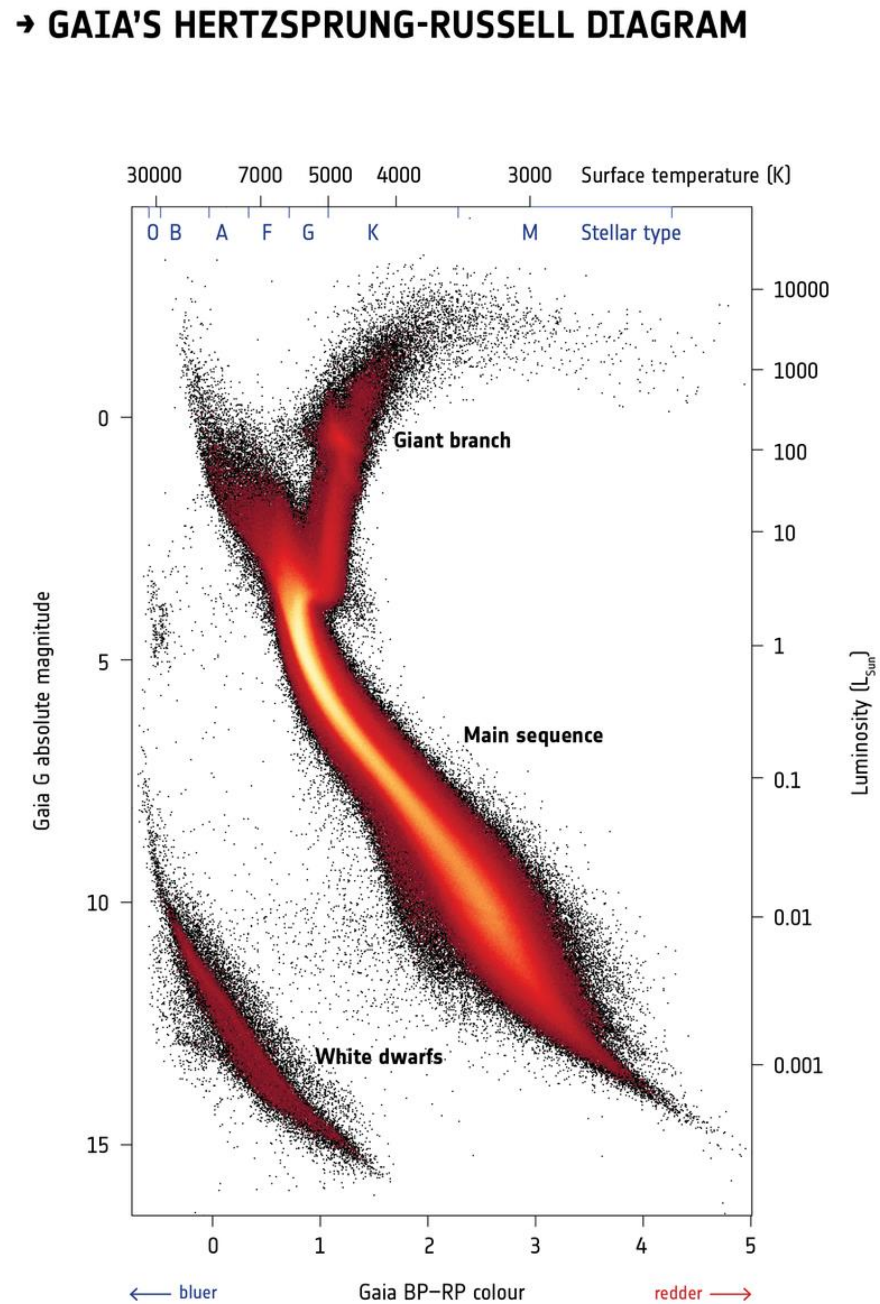
Separation of stellar timescales

- Dynamical (free-fall, sound-crossing) timescale
- (Viscous timescale)
- Thermal (Kelvin-Helmholtz) timescale
- Nuclear timescale

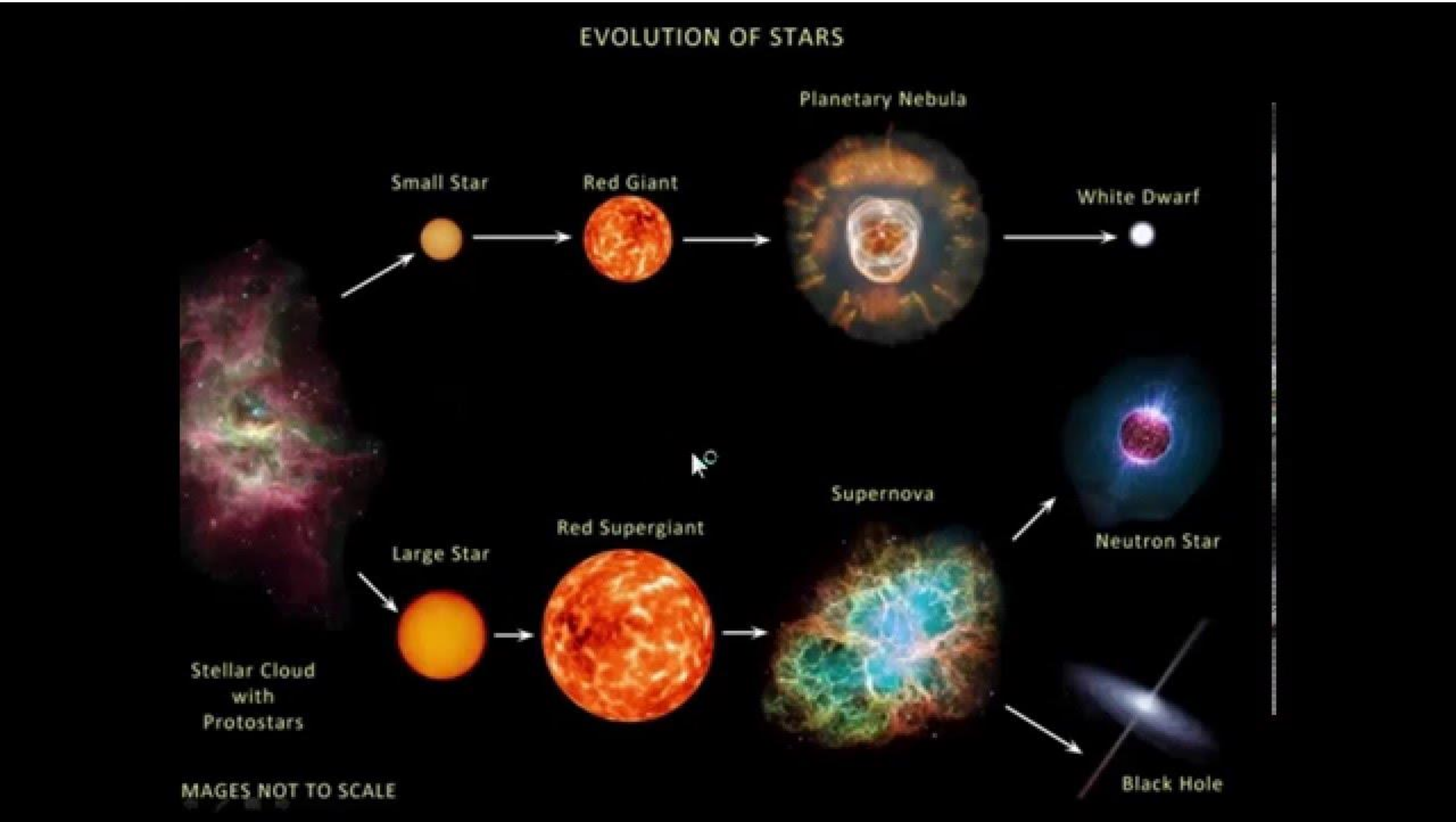
Why do stars evolve?

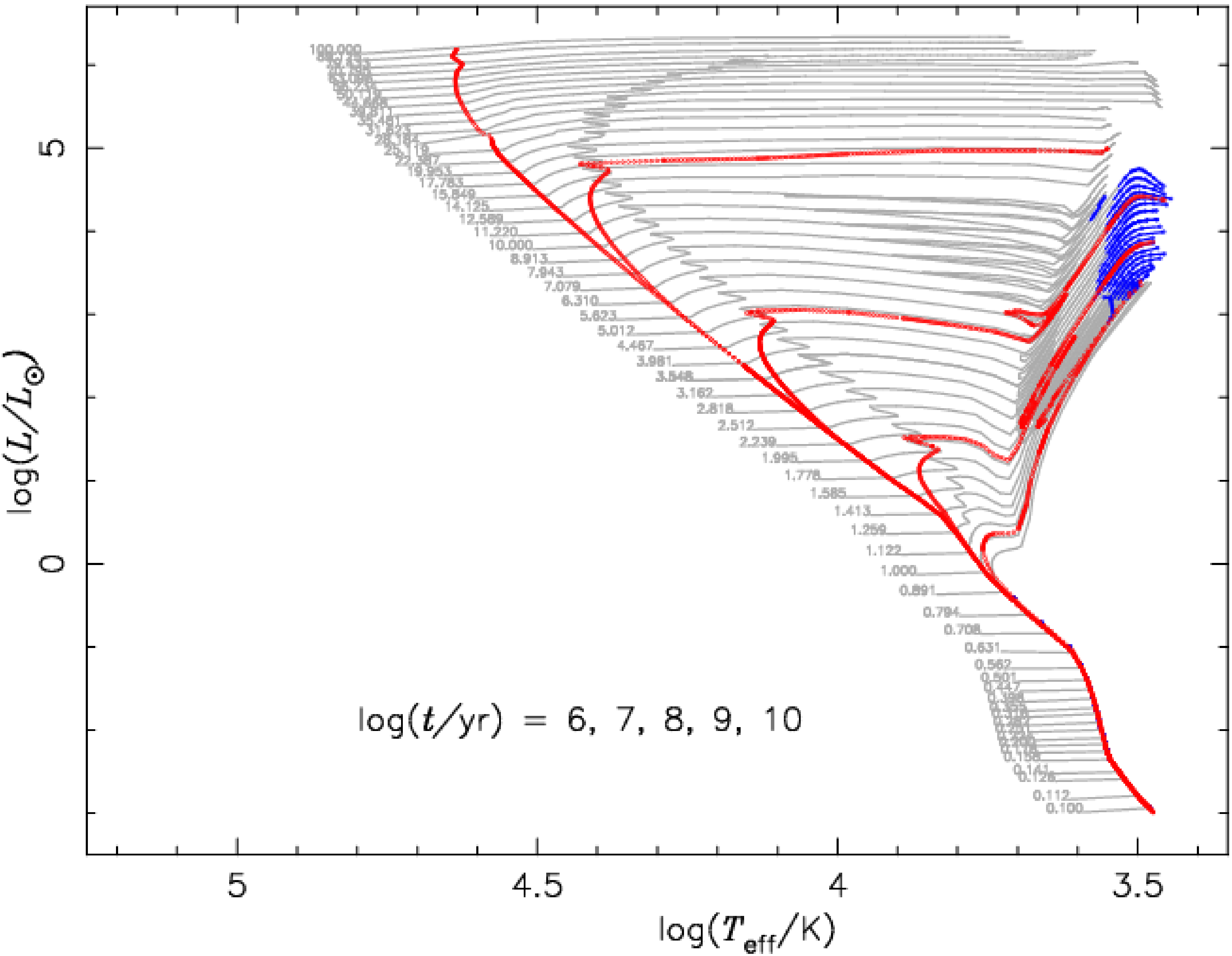


Main parameters of stars



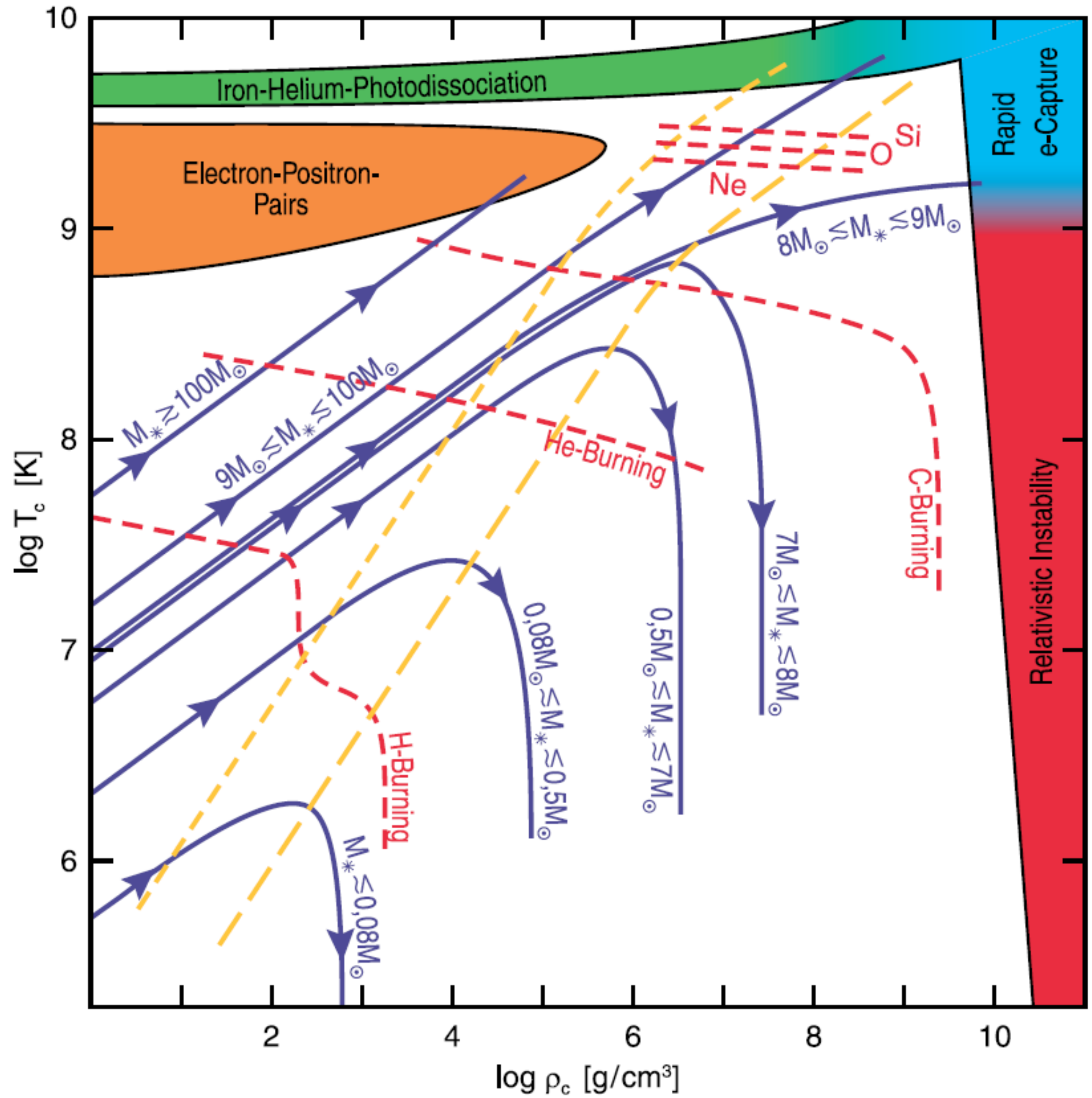
Stellar evolution




log(t/yr) = 6, 7, 8, 9, 10
log(L/L⊙)
log(Teff/K)
5
4.5
4
3.5
0

Single star evolution before core-collapse

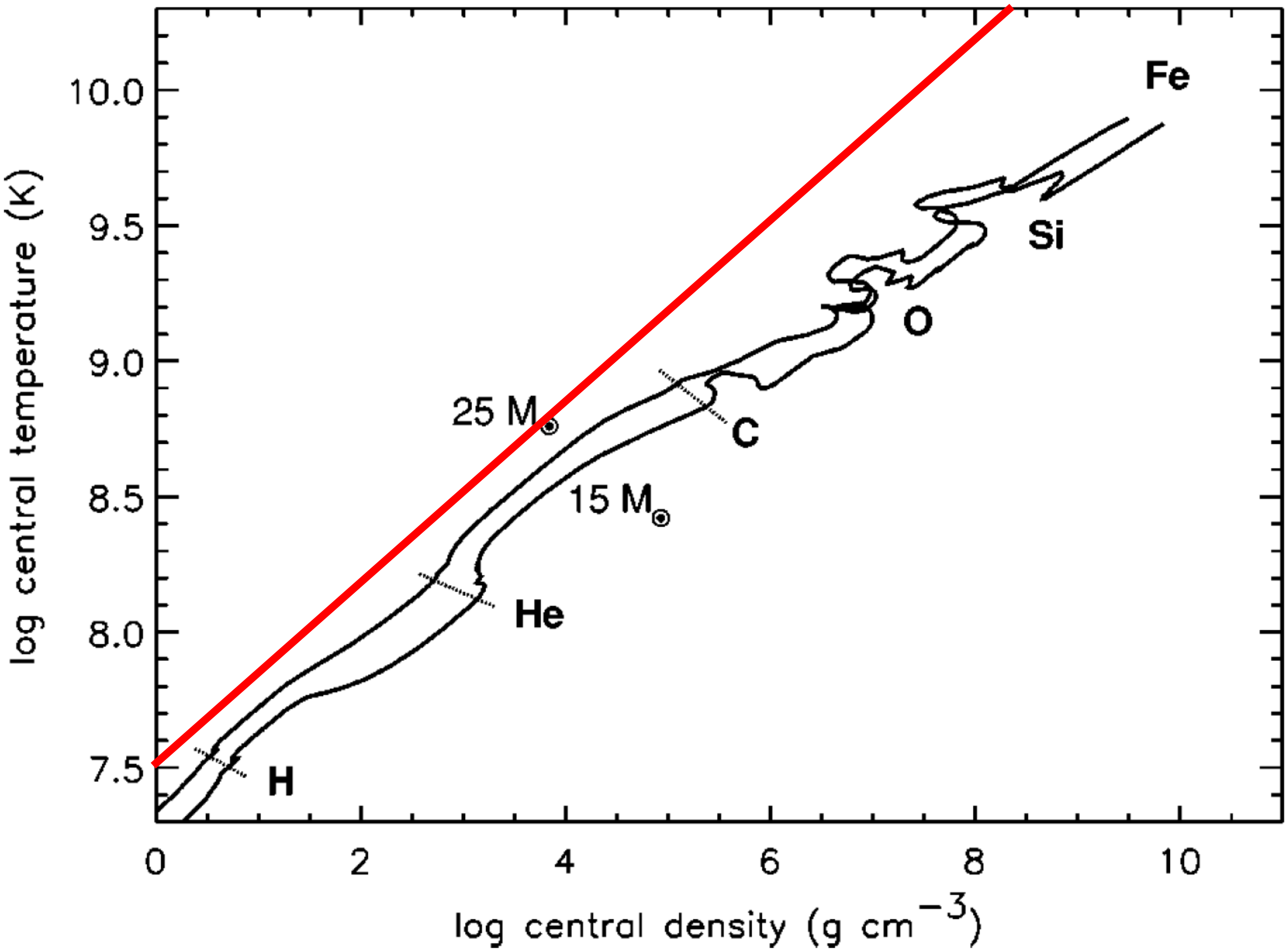
Central temperature and pressure



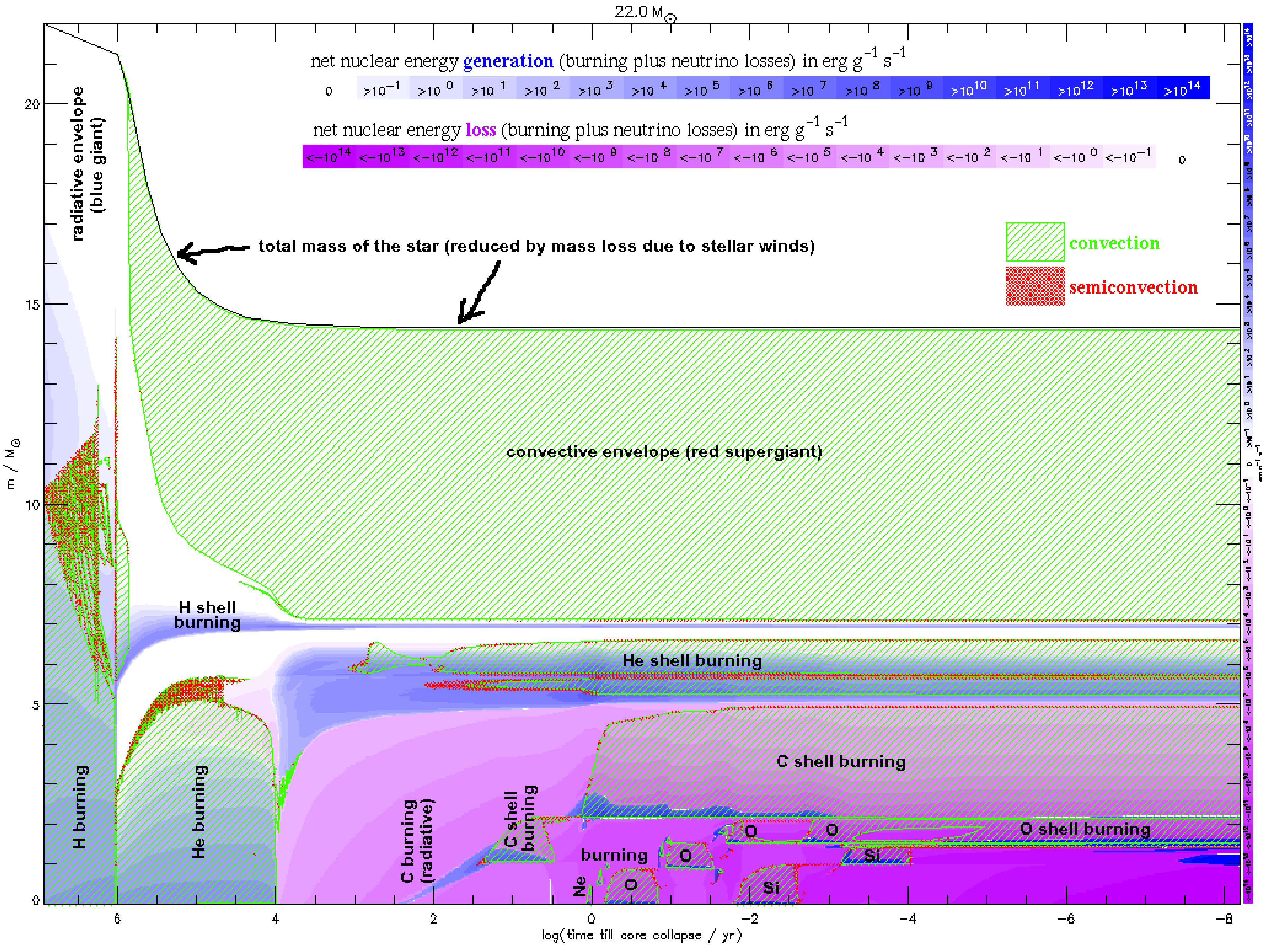
Janka (2012)

Single star evolution before core-collapse

Central temperature and pressure



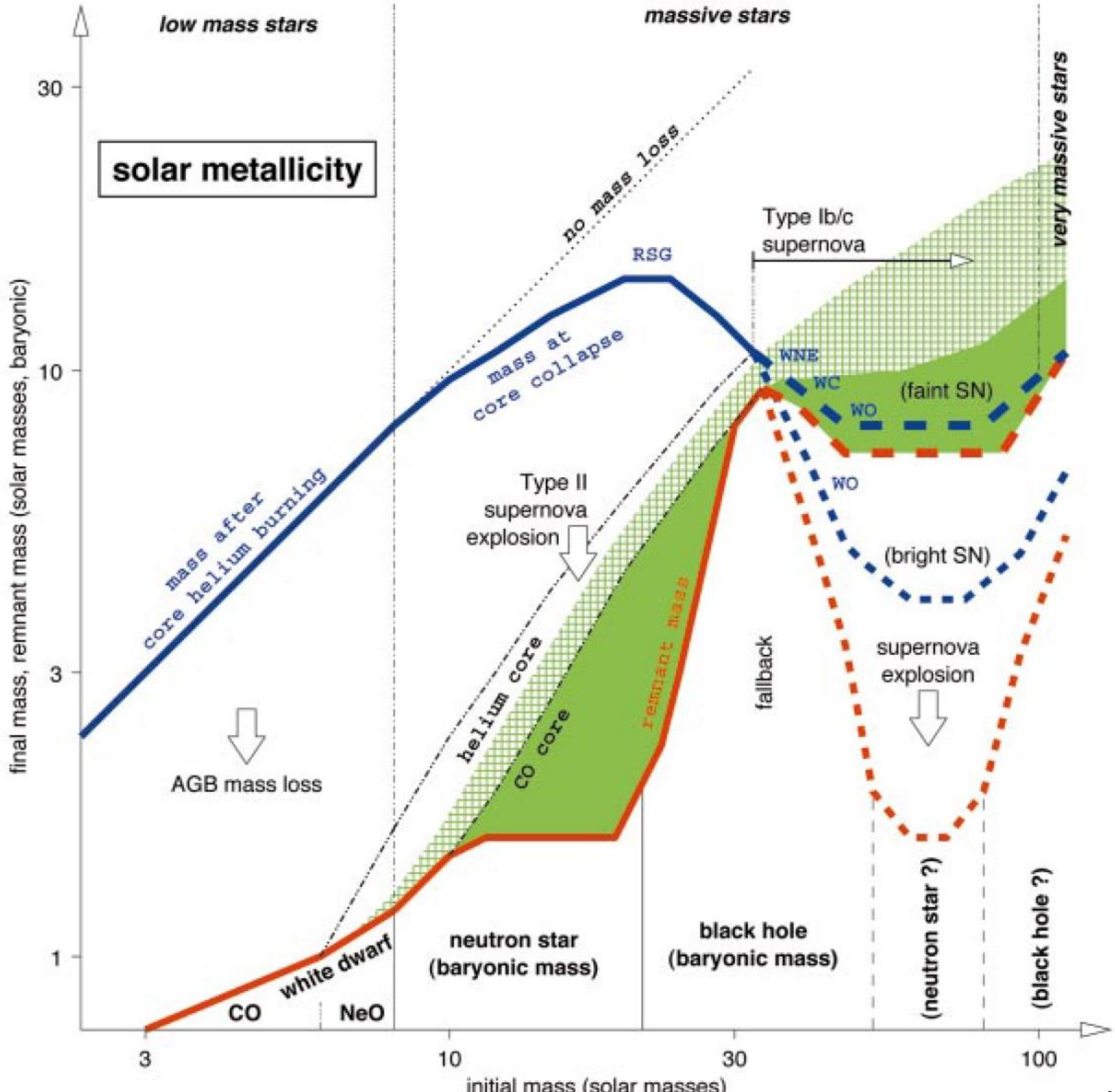
Woosley et al. (2002)



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



Woosley et al. (2002)