Section 6.
End of massive stars

6.1 Dynamical stability of stars

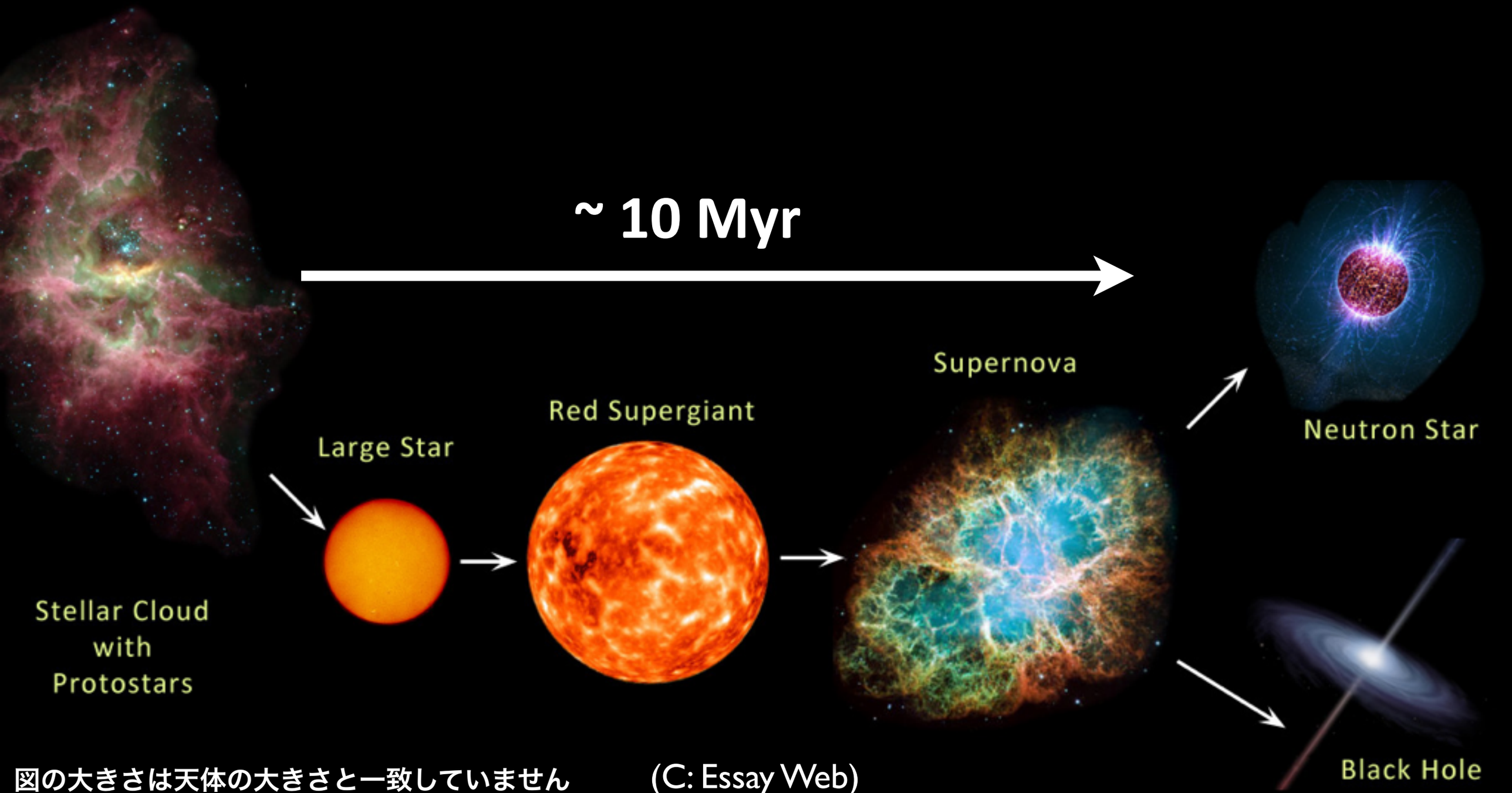
6.2 Core-collapse of massive stars

Let's understand these questions with the words of physics

- Why are stars so luminous?
- Why do stars show $L \sim M^4$?
- Why do stars evolve?
- Why does the destiny of stars depend on the mass?
- Why do some stars explode?
- Why don't normal star explode?
- Why does stellar core collapses?
- Why is the energy of supernova so huge?
- …

1. Massive stars

M > 10 Msun



図の大きさは天体の大きさと一致していません

(C: Essay Web)

H

He

C + O

Ne + Mg

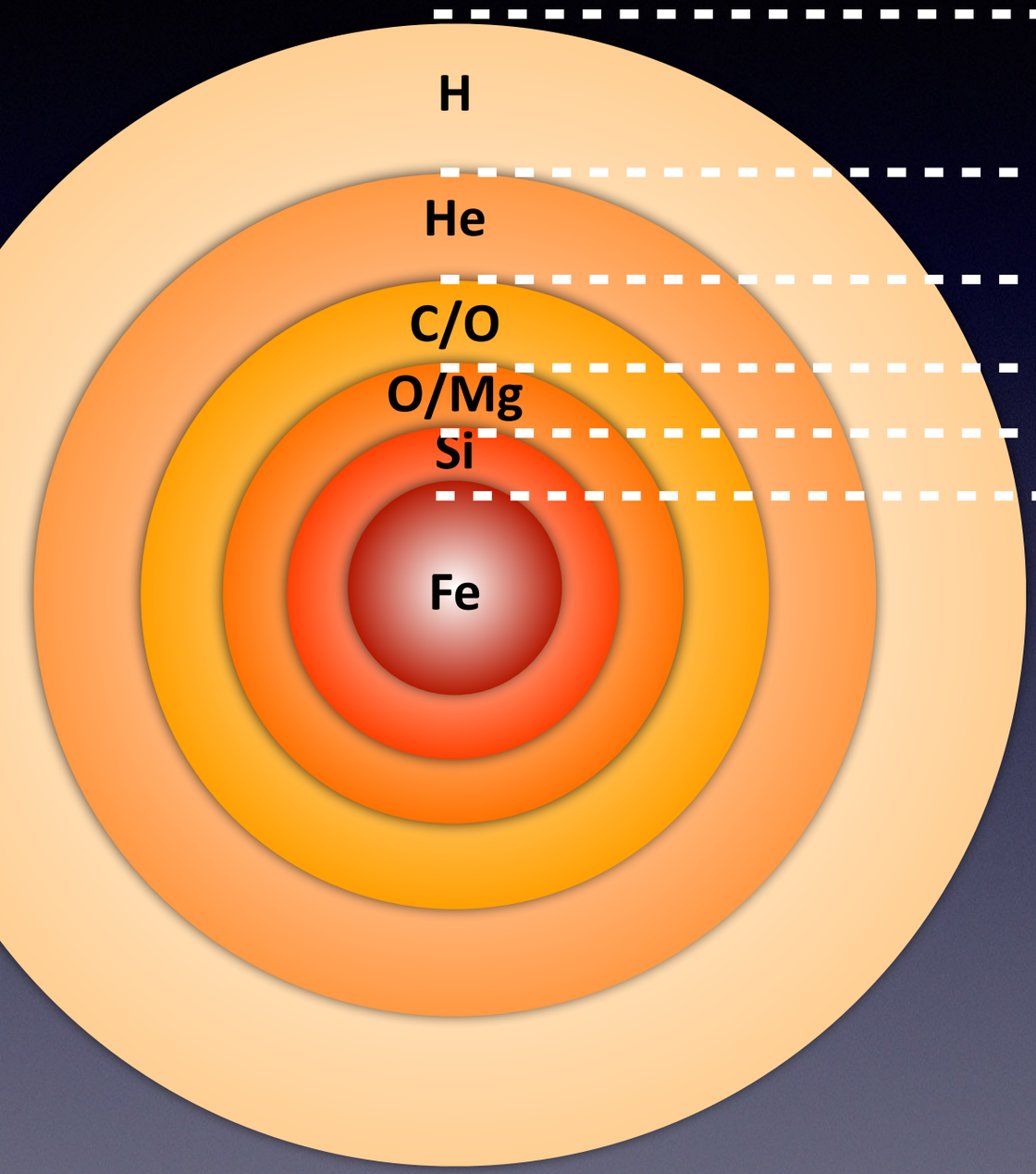
Si

Fe

Images are not to scale

20 Msun star

(~16 Msun before the collapse)



Mass (Msun)	R (Rsun)	Free-fall time (s)
16	1000	3×10^7 (1yr)
6	0.5	300
5	0.2	50
4	0.08	20
2	0.005	1
1.5	0.003	0.1

$R_{sun} = 7 \times 10^{10}$ cm

$R(\text{Fe core}) \sim 0.003 \times 7 \times 10^{10}$ cm
$\sim 2 \times 10^8$ cm $\sim$ 2,000 km

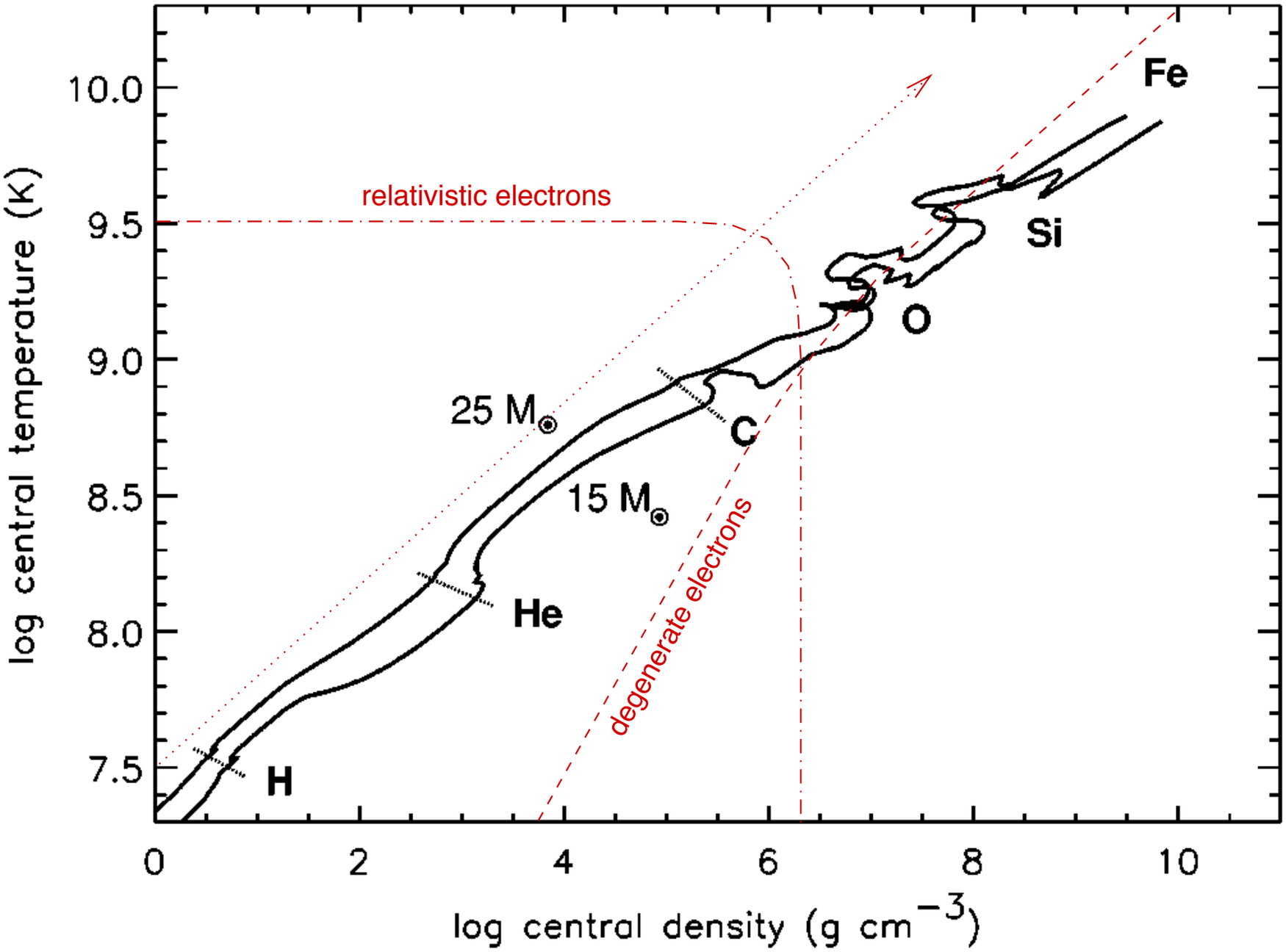
1000

H

He

0.5

Rho-T diagram



textbook by Pols

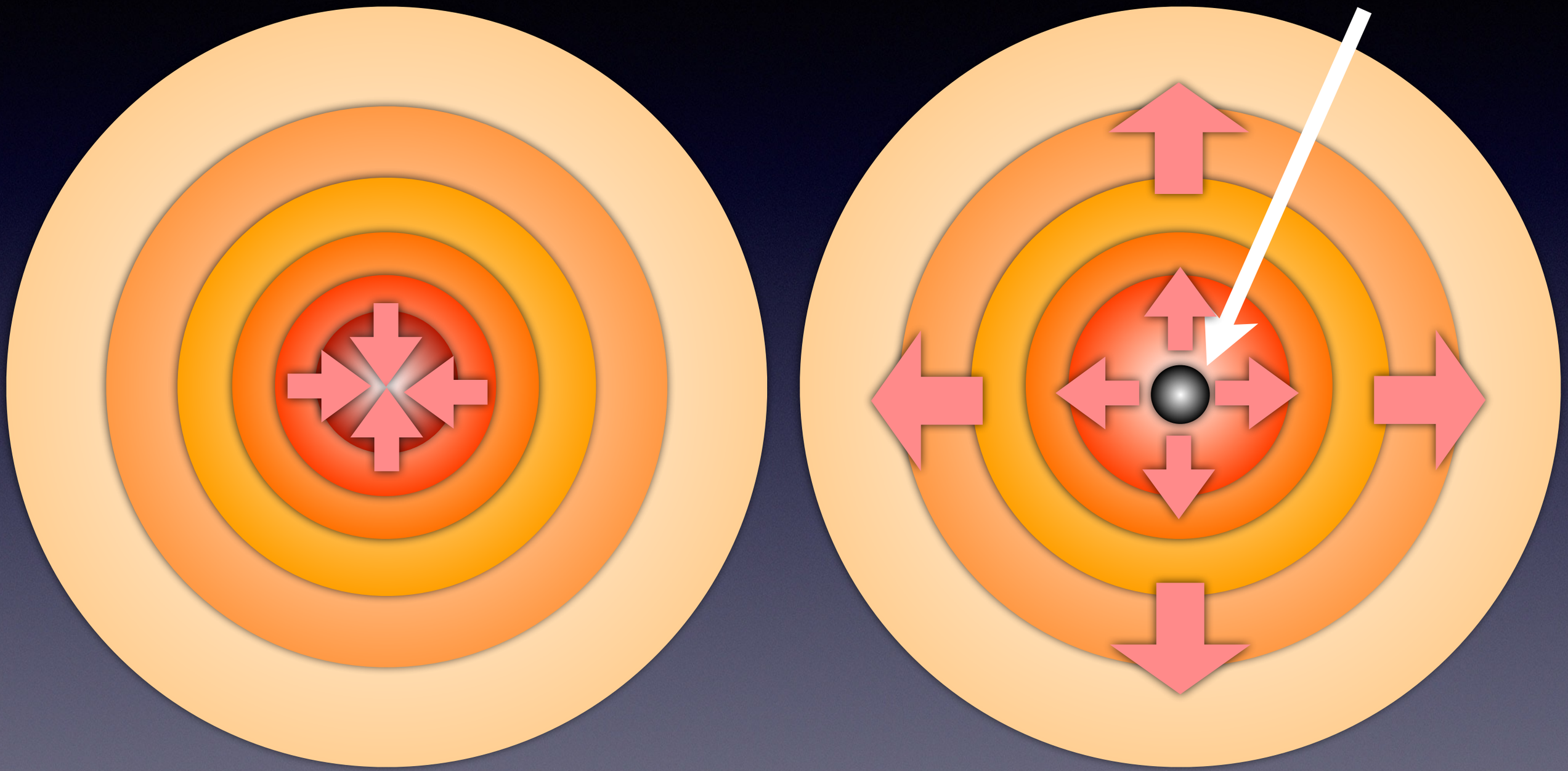
Timescales for nuclear burning stages

Table 12.1. Properties of nuclear burning stages in a 15 $M_\odot$ star (from Woosley et al. 2002).

burning stage	T (10^9 K)	ρ (g/cm^3)	fuel	main products	timescale
hydrogen	0.035	5.8	H	He	1.1×10^7 yr
helium	0.18	1.4×10^3	He	C, O	2.0×10^6 yr
carbon	0.83	2.4×10^5	C	O, Ne	2.0×10^3 yr
neon	1.6	7.2×10^6	Ne	O, Mg	0.7 yr
oxygen	1.9	6.7×10^6	O, Mg	Si, S	2.6 yr
silicon	3.3	4.3×10^7	Si, S	Fe, Ni	18 d

Collapse
(< 1 sec)

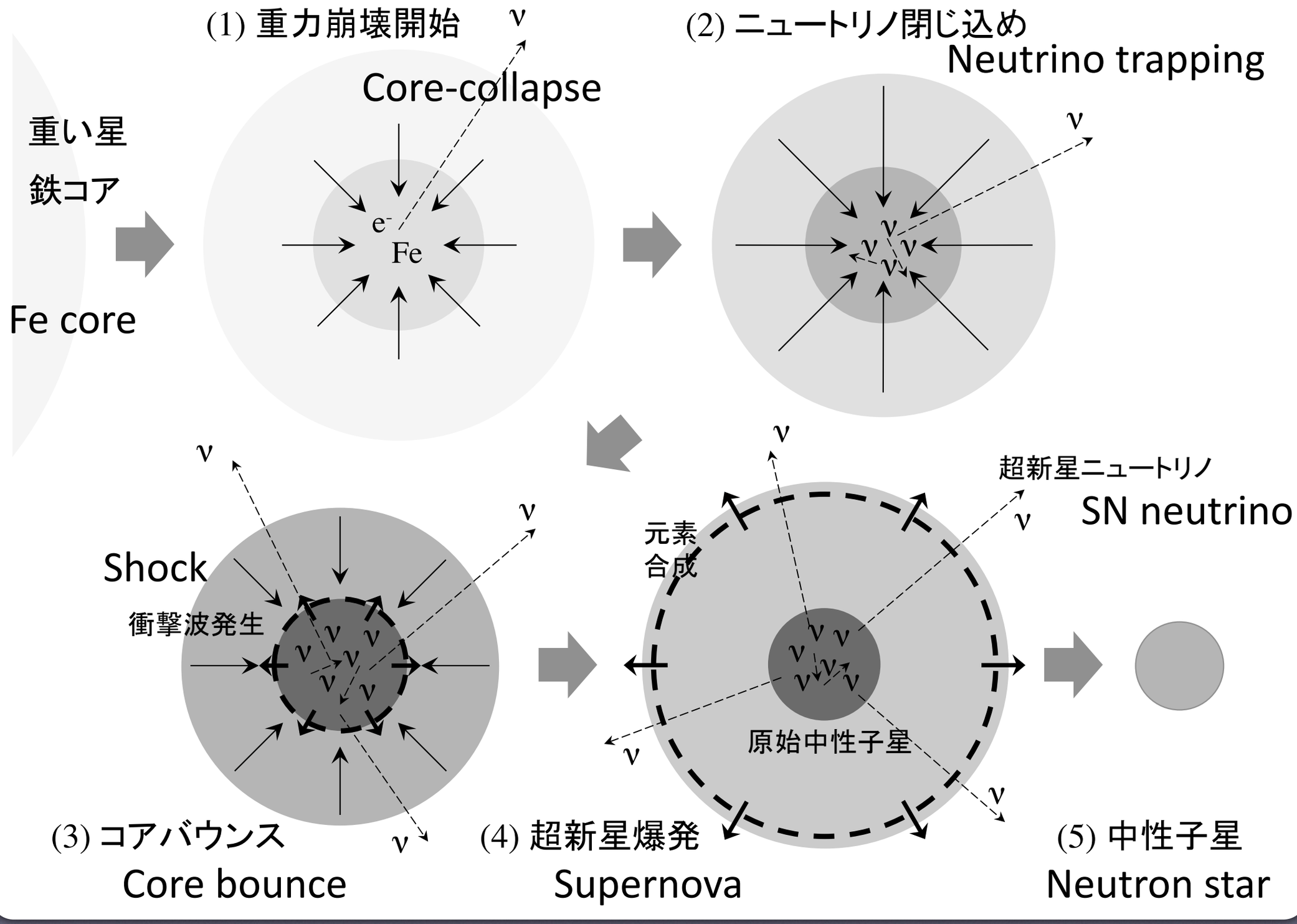
Neutron star
or
Black hole



Supernova!



Why does a core of massive star collapse?
(Why don’t normal star collapse or explode?)



(C) 原子核から読み解く超新星爆発の世界

住吉光介さん著 (Kosuke Sumiyoshi)

Summary: End of massive stars

- **Stability of star**
  - Dynamically unstable if adiabatic index $\gamma < 4/3$
  - Degenerate Fe core => close to instability
- **What trigger the core-collapse?**
  - High density => electron capture
  - High temperature => Fe disassociation