Section 5.
Stellar evolution (II)

5.1 Equation of state

5.2 Evolutionary track

Let’s understand these questions with the words of physics

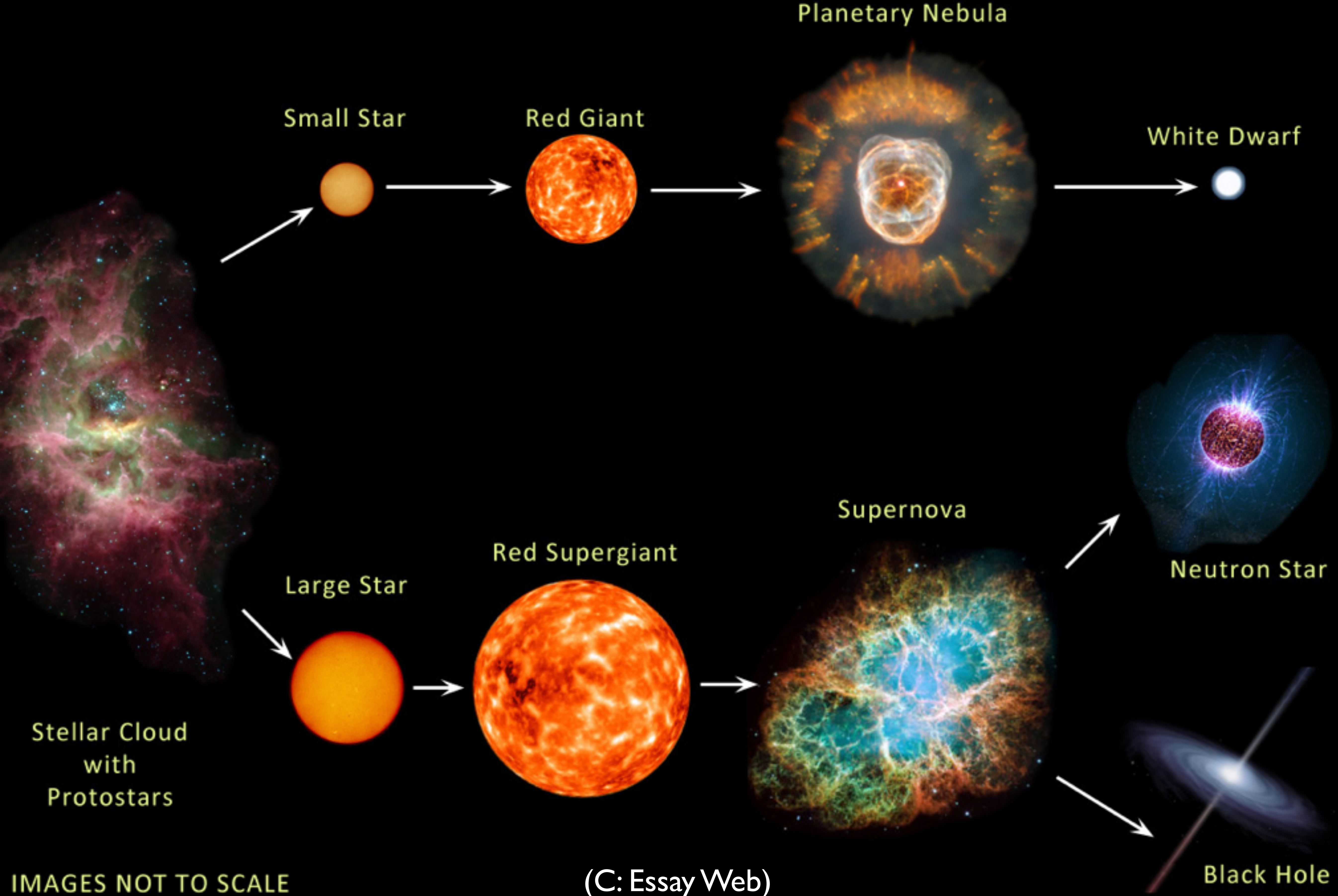
- Why are stars so luminous?
- Why do stars show $L \sim M^4$?
- Why do stars evolve?
- Why does the destiny of stars depend on the mass?
- Why do some stars explode?
- Why don’t normal star explode?
- Why does stellar core collapses?
- Why is the energy of supernova so huge?
- …

Section 5.
Stellar evolution (II)

5.1 Equation of state

5.2 Evolutionary track

Stellar life



(C: Essay Web)

Why does the destiny of the stars depend on the mass?

Microscopic properties of the gas play important roles

Assignment 2

2a. Derive pressure of ideal gas from the Maxwell distribution

2b. Derive pressure of degenerate electrons
(both for non-relativistic case and relativistic case)

2c. Derive radiation pressure from Planck function

2d. Draw the regions where

- ideal gas pressure
- degenerate pressure of non-relativistic electrons
- degenerate pressure of relativistic electrons
- radiation pressure

become dominant in the rho-T diagram.

レポート課題 2

2a. マクスウェル分布から
理想気体の圧力の式を導け

2b. 電子が非相対論的、超相対論的なときの
縮退圧の式を導き、実際に数字を入れて計算せよ

2c. プランク関数から輻射圧の式を導け

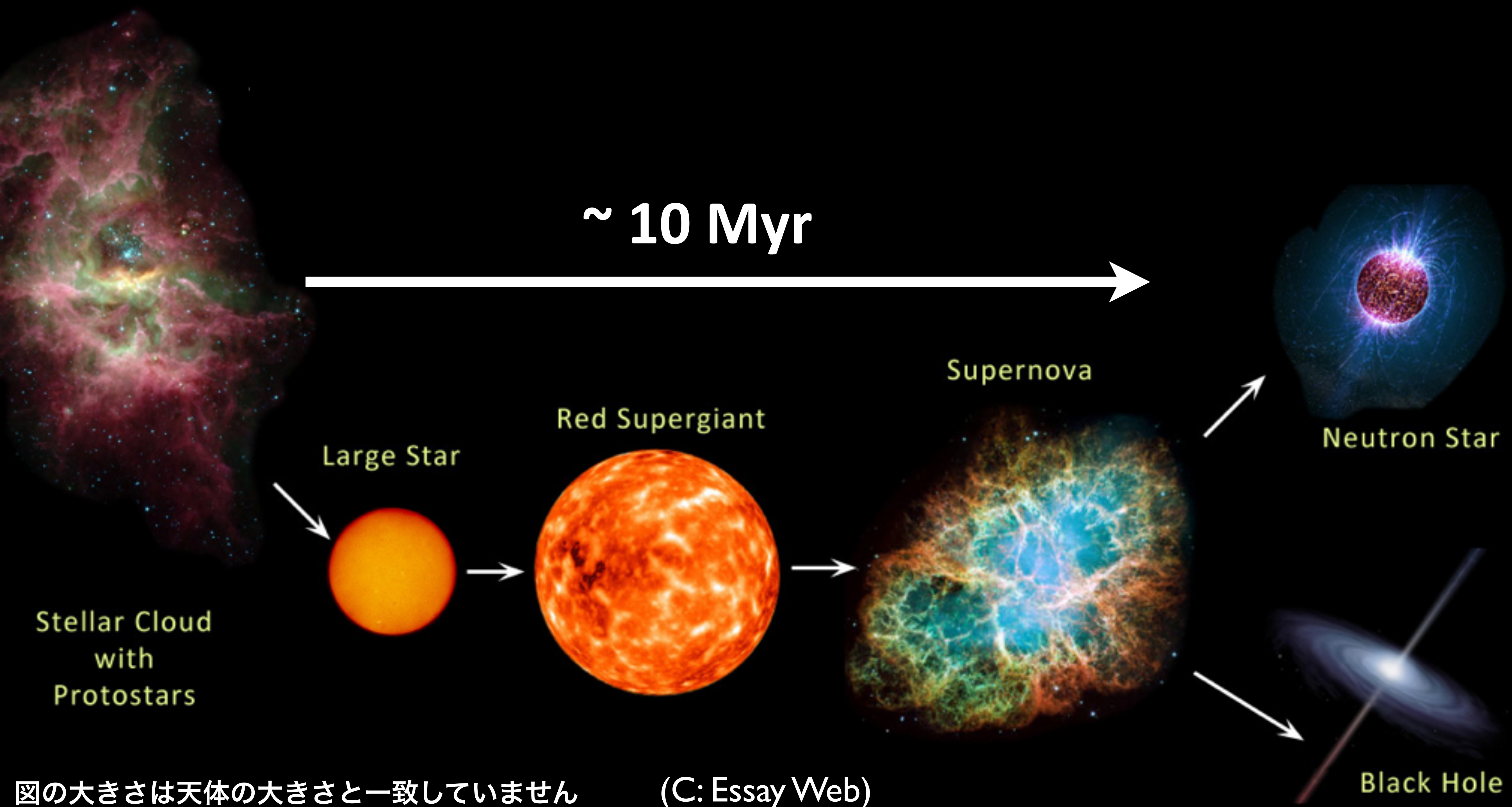
2d. 密度 - 温度平面で

- 理想気体のガス圧
- 電子の縮退圧（非相対論的）
- 電子の縮退圧（超相対論的）
- 輻射圧

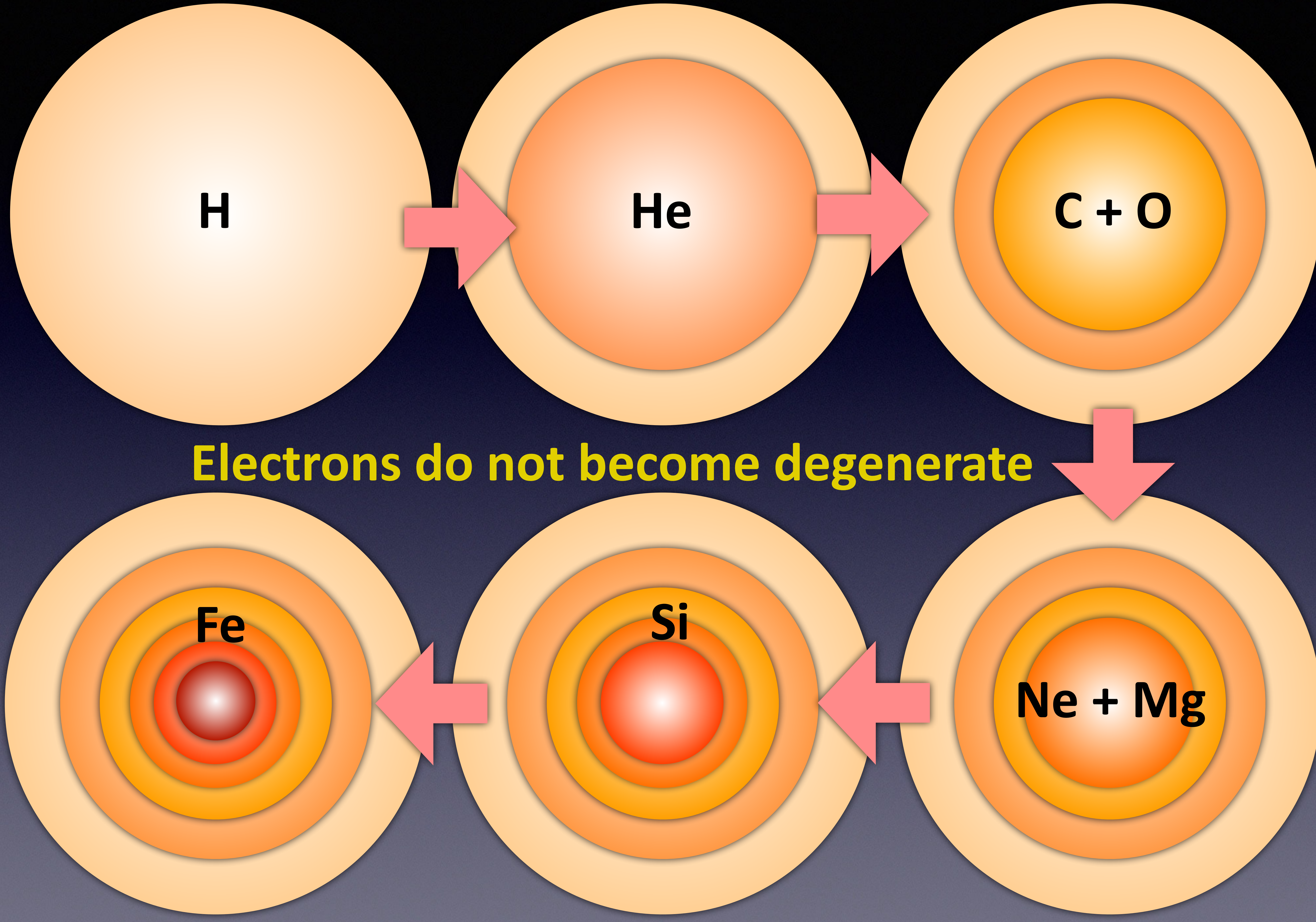
がそれぞれ支配的になる境界を求め、図示せよ

1. Massive stars

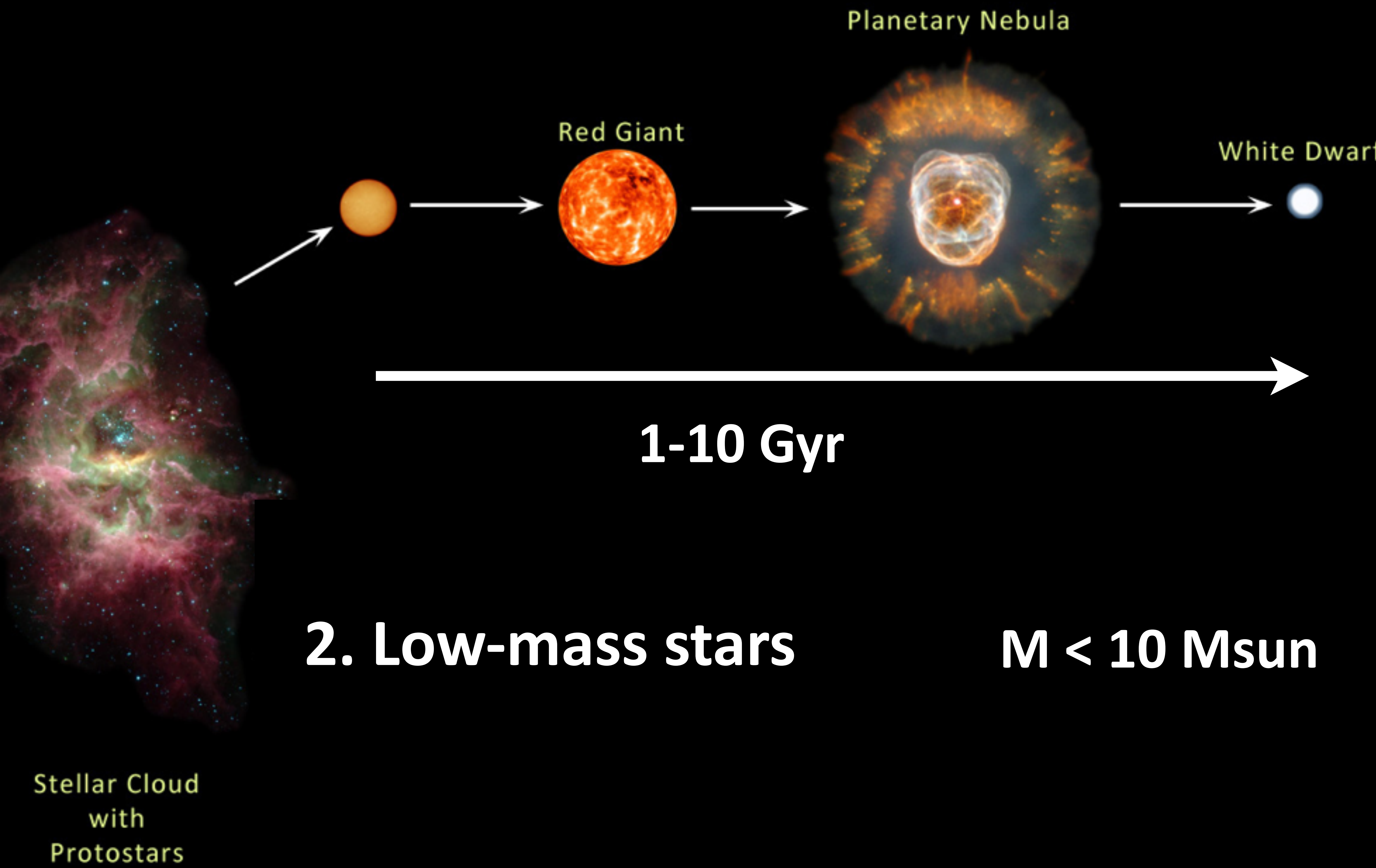
M > 10 Msun



図の大きさは天体の大きさと一致していません　(C: Essay Web)



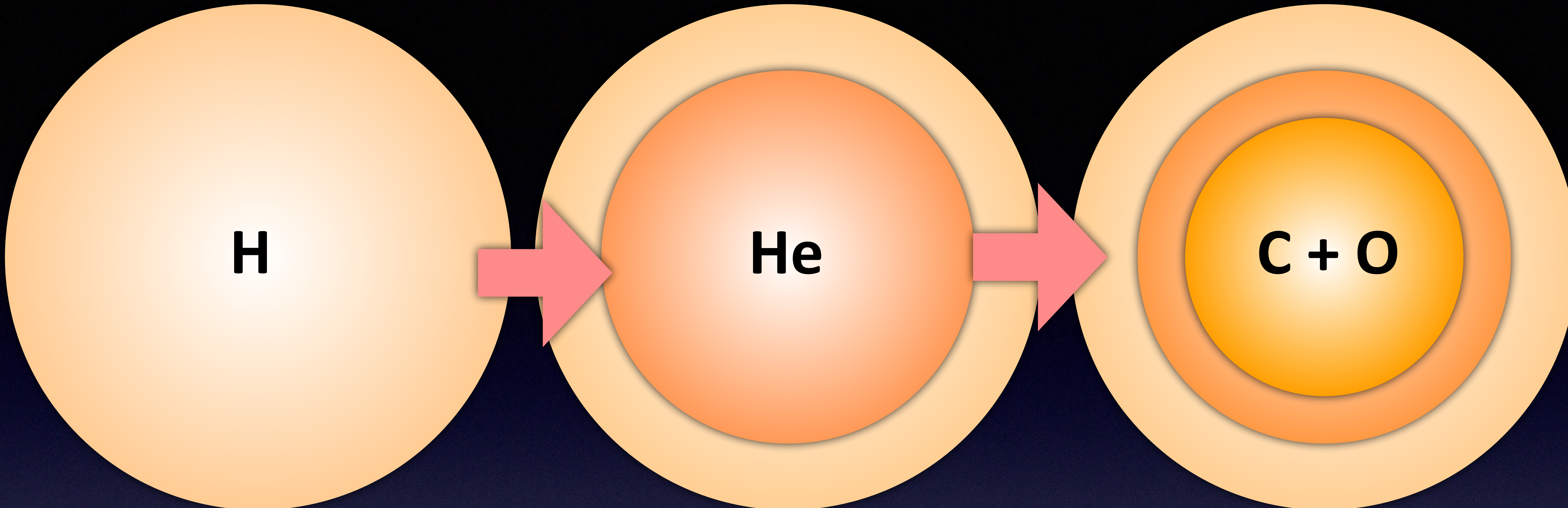
Images are not to scale



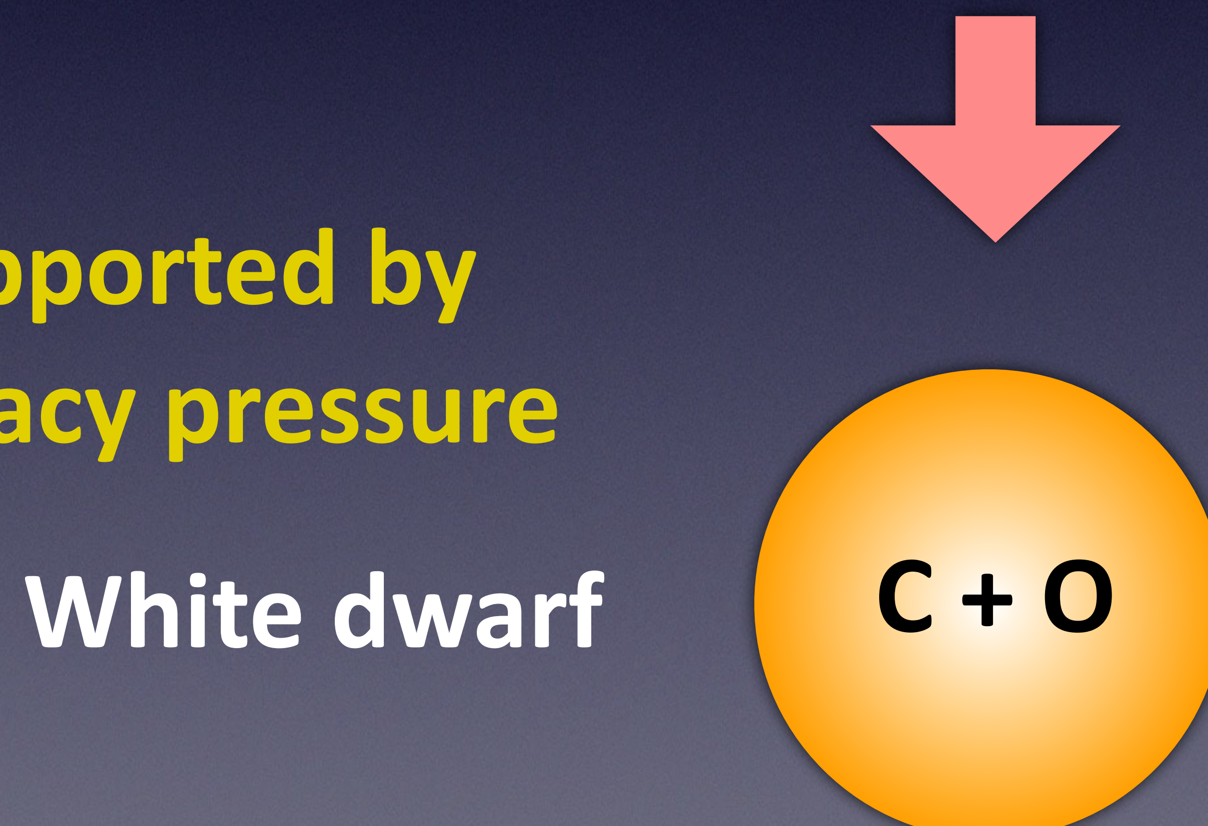
2. Low-mass stars

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)

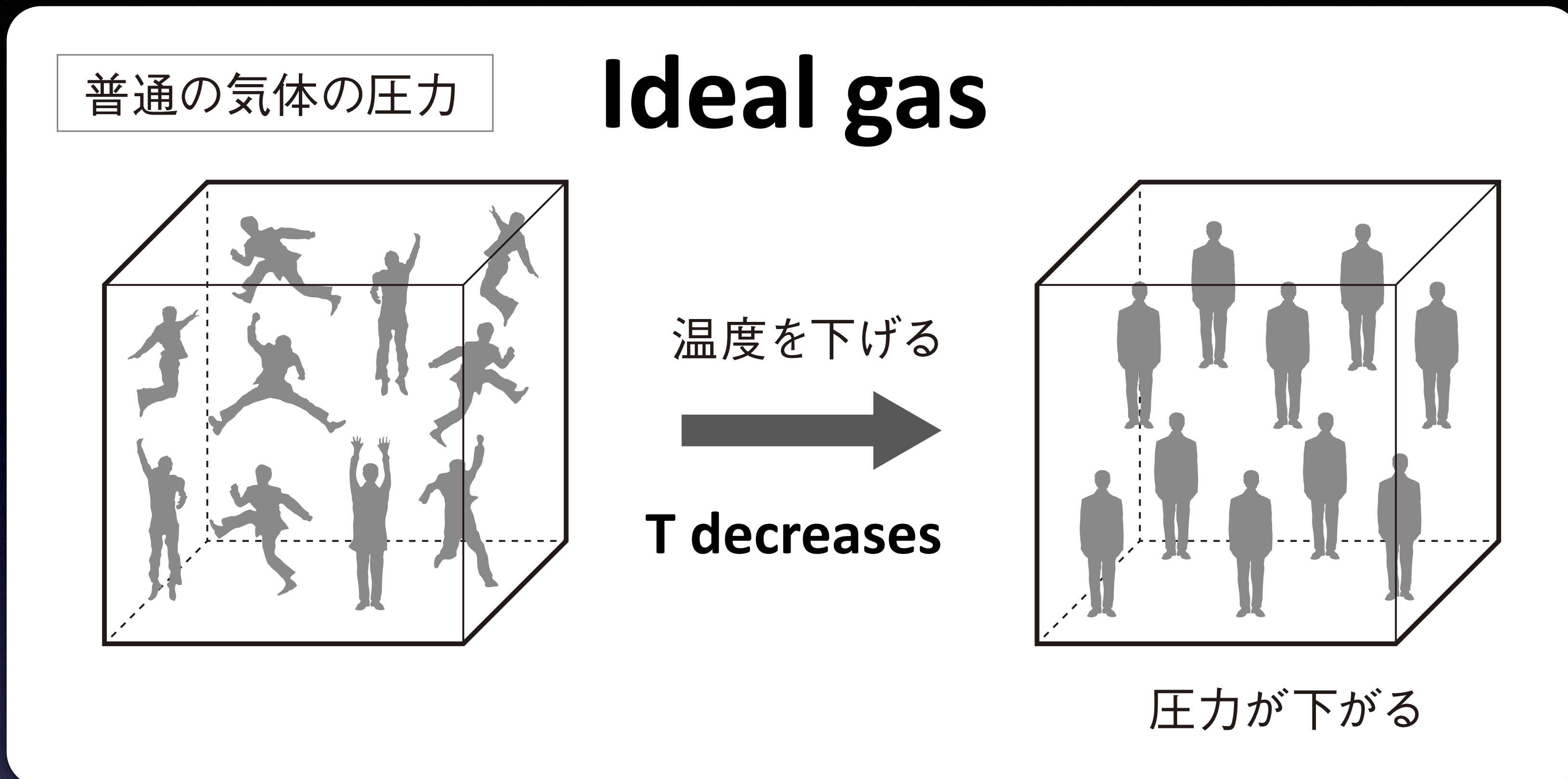


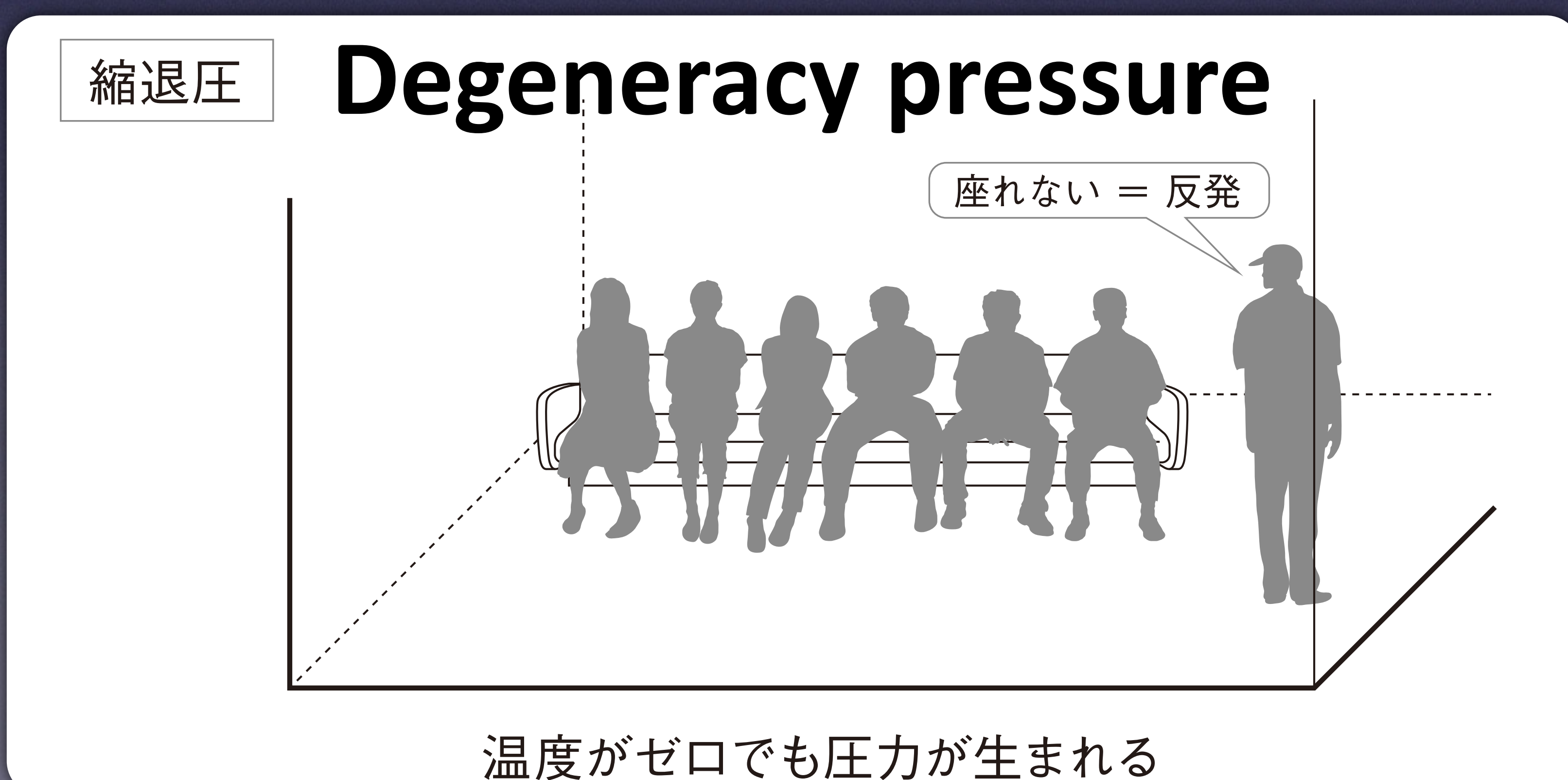
Stars can be supported by electron degeneracy pressure



Images are not to scale

White dwarf: supported degeneracy pressure





P is non-zero even at T=0

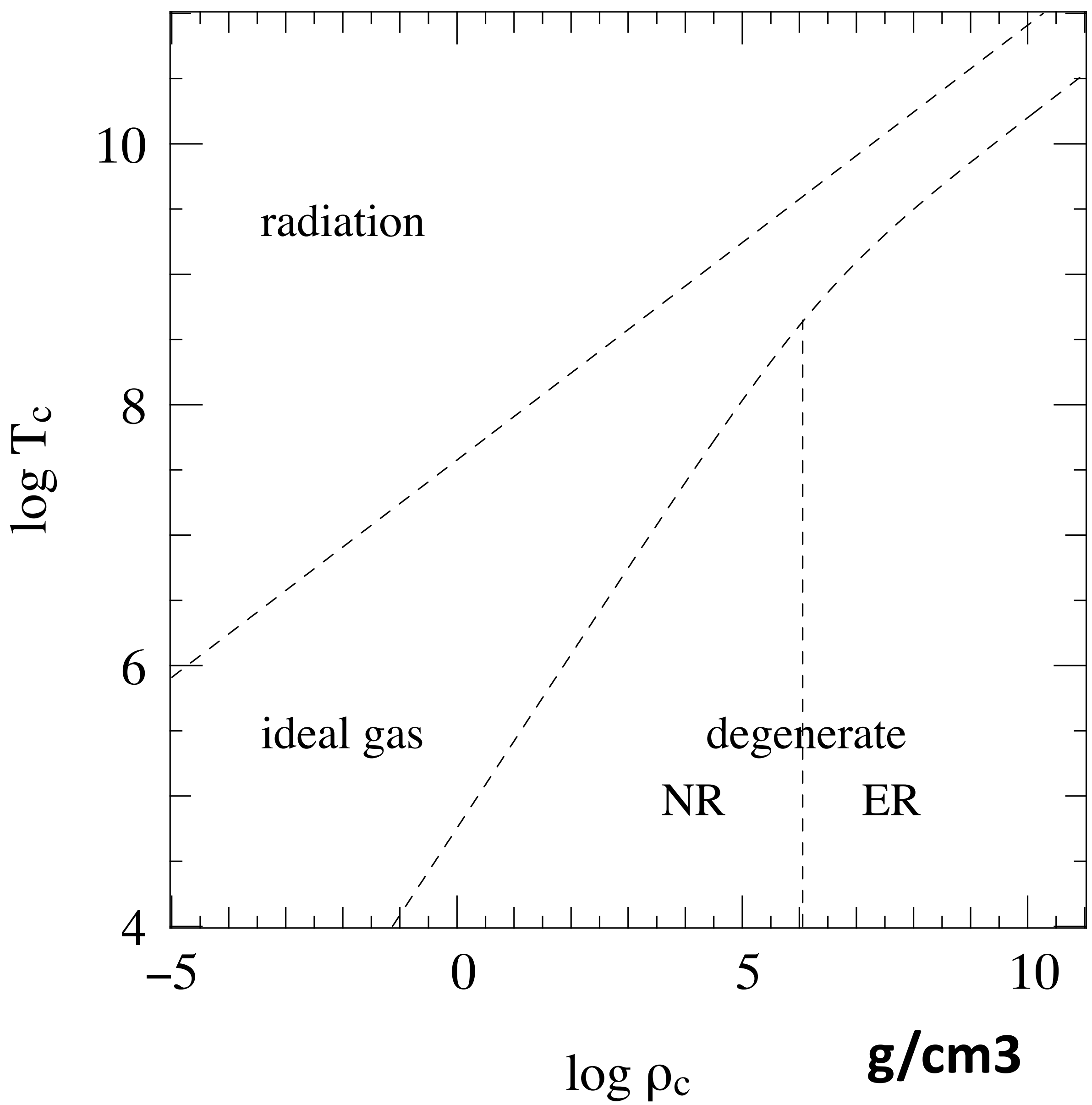
星が「死ぬ」とはどういうことか
（ベレ出版）

Section 5.
Stellar evolution (II)

5.1 Equation of state

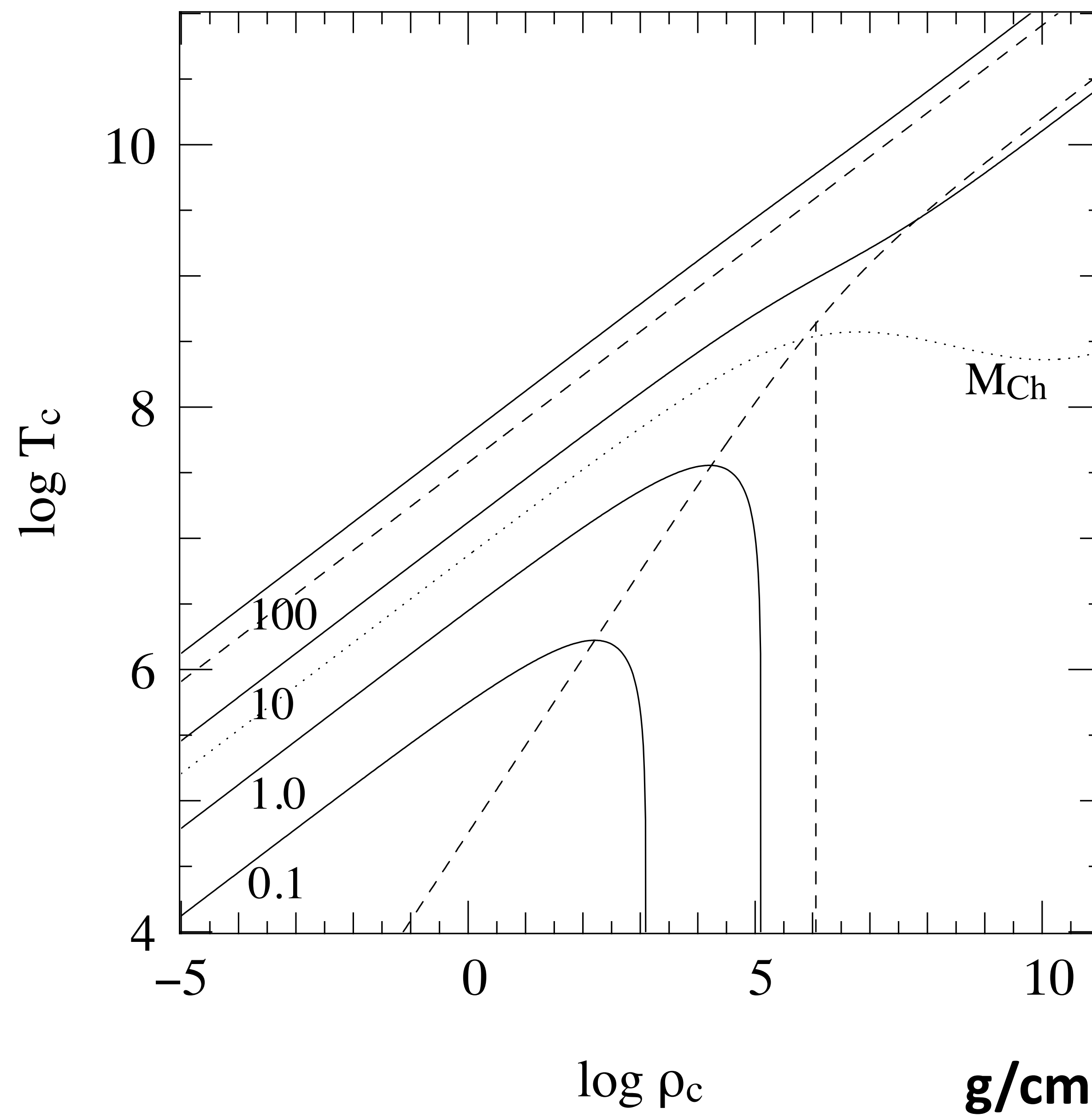
5.2 Evolutionary track

EOS



g/cm3

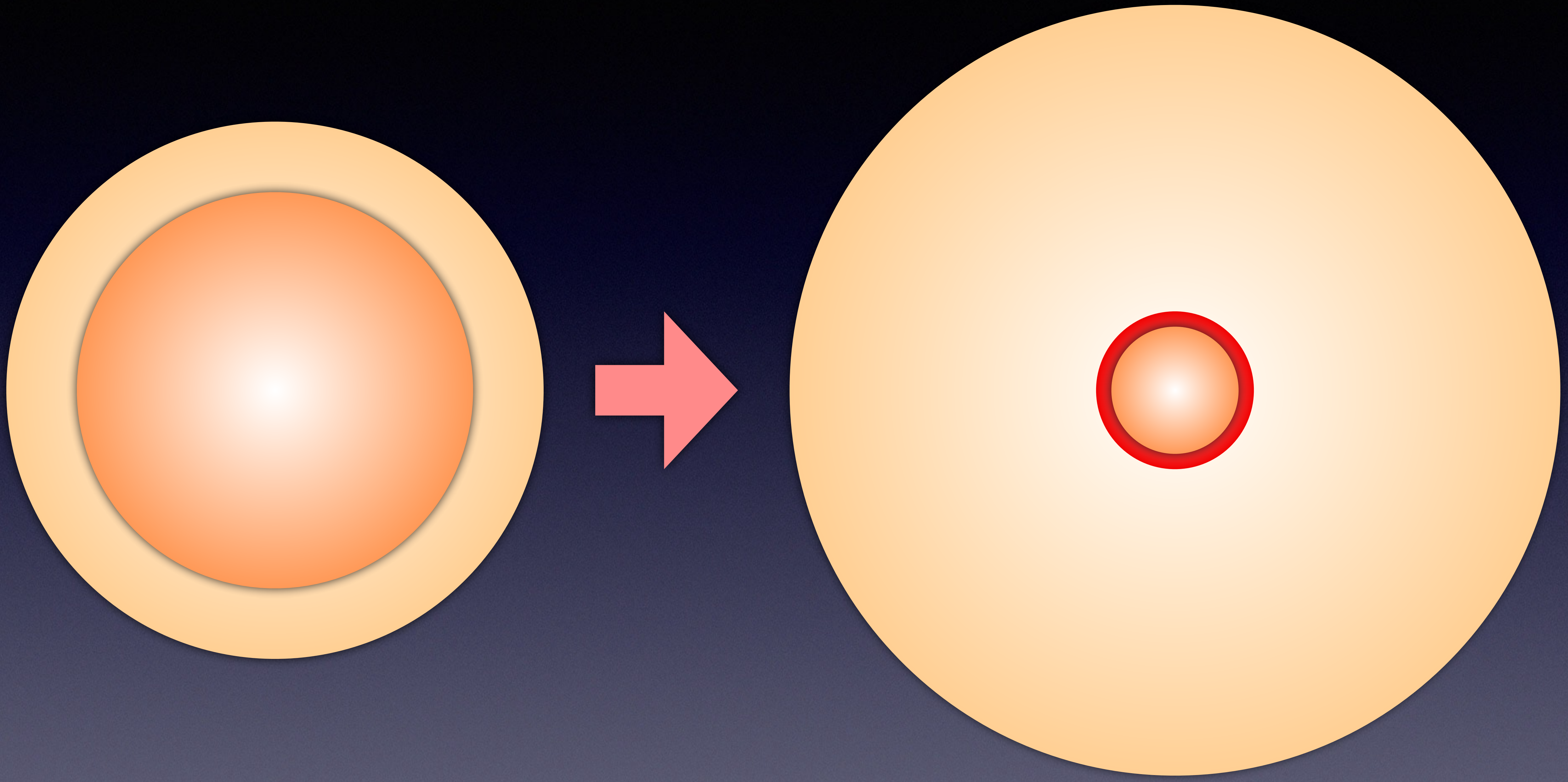
Evolution of T_c and ρ_c



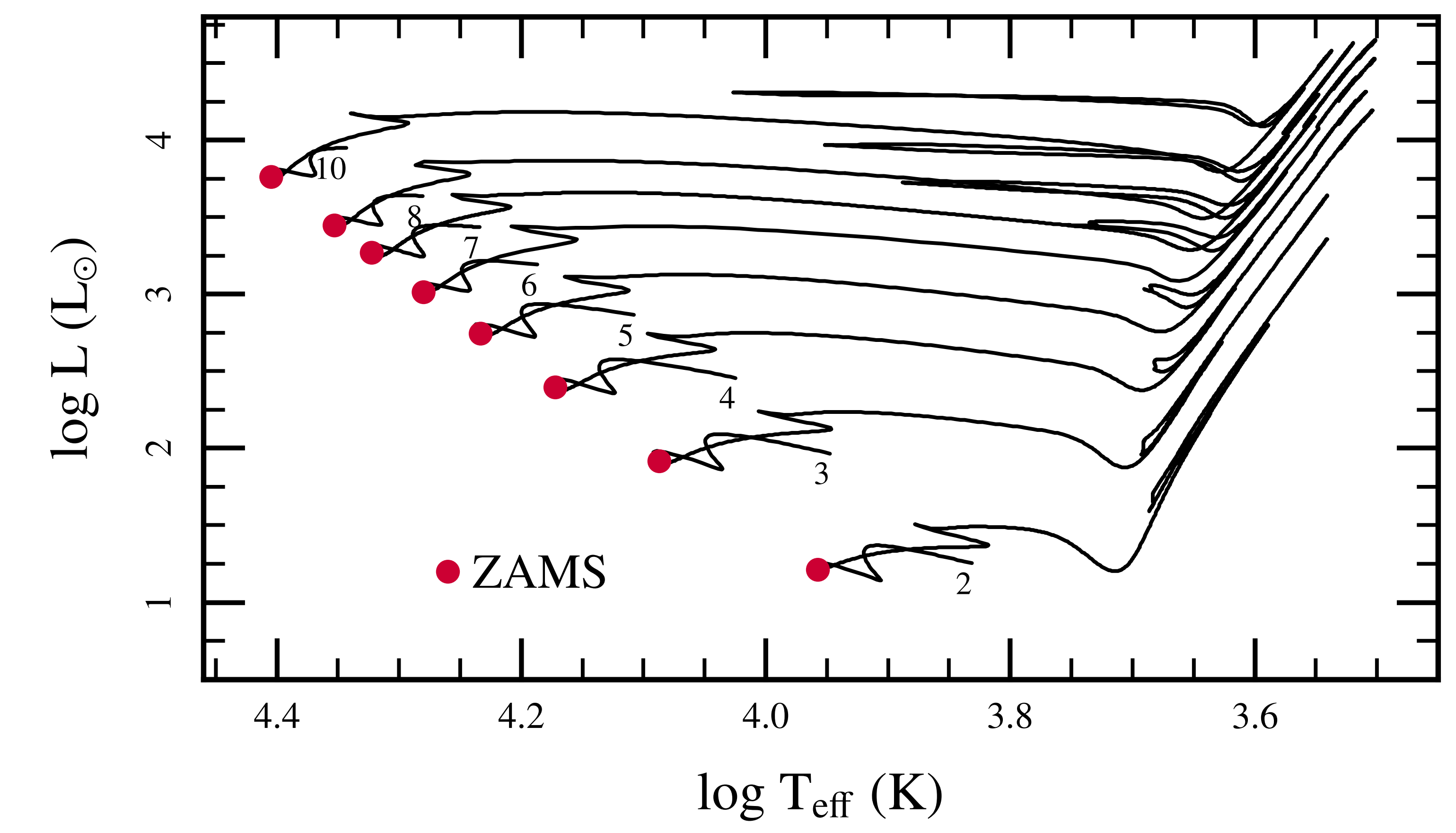
g/cm3

textbook by Pols

Contraction of the core
= Expansion of the envelope

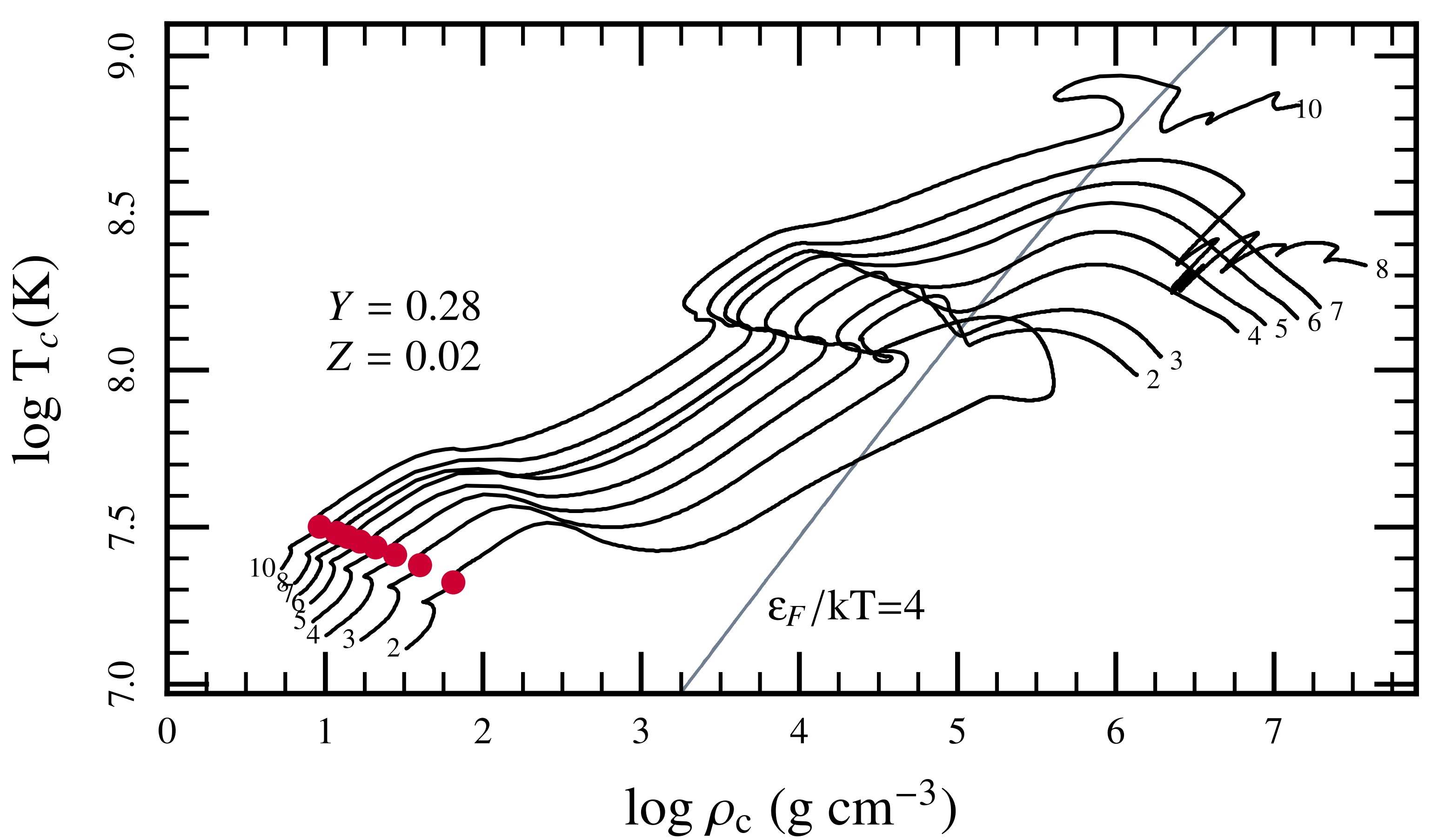


Shell burning => energy generation
(more than required to support the envelope)



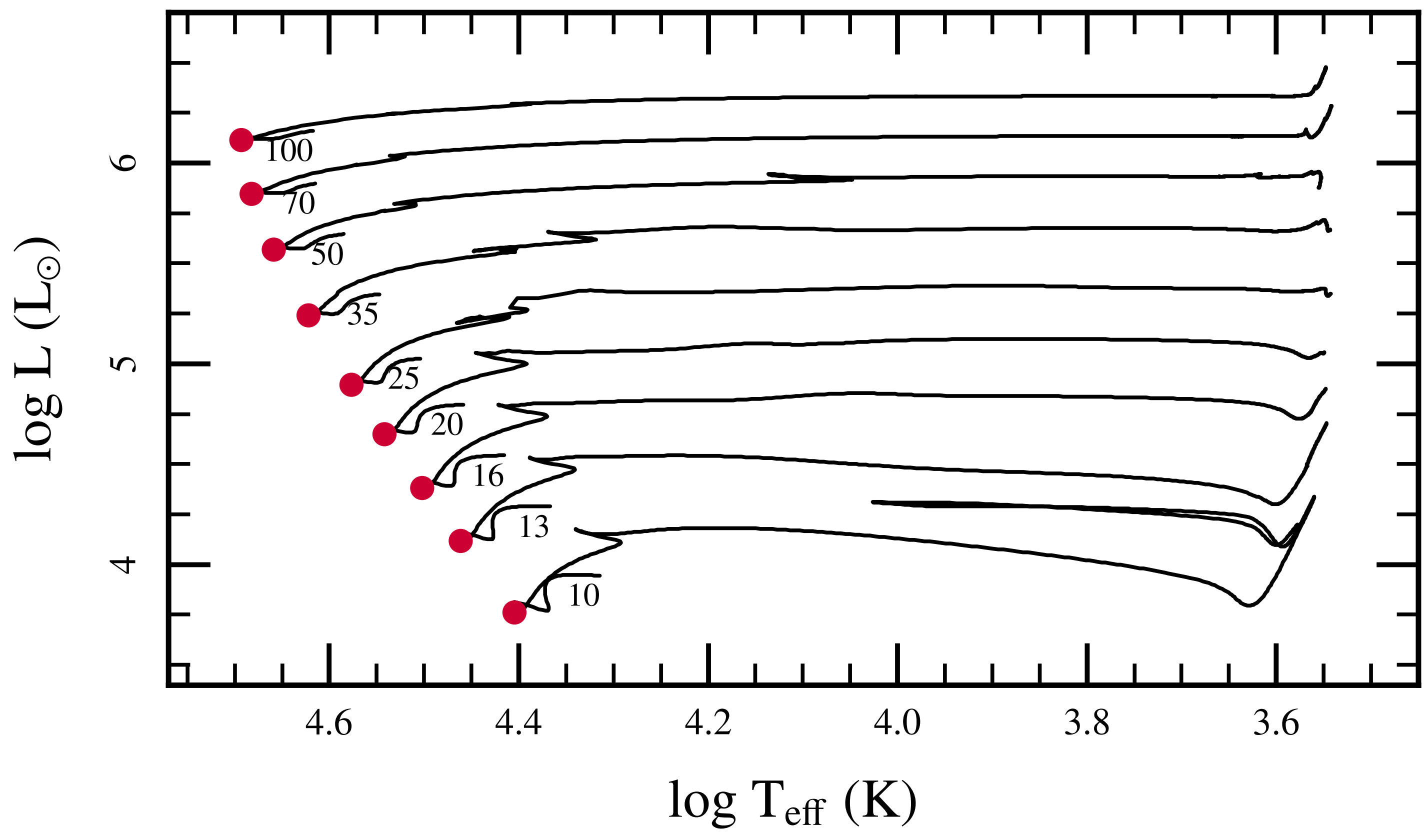
Low/intermediate mass stars

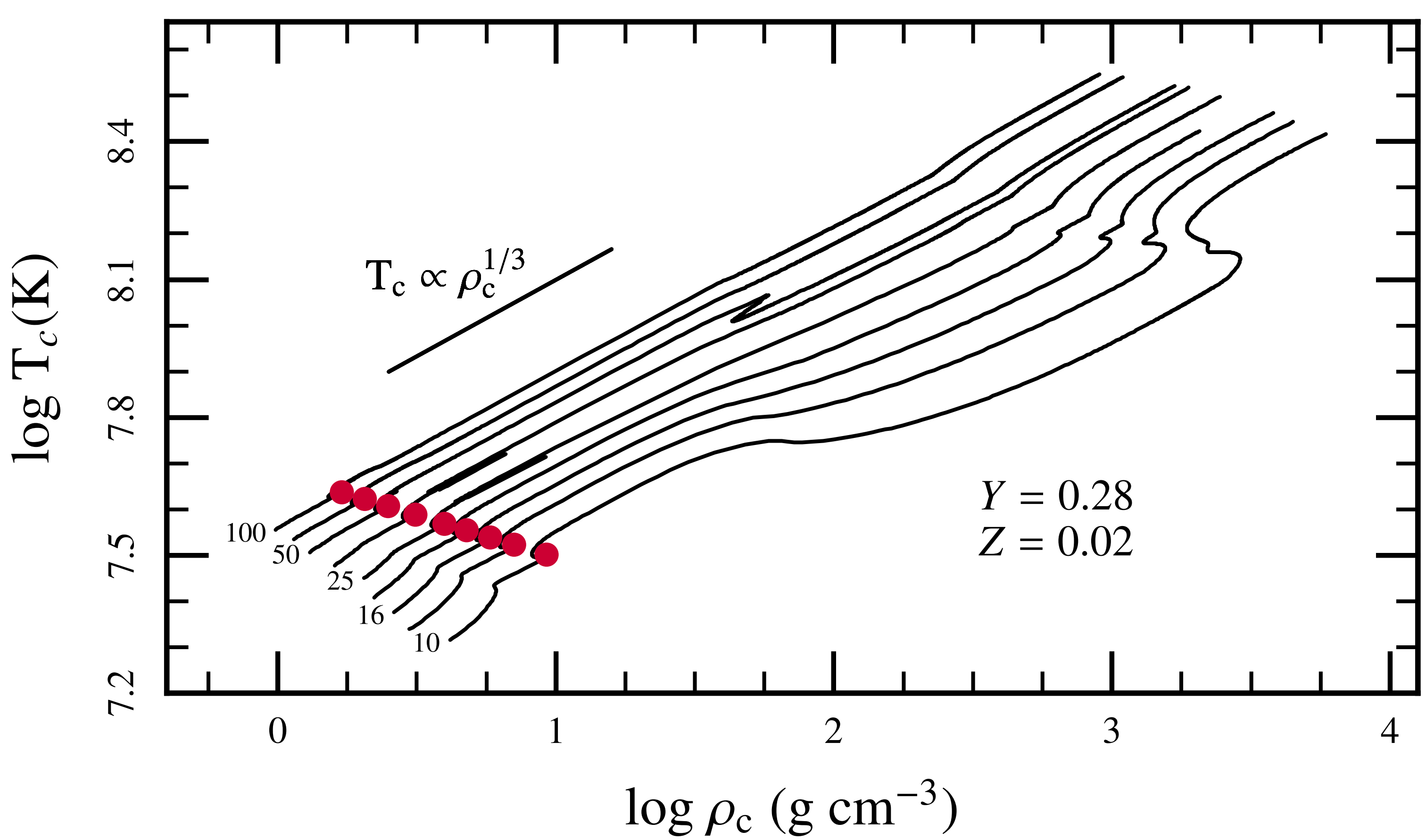
Core contraction
=> Expansion of the envelope
=> Red giant



Paxton et al. 2011

Massive stars (until He-burning)





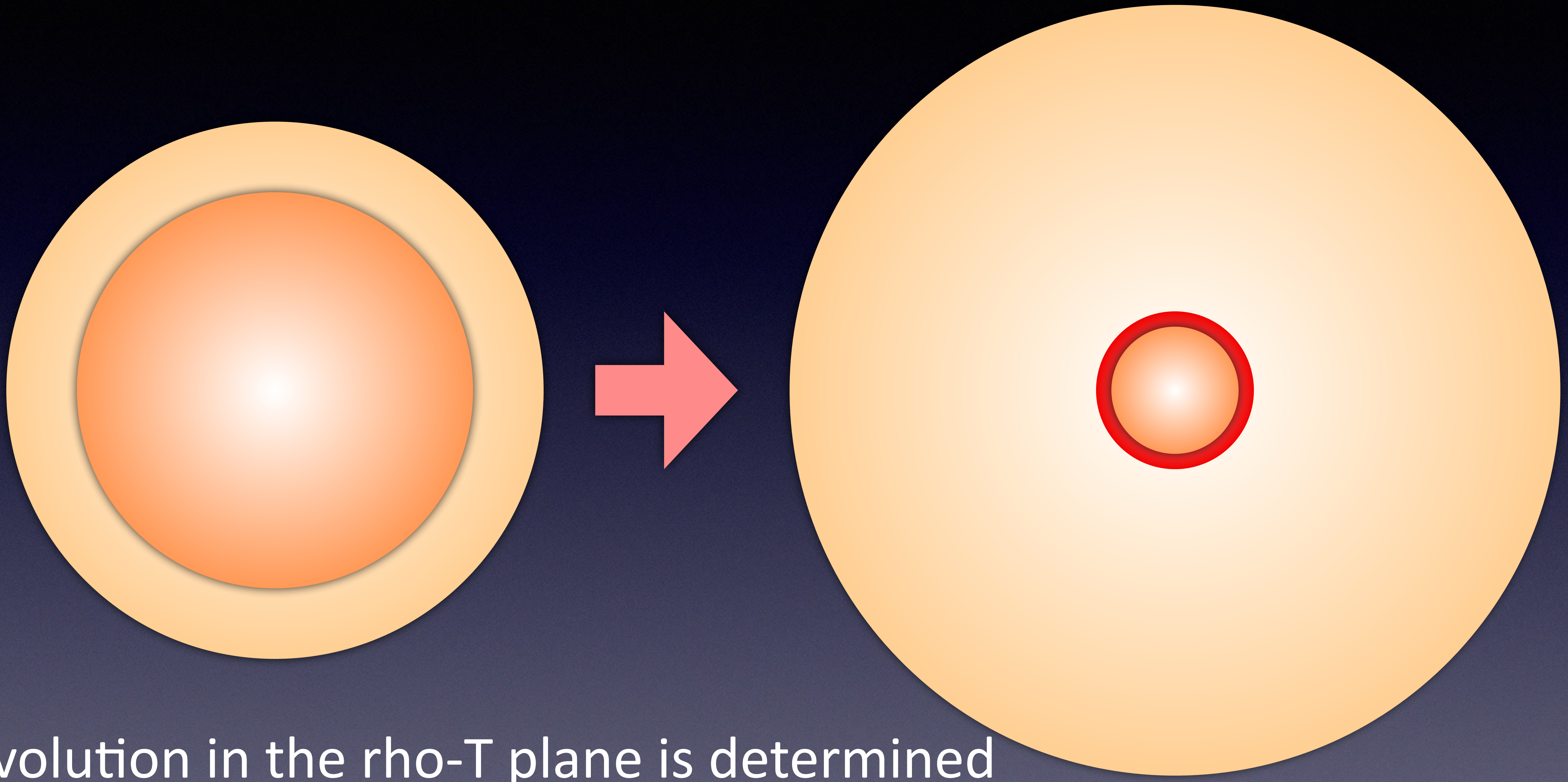
Core contraction

=> Expansion of the envelope

=> Red super giant

Paxton et al. 2011

Contraction of the core = Expansion of the envelope



Evolution in the rho-T plane is determined by the properties of the core

$T \sim M^{2/3} \rho^{1/3}$

M decreases => Lower part of the ρ-T plane

Summary: stellar evolution (II)

- **Properties of gas (microscopic)**
  ==> properties of stars (macroscopic)
- **Equation of states**
  - Ideal gas $P \sim \rho T$
  - Degeneracy pressure $P \sim \rho^{5/3}$ (non-rel)、 $P \sim \rho^{4/3}$ (rel)
  - Radiation pressure $P \sim T^4$

  => Important in different areas in the rho-T diagram
- **Stellar evolution**
  - Stars stop contraction when supported by degeneracy pressure
    => No temperature rise => End of nuclear burning
  - The core of low mass stars become generate

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?
- …

Thermodynamics

Electromagnetism

Classical mechanics

Statistical mechanics

Astrophysics

Hydrodynamics

Quantum mechanics

Relativity

Nuclear physics