Section 6.
Stellar evolution (III)

6.1 Equations for stellar evolution

6.2 Calculations of stellar evolution

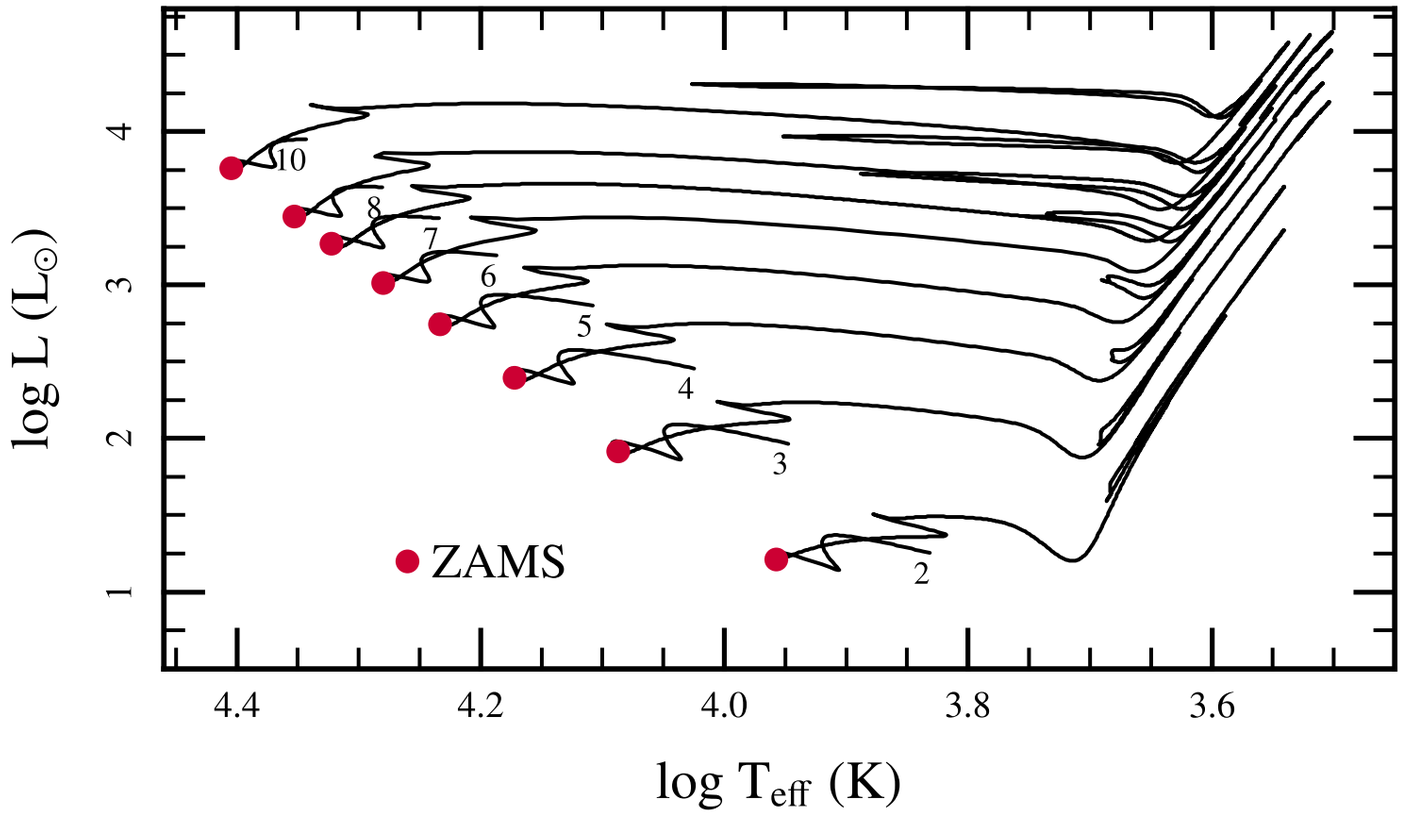
Let's understand these questions with the words of physics

- 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 6.
Stellar evolution (III)

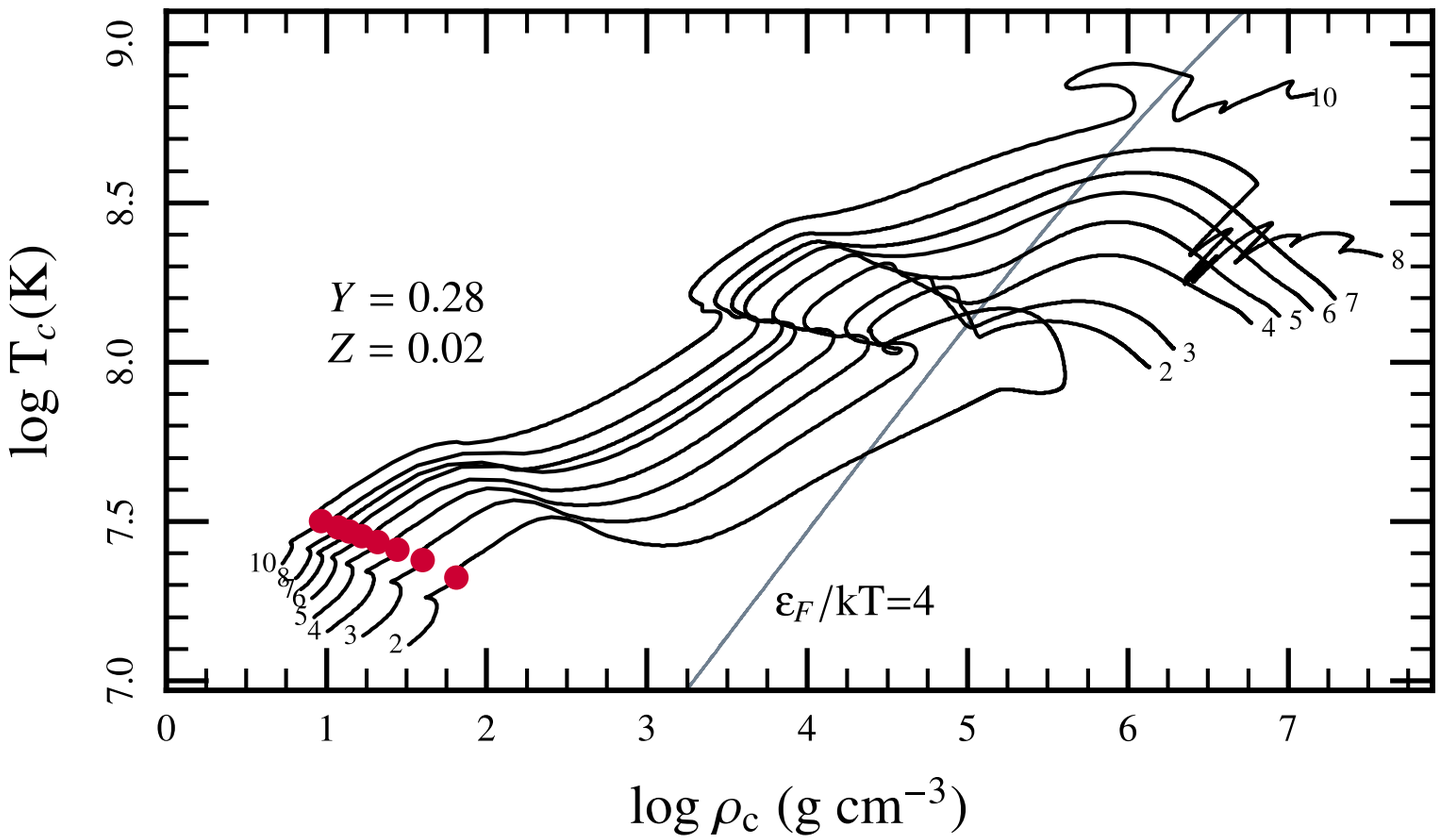
6.1 Equations for stellar evolution

6.2 Calculations of stellar evolution

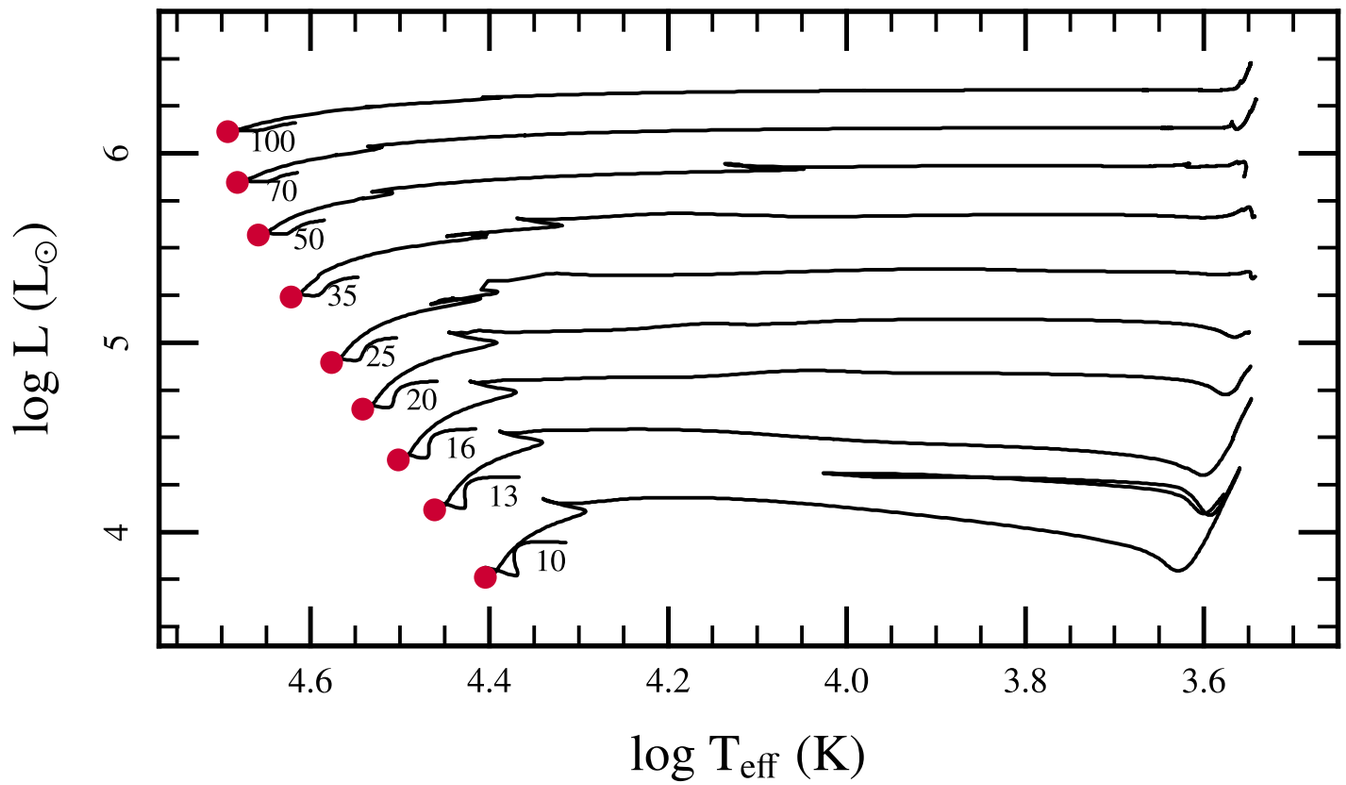


Low/intermediate mass stars

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

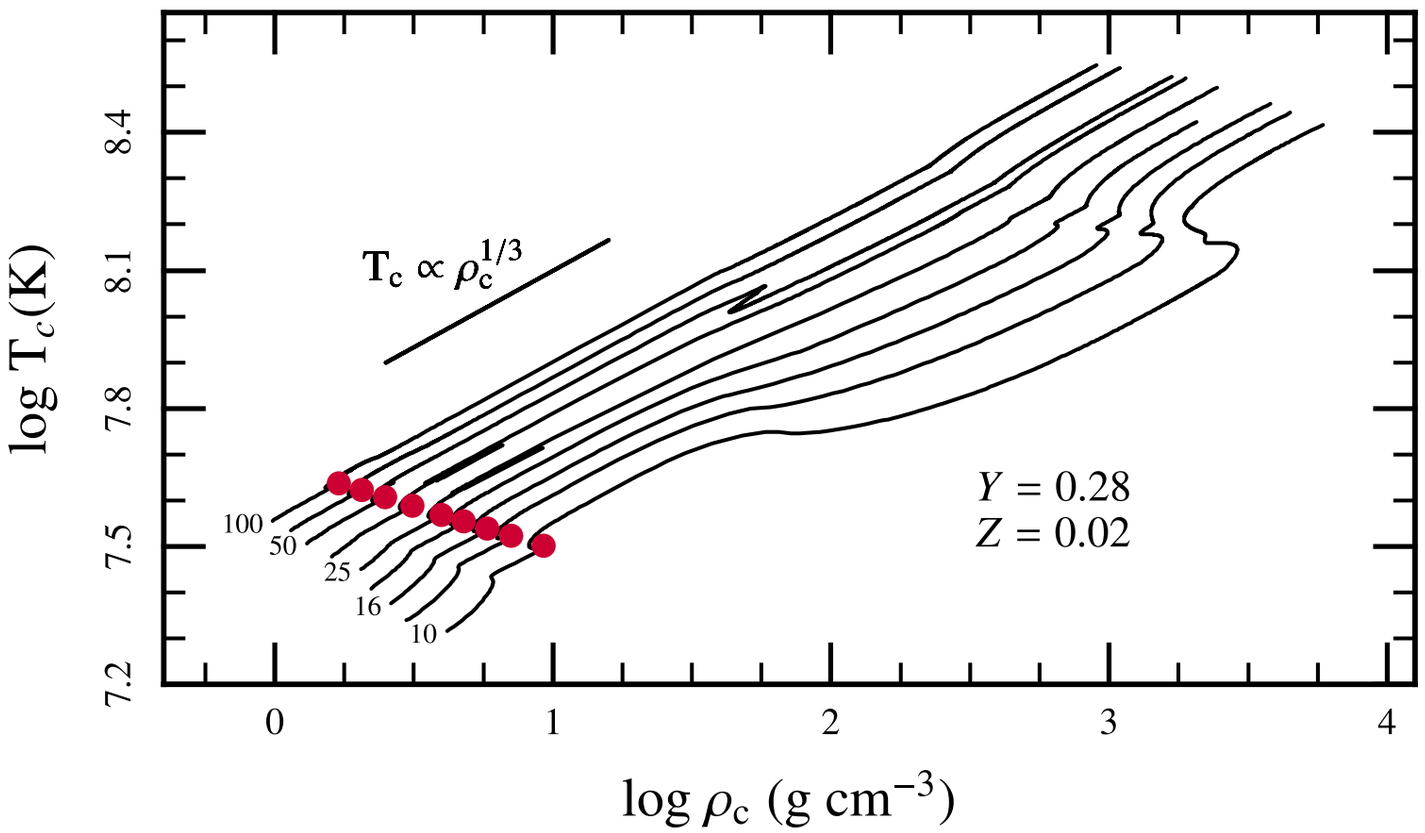


Paxton et al. 2011



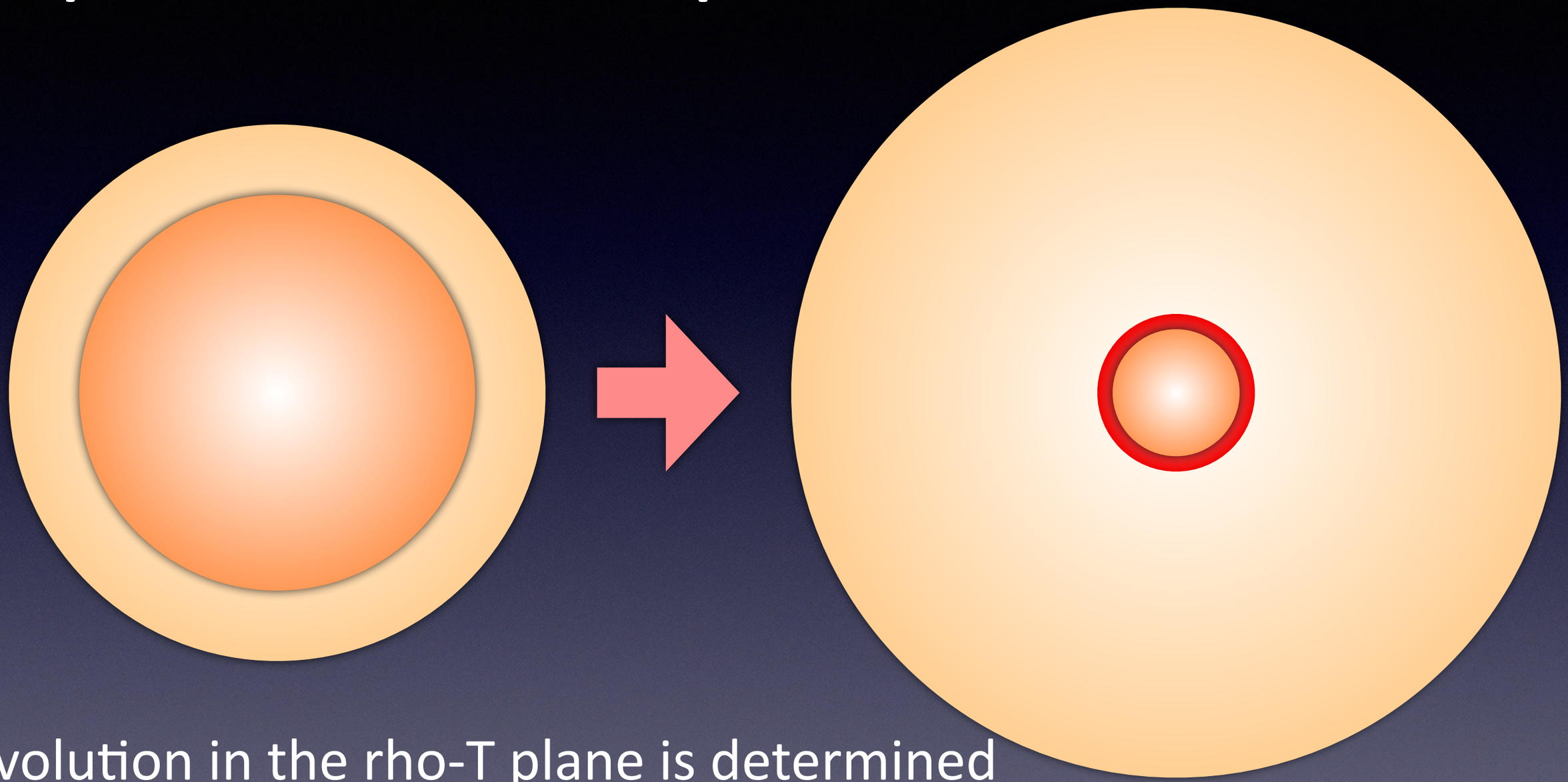
Massive stars (until He-burning)

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



Paxton et al. 2011

Contraction of the core
= Expansion of the envelope



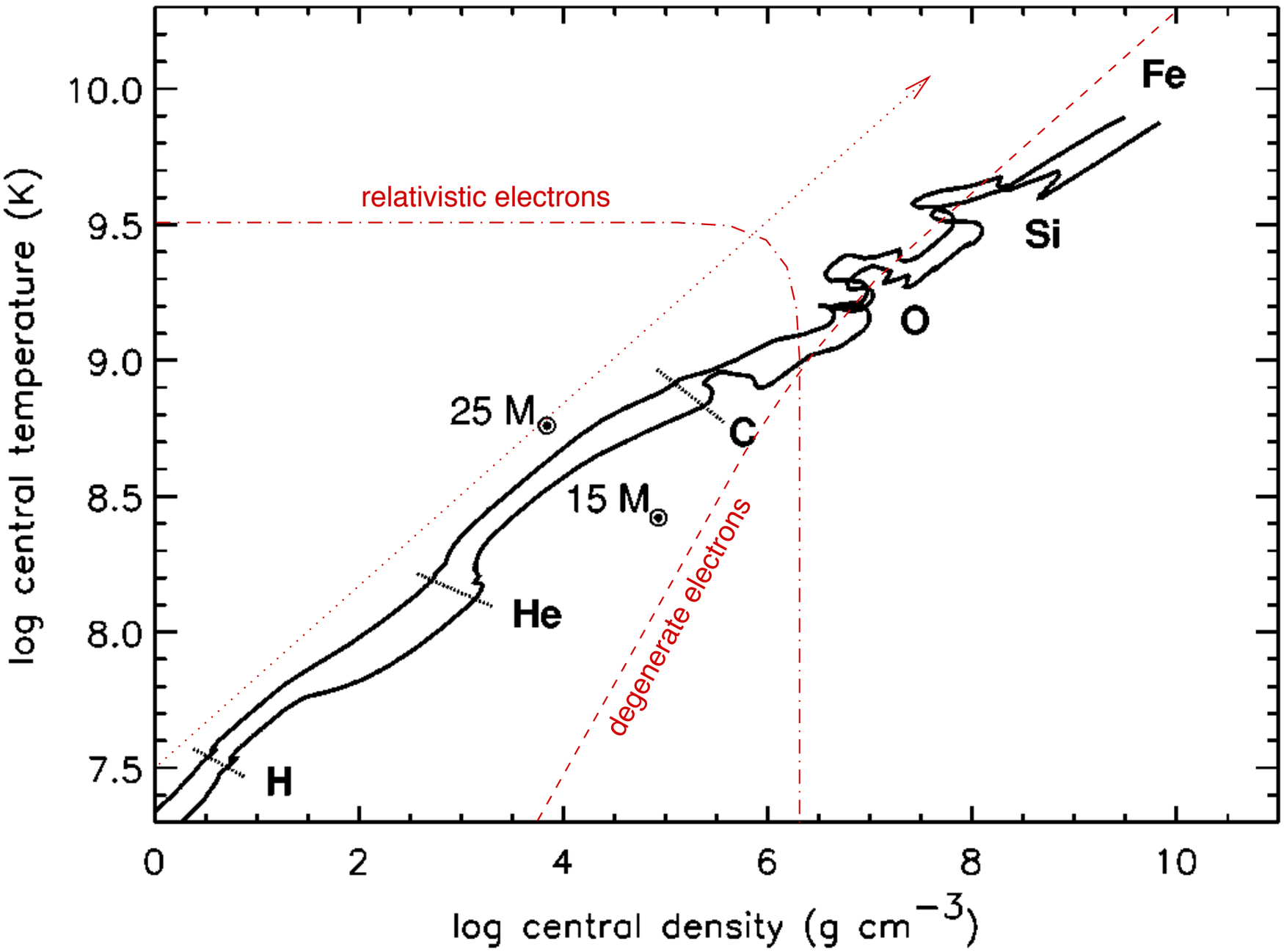
Evolution in the rho-T plane is determined
by the properties of the core

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

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

Massive stars (until Si burning)

Finally degeneracy pressure becomes important



textbook by Pols

How can we calculate stellar evolution?

Section 6.
Stellar evolution (III)

6.1 Equations for stellar evolution

6.2 Calculations of stellar evolution

MESA code

http://mesa.sourceforge.net/index.html

MESA
Modules for Experiments in Stellar Astrophysics

MESA

*You may also want to visit **the MESA community portal**, where users share the inlists from their published results, tools & utilities, and teaching materials.*

Why a new 1D stellar evolution code?

The MESA Manifesto discusses the motivation for the MESA project, outlines a MESA code of conduct, and describes the establishment of a MESA Council. Before using MESA, you should read the **manifesto document**. Here's a brief extract of some of the key points

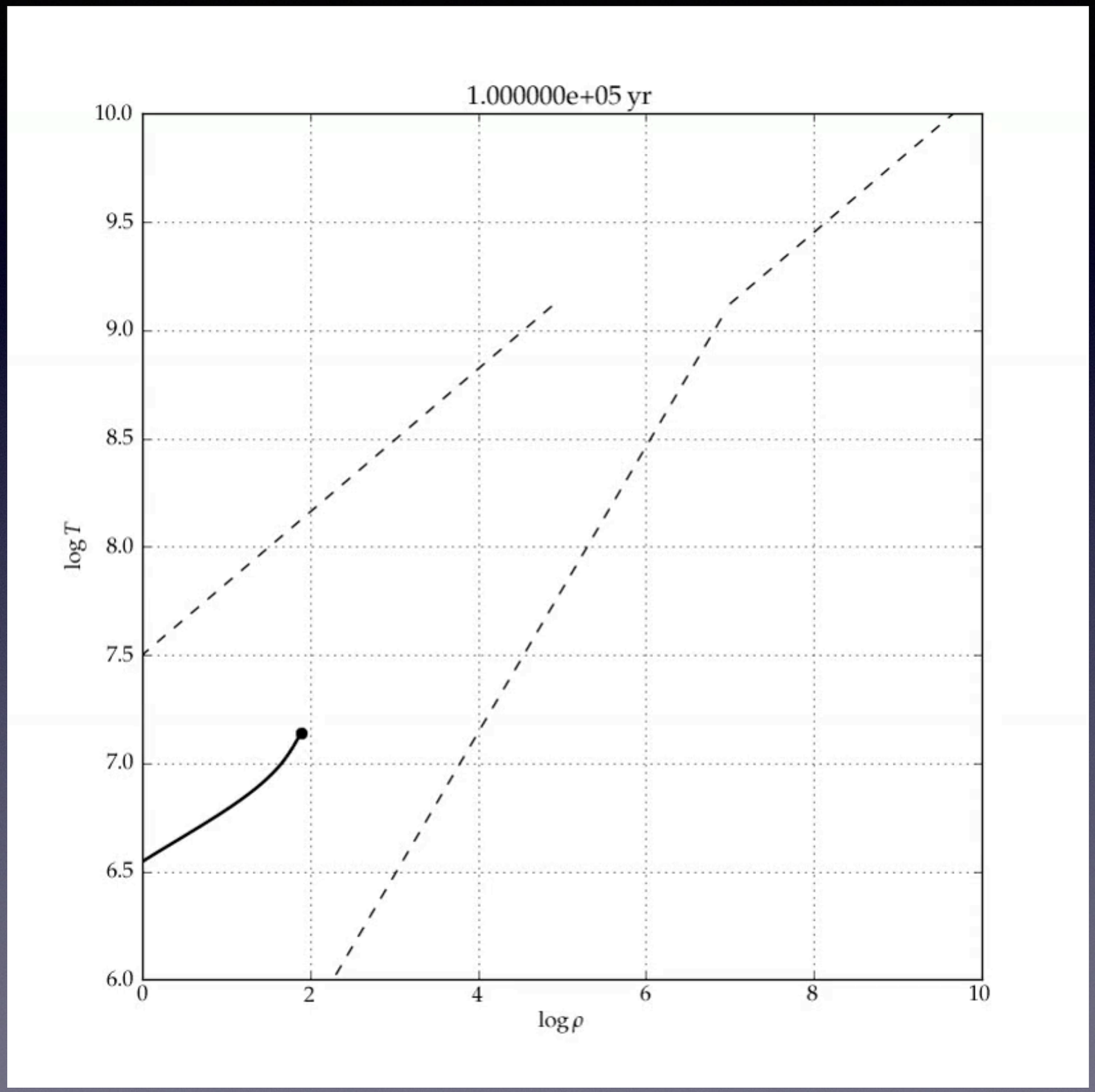
Stellar evolution calculations remain a basic tool of broad impact for astrophysics. New observations constantly test the models, even in 1D. The continued demand requires the construction of a general, modern stellar evolution code that combines the following advantages:

- **Openness**: anyone can download sources from the website.
- **Modularity**: independent modules for physics and for numerical algorithms; the parts can be used stand-alone.
- **Wide Applicability**: capable of calculating the evolution of stars in a wide range of environments.
- **Modern Techniques**: advanced AMR, fully coupled solution for composition and abundances, mass loss and gain, etc.
- **Comprehensive Microphysics**: up-to-date, wide-ranging, flexible, and

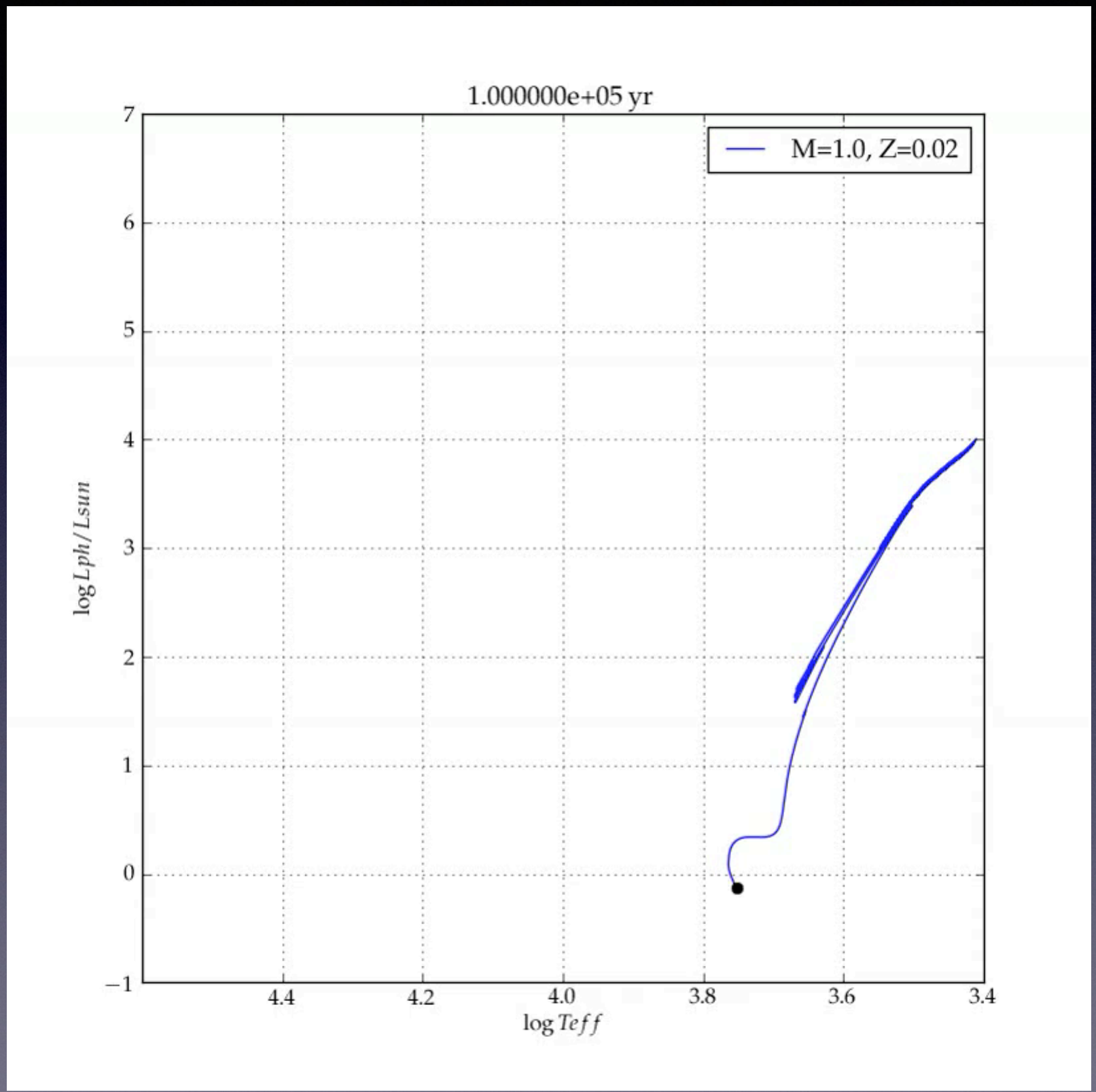
Latest News

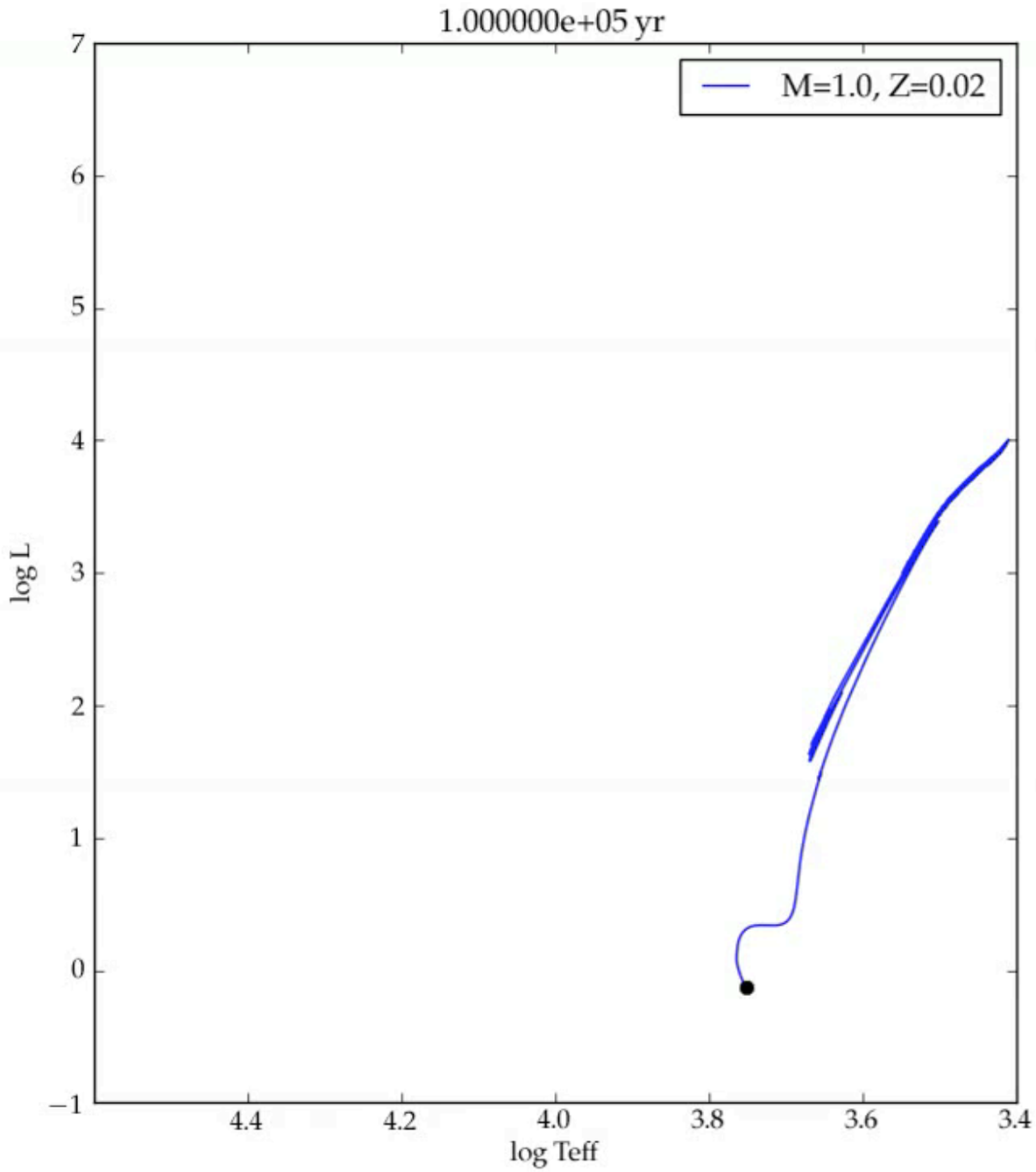
- 10 Aug 2016
  » **Documentation Archive**
- 19 Jun 2016
  » **Release 8845**
- 03 Feb 2016
  » **Release 8118**
- 29 Jan 2016
  » **New MESA SDK Version**
- 10 Jan 2016
  » **Summer School 2016**
- 27 Sep 2015
  » **Instrument Paper 3**
- 14 Sep 2015
  » **MESA-Web Updates**
- 08 Sep 2015
  » **New MESA SDK Version**
- 03 Sep 2015
  » **Updated MESA Maps**
- 27 Aug 2015
  » **Summer School Success!**

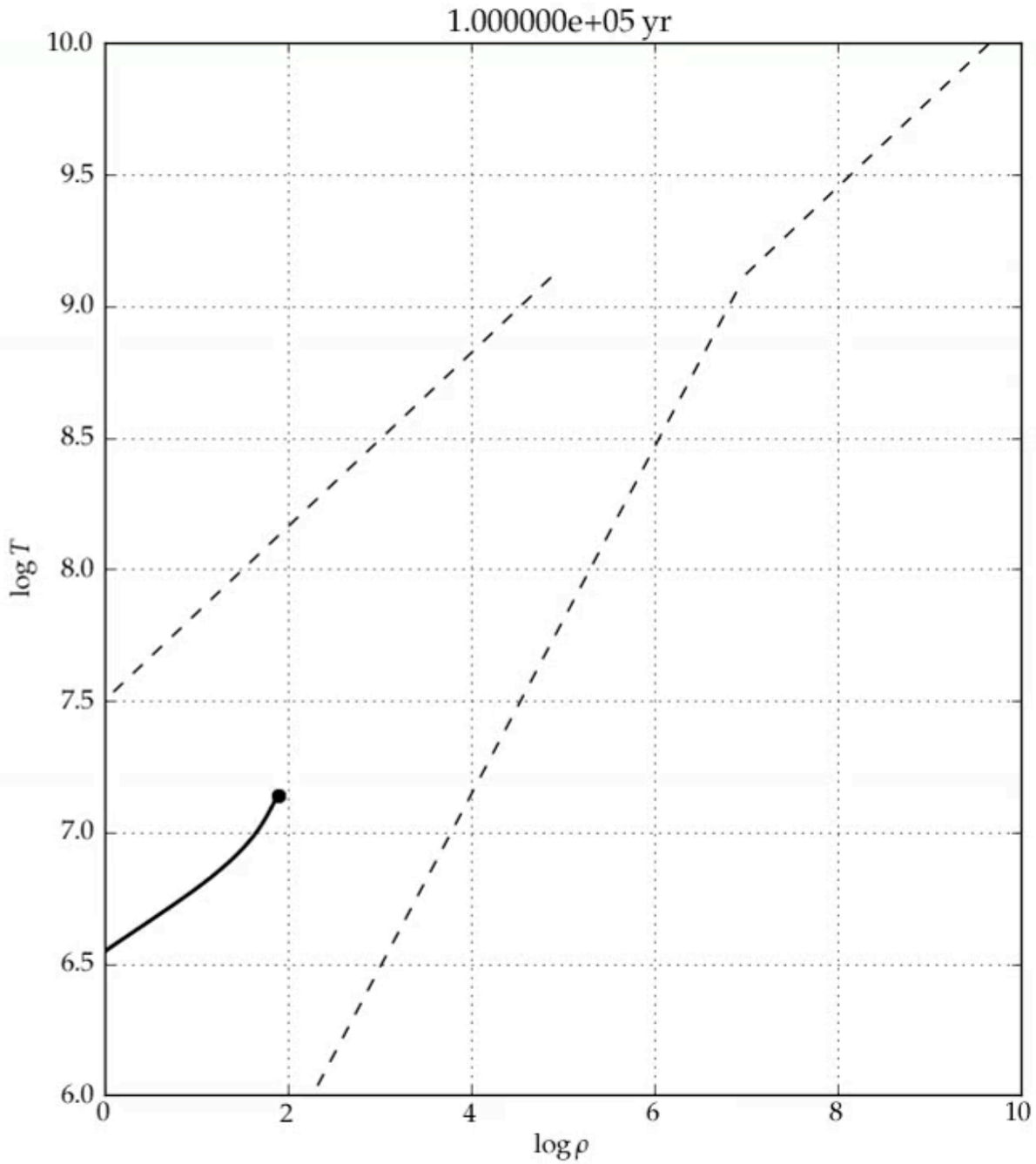
1 Msun (ρ-T)



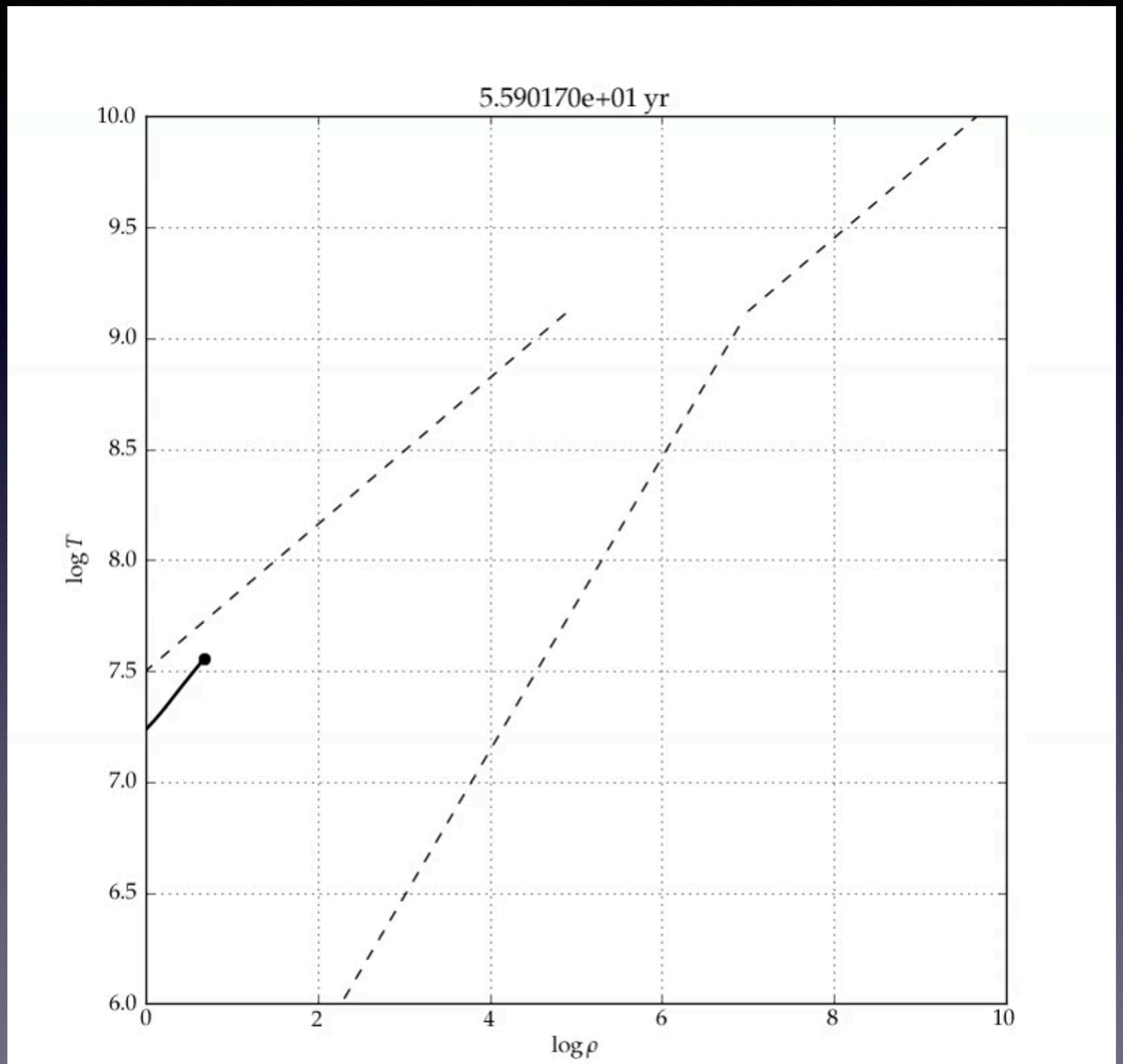
1 Msun (HR diagram)



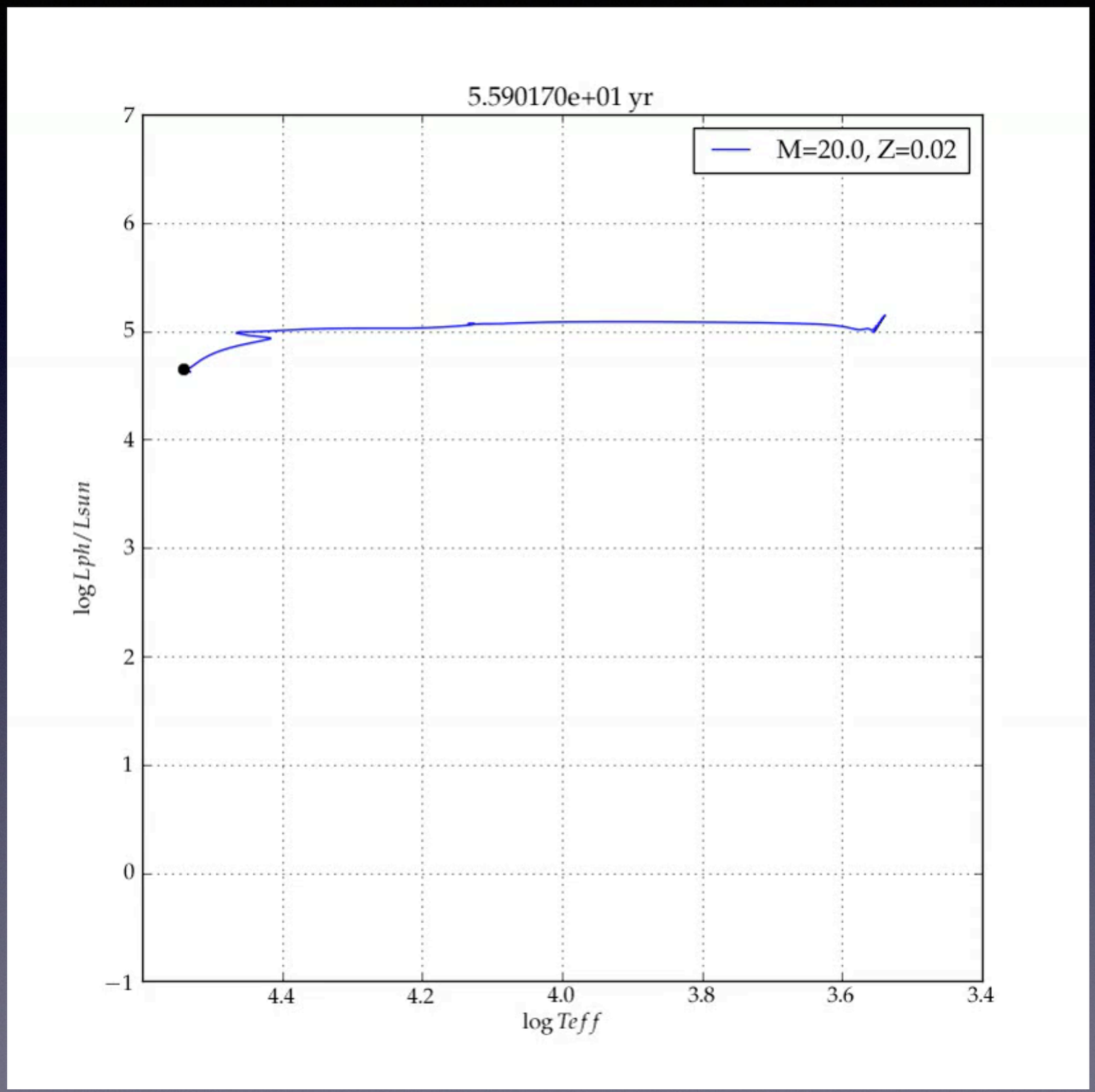

1.000000e+05 yr
M=1.0, Z=0.02
log L
log Teff
7
6
5
4
3
2
1
0
−1
4.4
4.2
4.0
3.8
3.6
3.4

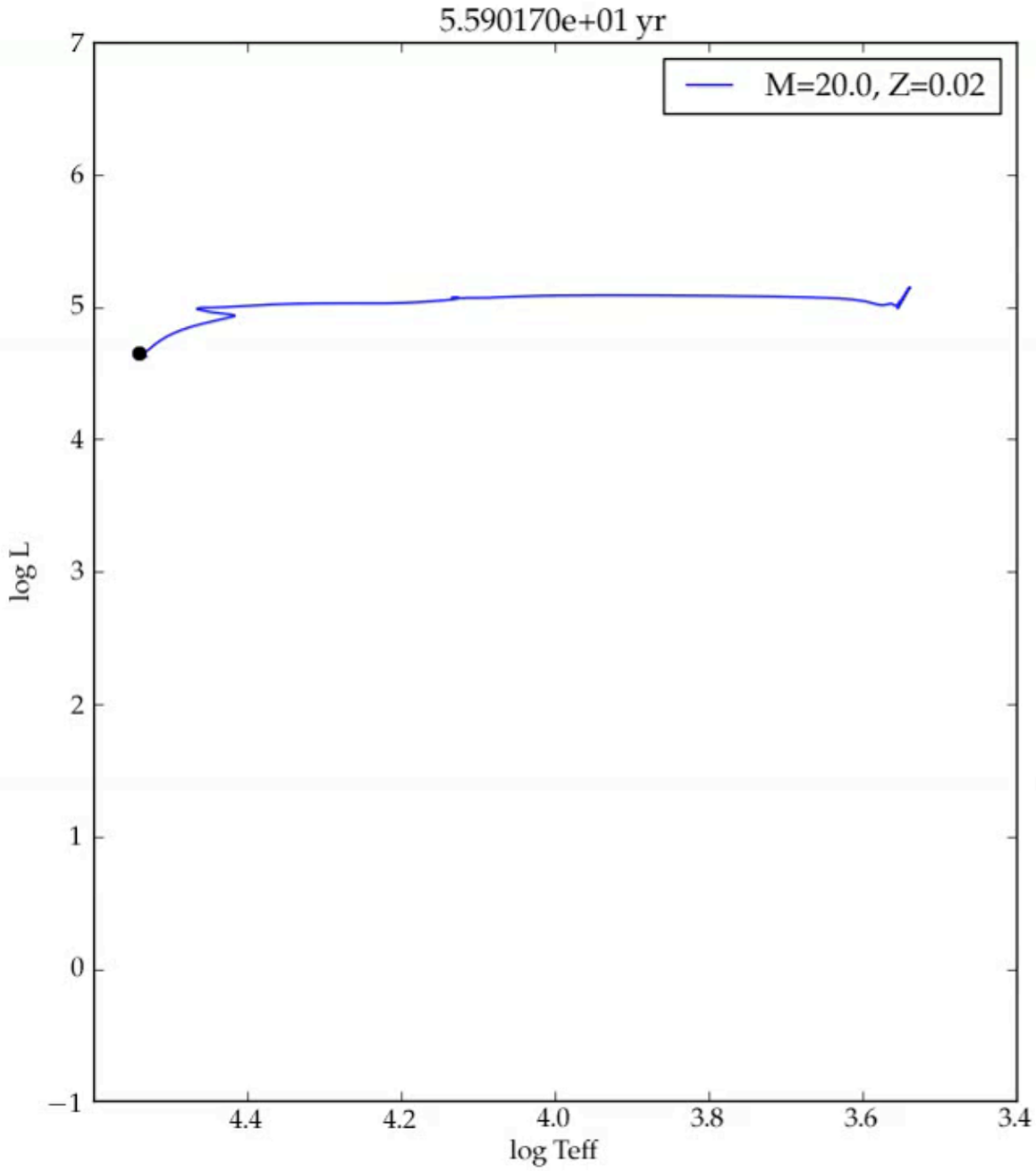

1.000000e+05 yr
log T
log ρ
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
0
2
4
6
8
10

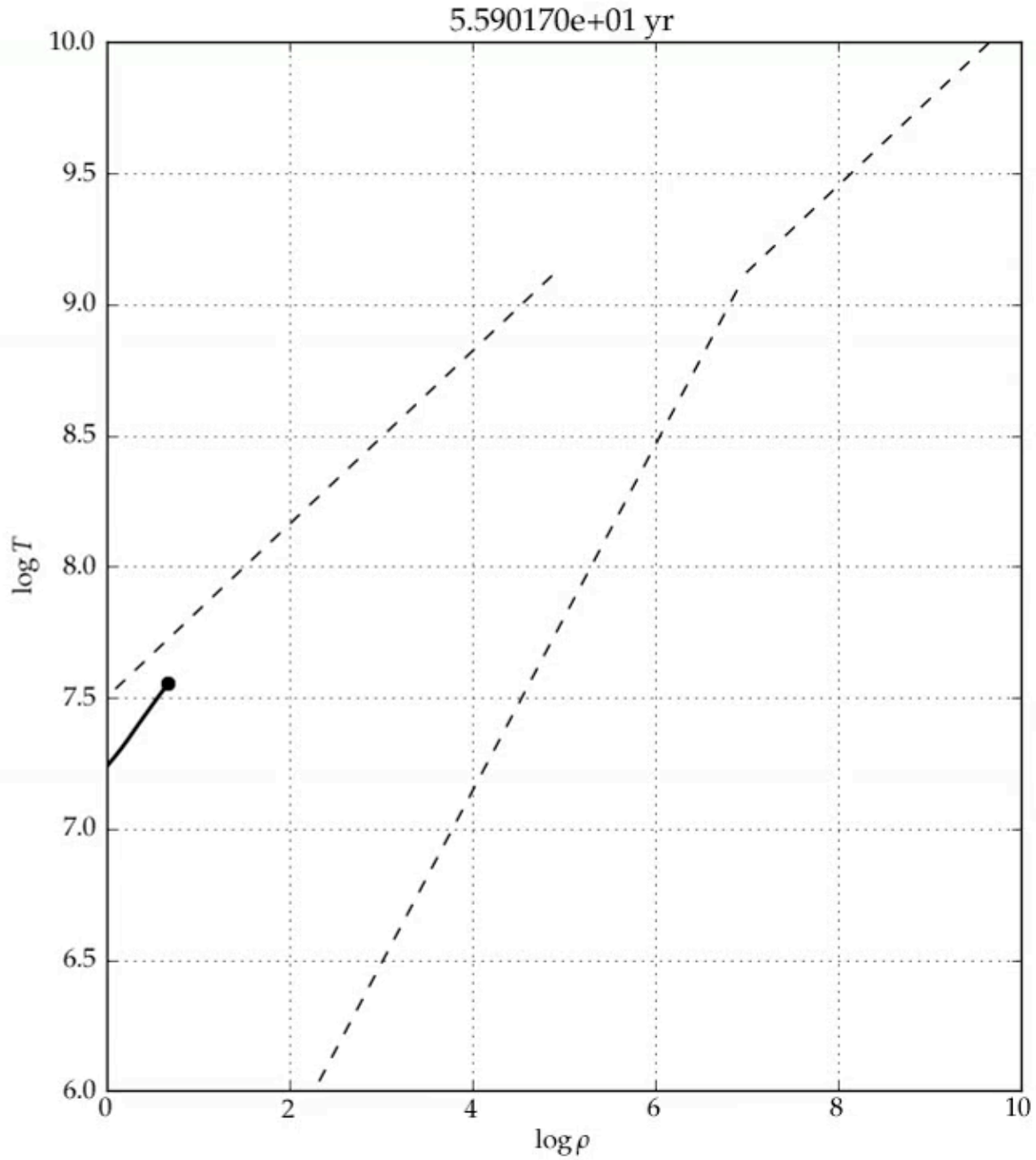
20 Msun (ρ-T)



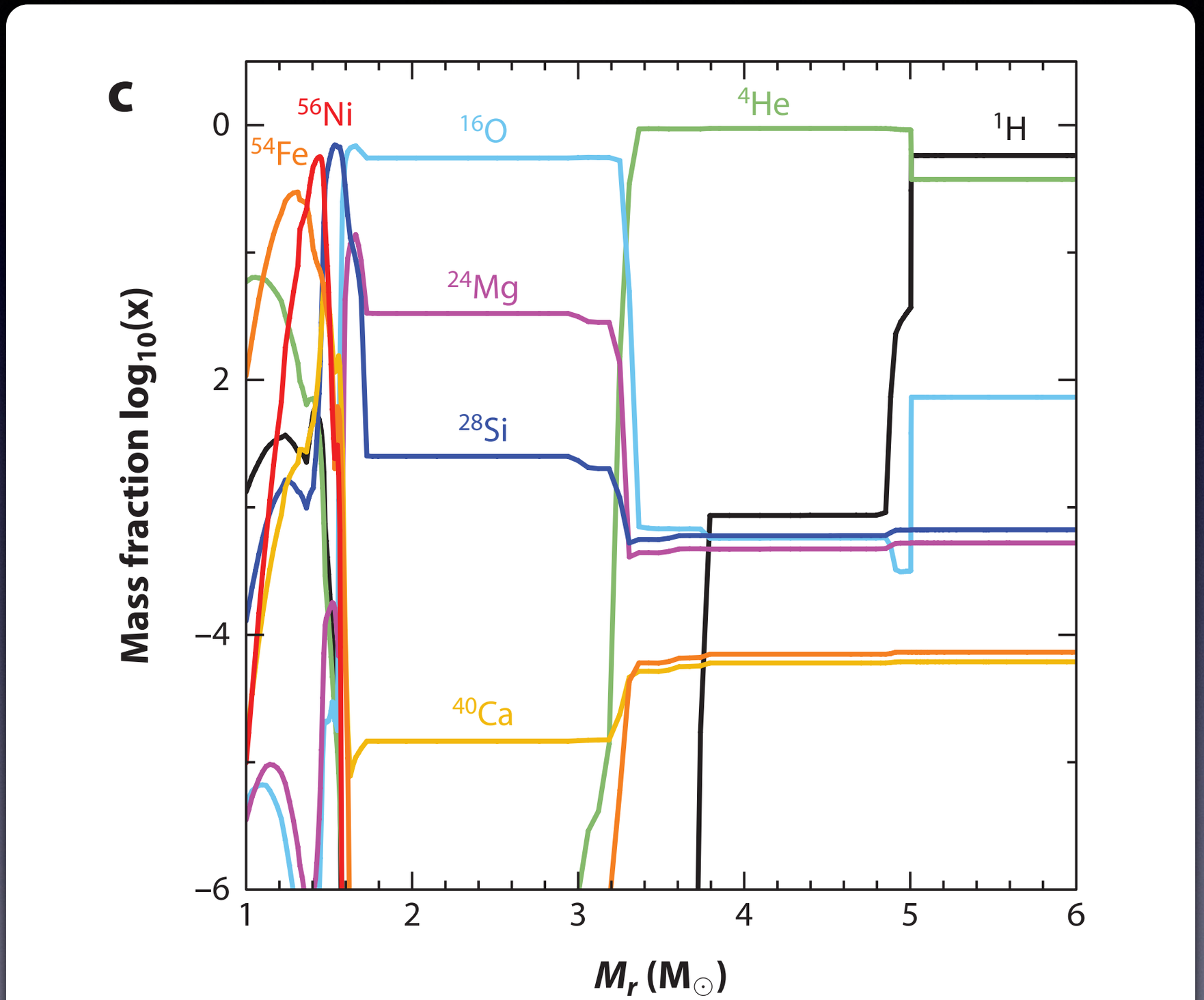
20 Msun (HR diagram)




5.590170e+01 yr
M=20.0, Z=0.02
log L
log Teff
7
6
5
4
3
2
1
0
−1
4.4
4.2
4.0
3.8
3.6
3.4

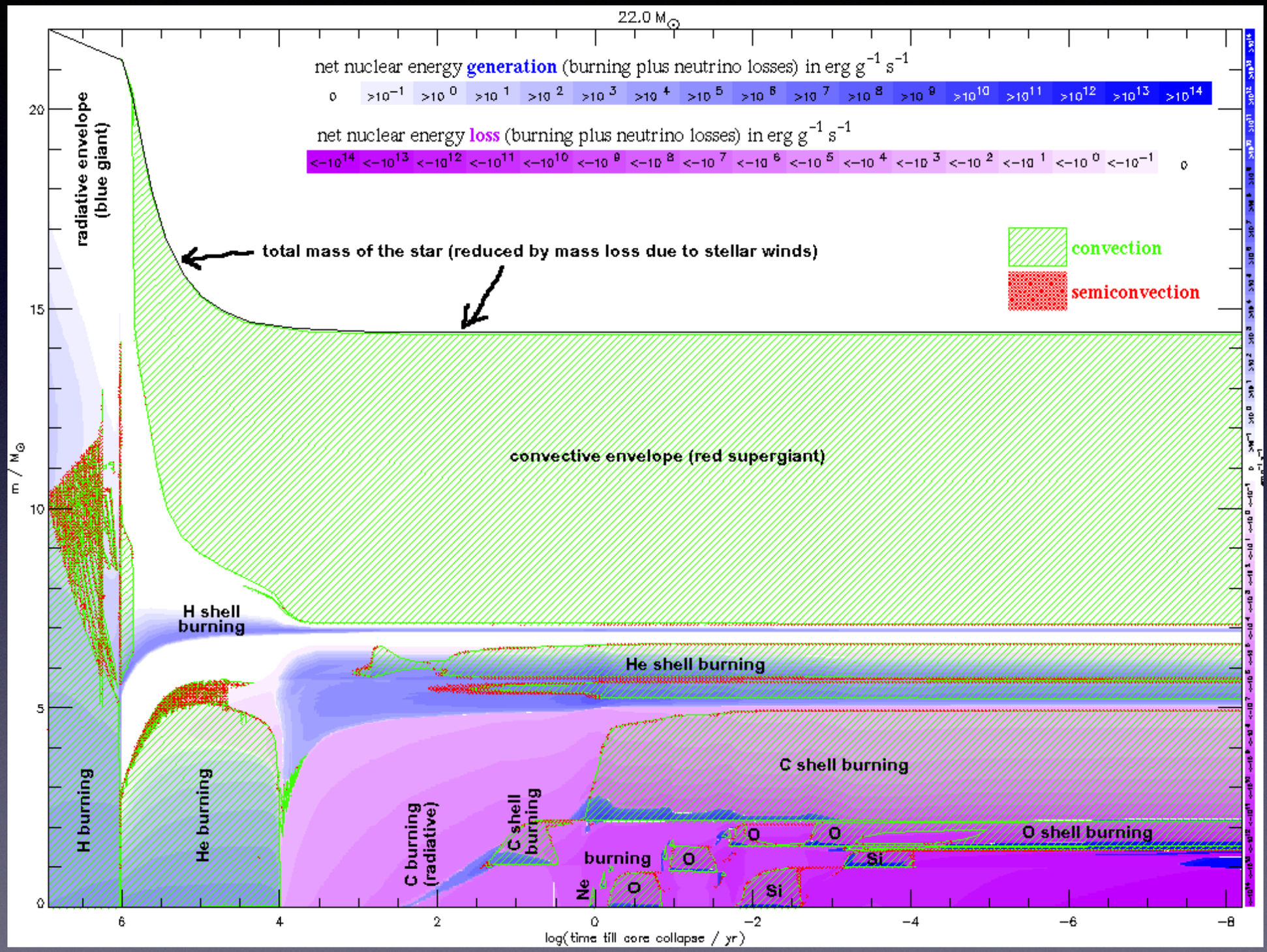

5.590170e+01 yr
log T
log ρ
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
0
2
4
6
8
10

Elemental distribution before core-collapse SN



Nomoto+13

“Kippenhahn diagram”



(C) A. Heger
https://2sn.org/stellarevolution/explain.gif

Summary: stellar evolution (III)

- **Equations for stellar evolution**
  - Equation of motion
  - Equation of state
  - Energy equation
  - Nuclear reactions
- **Stellar evolution calculations**
  - Series of hydrostatic configurations for a given initial mass
  - Rotation, metallicity and so on

Thermodynamics

Electromagnetism

Classical mechanics

Statistical mechanics

Astrophysics

Hydrodynamics

Quantum mechanics

Relativity

Nuclear physics