Section 6.
Low mass stars and white dwarfs

6.1 Evolution of low mass stars

6.2 White dwarfs

MESA code

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

MESA
Modules for Experiments in Stellar Astrophysics

- MESA home
- code capabilities
- prereqs & installation
- getting started
- using pgstar
- using MESA output
- beyond inlists (extending MESA)
- troubleshooting
- FAQ
- star_job defaults
- controls defaults
- pgstar defaults
- binary_controls defaults
- news archive
- documentation archive

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

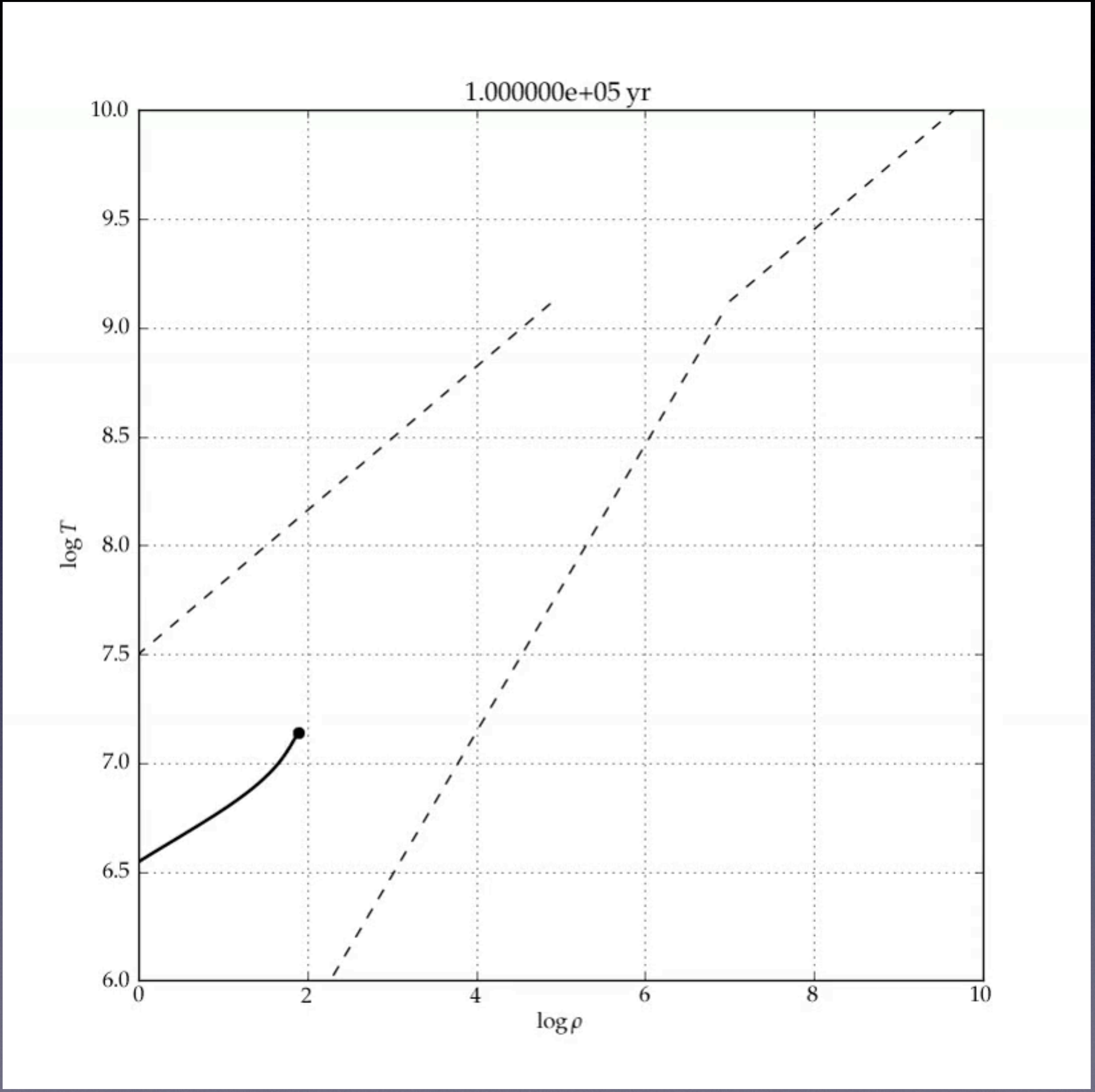
Stellar evolution calculations remain a basic tool of broad impact for astrophysics. New observations constantly test the models, even in 1D. The continued demand requires the construction of a general, modern stellar evolution code that combines the following advantages:

- **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

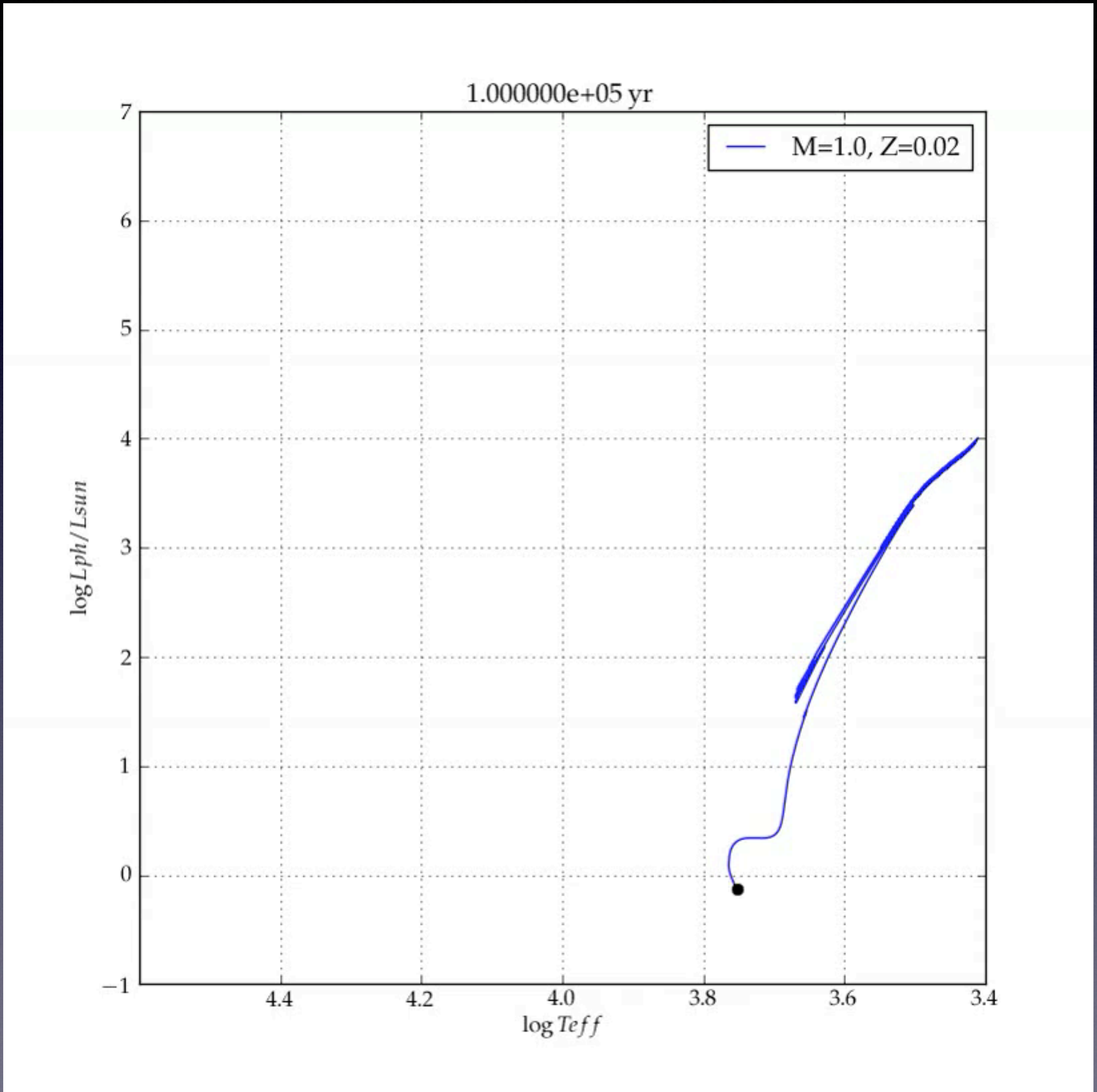
Latest News

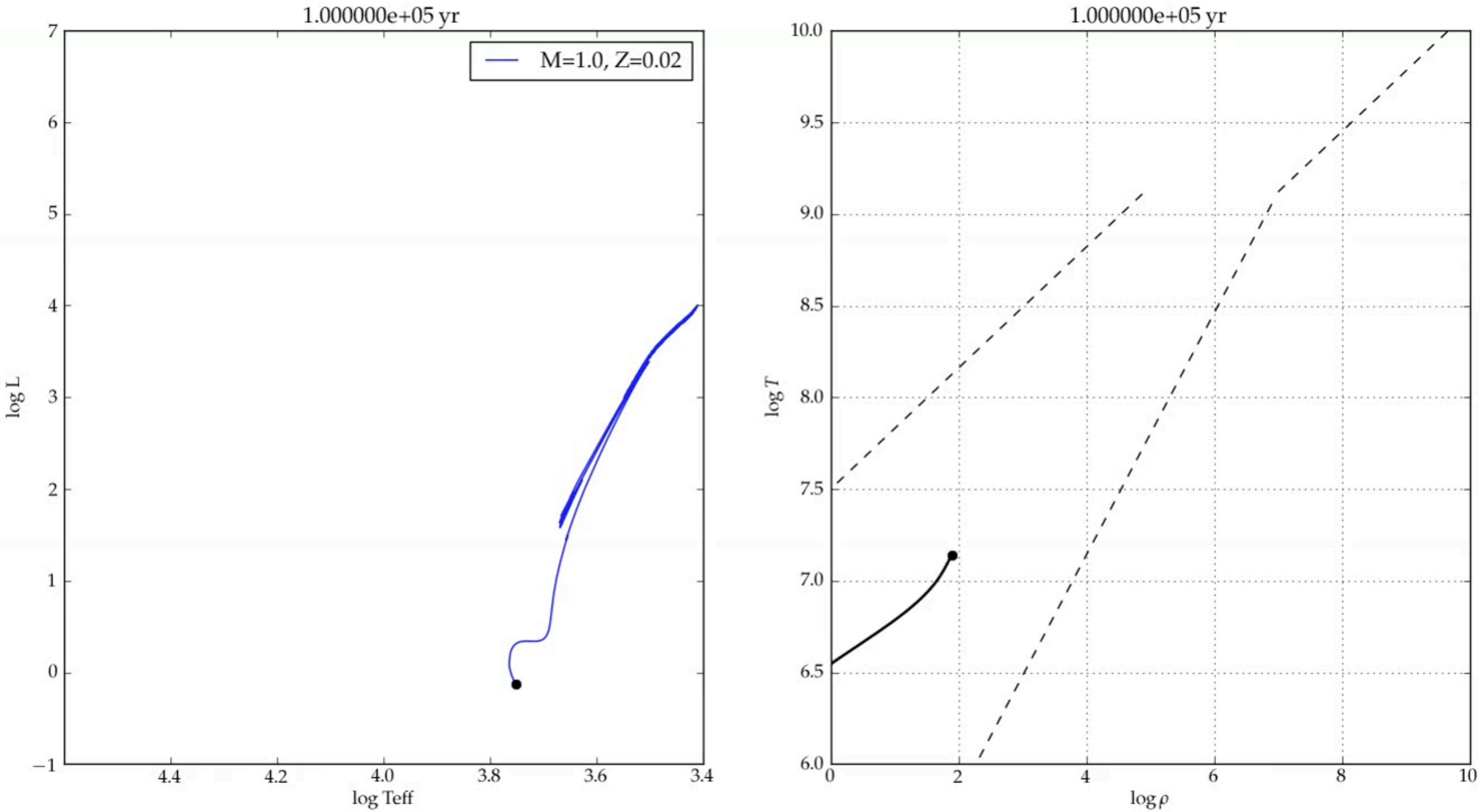
- 10 Aug 2016
  » **Documentation Archive**
- 19 Jun 2016
  » **Release 8845**
- 03 Feb 2016
  » **Release 8118**
- 29 Jan 2016
  » **New MESA SDK Version**
- 10 Jan 2016
  » **Summer School 2016**
- 27 Sep 2015
  » **Instrument Paper 3**
- 14 Sep 2015
  » **MESA-Web Updates**
- 08 Sep 2015
  » **New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

1 Msun (ρ-T)

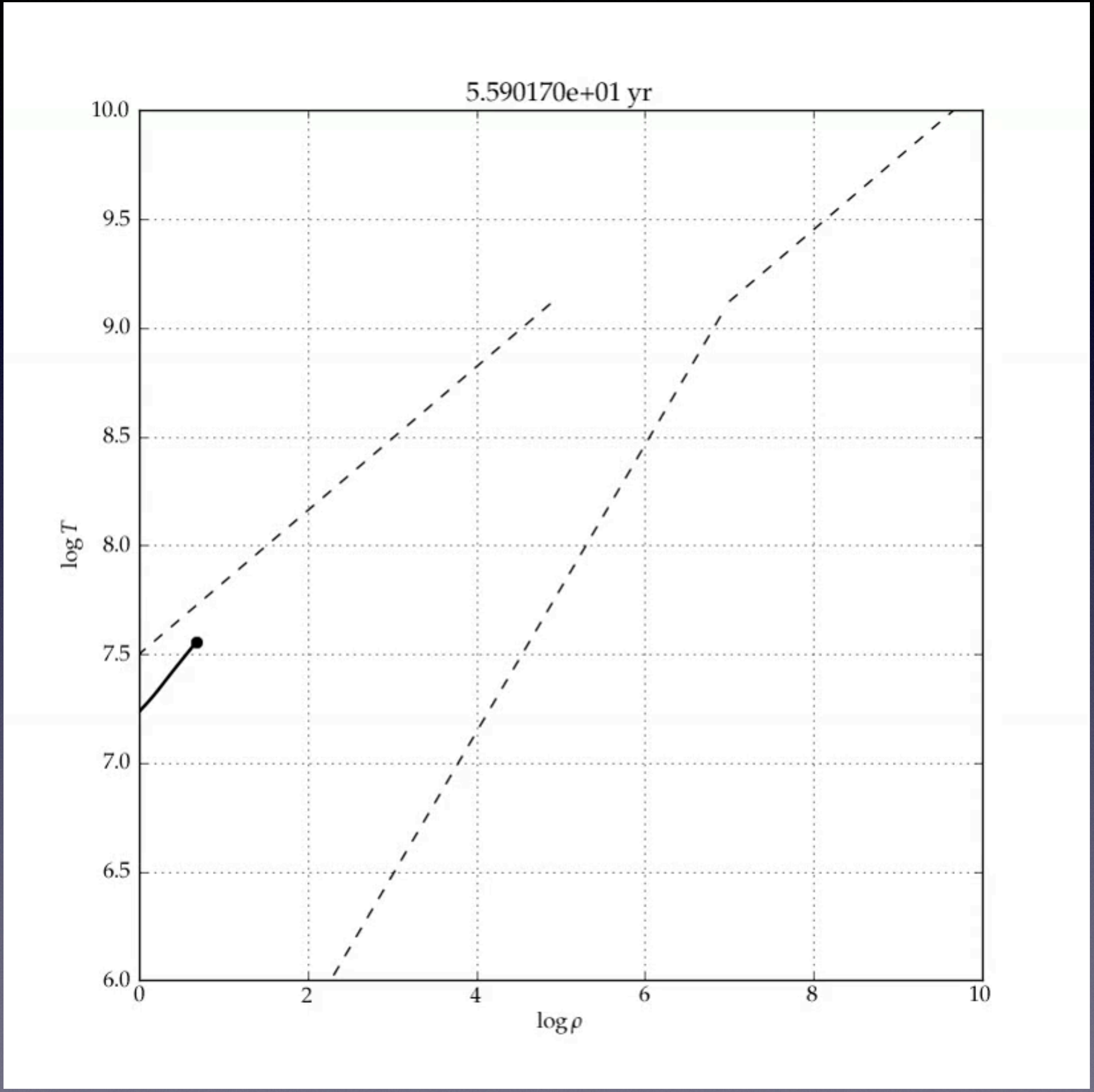


1 Msun (HR diagram)

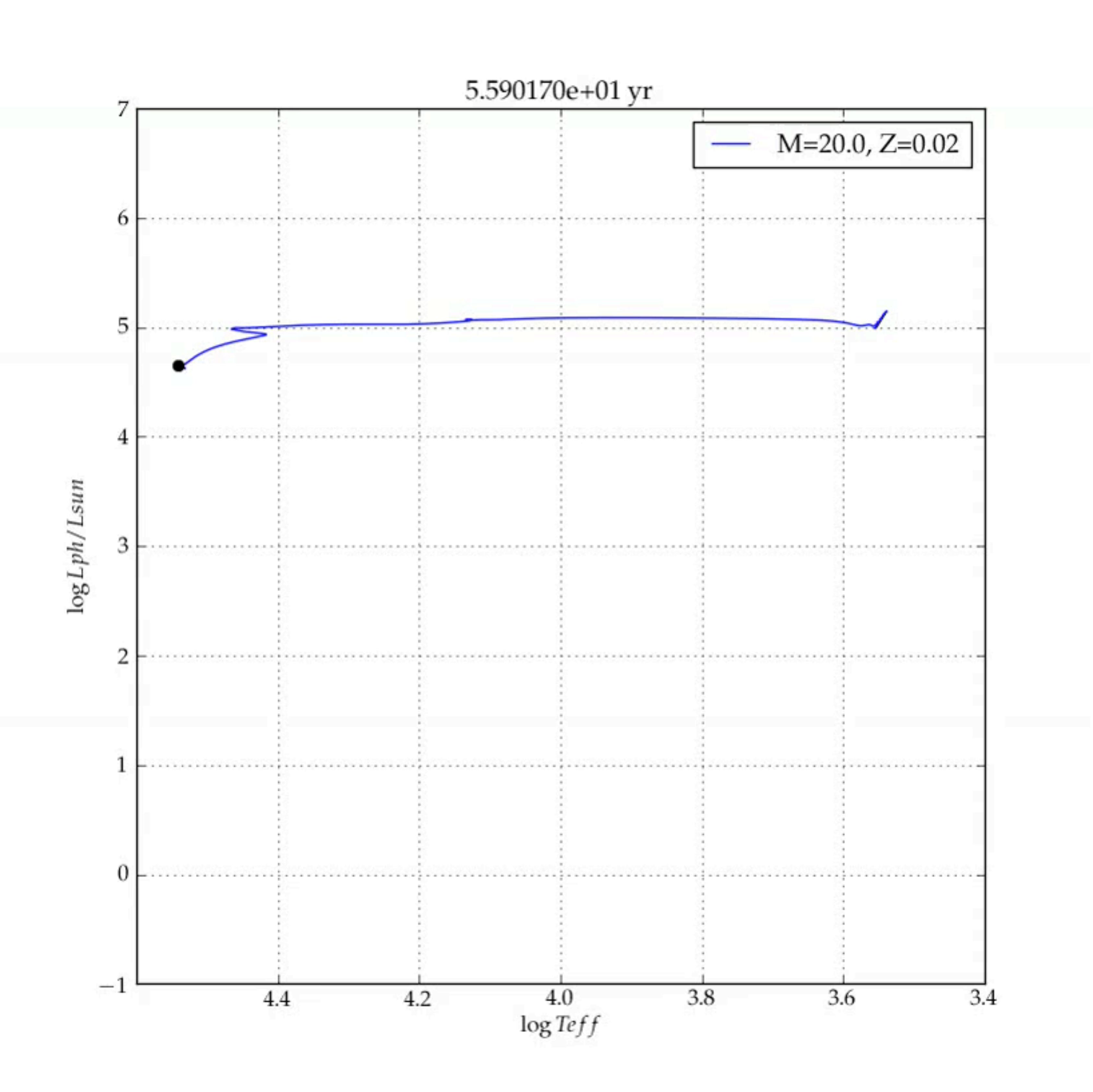


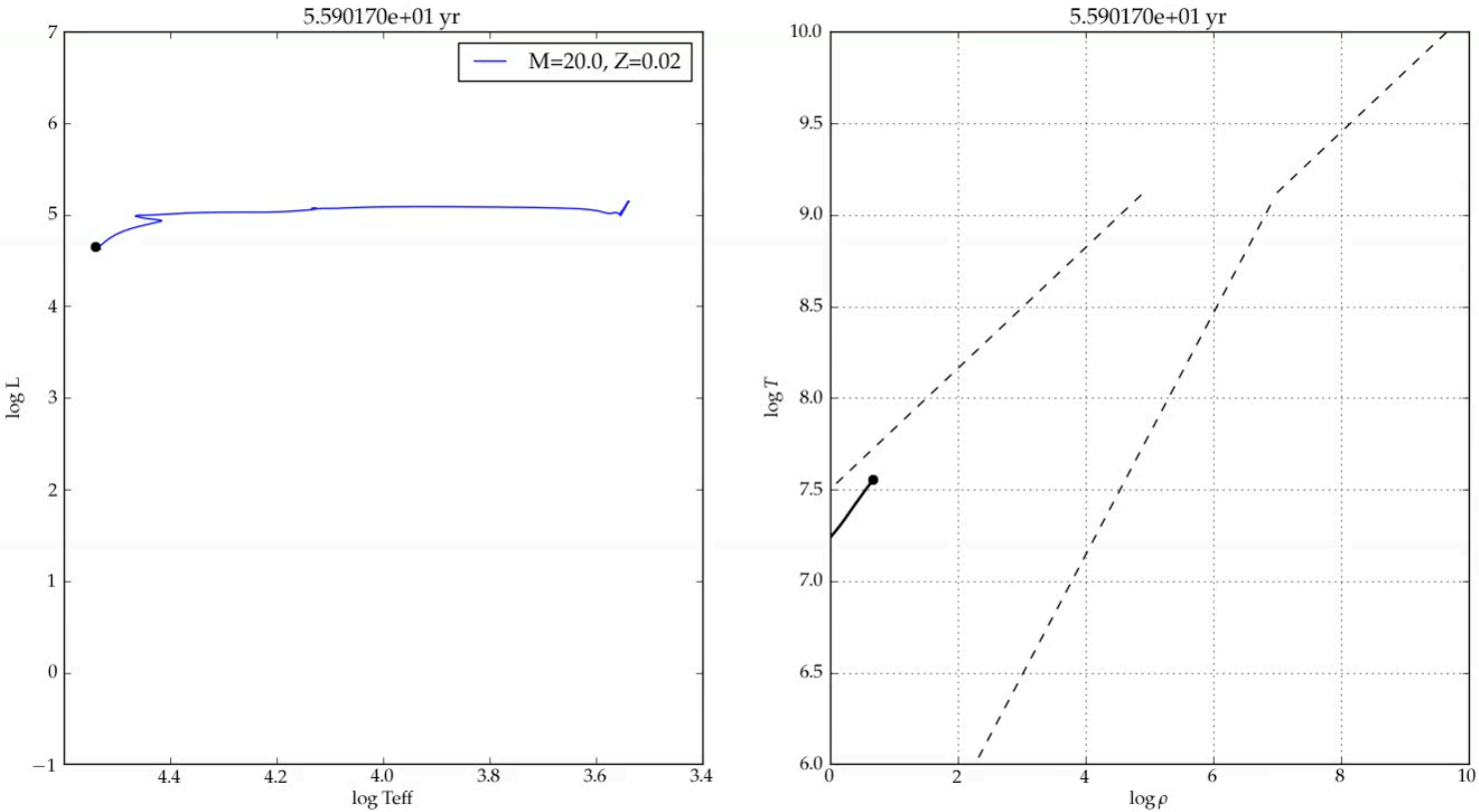

1.000000e+05 yr
M=1.0, Z=0.02
log L
log Teff
7
6
5
4
3
2
1
0
−1
4.4
4.2
4.0
3.8
3.6
3.4
1.000000e+05 yr
log T
log ρ
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
0
2
4
6
8
10

20 Msun (ρ-T)



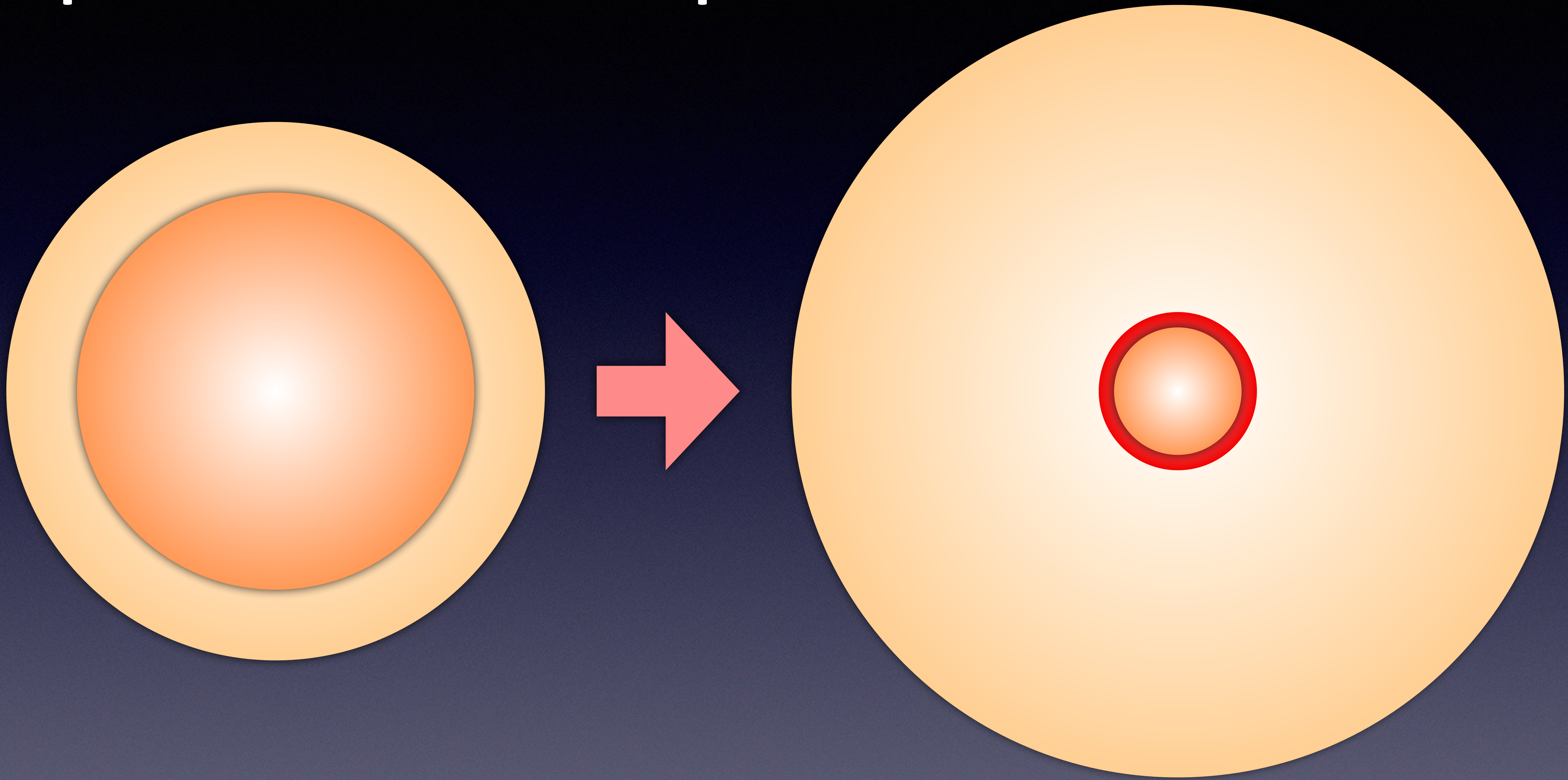
20 Msun (HR diagram)



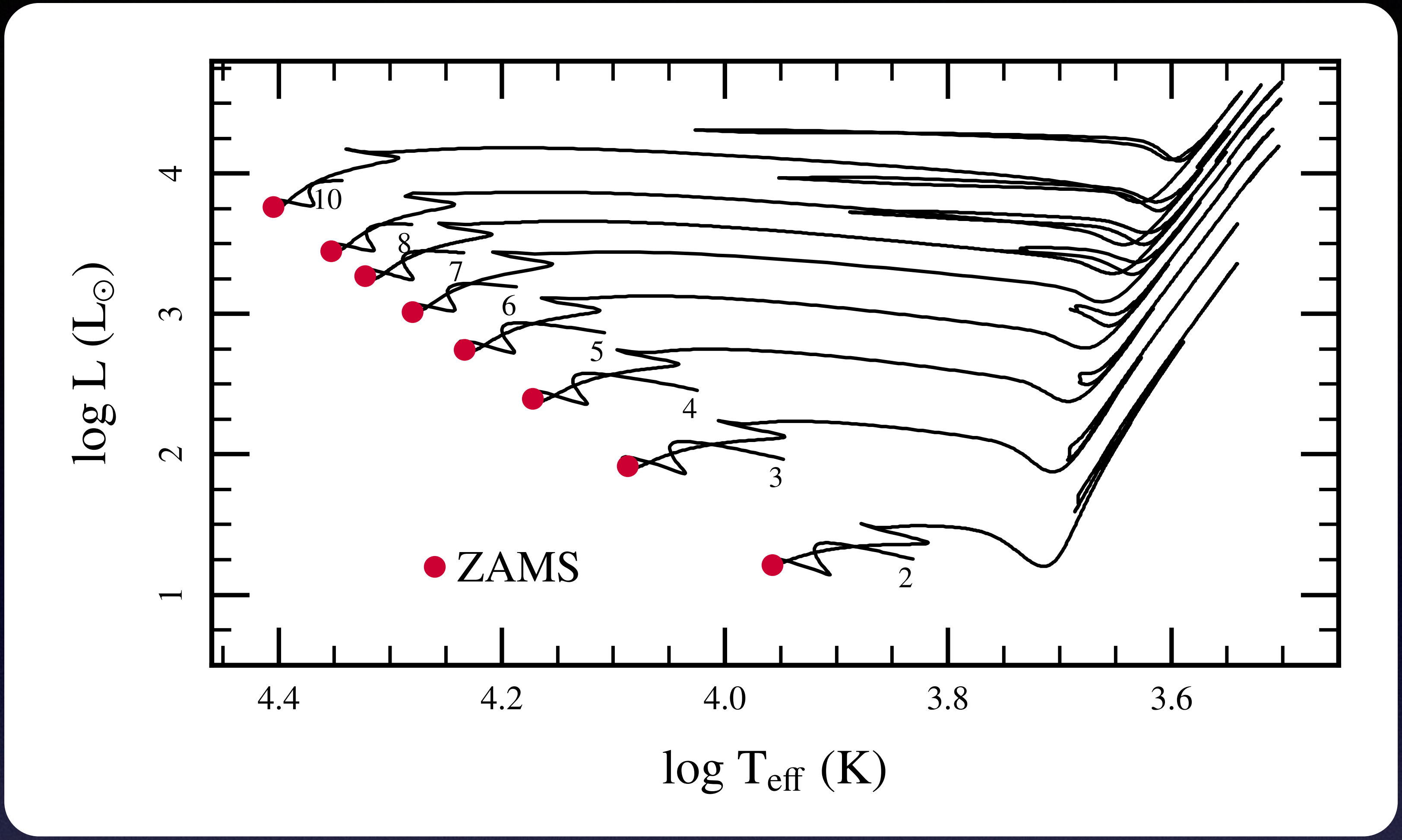


5.590170e+01 yr
M=20.0, Z=0.02
log L
log Teff
5.590170e+01 yr
log T
log ρ

Contraction of the core
= Expansion of the envelope

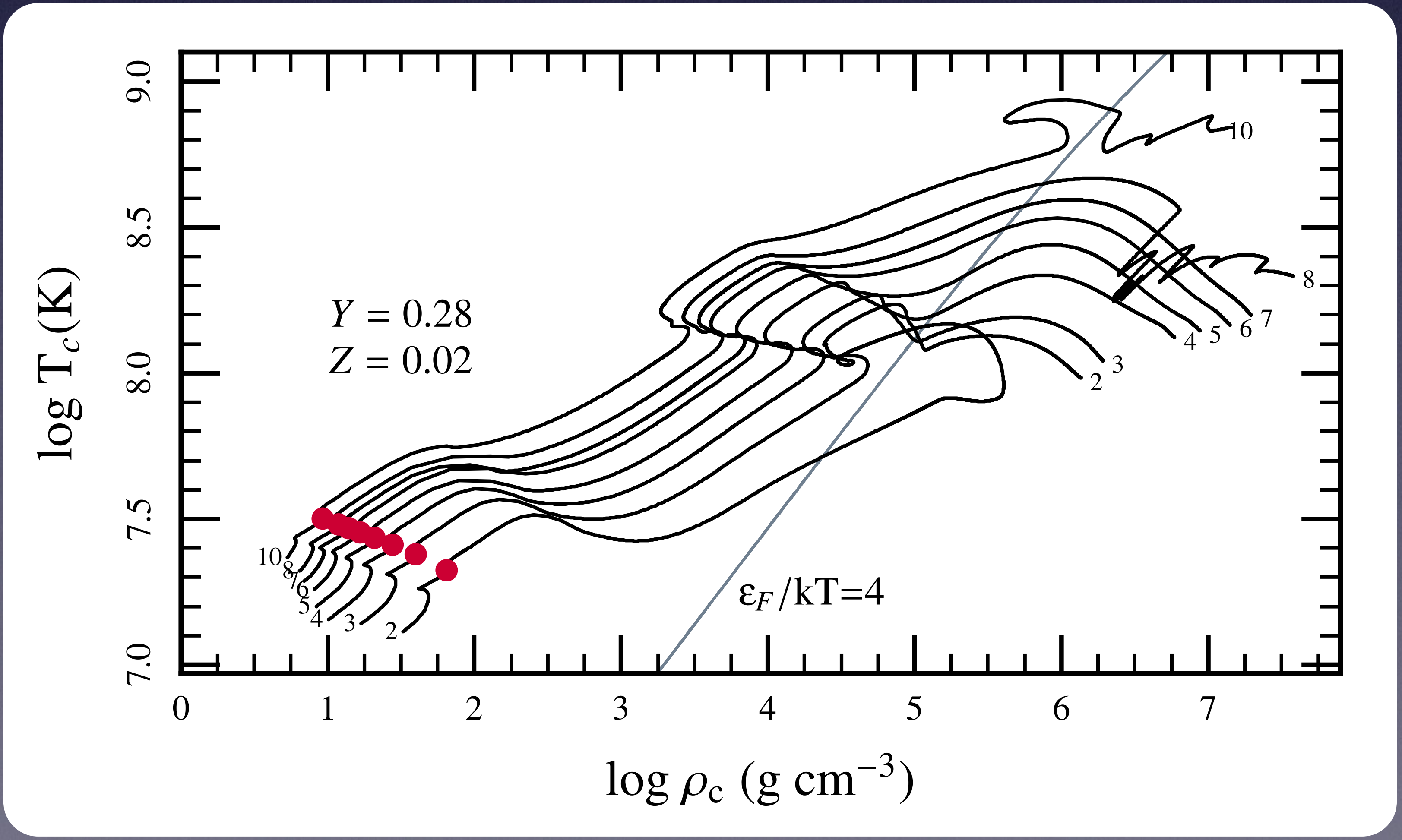


Shell burning => energy generation
(more than required to support the envelope)



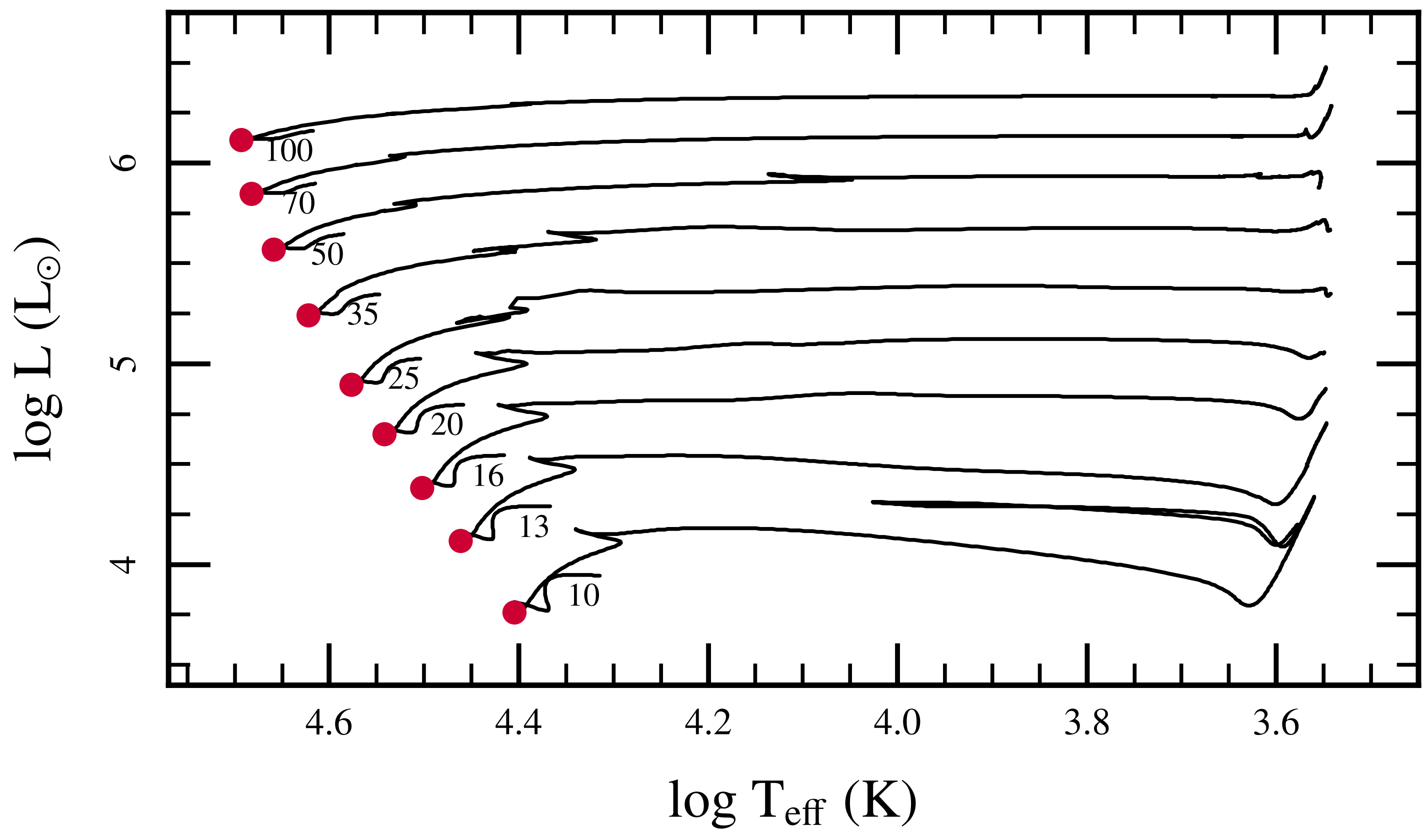
Low/intermediate mass stars

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

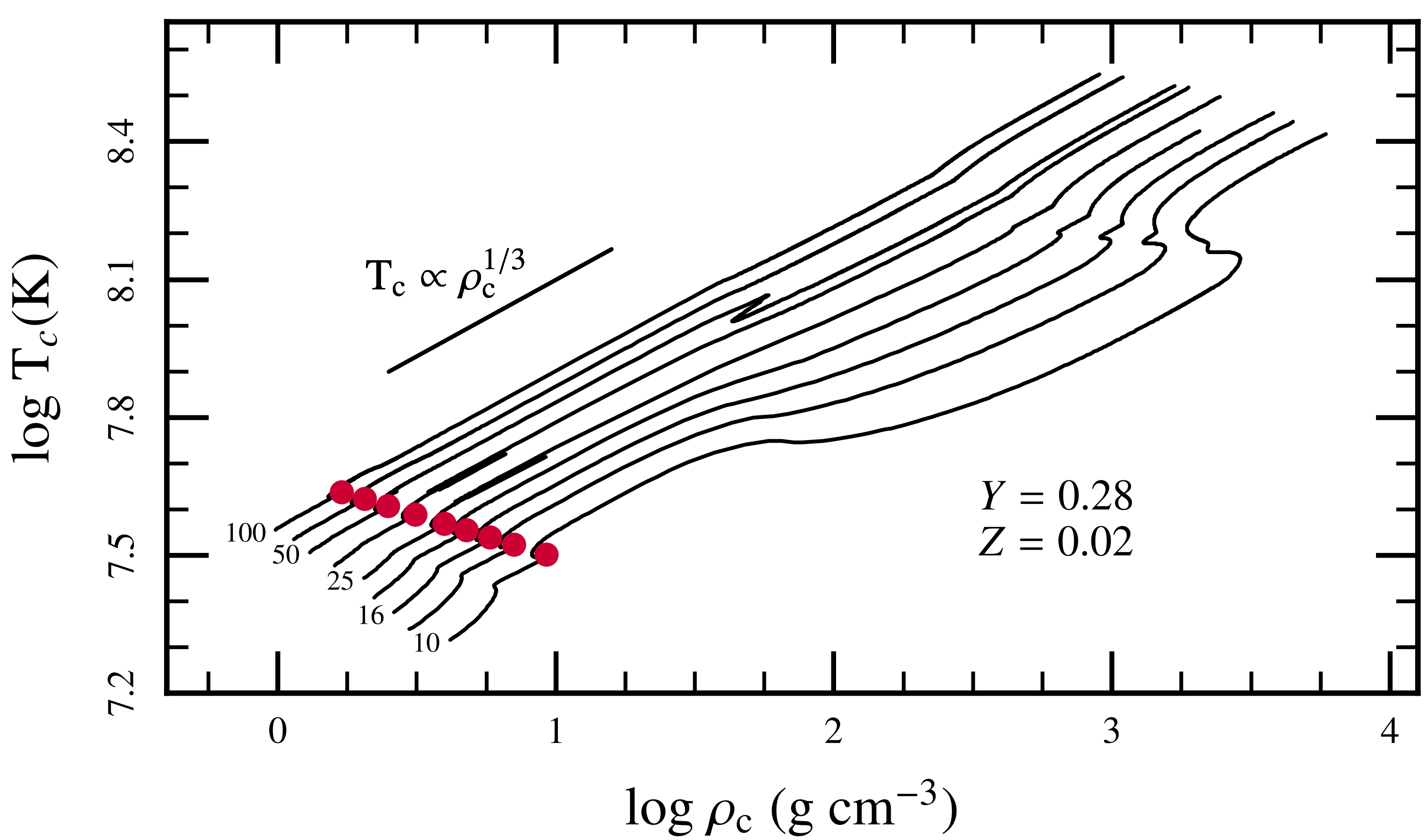


Paxton et al. 2011

Massive stars (until He-burning)

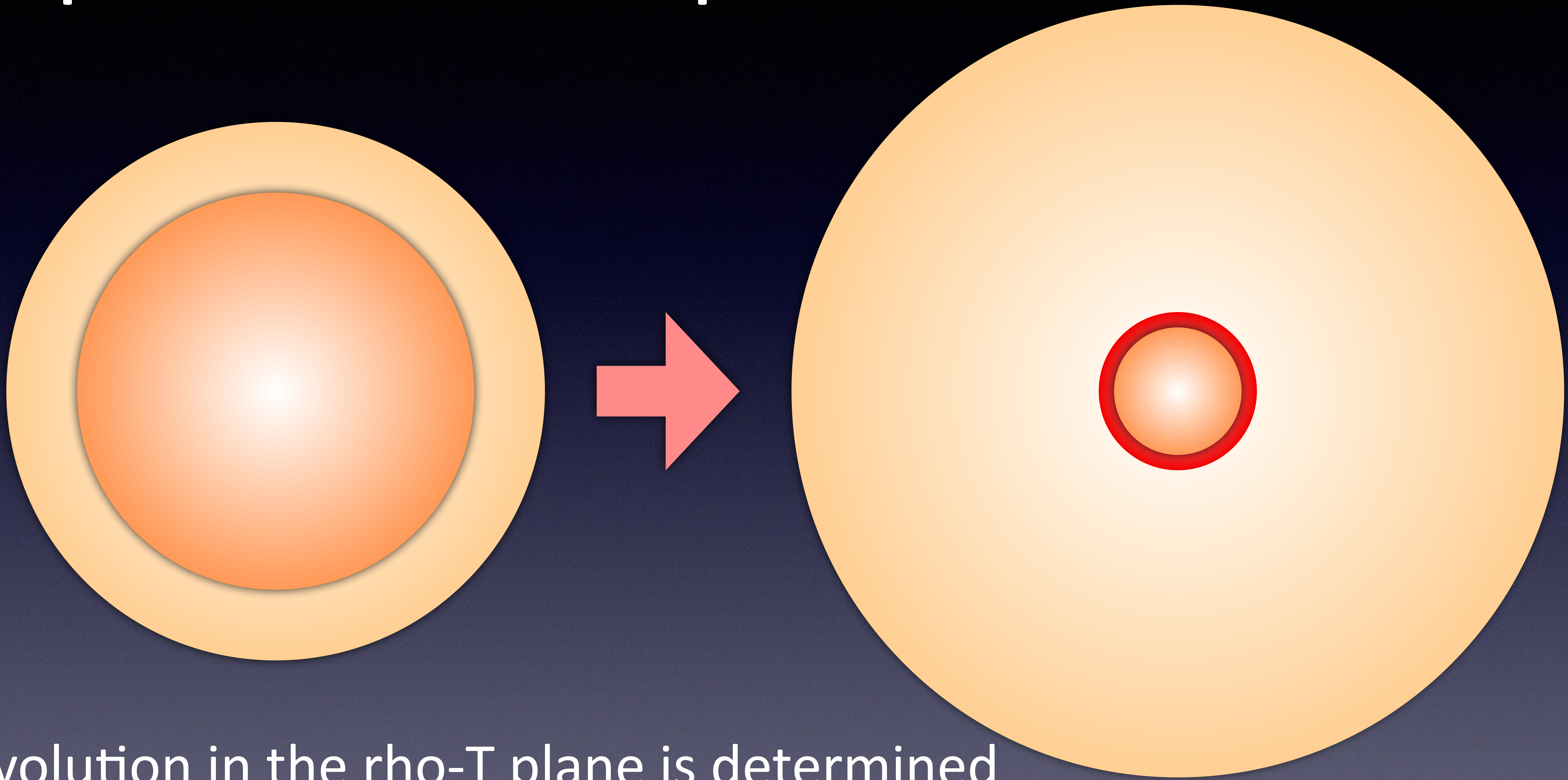


Core contraction
=> Expansion of the envelope
=> Red super giant



Paxton et al. 2011

Contraction of the core
= Expansion of the envelope



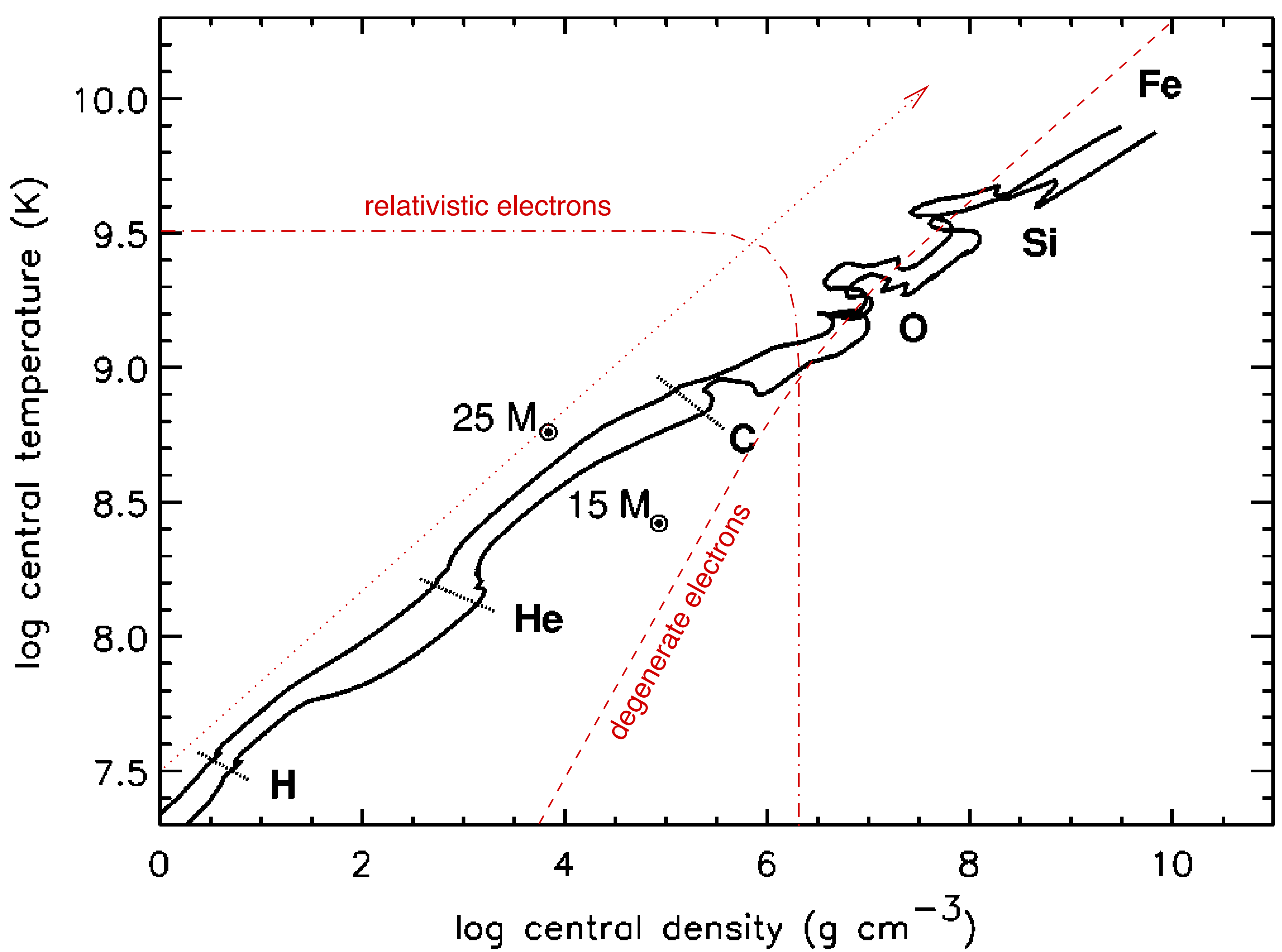
Evolution in the rho-T plane is determined by the properties of the core

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

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

Massive stars
(until Si burning)

Finally degeneracy pressure becomes important



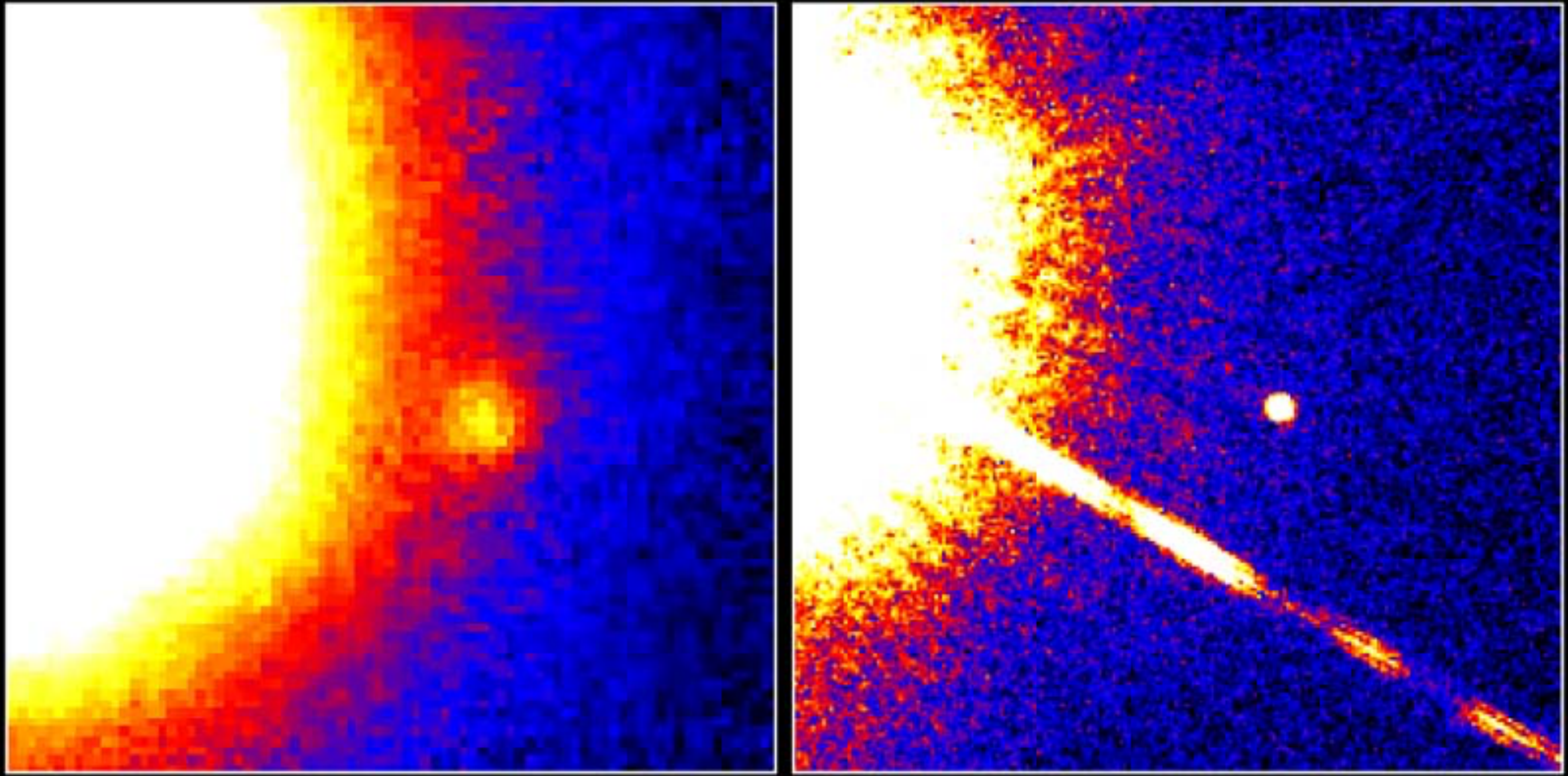
textbook by Pols

What about lower mass stars?

What is the minimum mass of the stars?

What is the fate of low mass stars?

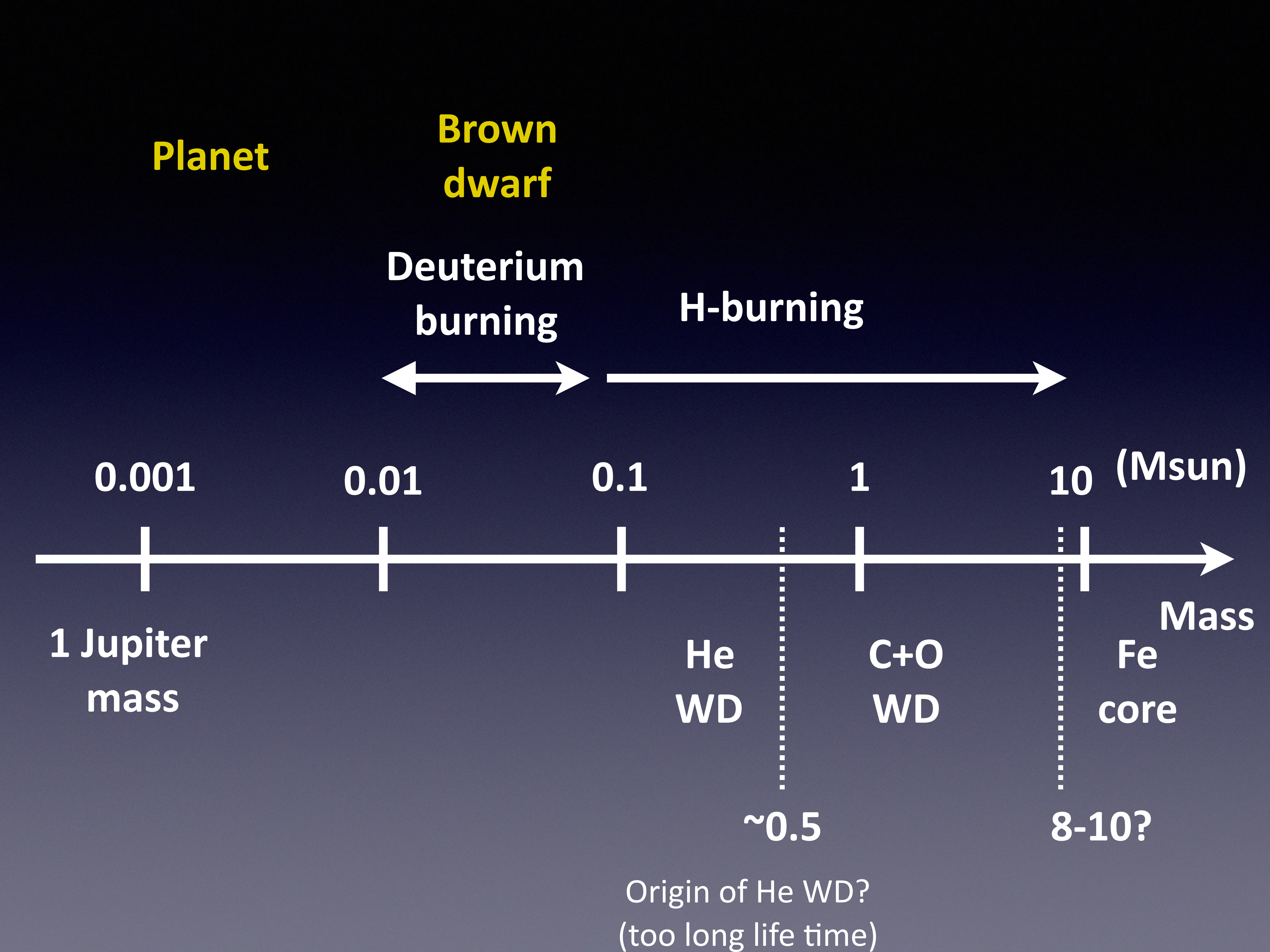
Brown Dwarf Gliese 229B



Palomar Observatory
Discovery Image
October 27, 1994

Hubble Space Telescope
Wide Field Planetary Camera 2
November 17, 1995

PRC95-48 · ST ScI OPO · November 29, 1995
T. Nakajima and S. Kulkarni (CalTech), S. Durrance and D. Golimowski (JHU), NASA


Planet
Brown dwarf
Deuterium burning
H-burning
0.001
0.01
0.1
1
10
(Msun)
Mass
1 Jupiter mass
He WD
C+O WD
Fe core
~0.5
8-10?
Origin of He WD?
(too long life time)

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https://kids.yahoo.co.jp/zukan/astro/winter/0001.html

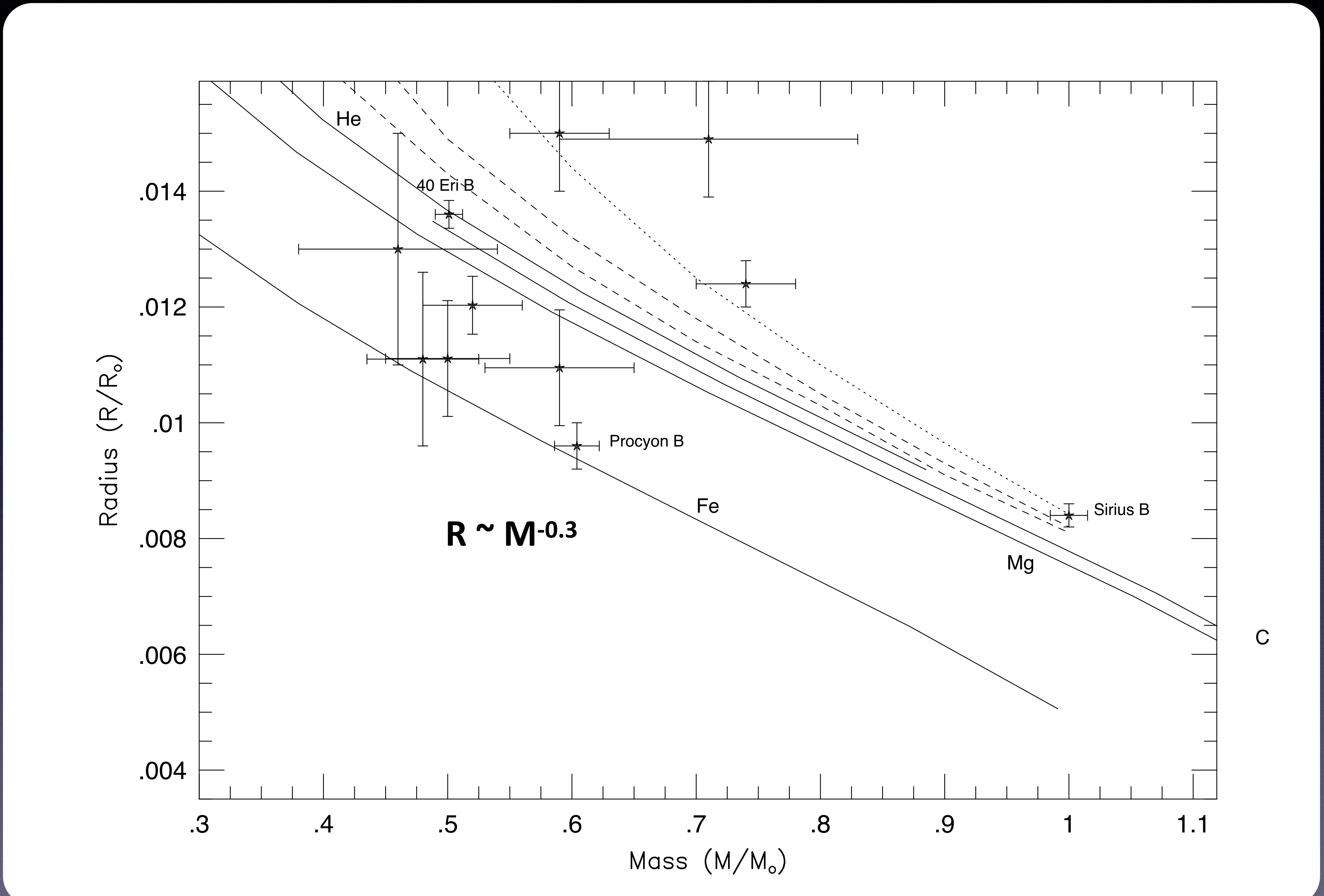
Cat's eye nebula

(J.P. Harrington and K.J. Borkowski, and NASA)

Helix nebula

(NASA, ESA, and C.R. O'Dell)

Mass-radius relation for white dwarfs



Provencal et al. 1998

More massive white dwarfs are smaller
Opposite to the main sequence stars

Why??

Summary: Low mass stars and white dwarfs

- **Low mass stars**
  - Maximum temperature to reach
  - M < 0.08 Msun: cannot reach H burning => brown dwarfs
- **White dwarfs**
  - Supported by electron degeneracy pressure
    => Stellar equations become independent on temperature
  - More massive stars have smaller radius
    $R \sim M^{-1/3}$ (non-relativistic)
  - Limit of relativistic electrons
    M = constant (Chandrasekhar limit) ~ 1.4 Msun