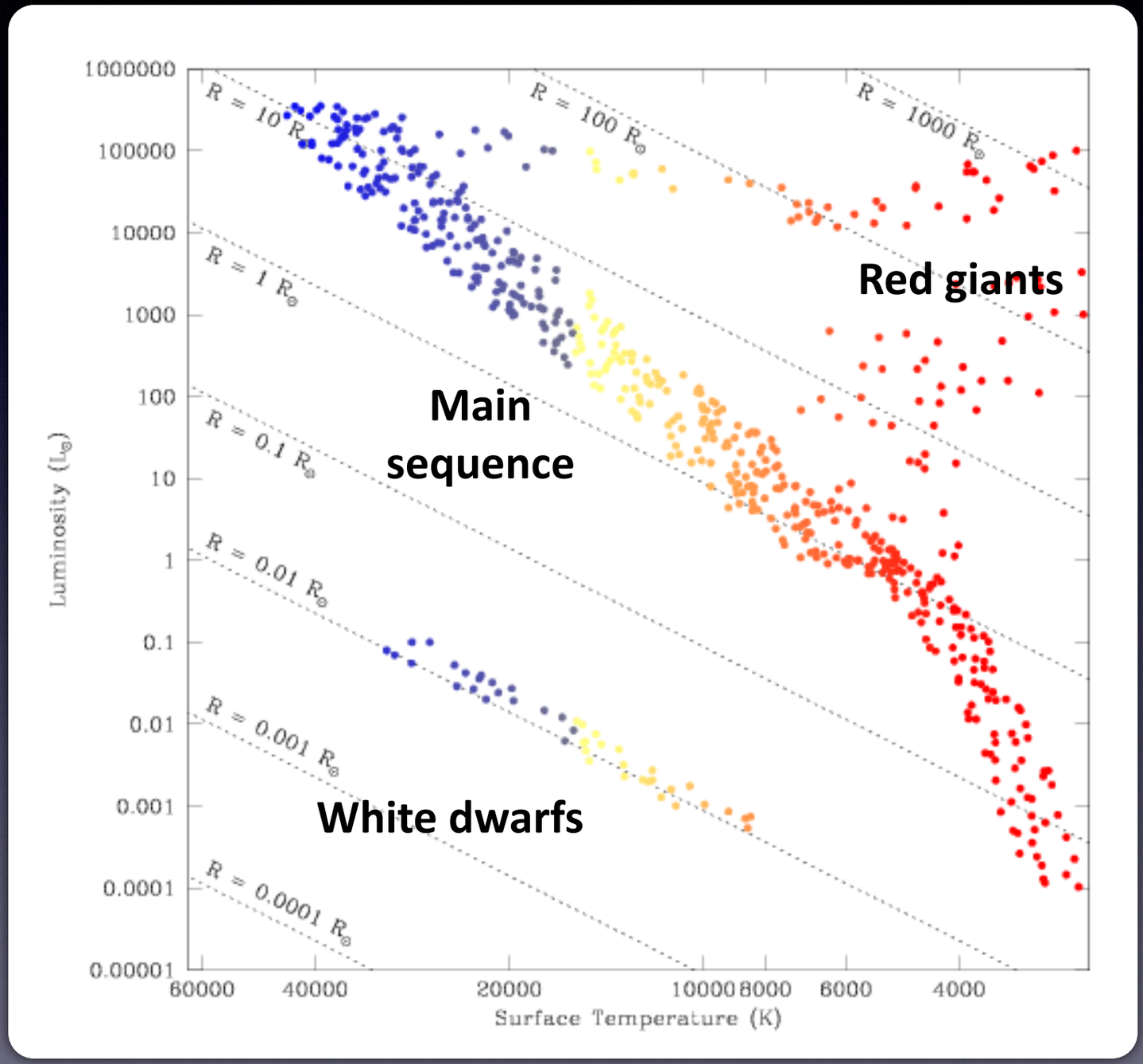
Section 7.
恒星の進化 (3)

7.1 恒星進化の方程式

7.2 恒星進化の計算

Hertzsprung-Russel diagram (HR図)

Luminosity (Lsun)



Temperature (K)

http://astronomy.nmsu.edu/geas/lectures/lecture23/slide04.html

さまざまな疑問を物理を使って理解しよう

- 星の中はどうなっているの？
- なぜ重い星の方が大きいの？
- なぜ星は明るく輝くの？
- なぜ重い星の方が明るいの？
- なぜ星は「進化」するの？
- なぜ質量で星の運命が変わるの？
- なぜ星は星でいられるの？
- なぜ一部の星は爆発するの？
- …

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

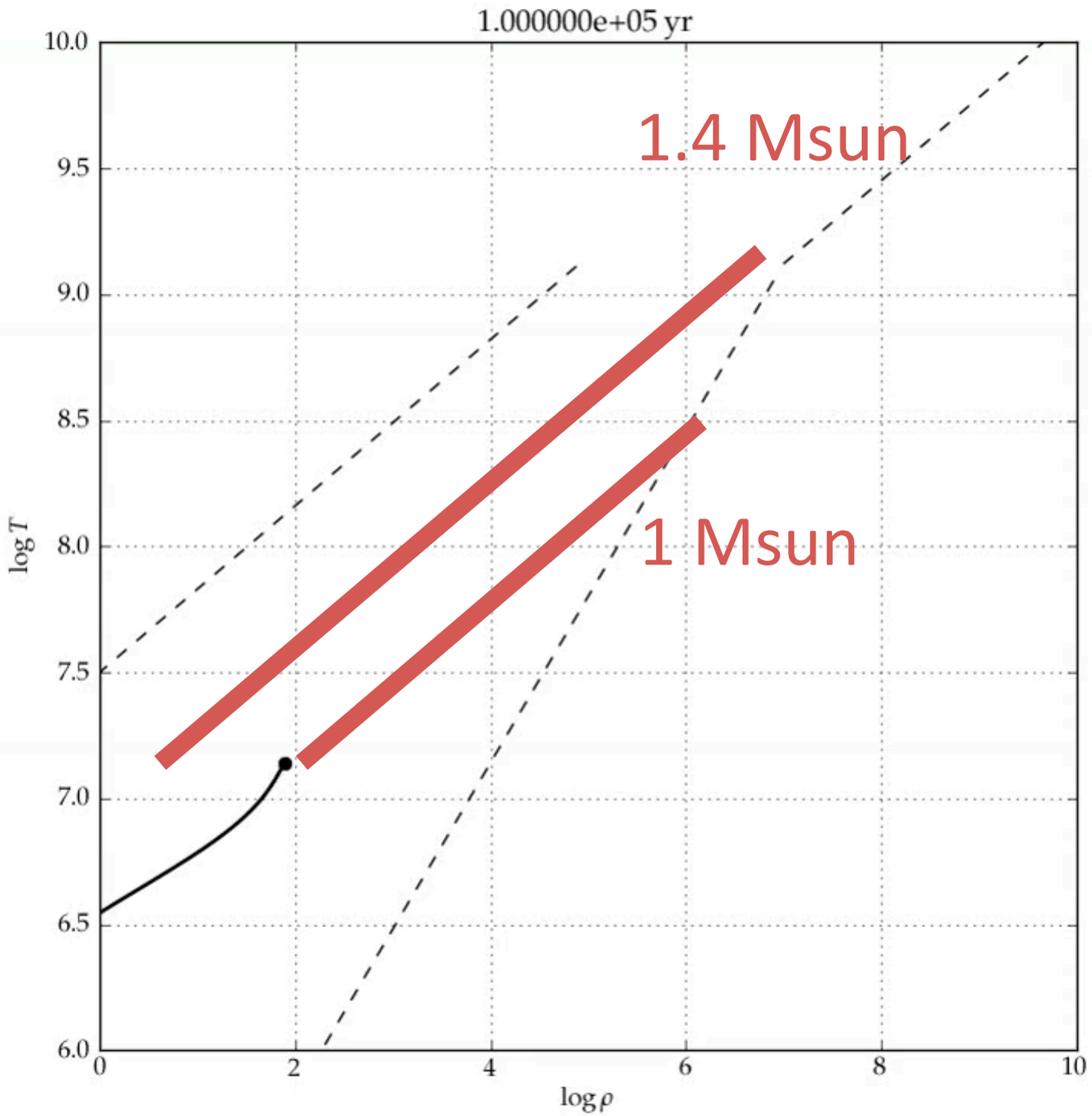
Stellar evolution calculations remain a basic tool of broad impact for astrophysics. New observations constantly test the models, even in 1D. The continued demand requires the construction of a general, modern stellar evolution code that combines the following advantages:

- **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

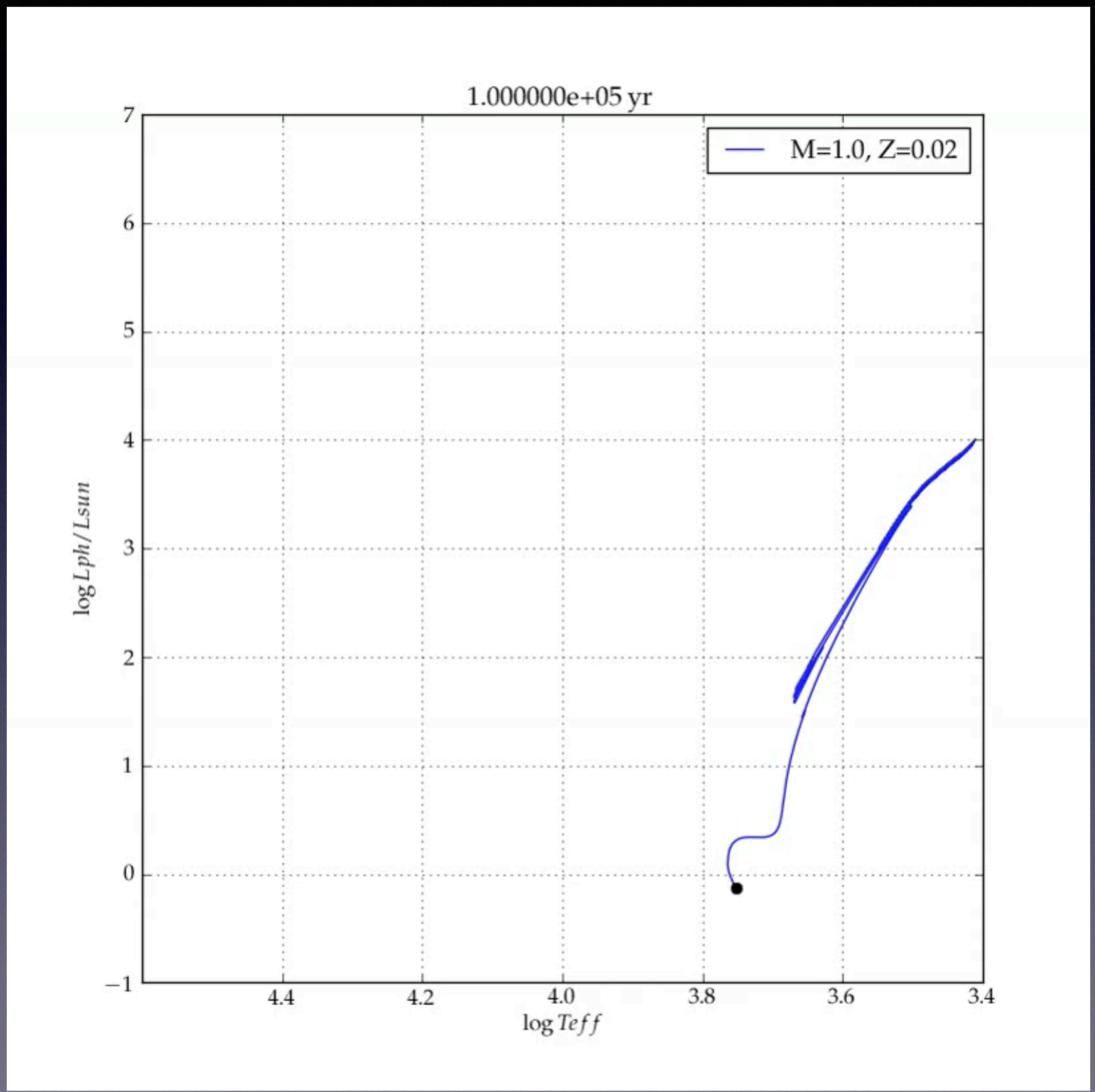
- 10 Aug 2016
  » **Documentation Archive**
- 19 Jun 2016
  » **Release 8845**
- 03 Feb 2016
  » **Release 8118**
- 29 Jan 2016
  » **New MESA SDK Version**
- 10 Jan 2016
  » **Summer School 2016**
- 27 Sep 2015
  » **Instrument Paper 3**
- 14 Sep 2015
  » **MESA-Web Updates**
- 08 Sep 2015
  » **New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

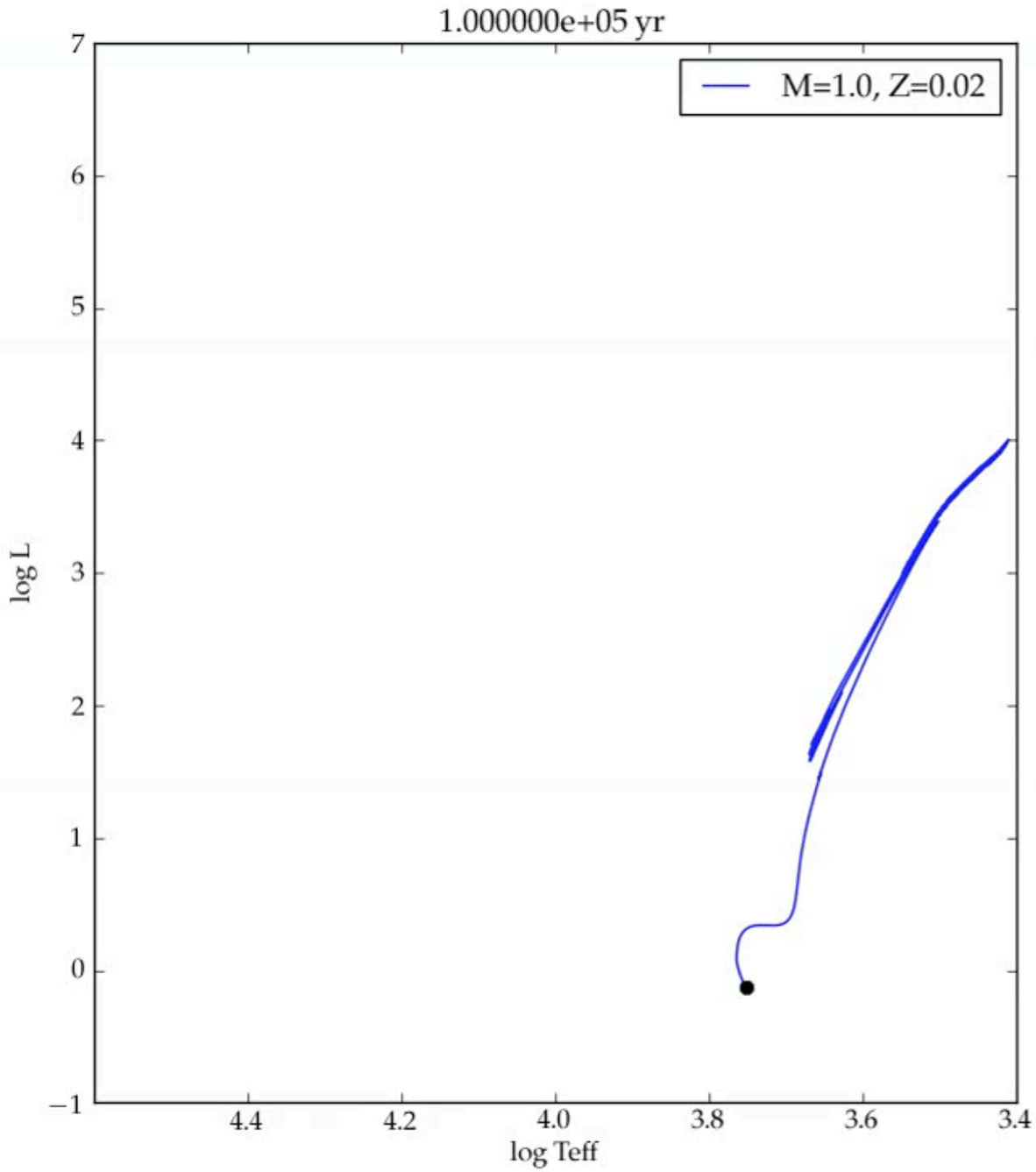
1 Msun (ρ-T)



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

1 Msun (HR diagram)

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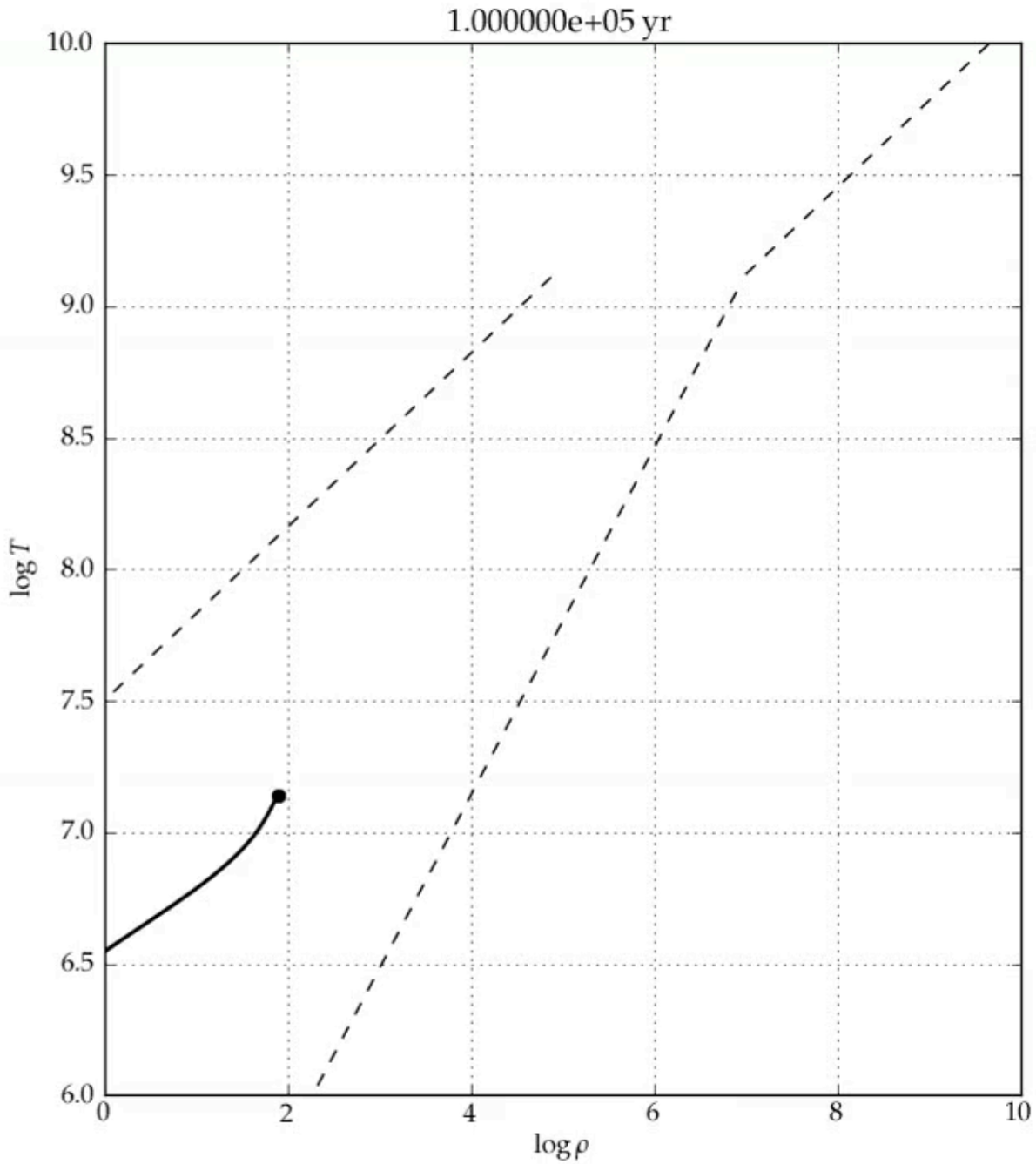
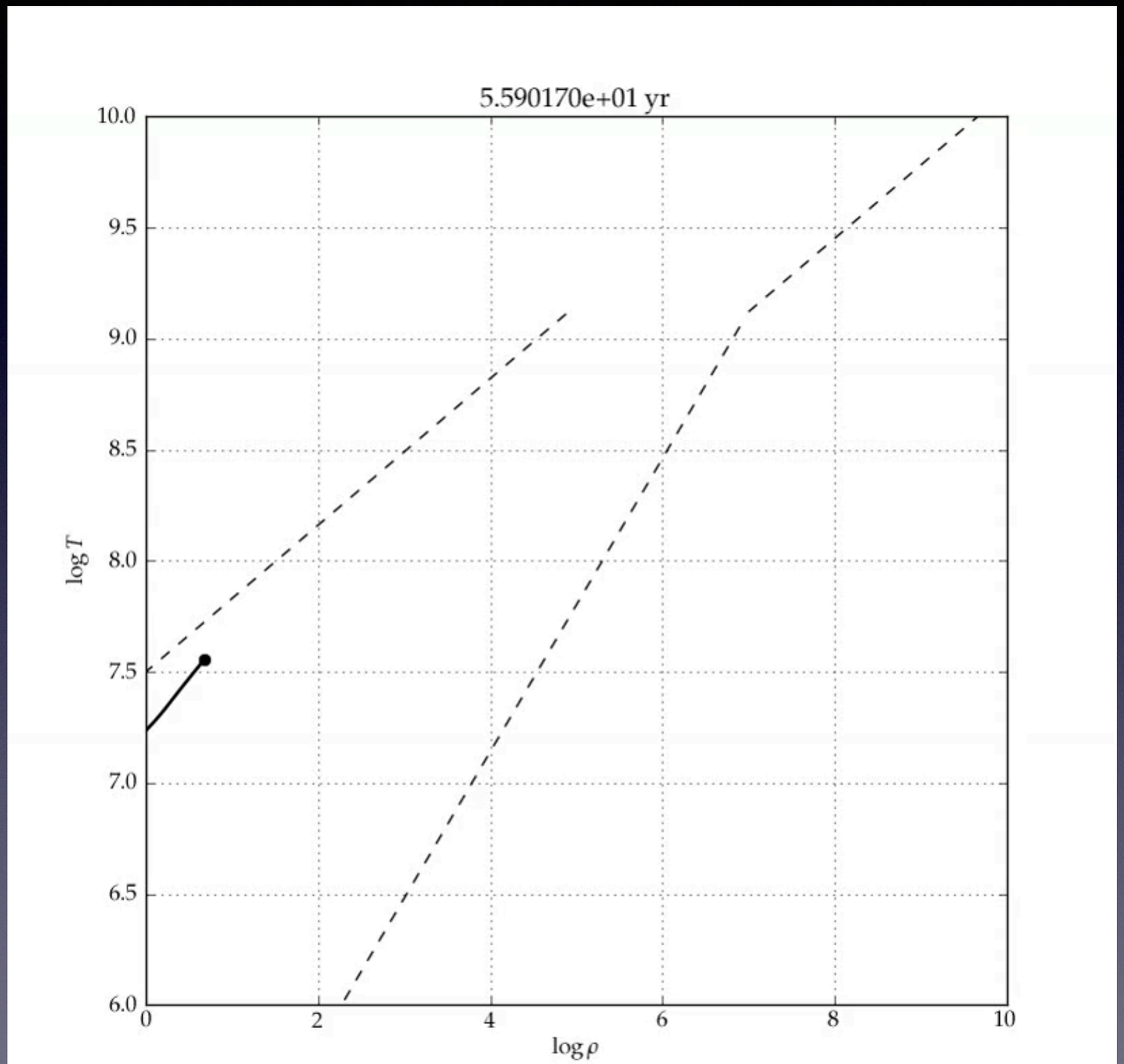
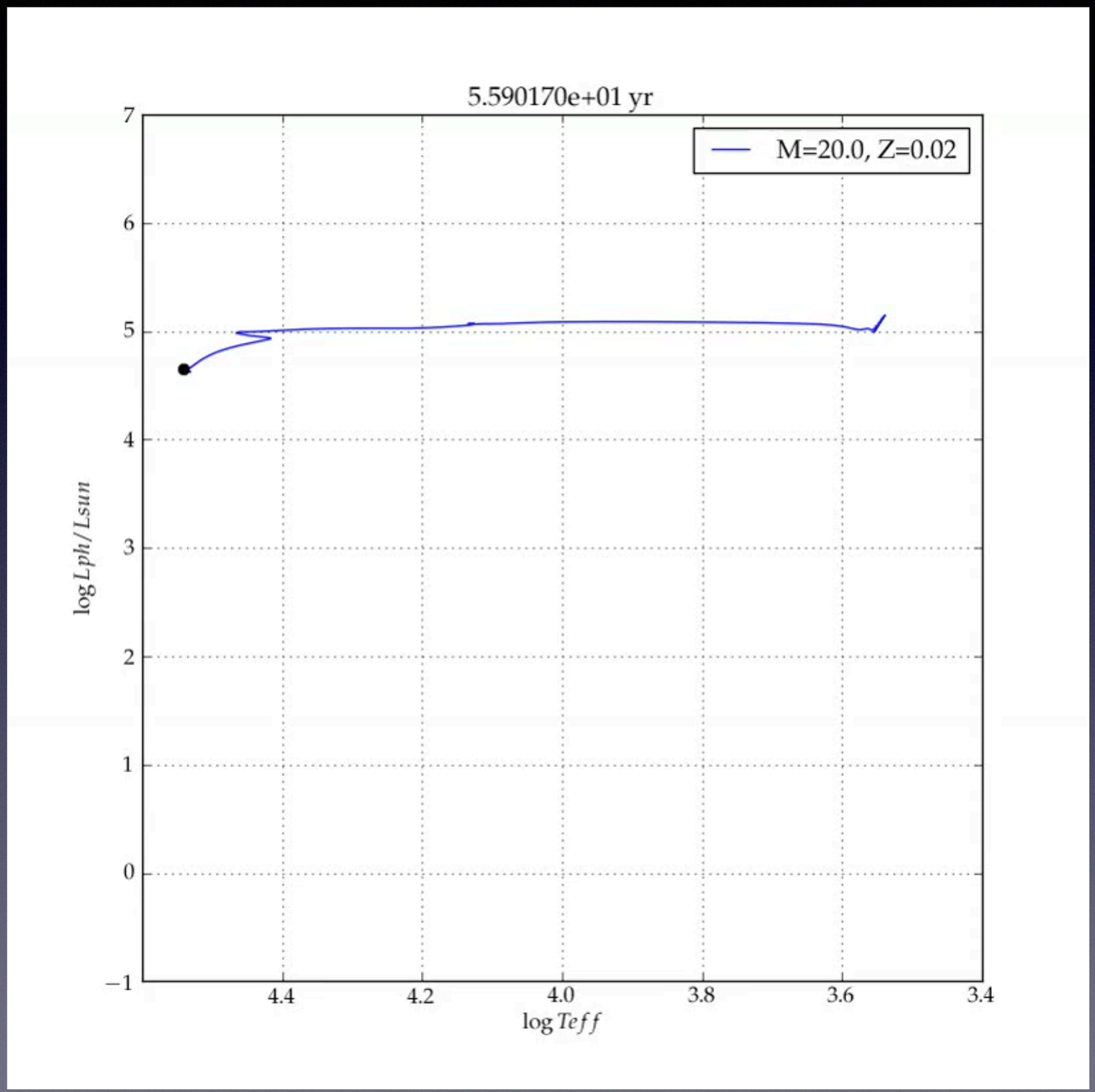
M=1.0, Z=0.02
log L
log Teff
7
6
5
4
3
2
1
0
−1
4.4
4.2
4.0
3.8
3.6
3.4

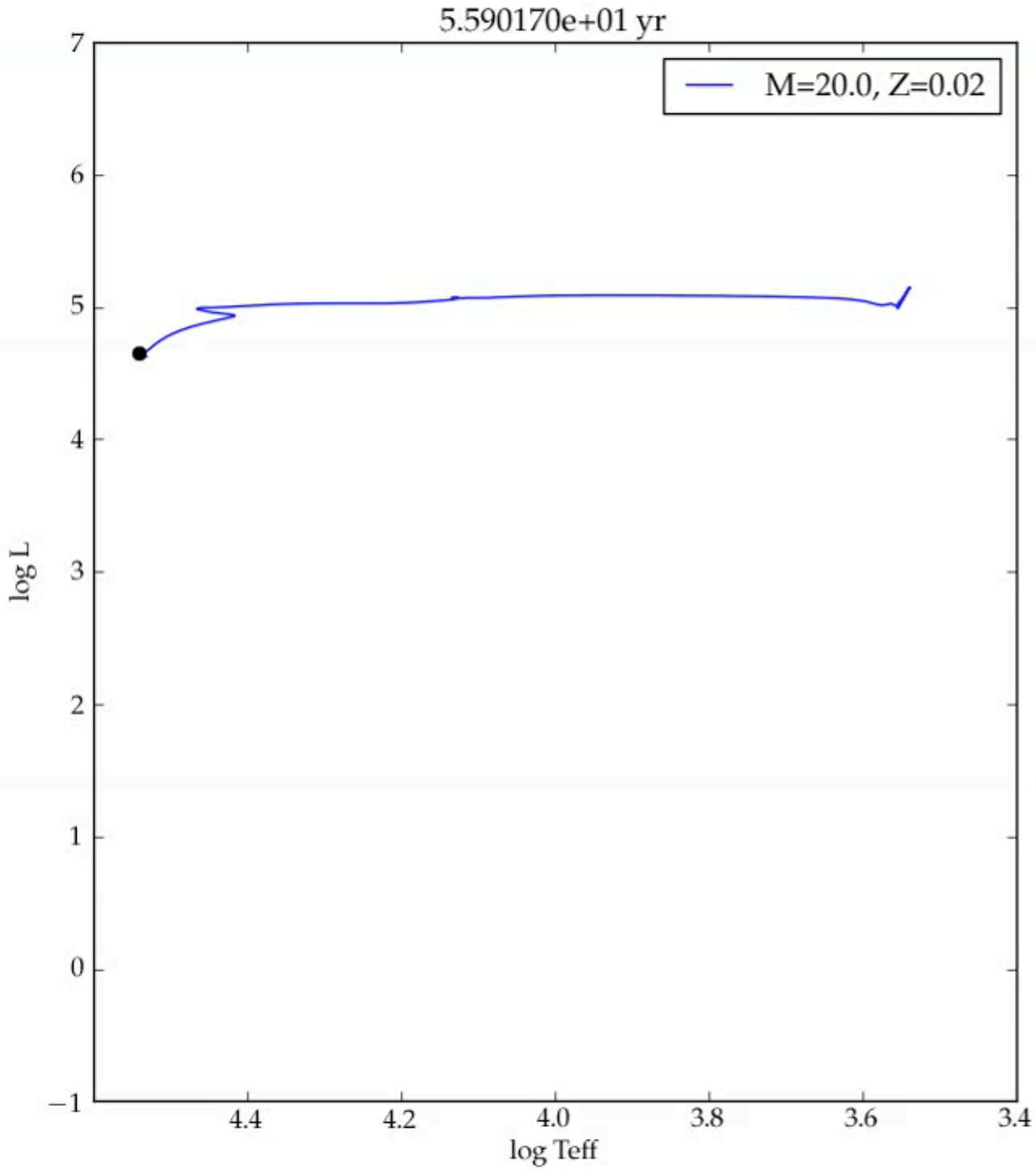

1.000000e+05 yr
log T
log ρ
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
0
2
4
6
8
10

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
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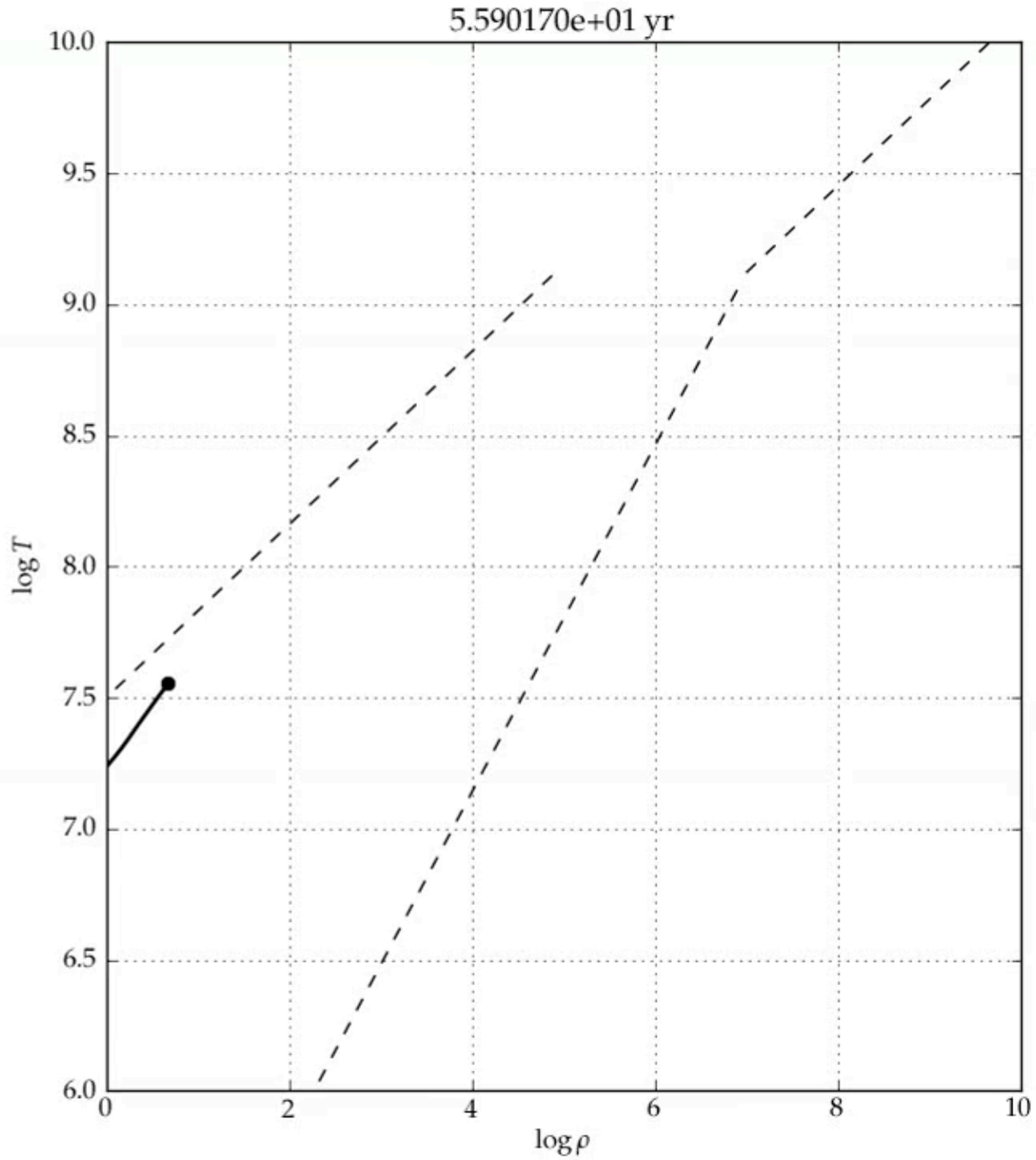
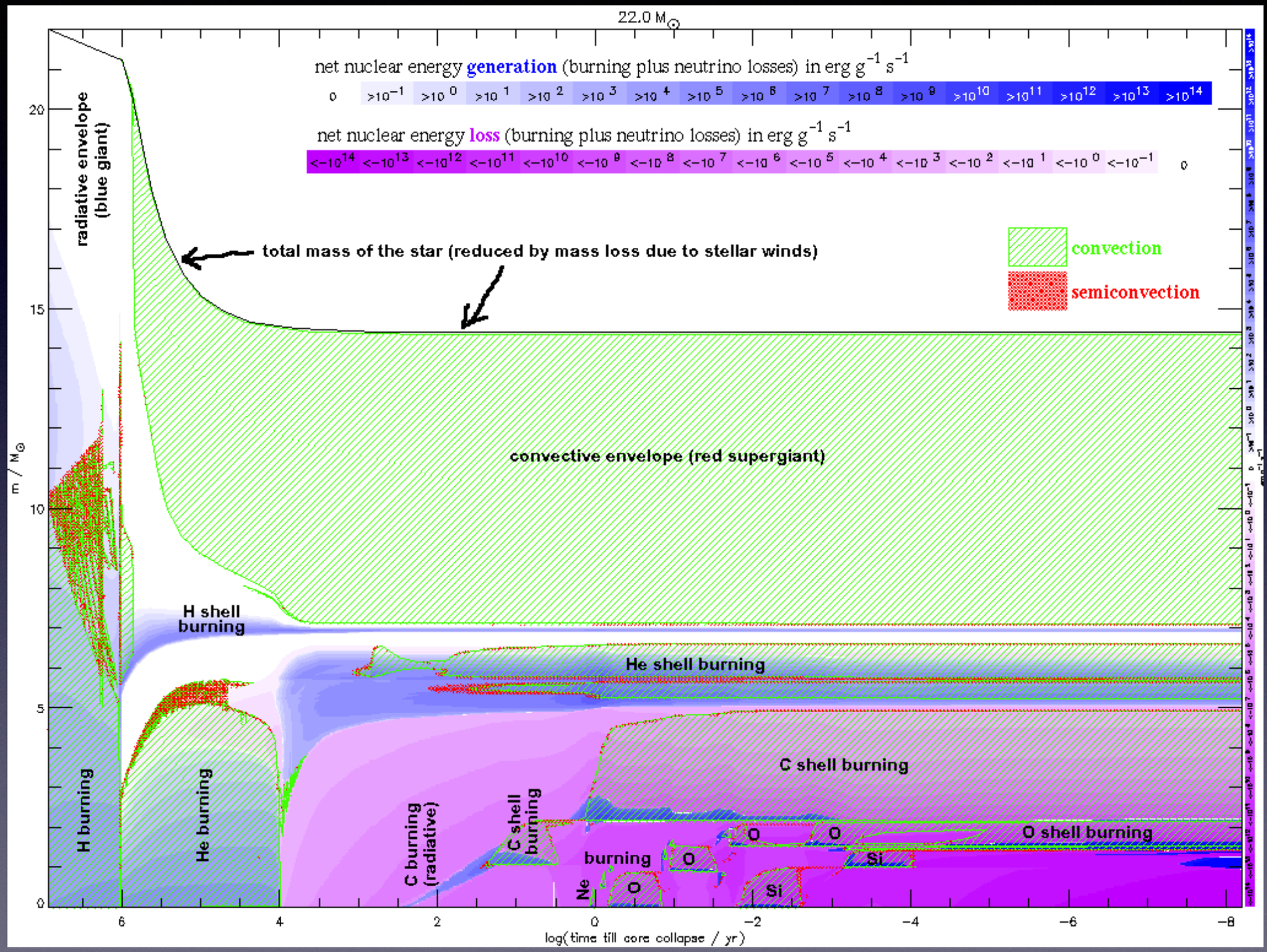
−1
4.4
4.2
4.0
3.8
3.6
3.4

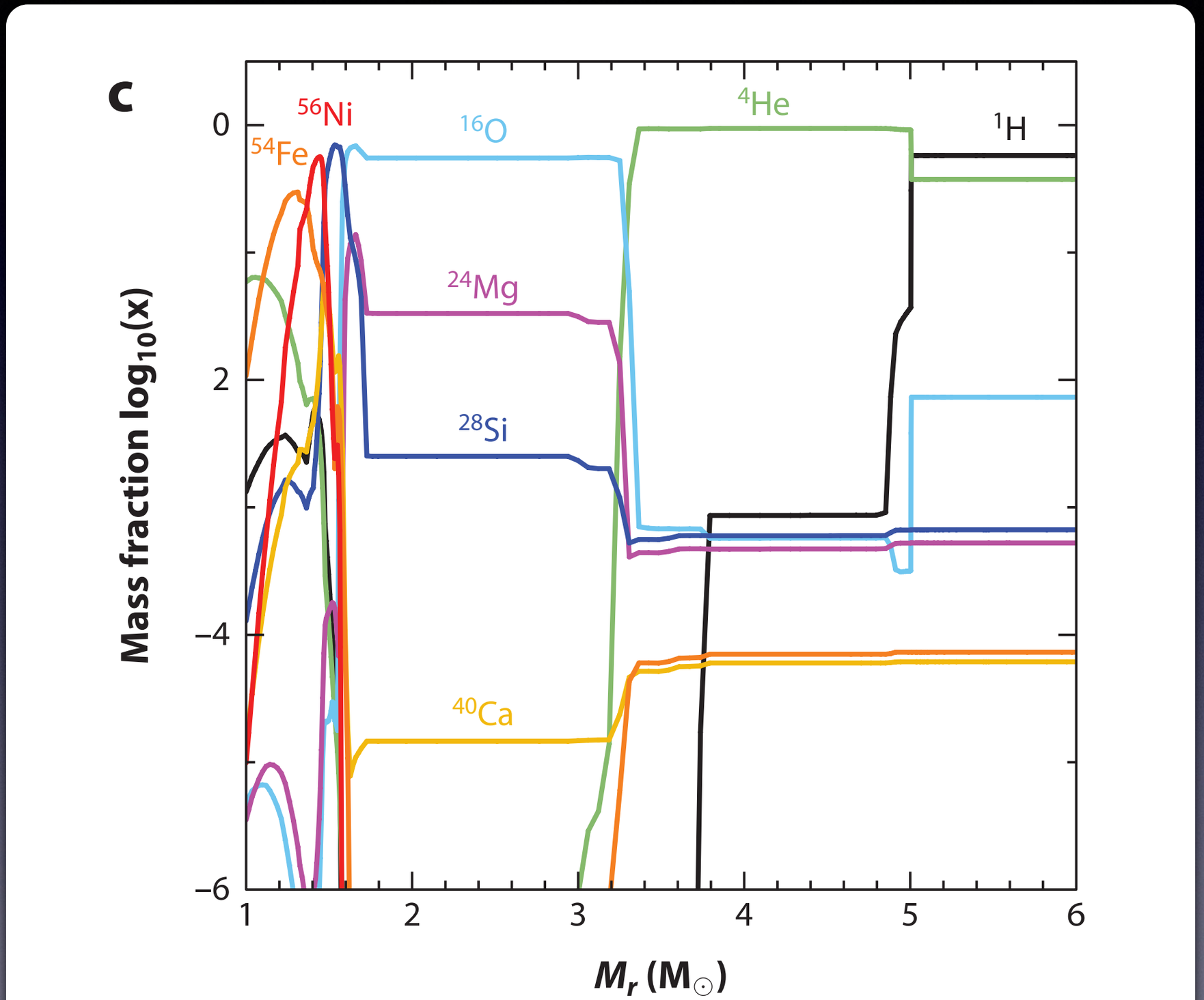

5.590170e+01 yr
log T
log ρ
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
0
2
4
6
8
10

“Kippenhahn diagram”



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

爆発直前の星の元素分布



Nomoto+13

まとめ

- **恒星進化の方程式**
  - 静水圧平衡 (運動方程式)
  - 状態方程式
  - エネルギー輸送
  - エネルギー生成 (核融合)
- **恒星進化の計算**
  - 各時間での平衡状態を求める
  - HR図上での進化 (星の明るさ、半径)
  - 星の中の元素組成の変化