Section 6.
恒星の構造 (2)

6.1 恒星進化の計算

6.2 ポリトロープモデル

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

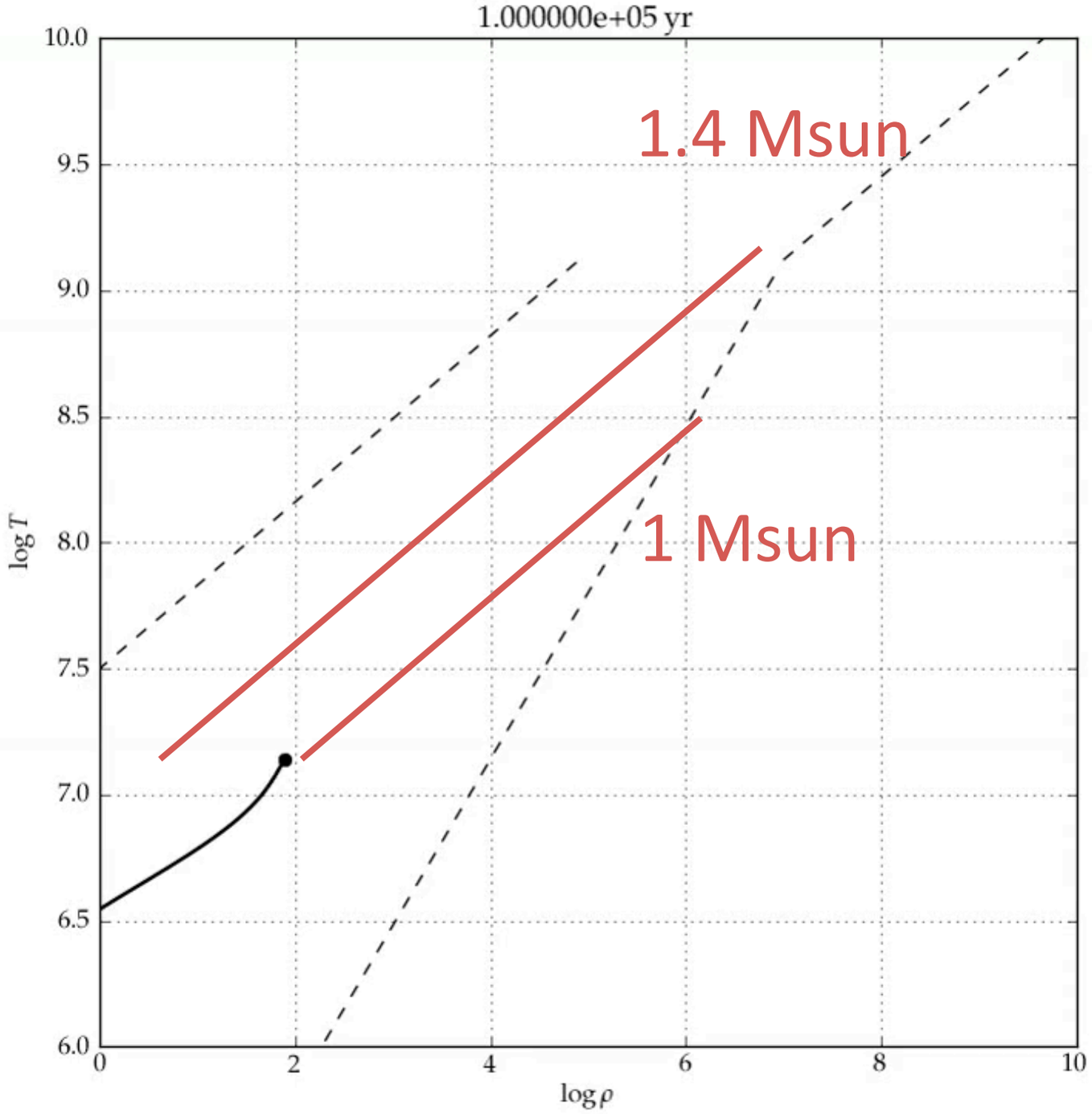
Stellar evolution calculations remain a basic tool of broad impact for astrophysics. New observations constantly test the models, even in 1D. The continued demand requires the construction of a general, modern stellar evolution code that combines the following advantages:

- **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

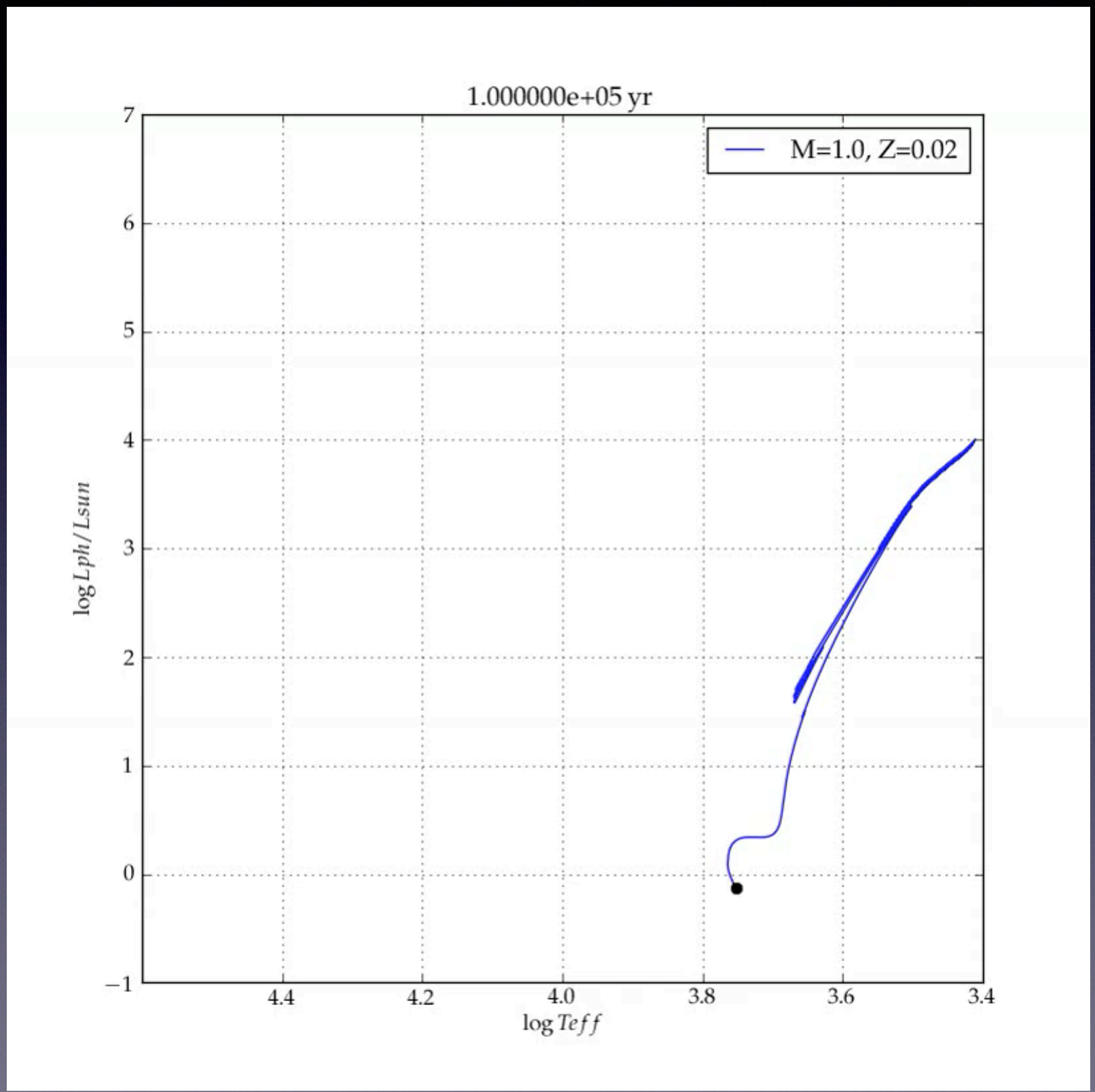
- 10 Aug 2016
  » **Documentation Archive**
- 19 Jun 2016
  » **Release 8845**
- 03 Feb 2016
  » **Release 8118**
- 29 Jan 2016
  » **New MESA SDK Version**
- 10 Jan 2016
  » **Summer School 2016**
- 27 Sep 2015
  » **Instrument Paper 3**
- 14 Sep 2015
  » **MESA-Web Updates**
- 08 Sep 2015
  » **New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

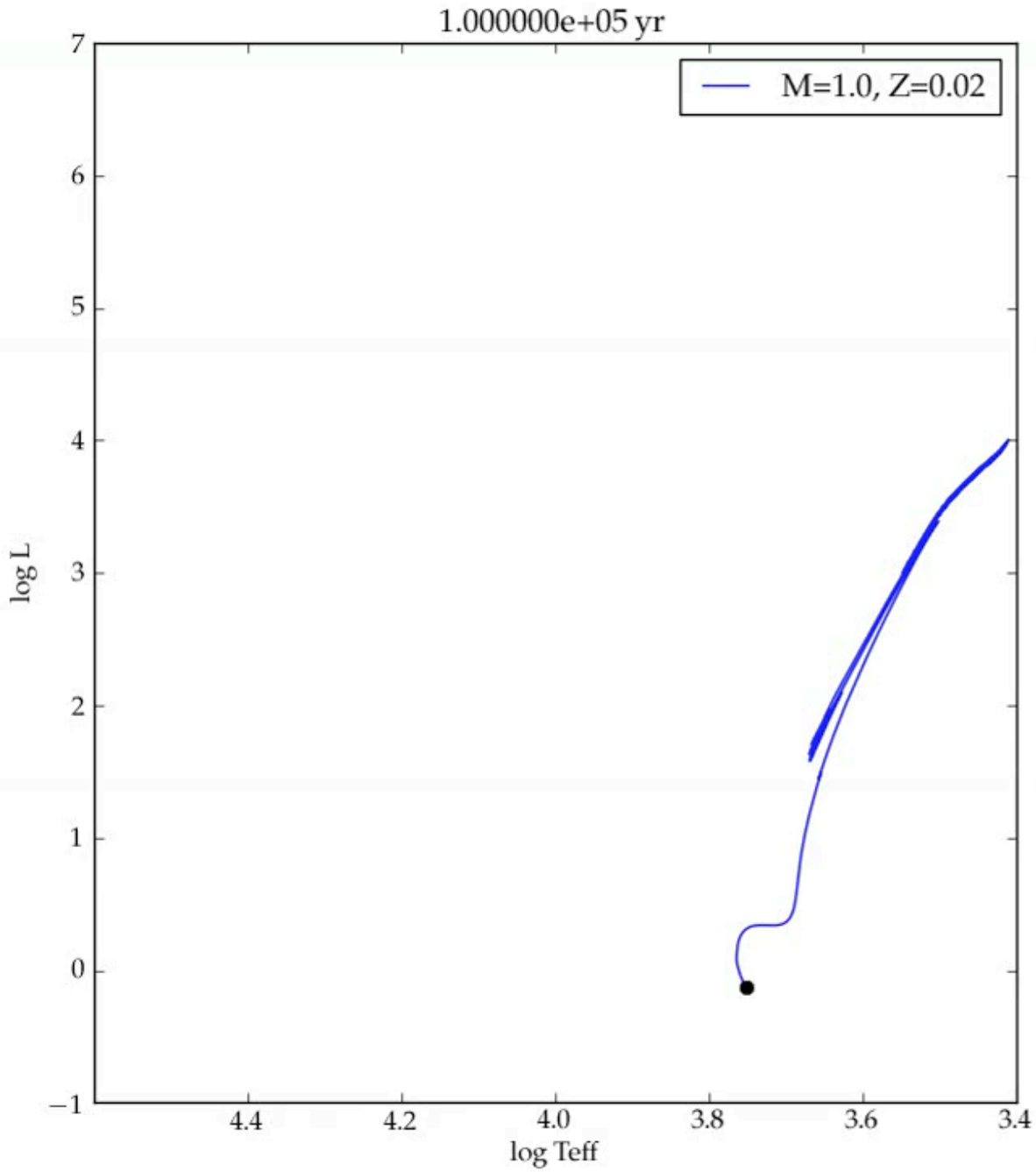
1 Msun (ρ-T)

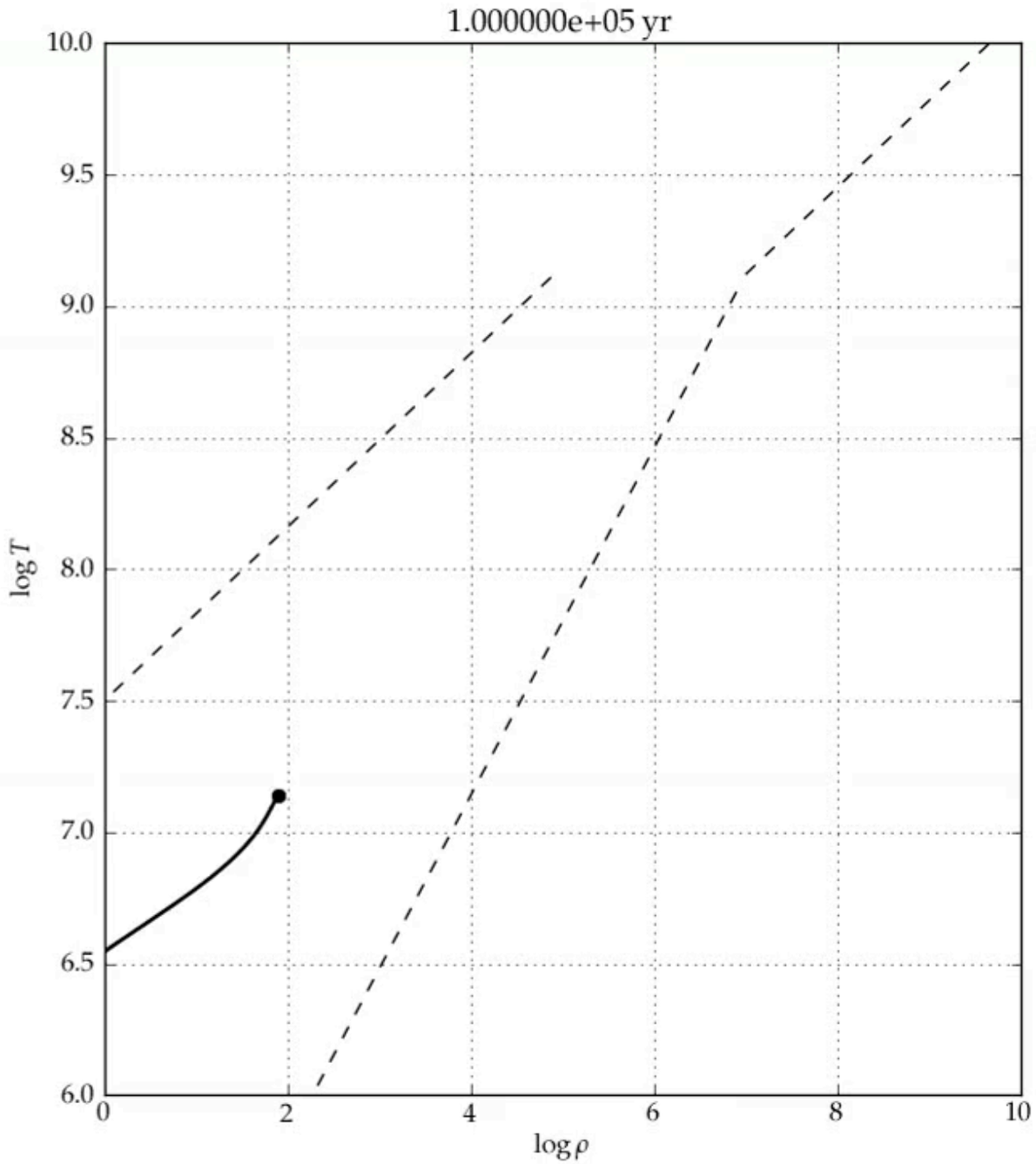


$T \sim M^{2/3} \rho^{1/3}$

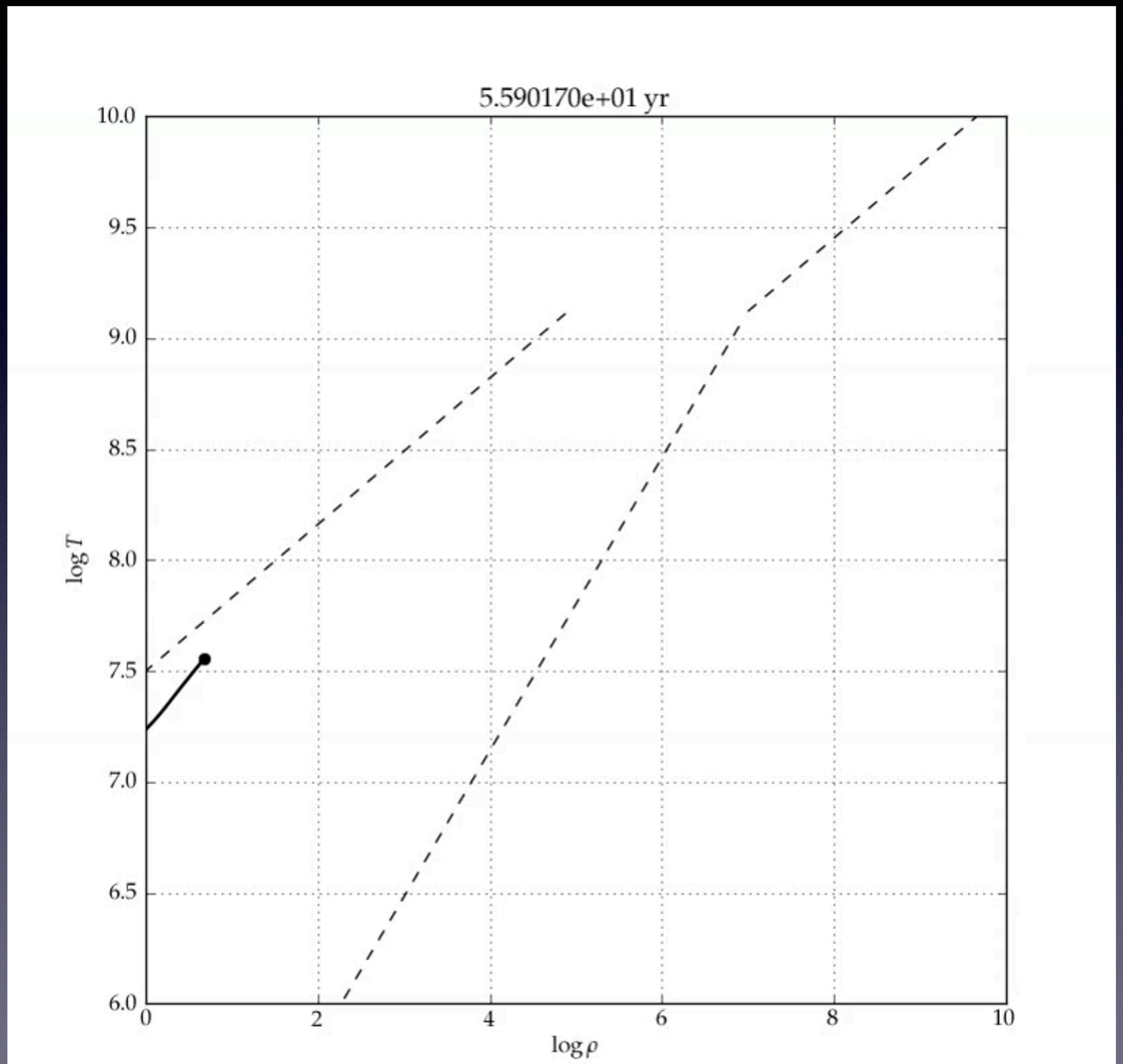
1 Msun (HR diagram)



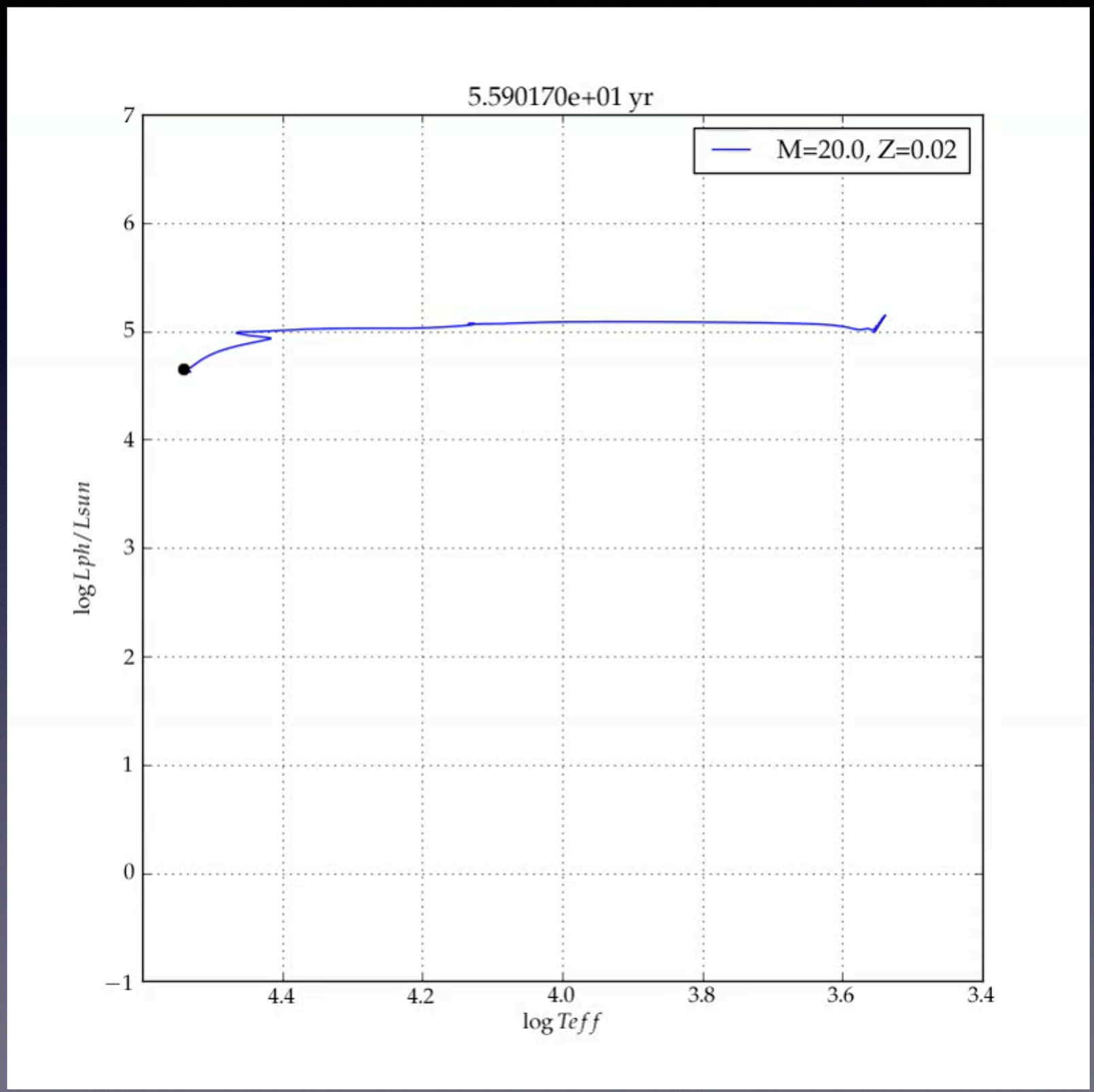

1.000000e+05 yr
M=1.0, Z=0.02
log L
log Teff
7
6
5
4
3
2
1
0
−1
4.4
4.2
4.0
3.8
3.6
3.4

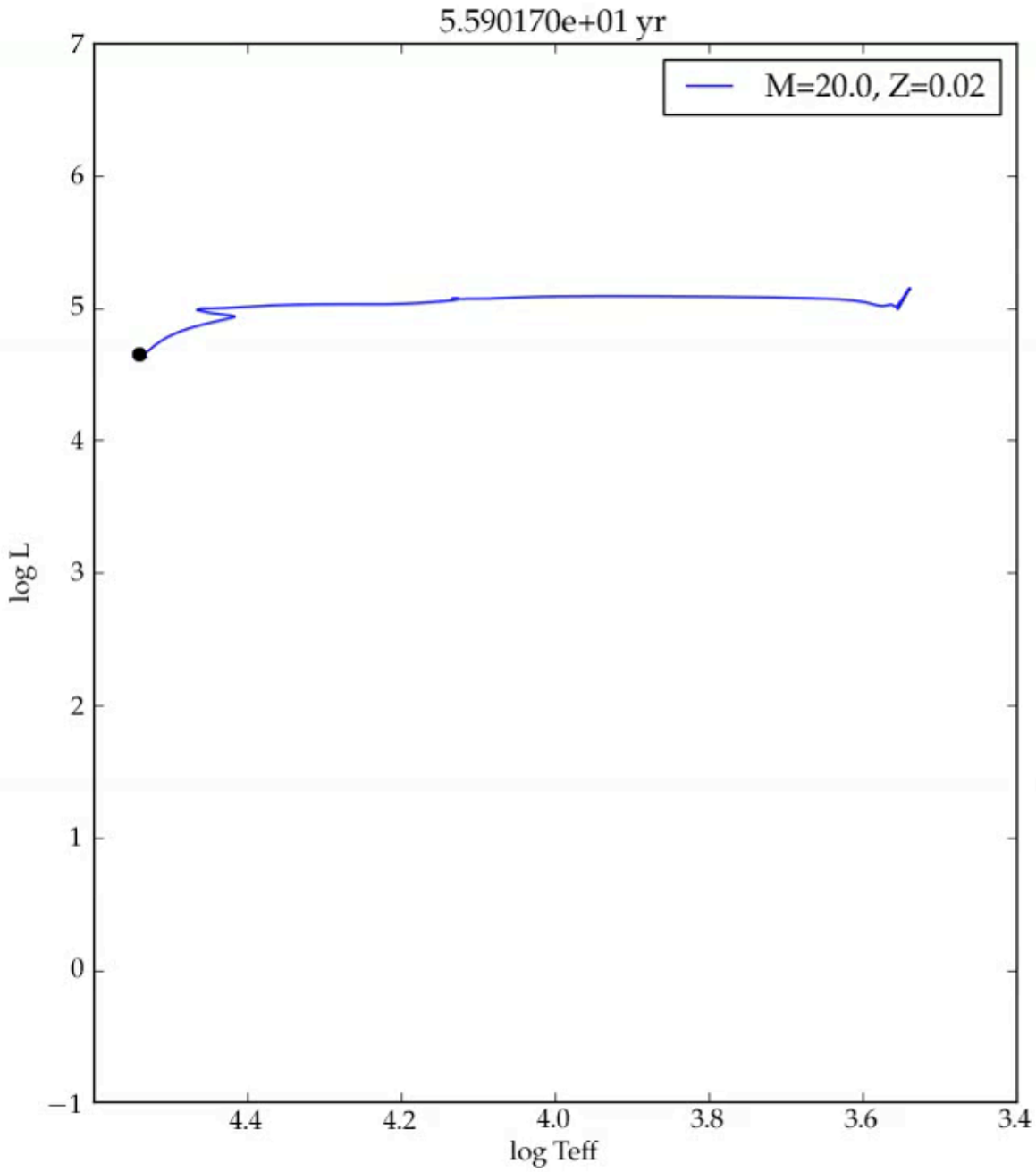

1.000000e+05 yr
log T
log ρ
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
0
2
4
6
8
10

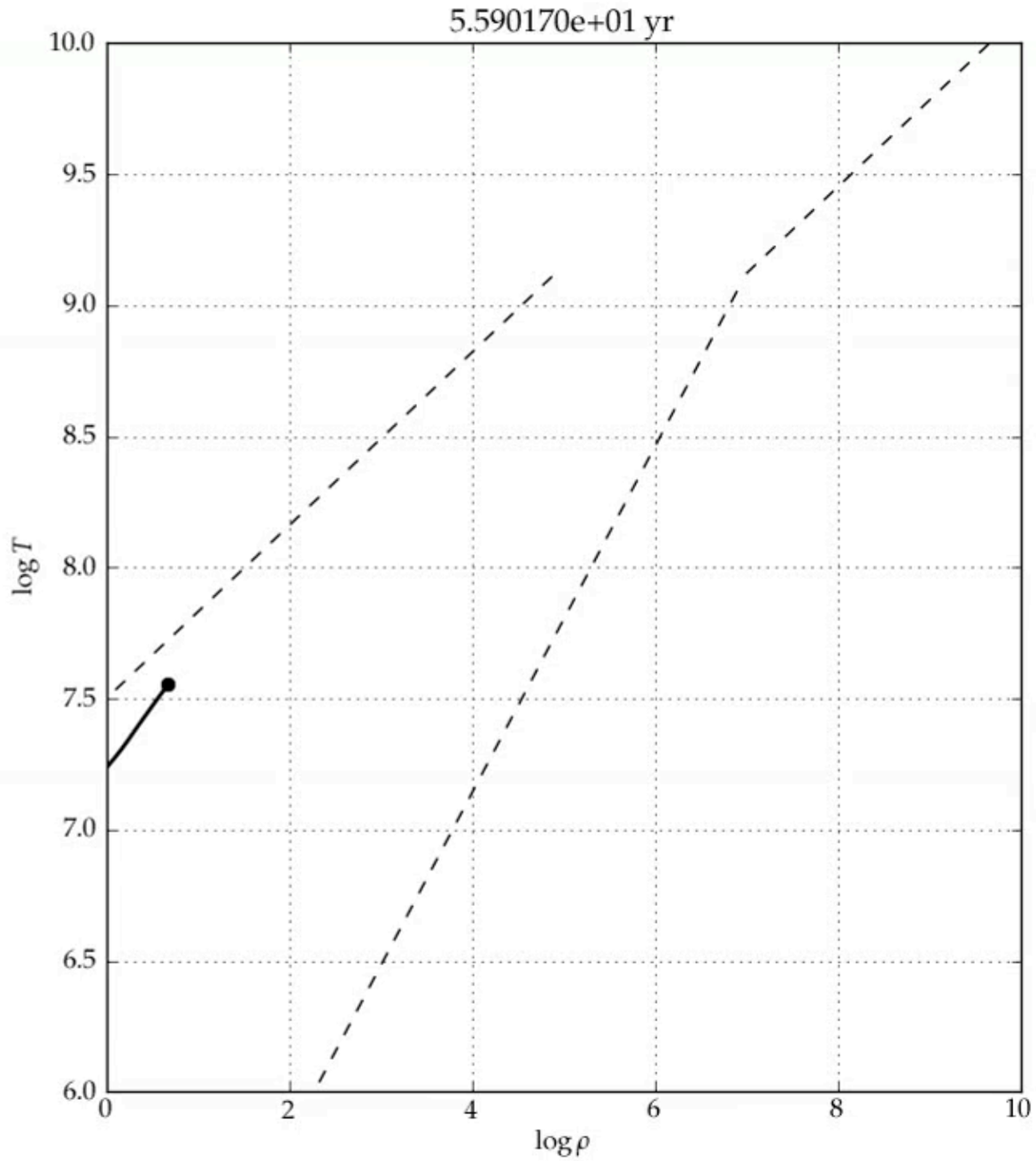
20 Msun (ρ-T)



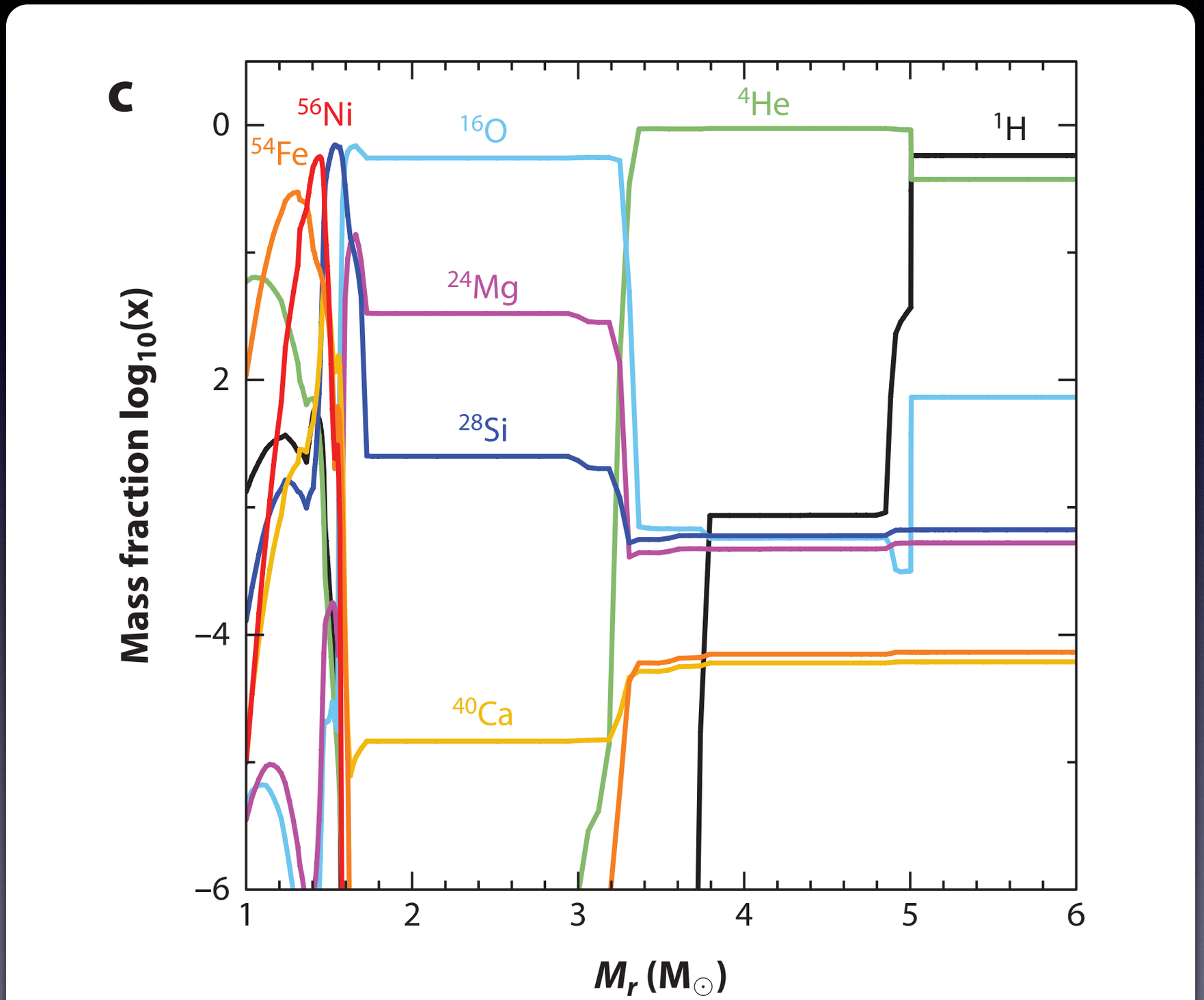
20 Msun (HR diagram)




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

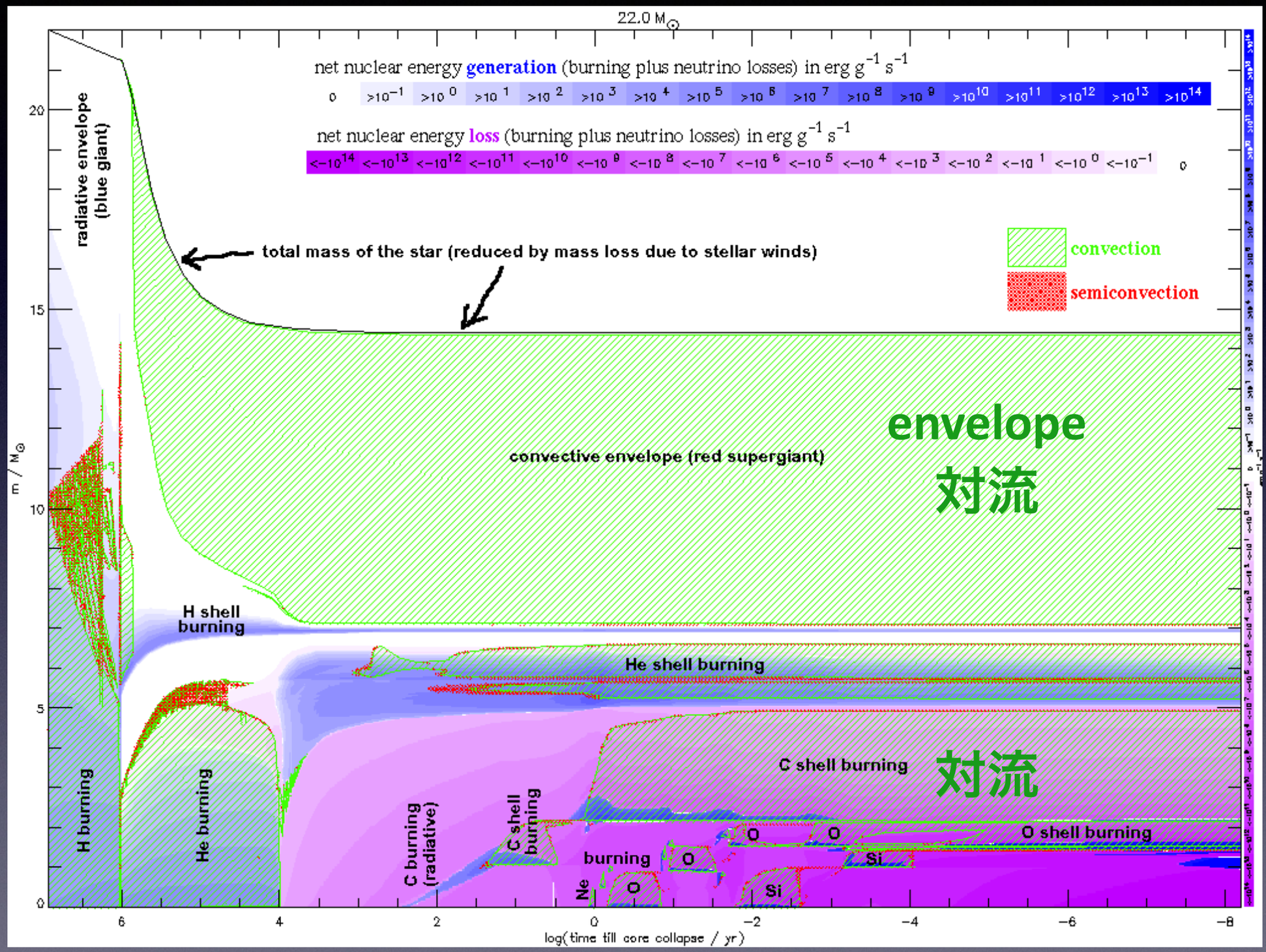

5.590170e+01 yr
log T
log ρ
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
0
2
4
6
8
10

爆発直前の星の元素分布



Nomoto+13

星の進化：“Kippenhahn diagram”



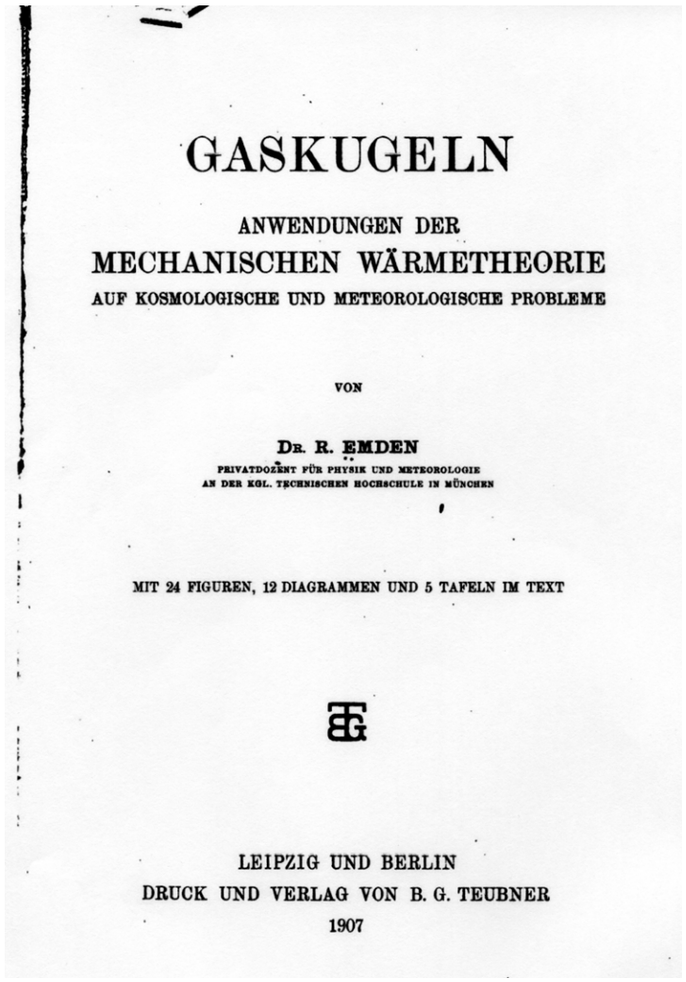
(C) A. Heger
https://2sn.org/stellarevolution/explain.gif

Section 6.
恒星の構造

6.1 恒星進化の計算

6.2 ポリトロープモデル

ポリトロープ　Lane (1870), Emden (1907)



GASKUGELN

ANWENDUNGEN DER
MECHANISCHEN WÄRMETHEORIE
AUF KOSMOLOGISCHE UND METEOROLOGISCHE PROBLEME

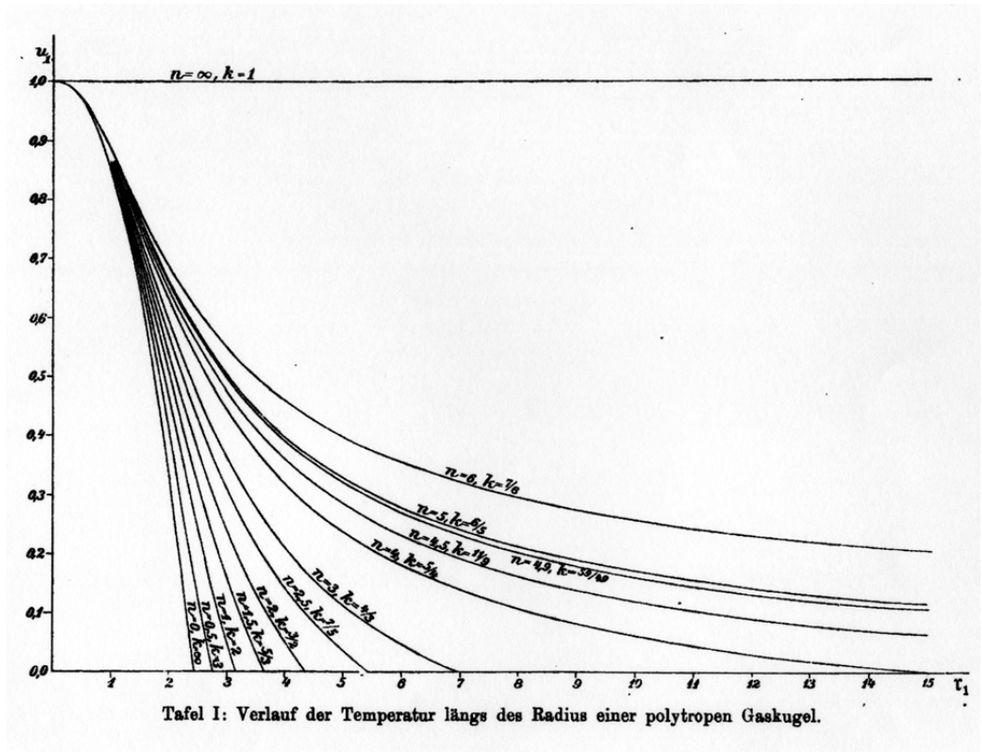
VON

DR. R. EMDEN
PRIVATDOZENT FÜR PHYSIK UND METEOROLOGIE
AN DER KGL. TECHNISCHEN HOCHSCHULE IN MÜNCHEN

MIT 24 FIGUREN, 12 DIAGRAMMEN UND 5 TAFELN IM TEXT

LEIPZIG UND BERLIN
DRUCK UND VERLAG VON B. G. TEUBNER
1907

図 13　エムデンの「ガス球論」の表紙（ [34] ）



Tafel I: Verlauf der Temperatur längs des Radius einer polytropen Gaskugel.

図 12　エムデンの無限の広がりを持つポリトロープ球内の相対的温度分布の計算例
パラメータは n はポリトロープ指数、k は比熱比 γ にあたる。[34]

木暮 (2011)

https://tenkyo.net/kaiho/pdf/2011_01/2011-01-03.pdf

現代天文学史

History of Modern Astronomy



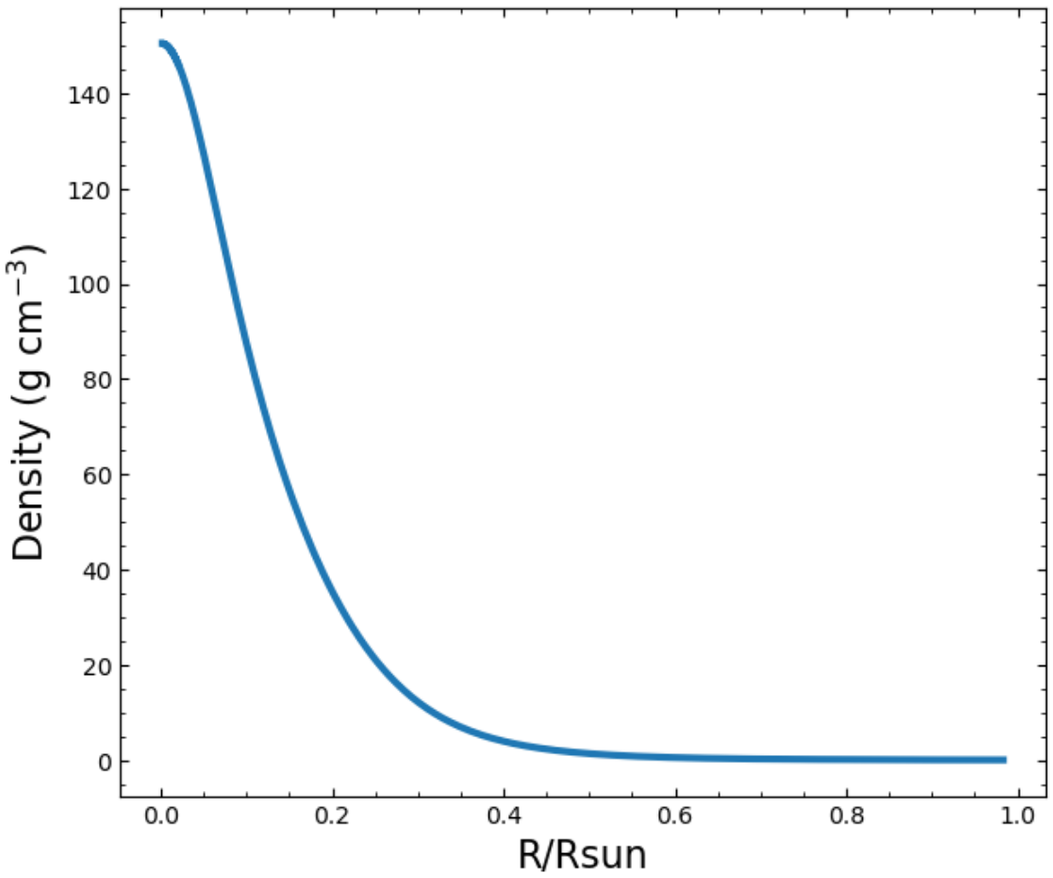


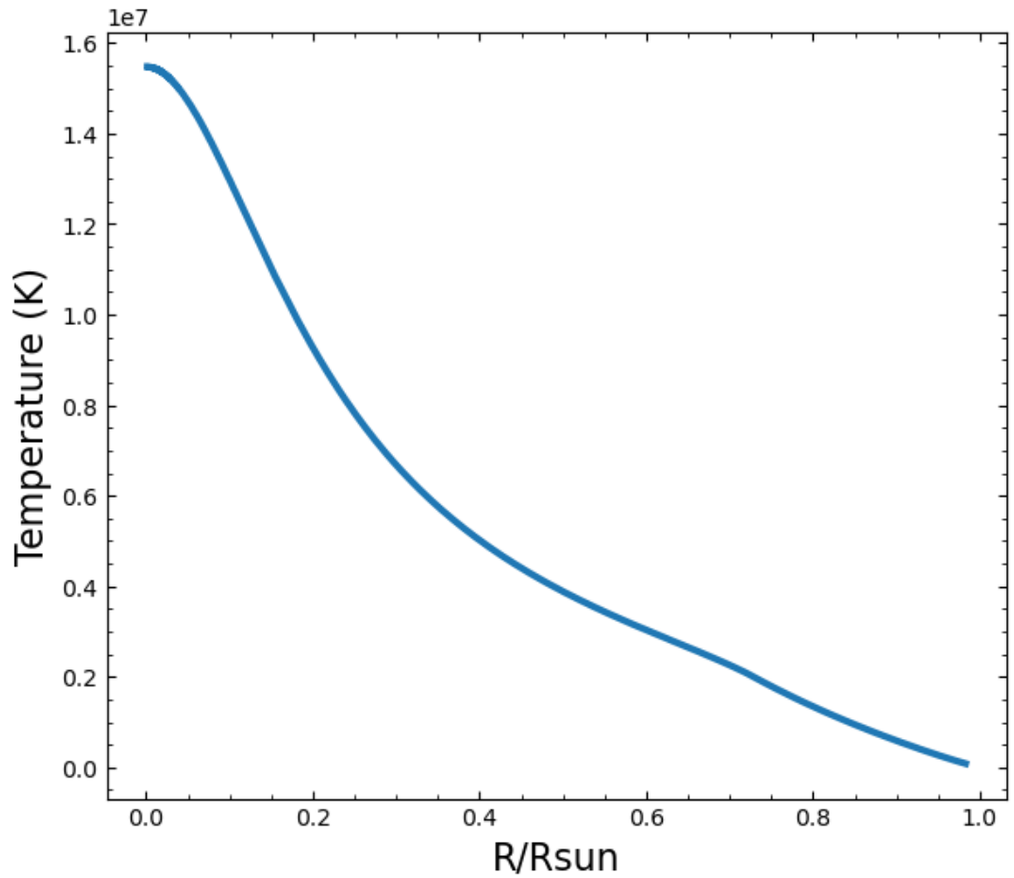
天体物理学の源流と開拓者たち

小暮智一
Tomokazu Kogure

京都大学学術出版会

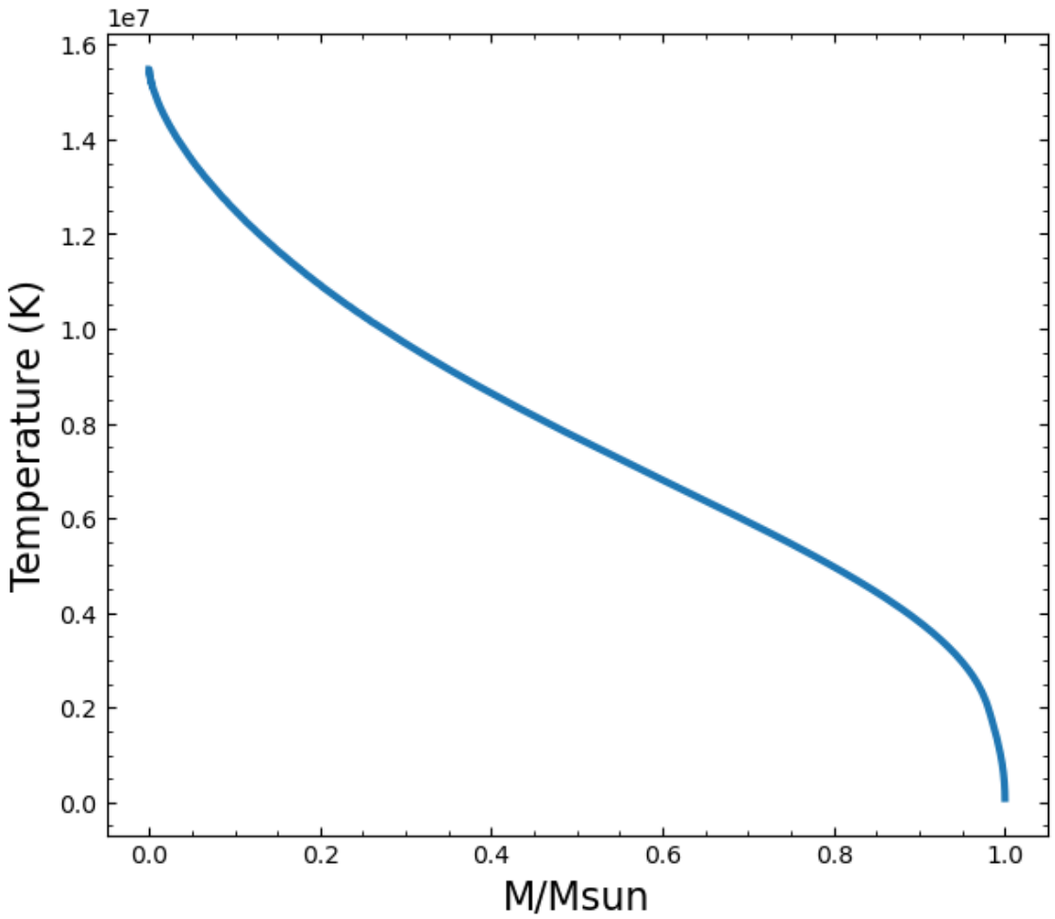
Standard Solar Model

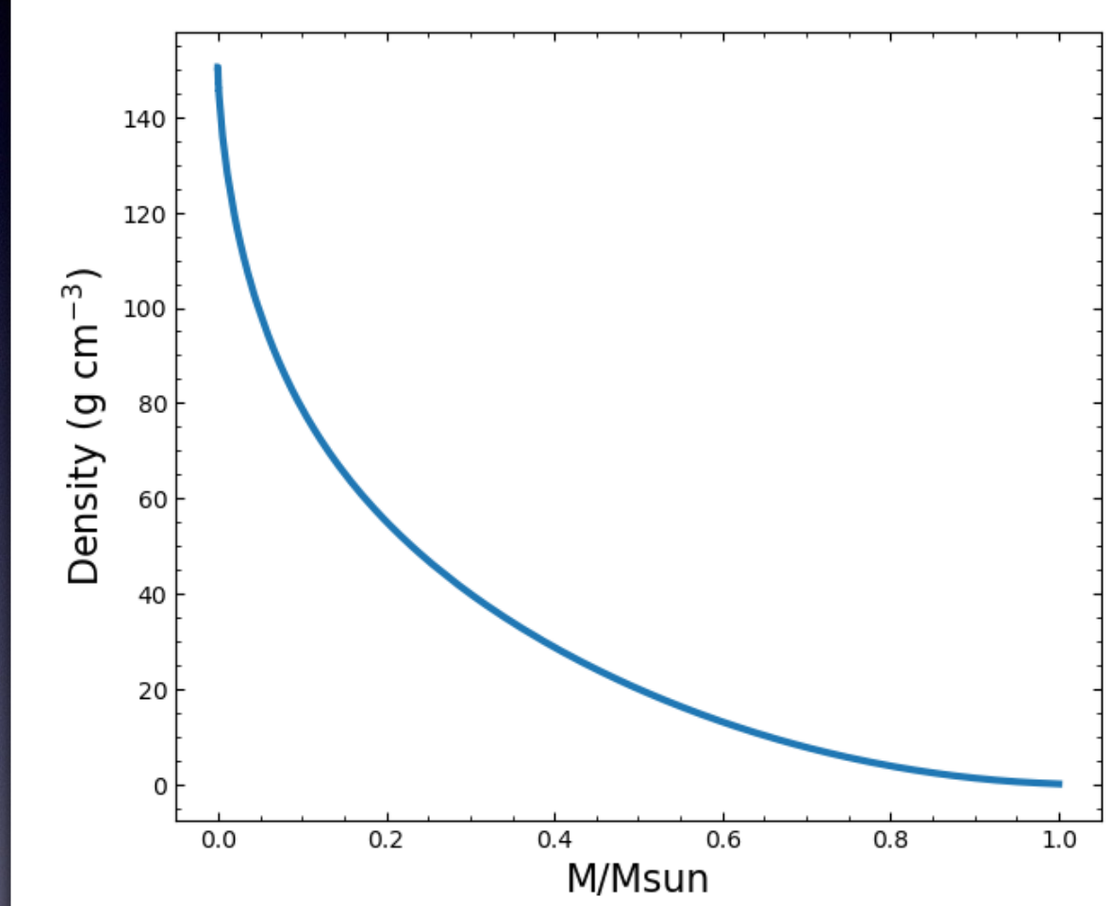




https://www.sns.ias.edu/~jnb/SNdata/sndata.html

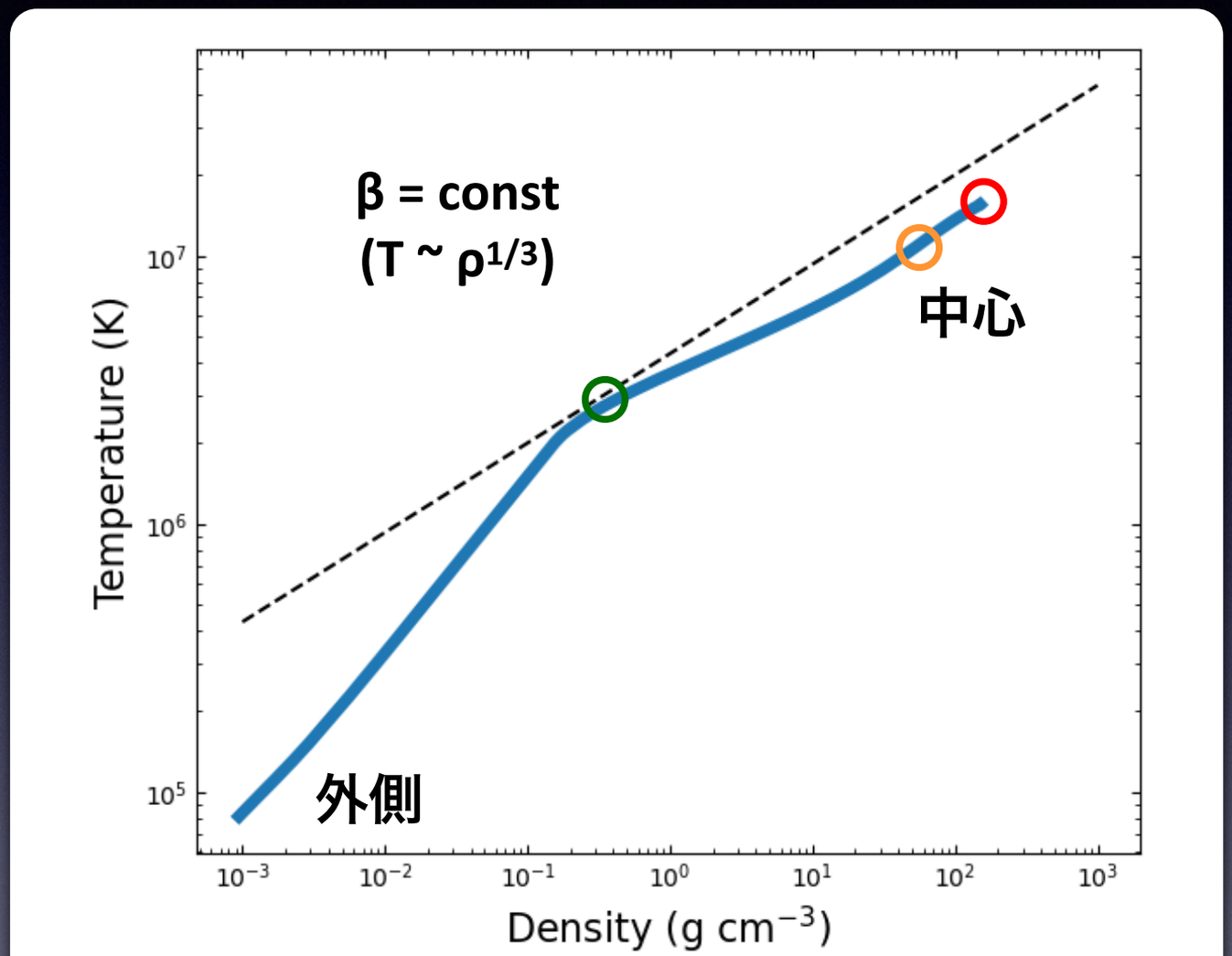
Standard Solar Model

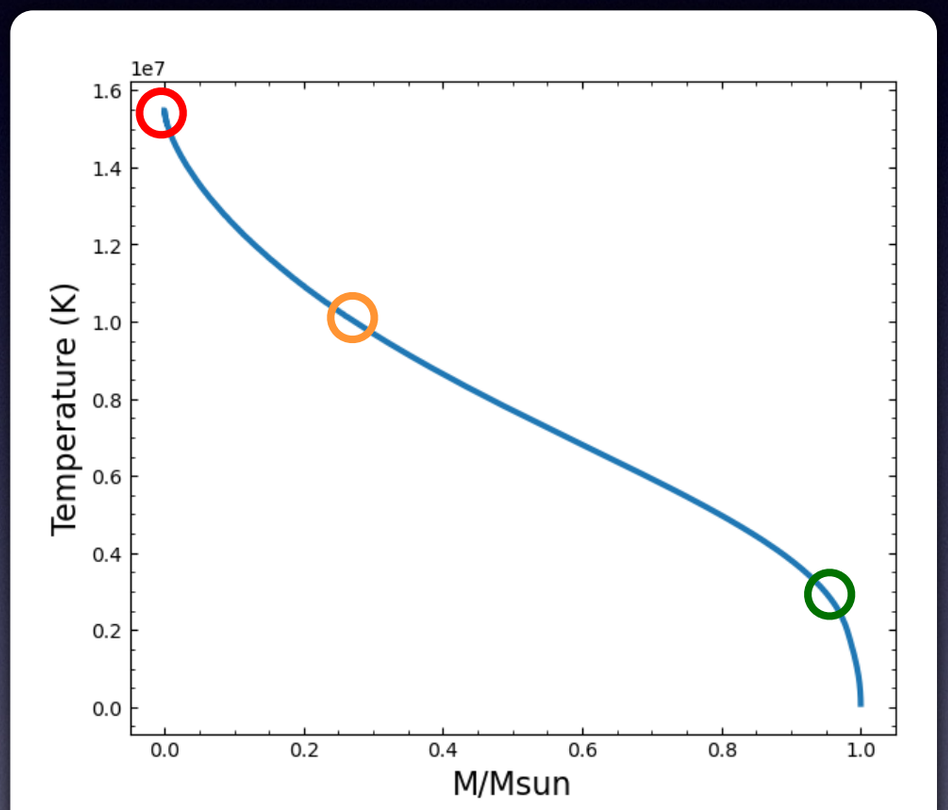




https://www.sns.ias.edu/~jnb/SNdata/sndata.html

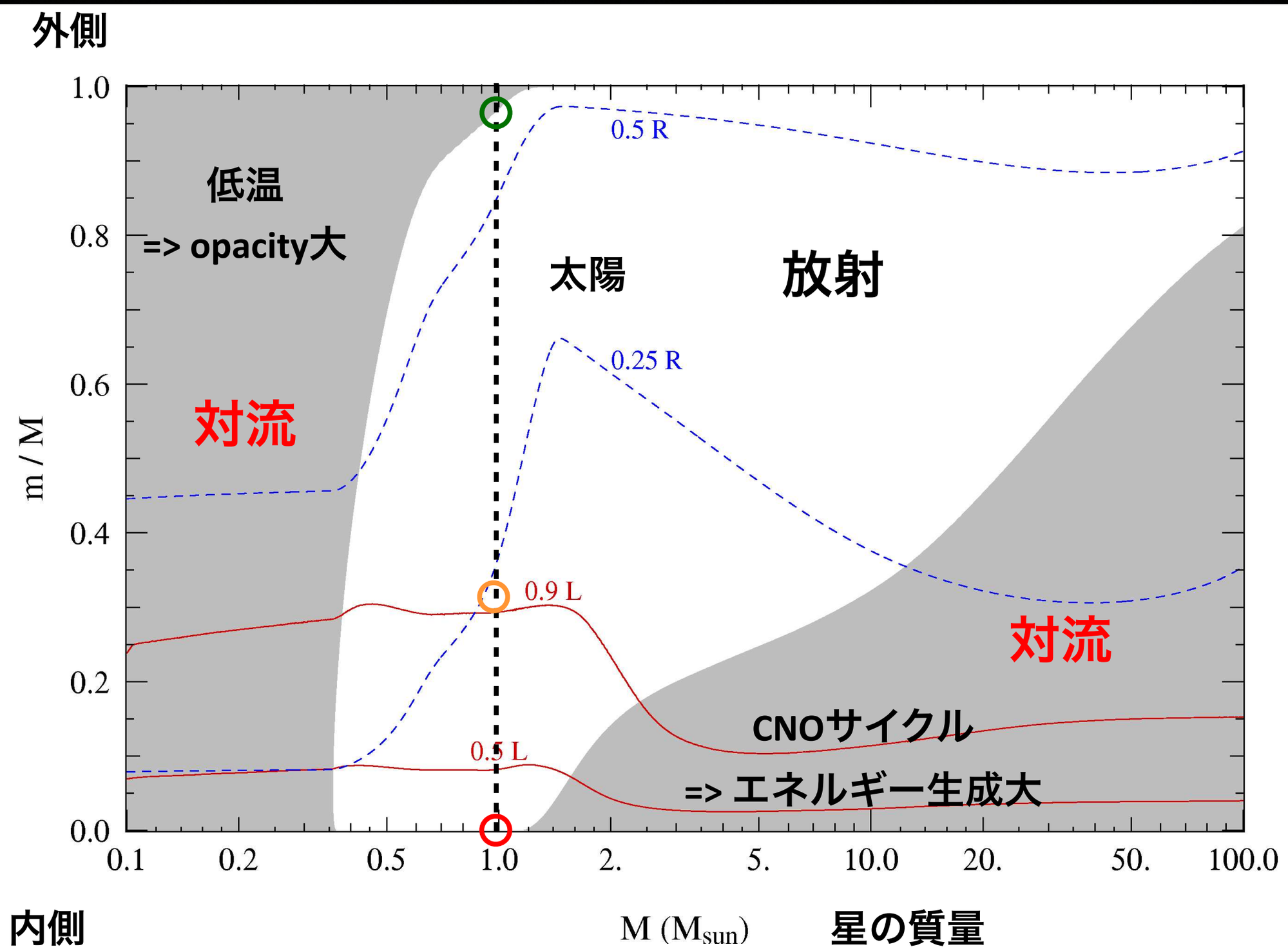
Standard Solar Model





https://www.sns.ias.edu/~jnb/SNdata/sndata.html

星内部のエネルギー輸送



Pols lecture note

レポート課題 5

5-1. レーンエムデン方程式を導け

5-2. n=1.5, 3の場合にレーンエムデン方程式を数値的に解け

(解いた方法も簡単に説明すること)

5-3. ポリトロープモデル (n=1.5, 3)の結果とStandard Solar Modelを比較し、考察せよ。

まとめ

- **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
- **ポリトロープモデル**
  - $P = K \rho^{1+1/n}$でかける場合
    - 縮退圧：EOS自体がこの形
    - 対流：星の構造がこの関係を満たす (断熱勾配)
    - エディントン標準モデル： ($\beta = P_{gas}/P = const$)