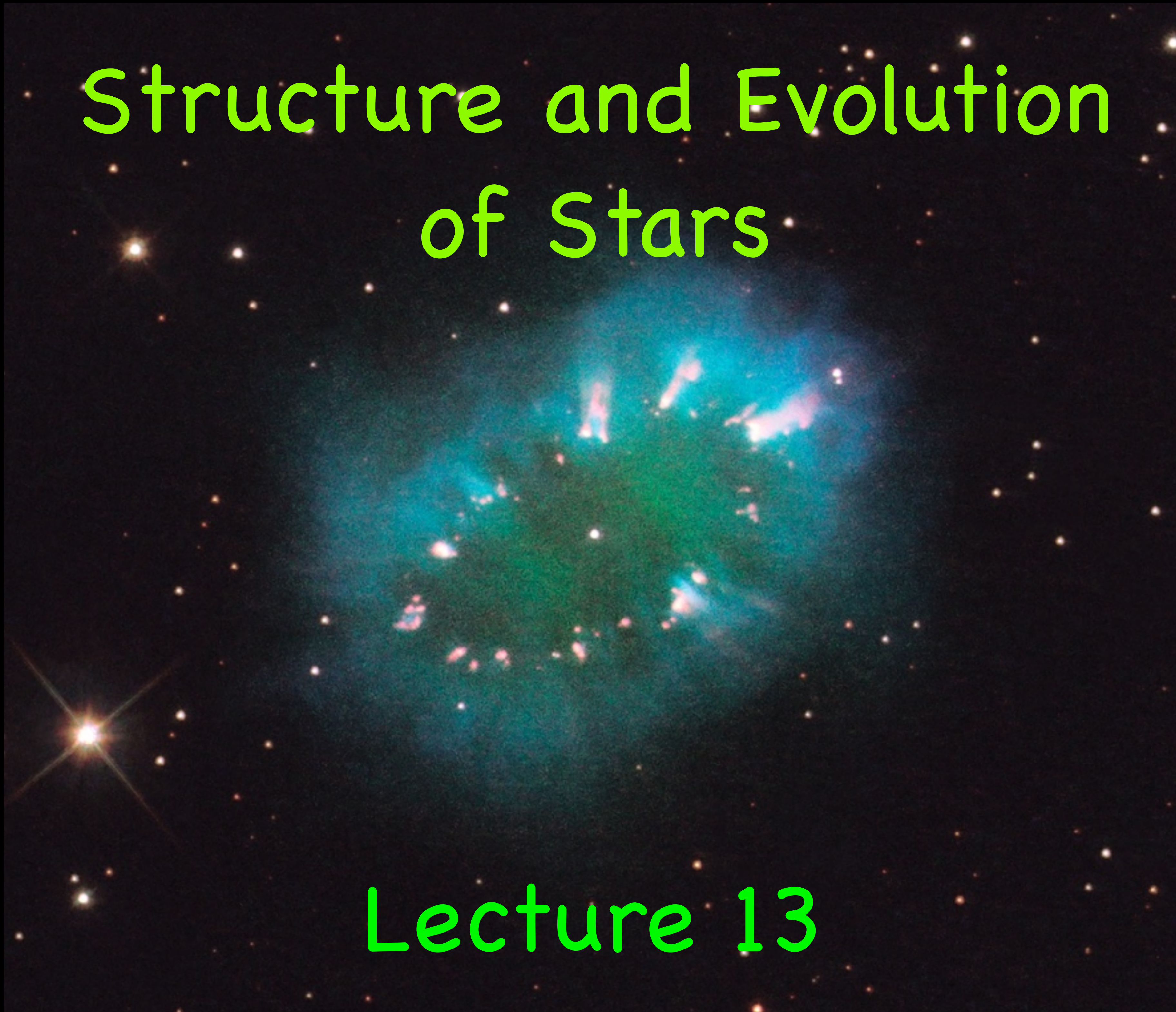
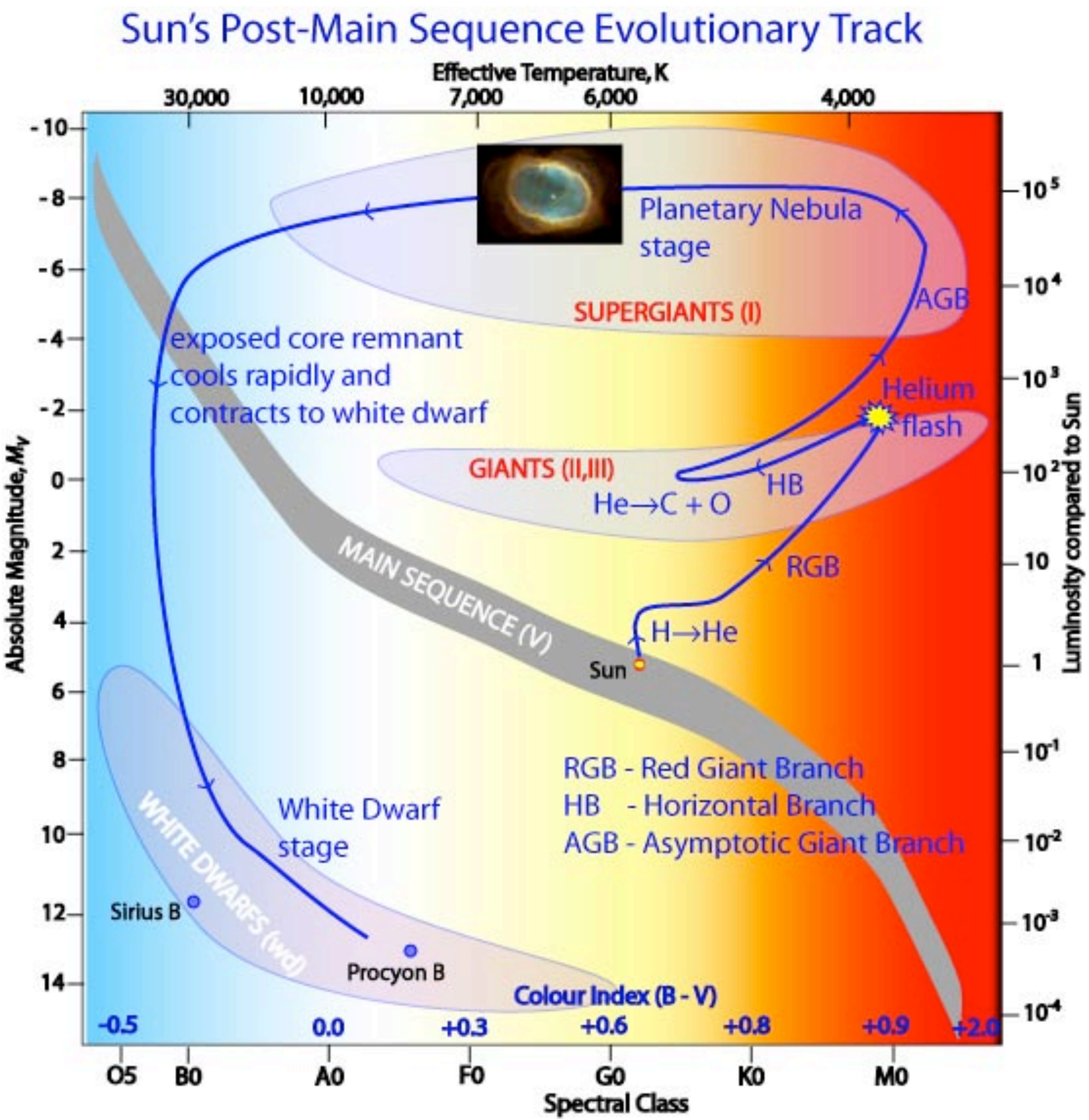
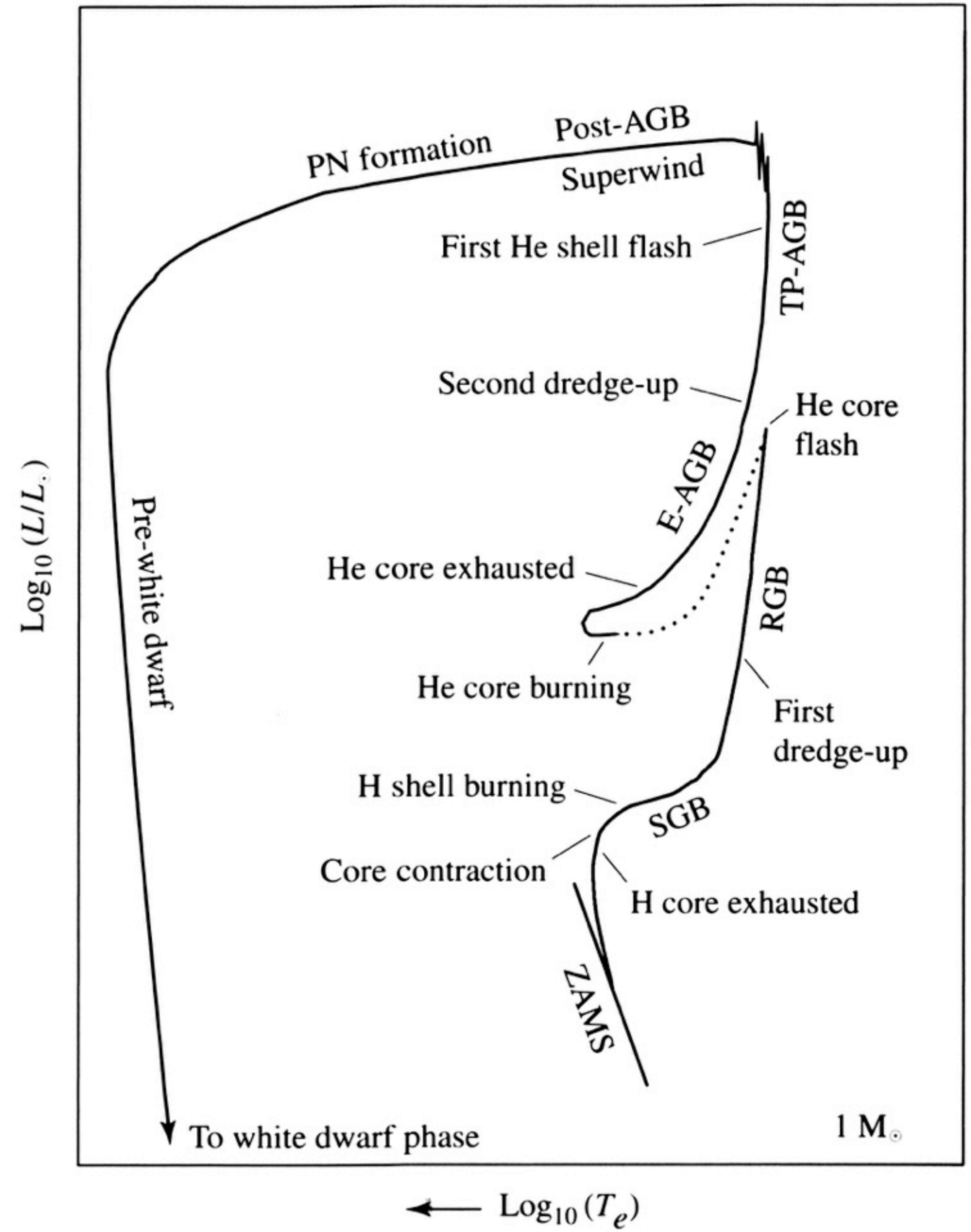
Structure and Evolution of Stars

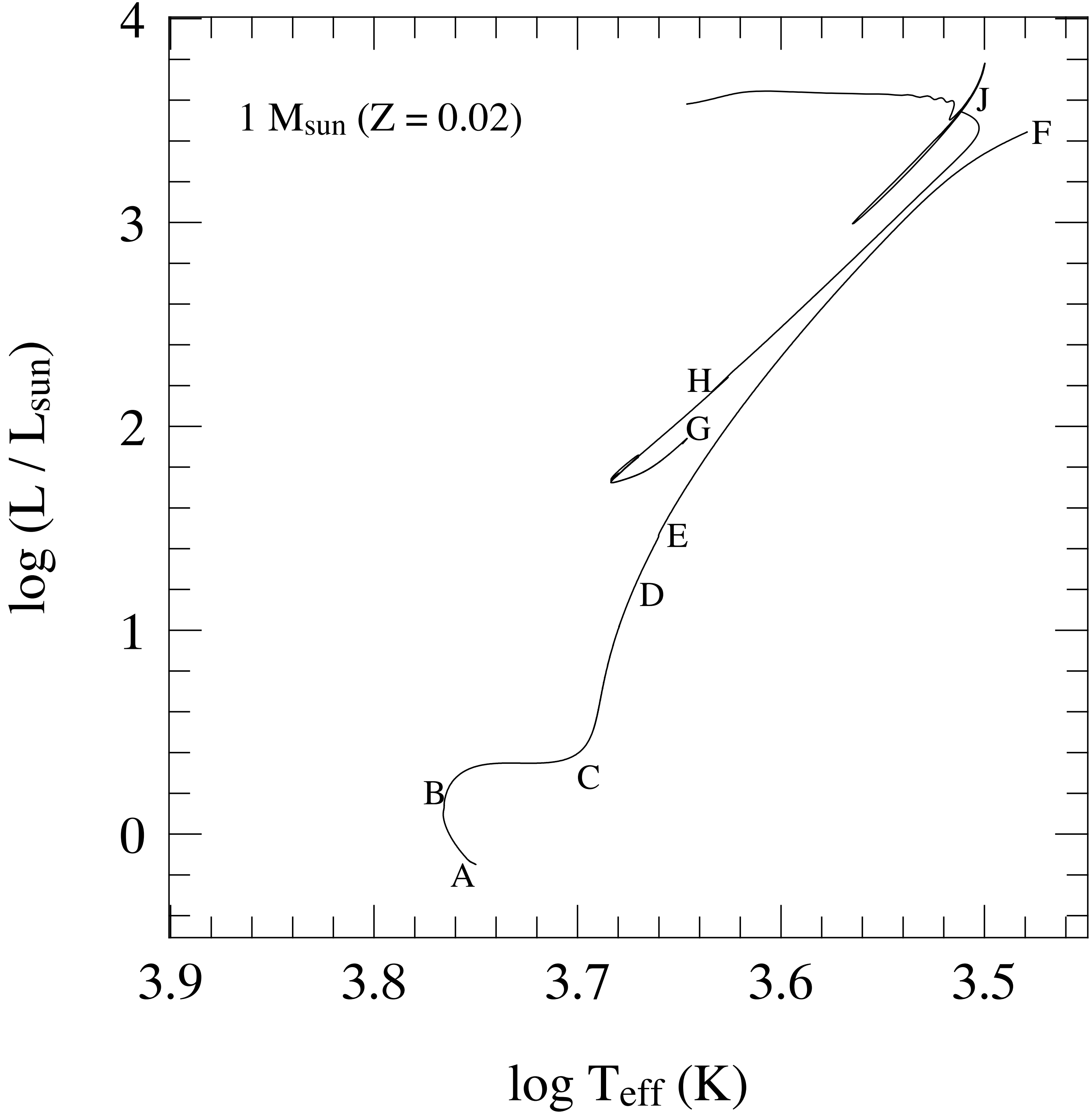


Lecture 13


Sun's Post-Main Sequence Evolutionary Track
Effective Temperature, K
30,000
10,000
7,000
6,000
4,000
Absolute Magnitude, M_V
-10
-8
-6
-4
-2
0
2
4
6
8
10
12
14
Luminosity compared to Sun
10^5
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
Planetary Nebula stage
AGB
SUPERGIANTS (I)
exposed core remnant cools rapidly and contracts to white dwarf
Helium flash
GIANTS (II,III)
HB
He→C + O
RGB
MAIN SEQUENCE (V)
H→He
Sun
RGB - Red Giant Branch
HB - Horizontal Branch
AGB - Asymptotic Giant Branch
White Dwarf stage
WHITE DWARFS (wd)
Sirius B
Procyon B
Colour Index (B - V)
-0.5
0.0
+0.3
+0.6
+0.8
+0.9
+2.0
O5
B0
A0
F0
G0
K0
M0
Spectral Class



Post-AGB
PN formation
Superwind
First He shell flash
TP-AGB
Second dredge-up
He core flash
E-AGB
He core exhausted
RGB
He core burning
First dredge-up
H shell burning
SGB
Core contraction
H core exhausted
ZAMS
Pre-white dwarf
To white dwarf phase
1 M⊙
Log10 (L/L⊙)
Log10 (Te)



1 Msun (Z = 0.02)
log (L / Lsun)
log Teff (K)
4
3
2
1
0
3.9
3.8
3.7
3.6
3.5
A
B
C
D
E
F
G
H
J

Why Do Low-Mass Stars Become Red Giants?

Richard J. Stancliffe[A,C], *Alessandro Chieffi*[A,B], *John C. Lattanzio*[A], *and Ross P. Church*[A]

[A] Centre for Stellar and Planetary Astrophysics, Monash University, PO Box 28M, Victoria 3800, Australia
[B] INAF–Istituto di Astrofisica, Spaziale e Fisica Cosmica, Via Fosso del Cavaliere, Rome, Italy
[C] Email: Richard.Stancliffe@sci.monash.edu.au

Abstract: We revisit the problem of why stars become red giants. We modify the physics of a standard stellar evolution code in order to determine what does and what does not contribute to a star becoming a red giant. In particular, we have run tests to try to separate the effects of changes in the mean molecular weight and in the energy generation. The implications for why stars become red giants are discussed. We find that while a change in the mean molecular weight is necessary (but not sufficient) for a $1\,M_\odot$ star to become a red giant, this is not the case in a star of $5\,M_\odot$. It therefore seems that there may be more than one way to make a giant.

Keywords: stars: evolution

1 Introduction

The question 'why do stars become red giants?' is perhaps one of the longest standing problems in stellar astrophysics. In a recent paper Sugimoto & Fujimoto (2000) provided a long list of work on the subject, with publication dates spanning over four decades. The problem has been approached from many different angles, from considerations of polytropic solutions (e.g. Eggleton & Cannon 1991) to detailed numerical modelling (e.g Iben 1993). Despite all the investigation into the subject, the question has yet to receive an answer that is satisfyingly simple and sufficiently rigourous[1]. There is still no consensus on why stars become red giants. Theories to explain the phenomenon are many and varied. Some assert that a 'softening' of the effec- that only a strong gravitational field could produce properties similar to red giants. Subsequently, Weiss (1983) extended their work to cover stars in the mass range $1 \leq M/M_\odot \leq 8$. Using polytropic models, Frost & Lattanzio (1992) later demonstrated that this could not be the sole cause.

Renzini et al. (1992) suggested that stars become red giants because of a thermal instability in their envelopes. In their view, expansion is initially driven by the envelope maintaining thermal equilibrium in response to increasing luminosity from the core. This expansion leads to local cooling and the recombination of heavy elements. An increase in the opacity results, trapping energy in the envelope. This leads to a runaway expansion that brings the star to the red giant branch. However, Iben (1993) subsequently

1 Introduction

The question 'why do stars become red giants?' is perhaps one of the longest standing problems in stellar astrophysics. In a recent paper Sugimoto & Fujimoto (2000) provided a long list of work on the subject, with publication dates spanning over four decades. The problem has been approached from many different angles, from considerations of polytropic solutions (e.g. Eggleton & Cannon 1991) to detailed numerical modelling (e.g Iben 1993). Despite all the investigation into the subject, the question has yet to receive an answer that is satisfyingly simple and sufficiently rigourous[1]. There is still no consensus on why stars become red giants. Theories to explain the phenomenon are many and varied. Some assert that a 'softening' of the effec-

Why Do Low-Mass Stars Become Red Giants?

Richard J. Stancliffe[A,C], *Alessandro Chieffi*[A,B], *John C. Lattanzio*[A], *and Ross P. Church*[A]

[A] Centre for Stellar and Planetary Astrophysics, Monash University, PO Box 28M, Victoria 3800, Australia
[B] INAF–Istituto di Astrofisica, Spaziale e Fisica Cosmica, Via Fosso del Cavaliere, Rome, Italy
[C] Email: Richard.Stancliffe@sci.monash.edu.au

Abstract: We revisit the problem of why stars become red giants. We modify the physics of a standard stellar evolution code in order to determine what does and what does not contribute to a star becoming a red giant. In particular, we have run tests to try to separate the effects of changes in the mean molecular weight and in the energy generation. The implications for why stars become red giants are discussed. We find that while a change in the mean molecular weight is necessary (but not sufficient) for a $1\,M_\odot$ star to become a red giant, this is not the case in a star of $5\,M_\odot$. It therefore seems that there may be more than one way to make a giant.

Keywords: stars: evolution

1 Introduction

The question 'why do stars become red giants?' is perhaps one of the longest standing problems in stellar astrophysics. In a recent paper Sugimoto & Fujimoto (2000) provided a long list of work on the subject, with publication dates spanning over four decades. The problem has been approached from many different angles, from considerations of polytropic solutions (e.g. Eggleton & Cannon 1991) to detailed numerical modelling (e.g Iben 1993). Despite all the investigation into the subject, the question has yet to receive an answer that is satisfyingly simple and sufficiently rigourous[1]. There is still no consensus on why stars become red giants. Theories to explain the phenomenon are many and varied. Some assert that a 'softening' of the effec-

that only a strong gravitational field could produce properties similar to red giants. Subsequently, Weiss (1983) extended their work to cover stars in the mass range $1 \leq M/M_\odot \leq 8$. Using polytropic models, Frost & Lattanzio (1992) later demonstrated that this could not be the sole cause.

Renzini et al. (1992) suggested that stars become red giants because of a thermal instability in their envelopes. In their view, expansion is initially driven by the envelope maintaining thermal equilibrium in response to increasing luminosity from the core. This expansion leads to local cooling and the recombination of heavy elements. An increase in the opacity results, trapping energy in the envelope. This leads to a runaway expansion that brings the star to the red giant branch. However, Iben (1993) subsequently

P. Church[A]

[A] Centre for Stellar and Planetary Astrophysics, Monash University, PO Box 28M, Victoria 3800, Australia
[B] INAF–Istituto di Astrofisica, Spaziale e Fisica Cosmica, Via Fosso del Cavaliere, Rome, Italy
[C] Email: Richard.Stancliffe@sci.monash.edu.au

Abstract: We revisit the problem of why stars become red giants. We modify the physics of a standard stellar evolution code in order to determine what does and what does not contribute to a star becoming a red giant. In particular, we have run tests to try to separate the effects of changes in the mean molecular weight and in the energy generation. The implications for why stars become red giants are discussed. We find that while a change in the mean molecular weight is necessary (but not sufficient) for a 1 $M_\odot$ star to become a red giant, this is not the case in a star of 5 $M_\odot$. It therefore seems that there may be more than one way to make a giant.

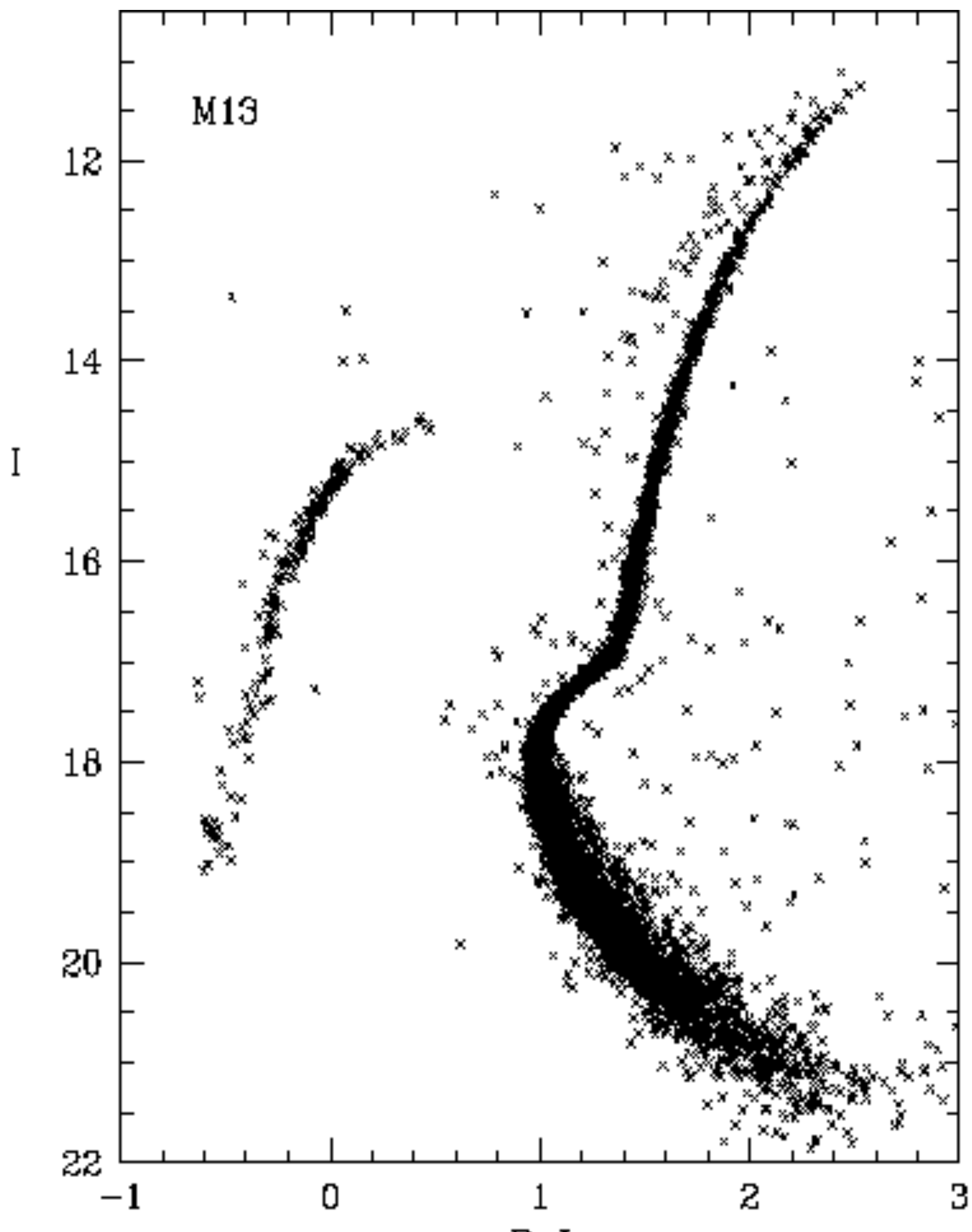
Keywords: stars: evolution

Introduction

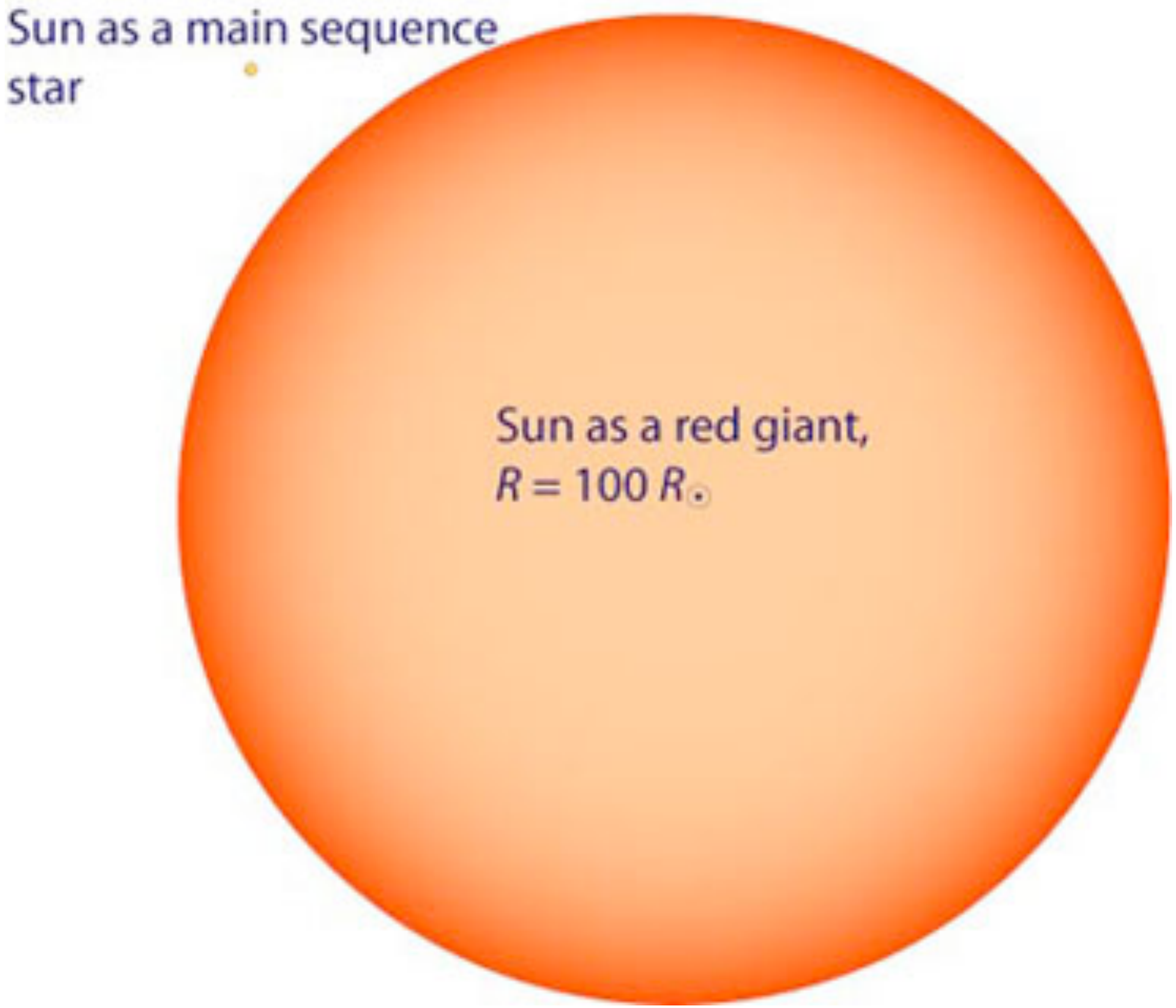
e question 'why do stars become red giants?' is pers one of the longest standing problems in stellar rophysics. In a recent paper Sugimoto & Fujimoto 00) provided a long list of work on the subject, with lication dates spanning over four decades. The blem has been approached from many different an-, from considerations of polytropic solutions (e.g. gleton & Cannon 1991) to detailed numerical moding (e.g Iben 1993). Despite all the investigation into

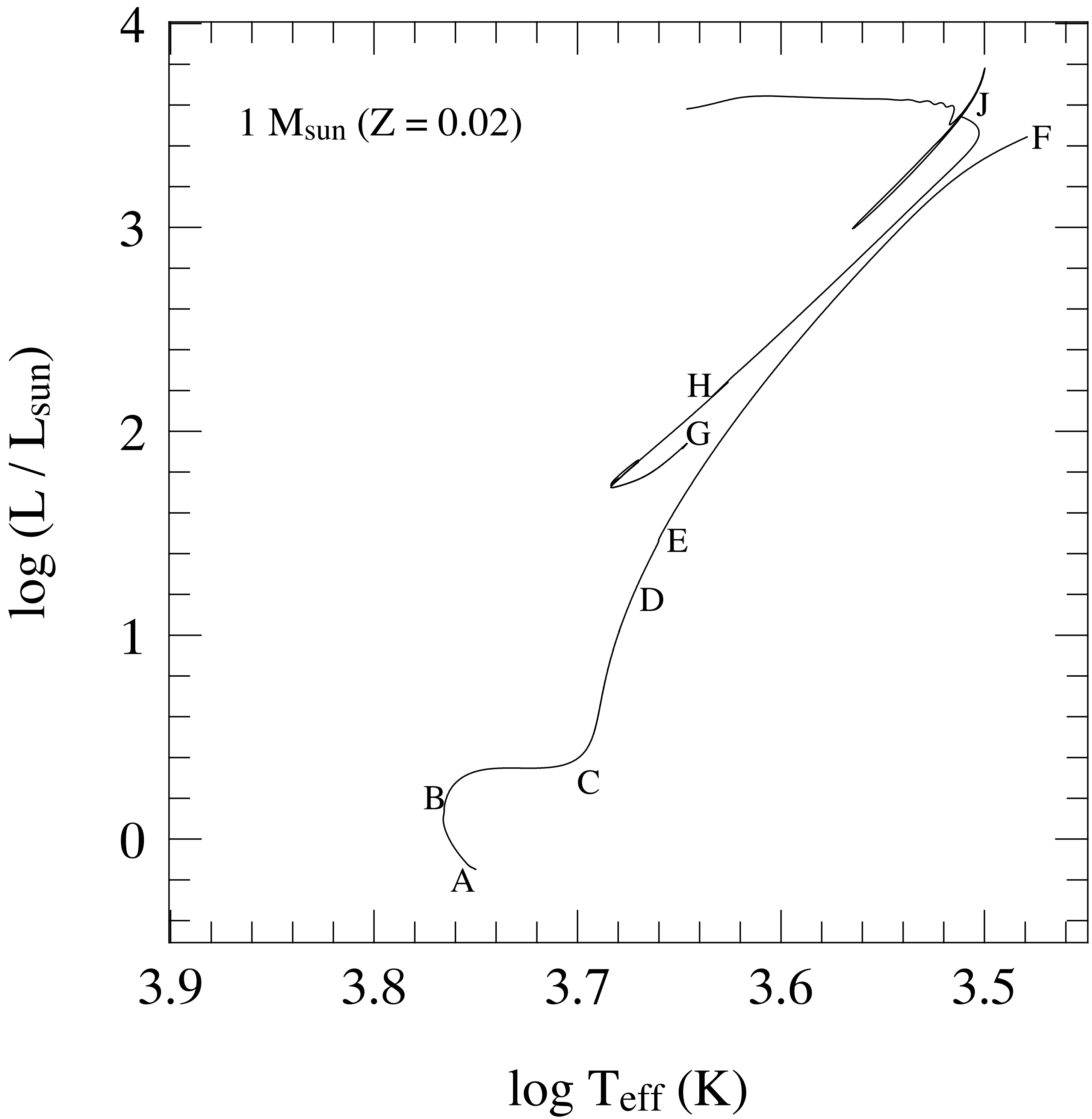
that only a strong gravitational field could prod properties similar to red giants. Subsequently, W (1983) extended their work to cover stars in the m range $1 \leq M/M_\odot \leq 8$. Using polytropic mod Frost & Lattanzio (1992) later demonstrated that could not be the sole cause.

Renzini et al. (1992) suggested that stars bec red giants because of a thermal instability in their velopes. In their view, expansion is initially driven the envelope maintaining thermal equilibrium in sponse to increasing luminosity from the core. T

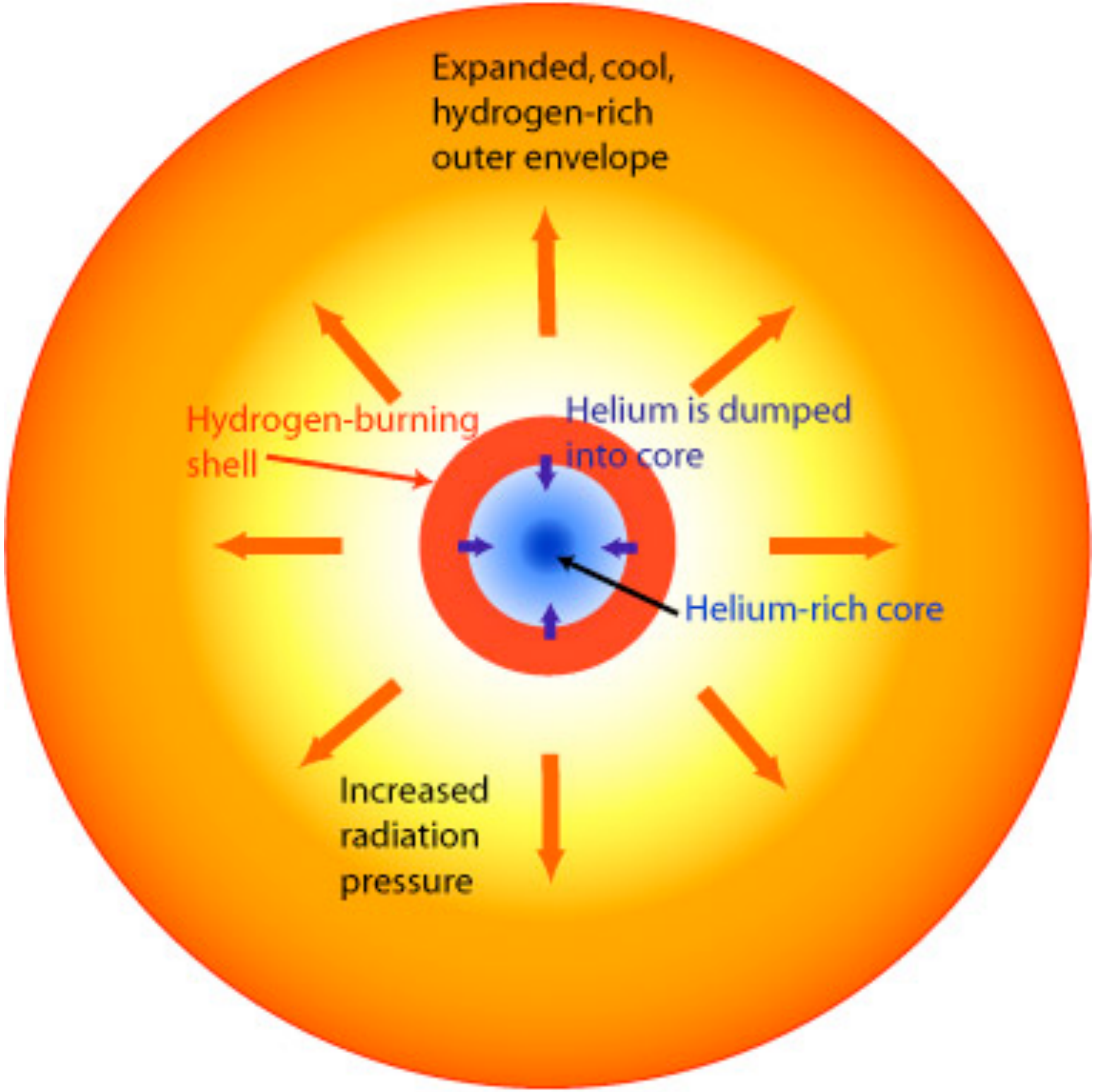

M13
I
12
14
16
18
20
22
B−I
−1
0
1
2
3

Comparison in size of Sun as a main sequence star and a red giant

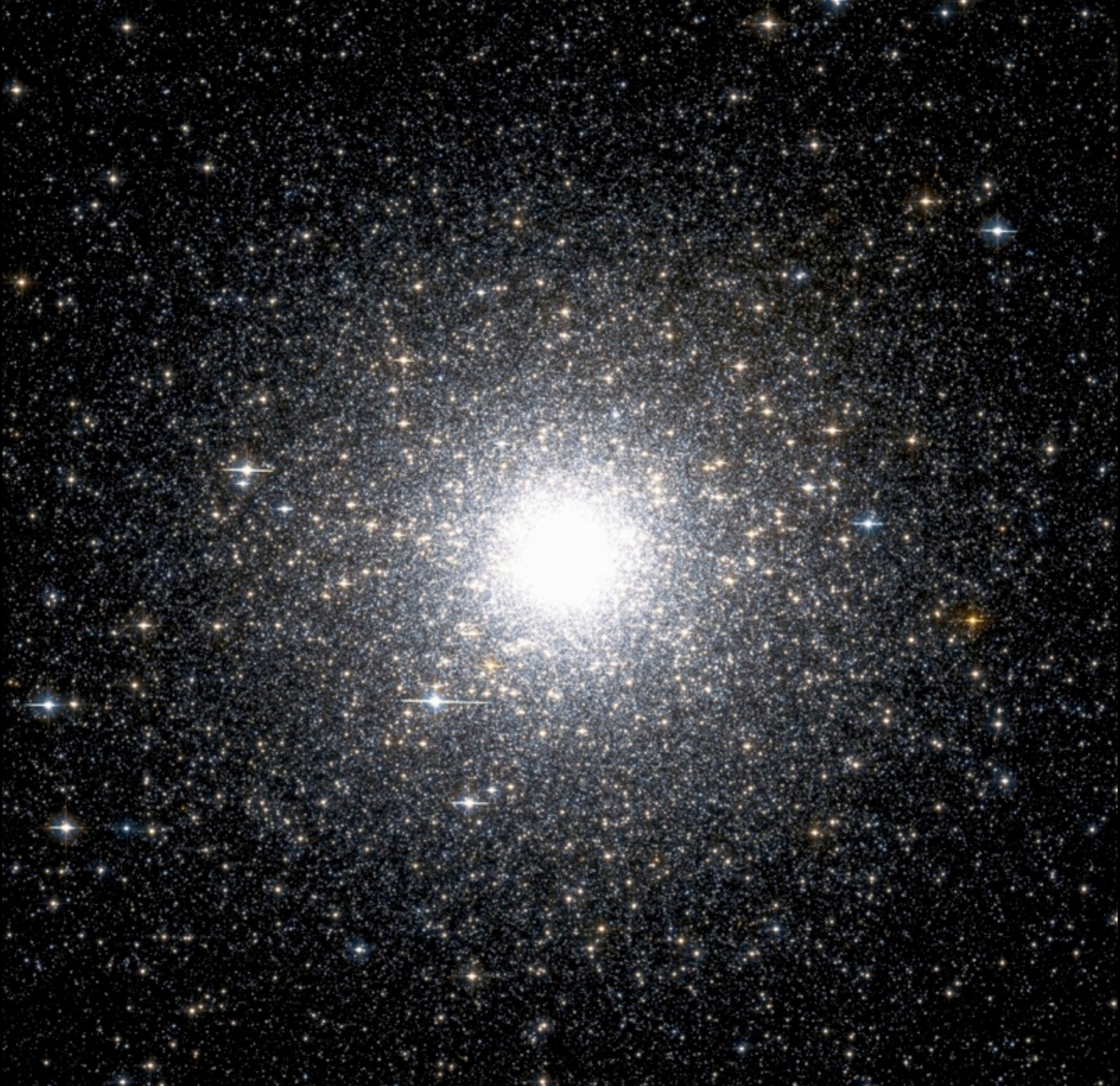




1 M_{sun} (Z = 0.02)
log (L / L_{sun})
log T_{eff} (K)
4
3
2
1
0
3.9
3.8
3.7
3.6
3.5
A
B
C
D
E
F
G
H
J



Hydrogen Shell Burning on the Red Giant Branch

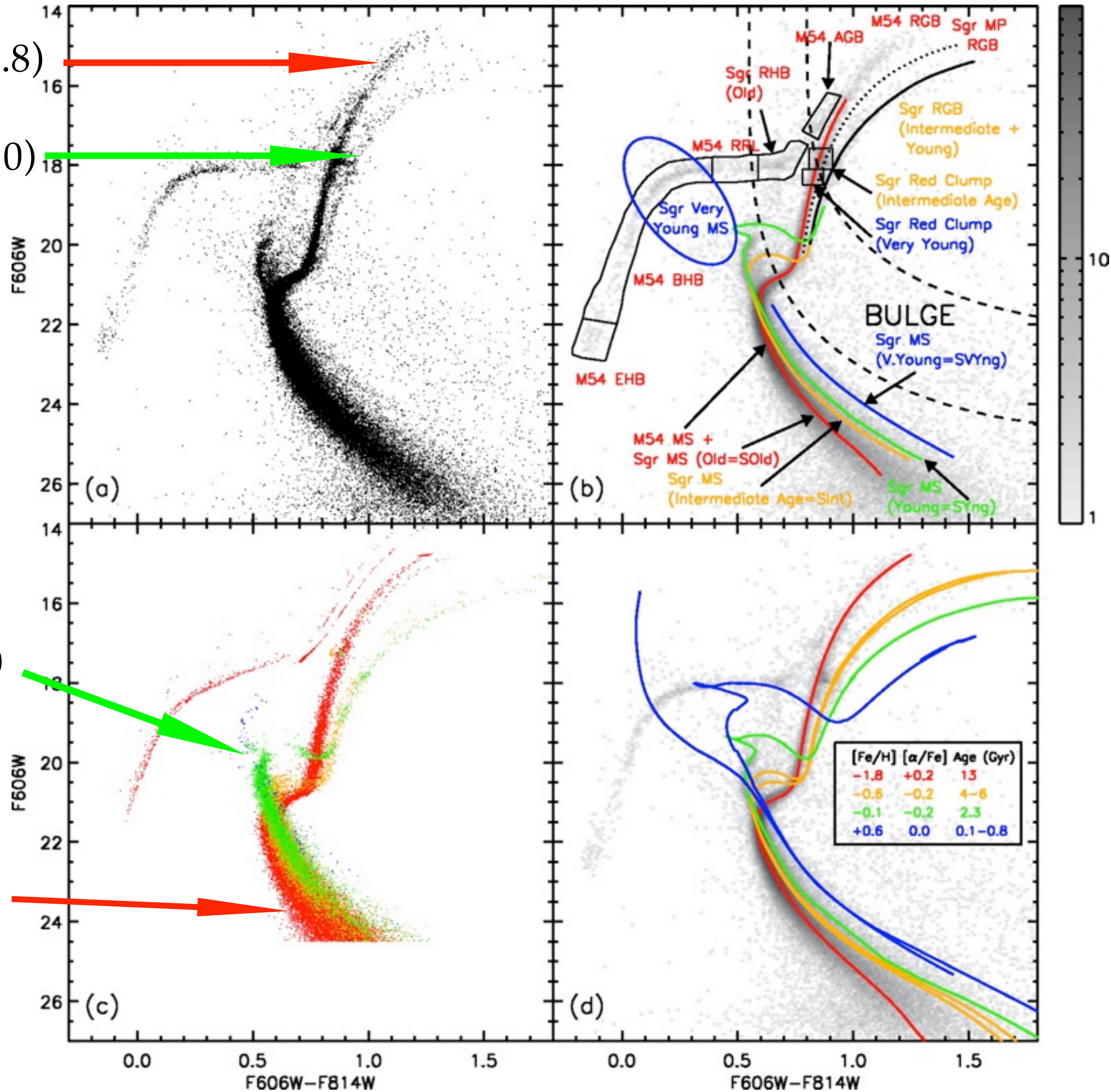


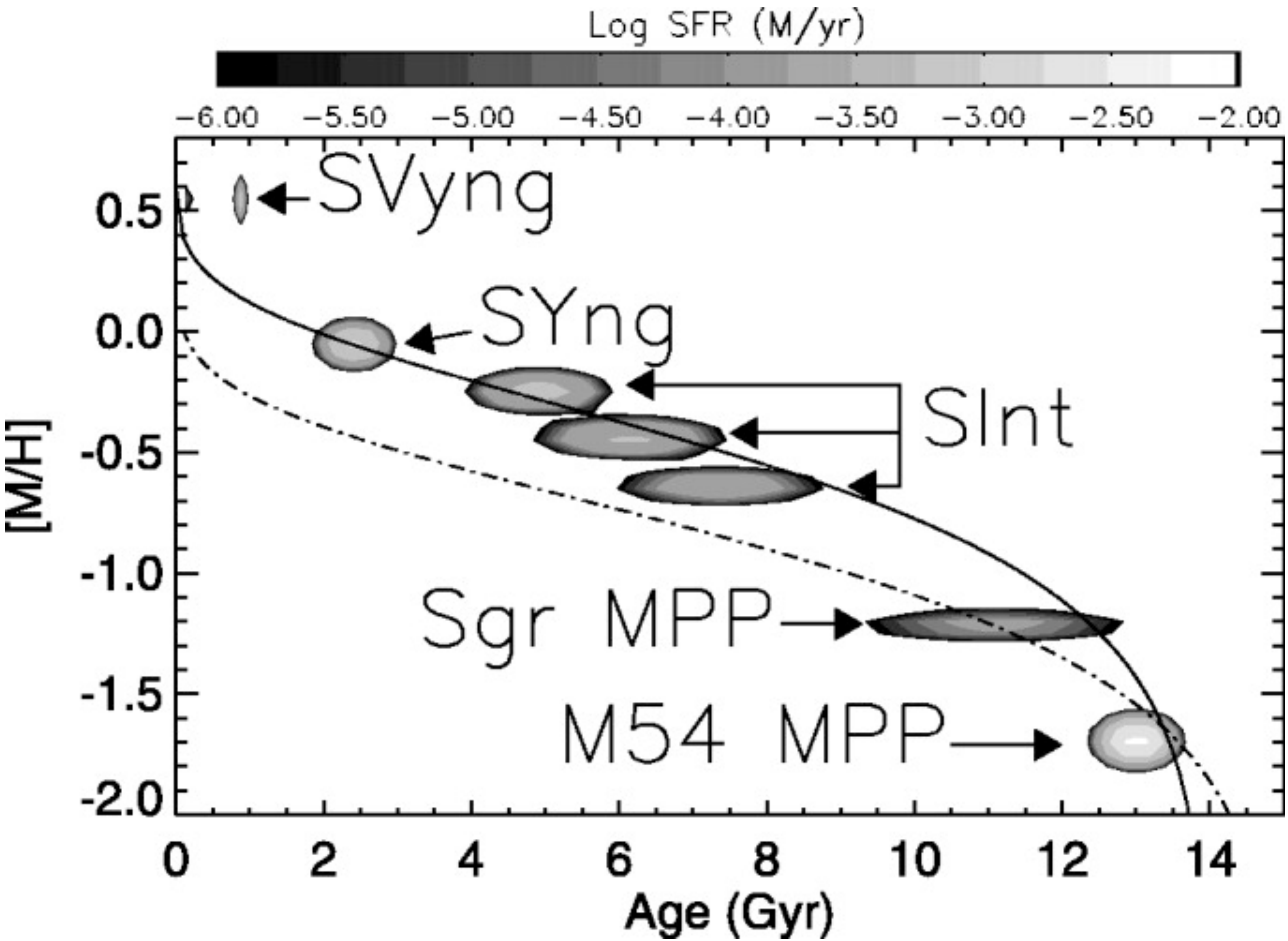
RGB of Old Pop ([Fe/H] = −1.8)

RGB of Young Pop ([Fe/H] = 0)

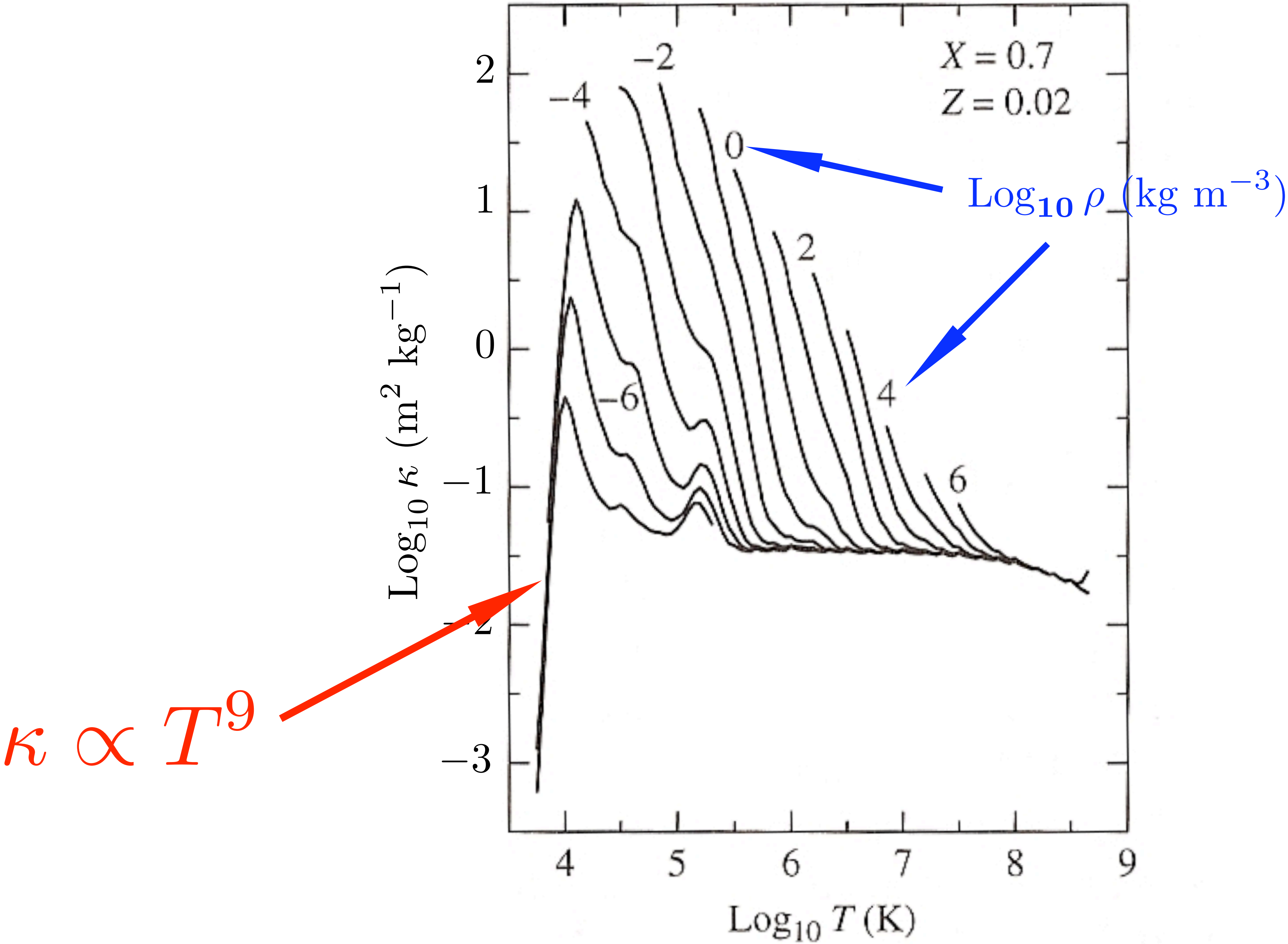
MS of Young Pop (<2 Gyr)

MS of Old Pop (12 Gyr)

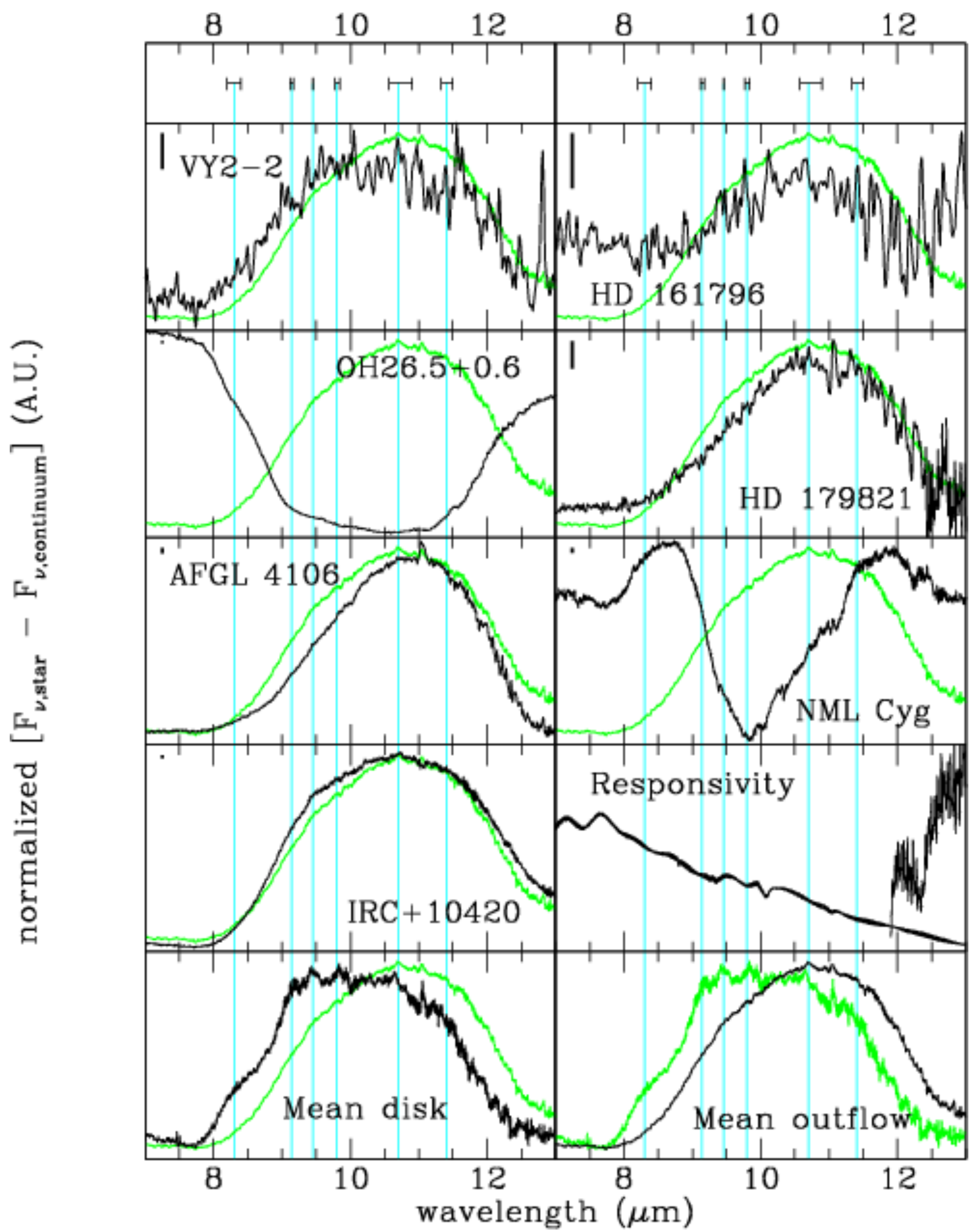




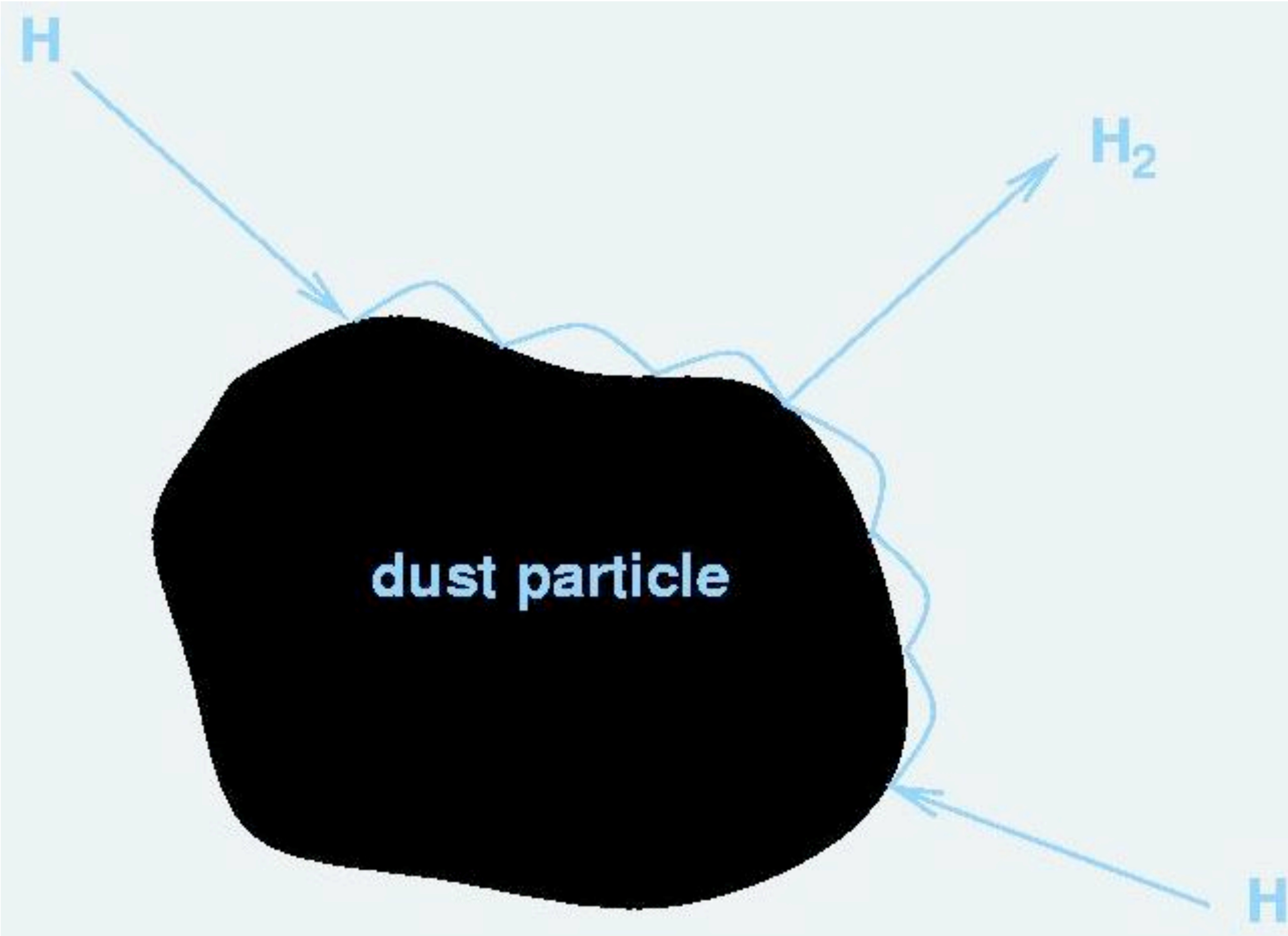
Siegel et al. 2007

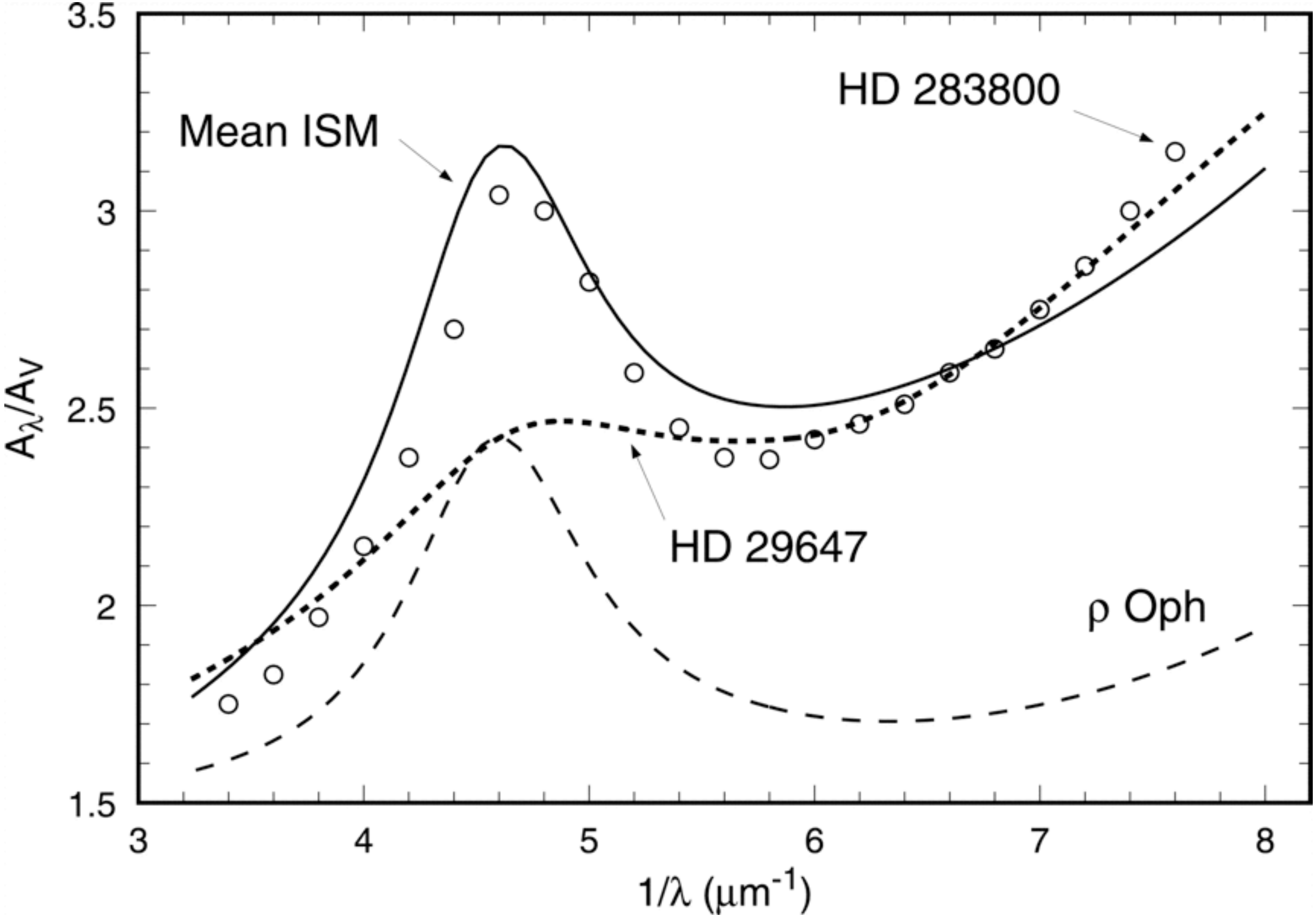


X = 0.7
Z = 0.02
−4
−2
0
2
4
6
−6
Log$_{10}$ ρ (kg m^{-3})
$\kappa \propto T^9$
Log$_{10}$ κ (m^2 kg^{-1})
Log$_{10}$ T (K)
2
1
0
−1
−2
−3
4
5
6
7
8
9

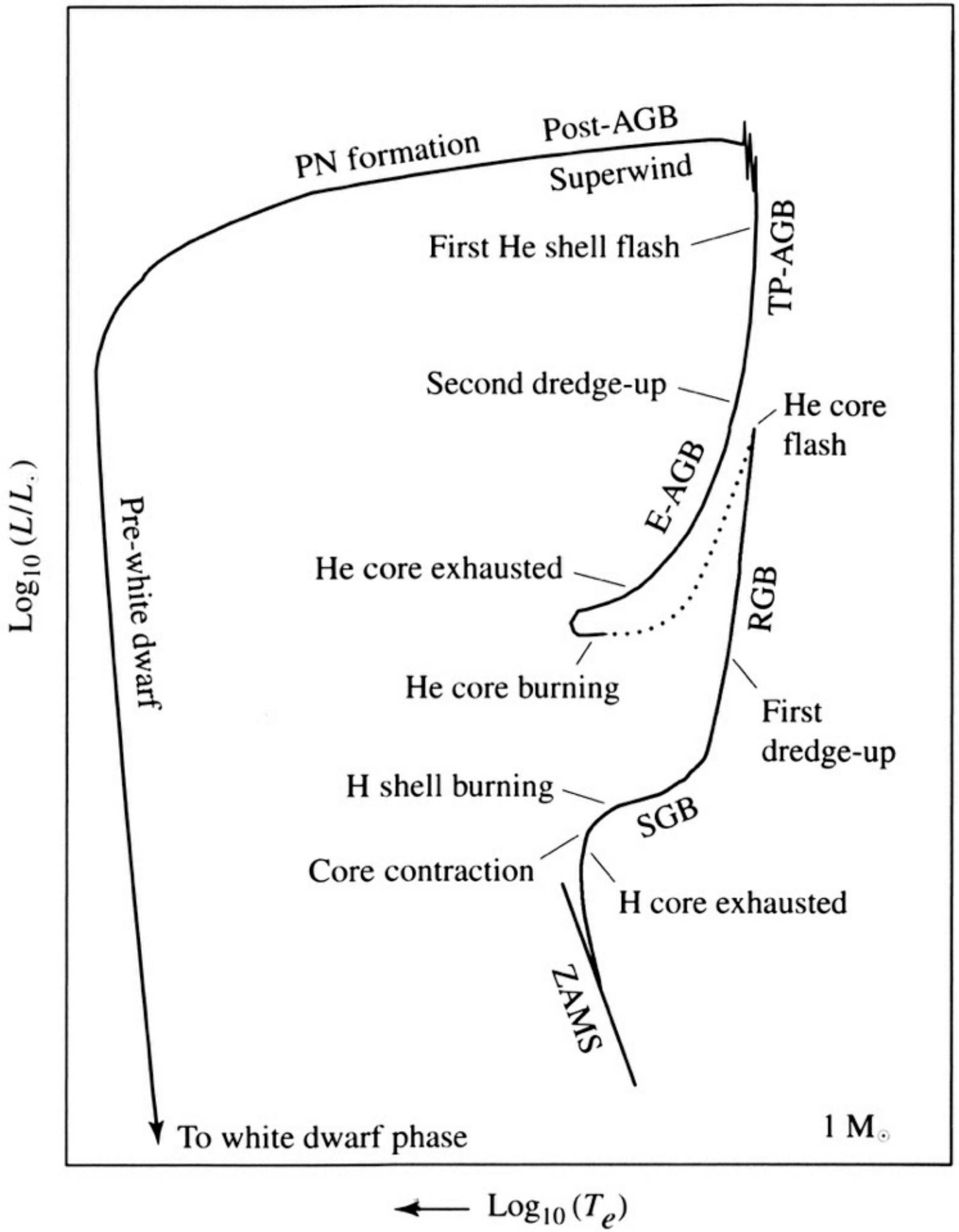


Molster et al. 2002

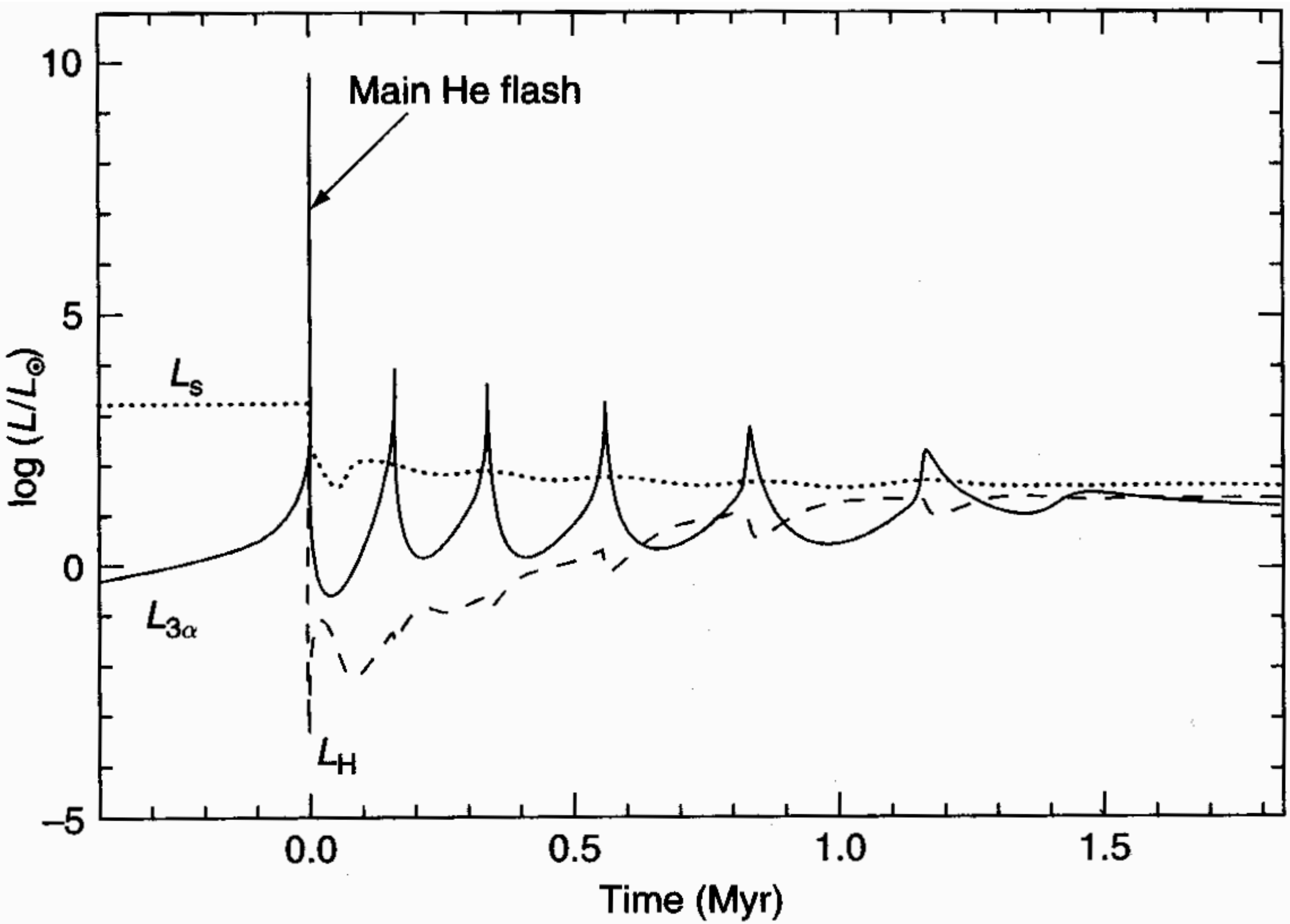

H
H2
dust particle
H



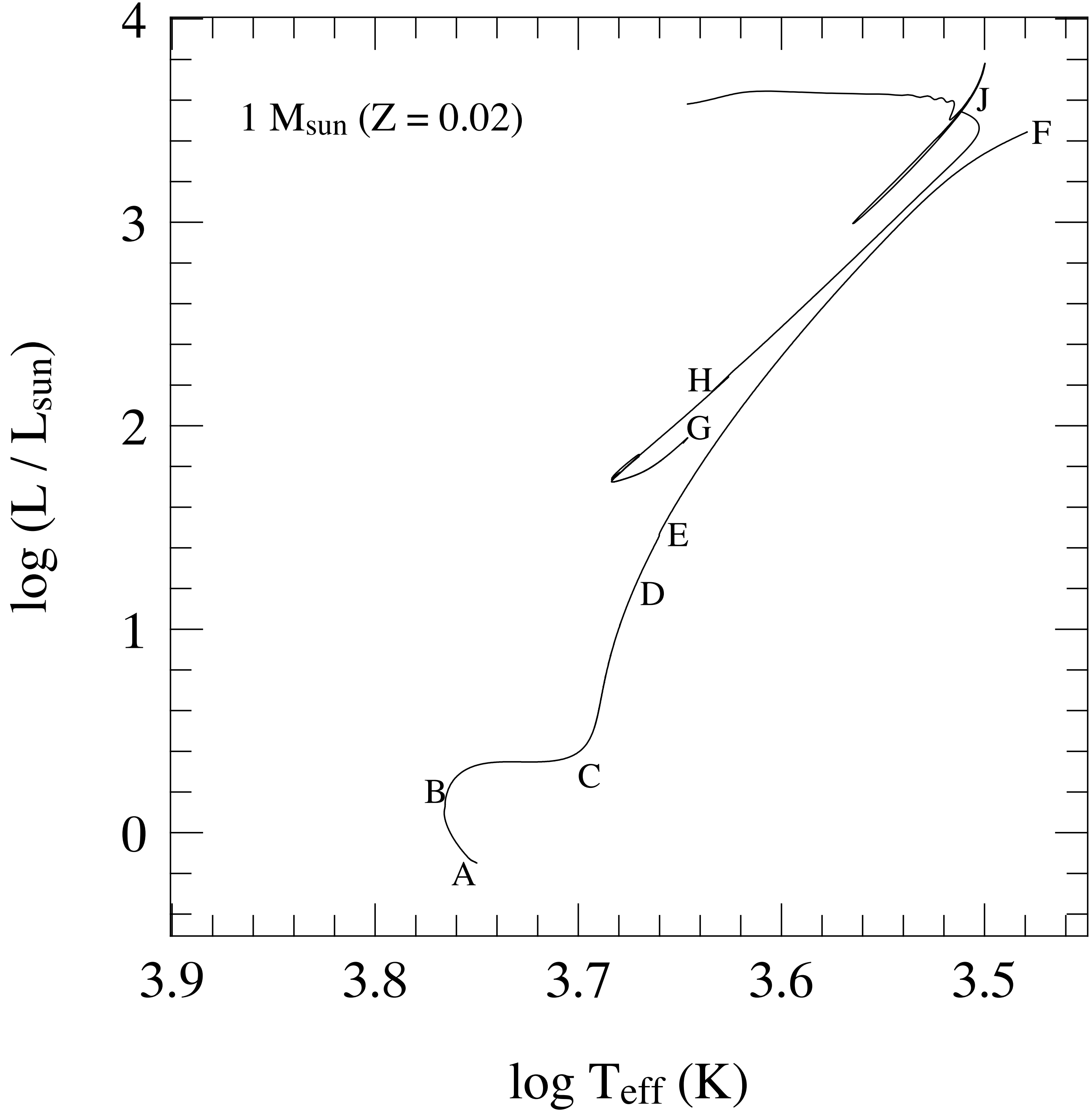
HD 283800
Mean ISM
HD 29647
ρ Oph
3.5
3
2.5
2
1.5
3
4
5
6
7
8
Aλ/AV
1/λ (μm-1)



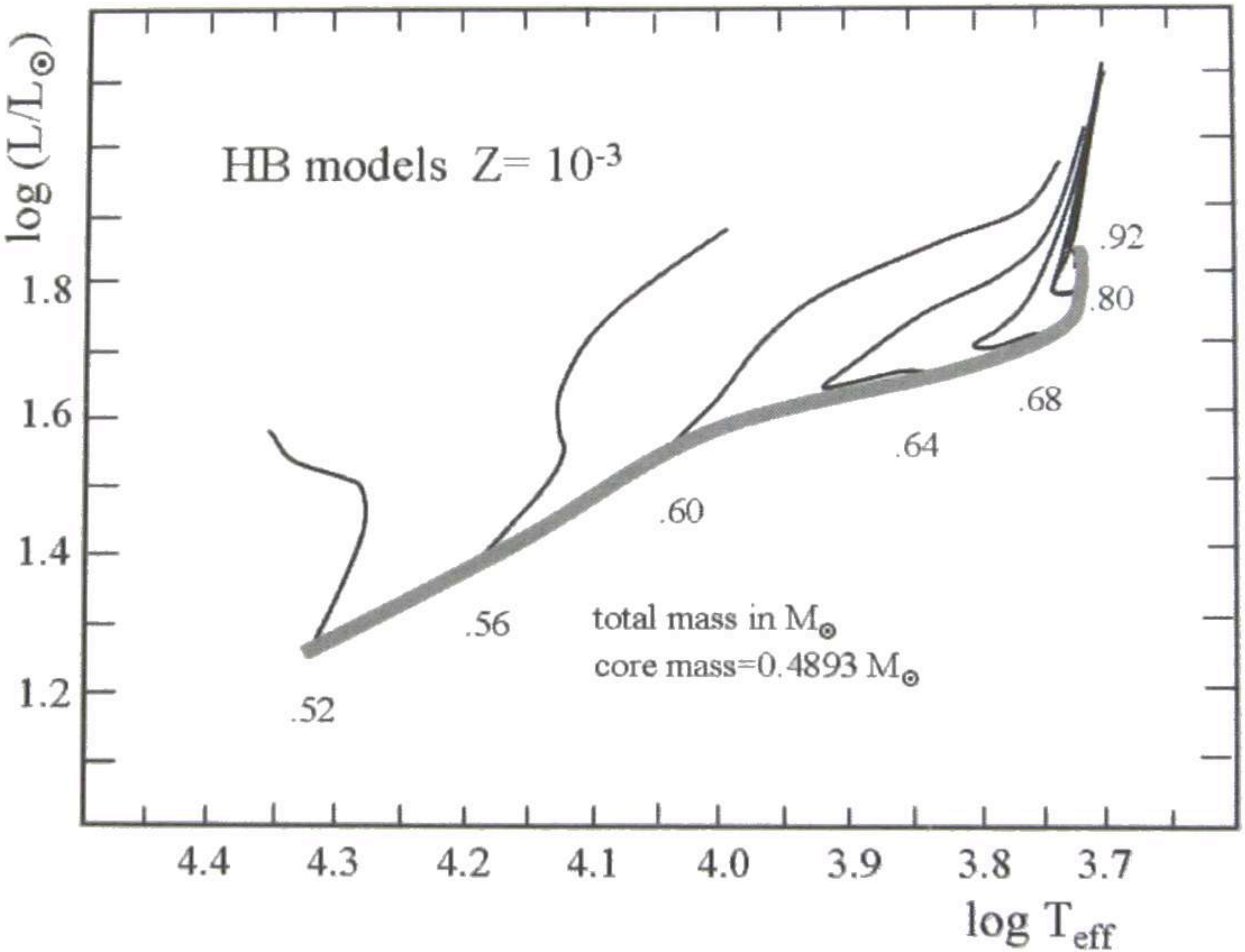
Post-AGB
PN formation
Superwind
First He shell flash
TP-AGB
Second dredge-up
He core
flash
E-AGB
He core exhausted
RGB
He core burning
First
dredge-up
H shell burning
SGB
Core contraction
H core exhausted
ZAMS
Pre-white dwarf
To white dwarf phase
1 M
Log10 (L/L)
Log10 (Te)



Main He flash
L_s
$L_{3\alpha}$
L_H
log $(L/L_\odot)$
Time (Myr)
10
5
0
−5
0.0
0.5
1.0
1.5



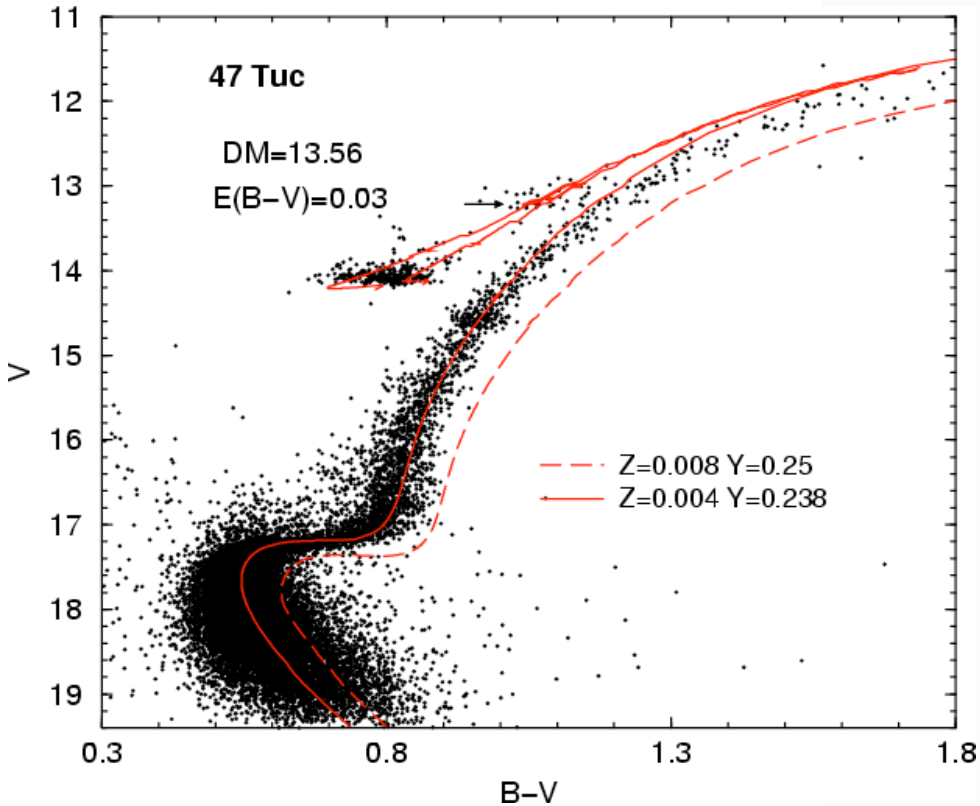
1 Msun (Z = 0.02)
A
B
C
D
E
F
G
H
J
4
3
2
1
0
3.9
3.8
3.7
3.6
3.5
log (L / Lsun)
log Teff (K)

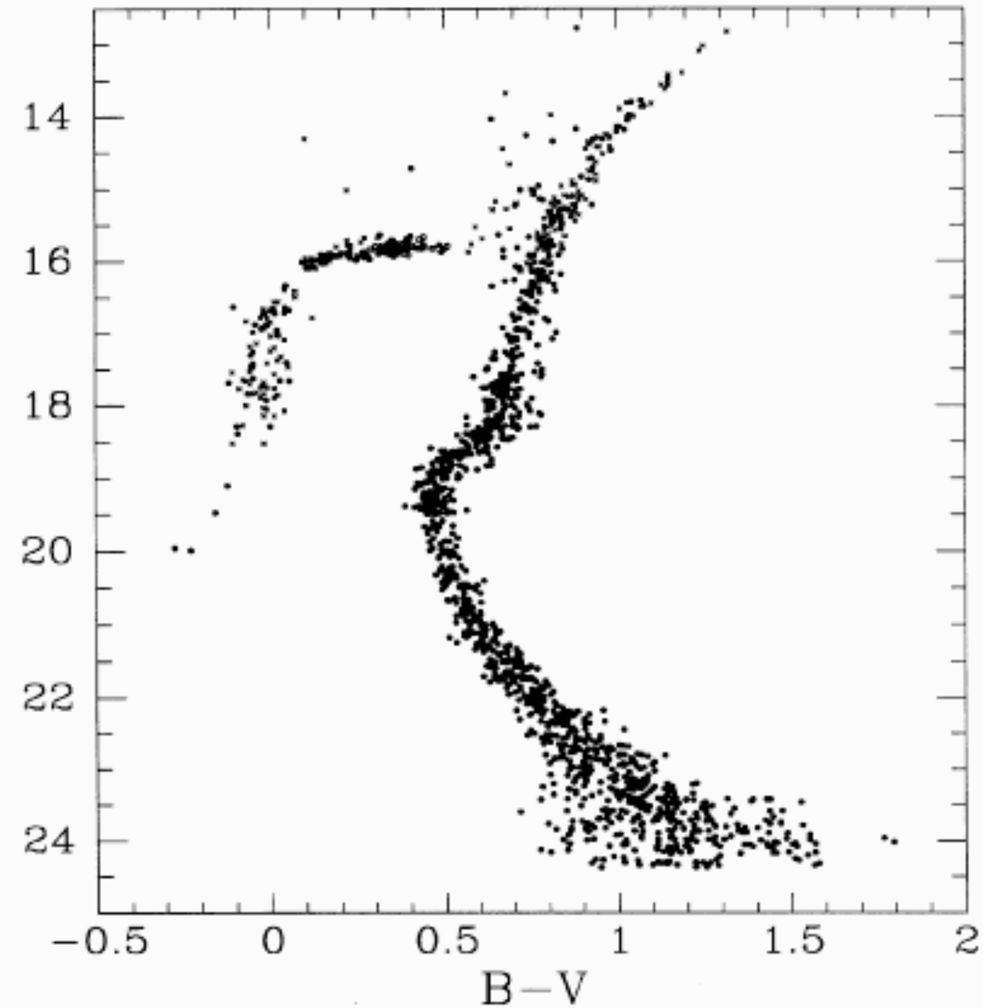

HB models Z= 10-3
log (L/L⊙)
1.8
1.6
1.4
1.2
.92
.80
.68
.64
.60
.56
.52
total mass in M⊙
core mass=0.4893 M⊙
4.4
4.3
4.2
4.1
4.0
3.9
3.8
3.7
log Teff

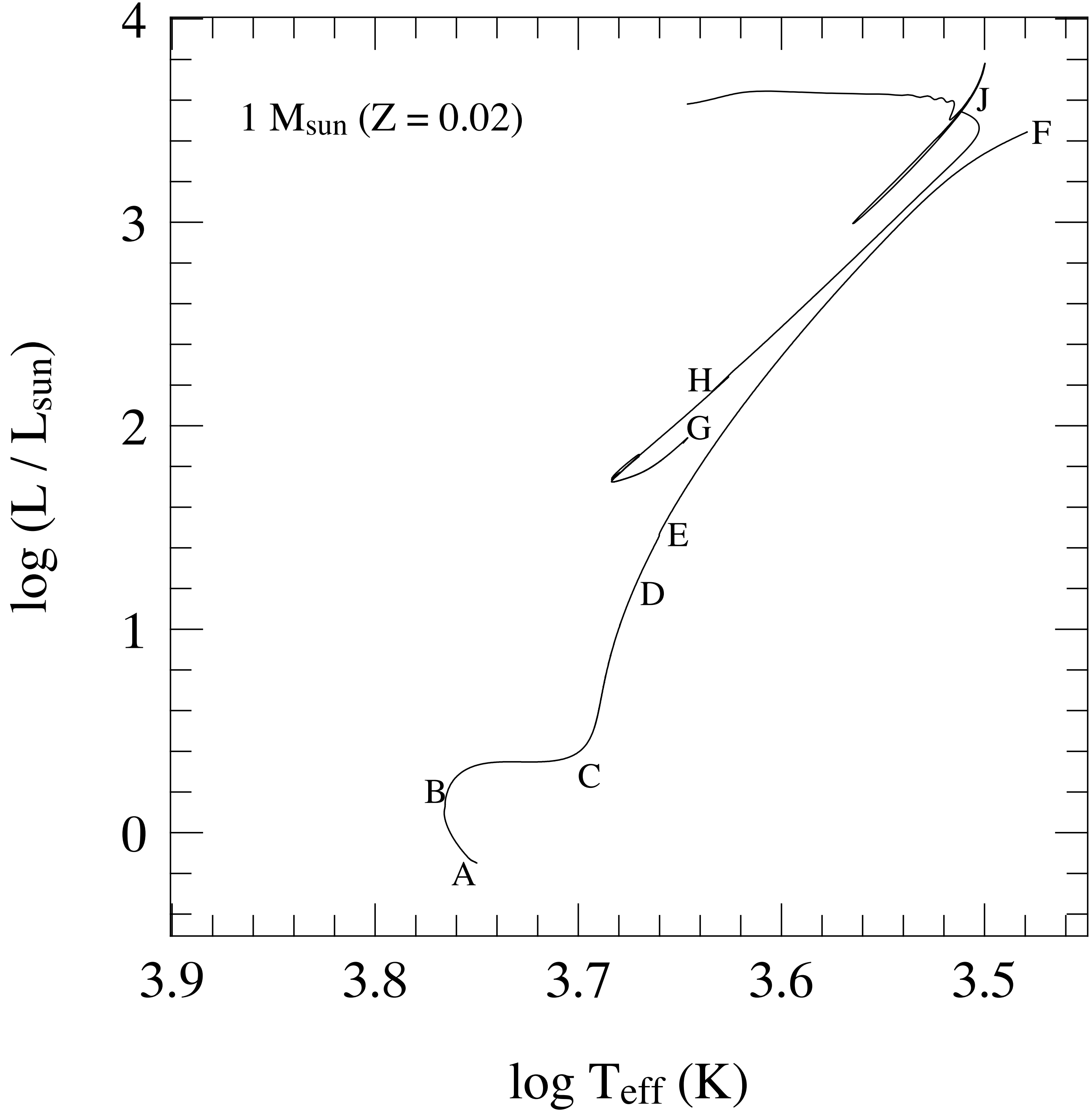
Two Globular Clusters

M15, [Fe/H] = − 2.4

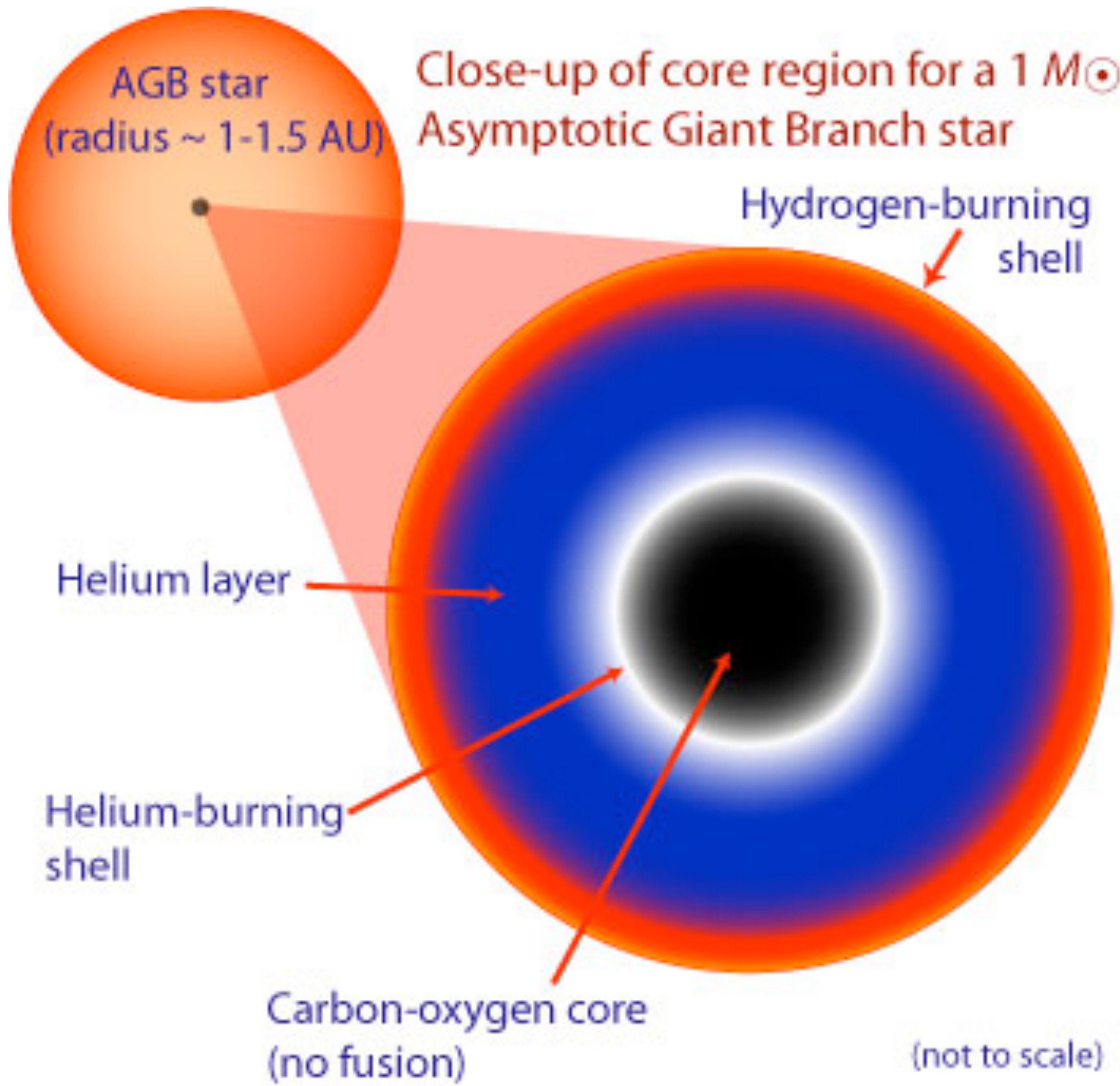
47 Tuc, [Fe/H] = − 0.8

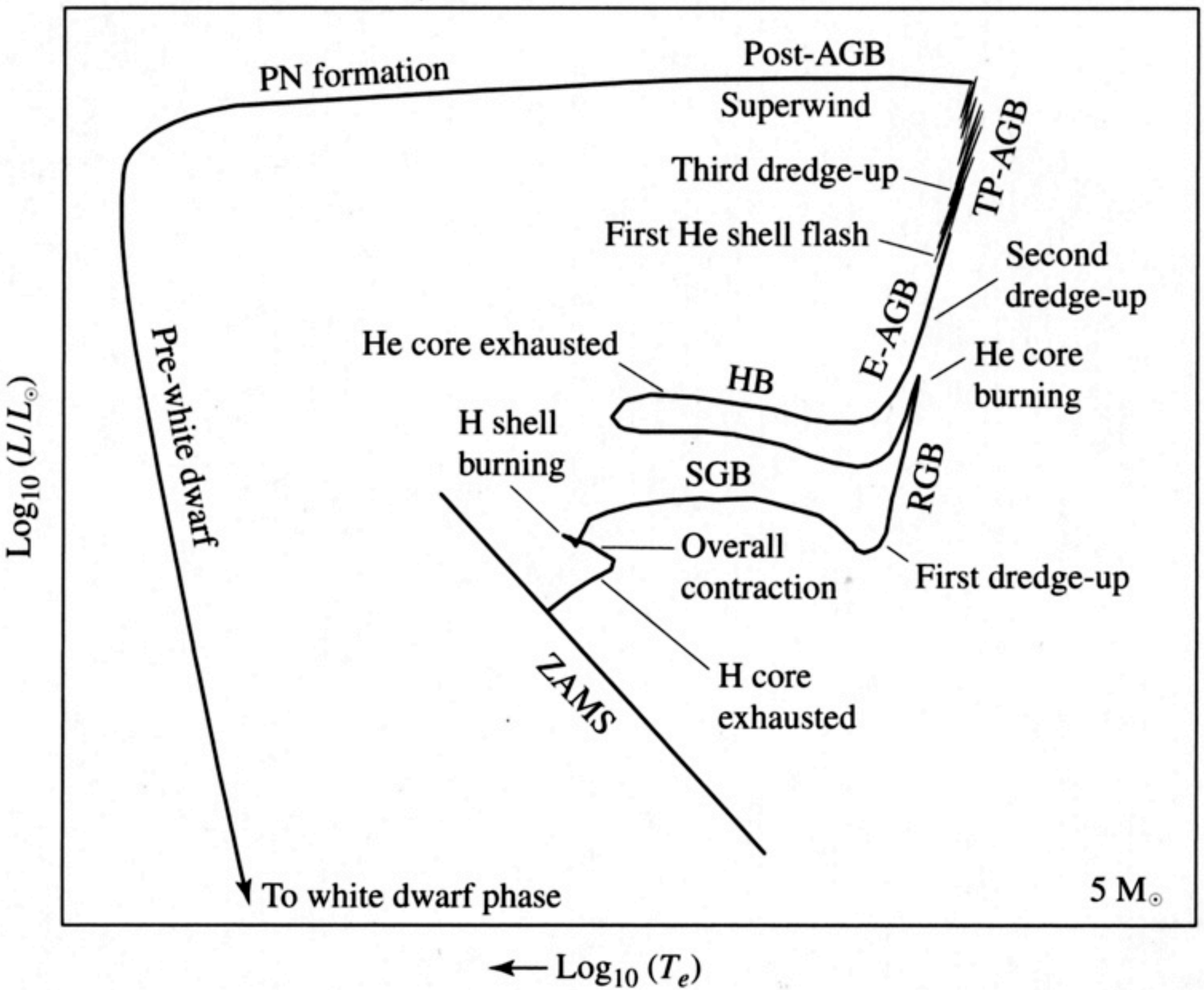




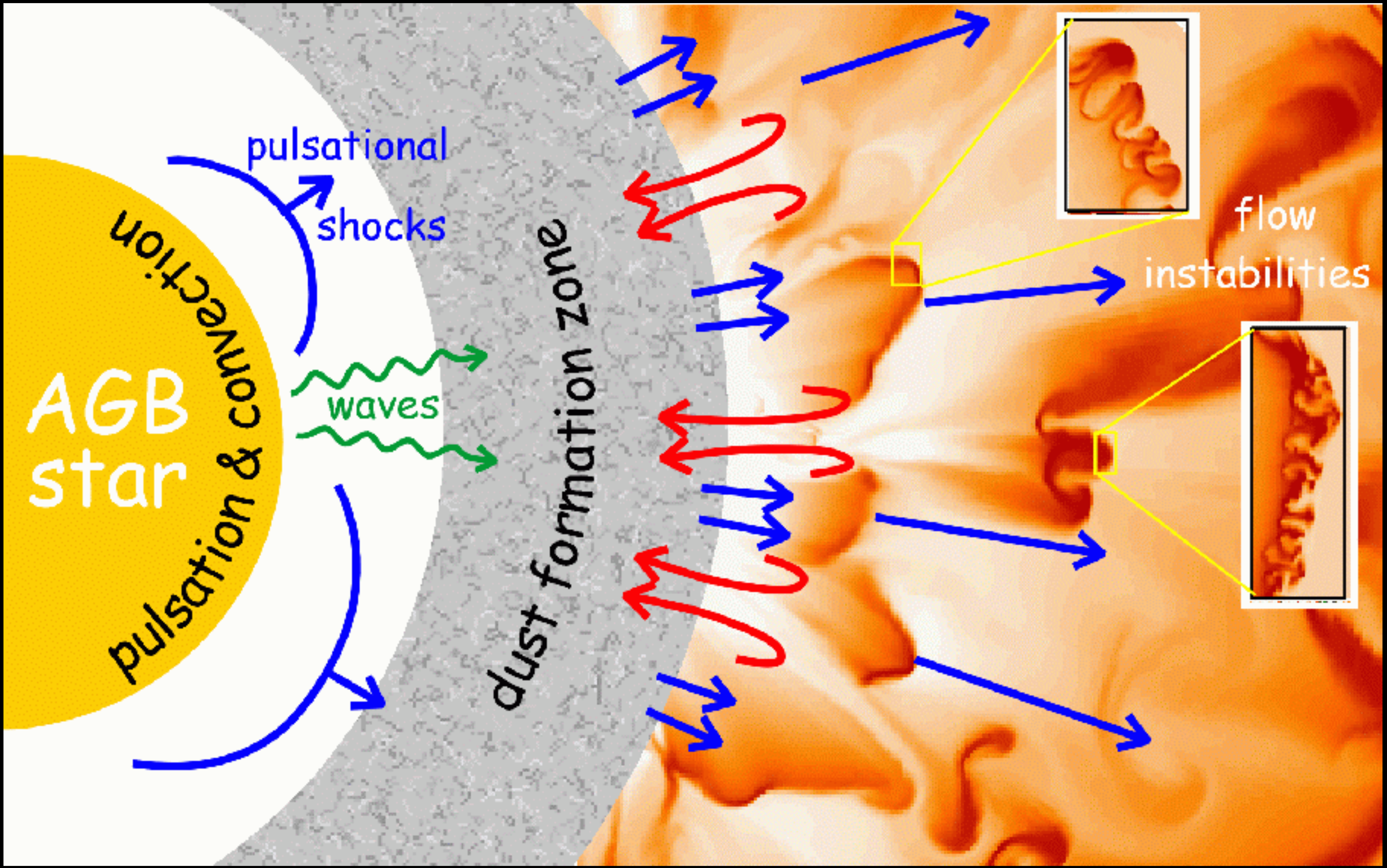


1 Msun (Z = 0.02)
A
B
C
D
E
F
G
H
J
log (L / Lsun)
log Teff (K)
4
3
2
1
0
3.9
3.8
3.7
3.6
3.5

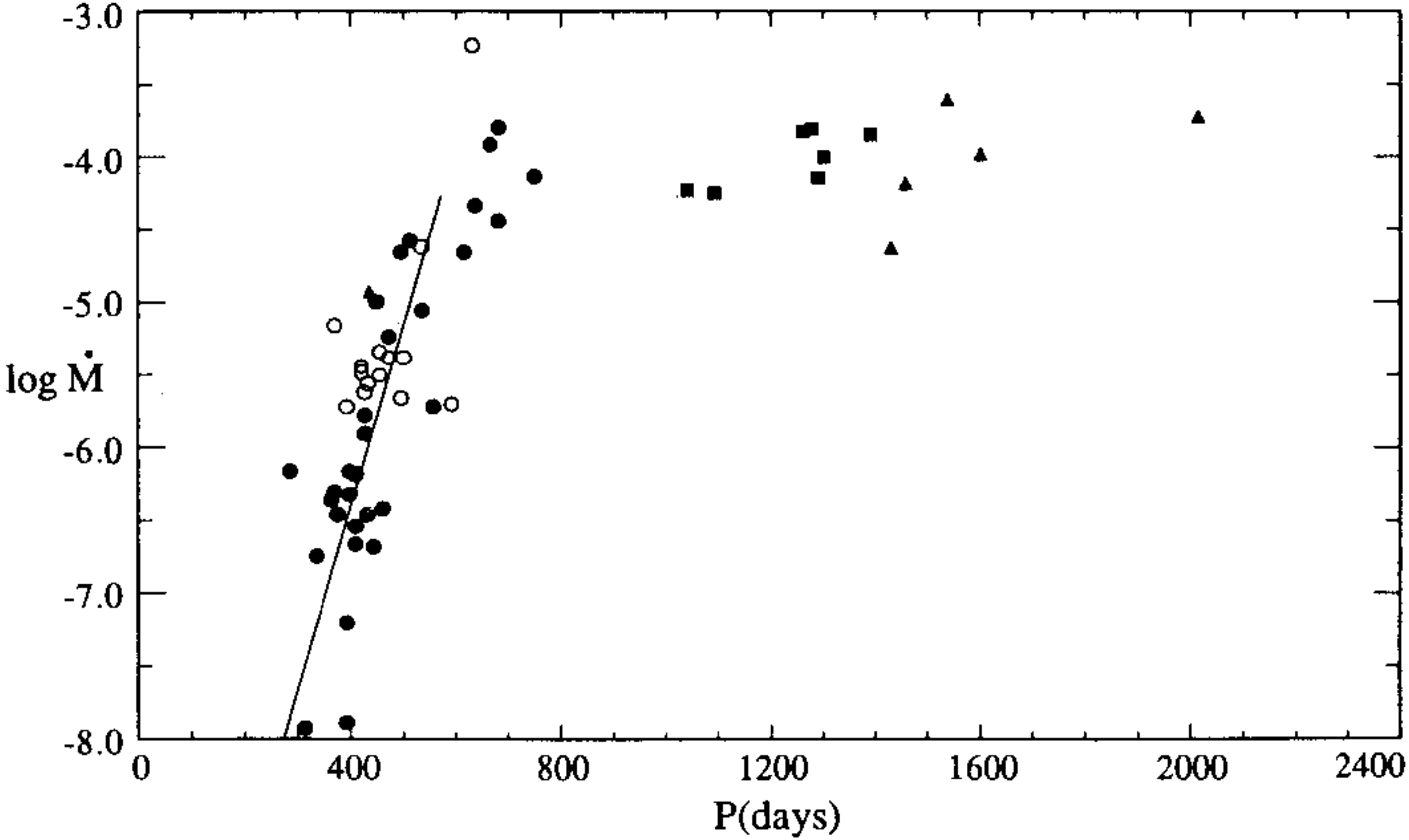

AGB star
(radius ~ 1-1.5 AU)
Close-up of core region for a 1 $M_\odot$
Asymptotic Giant Branch star
Hydrogen-burning
shell
Helium layer
Helium-burning
shell
Carbon-oxygen core
(no fusion)
(not to scale)

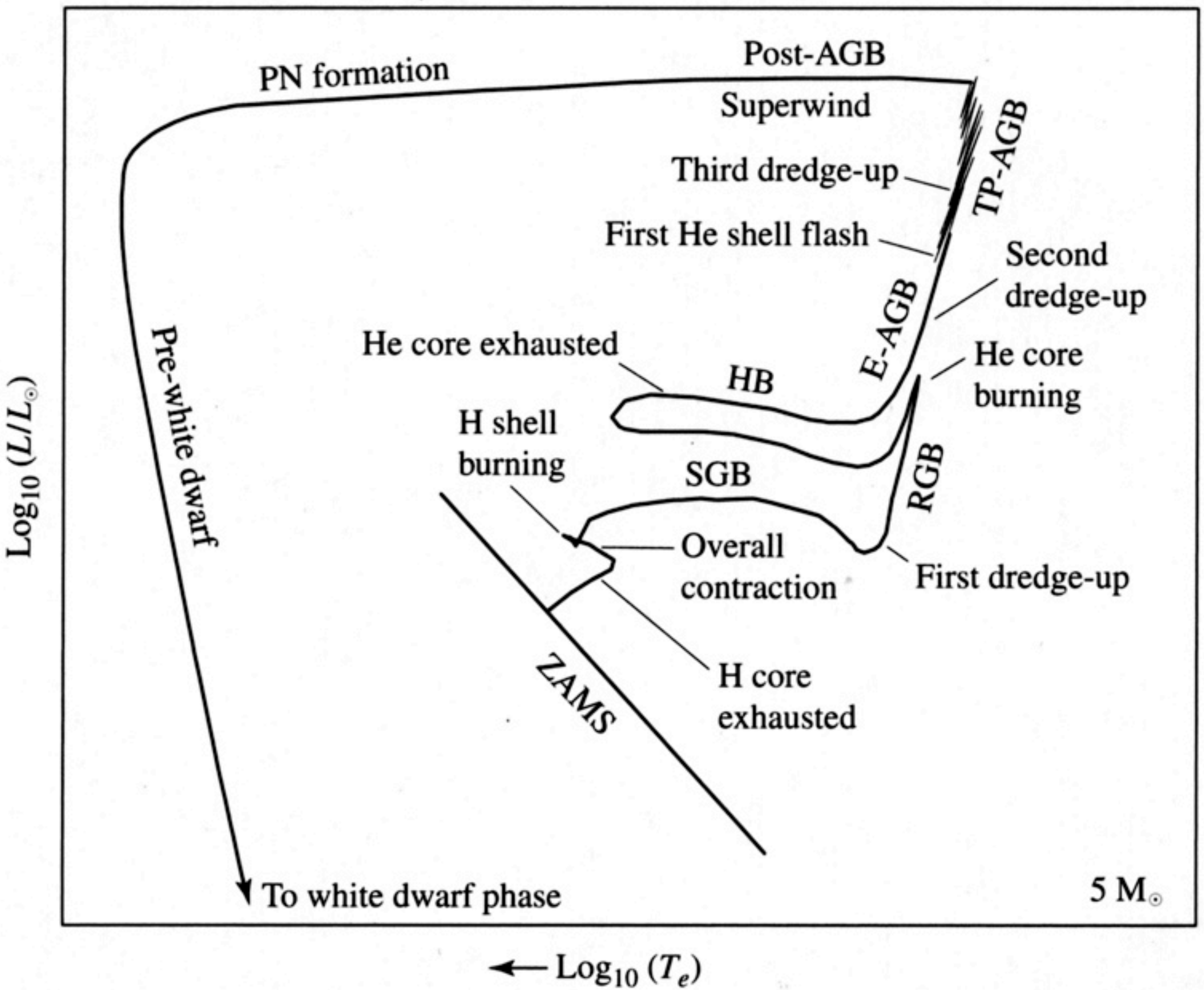


PN formation
Post-AGB
Superwind
Third dredge-up
TP-AGB
First He shell flash
Second dredge-up
E-AGB
He core exhausted
HB
He core burning
H shell burning
SGB
RGB
Overall contraction
First dredge-up
Pre-white dwarf
ZAMS
H core exhausted
To white dwarf phase
5 M$_\odot$
Log$_{10}$ $(L/L_\odot)$
← Log$_{10}$ (T_e)



AGB star
pulsation & convection
pulsational shocks
waves
dust formation zone
flow instabilities


-3.0
-4.0
-5.0
-6.0
-7.0
-8.0
log Ṁ
0
400
800
1200
1600
2000
2400
P(days)



Post-AGB
PN formation
Superwind
TP-AGB
Third dredge-up
First He shell flash
Second dredge-up
E-AGB
He core exhausted
HB
He core burning
H shell burning
SGB
RGB
Overall contraction
First dredge-up
Pre-white dwarf
ZAMS
H core exhausted
To white dwarf phase
5 M$_\odot$
Log$_{10}$ ($L/L_\odot$)
← Log$_{10}$ (T_e)

Helix Nebula • NGC 7293

Hubble Space Telescope • Advanced Camera for Surveys

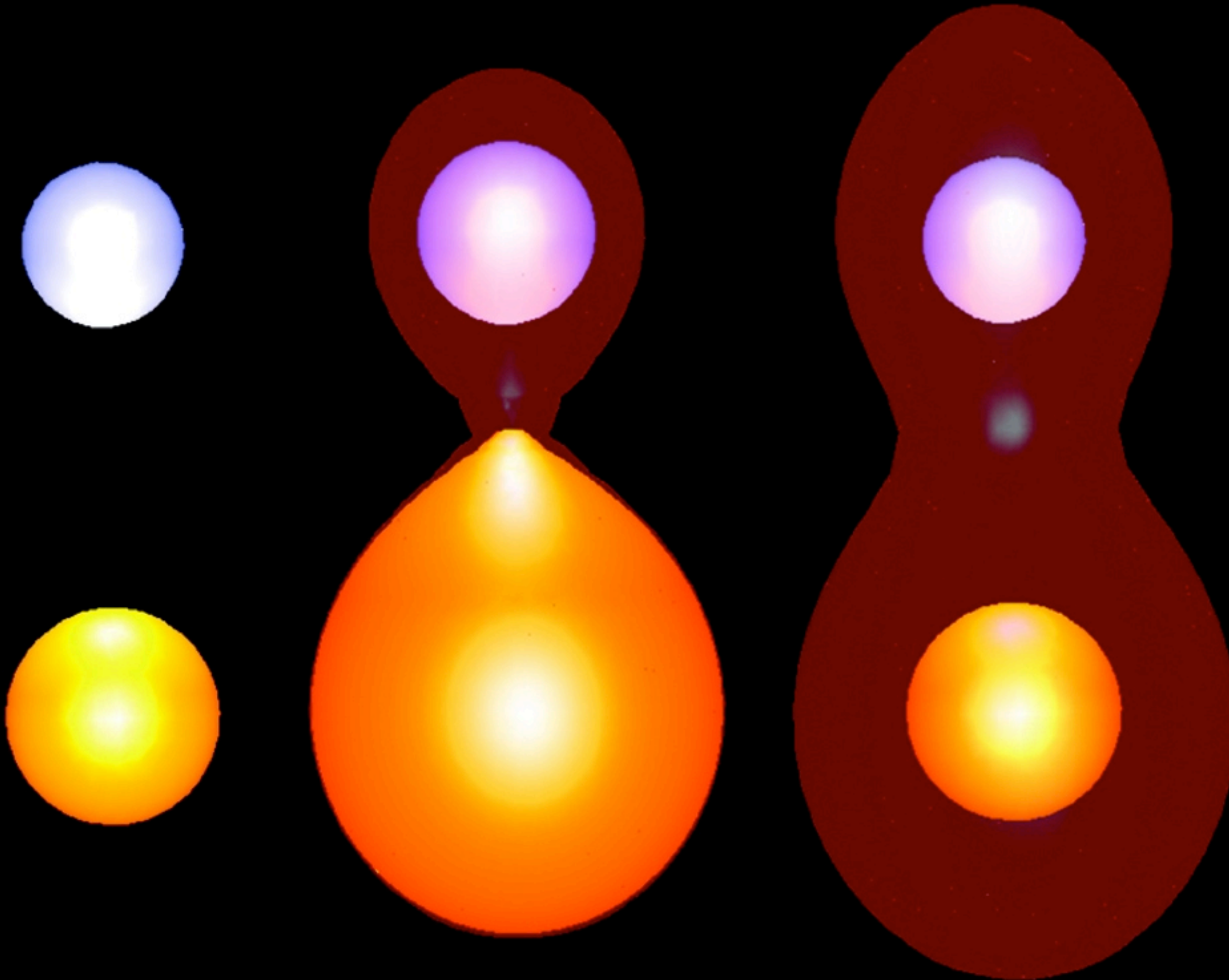
NOAO 0.9m • Mosaic I Camera

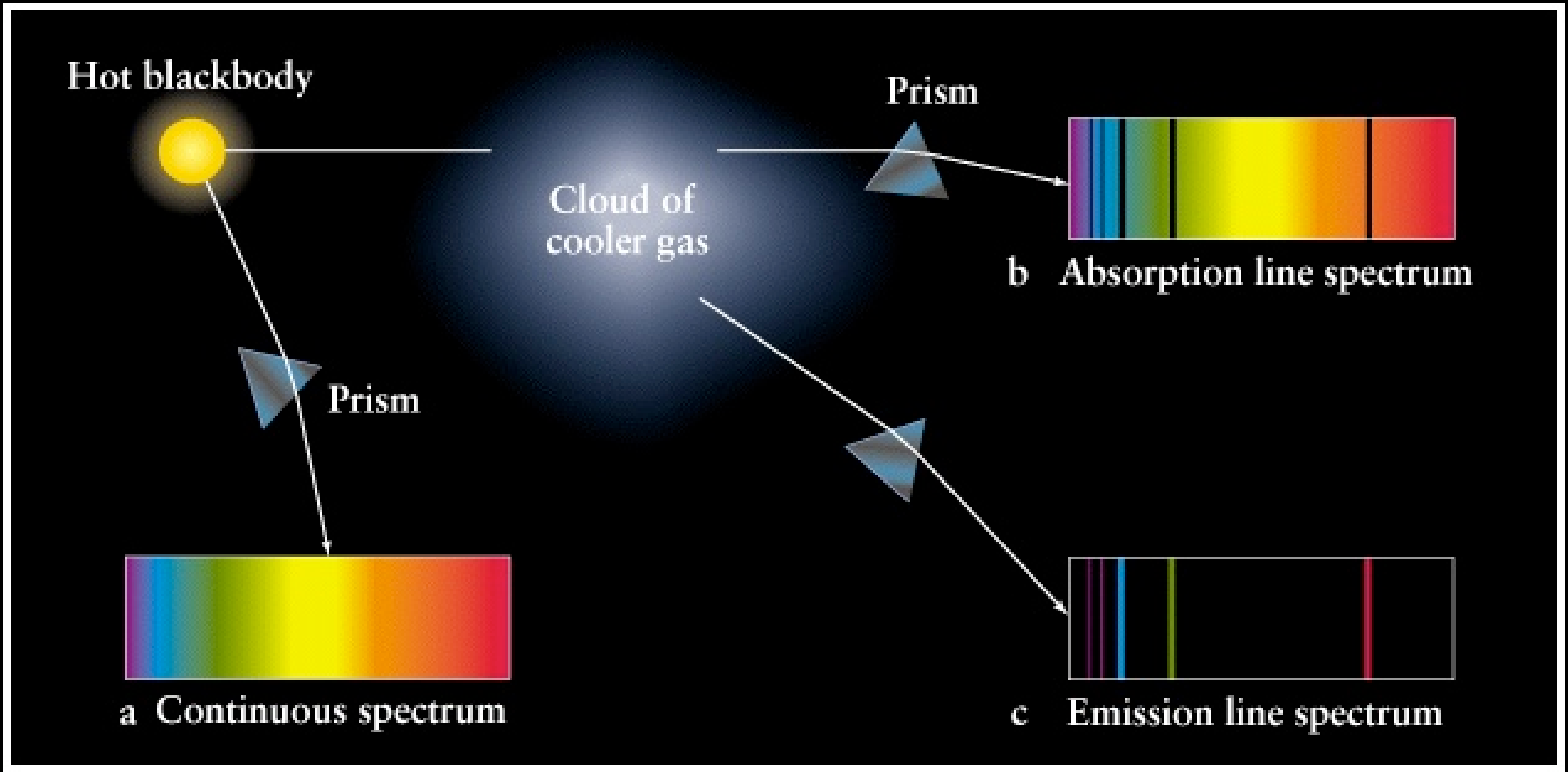
NASA, NOAO, ESA, The Hubble Helix Team, M. Meixner (STScI), and T.A. Rector (NRAO) • STScI-PRC03-11a

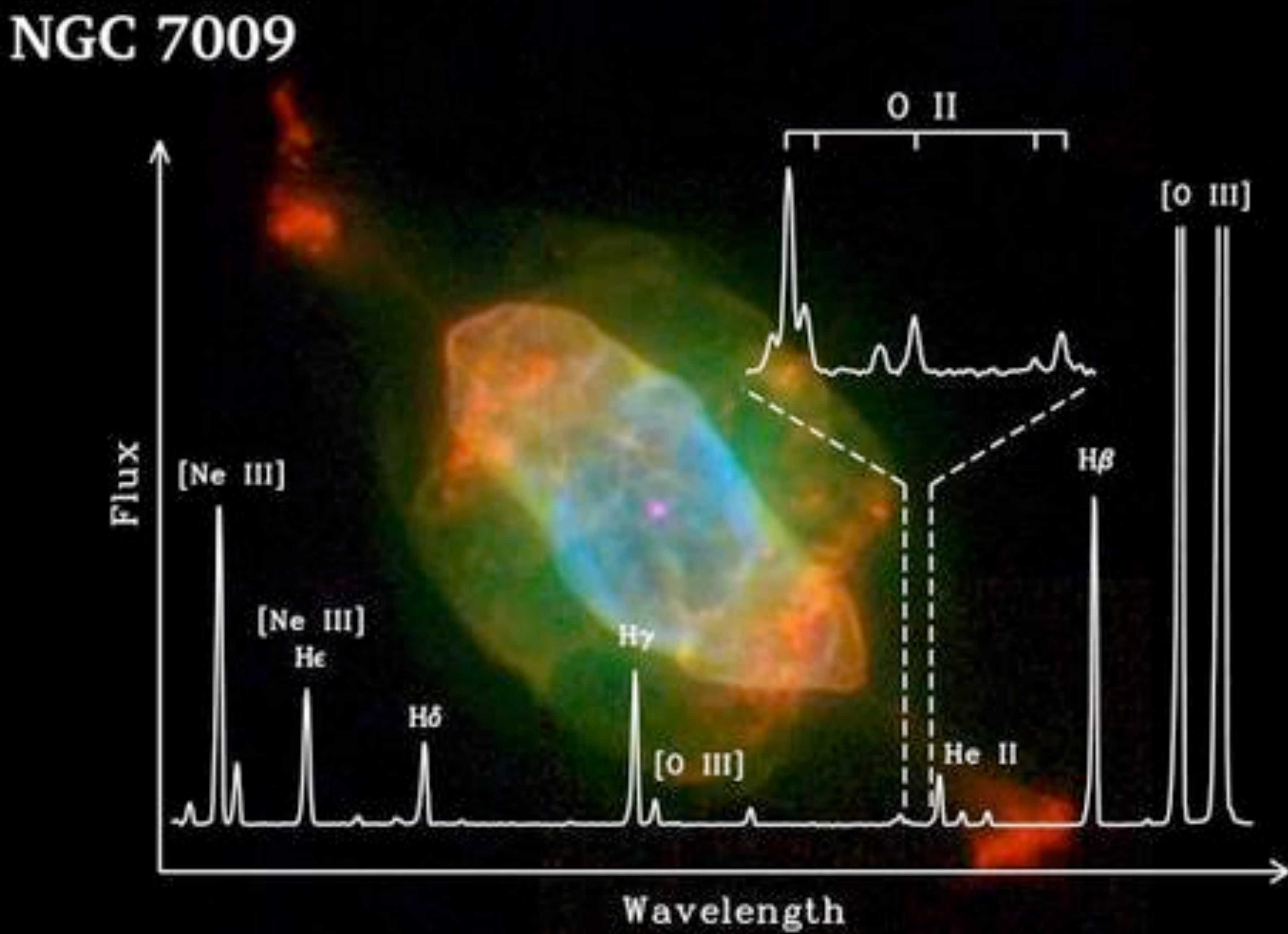
Cat's Eye Nebula • NGC 6543

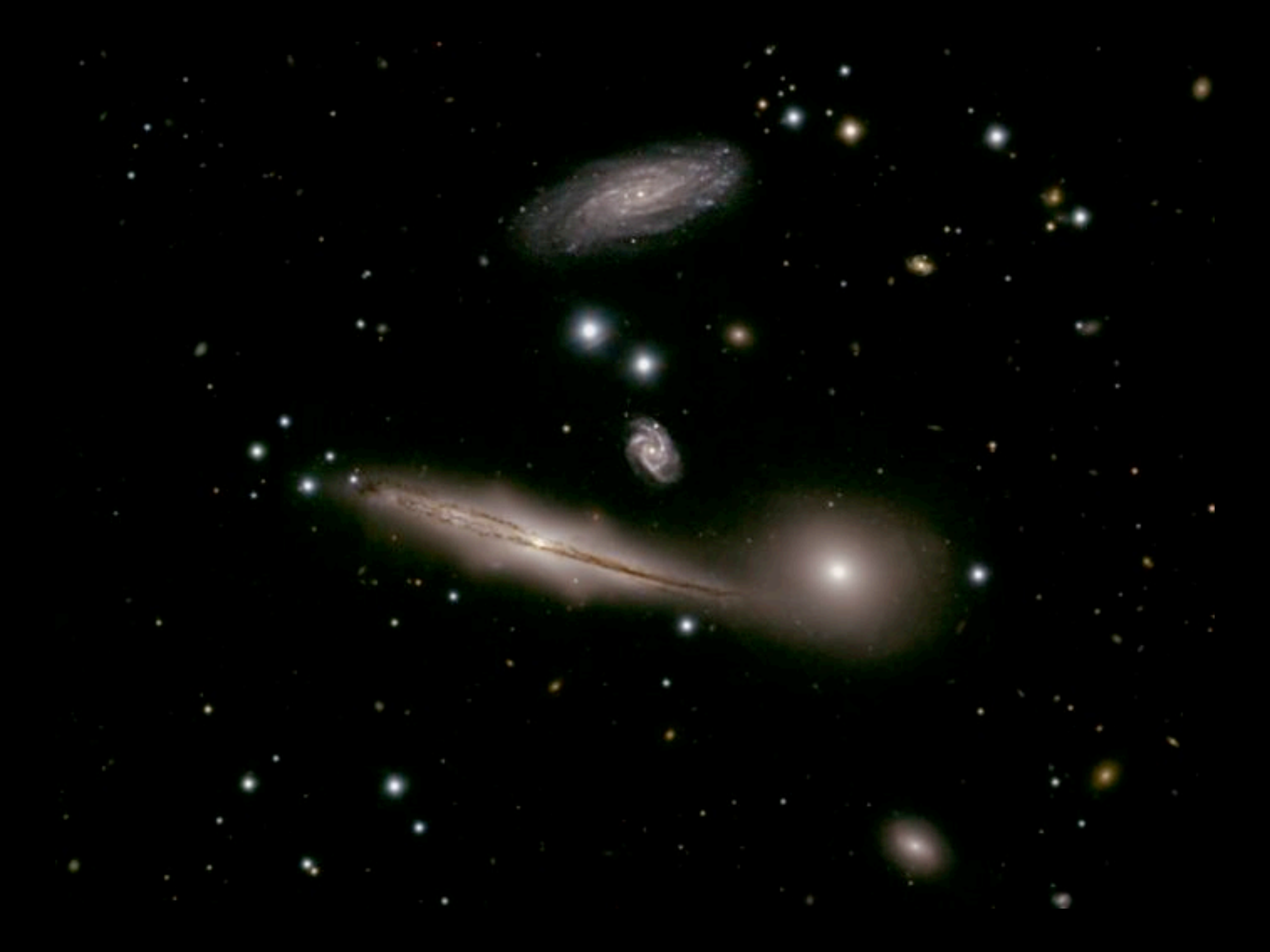
Hubble Heritage

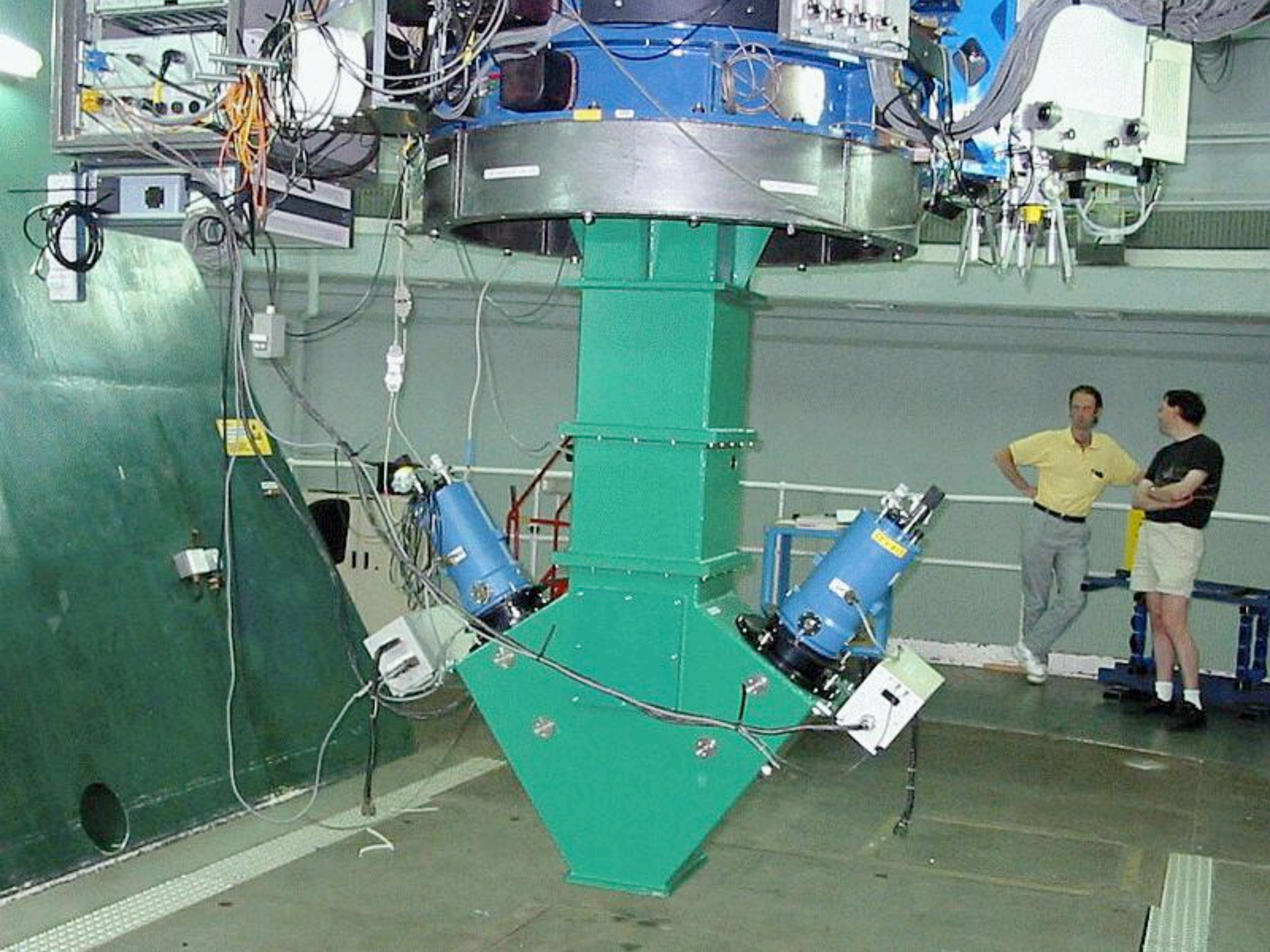
NASA, ESA, HEIC and The Hubble Heritage Team (STScI/AURA)
Hubble Space Telescope ACS • STScI-PRC04-27

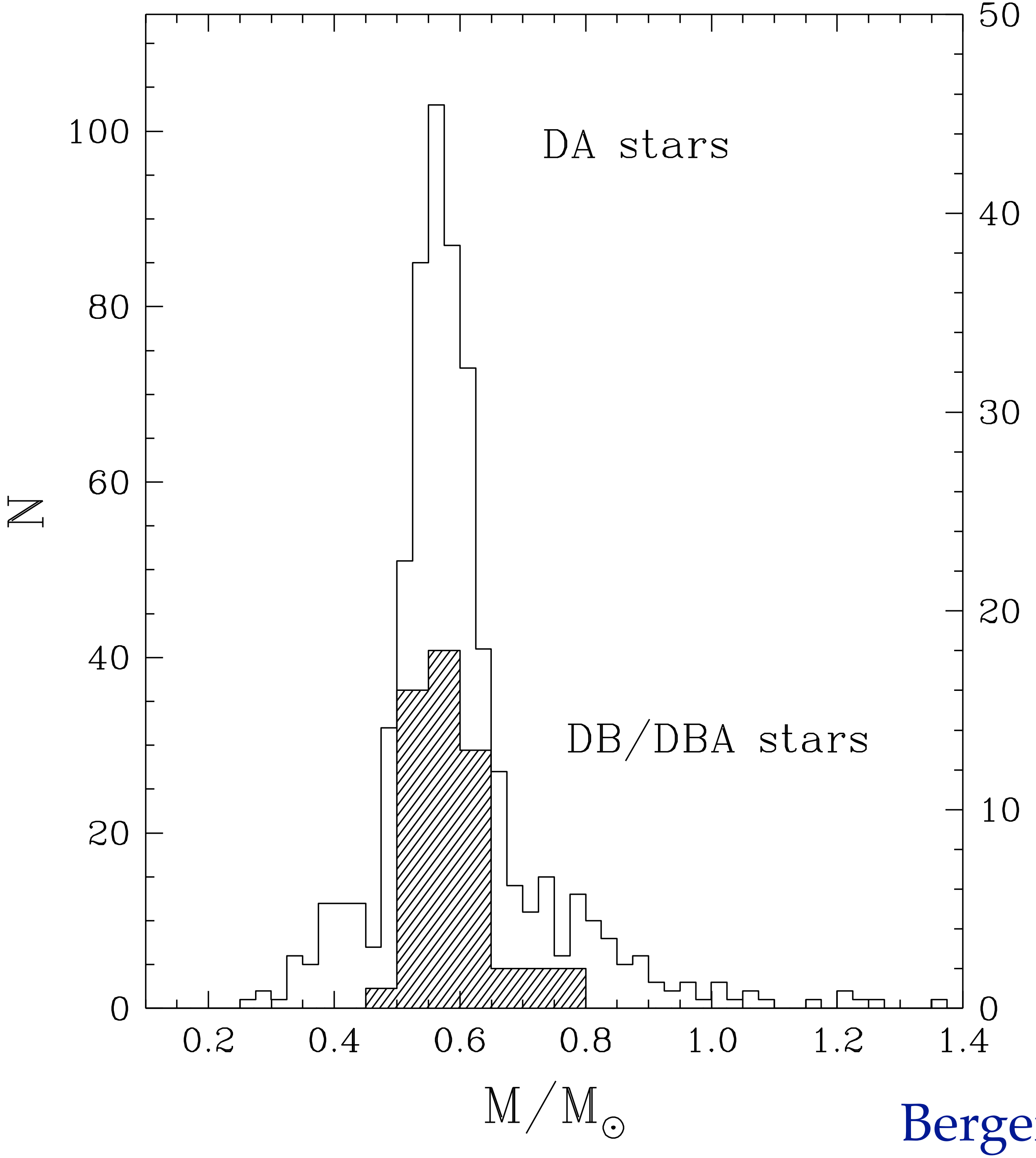



Hot blackbody
Prism
Cloud of
cooler gas
b Absorption line spectrum
Prism
a Continuous spectrum
c Emission line spectrum


NGC 7009
O II
[O III]
Flux
[Ne III]
Hβ
[Ne III]
Hϵ
Hγ
Hδ
[O III]
He II
Wavelength







Bergeron et al. 2007

The Life of the Sun