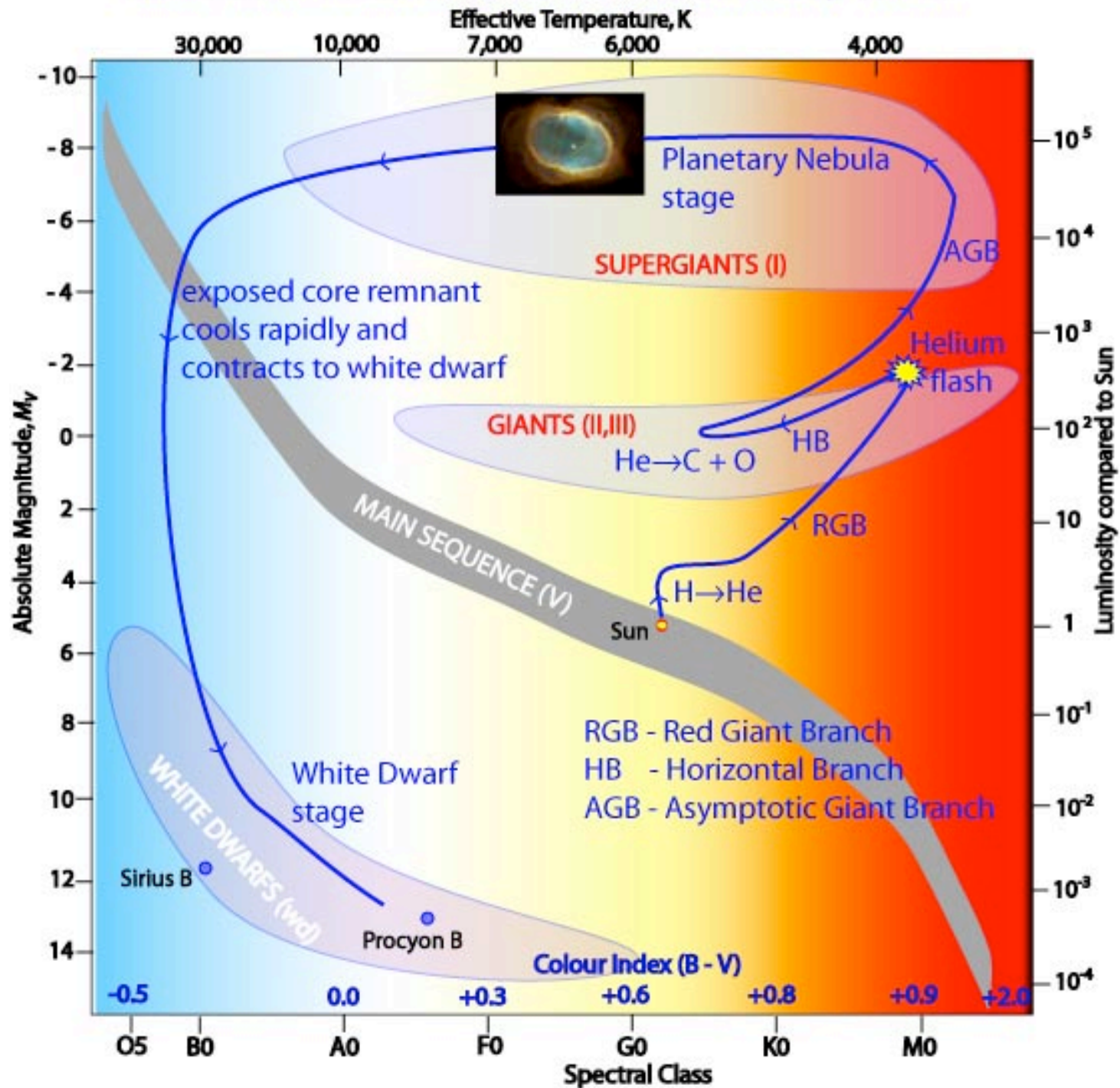


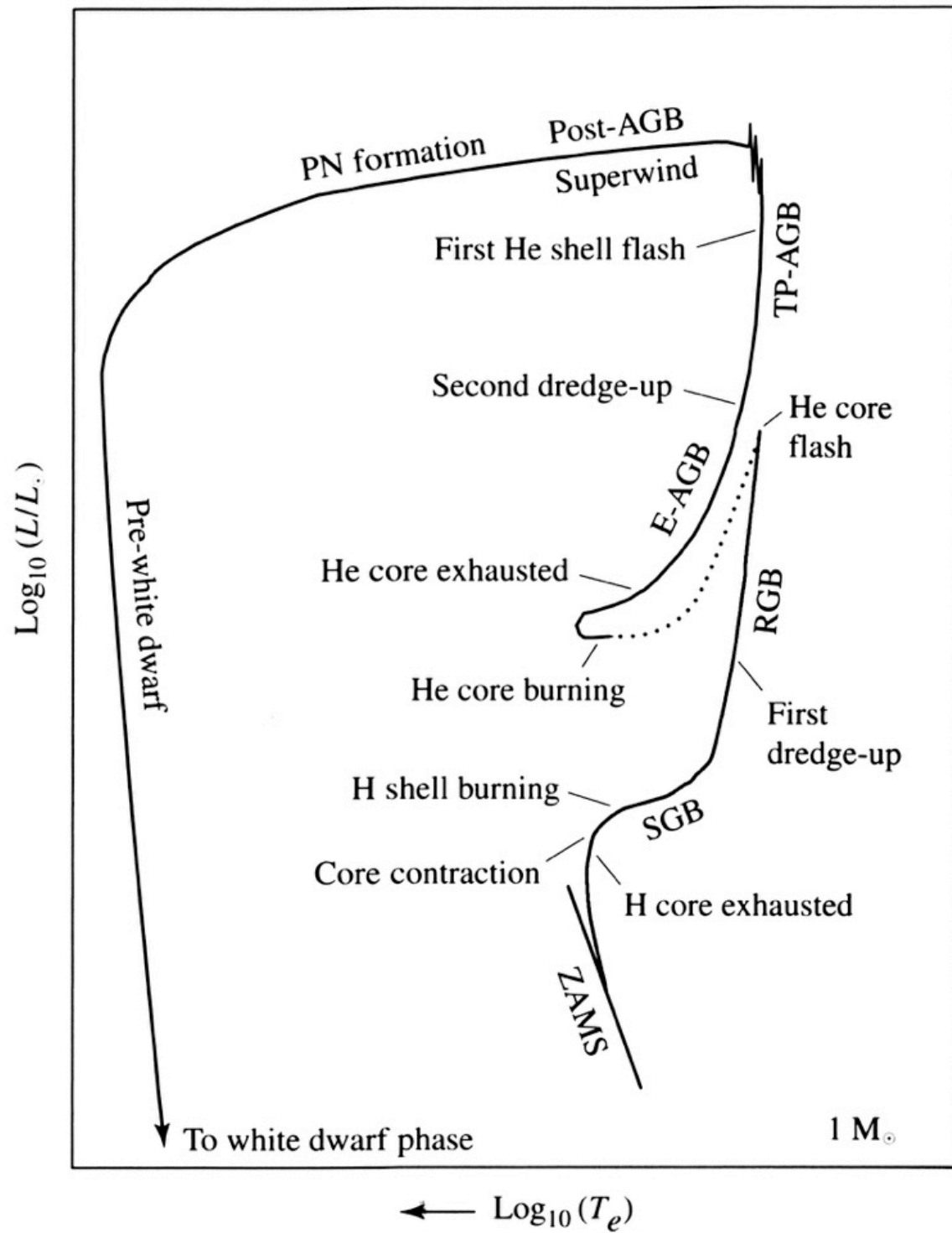
Structure and Evolution of Stars

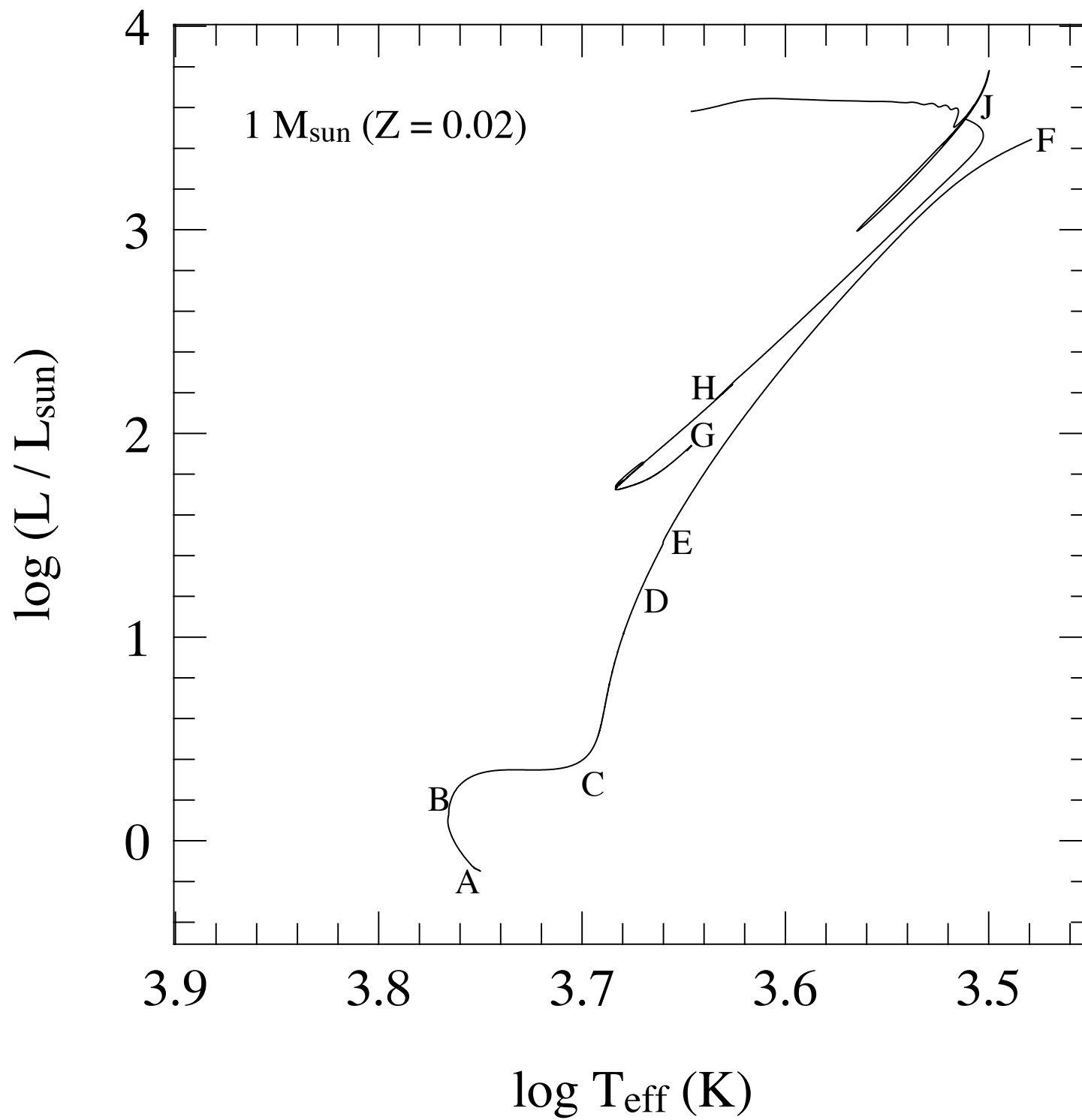


Lecture 13

Sun's Post-Main Sequence Evolutionary Track







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 rigorous¹. 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

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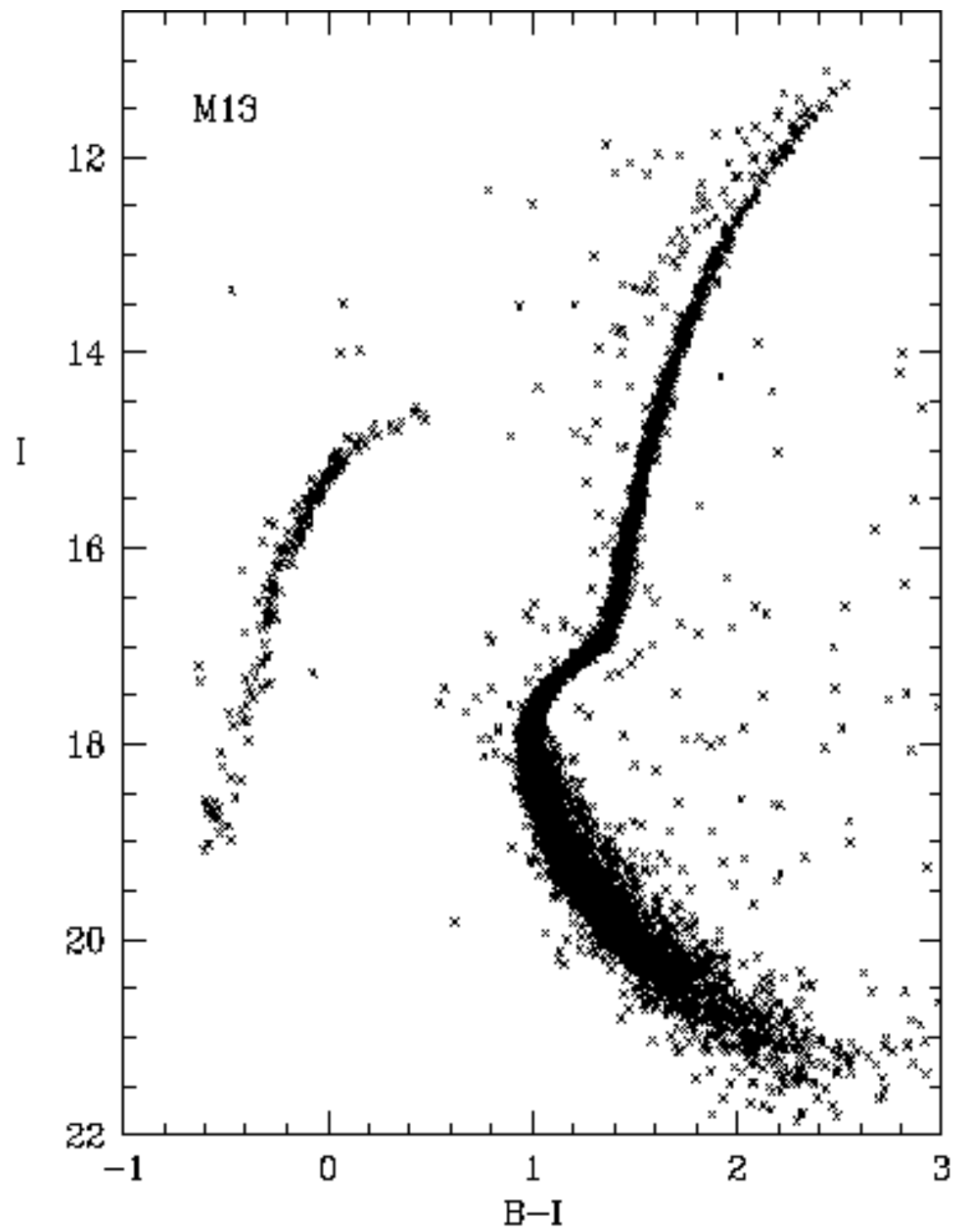
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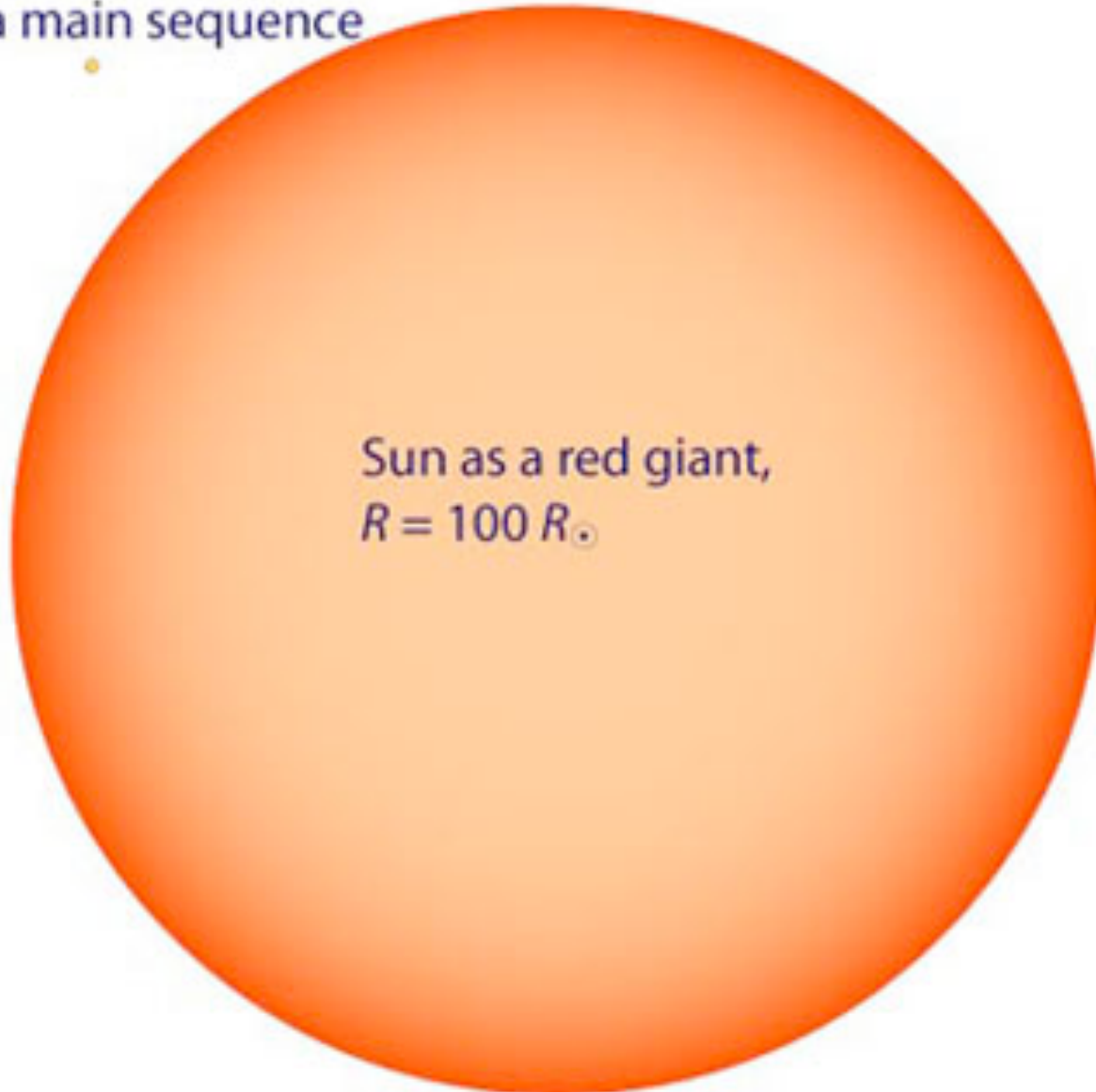


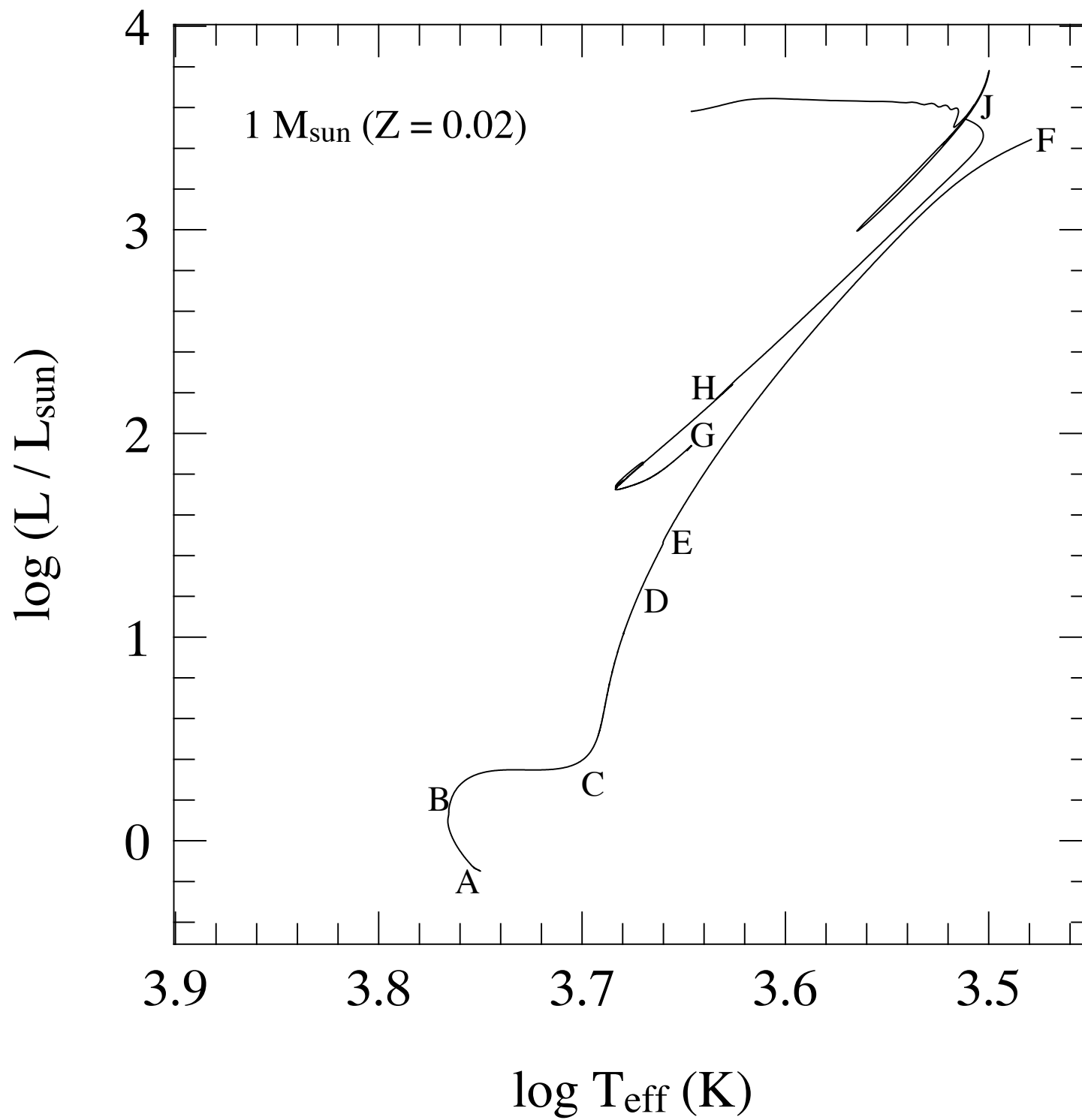
Comparison in size of Sun as a main sequence star and a red giant

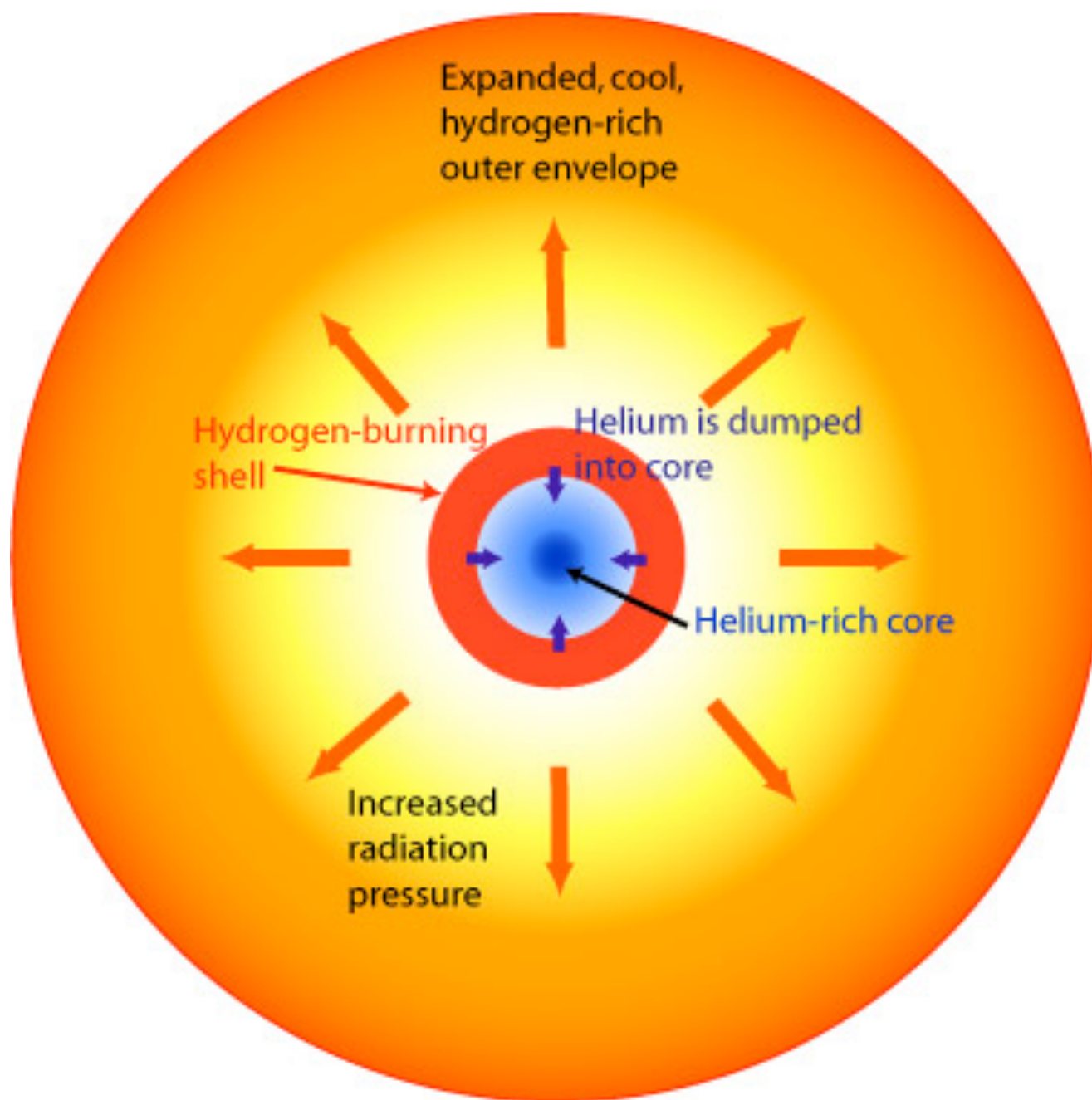
Sun as a main sequence
star



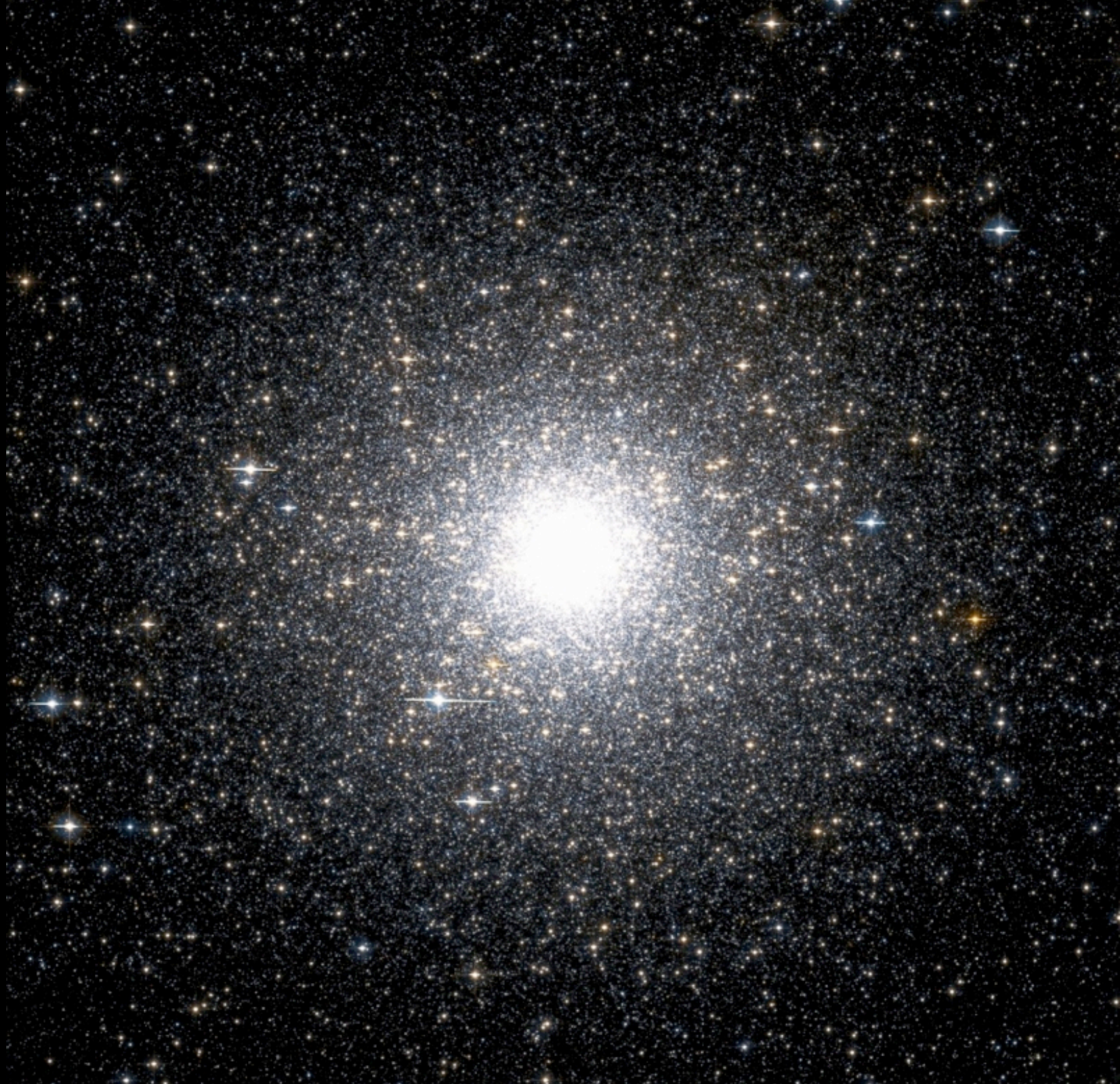
Sun as a red giant,
 $R = 100 R_{\odot}$







Hydrogen Shell Burning on the Red Giant Branch

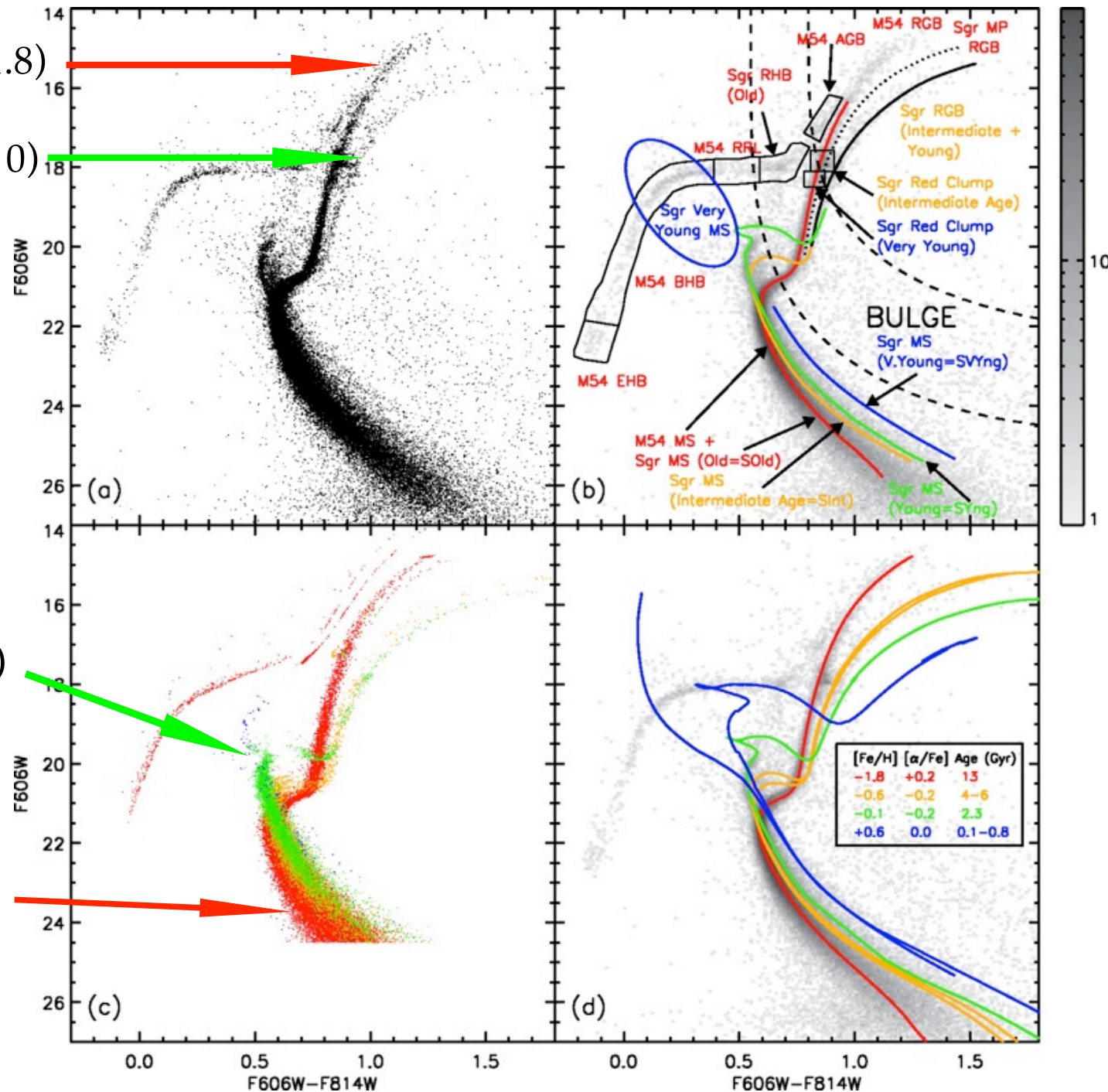


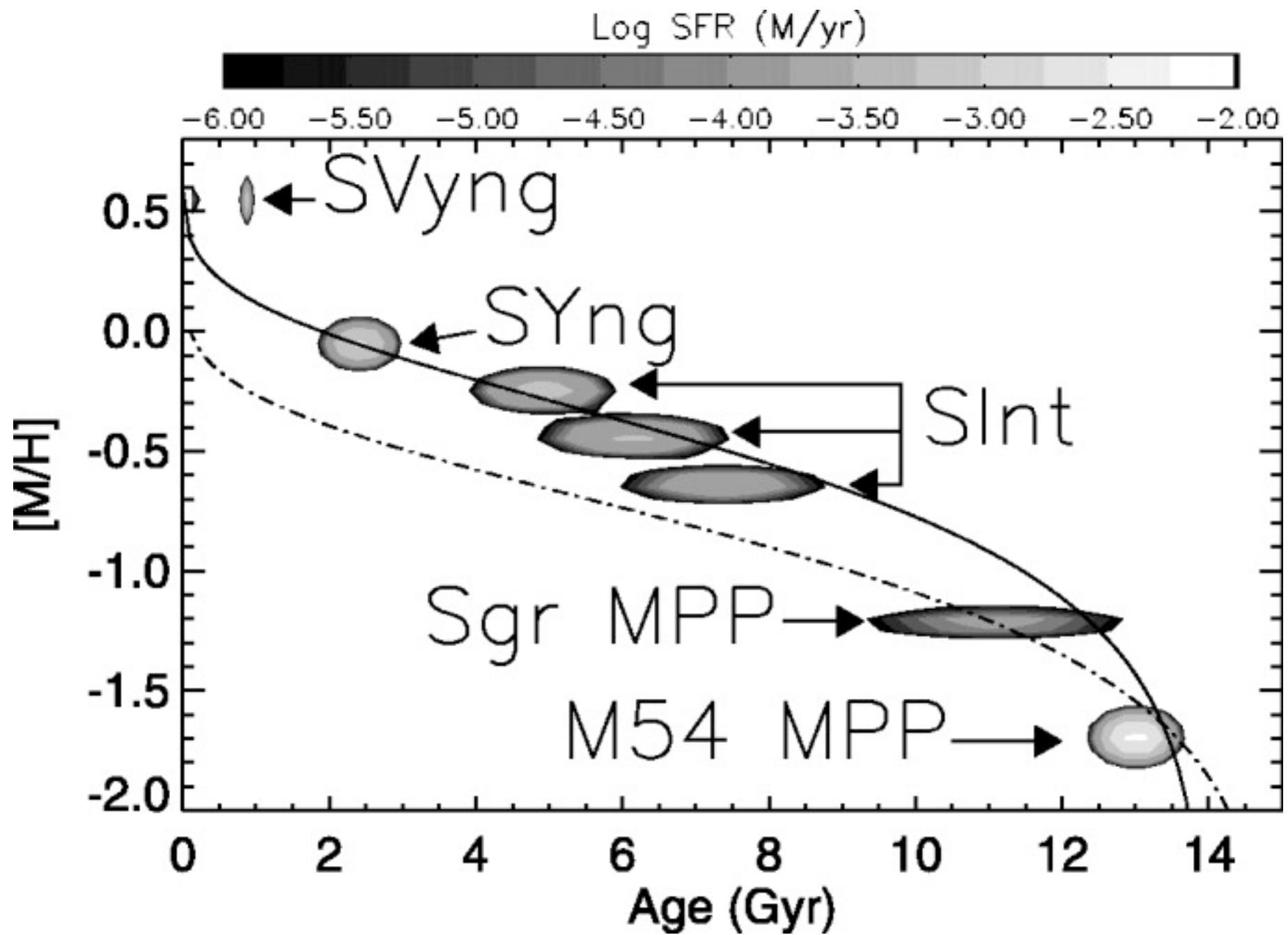
RGB of Old Pop ($[\text{Fe}/\text{H}] = -1.8$)

RGB of Young Pop ($[\text{Fe}/\text{H}] = 0$)

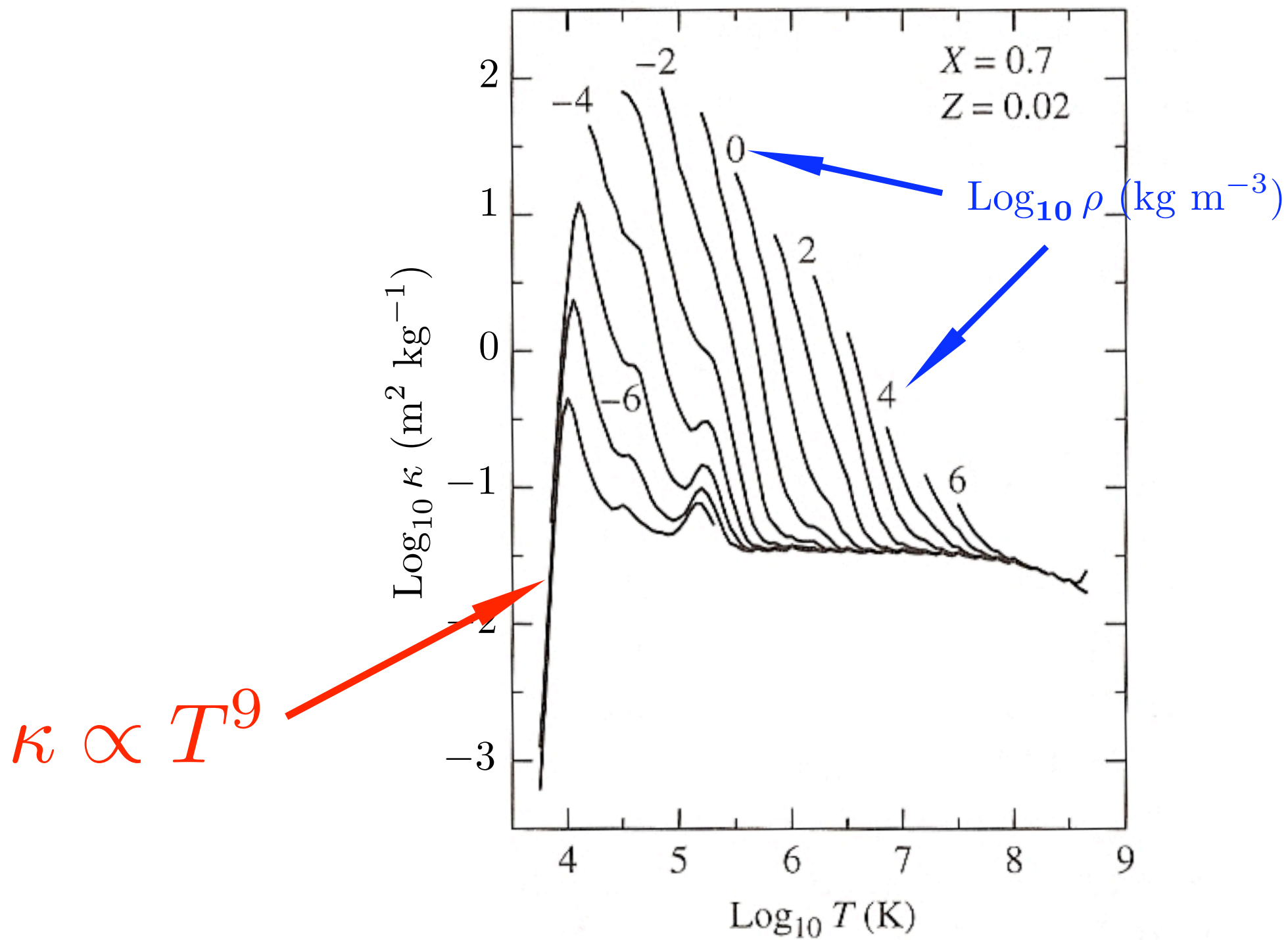
MS of Young Pop (< 2 Gyr)

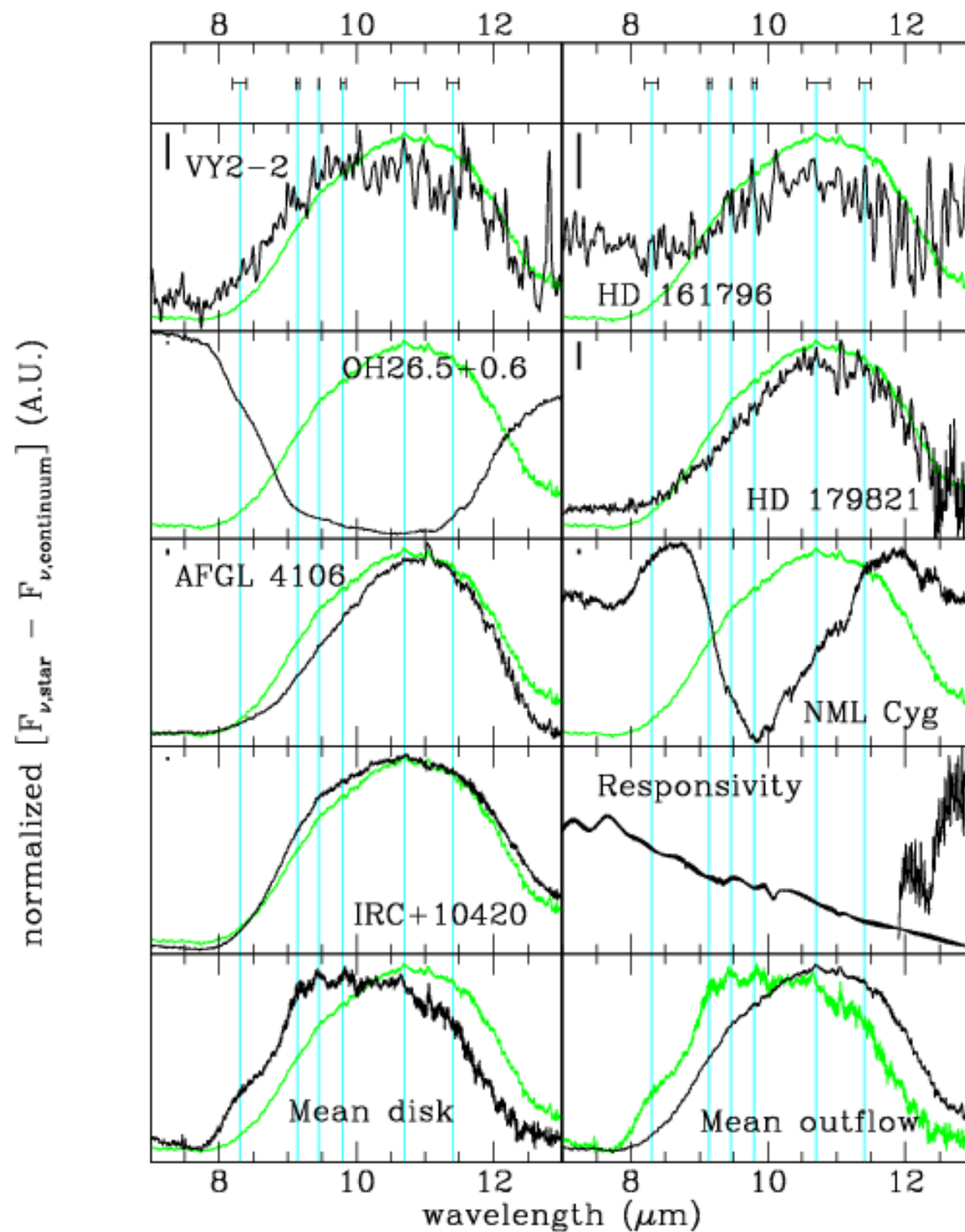
MS of Old Pop (12 Gyr)



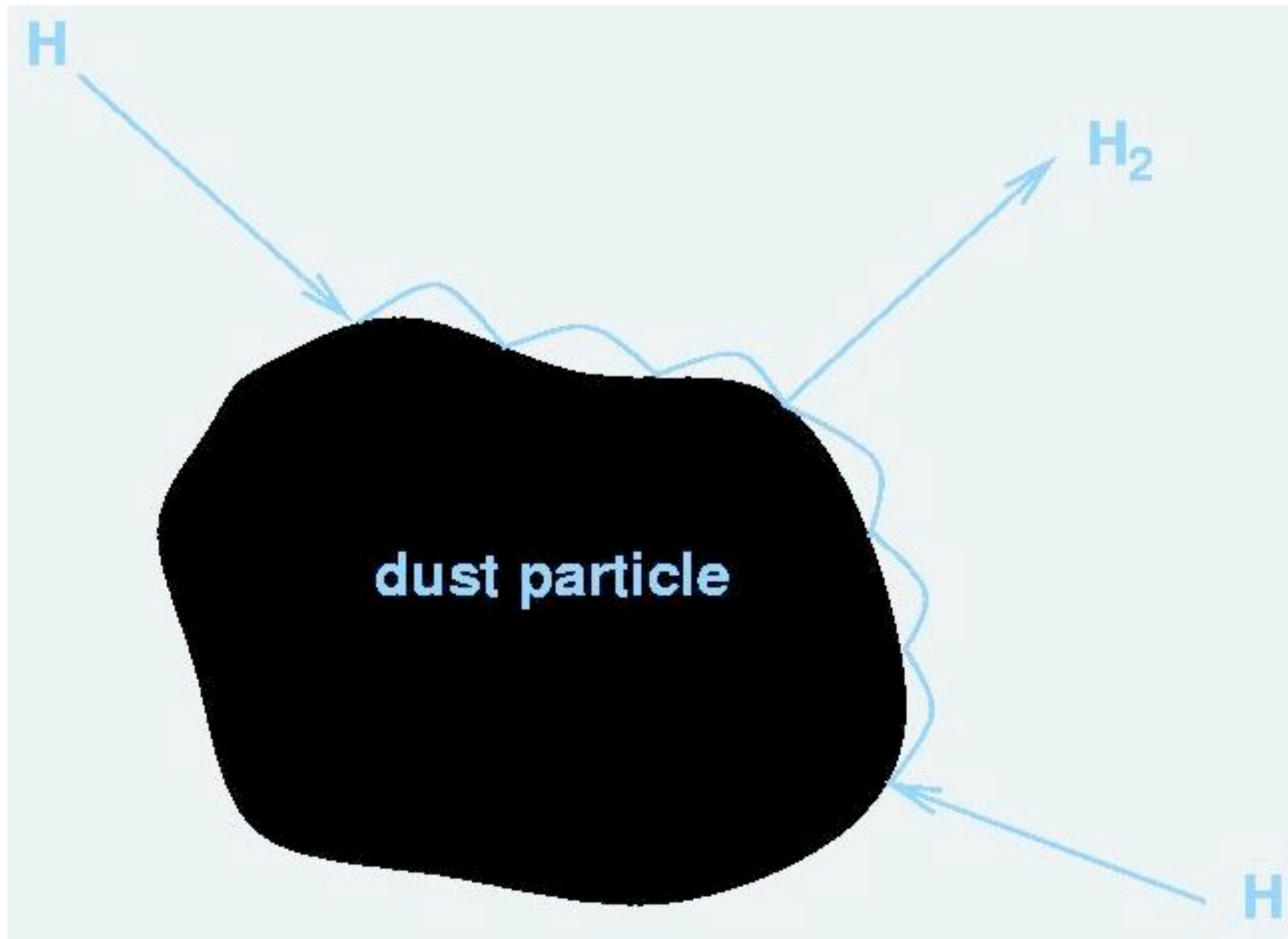


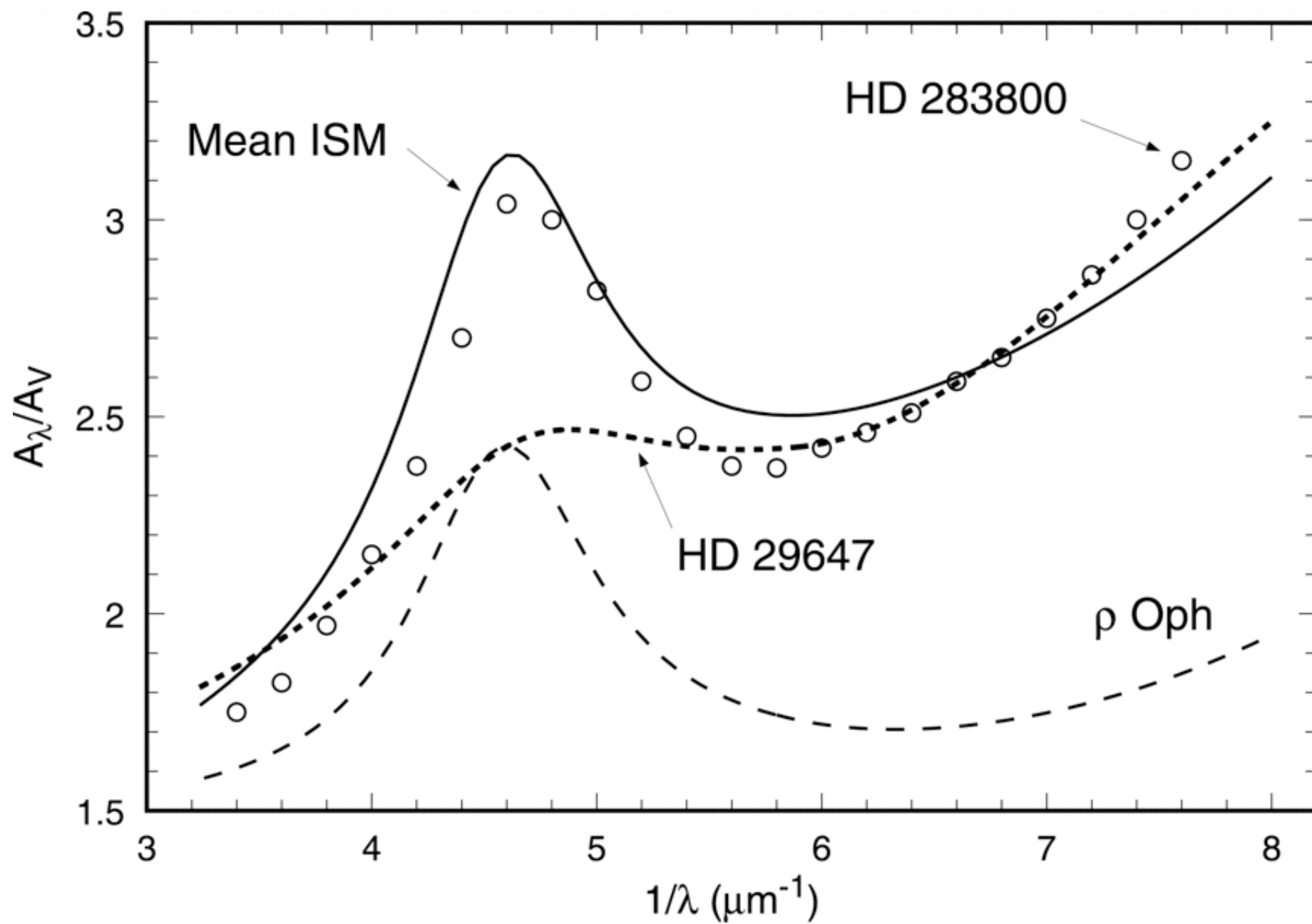
Siegel et al. 2007

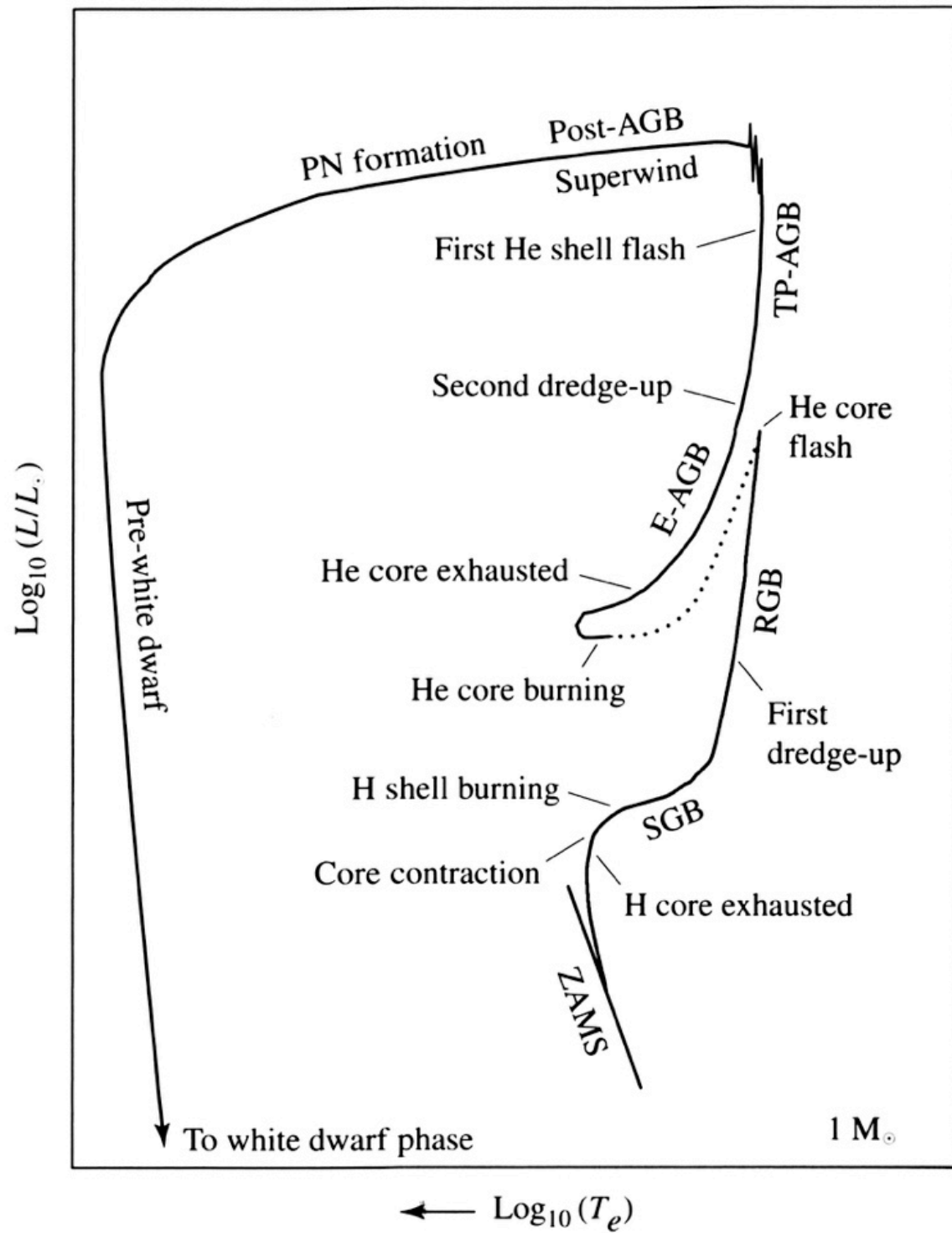


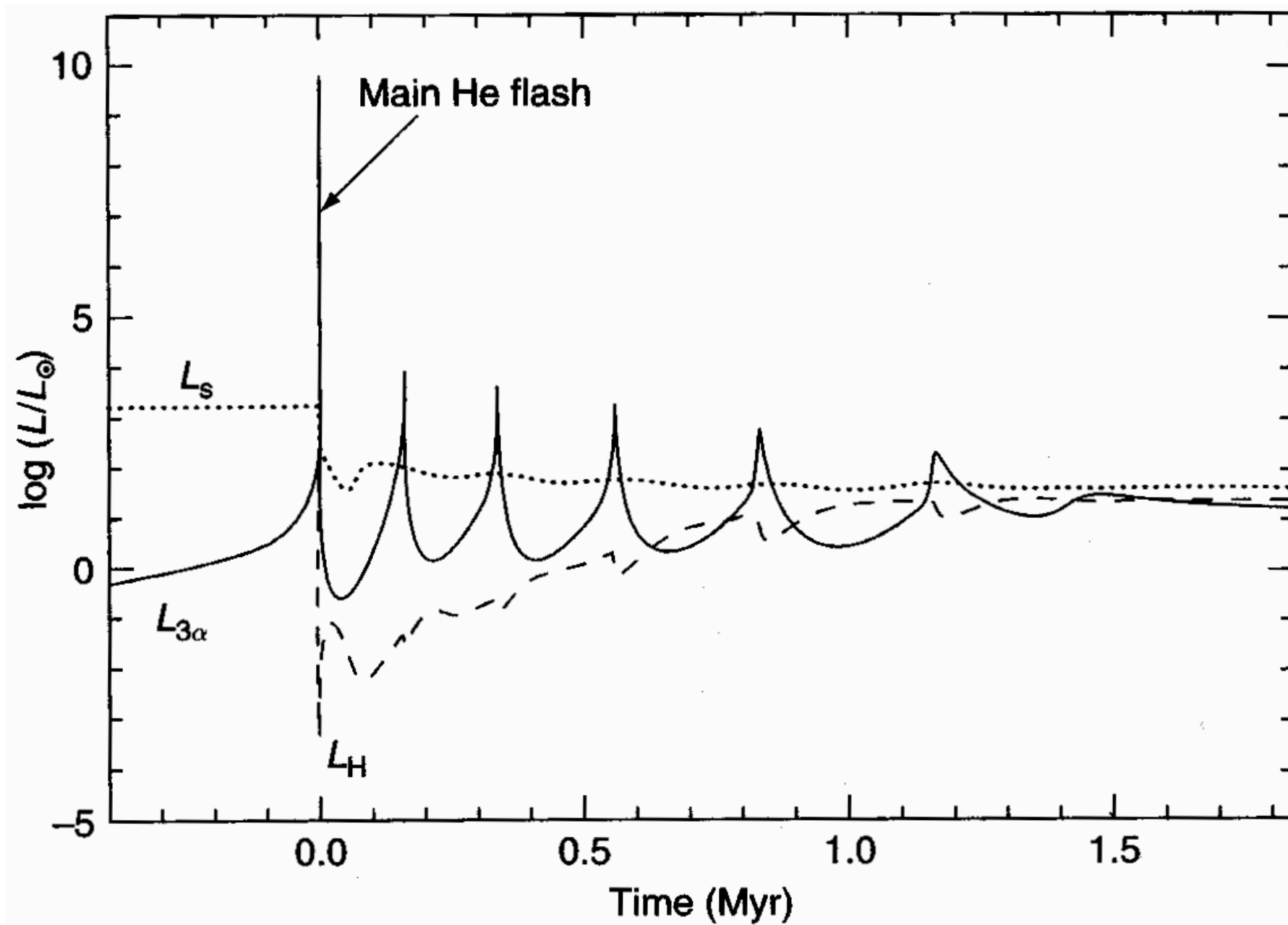


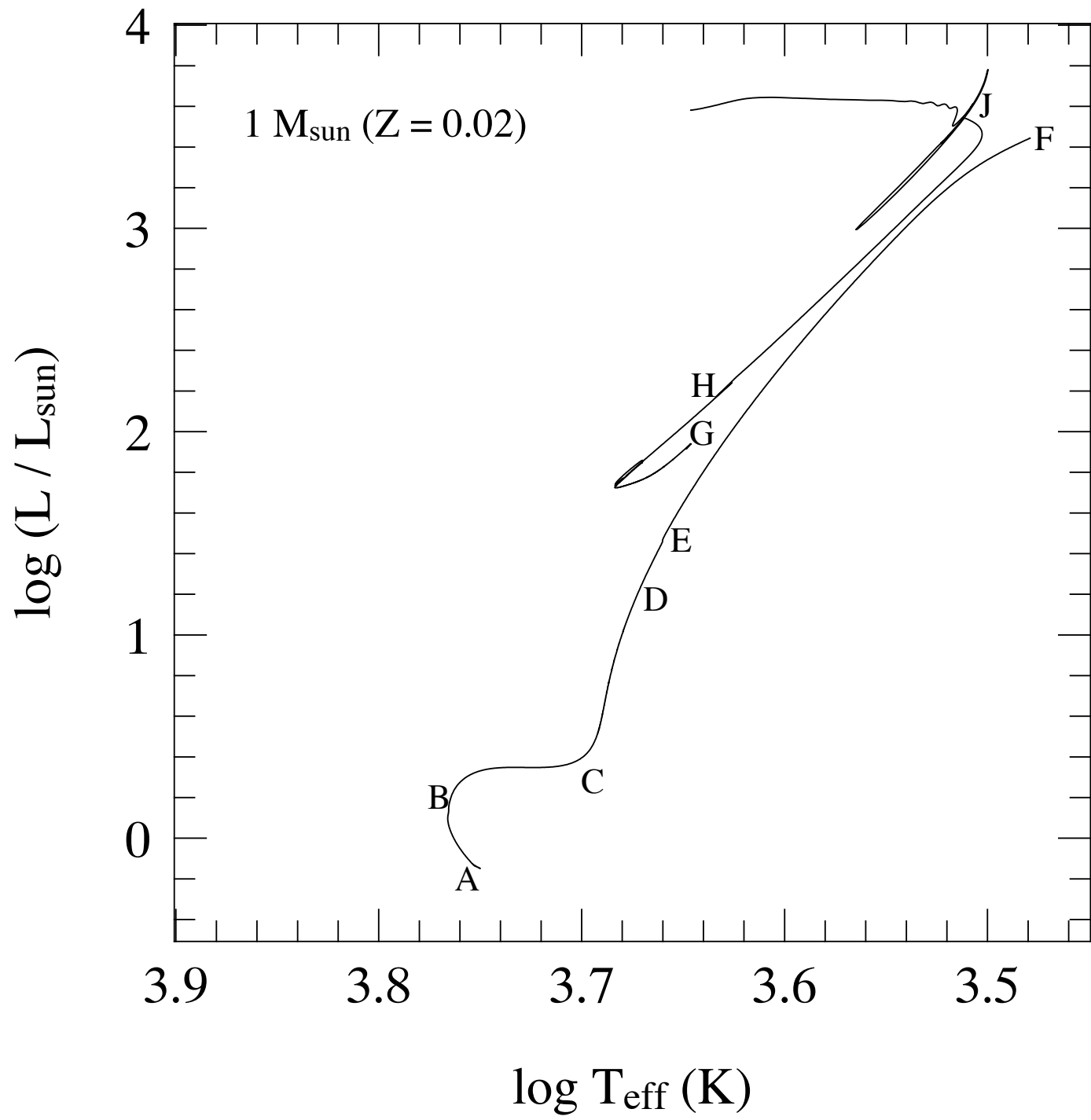
Molster et al. 2002

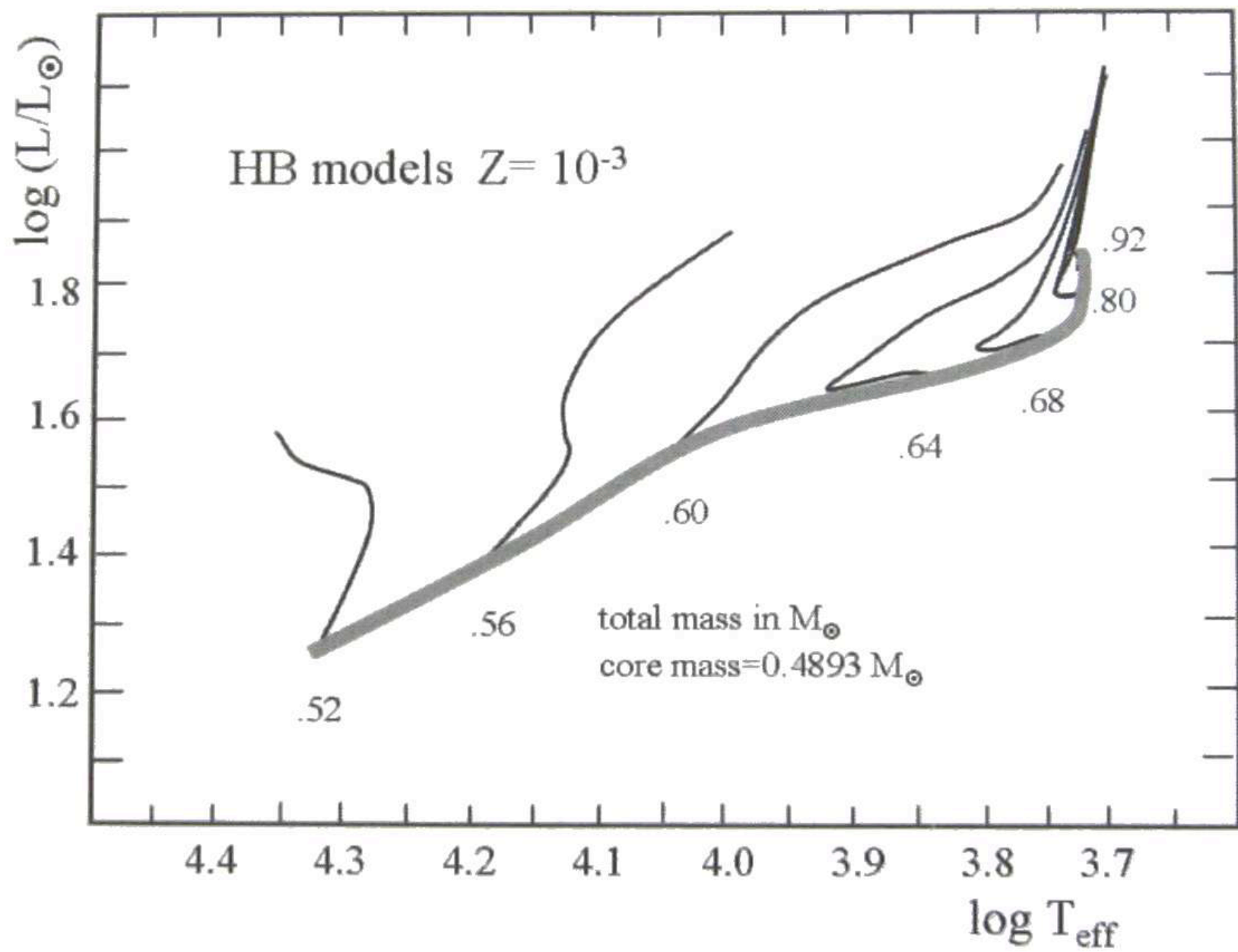








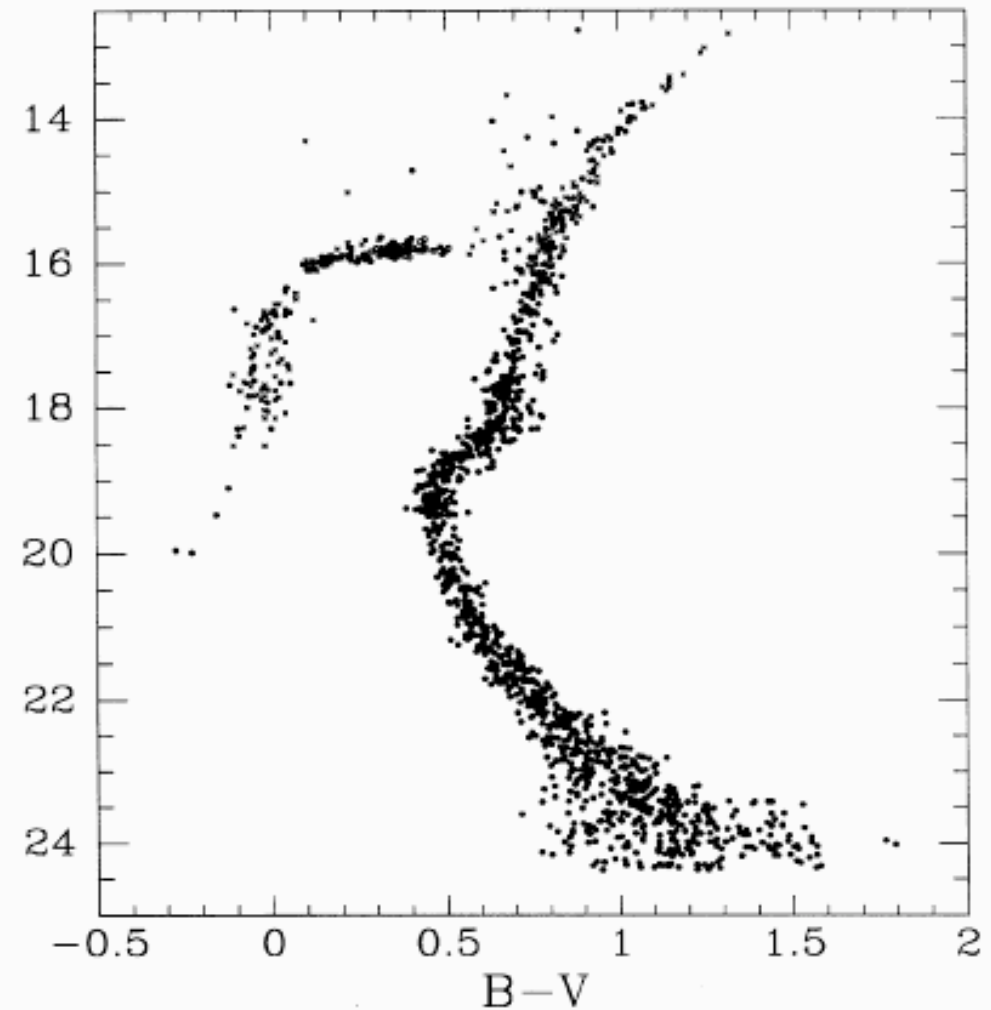
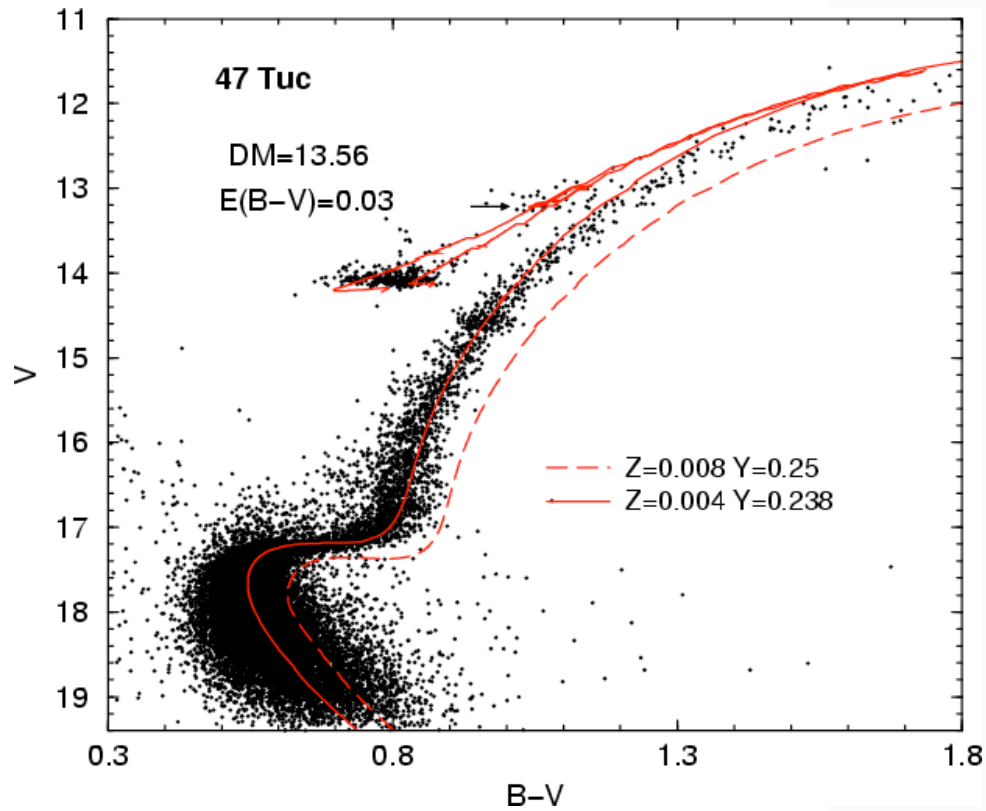


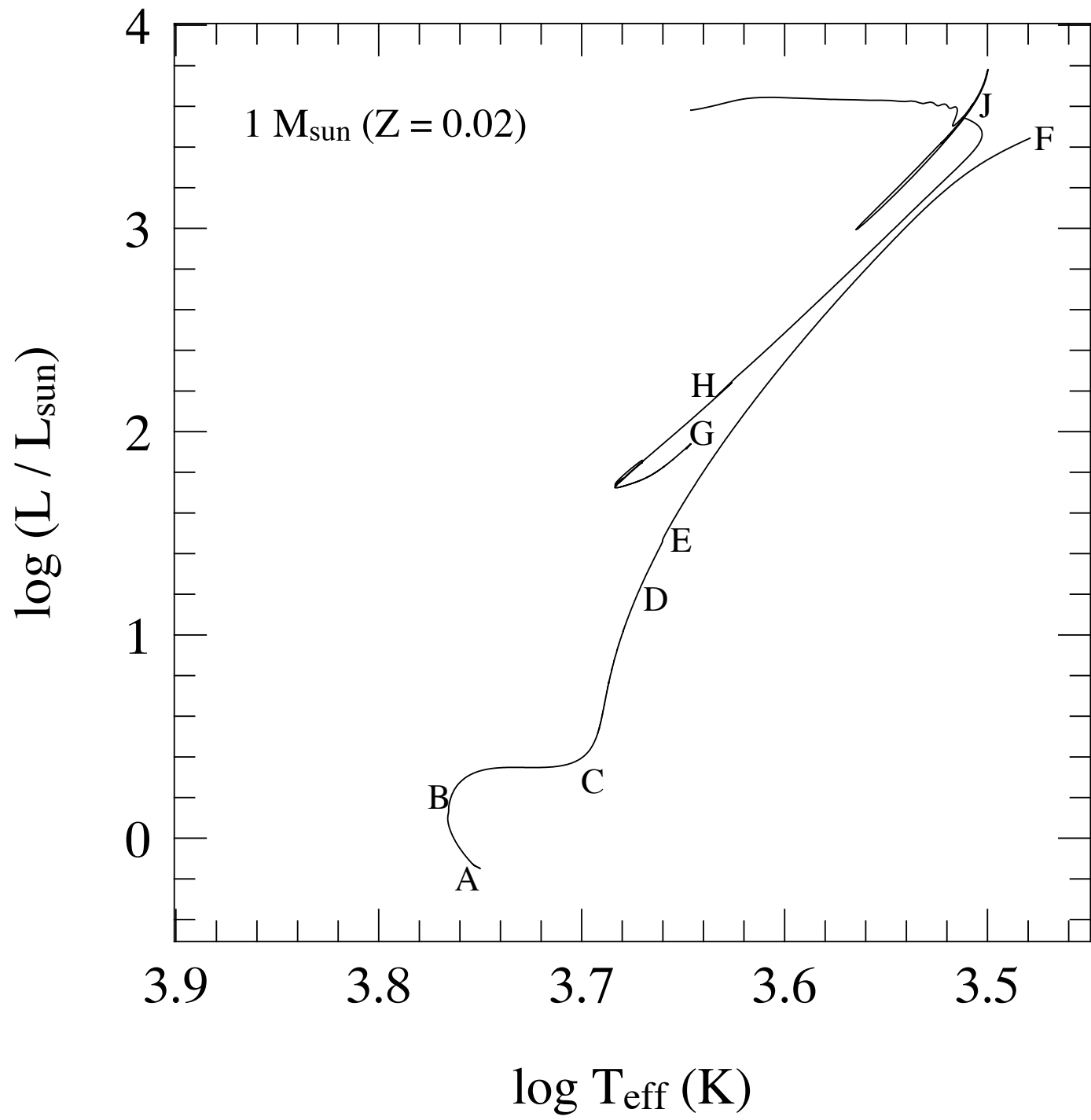


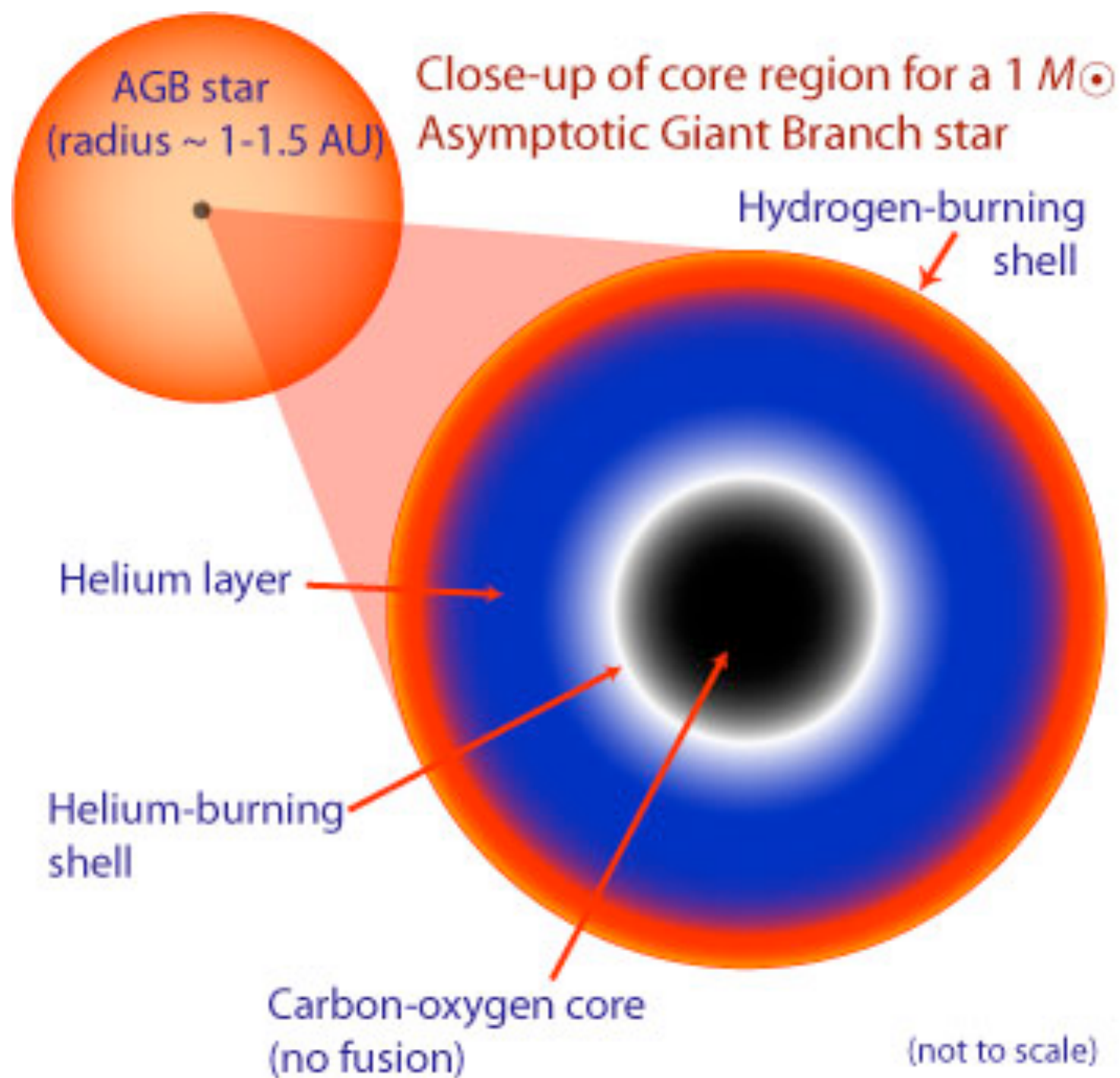
Two Globular Clusters

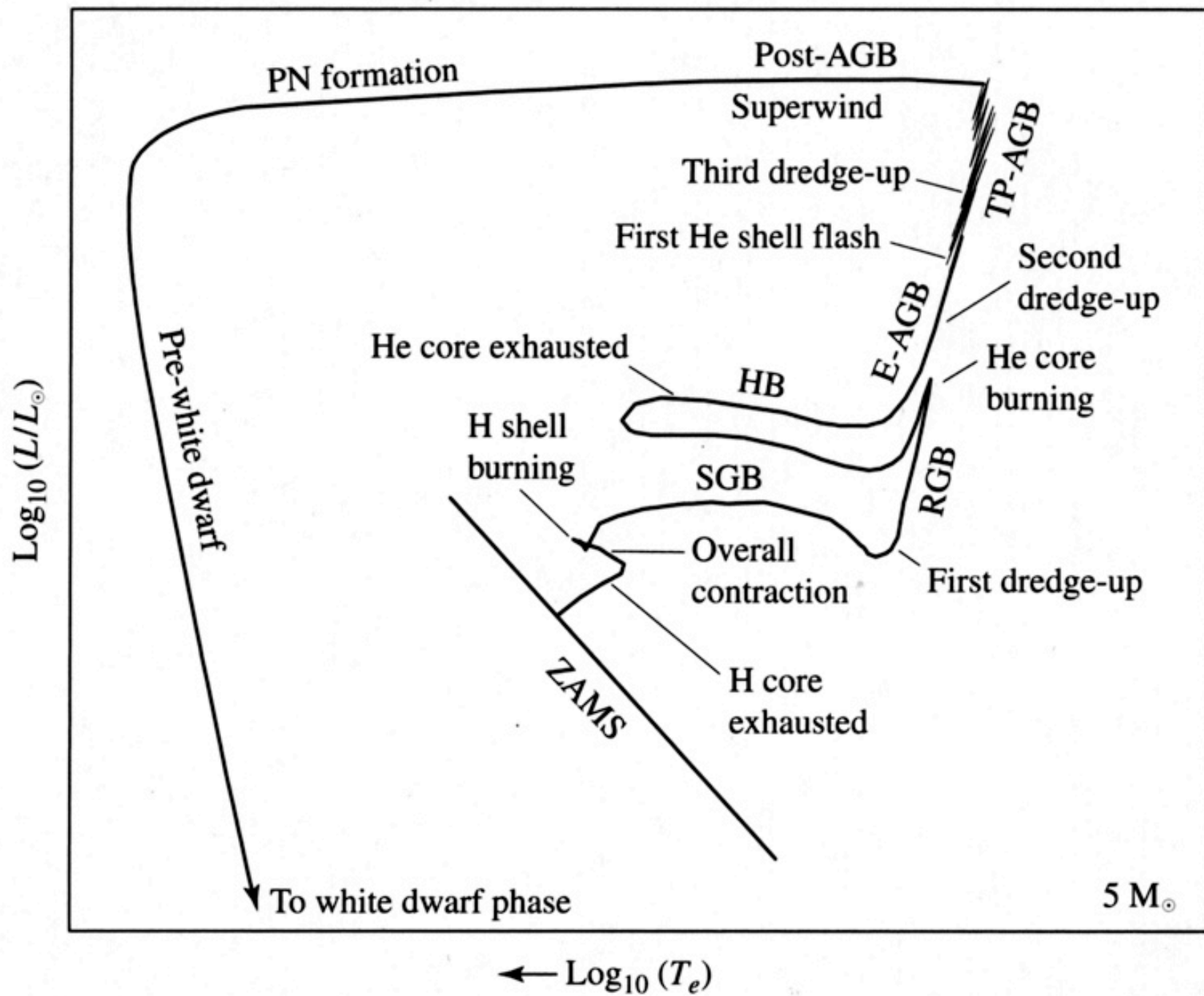
M15, $[\text{Fe}/\text{H}] = -2.4$

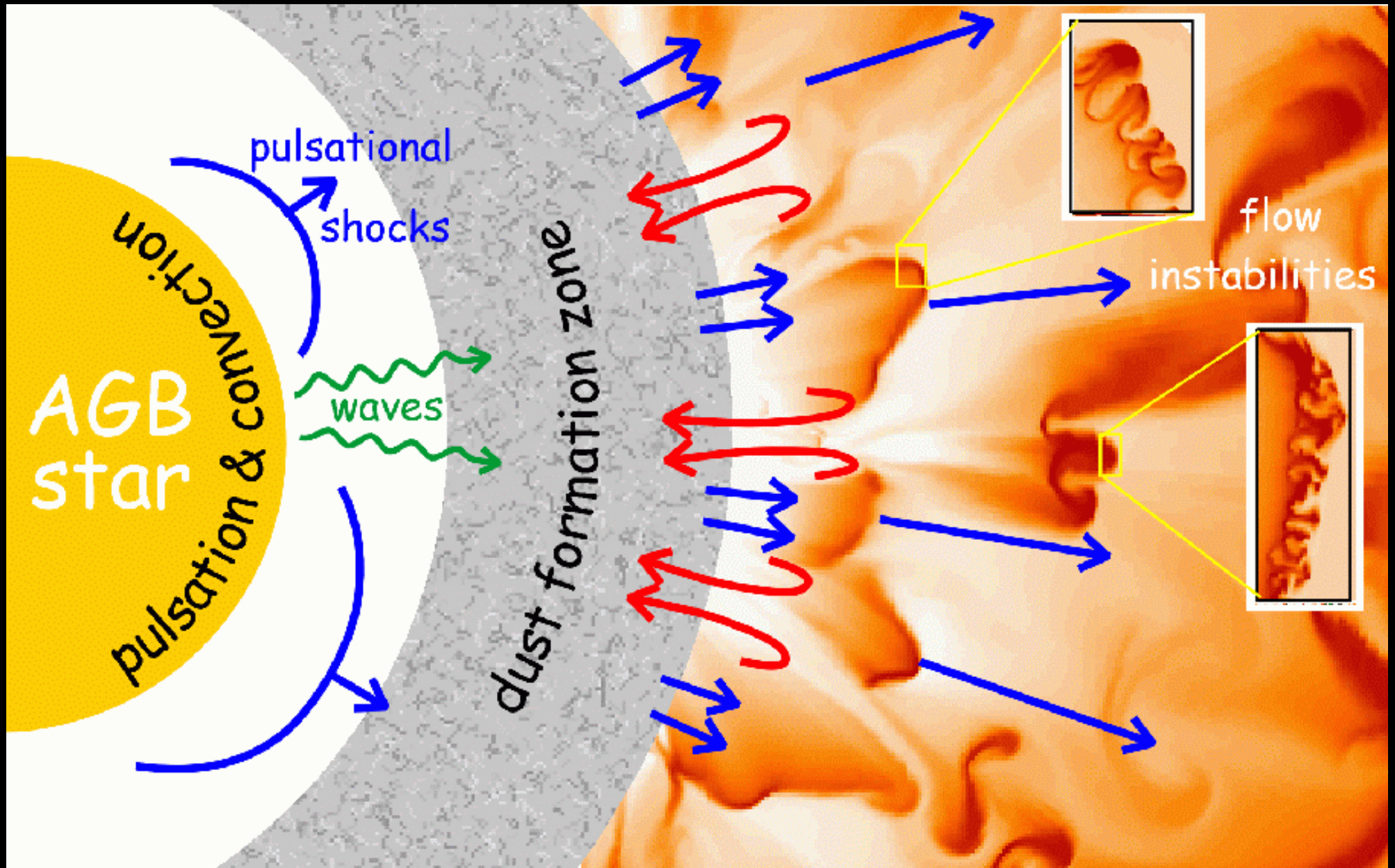
47 Tuc, $[\text{Fe}/\text{H}] = -0.8$



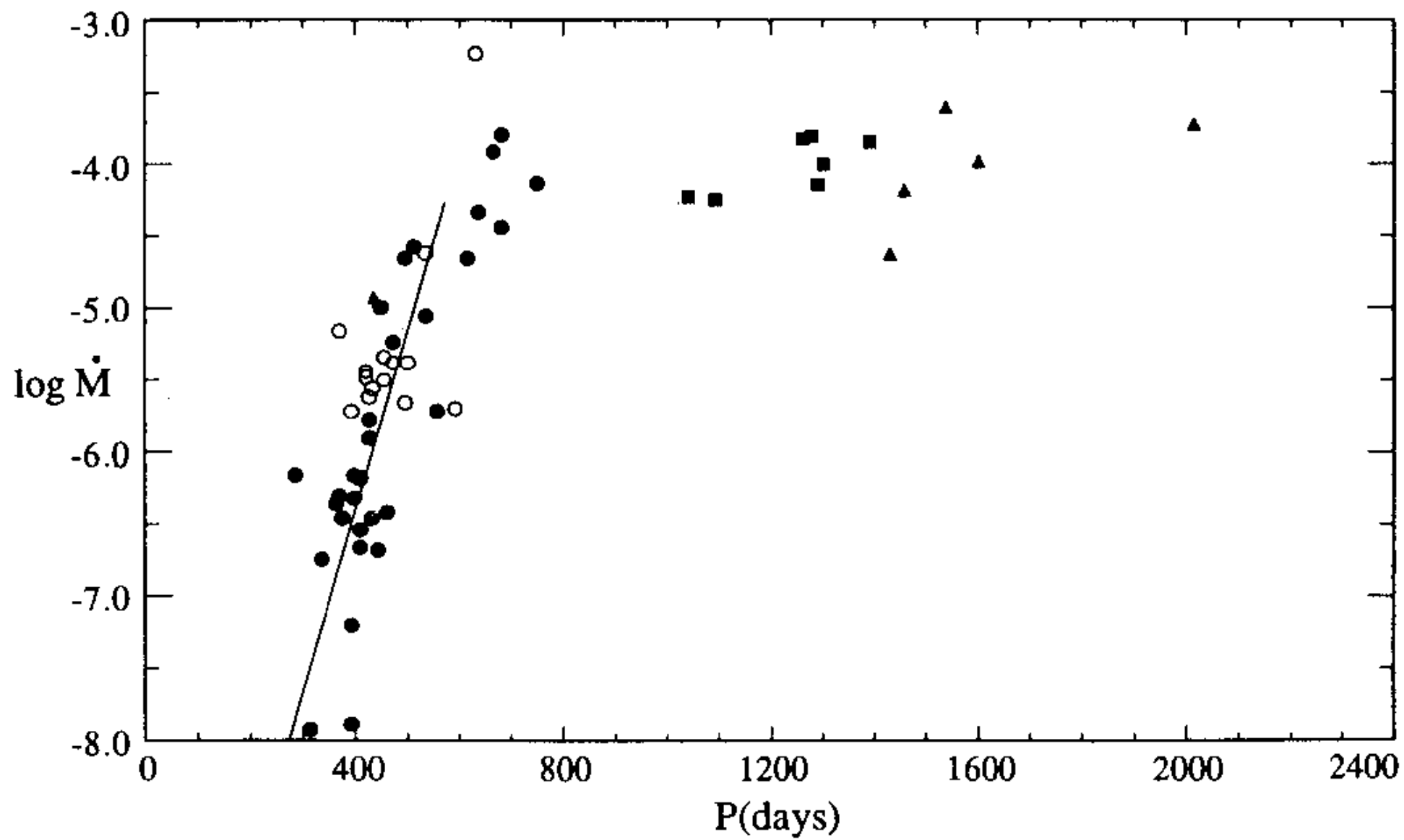


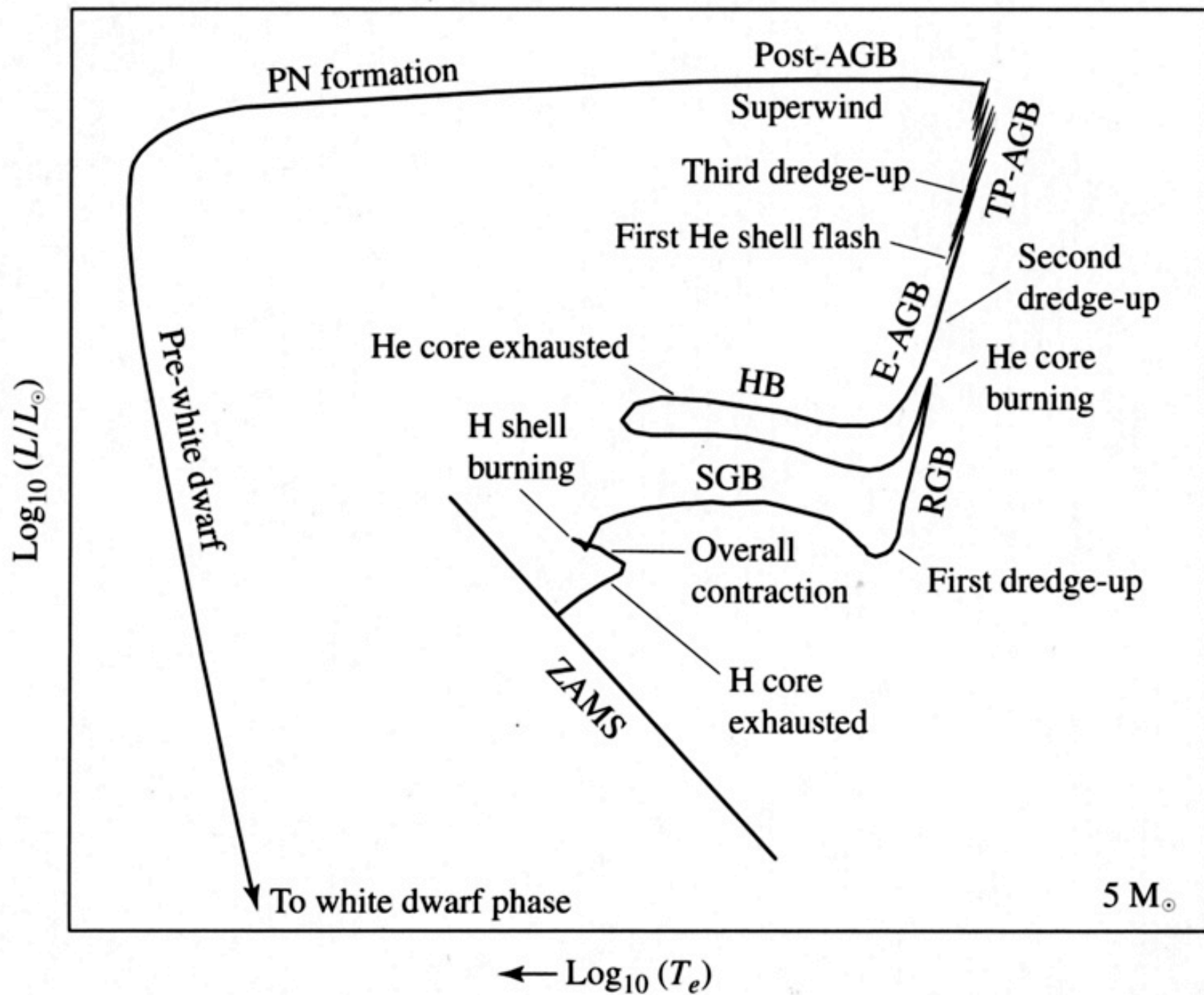














Helix Nebula • NGC 7293
Hubble Space Telescope • Advanced Camera for Surveys
NOAO 0.9m • Mosaic I Camera

Cat's Eye Nebula • NGC 6543

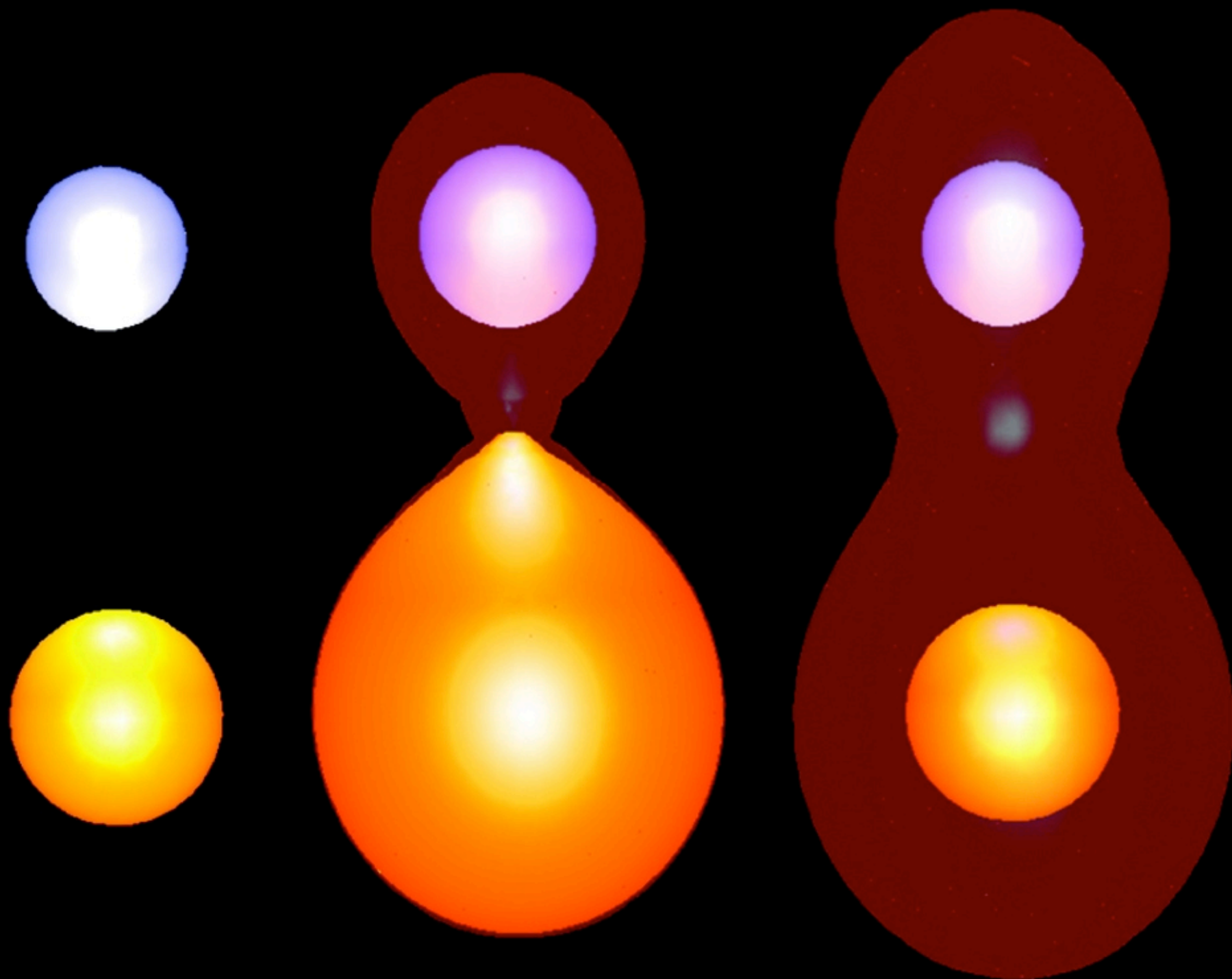


Hubble
Heritage











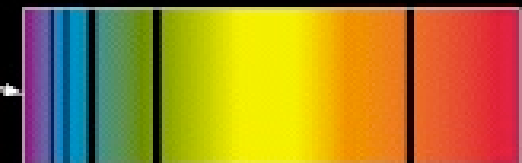




Hot blackbody

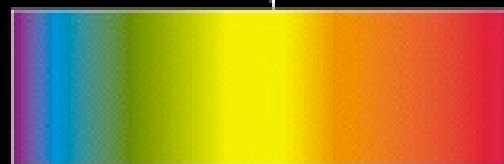


Prism



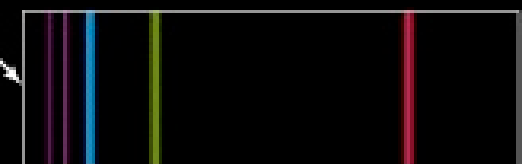
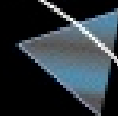
b Absorption line spectrum

Prism



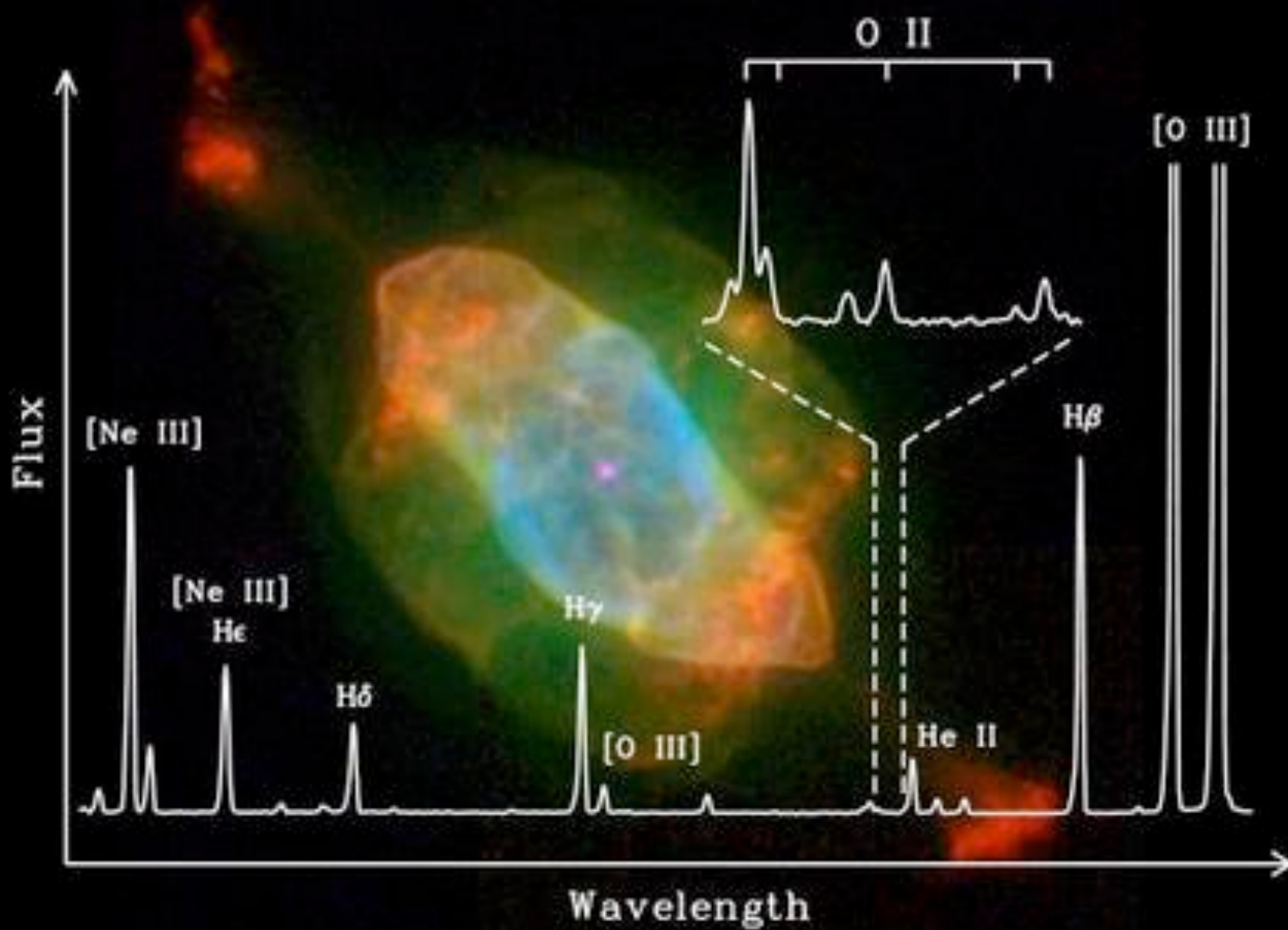
a Continuous spectrum

Cloud of cooler gas

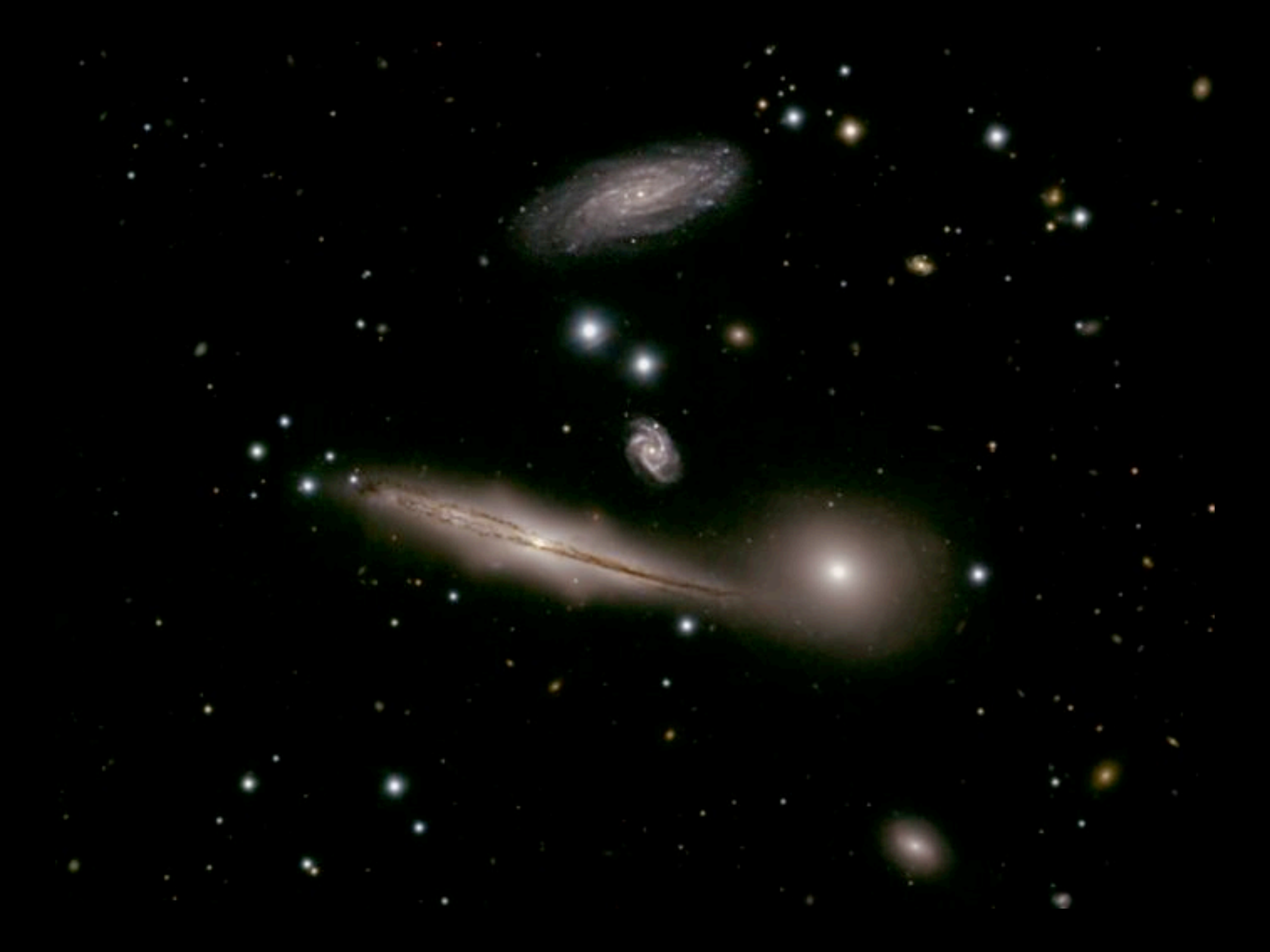


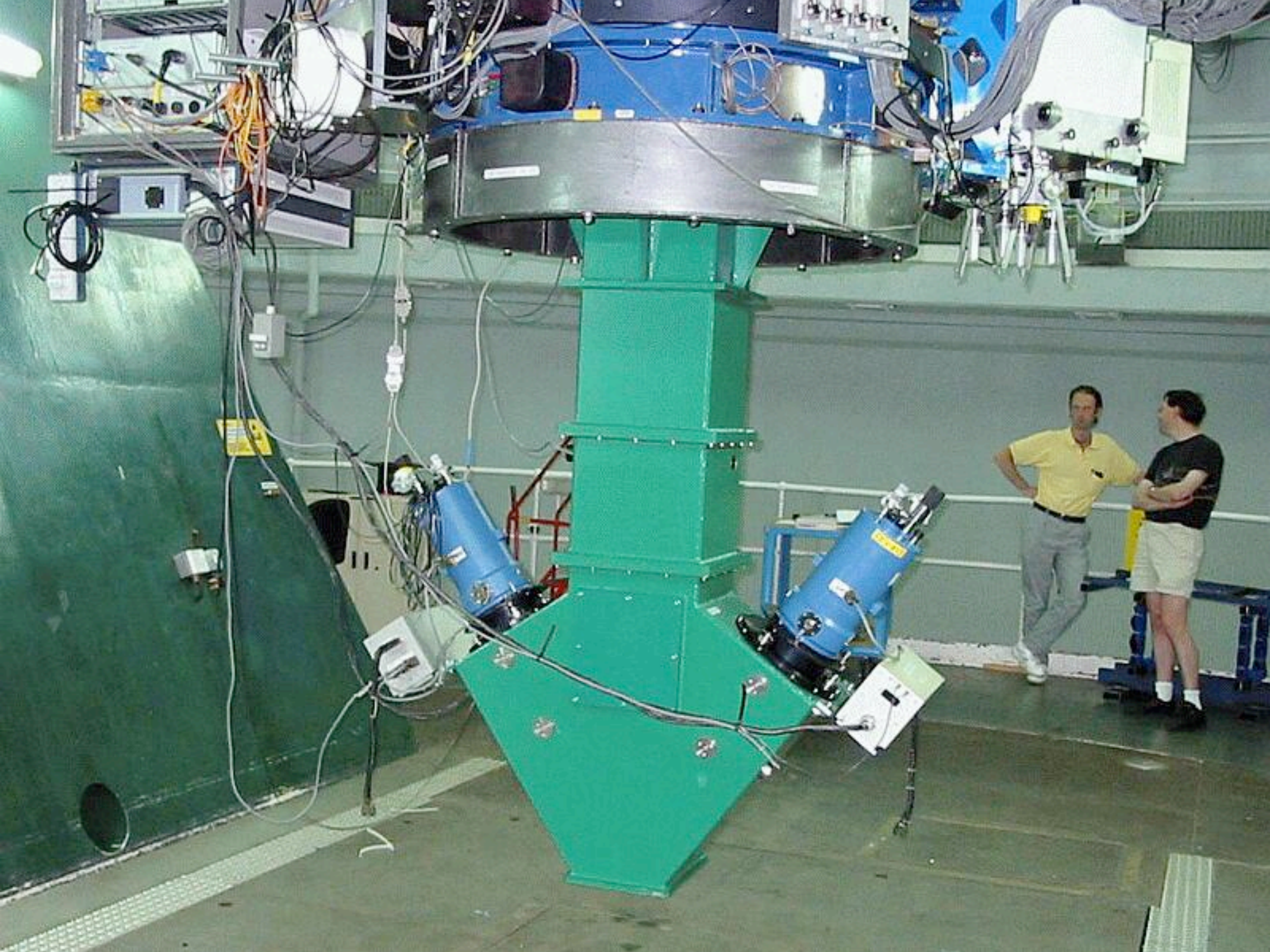
c Emission line spectrum

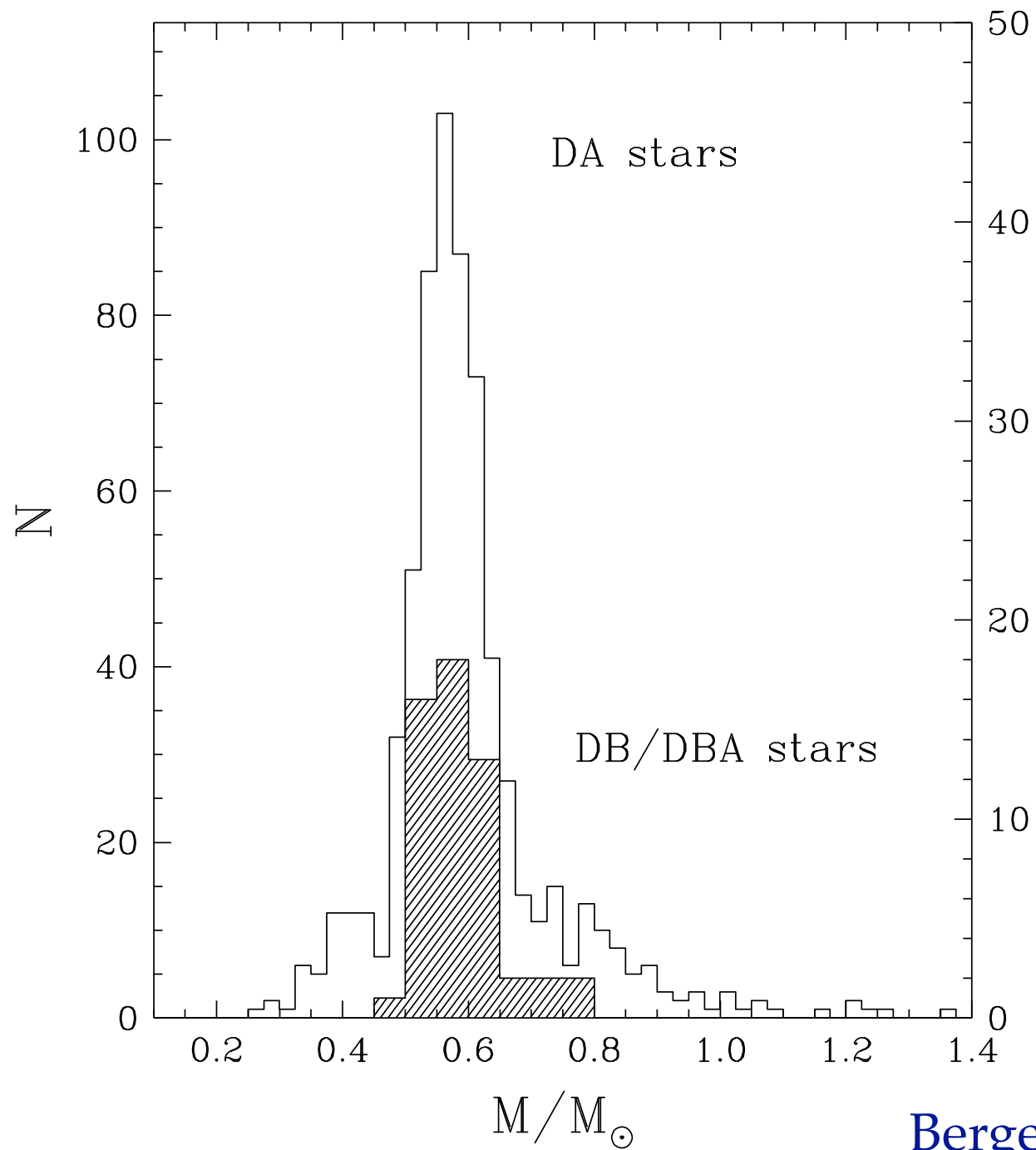
NGC 7009











Bergeron et al. 2007

The Life of the Sun

