

# Stages of Stellar Evolution I

H core burning

He core burning

H/He shell burning

Helium flash

Carbon ignition

Subgiant phase

Red Giants

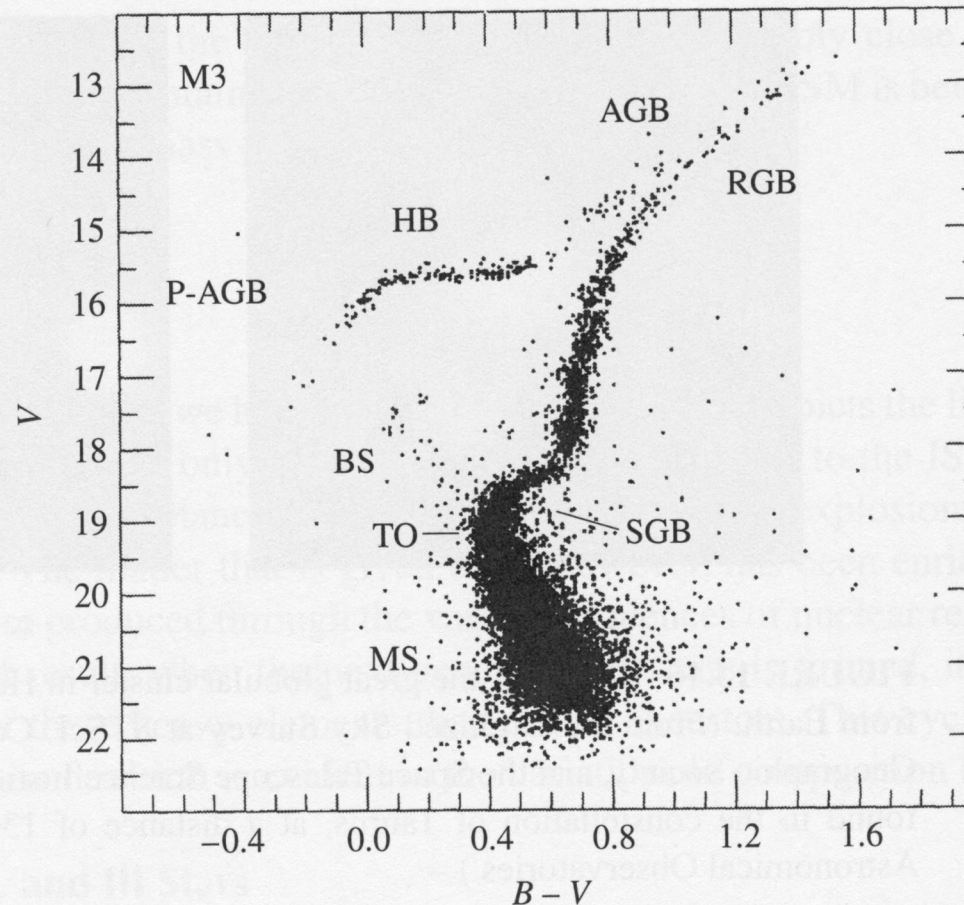
Supergiants

AGB

Endpoints

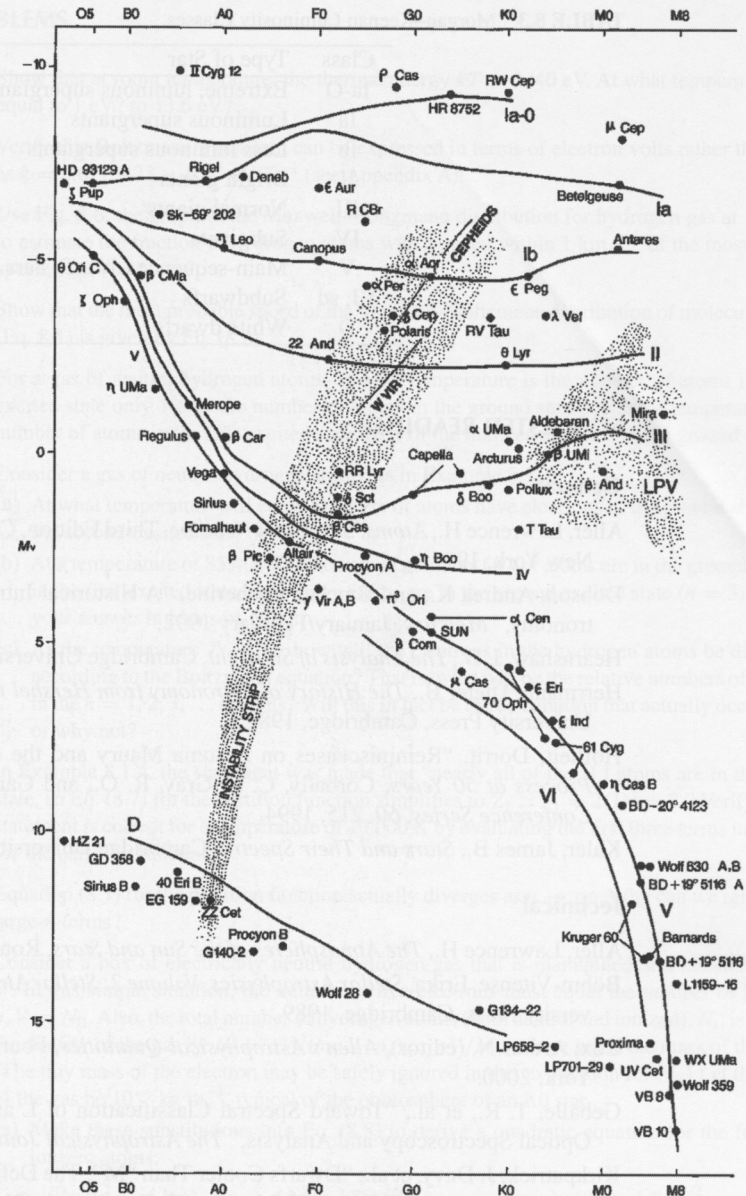
# Stages of Stellar Evolution II ( $< \sim 8 M_{\text{sun}}$ )

- Kelvin-Helmholtz/Hayashi
- Main Sequence
- Subgiant Branch
- Red Giant Branch
- Red Giant Tip
- Helium Core Flash
- Horizontal Branch
- Early Asymptotic Branch
- Thermal-pulse AGB (Schwarzschild-Harm)
- Dredge-up (1st, 2nd, 3rd)
- Mass Loss and AGB
- Post-AGB
- Planetary Nebula and PG 1159
- White Dwarf



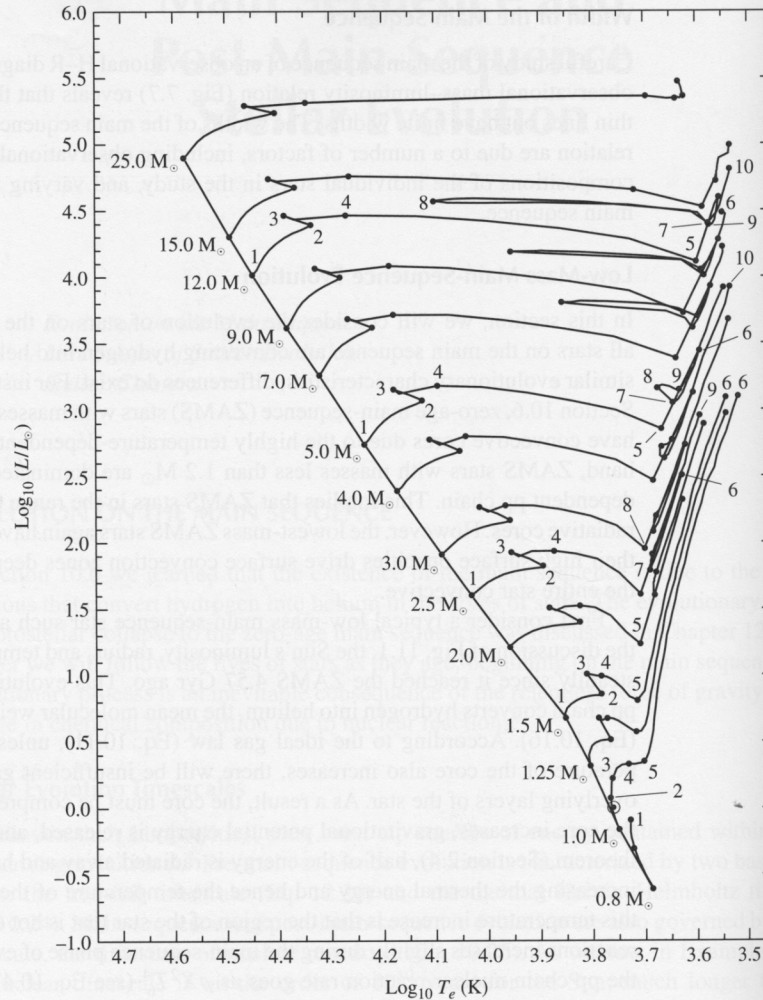
**FIGURE 13.17** A color-magnitude diagram for M3, an old globular cluster. The major phases of stellar evolution are indicated: main sequence (MS); blue stragglers (BS); the main-sequence turn-off point (TO); the subgiant branch of hydrogen shell burning (SGB); the red giant branch along the Hayashi track, prior to helium core burning (RGB); the horizontal branch during helium core burning (HB); the asymptotic giant branch during hydrogen and helium shell burning (AGB); post-AGB evolution proceeding to the white dwarf phase (P-AGB). (Figure adapted from Renzini and Fusi Pecci, *Annu. Rev. Astron. Astrophys.*, 26, 199, 1988. Reproduced with permission from the *Annual Review of Astronomy and Astrophysics*, Volume 26, ©1988 by Annual Reviews Inc.)

## Luminosity Classes:



**FIGURE 8.16** Luminosity classes on the H–R diagram. (Figure from Kaler, *Stars and Stellar Spectra*, © Cambridge University Press 1989. Reprinted with the permission of Cambridge University Press.)



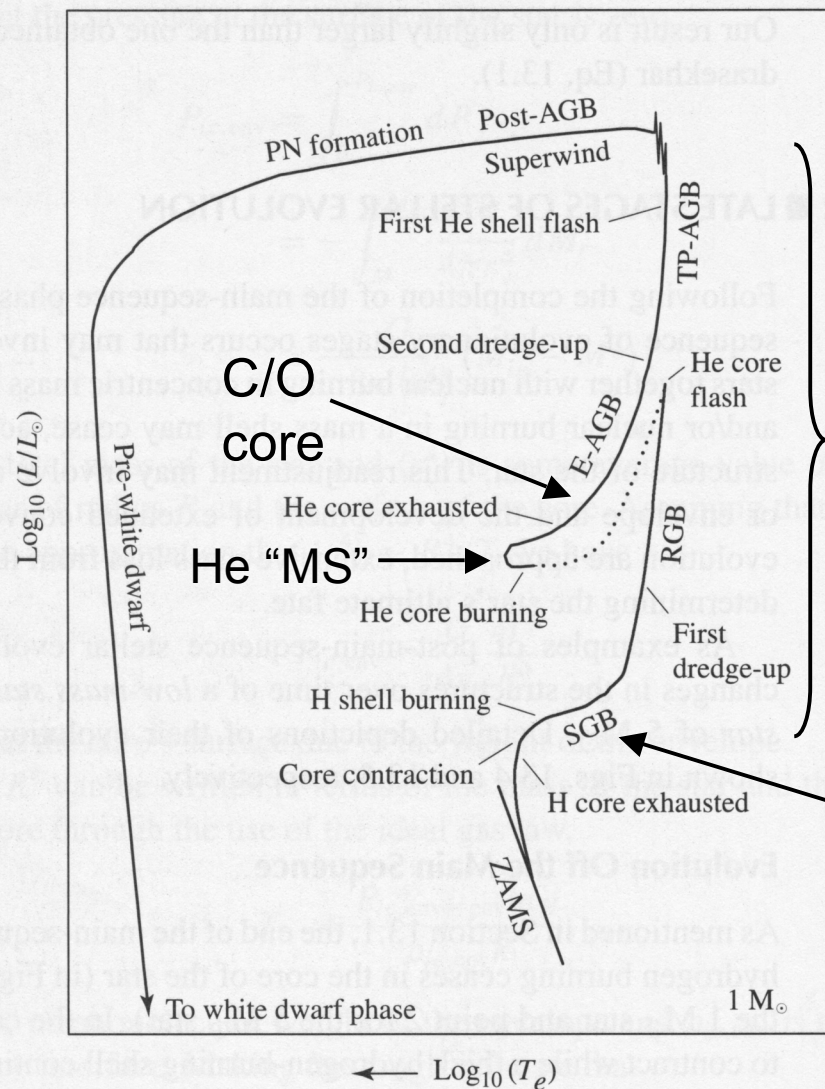


**FIGURE 13.1** Main-sequence and post-main-sequence evolutionary tracks of stars with an initial composition of  $X = 0.68$ ,  $Y = 0.30$ , and  $Z = 0.02$ . The location of the present-day Sun (see Fig. 13.2) is depicted by the solar symbol ( $\odot$ ) between points 1 and 2 on the  $1 M_{\odot}$  track. The elapsed times to points indicated on the diagram are given in Table 13.1. To enhance readability, only the points on the evolutionary tracks for  $0.8$ ,  $1.0$ ,  $1.5$ ,  $2.5$ ,  $5.0$ , and  $12.0 M_{\odot}$  are labeled. The model calculations include mass loss and convective overshooting. The diagonal line connecting the locus of points 1 is the zero-age main sequence. For complete, and annotated, evolutionary tracks of  $1 M_{\odot}$  and  $5 M_{\odot}$  stars, see Figs. 13.4 and 13.5, respectively. (Data from Schaller et al., *Astron. Astrophys. Suppl.*, **96**, 269, 1992.)

**TABLE 13.1** The elapsed times since reaching the zero-age main sequence to the indicated points in Fig. 13.1, measured in millions of years (Myr). (Data from Schaller et al., *Astron. Astrophys. Suppl.*, 96, 269, 1992.)

Initial Mass ( $M_{\odot}$ )	1 6	2 7	3 8	4 9	5 10
25	0 6.51783	6.33044 7.04971	6.40774 7.0591	6.41337	6.43767
15	0 11.6135	11.4099 11.6991	11.5842 12.7554	11.5986	11.6118
12	0 16.1150	15.7149 16.4230	16.0176 16.7120	16.0337 17.5847	16.0555 17.6749
9	0 26.5019	25.9376 27.6446	26.3886 28.1330	26.4198 28.9618	26.4580 29.2294
7	0 43.4304	42.4607 45.3175	43.1880 46.1810	43.2291 47.9727	43.3388 48.3916
5	0 95.2108	92.9357 99.3835	94.4591 100.888	94.5735 107.208	94.9218 108.454
4	0 166.362	162.043 172.38	164.734 185.435	164.916 192.198	165.701 194.284
3	0 357.310	346.240 366.880	352.503 420.502	352.792 440.536	355.018
2.5	0 595.476	574.337 607.356	584.916 710.235	586.165 757.056	589.786
2	0 1148.10	1094.08 1160.96	1115.94 1379.94	1117.74 1411.25	1129.12
1.5	0 2910.76	2632.52	2690.39	2699.52	2756.73
1.25	0 5588.92	4703.20	4910.11	4933.83	5114.83
1	0 12269.8	7048.40	9844.57	11386.0	11635.8
0.8	0	18828.9	25027.9		

RGB/AGB  
- envelope  
expansion



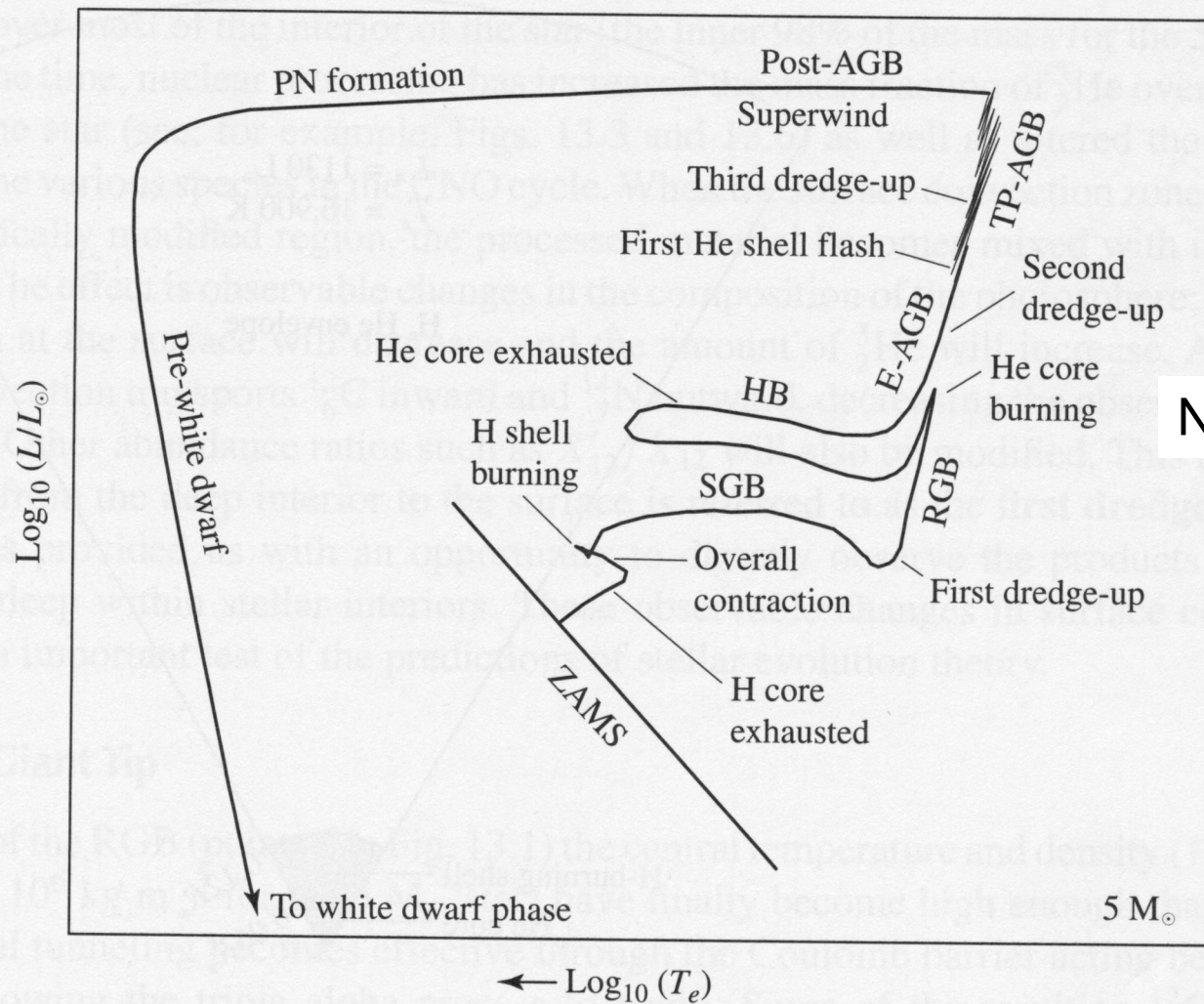
~Hayashi line -  
Convective  
Envelope

SC/KH

He flash <  
~2.0  $M_{\text{sun}}$  -  
H shell  
quenched

He MS  
faster;  
high L

**FIGURE 13.4** A schematic diagram of the evolution of a low-mass star of  $1 M_{\odot}$  from the zero-age main sequence to the formation of a white dwarf star (see Section 16.1). The dotted phase of evolution represents rapid evolution following the helium core flash. The various phases of evolution are labeled as follows: Zero-Age-Main-Sequence (ZAMS), Sub-Giant Branch (SGB), Red Giant Branch (RGB), Early Asymptotic Giant Branch (E-AGB), Thermal Pulse Asymptotic Giant Branch (TP-AGB), Post-Asymptotic Giant Branch (Post-AGB), Planetary Nebula formation (PN formation), and Pre-white dwarf phase leading to white dwarf phase.



**FIGURE 13.5** A schematic diagram of the evolution of an intermediate-mass star of  $5 M_{\odot}$  from the zero-age main sequence to the formation of a white dwarf star (see Section 16.1). The diagram is labeled according to Fig. 13.4 with the addition of the Horizontal Branch (HB).