Assignment 6 — Solutions [$Revision$: 1.2]

1. See Fig. 1 for the HRD.

   (a) The ZAMS is at the beginning of all of the tracks.

   (b) The KH contraction episode during H burning occurs on the massive-star tracks where they turn to the blue, toward the end of the main sequence phase.

   (c) Hydrogen shell burning begins for massive stars when they turn back toward the red. For low-mass stars, it begins when they reach the Hayashi line.

   (d) The point of helium core ignitions occurs at the local luminosity maximum of massive-star evolutionary tracks, when they reach the vicinity of the Hayashi line.

   (e) The Hayashi line is the locus of fully convective stars, and lies on the right of the HRD. The RGB and AGB trajectories bump up against it.

   (f) The RGB is where post-main sequence evolutionary tracks reach the Hayashi line, and turn sharply upward.

   (g) The AGB is where helium-burning models turn upwards after their redward evolution brings them close to the Hayashi line.

   (h) The $\log M/M_{\odot} = -0.4$ model never gets hot enough for helium burning; after hydrogen burning is complete, it evolves to the blue, and then follows a diagonal trajectory (toward low-T, low-L), which is characteristic of the cooling of degenerate objects.

   [16 points]

2. See Fig. 2 for the degeneracy plot.

   Stars that undergo the helium flash reach the ignition point ($T \approx 10^8$ K) with a substantially-degenerate core. This corresponds in the diagram to the tracks with $-0.2 \leqslant \log M/M_{\odot} \leqslant 0.2$. The model with $\log M/M_{\odot} = -0.4$ never reaches high enough temperatures for ignition to occur; instead, it eventually follows a degenerate cool-down. The models with $\log M/M_{\odot} \geqslant 0.4$ are either non-degenerate or insufficiently degenerate when helium ignition is reached, and so do not flash.

   CAVEAT: The data in the figure do not demonstrate the above answer very well. In fact, all of the models that *should* show a flash (i.e., $-0.2 \leqslant \log M/M_{\odot} \leqslant 0.2$) terminate before the helium ignition temperature is reached in the center of the core. What is happening is that a helium flash is occurring off-center (where the temperature is higher), and *EZ Web* is crashing.

   Also, although the $\log M/M_{\odot} = 0.4$ model reaches the helium ignition temperature to the right of the degeneracy line, it does not show a helium flash. This is because the degeneracy is only partial, and insufficient to cause a flash. This highlights the fact that the cutoff between degenerate and non-degenerate is not sharp, but 'fuzzy'.

   [7 points]

3. The identifications are as follows:

   (a) Type Ia — no hydrogen lines means type I, and the presence of a strong silicon line at 6150 Å indicates subtype a

   (b) Type II — hydrogen lines means type II

   (c) Type Ic — no hydrogen lines means type I, and the absence of strong silicon *and* the absence of helium indicates subtype c (note that there *is* a weak silicon line present, but it is at a longer wavelength than the 6150 Å line seen in type Ia SNe)

   (d) Type Ib — no hydrogen lines means type I, and the absence of strong silicon but the presence of helium indicates subtype b

   [8 points]

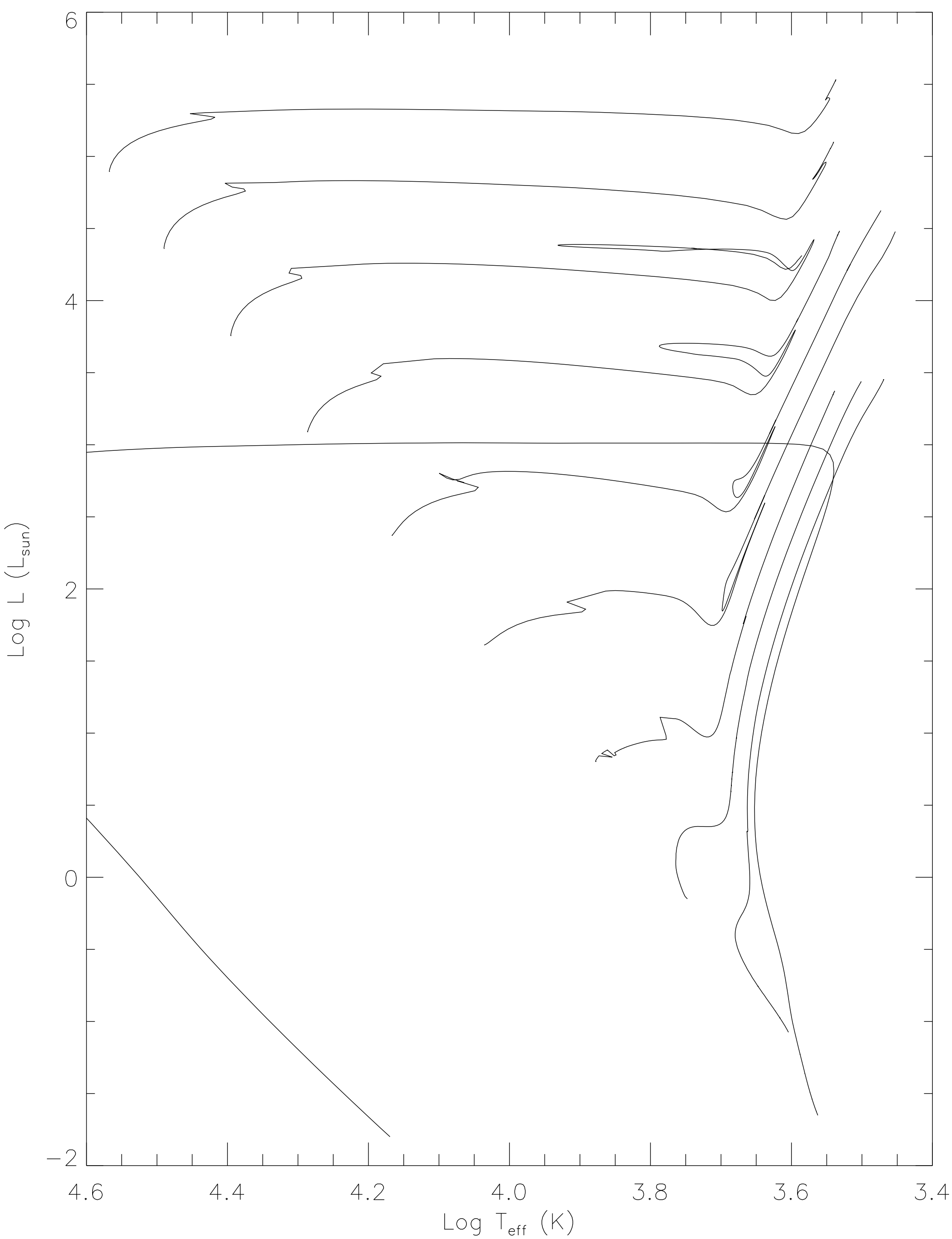

Figure 1: The Hertzsprung-Russell diagram, with the evolutionary tracks of the *EZ Web* models overplotted.

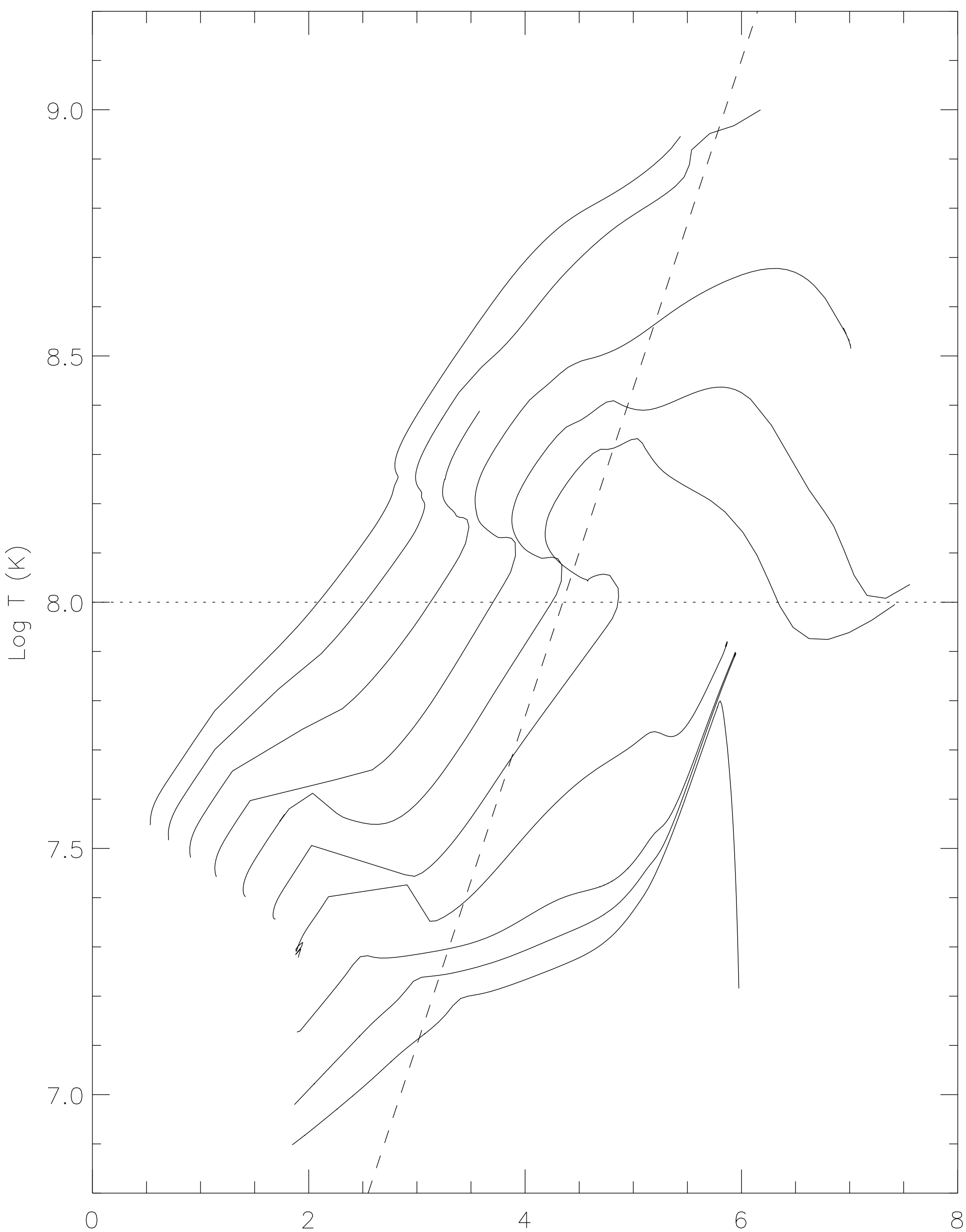

Figure 2: The $\log \rho_c$–$\log T_c$ diagram, with the evolutionary tracks of the *EZ Web* models overplotted. The dashed line shows the degeneracy boundary (degenerate to the right), and the dotted line shows the helium ignition threshold.