26 Stars notes 2019/10/30 - Wed - helium core ignition

Briefly go through directories in test suite.

26.1 Helium ignition and the core limit

Consider $M > 6M_\odot$. $M_c/M > 0.08$ when the H shell burning ignites. No isothermal solution is possible. (that is after burning of H runs out the star "discovers" that it can't support itself, and begins to contract) The He core contracts over a time set by the overall energy loss-rate. This is about the Kelvin-Helmholtz time,

$$t = \frac{GM^2/R}{L} \simeq 10^6 \text{ yr at } 6M_\odot$$

or 3×10^4 yr at $30M_\odot$. Refer to first figure of interior of $5M_\odot$ star on Kippenhanl figure and compare to previous figure. From C to D is the expansion of the giant, which happens quickly. This short-lived phase when the He core is contracting is referred to as the Hertzprung Gap. For higher mass stars core burning can ignite before reaching giant branch.

Now consider $2 < M < 6$. Then the initial value of $M_c/M < 0.08$ when H burning in core is completed. Core can be isothermal during H shell burning, and does not collapse until the H shell burning has forced $M_c > 0.08M$. This happens before the core becomes degenerate.

Finally $M < 2M_\odot$. Core becomes degenerate before $M_c > 0.08M$. Thus the He core can get much larger than S-C limit before the He ignites.

26.2 Evolution in density-temperature

make the plot of T_c verses ρ_c log-log. The virial theormem tells us that

$$T \propto \frac{M}{R}$$

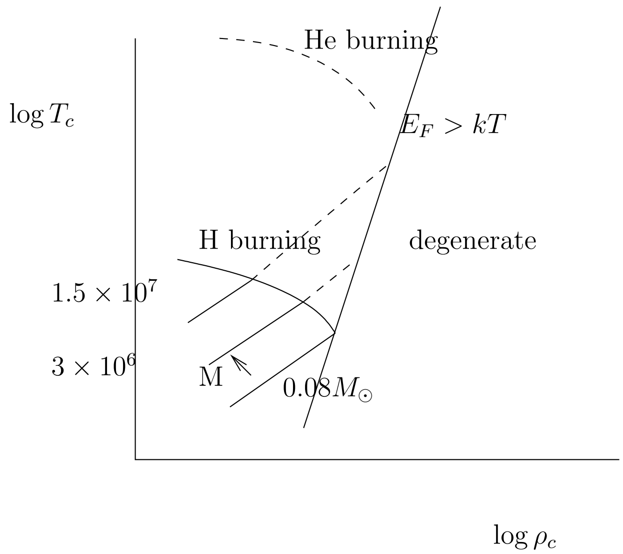
but then

$$\rho \propto \frac{M}{R^3}$$

but eliminating R gives

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

then plotting



Also degeneracy is when $E_F \sim kT$, $n \propto k_F^3$ and $E_F \propto k_F^2$ this tells us that $T \propto \rho^{2/3}$ for constant degneneracy. So the final fate of the star is determined by where the curves for burning intersect the degeneracy curves. Now refer to plots that show the calculated evolution in this diagram.

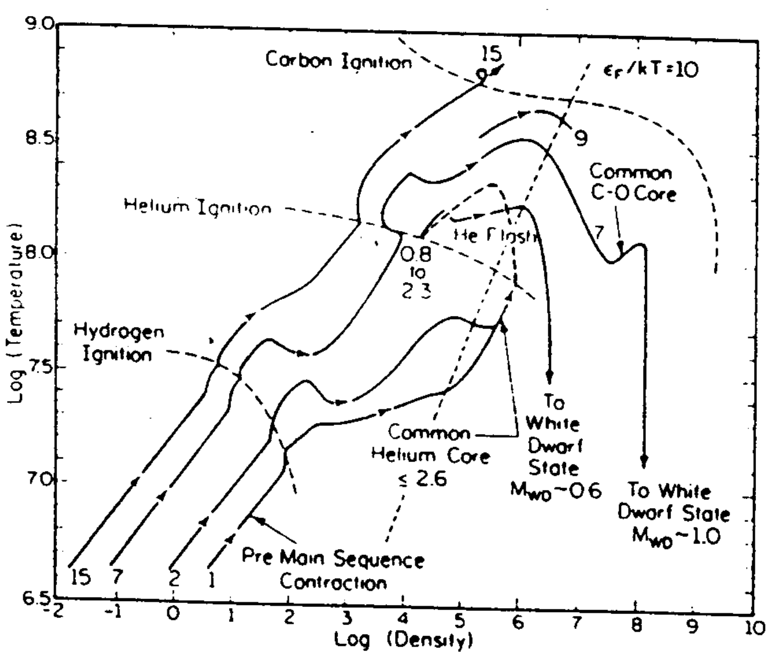
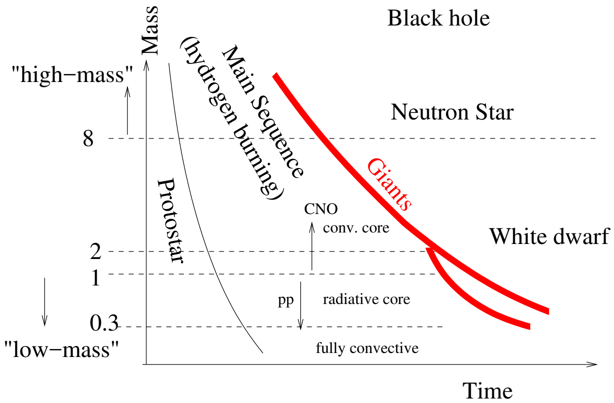


FIGURE 2.7. Central density versus central temperature for evolving stellar models. Reproduced, with permission, from I. Iben Jr. 1985, "The Life and Times of an Intermediate Mass Star," in *Quarterly Journal of the Royal Astronomical Society*, Volume 26, published by Blackwell Scientific Publications.

Also show similar figures from MESA paper (22, 29, 16, 14) and run examples of a 7 and 3 $M_\odot$ star in MESA.

26.3 Red Giants

A reminder of where we are in the phase diagram of the life of stars:



We are just at the end of the central H fusion phase. Today we will discuss the "first" giant phase for stars below $2M_\odot$. Trying to get to Helium fusion ignition for all masses of star.

In the Luminosity-Teff diagram, this is the "red giant branch".

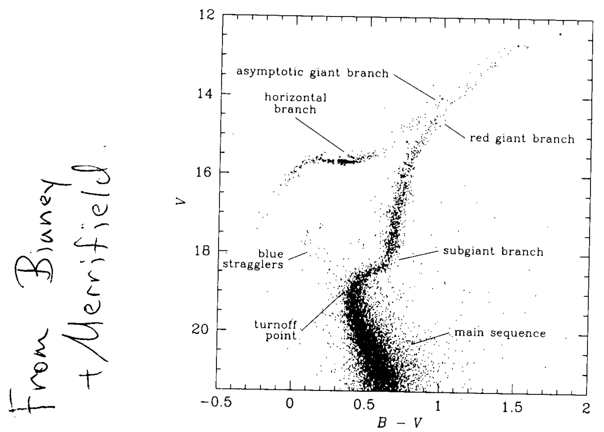


Figure 6.2 The color-magnitude diagram for the globular cluster M3. Known variable stars are shown as open circles, and the principal sequences are annotated. [From data published in Buonanno *et al.* (1994)]

During this phase the degenerate Helium core is built up until it ignites to transition to the central helium burning phase (called the "horizontal branch").

(Also some discussion of what $B-V$ color is (log of the flux ratio between two spectral ranges, 550nm and 440 nm.)

So the astronomy names for the phases are:

- **Red Giant Branch** - inert, degenerate He core ; burning H shell
- **Horizontal Branch** - core He burning

- **Asymptotic Giant Branch** - inert core (C and O or O and Ne) ; burning shells of H and He

26.4 Isochrones

Then next figures are from Binney and Merrifield, show the isocrones, which is the state one might find a cluster in. The lower right figure demonstrates the difficulty in dating a cluster with this method due to lower mass stars evolving parallel to the main sequence.

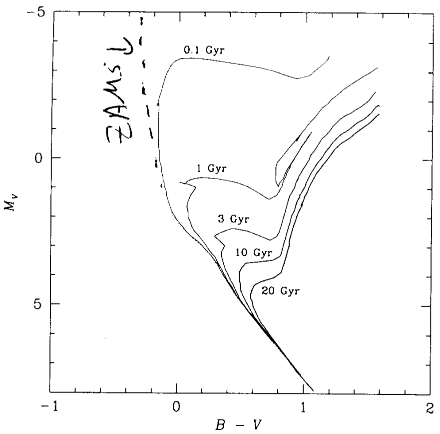


Figure 6.6 Theoretically calculated isochrones showing how a stellar population with $Z = 0.004$, $Y = 0.24$ evolves away from the ZAMS (dotted line) in the CM diagram. Each isochrones is labeled by its age. [From the calculations of Bertelli *et al.* (1994)]

From Binney + Merrifield

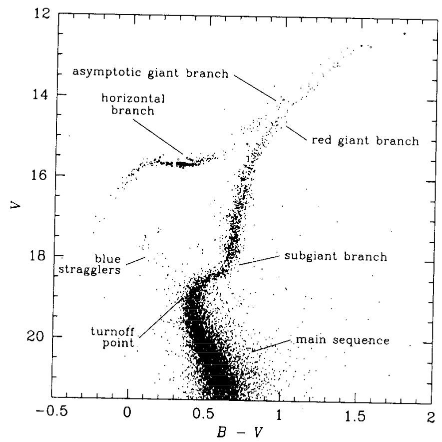


Figure 6.2 The color-magnitude diagram for the globular cluster M3. Known variable stars are shown as open circles, and the principal sequences are annotated. [From data published in Buonanno *et al.* (1994)]

Isochrones = constant time.

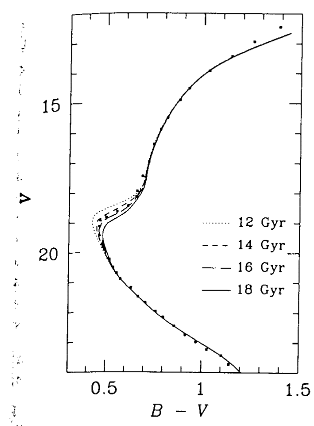


Figure 6.10 A family of isochrones with ages as marked fitted to the MS and SGB in the CM diagram of M15 (points). The adopted distance modulus in this fit is $(m - M) = 15.4$, and the color excess is $E(B - V) = 0.10$. A residual color correction of $\delta(B - V) = 0.015$ has also been applied. [After Durrell & Harris (1993)]