ASTR 565

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1 Problem 1.1: Variation of Luminosity with ϵ

The amount of energy generated by nuclear fusion in a star per second per unit mass is characterized by ϵ [erg g^{-1} s^{-1}]. This can be expressed as $\epsilon = \frac{dL}{dm}$ or $dL = \epsilon dm$, where L is luminosity and m is mass. If $\epsilon = 0$, then $dL = 0$, implying a constant L. Figure 1 shows a plot of both ϵ and L as functions of mass, normalized to a fraction of their maximum values. They illustrate that L only changes when ϵ has a value greater than zero. When ϵ falls back to zero, L is again constant at its maximum value.

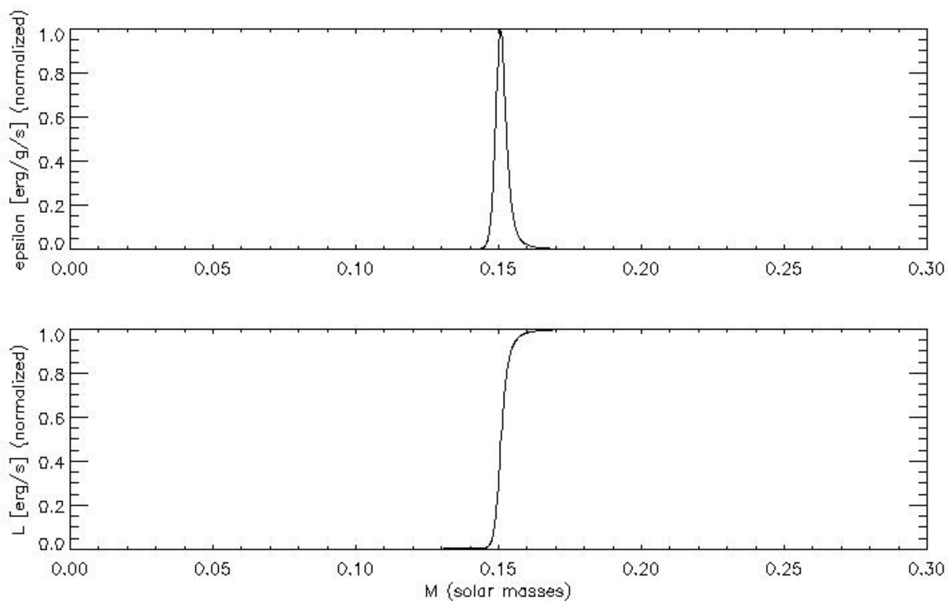

Figure 1: Variation of ϵ (top plot) and L (bottom plot) with mass.

Given the value on the x-axis at which these changes occure, this would suggest that nuclear reactions occur in a region containing about 15% of the star's total mass.

The values for these figures were obtained from the results of a model run using Modules for Experiments in Stellar Astrophysics (MESA).

2 Computer Problem 1.1: Effects of nuclear fusion reactions on the evolution of a star

2.1 Procedure

Two solar-mass stellar models were run using MESA. The first ('Model 1' henceforth) was run with the nuclear reactions rates turned off and was set to stop after reaching an age of 10 billion years. The second ('Model 2') was run with the nuclear reactions turned back on and set to stop just after the onset of hydrogen fusion, when the hydrogen abundance dropped below 0.7.

2.2 Results

The stellar model that included hydrogen fusion stopped when the star reached an age of about 1.5 billion years. Figure 2 shows an H-R diagram of both stars. The model with no nuclear burning reached a maximum temperature of about 21000 K while the model that included nuclear burning only reached a temperature of about 5600 K.

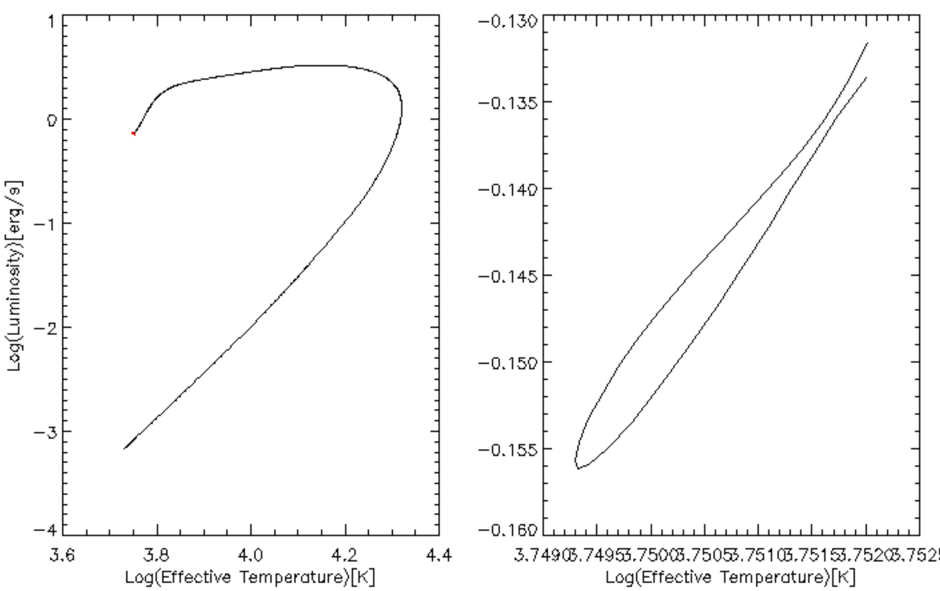

Figure 2: These H-R diagrams show the evolutionary tracks of both models. Model 1 is on the left, aged to about 10 billion years. Its evolutionary track starts at the endpoint with the highest luminosity. Model 2 is on the right, aged to about 1.5 billion years. Its evolutionary track also starts at the highest y-value. Model 2 is also plotted on top of Model 1 with a thicker line (in red), and is barely visible at the start of Model 1's evolutionary track.

2.3 Discussion

In general, a star spends about 90% of its lifetime on the Main Sequence (MS), fusing hydrogen into helium. Our "middle aged" sun is expected to evolve off the MS about 10 billion years after its birth, so we would expect hydrogen fusion to have started at an age of around 1 billion years. Since both models represent solar-mass stars, it would make sense for Model 2 to have an age of 1.5 billion years when the hydrogen abundance dropped below 0.7.

During the process of nuclear fusion, a fraction of a star's mass is converted to energy and radiated away. Without nuclear fusion, a star does not lose energy in this manner, and this extra energy is retained as heat, thus causing the temperature to be higher. Figure 3 shows how the luminosity and temperature of each star change as a function of age (where both were plotted up to the maximum age reached by Model 2 and normalized to their maxium values).

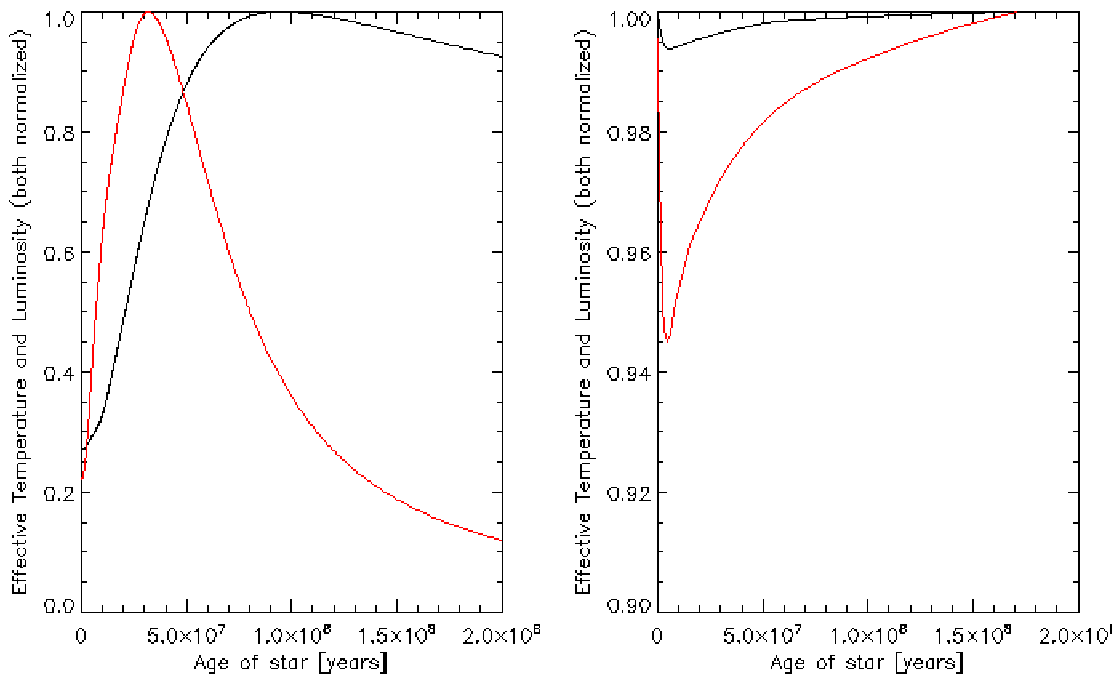

Figure 3: This plot shows how both temperature (black line) and luminosity (red line) change with a star's age. Model 1 is plotted on the left and Model 2 is plotted on the right.

Stars remain stable against collapse because their internal outward pressure balances the internal pressure due to gravity. This internal pressure comes from several sources, such as electron degeneracy, ideal gas, and radiation pressure from the photons produced during nuclear reactions. A star with no nuclear reacations will thus have a lower internal pressure. As it evolves, the star's temperature will increase until the internal pressure can no longer balance the pressure due to gravity. At this point, both temperature and luminosity start to decrease as the star collapses, which happens at an age of around 50 million years. This turnaround point is illustrated in the upper right hump in the lefthand plot in figure 1.