AY C10/L&S C70U **Name:** ________________________
Fall 2018
Worksheet 7
10/13/2018

This worksheet focuses on the Sun and the stars. There are 4 pages (including this cover page) and 4 questions. Accuracy is definitely desired, but effort and clear physical reasoning are far more important than the final answer, *especially* for the challenge problems.

---

1. In this problem, you will answer a few short questions about the Sun.
   (a) When stars form out of molecular clouds, their masses follow a distribution similar to that shown below (for the nearby Pleiades cluster). **Indicate the location of the Sun** on the plot—based on your result, do you think that the "typical" star has a mass **larger, lower, or equal** to that of the Sun?

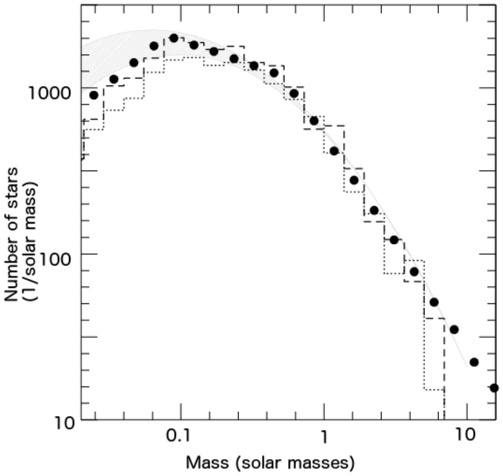

Figure 1: Number of stars at various masses in the Pleiades cluster.

   (b) The Sun has the following layers, in no particular order: photosphere, corona, chromosphere, radiative zone, convective zone, core. **Sort the layers** in order of increasing distance from the Sun's center. If you were to look straight at the Sun on a typical day, **which of these layers** would you see?

   (c) In one or two sentences, **explain the process** of convection.

2. Stars are powered by *nuclear fusion* of various elements in their cores; main-sequence stars in particular are supported by fusion of hydrogen into helium.

   (a) **Explain**, in one or two sentences, the significance of Einstein's formula $E = mc^2$ in the context of nuclear fusion.

   (b) The mass of the product in each hydrogen-to-helium fusion reaction is $6.644\,24 \times 10^{-27}$ kg while that of the reactants is 1.6904×10^{-27} kg. **Compute the energy released** by each reaction.

   (c) Suppose this reaction releases all of its energy as a single photon. **Compute its frequency**. **Is this frequency comparable** to what we observe at the Sun's surface, and why or why not?

   (d) Assume the Sun was born with a mass of 1.981×10^{30} kg, all pure hydrogen, and fuses 10% of its mass into helium on the main sequence.

      i. Using your result from the previous part, **how much total energy** does the Sun emit over its lifetime?

      ii. With a luminosity of 3.84×10^{26} W, **estimate the Sun's main-sequence lifetime**. Recall that luminosity is a power (energy per unit time).

   (e) Once a very massive star starts fusing iron into heavier elements, it rapidly experiences core collapse and explodes as a supernova. **Explain physically** why this is the case.

3. In this question, we review various physical concepts with the example of a 1 $M_\odot$ and 10 $M_\odot$ star in a binary system. The stars are separated by a distance of 1000 AU.

   (a) **Draw a diagram** of the system, indicating the position and distance between the stars. **Which star** would you expect to be closer to the center of mass of the system, and why?

   (b) Using Newton's modification of Kepler's laws, **compute the orbital period** of the system.

   (c) **Which star has a longer lifespan**, and why? Scaling off the mass-luminosity relation $L \propto M^4$, **compute the main-sequence lifetime** of each star. Recall that the Sun has a main-sequence lifetime of 10 billion years.

   (d) **Order and describe the evolutionary phases** *(protostar, giant, main sequence, white dwarf, etc.)*, from beginning to end, for the

      i. 1 $M_\odot$ star

      ii. 10 $M_\odot$ star

      For each star, **which stage** accounts for the majority of its total lifespan?

4. *Challenge Problem* When a star dies it releases its internal gravitational energy as light, $E_{\mathrm{supernova}} \approx GM_*^2/R_*$. The typical star that goes supernova has a mass $M_* \approx 20M_\odot$ and radius $R_* \approx 200R_\odot$. Assuming that this energy is released over the course of roughly 1 hour, **compute the typical luminosity** of a supernova. **How close to Earth** would a supernova have to explode to be dangerous to life on Earth?