The Hertzsprung-Russell Diagram and Stellar Evolution

The **Hertzsprung-Russell (HR) Diagram** is a scatter plot of stars' **surface temperature** vs. their **luminosity** (i.e., the total energy emitted per unit time). The diagram was created around 1910 by Ejnar Hertzsprung and Henry Norris Russell. They found that this scatter plot showed a few correlations, which led toward the earliest understanding of how stars live and die.

Everyone in the class is a star, so each one of you will be assigned a mass (in units of the Sun's mass: M_{sun}), a luminosity (in units of the Sun's luminosity: L_{sun}), a (surface) temperature (in units of Kelvin: K), and (main-sequence) lifetime (in units of years). Some of you will represent bright stars in our own night sky (written in italics on your stellar info card; note that some of these stars share names with characters in the Harry Potter Universe...), but all of you will represent actual stars that exist in our Milky Way Galaxy.

1. Now let's make a human HR Diagram! To do this, we need to plot surface temperature (x-axis) vs. luminosity (y-axis). Notice that the temperature axis is backwards from what you might expect (astronomers are weird like that). Everyone arrange themselves according to their star's temperature and luminosity. Remember, these are real values for stars in our Milky Way Galaxy. Do we have a problem with our scatter plot? How can we fix it?

2. Now let's try this again... Once again, everyone arrange themselves in the room according to their star's temperature and luminosity. Is this scatter plot random, or does it show a correlation?

This band of points is called the **main sequence**. All stars on the main sequence are in hydrostatic equilibrium and are fusing hydrogen to helium in their cores in order to produce energy and light. The Sun is currently on the main sequence and has been there for about 4.5 billion years. It will remain there for another 6.5 billion years or so.

As time goes on and stars evolve, they eventually run out of hydrogen fuel in their cores. This causes them to move off of the main sequence toward the upper right of the HR Diagram (where the **giant stars** are). After that, some stars explode as **supernova** while others eject **planetary nebula** and then become **white dwarfs**.

Let's assume all of you stars were born at the same time, perhaps in a big star cluster, which is how we think most stars form. Look Around You. This is how the HR Diagram of your cluster looks right after you were all born. Now let's move forward in time a bit and see what happens. Each of you stars has a main sequence lifetime, which represents how long you live on the main sequence. After that time, you have to move somewhere else in the HR Diagram (according to the rules of stellar evolution, or course!).

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3. Let's jump ahead 25 million years into the future. Stars with main sequence lifetimes less than 25 million years have to get off the main sequence and move somewhere else. How has our HR Diagram changed? What has happened to the stars that left the main sequence?

4. Next, let's go to 4.5 billion years after our cluster was born. This is the current age of the Sun. What can we say about the current state of the Sun's larger brother and sister stars? What about the smaller ones?

5. If we go to 10 billion years after our cluster was born, we just now start to see the Sun move off the main sequence. What kind of stars are left on the main sequence? What other kinds of stars do we have left in our cluster?

6. Let's now suppose an alien astronomer from another part of the Milky Way Galaxy observed our Sun and its brother and sister stars at this point in time. By measuring the temperature and luminosity of all the stars in the cluster, they would be able to make a Bleep-Blorp Diagram (assuming those are the names of the two alien scientists who first created what we call an HR Diagram) that looked just like how our class looks right now. What important piece of information could they determine about our cluster (and the Sun)? HINT: If the aliens observed our cluster again in a billion years, how could they tell that a billion years had passed from their stellar observations alone?

7. Finally, let's assume that our cluster was born in the very first generation of stars. This means that the present day is about 14 billion years later. At this point, what kind of stars are left on the main sequence? What other kinds of stars do we have left in our cluster?