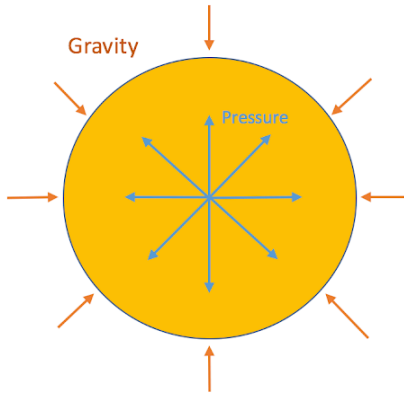


The Lives of Stars



<http://large.stanford.edu/courses/2017/ph241/stayner2/images/f1big.png>

A star is a dynamic, ever changing rotating celestial object made of gas, mostly hydrogen and helium. Stars form in clusters, from clouds of gas pulled together by gravity when, under immense pressure and heat, fusion occurs, signaling the birth of the star.

The rotation of the gases in the star exert a pressure *outward*, balanced by the force of gravity pulling the gases *inward*. The size of a star is largely determined by the quantity of the gases present and the balance of these opposing forces.

Stars have life cycles. They come into being, they evolve, they consume their fuel, and they die. The fate of a star is cast by its initial mass, which uniquely determines its evolution – how bright it is, how long it will last and, in the end, how it will die.

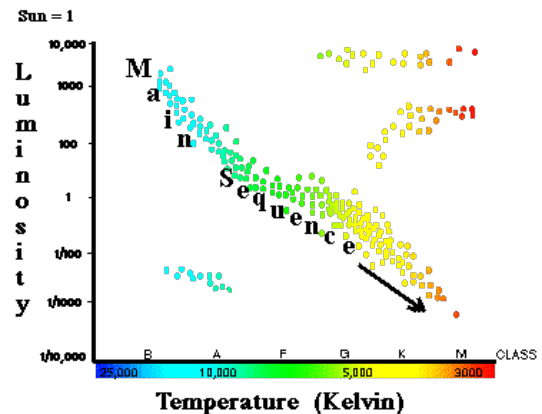
Watch the intro video for Lives of the Stars; <https://youtu.be/CufD2YgfoAI>

Setting the Stage

The initial state of a star, its *spectral class* (temperature and color) and its *luminosity*, can be represented graphically by what astrophysicists call an H-R Diagram, named after the scientists helped to discover these patterns (Hertzsprung and Russell).

The “birth” position of a star will occur in a region that astrophysicists call the *main sequence*.

You will learn to identify the luminosity and temperature of stars at various times in their lives, and to plot their positions on the H-R diagram over time..



https://www.courses.psu.edu/astro/astro010_pjm25/hertzsprung2.html

Part 1: Star in a Box – Getting Acquainted

Star in a Box is an interactive simulation allowing you to select a stellar mass, and from that mass, track the evolutionary trajectory or luminosity versus temperature over time. Go to:

<https://starinabox.lco.global/> on your computer (or just search for “*starinabox*”) and open the lid!

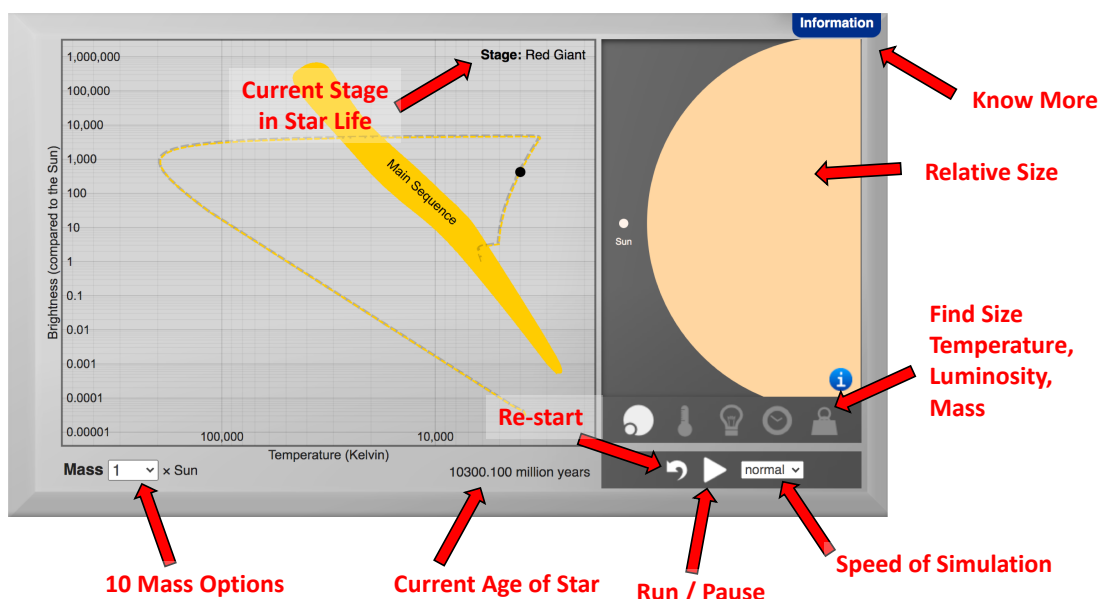


Figure 1. Star in a Box screen.

The main window traces the path of a star in the main sequence, and its **evolutionary stages** once it begins to run out of fuel and leaves the main sequence. Along the trajectory, you will be able to determine when the star begins to run out of fuel and ultimately when it explodes. You will initially select the **stellar mass** for each run. You may control the **speed** at which the star of a given mass evolves, and pause to know where the star is located in its trajectory at any particular age.

The (right) side window displays the **size** and **color** of the star compared to our sun, along its evolutionary path. Notice you can use the “cross hairs” to identify both the **luminosity** and **temperature** at any point on the chart.

To get you started, open the lid and play with different options to familiarize yourself with what you can control and what you observe, and try to answer the following:

1. In the space to the right, draw a sketch of the main sequence of a H-R diagram and label the axes. Use the colored paper dots provided in your materials to show the initial relative positions of stars that are
 - a. 0.2 times the mass of the sun
 - b. 1 times the mass of the sun
 - c. 20 times the mass of the sun
 - d. 40 times the mass of the sun

2. Run the simulation to determine how many years will it take before $40 M_{\text{sun}}$ star leaves the main sequence?
 - a. How about a $1 M_{\text{sun}}$ star (our own star, the sun)?
 - b. A $20 M_{\text{sun}}$ star?
3. Calculate how long will it be before our Sun leaves the main sequence (it is about 5 billion years old today).
4. What does a $40 M_{\text{sun}}$ star become at the end of its life?

Part 2: Making Your Own H-R Diagram

Now is your chance to create your own H-R diagram using data obtained from Star in a Box. Star in a Box will allow you to “time evolve” a star cluster, from the available masses, from birth to a predetermined age or number of years (see below).

To do this, you will need:

Log scale graph paper (provided)

Colored paper dots (provided), corresponding to relative star size and corresponding temperature (red, orange, yellow green, blue)

Glue stick or transparent tape

Pen or pencil

Computer with internet (for Star in a Box simulation)

Note:

Typically, we would assign students to work in groups, each group assigned a specific age to which to run the simulation for the 10 possible stellar masses, and then compare resulting H-R diagrams.

We assign ages that provide enough variation to make interesting comparisons: **2, 9, 24, 70, 180, 1200, 10 000 million, and 62.7 billion**. If you are working independently (remotely), pick two (or more) target ages of your choice (one shorter, one longer) for comparison.

Procedure

1. Using the Star in a Box simulation, pick a target star cluster age from the lower range (**9, 24, 70 million years**) from the list above.
2. Run and pause the simulation, at this target age, for one of the stellar masses from the star cluster.

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Teaching suggestions

You might think about beginning the session with a whiteboard and questions, just to get some conversation going, “What do you know about stars?” and based on students’ answers direct questions toward color, size, mass... and follow up with “”whys to get at naïve ideas and misunderstood concepts. Follow-ups might be “Why do stars shine?” “Name a star,” “Where so stars get their energy?,” “How long do stars last?,” etc.

A brief introduction can orient students in using the Star in a Box simulation, for example, using our sun, and identifying when it becomes a red giant, white dwarf, and comparing relative size, changes in mass, luminosity and temperature through its life span.

Discussions about comparisons in color and luminosity against mass and other aspects of stellar lifecycles can be done after students have completed their H-R diagrams, and become familiar with the terminology, which can be overwhelming at first.

Step back and think about the less obvious. For example, Stars enlarge toward the ends of their lives. They get bigger, but have less mass. Ask students to explain what is happening in terms of density, and the interplay of outward pressure, versus gravitational forces.

Make explicit that (1) the 10 stars represented here are a cluster, an open cluster, gravitationally bound; (2) the age of the cluster can be estimated by which stars are leaving the main sequence; (3) stars do not move up and down on the sequence and leave the sequence at respective turn-off points; (4) stars maintain the same mass, despite that they may get larger, a consequence of the dynamic equilibrium between the forces of pressure and gravity, drive by heat generated in the core; (5) larger stars have more H in the core and therefore “burn” hotter and faster.

Common misconceptions from the literature include the following which can make good “fact or fiction questions:

- Stars really twinkle.
- The only stars we can observe are those in our own Milky Way galaxy.
- Polaris, the North Star, is the brightest star in our sky.
- Smaller stars run out of fuel before the larger ones.
- Stars are pretty much all the same.
- Most stars are smaller than our Sun.
- A shooting star is a star at the end of its life, falling through the sky.
- Stars appear white.
- All stars explode (go supernova) at the end of their "lives."
- Stars live forever.
- Stars are a part of our Solar System.
- Stars in a constellation are close to each other.
- Stars are balls of gas that "burn."
- Stars are made of fire.

In doing Part 2 of the lesson, divide students into teams of 2-4. Assign ages to run the simulation, a different age for each group, to be able to compare the life cycles of stars of different masses over time. Suggested masses that provide enough variation to do this include (in millions of years): 2, 9, 24, 70, 180, 1200, 10 000, and 62.7 billion.

Possible discussion starters:

1. List some general conclusions you think you could draw by comparing your two H-R diagrams (think about star masses, colors, life spans, destinies) relative to the stars represented in the clusters.

2. List the major stages in the life cycle for a star the size of our sun.
3. What do stars, whose mass is above a certain (very large) mass, become at the end their lives?
4. Which stars are more massive, blue stars or red stars?
5. Which are more luminous, blue stars or red stars?
6. Which stars die sooner, blue stars or red stars?

Stickers of various sizes can be purchased through Amazon; Chromalabel makes a full assortment of colors and sizes.

Possible Resources:

Agan, L., 2004, Stellar Ideas: Exploring Students' Understanding of Stars, Astronomy Education Review, Issue 1, Volume 3:77-97.

Student Sample Data

