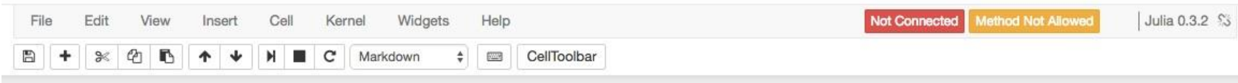
The H-R Diagram: Sizing up the Sun



Introduction and Background

The H-R Diagram is an important tool for helping us understand a range of stellar properties. In addition to temperature and luminosity, it may be used to infer stellar masses and sizes. Astronomers can use a star's location on the main sequence as a way to estimate its approximate lifespan.

In this investigation, you will compare the characteristics of stars in a cluster to those of our Sun, to get a sense for how our local star compares to others. In so doing, you will employ the same mathematical techniques that professional astronomers have derived to learn about stellar properties.

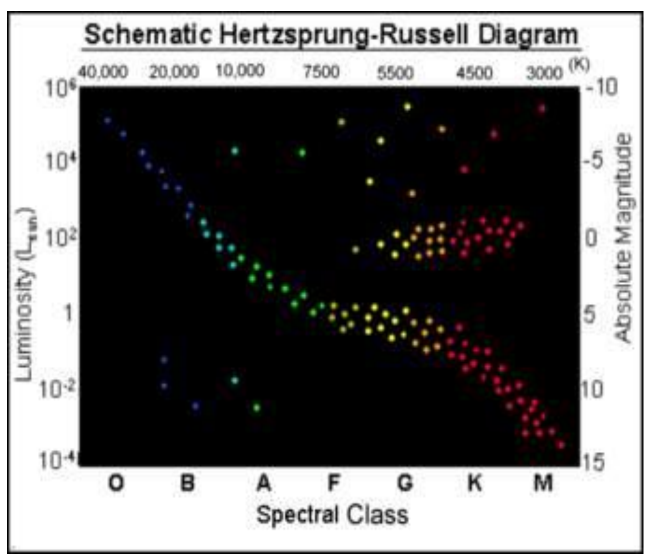
Procedure and Data

You will now call up the data for your assigned cluster.

Type in the name of your cluster and press Enter:

LSST image number: 20221274993 — Cluster name: LSST 8433

Center coordinates: Right Ascension 05 h33m 00s — Declination +00d 13m 00s



Can you visualize which of these stars might belong to the cluster?

Use your mouse to draw a closed polygon that outlines the boundaries of the cluster. Make your best estimate of where these boundaries exist.

You now see a plot of all the data for stars in your cluster displayed as an H-R Diagram.

You can use the magnifying glass tool to enlarge the H-R Diagram, and the Position tool to navigate to different areas of the H-R Diagram.

Hover over the stars on the H-R Diagram to read their temperature and luminosity values.

In order to compare the stars in this cluster to the Sun, you will have to add a point on the H-R Diagram to mark the location of the Sun. The Sun has a luminosity of 1 and a surface temperature of 5778 K. Find its approximate location on the main sequence and double-click on it. A dot will appear on the diagram showing where you marked the location of the Sun.

Estimating stellar mass

The mass of the Sun is 1.989×10^{30} kg, which is about 333,000 times heavier than Earth. But how does it compare to other stars? Jakob Halm, a German astronomer, was the first to uncover that there was a relationship between the mass of a main sequence star and its luminosity. Over the years, the equations have been refined, depending on the mass of the star. In the equations below, the symbols $L_\odot$ and $M_\odot$ are the symbols for the luminosity and mass of the Sun.

$$\frac{L}{L_\odot} \approx .23\left(\frac{M}{M_\odot}\right)^{2.3} \qquad (M < .43M_\odot)$$

$$\frac{L}{L_\odot} = \left(\frac{M}{M_\odot}\right)^{4} \qquad (.43M_\odot < M < 2M_\odot)$$

$$\frac{L}{L_\odot} \approx 1.5\left(\frac{M}{M_\odot}\right)^{3.5} \qquad (2M_\odot < M < 20M_\odot)$$

$$\frac{L}{L_\odot} \approx 3200\frac{M}{M_\odot} \qquad (M > 20M_\odot)$$

Mass

To view the range of star masses along the main sequence, click the Mass button, then hover over a star on the H-R Diagram.

To inspect the distribution of main sequence star masses in your cluster, click here to view a histogram.

Mass Histogram

Estimating stellar radius

The Stefan-Boltzmann equation predicts the size of a star from its luminosity. If we use solar luminosity units (Sun =1), the equation is:

$$L = R^2T^4$$

where L is the luminosity of the star relative to the Sun, R is the radius of a star, and T is the Temperature of the star.

Since the H-R Diagram records both temperature and luminosity, we can rearrange this equation to determine the size of the star:

$$\sqrt{(L / T^4)} = R$$

We can express temperature (T) and radius (R) as ratios compared to the Sun. To see how this works, consider a star with the same luminosity as the Sun (1) and a surface temperature that is twice as hot as the Sun. Substituting the in the equation above,

$$\sqrt{(1/2^{4)}} = R$$
$$R = .25$$

The star is considerably smaller, having only ¼ the Sun's radius.

Unlike the previous relationship, this equation applies to both giant and white dwarf stars as well as those on the main sequence.

To view the range of star sizes, click the Size button, then hover over a star on the H-R Diagram.

Size

To see the distribution of the range of star sizes in your cluster, click here to view a histogram.

Size Histogram

Estimating stellar lifespans

Stars spend about 90% of their lifetimes on the main sequence. The initial mass of a star determines its life span. We know the approximate age of the Sun from radiogenic dating of ancient solar system objects, such as meteorites and the oldest moon rocks. But how much longer will the Sun remain stable?

The lifespan of a star depends on two factors: how much hydrogen is available for nuclear fusion, and the rate at which fusion is proceeding. Luminosity gives an estimate of the energy output of the star. More luminous main sequence stars are hotter and consume hydrogen at a faster rate.

The main sequence lifetime of a star can be estimated by this relationship:

$$T_{ms} = 10^{10} \text{ x } \left(\frac{m_{Sun}}{m_{star}}\right)^3$$

where m variables represent the respective masses of the Sun compared to another star, and T_{ms} is its main sequence lifetime in years.

To view the range of main sequence lifetimes, click the Life span button, then hover over a star to see its predicted life span.

Life span

To see the distribution of main sequence star life spans in your cluster, click here to view a histogram.

Life spans Histogram

Now use these tools to investigate and discuss the questions below.

Discuss and report

Take a few minutes with your partner or small group to investigate and discuss the following:

1. What were the mass values and colors of the most and least massive main sequence stars in your cluster?
2. Complete this sentence: High mass stars in the main sequence have _____ (high, low) temperatures.
3. What was the most common main sequence star mass (range) in your cluster?
4. What were the sizes of the largest and smallest stars in your cluster?
5. In which areas of the H-R Diagram were the smallest and largest stars located?
6. What was the most common star size in your cluster?
7. What were the shortest and longest life spans of the main sequence stars in your cluster?
8. Complete this sentence: Very cool main sequence stars have _____ (long, short) life spans.
9. What was the most common main sequence star life span in your cluster?
10. The estimated age of the Sun is about 5 billion years. How much longer will the Sun remain a stable main sequence star?
11. As a star evolves off the main sequence, it becomes cooler and increases in size. Which of these two factors contributes to its increase in luminosity?
12. Blue main sequence stars possess enormous amounts of hydrogen. Considering their main sequence lifetimes, what must be true about their rate of hydrogen consumption?

Summary

Now that you have had a chance to discuss these questions, write a summary in the text box below that explains how the mass, luminosity and life span of the Sun compares to stars in your cluster. Do the characteristics of the Sun represent an extreme example in your cluster? Are they similar to an average star in your cluster?

When you are done, click Submit to send your completed notebook to your teacher.

Submit