Lab 5: Creating an H-R Diagram — PC 133: Astronomy, Block 8

Name: Lab section (circle one): Tue/Thu (Due 9am Thu) Wed/Fri (Due 9am Fri)

Group members:

Learning Goals:

- Use observations to examine the relationship between the luminosity and temperature of main-sequence stars.
- Understand the relationship between color index and stellar temperature.
- Relate absolute magnitudes to stellar luminosity.
- Determine the radii of main sequence stars across a range luminosities and temperatures.
- Reason out which of two star clusters is older by understanding the lifetimes of different stars.

Introduction:

In this lab, we will use data from the Gaia Space Telescope, a state-of-the-art telescope that has compiled data on billions of stars in the Milky Way galaxy. The data is already in a spreadsheet template on canvas – you will need to complete the spreadsheet in part 6. In order to better understand how astronomers use the concepts from class to learn about stars that are thousands of lightyears away, we will do some sample calculations in parts 1-5.

Part 1: Apparent Magnitudes and Colors

The apparent magnitude of a star is a measure of how bright it looks – this can depend on the intrinsic brightness, or luminosity, of the star, as well as how far away it is. Astronomers measure magnitudes in certain "bands" of light (essentially filters that let through only greenish light, or only a range of infrared light, blue light etc.). The measurement of these magnitudes is called photometry.

The Gaia Space Telescope measures magnitudes in three different bands, but we'll focus on just one for now: the green/visible band. This band measures the brightness of a star in greenish/ visible light and is denoted m_G.

Gaia also measures both a "Blue-Pass" and "Red-Pass" magnitude – m_{BP} and m_{RP} respectively – and computes the color of each star from these measurements. We denote this color as: $m_{BP} - m_{RP}$, the difference in the blue and red magnitudes. Like magnitudes, colors can seem “backward” to us, so take a moment to think about the BP and RP magnitudes of a very red star. This star would be very faint in blue light, so the BP magnitude would be a large number, while the RP magnitude would be a lower or perhaps a negative number due to its brightness in red light. The $m_{BP} - m_{RP}$ color would then be a large number minus a small number. As a result, the higher the number is for color, the redder the star. Lower numbers for the color will indicate a bluer star.

Looking at the first star listed in the NGC 188 open cluster in the context of some of the other stars in the cluster, is the star redder or bluer or somewhere in between? Why?

Part 2: Temperature Calculations

As hot stars are brighter in blue light than red, color must be related to temperature. Through some calibration work, astronomers have determined this color is related to the temperature via the equation below, where we use C as shorthand for the $m_{BP} - m_{RP}$ color:

$$T = \frac{5040\ K}{0.49 + 0.50C - 0.03C^2}$$

Determine the temperature of the first star listed in the NGC 188 open cluster.

Part 3: Distance and Absolute Magnitude Calculations

Astronomers can measure the distance to stars in the Milky Way Galaxy via their parallax – a quantity that the Gaia Space Telescope is very good at measuring. We can compute the distance from the parallax via the equation:

$$d(parsecs) = \frac{1}{p\ (arcseconds)}$$

Once we know the distance of a star, we can combine this knowledge with its apparent magnitude in order to understand how bright that star is intrinsically – the absolute magnitude M_G. This can be done via the equation:

$$M = m - 5\log_{10}\left(\frac{d}{10\ pc}\right)$$

Determine the distance to the first star in the NGC 188 cluster and compute its absolute magnitude.

Part 4: Luminosity Calculations

While the apparent magnitude depends on how far away an object is, the *absolute* magnitude describes a star's intrinsic brightness. As such, it is related to a star's *luminosity*. This relationship is described by the following equation, where the magnitude of the sun in Gaia's G-band is $M_{G\odot} = 4.67$ and the Sun's luminosity is $1L_{\odot}$:

$$M_{\odot} - M = 2.5 \cdot \log_{10} \frac{L}{L_{\odot}}$$

Determine the luminosity of the first star in the NGC 188 cluster. What units is your answer in?

Part 5: Radius Calculations

Luminosity is the total energy output from a star. It is the product of the total area of a star and the intensity of light, $I = \sigma T^4$, where $\sigma = 5.67 \cdot 10^{-8} \frac{W}{m^2 K^4}$. In other words:

$$L = \sigma A T^4$$

Or in terms of solar luminosity ($L_{\odot}$) and the Sun's temperature (about 5800 K):

$$\frac{L}{L_{\odot}} = \frac{A}{A_{\odot}} \left(\frac{T}{T_{\odot}}\right)^4$$

Use the results from earlier parts of this lab to determine the *radius* of the sample star.

<u>Part 6: Putting it all together with HR Diagrams and Gaia Space Telescope Data</u>
An Excel template is included with this lab. Please complete the necessary formulae in order to determine the temperature, distance, absolute magnitude, luminosity, and radius of the stars in each of two star-clusters observed by the Gaia Space Telescope: M67 and NGC 188.

Please be sure to look up or ask about Excel shortcuts. Save for typing out a formula or formatting a graph, if a task in Excel takes longer than one second, you are likely missing a useful shortcut (e.g., do not drag a formula cell for 5000 lines – instead you can double click the small green box on the bottom right of the cell). <u>You will need to turn in your spreadsheet on canvas or have it checked off in lab.</u>

Next, plot both clusters on a Color-Magnitude (HR) Diagram in order to determine which cluster is older. You will have to invert your y-axis, as lower or negative magnitudes correspond to more luminous stars. To do this, click on the vertical axis of your graph and go to axis options. Under this menu there should be an option to put "values in reverse order."

Make a rough sketch of your Color-Magnitude diagram below (ideally using two different colors to distinguish the different curves) and use it to answer the following questions:

1. Where on the diagram are the hot, luminous stars located?
2. Where on the diagram do stars have the largest radii?
3. Which open cluster is older? Please explain in <u>at least a few sentences</u> how you know.