

NAME: _____

COLOR MAGNITUDE DIAGRAMS

What will you learn in this Lab?

This lab will introduce you to Color-Magnitude, or Hertzsprung-Russell, Diagrams: one of the most useful diagnostic tools developed in 20th century astronomy. These plots can tell us much about the physical nature of stars, including their size, temperature, age and ultimate destiny. Using the Starry Night Pro software in our lab, you will construct your own CM diagrams and learn more about some of the stars you'll be looking at in the spring night sky this semester. You will also try to estimate the ages of a few stars.

What do I need to bring to the Class with me to do this Lab?

For this lab you will need:

- A copy of this lab script
- A pencil
- A scientific calculator

Introduction:

In the first half of the 20th century, two astronomers, E. Hertzsprung and H.N. Russell, independently came up with a remarkable way of looking at the observed properties of stars. The observable properties of stars are quite simple: how bright they are and what color they are. These quantities can be converted into more useful properties by using some additional laws of astronomy.

First, *Wien's law* relates the *color* of a star to the *surface temperature* of that star. Specifically that:

$$\lambda_{\max} T = \text{constant}$$

which means that the wavelength of the *brightest color* in the stars spectrum (ie. λ_{\max}) is directly related to the star's *surface temperature*. As the star gets hotter the wavelength or color of the brightest part of the spectrum gets smaller, or more blue. Conversely, the cooler the star, the redder the star. This produces, at times, the counterintuitive result that hotter things are more blue, and colder things are more red. Anyway, if you can measure the brightest *color* in a stars

spectrum, which is generally speaking the color the star appears to the naked eye, then you can make an estimate of the star's *surface temperature*.

The second piece in this puzzle is the application of *Stefan's law*. This law predicts the total amount of energy a star (or any hot object for that matter) should emit as radiation per second per unit area, using:

$$E = \sigma T^4$$

where σ is Stefan's constant. That is, if you know the *surface temperature* of a star then you can predict how much *energy* is being emitted by each square meter of that star's surface.

The third piece of this puzzle comes from an alternate expression of *Stefan's law* using *Luminosity* instead of energy per unit area. A star's luminosity is the total energy radiated per second from the entire surface of the star. So, it is possible to express a star's luminosity as:

$$L = 4\pi R^2 \sigma T^4$$

where we've taken the first version of the law above, and simply multiplied it by the surface area of a sphere to give the expression for luminosity. But, you're saying, how do we know the radius of a star? It's way too far off to measure directly.

The final piece we use to calibrate the system, and so the whole H-R diagram, is the application of the *inverse-square law* for nearby stars. If a star is close enough to us we see it move relative to distant stars as we orbit the Sun through *Parallax*. By measuring how much it appears to move we can estimate the distance to the star. If we know the distance to the star, and we can measure how bright the star *appears* to be, then we can infer how bright the star is if you're standing *next* to it, using the inverse-square law. This latter law is simply the effect that the *farther* off you stand from a bright light, the *fainter* it looks, as the light gets spread over a larger and larger sphere centered on the light. The surface area of a sphere is given by $4\pi R^2$, where R is the radius of the sphere, or in the case of a light it's the distance between you and the light bulb. So as you get further away from the light, the area of the sphere the light is spread over goes up faster, as the square of that distance. So, the law is called the inverse-square law: inverse because the light level received drops, and square because of the size of the sphere the light is spread over.

So, for the closest star you can independently determine the star's distance, brightness, temperature and size. Rather amazing given how far from these things we really are. Once this has been done for a group of the nearest stars, we can calibrate the various types of stars that there are. These categories are called *spectral types* and allow us to group together stars with the same types of observed spectra, colors and brightnesses. This is what ends up on an H-R diagram. Figure 1 on the following page is an example of such an HR diagram.

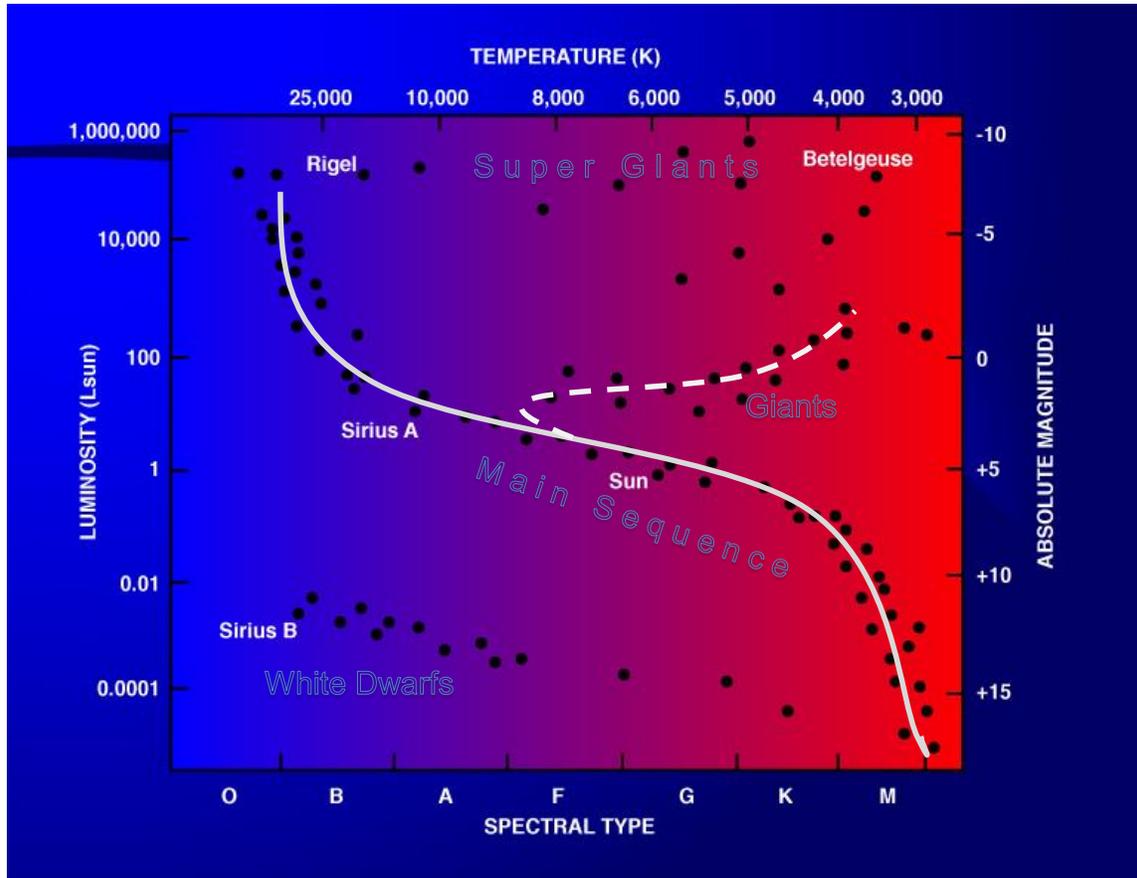


Figure 1. HR Diagram of stars in the Orion constellation.

As you can see in Figure 1 above, if you take a random part of the sky (this is a sample of stars from the region around the constellation Orion), the stars form very distinct regions. An H-R diagram is essentially a graph of stars with each star's location determined by their brightness or luminosity in the vertical (or y) direction, and by temperature in the horizontal (or x) direction. The vertical scale is shown in units of absolute magnitude on the right, and as multiples of our Sun's luminosity, L_{\odot} on the left. The horizontal scale is shown in temperature (Kelvin) across the top and by spectral type across the bottom.

The solid white line that runs diagonally across the diagram highlights the region called the Main Sequence where stars spend most of their normal hydrogen-burning lives. It is when they depart this region that very interesting things start to happen to the size and internal structure of a star. Stars to the left are very hot, stars to the right are quite cool. Stars at the top are intrinsically very bright, stars at the bottom are quite faint. That is how an H-R diagram works. The region names indicated show where stars of various types end up on this diagram.

One final thing you can use an H-R diagram to do is to tell the age of a cluster of stars. The idea is that as a star gets older and starts to evolve its position on the diagram changes and it moves away from the main sequence as traced by the dashed white line in Figure 1 above. The very hot stars evolve fastest, the less hot ones evolve more slowly. So if you look at a cluster of stars (the assumption being that they all formed together at the same time) then wherever you see stars starting to move away from the main sequence, the so-called “turn off”, then you know the age of the cluster.

This approach has been calibrated and is shown below in Figure 2. On that figure you'll see that there are horizontal marks indicating various ages from 10^7 to 10^{10} years! The way you determine the age of a cluster, or star, is you find where the Main Sequence stars start to move away from the well defined grouping by that name. Young stars move away higher up the H-R diagram than do older stars. By finding the “turn-off” point for a star or cluster you have a snap-shot of a critical point in the star’s evolution and can determine the age of the star(s).

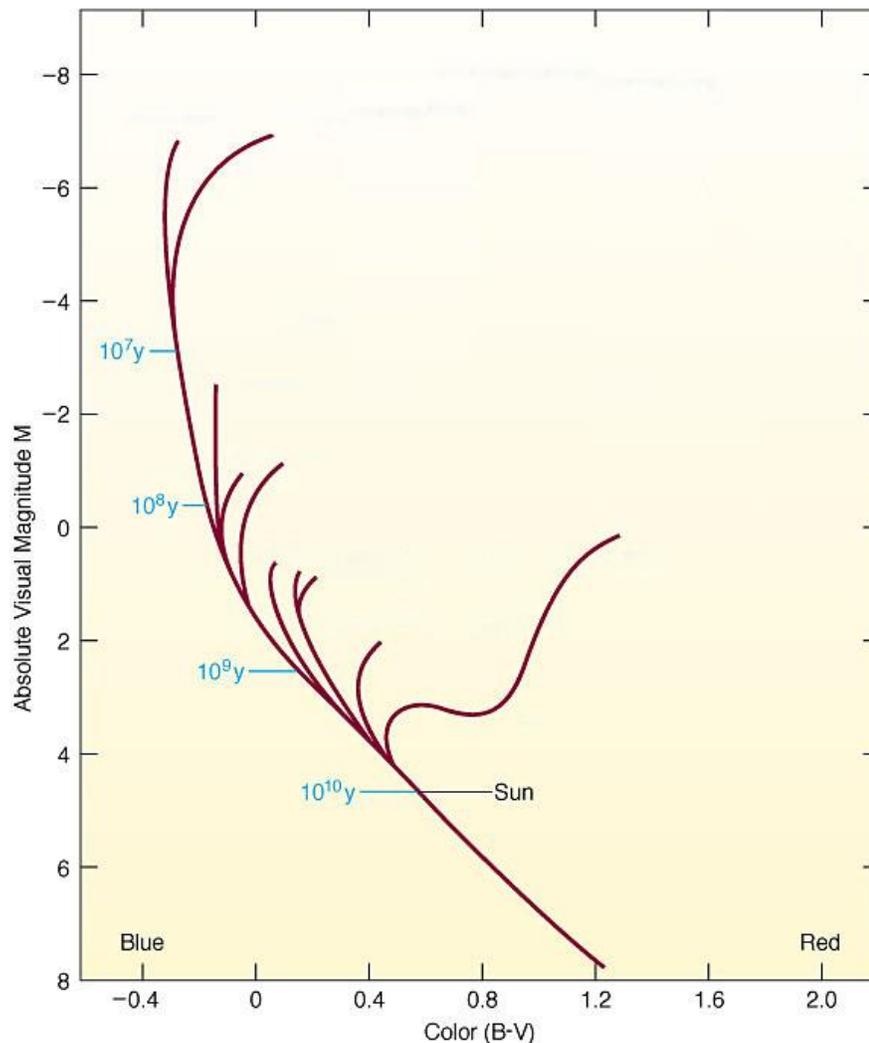
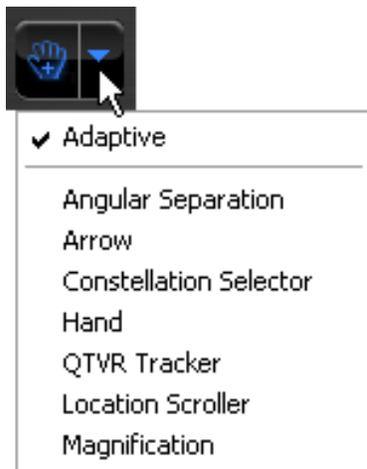


Figure 2. Representation of various turn-off traces and related ages.

General Information for operating the *Starry Night* program

Starry Night is a very powerful virtual planetarium program that can show the sky on any date in any year from any location. It has easy to use controls, a few of which are described below:

In the very upper-left corner is your tool selection tool. By default, SN opens in adaptive mode which allows you to click and drag around the scene, and brings up information when you hover over objects in the sky. You can play around with the other options. The most useful ones you'll use in lab are:



Angular Separation – This tool lets you accurately measure the separation between two objects in the main window. Click on the first object, then drag to the second object. The angular separation between the two objects will be displayed, as well as the physical distance between them.

Arrow – Allows you to point at certain objects in the main window, and SN will tell you what it is, and information about the object.

Constellation – As you pan through the night sky, clicking will bring up the constellation label and art

for the object you click on.

Hand – The hand tool lets you click and drag to pan around the main window.

Magnification – The magnification mode allows you to click anywhere in the main window and it will zoom in to that point. Alternatively, you can also click and drag a box, that you want to zoom to.

The panel along the top functions as your information display.



Time and Date

Starry Night opens up to the current date/time. By clicking on any of the date/time elements you can enter a

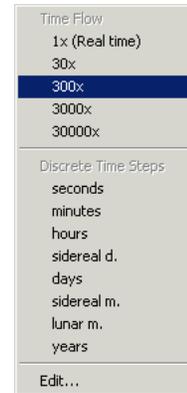
new value. You can also always reset it to the current time, sunrise, or sunset today by clicking on the buttons below the display.



Time Flow Rate

By default SN advances at the same rate as real time, hence the 1x speed. Of course this is absurdly slow, so you can click on the arrow next to the rate to select a different speed. Or, you can even select a discrete time step so that SN plays forward 1 day at a time or other interval.

You can move one step at a time by using the buttons at either end of the button panel. The inner arrow buttons will change the display real time – i.e. one second per second. The stop button halts any display updates. This will be your most useful tool for this lab exercise!



Viewing Location

By default, this should be set to Phoenix, AZ. But you can also pick a different location to see what the sky looks anywhere in the world! If you're lost, the Home button will always take you back to Phoenix at the current time. The two arrow buttons next to Home will allow you change your viewing altitude.



Gaze

This displays the altitude/azimuth coordinates of where you're looking.



Zoom

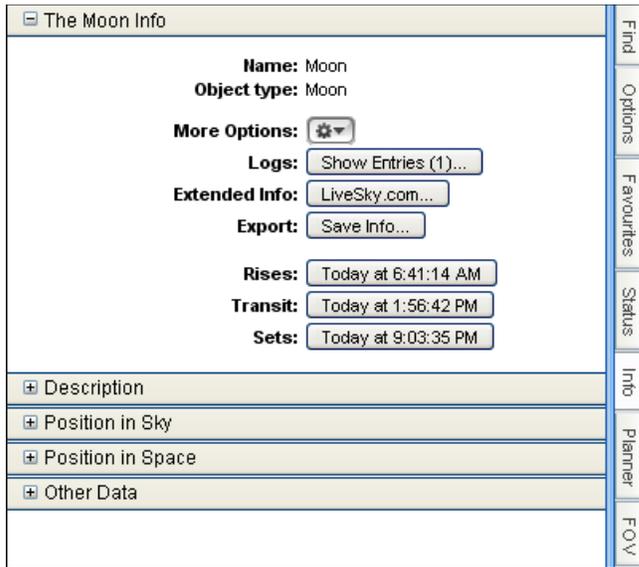
This shows your angular field of view. In general, you can zoom in and out by using the scroll wheel on your mouse. Or you can use the (-) or (+) buttons.

Moreover, you also have a number of side panes that can allow you to pull up favorites, labels, or other information:

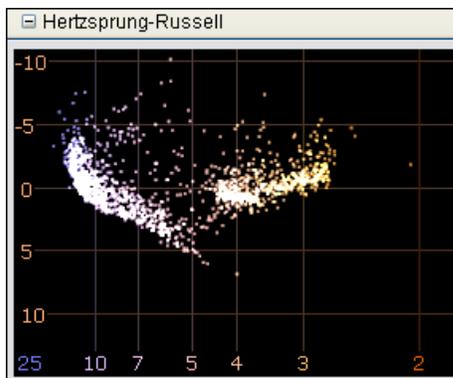


Clicking on a pane causes the pane to slide out, revealing a set of controls. The most useful one for this lab, is under the **Status** pane. Click  on the next to **Time** layer to expand it. Here, you will see a more detailed view of the Time and Date display. But the most useful for this lab is the Julian date!

Specific instructions for use of Starry Night Pro 6 in tonight's lab:



1.) Click on the Status tab, which should then include a submenu with an option for "H-R (Hertzsprung-Russell diagram).



2.) This should bring up small window with the HR diagram for all the stars in your main screen's field of view.

Procedure

After all that, let's start using what we've learned and do some interesting work. You will be using Starry Night to complete the table on the following page. You may need to turn off the daylight to see some of the listed constellations. For each constellation, pick the brightest and most familiar stars and use the color-magnitude diagram for the region to determine their properties. Record the data in the table provided for later use. For each star you simply point the cursor at the star and a red point will appear in the H-R diagram window indicating its position on the diagram. You will need to switch the x axis between temperature and spectral type to get all the data you need.

Const.	Star	Sp. Type	Temp. (K)	Abs. Mag.	Distance	Luminosity	Type
Orion							
Taurus							
Leo							
Gemini							
Ursa Major							
Auriga							

In each case the distance to the star will be displayed when you point the cursor at it. The Type asked for is whether the star is Main Sequence (MS) or is a Giant, Supergiant, etc. For each star you are also being asked to calculate the luminosity of the star. For this you will need one more equation.

4. Use the scrollbars to move your field of view onto a part of the Milky Way and again examine the HR diagram. Are there more main sequence stars than giants or vice versa?

5. Now move to a part of the sky well away from the plane of the Milky Way. Are there more main sequence stars than giants or vice versa?

6. What does this tell you about the relative ages of stars in the plane of the Milky Way compared to those out of the plane, as we see them?

7. What does this mean physically about the two regions with regards to star formation and the evolution of the Galaxy?

8. Finally, scan around the sky to see if you can find any stars that are just to the upper right from the main sequence. These are stars that are in the process of evolving away from the main sequence and so adhere to the calibration for this observed phenomenon, presented in the diagram on page 4.
 - a. Based on the star's location on the HR diagram, estimate the star's absolute magnitude.

 - b. Likewise, determine the star's (B-V) color value.

 - c. Using your answers from above and Figure 2 on page 4, estimate the star's likely age.

9. For **Main Sequence stars**, the luminosity of a star depends on its mass:

$$L \propto m^n \quad (\text{where } n \text{ ranges from } 2 \text{ to } 3.5)$$

In other words, a more massive main sequence star will also be more luminous.

- a. Which of your Main Sequence stars do you expect to be the most massive?

- b. Where on the main sequence (ie., what color) are the most massive stars found?

10. If all the stars in your table were twice as far away, but the apparent brightness remains the same, would the luminosities you calculated be larger or smaller? Why?

11. Similarly, if each star were instead half the temperature you measured, would the luminosity increase or decrease? Why and by how much?

12. The HR diagram underpins a lot of observations and developed theory about stellar evolution. It has been a vital tool in astronomy since the early part of the 20th century. An added complication comes from the fact that light from stars can be reduced or “reddened” by intervening dust in the interstellar medium. How would large amounts of dust affect our estimates of stellar properties (ages and distances) for stars far from us?

Summarize what you have learned in tonight’s lab: