# Does the HR Diagram Change Over Time?

## Course Outcomes Met

1. Communicate scientific issues effectively in oral and written form;
2. Effectively collect, analyze and present data and correctly construct and interpret charts, graphs and tables to draw scientific conclusions;
3. Apply the fundamental concepts and methodologies of physics and/or chemistry to investigate a scientific theme.
4. Distinguish scientific studies from popular opinions by employing critical thinking skills and the scientific method;

Tools used in this activity:

1. PhET black body simulator
2. Real star data from the Hipparcos satellite

## A. Getting The Idea

We’re going to construct an HR diagram for a group of stars that all formed at the same time. For this purpose, we’ll use the open cluster that is easiest to see from Earth, the Pleiades. If you can find Orion, the Pleiades are right next door. Here’s a picture.



Orion, the Hunter, is on the left. The line of three bright blue stars is his belt. His left shoulder is the bright red star Betelgeuse. Betelgeuse connects in a sort of straight line to another red star to the right, Aldebaran. If you follow that line on to the right, you see a little tiny dipper of stars. That’s the Pleiades. You can see 6 of them (7 if you have really good eyes), but there are hundreds in the cluster. Those are just the brightest ones.

Close up, the Pleiades looks like this.



1. From your reading about star formation, why would we think the Pleiades are all about the same age?

2. Would you say the stars in the Pleiades are young, old, or middle aged? Think about what you learned from the Hoe Long Do Stars Live? activity.

To make an HR diagram, we need to measure temperature. Astronomers have a variety of ways to measure this. We’ve looked at peak wavelength, and we’ve also looked at spectral class. A third way, which has the advantage of being able to automate easily, is called the B – V color index. You get this by measuring the visual magnitude through a standard blue filter (B) and also through a standard green filter (V because green is the center of the visible spectrum). Then you subtract B – V.

3. Why should the color index be related to the temperature of stars? You might want to refer to the PhET simulator you used in the How hot are stars? activity.

<https://phet.colorado.edu/sims/html/blackbody-spectrum/latest/blackbody-spectrum_en.html>

4. What should be true of the B-V color index for blue stars vs. red ones? If you look at the intensities in blue and green on the simulator, you should be able to see the difference.

***Check your results with your instructor at this point***

## B. Some Actual Data

The second thing we need to know is absolute magnitude. Visual magnitude is easy to get but to determine absolute magnitude, we need to know the distance to the star. Fortunately, we’ve learned how to get the distance, at least for stars that are not too far away, by measuring their parallax angle. At the end of the How Far Away Are Stars activity, we had a very simple equation to get the distance in parsecs if we know the parallax in seconds of arc.

The atmosphere makes parallax measurements from Earth hard, but several years ago the European Space Agency launched a satellite named Hipparcos whose sole purpose was to make very precise parallax angle measurements out to a great distance. They got some other data besides, but parallax was the main point. We’re going to use actual Hipparcos data in this activity.

To locate objects, we use their Right Ascension (RA) and declination (dec) coordinates. You can think of these as longitude and latitude in the sky respectively.

In the Hipparcos data, the B – V value will actually be given to you. We’re going to have to work at it to get the absolute magnitude. First we’ll see how to set it up and then we’ll let Excel do all the tedious calculations.

You can access a Java tool that shows an image of the sky with all Hipparcos data at <https://www.cosmos.esa.int/web/hipparcos/java-tools/show-sky>. Let’s start with one of the brightest stars in the sky, Sirius.

Start the app and click Show Sky. By default, the app shows you Hipparcos data as well as that from a previous satellite, Tycho. Tycho’s data is considerably less accurate and sometimes meaningless (e.g. a negative parallax just means the uncertainty in the measurement is bigger than the measurement). Lets just look at Hipparcos so uncheck the Tycho (View TYC) box. You should see nothing but red dots..

The RA and dec for Sirius are RA = 101.2871541o and dec = -16.71612o. (Negative means it is in the Southern sky. Enter the coordinates at the bottom of the screen and click on View. The applet will draw the region of sky around Sirius. The larger the circle, the brighter the star. Click on Sirius, which should be hard to miss, then click Get Info.

A window will open in your web browser with a LOT of information. We are primarily interested in three lines in the data. Line H11 gives the Trigonometric Parallax in mas (milli-arc-seconds). Line H5 gives the visual magnitude. If it is somewhere around -1.44, you got the right star. And line H37 gives the B – V color index.

1. Convert the parallax angle from milli-arc-seconds to arc seconds and use the equation from the end of the star distance activity to calculate how far away it is in parsecs.

2. Let’s do a few more to make sure we have the hang of it. Fill out the rest of the entries in this table.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **RA** | **Dec** | **Visual Magnitude (H5)** | **Parallax (mas – H11)** | **Parallax (arcsec)** | **Distance (parsecs)** |
| 100.521 | -15.209 |  |  |  |  |
| 99.648 | -16.874 |  |  |  |  |
| 100.392 | -17.534 |  |  |  |  |
| 102.203 | -16.211 |  |  |  |  |

## C. Finding the Absolute Magnitude

One of your red equations from Classifying Stars II was

IA / IB = (2.512)(mB - mA)

but remember the 2.512 number is really 1001/5 so we can rewrite this equation as

We got this equation to compare the brightness of two stars but we can also compare the brightness of the same star seen from two different distances. The luminosity is defined to be the intensity 10 pc away from the star. Similarly, the absolute magnitude is defined to be the visual magnitude at 10 pc away. Let’s let those be position A. The apparent values will be B, so *mB* is what we called *m* before, the apparent visual magnitude. Similarly, *mA* is what we called *M* before, the absolute magnitude. So

If you imagine switching a star on and off very fast, the light emitted while it was on travels equally in all directions and is distributed across the surface of an ever expanding spherical shell. The intensity is the amount of light in each square meter of that shell so this leads to the famous inverse square law relating intensity to luminosity (here’s where distance comes in).

If we substitute this in the previous equation, for both *I*  and *I*10, the luminosity L cancels out as does the 4π and we’re just left with

taking the dreaded logarithm of both sides

And our goal was to find absolute magnitude *M* so solve for it:

And there you have it. Knowing the distance *r* in parsecs and the visual magnitude *m*, we can work out the absolute magnitude.

1. Let’s apply this to the stars from the previous table.

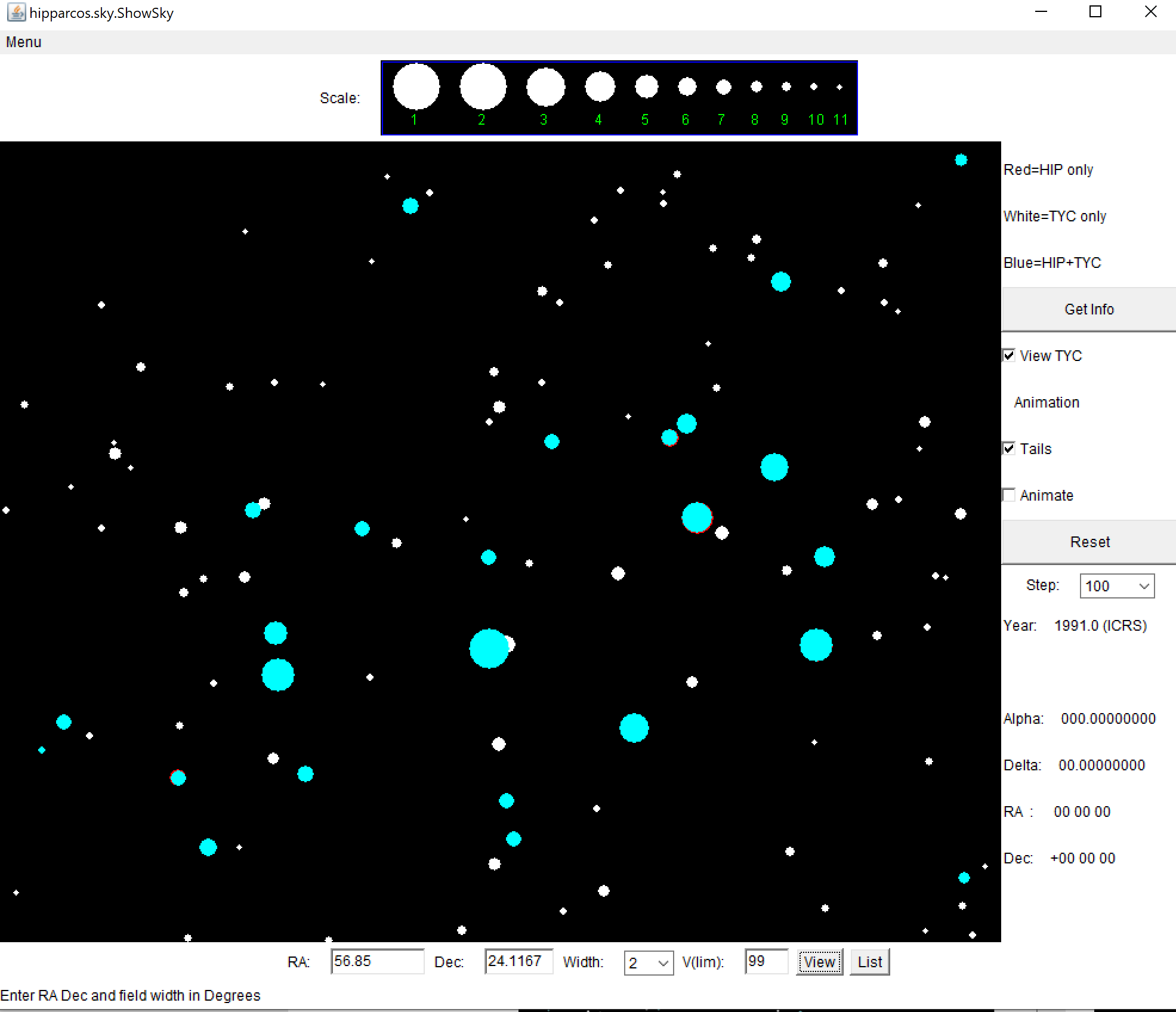
|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **RA** | **Dec** | **Visual Magnitude** | **Distance (pc)** | **Absolute magnitude** |
| 100.521 | -15.209 |  |  |  |
| 99.648 | -16.874 |  |  |  |
| 100.392 | -17.534 |  |  |  |
| 102.203 | -16.211 |  |  |  |

***Check your results with your instructor before proceeding***

## D. The Pleiades

The center of the Pleiades is at RA = 56.85o and Dec = 24.1167o. The Pleiades is almost 2 degrees wide, so you can set the width to 2. Hipparcos didn’t take a whole lot of data here so we’ll have to use the Tycho data as well. Check the box for that and click View.

You should see something like this.



1. Each member of your group should collect data on 10 *different* stars in this field. Remember, you need visual magnitude, parallax and color index.

2. Assemble all your group’s data in a spreadsheet and do the distance and absolute magnitude calculations. What do you notice in your data? In Excel, the command for doing a log of something is =LOG10(something).

3. The spreadsheet HIP.csv contains a larger sample of data. Try doing the same thing for it. Again, what do you notice in the results?

4. You should see some negative parallax angles in the data. How did this affect your calculations?

5. There are at least two major reasons why negative *measured* angles could be negative. See if you can come up with one of them.

6. Do you think all of the stars in these spreadsheets are actually members of the Pleiades cluster? Explain your reasoning.

***Check your results with your instructor at this point***

Sorting out which stars are members of the Pleiades from which ones are not is a bit tricky and complicated. So we aren’t going to pursue that question any further. Assume you put your graduate students to work on that part.

There are actually several thousand stars in the Pleiades. The only data I could find for them is in a paper that is so old the pdf is just page images and I’ve not been up to the task of transcribing all of that. The spreadsheet Pleiades data.xlsx is the largest one I could find that was in an electronic format.

7. Make two HR diagrams, one from the HIP.csv spreadsheet and the other from the Pleiades data.xlsx one. What changes when you sort Pleiades stars from non-Pleiades stars?

8. Compare the Pleiades HR diagram to the one for all stars that you made in Classifying Stars II. What is different?

9. Thinking about your reading on star formation, how would you explain the difference?

***Questions***

1. Crackpottery can sometimes be dressed up to give the appearance of science. The way flat-earthers treat parallax is a good example. Consider, for example, this:

<https://geocentric.fandom.com/wiki/Negative_Parallax_-_a_Problem_for_Heliocentrism>

The phrase “bad measures” is doing a lot of heavy lifting in this argument. Think carefully about what you have learned about scientific measurements and uncertainty, and see if you can figure out the two major claims in this document that are wrong.

***Check your results with your instructor at this point***