# Star Clusters & Supernovae

Adapted from the University of Nebraska-Lincoln

ASTR 1020

Name:

## Overview

In this activity, you will explore several runs of the cosmic distance ladder and become familiar with their technique, scientific use, and limitations.

## Objectives

After completing this activity students will be able to:

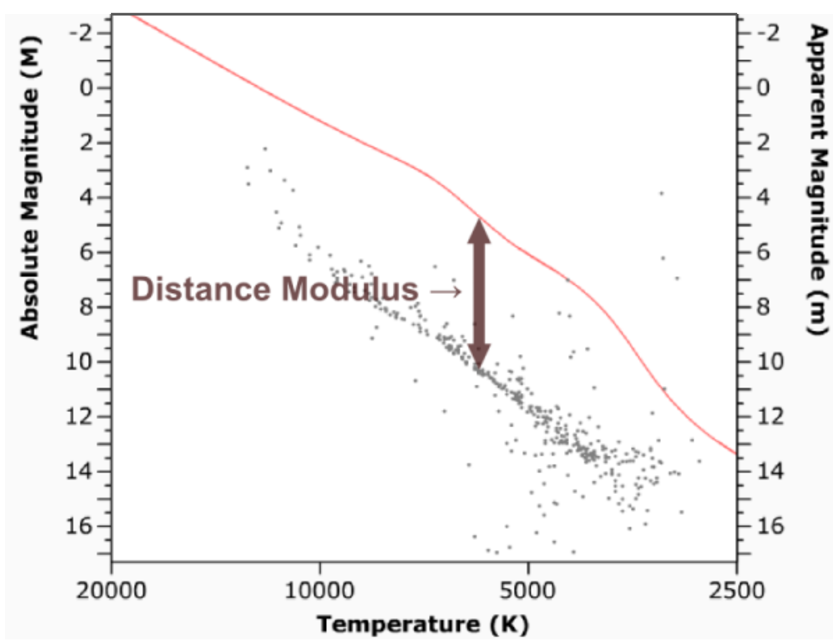
- Describe the distance measurement methods of main sequence fitting and supernovae
- Use star clusters to determine ages and distances of the clusters

**Note: If a question is labeled "**THOUGHT QUESTION**" we are looking for you to show critical thinking/justification in your answer, not a "correct" answer**

## Definitions

Here are some terms from lecture that we will be using today in lab:

- **Apparent magnitude** – *m*; the apparent brightness of a celestial object as measured from Earth.
- **Parsec** – equal to 3.26 light-years; the distance an object must be to have a parallax angle of 1 arcsecond.
- **Absolute magnitude** – *M*; the brightness of a celestial object as measured from 10 parsecs.
- **Distance Modulus** – *m-M*; the difference between an objects apparent and absolute magnitudes.




- **Main Sequence Turn-Off** – the point on the HR Diagram where stars in a star cluster begin to evolve off the main sequence after their hydrogen supply is exhausted.

# Part 1. Evolution of Star Clusters

While investigating various types of star clusters, we make certain reasonable assumptions about the stars found in each cluster. Namely, we assume all of the stars in a given cluster began to form at approximately the same time, and that a given cluster formed form the same cloud of gas and dust. If they began to form at the same time, we can determine the approximate age of a star cluster. Finally, all of the stars within a cluster can also be considered to be the same distance from us.

A given star cluster will have its own unique main sequence. Since bluer stars burn through their fuel quicker, and therefore live much shorter lives than their redder counterparts, the upper main sequence evolves much faster than the lower part. So, the more blue stars a cluster has on its main sequence, the younger it must be. In other words, the higher the main sequence turn-off is, the younger the cluster is.

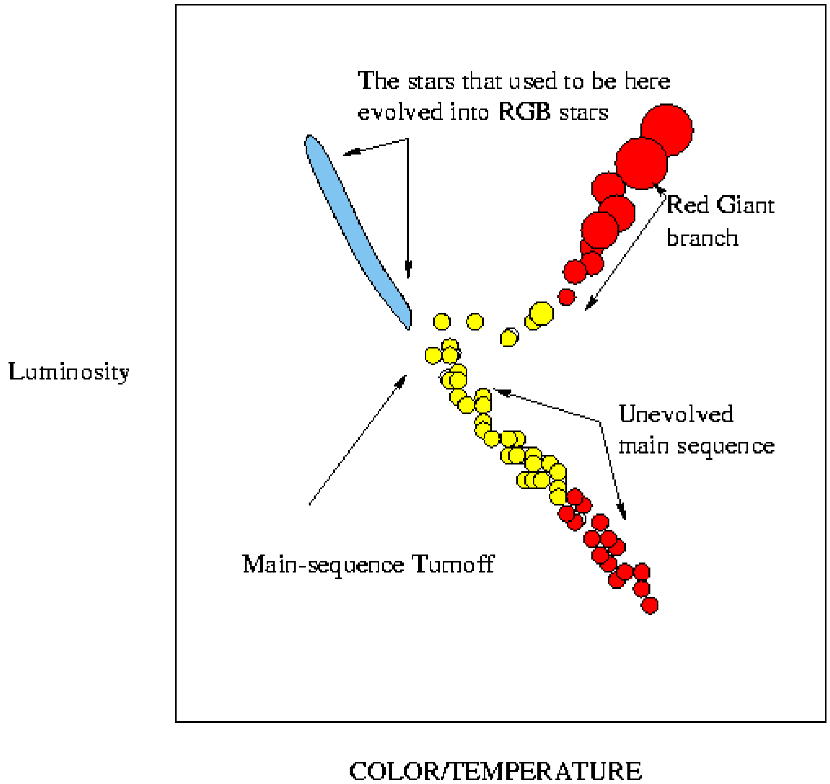



**Figure 1: Example of the main sequence turn-off**
Image credit: www.ucolick.org

To get started, open the NAAP Labs simulator, click '14. Cosmic Distance Ladder,' 'HR Diagram Star Cluster Fitting Explorer.' Ignore the solid red line for now. Under 'Cluster Selection,' select 'Pleiades.'

1. Note that there are several stars that are above the main sequence in the upper left of the HR diagram. Why are these stars not on the main sequence?'

2. Also note that there are several stars below the main sequence, especially near temperatures of ~5000 K. Why are these stars not on the main sequence?

3. At approximately what temperature is the main sequence turn-off occurring for the Pleiades star cluster?

4. Now select the NGC 188 star cluster. At approximately what temperature is the main sequence turn-off occurring for this cluster?

5. Which of these clusters is younger than the other? Why?

6. Based on the location of the main sequence turn-off for each cluster, place these in order from youngest to oldest in Table 1 below, where 1 is the youngest and 8 is the oldest.

**Table 1: Relative star cluster ages**

| Cluster Name | Age |
|---|---|
| | 1 (youngest) |
| | 2 |
| | 3 |
| | 4 |
| | 5 |
| | 6 |
| | 7 |
| | 8 (oldest) |

## Part 2. Main Sequence Fitting

Main sequence fitting determines distances using HR Diagrams of clusters of stars. These stars are gravitationally bound, all located at the same distance, and formed at the same time from the same cloud of gas and dust. Main sequence fitting compares the location of the main sequence (where *m* is on the y axis) for the cluster stars to the location of the main sequence for nearby stars whose distances are measured from parallax (so these stars' *M* is on the y-axis). Any difference in position between the main sequences must be due to the distance of the cluster. The vertical position of the cluster main sequence is adjusted vertically so that it lines up with the main sequence of nearby stars. The amount of vertical adjustment gives the distance modulus.

If you move the cursor into the HR diagram, the cursor will change to a handle, and you can shift the *m* scale by clicking and dragging. Grab the Pleiades data and drag it until the two main sequences are best overlapped (example shown in Figure 2).

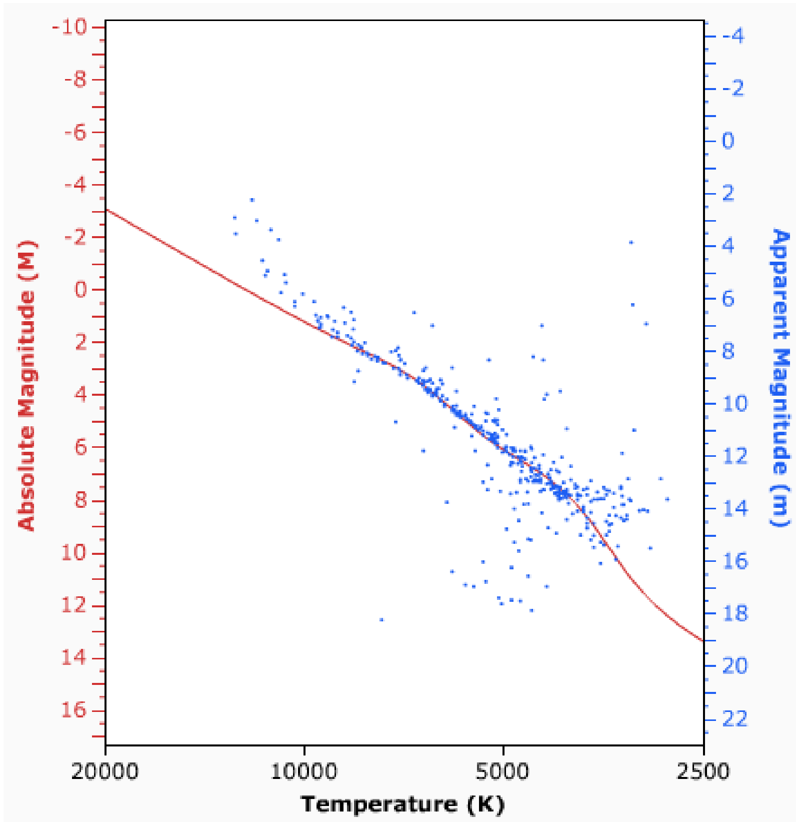



**Figure 2: Main sequence fitting example for the Pleiades star cluster**

We can now relate the two y-axes. Click on 'show horizontal bar' which will label the *M* (left) and *m* (right). Entering these into the 'Distance Modulus Calculator' will give you the distance to the cluster in parsecs.

7. Select the 'Hyades' cluster in the 'Cluster Selection' panel and fill in the distance modulus data in Table 2 below:

**Table 2: Distance modulus for the Hyades star cluster**

| *m* | *M* | *D* (parsecs) |
|---|---|---|
| | | |

8. Select the 'M67' cluster in the 'Cluster Selection' panel and fill in the distance modulus data in Table 3 below:

**Table 3: Distance modulus for the M67 star cluster**

| *m* | *M* | *D* (parsecs) |
|---|---|---|
| | | |

## Part 3. Supernovae

Astronomers recognize two main types of Supernovae explosions. Type I supernovae involve a white dwarf that is part of a binary system. A white dwarf is an earth-size ball of carbon and oxygen nuclei that is the collapsed core of a low mass star. If material flows rapidly from the binary companion star onto the white dwarf, a sudden burst of fusion is triggered and causes a Type I supernova.

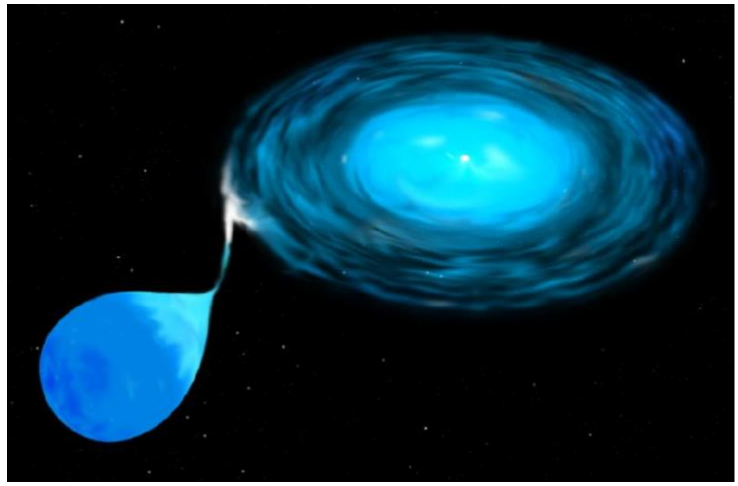


Image Credit: STSci

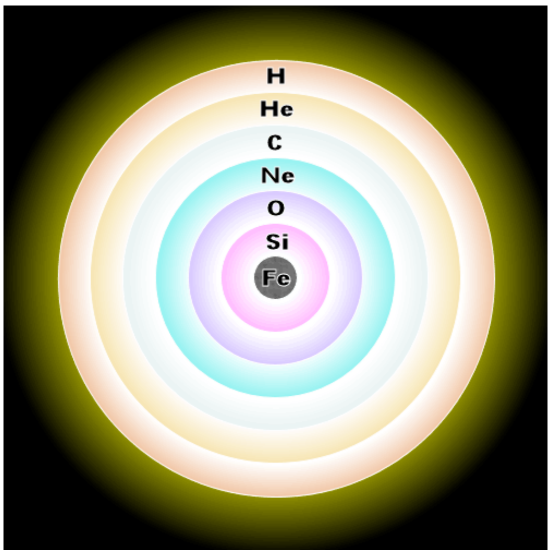



Image credit: R. J. Hall

Type II supernovae involve very massive stars at the ends of their lives. These stars fuse progressively more massive nuclei in their cores – carbon, oxygen, magnesium, silicon – and finally a core of iron is formed. Fusion of elements heavier than iron no longer release energy to oppose the gravity of the star. So, the core is crushed to incredibly high temperatures and pressures by the weight of the overlying materials, and all of the overlying layers "bounce" off of the core region. This Type II supernova is less energetic than the Type I and typically a massive object such as a neutron star or black hole is formed.

Because supernovae are such energetic events, astronomers can observe them at great distances. Type I supernovae are very uniform (with very uniform light curves – see Figure 3), they are much more useful to astronomers as distance indicators than Type II Supernovae. Type I supernovae easy to calibrate for standard candles since astronomers can calculate the amount of energy produced in the fusion that occurs before a Type I supernova.

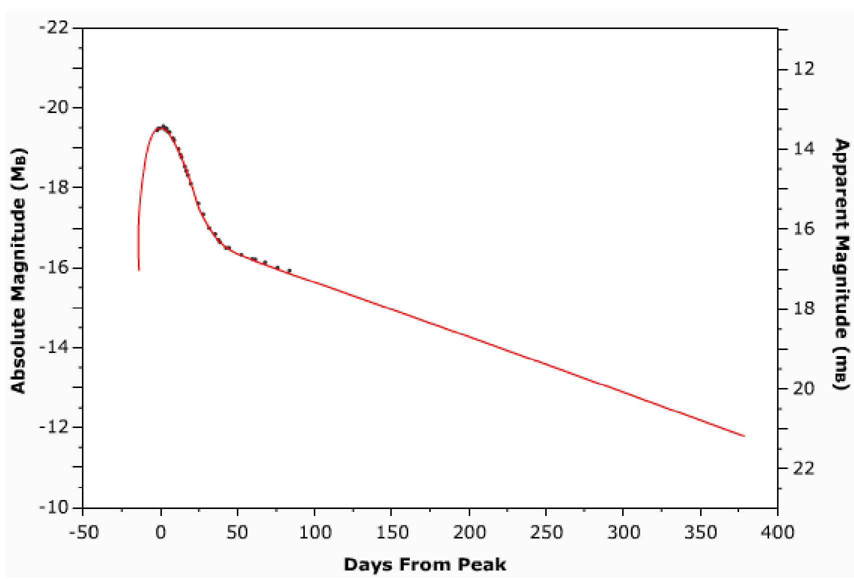



**Figure 3: Example fit of supernovae data to a Type I profile**

Go back to the ‘Cosmic Distance Ladder’ page in the simulator, then select ‘Supernovae Light Curve Explorer.’ The red line illustrates the expected profile for a Type I supernova in terms of its absolute magnitude. Data from various supernovae can be graphed in terms their apparent magnitude. It is then possible to fit the data to the Type I profile with the appropriate shifts in time and magnitude, shown above in Figure 3, just like main sequence fitting. Once the data fit the profile, then the difference between *m* and *M* (labeled if ‘show horizontal bar’ is selected) again gives the distance modulus.

9. Select the ‘1994ae’ supernova in the selection panel and fill in the distance modulus data in table 4 below:

**Table 4: Distance modulus for SN 1994ae**

| ***m*** | ***M*** | ***D* (parsecs)** |
|---|---|---|
| | | |

10. Select the ‘1993J’ supernova in the selection panel and fill in the distance modulus data in table 5 below:

**Table 5: Distance modulus for SN 1993J**

| ***m*** | ***M*** | ***D* (parsecs)** |
|---|---|---|
| | | |

11. Which of these supernovae were observed for a longer period of time? (Hint. The blue dots are observation data points)

12. **THOUGHT QUESTION:** Which supernova do you think would produce a more accurate distance measurement? Why?

13. **THOUGHT QUESTION:** Select the ‘1987A’ supernova in the selection panel. Explain why it is not possible to determine the distance to this supernova.