TUTORIAL 5

Class Assignment

1 Stellar evolution

When we classify stars, we try to use quantitative measurements of their properties, so that we can better understand how stars differ from one another, and why those differences occur. The most fundamental properties of a star are its mass and age. The progress of a star's life is predestined by its mass, because ultimately the mass determines how much energy the star can produce and how quickly it will do so, while the age of a star tells you how far along it is in its evolution.
You can refer to Figure 1. Recall the previous lecture on stellar evolution. You have been introduced to the various evolutionary stages a star experiences depending on its mass.

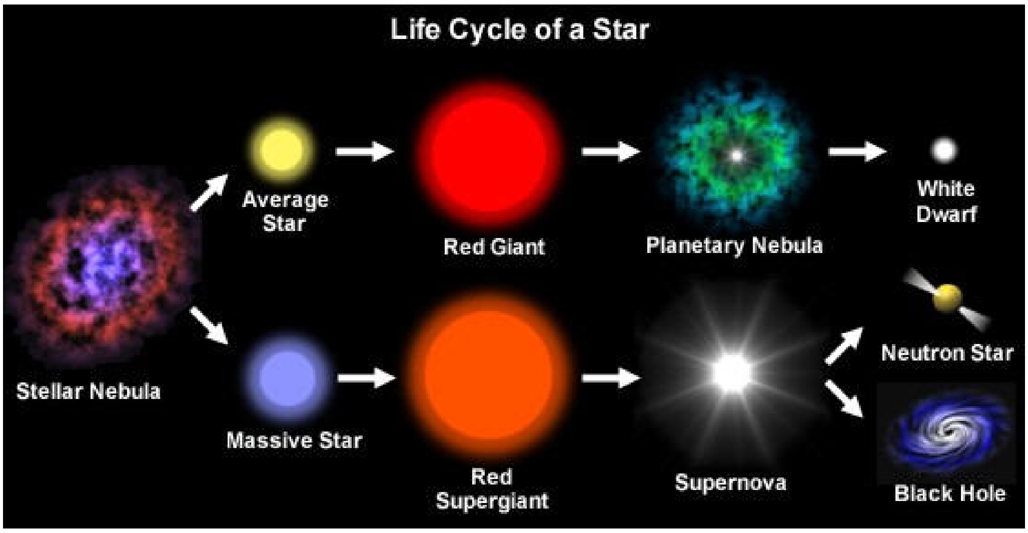


Figure 1

Instructions:
For this exercise, you will need to make use of an animation named 'Star in a box' found at:
https://starinabox.lco.global
This animation illustrates how stars with different stellar masses have different fates in terms of their evolution. With this simulation, you will be able to observe the luminosity and temperature dependence on the mass of stars and their age as they evolve from the main sequence to other evolutionary stages.

1. Initialise the animation. Select the advanced version and click on Open the lid.

2. The black dot on the screen represents the current position of your star on the H-R diagram.

Select the mass of your star from the mass list given in the bottom left of the screen, based on the masses given in Table (1) below. You can note the size comparison of your star with the sun.

3. For each star, note the corresponding parameters like the mass, temperature etc. as the star evolves over time, given in the panel to the right of the screen. Fill the table given below.

4. On the bottom of the same panel click the play button to start the evolutionary journey of your star. Select a suitable speed such that you can properly observe each stage of the evolution.

5. You can now observe the evolution of your star on the H-R diagram at the rate you selected. Observe the various evolutionary tracks that the star follows (dashed yellow line) and how the parameters change with respect to time. You might have to play the same animation a few times to complete your study.

6. After filling in the table, attempt the ranking exercise (Q2).

Q1. Fill in Table 1 given below.

Mass of star (M_{sun})	Initial Temperature & luminosity	Evolutionary stages followed	Minimum Temperature attained by star	Maximum Luminosity attained by star	Mass of the final evolutionary stage
0.2					
1					
6					
20					
40					

Table 1

Q2. The Figure 2 below shows main sequence stars of various sizes.

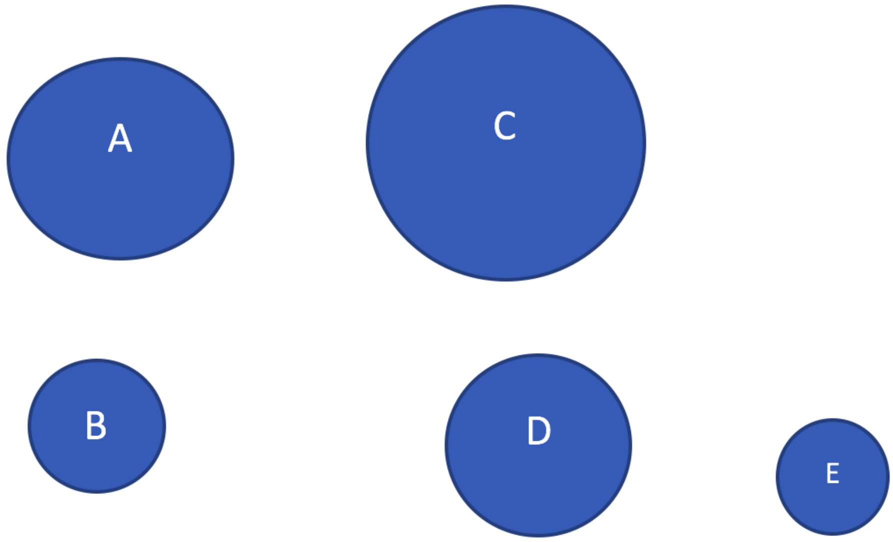


Figure 2

A) Ranking Instructions: Rank, from least to most, the mass of the stars:
Least 1_____2_____ 3_____4_____5_____ Most
Carefully explain your reasoning for ranking this way:

B) Ranking Instructions: Rank, from hottest to coolest, the temperature of these stars on the main sequence:
Hottest 1_____2_____ 3_____4_____5_____ Coolest
Carefully explain your reasoning for ranking this way:

C) Ranking Instructions: Rank, from greatest to least, the luminosity of the stars:
Greatest 1_____2_____ 3_____4_____5_____ Least
Carefully explain your reasoning for ranking this way:

D) Ranking Instructions: Rank, from longest to shortest, the total main sequence lifetime of the stars:
Longest 1_____2_____ 3_____4_____5_____ Shortest
Carefully explain your reasoning for ranking this way:

2 Cepheid Variables

Previously, you have learned about the trigonometric parallax method, which is used to measure the distances to the nearby stars. Using this method, distances up to a few hundred parsecs can be measured accurately. For distances beyond that, however, different methods must be adopted. One such method uses Cepheid variables.

Cepheid variable stars are named after $\delta-$Cephei, the first variable star discovered in the constellation of Cepheus. Cepheid variable stars are luminous stars, thus discoverable at large distances, that change their brightness with a regular period ranging from a few days to hundred days. By observing Cepheid variables in nearby galaxies, we can estimate the distance to them. A typical Cepheid light-curve, which is a plot of the varying intensity of light over a period of time is shown in Figure 3. From such light-curves, a characteristic sharp rise in the the brightness followed by a more gentle drop is quite easily observed and recognised.

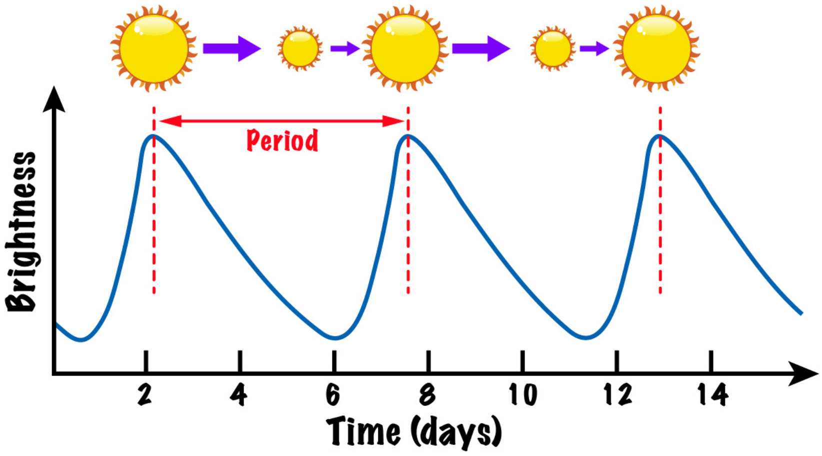


Figure 3

Recall the Distance modulus formula, given by

$$(m - M) = (5 \log_{10} d) - 5$$

Where m is the apparent magnitude, M is the absolute magnitude and d is the distance to the object. To calculate distances to Cepheid variables, one must know m and M.

1) There exists a well-defined relationship between the average intrinsic luminosity, or absolute magnitude (M), and the period (P) of a Cepheid variable, measured in days. It is given by:

$$M = -2.78\, log(P) - 1.35$$

The time period (P) of the Cepheid variable can be measured from the light curve (Figure 3).

2) For a Cepheid variable, the apparent magnitude 'm' varies over a period of time as seen in Figure 3. Therefore, in such cases, we use the average apparent magnitude of the Cepheid variable, $< m >$. To calculate $< m >$, you first have to note the minimum and maximum apparent magnitudes (m_{min} and m_{max}) from the light curves. Once you have these values, you simply have to take an average of them.

Your task is to calculate the distance to the galaxy M100. It is one of the brightest galaxies in the Virgo cluster and is very similar to our own Milky Way galaxy. Within M100, several Cepheid variable stars were observed by the Hubble Space Telescope. One such observation is illustrated in Figure 4.

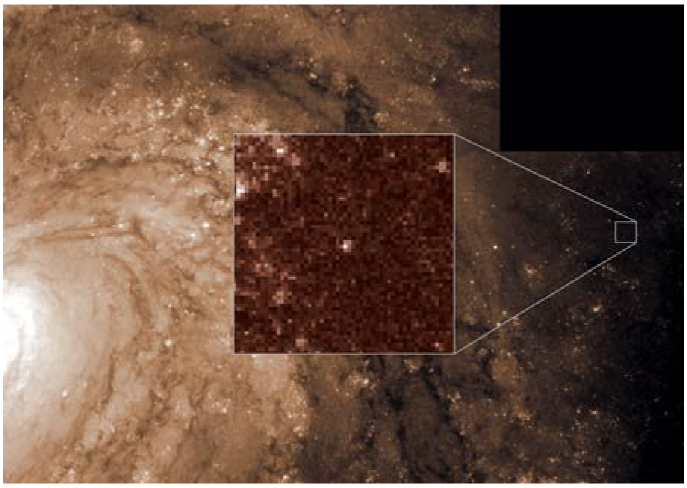


Figure 4: The central box shows the Cepheid variable in the galaxy M100.

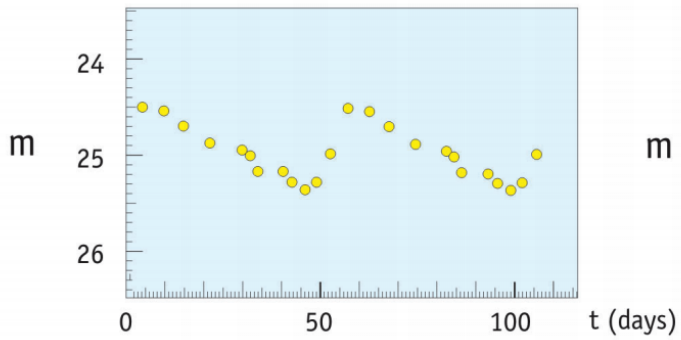
INSTRUCTIONS:

1) You are given the light curves of 6 Cepheid variable stars observed in M100. Calculate M and $< m >$ with the help of the steps mentioned above.
To make calculations more efficient, an excel sheet is available on the course website: www.astro.rug.nl/EDUCATION/main_en.html#overview. Using this excel sheet, you can easily calculate M and $< m >$ for all the given Cepheids.
2) Use the distance modulus formula to estimate the distances to the Cepheid variables.
3) Fill in your answers in Table 2.
4) Find the distance to the host galaxy M100 by taking an average of the distances of the 6 Cepheid variables.

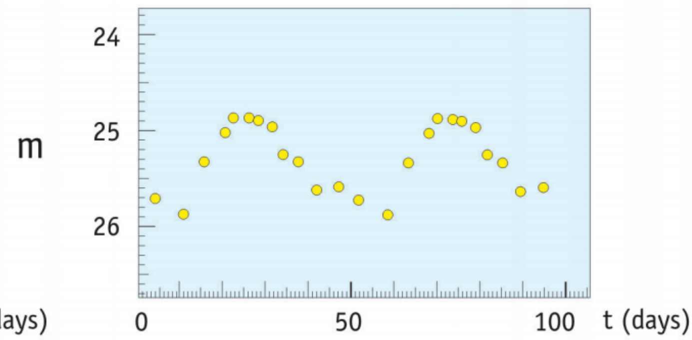
Cepheid Variable	<m>	M	d (Mpc)	Distance to galaxy (Mpc)
1				
2				
3				
4				
5				
6				

Table 2

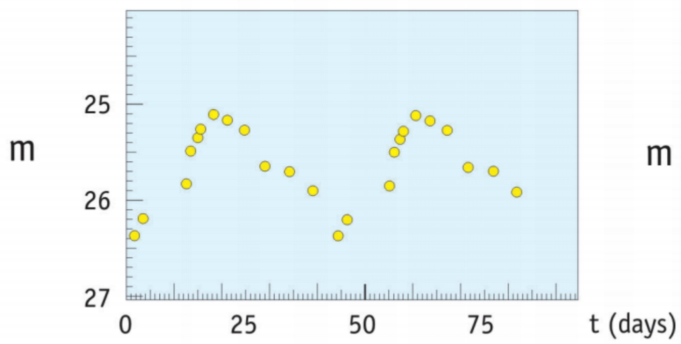
Cepheid 1



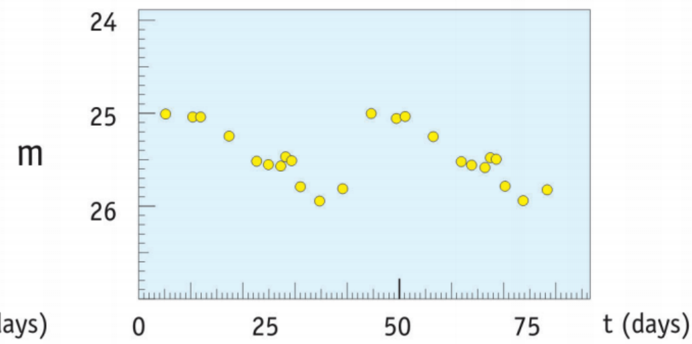
Cepheid 2



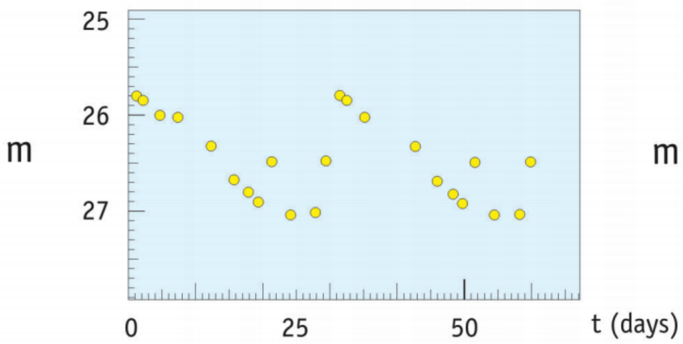
Cepheid 3



Cepheid 4



Cepheid 5



Cepheid 6