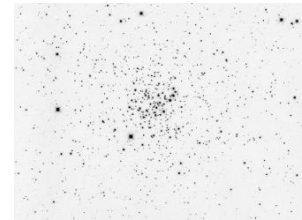Name: _____

Partner(s): _____

1102 or 3311: _____

Desk # _____

Date: _____

M67

# Determining the Age of a Cluster

**Purpose**
- Understand how HR diagrams reveal information about stellar evolution
- Use an HR diagram to determine the age of a star cluster
- Use RR Lyrae variable stars to determine the distance to a star cluster

**Equipment**
- Spreadsheet or graph paper
- Data file (cluster_data.csv) (see the online lab manual)

**Question 1: Review of the HR diagram.** You already know that we can determine the spectral type of a star by analyzing its light with a spectrograph. We can then classify stars by spectral type.

a) What is the relation between the OBAFGKM sequence of spectral types and surface temperature?

b) Using the diagram below, which star is bluer, Spica or the Sun?

c) Which star has the largest luminosity, Deneb or Sirius?

d) Which star is bigger (i.e. larger diameter), Betelgeuse or Procyon B?
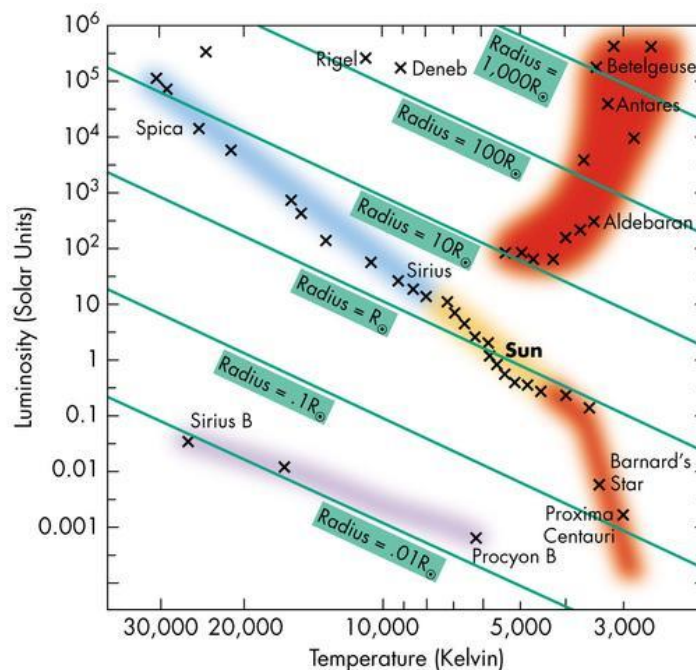
e) Using the diagram below, make a rough estimate of the colour, luminosity and size of a low mass star (one solar mass) at five different stages of its evolution. You can give a range of values if needed. Answer in the table provided.
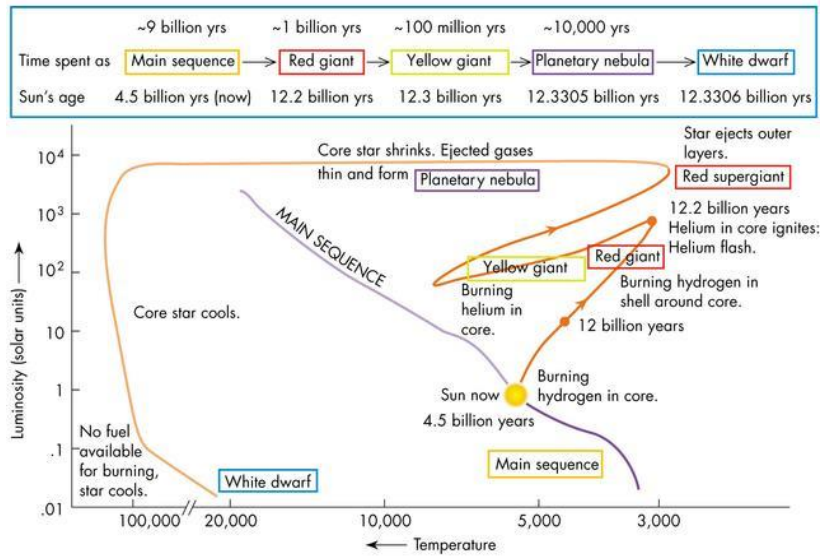


| Stage | Colour | Luminosity | Size (in solar radius) |
|---|---|---|---|
| Main sequence | | | |
| Helium flash | | | |
| Ejection of outer layers | | | |
| White dwarf | | | |

f) Using the diagram below, make a rough estimate of the colour, luminosity and size of a massive star at different stages of evolution. Answer in the provided table.
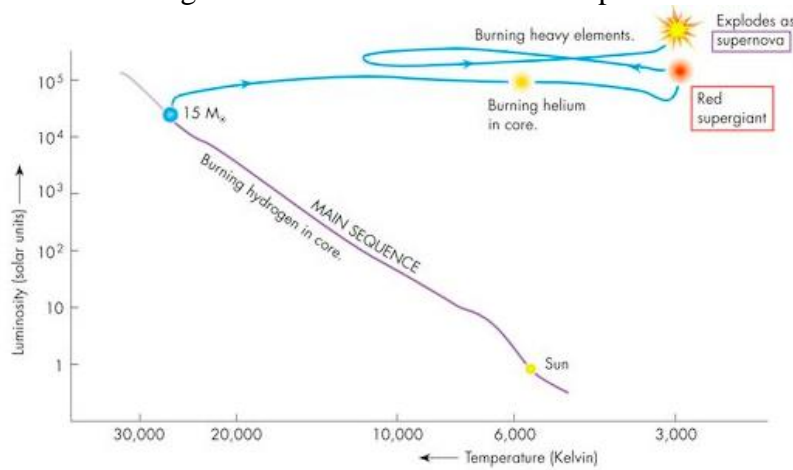


| Stage | Colour | Luminosity | Size (in solar radius) |
|---|---|---|---|
| Main sequence | | | |
| Supernova | | | |

You know how to find the spectral type (and temperature) of a star using a telescope and a spectrograph.  However, to find the position of a star in the HR diagram, you also need to measure its luminosity.

   g)  What makes it so difficult to measure the luminosity of a star?

   h)  How can we overcome this difficulty by studying a single cluster of hundreds of stars that were born roughly at the same time?  Explain how you could determine the luminosity of the stars of the cluster after drawing the HR diagram of the cluster.

**Question 2:  Cluster age.**  If you plot the temperature and apparent brightnesses of all the stars of a given cluster on a HR diagram, the more massive stars will have left the main sequence while the less massive ones will still be burning their hydrogen.  The HR Diagram for that cluster will thus exhibit a turnoff point.
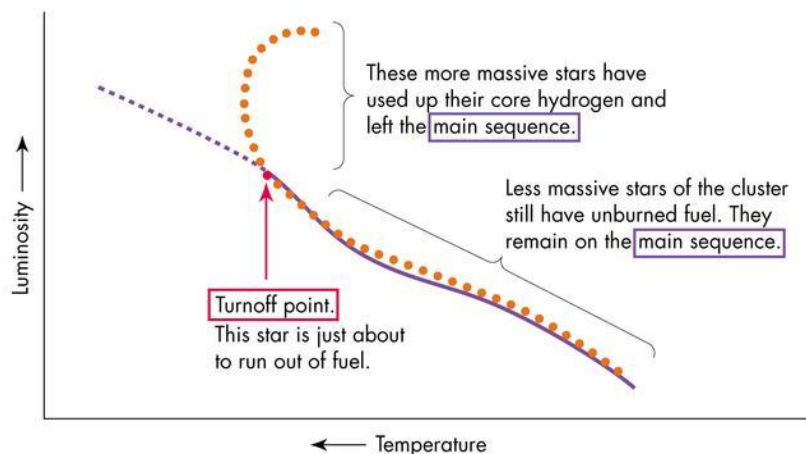
Here are HR diagrams for 4 star clusters. Rank each cluster from youngest to oldest and explain how you can determine the relative age of each cluster.
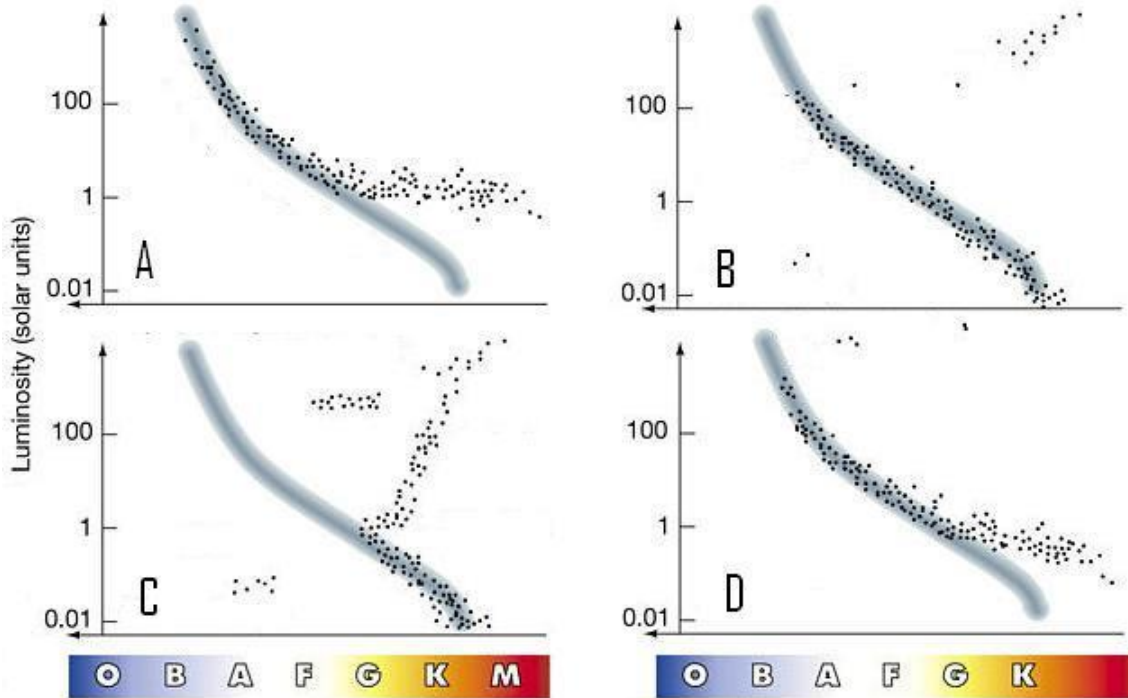


**Question 3: The Colour-Magnitude diagrams of 47 Tuc and M45.** HR-diagrams can be drawn in many different ways. The horizontal axis can be the spectral type, the surface temperature or the colour of stars. The vertical axis can be luminosity or brightness or magnitude of the stars. For this question, you will use a colour-magnitude diagram. To calculate the colour index of a star, the brightness of the star is measured through different colour filters. A filter only lets light of specific wavelengths through.

a)  If you were to look through a red filter, everything would appear different shades of red. Explain why.

Stars are blackbodies and will appear brighter in one filter than in another. The difference between these two measurements is the colour index of the star. For example, a massive blue star will let a lot of light through a blue filter and very little through a yellow filter. Its blue magnitude (B) will be a small number and its yellow magnitude (V) will be a large number. The brighter the star, the smaller the magnitude, so the colour index B-V will be small. See Table 1.

Table 1: The colour index and lifetime of main sequence stars:

| Spectral Type | Colour (B-V) | Lifetime (million years) |
|---|---|---|
| O | -0.4 | Less than 1 |
| B | -0.2 | 30 |
| A | 0.2 | 400 |
| F | 0.5 | 4000 |
| G | 0.7 | 10000 |
| K | 1.0 | 60000 |
| M | 1.6 | More than 100000 |

During your last observing trip, you collected data for the open cluster M45 and the globular cluster 47 Tuc. You measured the magnitude of the stars with a blue filter then a yellow filter. You calculated the difference between the two magnitudes: B-V. Being an experienced astronomer, you know that the bigger B-V index, the redder the star and the smaller the B-V index, the bluer the star. You also measured the apparent magnitude of each star (or just "magnitude").

b)  Plot magnitude versus B-V for each cluster. Use either graph paper or a spreadsheet. Share the workload and draw one graph each. The data are in cluster_data.csv on Brightspace.

- Your colour axis should run from -0.4 to +1.6 with divisions of 0.2.
- The vertical axis is different in each of the two graphs.
- Don't forget that magnitudes are backwards, so that smaller numbers mean brighter stars!
- Submit your graph (in pdf format) to Brightspace assignment folder <u>or</u> attach your graph with this lab manual.

c)  Estimate the age of each cluster and explain your reasoning.

**Question 4: Determining the distance to a globular cluster using RR Lyrae stars.** RR Lyrae stars are old, low-mass stars that are variable: their luminosity is not constant. A single globular cluster may have dozens of RR Lyrae stars. The following graphs show light curves of four RR Lyrae in the Draco dwarf galaxy. The horizontal axis is time in period and the vertical axis gives the magnitude of each star. Notice the similarities between the four graphs: they have roughly the same variations of magnitude, both in amplitude (20.5 to 19.5) and period (0.56 days). All RR Lyrae stars have more or less the same average luminosity, so astronomers can use them as standard candles.
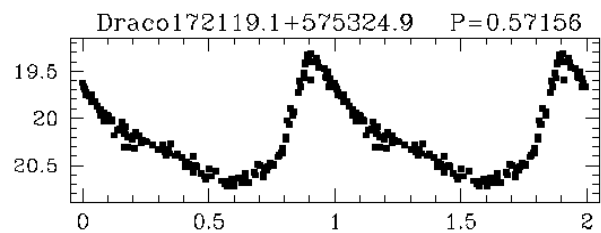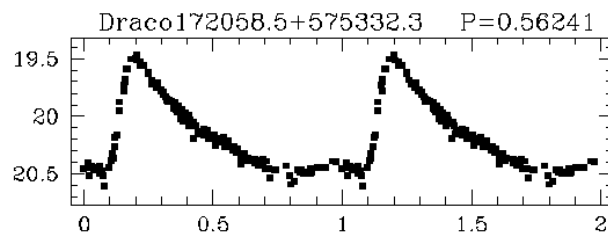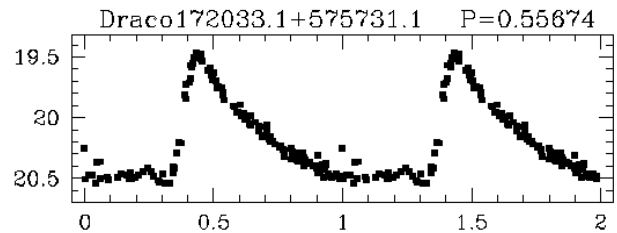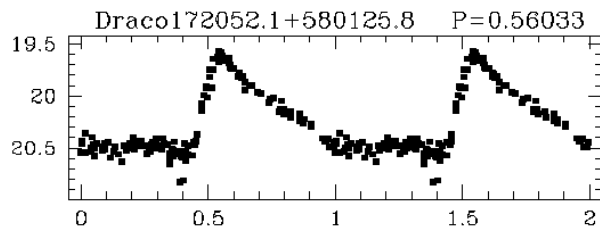


a) Explain to an apprentice astronomer how to determine the distance to Draco. Describe the method using either words or equations, but do not do any calculation. Explain every step in detail: how many nights you need, what instruments you need (photometer, spectrometer, filters), how you will proceed with the data, etc. Justify your choices. This is not an easy question. Brainstorm with your partner, but also with other groups.

b) **(ASTR1102 only)**

Knowing that:
- The average absolute magnitude *M* of a RR Lyrae is 0.75 +/- 0.20
- Dust on the line of sight between you and the cluster increases the apparent magnitude *m* by 0.10.

If the distance to the cluster *d* is expressed in parsecs:

$$m = M + 5\log\left(\frac{d}{10}\right)$$

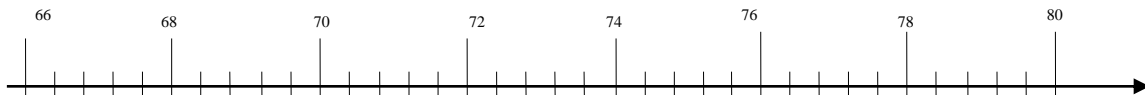i) Calculate the distance to Draco in parsecs.

ii) Calculate the maximum upper and the minimum lower possible values for *d*. (Hints: What is the average value for *m*? What is the uncertainty in m considering you estimated the average by eye? What is the uncertainty in *M* ?)

iii) Write you answer in this standard format: $d = (5.9^{+0.2}_{-0.6})\text{pc}$.

Here is an extract of the original scientific paper. Bonanos et al, The Astronomical Journal, volume 127 (2004), pages 861-867:

"We present the first CCD variability study of the Draco dwarf spheroidal galaxy. The data were obtained with the Fred Lawrence Whipple Observatory 1.2 m telescope on 22 nights, over a period of 10 months, covering a 22×22 field centered at =17h19m57.5s, =57°50'05" (J2000.0). The analysis of the BVI images produced 163 variable stars, 146 of which were RR Lyrae: 123 RRab, 16 RRc, 6 RRd, and one RR12. The other variables include a SX Phe star, four anomalous Cepheids, and a field eclipsing binary. Using the short distance scale statistical parallax calibration of Gould & Popowski and 94 RRab stars from our field, we obtain a distance of 75.8+/- 0.7(stat) +/- 5.4(syst) kpc."

    iv) On the given axis, draw the range of values found by Bonanos et al. and by you. Does your calculation agree with the results of Bonanos et al.? Comment and provide a detailed explanation.

```
  66          68          70          72          74          76          78          80
  |           |           |           |           |           |           |           |
──┼──┼──┼──┼──┼──┼──┼──┼──┼──┼──┼──┼──┼──┼──┼──┼──┼──┼──┼──┼──┼──┼──┼──┼──┼──►
```

Instructor's initial: _____