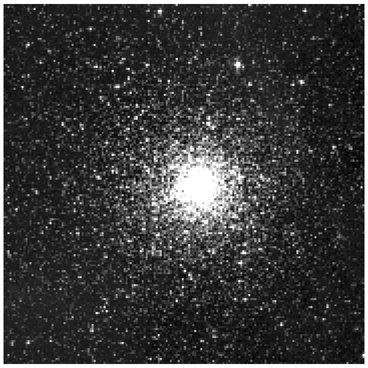
RR Lyrae Stars and the Distance to M4



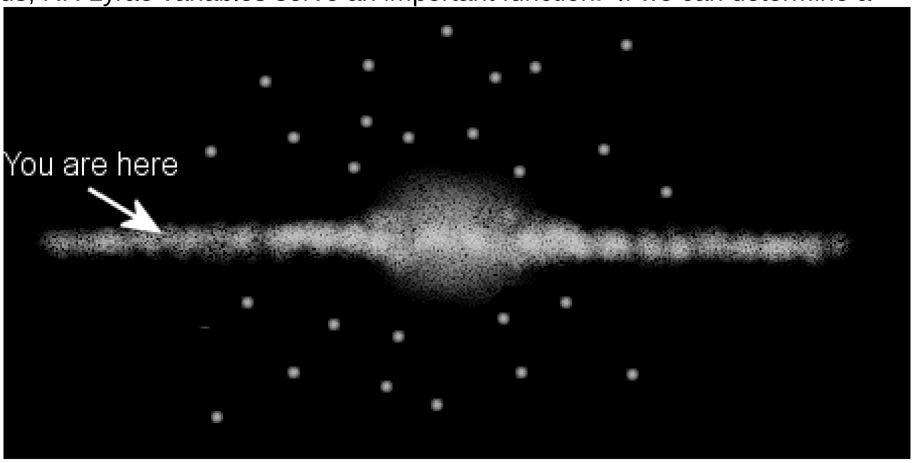
Objective

To determine the distance to the globular cluster, Messier 4 (M4), by using observations of an RR Lyrae star and the mean absolute magnitude for RR Lyrae variables.

Introduction

As stars evolve, their atmospheres become unstable and the star becomes intrinsically variable. Some stars vary erratically, some semi-regularly, and some regularly. Two special classes of regular variable stars have become the keys to determining distances within our galaxy and distances to neighboring galaxies. The **Cepheid variables** are evolved, massive stars and lie within the crowded spiral arms of a galaxy. Since they are a stage in the life of a massive star, and the stage is very short-lived, there are relatively few of them in a galaxy. Cepheid variables have periods that range from a few days to a few hundred days. The other class of variable stars, the ones we are concerned with here, are **RR Lyrae variables** (named after the prototype star RR in the constellation of Lyra). RR Lyrae stars are evolved old, low-mass stars and can be seen in the halos of galaxies, especially in globular clusters, as well as in the disks of galaxies. They are a stage in the evolution of a lower-mass star, and therefore are generally more numerous than Cepheids. A single globular cluster may have dozens of RR Lyrae stars within its population of stars. Periods of RR Lyrae stars are typically 0.5 to 1 day, making it possible to see one or more periods (cycles) in a single night of observations.

Astronomers have observed thousands of Cepheid and RR Lyrae variables. As might be expected from the types of stars that become Cepheids, these stars are very luminous, with luminosities ranging from 100 to over 10,000 times that of the Sun. Through calibration of hundreds of RR Lyrae stars, astronomers have found that these stars are much les luminous—on average only 40-50 times as luminous as our Sun—than the Cepheids. The RR Lyrae stars have a **mean absolute** magnitude (*M*) of 0.75. Even though they are not very luminous, RR Lyrae variables serve an important function. If we can determine a **mean apparent** magnitude (*m*) for an individual star in a globular cluster, we can calculate the distance to the star and thus the globular cluster by using the magnitude equation. Look ahead in your text to the chapter on the Milky Way, and think about what we would learn if we knew the distances to the globular clusters as well as their location in our night sky.



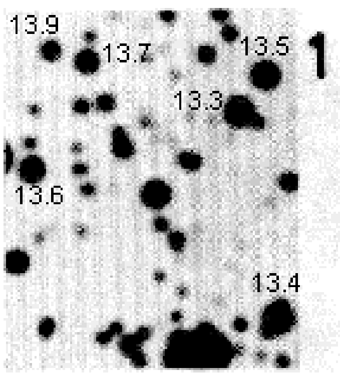
In this exercise, we will use this calibration and the equation to determine the distance to the globular cluster, M4. At 7000 light years distance (2150 pc), M4 (fourth object in the Messier Catalog of star clusters and nebulae) is the nearest globular cluster, as seen from its large apparent size. It contains more than 100,000 stars, including many RR Lyrae variables. M4 lies in a direction close to the huge Rho Ophiuchi dust complex (a picture in linked on-line) and therefore suffers substantial dust obscuration. From our point of view, this dust dims the stars in the globular cluster by about 1 magnitude.

Procedure

View on-line a full-field view of M4 and an enlargement of its northeastern part (PSS #863E). One of the stars in M4, No. 42 in a catalog of the variables found there, is identified. You will also find a series of 20 pictures of #42 and its neighboring stars. These 20 pictures were taken over the course of 12 hours one (winter?) night. The star #42 is easy to spot as it is obviously changing size (and thus luminosity) between frames, but if you do not see it right away, it is at the center of each photograph.

To determine the magnitude of a star, astronomers choose a number of "standard" stars within each frame and calibrate the variable star against these standards. We will do a similar process here, using just one image of the series, frame 1, to do so. Within this frame are six standard stars. They are identified in frame No. 1 shown below. Using the calibration of standard stars, we find a "diameter-vs-apparent-magnitude" correlation by assuming the two are related linearly. Once we have this, we simply measure the diameter of Star #42 and determine the corresponding apparent magnitude. Since the change in the star takes as time passes, we then graph apparent magnitude versus time to see the change in its brightness.

Exercise



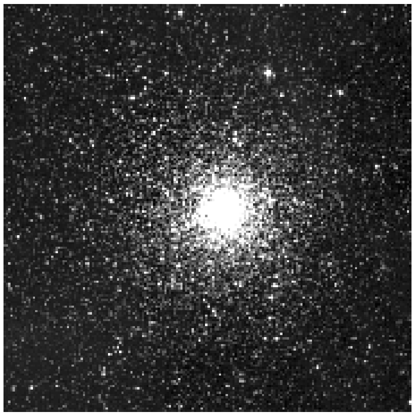
At the left is a reproduction of image #1 of the star field showing the standard stars and their calibrated magnitudes. Click on this image (on-line!) to get the interactive image, and follow directions as given with the image. You will be determining the diameters of the six standard stars, in pixels (watch out for blended stars!).

Once you have calculated the diameters of the standard stars, plot apparent magnitude vs diameter on the "calibration of the standard stars" graph. You will then have a graph of the apparent magnitude of each standard star (*y axis*) as a function of its measured diameter in pixels (*x axis*). Draw a best-fit **STRAIGHT** line through the points (remember, our scientific methods lesson?). This graph will be used to derive the magnitude of variable star No. 42 in each frame.

Measure the diameter, in *pixels*, of star #42 (the center "dot") in each frame shown in the series of 20 pictures. The frames have been randomized to avoid biased measurements (good scientific methods!). Take the series of 20 measurements and write the diameters in column 3 of Table 2. When finished with these measurements, have your partner take the other series of 20 measurements and write the diameters in column 4 of Table 2. Average the two diameters for each frame and write the averages in column 5. Using your calibration-of-apparent-magnitude-versus-diameter graph from the standard stars, interpolate the apparent magnitude for the *variable* star for each frame and record in column 6. Plot apparent magnitude vs. time (where the time is given in the fraction of the day since the observations started) on an apparent magnitude of star 42 versus time graph.

First, "connect-the-dots" and then, when you have an idea of what the "light curve" looks like, draw a smooth curve through the data points.

REMINDER: the graph has the smallest magnitude value (for brightest) at the top of the "*y*" axis and the largest magnitude value (for dimmest) at the bottom of the "*y*" axis. Please make sure your graph looks similar to the sample graph.



Name ____

Partner's Name ______________________________________

Table 1: Calibration of the Standard Stars (Apparent Magnitude vs. Diameter)

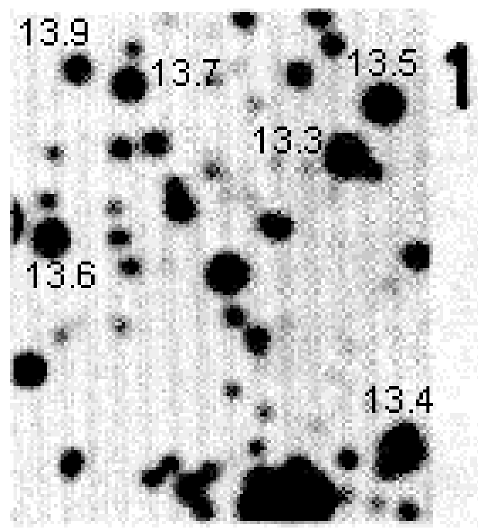
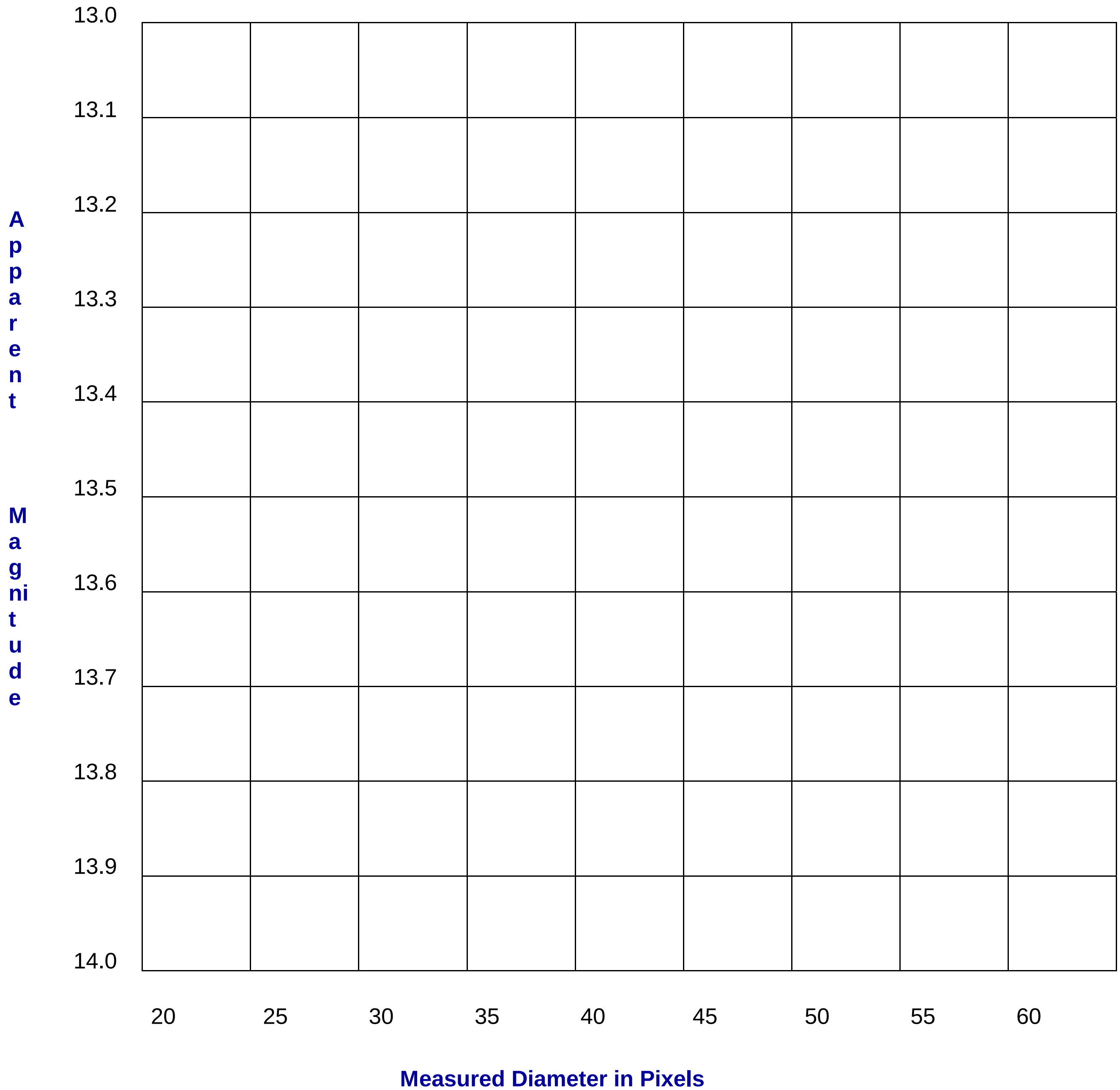
Apparent Magnitude (m)	**Diameter 1 (pixels)**	**Diameter 2 (pixels)**	**Average Diameter**	**TO: Clickable Image**
Example	**252-202= 50**	**249-201= 48**	**49**	 **TO: Clickable Image (On-Line)**
13.3				
13.4				
13.5				
13.6				
13.7				
13.9				

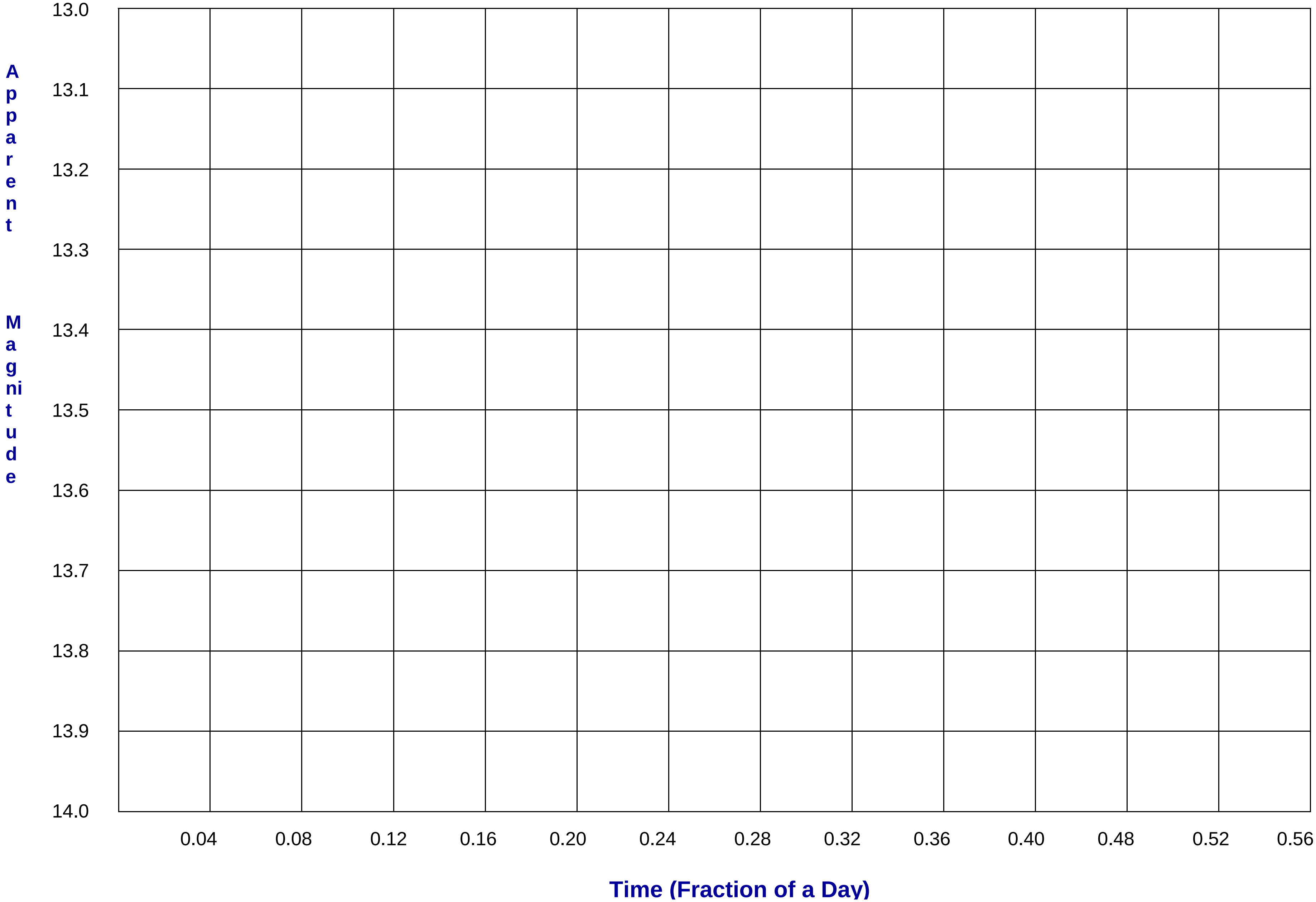
Table 2: Apparent Magnitude vs. Time for Star #42

Frame	Time (fraction of a day)	Diameter 1 (pixels)	Diameter 2 (pixels)	Average Diameter	Apparent magnitude (4 significant digits)
0	Example	156-101= 55	157-104= 53	54	13.23
1	0.24				
2	0.15				
3	0.18				
4	0.52				
5	0.53				
6	0.38				
7	0.05				
8	0.26				
9	0.08				
10	0.07				
11	0.37				
12	0.30				
13	0.11				
14	0.48				
15	0.09				
16	0.32				
17	0.22				
18	0.40				
19	0.44				
20	0.02				

Calibration of Standard Stars



Apparent Magnitude of Star No. 42 versus Time



Calculations

1. Is there more than one period in the data? How long is the period of the variable star in a fraction of a day? In hours? Have you identified this star, therefore, as an RR Lyrae variable? (Finding another light curve for an RR Lyrae star would help; see lecture notes.)

2. To calculate the mean apparent magnitude of star #42, determine the brightest and the dimmest the star got over this time period and pick a magnitude halfway in between those two values. This is a number that is similar to an average. Since we may not always have a complete light curve, or may have observed the star unequally over time, the middle value of the apparent magnitudes is a better number to choose. Showing all of your calculations here, and remembering that the mean absolute magnitude of an RR Lyrae star is 0.75, calculate the distance to star #42, and thus M4, using the magnitude equation.

    a. What is the mean apparent magnitude of star #42?

    b. What is the distance to star #42? Express your answer in 2 significant digits (example: the number 1800 has 2 significant digits).

Distance (d) = _______ pc

Questions

1. Uncertainties in the distance determination:

    We will assume the uncertainty in your measurements of the diameter of the standard stars and Star #42 (plus there are uncertainties in the magnitudes for the standard stars) leads to an uncertainty in the average apparent magnitude of 0.2 magnitudes.

    Given this uncertainty, what is the brightest **the mean** apparent magnitude might be? Dimmest?

    Using these two numbers, calculate the acceptable range in distances to M4, given your data. Do this by using the smallest possible mean apparent magnitude and largest possible mean apparent magnitude in the magnitude equation. Show all calculations here for (m-M+5)/5 (feel free to use the calculator available on-line).

    Brightest (smallest number) mean apparent magnitude: __________

    Closest distance: d = _________ pc (2 significant digits)

    Dimmest (largest number) mean apparent magnitude: __________

    Farthest distance: d = _________ pc (2 significant digits)

2.

a. Carefully reread the introduction to this lab and write down the ***actual*** distance to M4. Within your uncertainties, calculated in **"a"** above, does your value for the distance to M4 agree with the actual value? Be sure to comment on what you find.

b. Quantitatively, how would your distance to M4 change if you remembered that there was a lot of dust in between you and the globular cluster, dimming star #42 by 1.0 magnitude? Recalculate the distance to M4 by subtracting 1 magnitude from your mean apparent magnitude (from #2 above; for example, without the dust, the mean apparent magnitude would be 12.5 instead of 13.5.):

c. Discuss your findings from the previous 2 questions.

3.

a. List two advantages of using RR Lyrae for determining distances.

b. What would be primary disadvantage of using RR Lyrae variables?

4. Recall what RR Lyrae stars are good for (in other words, what this lab is all about). Let's suppose you were given enough time on a telescope to monitor RR Lyrae variables in all of the 150 or so globular clusters of the Milky Way. What would you learn? How would you apply this knowledge to help us learn more about the Milky Way?