Astronomy 1143: Assignment 1

This assignment is due at the beginning of class on *Friday*, September 14.

You may consult with others in the class when you are working on the homework, but you should make a first attempt at everything on your own before talking to others, and you must write up your eventual answers independently.

You are *welcome* to come to my office hours or Dan Stevens's office hours for advice. You should get as far as you can on the assignment *before* you come to office hours, so that you know what points you are stuck on.

The office hour times and office numbers are listed on the syllabus. Wednesday afternoon office hours will start out in the classroom (right after class), and we'll stay there unless/until we need to vacate the room for another class. If you are unable to attend the scheduled office hours because of unavoidable conflicts, you can e-mail Dan or me to schedule an appointment.

The last of the attached sheets has marked graph paper that you should use for Part II and turn in with your answer. Other than that, please write your answers on separate sheets (not this handout). Please staple or paper clip all sheets together. Be sure that your name is on your assignment. It's your responsibility to write clearly enough that we can grade your answers. For questions that require calculations, you should first work out your answers on scratch paper, but the solution you turn in should show enough of your work that we can tell how you got to your answer.

Part I: Some Short Questions (35 points)

Parts (a)-(c) are worth 5 points each, parts (d) and (e) are 10 points each.

(a) Ancient Greek philosophers argued that the earth could not be revolving around the sun because parallax would make the apparent positions of stars shift back and forth on the sky, and no such effect was seen. What was wrong with this argument?

(b) With a modern telescope, you measure the parallax of Star A, which you know (based on a detailed study of its light) to be very similar to the sun. You find that the distance of the star is 10 parsecs. You also measure the parallax of Star B, which you find to be at a distance of 30 parsecs. The *apparent flux* of Star B is the same as that of Star A, i.e., $f_B = f_A$. What is the *intrinsic luminosity* of Star B relative to the sun's luminosity? You should give your answer as the ratio $L_B/L_\odot$; you do not need to convert the luminosity to watts.

(c) Use the luminosity of the sun, $L = 4 \times 10^{26}$ watts, and the apparent flux of the sun at earth, $f_\odot = 1400\,\mathrm{watts/m^2}$, and the standard candle formula for distance, $d = \sqrt{L/4\pi f}$, to find the distance from the earth to the sun, in meters. How does your answer compare to the value I gave in class for the Astronomical Unit?

(d) Do you think the universe is finite or infinite? If you think it is finite, do you think it has an edge? Explain, briefly, the reasoning behind your answer.

Your answer to this question should be a one-paragraph (e.g., 3-8 sentences) essay, in complete sentences. Your answer will receive full credit provided it is sensibly explained and clearly written.

(e) Do you think that the earth is at a "special" place in the universe? Why or why not? For purposes of this question, you can interpret the word "special" in whatever way you wish.

Your answer to this question should be a one-paragraph essay, in complete sentences. Your answer will receive full credit provided it is sensibly explained and clearly written.

Part II: A Cepheid distance to the galaxy M81 (45 points)

Parts (a)-(c) are worth 5 points each, parts (d)-(f) are worth 10 points each.

(a) The table below lists the pulsation periods (in days) and luminosities (in solar luminosities $L/L_\odot$) for 10 Cepheid variables, whose distances were measured via parallax using Hubble Space Telescope. I took these numbers from a research paper published in 2007 in The Astronomical Journal, by George Benedict and collaborators. The authors of this paper used their distance measurements and the apparent fluxes of the Cepheids to determine the luminosities from $d = \sqrt{L/4\pi f}$.

Table 1

Star	Period (days)	$L/L_\odot$
A	3.7	1225
B	4.4	1737
C	4.5	1419
D	5.4	2089
E	5.8	1995
F	7.0	2535
G	7.6	3311
H	9.8	3500
I	10.2	3530
J	33.6	11800

On the sheet of graph paper attached to the end of the assignment, plot the positions of these 10 Cepheid variables, marking each with a circle at its period and luminosity.

With a ruler, draw a straight line that goes approximately through the middle of the points.

(b) The second-to-last page of the assignment has a plot showing measurements of three Cepheid variables in the galaxy M81 (short for Messier 81). These measurements were made by OSU graduate student Jill Gerke and her advisor Prof. Chris Kochanek, using the Large Binocular Telescope, and they were published in a paper in 2011 in The Astrophysical Journal.

Each point shows a measurement of the brightness of the Cepheid, and the horizontal axis shows when the measurement was made (measured in days, from an arbitrary starting point). In addition to the points, there are curves that show models (based on how typical Cepheids behave) fitted to the points. The curves fit the points well, and they provide a good guess for what the brightness of the Cepheid was in between the measurements.

The period of the Cepheid is the time it takes to go from maximum brightness down to minimum and back to maximum brightness again.

Measure the periods of the three Cepheids from the graph, and write them down as your answer for this part. It is easiest to do this measurement from the curves rather than the points; try to get an answer to the nearest day.

(c) Mark the three Cepheids as squares along the straight line that you drew on the graph in part (a), at the period that you measured in part (b). By reading off from the left side of the graph, estimate the luminosity $L/L_\odot$ of these three Cepheids. Write down your estimates of $L/L_\odot$ for the three stars as your answer for this part.

When you do this, you are implicitly assuming that the Cepheids in M81 are similar to the Cepheids in the Milky Way — i.e., that Cepheids of the same period have the same luminosity in M81 and in the Milky Way.

(d) Let L represent the intrinsic luminosity of a Cepheid, f represent its apparent flux, and d its distance. Using the equation $f = L/4\pi d^2$, and the equivalent equation for the sun $f_\odot = L_\odot/4\pi d_\odot^2$, demonstrate mathematically that

$$\frac{d}{d_\odot} = \sqrt{\frac{L}{L_\odot}} \times \sqrt{\frac{f_\odot}{f}}.$$

(Hint: Start by taking the ratio of the two equations. Manipulate the resulting equation to get $d/d_\odot$ on the left hand side. See the "Manipulating Equations" handout for reference if you need it.)

(e) For the three Cepheids, the apparent fluxes are:

Star 1: $\frac{f}{f_\odot} = 2.6 \times 10^{-20}$.

Star 2: $\frac{f}{f_\odot} = 7.2 \times 10^{-21}$.

Star 3: $\frac{f}{f_\odot} = 2.2 \times 10^{-20}$.

(I saved you quite a lot of otherwise tedious work by calculating these ratios from the measurements for you. Note that 10^{-20} is a very small number. Not surprisingly, the apparent fluxes of these distant Cepheids are much, much, much fainter than the apparent flux of the daytime sun.)

Using the equation given in (d), estimate (and write down) $d/d_\odot$ for each of the three Cepheids. How closely do your answers agree?

(The three Cepheids are all in the same galaxy, so the answers shouldn't be radically different, but there will be some differences because the measurements are imperfect.)

(f) Remember that $d_\odot = 1\,\text{AU}$, so $d/d_\odot$ is just the distance to the Cepheid in AU. Remember that there are 206,265 AU in 1 parsec. Calculate (and write down) the distances to the three Cepheids in parsecs.

Remember that 1 parsec is 3.26 light years. Based on the average of your three distance measurements, how long has the light from stars in M81 been traveling to reach the earth?

Part III: The Center is Everywhere (20 points)

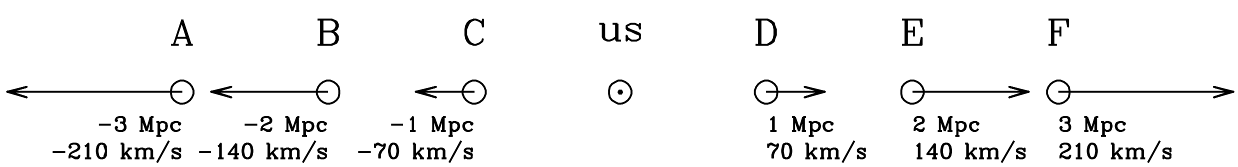
Parts (a)-(d) are worth 5 points each.

The diagram below shows a simple illustration of Hubble's velocity-distance relation, which is described by the equation $v = H_0 d$ that we will discuss in class. The circle in the middle represents the Milky Way galaxy, and the other circles mark the positions of six other galaxies.

The distances of these galaxies from the Milky Way are listed below the points, in Mpc (1 Mpc = 1 megaparsec = 1 million parsecs). Note that positions to the left of the page have negative values and positions to the right of the page have positive values.

Arrows illustrate the velocities of the galaxies relative to the Milky Way, and the velocity values are listed below the points, in $\mathrm{km\,s^{-1}}$. Note that galaxies moving to the right have positive velocities and galaxies moving to the left have negative velocities.

These positions and velocities follow Hubble's law with a Hubble constant $H_0 = 70\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$ — e.g., the galaxy with position $d = 3\,\mathrm{Mpc}$ has velocity $v = 210\,\mathrm{km\,s^{-1}}$, and the galaxy with position $d = -2\,\mathrm{Mpc}$ has velocity $v = -140\,\mathrm{km\,s^{-1}}$.



(a) You are driving on a highway at a respectable speed of 110 km/hour. (The highway is in Germany, so your speedometer is marked in km/hour instead of miles/hour.) A reckless driver barrels past you in the left lane traveling at 160 km/hour. What is the speed of the reckless driver's car *relative* to your car?

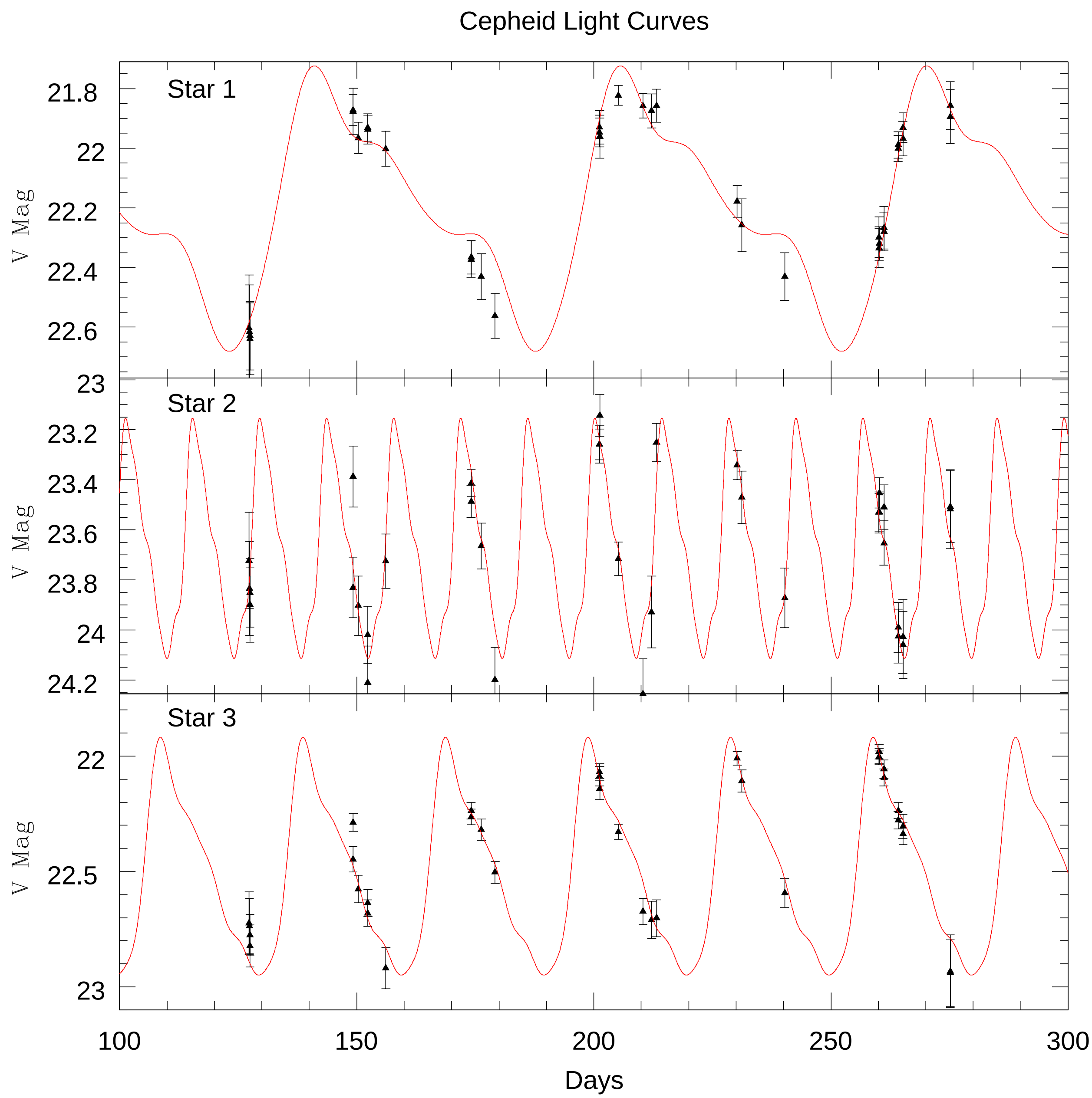
(b) Suppose that you were an astronomer living in Galaxy E, instead of in the Milky Way, and you measured the positions and velocities of the other galaxies shown in the diagram. As seen from Galaxy E:
- What is the position (in Mpc) and velocity (in $\mathrm{km\,s^{-1}}$) of galaxy F?
- What is the position and velocity of galaxy D?
- What is the position and velocity of galaxy A?

Use positive numbers for the position of galaxies to the right of Galaxy E and negative numbers for the position of galaxies to the left of Galaxy E. Use positive numbers for the velocity of galaxies that are moving to the right *relative to Galaxy E*, and negative numbers for the velocity of galaxies that are moving to the left relative to Galaxy E.

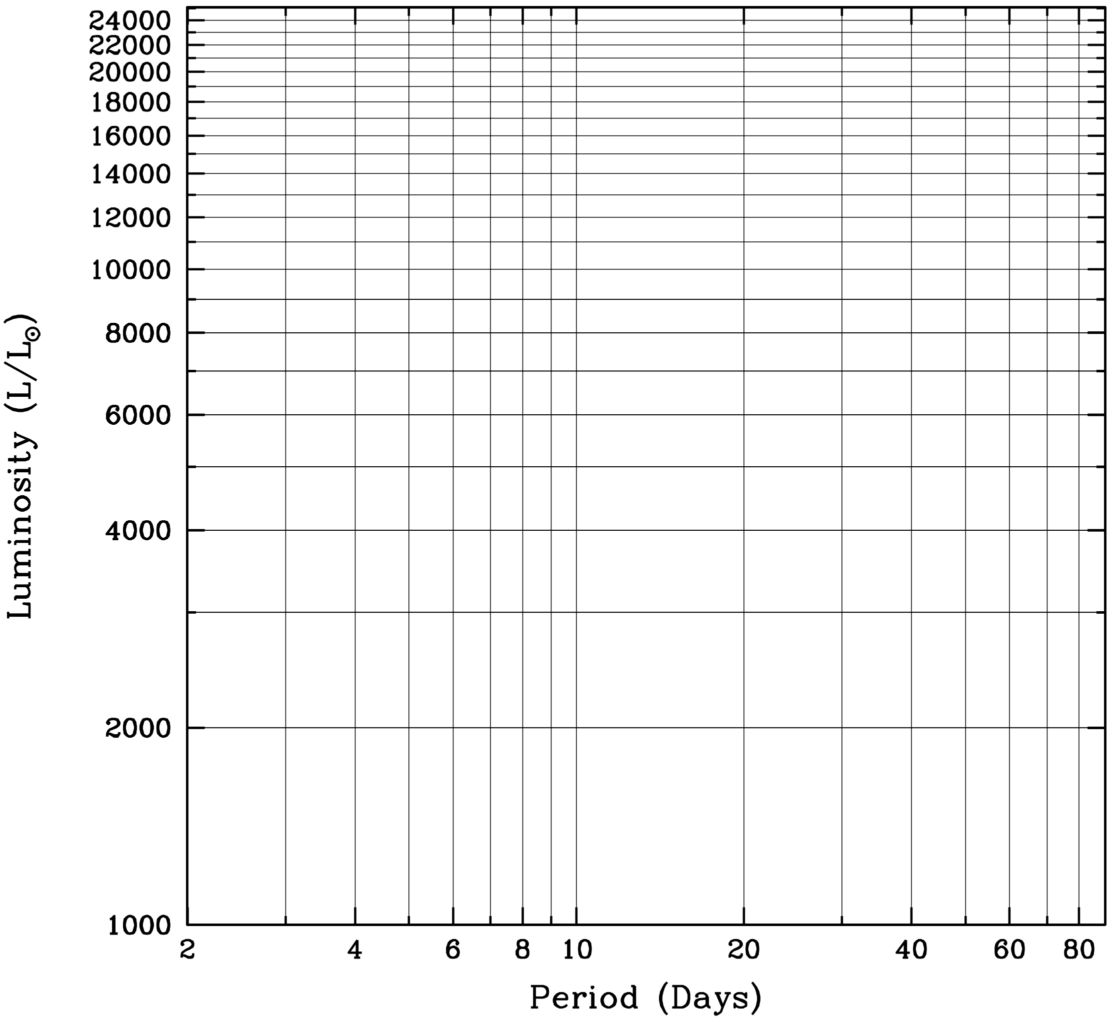
(c) Now suppose that you were an astronomer living in Galaxy A. As seen from Galaxy A:
- What is the position and velocity of galaxy B?
- What is the position and velocity of galaxy D?
- What is the position and velocity of galaxy E?

(d) On the basis of what you found in b and c, respond (in 2-4 sentences) to the following statement:

Hubble's law shows that other galaxies are moving away from the Milky Way, with a velocity that is proportional to distance. From this we can conclude that the Milky Way is at the center of the universe, since observers in other galaxies would not see the same kind of regular expansion.



Light curves (apparent brightness versus time) for three Cepheid variable stars in the galaxy M81, as measured by Jill Gerke and her collaborators.



Graph paper for Part II.