Astronomy (Schroeder) Name: ______________________________
fall, 2011

Exercise 11

Due Friday, November 18, 5:00 pm

Your mission is to calculate the "age of the universe" (that is, the time since everything we can see was in about the same place).

Sound difficult? It really isn't. All you need to know is how far away some galaxies are, and how fast they're moving away from us. Measuring speeds of galaxies is relatively easy (if you have a suitable telescope and spectrograph); the hard part is measuring the distances. In this exercise you will use real data from supernova observations to estimate the distances to a dozen galaxies.

The basic assumption is that all type-Ia supernova explosions have about the same intrinsic luminosity. (This assumption is reasonable because they all result from the implosion of a white dwarf star that has barely reached the Chandrasekhar limit.) The table on the next page lists several far-away supernovas that were observed between the years 1993 and 1996. For each supernova, the table lists the maximum apparent brightness (which indicates distance) and the redshift (which indicates speed).

The apparent brightnesses are in units that are relative to a particular type-Ia supernova (1974G) that exploded in the galaxy NGC 4414 in 1974. So I've assigned that supernova a brightness of 1.0; all the others are measured in comparison. Furthermore, NGC 4414 is a galaxy in the Virgo cluster whose distance has recently been measured with pretty good accuracy, using Cepheid variable stars as standard candles. In this exercise, you may simply assume this galaxy to be at a known distance of 60 million light-years.

Your first task is to calculate the distances to the other supernovas in the table, based on their brightnesses. I'll do the first one for you: Supernova 1993ac had an apparent brightness of 0.0066 (compared to SN 1974G), meaning that it was fainter by a factor of $1/0.0066 = 152$. Because apparent brightness is inversely proportional to distance squared, this implies that it was farther away by a factor of $\sqrt{152} = 12.3$. So SN 1993ac (and its host galaxy) must be 12.3 times as far away as NGC 4414, or about 740 million light-years.

Please check my math, then use the same procedure to calculate the distances to the other supernovas in the table. Express your distances in millions of light-years. (If you wish, you may do the calculations on a computer spreadsheet, then attach a printout.)

The redshifts in the table are simply the fraction by which the spectral lines of each supernova (or its host galaxy) are shifted toward longer wavelengths. As you know, this fraction is the same as the speed of the galaxy, expressed as a fraction of the speed of light. For our purposes, these are the most convenient units to use; there is no need to convert to kilometers per second.

Now plot a graph of speed (vertically) vs. distance (horizontally) for these supernovas (and their host galaxies). You may either plot the graph by hand on the graph paper provided, or use the "scatter plot" option in a computer spreadsheet program. Either way, please make the graph large enough to fill most of a sheet of paper. Label each axis carefully, and label each point on the graph with the name of the supernova (e.g., 1993ac). Once you have your graph, use a ruler or straight edge to draw the best possible straight line through your data points. (Do not try to draw the line automatically on a computer!) Your line will not pass through all the data points, but it should come close to most of them, with about as many on one side as on the other. This line represents an estimate of what the true "Hubble flow" velocities would be at each distance, without measurement inaccuracies or other extraneous effects.

Supernova Data
(from Riess, et al., *Astron. J.* **117**, 707.)

Supernova	Brightness	Distance	Redshift
1974G	1	60 mly	0.0024
1993ac	0.0066	740 mly	0.049
1993ae	0.0692	________	0.019
1994M	0.0288	________	0.023
1994S	0.1213	________	0.015
1994T	0.0115	________	0.035
1994Q	0.0275	________	0.029
1995ak	0.0308	________	0.023
1995ac	0.0133	________	0.050
1996C	0.0231	________	0.030
1996ab	0.0015	________	0.124
1996bl	0.0147	________	0.036
1996bo	0.0550	________	0.017
1996bv	0.0780	________	0.017

Finally, answer each of the following questions.

1. Is it generally true that the more distant galaxies are moving away from us faster, as Hubble's Law states? How can you tell from your graph?

2. Strictly speaking, according to Hubble's Law, all the dots on the graph should lie exactly on a straight line. Obviously they don't. What are some reasons why they don't? (Please be as specific as you can.)

3. Consider a hypothetical galaxy that obeys the Hubble Law perfectly, that is, a galaxy whose dot would lie precisely on your straight line. If this galaxy is moving away from us at 1/10 the speed of light, how far away is it? (Please show how you determined this on your graph.)

4. Use your answer to the previous question to make an estimate of the "age of the universe", that is, the time since everything we can see was in about the same place. Show your work and explain your reasoning.

5. Repeat your calculation of the "age of the universe", using a hypothetical galaxy that is moving away from us at 1/20 the speed of light.

6. List some reasons why your estimate of the "age of the universe" is probably not exact. (Try to list as many *specific* reasons as you can.)

Graph of Radial Velocity vs. Distance for Selected Galaxies