Astronomy 102, Fall 2006 — Review Problems #5

1. Suppose that we calculate an expansion rate by looking at the brightness and redshift of a supernova in a galaxy; we know the true luminosity of the supernova. Now suppose that we later discover that this supernova was hidden behind some dust. Have we *overestimated* or *underestimated* the expansion rate of the Universe? Explain.

2. How long will it take for the Universe to be 1% bigger than it is right now, assuming that the expansion rate of the Universe does not change during that time?

3. A Type Ia supernova (SN Ia) has a luminosity of $5.8 \times 10^9 \, L_\odot$ at maximum light; it is this high luminosity that makes them visible to such great distances.

(a) You discover and observe a supernova in a distant galaxy. In your telescope, you observe it to have a brightness that is 1.6×10^{-7} times the brightness you observe for Vega. How far away is this galaxy (in Megaparsecs (Mpc))?

(b) You measure a redshift for this galaxy of $z = 0.062$. Using just the data from this galaxy and this supernova, what would you calculate the Hubble Time to be?

(c) If a second supernova explodes in this galaxy 200 million years after the explosion of the supernova you observed, how long from now *or* how long ago does this second supernova explode? (Be sure to indicate whether it happens in the future or the past.)

4. The Cosmic Microwave Background shows a redshift of about $z_{\rm CMB} = 1100$.

Right now, the density of the various components of the Universe as a whole are:

- Dark Energy: 6.7×10^{-30} g/cm^3
- Dark Matter: 2.4×10^{-30} g/cm^3
- Normal Matter: 0.5×10^{-30} g/cm^3

(a) What is the ratio of the size of the Universe at the time the CMB was emitted to the size of the Universe now?

(b) What was the density of Dark Matter at the time when the CMB was emitted? (HINT: remember how volume changes with length!)

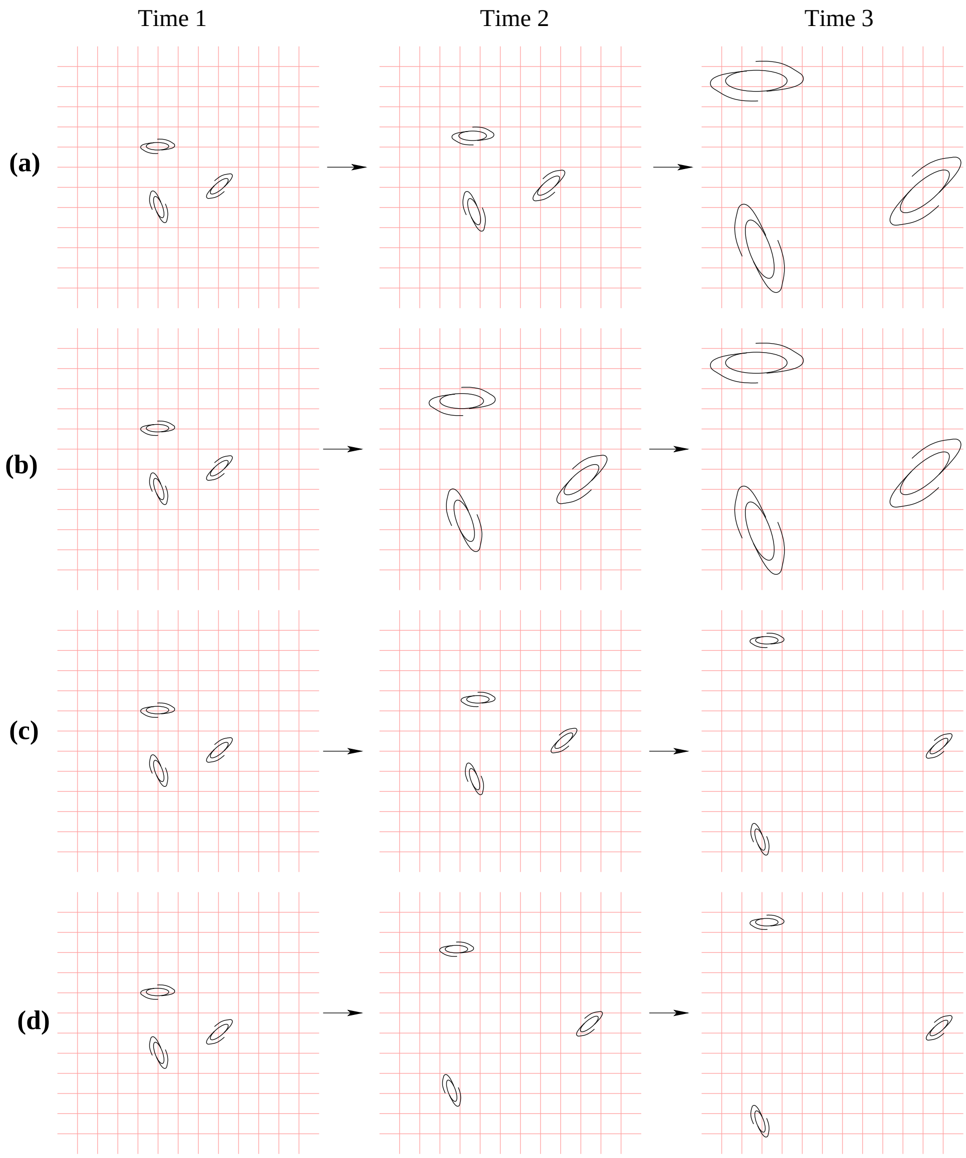
(c) What was the density of Dark Energy at the time when the CMB was emitted? Assume that Dark Energy is just vacuum energy, as we've discussed in class.

(d) What was the density of Normal Matter at the time when the CMB was emitted?

(e) Make a plot of density (y-axis) versus time (x-axis). Plot the density of Dark Matter vs. time, and the density of Dark Energy vs. time. Your plot doesn't have to be perfect, it just has to get the general trends right. Include at least times from when the Universe was 1/4 its current size until today; indicate on the horizontal axis where both times are. (You don't actually have to give a time value in years.) (If you wish, you may use a log-scaling for the vertical axis, and go back to the time of the CMB. If you don't understand this, don't worry about it.)

(f) Suppose some sort of strange hypothetical plasma creature was living in the Universe just before the CMB was emitted. Draw the "pie diagram" they would for what the Universe is composed of, similar to the "pie diagram" we draw for the components of the Universe today.

5. Each sequence of three drawings shows the position of three galaxies in the expanding Universe at three different times. Time 1 represents right now. The number of years between Time 1 and Time 2 is the same as the number of years between Time 2 and Time 3. Which of the following drawings is the best approximation of the present expansion of our Universe as we currently understand it? Explain why you chose the one you chose. (The faint lines are drawn for your reference, and are not supposed to be part of the Universe.)



6. Much of this problem will involve drawing on the Hubble diagram below:

(a) Draw a point on the plot that represents us, right now. (I.e. lookback time=0.) (What is the redshift for right now?)

(b) You measure the distance to a galaxy, and find that it is 1 billion light-years away. You measure the redshift of the galaxy and you find that it is $z = 0.067$. What is the ratio of Size Now/Size Then for this galaxy? What is the lookback time for this galaxy? Plot a point for this galaxy on the Hubble Diagram.

(c) You measure the distance to another galaxy, and find that it is 2 billion light-years away. If the expansion rate has been constant for the last 2 billion years, what redshift will you measure for this galaxy? What is the ratio of Size Now/Size Then for this galaxy? What is the lookback time for this galaxy? Plot a point for this galaxy on the Hubble Diagram.

(d) Given the three points above, you can draw on the plot and read off what t_H is. Do that. What t_H do you get? How does it compare if you just used the data in parts (b) and (c) to calculate t_H? (You should get about the same answer, but it may be a little different if your drawing isn't perfect. That's OK.)

(e) Indicate on the drawing above what interval (the length of a line in some direction) corresponds to t_H.

(f) Consider aliens who were cruising around in the Galaxy 6 billion years ago. Assume that the Universe has had a constant expansion rate for the last 6 billion years. If you were to plot a point for 6 billion years ago under this assumption, where would you plot it? Draw a point and label it "f".

(g) Now suppose that the Universe's expansion has always been *decelerating*. Draw the plot of size versus time for the Universe.

(h) Draw an interval on the plot that corresponds to t_U, the age of the Universe right now.

(i) Consider aliens who were cruising around in the Galaxy 6 billion years ago, but now under the assumption that the Universe has been decelerating as in (g). Draw a point labelled “i” to represent the Galaxy 6 billion years ago on this decelerating Universe.

(j) Draw a tangent line to decelerating Universe curve at the point you plotted in (i). Indicate what t_H is 6 billion years ago in the diagram. How does this t_H compare (qualitatively) to the t_H that you would have drawn and calculated in (f)?

(h) How does the ratio of the age of the Universe to the Hubble time (t_U/t_H) compare for (1) Us, (2) the point you drew in (f), and (3) the point you drew in (i)?

(g) Take a deep breath. This was a long problem.