ISP 205
Review Questions, Week 15

This is not required homework. It will not be graded. Answers will be supplied on Tuesday.

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1. What force tries to slow down the rate of expansion of the universe? *Gravity. All matter pulls on all other matter – this includes normal matter (i.e. atoms) and also Dark Matter.*

2. How do we know that the rate of expansion of the universe is speeding up (accelerating)? *We can use Type Ia supernova explosions as "Standard Candles". They are objects with known luminosity, so if we measure the flux (apparent brightness) we can find the distance. That tells us the "lookback time" … the distance in light years is how many years ago the light was emitted by the supernova. That tells us the position of that particular supernova on the x-axis of a plot such as Fig. 16.16 in your textbook. The redshift of the supernova tells us the scale factor R(t) – how many times smaller the universe was at the time the light was emitted – which gives the position on the y-axis of the plot. The points for the supernovae trace out a curve that corresponds to a universe that at first had its rate of expansion slow down, but now has it speeding up.*

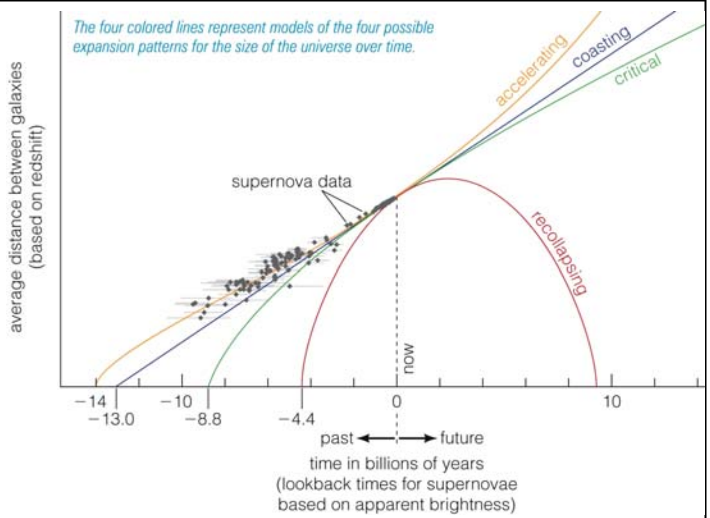

Figure 16.16 from the textbook "The Essential Cosmic Perspective".

3. What causes the acceleration? *Dark Energy, which acts as a force that pushes every piece of the universe away from every other piece, and which gets stronger the farther apart the pieces get. We have no idea what Dark Energy actually is.*

4. How do we know that the universe has a "flat" geometry? *The Cosmic Microwave Background (CMB) has small variations in its brightness at different locations on the sky. These trace fluctuations in density in the gas that existed back at time when the CMB was produced. That happened when the universe was only 380,000 years old, and we know from some very basic calculations what the size of those density fluctuations was at that time, in terms of proper distance units (i.e. miles). We can measure the angle that such a density fluctuation subtends on the sky. We also know the distance to these structures because we know the light-travel time, so the angle that they subtend on the sky tells us whether the light coming to us from the opposite sides of such a fluctuation has come to us in a straight line, or whether it has followed a curved path due to the universe being curved. The measurements show that it has followed a straight path = a flat universe.*

5. What fraction of the total content of the universe is in the form of Dark Energy? *73%. This is the mass equivalent of the amount of Dark Energy per unit volume. The conversion between mass and energy is calculating by using* $E=mc^2$.

6. What fraction of the total content of the universe is in the form of Dark Matter? Of all kinds of matter put together? *23% is in the form of Dark Matter, 27% is in the form of all kinds of matter combined (but these numbers get revised by small amounts as more measurements are made, so you might see slightly different values elsewhere).*

7. How do we know the values of the two fractions in questions (5) and (6)?

   [Step 1]. Dark energy and matter both have the same effect on the curvature of the universe (this is not what you would expect in a simple picture, but it does work out this way). That means that the curvature tells us the <u>*sum*</u> *of the dark energy + matter densities.*

   [Step 2]: The rate of acceleration of the expansion of the universe tells us the <u>*difference*</u> *between the amount of dark energy (which acts to speed up the expansion) and the amount of matter (whose gravitational attraction acts to slow down the expansion). The difference between these oppositely-directed forces is the net force which pushes on each piece of the universe.*

   [Step 3]: Solve the two equations:

$$\text{(curvature)} = \text{(dark energy)} + \text{(matter)} \qquad \text{[EQUATION 1]}$$
$$\text{(acceleration)} = \text{(dark energy)} - \text{(matter)} \qquad \text{[EQ. 2]}$$

$$\text{(curvature)} - \text{(acceleration)} = 2\times\text{(matter)} \qquad \text{SUBTRACT EQ. 2 FROM EQ.1}$$
$$\text{(curvature)} + \text{(acceleration)} = 2\times\text{(dark energy)} \qquad \text{ADD EQ. 2 TO EQ. 1}$$

8. What will happen to the universe in the long-term future? *The outward push of Dark Energy has become stronger than the retarding force of gravity, so the expansion rate is increasing. Unless Dark Energy changes its behavior, this situation will just get more and more extreme, so the expansion rate will steadily increase and the universe will expand forever. This means that the universe will get less and less dense, and colder and colder. Stars will stop being formed, and eventually the stars will stop shining.*