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.*

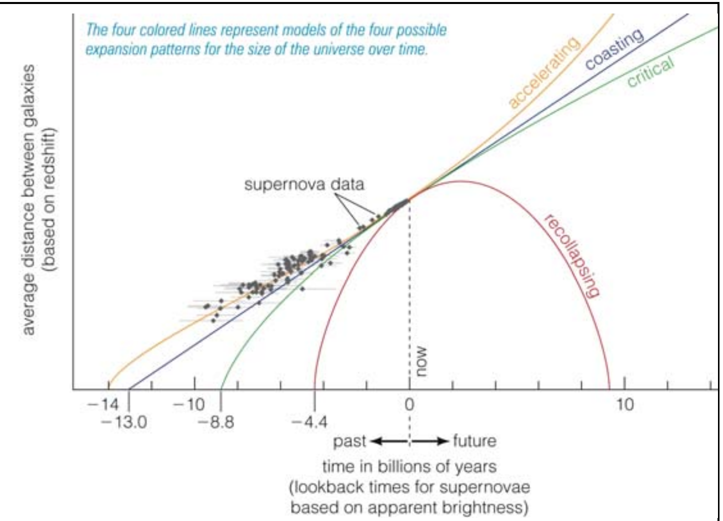

Figure 16.16 from the textbook "The Essential Cosmic Perspective".

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. What fraction of the total content of the universe is in the form of Dark Energy? *73%. This is computed by knowing the amount of Dark Energy per unit volume, and then using $E=mc^2$ to convert that to an equivalent amount of mass per unit volume that can then be compared to the density of normal matter and Dark Matter.*

5. 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).*

6. 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.

7. What are the three problems that occur if we just try to extrapolate the nature of today's universe back to the earliest times? *The three problems that I discussed in class are:*

   (1) Where did the seeds of galaxy formation come from? Those "seeds" are the 1 part in 100,000 density fluctuations that we can detect in the CMB radiation. But why wasn't the universe absolutely uniform by the time you average over the rather large size scales covered by those density fluctuations?

   (2) The "Horizon Problem": If you look at the CMB in any two opposite directions on the sky (i.e. any two directions that are 180° apart), you are seeing two different locations very far apart in the universe, as they existed at the time the CMB was released when the universe was only 380,000 years old. The CMB brightness shows that their temperatures were identical to 1 part in 100,000, and the same thing for their densities. Things get to have the same temperature and density by exchanging energy back and forth until they are in equilibrium. Yet, if the expansion of the universe had always been following the same curve on Fig 16.16 that it is following now, those two pieces of the universe should never have been able to transfer information between each other. There was never enough time for even light to travel between them. So how did they manage to come out so nearly identical?

   (3) The "Flatness Problem": The gravitational attraction supplied by the initial density of matter was in essentially perfect balance with the kinetic energy that is due to the overall expansion of the universe. There is no obvious reason why this should be the case. In the conditions of the early universe, when Dark Energy was not important, this balancing act has a one-to-one correspondence with the universe having had a flat geometry, so this is called the "flatness problem". Why is the universe flat? Or equivalently, why were gravitational and kinetic energy so perfectly balanced at the start?

8. What do we mean by inflation? *This is the name given to a very strange phenomenon that may or may not have happened, in which the overall size of the universe (described by the Scale Factor R(time)) , stretched out by an immense factor (we are talking about getting something like 1,000,000,000,000,000,000,000,000,000,000 bigger) in a tiny fraction of a second.*

9. How does inflation solve the three problems referred to in question (7)? *Inflation would be a discontinuous jump in the size of the universe as described by plots like Figure 16.16, so using the curve we are following today to extrapolate back to see what happened at the earliest times would give the wrong answers.*

   (1) Where did the seeds of galaxies come from? On very small scales such as within atoms, there always have to be point-to-point variations in density and temperature (the field called "Quantum Mechanics" explains why this happens). When the universe suddenly stretched out, those small-size-scale fluctuations stretched out with it, producing the much more extensive fluctuations that are seen in the CMB.

   (2) The Horizon Problem. The places that now seem very far apart were actually much closer together before inflation occurred, so they in fact did have enough time to slosh energy back and forth between them and get their temperatures and densities into equilibrium. Then inflation moved them so far apart that they could no longer communicate.

(3) The flatness problem. The universe could have had any sort of curvature before inflation, but after everything suddenly got 10^{30} times farther apart, the part of the universe that is close enough for us to have had time to see it is bound to look very close to being perfectly flat. It is like the difference between being able to easily see that the surface of a marble is curved and being able to easily see that the surface of the Earth is curved… except the difference in the radius of curvature is vastly larger when you compare the universe just before and just after inflation.

10. 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.*