INFLATION

(L-2)

If the Big Bang happened in one great whoosh, why do we have areas of high density like star clusters and galaxies, and area of low density like interstellar space? That is, why didn't matter distribute itself more evenly? Also, what is this I'm hearing about our losing stars, about the possibility that right now the universe is expanding at such a ferocious rate that the only stars we will see in the future will be those that reside *inside our own galaxy*?

Both of these topics are intimately related to the idea of *inflation*. We will use a balloon to model the expanding universe. This should be fun. (Let's face it, balloons are always fun!)

Part A: (initial set-up)

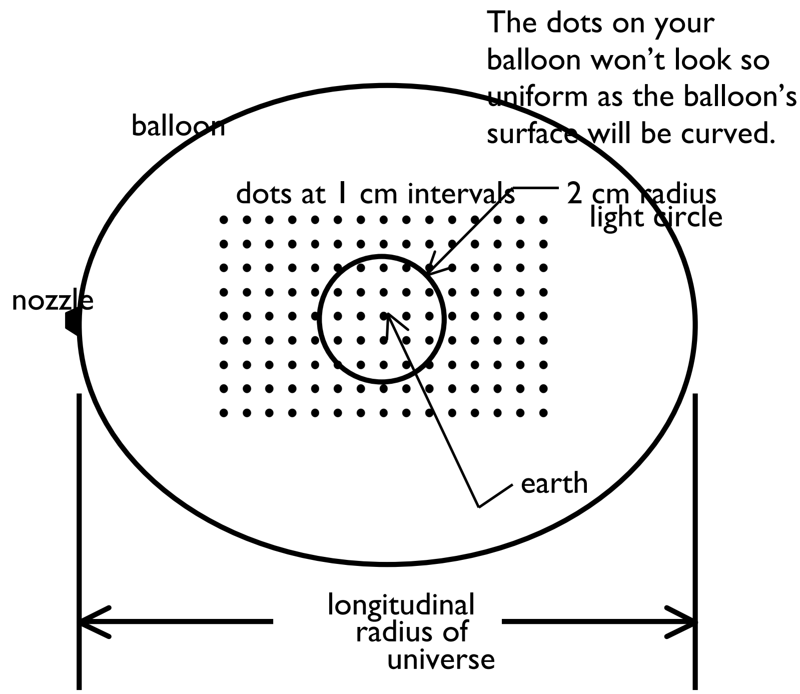
a.) You are going to be taking data, so reproduce the table shown below. In fact, reproduce it twice labeling the first one "normal expansion" and the second one "inflationary expansion."

time	# dots	light radius (cm)	balloon radius (cm)

b.) Take a balloon, stretch it, blow it up as large as you dare (don't pop it--we don't have extras) allowing it to expand close to its maximum size, then deflate it.

c.) With the balloon deflated, give it enough air so that its *nozzle to seam* diameter (i.e., its *longitudinal* diameter) is around 10 centimeters. Use a centimeter stick on this, but don't be overly anal about accuracy. Once there, twist the nozzle (don't tie it) for security.

d.) On the opposite side of the balloon from its nozzle, you should find a dot-like seam (this should be close to exactly opposite the nozzle). With the balloon inflated to the 10 cm diameter, use a permanent marker to put a dot *halfway between* that dot-like seam and the nozzle. Once done, begin to place dots at *one centimeter intervals* creating the dot grid shown on the next page. It should span approximately half of the balloon's surface (you don't have to be super accurate about this, but be as uniform as possible--see NOTE after *Procedure g*). The sketch shows it all.



e.) Using your centimeter stick, draw a two-centimeter radius circle as accurately as you can centered on that first dot. (From here on, we will assume that that central dot is the earth.)

Note 1: What does this circle signify? Remember, we are using the balloon to model the expanding universe. In doing so, we are assuming that after a certain amount of time (we will call this *one time unit*), the overall universe has expanded to the size of our balloon, or 10 centimeters. *During that time*, light will have had the opportunity to travel some distance (not necessarily 10 centimeters, but some distance). We are going to assume that when the universe is 10 centimeters across, light will have had time to travel only 2 centimeter. In other words, that 2 centimeter circle identifies the distance light can travel after *one time unit* of time since the Big Bang.

Note 2: Yes, this suggests that early on the universe expanded faster than the speed of light. Don't get hung up on this. This doesn't violate Einstein's view of the universe, though it may see to (we will talk about this more later). In any case, we have to start somewhere. I'm choosing to start with this set of assumptions.

f.) Acknowledging that the light radius identifies the distance light can travel after time *t = 1 time unit* from the Big Bang, record this time on your "normal expansion" data table (i.e., put a *1* under *time*). Also, put a *2 centimeter* under the "light radius" for the *t = 1* point in time, and *10 centimeters* for the *balloon radius* at that instant.

g.) If our planet happened to be located at the central dot on the balloon (that is the assumption we have made), we should be able to see any star that is inside the light circle (light from stars outside the light circle will not have had enough time to get to us, so we won't see them). To get feel for how many stars we *can* see, relatively speaking, count the number of dots inside the *light circle*. Record that number in the *1 unit time* row under *number of dots*.

Note: If your circle is accurate, there should be nine dots inside the circle with four additional dots right on the line (you won't be including the dots on the line in this lab). If you have more or less, it's OK as it simply means your circle isn't as accurate as it might be. Don't worry about that. Record *what you have*, not what I say you should have.

Part B: ("normal universal" expansion)

h.) Let's assume that at *t = 2 time units*, the universe has expanded to a diameter of 20 centimeters (in fact, blow the balloon up to approximately 20 centimeters). Record that time and balloon diameter on your table.

i.) Let's assume that during the *1 time unit* of time between the *t = 1* and *t = 2 time unit* mark, light doubles its range. That is, on the new universe (i.e., the balloon blown up to a 20 centimeter diameter), draw a new circle of radius *4 centimeters*. This is the distance light has been able to travel after *2 time units* after the Big Bang. Record this new *light radius* in your table.

j.) You should find that this radius is outside the original circle you drew. Count the number of dots inside this new circle. **Note that if there are *more* than the first situation, it means that stars we couldn't see at the first point in time are now visible to us at the second point in time. In other words, the *visible* universe has enlarged over that time interval**.

k.) Now, blow the balloon up to 30 centimeters. Assume this takes us to *t = 3 time units* and that the light circle radius has expanded to *6 centimeters*. Draw that light circle and record the number of dots inside that new circle. Also record all of the other information the table requests.

l.) You now have all the information you need to produce a *visible universe* graph as a function of time for a "normal expansion" situation.

Part C: (inflationary universal expansion)

m.) Allow your balloon to deflate back down to the 10 centimeter balloon diameter. Again, assume this is the size of the universe after *one time unit's* worth of time, and assume that at that point in time, the light circle measures *2 centimeter* in radius. In other words, go back to the original, initial situation.

n.) Now blow the balloon up to 20 centimeters. For this scenario, let's again assume that this brings us time to time *t = 2 time units*, but let's additionally assume that during that time period between *t = 1* and *t = 2 time units*, the light circle's radius only grows by .4 centimeters.

Note: The speed of light hasn't changed, so this evidently simulates a situation in which the universe expands very, very fast (i.e., from 10 cm to 20 cm in such a short time interval that light only increases its light circle radius by .4 centimeters).

o.) Draw that 2.4 centimeter circle on the new balloon, count the number of dots inside the circle, and record all the pertinent information in your second table. (Note that you may find you have *fewer* dots inside your circle than you had before).

p.) Now, blow the balloon up to 30 centimeters. Identify that time as $t = 3$ *time units* and assume the light circle's radius has grown to 2.8 centimeters. Draw this new radius on the balloon, count the number of dots inside the circle, and record all the pertinent information in your second table.

q.) You now have all the information you need to produce a *visible universe* graph as a function of time for an "inflation" situation.

Part D: (flat Euclidean versus curved Minkowskian geometry)

r.) Bring your balloon to class. When there we will do the following: Using a straight edge, draw a triangle on a flat piece of paper. Use a protractor and determine the number of degree inside the triangle. Record this number.

s.) Using a straight edge as best you can, draw a GIGANTIC triangle on the side of your balloon when it is blown up to a 30 centimeter diameter. Make the lines as locally "straight" as possible. Again, use a protractor to determine the number of degrees inside the triangle. Record this number.

CALCULATIONS

Part A: (set-up)

0.) Nothing to do in this section.

Part B: (normal universe expansion)

1.) Using the data you were given, make a half-page grid and graph the number of dots as a function of time for the "normal universe" expansion data. Be sure to scale your grid so that you use the whole graph.

2.) Looking at your graph, what is happening to the number of stars the earth can see as time proceeds with this kind of inflation?

Part C: (inflation expansion)

3.) Using the data you were given, make a half-page grid and graph the number of dots as a function of time for the "inflation universe" expansion data.

4.) Looking at your graph, what is happening to the number of stars the earth can see as time proceeds with this kind of expansion?

5.) From what has been said in class, which type of expansion does the universe appear to be experiencing at this particular point in real time.

Part D: (triangles in different geometries)

5.) You added up the interior degrees of a triangle drawn on a Euclidian (read this "flat") surface. What number did you get?

6.) You added up the interior degrees of a triangle drawn on your balloon's surface (i.e., on a curved surface--this will be our not so accurate model for Minkowskian geometry . . . though Minkowskian geometry is really much odder than this). What number did you get?

7.) How did your total degrees compare for the two situations? What does this tell you about the geometry of space, assuming it is not "flat?" (Feel free to be very vague and esoteric with this.)