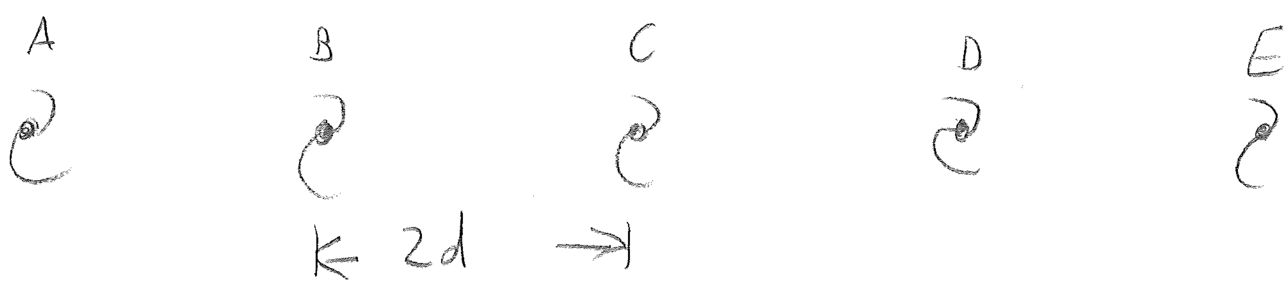
INST 2403 Activity

The Expanding Universe

One of the most important observation of cosmological relevance is the *Hubble law*. In the 1920s Edwin Hubble documented a correlation between a distant galaxies redshift or recessional velocity and its distance. This direct proportionality between the two quantities means that a galaxy twice as distant as a reference galaxy moves away from us twice as fast as the reference galaxy. What is the interpretation of this pattern of Nature? This is the subject of this activity.

1. Consider a one-dimensional universe, with 5 galaxies all a distance d from its neighbor. For definiteness, let's say d = 1 billion ly. Sketch this universe using a scale where 1 billion ly = 1/2 inch and label the galaxies A,B,C,D,E, with C as the middle galaxy.

2. Now imagine that this universe has expanded to twice its size, as if the galaxies where mounted on a rubber string that was stretched to twice its size. Draw this expanded universe.



3. Make a table indicating by how much each galaxy has moved from a reference point. Take the middle galaxy C as this reference point.

	A	B	C	D	E
has moved	2d	d	0	d	2d

4. Come up with a simple law that describes the distance change (and thus the velocity) of a galaxy as a function of its distance from galaxy C.

distance change is proportional to distance itself

5. Is this law compatible with Hubble's law? Why or why not?

Yes, Hubble's law states this proportionality: $V = \Delta d \times t = H_0 d$

6. Is the galaxy C special because all other galaxies are moving away from **it**? Redo the table of 3. With galaxy B as the reference point.

C is not special!

	A	B	C	D	E
has moved from B	d	0	d	2d	3d

7. What is the Hubble constant in this universe if the time it took the universe to double its size is one billion years?

$V = \frac{1 \text{ bill. ly}}{1 \text{ bill. yr}} = 1 \frac{c \cdot yr}{yr} = 300{,}000 \frac{km}{s}$ So $H_0 = 300000 \frac{km/s}{\text{bill ly}}$

8. What is the Hubble constant in this universe if the time it took the universe to double its size is two billion years?

2 × the expansion time ⇒ slower expansion ⇒ Hubble const. smaller by ½ ⇒ $H_0 = 150000 \frac{km/s}{\text{bill ly}}$

9. How is the Hubble constant related to the expansion rate of the universe?

See above, it tells us how fast the universe is expanding.

10. Now on to something different. It seems curious that the universe should always expand at the same rate, i.e. that the Hubble constant is a constant. To see if this is strange or natural, let's explore two scenarios. In the first scenario, early in the universe's history, galaxies were very close to each other. If they had some velocity relative to each other making their mutual distances larger and larger, what would the effect of large gravitational forces between the galaxies be? Would they speed up, slow down, or leave the velocities the same?

Slow down the expansion

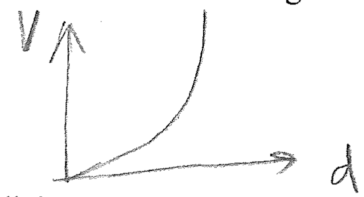
11. In scenario two, late in the universe's history, the galaxies are far away from each other. How do the forces and their effect differ from scenario 1?

Still slows down the expansion, but less since the forces are weaker

12. What is the conclusion? Is it strange or normal that the Hubble constant is constant?

It is strange!

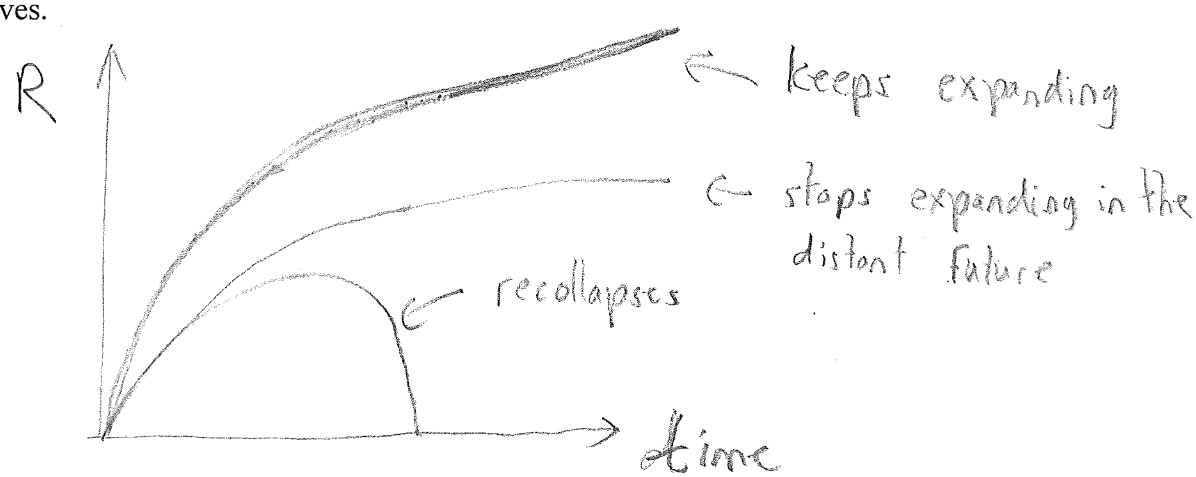
13. Draw Hubble plot in which the Hubble constant is not constant. Specifically, assume that the Hubble constant is large initially, and then get smaller over time.



14. Let's call the distance between two very distant galaxies, say the Milky Way and a galaxy at the edge of the observable universe the *radius of the universe*. As time goes by, how does the radius of the universe change?

It gets bigger, but the rate of grows slows over time

15. Draw the radius of the universe as a function of time. Because the expansion of the universe slows down due to mutual gravity of its galaxies, there are three possibilities. Either the universe expands forever, or it eventually stops expanding, or the universe expands up to a point and then shrinks or re-collapses. Draw these three curves.



16. The "fate of the universe" depends on which curve the universe is on. This is determined by the amount of gravitational force between galaxies. On which parameter does thus the fate of the universe depend?

The mass contained in the universe, often expressed as the ratio of actual density (mass/vol) and the critical density: $\Omega_0 \equiv \frac{\Omega}{\Omega_{critical}}$

for a universe that stops expanding eventually