ASTR 311 Tutorial 6: The Expanding Universe

Since the Big Bang nearly 14 billion years ago, the Universe has been expanding. We know that because we're watching other galaxies, or as Edwin Hubble called them, nebula:

> *We find them smaller and fainter, in constantly increasing numbers, and we know that we are reaching into space, farther and farther, until, with the faintest nebulae that can be detected with the greatest telescopes, we arrive at the frontier of the known universe.*
>
> Edwin Hubble, *The Realm of the Nebula* (1936)

And these galaxies are following a curious pattern: the farther away the galaxy, the faster it is moving away from us. This discovery, made by Hubble in 1929, is known as the Hubble Law.

The Hubble Law comes with an optical illusion: it looks like we're at the center of the Universe. Are we really that special? In this Tutorial, you'll clear up this illusion.

Edwin Hubble

Part 1: Observe the Expanding Universe

Imagine it's 7 billion years in the future and the Universe is 21 billion years old. You just received a new map of the distribution of galaxies (the map called Map21 on the overhead transparency). In the Library you find a map of galaxies when the Universe was only 14 billion years old (the map called Map14 on paper). You'll compare the two maps to determine how the Universe has changed in the last 7 billion years.

1. Select a letter of the alphabet by using the first letter of the first name of the partner born earlier in the year. This is your home galaxy for the rest of the tutorial.
2. Circle your galaxy on Map21 and Map14.
3. Place Map21 on top of Map14 so that your home galaxy lines up. Align Map21 so it is "squarely" on top of Map14 (make the edges of the pages parallel.)
4. Use the Post-It notes to "glue" Map21 to Map14. You don't want Map21 to move while you're making measurements.
5. For each galaxy A–Z, use the ruler and overhead pen to **draw an arrow** on the tranparency from the Map14 location to the Map21 location (A to A, B to B, etc.)

Part 2: Measure the Expanding Universe

One partner got to choose the home galaxy; now the other partner gets to choose: For each letter in the other partner's first name, measure

6. the distance (in **millimetres**) from your home galaxy to the galaxy on Map21 (the tranparency). The scale of the map is 1 mm = 1 Mpc (megaparsec).
7. the distance (in **millimetres**) that galaxy travelled in the last 7 billion years (the length of the arrow between the two positions)

Record the "Map21 Distance" and the "Distance Travelled" in the Table below.

Galaxy	Map21 Distance mm (or Mpc)	Distance Travelled mm (or Mpc)	Recession Velocity Mpc/Gyr

8. Since you know how far each galaxy travelled in 7 billion years, calculate each galaxy's recession velocity:

$$\text{recession velocity} = \frac{\text{distance}}{\text{time}} = \frac{\text{Distance Travelled}}{7}$$

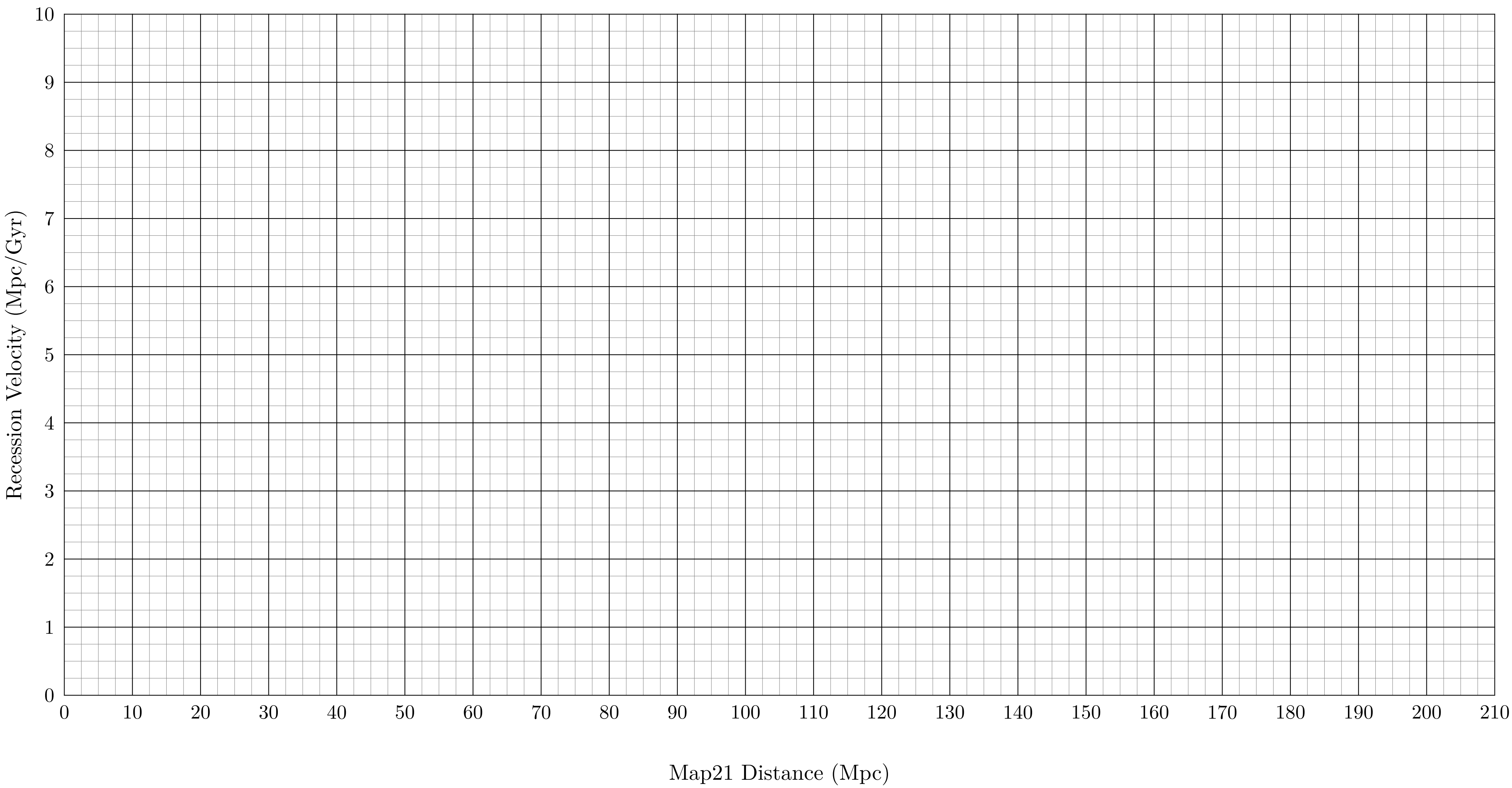
9. Add your home galaxy (distance 0 Mpc) and how far it moved (hint: it didn't!) to the Table of data.

To analyze the data, make a graph that compares the recession velocity to the 21-billion-year distance:

10. For each galaxy you measured (including your home galaxy), make a dot in the graph on the next page according to the galaxy's Map21 Distance and its recession velocity. Label the dot with the letter of the galaxy. When you've plotted all the galaxies, draw the best straight line through the dots on the graph.
11. The **slope of the line** in the graph is the **Hubble constant** for your Universe. Let's call it H. To calculate the slope, find the vertical and horizontal changes on the graph from your **home galaxy** to the **most distant galaxy** you plotted, and then divide:

$$H = \frac{\text{(vertical) change in recession velocity}}{\text{(horizontal) change in Map21 distance}} = \frac{\underline{\qquad\qquad} \text{ Mpc/Gyr}}{\text{Mpc}} = \underline{\qquad\qquad} \frac{\text{Mpc/Gyr}}{\text{Mpc}}$$

The Expanding Universe



Name ______________________________ ID No. ________________ Tutorial Day/Time ________________

Part 3: Questions

Please hand in this worksheet when you are finished.

1. Look back at all the arrows you drew on the maps. Imagine you're want to check if you did it right by talking a friend in another ASTR 311 tutorial section on the phone (that is, with words only – no pictures). How would you describe the way the galaxies moved so your friend could say, "Yeah, we got that."

2. The real Hubble constant $H_o = 72$ km/s/Mpc tells us how fast our real Universe is expanding. Each volume of space 1 Mpc across is expanding at 72 km/s so a galaxy 1 Mpc away looks like it's moving away from us at 72 km/s. For larger distances, each 1-Mpc-wide volume adds another 72 km/s to the velocity.

   The Hubble constant H you found in Part 2 tells you how this tutorial's universe is expanding. Imagine a volume of space 1 Mpc across (1 mm on the maps). How fast is that volume expanding? ______________ Mpc/Gyr 100 Mpc across? ______________ Mpc/Gyr Find a galaxy on Map21 that is about 100 mm from your home galaxy. How fast is that galaxy moving (calculate its recession velocity) ______________ Mpc/Gyr Do your two results agree? _____________

3. Check your results with another group. Are they the same or different?

ours and theirs	same	different
home galaxy	☐	☐
measured galaxies	☐	☐
Hubble constant H	☐	☐

   Why does everyone in the room have (nearly) the same H?

4. Imagine running the expansion backwards in time to the Big Bang, from 21 billion years to 14 to 7 to 0.... Where does it appear all the galaxies started from? _____________ Ask another group where their galaxies all started from _____________ Where is the center of the Universe, anyway? Your home? Their home? Everywhere? Nowhere?

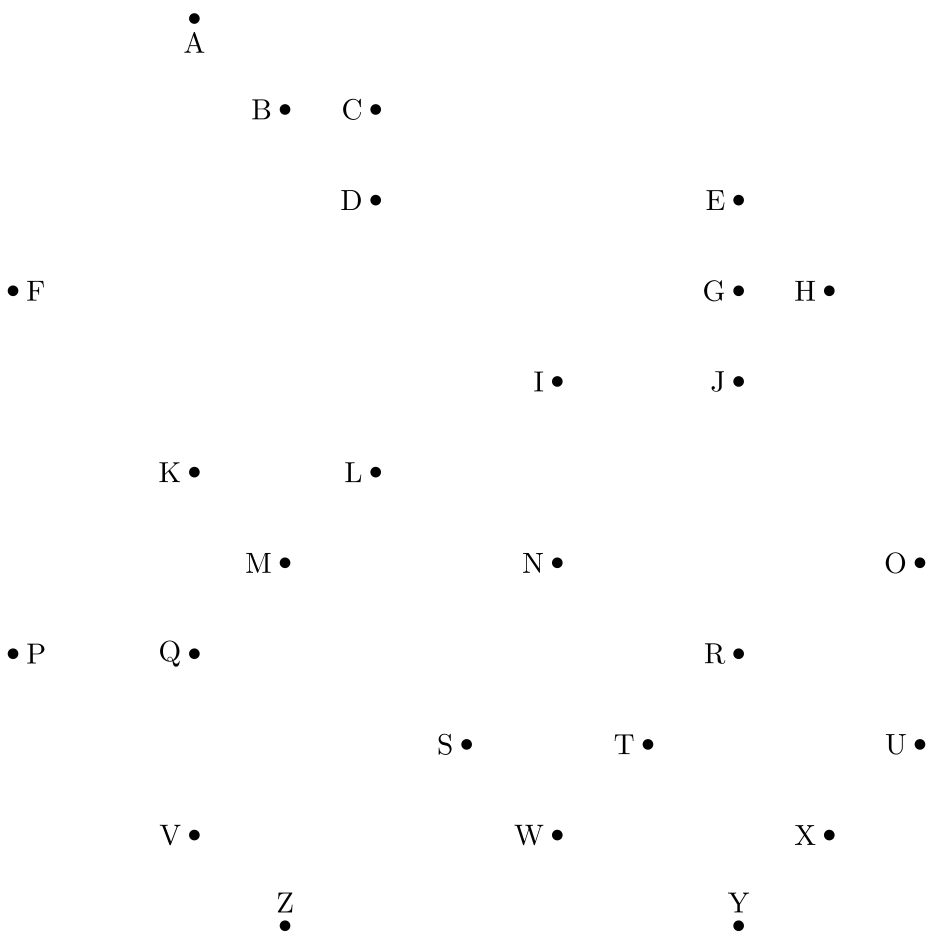
5. Two students are discussing the Hubble Law: the farther away a galaxy is, the faster it seems to be going.

   Student A Galaxies are moving through the vacuum of space at different speeds, some faster, some slower. The ones that travelled farther since the Big Bang are the ones that travel faster.

   Student B The galaxies are not actually flying through space. The space between us and the galaxy is expanding. The bigger the space, the more the expansion and the faster the galaxy looks like it's moving away.

   Do you agree or disagree with either or both students? Explain.

14 billion years



21 billion years