Galaxies and the History of the Universe

In this activity, you will explore how galaxies move within the cosmos, and how their positions and movement tell us about the history of our universe.

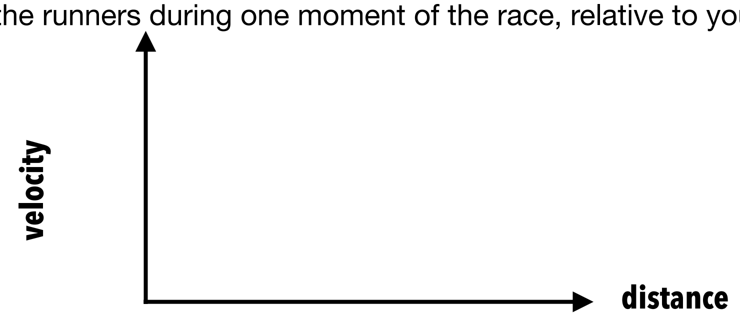
1. Practice graphing velocity vs. distance.

What would you expect the velocity vs. distance graphs to look like for the following scenarios? (Your graphs do not need to include units or scales, but do **show where 0 is for both axes**. **Positive velocities are AWAY** from you. **Negative velocities are TOWARD** you.)

a. "Static universe" analogy: You are standing still in a park with five trees. Graph velocity vs. distance of the trees, relative to you. Explain your reasoning.

b. "Random motion universe" analogy: You are at a shopping mall with five friends. You are waiting in a sitting area while the others shop at different stores. Graph velocity vs. distance of your friends, relative to you. Explain your reasoning.

c. "Expanding universe" analogy: You and five other people are standing close together in a line. Imagine that the people in front of you start running a race, but each person in the line runs faster than the person behind them and doesn't change speed. Graph velocity vs. distance of the runners during one moment of the race, relative to you. Explain your reasoning.



What does the line of runners look like compared to the start of the race?

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Now you will examine real astronomical data to determine how galaxies in our universe behave. In the online interactive environment, you will:

- use actual spectra data to determine galaxy velocities
- use a galaxy's size in the sky to estimate how far away it is

2. **Open the Hubble and the Big Bang Interactive.**

   projects.wwtambassadors.org/hubble-big-bang

3. **Choose four galaxies to collect data for and fill in the table below.**

   (You may work with a partner and combine your data to include all eight galaxies).

Velocity calculation:

$$v = c\left(\frac{\lambda_{\text{obs}}}{\lambda_{\text{rest}}} - 1\right)$$

v is the galaxy's velocity in km/s

c is the speed of light: $300,000$ km/s

λ_{obs} is the observed wavelength of H-α in the galaxy's spectrum

λ_{rest} is the rest wavelength of H-α: 656.3 nm (nm stands for nanometer, which is 1 billionth of a meter)

Distance estimation:

- When measuring the galaxy's angular size, be sure to rotate the galaxy until **its longest dimension is vertical**, then match the viewport to the **galaxy's extent** (not the circle marking the galaxy).
- So that another scientist could reproduce your work, describe how you have chosen to define the galaxy's "edge" in your measurements:

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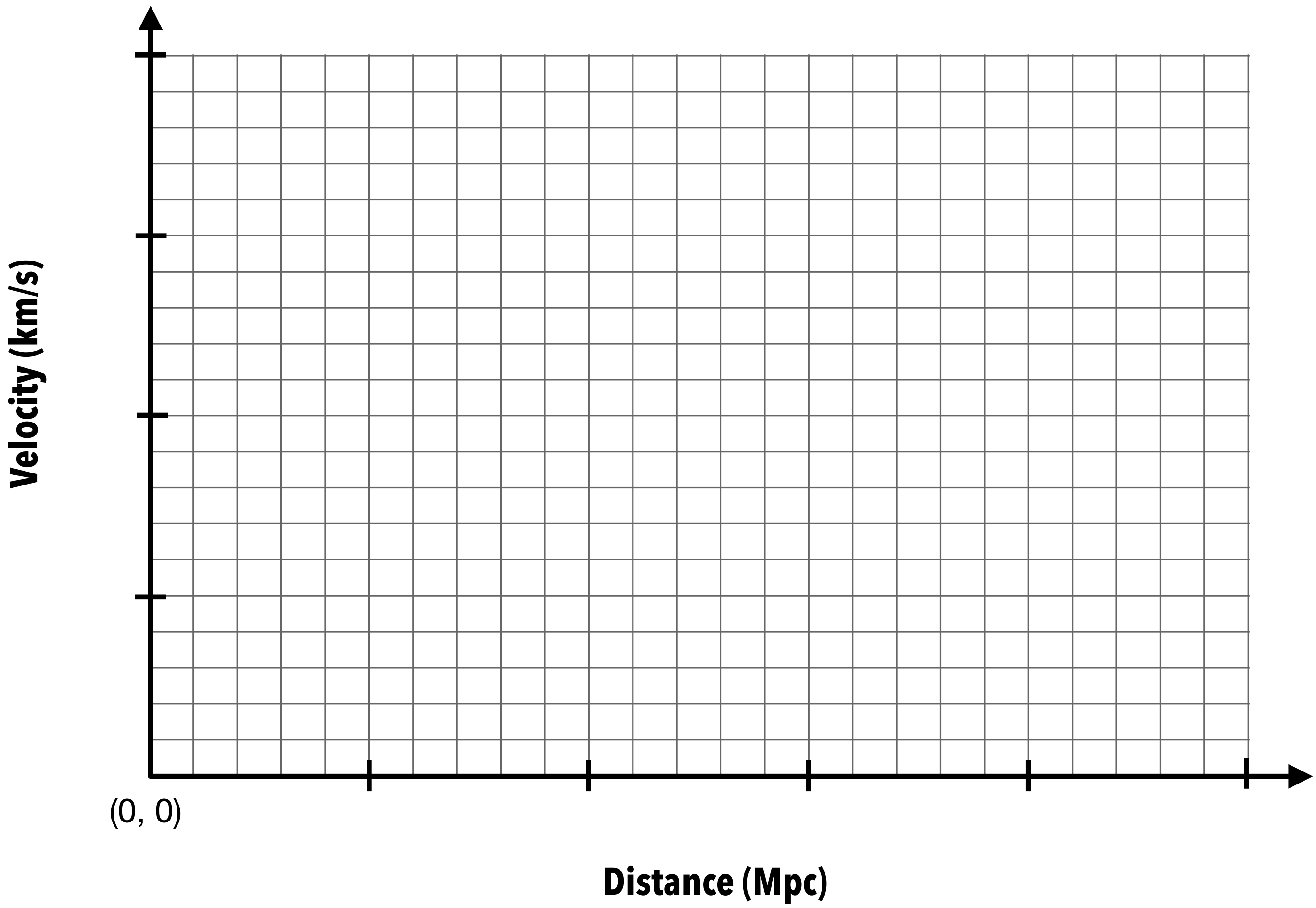
- Remember that galaxies of one type are not actually all the same size, so our estimated distances have large uncertainties.

Galaxy name (you can shorten it as long as you can still identify it)	**Estimated distance to galaxy (Mpc)**	**Observed wavelength of H-α line (nm)**	**Velocity of galaxy (km/s)**

4. **Graph the velocity vs. distance for your galaxies.**
    - Identify the largest velocity and distance values in your (and if applicable, your partner's) data and use them to set an appropriate scale for your graph.
    - Label the axis hash marks with velocity and distance values relevant to your graph's scale. (Your graph might not have the same scale as your classmates' graphs).



5. **Compare your graph with the sketches you made in Question 1 and identify what type of universe is consistent with your galaxy data:**

    a. static universe   b. a random-motion universe   c. an expanding universe

6. **Draw a trendline through your data points and calculate its slope.**

- Our Milky Way is at (0, 0) on the graph, so the **trendline should go through the origin.**
- Roughly the same number of data points should be above and below the trendline.
- Because the trendline goes through the origin, **the slope is equal to any *y*-value on the line divided by the corresponding *x*-value**.
- Identify the unit of the slope. (It is the unit of the *y*-variable divided by the unit of the *x*-variable and will likely seem unusual.)

Value of slope = _______________ Unit of slope:_________________

7. **Your galaxy data and what they tell us about the universe.**

a. Let us reconsider Question 1c about the runners, where each runner runs faster than the person behind them. Describe in words what the velocity vs. distance graph for the runners looks like at some moment after the race has started:

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b. After the runners have been running for some time, describe in words what has happened to the line of runners compared with the start.

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c. If you "run the movie backward," what happens to the line of runners?

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d. Now consider your galaxy data and the trendline you drew. In what ways are your galaxies like the runners?

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e. Based on your data, what can you conclude about what is currently happening to the universe?

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f. If you "run the movie of the universe" backward, what do you expect to find?

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g. Explain how your galaxy data support the big bang theory of an expanding universe.

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h. The slope you calculated in Question 6 is your estimate of the Hubble constant (H_0, pronounced "h-nought"). Write your estimated value and its unit here:

H_0 =_______________