**Hubble Law Pre-Lab Reading and Quiz**

In 1929 Edwin Hubble announced what is probably the single most important discovery for astronomy in the 20th century — that virtually all observable galaxies are moving away from us at very high speeds, and that the recession speed of a galaxy is directly proportional to its distance from us. As an observational result, it is rather simple (though it took a great deal of careful work to obtain), but philosophically, this is a bombshell.

First and foremost, this result implies that everything in the universe is getting further and further away as time passes. Quite literally, the entire universe is expanding. We do not live in a static universe, where objects just sit stationary in space and therefore can be found in the same location at all times. We live in a dynamic universe which is changing all of the time, and changing in a very systematic way. It really looks like the motion of the universe is the result of some giant explosion. And where did that explosion originate? Right here.

That’s troubling, because it implies that we occupy a special place in the universe: the center. After all, the galaxies are all receding from us, and the speed with which they recede from us is proportional to the distance between us and them. Over the years, models that have placed us in a special, central location in the universe have always proved incorrect. The Greeks believed that the Earth was the center of the solar system, and this belief was held until Copernicus and Kepler showed it to be incorrect. The Sun was thought to be at the center of the galaxy until Shapley showed that it was not. Even the galaxy was thought to be the entirety of the universe until Hubble showed that spiral nebulae are other galaxies as big and massive as the Milky Way. Time and time again, we’ve discovered how insignificant we are, and that the place we occupy in the universe is not special.

And yet Hubble’s simple result says that the universe, on the largest scales measured, knows where we are; that we occupy a truly special place from which all of the observable galaxies in the universe appear to be receding. In a very real sense, it would appear that we are the center of the universe.

Or are we? In this lab, we’ll examine the implications of Hubble’s law, or, as it is often called today, the Hubble Law. We’ll create a model “universe” which obeys the Hubble Law, and we’ll examine it from different locations within it. We will see how knowing something about the Hubble Law tells us the size and age of the universe, and something about its past history. We might even learn something about the universe’s future. All this from nothing more than Slinkies and paper clips.

**A Little Background**

Edwin Hubble (1889-1953) was an American astronomer from Missouri. He earned his Ph.D. the Yerkes Observatory (part of the University of Chicago) in 1917, and after serving in the military in World War I, accepted a position as an astronomer at the then-new Mt. Wilson Observatory near Los Angeles in 1919. This was a very sought-after position, because the Mt. Wilson Observatory was home to the new 100-inch diameter Hooker Telescope, the largest telescope in the world at the time.

Hubble was very interested in the spiral nebulae and was quite aware of the debates between Shapley and Curtis, as well as many others, over the distances to these objects. He knew that if these objects were far away, beyond the edge of the Milky Way Galaxy, they must be "island universes" rivaling the Milky Way in mass and numbers of stars. Moreover, discovering that the spiral nebulae were very distant would also prove that  the universe was truly huge in scale.

Hubble used the Hooker Telescope to identify and image individual variable stars in the spiral nebulae. By observing their periodic variability, he was able to show that these objects were in fact highly luminous Cepheid variables. As you well know, the period of a Cepheid variable is proportional to its luminosity, and so Hubble could determine the luminosities of these bright stars. He then compared the luminosities of the stars with their observed fluxes, and showed conclusively that many spiral nebulae were thousands of kpc away and must be separate from the Milky Way.

So Hubble was mainly a distance measurement guy. He combined his distance measurements (from Cepheid variable studies) with velocity measurements made primarily by spectroscopist Vesto Slipher (1875-1969) of the Lowell Observatory in Arizona. With an aperture of only 24 inches, Slipher's telescope at Lowell was smaller than Hubble's, but Slipher had built an extremely accurate spectrograph that was capable of the very precise wavelength measurements necessary for velocity determination via the Doppler Effect.  It was really the combination of cutting-edge measurements of both distance and velocity that made Hubble's results possible. Hubble ends up getting more credit than Slipher because he recognized the value in combining their results, and clearly understood the massive implications of the Hubble relation.

In this lab, you'll take a look at some of Hubble's (and Slipher's) original data, as well as some more recent data from more modern instruments. You'll also construct your own universe from a slinkie and paper lips, and see how a uniformly expanding universe must have a Hubble law relationship between distance and velocity. Finally, you'll see how understanding this relation leads not only to the conclusion that the universe is expanding, but yet another bombshell -- that the universe (and time) had a beginning.

**Pre-Lab Quiz**

1. What was the name of the telescope Edwin Hubble used to identify Cepheid variable stars in distant galaxies?
	1. The Hooker Telescope
	2. The Lowell Observatory
	3. The Hubble Space Telescope
	4. The Mt. Wilson Observatory
2. Why was Vesto Slipher able to measure the velocities of the spiral nebulae so well?
	1. He was able to measure the periods of Cepheid variable stars.
	2. He built a very accurate spectrograph.
	3. He had access to the largest telescope in the world at that time.
	4. He discovered the Doppler effect.
3. Why is it troubling to discover that all galaxies in all directions are moving away from us?
	1. Because it suggests that we're in the center of the universe.
	2. Because it indicates that we've made some mistake in our Doppler effect measurements.
	3. Because in a homogeneous universe, galaxies should have random motions.
	4. Because we're worried about getting lonely.
4. This lab will involve
	1. slinkies and paper clips.
	2. rubber bands and push pins.
	3. springs and pulleys.
	4. rulers and thumb tacks.