

Astro 101 Hubble Law Lab: Instructor Notes

1. The Hubble Law Lab at Bucknell University

Bucknell University has run the WWT-enhanced Hubble Law lab in its introductory astronomy course since 2014. It is part of a semester-long course that discusses extrasolar astronomy in three 50-minute lectures and one three-hour lab section per week. Lab sections average approximately twenty students. The following statements refer to the way that the lab is regularly run at Bucknell.

- Students complete a pre-lab reading assignment and quiz before the lab period. The reading assignment is approximately a page and a half long and discusses the expansion of the universe, and the history behind Edwin Hubble's groundbreaking discovery. The quiz consists of four questions based on the reading.
- In lab, students typically work in groups of two at lab desks equipped with large "slinky"-type springs, paper clips, and a networked Windows computer. They are guided by a lab packet that also contains questions and spaces for student calculations and written responses.
- At the end of the lab period, students complete a quiz that is based on components of the WWT tour, measurements and calculations, and conclusions they've reached during the lab. The quiz is four questions long, and depending on the preference of the instructor, the students will either work individually or with their partner.
- Lab staffing usually consists of one instructor and one undergraduate TA who is not necessarily (and not usually) a physics and astronomy major.
- This lab requires about two and a half hours of in-class time. The approximate timing for the various lab activities is indicated in the table below:

Lab Activity	Approximate Time for Students to Complete
Pre-lab reading and quiz	20 minutes (typically done before the lab period)
Initial spreadsheet calculations and desktop modeling of an expanding universe	40-60 minutes
First WWT tour	15 minutes
Second spreadsheet and calculations (galaxy spectrum analysis and redshift calculation)	30-40 minutes
Second WWT tour	15 minutes
Post-lab quiz	15-20 minutes

2. Equipment Requirements

- a. “Desktop universe” requirements – Students use a 4-inch diameter plastic “Slinky” spring as their one-dimensional expanding universe (see below),



and colored paper clips as galaxies affixed to individual coils of the spring. We mounted the ends of the spring onto 4” x4” wooden blocks. A meter stick is used to measure the separation between galaxies as the universe expands.

- b. Software Requirements and Suggestions
 - a. WorldWide Telescope must be installed on the Windows PCs being used for the lab, in order for the two tours to run. WWT can be downloaded here: <http://worldwidetelescope.org/Download/> .
 - b. The WWT Ambassadors page has resources for learning how to install and use WWT here: <http://wwtambassadors.org/learn-how-use-worldwide-telescope> .
 - c. Bucknell stores the tour on a campus server that all students can access, instead of putting a copy of the tour on each lab computer.
 - d. We also found it helpful to have the students access a link to the tour itself, instead of opening WWT and then loading the tour.
 - e. Students also use Microsoft Excel during this lab activity. A standard installation of Excel as part of the Microsoft Office is sufficient.

3. A Step-by-step Description of the Lab Activity

- a. Pre-lab reading and quiz

The document *Hubble Law Pre-Lab Reading and Quiz.doc* contains background reading on the historical development of the Hubble Law and its implications for our understanding of the structure and evolution of the universe. This document also contains a four-question, multiple-choice quiz based on the reading. This material can be used with online course management software (we use Moodle at Bucknell) to create an online pre-lab assignment for students. At

Bucknell, we allow students to take the quiz as many times as they choose, and require that they answer all four questions correctly before beginning the lab.

The lab also relies on the application of the Doppler Effect to determine recession velocities from galaxy spectra. Students should have some familiarity with this concept before beginning this lab activity, either from in-class lecture and discussion, or from reading assignments. We have used the following YouTube video as an introduction to this concept:
<https://www.youtube.com/watch?v=h4OnBYrbCjY>

b. Hubble's data and the Hubble Law

Students are guided through the lab activity with the document *Hubble Law Lab Writeup for Students.doc*, which can be modified for use at any institution. This document contains the instructions necessary for completing the lab activity, as well as space for student calculations, plotting, and responses to posed questions. It is intended as a student's record of the lab activity, and can be collected and graded as the instructor sees fit.

In the first part of the lab activity, students open the Microsoft Excel file *HubblesData.xlsx* to examine the original dataset Edwin Hubble used in his landmark 1929 paper. Students fit a straight line through these data to determine a value for the Hubble constant. They then compare this dataset with the data from the Hubble Space Telescope Key Project, examining how these datasets differ, and why the Hubble constants derived from the two datasets differ so widely.

c. A Desktop Expanding Universe

Students then turn to a large "slinky"-type spring, which represents an expanding universe on their desktops, and attach "galaxy" paper clips to coils in the spring. They stretch the spring to simulate expansion, and then measure the change in distance between the galaxies. They interpret this change in distance in terms of velocity, and plot a Hubble Law for their desktop universe.

Through subsequent analysis, students examine how their Hubble Law plot would look if viewed from the perspective of another galaxy (it looks the same), and they infer an age for their expanding universe from their Hubble constant.

d. WWT Tour I: Charting the Universe in Redshift

The first of two WWT tours introduces the idea of using the Hubble Law to infer the distances to objects in an expanding universe. It describes the process of determining a redshift from galaxy spectra, and defines a sample of 50 galaxies for further analysis.

e. Measuring Redshifts from Galaxy Spectra

Students are guided through the process of downloading galaxy spectra from the Sloan Digital Sky Survey (SDSS) database using WWT. They then input these data into a Microsoft Excel spreadsheet (*GalaxyRedshiftCalculator.xlsx*) for redshift determination. Students identify prominent spectral lines, and fit the pattern of absorption lines in galaxy spectra to determine a

galaxy's redshift. From the redshift, students determine a recession velocity for each galaxy, and, using the Hubble Law, a distance.

f. Redshift surveys and the Large-scale Structure of the Universe

In the second WWT tour, students see how the redshifts determined via the method they followed produce a “pencil beam” survey of the three-dimensional distribution of galaxies in the universe. They compare these data with larger redshift surveys, the 1980's CfA Redshift survey and the more current and much larger SDSS survey.

They explore the inhomogeneous distribution of galaxies in the universe, and identify clusters and voids in the distribution. The tour closes with a discussion of how gravitational forces in an expanding universe can be responsible for the observed structure.

g. Post-lab quiz

A four-question post-lab quiz (*Hubble Law Lab Post Lab Quiz.docx*), containing a mix of both quantitative and qualitative questions, is available in editable format. At the conclusion of the lab activity, students take the quiz in written form, and these materials can be collected for grading purposes. At Bucknell, we review and grade both the student responses on the lab writeup and the post-lab quiz.