

Hubble's Law and the Expanding Universe

Your Galaxy: _____

1. Hubble Type

Galaxies are subdivided into four major classes: *spirals*, *ellipticals*, *irregulars*, and *peculiar*s. The classification is based on their appearance:

Spiral – Disk shape (flat); has spiral arm features.
 Elliptical – Close to spherical; featureless.
 Irregular – No symmetry; chaotic appearance.
 Peculiar – "Strange" features like tails, bars, etc.

What is the Hubble type of your galaxy*?

2. Angular diameter distance

Suppose we assume that all galaxies are about the same intrinsic size. (Not a great assumption, but better than nothing.) Based on the apparent size of your galaxy relative to the others in the sample at your table, would you classify it as *close*, *medium distance*, or *far-away*?

3. Cepheid distance

At the bottom of your galaxy's page is printed the "faintness" (inverse brightness) of a Cepheid variable in that galaxy**, *relative to a Cepheid in the nearby galaxy M31, which is at a distance of 800 kpc (0.8 Mpc)*. Write this value down:

_____ x fainter

Use the inverse square law ($b \propto 1/d^2$) to estimate how much further the galaxy is from us than M31.

_____ x further away

Now convert this to megaparsecs:

_____ Mpc

4. Spectral Type

Is your galaxy's spectrum dominated primarily by *absorption* lines, or *emission* lines*?

Strong emission lines indicate lots of young stars (they originate from hydrogen-rich nebulae surrounding massive stars, similar to the Orion nebula in our own galaxy.) Strong absorption lines indicate lots of old stars (the Sun, for example, has strong absorption features and almost no emission lines.)

Is your galaxy dominated by young or old stars*?

5. Redshift and recessional velocity

Your galaxy spectrum should have two "zoom in" windows on two common spectral features: a prominent pair of absorption lines (due to calcium) and a prominent emission line (of hydrogen). The *rest wavelength* of each line is marked on the plot.

Choose the most prominent of the three lines (ignore the other two) and do the following:

Measure the *observed wavelength*: $\lambda =$ _____ Å

Write down the *rest wavelength*: $\lambda_o =$ _____ Å

Subtract to get the Doppler shift: $\Delta\lambda =$ _____ Å

Calculate the redshift:

$$z = \frac{\Delta\lambda}{\lambda_o} = \frac{\quad}{\quad} = \quad$$

Now, use the low-velocity Doppler approximation ($z = v/c$) to estimate the velocity at which the galaxy is moving away from us. ($c = 3 \times 10^5$ km/s).

$$v = (\quad) \times (\quad) = \quad \text{km/s}$$

* If the galaxy looks like a cross of two different types / populations, feel free to write down both.

** Minor caveat: Most of the galaxies distributed here are actually too far away for individual Cepheids to be observable, even with the Hubble Space Telescope, and the values quoted for their brightnesses here are hypothetical; inferred from the known distances. However, other objects (such as populations of red giants or supernovae) can be used in their place, or the angular diameter distance method can be used more quantitatively.

Hubble's Law and the Expanding Universe

One of the most surprising discoveries in the history of astronomy, and the one which marked the birth of cosmology as a scientific (as opposed to a religious or philosophical) pursuit was the discovery that the Universe is expanding, and therefore changing with time. The observations establishing this conclusion were first performed by Edwin Hubble in the 1920s, using the telescopes at Palomar Observatory in southern California.

Today in section, we will use slightly more modern data (spectra taken by Rob Kennicutt, Jr. at the University of Arizona, and compiled by Luis Mendoza and Bruce Margon at the University of Washington, in addition to images from the Palomar Observatory Sky Survey) to try to see if his conclusions still hold up. Each student is responsible for one galaxy, but please do collaborate as a group in performing the measurements.

Once you have the information necessary, plot your galaxy on the Hubble diagram and write down its information in the table. We will then do 8-11 as a class at the end of the period. (Please be sure you're finished plotting by 10 minutes before the hour to give us enough time to do so.)

1-5. See reverse for instructions.

6. Plot your galaxy's *Cepheid distance* and *recession velocity* on the Hubble diagram drawn on the board. Indicate with a caption whether the galaxy looked close (C), medium distance (M), or far away (F).

7. Fill in the table with the galaxy's *Hubble type* and whether it is dominated by *young* or *old* stars.

8. Is there a correlation between the type of a galaxy and the kinds of stars it is made of? What kinds of galaxies have lots of young stars, and what kinds of galaxies have mostly old stars?

9. Of the galaxies we looked at, were *any* of them moving *towards* us? (An object moving towards us would have $\lambda < \lambda_0$ and therefore a "negative" Doppler shift.) What does that suggest about the universe?

10. Is there a correlation between the speed of recession and the distance of a galaxy? What does this imply? If there is a correlation, why is it not "perfect"?

11. Fit a line to the points on the class Hubble diagram. Choose an arbitrary point near the end of this line: we want to measure its slope.

Measure the "rise" from the origin to this point: _____ km/s

Measure the "run" from the origin to this point: _____ Mpc

Divide them (rise over the run) to get the slope: _____ km/s / Mpc

What is this value known as?