

HUBBLE CONSTANT EXPERIMENT

Monday, May 6, 2024

1 Introduction

In this “lab” you will measure how fast the Universe is expanding, how old it is, and the distance to some nearby galaxies.

To determine the Hubble constant, one needs to know two things about a set of distant objects: (i) their distances from us, and (ii) the velocities with which they are moving away from us.

The velocity of a nearby galaxy is usually relatively easy to measure by obtaining its spectra and measuring the redshift. Finding its distance is what has caused so many problems for the last 70+ years.

To measure the distance to an object we need to identify a characteristic of the object (such as size or brightness) whose absolute value is known to us. We will assume that all spiral galaxies are the same size (this is not strictly true, but close enough for our purpose here). Therefore, if a galaxy looks small then it must be far away. By measuring a galaxy’s apparent size, you will be able to estimate its distance from us.

2 Procedure

You are given pictures and spectra from 9 galaxies in this project. You need to make some measurements from these images and enter it into the blank table given below. You will then use data from this table to draw a graph and measure the slope of the best fitting line.

2.1 Step 1: Galaxy size and distance

In Fig. 1 you are given 9 images of galaxies. For each galaxy, measure the length along its longest direction in mm out to the farthest point that you can see any light from the galaxy, and then enter the numbers into column 2 of the table; see Fig. 2.

Next, you need to convert the measurements you made, which should be in mm, into an angle (this is the angle that the galaxy subtends on the sky). To do this conversion, you need to know that the angular size of Galaxy 2 is 15 arcseconds. In other words,

$$\text{angular size of galaxy in arcsec} = \frac{15 \times \text{size in mm of the galaxy}}{\text{size in mm of Galaxy 2}} \quad (1)$$

Use this number to convert all your measurements into arcseconds and enter them into the table (column 3).

The next step is to convert the angular sizes of the galaxies into distances. You can do this by assuming that all of the galaxies are the same size and have diameters of 0.01 Megaparsecs. You can

then convert the angular sizes to distances, see Fig. 3. To do this use the following formula:

$$\text{Distance to galaxy} = \frac{0.01 \times 206,265 \text{ (in Mpc)}}{\text{Angular size in arcsec (column 3 in your table)}}, \quad (2)$$

where 206,265 is the conversion factor from arcsec to radians.

Check: for Galaxy 2, you should get a distance of 137 Mpc. Now enter your answers for distance into the table (column 4).

2.2 Step 2: Galaxy recessional velocity

Now, you need to measure the velocities or redshifts of the galaxies. By measuring the wavelength of known spectral features (in your case, bright emission lines) and comparing to the rest wavelength (given by a reference example spectrum) you can measure the redshift between the observed spectra and the calibration. All the lines in one galaxy's spectrum will be shifted by the same amount so you can use any line you choose from the spectrum.

Look at the calibration spectrum given in Fig. 4. Notice that there are many emission lines, from various elements. You will only need to focus on the Oxygen II line at 372.7 nm, the H β line at 486.1 nm, and the Oxygen III lines at 500.7 nm.

These numbers are the wavelengths of the emission lines when the object is at rest. As you can see by looking at the galaxy spectra, the wavelengths of these lines have changed (due to the redshift). Note that relative height of the lines will change from spectrum to spectrum; this is not important, only the positions of the lines matters. To be sure you have correctly cross-identified the lines try to convince yourself that you have matched the pattern of lines properly (even if not all the lines are present).

The redshift is calculated using the following relationship:

$$\text{Redshift (usually denoted as } z) = \frac{\text{Observed wavelength} - \text{Rest wavelength}}{\text{Rest wavelength}}. \quad (3)$$

The velocity of the galaxy is the redshift, z , times the speed of light ($c = 300,000$ km/s). For each galaxy, choose a prominent line and calculate: the wavelength shift, the redshift, and the velocity. Enter these data into column 8 in the table.

2.3 Step 3: Putting it all together

On the sheet of graph paper (see Fig. 5), make a plot of recession velocity (along the y -axis) versus distance (along the x -axis). The horizontal axis should have units of Mpc, and the vertical axis should have units of km/s. After you have plotted the data, use a ruler to draw the straight line that best goes through the points (do not connect the points). Make sure the line also runs through the origin (velocity = 0, distance = 0).

The Hubble constant is given by the slope of the line you just drew. Calculate the slope using a point on the line and dividing the y -value of that point by the x -value of that point. What do you get for the Hubble constant (in units of km/s/Mpc)?

2.4 Step 4: The age and size of the Universe

By converting the km into Mpc and inverting the Hubble constant we arrive at a quantity in units of seconds of time. Through more detail than we want to cover here, it turns out that this is a reasonable estimate of the age of the Universe. Calculate the age of the Universe, using the conversion that

$$1 \text{ Mpc} = 3.09 \times 10^{19} \text{ km}, \quad (4)$$

and present the result in years.

To get an estimate of the size of the universe simply put Hubble's constant (usually denoted by H_0) in the relationship:

$$\text{Size} = \frac{\text{Speed of light}}{\text{Hubble's constant}}. \quad (5)$$

Give your answer in Mpc.

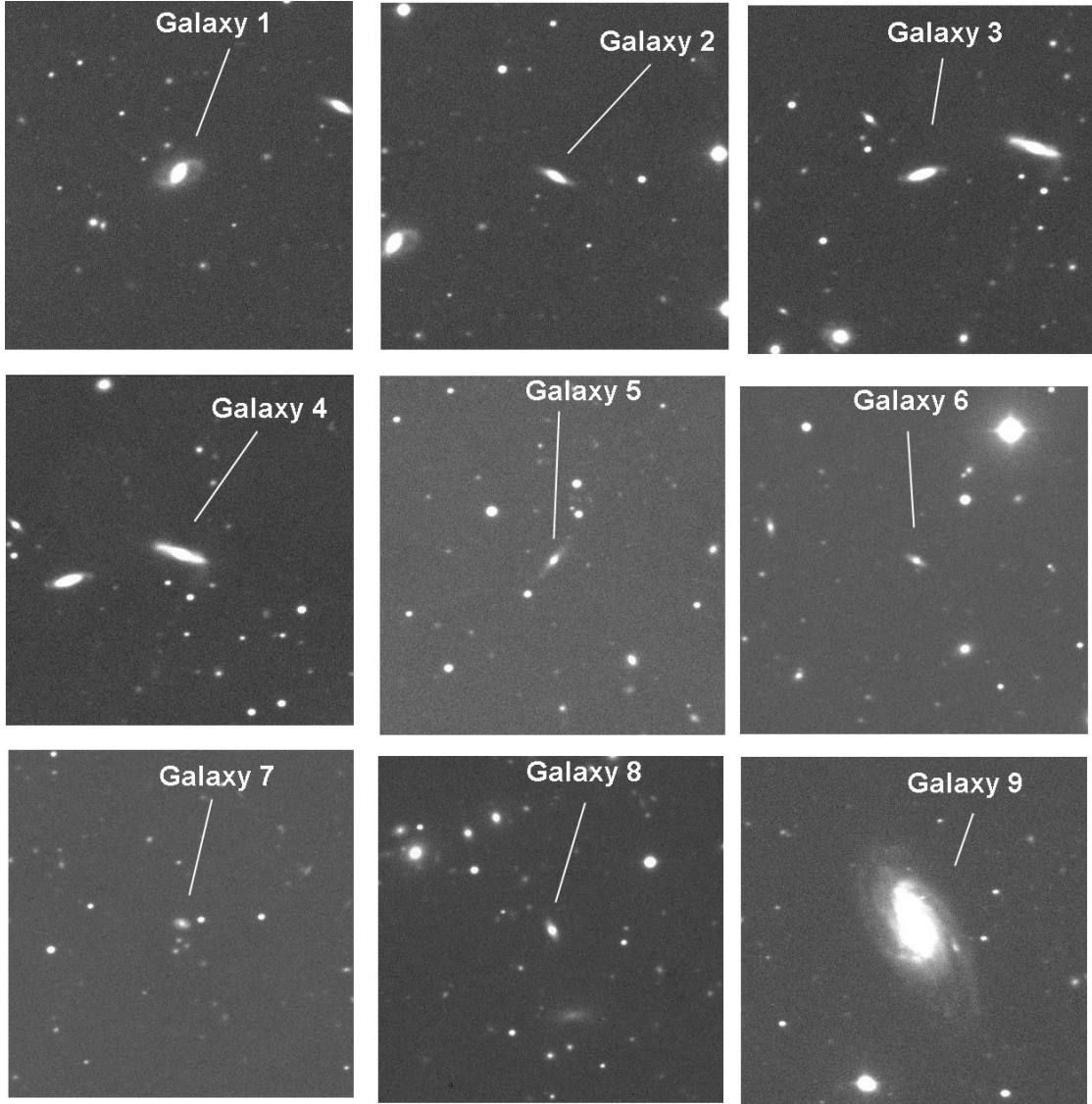


Figure 1: Images of nine galaxies.

GALAXY NUMBER	SIZE IN MM	ANGULAR SIZE IN ARCSEC	DISTANCE IN Mpc (x-axis of graph)	REST WAVE-LENGTH (nm)	OBSERVED WAVE-LENGTH (nm)	RED SHIFT Z	VELOCITY Km/s (y-axis of graph)
Galaxy 1							
Galaxy 2	10	15	137	372.7	388.0	0.04	12,000
Galaxy 3							
Galaxy 4							
Galaxy 5							
Galaxy 6							
Galaxy 7							
Galaxy 8							
Galaxy 9							

Figure 2: Table.

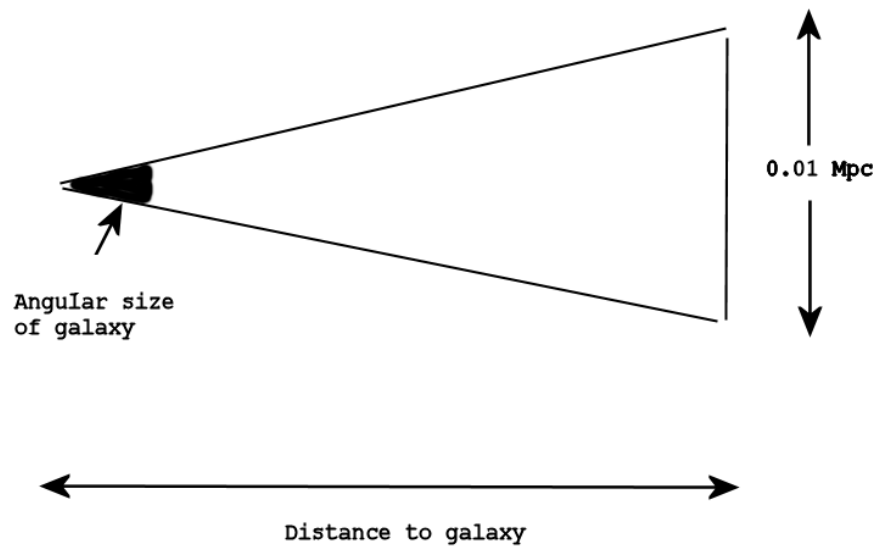


Figure 3: Conversion of angular size to distances.

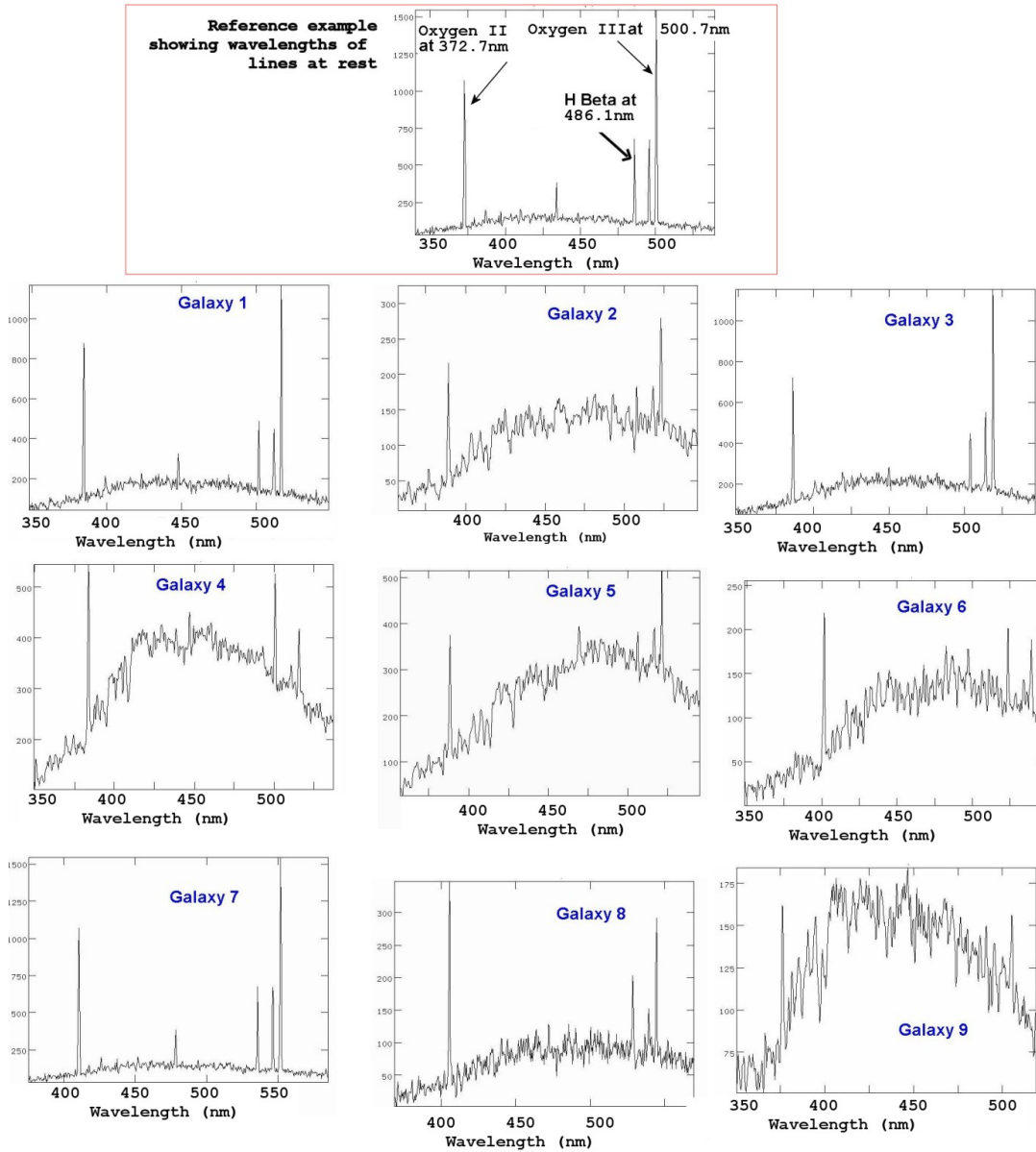


Figure 4: Spectra of nine galaxies.

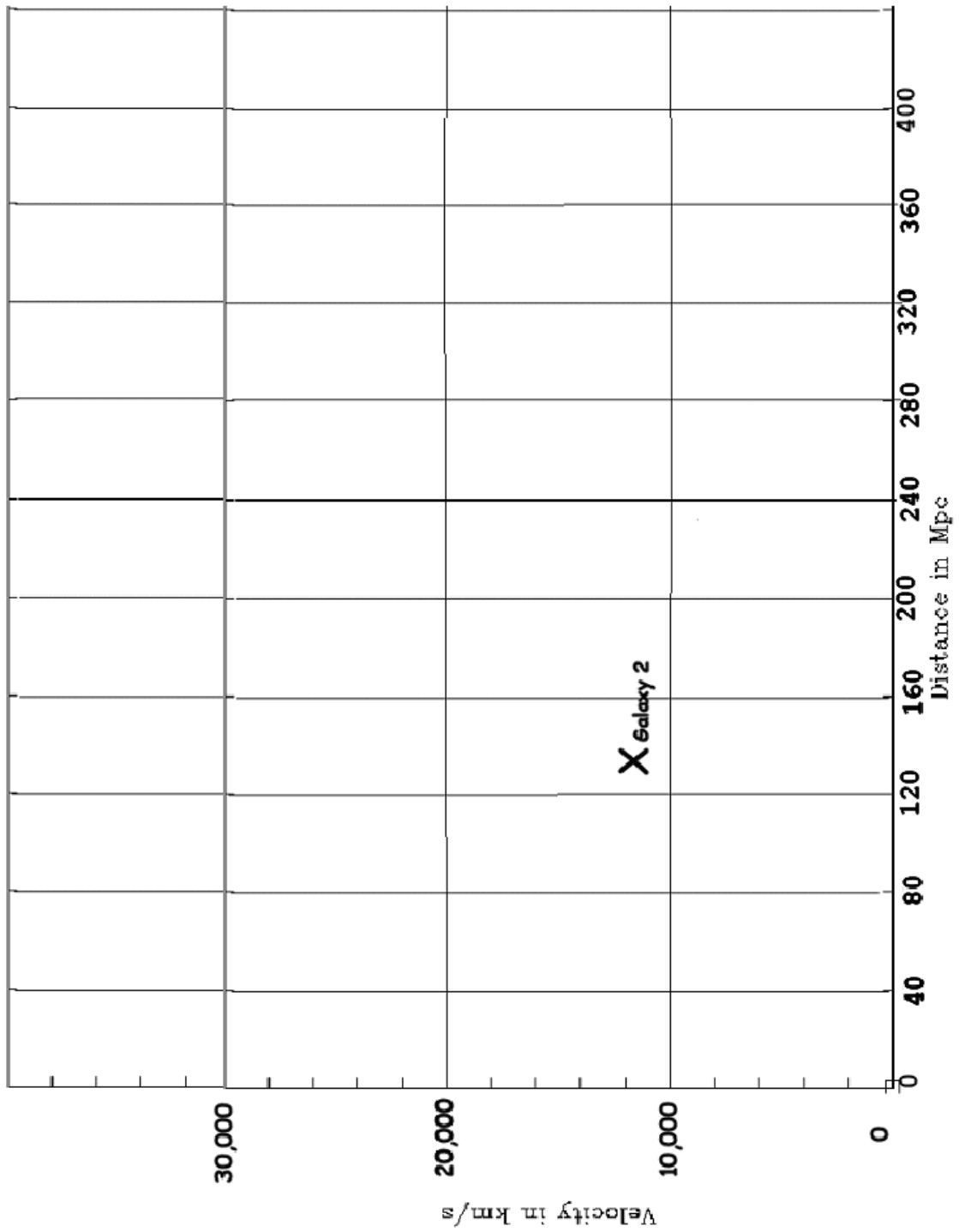


Figure 5: Graph to determine the Hubble constant.