Exercise 1. In scientific notation, the distance to the farthest object we can see is 1.42×10^{23} km away. Students should realize that it's much easier to write 10^{23} than to write twenty-three zeroes.

Exercise 2.

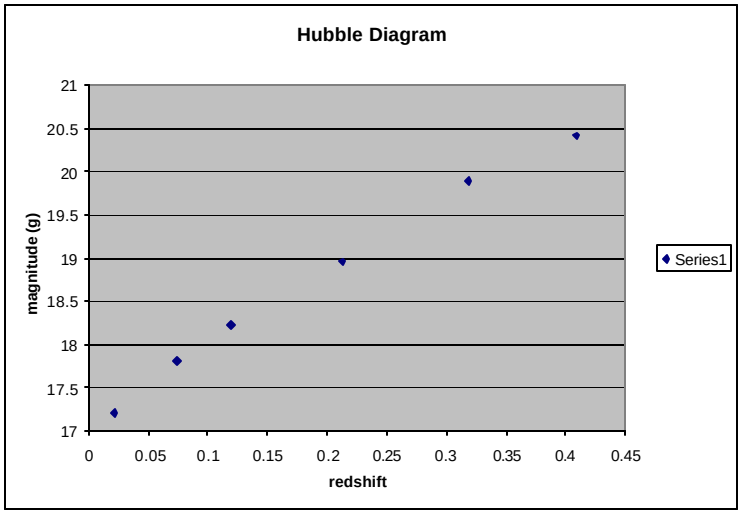
Galaxy ID	Magnitude
2255030708076599	17.21
2255030176055416	17.81
850263135551689	18.22
1970863320596625	18.96
1970729935896898	19.89
1970862004699322	20.42

Question 1. As objects get farther away, their light appears dimmer, just as a candle across the room looks dimmer than a candle held at arm's length. If we assume that all galaxies output the same amount of light, then any difference in the galaxy's apparent brightness will be due to its distance from Earth. Magnitude measures the apparent brightness of a galaxy. Therefore, different magnitudes correspond to different distances from Earth.

Exercise 3.

Galaxy ID	Redshift
2255030708076599	0.021
2255030176055416	0.073
850263135551689	0.119
1970863320596625	0.212
1970729935896898	0.318
1970862004699322	0.409

Exercise 4.

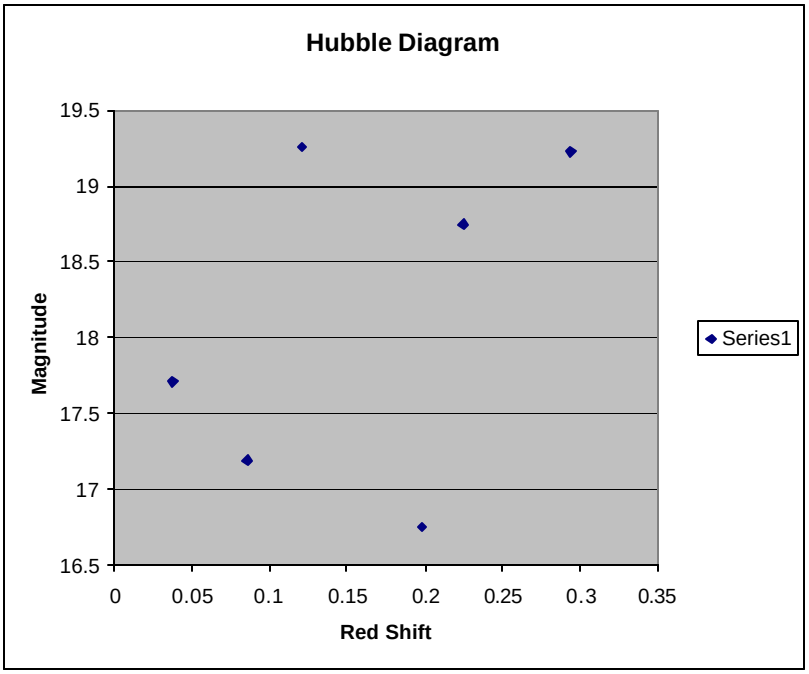


Exercise 5. The fit is 99.3%, meaning that a straight line is a good fit to the data.

Exercise 6.

Galaxy ID	Magnitude	Redshift
2255047637270742	17.71	0.038
2255029921448000	17.19	0.085
850263135551689	19.26	0.121
1790730196140213	16.75	0.198
1970729645572368	18.75	0.225
1970729134850571	19.23	0.294

Exercise 7.



The fit of the data is 17.02%, which means that a straight line does not fit these data.

Question 2: If the distance to a galaxy found from magnitudes do not agree with its distance found with apparent sizes, then the galaxy is unusual in some way. Either it is brighter/fainter than a typical galaxy of its size, or it is larger/smaller than a typical galaxy of its brightness.

Question 3. There are many possible answers to this question. Large cities have more buildings in the same area than small towns do. Usually, they also have taller buildings than small towns. They may have certain types of buildings, such as hospitals or airports, that small towns lack. They may see an object such as a car, for which they know the size, and be able to use it to judge distances (this is similar to the concept of a "standard candle").

Similarly, large clusters have many more galaxies in the same area than small groups do. However, there is no correlation between galaxy size and cluster size – larger clusters do

not necessarily have larger galaxies. However, large clusters are more likely to have rare galaxies, like the "rare buildings" – hospitals and airports – in large cities. This is because clusters have larger numbers of galaxies, and by looking at larger numbers of galaxies, you are more likely to find a rare galaxy.

Exercise 8. Most galaxies within the same cluster have similar colors, sizes, and brightnesses. Clusters can have different types of galaxies, although more distant clusters tend to have more elliptical galaxies.

Question 4. If Hubble and Humanson saw that one approach gave them a smaller data scatter – that is, the redshift-distance data they found came closer to graphing a straight line – they would know that that particular approach was a better way to measure relative distance.

Exercise 9. The largest, whitest galaxies belong to the nearest cluster. The smaller, more bluish galaxies belong to the medium cluster. The small, faint, reddish galaxies belong to the most distant cluster.

Exercise 10. Answers will vary depending on which galaxies students selected and what measure of relative distance they chose. Because they must choose need galaxies with redshifts available, they should have selected at least the ten galaxies in the table below.

The table lists magnitudes in the green wavelength and the relative distances calculated from those magnitudes. Using green-wavelength magnitudes of these ten galaxies is a simple way to find relative distance, but it produces large data scatter. If students use a different method, they will probably find better estimates of relative distance.

Galaxy ID	Right Ascension	Declination	Green Magnitude	Relative Distance
2255031254843512	178.152981	0.915194	16.36	1
2255031254843527	178.181586	0.974817	17.42	1.63
2255048446836831	178.159608	1.06589	17.92	2.04
2255048446902406	178.284604	1.122476	18.09	2.20
2255031254843544	178.223124	0.894348	18.34	2.48
2255031254974636	178.379048	0.972349	20.04	5.40
2255031254909042	178.260686	1.040557	20..08	5.52
2255031254909306	178.298469	1.013883	20.43	6.48
2255031254909183	178.270379	1.0284	20.75	7.50
2255031254909137	178.250333	1.019779	20.79	7.64

Exercise 11. Distances should be roughly similar to the distances found in exercise 10.

Exercise 12: Students should find the entries in the table from the spectrum. The correct spectral lines are marked H_α, H_β, H_γ, and H_δ.

Exercise 13. Students should find the following redshifts:

Spectrum Number	Redshift
447	0.138
453	0.025
455	0.047
522	0.137
523	0.399
525	0.398
526	0.228
527	0.49
530	0.403
580	0.303

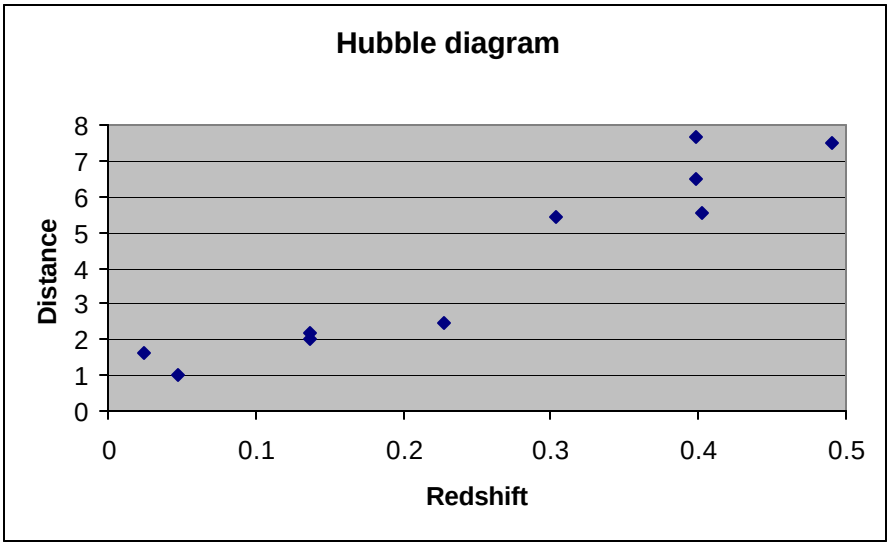
Exercise 14. Results from Exercise 13 should be similar to the values from Get Spectra.

Exercise 15. The average redshift for the galaxies in Exercise 13 is 0.257. The average redshift of all the galaxies in the SDSS database is about 0.1. Galaxies range from a redshift of about 0.01 to about 0.5. Quasars have an average redshift of about 1.5. Their redshifts range from about 0.1 to about 6.

Question 5. The Hubble diagram shows that galaxies are moving away from us, and that the farther a galaxy is, the faster it moves. Students should realize that to get from this observation to the expanding universe picture, they need to assume that the universe is fairly uniform on a large scale – that is, galaxies can be found in roughly equal amounts in all directions. They also need to assume that galaxies are redshifted, and not blueshifted, in all directions of the sky. If Earth were moving through the universe, then behind us, we would see redshifts, and ahead of us, we would see blueshifts. If the universe as a whole were expanding, we would see redshifts wherever we looked.

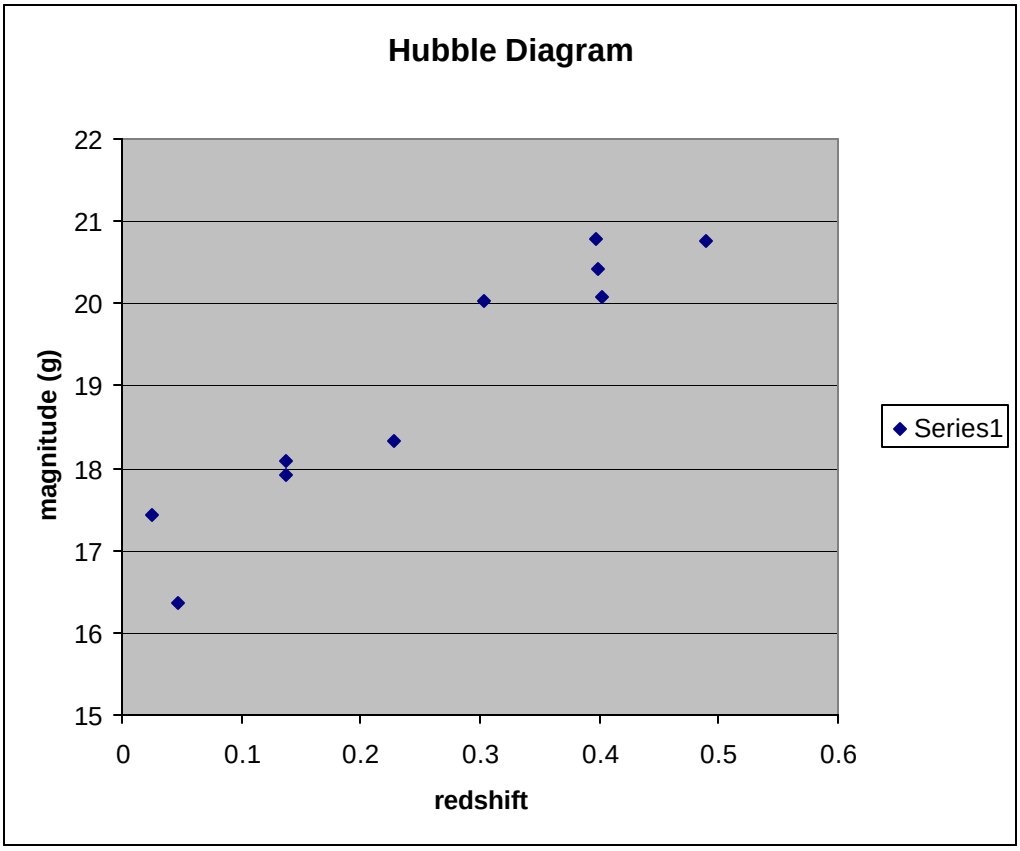
Students could test both these assumptions with Skyserver. They could make a Hubble diagram in many different parts of the sky to verify that redshifts appear everywhere. They could also count galaxies in different parts of the sky to verify that galaxies are roughly uniformly distributed.

Exercise 16. Using the values of relative distance obtained from the green wavelength magnitudes gives the following Hubble diagram:



A trendline through this data has a fit of 90.8%, meaning a straight line is a good fit to the data.

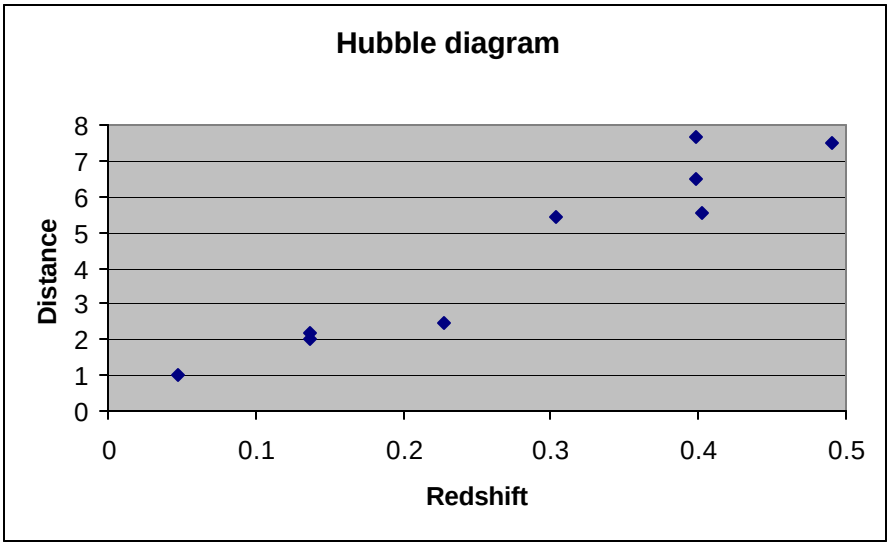
If the students used magnitudes instead, they may see the following diagram (fit 91.8%).

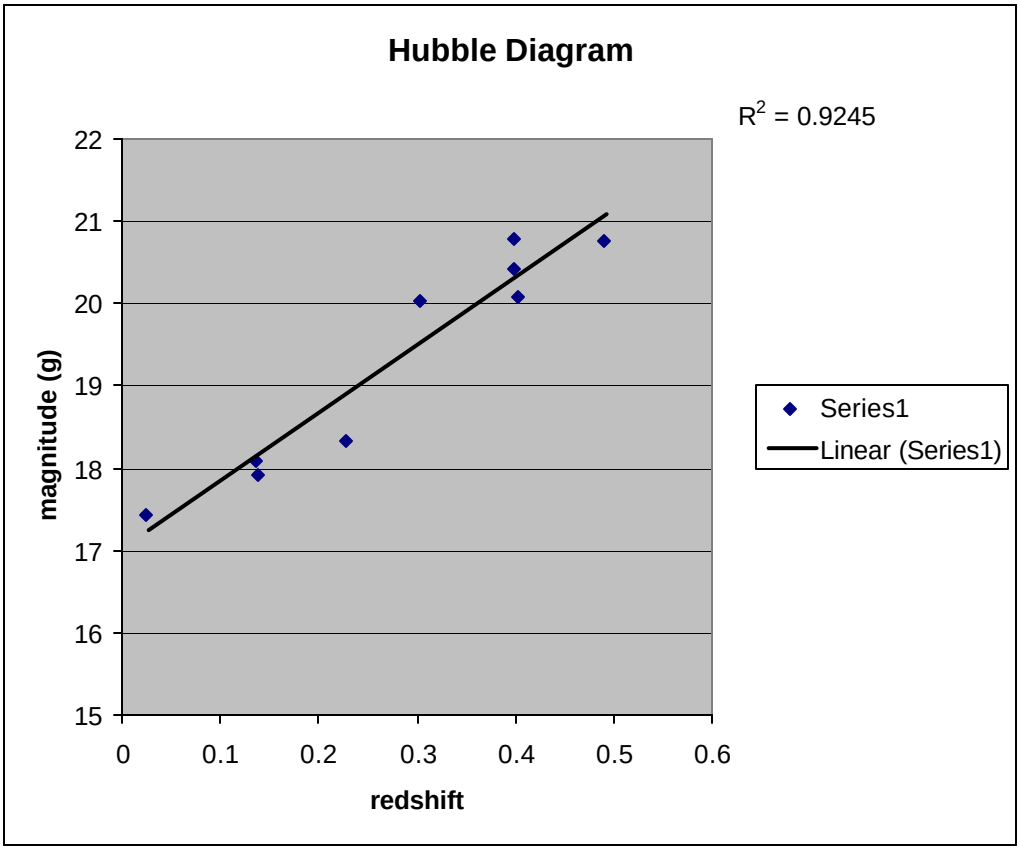


If students used a different method to find the relative distance, their diagrams will look slightly different.

Exercise 17. Galaxy ID 2255031254843527 is unusually dim for a galaxy at its distance. Because it is dim, using its relative magnitude to measure distance makes the galaxy appear farther from Earth than it actually is.

Here is the Hubble diagram with galaxy ID 2255031254843527 removed:



The fit has improved slightly, to 91.8%.

Or, if they used magnitudes, they would get: