Getting the Distances to Astronomical Objects

One of the main themes of this entire course has been an on-going discussion about how astronomers find the distances to the many different kinds of astronomical objects. Good quality distance estimates can significantly improve our knowledge and theories about the formation and evolution processes of the universe and astronomers are always looking to refine their techniques.

Recall what you have learned about how the different distance methods work. You should be able to think of five different methods and how they are applied. List them below. Add a comment about the approximate limiting distance of each and to what objects they are applied.

1.

2.

3.

4.

5.
flat universe:

Figure 19.19 shows these three options nicely.

Einstein’s cosmological constant:

Check out Figure 19.23.

the flatness problem:

the smoothness problem:

inflation:
The Cosmic Microwave Background Radiation

Section 19.4 is extremely important. The Big Bang theory predicts that the universe should still contain radiation left over from its formation and over the years astronomers have used a variety of telescopes to detect the predicted radiation at the expected wavelength and temperature; this correlation between theory and observation is one of the key foundations of cosmology. This represents major confirmation of the Big Bang. Make sure you understand the basics of this confirmation and how Wien’s law figures into it.

What is the temperature of the universe and how does an astronomer estimate it?

The Future of the Universe

critical mass density of the universe:

A major component of any discussion of the future destiny of the universe is an estimate of the amount of material (mass) the universe contains within its volume—this mass per unit volume is called the density of the universe. A comparison between this estimated density and the critical density is important for any estimate of whether the universe will be open, closed or flat in the distant future.

open universe:

closed universe:
Why was Hubble's original value so different from this?

What would the value of the Hubble constant be if you quoted the number in kilometers/second per Megaparsec instead? Hint: you need to recall the number of light-years in a parsec.

The Hubble Law and the Big Bang

Section 19.3 is a very important one. It describes how we can, in effect, use the Hubble Law—the expansion of space—to “run time backwards” to when the universe began. If we see an expanding universe today and assume that the expansion has been at least roughly constant, we can—in our mind’s eye—imagine a time in the past when the galaxies we see as being so far apart today were much closer together. If we “go” back in time long enough, there must have been a point when all the matter and energy we see in the universe today was compressed into one very very small space.

Astronomers consider the birth of the universe to have occurred at the moment this tightly compressed region began to expand and have called it the Big Bang. As we will discuss in class, astronomers can “run” the expansion of space backwards; because we know the rate of expansion today (from the Hubble constant), we can estimate how long ago the Big Bang occurred. This estimate of the age of the universe is called the Hubble time.

If the Hubble constant $H_o = 65 \text{ km/s/Mpc}$, how long ago did the Big Bang occur?
result of the motion of the galaxy. The shift is towards the “red” end of the spectrum, that is, the absorption lines appear at longer wavelengths than they would if the galaxy was not moving. The red shift indicates that the galaxy is moving away from us (receding). The higher the recession velocity, the greater the shift. Recession velocity is measured in kilometers per second. Remember that velocity = speed + direction.

- look at the Hubble Law graph plotted for many other galaxies (Figure 19.6). Look on the y-axis (the vertical scale) of the graph and find the speed of Galaxy A.
- draw a horizontal line connecting this speed on the scale to the Hubble Law line on the graph.
- connect this point on the Hubble Law line vertically downward to the x-axis (the horizontal scale) of the graph. Your vertical line will hit the x-axis at a certain distance measured in Megaparsecs.
- this is your estimate of the distance to Galaxy A.

What kinds of factors have affected your distance estimate? You should be able to think of three or four.

Estimating the Expansion Rate of the Universe

The Hubble Law has also given astronomers a means to estimate the rate of expansion of the universe. Astronomers have speculated for decades that the universe—space itself—is getting larger and taking the galaxies with it. Think of galaxies as coins taped to the surface of a balloon. The balloon gets bigger as more air is blown into it. The coins themselves do not change in size but they get further apart from each other as the balloon gets larger. No matter which coin you consider, all others seem to be moving away from that coin as the balloon expands. In the same way, an observer in every galaxy would see that all other galaxies are moving away and the more distant a galaxy, the faster it moves. Check out Figure 19.4 for another neat analogy using paper clips and ants.

As astronomers have built up increasingly precise information about recession velocities and distances of galaxies over the years, the Hubble Law graph has become a good indicator for the current expansion rate of the universe. The slope of the graph is given in Figure 19.6 and is called the Hubble constant, $H_0$.

What is the current value of the Hubble constant, $H_0$? Make sure you include the units with the number.
The Expanding Universe

The Cosmological Principle

In order to make any kind of sense about the structure and evolution of the universe and keep their theories “real”, astronomers have had to lay down some ground rules for the assumptions they make. Science fiction can’t intrude here—for example, astronomer Joe Blow can not just decide that gravity doesn’t apply to the part of the universe he is interested in studying. These ground rules have been accepted by astronomers all over the world. Collectively, the rules are called the Cosmological Principle.

The universe is homogenous:

The universe is isotropic:

The physics we see applies everywhere:

Using the Hubble Law

The Hubble Law is the relationship between the recession velocity and the distance of a galaxy. The law can be used in several different ways to obtain information about individual galaxies and about the universe in general. Figure 19.3 is very important, as are 19.4 and 19.6.

Estimating the Distance to a Galaxy

- photograph the spectrum of the galaxy (let’s call it Galaxy A).
- take note of the “shift” of the absorption lines in the galaxy’s spectrum; the lines do not appear in their correct places along the wavelength scale. Remember that this Doppler shift is a