6.0: Measuring Cosmic Distances Introduction

Video Transcript

During many celebrations and holidays, such as New Year's Eve around the world or Fourth of July in the United States, fireworks are an integral part of the festivities.

But if you cannot see the surrounding landscape, the buildings and houses, and if the night was completely dark, no streetlights or house lights, would you be able to tell how far away they were? Would you need to touch them to tell how far away they were?

Looking at the night sky you see thousands of points of light. If you observe them for long enough, you'll notice a few move relative to the others. These are the planets of our solar system, yet they still appear to be only points of light. How can their distances be determined? And what about the distances to stars in our galaxy, or to galaxies outside our own? How can we measure their distances?

In this chapter, we will discover the tools, including the mathematics and measurement techniques, used by astronomers to determine cosmic distances.

The Universe is incomprehensibly vast by earthly standards, and we cannot go to other stars or galaxies with a tape measure or pace out the distances to them. Despite these limitations, one of the most important methods we have to understand what objects are and how they work is understanding their distances. Without a knowledge of cosmic distance, we cannot understand how much energy a faraway object is emitting. In physics (including astrophysics), knowing the energy produced by a system is fundamental to developing models that describe the nature of that system. In this chapter, you will learn how scientists measure the distances to and between objects in the Universe.

Astronomers use three basic types of techniques to measure cosmic distances:

- *Direct Geometric Methods:* These methods use simple geometry, that of similar triangles, to measure the distance to an object. Geometrically determined distances are the most trustworthy because they do not rely on any properties of the objects themselves. As a result, no theoretical uncertainties about the objects can interfere with geometric distances. Unfortunately, geometric methods become difficult to use as objects become more distant, as we shall see.
- *Standard Ruler:* We can use this if we know how big an object is inherently. This method relies on the fact that the farther away an object is, the smaller it looks, in a mathematically predictable way. By measuring an object's apparent size and comparing to its known intrinsic size, we can deduce its distance. This method is not strictly geometrical in nature because it requires us to know something about the object being measured - its size - that we might have know with high precision.
- *Standard Candle:* We can use this method if we know how bright an object is inherently. This method relies on the fact that the farther away an object is, the dimmer it looks, in a mathematically predictable way. By measuring an object's apparent

brightness and comparing to its known intrinsic brightness, we can deduce its distance.

Different techniques work well for different distances. For instance, the geometrical method called parallax can only be used for very nearby stars. On the other hand, Type Ia supernovae, which can be used as standard candles, are so rare that the likelihood of seeing one nearby is quite small, but we see many of them at large distances. For in-between distances, other methods are available. We must use a method (or methods) appropriate to the distance of interest. Aside from the geometrical methods, the techniques used for objects farther away typically rest on calibrations from studies of similar objects that are relatively close and that have known distances from some other method. In this way, we build up a hierarchy of techniques to measure distances. This hierarchy is often called the cosmic distance ladder. To be confident that the ladder is giving us accurate results, we must use multiple independent techniques when possible. If they all give a consistent distance, we can be fairly certain that our measurements are in the right ballpark. We will discuss several of the important distance determination methods in turn.
