6.1: What are Gravitational Waves?

In 2016, scientists published the first paper announcing the detection of gravitational waves. This was a very big deal, not only because it verified a very old prediction of General Relativity, but also because it was an experimental feat.

To understand what a gravitational wave is, let's first try to understand how charged particles interact through electromagnetism. We know that oppositely charged particles attract one another with a force that depends on the distance between them. Suppose we have a positively charged particle named Paula and a negatively charged particle named Nigel. What happens to the strength of the attractive force between Paula and Nigel if you suddenly move Paula? Does the force exerted on Nigel change immediately, or is there a delay? We now know that the answer is that there is a delay. When you suddenly move Paula, it creates an electromagnetic wave that propagates outward, and only when the wave reaches Nigel does Nigel register that anything changed. This is the principle behind all wireless communication; you wiggle the electrons in an antenna, which creates an electromagnetic wave that propagates outward. When that electromagnetic wave strikes another antenna, it causes the electrons in that antenna to wiggle as well (albeit a much weaker wiggle because the intensity of the wave decreases with distance).

Now think of the earth revolving around the sun. If you suddenly moved the sun, would the earth feel the effect immediately, or would there be a delay? If we were studying Newtonian mechanics, we would say that it happens immediately. But General Relativity predicts that there would be a delay because the movement of the sun creates a wave in spacetime that propagates outward and eventually strikes the earth. Much like with an antenna, though, the intensity of the wave decreases with distance. And since space is largely empty with vast distances between objects, the effects of these gravitational waves are very small.

The other obstacle in detecting gravitational waves is that there are not that many good sources. In order to have any hope of detecting a gravitational wave, you need a very heavy object with a large acceleration. Fortunately, black holes are very heavy, and sometimes two black holes get near enough to each other that they start to orbit one another. The vast majority of detected gravitational waves have come from such sources, and they will be the primary focus of this chapter.