29.7 THE ANTHROPIC PRINCIPLE

Learning Objectives

By the end of this section, you will be able to:

- Name some properties of the universe that, if different, would have precluded the development of humans

Despite our uncertainties, we must admit that the picture we have developed about the evolution of our universe is a remarkable one. With new telescopes, we have begun to collect enough observational evidence that we can describe how the universe evolved from a mere fraction of a second after the expansion began. Although this is an impressive achievement, there are still some characteristics of the universe that we cannot explain. And yet, it turns out that if these characteristics were any different, we would not be here to ask about them. Let's look at some of these "lucky accidents," beginning with the observations of the cosmic microwave background (CMB).

Lucky Accidents

As we described in this chapter, the CMB is radiation that was emitted when the universe was a few hundred thousand years old. Observations show that the temperature of the radiation varies from one region to another, typically by about 10 millionths of a degree, and these temperature differences signal small differences in density. But suppose the tiny, early fluctuations in density had been much smaller. Then calculations show that the pull of gravity near them would have been so small that no galaxies would ever have formed.

What if the fluctuations in density had been much larger? Then it is possible that very dense regions would have condensed, and these would simply have collapsed directly to black holes without ever forming galaxies and stars. Even if galaxies had been able to form in such a universe, space would have been filled with intense X-rays and gamma rays, and it would have been difficult for life forms to develop and survive. The density of stars within galaxies would be so high that interactions and collisions among them would be frequent. In such a universe, any planetary systems could rarely survive long enough for life to develop.

So for us to be here, the density fluctuations need to be "just right"—not too big and not too small.

Another lucky accident is that the universe is finely balanced between expansion and contraction. It is expanding, but very slowly. If the expansion had been at a much higher rate, all of the matter would have thinned out before galaxies could form. If everything were expanding at a much slower rate, then gravity would have "won." The expansion would have reversed and all of the matter would have recollapsed, probably into a black hole—again, no stars, no planets, no life.

The development of life on Earth depends on still-luckier coincidences. Had matter and antimatter been present initially in exactly equal proportions, then all matter would have been annihilated and turned into pure energy. We owe our existence to the fact that there was slightly more matter than antimatter. (After most of the matter made contact with an equal amount of antimatter, turning into energy, a small amount of additional matter must have been present. We are all descendants of that bit of "unbalanced" matter.)

If nuclear fusion reactions occurred at a somewhat faster rate than they actually do, then at the time of the initial fireball, all of the matter would have been converted from hydrogen into helium into carbon and all the way into iron (the most stable nucleus). That would mean that no stars would have formed, since the existence of stars depends on there being light elements that can undergo fusion in the main-sequence stage and make the stars shine. In addition, the structure of atomic nuclei had to be just right to make it possible for three helium atoms to come together easily to fuse carbon, which is the basis of life. If the *triple-alpha process* we discussed in the chapter on **Stars from Adolescence to Old Age** were too unlikely, not enough carbon would have formed to lead to biology as we know it. At the same time, it had to be hard enough to fuse carbon into oxygen that a large amount of carbon survived for billions of years.

There are additional factors that have contributed to life like us being possible. Neutrinos have to interact with matter at just the right, albeit infrequent, rate. Supernova explosions occur when neutrinos escape from the cores of collapsing stars, deposit some of their energy in the surrounding stellar envelope, and cause it to blow out and away into space. The heavy elements that are ejected in such explosions are essential ingredients of life here on Earth. If neutrinos did not interact with matter at all, they would escape from the cores of collapsing stars without causing the explosion. If neutrinos interacted strongly with matter, they would remain trapped in the stellar core. In either case, the heavy elements would remain locked up inside the collapsing star.

If gravity were a much stronger force than it is, stars could form with much smaller masses, and their lifetimes would be measured in years rather than billions of years. Chemical processes, on the other hand, would not be sped up if gravity were a stronger force, and so there would be no time for life to develop while stars were so short-lived. Even if life did develop in a stronger-gravity universe, life forms would have to be tiny or they could not stand up or move around.

What Had to Be, Had to Be

In summary, we see that a specific set of rules and conditions in the universe has allowed complexity and life on Earth to develop. As yet, we have no theory to explain why this “right” set of conditions occurred. For this reason, many scientists are beginning to accept an idea we call the **anthropic principle**—namely, that the physical laws we observe must be what they are precisely because these are the only laws that allow for the existence of humans.

Some scientists speculate that our universe is but one of countless universes, each with a different set of physical laws—an idea that is sometimes referred to as the **multiverse**. Some of those universes might be stillborn, collapsing before any structure forms. Others may expand so quickly that they remain essentially featureless with no stars and galaxies. In other words, there may be a much larger multiverse that contains our own universe and many others. This multiverse (existing perhaps in more dimensions that we can become aware of) is infinite and eternal; it generates many, many inflating regions, each of which evolves into a separate universe, which may be completely unlike any of the other separate universes. Our universe is then the way it is because it is the only way it could be and have humans like ourselves in it to discover its properties and ask such questions.

LINK TO LEARNING

View the **2011 introductory talk (https://openstax.org/l/30mulcosinfla)** on the Multiverse and Cosmic Inflation by Dr. Anthony Aguirre of the University of California, part of the Silicon Valley Astronomy Lecture Series.

It is difficult to know how to test these ideas since we can never make contact with any other universe. For most scientists, our discussion in this section borders on the philosophical and metaphysical. Perhaps in the future our understanding of physics will develop to the point that we can know why the gravitational constant is as strong as it is, why the universe is expanding at exactly the rate it is, and why all of the other “lucky accidents” happened—why they were inevitable and could be no other way. Then this anthropic idea would no longer be necessary. No one knows, however, whether we will ever have an explanation for why this universe works the way it does.

We have come a long way in our voyage through the universe. We have learned a remarkable amount about *how* and *when* the cosmos came to be, but the question of *why* the universe is the way it is remains as elusive as ever.