

explore much more than just the objects in our universe and the latest discoveries about them. We will pay equal attention to the *process* by which we have come to understand the realms beyond Earth and the tools we use to increase that understanding.

We gather information about the cosmos from the messages the universe sends our way. Because the stars are the fundamental building blocks of the universe, decoding the message of starlight has been a central challenge and triumph of modern astronomy. By the time you have finished reading this text, you will know a bit about how to read that message and how to understand what it is telling us.

## 1.1 The Nature of Astronomy

*Astronomy* is defined as the study of the objects that lie beyond our planet Earth and the processes by which these objects interact with one another. We will see, though, that it is much more. It is also humanity's attempt to organize what we learn into a clear history of the universe, from the instant of its birth in the Big Bang to the present moment. Throughout this book, we emphasize that science is a *progress report*—one that changes constantly as new techniques and instruments allow us to probe the universe more deeply.

In considering the history of the universe, we will see again and again that the cosmos *evolves*; it changes in profound ways over long periods of time. For example, the universe made the carbon, the calcium, and the oxygen necessary to construct something as interesting and complicated as you. Today, many billions of years later, the universe has evolved into a more hospitable place for life. Tracing the evolutionary processes that continue to shape the universe is one of the most important (and satisfying) parts of modern astronomy.

## 1.2 The Nature of Science

The ultimate judge in science is always what nature itself reveals based on observations, experiments, models, and testing. Science is not merely a body of knowledge, but a *method* by which we attempt to understand nature and how it behaves. This method begins with many observations over a period of time. From the trends found through observations, scientists can *model* the particular phenomena we want to understand. Such models are always approximations of nature, subject to further testing.

As a concrete astronomical example, ancient astronomers constructed a model (partly from observations and partly from philosophical beliefs) that Earth was the center of the universe and everything moved around it in circular orbits. At first, our available observations of the Sun, Moon, and planets did fit this model; however, after further observations, the model had to be updated by adding circle after circle to represent the movements of the planets around Earth at the center. As the centuries passed and improved instruments were developed for keeping track of objects in the sky, the old model (even with a huge number of circles) could no longer explain all the observed facts. As we will see in the chapter on [Observing the Sky: The Birth of Astronomy](#), a new model, with the Sun at the center, fit the experimental evidence better. After a period of philosophical struggle, it became accepted as our view of the universe.

When they are first proposed, new models or ideas are sometimes called *hypotheses*. You may think there can be no new hypotheses in a science such as astronomy—that everything important has already been learned. Nothing could be further from the truth. Throughout this textbook you will find discussions of recent, and occasionally still controversial, hypotheses in astronomy. For example, the significance that the huge chunks of rock and ice that hit Earth have for life on Earth itself is still debated. And while the evidence is strong that vast quantities of invisible “dark energy” make up the bulk of the universe, scientists have no convincing explanation for what the dark energy actually is. Resolving these issues will require difficult observations done at the forefront of our technology, and all such hypotheses need further testing before we incorporate them fully into our standard astronomical models.

This last point is crucial: a hypothesis must be a proposed explanation that can be *tested*. The most straightforward approach to such testing in science is to perform an experiment. If the experiment is

conducted properly, its results either will agree with the predictions of the hypothesis or they will contradict it. If the experimental result is truly inconsistent with the hypothesis, a scientist must discard the hypothesis and try to develop an alternative. If the experimental result agrees with predictions, this does not necessarily prove that the hypothesis is absolutely correct; perhaps later experiments will contradict crucial parts of the hypothesis. But, the more experiments that agree with the hypothesis, the more likely we are to accept the hypothesis as a useful description of nature.

One way to think about this is to consider a scientist who was born and lives on an island where only black sheep live. Day after day the scientist encounters black sheep only, so he or she hypothesizes that all sheep are black. Although every observed sheep adds confidence to the hypothesis, the scientist only has to visit the mainland and observe one white sheep to prove the hypothesis wrong.

When you read about experiments, you probably have a mental picture of a scientist in a laboratory conducting tests or taking careful measurements. This is certainly the case for a biologist or a chemist, but what can astronomers do when our laboratory is the universe? It's impossible to put a group of stars into a test tube or to order another comet from a scientific supply company.

As a result, astronomy is sometimes called an *observational* science; we often make our tests by observing many samples of the kind of object we want to study and noting carefully how different samples vary. New instruments and technology can let us look at astronomical objects from new perspectives and in greater detail. Our hypotheses are then judged in the light of this new information, and they pass or fail in the same way we would evaluate the result of a laboratory experiment.

Much of astronomy is also a *historical* science—meaning that what we observe has already happened in the universe and we can do nothing to change it. In the same way, a geologist cannot alter what has happened to our planet, and a paleontologist cannot bring an ancient animal back to life. While this can make astronomy challenging, it also gives us fascinating opportunities to discover the secrets of our cosmic past.

You might compare an astronomer to a detective trying to solve a crime that occurred before the detective arrived at the scene. There is lots of evidence, but both the detective and the scientist must sift through and organize the evidence to test various hypotheses about what actually happened. And there is another way in which the scientist is like a detective: they both must prove their case. The detective must convince the district attorney, the judge, and perhaps ultimately the jury that his hypothesis is correct. Similarly, the scientist must convince colleagues, editors of journals, and ultimately a broad cross-section of other scientists that her hypothesis is provisionally correct. In both cases, one can only ask for evidence “beyond a reasonable doubt.” And sometimes new evidence will force both the detective and the scientist to revise their last hypothesis.

This self-correcting aspect of science sets it off from most human activities. Scientists spend a great deal of time questioning and challenging one another, which is why applications for project funding—as well as reports for publication in academic journals—go through an extensive process of *peer review*, which is a careful examination by other scientists in the same field. In science (after formal education and training), everyone is encouraged to improve upon experiments and to challenge any and all hypotheses. New scientists know that one of the best ways to advance their careers is to find a weakness in our current understanding of something and to correct it with a new or modified hypothesis.

This is one of the reasons science has made such dramatic progress. An undergraduate science major today knows more about science and math than did Sir Isaac Newton, one of the most renowned scientists who ever lived. Even in this introductory astronomy course, you will learn about objects and processes that no one a few generations ago even dreamed existed.

### 1.3 The Laws of Nature

Over centuries scientists have extracted various *scientific laws* from countless observations, hypotheses, and experiments. These scientific laws are, in a sense, the “rules” of the game that nature plays. One remarkable