

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

discovery about nature—one that underlies everything you will read about in this text—is that the same laws apply everywhere in the universe. The rules that determine the motion of stars so far away that your eye cannot see them are the same laws that determine the arc of a baseball after a batter has hit it out of the park.

Note that without the existence of such universal laws, we could not make much headway in astronomy. If each pocket of the universe had different rules, we would have little chance of interpreting what happened in other “neighborhoods.” But, the consistency of the laws of nature gives us enormous power to understand distant objects without traveling to them and learning the local laws. In the same way, if every region of a country had completely different laws, it would be very difficult to carry out commerce or even to understand the behavior of people in those different regions. A consistent set of laws, though, allows us to apply what we learn or practice in one state to any other state.

This is not to say that our current scientific models and laws cannot change. New experiments and observations can lead to new, more sophisticated models—models that can include new phenomena and laws about their behavior. The general theory of relativity proposed by Albert Einstein is a perfect example of such a transformation that took place about a century ago; it led us to predict, and eventually to observe, a strange new class of objects that astronomers call *black holes*. Only the patient process of observing nature ever more carefully and precisely can demonstrate the validity of such new scientific models.

One important problem in describing scientific models has to do with the limitations of language. When we try to describe complex phenomena in everyday terms, the words themselves may not be adequate to do the job. For example, you may have heard the structure of the atom likened to a miniature solar system. While some aspects of our modern model of the atom do remind us of planetary orbits, many other of its aspects are fundamentally different.

This problem is the reason scientists often prefer to describe their models using equations rather than words. In this book, which is designed to introduce the field of astronomy, we use mainly words to discuss what scientists have learned. We avoid complex math, but if this course piques your interest and you go on in science, more and more of your studies will involve the precise language of mathematics.

1.4 Numbers in Astronomy

In astronomy we deal with distances on a scale you may never have thought about before, with numbers larger than any you may have encountered. We adopt two approaches that make dealing with astronomical numbers a little bit easier. First, we use a system for writing large and small numbers called *scientific notation* (or sometimes *powers-of-ten notation*). This system is very appealing because it eliminates the many zeros that can seem overwhelming to the reader. In scientific notation, if you want to write a number such as 500,000,000, you express it as 5×10^8 . The small raised number after the 10, called an *exponent*, keeps track of the number of places we had to move the decimal point to the left to convert 500,000,000 to 5. If you are encountering this system for the first time or would like a refresher, we suggest you look at [Appendix C](#) and [Example 1.1](#) for more information. The second way we try to keep numbers simple is to use a consistent set of units—the metric International System of Units, or SI (from the French *Système International d’Unités*). The metric system is summarized in [Appendix D](#) (see [Example 1.2](#)).

LINK TO LEARNING



Watch this [brief PBS animation \(https://openstax.org/l/30scinotation\)](https://openstax.org/l/30scinotation) that explains how scientific notation works and why it’s useful.

A common unit astronomers use to describe distances in the universe is a light-year, which is the distance light