The Birth of Astrophysics

Galileo Galilei

At about the same time that Tycho Brahe and Johannes Kepler were striving to understand the motion of heavenly bodies, the Italian scientist Galileo Galilei (fig. 2.25) was also trying to understand the heavens. However, his approach was entirely different.

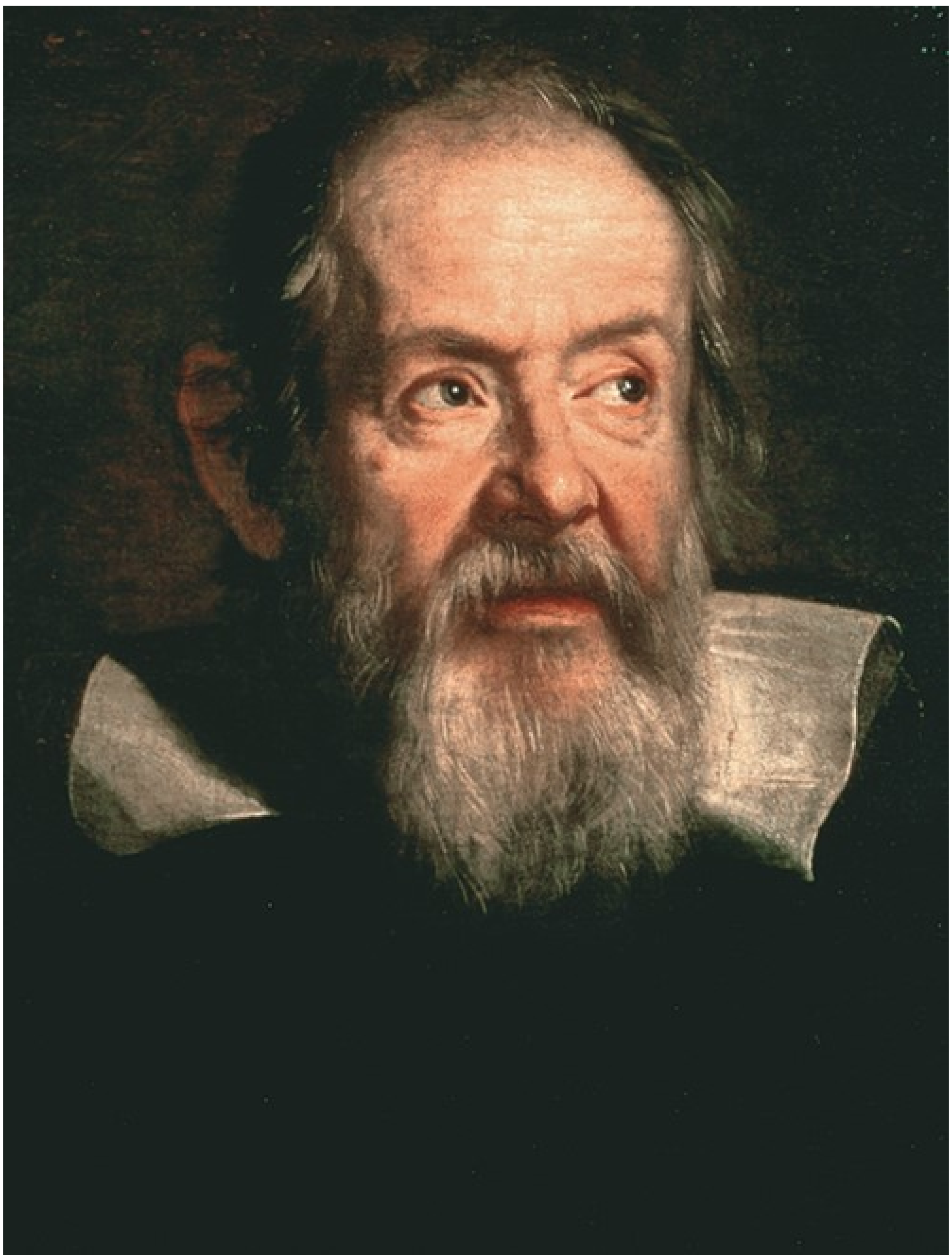

FIGURE 2.25
Galileo Galilei (1564–1642).

Galileo was interested not just in celestial motion but in all aspects of motion. He studied falling bodies and swinging weights hung on strings, and tried to find universal laws of motion. In addition, he used the newly invented telescope to study astronomical objects. Galileo did not invent the telescope himself. That invention seems to have been the work of the Dutch spectacle-maker Johannes (Hans) Lippershey. However, Galileo was the first person we know of who used the telescope to study the heavens and published his interpretations of his findings.* His book *Starry Messenger* was published in 1610. What he found was astonishing.

In looking at the Moon (fig. 2.26A), Galileo saw that its surface had mountains and was in that sense similar to the surface of the Earth. Therefore, he concluded that the Moon was not some mysterious ethereal body but a ball of rock. He looked (without taking adequate precaution) at the Sun and saw dark spots (now known as sunspots) on its surface. He noticed that the position of the spots changed from day to day, showing not only that the Sun had blemishes and was not a perfect celestial orb but that it also changed. Both these observations were in disagreement with previously held conceptions of the heavens as perfect and unchangeable. In fact, by observing the changing position of the spots from day to day, Galileo deduced that the Sun rotated.

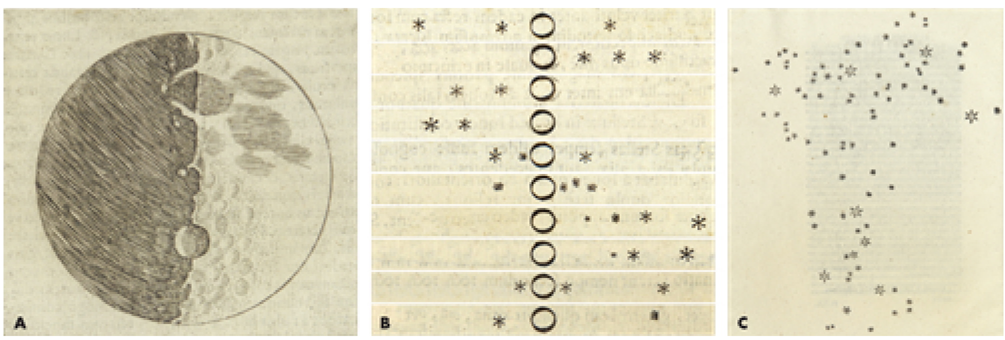

FIGURE 2.26
Drawings from Galileo’s 1610 book *Sidereus Nuncius (Starry Messenger)*. (A) A sketch of the Moon seen through his telescope, showing mountainous features. (B) A series of diagrams of Jupiter and its moons, seen shifting from night to night as they orbited Jupiter. (C) Numerous faint stars near the belt and sword of the constellation Orion, illustrating the existence of stars too faint to be seen with the unaided eye.

Galileo looked at Jupiter and saw four smaller objects orbiting it, which he concluded were moons of the planet (fig. 2.26B). When Galileo’s contemporary, Johannes Kepler, saw these moon’s through a small telescope, he gave them the name **satellites** because their motion around the planet made him think of attendants or bodyguards—*satelles*, in Latin. These four moons of Jupiter are known today as the Galilean satellites in honor of Galileo’s discovery. They proved unambiguously that there were at least *some* bodies in the heavens that did not orbit the Earth, and they raised the fundamental question of what force held them in orbit around Jupiter.

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Galileo also discovered that the sky was populated with an uncountable number of stars everywhere he looked (fig. 2.26C). This single observation, by demonstrating that there were far more stars than previously thought, shook the complacency of those who believed in the simple Earth-centered Universe.

When Galileo looked at Saturn, he discovered that it did not appear as a perfectly round disk but that it had blobs off the edge. However, his telescope was too small and too crudely made (inferior to inexpensive modern binoculars) to show these as rings. That discovery that had to wait until 1656, when they were first recognized by the Dutch scientist Christiaan Huygens as features that were detached from the planet.

Galileo observed that Venus went through a cycle of phases, like the Moon, as shown in figure 2.27. The relation between the phase of the planet and its position with respect to the Sun left absolutely no doubt that Venus must be in orbit around the Sun, because if it orbited the Earth it would always remain in a crescent phase (fig. 2.28). Perhaps more than any other observation, this one dealt the death blow to the old geocentric model of planetary motion.

FIGURE 2.27
Images of Venus made with a small telescope in 2004 show it changing from a gibbous phase on the far side of the Sun to a crescent phase as it passes between the Earth and Sun.

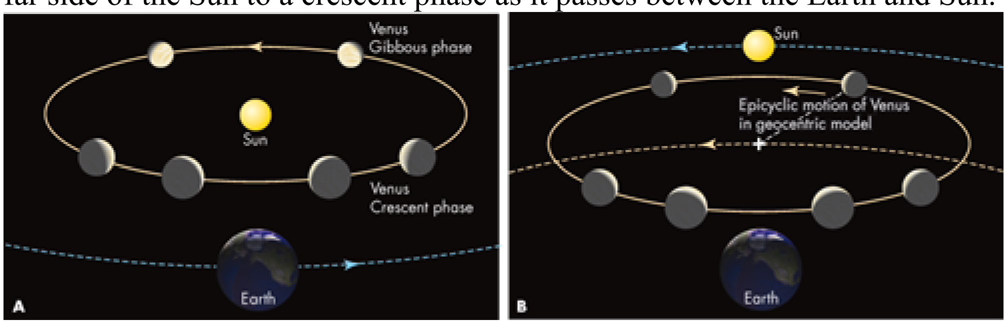

FIGURE 2.28
As Venus orbits the Sun, it goes through a cycle of phases (A). The relation between phase and the planet's position with respect to the Sun shows conclusively that Venus cannot be orbiting the Earth. The gibbous phases Galileo observed occur for the heliocentric model but cannot happen in the Earth-centered Ptolemaic model (B), where Venus is shown on its epicycle.

Galileo's contributions to science would be honored even had he not made all these important observational discoveries, for he is often credited with originating the experimental method for studying scientific problems. From his experiments on the manner in which bodies move and fall, Galileo deduced the first correct "laws of motion," laws that ultimately led Newton to his explanation of why the planets obey the laws of planetary motion that Kepler discovered.

ANIMATION

The phases of Venus according to the Ptolemaic and Copernican systems

Galileo’s probings into the laws of nature led him into trouble with religious “law.” He was a vocal supporter of the Copernican view of a Sun-centered Universe and wrote and circulated his views widely and somewhat tactlessly. His exposition followed the style of Plato, presenting his arguments as a dialog between a wise teacher (patterned after himself) and an unbeliever in the Copernican system named Simplicio who, according to his detractors, was patterned after the pope. Although the pope was actually a friend of Galileo, more conservative churchmen urged that Galileo be brought before the Inquisition because his views that the Earth moved were counter to the teachings of the Catholic Church. Considering that his trial took place at a time when the papacy was attempting to stamp out heresy, Galileo escaped lightly. He was made to recant his “heresy” and was put under house arrest for the remainder of his life. Only in 1992 did the Catholic Church admit it had erred in condemning Galileo for his ideas.

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Isaac Newton

Isaac Newton (fig. 2.29), who was born the year Galileo died, is arguably the greatest scientist of all time. Newton’s contributions span mathematics, physics, and astronomy. Moreover, Newton pioneered the modern studies of motion, optics, and gravity. In his attempts to understand the motion of the Moon, Newton not only deduced the law of gravity but also discovered that he needed mathematical methods for calculating the gravitational force of a spherical body and that no such methods were then available. This realization led him to invent what we now know as calculus.


FIGURE 2.29
Isaac Newton (1642–1727)

What is especially remarkable about Newton's work is that the discoveries he made in the seventeenth century still form the core for most of our understanding of gravity and the motion of bodies, discoveries we will discuss in more detail in chapter 3. In chapter 4 we will discuss some of Newton's ideas and discoveries about light, ideas that are also still in use.

Newton was a fascinating individual. He came from very modest origins and rose to high positions not only in academia but also in the government. He was Warden of the Mint and is alleged to have invented milling, the process whereby grooves are cut in the edge of coins to detect metal being pared off them, which would debase their value. He was also a deeply religious man and wrote prolifically on theological matters as well as science.

Newton's laws of motion, when combined with his law of gravity, were successfully applied for the next 200 years to essentially all problems of the motion of astronomical bodies. They still form the foundation for space flight today. These laws allow one to predict all future astronomical motions from a detailed knowledge of current motions, positions, and forces. Such a "clockwork universe" had no room for mystical effects of celestial bodies on human affairs such as had been part of the belief system of astrology, which had been part of the subject of astronomy until the seventeenth century. See Extending Our Reach: "Astronomy and Astrology."

EXTENDING *our reach*
ASTRONOMY AND ASTROLOGY

Astrology is an ancient belief, thousands of years old, that the positions and patterns of celestial bodies in the sky exert an influence on the course of human events, or foretell the future. Astronomy and astrology were not considered separate subjects before the seventeenth century.

Actually, one motivation behind the astronomical discoveries of the Renaissance was the hope of better understanding the motions of celestial bodies in order to cast more accurate horoscopes. The idea of a horoscope is that the positions of celestial bodies at the time of a person's birth (particularly the position of the Sun in the zodiac) along with their current positions could provide predictive power over human events. It might be believed, for example, that when the planet Mars is in the birth constellation of the leader of a country, then war is likely or even advised, so predicting the position of the planets accurately would be a critical ability of an astronomer.

Kepler and Galileo both cast horoscopes, and both pondered whether their new discoveries, such as the existence of satellites around the planets, might provide new insights into astrology. However, Newton's discoveries of the laws of motion and gravity removed the mystery of the motions of the Sun, Moon, and planets. He and subsequent astronomers gave little or no credence to astrology, and it was dropped from studies of astronomy.

Carefully conducted studies show that astrology has no predictive power. A simple test can be done in a classroom by passing out horoscopes from the previous day with all indication of the astrological "signs" removed. On average about 1 in 12 students—which is what is expected by random chance—will pick the horoscope that was intended for them. This is not to say that astrologers never offer useful advice or even cast horoscopes that seem to be accurate. In fact, students trying to select from anonymized horoscopes often express surprise that so many of the horoscopes seem appropriate. A skillfully written horoscope apparently offers advice and predictions that are so general that they seem true for almost anyone. This makes astrology a belief system rather than a predictive science.

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New Discoveries

Newton's enormous contributions tend to overshadow other advances in astronomy during the eighteenth and nineteenth centuries. That period began with observational discoveries that increased astronomers' confidence in using physical laws to understand the structure and workings of astronomical bodies. However, by the end of the period, newly found physical laws gave astronomers totally new tools for studying the heavens. In fact, the increasing use of the word *astrophysics* describes that shift well.

The shift of stars due to parallax as the Earth orbits the Sun was not detected until 1838, but proof of the Earth's motion was discovered in 1729. The motion of the Earth actually causes the observed positions of all stars to shift throughout the year because as the Earth moves through space, the angle of the light entering a telescope changes. This is the same effect that causes droplets to hit the front of your body more than your back as you run through falling rain. Your motion causes the rain to appear to fall at an angle toward your front side, and likewise the Earth's motion makes the light appear to come in at an angle toward the direction of the Earth's motion as it orbits the Sun.

Unexpected discoveries play a major role today in expanding our knowledge of the heavens, no less so than in the time immediately after Newton's death. For example, in 1781 the English astronomer Sir William Herschel discovered the planet Uranus. He also discovered that some stars have companion stars in orbit around them. The motion of such double stars offered additional tests of Newton's laws, but the most striking triumph of these laws of motion was their explanation of irregularities in the orbital motion of Uranus. Such irregularities hinted that another body was exerting a gravitational force on Uranus, and from Newton's laws, astronomers could calculate the position of the unseen body. As we will discuss further in chapter 10, a search of the sky near the calculated position revealed the planet Neptune.

New Technologies

Steady improvements in telescopes played an important role during this period. For example, refinements in optics allowed astronomers to build bigger telescopes and thereby observe much fainter objects. Among these objects, astronomers found dim, fuzzy patches of light—the so-called *nebulae* (fig. 2.30). Some of these were gas clouds within the Milky Way; others turned out to be external star systems similar to the Milky Way.

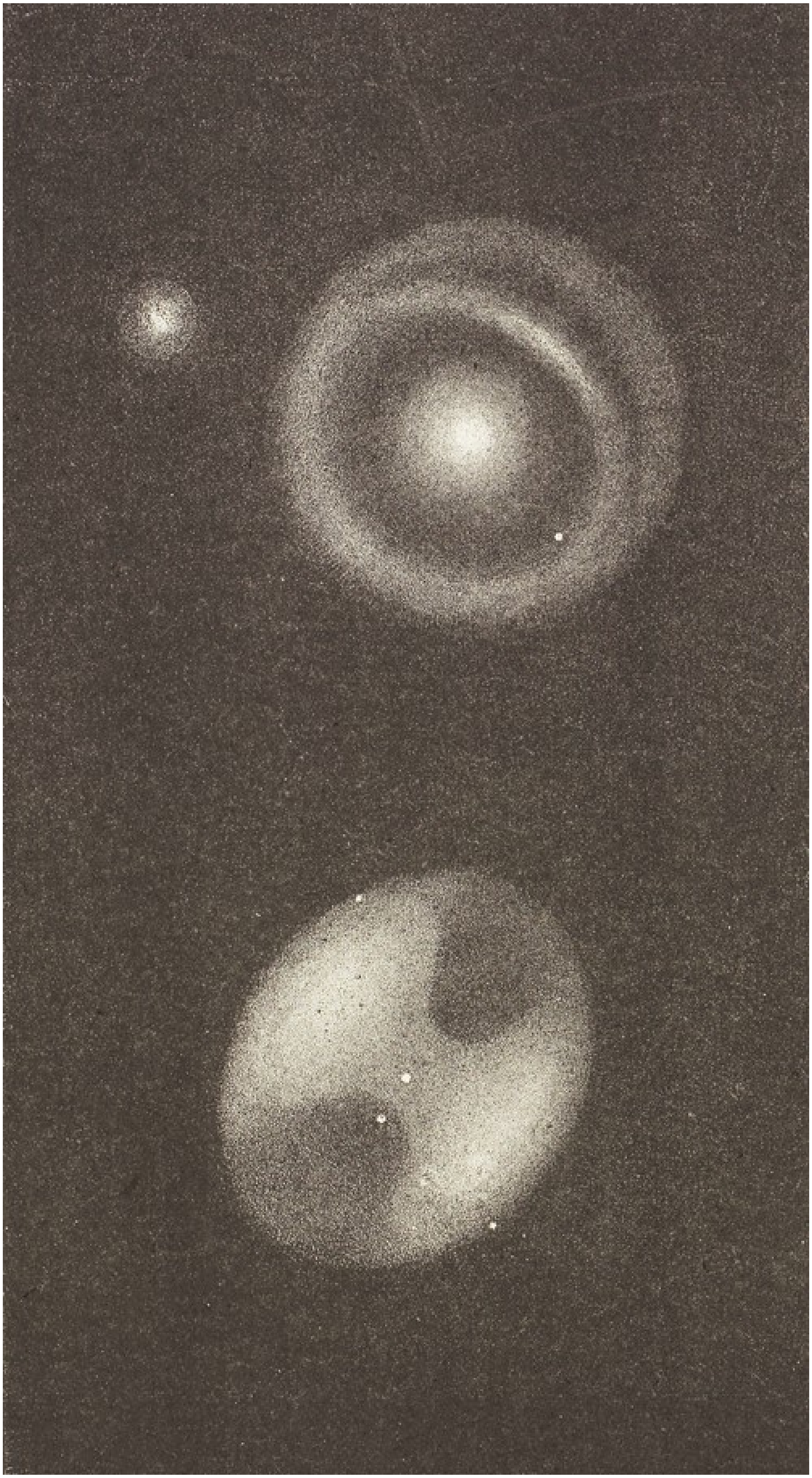

FIGURE 2.30
Sketches of nebulae as seen by Sir John Herschel in the early 1800s.

Another important technological advance was the application of photography to astronomy, starting in the middle of the nineteenth century. Photographic film gave astronomers permanent records of what they saw, and because film could store light during long exposures, astronomers were now able to detect objects much fainter than the eye could see in a single moment.

The scientific and technical advances described here have a direct bearing on astronomy, but scientific discoveries often influence totally unconnected areas. For example, during the eighteenth and nineteenth centuries, many scientists were studying the nature of matter and heat. The study of heat was prompted, at least in part, by a desire to improve the newly invented steam engine. Understanding the generation of heat and energy in turn gave new insights into how stars work, but it also presented a mystery—stars were generating far more power than could be explained by any known source of energy. This conundrum was finally resolved with the discovery of nuclear energy in the twentieth century.

It was also not until the twentieth century that the discovery of a tiny discrepancy in the motion of Mercury, as calculated using Newton's work, showed scientists that Newton's laws were not the last word on planetary motion. His descriptions of motion require modification if we are to correctly describe motion at speeds near that of light or where gravitational fields are very intense. These modifications are incorporated in Einstein's theories of relativity, described in essay 2.