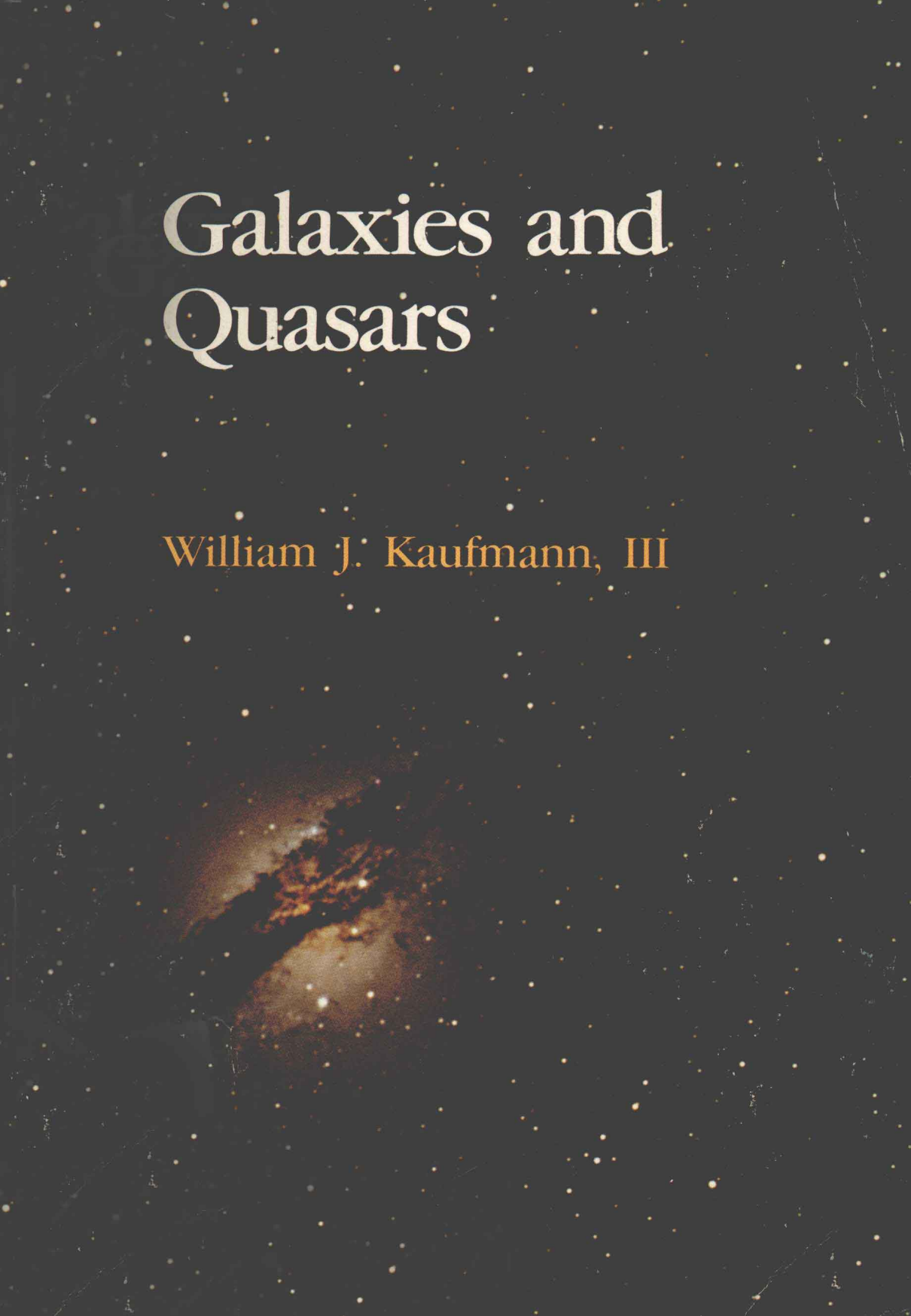
Galaxies and Quasars

William J. Kaufmann, III



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Preface

For thousands of years, people have gazed into the heavens and asked many of the same questions that we ask. How big is the universe? Where did it come from? Does the universe have an edge? A center? When did it begin? And will it ever come to an end?

As human beings, we are not satisfied with endless observations alone. It is not enough to go out night after night and simply make long lists of what we see in the sky. Instead, we want to know *why* things are the way they are. We want a *cosmology,* a theory from which we can understand the properties, evolution, and nature of the universe as a whole.

Ever since the dawn of civilization, every society and every religion has had a cosmology at the core of its teachings. In ancient times, these cosmologies were based primarily on divine revelation. The heavens were populated with gods and heroes, demons and monsters. The creation and behavior of the cosmos was seen as a direct result of supernatural forces.

Modern civilization really began when people no longer needed to view the universe as the stage on which gods and demons acted out their supernatural roles. Basic aspects of modern science and technology originated when we realized that the behavior of the universe could be entirely understood from the viewpoint of physical interactions between matter and radiation. Of course, this orientation removes much of the romanticism from the heavens. For example, the ancient Chinese believed that solar eclipses were caused by a terrible monster who devours the sun. During an eclipse, the citizenry were entreated to make a great commotion to scare off the

monster, lest the sun be permanently devoured. Of course, their efforts were always rewarded. The modern explanation in terms of the moon's orbit about the earth does not seem quite as intriguing or fascinating.

Although a measure of fantasy and romanticism may have been lost, surely tremendous powers have been gained. With each new discovery about the cosmos, we have gained significant insights into the true nature of physical reality. These revelations have often had a direct translation into technology, thereby affecting the economies and politics of modern societies. Some of these changes are subtle, but others are profound. For example, the realization that thermonuclear reactions are occurring at the sun's center leads directly to the knowledge of how to build a hydrogen bomb.

Modern cosmology was born in the 1920s. Prior to that time, we did not know that galaxies exist. We did not know that we live in an expanding universe. Our current understanding of the structure of the universe is only half a century old. And virtually everything that everyone believed prior to that time is wrong. Prior to the 1920s, we simply did not have enough data to construct a complete picture.

But we have only begun to scratch the surface. Our efforts over the past few decades constitute a faltering glimpse as we peer for the first time across billions of light years. Quasars were discovered only twenty years ago. And the discovery of the cosmic microwave background is even more recent. Observations of the heavens at ultraviolet, infrared, and X-ray wavelengths are less than a decade old.

Surely our cosmology will be dramatically affected by this ongoing exploration of the distant universe. This exploration, which often leads us into totally unexpected domains, is one of the noblest quests of the human intellect. In the seventeenth century, Isaac Newton's ideas about gravity and his explanation of the orbits of the planets about the sun set the stage for the Industrial Revolution. An understanding of the evolution of galaxies or the nature of quasars could easily have an equally profound effect on the future course of civilization.

June 1979 William J. Kaufmann, III

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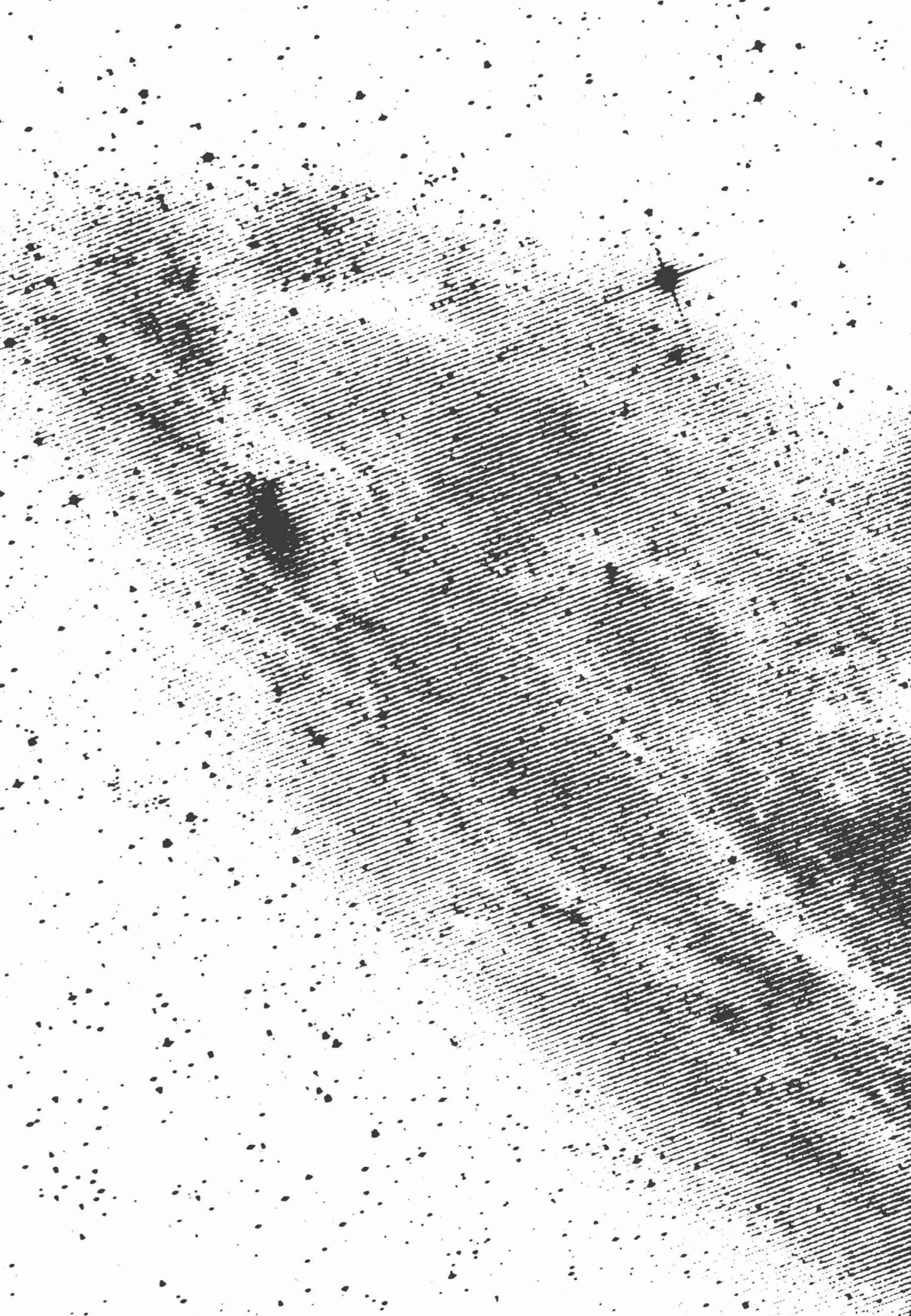

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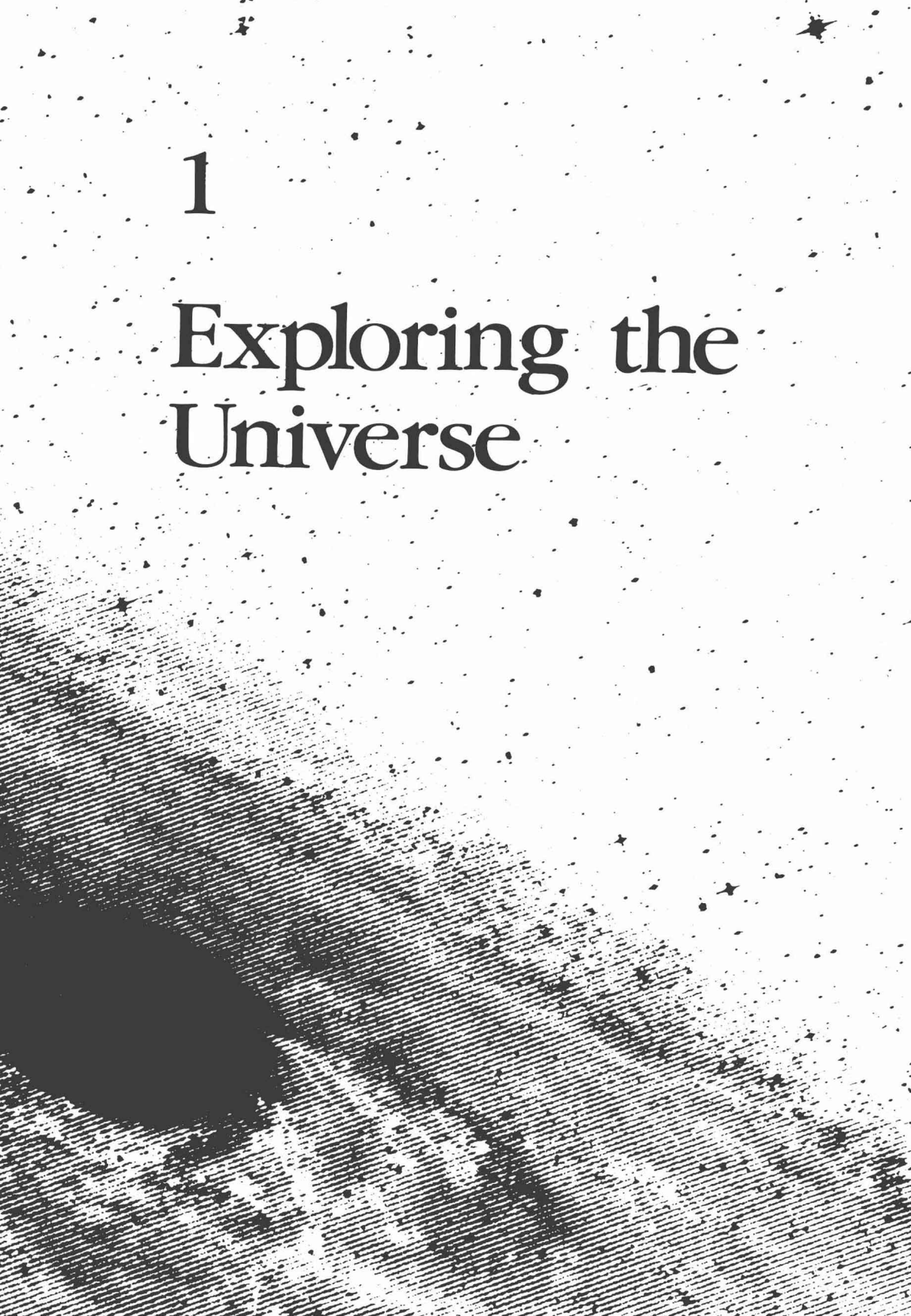
Exploring the Universe



It was said that they foretold the deaths of kings. Pestilence and plague were always predicted in the wake of these evil celestial omens. Misery and suffering would be long and hard. The devout crossed themselves and with bowed heads could be heard chanting "Dear God, protect us from the Turk, the Devil, and the Comet." The skies would surely be filled with comets on Judgment Day. Comets would herald the end of the world.

All of these medieval superstitions largely evaporated during the eighteenth century. In 1705, the English astronomer Edmund Halley published a book in which he demonstrated that comets are really members of our solar system. Halley was particularly intrigued by sightings of bright comets in 1531, 1607, and 1682. He argued that these sightings could be explained by a single comet that orbits the sun every 76 years. Halley did not live long enough to see the predicted return of his comet in 1758. But by then his ideas were accepted without question. In addition to the planets, our sun is orbited by numerous comets that occasionally produce some of the most spectacular and awe-inspiring sights in the sky.

Today we know that the solid portion of a comet consists of a frozen chunk of dust and ice that measures only a few kilometers across. A typical comet follows a highly elongated orbit that occasionally brings this frozen mixture into the inner regions of the solar system. As this interplanetary iceberg approaches the sun, the ices are vaporized. A large cloud of gases begins to develop. Blistering solar radiation causes these gases to glow, and the solar wind blows the shimmering material away from the comet's head into a long, billowing tail. *If* the comet's orbit happens to pass very near the sun (so that a large fraction of the ices are vaporized), and *if* the orbit also happens to pass near the earth (so that we can easily see the glowing gases), then we are treated to a dramatic sight that dominates the skies for many nights. An excellent example of a comet is shown in Figure 1-1.

Comet hunting became a popular fad during the late 1700s. Nearly everyone who had a decent telescope spent many long hours scanning the skies. With a little luck and a great deal of patience, it was possible to discover new members of our solar system. Prizes, medals, honors, and awards were heaped on the fortunate as-

Figure 1-1 A Comet
This beautiful comet dominated the skies during August 1957. Night after night it could be seen drifting slowly past the background stars. After a few weeks, the comet faded from view as it returned to the frigid depths of interplanetary space. (Hale Observatories.)

tronomer who happened to find a comet that produced a particularly spectacular sight.

But there were some problems. In order to be the discoverer of a comet, it is necessary to sight the object before it develops a long, conspicuous tail. The comet must be sighted while it is still quite faint. Astronomers therefore searched for faint, fuzzy objects in the sky that might be comets on their way toward the sun. But there are many faint, fuzzy objects across the sky that are *not* comets. These features are called *nebulas,* from the Latin word meaning "cloud." Nebulas proved to be very frustrating to the dedicated comet hunter.

To cope with this troublesome situation, the famous French comet hunters Charles Messier and Pierre Mechain made a list of 103 nebulas that were sometimes mistaken for distant comets. This list, called the *Messier Catalogue,* was published in 1781 (see the Appendix). The purpose of the list was to cut down the number of false alarms. Objects in the *Messier Catalogue* were to be ignored by comet hunters.

About half of the objects listed in the *Messier Catalogue* turned out to be clusters of stars. Some of these clusters are loose groupings of stars. These are called *open clusters.* Long-exposure photography through a telescope reveals that a typical open cluster contains several hundred stars, as shown in Figure 1-2.

Twenty-six open clusters were listed by Messier in his catalog. The remaining 29 clusters are called *globular clusters* because of their distinctive spherical appearance. A typical globular clusters, such as that shown in Figure 1-3, contains more than 100,000 stars.

Some of the objects on Messier's list actually are glowing clouds of interstellar gas and dust. These nebulas include the birthplaces of stars, such as the famous Orion Nebula (the 42nd object on Messier's list) shown in Figure 1-4. Other nebulas are stellar graveyards, such as the Crab Nebula (the 1st object on Messier's list) shown in Figure 1-5. There are about a dozen of these true nebulas on Messier's list. As with all of the objects in the *Messier Catalogue,* these nebulas look like tiny, faint, fuzzy patches of haze when viewed through a small telescope. The dramatic pictures on these pages are

Figure 1-2 The Open Cluster M67 (also called NGC 2682) *About two dozen open star clusters are listed in the* Messier Catalogue. *This open cluster (the 67th object on Messier's list) is located in the constellation of Cancer and contains several hundred loosely grouped stars. (Kitt Peak National Observatory.)*

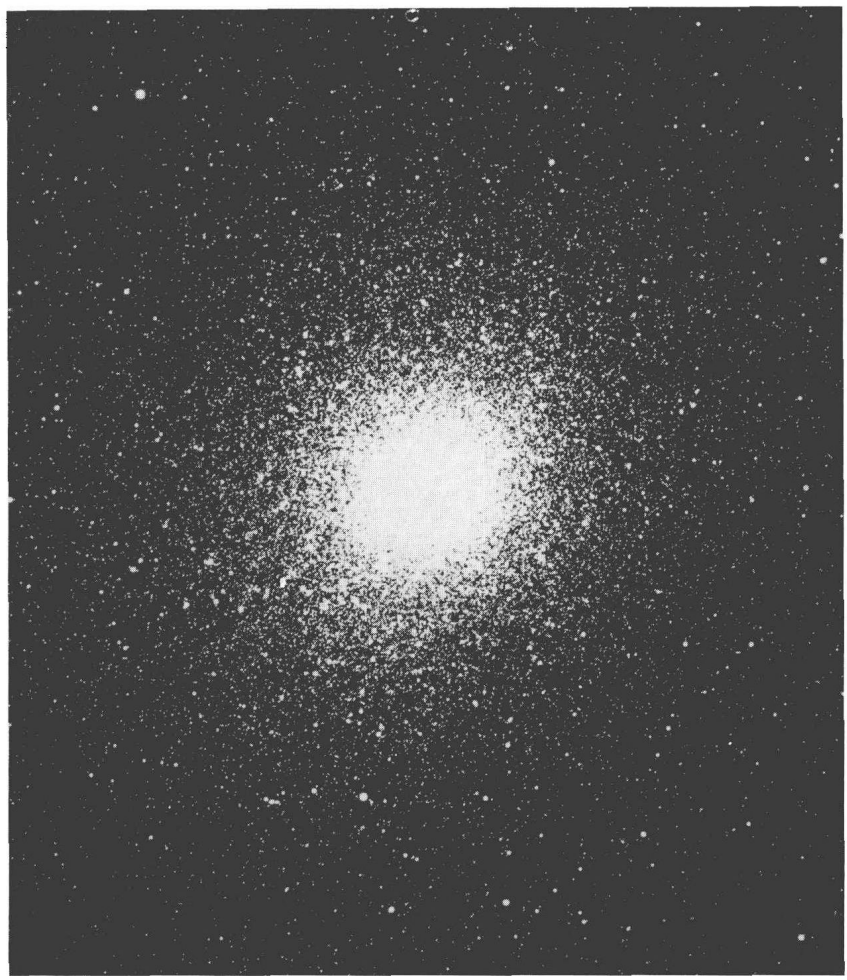


Figure 1-3 The Globular Cluster M5 (also called NGC 5904) *More than two dozen globular star clusters are listed in the* Messier Catalogue. *This globular cluster (the 5th object on Messier's list) is located in the constellation of Serpens and contains more than 100,000 densely grouped stars. (Kitt Peak National Observatory.)*

obtained by long-exposure photography through some of the world's largest telescopes.

All of these objects—star clusters and true nebulas—make up about two-thirds of Messier's list. They were never terribly controversial. Gradually, as data accumulated over the years, a giant picture began to emerge from which all of these objects could be understood and appreciated. For example, as we shall see in a later chapter, the locations of star clusters revealed the structure of our Milky Way Galaxy. And as astrophysicists began to understand the life cycles of stars, we learned that some nebulas are stellar embryos while others are stellar corpses.

But about a third of the objects in the *Messier Catalogue* are neither star clusters nor true nebulas. Although they were called "nebulas" for almost two centuries, these objects are definitely not glowing clouds of interstellar gas. These mysterious "nebulas," such as the Andromeda "Nebula" shown in Figure 1-6, became extremely controversial. For many years they were the subject of heated debates and vigorous arguments. The final resolution was destined to give humanity profound insight into the true nature of the universe as a whole.

About the same time that Messier was compiling his famous list, a German-born musician became interested in astronomy. William Herschel had moved from Hanover to London as a young man and at the age of 35 happened to purchase an astronomy book. He was so enthralled by what he read that he decided to build several large telescopes for himself. Indeed, Herschel probably spent more time looking through a telescope than anyone before him. His diligence was rewarded in 1781, when, at the age of 43, he accidentally discovered Uranus, the seventh planet from the sun.

William Herschel is responsible for some of the most important advances in astronomy during the late 1700s and early 1800s. For example, he was the first person to try to discover our location within the Milky Way Galaxy. Ever since Galileo first pointed his telescope toward the skies, it was realized that the hazy band of light called the Milky Way actually consists of millions of very faint stars. A portion of the Milky Way is shown in Figure 1-7. Because the Milky Way extends completely around the sky in one continuous encircling

Figure 1-4 The Orion Nebula (called M42 or NGC 1976)
Many young stars are scattered throughout this huge cloud of gas in the constellation of Orion. Intense ultraviolet radiation from these young stars causes the gas to shine. This nebulosity (the 42nd object on Messier's list) is just barely visible to the naked eye as a faint, fuzzy "star" in Orion's sword. (Lick Observatory.)

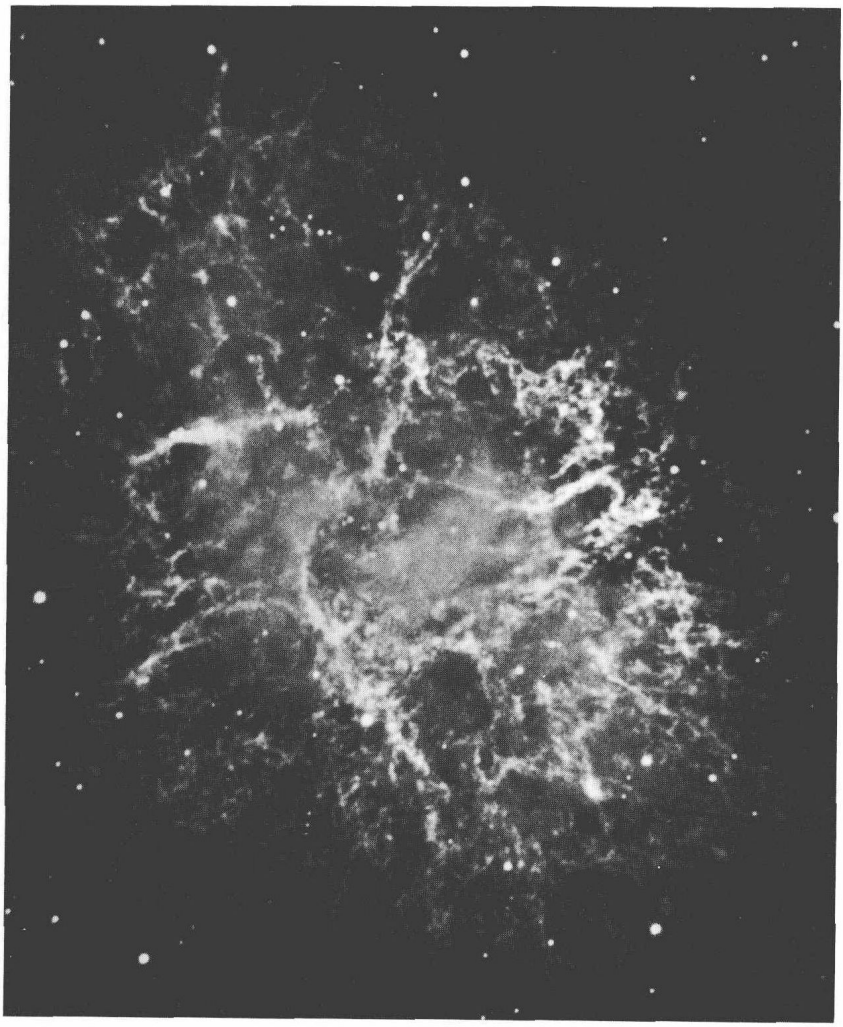


Figure 1-5 The Crab Nebula (called M1 or NGC 1952)
This beautiful nebulosity (the 1st object on Messier's list) is the corpse of a star. Nine hundred years ago, a star ended its life with a violent supernova explosion. The stellar remnant of this cataclysm is located in the constellation of Taurus. (Lick Observatory.)