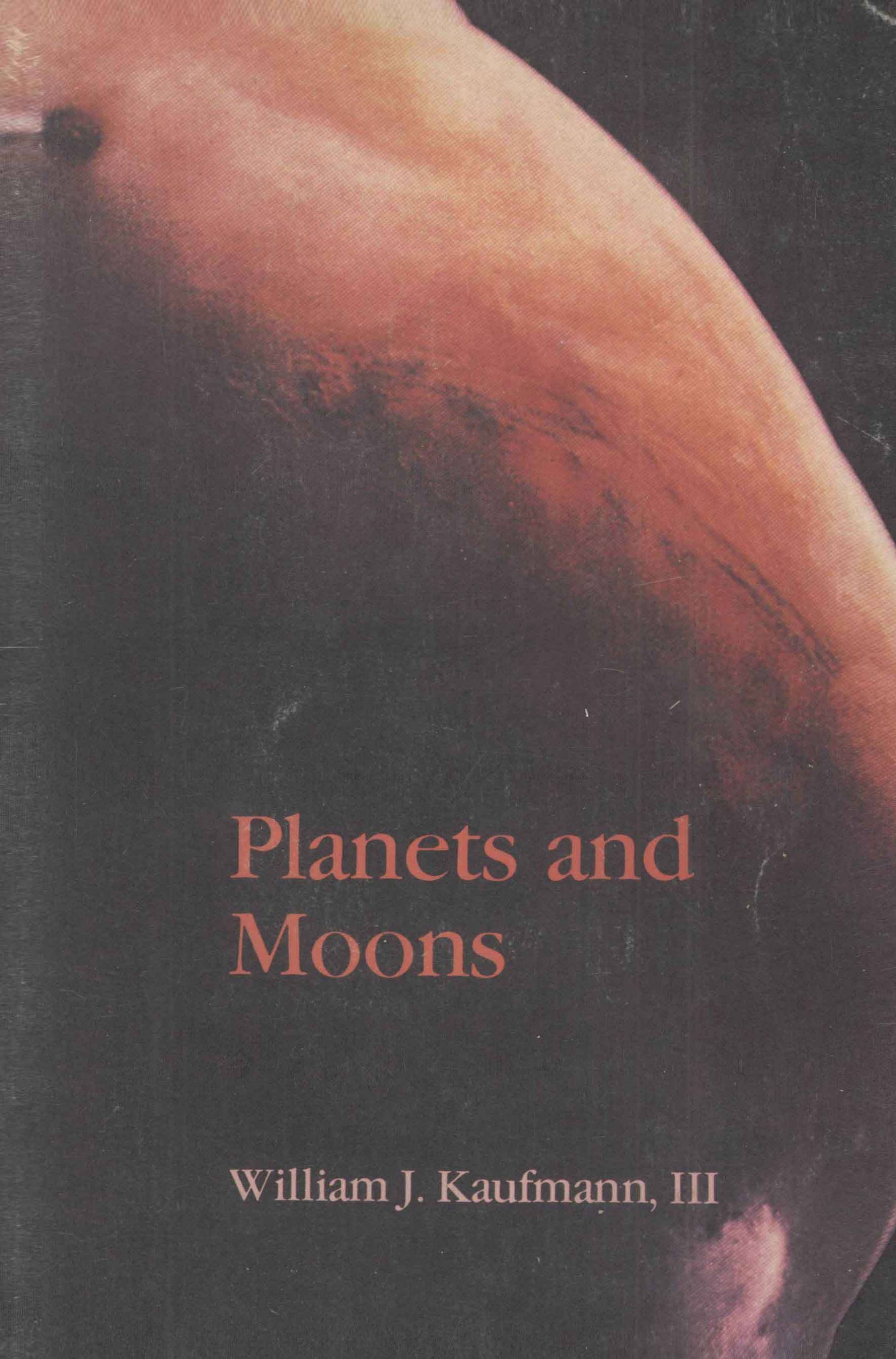

Planets and Moons

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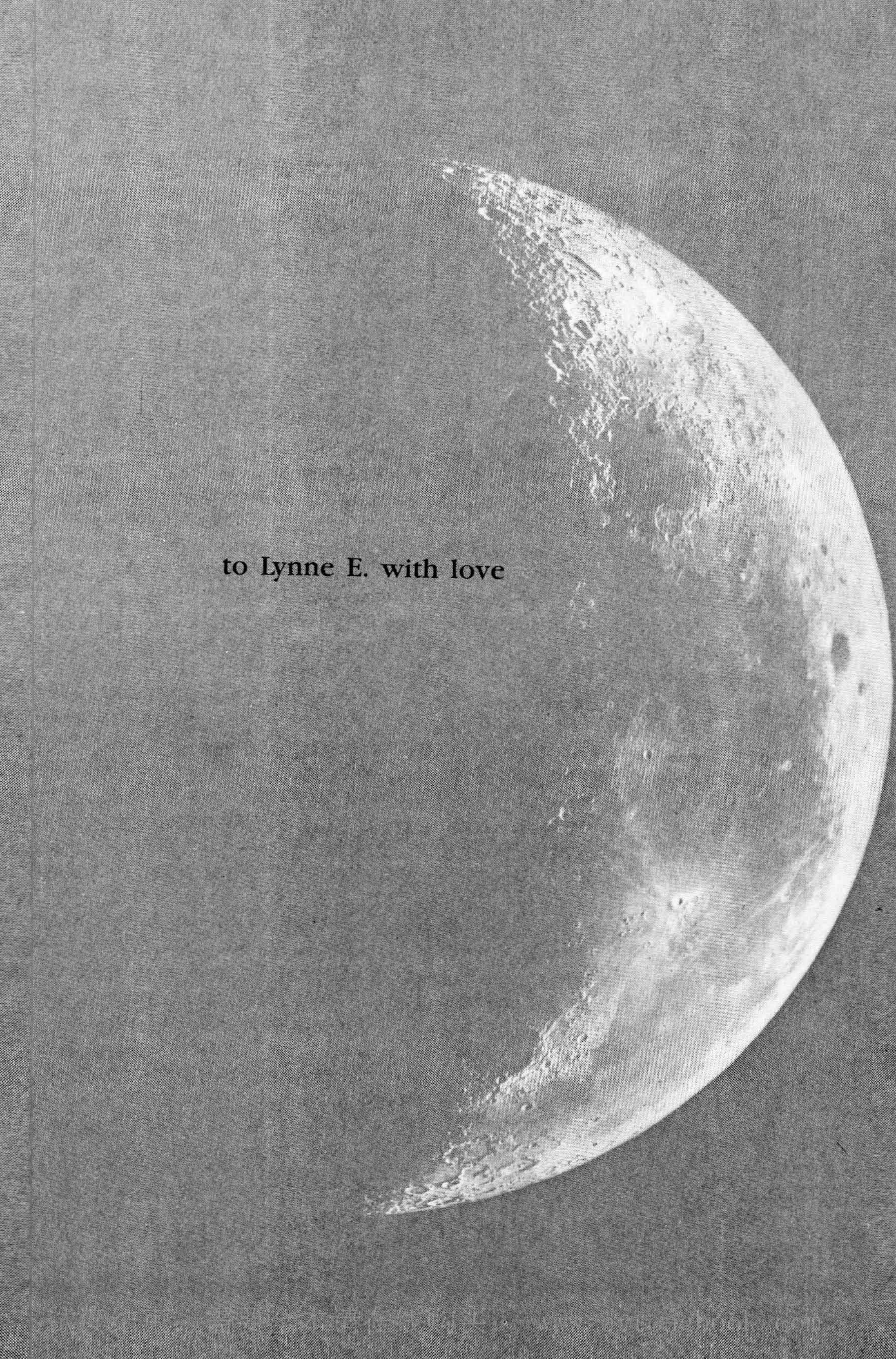
to Lynne E. with love



Preface

To be the first to see what no one has ever seen; to go where no person has ever gone; to experience, to think, and to feel that which is not yet in the repertoire of human consciousness. This is the inspiration of the scientists who reach for the planets and beyond to the stars. It is a true frontier populated with pioneers. But these explorers are totally unlike any of their predecessors. Years of patient, careful planning are followed by meticulous construction of bizarre vehicles in sterile, dust-free rooms. Then comes the long wait, the coasting across the black void of interplanetary space. And it all pays off—the labors, the expenses, the anxieties, the frustrations—as mechanical eyes with robot hands come to life and a transistorized voice begins to speak. Few experiences are more exciting than being present as we receive our first view of the craters of Mercury or dig our first trench on Martian soil.

This is what it means to live in the twentieth century. We have walked on the moon and seen beneath the clouds of Venus. And we are all part of this venture. For thousands of years, people have gazed up at our satellite and seen those familiar man-in-the-moon features that perpetually face our planet. Yet *we* were alive when humanity first saw the hidden side of the moon. For a one-time, per capita expenditure of *less* than the cost of a single pack of cigarettes, *we* financed a voyage past the rings of Saturn. We live in a time of adventure and exploration on the grandest scale. What we find shall surely prove as far-reaching as the discoveries of Columbus and Magellan.

This is our legacy. And just as the revelation of new continents profoundly affected the course of Renaissance Europe, our interplanetary explorations will certainly play a significant role in shaping the future of humanity for centuries to come.

October 1978 — William J. Kaufmann, III

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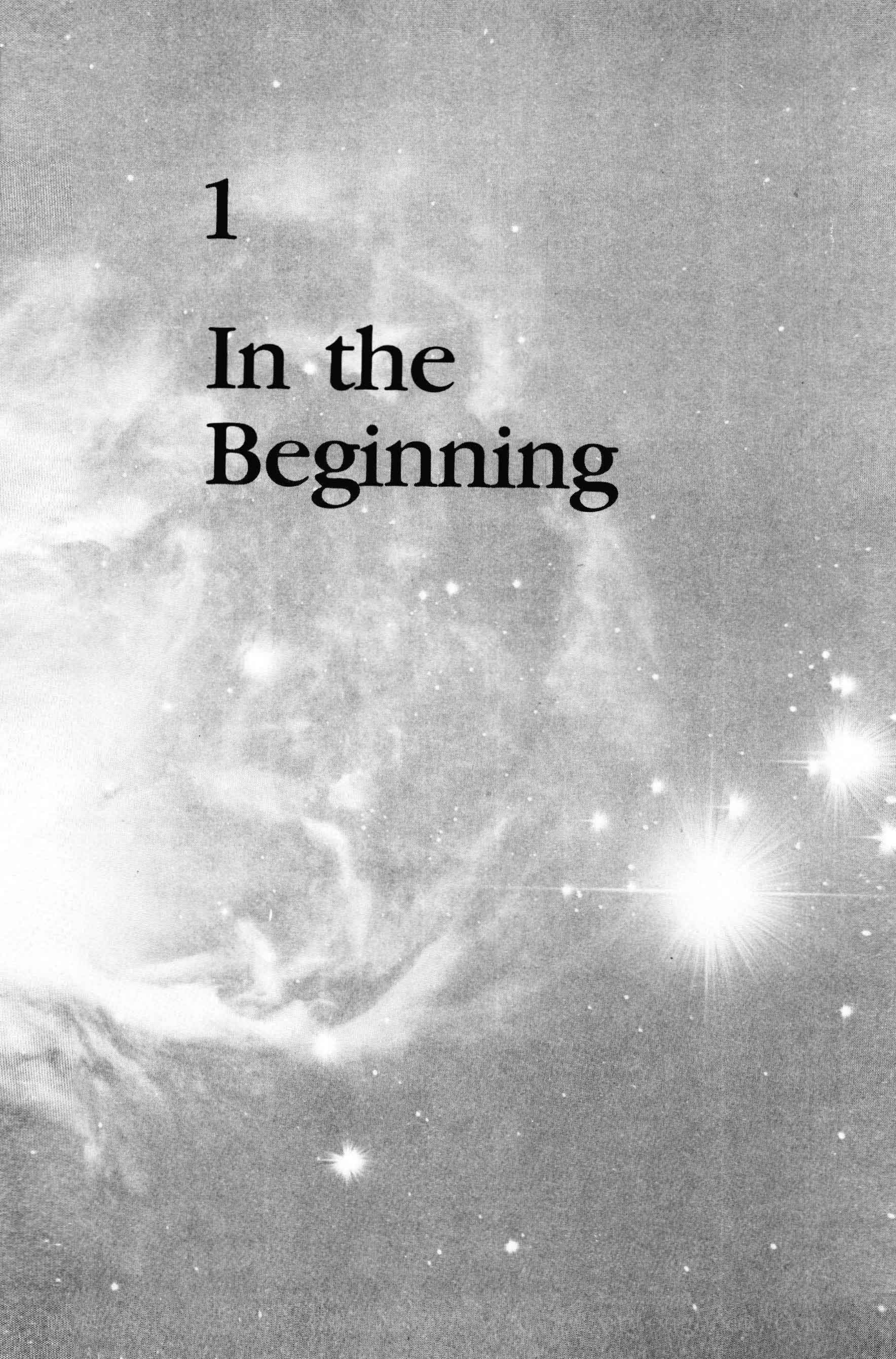
In the Beginning



It must have been cold—incredibly cold—5 billion years ago. Right here, where there are now trees and streets and people—right here in our own tiny corner of the galaxy. But long ago—so very long ago—before the birth of the sun and the creation of the planets. Stretching for billions upon billions of miles in all directions—the sparse interstellar medium—a frigid, nearly perfect vacuum in the blackness between the ancient stars.

It must have been cooler than 50 degrees above absolute zero. For comparison, "room temperature" is nearly 300 degrees above absolute zero, and the oxygen in the air we breathe liquefies at 90 degrees above absolute zero. But the primordial interstellar gas was in no danger of freezing or liquefying; the atoms were so widely spaced that they had too little opportunity to collide and stick to each other.

It must have been a nearly perfect vacuum: only a dozen atoms per cubic centimeter (which is the same as 200 atoms per cubic inch). For comparison, the air we breathe contains roughly 30 million trillion atoms per cubic centimeter. A space traveler would hardly have been aware that he or she was in the midst of a huge, primordial cloud of gas and dust from which our solar system would eventually be born.

Hydrogen was by far the most abundant substance. Nearly three-quarters of the interstellar cloud, by weight, consisted of hydrogen. And almost one-quarter of the cloud, by weight, was helium. In terms of numbers, this means that there was one helium atom for every dozen hydrogen atoms.

This preponderance of hydrogen and helium in interstellar space completely overshadowed the abundances of all the heavier elements. Since over 95 percent of the mass of the interstellar cloud consisted of hydrogen and helium, only a few percent was left over for all the heavier elements combined. Some of these heavier elements existed in the form of very tiny dust particles, typically a thousandth of a millimeter in size. But these substances were so rare that the dust grains were few and far between. A space traveler would have found only a hundred of these microscopic dust particles in an entire cubic kilometer (which is roughly the same as 400 per cubic mile) inside the interstellar cloud.

Figure 1-1 The Orion Nebula
Stars and planets are created in huge interstellar clouds of gas and dust. At the time of star-creation, the cloud is very cold and dark. But after star-birth, radiation from the young stars can cause the cloud to glow with unprecedented beauty. Newborn stars are embedded in this spectacular nebula in the constellation of Orion. (Lick Observatory.)

These widely spaced dust grains consisted mostly of silicon, magnesium, aluminum, and iron—exactly the same substances from which ordinary rocks are made. But, in addition, other familiar elements such as oxygen, carbon, and nitrogen occasionally existed in the form of organic molecules. Dozens of different organic molecules are found in interstellar space. This means that the chemical building blocks of life were present long before our sun and the planets began to form.

There are two theories about how the solar system began. The primordial interstellar cloud could not start forming the solar system by itself; the cloud was simply too diffuse. Something must have happened to compress the cloud.

We live in a spiral galaxy whose overall appearance is similar to the galaxy shown in Figure 1-2. Some astronomers believe that a spiral arm of our galaxy passed through our region of space some 5 billion years ago. This would have caused a slight compression of the interstellar cloud, and star-creation could have begun. Indeed, we find many young stars and glowing gas clouds outlining the spiral arms of distant galaxies.

Other astronomers believe that a nearby massive star became a supernova. During the final few hours of its existence, this ancient and unknown star was torn apart in nature's most cataclysmic detonation. The resulting shock wave would have been sufficient to compress our interstellar cloud, and star-creation could have begun. The remains of a star that became a supernova only 20,000 years ago is shown in Figure 1-3. Similar nebulosity of the supernova that started the sun's formation has long since disappeared. Nevertheless, scientists analyzing meteorites have recently discovered unusual abundances of certain elements that would have easily been produced by a nearby supernova explosion.

Prior to compression, our primordial interstellar cloud had been in equilibrium. The force of gravity, which tried to make the cloud contract, was exactly balanced by the gas pressure inside the cloud. But after compression (either by passage through a spiral arm or from a supernova explosion), the microscopic dust grains in the cloud were squeezed closer together than before. After compression, there might have been as many as 10,000 dust grains per cubic

Figure 1-2   A Spiral Galaxy
Our galaxy—if we could see it from a great distance—would look like this galaxy in the constellation of Ursa Major. Our galaxy contains over 100 billion stars and measures 100,000 light years in diameter. We are located two-thirds of the way from the center, between two spiral arms. (Kitt Peak National Observatory.)

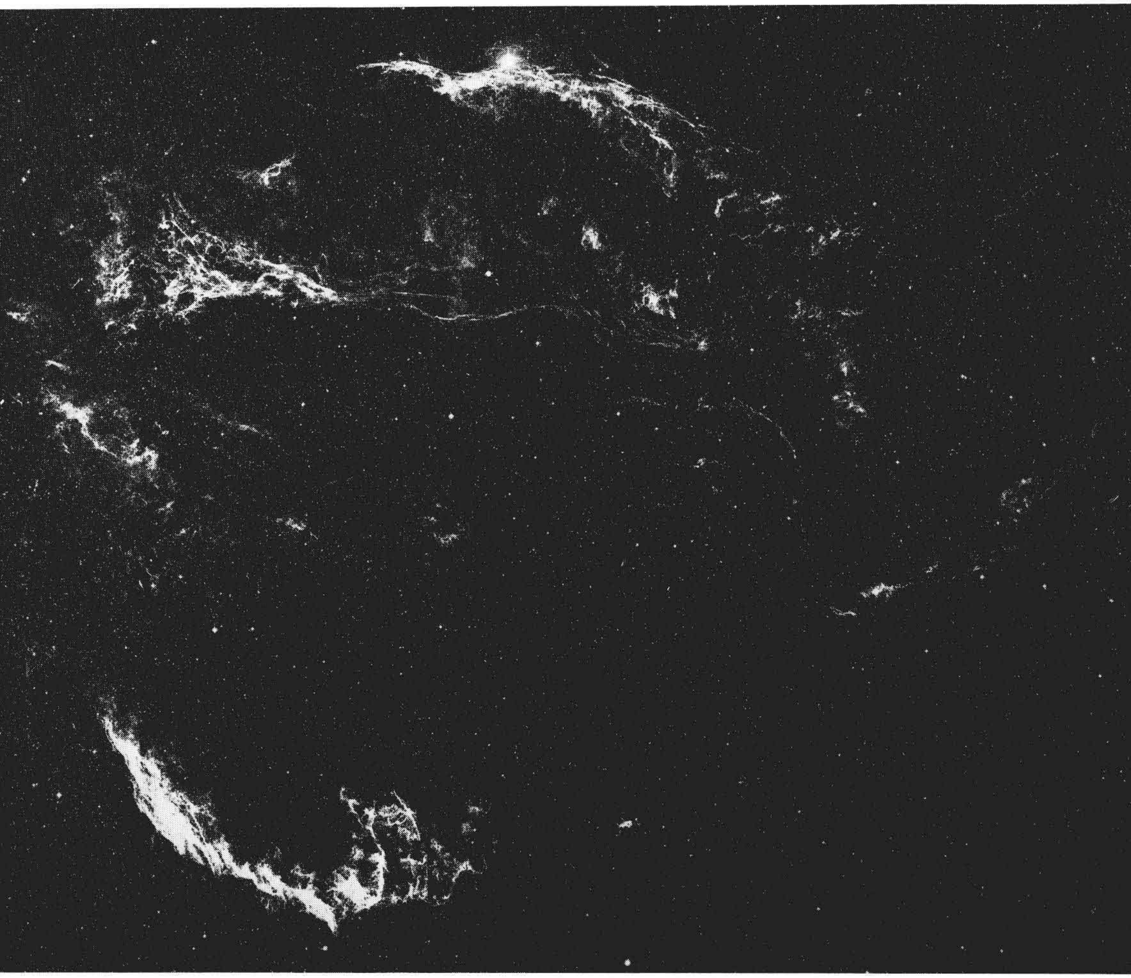


Figure 1-3 A Supernova Remnant
Massive stars end their life cycles with supernova explosions. These wispy, glowing clouds in the constellation of Cygnus are from a star that blew itself apart 20,000 years ago. The nearly spherical nebula is 120 light years in diameter. Shock waves from supernova explosions can compress cool interstellar clouds and start star-creation elsewhere in the galaxy. (Hale Observatories.)

kilometer—a hundredfold increase in the density of dust. This increase had the immediate effect of shielding the inner portions of the interstellar cloud. Light from nearby stars could no longer shine through the cloud.

The obscuring effect of interstellar dust grains played an important role in the genesis of our solar system. Since starlight could no longer penetrate and warm our cloud, the temperature of the gas inside the cloud began to plunge toward absolute zero. Gas pressure and gas temperature always go hand in hand. Consequently, as the temperature declined, the pressure that the gas could exert also decreased. The outward gas pressure of the cloud was no longer able to resist the inward push of gravity. Gravity won and the cloud began to contract.

Astronomers often find cool, dark, contracting clouds of interstellar gas and dust that are at the initial stages of star-creation. As shown in Figure 1-4, these so-called globules are most easily seen when silhouetted against a bright nebulosity. A typical globule is a few light years in size and contains enough matter to make dozens of solar systems.

As our globule contracted under the influence of gravity, eddies and slowly rotating whirlpools began to develop from random turbulence within the cloud. These eddies caused the cloud to break up into smaller peices. One of these slowly rotating cloud fragments was destined to become our solar system.

As our cloud fragment continued to contract, its rate of rotation began to speed up. This rotation caused our cloud fragment to become distinctly disk-shaped. This was the *primordial solar nebula.* It measured 10 billion kilometers across (roughly the same size as Neptune's orbit), was nearly 200 million kilometers thick (roughly the same as the distance from the earth to the sun), and contained twice as much matter as is presently found in the solar system.

Gravity continued to dominate the early evolution of the primordial solar nebula as more and more matter contracted toward the center of the disk. This infalling gas caused the central regions of the solar nebula to become significantly hotter than the outer regions. The interstellar dust grains in the inner regions were soon