

Chapter 2

Rocks and Dust in the Planetary Neighborhood

The planet we live on, the Earth, is a chunk of rock partially covered with liquid water and overlaid with a thin blanket of gaseous atmosphere. Liquid oceans and polar ice caps cover three quarters of the Earth's surface. The continents, on which we walk and build our cities and villages, are made up of rocks. However, the rocky crust of the Earth is not limited to the continents, but extends to the ocean floors. These rocks are aggregates of minerals, which are solid-state compounds of common elements such as oxygen, silicon, aluminum, iron, calcium, sodium, potassium, and magnesium. Three of our Solar System neighbors, Mercury, Venus, and Mars, have similar rocky surfaces and the four together are collectively known as the "terrestrial planets". The rocky nature of Mars is most vividly illustrated by the landscape images sent back by the Martian rovers *Spirit*, *Opportunity*, and *Curiosity*. In contrast, the other four planets in the outer Solar System—Jupiter, Saturn, Uranus, and Neptune—are gaseous in nature and do not possess a solid surface. The only anomaly is Pluto, the outermost member, which is believed to be made up of water ice and is no longer considered a planet.

Most planets have moons that revolve around them. Our own Moon, the only natural satellite of the Earth, is also rocky. When Galileo Galilei (1564–1642) observed the Moon with a telescope in 1610, he did not find a perfect, smooth celestial body, but instead an uneven and rough surface. The majority of the topographical features of the Moon turned out to be craters, or scars left over from external impact events. The rocky nature of the Moon is clearly illustrated by the Apollo astronauts who walked and drove vehicles on the surface of the Moon. Other planetary satellites, such as the Martian moons Phobos and Deimos, are also rocky. So are the moons of Jupiter such as Io, Europa, Ganymede, and Callisto. So is the largest moon of Saturn—Titan. Pictures brought back by the European Space Agency's *Huygens probe* showed the rocky nature of Titan's surface most clearly and dramatically (Fig. 2.1).

On a smaller scale, there are the asteroids. Asteroids are small, rocky objects that revolve around the Sun. The largest asteroid known, Ceres, has a size of 940 km and a mass 10,000th that of the Earth. Many asteroids are concentrated in the "asteroid belt" between the orbits of Mars and Jupiter. The number of asteroids known

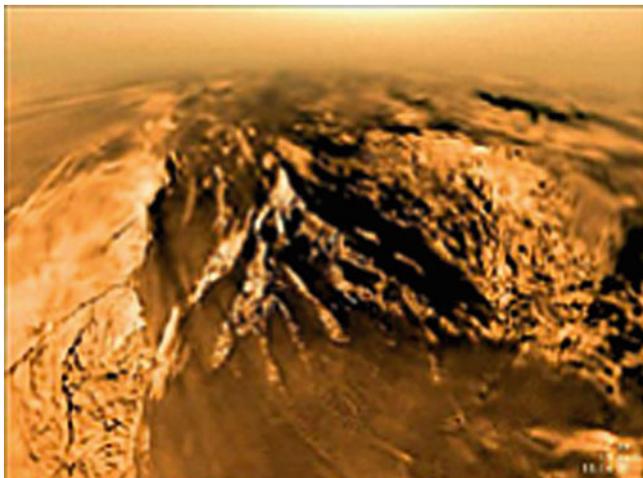


Fig. 2.1 A view of Titan's surface taken by the *Huygens probe*.
A view of the surface of Titan as taken by the *Huygens probe* during its fall through Titan's atmosphere after its release from the *Cassini* spacecraft on January 14, 2005. Photo credit: ESA



Fig. 2.2 Images of the asteroids Gaspra and Ida.
These images of Gaspra (*left*) and Ida (*right*) were taken by the *Galileo* spacecraft. Marks left by past impacts can clearly be seen on the surface. The longest dimension is about 20 km for Gaspra and 50 km for Ida. Photo credit: NASA/JPL

exceeds 100,000, a number likely to increase rapidly as larger telescopes are put into action for their search. Close-up photographs taken by spacecrafts have revealed that asteroids are irregular objects. When the *Galileo* spacecraft flew by the asteroid 951 Gaspra on October 29, 1991, the pictures of the asteroid showed that its surface is marred by deep scars created by a long history of impact events. The images of Gaspra and Ida (Fig. 2.2) and of Vesta (Fig. 2.3) definitely carry home the message that these heavenly bodies look very much like ordinary rocks.

If asteroids are rocky, then it would be possible to land on them. Indeed a Japanese space mission did exactly that. The *Hayabusa mission* was launched on May 9, 2003 and reached asteroid 25143 Itokawa in September 2005. It descended on the asteroid in November 2005 and collected samples from the surface of the



Fig. 2.3 Image of the asteroid Vesta.

This picture of Vesta was taken by the *Dawn* spacecraft. *Dawn* was launched in September 2007 and reached the asteroid in July 2011 after an almost 4 year journey across the Solar System. At a distance of 41,000 km, the surface of Vesta can be clearly seen to have a rocky appearance. The main difference between asteroids and the Earth and the Moon is that they are not necessarily spherical in shape. However, Vesta is nearly spherical with a diameter of about 500 km. Photo credit: NASA/JPL

asteroid before returning to Earth on June 13, 2010. A capsule containing the rock sample was released from the spacecraft and landed safely in Australia. Although the amount of asteroid materials contained in the return sample was small, it did allow scientists a direct look into the chemical composition of the asteroid and establish the asteroid origin of some of the meteorites collected on Earth.

How small can an asteroid be? There is no clear definition on the minimum size of an asteroid. We do know that solid debris of all sizes are present in the interplanetary space. The commonly used dividing line is a size of 100 m, although this is entirely arbitrary. Any object larger than 100 m is called an asteroid, smaller a “meteoroid”, which we define as small asteroids with orbits around the Sun that cross the Earth’s orbit. When a meteoroid enters the Earth’s atmosphere, the friction of its fall heats up the surrounding air, leading to a streak of light across the sky which we see as a meteor (commonly known as a “shooting star”). Although now we can predict the coming of meteor showers, we still cannot predict the exact occurrence of an individual meteor. Meteors are examples of the changeable nature of the heavens. Although the Sun, the Moon, the stars, and the planets all have regular, predictable movement patterns in the sky, the coming of meteors cannot be predicted. Such unpredictable events in the heavens have been used for astrological purposes. For example, the occurrence of a meteor was interpreted in China as a sign for the fall of a major figure, a court official, a commanding general.

On a typical clear moonless night, several meteors can be observed in an hour across the sky. These are called sporadic meteors as their appearance can be sudden and unpredictable, and they seem to appear in random directions in the sky. These are in contrast to shower meteors, which seem to originate from a fixed point in the sky and can be expected to occur at certain times of the year. For example, a meteor shower that occurs every August seems to radiate from the constellation of Perseus and is named the Perseid meteor shower. In 1833, a spectacular meteor shower was

Fig. 2.4 Engraving showing the 1833 Leonid meteor showers. Meteor showers can be dramatic events as seen in this engraving showing the 1833 Leonid meteor showers



seen to come from the constellation of Leo (Fig. 2.4). It has been said that the great meteor shower of 1833 was responsible for the ignition of public interest in astronomical research in the USA. This meteor shower, named the Leonid meteor shower, had a repeat performance on 1866. In fact, the historical record shows that this same meteor shower has been observed as early as 899 AD. We now know that the periodic nature of meteor showers is related to earth-orbit crossing comets (Chap. 18).

As a meteoroid passes through the atmosphere it burns itself up due to atmospheric friction and gives off visible light in the process. It may also fragment into multiple pieces. Sometimes a meteoroid will be completely vaporized in its passage through the atmosphere. In fact, most meteoroids lose most of their mass. If a fraction of the meteoroid survives at all through the atmosphere, its remnant on the ground is called a meteorite.

Falls of meteorites have been recorded throughout history, dating back over 1,000 years. The oldest meteorite fall on record is the Nogata meteorite recovered in Japan on May 19, 861 A.D. The earliest European record was that of the Ensisheim meteorite in 1492. The meteorite that fell on June 16, 1794 was at a location near a major European city, Siena, Italy, and was witnessed by many people. In spite of the numerous reports of meteorite falls in Europe, they were not taken seriously. In China, Japan, and Korea, imperial and provincial records contained hundreds of

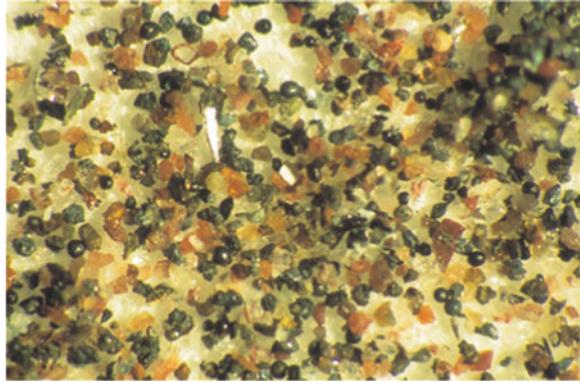
reported cases of meteorite falls, but there was little interest in seeking out the origin of these events. In Europe, the more religious considered meteorites to be acts of the devil. Those who were brave or imaginative enough to suggest otherwise were condemned as heretics. There was a strong belief that the heavens are divine, holy, and unchanging. Since the time of Aristotle, the celestial sphere was seen to be separate and detached from the terrestrial earth, where hurricanes, floods, volcanos, earthquakes, and other unpredictable misfortunes happen. In religious circles, such calamities were commonly believed to be caused by sins of men. This is in stark contrast to the heavens which are peaceful and everlasting. There was a strong reluctance to associate temporal phenomena such as meteors with anything in the celestial sphere. Mud and rocks are supposed to be confined to the domains of the Earth, and could not have descended from the heavens.

Even in modern times, meteorites were thought to be created in the atmosphere by lightning, or by accretion of volcanic dust. One of the most famous quotes was that of Thomas Jefferson (1743–1826), who reacted to the reported 1807 fall of a meteorite in Connecticut with the comment “it is easier to believe that two Yankee professors would lie than that stones should fall from heaven”. In 1794, a German scientist, Ernst Friederick Chladni (1756–1827), suggested that meteorites are the result of fireballs, and meteorites do not originate from the clouds, but from outside of the Earth. His idea received no support from his contemporary scholars. In 1802, an English chemist, Edward Charles Howard (1774–1816), analyzed four meteorites and found their chemical composition to be similar but different from terrestrial rocks. It was the chemical analyses and microscopic examinations of meteorites that finally persuaded the scientific community of the extraterrestrial origin of meteorites and that did not happen until the early nineteenth century.

Before 1969, there were only 2100 known meteorites catalogued. The remarkable increase in the recovery of meteorites in recent years is due to the activities in Antarctica. Although meteorites fall randomly all over the world, the white, icy background of Antarctica makes it much easier to spot one. Also since the rocky surface of Antarctica is hidden below 3,000 m of ice, any piece of rock one sees on the surface is likely to be extraterrestrial in origin. A meteorite fallen on ice is also less likely to have been damaged and is better preserved through time. The first meteorite in Antarctica was found in 1912, but in 1969, the Japanese Antarctic Research Expedition found 9 meteorites near Yamato Mountains and realized that the movement of ice sheets can bring meteorites close together in concentrated groups. Since then there have been many search programs by different countries. For example, the American Antarctic Search for Meteorites (ANSMET) team has recovered over 20,000 meteorites. As of 2012, there are over 45,000 known meteorites. Other promising recovery sites are deserts, where the barren landscape also allows for easy identification. Successful recoveries have been made in deserts in Chile, Namibia, and Australia.

One good thing about meteorites is that we can pick them up and examine them. An initial impression of meteorites is that they resemble rocks. This in itself is significant, as meteorites are extraterrestrial objects; we have direct, first-hand experience that there are rocks in the sky. However, they are on average heavier than a rock of similar size on Earth.

Fig. 2.5 Micrometeorites collected in Antarctica. This sample of micrometeorites was collected by a French–Italian expedition to Antarctica in 2003. Image credit: CNRS Photothèque, Michel Maurette



Although we generally associate meteoroids with macroscopic objects of meters or centimeters in size, the remnants of small meteoroids (those of golf balls or marbles sizes) may leave too small a remnant to be seen by the eye. A very small meteoroid (with sizes smaller than a millimeter) may even float through the atmosphere without burning. The remnants of these meteoroids are called micrometeorites (Fig. 2.5). Samples of these particles have been collected in Greenland and Antarctica where they are easier to spot on an ice/snow surface. From the collected samples, it is estimated every year 40,000 tons of micrometeorites land on the Earth.

Our current thinking of the origin of micrometeorites is that they are remnants of comets. Since micrometeorites come from space, they must be flying around in interplanetary space. As solid objects, the terrestrial planets, moons, and asteroids can reflect sunlight and can be seen as bright visual objects in the sky. Smaller solids like meteoroids can also be seen as meteors as they burn through the atmosphere.

Although meteorites can be found by just random searching of the ground, they are much easier to find if we know that one is falling. The fall of a large meteorite is often accompanied by bright fireballs and loud sonic booms. On average, two or three large fireballs are observed worldwide per night. In a way, a fireball is just a very bright meteor (Fig. 2.6). The International Astronomical Union defines a fireball as a meteor that is brighter than any of the planets. These falls often create quite an alarm among the populations that witnessed them. Nowadays, the sky is systematically watched for fireballs through the installation of a system of wide-angle cameras. By comparing the images of the fireballs in different cameras, the location of the fall can be identified, therefore increasing the chance of recovering the meteorite.

One of the earliest records of tracking the fall of a meteorite is the meteorite that landed near Orgueil in southern France on May 14, 1864. A brilliant fireball accompanied by loud explosions was seen and heard all over southern France shortly after 8 PM. Most of the stones fell near the village of Orgueil and over 20 pieces of black rock were immediately collected by local villagers. The largest



Fig. 2.6 Fireballs.

This picture of a fireball was taken on September 30, 2008 at the Black Mesa State Park in Oklahoma, USA by Howard Edin. This fireball meteor appeared about 2 AM and can be seen passing through the constellations of Taurus (*top*) and Orion. Photo credit: Howard Edin

Fig. 2.7 Carbonaceous chondrite meteorites. Carbonaceous chondrite meteorites such as the Allende shown in this picture are often black or dark gray in color, and are rich in carbon. These are the kinds of meteorites in which extraterrestrial organics are found. Photo credit: Toby Smith



piece is as large as a man's head, but typically the collected pieces are fist-sized objects. A total of 11.5 kg of the meteorite remnants were recovered, with the largest piece (9.3 kg) now residing in the Paris Museum. Between 1864 and 1894, 47 pieces of scholarly work were published on the meteorite.

As times moved on, scientists found that one of the distinguishing features of meteorites is their texture. Inside the meteorites are millimeter-size ellipsoidal structures called chondrules. The shapes and structures of the chondrules led us to believe that these chondrules were formed in a molten state. One special kind (about 4 % of all the meteorites that fall to the Earth) is called carbonaceous chondrites (Fig. 2.7). They are among the most primitive objects in the Solar System.

In 1834, a Swedish chemist, Jöns Jacob Berzelius (1779–1848), was the first to discover that meteorites contain organic materials. Berzelius was considered the

Fig. 2.8 Murchison meteorite.

The meteorite that fell near the town of Murchison, Australia, is one of the carbonaceous meteorites that are found to contain a large amount of organic material



father of Swedish chemistry and his proposed system of chemical notation using a combination of letters and numbers to signify elements and their proportions (e.g., H_2O) in a compound is still in use today. Confirmation of this discovery had to wait over a hundred years. In March, 1961, Bartholomew Nagy and Douglas Hennesy of Fordham University in New York, together with a petroleum chemist, Warren Meinschein, from the ESSO Research Corporation, reported in a meeting of the New York Academy of Sciences that they found hydrocarbons in the Orgueil meteorite that resemble products of life. Nagy and his team performed their analysis on a sample obtained from the Museum of Natural History in New York. They took incredible care to avoid the possibility of contamination. Using a mass spectrometer, they identified various hydrocarbons including paraffins similar to those found in animal products such as butter. From this study, Nagy concluded that these organic compounds are indications of biogenic activities beyond the Earth.

In a paper published 3 weeks after the New York meeting, John Desmond Bernal (1901–1971) of the University of London commented on Nagy's report and discussed the possible origin of the organics. If the hydrocarbons are the products of life, then they must have been inherited from a planetary body, from which the Orgueil meteorite originated. However, most bodies in the asteroid belt are believed to be too small and too dry to harbor life. He even speculated that the Orgueil meteorite could have been sent from the primitive Earth, and arrived back at the Earth after a journey lasting millions of years in interplanetary space. The possibility that the meteorite came from an Earth-like planet in another solar system was also mentioned. In any case, the presence of organics in meteorite is difficult to explain.

On September 28, 1969, half a ton of fragments of a meteorite fell near the town of Murchison in Victoria, Australia. Following a bright fireball and a loud boom, fragments of the fallen meteorite were found over an area larger than 13 square km. Individual pieces as large as 7 kg were recovered. A fragment of the Murchison meteorite is shown in Fig. 2.8. Analysis of the Murchison meteorite by John Cronin and Sandra Pizzarello of Arizona State University has shown they contain complex organic compounds with both aromatic (ring-like) and aliphatic (chain-like) structures. The term "aromatics" was first used in the mid-nineteenth century to refer to chemical substances with notable aromas, but now the term is used to refer to a class of molecules consisting of rings of six carbon atoms. The simplest example is benzene, which consists of six carbon atoms arranged in the form of a

ring with six hydrogen atoms each attaching to one carbon atom. In contrast, aliphatic compounds consist of carbon atoms arranged in the form of a chain. Both aromatic and aliphatic compounds form the basis of molecules of life. Many common biochemical substances, including amino acids, fatty acids, purines, pyrimidines, and sugars are found in the Murchison meteorite.

One of the people who has contributed much to our modern understanding of organics in meteorites is Sandra Pizzarello. She was originally from Venice, Italy and already had four children before she moved to the U.S. with her husband. When her youngest child went to grade school, she decided to go back to university to study biochemistry. One of her teachers was a young professor named John Cronin. From that point on, Pizzarello and Cronin carried on decades of collaboration, discovering and analyzing organics in meteorites.

On the morning of January 18, 2000, a fireball appeared in the sky of the Yukon Territory of Canada, and the colorful event lasting over 10 min was witnessed by hundreds of observers. However, subsequent aerial flights were unable to find a crater or a site of impact of the meteorite. Fortunately, fragments were found within 1 week on the frozen surface of Tagish Lake. This is a big break for scientists as the frozen lake was perfect for keeping the meteorite in pristine condition.

I consider meteorites gifts from heaven, as they give us the direct and complete access to extraterrestrial material. We can examine meteorites by visual inspection, subject them to passive observations by instruments, as well as perform active manipulations by experiments. This is far superior to the limited ability of remote astronomical observations of celestial objects. We can measure and determine their physical and chemical properties, and derive the abundance of various chemical components as well as their isotopic ratios. Laboratory techniques that have been applied to meteorites include spectroscopy, nuclear magnetic resonance (NMR), X-ray absorption near-edge structure (XANES), and electron paramagnetic resonance (EPR).

If we go to the countryside away from the artificial light of the cities and step out about 1 h after sunset on a clear, moonless evening in the Spring, we can see a cone of diffuse light shaped like a pyramid spread out near the horizon with the brightest region near the point where the Sun has just set. This cone of light is called the zodiacal light (Fig. 2.9). The zodiacal light is best viewed from the tropics near the equator as it spreads out high in the sky. At high Northern or Southern latitudes, the zodiacal light lies closer to the horizon. At its best, the brightness of the zodiacal light can rival that of the Milky Way. However, the nature of the two is very different. Although it appears diffuse to the naked eye, the Milky Way is made up of light from billions of distant stars in our Galaxy (Fig. 2.10). The zodiacal light is much closer; it originates from the ecliptic, the plane in the Solar System where most of the orbits of the planets lie. If we observe the zodiacal light with a telescope, we will not be able to separate it into distinct stars. In fact, the zodiacal light originates from sunlight reflected by a large collection of tiny dust particles on the ecliptic plane. These particles are so small that we cannot see them with our eyes if we hold them in our hands. The particles that are responsible for the zodiacal light have sizes between a fraction of a micrometer (μm , or one thousandth of a millimeter) to several micrometers and they are called interplanetary dust particles.

Fig. 2.9 Zodiacal light.
This picture of the Zodiacal Light was photographed by Dominic Cantin near Quebec City, Canada. The bright spot near the horizon is the planet Venus. Photo credit: Dominic Cantin



Fig. 2.10 The Milky Way.
A panoramic view of the Milky Way. The dark patches in this picture are due to absorption by interstellar dust along the light of sight. The center of the Milky Way galaxy is located in the constellation Sagittarius, close to the border of Scorpius and Ophiuchus. Photo credit: Wei-Hao Wang



The origin of the dust particles that make up the zodiacal light is, however, unclear. They could come from fragments of either asteroids or comets. From an analysis of the radiative forces on these particles from solar radiation as well as gravitational forces exerted by the planets, Peter Jenniskens of the SETI Institute in Mountain View, California, came to the conclusion that they are most likely to be of cometary origin.

Our modern studies of interplanetary dust particles are not limited to the observation of reflected sunlight from these particles. In fact, we can go out and actively collect them in the upper atmosphere. By using high-flying aircraft, we can collect samples of interplanetary dust particles and bring them back to Earth for scientific analysis. We will talk more in detail about them in Chap. 16.

So we have solid rocks in the inner Solar System in the forms of asteroids and interplanetary dust particles, and they occasionally run into the Earth. The fall of asteroids through the atmosphere may leave visible trails in the form of meteors, marks on the Earth's crust, or remnants on the ground as meteorites. However, the Solar System does not end at the orbit of Pluto and astronomers now believe that there are many rocky objects belonging to the Solar System beyond the orbit of Pluto. Pluto is in fact only one of tens of thousands of objects in a thick ring around the Sun. This ring extends to 50 astronomical units (A.U., the distance between the Earth and the Sun) and is named the Kuiper Belt in honor of Gerard Peter Kuiper (1905–1973), who together with Kenneth Essex Edgeworth (1880–1972) predicted its existence. The Kuiper Belt is probably the remnants left over from the formation of the Solar System, where the inner part condensed into the major planets, leaving the thousands of small, icy objects stranded in the outer parts.

The first Kuiper Belt Object (KBO) was discovered in 1992. Since then nearly one thousand new members of the Solar System have been found, several of which are as big, or even bigger, than Pluto. These discoveries have raised doubts about whether Pluto can genuinely be called a planet, as it is no different in character from the other KBOs. The issue on the status of Pluto was debated by the International Astronomical Union in 2006 during its General Assembly in Prague. The General Assembly is held once every 3 years and is the occasion where astronomers from all over the world gather to disseminate the latest astronomical discoveries and to debate policy issues. As a result of a vote by the delegates present in Prague, Pluto was removed from the list of planets. This outcome was a surprise to the general public, whom for years have been told that there are nine planets but now all of a sudden found that there are only eight. This demotion of Pluto is not because astronomers have a change of heart but because new discoveries in our Solar System studies put the nature of Pluto in a new light.

We now believe there are over 100,000 KBOs with sizes larger than 100 km populating the Kuiper Belt. If we count smaller objects, the numbers are staggering. Extrapolating from the discovery of KBOs of sizes as small as 10 m in 2006 by Taiwanese astronomer Hsiang Kuang Chang, the population of such small bodies in the Kuiper Belt is estimated to be in the quadrillions (10^{15}).

So is the Kuiper Belt the outer limit of the Solar System? No, beyond the Kuiper Belt is an immense sphere called the Oort Cloud (named after Jan Hendrik Oort,

1900–1992) which extends from 3000 to 100,000 AU from the Sun. The outer edge of the Oort Cloud extends one third of the way to our nearest stellar neighbor Proxima Centauri. This Oort Cloud is the home of the long-period (>200 years) comets, which when perturbed by the passage of a nearby star, can venture periodically into the inner Solar System. While on this journey, the proximity to the Sun causes its icy surface to evaporate, giving it a beautiful tail that we admire. For the other dormant comets that reside in the Oort Cloud, the Sun is too far away and its radiation too weak to cause any harm. Current estimates put the number of comets in the Oort Cloud in the trillions, or even tens of trillions.

So the Earth and its surroundings have a lot of solid materials. The size of these solids ranges from less than a micrometer (in the form of interplanetary dust) to kilometers in the form of asteroids and planetary satellites. As the Earth moves around the Sun, it passes through this concentration of interplanetary dust particles and accretes about a hundred tons every day. Unknown to most of us, we absorb a large amount of invisible fine dust from space. Our Earth is therefore not a closed system as we are constantly bringing in extraterrestrial materials into our local environment. We can consider this a form of rain from heaven.

Where did these rocks come from? For one hundred years, scientists believed that the Solar System was created out of a collapsed interstellar cloud of dust and gas. Rotating together, these primordial gases are stirred and mixed in an oven-like condition. When these gases cooled, molten rocks condensed out of this primordial nebula, giving us the planets, asteroids, comets, meteoroids, and other minor solid bodies in the outer Solar System.

In this picture, every piece of solid in the Solar System was freshly made. All molecules and dust that it inherited from the parent interstellar cloud were completely destroyed. All the memories were erased and all connections to the past were lost. Is that really the case? Now astronomers are finding evidence that it may not be completely true. In the remaining chapters of this book, we will discuss the discovery of stardust, small solid particles made by stars. This discovery shows that solids are not the sole domain of the Earth and the Solar System, but in fact are present in stars and in the Galaxy as well. Due to the existence and prevalence of these solid particles in the general interstellar space, the Solar System may not be completely isolated from the rest of the Galaxy as previously thought. There is evidence that the early Solar System has been enriched/contaminated by stardust. The Solar System was not a completely new entity formed 4.6 billion years ago, but has inherited materials from other stars in the Galaxy. This star-Solar System connection is the theme that we will explore in this book.

A brief summary of this chapter

Earth and surroundings have a lot of solid materials. Earth is not a closed environment.

Key words and concepts in this chapter

- Different forms of solids in the Solar System
- Planets and planetary satellites
- Asteroids
- Meteoroids, meteors, meteorites, and micrometeorites
- Extraterrestrial origin of meteorites
- Organics in the Orgueil and Murchison meteorites
- Zodiacal light and interplanetary dust particles
- Kuiper Belt objects
- Rain from heaven

Questions to think about

1. Is it surprising that there can be rocks that fall from the sky? Put yourself in the minds of people 200 years ago and discuss why it was so difficult for people to accept the extraterrestrial origin of meteorites.
2. Meteorites provide us a link to the extraterrestrial world. What are our other links? Can you compare the effectiveness of these links in learning about the extraterrestrial world?
3. At the meeting of the New York Academy of Sciences in 1961, Nagy, Meinshein and Hennessy were quoted to state that “biogenic processes occur and that living forms exist in regions of the universe beyond the earth” (Bernal, J.D. 1961, *Nature*, **190**, 129). Do you think it is possible?
4. Since the beginning of the twentieth century, astronomers have been studying galaxies as far as billions of light years away. The Kuiper Belt is in our Solar System and is relatively nearby, but they were not known until the late twentieth century. Why did astronomers pursue objects so distant and at the same time were so ignorant about objects in our own backyard?
5. The Earth is subjected to a constant rain of external fine dust particles at a rate of a hundred tons a day. What are the effects of this rain? Should we be concerned about it?



<http://www.springer.com/978-3-642-32801-5>

Stardust

The Cosmic Seeds of Life

Kwok, S.

2013, XXII, 267 p. 74 illus., 50 illus. in color., Softcover

ISBN: 978-3-642-32801-5