

the continents were separated from Pangaea (see Section 6-2). The impact explanation of the Great Dying is not universally accepted. Another possible explanation is a massive amount of volcanic eruption that darkened the skies and changed the climate.

Could a catastrophic impact happen again? So many asteroids cross Earth's path that scientists agree that it is a matter of "when" rather than "if." The good news is that studies of craters show that larger asteroids strike Earth significantly less often than do smaller ones. Although asteroids large enough to create Meteor Crater strike Earth about once every 10,000 years, killer asteroids, like the one that killed

off the dinosaurs, collide with Earth only once every 100 million years. The threat of a catastrophic impact by an asteroid or comet in our lifetimes, thankfully, is remote.

How did the Chicxulub crater move from the Pacific to the Caribbean?

### 9-14 Frontiers yet to be discovered

The years of the *Pioneer* and *Voyager* spacecraft were the first golden era of solar system research. We are now in another such period, with spacecraft either in development or already en route to planets, asteroids, comets, and even, as we will see shortly, out observing the weather in space. From studies of solar system debris, astronomers hope to learn whether life on Earth was brought here from elsewhere by asteroid or meteoroid impacts. They also hope to answer such questions as the evolutionary history of the space debris; how much of Earth's water came here during the planet's formation and how much landed afterward from comet impacts; whether the asteroids have sufficiently valuable compositions to justify mining them; whether comets can be harvested to supply water and other materials for people colonizing the solar system; and whether the Oort cloud really exists.

### SUMMARY OF KEY IDEAS

- Astronomical objects smaller than the eight planets are classified as dwarf planets or small solar-system bodies (SSSBs).
- A variety of other names, including asteroids, comets, meteoroids, trans-Neptunian objects, Kuiper belt objects (KBOs), and Oort cloud objects, overlap with "dwarf planet" and "SSSB."
- KBOs and Oort cloud objects are trans-Neptunian objects—they orbit farther from the Sun than the outermost planet.
- To date, three objects—Pluto, Ceres, and Eris—have been classified as dwarf planets.

- Pluto, a KBO and dwarf planet, is an icy world that may well resemble the moon Triton.

- Other objects orbit the Sun beyond Neptune. For example, at least 1277 KBOs have been observed. A few potential Oort cloud objects have also been identified.

#### Asteroids

- Tens of thousands of belt asteroids with diameters larger than a kilometer are known to orbit the Sun between the orbits of Mars and Jupiter. The gravitational attraction of Jupiter depletes certain orbits within the asteroid belt. The resulting Kirkwood gaps occur at simple fractions of Jupiter's orbital period.

- Jupiter's and the Sun's gravity combine to capture Trojan asteroids in two locations, called *stable Lagrange points*, along Jupiter's orbit.

- The Apollo asteroids move in highly elliptical orbits that cross the orbit of Earth. Many of these asteroids will eventually strike the inner planets.

#### Comets

- Many comet nuclei orbit the Sun in the Kuiper belt, a doughnut-shaped region beyond Pluto. Billions of cometary nuclei are also believed to exist in the spherical Oort cloud located far beyond Pluto.

- Comet nuclei are fragments of ice and rock often orbiting at a great inclination to the plane of the ecliptic. In the Kuiper belt and Oort cloud they have fairly circular orbits. When close to the Sun, they generally move in highly elliptical orbits.

- As an icy comet nucleus approaches the Sun, it develops a luminous coma surrounded by a vast hydrogen envelope. A gas (or ion) tail and a dust tail extend from the comet, pushed away from the Sun by the solar wind and radiation pressure.

#### Meteoroids, Meteors, and Meteorites

- Boulders and smaller rocks in space are called *meteoroids*. When a meteoroid enters Earth's atmosphere, it produces a fiery trail, and it is then called a *meteor*. If part of the object survives the fall, the fragment that reaches Earth's surface is called a *meteorite*.

- Meteorites are grouped in three major classes according to their composition: iron, stony-iron, and stony meteorites. Rare stony meteorites, called *carbonaceous chondrites*, may be relatively unmodified material from the primitive solar nebula. These meteorites often contain organic hydrocarbon compounds, including amino acids.

- Fragments of rock from "burned-out" comets produce meteor showers.

- An analysis of the Allende meteorite suggests that a nearby supernova explosion may have been involved in the formation of the solar system some 4.6 billion years ago.
- An asteroid that struck Earth 65 million years ago probably contributed to the extinction of the dinosaurs and many other species. Another impact caused the “Great Dying” of life 250 million years ago. Such devastating impacts occur on average every 100 million years.

### WHAT DID YOU THINK?


- 1** *Are the asteroids a former planet that was somehow destroyed? Why or why not?* No. The gravitational pull from Jupiter prevented a planet from ever forming in the asteroid belt. Also, the total mass of the asteroids is much less than even the mass of tiny Pluto, a dwarf planet.
- 2** *How far apart are the asteroids on average?* The distance between asteroids averages 10 million km.
- 3** *How are comet tails formed? Of what are they made?* Ices in comet nuclei are turned into gas by absorbing energy from the Sun. Debris is released in this process. Sunlight and the solar wind push on the gas and dust, creating the tails.
- 4** *In what directions do a comet’s tails point?* Comets’ gas tails point directly away from the Sun; their dust tails make arcs pointing away from the Sun.
- 5** *What is a shooting star?* A shooting star is a piece of space debris plunging through Earth’s atmosphere—a meteor. It is not a star.

### Key Terms for Review

- |                             |                                  |
|-----------------------------|----------------------------------|
| amino acid, 278             | iron meteorite, 277              |
| Apollo asteroid, 262        | Kirkwood gaps, 260               |
| asteroid belt, 259          | Kuiper belt, 264                 |
| belt asteroid, 259          | long-period comet, 271           |
| carbonaceous chondrite, 278 | meteor, 273                      |
| chondrites, 278             | meteor shower, 274               |
| coma (of a comet), 266      | meteorite, 273                   |
| dust tail (of a comet), 268 | meteoroid, 273                   |
| dwarf planet, 255           | nucleus (of a comet), 266        |
| gas (ion) tail, 268         | Oort cloud, 265                  |
| hydrogen envelope, 266      | planet, 255                      |
| impact crater, 274          | radiation (photon) pressure, 268 |
|                             | short-period comet, 271          |

- |  |                             |
|--|-----------------------------|
| Small Solar-System Bodies (SSSBs), 255 | stony-iron meteorite, 277   |
| stable Lagrange points, 261            | Trojan asteroid, 261        |
| stony meteorite, 276                   | Widmanstätten patterns, 277 |

### Review Questions

1. A piece of space debris that you pick up from the ground is called a(n): a. asteroid, b. meteoroid, c. meteor, d. meteorite, e. comet
2. Space debris that is a roughly equal mix of rock and ice is called a(n): a. asteroid, b. comet, c. meteoroid, d. meteorite, c. meteor
3. Which is the rarest type of meteorite in space? a. irons, b. stony-irons, c. stony meteorites
4. Which part of a comet is solid? a. nucleus, b. halo, c. gas tail, d. dust tail, e. coma
5. Suppose you were standing on Pluto. Describe the motions of Charon relative to the horizon. Under what circumstances would you never see Charon?
6. Describe the circumstantial evidence that supports the idea that Pluto is one of a thousand similar icy worlds that once occupied the outer regions of the solar system.
7. What role did Charon play in enabling astronomers to determine Pluto’s mass?
8. Why are asteroids, meteoroids, and comets of special interest to astronomers who want to understand the early history of the solar system?
9. Describe the objects in the asteroid belt, including their sizes, orbits, and separation.
-  10. To test your understanding of the asteroid belt, do Interactive Exercise 9-1 on the Web. You can print out your results, if required.

11. Why are there many small asteroids but only a few very large ones?
12. Describe the different chemistries of the two tails of a comet.
13. In what directions do comet tails point, and why?
14. What are the Kirkwood gaps, and what causes them?
15. What are the Trojan asteroids, and where are they located?
16. Describe the three main classifications of meteorites. How do astronomers believe that these different types of meteorites originated?
17. Why do astronomers believe that the debris that create many isolated meteors come from asteroids, whereas the debris that create meteor showers are related to comets?