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ASTRONOMY

Chapter 13 COMETS AND ASTEROIDS: DEBRIS OF THE SOLAR SYSTEM

PowerPoint Image Slideshow

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9.1 ASTEROIDS AND METEORITES

Most meteorites are pieces of asteroids

Meteoroid: Small rocky or metallic body in space.
(outside of Earth's atmosphere)

- **Meteor:** The bright trail left by a meteorite.

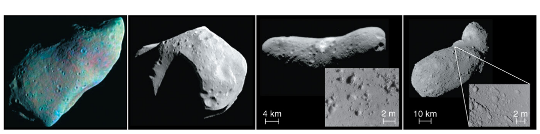
(passing through the atmosphere)

- **Meteorite:** A rock from space that falls through Earth's atmosphere.

(gone through the atmosphere on Earth's surface)

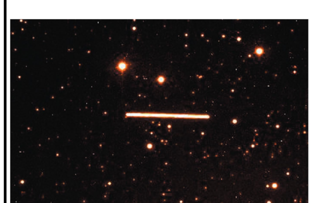
Asteroid Facts

- Asteroids are rocky leftovers of planet formation.
- The largest is Ceres, diameter ~1000 km.
- There are 150,000 listed in catalogs, and probably over a million with diameter >1 km.
- Small asteroids are more common than large asteroids.
- All the asteroids in the solar system wouldn't add up to even a small terrestrial planet.



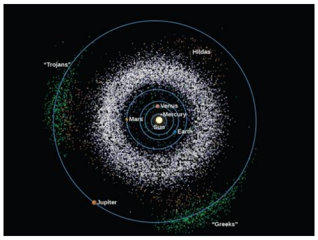
Asteroids are cratered and not round.
(Not enough gravity to make it spherical they are potato shaped)

Discovering Asteroids



- Asteroids leave trails in long-exposure images because of their orbital motion around the Sun.

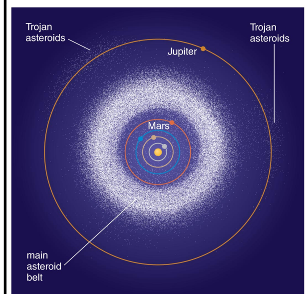
Asteroid Orbits



Asteroids in the Solar System (Fig 13.2).
This computer-generated diagram shows the positions of the asteroids known in 2006.

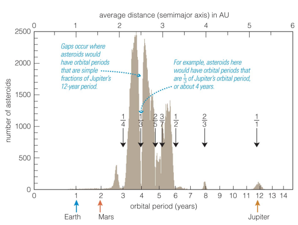
- Most asteroids orbit in a belt between Mars and Jupiter.
- *Trojan asteroids* follow Jupiter's orbit.
- Major collision occurs every 100,000 yrs within the asteroid belt and occasionally the planets.
- Orbits of *near-Earth asteroids* cross Earth's orbit.

Origin of Asteroid Belt



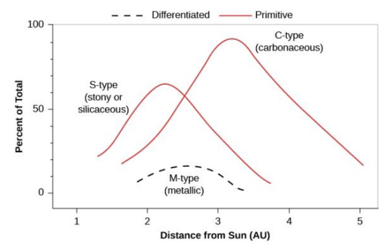
- Rocky planetesimals between Mars and Jupiter did not accrete into a planet.
- Jupiter's gravity, through influence of orbital resonances, stirred up asteroid orbits and prevented their accretion into a planet.

Orbital Resonances



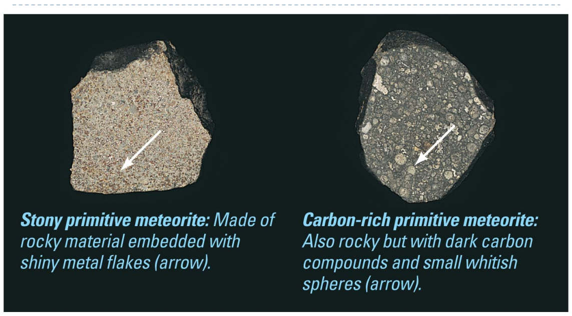
- Asteroids in orbital resonance with Jupiter experience periodic nudges.
- Eventually those nudges move asteroids out of resonant orbits, leaving gaps in the belt.

Composition and Classification



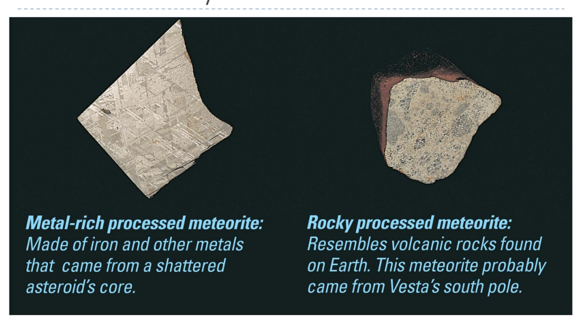
- **Where Different Types of Asteroids Are Found (Fig 13.3).**
Asteroids of different composition are distributed at different distances from the Sun. The S-type and C-type are both primitive; the M-type consists of cores of differentiated/processed parent bodies.

Primitive Meteorites



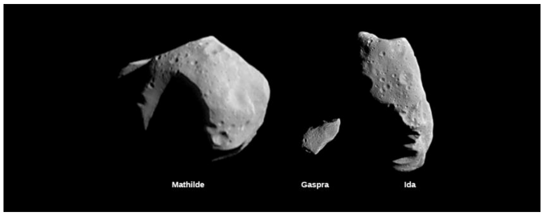
a Primitive meteorites.

Differentiated/Processed Meteorites



b Processed meteorites.

Figure 13.5



- **Mathilde, Gaspra, and Ida.** The first three asteroids photographed from spacecraft flybys, printed to the same scale. Gaspra and Ida are S-type and were investigated by the Galileo spacecraft; Mathilde is C-type and was a flyby target for the NEAR-Shoemaker spacecraft. (credit: modification of work by NEAR Project, Galileo Project, NASA)

Vesta

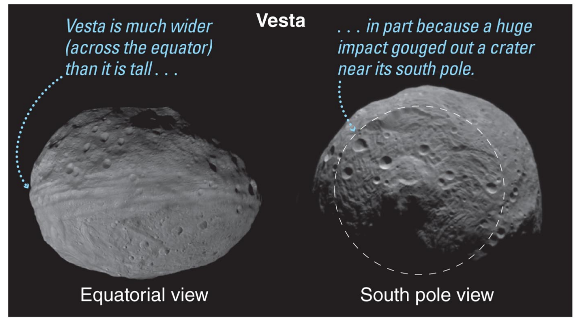
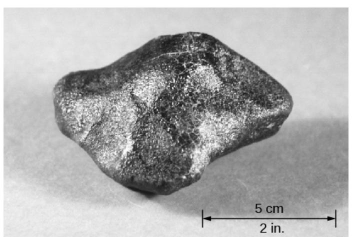


Figure 13.4

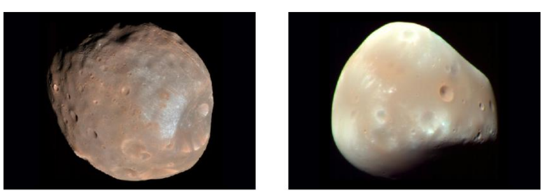


- **Piece of Vesta.** This meteorite (rock that fell from space) has been identified as a volcanic fragment from the crust of asteroid Vesta. (credit: modification of work by R. Kempton (New England Meteoritical Services))

Figure 13.6

- **Ida and Dactyl.** The asteroid Ida and its tiny moon Dactyl (the small body off to its right), were photographed by the Galileo spacecraft in 1993. Irregularly shaped Ida is 56 kilometers in its longest dimension, while Dactyl is about 1.5 kilometers across. The colors have been intensified in this image; to the eye, all asteroids look basically gray.

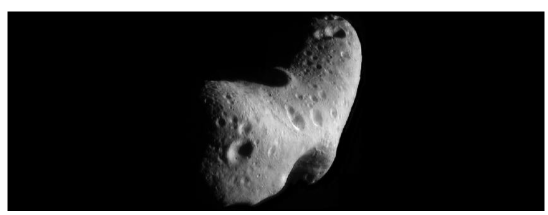
Figure 13.7



(a) (b)

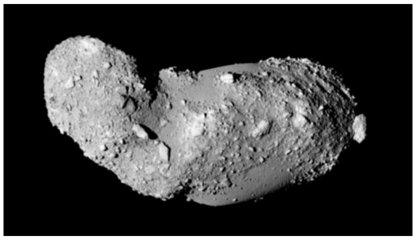
- **Moons of Mars.** The two small moons of Mars, (a) Phobos and (b) Deimos, were discovered in 1877 by American astronomer Asaph Hall. Their surface materials are similar to many of the asteroids in the outer asteroid belt, leading astronomers to believe that the two moons may be captured asteroids. (credit a: modification of work by NASA; credit b: modification of work by NASA/JPL-Caltech/University of Arizona)

Figure 13.8



- **Looking Down on the North Pole of Eros.** This view was constructed from six images of the asteroid taken from an altitude of 200 kilometers. The large crater at the top has been named Psyche (after the maiden who was Eros' lover in classical mythology) and is about 5.3 kilometers wide. A saddle-shaped region can be seen directly below it. Craters of many different sizes are visible. (credit: modification of work by NASA/JHUPL)

Figure 13.9

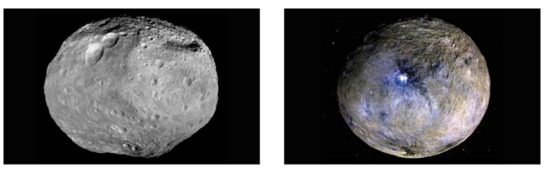


- **Asteroid Itokawa.** The surface of asteroid Itokawa appears to have no craters. Astronomers have hypothesized that its surface consists of rocks and ice chunks held together by a small amount of gravity, and its interior is probably also a similar rubble pile. (credit: JAXA)

Figure 13.10

- **Hayabusa Return.** This dramatic image shows the *Hayabusa* probe breaking up upon reentry. The return capsule, which separated from the main spacecraft and parachuted to the surface, glows at the bottom right. (credit: modification of work by NASA Ames/Jesse Carpenter/Greg Merkes)

Figure 13.11



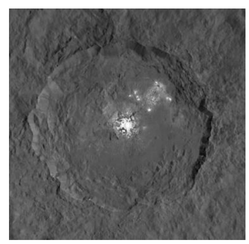
(a) (b)

- **Vesta and Ceres.** The NASA *Dawn* spacecraft took these images of the large asteroids (a) Vesta and (b) Ceres.

(a) Note that Vesta is not round, as Ceres (which is considered a dwarf planet) is. A mountain twice the height of Mt. Everest on Earth is visible at the very bottom of the Vesta image.

(b) The image of Ceres has its colors exaggerated to bring out differences in composition. You can see a white feature in Occator crater near the center of the image.

Figure 13.12



- **White Spots in a Larger Crater on Ceres.** These bright features appear to be salt deposits in a Ceres crater called Occator, which is 92 kilometers across.

13.2 ASTEROIDS AND PLANETARY DEFENSE

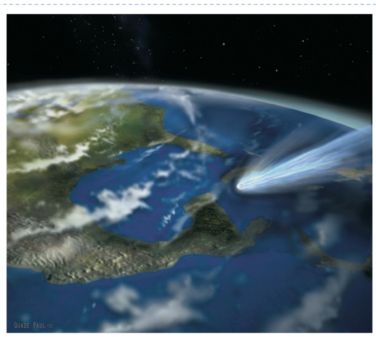
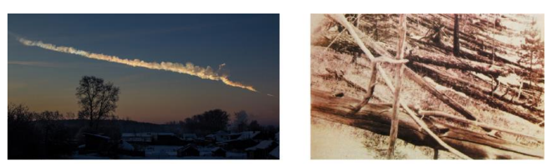


Figure 13.13



(a) (b)

- **Impacts with Earth.**

(a) As the Chelyabinsk meteor passed through the atmosphere, it left a trail of smoke and briefly became as bright as the Sun.

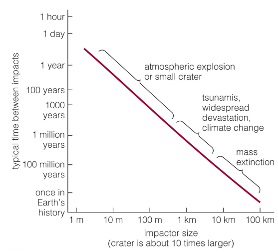
(b) Hundreds of kilometers of forest trees were knocked down and burned at the Tunguska impact site. (credit a: modification of work by Alex Alishevskikh)

Meteor Crater, Arizona: 50,000 years ago (50-meter object)

Tunguska, Siberia: June 30, 1908 A ~40-meter object disintegrated and exploded in the atmosphere.

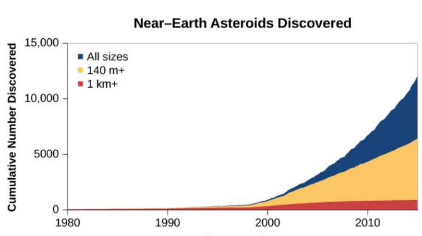
An asteroid detonates in the sky above Chelyabinsk, Russia in February 2013, releasing energy equivalent to a 500 kiloton nuclear bomb. (30 times larger than the nuclear bombs dropped in World War II)

Frequency of Impacts



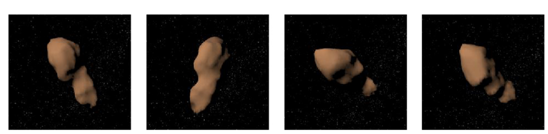
- Small impacts happen almost daily.
- Impacts large enough to cause mass extinctions are many millions of years apart.

Figure 13.14



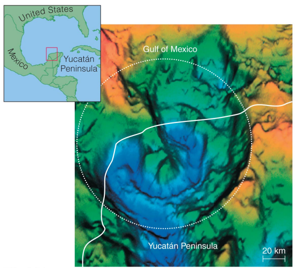
- **Discovery of Near-Earth Asteroids.** The accelerating rate of discovery of NEAs is illustrated in this graph, which shows the total number of known NEAs, the number over 140 kilometers in diameter, and the number over 1 kilometer in diameter, the size that poses the dominant impact risk on Earth.

Figure 13.15



- **Near-Earth Asteroid.** Toutatis is a 5-kilometer long NEA that approached within 3 million kilometers of Earth in 1992. This series of images is a reconstruction its size and shape obtained from bouncing radar waves off the asteroid during its close flyby. Toutatis appears to consist of two irregular, lumpy bodies rotating in contact with each other. (Note that the color has been artificially added.) (credit: modification of work by NASA)

Likely Impact Site



- Geologists found a large subsurface crater about 65 million years old in Mexico.
- Size of crater suggests impacting object was ~10 km in diameter.
- Impact of such a large object would have ejected debris high into Earth's atmosphere.

Consequences of an Impact

- A meteorite 10 km in size would send large amounts of debris into the atmosphere.
- Debris would reduce the amount of sunlight reaching Earth's surface.
- The resulting climate change may have caused mass extinction.

Iridium: Evidence of an Impact

- Iridium is very rare in Earth surface rocks but is often found in meteorites.
- Luis and Walter Alvarez found a worldwide layer containing iridium, laid down 65 million years ago, probably by a meteorite impact.
- Dinosaur fossils all lie below this layer.

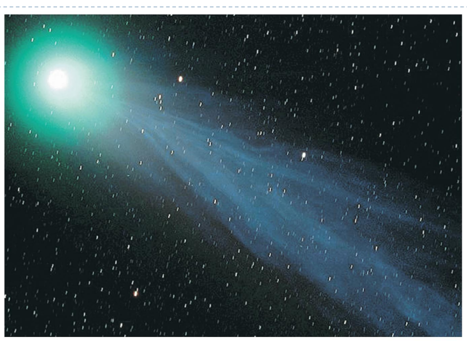
Iridium Layer

No dinosaur fossils in upper rock layers

Thin layer containing the rare element iridium

Dinosaur fossils in lower rock layers

13.3 COMETS



a Comet Hyakutake.

Figure 13.1

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- **Hale-Bopp.** Comet Hale-Bopp was one of the most attractive and easily visible comets of the twentieth century. It is shown here as it appeared in the sky in March 1997. You can see the comet's long blue ion tail and the shorter white dust tail. You will learn about these two types of comet tails, and how they form, in this chapter. (credit: modification of work by ESO/E. Slawik)

Figure 13.16

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- **Comet Halley.** This composite of three images (one in red, one in green, one in blue) shows Comet Halley as seen with a large telescope in Chile in 1986. During the time the three images were taken in sequence, the comet moved among the stars. The telescope was moved to keep the image of the comet steady, causing the stars to appear in triplicate (once in each color) in the background. (credit: modification of work by ESO)

Figure 13.18

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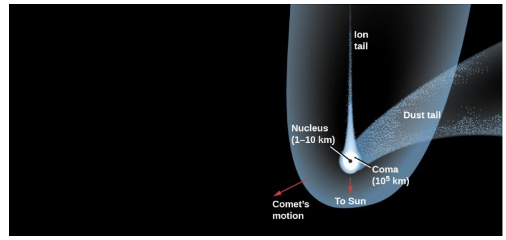
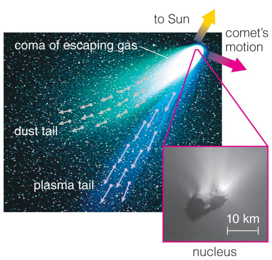


- **Parts of a Comet.** This schematic illustration shows the main parts of a comet. Note that the different structures are not to scale.

Nucleus of Comet



b Anatomy of a comet. The larger image is a ground-based photo of Comet Hale–Bopp. The inset shows the nucleus of Halley's Comet photographed by the *Giotto* spacecraft.

- A "dirty snowball"
- Source of material for comet's tail

Figure 13.23

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- **Comet Tails.**
  - (a) As a comet nears the Sun, its features become more visible. In this illustration from NASA showing Comet Hale-Bopp, you can see a comet's two tails: the more easily visible dust tail, which can be up to 10 million kilometers long, and the fainter gas tail (or ion tail), which is up to hundreds of millions of kilometers long. The grains that make up the dust tail are the size of smoke particles.
  - (b) Comet Mrkos was photographed in 1957 with a wide-field telescope at Palomar Observatory and also shows a clear distinction between the straight gas tail and the curving dust tail. (credit a: modification of work by ESO/E. Slawik; credit b: modification of work by Charles Kearns, George O. Abell, and Byron Hill)

Figure 13.22

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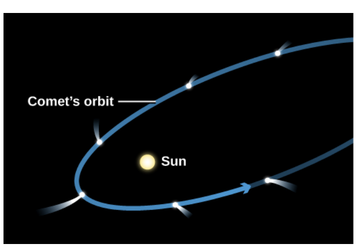

- **Comet Orbit and Tail.** The orientation of a typical comet tail changes as the comet passes perihelion. Approaching the Sun, the tail is behind the incoming comet head, but on the way out, the tail precedes the head.

Figure 13.20

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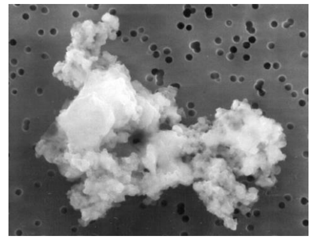
- **Close-up of Comet Halley.** This historic photograph of the black, irregularly shaped nucleus of Comet Halley was obtained by the ESA *Giotto* spacecraft from a distance of about 1000 kilometers. The bright areas are jets of material escaping from the surface. The length of the nucleus is 10 kilometers, and details as small as 1 kilometer can be made out. (credit: modification of work by ESA)

Figure 13.21

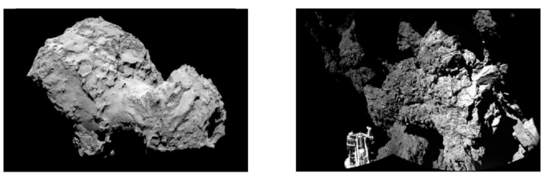
- **Head of Comet Halley.** Here we see the cloud of gas and dust that make up the head, or coma, of Comet Halley in 1986. On this scale, the nucleus (hidden inside the cloud) would be a dot too small to see. (credit: modification of work by NASA/W. Liller)

Figure 13.19



- **Captured Comet Dust.** This particle (seen through a microscope) is believed to be a tiny fragment of cometary dust, collected in the upper atmosphere of Earth. It measures about 10 microns, or 1/100 of a millimeter, across. (credit: NASA/JPL)

Figure 13.24



(a) (b)

- **Comet 67P's Strange Shape and Surface Features.**

(a) This image from the *Rosetta* camera was taken from a distance of 285 kilometers. The resolution is 5 meters. You can see that the comet consists of two sections with a connecting "neck" between them.

(b) This close-up view of Comet Churyumov-Gerasimenko is from the *Philae* lander. One of the lander's three feet is visible in the foreground. The lander itself is mostly in shadow.

Figure 13.25

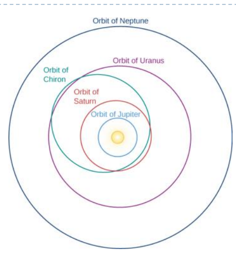
(a) (b) (c)

- **Gas Jets on Comet 67P.**

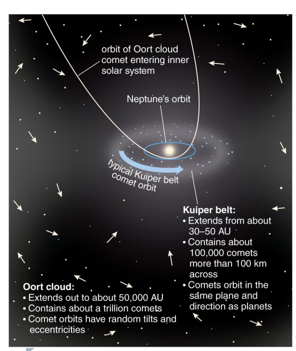
(a) This activity was photographed by the *Rosetta* spacecraft near perihelion. You can see a jet suddenly appearing; it was active for only a few minutes.

(b) This spectacular photo, taken near perihelion, shows the active comet surrounded by multiple jets of gas and dust. (credit a, b: modification of work by ESA/Rosetta/MPS; credit c: modification of work by ESA/Rosetta/NAVCAM)

13.4 THE ORIGIN AND FATE OF COMETS AND RELATED OBJECTS



- **Chiron's Orbit.** Chiron orbits the Sun every 50 years, with its closest approach being inside the orbit of Saturn and its farthest approach out to the orbit of Uranus.



Only a tiny number of comets enter the inner solar system; most stay far from the Sun.

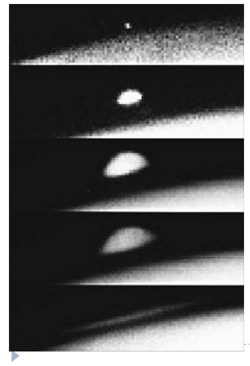
Oort Cloud:
Comets on random orbits extending to about 50,000 AU

Kuiper Belt:
Comets on orderly orbits at 30-100 AU in disk of solar system

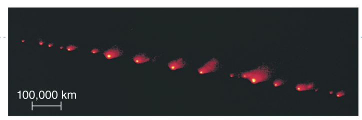
b This digital composite photo, taken in Australia during the 2001 Leonid meteor shower, shows meteors as streaks of light (with stars and nebulae visible in the background). The large rock is Uluru, also known as Ayers Rock.

Comets eject small particles that follow the comet around in its orbit and cause meteor showers when Earth crosses the comet's orbit.

Major Impacts



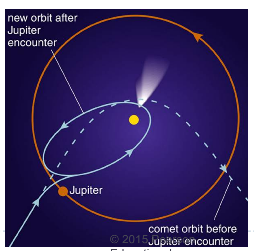
- Small objects impact all of the planets every day
- Evidence suggests larger impacts are also still occurring, such as the impact of comet Shoemaker-Levy 9 into Jupiter in 1994.
- Impact plume from a fragment of comet SL9 rises high above Jupiter's surface.

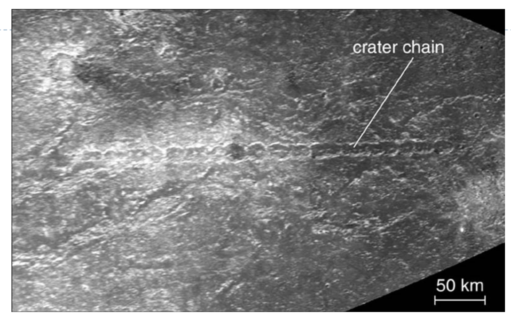


a Jupiter's tidal forces ripped apart the single comet nucleus of SL9 into a chain of smaller nuclei.

Comet SL9 caused a string of violent impacts on Jupiter in 1994, reminding us that catastrophic collisions still happen.

Tidal forces tore it apart during a previous encounter with Jupiter.





This crater chain on Callisto probably came from another comet that tidal forces tore to pieces.

Figure 13.29

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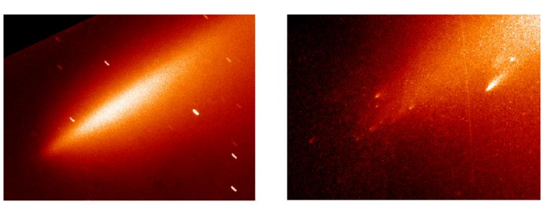

(a) (b)

- **Breakup of Comet LINEAR.** (a) A ground-based view with much less detail and (b) a much more detailed photo with the Hubble Space Telescope, showing the multiple fragments of the nucleus of Comet LINEAR. The comet disintegrated in July 2000 for no apparent reason. (Note in the left view, the fragments all blend their light together, and can't be distinguished. The short diagonal white lines are stars that move in the image, which is keeping track of the moving comet.)

Figure 13.30

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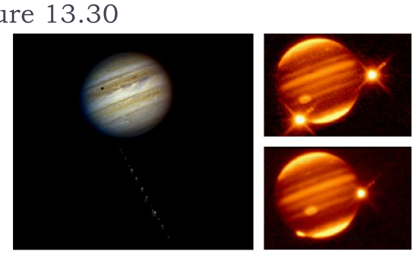
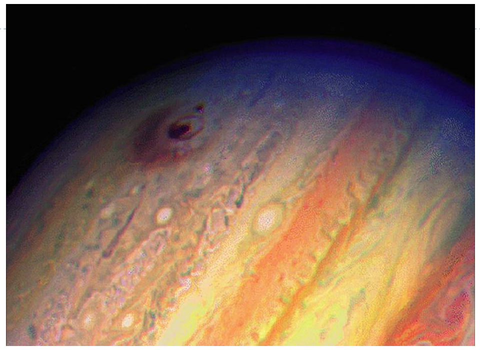


(a) (b)

- **Comet Impact on Jupiter.**

(a) The "string" of white objects are fragments of Comet Shoemaker-Levy 9 approaching Jupiter.

(b) The first fragment of the comet impacts Jupiter, with the point of contact on the bottom left side in this image. On the right is Jupiter's moon, Io. The equally bright spot in the top image is the comet fragment flaring to maximum brightness. The bottom image, taken about 20 minutes later, shows the lingering flare from the impact. The Great Red Spot is visible near the center of Jupiter. These infrared images were taken with a German-Spanish telescope on Calar Alto in southern Spain.



Dusty debris at an impact site

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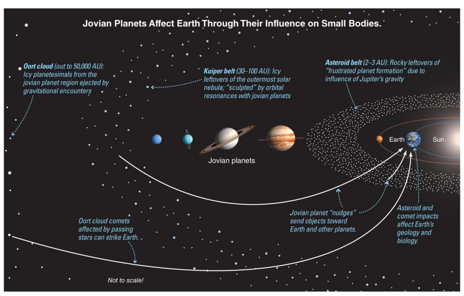
Figure 13.31

- **Impact Dust Cloud on Jupiter.** These features result from the impact of Comet Shoemaker-Levy 9 with Jupiter, seen with the Hubble Space Telescope 105 minutes after the impact that produced the dark rings (the compact back dot came from another fragment). The inner edge of the diffuse, outer ring is about the same size as Earth. Later, the winds on Jupiter blended these features into a broad spot that remained visible for more than a month. (credit: modification of work by H. Hammel, MIT, and NASA/ESA)

Influence of Jovian Planets



Jupiter has directed some comets toward Earth but has ejected many more into the Oort Cloud.

How big can a comet be?

Is Pluto a planet?

- Much smaller than the eight major planets
- Not a gas giant like the outer planets
- Has an icy composition like a comet
- Has a very elliptical, inclined orbit
- Pluto has more in common with comets than with the eight major planets.

Links

Reading

- 13.1
- 13.2
- 13.3
- 13.4