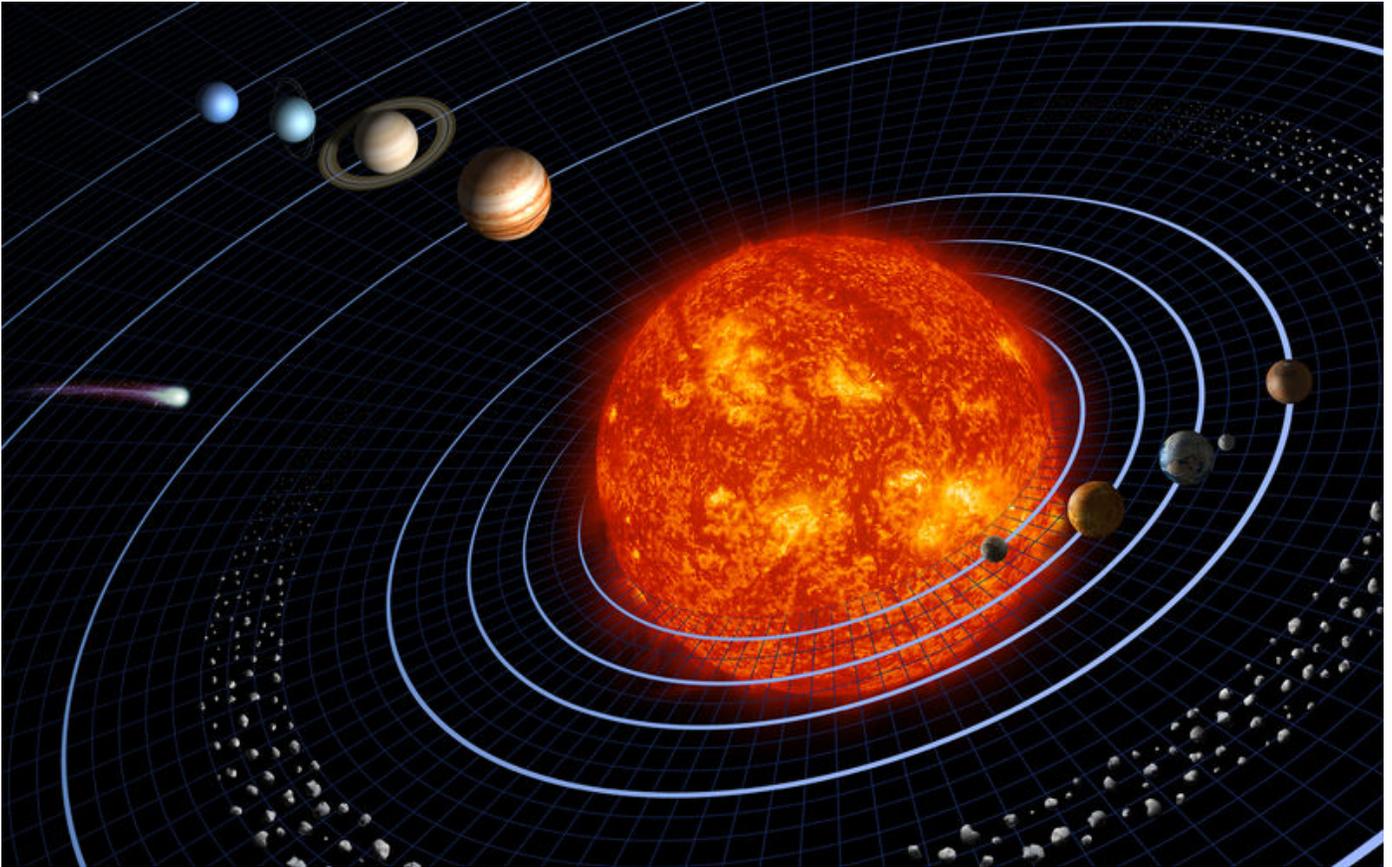


A BRIEF DESCRIPTION OF OUR SOLAR SYSTEM



In this NASA/JPL artist's diagram of our solar system (not to scale), we see the *Sun* in the center. Toward the right middle foreground are the 4 rocky "inner planets" in their orbits - *Mercury*, *Venus*, *Earth* (with our *Moon* beside it), and *Mars*. Next, are lots of rocks orbiting in the *Asteroid Belt*. Pictured toward the back of the illustration are the 4 gas giant "outer planets" - *Jupiter*, *Saturn*, *Uranus*, and *Neptune*. To the left is a comet traveling in from either the *Kuiper Belt* or the *Oort Cloud* (which are both farther away from the *Sun* than any of the planets).

1. Our *Sun* is an average star and the closest star to *Earth* in the *Milky Way* galaxy containing billions of stars. (Q&A: *Which is the next closest star?*)
2. Our solar system includes all the planets, moons, asteroids, meteoroids, comets, dust, ice, and gas orbiting the *Sun*.
3. What are referred to as the "inner planets" of our solar system (*Mercury*, *Venus*, *Earth* and *Mars*) have solid rocky surfaces, so if we could land on them, we could stand on them. (Q&A: *Have people landed on any other planets?*)
4. Farther out beyond *Mars* is the *Asteroid Belt* of almost uncountable rocks (some only a few feet wide and some hundreds of miles wide). These rocks never formed into a planet and are orbiting in a transitional area between the inner rocky planets and the outer gas giants. Most, but not all, meteorites are pieces of asteroids (some meteorites are pieces of our *Moon*, the planet *Mars*, possibly *Mercury*, and also comet nuclei).
5. Beyond the *Asteroid Belt* are the "outer planets" (*Jupiter*, *Saturn*, *Uranus* and *Neptune*), huge spheres of gas that don't have solid surfaces, so we couldn't land or stand on them. Distances from the *Sun* to the inner planets and out to *Jupiter* and *Saturn* are measured in millions of miles, whereas distances to *Uranus* and *Neptune* are billions of miles. (Q&A: *Could you count to a billion?*)
6. Orbiting the *Sun* farthest out in the severe cold of space are comets in the *Kuiper Belt* (several billions of miles distant) and in the *Oort Cloud* (distances extending out trillions of miles; half way to the next star). If a comet's orbit is more elliptical (rather than circular), it may cause that comet to periodically travel in closer to the *Sun*, where solar radiation and the solar wind cause its solid frozen nucleus to develop two glowing tails of particles and gas (always facing away from the *Sun*), plus a coma (cloud around the nucleus) that shines by reflecting sunlight as ice sublimates directly to gas. A comet in the night sky, over our backyard, appears as a fuzzy-looking blob of light because mostly what we can see is the glowing coma. (Q&A: *How often do comets come close enough to Earth for us to observe them?*)
7. Our *Earth* has a moon (which we call "*The Moon*") that orbits around us. The planets *Mercury* and *Venus* have no moons circling them, while *Mars*, *Jupiter*, *Saturn*, *Uranus* and *Neptune* have more than one moon. (Q&A: *Which planet has the most moons that have been documented?*)
8. Pieces sometimes are knocked off solid surface planets, moons, asteroids, and comet nuclei (by impact of other rocks); those pieces that may later fall from space onto *Earth* are called meteorites. The *SpaceRocksWithDrLen.com* specimens that you hold in your hands are fragments of different classifications of meteorites recovered from all seven continents on Earth. (Q&A: *In addition to Earth where else could meteorites land?*)

METEORITES ARE PIECES OF OUR SOLAR SYSTEM: ASTRONOMY THAT FALLS FROM THE SKY

We can all learn much more at our public library.  In the United States, knowledge is free to everyone.

(KEY VOCABULARY WORDS ARE IN BOLD PRINT)

Meteoritics is the scientific study of meteorites (*the oldest rocks that we've been able to obtain*). Most are usually about 4.4 to 4.6 billion years old. This science depends upon the work of specialists, such as astronomers, biologists, chemists, geologists, artists, physicists, mathematicians, photographers, teachers and astronauts/cosmonauts.

Meteoriticists bring together specialized research and fieldwork to study meteorite characteristics and learn more about the formation and history of our solar system.

Traces of gas and solid matter from when the solar system was forming are still present and barely changed in many meteorites. By comparison, natural forces such as weathering, erosion, tectonics, volcanic eruptions, quakes, and impacts on the surface of our planet are always changing Earth rocks.

(Q&A: *What are some examples of Earth rocks that get changed by natural forces?*)

Our **Sun**, (*an average star*), contains about 99.9% of all the **solar system's** matter. Stars **emit** their own light, whereas planets, moons, asteroids and comets **reflect** light.

(Q&A: *What is the original source of that reflected light?*)

The **planets** and most asteroids, revolve around the Sun counter-clockwise (*the same direction that the Sun rotates on its axis*) in fairly flat orbits. The orbiting planets are spread out from the Sun at increasingly greater distances in miles (*illustrated on page 1*): **Mercury**, 36 million; **Venus**, 67 million; **Earth**, 93 million; **Mars**, 142 million; **Jupiter**, 483 million; **Saturn**, 886 million; **Uranus**, 1 billion, 780 million; **Neptune**, 2 billion, 790 million.

(Q&A: *Why was **Pluto**, at 3 billion, 670 million miles kicked out of our solar system?*)

In addition to the planets and their **moons**, there are other rocks in space; debris left over from the formation of our solar system through condensation and accretion of a cloud of gas and dust approximately 4.6 billion years ago.

Some **meteoroid** rocks are as small as a grain of sand at the beach. The biggest of the rocks, larger than 329 feet across, with a weight of 10,000 tons or more, are called **asteroids**; most orbit the Sun in the wide flat **Asteroid Belt** (*page 1 painting*). The asteroid belt is a transition area located roughly midway between the orbits of Mars and Jupiter in our solar system. Asteroids are composed of stone, metal, and ice that never formed into a planet. Some planetary moons may be asteroids captured by gravity, but not Earth's Moon.

(Q&A: *Can you name the solid surface planets and the gas giants?*)

In addition to the main-belt asteroids, some stray Earth-crossing asteroids (*possibly hitting our world again someday*) have elongated orbits that take them among the orbits of the inner solar system planets, (probably deflected there by gravitational "tugs" of Mars and Jupiter, the planets nearest (*orbiting on either side*) of the Asteroid Belt).

The largest asteroid known, *Ceres*, measures about 564 miles in diameter. The brightest asteroid is *Vesta*. NASA's *Dawn* spacecraft is now in the Asteroid Belt.

Space rocks sometimes smash into each other while in orbit and break apart, causing fragments to fly off in different directions.

In addition, some space rocks crash into planets and moons. When they hit solid-surface planets or moons, fragments are often thrown off into space.

(Q&A: *What happens when a space rock hits one of the gas giant planets?*)



THIS IS WHAT A **METEOR** LOOKS LIKE; A QUICK STREAK OF LIGHT SEVERAL MILES UP IN EARTH'S ATMOSPHERE.

Sometimes, a space rock, any size, (*piece of planet, moon, asteroid, meteoroid, comet*), is pulled into Earth's atmosphere by Earth's gravity, or plows into Earth's atmosphere, because it's traveling in a different direction. When this happens, the air in front of it is compressed and super-heated into a plasma of ionized gas from *ram pressure*, but the rock's outside only burns and melts in the extreme heat, (*which can be hotter than 3,000 degrees*). Even though it's flying at speeds between about 27,000 miles per hour to over 160,000 mph, its inside doesn't get hot.

The sudden streak of light in the sky caused by this glowing **meteor** lasts only a few seconds or as little as a fraction of a second, (*depending on the size and speed of the burning rock (meteoroid)*).

Very large meteor fireballs are called *bolides*; some of them even leave a trail of smoke (*persistent train*) behind in the air.

Observers on the ground may also feel shock waves and hear the larger meteors, because they cause **sonic booms**.

Military jet fighter planes (and space craft) can also cause sonic booms as they accelerate to faster than the speed of sound through the atmosphere (and when they subsequently decelerate back down to slower than the speed of sound).

(Q&A: *How fast does sound travel in the air?*)

If a space rock weighs at least a ton and is about three feet in diameter or more, it may not burn up altogether as a meteor in the atmosphere (*often at an altitude between 6 to 50 miles*) and whatever solid piece is

left, lands on Earth as a **meteorite**. (*However, few meteors drop meteorites.*)

Most meteorites reaching Earth cause only minor **percussion pits** (thud!) in the soil, (*close to the actual size of the meteorite*), because the rock gets slowed down in the air by friction drag and then just drops (*similar to an apple falling from a tree*). However, large rocks from space (*weighing more than a few hundred tons*) are slowed very little during their flight down through the air, and when one of them slams into the ground the force of the sudden stop causes it to disintegrate violently. Pieces are thrown high into the air and later fall back to Earth. What we have left on the ground is an **impact crater** surrounded by fragments of the space rock (and local Earth rocks). The diameter of the crater is generally about 10 times wider than the meteorite and the depth is about 1/10th the crater's diameter, depending upon speed, size, angle of impact, and the hardness or softness of the ground impacted.

Astronomers have observed, using telescopes and spacecraft, impact craters on our Moon, other planets, moons of other planets, asteroids, and comets in our solar system. Some NASA astronauts have personally examined lunar craters by flying to our Moon in Apollo spacecraft, landing on the surface, and picking up rocks.

Q&A: *How many men and women have walked on Earth's Moon so far?*

Meteorite showers are falls of rocks hitting the ground from a larger meteorite that broke up while still in the air. Meteorites discovered on the ground, that no one saw falling, are called finds.

Far different from meteorite showers, **meteor showers** occur at predictable times during the year. (*We can look on an astronomy calendar*). All the meteors during each shower seem to be coming from the same direction in the night sky. They are caused by the Earth passing through a swarm of tiny rocky particles scattered behind in space along the orbit of a *periodic comet* that came by (from the Kuiper Belt of comets billions of miles away, or the Oort Cloud of comets trillions of miles away).

Because they are so small, shower meteors burn up completely high in Earth's atmosphere.

A comet's *nucleus* (resembling a *dirty snowball*, *icy dirtball*, or even astronaut *freeze-dried ice cream*) partially *sublimates*, as its orbit brings it closer to the Sun's heat, and a glowing *coma* and *two tails* are formed (of ionized gas from the coma and dust particles) that we may be able to see. A trailing *debris stream* of grit, grains of sand, and small pebbles (that we can't see) falling off the nucleus, spreads out and remains long after the (then smaller) comet has orbited around the Sun and gone back out of sight into deep space.



NASA JPL

MILLIONS OF MILES OUT IN SPACE, THE COMA AND TAILS OF COMET *HALE-BOPP* LOOKED MORE LIKE A FUZZY STAR TO US ON THE EARTH IN 1997.

When we see one at night, a meteor is usually a quick streak of light in Earth's atmosphere, but we may be able to see a glowing comet, that is millions of miles away in space, for months up in the sky.



THE TUNGUSKA EVENT

In June 1908 a falling space rock (asteroid or comet nucleus) exploded five miles up in Earth's atmosphere over the Tunguska River in Siberia, Russia; the blast knocked down millions of trees below and molten metal rain fell.

It might be a meteorite !

Most meteorites are pieces of **asteroids**, while some have been identified from The Moon, planet Mars, and comets. There are three main classifications of meteorites: 1. **STONES**, 2. **STONY-IRONS**, and 3. **IRONS**. Scientists further divide those groups into many sub-classifications. (*A few meteorites don't fit any established categories.*)

STONES and **STONY-IRONS** are sometimes difficult to spot, when meteorite hunters may **find** one, if it's lying around on the ground with other Earth rocks (*unless perhaps someone saw it **fall** from the sky*). Stone or stony-iron meteorites can look a lot like Earth rocks when they've all been out in the weather together for many years.

Bare metal iron is rare on Earth; iron usually has to be first *smelted* out of iron-ore rocks, then we can make things such as a blacksmith's anvil. If we find a (*heavier than we might expect for its size*) very hard rock that looks like it's made of rusty metal, and maybe even has **thumbprints** (*regmaglyphs*) on the outside as if it melted like chocolate does in your hand (not M & M's candy), it might be an **IRON** meteorite from space.

The best way to find out for sure whether an interesting rock we found is a meteorite would be show it to a scientist, such as a professor of geology at a university, BUT first you can test if it'll attract a small bar **magnet** on a string (most meteorites will).

1. STONE METEORITES

Stone meteorites are made up of mainly minerals (*naturally-occurring, inorganic elements or chemical compounds with crystalline structures*) containing silicon and oxygen, plus a little metal.

2. STONY- IRON METEORITES

Stony-Irons are mixes of the substances that make up stone meteorites and iron meteorites.

3. IRON METEORITES

Iron meteorites are almost completely made up of nickel-iron metal.

(Q&A: Where could we research more about elements, minerals, and chemical compounds?)

THE CANYON DIABLO METEORITE AND "METEOR CRATER"



DR. LEN'S VIEW FROM A PLANE CIRCLING LOW AND SLOW ABOVE BARRINGER "METEOR CRATER"
•IN THE COCKPIT WITH VETERAN AIR FORCE AND COMMERCIAL PILOT CAPT. JIM COOK, DFC



ON THE RIM: THE VIEW 4,100 FEET ACROSS THE CRATER
•STUDYING WITH USGS IMPACT GEOLOGIST DR. DAVID RODDY

DURING A *SPACE ROCKS* WORKSHOP, STUDENTS HOLD IN THEIR HANDS A CANYON DIABLO METEORITE SPECIMEN AND EARTH ROCK (*PICTURED BELOW ON THE GROUND*) TO DETERMINE DIFFERENCES USING BASIC SCIENCE SKILLS.



The impacting meteorite that formed "Meteor Crater" accreted in space over 4 billion years ago and hit the Earth 49,000 +/- 300 years ago. Its original total mass was over 100 feet wide and weighed about 300,000 tons, with a speed through the atmosphere estimated up to 40,000 miles per hour. It disintegrated from the tremendous force of slamming into the high desert sandstone and driving a shock wave downward into the Arizona bedrock and back upward into the meteorite and the air. 90% of the Canyon Diablo meteorite was vaporized instantly from the resulting 1200 degree impact temperature; some fragments were thrown eleven miles away while winds over 600 mph scoured the ground surrounding the crater. (*For comparison, that is twice the speed of the strongest winds ever observed inside an F5 tornado ripping through Tornado Alley in the United States Midwest.*) Barringer Crater, near Winslow, Arizona, (incorrectly, but popularly called "Meteor Crater"), is the best-preserved meteorite impact crater on Earth.

This giant hole in the ground is still about 4,100 feet wide and 570 feet deep; 20 different football games could be played on the floor of the crater, all at the same time! An extensive visitors center and museum, next to the rim, are open to the public. (The late Dr. Roddy trained NASA astronauts in this crater before their Apollo lunar missions to gather rock and dirt (regolith) specimens on our Moon.)

METEORITIC IMPACT FALLS AND FINDS RECOVERED FROM ALL SEVEN CONTINENTS ON EARTH



17 RARE FRAGILE FRAGMENTS DISPLAYED IN A RIKER MOUNT FOR CAREFUL HAND-HELD STUDY: SPECIMENS THAT STUDENTS ASK ABOUT MOST OFTEN ARE INDICATED IN **BOLD** TYPE.

NAME	CLASSIFICATION	FOUND	DESCRIPTION HIGHLIGHTS
●TOP ROW (LEFT TO RIGHT)			
PEEKSKILL	Stone meteorite	USA	Hit teenaged girl's parked car
BJURBOLE	Chondrules	Finland	Oldest solid substance in our solar system
ABEE	Stone meteorite	Canada	May be from within orbit of planet Mercury
ALLENDE	Stone meteorite	Mexico	Contains stardust from another star
MURCHISON	Stone meteorite	Australia	Fragment of a comet nucleus
●MIDDLE ROW (LEFT TO RIGHT)			
MILLBILLILLIE	Stone meteorite	Australia	Knocked off <u>asteroid VESTA</u>
ZAGAMI	Stone meteorite	Nigeria	Knocked from planet Mars
DAR AL GANI 262	Stone meteorite	Libya	Knocked off our Moon's highlands
NORTHWEST AFRICA 032	Stone meteorite	Morocco	Knocked out of our Moon's mare
NORTHWEST AFRICA 482	Stone meteorite	Algeria	Knocked off our Moon's far side
THIEL MOUNTAINS	Stony-Iron meteorite	<u>Antarctica</u>	Found on glacier ice
K-T BOUNDARY	Iridium metal sediment	Italy	From dinosaur extinction asteroid impact
●BOTTOM ROW (LEFT TO RIGHT)			
IMILAC	Stony-Iron meteorite	Chile	Found in Atacama Desert (driest on Earth)
MOLDAVITE	Tektite	Czechoslovakia	Earth impact glassy material
CANYON DIABLO	Rock flour	USA	Earth bedrock pulverized by impact
TUNGUSKA EVENT	Metal raindrop	Russia	From explosion in the air over Siberia
TUNGUSKA EVENT	Tree bark	Russia	Spruce knocked down by Siberian explosion



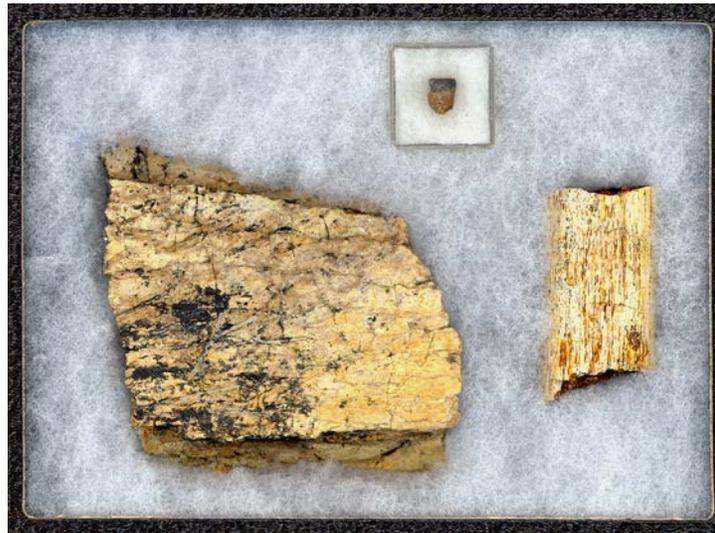
WHATEVER HAPPENED TO ALL THOSE DINOSAURS?

Earth's **K-T Boundary**, a thin layer of sediment in the ground around the globe (*between the Cretaceous and Tertiary geologic periods sixty-five million years ago*), contains an excess of the rare metal **iridium**, (*common in meteorites, but not common in Earth rocks*). Research indicates this iridium is from an **asteroid**, about **six miles in diameter**, hitting the Earth at a speed estimated between 50,000 and 100,000 miles an hour. A combination of natural effects then killed off two-thirds to three-quarters of all plants and animals, including the **dinosaurs**. It was an awful time to be on the Earth. *Space Rocks* workshop students get to hold **iridium** left by the impact, plus fossil fragments of school bus-size Triceratops (one of the last dinosaur species.)

The massive asteroid impact formed the **Chicxulub Crater**, five miles deep and over 100 miles wide, under the sea and overlapping the northwest tip of the Yucatan Peninsula in what is now Mexico. Sound of the impact was so loud that it was destructive and deadly. Shock waves traveled around (and possibly through) the Earth like a bell being rung. The ground shook with earthquakes, and volcanoes erupted on the opposite side of the world. Superheated asteroid and Earth rock fragments were thrown up miles above the planet by the force of impact, and remnants that didn't totally escape the pull of gravity, rained back down as broiling debris causing the normally blue sky to glow red hot while the air became fouled with poisonous gases and acid mist. Ash, soot, and smoke were spread around the Earth by the stormy weather that followed.*

Land and sea sediments indicate a **tsunami** (*tidal wave*) estimated at hundreds of feet (to possibly as high as the Rocky Mountains) and moving at hundreds of miles an hour, splashed over a huge area of North, Central, and South America. (*Surfers call it the ultimate one-ride wave.*) Earth's climate changed drastically, with temperatures at first becoming hotter from the extreme heat that ignited wildfires worldwide. Then temperatures dropped to freezing from the ensuing day-and-night blackness of an **impact winter**, while sunlight was blocked out completely for months, until the thick haze (*much worse than the worst big-city smog*) in the air gradually settled to the surface.

*In July 2002, we observed a similar phenomenon, when ordinary summer weather movement carried smoke from forest fires in northern Quebec, Canada, into the sky over southern New England, partially blocking sunlight and turning the air a dirty looking yellowy-gray color.



Displayed in a Riker Mount so students can hold them without the jagged edges crumbling, are Triceratops fossils dug up by paleontologists during fieldwork in Wyoming and Montana, (*clockwise from top*) tooth, rib section, frill fragment.



We can't use our brains on drugs; that's why it's called dope!