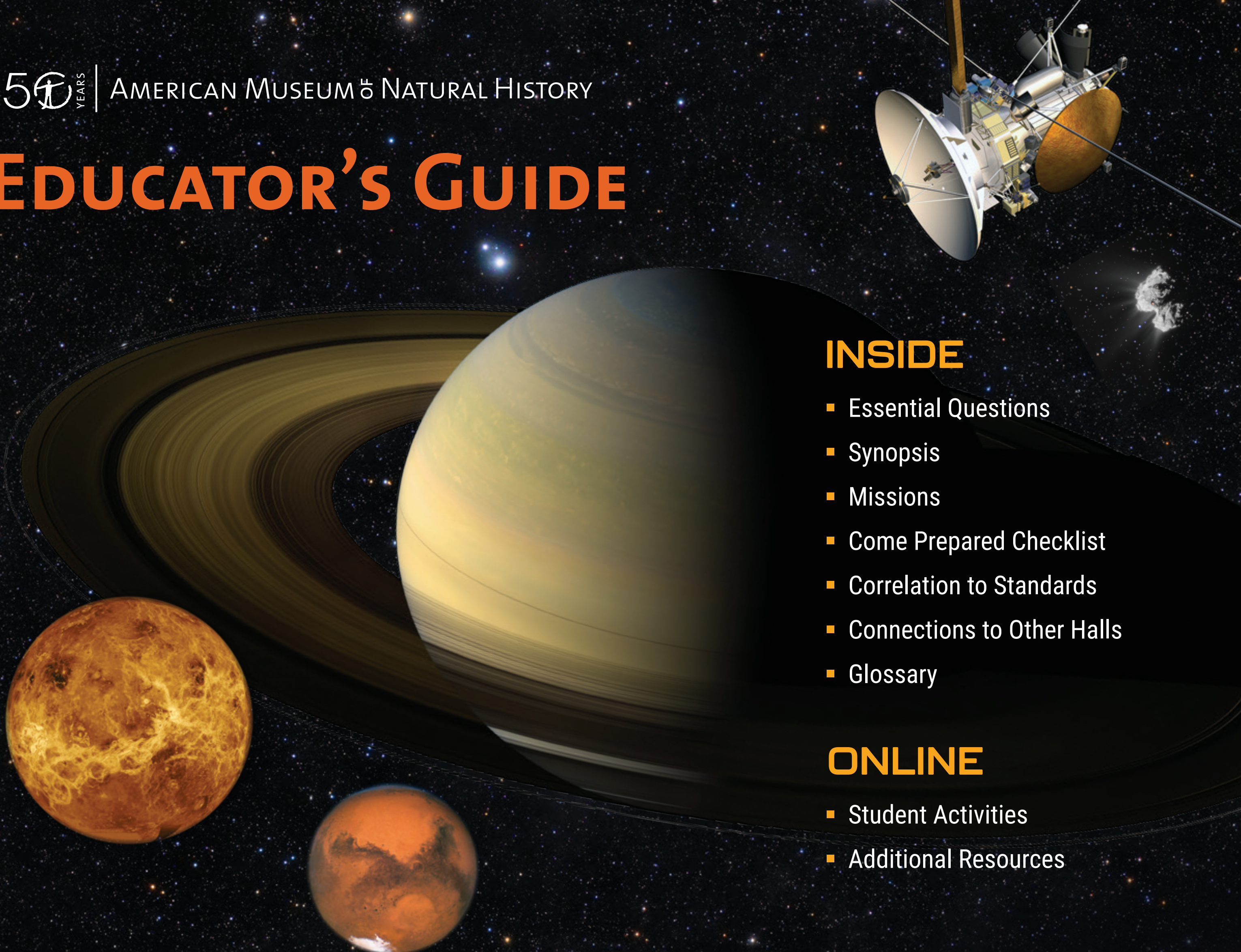
150 YEARS | AMERICAN MUSEUM OF NATURAL HISTORY

EDUCATOR'S GUIDE



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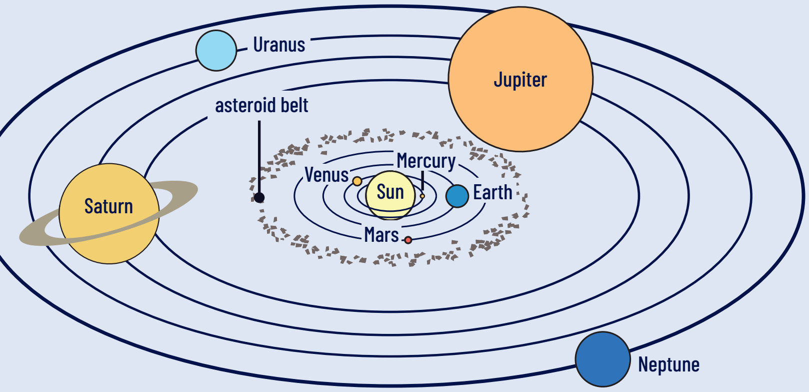
WORLDS BEYOND EARTH

amnh.org/worlds-beyond-earth-educators

Essential Questions

What is the solar system?

Our solar system consists of our star—the Sun—and all the billions of objects that orbit it. These objects, which are bound to the Sun by gravity, include the eight **planets**—Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune; several **dwarf planets**, including Ceres and Pluto; hundreds of **moons** orbiting the planets and other bodies, including Jupiter's four major moons and Saturn's seven, and, of course, Earth's own moon, the Moon; thousands of **comets**; millions of **asteroids**; and billions of icy objects beyond Neptune. The solar system is shaped like a gigantic disk with the Sun at its center. Everywhere we look throughout the universe we see similar disk-shaped systems bound together by gravity. Examples include faraway galaxies, planetary systems orbiting nearby stars, and the system of moons orbiting Jupiter, which resembles the solar system itself. Disks are common because when a cloud of material (such as gas or dust) surrounds a massive rotating object (such as a star, planet, or black hole), it will flatten out like a spinning ball of pizza dough.



The solar system. The asteroid belt, a ring of irregularly shaped objects, lies sparsely distributed between the orbits of Mars and Jupiter. Four hot, rocky planets with geological processes similar to those of Earth—including Earth itself—orbit between the Sun and the asteroid belt. Four cold planets orbit beyond the asteroid belt: first the gas giants Jupiter and Saturn, and then two ice giants, Uranus and Neptune. (Graphic is not to scale.)

How do scientists study the worlds within our solar system?

Throughout history people have observed the skies, first with our naked eyes and then with the help of land-based instruments like telescopes. Early philosophers believed Earth was the center of the universe, but as early as the fourth century BCE, evidence such as the curve of the horizon and the motion of the planets convinced some observers that Earth was a ball revolving around the Sun.

In the 20th century, humans began leaving Earth. NASA's Apollo space program was the first to land humans on another world, carrying 12 human astronauts to the Moon's surface. Since then we've sent our proxies—robots—on missions near and far across our solar system. Flyby missions allow limited glimpses; orbiters survey surfaces; landers get a close-up understanding of their landing location; and rovers, like human explorers, set off across the surface to see what they can find and analyze.

The results of these explorations are often surprising. With the Moon as our only reference, we expected other worlds to be cold, dry, dead places, but exploration has revealed astonishing variety in our solar system. Mars, for example, has a long history of water, with dry lakebeds and gullies showing that liquid water once flowed abundantly on its surface; a lake of water lies beneath its southern polar ice cap today. Gravitational forces from Jupiter's enormous mass heat the interior of the planet's moon Io, where Voyager 1 saw lava erupting from active volcanoes onto its frosty surface. And the Galileo spacecraft discovered evidence that liquid water lies beneath the frozen surface of Jupiter's moon Europa.

What makes Earth habitable?

Along with Mars and Venus, Earth lies in what is often referred to as the Goldilocks Zone: near enough to the Sun to be warm enough for liquid water, but not so close that it's too hot to sustain life. But temperature isn't the only consideration. Earth has many factors that allowed life to evolve and flourish. The atmosphere, a gas blanket of mostly nitrogen and oxygen, protects Earth's surface from harmful solar radiation while letting through enough of the Sun's warmth. Carbon dioxide, a small, important component of the atmosphere, helps trap that warmth, but human activity over the past 200 years has pumped more and more of this greenhouse gas into the atmosphere, with dangerous consequences. Earth's churning, molten iron outer core produces a magnetic field that surrounds the planet; this magnetosphere protects us by deflecting the bulk of the charged particles streaming from the Sun, known as the solar wind. Mars and Venus lack protective magnetospheres; on Mars the solar wind stripped away most of the atmosphere, and on Venus it stripped away the water necessary for life. The Moon, too, helps by stabilizing Earth's rotation and causing tides, which transfer heat around the oceans and churn their water along coastlines. Those in-between, intertidal areas had favorable conditions for the evolution of life. If conditions on Earth had been just a little bit different, perhaps we would not be here.

Synopsis

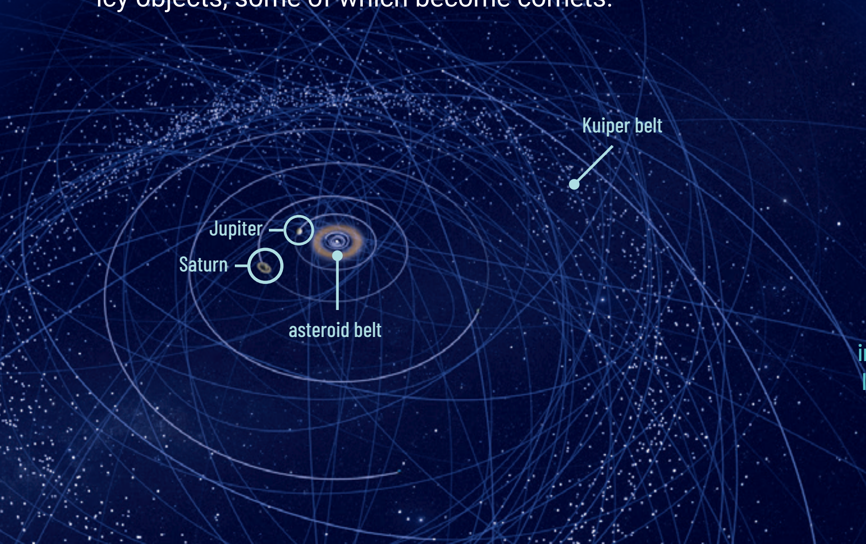
1 The Moon was the perfect choice for our first voyage to another world

Our closest neighbor, it's only a few days' journey away by spacecraft. Dark patches of ancient lava tell us that long ago the Moon was volcanically active, just like Earth, but the gray scars of ancient, giant craters made by comets and asteroids crashing into the Moon's surface tell us that its dynamic days ended billions of years ago. Although the Moon is the only alien world we've been to in person, we've launched our proxies—robots—to visit it and other worlds in our solar system.

Earth's Moon

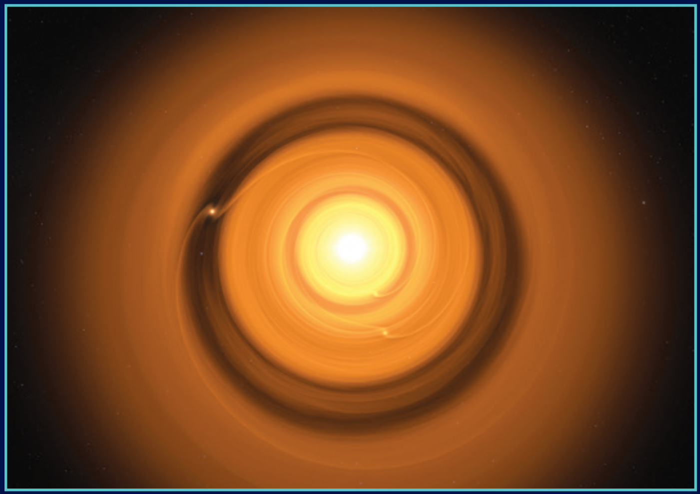
2 The solar system is a giant disk containing billions of objects circling our Sun

Closest to the Sun are the four rocky planets: hot little Mercury, then Venus, Earth, and Mars. Next, the asteroid belt, with its millions of rocky worlds, marks the boundary between the inner and outer solar system. Despite their high numbers, if you squeezed all the asteroids together into one object, it would have a mass less than that of our Moon. On the cold side of the asteroid belt sit the largest planets: the gas giants Jupiter and Saturn. Next are the coldest: Uranus and Neptune. Still farther out lies the Kuiper Belt, home to millions of smaller frozen worlds. And farthest of all is the mysterious Oort cloud, with trillions of icy objects, some of which become comets.



3 The solar system started out as a cloud of gas, ice, and dust

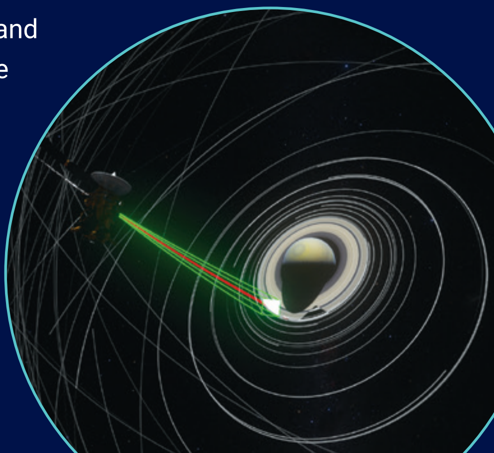
Just over four and a half billion years ago, gravity caused this cloud to collapse in on itself, forging a central star, our Sun, surrounded by a swirling disk of debris. The planets formed within this disk, along with diverse objects like moons, comets, and asteroids. Scientists think each planet carved out its own orbit, growing as it incorporated the material in its path.



computer simulation of a solar system forming

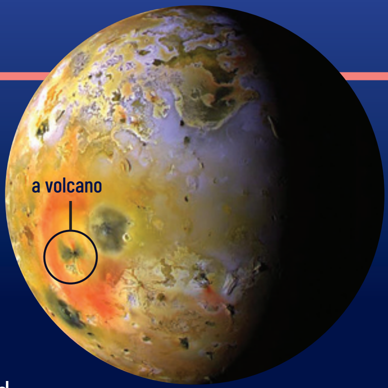
4 Planets grow up as part of a family

Take Saturn, our solar system's second largest planet. It's surrounded by more than 80 moons. Moons can be just as fascinating as the planets they orbit. For example, Saturn's largest one, Titan, has a thick atmosphere and weather just as Earth does—only it's too cold for liquid water, so its bedrock is made of frozen water (ice), and its raindrops are made of liquid methane, or natural gas (CH_4).



Cassini spacecraft capturing images of Saturn's rings. White lines represent the orbit paths of Saturn's moons.

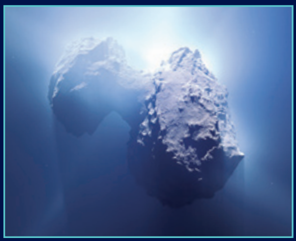
5 Jupiter's family is hotter than you'd think



Jupiter's moon Io

At 800 million kilometers from the Sun, giant Jupiter and its dozens of moons seem like they'd be pretty frigid. But as Voyager 1 saw, its fourth largest moon, Io, has active volcanoes! Io is caught in an intricate gravitational dance with one of its sister moons, Europa, along with Jupiter itself. Gravitational forces squash and stretch Io's rocky insides until they melt and erupt. The Galileo spacecraft confirmed that Jupiter too is a dynamic world, with hot, liquid, metallic hydrogen churning around its rocky core and generating a magnetic field. And hidden beneath Europa's icy crust is a liquid ocean of salty water.

6 Comets carry chemical riches across the solar system



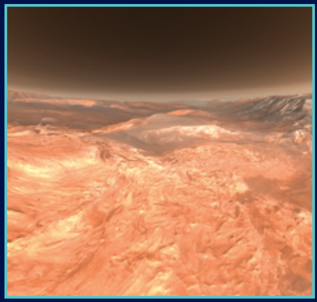
Comet 67P

When the Rosetta spacecraft visited comet 67P, it detected not just frozen water and rock dust, but also amino acids—the basic building blocks of life! Little objects like this (67P is just a few kilometers across) can collide with planets and moons, delivering their bounty of water and potentially lifegiving organic ingredients. As a comet gets closer to the Sun, its ice transforms into gas that streams off into space, carrying dust grains that could become shooting stars when they cross Earth's orbit.

7 Venus is Earth's toxic twin

Venus, our nearest neighbor planet, is similar in size to Earth, made of the same materials, and like Earth and Mars it inhabits the same just-right planetary neighborhood, not too hot and not too cold, called the Goldilocks Zone. But Venus is missing one vital ingredient: a magnetic field. Without it, Venus has had no protection from the solar wind, which stripped away Venus's water and turned the planet into a carbon-dioxide greenhouse too hot for life. The planet's surface is hot enough to melt lead! Going to Venus deepened our understanding of global warming; pumping carbon dioxide into our atmosphere is raising temperatures and threatening life on Earth.

8 Mars was once more like Earth—but only briefly



a deep, water-carved canyon on Mars, evidence that liquid water once flowed on the planet's surface

Liquid water once ran over the surface of Mars; flash floods carved out the terrain. The dynamic planet's active volcanoes included Olympus Mons, the highest peak in the solar system. And its molten core generated a magnetic field that protected the planet from much of the solar wind. But at about half the size of Earth, Mars cooled too fast to maintain its magnetic field and hang onto its water. It lost most of its atmosphere, leaving behind a dry, frozen desert.

9 Earth is just right for life

Not only does Earth orbit the Sun in the Goldilocks Zone, it's just the right size to maintain a hot, dynamic interior where churning liquid iron generates a magnetic field. Shielding Earth's atmosphere from harmful solar radiation, the magnetic field plays a vital role in creating a biologically safe space where, over the course of billions of years, complex life was able to evolve. Earth is the only world we know of with sparkling blue oceans and lush green forests: a perfect home. Now it's up to us to sustain it.

Earth's magnetosphere deflects harmful solar radiation, protecting not only delicate satellites and electronic equipment, but also the atmosphere necessary for life itself.

Missions

Unlike the distant stars, the solar system is our cosmic neighborhood, so when we want to know more about its worlds, we can go take a look. If a world is inconveniently far to visit in person, we can still send robots as extensions of ourselves.

APOLLO 15

DESTINATION: The Moon

WHEN: 1971

WHO: David Scott, Alfred Worden, James Irwin

PURPOSE: To explore the surface of the Moon and to bring back samples

ACCOMPLISHMENTS: The astronauts sampled three different kinds of lunar structure: the Apennine Front, produced by a collision between the Moon and a large object; horizontal lava flows in an impact basin; and a ray of ejecta from a geologically recent crater. One sample, later named "Genesis Rock," turned out to be 4 billion years old—the oldest Moon rock found until then.

CASSINI AND HUYGENS

DESTINATION: The Saturn system

WHEN: 1997–2017

PURPOSE: To learn about Saturn, its moons and rings, and the properties of gaseous planets

ACCOMPLISHMENTS: From its orbit around Saturn, the Cassini space probe made an extensive survey of the planet, its moons, and its rings. It extended its mission twice, returning data and images for an extra nine years before plunging into Saturn's atmosphere to its planned destruction in 2017. Among its many discoveries were the exact length of a day on Saturn (10 hours, 33 minutes, and 38 seconds) and the age of its rings (a mere 10 to 100 million years). Cassini carried the Huygens probe that touched down on a world in the outer solar system. On Titan, Huygens discovered clouds and seas of methane and dunes made of particles of water ice.

VOYAGER 1 AND 2

DESTINATION: Jupiter, Saturn, and interstellar space

WHEN: Launched 1977; ongoing

PURPOSE: To learn about the Jupiter system, the Saturn system, and the outer reaches of the solar system, and to carry messages beyond our solar system

ACCOMPLISHMENTS: Flying by Jupiter, Voyager 1 discovered a thin ring around the planet as well as two new moons; flying by Saturn, it discovered new moons and shed light on the structure of Saturn's rings. Voyager 2 flew by all four outer planets. Crossing into interstellar space, both measured the interstellar environment.

ROSETTA

DESTINATION: Comet 67P

WHEN: 2004–2016

PURPOSE: To follow, orbit, and land on a comet

ACCOMPLISHMENTS: After a 10-year journey through the solar system, Rosetta arrived at comet 67P, which it orbited, studying the comet's environment and nucleus. It sent a lander to the surface, which tested for organic compounds, before Rosetta crashed into the comet itself two years later. Around the comet the mission found large amounts of oxygen gas that was the product of ice from the comet interacting with solar radiation. It measured the isotopic composition of the water there, which turns out to be quite different from that of water on Earth, suggesting that our planet's water did not arrive here on comets from the Kuiper Belt like 67P.

GALILEO

DESTINATION: Asteroid Gaspra, Comet Shoemaker-Levy 9, and Jupiter

WHEN: 1989–2003

PURPOSE: To learn about Jupiter and its moons

ACCOMPLISHMENTS: Among its many discoveries, Galileo observed an electric field around Jupiter and vast thunderstorms on it; the temperature and composition of volcanoes on its moon Io; an ocean of salty liquid water lying beneath the icy surface of its moon Europa; and a magnetic field around its moon Ganymede. Galileo also discovered a tiny moon orbiting an asteroid and observed a comet colliding with Jupiter's atmosphere.

MAGELLAN

DESTINATION: Venus

WHEN: 1989–1994

PURPOSE: To take high-resolution radar images of the surface of Venus, and to study the planet's topography, geology, and gravity

ACCOMPLISHMENTS: During an extended mission of 243 days and more than 15,000 orbits, Magellan used cloud-piercing radar to map 83.7 percent of the planet's hitherto hidden surface. Its high-resolution images showed evidence of volcanic action, tectonic movement, lava channels, and pancake-shaped domes.

MARS ORBITERS AND ROVERS

DESTINATION: Mars

WHEN: 1997–ongoing

PURPOSE: To explore the surface of Mars

ACCOMPLISHMENTS: Little Sojourner explored areas near Ares Vallis, its landing site, discovering that water floods had shaped the terrain. Spirit and Opportunity found further evidence of water. Curiosity has been searching for evidence that Mars could have supported life, and has discovered organic materials—building blocks of life—in Martian rocks.

COME PREPARED CHECKLIST

- ☐ **Plan your visit.** For information about reservations, transportation, and lunchrooms, visit amnh.org/plan-your-visit/field-trips.
- ☐ **Read the Essential Questions** in this guide to see how themes in the space show connect to your curriculum. Identify the key points that you'd like your students to learn.
- ☐ **Review the Synopsis** for an advance look at what you and your class will be watching.
- ☐ **Download student activities** at amnh.org/worlds-beyond-earth-educators. Designed for use before, during, and after your visit, these activities focus on themes that correlate to the standards.

ARRIVAL TIME

Please plan to arrive at the space show boarding area, located on the **1st floor of the Rose Center**, 15 minutes before the show starts.

CORRELATION TO STANDARDS

A Framework for K-12 Science Education

Scientific and Engineering Practices • Developing and using models • Planning and carrying out investigations • Analyzing and interpreting data
Crosscutting Concepts • Patterns • Cause and effect • Scale, proportion, and quantity • Systems and system models • Stability and change
Disciplinary Core Ideas • PS2.A: Forces and Motion • PS2.B: Types of Interactions • ESS1.A: The Universe and Its Stars • ESS1.B: Earth and the Solar System • ESS2.A: Earth Materials and Systems • ESS2.C: The Roles of Water in Earth's Surface Processes

GLOSSARY

asteroid: a small, rocky object that orbits the Sun; most are confined to the main asteroid belt

comet: a "dirty snowball" of frozen gases, rock, and ice that orbits the Sun

interstellar: between the stars of our galaxy, beyond the solar system

moon: a natural object that orbits a planet or asteroid

planet: an object that orbits the Sun, is massive enough to have become spherical, is not a moon, and has removed small objects from the area around its orbit, called its orbital zone; a **dwarf planet** has not removed all objects from its orbital zone, but it meets all the other criteria for a planet

CONNECTIONS TO OTHER HALLS

ARTHUR ROSS HALL OF METEORITES

Students can get close to meteorites and look for clues about how our solar system formed and evolved. They can find out about sample-return missions to other worlds in the Building Planets section.

CULLMAN HALL OF THE UNIVERSE

Students can visit the Planets Zone to explore the variety of worlds. They can walk along the Cosmic Pathway to experience the history of the universe and can circle the Scales of the Universe to understand the relative sizes of different objects.

GOTTESMAN HALL OF PLANET EARTH

Students can examine an outstanding collection of geological specimens for a close look at one planet: our own Earth. They'll find sections on the Earth-Moon system, volcanism, how Earth formed, and what makes Earth habitable.

CREDITS

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