MOONS
WORLDS OF MYSTERY

AN EDUCATOR'S GUIDE

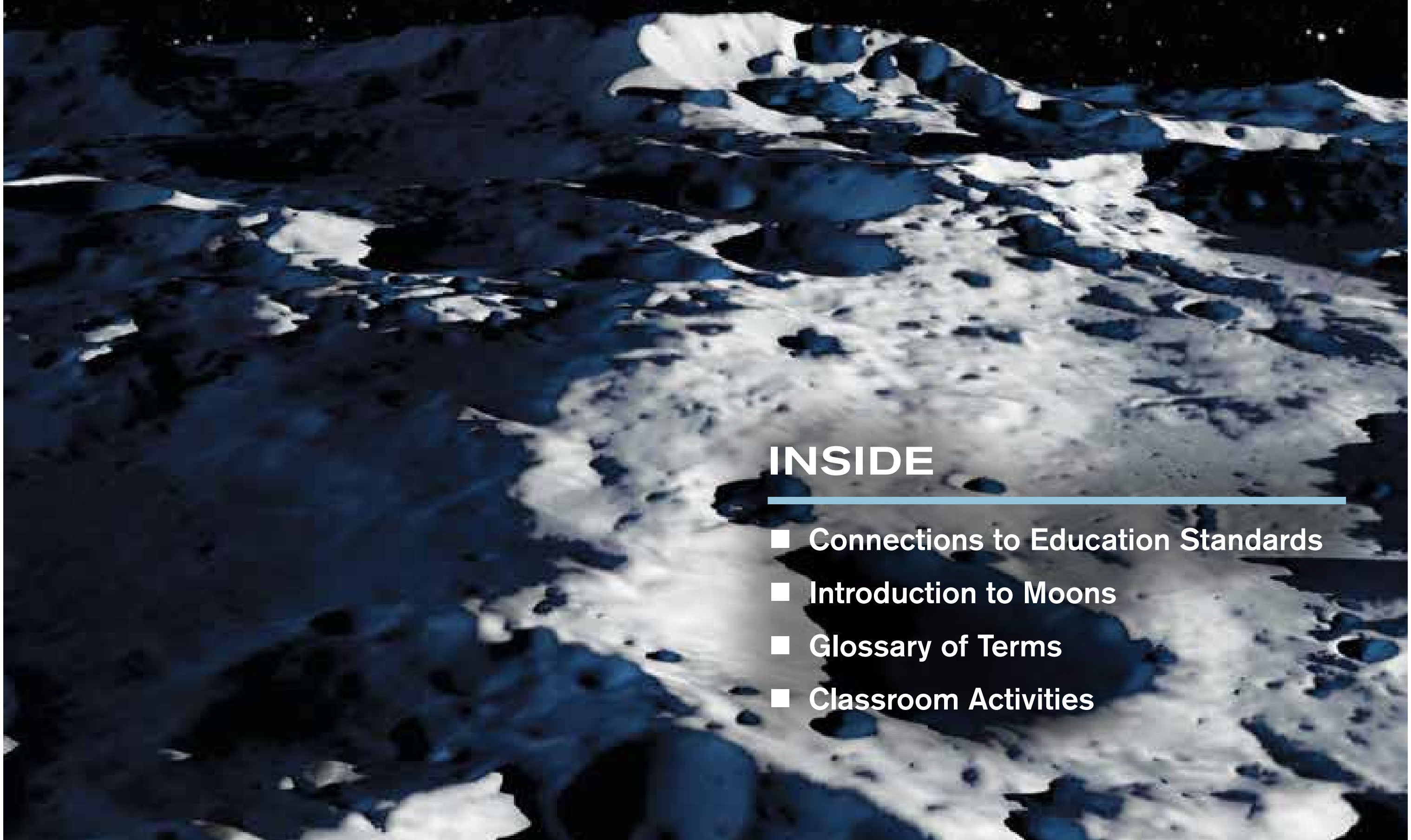

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Photo © Michael Malyszko

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About This Guide

How to Use This Guide

This guide is meant to be a supplement for teachers bringing their students to the Planetarium show *Moons: Worlds of Mystery* at the Museum of Science, Boston.

- The suggested age group for this show is grades 3 – 12.
- Suggested activities and follow-up questions are included in this guide.
- **Bolded words** are defined further in the glossary (page 17).

Contact Information

- For questions regarding *Moons: Worlds of Mystery,* email schoolplanetarium@mos.org.
- For general field trip planning resources, visit mos.org/educators.
- For school group reservations, call Science Central, open daily (9:00 a.m. – 5:00 p.m.), at 617-723-2500, 617-589-0417 (TTY).

Credits

Moons: Worlds of Mystery was produced by the Museum of Science, Boston (mos.org). This guide was developed by the Charles Hayden Planetarium staff.

ABOUT THE CHARLES HAYDEN PLANETARIUM

THE EXPERIENCE

The Charles Hayden Planetarium at the Museum of Science offers visitors of all ages an immersive space exploration experience. Detailed and accurate star maps and digital video are projected onto the 57-foot-wide dome overhead, allowing students to appreciate the vastness of space in three dimensions.

ACCESSIBILITY

The Charles Hayden Planetarium is wheelchair accessible. Show scripts for *Moons: Worlds of Mystery* are available upon request. Please contact schoolplanetarium@mos.org with questions about further accessibility needs, including assistive-listening devices and closed-captioning for the hearing impaired.

Connections to Education Standards

The general education standards that are explored in this show are listed below.

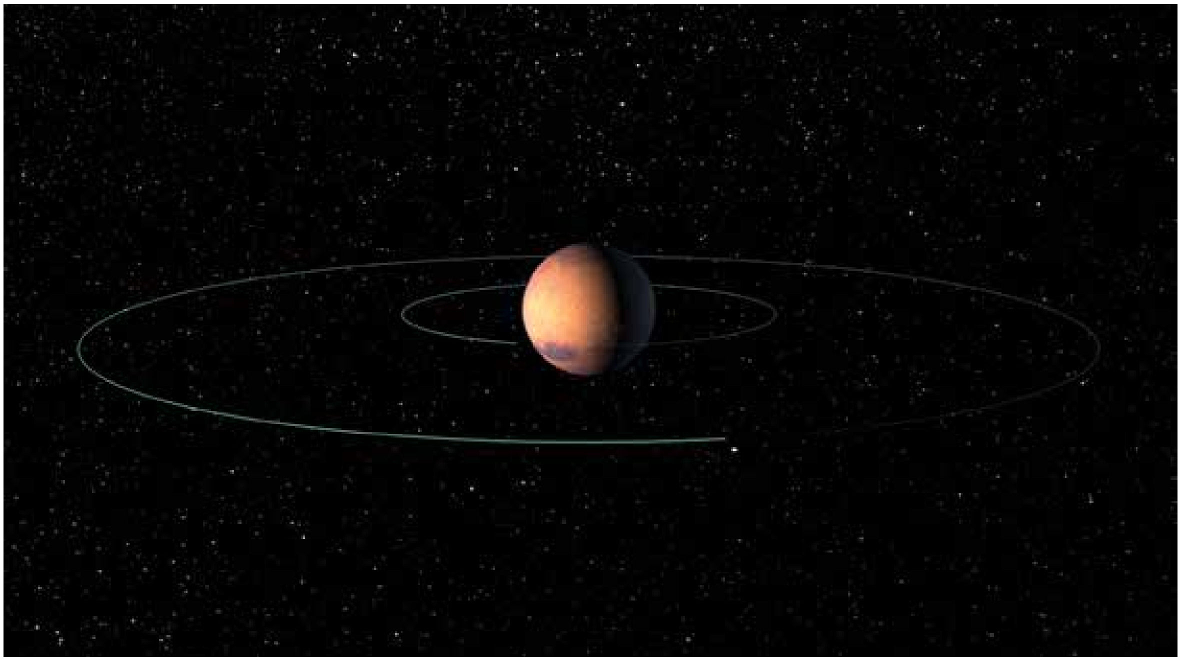
National Science Education Standards

GRADE LEVEL	CONTENT STANDARDS
All	Abilities necessary to do scientific inquiry
	Understanding about scientific inquiry
	Science as a human endeavor
K – 4	Light, heat, electricity, and magnetism
	Characteristics of organisms
	Changes in the Earth and sky

GRADE LEVEL	CONTENT STANDARDS
5 – 8	Transfer of energy
	Structure of the Earth system
	Earth in the solar system
9 – 12	Motions and forces
	Interactions of energy and matter
	The origin and evolution of the Earth system
	Understanding about science and technology

Massachusetts Science and Technology/Engineering Frameworks

GRADE LEVEL	CONTENT STANDARDS
3 – 5	The water cycle
	The Earth in the solar system
	States of matter
6 – 8	Earth's history
	The Earth in the solar system
9 – 12	Matter and energy in the Earth system
	Earth processes and cycles
	Heat and heat transfer



Phobos and Deimos, the two tiny moons of Mars, orbit the planet in a matter of hours. *Image © Museum of Science*

When you imagine the solar system, you often think of the Sun and its eight planets. Maybe the asteroid belt or a comet. But what about **moons**? What do they contribute to the whole system, and what do they look like? Our Moon is certainly visible from the Earth—we've even traveled there! But there are more than one hundred known moons throughout the solar system, orbiting five of the other planets and even some of the asteroids and **Kuiper Belt objects**.

Our Moon has been a constant source of wonder for humanity. Formed from a violent collision early in our solar system's history, the Moon has contributed not only to Earth's stability, but possibly even to the conditions making our planet habitable for early life.

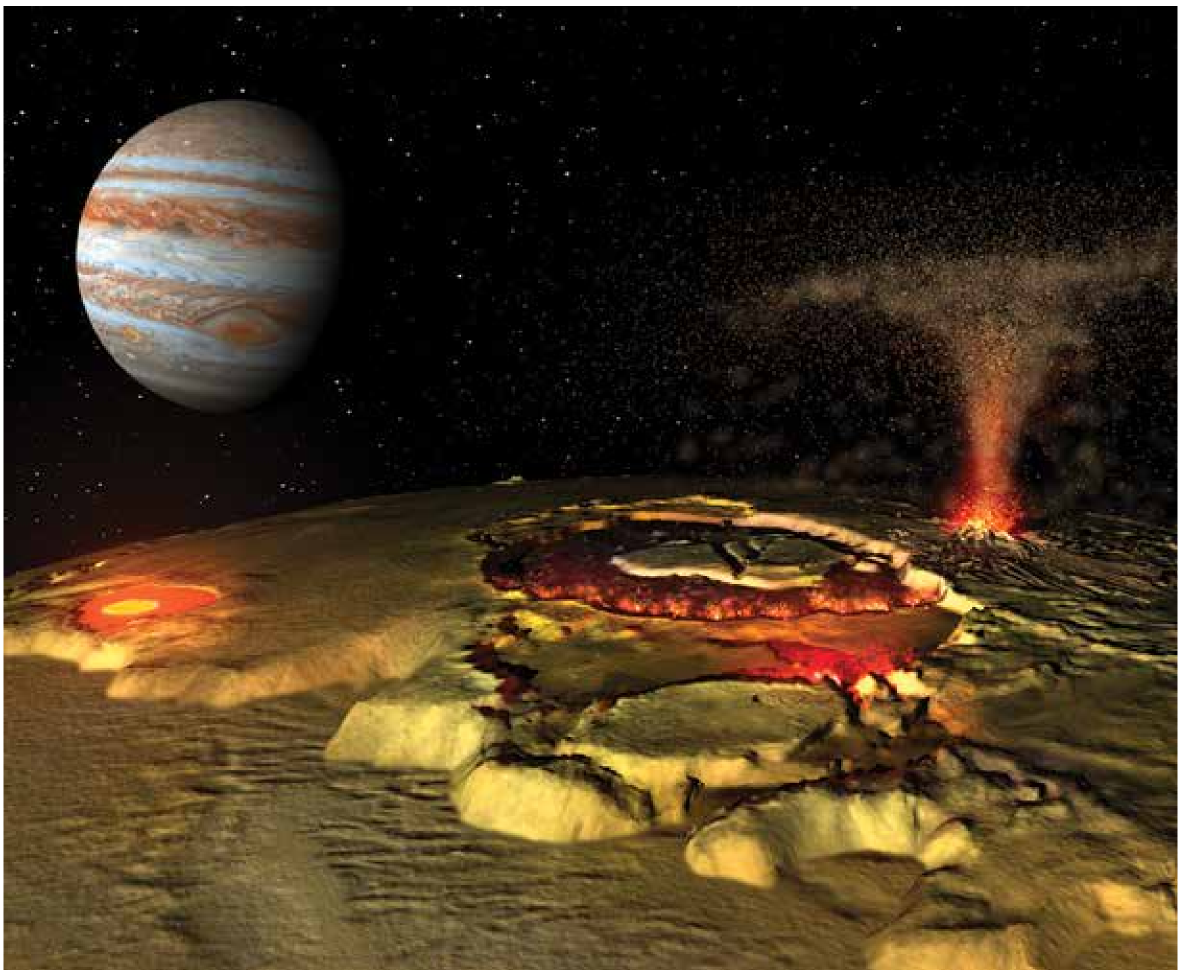
Galileo Galilei was the first true explorer of moons, and his discovery of Jupiter's four largest moons radically changed the study of astronomy. Since then, the rise of new technologies has allowed humanity to scout the solar system for more moons, and their discoveries have turned up many surprises.

For example, moons are incredibly diverse in both appearance and dynamics. Jupiter's moons run the gamut from Io's volcanic inferno to Europa's icy subsurface oceans.

Moons are also vital parts of the solar system. Their gravity and interactions govern phenomena such as tidal force and planetary ring structure. Their influence can be felt on any scale.

Perhaps most intriguing is the exploration of moons that could support extraterrestrial life. Titan's liquid oceans of ethane and methane and Europa's vast subsurface water oceans are prime targets for this study, and encourage us to reevaluate just what conditions are suitable for life.

The discovery of moons orbiting asteroids and Kuiper Belt objects like Pluto shows just how vast and diverse our solar system really is. With these revelations, it is exciting to wonder where humanity's curiosity and imagination will take us next.



Io, one of Jupiter's large moons, is covered in active volcanoes.

Image © Museum of Science

Major Themes: Moons as Diverse Worlds

Not all moons are dry, dusty, cratered worlds like our Moon. Each has a unique history and relationship with its planetary partner, and some have actively evolving surfaces. Some notable examples are:

Io

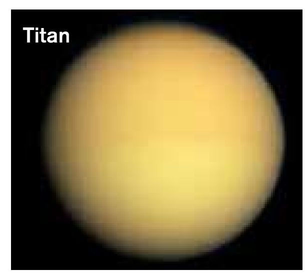
- Orbits Jupiter
- Strong tidal forces contort crustal rock, creating lots of heat
- Over 400 active volcanoes

Europa

- Orbits Jupiter
- Liquid ocean under icy crust
- Tidal forces provide heat to warm the ocean and prevent freezing

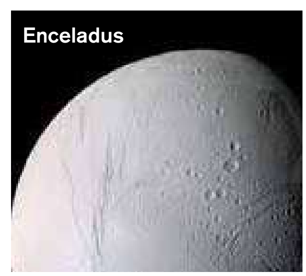
Titan

- Orbits Saturn
- Second largest moon in our solar system—larger than Mercury!
- Has a thick atmosphere
- Has lakes and rivers of liquid methane and ethane, which undergo a cycle similar to the water cycle on Earth



Enceladus

- Orbits Saturn
- Geysers at south pole erupt icy particles which may contribute to Saturn's rings



Triton

- Orbits Neptune
- **Retrograde orbit** suggests it was likely captured from the Kuiper Belt
- Has active geysers that erupt plumes of nitrogen and dust

Io Image Courtesy of NASA/JPL/University of Arizona; Europa Image Courtesy of NASA/JPL/Ted Stryk; Titan and Enceladus Images Courtesy of NASA/JPL/Space Science Institute; Triton Image Courtesy of NASA/JPL/USGS

Charon

- Orbits Pluto
- About half the size of Pluto, causing the two objects to orbit a point in space outside Pluto itself (the **barycenter**)
- Locked in **synchronous orbit** with Pluto

Major Themes: Moons as Part of a System

Even though they are individual worlds with varying histories and circumstances, moons are vital parts of the systems they inhabit.

For example, tidal forces work on a primary and its satellites at all scales. In the same way that the Moon's gravitational pull generates Earth's tides, the combined gravity of Jupiter and its moons creates tremendous tidal heating to fuel the volcanoes on Io. The tidal pull of this system also provides sufficient heat to warm subsurface oceans on Europa and other Jovian moons.

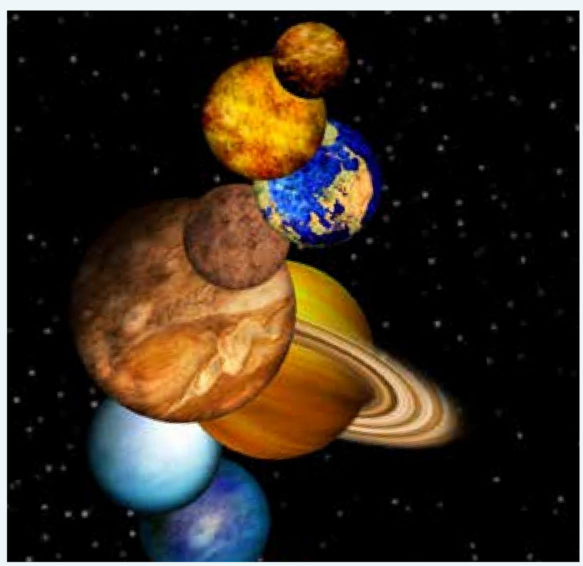
On a smaller scale, shepherd moons like Saturn's Pandora and Prometheus use their gravity to interact with nearby objects, such as the particles making up Saturn's rings. Their influence leaves gaps and sharply defined edges in the rings.

Earth's Moon exerts a constant, steadying effect on several of our planet's motions. Some systems, however, are set up for less stable outcomes. For example, some of Uranus's moons are doomed to future collisions (which could create more moons!). On any scale, it is clear that moons are more than passive bystanders in the solar system.

PLANETS AND THEIR MOONS:

(as of December 2012)

Mercury:	**0**
Venus:	**0**
Earth:	**1**
Mars:	**2**
Jupiter:	**66**
Saturn:	**62**
Uranus:	**27**
Neptune:	**13**



Delving Deeper: Earth's Moon

A view of Earth rising behind our Moon.

Image © Museum of Science

Why is Earth's Moon Important?

Without the Moon, life on Earth might be very different, or it might not have come to exist at all! The most important influence of the Moon is tidal force. But tides accomplish more than just the rise and fall of the oceans—they can affect the motions of the entire planet.

▪ Slowing of the Earth's Rotation

Billions of years ago, the young Earth could have had a day as short as 9 hours. However, the Moon's gravitational pull on Earth's tidal bulges has slowed the Earth's rotation significantly over time. Without this calming influence, the Earth would be subject to faster winds and more devastating storms.

▪ Stabilization of the Earth's Axis

Without the Moon, the tilt of the Earth's axis would vary wildly over time. The most direct consequence of this wobbling is that the Earth would constantly undergo dramatic changes in climate. Some scientists theorize that the stability the Moon brings to Earth's axis has allowed complex life to evolve and flourish on the planet.

▪ Tides and Nutrient Mixing

Our daily tides act like a mixing spoon for marine ecosystems, stirring rich sea life from the ocean bottom toward the surface to interact with fish and other creatures. Without this mixing, ecosystems would suffer, which might have larger implications for global phenomena like the carbon cycle.

Moon Formation Processes

Moons can be formed by several very different processes:

- **Co-formation:** These moons formed out of the early **solar nebula**, at the same time as their corresponding planetary body. Their orbits tend to be in the same direction as the spin of the primary. Examples include Jupiter's Io, Europa, Callisto, and Ganymede.
- **Collision:** These moons formed later in the solar system's timeline, when one or more objects collided and broke into smaller pieces. Collisions can occur between objects already in orbit around a primary, between objects "wandering" through the solar system, or even with the primary itself. Examples include Earth's Moon and Jupiter's Himalia.
- **Capture:** These moons often formed elsewhere in the solar system but were captured by the primary's gravity after a chance encounter. Their orbits are often retrograde, or backward in relation to the spin of the primary object. Examples include Mars's Phobos and Deimos, and Neptune's Triton.

The Formation of Saturn's Rings

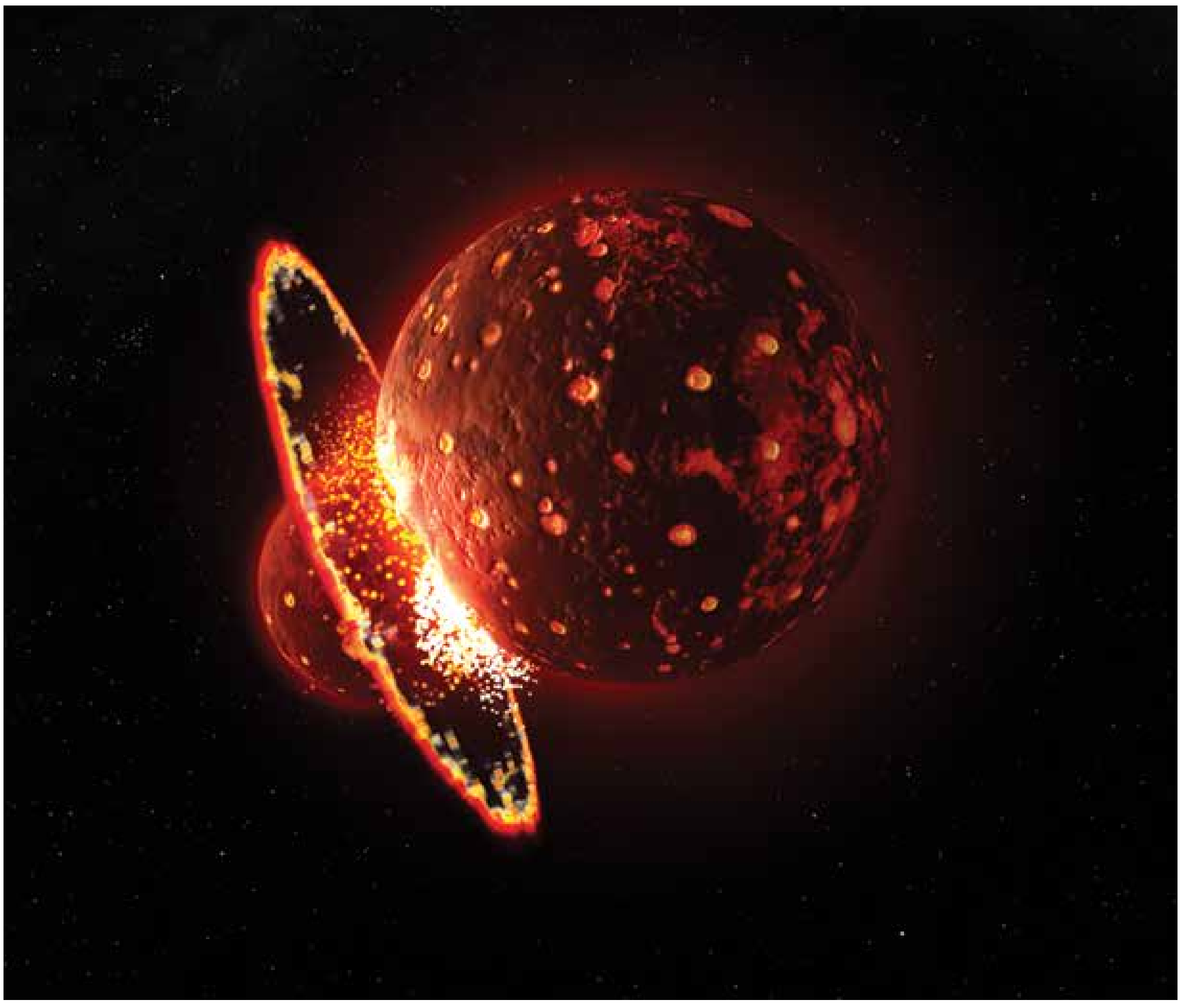
Astronomers believe that Saturn originally formed without a set of rings. Instead, the formation of the rings is best explained by the destruction of a large moon that got too close to the planet. When an object crosses the **Roche limit** of a larger body, tidal force will be strong enough to tear the smaller object apart. Billions of years ago, this large Saturnian moon would have crossed the Roche limit, at which point its icy crust would have been ripped apart. The resulting particles went into orbit around the planet, creating the bulk of today's visible rings. The rocky inner core of the moon crashed into the planet too quickly to be torn apart itself.

Saturn's rings were formed from the destruction of a large moon.

Image © Museum of Science

Formation of Earth's Moon

Scientists agree that Earth did not originally form with the Moon we have today. The leading theory about our Moon's origin suggests that a Mars-sized body collided with the young, molten Earth. The Moon was then formed out of the resulting debris. Over billions of years, the Moon's surface evolved as lava flows cooled into the dark maria and countless collisions littered the highlands with craters.



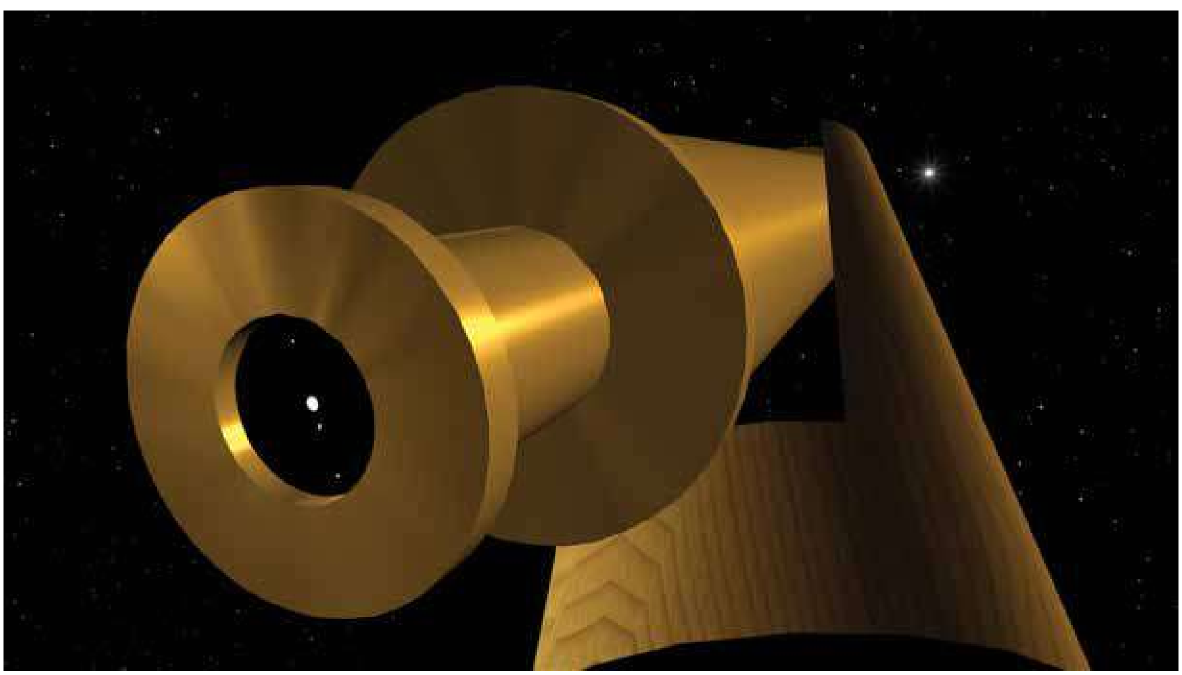
Scientists believe our Moon formed after the young Earth collided with a large planetary body early in the solar system's history. The resulting debris from the collision coalesced to create our Moon. *Image © Museum of Science*

Delving Deeper: Exploration and Spacecraft

Galileo was the pioneer of moon exploration and discovery. But with the rise of spacecraft and digital imaging, our ability to find and study moons has improved exponentially. Our information has increased as a direct result of humanity's effort and endless imagination.

Galileo and His Telescope

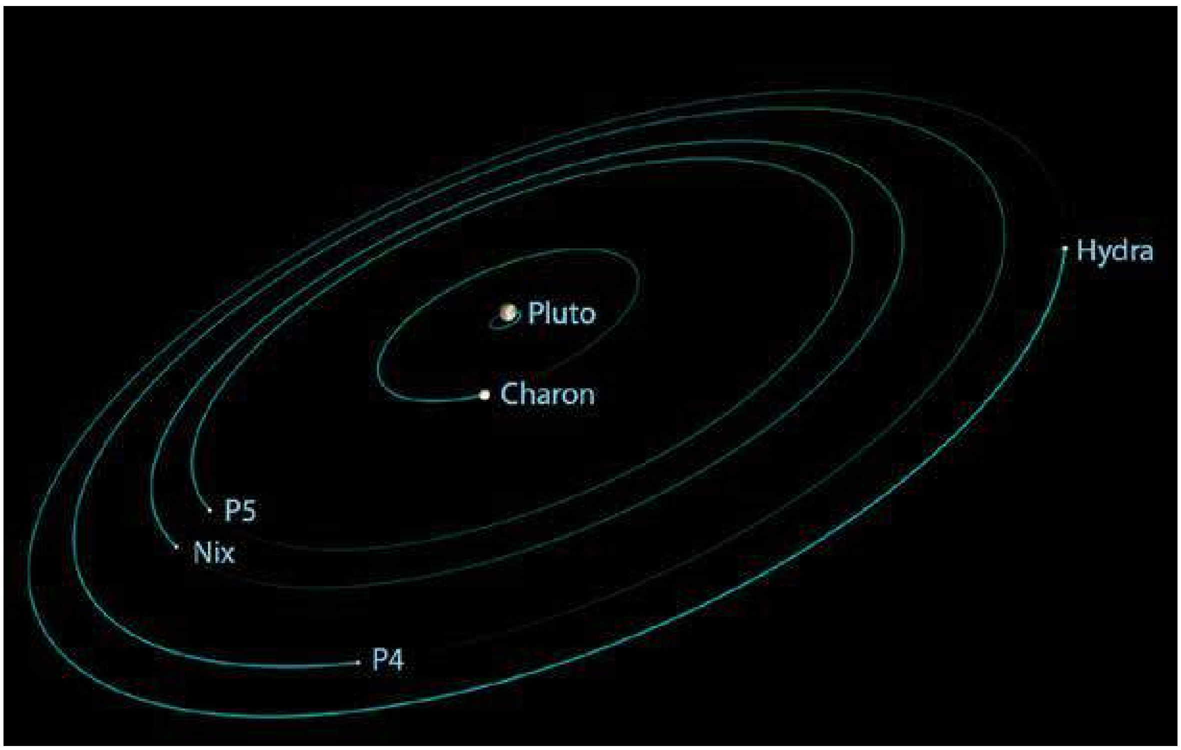
Galileo Galilei (1564 – 1642) discovered the first evidence for moons around another planet on January 8, 1610. Observing Jupiter with a telescope, he noted several bright dots near the planet. From night to night, these dots changed their positions relative to Jupiter, allowing Galileo to eventually conclude that they were, in fact, in orbit around the planet. Prior to this discovery, astronomers believed that everything orbited the Earth. Jupiter's Galilean moons (Io, Europa, Callisto, and Ganymede) heralded a significant shift in the study of astronomy.



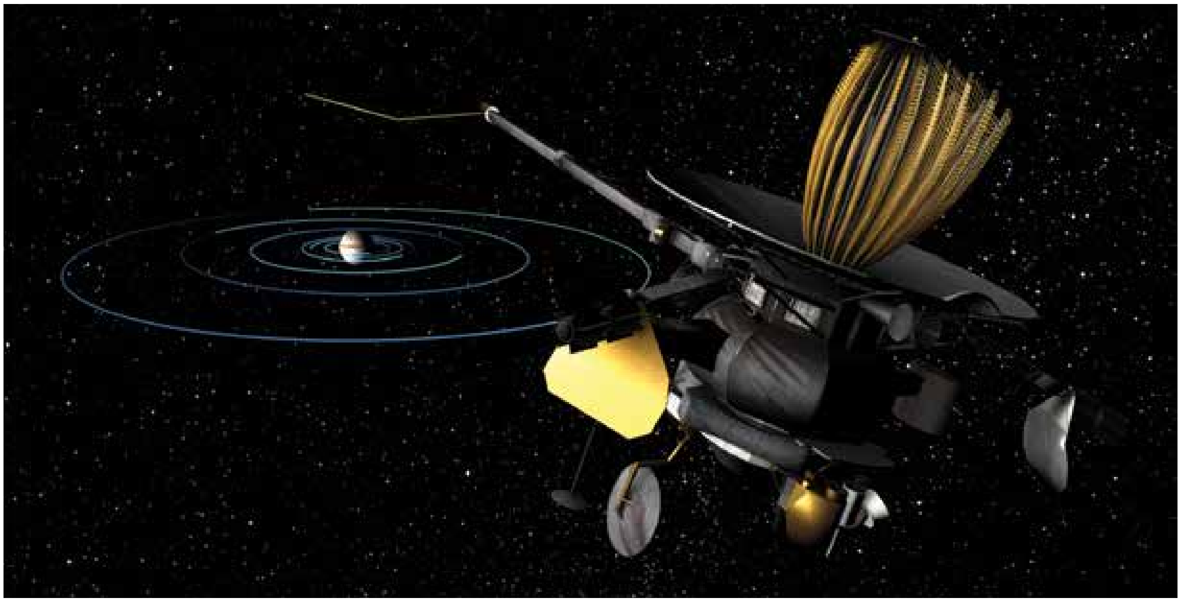
A view of Jupiter and its four largest moons, as seen from Earth. This is similar to how Galileo may have observed them through his telescope. *Image © Museum of Science*

Pluto Has Five Moons!

Until 2011, astronomers knew of three moons in orbit around tiny dwarf planet Pluto: Charon, Nix, and Hydra. Then, in June 2011, the Hubble Space Telescope discovered a fourth moon. Designated "P4," this moon is estimated to have a diameter between 8 and 21 miles. Almost a year later, in the summer of 2012, Hubble spotted a fifth moon. "P5" has a diameter between 6 and 16 miles. Scientists believe that Pluto's moons are fragments from a collision between Pluto and another large Kuiper Belt object billions of years ago.



Dwarf planet Pluto has at least five moons, two of which were recently discovered. *Image © Museum of Science*



The Galileo spacecraft approaching Jupiter. Continuous improvements in technology have allowed humans to explore the solar system in incredible detail.

Image © Museum of Science

Spacecraft: Moon Hunters

Spacecraft—past, present, and future—contribute significantly to the study of moons in our solar system. Their ability to travel makes it easier to identify small moons and also to examine surface features. Some especially significant missions and their targets are listed below:

PLANETARY OBJECT STUDIED	SPACECRAFT NAME	YEARS OF OPERATION
Moon	*Luna* series	1959 – 1976
	Apollo program	1961 – 1972
	Clementine	1994
	Chang'e series	2007 – current
	Chandrayaan series	2008 – current
	LRO/LCROSS	2009 – current
Mars	*Mars Reconnaissance Orbiter*	2005 – current
Asteroid belt	*Galileo*	1989 – 2003
Jupiter	*Voyagers 1* and *2*	1977 – current
	Galileo	1989 – 2003
	Juno	2011 – current
Saturn	*Voyagers 1* and *2*	1977 – current
	Cassini	1997 – current
	Huygens	2004 – 2005
Uranus	*Voyager 2*	1977 – current
Neptune	*Voyager 2*	1977 – current
Kuiper Belt objects	*New Horizons*	2006 – current

Landing on Titan

The *Cassini* spacecraft, launched to Saturn in 1997, carried along a very important passenger: the *Huygens* atmospheric entry probe. Supplied by the European Space Agency, *Huygens* detached from *Cassini* on December 25, 2004 and landed on Titan on January 14, 2005. The probe transmitted data about the moon's atmosphere during its descent, and continued to beam information from the surface to *Cassini* for 90 minutes. From pictures sent back by the probe, it appeared to have landed in a plain strewn with pebbles of water ice.

Titan was targeted for a landing because of evidence of oceans of methane and ethane on the surface. These oceans made Titan the only other solar system body known to have a surface with standing bodies of liquids.

Artistic interpretation of a methane lake on the surface of Titan. *Image © Museum of Science*

Glossary of Terms

Barycenter: The center of mass around which two planetary bodies orbit. In the case of the Earth and the Moon, the barycenter is inside the Earth. In the case of Pluto and one of its moons, Charon, the barycenter is in space, between the two.

Kuiper Belt objects: A collection of small, icy objects orbiting the Sun beyond Neptune. Pluto, the largest of these objects, has at least five moons.

Maria: Dark regions on the Moon's surface, where lava once flowed and then cooled.

Moon: A celestial object that orbits a planet or smaller body, such as a dwarf planet or asteroid.

Primary: Refers to the dominant gravitational body (whether a planet, asteroid, or Kuiper Belt object) around which a moon orbits.

Retrograde orbit: An orbit that is in the opposite direction of the primary's rotation.

Roche limit: The distance within which a celestial body will be pulled apart due to the tidal force of the larger body it is orbiting. Within the Roche limit, the tidal force of a primary will overwhelm the gravitational force needed to hold a moon together, tearing it into small pieces that will continue to orbit the larger body.

Shepherd moon: A small moon associated with planetary ring systems. The gravity from the moon affords a sharply defined edge to the rings.

Solar nebula: The rotating, disc-like cloud of gas and dust surrounding the young Sun, from which all objects in the solar system were formed.

Synchronous orbit: An orbit that occurs at the same speed at which the parent body is rotating. Satellites in synchronous orbit may appear to remain stationary in the sky.

TEACHER TIP

DOWNLOAD FIELD TRIP GUIDES!

Use these handy activity sheets for chaperones and students to make the most of their day at the Museum. Download them before your visit: mos.org/educators.

Online Learning Tools

These websites are intended to provide access to further information about moons.

Lunar Reconnaissance Orbiter Education and Public Outreach

lro.gsfc.nasa.gov
Click on "Education + Outreach"

Cassini Solstice Mission Education and Public Outreach

saturn.jpl.nasa.gov
Click on "Education"

Galileo Mission Education and Public Outreach

solarsystem.nasa.gov
Click on "Education"

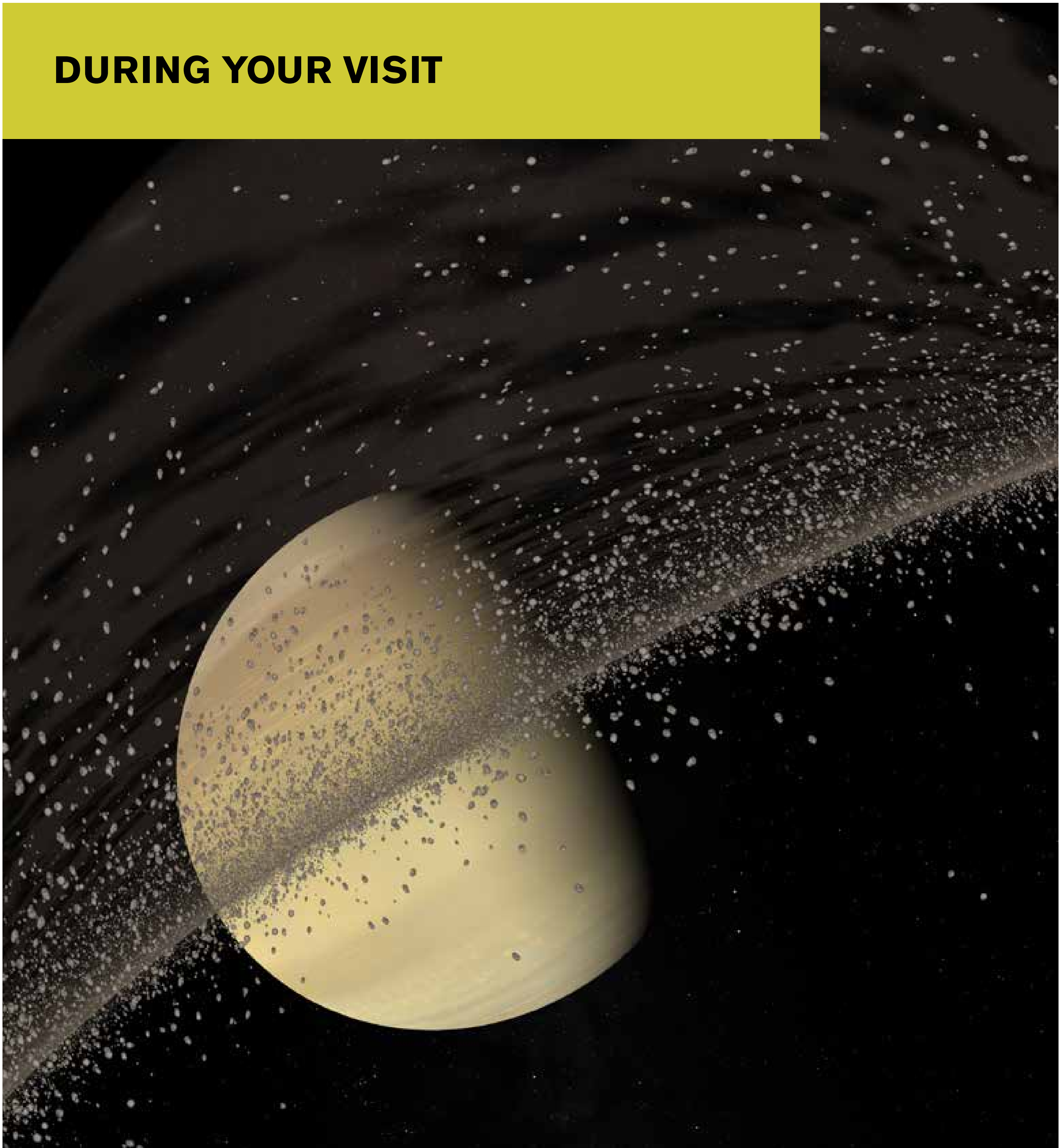
Cassini-Huygens Mission Webpage

sci.esa.int
Click on "Missions" and choose "Cassini-Huygens"

Voyager: The Interstellar Mission Webpage

voyager.jpl.nasa.gov

DURING YOUR VISIT



Related Museum Programming ▪ Live Planetarium Shows

Related Museum Programming

MOONS WORLDS OF MYSTERY

Your journey to the stars continues! With astronomy-related offerings located throughout the Museum's Exhibit Halls, you and your students can continue your extraterrestrial explorations for a day filled with the excitement of learning.

Photo © Michael Malyszko

Cosmic Light Exhibit *Outside Planetarium, Red Wing, Level 1*

Explore concepts such as solar system relationships, the electromagnetic spectrum, and the scale of the universe.

Earth & Space Exploration

Live presentation in the Gordon Current Science & Technology Center, *approximately 20 minutes, check schedule at mos.org/daily*

Watch a demonstration on the changes happening on our planet, or explore the solar system and beyond with a presentation on the latest space missions.

Exhibit Halls admission required. Advance registration available for school groups (minimum 25 people). Email presentationrequests@mos.org at least two weeks prior with requested show title, date of visit, and number attending.

Photo © Nicolaus Czarnecki

To the Moon *Blue Wing, Level 1*

Created in July 2009 in celebration of the 40th anniversary of the first Moon landing, this exhibit features full-size models of the Apollo and Mercury capsules and a graphic timeline documenting this significant era of human space exploration. *Exhibit Halls admission required.*

The Light House *Blue Wing, Level 2*

Ranging from radio waves (larger than a football field) to gamma rays (a billion times smaller than a pinhead), wavelengths are all invisible to the human eye, except for the section of the spectrum known as visible light. In this exhibit, you can explore the science behind light and color. *Exhibit Halls admission required.*

Gilliland Observatory

Weather permitting; Fridays, 8:30 – 10:00 p.m.; March – November

Enjoy stargazing at the Museum's rooftop observatory! The Gilliland Observatory is equipped with a computer-controlled Celestron CGE 1100 Schmidt Cassegrain telescope and is staffed by knowledgeable Museum employees.

Please call the Gilliland Observatory hotline, 617-589-0267, which is updated at 5:30 p.m. on Friday nights with information about that night's observing session. Admission is free thanks to the generosity of the Lowell Institute (parking charges still apply).

Live Planetarium Shows

moons WORLDS OF MYSTERY

Live shows are highly interactive, encouraging students to participate with a Planetarium educator as they learn about various topics in astronomy, earth science, and physics.

These programs are flexible; whenever possible, the Planetarium attempts to address topics that match your classroom studies. Reserved groups can make requests up to two weeks in advance by emailing schoolplanetarium@mos.org. *All shows are 35 – 45 minutes in length.*

Secrets of the Sky *Grades Pre K – 2*

This light-hearted musical program uses intrigue to spark students' interest in astronomical phenomena.

The Sky Tonight *Grades 3 – 5*

This Earth-based star show addresses seasonal events as well as constellation and planet identification. It is specifically designed to familiarize students with the night sky and to encourage their appreciation for its mysteries.

Photo © Michael Malyszko

Explore the Solar System *Grades 3 – 5*

Explore our solar system and learn about the motions and properties of its thousands of components—the Sun, planets, moons, asteroids, and comets.

Explore the Galaxy *Grades 6 – 8*

Examine our solar system, then journey onward through our stellar neighborhood to visit the birthplaces of stars and discover first-hand the size and scale of the Milky Way galaxy.

Explore the Universe *Grades 9 – 12*

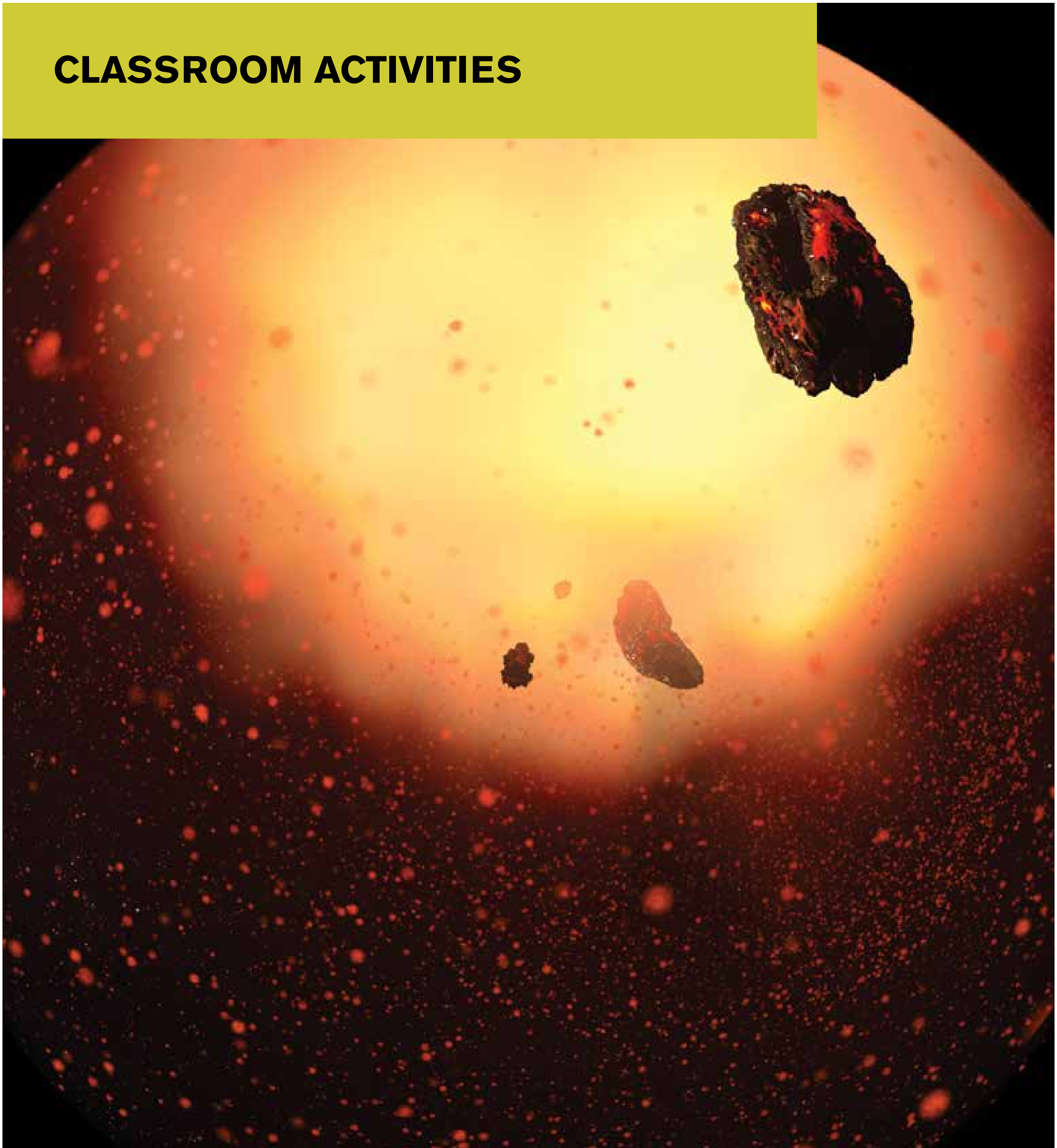
Take a grand tour of the cosmos, from Earth all the way to the farthest reaches of space and time, exploring cosmic mysteries and phenomena that are confounding scientists along the way.

Photo © Michael Malyszko

TEACHER TIP

NEED HELP PLANNING YOUR FIELD TRIP? Ensure that your visit is a valuable learning experience by consulting with a Museum educator to plan a focused visit. Call the field trip planning line at 617-589-0172.

CLASSROOM ACTIVITIES



Grades 3 – 5 ▪ Grades 6 – 8 ▪ Grades 9 – 12

Classroom Activities (Grades 3 – 5)

The following activities are designed to help you introduce your students to the concept of moons in the solar system. Use them before your Museum visit to maximize your field trip experience.

BEFORE YOUR VISIT

ACTIVITY 1
CRATER CRAFTING

lpi.usra.edu/education/explore/LRO/activities/craterCreations/

Craters are found on celestial bodies throughout the solar system. Though they are the scars of explosive collisions, they can also tell us a lot about the history of the object they impact. For example, surfaces with more craters are known to be older, while surfaces with relatively few craters are younger and have been more recently resurfaced by processes such as erosion or volcanic activity.

This activity features a classic technique of crater-making in the classroom: students drop items into flour covered by a thin layer of cocoa powder to create and observe "craters." These materials make it easy to study the physics and anatomy of crater formation. Try adding the following changes to the experiment to test further hypotheses:

1) Drop objects of different sizes from the same height. Do the crater sizes change?

2) Drop objects of different masses from the same height. Do heavier objects make bigger or deeper craters?

3) Drop the same object from a variety of heights. How does the crater change with increasing heights?

4) Try dropping the same objects into sand instead of flour. Do the craters' sizes or shapes change in different materials?

National Standards

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry
- Science as a human endeavor
- Light, heat, electricity, and magnetism
- Characteristics of organisms
- Changes in the Earth and sky

Massachusetts Frameworks

- The water cycle
- The Earth in the solar system
- States of matter

Classroom Activites (Grades 3 – 5)

BEFORE YOUR VISIT

ACTIVITY 2

IMPACT PAINTINGS

lpi.usra.edu/education/explore/marvelMoon/activities/familyNight/craterCreations/index.shtml

Students work in pairs to create and interpret cratered landscapes, estimating age and the order of events. This fun activity combines art and science to test the scientific method.

TEACHER TIP

ASK YOUR STUDENTS THESE GUIDED QUESTIONS RELATED TO EDUCATION STANDARDS:

- Do you think all moons in the solar system look like our Moon?
- What makes something a moon?
- Why might larger planets have more moons?
- Do you think all moons are round like our Moon?
- What can craters tell us about a moon?
- What tools would you use to discover or study a moon?

Classroom Activities (Grades 6 – 8)

The following activities are designed to help you introduce your students to the concept of moons in the solar system. Use them before your Museum visit to maximize your field trip experience.

BEFORE YOUR VISIT

ACTIVITY 1
CRATER CRAFTING

lpi.usra.edu/education/explore/LRO/activities/craterCreations/

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ACTIVITY 2
LEARN ABOUT GRAVITY AND TIDES

sunshine.chpc.utah.edu/labs/tides/menu_tide.swf

This interactive program allows students to see the effect of tides on the orbiting Earth-Moon-Sun system, as well as to test scenarios such as the Earth having a second moon. There is also a teacher version of the site available, with further activities and worksheets.

National Standards

- Transfer of energy
- Structure of the Earth system
- The Earth in the solar system

Massachusetts Frameworks

- Earth's history
- The Earth in the solar system

Classroom Activites (Grades 6 – 8)

BEFORE YOUR VISIT

ACTIVITY 3
IMPACT PAINTINGS

lpi.usra.edu/education/explore/marvelMoon/activities/familyNight/craterCreations/index.shtml

Students work in pairs to create and interpret cratered landscapes, estimating age and the order of events. This fun activity combines art and science to test the scientific method.

TEACHER TIP

ASK YOUR STUDENTS THESE GUIDED QUESTIONS RELATED TO EDUCATION STANDARDS:

- Do moons only go around planets?
  What else in the solar system can they go around?
- What would a moon need to support life?
- How do we study moons?
- Why might larger planets have more moons?

Classroom Activities (Grades 9 – 12)

The following activities are designed to help you introduce your students to the concept of moons in the solar system. Use them before your Museum visit to maximize your field trip experience.

BEFORE YOUR VISIT

ACTIVITY 1
MOON MAPPERS

cosmoquest.org/mappers/moon/

Using images from the Lunar Reconnaissance Orbiter Camera (LROC), students can assist NASA scientists with their research. Tutorials show users how to mark craters on high resolution images of the Moon, and their contributions help improve computer algorithms and mark interesting features for study.

ACTIVITY 2
ORBITS OF JUPITER'S MOONS AND KEPLER'S 3RD LAW

solarsystem.nasa.gov/educ/lesson-view.cfm?LS_ID=1102

Students use images of Jupiter's Galilean moons to find their orbital periods and orbital radii, and find a "constant" relationship between orbital period and orbital radius to arrive at Kepler's 3rd Law.

TEACHER TIP

ASK YOUR STUDENTS THESE GUIDED QUESTIONS RELATED TO EDUCATION STANDARDS:

- How can we tell the age of a moon's surface?
- What can craters tell us about a moon?
- How does our Moon affect the Earth?
- What would a moon need to support life?
- Could we have tides without the Moon?

National Standards

- Motions and forces
- Interactions of energy and matter
- The origin and evolution of the Earth system
- Understanding about science and technology

Massachusetts Frameworks

- Matter and energy in the Earth system
- Earth processes and cycles
- Heat and heat transfer