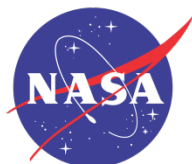




Exploring the Solar System: A Professional Development Training

Fairfield Inn & Suites, Titusville, Florida
September 6 – 7, 2016

Sponsored by the NASA Science Mission Directorate (SMD)

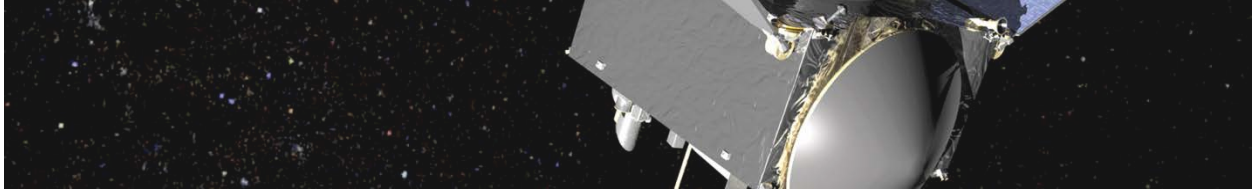


Presented by the Lunar and Planetary Institute





OSIRIS-REX™
ASTEROID SAMPLE RETURN MISSION



Exploring the Solar System: A Professional Development Training

Agenda

Tuesday, September 6

Welcome and Introductions

Activity: Sorting the Solar System

Presentation: Making Our Solar System: Planetary Formation and Evolution

- Dr. Michelle Kirchoff, Southwest Research Institute

Discussion: Active Accretion Activity

Activity: Planet Swap

Activity: Jump to Jupiter

Presentation: All About Asteroids

- Dr. Michelle Kirchoff, Southwest Research Institute

Activity Stations: Impact Cratering

Presentation: Meteorites and what they tell us About the Solar System

- Ms. Zoe Landsman, University of Central Florida

Participant Collaboration/Reflection

Activity: Edible Rocks

Close of Day 1

Wednesday, September 7

Questions from Day 1

KSC Tour Logistics

Activity: Meteorite Kits

Activity: Strange New Planet

Presentation: Exploring Asteroids: A History

Participant Collaboration/Reflection

Activity: Investigating the Insides

Presentation: The OSIRIS-REx Asteroid Sample Return Mission: Reaching New Frontiers

- Dr. Dolores Hill, TUniversity of Arizona

Activity: Down to the Core

Discussion: Online Solar System Exploration Resources

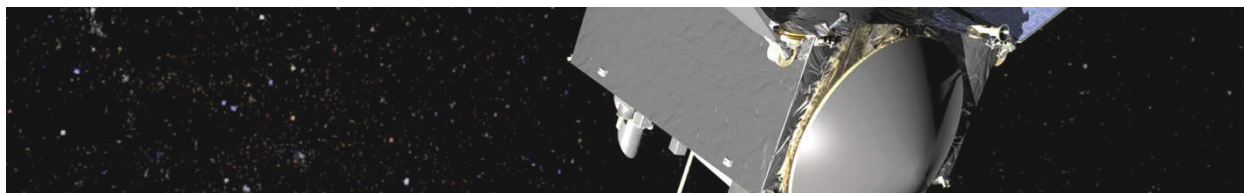
Discussion: Your Future Events & Webinars

Discussion: OSIRIS-REx Launch Viewing Logistics

Evaluation

Close of Day 2





Exploring the Solar System: A Professional Development Training

Activities Overview

Sorting the Solar System

nightsky.jpl.nasa.gov/download-view.cfm?Doc_ID=459

Using images of solar system objects, this activity prompts discussions of the characteristics of asteroids, comets, planets, and moons. Practice scientific thinking by sorting objects into categories according to their common qualities.

Active Accretion

discovery.nasa.gov/education/pdfs/Active%20Accretion_Discovery_508.pdf

Participants model the accretion of specks of matter in our early solar system into chondrules and asteroids—and they do it dynamically. This activity is a great way to teach cool science concepts about our solar system’s early formation and the development of asteroids and planets while burning off energy. Participants end by discussing the strengths and limits of this model.

Planet Swap

In this activity, participants attempt to assemble a meaningful sentence by successively turning over cards with words on them. The point is made that we change our ideas of what a story may be as we gather more information. In addition, people who have similar information may not agree on its meaning. Science works this way.

Jump to Jupiter

www.lpi.usra.edu/education/explore/solar_system/activities/familyOfPlanets/jumpJupiter

Participants jump through a course from the grapefruit-sized “Sun,” past poppy-seed-sized “Earth,” and on to marble-sized “Jupiter” — and beyond! By counting the jumps needed to reach each object, children experience first-hand the vast scale of our solar system.

Crater Creations

www.lpi.usra.edu/education/explore/mars/surface/craters.shtml

In this activity, teams of children ages 8-13, experiment to create impact craters and examine the associated features. The children observe images of craters and explore how the mass, shape, velocity, and angle of impactors affects the size and shape of the crater.

Splat!

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

Participants model ancient lunar impacts using water balloons. Like huge asteroids, the water balloons are destroyed on impact and leave a splash (i.e. a “crater”) that is 10 to 20 times wider than the impactor.

Making Regolith

ares.jsc.nasa.gov/interaction/lmdp/documents/58199main_Exploring_The_Moon.pdf

Participants drop impactors onto layers of graham crackers! The process models how impacts throughout the Moon's history have broken rocks down into a mixture of dust, rocks, and boulders that covers the lunar surface.

Edible Rocks

ares.jsc.nasa.gov/education/program/ExpMetMys/LESSON8.PDF

Participants analyze and discuss candy bars with the same terminology used by geologists to study rocks from space.

Meteorite Kits

An introduction to meteorites developed and compiled by Dr. Larry Lebofsky of the Planetary Science Institute.

Strange New Planet

www.lpi.usra.edu/education/explore/beyondEarth/activities/newPlanet.shtml

In this simulation of space exploration, participants plan and carry out five missions to a “planet” and communicate their discoveries to their family or a friend.

Investigating the Insides

www.lpi.usra.edu/education/explore/solar_system/activities/insides

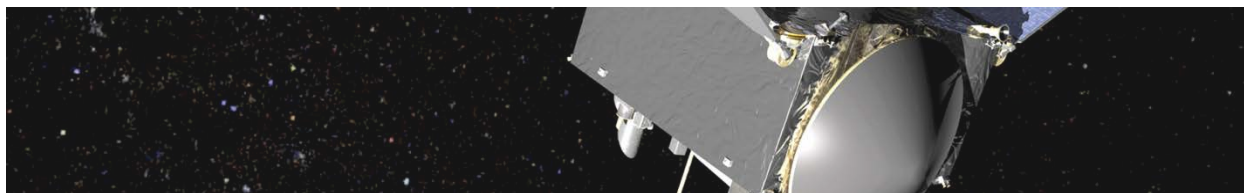
In this 30-minute activity, teams of children, ages 10 to 13, investigate the composition of unseen materials using a variety of tools. This open-ended engagement activity mimics how scientists discover clues about the interiors of planets with cameras and other instruments on board a spacecraft.

Down to the Core

pbskids.org/designsquad/parentseducators/guides/mission_down_to_the_core.html

Participants design and build a device that can take a core sample from a potato.





Exploring the Solar System: A Professional Development Training

Solar System Exploration Resource List

OSIRIS-REx Asteroid Sample Return Mission

www.asteroidmission.org

The OSIRIS-REx mission website maintained by the University of Arizona.

NASA's OSIRIS-REx Website

www.nasa.gov/osiris-rex

The OSIRIS-REx mission website maintained by NASA.

NASA's Robotic Exploration of the Solar System

solarsystem.nasa.gov

Launched in October 1998, this site strives to be a real-time, living encyclopedia of robotic exploration of our solar system.

NASA's Eyes

eyes.nasa.gov

Take virtual tours of the Earth, the solar system and beyond from the real-time perspective of spacecraft!

NASA Wavelength

nasawavelength.org

NASA Wavelength is your pathway into a digital collection of Earth and space science resources for educators of all levels – from elementary to college, to out-of-school programs.

Explore

www.lpi.usra.edu/education/explore

The Lunar and Planetary Institute's Explore program provides hands-on space science activities and supporting resources for out-of-school time programs at libraries, camps, museums, planetariums, librarians, and clubs.

CosmoQuest

cosmoquest.org

Scientific discoveries ranging from finding new planets orbiting alien stars to finding light echoes from quasars are all being made by everyday people working as citizen scientists. Get involved today!

Vesta Mappers

Diminutive Vesta is too small to gravitationally pull itself into a sphere. On this tiny world, you'll see craters shaped like nothing else on CosmoQuest, and help scientists map craters and ridges.

Vesta Trek

vestatrek.jpl.nasa.gov

Vesta Trek is a NASA web-based portal for exploration of Vesta, one of the largest asteroids in the Solar System. This portal showcases data collected by NASA's Dawn spacecraft.

Fireballs in the Sky Mobile App

fireballsinthesky.com.au/download-app

The Fireballs in the Sky app allows you to get involved with the Desert Fireball Network research by reporting your own meteor sightings to their scientists. They use your reports to track the trajectories of meteors – from their orbit in space to where they might have landed on Earth.

Stellarium

www.stellarium.org

Stellarium is a free open source planetarium for your computer. It shows a realistic sky in 3D, just like what you see with the naked eye, binoculars or a telescope.

Night Sky Network

nightsky.jpl.nasa.gov/clubs-and-events.cfm

The Night Sky Network is a nationwide coalition of amateur astronomy clubs bringing the science, technology, and inspiration of NASA's missions to the general public.

NASA/JPL Solar System Ambassadors

www2.jpl.nasa.gov/ambassador/directory.htm

Solar System Ambassadors is a nationwide program consisting of volunteers who communicate the excitement of NASA/JPL's space exploration missions and information about recent discoveries to people in their local communities.

International Observe the Moon Night

observethemoonnight.org

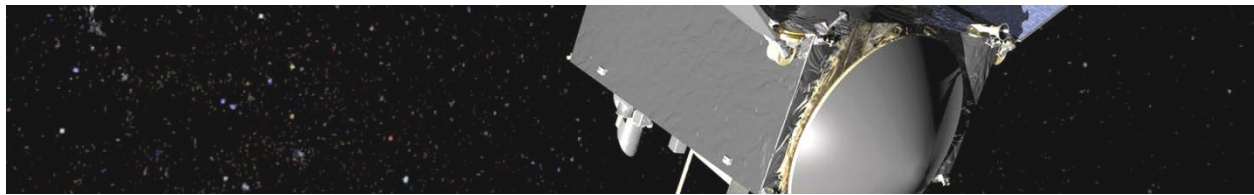
International Observe the Moon Night (InOMN) is an annual worldwide public event that encourages observation, appreciation, and understanding of our Moon and its connection to NASA planetary science and exploration.

2017 Total Solar Eclipse

eclipse2017.nasa.gov

The first total solar eclipse to sweep across the entire U.S. since 1918 is happening on August 21, 2017. If you've never seen a total solar eclipse, here's a great opportunity to do so. NASA is here to help you prepare for this wondrous natural spectacle.





Exploring the Solar System: A Professional Development Training

Participant List

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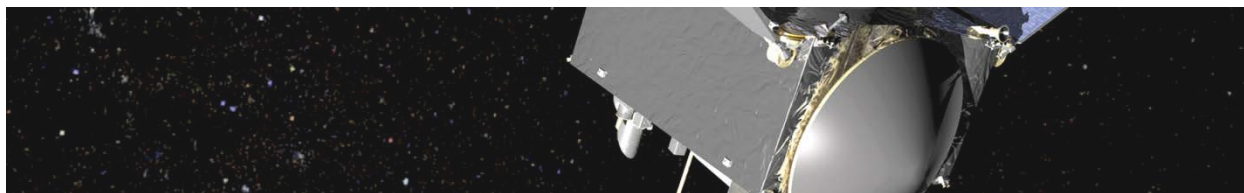
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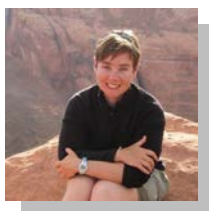
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Presenter List



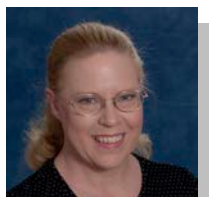
Yolanda Ballard
Education Assistant
Lunar and Planetary Institute

Yolanda has been at the LPI since September 2010. She assists with all the administrative duties for the education team, and serves as one of the primary contacts. I assist with the coordination of meetings, purchasing, and agreements. I also support the team in the preparation of workshops, acquisitions, and shipping of materials, and am the liaison between our team and other departments.



Dr. Sanlyn Buxner
Education Specialist & Research Scientist
Planetary Science Institute

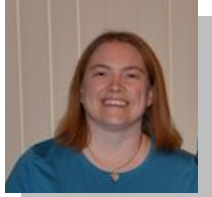
Sanlyn Buxner is an education specialist and research scientist at the Planetary Science Institute in Tucson, AZ. She has worked in space science outreach for the past 20 years doing NASA mission outreach, university teaching, informal education, teacher training, museum work, and field programs for teens and adults. She is a co-investigator on NASA Science Mission Directorate's education cooperative agreement CosmoQuest: Engaging Students & the Public through a Virtual Research Facility.



Dr. Dolores Hill
Senior Research Specialist
Lunar and Planetary Laboratory, University of Arizona

Dolores is a member of NASA's OSIRIS-REx asteroid sample return mission Communication and Public Engagement team, OSIRIS-REx Ambassadors lead, and co-lead of its Target Asteroids! citizen science program (White House Champion of Change for Citizen Science 2013). Since 1981 Dolores has analyzed a wide range of meteorites at the University of Arizona's Lunar and Planetary Laboratory using neutron activation analysis and electron microprobe techniques and provided technical support to space missions. She is a member of the International Meteorite Collectors Association and acting coordinator of the

Meteorite Section of the Association of Lunar and Planetary Observers. In addition to her work analyzing meteorites, she has a lifelong interest in amateur astronomy. Dolores is a longtime member of the Tucson Amateur Astronomy Association, co-founded the Sunset Astronomical Society in Midland, Michigan and was a member of the Warren Astronomical Society in the Detroit-area. Near-Earth asteroid (164215) Doloreshill is named after her. She looks forward to seeing samples of near-Earth asteroid Bennu in 2023!



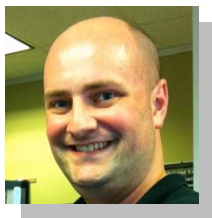
Dr. Michelle Kirchoff
Planetary Research Scientist
Southwest Research Institute

Michelle is a planetary research scientist at Southwest Research Institute in Boulder, Colorado. She uses remote sensing data of solar system objects to better understand the evolution of the solid planets and satellites. Her current projects include using impact crater distributions on the Moon to resolve the relatively recent bombardment of the Earth-Moon system, determining if subsurface ice is currently present at Mars' equator and if not when it was removed, and constraining when surfaces of Saturn's satellites were altered by internal geologic processes such as volcanism. Previous work has involved modeling the formation of mountains on Jupiter's moon Io and understanding the properties of very heavily cratered surfaces.



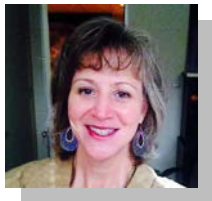
Zoe Landsman
Ph.D. Candidate
University of Central Florida

Zoe Landsman is a Ph.D. candidate in Planetary Science at the University of Central Florida's Department of Physics. She received her Bachelor of Science degree in Physics from the University of Central Florida in 2011. Her research area is the study of asteroid composition and other asteroid surface properties using visible and infrared spectroscopy. She also regularly participates in astronomy education and public outreach activities in the Central Florida community.



Andy Shaner
Public Engagement Lead
Lunar and Planetary Institute

Andy is the Public Engagement Lead at the Lunar and Planetary Institute (LPI) in Houston, TX. He is the education and public outreach (E/PO) lead for the LPI – JSC NASA SSERVI team and the E/PO lead for the ChemCam instrument onboard the Curiosity rover. Andy actively assists colleagues in the planning and implementation of professional development trainings for formal and informal educators. He also plans and implements programming for the general public. Andy received a B.A. in Secondary Education with teaching licensures in physics and earth & space science from Wichita State University and an M.A. in Teaching and Teacher Education with a minor in planetary science from the University of Arizona.



Christine Shupla
Education Lead
Lunar and Planetary Institute

Christine Shupla supervises day-to-day operations for the Education department at the Lunar and Planetary Institute, and coordinates LPI's formal education efforts. She is the principal investigator for the Sustainable Trainer Engagement Program (STEP), and leads a number of teacher professional development programs. Ms. Shupla's bachelor's degree is in Astronomy, and she has a master's in Curriculum and Instruction. Prior to her work at LPI, Ms. Shupla spent approximately 15 years in the planetarium field, managing the planetarium and creating and presenting planetarium shows to approximately a million people.





OSIRIS-REX™
ASTEROID SAMPLE RETURN MISSION

Sorting the Solar System

What's this activity about?

Big Questions:

- What types of objects are in our Solar System?
- Why do the definitions of the objects change?

Big Activities:

- Using images of Solar System objects, start discussions of the characteristics of asteroids, comets, planets, and moons.
- Practice scientific thinking by sorting objects into categories according to their common qualities.

Participants:

From the club: A minimum of one person.

With larger groups, up to four presenters can participate.

Visitors: This activity is appropriate for families, the general public, and school groups ages 10 and up. With small groups, one set of cards can be used. Four sets are included for use in classrooms or larger groups.

Also, a large set of objects is included in this manual. You may print them yourself, but it is recommended that you do this at a print shop. Printing them requires a lot of ink.

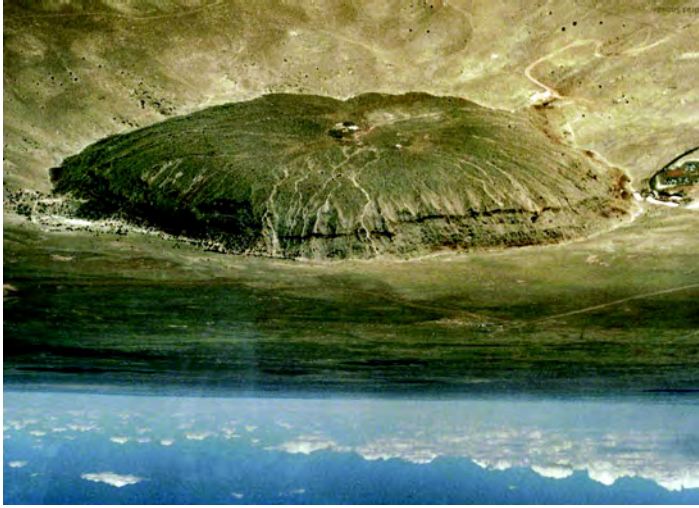
Duration:

Ten minutes, up to a half hour, depending on the depth of questions and conversation.

Topics Covered:

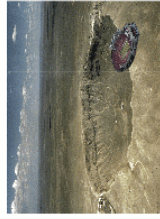
- Review of the diversity of objects in our Solar System
- How scientists use common characteristics to classify the world around us





Barringer Crater

- This crater is located in Arizona, USA
- It was created 50,000 years ago by a chunk of **METAL** from space
- It measures about **1.2 km** in diameter



Size of crater compared to a stadium



Ceres

- Ceres is the largest object between the orbits of Mars and Jupiter
- It is made mostly of **ROCK** and **ICE**
- Ceres is about **950 km** in diameter

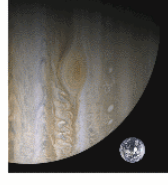


Ceres (bottom left) compared to the Earth and Moon

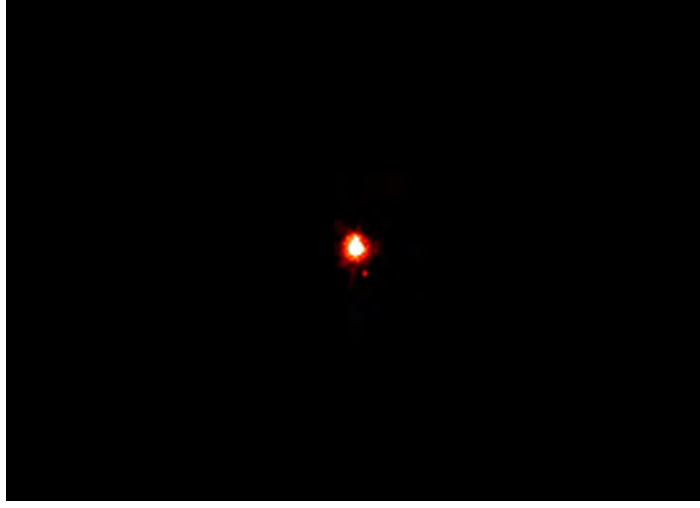
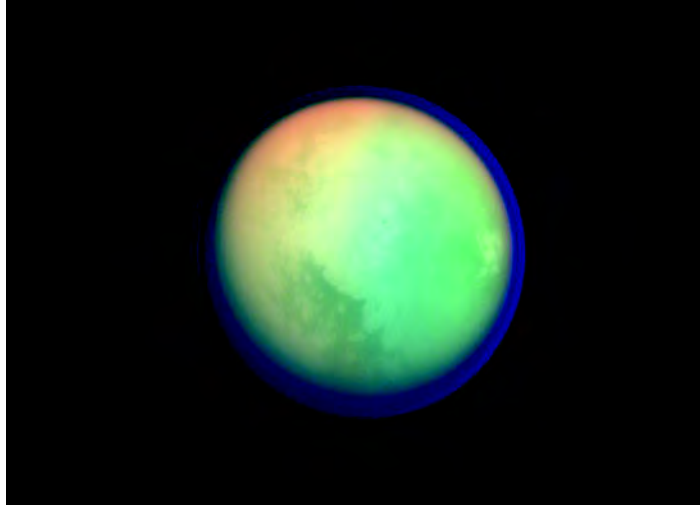


Earth

- It orbits the Sun between Venus and Mars
- Earth is made of **ROCK**, a **METAL** core and both solid and liquid **ICE** (water, that is) on its surface
- Its diameter is **12,650 km**

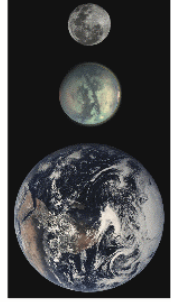


Size of Earth compared to Jupiter



Titan

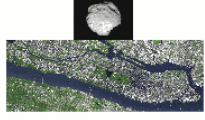
- Titan orbits Saturn
- It is made of **ROCK** and **ICE** and has a thick atmosphere
- It is **5,150 km** in diameter, between the size of the Earth and Moon



Size of Titan (center) compared to the Earth and Moon

Wild 2

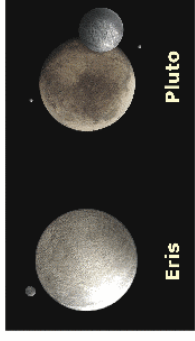
- Wild 2 orbits the Sun between Mars and Jupiter, though its orbit used to be much more distant
- It is made of **ICE** and **DUST**
- It is about **4 km** across



Size of Wild 2 compared to Manhattan

Eris

- The orbit of Eris is very distant, mostly beyond Pluto's orbit.
- It is made of **ICE** and **ROCK**
- The diameter of Eris is about **2,600 km**

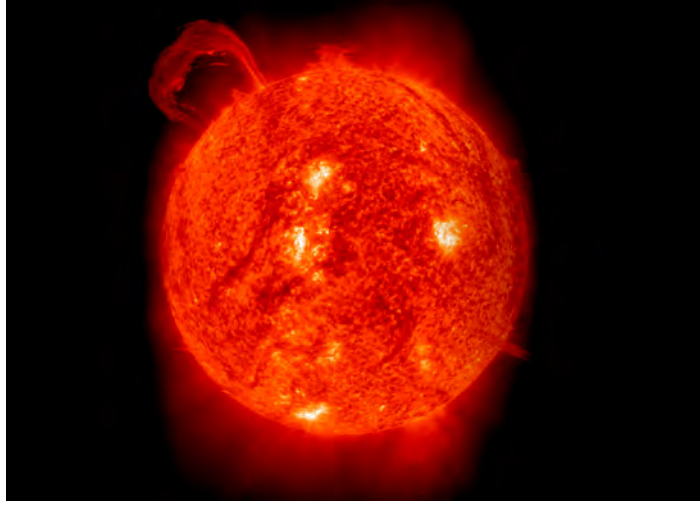


Size of Eris compared to Pluto



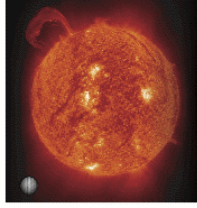
Shoemaker-Levy 9

- Its orbit originally took it beyond Pluto. After it was captured by Jupiter's gravity, it was torn apart and eventually smashed into Jupiter.
- Made of **ICE** and **ROCK**
- Largest pieces were **1km** and left huge marks on Jupiter

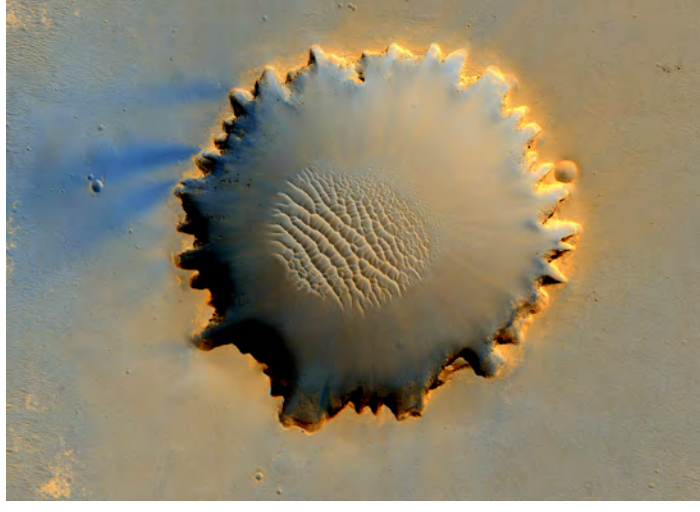


Sun

- The Sun is located in the center of our Solar System
- It is made mostly of hydrogen and helium **GAS**
- The Sun is **1.4 million km** in diameter



Size of Sun compared to Jupiter



Victoria Crater

- This crater is one of the smaller craters on Mars
- The rim's jagged edges are due to erosion caused by **ROCK** and **DUST**
- It is **750 meters** across



Size of crater compared to a stadium



Pluto & Charon

- Pluto and Charon orbit each other, together are mostly outside Neptune's orbit
- These round objects are made of **ICE** and **ROCK**
- Pluto is about **2,300 km** across

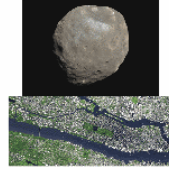


Size of Pluto & Charon compared to Earth and Moon

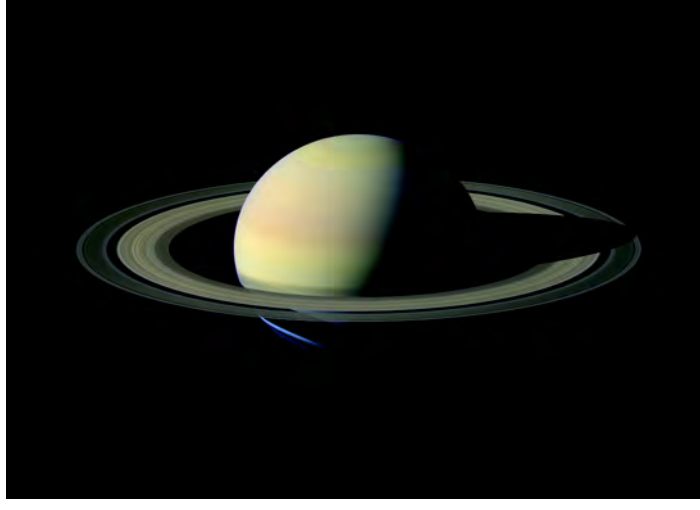


Phobos

- Phobos closely orbits Mars and will eventually collide with it
- It is mostly made of **ROCK** but may have **ICE** inside
- Phobos is about **11 km** across

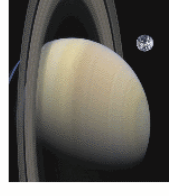


Size of Phobos compared to Manhattan

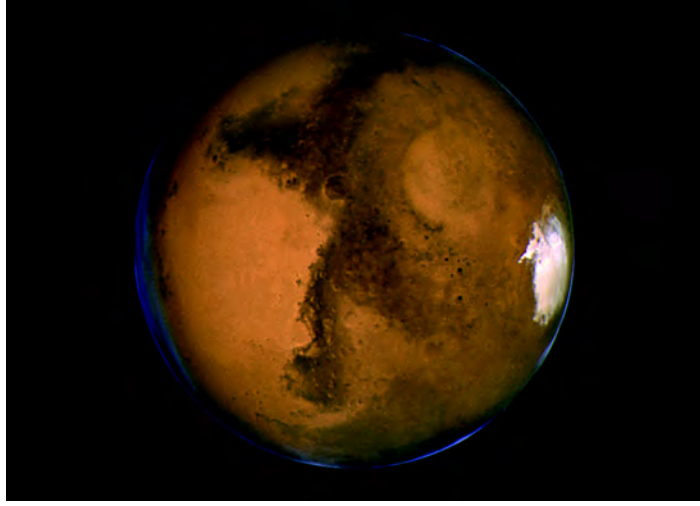
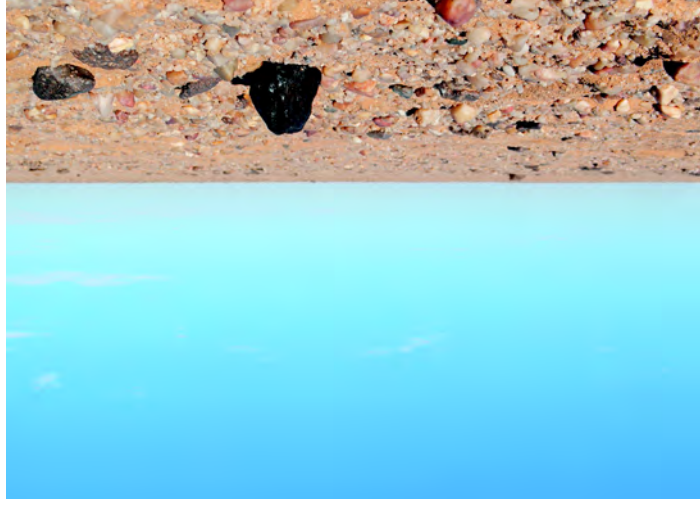


Saturn

- Saturn orbits the Sun between Jupiter and Uranus
- Saturn is mostly made of **GAS**
- The main body is **120,000 km** across



Size of Saturn compared to Earth



Meteorite

- Meteorites are pieces of asteroids that land on other worlds
- They are made of **METAL** and **ROCK**
- Almost all meteorites on Earth are smaller than **1 meter**



Meteor

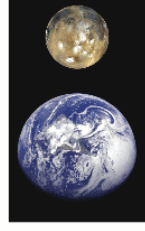
- Meteors occur in Earth's atmosphere, about 75km above the surface
- We see the glowing pieces of **ROCK**
- The pieces of rock are mostly less than **1cm**, or the size of a coin



Size of rock compared to a coin

Mars

- The orbit of Mars is between Earth and the Asteroid Belt
- Mars is made of **ROCK** with a **METAL** core and some solid **ICE** on its surface
- It is **6,800 km** in diameter, about half as wide as the Earth

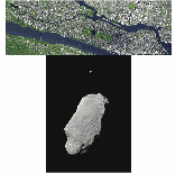


Size of Mars compared to Earth



Ida and Dactyl

- Together they orbit the Sun between the orbits of Mars and Jupiter. Dactyl (the smaller object) orbits Ida.
- They are mixtures of **ROCK** and **METAL**
- Ida is about **15 km** across

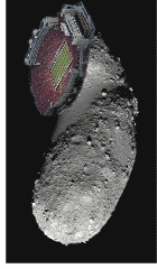


Size of Ida compared to Manhattan



Itokawa

- Itokawa's orbit crosses the orbits of Earth and Mars but is not a threat to either
- It is made of a loose pile of boulders made of **ROCK** and **METAL**
- Its longest side is **535 meters**

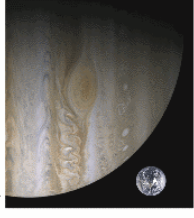


Size of Itokawa compared to a stadium



Jupiter

- Jupiter orbits the Sun between the Asteroid Belt and Saturn
- It is made of **GAS**
- Its diameter is about **143,000 km**



Size of Jupiter's Red Spot compared to Earth

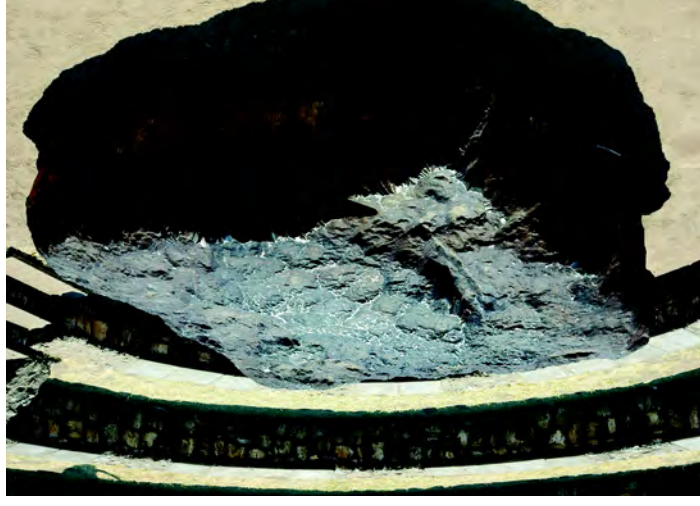


lapetus

- lapetus orbits Saturn
- This walnut-shaped object is made of **ICE** with some **ROCK**
- It is **1,500 km** across, or about half as wide as the Earth's Moon



Size of lapetus compared to Moon



Hoba

- This object landed on Earth 80,000 years ago in what is now the country of Namibia
- Hoba is made of **METAL**
- It measures about **3 meters** across



Hale-Bopp

- Hale-Bopp orbits between Earth's orbit and the distant Solar System — far beyond the orbit of Pluto
- Hale-Bopp is made of **ICE** and **DUST**
- The tail shown here extends more than **1 million km**





Earth's Moon

- The Moon orbits Earth
- It is made of **ROCK** with a small **METAL** core
- The Moon is **3,500 km** in diameter or about $\frac{1}{4}$ the width of Earth



Size of Moon compared to Earth



Gaspra

- This object orbits the Sun between Mars and Jupiter
- It is made of a mixture of **ROCK** and **METAL**
- It is **18 km** on the longest side



Size of Gaspra compared to Manhattan



Hale-Bopp

- Hale-Bopp orbits between Earth's orbit and the distant Solar System — far beyond the orbit of Pluto
- Hale-Bopp is made of **ICE** and **DUST**
- The tail shown here extends more than **1 million km**



Key to Sorting the Solar System Cards

Object	Description	Size (km)	Picture Credits
Barringer Crater	Also known as Meteor Crater, it is located in Arizona, USA. Created by the impact of a meteorite about 50,000 years ago, this crater was formed before humans inhabited the Americas.	1.2	B.P. Snowder
Ceres	Ceres is the largest object in the Asteroid Belt. The International Astronomical Union classifies Ceres as a Dwarf Planet. It is the target of the Dawn spacecraft in 2015.	950	NASA, ESA, J. Parker (SwRI) et al.
Earth	Earth is the third planet from the Sun and is the fifth largest planet in the Solar System. About 71% of Earth's surface is water, the remainder consists of land.	12,650	Taken from Apollo 17 in 1972, credit NASA
Earth's moon	The moon is the fifth largest satellite in the Solar System. It is the only celestial body on which humans have landed. Although it appears bright in the sky, it is actually as dark as coal.	3,500	NASA/JPL/USGS
Eris	Eris is a Dwarf Planet with a moon called Dysnomia. It is more massive than Pluto and orbits the Sun three times farther. It was discovered in 2005 and caused a stir after initially being described as the 10th planet.	2,600	NASA/ESA/M. Brown
Eros	Eros was the first near-Earth asteroid discovered. It is also one of the largest. The probe NEAR Shoemaker landed on this asteroid in 2001. Eros orbits between Earth and Jupiter, crossing Mars's orbit.	34	NASA/JPL/JHUAPL
Gaspra	Gaspra is an asteroid that orbits the inner edge of the main Asteroid Belt. The Galileo spacecraft flew by Gaspra on its way to Jupiter.	18	NASA/JPL/USGS
Hale-Bopp	Hale-Bopp was one of the brightest and most widely viewed comets of the 20th century. It came into the inner Solar System in 1997 and has an orbital period of over 4,000 years.	1,000,000	E. Kolmhofer, H. Raab; Johannes-Kepler-Observatory
Hoba	The Hoba meteorite is the largest known meteorite on Earth. It landed here about 80,000 years ago in what is now Namibia. Hoba weighs over 60 tons and is the most massive piece of naturally-occurring iron on Earth's surface.	0.003	Patrick Giraud
Iapetus	Iapetus is the third largest moon of Saturn. It has an equatorial ridge that makes it look a bit like a walnut, as well as a light and a dark side. Astronomers think that the dark side is covered with a thin layer of residue from the icy surface sublimating.	1,500	NASA/JPL/Space Science Institute
Ida and Dactyl	Ida is a main belt asteroid and the first asteroid found to have a moon, Dactyl. It was imaged by the Galileo spacecraft on its way to Jupiter.	15	NASA/JPL
Itokawa	Asteroid Itokawa crosses the orbits of both Mars and Earth. It is a rubble pile of rocks. In 2005, the Hayabusa probe landed on Itokawa to collect samples.	0.5	ISAS, JAXA
Jupiter	Jupiter is the largest planet in the Solar System, more massive than all the other planets combined. This gas giant has been explored by many spacecraft, notably the Galileo orbiter. It has four large moons and dozens of smaller moons.	70,000	NASA/JPL/University of Arizona

Key to Sorting the Solar System Cards

Object	Description	Size (km)	Picture Credits
Mars	Mars is the fourth planet from the Sun. Iron oxide gives it a reddish appearance. It has polar ice caps and a very thin atmosphere. Two tiny moons might be captured asteroids.	6,800	NASA
Meteor	Small pieces of asteroids or comets collide with Earth's atmosphere to create meteors. The compressed air in front of the rock heats up, causing it to glow and leave a trail of ionized gas.	0.00001	Chuck Hunt
Meteorite	Most meteorites are pieces of the Asteroid Belt that land on Earth's surface. Over 90% of meteorites are considered stony meteorites. About 5% are iron meteorites. Both types contain a significant amount of iron.	0.001	Dr. Svend Buhl www.meteorite-recon.com
Phobos	Phobos is the largest moon of Mars, but still quite small. It is likely a captured asteroid and will break up and crash into Mars in the next 40 million years.	11	NASA/JPL- Caltech/University of Arizona
Pluto and Charon	Pluto is the 2nd largest dwarf planet in the Solar System (after Eris). It has a large moon Charon and two smaller moons, Nix and Hydra. Pluto and Charon are sometimes treated as a binary system since their center of gravity is between the two.	2,300	ESA/ESO/NASA
Saturn	Saturn is the second largest planet in the Solar System. It is made of gas and has very thin icy rings. It also has dozens of moons. The Cassini-Huygens spacecraft has been orbiting Saturn since 2004.	120,000	NASA/JPL/Space Science Institute
Shoemaker-Levy 9	Comet Shoemaker-Levy 9 provided the first direct observation of the collision of extraterrestrial solar system objects. It broke into many fragments, called the "String of Pearls," and impacted Jupiter in 1994.	1	NASA/HST
Sun	The Sun is the star at the center of our Solar System, about 150 million km from Earth. It contains 99.9% of all the mass in our Solar System. It travels once around the Milky Way Galaxy in about 250 million years.	1,400,000	ESA/NASA/SOHO
Titan	Titan is the largest moon of Saturn, comprising 96% of the mass of all Saturn's moons combined. It is a cold world with a thick nitrogen atmosphere and liquid methane lakes on its surface. The Huygens probe landed on its surface in 2005 and took pictures of icy conditions.	5,150	NASA/JPL/Space Science Institute NASA/JPL-
Victoria Crater	This impact crater near the equator of Mars was visited by the Mars Exploration Rover <i>Opportunity</i> . The scalloped edges of the crater are caused by erosion. Although Mars has very little atmosphere, it does have dust storms.	0.75	Caltech/University of Arizona/Cornell/Ohio State University
Wild 2	Comet Wild 2 is officially named 81P/Wild. It once orbited beyond Jupiter but got too close to the giant planet in 1974 and was tugged into a smaller orbit between Jupiter and Mars. The Stardust sample return mission took pictures and captured some of the comet's coma in 2004.	4	NASA/JPL-Caltech

Helpful Hints

Common *misconceptions* addressed by these resources:

- The Solar System contains more than one star
- The planets are the only things in our Solar System
- Science is a rigid set of facts to be memorized

Other Games:

Sort It:

With a group of 20+, give each person a card and ask them to sort themselves by size, distance from the Sun, common materials, alphabetically, or shape. There may be more than one way to sort. All reasonable attempts should be accepted.

With smaller groups, each person (or group of up to 3 people) gets their own deck to answer the same questions. The first group to sort them correctly wins. Allow each group to finish and hold their hand up when they're done. Once they raise their hand, they can't change their order. If the first group has anything out of order, go to the second, and so forth.

20 Questions:

Have the presenter pick an object but don't tell the visitors. Let the visitors take turns asking yes/no questions until they guess the object. The person who guesses correctly gets to pick the next object. Give time during games and between rounds for visitors to look at the backs of the cards.

Background Information

This activity was adapted from a classroom activity originally developed by Anna Hurst Schmitt for the Teacher's Newsletter Universe in the Classroom:
<http://www.astrosociety.org/education/publications/tnl/70/pluto.html> - 10

For a history of the definition of a planet, see these websites:
<http://www2.ess.ucla.edu/~jlm/epo/planet/planet.html>

<http://www.astrosociety.org/education/publications/tnl/70/pluto.html>

<http://www6.cet.edu/dawn/multimedia/makeplanet.asp>

Detailed Activity Description

Sorting Our Solar System

Misconception Tip:

Many people don't understand the difference between Solar System, Galaxy and Universe. Here is a chance to talk at length about the smallest of these scales.

Presentation Tips:

These cards can be used to illustrate many points. The activity described here is one example, but you may find others that work in different situations. You can also find other ideas in the "Helpful Hints" section.

Using more than one deck and breaking visitors into small groups can be interesting because they see that there are different ways to categorize the same objects.

If you would like to use more than one set of cards, it is recommended that you print them on various color card stock. The individual sets get easily combined into a single pile if they are all one color.

Before you get started:

Remove the Ceres card from the deck and put in your pocket. You will bring this out later.

Leader's Role	Participants' Role (Anticipated)
<p><u>To say:</u> What kinds of things do we find in our Solar System?</p> <p>Ahh! How many stars are there in our Solar System?</p> <p>There is actually only one star in our Solar System. The term "Solar System" refers just to our own star, the Sun and everything orbiting it. That includes planets, like you said. What else is in the Solar System that's not here on Earth?</p> <p><u>To do:</u> Bring out all of the Solar System Cards, except for Ceres.</p> <p><u>To say:</u> Great! Take a look at this. I've got pictures here that represent a sample of the different kinds of objects found in our Solar System. Now, you can't tell how big each object is just from the picture. Some pictures are taken close up and others from far away. You'll want to check the backs of the cards to see how big each object is. What else does the back of the card tell us?</p> <p>To do: Pick up one of the cards (in the following example, we are using Gaspra)</p> <p><u>To say:</u> Scientists sort things by their physical characteristics. What are some characteristics of this object? Can you describe what it looks like?</p>	<p>Planets, stars, people, airplanes</p> <p>Billions and billions</p> <p>Comets, moons, asteroids</p> <p>Where it is, what it's made of, how big it is</p> <p>It's lumpy. And brown, and has craters</p>



Leader's Role	Participants' Role (Anticipated)
<p><u>To say:</u> Great! We also know from the information on the back that it's as big as a city and that it orbits the Sun between Mars and Jupiter. These are characteristics too.</p> <p>Now it's your turn to be the scientist. Work together to sort these objects into some categories using their characteristics. Get creative! You get to choose the categories.</p>	<p>Participants sort the cards into various groups.</p>
<p>Presentation Tip: If you are working with a large group, give each person a card and have them sort themselves into categories. This can be very fun and collaborative!</p>	
<p><u>To say:</u> There are no limits to the number of categories you can have. But think about the characteristics that objects in each of your categories have.</p> <p>Tell me about the categories you picked.</p> <p>Did any of the objects fit into more than one category? Tell me why you decided on the category you put them in.</p> <p>Okay, now where would this object fit?</p> <p><u>To do:</u> Hand the group the Ceres card.</p> <p><u>To say:</u> What characteristics does it share with that group? Could it fit in more than one group?</p> <p>(Extension) Could you refine your category definitions so that nothing fits in more than one category?</p>	<p>Describe groups</p> <p>Usually they do</p> <p>Put it in one of the categories</p> <p>Sometimes the groups are flexible enough</p>

Leader's Role	Participants' Role (Anticipated)
<p><i>To say:</i></p> <p>This is great! You are being real scientists. This is exactly what biologists, chemists, geologists, and astronomers do. And as new bacteria or birds or fossils are found, they use their knowledge of what has already been discovered to help them think about this new object.</p> <p>That's exactly what happened when Eris was discovered. Eris is another Pluto-sized object that's also orbiting way out past Neptune. And many more objects are being found out there all the time.</p> <p>Sometimes new discoveries even cause the definitions to change! The definition of a planet changed in 2006 and a whole new category was created: dwarf planet. That category includes both Ceres and Pluto.</p> <p>(If before an observing evening) Can you see any of these categories in the sky right now?</p> <p>Actually, do you see that bright star-like light over there? Well, it's not a star at all. That's Jupiter! Which category does that fit onto?</p>	<p>Sun or Moon or none</p>

Materials

What materials from the ToolKit do I need?

In the activity bag:

At least one set of Solar System Cards (4 sets included in 2 decks)

What must I supply?

- Table or flat surface for organizing the cards, unless you have a big group that can hold one card each

Where do I get additional materials?

You can order additional sets, while supplies last, from the Night Sky Network. For more information, send an email to: nightskyinfo@astrosociety.org

To make additional copies of the cards, just print the following five pages in color, *one-sided* on card stock (or other thick paper).

Cut each page into 3 strips so that the image and description stay together.



Fold each strip in half to make two-sided cards. You can paste them with glue or tape around the edges.

For large groups where each person will hold a single card, you may want to print the large size cards. In that case, simply fold them in half and glue them together, as shown.



This activity can be done with any set of images in any size. The Hubble Site and the NASA Image archive have a wealth of pictures of Solar System objects.

- <http://hubblesite.org/newscenter/>
- <http://www.nasa.gov/multimedia/imagegallery/>

Where could I use this activity?

ACTIVITY	Star Party	Pre-Star Party – Outdoors	Pre-Star Party – Indoors	Girl Scouts / Youth Group Meeting	Classroom			Club Mtg	Gen Public Presentation (Seated)	Gen Public Presentation (Interactive)
					K-4	5-8	9-12			
Sorting the Solar System		✓	✓	✓		✓	✓	✓	✓	✓

What do I need to do before I use this activity?

What materials from the ToolKit are needed for this activity?	What do I need to supply to run this activity that is not included in the kit?	Preparation and Set Up
At least one set of Sorting the Solar System Cards. Four sets are included for use with larger groups.	A table or flat surface is preferred.	Remove the Ceres card from the deck(s). These will be used later.



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ASTEROID SAMPLE RETURN MISSION

DISCOVERY & NEW FRONTIERS Programs

ACTIVE ACCRETION—An Active Learning Game on Solar System Origins

In *Active Accretion*, middle school students model the accretion of specks of matter in our early solar system into chondrules and asteroids—and they do it dynamically. *Active Accretion* is a great way to teach cool science concepts about our solar system's early formation and the development of asteroids and planets while burning off energy. Students will end by discussing the strengths and limits of their model.

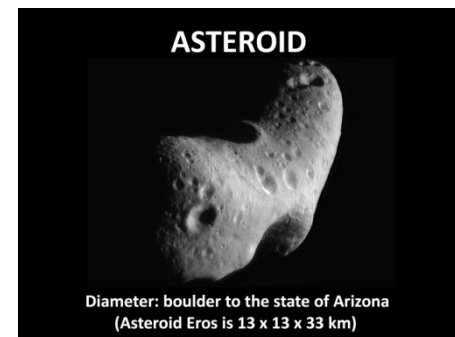
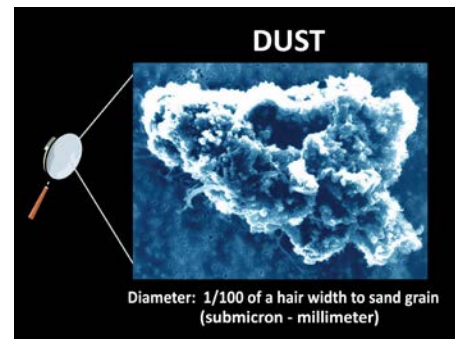
Introduction

Ask students how they think bodies in the solar system formed.

Explain that they will be watching a short music video that shows the diversity of bodies that make up the solar system.

- Show the *Space School Musical* clip, "Planetary Posse." (<http://discovery.nasa.gov/musical/>)
- Questions to elicit student ideas:
 - How did this music video expand your thinking about the solar system?
 - What did you learn?
 - How do you think these diverse bodies—planets, asteroids—came to be?

Explain that scientists think that our solar system was a big cloud of gas and dust in the beginning of its formation. Some event made it begin to spin, and it eventually spun down into a disk of matter swirling around a massive, glowing center, our protosun (think of it as a baby Sun).



Sample Student Role Cards

TIP!

Who's seen dust in your home? Who's seen the dust clump into those dust bunnies that skitter under the bed or in the corner? Similar to what it was like in the early solar system, the dust particles "accrete" - or gather together.



As material moved around the protosun, dust grains in the disk collided with each other and started sticking together to form larger rocks. These rocks in turn collided with other rocks and either gravity held them together or they broke into smaller pieces, depending on the kind of collision and the relative gravity of the individual rocks. **Over the next few million years, these rocks combined into larger and larger bodies and eventually formed the planets and other large bodies we have today.** Evidence of these collisions is seen on the surface of the planetary bodies, including asteroids, in the form of craters left by the impacts.

In today's activity, we will actively model one theory that describes how scientists think asteroids and planets formed: **Accretion.**

The Activity

SETTING: A large open area, such as a gym or playground, where students can run.

MATERIALS:

Student Role Cards:

- *Dust* cards for each child, half that number of *Chondrules*, a quarter of that for the number of *Meteoroids*, and an eighth of that for *Asteroids*. (32, 16, 4, 2 for example)
- Video Clip “Asteroids” from *Space School Musical*
- Computer(s) with Internet for *Alien Earth* computer interactive option.

DIRECTIONS:

Similar to “tag,” the goal is to tag as many students as you can as the game progresses. Learn how dust particles accrete to form chondrules, which accrete into meteoroids, which accrete to form asteroids!

When you tag a person, link arms and keep orbiting, gathering dust particles, chondrules, etc., until you are large enough to form an asteroid.

- **Distribute Dust Cards** to each student
 - All students will represent **dust** at the start of the game.
 - Have one student (or teacher/parent) be the Sun. Have that person stand in the middle of a circle of students
 - Dust particles will be orbiting the Sun!
- Students **gather** close to the center for directions.
 - The dust particles will jog (not run) in a circular path around the “Sun,” which is in the center of the large open area—playground, gym, etc.
 - Counter-clockwise—as all planets and asteroids move about the Sun!
 - As they jog, students should keep their arms to their sides until they come close to another student.
- **Spread out** so that the ring is large enough for safe orbiting.
 - If one dust particle tags another, they form a pair and can now extend their arms in order to tag other dust particles.
 - Allow this to continue for several minutes and then **call time**.



- **Explain** that the students who are paired up are called **chondrules**.
- **Exchange** the Dust cards for a new “chondrule” card, one for each pair of students.
 - Have the kids do another round
 - When the chondrules tag the dust particles (one or more) the group will stay together and can try to tag others.
- **Play** a second round. After a few more minutes, **call time**.
 - At this point, students will notice that there are groups of various sizes...some dust, some chondrules, and some even larger!
 - Student groups of 4-10 are called **meteoroids**.
- **Exchange** as before, including changing the chondrule cards for a new “meteoroid” card.
 - Note meteoroids have a large size range!
- **Play** a third round
 - For student groups of 11 or more kids are called **asteroids**.
- **Give** a new “asteroid” sign to each of the student groups of 11 or more. As they tag the chondrules or dust particles, they form much larger clusters.
 - The asteroid that forms the largest cluster after the allotted time can be designated “Ceres,” the largest asteroid, while the second can be designated “Vesta.” These are the targets of NASA’s Dawn mission.
 - Repeat the game and see if the results change.
 - Review the explanation and ask students the follow-up questions.



Chondrules accreting into a meteoroid

FOR DISCUSSION DURING ACCRETION!

What force causes these small dust particles to come together?

- Allow student responses. Many may say ‘gravity.’ While gravity is the force that holds the dust particles in orbit around the Sun, explain that these small dust particles do not have enough mass for the force of gravity to cause them to come together.

What other forces cause things to stick together?

- Know how socks stick to the inside of the dryer or how a balloon sometimes sticks to the wall? We call this static electricity. In the case of interstellar dust particles, we call the forces electrostatic. *Electrostatic forces are the cause of accretion until the particles are massive enough for gravity to cause attraction.*

Discussion/Explanation Following the Game

Chondrules (spherical drops of once molten or partially molten minerals):

- are considered the building blocks of the planets.
- provide very good information on the earliest history of the solar system.

Meteoroids:

- are solid objects traveling around the Sun in a variety of orbits and at various velocities, ranging in size from small pebbles to large boulders.
- some cluster in streams called meteor showers that are associated with a parent comet.
- have various compositions and densities, ranging from fragile snowball-like objects to nickel-iron dense rocks.
- most burn up when they enter Earth's atmosphere.

Small Asteroids:

- are 4.5 billion years old, as old as the solar system.
- some are made up of chondrules and other material that holds them together.
- have many variations, due partly to differences in the number, size, shape, and varying mineral content of the chondrules, and where they were formed in the solar system (close to the hot Sun, far from the Sun?).

Scientists think that asteroids formed by accretion of these dust particles in the solar nebula, the disk of gas and dust that rotated in a flattish disk shape around the early Sun. Just as in our game, dust particles accreted (came together) into larger and larger bodies: chondrules, then small rocks, and then protoplanets and planets. **Wow!**



Cheerful left-over dust particle

Post-Activity Discussion Questions:

"How could dust become a rock?"

This excellent question arose during classroom trials. One way to think about this is for students to consider the tremendous amount of time involved in solar system formation. Over thousands and thousands of years, billions of dust particles eventually form into tiny grains like sand, then into little pebbles, and so forth.

were asteroids? Was the movement of the two students *after the interaction* the same or different? Was the movement of student dust particles the same as that of the student chondrules?

4. What did you notice about the dust particles at the end of the activity?

1. What happened to the student dust particles at the beginning of the game?
2. How did the student chondrules interact with the student dust particles? Was the movement of the two students the same or different?
3. What happened when there



Wiped out dust particle

Wrap-up:

- How is the model different than the real thing?
(In the activity dust (students) moved faster in an attempt to “catch” smaller objects. In reality the dust particles clump together because of electrostatic attractions and do not move faster in order to clump together. Similarly, large clumps were attracted to like and unlike dust grains in order to form planetesimals due to gravity.)
- Why are models and simulations useful?
(While not completely accurate, physical models are useful to better understand processes that happened in the past that are not observable now.)
- What questions do you have?

ASTEROIDS! EXTENSION ACTIVITIES

1. *Space School Musical*, “The Asteroid Gang”

What comes to mind when you hear the term “asteroid?”

- In classroom trials, fifth grade students said, “large rocks that orbit the Sun,” “meteor shower”, or “comet.”

How have asteroids been depicted in movies and TV?

- Students may refer to films like *Star Wars*, where asteroids are violent or hazards that spacecraft must maneuver through.
- Explain that in the asteroid belt today, these bodies are very far apart and that NASA mission spacecraft like Dawn can fly safely through the belt without worrying about maneuvering to safety, rarely coming within even hundreds of kilometers of another body of any size.

Show the *Space School Musical* clip, “The Asteroid Gang.” Then ask students:

- How does this music video expand your thinking about asteroids? What did you learn?
- What do you like about the video?
- What does this asteroid gang model about asteroids that seems accurate?
- What does the asteroid gang model about asteroids that might not be accurate?



The Asteroid Gang from *Space School Musical*

2. *ALIEN EARTH'S* COMPUTER ACTIVITY

In *Active Accretion*, what would happen if another large group of (maybe 100) students, which might represent a large planet like Jupiter, entered the circular path where the students have been jogging?

Show this website, as a demo to start, and then allowing students to explore in pairs:

<http://www.alienearths.org/online/starandplanetformation/planetfamilies.php>

- The interactive is ideal if student can play the interactive in pairs after a demonstration.

- Place several small bodies onto the screen. Have students generate a list of questions they would like to ask about how these bodies move through space.
- Place Jupiter in the mix and allow students to observe what happens. What force would explain this?
- What other combinations of planets would students like to try?

Compare the virtual simulation with the physical modeling.

- How are they similar? How are they different?
- How are both of these different than the real thing?
- Why are models and simulations useful?
- What questions do students have?

3. WHAT'S THE DIFFERENCE BETWEEN A METEOROID, METEOR, AND METEORITE?

Have students complete a word association.

- On a piece of paper, have students write down the first thing that comes to their mind when they hear the term "meteorite."
- Don't give students much time to think about it, just have them record their first impression.
- Have students listen to the jingle for meteorite found at:
<http://discovery.nasa.gov/multimedia/jingles.cfm>
- Ask students to revise their first impressions based on what they heard.
- Repeat this procedure for Meteor and Meteoroid.
- Ask students to use what they learned in the jingle to make a cartoon that tells a story and shows all three terms being used.

Standards Addressed

Grades 5-8

Earth in the Solar System

- The Earth is the third planet from the Sun in a system that includes the moon, the Sun, other planets and their moons, and smaller objects, such as asteroids and comets.
- Most objects in the solar system are in regular and predictable motion.
- Gravity is the force that keeps planets in orbit around the Sun and governs the rest of the motion in the solar system.

Grades 9-12

The Origin and Evolution of the Earth System

- The Sun, the Earth, and the rest of the solar system formed from the solar nebula - a vast cloud of dust and gas - 4.6 billion years ago.

Grades K-12

Evidence, Models, and Explanation

- Models are tentative schemes or structures that correspond to real objects, events, or classes of events, and that have explanatory power.



Active Accretion: Additional Teacher Background

Modern Solar System Origin Theory

The current *Condensation Theory of Solar System Formation** was the brain child of French philosopher Rene Descartes, who lived in the 17th century. In the 18th century, Pierre Simon de Laplace revised this theory. Both of these early astronomers based their theories on a disk-shaped solar nebula that formed when a large cloud of interstellar gas contracted and flattened under the influence of its own gravity. In the modern theory, interstellar dust is composed of microscopic grain particles that:

- are thin, flat flakes or needles about 10^{-5} m across;
- are composed of silicates, carbon, aluminum, magnesium, iron, oxygen, and ices;
- have a density of 10^{-6} interstellar dust particles/m³.

In **Active Accretion**, these interstellar dust grains are simply referred to as 'dust.' There is some evidence that interstellar dust forms from interstellar gas. Interstellar gas, the matter ejected from the cool outer layers of old stars, is 90 percent molecular hydrogen (H₂) and 9 percent helium (He). The remaining 1 percent is a mixture of heavier elements, including carbon, oxygen, silicon, magnesium and iron. The interstellar dust from which the planets and asteroids formed was that mixture of heavier elements. The hydrogen and helium from the nebula was involved in the formation of our infant Sun and are its major components today.

According to the *Condensation Theory*, the formation of planets in our solar system involved three steps, with the differentiation between planet and asteroid formation being a part of the second step.

Step 1: Planetesimals form by "*sticky collision*" accretion

During this phase of formation, dust grains formed **condensation nuclei** around which matter began to accumulate. This vital step accelerated the critical process of forming the first small clumps of matter, which then start to **collide** with each other at **low velocities**. The particles eventually stick together through **electrostatic forces**, forming larger aggregates of similar types of constituents. Over a period of a few million years, further collisions make more compact aggregates and form clumps a few hundred kilometers across. At the end of this first stage, the solar system contained millions of **planetesimals**—objects the size of small moons, having gravitational fields just strong enough to affect their neighbors.

Step 2: Planetary embryos/cores form by *gravitational accretion*

The loose, granular structure of planetesimals formed in Step 1 made it possible for them to continue to

- form more massive bodies through **collisional coagulation** of “nebular dustballs” and
- prevent these small objects from bouncing off by absorbing the object’s energy during collision.

The more mass the planetesimals accumulated, the greater their **gravitational attraction** would be for surrounding objects of all sizes—from dust grains to small planetesimals—until kilometer-sized planetesimals would collide with objects made up of several planetesimals. The result would be that these large planetesimals that were loose aggregates with differing compositions. This **gravitational accretion** led to protoplanet formation.

As the protoplanets grew, their strong gravitational fields began to produce many **high-speed** collisions between planetesimals and protoplanets. These collisions led to **fragmentation**, as small objects broke into still smaller chunks, most of which were then swept up by the protoplanets, as they grew increasingly large. A relatively small number of 10-km to 100-km fragments escaped capture to become the asteroids and/or comets.

Step 3: Planetary development

When the early asteroids were fully formed, the gas and dust continued to form planetesimals. The system of embryos in the inner solar system becomes unstable and the embryos started to collide with each other, forming the **terrestrial planets** over a period of 10^7 to 10^8 years. The largest accumulations of planetesimals became the planets and their principal moons.

In the third phase of planetary development, the four largest protoplanets swept up large amounts of gas from the solar nebula to form what would ultimately become the **jovian planets** (gas giants). The smaller, inner protoplanets never reached that point, and as a result their masses remained relatively low.

- * Often called the *modern* theory, the *Condensation Theory of Solar System Formation* built on the oldest of evolutionary models, the *Nebular Contraction Theory*.

Additional Resources

Concept adapted for NASA’s Discovery Program from the Lesson 10: Building Blocks of Planets Activity C: “Crunch! Accretion of Chondrules and Asteroids” activity from *Exploring Meteorite Mysteries*

<http://ares.jsc.nasa.gov/Education/Activities/ExpMetMys/ExpmetMys.htm>

Chaisson, E., and McMillan, S. (2008). *Astronomy today*. San Francisco: Pearson Addison Wesley.

Hahn, J. (2005). When giants roamed. *Nature*, 435, 432–433. doi:10.1038/435432a

Laboratory for Atmospheric and Space Physics. *How planets form*. Retrieved from http://lasp.colorado.edu/education/outerplanets/solsys_planets.php

Morbidelli, A., Bottke, W. F., Nesvornyy, D., & Levison, H. F. (2009). Asteroids were born big. *Icarus*, 204, 558–573.

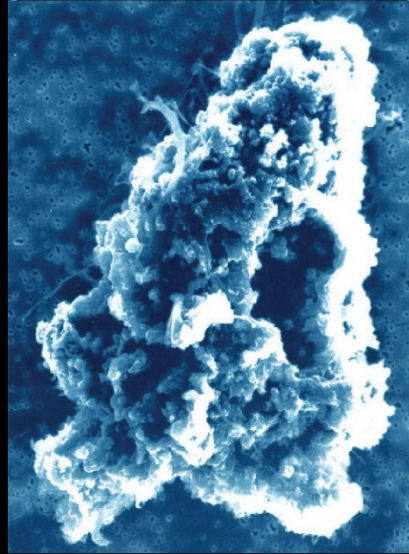
Peebles, C. (2000). *Asteroids: A history*. Washington, DC: Smithsonian Institution Press.

Active Accretion

NASA’s Discovery and New Frontiers Programs

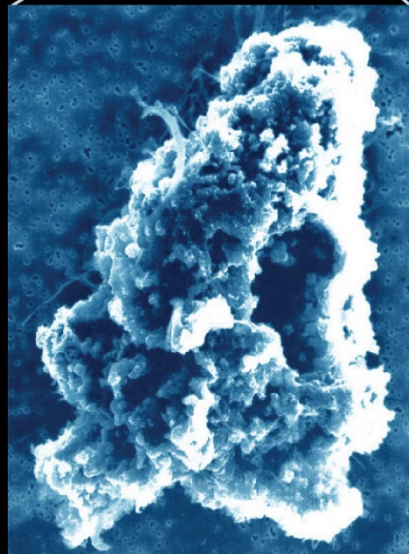
<http://discovery.nasa.gov/>

DUST



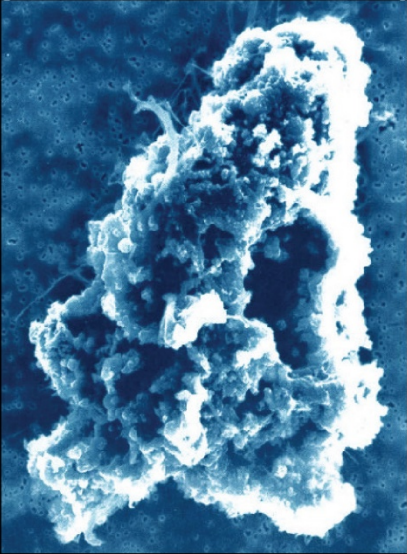
Diameter: 1/100 of a hair to sand grain
(submicron - millimeter)

DUST



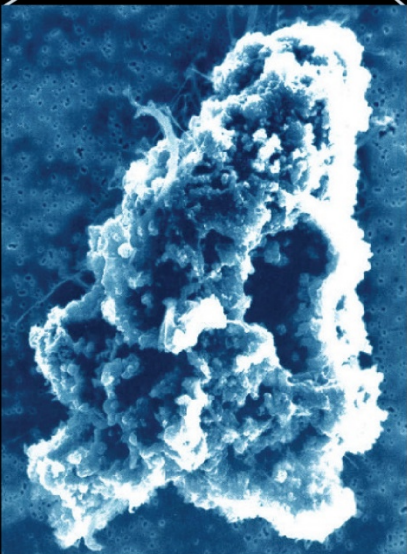
Diameter: 1/100 of a hair to sand grain
(submicron - millimeter)

DUST



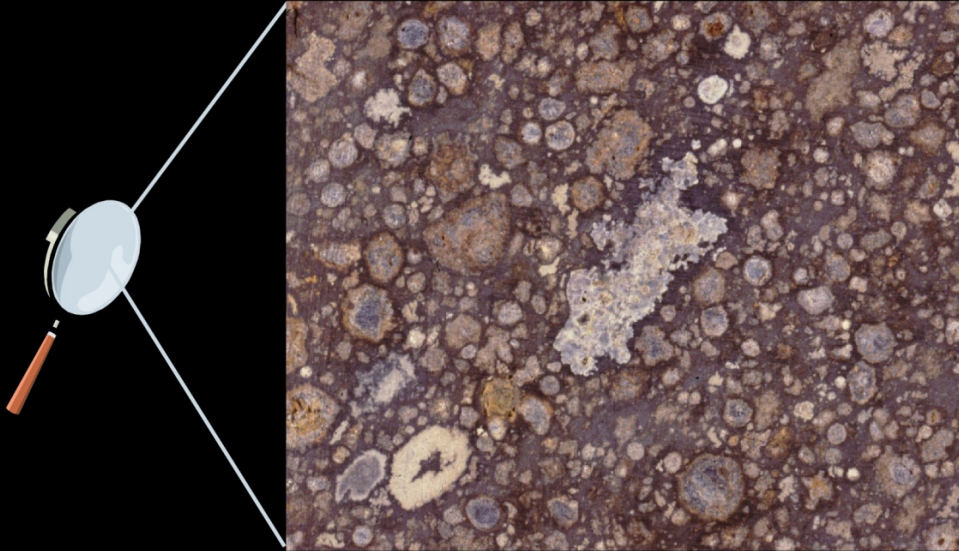
Diameter: 1/100 of a hair to sand grain
(submicron - millimeter)

DUST



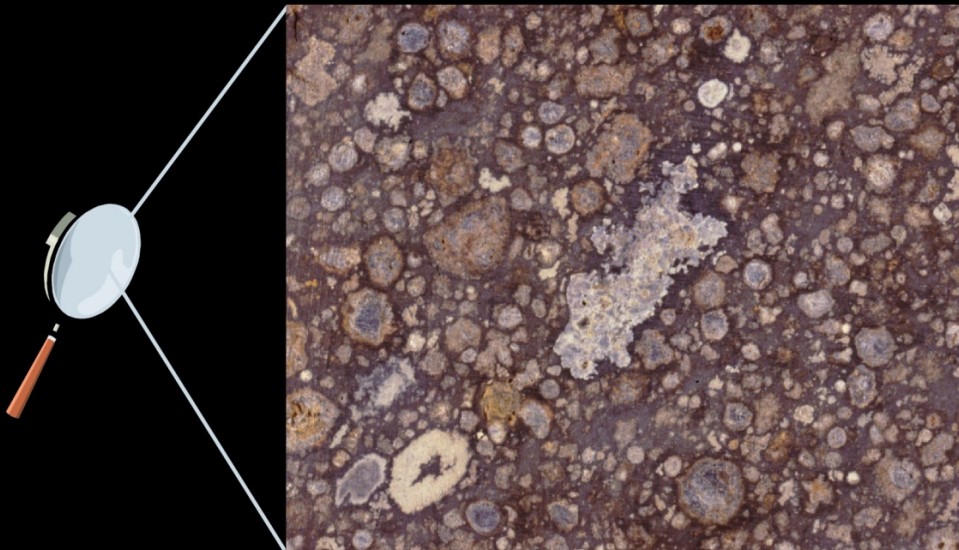
Diameter: 1/100 of a hair to sand grain
(submicron - millimeter)

CHONDRULES



**Diameter: sand grain to pebble
(millimeter - several centimeters)**

CHONDRULES



**Diameter: sand grain to pebble
(millimeter - several centimeters)**

Meteoroid



**Diameter: pebble to boulder
(centimeter - tens of meters across)**

Meteoroid



**Diameter: pebble to boulder
(centimeter - tens of meters across)**

ASTEROID



**Diameter: boulder to the state of Arizona
(Asteroid Eros is 13 x 13 x 33 km)**



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Planet Swap

*Modified from Dogs and Turnips, by Al Janulaw and Judy Scotchmoor,
http://www.ucmp.berkeley.edu/education/dynamic/session4/sess4_act1.htm*

Overview:

In this lesson students attempt to assemble a meaningful sentence by successively turning over cards with words on them. The point is made that we change our ideas of what a story may be as we gather more information. In addition, people who have similar information may not agree on its meaning. Science works this way.

Lesson Concepts:

Scientific ideas are developed through reasoning.

Theories are central to scientific thinking.

Science does not prove or conclude; science is always a work in progress.

Science corrects itself.

Standards Addressed:

Scientists develop explanations using observations (evidence) and what they already know about the world (scientific knowledge). Good explanations are based on evidence from investigations.

Grade Span: 6-8 or 9-12

Materials:

- One set of cut-apart sentence words for each group, printed on paper that will not allow the students to see the words on the back. If the sets are to be re-used they should be laminated.
- One Student Worksheet for each group

Advance Preparation:

Laminate and cut apart the sentence words.

Time: 30 minutes

Grouping: threes or fours, then whole class

Teacher Background:

Scientists gather information and hypothesize about possible explanations of what they have found. Planetary scientists examine data from telescopes and other instruments on missions and work to assemble the story of the planet's structure, features, and history. As more information is gathered, hypotheses change. The literature is searched, data are examined, information is shared with other scientists, new missions are sent, and hypotheses are modified again and again. As scientists work toward a closer approximation of the truth, the premise is that reality exists. In this activity,

students gather information and work toward a closer approximation of the actual sentence. Note that there is a built-in ambiguity in the sentence and several reasonable "correct" answers are possible. Despite the artificiality of this activity, some aspects of the experience closely resemble real-life science.

Teaching Tips:

Encourage students to keep their "research" within their group until sharing time at the end. Let them know that you hope to have each group find out the "answer" on its own and the premature sharing would take away that opportunity for them.

Procedure:

1. Pass out the Student Worksheets and word cards. Have each group spread out its word cards face down on the table.
2. Tell the class that the words form one long sentence that also tells a story. The goal is to figure out the story from the words they turn over.
3. Have each group turn over five cards at random and write what they think the story is on their worksheet (Prediction #1). After they have done this, ask them if it would help to have more information. They will, of course, answer yes.
4. Have the groups turn over five more cards and record their new sentence on the worksheet (Prediction #2). After they have done this ask them if their idea of the sentence changed with more information. Discuss briefly, but do not have groups share their results, just yet.
5. Have the groups turn over five more cards and record their revised sentence (Prediction #3).
6. Allow groups to share with the class what they think the sentence says. Discuss the possible reasons why groups have different answers. Ask them how this might be similar to a mission visiting a planet. (Scientists may not have all the information.) Ask why scientists might not agree on explanations of things. (Scientists may have different information or interpret things differently.)
7. Allow all groups to turn over all the cards and to revise their predictions (Prediction #4). Have groups share out their "final" results. Chances are that the groups will still not have exactly the same sentences. Ask why they didn't. Ask why scientists may not have the same explanations for things even though they may have exactly the same information. (They may have come with different background information or interpret the same information differently.)

EARLY	IN	THE	FORMATION	OF
THE	SOLAR	SYSTEM	THE	GAS
GIANT	PLANETS	MAY	HAVE	MIGRATED
CLOSER	TO	THE	SUN	AND
URANUS	AND	NEPTUNE	MAY	HAVE
SWAPPED	PLACES.			

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CLOSER	TO	THE	SUN	AND
URANUS	AND	NEPTUNE	MAY	HAVE
SWAPPED	PLACES.			

5	4	3	2	1
10	<u>9</u>	8	7	<u>6</u>
15	14	13	12	11
20	19	18	17	16
25	24	23	22	21
			27	26

5	4	3	2	1
10	<u>9</u>	8	7	<u>6</u>
15	14	13	12	11
20	19	18	16	16
25	24	23	22	21
			27	26

Student Worksheet

People in group _____

Date _____

Period _____

Prediction #1

Prediction #2

Prediction #3

Prediction #4



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Explore Jupiter's Family Secrets: JUMP TO JUPITER

OVERVIEW —

Participants jump through a course from the grapefruit-sized “Sun,” past poppy-seed-sized “Earth,” and on to marble-sized “Jupiter” — and beyond! By counting the jumps needed to reach each object, children experience first-hand the vast scale of our solar system.

WHAT'S THE POINT?

- 🍷 The solar system is a family of eight planets, an asteroid belt, several dwarf planets, and numerous small bodies such as comets in orbit around the Sun.
- 🍷 The four inner terrestrial planets are small compared to the four outer gas giants.
- 🍷 The distance between planetary orbits is large compared to their sizes.
- 🍷 Models can be used to answer questions about the solar system.

MATERIALS —

Facility needs:

- ☐ A large area, such as a long hallway, a sidewalk that extends for several blocks, or a football field (see Preparation section for setup options)
- ☐ A variety of *memorable* objects used to represent the Sun and planets, such as (use *Jump to Jupiter: Planet Sizes and Distances* to identify an appropriately-sized substitutes as needed):
 - ☐ 1 (4 inch) grapefruit
 - ☐ 2 (½ inch) marbles
 - ☐ 2 peppercorns
 - ☐ 2 poppy seeds
 - ☐ 3 pepper flakes
 - ☐ 1 pinch of fine sand or dust
- ☐ 1 set of solar system object markers created (preferably in color) from:
 - 1 set of *Jump to Jupiter: Planet Information Sheets_OR*
 - Posters created by the participants OR
 - Optional: 1 set of Our Solar System lithographs (NASA educational product number LS-2013-07-003-HQ):
http://solarsystem.nasa.gov/docs/000-SolarSystemLithosCombined_Rev1_FC.pdf
- ☐ 12 (3') stakes or traffic cones or sign stands



Credit: Enid Costley, Library of Virginia

For each child:

- ☐ 1 *Jump to Jupiter poem*
- ☐ 1 pencil or pen

For the facilitator:

- ☐ Measuring wheel
- ☐ 1 meter- or yard-stick

- ☐ Mallet or heavy object (for placing stakes in the ground)
- ☐ Tape
- ☐ Examples of the objects used in the solar system scale model course:
 - ☐ 1 (4 inch) grapefruit
 - ☐ 2 (½ inch) marbles
 - ☐ 2 peppercorns
 - ☐ 2 poppy seeds
 - ☐ 3 pepper flakes
 - ☐ 1 pinch of fine sand or dust
- ☐ *Jump to Jupiter: Planet Sizes and Distances*



Participants use one-meter jumps or very large steps to measure the distances between markers. Credit: Lunar and Planetary Institute

PREPARATION —

- Determine how many planets your space accommodates before you start.
- Set up a solar system course using *Jump to Jupiter: Planet Sizes and Distances*
 - It does not have to be in a straight line. The course may fold back on itself. (Uranus is half way between the Sun and Pluto, so have the participants turn back at the Uranus marker.)
 - *You do not have to use all the planets!* You can modify the course by using only the inner planets and Jupiter.
 - It is helpful to have the grapefruit “Sun” visible at the beginning of the course.
 - Mark each object’s position with a stake, traffic cone, or sign stand.
- Alternatively, create your own larger or smaller course; use the Exploratorium museum’s online calculator (http://www.exploratorium.edu/ronh/solar_system) to determine the scaled sizes and distances of the planets. A larger course will make the planets larger and easier to see; a smaller course may fit in tighter location.
- Another alternatively, invite the participants create their own course! Provide children ages seven and up with solar system information and materials to create the markers, and ask tweens and teens to determine the scaled sizes of the solar system objects, as well as their relative distance from the Sun.
- Attach the information sheet or lithograph for each solar system object to the appropriate stake, traffic cone, or sign stand.

ACTIVITY —

1. Share ideas and knowledge.

- Frame the activity with the main message: Space is full of...SPACE!
- Explain that the participants will use a scale model to explore the distances between solar system objects. Use open-ended questions and invite the participants to talk with you and each other about their prior experiences with scale models.
- Invite the participants to offer questions to the group about planets, the dwarf planets Ceres and Pluto, and asteroids in our solar system. As the participants name the different objects, ask them to choose the best representative — based on size — from the beads, salt crystals, etc. that were used to construct the solar system course.

As much as possible, encourage the participants to offer information and questions. This model can be used to answer questions such as:

- How do the planets compare in size?
- How big does the Sun appear to be from Earth? From Jupiter?
- How does the distance between the Sun and Pluto compare to the distance between the Sun and the next closest star system (Alpha Centauri)?
- Which destination is closer for a spacecraft: Venus or Mars?
- Are some planets closer together than others?
- Could an accurate model of the solar system fit on my bookshelf at home?

2. Guide the participants as they explore the solar system scale model to answer their questions.

Optional: If the distances are large, have facilitators at each marker to guide the children with questions and information and keep them moving to other markers.

- a. Leave the “Sun” at the beginning of the course for their reference.
- b. Provide the meter- or yard-stick for the children to practice jumping that length.
- c. Offer the “Jump to Jupiter” poem and pencils or pens. Ask the children to count the total number of (one-meter) jumps from the Sun it takes to get to each marker. Explain that the poem has a place for them to enter each distance.
- d. Suggest that the participants find information about each solar system object by reading the signs.

Engage participants at the markers with questions such as:

- How many jumps did it take to arrive at this planet (or asteroid belt or Pluto)?
- How big does the grapefruit “Sun” look from here? Imagine what the real Sun would look like in the sky of this planet/dwarf planet!
- What do you think is happening to the temperature as you travel further away from the Sun?
- At the last marker of the course, compare the immense scale of our solar system to the even larger distances to other stars. At this scale, Alpha Centauri A would be slightly larger than a grapefruit and about 1,800 miles (3,000 kilometers) away — roughly the distance between Washington, D.C. and Mexico City!

3. Have the participants describe what they discovered by exploring the model.

4. Remind the participants that the model isn’t perfect. In space, the planets are in motion as they orbit the Sun. Only rarely do four or more planets “line up.” Have them imagine the circles that each planet would trace! Or, if desired, invite a few participants to carry a selection of planet models in large circles around the “Sun” to demonstrate their orbits.

5. Conclude. Draw on the participants’ discoveries to summarize the experience, including:

- Space is full of...SPACE! The planets are small compared to the Sun, and they are spread far, far apart.
- Jupiter is the largest planet.
- Ceres is the largest asteroid in the asteroid belt, but it is smaller than Pluto and much smaller than the planets.
- The inner terrestrial planets — Earth, Mercury, Mars, and Venus — are relatively close together. Venus is Earth’s closest neighbor (after the Moon). The giant planets (Jupiter, Saturn, Uranus, and Neptune) get farther and farther apart.
- There is an enormous distance between the Sun and even the closest stars.
- Temperatures can reach a scalding 800°F (425°C) on Mercury and even warmer on Venus (850°F!) due to its thick atmosphere. After Earth’s balmy –125 to 130°F (-87 to 54°C), the

temperatures begin to plummet rapidly. It is -234°F (-145°C) at Jupiter's cloud tops, and a frigid -387°F (-233°C) on Pluto.

- From each marker, the grapefruit "Sun" will look just like it does in the sky of that object. From "Earth," *the real Sun appears to take up half a degree (or arc) in the sky. The grapefruit "Sun" appears to be the same size; it can be covered with a pinkie finger held at arm's length.*

CORRELATION TO STANDARDS

Next Generation Science Standards

Disciplinary Core Ideas:

ESS1.B: The solar system consists of the sun and a collection of objects, including planets, their moons, and asteroids that are held in orbit around the sun by its gravitational pull on them.

Science and Engineering Practices

- Developing and Using Models: Develop and/or use a model to represent amounts, relationships, relative scales (bigger, smaller), and/or patterns in the natural and designed world(s).
- Developing and Using Models: Identify limitations of models.
- Analyzing and Interpreting Data: Use observations (firsthand or from media) to describe patterns and/or relationships in the natural and designed world(s) in order to answer scientific questions and solve problems.
- Using Mathematics and Computational Thinking: Use counting and numbers to identify and describe patterns in the natural and designed world(s).

Crosscutting Concepts

- Patterns: Patterns in the natural and human designed world can be observed, used to describe phenomena, and used as evidence.
- Scale, Proportion, and Quantity: Natural objects exist from the very small to the immensely large.
- Scale, Proportion, and Quantity: Students observe time, space, and energy phenomena at various scales using models to study systems that are too large or too small. They understand phenomena observed at one scale may not be observable at another scale.

The Nature of Science

- Scientific Investigations Use a Variety of Methods: Science investigations use a variety of methods and tools to make measurements and observations.

Jump to Jupiter!

Planet Sizes and Distances

The chart below gives the scaled sizes and distances of the planets, Pluto, and asteroid belt if the Sun was the size of a softball or grapefruit. One very large jump is roughly equal to a meter. As you can see, most of space is just that, SPACE! It gets awfully cold out there as you travel away from the Sun!

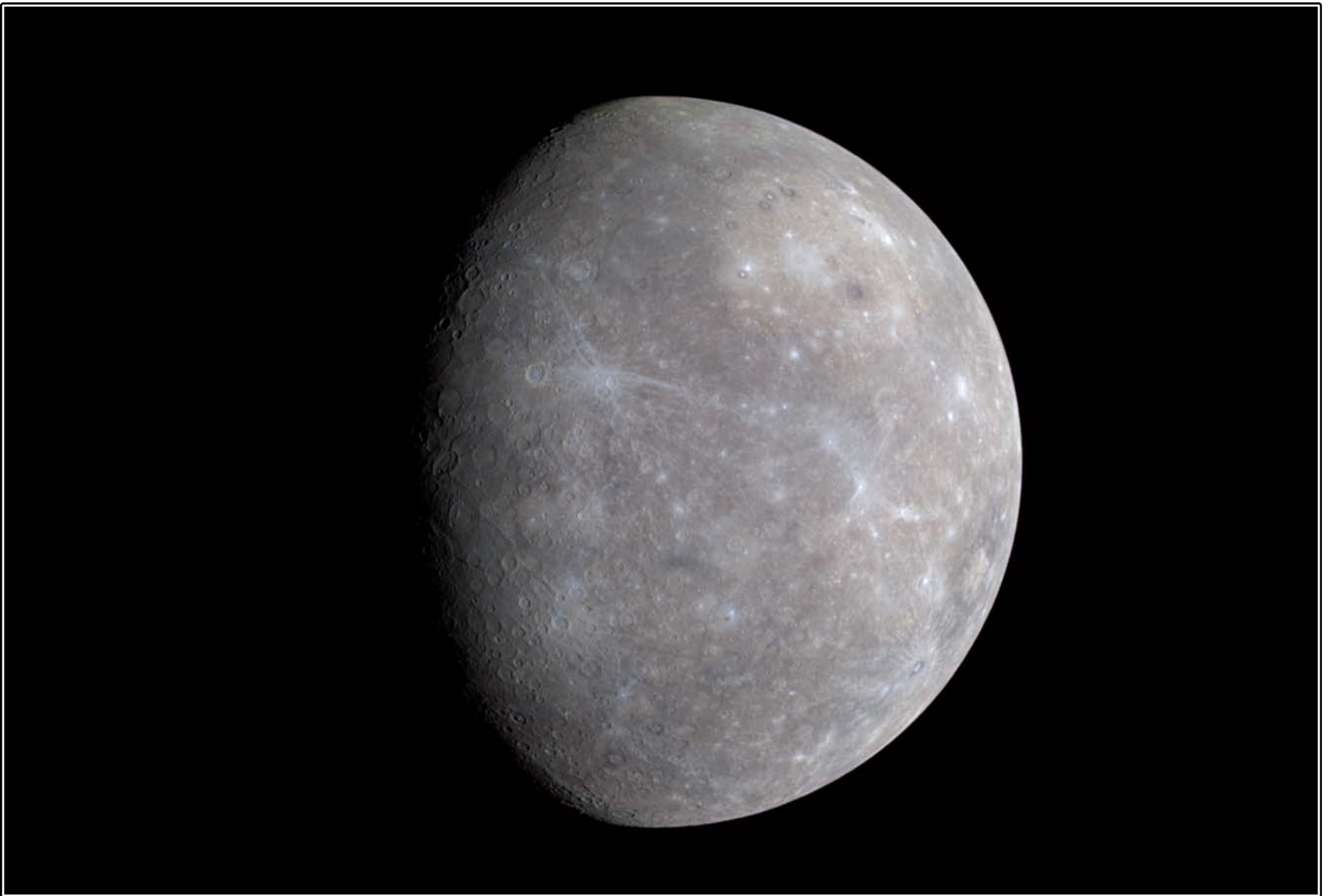
	Scaled Diameter (reduced by a factor of 10 billion)	Scaled Average Distance from Sun (reduced by a factor of 10 billion)	Approximate Total Number of Jumps from Sun
Sun	5.5" (14 cm) (softball or grapefruit)	-	-
Mercury	0.02" (0.049 cm) (pepper flake)	5.8 m	6
Venus	0.05" (0.12 cm) (poppy seed)	10.8 m	11
Earth	0.05" (0.13 cm) (poppy seed)	15.0 m	15
Mars	0.03" (0.068 cm) (pepper flake)	22.8 m	23
Ceres (Asteroid Belt Object)	0.004" (0.1 mm) (dust)	41.4 m	41
Jupiter	0.5" (1.4 cm) (marble)	77.8 m	78
Saturn	0.5" (1.2 cm) (marble)	142.4 m	142
Uranus	0.2" (0.51 cm) (peppercorn)	287.1 m	287
Neptune	0.2" (0.50 cm) (peppercorn)	449.8 m	450
Pluto	0.023 cm (pepper flake)	590.6 m	600

Jump to Jupiter!

<p>I'm the one star in this special place. You'll find me in the center. Just guess my name to start this game, Then you may surely enter.....</p>	<p>Star's name: _____</p> <p>Total jumps: _____</p>
<p>I orbit fast, but s l o w l y turn, With a 1,400-hour day! I'm the first. My name is _____, I'm small and I am gray.</p>	<p>Total jumps: _____</p>
<p>Because my ghastly atmosphere is mainly CO₂, It's like a scorching greenhouse of 900 degrees. It's true! My name is _____, I'm yellow and the hottest, And all I can say is, "Whew!"</p>	<p>Total jumps: _____</p>
<p>I'm glad I'm home to boys and girls, Even though I do seem "blue", I'm planet_____ and a little larger than Venus (that's your clue!)</p>	<p>Total jumps: _____</p>
<p>I'm reddish-rust, with rocks and dust And a 24-hour day. I'm _____ and I am close in size To Mercury, I'd say!</p>	<p>Total jumps: _____</p>

<p>I'm a band that's full of rocks and dust That travel in between the inner and outer solar system's planetary scene. And because I'm a band of asteroids, I felt, I should be called the _____.</p>	<p>Total jumps: _____</p>
<p>I'm full of gas, with colorful stripes, And a really enormous girth. I am mighty _____ and I'm over ten times as wide as Earth!</p>	<p>Total jumps: _____</p>
<p>I'm yellow and my ammonia haze covers each and every thing. I'm _____ and my beauty's found within my icy rings!</p>	<p>Total jumps: _____</p>
<p>Methane gas colors my atmosphere blue. My axis is tilted so I spin on my side. I'm _____! Next to Saturn, I'm small, Compared to neighbor Neptune, I'm a little wide.</p>	<p>Total jumps: _____</p>
<p>It takes me over sixty thousand days to go one whole year through! I'm the last giant planet. I'm _____, and just a little darker blue.</p>	<p>Total jumps: _____</p>
<p>With comets and other dwarf planets I orbit in an oval path Count the miles to get to _____ — It will take a lot of math!</p>	<p>Total jumps: _____</p>

Mercury



MESSENGER, a recent robotic explorer, was able to show us this side of Mercury, which we've never seen before. Credit: NASA/Johns Hopkins University Applied Physics Laboratory/Carnegie Institution of Washington.

Fun facts:

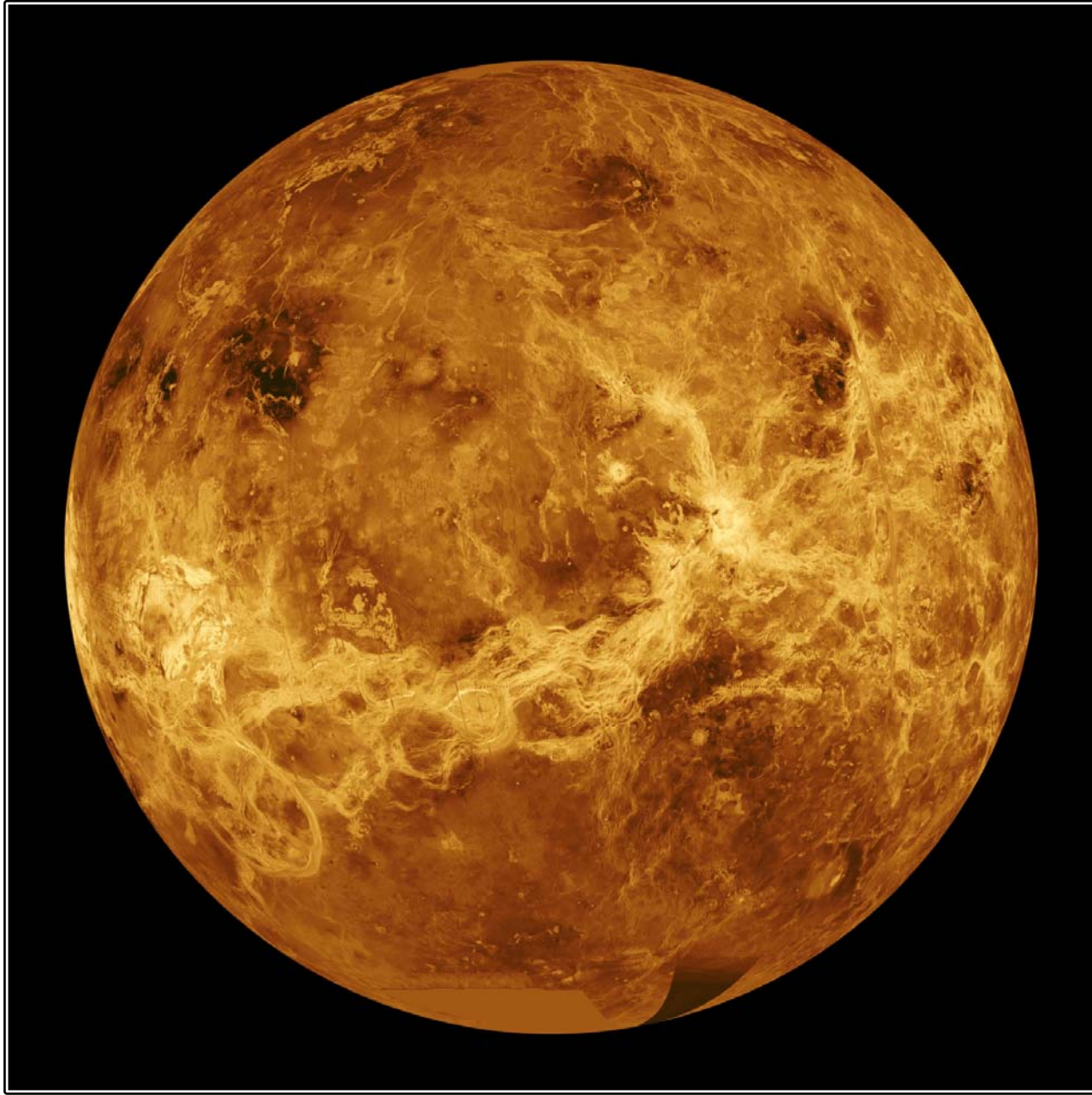
- Mercury is the smallest planet in our solar system - only slightly larger than the Earth's Moon.
- Mercury has a solid, cratered surface, much like the Earth's Moon.
- Mercury has a huge core! The width (diameter) of the core is approximately 75% of that of the entire planet (Earth's is about 54%).
- Mercury does not have any moons or rings.

Robot explorers:

- *Mariner 10* – flew by Mercury three times in 1974-1975, giving us our first glimpse of the innermost planet in the solar system. The same side of Mercury was sunlit during the flybys, so Mariner 10 only saw one side of the planet.
- *MESSENGER* – launched from Earth in 2004, the MESSENGER spacecraft flew past Mercury three times before going into orbit around Mercury in 2011. It was the first spacecraft to orbit Mercury, providing pictures and data from all over the planet.

Distance: 36 million miles (58 million km) from the Sun.

Venus



Because we cannot see beneath Venus' clouds, scientists use radar to learn about the surface. They then used computers to make radar information into this global picture of Venus. Credit: NASA/JPL.

Fun facts:

- Venus' thick and toxic atmosphere is made up mostly of carbon dioxide (CO₂) and nitrogen (N₂), with clouds of sulfuric acid (H₂SO₄) droplets.
- Venus is the hottest planet in the solar system. Its surface experiences extremely high temperatures of almost 480°C (900°F), more than hot enough to melt lead!
- Venus spins backwards (retrograde rotation) when compared to the other planets. This means that the Sun rises in the west and sets in the east on Venus.

Past robot explorers:

- *Mariner 2* – flew by Venus in 1962, becoming the first spacecraft to send back information from another planet.
- *Magellan* – in orbit around Venus from 1990 to 1994, it mapped 98% of the Venusian surface using radar.
- *Venus Express* – European Space Agency mission that arrived in orbit around Venus in 2006 and studied the atmosphere and surface of Venus until 2015.

Future robot explorers:

- *Akatsuki* / *PLANET-C* – Japan Aerospace Exploration Agency mission that will study the atmospheric circulation of Venus.

Distance: 67 million miles (108 million km) from the Sun.

Earth



A 'Blue Marble' image of the Earth taken from the VIIRS instrument aboard NASA's Earth-observing satellite Suomi NPP. This global picture of the Earth's surface was created using many pictures taken by the satellite. From orbit, it is easy to see features relatively unique to Earth: our atmosphere (the clouds) and liquid water on the surface (everywhere that's blue). Credit: NASA/NOAA/GSFC/Suomi NPP/VIIRS/Norman Kuring.

Fun facts:

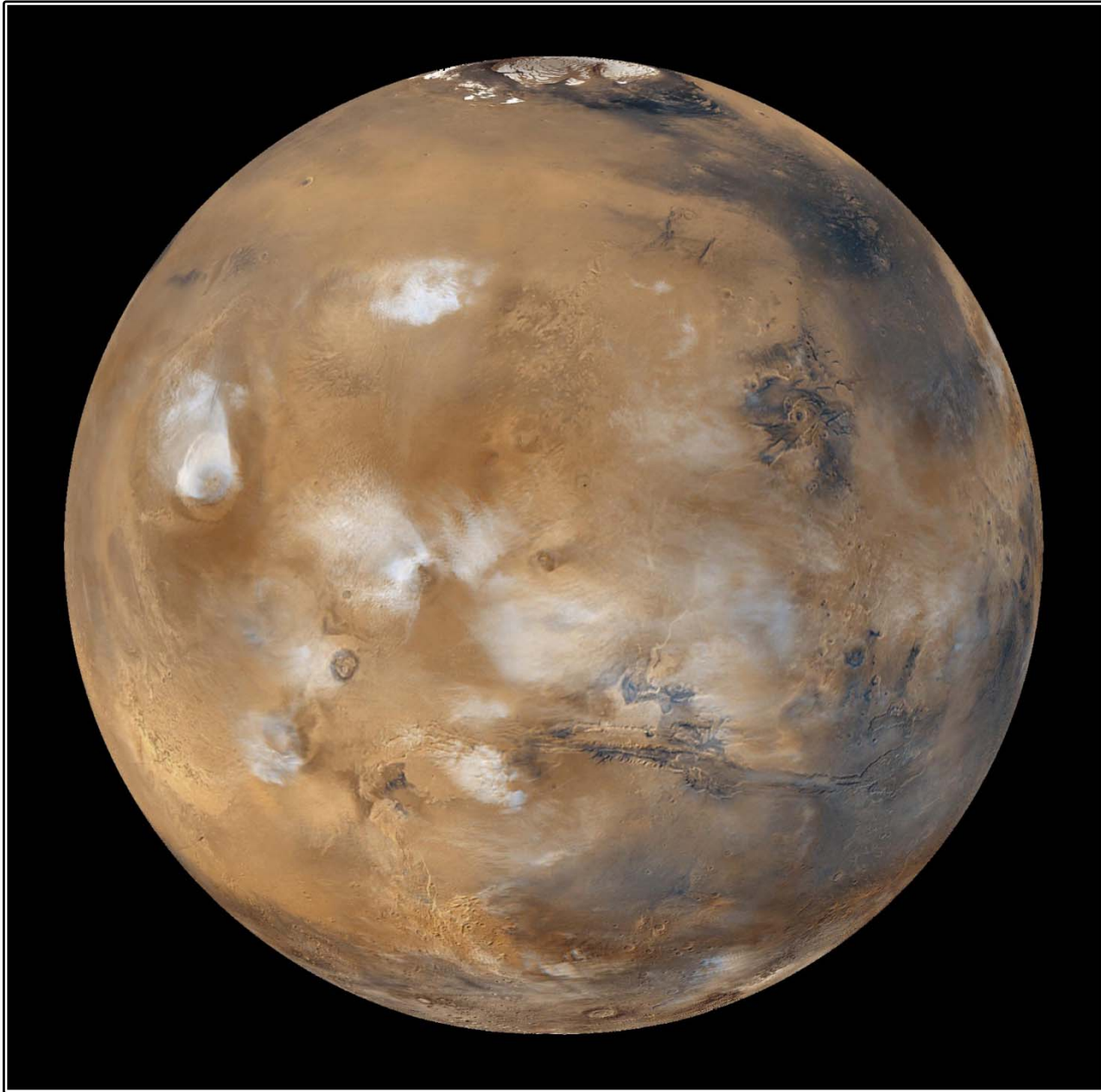
- Earth is a rocky planet, also known as a terrestrial planet, with a solid and constantly changing surface of mountains, valleys, canyons, plains, and much more.
- Earth is different from other terrestrial planets in our solar system because it has oceans. Seventy percent of our planet is covered in water.
- Earth is the only place in the universe known to harbor life.

Current robot explorers:

- *Landsat* – Landsat spacecraft have been photographing Earth for over 40 years. Such a long record of images is useful for those who work in agriculture, geology, forestry, regional planning, education, mapping, and global change research. Landsat images are also used for emergency response and disaster relief.
- *Orbiting Carbon Observatory 2 (OCO-2)* – studies atmospheric carbon dioxide.
- *Soil Moisture Active Passive (SMAP)* – measures soil moisture and freeze/thaw cycles.

Distance: 93 million miles (150 million km) from the Sun.

Mars



Twelve orbits a day provided the Mars Global Surveyor MOC wide angle cameras a global "snapshot" of weather patterns across the planet. Here, bluish-white water ice clouds hang above the Tharsis volcanoes. Credit: NASA/JPL-Caltech/MSSS.

Fun facts:

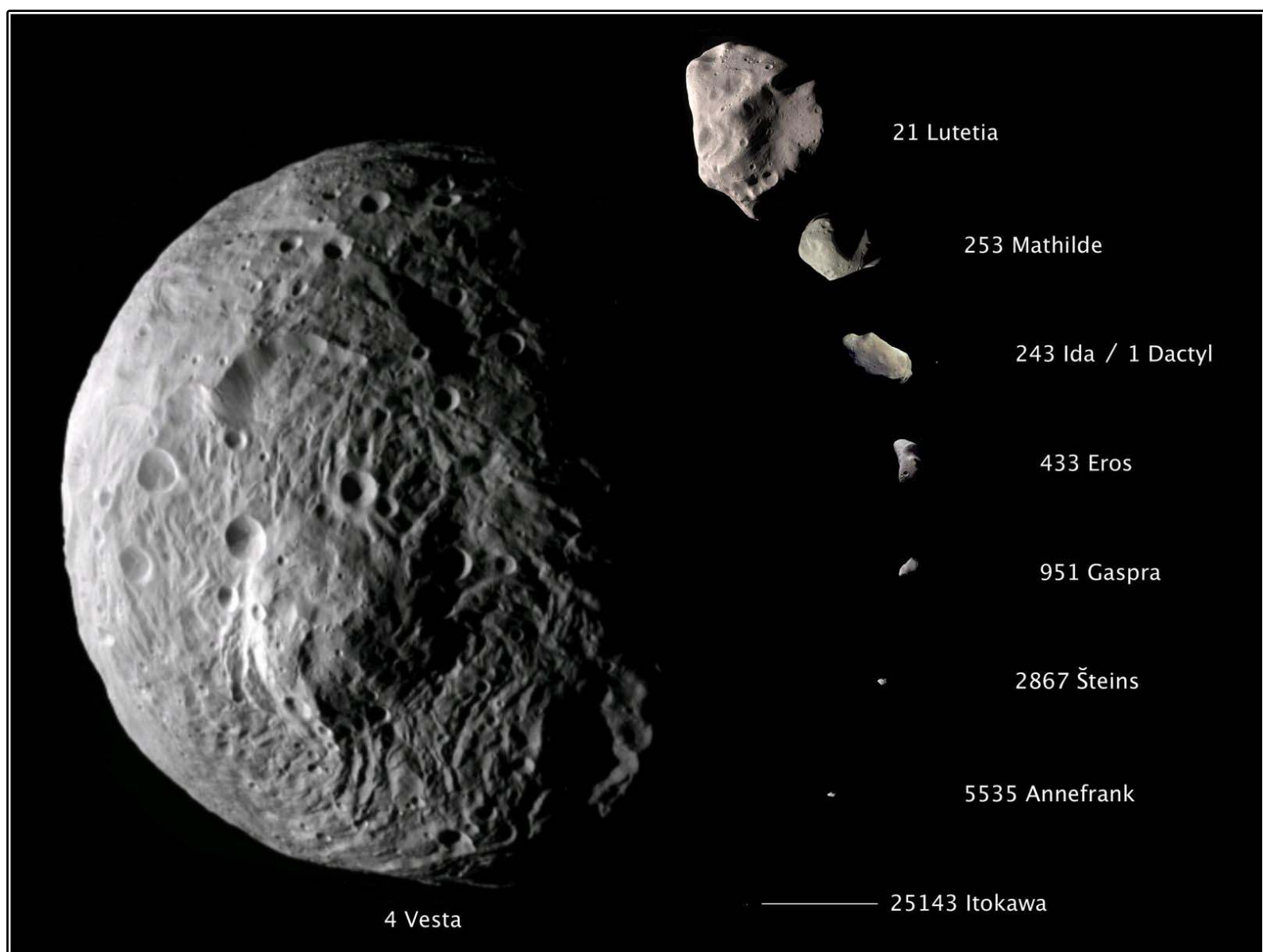
- Mars' solid surface has been altered by volcanoes, impacts, crustal movement, and dust storms.
- At this time in the planet's history, Mars' surface cannot support life as we know it. Current robot explorers studying Mars on the surface and from orbit are determining Mars' past and future potential for life.
- Mars has two moons named Phobos and Deimos.
- Mars is known as the Red Planet because iron minerals in the Martian soil oxidize, or rust, causing the soil – and the dusty atmosphere – to look red.

Current robot explorers:

- *Curiosity* – demonstrated new heavy-load Mars landing technologies, found ancient Mars could have had the right chemistry to be a suitable home for life, and found evidence that water once flowed knee-deep in an ancient streambed in Gale Crater.
- *Mars Reconnaissance Orbiter (MRO)* – in orbit around Mars since 2005, it has revealed that Mars is a world more dynamic and diverse than was previously realized.
- *MAVEN* – studies Mars' atmosphere to determine the history of Mars' atmosphere and climate and liquid water.

Distance: 142 million miles (228 million km) from the Sun.

Asteroids



This composite image shows the comparative sizes of nine asteroids. Vesta, which is also considered a protoplanet because it's a large body that almost became a planet, dwarfs all other small bodies in this image, with its diameter sizing up at approximately 330 miles (530 km). Credit: NASA.

Fun facts:

- Asteroids are solid, rocky, irregular bodies that do not have atmospheres.
- More than 150 asteroids are known to have a small companion moon (some have two moons). The first discovery of an asteroid-moon system was of asteroid Ida and its moon Dactyl in 1993.
- Asteroids that pass close to Earth are called near-Earth asteroids (NEOs).

Current robot explorers:

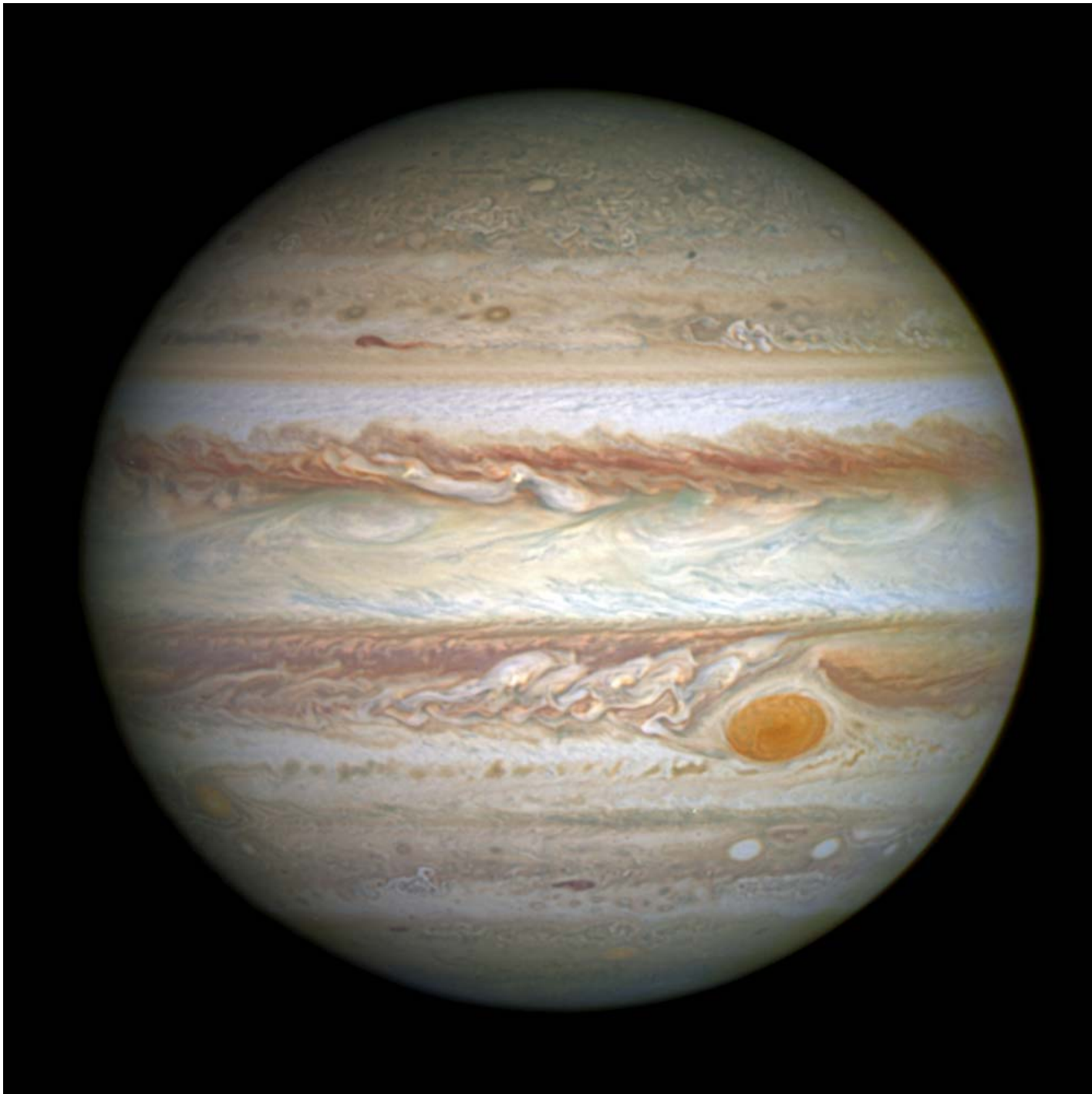
- *Dawn* – orbited large asteroid Vesta for one year before traveling to dwarf planet Ceres, becoming the first spacecraft to orbit two bodies and the first to visit a dwarf planet.
- *Hayabusa 2* – Japan's Hayabusa 2 is designed to study asteroid 1999 JU3 from multiple angles, using remote-sensing instruments, a lander and a rover. It will collect surface and possible subsurface materials and return the samples in a capsule to Earth for analysis.

Future robot explorers:

- *OSIRIS-REx* – launching in 2016, it will use a robotic arm to pluck samples from an asteroid to help better explain our solar system's formation and how life began.

Distance: 197 million miles (329 million km) to 287 million miles (479 million km) from the Sun.

Jupiter



Jupiter's monster storm, the Great Red Spot, was once so large that three Earths would fit inside it. But new measurements by NASA's Hubble Space Telescope reveal that the red spot, which has been raging for at least a hundred years, is only the width of one Earth. Credit: NASA/ESA/A. Simon (Goddard Space Flight Center).

Fun facts:

- Everything visible on the planet is a cloud. The parallel reddish-brown and white bands, the white ovals, and the large Great Red Spot persist over many years despite the intense turbulence visible in the atmosphere.
- Jupiter's width (diameter) is eleven times that of Earth, so even its smallest storms are comparable in size to the largest hurricanes on Earth.

Past robot explorers:

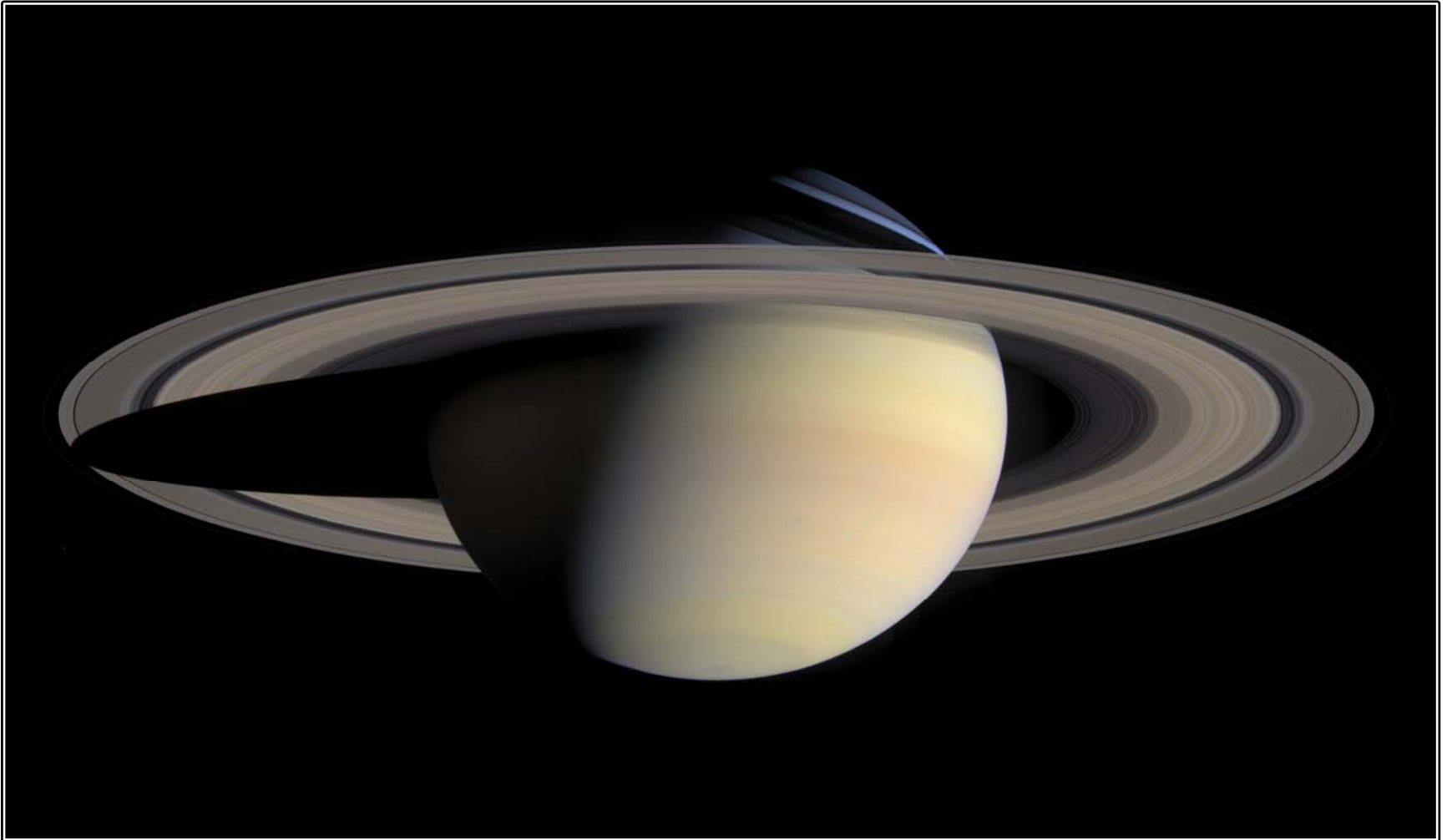
- *Galileo* – the first spacecraft to orbit Jupiter, Galileo discovered an intense radiation belt above Jupiter's cloud tops.

Future robot explorers:

- *Juno* – arriving in orbit around Jupiter in 2016, it will observe Jupiter's gravity and magnetic fields, atmospheric dynamics and composition, and the coupling between the interior, atmosphere and magnetosphere that determines the planet's properties and drives its evolution.

Distance: 483 million miles (778 million km) from the Sun.

Saturn



This global picture of Saturn and its rings was created using many pictures taken by the Cassini spacecraft over many orbits. In this picture, Saturn blocks the light from the Sun, casting a shadow on the rings behind the planet. Credit: NASA/JPL/Space Science Institute.

Fun facts:

- Saturn's atmosphere is made up mostly of hydrogen (H₂) and helium (He).
- Saturn has 53 known moons with an additional nine moons awaiting confirmation of their discovery – that is a total of 62 moons!
- Saturn has the most spectacular ring system of all the giant planets, which is made up of seven rings with several gaps and divisions between them.
- When Galileo Galilei was observing the planet Saturn in the 1600s, he couldn't see the rings clearly. At first, he thought the rings were two other planets next to Saturn and drew them in his notes. Later, he thought Saturn was a planet with arms or handles. These "handles" were, in fact, the rings of Saturn.

Past robot explorers:

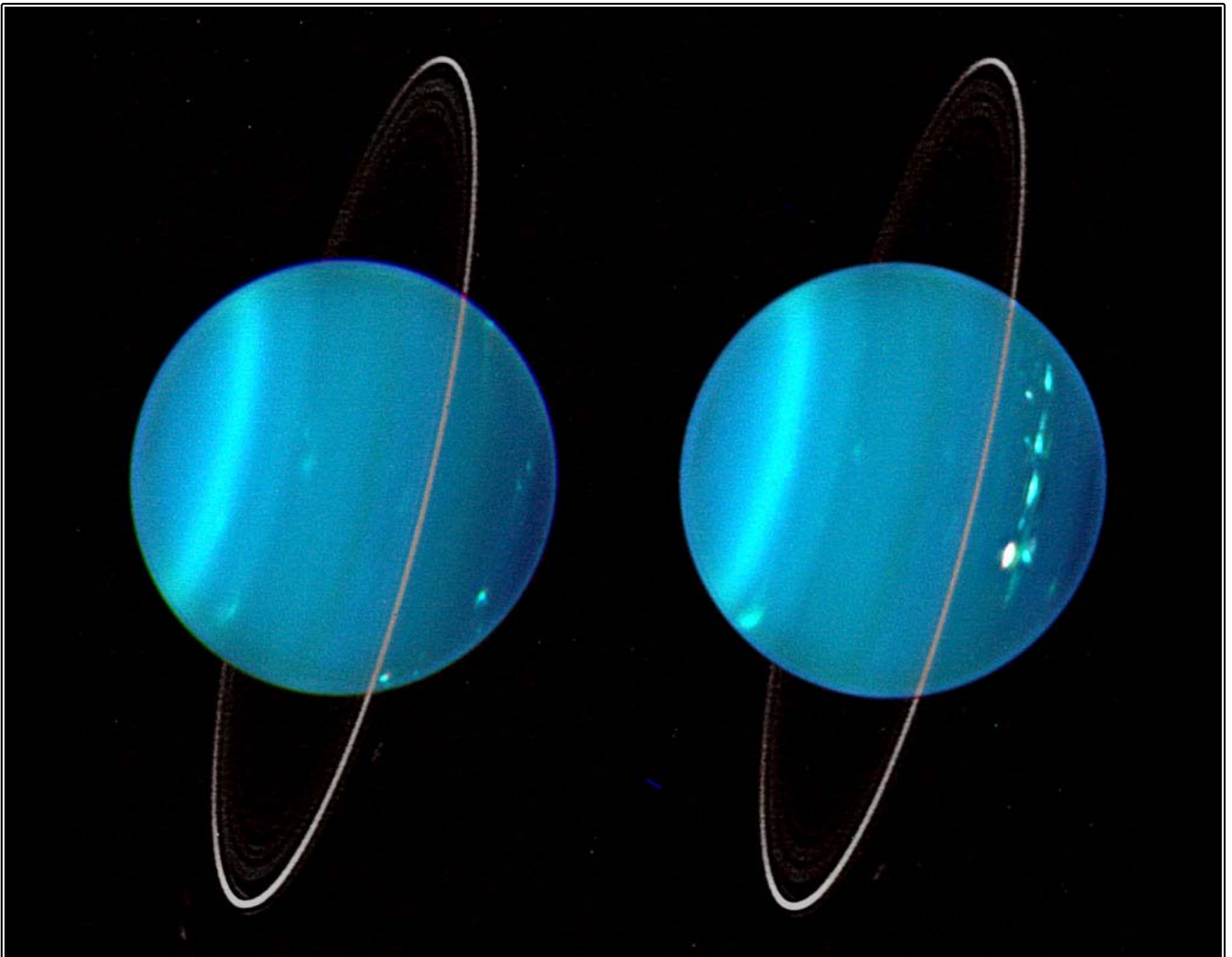
- *Huygens* – a European Space Agency mission, the Huygens lander became the first spacecraft to land on a moon of another planet when it touched down on the surface of Titan, Saturn's largest moon, in 2005.

Current robot explorers:

- *Cassini* – the first spacecraft to orbit Saturn, it provided us with the first detailed information about Saturn and its family of moons and rings.

Distance: 886 million miles (1.4 billion km) from the Sun.

Uranus



Infrared images of the two hemispheres of Uranus were combined to make this picture showing the cloud bands and storms raging on Uranus. Also visible are the planet's rings, showing how Uranus is tilted on its side. Credit: Lawrence Sromovsky, University of Wisconsin-Madison/ W.W. Keck Observatory.

Fun facts:

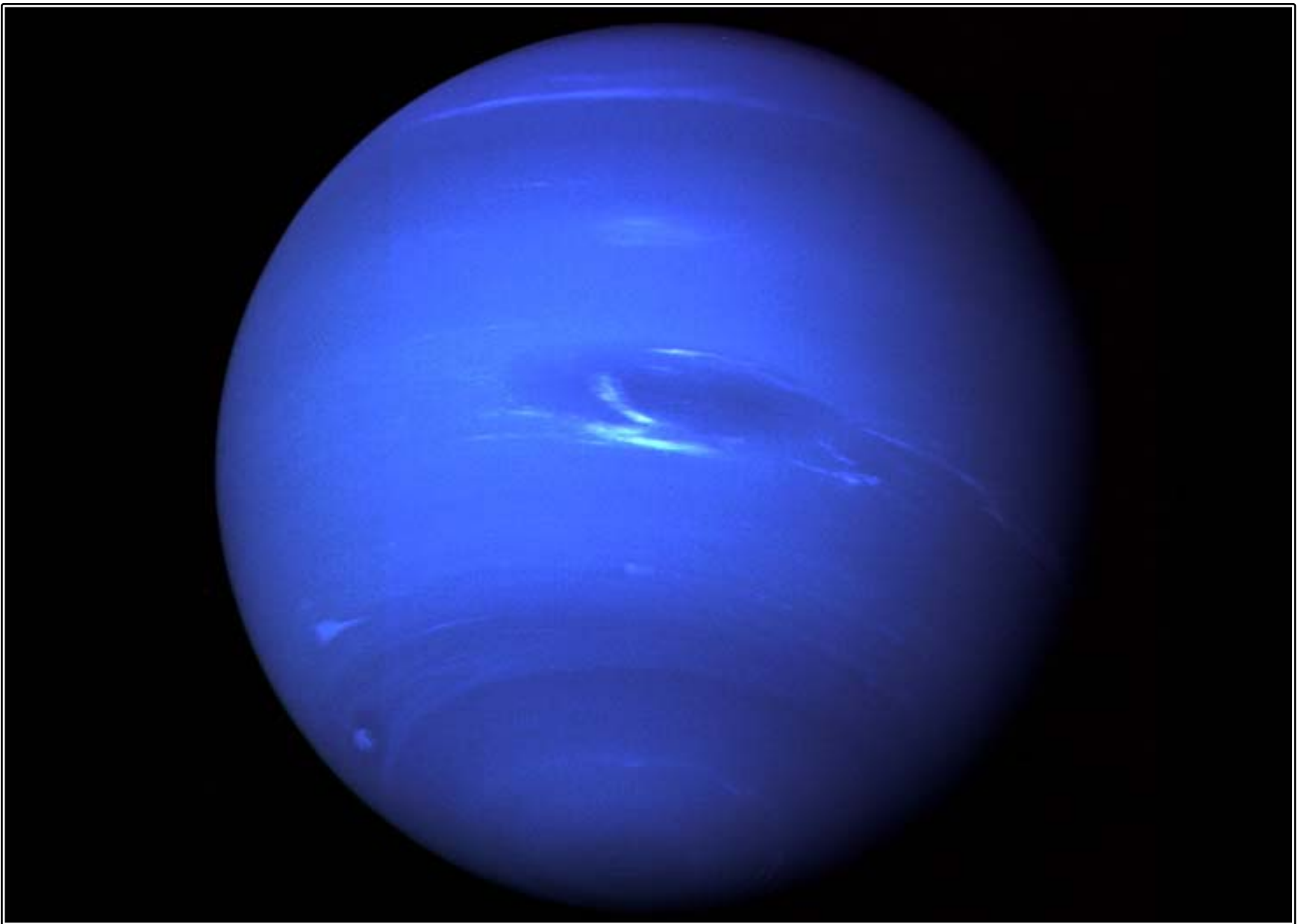
- Long ago, a giant object may have hit Uranus and changed its rotation. This causes Uranus to spin backwards, like Venus. Unlike any of the other planets, Uranus rotates on its side, which means it rolls like a ball, rather than spins like a top.
- Uranus has 13 known rings. The inner rings are narrow and dark and the outer rings are brightly colored.
- Uranus has 27 moons. Uranus' moons are named after characters from the works of William Shakespeare and Alexander Pope.
- Uranus has a blue tint caused by a small amount of methane (CH_4) in its atmosphere, which is mostly made up of hydrogen (H_2) and helium (He).

Past robot explorers:

- *Voyager 2* – the only spacecraft to have flown by Uranus, it discovered evidence of an ocean of boiling water about 480 miles (800 km) below the cloud tops. The spacecraft discovered ten new moons and two new rings.

Distance: 1.8 billion miles (2.9 billion km) from the Sun.

Neptune



Neptune has a large storm called the Great Dark Spot. Scientists named the fast-moving bright feature "Scooter." Credit: NASA.

Fun facts:

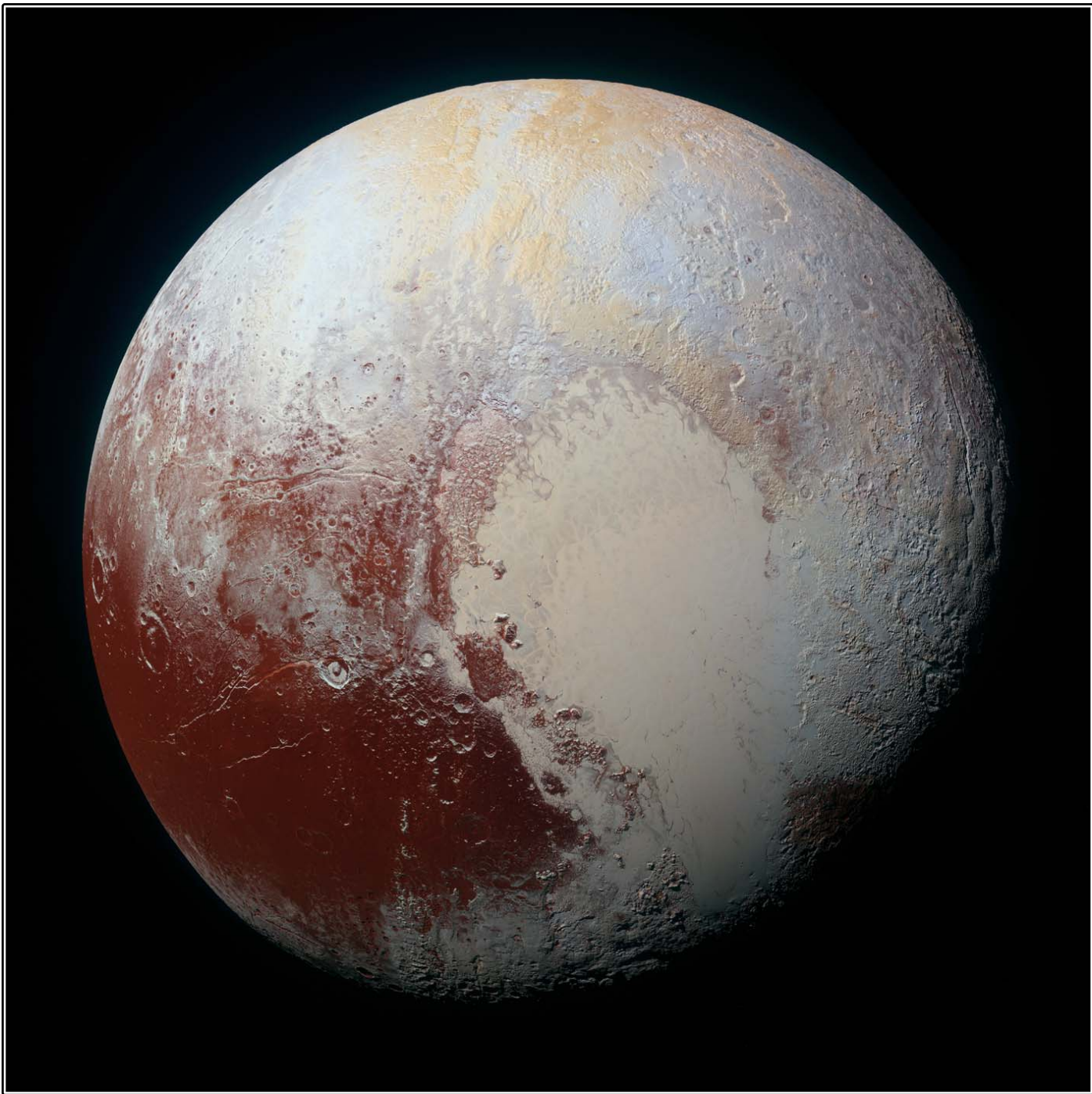
- Neptune's atmosphere is blue because of methane (CH_4) and is made up mostly of hydrogen (H_2) and helium (He).
- Neptune has 13 moons. Neptune's moons are named after various sea gods and nymphs in Greek mythology.
- Neptune has six rings.
- Sometimes, during the course of Neptune's orbit, dwarf planet Pluto is actually closer to the sun, and us, than Neptune. This is due to Pluto's unusual elliptical (egg-shaped) orbit.
- One year on Neptune lasts 165 Earth years. One Neptune day lasts 16 hours.

Past robot explorers:

- *Voyager 2* – the only human-made object to have flown by Neptune, it passed less than 3,000 miles (5,000 km) above the planet's cloud tops in the closest approach of its entire tour. It discovered five moons, four rings, and a "Great Dark Spot" that vanished by the time the Hubble Space Telescope imaged Neptune five years later. Neptune's largest moon, Triton, was found to be the coldest known planetary body in the solar system, with a nitrogen ice "volcano" on its surface.

Distance: 2.8 billion miles (4.5 billion km) from the Sun.

Pluto



Pluto has many colors on its surface, which are darkened in this picture to make them easier to see. Scientists are working to understand what caused these different features. Credit: NASA/JHUAPL/SwRI.

Fun facts:

- Pluto has five known moons. Its largest moon, Charon, orbits very close to Pluto.
- Pluto has a thin atmosphere that expands when it comes closer to the sun and collapses as it moves farther away – similar to a comet.
- Pluto is about two-thirds the diameter of Earth's Moon.
- Pluto was considered a planet from 1930, when it was first discovered, until 2006. Scientists discovered many worlds that, like Pluto, orbit far from the Sun. Scientists decided to call Pluto, Ceres, and other similar small worlds “dwarf planets.”
- One day on Pluto takes about 153 hours. Pluto makes a complete orbit around the Sun (one year on Pluto) in about 248 Earth years.

Past robot explorers:

- *New Horizons* – flew through the Pluto system in 2015, becoming the first and only spacecraft to explore Pluto up close. The spacecraft will travel to other distant worlds in the coming years.

Distance: 3.7 billion miles (5.9 billion km) from the Sun.



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Geologic Scene Investigators: Part 1 – Scratching the Surface Crater Creations

from *Explore: Mars Inside and Out*

www.lpi.usra.edu/education/explore/mars/surface/craters.shtml

Overview

In the 30-45 minute *Crater Creations* activity, teams of children ages 8-13, experiment to create impact craters and examine the associated features. The children observe images of Martian craters and explore how the mass, shape, velocity, and angle of impactors affects the size and shape of the crater.

This activity has been modified from *Impact Craters*, an activity in *Exploring the Moon: a Teacher's Guide with activities for Earth and Space Sciences*, NASA Education Product EG-1997-10-116-HQ by J. Taylor and L. Martel (http://www.spacegrant.hawaii.edu/class_acts/EP-306.html).

What's the Point?

- Impact craters are caused when an impactor collides with a planet.
- A crater's size and features depend on the mass, velocity, and incoming angle of the impactor.
- Impact craters provide insights into the age and geology of a planet's surface.
- Models – such as the children are using here - can be tools for understanding the natural world
- Geologists use features on Earth to help them understand how similar features may have formed on other planets, like Mars

Materials

For each child:

- One GSI Journal *Mars Inside and Out* or One GSI Journal *Part 1: Scratching the Surface*
- One pencil

For each team of 4-8 children:

- A large pan or box such as a dish pan, aluminum baking pan, or copy paper box lid, (larger pans allow children to drop more impactors before having to re-smooth or resurface)
- Enough sand, sugar, rice, or oatmeal to fill the pan about 4 inches
- Enough flour to make a 1" to 2" deep layer
- 1 heaping cup of powdered cocoa
- A sifter
- A large trash bag or piece of cloth or plastic to place under the crater box
- Several objects that can be used as impactors, such as large and small marbles, golf balls, rocks, bouncy balls, and ball bearings. Use your imagination!
- Ruler
- Paper and pencil
- Images of craters from the *Setting the Scene* activity
- Safety glasses

For the Facilitator:

- Background Information - www.lpi.usra.edu/education/explore/mars/background

Preparation

- Prepare an area large enough to accommodate the crater boxes for the number of teams participating. Allow several feet between each box.
- Prepare the appropriate number of crater boxes
 - Fill a pan 4 inches deep with sand, sugar, rice, or oatmeal
 - Add a 1 to 2 inch layer of flour
 - With the sifter, sprinkle a thin layer of powdered cocoa on top of the flour (just enough to cover the flour)
 - Provide several impactors, a ruler, and images of craters beside each box

Activity

1. Introduce the activity by asking the children what they think will happen when an impactor – a heavy object – is dropped into one of the boxes.

2. Divide the children into groups of 3 to 5 and have each group stand by a box.

Invite them to begin experimenting by having them select one impactor to drop and determining from what height they will drop it (encourage them to not throw their impactor). What do they think will happen? Have each teams drop their impactor one at a time.

- What do they observe?
- Does the feature that was created look like any of the features they observed on the surface of Mars or Earth?
- Which features? *Craters – roughly circular depressions on the surface of a planet.*
- How are they similar? Different? *Some similarities include the circular shape and depression, and the material that is excavated from the crater and forms a rim – the ejecta. Some differences include the fact that the impactor is still present in the model. Long bright streaks – rays - probably extend out from the crater they created; these also occur in some places on Mars and the Moon..*

After each crater creation, ask them to carefully remove their impactor, to make the crater clearly visible (in reality, impactors are completely - or almost completely - obliterated upon impact; any remains of the impactor are called "meteorites").

3. Now, taking turns, let the children experiment with creating craters! Have each group conduct an experiment by changing one variable to see how it affects impact crater size. Experiments could explore different impactor sizes, weights, distances dropped, or angles of impact. For example, one group could drop the same impactor from different heights (modeling different velocities of the incoming impactors), and another group could experiment by dropping different sized impactors from the same height. If the children want to experiment with angles of impact they will need to

throw the impactors at the box; caution should be used to make sure no one is standing on the opposite side of the box in case the impactor misses. Invite the children to predict what will happen in their experiment. Have the children measure the width and depth of each impact crater formed in their experiment.

- What did the groups observe?
- How did the weight of objects affect the size and depth of the crater you created?
- How did the size of the object affect the size and depth of the crater?
- How did dropping or throwing the impactors from different heights affect the size and depth of the craters they formed?

In Conclusion

Have the children reflect on what they observed and the images from Mars and Earth. Invite them to record what they learned in their *GSI Journals*.

- What features did the children create in their models? *Impact craters.*
- Do similarly shaped features occur on Mars or Earth? *Yes, both.*
- How are they different? *The craters on Mars are much, much larger.*
- How do the children think the craters on Mars and Earth formed? *By large impactors – asteroids or comets - striking the Earth and Mars.*
- Scientists have not actually seen any large asteroids or comets hit Mars, but they think the large craters on Mars - and on other planets and moons - were created by them. Scientists have observed very small asteroids hitting Earth and several pieces of Comet Shoemaker-Levy struck Jupiter. When the children see "shooting stars" – more accurately called "meteors" – they are seeing tiny dust to sand-sized "asteroids" that are streaking toward Earth's surface. They are too small to make craters or leave any meteorites to collect.
- What evidence might scientists have to make them think impactors created these craters? *Scientists experiment with models – like the children did – to determine what type of feature an impactor might leave behind. They also have other evidence from some craters on Earth – like fragments of the asteroid (meteorites), or alterations to the rocks and minerals at the impact site caused by the impactor striking the ground at high speed.*

Invite the children to reflect on what they learned during all of their different investigations.

- How might observations on Earth help scientists interpret what they see on other planets? *Scientists study features – like volcanos – on Earth to understand their shape and size, what they are made of, and how they form. On Earth, this information can be used to predict where volcanos may form, and when they may erupt. By understanding volcanos on Earth, scientists can interpret what they see on other planets. If they see a feature that is similar in shape and detail to volcanos on Earth, even if the volcano is not erupting, they can interpret that it is a volcano – and this tells them about the history of the planet.*

- How might relying on Earth observations not be a good model for scientists to use when studying other planets? *Other planets may have characteristics that are not the same as on Earth. Titan, the large moon of Saturn, has features that look like river channels, but these were carved by liquid methane – not water!*

If things might be different, why not stop trying to understand other planets until we can go there? First, what's the fun of that? And second, it may be a long time until we get there! Planetary geology is about creating a picture of what it is like on a planet and how it has changed over time. Geologists use every piece of evidence they can – images from telescopes and spacecraft, information from rovers – to help them paint this picture. As they get more information, they alter the picture to fit the evidence. By studying what is available, scientists can help to identify the important questions that we should address in future robotic and human missions! And by understanding how planets change – and why – we can better understand how Earth has and will change. Learning about the history of water on Mars can tell us more about our own future.



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Explore Marvel Moon: KID MOON: SPLAT!

OVERVIEW —

Participants model ancient lunar impacts using water balloons. Like huge asteroids, the water balloons are destroyed on impact and leave a splash (i.e. a “crater”) that is 10 to 20 times wider than the impactor.

WHAT’S THE POINT?

- 🔭 Impact craters and basins are caused when an impactor, such as an asteroid or comet, collides with a planet or moon.
- 🔭 The size of an impact crater or basin depends on the speed and size of the asteroid or comet before the collision and the material it impacts. Most impact craters will be 10 to 20 times the size of the impacting asteroid.
- 🔭 Models can be tools for understanding the natural world.

MATERIALS —

Facility needs:

- ☐ An outdoor area, such as a concrete patio or parking lot

For each child:

- ☐ Water balloon
- ☐ Kid Moon: Splat! comic panel
- ☐ Ruler
- ☐ Pencil

For the facilitator:

- ☐ Splat! children’s guide
- ☐ Access to water
- ☐ (Option) bucket or tub for holding water balloons

PREPARATION —

- If possible, tell participants ahead of time to wear an old shirt or apron, or you may wish to provide trash bags for them to wear. Have a towel handy for cleaning spills.
- Either prepare enough water balloons for each participant, or identify where and how they will make their own.
- Identify a safe location for dropping them.
- Provide the balloons — contained in the bucket, if desired — at that location with clipboards and rulers or tape measurers.

ACTIVITY —

1. Share ideas and knowledge.

- What do the participants know about craters? Invite them to share their ideas about where they are and how they form.

2. Let the participants know that they will be experimenting with a model of the impact process, using water balloons.
 - What will the water balloon represent? [The impactor—an asteroid or comet]
 - What will represent the crater? [The splash marks]
3. Go outside and hand out the filled water balloons and rulers. (For less disciplined groups, you may want to hand out one balloons, and have the rest of the group watch the experimental impact before handing out the second balloon.)
4. Have participants measure and record the balloon's width.
5. Have them break a balloon by throwing it onto an outdoor concrete patio or sidewalk, taking care to avoid each other.
6. Participants should measure the width of the impact (splash of water) that has been created.
 - What happened to the asteroid or "impactor"? [It exploded.]
 - What happens to comets or asteroids that impact a planet or the Moon? [They explode.]
7. Ask participants to calculate the ratio of the size of the balloon to the size of the impact, and compare their results.
8. Hold a group discussion:
 - In what ways does this model work for an asteroid or comet impact on the Moon? What ways does the model fail? [This model does not show the depth of craters, the ridges and mountains that can form. Other models, like impact boxes, can show these features but not the scale.]
 - What was the range of ratios that the students calculated? [The impact area should be about 10-20 times bigger.]
 - Is a crater on the Moon bigger or smaller than the asteroid that made the crater? [Craters are bigger than the asteroids.]
 - Invite participants to predict what would if they threw the balloons faster. *What might happen when an asteroid or comet is moving faster?* [The crater might be larger.]

BACKGROUND —

The size of an impact crater depends on the speed and size of the asteroid or comet before the collision. A faster impact will create a larger crater. Typically, asteroids hit Earth at about 20 kilometers (slightly more than 12 miles) per second. Such a fast impact produces a crater that is approximately 20 times larger in diameter than the asteroid. Most impacts will be 10 to 20 times the size of the asteroid. Smaller planets have less gravitational "pull" than large planets; asteroids and comets will strike at lower speeds.

CONCLUSION

Once they have completed the experiment, participants should understand that the large circular features they observe on the Moon (and other planets and asteroids) are impact basins. They were formed by large impactors — asteroids or comets — striking its surface. Craters and basins on the Moon are larger than the asteroids and comets that created them — 10 to 20 times larger!

Impactors are like water balloons because they are destroyed upon impact, and very little of the asteroid or comet remains. (Remnants of asteroids found on a planetary surface are called meteorites.) Asteroids are much more rocky and moving faster than the balloons in this model; they are far more damaging.

Scientists experiment with physical models and computer models to determine the effects of an impactor. Their models use projectiles that can move at high speeds and impact different types of materials. They also study impact craters on Earth, like Barringer Crater (Meteor Crater) in Arizona to understand impact processes.

CORRELATION TO STANDARDS

Next Generation Science Standards

4-PS3-3. Ask questions and predict outcomes about the changes in energy that occur when objects collide.

MS-ESS2-2. Construct an explanation based on evidence for how geoscience processes have changed Earth's surface at varying time and spatial scales.

Disciplinary Core Ideas:

ESS1.B: The solar system consists of the sun and a collection of objects, including planets, their moons, and asteroids that are held in orbit around the sun by its gravitational pull on them.

ESS1.C: The History of Planet Earth: Some events happen very quickly; others occur very slowly, over a time period much longer than one can observe.

Science and Engineering Practices

- Developing and Using Models: Develop and/or use models to describe and/or predict phenomena.
- Developing and Using Models: Identify limitations of models.
- Using Mathematics and Computational Thinking: Apply mathematical concepts and/or processes (e.g., ratio, rate, percent, basic operations, simple algebra) to scientific and engineering questions and problems.

Crosscutting Concepts

- Patterns: Patterns in the natural and human designed world can be observed, used to describe phenomena, and used as evidence.
- Scale, Proportion, and Quantity: Students observe time, space, and energy phenomena at various scales using models to study systems that are too large or too small. They understand phenomena observed at one scale may not be observable at another scale.

The Nature of Science

- Scientific Investigations Use a Variety of Methods: Science investigations use a variety of methods and tools to make measurements and observations.

CHECK IT OUT	WHAT TO DO	WHAT TO ASK...
<div>1</div> <p>The young Moon was hit by large asteroids.</p>	<p>Model your own impact with a water balloon!</p> <p>Record your measurements on the <i>Kid Moon: Splat!</i> comic panel.</p>	<p>How wide across is your water balloon?</p>

CHECK IT OUT	WHAT TO DO	WHAT TO ASK...
<p>2</p> <p>These impacts left scars that we can see today: impact basins — really big craters!</p>	<p>Break the balloon by throwing it onto an outdoor concrete patio or sidewalk.</p> <p>Record your measurements on the <i>Kid Moon: Splat!</i> comic panel.</p>	<p>How big is the splash (the “crater”)?</p>

CHECK IT OUT	WHAT TO DO	WHAT TO ASK...
<p>3</p> <p>Craters on the Moon are larger than the asteroids that created them — 10 to 20 times larger!</p> <p>Like the water balloon, the impactors broke apart when they hit the Moon.</p>	<p>Calculate the ratio of the size of the impact to the size of the balloon.</p> <p>Record your measurements on the <i>Kid Moon: Splat!</i> comic panel.</p>	<p>How much larger is your splash compared to the size of the balloon?</p> <p>Asteroids and comets travel much faster than you can throw a balloon. They are also rocky and hard. What do you think would happen if you threw the balloon faster?</p> <p>How would the “splash” caused by an impactor on the Moon look compared to the balloon’s splash?</p>

Kid Moon: Splat!

Impactor size: _____

(balloon size)



Crater size: _____ (splash width)

Crater size ÷ balloon size = _____

Wow! That was a big splat! Where did all of those big water balloons – I mean comets and asteroids – come from? That's what I'm working to figure out.





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MAKING REGOLITH

This activity has been modified from "Regolith Formation," an activity in [Exploring the Moon, A Teacher's Guide with Activities for Earth and Space Sciences](#), NASA Educational Product EG-1997-10-116 – HQ by J. Taylor and L. Martel.

OVERVIEW —

Participants drop impactors onto layers of graham crackers! The process models how impacts throughout the Moon's history have broken rocks down into a mixture of dust, rocks, and boulders that covers the lunar surface.

WHAT'S THE POINT?

- 🪨 The Moon's surface is pulverized by ongoing impacts, which have formed a very fine, dusty lunar "soil" — regolith.
- 🪨 Models — such as those the children are using here — can be tools for understanding the natural world

MATERIALS —

- 1 large cardboard box (~2" per side) with high sides
- 10 –15 graham crackers (enough to cover the bottom of the box with two layers)
- Fist-sized rock or a (1-lb.) box of baking soda wrapped in aluminum foil

ACTIVITY —

1) As a single group invite the children to think about different ways regolith can form on Earth:

- What helps to break down rock on Earth? *Flowing water, the expansion of freezing water, wind and wind-carried particles, plant roots widening cracks in rocks. The children may think of some of these ideas; the next part of the activity will give them firsthand experience with flowing water and wind.*
- How might formation of regolith on the Moon be different from Earth?

2) Divide the children back into groups and provide each group with the container of graham crackers and large rock. The graham crackers are the lunar surface, the rock is a large asteroid! Ask the children to drop the asteroid, from about waist high, into the container.

- What happens?
- Have them repeat the process 5 times. What do they observe?
- Have them repeat the process ~20 more times. What do they observe?

3) Bring the children back together to discuss their observations and thoughts.

- What process does this represent? *Impactors striking the surface of the Moon — or Earth! — breaking down the surface rocks into regolith.*
- What changed from one impact to five to twenty? *The graham cracker rocks became more broken and the crumb regolith became thicker and finer.*

- What does this tell us about how impacts by asteroids and comets contribute to the breakdown of rocks?
- Does this happen on Earth? *Yes, but only rarely. Earth's surface is constantly "recycled" by wind and water and other processes, so the evidence of many of these craters has been erased. Earth's atmosphere also helps to protect us from being struck by smaller asteroids; they burn up in our atmosphere, making the beautiful streaks of light — meteors — that we occasionally see.*
- Do impacts occur on the Moon? *Yes, also rarely now, but wind and water do not flow on the Moon's surface. Once craters form, they are not altered by other processes unless they get hit by another rock from space! The Moon's surface preserves a record of almost four and a half billion years of impact, after impact, after impact, after impact!*
- Do impacts help form regolith on the Moon? *You bet! They are the main process forming lunar regolith.*

FACILITATOR BACKGROUND INFORMATION

What is regolith?

You don't notice it from the surface of the Earth, but the Moon's surface is covered in a fine, loose material called *regolith*. Lunar regolith is formed by the weathering of rocks that make up the Moon's crust. Because the Moon lacks an atmosphere, water and wind are not present to break down rock, as they do on the Earth. However the Moon, like all objects in the solar system, has been bombarded by rocky objects since the formation of the solar system. Over four billion years of impacts has broken up much of the Moon's original crust to create a global blanket of regolith on the lunar surface. The depth of this regolith varies from region to region but it is found everywhere. Humanity's first experience with lunar regolith occurred when Neil Armstrong first stepped onto the Moon in 1969 and collected a sample of regolith to bring back to Earth.



Regolith forms on all objects in the solar system with a solid surface, including the Earth. Regolith forms on Earth when bedrock weathers down into smaller, loose particles, from water, wind, and sometimes (though quite rare) meteorite impacts.

A Word on Words. . .

The term "soil" may be used in this activity because children are familiar with "soil." However, "regolith" is a more appropriate term.

Soil: the unconsolidated (loose) top layer of material on Earth's surface that is made of minerals and, usually, organic matter in which plants grow.

~ LPI EDUCATION/PUBLIC ENGAGEMENT SCIENCE ACTIVITIES ~

Regolith: a general term for the layer of loose rock material that forms the surface of a planet — including Earth! — and covers the rock. Soil is a type of regolith. Other types of regolith include volcanic ash, materials deposited by a glacier or river, sand dunes, the red rocky surface materials of Mars, and the layer of material on the lunar surface.

Dirt: a term used by small children and gardeners to describe soil; a term used by scientists when they are unimpressed with the qualities of the regolith they are investigating or when they are more interested in the layers of rock beneath the regolith. May also refer to information, often of a negative connotation (e.g., "I have the dirt on you").



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Explore Marvel Moon: Edible Rocks

This activity is modified from “Edible Rocks” published in *Exploring Meteorite Mysteries*:
<http://ares.jsc.nasa.gov/education/program/ExpMetMys/LESSON8.PDF>

OVERVIEW —

Children analyze and discuss candy bars with the same terminology used by geologists to study rocks from space.

WHAT'S THE POINT?

- Space rocks called meteorites sometimes fall on Earth and provide us with clues about the solar system's formation.
- Geologists use certain terms to describe characteristics of rocks that they find in the field.
- Large space rocks have hit the Earth in the past, making craters and causing extinctions.
- The use of candy can attract new audiences such as tweens and expand family involvement to include fathers and teens.

MATERIALS —

For the Facilitator

- ☐ Plastic table cloths
- ☐ Paper towels
- ☐ Hand wipes
- ☐ Meteorite/candy comparison images
- ☐ Vocabulary list
- ☐ Brief Facilitation Outline

For Each Group of 10 Children

Individually wrapped chocolate candies and/or granola bars that mimic meteorites such as:

- 5 Chocolate
- 5 Nestle Crunch™
- 5 Three Musketeers™
- 5 Chocolate-dipped granola bars, any variety
- 10 Small plastic bags for samples
- 10 Plastic knives
- 10 Paper plates
- Colored pencils for each team
- Pens or pencils
- 10 copies of Edible Rocks Field Notes

Supporting Videos

- History Channel – The Secrets of Meteorites. <http://www.history.com/shows/how-the-earth-was-made/videos/the-secrets-of-meteorites>
- PBS NOVA – Hunting for Meteorites. <http://www.pbs.org/wgbh/nova/space/matson-meteorite.html>
- Science Channel's Meteorite Men. <http://www.sciencechannel.com/tv-shows/meteorite-men/videos/meteorite-men-truth-about-meteorites/>
- Killer Asteroids. <http://www.killerasteroids.org/>
- NASA Goddard Scientific Visualization Studio – Asteroids. <http://svs.gsfc.nasa.gov/search/Keyword/Asteroid.html>

PREPARATION —

Put the plastic table cloths on the tables.

ACTIVITY —

1. **Introduce the activity:** Meteorites are pieces of asteroids (space rocks made of the material remaining from the formation of our solar system) that make it to the surface of a planet. They can provide clues about how the planets in our solar system were formed. Asteroids can have a huge impact on life on Earth, such as when one struck the Earth 65 million years ago, resulting in the extinction of the dinosaurs.
2. Optional: Watch a video clip about meteorites.
3. Offer each child his or her choice of two “meteorite” (candy) samples. Invite the children to **cut their samples in half and observe and describe the characteristics of the samples** in the same way that a geologist describes rocks from space. If desired, provide the *Edible Rocks Field Notes* and encourage the children to draw and describe their samples.
4. Encourage the children to **describe their observations using familiar vocabulary**— but without using food terms! Prompt the children to talk to each other and/or with their families about what they observe. Provide the *Meteorite Candy Comparison Images* and discuss how the different candy “meteorites” are similar to — and different from — real space rocks.

For example: Nestle Crunch™ would be described as follows: The outer layer is a thin coat of light brown material (i.e., chocolate) and there are light-colored round chunks inside (i.e., puffed rice).



5. After they have described the samples with familiar vocabulary, encourage older children to **use terms from the meteorite vocabulary list** in their descriptions.

Different types of meteorites can each be represented by a type of candy, as listed below:

Chondrules – Nestle Crunch™
Fusion crust – 3 Musketeers™
Matrix – Nestle Crunch™ (the chocolate)
Vesicles – Nestle Crunch™ / chocolate bar
Porous – chocolate-dipped granola bar / 3 Musketeers™
Unfractured – chocolate bar

6. **Hold a discussion** with the entire group; comparing their descriptions of each sample type. Allow the children’s thinking to be shaped by the experience — refrain from giving your own

~ LPI EDUCATION / PUBLIC ENGAGEMENT SCIENCE ACTIVITIES ~

conclusions. Encourage them to talk to each other (in pairs or small groups) as they note their observations. Possible discussion prompts:

- a. What does the outside look like? Did anyone see anything else or different?
- b. What do you see on the inside? Does anyone have anything to add to that description?
- c. Describe the appearance of both the outside and inside of each piece of candy (using both familiar and new vocabulary terms).
- d. Discuss the differences and similarities between the different “rocks” (candy).
- e. Compare these “rock” samples to the meteorite images. How are they similar?
- f. How are they different?

Facilitator's Notes: This activity highlights the process of science. Observation, description, and characterization / classification of objects are important components of how science is actually done.

IN CONCLUSION —

Summarize that meteorites provide windows into the very beginnings of our solar system delivered to us – we don't even have to go into space to get them! Meteorites can have an impact on life, including causing extinctions, so scientists want to learn as much as they can about these rocks. Scientists study them and describe them using terms like the ones just used in the activity.

CORRELATION TO STANDARDS

Next Generation Science Standards:

HS-ESS1-6. Apply scientific reasoning and evidence from ancient Earth materials, meteorites, and other planetary surfaces to construct an account of Earth's formation and early history.

Disciplinary Core Idea: The solar system contains many varied objects held together by gravity.

Crosscutting Concepts:

- Patterns: students identify similarities and differences in order to sort and classify natural objects and designed products.

Science and Engineering Practices:

- Practice 2 Developing and Using Models: Compare models to identify common features and differences.
- Practice 4 Analyzing and Interpreting Data:
 - Record information (observations, thoughts, and ideas).
 - Use and share pictures, drawings, and/or writings of observations.
 - Use observations (firsthand or from media) to describe patterns and/or relationships in the natural and designed world(s) in order to answer scientific questions and solve problems.

Common Core English Language Arts

CCSS.ELA-Literacy.SL.5.1.c: Pose and respond to specific questions by making comments that contribute to the discussion and elaborate on the remarks of others.

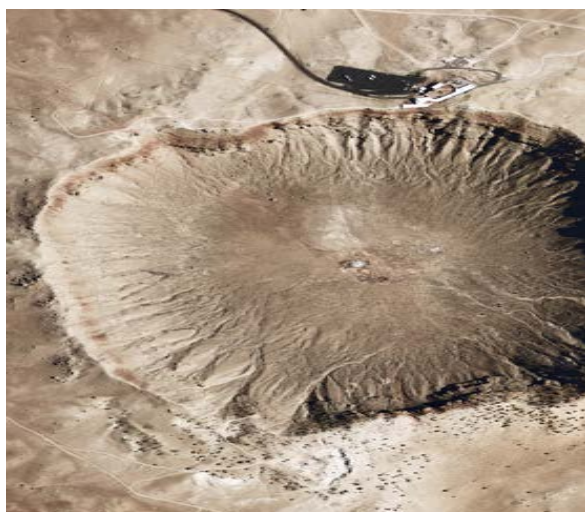
CCSS.ELA-Literacy.SL.5.1.d: Review the key ideas expressed and draw conclusions in light of information and knowledge gained from the discussions.

FACILITATOR BACKGROUND INFORMATION

When we build things, there are often building materials left over. Asteroids are bits of building material remaining from the formation of our solar system. During the solar system's formation, bits of dust and rock bumped into each other, sometimes sticking together – accreting – and sometimes scattering. But even after the planets formed, there remained residual materials – asteroids.

Asteroids are an incredible scientific resource – as scraps of the original building material of the solar system, they tell us about our own origins. Scientists are studying pieces of asteroids that have fallen to Earth's surface – meteorites – to learn more.

An **asteroid** is a rocky, airless world that orbits our Sun but is too small to be called a planet. Little chunks of rock and debris in space are called **meteoroids**. They become **meteors** – or shooting stars – when they fall through a planet's atmosphere, leaving a bright trail as they are heated to incandescence by the friction of the atmosphere. Pieces that survive the journey and hit the ground are called **meteorites**.



Meteor Crater (Barringer Crater). Credit: U.S. Geological Survey.

Most meteorites found on Earth are pebble to fist size, but some are larger than a building. The iron-nickel metal meteorite that formed the Barringer Meteorite Crater in Arizona (left image), which is about 1 kilometer (0.6 mile) across, was as big as half a football field -- approximately 50 meters (164 feet) in diameter.

A very large asteroid impact 65 million years ago, which created the 300-kilometer-wide (180-mile-wide) Chicxulub crater on the Yucatan Peninsula, is thought to have contributed to the extinction of about 75% of marine and land animals on Earth at the time, including the dinosaurs.

Meteorites may look very much like Earth rocks, or they may have a burned exterior. Some may have depressioned (thumbprint-like), roughened, or smooth exteriors. This fusion crust is formed as the meteorite is melted by friction as it passes through the atmosphere. Because many meteorites contain iron,

they may be magnetic. There are three major types of meteorites: the "irons," the "stones," and the stony-irons. Most of the meteorites that fall to Earth are stony, but more of the meteorites that are discovered long after they fall are irons – because they are so dense, these heavy objects are easier to distinguish from Earth rocks than stony meteorites.

Meteorites have many different textures and features. Chondrites, a type of stony meteorite, contain round grains called chondrules surrounded by fine-grained material called matrix. Some meteorites have vesicles, holes caused by solidification of the meteorite around gas bubbles. Others are porous; this means there is space between grains in the meteorite. If a meteorite is ejected from its parent asteroid or planet without being broken, it is unfractured. Meteorites originating closer to the impact that ejected them will be more fractured.

Meteorite types include:

- **Chondrite** – stony meteorites made primarily of rock and also contain chondrules and small pieces of iron / nickel metal
- **Achondrite** – stony meteorite that does not contain chondrules or metal, previously the mantle / crust of a large asteroid
- **Iron** – meteorite made primarily of iron / nickel metal, previously the core of a large asteroid
- **Breccia** – rock composed of pieces of rock and/or minerals broken by meteorite impacts cemented together by a fine-grained matrix

More than 50,000 meteorites have been found on Earth. Most come from asteroids; a few originate from the Moon and Mars. Meteorites also fall on other solar system bodies. The Mars Exploration Rover, Opportunity, has discovered six meteorites during its travels on Mars.



This meteorite, discovered by the Opportunity rover on Mars, is about the size of a basketball. Image credit: NASA / JPL.

REFERENCES

NASA Astromaterials Research and Exploration Science (1997) Exploring Meteorite Mysteries: A Teacher's Guide with Activities for Earth and Space Sciences. What Are They? Edible Rocks.

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NASA Jet Propulsion Laboratory (2016) Solar System Exploration – Asteroids.

<https://solarsystem.nasa.gov/planets/asteroids>

NASA Jet Propulsion Laboratory (2016) Solar System Exploration – Meteors and Meteorites.

<https://solarsystem.nasa.gov/planets/meteors>

Meteorite/Candy Comparison Images

1. (a) Chondrite / (b) Nestle Crunch
2. (a) Achondrite / (b) 3 Musketeers
3. Iron meteorite
4. Breccia
5. Chondrules - round objects
6. Fusion crust - dark coating



Explore Marvel Moon: Edible Rocks

Brief Facilitation Outline

1. Distribute the samples and (if desired) the Edible Rocks Handout to each team of two children. Allow the teams to choose their samples if possible (two samples per team).
2. Explain that each team is responsible for describing and drawing its samples. Encourage the children to describe their observations using familiar vocabulary; however, use no food terms. Example: The outer layer is a thin coat of light brown material containing cream or tan colored round chunks (i.e., chocolate candy bar coating that contains peanuts).
3. After they have described the samples with familiar vocabulary, encourage the children to use terms from the meteorite vocabulary list in their descriptions.
4. Emphasize that working together is important! If children have difficulty describing their candy bars, encourage them to interact with other groups for help. Discuss with the entire group; compare their descriptions of the samples.

Possible discussion questions:

What does the outside look like?

What do you see on the inside?

Describe the appearance of both the outside and inside of each piece of candy (using both familiar and new vocabulary terms).

Discuss the differences and similarities between the different "rocks" (candy).

Compare these "rock" samples to meteorites using the meteorite candy comparison images. How are they similar?

How are they different?

Explore Marvel Moon: Edible Rocks

Vocabulary List

- ❑ **Meteorite** - piece of rock from space that survives the trip through the atmosphere of a planet and reaches the surface
- ❑ **Description terms**
 - **Chondrules** - round grains found in chondrites (see bottom left image)
 - **Fusion crust** - black coating of the outside of the meteorite caused by melting of the rock from friction with the Earth's atmosphere (see bottom right image)
 - **Matrix** - fine-grained material around larger pieces
 - **Vesicles** - holes (caused from solidification around gas bubbles)
 - **Porous** - contains holes / cavities between grains
 - **Unfractured** - not broken, no cracks



*A slice from the 4.5-billion-year-old Allende meteorite showing several round chondrules.
Image credit: [Basilicofresco, Wikimedia Commons](#)*



*Fragments of the Cheljabinsk meteorite showing the fusion crust.
Image credit: [Didier Descouens Wikimedia Commons](#)*

Edible Rocks Field Notes

Sample	Describe your rock sample	Draw your rock sample
Sample 1		
Sample 2		



OSIRIS-REX™
ASTEROID SAMPLE RETURN MISSION

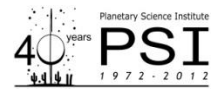
Introduction to Meteorites

Developed and compiled by Larry Lebofsky, PSI



Sikhote-Alin, Iron Meteorite

Photo Credit: Larry Lebofsky



Created in collaboration with The International Meteorite Collectors Association (IMCA)

Big Ideas:

- **At present, meteorites are our only chance to study material from asteroids, Mars, and much of the Moon.**
- **Meteorites are classified into three groups: stone, stony-iron, and iron.**
- **Primitive stone meteorites come from asteroids that have not changed much since the formation of the Solar System 4.57 billion years ago.**
- **Differentiated stone meteorites come from the surfaces of melted asteroids, the Moon, or Mars.**
- **Stony-iron and iron meteorites come from the interiors of melted asteroids.**
- **Asteroids and comets may have brought water and organics to Earth—the building blocks of life.**

Solar System Objects:

- An asteroid is an object that orbits the Sun, but smaller than a planet. They range in size from a few meters to nearly a thousand kilometers across. The image below is of the 525 kilometer diameter asteroid 4 Vesta taken by the Dawn spacecraft. The largest asteroid, 1 Ceres, is 940 kilometers in diameter and is big enough to be “round.” It is also considered to be a dwarf planet.



Photo Credit: NASA

- A meteoroid is an object that orbits the Sun, but is smaller than an asteroid. They range in size from a speck of dust to a few meters across.
- A comet is an object that orbits the Sun. Comets are mostly icy and so, when close to the Sun, they display a visible coma and sometimes a tail. Comets range in size from a few tens of meters to tens of kilometers across. The image below is of Comet McNaught taken in 2007.



Photo Credit: Sebastian Deiries/ESO

Objects in the Atmosphere:

- When a meteoroid enters the Earth's atmosphere, it is heated up as it passes through the atmosphere. The glow of the meteoroid and the trail of heated gas and particles is called a meteor. Incorrectly called "shooting stars," most will burn up completely in the atmosphere.
- Meteor showers can be seen from any location, but it is better to get away from city lights to see them. Most are related to material from comet tails.



Photo Credit: NASA

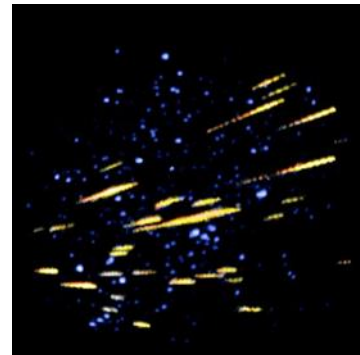


Photo Credit: NASA

- A **fireball** is a brighter-than-usual meteor. It is usually defined as a meteor brighter than the planet Venus at its brightest. The image below is a Geminid fireball over the Mojave Desert.



Photo Credit:: Wally Pacholka

Objects on the Ground:

- A meteoroid or piece of a small asteroid (large objects may get totally vaporized upon impact) that has survived passage through the atmosphere is called a meteorite. The meteorite on below is called Hammada al Hamra 335 and was found in Libya in 2004. Meteorites are named for the location where they were found. It is about 2.5 cm (1 inch) across and weighs 46 grams (1.6 oz).



Photo Credit: Dr. Svend Buhl, IMCA #6540
www.niger-meteorite-recon.de

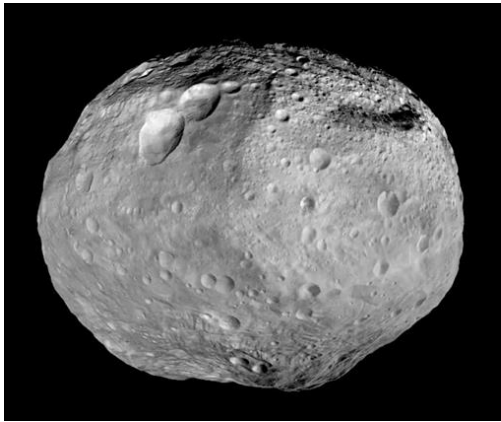
- The only other rocks from another world (other than meteorites) are **lunar rocks**. **Lunar rocks** are rocks brought back from the Moon by US astronauts, though a small amount of lunar material was brought back by robotic missions from the Soviet Union. Below is a lunar rock brought to Earth by the Apollo 17 crew.



Photo Credit: NASA

Where Meteorites Come From:

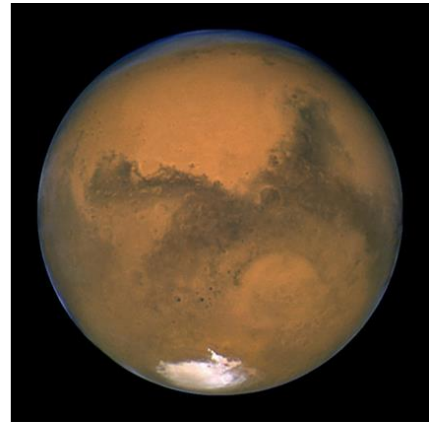
- Most meteorites come from asteroids, but, rarely, they come from the Moon or Mars. There are no *known* meteorites from a comet.
- Meteorites are the only way that we can study material from asteroids, the Moon (other than Moon rocks), or Mars (other than the Mars rovers).



Asteroid 4 Vesta
Mean Diameter About 525 km
Photo Credit: NASA, Dawn Mission



Moon
Diameter = 3,474 km
Photo Credit: Gregory H. Revera,
Wikimedia Commons



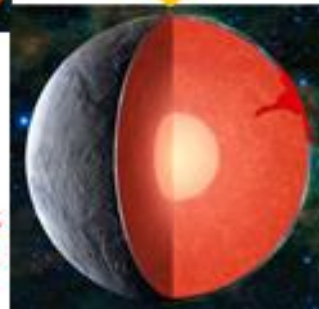
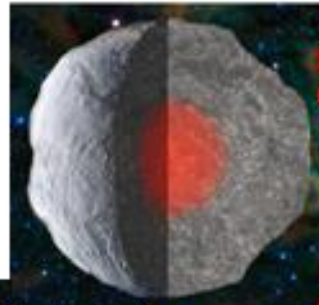
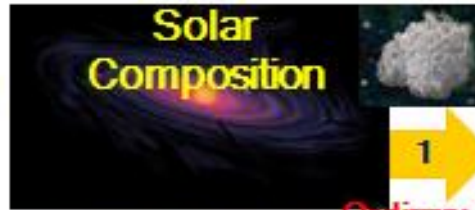
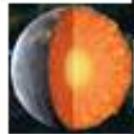
Mars
Diameter = 6,672 km
Photo Credit: Hubble Space Telescope

Asteroid "Parent Bodies":

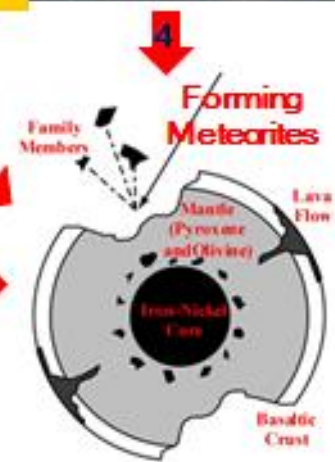
Relations Between Important Planetary Materials

1. Solids condense, lose hydrogen and helium (accretion)
2. Low heat (some melting or hydration), lose carbon and water
3. High heat, differentiation
4. Meteorites form from any asteroid

Achondrites,
Stony-Irons,
Irons



Ordinary
Chondrite,
E-Chondrite,
Carbonaceous
Chondrite



Meteorite Types



Stone

Franconia
Photo Credit: Larry Lebofsky

Stony-Iron



Esquel
Photo Credit: Wikimedia

Sikhote-Alin
Photo Credit: Larry Lebofsky

Iron

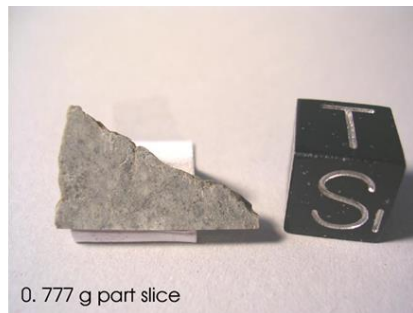


Stone Meteorites:

- Stone meteorites fall into two major groups, primitive and differentiated.
 - Primitive: Chondrites—sometimes heated, but NOT to the point of melting
 - Some may be metamorphosed due to heating or aqueous alteration (water).
 - Differentiated: Achondrites—heated to the point of melting
 - The result of differentiation, but sometimes due to local melting (impacts)



Allende, 48g
Photo Credit: Anne Black



NWA 4483 — Lunar Achondrite



NWA 2774 — Ordinary Chondrite
Photo Credit: Greg Hupe

Chondrites and Chondrules:

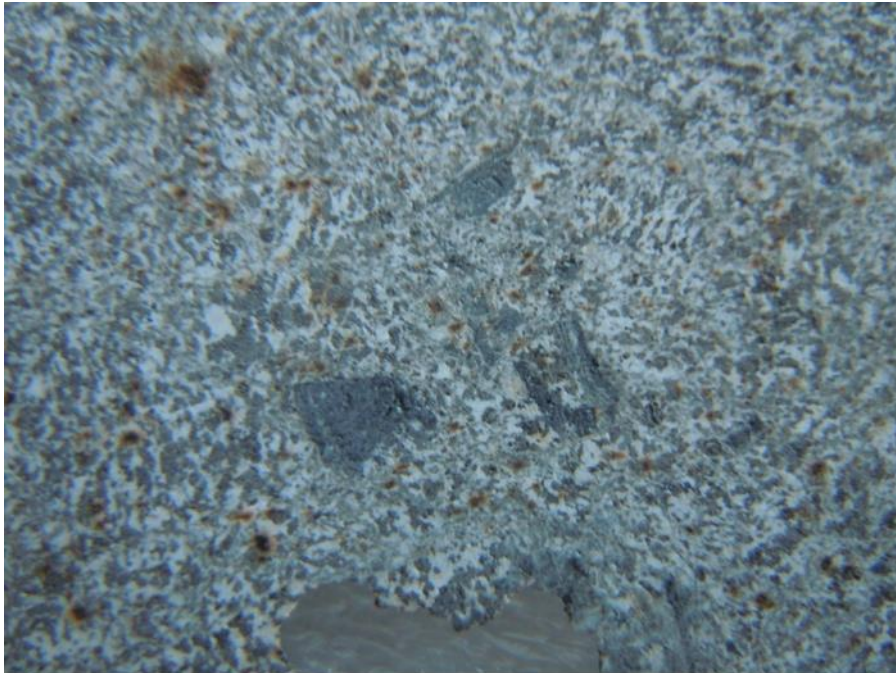
- Primitive meteorites are called **chondrites**. Chondrites represent the primitive building blocks of the Solar System.
- **Chondrules** are the major constituent of most chondritic meteorites. Chondrules formed as molten or partially molten droplets before becoming part of the chondrite parent bodies, forerunners of asteroids and planets.
- Most chondrites also contain distinctive silvery-colored flakes of iron-nickel metal.
- Terrestrial rocks do not contain chondrules.



Photo Credit: Greg Hupe, IMCA #3163

Achondrites:

- Differentiated meteorites are called achondrites.
- Because they have melted, achondrites do not contain chondrules.
- Also, because gravity separates the heavier iron-nickel metal from the lighter rocky material, achondrites do not contain the shiny metal seen in chondrites.
- Pictured below is an enlarged image of NWA 3137. Eucrites are achondrite meteorites that are thought to come from the asteroid Vesta.



NWA 3137, Eucrite
Photo Credit: Larry Lebofsky

Stony-Iron Meteorites:

- **Stony-iron** meteorites consist of almost equal amounts of nickel-iron (FeNi) alloy and silicate minerals.
 - The **pallasite** subgroup is characterized by olivine crystals surrounded by an FeNi matrix. Pallasites are thought to be the core-mantle boundary of differentiated asteroids.
 - The **mesosiderite** subgroup consists of silicates in the form of heterogeneous aggregates intermixed with FeNi alloy. Thought to be formed by local melting by impacts.



Brenham—Pallasite
Photo Credit: McCartney Tayler



NWA 1879—Mesosiderite
Photo Credit: Adam Hupe



Fukang—Pallasite
Photo Credit: Anne Black

Iron Meteorites:

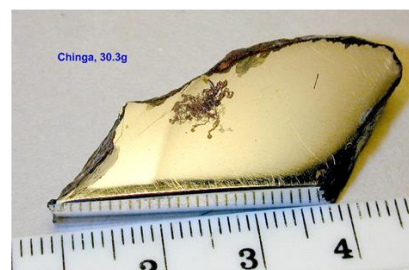
- Characterized by the presence of two nickel-iron (FeNi) alloys: kamacite (Ni poor) and taenite (Ni rich)
- Iron meteorites are further classified by sub-groups:
 - **Hexahedrites** (4-6% Ni)
 - **Octahedrites** (6-12% Ni)
 - **Ataxites** (12+% Ni)
- The octahedrite below shows a **Widmanstätten pattern** which depicts the structure of kamacite and taenite crystals in many iron or stony-iron meteorites. It is revealed when the surface of an iron or stony-iron meteorite is etched with a weak acid.



Fredericksburg—Hexahedrite
Photo Credit: Anne Black



Cape York—Octahedrite
Photo Credit: Anne Black



Chinga—Ataxite
Photo Credit: Anne Black

Best Places to Find Meteorites:

- Antarctica
 - The best place in the world to find meteorites is Antarctica. Meteorites fall on the ice and are preserved in it. Since 1969 scientists have found thousands of meteorites in Antarctica.
- Deserts
 - Hundreds of meteorites fall to Earth each year, but most are not seen because they land in the ocean or unpopulated areas. Many are found in deserts because the heat and dryness keep them from rusting away.



Photo Credit: NASA

Tektites:

- **Tektites** are pieces of natural glass that are created when large meteorites impact the Earth's surface. The released energy, in the form of heat, melts the silicates in the surrounding soil, creating this natural glass.
- Tektites are often shaped like spheres, dumbbells, or teardrops.
- The unique shape of tektites is now believed to be a result of how they spin as they cool rather than aerodynamically-shaped. Aerodynamically-shaped tektites (button-shaped) are rare.



Photo Credit: Unknown

Earth Rocks vs. Meteorites

While Earth rocks can be broadly classified as igneous, metamorphic, and sedimentary, meteorites are broadly classified, based on composition, as iron, stony-iron, and stony. However, based on how they were formed, meteorites are classified as differentiate and undifferentiated—was the parent body of the meteorite (an asteroid, the Moon, or Mars) large enough for the object to have melted and formed a crust, mantle, and core? Or, was the meteorite parent body too small and thus represent material that has been relatively unaltered since the parent body first formed out of the solar nebula?

In the Meteorite Mini-kits are four meteorites and an impact rock, a tektite.

Stony Meteorite:

Stone meteorites represent about 97% of all of the meteorites either found or seen to fall. This group of meteorites includes *chondrites* and *achondrites*. See http://meteorites.wustl.edu/meteorite_types.htm for statistics on all meteorites.

Primitive Meteorite:

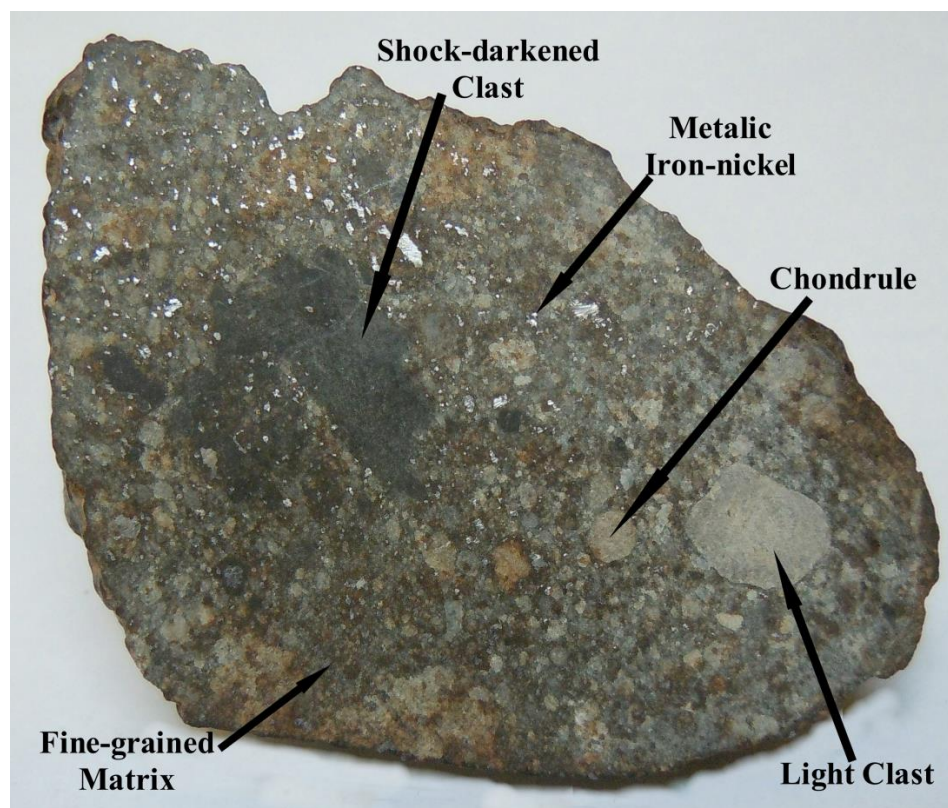
A primitive meteorite refers to a meteorite that has a composition similar to that of the Sun, minus the “volatile” elements (hydrogen, helium, for example). These are thought to come from undifferentiated asteroids, some of which may have been mildly heated. These meteorites include the *chondrites* as well as the primitive achondrites. Very characteristic of chondrite are relic chondrules and chemical compositions close to the composition of [chondrites](#). These observations are explained as melt residues, partial melting, or extensive recrystallization. <http://www.meteoris.de/basics/class2.html>, http://en.wikipedia.org/wiki/Primitive_achondrite, Dr. Alan Rubin: “Secrets of Primitive Meteorites,” in *Scientific American* February 2013.

Chondrites:

Stony meteorites make up about 97% of all known meteorites and chondrites make up about 95% of the stony meteorites. Ordinary chondrites make up more than 95% of the known chondrites (hence the term “ordinary.”) Chondrites are primitive (undifferentiated) meteorites. Chondrites are stony (non-metallic) meteorites that are made up mostly of silicates, traces of iron, and sometimes carbon and water. Many, but not all, chondrites contain chondrules. Chondrules form as molten or partially molten droplets in space before being [accreted](#) to their parent [asteroids](#). Chondrites represent one of the oldest solid materials within our Solar System and are believed to be the building blocks of the [planetary](#) system. Chondrites have not been modified due to melting or differentiation of the of the parent body. Three of the meteorites in Mini-kits are ordinary chondrites.

The whole and one of the cut meteorites are NWA 869s—the 869th meteorite found in Northwest Africa to be classified. While all of the NWA 869s show weathering, the whole ones show more weathering and so are not as valuable as the less-weathered ones. NWA 869 is an ordinary chondrite and specifically a chondritic breccia. Regolith breccias are rocks composed of broken fragments of [minerals](#) or rock [cemented](#) together by a fine-grained [matrix](#). The rock formed from impact ejecta which was later buried by newer impacts and [lithified](#) (solidified) due to the pressure from overlying layers. However, the pressure was not enough to heat and destroy the chondrules.

The other cut meteorite is also a chondrite. In this case, the rock has been heated enough (most likely impact shock heating).



Metamorphism:

Metamorphism is the change of [minerals](#) or [geologic texture](#) (distinct arrangement of minerals) in pre-existing [rocks](#), without the rock melting into liquid [magma](#) (a [solid-state](#) change). The change occurs primarily due to heat, pressure, and the introduction of chemically active fluids (water). The [chemical components](#) and [crystal structures](#) of the minerals making up the rock may change even though the rock remains a [solid](#). Metamorphism typically occurs between about 200°C and melting at about 850°C. Three types of metamorphism exist: [contact](#), dynamic and [regional](#). <http://en.wikipedia.org/wiki/Metamorphism>. In meteorites, metamorphism usually occurs through alteration by water or by impact shock heating.

Iron Meteorite

Iron meteorites are differentiated meteorites and are thought to represent the cores of differentiated asteroids. Iron meteorites consist of almost pure metallic iron with small amounts of nickel and sulfur. Polished faces are commonly treated with dilute nitric acid to bring out the Widmanstätten pattern—parallel patterns of lines intersecting at various angles delineating bands of crystals of kamacite (low nickel) and taenite (high nickel) iron alloys. Iron meteorites were once completely molten and, as indicated by sizes of some individual crystals as large as several meters, cooled slowly over millions of years. It is estimated that the parent bodies of the iron meteorites ranged from a little over 100 km to nearly 1,000 km (the size of Ceres) in diameter. Irons are grouped by chemical composition. Known irons originate from 60–70 parent bodies.

Tektite:

A tektite is an Earth rock that has been melted (or vaporized) by hypervelocity impact. The material has been ejected from the impact crater and, as the molten material reenters the atmosphere, cools rapidly forming unusual shapes due to passage through the atmosphere, spinning, and landing while still slightly soft. While it is the result of the impact of a large “rock from space,” it is not a meteorite, it is an impactite.

Tour of the Meteorite Mini-Kit



- Determine your audience's prior knowledge about meteorites
- Demonstrate that one way of identifying a meteorite is by weight (density) and why
- Lead your audience through a series of investigations of the rocks in the Mini-Kit, having them guess which ones they think are meteorites and why
 - Look at the rocks or sketch them without picking them up
 - Pick them up
 - Examine the rocks with the tools they have been given (magnifier and magnets)
 - For closure, tell them that this is exactly what scientists do

Discussion Questions (for interpretation):

- Comparing the pumice to the Earth rock, why is one heavier than the other? (The pumice has holes and the other does not.)
- Why is the whole meteorite heavier than the pumice or Earth rock? (The meteorite is made of heavier "stuff.")
- Why is the little meteorite attracted to a magnet (it is not magnetic!)? (It is made of metal—iron.)
- Are the meteorites attracted to a magnet? (Yes.)
- When you look at the surfaces of the two cut meteorites, what do you see? (Little shiny flakes.)
- Why are the meteorites attracted to a magnet? (They contain little flakes of iron.)
- Why are the meteorites heavier than the Earth rock? (They contain little flakes of iron!)

Information About the Meteorites

- All of the meteorites are older than the Earth. They are the “building blocks” that made the Earth. They are 4.56 billion years old!
- There are no Earth rocks that contain pure metal (iron and nickel) as do the meteorites (others are attracted to magnets, but the flakes of metal are unique to meteorites).
- No Earth rocks contain chondrules.
- The iron meteorite is from the core of an asteroid.
- The chondrite meteorites came from asteroids that were too small to have melted, so we are seeing the iron as it was when the Solar System was forming.

Tie Into NGSS:

- The Next Generation Science Standards (NGSS) Performance Expectations include: “What makes up our solar system?” NGSS emphasizes the Crosscutting Concepts of Patterns and Scale, Portion, and Quantity. NGSS also states that the Nature of Science (NOS) should be an “essential part” of science education. NOS topics include, for example, understanding that scientific investigations use a variety of methods, that scientific knowledge is based on empirical evidence, that scientific explanations are open to revision in light of new evidence, and understanding the nature of scientific models.
- The Mini-Kits lend themselves perfectly for incorporating the Nature of Science into an activity that also introduces teachers and their students to meteorites.



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ASTEROID SAMPLE RETURN MISSION

Strange New Planet

Adapted from *Mars Activities: Teacher Resources and Classroom Activities*, a Mars Education Program product from the Jet Propulsion Laboratory and Arizona State University.

OVERVIEW —

In this simulation of space exploration, participants plan and carry out five missions to a “planet” and communicate their discoveries to their family or a friend.



WHAT'S THE POINT?

- 🔭 Scientists plan space exploration missions based on previous scientific knowledge and investigations. Different kinds of investigations answer different kinds of questions.
- 🔭 Space missions are scientific investigations that involve observing and describing planets, asteroids, and moons. Sample return missions allow scientists to collect and analyze specimens.
- 🔭 Space scientists use technology, such as telescopes and robotic spacecraft, to help them make better observations. Robotic spacecraft may fly by or orbit a planet, or they may investigate the surface (landers and sample return missions).
- 🔭 Scientists and engineers often work in teams with different individuals doing different things that contribute to the results. The team members work together to gather and analyze data, and they use that data to plan future investigations.

MATERIALS —

Facility needs:

- ☐ A (30' x 6' or larger) hallway or open space
- ☐ A stool, pedestal, or stand

For the facilitator:

- ☐ Craft and food items for constructing one or more “planets,” each constructed from:
 - 1 (4-8”) Styrofoam® ball
 - 1 (1-lb.) container of modeling clay or case of Play-Doh® in a variety of colors, to depict features
 - A selection of “planet” surface features: cotton balls or gauze, felt, toothpicks
 - “Life” (optional): whole cloves, or small green leaves from a plant such as thyme
 - Glue or tape
 - 2–4 markers of different colors
- ☐ 1 measuring tape
- ☐ 1 roll of masking tape
- ☐ 1 permanent marker

For each audience of 10-15 participants:

- ☐ 1 or more “telescopes on Earth,” each constructed from
 - 1 cardboard or rolled paper tube
 - 1 (5” x 5”) blue cellophane square
 - 1 rubber band
- ☐ 1 or more additional cardboard or rolled paper tubes to serve as the “telescope in space”
- ☐ Optional: 1 set of walkie-talkies for the group to share
- ☐ 5-7 observation sheets, printed on cardstock
- ☐ 5-7 pencils and/or colored pencils
- ☐ Optional: 5-7 flag stickers

- Optional: 5-7 toothpicks for “planting” the flag

PREPARATION —

- Create a “planet” using the craft and/or food materials. Decorate the planet with beads, stickers, sequins, candy, marbles, scents (optional), etc., to make the object interesting to observe. Some of these materials should be placed discreetly so that they are not obvious upon brief or distant inspection. Features might include:
 - Cotton-ball or gauze “clouds”
 - White patches of “ice”
 - Indented craters
 - “Rifts” cut into the surface
 - “Volcanos” or “mountains”
 - A “moon” grape attached with toothpicks
 - Cloves, small green leaves, or other signs of “life.”
- Prepare a hallway or large, open area with the “planet” elevated at one end on a pedestal or stool. Leave a clear path around the “planet” for the participants to walk in a complete circle (“orbit”) around them from a distance of about 2 feet.
- Using tape and a marker, provide labels on the floor for where observers should stand at each stage of exploration. Space the labels out so over a distance of about 20 feet (measurements are approximate):
 - Telescope on Earth (20 feet from the “planet”)
 - Telescope in Space (21 feet from the “planet”)
 - Space Probe (10 feet from the “planet”)
 - Orbiter (2 feet from the “planet”)
 - Lander (next to the “planet”)
- Create a “mission control” area at the farthest point from the “planet” (with seating, if desired).
- Make at least one “telescope on Earth” by attaching a blue cellophane square to one end of a paper towel tube of rolled piece of paper using a rubber band. If multiple teams will view the “planet” at the same time, make one “telescope on Earth” and one “telescope in space” for each team. (Alternatively, provide time during the activity for the participants to make their own “telescopes.”)
- Optional: If the walkie-talkies will be used, test them beforehand for battery strength and to set them to the clearest channel.





ACTIVITY —

1. Share ideas and knowledge.

- Frame the activity with the main message: Exploration allows us to build new knowledge on the discoveries of others.
- Brief participants on their mission: to plan and carry out the exploration of a new “planet” as if they are looking through a telescope from Earth or traveling to the planet as a space probe, orbiter, lander, or sample return mission.
 - One person from each team will serve as an “observer.”
 - Remaining team members will stay at “mission control” and use the observation sheets and pencils to record what they learn from the observers at each stage of exploration.

~ LPI EDUCATION/PUBLIC ENGAGEMENT SCIENCE ACTIVITIES ~

- Optional: Have the group take turns using the walkie-talkies to report back observations to “mission control.” Begin with a demonstration on how the walkie-talkies work.
- 2. Guide the participants as they plan, then carry out, the following five stages of exploration.** Team members will take turns being the “observer,” who will look at the “planet” from each marker and report the “planet’s” colors, shapes, and textures to mission control. Teams use this information to decide together on how best to proceed at the next stage of exploration. (Optional: use walkie-talkies to incorporate technology into this process). *After each step, each team must have and report out scientific questions in order to continue with a new mission; NASA never sends a mission without science questions they want answered.*
- a. Telescope observations:
 - i. Observers look through cellophane-covered tubes to study the “planet” as it would appear from Earth-based telescopes.
 - ii. Observers look through tubes (without cellophane) to study the planet as it would appear from Earth orbit.
 - iii. Ask the participants to consider how the blue cellophane represents the Earth’s atmosphere and discuss what affect the Earth’s atmosphere would have on our ability to see details on the planet’s surface.
 - b. Space probe: Observers view the “front” side (the side they just viewed from a distance) of the “planet.”
 - c. Orbiter: Observers walk around the “planet” in a circle (orbit) at a distance of 2 feet.
 - d. Lander:
 - i. Each team uses their prior observations to decide where they would like to send a lander and what feature(s) they would like to examine.
 - ii. Observers mark their “landing site” by planting a toothpick, with a flag sticker attached, onto their chosen site. Observers then study only that spot for up to about five minutes.
 - e. Optional: Sample return mission:
 - i. Each team uses their prior observations to decide what sample they would like to collect.
 - ii. Observers return to the “Lander” marker to collect one sample (a tiny pinch) from the “planet.” They bring the sample back to mission control for examination in a scientific laboratory.
- 
- 
- 3. Have the participants describe what they discovered by exploring the model planet, based on their observations.**

CONCLUSION

Draw on the participants’ discoveries to summarize the experience, and encourage teams to talk with each other. Prompt conversation with questions such as:

- What did you first observe through the “telescopes”? How did the blue cellophane affect what you saw?

~ LPI EDUCATION/PUBLIC ENGAGEMENT SCIENCE ACTIVITIES ~

- How did your understanding of the “planet” and its features change with each stage of exploration?
- What evidence can each team provide to argue that there is — or is not — life on the “planet”?
- How did talking to your teammates help you decide what you were seeing and what to look for during the next stage of exploration?
- How did your drawings — your scientific understanding — change as you learned more?
- What questions will you be able to answer based on your sample?
- What real planet would you like to explore?

FACILITATOR BACKGROUND INFORMATION

One critical aspect of science education is teaching what science fundamentally is and how it is conducted. The Nature of Science includes exploring the relationship between science and technology (see the Next Generation Science Standards below.) The history of planetary exploration can be used to demonstrate this relationship. As scientists make new discoveries, they form new questions. Sometimes these questions inspire the design of new instruments. As new technology extends our capabilities, it gathers data that often surprise us, answering questions we didn’t even know we had.

How do scientists explore planets? Telescopes on Earth and in orbit around Earth provide scientists with information about our solar system. That information is used to plan where spacecraft fly and where they “point their cameras.” NASA and other agencies send robotic spacecraft to fly by, orbit, or land on other planets and moons. With each mission, scientists added new knowledge to our understanding of the solar system.

Only one other body in our solar system has been visited by humans — the Moon! The Apollo astronauts brought back nearly 850 pounds of lunar samples, which scientists continue to study today. Chunks of planets and asteroids sometimes land on Earth as meteorites, giving scientists the chance to study pieces of other worlds.

Some spacecraft — probes — travel very fast and don’t slow down to stay long at a planet. Orbiters circle around a planet or moon for an extended period of time. Landers land on a planet or moon to study a particular place (rovers are able to move and visit more than one place in the area).

Sample return missions are extremely expensive. Samples from the Moon collected during the Apollo missions cost \$28,500 per pound! (Their value to science and society, however, could be considered much greater than their cost!) Spacecraft have also brought samples back from a comet, an asteroid, solar wind, and low-Earth orbit.

Scientists talk to each other about what spacecraft show them, and use their observations to plan the rest of the mission — sometimes even changing where the spacecraft or lander will go next!

REFERENCES

Adapted from *Mars Activities: Teacher Resources and Classroom Activities* (<http://mars.jpl.nasa.gov/classroom/pdfs/MSIP-MarsActivities.pdf>), a Mars Education Program product from the Jet Propulsion Laboratory and Arizona State University.

Planetary Exploration in Science Education. The Universe in the Classroom (2016). No. 90, Astronomical Society of the Pacific. <https://www.astrosociety.org/wp-content/uploads/2016/01/uic90.pdf>

CORRELATION TO STANDARDS

Next Generation Science Standards



is managed by Universities Space Research Association on behalf of NASA
<http://www.lpi.usra.edu/education>



Science and Engineering Practices

- Asking Questions and Defining Problems: Ask questions that arise from examining models or a theory, to clarify and/or seek additional information and relationships
- Developing and Using Models: Distinguish between a model and the actual object, process, and/or events the model represents.
- Developing and Using Models: Identify limitations of models.
- Planning and Carrying Out Investigations: Make observations and/or measurements to produce data to serve as the basis for evidence for an explanation of a phenomenon or test a design solution.
- Analyzing and Interpreting Data: Use observations (firsthand or from media) to describe patterns and/or relationships in the natural and designed world(s) in order to answer scientific questions and solve problems.
- Constructing Explanations and Designing Solutions: Make observations (firsthand or from media) to construct an evidence-based account for natural phenomena.
- Engaging in Argument from Evidence: Respectfully provide and receive critiques from peers about a proposed procedure, explanation, or model by citing relevant evidence and posing specific questions.

Crosscutting Concepts

- Patterns: Patterns in the natural and human designed world can be observed, used to describe phenomena, and used as evidence.
- Structure and Function: Students observe the shape and stability of structures of natural and designed objects are related to their function(s).

The Nature of Science

- Scientific Investigations Use a Variety of Methods: Science methods are determined by questions.
- Scientific Investigations Use a Variety of Methods: Science investigations use a variety of methods and tools to make measurements and observations.
- Scientific Knowledge is Open to Revision in Light of New Evidence: Scientific explanations are subject to revision and improvement in light of new evidence.
- Scientific Knowledge is Open to Revision in Light of New Evidence: Science findings are frequently revised and/or reinterpreted based on new evidence.
- Science is a Human Endeavor: Most scientists and engineers work in teams.
- Science is a Human Endeavor: Creativity and imagination are important to science.
- Science is a Human Endeavor: Advances in technology influence the progress of science and science has influenced advances in technology.
- Science Addresses Questions About the Natural and Material World: Scientific knowledge is constrained by human capacity, technology, and materials.



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Investigating the Insides

A digital version (with hyperlinks) of "Explore! Jupiter's Family Secrets" is at —
http://www.nasa.gov/mission_pages/juno/education/explore.html

Overview

Investigating the Insides is a 30-minute activity in which teams of children, ages 10 to 13, investigate the composition of unseen materials using a variety of tools. This open-ended engagement activity mimics how scientists discover clues about the interiors of planets with cameras and other instruments on board a spacecraft.

What's the Point?

- The interior of a planet cannot be studied directly; scientists must infer the composition and structure from their observations.
- Different instruments provide different forms of indirect evidence.
- Scientists use their observations (evidence) to build on what they already know about the universe.
- Scientific explanations are built on existing evidence and models. New technologies help scientists find new evidence and construct new models. Science advances when these are incorporated into our knowledge of the universe.
- Models offer a useful way to explore properties of the natural world.

Materials

For each group of 20 to 30 children:

- 5–7 extra-large, dark blue balloons, filled with air and other assorted materials (below)
- 2 compasses or magnets
- Paperclips
- 1–3 strong magnets, such as cow magnets (available from pet/farm supply stores or science education product retailers)
- Scraps of paper
- 10–20 beads
- 5–10 marbles
- Optional: Whipped cream from a bottle with a nozzle
- Optional: Water
- 2 small scales (such as postage scales)
- 2 liquid crystal temperature strips (available in most pet stores or stores that sell aquarium fish)
- 2 magnifying glasses
- Optional: 2 laser pointers
- Optional: 2 ear thermometers

For each child:

- His/her [My Trip to Jupiter Journal](#) or just the relevant ["Investigating the Insides"](#) page
- 1 pencil or pen

For the
facilitator:

- **Background information:** [Secrets of the Solar System Family](#)
- [Shopping list](#)

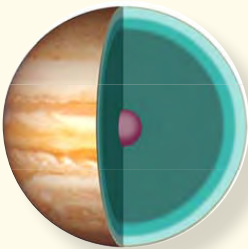
Preparation

- Review the background information.
- Prepare the balloons: After stretching out the balloon, place a magnet, one or more paper-clips, several beads, or several marbles in it and inflate it. Repeat for each balloon. If possible, add some water to several of the balloons and then finish inflating them before tying the ends. Tie a secure knot in the end of each balloon.
- Set out the remainder of the materials on a variety of tables for the children to use.

Activity

1. Ask the children how scientists study planets.

- Are there different tools we can use to study planets? *We can use telescopes, and can send robotic spacecraft to the planets. There are different instruments on spacecraft and on telescopes, like cameras and sophisticated detectors, that can be used to study planets.*
- How can we study what's inside a planet? *No instruments can "see" inside a planet. We need to use indirect methods to study planetary interiors.*



Facilitator's Note

This activity serves as an open-ended engagement activity on how we study the planets. Scientists are able to directly observe some of a planet's characteristics, such as location in the solar system, size, mass, density, gravity, external composition, and more. Mathematicians were able to calculate the planets' orbits based on observations of their movements across the night sky. Telescopes and tools that measure invisible wavelengths of light, called spectrometers, allowed scientists a closer look at the planets' external compositions.

Scientists study the interiors through models they create, which are based on a planet's observable characteristics. Earth's interior is studied in part through seismic data. The giant planets and Earth all have magnetic fields, which are detectable by the radio signals they emit. Magnetic fields are generated deep within planets, so they provide clues to the internal structure and composition. Orbiting spacecraft experience slight variations in their trajectories that help scientists understand a planet's gravity well. By measuring the gravitational pull, scientists can tell more about how a planet's heavy material is distributed in its interior. That information will help them make educated inferences about a planet's composition.

2. Share that the Juno mission launched in August 2011 to study Jupiter. One of its goals is to study Jupiter's structure using different kinds of sophisticated instruments. Juno will measure the atmosphere's temperature and amounts of water and ammonia at different depths. This information will help scientists understand the winds deep in Jupiter's atmosphere and piece together Jupiter's internal structure. JunoCam will take pictures of the planet, which scientists and students will use to study the poles. Juno will study Jupiter's magnetic field. It has cameras and sensors that will study Jupiter in visible light, in ultraviolet, infrared, and radio. It will keep track of how its orbit is slightly changed by the amount of pull from Jupiter; this will provide clues about Jupiter's gravity field. While some of these instruments will provide clues about the inside of Jupiter, none of them will be able to see inside the planet.

- What's a model?
- How does a planet compare with a balloon? *We can only see the surfaces or outer layers of planets, just like we can only see the outside of a balloon.*
- What are some ways we can determine what is inside of these balloons? *We can feel the balloons and shake them. We can use tools like thermometers, scales, magnets, and compasses to learn more about what's inside the balloon.*

5. One at a time, invite each group to share their observations with the others. Ask the groups to share their hypothesis on what is inside their balloons.

- What materials do they think are inside their balloons? Are they hard (solid), sloshy (liquid), or feel like a normal balloon (filled with gas)?

Ask the children to compare their balloons to planets.

- Reiterate that Juno will investigate Jupiter — like the children did with their balloons — using a variety of sophisticated instruments.



Juno will use sophisticated instruments, such as a [microwave radiometer](#) and [magnetometer](#). For more information about the instruments on board the Juno spacecraft, visit [the Juno spacecraft and instrument webpage](#).

Share with the children that scientists can never see exactly what is a planet or how its inside materials are arranged. Scientists cannot “pop” the planet to see if they are right! Their interpretation is based on the evidence they gathered. Their interpretation may be altered in the future as more evidence is collected, or new instruments are created.

If possible, build on the children's knowledge by offering them a future Jupiter's Family Secrets activity. Ten-year-old children may wrap-up their investigations of Jupiter by attending the concluding activity, [My Trip to Jupiter](#), where they create scrapbooks to document their own journeys into Jupiter's deepest mysteries! Invite children ages 11 to 13 to return for the next program and use some of these tools to investigate [Neato-Magneto Planets](#)!

Investigating the Insides

Correlations to National Science Education Standards

Grades 5–8

Science as Inquiry — Content Standard A

Abilities Necessary to Do Scientific Inquiry

- Different kinds of questions suggest different kinds of scientific investigations. Some investigations involve observing and describing objects, organisms, or events; some involve collecting specimens; some involve experiments; some involve seeking more information; some involve discovery of new objects and phenomena; and some involve making models.
- Scientific explanations emphasize evidence, have logically consistent arguments, and use scientific principles, models, and theories. The scientific community accepts and uses such explanations until displaced by better scientific ones. When such displacement occurs, science advances.

Investigating the Insides

As a scientist, you are going to use various tools and senses to study what is inside of a balloon.

Use your senses! What do you feel and hear when you pick up and move the balloon?

The balloon seems _____



Investigate with tools: a scale, a magnet, a paper clip, a magnifying glass, and any other tools you find to study your balloon.

Using the tools, I discovered that the balloon _____

(HINTS: Is the balloon heavy or light?
Is there more than one thing inside of the balloon?
What does it sound like? Is it magnetic?
Is it attracted to a magnet?)

Based on my observations, I **infer** that there is or are _____

_____ inside my balloon.



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Asteroid Mappers Tutorial – featuring Vesta

First of all, we can answer a few of your questions!

Why are we mapping craters?



Craters can tell planetary scientists a lot about a surface, such as its age, what kinds of erosion processes may have occurred, and what kind of material may be just under the surface.

To study all these things, we need to know where impact craters are, how many there are, and different things about them. This gives us the basic task of **CosmoQuest Asteroid Mappers** - Find craters!

What is CosmoQuest Asteroid Mappers currently studying?

Asteroid Mappers is launching with the goal of helping scientists develop a statistical foundation for understanding the age of planetary surfaces, particularly Vesta, one of the largest asteroids in the asteroid belt between Mars and Jupiter. Vesta is a unique body because of its size and history, so even though the tasks are the same between Moon Mappers and Asteroid Mappers, the craters and surfaces on Vesta aren't as well behaved as the moon, so new challenges already exist! In addition, Asteroid Mappers will push the boundaries of existing citizen science to find out just how good the public can get at higher level mapping tasks.

The public is full of talented people with interest in science and both the time and skills needed to help us learn more about our solar system. And it's way more fun when we all work together. Not only that, but in the process, we hope the public can not only enjoy the return from the mission, but also get a real feel for how science is done and what it is like to be a scientist.

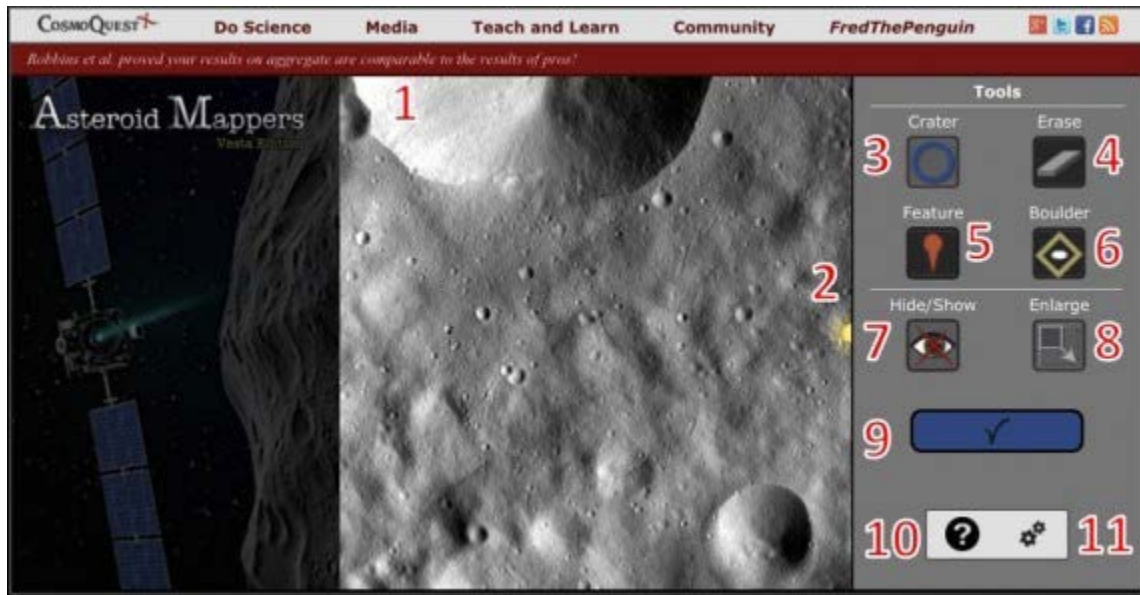
What we're hoping is that more eyes on more images will help remove personal bias from the interpretation of cratering ages, all the while letting the public learn and enjoy, and helping save time for scientists in the future so they can work on the aspects of the analysis that really do need a PhD!

How do we get started?

Open your web browser and go to http://cosmoquest.org/?application=vesta_mappers. There you will be asked to register as a new user. Enter your information and create your password to register. Then you will be shown the mapper interface – you're ready to start!

Asteroid Mappers Interface

The Asteroid Mappers interface and task really is what it sounds like: We simply have you map the surface of Vesta.



The above image is what you will be presented with during the main tasks for Vesta Mappers. The numbers below refer to the numbers in the image.

1.This is an image taken of the surface of Vesta. It is what we want you to map out for us. Some images have a black edge, as shown here, and that is okay.

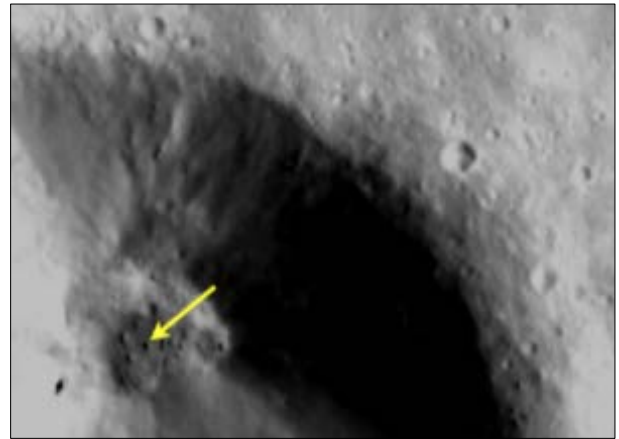
2.The **yellow sun marker** indicates the direction from which sunlight is coming.

3.The **Mark Crater tool** is what you'll use the most. When this screen grab was taken, that was the tool that was selected, indicated by the light background. To use the **Mark Craters tool**, select it, and then draw on the image. Start at the edge or rim of a crater you want to mark, hold the mouse button down, and drag until you reach the other edge of the crater. If the crater is smaller than our minimum size, the crater you draw will remain red and will disappear when you release the mouse button. If it's big enough to be counted, it will turn green.

4. **Erase** does what it sounds like — if you have this tool selected, move your mouse over the feature you have marked, click, and you will erase it.

5. **Feature** lets you put down a flag on the image in the location of a feature that you think is particularly interesting and allows you to choose from a menu of possibilities.

6. **Boulder** allows you to mark large rocks or boulders on the surface. See the image right for an example, pointed out with a yellow arrow. You can tell a boulder from a crater by the orientation of the shadows as they are reversed from those of the craters. (The light/dark are left/right for craters in this image, whereas boulders and other raised surfaces are right/left).



7. You can use **Hide and Show** to toggle the marks you've made on or off.

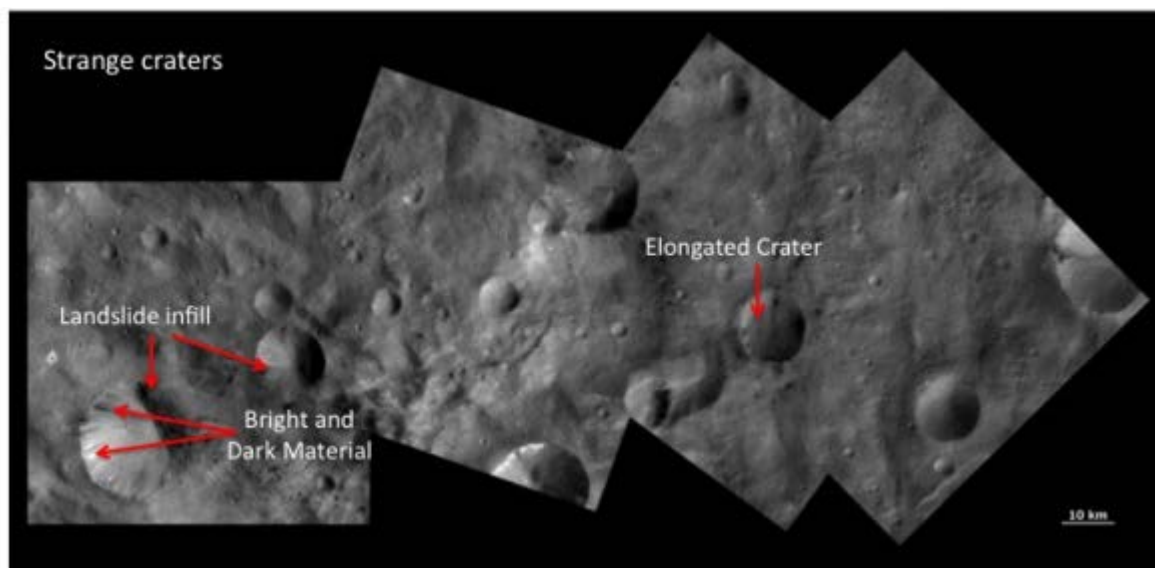
8. **Enlarge** allows you to enlarge the image and crater marking tool.

9. Submit the image by clicking the button with the **Done Checkmark** when you are done!

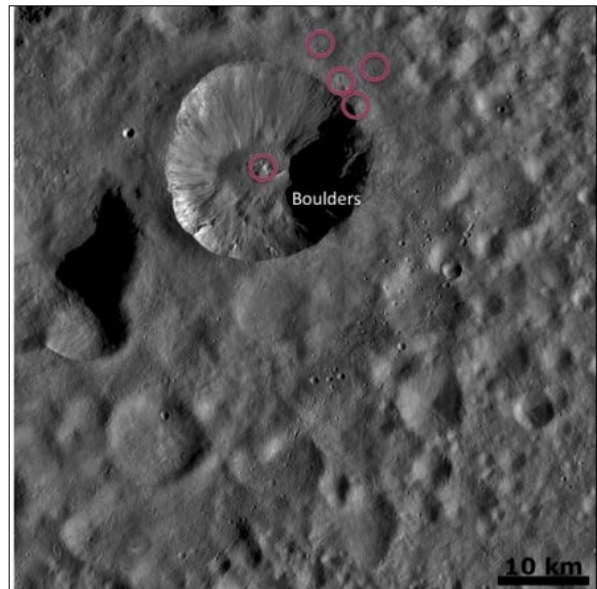
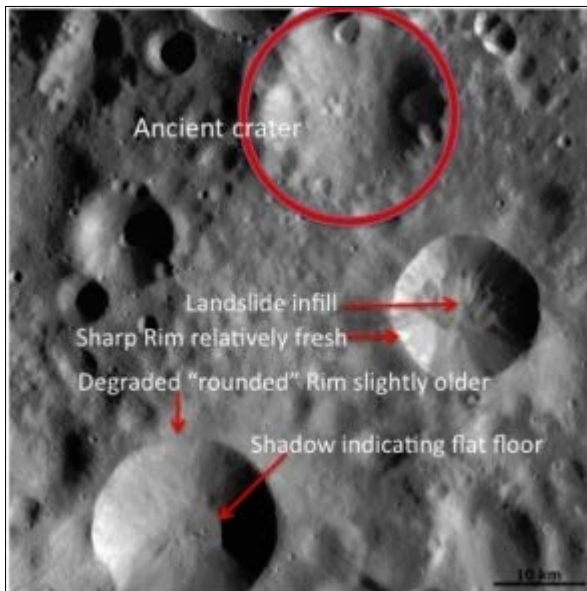
10. **Help** takes you to FAQ, Tutorials, and the option to open the image in a new tab.

11. **Settings** allows you to toggle the zoom box on and off, show or hide the zoom and move tools (especially useful on mobile), and switch between the **Rim to Rim** circle method or the original **Center to Rim** method.

Basic Feature Guide



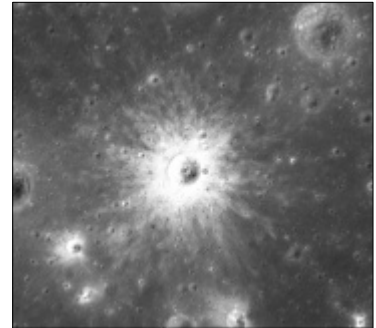
There are many, many different types of features on planetary surfaces such as Vesta. Above and below are some example features that you may come across in your explorations:



Light Albedo Feature

When craters are formed, the impact scatters about the crater a blanket of bright material. Called an ejecta deposit, it is made of pulverized material.

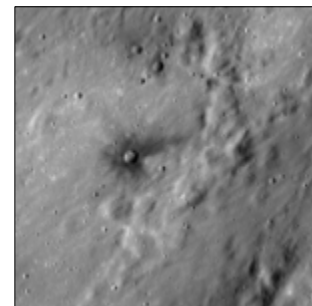
This ejecta appears very bright when first formed, but slowly fades as it ages due to interactions with micrometeorites and the radiation of space. When you see craters with bright ejecta and bright rays, you are seeing some of the youngest features. Studying young craters is an important part of asteroid science, but to do that, we need to know where they are!



Dark Albedo Feature

Dark features can come from either volcanic eruptions, or more commonly through special, impact craters.

Sometimes an impact event that forms a crater punches through the top, light-colored layer and excavates a darker layer from underneath. When this happens, the dark colored material gets thrown into the air and falls to the surface to form a crater ejecta. This material appears dark in contrast to the surrounding surface, so we mark it as a dark albedo feature.



Boulders

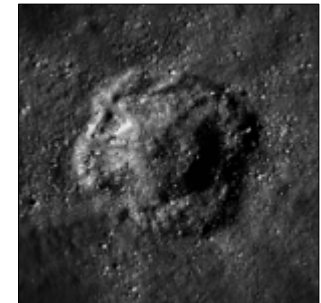
Boulders are strewn across the surface of Vesta, but they are highly non-uniform. Sometimes we find them at the bottom of craters, sometimes on crater walls. Other times strewn around the rims of large craters. We may even find evidence of rolling boulders.



And yet, there are many craters that don't seem to have any boulders in or near them whatsoever. Help us figure out where they are by marking them with the **Mark Boulder** tool. Look carefully, as they may be very small!

Concentric Craters

Sometimes craters look like there is one crater nested just inside a slightly larger crater. This is not a freak accident, where one crater impacted just inside another one (though that does occur, but very very rarely).



Scientists think these craters form when the region impacted consists of two layers of very different material; a weak rubble (or regolith) layer on top of a harder rock layer. The weak layer is more easily ejected by the impact than the hard layer, forming a slightly larger crater in the regolith than in the rock below. These craters allow us to understand the depth of different layers of material in different regions of the moon.

Crater Chains

One of the most intriguing types of feature is the crater chain. These streaks of craters can be formed through the following methods.



First, a broken object hitting the asteroid or material scattered during a "primary" impact event causes a streak of craters.

Also, when a large crater is formed, the impact can hurl large blocks of material (ejecta) that land in a row. This forms chains of craters that we call "secondary craters" (since they formed as a result of the main, primary crater). If you see a bunch of craters in a row, the most common explanation is that they formed from these secondary impacts.

Finally, in some, much rarer cases, crater chains can also form when a string of broken up asteroid or comet pieces hits. Gravitational disruptions and impacts between objects can sometimes break up comets and asteroids. These broken up pieces may continue along the same orbital path, but spread out as they travel. When these strings of rock or ice hit an object they can form crater chains.



Odd Shaped Feature

What to do if you see something that looks weirdly shaped and you don't know what it is? Or, you know what it is but we don't have a specific selection option for it, say, an elliptical crater. Use this classification.

Odd Albedo Feature

If you see a feature that doesn't seem to have any three-dimensionality to it but is rather a bright or dark splotch, select this option. We never know what we might find!

Unknown

We may not have a pull-down item for something that you see. You may not know at all what you see other than it's weird – you can't tell if it's light or dark, there's a topography difference, or anything else. Use this option if all else fails.



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Notes

Notes