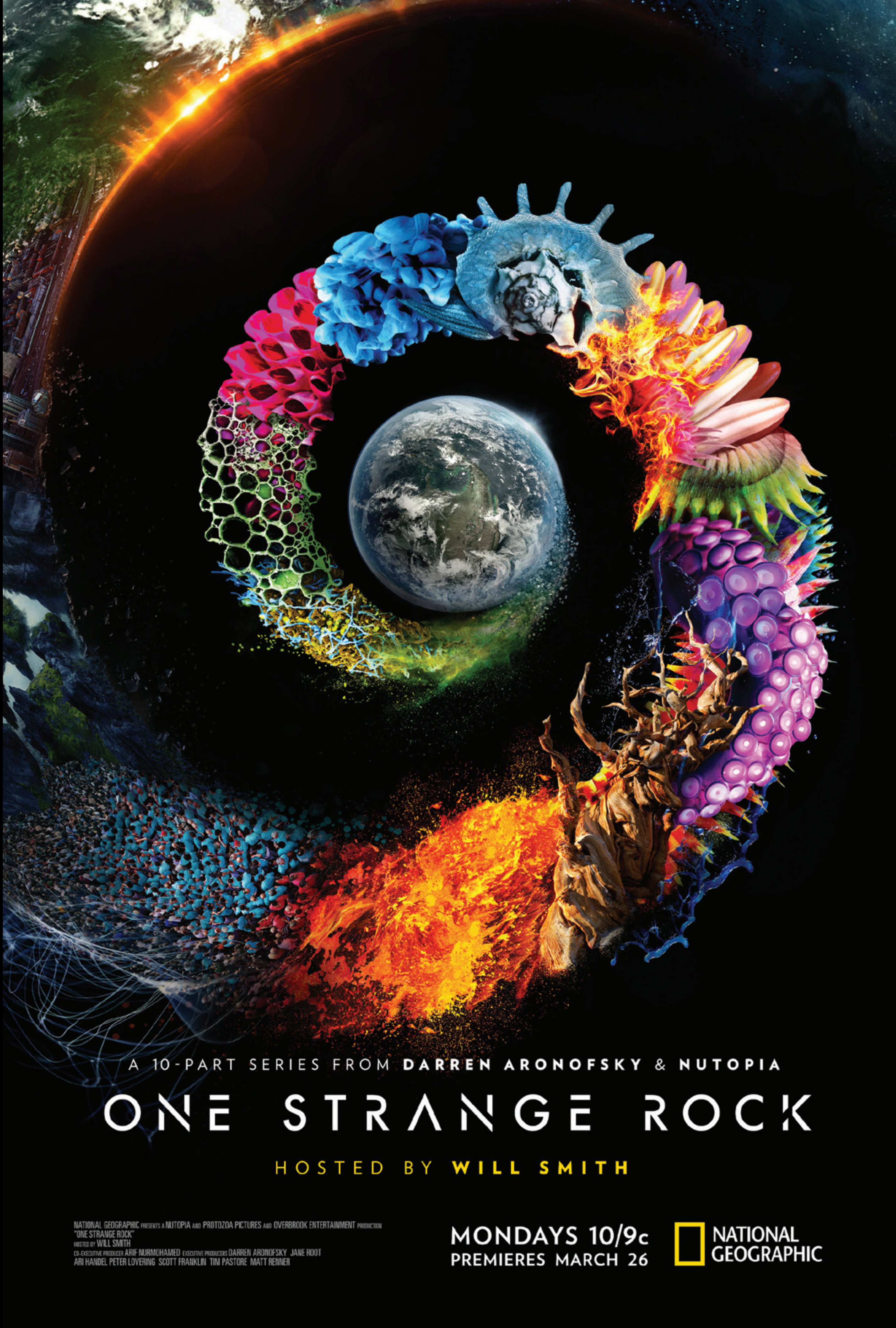
Curriculum Guide



JOURNEYS IN FILM
educating for global understanding

One Strange Rock

Curriculum Guide

Journeys in Film

www.journeysinfilm.org

JOURNEYS IN FILM
educating for global understanding

NUTOPIA AND PROTOZOA PICTURES AND
OVERBROOK ENTERTAINMENT PRODUCTION

NATIONAL GEOGRAPHIC

Educating for Global Understanding

www.journeysinfilm.org

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JOURNEYS IN FILM™
educating for global understanding

About *Journeys in Film*

Founded in 2003, ***Journeys in Film*** operates on the belief that teaching with film has the power to prepare students to live and work more successfully in the 21st century as informed and globally competent citizens. Its core mission is to advance global understanding among youth through the combination of age-appropriate films from around the world, interdisciplinary classroom materials coordinated with the films, and teachers' professional-development offerings. This comprehensive curriculum model promotes widespread use of film as a window to the world to help students to mitigate existing attitudes of cultural bias, cultivate empathy, develop a richer understanding of global issues, and prepare for effective participation in an increasingly interdependent world. Our standards-based lesson plans support various learning styles, promote literacy, transport students around the globe, and foster learning that meets core academic objectives.

Selected films act as springboards for lesson plans in subjects ranging from math, science, language arts, and social studies to other topics that have become critical for students, including environmental sustainability, poverty and hunger, global health, diversity, and immigration. Prominent educators on our team consult with filmmakers and cultural specialists in the development of curriculum guides, each one dedicated to an in-depth exploration of the culture and issues depicted in a specific film. The guides merge effectively into teachers' existing lesson plans and mandated curricular requirements, providing teachers with an innovative way to fulfill their school districts' standards-based goals.

Why use this program?

To be prepared to participate in tomorrow's global arena, students need to gain an understanding of the world beyond their own borders. ***Journeys in Film*** offers innovative and engaging tools to explore other cultures and social issues, beyond the often negative images seen in print, television, and film media.

For today's media-centric youth, film is an appropriate and effective teaching tool. Journeys in Film has carefully selected quality films that tell the stories of young people living in locations that may otherwise never be experienced by your students. Students travel through these characters and their stories: They drink tea with an Iranian family in Children of Heaven, play soccer in a Tibetan monastery in The Cup, find themselves in the conflict between urban grandson and rural grandmother in South Korea in The Way Home, watch the ways modernity challenges Maori traditions in New Zealand in Whale Rider, tour an African school with a Nobel Prize-winning teenager in He Named Me Malala, or experience the transformative power of music in The Music of Strangers: Yo-Yo Ma & the Silk Road Ensemble.

In addition to our ongoing development of teaching guides for culturally sensitive international films, Journeys in Film brings outstanding documentary films to the classroom. Working with the Rossier School of Education at the University of Southern California, Journeys in Film has identified exceptional narrative and documentary films that teach about a broad range of social issues in real-life settings such as famine-stricken and war-torn Somalia, a maximum-security prison in Alabama, and a World War II concentration camp near Prague. Journeys in Film guides help teachers integrate these films into their classrooms, examining complex issues, encouraging students to be active rather than passive viewers, and maximizing the power of film to enhance critical thinking skills and to meet the Common Core Standards.

Journeys in Film is a 501(c)(3) nonprofit organization.

A Letter From Liam Neeson

Working in films such as *Michael Collins* and *Schindler's List*, I've seen the power of film not only to entertain, but also to change the way audiences see themselves and the world. When I first met Joanne Ashe, herself the daughter of Holocaust survivors, she explained to me her vision for a new educational program called ***Journeys in Film: Educating for Global Understanding***. I grasped immediately how such a program could transform the use of film in the classroom from a passive viewing activity to an active, integral part of learning.

I have served as the national spokesperson for ***Journeys in Film*** since its inception because I absolutely believe in the effectiveness of film as an educational tool that can teach our young people to value and respect cultural diversity and to see themselves as individuals who can make a difference. ***Journeys in Film*** uses interdisciplinary, standards-aligned lesson plans that can support and enrich classroom programs in English, social studies, math, science, and the arts. Using films as a teaching tool is invaluable, and ***Journeys in Film*** has succeeded in creating outstanding film-based curricula integrated into core academic subjects.

By using carefully selected documentary and international films that depict life in other countries and cultures around the globe, combined with interdisciplinary curricula to transform entertainment media into educational media, we can use the classroom to bring the world to every student. Our film program dispels myths and misconceptions, enabling students to overcome biases; it connects the future leaders of the world with each other. As we provide teachers with lessons aligned to Common Core Standards, we are also laying a foundation for understanding, acceptance, trust, and peace.

Please share my vision of a more harmonious world where cross-cultural understanding and the ability to converse about complex issues are keys to a healthy present and a peaceful future. Whether you are a student, an educator, a filmmaker, or a financial supporter, I encourage you to participate in the ***Journeys in Film*** program.

Please join this vital journey for our kids' future. They are counting on us. ***Journeys in Film*** gets them ready for the world.

Sincerely,

Introducing *One Strange Rock*

Narrated by astronauts, the only persons to have had the opportunity to see our home planet from space, the National Geographic documentary *One Strange Rock* addresses a very fundamental question raised by humankind's exploration of the Cosmos: Why is the Earth, the third rock from the sun, so very different from the rest of our solar system?

This documentary tells the story of Earth's history as seen from a planetary perspective. Within our solar system, planet Earth is utterly unique among the planets, moons, and dwarf planets found there. The inner four planets are rocky, and the four outer planets are large gaseous bodies, with little or no true surface on which to stand. Pluto, with its solid surface made of methane, rocky debris, and water ice, is now relegated to the status of a "dwarf" planet and appears to have been captured by the sun's gravity. Only Earth has a breathable atmosphere, the ability to "heal" itself following planetary bombardment in its early history and more recent "extinction events," and very large amounts of liquid water on its surface.

Earth is unique because this is where life has developed and is sustained. The evolution of life over time has terraformed a once barren rock into a paradise perfect for life. The past and present state of the Earth's biosphere has made our home planet into our only home. *One Strange Rock* tells Earth's story from its very violent and fiery beginning, 4.5 billion years ago, through the development of microbial life 3.9 billon years ago, to its present state, hosting millions of living species. Fasten your seat belts—you and your students are in for a very exciting and educationally stimulating ride.

The *One Strange Rock* documentary consists of 10 episodes, each 50 minutes long, ideal for use in multiple class periods or as potential homework assignments. The documentary draws on the experiences and individual stories of eight astronauts who bring insight and emotion to the telling of the Earth's amazing story. A dynamic mix of exciting new science and dramatic videography, *One Strange Rock* weaves a compelling case for the way our space program has revolutionized our understanding of the Earth and of our place in the universe.

The documentary begins with an episode entitled ***Gasp***, which describes the role of microbes in the development of our present atmosphere, as well as the role of diatoms and green plants in a delicate balancing act. ***Storm*** tells the story of how the Earth has "healed" itself following the cosmic bombardment of the early accretionary period of development, as well as following the five major extinction events of the more recent past. ***Shield*** describes the many ways the Earth shields life from the harmful effects of the sun (the protective ozone layer, the magnetic field deflecting the solar wind, the warming effect of greenhouse gases, natural and anthropogenic). ***Genesis*** discusses the role that liquid water has played in the development of organic chemicals and eventually of microbes. ***Alien*** focuses on the "Cambrian explosion" and its role in the dramatic evolution of complex plants and animals, and eventually, the invasion of the land. ***Survival*** emphasizes that the Earth is all about recycling, from subduction and seafloor spreading zones and plate tectonics and volcanoes to the life cycles (birth, growth, and death) of all living things. ***Awakening*** addresses the current understanding of how life and our strange rock combined, through almost impossible coincidences, to create consciousness. ***Terraform*** addresses how the three things needed for life (an energy source, liquid water, and organic compounds) have evolved from barren rocks, all thanks to microbes. The episode ***Escape*** highlights how we have made limited attempts to leave our planet (the *Apollo* moon mission, long-duration stays aboard the International Space Station, etc.), as well as just how alien our neighboring planets are. Finally, ***Home*** focuses on the uniqueness of the Earth and the tremendous diversity of the life forms that inhabit it, as well as how seeing the Earth from the moon triggered efforts to promote environmental efforts to protect our planet.

The stunning photography, the commentary by real astronauts, and the sheer majesty of the subject in this documentary will provide your students with a remarkable learning opportunity.

Film credits:

NATIONAL GEOGRAPHIC PRESENTS

A NUTOPIA AND PROTOZOA PICTURES AND OVERBROOK ENTERTAINMENT PRODUCTION

"ONE STRANGE ROCK"

HOSTED BY WILL SMITH

CO-EXECUTIVE PRODUCER ARIF NURMOHAMED EXECUTIVE PRODUCERS DARREN ARONOFSKY JANE ROOT

ARI HANDEL PETER LOVERING SCOTT FRANKLIN TIM PASTORE MATT RENNER

For National Geographic

CEO: Courteney Monroe

EVP, Global Communications and Talent Relations: Chris Albert

Specialist, Education Initiative, Communications: Tracy Smith

To the Teacher

Journeys in Film lessons were designed to support and amplify the many stimulating educational opportunities and concepts raised by the *One Strange Rock* documentary. No single lesson is matched to any one episode, but rather, each lesson addresses several of the themes introduced by the documentary. However, here are some suggested lesson/episode pairings.

Lesson 1. A Tour of the Solar System, a slide presentation (with text) is essential to understanding the key *One Strange Rock* message: The Earth is unique compared with all the other planets. (Episodes: *Storm, Home, Shield*)

Lesson 2. The Goldilocks Planets, also a slide presentation (with text) essential to understanding how fundamentally different Venus and Mars are from the Earth. This lesson allows students to explore Mars and Venus using online *Google Maps* tools. (Episodes: *Storm, Home, Survival, Shield*)

Lesson 3. The Soil Is "Alive": The GAIA Hypothesis, uses hands-on qualitative field methods that show students that soil is alive. (Episodes: *Home, Terraform*)

Lesson 4. Mighty Microbes, supports episodes highlighting the role microbes have played in the creation of the atmosphere and the development of life. (Episodes: *Survival, Terraform, Awakening, Genesis*)

Lesson 5. The History of Life, the changing life forms over time. (Episodes: *Survival, Terraform, Awakening, Genesis, Alien*)

Lesson 6. Seeing Earth From Space, a creative writing approach to seeing the Earth after a student-based mission to Mars. (Episodes: *Escape, Home, Gasp*)

Lesson 7. The History of the Space Program, a hands-on review of how we launched human missions to orbit, the moon and beyond. (Episodes: *Escape, Home, Survival, Terraform*)

Lesson 8. The Air We Breathe, a detailed look at our atmosphere and how humans are now changing its chemistry. (Episodes: *Home, Survival, Terraform, Shield, Gasp*)

For more information about this and other free ***Journeys in Film*** curriculum and discussion guides, please see the ***Journeys in Film*** website at www.journeysinfilm.org.

A Tour of the Solar System

Enduring Understandings

- Planet Earth is unique when compared with the rest of the solar system.
- No two planets in the solar system are alike; we know this thanks to the National Aeronautics and Space Administration (NASA), the European Space Agency (ESA), and our enduring quest for knowledge.
- We must appreciate our home planet and take care of it.

Essential Questions

- How does our remote sensing technology reveal the wonders of our solar system?
- Could life as we know it exist on any of the other inner planets (Mercury, Venus, and Mars)?
- How does the exploration of our solar system allow us to better understand our place here on planet Earth?
- In our solar system, how common are the essential precursors of life, such as liquid water, an energy source, and basic chemical building blocks (carbon, nitrogen, hydrogen, and others)?
- Are we alone in the universe?

Notes to the Teacher

This lesson is designed to give your students an understanding of the incredible variations in the planets and moons of the solar system. We have now sent spacecraft to all of the eight planets and Pluto (now classified as a dwarf planet) within our solar system and have discovered that no two are alike and that none of them are anything like the Earth. This lesson is intended to create a sense of wonder and awe in your students and to stimulate a lot of questions that will trigger very active discussions both in the classroom and out.

The episodes from *One Strange Rock* that are most relevant to this lesson are "Storm," "Home," and "Shield." You should plan on showing as many of these episodes as time permits during the lesson. Alternatively, you could use one as an introduction to the lesson and show one or two more while students are working on their research on individual planets.

This lesson has been built around a slideshow of 45 slides, each tied to a numbered script; slide #1 goes with text #1, etc., providing the teacher with some basic facts about each planet. The only moon included here is Titan, one of Saturn's many moons (62 and counting), the largest moon in the solar system, and one that may hold answers regarding how the Earth may have formed. The lesson also focuses on several spacecraft missions to the inner and outer planets, as well as Pluto (Magellan, MESSENGER, Voyager, Cassini, Galileo, Juno, New Horizons, and others). Lesson 7, The History of the Space Program, may be a useful companion lesson. The most important message to be gained from this lesson is that the Earth is unique among the other planets because life developed and evolved here. It is truly One Strange Rock.

Before the lesson begins, review the slideshow in Appendix 1 of this guide and decide which slides to use. You may feel the 45 slides are too many for your particular grade level or class; if so, make a selection. You may also want to add some of your own slides. You should also decide how many class periods you wish to use to present the slides. You may decide to make copies of the relevant section of text from **Teacher Resource 1** for use by the students.

In addition to watching the slide presentation, students select a specific planet or moon to investigate more thoroughly and present a report to the class giving a more detailed description of their planet or moon. **Handout 1** provides a research organizer to help students begin this project. You may also devote a class period (or more) to questions regarding life on other planets or in the universe, citing lines of evidence for or against. Finally, the space program continues to make new and exciting discoveries almost every week, many of which are reported in the news. Keep alert for the latest discoveries. Many resources from NASA and ESA useful to supplement this lesson can be found online using Google or similar search engines.

Before the lesson, review the slides and the accompanying text material provided for each slide. The text provided is not intended to cover everything, but rather to give an interesting overview of each planet, how the solar system was formed, and why the four inner "terrestrial" planets differentiated and separated themselves from the four outer "gas body" planets. Certainly, several of the National Geographic episodes from *One Strange Rock* will serve as an exciting and dramatic resource for this lesson. Consider providing one or both of the "Tour of the Solar System" text and the slide presentation online for your students.

Several recent films (*Hidden Figures, The Martian*) and documentaries can also be included in class discussions to make this lesson relevant and timely. National Geographic also has a *MARS* series with comprehensive curriculum support materials on the ***Journeys in Film*** website (www.journeysinfilm.org). NASA is preparing for a mission to Mars in the mid-2030s, so ask your students if they would like to become an astronaut in time to be selected as a crewmember. Make this lesson exciting.

Note that Lesson 2 of this guide, "The Goldilocks Planets," provides a set of handouts that allow students to explore Mars and Venus using *Google Mars* and *Google Venus* online tools. You may wish to use one or both of these for a more in-depth student investigation of the Earth's twin and the red planet. If you decide to use these, start with *Google Mars* because the online tool is more fully developed and user-friendly. *Google Mars* also provides topographic data, as well as both visible and infrared data options. In the Google Mars exercise, students explore for evidence of past liquid water on Mars, conduct crater counts to identify the relative age of different Martian surfaces, and speculate about whether Mars ever had tectonic activity similar to Earth's. *Google Venus* provides fewer online options and will work best if the students have completed *Google Mars* first.

Next Generation Science Standards (NGSS) addressed by this lesson

MS-ESS1-2.
Develop and use a model to describe the role of gravity in the motions within galaxies and the solar system. Clarification Statement: Emphasis for the model is on gravity as the force that holds together the solar system and Milky Way galaxy and controls orbital motions within them. Examples of models can be physical (such as the analogy of distance along a football field or computer visualizations of elliptical orbits) or conceptual (such as mathematical proportions relative to the size of familiar objects, such as students' school or state). Assessment Boundary: Assessment does not include Kepler's Laws of orbital motion or the apparent retrograde motion of the planets as viewed from Earth.

MS-ESS1-3.
Analyze and interpret data to determine scale properties of objects in the solar system. Clarification Statement: Emphasis is on the analysis of data from Earth-based instruments, space-based telescopes, and spacecraft to determine similarities and differences among solar system objects. Examples of scale properties include the sizes of an object's layers (such as crust and atmosphere), surface features (such as volcanoes), and orbital radius. Examples of data include statistical information, drawings and photographs, and models. Assessment Boundary: Assessment does not include recalling facts about properties of the planets and other solar system bodies.

Science and Engineering Practices
Developing and Using Models
Modeling in 6–8 builds on K–5 experiences and progresses to developing, using, and revising models to describe, test, and predict more abstract phenomena and design systems.

- Develop and use a model to describe phenomena. (MS-ESS1-1), (MS-ESS1-2)

Analyzing and Interpreting Data
Analyzing data in 6–8 builds on K–5 experiences and progresses to extending quantitative analysis to investigations, distinguishing between correlation and causation, and basic statistical techniques of data and error analysis.

- Analyze and interpret data to determine similarities and differences in findings. (MS-ESS1-3)

Disciplinary Core Ideas
ESS1.A: The Universe and Its Stars
- Patterns of the apparent motion of the sun, the moon, and stars in the sky can be observed, described, predicted, and explained with models. (MS-ESS1-1)
- Earth and its solar system are part of the Milky Way galaxy, which is one of many galaxies in the universe. (MS-ESS1-2)

ESS1.B: Earth and the Solar System

- 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. (MS-ESS1-2),(MS-ESS1-3)
- The solar system appears to have formed from a disk of dust and gas, drawn together by gravity. (MS-ESS1-2)

Duration

Four to eight class periods

Assessment(s)

Brainstorming before the slide presentation

Class discussions

Student or group project and presentations

Materials needed

The "Tour of the Solar System" slideshow (available in Appendix 1 of this guide)

Teacher Resource 1 (the accompanying numbered text for use with the slideshow)

Whiteboard or overhead

Computers with Internet access

Access to *One Strange Rock* documentary, especially one or more of the following episodes as time permits: "Storm," "Home," "Shield"

Handout 1: Beginning Your Research

Procedure

1. Explain to students that they are going to view part of a documentary from National Geographic entitled *One Strange Rock*. Ask students to brainstorm: Why would a series of films about the planet Earth be called by that title? Ask them to consider what is "strange" about our planet and why it is called a "rock" when 70 percent of the planet's surface is covered with water. Ask if they think there is life on other planets. How many think UFOs are real?

2. Show the images you have selected from the slideshow "A Tour of the Solar System." Use the numbered text descriptions as prompts for presenting the images. Take your time, stopping whenever necessary for students to ask questions. Use the chalkboard to list any words with which students seem unfamiliar, so that you can come back and review them later.

3. If you have decided to make copies of the descriptions for use by the students (see Notes to the Teacher above), distribute these copies for review after you have shown the slides.

4. Hold a class discussion of the materials covered in the slide presentation. Some possible questions to start the discussion are:
   - What qualities differentiate the planets from one another?
   - What features of the planets surprised you?
   - What is the interior of the planet Earth like? How does this affect its surface?
   - Which other planets might be habitable, based on what you know now?
   - How do scientists gather information about planets that are at such a great distance?
   - Do you think it will be feasible for humans to travel to more distant planets some day? Why, or why not?

5. Show the *One Strange Rock* video(s) that you have selected for use with this class.

6. Distribute **Handout 1: Beginning Your Research.** If desired, organize students into groups and assign a planet to each group. You may also wish to have students work independently.

7. Give students sufficient time, either during class or for homework, to find the most current and comprehensive knowledge about the planet. In conclusion, they should answer the question: Could life have developed on the planet they select? They should cite lines of evidence supporting their answer to the question, based on lessons learned from the *One Strange Rock* documentary.

8. Provide the opportunity for students and student groups to present and discuss their findings about their planet to the class, either through oral, PowerPoint, or poster presentations.

A Tour of the Solar System—Text

The following text is designed to accompany a slide presentation entitled "A Tour of the Solar System." This presentation was developed to provide students with the understanding that planet Earth is truly unique among the eight planets in our solar system. The reason for this uniqueness is that life is present only on this "One Strange Rock," the third "rock" from the sun. The National Geographic program *One Strange Rock* will present this concept in very dramatic form, through the perspective of astronauts who have had the experience of viewing our planet from space. This slideshow will allow your students to fully understand just how strange our home planet really is.

Slide	Descriptive Text
1, 2, 3.	The first three slides show a graphic illustration of the members of our solar system, including the inner four terrestrial planets (Mercury, Venus, Earth, and Mars) and the four outer planets (the giant gas bodies of Jupiter, Saturn, Uranus, and Neptune). The inner four are called terrestrial planets because they are rocky and have a surface we could stand upon. The outer four are mostly atmosphere and don't have any known solid surface to stand on. Due to the differentiation process that occurred as the initial planetary disk was being formed, the heavier elements accreted into the solid planets formed nearest the infant sun, while the lighter gaseous elements formed the massive gas bodies. A very recent discovery now indicates that Uranus and Neptune have significant amounts of water, ammonia, and methane ices, and they are called "ice giants." Slide 1 shows the illustration, while slides 2 and 3 add the terms "terrestrial planets" (Slide 2) and "gas giants" (Slide 3).
4.	The planetary disk (sometimes called a planetary nebula), the initial appearance of the early sun in the middle and proto-planets being formed from the accretion of interstellar dust, the heavier dust particles being pulled closer to the sun, and the lighter elements farther away from the sun. This accretionary period in the formation of the primitive Earth is dramatically presented in the *One Strange Rock* episode called "Storm."
5, 6.	Two slides showing images of our sun both with and without sunspots (Slide 5), representing a solar maximum (lots of sunspots) and solar minimum (few if any sunspots) of a typical solar cycle (Slide 6). A period of 11 years (more or less) occurs between one solar max and the next solar max. A solar max represents the time when the greatest amount of solar energy is coming from the sun, while a solar min is when the least amount of energy is coming from the sun.
7.	This slide presents the long-term record of sunspot activity between 1609 and 2007. The next slide will give us sunspot activity up to 2015. Ask your students if they know who was measuring and counting sunspots in 1609. The answer is Galileo, who discovered sunspots in 1609 using his primitive telescope and projecting the image onto paper. Slide 7 shows both the Maunder Minimum (a period between 1645 and 1715 when no sunspots were recorded by astronomers) and the Dalton Minimum (when the solar maxes between 1800 and 1825 were weaker than the previous and the following ones). No one knows why either of these periods of very weak solar output occurred. It is important to note that there are significant variations in solar maxima, and these are known to influence our weather (warmer periods during higher solar maxima, cooler during periods of lower ones). As we will see in the next slide, that connection between solar maxima and global weather is not seen in the current debate over causes of global warming.

Teacher Resource 1 ▸ p. 2

A Tour of the Solar System—Text

8.	The solar cycles since the end of the Maunder Minimum have been counted, and our current cycle is #24. Solar cycles 22, 23, and 24 are shown in Slide 8. Note that since 1990, each solar max has been recording fewer sunspots; the current solar max in 2014 had only about 100 sunspots, while cycle 23 had approximately twice as many. We should be seeing lower global temperatures, but temperatures since 1990 have been at record highs (Data recorded since 1890, when accurate temperature records begin).
9.	The solar wind is the term applied to the constant stream of charged high-energy particles (mostly electrons and protons) coming from the corona, the upper atmosphere of the sun. These particles, also called solar wind plasma, escape the sun's gravity and flow outward in all directions. Slide 9 is an artist's conception of how solar wind interacts with the Earth's own magnetic field. Note that the diagram is not to scale, since the Earth is 93,000,000 miles from the sun, not next to it. Also note how much of the solar wind is deflected past the Earth, protecting it from constant bombardment by the solar wind. The Earth's strong magnetic field is thought to be due to the differential rotation of the core, relative to the planet's rotation, creating a dynamo effect. Mercury is not known to have a magnetic field, and Mars has only a very weak magnetic field.
10.	A more detailed diagram illustrating how some solar wind particles are actually attracted to the North and South Poles of the Earth, following the planet's magnetic lines of force. Under certain seasonal conditions, these charged particles interact with atoms in the Earth's atmosphere, creating the aurora borealis and aurora australis (northern and southern lights).
11.	An example of the aurora borealis, or northern lights. Most of the other planets also exhibit auroras. Mercury is the exception.
12.	The planet Mercury looks much more like our moon than any other planets in the solar system. Heavily pock-marked by impact craters, Mercury is the smallest of the eight planets and the closest to the sun. Mercury is unusual in that it has no moons. It was named for the swift Roman messenger of the gods because it moves quickly around the sun (orbits in 88 days). Mercury is small (only slightly larger than our moon) but is very dense. There have been four spacecraft to visit Mercury; the first, Mariner 10, made a 1974 fly-by, and most recently MESSENGER orbited the planet in 2008. It has a very thin atmosphere and a surface temperature that ranges from hot (427° C) on the sunlit side to cold (minus 180° C) on the night side. No spacecraft have landed on Mercury because no spacecraft would be able to survive such dramatic temperature shifts.
13.	A cutaway view of the likely interior of Mercury. Because it is so dense, it must have a large solid core, likely composed of iron and other heavy metals. It also must have a dense solid mantle, perhaps made of silicon and aluminum, similar to granite found on Earth.
14.	One of MESSENGER's primary orbital missions was the use of imaging radar to map the topography of Mercury. The result is a topographic map like the one shown in Slide 14, in which highest terrain is false-colored red, while the lowest is blue. MESSENGER stands for "Mercury Surface, Space Environment, Geochemistry and Ranging." Ask your students why else it might have been named MESSENGER.

Teacher Resource 1 ▸ p. 3

A Tour of the Solar System—Text

15.	Venus has a very dense atmosphere composed mostly (98 percent) of carbon dioxide (CO_2) and is a great example of a runaway greenhouse planet. Due to the amount of CO_2, a powerful greenhouse gas, the temperature on Venus is nearly twice (432° C) that of the average temperature of Mercury (147° C), even though it is farther away from the sun. (Venus is the second planet from the sun). Venus' cloud cover is so dense that telescopes on Earth have never seen its surface. We now can see through its dense atmosphere using a synthetic aperture imaging radar on an orbiting spacecraft called Magellan, launched in 1989. Because of its bright clouds, Venus is very bright when seen by naked eye from Earth. Because it is so close to the sun, it is often thought of as either a bright "evening star" or a "morning star," seen at either sunset or sunrise. Of course, it is a planet and not a star.
16.	Here is what the Magellan spacecraft saw once its radar penetrated Venus' dense atmosphere. The colors seen in the radar image are false color, since radar images are black and white. The lighter yellow areas are the smoothest surfaces, while the darker orange, brown, and black areas are increasingly rougher (likely mountains and craters). Most of the craters seen are volcanoes, although there are also some impact craters. With such a dense atmosphere, few meteors make it to the surface.
17.	The interior of Venus, inferred from its density and measurements of anomalies in its mass, as determined by the Magellan spacecraft.
18.	*Maat Mons*, a large volcano on the surface of Venus, is more than a mile high; this 3-D radar image gives a sense of vertical relief. Again, the yellow color is a smooth lava flow, and the brown color represents rougher terrain.
19.	A size comparison of Venus and Earth. Venus is seen by radar looking through its dense sulfuric acid clouds. Venus is hot (more than 800° F) and rains acid rain. Hardly a twin. Venus is the first of the three "Goldilocks planets," because it is in what scientists call the "habitable zone," where life as we know it could exist. However, Venus is much too hot for life, largely because water could not exist in a liquid state.
20.	The planet Earth, as seen from Apollo 17 on December 7, 1972. How different Earth is from Venus. Ask your students why Earth is so different. The answer is because life exists here, and life has modified the primitive Earth to become more habitable, one of the characteristics of life. Water occurs as a liquid on the surface of Earth and as an aerosol and as water vapor in Earth's atmosphere, and water is essential for life. The average temperature on Earth (61° F, or 16° C) is perfect for life as we know it and is moderated largely by trace gases in the atmosphere, such as CO_2 and water vapor, both strong greenhouse gases. Finally, thanks to plants and photosynthesis, aerobic life is supported by an oxygen-rich atmosphere (78 percent nitrogen, 21 percent oxygen, and one percent trace gases). As the second Goldilocks planet, Earth is just right for life.
21.	The interior of Earth is quite well known, not because we have visited the interior, but from the study of earthquakes. By studying the way in which seismic waves, created by earthquakes, travel through the Earth, we now know that the interior is layered, with a thin outer crust, a thick mantle, some of which is fluid, an outer core that appears to be semi-fluid, and a small solid inner core, likely composed of iron and nickel. Who knew earthquakes could be so useful?

A Tour of the Solar System—Text

22.	The surface of the Earth exhibits many volcanic eruptions (50–60 per year, or roughly one per week), which, along with continental drift, are part of a massive recycling process called plate tectonics. New crust is created at mid-ocean spreading zones, and old crust is subducted (pulled down and melted) along the edges of some continents (for example, the Pacific Coast of the Americas). Most of the Earth's volcanoes occur at either the spreading zones or the subduction zones.
23.	On to Mars. Mars is the third Goldilocks planet, often called the red planet because of the amount of red dust in its thin atmosphere. Even from the Martian surface, NASA's Mars rovers have imaged the sky as reddish or orange. The surface color red is due to a very fine reddish dust layer over essentially all surfaces. The dust is red due to ferric (iron) oxide particles. There is no liquid water found on the surface, although there has been some evidence of subsurface water, likely in the form of water ice. The image of Mars seen in Slide #23 shows a polar ice cap made up of water ice and dry ice (frozen CO_2).
24.	This image, as seen from Mars orbit, shows the planet's thin atmosphere. The Martian atmosphere is approximately 100 times thinner than that of Earth and is made up mostly of CO_2 (95 percent). Although CO_2 is a greenhouse gas, the atmosphere is so thin that there is not enough of it to warm the planet. The average temperature on Mars is approximately minus 60° C. Mars is a small planet compared with Venus and Earth and doesn't have enough gravity to keep a thicker atmosphere. In addition, Mars lacks a global magnetic field that would protect the surface from the charged particles of the solar wind, further eroding its thin atmosphere. Mars is too cold.
25.	The interior of Mars suggests a simpler layering than Earth's, with a thin crust, thick mantle, and large solid core. There is some evidence to indicate limited plate tectonics may have occurred on Mars in the distant past, including the occurrence of volcanoes, such as *Olympus Mons*. There is also evidence that Mars once had surface water and perhaps a lot of it, including the presence of *Valles Marineris*, a massive canyon longer than the United States is wide.
26.	The volcano *Olympus Mons* on Mars. It is the largest known volcano in the solar system, over 13 miles high. It is a shield volcano, similar to the types of volcanoes in Hawaii, but much larger. Shield volcanoes typically produce smooth lava.
27.	*Valles Marineris* is a very large canyon that provides evidence that at a time in the distant past, large amounts of liquid water flowed on the surface of Mars. Note the typical dendritic patterns typical of streams flowing into the canyon proper.
28.	NASA's Mars rover Curiosity was launched on November 26, 2011, and landed on Mars on August 6, 2012. It carries a complete science lab that has analyzed many samples of the Martian "soil" and sub-surface. Curiosity has traveled along the rim of Gale crater for the past five years, looking for evidence of microscopic life on the red planet. It even has a 10× microscope on board.

A Tour of the Solar System—Text

29.	In 1977, NASA launched two deep space probes called Voyager to study the outer planets (Jupiter, Saturn, Uranus, and Neptune), in a mission termed the "Grand Tour." Although these outer planets had been studied extensively using telescopes, this mission would be the first to actually visit each of these planets and some of their moons. At the time, Carl Sagan, a famous astronomer, championed a plan to include a gold record carrying greetings (in many languages) from the people of planet Earth as well as many photographs of life and landscapes as part of the payload of each Voyager.
30.	A montage of the four outer planets and some of their moons that the two Voyager spacecraft have visited during the 35-year-long Grand Tour. Both Voyagers have now left our solar system and are exploring interstellar space. Each spacecraft carried a range of instruments to make images of the planets visited, creating amazing close-ups and revealing many new moons and rings as well as and measuring unknown magnetic fields and atmospheric chemistry. The discoveries made by the Voyager mission have led to new missions to these outer planets, including the Galileo mission to orbit Jupiter, the Cassini mission to Saturn, and the New Horizons mission to the dwarf planet Pluto (not visited by Voyager).
31.	Jupiter, the largest planet in our solar system, is a gas giant–mostly atmosphere, with perhaps a small rocky core. Due to its size and reflective clouds, it is the third brightest object in the night sky, after Venus and the moon. Although this image is from the Hubble Space Telescope, the Voyager mission gave us our first close-up images of Jupiter and its moons. The Great Red Spot, seen as orange in this image, is a large storm in Jupiter's upper atmosphere, first seen and described by Giovanni Cassini in 1665, making it over 400 years old. Jupiter is known to have at least 69 moons, some very small. The four largest moons were described by Galileo and are thus called the Galilean moons (Ganymede, Europa, Calisto, and Io). Jupiter also has a very thin ring. Europa has an icy surface and possibly a liquid water ocean beneath. The most recent NASA mission to Jupiter is Juno, arriving in orbit on July 4, 2016. The next space mission will be launched in 2022 by the European Space Agency (ESA) and will study the icy moons (including Europa).
32.	A Voyager close-up image of Jupiter's Great Red Spot. The Great Red Spot is larger than the diameter of the Earth. The colors seen in this image tell us about the chemical composition of the atmospheric gases found in the planet's upper atmosphere (74 percent hydrogen, 25 percent helium, and one percent trace gases). Note the turbulent nature of the atmospheric bands as they slide past one another.
33.	An amazingly beautiful image of the turbulent atmospheric clouds on Jupiter, as acquired by the Juno spacecraft in December of 2017. Could an artist do a better job?
34.	Saturn as seen by Voyager in a fly-by of the planet. Prior to the Voyager mission, Saturn was thought to be the only planet with a ring system, but now we know that Jupiter, Uranus, and Neptune also have rings, although very faint ones. Saturn is very similar to Jupiter in having bands of upper atmospheric clouds, and it is also similar in chemical composition. Saturn is a gas giant and the second largest planet in our solar system, next in size to Jupiter. Like Jupiter, Saturn has a strong magnetic field and thus must have a solid inner rocky core, surrounded by both metallic and liquid hydrogen. Saturn has at least 62 moons, including Titan, the largest moon in the solar system.

Teacher Resource 1 ▸ p.6

A Tour of the Solar System—Text

35.	A Voyager image of some of Saturn's rings. The recent Cassini mission to Saturn has allowed scientists to gain a much better understanding of Saturn's ring system. The rings are now known to be made up of mostly water ice particles, ice produced by some of Saturn's icy moons that have ice volcanoes, or geysers. These volcanoes or geysers appear to be providing the ice particles that make up the rings. This is very new information, just over a decade in the making, and comes to us from the Cassini mission scientists at NASA's Jet Propulsion Lab in Pasadena, California.
36.	Titan, Saturn's largest moon, and the largest moon in our solar system. Titan is approximately the same size as Mercury. Launched in 1997, the Cassini spacecraft that went into orbit around Saturn carried a lander called *Huygens*, developed by the European Space Agency (ESA). The *Huygens* lander was designed to parachute through the dense atmosphere of Titan, sampling the atmospheric composition and landing on the surface in 2005.
37.	A Cassini image of the atmosphere of Titan. Prior to the Cassini mission, scientists knew that Titan had a nitrogen-rich atmosphere, based on its spectral properties, but now the *Huygens* lander would pass through the atmosphere and actually sample it on the way down to the surface. Now we know that Titan has lakes and seas made up of liquid methane and ethane, with dendritic surface features that look like rivers. Titan is a hydrocarbon-rich world unlike any other planet or moon in the solar system. Remember, Earth's atmosphere is nitrogen-rich (78 percent).
38.	These are images taken as the *Huygens* lander parachuted down through Titan's atmosphere, indicating the landscape of Titan. Notice the apparent river system in the left-hand image and the open liquid of methane or ethane lakes or seas seen in both images. The circles represent the approximate location of the landing site. Can you believe that these are images of the surface of one of Saturn's moons?
39.	A further enlargement of the landing site (on the left) and an image of the surface of Titan. Notice that the apparent "rocks" have rounded edges. What does that tell you about how they were formed? These "rocks" are actually water ice.
40.	An artist's conception of the surface of Titan, along with the *Huygens* landing craft. Note the parachute shroud lines and the parachute in the upper left. Also note that all the blocks of water ice (determined by spectral analysis by the lander's multispectral camera) are rounded. The lander not only survived the descent to the surface, it continued to operate, snapping images and analyzing the chemistry of the surface materials for over an hour, until its batteries failed. Absolutely amazing.

Teacher Resource 1 ▸ p.7

A Tour of the Solar System—Text

41.	On to Uranus and some of its moons. Uranus is the third largest planet (after Jupiter and Saturn) in the solar system. Uranus and Neptune are giant gas bodies, but, unlike Jupiter and Saturn, they now appear to have large volumes of solid ice in and below their clouds. The latest term for this type of planet is "ice giant." The clouds are mainly hydrogen and helium (like those of Jupiter and Saturn), but the ice found is mostly water ice, as well as ammonia (NH_4) and methane (CH_4) ices. A solid icy core may also be found in both planets. As shown in this Voyager image of Uranus, the planet rotates on its side, as indicated by the position of its equatorial ring. All of the other seven planets rotate essentially vertically. It is speculated that Uranus had a very close encounter with another body passing near enough to it to knock it off its original vertical axis.
42.	As noted in the description of Uranus, Neptune is an ice giant and is the fourth largest planet based on diameter. Neptune is the eighth planet from the sun and has atmospheric bands that appear blue in this Voyager image, due to the relatively high levels of methane in its upper atmosphere. Neptune has 14 known moons and three rings, all discovered by the Voyager mission.
43.	Now, let's talk about Pluto and the NASA New Horizons spacecraft, which traveled for nearly 10 years to reach the dwarf planet just to do a fly-by in July of 2015. During the fly-by, the spacecraft worked perfectly, snapping images and scanning the spectral characteristics of Pluto's surface features. Pluto has surprised scientists in many ways.
44.	Because it was a fly-by, only one side of the dwarf planet was studied, but it was enough to rewrite our understanding of what Pluto was made of. The most obvious feature on the side imaged is a large, white, heart-shaped area called *Sputnik Planitia*, composed largely of nitrogen ice. The mountains surrounding *Sputnik Planitia* are made of water ice. A closer look shows more surprises. New Horizons also collected data from Pluto's large moon Charon during the fly-by.
45.	The nitrogen ice of *Sputnik Planitia* is seen to consist of polygonal blocks, which on closer inspection appear to exhibit ripples, similar to sand dunes, but obviously not made of sand. As noted, the mountains are made of water ice. Pluto is very different from anything else seen in the solar system. It should be said that the striking differences between Pluto (small, solid, made of ices of different compositions, etc.) and the four outer gas bodies (large, mostly atmospheric gases, some with ice crystals, all with rings) add further justification to demoting Pluto to dwarf planet status. Stay tuned for many more discoveries to come from Pluto as the NASA researchers continue to wade through the massive amounts of data from this recent fly-by.

Handout 1 ▸ P. 1

Beginning Your Research

Your name ____

Other members of your group, if applicable:

____

____

Name of planet, moon, or dwarf planet you are researching: ______________________________________

Online or print resources you plan to use: (Continue on back if necessary.)

1. ____

2. ____

3. ____

How big is your planet or moon?

What is its distance from the sun or, if a moon, from the planet it orbits?

Describe its atmosphere. What is its atmospheric pressure?

Handout 1 ▸ P.2

Beginning Your Research

Describe the range of temperatures on this planet or moon.

What are its most important physical or topographical features?

When was it first discovered? By whom?

What is the origin of its name?

Handout 1 ▸ P.3

Beginning Your Research

Is there any evidence of water on its surface?

Does your planet have moons or rings? If so, what is their composition?

Could life have developed on this planet? What evidence do you have for your conclusion?

Would this planet be habitable for humans? If so, under what conditions?

The Goldilocks Planets

Enduring Understandings

- The planets Venus, Earth, and Mars are all located within the habitable zone of the solar system, and yet each is fundamentally different.
- Venus is very hot, Mars is very cold, and Earth is just right for sustaining life as we know it.
- Earth is so different because life has developed here.
- Life modifies its environment to promote its survival.

Essential Questions

- What determines conditions on each of the Goldilocks planets?
- Is there a possibility of life elsewhere in the solar system? In the universe?
- How do we learn about conditions on other planets?
- What is the evidence that Mars once had water?

Notes to the Teacher

This lesson consists of two parts: a slide presentation with accompanying text focused on the "Goldilocks planets" (Venus, Earth, and Mars) and a set of activities that provide students with hands-on introductions to both *Google Venus* and *Google Mars* online applications; there is an additional set of three slides of Mars and Venus to supplement this part if desired. Prior to using either the slideshows or the *Google Venus* and *Google Mars* handouts, review the materials and decide how much time you want to devote to each activity. The slide shows are in Appendices 2 and 3 at the end of this guide.

The *One Strange Rock* documentary consists of 10 episodes, each approximately 50 minutes long, some of which should be shown to the class as part of this lesson. The ones that link most closely to this lesson are "Storm," "Home," "Survival," and "Shield." All of these materials will certainly prompt student discussions, so factor in enough time to allow such discussions to occur.

The first slide presentation allows your students to learn about the similarities and differences of Venus, Earth, and Mars. These three planets fall within what astronomers refer to as the habitable zone of the solar system. This is the region in which life as we know it could potentially survive as determined based on the orbital distance of each planet from the sun and whether the planet possesses a greenhouse atmosphere. The slideshow begins with information about the recent discoveries of "exo-planets" that are now known to orbit stars well beyond our solar system. Nearly every week, new exo-planets are being discovered using the Kepler space telescope, a tool designed to detect tell-tale signs of such distant planetary systems. Use as much or as little of the slide presentation as you feel is appropriate for your class. Add your own ideas or knowledge as desired. Note that some of the slides overlap with the presentation in Lesson 1, so if you have taught that lesson, you may either cull those slides or repeat them as a quick review. You may wish to reproduce the slideshow text (**Teacher Resource 1**) to give to your students.

As your students will see, Venus is much too hot to sustain life, due to a runaway greenhouse effect (too much CO_2), and Mars is too cold due to its inability to keep an effective greenhouse effect. The slideshow will introduce students to what we have learned about Venus and Mars and how we know it, introducing them to the amazing discoveries made by NASA spacecraft and rovers in the past four decades. Using the *Google Venus* and *Google Mars* tools available online will allow students to explore the surfaces of both planets, studying features such as volcanoes, lava flows, mountains, and valleys, as well as using topographic data that will let them determine how liquid water may have flowed in the past. Students are asked to participate in class discussions and to submit an essay on a topic of interest.

For Part 2 of the lesson, photocopy the handouts using a color copier if possible. The images on the handouts are also available on a second slide presentation with this lesson, in case you would like to project them and discuss them with the class.

You should use *Google Mars* first, before using *Google Venus,* because the *Google Mars* online tool is more developed and more user-friendly. In addition, the spatial resolution (clarity of fine surface features) used in *Google Mars* is much better because of the large number of NASA and ESA orbital spacecraft using high-resolution cameras and multispectral (visible and infrared sensors) imagers. Also, a number of NASA rovers continue to provide exciting new data in the quest for liquid water on Mars. *Google Mars* also provides topographic data as well as both visible and infrared data options.

Google Venus, on the other hand, is far less versatile, given that there is much less data other than the low-spatial resolution *Magellan* orbital radar data available. In addition, there have been very few landers sent to Venus, and those that were successful in landing on the surface operated less than two hours, due to the very high surface temperatures (800°F). Wiring, soldering, and instruments simply melted, resulting in very little data collected and transmitted back to Earth.

If you choose to use the online *Google* tools and the many online resources, check with your tech specialist before the lesson to address any access issues specific to your school. These online resources, particularly those from NASA, are very useful to the students.

Suggested answers for both Handouts 1 and 2 can be found on the Teacher Resource Sheet following each handout.

COMMON CORE STANDARDS ADDRESSED BY THIS LESSON

CSS.ELA-LITERACY.RST.9-10.3
Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks, attending to special cases or exceptions defined in the text.

CCSS.ELA-LITERACY.RST.9-10.4
Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to *grades 9–10 texts and topics*.

CCSS.ELA-LITERACY.RST.11-12.7
Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem.

NEXT GENERATION SCIENCE STANDARDS ADDRESSED BY THIS LESSON

HS-ESS1-1.
Develop a model based on evidence to illustrate the life span of the sun and the role of nuclear fusion in the sun's core to release energy that eventually reaches Earth in the form of radiation.

HS-ESS1-5.
Evaluate evidence of the past and current movements of continental and oceanic crust and the theory of plate tectonics to explain the ages of crustal rocks.

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.

HS-ESS2-1.
Develop a model to illustrate how Earth's internal and surface processes operate at different spatial and temporal scales to form continental and ocean-floor features.

Duration of lesson

Slide presentation (two to three 50-minute class periods, allowing for discussion).

Activities using *Google Venus* and *Google Mars* (one to two class periods for each activity)

Total: four to seven class periods

Assessments

Student engagement in class discussions

Student participation in the *Google Mars* and *Google Venus* explorations and completion of handouts.

Student essays

Materials needed

Access to one or more *One Strange Rock* episodes

The slide presentations for Lesson 2 in Appendices 2 and 3 at the end of this guide.

Projector for slideshow

Photocopies of **Handout 1: *Google Mars*: Exploration of Mars** and **Handout 2: Using *Google Venus* to Explore Earth's Twin**

Student access to online resources *Google Mars* and *Google Venus*.

Procedure

Part 1: Understanding the Goldilocks planets

1. Show as many of the relevant episodes from *One Strange Rock* as time will permit. (See Notes to the Teacher for suggestions about episodes.) Allow time after each episode for questions and discussion.

2. Present the Goldilocks Planets slideshow, narrating using some or all of the text provided in **Teacher Resource 1**. Provide time as you go through the slides for students to ask questions.

3. Hold a class discussion using the material covered. Feel free to let these discussions be freewheeling. Some starter questions are:
   - Why is Venus so hot and Mars so cold?
   - Why is Earth just right?
   - Are we alone in the solar system? In the universe?
   - What have we learned about Mars from the NASA rovers?
   - Why don't we have any rover data from Venus?
   - Why isn't there any liquid water on either Venus or Mars now?
   - What is the evidence that Mars had liquid water on its surface in the past?
   - Would you be interested in being one of the crewmembers selected by NASA for the first Mars mission?

Part 2: Exploring our neighboring planets

1. Distribute **Handout 1: *Google Mars*: Exploration of Mars**. Review the directions at the beginning. If desired, project the first slide from the slide presentation on Mars and Venus to help students follow the text.
2. Have students access *Google Mars*. If you are doing this as a class and all students have computer access, have them experiment briefly with the various options available and identify the tools included with the map.
3. Assign students to work in pairs on Exercise 1: Liquid Water on Mars. When they have had sufficient time, discuss their answers with the class as a whole and clear up any misconceptions or questions. Note: Suggested answers for both Handouts 1 and 2 can be found on the Teacher Resource Sheet following each handout.
4. Have students work through Exercise 2: Determining the Relative Age of Martian Surfaces and Exercise 3: Evidence of Plate Tectonic Activity on Mars. Take time in class to have a discussion on their findings.
5. Distribute **Handout 2: Using *Google Venus* to Explore Earth's Twin.** Go through the introductory text with them to be sure they understand, and, if desired, project the second and third slides that show the images from Handout 2.
6. Have students locate the *Google Venus* website on their computers. Explain to students the limitations of the *Google Venus* program using the information in Notes to the Teacher.
7. Have students work through the questions on the handout as you circulate to help them. When they have had sufficient time to work, hold a class discussion on their findings to clear up any misconceptions or questions.
8. Have the students select one of the topics covered in this lesson, do additional research, and write an essay that explores the topic in more depth.

Teacher Resource 1
p. 1

Goldilocks Planets Slideshow Text

This text is designed to accompany a slide presentation entitled "The Goldilocks Planets." How did Earth become "just right" for the development of life as we know it? This presentation was developed to provide students with an understanding that planet Earth is one of three planets located within what astronomers call the "habitable zone" within our solar system. Venus, Earth, and Mars all occur within this zone, but Venus is much too hot (800°F), and Mars is much too cold (minus 80°F). Only planet Earth has the right mix of an energy source, liquid water, an atmosphere with the right mix of oxygen and greenhouse gases, and the organic building blocks essential for life. Evidence suggests that these three planets evolved from similar starting points (toxic atmospheres, adequate amounts of liquid surface water, rocky surfaces made up of similar minerals, etc.), but now each has evolved over time to its present state.

One of the characteristics of life is that it modifies its environment to sustain itself. The reason for Earth's uniqueness is that it is the only planet with abundant life. This is *One Strange Rock*, the third rock from the sun. The National Geographic program, *One Strange Rock*, presents the science behind the evolution of the Earth in very dramatic form, through the unique perspective of astronauts who have had the experience of viewing our planet from space. This slideshow will allow your students to more fully understand just how unique our home planet is and why it became "just right," despite all three planets probably having very similar origins.

Slide	Descriptive Text
1.	This is a graphic illustration of the members of our solar system, including the inner four terrestrial planets (Mercury, Venus, Earth, and Mars) and the four outer planets (the giant gas bodies, Jupiter, Saturn, Uranus, and Neptune). The inner four are called terrestrial planets because they are rocky and have a surface we could stand upon. The outer four are mostly atmosphere and don't have any known solid surface to stand on. Due to the differentiation process that occurred as the initial planetary disk was being formed, the heavier elements accreted into the solid planets formed nearest the infant sun, while the lighter gaseous elements formed the massive gas bodies. A very recent discovery now indicates that Uranus and Neptune have significant amounts of water, ammonia, and methane ices, and they are called "ice giants." Notice that Pluto is shown as a dwarf planet, barely visible in the lower right corner.
2.	An artist's conception of the "habitable zone" around a hypothetical star, as determined by the orbital distance from the star. Kepler-22 is a star system discovered in 2009 and confirmed in 2011, using the Kepler Space Telescope. Kepler-22 has been determined to have an exo-planet (22b) within the star's habitable zone. Kepler-22b is more than twice the size of Earth and is about 25 percent less bright. The Kepler-22 system is about 620 light years from Earth. At this point, we know nothing about Kepler-22b. Because of its estimated size and mass, it may be similar to Earth, or it may be a small gas planet.

Teacher Resource 1
p. 2

Goldilocks Planets Slideshow Text

3.	A comparison of our solar system and the Kepler-22 system, discovered to have one or more Earth-sized planets (called exo-planets) orbiting a star. The Kepler Telescope was designed specifically to detect exo-planets.
4.	The Kepler Space Telescope, launched by NASA in 2009 into an Earth-trailing heliocentric orbit (circling the sun and not the Earth). To date, the Kepler Telescope has discovered over 20 star systems with exo-planets that occur within the habitable zones of their stars. Does this mean Kepler-22b may have life?
5.	Are we alone in the universe? The Kepler Telescope is being used to detect potential Goldilocks planets outside of our solar system.
6.	Venus, Earth, and Mars were all potential Goldilocks planets when they first formed, but today only Earth is a habitable planet. In this montage, the surface of Venus is seen through its dense cloud cover by using the Magellan spacecraft's cloud-penetration imaging radar. Note that Earth and Venus are very similar in size, while Mars is much smaller.
7.	Venus seen with and without its dense cloud cover. Its surface is pockmarked with massive volcanoes (dark reddish areas), plains (orange), and lava flows (yellow areas). The very dense atmosphere is mostly CO_2 (95 percent), a powerful greenhouse gas that traps heat, creating a surface temperature that is, on average, twice as hot as Mercury's sunlit side, even though Venus is farther from the sun.
8.	The Soviet spacecraft *Venera 13* on the surface of Venus in 1982. A total of 10 *Venera* spacecraft have landed on the surface, some returning images. The partial disk-shaped object on the surface is likely a lens cap. *Venera* is the Russian word for Venus. Due to the extreme conditions (very high temperatures and 100 times the atmospheric pressure of Earth) on the surface, transmission of data failed within minutes (23) to hours (2). Note the flat, plate-like surface material, typical of a smooth lava flow.
9.	A 3-D radar image of *Maat Mons*, a mile-high shield volcano on Venus. In this false-color image, Magellan radar data were overlaid on orbital topographic data, a yellow lava flow is seen in the foreground, and the orange-brown areas are more rough surface material, possibly ash flows or chunky lava. *Ma'at* was the Egyptian goddess of truth and justice, and *Mons* is Latin for mount.
10.	A diagram presenting the likely interior of Venus, showing a thin surface crust, a thick mantle, and central core. The surface of Venus exhibits lava flows and volcanic activity but no evidence of plate tectonics. This may mean its mantle is not as convective as Earth's or that its crust is too thick to allow plates to form and move about. More about this once we discuss Earth's plate tectonics.
11.	The famous "Blue Marble" image of the Earth as seen from Apollo 17 on December 7, 1972. Clearly visible are the extensive amount of water, either in its large liquid oceans or in its atmosphere (water vapor and clouds), its multicolored land surfaces, much of which is green, and its large southern ice cap (frozen water). Venus is a very hostile world, literally a pressure cooker, when compared with Earth.

Teacher Resource 1
p.3

Goldilocks Planets Slideshow Text

12.	The interior of the Earth is much better known than the interior of either Venus or Mars. This is because of seismology, the study of earthquakes. Based on earthquake data, the interior is known to be layered, as shown in the diagram. The outermost layer is the lithosphere (*Lithos* is Greek for rocky), which is composed of two types of plates, continental and oceanic. The continental plates are granitic, made of lighter silicate minerals, and the oceanic plates are basaltic, made of denser iron and magnesium minerals. Both types of plates float on the very hot plastic upper mantle, where convection currents slowly move the plates about (plate tectonics). Little is known about the lower mantle, other than that seismic waves travel at different velocities in the upper mantle than in the lower mantle. Below the mantle is the Earth's core, an outer core of liquid iron and an inner core of solid iron. The rotation of the inner core relative to the outer core and mantle creates a dynamo effect, resulting in the magnetic lines of force (the strong magnetic field) typical of the Earth.
13.	A diagram representing the solar wind (charged particles streaming from mass coronal ejections occurring on the sun), deflecting these dangerous particles away from the Earth. In this diagram, the planet above the Earth represents Venus, and the smaller one below the Earth represents Mars. Venus has only a weak magnetic field, likely caused by the rotation of its dense atmosphere interacting with the solar wind, and Mars has an even weaker magnetic field. The limited magnetic fields of Venus and Mars indicate that neither planet currently has an active core dynamo.
14.	The Earth's active geologic processes (volcanoes, earthquakes, plate tectonics, and erosion) are all part of a planetary recycling program. The Earth's crust is continually being created and destroyed. Here is a volcano in the Aleutian Island chain, emitting a great deal of volcanic dust and producing lava flows. On average, there are approximately 50-60 volcanic eruptions occurring every year (about one per week). Most of these occur beneath the oceans. Much of the material produced by volcanoes is coming from both melted crust and the mantle. This is how we are able to learn about the interior of the Earth. We have never traveled to the center of the Earth, not even close, regardless of what Jules Verne wrote.
15.	This illustration shows the global distribution of earthquake epicenters. Note that over 350,000 earthquakes occurred in the 35 years covered in the study, averaging well over 10,000 quakes per year. Not all of these were large enough to be felt, but that is still lots of earthquakes. Also notice the pattern of the seismic activity: lots along the west coasts of the Americas, lots in the Mediterranean and the Far East, and lots like the seams on a baseball, down the center of the Atlantic and Indian Oceans and in a ring around the Pacific Ocean. What is really interesting is that 99 percent of these earthquakes define the boundaries of the tectonic plates. Earthquakes occur at the planet's recycling center.

Goldilocks Planets Slideshow Text

16.	The map of the continents and oceans shows the location of the major tectonic plates on our planet, and the arrows indicate the direction of movement of the plates. The red, teeth-like symbols indicate a subduction zone, where the heavier edge of an oceanic plate slips under a lighter edge of a continental plate, and the solid red lines indicate the location of a sea floor spreading zone. Notice that South America and Africa are moving away from each other. The Mid-Atlantic Ridge, a sea floor spreading zone, is pushing these two continents apart. On the west coast of South America is a subduction zone, where the heavier Nazca oceanic plate is slipping under the lighter South American plate. The diagram below, (b), illustrates both a sea floor spreading zone, where new ocean crust is being created by upwelling of material from the mantle below, and a subduction zone, where old crust is being melted for recycling. The erupting volcano in the diagram is one way in which the old melted crust can produce new crust. Also shown is an island arc in the ocean. The Hawaiian Islands are an example of such a chain of islands.
17.	Much of what we know about the geologic and ecologic processes occurring on Earth and the other two Goldilocks planets has been facilitated through the use of remote sensing. Remote sensing is the technology that allows humans to collect data (visual, temperature, chemical, etc.) without actually coming in contact with an object. Photography was one of the first examples of remote sensing. With the development of the space program, we have been able to visit and collect data from all eight of the planets in the solar system, as well as many of the moons, asteroids, comets, and dwarf planets and the sun There are two types of remote sensing systems being used today. These are passive systems, such as cameras and multispectral and hyperspectral sensors, which collect data reflected from the sun, and active systems, such as radar and lidar, which bounce radio or light waves, respectively, off of a surface (like Venus) and collect the return signal. In these two diagrams, the number "1" represents the source of energy (sun or radio beam), "2" is the returned energy (images), and "3" is the transmission of the data to Earth from a spacecraft doing the remote sensing. Today, there are a large number of Earth-orbiting satellites that are used to detect, map, and monitor a wide range of features on the Earth's surface and those features characterizing our neighboring planets, moons, etc.
18.	An example of remote sensing as a key tool used to map, measure, and monitor the Earth's surface features is the study of vegetative land cover types. Reflectance data in the electromagnetic spectrum, including the visible (blue, green, and red) and infrared (IR – both reflected and thermal), have been used to create very detailed vegetation maps like the one shown here. Not only can the types of vegetation be precisely mapped, but also seasonal and developmental changes in each type of vegetation can be measured and documented.

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Goldilocks Planets Slideshow Text

19.	Knowing the types of vegetation and its distribution around the planet is important, because vegetation plays a very important role in the cycling of water (in the form of water vapor) within the atmosphere. To monitor amounts of water vapor (as well as oxygen and carbon dioxide) at different levels in and above vegetation canopies, towers such as the Amazon Tall Tower Observatory (ATTO) are used by scientists around the planet. The ATTO is over 1,000 feet tall and is the tallest structure in the Amazon. As noted in *One Strange Rock*, this tower has discovered a "river that flies," a massive flow of water vapor, from the Atlantic to the Andes, coming from rain forest transpiration, carrying more water than the Amazon River.
20.	Transpiration is the loss of water vapor through stomates in the lower epidermis of leaves. Transpiration, in addition to cycling water back to the atmosphere, pulls water and nutrients from the soil into the plant's roots, contributing to the process of photosynthesis. Transpiration accounts for more water vapor transferred to the atmosphere from an acre of forest than evaporation from an acre of an open body of water. Transpiration is a major part of the water cycle on Earth, recycling water as well as driving nutrient uptake.
21.	Of the terrestrial planets, the first two (Mercury and Venus) have no moons, while the outer two (Earth and Mars) have moons. Mars' two moons are very small and likely were captured, perhaps from the asteroid belt between Mars and Jupiter. Earth's moon is very different, and so we should spend some time thinking about where it may have come from. Was it a capture, or did it have another origin?
22.	The NASA mission patch for the Apollo 11 first moon landing on July 20, 1969. The lunar landing craft was called the *Eagle* and carried a crew of two, Neil Armstrong, the first man to walk on the moon, and Edwin "Buzz" Aldrin, the second man to walk on the moon.
23.	The crew of Apollo 11. While Armstrong and Aldrin traveled to the lunar surface, Mike Collins remained in lunar orbit in the Apollo command module. Neil Armstrong inspired a generation when he said, "That's one small step for a man, one giant leap for mankind," as he stepped from the lunar landing module. (Buzz Aldrin was the inspiration for the Buzz Lightyear action figure.)
24.	In addition to walking on the moon, Armstrong and Aldrin, as well as the other 10 men who would walk and ride on the lunar surface, collected samples of lunar rocks. Of the samples of "moon rocks" collected, the most common types were basalts and breccias. The basalts were from lava flows (the "maria" or seas) where the Eagle landed, on the Sea of Tranquility, and the breccias were fragments of much older rock transported by meteorite impacts from other sites.

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25.	An analysis of the many lunar samples collected is most interesting. The most common elements on the Earth and moon are silicon and oxygen, in the form of silicate minerals (SiO_2) that are complexed with iron (Fe), magnesium (Mg), and aluminum (Al). Calcium (Ca) is also found on the moon. The lunar lowlands are the lava flows (maria), while the lunar highlands are the surrounding mountains. In looking at a full moon, the darker areas are the maria (plural for the Latin *mare*, meaning sea), and the lighter areas are the mountains. (See Slide 19.)
26.	One of the current hypotheses regarding the origin of the moon is called the Theia hypothesis; it proposes that a Mars-sized planet collided with Earth in the early formation of the solar system, blasting out a large chunk of Earth that would become the moon. This hypothesis is supported by the very large size of our moon compared with the small moons of Mars, as well as the similar chemical composition of Earth and the moon. It has also been noted that the diameter of the moon is similar to the circular form of the Pacific Ocean.
27.	A size comparison of the primitive Earth, the hypothesized planet Theia, and the asteroid Lares. Lares is estimated to be the size of the asteroid that collided with the Earth 65 million years ago, causing the extinction of the dinosaurs.
28.	Finally, we need to look more closely at the planet Mars, also one of the potential Goldilocks planets. Mars is much smaller than either Venus or Earth, resulting in less gravity, which seriously reduces the amount of atmosphere it can keep. It does have water, but mostly in frozen ground water. In this image, we see a polar cap of both water ice and carbon dioxide ice (dry ice), which sublimate seasonally to modify atmospheric CO_2 levels.
29.	The Martian atmosphere is very thin, and even though it is mostly CO_2, it is not enough to act as an effective greenhouse effect. As a result, the surface of Mars is very cold (an average of minus 80° C). Mars' weak gravity is not the only reason for a thin atmosphere. The planet's weak magnetic field allows the atmospheric gases to be stripped away.
30.	Although liquid water is not found on Mars today, there is a lot of evidence that in the past, liquid water was present. *Valles Marineris* is an example of a very large canyon that runs east-west near the Martian equator. It is as long as the U.S. is wide and is marked with many dendritic side valleys carved by long periods of liquid surface water in the form of rivers.

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31.	The Viking lander acquired this as one of first surface images of Mars, in 1976. In this image, evidence of the thin atmosphere is seen in the scattered light on the horizon. It would have been black, like on the moon, if there was no atmosphere. Both the sand and the rocks are red, due to high levels of iron (Fe). As we know, Mars is known as the red planet due to this large amount of iron across the planet. We cannot refer to the sand as soil, since soil contains living organisms, and now, over 40 years later, none of the current Mars rovers have found any evidence of life on Mars.
32.	Speaking of Mars rovers, here is a photo of the rover Opportunity, photographed on Earth. Launched in 2003, two identical rovers, Spirit and Opportunity, were part of NASA's MER (Mars Exploration Rover) program to explore for evidence of past or present water on Mars. The two rovers landed in different locations, Spirit in an apparent lakebed and Opportunity on the other side of Mars at *Meridiani Planum,* an outwash plane of *Valles Marineris,* both apparently produced by running water. Spirit discovered pure silica, a mineral known to be produced in hot springs on Earth, and Opportunity discovered layered terrain composed of hydrated bedrock containing crystalline hematite indicative of sedimentary processes and clay minerals indicative of weathering processes. Spirit got stuck when one of its wheels malfunctioned in 2009 and stopped operating in 2010. Opportunity is still operating and continues to collect and transmit data as of January 13, 2018. Designed to operate for 90 sols (time measured in Martian days, called sols, of 25 hours each), Spirit operated for over 5 Earth years, while Opportunity is still operating 14 years after landing.
33.	Launched in 2011, the NASA Mars rover Curiosity landed on August 6, 2012, on *Aeolis Palus*, a plain on Mars near Gale crater (see map in the next slide). A 6th grade student named Clara Ma, in a competition sponsored by NASA and the Disney Corporation, named this lander. Curiosity has operated on Mars for the past 5 years and has detected extensive areas containing hydration salts and perchlorates typical of evaporation of liquid water on Earth. This suggests that Gale crater, caused by a meteor impact during the formation of Mars 3.5 billion years ago, was once filled with water. An analysis of deuterium/hydrogen ratios suggests that liquid water in the area was lost to space in ancient times (3 billion years ago?).
34.	As a result of data from NASA rovers, we now know that liquid water was likely abundant in the planet's early history, possibly in the form of a shallow ocean. This slide presents spectral data for the chemical make-up of a Martian rock, derived from the Curiosity rover's ChemCam. The rock is a type of granite-like material, made up of silicon dioxide, such as quartz, plus iron and magnesium, such as basalt.
35.	As part of this lesson, you should begin to familiarize yourself with some of the major surface features of Mars (*Valles Marineris*, *Olympus Mons,* Gale crater, etc.). This slide is a map of the entire surface of Mars, showing the locations of the NASA landers and rovers. You can also become familiar with the surface of Venus and Mars by *Google Venus* and *Google Mars*, as seen in the next two slides.

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Goldilocks Planets Slideshow Text

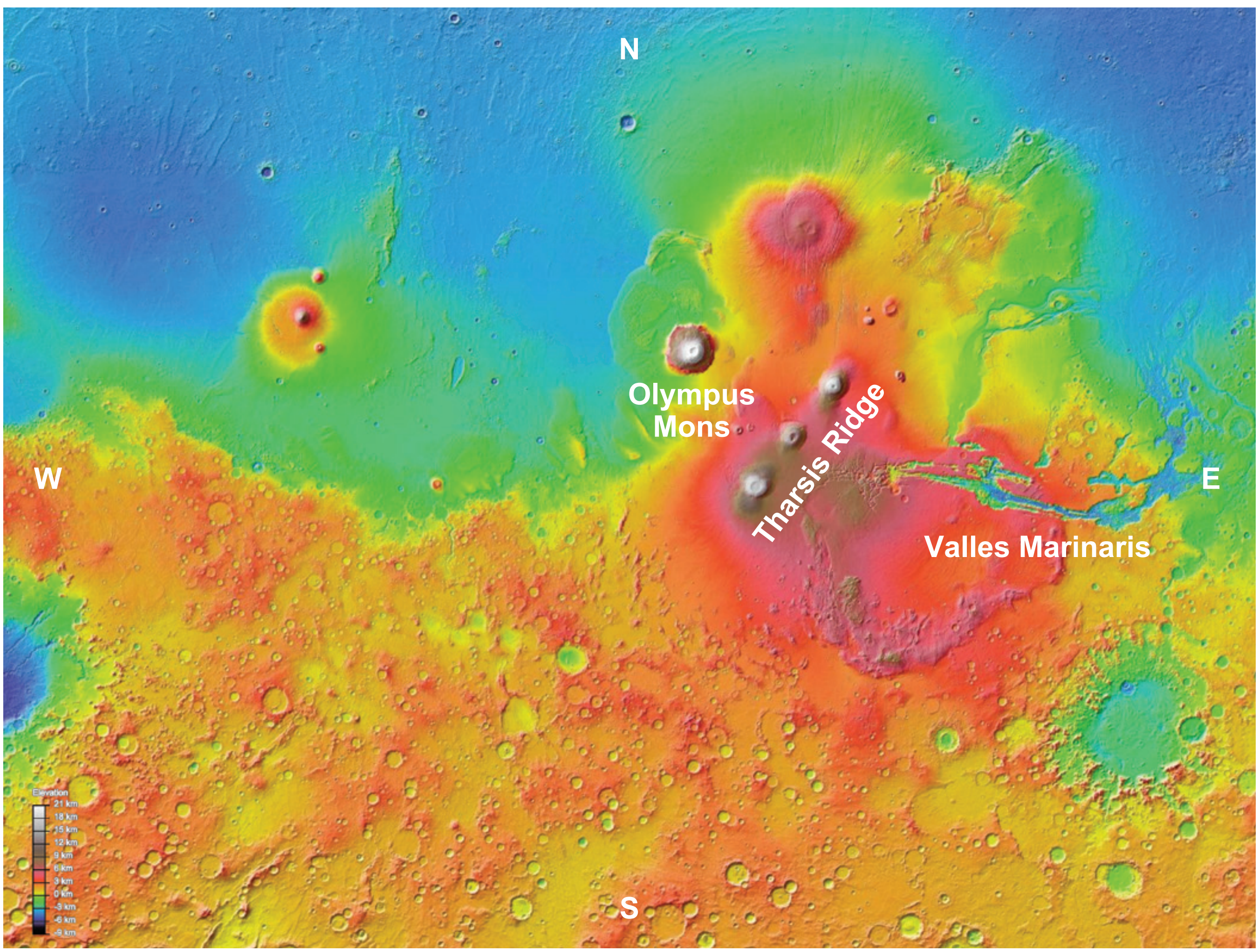
36.	*Google Venus* allows you to maneuver over and zoom in on the surface of Venus, as seen by the *Magellan* spacecraft.
37.	*Google Earth* allows you to zoom in on your own school and the surrounding areas. How does Earth differ from Venus?
38.	*Google Mars* allows you to maneuver over and zoom in on the surface of Mars, as imaged by a number of NASA and ESA orbital missions. How does the surface of Mars differ from that of Venus?
39.	The Goldilocks planet Earth.
40.	The launch of the first NASA Orion crew capsule in 2014. NASA is serious about manned Mars missions in the mid-2030s. The Orion crew capsule will also be used to place humans on an asteroid by 2020, assuming adequate funding and national commitment. The current Orion crew capsule is designed to carry four crew members and is the approximate size of a large SUV or small school bus.

Handout 1 ▸ p.1 *Google Mars*: Exploration of Mars

In this activity you will use *Google Mars* to explore the surface of Mars, interpret its surface topography, and visit some of the Mars landers. The data used have been created by orbital images acquired by a number of NASA orbital spacecraft, including the Mars Reconnaissance Orbiter and Mars Odyssey. This image data set was created using real Mars data by NASA researchers at the Jet Propulsion Laboratory, Goddard Space Flight Center, and Arizona State University.

You should watch the slideshow presentation in Lesson 2 on the Goldilocks planets before you begin this activity.

Begin by opening *Google Mars* in your browser at http://www.google.com/mars/. You should see the interactive color image of the Mars surface. The figure below has been labeled with the cardinal directions and key surface features discussed in the exploration activities. Locate these features on your computer screen.



Handout 1 ▸ P.2 *Google Mars*: Exploration of Mars

- The colors represent differences in topographic elevation, with white being the highest elevations and blue being the lowest. An elevation scale is displayed in the lower left corner of the image. Note the range of elevations in kilometers, measured both below the mean elevation (black, blue, and green), the mean elevation itself (yellow), and above the mean elevation (pink, orange, and gray).
- In the upper left corner of the image on your screen are displayed viewing options: Elevation (this image); Visible (in black and white), and Infrared (also in black and white except for close-up images of *Olympus Mons* and *Valles Marineris).* Try these options to see the different maps available.
- Above the viewing options, and outside the image, are displayed options for labeling surface features. These options are: Regions, Spacecraft, Stories, Mountains, Canyons, Dunes, Plains, Ridges, and Craters. Note that none of the latest Mars rovers are listed under the Spacecraft option.
- In the lower right corner of the image are "+" and "–" signs, which will allow you to zoom in or out of the image. Note that if you zoom out enough, you will see a repeating pattern of surface features.

You are now ready to begin exploring Mars. You will conduct a series of exercises designed to let you use the data provided to conduct your own research to address these three key questions:

- If there ever was water on Mars, where was it located? In canyons like *Valles Marineris*? In what direction did it flow? Could Mars have had oceans in the past? Looking at the outwash plains of *Valles Marineris*, what lines of evidence can be seen for the direction of flow?
- Are the different surfaces of Mars also of different ages? Are some regions older than others? How do astronomers determine differences in surface age?
- Is there any evidence of plate tectonics having operated on Mars? What lines of evidence can you cite that support or reject the view of past or present plate tectonics having shaped the surface of Mars?

Google Mars: Exploration of Mars

Exercise 1: Liquid Water on Mars. Locate *Valles Marineris* on this image. Notice that it runs east-west, essentially at the equator. Zoom in (one "+" click) on this massive canyon using the Elevation (colored) image so that the canyon nearly fills your computer screen. Write down your ideas on the three key questions. You may also draw and label what you see.

a. How does the western end (on the left) differ from the eastern end? Does either end have narrow, river-like (dendritic) features? If so, what do you think it means?

b. Zoom in two "+" clicks and then drag the image over to the western end of the canyon. Describe what you see.

c. Drag the image to the central part of the canyon and "+" click several more times. Study the canyon walls, noticing the changing colors from the top (pink) down through yellow and green to the bottom (blue). Estimate the elevation change, both in kilometers and miles. How deep is *Valles Marineris*? How deep is the Grand Canyon on Earth? Which canyon is deeper?

d. Note that there are faint lines in the upper surface of the canyon running parallel to each other and to the east-west length of the canyon. These are also seen on the moon and are called "rills." They appear to be stretch marks, although their origins are still being debated. What do you think they might be?

Handout 1 ▸ P.4 *Google Mars*: Exploration of Mars

e. Now zoom out with a few "–" clicks and drag the image so you can view the eastern end of the canyon, where the canyon turns to the north. Note that the topography changes much more gradually and the canyon bottom become much wider. Locate the area where the canyon trends north through the green and cratered terrain. At this point, the canyon becomes very wide. Zoom in to where you see green teardrop-shaped "islands" against the blue canyon bottom. What could have formed these strange features?

f. Based on all that you have seen in this study of *Valles Marineris*, cite at least three lines of evidence that would support the hypothesis that large amounts of water formed this grandest of all grand canyons. Also indicate which way you think the hypothetical water flowed (west to east or east to west).

g. If Mars ever had an ocean, where would it have been located (Northern Hemisphere or Southern Hemisphere)? Based on what evidence?

Handout 1 ▸ P.5 *Google Mars*: Exploration of Mars

Exercise 2: Determining the Relative Age of Martian Surfaces. Astronomers have long used the technique of **crater counting** to determine the relative ages of different surfaces: a surface that is heavily cratered is assumed to be older than a surface with fewer craters. This is based on the assumption that over time, a variety of materials (asteroids, meteors, comets, and dust) have impacted all of the planets and moons in our solar system, leaving impact craters on most solid surfaces. Crater Lake in Oregon is an example of such an impact crater. In the early stages of development of the inner terrestrial planets of our solar system (Mercury, Venus, Earth, and Mars), bombardment was likely more frequent than today.

Impact craters appear to be very flat and circular, with some exhibiting central peaks; they are not associated with a mountain. Volcanic craters generally are at the summit of a mountain, with either gentle sloping sides (a shield volcano) or steep slopes (a cinder cone). *Olympus Mons* on Mars is an example of a shield volcano, with two or more impact craters at or near the summit. The crater counting method only works with impact craters.

In this exercise, we will look at the youngest surface area on Mars, the oldest surface area, and some area in between. Let's begin by looking for impact craters around *Valles Marineris.* Zoom in two or three "+" clicks, so the zoom factor allows you to see both the western and eastern ends of the canyon.

a. Notice that to the east (the right) on the elevated terrain (green, yellow, and orange), multiple impact craters are seen, while to the west (left), the highest terrain (mostly red or orange) has very few impact craters. Which terrain is the youngest? Which is the oldest?

b. Looking at the point where the canyon widens and begins to turn north, above the canyon along the boundary of yellow and orange elevation, note the two similar-sized large craters. The one to the northeast has three large impact craters within it, while the one to the southwest has only small craters in it. Do you think both are the same age? Why or why not?

Handout 1 ▸ P.6 *Google Mars*: Exploration of Mars

c. Zooming out and focusing on the western end of the canyon, do you see many impact craters? This must be a relatively young level area. Can you hypothesize why this is younger?

d. Further to the west, find three volcanic craters in a diagonal line. These are the *Tharsis Ridge* volcanoes. Note how different they look compared with impact craters. Do you think they are relatively young? Is one younger than the others, based on counting craters? A possible explanation for the relatively young terrain to the east may be that it is the result of successive lava flows from these volcanoes. What do you think?

e. Zoom out and drag the image to the north. Note that the northern hemisphere of Mars is much lower than the mountainous and more or less heavily cratered southern hemisphere. One hypothesis for this is that a large shallow ocean covered much of the northern hemisphere, either protecting the area from bombardment or covering older craters with sediments. Far to the north, we see what appears to be a rippled or layered terrain that is higher (green) than the area below it to the south. The green areas are the northern polar ice cap (both water ice and CO_2 ice or dry ice) that sublimates in the Martian summer and then re-forms in the Martian winter. Note the total lack of impact craters. This is the youngest surface on Mars.

Handout 1 ▸ P.7 *Google Mars*: Exploration of Mars

Exercise 3: Evidence of Plate Tectonic Activity on Mars. This exercise addresses the question of whether Mars has either had tectonic activity in the past or currently has it. Tectonic activity assumes a semi-liquid mantle that causes plates to float or drift very slowly on convection currents within the mantle. Movement of the plates produces rifts (spreading zones) and either subduction or buckling (ridges) where two plates come together. Hot mantle material can erupt onto the surface in the form of volcanoes. Another point to consider is that Mars has a very weak magnetic field.

For this activity, synthesize the data you have collected in the previous exercises on liquid water on Mars and crater counts to list your reasons in favor of tectonic activity or against it.

Teacher Resource 2 p. 1

Handout 1 Answer Sheet

1.) Liquid Water on Mars exercise.

a. The western end is narrow, while the eastern end is wider, which likely means water flowed from west to east.

b. Dendritic or branching patterns that look like rivers created them.

c. *Valles Marineris* is deeper than the Grand Canyon.

d. These rills are thought to be either stretch marks or crumpling marks. There is no correct answer.

e. Teardrop shapes of these land forms ("islands") must have been carved by running water.

f. 1. The western end is narrower than the eastern end.

2. The presence of dendritic channels typical of rivers and tributaries.

3. The western end is at a higher elevation than the eastern end.

4. The teardrop-shaped "islands" on the eastern end were most likely formed by running water.

These lines of evidence support the flow of water from west to east (finally flowing north at the eastern-most end of *Valles Marineris.*

g. The northern hemisphere, based on the elevation data (the smooth northern hemisphere is lower than the mountainous southern hemisphere).

2.) Determining the Relative Age of Martian Surfaces exercise.

a. The terrain with the fewest impact craters is the youngest, while the one with the most craters is the oldest.

b. They are not the same age, because the one with the three large impact craters is the oldest.

c. It has fewer impact craters.

d. They are relatively young because they don't have many impact craters (only one?), and yes, the relatively young terrain to the east could be a recent lava flow from one or more of the *Tharsis Ridge* volcanoes.

e. Yes, it is the youngest terrain on Mars, because it is re-formed every Martian year.

3.) Evidence of Plate Tectonic Activity on Mars exercise.

There is some evidence that Mars may have had an active plate tectonic mechanism in the past. Possible evidence of past tectonic activity is that Mars has had past volcanic activity (*Olympus Mons* and the *Tharsis Ridge* volcanoes). The limited number of impact craters associated with these volcanoes would imply that the volcanic activity was relatively recent. The linear pattern of the *Tharsis Ridge* volcanoes suggests that they may have been located over a subduction zone, but this is speculative. None of the Mars landers on the surface have detected any seismic activity.

See what your students come up with based on their observations. There are no right or wrong answers to this question.

Handout 2 ▸ P.1

Using *Google Venus* to Explore Earth's Twin

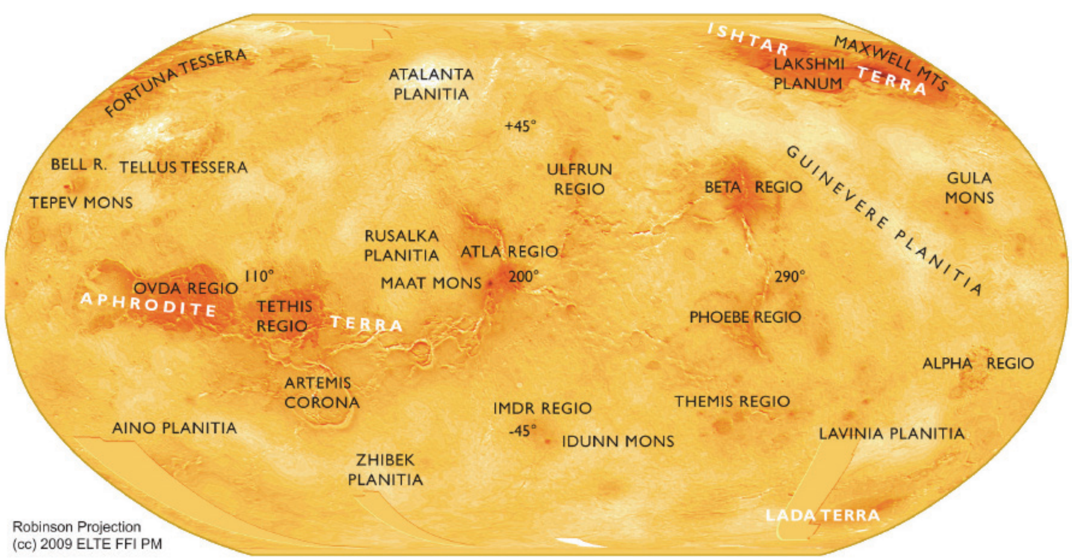
In the *Google Mars* exercise, you were asked to:

- Explore for evidence of past liquid water on Mars.
- Conduct crater counts to identify the relative age of different Martian surfaces
- Speculate about whether Mars ever had tectonic activity similar to Earth's.

1. Using *Venus –Google Maps* (www.google.com/maps/space/venus), you are going to do the same set of activities as you did for Mars. This online tool is far less useful, other than to allowing you to see the surface of this very alien world, with surface features labeled.

You can click and drag the image to move around (side to side and up and down) and use the zoom slide (in the far lower right corner) to move in and out. This zoom slide is limited in the ability to move out far enough to see the entire planet. You can collapse the left side panel to see more of the image. In this image, north is at the top and south is at the bottom. West is to the left and east is to the right. When the image is first displayed, it is with the equator centered on your screen, with an obvious yellow band running from west to east.

Your screen image will look like this but is elongated east/west due to the fact that there are no data for the north (top) or south (bottom) parts of the image. The *Magellan* spacecraft was in a near polar orbit that did not collect radar data for the polar regions of Venus.



This is a global map of the surface of Venus, based on *Magellan* radar data. Notice that *Maat Mons* is in the approximate center of the map. Compare the features shown on this map with the labeled features on your screen image. (Unfortunately, the colors shown here do not match colors of either the image above or your screen image.)

Handout 2 ▸ P.2

Using *Google Venus* to Explore Earth's Twin

2. As with *Google Mars,* the image of Venus is shown in the form of a repeating panel, so as you move east or west, you will see the same features repeated. Since this image was acquired using the imaging radar system on the orbiting *Magellan* spacecraft, and because the radar system data are of low spatial resolution, in the *Google Venus* image, even when you zoom in, surface details are poorly resolved. Even with the less than ideal options and resolution, you can see interesting patterns on the surface. The circular patterns are either impact craters or volcanoes, and the yellow stream-like patterns are lava flows. *Maat Mons* (the largest volcano in the solar system) is not labeled on your screen image, but can be found by locating *Rusalka Planitia*, *Alta Regio*, and *Jokwa Linea* on the screen image. Can you figure out what terms like *Mons*, *Planitia*, and *Regio* mean?

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3. Now, investigate the screen image, looking for the features you located on Mars. Please address the following:

Exercise 1: Liquid Water on Venus. Remember that on Mars you saw several features at *Valles Marineris* that suggested the feature was likely caused by actively running liquid water (dendritic or river-like features at one end, a very deep canyon, and teardrop-shaped "islands" at the other end). Do you see any such features here on Venus?

Do you see any river-like features here on Venus? If so, what are they, and how do they differ from what you saw at *Valles Marineris*?

Given the very high surface temperatures found on Venus, would you expect to find liquid water on Venus? Why or why not?

Handout 2 ▸ P.3

Using *Google Venus* to Explore Earth's Twin

Exercise 2: Crater Counts. Conduct crater counts to identify the relative age of different surfaces on Venus. Can you see different types of craters on Venus? What are they, and how can you tell them apart? (*You can use drawings to show the differences*).

Do you see many impact craters? If so, are they large or small?

Given Venus' very dense CO_2-rich atmosphere and sulfuric acid cloud cover, do you think many meteors or comets could survive to reach the surface? Would you expect to see many small impact craters?

Locate the approximate area on the image where *Maat Mons* is found. Zooming in, can you see more surface details?

Handout 2 ▸ P.4

Using *Google Venus* to Explore Earth's Twin

Do you think acid rain falling from the sulfuric acid clouds has eroded many of the surface features on Venus?

Given the very high temperatures on Venus, do you think acid rain, or any other kind of rain, could fall, or would it evaporate before hitting the surface?

Exercise 3: Speculate About Whether Venus Ever Had Tectonic Activity Similar to Earth's: Venus is known to have many volcanoes and lava flows. Both of these features suggest that Venus may have a semi-liquid mantle beneath the surface crust. That suggests it should have some tectonic activity. Venus also has *Aurora* similar to our Northern Lights, indicating a solid core rotating differently from the rest of the planet, generating a magnetic field. This also suggests a possible fluid mantle, thus potential tectonic activity.

Can you see any surface evidence of tectonic activity (rifts or subduction) on Venus?

Do you think it is possible that active tectonic processes (frequent volcanic eruptions, heavy lava flows) on Venus may actually resurface the planet, masking the signs of tectonic processes?

4. Any final thoughts about life ever developing on Venus?

Teacher Resource 3

Answer Sheet for Handout 2

1.) Liquid Water on Venus exercise.

a. No
b. No
c. No. The surface temperature is much too high (approximately 800° F), since water would boil away above 21° F.

2.) Conduct crater counts to identify the relative age of different surfaces on Venus.

a. There are volcanic craters and impact craters on Venus.
b. The impact craters are very large.
c. No.
d. No.
e. Yes.
f. It would evaporate before reaching the surface, due to the high temperatures.

3.) Speculate about whether Venus ever had tectonic activity similar to Earth's.

a. Venus has volcanic activity. No obvious rifts or subduction features.
b. Venus has aurora and a magnetic field and thus must have a solid core (probably of iron) and a fluid mantle and possibly an asthenosphere.
c. Yes. Lots of lava flows.
d. What would life look like if it developed on Venus? Allow your students to speculate on this question.

The Soil Is "Alive": The Gaia Hypothesis

Enduring Understandings

- All living organisms respire, and this continuing process, as well as photosynthesis and chemosynthesis, has made life possible on Earth.
- There is a world in the soil beneath our feet that we cannot see, but it is an essential part of the Earth's self-regulation.
- Organisms change in response to changes in the environment.
- There is an interconnection of all life on Earth and the living conditions on Earth.

Essential Questions

- What was the by-product of respiration in the earliest life forms on Earth?
- How does respiration differ from breathing? Are they the same thing?
- How has life changed in response to increased O2 levels in the atmosphere?
- Of what importance is microbial life to the CO2 balance of Earth?
- What role have microbes played in the evolution of Earth's atmosphere?
- Why is CO2 an indicator of living organisms?

Notes to the Teacher

Gaia (also spelled Gaea) was the ancient Greek Earth Mother goddess. She gave birth to the heavenly gods, the ocean gods, the Giants, and all mortal creatures. (See more information at https://greekgodsandgoddesses.net/goddesses/gaea/.) The root word *geo-*, meaning Earth, comes from the same source as her name. The Roman version of this goddess was named Terra, and her name also signifies Earth in Latin. The Gaia hypothesis was first developed by chemist James Lovelock and microbiologist Lynn Margulis. It holds that the organic and inorganic elements of the earth work together to create a self-regulating system that maintains conditions on Earth for life to exist.

The *One Strange Rock* episodes "Home" and "Terraform" would be the most appropriate episodes to show with this lesson. Be sure to allow time for students to ask questions and discuss the episodes after viewing.

You will be using an indicator solution called bromothymol blue to detect qualitatively the presence of carbon dioxide (CO_2). When CO_2 dissolves in water, a weak acid is formed, and the indicator in the bottle will change color. Although you cannot measure the amount of CO_2 produced with this technique, you will know that it is present. A gas chromatograph or other methods would be used for more quantitative studies.

The soil beneath our feet is teeming with life, from the obvious macroscopic organisms, such as insects and worms, to the microscopic life forms of bacteria, yeast, and fungi. There are several criteria that must be met in order to be considered a living organism, but the one we will be exploring is respiration, or the process of utilizing O_2 at the cellular level to produce energy. To perform the exchange of gases, many organisms "breathe" in oxygen and exhale carbon dioxide (a greenhouse gas) into the atmosphere. Some microorganisms, such as methanogenic bacteria, produce or release the greenhouse gas methane. Scientists measure changes in the production of these greenhouse gases in an attempt to better understand global climate change.

Explain to your students that the term "breathe" is placed in quotation marks because a great many organisms, such as bacteria, green plants, fungi, etc., respire ($C_6H_{12}O_6 + O_2 \Rightarrow CO_2 + HOH$) but do not breathe. Technically, breathing is the mechanical process by which lungs inhale oxygen and exhale carbon dioxide.

Before heading out to the field with your students, do a pre-activity demo.

Materials:

250-mL Erlenmeyer flask
Plastic straw
Bromothymol blue indicator

1. Place 50 mL of bromothymol blue indicator into an Erlenmeyer flask. Insert a straw into the flask, and gently blow bubbles into the solution.
2. The solution will change from a blue color to green.
3. Ask students what is being introduced into the indicator solution that could be causing the color change.
4. Connect the idea of human breathing and respiration to that of other organisms.
5. Ask the students if they think it would be possible to test for the products of respiration exhaled by other organisms.

Next, prep your yeast solution for Part 1.

Materials:

Water or soda bottle
One packet of dry yeast
Sugar
One-hole stopper
Air tubing

1. Add 1 teaspoon or 1 packet of dry yeast to 150 mL of warm water.
2. Add 1 teaspoon of sugar to the yeast and water mixture.
3. After approximately 5 minutes, the yeast mixture should look bubbly and frothy.
4. Transfer the yeast mixture to a water or soda bottle.
5. Insert the one-hole stopper into the bottle.
6. Insert one end of the air tubing into the hole. This should be a snug fit. Make sure the end of the tubing is not submerged in the yeast mixture

Assemble your indicator bottle, connecting the two sides.

Materials:
Water or soda bottle
Bottle of yeast solution with air tubing

1. Pour 100 mL of undiluted bromothymol blue into the soda bottle and insert the other end of the tubing all the way to the bottom of the bottle. Be sure that the end of the tubing is beneath the surface of the indicator solution.
2. When both stoppers are inserted into their respective bottles, the CO_2 produced by the yeast will travel from the yeast bottle through the tubing and bubble into the bromothymol blue. As the CO_2 dissolves, the liquid will become slightly acidic, and the indicator will change from blue to green.

Prep the greenhouse gas capture bottle for Part 2. (See diagrams in **Handout 1**.)

Materials:

Two clear plastic soda bottles
One-hole rubber stopper

1. Cut one bottle in half.
2. Place the one-hole rubber stopper in the bottle's neck
3. Insert one end of aquarium air tubing into the hole, making sure that the fit is secure and air cannot leak out.
4. Place the two-hole stopper in the second bottle. (This bottle is not cut.)
5. Insert tubing through one hole and run the tubing to the bottom of the bottle. In the second hole, place a transfer pipette, and once again make sure that both holes are airtight.
6. Pour 100 mL of undiluted bromothymol blue into the remaining soda bottle and insert the other end of the tubing all the way to the bottom of the bottle. Be sure that the end of the tubing is beneath the surface of the solution.

Safety Considerations

- Do not let the pressure build inside the plastic bottles.
- Bromothymol blue can be a skin irritant and, of course, one should not drink it.
- Remind students to be careful when cutting the bottle.
- Have students wear eye protection.
- Wash hands before and after the experiment.

Common Core Standards addressed by this lesson

CCSS.ELA-Literacy.RST.6-8.1
Cite specific textual evidence to support analysis of science and technical texts.

CCSS.ELA-Literacy.RST.6-8.3
Follow precisely a multistep procedure when carrying out experiments, taking measurements, or performing technical tasks.

CCSS.ELA-Literacy.RST.6-8.4
Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to *grades 6-8 texts and topics*.

CCSS.ELA-Literacy.RST.6-8.7
Integrate quantitative or technical information expressed in words in a text with a version of that information expressed visually (e.g., in a flowchart, diagram, model, graph, or table).

CCSS.ELA-Literacy.RST.6-8.8
Distinguish among facts, reasoned judgment based on research findings, and speculation in a text.

CCSS.ELA-Literacy.RST.6-8.9
Compare and contrast the information gained from experiments, simulations, video, or multimedia sources with that gained from reading a text on the same topic.

CCSS.ELA-Literacy.RST.9-10.1
Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions.

CCSS.ELA-Literacy.RST.9-10.2
Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text.

CCSS.ELA-Literacy.RST.9-10.3
Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks, attending to special cases or exceptions defined in the text.

CCSS.ELA-Literacy.RST.9-10.4
Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to *grades 9-10 texts and topics*.

CCSS.ELA-Literacy.RST.9-10.5
Analyze the structure of the relationships among concepts in a text, including relationships among key terms (e.g., *force, friction, reaction force, energy*).

CCSS.ELA-Literacy.RST.9-10.7
Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart), and translate information expressed visually or mathematically (e.g., in an equation) into words.

CCSS.ELA-Literacy.RST.9-10.8
Assess the extent to which the reasoning and evidence in a text support the author's claim or a recommendation for solving a scientific or technical problem.

CCSS.ELA-Literacy.RST.9-10.9
Compare and contrast findings presented in a text to those from other sources (including their own experiments), noting when the findings support or contradict previous explanations or accounts.

Next Generation Science Standards

Middle School (6–8)

MS-LS1-5
From Molecules to Organisms: Structures and Processes
Construct a scientific explanation based on evidence for how environmental and genetic factors influence the growth of organisms.

MS-LS1-7
From Molecules to Organisms: Structure and Processes
Develop a model to describe how food is rearranged through chemical reactions forming new molecules that support growth and/or release energy as this matter moves through an organism.

MS-LS2-1
Ecosystems: Interactions, Energy, and Dynamics
Analyze and interpret data to provide evidence for the effects of resource availability on organisms in an ecosystem.

MS –LS2-3
Ecosystems: Interactions, Energy, and Dynamics
Construct an explanation that predicts patterns of interactions among organisms across multiple ecosystems.

MS-LS2-3
Ecosystems: Interactions, Energy, and Dynamics
Develop a model to describe the cycling of matter and flow of energy among living and nonliving parts of an ecosystem.

MS-LS2-4
Ecosystems: Interaction, Energy, and Dynamics
Construct an argument supported by empirical evidence that changes to physical or biological components of an ecosystem affect populations.

MS-LS4-1
Biological Evolution: Unity and Diversity
Analyze and interpret data for patterns in the fossil record that document the existence, diversity, extinction, and change of life forms throughout the history of life on Earth under the assumption that natural laws operate today as in the past.

MS-LS4-2
Biological Evolution: Unity and Diversity
Apply scientific ideas to construct an explanation for the anatomical similarities and differences among modern organisms and between modern and fossil organisms to infer evolutionary relationships.

MS-LS4-4
Biological Evolution: Unity and Diversity
Construct an explanation based on evidence that describes how genetic variations of traits in a population increase some individuals' probability of surviving and reproducing in a specific environment.

Next Generation Science Standards

High School (9–12)

HS-LS1-7.
From Molecules to Organisms: Structures and Processes
Use a model to illustrate that cellular respiration is a chemical process whereby the bonds of food molecules and oxygen molecules are broken and the bonds in new compounds are formed, resulting in a net transfer of energy.

HS-LS2-3.
Ecosystems: Interactions, Energy, and Dynamics
Construct and revise an explanation based on evidence for the cycling of matter and flow of energy in aerobic and anaerobic conditions.

HS-LS4-4.
Biological Evolution: Unity and Diversity
Construct an explanation based on evidence for how natural selection leads to adaptation of populations.

HS-LS4-5. B
Biological Evolution: Unity and Diversity
Evaluate the evidence supporting claims that changes in environmental conditions may result in (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species.

NGSS Crosscutting Concepts

- Cause and Effect
- Systems and Systems Models
- Stability and Change

NGSS Practices

- Asking Questions and Defining Problems
- Developing and Using Models
- Planning and Carrying Out Investigations
- Constructing Investigations and Designing Solutions
- Engaging in Argument From Evidence
- Obtaining, Evaluating, and Communicating Information

Duration of lesson

One to two one-hour periods

Assessment

Group discussion

Student sketches of their capture unit

Essay questions and answers

Materials Needed

For each lab group:

- Four plastic water bottles
- Two two-hole rubber stoppers
- Two one-hole rubber stoppers
- Latex tubing or aquarium tubing
- Yeast
- Warm water
- Sugar
- 250-mL beakers
- Bromothymol blue indicator
- Plastic transfer pipette
- Small garden spade
- **Handout 1: Lab: The Gaia Hypothesis and Atmospheric Chemistry**
- **Handout 2: Questions for Research**

Procedure

1. Write the words "GAIA HYPOTHESIS" on the board. Ask students who or what is meant by the word "Gaia." Discuss the Greek myth of Gaia (see Notes to the Teacher) and ask what meaning it might have in modern times.
2. Ask students what is required for something to be considered alive. (The five indicators of life: it is made of cells, it uses energy, it grows, it reproduces, and it moves and adapts to the environment.)
3. Discuss the difference between the terms "macroscopic" and microscopic." (Macroscopic things can be seen with the naked eye; microscopic means invisible or indistinct without the aid of a microscope.)
4. Discuss the transition of an oxygen-poor atmosphere to one that is oxygen-rich. Include in your discussion the differences between the early atmosphere and the role bacteria played in the formation and development of an oxygen-rich atmosphere.
5. Discuss the role of free oxygen in the atmosphere and the subsequent formation of ozone in the progression of life from the ocean onto land.
6. Organize the class into lab groups and distribute **Handout 1: The Gaia Hypothesis Lab**. Review the handout and go over your safety procedures.
7. Conduct your demonstration of the lab as described in Notes to the Teacher. Then give students time to work on the lab while you circulate to supervise and answer questions.

8. After discussing the results of the lab, distribute **Handout 2: Questions for Research**. Give students time to research and formulate answers to each question. This may be done in class or as a homework assignment.

9. While students are working on their research, show the *One Strange Rock* episodes "Home" and "Terraform." Allow time for student discussion and questions.

10. Conclude by reviewing student answers to the essay questions in a whole-class discussion. You may wish to allow students to add information to their answers as the discussion proceeds.

Suggested responses:

1. Why do we call CO_2 and methane greenhouse gases?

A greenhouse allows sunlight to pass through into the interior, where it is absorbed and re-emitted as infrared light. The infrared light does not pass through the greenhouse material and will be absorbed by the gases inside, resulting in increasing interior temperature. Similarly, carbon dioxide and methane in the atmosphere will absorb infrared light, and the temperature of the atmosphere increases.

2. How is Earth's atmosphere similar to the plastic of the collection bottle?

Light from the sun travels through the atmosphere. As light is absorbed and then re-emitted in the infrared wavelengths, the greenhouse gases of the atmosphere absorb the infrared light, preventing its escape into space. The plastic of the bottle functions similarly in that the infrared cannot easily pass through, and the temperature inside the bottle increases.

3. Why are we worried about CO_2 levels if CO_2 is part of the natural process of living things?

Although there are natural fluctuations of greenhouse gases, we should be concerned about anthropogenic contributions (those made by humans). Atmospheric carbon dioxide can be removed from the atmosphere by rainfall and subsequently sequestered in sediments. As climate changes in response to greenhouse gas concentrations, our contributions can occur at a rate exceeding nature's ability to recycle the carbon dioxide.

4. Scientists can't use qualitative indicators like bromothymol blue in the atmosphere. So how do they measure the CO_2 levels?

Samples of gases are analyzed using a gas chromatograph to produce quantitative measurements in parts per million, or ppm.

5. How might human activities increase or decrease the biological contribution of CO_2?

Answers will vary but may include land use practices affecting the soil biome, such as farming practices or construction practices.

6. How is CO_2 removed from the atmosphere to become part of the rock record?

Carbon dioxide dissolved in precipitation produces a weak acid. This weak acid can react with rocks and minerals to produce carbonate-rich sediments.

7. Trace how the CO_2 released by a microorganism in the soil might become part of a gastropod's shell in the ocean.

Microorganism in soil → atmosphere → dissolved in precipitation → ocean → gastropod

8. Infer what Earth's temperature would be like without CO_2.

Since CO_2 decreases heat loss to space, periods of low atmospheric CO_2 are associated with lower global temperatures.

8. How could the Gaia hypothesis be used to explain the change in bacteria from oxygen producers to CO_2 producers?

The early atmosphere was oxygen-poor but CO_2-rich. Early life forms utilized the CO_2 and released O_2 as a waste product. As the concentration of oxygen increased in the atmosphere, a biological response would have led to the development of life capable of utilizing oxygen.

Extension Activities:

1. You can set a system up right in the classroom using soda bottle terrariums. Possible independent variables include: water content, soil type, water hardness, temperature, plant types, macroscopic organisms, light, or the introduction of pollutants that will percolate between the pore spaces in your soil.
2. Have the students construct a diagram or diorama depicting the movement of CO_2 as it cycles through the ecosystem.
3. If you have the time and the space, you could make this a "long-term" study over a couple of days. Have your students check the system every day for color change in the indicator solution. Students could also test different soils, such as forest floor, lawns, beach sand, and marsh soil.

Handout 1 ▸ P.1

Lab: The Gaia Hypothesis and Atmospheric Chemistry

Follow the directions below carefully. A series of photographs at the end of the handout will help you. For your safety:

- Do not let the pressure build inside the plastic bottles.
- Bromothymol blue can be a skin irritant and, of course, one should not drink it.
- Be very careful when cutting the bottle.
- Wear eye protection.
- Wash your hands before and after the experiment.

Part 1: Setting up a positive test

Be prepared. Sometimes the best made plans fail to work as well as you would like or fail to work at all. Running a positive test will help you and your students envision what should happen in an ideal situation.

1. Place 100 mL of bromothymol blue indicator into an empty and clean water or soda bottle. The amount of indicator can be variable; you just need enough to submerge one end of the plastic tubing.

2. Place the two-hole stopper into the bottle, and run the plastic tubing to the bottom of the indicator. In the other hole, place the pipette. Both should fit snugly.

3. Fill the second water bottle halfway with warm water; add a little sugar and a teaspoon of yeast. The yeast is dormant but will become active and consume the sugar. The waste products from the consumption of the sugars include ethanol alcohol, lactic acid, acetone, hydrogen gas, and CO_2.

4. Place the one-hole stopper into the yeast bottle, and insert the tubing. The tubing and stopper assembly for the yeast bottle should have the tubing above the yeast and water mixture. The tubing for the indicator bottle should go into the indicator solution like a straw into a soda. As the yeast produces CO_2, the gas should move through the tubing and into the indicator solution. You will know this has happened by a change in color.

5. If the pressure of the CO_2 is too low, remove the pipette in the stopper of the indicator bottle and gently squeeze. While squeezing the bottle, replace the pipette sealing the hole and release the bottle. Gases should be drawn through the tubing and bubble into the indicator solution.

Handout 1 ▸ P.2

Lab: The Gaia Hypothesis and Atmospheric Chemistry

Part 2: Testing the Soil

This will require more patience and likewise more time, but the idea is the same. The organisms living in the soil are going through their routines of life, which include breathing and respiration. By monitoring CO_2 production, researchers can gain some insight into the role of the soil biome in the contribution to atmospheric CO_2.

1. Your indicator bottle will be set up exactly as it was in Procedure Part 1.
2. Carefully cut the second bottle in half from the bottom. You will want to use the top half for the next step. The stopper and tubing assembly should be inserted at this point.
3. Use a potting shovel to cut a circle into the soil matching the diameter of the bottle. Twist the cut bottle gently while pushing it down into the soil, and pack the soil around the cut edge. You have just created a model of the earth and atmosphere. The atmosphere traps greenhouse gases just as the bottle will trap CO_2.
4. Now we wait. The organisms in the soil have no idea that a greenhouse has been constructed over their patch of soil, so they continue to breathe. The CO_2 becomes trapped in the water bottle greenhouse, and the concentration begins to build. If enough CO_2 is produced, it will be forced to travel through the tubing and into the indicator solution.
5. After 30 to 45 minutes, loosen the pipette on the indicator bottle, and gently squeeze and hold while replacing the pipette.
6. Release the bottle. You should see bubbles in the indicator as the higher pressure in the "greenhouse" portion pushes gases into the lower pressure of the collection bottle. The presence of carbon dioxide produced by the organisms in the soil will turn the indicator from blue to green. This step can be repeated.

Handout 1 ▸ P.3

Lab: The Gaia Hypothesis and Atmospheric Chemistry

Photograph 1. Materials for the Collector

- Two empty and clean plastic drink bottles
- One one-hole rubber stopper
- One two-hole rubber stopper
- Aquarium tubing
- Plastic pipette

Photograph 2. Procedure Part 1

- Insert tubing through both rubber stoppers. Use the two-hole stopper for the yeast bottle.
- Insert the pipette snugly into the remaining hole.
- Tubing should reach the bottom of the indicator bottle.
- Tubing should be above the yeast mixture in the second bottle.

Photograph 3. Procedures 1 and 2

- Stopper assembly for the indicator bottles.
- Remove the pipette and gently squeeze the bottle and hold.
- Replace the pipette and release the bottle.
- Gases will be drawn from the connected bottle and will bubble into the indicator.

Photograph 4. Procedure 2

- Cut the top from one bottle.
- Assemble stoppers.

Photograph 5. Final assembly of a unit.

- Use garden spade to cut a circle into the soil.
- Insert the edge of the cut bottle into the circle and pack the loose soil around the edge.
- (Note that if a one-hole stopper is used in the cut bottle, a second pipette will not be necessary.)

Handout 2 ▸ P.1

Questions for Research

1. Why do we call CO_2 and methane greenhouse gases?

2. How is Earth's atmosphere similar to the plastic of the collection bottle?

3. Why are we worried about CO_2 levels if CO_2 is part of the natural process of living things?

Handout 2 ▸ P.2

Questions for Research

4. Scientists can't use qualitative indicators like bromothymol blue in the atmosphere. So how do they measure the CO_2 levels?

5. How might human activities increase or decrease the biological contribution of CO_2?

6. How is CO_2 removed from the atmosphere to become part of the rock record?

Handout 2 ▸ P.3

Questions for Research

7. Trace how the CO_2 released by a microorganism in the soil might become part of a gastropod's shell in the ocean.

8. Infer what Earth's temperature would be like without CO_2.

9. How could the Gaia hypothesis be used to explain the change in bacteria from oxygen producers to CO_2 producers?

Mighty Microbes

Enduring Understandings

- Water, as the universal solvent, allowed for the transport, separation, and recombination of organic and inorganic materials, which was essential in the development of life on Earth.
- The transport, separation, and recombination of nutrients and inorganic materials led to the formation of membranes.
- Many chance events ultimately provided the mixture of specific materials to form primitive membranes, leading to the development of life forms.
- The presence of water elsewhere in the universe suggests similar processes could occur on other planets, with the possibility of life.

Essential Questions

- Why were the adhesive and cohesive properties of water essential to the development of life?
- How do cell processes depend upon the properties of water?
- What environmental factors could have led to the development of coacervates on primitive Earth?
- Why are the fluid characteristics of a membrane so important to life?
- How did organic molecules become enclosed in membranes to form the archaeons?
- How could archaeons survive primitive Earth's hostile conditions?
- Could archaeons have evolved to form bacteria, or did they co-evolve?
- What evidence suggests that some prokaryotic cells evolved to form eukaryotic cells?

Notes to the Teacher

It is important to stress at the beginning of this unit that there is no fossilized evidence for the evolution of cells. The information provided in this unit reflects the generally accepted theory for how cells were formed on Earth. However, there are other theories for how life came to be on Earth.

There are four episodes from *One Strange Rock* that are especially relevant to this lesson: "Survival," "Terraform," "Awakening," and "Genesis." Show as many episodes as time will permit, and allow time for student discussion and questions.

The suggested order of the lessons provided can be altered depending upon each teacher's approach to this unit and the time needed to perform the activities. The lesson has four parts, each taking a minimum of two class periods of 45 minutes to one hour. Each part takes a hands-on approach to learning, followed by individual and/or group analysis and class discussion of key concepts.

Part 1 focuses on the chemical properties of water molecules, specifically cohesion and adhesion. Prior to this exploration, students should be familiar with the difference between polar and non-polar molecules/compounds and with adhesion and cohesion.

Before the first class session, make a copy of **Handout 1: What Are the Properties of Water That Are Essential to Life?** for each student. For each group of two students, prepare one screened canning jar. Construct the screened canning jar by replacing the lid insert with a circular piece of window screening. Make sure to schedule adequate time to prepare the jar set-up because it can be time-consuming. Laminate white paper cards that will cover the top of the jar. Mix the gelatin and grated orange peels in a square or rectangular mold. After the gelatin has solidified, cut into one-half inch cubes. For each group, a plastic cup, a small coated paper plate, a microscope slide, cooking oil, dishwashing detergent, a felt-tip marker, and a disposable pipette are needed.

The activity will take approximately 45 minutes to one hour. The day after the exploration is completed, each group will discuss their observations and respond to questions on the question sheet provided. After that discussion is completed, have the students share their answers to the questions as a whole class. Provide the background information, **Handout 2: Properties of Water That Are Essential to Life Informational Sheet**, and discuss as a class the reasons for the exploration observations and how water was important to the development of life and to sustaining life.

For additional information on adhesive and cohesive properties of water, refer to:

https://water.usgs.gov/edu/adhesion.html and

https://chem.libretexts.org/Core/Physical_and_Theoretical_Chemistry/Physical_Properties_of_Matter/States_of_Matter/Properties_of_Liquids/Cohesive_and_Adhesive_Forces

Part 2 explores the development of organized droplets that can resemble one-celled organisms. The droplets are formed from proteins, carbohydrates, and other materials in a solution under certain environmental conditions.

Before starting this part of the lesson, make a copy of **Handout 3: What Conditions on Primitive Earth Could Have Led to the Development of Coacervates?** for each student. You will also need pH paper, 0.1 M hydrochloric acid, gelatin powder, gum arabic powder, and a living amoeba culture or prepared amoeba slides. To make the one percent gelatin solution, mix five grams of gelatin with 500 mL of distilled water. To make the one percent gum arabic solution, mix five grams of gum arabic with 500 mL of distilled water. The coacervate solution consists of the one percent gelatin and one percent gum arabic mixture. Prepare the coacervate solution by mixing five parts (by volume) of one percent gelatin solution plus three parts (by volume) one percent gum arabic solution. For each group, two small test tubes, a test tube rack, a disposable pipette, four slides, four coverslips, Parafilm or test tube stoppers, a graduated cylinder, an amoeba slide, a felt-tip marker, and a microscope (with a minimum 400× magnification) are needed. Be sure students have been trained in microscopy prior to this exploration.

The activity will take 45 minutes to one hour to complete. During the second class period, each group will discuss and complete the question sheet provided. After the group work is completed, have the students discuss as a class their group answers to the questions.

Some additional resources for this activity:

BSCS Blue: *Biological Science—A Molecular Approach*. 1996 (5th edition), and all previous editions. Investigation 4C: Coacervates (pages 630-631)

https://openi.nlm.nih.gov/detailedresult.php?img=PMC3977416_BMRI2014-180549.001&req=4

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4763778/figure/fig01/

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3390999/figure/f1-ijn-7-2975/

http://www.indiana.edu/~ensiweb/lessons/coac.ws.pdf

Part 3 of the lesson focuses on the structure and function of cell membranes using soap bubbles to model the cell membrane. Before the first class session, make a copy of **Handout 4: Why Are Membranes So Important to Life?** for each student. In advance of the activity, purchase 12 dozen wood clothespins with rounded heads, one ball of cotton string, one bag of straws, one roll of red, thinly insulated 24 AWG magnet wire (if not purchasing bubble wands), two different spools of cotton thread, six large rectangular plastic food containers, index cards, dishwashing detergent (Joy brand or equivalent), and high fructose corn syrup (Karo brand or equivalent).

Prepare a bubble mixture consisting of 100 mL of water mixed with 10 mL of dishwashing detergent and one tablespoon of corn syrup. Make the straw and string bubble maker, the small round cotton string pore maker, a twisted thread representing DNA, and the ten-inch wire bubble wand prior to the exploration; refer to the Lesson 4 slide presentation in Appendix 4 at the end of this guide for details. Give each group of four students a plastic tray with the bubble mixture, a bubble maker, 24 wooden clothespins, a penny, a small round cotton string, a twisted thread DNA model, a few small pieces of index card, straws, absorbent material to cover tables, a pencil, and a pair of scissors.

Each of the two activities will take 45 minutes to one hour to complete. During the third class period, each group will discuss and complete the question sheet provided. After the group work is completed, have the students discuss as a class their group answers to the questions. Discuss as a class how the observed physical properties of the soap bubble membrane model that of the cell membrane.

A few useful references:

Douglas Zook, *Microcosmos Curriculum Guide to Exploring Microbial Space*, published by Boston University, 1992

https://www.bioexplorer.net/phospholipid-bilayer.html/

Part 4 focuses on the ability of cells to survive in extreme environments. *Halobacterium salinarum* is a halophile archaeon that is able to survive in an environment with high salt concentrations. *Escherichia coli* is a bacterium. Both microbes are Biosafety Level-1 organisms that can be used in a high school. However, check state and local guidelines before performing this activity. The activity may also be modified to be done using only *H. salinarum*.

Before the first class session, make a copy of **Handout 5: In What Salt Concentration Can Single-Celled Organisms Survive?** for each student. In advance of the presentation, 24 Petri dishes, 24 disposable plastic inoculation loops, biohazardous waste bags, 100 grams of nutrient agar, one container of table salt (not iodized), one *E. coli* culture, and one *H. salinarum* culture must be purchased for a class of 24 students. An autoclave or pressure cooker type sterilizer and incubator are also needed. The microbial cultures must be placed in an incubator or out on a prep room counter. The nutrient agar with 1, 5, 10, 15, and 25 percent sodium chloride concentrations must be mixed with deionized or distilled water and sterilized in an autoclave or steam sterilizer and poured into the agar dishes prior to the start of the lab. Each group of four students will obtain five nutrient salt agar Petri dishes ranging from 1 to 25 percent sodium chloride concentration, five disposable plastic inoculation loops, and a felt-tip marker.

On the first day of the activity, it will take approximately 20 minutes to plate the *H. salinarum* and *E. coli*. The observations of the plated cultures after 24–48 hours and group discussion of the observations will take 45 minutes to one hour. On the third day, have the students discuss as a class their observations and how archaeons were able to survive early Earth's hostile environment and how they could have evolved to form other early types of cells, such as bacteria.

References:

- https://www.carolina.com/teacher-resources/Interactive/halobacteria-making-microbiology-manageable/tr10761.tr for information on *H. salinarum*. *H. salinarum* and *E. coli* are classified as Biosafety Level 1 non-pathogenic organisms that can be ordered from Carolina Biological and safely used in a high school classroom.
- https://microbewiki.kenyon.edu/index.php/Halobacterium
- https://www.atcc.org/products/all/700922 for information on *H. salinarum* NRC – 1
- http://static.nsta.org/pdfs/TipsForSafeHandlingOfMicroorganisms20160412.pdf, "Tips for the Safer Handling of Microorganisms in the Science Laboratory, approved by NSTA Safety Advisory Board – 31 March 2016" for information on the safe handling of microorganisms.

- https://books.google.com/books?id=q57_vr02_ycC&pg=PA77&lpg=PA77&dq=can+microbes+be+destroyed+using+bleach+in+a+high+school+science+lab?&source=bl&ots=ehaaAsZzO3&sig=DgI9VfZ0AEIQkFzCO-nsWZ9 kguI&hl=en&sa=X&ved=0ahUKEwjwu4am2f3XAhVIy0MKHeVZAKEQ6AEIOjAD#v=onepage&q=can%20microbes%20be%20destroyed%20using%20bleach%20in%20a%20high%20school%20science%20lab%3F&f=false for The NSTA Ready-Reference Guide to Safer Science, Vol. 3—Decontamination Techniques, p. 77.
- James G. Cappuccino and Chad T. Welch. *Microbiology: A Laboratory Manual*, 11th edition, Pearson, 2016.

Next Generation Science Standards

https://www.nextgenscience.org/search-standards

HS-LS1-2.
Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms.

HS-LS1-6.
Construct and revise an explanation based on evidence for how carbon, hydrogen, and oxygen from sugar molecules may combine with other elements to form amino acids and/or other large carbon-based molecules.

HS-LS2-3.
Construct and revise an explanation based on evidence for the cycling of matter and flow of energy in aerobic and anaerobic conditions.

HS-LS2-5.
Develop a model to illustrate the role of photosynthesis and cellular respiration in the cycling of carbon among the biosphere, atmosphere, hydrosphere, and geosphere.

HS-LS4-1.
Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence.

HS-LS4-5.
Evaluate the evidence supporting claims that changes in environmental conditions may result in (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species.

Duration of Lesson

Ten 45-minute to one-hour periods

Part 1. Two class periods

Part 2. Two class periods

Part 3. Three class periods

Part 4. Three-to-four class periods

Assessments

Completion of handouts

Group discussions

Diagram (summative assessment)

Materials needed

White board with white board markers or an interactive board, such as a smart board

For Part 1:

Canning jars with screw-on lids

Window screening

Laminate white paper cards

Clear gelatin

Small jar of grated orange peels

Plastic cups

Small coated paper plates

Microscope slides

Cooking oil

Dishwashing detergent

Disposable pipettes

Felt-tip markers

Handout 1: What Are the Properties of Water That Are Essential to Life?

Handout 2: Properties of Water That Are Essential to Life Informational Sheet

For Part 2:

Computer access for all students or classroom computer with projector

Wide-range pH paper

0.1 M hydrochloric acid

Gelatin powder

Gum arabic powder

Distilled water

Small test tubes

Test tube racks

Disposable pipettes

Microscope slides

Microscope coverslips

Parafilm or test tube stoppers

Graduated cylinder

Amoeba culture or prepared amoeba slides

Microscopes (with a minimum 400x magnification)

Felt-tip marker

Handout 3: What Conditions on Primitive Earth Could Have Led to the Development of Coacervates?

For Part 3:

- 12 dozen wood clothespins with rounded heads
- One ball of cotton string
- One bag of straws
- One roll of red 24 AWG magnet wire or bubble wands
- Two different colored spools of cotton thread
- Six large rectangular plastic food containers
- Index cards
- Dishwashing detergent (Joy brand or equivalent)
- High fructose corn syrup (Karo brand or equivalent)
- Pennies
- Absorbent material
- Pencils
- Scissors
- **Handout 4: Why Are Membranes So Important to Life?**
- Slide presentation in Appendix 4 at the end of this guide

For Part 4:

- 24–30 Petri dishes
- 24–30 disposable plastic inoculation loops
- Biohazard waste bags
- 100 grams of nutrient agar
- One container of table salt (not iodized)
- One *E. coli* culture
- One *H. salinarum* culture
- Autoclave or pressure cooker type sterilizer
- Incubator
- Felt-tip markers
- **Handout 5: In What Salt Concentration Can Single-Celled Organisms Survive?**

Procedure

Before the lab begins, have students view as many of the relevant episodes from *One Strange Rock* as time will permit. (See Notes to the Teacher for suggested episodes that work well with this lesson.) Allow time for student discussion, questions, and reflection.

Part 1: What Are the Properties of Water That Are Essential to Life?

1. Before class, check to be sure that each station has the necessary supplies for the activity.

2. Ask students why water is so essential to life. Discuss their ideas briefly.

3. Distribute copies of **Handout 1: What Are the Properties of Water That Are Essential to Life?**

4. Review the directions on the Handout and answer any questions.

5. Arrange students into pairs. Provide each pair with a screened jar, card, and other materials needed for the lab.

6. Allow students sufficient time to do the activity while you circulate to supervise and answer any additional questions.

7. After the water activity is completed, have students discuss the questions at the end of the handout and fill in their answers to the questions; the group work will probably extend into the next class period. Then have the students discuss as a whole class their group answers to the questions. See **Teacher Resource 1** for suggested answers to the questions.

8. Distribute copies of **Handout 2: Properties of Water That Are Essential to Life Informational Sheet**. Read through the handout with the class. Discuss the chemical reason for their observations during the lab and how water is important to the development of life and to sustaining life.

Part 2: What Conditions on Primitive Earth Could Have Led to the Development of Coacervates?

1. Distribute copies of **Handout 3**, and after reading the Background Information, have students access the three URLs on their computers and study the images. Alternately, you may wish to project the images. Conduct a discussion of what the images show.

2. Review the directions on the handout and stress safety precautions.

3. Arrange students into pairs with each pair given the prescribed materials necessary. Suggest that they check to see that the lab set-up is complete and that they are familiar with all the materials.

4. Allow students sufficient time to do the activity while you circulate to supervise and answer any additional questions.

5. After the activity is completed, have students discuss the questions at the end of the handout and fill in their answers to the questions; the group work will probably extend into the next class period. Then have the students discuss as a whole class their group answers to the questions. See **Teacher Resource 2** for suggested answers to the questions.

Part 3: Why Are Membranes So Important to Life?

1. Distribute copies of **Handout 4** and read the Background Information with students, taking time to answer any questions they may have.

2. Review the directions on the handout for the lab.

3. Arrange students into groups of four with each group given the prescribed materials necessary. Suggest that they check to see that the lab set-up is complete

4. Allow students sufficient time to do the activity while you circulate to supervise and answer any additional questions.

5. After the activity is completed, have students discuss the questions at the end of the handout and fill in their answers to the questions; the group work will probably extend into the next class period. Then have the students discuss as a whole class their group answers to the questions. See **Teacher Resource 3** for suggested answers to the questions.

Part 4: In What Salt Concentration Can Single-Celled Organisms Survive?

1. Distribute copies of **Handout 5**, and read the Background Information with students, taking time to answer any questions they may have.

2. Review the directions on the handout for the lab.

3. Arrange students into pairs with each pair given the prescribed materials necessary. Suggest that they check to see that the lab set-up is complete

4. Allow students sufficient time to do the activity while you circulate to supervise and answer any additional questions.

5. After the activity is completed, have students discuss the questions at the end of the handout and fill in their answers to the questions; the group work will probably extend into the next class period. Then have the students discuss as a whole class their group answers to the questions. See **Teacher Resource 4** for suggested answers to the questions.

Summative Assessment

Construct a diagram showing the sequence of events that could have led to the formation of coacervates and eventually to the development of single-celled and multicellular microbes.

- Start the diagram with water flowing over the primitive Earth environment.
- Be creative and use sketches to show processes, substances, and interactions that led to the formation of microbes.
- Provide descriptive labels next to each sketch in the diagram.

Handout 1 ▸ P.1

What Are the Properties of Water That Are Essential to Life?

Background Information:

The unusual properties of water allowed life to evolve and exist on Earth.

Objective:

To observe surface tension, cohesive forces, and adhesive forces associated with water.

Materials:

Canning jar with screw-on screened lid

Laminated card

Screen

Plastic cup

Plastic disposable pipette

Microscope slide

Tap water

Cooking oil

Soap

Methods:

Part A:

1. Pour tap water through the screened jar lid until the jar overflows with water.
2. Place a laminated card over the top of the jar and hold the card down tightly with one hand.
3. While still holding the card on the jar, quickly invert the jar over a sink, so the card is now on the bottom of the jar.
4. While holding the jar inverted over the sink, carefully remove your hand from the laminated card.
5. Have a partner record your observations in Table 1, Part A.
6. While still holding the jar inverted over the sink, slowly and carefully slide the card out from under the jar with one hand while holding the jar steady with the other hand.
7. Have a partner record the observations in Table 1, Part A.
8. Now, tilt the jar a few degrees, again over the sink.
9. Have a partner record the observations in Table 1, Part A.

Handout 1 ▸ P.2

What Are the Properties of Water That Are Essential to Life?

Part B:

1. Fill up a small glass container so that the water is level with the top of the glass. Make sure the water is not bubbling over the top.

2. Use a pipette and slowly add more drops of water to the glass until the water begins to spill over.

3. Observe the water in the glass at eye level.

4. Have a partner record the observations in Table 1, Part B.

5. Next gently place a paper clip on the surface of the water.

6. Repeat step #5 until the paper clip floats on the water.

7. Have a partner record the observations in Table 1, Part B. Observations should focus on the procedure that allowed the paper clip to float.

Part C:

1. Thoroughly clean a microscope slide with soap. Rinse completely and dry with paper towel.

2. Apply a light film of cooking oil to one-half of the upper side of the slide. Leave the other half clean and dry.

3. Place one drop of water on top of the dry half of the slide.

4. Place another drop of water on the top of the oil-coated half of the slide.

5. Observe and sketch the shape of the water droplets on each side of the slide in Table 1, Part C. Make sure to sketch the water droplets as they appear both from the top and the side.

Part D:

1. Place a beaker in a sink.

2. Hold the plate containing the gelatin mold under the hot water faucet in the sink, so that running water will flow onto the gelatin and drain into the beaker. Imagine this is water heated by flowing over hot rock on primitive Earth.

3. Carefully turn on the hot water so that the flow rate is able to erode the gelatin with minimal splashing. Be careful not to burn your hands.

4. Observe and sketch the contents of the beaker in Table 1, Part D.

Handout 1 ▸ P.3

What Are the Properties of Water That Are Essential to Life?

Observations:

Sketch and describe what happened in each part of the exploration.

Table #1

Part A	Part B

Handout 1 ▸ P.4

What Are the Properties of Water That Are Essential to Life?

Part C	Part D

What Are the Properties of Water That Are Essential to Life?

Conclusion: Discuss the following questions with your group members and record your answers in the spaces provided.

1. In Part A, what properties of water prevented the water from breaking into droplets and falling when the laminated card was removed? Explain your answer.

2. In Part B, what properties of water allowed the paper clip to float on the surface of the water? Explain your answer.

3. In Part C, observations were made when water was placed on a clean surface, and a hydrophobic surface. What caused the difference in how water reacted with the two different surfaces? Explain your answer.

What Are the Properties of Water That Are Essential to Life?

4. In Part D, the gelatin and orange peels were transported into the beaker by the water. Explain how the transport of the gelatin was different compared with that of the orange peels.

5. Cells are dimensional structures that enclose dissolved materials. How do you think the properties of water observed might have been essential to the formation of cells?

Teacher Resource 1 ▸ P. 1

Answer Sheet for Handout 1

Note: Students have varying levels of understanding, and answers should be discussed and clarified by the teacher.

What Are the Properties of Water That Are Essential to Life?

1. In Part A, what properties of water prevented the water from breaking into droplets and falling when the laminated card was removed? Explain your answer.

- Water molecules, being polar, will tend to stick to the glass due to adhesion.
- Because water molecules are polar, they will stick to each other because of cohesion, preventing the mass of water from separating into individual droplets.
- Some students (depending upon their knowledge of physical science concepts) may view the water in the jar as one macroscale mass that is held in the jar due to ambient atmospheric pressure surrounding the jar and reduced air pressure in the head space of the jar.

[Note: Students should be directed to focus on the first two bullets above to stay within the context of this exploration.]

2. In Part B, what properties of water allowed the paper clip to float on the surface of the water? Explain your answer.

- The water molecules formed strong polar covalent bonds. When the paper clip was placed horizontally on the surface of the water, its weight was evenly dispersed across a larger surface and the strength of the polar covalent bonds in the water allowed for the suspension of the paper clip.
- When the paper clip was placed vertically on the surface of the water, the strength of the polar covalent bonds in the water was not great enough to support the weight of the paper clip.
- Surface tension forces between the paper clip and the water opposed the force of gravity on the paper clip, keeping the paper clip at rest when placed horizontally on the water's surface.
- The paper clip floated on the water because of buoyancy.

3. In Part C, observations were made when water was placed on a clean surface and a hydrophobic surface. What caused the difference in how water reacted with the two different surfaces? Explain your answer.

- When water is placed on a clean glass slide, the water molecules will spread out evenly into a thin film due to the water molecules being strongly attracted to the glass.
- When water is placed on a slide covered in oil, the attraction of the water to the glass is reduced, and the water is weakly attracted to the oil. However, the water molecules are strongly attracted to each other and thus form droplets on the surface of the slide.
- Oil and water do not mix and separate from each other.

Teacher Resource
1 ▸ P.2

Answer Sheet for Handout 1

4 In Part D, the gelatin and orange peels were transported into the beaker by the water. Explain how the transport of the gelatin was different compared with that of the orange peels.

- After heating the gelatin containing the suspended orange peels, water initially quickly flowed freely over the surface of the paper plate.
- As the gelatin dissolved, it was transported in solution into the beaker.
- The orange peels were not dissolved but were released from the gelatin and transported as a solid with the water along the surface of the paper plate into the beaker.

5. Cells are dimensional structures that enclose dissolved materials. How do you think the properties of water observed might have been essential to the formation of cells?

- Because water molecules are polar, they are strongly attracted to each other and other substances that are also polar in nature, which promoted the formation of structures like cell membranes.
- Due to the attraction of water to some other molecules, substances were attracted to the water and stuck together, promoting formation of structures that eventually led to the development of cells.
- Rock particles and other materials found on primitive Earth were mobilized and transported to other locations. Some of these materials came together in such a way that they eventually formed structures leading to the development of cells.

Handout 2

Properties of Water That Are Essential to Life Informational Sheet

Background Information:

Water has unusual properties that were essential in dissolving and transporting substances found on the primitive Earth; this eventually led to the development and functioning of cells.

Water is a **polar molecule**, which has slight negative and positive charges on opposite sides due to its asymmetrical bonds. Because of its polar nature, water is considered the **universal solvent**. Water will be attracted to other charged molecules. When water is strongly attracted to a substance, the substance is dissolved due to disruption in the attractive forces between atoms in the substance.

Note that not all substances will easily dissolve in water. Many organic substances, such as lipids and waxes, will not dissolve easily in water.

If a substance is **hydrophilic** ("water-loving"), it has a surface to which water is attracted. Substances that are hydrophilic will dissolve in water. If a substance is **hydrophobic** ("water-fearing"), it has a surface to which water is not attracted and it will not dissolve in water.

Cohesive forces are the forces that occur due to the attraction between molecules of the same substance. **Surface tension** occurs in a liquid when there are no atoms above the surface and therefore the water molecules exhibit strong intermolecular attractions upon other water molecules that are nearby. Because of surface tension, a hydrophobic object will sink in water if its density is greater than water. However, if a hydrophobic object is less dense than water, the object will float on the surface of the water. Surface tension allows some insects to move along the surface of water. Surface tension also enables a paper clip to float on water.

Adhesive forces are the forces that occur due to the attraction between molecules that are not the same. For example, when a paper towel is dipped in water, the water is attracted to the cellulose fibers and spreads throughout the paper, even against the force of gravity.

Handout 3 ▸ P.1

What Conditions on Primitive Earth Could Have Led to the Development of Coacervates?

Background Information:

Coacervates are organized droplets of proteins, carbohydrates, and other materials that formed in an aqueous (water) solution. Scientists believe that coacervates may have been important in the development of primitive cells.

Review the images below depicting coacervate formation at the following websites:

https://openi.nlm.nih.gov/detailedresult.php?img=PMC3977416_BMRI2014-180549.001&req=4

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4763778/figure/fig01/

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3390999/figure/f1-ijn-7-2975/

Objectives:

To observe that under certain conditions, proteins, carbohydrates, and other materials in a solution may form organized droplets called coacervates.

To compare the appearance of coacervates with amoebas or other one-celled organisms.

Materials:

Personal protective equipment (apron, gloves, and goggles)

Four microscope slides

Wide-range pH test paper

Four coverslips

Amoebas, living or prepared slides

Disposable plastic pipette

0.1 M HCl (hydrochloric acid)

Coacervate solution

10-mL graduated cylinder

Two test tubes

Test tube rack

Parafilm or stoppers for test tubes

Compound light microscope

Procedure:

1. Obtain a test tube of coacervate solution.
2. Measure and record the pH of the mixture.
3. Place a drop of the mixture on a slide.
4. Slowly place a coverslip over the mixture.

Handout 3 ▸ P.2

What Conditions on Primitive Earth Could Have Led to the Development of Coacervates?

5. Observe the slide under low power and high power of the compound microscope, adjusting the sub-stage iris diaphragm or aperture wheel to give maximum viewing contrast.

6. Make sketches and observations in Table 1.

7. Add dilute HCl to the test tube, one drop at a time, and mix until the mixture remains uniformly cloudy. **Important: Use caution when working with HCl. Immediately inform your teacher of any contact with skin or eyes, ingestion, and spills.**

8. When the mixture remains uniformly cloudy, take another pH reading.

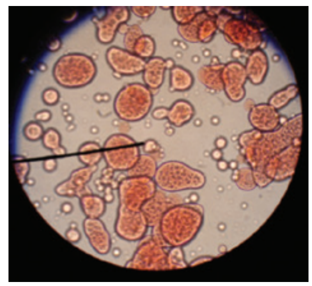
9. Place a drop of the mixture from step #7 on a slide with a coverslip.

10. Observe the slide under low power and high power of the microscope.

11. Look for coacervates, structures resembling those seen in Figure 1.

12. If no coacervates are observed, add another drop of acid to the test tube, mix, and observe under the microscope again. If coacervates are still not observed, carefully repeat steps 1–10.

Figure 1. An example of coacervates seen under 400× magnification.



Source: https://commons.wikimedia.org/wiki/File:Coacervats.JPG. Note that the image looks like it was taken with a microscope filter (orange color. Without a filter, the coacervates will be the color of the solution.

13. When coacervates are observed, make sketches and observations in Table 1. Be sure to note the total magnification and diaphragm setting of the microscope. Generally, under high power, the diaphragm setting must be increased for better visualization of the image.

14. Add dilute HCl to the test tube, one drop at a time, and mix and measure the pH after every third drop.

15. Continue step #14 until the solution becomes clear, and then measure the pH.

16. Place a drop of the mixture from step #15 on a slide with a coverslip.

17. Observe the slide under low power and high power of the microscope.

18. Make sketches and observations in Table 1.

19. Prepare a wet-mount of living amoebas or obtain a prepared slide of amoebas.

20. Make sketches and observations in Table 1.

Handout 3 ▸ P.3

What Conditions on Primitive Earth Could Have Led to the Development of Coacervates?

Observations:

Sketch and describe what happened in Part A and B of the exploration.

Table 1.

Initial Mixture of One Percent Gelatin and One Percent Gum Arabic Solution pH = ____________________	Coacervates Observed in Cloudy Mixture of One Percent Gelatin, One Percent Gum Arabic Solution, and HCl pH = ____________________
Sketches and Observations: **Total magnification:** ____________________ **Diaphragm setting:** ____________________	Sketches and Observations: **Total magnification:** ____________________ **Diaphragm setting:** ____________________

Handout 3 ▸ P.4

What Conditions on Primitive Earth Could Have Led to the Development of Coacervates?

Final Clear Mixture of One Percent Gelatin, One Percent Gum Arabic Solution, and HCl pH = ____________________	Living Preparation Slide of Amoebas or Prepared Amoeba Slide pH = ____________________
Sketches and Observations: Total magnification: ____________________ Diaphragm setting: ____________________	Sketches and Observations: Total magnification: ____________________ Diaphragm setting: ____________________

Handout 3 ▸ P.5

What Conditions on Primitive Earth Could Have Led to the Development of Coacervates?

Conclusion:

Discuss the following questions with your group members and record your answers in the spaces provided.

1. Where could the materials used to make coacervates in this exploration have come from on primitive Earth?

2. How did the pH range needed to form coacervates compare with the pH range under which many modern cells exist?

3. What characteristics of life do coacervates exhibit?

4. What characteristics of life are not exhibited by coacervates?

5. What might have happened to coacervates that allowed for the development of cells?

Teacher Resource
2 ▸ P. 1

Answer Sheet for Handout 3

Note: Students have varying levels of understanding, and answers should be discussed and clarified by the teacher.

What Conditions on Primitive Earth Could Have Led to the Development of Coacervates?

1. Where could the materials used to make coacervates in this exploration have come from on primitive Earth?
- Substances that were present on early Earth may have been transported by water and deposited into small water bubbles to form coacervates.

2. How did the pH range needed to form coacervates compare with the pH range under which many modern cells exist?
- Coacervates were formed at different pH concentrations. However, more coacervates were formed around a pH of 4-5. Many modern cells thrive in environments closer to a neutral pH.
- Lower pH values in some water on primitive Earth would support the development of certain pre-cells such as coacervates.
- As much of the water on Earth changed to a pH closer to neutral, many of the cells evolved to function at pH values closer to neutral.

3. What characteristics of life do coacervates exhibit?
- Coacervates have membranes that are selectively permeable.
- Coacervates are made of some organic molecules found in cells

4. What characteristics of life are not exhibited by coacervates?
Student answers will vary (and may be very creative).
- Cellular organization – possibly; primitive development of cell, but not specific prokaryotic or eukaryotic cell structure
- Reproduction – no visible division of cells observed
- Metabolism – no metabolic processes observed
- Homeostasis – possibly; ability to maintain structure at certain pH values
- Heredity – possibly; more coacervates at certain pH values
- Response to stimuli – possibly; more coacervates at certain pH values
- Growth and development – possibly; coacervates of various sizes
- Adaptation through evolution – possibly; more coacervates at certain pH values

5. What might have happened to coacervates that allowed for the development of cells?
- Coacervates may have enclosed additional, and more diverse, organic and inorganic substances that led to the development of specific structures, including nucleic acids.
- Coacervates may have combined with other coacervates to form more complex structures that evolved to become prokaryotic and eventually eukaryotic cells

Supplemental information on the effect of pH on the formation of coagulates in gelatin can be found here: https://prezi.com/rz8q_jockfxb/the-effect-of-ph-on-the-formation-of-coacervates-in-gelatin/. It is public and reusable and may assist the teacher with some aspects of the lab.

Handout 4 ▸ P.1

Why Are Membranes So Important to Life?

Background Information:

A lipid is a polymer generally made up of fatty acids and glycerol. Lipids are not soluble in water. Lipids are biomolecules that are hydrophobic. A living cell uses lipids to build plasma membranes and separate the water outside the cell from the water inside the cell.

The lipids in a cell membrane are phospholipids. A phospholipid is a single molecule made of a phosphate group (phosphorus and oxygen atoms) attached to two fatty acid chains and a glycerol. The phosphate group and glycerol form the hydrophilic end and the fatty acids form the hydrophobic end of the phospholipid.

The cell uses a bilayer of phospholipids to create a barrier between activities inside the cell and activities outside the cell. When phospholipids come in contact with water, they line up with their lipid "tails" pointing toward each other. This creates a hydrophobic barrier between the water inside the cell and the water outside the cell (the environment).

Figure 1 at right represents the structure of a phospholipid, consisting of a head (round part) and two tails:

- Phosphate group and glycerol (red)
- Fatty acid tails (blue)

Note that the head of the phospholipid is hydrophilic and the tails are hydrophobic.

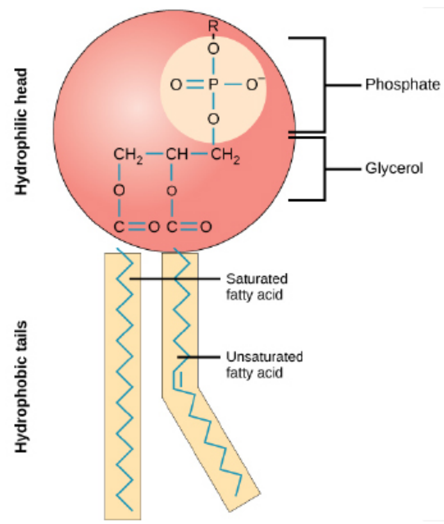
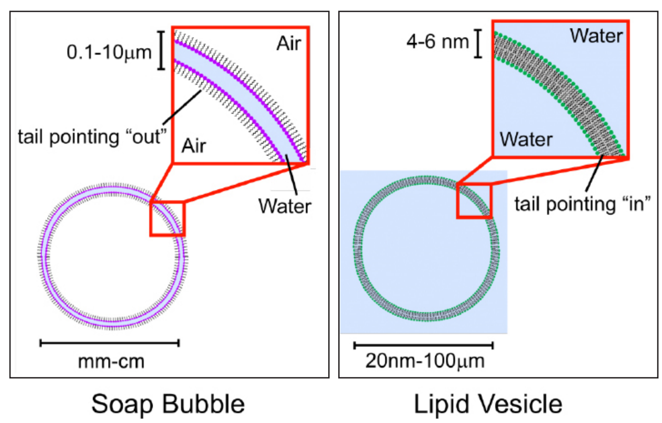


Figure 1. Source: https://upload.wikimedia.org/wikipedia/commons/b/bd/Figure_05_01_02.jpg



Soap Bubble Membrane and Phospholipid Membrane Structural Differences

Source: https://commons.wikimedia.org/wiki/File:Lipid_vesicle_vs_soap_bubble.svg

Handout 4 ▸ P.2

Why Are Membranes So Important to Life?

Objective:

To investigate the structure and properties of soap bubble membranes and how they are related to living cell plasma membranes.

Materials:

Wooden clothespins with round heads

Pennies

Ball of cotton string

Two Spools of cotton thread twisted into a small DNA double helix

Scissors

Plastic trays or bins

Straws

Aluminum wire or plastic bubble wand

Pencils

Index card

Absorbent material to cover tables

Water

Bubble mixture

Methods:

Part A: Clothespin Construction of Membranes

1. Construct a model of a cell membrane using the clothespins. Make the cell round.
   Assume the rounded tops of the clothespins are the phosphate groups and the straight ends of the pins are the lipid tails.

2. Using a pencil, sketch a drawing of the cell membrane's phospholipid bilayer model in the data table
   Color the hydrophilic phosphate groups and glycerol (heads) red.
   Color the hydrophobic fatty acid tails blue.
   Label the inside of the cell (ICF = intracellular fluid).
   Label the outside of the cell (ECF = extracellular fluid)

3. Construct a model of a soap bubble membrane using the clothespins.

4. Using a pencil, sketch a drawing of the soap bubble bilayer model in the data table.
   Color the hydrophilic heads red.
   Color the hydrophobic tails blue.

Handout 4 ▸ P.3

Why Are Membranes So Important to Life?

Part B: Flexible Membranes

1. Hold the bubble maker and place the bubble maker into the tray containing the bubble mixture. (The bubble holder is the rectangular frame made of two straws and string.)
2. Remove the bubble maker from the tray. There is now a thin film inside the bubble maker.
3. Bend the bubble maker into different shapes.

Part C: Self-Healing Membranes

1. Place one partner's soapy fingers/hand through the bubble.
2. Remove the hand from the bubble.

Part D: Selectively Permeable Membranes

1. Using the bubble wand, blow a bubble into the air.
2. Merge the bubble from step #1 with the bubble film on the bubble maker or a bubble in the tray.
3. Wet a penny and gently place it on top of the bubble.
4. Wet a very small piece of index card with soap and gently place it on top of the bubble, so that it passes into the bubble.
5. Wet the double helix model of DNA and gently place it on top of the bubble, so that it passes into the bubble.

Part E: The Fluid-Mosaic Membrane

1. Make a loop with string.
2. Dip the string in soap.
3. Place the string on the soap film of the bubble maker and pop the membrane within the loop.
4. Tip your film from side to side.

Part F: A Eukaryotic Cell

1. Try to make a bubble (or many bubbles) within a bubble to represent eukaryotic cell organelles.
2. Try to design more complex cells using the DNA model, pieces of index cards, string, or any other object available.

Handout 4 ▸ P.4

Why Are Membranes So Important to Life?

Observations

Cell Membrane Drawing	Soap Bubble Membrane Drawing

Handout 4 ▸ P.5

Why Are Membranes So Important to Life?

Conclusion: Discuss the following questions with your group members. Record your answers in the spaces provided.

What property of the membrane allowed it to be twisted without breaking?

Why is it important for a membrane to be both flexible and strong?

Why is it important that a membrane function both as a protective barrier and as a selectively permeable structure?

How do your observations help you understand how prokaryotic and eukaryotic cells may have formed?

Teacher Resource 3 ▸ P. 1

Answer Sheet for Handout 4 Why Are Membranes So Important to Life?

Note: Students have varying levels of understanding, and answers should be discussed and clarified by the teacher.

1. What property of the membrane allowed it to be twisted without breaking?
   - The membrane is considered a fluid because the phospholipid molecules can move within the layer to a limited degree. Because molecules within the membrane are able to move, they can rearrange in response to twisting.

2. Why is it important for a membrane to be both flexible and strong?
   - A membrane must be strong to be able to contain the cytosol and all of the structures within the cell.
   - The membrane must be flexible to resist rupture when there are moderate increases in internal and external pressure or distortion of the membrane.
   - The membrane must be flexible to allow material to pass through it without disrupting its structure.

3. Why is it important that a membrane function both as a protective barrier and as a selectively permeable structure?
   - To maintain the functioning of the cell, the membrane must keep unwanted materials out of the cell.
   - Nutrients, waste material, and other substances must pass through the cell membrane as needed in order for the cell to survive.

4. How do your observations help you understand how prokaryotic and eukaryotic cells may have formed?
   - Similar to a cell, the soap membrane maintained its structure when penetrated by materials from outside the membrane.
   - Similar to a cell, the soap membrane allowed some material to enter and exit with and without disruption.
   - As coacervates may have formed into cells, some substances may have been enclosed within the coacervate, leading to the development of cells. The small piece of index card and the DNA thread model remained suspended within the soap bubble, which may be analogous to coacervates enclosing substances within their membrane.
   - The large soap bubble membrane was able to enclose smaller soap bubble membranes. This may have been analogous to the formation of organelles within a eukaryotic cell.

Handout 5 ▸ P.1

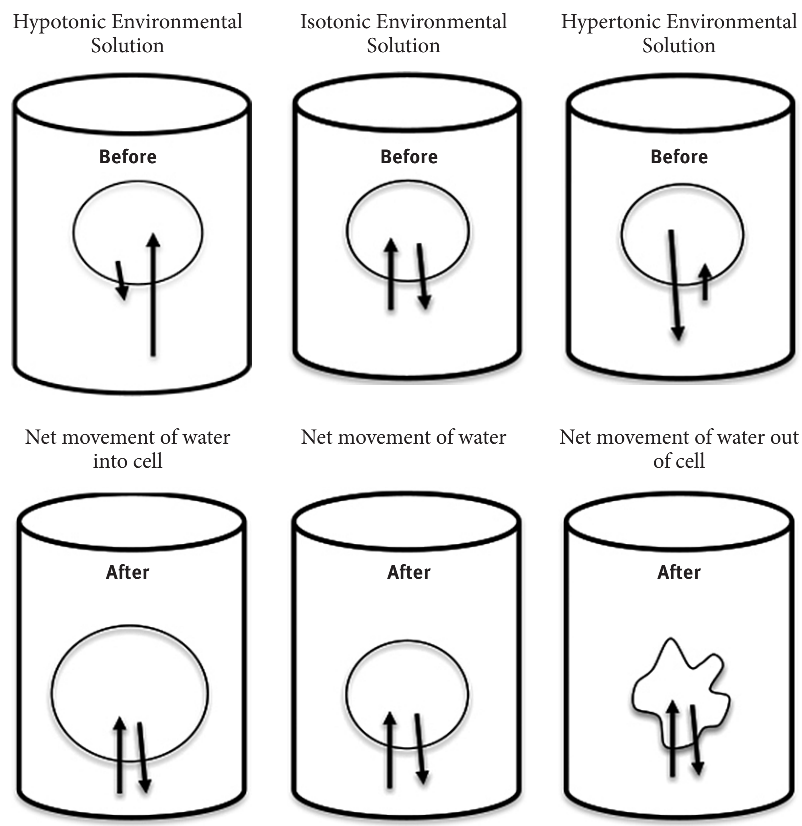
In What Salt Concentration Can Single-Celled Organisms Survive?

Background Information:

Osmosis is the movement of water molecules across a selectively permeable membrane from an area of higher concentration to an area of lower concentration.

When a cell is placed in an environmental solution containing a higher concentration of salt, the environmental solution (known as the **extracellular fluid**) is considered a **hypertonic solution**. Because the extracellular fluid has a higher solute and lower water concentration compared with the cell, it possesses a higher osmotic pressure and will tend to draw water out of the cell.

Conversely, when a cell is placed in an environmental solution containing a lower concentration of salt, the extracellular fluid is considered a **hypotonic solution**. Because the extracellular fluid has a lower solute and higher water concentration compared with the cell, it possesses a lower osmotic pressure, and water will tend to go into the cell.



Microorganisms live in a wide range of habitats with varying osmotic pressure environments. Since water is essential to life, the osmotic pressure of the environment surrounding a cell is a significant factor in cell survival.

H. salinarum is a member of the domain Archaea and the kingdom Archaebacteria.

E. coli is a member of the domain Bacteria (Eubacteria) and the kingdom Bacteria (Eubacteria)

Handout 5 ▸ P.2

In What Salt Concentration Can Single-Celled Organisms Survive?

Objective:

To observe the effect of osmotic pressure within various environments on the microorganisms *H. salinarum* and *E. coli.*

Materials:

H. salinarum culture incubated at 25° C

E. coli culture incubated at 37° C

Five nutrient agar plates ranging from 1 to 25 percent sodium chloride concentration

Bunsen burner (if not using disposable inoculating loops)

Inoculating loop

Felt-tip marker

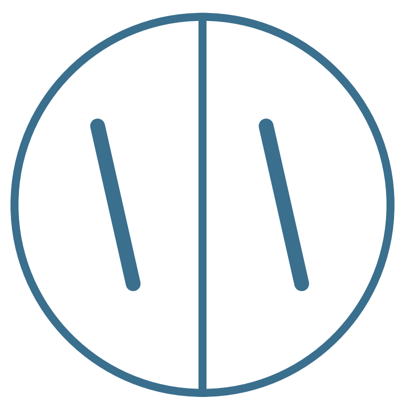
Autoclave or steam sterilizer

Incubator

Biohazardous waste bags

Methods:

1. Label the bottom of the Petri dishes with the initials of group members, date, and type of agar.
2. Be sure to label on the outer edges of the Petri dish bottom.
3. Use a felt-tip marker and divide each plate in half.
4. Label one half of the plate *H. salinarum* and the other half *E. coli*
5. Using a sterile technique, inoculate the *H. salinarum* and *E. coli* on the plates using a single-line inoculating technique on the appropriate labeled half of the plate.

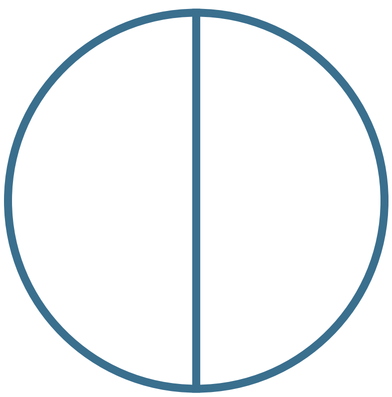
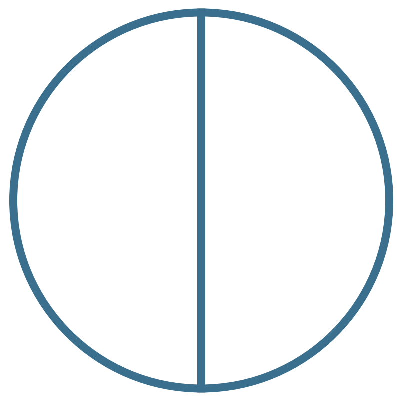


6. Incubate plates in an inverted position for 48–72 hours at 25° C.
7. Observe and record observations in Table 1.

Handout 5 ▸ P.3

In What Salt Concentration Can Single-Celled Organisms Survive?

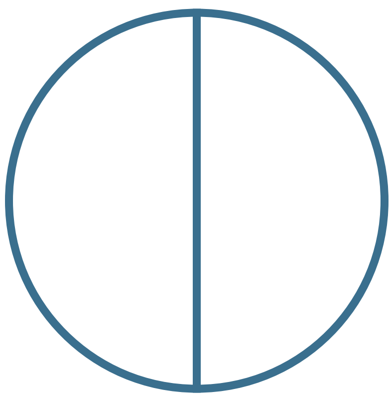
Table 1. Observations:

Plate	Plate
 *H. salinarum and E.coli* ________________ Hours 25°C Nutrient agar plate with one percent sodium chloride concentration	 *H. salinarum and E.coli* ________________ Hours 25°C Nutrient agar plate with 5 percent sodium chloride concentration
Observations and Comments:	Observations and Comments:

Handout 5 ▸ P.4

In What Salt Concentration Can Single-Celled Organisms Survive?

Plate



H. salinarum and E.coli

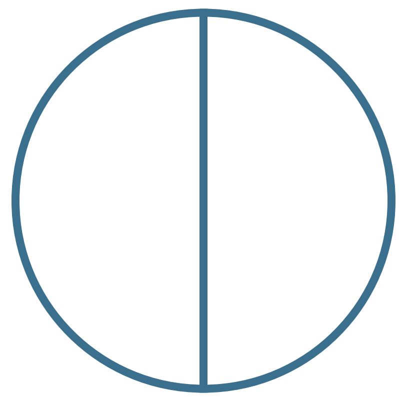
__________________ **Hours**

25°C

Nutrient agar plate with 10 percent sodium chloride concentration

Observations and Comments:

Plate



H. salinarum and E.coli

__________________ **Hours**

25°C

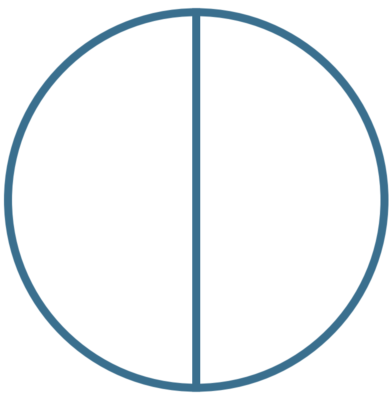
Nutrient agar plate with 15 percent sodium chloride concentration

Observations and Comments:

Handout 5 ▸ **P.5**

In What Salt Concentration Can Single-Celled Organisms Survive?

Plate



H. salinarum and E.coli

____________________ Hours

25°C

Nutrient agar plate with 25 percent sodium chloride concentration

Observations and Comments:

Conclusion:

Discuss the following questions with your group members. Record your answers in the spaces provided.

1. After reading the background information on osmotic pressure, what role do halophile membranes have in improving the chance of survival in a hostile environment?

2. You observed the effects of different concentrations of sodium chloride on *H. salinarum* and *E. coli*. Based upon these observations, which microbe do you think would have been more likely to survive on primitive Earth? Explain your reasoning.

Teacher Resource 4

Answer Sheet for Handout 1 In What Salt Concentration Can Single-Celled Organisms Survive?

Students have varying levels of understanding, and answers should be discussed and clarified by the teacher.

1. After reading the background information on osmotic pressure, what role do halophile membranes have in improving the chance of survival in a hostile environment?

- The halophile membrane allows nutrients to enter and exit the cell so that homeostasis is maintained when placed in a hypertonic (high salt concentration) environmental solution.
- The halophile membrane does not allow excess water to leave the cell via osmosis, thereby preventing the cell from undergoing plasmolysis.

2. You observed the effects of different concentrations of sodium chloride on *H. salinarum* and *E. coli.* Based upon these observations, which microbe do you think would have been more likely to survive on primitive Earth? Explain your reasoning.

- *H. salinarum* is better adapted to survive in high salt concentrations compared with *E. coli*
- Bacteria such as *E. coli* live in the intestines of warm-blooded mammals in an environment that is not as hostile as was the environment of primitive Earth. Therefore, it is unlikely that *E. coli* would have survived on primitive Earth.
- Because *H. salinarum* is an archaebacterium that lives in an extreme environment, it was more likely than *E. coli* to survive on primitive Earth. Experimentally, this is supported by the greater number of colonies of *H. salinarum* nutrient agar plates with the higher sodium chloride concentrations.

Teacher Resource 5 ▸ P.1

Guidance for Summative Assessment

Construct a diagram showing the sequence of events that could have led to the formation of coacervates and eventually to the development of single-celled and multicellular microbes.

- Start the diagram with water flowing over the primitive Earth environment.
- Be creative and use sketches to show processes, substances, and interactions that led to the formation of microbes.
- Provide descriptive labels next to each sketch in the diagram.

Student answers will vary, but should relate the explorations to the accepted theory as to the development of life on Earth

On primitive Earth, water flowed along the surface of the Earth, dissolving and transporting organic and inorganic substances.

Source: https://pixabay.com/en/waters-nature-reflection-wave-3085701/

Under certain conditions, some organic molecules found in water were attracted to each other, forming membranes that enclosed other organic molecules.

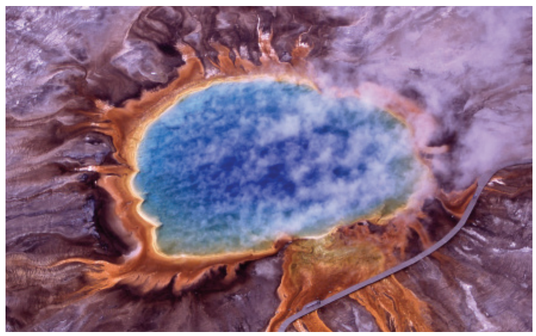
Source: https://commons.wikimedia.org/wiki/File:Coacervats.JPG

Time

Teacher Resource 5 ▸ P.2

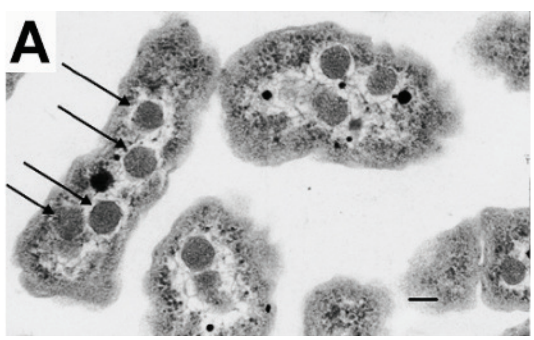
Guidance for Summative Assessment

An example of a archaebacterial is the modern extremophile. Extremophiles produce the colors seen in geothermal springs, and survive in conditions similar to those of primitive Earth. It is possible that coacervates were the precursors to these extremophiles.



Source: https://upload.wikimedia.org/wikipedia/commons/f/f5/Grand_prismatic_spring.jpg

As cells evolved, micro-compartments became more numerous, making cells more complex. This micrographic image of modern bacteria shows micro-compartments containing proteins.



Source: https:///upload.wikimedia.org/wikipedia/commons/3/35/Carboxysomes_EM_ptA.jpg

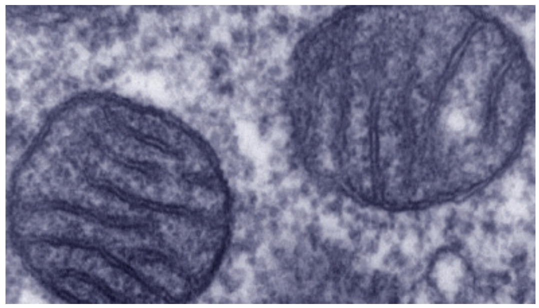
Time

Teacher Resource
5 ▸ P. 3

Guidance for Summative Assessment

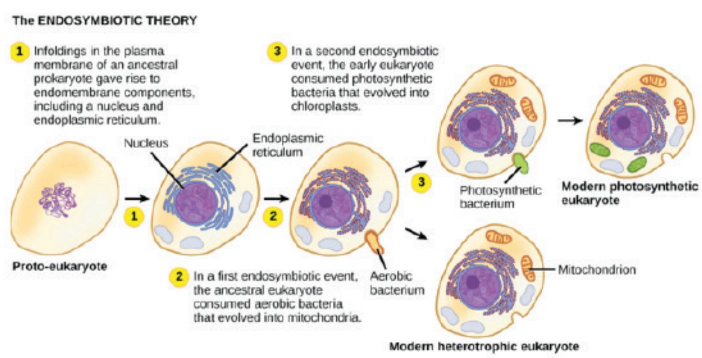
Many scientists believe that over time simple cells were enclosed within larger cells to form symbiotic relationships that led to the formation of eukaryotic cells.

Read the information in National Geographic's "The Greatest Merger in the History of Earth"at http://phenomena.nationalgeographic.com/2014/02/10/the-greatest-merger-in-the-history-of-life-on-earth/



Source: http://phenomena.nationalgeographic.com/files/2014/02/Mitochondria.jpg

Generally accepted theory on formation of eukaryotic cells



https://upload.wikimedia.org/wikipedia/commons/thumb/0/07/Figure_23_01_04.png/640px-Figure_23_01_04.png

Time

The History of Life

Enduring Understandings

- The evolution of life on Earth over geologic time has been punctuated by five mass extinctions.
- Development of new life forms following such extinctions suggests that the Earth is able to "heal" itself.
- Humans have actually lived on the Earth a short time in comparison with other life forms.
- Evolution results in constantly changing life forms and drives all life over time.
- The half-life of elements can be used to date fossils and rocks.

Essential Questions

- How have the five major extinction events impacted life on Earth?
- What are the possible causes of the five major extinction events?
- Are we witnessing the sixth major extinction event?
- How are fossils created and dated?
- When did complex life begin?
- How does evolution work?
- How can gases and electricity be turned into amino acids?

Notes to the Teacher

This lesson is designed to work in tandem with episodes of the National Geographic series *One Strange Rock* and classroom lectures regarding the material. *One Strange Rock* highlights the fact that planet Earth is unique within our solar system, and that its uniqueness is due to the presence of life here and the absence of life on the other planets. The series makes the significant point that the Earth appears to be able to "heal" itself from cosmic disasters, such as impacts from meteors like the Cretaceous-Tertiary (also called the K-T) extinction event 65 million years ago. The K-T event resulted in the end of a nearly 200-million-year rule of the dinosaurs, and the expansion of the newly arrived mammals. Animal species were not the only life forms impacted, since the same impact ended the dominance of major plant types (gymnosperms) and the origin of new ones (angiosperms). In addition to the history of life, the lesson will cover the role that extinction events have played in changing the trajectory of life.

The episodes that are particularly relevant to this lesson are these: "Survival," "Terraform," "Awakening," "Genesis," and "Alien." Have students see as many as time will permit in conjunction with doing the exercises outlined in the lesson.

You should thoroughly familiarize yourself with the background information and vocabulary that can be found in **Teacher Resource 1**. If desired, you can also photocopy this resource for your students.

You should review selected episodes from *One Strange Rock* and the activities prior to teaching the lesson, as some activities (Natural Selection Lab, Understanding the Miller–Urey) are best given via Google Classroom or other online class resources. Class time will be needed to allow students the opportunity to view the episode(s) prior to each lesson activity. Understanding the basics of organic chemistry is helpful for some of these activities but not imperative for this lesson.

Much of this lesson plan is project-based learning, which calls for ample student time to work on the activities at a reasonable pace. The mass extinction event activity may be used as a stand-alone unit to give students an understanding of its role in the overall process of evolution. Feel free to choose from among these activities to tailor the lesson to your students' needs. Before the lesson, make sufficient copies of the handouts to give to your students.

Part 1 is an opportunity for students to review what they already know about Earth's early history and for you to assess that knowledge. Before the lesson begins, get 14 large sheets of paper, newsprint, or poster board and put one of the following questions at the top of each sheet. Then post the sheets around the room.

1. How did our solar system and the Earth form?
2. Where did the moon come from?
3. What important resource came to Earth from meteorites?
4. Would you want to live on the early Earth's surface? Why?
5. Where and how did life as we know it begin?
6. When did oxygen form on Earth? What caused the increase of oxygen?
7. What is the Cambrian explosion? Why is it important?
8. What was the first species of animal to move from the water to land?
9. How did more oxygen affect species like insects?
10. What benefits do eggs provide for a species?
11. What caused dinosaurs to go extinct?
12. Where did the early mammals live during the mass extinction of the dinosaurs?
13. On which continent did humans evolve?
14. What benefit did walking on two legs give early hominid species?

In this part of the lesson, student pairs walk around the room, having two minutes to answer each of these questions. Every group does not have to get to every sheet; in fact, the answers would probably be repetitive. Five or six changes of position should yield a sampling of what students know and don't know. After this exercise, you will show as many episodes of *One Strange Rock* as time permits, with priority given to "Genesis," "Survival," "Awakening," and "Terraform."

In Part 2 of the lesson, students work with the concept of scale and research to create a geologic timeline. After illustrating a timeline and scale with events familiar to students, you will have them work with vast periods of time on a scaled timeline. They will need access to the Internet to research events to add to their timeline. Before beginning, educators should have enough paper for approximately 4.5 meters per group. Receipt paper is ideal for this, or you can cut long strips of freezer or shelf paper. Students will also need colored pencils or markers for adding events to the timelines.

The Miller–Urey and the origin of life hypothesis is the subject of Part 3. Prepare a lecture based on the notes in **Teacher Resource 1** to discuss early life on Earth; this resource can be found at the end of this lesson. After that, students will complete **Handout 2: Understanding the Miller–Urey Experiment**. You may wish to have students use an online classroom setting, such as Google Classroom, due to the linked resource. Be sure to work through the online experiment ahead of time yourself in order to feel comfortable with the simulation.

Part 4 deals with the Cambrian explosion. The first segment is a homework research assignment, for students to gather information about the Cambrian period using **Handout 3: The Cambrian Explosion**. A discussion in class gives students the opportunity to share information and recognize conflicting theories about its causes. This part of the lesson concludes with an 11-minute video from *The Economist* that includes animation and spectacular underwater imagery of sea life to explore the Cambrian.

The end of the video mentions the occurrence of mass extinction events in Earth's history. That is the topic of Part 5. Before this part of the lesson, students should have read and annotated **Handout 4** and done additional reading on one of the extinction events. You can assign the events or let students choose, but if they choose, make sure that someone is covering each topic. The discussion begins with the concept of extinction, brings in endangered species, and then segues to mass extinction events. A list of endangered species can be found at the U.S. Fish and Wildlife Service website at https://www.fws.gov/endangered/.

Part 6 of the lesson is on fossils. If you have some fossils of your own or your school has some in its possession, bring them to class. If not, you can assemble a slideshow of 6-10 slides easily using Google Images to give students a visual to start the lesson. After a discussion on the fossilization process and types of fossils, students use **Handout 5: Modeling the Half-Life of an Isotope** and work with Skittles to measure the rate of change and how radioactive decay can be used to date objects. Before the class, set up a Tupperware-type container for each lab group and drop 100 Skittles into each. Be sure you have enough Skittles for the activity. If desired, you can use pennies for this activity instead; rolls of pennies would not require so much counting. However, your students would probably prefer Skittles.

The project outline in Part 7 relies on students working both independently and cooperatively to learn more about fossilization. After a review of the different types of fossilizations, students research additional material on their own, share information with their group, and plan a slideshow. It is important that they use high-quality sources for research, and you may wish to dedicate some class time to discussing how to evaluate websites. Individual student artworks will extend the understanding of the process of fossilization and will give students practice at science illustration. You may want to conclude the class with a discussion of science illustration as a career for students interested in art and design. Some useful information about this is available at https://gnsi.org/science-illustration/careers-ed. Students who wish to learn more might with to read an interview with a science illustrator at https://blogs.scientificamerican.com/symbiartic/never-met-a-scientific-illustrator-meet-carol/.

There is a scoring guide in two parts in **Teacher Resource 2**. The first part is for the group slideshow; it is followed by three individual scoring guides for group members for the artwork. Together, the group score plus individual score add up to 100 points.

Part 8, the section on evolution and natural selection, begins with a lecture to give students context on natural selection and evolution; there is information in **Teacher Resource 1** that you may use for this. Then students work on a simulation available online from the Lawrence Hall of Science at the University of California, Berkeley. After "designing" three birds, they follow the process of natural selection in the simulation and complete a chart. Then they answer questions to understand the general principles of the process. You will need computer access for each student. For Step 2, students should discuss in small groups; the rest of the activity requires independent work.

Here are some additional resources you may find helpful:

National Geographic: *The Story of Earth*
https://www.youtube.com/watch?v=SYOarZKipnU

Cosmos: A Spacetime Odyssey — Cosmic Calendar
http://www.dailymotion.com/video/x3sjrbk

Galapagos Finch Evolution — HHMI BioInteractive Video
https://www.youtube.com/watch?v=mcM23M-CCog

The Origin of Birds — HHMI BioInteractive Video
https://www.youtube.com/watch?v=z4nuWLd2ivc

Does the Cambrian explosion pose a challenge to evolution?
http://biologos.org/common-questions/scientific-evidence/cambrian-explosion

Natural Selection
http://sepuplhs.org/high/sgi/teachers/evolution_act11_sim.html

Miller–Urey Experiment
https://www.ucsd.tv/miller-urey/

How Carbon Dating Works
https://www.youtube.com/watch?v=Kcuz1JiMk9k

Common Core Standards addressed by this lesson

Key Ideas and Details:

CCSS.ELA-Literacy.RST.6-8.1
Cite specific textual evidence to support analysis of science and technical texts.

CCSS.ELA-Literacy.RST.6-8.2
Determine the central ideas or conclusions of a text; provide an accurate summary of the text distinct from prior knowledge or opinions.

CCSS.ELA-Literacy.RST.6-8.3
Follow precisely a multistep procedure when carrying out experiments, taking measurements, or performing technical tasks.

CCSS.ELA-Literacy.RST.9-10.
Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions.

CCSS.ELA-Literacy.RST.9-10.2
Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text.

CCSS.ELA-Literacy.RST.9-10.3
Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks, attending to special cases or exceptions defined in the text.

Craft and Structure:

CCSS.ELA-Literacy.RST.6-8.4
Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to *grades 6–8 texts and topics*.

CCSS.ELA-Literacy.RST.6-8.5
Analyze the structure an author uses to organize a text, including how the major sections contribute to the whole and to an understanding of the topic.

CCSS.ELA-Literacy.RST.6-8.6
Analyze the author's purpose in providing an explanation, describing a procedure, or discussing an experiment in a text.

CCSS.ELA-Literacy.RST.9-10.4
Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to *grades 9–10 texts and topics*.

CCSS.ELA-Literacy.RST.9-10.5
Analyze the structure of the relationships among concepts in a text, including relationships among key terms (e.g., *force, friction, reaction force, energy*).

CCSS.ELA-Literacy.RST.9-10.6
Analyze the author's purpose in providing an explanation, describing a procedure, or discussing an experiment in a text, defining the question the author seeks to address.

Common Core Standards addressed by this lesson

Integration of Knowledge and Ideas:

CCSS.ELA-Literacy.RST.6-8.7
Integrate quantitative or technical information expressed in words in a text with a version of that information expressed visually (e.g., in a flowchart, diagram, model, graph, or table).

CCSS.ELA-Literacy.RST.6-8.8
Distinguish among facts, reasoned judgment based on research findings, and speculation in a text.

CCSS.ELA-Literacy.RST.6-8.9
Compare and contrast the information gained from experiments, simulations, video, or multimedia sources with that gained from reading a text on the same topic.

CCSS.ELA-Literacy.RST.9-10.7
Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words.

CCSS.ELA-Literacy.RST.9-10.8
Assess the extent to which the reasoning and evidence in a text support the author's claim or a recommendation for solving a scientific or technical problem.

NGSS Standards addressed by this lesson

MS-LS4-1.
Analyze and interpret data for patterns in the fossil record that document the existence, diversity, extinction, and change of life forms throughout the history of life on Earth under the assumption that natural laws operate today as in the past. [Clarification Statement: Emphasis is on finding patterns of changes in the level of complexity of anatomical structures in organisms and the chronological order of fossil appearance in the rock layers.] [Assessment Boundary: Assessment does not include the names of individual species or geologic eras in the fossil record.]

MS-LS4-2.
Apply scientific ideas to construct an explanation for the anatomical similarities and differences among modern organisms and between modern and fossil organisms to infer evolutionary relationships. [Clarification Statement: Emphasis is on explanations of the evolutionary relationships among organisms in terms of similarity or differences of the gross appearance of anatomical structures.]

MS-LS4-3.
Analyze displays of pictorial data to compare patterns of similarities in the embryological development across multiple species to identify relationships not evident in the fully formed anatomy. [Clarification Statement: Emphasis is on inferring general patterns of relatedness among embryos of different organisms by comparing the macroscopic appearance of diagrams or pictures.] [Assessment Boundary: Assessment of comparisons is limited to gross appearance of anatomical structures in embryological development.]

NGSS Standards addressed by this lesson

MS-LS4-4.
Construct an explanation based on evidence that describes how genetic variations of traits in a population increase some individuals' probability of surviving and reproducing in a specific environment. [Clarification Statement: Emphasis is on using simple probability statements and proportional reasoning to construct explanations.]

MS-LS4-6.
Use mathematical representations to support explanations of how natural selection may lead to increases and decreases of specific traits in populations over time. [Clarification Statement: Emphasis is on using mathematical models, probability statements, and proportional reasoning to support explanations of trends in changes to populations over time.] [Assessment Boundary: Assessment does not include Hardy-Weinberg calculations.]

HS-LS4-1.
Communicate scientific information indicating that common ancestry and biological evolution are supported by multiple lines of empirical evidence. [Clarification Statement: Emphasis is on a conceptual understanding of the role each line of evidence has relating to common ancestry and biological evolution. Examples of evidence could include similarities in DNA sequences, anatomical structures, and order of appearance of structures in embryological development.]

HS-LS4-2.
Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment. [Clarification Statement: Emphasis is on using evidence to explain the influence each of the four factors has on number of organisms, behaviors, morphology, or physiology in terms of ability to compete for limited resources and subsequent survival of individuals and adaptation of species. Examples of evidence could include mathematical models, such as simple distribution graphs and proportional reasoning.] [Assessment Boundary: Assessment does not include other mechanisms of evolution, such as genetic drift, gene flow through migration, and co-evolution.]

HS-LS4-3.
Apply concepts of statistics and probability to support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait. [Clarification Statement: Emphasis is on analyzing shifts in numerical distribution of traits and using these shifts as evidence to support explanations.] [Assessment Boundary: Assessment is limited to basic statistical and graphical analysis. Assessment does not include allele frequency calculations.]

HS- LS4-4.
Construct an explanation based on evidence for how natural selection leads to adaptation of populations. [Clarification Statement: Emphasis is on using data to provide evidence for how specific biotic and abiotic differences in ecosystems (such as ranges of seasonal temperature, long-term climate change, acidity, light, geographic barriers, or evolution of other organisms) contribute to a change in gene frequency over time, leading to adaptation of populations.]

HS-LS4-5.
Evaluate the evidence supporting claims that changes in environmental conditions may result in (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species. [Clarification Statement: Emphasis is on determining cause and effect relationships for how changes to the environment, such as deforestation, fishing, application of fertilizers, drought, and flood, and the rate of change of the environment affect distribution or disappearance of traits in species.]

NGSS Standards addressed by this lesson

MS-ESS1-4.

Construct a scientific explanation based on evidence from rock strata for how the geologic time scale is used to organize Earth's 4.6-billion-year history. [Clarification Statement: Emphasis is on how analyses of rock formations and the fossils they contain are used to establish relative ages of major events in Earth's history. Examples of Earth's major events could range from being very recent (such as the last ice age or the earliest fossils of *Homo sapiens*) to very old (such as the formation of Earth or the earliest evidence of life). Examples can include the formation of mountain chains and ocean basins, the evolution or extinction of particular living organisms, or significant volcanic eruptions.] [Assessment Boundary: Assessment does not include recalling the names of specific periods or epochs and events within them.]

MS-ESS2-2.

Construct an explanation based on evidence for how geoscience processes have changed Earth's surface at varying time and spatial scales. [Clarification Statement: Emphasis is on how processes change Earth's surface at time and spatial scales that can be large (such as slow plate motions or the uplift of large mountain ranges) or small (such as rapid landslides or microscopic geochemical reactions) and how many geoscience processes (such as earthquakes, volcanoes, and meteor impacts) usually behave gradually but are punctuated by catastrophic events. Examples of geoscience processes include surface weathering and deposition by the movements of water, ice, and wind. Emphasis is on geoscience processes that shape local geographic features, where appropriate.]

MS-ESS2-3.

Analyze and interpret data on the distribution of fossils and rocks, continental shapes, and seafloor structures to provide evidence of the past plate motions. [Clarification Statement: Examples of data include similarities of rock and fossil types on different continents, the shapes of the continents (including continental shelves), and the locations of ocean structures (such as ridges, fracture zones, and trenches).] [Assessment Boundary: Paleomagnetic anomalies in oceanic and continental crust are not assessed.]

HS-ESS1-5.

Evaluate evidence of the past and current movements of continental and oceanic crust and the theory of plate tectonics to explain the ages of crustal rocks. [Clarification Statement: Emphasis is on the ability of plate tectonics to explain the ages of crustal rocks. Examples include evidence of the ages of oceanic crust increasing with distance from mid-ocean ridges (a result of plate spreading) and the ages of North American continental crust decreasing with distance away from a central ancient core of the continental plate (a result of past plate interactions).]

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. [Clarification Statement: Emphasis is on using available evidence within the solar system to reconstruct the early history of Earth, which formed along with the rest of the solar system 4.6 billion years ago. Examples of evidence include the absolute ages of ancient materials (obtained by radiometric dating of meteorites, moon rocks, and Earth's oldest minerals), the sizes and compositions of solar system objects, and the impact cratering record of planetary surfaces.]

HS-ESS2-1.

Develop a model to illustrate how Earth's internal and surface processes operate at different spatial and temporal scales to form continental and ocean-floor features. [Clarification Statement: Emphasis is on how the appearance of land features (such as mountains, valleys, and plateaus) and sea-floor features (such as trenches, ridges, and seamounts) are a result of both constructive forces (such as volcanism, tectonic uplift, and orogeny) and destructive mechanisms (such as weathering, mass wasting, and coastal erosion).] [Assessment Boundary: Assessment does not include memorization of the details of the formation of specific geographic features of Earth's surface.]

Duration of the Lesson

Five to 15 class periods, depending on the level of detail and topics to be included.

Assessments

Completion of one or more of the following activities, depending on the teacher's interests and experience. One or more of the *One Strange Rock* episodes should be viewed by the students. Episodes entitled "Survival," "Terraform," "Awakening," and "Genesis" all have content that links with the activities listed below.

The National Geographic documentary *One Strange Rock*, one or more episodes

The *Understanding the Miller–Urey Experiment* worksheet

The *Geologic Time Scale* activity

The *Cambrian Explosion Reading* worksheet

The *Big Five Mass Extinction Events Reading* worksheet

The *Natural Selection* lab

The *Half Life* lab

The *Fossil Presentation* project

Materials needed

Paper

Meter sticks (or measuring tapes)

Scissors

Colored pencils

Receipt paper (approximately 2-inch width)

Computer and Internet access

Google classroom

Skittles (one-to-two large bags, depending on size of class)

Tupperware containers

Procedure

Part 1. Introducing *One Strange Rock*

1. Tell your students that they are soon going to watch episodes from a National Geographic series about the history of the Earth called *One Strange Rock*. But before that, you would like to see how much they already know about the early history of Earth.

2. Point out the newsprint sheets around the room and arrange students into pairs. Station one pair in front of each piece of paper and tell them that they will have two minutes to discuss the answer with their partners and record what they think is the answer. At a pre-arranged signal, they are to move to the next sheet to the right and do the same thing. Ask them not to repeat the information that is already on the sheet when they arrive at it but just to add new information if they have some. Begin the exercise.

3. When you feel enough time has elapsed, bring the class back together. Take each sheet, summarize the answers, and allow the students to ask questions.

4. Show the episodes from *One Strange Rock* that you have selected and instruct students to take notes on main ideas as they listen. Tell them to pay particular attention to information that answers the questions they have been considering.

Part 2. Geologic Time Scale

1. Review the concept of scale and how scale can be used in a timeline. Draw a sample timeline on the board to represent your students' approximate age. Starting at the left, divide it into years at one-foot intervals. Ask students to state for you the relationship between a scale and the timeline.

2. Ask students to mention important events (starting first grade, joining a Scout troop, a hospital stay, graduation from eighth grade, for example) that have occurred in their lives and mark these points on the scale. Point out that the timeline is actually a continuum that will continue into the future.

3. Distribute **Handout 1: Scale and Geologic Timeline.** Then work through the first few items on the handout together as a class.

   Suggested answers:

   a. 1,000
   b. 1,000
   c. 10
   d. 100
   e. 4.65 meters
   f. 0 meters
   g. 0.15 meters
   h. 2.85 meters
   i. 4.03 meters
   h. 4.65 meters

4. When you feel they are ready to work independently, divide the students into pairs or groups of three. Give them access to the Internet during class, or have them gather the data for homework and then add the events to their timelines the next day.

5. When the timelines are finished, you may wish to display them in class.

5. Debrief on the experiment: How many were able to complete it successfully? How many blew the experiment up in an explosion? What did they learn from this experiment?

6. Conclude the lesson by showing this brief video about Miller's experiment at https://www.youtube.com/watch?v=T_jVnWAEzEY.

Part 3. Miller–Urey Hypothesis

1. Review answers on the large sheet of paper that has student answers to Question #5 from Part 1: Where and how did life as we know it begin? Explain to students that today's class will be about two people who tried to answer that question with an experiment.

2. Give a talk about Miller and Urey and their experiment using the information in **Teacher Resource 1**.

3. Give students copies of **Handout 2: Understanding the Miller–Urey Experiment**, and review it briefly.

4. Provide students with Internet access so that they can answer the questions and perform the experiment.

   Suggested answers:

   1. Carbon dioxide, methane, hydrogen sulfide, little to no oxygen.
   2. Amino acids are carbon-based organic compounds that build proteins.
   3. Carbon, hydrogen, oxygen, and nitrogen.
   4. Carbon dioxide, methane, and hydrogen sulfide.
   5. **a.** Methane, hydrogen, ammonia, water.
      b. Amino acids are the building blocks of life.
      c. Similar to the atmosphere.

Part 4. Cambrian Explosion

1. For homework before this part of the lesson, distribute **Handout 3: The Cambrian Explosion** and tell students to research to fill in the handout as completely as possible.

2. The next day, go over the information that students have found, clearing up any confusion and filling in gaps using the information in **Teacher Resource 1** and your own study of the period.

   Probable student answers:

   a. The period was marked by rapid evolution in a relatively short time.
   b. 580 million years ago.
   c. Any land animals.
   d. They have a spinal cord.
   e. Soft-bodied organisms do not fossilize well.
   f. Runaway glaciation theory: Much of the world was bottlenecked by glaciers, only allowing for a few viable habitats. An increased amount of minerals moved into the water from glaciers grinding across land.
   g. Increased oxygen, predator/prey relationships, increased nutrients.

3. Show the video from *The Economist* "What Caused the Cambrian Explosion?" at https://www.youtube.com/watch?v=qNtQwUO9ff8. Ask students what new information they learned from the video to add to their understanding of the Cambrian period. Acknowledge and discuss the uncertainty that still marks this subject of scientific inquiry.

Part 5: Mass Extinction Events

1. Before this section of the lesson, assign **Handout 4: The Big Five Mass Extinction Events** to be read and annotated for homework. Assign one of the events to each student for further research, so that students can be "expert" resources during the discussion.

2. Begin the discussion by asking what the term "extinction" means. (No longer in existence.) Ask students to name some animals that are now extinct. (Dinosaurs, woolly mammoth, and saber-toothed tiger have long been extinct; West African Black rhinoceros, passenger pigeon, Tasmanian tiger, and Caribbean monk seal have all gone extinct in the last two centuries.) Ask why they think these animals have become extinct. (Over-hunting, loss of habitat.)

3. Help students relate the concept of extinction to currently threatened wildlife species, using examples from the U.S. Fish and Wildlife Service. (See Notes to the Teacher.) Point out that certain kinds of fish, birds, mammals, and plants are all endangered.

4. Ask students to define the term "mass extinction event" based on their reading for homework. (The extinction of a large number of species within a relatively short time.) Then have students who did extra reading on each of the mass extinction events in the handout share what they have found.

5. Conduct a class discussion using such questions as:

- What are the two important greenhouse gases discussed in this lesson? (Carbon dioxide [CO_2] and methane [CH_4].) How could each of them result in a mass extinction event? (Warming the planet and changing the climate.)
- What is the difference between a hydrocarbon and a carbohydrate? (Carbohydrates [$C_6H_{12}O_6$] are produced directly by plants, while hydrocarbons [CH_x] are the product of fossilization.)
- Which of the five major mass extinctions was the most damaging to life on Earth at the time? (The Permian.)
- In that most damaging mass extinction, what major type(s) of life forms existed before the extinction event? (Mainly amphibians and fishes, as well as the coal-forming floras.)
- In that most damaging mass extinction, what major type(s) of life forms existed after the extinction event? (Mainly the dinosaurs and the gymnosperms. Mammals may have been a minor part of the environment.)
- What is a clathrate, and how could it cause a mass extinction event? (Clathrates are methane ices, which release massive amounts of methane, a very strong greenhouse gas, thus warming the planet further.)

- How have the five major extinction events impacted life on Earth? (In each event, the trajectory of evolution was changed by the dramatic rise of new life forms.)
- Should you be concerned about the present climate change event? Why, or why not (Yes. The human population has the power to avert anthropogenic climate change.)
- Can you give an example of how the Earth can heal itself following an extinction event or an ice age? (Any of the dramatic changes in life forms following either an extinction event or following the changes in life forms after the last ice age.)

Part 6. Fossils

1. If you have a real example of a fossil, show it to the class. Ask them what they think it was and how it became fossilized. Alternately, you can show them some examples of fossils on the slides you created.

2. Discuss the diverse types of fossilization and ways to date fossils, using information from **Teacher Resource 1** and your own research.

3. Divide the students into lab groups and give each group a Tupperware-type container and 100 Skittles. Distribute **Handout 5: Modeling the Half-Life of an Isotope**. Review the instructions, and have students work through the activity, recording their findings and then answering the questions at the end. When they have completed the activity, lead a class discussion on their experience with this activity.

Answer key:

a. The "flipping" of Skittles from "S" to blank
b. Unstable = "S"; stable = blank side
c. 20 seconds, because generally half of the Skittles flip in 20 seconds
d. Approximately half of the unstable atoms decay.
e. Around 80,000 years

Part 7. Fossil Presentation

1. Review the five types of fossils described in **Teacher Resource 1** and discussed in the previous class (preserved in amber, trace fossils, natural casts, permineralization, and preserved remains).

2. Divide the class into groups and assign each group one type of fossil.

3. Distribute **Handout 6: Fossil Presentation Project** and review your expectations for this activity. Set dates for the slideshow presentations that allow sufficient time for research and planning.

4. Have students research their topics and create their original artwork for homework. Provide time in class for group sharing of information and planning the slideshow.

5. On the due date, have students present their slideshows and artworks. Display artworks in the classroom if desired.

6. Score the project based on the scoring guide in **Teacher Resource 2**, or use your own scoring method.

Part 8. Natural Selection

1. Depending upon the extent of your students' understanding of evolution and natural selection, share necessary information about these topics using information from **Teacher Resource 1**.

2. Distribute **Handout 7: Natural Selection Simulation Lab** and review what students are to do in this lab. Take them to the computer lab or use whatever means you have for computer access.

3. Identify groups for students to discuss the birds they created in Step 1 when they get to Step 2. After this discussion, tell them that they will work independently for the rest of the lab.

4. Allow students sufficient time to complete the simulation, fill in the handout table, and answer the questions at the end.

5. Hold a debriefing session to share findings. Answers to the lab will be unique to each student.

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Background Information and Glossary

The following information may be useful to both teachers and students for this unit:

- Organic Molecule Hypothesis: Organic molecules could be created by the addition of electric energy (lightning) into a mixture of gases.
  - The Miller–Urey experiment proved that organic molecules could be created from a mix of gases and electricity. In 1953, Stanley Miller and Harold Urey conducted a famous experiment that suggested life could arise from a combination of methane, hydrogen, water, ammonia, and electricity. Using gases and water vapor (proposed to be part of the original Earth's atmosphere), Miller and Urey first saw a layer of hydrocarbons followed by amino acids after about a week of running the experiment.
  - Meteorite Hypothesis: Organic molecules have been found on meteorites that landed on Earth. This hypothesis suggests that life was created somewhere else and "landed" on Earth.

Early Single-Celled Organisms

- Single-celled organisms changed the Earth's atmosphere. Before oxygen, all organisms would have been anaerobic (without oxygen).
- Cyanobacteria: A bacterium 3.5 billion years ago evolved the ability to photosynthesize, releasing the byproduct of oxygen. Once oxygen was in the atmosphere, this allowed the ability for aerobic prokaryotes (which need oxygen to live) to evolve.
- Endosymbiosis: Relationship in which one organism lives within the body of another, and both benefit from the relationship. This allowed for the evolution of the eukaryotic cells (containing membrane-bound organelles, such as nuclei, chloroplasts, and mitochondria).
- Sexual reproduction allows for increased diversity.

Multicelled Organisms

- After the development of single-celled prokaryotes and eukaryotes, multicellular organisms arose approximately 2.9 billion years ago.
- These multicellular organisms evolved into more complex marine colonies that lived underwater, as a means of protection from the sun's harmful ultraviolet rays.

Fossil Record

- Fossils are the physical record of life that existed in the past. There are a handful of different ways fossils can be created:
  - Permineralization: Occurs when minerals carried by water are deposited around a hard structure (shells, bone, wood, etc.). Over time, the minerals may replace the chemicals of the hard structure itself.
  - Natural Casts: Occur when minerals carried by water are deposited within the space (the cast) where an organism perished.

Background Information and Glossary

- Trace fossils: Record of activity of a living organism. Include nests, footprints, biochemicals produced by living organisms.
- Amber-preserved fossils: Amber is hardened tree resin that becomes covered in sediment. Sometimes organisms became trapped in tree resin or sap that is eventually preserved.
- Preserved remains: Entire organisms become encased in material such as ice or volcanic ash.
- Fossils are not common. Because there are only specific conditions that allow for fossilization to occur, most living organisms do not become fossils. Instead, most living organisms end up degrading back into their component minerals and elements.

How old are fossils?

- There are a few ways scientists can date objects:
    - Relative dating: Estimates the time during which an organism lived by comparing the placement of fossils of that organism with the placement of fossils in other older or younger layers of rock. Provides a general estimate, but not the actual age.
    - Radiometric dating: Uses the natural rate of decay of unstable isotopes found in materials to calculate the age of that material.
    - Isotopes: Atoms of the same element that have different numbers of neutrons. For example, carbon can have 6, 7, or 8 neutrons.
    - Half-life: Amount of time it takes half of the isotope sample to decay into a different element.

Paleontology

- Paleontology is the scientific study of life that existed prior to modern humans (before 10,000 years ago).
- Usually a combination of geology and biology.
- Fields of study include any living organisms prior to 10,000 years ago with the exception of humans.
- Archaeologist: Scientist who studies ancient humans.

Geologic Time Scale

- The geologic time scale is a representation of the history of the Earth, usually organized by major events or changes that have occurred. There are three basic units of time:
    - Eras: Tens to hundreds of millions of years, consisting of two or more periods.
    - Periods: Most commonly used, lasting tens of millions of years.
    - Epochs: Smallest units, lasing millions of years.
- It is generally accepted that the Earth formed about 4.6 billion years ago from a planetary nebula, which formed the solar system.

Cambrian Explosion

- The **Cambrian explosion** was a relatively short-span event, occurring approximately 541 million years ago in the Cambrian period.
- Most major animal phyla appeared, as indicated by the early fossil record, including trilobites.
- It lasted about 20-to-25 million years and resulted in the divergence of most modern organisms.

Teacher Resource 1 ▸ P.3

Background Information and Glossary

- Additionally, the event was accompanied by major diversification of other photosynthetic organisms, such as unicellular and multicellular aquatic plants, resulting in an increase of oxygen in the primitive Earth's atmosphere.
- Prior to the explosion, most organisms were simple, composed of individual cells occasionally organized into colonies.
- The increase in atmospheric oxygen eventually resulted in the development of ozone in the atmosphere.

Big Five Mass Extinction Events

- Mass extinction events occur when an unusually high percentage of species (both plants or animals) die off simultaneously or within a limited period of time in the geologic time scale.
- There have been five major mass extinction events since the beginning of the Cambrian period: the Ordovician-Silurian extinction; the Late Devonian extinction; the Permian extinction; the Triassic-Jurassic extinction; and the Cretaceous-Tertiary (K-T) extinction.
- The K-T extinction event is the best known because it resulted in the die-off of the dinosaurs and the rise of the mammals, but the Permian event was the most disastrous (known as the Great Dying) because over 95 percent of all animal species died out.
- Following each mass extinction, new and different life forms evolved, frequently exploiting ecological niches vacated by the previous but now extinct life forms. Sometimes the new forms are modifications of the old ones, and there is a great deal of evidence that one or more types of dinosaurs are actually alive and well today; we just call them birds.
- There are several theories that may have caused past mass extinction events, including catastrophic methane release, flood basalt volcanic eruptions, past climate change, and cosmic impact events like the K-T event.
- Many scientists suggest that we are currently witnessing the sixth mass extinction event, this one triggered by the current global climate change.

Tetrapods

- Tetrapods: Four-limbed vertebrates, including living (extant) and extinct reptiles, amphibians, mammals, and birds.
- Evolved from lobe-finned fishes.
  - Lobe-finned fishes have the ability to breath air and move on land short distances.
- The water was significantly more dangerous than land at this point.

The Invasion of the Land

- During the Silurian and Devonian periods of the Paleozoic era (approximately 450 million years ago), enough oxygen had been produced by aquatic photosynthetic (autotrophic) organisms, such as cyanobacteria and eukaryotic algae, that a protective layer of stratospheric ozone had developed in the Earth's atmosphere. The ozone layer filtered out

Background Information and Glossary

harmful UV rays from the sun and allowed both plants and animals to emerge onto land surfaces.

- The first land plants developed vascular tissues (xylem and phloem), allowing these photosynthetic autotrophs to become woody and erect, creating new habitats for evolving land animals.
- Shells and skeletons of both aquatic and land animals fossilize well during this period, as do roots, leaves, and woody stems of land plants.

The Paleozoic Era

- The Paleozoic era began with the Cambrian explosion and ended with the Permian period (280 million years ago).
- The Paleozoic included the Carboniferous period (345-310 million years ago), so-called due to the extensive development of the coal-forming forests that covered much of the land. During this time, sharks and amphibians were dominant types of animals, while the ancestors of modern-day horsetails and club mosses were giant trees of the coal-forming forests.
- The first true seed plants (gymnosperms and seed ferns) developed during the Carboniferous period, as did giant dragonflies with six-foot wingspans.

The Mesozoic and Cenozoic Eras

- The Mesozoic era began about 250 million years ago, following the Permian mass extinction event that killed off many marine animals (including trilobites) and coal-forming forests; it ended about 65 million years ago.
  - Known as the Age of Reptiles. Dinosaurs ruled the Earth, while primitive ferns and gymnosperms became the first modern forests, providing food for the herbivorous dinosaurs.
  - Birds and mammals also evolved in this era.
- The Cenozoic era began 65 million years ago. It is believed that the Mesozoic era ended with a catastrophic meteor impact that killed off many of the dinosaurs.
- With many of the reptiles and dinosaurs becoming extinct, small mammals that survived the impact event now had many more available niches and fewer predators. Thus, the Cenozoic is known as the Age of Mammals. To paleobotanists, it is also known as the age of the Angiosperms.

Evolution

- Evolution: Process of biological change by which descendants come to differ from their ancestors.
- Evolution is an explanation of how an organism is designed and why it looks and acts in a certain way.
- Adaptation: Inherited trait that gives an advantage to an individual organism.
- Diversity: The degree of variation of living things present in a particular system or ecosystem.

Developing the Concept of Evolution

- Carolus Linnaeus, a Swedish botanist, published *Systema Naturæ* in 1735, in which he classified organisms based on their similarities and called them species.

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Background Information and Glossary

- Linnaeus created the binomial naming (nomenclature) system (genus and species) used today.
- Linnaeus believed that some species may have arisen from hybridization or interbreeding between two separate species, the beginning steps in evolutionary theory.
- George Buffon discussed important ideas about relationships among organisms, sources of biological variation, and the possibility of evolution in *Histoire Naturelle* (1749)
- Erasmus Darwin, grandfather of Charles Darwin, proposed In *Zoonomia* (1795) that all living things were descended from one common ancestor.
- Jean Baptiste Lamarck proposed that evolution occurs due to environmental change over long periods of time in *Philosophie Zoologique* (1809).

Charles Darwin

- English naturalist, born 1809. At the age of 23, Darwin sailed around the world on the H.M.S. *Beagle* as the ship's naturalist (1832-1835).
- He noticed similarities between species on islands, most famously the Galapagos finches.
- Darwin spent significant time off the ship due to fieldwork and seasickness. (He spent only 18 months on the ship.) During his time off the ship, Darwin noticed many fossils, including oyster shells in the mountains. This gave Darwin the realization that the Earth was much older than 6,000 years (as was commonly accepted in Darwin's time), because it would take long periods of time to move the ocean floor to the mountains.
- Some of the fossils, including the extinct giant armadillo, suggested that living species could be related to the fossils.
- Darwin formulated his theory from 1837 to 1839, after returning from his voyage aboard H.M.S. *Beagle*, but it was not until two decades later that he gave it full public expression in *On the Origin of Species* (1859), a book that has deeply influenced modern Western society and thought.

Natural Selection

- Darwin developed the theory of natural selection, "survival of the fittest." Those individuals best adapted for certain habitats or environments will pass on their genetic information to their offspring.
- Natural selection is the mechanism by which individuals that have inherited beneficial adaptations produce more offspring on average than do other individuals without the adaptations.
- In nature, the environment is the selective agent. Thus, an organism must be adapted to its environment.

Evidence That Led to Darwin's Theory of Natural Selection

- Fossils: Similarities between fossils and current known species.
  - Paleontology: The study of fossils or extinct organisms. Continues to provide evidence of evolution and natural selection.
  - No fossil evidence has ever been found that contradicts the theory of natural selection.

Teacher Resource
1 ▸ P. 6

Background Information and Glossary

- Geography: Darwin noticed that island species were similar but not identical to one another or to species on the mainland.
- Biogeography: The study of the distribution of organisms around the world.
- Embryology: the prenatal development of gametes (sex cells), fertilization, and development of embryos and fetuses. Darwin noticed that barnacles and crabs (which are noticeably different) were quite similar when immature.

- Anatomy
    - Homologous structures: Features that are similar in structure but appear in different organisms and have different functions. Example: four limbs of moles, bats, humans. Each looks externally different, but evolutionarily speaking and internally, they are similar.
    - Analogous structure: Features that look similar but evolved differently in different situations. Example: whale fins and shark fins.
    - Vestigial structures: Unused features or remnants of organs or structures that originally had a function, but do not currently serve a function. Example: appendix, pelvic bone in snakes.

- DNA
    - All living things have DNA (deoxyribonucleic acid). Similar species share similarities in their DNA or genetics.
    - DNA sequence analysis: Technique used to show similarities and difference in the genetic code of an organism. The more similar the DNA, the more closely related two organisms are.
    - Pseudogenes: Sequences of DNA nucleotides that no longer function but are still carried through the genetic sequence.

Note: Alfred Russell Wallace (1823-1913) independently developed a theory on natural selection at the same time as Darwin. Wallace studied the Malay Archipelago and found that islands of close proximity had different yet similar species.

Genetic Variation

- Population: All the individuals of an organism or species in an area.
- Gene pool: All the different genes found within a population
- Having different genes within a population is vital to the survival of a species. The more diverse the genes (alleles), the better chance the species has to survive and adapt to a changing environment.
- Allele frequency: How common certain alleles are within a population.
- Genetic variation is important for the survival of a species, but how does a species end up with such variations?
    - Mutation: Random change in the DNA of a gene. This can result from many different causes, either environmentally or completely random.
    - Recombination: New gene (allele) combinations derived from two parents combining their genes.

Background Information and Glossary

- Gene flow: The movement of alleles from one population to another population.

Genetic Drift

- Genetic drift, or the loss of allele diversity, sometimes occurs within populations. A loss of genetic diversity increases the chance for a species to become extinct.
- Bottleneck effect: An environmental event that greatly reduces the numbers of individuals in a population. This can also occur due to human influences (such as overhunting, overharvesting, land use, etc.)
- Founder effect: One or a few individuals in a population colonize a new area. There are only a small number of individuals (or even one) to reproduce. Fewer individuals = less diversity.

Hardy–Weinberg Equilibrium

- Godfrey Hardy and Wilhelm Weinberg showed that genotype frequencies stay the same over time when certain conditions are met. That means it is possible for a population not to evolve. There are five conditions that must be met:
  - Very large population
  - No emigration or immigration
  - No mutation
  - Random mating
  - No natural selection
- Real populations almost never achieve all five conditions.
- Biologists can use the concept to better understand evolution and how a specific species is evolving or not evolving for specific traits.
- This concept can also be used to predict gene frequencies of future populations.
- As a species evolves, its genetics change, and in some cases, it becomes a new species completely. There are five factors that can lead to evolution:
  - Genetic drift: If the isolated population survives and remains isolated.
  - Gene flow: Multiple populations begin to mix and change alleles.
  - Mutation: Most mutations end up in death; however, sometimes a mutation can be beneficial and be enough variation to evolve a unique species.
  - Sexual selection: Selection of certain traits based on appearance.
  - Natural selection: Advantageous traits increase in frequency. This is not random, even though mutations and other factors are random.

Speciation

- As populations become isolated, changes in genes become more and more significant. Individuals begin to behave and appear differently from the other populations.
- Isolation can occur from geography and/or temporal (timing) isolation.

Background Information and Glossary

- Reproductive isolation occurs when members of different populations can no longer mate successfully. This is the final step before forming a unique species.
- Speciation: The rise of two species from one existing species.

General Terms Relating to Evolution

- Descent with modification: Adaptations that arise over many generations.
- Variation: Difference in physical traits of an individual from other individuals. Examples: Hair color, eye color, webbed feet, etc.
- Adaptation: Advantageous traits or features that allow an organism to better survive in its environment.
- Artificial selection: Process by which humans change a species by breeding it for certain traits. Darwin noticed this, which added to his natural selection theory.
- Heritability: The ability of a trait to be passed down from one generation to the next.
- Fitness: The measure of the ability to survive and produce more offspring.
- Punctuated equilibrium: Bursts of evolutionary activity followed by long periods of stability.
- Gradualism: The process of speciation that occurs over a long period of slow, gradual evolution.
- Coevolution: The process in which two or more species evolve in response to changes in each other. Example: Hummingbirds and flowers.
- Coevolution can also lead to a competitive "arms race" between species. Examples: Predator-prey relationships, plant defense from herbivores
- Extinction: The elimination of a species from Earth.

Primate Evolution

- Primates: Group of mammals (animals) with flexible hands and feet, forward-looking eyes, and enlarged brains relative to body size.
- Prosimians: Oldest living primate group.
- Anthropoids: Human-like primates. (Divided into humans, apes, and New World and Old World monkeys)
- Hominids: primates that walk upright and have opposable thumbs.

Handout 1

Scale and Geologic Timeline

NAME: ______________________________ **DATE:** ______________________

The earth is approximately 4.6 billion years old. We will be making a geologic time scale of the Earth, with a scale of 1 cm = 100 million years.

Part 1. Pre-lab questions

a. How many millions are in a billion? ____________

b. How many thousands are in a million? ____________

c. How many hundreds are in a thousand? ____________

Part 2. Factor conversion

d. If 1 m = 1 billion years, how many cm are in a billion years? ______________________________

e. If the earth is 4.65 billion years old, how many meters is that on the timeline? ____________________

Part 3. Starting the timeline

In groups of two, mark out and cut the Earth's timeline to the nearest cm on the paper provided.

Add the following events, at the correct measurement from the start of the timeline:

f. Using a red pencil, mark the start of the Earth 4.65 billion years ago. Distance from start:

____

g. Using a blue pencil, mark the creation of the moon, 4.5 billion years ago. Distance from start:

____

h. Using a green pencil, mark the beginning of oxygen on the Earth, 1.8 billion years ago. Distance from start:

____

i. Using a purple pencil, mark the end of the Cambrian period, 570 million years ago. Distance from start:

____

j. Using a black pencil, mark when humans first landed on the moon, in 1969. Distance from start:

____

Part 4. Geologic eras

Research five events from the chart below and add them to your timeline. You may do them all if you wish.

Precambrian Ends - Cambrian Begins
Cambrian Ends - Ordovician Begins
Ordovician Ends - Silurian Begins
Silurian Ends - Devonian Begins
Devonian Ends - Mississippian Begins
Mississippian Ends - Pennsylvanian Begins
Pennsylvanian Ends - Permian Begins
Permian Ends - Triassic Begins
Triassic Ends - Jurassic Begins
Jurassic Ends- Cretaceous Begins
Cretaceous Ends - Tertiary Begins
Tertiary Ends - Quaternary Begins
Quaternary

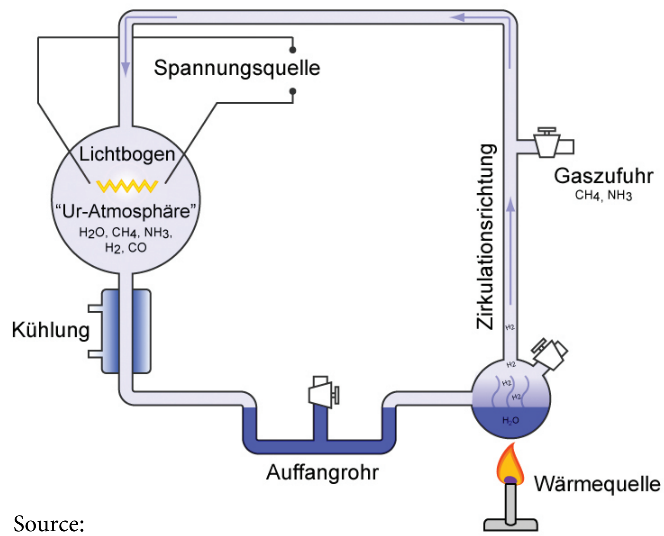
Handout 2 ▸ P.1

Understanding the Miller–Urey Experiment

NAME: ______________________________ **DATE:** ______________________

In 1953, Stanley Miller and Harold Urey conducted a famous experiment that suggested life could arise from a combination of gases and electricity. By mixing gases and water vapor (assumed to be part of the Earth's original atmosphere) with electricity, Miller and Urey first saw a layer of hydrocarbons (day 1), followed by amino acids after about a week of running the experiment.

At right is a model of the experimental apparatus. The experiment ran continuously. As gases mixed with electricity, they combined into more complex molecules. The gases were then cooled and reheated and mixed with more of the original gases. This process was repeated.



Source:

https://commons.wikimedia.org/wiki/File:Miller-Urey-Experiment.png

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Using the Internet, research the answers to the following questions:

1. What was the Earth's early atmosphere like?

2. What are amino acids?

Understanding the Miller–Urey Experiment

3. What four elements do all amino acids contain?

4. Which gases in the Earth's early atmosphere contained these elements?

Now go to this link at https://www.ucsd.tv/miller-urey/ and perform the experiment. Be sure to follow the directions.

a. What gases did you need to combine with the boiling water?

b. Why would the creation of amino acids be important to the beginnings of life?

c. How does this experiment reflect the early days of the Earth?

Handout 3 ▸ P.1

The Cambrian Explosion

Directions:

Research the Cambrian period, which has been called the "Cambrian explosion." Then answer the following questions:

a. Why does the Cambrian explosion pose a challenge for the theory of evolution?

b. Approximately when did the first sponges appear in the fossil record?

c. What modern animal groups did not arise during the Cambrian explosion?

d. What are the characteristics of the Chordata phylum?

Handout 3 ▸ P.2

The Cambrian Explosion

e. What is one possible explanation for incompleteness of the fossil record from the Cambrian?

f. Explain the runaway glaciation or “Snowball Earth” theory.

g. Aside from the runaway glaciation theory, what are other possible explanations for the Cambrian explosion?

Handout 4 ▸ P.1

The Big Five Mass Extinction Events

NAME: ______________________________ **DATE:** ______________________

The episodes from *One Strange Rock* highlight the fact that planet Earth is unique within our solar system and that its uniqueness is due to the presence of life here and the absence of life on the other planets. A significant point made in the series is that the Earth appears to be able to "heal" itself from cosmic disasters such as impacts from meteors like the Cretaceous-Tertiary (also called the K-T) extinction event 65 million years ago. The K-T event resulted in the end of a nearly 200 million-year rule of the dinosaurs and the expansion of the newly arrived mammals. Animal species were not the only life forms affected, since the same impact ended the dominance of major plant types (gymnosperms) and marked the origin of new ones (angiosperms). In addition to the history of life, the role that mass extinction events have played in changing the trajectory of life will be considered in this lesson.

Mass extinction events occur when an unusually high percentage of species (both plants and animals) die off simultaneously or within a limited period of time in the geologic time scale. Several theories have been proposed by scientists to explain the possible causes of such extinction events, including massive releases of methane gas from biologic or geologic sources, volcanic eruptions that release massive floods of rapidly flowing basaltic lavas, large-scale climate changes, such as ice ages, and finally, cosmic bombardment or impact events.

There have been five major mass extinction events since the beginning of the Cambrian: the late Ordovician, the late Devonian, the Permian, the late Triassic, and the Cretaceous-Tertiary (K-T) extinctions. Figure 1 represents the approximate timing of those five mass extinction events. A brief description of the types of life forms that existed at the time of each mass extinction is also given below. In addition to these descriptions, access the Internet to gain more specific information regarding each extinction event, determining:

- the prevailing life forms prior to the event
- the typical life forms that became extinct
- the possible cause(s)
- the remaining life forms that survived the extinction event.

1. **The Late Ordovician Mass Extinction.** The first known mass extinction event occurred during the late Ordovician-Silurian periods (about 450-440 million years ago); it was also the third largest mass extinction in Earth's history. During the Ordovician, most life was in the sea, so marine families such as trilobites, brachiopods, and graptolites were dramatically reduced in number.

2. **The Late Devonian Mass Extinction.** Nearly 75 percent of existing species on Earth died out in the second largest mass extinction event during the late Devonian (about 410-360 million years ago). Invasion of the land by previously marine plants and animals occurred during the late Silurian and early Devonian periods, and this transition may have been a factor. Life forms in shallow seas were most heavily decimated, and coral reefs and the animals associated with them were especially affected. Changes in the Earth's atmosphere (increasing amounts of oxygen due to photosynthesis) during this time led to

Handout 4 ▸ P.2

The Big Five Mass Extinction Events

the creation of ozone, which filtered out damaging UV radiation, allowing the development of new habitats on the land and the development of totally new terrestrial species of plants and animals.

3. **The Permian Mass Extinction.** While the Cretaceous-Tertiary (K-T) extinction event is the best known because it resulted in the die-off of the dinosaurs and the rise of the mammals, the Permian mass extinction event, following the Carboniferous period, was the most disastrous (also known as the Great Dying) because over 95 percent of all animal species died out, many of them fish and amphibians. The plants of the Carboniferous period, the coal-forming floras, consisting of large trees such as *Lepidodendron* and *Calamites*, were totally lost during the Permian extinction. This dramatic die-off set the stage for the rise of the dinosaurs.

4. **The Late Triassic Mass Extinction.** The last 18 million years of the Triassic period were marked by several (two to four) phases of extinction events that combined to create the Triassic-Jurassic mass extinction event (about 218-200 million years ago). Many types of dinosaurs died out, to be replaced by new types of dinosaurs. Climate change, flood basalt eruptions, and an asteroid impact have all been cited as possible causes for this loss of life (approximately 35 percent of marine animals and 50 percent of terrestrial animals).

5. **The Cretaceous-Tertiary mass extinction**. The K-T extinction (from the German word *Kreide,* meaning chalk), well-known for the death of the dinosaurs, is now considered to be due to the impact 65 million years ago between Earth and a massive asteroid or comet. The K-T boundary is marked in sedimentary rock strata around the world, consistent with such a global impact, and is identified by a thin layer of chalk containing an extremely rare element called iridium. Iridium is common in asteroids and comets but is very rare in the Earth's crust, thus supporting the impact hypothesis. Many other organisms in addition to the dinosaurs perished at the end of the Cretaceous, including the ammonites, many flowering plants, and the last of the pterosaurs, leading to the rise of the mammals and birds as well as many new flowering plants (angiosperms).

Important lessons learned

Following each mass extinction, new and different life forms evolved, frequently exploiting ecological niches vacated by the previous but now extinct life forms. Sometimes the new forms are modifications of the old ones, and there is a great deal of evidence that one or more types of dinosaurs are actually alive and well today; we just call them birds. A study of these mass extinction events tells us that the evolution of life has not been a slow and steady process, but rather has been punctuated by a range of catastrophic events. As someone once said, "Life is what happens while you are making other plans."

Handout 4 ▸ P.3

The Big Five Mass Extinction Events

Potential Causes of Mass Extinction Events

There are several theories about what that may have caused past mass extinction events, including catastrophic methane release, flood basalt volcanic eruptions, past climate change, and cosmic impacts like the K-T event. These potential causes are described in more detail below.

1. **Catastrophic Methane Release**. The rapid release of methane, a very powerful greenhouse gas, has been suggested as a possible cause of previous mass extinction events. Methane ice (also called clathrates) is an ice-like substance created from water and methane in deep-sea bottoms, arctic lakes, and permafrost. Clathrates form when temperatures are at or near freezing and when the pressure of overlying water and/or sediments creates the right conditions. When these conditions change, the methane trapped in the clathrate matrix is released as methane gas. Global warming results and causes further clathrate melting and methane release. (Such a global release of methane is considered the most likely explanation for the abrupt retreat of the continental ice sheets at the end of the last ice age, 12,000-14,000 years ago) The resultant soaring temperature causes such stress to plant and animal life that mass extinction follows. (Consider the loss of woolly mammoths, saber-toothed tigers, and many other ice age mammals as the ice sheets retreated.)

2. **Basalt Flood Eruptions.** Such flood basalt eruptions are a type of large-scale volcanic activity, both in terms of spatial extent and duration of time, rapidly covering large areas over many years, decades, or even thousands or millions of years. These eruptions can occur on land or on the ocean floor. The lava from such an eruption can cover hundreds of thousands of miles/kilometers. Large basalt plateaus and mountains can result from the huge volume of newly surfaced rock. The huge volume of lava is accompanied by a similarly large release of volcanic gases such as toxic sulfur dioxide and carbon dioxide. These can affect climate and cause sulfuric acid rain, so flood basalts are thought to be a potential cause of mass extinctions by eradicating key environmental niches and changing the chemistry of the atmosphere.

3. **Climate Change.** Earth's climate is not constant or stable. Over geologic time, the Earth's dominant climate has gone from ice ages to tropical environments and from lush jungles to searing deserts. A study of the most recent ice age illustrates such relatively rapid changes. The Sahara Desert contains "oceans" of sand now covering the stumps and roots of tropical trees that grew there as recently as 8,000 years ago. One of the early missions of the space shuttle *Columbia* carried radar (SIR-A, for Shuttle Imaging Radar-A) that penetrated the dry sands, revealing a network of riverbeds. When such climate change occurs abruptly, either in the form of a global warming or cooling, animals and plants have no time to adapt, resulting in mass extinction events.

Handout 4 ▸ P.4 The Big Five Mass Extinction Events

4. **Impact Events.** These have been proposed as causes of mass extinction; for example, there was the K-T impact when the Earth was struck by a comet or meteor large enough to create a huge global shockwave. Widespread dust and debris rained down, lasting long enough to disrupt global photosynthetic activity, affect the global food chain, and result in global climate change, causing extinction on a global scale—the demise of the dinosaurs.

5. The end of the Cretaceous has been linked to an impact that left the Chicxulub crater (pronounced Chee-cha-LUBE) in the seabed north of the Yucatán peninsula of Mexico. Impacts have also been blamed for other mass extinctions, but the timing and links between cause and effect for these are still debated by scientists.

   Many scientists suggest that we are currently witnessing the sixth mass extinction event, this one triggered by the current global climate change or global warming. We know that our climate has always changed; think of the last ice age that ended abruptly 12,000-14,000 years ago, after lasting approximately 90,000 years. Scientists know what caused those past changes. The cause of this current phase of warming is also known by scientists to be the ever-increasing levels of CO_2 in the Earth's atmosphere, the result of uncontrolled burning of fossil fuels. Remember, these fossil fuels, especially coal and oil, are the fossilized carbohydrates, converted into hydrocarbons, originally produced by photosynthesis over a hundred million years. In a little over 250 years we have been converting the billions of tons of stored CO_2 in those hydrocarbons into atmospheric CO_2. **It has taken us less than 300 years (since 1750) to nearly double the amount of CO_2 in our atmosphere (from 280 ppm in 1750 to 410 ppm in 2017).**

Handout 5 ▸ P.1

Modeling the Half-Life of an Isotope Using Skittles

NAME: ______________________________ **DATE:** ______________________

Background:

Scientists regularly use radiometric dating to figure out the age of a fossil.

Radiometric dating uses the isotopes of elements to determine how old an object is. Isotopes are elements with differing numbers of protons and neutrons. For example, carbon-12 (6 protons and 6 neutrons) and carbon-14 (6 protons but 8 neutrons) are both isotopes of carbon. However, carbon-14 is not stable and will eventually lose the extra neutrons and turn into carbon-12. The rate of decay is called the "half-life." By comparing the amount of stable isotopes to unstable isotopes, scientists can date objects, even really old ones. Follow this link for an in-depth explanation: https://www.youtube.com/watch?v=Kcuz1JiMk9k&t=7s

Procedure:

1. Place Skittles, each with the "S" facing up, into the container. Each Skittle represents an atom of an unstable isotope. Place the lid securely on the container.

2. Holding the container level, shake for 20 seconds. Then set the container on the table and remove the lid. Remove only Skittles that show the blank side up (tails).

3. Count the Skittles you removed and record this number in the data table under Trial 1; make sure you are recording the TOTAL number of tails that have been removed (cumulative). Also record the number of S-showing Skittles that are left.

4. Repeat steps 2 and 3 until there are no Skittles left in the container.

5. Repeat steps 1 through 4 and record your data in the table under Trial 2.

6. Calculate the averages for each time period and record these numbers in the data table.

Handout 5 ▸ P.2

Modeling the Half-Life of an Isotope Using Skittles

	Trial 1 A	Trial 1 B	Trial 2 C	Trial 2 D	Averages	Averages
Total Shaking time (s)	# removed (total)	# of “S” remaining	# removed (total)	# of “S” remaining	Columns A and C (No “S”)	Columns B and D (“S”)
0						
20						
40						
60						
80						
100						
120						
140						

Conclusion:

a. In this model, what represents the process of radioactive decay?

Handout 5 ▸ P.3

Modeling the Half-Life of an Isotope Using Skittles

b. Which side of the Skittle represented the unstable isotope? Which side represented the stable atom?

c. In this model, what was the half-life of the Skittles? Explain.

d. What can you conclude about the total number of atoms that decay during any half-life period of the Skittles?

e. If the time was 20,000 years instead of seconds, approximately how old would the object be if there were 6 Skittles "S" up?

Handout 6 ▸ P.1

Fossil Presentation Project

NAME: ______________________________ **DATE:** ______________________

In this project, you will investigate one of the ways in which a fossil can be created.

1. Research one of the five ways a fossil can be created, as your teacher has assigned:

- Preserved in amber
- Trace fossils
- Natural casts
- Permineralization
- Preserved remains

2. Work with your team to prepare a slideshow presentation to provide the following information:

- The steps necessary for the fossil to be created
- The locations around the world where this type of fossilization occurs
- Five examples of fossils with species identification and the location where found
- At least three reasons why fossils are important to science
- How often your specific type of fossil is found
- Ways that these fossils are aged
- Works-cited slide that includes at least three sources you used

3. Individually, create a piece of art representing one of your fossils. This could be a model, sculpture, drawing, or painting (or any other artistic representation approved by your teacher). Be sure to include:

- Name of species (common and scientific)
- Where the species lived (habitat and location)
- Use of color as appropriate

4. Present your slideshow and artworks to the class following your teacher's directions.

Teacher Resource 2 ▸ P.1

Scoring Guide for Fossil Presentation

This scoring guide has two sections, one for the group slideshow and the second for individual artwork and presentation. The numbers in parentheses indicate total possible points for each criterion.

Group scoring guide **Group topic:** ____________________

Slideshow:	Points awarded
The steps necessary for the fossil to be created (10)	
Where this type of fossilization can occur (5)	
Five examples of fossils with species identification and location found (15)	
Why fossils are important to science (at least three reasons) (10)	
How often this specific type of fossil is found (5)	
Ways that these fossils are aged (10)	
Works-cited slide (at least three sources) (10)	
Total group points (65)	

Teacher Resource
2 ▸ P.2

Scoring Guide for Fossil Presentation

Individual scoring guide **Student name:**________________________________

Total points earned by student's group from slideshow (65)	
Artwork, including name of species (common and scientific), habitat and location, and appropriate use of color (25)	
Participation in presentation of slideshow to class (10)	
TOTAL possible points (100)	

Individual scoring guide **Student name:**________________________________

Total points earned by student's group from slideshow (65)	
Artwork, including name of species (common and scientific), habitat and location, and appropriate use of color (25)	
Participation in presentation of slideshow to class (10)	
TOTAL possible points (100)	

Individual scoring guide **Student name:**________________________________

Total points earned by student's group from slideshow (65)	
Artwork, including name of species (common and scientific), habitat and location, and appropriate use of color (25)	
Participation in presentation of slideshow to class (10)	
TOTAL possible points (100)	

Handout 7 ▸ P.1 Natural Selection Simulation Lab

Name: ______________________________ **Date:** ______________________

Natural selection is the process in which the organism best adapted for the environment survives and reproduces. In this lab, we will simulate how environmental factors can affect species survival.

Head to http://sepuplhs.org/high/sgi/teachers/evolution_act11_sim.html and begin the simulation. Read all directions carefully. As you follow the simulation, fill out Table 1 on this page and Table 2 on the next page.

1. Describe the birds that you have made. (5 pts):

Table 1:

	Bird Coloring	Bird Size	Beak Size & Shape
Bird 1			
Bird 2			
Bird 3			

2. Discuss in your group which birds are the best fit for the environment at the beginning of the simulation (before you start with the next part of the simulation). Which are best adapted, and which are poorly adapted? How do you think your population will change over time? Summarize your discussion below. (15 pts)

Handout 7 ▸ P.2 Natural Selection Simulation Lab

Table 2. Fill out as you run the simulation (20 pts)

	Bird1	Bird 1	Bird 2	Bird 2	Bird 3	Bird 3
Time Period	Mutation	Population	Mutation	Population	Mutation	Population
Starting						
50,000 years						
100,000 years						
150,000 years						
200,000 years						
250,000 years						
300,000 years						
350,000 years						
400,000 years						
450,000 years						
500,000 years						

Handout 7 ▸ P.3

Natural Selection Simulation Lab

3. Create a data table to record the data for the second part of the simulation. (It may be better to create three different data tables for each of the regions. You do not need to record the mutations, just the populations.) (20 pts)

4. Upon completion of Table 2, answer the following questions in full sentences on a separate sheet of paper.

A. In multiple paragraphs, describe what happened in the second part of the simulation. Be sure to include the environment created, food availability, predators, and adaptations of the bids. Explain what happened in the simulation, why the most successful birds were successful, and why the less successful birds were not well adapted for their environment (30 pts)

B. Which bird after 500,000 years was best adapted for the environment? Why is this the case? (5 pts)

C. Did any of your birds go extinct? If so, what factors caused them to go extinct? (5 pts)

D. Are you surprised by your results? Why or why not? (5 pts)

E. Conduct some research on the Galapagos finches and answer the following questions:

(1) Why are the Galapagos finches so important to the theory of natural selection? (5 pts)

(2) Do you expect any of these finches will go extinct in the next few thousand years? Explain your reasoning for this answer. (10 pts)

(3) Scientists see that natural selection and adaptations in the Galapagos finches occurs much more rapidly than thousands of years. Provide a real-life example of one of the finch species currently adapting to its environment. (5 pts)

F. Using what you now know about natural selection, write a paragraph describing what *Homo sapiens* may look like in 100,000 years, keeping these things in mind: technology, environment, intelligence, and adaptations. (10 pts)

Seeing Earth From Space

Enduring Understandings

- Great discoveries happen when people are willing to face the unknown, work through emotional and physical challenges, and focus on a worthwhile common goal.
- Humans are as unique as the strange rock from which they come, and it is that uniqueness that turns an empty void into the journey of a lifetime.

Essential Questions

- How does looking at planet Earth from space make you feel?
- What is life like for astronauts and cosmonauts aboard the International Space Station (ISS) or during a long space flight?
- What are the negative effects of living in "zero gravity"?
- What would a trip to Mars be like?
- How would prolonged space travel affect both the physical and emotional conditions of the astronauts?

Notes to the Teacher

This lesson is a creative writing lesson that uses the traditionally identified parts of a plot as an organizing device for a short story. While students write their stories as individuals, an extension activity groups individuals into collaborative crews to combine their characters and events into a more expansive joint story.

The most useful episodes of *One Strange Rock* for this lesson are probably "Escape," "Home," and "Gasp," but all episodes will contain some relevant information and will inspire student efforts to craft a narrative.

One to two days before this class, students should be given **Handout 1: Preparing for Your Journey to Mars**. You may wish to introduce them briefly at this time to the National Aeronautics and Space Administration website at www.NASA.gov, an excellent resource to help students complete this assignment. Be sure to arrange for them to print the images you want for class in school, at least for those who do not have access to a good printer at home. Another option, if the technology is available, is to have the students submit their pictures to you electronically to be assembled as a PowerPoint presentation. This can be shown slowly as students sit silently to write their word reactions.

There are two slideshows in this *One Strange Rock* unit, meant for Lessons 1 and 2, that could be useful for this lesson as well. The first is "A Tour of the Solar System," and the second is "The Goldilocks Planets." You can download them from www.journeysinfilm.org.

Procedure

As students work through the writing process, give them inspiration by showing episodes from the National Geographic series *One Strange Rock.* See Notes to the Teacher for suggestions about the best episodes to use for this lesson. Be sure to allow time for student reactions and questions.

Part 1: The Journey to Mars: Setting and Exposition

1. Several days before the lesson begins, explain to students that the goal of an upcoming assignment will be to complete a creative short story about an imagined mission to Mars. Distribute **Handout 1: Preparing for Your Journey to Mars**. Go over the instructions with your students.

2. On the day the lesson begins, ask students to share some of the facts that they recorded on the handout, as time permits. Allow a free-ranging discussion about these statements, giving students time to respond or formulate questions. Then collect the handouts.

3. After making sure students have signed the images they printed, have them hang them around the room using whatever method you prefer. (Check for appropriateness.)

4. Explain that the next activity is to be completed in silence. After all, space is a silent place. Give them five minutes to walk silently from picture to picture and write down in their notebook one word that conveys their response to each image. It can be a word that expresses emotion or a descriptive word. If you have chosen to create a PowerPoint presentation from electronically submitted images, show that at this time, and have students write their single-word responses in silence.

5. On the board, write the following prompt: "I had no idea the view from here would be so…." Explain that this exercise will help them establish a setting for the story they are going to write. Give the students 10-15 minutes to respond to the prompt, using the word list they just created in their notebooks about the slideshow or images around the room. As they respond to the prompt, they should begin to think about a main character for their story and the reactions he or she might have to some of the images or to any conflicts implied in the discussion of the shared class facts.

6. Define the term *exposition* (the part of the story that introduces and provides background on the character and setting; the way it is written often establishes the mood of the story).

7. For homework, have students type their initial thoughts into a rough exposition for their story. Encourage them to add additional thoughts and expand on some of their ideas.

Part 2: Building Your Character

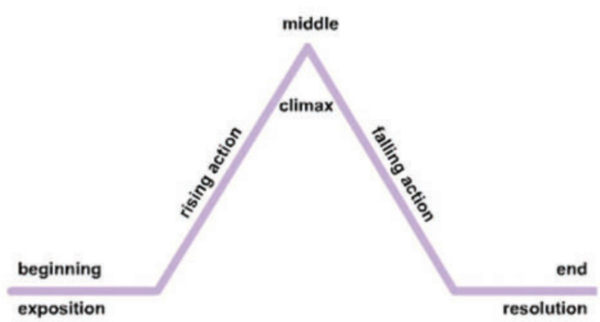
1. Review with students how we learn about a character in a story (what the character says, what the character does, what others say about the character, how others respond to the character, and what an omniscient author tells you about the character).

2. Tell students they are going to have to think about how their character might respond to a voyage to Mars. Distribute **Handout 2: Building Character**.

3. Read the prompt on the handout together and discuss it with the class, clearing up any questions students might have.
4. Emphasize to students that their character can be based on themselves or on someone they know. Alternately, they can make up an entirely fictional character.
5. Ask them to begin brainstorming and writing down ideas in their notebooks in response to the prompt. Have them continue for homework.

Part 3: Internal Conflict and Rising Action

1. Draw the traditional plot diagram of a story on the board:



Source: https://upload.wikimedia.org/wikipedia/commons/2/24/Plotmountain.jpg

2. Point out to students that they have written the first part of their story, the exposition. Now it is time for "rising action," when the main conflict of the story is introduced.
3. Define conflict (a struggle between opposing forces).
4. Review the idea that conflict can be internal or external. Define internal conflict (a psychological struggle within the mind of a character). Ask students to give examples of someone with internal conflict in a book they have read or a film they have seen.
5. Discuss what kinds of internal struggles one might have if one were on a long space journey (fear, homesickness, boredom).
6. Distribute **Handout 3: Facing the Unexpected**. Read through the prompt with students and answer any questions. Allow them to start brainstorming and writing, and have them finish for homework if necessary. You may wish to start individual writing conferences at this point.

Part 4: External Conflict and Rising Action

1. Discuss with students the kinds of internal struggles that they wrote about for their most recent prompt.
2. Now suggest that they might think of something that would shake their character out of boredom, homesickness, or another malaise: a potential system failure. Ask: What could go wrong on a spaceship? What could cripple a ship? Suggest that they might want to research shuttle system failure and redundancies.
3. Introduce other possible crises for discussion:
   a. the potential impact of passing through a micro-meteor shower
   b. a psychological breakdown experienced by a member of the crew
   c. the flu, which affects all members of the crew

4. Ask them to suggest other possible events that could threaten the mission. Then review in more detail the concept of external conflict (a struggle between the main character and an external force).

5. Review the main types of external conflict: character versus character(s), character versus society, character versus nature. Ask students to give examples of each from books they have read or films they have seen.

6. Distribute **Handout 4: Facing the Unknown.** Read through the prompt with students and answer any questions. Allow them to start brainstorming and writing, and have them finish for homework if necessary. Continue with individual writing conferences.

Part 5: Climax or Turning Point

1. Write on the board: "Success is a journey, not a destination. The doing is often more than the outcome." Explain that this is a quotation from a famous tennis player, Arthur Ashe. Ask if any students have heard people say similar things. Then ask if they believe this idea to be true from their own experience.

2. Ask students how they would feel if, after a long car trip, they had to just turn around and go home without getting out. Then share the next writing prompt on **Handout 5: Stop the Ship! I Want to Get Off!**

3. Read through the prompt with your students and ask how they feel about it; some may express disappointment. Encourage them to explore the multiple feelings that might arise in such a situation.

4. Allow them to start brainstorming and writing; have them finish for homework if necessary. Continue with individual writing conferences.

Part 6: Falling Action and Resolution (Denouement)

1. Tell students that their characters are now approaching the end of their journey. Ask them how they think their characters will respond.

2. Point out that in the 2030s NASA plans to send a real mission to Mars, to explore, to choose a location for a settlement, and to begin the process of colonizing the red planet. Suggest that students might want to do some research about this actual project. You can even point out that some of the members of this NASA mission might be their own age now.

3. Ask students how they think the members of the NASA mission will be received when they return home. How will they feel when they set foot on Earth again? Give students a chance to explore mixed emotions.

4. Distribute **Handout 6: There's No Place Like Home**. Read through the prompt with students and answer any questions. Allow them to start brainstorming and writing, and then have them finish for homework if necessary. Continue with individual writing conferences.

5. Announce a final due date for a good draft of these individual stories.

Extension Activity

Students will work in groups of four or five to connect their individual stories creatively. Now what happens to one crewmember affects all crewmembers. Decisions will need to be made on how to combine the rising action of each story, address each other's internal conflicts, and create new dialogue around key moments in the journey. Now that the "crew" is together, everyone will need a specific duty. **Handout 7** includes suggestions for crew member titles and responsibilities. Encourage students to choose a job that allows them to use their individual strengths. In some cases, the teacher may need to assign the jobs.

Handout 1

Preparing for Your Journey to Mars

Name: ______________________________ **Date:** ____________________

We will soon begin a journey to the planet Mars. Visually, you will be astounded by the beauty and vastness of space. We will encounter situations that will challenge us, both physically and emotionally. To be prepared, you will undergo intense physical training. Your physical and mental condition will be pushed to the limit.

What exactly are you preparing for? Spend at least 30 to 45 minutes online at www.nasa.gov, researching the International Space Station, space travel, and exploration. Look carefully at the images and read the fascinating stories told by astronauts and cosmonauts. You will soon be one of them, so learn from their experiences.

Choose five interesting facts to share with the class.

1.

2.

3.

4.

5.

Choose two images to share with the class, print them out, and bring them to class on the day assigned. Or if your teacher requests it, submit the images electronically to be assembled into a PowerPoint presentation.

Handout 2

Building Character

Name: ______________________________ **Date:** ____________________

We will soon begin our journey to Mars. It will take nearly a year if everything runs perfectly, and you will be travelling on a ship the size of a school bus with several other crew members. This journey will be a true test of endurance, patience, tolerance, and ability to keep calm under pressure. You will experience what only a handful of individuals have experienced: space travel. It is an opportunity you may only have once, so you must be ready.

For you to appreciate every detail of your journey and survive a year in a tiny space ship with other astronauts, you need to address both emotional and physical challenges.

- What hard truths must you recognize about yourself?
- How will you interact with others in such tight quarters?
- What distractions will follow you through space?
- Will you be able to maintain a cool head and confidence in the face of adversity?

You will face physical challenges as well. Living in zero gravity will take its toll on daily functions, such as eating, digestion, and exercise.

Regardless of your emotional and physical situation, you have no choice but to work through your daily struggles; there is no way to return home. You must find a way to cope. Arm yourself with information about other astronauts. Check in with the team in the International Space Station. Learn what experiences have pushed them to the limit and how they coped in order to complete a successful mission.

Handout 3

Facing the Unknown

Name: ______________________________ **Date:** ______________________

You have been traveling toward Mars for almost three months. You are only one-fourth of the way through your journey. You long ago passed the moon, and every day you wake up to a solar system filled with stars that never seem to get any closer. You peep out of the tiny windows into the vastness of space.

- What do you see in front of you? Is Mars in sight?
- What do you see behind you?
- Has the Earth gotten smaller and smaller behind you?
- What keeps you focused on your journey when the final goal is still nine months away, and just a tiny dot that never seems to grow bigger? How do you pass your time?
- Are you sorry that you have come, or are you eager to proceed on the journey? Why?

Handout 4

Facing the Unexpected

NAME: ______________________________ **DATE:** ______________________

All your training, science, math, study of space, and self-analysis did not prepare you for this shocking event. You are a little over six months into your journey and you and your crewmates are faced with an unbelievable shock.

Create one scenario that tests your strength and questions your ability to complete the mission. Describe the threat in vivid terms and work to develop a mood of tension that will create anxiety in your character and perhaps in your reader.

You must find a solution. The solution depends on the problem, and creating the problem is an opportunity to finally realize your biggest fear or question about space. Create a plan to address this shocking event.

Remember that your actions should be in keeping with your character's personality for the solution to seem credible. This is an opportunity for creative character soul-searching and internal dialogue. It is also a good opportunity to pull in details from the character's back story. When was a time he or she made it through a major discouragement and found a way to relight the fire of enthusiasm?

Handout 5

Stop the Ship! I Want to Get Off!

Name: ______________________________ **Date:** ____________________

You have the honor of being a crewmember on the historic first journey to Mars. This first trip is meant as a fly-by exploration exercise to pave the way for future Mars landings. You have just spent a year travelling through space and you cannot even get out to stretch your legs. You knew this when you volunteered for the mission, and you thought you would be okay with it. After all, isn't it just about the journey?

But it was a very long journey and, after a few weeks, the excitement wore off. Now you are so close to Mars, you feel you could reach out and touch it. But that is not the mission. You and your little ship will swing into orbit around Mars, take a good look, select potential landing sites for the next crew, and then head home.

How can this be good enough? What difference can your role in this mission make to future Mars missions? Does this trip even matter? This is the turning point in your journey (literally and figuratively). How you solve this emotional crisis will set the tone for your trip home. What are you going to do?

Handout 6

There's No Place Like Home

Name: ____________________ **Date:** ____________________

You can see Earth in the distance as you enter the final few days of your journey. The "Big Blue Marble" is a welcome sight, and you are excited to return home. But you are anxious, too. You have been away for almost two years, and you start anticipating the changes.

- How does the Earth look to you now, after nearly two years in the void of space and seeing the barren, lifeless red planet?
- The world has been following your journey, and you are a national hero. How will this impact you?
- How are you going to readjust to everyday life?
- What is the first thing you will do when you arrive home?

As you anticipate the homecoming, you and the rest of your crew spend some time reflecting on the overall journey.

- What has it all been for? Has it been worth it?
- What was the most life-changing part of this journey?
- How has your two-year sacrifice contributed to the future of space exploration?
- What impact has it had on you?

Handout 7

We Are Not Alone: Collaboration for Success

Name: ______________________________ **Date:** ______________________

You are about to embark on a different kind of journey: writing a collaborative story with your fellow crew members. Have your group read through the following roles and assign them to a suitable crew member:

Titles and Duty Descriptions for the Collaborative Story

Cohesion Commander: Your job is to consistently make sure the group essay mission is progressing smoothly. Keep your group on task and monitor the idea input for logical flow. Occasionally your group might lose focus and find themselves needing encouragement or redirection. Your job is to draw everyone together again, using phrases such as: "We need to say that a little differently to stay on course" or "That seems kind of foggy, let's clear that up before we put it in our essay." Cohesiveness is your job, every step of the way.

Vocabulary Impact Engineer: Your job is to check spelling and check for correct and creative use of words. You may use a dictionary or thesaurus to help. You may need to research correct terminology used on a space mission. Your crewmates need you to be vigilant about terminology, because when lives are at stake, clear communication is vital. Word precision is an editing process that requires constant attention.

Flight Navigator: You are the evidence-verifier, quote-finder, and context coordinator for this collaborative story. It is your duty to work closely with your Cohesion Commander to make sure all evidence is used in correct context and all events are presented in the most plausible way possible.

Flight Medic: You will work closely with the entire crew to verify grammar and mechanics in the essay. You may use any sources available to you for this job. When several people join different essays, there might be variations in point of view and tense. The flight mechanic is responsible for equalizing everything.

(Optional position)

Assembly and Presentation Technician – You are the visual aid and presentation leader. In order to present your story to the class, you will need to produce a visual aid to coincide with your group's story. Use your technology prowess to present your mission in the heroic light it deserves. You will direct the creative reading of the story by your crewmates.

Individual travel log and mission debrief: Along with your assigned duty, you should keep a log of your individual contributions to the essay. What pieces of writing did you contribute? What creative ideas did you share? What did you like (or not) about this group effort and your participation as an individual crewmember?

After your group has presented your collaborative story, you will write a reflective essay that will include the details from your travel log and your thoughts on the process. It should be two to three pages, typed and double-spaced. This should be written in first person as a reflection on your overall journey.

Lesson 7 (HISTORY, PHYSICS, SOCIAL STUDIES)

JOURNEYS IN FILM™
educating for global understanding

The History of the Space Program

Enduring Understandings

- The Cold War led to technology that ultimately enabled us to explore our solar system and beyond.
- Our understanding of the solar system changes with each new discovery.
- Studying other planets and their moons can enhance our understanding of Earth and its unique (strange) placement in the solar system.

Essential Questions

- When did we begin to explore space, and how did we get there?
- How did tools of war – rockets and artificial satellites – lead to missions to explore space?
- How do data from space missions enhance our continuously evolving model of the solar system?
- What kinds of data are relayed from space missions to Earth, and how do we make sense of them?
- How does space exploration help us understand our own planet?
- How was the environmentalist movement triggered by space exploration?
- Why is planet Earth so different (strange) compared with all the other planets in our solar system?

Notes to the Teacher

This lesson is an investigation into the history of space travel. With an introductory video clip, class discussion, and worksheet, students are then split into teams to research a chapter of the overall story. During the lesson, give students the opportunity to view episodes from the National Geographic documentary series *One Strange Rock*. The episodes entitled "Escape," "Home," "Survival," and "Terraform" are particularly relevant.

Part 1 begins with a video clip from Carl Sagan in which he discusses the importance of Earth to the human race and how essential it is to care for it. Sagan was an American astronomer who taught for most of his life at Cornell University, where he directed the Laboratory for Planetary Studies. He wrote many popular books on space and consulted for films as well. His television series *Cosmos* was extremely popular. The video clip can be found at https://www.youtube.com/watch?v=GO5FwsblpT8.

Here are some additional resources for you or your students to learn more about Carl Sagan and his contributions:

A National Geographic article by Dan Vergano about Sagan's life and work
https://news.nationalgeographic.com/news/2014/03/140316-carl-sagan-science-galaxies-space/

A Smithsonian article about why Sagan is irreplaceable
https://www.smithsonianmag.com/science-nature/why-carl-sagan-truly-irreplaceable-180949818/

Sagan's *Cosmos* television series is available on YouTube. The first episode is at
https://www.youtube.com/watch?v=FT_nzxtgXEw.
In 2014, Neil DeGrasse Tyson did a reboot of the series, which can now be seen on streaming services like Netflix.

Journeys in Film: One Strange Rock

After students have watched the video, they can work with **Handout 1: The Pale Blue Dot**, which excerpts some of the text from the video. If you would prefer that they have the entire text to use, it can be found at http://www.planetary.org/explore/space-topics/earth/pale-blue-dot.html.

Part 2 is a research assignment. Seven topics are provided, but fewer could be used, or more could be created, if class size requires. Groups should be between two and four students, and, depending on the length of the class periods, at least three 50-minute classes should be allowed for research and creation of the presentations. This lesson allows for flexibility in expectations. Requirements could be for a 7-10 slide presentation or longer, depending on time available and student ability.

Copy the first page of **Handout 2: Research Assignments** for all students and then enough copies of the following pages so that there is an assignment for each student. If you have an additional topic you would like to add, make up a page with background information, possible resources, and questions to investigate for that topic. Give some thought to how you wish to assign groups: by student choice, by random drawing, by ability grouping, etc.

No previous knowledge of the history of the space program is required, as students will be immersing themselves in history using primary sources – presidential addresses, press releases, NASA official video and text, and more. Some primary resource material is suggested for each topic, but feel free to use other relevant materials that you find.

In establishing the assignment, you might wish to spend some time discussing how to judge whether a website is reliable. You should also be clear about your expectations for primary sources; define and clarify the term if students are unfamiliar with it.

When students seem knowledgeable about their topic, they will work on a concept map using **Handout 3: Timeline Planning**. If you need more information about concept mapping, there is a useful tutorial at http://ctl.byu.edu/tip/concept-mapping.

Part 3 of the lesson is the series of student presentations, followed by filling in the timeline. Before the presentations, set up your timeline. There are several options for constructing the class timeline. A physical timeline, made of simple images or elaborate posters representing each presentation could be created in a classroom, hallway, or open school space. Set up a series of poster boards or use freezer paper as a basis for the timeline; draw a long horizontal line and mark off years, going up to the 2030s. You may wish to color-code each topic, using green magic markers for one group, blue for another, etc., since many of these events occurred simultaneously.

Alternately, a virtual timeline can be constructed by using a website or a master slideshow with links to each group's presentations. Google Docs makes sharing projects simple, but Microsoft PowerPoint has sharable links as well. If groups use other presentation platforms, such as Prezi, the presentation can be shared by a link. The comfort level of the teacher and students with technology can determine how much of this is used for this lesson.

During the presentations, students who are listening should take notes and ask questions of the presenters. Encourage active participation.

For students who have high interest in space or need enrichment, suggest the extension activity as an option. This could also be a longer-term assignment for the class as a whole. Comparing an older text to a newer book and/or film is a way to bring science, literature, and popular films together. The full text can be found online at https://archive.org/details/ProjectMars.

Common Core Standards/Next Generation Science Standards addressed by this lesson

CCSS.ELA-LITERACY.RST.11-12.1
Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.

CCSS.ELA-LITERACY.RH.11-12.2
Determine the central ideas or information of a primary or secondary source; provide an accurate summary that makes clear the relationships among the key details and ideas.

CCSS.ELA-LITERACY.RST.11-12.4
Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to *grades 11-12 texts and topics*.

CCSS.ELA-LITERACY.RST.11-12.5
Analyze how the text structures information or ideas into categories or hierarchies, demonstrating understanding of the information or ideas.

CCSS.ELA-LITERACY.RH.11-12.7
Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., visually, quantitatively, as well as in words) in order to address a question or solve a problem.

CCSS.ELA-LITERACY.RH.11-12.9
Integrate information from diverse sources, both primary and secondary, into a coherent understanding of an idea or event, noting discrepancies among sources.

Duration of the Lesson

Three to five class sessions

Assessments

Individual research projects linked to a class timeline

Participation in class discussion

Materials needed

Ability to project video clip "The Pale Blue Dot"

Internet access for research

Photocopies of **Handouts 1-4**

Photocopies of **Handout 5** (optional)

Tech skills to make a virtual timeline — a "hyperdoc" where students insert a link to their project on a main page— or poster board or freezer paper and markers to make a traditional timeline for display in a hallway or room

Procedure

Part 1: The Pale Blue Dot

1. Introduce students to Carl Sagan using the information provided in Notes to the Teacher.
2. Show the video clip "The Pale Blue Dot" at https://www.youtube.com/watch?v=GO5FwsblpT8.
3. Distribute **Handout 1: The Pale Blue Dot.** Have students answer questions individually, and then share their responses with a neighbor.
4. Use the questions to start a class discussion about this compelling piece, and discuss why exploring space is important to humans and our relationship with Earth.

Part 2: Chapters in Space Exploration

1. List the research topics from **Handout 2: Research Assignments** on the board and briefly explain each.
2. Group students in small teams according to your preferred method and distribute copies of the handout as described in Notes to the Teacher.
3. Explain that each team is going to research one of the topics, or encourage students to develop their own subtopics. Point out that **Handout 2** describes specific requirements for research and suggested primary sources and questions for each. Explain that each team will look at a chapter of the history of the exploration of space using at least one primary source and create a digital presentation of their findings.

4. If necessary, review the meaning of primary source and give examples from the space program. Tell students that many of the suggested resources on their handout have primary sources.

5. Suggest that they go beyond the suggested resources to develop leads to reliable websites on their own.

6. Set intermediate and final deadlines for the project and make clear what your expectations are for the presentation.

7. Allow sufficient time for teams to do their research, either during class time or as homework, and to meet in groups to plan their presentations.

8. When student groups seem sufficiently knowledgeable about their topics, distribute **Handout 3: Timeline Planning** and have each group draw a concept map of their topic. Have them date each event on the concept map.

[Note: The time when students are doing their research would be an excellent time to show one or more episodes from *One Strange Rock* during class time. See Notes to the Teacher for suggested episodes to accompany this lesson. Be sure to allow adequate class time for student discussion and questions.]

Part 3: Presentations and Timeline

1. Distribute copies of **Handout 4: Presentation Feedback**.

2. Have groups give their presentations in the order indicated on the handout. Tell students who are not presenting at the moment to take notes and prepare questions using the handout. After each group's presentation, allow time for the "audience" to ask questions and comment.

3. If you are using a physical timeline, hang it on the classroom wall or bulletin board and give students the opportunity to mark off significant events. If you are using a virtual timeline, make sure students understand how to access it and enter information on it.

4. Once the presentations are completed, have each student group fill in relevant events on the classroom timeline.

Extension Activity: Literature Connection

You might wish to team teach with a literature teacher for this activity. Have students read all or part of Wernher von Braun's 1953 book *The Mars Project* and then compare his insights to the movie *The Martian* or the National Geographic video series *MARS*. How close were his predictions about interplanetary travel? How has our understanding of our neighbor planet changed in the last half-century?

Handout 1 ▸ P.1 The Pale Blue Dot

Directions:

Watch Carl Sagan's video clip and listen carefully to his words. Then answer the questions that follow. If you would like to read the full text of the video clip, you can find it at http://www.planetary.org/explore/space-topics/earth/pale-blue-dot.html.

Look again at that dot. That's here. That's home. That's us. On it everyone you love, everyone you know, everyone you ever heard of, every human being who ever was, lived out their lives. The aggregate of our joy and suffering, thousands of confident religions, ideologies, and economic doctrines, every hunter and forager, every hero and coward, every creator and destroyer of civilization, every king and peasant, every young couple in love, every mother and father, hopeful child, inventor and explorer, every teacher of morals, every corrupt politician, every "superstar," every "supreme leader," every saint and sinner in the history of our species lived there--on a mote of dust suspended in a sunbeam….

The Earth is the only world known so far to harbor life. There is nowhere else, at least in the near future, to which our species could migrate. Visit, yes. Settle, not yet. Like it or not, for the moment the Earth is where we make our stand.

It has been said that astronomy is a humbling and character-building experience. There is perhaps no better demonstration of the folly of human conceits than this distant image of our tiny world. To me, it underscores our responsibility to deal more kindly with one another, and to preserve and cherish the pale blue dot, the only home we've ever known.

—Carl Sagan, *The Pale Blue Dot,* 1994

Handout 1 ▸ P.2

The Pale Blue Dot

1. How do we know, right away, that Carl Sagan is talking about the Earth?

2. How does Carl Sagan describe the many kinds of people living on the Earth? What would you add?

3. How does this poetic reading make you feel? Describe your reaction to the video and the image.

4. What are some ways that Sagan makes humans seem small in both size and importance?

5. What message does Sagan want to get across in the last paragraph?

Handout 2 ▸ P.1 Research Assignments

For this activity, you and your group will research a chapter of the history of the space program. For each topic, you will create a digital presentation of your findings, which can be in the form of a slideshow or other presentation or a website. Your job is to teach your peers about the topic you are assigned. What motivated the people involved? What challenges did they face? Who were the key players? What successes and failures can be seen in this stage of space exploration? What was learned from this stage? How did it fit into the overall quest for exploring space?

Many valid sources exist online regarding the space program. Use trusted sites from NASA or other government organizations, or use educational resources.

Speeches from the period, video footage of actual launches or landings, mission notes, etc., are all available online in the public domain. Include at least one of these primary sources in your research and share your findings in your presentation.

Suggested questions for each topic are included below, but feel free to investigate further for each or even add topics of your own.

Topic 1: Sputnik 1 and 2, Explorer 1, and Vostok

The history of space exploration began in a time of great international tension. The United States and the Soviet Union, at odds politically and philosophically, both were trying to protect themselves from the other. Nuclear war was on the horizon, and the ability to launch intercontinental ballistic missiles became a reality.

Suggested resources:

Eisenhower Sputnik Conference memo
https://www.archives.gov/education/lessons/sputnik-memo

Telegram congratulating Khrushchev on manned space flight
https://www.jfklibrary.org/Asset-Viewer/HrokebN1GoyeVrdAvZpEfQ.aspx

Memorandum relaying the conversation between President Kennedy and Premier Khrushchev
https://www.jfklibrary.org/Asset-Viewer/a6otKt8gkkecQ_RUIeAdcg.aspx

Questions to investigate:

1. Why was the Soviet launch of Sputnik 1 and 2 such a shock to the U.S.?
2. What was special about Sputnik 2?
3. Who or what was Laika?
4. What was the role of Yuri Gagarin?
5. How did Americans respond? What role did American innovators like Robert Goddard and Wernher Von Braun play in America's early space program?

Handout 2 ▸ P.2

Research Assignments

Topic 2: JFK and Apollo Missions to the Moon

In 1962, President John F. Kennedy pledged that the United States would put a man on the moon and return him safely to Earth before the decade was out. This was a very bold and risky goal in 1962, at a time when the U.S. had launched the first astronaut (John Glenn) into Earth orbit only months before. The Mercury program was the first mission to orbit the Earth, followed by the Gemini program designed to orbit a two-man crew, leading to the Apollo moon mission. On July 20, 1969, Kennedy's goal became a reality, accomplishing what seemed to be the impossible in just eight short years.

Suggested resources:

Special message to Congress on urgent national needs, 25 May 1961
https://www.jfklibrary.org/Asset-Viewer/Archives/JFKPOF-034-030.aspx
(The section on space begins on page 9 of the transcript and around 31:30 in the audio.)

John Glenn's orbital flight
https://www.youtube.com/watch?v=CVZm8VmMRpA

Apollo 11 Mission Report
https://www.hq.nasa.gov/alsj/a11/A11_MissionReport.pdf

The Eagle has landed
https://www.youtube.com/watch?v=5QS3JSRGk30

Questions to investigate:

1. Describe John Glenn's first trip to space.
2. What was Luna 9? Were we the first to land on the moon?
3. When did we first orbit the moon?
4. Why was the photo "Earth Rise" so significant?
5. Why was the U.S. moon landing so significant?
6. What tragedies and near-tragedies occurred during our quest to explore the moon?
7. How did the U.S. and Soviet Union both compete and work together in this goal of landing a man on the moon?
8. What did we learn about the moon during these missions, and how did it help us understand the Earth?

Handout 2 ▸ P.3

Research Assignments

Topic 3: Unmanned Early Space Missions: Voyager, Mariner, Pioneer, Venera, and Viking

These missions were first to fly by, orbit, and land on other planets, beginning our understanding of worlds other than our own. This continuing space exploration has led to our understanding of just how unique and strange our planet is compared with the other seven planets, hundreds of moons, and a dwarf planet (Pluto).

Suggested resources:

Exploration of the planets – NASA 1971
https://www.youtube.com/watch?v=_ds8_IFDp1o

Video transcript
https://www.archives.gov/files/social-media/transcripts/transcript-exploration-of-planets-649404.pdf

Questions to investigate:

1. What were the missions or goals of these various programs?
2. What kinds of instruments did they have on board?
3. What types of data were collected by these instruments?
4. What is the difference between a camera and a multispectral digital device?
5. Which planets did they investigate, and what kinds of information did they send us?
6. How do the data collected by these instruments travel to Earth?
7. What was the source of power used by these early missions?
8. For a deep space mission like Voyager, could solar panels be used to provide power to the instruments?
9. In the case of the Voyager spacecraft, why did they carry a "golden record"? What did it contain?
10. What did we learn about these planets, and how did this knowledge help us understand the Earth?

Handout 2 ▸ P.4 Research Assignments

Topic 4: Space Shuttle Missions

The space shuttle missions relied on a reusable shuttle, making this period of space travel almost routine. Unfortunately, disastrous losses of the shuttles *Challenger* (January 28, 1986) and *Columbia* (February 1, 2003) resulted in the deaths of 14 crew members, including Christa McAuliffe, the first civilian member of the *Challenger* crew and the first teacher in space. The term "shuttle" implied moving back and forth. Only in the latter years of the space shuttle (the Space Transportation System, or STS) did the shuttle become a way to travel to and from the International Space Station.

Suggested resources:

Teacher in Space – Lesson plans
https://www.challenger.org/challenger_lessons/christas-lost-lessons/

NASA's space shuttle webpage:
https://www.nasa.gov/mission_pages/shuttle/flyout/index.html

Questions to investigate:

1. Before the existence of the ISS, what were the purposes of some of the STS missions?
2. What role did the STS play in the development of the ISS?
3. Who was Christa McAuliffe?
4. Now that the STS progress has been cancelled, how do astronauts and cosmonauts travel to and from the ISS?
5. What was the cause of the loss of *Challenger* during the launch on January 28, 1989?
6. What was the cause of the loss of *Columbia* during re-entry on February 1, 2003?
7. How were the problems that caused the loss of *Challenger* and *Columbia* corrected?
8. What were some of the major accomplishments of the STS program?

Research Assignments

Topic 5: Space Stations Solyut, Mir, and ISS

Living and working in space for extended periods of time is a challenge, physically, mentally, and emotionally. What would it be like to live in a zero-gravity environment, not to be able to step outside for a breath of fresh air, to spend all day with the same people in a contained environment? The first space station, Salyut 1, was launched by the Soviets in 1971; it was launched in one piece and abandoned when its supplies were used up. The second generation of Russian stations, Mir, was modular, allowing for more flexibility. The International Space Station is also modular, with new modules added by both the Russians and the United States; it has been in operation since its launch in 1998.

Suggested resources:

A history of Russian space stations from PBS
http://www.pbs.org/spacestation/station/russian.htm

International Space Station updates
https://www.nasa.gov/mission_pages/station/main/index.html

The Mir space station
https://history.nasa.gov/SP-4225/mir/mir.htm

Questions to investigate:

1. Which country had the first space station? What kinds of problems occurred in trying to get a crew to the space station?
2. How many space stations have orbited the Earth?
3. What was the original intended purpose of having an orbiting space station? What is the current purpose of the ISS?
4. How many crew members are on the ISS? Where are they from?
5. When did cooperation occur between countries in manning and maintaining space stations?
6. What kinds of experiments are currently being conducted on the ISS?
7. Who is Scott Kelly and why is his mission important?

Handout 2 ▸ P.6

Research Assignments

Topic 6: Mars Exploration

At the present time, the U.S. has put both landers and rovers on the surface of Mars. In 1976, two Viking landers were the first to make a soft landing and to send back dramatic images from the surface. The first rover, called Sojourner, traveled a few meters from the Pathfinder landing craft in 1997. Since then, ever more sophisticated rovers have explored more of the Martian surface, engaging in NASA's mission: to "follow the water," in an effort to discover evidence of past or present life. However, NASA's future goal is to send humans to Mars in the mid-2030s

Suggested resources:

NASA's webpage on preparing for the journey to Mars in the 2030s
https://www.nasa.gov/topics/journeytomars/index.html

A concept video from SpaceX
https://www.youtube.com/watch?v=0q078R_yYFA

Questions to investigate:

1. Do you think sending humans to Mars is important?
2. Why is finding water on Mars so important?
3. What was a major goal of the Viking landers?
4. What have we learned about Mars from the Pathfinder mission?
5. What have we learned from the Mars rovers Spirit, Opportunity, and Curiosity?
6. Where on Mars is Curiosity located, and why was that area selected for study?
7. What is the Orion spacecraft, and what is its mission?
8. How long would it take humans to travel from Earth to Mars?
9. What does NASA's MarsHab look like, and what is its function?
10. Would you like to be a member of the first Mars mission crew? Why or why not?
11. Is the funding available to complete a manned Mars mission in the 2030s?

Handout 2 ▸ P.7

Research Assignments

Topic 7: Hubble Space Telescope

The Hubble Space Telescope (or HST) was launched in 1990 but immediately developed an "eyesight" problem – the images of distant galaxies sent back to Earth were blurry. One of the reasons for the blurred vision was that the original system used was actually designed as a "spy" satellite, one that looked down, through the distortions of the Earth's atmosphere. As a telescope looking out at the universe, it no longer needed to look through the atmosphere because it was above it, so corrective lenses were needed to fix the blurred vision. A space shuttle servicing mission in 1993 brought corrective optics to the HST, and the new images were spectacular. Since then, an additional four servicing missions have occurred, replacing parts that failed over time and adding new instruments to the telescope. At present, it is still operating, 17 years in Earth orbit.

Suggested resources:

The website for the Hubble Space Telescope
http://hubblesite.org/

The Hubble website from the European Space Agency
https://www.spacetelescope.org/

Questions to investigate:

1. Why has the HST been so important in developing our understanding of the universe?
2. Is the HST only used to study stars and galaxies?
3. How have the problems with the Space Shuttle, such as the disastrous losses of *Challenger* and *Columbia*, affected maintaining the HST?
4. Do you have a favorite HST image? If so, please describe it.
5. What has the HST told us about how stars are "born"?
6. What are the key pieces of information, gathered by the HST, that have supported the Big Bang theory?

Handout 3

Timeline Planning

Arrange your presentations (either physical, as a poster or image, or digital) in a way that makes sense to you. Sketch the topics as a concept map below. The topics may overlap chronologically or by content; they may be related by common ideas and individuals. Be sure to include relevant dates. This activity will help your class plan the organization of your timeline.

Handout 4 ▸ P.1 Presentation Feedback

As each group makes its presentation, use this workspace to write down questions and comments for the group. As time allows, class discussion may answer some of these questions, or you may use them as a springboard for further study.

Topic 1: Sputnik/Explorer/Vostok

Comments	Questions

Handout 4 ▸ P.2 Presentation Feedback

Topic 2: JFK/Apollo Missions

Comments	Questions

Topic 3: Unmanned Early Space Missions: Voyager/Mariner/Pioneer/Venera

Comments	Questions

Handout 4 ▸ P.3

Presentation Feedback

Topic 4: Space Shuttle Missions

Comments	Questions

Topic 5: Space Stations Solyut/Mir/ISS

Comments	Questions

Handout 4 ▸ P.4

Presentation Feedback

Topic 6: Mars Exploration

Comments	Questions

Topic 7: Hubble Space Telescope

Comments	Questions

Handout 5

The Literature Connection

Read Wernher von Braun's book *The Mars Project* and compare it to the movie *The Martian* or the National Geographic video series *MARS*. Compare and contrast von Braun's ideas about the planet with modern knowledge about Mars and strategies for exploring it.

A full copy of the text of von Braun's book can be found online at https://archive.org/details/ProjectMars.

- How has our understanding of our neighboring planet (Mars) changed in the last half-century?
- What do we know today about the possibility of life on Mars, as a result of having sent landers (such as Viking) and rovers (Spirit and Opportunity, as well as Curiosity)?
- Why do you think we actually need to send humans to Mars?
- How long would a round-trip to Mars take, assuming we simply orbited the planet instead of landing on its surface?
- What lessons did we learn from going to the moon that will serve as a model for a future Mars mission, now planned for the mid-2030s?
- If the first Mars mission is launched in 2035, how old will you be, and how old will you be when the astronauts return to Earth?
- Would you like to train to become an astronaut for that Mars mission?
- Why was the Mars mission presented in the movie *The Martian* called *Ares* and the Earth-Mars shuttle spacecraft called *Hermes*?
- Why was the first U.S. manned orbital mission called Mercury, to be followed by Gemini and Apollo?
- Why was Apollo 11 the first lunar landing and not Apollo 1 or Apollo 2?

You can present your response to this assignment in a written report, a digital presentation, or a video response. If you choose to do the video, work with a partner and have one person be the interviewer and one a Mars expert who answers the questions as if on an in-depth news show.

The Air We Breathe

Enduring Understandings

- The changes in our Earth's climate have both natural and man-made causes. However, the scientific data support that the recent dramatic climate changes are human-driven.
- The scientific methods used to discover what was happening to the Earth thousands of years ago are understandable, attainable, and repeatable.
- Since the problem has been human-driven, so is the solution. A social change is required to help bring the Earth back into its natural cyclical pattern.

Essential Questions

- How do we reduce the human impact on global climate change?
- What is global climate change? How has it changed due to human influence?
- What areas of our lives are affected most by climate change?
- What are the scientific principles involved with capturing ice core data?
- How does the Keeling curve affect our understanding of the causes of climate change?
- How can we spread awareness and reduce our carbon footprint?

Notes to the Teacher

The following excerpt was taken from the NASA Global Climate Change website https://climate.nasa.gov/ to provide a brief introduction and background for the teacher on the facts surrounding climate change. This source and others listed on the site and in the Additional Resources section will be useful throughout the lesson.

> *The Earth's climate has changed throughout history. Just in the last 650,000 years there have been seven cycles of glacial advance and retreat, with the abrupt end of the last ice age about 7,000 years ago marking the beginning of the modern climate era — and of human civilization. Most of these climate changes are attributed to very small variations in Earth's orbit that change the amount of solar energy our planet receives.*
>
> *The current warming trend is of particular significance because most of it is extremely likely (greater than 95 percent probability) to be the result of human activity since the mid-20th century and proceeding at a rate that is unprecedented over decades to millennia.*
>
> *Earth-orbiting satellites and other technological advances have enabled scientists to see the big picture, collecting many different types of information about our planet and its climate on a global scale. This body of data, collected over many years, reveals the signals of a changing climate.*

The heat-trapping nature of carbon dioxide and other gases was demonstrated in the mid-19th century. Their ability to affect the transfer of infrared energy through the atmosphere is the scientific basis of many instruments flown by NASA. There is no question that increased levels of greenhouse gases must cause the Earth to warm in response.

Ice cores drawn from Greenland, Antarctica, and tropical mountain glaciers show that the Earth's climate responds to changes in greenhouse gas levels. Ancient evidence can also be found in tree rings, ocean sediments, coral reefs, and layers of sedimentary rocks. This ancient, or paleoclimate, evidence reveals that current warming is occurring roughly ten times faster than the average rate of ice-age-recovery warming.[1]

The NASA site then provides a list of topics that you and your students can explore regarding the evidence that supports rapid climate change, including:

1. Global temperature rise
2. Warming oceans
3. Shrinking ice sheets
4. Glacial retreat
5. Decreased snow cover
6. Sea level rise
7. Declining Arctic sea ice
8. Extreme events
9. Ocean acidification

This lesson is designed to teach students about anthropogenic climate change and possible solutions to the problem. Topics include photosynthesis, Keeling curve, ice core data, sediment cores, evidence to support climate change, human behavior and lifestyle, and how to raise awareness to promote change.

The National Geographic series *One Strange Rock* has five episodes that are particularly relevant to this lesson: "Home," "Survival," "Terraform," "Shield," and "Gasp." Try to show as many as time permits in conjunction with the lesson. Be sure to allow sufficient time for student discussion and questions.

The lesson is divided into four parts that build on one another based on time and subject material. The first part introduces students to photosynthesis and the air they breathe. It is geared to teach students the basic inputs and outputs of photosynthesis and the light-dependent and light-independent reactions. This will help students understand that plants do not convert carbon dioxide into oxygen as many people believe. Instead, the oxygen they breathe comes from the splitting of water, and the carbon dioxide is transformed into structural and energy molecules needed by the plant. This section could take one to two days based on the level of detail for photosynthesis required for your students. You should watch the video from Paul Anderson's Bozeman Biology site on photosynthesis at https://www.youtube.com/watch?v=g78utcLQrJ4 ahead of time, prepare notes for class discussion, and have a few packs of sticky notes before class.

Part 2 allows for lab-based explorations to help students understand how the ice core data are collected. Students have opportunities to problem-solve, design a solution, and build a model that most effectively captures carbon dioxide. This

1 https://climate.nasa.gov/evidence/

part should take a full two days and will require a table of spare parts for students to design their own CO_2 chambers. You may also want to add a day for students to present their models and explain the choices they made for their design.

Part 3 introduces students to the Keeling curve data set and has them complete basic climate change research. This is a critical step to prepare students for the student activism project as it lays the groundwork to begin to understand the complexities of climate change science and the evidence that attributes the most recent dramatic changes in carbon dioxide concentrations to human activities. This part will take three days and will require copies of **Handout 1, Handout 2, and Handout 3** for each student. There are corresponding Teacher Resource pages after each handout that will guide you in class discussions.

The final part will take four to seven days, depending on how much work is assigned outside of class. After a class brainstorming session, students will choose a topic they will work on to create positive change regarding climate change. Students will research how their topics affect global change and submit a proposal for their project work. The teacher will consult with students, approve their plans, and make adjustments as necessary. The student proposals should articulate plans to share information with others outside of the classroom (the public) and document how they are promoting positive change. When students have completed their project work, they will share with the class in small groups or whole class presentations. Inviting administration, families, or local business leaders would help to show the importance of the work and support for the students. Audience members may participate by providing questions and meaningful feedback to each presenter/group.

Common Core Standards addressed by this lesson

CCSS.ELA-Literacy.RST.9-10.1
Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions.

CCSS.ELA-Literacy.RST.9-10.3
Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks, attending to special cases or exceptions defined in the text.

CCSS.ELA-Literacy.RST.9-10.7
Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words.

CCSS.ELA-LITERACY.RH.11-12.7
Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., visually, quantitatively, as well as in words) in order to address a question or solve a problem.

CCSS.MATH.CONTENT.HSF.IF.B.4
For a function that models a relationship between two quantities, interpret key features of graphs and tables in terms of the quantities, and sketch graphs showing key features given a verbal description of the relationship.

CCSS.MATH.CONTENT.HSF.IF.B.5
Relate the domain of a function to its graph and, where applicable, to the quantitative relationship it describes.

CCSS.MATH.CONTENT.HSF.IF.B.6
Calculate and interpret the average rate of change of a function (presented symbolically or as a table) over a specified interval. Estimate the rate of change from a graph.

NGSS Standards addressed by this lesson

Downloaded from the NGSS website at https://www.nextgenscience.org/

HS.Interdependent Relationships in Ecosystems
Students who demonstrate understanding can:

HS-LS2-6.
Evaluate the claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem. [Clarification Statement: Examples of changes in ecosystem conditions could include modest biological or physical changes, such as moderate hunting or a seasonal flood, and extreme changes, such as volcanic eruption or sea level rise.]

HS-LS2-7.
Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity. [Clarification Statement: Examples of human activities can include urbanization, building dams, and dissemination of invasive species.]

HS-LS4-6.
Create or revise a simulation to test a solution to mitigate adverse impacts of human activity on biodiversity. [Clarification Statement: Emphasis is on designing solutions for a proposed problem related to threatened or endangered species or to genetic variation of organisms for multiple species.]

The performance expectations above were developed using the following elements from the NRC document A Framework for K-12 Science Education.

Science and Engineering Practices

Constructing Explanations and Designing Solutions
Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories.

- Design, evaluate, and refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. (HS-LS2-7)

Disciplinary Core Ideas

LS2.C: Ecosystem Dynamics, Functioning, and Resilience
- A complex set of interactions within an ecosystem can keep its numbers and types of organisms relatively constant over long periods of time under stable conditions. If a modest biological or physical disturbance to an ecosystem occurs, it may return to its more or less original status (i.e., the ecosystem is resilient), as opposed to becoming a very different ecosystem. Extreme fluctuations in conditions or the size of any population, however, can challenge the functioning of ecosystems in terms of resources and habitat availability. (HS-LS2-2),(HS-LS2-6)
- Moreover, anthropogenic changes (induced by human activity) in the environment—including habitat destruction, pollution, introduction of invasive species, overexploitation, and climate change—can disrupt an ecosystem and threaten the survival of some species. (HS-LS2-7)

LS4.D: Biodiversity and Humans
- Biodiversity is increased by the formation of new species (speciation) and decreased by the loss of species (extinction). (secondary to HS-LS2-7)
- Humans depend on the living world for the resources and other benefits provided by biodiversity. But human activity is also having adverse impacts on biodiversity through overpopulation, overexploitation, habitat destruction, pollution, introduction of invasive species, and climate change. Thus, sustaining biodiversity so that ecosystem functioning and productivity are maintained is essential to supporting and enhancing life on Earth. Sustaining biodiversity also aids humanity by preserving landscapes of recreational or inspirational value. (secondary to HS-LS2-7), (HS-LS4-6)

NGSS Standards: addressed by this lesson

ETS1.B: Developing Possible Solutions

- When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. (secondary to HS-LS2-7),(secondary to HS-LS4-6)
- Both physical models and computers can be used in various ways to aid in the engineering design process. Computers are useful for a variety of purposes, such as running simulations to test different ways of solving a problem or to see which one is most efficient or economical, and in making a persuasive presentation to a client about how a given design will meet his or her needs. (secondary to HS-LS4-6)

Crosscutting Concepts

Cause and Effect

- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. (HS-LS2-8),(HS-LS4-6)

Scale, Proportion, and Quantity

- The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs. (HS-LS2-1)
- Using the concept of orders of magnitude allows one to understand how a model at one scale relates to a model at another scale. (HS-LS2-2)

Stability and Change

- Much of science deals with constructing explanations of how things change and how they remain stable. (HS-LS2-6),(HS-LS2-7)

Duration of the Lesson

Part 1: one to two class periods–Photosynthesis Brainstorm and Background

Part 2: one to two class periods–CO2 Lab Explorations

Part 3: two to three class periods–Keeling Curve, Webquest, Ecological Footprint

Part 4: four to seven class periods–Student Activism Project and Presentations

Assessments

Brainstorming notes

Handouts, webquest, and worksheets

Class discussions

Student or group project and presentations

Materials needed

Sticky notes

Handout 1: What Is the Keeling Curve?

Handout 2: Exploring Earth's History and Understanding Climate Change

Handout 3: What is Your Ecological Footprint?

Handout 4: Student Activism Project Proposal

Handout 5: Student Activism Project Assignment

Whiteboard or overhead to record and display class ideas and questions

Table of spare parts for students to design CO2 chambers (milk jugs, plastic containers, glue guns, scissors, etc.)

Computers with Internet access

One Strange Rock documentary

Procedure

Part 1. Photosynthesis Brainstorming and Background

1. Begin class by asking students "Where does most of the matter of a tree come from?" Have students brainstorm a list of what makes up the tree, such as wood, bark, leaves, flowers, roots, and fruit, to have an idea of what makes up all the matter of a tree. Then brainstorm a list of possibilities of what plants need to grow. Accept all ideas at first and list them on the board. Students may say light, carbon dioxide, water, oxygen, chlorophyll, chloroplasts, minerals, soil, leaves, etc. Then have students write down the one choice that they think is the best answer on a sticky note. Help students create a bar graph on the class whiteboard with all of the choices.

2. Start a class discussion about the results to see what students know or remember about photosynthesis. You may be able to construct the basic photosynthesis chemical formula of inputs and outputs by working together as a group: light + carbon dioxide gas + water yields oxygen gas + glucose (food). This can then lead to writing the formula using the chemical symbols: $6\ CO_2 + 6H_2O +$ energy$\longrightarrow C_6H_{12}O_6 + 6O_2$.

3. Watch the video from Paul Anderson's Bozeman Biology site on photosynthesis https://www.youtube.com/watch?v=g78utcLQrJ4 and assign appropriate textbook reading for your level of student. The goal is to spend the next class day learning about the light-dependent and light-independent reactions of photosynthesis and to make sure students know when each reactant and product are utilized in the process.

4. Once you have covered photosynthesis, ask students if they would like to change their answer to the matter question or if they now know the correct response. The two big points to stress are that the oxygen we breathe comes from plants splitting water in the light-dependent reactions and that most of the matter of a tree comes from the carbon dioxide being fixed with the hydrogen from water in the light-independent reactions (Calvin cycle) making G3P, which serves as the basic building blocks for the plant's energy and structural needs.

Part 2. CO_2 Lab Explorations

1. Begin the class with the video "CO_2 in the Ice Core Record" at https://www.youtube.com/watch?v=oHzADl-XID8&t=102s. Upon completion, begin a classroom discussion about the idea of capturing trapped air from melting ice. Ask students, "How could we recreate these experiments to capture CO_2 levels at the high school (middle school) level?"

2. Explain that students will need to determine a way to capture and measure the CO_2 released when sodium bicarbonate tablets (Alka Seltzer) are dropped into normal tap water. You should have all available equipment out on the desk to show students what they will have to work with. This may or may not include a CO_2 sensor made by Vernier or Pasco among others. Have students brainstorm in groups.

3. Challenge students to come up with the most efficient way to capture and collect these data. Allow students time to discuss and come up with a plan.

4. Have students present and discuss their work. They should be prepared to discuss their findings and be able to elaborate on their choices in procedure. They may also want to incorporate "things that went well" and/or "suggestions toward future improvement."

5. The idea of the final challenge problem is to provide students a frame of reference for how scientists measure atmospheric gases released from 800,000-year-old ice. Students are duplicating scientific methods to reinforce how scientists can tell what was going on in the Earth's atmosphere so long ago.

Part 3. Keeling Curve, Climate Change Webquest, and Ecological Footprint Activity

1. Pass out **Handout 1: What Is the Keeling Curve?** and have students work with partners to analyze the graph and answer the questions. Students can finish for homework if they run out of time.

2. Have students report out their answers and discuss the difference between the carbon dioxide levels increasing overall as a result of increased fossil fuel burning and the annual increase and decrease as a result of deciduous trees leafing in the spring and senescing in the fall. Help students connect back to photosynthesis by showing them the formula and helping them to see the inputs and outputs of photosynthesis to understand why carbon dioxide levels drop in the spring/summer and increase in the fall/winter. Note that there are Teacher Resource sheets following each of the three handouts to guide you in class discussions.

3. (Optional) Explore photosynthesis labs with CO_2, O_2 probes, and baby spinach in a chamber. Expose the spinach to light and dark recording levels to see when the plant is doing cellular respiration and photosynthesis.

4. Start the research necessary for the Student Activism Project by having students work through the climate change webquest on **Handout 2: Exploring Earth's History and Understanding Climate Change** and then the **Handout 3: What is Your Ecological Footprint?** activity. (Complete the activities yourself ahead of time to anticipate student questions and help them navigate the websites. Work through your own ecological footprint to be able to share your results with the class.) Have students post their results on the board, so they can calculate a class average on step 4 of the worksheet.

Part 4: Student Activism Project

[Note: The period of time when students are planning their activism project independently is an excellent time to show episodes from *One Strange Rock* in your classroom. Be sure to allow adequate time for student discussion and questions. Suggestions for the most relevant videos for this lesson may be found in Notes to the Teacher.]

1. Begin class by posing the question to students: In what areas of our community/country/world should we make important changes in order to slow climate change? Start a class list to which they can add responses, and provide one example to start the list (for example, food, transportation, electricity, clothing, housing). Then instruct students to record three responses they might include on the list. Try to have each student contribute at least one idea.

2. When the list exceeds the number of students in the class or you're satisfied that the responses include the most important areas, assign each student one of the criteria as a topic for their project.

3. Distribute **Handout 4: Climate Change Activism Project Proposal** and **Handout 5: Climate Change: Student Activism Project**. Give students adequate time to research and plan their projects.

4. Meet with students to discuss their proposals and make adjustments as necessary.

5. After students have completed the Awareness Campaign and the Action Campaign, give them the opportunity to share what they have accomplished with the class in whole-class or group presentations.

Journeys in Film: One Strange Rock

Handout 1 ▸ P.1

What Is the Keeling Curve?

Directions:

Review the graph on the next page carefully before you respond to the questions below. The jagged line represents the "monthly mean" and the relatively straight line represents the "long-term trend" of atmospheric carbon dioxide.

1. What do the data in this graph indicate? Be complete in your response.

2. The oldest available data point from the Keeling curve was from 1958 and had a readout of 315.70 ppm. The most current available data point is from 2017 and had a readout of 407.46 ppm. Calculate the average rate of change (slope) between these two data points. Interpret your results. Please remember to include units.

3. Why do you think the "monthly mean" line shows a single rise and fall each year? Explain your answer.

4. Why do you think the "long-term trend" line is steadily increasing? Use the terms and concepts you learned about the carbon cycle in your response.

Handout 1 ▸ P.2

What Is the Keeling Curve?

5. Why do you think the sharp drop in CO_2 levels occurs between the months of May and September/October?

6. What role does the Earth's vegetation play in shaping the annual CO_2 cycle of levels shown in the Mauna Loa data?

7. The Mauna Loa Observatory is located in the Northern Hemisphere, while other CO_2 observatories are located in the Southern Hemisphere. How different do you think the Southern Hemisphere CO_2 levels would be?

Handout 1 ▸ P.3 What Is the Keeling Curve?

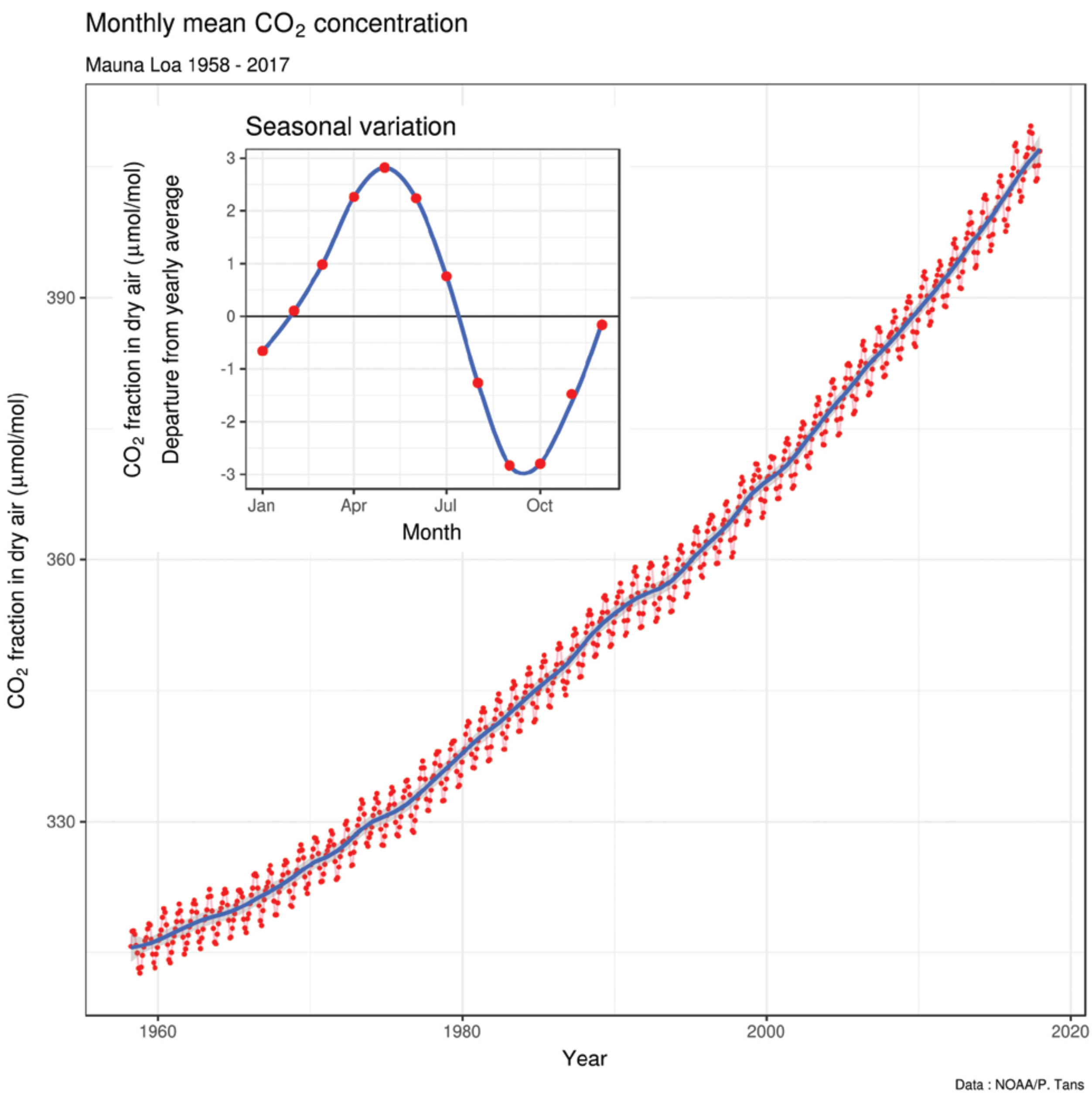


Figure 1. The "Keeling curve," a long-term record (1958-2017) of atmospheric CO_2 concentration measured at the Mauna Loa Observatory (Keeling et al.). The insert shows a single annual CO_2 cycle. Note that the annual CO_2 peak occurs in May and the lowest levels occur in September and October.

Source: Data from Dr. Pieter Tans, NOAA/ESRL and Dr. Ralph Keeling, Scripps Institution of Oceanography at https://commons.wikimedia.org/wiki/File:Mauna_Loa_CO2_monthly_mean_concentration.svg.

Teacher Resource
1 ▸ P. 1

Answer Sheet for Handout 1

1. What do the data in this graph indicate? Be complete in your response.

The data in the graph represent how much carbon is in the atmosphere in ppm each year since 1958. It shows a positive trend, since that amount is increasing from 1958 to 2017. Students can look up Charles David Keeling to learn more about the history of the data collection.

2. The oldest available data point from the Keeling curve was from 1958 and had a readout of 315.70 ppm. The most current available data point is from 2017 and had a readout of 407.46 ppm. Calculate the average rate of change (slope) between these two data points. Interpret your results. Please remember to include units.

To calculate the slope or rate of change, you need to subtract the two y-coordinates. After finding the difference between the amounts of CO_2 *(407.46 – 315.70 = 91.76), you need to divide by the total number of years that have transpired, 59 (2017 – 1958 = 59). So 91.76 divided by 59 equals 1.555. This represents the average growth in* CO_2 *in ppm each year since they started to record the data.*

3. Why do you think the "monthly mean" line shows a single rise and fall each year? Explain your answer.

The rise in CO_2 *begins in October and continues until mid to late April, which corresponds with deciduous trees in the Northern Hemisphere losing their leaves and entering dormancy for the winter. The photosynthetic activity significantly drops, since the majority of Earth's vegetation (and deciduous trees) are in the Northern Hemisphere. Also, the decomposition of the fallen leaf material can result in* CO_2 *emissions from cellular respiration. The annual decline in* CO_2 *begins in April and continues to October, which corresponds with the trees and vegetation leafing out and converting* CO_2 *into glucose in the process of photosynthesis.*

4. Why do you think the "long-term trend" line is steadily increasing? Use the terms and concepts you learned about the carbon cycle in your response.

See responses in Handout 2 for more information on human impact on the carbon cycle and climate change. Overall, the steady increase is a result of human activity, such as fossil fuel use for industry, heating, and transportation. Also, habitat conversion removes forests and vegetation. Both impacts result in a shift of sources and sinks moving more carbon into the atmosphere that was stored in the Earth and trees.

Answer Sheet for Handout 1

5. Why do you think the sharp drop in CO_2 levels occurs between the months of May and September/October?

See Question #3. You may need to review photosynthesis and cellular respiration to help students understand the annual cycle.

6. What role does the Earth's vegetation play in shaping the annual CO_2 cycle of levels shown in the Mauna Loa data?

Similar to Questions #3 and #5. Encourage students to explore Earth's forests using Google Earth, other images, biome maps, etc. to see where the vegetation is located by hemisphere and where most of the deciduous forests are located. May need to review seasons for each hemisphere with students.

7. The Mauna Loa Observatory is located in the Northern Hemisphere, while other CO_2 observatories are located in the Southern Hemisphere. How different do you think the Southern Hemisphere CO_2 levels would be?

Answers may vary. Other sample sites around the globe have collected similar data to the Keeling curve. The Southern Hemisphere CO_2 readings lag behind those of the Northern Hemisphere because the majority of population-based CO_2 emissions are located in the Northern Hemisphere.

Handout 2 ▸ P.1

Exploring Earth's History and Understanding Climate Change

Directions for the Webquest:

Using the first link below, work through the slides and videos in the interactive PowerPoint presentation titled "Paleoclimate — A History of Change." Take notes as you move through the information.

Howard Hughes Medical Institute (HHMI) — Paleoclimate — A History of Change
http://media.hhmi.org/biointeractive/click/paleoclimate/

When you have finished, explore the two remaining sites below to understand the complexities of climate change.

NASA
http://climate.nasa.gov/evidence/

HHMI – Geologic Carbon Cycle
http://www.hhmi.org/biointeractive/geologic-carbon-cycle

Use your research to answer the following questions:

1. How has the Earth's climate changed?

2. How far back can scientists track the changes in climate?

3. What causes climate change?

Handout 2 ▸ P.2

Exploring Earth's History and Understanding Climate Change

4. What are greenhouse gases? Name examples of greenhouse gases. How does each contribute to climate change?

5. List and explain as many sources as possible of greenhouse gases.

6. How do humans contribute to climate change?

7. How long have humans been affecting Earth's climate?

8. List and explain at least five things you can do to reduce greenhouse gas emissions.

Answer Sheet for Handout 2

Below are possible responses. Please keep in mind that there is more information and detail to explore with climate change science

1. How has the Earth's climate changed?

Over time, Earth's climate has changed drastically. Earth's climate is a complex system controlled by many factors. There are two major factors that have caused most of this change. They are solar radiation and the composition of Earth's atmosphere. Both of these factors have changed the way temperature is working today. There have been times where the Earth is much warmer and cooler than it is today. Changes, like temperature, happen because the chemical composition of the atmosphere has changed over time. This results in varying the strength of the greenhouse effect. It could also be because the amount of solar radiation has varied over time.

The Earth's climate naturally changes very slowly and has a consistent pattern of change (warming and cooling periods). Human activities have released greenhouse gases, such as carbon dioxide. As a result, the climate has rapidly changed and is continuing to do so at rates that have never been reached before.

2. How far back can scientists track the changes in climate?

Scientists have found that the climate has changed over the past 70 million years. Scientists can track the natural warming and cooling patterns on Earth by examining the relative amounts of two oxygen isotopes. They measure the abundance of the two isotopes in the calcium carbonate shells of marine creatures that are found in ocean sediments. Here is a link to a good video that explains the science behind this method of tracking the different ice ages and interglacial periods: https://www.youtube.com/watch?v=YfRDNyB1XOY

3. What causes climate change?

There are two major factors that have caused most of climate change: solar radiation and the composition of Earth's atmosphere. Both of these factors have changed the way temperature is working today.

Because of variations in solar energy, ice ages have waxed and waned for the past million years. Small changes in Earth's orbit around the sun also affect the amount and distribution of solar energy striking the planet.

Atmospheric composition affects climate through the concentration of greenhouse gases, including carbon dioxide, methane, and water vapor. CO_2 *stays in the atmosphere for a long time, and the concentration varies significantly over time, resulting in changes of temperature.*

Teacher Resource 2 ▸ P.2

Answer Sheet for Handout 2

4. What are greenhouse gases? Name examples of greenhouse gases. How does each contribute to climate change?

Greenhouse gases are in the atmosphere, and they absorb and emit radiant energy. Greenhouse gases absorb and emit in the thermal infrared range. This process results in the cause of the greenhouse effect.

In Earth's atmosphere, the greenhouse gases include water vapor, carbon dioxide, methane, nitrous oxide, and ozone. Water vapor is a more short-term gas and only lasts a few weeks, and carbon and methane last a long time. Without greenhouse gases, the average temperature of Earth's surface would be about 0 °F. Greenhouse gases warm the Earth by absorbing energy and slowing the rate at which the energy escapes to space. According to the United States Environmental Protection Agency (EPA) "they act like a blanket insulating the Earth."

5. List and explain as many sources as possible of greenhouse gases.

Water vapor, carbon dioxide, methane, and nitrous oxide are greenhouse gases. A greenhouse gas is any gas that contributes to the greenhouse effect by absorbing infrared radiation; for example, carbon dioxide and chlorofluorocarbons are greenhouse gases. Each greenhouse gas is different. Water vapor is the most abundant greenhouse gas.

Water vapor increases as the Earth's atmosphere gets warmer. When the Earth's atmosphere gets warmer, the possibility of clouds and precipitation also increases, resulting in some of the most important feedback mechanisms to the greenhouse effect.

Carbon dioxide is released through natural processes like "respiration and volcano eruptions and through human activities such as deforestation, land use changes, and burning fossil fuels." Because of humans' increase in the amount of CO_2, it is the most important long-lived force in climate change.

Methane is a hydrocarbon gas and is produced through both natural sources and human activities. This includes decomposition of wastes in landfills, agriculture, and especially rice cultivation, as well as ruminant digestion and manure management associated with domestic livestock. Methane is a far more active greenhouse gas than carbon dioxide.

Nitrous oxide is a powerful greenhouse gas. It is produced by soil cultivation practices, especially the use of commercial and organic fertilizers, fossil fuel combustion, nitric acid production, and biomass burning.

Teacher Resource 2 ▸ p.3

Answer Sheet for Handout 2

6. How do humans contribute to climate change?

See responses above. Scientists have high confidence that global temperatures will continue to rise for decades to come because of the greenhouse gases that are produced by human activities. According to NASA, "The planet's average surface temperature has risen about 2.0 degrees Fahrenheit since the late 19th century." This change was largely driven by increased carbon dioxide produced by humans and other human-made emissions into the atmosphere. Greenhouse gases in the atmosphere today are the highest the world has experienced in the past 650,000 years. Carbon dioxide enters the atmosphere through burning fossil fuels (coal, natural gas, and oil), solid waste, trees, and wood products.

7. How long have humans been affecting Earth's climate?

Changes in Earth's climate are extremely likely to be a result of human activity since the mid-20th century and "proceeding at a rate that is unprecedented over decades to millennia" according to NASA. In the United States, greenhouse gas emissions caused by human activities increased by 7 percent from 1990 to 2014. Electricity generation is the largest source of greenhouse gas emissions in the United States, followed by transportation.

8. List and explain at least five things you can do to reduce greenhouse emissions.

a. *Buy food and other products with less packaging that will end up in landfills because this will only contribute to the building of greenhouse gases (recycle!).*

b. *Reduce heating and air conditioning in your home because it will result in less burning of fossil fuels that are a big source of CO_2.*

c. *Drive less because your car gives off pollution (CO_2).*

d. *Plant trees because they take in CO_2 and release oxygen as a result of photosynthesis.*

e. *Turn off lights when you aren't using them because they generate heat and take energy to keep on. This energy comes from the burning of fossil fuels.*

Handout 3 ▸ P.1

What Is Your Ecological Footprint?

Part 1:

Explore the link below to learn about an ecological footprint.

http://www.footprintnetwork.org/our-work/ecological-footprint/

Answer the questions below.

1. Describe the concept of an ecological footprint. What is it?

2. Explain the types of information needed to calculate an ecological footprint.

Part 2:

Now calculate your own ecological footprint by going to the following URL.
Answer the questions below once you have finished.

http://www.footprintcalculator.org/

3. What are the results of your personal ecological footprint?

4. How many Earths are you currently using? Please explain what this means.

Handout 3 ▸ P.2

What Is Your Ecological Footprint?

5. Are you surprised by your ecological footprint results? Please explain why or why not.

6. What is the average number of Earths currently in use by this class?

7. How does the class average compare with the ecological footprint of the United States?

8. Based on the data provided on the Global Footprint Network Website at http://data.footprintnetwork.org/#/, how does the ecological footprint of the United States compare with that of other countries in the world?

9. List and explain four solutions or changes from the website that you could make to reduce your ecological footprint.

Teacher Resource 3 Answer Sheet for Handout 3

1. Describe the concept of an ecological footprint. What is it?

An ecological footprint accounting measures the demand on and supply of nature. On the demand side, the ecological footprint measures the ecological assets that a given population requires to produce the natural resources it consumes (including plant-based food and fiber products, livestock and fish products, timber and other forest products, space for urban infrastructure) and to absorb its waste, especially carbon emissions. The ecological footprint tracks the use of six categories of productive surface areas: cropland, grazing land, fishing grounds, built-up land, forest area, and carbon demand on land. On the supply side, a city, state, or nation's biocapacity represents the productivity of its ecological assets (including cropland, grazing land, forest land, fishing grounds, and built-up land). These areas, especially if left unharvested, can also absorb much of the waste we generate, especially our carbon emissions.

2. Explain the types of information needed to calculate an ecological footprint.

Refer to information in Question #1 above and the website for more information.

3. What are the results of your personal ecological footprint?

Answers will vary.

4. How many Earths are you currently using? Please explain what this means.

Answers will vary.

5. Are you surprised by your ecological footprint results? Please explain why or why not.

Answers will vary.

6. What is the average number of Earths currently in use by this class?

Have students list their results on the board and work as a group to calculate the average.

7. How does the class average compare with the ecological footprint of the United States?

Currently, the United States on average has an ecological footprint of 5 Earths.

8. Based on the data provided on the Global Footprint Network Website at http://data.footprintnetwork.org/#/, how does the ecological footprint of the United States compare with that of other countries in the world?

Have students explore the different data sets and measurements in this link. You could have them report on a country or region they choose, or you could have groups explore each continent/region and report to the class.

9. List and explain four solutions or changes from the website that you could make to reduce your ecological footprint.

Students are able to click on the "Explore Solutions" tab after they complete their ecological footprint. The solutions are divided into the following categories: City, Energy, Food, Population. Have students explore the information and report one or two interesting facts they learned.

Handout 4 ▸ P.1

Climate Change Activism Project Proposal

In what area of our community/country should we make important changes? (For example, food, transportation, electricity, clothing, housing, etc.)

How will you share your information related to your topic? What format will you use to effectively connect with people? (For example, social media, flyers, magazines, billboards, signs, soapbox speeches, YouTube video, music/song writing, performance, marches, protest signs, etc.)

What are five sources of information you might use to educate yourself and others?

Handout 4 ▸ P.2

Climate Change Activism Project Proposal

What are five examples of evidence/information you might share with others?

How will you actively create change? What are you doing personally to reduce your carbon footprint? What are you doing to influence societal changes? (For example, responsible practices such as being efficient, ethical consumption, influencing public policy, supporting renewable energy, time/labor donation, voting or political advocacy, collection drives)

Additional educational/project requirements from your teacher:

Handout 5 ▸ P.1

Climate Change: Student Activism Project

At the heart of human history is understanding how changes in society can be accomplished. Based on what you've seen in the film and what you've already learned in class, design a campaign to inform others about global climate change and participate in bringing change to our society. Change starts with us, but it can also include imploring others to do the same on a larger scale. In this project, you'll have to the chance to do both.

To be successful you must complete three parts:

1. Project Proposal
2. Awareness Campaign
3. Action Campaign

Step 1

Climate Change Activism Project Proposal (See **Handout 4**.)

Step 2:

Create an **AWARENESS CAMPAIGN** that spreads information about how your topic affects global climate change so that people are aware of both the problem and possible solutions to it.

a. You must share important information about climate change with your target demographic beyond the classroom. Consider these examples as possible formats for your campaign: social media, flyers, signs, billboards, magazines, soapbox speeches, YouTube video, music/song writing, performance, marches, protest signs, etc.

b. You must explain the problem and provide evidence of its effect on global climate change. Your topic will potentially concern these aspects of climate change:

Global temperature rise
Warming oceans
Shrinking ice sheets
Glacial retreat
Decreased snow cover
Sea level rise
Declining Arctic sea ice
Extreme events
Ocean acidification

c. You must provide at least two potential solutions to the problem (e.g., responsible practices, such as saving electricity, time/labor donation, voting or political advocacy, collection drives, grant writing, protests).

Handout 5 ▸ P.2

Climate Change: Student Activism Project

Step 3

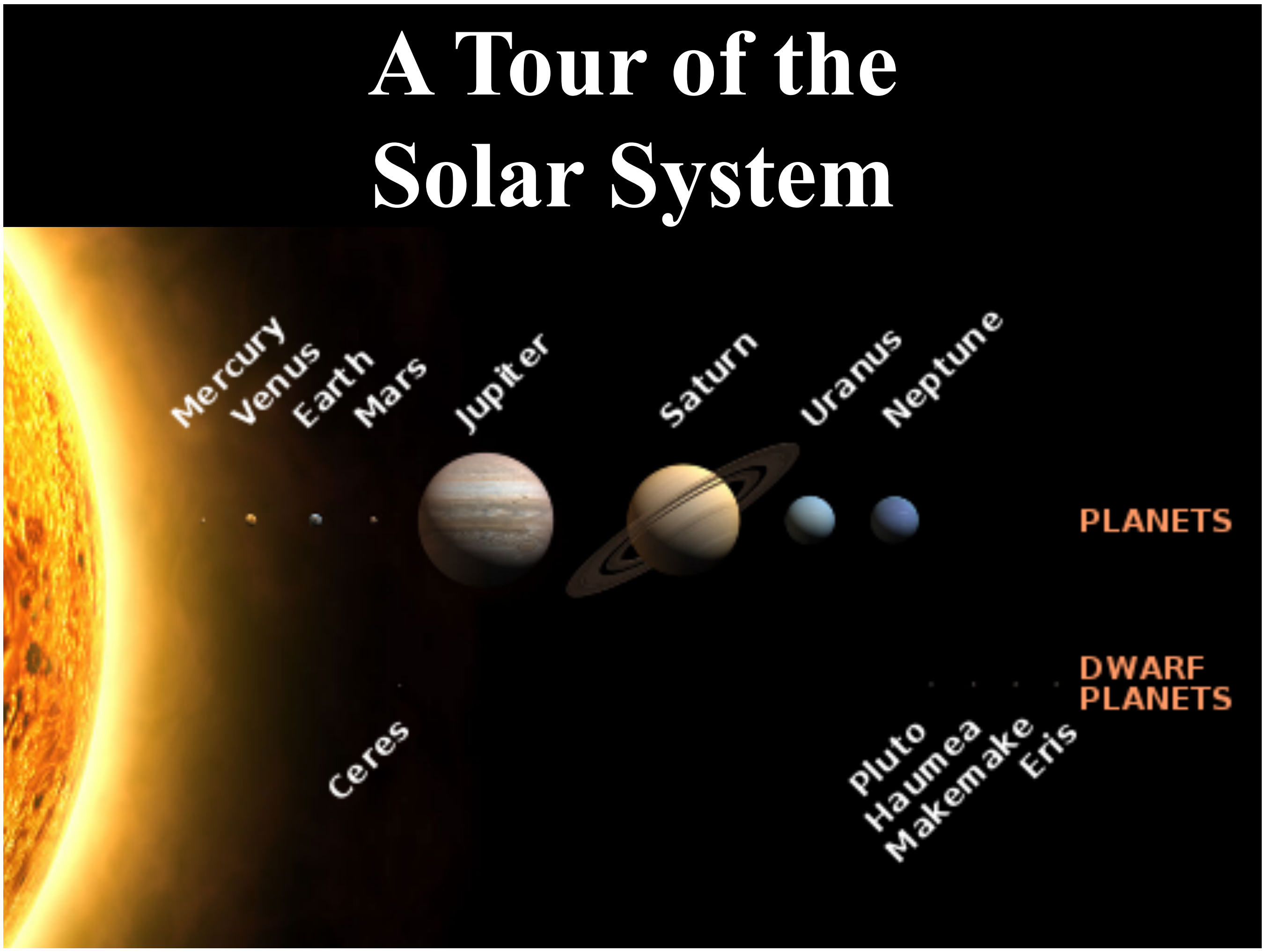
TAKE ACTION. Document practices that make a difference through an Action Campaign. What can you and others do about global climate change at home or in our society?

a. What are you doing personally to reduce your carbon footprint? Choose the best, most appropriate methods that will, even on a small level, solve the problem. (For example, responsible practices such as being efficient, ethical consumption, etc.)

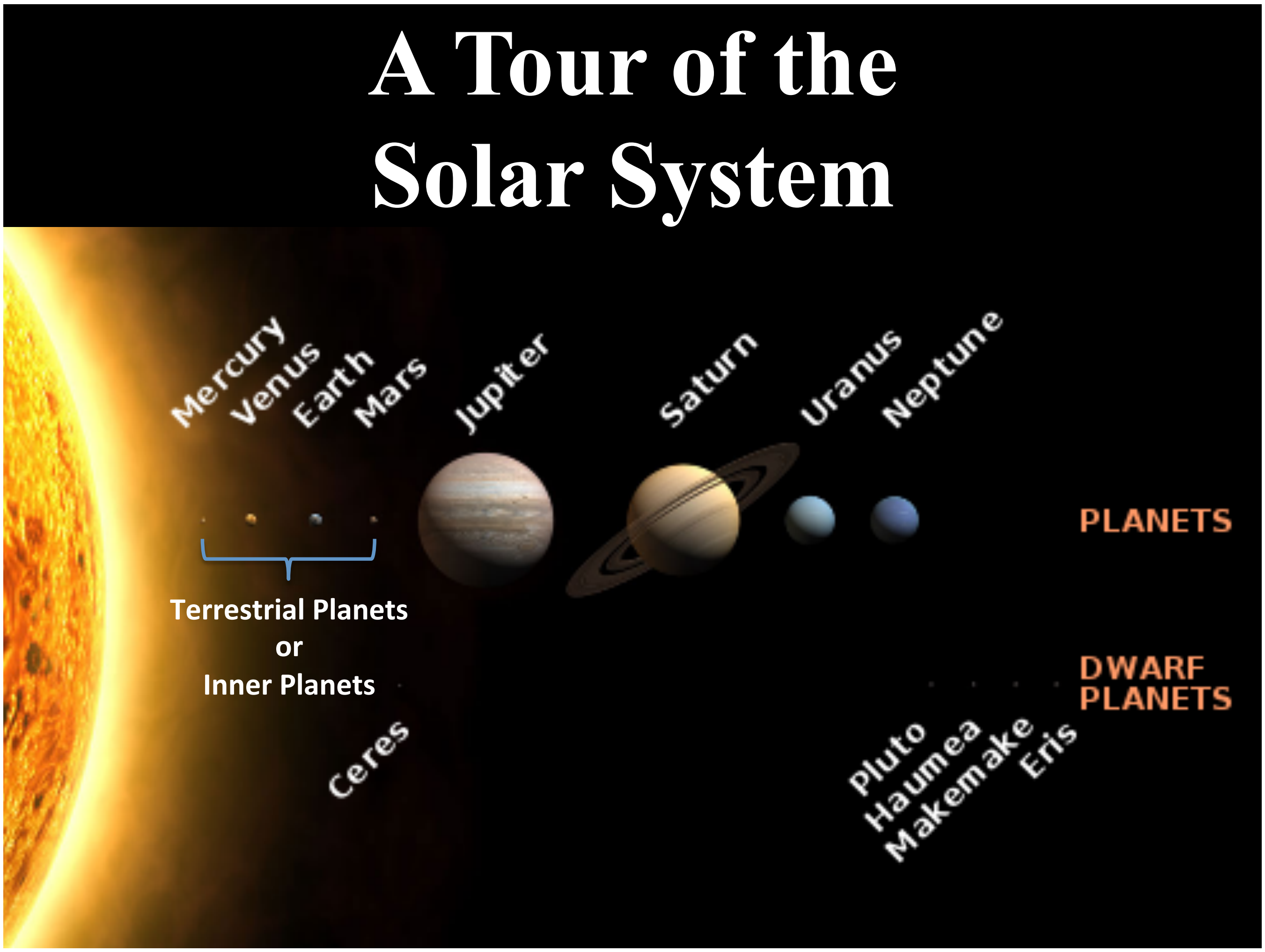
b. What are you doing to influence changes that go beyond yourself? (For example, influencing public policy, supporting renewable energy, time/labor donation, voting or political advocacy, writing a letter to a business or politician who has the power to effect change.)

Lesson 1 Slide Presentation:

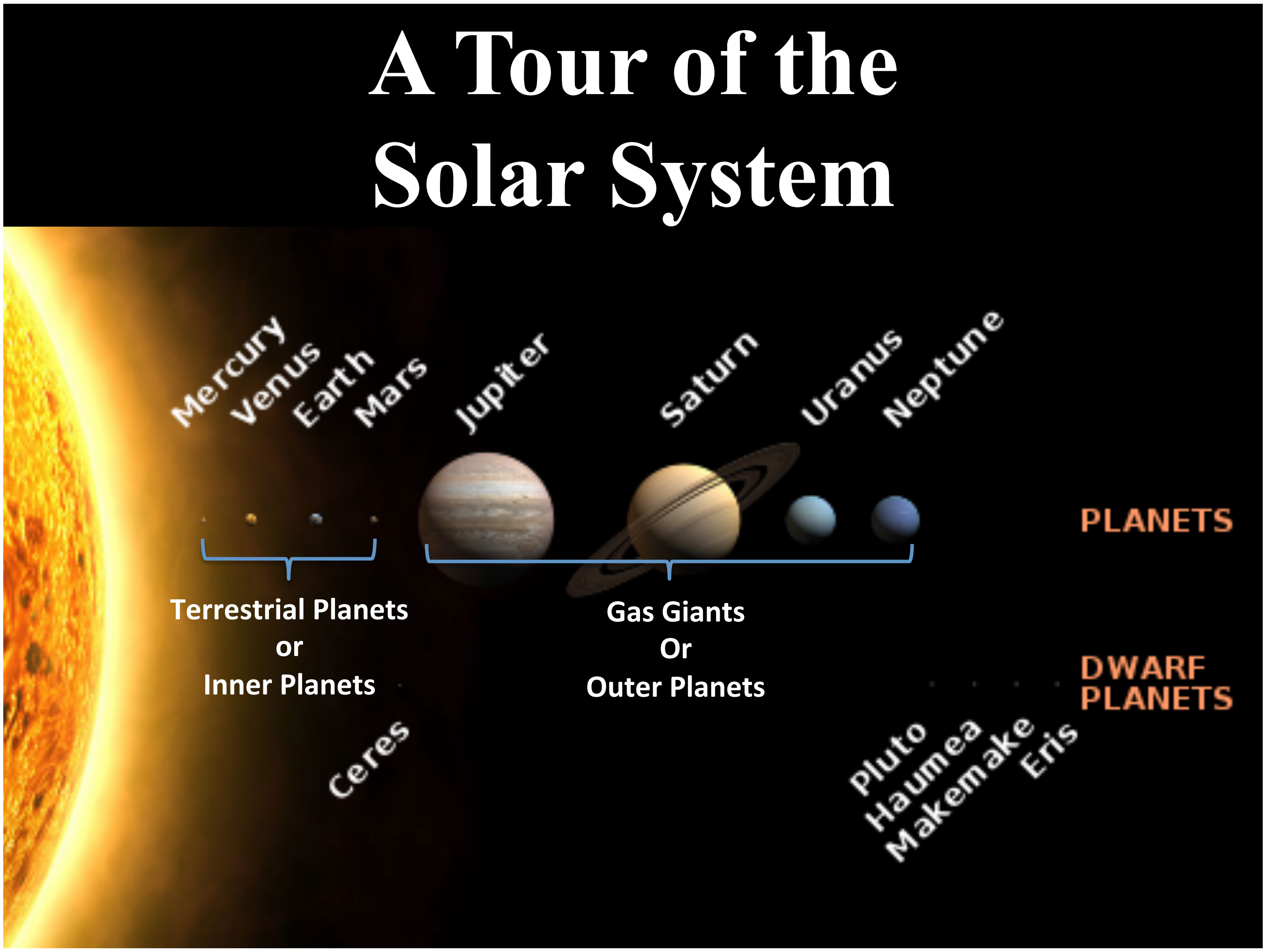
A Tour of the Solar System


A Tour of the
Solar System
Mercury
Venus
Earth
Mars
Jupiter
Saturn
Uranus
Neptune
PLANETS
DWARF
PLANETS
Ceres
Pluto
Haumea
Makemake
Eris

Slide 1

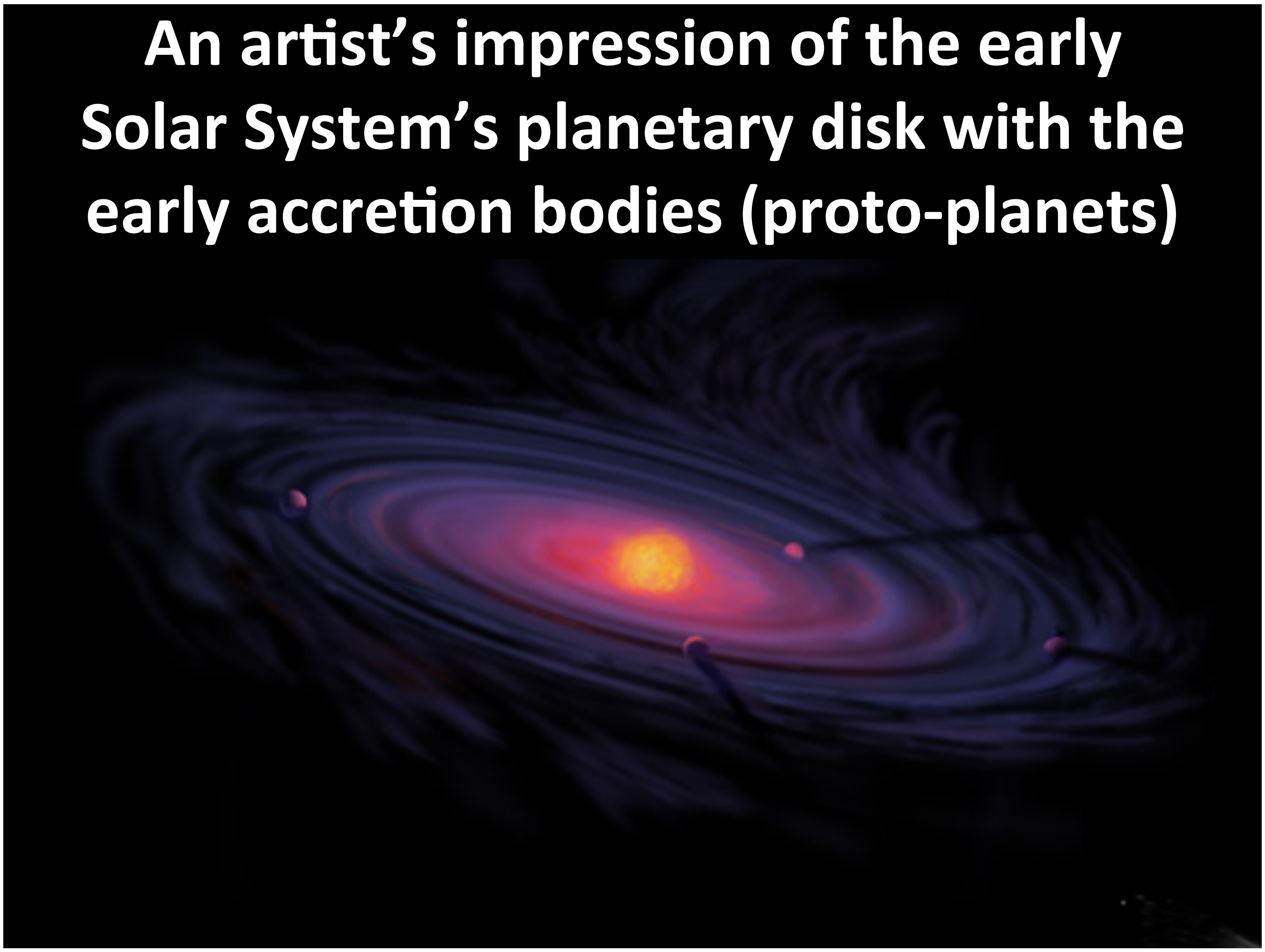

A Tour of the
Solar System
Mercury
Venus
Earth
Mars
Jupiter
Saturn
Uranus
Neptune
PLANETS
Terrestrial Planets
or
Inner Planets
DWARF
PLANETS
Ceres
Pluto
Haumea
Makemake
Eris

Slide 2

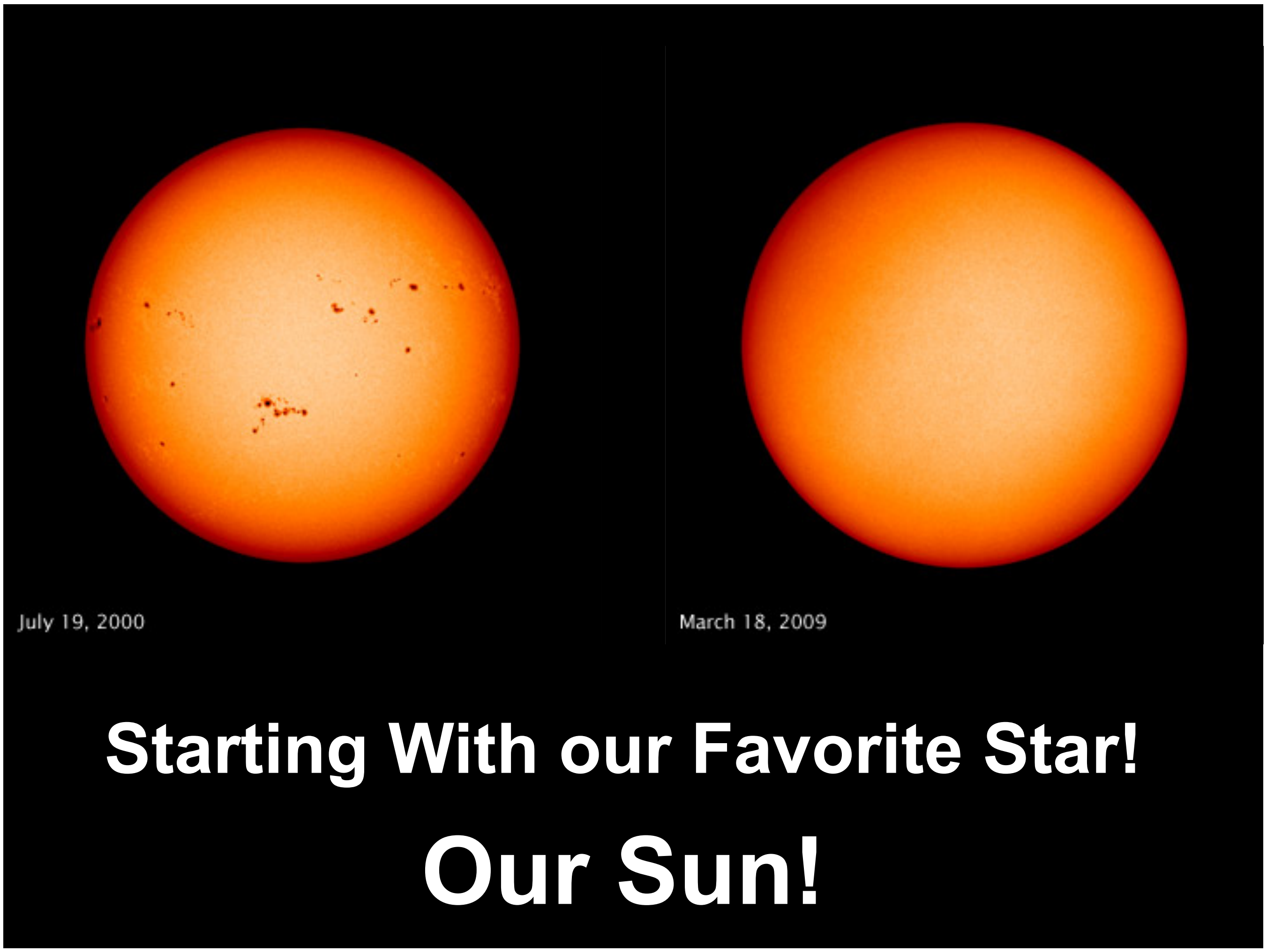


A Tour of the Solar System
Mercury
Venus
Earth
Mars
Jupiter
Saturn
Uranus
Neptune
PLANETS
Terrestrial Planets
or
Inner Planets
Gas Giants
Or
Outer Planets
DWARF PLANETS
Ceres
Pluto
Haumea
Makemake
Eris

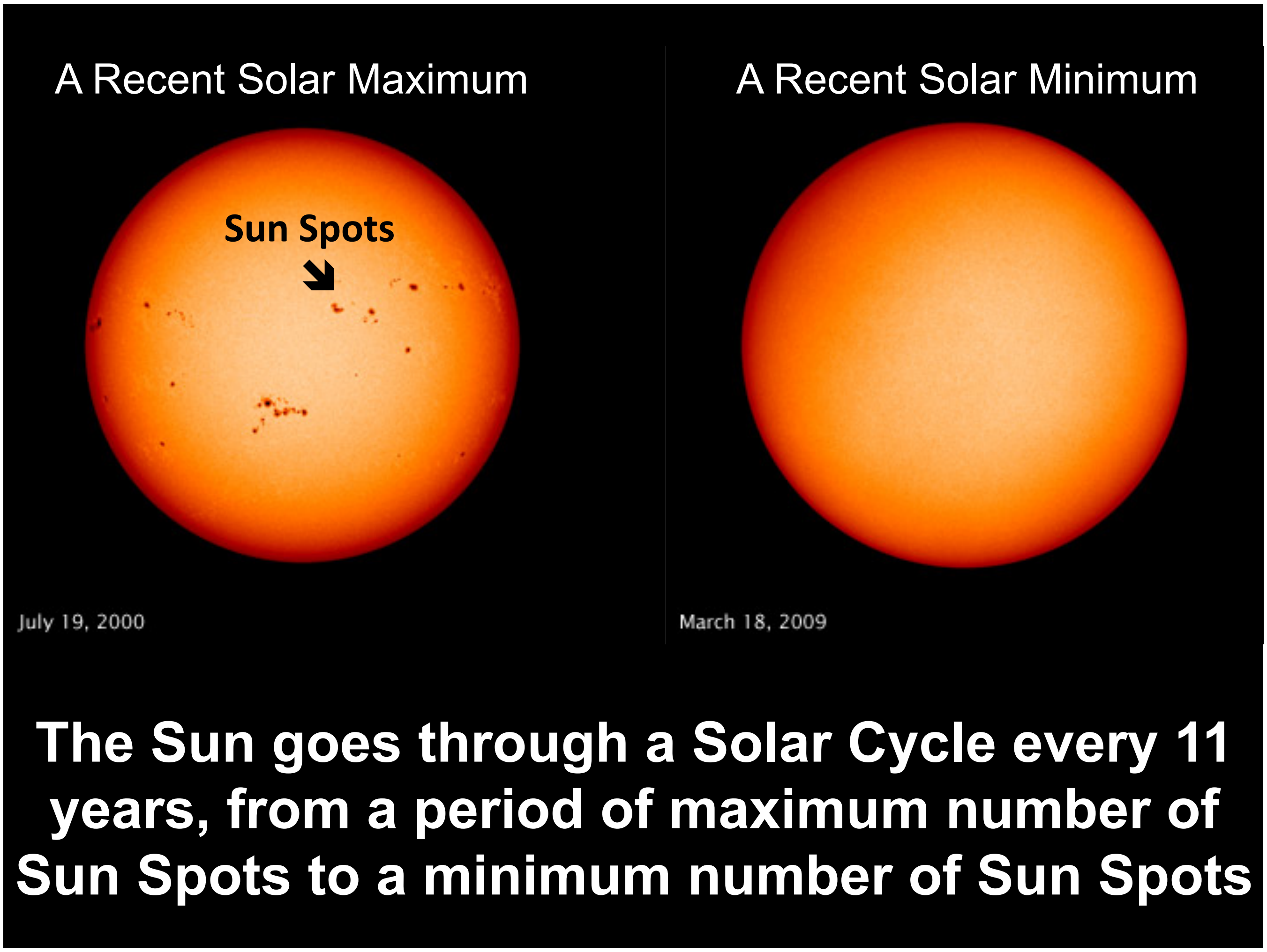
Slide 3


An artist’s impression of the early
Solar System’s planetary disk with the
early accretion bodies (proto-planets)

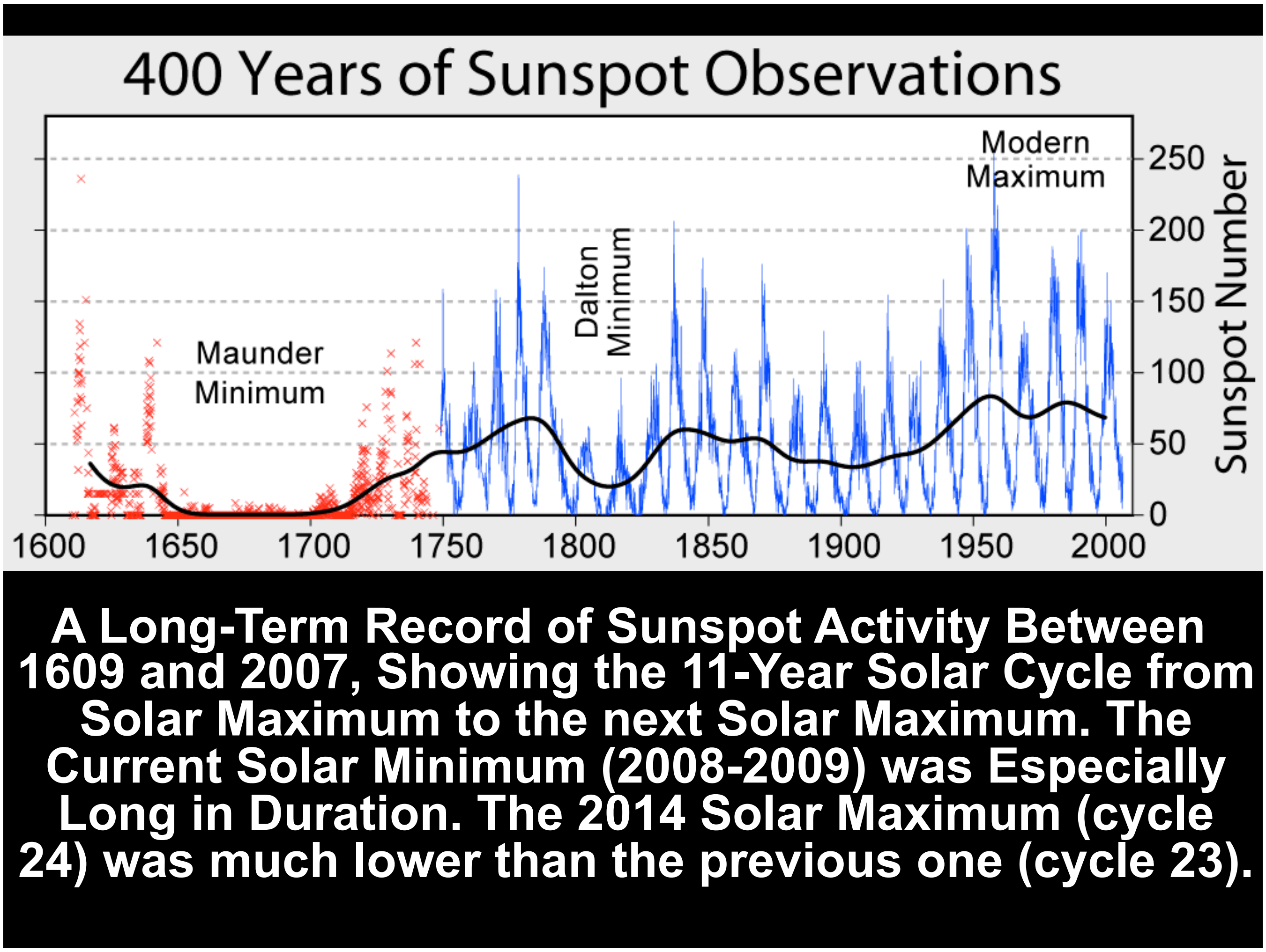
Slide 4


July 19, 2000
March 18, 2009
Starting With our Favorite Star!
Our Sun!

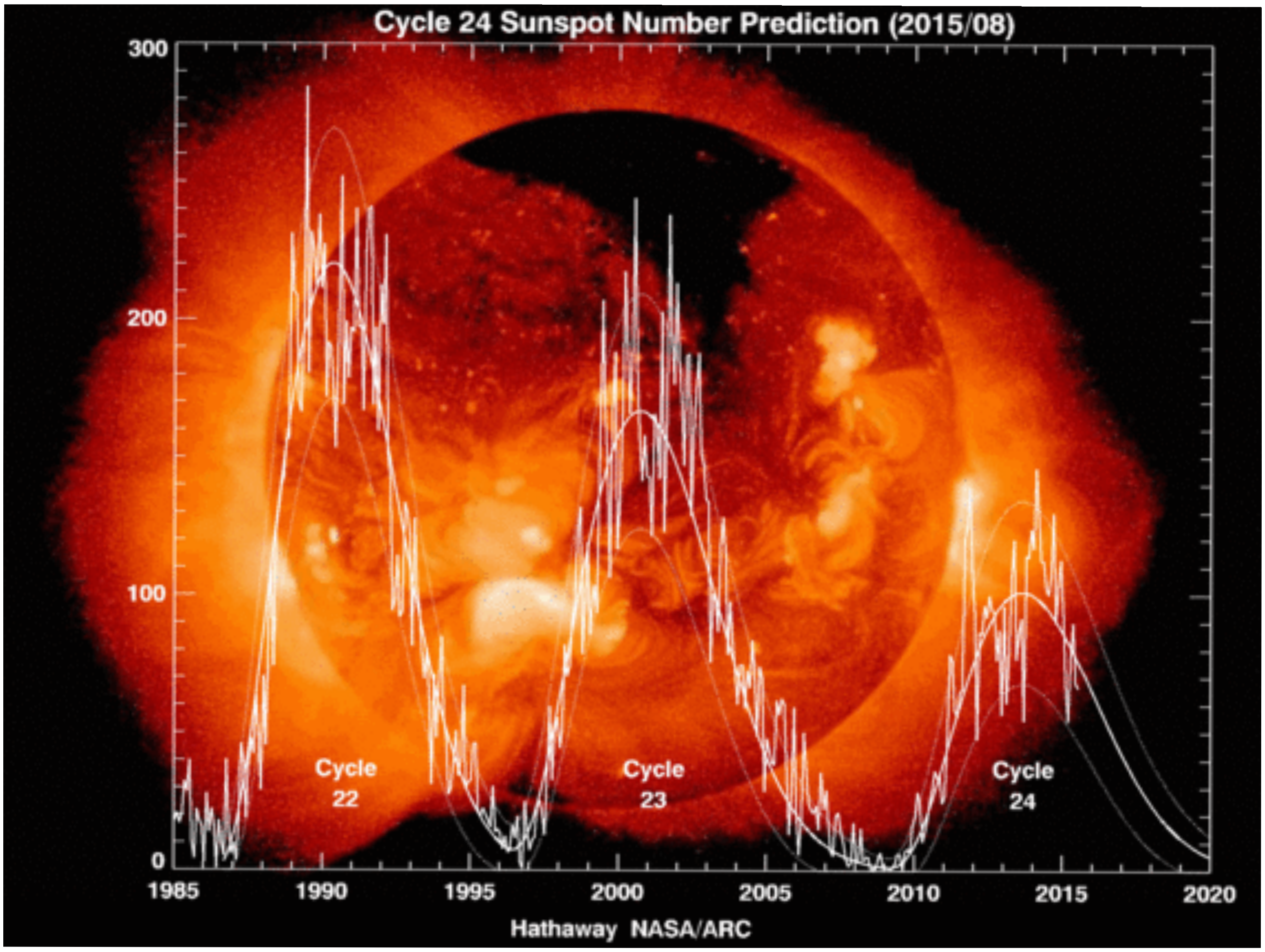
Slide 5


A Recent Solar Maximum
A Recent Solar Minimum
Sun Spots
July 19, 2000
March 18, 2009
The Sun goes through a Solar Cycle every 11 years, from a period of maximum number of Sun Spots to a minimum number of Sun Spots

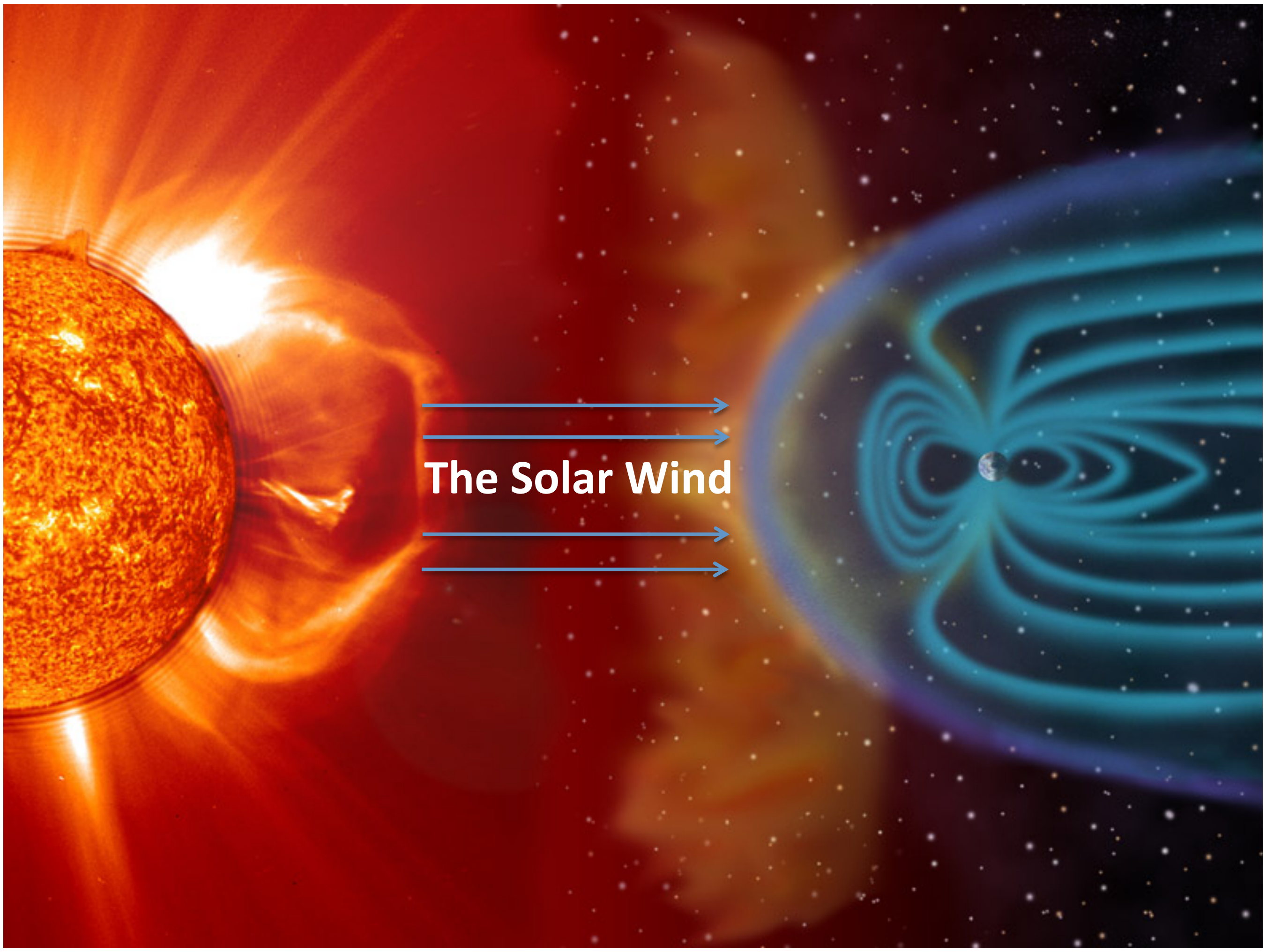
Slide 6


400 Years of Sunspot Observations
Maunder Minimum
Dalton Minimum
Modern Maximum
Sunspot Number
0
50
100
150
200
250
1600
1650
1700
1750
1800
1850
1900
1950
2000
A Long-Term Record of Sunspot Activity Between 1609 and 2007, Showing the 11-Year Solar Cycle from Solar Maximum to the next Solar Maximum. The Current Solar Minimum (2008-2009) was Especially Long in Duration. The 2014 Solar Maximum (cycle 24) was much lower than the previous one (cycle 23).

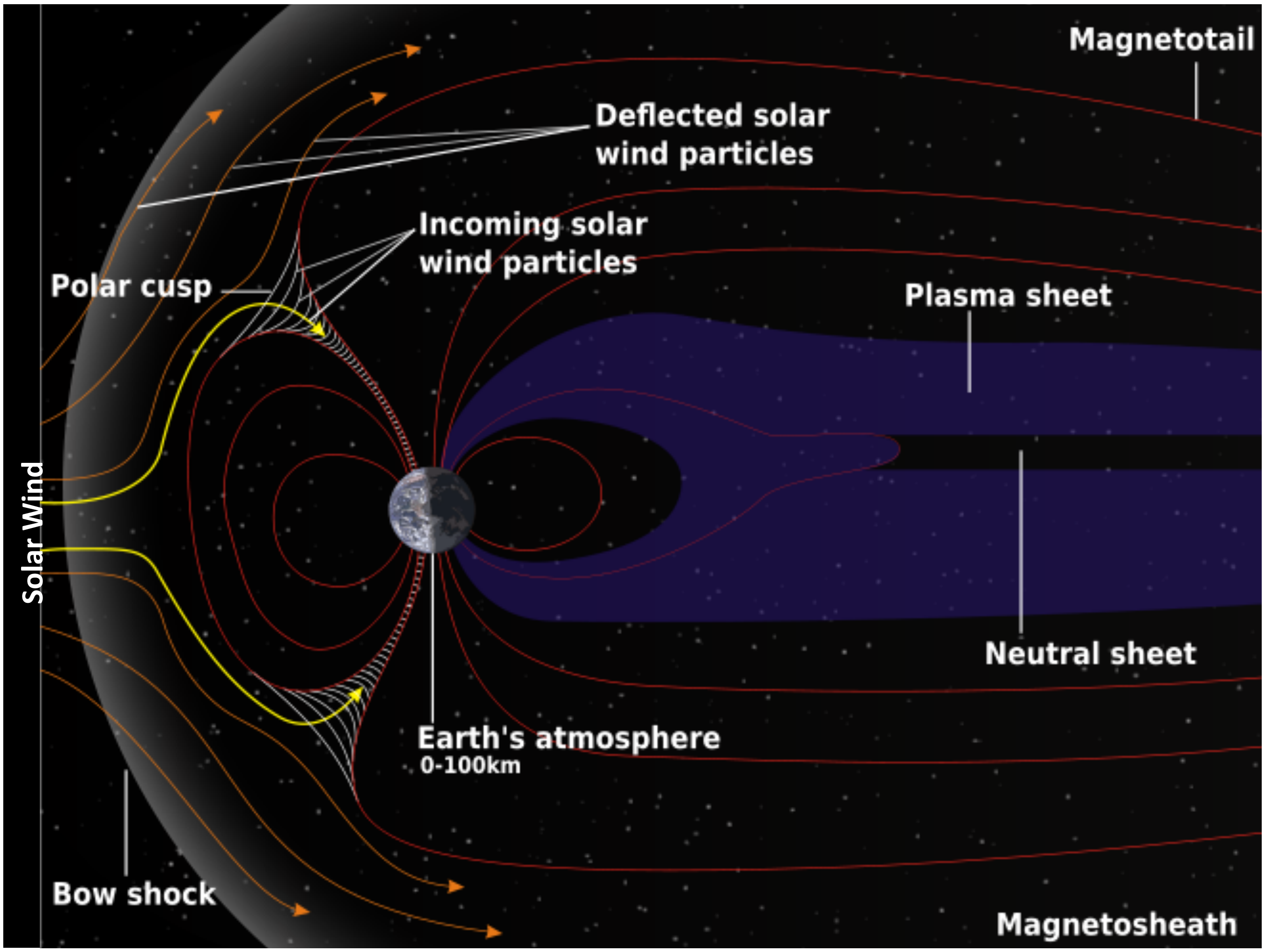
Slide 7


Cycle 24 Sunspot Number Prediction (2015/08)
300
200
100
0
1985
1990
1995
2000
2005
2010
2015
2020
Cycle 22
Cycle 23
Cycle 24
Hathaway NASA/ARC

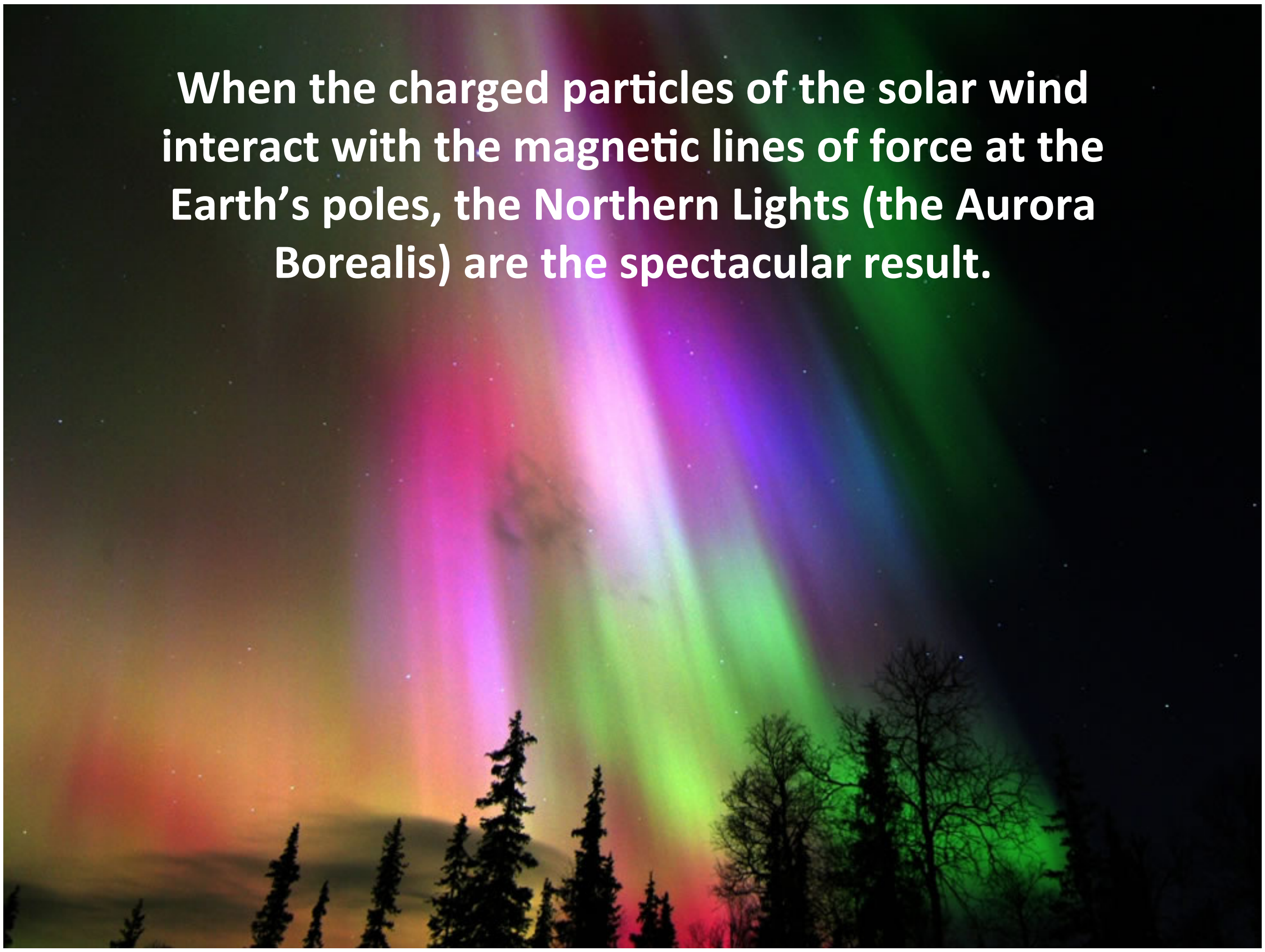
Slide 8



Slide 9

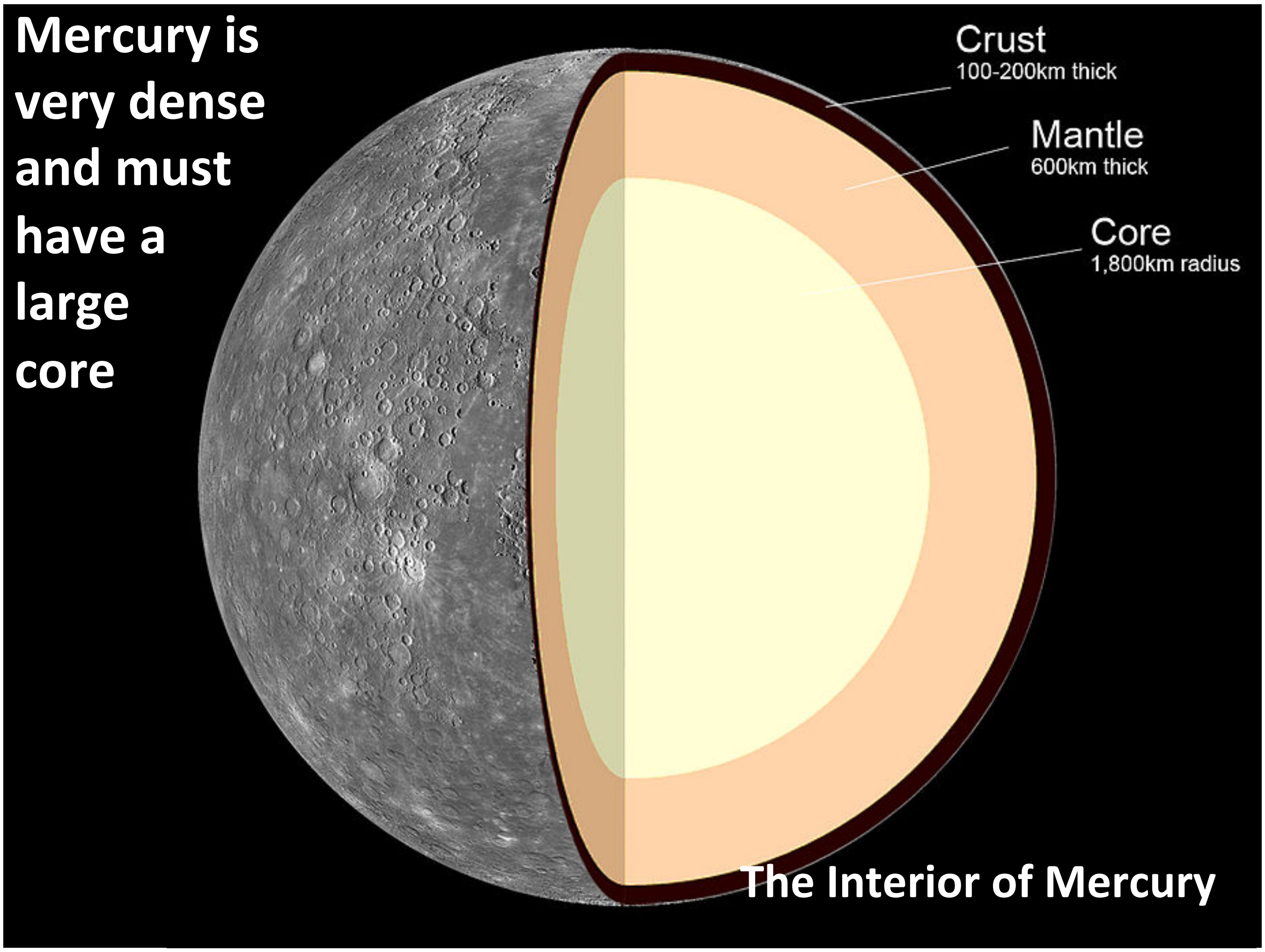

Magnetotail
Deflected solar wind particles
Incoming solar wind particles
Polar cusp
Plasma sheet
Solar Wind
Neutral sheet
Earth's atmosphere
0-100km
Bow shock
Magnetosheath

SLIDE 10

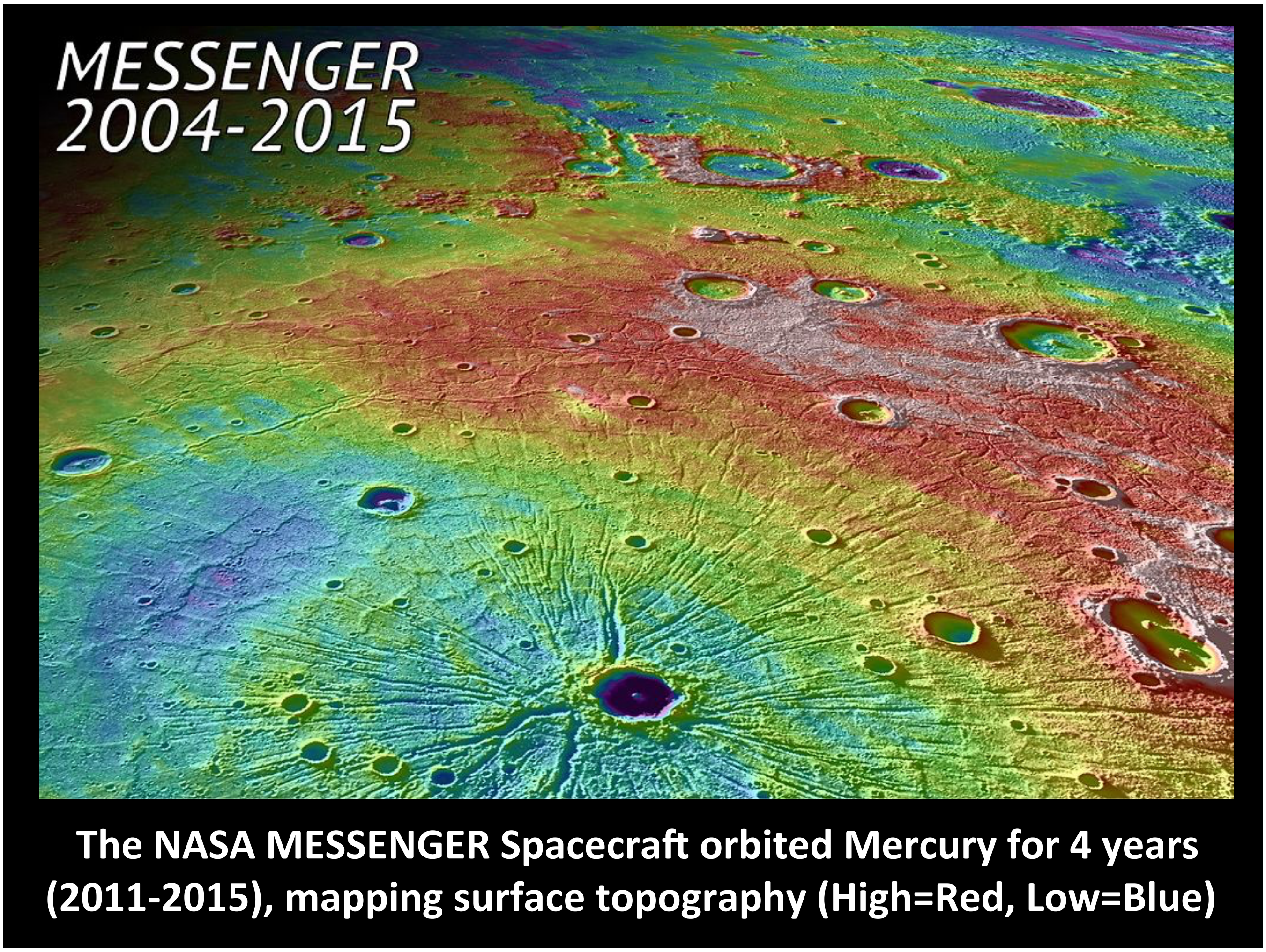

When the charged particles of the solar wind interact with the magnetic lines of force at the Earth's poles, the Northern Lights (the Aurora Borealis) are the spectacular result.

Slide 11

Slide 12

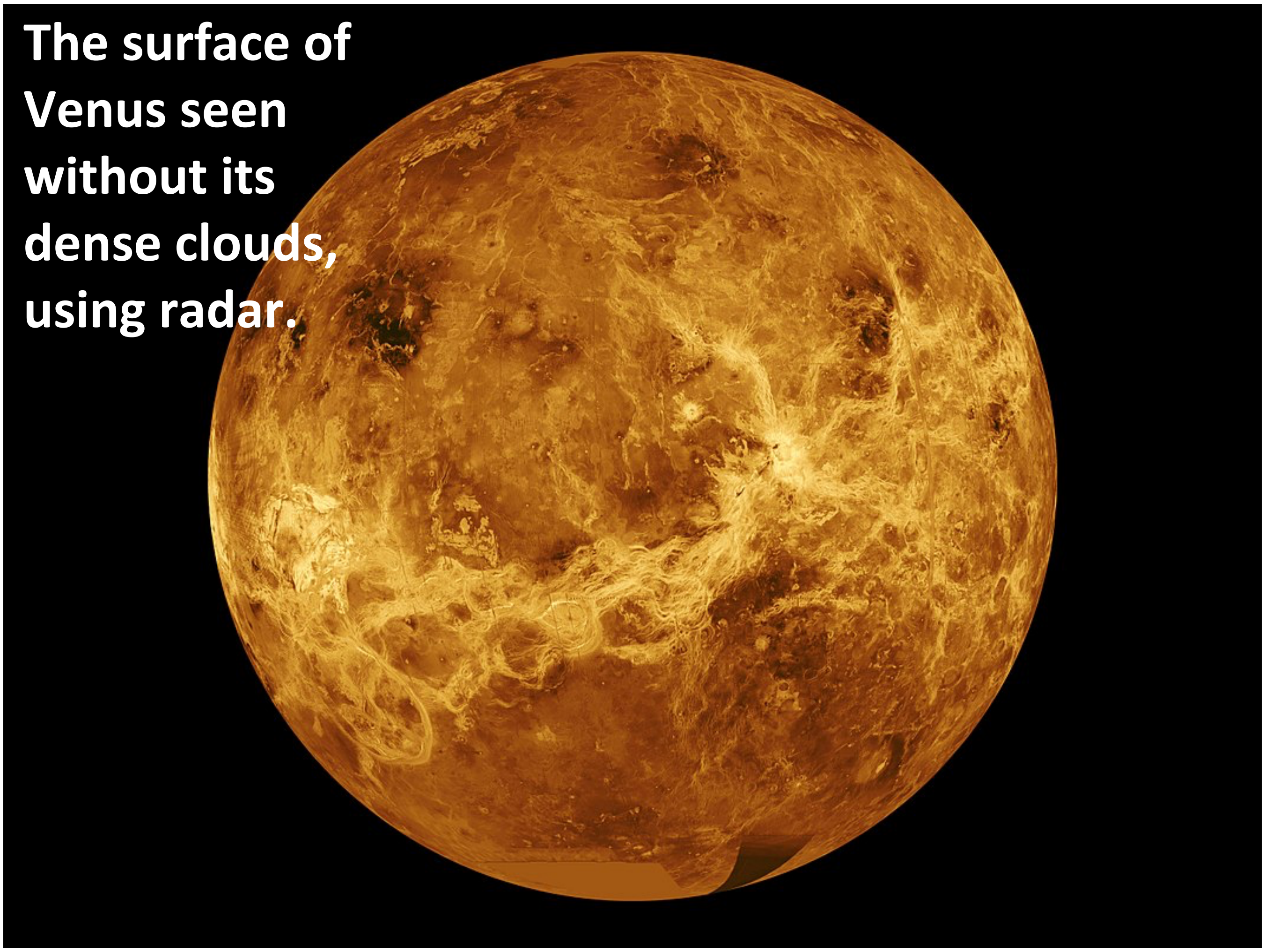

Mercury is very dense and must have a large core
Crust
100-200km thick
Mantle
600km thick
Core
1,800km radius
The Interior of Mercury

Slide 13

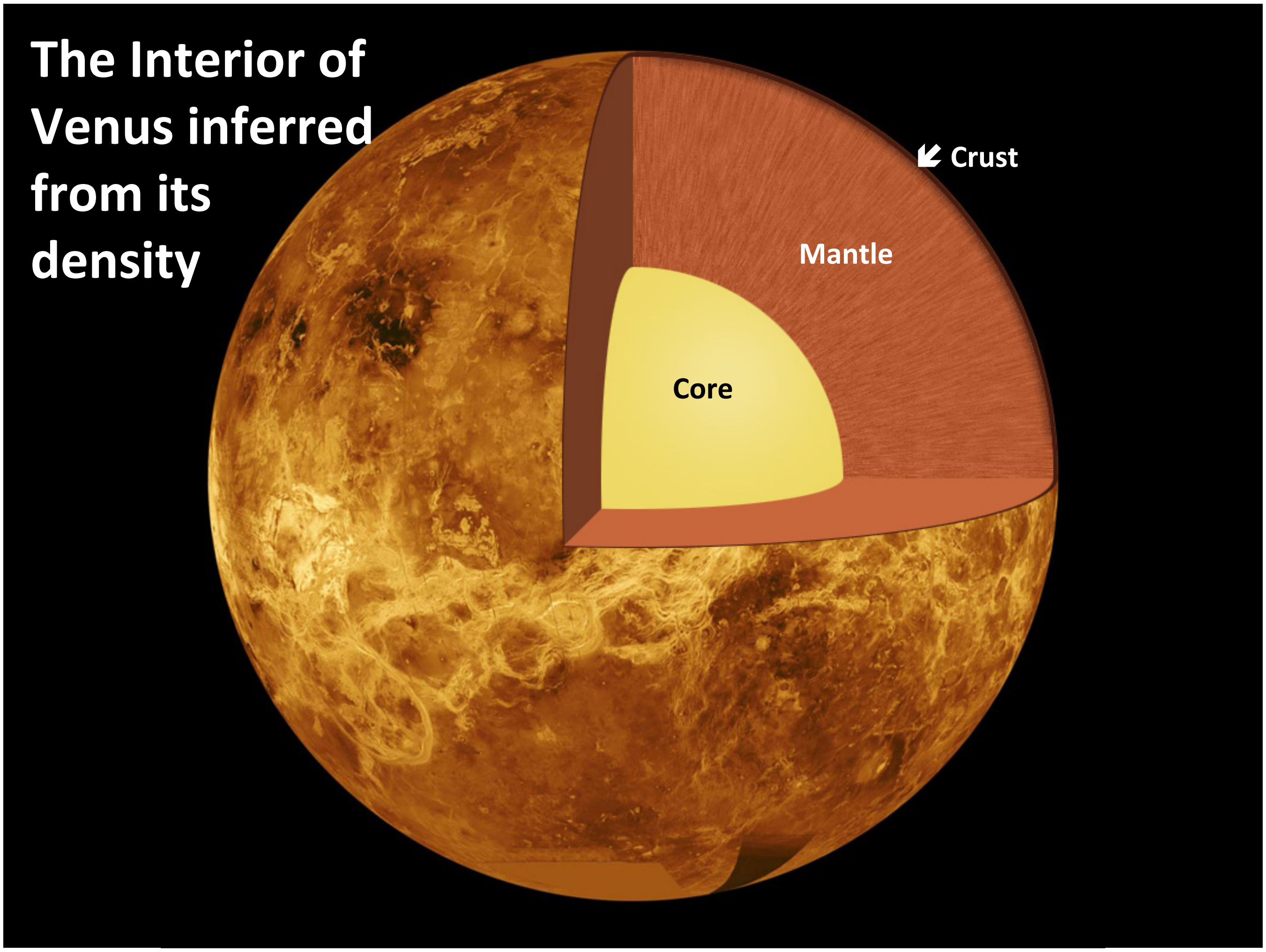

MESSENGER
2004-2015
The NASA MESSENGER Spacecraft orbited Mercury for 4 years
(2011-2015), mapping surface topography (High=Red, Low=Blue)

Slide 14

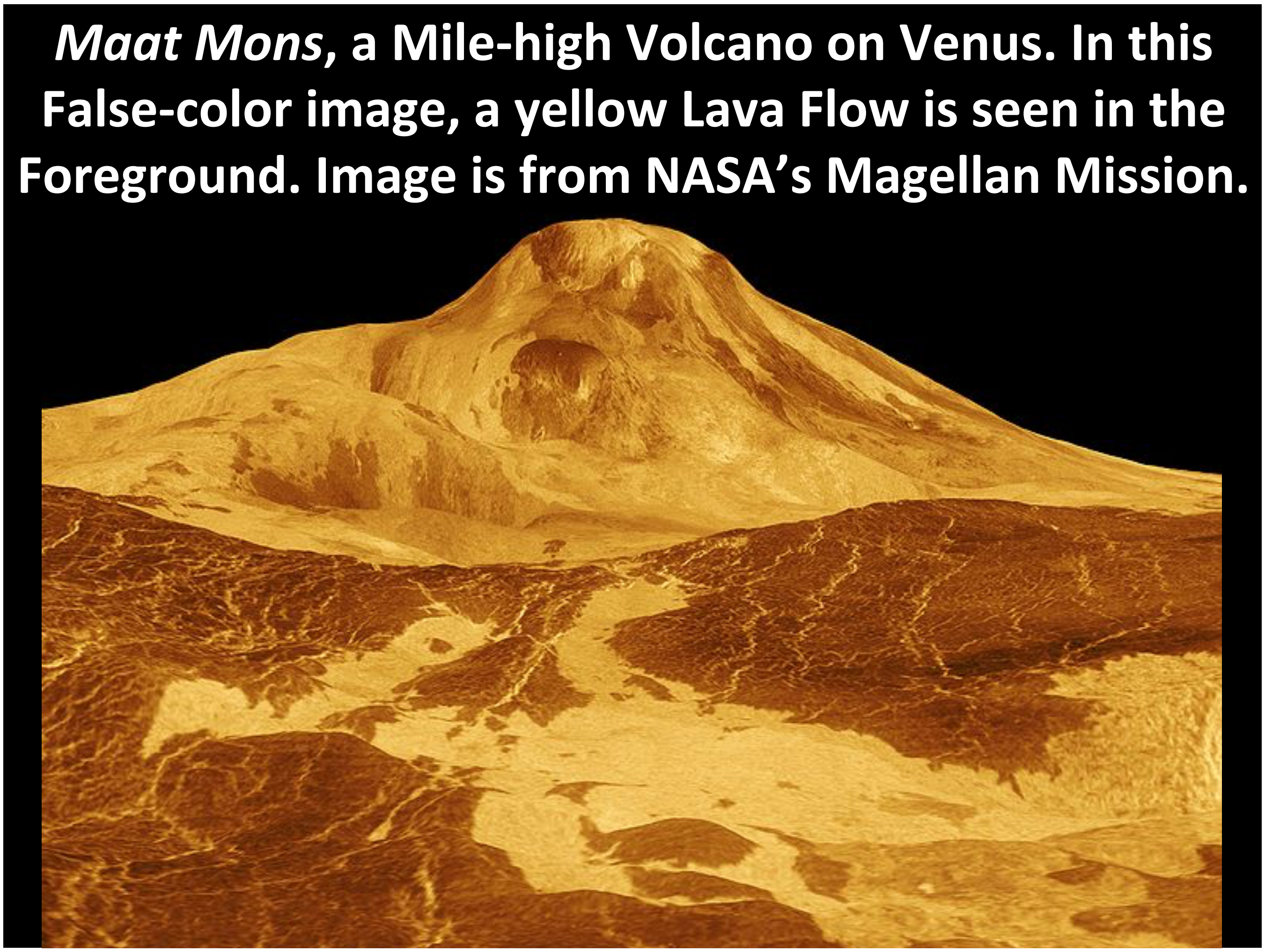
Slide 15


The surface of Venus seen without its dense clouds, using radar.

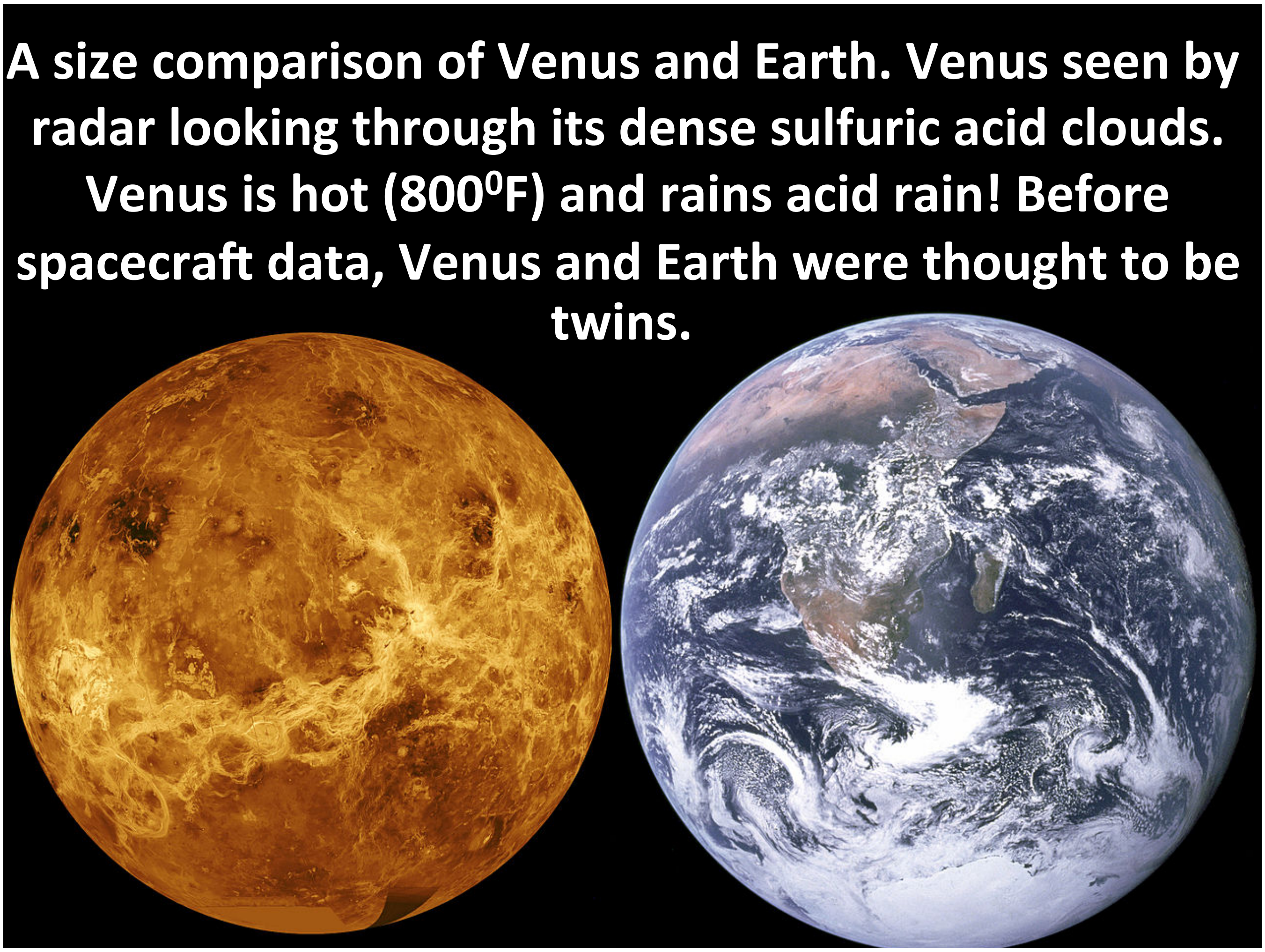
Slide 16


The Interior of Venus inferred from its density
Crust
Mantle
Core

Slide 17


Maat Mons, a Mile-high Volcano on Venus. In this
False-color image, a yellow Lava Flow is seen in the
Foreground. Image is from NASA's Magellan Mission.

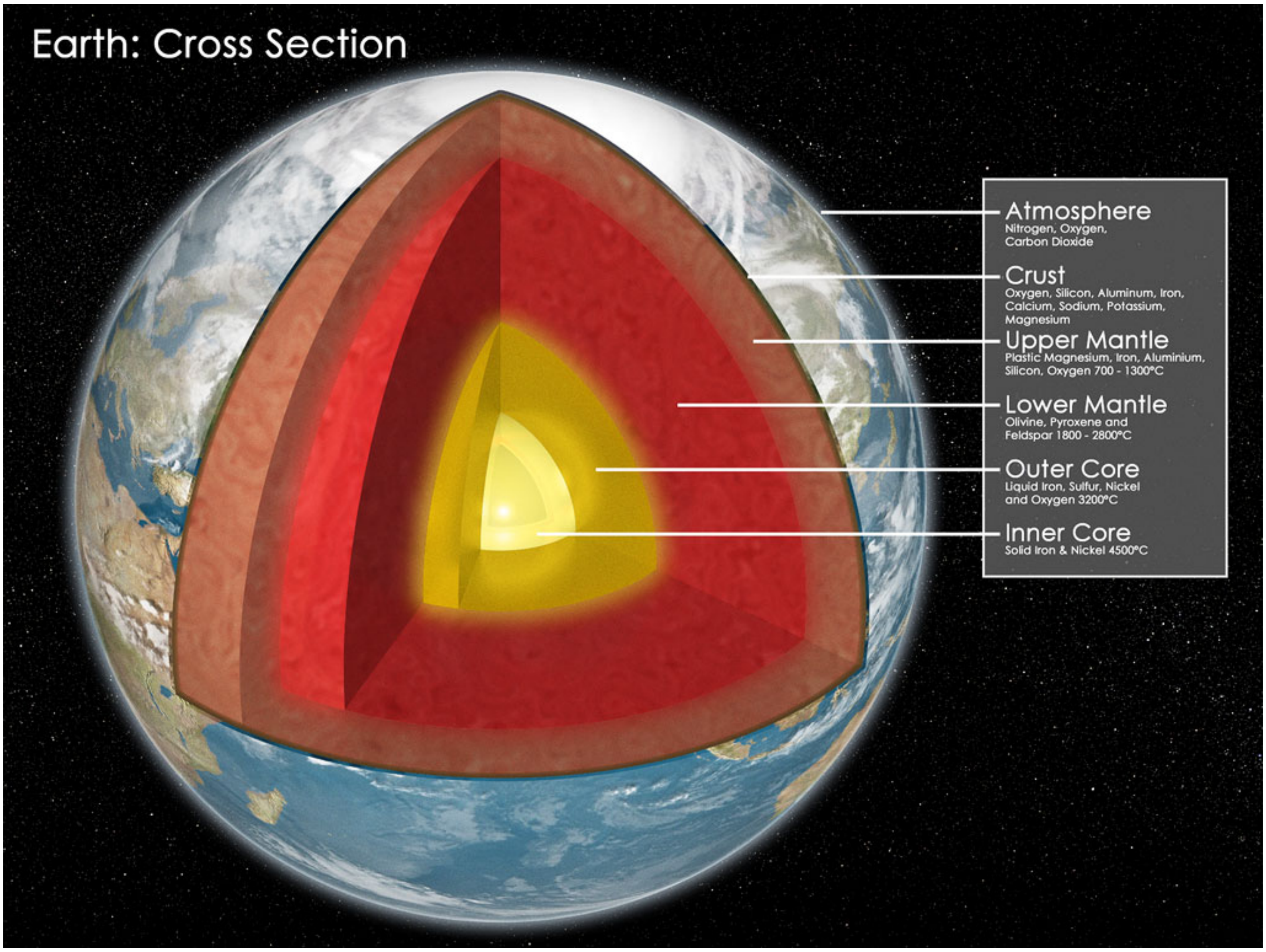
Slide 18


A size comparison of Venus and Earth. Venus seen by radar looking through its dense sulfuric acid clouds. Venus is hot (800^{0}F) and rains acid rain! Before spacecraft data, Venus and Earth were thought to be twins.

Slide 19


The famous “Blue Marble” image of the Earth as seen from Apollo 17 on December 7, 1972. Look how different Earth is from Venus.

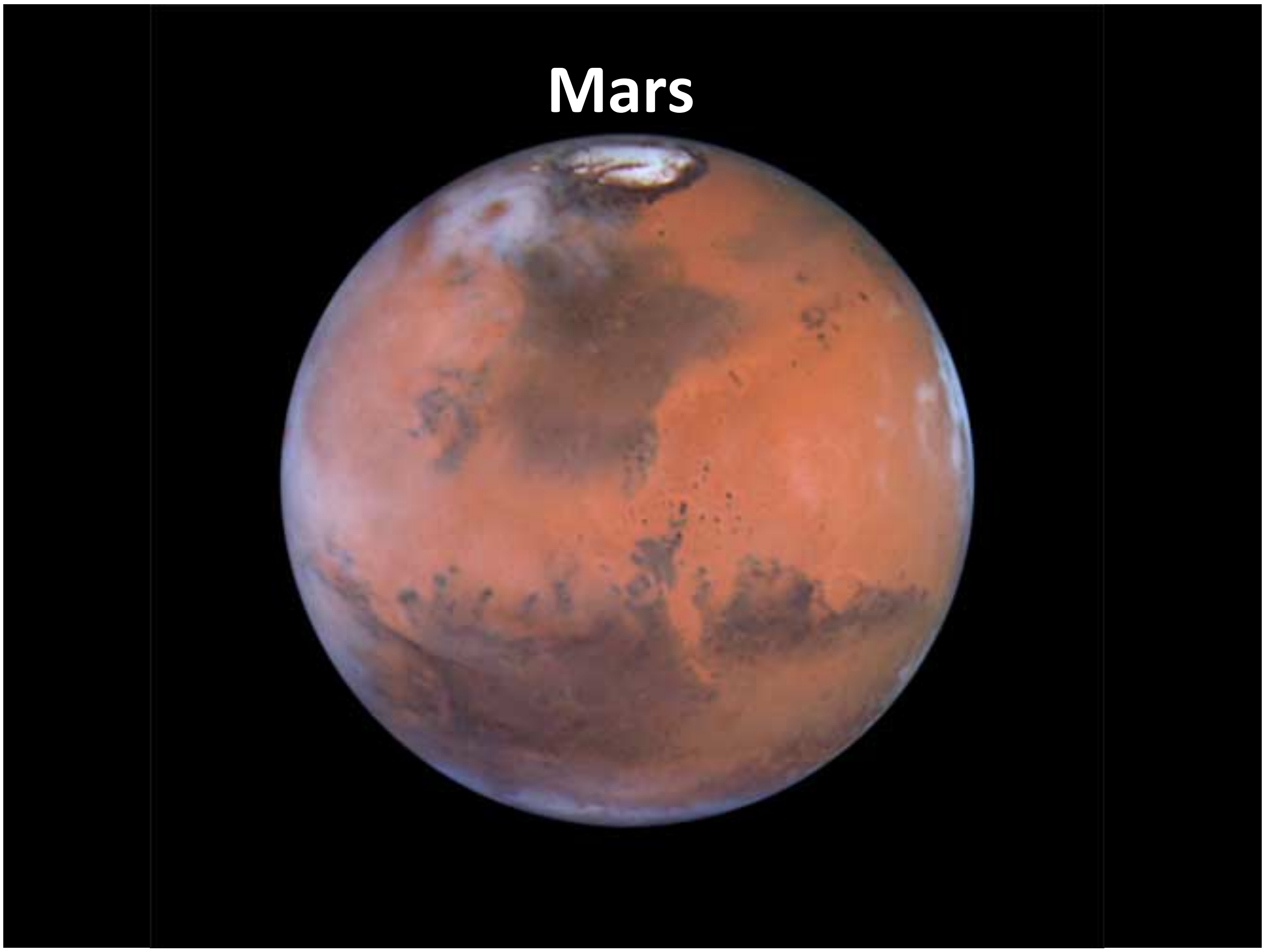
Slide 20


Earth: Cross Section
Atmosphere
Nitrogen, Oxygen, Carbon Dioxide
Crust
Oxygen, Silicon, Aluminum, Iron, Calcium, Sodium, Potassium, Magnesium
Upper Mantle
Plastic Magnesium, Iron, Aluminium, Silicon, Oxygen 700 - 1300°C
Lower Mantle
Olivine, Pyroxene and Feldspar 1800 - 2800°C
Outer Core
Liquid Iron, Sulfur, Nickel and Oxygen 3200°C
Inner Core
Solid Iron & Nickel 4500°C

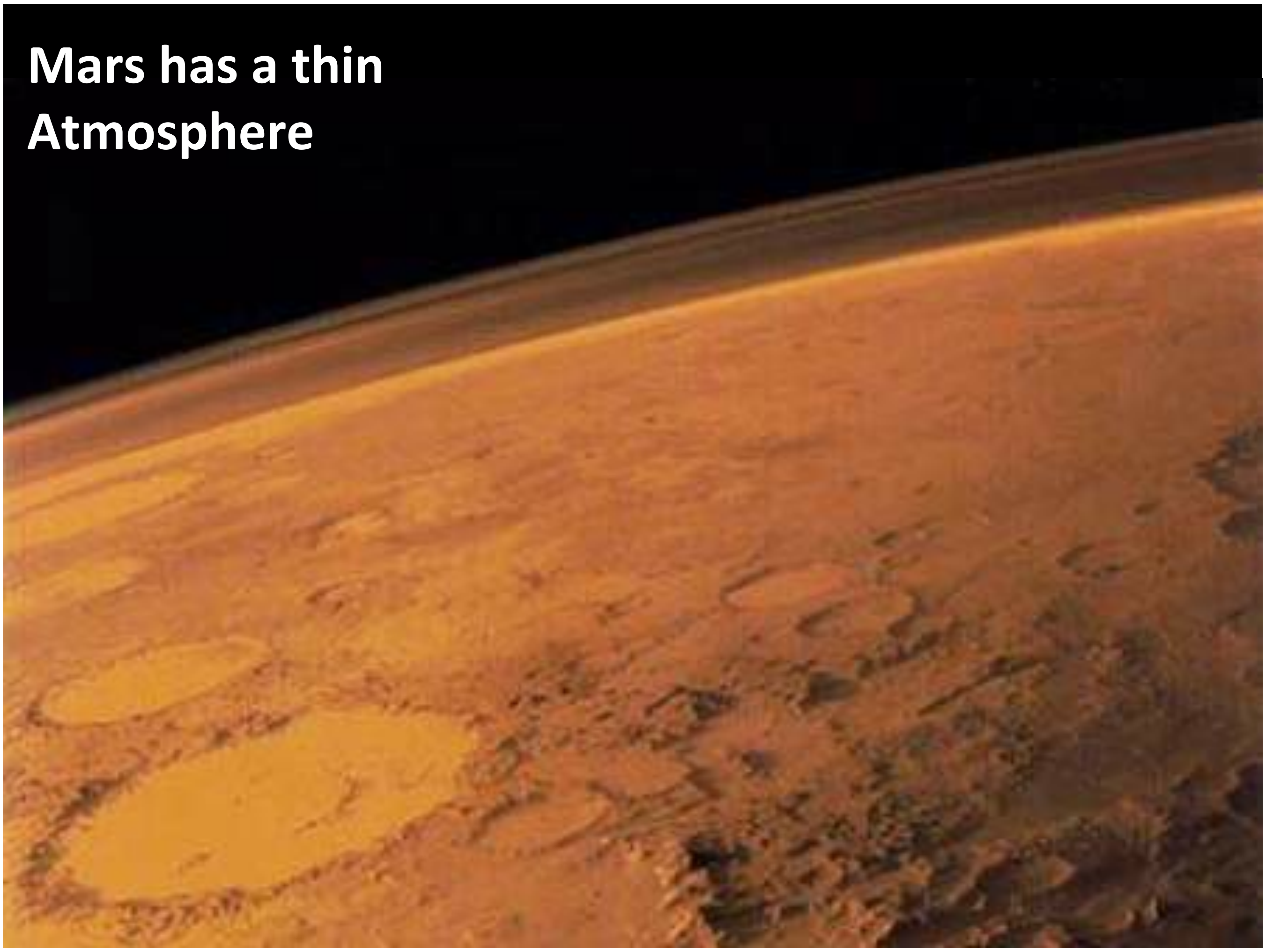
Slide 21

A volcanic eruption in the Aleutian Islands of Alaska

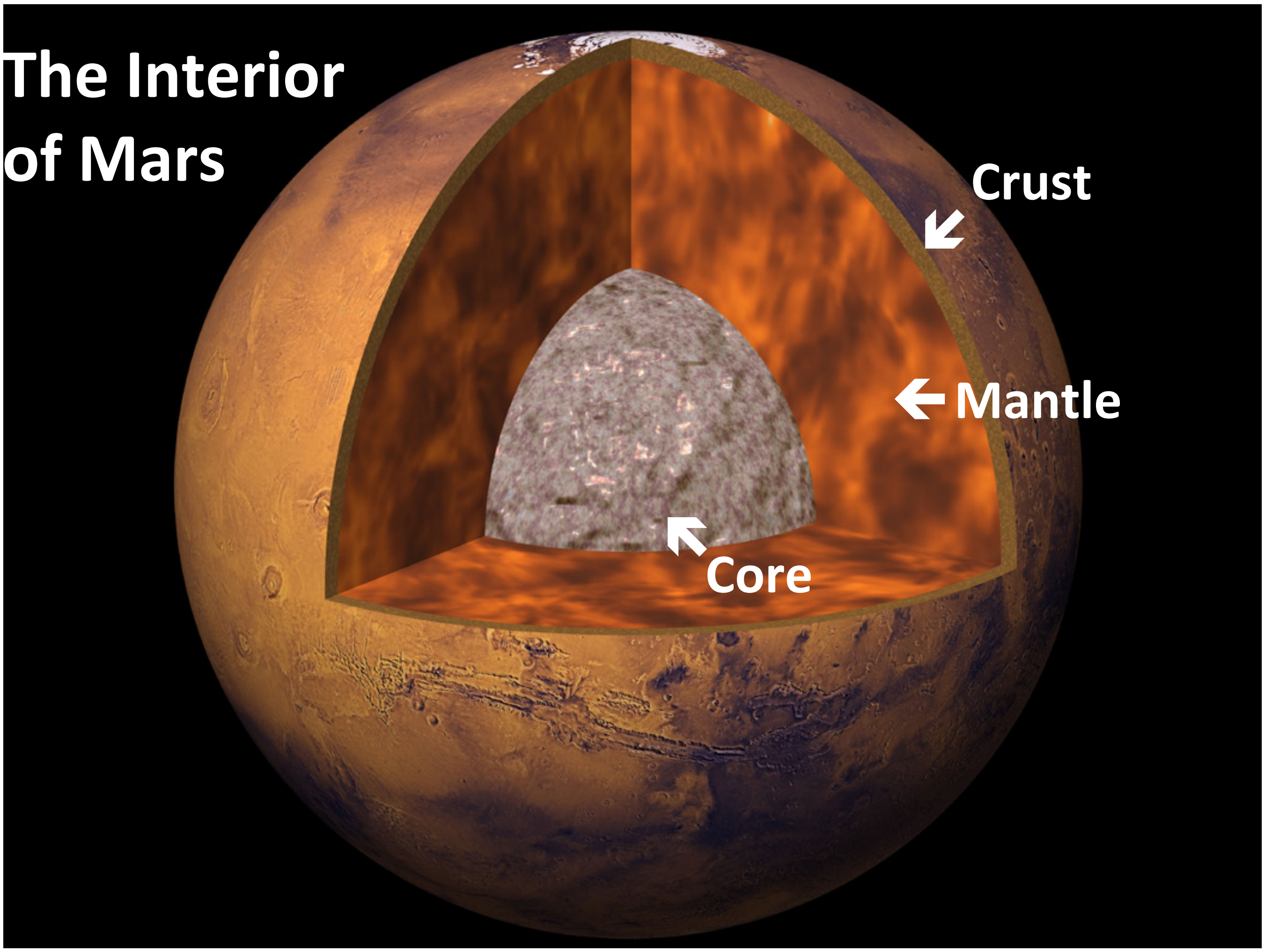
Slide 22



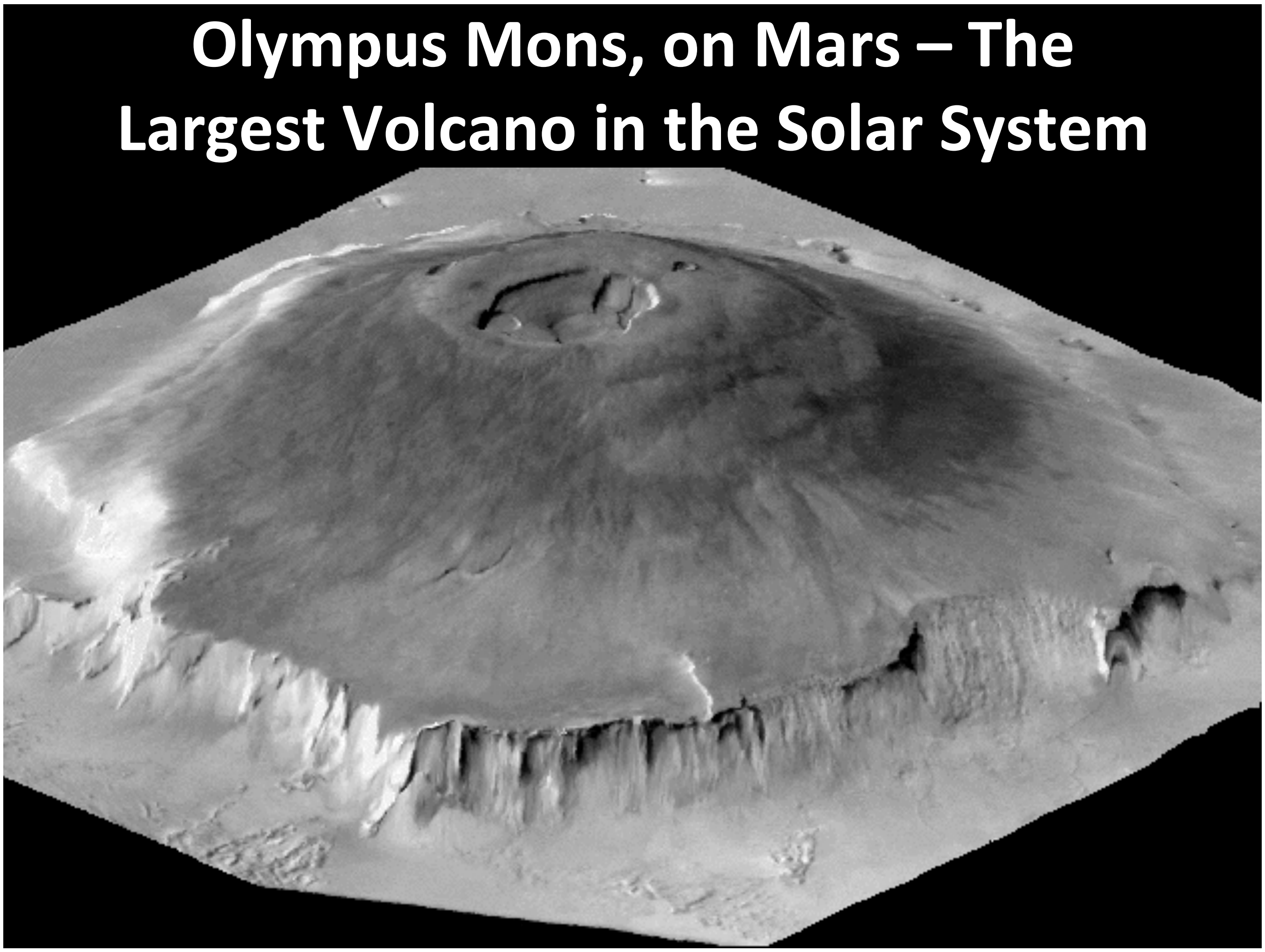
Slide 23



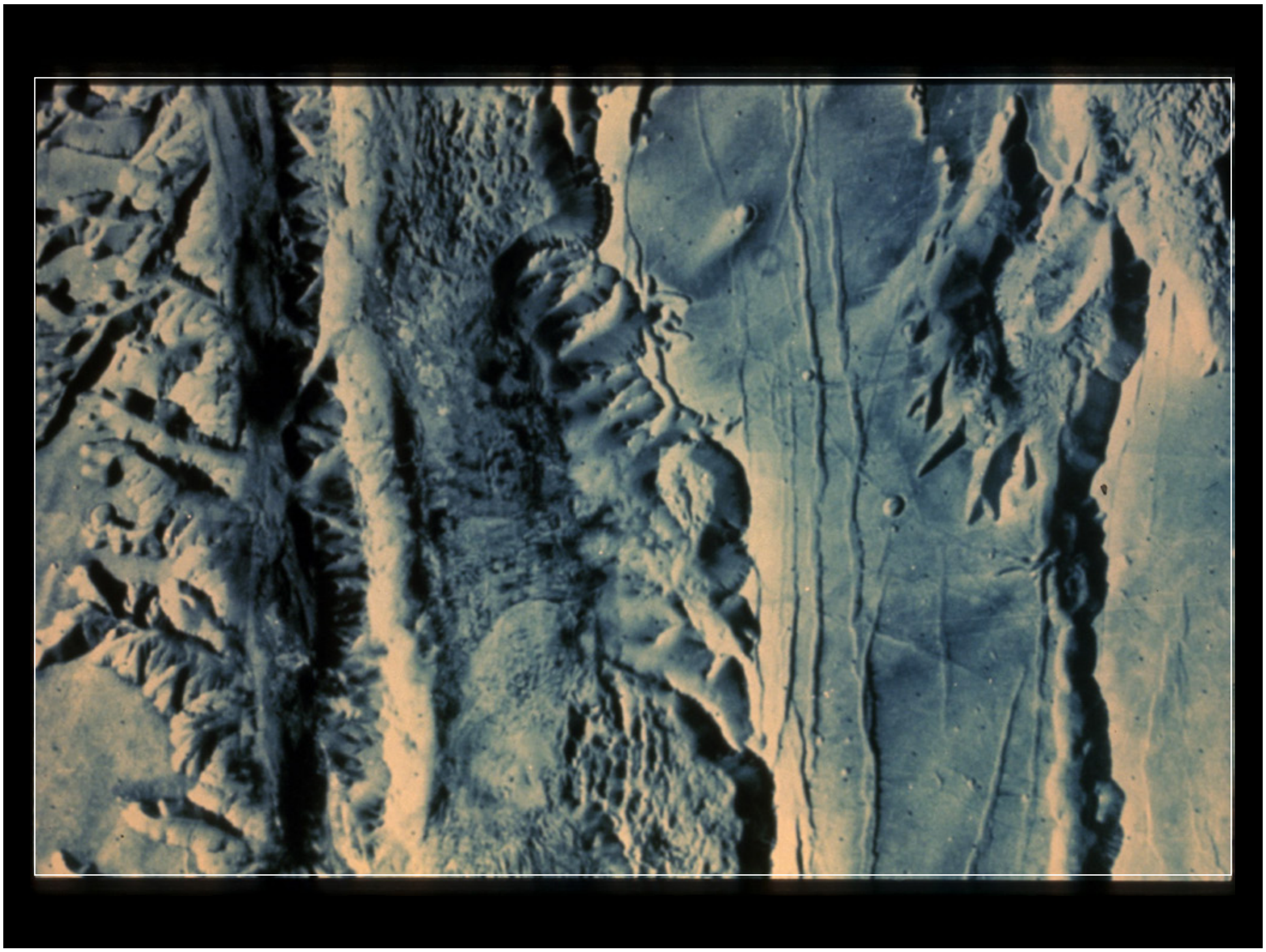
Slide 24



Slide 25


Olympus Mons, on Mars – The
Largest Volcano in the Solar System

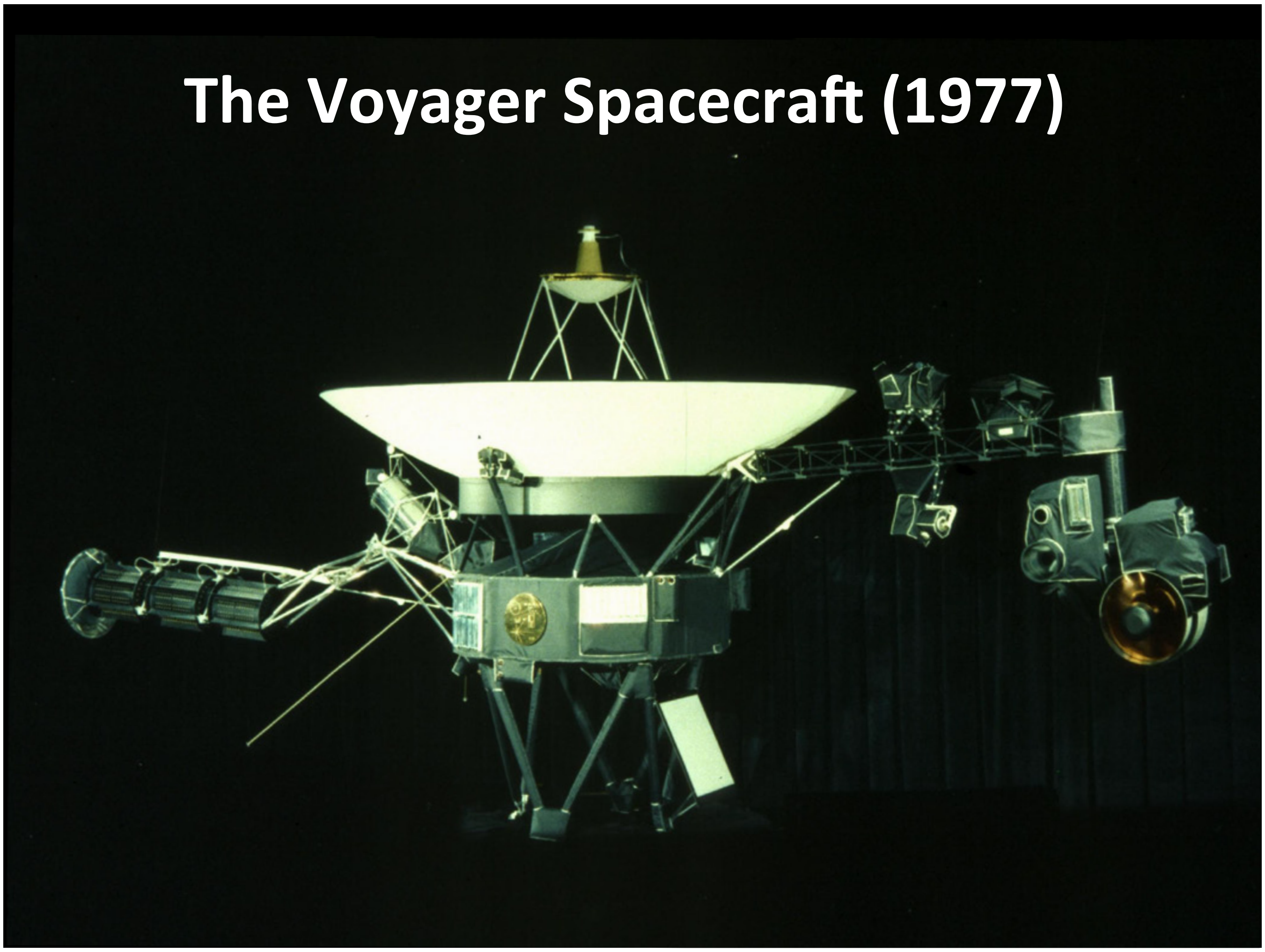
Slide 26



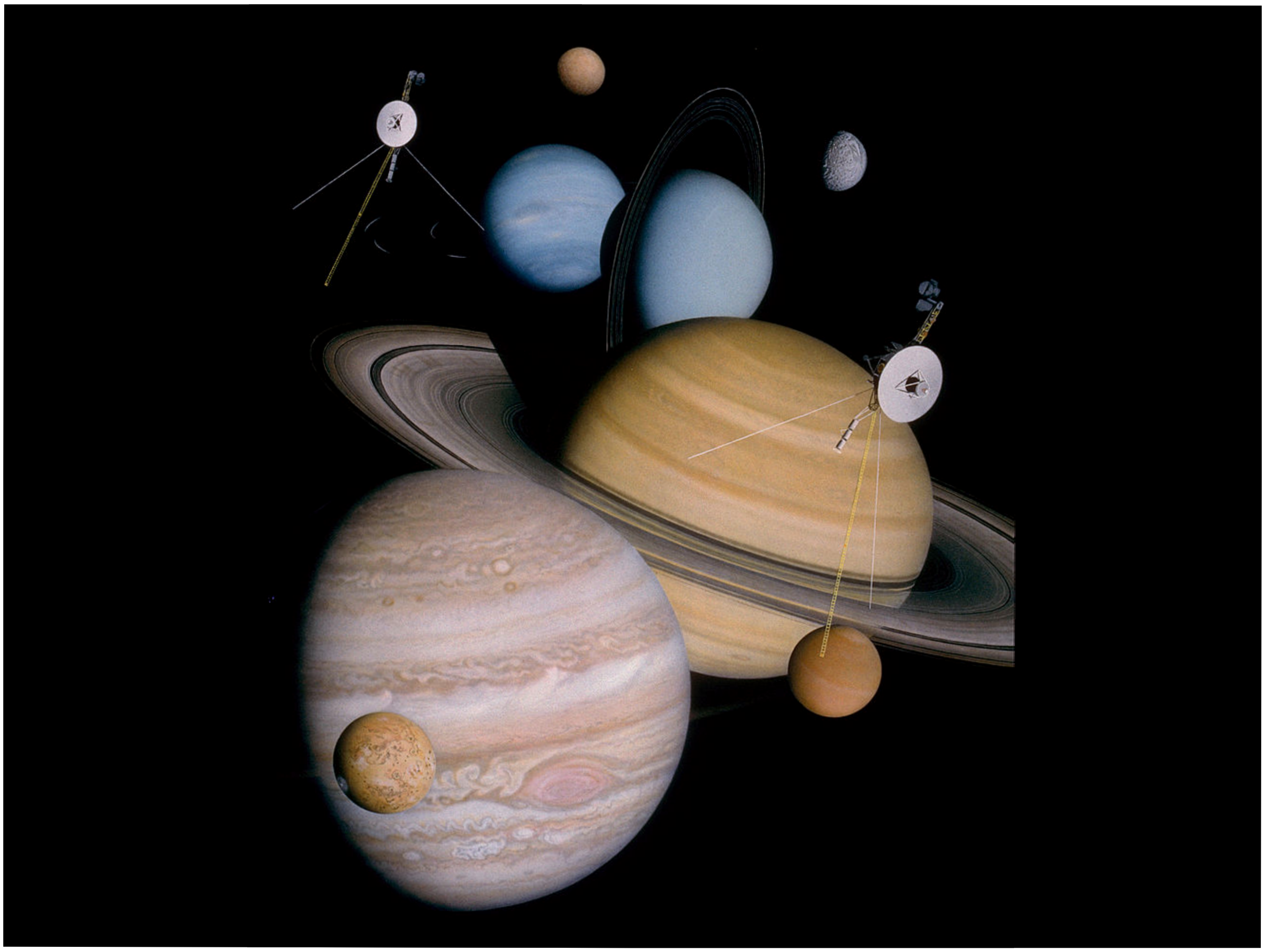
Slide 27

NASA’s Mars Rover “Curiosity” launched on Nov. 26, 2011, and landed on Aug. 6, 2012. It carries a complete science lab that has analyzed many samples of the Martian “soil” and sub-surface

Slide 28

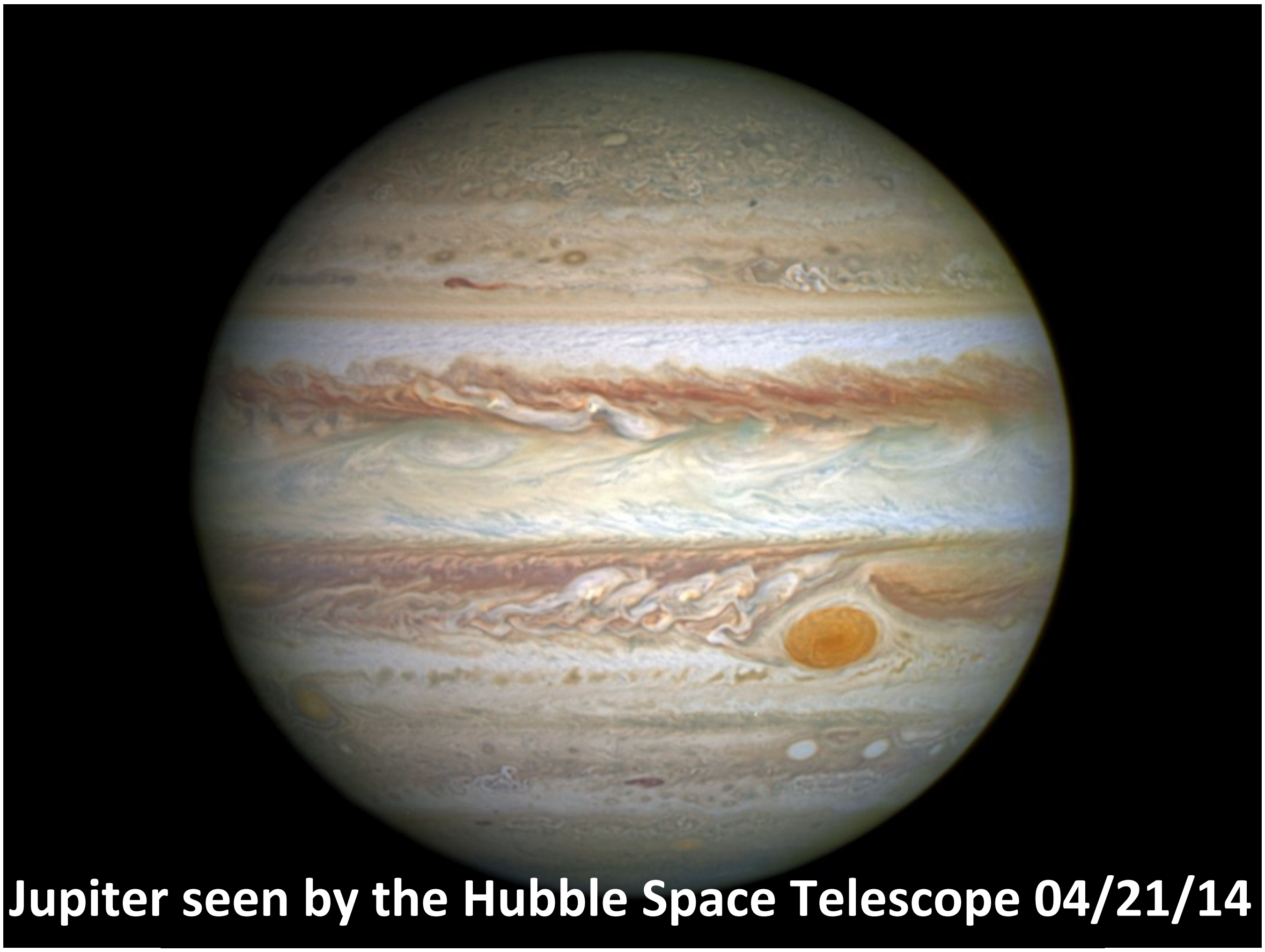


Slide 29

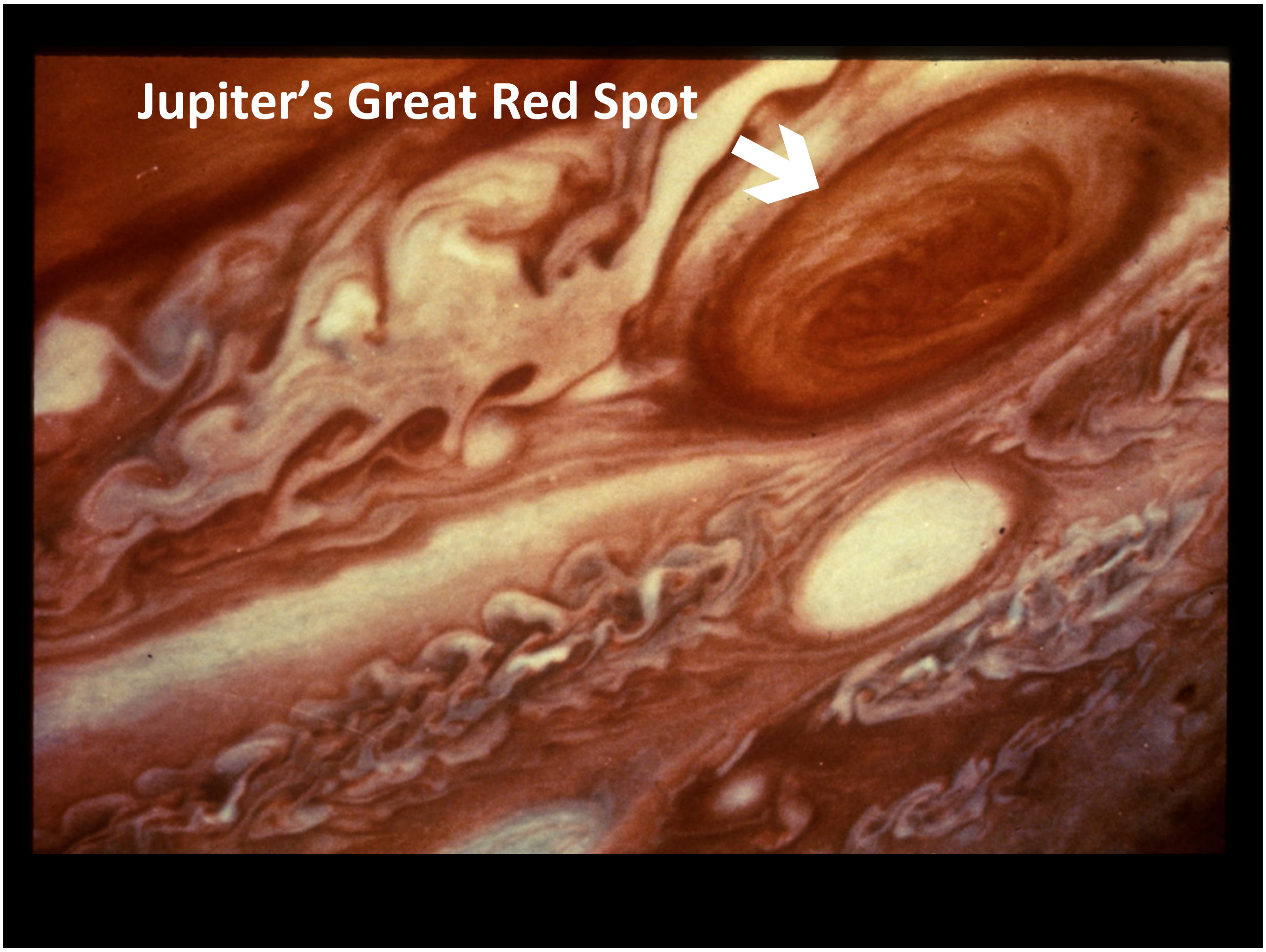


Slide 30

JOURNEYS IN FILM
educating for global understanding



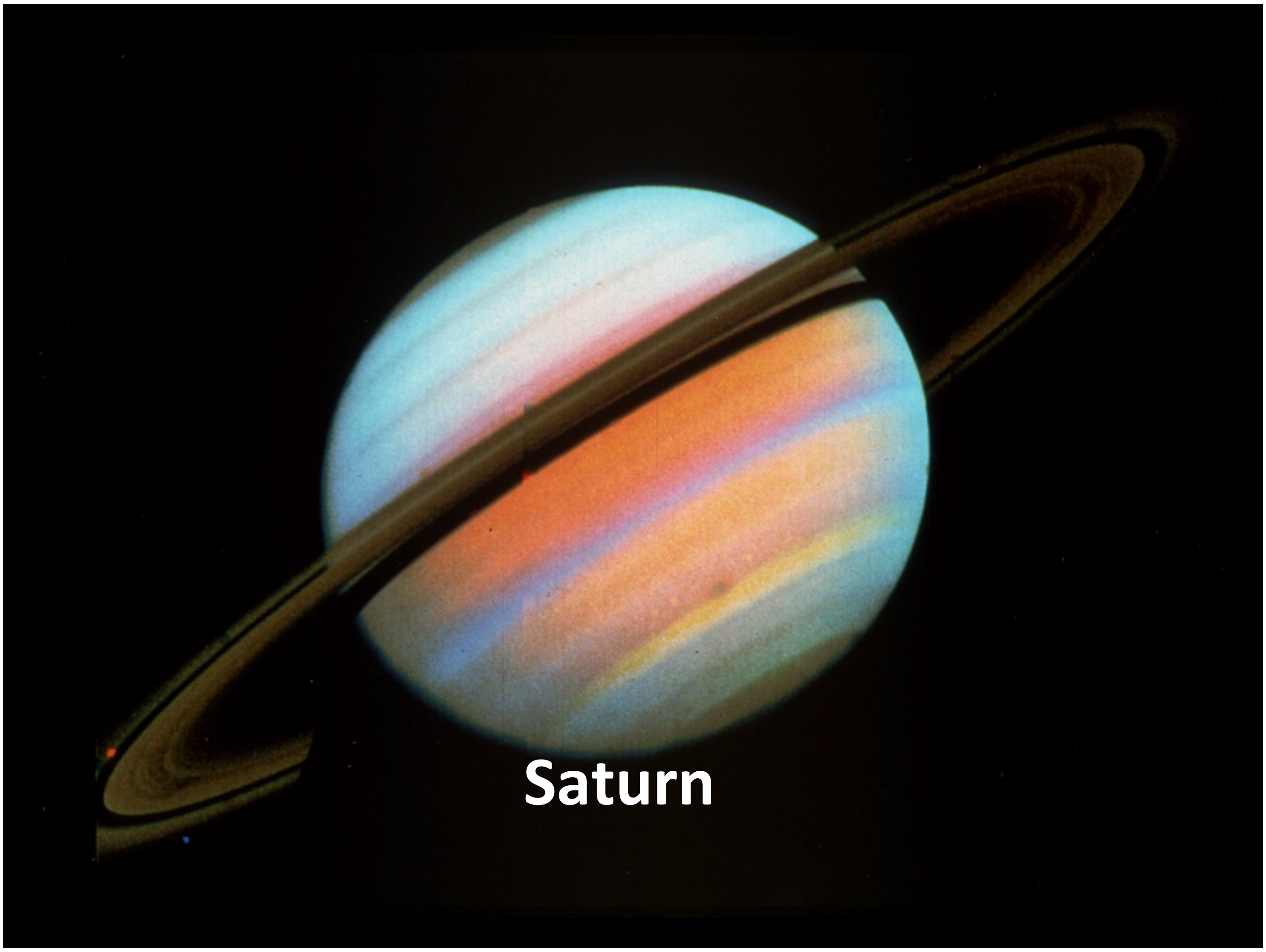
Slide 31



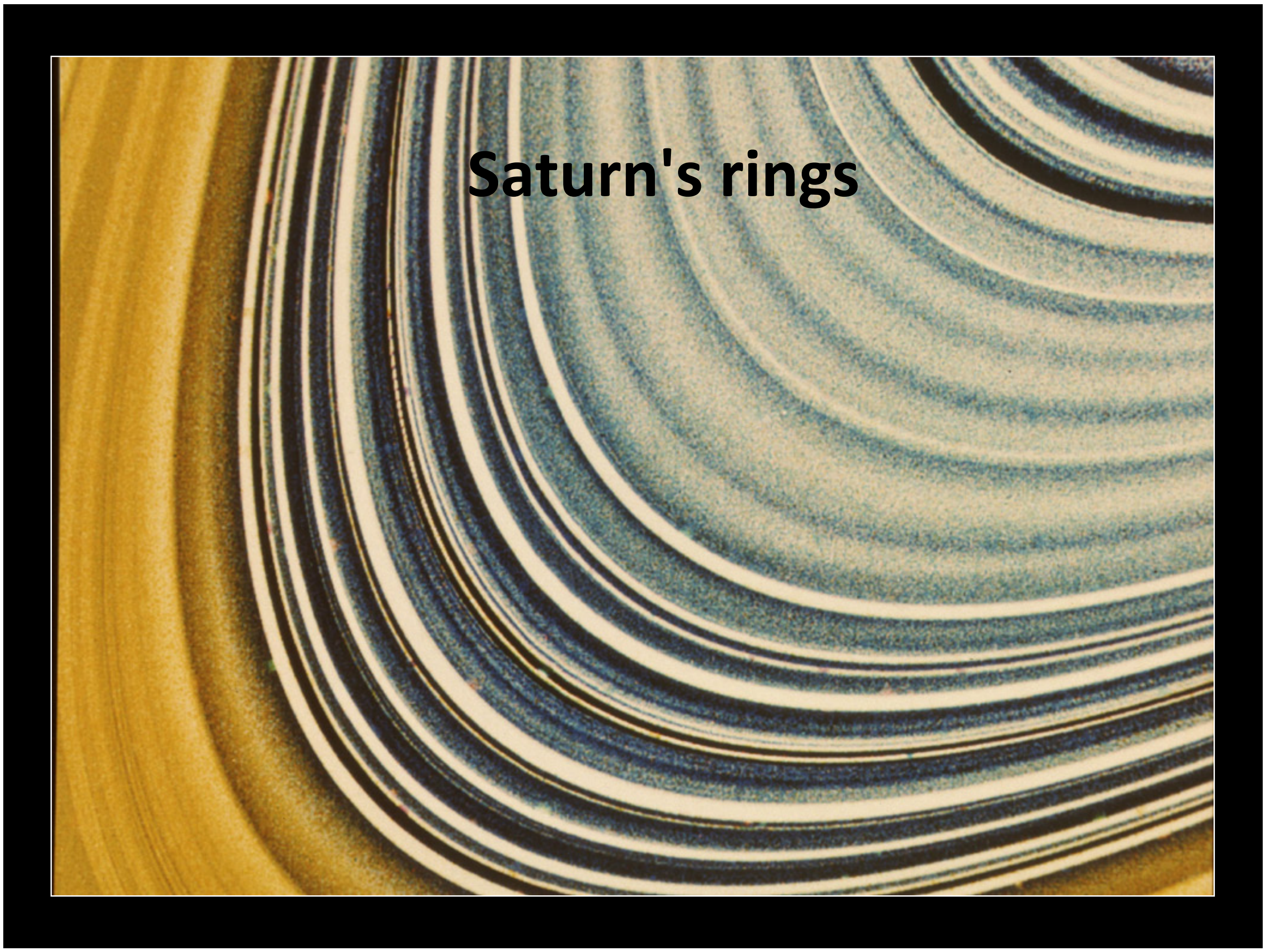
Slide 32


A close-up of Jupiter's turbulent clouds
taken by NASA's *Juno* Mission on 12/06/17

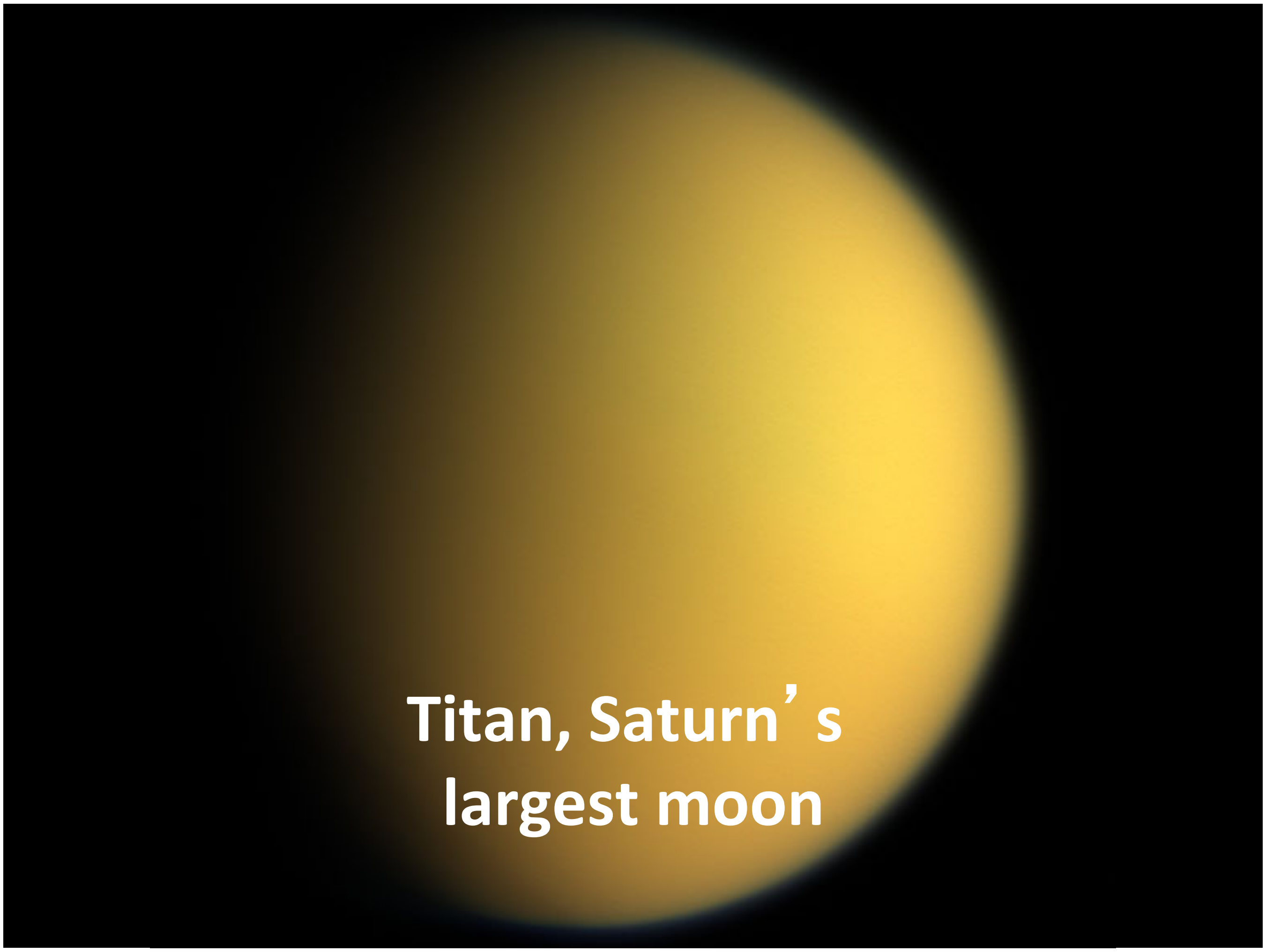
Slide 33



Slide 34

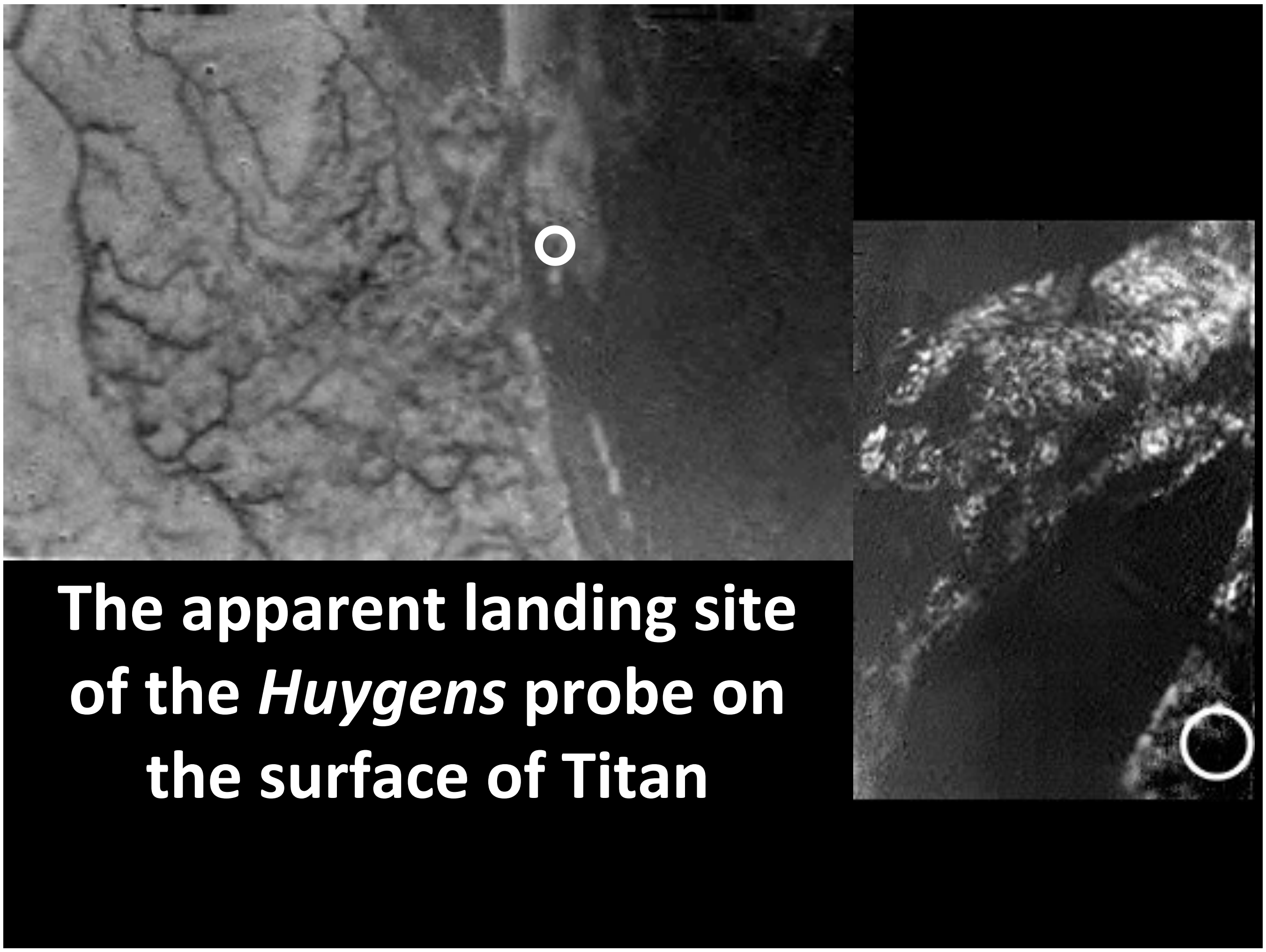


Slide 35

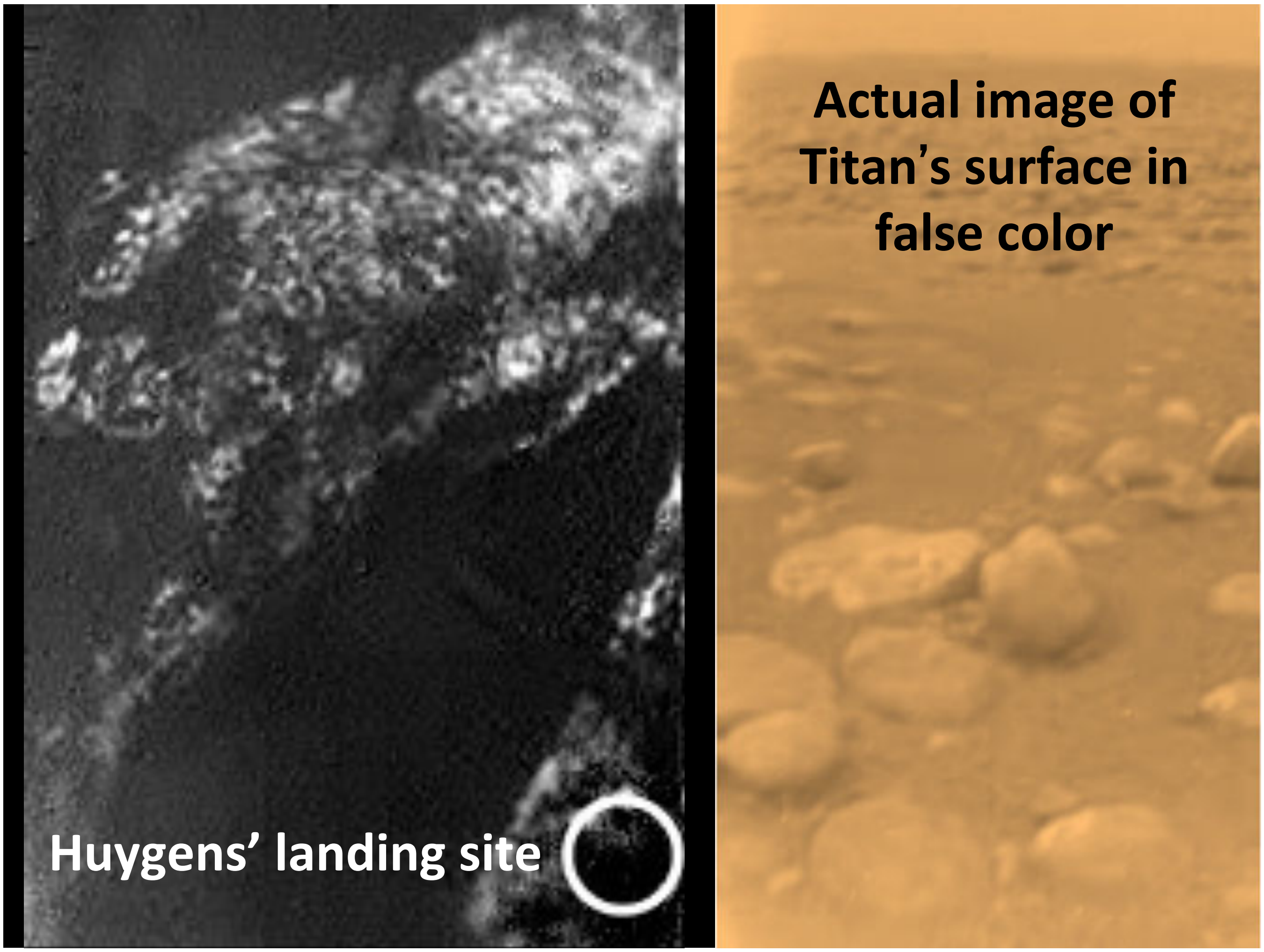


SLIDE 36

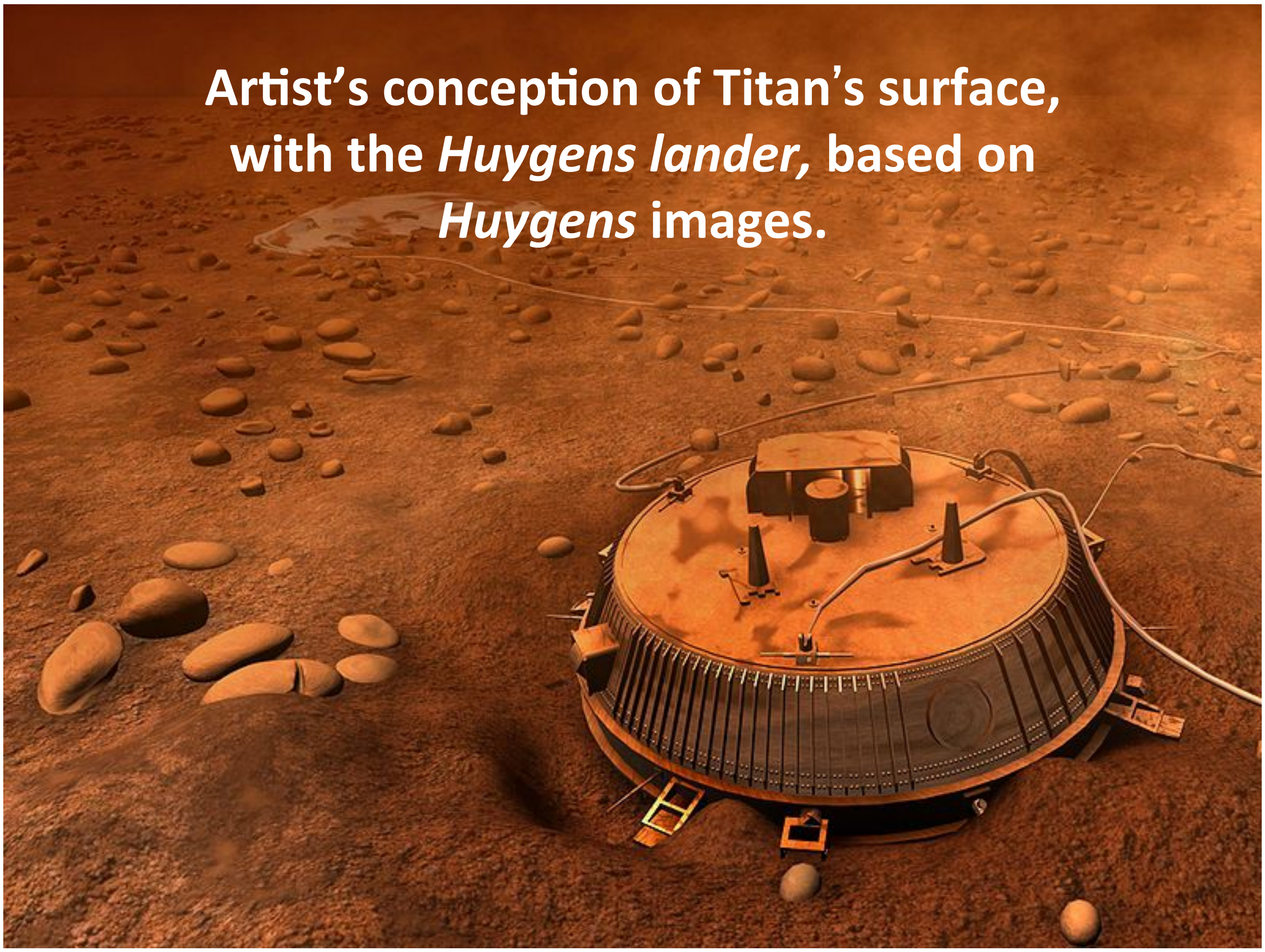
Slide 37


The apparent landing site of the *Huygens* probe on the surface of Titan

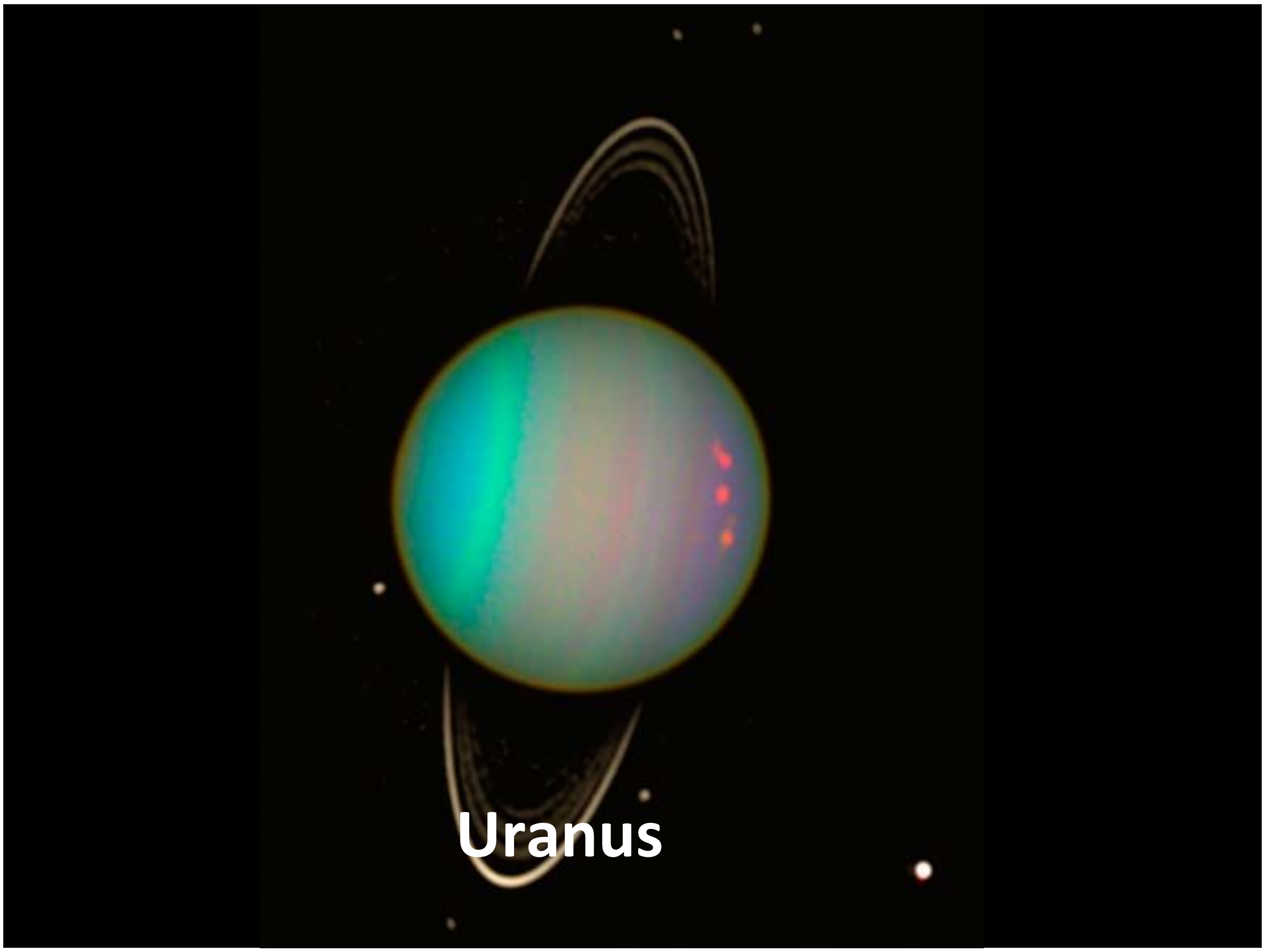
Slide 38


Huygens' landing site
Actual image of Titan's surface in false color

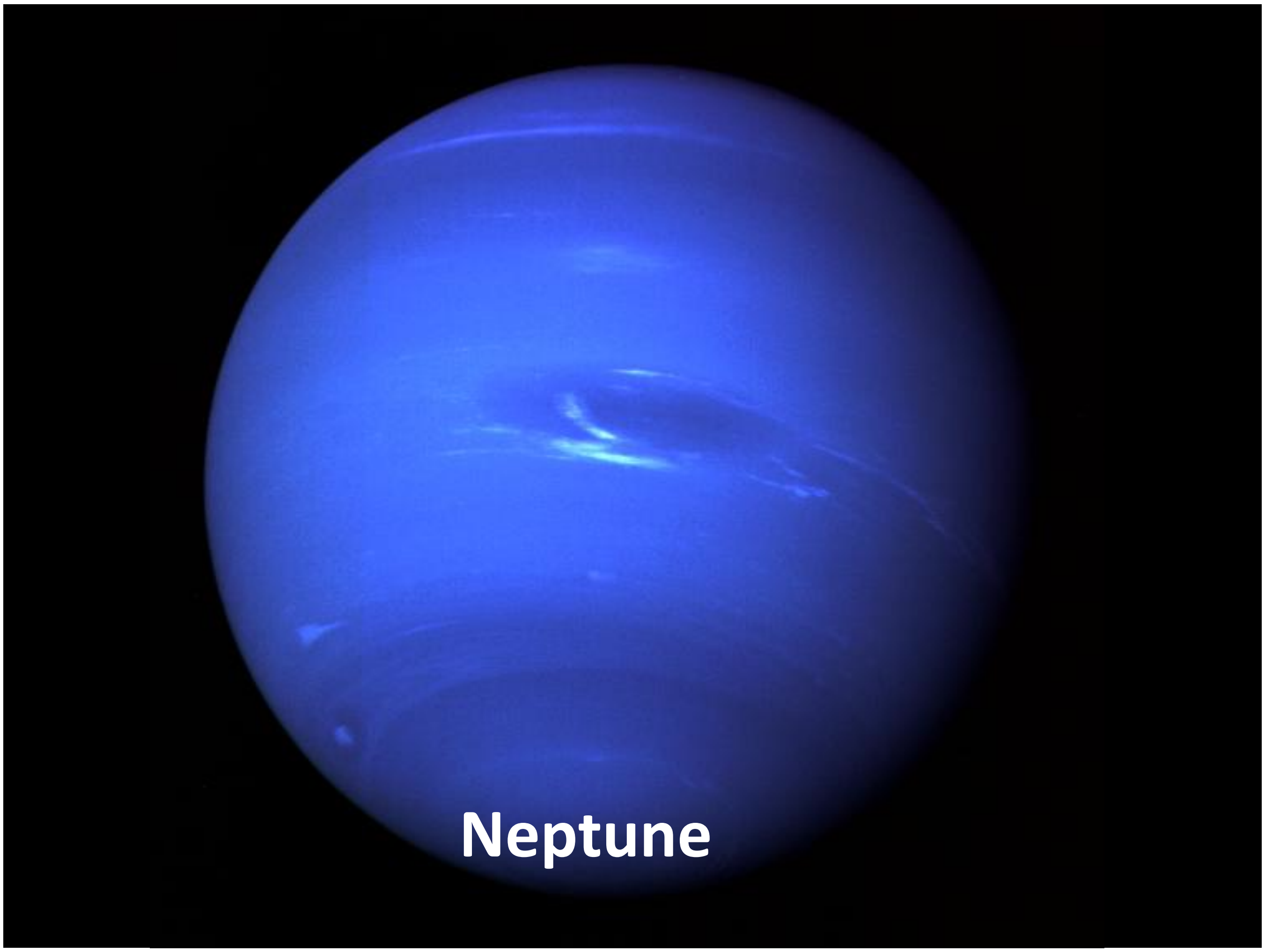
SLIDE 39


Artist's conception of Titan's surface, with the *Huygens lander,* based on *Huygens* images.

Slide 40



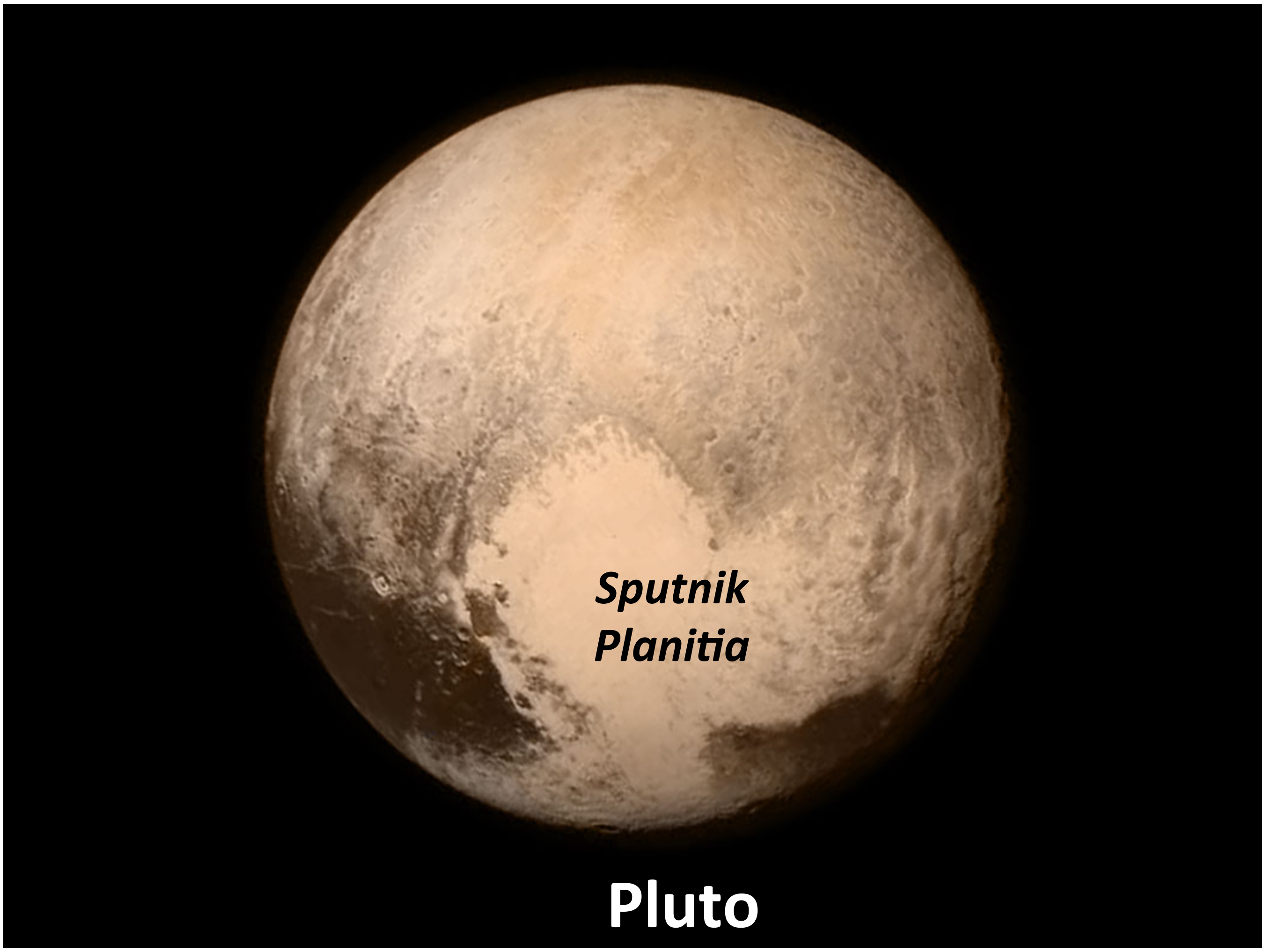
Slide 41



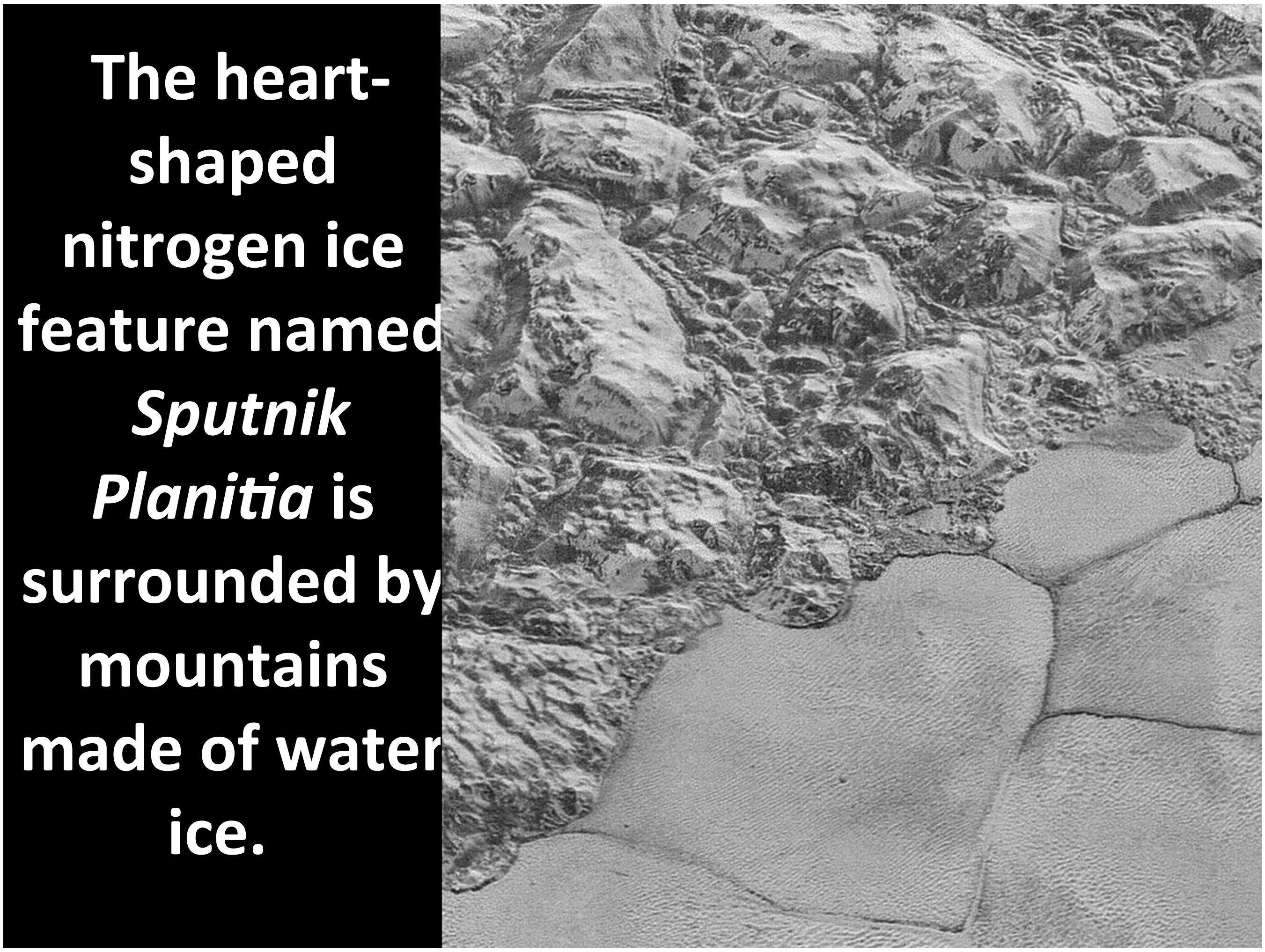
Slide 42


The New Horizons Spacecraft
did a fly-by of Pluto in July of 2015

Slide 43



Slide 44


The heart-shaped nitrogen ice feature named *Sputnik Planitia* is surrounded by mountains made of water ice.

Slide 45

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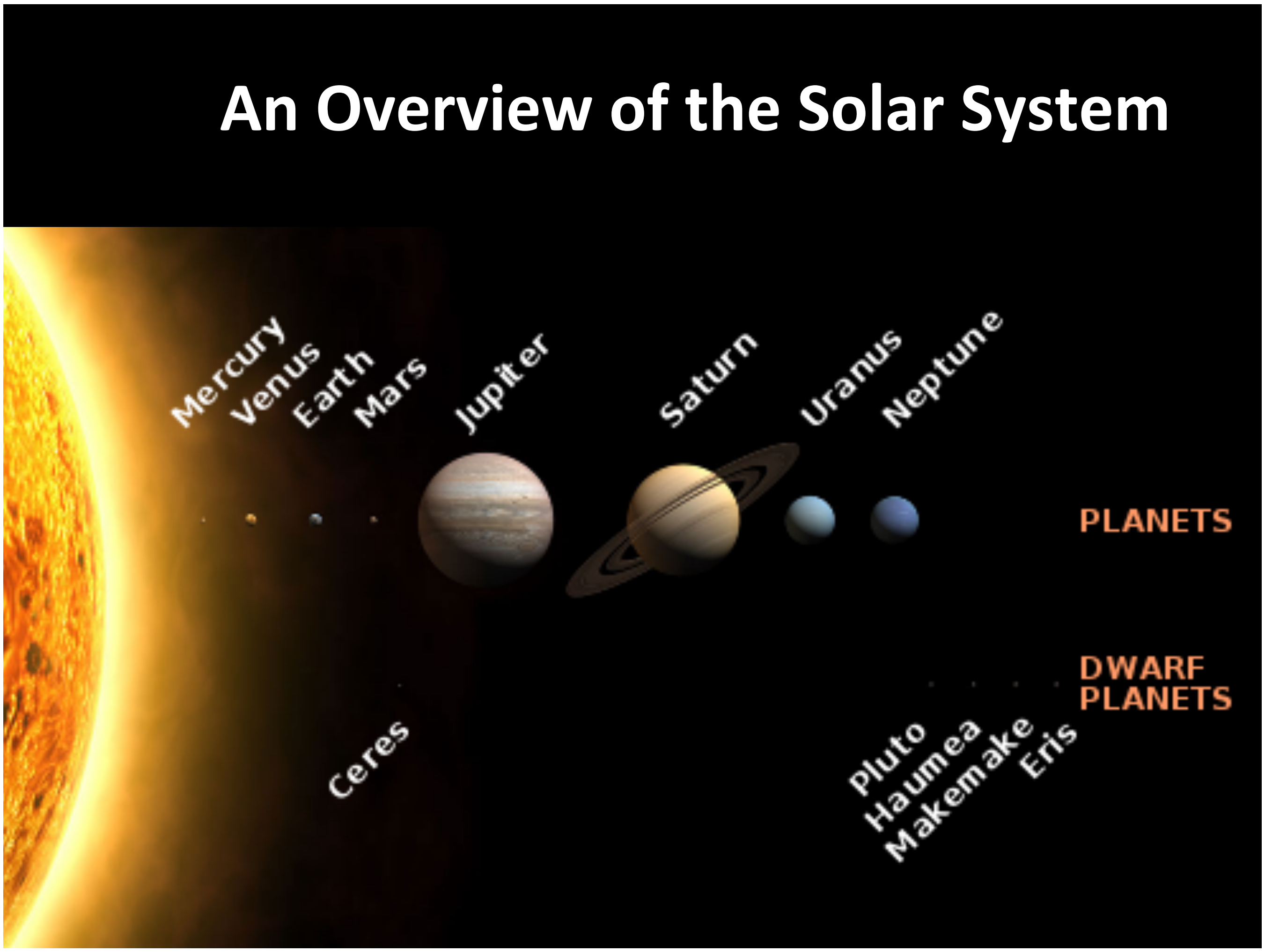
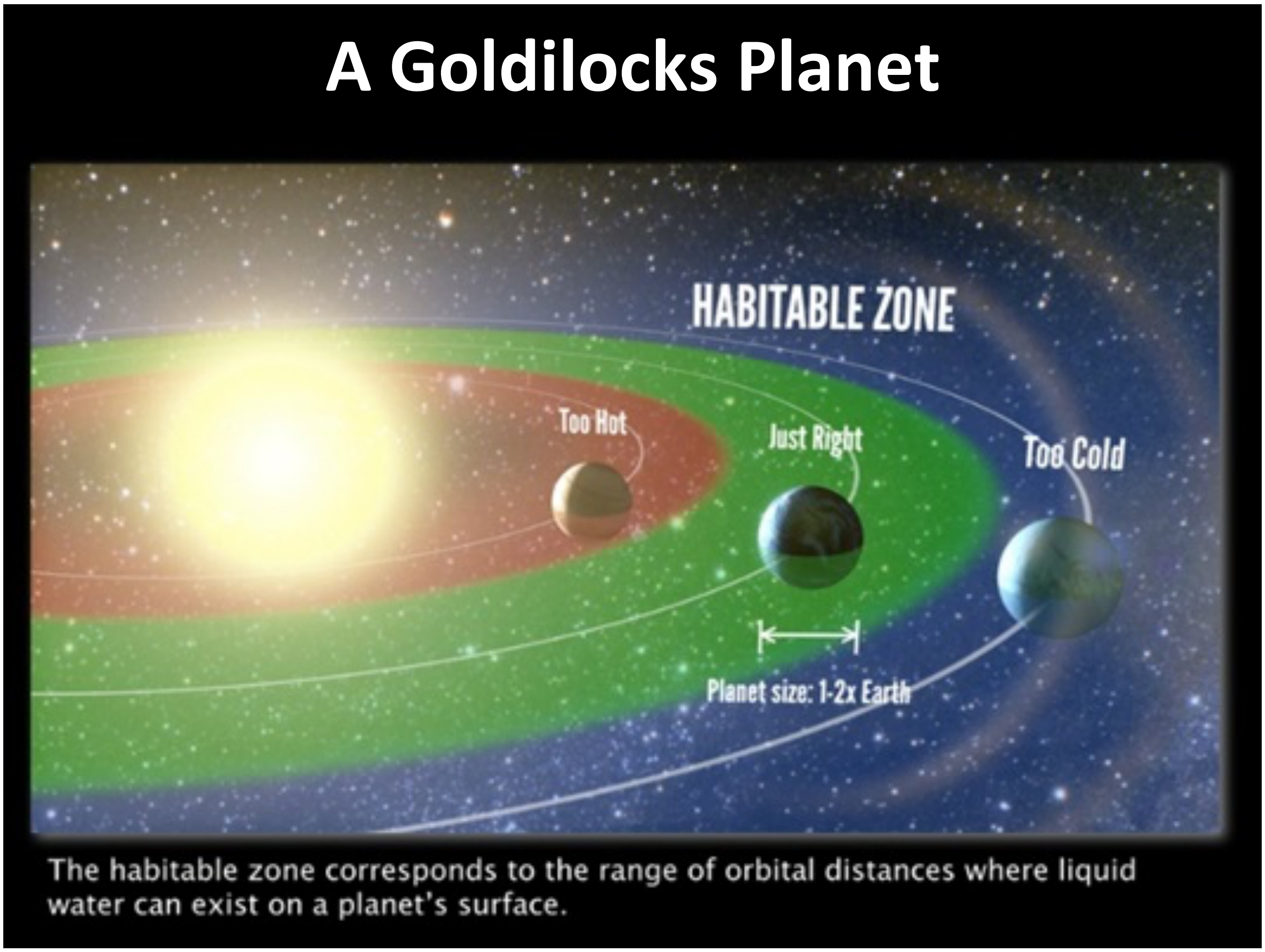
Lesson 2 Slide Presentation:

An Overview of the Universe

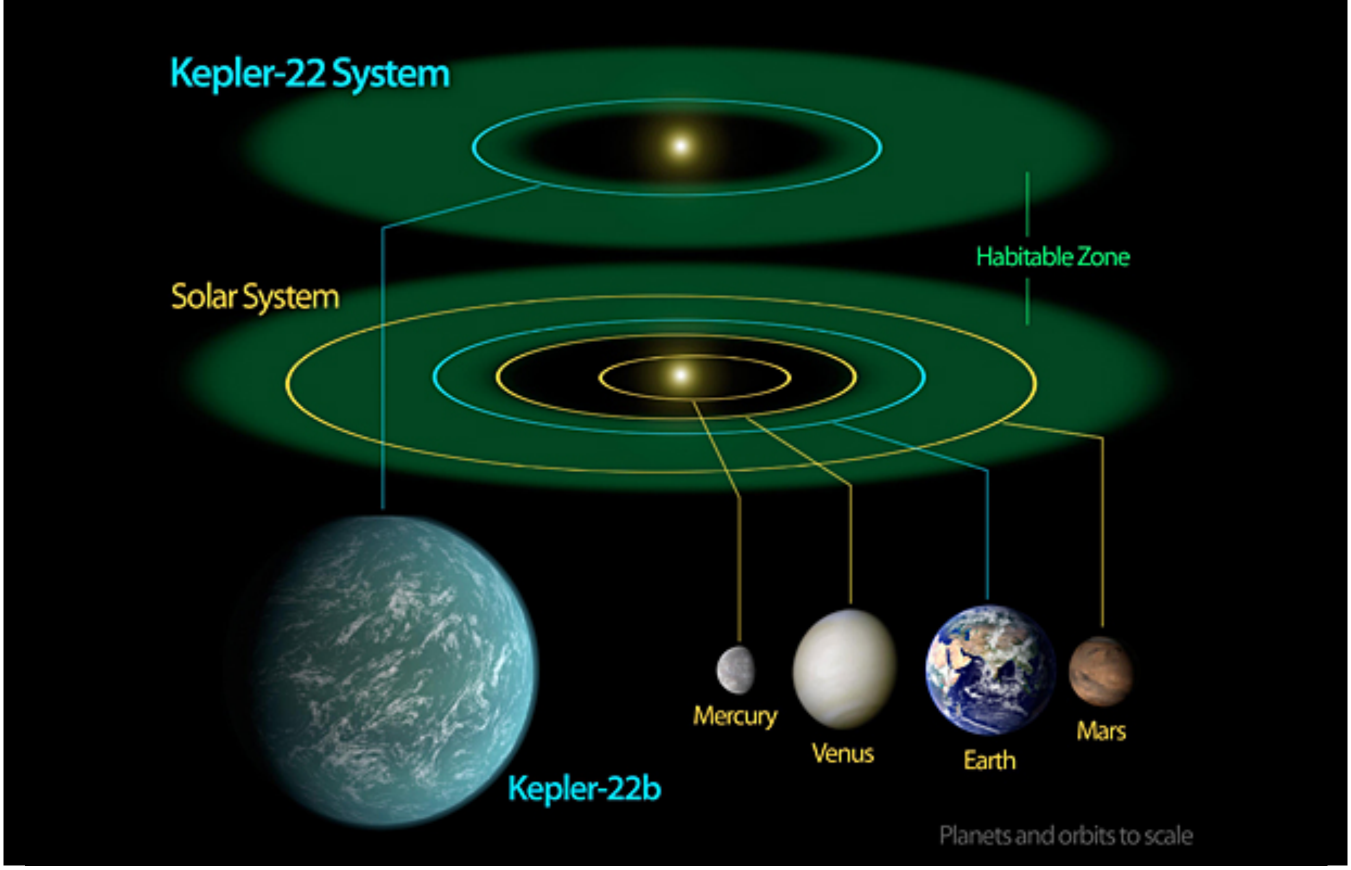

An Overview of the Solar System
Mercury
Venus
Earth
Mars
Jupiter
Saturn
Uranus
Neptune
PLANETS
DWARF PLANETS
Ceres
Pluto
Haumea
Makemake
Eris

Slide 1


A Goldilocks Planet
HABITABLE ZONE
Too Hot
Just Right
Too Cold
Planet size: 1-2x Earth
The habitable zone corresponds to the range of orbital distances where liquid water can exist on a planet's surface.

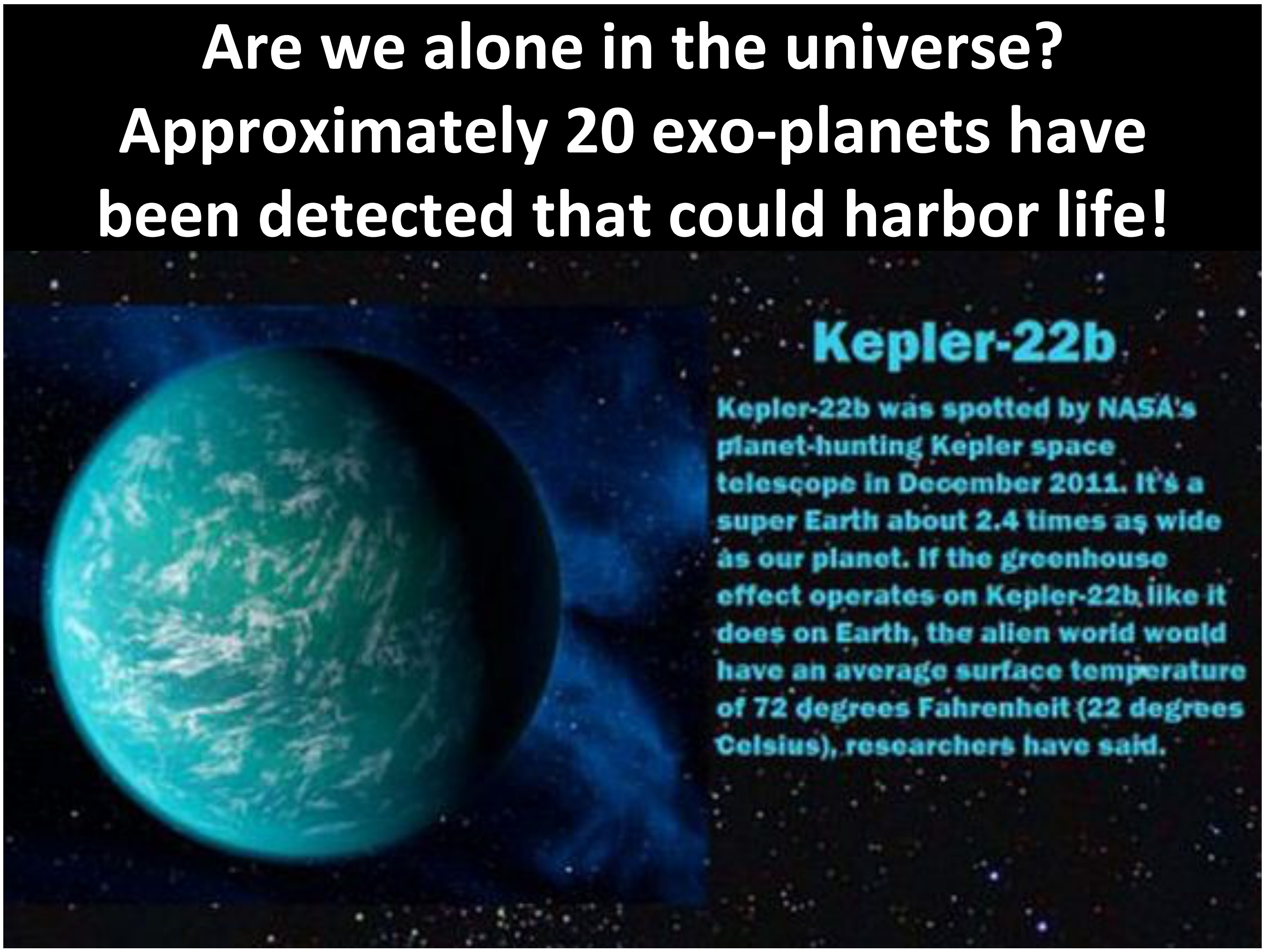
Slide 2

Only Venus, Earth and Mars are in the Habitable Zone of our solar system. Also shown is Kepler 22.

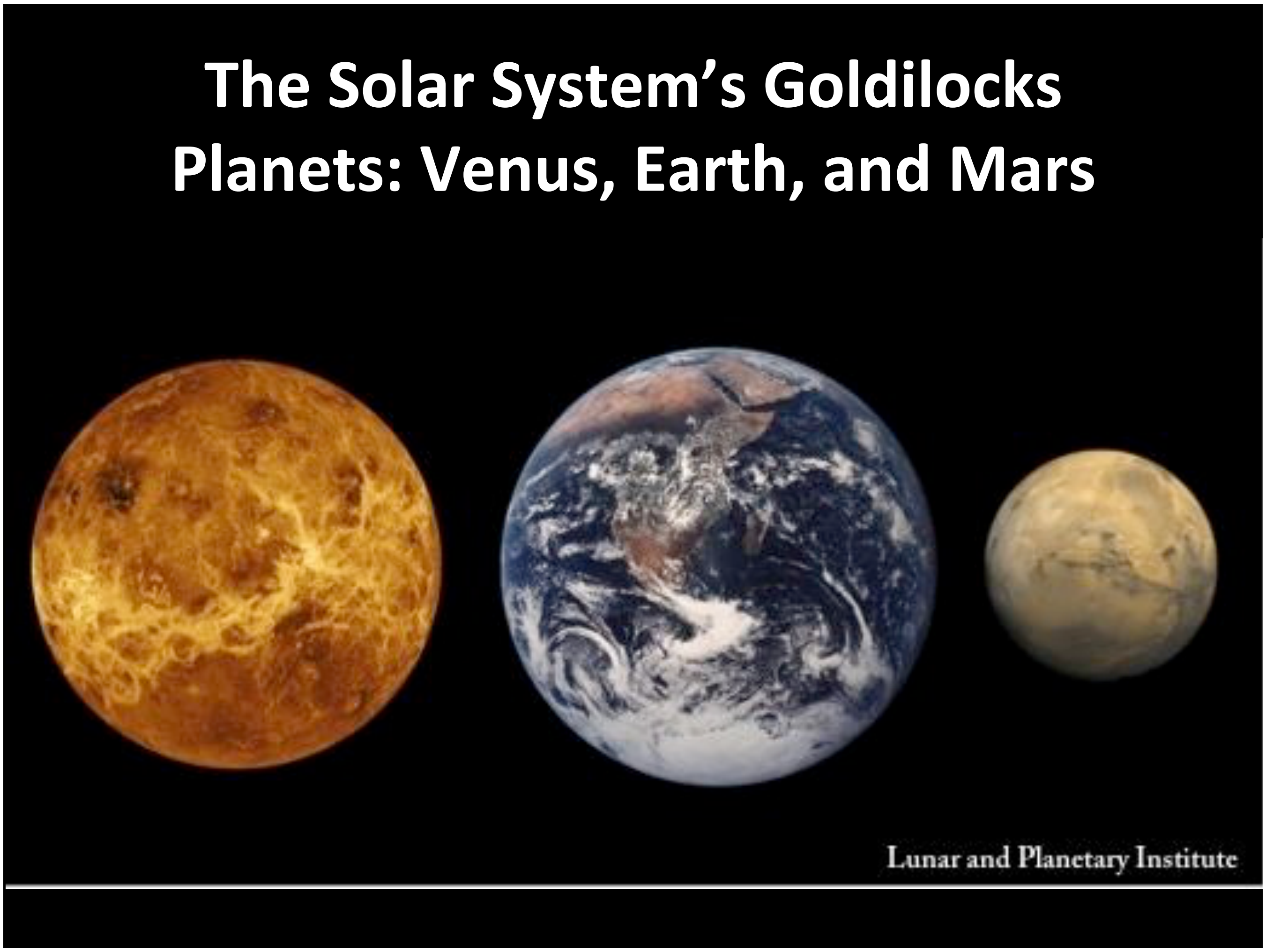


Slide 3

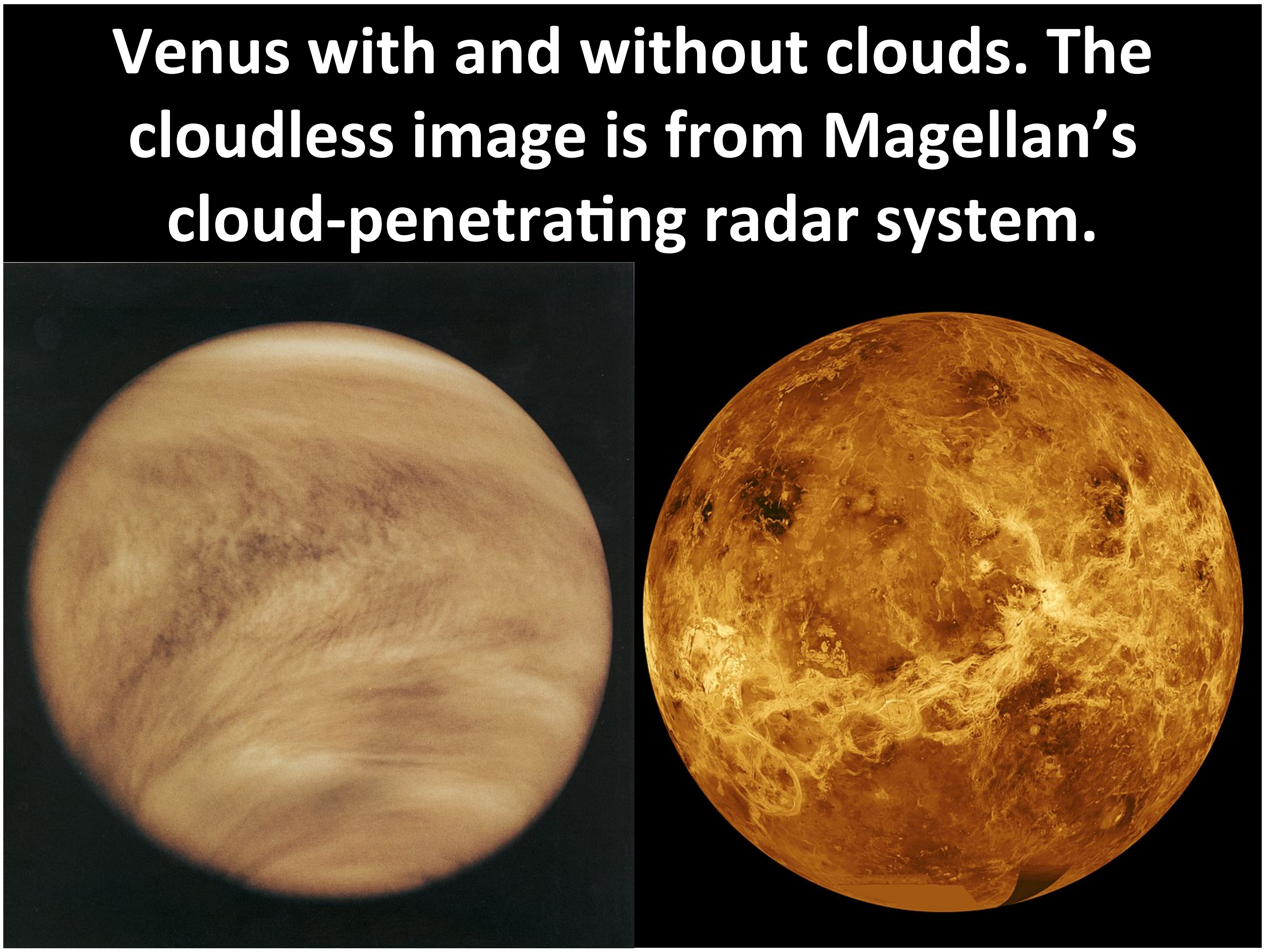
Slide 4


Are we alone in the universe?
Approximately 20 exo-planets have been detected that could harbor life!
Kepler-22b
Kepler-22b was spotted by NASA's planet-hunting Kepler space telescope in December 2011. It's a super Earth about 2.4 times as wide as our planet. If the greenhouse effect operates on Kepler-22b like it does on Earth, the alien world would have an average surface temperature of 72 degrees Fahrenheit (22 degrees Celsius), researchers have said.

Slide 5


The Solar System's Goldilocks Planets: Venus, Earth, and Mars
Lunar and Planetary Institute

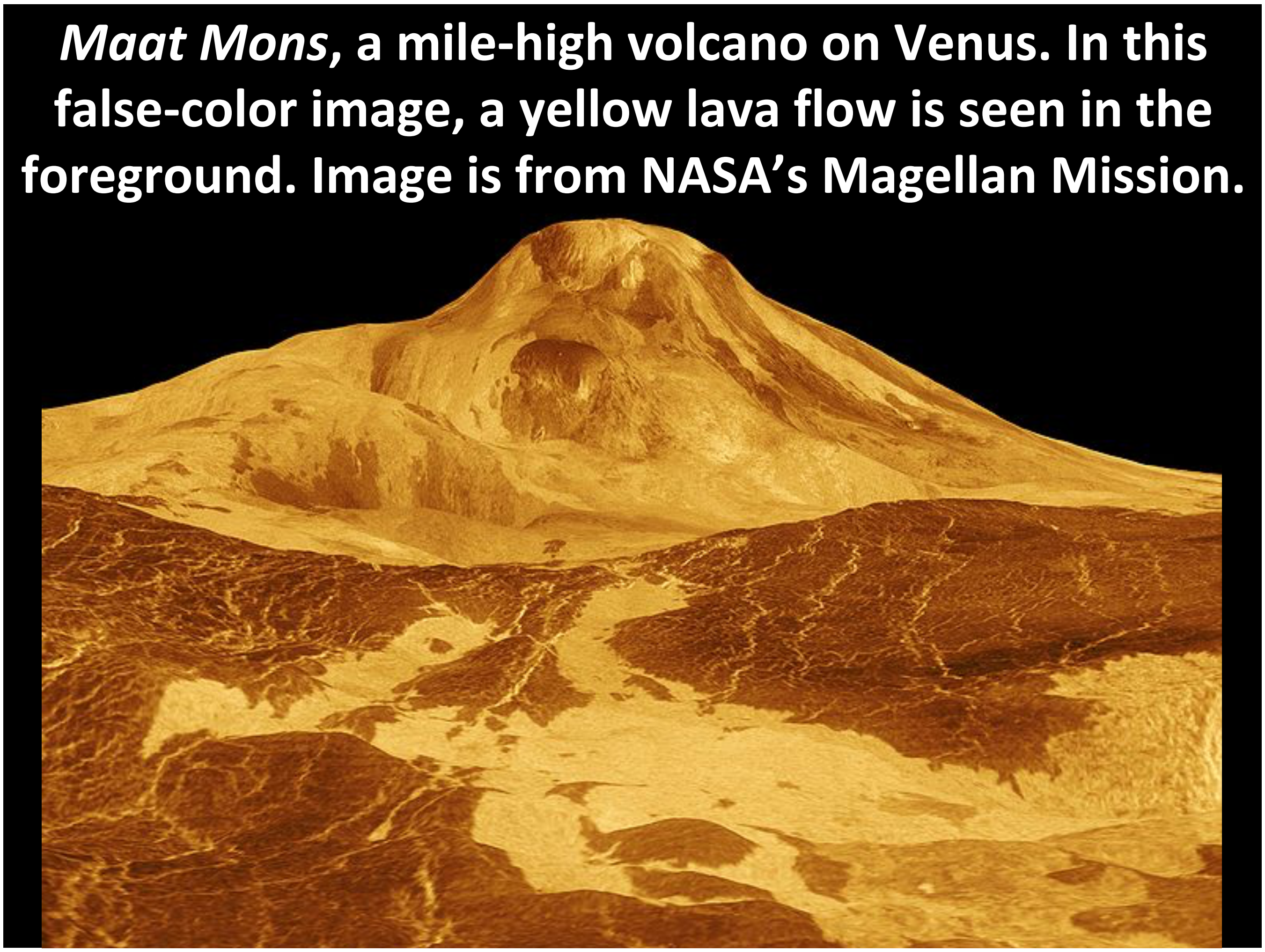
Slide 6


Venus with and without clouds. The cloudless image is from Magellan's cloud-penetrating radar system.

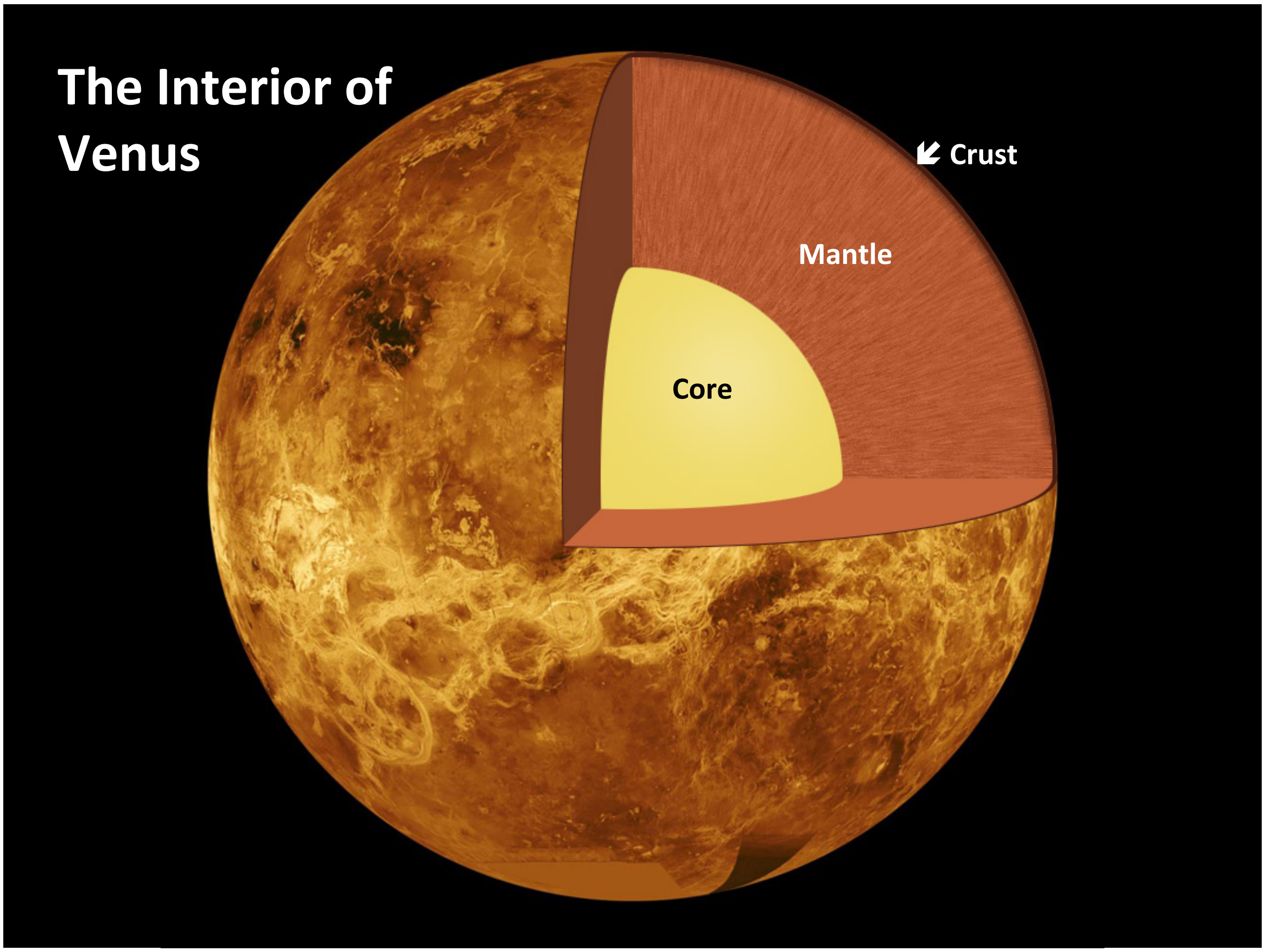
Slide 7

The Soviet spacecraft *Venera 13* on the surface of Venus in 1982. The partial disk-shaped object on the surface is likely a lens cap.

Slide 8


Maat Mons, a mile-high volcano on Venus. In this false-color image, a yellow lava flow is seen in the foreground. Image is from NASA's Magellan Mission.

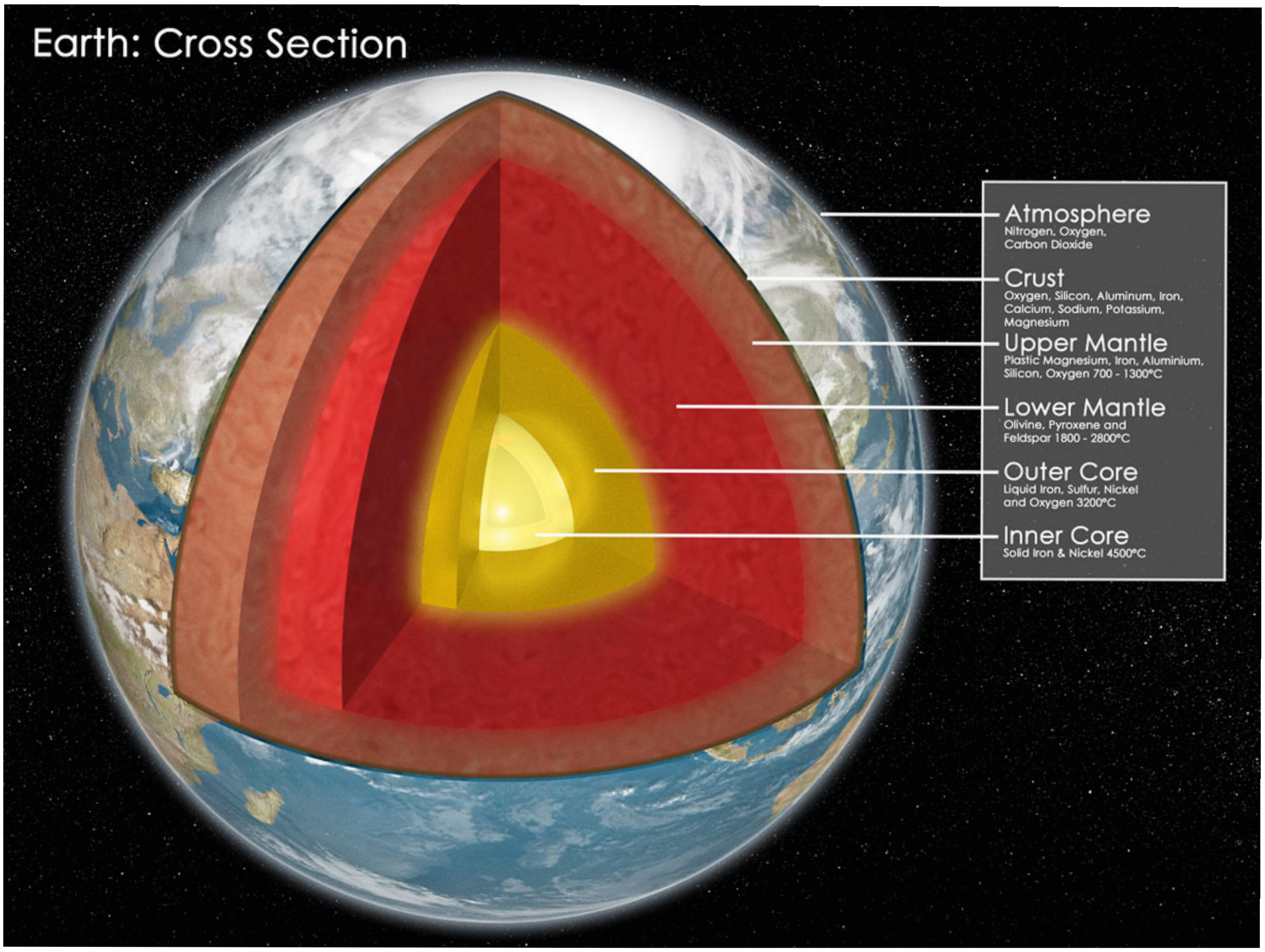
Slide 9



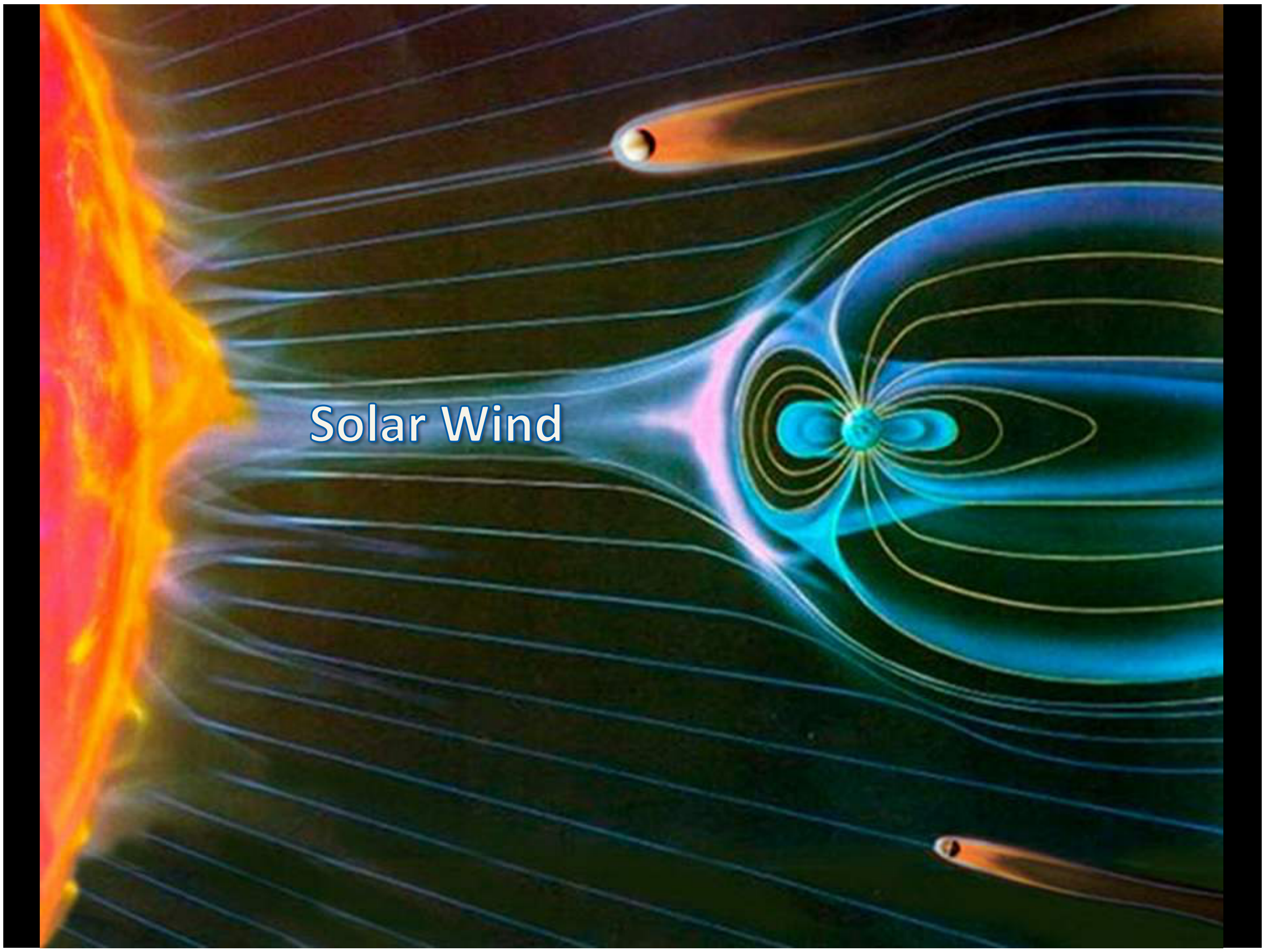
Slide 10


The famous "Blue Marble" image of the Earth as seen from Apollo 17 on December 7, 1972.

Slide 11


Earth: Cross Section
Atmosphere
Nitrogen, Oxygen, Carbon Dioxide
Crust
Oxygen, Silicon, Aluminum, Iron, Calcium, Sodium, Potassium, Magnesium
Upper Mantle
Plastic Magnesium, Iron, Aluminium, Silicon, Oxygen 700 - 1300°C
Lower Mantle
Olivine, Pyroxene and Feldspar 1800 - 2800°C
Outer Core
Liquid Iron, Sulfur, Nickel and Oxygen 3200°C
Inner Core
Solid Iron & Nickel 4500°C

Slide 12



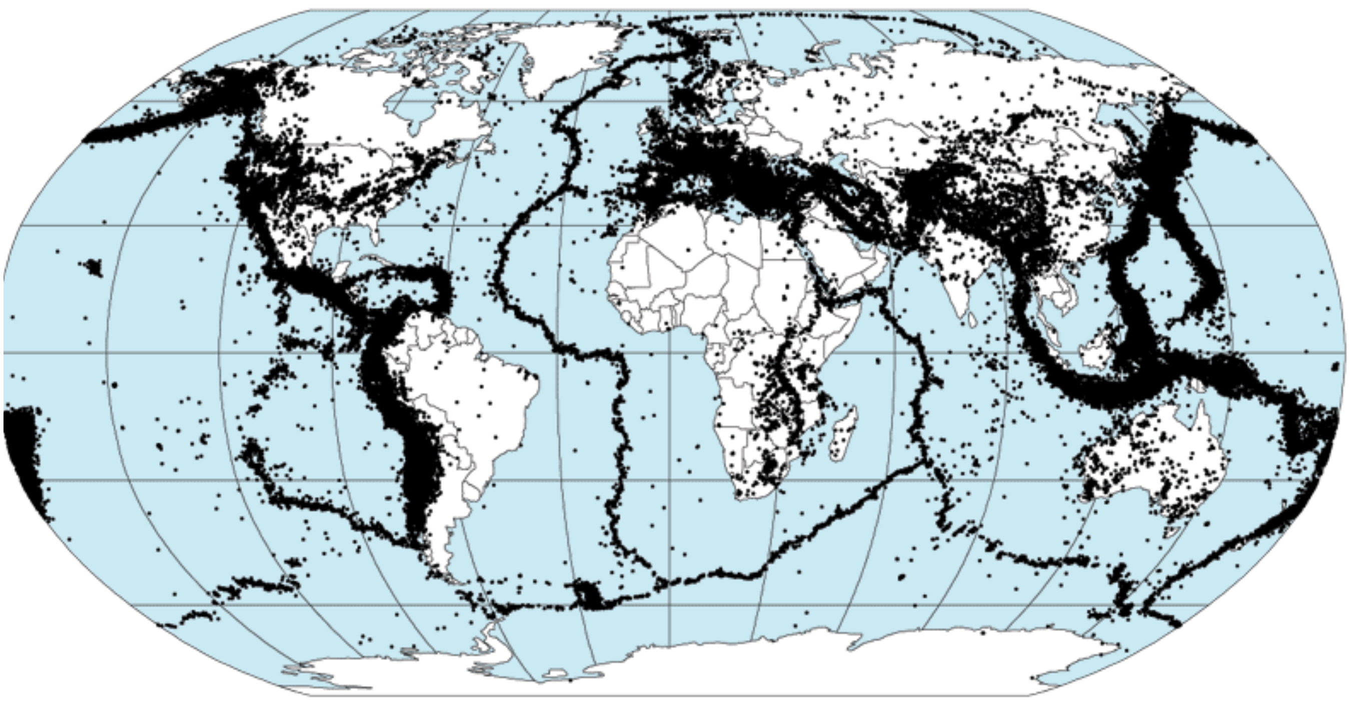
Slide 13

A volcanic eruption in the Aleutian Islands of Alaska

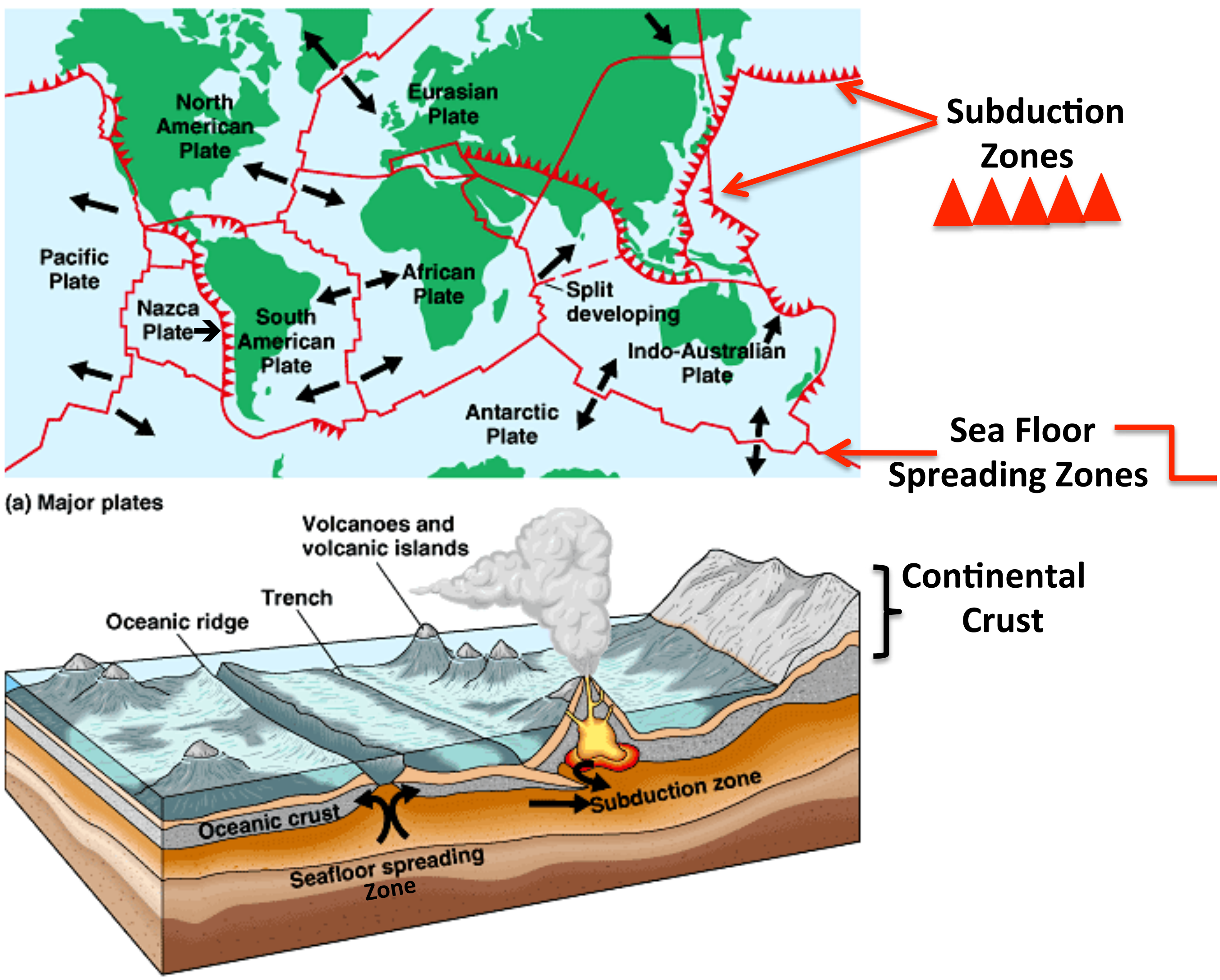
Slide 14

Earthquake Activity

Preliminary Determination of Epicenters
358,214 Events, 1963 - 1998



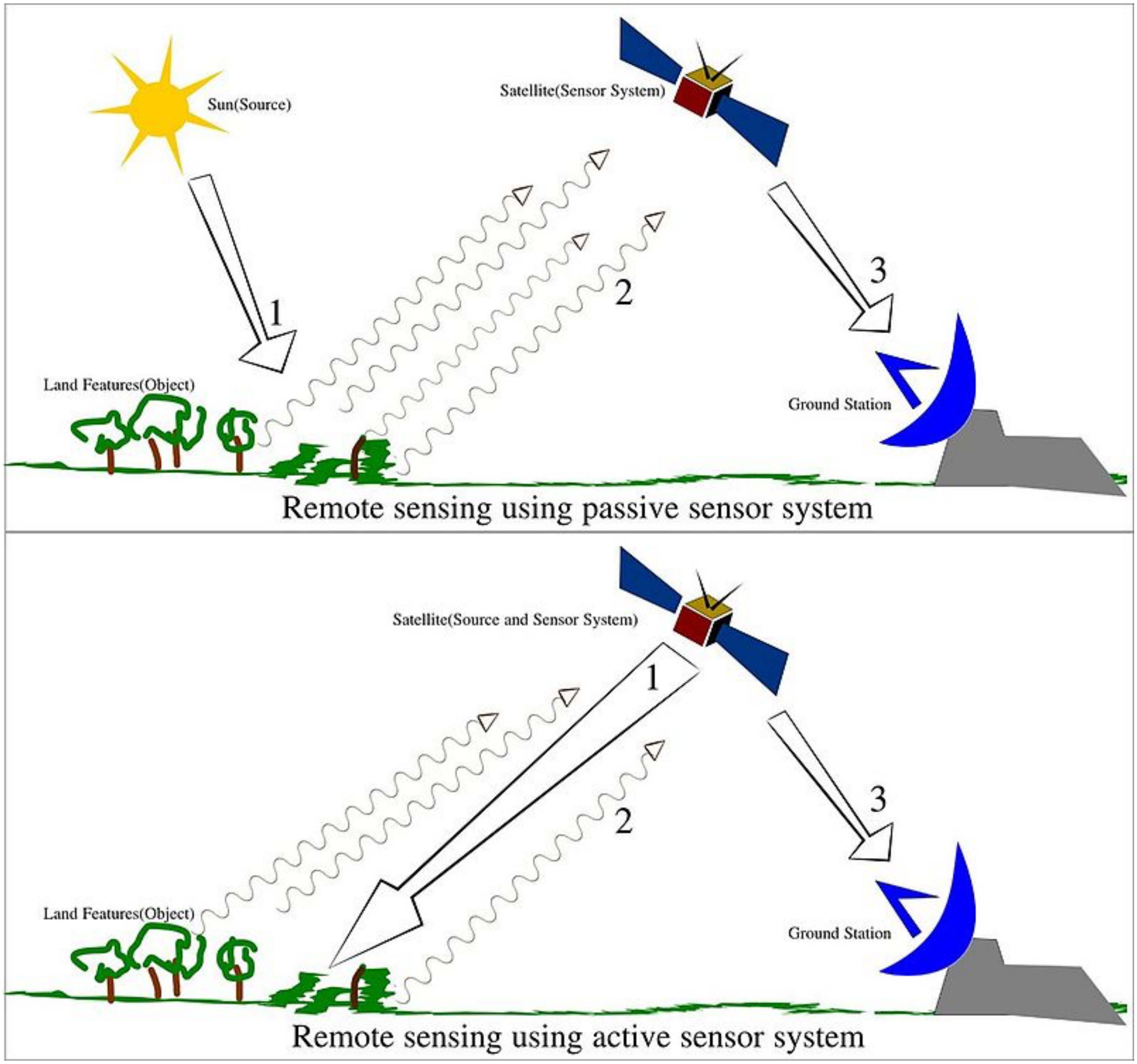
Slide 15



(b) Events at plate boundaries

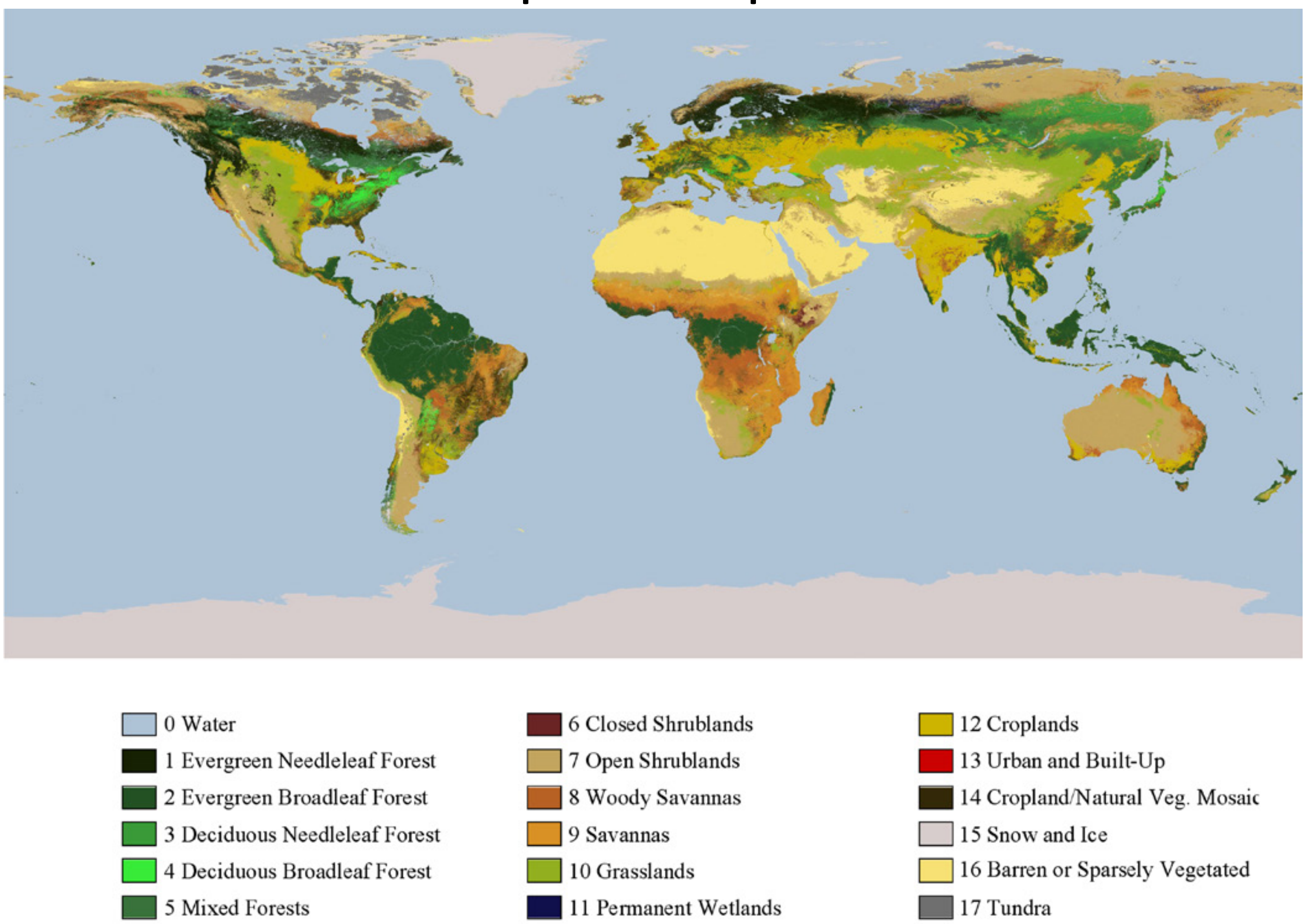
Slide 16

Types of Earth Remote-Sensing Systems



Slide 17

NASA Land Cover Map Based on Spectral Characteristics

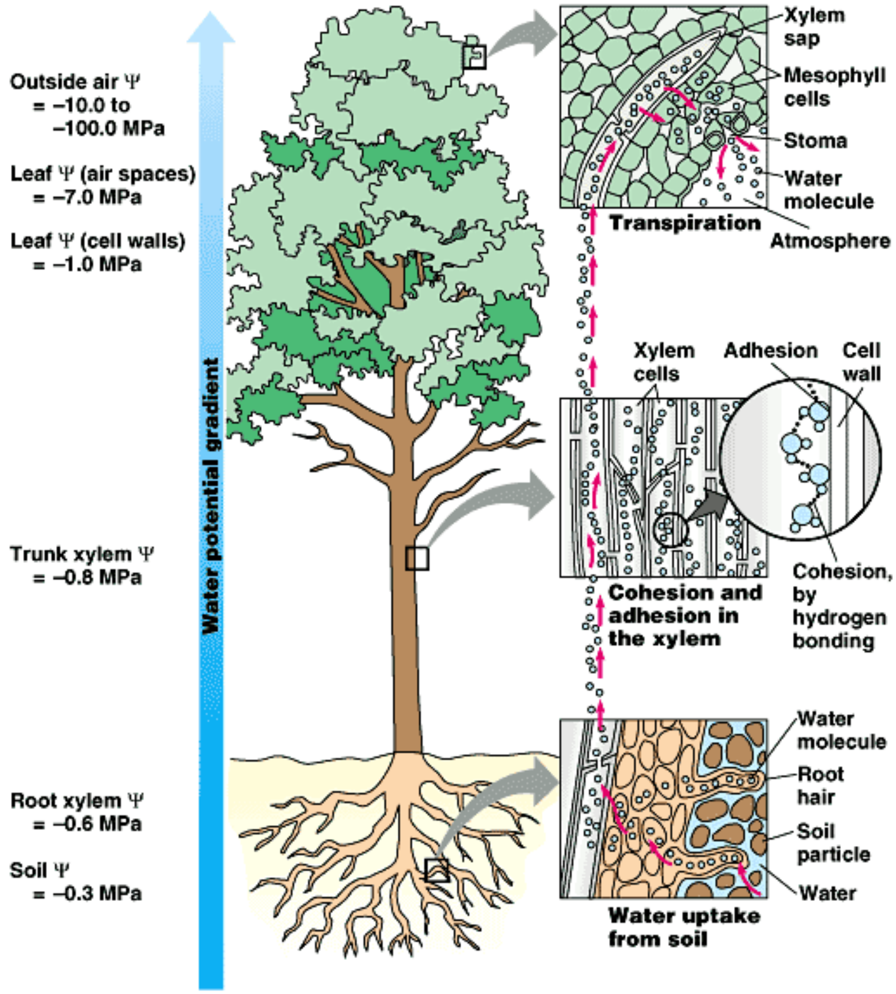


Slide 18

The Amazon Tall Tower Observatory (ATTO) in the Amazon Rainforest conducts atmospheric research

Slide 19

Transpiration is the loss of water vapor through stomates in the lower epidermis of leaves. Transpiration pulls water and nutrients from the soil into the plant's roots, contributing to the process of photosynthesis.



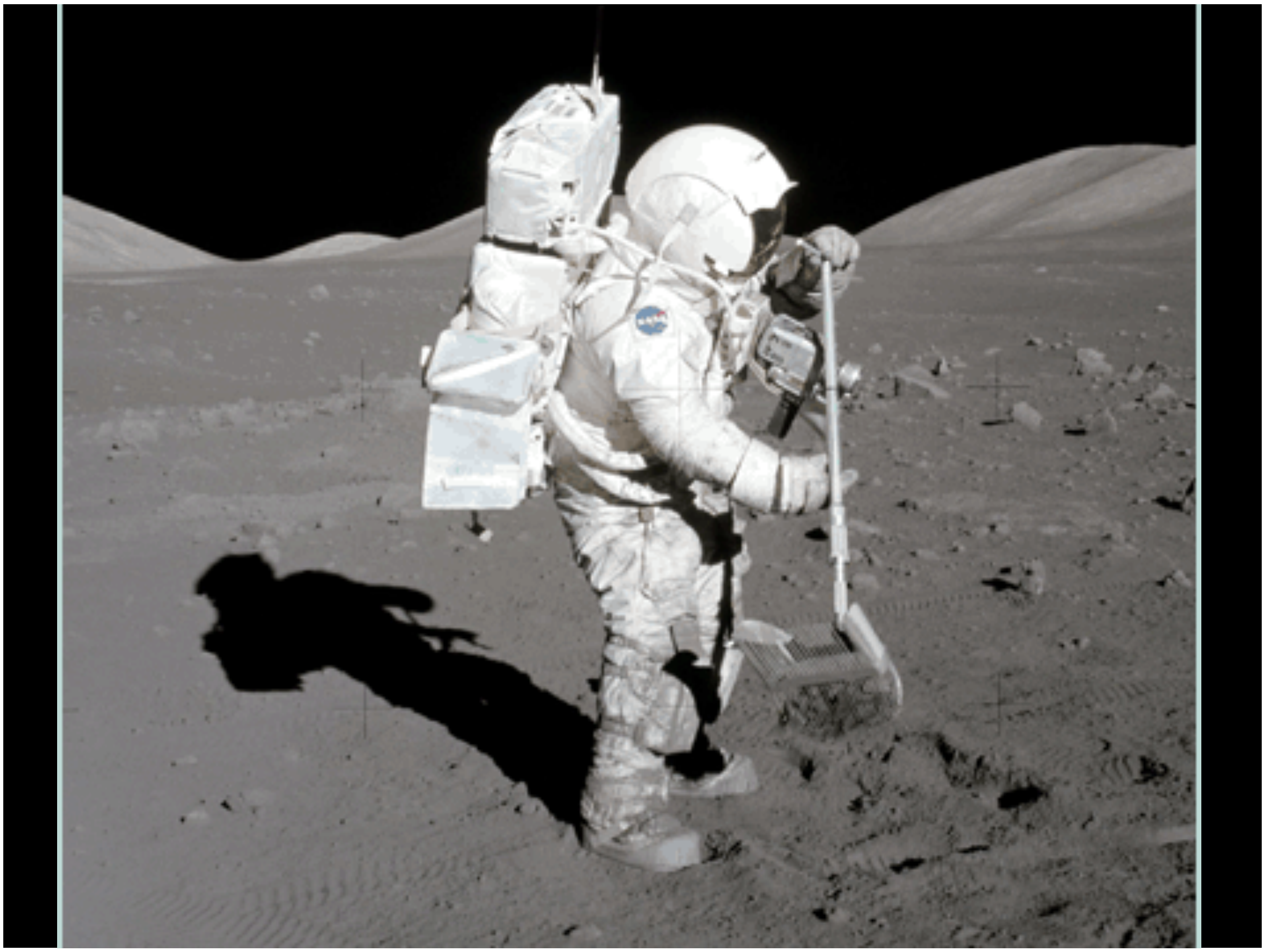
Slide 20

Slide 21

Slide 22

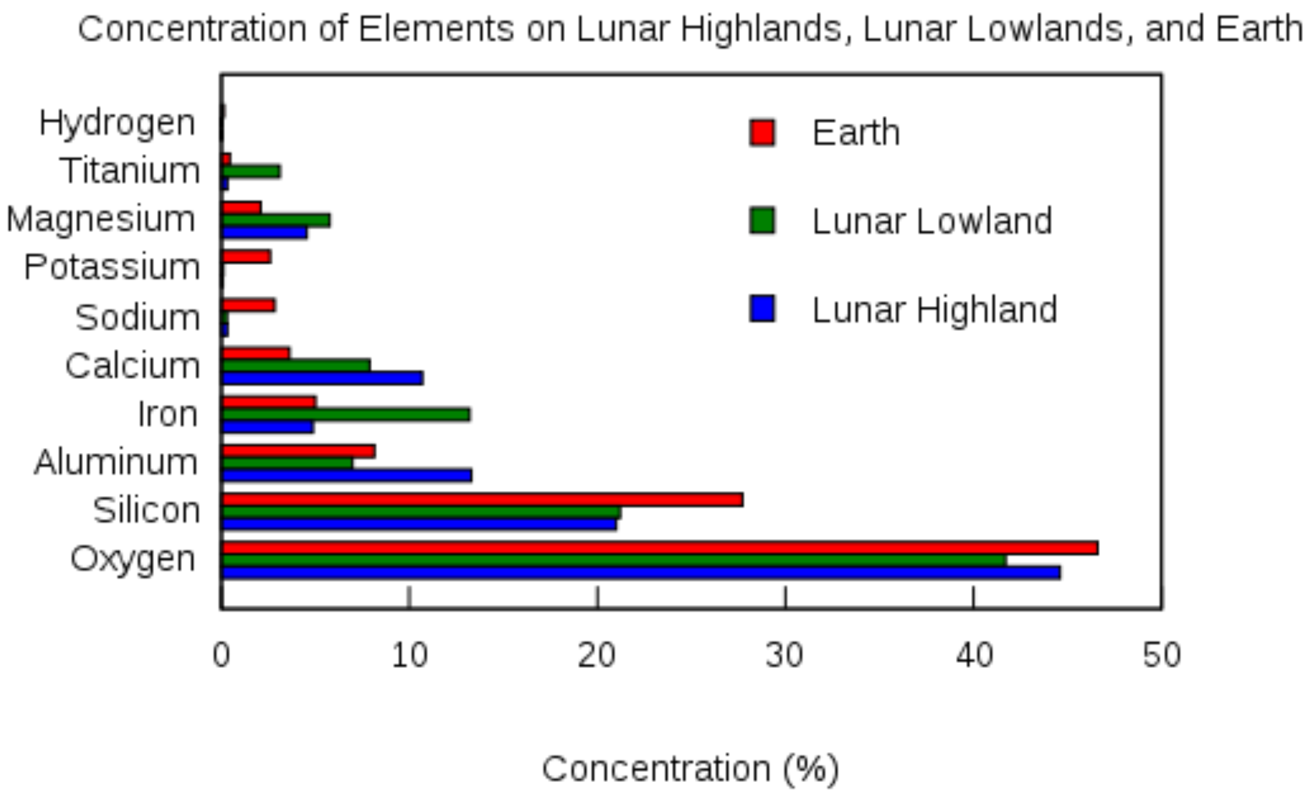

The Apollo 11 Astronauts
Mike Collins
Neil Armstrong
Edwin "Buzz" Aldrin

Slide 23



Slide 24

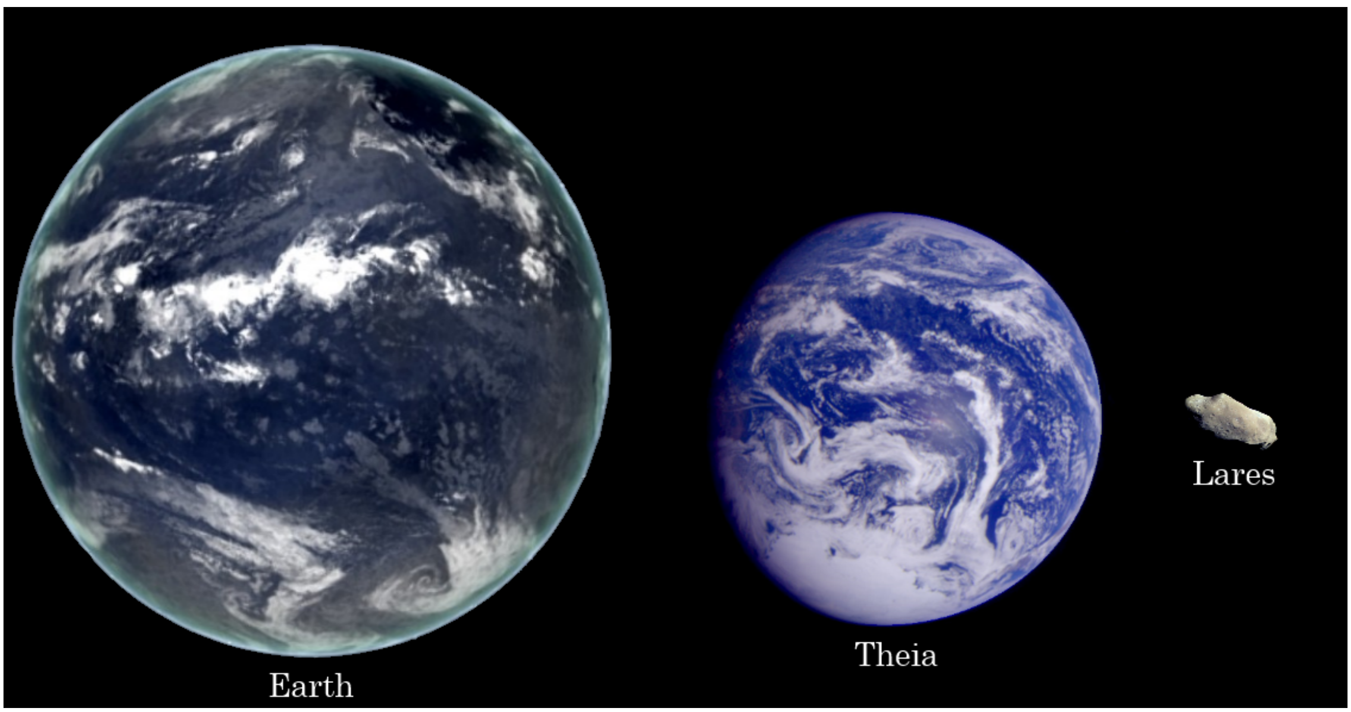
A Comparison of the Mineralogy of the Earth and Moon



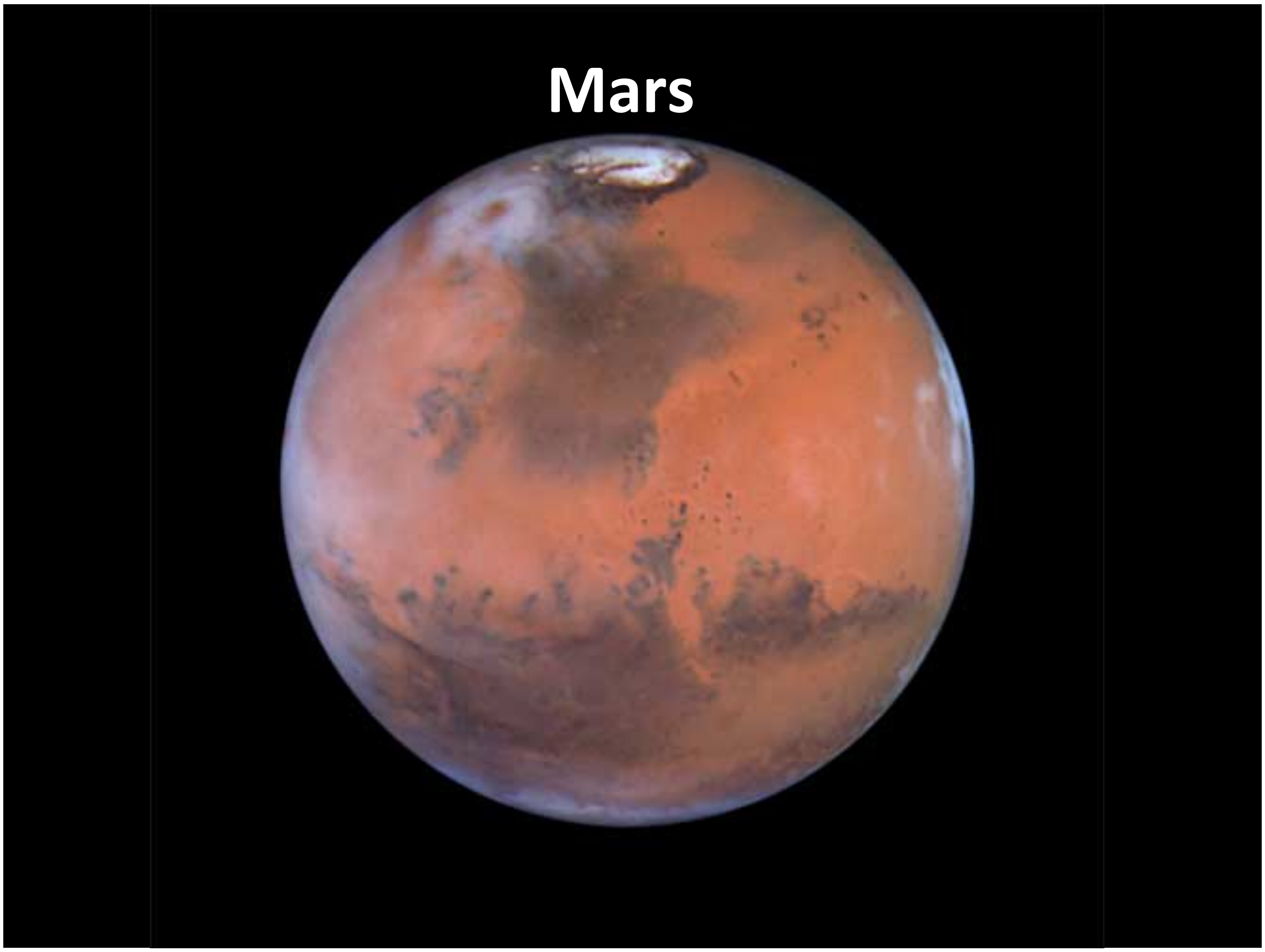
Slide 25

Slide 26

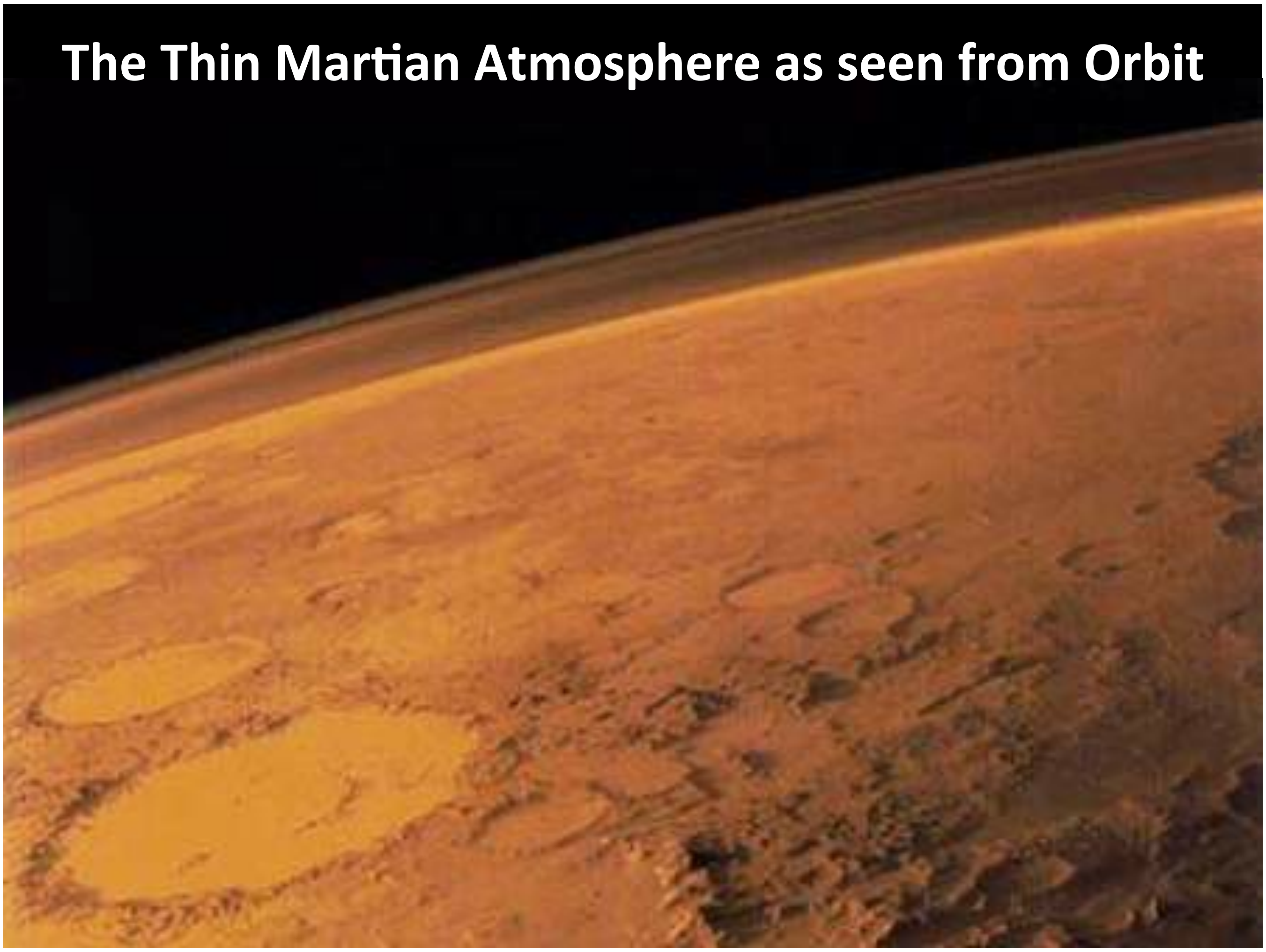
A size comparison of the primitive Earth, the hypothesized Proto-Planet *Theia*, and the asteroid *Lares.*



Slide 27



Slide 28

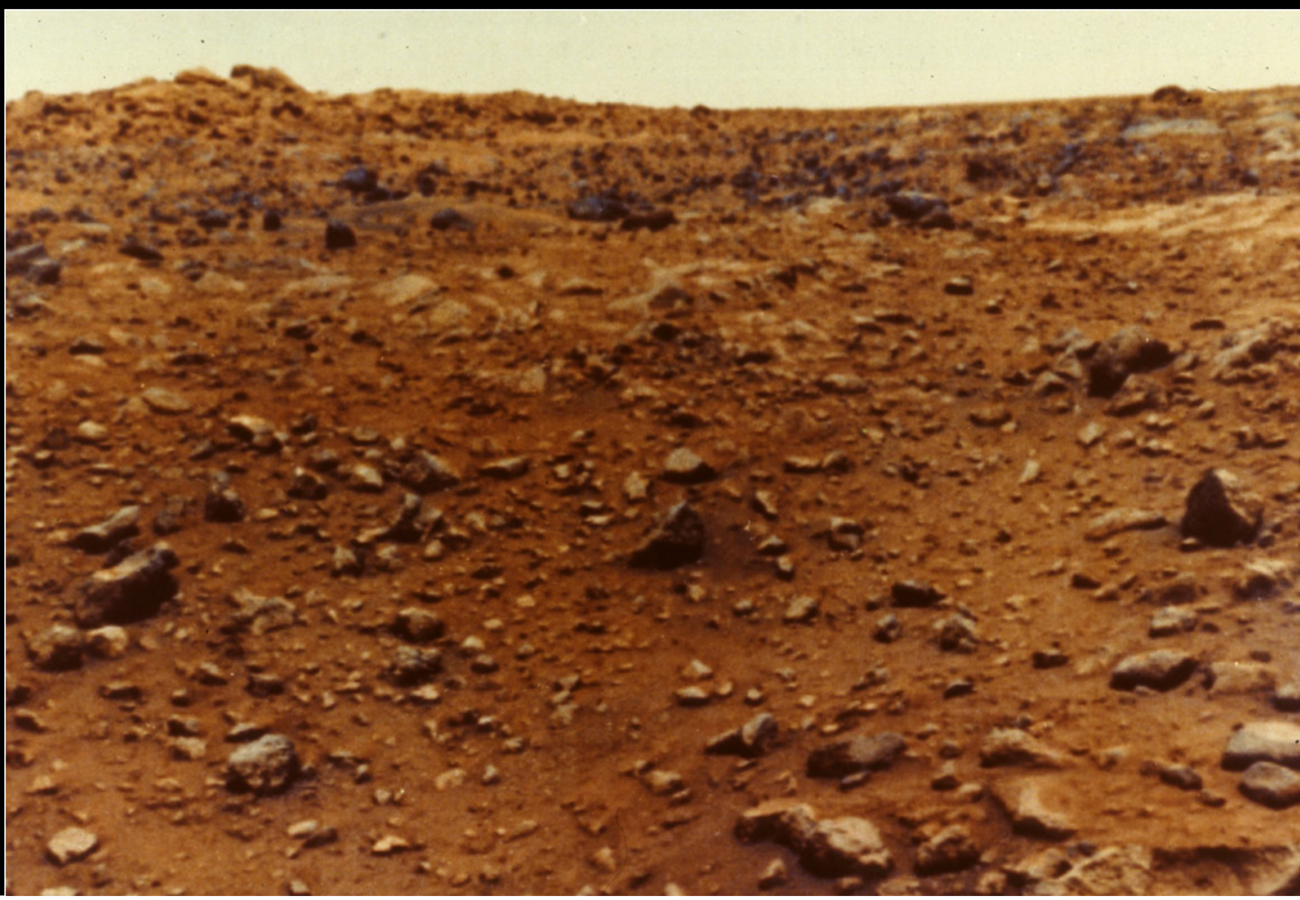


Slide 29

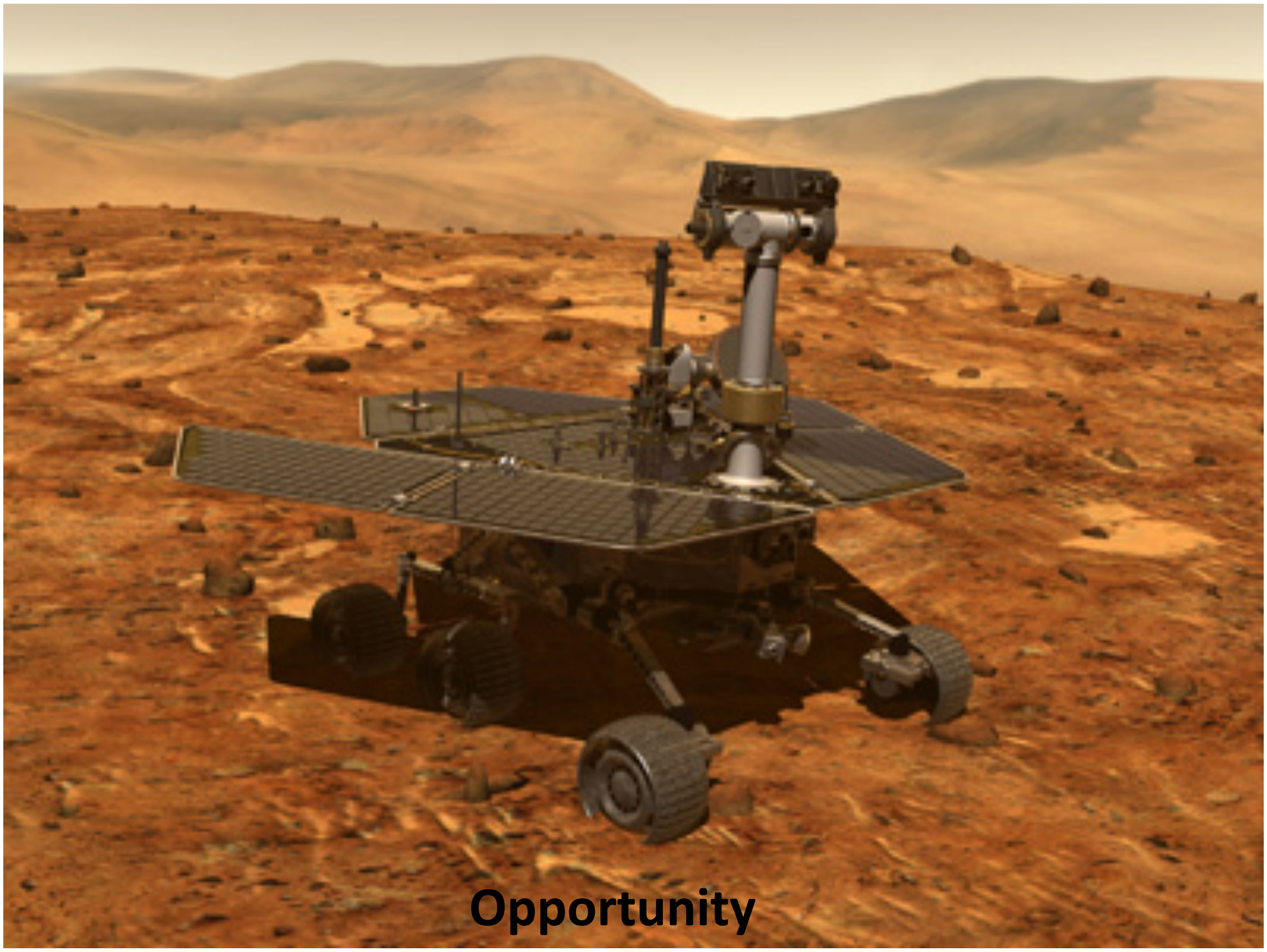

Valles Marinaris is a great place to look for evidence of Liquid Water in the Past.

Slide 30

Viking provided our first view of the Martian surface.



Slide 31

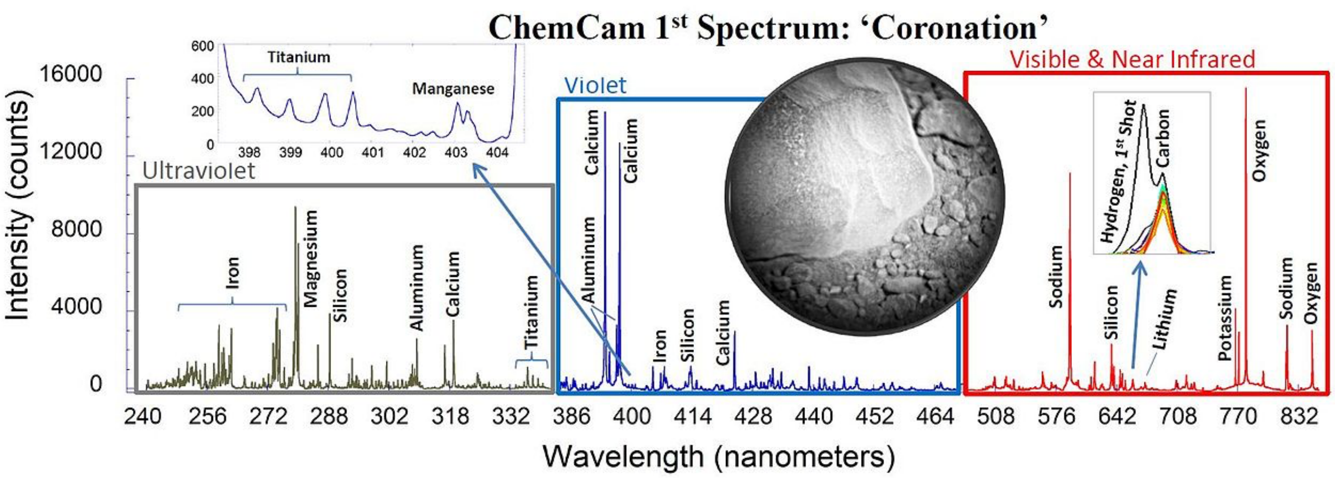


Slide 32

NASA's Mars Rover "Curiosity" launched on Nov. 26, 2011, and landed on Aug. 6, 2012. It carries a complete science lab that has analyzed many samples of the Mars "soil" and sub-surface.

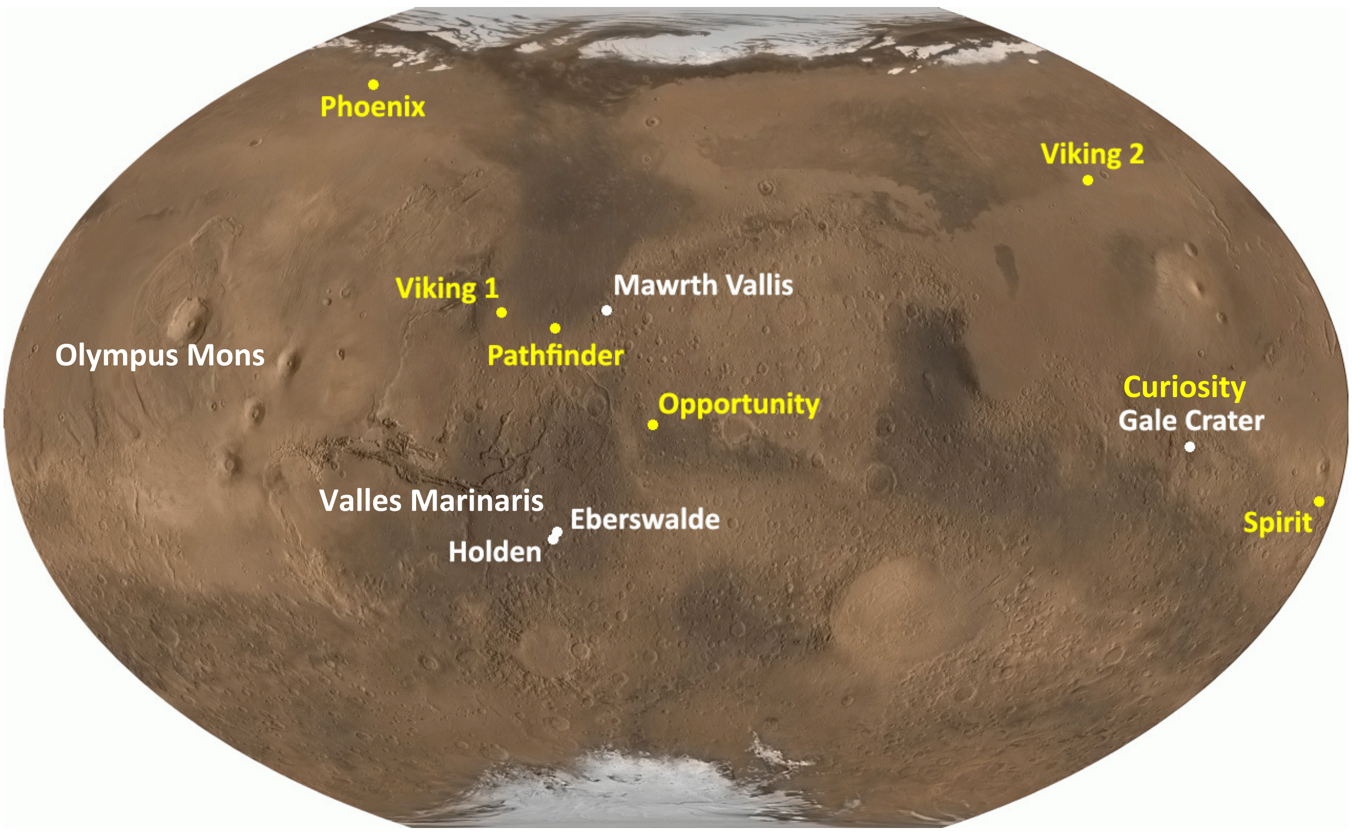
Slide 33

Data from the laser spectrometer (ChemCam) mounted on the mast of *Curiosity*, giving the elemental composition of a Martian rock sample

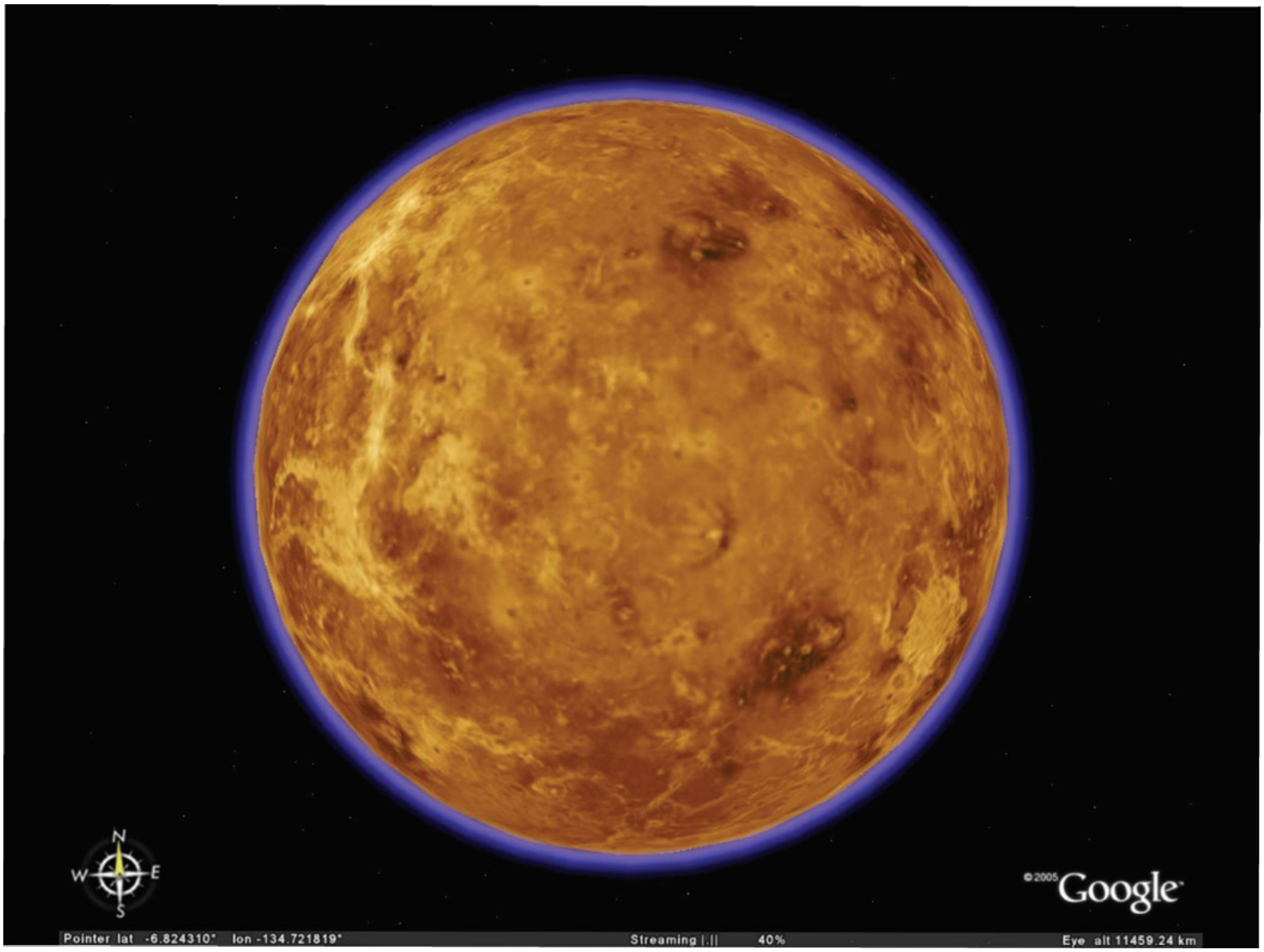


Slide 34

A Global Map of Mars showing the location of NASA Landers



Slide 35

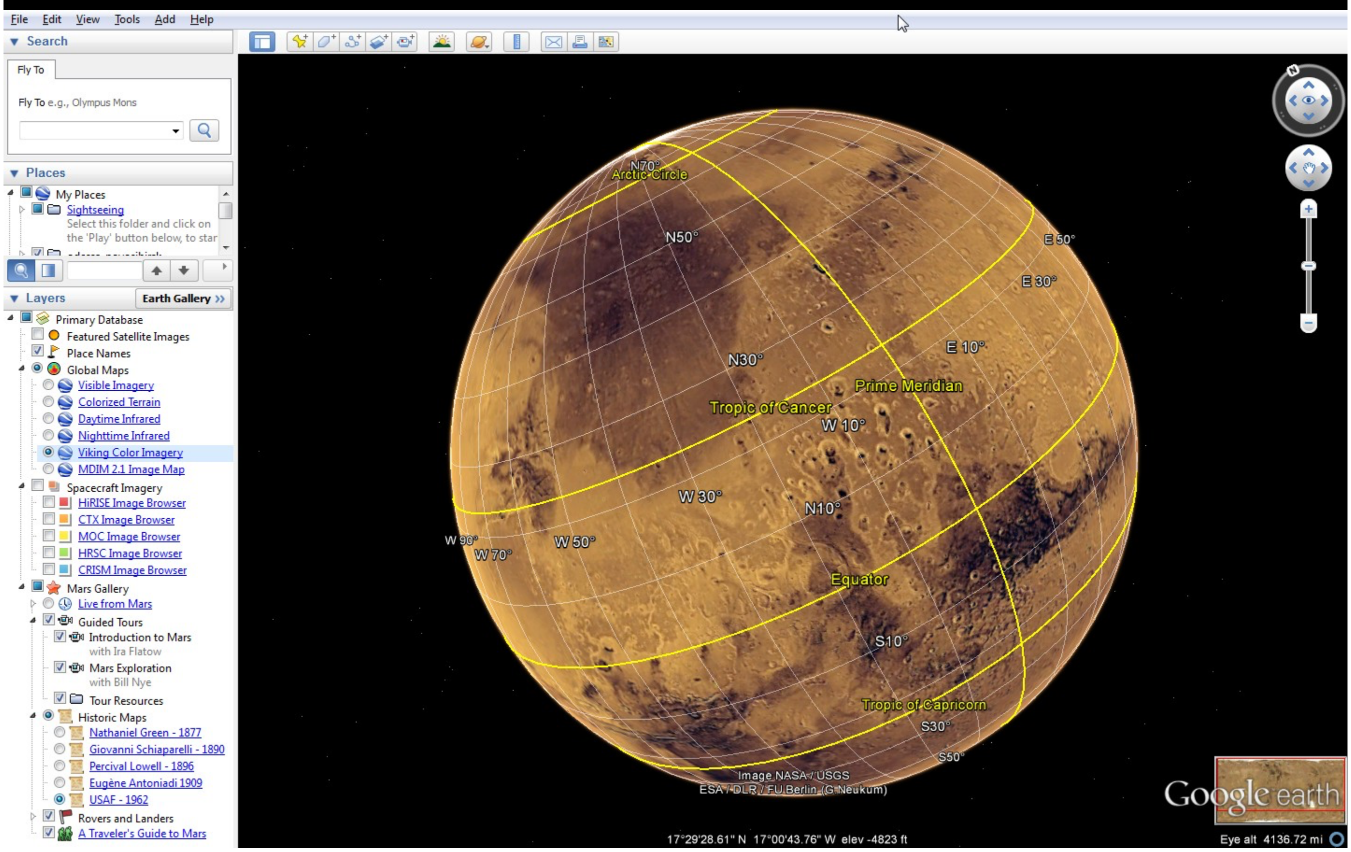

N
W
E
S
©2005 Google
Pointer lat -6.824310° lon -134.721819°
Streaming |.|| 40%
Eye alt 11459.24 km

Slide 36


Explore Google Earth
Image Landsat / Copernicus
US Dept of State Geographer
© 2017 Google
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Google Earth

Slide 37

Google Mars Activity to Explore the Surface of Mars



Slide 38

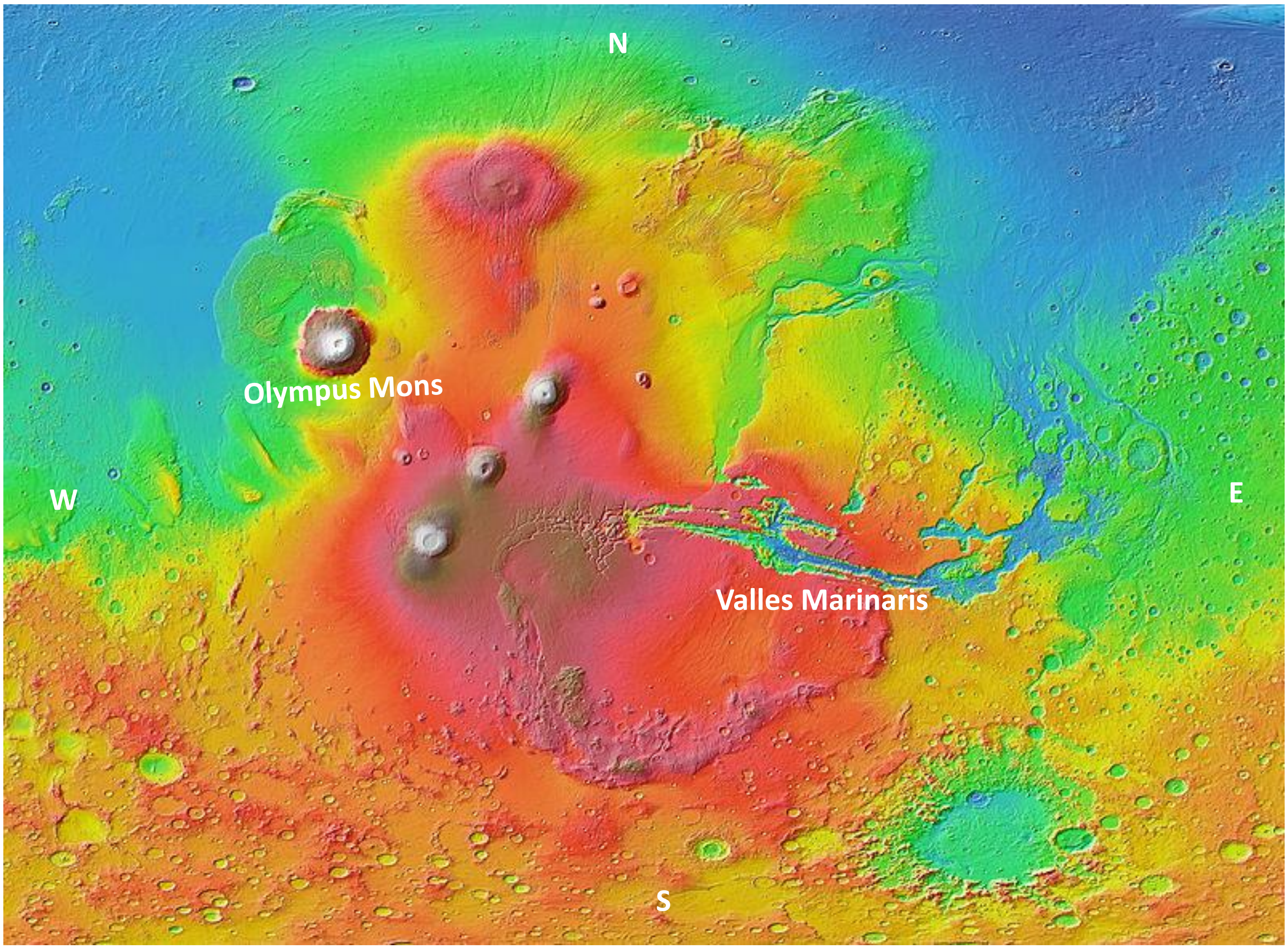
Slide 39


Today, NASA is preparing the *Orion* Mission to Mars, scheduled for the 2030s. Here we see the Delta IV heavy rocket lifting off from Cape Canaveral carrying NASA's *Orion* Mars Exploration Flight Test (EFT) spacecraft for an initial orbital test flight on December 5, 2014.

Slide 40

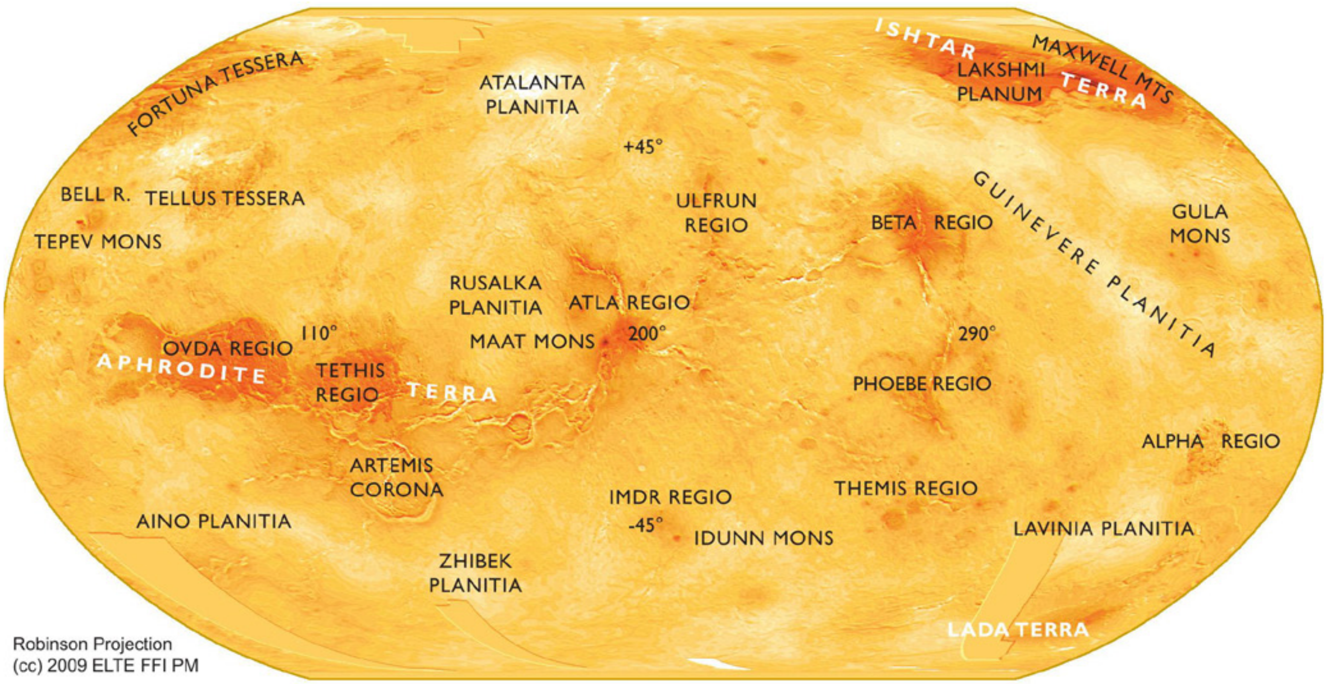
Lesson 2 Slide Presentation:

Mars and Venus Images



SLIDE 1

A Global Map of Venus



Slide 2

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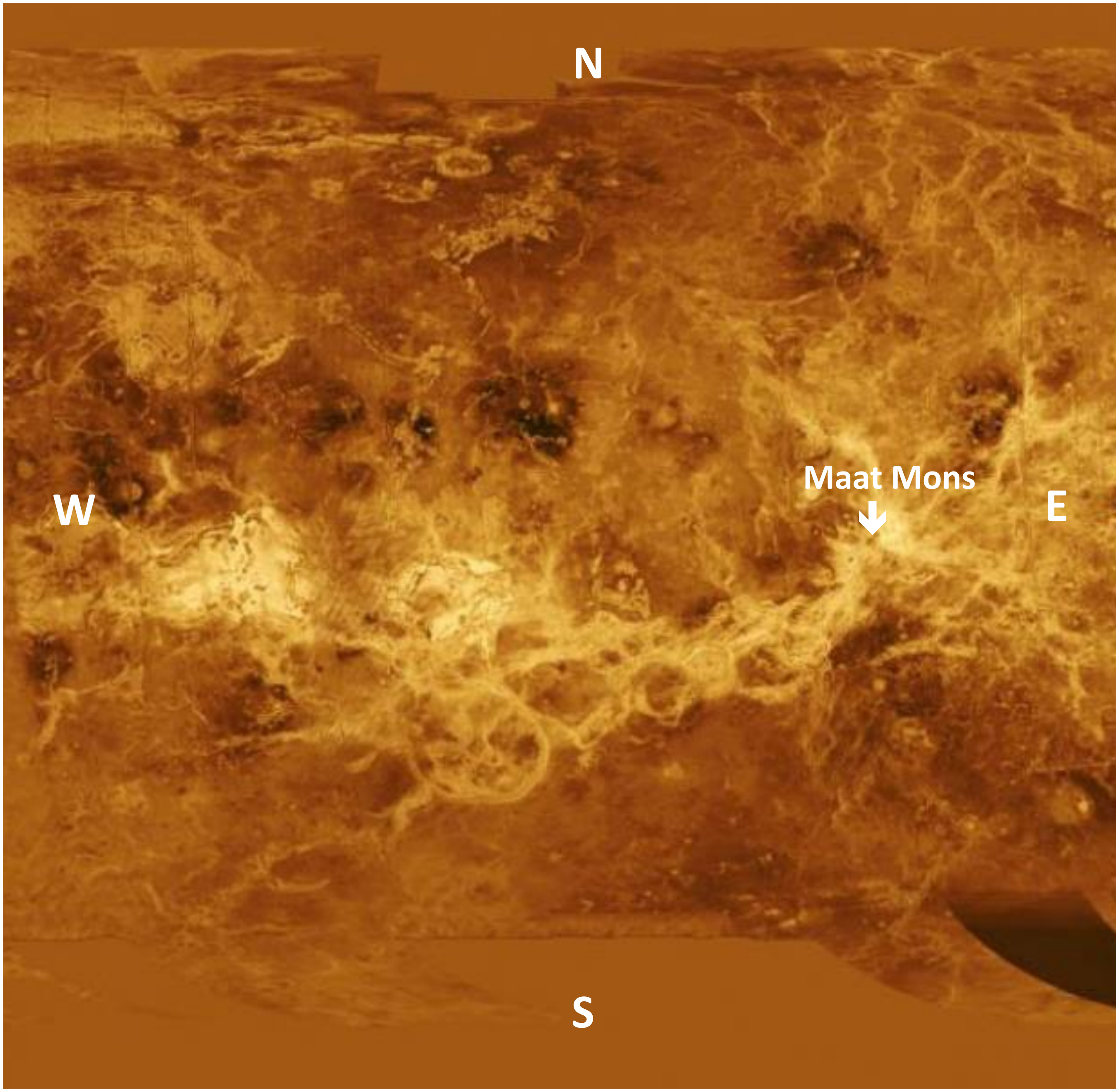


Slide 3

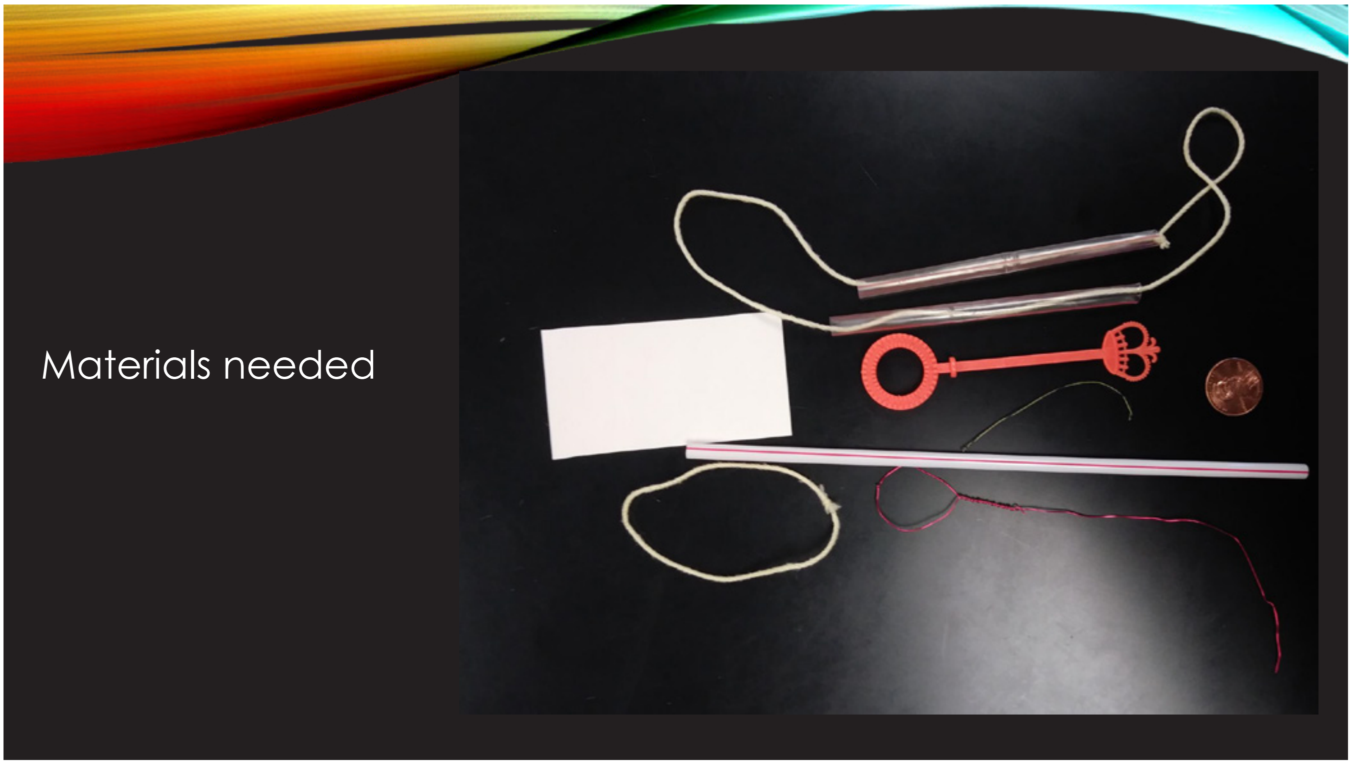
Lesson 4 Slide Presentation:

Mighty Microbes Lab

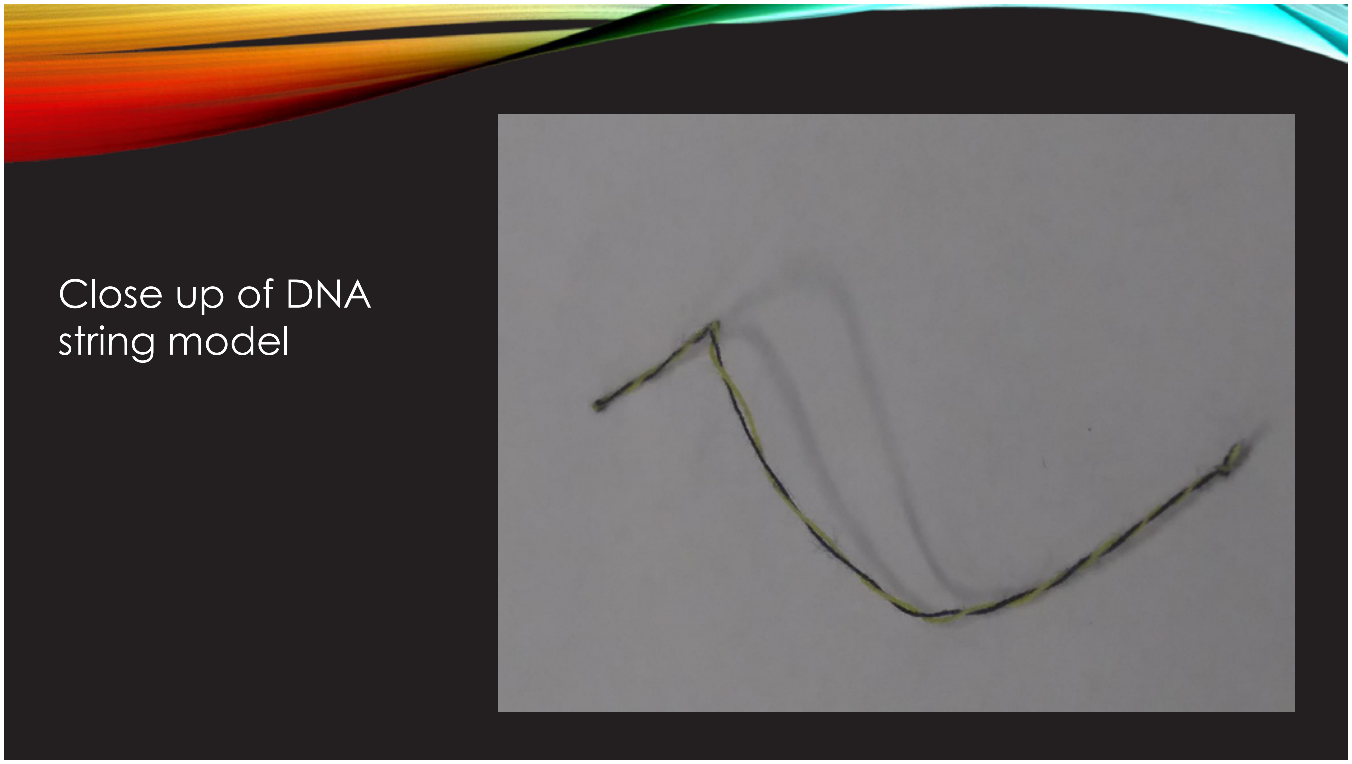
Slide 1

Slide 2

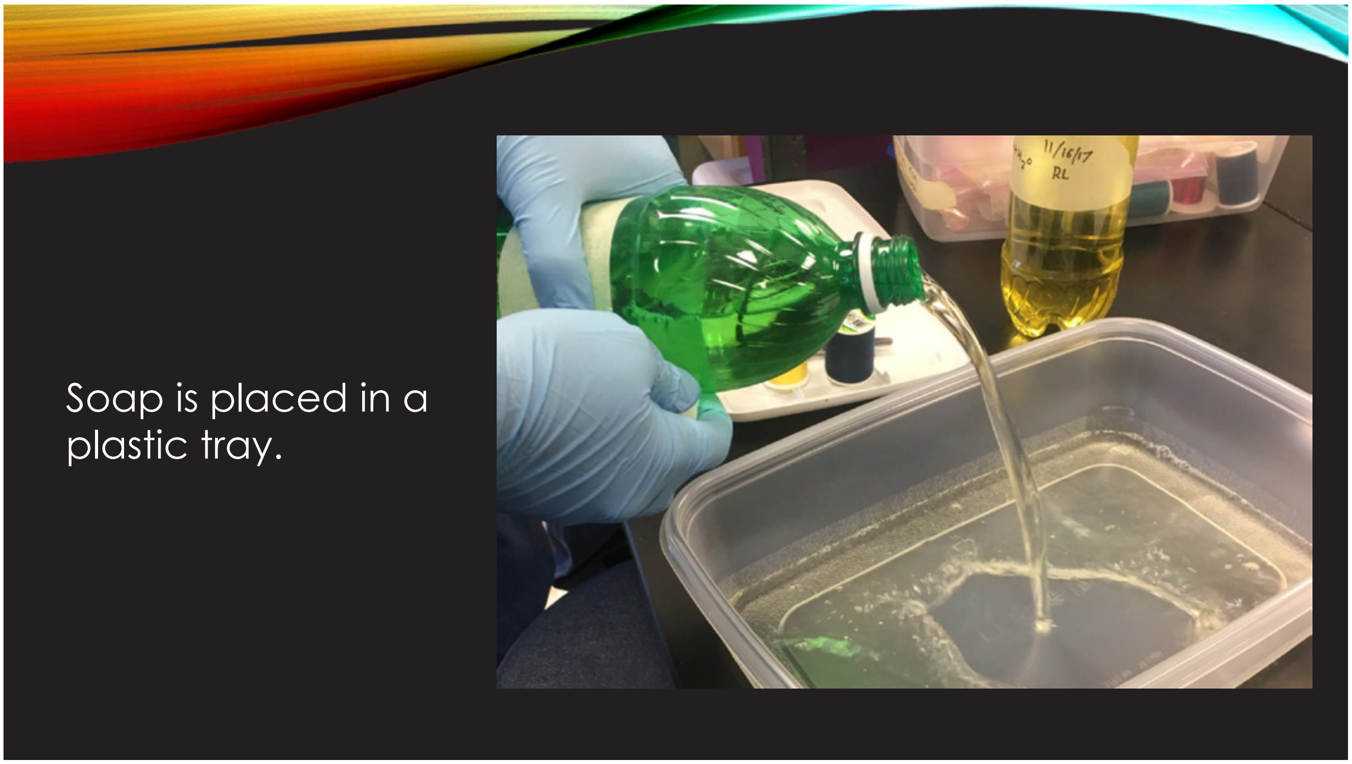
Slide 3



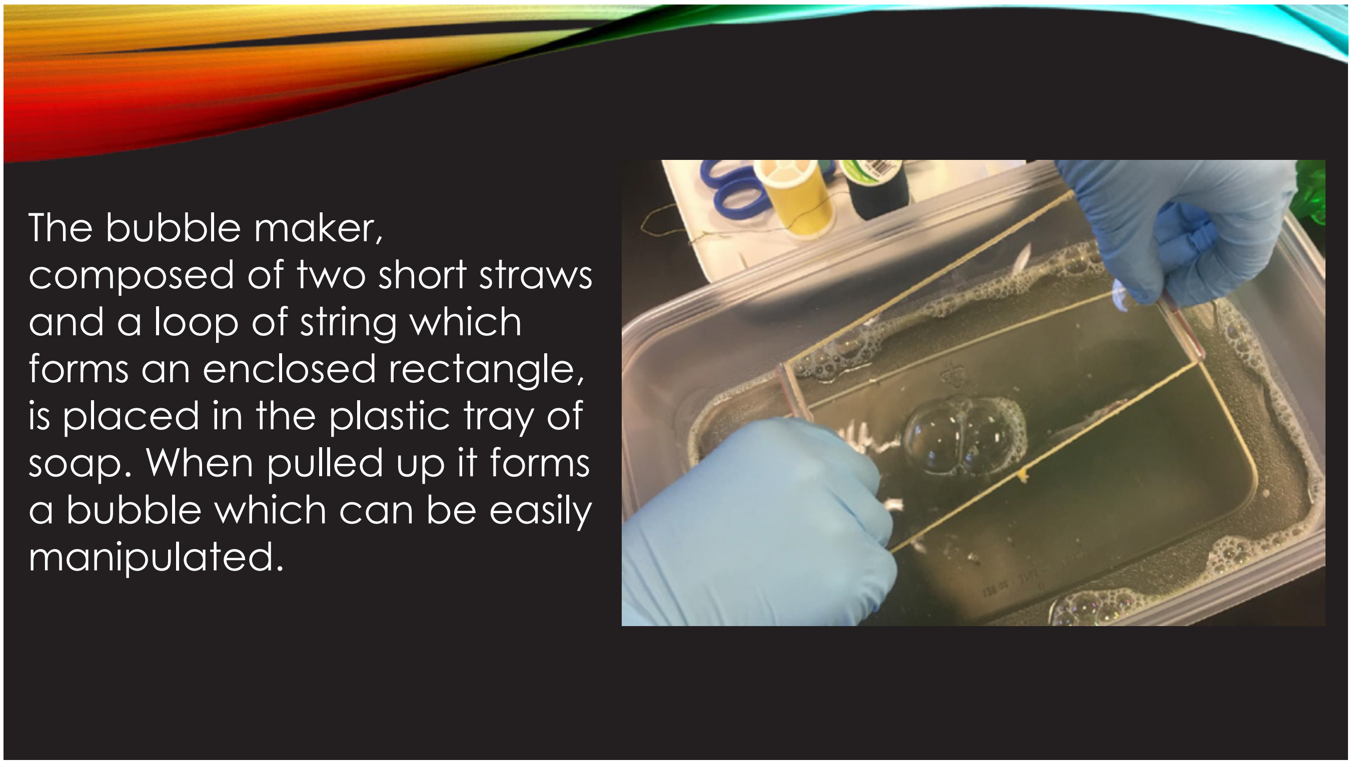
Slide 4



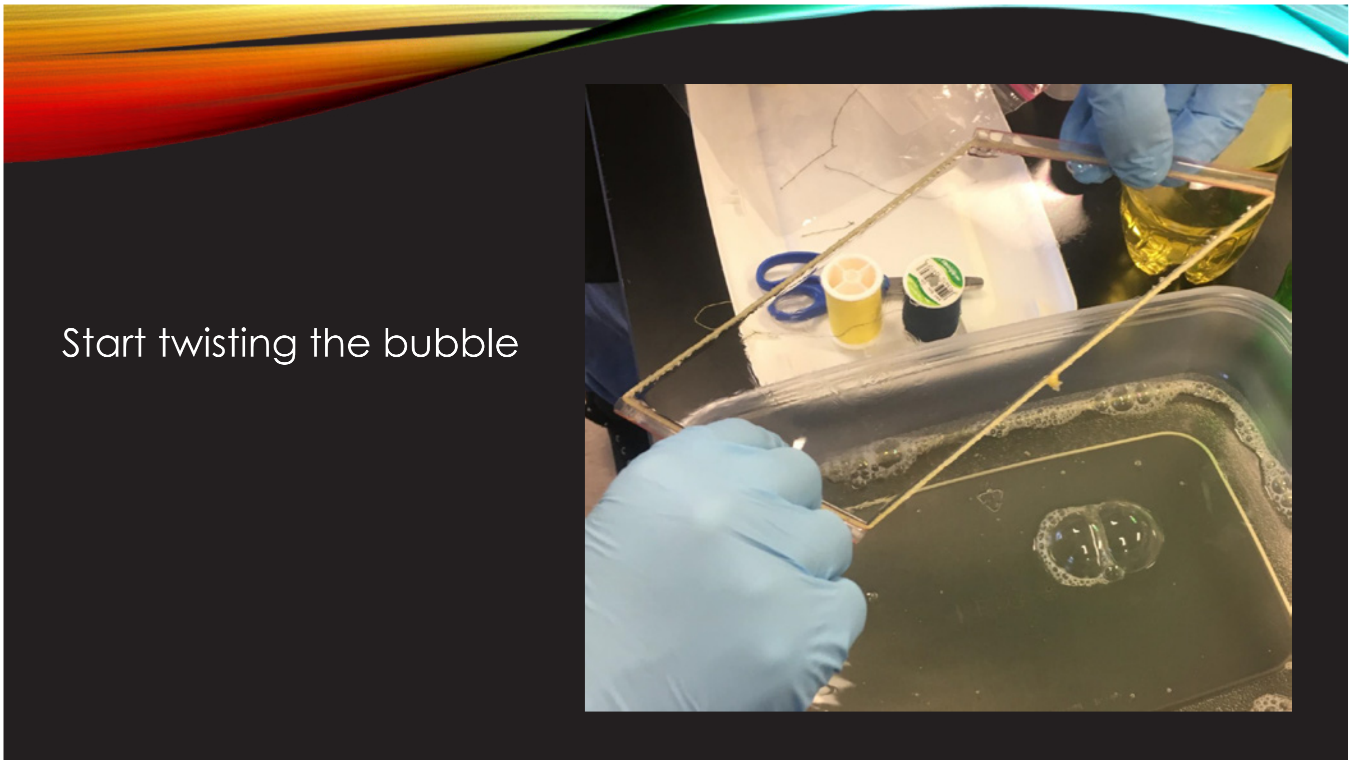
Slide 5



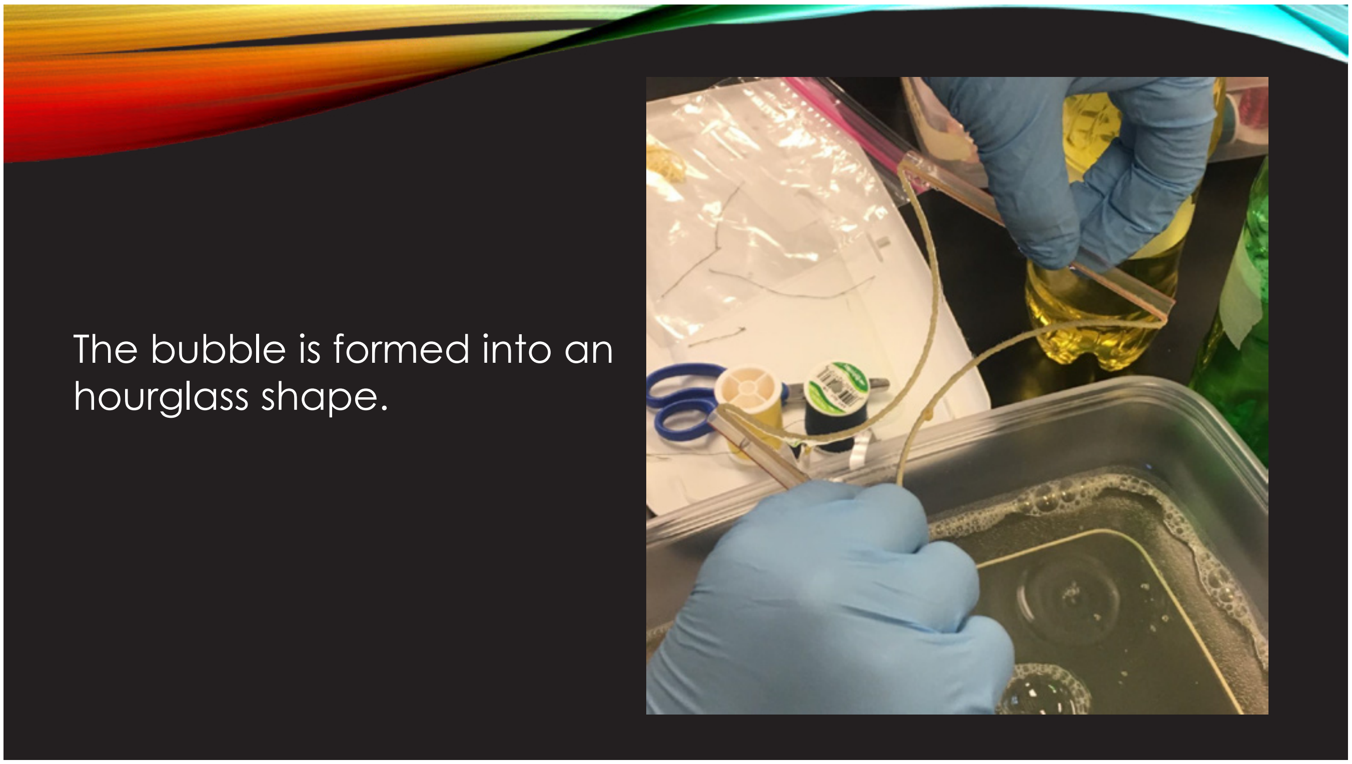
Slide 6


The bubble maker, composed of two short straws and a loop of string which forms an enclosed rectangle, is placed in the plastic tray of soap. When pulled up it forms a bubble which can be easily manipulated.

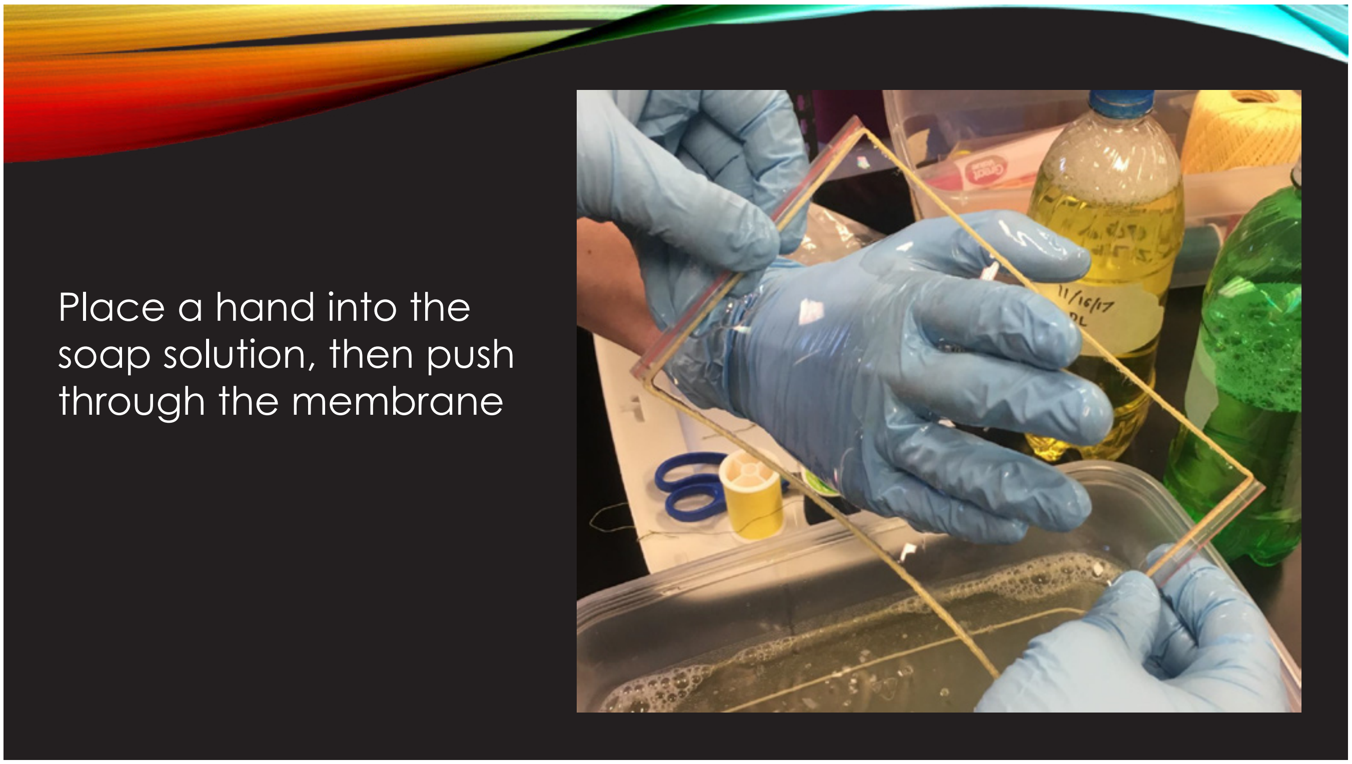
Slide 7



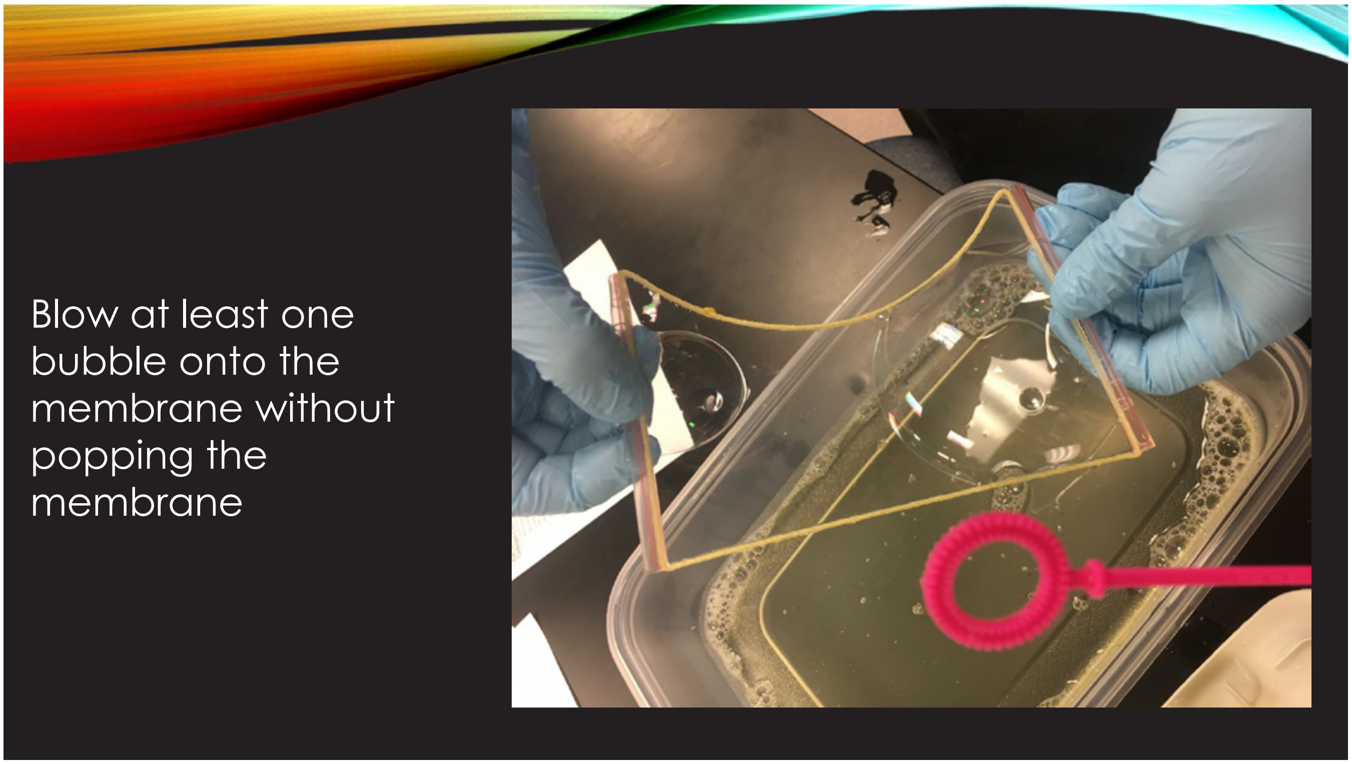
SLIDE 8



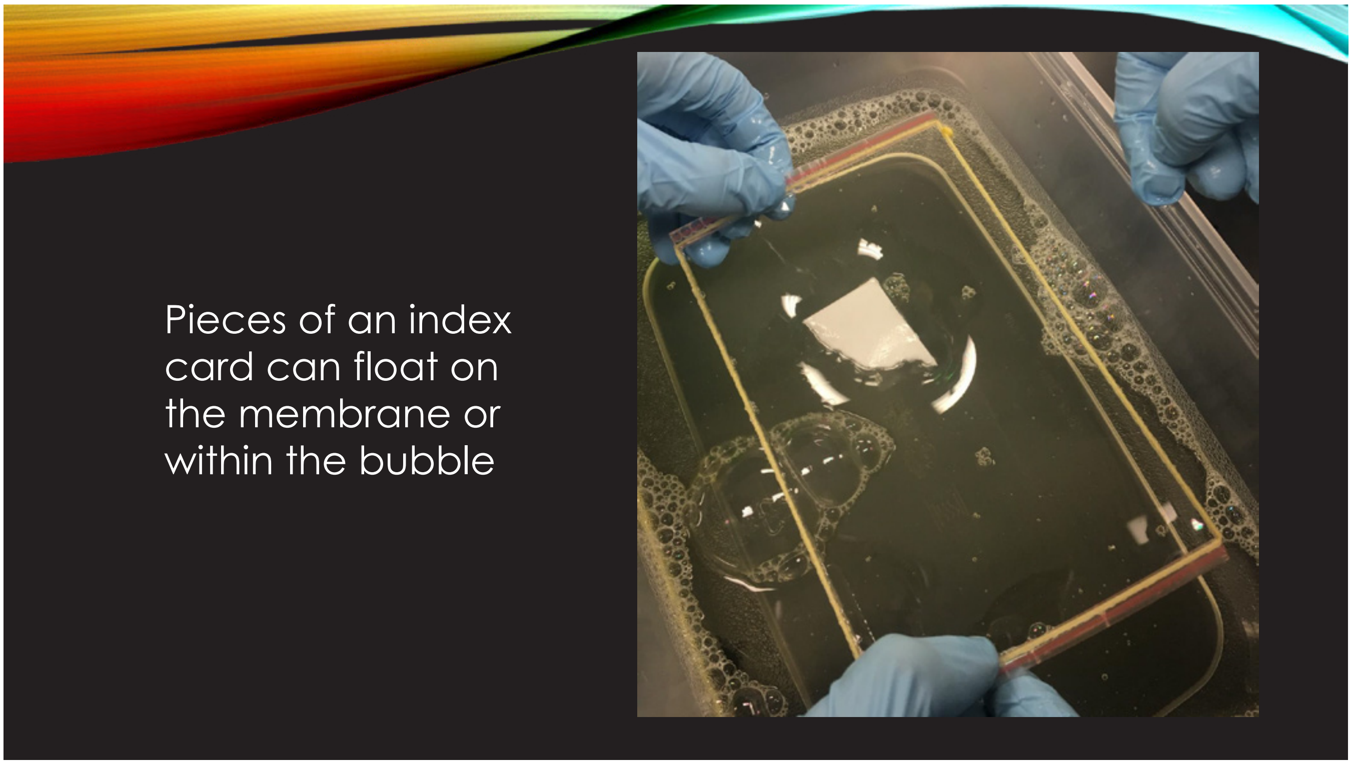
Slide 9


Place a hand into the soap solution, then push through the membrane

Slide 10

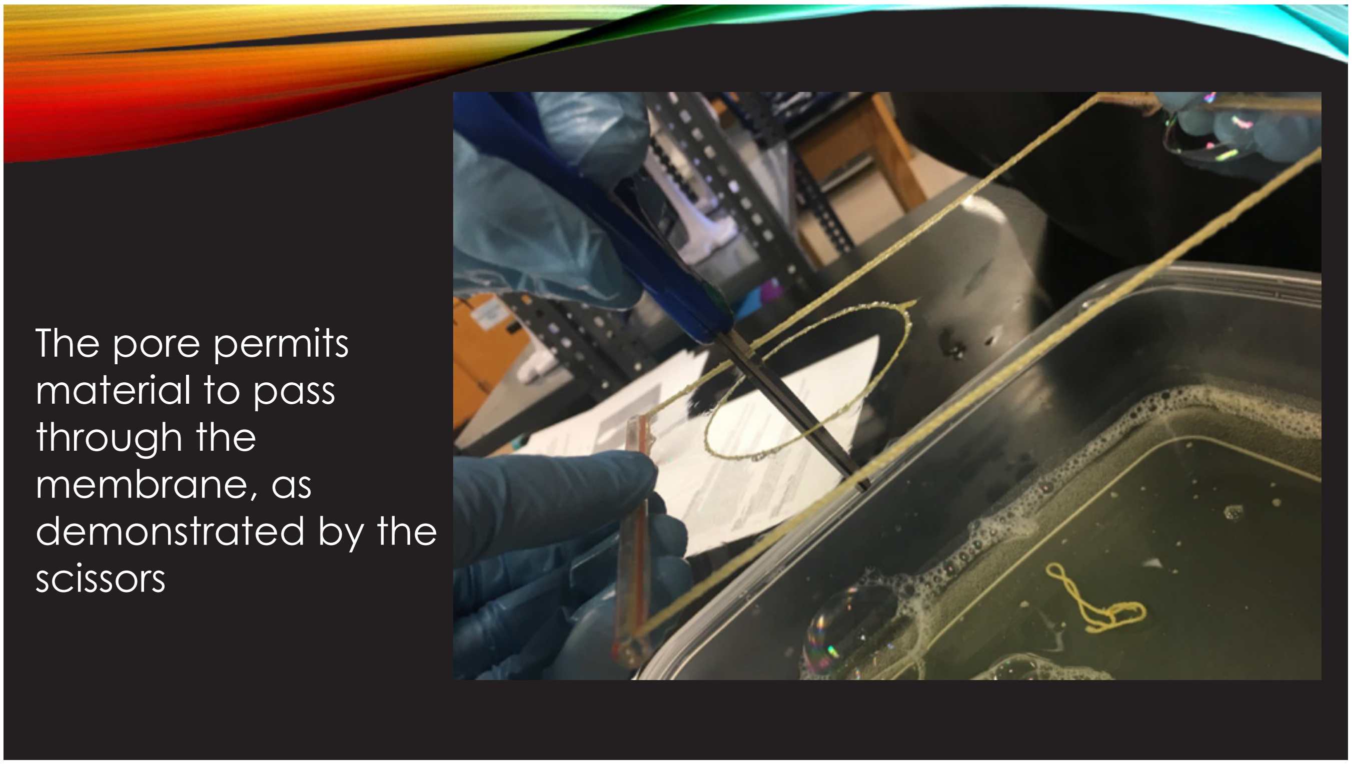

Blow at least one bubble onto the membrane without popping the membrane

Slide 11

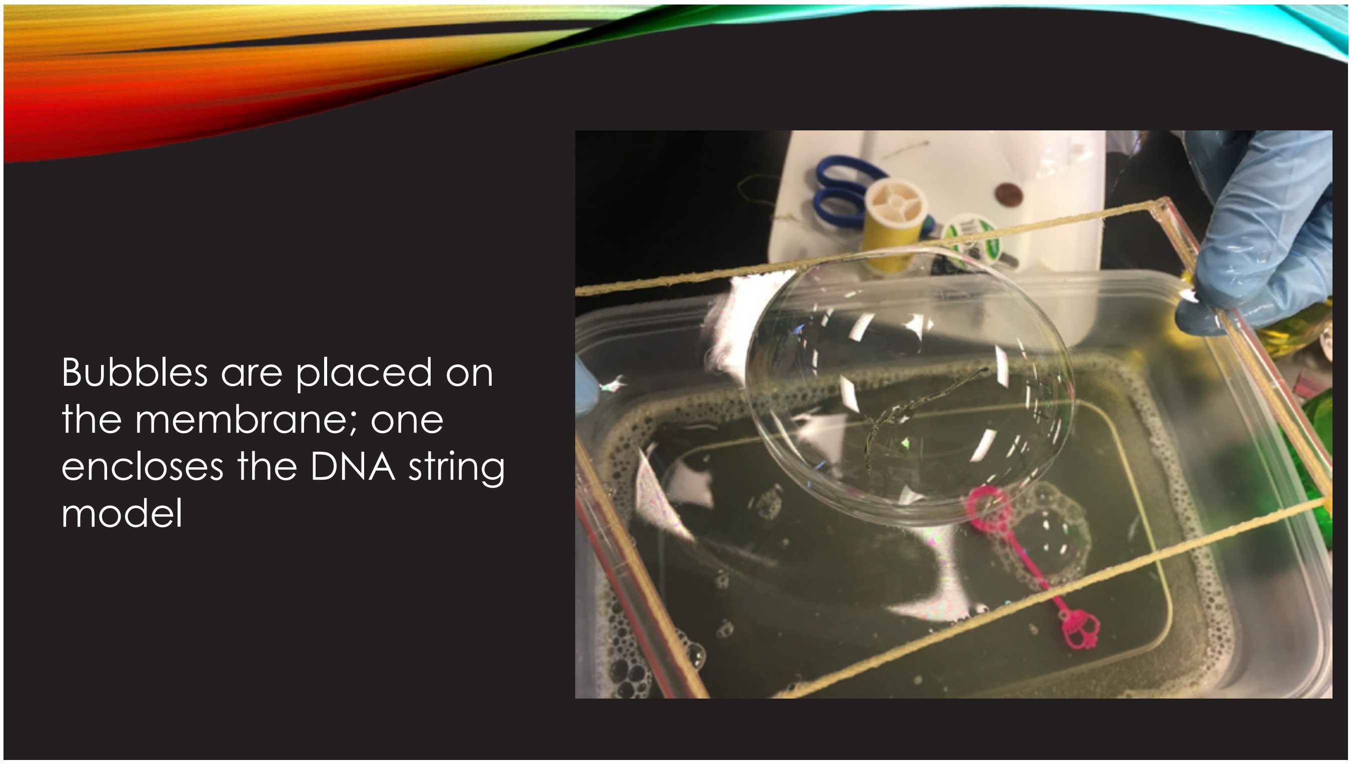

Pieces of an index card can float on the membrane or within the bubble

Slide 12

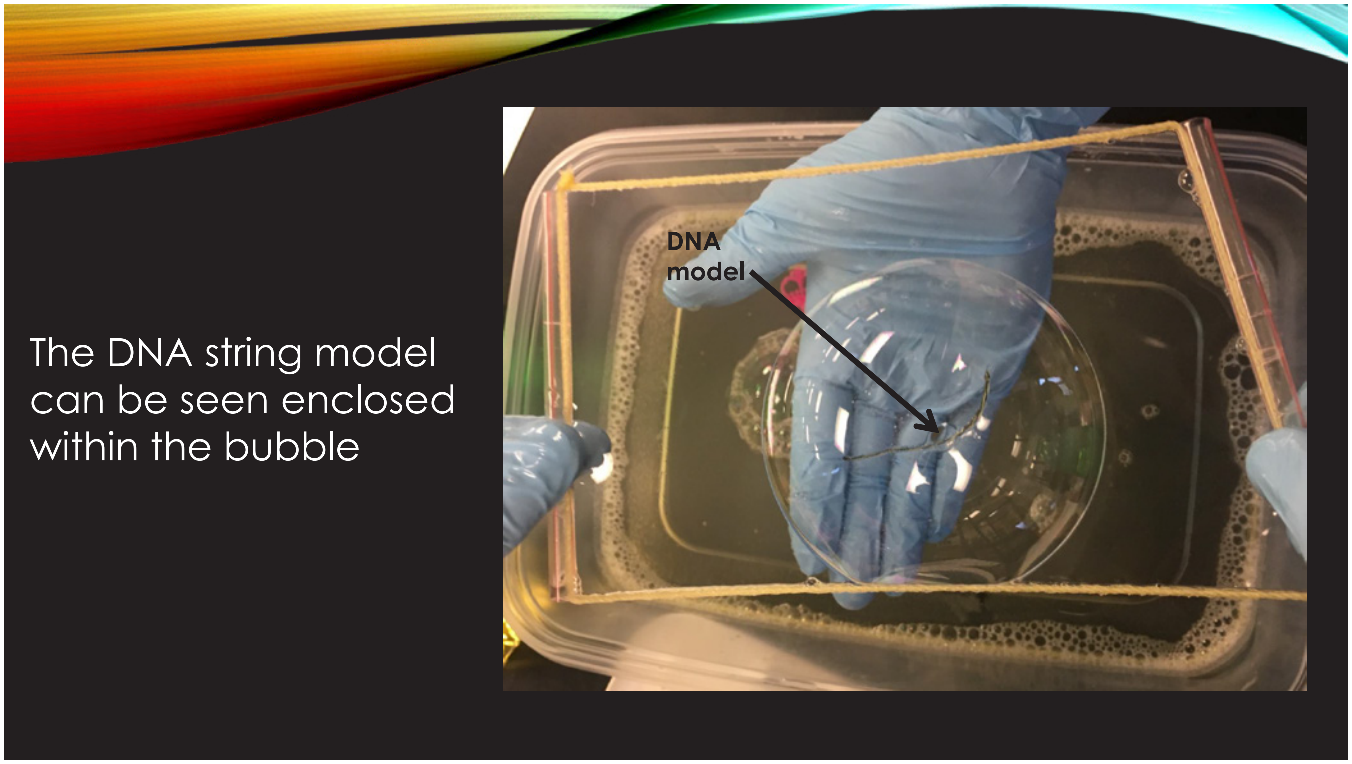
Slide 13


The pore permits material to pass through the membrane, as demonstrated by the scissors

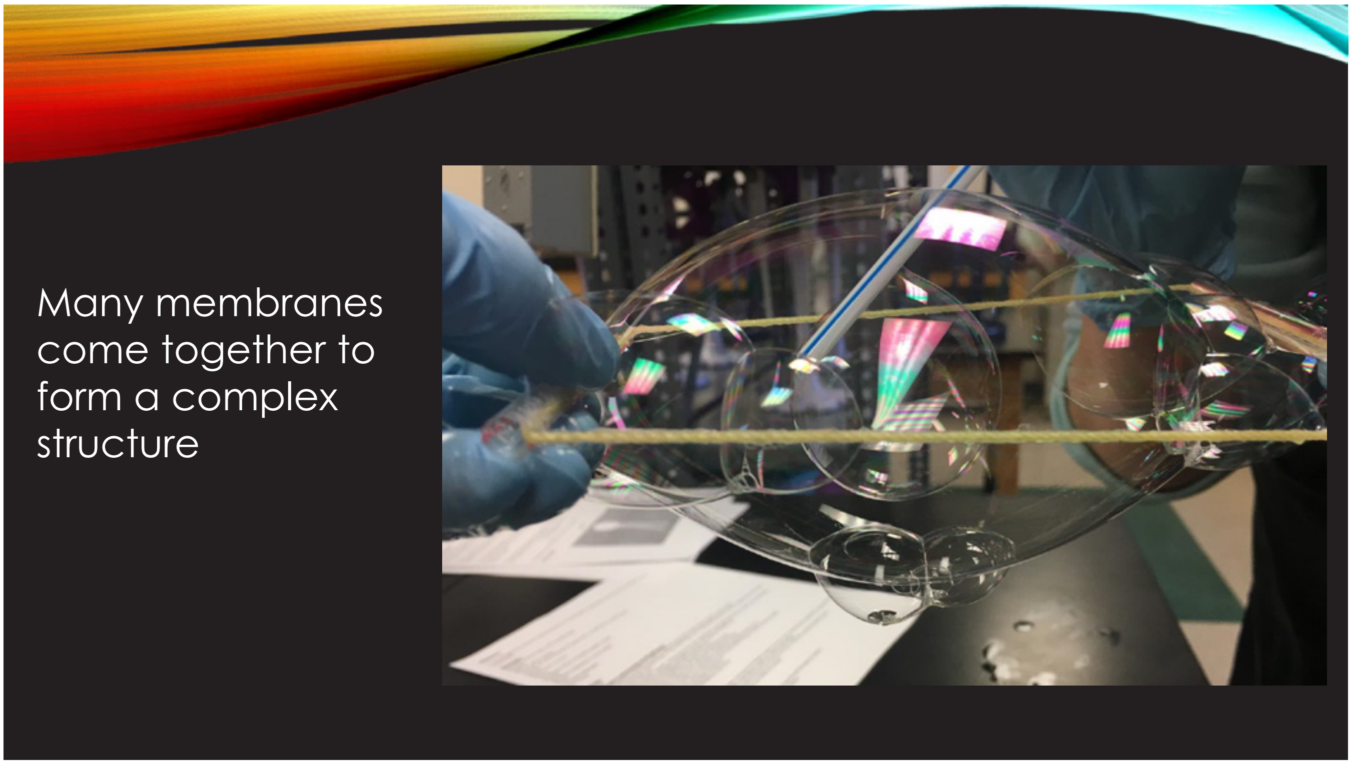
Slide 14


Bubbles are placed on the membrane; one encloses the DNA string model

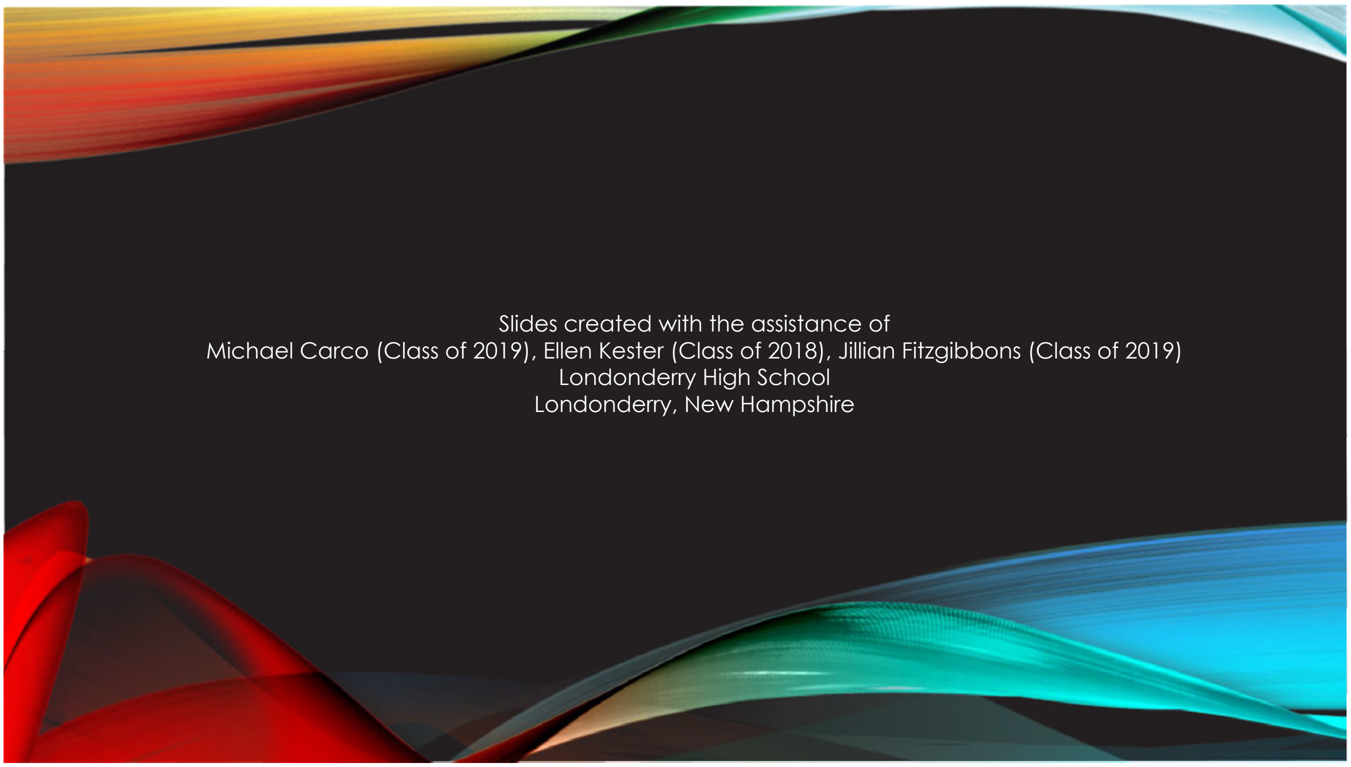
Slide 15


The DNA string model can be seen enclosed within the bubble
DNA model

Slide 16



Slide 17


Slides created with the assistance of
Michael Carco (Class of 2019), Ellen Kester (Class of 2018), Jillian Fitzgibbons (Class of 2019)
Londonderry High School
Londonderry, New Hampshire

Slide 18

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