LESSON 67:
ASTEROID SAMPLE RETURN MISSION (OSIRIS-REX)

An asteroid sample return mission to the asteroid Bennu was launched by NASA on September 8, 2016. This mission is called OSIRIS-REx. The acronym OSIRIS- REx is taken from the Egyptian god, Osiris, and represents a summary of the mission concept and goals. It stands for Origin, Spectral Interpretation, Resource Identification, Security and Regolith Explorer which are explained on the mission's web page. The purpose of the mission is to answer questions central to the origin and destiny of the Solar System. Bennu is a carbon-rich asteroid that may contain molecular records of the origins of life in the Solar System. NASA also monitors Bennu because its orbit crosses Earth's orbit and there is a potential for collision late in the 22nd century. To assess the impact potential NASA needs to understand Bennu's physical and chemical properties better. More accurate information will allow future scientists to develop a plan to avoid a collision with our planet. The details of the OSIRIS-REx mission have been provided by NASA at this address.

Next Generation Science Standards (NGSS):

- Discipline: Earth and Space Sciences.
- Crosscutting Concept: Stability and change.
- Science & Engineering Practice: Constructing explanations and designing solutions.

GRADES K-2

NGSS: Earth's Place in the Universe: Use observations of the sun, moon, and stars to describe patterns that can be predicted.

What is an asteroid? An asteroid is a large solid, rocky, and (usually) irregular object. Asteroids do not have an atmosphere and orbit the Sun. They are too small to be considered planets and are not made up mostly of ice and gases so they are not comets either. Asteroids vary in size from dust particles to objects nearly 600 miles (1000 kilometers) in diameter. There are tens of thousands of asteroids orbiting the Sun in the main asteroid belt between the orbits of Mars and Jupiter. Ceres is the first and largest asteroid discovered (it was reclassified as a dwarf planet in 2006) and has more mass than all the other objects in the asteroid belt put together. Several notable asteroids are shown in this linked image.

GRADES K-2 (CONTINUED)

Some asteroids have orbits that pass close to Earth's orbit and are called near-earth objects. These objects have the potential to collide with Earth; Bennu is one such object. This asteroid is 1650 feet (500 meters) across and is a rare carbon-rich asteroid. A set of radar images for Bennu, first called 2005 WK4, are here.

What else do you know about planets, asteroids, and comets in our Solar System? Currently we know of eight planets and five dwarf planets in our solar system. (Astronomers are exploring the sky for a ninth planet predicted to exist by some scientists but which has not been found—and may not actually be there at all.) The eight planets are larger bodies which have become rounded through gravitational forces and which have cleared their orbits of asteroids through collisions or by altering the asteroids' orbits. Dwarf planet are much smaller bodies which are not as rounded because their gravitational forces are smaller. Most dwarf planets have orbits beyond Neptune in the Kuiper Belt. Can you name all of the planets? Dwarf planets? The planets include four terrestrial planets, two gas giant planets and two icy giant planets. The Kuiper Belt is further from the sun and contains thousands of icy and rocky objects classified as comets. When the orbits of these icy and rocky objects approach the sun, they release gas and dust particles trails and are visible as comets. This visible feature that allows us to identify a comet in contrast to an asteroid. Some notable comets are Halley and Hale-Bopp.

Suggested Activity: Answer and discuss the following questions based on your existing knowledge or by researching some of the linked websites or rereading the lesson information.

- What else do you know about planets, asteroids, and comets in our Solar System?
- Can you name all of the planets?
- Can you name all of the known dwarf planets?

GRADES 3-5

NGSS: Earth's Place in the Universe: Identify evidence from patterns in rock formations and fossils in rock layers to support an explanation for changes in a landscape over time.

While most asteroids orbit the Sun in the region between Mars and Jupiter, some of them have orbits which cross the Earth's orbit as Bennu does. It is important to understand the orbits of these asteroids because of the possibility that they will collide with Earth. What is the distinction between an asteroid and meteoroid? Both are small rocky objects in our Solar

System, but meteoroids are considered to be smaller than asteroids. When one says

GRADES 3-5 (CONTINUED)

"asteroid," one thinks of something that is tens of feet across or larger; when one says "meteoroid," one thinks of something that is less than a foot across. The distinction is not at all sharp and in between those two sizes either word will do.

When a large-enough meteoroid enters the Earth's atmosphere, it gets very hot and glows brightly. A meteoroid that is doing this is called a meteor. If the meteoroid does not burn up and reaches the Earth's surface, it is then called a meteorite. Can you name an asteroid and a meteoroid that collided with Earth in the past? An asteroid collision creating the Chicxulub Crater in Mexico is thought to have caused the mass extinction of life 65 million years ago and recent Chelyabinsk meteorite exploded over Russia. To find information on NASA's monitoring of asteroids (and comets) check out this site.

Can you think of the ways we might learn about our Solar System and answer questions about its origin and destiny? We can observe the planets and stars through telescopes in our backyard or from space, such as Hubble or the James Webb Telescope. We can send spacecraft to the Earth's moon (Lunar Missions), the planets (Voyager 2) and nearby objects. We also learn about our Solar System by collecting samples and returning them to Earth for scientific study. Stardust was a sample return mission to a comet to collect extraterrestrial material; Hayabusa returned a minute sample from an asteroid and Hayabusa 2 is currently orbiting another asteroid with an eye to returning samples from it. Another way we get free samples is collecting meteorites after they hit the Earth. The sample return mission to Bennu is a next step in learning about our Solar System.

Suggested Activity: Answer and discuss the following questions based on your existing knowledge or by researching some of the linked websites or rereading the lesson information.

- What else do you know about planets, asteroids, and comets in our Solar System?
- What is the distinction between an asteroid and meteoroid?
- Can you think of the ways we might learn about our Solar System and answer questions about its origin and destiny?

GRADES 6-8

NGSS: Earth's Place in the Universe: Analyze and interpret data to determine scale properties of objects in the solar system.

GRADES 6-8 (CONTINUED)

How was the Solar System formed? What is the inside of an asteroid like? How does the formation of Bennu relate to the formation of the Solar System? What will happen to the Solar System in the distant future? Will Bennu collide with the Earth two hundred years from now? The OSIRIS-REx mission was designed to help answer these and other questions. You can see how it addresses these questions by exploring NASA's web pages on the OSIRIS - REx mission. A You-Tube movie explains the mission of OSIRIS-REx which launched September 8, 2016 on its trip to Bennu and will return September 2023.

You have probably heard something about our robotic missions to Mars and you probably know about the astronauts that went to the Moon. However, do you know why we chose these missions and why we would want to go to an asteroid? The ways we can learn about the origin and destiny of the Solar System is by studying the objects that make it up. The way we do this is by visual or telescopic observations (optical, infrared, radio, ultraviolet, adaptive optics, radar and spectroscopy), space missions (fly-bys, orbiters, landers, rovers, and sample return) and from samples (meteorites and returned samples).

Until the last century, the only means was normal visual observations, optical telescopes and meteorite sample. All of the planets in our solar system are visible from Earth with the unaided human eye except for Uranus and Nepture which are the farthest from the Sun. The dwarf planet, Ceres is in the asteroid belt and the other dwarf planets, Pluto, Eris, Haumea, and Makemake, are in the Kuiper Belt outside the orbit of Neptune. The planets are visible because of the light they reflect from the sun. The farther a planet is from the sun, the less light shines on it per unit surface area to reflect, making the planet more difficult to see. Other factors which affect the visibility of planet are its size—a smaller planet has less surface to reflect the Sun's light—and the reflectivity of the planet's surface. Increasing distance from the Earth also makes it more difficult to see a planet and also to see the features on its surface. The scattering of light in our atmosphere makes it more difficult to make out the planet's surface.

The telescopes which have been placed in Earth's orbit by NASA avoid the scattering of light in the atmosphere and allow us to see dimmer objects. Telescope on Earth now have adaptive optics, which actually bend the shape of the mirror slightly, to compensate for the scattering of light as well. We have also learn to observe in region of the light spectrum other than visible light. All of this has allowed us to discover much more about our Solar System and find asteroids such as Bennu.

GRADES 6-8 (CONTINUED)

Bennu is a near-earth asteroid discovered in 1999, which is rich in carbon compounds thought to be the building blocks of our solar system. It may also contain clay mineral formed from rocks in the presents of water. Scientists have studied Bennu in the visible and infrared light spectrum and with radar. Bennu's orbit crosses the Earth's orbit and it may hit the earth at some point in a series of eight passes around the Sun between the years 2175 and 2196. Because of uncertainties in predicting the motion of asteroids that far into the future, scientists do not know for certain whether or not it will actually hit the Earth. Right now they give it a probability of 0.037% (one chance in 2,700) of hitting the Earth; because it is so big (1,600 feet in diameter), though, an impact would be very destructive. People would like to make sure of it so that if it is definitely predicted to hit the Earth we can move it out of the way. Making sure depends on knowing Bennu's physical properties. Bennu was selected from over 500,000 known asteroids for the OSIRIS-REx mission because of its near-Earth orbit and the energy required to reach its orbit, because of the need to understand its physical properties better, and because its carbon material is from the early solar system and may include volatile molecules, organic compounds and amino acids.

~~Suggested Activity~~: Answer and discuss the following questions based on your existing knowledge or by researching some of the linked websites or rereading the lesson information.

- What else do you know about planets, asteroids, and comets in our Solar System?
- Do you know how old or how big the Universe is?
- Have you seen the Milky Way galaxy in the night sky?
- Do you know what the objectives of the OSIRIS-REx mission is and how the asteroid Bennu will help with the answers to question of our existence?
- Do you know why we chose these missions and why we would want to go to an asteroid?

GRADES 9-12

NGSS: Earth's Place in the Universe: Use mathematical or computational representations to predict the motion of orbiting objects in the solar system.

An asteroid sample return mission to the asteroid, Bennu, was launched by NASA on

September 8, 2016. The purpose of the mission is to answer questions central to the existence of the Solar System—its origin and destiny. More immediately, it is also

GRADES 9-12 (CONTINUED)

designed to answer questions about Bennu's mass and composition and the forces acting on it—not just the force of gravity, but also the Yarkovsky force caused by the light from the Sun. To this end, the spacecraft was designed to do many things: map the asteroid, document various sample sites, document a specific selected site in more detail, collect and return a sample of the asteroid's surface material (called "regolith"), and measure the asteroid's orbital deviation due to sunlight and the emission of heat from the asteroid. After the data are collected scientists will compare the results to what we know from our ground-based observations. The specific missions are described in detail on the Osiris-REx mission page.

The mission was launched from Cape Canaveral, Florida, on September 8, 2016 and is planned to return seven years later in September 2023. From 2023 to 2025, scientists will analyze part of the returned sample; most of the sample, 75 percent, will be preserved for future scientists to analyze. The spacecraft was launched on an Atlas V 411 rocket. The space craft was accelerated by the Atlas rocket to a hyperbolic escape velocity of 5.4 km/sec (>12,000 mph) in order to go into orbit around the Sun. Additional maneuvers were performed in deep space to change the speed by 0.52 km/sec (1,163 mph). After a year in solar orbit, the spacecraft performed a flyby of Earth to use the Earth's gravitational field to increase its speed and orbital inclination for the rendezvous with Bennu.

The approach to Bennu begins two million miles from Bennu in August 2018 at which point it will begin to match Bennu's orbital speed and direction. Bennu's speed is 63,000 mph, so OSIRIS-REx will have to brake by 0.53 km/s (1,186) resulting in an approach velocity of 20 cm/sec (~0.45 mph). Once the spacecraft is flying in formation with Bennu, OSIRIS-REx will begin the survey and mapping of Bennu. The Preliminary Survey will look for plumes and satelites and measure its non-gravitational acceleration from the Yarkovsky effect. The spacecraft navigation will switch modes to use images of Bennu's surface and then conduct detailed surveys to obtain global spectral, thermal and geological properties. Next the spacecraft will complete high resolution mapping to determine the site on Bennu's surface from which to take a sample.

There are five instruments on the spacecraft to obtain data. There are three cameras on the spacecraft. The cameras will acquire the asteroid (determine exactly where it is relative to the spacecraft); provide the global mapping, high resolution images, color maps looking for plumes from outgassing; and document the sample acquisition event and the touch and go (TAG) maneuver. Light detection and ranging (LIDAR) will be used to measure the distance

GRADES 9-12 (CONTINUED)

to Bennu and provide high-definition topographical maps. A thermal emission spectrometer will collect infrared spectral data to determine the mineral and temperature information for Bennu. The heat energy emitted (measured by the temperature) will provide information on the surface physical properties and composition for the global maps and sample-site areas. An additional visible and infrared spectrometer will measure the visible light and infrared light.

The wavelength of the light received from Bennu will provide chemical information based on the unique spectral signature. This will identify the mineral and organic material globally and at the sample sites; minerals can be identified by their unique infrared spectral signatures. A third spectrometer will operate in the X-ray range will identify the chemical elements present on Bennu. This spectrometer takes advantage of solar X-rays and solar wind interaction with the material on Bennu's surface. The solar x-rays are absorbed by the atoms and re-emitted with energy characteristic of the element (called "fluorescence"). This imaging spectrometer or telescope records the fluorescence line emissions to identify the different elements.

In July 2020 after selecting the sample site, the spacecraft will position itself over it. The spacecraft will perform a Touch-And-Go (TAG) maneuver at a velocity of 10 cm/sec (0.22 mph) using the sampler head on an articulated arm. When the sampler head presses against the surface (for a total of five seconds), a burst of nitrogen gas will stir up the loose surface regolith—at least 60 grams and up to two kilograms—and direct it into the sampler chamber. The sample will be placed in the Sample Return Capsule (SRC) for the return to Earth. The SRC design is based on that of the Stardust mission which was a sample return mission to Comet Wild 2 in 2006.

The spacecraft will leave Bennu in March 2021 with a speed of 0.32 km per sec (716 mph) to intersect Earth's orbit in September 2023. Four hours before reaching the Earth's atmosphere, the spacecraft will jettison the SRC on a trajectory toward Earth. The spacecraft will perform a deflection maneuver of 17.5 m/sec (39 mph) to place it in a stable orbit around the Sun. The SRC will enter the Earth's atmosphere at 12.4 Km/s (27,738 mph). An aeroshell with a heat shield will protect the sample and remove 99% of the kinetic energy. At an altitude of 33.5 km (20.8 miles), the drogue chute (small parachute) will deploy and at 3 km (1.9 miles) the main parachute will slow the capsule for a soft landing in the Utah desert on September 24, 2023.

GRADES 9-12 (CONTINUED)

Back on Earth the sample material will be analyzed to determine its chemical composition. Among other things, scientists will look for organic compounds like amino acids and sugar which are the building blocks of life.

In addition to its primary mission, OSIRIS-REx is taking images of the asteroid Victoria, star fields in the Taurus and Orion constellations, and Jupiter and its moons. The star tracker on OSIRIS-REx can use the stars for navigation as early sailors did. Other images, videos and collectables are available on the web page showing details of the spacecraft design, its instrumentation, mission details, phases of the spacecraft assembly, launch into space, the trajectory, Bennu's journey, and asteroid fact sheets.

Suggested Activity: Answer and discuss the following questions based on your existing knowledge or by researching some of the linked websites or rereading the lesson information.

- What else do you know about planets, asteroids, and comets in our Solar System?
- What is the velocity that the OSIRIS-REx must reach in order to escape the Earth's gravitational force?
- How does this velocity differ from the orbital velocity of a geosynchonous satellite of earth?
- What is the difference between a geostationary and a geosynchronous satellite? OSIRIS-REx will go into orbit around the sun. What is Earth's orbital velocity around the Sun?
- On OSIRIS-REx's mission, what is the total distance traveled to Bennu and back (include the distance while the spacecraft is traveling in formation with Bennu)?

Sixty Years Ago in the Space Race:

August 1, 1958: The Hardtack Teak test involved a Redstone rocket launching a hydrogen bomb to an altitude of 48 miles where it detonated. The fireball could be seen from Hawaii for a half hour.

August 12, 1958: The Hardtack Orange test saw a Redstone rocket launching another hydrogen bomb to an altitude of 27 miles where it detonated.