National Aeronautics and Space Administration

OSIRIS-REx

ASTEROID SAMPLE RETURN MISSION

PRESS KIT

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www.nasa.gov

TABLE OF CONTENTS

INTRODUCTION

NASA's OSIRIS-REx (Origins, Spectral Interpretation, Resource Identification and Security – Regolith Explorer), the first U.S. mission to collect a sample from an asteroid, will return to Earth on Sept. 24, 2023, with material from asteroid Bennu. Upon arrival, the OSIRIS-REx spacecraft will release the sample return capsule for a landing in the Utah desert. The pristine material from Bennu – rocks and dust collected from the asteroid's surface in 2020 – will offer generations of scientists a window into the time when the Sun and planets were forming about 4.5 billion years ago.

This press kit contains information the media will need to cover NASA's OSIRIS-REx asteroid sample return mission.

10 Things to Know About OSIRIS-REx Asteroid Sample Return

1 OSIRIS-REx will deliver the largest asteroid sample ever received on Earth, estimated to hold about half a pound of Bennu's material or 8.8 ounces +/- 3.6 ounces (250 grams +/- 101 grams).

2 OSIRIS-REx's sample return capsule will touch down in the Utah western desert on Sept. 24 at 8:55 a.m. MDT (10:55 a.m. EDT/9:55 a.m. CDT). It will land within a 37-mile by 9-mile ellipse (58 km by 14 km) within Department of Defense property at the Utah Test and Training Range and Dugway Proving Grounds.

3 On Sept. 25, the day after the sample lands in Utah, the sample will be transported to NASA's Johnson Space Center. Over the next two years, the science and curation teams will catalog the sample and conduct the analysis needed to meet the mission's science goals. Approximately six months after return, a sample catalog will be released, and samples from Bennu will also be made available for research by scientists around the world for decades to come.

Animation credit: NASA

4 NASA's Johnson Space Center curation lab will distribute portions of asteroid Bennu sample to a sample analysis team of more than 200 members from more than 35 globally distributed institutions.

5 The OSIRIS-REx sample will be distributed as follows:

• The team will have access to about 25% of the returned sample to achieve the mission's science goals.

• 4% of the total returned sample will be delivered to the CSA (the Canadian Space Agency), which contributed the OSIRIS-REx Laser Altimeter (OLA) instrument aboard the spacecraft, and which supports the Canadian co-investigators on the OSIRIS-REx science team.

• 0.5% of the total returned sample will be delivered to JAXA (Japan Aerospace Exploration Agency) as part of a partnership between the two space agencies that includes NASA support for the Hayabusa2 mission and the exchange of scientists and samples between the two missions.

• A portion of the Johnson-curated material will be sent to a secure backup facility in White Sands, New Mexico, similar to the procedure followed for the Apollo Moon rocks.

• The remainder of the sample will be publicly available for analysis by request by scientists around the world and curated such that a large fraction will be stored and available to future generations of researchers.

6 NASA's OSIRIS-REx is not the first mission to deliver an asteroid sample to Earth. The JAXA Hayabusa mission brough back specks from asteroid Itokawa, and the JAXA Hayabusa2 mission brought back about 1/5 ounce (5 grams) of asteroid sample from Ryugu in November 2021. JAXA shared 10% of their sample with NASA. NASA will share 0.5% from the asteroid Bennu with Japan.

7 About 20 minutes after the OSIRIS-REx spacecraft releases its sample return capsule, the spacecraft will fire its engines to set off on a new mission to explore asteroid Apophis under a new name: OSIRIS-APEX (OSIRIS–Apophis Explorer). OSIRIS-APEX will reach Apophis in 6 years, in 2029, just after the asteroid makes its closest approach to Earth.

8 OSIRIS-REx is a robotic mission.

9 NASA researchers chose to study asteroid Bennu for two main reasons: (i) it's rich in carbon, meaning it could contain the chemical building blocks of life, and (ii) every few years, Bennu flies relatively close to Earth, crossing Earth's orbital path, making it accessible to a mission like OSIRIS-REx. Also, it has a (very small) chance of hitting Earth next century, meaning studying Bennu can help us learn how to be prepared to defend against an impact. **Learn more at 10 reasons why Bennu.**

10 NASA's Goddard Space Flight Center in Greenbelt, Maryland, provides overall mission management, systems engineering, and the safety and mission assurance for OSIRIS-REx. Dante Lauretta, of the University of Arizona, Tucson, is the principal investigator. The university leads the science team and the mission's science observation planning and data processing. Lockheed Martin Space in Littleton, Colorado, built the spacecraft, provides flight operations, and is responsible for capsule recovery. Goddard and KinetX Aerospace are responsible for navigating the OSIRIS-REx spacecraft. Curation for OSIRIS-REx, including processing the sample when it arrives on Earth, will take place at NASA's Johnson Space Center in Houston. International partnerships on this mission include the OSIRIS-REx Laser Altimeter instrument from the CSA and asteroid sample science collaboration with the JAXA's Hayabusa2 mission. OSIRIS-REx is the third mission in NASA's New Frontiers Program, managed by NASA's Marshall Space Flight Center in Huntsville, Alabama, for the agency's Science Mission Directorate in Washington.

Image credit: NASA/Keegan Barber

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How to Watch OSIRIS-REx Sample Capsule Landing (Live and On Demand)

NASA's live broadcast of the landing starts at 10 a.m. EDT (8 a.m. MDT/9 a.m. CDT) on Sept. 24. NASA will also host a post-landing press conference 2 hours after the broadcast ends.

News briefings and landing commentary will be livestreamed on **NASA TV**, **NASA.gov/live** and **YouTube.com/NASA**. On-demand recordings will also be available after the live events have finished on YouTube.

NASA TV channels are digital C-band signals carried by QPSK/DVB-S modulation on satellite Galaxy-13, transponder 11, at 127 degrees west longitude, with a downlink frequency of 3920 MHz, vertical polarization, data rate of 38.80 MHz, symbol rate of 28.0681 Mbps and 3/4 FEC. A Digital Video Broadcast-compliant Integrated Receiver Decoder is needed for reception. For more information about NASA TV's programming schedule, visit **https://www/nasa.gov/ntv**.

A clean feed of mission activities will also be available on the NASA TV media channel and on **https://www.nasa.gov/live**.

Spanish Language Broadcast

NASA will stream the OSIRIS-REx landing in Spanish.

Products and Events

News, updates, and other information about the NASA's OSIRIS-REx mission will be available at **nasa.gov/osiris-rex**. To follow the mission team's preparations and mission updates please visit **OSIRIS-REx mission blog**.

Video and Images of OSIRIS-REx

OSIRIS-REx has an extensive multimedia gallery with video, animations, and images on the NASA Scientific Visualization Studio website, **https://svs.gsfc.nasa.gov/Gallery/OSIRIS-REx.html**. B-roll of the landing and recovery rehearsals will be posted on this site.

Images of the spacecraft and asteroid Bennu can be found on the University of Arizona's mission website, **https://asteroidmission.org**.

The NASA image use policy is available at: **https://www.nasa.gov/multimedia/guidelines/index.html**.

Media Events

The most current information about upcoming OSIRIS-REx asteroid sample delivery will be found on **https://www.nasa.gov/osiris-rex**. More information on NASA TV and streaming channels can be found in the Watch Online section.

Social Media

Join the conversation and get mission updates about OSIRIS-REx via these accounts:

X: **@NASASolarsystem**, **@NASA**
Facebook: **/NASASolarSystem**, **/NASA**
Instagram: **@NASASolarsystem**, **@NASA**

Image credit: NASA/Joel Kowsky

News Conferences

Aug. 30: Pre-landing News Conference at Dugway in Utah at 3 p.m. MDT (5 p.m. EDT)

Sept. 22: Pre-Landing Media Telecon

Sept. 24: Post Landing Press Conference in Utah

Oct. 11: Bennu Sample Reveal at NASA's Johnson Space Center

Satellite Tours

NASA will host a satellite tour the week of landing in English and Spanish on Friday, Sept. 22.

Media Credentialing

A copy of NASA's **media accreditation** policy is available online.

The Department of Defense's Utah Test and Training Range is located 80 miles southwest of Salt Lake City, Utah, next to Army's Dugway Proving Ground. Media will have to travel to Dugway's Visitor Control to check in and receive badging.

NASA hosted a media teleconference on Monday, June 26, to answer questions about logistics for covering the landing. Audio of the media call streamed live on the agency's website, and is available **online**.

Airport:
The closest airport to the Army's Dugway Proving Ground, is **Salt Lake City International Airport | Salt Lake City**

Where to stay:
Hotels within 1 hour drive of Army's Dugway Proving Ground are booked. The next closest hotels are in Salt Lake City, Utah.

Environment:
Dugway is one of the Army's most remote bases. Media should dress for the environment. Please wear closed toe shoes and no heels.

NASA, Army, and Air Force are working together to provide a safe and comfortable working environment for the media. The agency is renting a tent and will provide some heating and cooling. We will provide tables, chairs, and power.

Internet:
No internet access will be provided. Please bring your own hot spot. AT&T is the only service provider available on the installation. NASA is making every effort to provide internet for email, research and filing stories for landing day.

Live Trucks:
TV stations are allowed to bring live satellite trucks and can park them near the location of news conferences.

Image credit: NASA/ University of Arizona

Image credit: NASA/Keegan Barber

OSIRIS-REx Sample Return

NASA's OSIRIS-REx (Origins, Spectral Interpretation, Resource Identification, and Security – Regolith Explorer), the first U.S. asteroid sample return mission, is scheduled to deliver its sample of asteroid Bennu to Earth on Sept. 24, 2023. Asteroid Bennu is a time capsule from the formation of the solar system 4.5 billion years ago. A sample of this carbon-rich asteroid will help scientists investigate planet formation and the origin of organics and water that could have led to life on Earth, and the data collected while the spacecraft was at Bennu also aids our understanding of asteroids like Bennu that could impact Earth. The study of Bennu addresses multiple NASA Solar System Exploration objectives to understand the origin of the solar system and the origin of life.

The spacecraft launched on Sept. 8, 2016, arrived at Bennu in December 2018, and, after mapping the asteroid for almost two years, collected a sample from the surface on Oct. 20, 2020. The team estimates that 250 grams (+/- 101 grams) of rocks and dust were collected. The spacecraft departed Bennu's vicinity on May 10, 2021, and is scheduled to deliver the sample to Earth the morning of Sep. 24, 2023, at the U.S. military's Utah Test and Training Range (UTTR) in the Utah desert.

Once it arrives in Earth's vicinity, the spacecraft will jettison the sample return capsule (SRC), which is the only part of the spacecraft to land back on Earth. About four hours after being released, the SRC will land under parachute in the desert. The main spacecraft will then perform a maneuver to put itself on the trajectory for its next mission to encounter the asteroid Apophis, and this extended mission will then take the name OSIRIS-APEX.

On Earth, the SRC will be retrieved by helicopter and taken to a temporary clean room at UTTR to undergo a preliminary checkout. The next day, the capsule and its contents are scheduled to be flown by airplane to NASA's Johnson Space Center, where a new permanent clean room has been built for the long-term study of the sample.

Sample Return and Recovery

WHO NASA, University of Arizona, Lockheed Martin, Department of Defense's Utah Test and Training Range, Army's Dugway Proving Ground and Hill Air Force Base.

WHAT On Sept. 24, 2023, NASA's OSIRIS-REx will be the first U.S. mission to deliver samples from an asteroid to Earth. NASA will broadcast and stream the landing live starting at 10 a.m. EDT (8 a.m. MDT/9 a.m. CDT). OSIRIS-REx will deliver the largest asteroid sample ever received on Earth, estimated to hold about half a pound of Bennu's material or 8.8 ounces +/- 3.6 ounces (250 grams +/- 101 grams).

WHEN Rain or shine, OSIRIS-REx's Sample Return Capsule (SRC) will touch down in the Utah western desert on Sept. 24 at 8:55 a.m. MDT(10:55 a.m. EDT/9:55 a.m. CDT).

WHERE The SRC will land within a 37-mile by 9-mile ellipse (58 km by 14 km) within Department of Defense property at the Utah Test and Training Range and Dugway Proving Ground.

WHY Asteroid Bennu is a well preserved 4.5-billion-year-old remnant of our early solar system. Scientists believe a sample from Bennu will help them learn how our solar system and planets evolved.

Bennu is a carbon-rich, near-Earth asteroid that serves as a time capsule from the earliest history of our solar system.

A sample of a carbonaceous asteroid will help scientists investigate planet formation and the origin of organics that may have led to life on Earth.

HOW The OSIRIS-REx spacecraft will release the capsule at 4:42 a.m. MDT, 5:42 a.m. CDT, and 6:42 a.m. EDT. The capsule will enter the Earth's atmosphere four hours later, aiming to land it inside a 250 square mile ellipse at the Department of Defense's Utah Test and Training Range.

The capsule has no GPS or beacon to track it. As a result, the Air Force and NASA will use tracking cameras on the ground and in the air to track the sample capsule from space all the way to the ground.

Recovery helicopters will fly to the touch down site, recover the capsule and fly it via long line sling to the temporary clean room at the Dugway Proving Ground.

The recovery team will spend a day disassembling the capsule, removing the sample canister, and preparing it to fly to Houston, ideally, the next day.

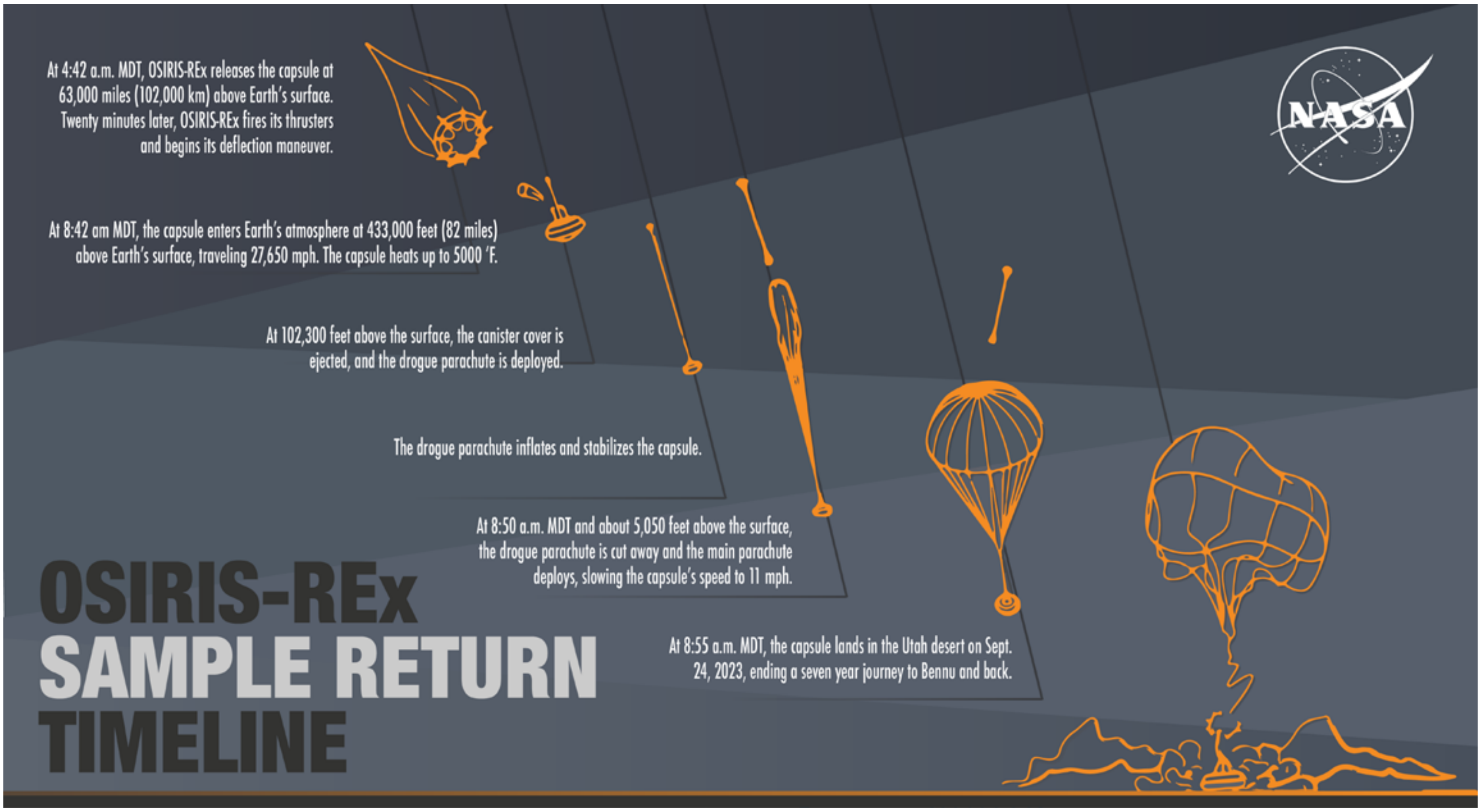


Image credit: University of Arizona/ Heather Roper (Larger version in back of press kit)

Sample Capsule Landing Timeline on Sept. 24:

4:42 a.m. MDT (6:42 a.m. EDT): OSIRIS-REx releases the sample return capsule.

5:02 a.m. MDT (7:02 a.m. EDT): OSIRIS-REx spacecraft begins deflection maneuver.

8:42 a.m. MDT (10:42 a.m. EDT): Capsule enters Earth's atmosphere at 433,000 feet (82 miles) above Earth's surface, traveling 27,650 mph.

8:43 a.m. MDT (10:43 a.m EDT): Peak heating reaching over 5,000° F.

8:44 a.m. MDT (10:44 a.m. EDT): Drogue chute (smaller chute) deployment at 102,300 feet above the surface.

****8:45 a.m. MDT (10:45 a.m. EDT):** The OSIRIS-REx spacecraft will make its closest approach to the Earth; passing 484 miles above the surface.

8:50 a.m. MDT (10:50 a.m. EDT): Main chute deploys at 5,050 feet above the surface.

8:55 a.m. MDT (10:55 a.m. EDT): Touchdown at 11 mph.

*** At 4:42 a.m. MDT, OSIRIS-REx releases the capsule about 63,000 miles from Earth. The spacecraft continues on for another 20 minutes before firing its thrusters to change its velocity by 147 mph (237 km/h). This maneuver causes the spacecraft to miss Earth by 484 miles, and sends it on its way to rendezvous with asteroid Apophis in 2029.*

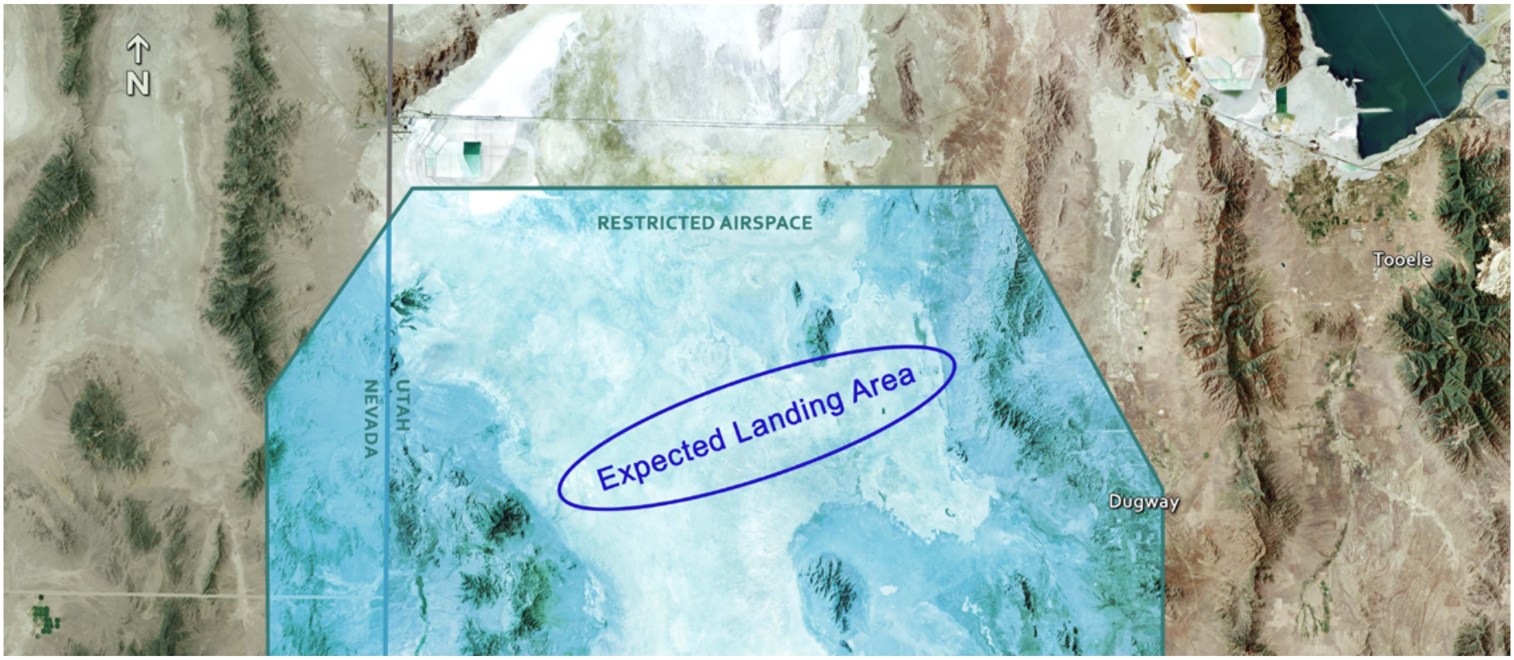


Image credit: NASA/USGS/Landsat 8

Landing Location

The capsule will land in the Department of Defense's Utah Test and Training Range, an area of the desert set aside by the U.S. Government for activities requiring a large safety footprint.

Utah Test and Training Range

The 2.3 million acre Utah Test and Training Range (UTTR) is a Department of Defense Major Range and Test Facility Base and provides an ideal location for operational testing and evaluation that requires a large safety footprint. UTTR is used in a training capacity for air-to-air-combat, air-to-ground inert and live practice bombing and gunnery training by DOD aircrews. The UTTR provides a vast area of realistic terrain for world-class test and training scenarios to ensure the war fighter is prepared to deploy at a moments' notice to win any conflict with decisive air and space power.

The range also supports a wide variety of other operations, in this case, assisting in the recovery of NASA's OSIRIS-REx sample capsule. During the recovery operation, Air Force controllers in the Utah Test and Training Range Mission Control Center on Hill Air Force Base, near Salt Lake City, will track the capsule as it reenters the Earth's atmosphere and moves across Utah into the range's airspace. Within seconds, the Air Force range control officer will be able to locate the capsule with radar and cameras and communicate the precise location to the recovery team on the ground. The Air Force's On-Scene Commander will be the first to approach the capsule after touchdown as he ensures the recovery area is clear of potential dangers and all capsule parachute charges are safe. The capsule will then be transported by range-controlled helicopters to a temporary clean room in the Utah Test and Training Range's facility on Dugway Proving Ground.

Dugway Proving Ground

Dugway Proving Ground (DPG) is the most remote and isolated Army installation in the continental United States. At 1,252 square miles, approximately 800,000 acres, the installation is roughly the size of the state of Rhode Island. DPG is responsible for testing and evaluating nearly all Department of Defense chemical and biological defense capabilities including warfighter protective gear, detectors, and decontamination systems while also remaining a good steward of the environment. Protecting environmental and cultural resources is a top priority of the Dugway mission. Dugway partners with the Utah Test and Training Range (UTTR) to provide nearly 8,000 square miles of restricted airspace, which makes a mission like the OSIRIS-REx sample recovery possible.

The partnership between Dugway and UTTR includes the UTTR tenancy in Dugway's Avery area. This is where NASA's cleanroom facilities have been established and where the sample will be taken after recovery. DPG maintains a good working relationship and open dialogue with the native tribes in the area. Earlier this year Dugway and Tribal leaders participated in a conversation with Army and other DOD organizations about how best to protect dedicated land.

Image credit: NASA/Joel Kowsky

Mission Milestones

Sept. 8, 2016: OSIRIS-REx Launch

Sept. 22, 2017: OSIRIS-REx flies by Earth (Gravity Assist)

Dec. 3, 2018: OSIRIS-REx arrives at asteroid Bennu

Oct. 20, 2020: OSIRIS-REx successfully collects a sample from the surface of Bennu

April 7, 2021: OSIRIS-REx completes its last flyover of Bennu

May 10, 2021: OSIRIS-REx starts its journey back to Earth

Sept. 24, 2023: OSIRIS-REx spacecraft will deliver the asteroid sample to Earth and divert to its next mission.

Landing Specs

Time it takes for sample return capsule to land: Two minutes after hitting the atmosphere a drogue chute will be deployed to keep the capsule stable. Seven minutes after hitting the atmosphere the main parachute will be deployed. The capsule will land 13 minutes after hitting the atmosphere.

Closest approach of OSIRIS-REx spacecraft to Earth: 484 miles (783 km) altitude

Speed: When the sample return capsule enters Earth’s atmosphere, it will be traveling at 27,650 mph (12.36 km/s)

Image credit: NASA/Dimitri Gerondidakis

Spacecraft Specs

Length: 20.25 feet (6.2 m, with solar panels deployed)

Width: 8 feet (2.43 m) x 8 feet (2.43 m)

Height: 10.33 feet (3.15 m)

Length of the sampler arm: 11 feet (3.35 m)

Dry Mass (unfueled): 1,940 pounds (880 kg)

Wet Mass (fueled) at launch was: 4,650 pounds (2,110 kg). As of May 2023, the spacecraft weighs 2,678 pounds (1215 kg).

Power: Two solar panels generate between 1,226 watts and 3,000 watts depending on the spacecraft's distance from the Sun.

Solar Arrays 91.5 sq/ft (8.5 sq/meter) on 2-axis gimbals

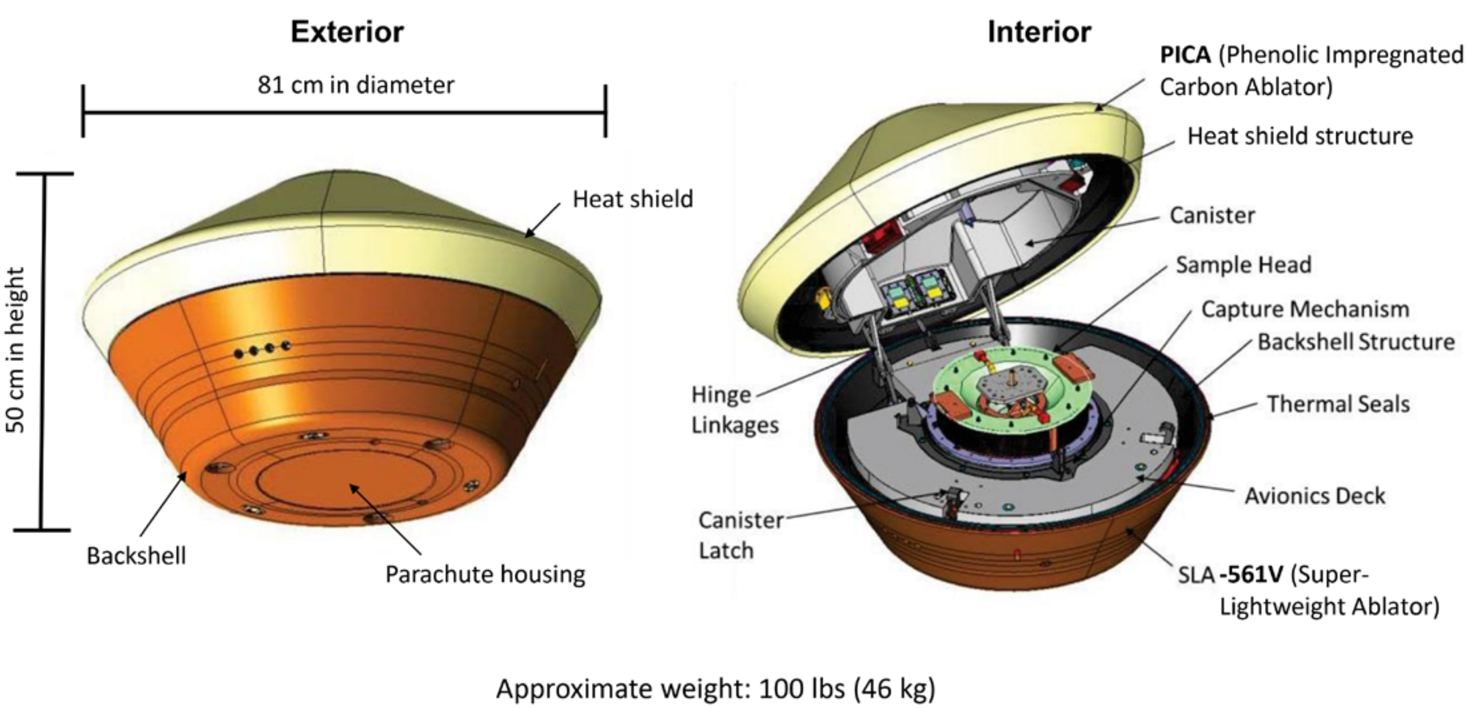


Image credit: Lockheed Martin

Sample Return Capsule Specs

Weight: About 110 pounds (50kg)

31 inches (81 centimeters) in diameter

20 inches (50 centimeters) tall

Main parachute is about 24 feet (7.3 meters) in diameter.

Drogue parachute is 31.5 inches (80 centimeters) in diameter.

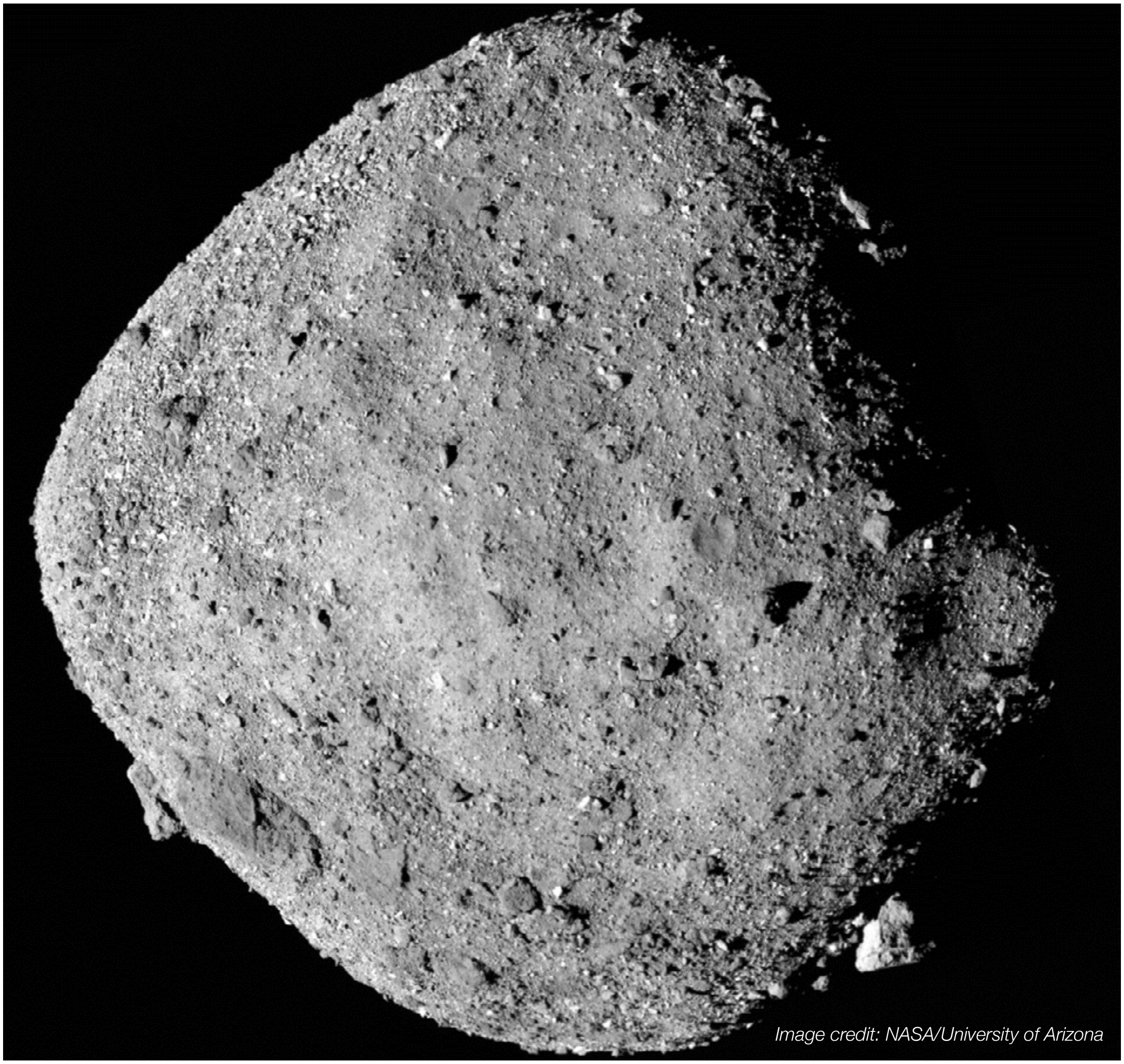


Image credit: NASA/University of Arizona

Why Bennu?

We chose to study asteroid Bennu for two main reasons: (i) it's rich in carbon, meaning it could contain the chemical building blocks of life, and (ii) it has a (very small) chance of hitting Earth next century, meaning studying Bennu can help us learn how to be prepared to defend against an impact. Also, every few years, Bennu flies relatively close to Earth, crossing Earth's orbital path, making it accessible to a mission like OSIRIS-REx.

Bennu is made up of rocks. Specifically, primitive rocks that formed billions of years ago on a larger "parent" asteroid, from which Bennu broke off by the force of an impact. These rocks carry organic compounds and minerals suggesting that veins of water once flowed within the parent asteroid. Bennu also has the potential to give us insight into the origins of our solar system, as well as the origin of life on our planet. Asteroids like Bennu may have delivered water and organic compounds (the building blocks of all known life) to Earth by colliding with it early in its history. Analyzing the returned samples will help shed light on this possibility.

Why Bennu? 10 reasons

Sample Curation: Studying the Samples

The rocks and dust, called regolith, were collected from Bennu's surface in 2020. Bennu is likely to be a well preserved, 4.5-billion-year-old remnant of the early solar system, so the samples should provide insight into the role that similar asteroids played in the formation of planets and the delivery of organic material and water to Earth that may have ultimately led to life. Data collected from the OSIRIS-REx mission will also help scientists better understand asteroids that could impact Earth and inform future asteroid deflection efforts.

To investigate these questions, scientists must carefully preserve, protect, and handle the asteroid samples, which will be examined and stored in a new curation facility managed by NASA's Astromaterials Research and Exploration Science division, or ARES, at the agency's Johnson Space Center in Houston. The division is home to the world's most extensive collection of extraterrestrial materials — including lunar rocks, solar wind particles, meteorites, cosmic dust, and comet samples.

For two years, from late 2023 to late 2025, the science team will characterize the samples and conduct the analysis needed to meet the mission's science goals.. A cohort of more than 200 scientists around the world will explore the regolith's properties, including researchers from many US institutions, NASA partners JAXA (Japan Aerospace Exploration Agency) and CSA (Canadian Space Agency), and other scientists from around the world. NASA will preserve at least 70% of the sample at Johnson for further research by scientists worldwide, including future generations of researchers

With help from the ARES curation laboratories, scientists around the globe are still analyzing new caches of Moon rocks preserved since the Apollo missions in the Apollo Next Generation Sample Analysis initiative. Lessons learned from Apollo and other missions have advanced the science behind sample protection, contingency planning, and contamination control. This legacy will continue with the Bennu samples, which will be preserved for study by scientists not yet born, using technologies not yet invented, to answer fundamental questions about the solar system.

Image credit: Rowan University/Harold Connolly

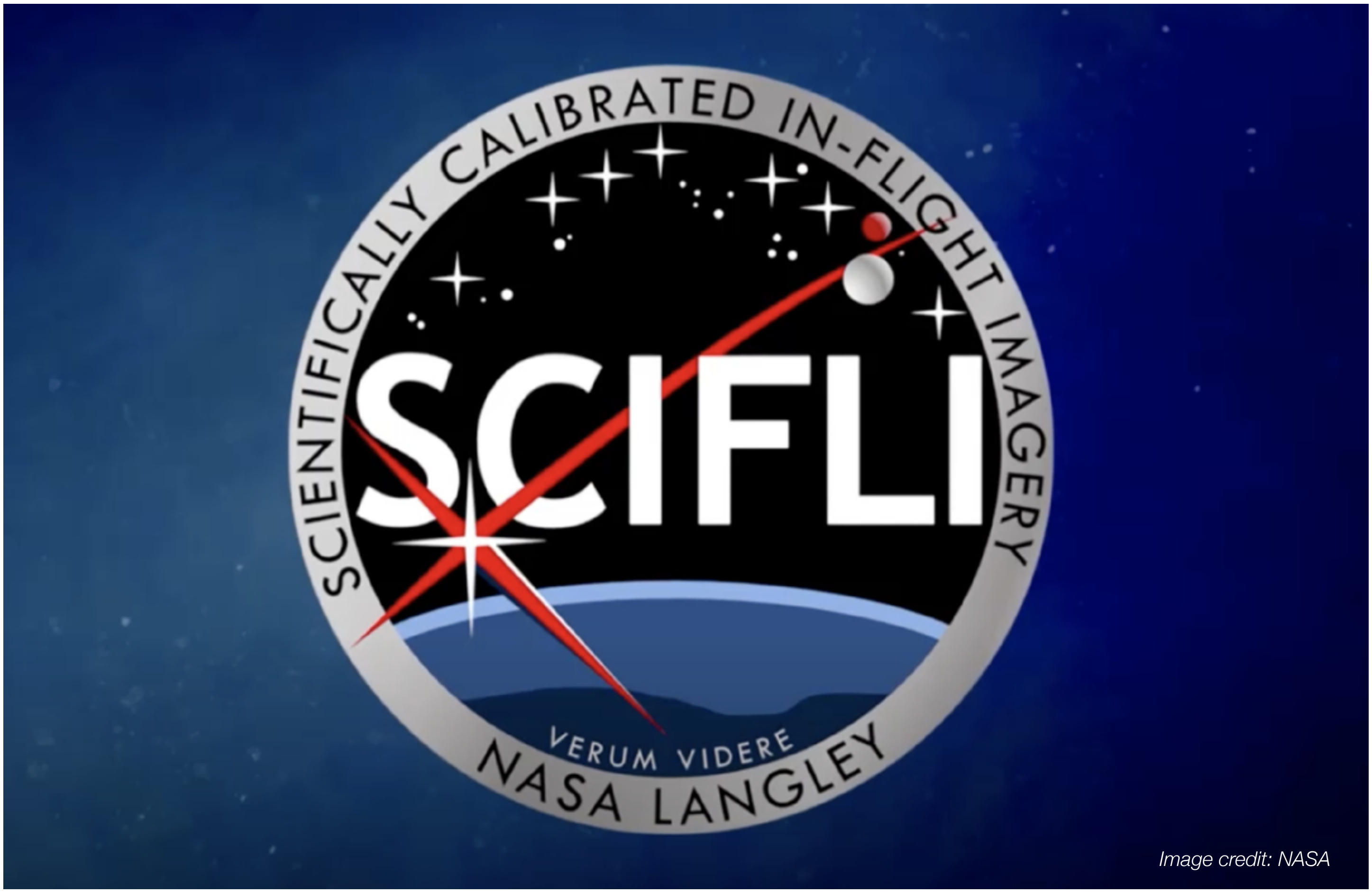


Image credit: NASA

Scientifically Calibrated In-Flight Imagery

The Scientifically Calibrated In-Flight Imagery (SCIFLI) team at NASA's Langley Research Center in Hampton, Virginia, collects real-time visual, infrared, and spectral data on vehicles while they are in flight. Doing so helps researchers gain insight into some of the most challenging questions in fluid dynamics, provides essential engineering data, and documents vital flight safety systems.

During the Hypervelocity OSIRIS-REx Reentry Imaging & Spectroscopy (HORIS) mission, SCIFLI — along with international partners including JAXA (Japan Aerospace Exploration Agency), Rocket Technologies International and the University of Southern Queensland in Australia, and the University of Stuttgart in Germany — will image the hot, quick reentry of OSIRIS-REx. Using special imaging techniques on multiple aircraft and at ground stations along the path of reentry, the team will collect data on the capsule's surface temperature, trajectory, and the plasma environment surrounding the capsule. These datasets will help researchers better understand high speed atmospheric entries and how the OSIRIS-REx capsule's thermal protection system functions under extreme conditions.

With each successful mission, SCIFLI extends the experimental nature of wind-tunnel testing and computational aerothermal analysis by observing vehicles under real flight conditions. In addition to collecting these invaluable data, SCIFLI supports commercial and NASA missions by ensuring the safety of the vehicles and astronauts aboard.

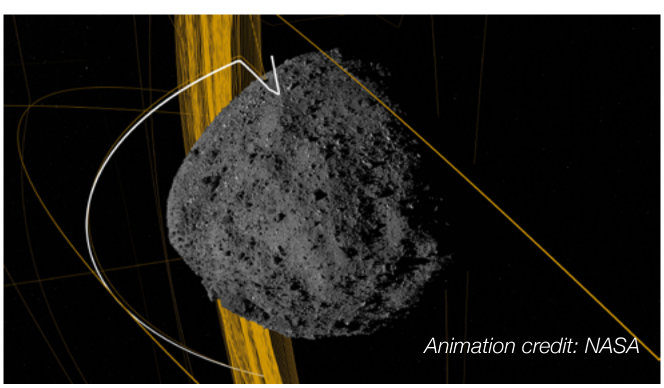
Navigation around Bennu

OSIRIS-REx did not have a GPS telling it to turn right or left as it navigated Bennu. And unlike around Earth or Mars, where the forces on a spacecraft are dominated by gravity, the gravitational force from Bennu acting on OSIRIS-REx was tiny, allowing other forces to have a greater effect on the spacecraft's trajectory. These perturbing forces include solar pressure from photons reflecting off of the surface of the spacecraft and thermal radiation from the spacecraft itself. Consequently, determining the precise position of the spacecraft relative to the asteroid required careful modeling of these small forces and frequent navigation observations. The navigation team relied on both background stars and maps of the asteroid's surface to do this.

The team used star-based navigation as OSIRIS-REx approached the asteroid. The navigation team took angular measurements between Bennu and the stars visible near the horizon to pinpoint the asteroid's location. During this time, scientists studied Bennu's rotation and pole axis, as well as observed whether the asteroid wobbled in its orbit around the Sun. The science team also created maps of the asteroid's surface that were used in the second stage of navigation.

Once OSIRIS-REx arrived at Bennu, the team switched to landmark-based navigation. Landmark navigation is based on the maps created by the science team, and used the same technique that pilots use when approaching a familiar location from the air. Pilots look down and see familiar landmarks, and by observing many of them, they can estimate where the airplane is and what direction they are flying. The OSIRIS-REx team used a very similar technique to locate the position and measure the velocity of the spacecraft with high precision.

NASA's Goddard Space Flight Center in Greenbelt, Maryland, and KinetX Aerospace are responsible for navigating the OSIRIS-REx spacecraft.


Animation credit: NASA

Sampling

On Oct. 20, 2020, OSIRIS-REx unfurled its robotic arm, and in a first for the agency, briefly touched an asteroid Bennu to collect dust and pebbles from the surface for delivery to Earth in 2023.

At 1:50 p.m. EDT that day, OSIRIS-REx fired its thrusters to nudge itself out of orbit around Bennu. It extended the shoulder, then elbow, then wrist of its 11-foot (3.35-meter) sampling arm, known as the Touch-And-Go Sample Acquisition Mechanism (TAGSAM), and transited across Bennu while descending about a half-mile (805 meters) toward the surface. After a four-hour descent, at an altitude of approximately 410 feet (125 meters), the spacecraft executed the "Checkpoint" burn, the first of two maneuvers to allow it to precisely target the sample collection site, known as "Nightingale" in the Hokioi crater.

Ten minutes later, the spacecraft fired its thrusters for the second "Matchpoint" burn to slow its descent and match the asteroid's rotation at the time of contact. It then continued a treacherous, 11-minute coast past a boulder the size of a two-story building, nicknamed "Mount Doom," to touch down in a clear spot in a crater on Bennu's northern hemisphere. The size of a small parking lot, the site Nightingale site is one of the few relatively clear spots on this unexpectedly boulder-covered space rock.

Real-time data indicated the TAGSAM successfully contacted the surface and fired a burst of nitrogen gas. The gas stirred up dust and rocks on Bennu's surface, some of which were captured in the TAGSAM sample collection head.

The spacecraft carried out TAG autonomously, with pre-programmed instructions from engineers on Earth.

Lockheed Martin Space provides flight operations, built the spacecraft and developed TAGSAM.

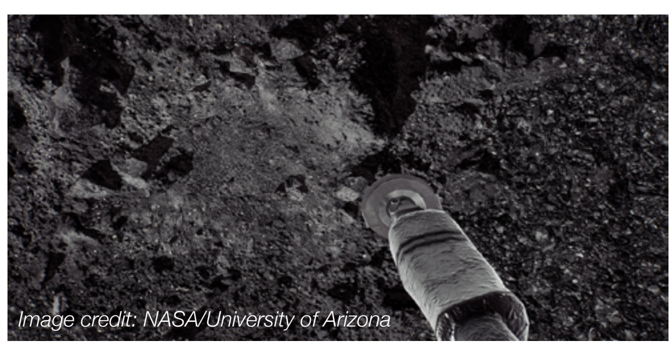


Image credit: NASA/University of Arizona

The Science Behind Bennu

Asteroids May Have Formed from Collision in Space

Bennu, the target asteroid for the OSIRIS-REx mission, and Ryugu, the target of the JAXA (Japan Aerospace Exploration Agency) Hayabusa2 asteroid sample return mission, are composed of fragments of larger bodies that shattered upon colliding with other objects. The small fragments reaccumulated to form aggregate bodies. both classified as “spinning-top” asteroids, Bennu and Ryugu may have formed in this way from the same original shattered parent body. Until studying Bennu up close, scientists thought that this shape with its pronounced equatorial ridge formed as the result of thermal forces, called the YORP effect. The YORP effect increases the speed of the asteroid’s spin, and over millions of years, material near the poles could have migrated to accumulate on the equator, eventually forming a spinning-top shape. However, using computer simulations that model the impact that broke up Bennu’s parent body, researchers showed that these asteroids either formed directly as top-shapes, or achieved the shape early after their formation in the main asteroid belt, ruling out that the asteroids experienced a recent re-shaping due to the YORP effect.

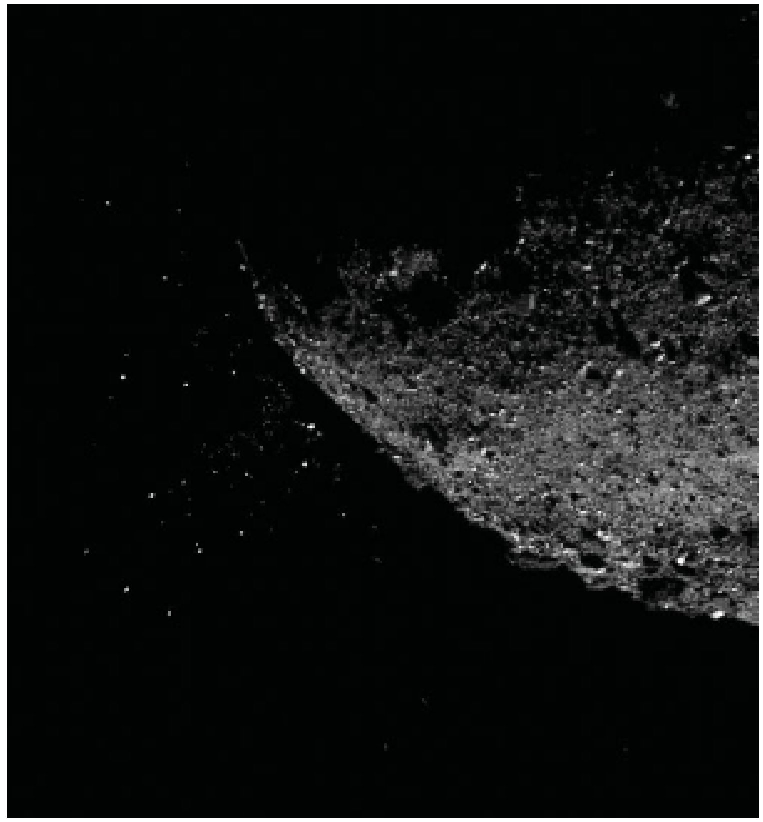


Image credit: NASA/University of Arizona/Lockheed Martin

Sunlight Can Crack Rocks on Bennu

OSIRIS-REx documented the first direct evidence of erosion driven by harsh temperatures between daytime and nighttime. Rocks on asteroid Bennu appear to be cracking as a result of heating from sunlight during Bennu’s “day” and contracting as they cool down at night, causing stress that forms cracks that grow slowly over time. Daytime highs on Bennu can reach almost 260°F (127°C), and nighttime lows plummet to about -100°F (-73°C).

Spewing Pebbles

While studying asteroid Bennu up close, NASA’s OSIRIS-REx spacecraft witnessed periodic outbursts of material being kicked up from the surface totaling more than 300 such events. Once it was determined that these small, slowly moving rocks were not a hazard to the spacecraft, a dedicated observation campaign revealed details of the activity and the processes that may be causing it. Some particles were observed to escape into space, others briefly orbit the asteroid, and most fall back onto its surface after being launched. Various mechanisms could cause the phenomena, including released water vapor, impacts by meteoroids, and rocks cracking from thermal stress. The two latter mechanisms were found to be the most likely driving forces. It is likely that these ejections produce a very small Bennu meteor shower in the southern hemisphere of Earth every September.

Bennu Shows its True Colors

Measurements also confirmed that Bennu is one of the darkest objects in the solar system, reflecting only 4% of the sunlight that reaches it but also more varied in brightness than expected. This diversity results from a combination of different materials inherited from Bennu’s parent body and different durations of exposure to the space environment. In space, weathering is caused by exposure to solar wind and the rain of tiny micrometeorites. On the Moon’s surface and many asteroids, space weathering darkens and reddens surfaces. Not so on Bennu, which has become brighter and bluer in response to space weathering. The freshest material on Bennu, such as that found at the Nightingale sampling site in the Hokioi crater, is redder than average. That means the mission collected some of the freshest material on the asteroid.

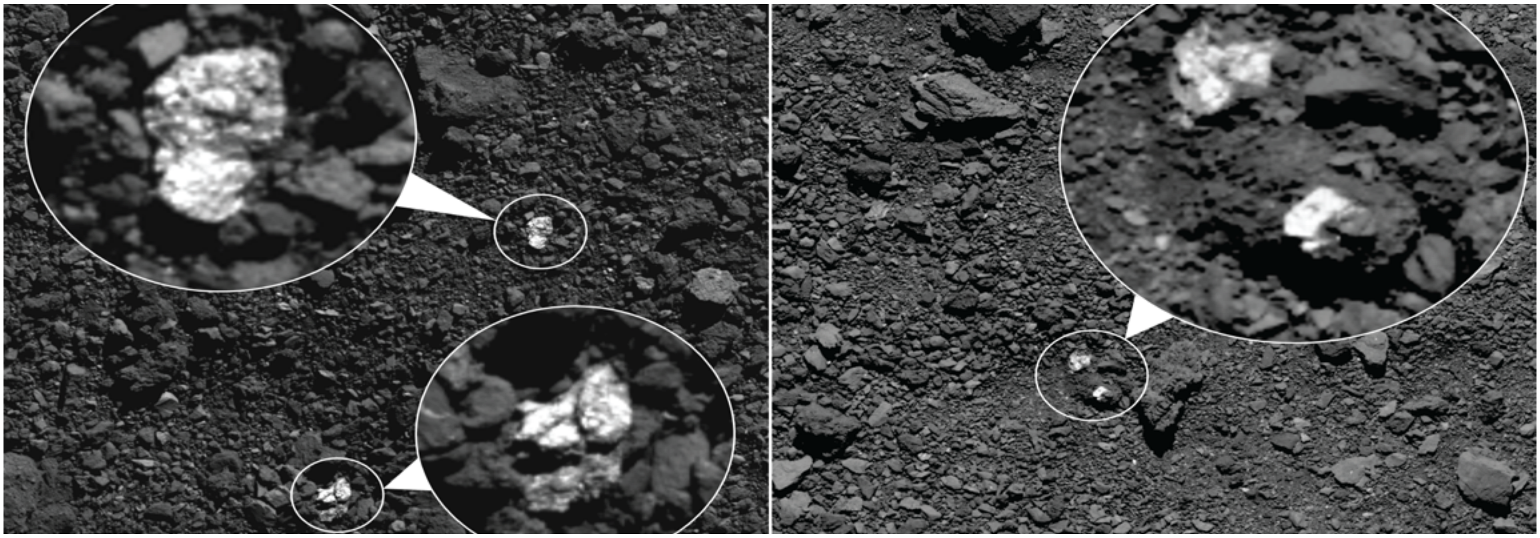


Image credit: NASA/University of Arizona

Vesta Meteorites on Bennu

Six boulders ranging in size from 5 to 14 feet (about 1.5 to 4.3 meters) scattered across Bennu's southern hemisphere and near the equator are much brighter than those typically found on the asteroid. Because they match material from another asteroid, Vesta, scientists believe that Bennu inherited this material from its parent asteroid after it was struck by a "vestoid" (a fragment from Vesta). Then, when the parent asteroid was catastrophically disrupted, a portion of its debris accumulated under its own gravity into Bennu.

An Asteroid with a Watery Past

Observations made by the spacecraft as it observed Bennu was evidence of water—from hydrated minerals to minerals that formed in water, including large veins of carbonate. While Bennu itself is too small to have ever hosted liquid water, the findings indicate that liquid water was present at some time on Bennu's parent body, a much larger asteroid.

Organics on the Surface

The mission revealed that carbon-bearing, organic material is widespread on the asteroid's surface, including at the Nightingale sampling site in the Hokioi crater.

A Surprising Shape

Bennu is a diamond-shaped pile of rubble floating in space, but there's more to it than meets the eye. Data obtained by the OSIRIS-REx Laser Altimeter, or OLA, has allowed the mission team to develop a global model of the asteroid that, at nearly 8-inch resolution (20 cm), is unprecedented in detail and accuracy. A detailed analysis of the asteroid's shape revealed subtle ridge-like mounds on Bennu that extend from pole-to-pole. The model also shows that Bennu's northern and southern hemispheres have somewhat different shapes. The southern hemisphere appears to be smoother and rounder, which the scientists believe is a result of loose material getting trapped by the region's numerous large boulders.

Pelted by Space Debris

Studying impact marks on the surface of asteroid Bennu revealed that, despite forming more than 100 million years ago from the breakup of the 4.5-billion-year-old parent asteroid in the asteroid belt, it was kicked out and wandered into Earth's neighborhood very recently, only 1.75 million years ago. These results were obtained from calculations based on high-resolution images taken by the spacecraft during its two-year survey campaign that allowed researchers to study even tiny craters from space debris on Bennu's boulders.

"Spongy" Rocks Responsible for Bennu's Craggy Surface

Data from the mission suggest that asteroids with highly porous rocks, such as Bennu, should lack fine-grain material on their surfaces. Bennu's fine surface material is not randomly distributed, but less abundant where rocks are more porous, which is the case on most of the surface. The team concluded that very little fine material is produced by Bennu's highly porous rocks. The voids in rocks cushion the blow from incoming meteors.

Additionally, cracking caused by the heating and cooling of Bennu's rocks as the asteroid rotates through day and night proceeds more slowly in porous rocks than in denser rocks, further frustrating the production of fine regolith.

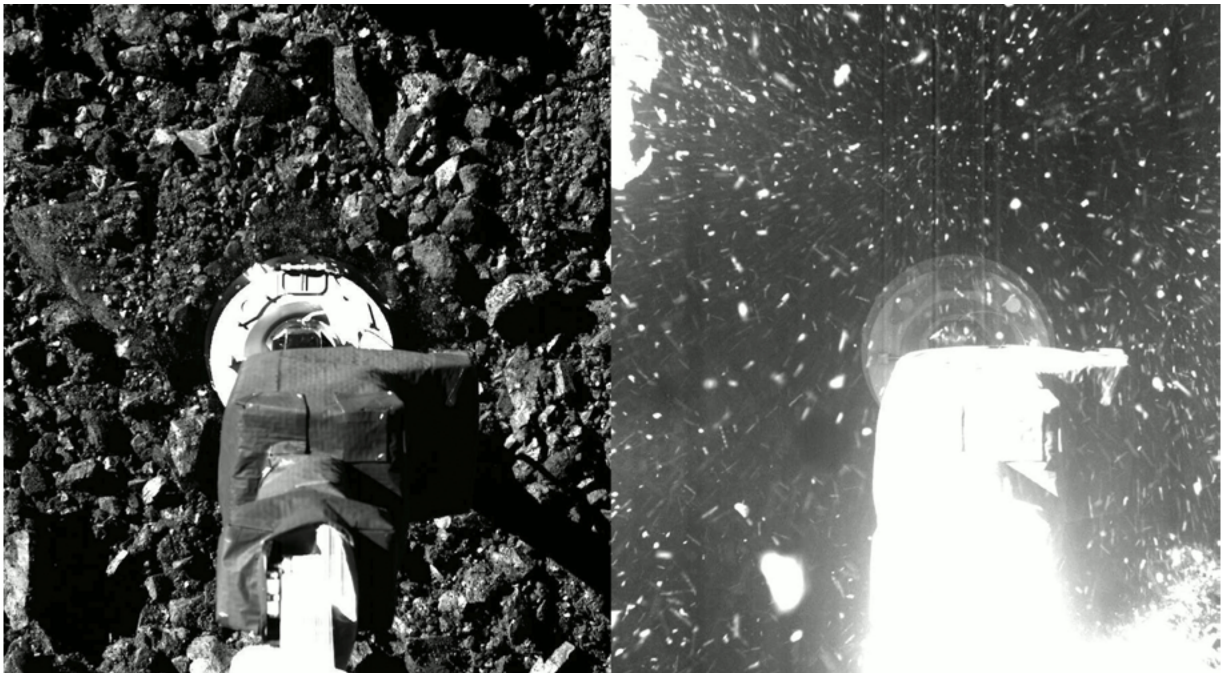


Image credit: NASA/University of Arizona

A Tough Place to Sample

Bennu's surface turned out to be rougher than expected, prompting mission engineers and scientists to reevaluate some of the approaches designed around the mission's primary goal: collecting a sample of surface material, or regolith, and returning it to Earth. Instead of having the equivalent of half a football field to navigate in (164 ft; 50 m), the spacecraft had to operate within the confines of sampling sites that are the size of a few parking spaces (26 ft; 8 m). The asteroid's surface turned out to packed with more than 200 boulders larger than 33 feet (10 m) in diameter and many more that are 3 feet (1 m) or larger. The largest boulder measures 63 yards (58 m) across.

Like Punching a Ball Pit

When OSIRIS-REx swooped in to grab a sample of material from Bennu, the sampling head dove right in with almost no resistance. It turns out that the particles making up Bennu's exterior are so loosely packed and lightly bound to each other that they act more like a fluid than a solid. If a person were to step onto Bennu, they would feel very little resistance, as if stepping into a pit of plastic balls.

Boulder Science

Bennu's abundant dark boulders turned out to be weaker and more porous than the rarer bright boulders. However, both boulder types are weaker than scientists expected. Scientists think that the dark boulders would not survive the journey through Earth's atmosphere as meteorites. It's therefore likely that the returned samples of asteroid Bennu which enter Earth's atmosphere protected in the sample return capsule will provide material absent in meteorite collections.

Assessing Impact Risk

Precision-tracking data from the OSIRIS-REx spacecraft allowed scientists to better understand the orbit of Bennu around the Sun, confirming that the asteroid has a significantly decreased risk of impacting Earth late in the next century, and improving our ability to predict orbits of many other asteroids. Scientists were able to significantly reduce uncertainties about asteroid Bennu's orbit and determine the likelihood of the asteroid impacting Earth between now and the year 2300 to be about 1 in 1,750, or 0.057%. Though there is no possibility of an impact in the next 100 years, the researchers were also able to identify Sept. 24, 2182, as the most significant single date, with an impact probability of 1 in 2,700, or about 0.037%. Although the chances of hitting Earth are low, Bennu is still one of the two most hazardous known objects in the solar system, along with another asteroid called 1950 DA. After releasing the sample return capsule at Earth, the spacecraft will depart on a new mission. Now called OSIRIS-APEX, it will journey to investigate asteroid Apophis, another asteroid with a small chance of hitting Earth. There is no risk of Apophis impacting Earth for at least a century.

Instrument Deck

OCAMS

OSIRIS-REx Camera Suite (OCAMS): OCAMS provided global image mapping and sample site imaging and characterization of Bennu. It also documented the entire sampling event during the TAG maneuver. OCAMS consists of three cameras: PolyCam, MapCam and SamCam. PolyCam, an 8-inch (20-centimeter) telescope, was the first of the cameras to acquire images of the asteroid and provided high-resolution images at long range. It was refocused to image below 1⁄2 inch (1 centimeter) during the reconnaissance of potential sampling sites. MapCam searched for satellites around the asteroid and for outgassing plumes. It also provided high-resolution images and characterize of the candidate sample sites. SamCam recorded the sample collection process. The University of Arizona built the OCAMS camera suite.

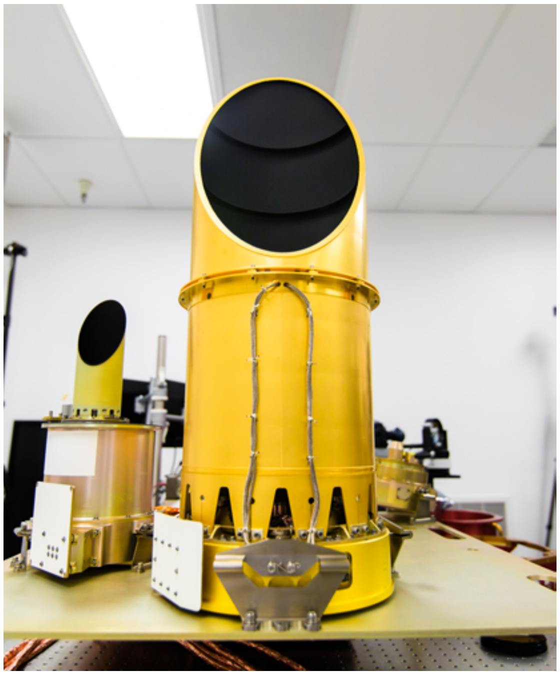


Image credit: University of Arizona/Symeon Platts

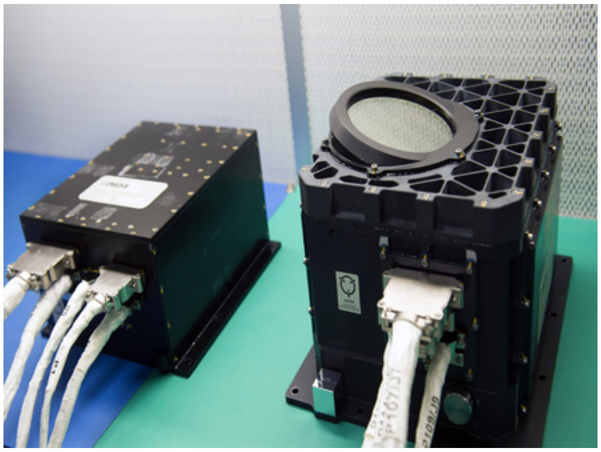


Image credit: NASA/Debbie McCallum

OLA

OSIRIS-REx Laser Altimeter (OLA): OLA is a scanning LIDAR (Light Detection and Ranging) instrument that works similarly to radar, but uses infrared light instead of radio waves to measure distance. It collected data to produce global three dimensional topographic maps of the entire asteroid and higher resolution local maps of candidate sample sites. OLA consists of two lasers, one high-energy transmitter for ranging and mapping at a distance of 0.6 to 4.7 miles (1-7.5 kilometers) and one low-energy transmitter to be used at distances of less than 0.6 miles (1.5 kilometers). It also supported navigation and gravity analysis. OLA is a contributed instrument from the CSA (the Canadian Space Agency).

OVIRS

OSIRIS-REx Visible and Infrared Spectrometer (OVIRS): OVIRS measured light reflected off the asteroid in wavelengths ranging from 0.4 to 4.3 micrometers to provide mineral and organic spectral maps and local spectral information of candidate sample sites. These maps allowed the team to identify minerals and organic material on the surface of Bennu. OVIRS was built by NASA's Goddard Space Flight Center.

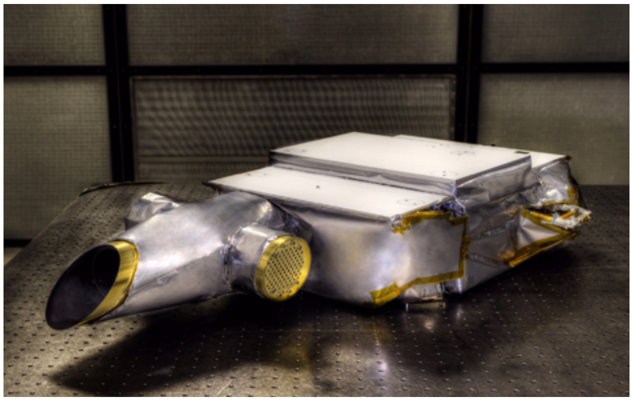


Image credit: NASA/Bill Hrybyk

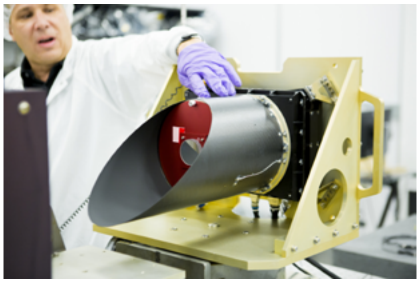


Image credit: University of Arizona/ Charles Leight

OTES

OSIRIS-REx Thermal Emission Spectrometer (OTES): OTES collected thermal infrared data in wavelengths between 5 and 50 micrometers to develop mineral and thermal emission spectral maps and local spectral information of candidate sample sites. Like OVIRS, this instrument identified minerals, such as carbonates, sulfates, and oxides. It measured the total thermal emissions from Bennu and its surface temperature. Arizona State University built the instrument.

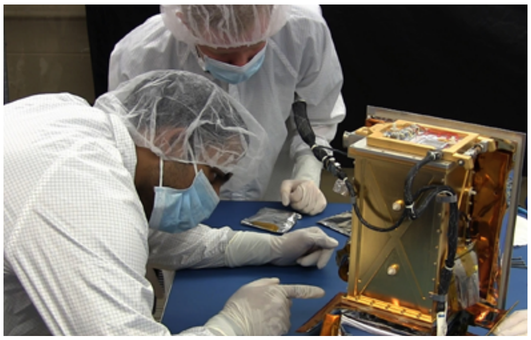


Image credit: MIT/William Litant

REXIS

Regolith X-Ray Imaging System (REXIS): REXIS is a student collaboration experiment. It complemented the mineral mapping capabilities from the other OSIRIS-REx instruments. Over the course of the mission, more than 100 students from Massachusetts Institute of Technology (MIT) and Harvard participated in the REXIS project.

TAGCAMS

Touch and Go Camera Systerm (TAGCAMS): TAGSAM is part of the guidance, navigation and control system on OSIRIS-REx. TAGSAMS consists of two redundant Navigation Camers, or "NavCams" and the single "StowCam." The NavCams are used for optical navigation of the spacecraft. NavCam imaged track star-field and landmarks on Bennu to determne the spacecraft position during mission operations. Each NavCam is a EAM-M50 5 megapixel monochrome camera and is capable of acquiring still images and high definition video. The StowCam was used to verify proper stoage of the asteroid sample with the spacecraft return capsule. StowCam is a ECAM-C505 megapixel color camera and is capable of acquiring still images and high definition video. Malin Space Science Systems provided TAGCAMS.

Image credit: Lockheed Martin

HIGH AND LOW GAIN ANTENNAS

High Gain and Low Gain Antennas: The Radio Science team used the high and low gain antennas, part of the Telecommunications Subsystem, to communicate with the Deep Space Network (DSN) on Earth in order to obtain accurate Doppler and range measurements of the spacecraft. The radiometric tracking data was used to measure the mass and gravity field of Bennu, which constrained the internal structure of the asteroid and refine the Yarkovsky measurements. The radio science team is at University of Colorado, Boulder.

Image credit: Lockheed Martin

Project Management

NASA's Goddard Space Flight Center in Greenbelt, Maryland, provides overall mission management, systems engineering, and the safety and mission assurance for OSIRIS-REx. Dante Lauretta of the University of Arizona, Tucson, is the principal investigator. The university leads the science team and the mission's science observation planning and data processing. Lockheed Martin Space in Littleton, Colorado, built the spacecraft and provides flight operations. Goddard and KinetX Aerospace are responsible for navigating the OSIRIS-REx spacecraft. Curation for OSIRIS-REx will take place at NASA's Johnson Space Center in Houston. OSIRIS-REx is the third mission in NASA's New Frontiers Program, managed by NASA's Marshall Space Flight Center in Huntsville, Alabama, for the agency's Science Mission Directorate in Washington.

International Partnerships

International partnerships on this mission include the CSA (the Canadian Space Agency), which contributed the OSIRIS-REx Laser Altimeter instrument, JAXA's Hayabusa2 sample science collaboration, and France's CNES (Centre National d'Etudes Spatiales).

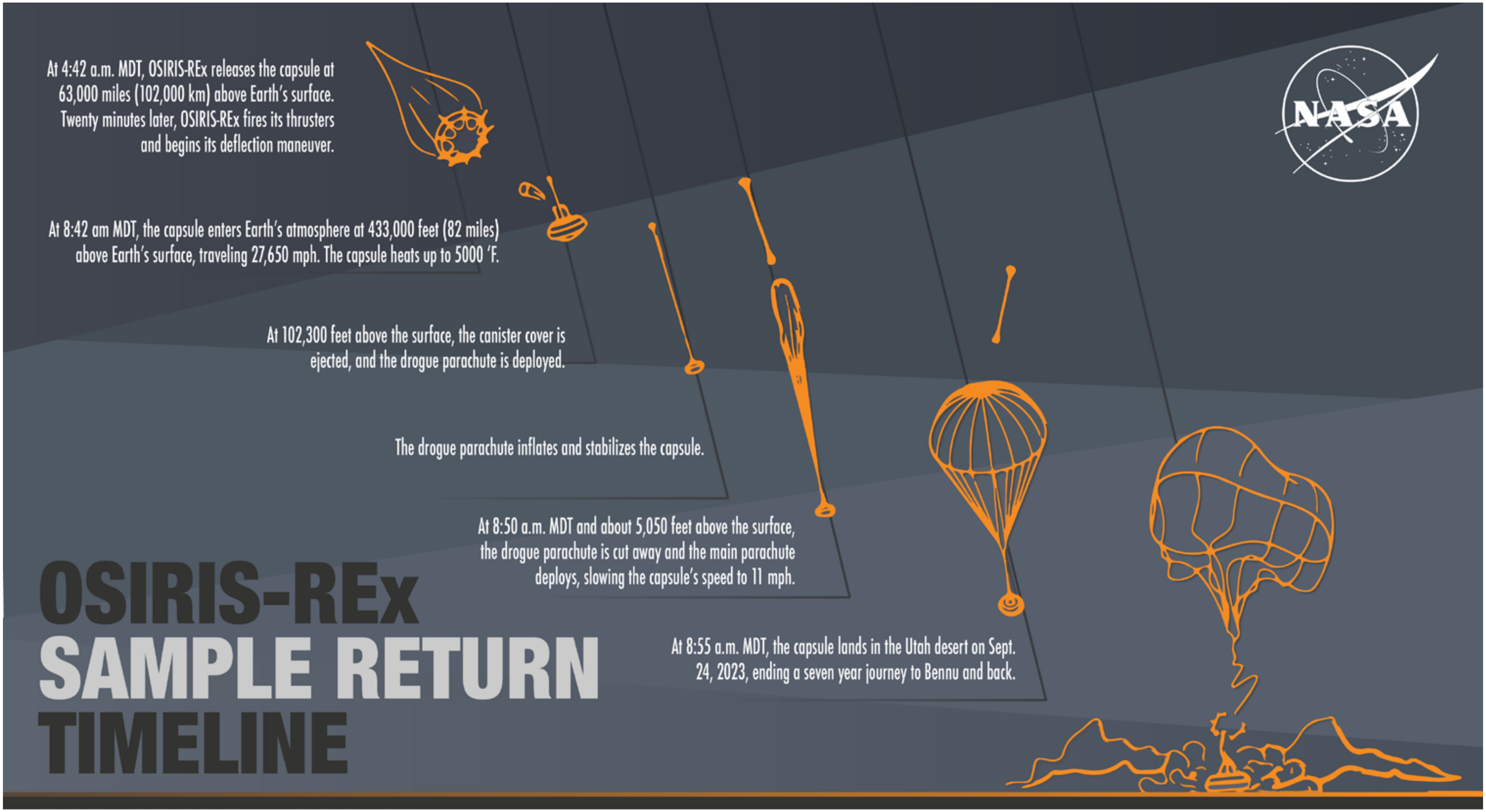


Image credit: University of Arizona/ Heather Roper