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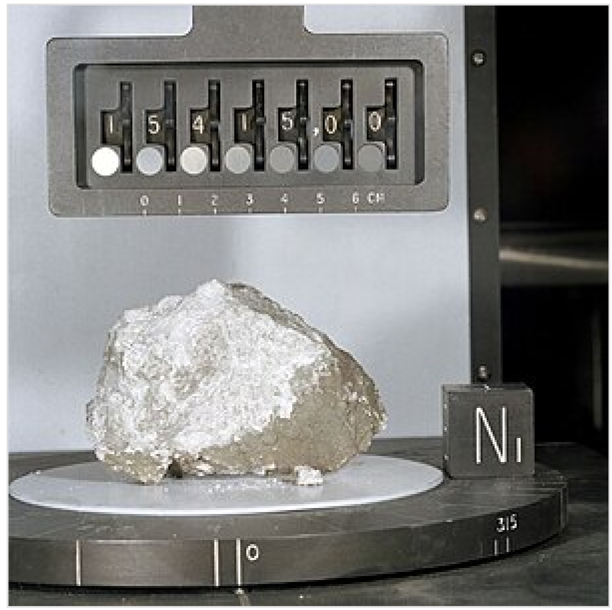
Sample-return mission



The "Genesis Rock", returned by the Apollo 15 lunar mission in 1971.

A **sample-return mission** is a spacecraft mission with the goal of collecting and returning tangible samples from an extraterrestrial location to Earth for analysis. Sample-return missions may bring back merely atoms and molecules or a deposit of complex compounds such as loose material ("soil") and rocks. These samples may be obtained in a number of ways, such as soil and rock excavation, mining, or a collector array used for capturing particles of solar wind or cometary debris.

Up to the present, humanity has collected samples of six identified Solar System bodies, as well as samples of the solar wind. These samples were acquired through three methods: The collection of samples of Earth itself, the collection of meteorites that have fallen on Earth, and the collection of samples through sample-return missions. Samples of Moon rock from Earth's Moon were collected both from meteorites and through robotic and crewed sample-return missions. The comet Wild 2 and the asteroid 25143 Itokawa were visited by robotic spacecraft, which returned samples to Earth. Furthermore, samples for three identified Solar System bodies were only collected by means other than sample-return missions: samples from Earth itself, samples from Vesta in the form of HED meteorites, and samples from Mars in the form of Martian meteorites.

Scientific use

Samples available on Earth can be analyzed in laboratories, so we can further our understanding and knowledge as part of the discovery and exploration of the Solar System. Until now many important scientific discoveries about the Solar System were made remotely with telescopes, and some Solar System bodies were visited by orbiting or even landing spacecraft with instruments capable of remote sensing or sample analysis. While such an investigation of the Solar System is technically easier than a sample-return mission, the scientific tools available here on Earth to study such samples are far more advanced and diverse than those that can go on spacecraft. Analysis of samples on Earth allows to follow up any findings with different tools, including tools that have yet to be developed; in contrast, a spacecraft can carry only a limited set of analytic tools, and these have to be chosen and built long before launch.

A meteorite from Vesta that fell on Africa

Samples analyzed on Earth can be matched against findings of remote sensing, for more insight into the processes that formed the Solar System. This was done, for example, with findings by the Dawn spacecraft, which visited the asteroid Vesta from 2011 to 2012 for imaging, and samples from HED meteorites (collected on Earth until then), which were compared to data gathered by Dawn.[1] These meteorites could then be identified as material ejected from the large impact crater Rheasilvia on Vesta. This allowed deducing the composition of crust, mantle and core of Vesta. Similarly some differences in composition of asteroids (and, to a lesser extent, different compositions of comets) can be discerned by imaging alone. However, for a more precise inventory of the material on these different bodies, more samples will be collected and returned in the future, to match their compositions with the data gathered through telescopes and astronomical spectroscopy.

One further focus of such investigation—besides the basic composition and geologic history of the various Solar System bodies—is the presence of the building blocks of life on comets, asteroids, Mars or the moons of the gas giants. Several sample-return missions to asteroids and comets are currently in the works. More samples from asteroids and comets will help determine whether life formed in space and was carried to Earth in the form of meteorites. Another question under investigation is whether extraterrestrial life formed on other Solar System bodies like Mars or on the moons of the gas giants, and whether life might even exist there today. The result of NASA's last "Decadal Survey" was to prioritize a Mars sample-return mission, as Mars has a special importance: it is comparatively "nearby", might have harbored life in the past, and might even be able to sustain life today. Jupiter's moon Europa is another important focus in the search for life in the Solar System. However, due to the distance and other constraints, Europa might not be the target of a sample-return mission in the foreseeable future.

Planetary protection

Planetary protection aims to prevent biological contamination of both the target celestial body and the Earth—in the case of sample-return missions. No sample has yet been returned with alien life in it. A sample-return from Mars or other location with potential to host life, is a category V mission under COSPAR which directs to containment of any unsterilized sample returned to Earth. This is because it is unknown the effects of such hypothetical life would be on humans or on the biosphere of Earth.[2] For this reason, Carl Sagan and Joshua Lederberg argued in the 1970s that we should do sample-return missions classified as category V missions with extreme caution, and later studies by the NRC and ESF agreed.[2][3][4][5][6]

Sample-return missions

First missions

The manned US Apollo 11 mission in July 1969 achieved the first successful sample return from another Solar System body. It returned approximately 22 kilograms (49 lb) of Lunar surface material. This was followed by 34 kilograms (75 lb) of material from Apollo 12 and a further 326 kilograms (719 lb) of material from four more missions from the manned Apollo program.


Apollo 11 was the first mission to return extraterrestrial samples.

Perhaps one of the most significant advances in sample-return missions occurred in 1970 when the robotic Soviet mission known as Luna 16 successfully returned 101 grams (3.6 oz) of lunar soil. Likewise, Luna 20 returned 55 grams (1.9 oz) in 1974, and Luna 24 returned 170 grams (6.0 oz) in 1976. Although they recovered far less than the Apollo missions, they did this fully automatically. Apart from these three successes, other attempts under the Luna programme failed. The first two missions were intended to outstrip Apollo 11 and were undertaken shortly before them in June and July 1969: Luna E-8-5 No. 402 failed at start, and Luna 15 crashed on the Moon. Later, other sample-return missions failed: Kosmos 300 and Kosmos 305 in 1969, Luna E-8-5 No. 405 in 1970, Luna E-8-5M No. 412 in 1975 at unsuccessful launches, and Luna 18 in 1971 and Luna 23 in 1974 at unsuccessful landings on the Moon.[7]

In 1970, the Soviet Union planned for a 1975 first Martian sample-return mission in the Mars 5NM project. This mission was planned to use an N1 rocket, but as this rocket never flew successfully, the mission evolved into the Mars 5M project, which would use a double launch with the smaller Proton rocket and an assembly at a Salyut space station. This Mars 5M mission was planned for 1979, but got canceled in 1977 due to technical problems and complexity; all hardware was ordered destroyed.[8]

New missions after a 20-year hiatus

NASA has a long-term stratospheric flight program to collect cosmic dust.[9][10][11]

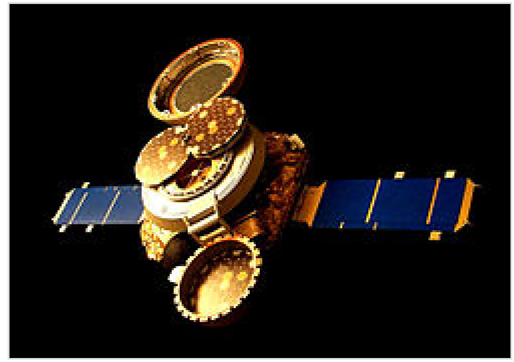
The 1984 LDEF mission returned chondritic and iron-nickel impactors,[12] as did the 1992 EURECA mission.

The *Earth-Orbital Debris Collection (ODC)* experiment was deployed on the Mir space station for 18 months during 1996–1997 and used aerogel to capture particles from low Earth orbit, consisting of interplanetary dust and man-made particles. Far from being "the last sample-return mission... in... twenty years", ODC was a portable version of an LDEF collector, decreasing collection time significantly, and effective area by orders of magnitude.

The next mission to return extraterrestrial samples was known as *Genesis*—it was able to return solar wind samples to Earth from beyond Earth orbit. Unfortunately, the *Genesis* capsule failed to open its parachute while re-entering the Earth's atmosphere and crash-landed in the Utah desert in 2004. There were fears of severe contamination or even total mission loss, but scientists have managed to save many of the samples, which were the first to be collected from beyond lunar orbit. *Genesis* used a collector array made of wafers of ultra-pure silicon, gold, sapphire, and diamond. Each different wafer was used to collect a different part of the solar wind.

Sample-return capsule from the Stardust mission

Genesis was followed by NASA's *Stardust* spacecraft, which returned comet samples to Earth on January 15, 2006. It safely passed by Comet Wild 2 and collected dust samples from the comet's coma while imaging the comet's nucleus. *Stardust* used a collector array made of low-density aerogel (99% of which is empty space), which has about 1/1000 of the density of glass. This permits the ability to collect the cometary particles without damaging them due to high impact velocities. Particle collisions with even slightly porous solid collectors would result in destruction of those particles and damage to the collection apparatus. During cruise, the second side of the array collected at least seven interstellar dust particles.[13]



An artist's rendering of *Genesis* collecting solar wind.

In June 2010 the Japan Aerospace Exploration Agency (JAXA) Hayabusa probe returned asteroid samples to Earth after a rendezvous with (and a landing on) S-type asteroid 25143 Itokawa. In November 2010, scientists at the agency confirmed that, despite failure of the sampling device, the probe retrieved micrograms of dust from the asteroid, the first ever brought back to Earth in pristine condition.[14]

The Russian Fobos-Grunt was a failed sample-return mission that was supposed to return samples from **Phobos**, one of the moons of Mars. It was launched on November 8, 2011. However, the probe failed to leave Earth orbit and crashed after several weeks into the southern Pacific Ocean.[15][16]

Current missions

The Japan Aerospace Exploration Agency (JAXA) launched the improved Hayabusa2 space probe on December 3, 2014 and plans to return asteroid samples by 2020. *Hayabusa2* arrived at the target asteroid C-type asteroid 162173 Ryugu (formerly designated 1999 JU_3) on 27 June 2018[17]. It is expected to survey the asteroid, which is a near-Earth asteroid, for a year and a half during which time it will collect samples multiple times, depart in December 2019, and return the samples to Earth in December 2020.[18]

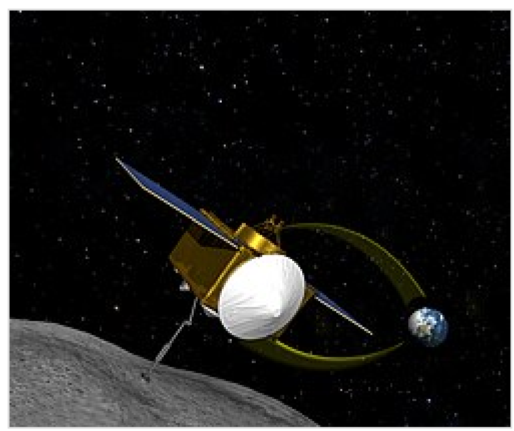


Illustration of OSIRIS-REx collecting a sample from asteroid 1999 RQ_{36}

The OSIRIS-REx mission was launched in September 2016 on a mission to return samples from the asteroid 101955 Bennu.[19][20] The samples are expected to enable scientists to learn more about the time before the birth of the Solar System, initial stages of planet formation, and the source of organic compounds that led to the formation of life.[21]

Future missions

Ascent vehicle in its protective shroud, 2009 ESA-NASA design.[22]

There were plans to launch a Mars Sample Return (MSR) mission in 2004, but following the twin-failures of the Mars Climate Orbiter and Mars Polar Lander, MSR was cancelled. NASA has long planned a Martian sample-return mission, but has yet to secure the budget to successfully design, build, launch, and land a probe that would do just that. There have been mission proposals in the past, but most have not made it far beyond the drawing boards. The mission remained on NASA's roadmap for planetary science as of the 2013 Planetary Science Decadal Survey.[23] A Mars sample-return mission in collaboration with Europe (as part of the Aurora programme) was proposed launch around 2018. Due to budget cuts at NASA, the future of this mission is uncertain.

China is planning to conduct a Chang'e 5 lunar sample return around 2019. If successful, it would make the first lunar sample return in over 40 years. Russia has plans for Luna-Grunt mission to return samples from the Moon by 2021 and Mars-Grunt to return samples from Mars 5–10 years later. Also, Russia plans to repeat Fobos-Grunt mission near 2024.

In September 2012, NASA announced concept studies on several strategies of returning a sample of Mars to Earth—including a multiple-launch scenario, a single-launch scenario and a multiple-rovers scenario—for a mission beginning as early as 2018.[24] JAXA is developing the MMX mission, a sample-return mission to Phobos that will be launched in 2024.[25] Of the two moons, Phobos's orbit is closer to Mars and its surface may have adhered particles blasted from the red planet; thus the Phobos samples collected by MMX may contain material originating from Mars itself.[26]

China has plans for a Mars sample-return mission by 2030.[27][28] Also, the Chinese Space Agency is designing a sample-retrieval mission from Ceres that would take place during the 2020s.[29]

Methods of sample return

Sample-return methods include, but are not restricted to the following:

Collector array

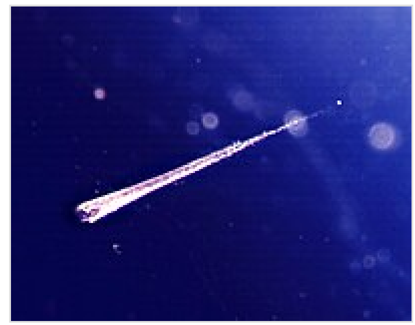
A collector array may be used to collect millions or billions of atoms, molecules, and fine particulates by using a number of wafers made of different elements. The molecular structure of these wafers allows the collection of various sizes of particles. Collector arrays, such as those flown on *Genesis*, are ultra-pure in order to ensure maximal collection efficiency, durability, and analytical distinguishability.

Collector arrays are useful for collecting tiny, fast-moving atoms such as those expelled by the Sun through solar wind, but can also be used for collection of larger particles such as those found in the coma of a comet. The NASA spacecraft known as *Stardust* implemented this technique. However, due to the high speeds and size of the particles that make up the coma and the area nearby, a dense solid-state collector array was not viable. As a result, another means for collecting samples had to be designed as to preserve the safety of the spacecraft and the samples themselves.

A Genesis collector array consisting of a grid of ultra-pure wafers of silicon, gold, sapphire, and diamond

Aerogel

Aerogel is a silicon-based porous solid with a sponge-like structure, 99.8% of whose volume is empty space. Aerogel has about 1/1000 of the density of glass. An aerogel was used in the *Stardust* spacecraft because the dust particles the spacecraft was to collect would have an impact speed of about 6 km/s.[30] A collision with a dense solid at that speed could alter their chemical composition or perhaps vaporize them completely.



A particle captured in aerogel

Since the aerogel is mostly transparent, and the particles leave a carrot-shaped path once they penetrate the surface, scientists can easily find and retrieve them. Since its pores are on the nanometer scale, particles, even ones smaller than a grain of sand, do not merely pass through the aerogel completely. Instead, they slow to a stop and then are embedded within it.

The *Stardust* spacecraft has a tennis-racket-shaped collector with aerogel fitted to it. The collector is retracted into its capsule for safe storage and delivery back to Earth. Aerogel is quite strong and easily survives both launching and outer-space environments.

Robotic excavation and return

Some of the most risky and difficult types of sample-return missions are those that require landing on an extraterrestrial body such as an asteroid, moon, or planet. It takes a great deal of time, money, and technical ability in order to even initiate such plans. It is a difficult feat that requires that everything from launch to landing to retrieval and launch back to Earth be planned out with high precision and accuracy.

This type of sample return, although having the most risks, is the most rewarding for planetary science. Furthermore, such missions carry a great deal of public outreach potential, which is an important attribute for space exploration when it comes to public support. The only successful robotic sample-return missions of this type have been the Soviet Luna landers.

List of missions

Crewed missions

Launch date	Operator	Name	Sample origin	Samples returned	Recovery date	Mission result
16 July 1969	United States	Apollo 11	Moon	22 kilograms (49 lb)	24 July 1969	Successful
14 November 1969	United States	Apollo 12	Moon	34 kilograms (75 lb)	24 November 1969	Successful
11 April 1970	United States	Apollo 13	Moon	—	17 April 1970	Failed
31 January 1971	United States	Apollo 14	Moon	43 kilograms (95 lb)	9 February 1971	Successful
26 July 1971	United States	Apollo 15	Moon	77 kilograms (170 lb)	7 August 1971	Successful
16 April 1972	United States	Apollo 16	Moon	95 kilograms (209 lb)	27 April 1972	Successful
7 December 1972	United States	Apollo 17	Moon	111 kilograms (245 lb)	19 December 1972	Successful
22 March 1996	United States / Russia	Earth-Orbital Debris Collection	Low Earth orbit	Particles	6 October 1997	Successful[31]
14 April 2015	Japan / United States	Tanpopo mission	Low Earth orbit	Particles	February 2018[32]	Successful

Robotic missions

Launch date	Operator	Name	Sample origin	Samples returned	Recovery date	Mission result
14 June 1969	Soviet Union	Luna E-8-5 No. 402	Moon	—	—	Failure
13 July 1969	Soviet Union	Luna 15	Moon	—	—	Failure
23 September 1969	Soviet Union	Cosmos 300	Moon	—	—	Failure
22 October 1969	Soviet Union	Cosmos 305	Moon	—	—	Failure

Launch date	Operator	Name	Sample origin	Samples returned	Recovery date	Mission result
6 February 1970[7]	Soviet Union	Luna E-8-5 No. 405	Moon	—	—	Failure
12 September 1970	Soviet Union	Luna 16	Moon	101 grams (3.6 oz)	24 September 1970	Success
2 September 1971	Soviet Union	Luna 18	Moon	—	—	Failure
14 February 1972	Soviet Union	Luna 20	Moon	55 grams (1.9 oz)	25 February 1972	Success
2 November 1974	Soviet Union	Luna 23	Moon	—	—	Failure
16 October 1975	Soviet Union	Luna E-8-5M No. 412	Moon	—	—	Failure
9 August 1976	Soviet Union	Luna 24	Moon	170 grams (6.0 oz)	22 August 1976	Success
7 February 1999	United States	Stardust	81P/Wild	Particles	15 January 2006	Success
8 August 2001	United States	Genesis	Solar wind	Particles	9 September 2004	Success (partial)
9 May 2003	Japan	Hayabusa	25143 Itokawa	Particles	13 June 2010	Success (partial)
8 November 2011	Russia	Fobos-Grunt	Phobos	—	—	Failure
3 December 2014	Japan	Hayabusa2	162173 Ryugu	—	December 2020	Ongoing
8 September 2016	United States	OSIRIS-REx	101955 Bennu	—	2023	Ongoing
2019	China	Chang'e 5	Moon	—	2019	Planned
2024	Japan	MMX	Phobos	—	2029	Planned

Comet sample return

Various comets have been studied for sample return including:[33] The Stardust mission returned coma samples, Deep Impact collided with a nucleus, and Rosetta's lander landed, but to date no sample return mission has been conducted. Scavenging space dust for comet debris

- 9P/Tempel 1 (Deep Impact target)
- 19P/Borrelly (DS1 target)
- 81P/Wild 2 (Stardust target)
- 67P/Churyumov–Gerasimenko (Rosetta target and possibly also CAESAR propoal)
- 21P/Giacobini-Zinner (ICE target)
- 22P/Kopff (CRAF target (not launched))
- 6P/d'Arrest (in-fulfilled target of the lost CONTOUR)
- 43P/Wolf-Harrington

- 46P/Wirtanen (former target of Rosetta)

See also

- Asteroid mining
- Discovery and exploration of the Solar System
- Exploration of Mars
- Exploration of the Moon
- Extraterrestrial sample curation
- List of lunar probes
- Robotic exploration of the Moon
- Space exploration
- Timeline of Solar System exploration

Spaceflight portal

Space portal

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External links

- Mars Exploration: *Sample Returns* (https://web.archive.org/web/20051129044954/http://mars.jpl.nasa.gov/missions/samplereturns.html) Jet Propulsion Laboratory Mars Exploration Program on sample return missions.
- Stardust *Homepage* (http://stardust.jpl.nasa.gov/) Jet Propulsion Laboratory *Stardust* mission website.
- Genesis Mission *Homepage* (http://genesismission.jpl.nasa.gov/) Jet Propulsion Laboratory *Genesis* mission website.
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