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EXPLAINER

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What samples from space have taught us

Alastair Gunn explains what scientists have learnt in the 20 years since the first unmanned mission brought materials back from alien worlds

One of the best ways to study the Universe is to inspect actual materials from our celestial neighbours. Some naturally fall to Earth as meteorites, but these are few and far between, limited in their origins and are not likely to be pristine. That's why scientists have put great efforts into remotely grabbing samples of the Solar System's worlds and returning them to Earth. These sample-return missions (SRMs) provide important insights which cannot be obtained by any other means.

Scientists use a huge range of exotic-sounding techniques to analyse these samples, including electron microscopy, spectroscopic analysis, isotope analysis and even muon beam imaging. Together, the results can reveal a treasure trove of data: when, where and how the object formed, its history and evolution, and its relation to other objects.

So far, there have been 17 successful SRMs which all told have returned about 384kg (847lb) of Moon rocks, about 128g (4.5oz) of asteroid material and about one milligram (0.000035oz) of comet dust to Earth. So, what have these missions taught us about the Solar System?

Lunar rock

Lunar samples were first returned by the six manned Apollo missions, the Soviet Union's three robotic Luna missions and, most recently, China's Chang'e 5 and 6.

Analysis provided evidence for the giant impact theory: that the Moon was the result of a titanic collision between a proto-planet (called 'Theia') and the proto-Earth. Lunar samples have also shown that the Moon's core formed quickly, that its crust has been mixed and remelted many times by colossal impact events, and that lava was erupting on the Moon as recently as 120 million years ago.

Today, there are ways of analysing samples that were unheard of during the Apollo and Luna eras of the 1960s and 1970s, such as X-ray-computed tomography (CT) and non-destructive electron-beam mapping. Thankfully, NASA had the foresight to seal up quantities of lunar material for later

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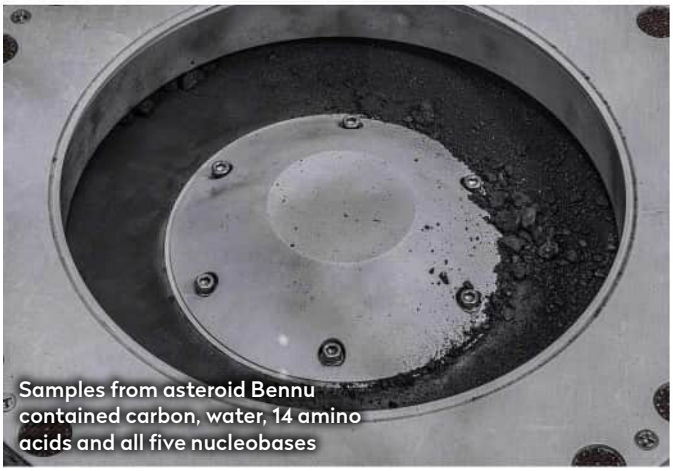
▲ Apollo 14 crew inspect part of their 42kg (93lb) haul from Fra Mauro, rocks which revealed the Moon's surface has been repeatedly shattered and remelted by colossal impacts

▲ An untouched Apollo 17 core sample being opened for the first time in 2022



Samples from asteroid Bennu contained carbon, water, 14 amino acids and all five nucleobases

Next stop: Mars. Japan's MMX will collect materials from Martian moon Phobos

analysis. The first batch of these pristine samples was opened in 2019.

Asteroids and comets

There have been three asteroid SRMs – Hayabusa, Hayabusa2 and OSIRIS-REx – and one comet SRM, Stardust.

Japan's Hayabusa, launched in 2003, visited the small near-Earth asteroid Itokawa, returning in December 2010. From the 1,500 micron-sized grains of material it brought back, researchers concluded that Itokawa was likely originally part of a larger asteroid and may have experienced hydrothermal processes in its youth.

The follow-up, Hayabusa2, brought back about 5.4g (0.19oz) of material from the near-Earth asteroid Ryugu. Analysis revealed Ryugu's parent body (possibly the asteroid 142 Polana) was rich in liquid water at some point in its past.

NASA's OSIRIS-REx visited the asteroid Bennu, returning 121.6g (4.3oz) of material in September 2023 that revealed Bennu too had a watery past. Furthermore, it contained traces of 14 of the 20 amino acids that make up proteins in Earth-bound life, and all five of the nucleobases in DNA and RNA molecules. This has added to the evidence that life on Earth may have been kickstarted by the arrival of material from outer space.

Twenty years ago, the very first unmanned SRM, NASA's Stardust, arrived back at Earth carrying microscopic dust particles from the coma of comet 81P/Wild. Analysis confirmed that the comet originated in the outer regions of the Solar System, unlike meteorites, most of which were formed in the inner Solar System.

Other returned samples

NASA's Genesis mission to capture solar wind particles crashed in the Utah desert in 2004. Despite extensive damage, scientists were able to retrieve samples that showed the elemental composition of the solar wind has not changed for at least 100 million years. The Orbital Debris Collection (ODC) experiment on the Mir space station in 1996/7 collected small particles from low Earth orbit, but researchers couldn't distinguish between natural and human-made materials.

There are plans for further SRMs in the decades ahead. Japan is developing the Martian Moons Exploration (MMX) mission to retrieve samples from Mars's moon Phobos. In May 2025, China's National Space Administration launched Tianwen-2 to the near-Earth asteroid Kamo'oalewa. Its expected homecoming is in November 2027.

NASA and ESA also have a project to return Mars samples to Earth. Although the idea is still in the design stage and at risk due to budget reassessments, NASA's Perseverance rover has been collecting Martian samples since 2021, storing them in 43 cylindrical tubes on the Martian surface for eventual retrieval. China is also developing a Mars SRM, the Tianwen-3 mission, as well as a facility to handle the samples once returned, with the aim of launching around 2028–30.

All in all, the 17 sample-return missions to date have cracked open the secrets of the formation and evolution of the Solar System, and even our place within it. And these precious fragments of alien worlds promise to keep revealing fascinating science for decades to come.

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