With X-ray analysis, an asteroid provides a view into our solar system's past

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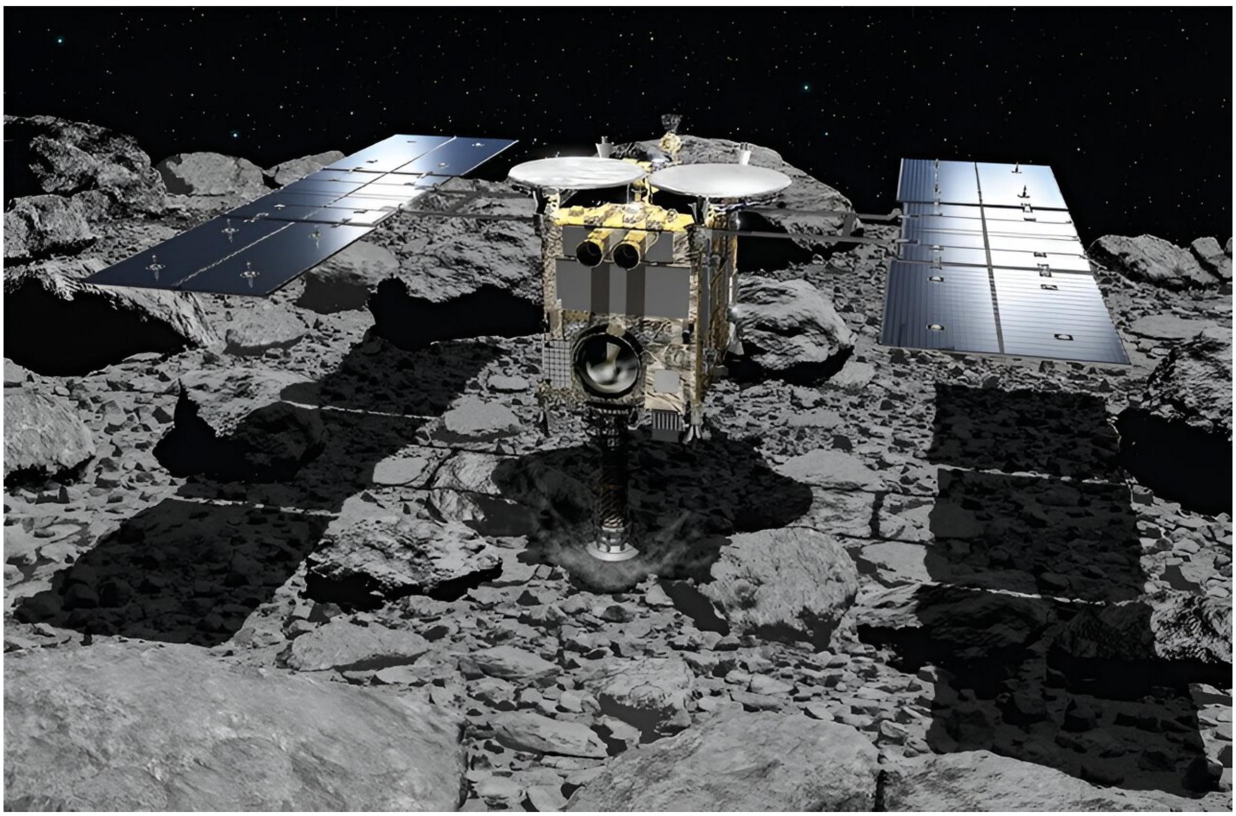

Artwork showing the Hayabusa2 spacecraft retrieving a sample from the surface of the asteroid Ryugu. Credit: Akihiro Ikeshita

Imagine opening a time capsule, hoping to learn about the ancient past. Except, instead of a box or a chest, it's an asteroid that could provide insights into the very dawn of life on Earth.

That was the situation that researchers using the Advanced Light Source (ALS) faced. As the ALS is a Department of Energy (DOE) Office of Science user facility, the team that works there sees a lot of unusual items, from materials for solar cells to particles influenced by wildfires. But even for this crew, a sample from an asteroid was unusual.

Fortunately, the innovative tools available at the ALS allowed them to support scientists digging into the history of these rocks delivered from space.

Just like studying rocks on Earth can tell us about Earth's early history, studying primitive small bodies such as asteroids, meteorites, and comets can tell us about our solar system's history.

Chondrites are a particularly useful type of meteorite. They are undifferentiated and chemically primitive. The rocks in them trace back to dust and small grains in the early solar system that came together to form a large parent body.

A certain type of chondrites (called carbonaceous chondrites) preserve relatively abundant chemicals that are easily vaporized, including carbon and water. These are the building blocks of life on Earth. By studying these preserved materials, scientists can investigate one of humanity's fundamental questions: "Where did we come from?"

The team using the ALS examined a sample from the surface of a carbonaceous-type asteroid, Ryugu. They expected this asteroid to be similar to carbonaceous chondrite meteorites. Ryugu is relatively close to Earth, compared to asteroids in the main belt between Mars and Jupiter.

Scientists hypothesize that Ryugu is a rubble-pile asteroid. They think that it formed when an object hit its parent body and then the rocks that were ejected re-coalesced into a new asteroid. After that process, the asteroid moved from the main belt to near-Earth orbit.

The Japan Aerospace Exploration Agency (JAXA)'s spacecraft, Hayabusa2, collected samples from two locations on the surface of Ryugu in 2019 and returned them to Earth in 2020. The curatorial work at JAXA found a total of 5.4 g of sample.

The agency allocated a small portion of the sample to the Hayabusa2 initial analysis team, consisting of about 400 scientists around the world. Hikaru Yabuta at Hiroshima University led one of six sub-teams of the initial analysis team.

Ultrathin sections of the asteroid particles arrived at the ALS at DOE's Lawrence Berkeley National Laboratory. The ALS allows scientists to precisely identify the elements and molecules inside materials. It uses a particle accelerator to produce extraordinarily bright X-ray beams. Like the X-rays at a doctor's office, they reveal information about what is inside an object. But instead of just highlighting bones, these X-rays allow scientists to probe the chemical and structural properties of the matter itself.

First, the team carefully scanned the sample in long horizontal rows—like text in a book—with X-rays. By measuring how the X-rays change as the scanning happens, scientists could identify individual grains of organic material in the asteroid sample. These grains were tiny—only 100 times bigger than a strand of DNA.

Once the scientists identified grains of interest, they used X-rays to reveal the type of chemical bonds in the organic carbon grains. In this case, the researchers used the process to map out the various elements and functional groups (specific arrangements of atoms) in the sample.

Based on this analysis, the scientists found four different types of carbon compounds as well as different types of structures. After identifying these materials, the scientists compared them to similar meteorites that they already knew the history of.

Piecing together all of this data allowed them to outline a broad history of the asteroid during the early solar system, which formed about 4.6 billion years ago. The chemical compositions of the organic carbon in the samples indicated that Ryugu's organic matter resulted from the precursors to that matter changing during a chemical reaction with liquid water on the asteroid's parent body.

The isotopes of carbon in the samples reflected that the organic precursors came from the extremely cold environment of space (about -200°C). The team was the first to prove the direct link between organic matter in the carbonaceous asteroid and the similar organic matter in primitive carbonaceous chondrites (meteorites).

There was one type of material notably missing—graphite. Graphite is a familiar form of carbon used in pencil leads. In asteroids, graphite or graphite-like material is a sign that the carbon was formed by radiogenic heating in parent bodies for several million years. The lack of it suggests that the sample collected from the asteroid was never exposed to heat above 390°F (200°C).

Studying the material from Ryugu wasn't the first or likely the last time that scientists will use the ALS to take a close look at rocks from space. Researchers used the ALS to analyze dust particles from the comet 81P/Wild 2 collected by NASA's spacecraft Stardust in 2006.

They found that the comet dust contained organic matter. This matter was composed of nitrogen- and oxygen-bearing chemical bonds as well as types of organic matter similar to that observed from the asteroid Ryugu and other chondritic meteorites.

These studies demonstrated tools and techniques that have proven useful for analyzing samples like those from NASA's OSIRIS-REx mission. This mission collected samples from the asteroid Bennu. In the fall of 2023, it returned them to Earth. The agency recently released a [catalog of samples](#) for scientists to study.

The ALS and other light sources allow us to draw lines from the earliest history of our solar system to today. Through shedding light on the objects in our current solar system, the DOE Office of Science scientists and user facilities may one day help us better understand how Earth became habitable.

Provided by US Department of Energy

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