October 4, 2022
High Energy Accelerator Research Organization (KEK)
Japan Proton Accelerator Research Complex (J-PARC) Center
Japan Atomic Energy Agency (JAEA)

Muon experiment reveals more detail of asteroid Ryugu

Stone samples brought back to Earth from asteroid Ryugu have had their elemental composition analyzed using an artificially generated muon beam from the particle accelerator in Japan Proton Accelerator Research Complex (J-PARC). Researchers found a number of important elements needed to sustain life, including carbon, nitrogen, and oxygen, but also found the oxygen abundance in asteroid Ryugu was different from all meteorites that have been found on Earth, reports a new study in *Science*.

In 2014, the unmanned asteroid explorer Hayabusa 2 was launched into space by the Japan Aerospace Exploration Agency (JAXA) with a mission to bring back samples from asteroid Ryugu, a type C asteroid that researchers believed was rich in carbon. After successful landing on Ryugu and collecting samples, Hayabusa 2 returned to Earth in December 2020 with samples intact.

Since 2021, researchers have been running the first analyses of the samples, led by University of Tokyo Professor Shogo Tachibana. Split into several teams, researchers have been studying the samples in different ways, including stone shapes, elemental abundance, and mineral composition.

Ryugu samples awaiting muon analysis
The Ryugu samples are in the area circled in white and wrapped in copper foil. During analysis, silver holder was removed, and samples were placed in a copper-only space except for the sample.

In this study, led by Tohoku University Professor Tomoki Nakamura, the Institute for Materials Structure Science(IMSS) of High Energy Accelerator Research Organization (KEK), Osaka University, the Kavli Institute for the Physics and Mathematics of the Universe (Kavli IPMU) of University of Tokyo, Japan Atomic Energy Agency (JAEA), Kyoto University, International Christian University, Institute of Space and Astronautical Science (ISAS) of JAXA and Tohoku University have applied elemental analysis methods using negative muons, elementary particles produced by the accelerator at J-PARC. They applied the method to stones from the asteroid Ryugu (Figure 1), succeeding in nondestructively determining their elemental compositions.

This is important, because if asteroids were built at the beginning of the formation of the Solar System itself, then they would still withhold information about the average elemental composition at that time, and therefore that of the entire Solar System.

Analysis of meteorites that have fallen to Earth have been carried out in the past, but it is possible these samples have been contaminated by the Earth's atmosphere. So, until Hayabusa 2, no one knew what the chemical composition of C-type asteroid was for sure (S-type asteroid composition was revealed by Hayabusa mission).

Figure 1: a sample of the asteroid Ryugu. (Credit: JAXA)

But the researchers faced a challenge. Muon elemental analysis has been used for relatively large samples, such as archaeological samples, and has not been used for samples weighing less than 1 grams.

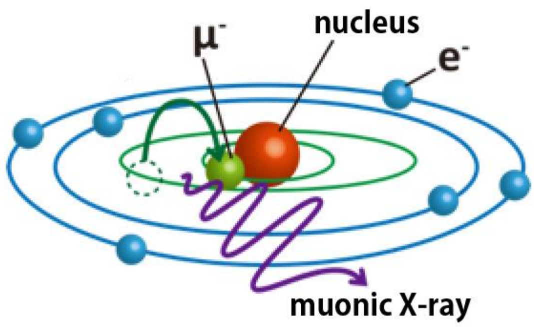

Figure 2: A muonic X-ray created after a muon is captured by an atom of irradiated material.

The team had developed a new method, which involved shooting a quantum beam, or specifically a beam of negative muons, produced by one of the world's largest high-energy proton accelerators J-PARC in Ibaraki prefecture, Japan, to identify the chemical elements of sensitive samples without breaking them.

Muons are one of the elementary particles in the universe. When a negative muon is captured by the irradiated sample, a muonic atom is formed (Figure 2). The muonic X-rays emitted from the new muonic atoms have high energy, and so can be detected with high sensitivity. This method was used to analyze the Ryugu samples.

But there was another challenge. In order to keep the samples from being contaminated by the Earth's atmosphere, the researchers needed to keep the samples out of contact with oxygen and water in the air. Therefore, they had to develop an experimental setup, casing the sample in a chamber of helium gas (Figure 3). The inner walls of the chamber were lined with pure copper to minimize the background noise when analyzing the samples.

Figure 3: The custom-made experiment setup developed to avoid the samples from being contaminated by the Earth’s atmosphere. The interior is filled with helium gas, and the chamber is lined with pure copper to minimize background noise. (Credit: KEK IMSS)

In June 2021, 0.1 grams of Ryugu asteroid were brought into J-PARC, and the researchers ran their muonic X-ray analysis, which produced an energy spectrum (figure 4). In it, they found the elements needed to produce life, carbon, nitrogen and oxygen, but they also found the sample had a composition similar to that of carbonaceous chondrite (CI chondrite) asteroids, which are often referred to as the standard for solid substances in the Solar System. This showed the Ryugu stones were some of the earliest stones to have formed in our Solar System.

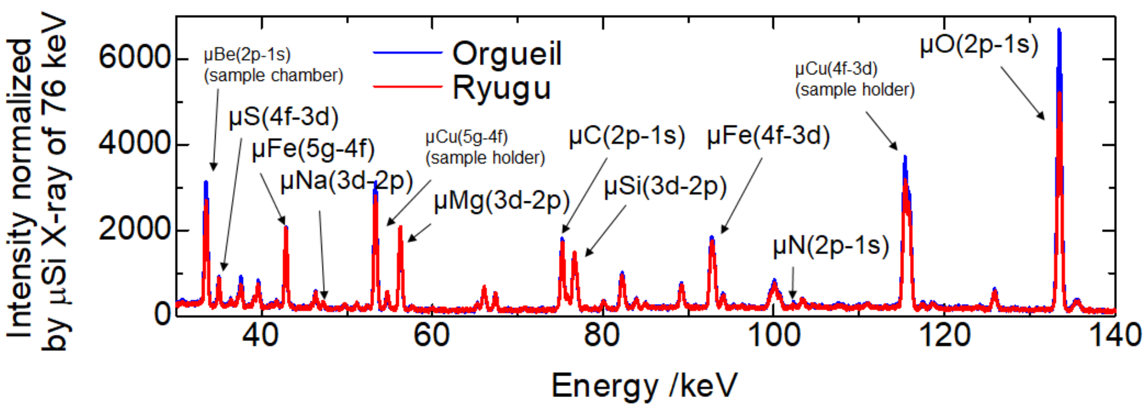

Figure 4: Muonic X-ray spectral comparison of asteroid Ryugu sample and CI chondrite Orgueil

However, while similar in composition to CI chondrites, the Ryugu sample’s oxygen abundance was about 25 per cent less than that of the CI chondrite. The researchers say this could indicate that the excess oxygen abundance in CI chondrites could have come from contamination after they entered Earth's atmosphere. Ryugu stones could become a new standard representative of the Solar System.

The team’s results show the success of the muonic X-ray method, and that it can be used to analyze samples from future space missions.

Details of this study were published in *Science* on September 22.

Note : The Muon Analysis Team was formed to perform the muon analysis and belongs to the "Stone Material Analysis Team." Members include: KEK/J-PARC Materials and Life Science Experimental Facility Professor Emeritus Yasuhiro Miyake, Assistant Professor Izumi Umegaki, Assistant Professor Soshi Takeshita, Professor Koichiro Shimomura, Japan Atomic Energy Agency Chief Researcher Takahito Osawa, Osaka University Associate Professor Kazuhiko Ninomiya, Professor Kentaro Terada, Specially Appointed Researcher I-Huan Chiu, University of Tokyo Professor Tadayuki Takahashi, graduate student Shunsaku Nagasawa, Assistant Professor Shin’ichiro Takeda, Project Researcher Miho Katsuragawa, graduate student Takahiro Minami, Kyoto University Associate Professor Akihiro Taniguchi, International Christian University Professor Kenya Kubo, Japan Aerospace Exploration Agency Associate Professor Shin Watanabe, Tokyo University of the Arts part-time lecturer Kazumi Mizumoto, RIKEN Chief Scientist Toshiyuki Azuma, and Tohoku University Professor Tomoki Nakamura and graduate student Taiga Wada.

Group photo of the researchers (Credit: KEK IMSS)

Paper details (includes results outside of the Muon Analysis Team)
Journal: *Science*
Paper title: Formation and evolution of carbonaceous asteroid Ryugu: Direct evidence from returned samples
Authors: T. Nakamura et.al
DOI：10.1126/science.abn8671 (published September 22, 2022)
https://global.jaxa.jp/press/2022/09/20220923-1_e.html

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