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MASCOT IN WONDERLAND

Breaking new ground with the Hayabusa2 mission

QUIETER FLIGHT

AUTOMATED TRANSPORT

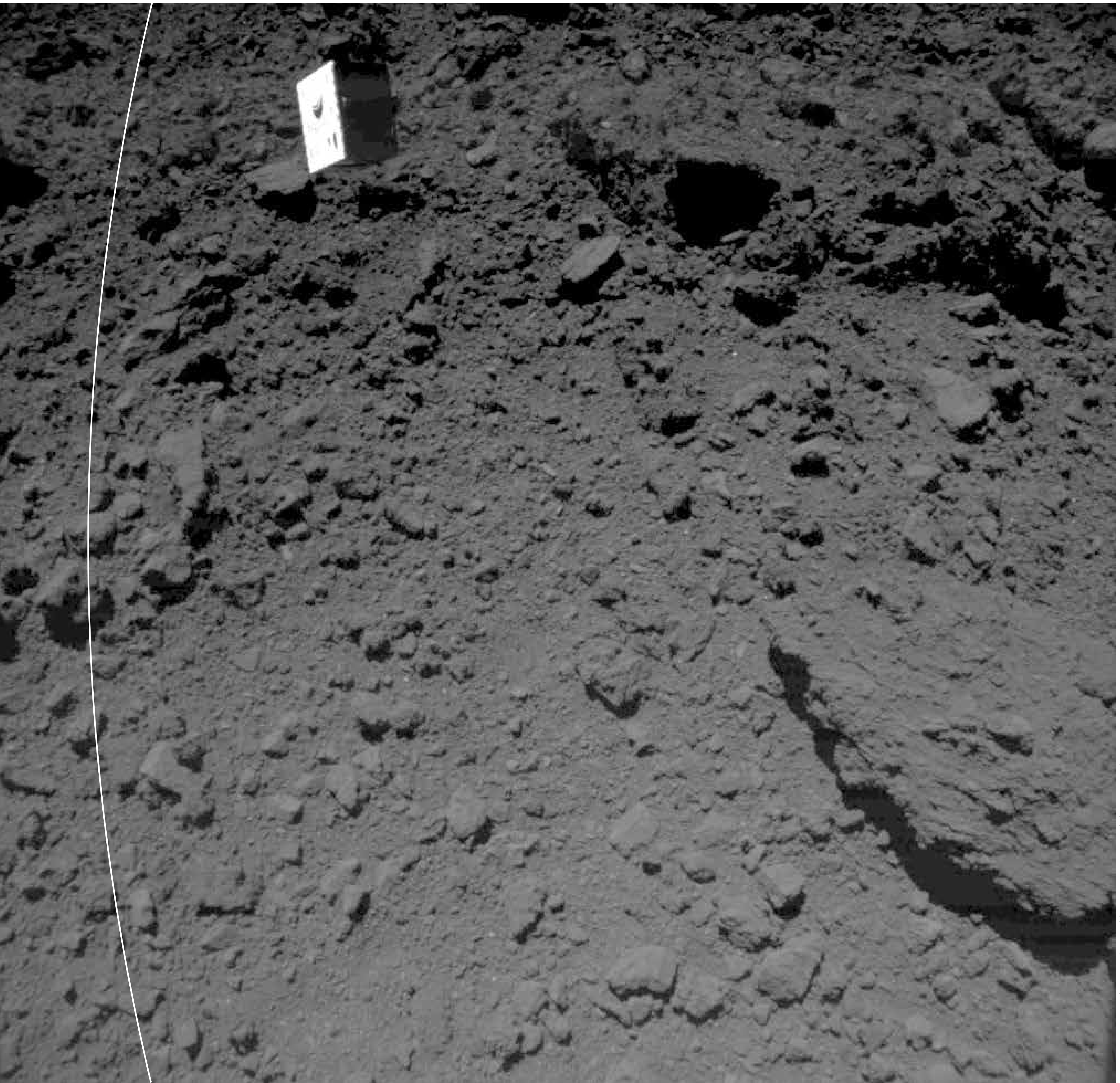
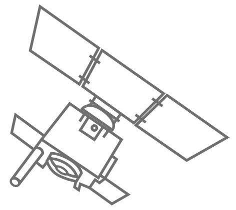


Image: JAXA/U Tokyo/Kochi U/Rikkyo U/Nagoya U/Chiba Inst Tech/Meiji U/U Aizu/AIST

A photograph that will receive a prominent place in the book about 60 years of space travel history. Shortly after the separation of MASCOT 51 metres above the asteroid's surface, the Hayabusa2 space probe's imaging system captured the descent of the French-German landing device over Ryugu's boulder-strewn surface.

MASCOT IN WONDERLAND



The Day of German Unity – 3 October – in 2018 will not be forgotten by those at DLR's Microgravity User Support Center (MUSC) in Cologne. It was a very special day that started very early at the control centre. Most of the MASCOT team was already there on the previous evening. And the remaining scientists from Germany, France and Japan arrived shortly before midnight. Four experiments, four teams. There was a quiet, concentrated atmosphere full of tension, amidst dozens of monitors and open laptops. Everyone tried to be as calm as necessary, but also as focused as possible. An otherworldly event was about to take place on the other side of the Sun, some 300 million kilometres from Earth. At precisely 03:57 and 21 seconds CEST, an asteroid lander would play the role of its life – and the team back on Earth would not be able to intervene. The microwave-sized Mobile Asteroid Surface Scout – MASCOT – fully equipped with high-tech robotics, would separate from the Hayabusa2 spacecraft at an altitude of 51 metres and begin its descent to the approximately 900-metre-diameter asteroid Ryugu.

The Hayabusa2 mission and the MASCOT lander are breaking new ground in space research

By Ulrich Köhler

"Separation from Hayabusa2 confirmed," announces MASCOT project manager Tra-Mi Ho from the DLR Institute of Space Systems. "The magnetometer telemetry indicates it." Celebration! All is nominal – the magic word all those involved in spaceflight missions want to hear. Silence reigns. The wait for the most important moment of the mission begins. MASCOT has no propulsion system and is descending towards Ryugu in free fall at a speed of a few centimetres per second. Intervention from the ground station is not possible and futile, as it takes a signal over 17 minutes to reach the lander. Six minutes later – and 10 earlier than expected – at precisely 04:03, Operations Manager Christian Krause reports: "MASCOT has a first ground contact." Once again, there is cheer. MASCOT is finally in a place like no place on Earth. A land full of wonder, mystery and danger! This time, however the jubilation is cautious, as most of the team is surprised by how quickly the lander has descended and made its initial contact with the surface. The DLR-developed German-French MASCOT would continue to travel several metres with uncontrolled movements from the first point of ground contact before reaching its provisional final position in the asteroid's minimal gravitational field. That, too, happens nominally.

MASCOT, the box-shaped instrument rack made of sturdy carbon fibre composite measuring 30 x 20 x 20 centimetres and weighing just 10 kilograms, came to a standstill. The gravitational pull on Ryugu is only about one sixty-thousandth of that on Earth, which means that MASCOT weighs less than one gram there. The 'rolling', like dice on a game board, has no effect on the mechanical structure or the technology and the instruments in its interior. The engineers have extensively tested this beforehand. MASCOT carries four experiments. The lander made it to its planned landing site, located at 310 degrees east and 30 degrees south. The scientists spontaneously named it 'Alice's Wonderland', after the eponymous children's book by Lewis Carroll.

It was noon on Ryugu, where both day and night last just three hours and 45 minutes. The radio link to the Hayabusa2 mothercraft, which had ascended to an altitude of 10 kilometres to receive signals from MASCOT, was stable. During the lander's descent, the MASCAM camera system acquired 20 images and transmitted them to the probe. They show an asteroid landscape strewn with angular boulders and sharp stones. MASCOT's first contact with Ryugu was on a five-metre rock. Rubble fills the landscape, but there is no dust in sight – what a surprise! Hayabusa2's three cameras captured the lander's descent in numerous pictures, allowing for MASCOT's free fall on the asteroid and rolling movements to be reconstructed.

Image: JAXA

Hayabusa2 is a very complex space mission. The main task is the exploration of Ryugu, an approximately one-kilometre-diameter, primitive asteroid from the time of planet formation. The highlight will be three samples taken in the coming year. By the end of 2020, a capsule with asteroid material will arrive on Earth.

Landing on its back!

Upon its first contact with the ground, MASCOT bounced and subsequently touched the ground eight more times. It reached its resting position half an hour later. As programmed into the on-board computer, MASCOT immediately started conducting experiments with its four instruments on Ryugu's surface. At the same time, the first housekeeping data from MASCOT started to arrive at the control centre in Cologne via Hayabusa2: state of charge of the battery, temperature of the instruments, memory usage, orientation data, status of the data transmission. Following analysis of the data, the scientists and mission control got a real scare – MASCOT was lying on its back like a turtle. This was not unusual, because the odds that a box-shaped body with six flat sides would immediately end up in the right orientation to conduct the experiments was about one to six. Precisely for this reason, a system was developed to enable MASCOT to automatically change its position – a tungsten metal weight that would be rotated with a swing arm, providing the necessary momentum for MASCOT to flip itself over and even hop across the surface thanks to Ryugu's low gravitational pull.

But MASCOT did not make this swing! A short and intensive meeting took place in Cologne. A decision had to be made fast, since the battery's lifetime was just 16 hours. The signals of the position sensors should have recognised the erroneous position and sent a command to the swing arm mechanism autonomously. But since this did not happen, a decision was made to send a command to the motionless landing device to make it turn 180 degrees. Although this meant losing some valuable exploration time, there was no alternative. The camera, spectrometer and radiometer were just looking into space! Then, there was a big sigh of relief – the manoeuvre produced the desired effect, and MASCOT was now in a favourable position. The instruments then began to carry out their measuring sequences automatically. Meanwhile, the small lander had already been on the asteroid for a full day-and-night cycle. MASCOT's second day on Ryugu began at 09:52, almost six hours after first contact.

Hayabusa2 – Impossible is nothing

Past and future: The Hayabusa2 space probe, which was launched on 3 December 2014, reached asteroid Ryugu in June 2018. The Japanese Aerospace Exploration Agency JAXA's mission is highly complex. Initially, the 'Peregrine Falcon' observed the asteroid from its 'home' position at an altitude of 20 kilometres. The probe is the successor of the Hayabusa mission, which took samples from the asteroid Itokawa in 2005 and, despite considerable technical difficulties, delivered them to Earth in 2010. The second Peregrine Falcon will collect more material, do so from more than one location, and from a Near-Earth Asteroid. The scenario for this is extremely complex and challenging – from the approach of the Hayabusa2 space probe in early 2019 to one metre above the surface, through to touchdown on Ryugu and the activation of its cylinder-shaped sampler horn. A tantalum projectile will be fired from this horn into the asteroid, to stir up the surface material. The dust that rises into the collecting horn will then be fixed and sealed in a container. This will be repeated at a second location.

The third and final sample collection will be truly spectacular. Hayabusa2 will deploy the Small Carry-on Impactor (SCI), a kinetic impactor consisting of a 2.5 kilogram copper projectile accelerating at two kilometres per second to Ryugu's surface by an explosive propellant charge. To ensure that this does not damage the spacecraft, Hayabusa2 will take cover on the other side of the asteroid. A simultaneously deployed miniature camera will record the impact. Hayabusa2 will then approach the artificial crater, where it will touch down and collect the freshly disturbed asteroid material, which has not or hardly been affected by cosmic radiation and the solar wind. Hayabusa2 will return to Earth in 2020, carrying these samples. In addition to deploying MASCOT, eight partially moveable mini-devices will be placed on the asteroid during the mission. These will mark the artificial crater or record the landscape with stereo cameras. No previous exploration mission has ever used such innovative and unconventional technology.

Observing a celestial body up close using a space probe is highly valuable to scientific research, while taking samples and delivering them to Earth is the ultimate achievement. Finally, conducting experiments on the surface really is the cherry on the cake. The MASCOT lander, developed by DLR and the French space agency CNES, embodies a completely new concept for landing on a body with an exceptionally low gravitational pull. DLR's MASCAM camera, which began taking images during the descent, photographed the surrounding area from the landing site all the way to the horizon in high resolution. A total of 120 images were acquired – more than twice as planned – and the light-emitting diodes allowed pictures to be taken even at night. The French MicrOmega infrared spectrometer investigated the mineralogical composition of the asteroid's material through the direct contact of its sensor on MASCOT with the surface. The MasMag magnetometer, developed at the Technical University Braunschweig, collected data on Ryugu's possible magnetic field, which would have been imposed on the small body in the early days of the Solar System. Finally, DLR's MARA radiometer recorded the surface temperature and thermal properties of the regolith.

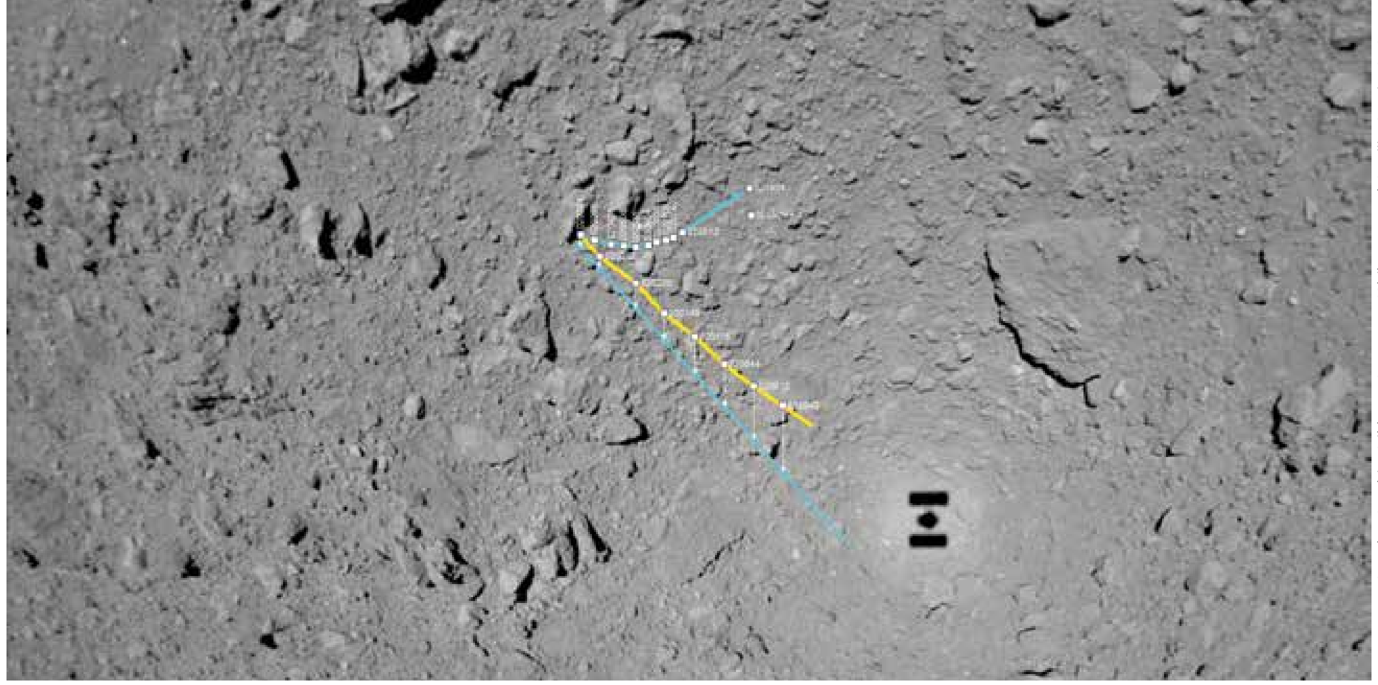
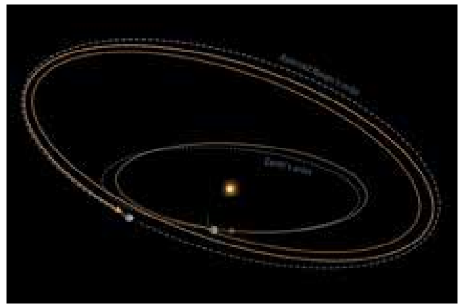


Image: JAXA/U Tokyo/Kochi U/Rikkyo U/Nagoya U/Chiba Inst Tech/Meiji U/U Aizu/AIST

The imaging system of the Japanese Hayabusa2 spacecraft followed MASCOT's descent. The probe's shadow can be seen on the lower right. The dots in the image indicate the times at which the pictures of MASCOT were taken. The yellow line marks the positions at which MASCOT was still descending towards Ryugu. The blue line, below the yellow line, is the projection of these positions onto the asteroid surface. This shows that MASCOT covered a near-straight flight path.



The orbit of asteroid Ryugu approaches Earth's orbit to as close as 95,000 kilometres

Seventeen exciting hours in the MASCOT control centre at the DLR site in Cologne

DLR's MASCAM camera reveals a big surprise; stones, rocks and boulders everywhere – but no dust.

Image rechts: MASCOT/DLR/JAXA

Primordial material with a latent threat

Asteroids are the remnants of planetary formation. More than 750,000 such bodies are known, most of which orbit the Sun in the Main Asteroid Belt, between Mars and Jupiter. Above all, there are asteroids whose paths cross that of the Earth around the Sun. Today, around 17,000 such asteroids have been catalogued. Most of their orbits are sufficiently well known and pose no threat to Earth. One of the major topics of exploration is the characterisation of these near-Earth objects (NEOs) and the avoidance of collisions with Earth through the use of technology. With Hayabusa2 and MASCOT, scientists are hoping to achieve two objectives. Firstly, they aim to obtain information from Ryugu – a representative of a particularly 'primitive', carbon-rich class of asteroids that originates from the earliest period of the Solar System – about the formation of planets. Secondly, the scientists want to know exactly what asteroids crossing Earth's orbit are made of.

MASCOT's third day on Ryugu began on 3 October 2018 at 17:30 local time in Cologne. At this moment, the lander made a small movement on command – a 'mini-move' – to optimise the position of the sensors. And the measurements continued. At 20:04, the last jump is commanded to MASCOT from the control room. Rationally, as engineers can sometimes be, they announced the End of Life phase of the mission. The lander began at the beginning … and continued until the end. Yet the measurement programme continued through to 21:00 that evening in Cologne, far into its mission – and its maximum battery life. Contrary to the calculations, the battery continued to provide power until contact with MASCOT was broken off by radio silence and imminent nightfall. Instead of 16 hours, the experiments were conducted for 17 hours and seven minutes, a highly valuable full hour more than planned.

The palace of the dragon god

In Japanese mythology, Ryugu is the underwater palace of the dragon god. Legend has it that a brave fisherman was once rewarded with a visit to the magnificent building. He brought back a treasure chest with a secret hidden inside it. Indeed, MASCOT's findings together with the dust samples that Hayabusa2 collects from the asteroid Ryugu, which will reach Earth in a hermetically sealed landing capsule, could well be considered a scientifically valuable treasure from the asteroid realm. Exploring Ryugu from up close, confirming and enhancing these insights with the small MASCOT lander, and analysing the samples will revolutionise observations of this type of asteroid. Hayabusa2 could thus become the standard on which future telescopic observations, in particular, are based.

Ulrich Köhler is a planetary geologist at the DLR Institute of Planetary Research and was present during NASA's Jupiter Galileo probe flyby of asteroid Gaspra in 1991, when an asteroid was photographed up close for the very first time.

MASCOT – BORN AT DLR

The DLR Institute of Space Systems in Bremen was responsible for developing and testing the lander in collaboration with France. The DLR Institute of Composite Structures and Adaptive Systems in Braunschweig was responsible for the lander's stable structure. The DLR Institute of Robotics and Mechatronics in Oberpfaffenhofen developed the swing arm that allows MASCOT to hop across the asteroid. The DLR Institute of Planetary Research in Berlin contributed the MASCAM camera and MARA radiometer. The asteroid lander was monitored and operated from the MASCOT control centre at the Microgravity User Support Center (MUSC) at the DLR site in Cologne.