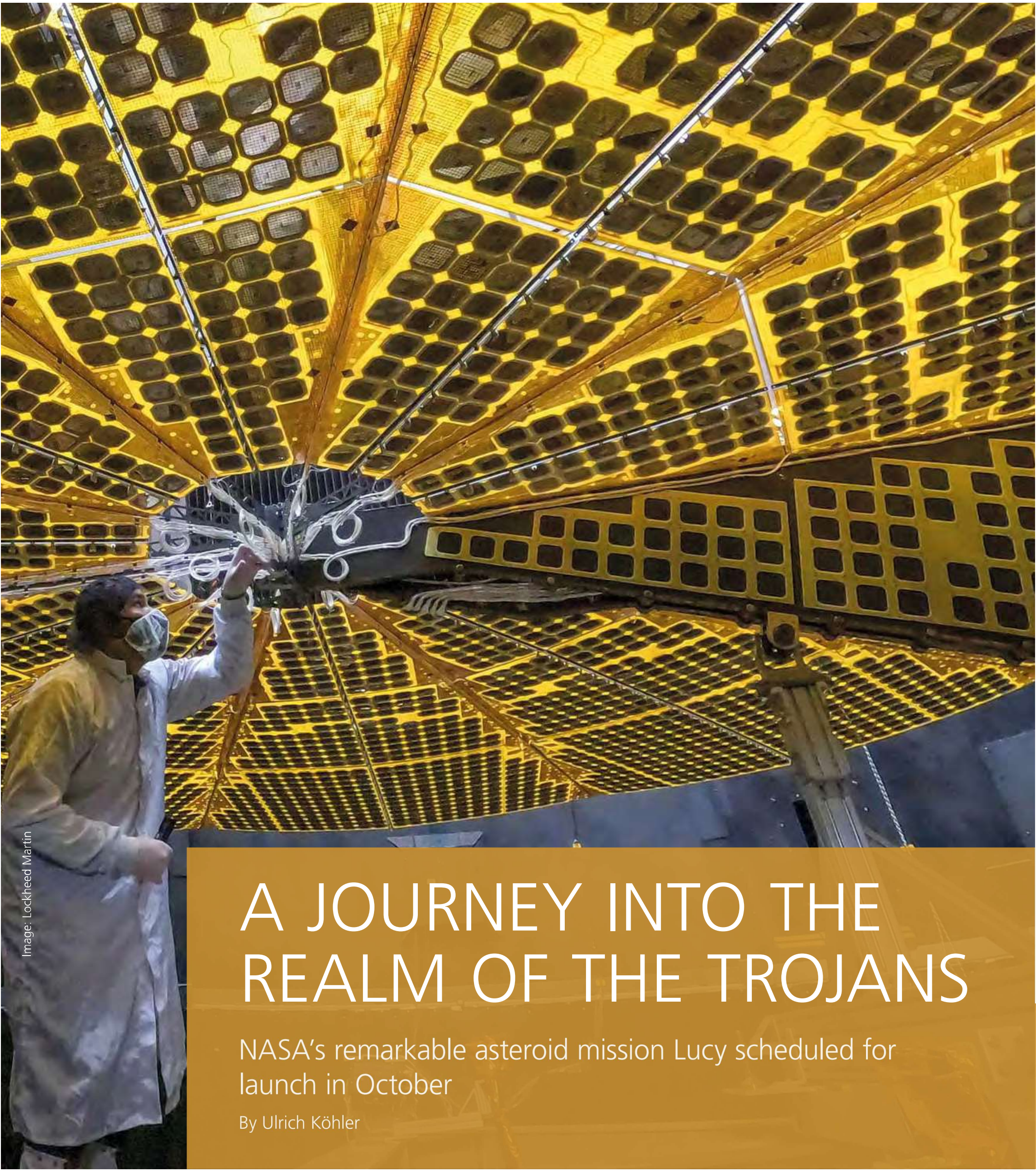


Image: Lockheed Martin

# A JOURNEY INTO THE REALM OF THE TROJANS

## NASA's remarkable asteroid mission Lucy scheduled for launch in October

By Ulrich Köhler

In early 2021, the deployment of the two 7.3-metre-diameter solar panels was tested under space conditions.

**How did the Solar System form? Why did the planets develop so differently from one another? Planetary research now has an idea of how matter in the disc of gas and dust orbiting the young Sun agglomerated to form the first protoplanets 4.5 billion years ago. However, many questions have yet to be answered, not least those relating to the origin of life on Earth. Where did Earth's water come from? How about the building blocks of life? Were they on Earth from the beginning, or were they carried there at a later stage by small celestial bodies, asteroids and comets? In October 2021, NASA's Lucy spacecraft will embark on a 12-year journey to answer these and more questions – and DLR will be right there.**

Image: NASA

In the laboratory at NASA's Goddard Space Center in Greenbelt, Maryland, two researchers work on L'Ralph, the most complicated instrument on the Lucy mission. It comprises a camera that will take colour images and an infrared spectrometer.

Lucy's targets are the Jupiter trojans, small bodies up to 250 kilometres in diameter located in two regions that precede or follow Jupiter, the largest planet in the Solar System, by a fixed distance along its orbit. The locations at which this is possible are called Lagrange points. These are positions in space where the gravitational forces of a two-body system like Earth and the Sun balance out. There are five such points, numbered from Lagrange-1 (L1) to Lagrange-5 (L5) and named after the Italian-French astronomer and mathematician Joseph-Louis de Lagrange (1736–1813). Two of these Lagrange points, L4 and L5, are always stable and each form the third apex of an equilateral triangle with 60-degree angles to the Sun and Jupiter. This will be the first time that bodies orbiting the Sun at Lagrange points along a planet's orbit have been visited by a spacecraft. Achieving this has been a top priority in planetary research for many years.

### The somewhat different asteroids

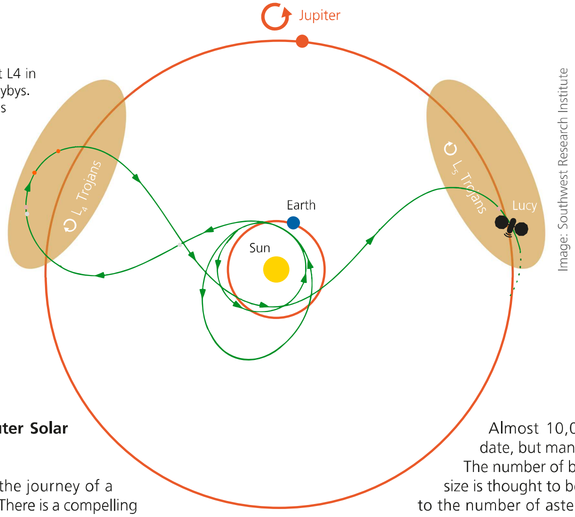
Although the existence of asteroids has long been common knowledge, the first observation of an asteroid took place just 220 years ago. On the night of 1 January 1801, while looking for an unknown planet, the director of the observatory in Palermo, Giuseppe Piazzi, observed a 'star' in the unusually large 'void' between the orbits of Mars and Jupiter, in the Taurus constellation. He noticed that its position changed on the nights that followed. Piazzi had discovered the asteroid Ceres, the largest body in the expanse between the two planets.

More discoveries soon followed. Today, we know of more than one million small bodies in the Main Asteroid Belt. These are thought to be the remnants of the planet-forming process: debris made of rock, metals and – in the farthest reaches of the Solar System – ice, which could not agglomerate to form a planet due to the disruptive effect of Jupiter's gravitational pull. The countless craters on Mars, the Moon and Mercury tell us that Jupiter, which has 2.5 times more mass than all other planets combined, regularly redirects bodies from the Main Asteroid Belt into the inner Solar System. There they collide with the terrestrial planets, forming craters – far more frequent billions of years ago than today. On Earth, these traces have been almost completely erased by the dynamic processes occurring on the surface. At the same time, Jupiter is forcing the majority of the asteroids onto stable orbits – a process that may have even ensured the survival of life on Earth.

Spaceflight makes it possible to observe asteroids up close. In the 1990s, the Galileo spacecraft flew past the asteroids Gaspra (1991) and Ida (1993) on its way to Jupiter. Between 2011 and 2018, NASA's Dawn orbiter observed the asteroids Vesta and Ceres at close range for many months from different orbits, using a camera developed by DLR and the Max Planck Society. Ceres, which measures almost 1000 kilometres across, has since been 'promoted' to the status of dwarf planet. The two Japanese Hayabusa spacecraft even touched down on asteroids and collected samples. NASA's OSIRIS-REx is currently on its way back to Earth, carrying dust from the asteroid Bennu.

Image: SwRI

Artist's impression of the Lucy spacecraft flying past one of the Trojan asteroids




Lucy will reach Jupiter's Trojans at L4 in April 2025 following two Earth flybys. There, it will observe the asteroids Eurybates, Polymele, Leucus and Orus from close range before returning towards Earth in 2029. The spacecraft will use Earth's gravity to accelerate again in 2030/31 and fly to the L5 point to investigate the asteroid Patroclus in 2033.

**Time capsules from the outer Solar System**

Lucy is about to embark on the journey of a lifetime to the Jupiter Trojans. There is a compelling scientific reason for the mission: researchers believe that, unlike the main belt asteroids, these Trojans have less in common with the bodies of the inner Solar System and more in common with its outer regions. The realm of the gas giants and their ice moons begins with Jupiter, at almost five times the distance from Earth to the Sun. Even further out, beyond Neptune, stretch the regions where the comets, bodies of dust and ice, once originated. This is the zone of the trans-Neptunian objects, including Pluto.

Just as the main belt asteroids are remnants of the formation of the four terrestrial planets, the Jupiter Trojans are likely to be remnants of the source material of the outer planets, which formed at very different distances from the Sun. Like the comets, these asteroids are 4.5 billion-year-old 'time capsules' from the age of planetary formation. They may even contain organic molecules made of carbon and hydrogen that later made their way from there into the inner Solar System, and thus to Earth. These substances could have played an important role in the emergence of life almost four billion years ago. They may also harbour tholins, the red-brown, organic nitrogen compounds discovered on Pluto and its companion Charon. Until now, the Trojans have only been observed with telescopes. This is difficult, as they are made of very dark material and are much further away from Earth than the main belt asteroids. Yet even these studies indicate that the Trojans must be very different in nature.

Almost 10,000 Trojans are known to date, but many more are believed to exist. The number of bodies over one kilometre in size is thought to be close to a million – similar to the number of asteroids in the Main Asteroid Belt. The Heidelberg astronomer Max Wolf (1863–1932) discovered the first Trojan on Jupiter's orbit in 1906. He named it after Achilles, the supposedly invincible Greek hero (if only it hadn't been for his heel!) from the mythical battle between the Hellenes and Troy. This is how the Trojans got their collective name. Inspired by Homer's epic, The Iliad, the assembly of asteroids known as the 'Greeks' form an 'army camp' at the L4 point on Jupiter's orbit, hurrying ahead of the planet, and the 'Trojans', intent on defending their city, Troy, are located at L5. Jupiter's gravitational pull creates a particular dynamic within both camps, but there is no transfer between them. This back and forth is not yet well understood.

**Setting a course into the unknown**

NASA selected Lucy as the successful Discovery class mission in 2017, along with another asteroid mission called Psyche. The latter will embark on a journey to the 220-kilometre main belt asteroid Psyche, a body made almost entirely of metal, in August next year. The name Lucy is not an abbreviation, as is so often the case with NASA missions. It refers to one of the most important discoveries in anthropological research: that of the 3.2 million-year-old partial female skeleton of Australopithecus afarensis in Ethiopia, known as an 'early human'. Palaeontologist Donald Johanson, who discovered Lucy, celebrated by throwing an exuberant party with his team on the evening of that November day in 1974. As the night wore on, the Beatles' perennially popular song Lucy in the Sky with Diamonds played repeatedly on the tape recorder. There is still some speculation over the initial letters of the three title nouns, but the skeleton needed a name. With her bones, scientists were able to decipher the origins of humankind. The NASA spacecraft is also intended to help, in a figurative sense, decode the origins of the Solar System.

The Lucy mission will see a number of striking milestones. Following the launch of the 1.5-tonne spacecraft and two Earth flybys, its first destination will be the four-kilometre asteroid 52246 Donaldjohanson, named after the palaeontologist who discovered Lucy, located in the Main Asteroid Belt. Johanson, born in 1943, is still a professor at Arizona State University today. Although the flyby will be used to test Lucy's instruments and operations, Donaldjohanson is also of scientific interest, as it belongs to a rare class of asteroids. Only after this visit will Lucy approach Jupiter's orbit and the L4 point, home to the 'Greeks'. Five close flybys are planned here between 2025 and 2028, the first at Eurybates, named after the herald of Odysseus, and its moon, Queta. Then, in a spaceflight first, it will return from Jupiter's orbit back to Earth to build the momentum to reach its next destination. Lucy will then visit the 'Trojans' at L5 and examine the 122-kilometre binary system of Patroclus and Menoetius.

The mission will officially end there, in 2033. By then, Lucy will have made three and a half large loops around the Sun and travelled four billion kilometres in between the orbits of Earth and Jupiter. The team speaks enthusiastically about Lucy's 'resourceful trajectory' – calculated through careful planning and some good fortune – that will make it possible to fly past seven of the most primordial bodies in the Solar System with a single spacecraft. This promises a rich scientific yield from a class of bodies that could give us decisive answers to big questions about the early days of the distant outer planets, and should also provide insight into Earth's early history.

**Ulrich Köhler** is a planetary geologist at the DLR Institute of Planetary Research, where he is also responsible for public outreach. In his more than 30 years at DLR, he has seen asteroids become increasingly important for Solar System research.

## LUCY – A NASA DISCOVERY CLASS MISSION

Lucy is being built by Lockheed Martin Space in Denver, Colorado. Its launch mass is 1550 kilograms, of which 729 kilograms are propellant. The launch vehicle will be an Atlas V 401. Power will be generated by two solar panels that provide 504 watts at the greatest distance from the Sun of around 1.4 billion kilometres – a record for this distance. The mission will be controlled from NASA's Goddard Space Flight Center. Harold F. Levison of the Southwest Research Institute in Boulder, Colorado, is the Principal Investigator. The scientific payload consists of a high-resolution panchromatic (black-and-white) camera, a multispectral camera, an imaging infrared spectrometer as well as a spectrometer for measuring the thermal radiation of the asteroids.


On 4 January 2020, members of the Lucy science team, including DLR planetary scientist Stefano Mottola (to the right of the pillar, behind team leader Harold Levison, with beard), discovered that the target asteroid Eurybates has a satellite barely one kilometre in size – Queta.

DLR is represented in the Lucy science team by **Stefano Mottola** from the DLR Institute of Planetary Research. Mottola was heavily involved in the Rosetta, Dawn and Hayabusa2/MASCOT missions and studies the light curves of asteroids using ground-based telescopes. The planetary researcher, who specialises in asteroids and comets, will support Lucy with telescope observations of the target asteroids to optimise the flybys. He will also assist the mission with calculations of the shapes of celestial bodies, image mosaics, atlases and mapping their brightness and composition. The shape of the asteroids will be derived using the mission's navigation cameras. **Martin Pätzold** of the University of Cologne will investigate the mass and composition of the asteroids by evaluating the Doppler effect in radio signals. His work is being financed by the German Space Agency at DLR.


(artist's impression)