

A Dark World of Ice

A space probe has journeyed to Ceres for the first time. Scientists from the **Max Planck Institute for Solar System Research** in Göttingen are using its two onboard cameras to explore the dark surface of the dwarf planet. They have already discovered signs of frozen water – but is there also an ocean slumbering deep below the craters?

TEXT **THORSTEN DAMBECK**

Some things are relative – a tenet that applies to asteroids as well. Take Ceres, for example, which the International Astronomical Union has listed in the dwarf planet category since 2006. This “dwarf,” which is named for the Roman goddess of agriculture and fertility, is simultaneously the largest of the innumerable small bodies that orbit the Sun between Mars and Jupiter.

Geometrically speaking, Ceres is an ellipsoid. At first sight, however, it resembles a sphere with an average diameter of 946 kilometers. Its planetary body is not perfect, of course; stamped on the ellipsoid is a landscape that descends as deep as 7.5 kilometers and towers up to a height of 4 kilometers in other places. This 3.2 percent variation spans a much greater range than that of our own moon (1 percent). Compared with its sister Vesta in the asteroid belt, for which this figure is around 15 percent, the variations in Ceres’ topography are merely moderate – relatively speaking.

NASA’s *Dawn* space probe traveled to both of these miniature planets after setting off on its journey in 2007. *Dawn*’s first port of call was Vesta in summer 2011. The terrestrial scout spent

around 14 months exploring this world from its orbit. The probe then ignited its electric ion thruster once again and set off toward Ceres, arriving in March 2015. It has been circling Ceres closely from different orbits ever since.

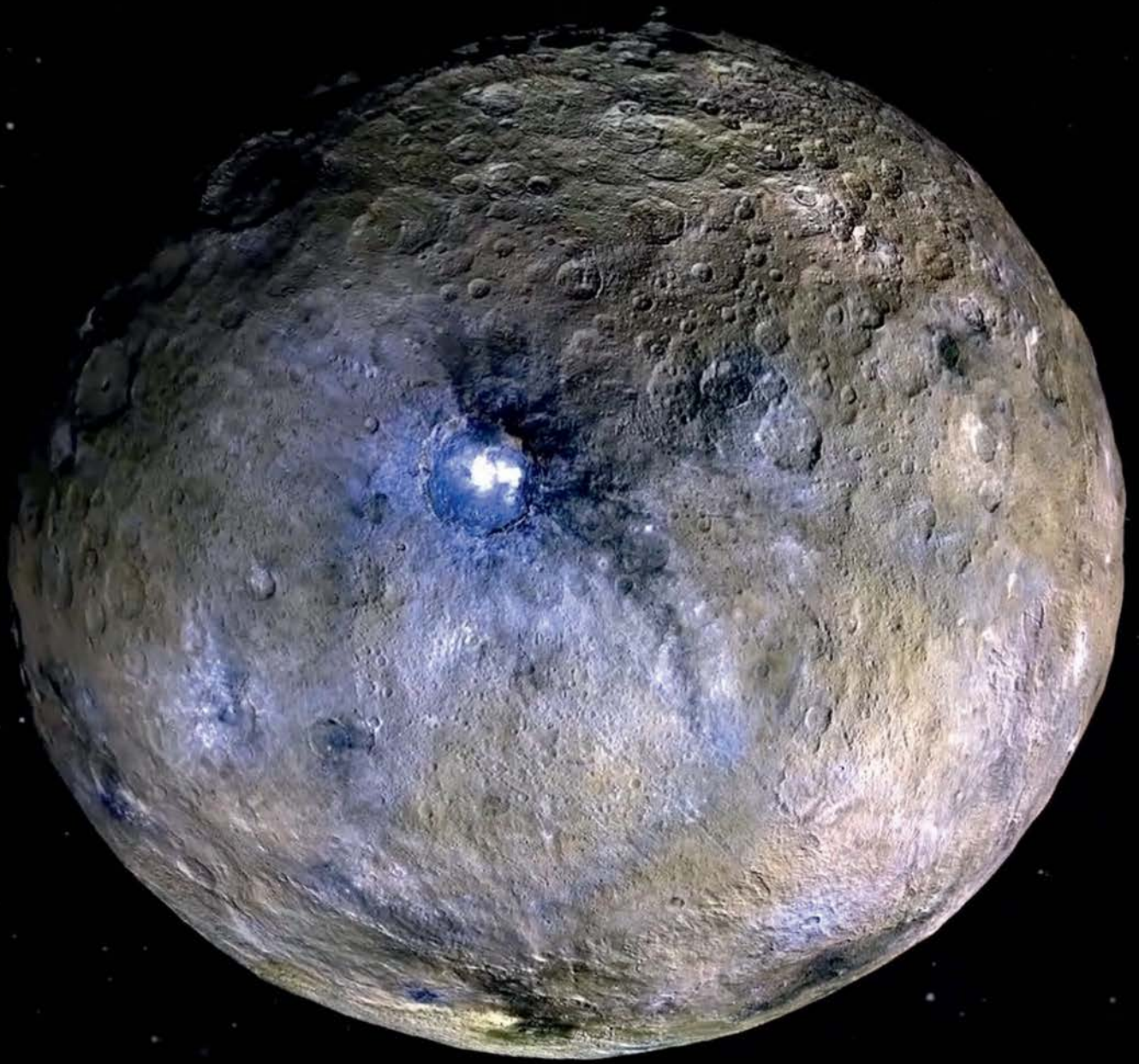
COMPLEX GEOLOGY FASCINATES THE RESEARCHERS

The scientific camera system is one of *Dawn*’s high-profile onboard experiments. It comes from the Max Planck Institute for Solar System Research in Göttingen. The two so-called framing cameras are *Dawn*’s eyes, so to speak, and they play a key role in the exploration of the two celestial bodies (see box on page 56). Now, their gaze is directed at Ceres. Most of its surface is as dark as fresh asphalt; on average, only 9 percent of incident light is reflected. The researchers are fascinated all the same: the dwarf planet is a world with a complex geology. Although much of what the flood of images is now revealing hasn’t yet been evaluated, even the preliminary analyses have unearthed unexpected details.

Dawn is the first visitor to Ceres; last year was the first time a space probe managed to get this far. Although Ce-

res was discovered more than two centuries ago by Italian astronomer Giuseppe Piazzi, very little exploration had been done there. The story of its discovery is a cosmic cliffhanger: As early as the end of the 18th century, there was widespread skepticism among scientists as to whether the conspicuous gap between Mars and Jupiter really was empty. Could an undiscovered planet be lurking there?

A group of German astronomers – the “celestial police” – systematically hunted down the suspected celestial body in the zodiacal sky. And lo and behold: on New Year’s Eve 1801, a previously unknown object was detected – Ceres. This discovery was not, however, attributable to any of the celestial police officers, but was made at the observatory in Palermo. The new “wandering star” was almost the exact same distance from the Sun that had been predicted by the Titius-Bode law for the planet they were searching for. This empirical law, named for the two scholars Johann Titius and Johann Bode, had already correctly reproduced the distance between the Sun and Uranus, which had been discovered two decades earlier. Ceres was now considered to be a planet, just like Uranus. >



Dwarf in space: This false color image shows different material on Ceres' surface. The bright regions in the Occator crater appear clearly, near the center of the image.

But the discovery of Ceres was only the beginning; there was apparently a whole gang of undiscovered planets beyond Mars: Pallas and Juno were found soon afterwards, and Vesta followed in 1807. In 1850, they were already so numerous that the designation dwarf planet gained acceptance. By the turn of the 20th century, 462 members of Ceres' species had been tracked down, and its status as a planet was now long gone. Today, almost half a million known specimens inhabit the main asteroid belt between Mars and Jupiter. Most of them are relatively small; Ceres alone accounts for around one-third of the total mass of the belt.

EAGLE-EYED CAMERA STUDIES IMPACT CRATERS

Back to the present: Researchers in the international *Dawn* team have meanwhile presented the first geological maps of Ceres. These, however, are

based on observations with the framing cameras that were undertaken from a relatively large distance (4,424 kilometers). Since January, *Dawn* has been directing its eagle eye toward the crater-covered surface. On its new orbit, the probe approaches Ceres to within 385 kilometers.

"Now, with significantly better resolution, we can investigate many of the surface details that we have known about since *Dawn* reached Ceres," says Max Planck researcher Andreas Nathues, who manages the camera experiment from Göttingen. The planet researchers particularly study the different manifestations of the impact craters on Ceres.

A recent image shows Kupalo, an impact crater measuring around 25 kilometers across; it is named for a Slavic fertility goddess and is located in the southern hemisphere. Conspicuous bright stripes spread out radially on the inside of the crater rim. They were pre-

sumably formed as a result of landslides on the slopes. Kupalo doesn't have a central peak, as is usually the case with impact craters of this size.

Instead, its center is home to a mountain chain that extends for more than seven kilometers. Several similar mountain chains are repeated near the crater rim, whose shape also deviates conspicuously from a circle. Kupalo's crater bottom is otherwise almost flat and has no subsequently formed smaller craters – an indication of a relatively young age. Several bright spots can be seen in its interior, but more about those later.

The Messor crater (diameter: 42 kilometers) also attracts attention due to its unusual shape. Like Kupalo, its rim also has an irregular shape, and it doesn't have a central peak either. Moreover, the crater bottom has a marked wave-like pattern. Messor is superimposed onto an older crater whose relics are still evident. Messor is



THE EYES OF THE SCOUT

The eyes of NASA's *Dawn* probe are made in Germany: the two framing cameras. Apart from mapping the surface, they are used for probe navigation. Each camera weighs 5.5 kilograms. They can take white-light and color photos and have seven filters in the spectral range from visible light to near infrared for this purpose. The camera system is a collaborative project: it was developed and built by the Max Planck Institute for Solar System Research in Göttingen in collaboration with the DLR Institute of Planetary Research in Berlin, and the Institute of Computer and Network Engineering at the Technical University of Braunschweig.

In addition to the high-resolution photographs, it can record views of the surface with 3-D effect, which can also be made into a montage to create virtual fly-bys. Three further onboard experiments round out the scientific payload: the infrared spectrometer from Italy, with which the researchers analyze the mineral composition and the temperature distribution on Ceres' surface; the gamma and neutron spectrometer from the US, which is responsible for determining the chemical elements in the surface rock; and a radio wave experiment that is used mainly to measure the gravitational field of the celestial body and for position determination.

obviously an older crater, because its interior contains almost as many smaller impact craters as are found outside the crater.

A further crater, around 30 kilometers in diameter and as yet unnamed, has a prominent central peak and distinct terraces that cover the entire crater bottom. These structures also indicate that an asteroid struck material that had a high degree of mobility immediately after the impact. An indication of frozen water in the ground?

OUTER LAYERS ARE NOT MADE OF HARD ROCK

A different crater, the 125-kilometer Dantu, appears on the images to be conspicuously flat with a network of cracks such as those we know in a similar form from lunar craters, for example the young crater Tycho. “The outer layers of Ceres aren’t made of hard rock, and this was likely crucial for the formation of these cracks. When the asteroid struck, frozen water below the surface probably melted, at least partially. If it subsequently cools down, it can contract considerably and form many cracks,” says Max Planck scientist Martin Hoffmann.

Unlike the situation on our own moon, frozen water has played an important role in the formation of these structures. The fact that Ceres also contains ice had already been expected before the *Dawn* mission. “Ceres’ low average density of 2.16 grams per cubic centimeter can’t be explained any other way than by a high proportion of frozen water,” explains Andreas Nathues. The comparison with Saturn’s moon Rhea, which also contains large amounts of ice, is an indication of frozen water in Ceres’ surface material.

“The irregular shapes of Ceres’ craters resemble those on Rhea,” explains Carol Raymond from the *Dawn* team. The craters on Ceres are unlike those on Vesta, the subject of the probe’s earlier study. “The craters on Ceres are very dissimilar to those on Vesta,



Short-range reconnaissance: The *Dawn* space probe was launched in 2007, flew past the asteroid Vesta in summer 2011 and swung into an orbit around Ceres on March 6, 2015. Since January, the space probe has come to within 385 kilometers of the dwarf planet.

which are bowl shaped,” says the researcher from the Jet Propulsion Laboratory in California.

Ceres has almost the same surface gravity as Saturn’s moon Rhea – the difference between the two celestial bodies is a mere 4 percent. The indications that tell of ice on Ceres, such as the morphology of the impact craters, are only indirect at present. Direct measurements, for example with the onboard infrared spectrometer, aren’t yet available. Hoffmann and Nathues are nevertheless convinced that frozen water played a crucial role in the geology: melted by the heat of the impact, it formed many structures as it subsequently froze, structures that are much less pronounced or even lacking completely when objects impact solid rock. “Even though we don’t yet understand these processes in detail, they could explain the fracture lines, the terraces, the lack of simple central peaks and the irregular crater rims,” says Andreas Nathues.

But back to the unusually bright deposits that were found on Dantu, for example. The Max Planck researchers had already discovered similar ones on other parts of the surface; even on the approach to Ceres, the cameras were dazzled by bright spots on the surface. They initially appeared on the photos as overexposed spots – a completely surprising observation, according to Martin Hoffmann. Last December, a team headed by Nathues and Hoffmann reported in the science journal *NATURE* that the conspicuous spots weren’t rare at all, and that 130 of them had already been identified on Ceres.

SALT DISSOLVED IN WATER IS LEFT BEHIND

With measurements in laboratories in Canada and the US, the researchers attempted to imitate the color signal of these spots recorded with the framing cameras. The result: the bright surface material is likely salt. It presumably

Cornucopia for planetologists: The study of craters provides deep insight into the geology of Ceres. Each of these remnants of asteroid impacts tells its own story, whether it is Dantu, Kupalo, Messor, Occator or Oxo (from left). The bright deposits all over the surface have particularly astonished the researchers. This is apparently material that consists of hydrous magnesium sulfate or other salts. In the Occator crater – shown here in a color-coded topographic view – haze can also form at the crater bottom when the Sun has risen.



consists of hydrous magnesium sulfate or other bright salts as also occur in terrestrial salt lakes, in Torrevieja and La Mata on the Spanish Costa Blanca, for instance. Nathues therefore presumes not only that Ceres' surface conceals ice, but that this ice is partially mixed with salt.

As soon as this mixture is exposed by asteroid impacts or is transported to the surface by internal forces, it can slowly sublime, or transition directly from the solid into the gaseous state.

The salt that was originally dissolved in the water is left behind. "Investigating these bright deposits on Ceres' surface will be one of the main objectives for the *Dawn* mission over the coming months," predicts Martin Hoffmann.

HAZE DEPENDS ON THE POSITION OF THE SUN

Some of the bright areas have even more to offer, such as the relatively young crater Occator in the northern hemi-

sphere, which is around 80 million years old and has a diameter of over 90 kilometers. Inside its crater walls, which can be as deep as 4 kilometers, the framing cameras have even detected the brightest spots on the whole surface. What's more, the photos show that haze forms on the crater bottom after the Sun has risen. But this mist becomes visible only when Occator is photographed at a very low angle. In the diurnal rhythm, the patches of haze clear as soon as the Sun is near or already below the horizon.

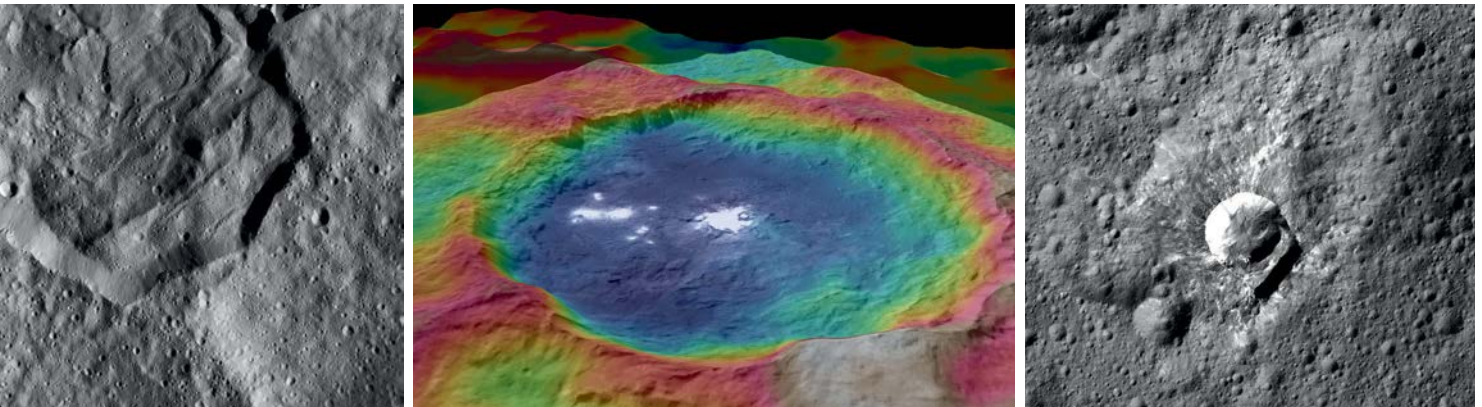
This finding also supports the hypothesis of subsurface frozen water, although it is still not clear how exactly the haze forms. According to Andreas Nathues, it probably happens through openings in the ground, when frozen water sublimates into the vacuum of space. Since dust particles are also entrained in the process, it resembles the outgassings of comets.

The second brightest structure on Ceres' surface, 8-kilometer-wide Oxo crater, is also comparatively young. The photos show bright spots and haze here as well. If the indications for ground ice are confirmed, then the framing cam-



Orientation on a distant world: Andreas Nathues (left) and Martin Hoffmann inspect a global mosaic of the dwarf planet Vesta. The *Dawn* probe journeyed to it as the first stop on its tour. The two framing cameras on board were developed and built by, among others, the Max Planck Institute for Solar System Research in Göttingen.

Photos: NASA/JPL-Caltech/UCLA/MPS/DLR/IDA (2); photo: Ronald Schmidt (bottom)



eras will have proved for the first time from close up that ice is present in the asteroid belt. Although this region of the solar system is actually too warm for it, ice can evidently remain stable over long periods here when there is a layer of surface rock protecting it against vaporization.

Dawn's observations corroborate measurements taken by the European space telescope *Herschel*, which had already discovered the spectral fingerprint of water vapor in the infrared light of the dwarf planet. One of the two possible sources of vapor discovered by *Herschel* coincides with the position of the Occator crater. According to the analyses undertaken by Nathues' team, so-called hydrated magnesium sulfates – that is, hydrous mineral salts – are an important constituent of the bright ground material. Many of the other bright regions on Ceres, in contrast, probably consist of dried-up salts. The activity that is still ongoing at the Occator crater apparently stopped some time ago at these other locations.

A further current investigation is likewise devoted to Ceres' surface minerals. The researchers used *Dawn's* infrared spectrometer to measure the spectral distribution of the reflected light at wavelengths between 0.4 and 5 micrometers. Cristina De Sanctis from the Istituto di Astrofisica e Planetologia Spaziali (IAPS) in Rome concludes from the measurements that sheet silicates containing ammonium occur widely on Ceres. These substances could pos-

sibly have been formed by reactions with organic material or ammonium ice when Ceres was still very young.

DID THE DWARF PLANET MIGRATE TO THE ASTEROID BELT?

The latter, however, is stable only at the very low temperatures found in the outer solar system, which in turn would indicate that pebble-sized objects drifted from regions far from the Sun into the asteroid belt, where they were taken up by the bodies already there. Or did Ceres once migrate from somewhere near Neptune's orbit into today's asteroid belt, as De Sanctis puts forward for discussion? The Göttingen-based researchers have remained rather more cautious here. The evaluation of the measurements is still ongoing; Ceres' origin can be assessed only when this is complete.

And another important question heads the to-do list of the *Dawn* re-

searchers: Does Ceres' solid crust sit atop an ocean like the one planetologists have discovered on Europa? Although Ceres is much smaller than this particular moon of Jupiter, the dwarf planet is relatively large when compared with the even smaller Enceladus, which orbits Saturn and also has such an ocean. Although they don't yet take *Dawn's* observations into account, the latest computer simulations appear to indicate that this could be the case with Ceres as well.

According to the calculations, a zone in which the ice has melted could start 5 to 33 kilometers below the surface; the uncertainty in this figure results from the spread of assumptions that were made for the calculation. If the hypothetical ocean were very salty, it could exist under an even thinner surface layer. *Dawn's* eyes and the other instruments on board have the opportunity to find answers until early 2017. After that, the probe will run out of fuel. ◀

TO THE POINT

- The *Dawn* space probe has been orbiting the dwarf planet Ceres since March 2015.
- Ceres is a world with a complex geology. Some craters have interesting structures; frozen water evidently played a major role in their formation.
- White spots appear all over the surface – salt. It presumably consists of hydrous magnesium sulfate or other bright salts as occur in terrestrial salt lakes.
- Simulation calculations indicate the possibility that an ocean lies hidden beneath Ceres' surface.