Did dwarf planet Ceres originate in the asteroid belt?

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Arriving at its destination: This illustration shows how the Dawn space probe reaches the dwarf planet Ceres. Credit: NASA/JPL-Caltech

The dwarf planet Ceres has a diameter of almost 1,000 kilometers and is located in the asteroid belt. In the television series "The Expanse," Ceres gained new fame as the main base of the so-called 'belters': in this series, which is based on real physics, humans colonize the asteroid belt for mining.

Ceres is no less prominent in the real world either. For a long time, however, it was not entirely clear whether the dwarf planet had formed in the asteroid belt or whether it had migrated inwards from the edge of the solar system. A research team led by the Max Planck Institute for solar system Research in Göttingen has found ammonium-rich deposits in the Consus crater in data from NASA's Dawn space probe, which reveal a lot about Ceres' origin.

Dwarf planet Ceres is an unusual "inhabitant" of the asteroid belt. With a diameter of around 960 kilometers, it is not only the largest body between the orbits of Mars and Jupiter; unlike its rather simple "fellow inhabitants," it is also characterized by an extremely complex and varied geology. Years ago, NASA's Dawn space probe discovered widespread ammonium deposits on the surface of Ceres.

Some researchers assume that frozen ammonium played a role in the formation of the dwarf planet. However, ammonium is only stable in the outer solar system, which indicates an origin far from the asteroid belt. However, new findings from the Consus crater speak against this.

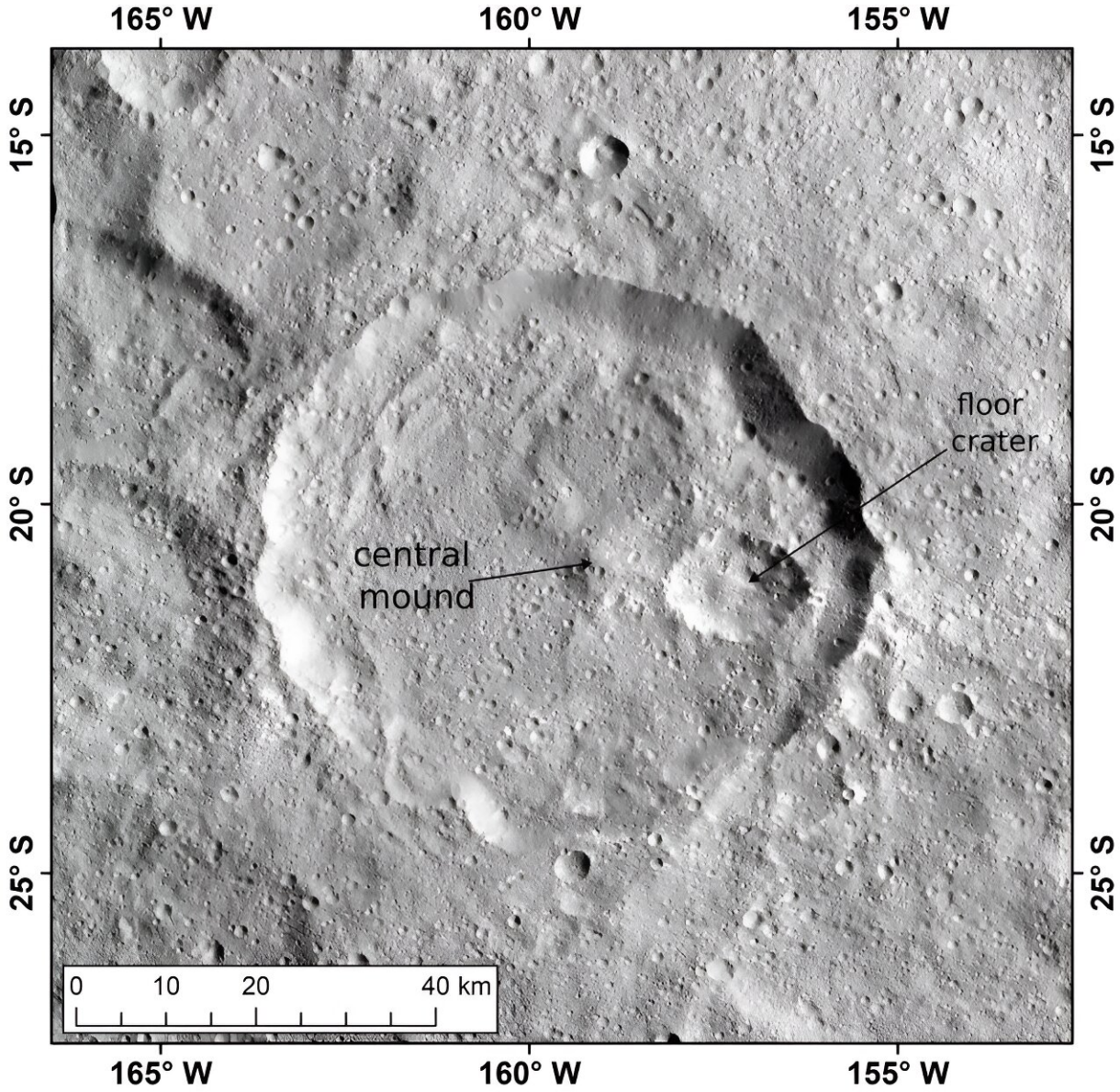
Freezing vulcanism

Ceres appeared to have been the scene of unique cryovolcanism until recently—and probably still is. The underlying data was obtained by NASA's Dawn space probe when it studied Ceres up close from 2015 to 2018. The data point to an eventful past in which Ceres changed and evolved over many billions of years.

Light-colored, whitish salt deposits can be found in several impact craters. Deposits in the Consus crater could indicate ammonium-rich material that has reached the surface from the depths of the dwarf planet due to Ceres' volcanism. More precisely, researchers believe the deposits are remnants of a brine that has seeped to the surface from a liquid layer

between the mantle and crust over many billions of years.

Images and measurement data from the Consus crater, which the team has now analyzed in greater detail than ever before, now show such material that is yellowish in color. The presence of ammonium, therefore, does not necessarily indicate an origin in the outer solar system—Ceres could have formed where it is orbiting today.



Consus Crater is located in the southern hemisphere of dwarf planet Ceres. The most striking structure in its interior is a smaller crater ("floor crater") in its eastern half. A flat central mountain rises up in the center of Consus Crater. Credit: Max Planck Society

A crater within a crater

Conus Crater is located on Ceres' southern hemisphere. With a diameter of around 64 kilometers, it is not one of the dwarf planet's particularly large impact craters. Images taken by Dawn's scientific camera system, which was developed and built under the lead of the MPS, show a circumferential crater wall that rises about 4.5 kilometers above the crater floor and has partially eroded inwards.

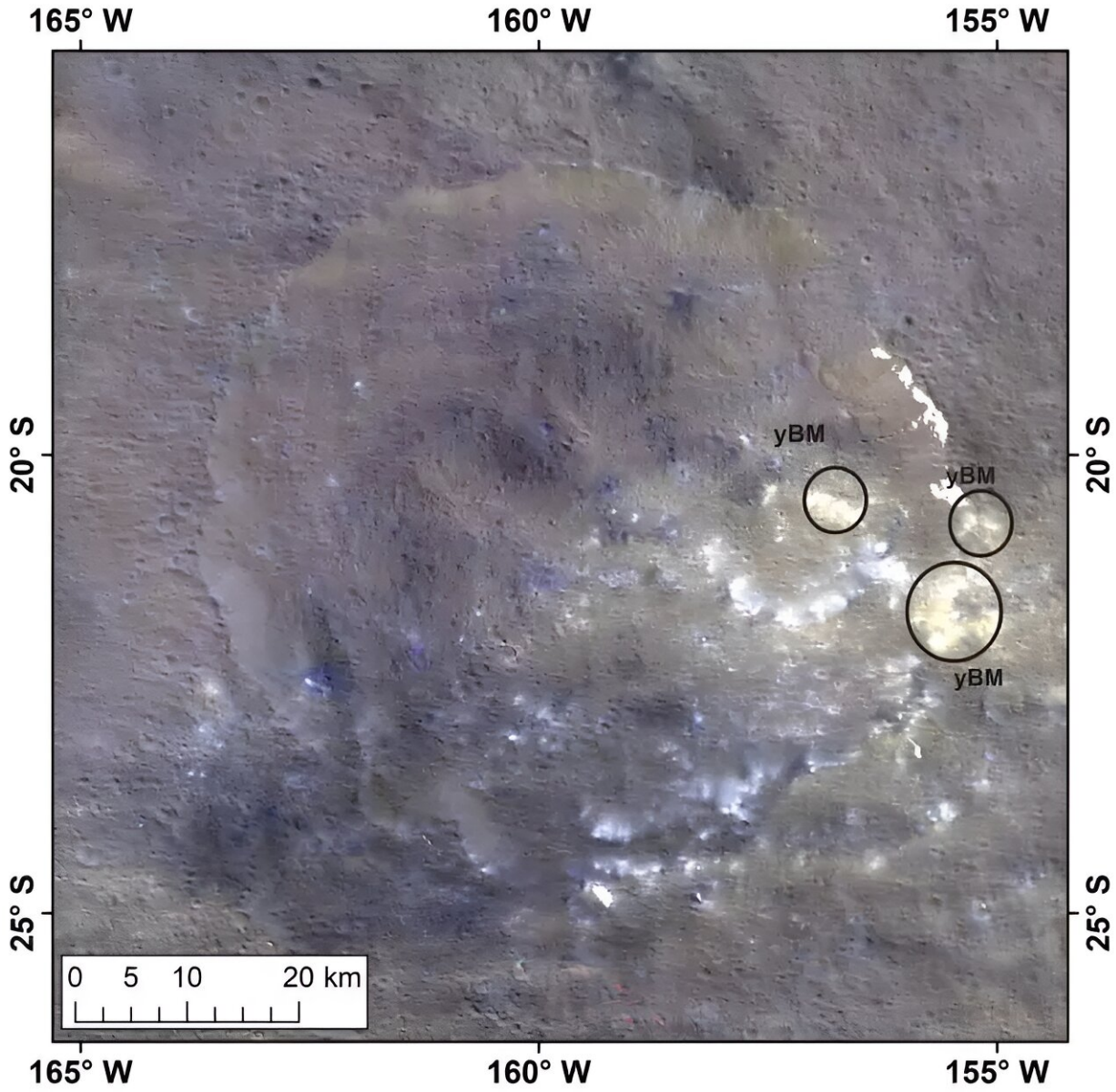
It encloses a smaller crater covering an area of about 15 kilometers by eleven kilometers that dominates the eastern half of Consus' crater floor. The yellowish, bright material is found in isolated speckles exclusively on the edge of the smaller crater and in an area slightly to the east of it.

As the new analysis of data from the camera system and the VIR spectrometer suggests, the yellowish bright material in Consus Crater is rich in ammonium. In traces, the compound, which differs from ammonia by an additional hydrogen ion, is almost omnipresent on the surface of Ceres in the form of ammonium-rich minerals. The research is published in the *Journal of Geophysical Research: Planets*.

In the past, scientists believed that these minerals could only have formed through contact with ammonium ice in the cold at the outer edge of the solar system, where frozen ammonium is stable over long periods of time. In closer proximity to the sun, it evaporates quickly. Ceres must therefore have formed at the edge of the solar system and only later

"relocated" to the asteroid belt, they inferred.

The current study now shows for the first time a connection between ammonium and the salty brine from Ceres' interior. The team argues that, therefore, the dwarf planet's origin does not necessarily have to be in the outer solar system. Ceres could also be truly native to the asteroid belt.



The yellowish bright material, marked here as “yBM”, is found exclusively on the edge of the smaller crater and in its immediate eastern vicinity. Credit: Max Planck Society

Ammonium from the depths

The researchers assume that the components of ammonium were already contained in Ceres' original building blocks. As ammonium does not combine with the typical minerals in Ceres' mantle, it gradually accumulated in a thick layer of brine that extended globally between the dwarf planet's mantle and crust.

Cryovolcanic activity caused the ammonium-rich brine to rise repeatedly over the course of billions of years, and the ammonium it contained gradually seeped into the large-scale phyllosilicates of Ceres' crust. Phyllosilicates, which are characterized by a layer-like crystal structure, are also widespread on Earth, for example in clayey soils.

"The minerals in Ceres' crust possibly absorbed the ammonium over many billions of years like a kind of sponge," explains MPS scientist Dr. Andreas Nathues, first author of the current study and former Lead Investigator of Dawn's camera team.

There is much to suggest that the concentration of ammonium is greater in deeper layers of the crust than near the surface. The few places on the surface of Ceres where conspicuous patches of the yellowish-bright material can be found outside Consus Crater are also located within deep craters.

As the current study shows in detail, the impact that created the small

eastern crater only 280 million years ago is likely to have exposed material from the deep, particularly ammonium-rich layers in Consus Crater. The yellowish-bright speckles to the east of the smaller crater are material that was ejected as a result of the impact.

"At 450 million years, Consus Crater is not particularly old by geological standards, but it is one of the oldest surviving structures on Ceres. Due to its deep excavation, it gives us access to processes that took place in the interior of Ceres over many billions of years—and is thus a kind of window into the dwarf planet's past," says MPS researcher Dr. Ranjan Sarkar, a co-author of the study.

More information: A. Nathues et al, Consus Crater on Ceres: Ammonium-Enriched Brines in Exchange With Phyllosilicates?, *Journal of Geophysical Research: Planets* (2024). DOI: 10.1029/2023JE008150

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