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How Pluto got its heart

The mystery of how Pluto got a giant heart-shaped feature on its surface has finally been solved by an international team of astrophysicists led by the University of Bern and members of the National Center of Competence in Research (NCCR) PlanetS. The team is the first to successfully reproduce the unusual shape with numerical simulations, attributing it to a giant and slow oblique-angle impact.

Ever since the cameras of NASA's New Horizons mission discovered a large heart-shaped structure on the surface of the dwarf planet Pluto in 2015, this "heart" has puzzled scientists because of its unique shape, geological composition, and elevation. A team of scientists from the University of Bern, including several members of the NCCR PlanetS, and the University of Arizona in Tucson have used numerical simulations to investigate the origins of Sputnik Planitia, the western teardrop-shaped part of Pluto's "heart" surface feature. According to their research, Pluto's early history was marked by a cataclysmic event that formed Sputnik Planitia: a collision with a planetary body about 700 km in diameter, roughly twice the size of Switzerland from east to west. The team's findings, which were recently published in *Nature Astronomy*, also suggest that the inner structure of Pluto is different from what was previously assumed, indicating that there is no subsurface ocean.

A divided heart

The "heart", also known as the Tombaugh Regio, captured the public's attention immediately upon its discovery. But it also immediately caught the interest of scientists because it is covered in a high-albedo material that reflects more light than its surroundings, creating its whiter color. However, the "heart" is not composed of a single element. Sputnik Planitia (the western part) covers an area of 1200 by 2000 kilometers, which is equivalent to a quarter of Europe or the United States. What is striking, however, is that this region is three to four kilometers lower in elevation than most of Pluto's surface. "The bright appearance of Sputnik Planitia is due to it being predominantly filled with white nitrogen ice that moves and convects to constantly smooth out the surface. This nitrogen most likely accumulated quickly after the impact due to the lower altitude," explains Dr. Harry Ballantyne from the University of Bern, lead author of the study. The eastern part of the "heart" is also covered by a similar but much thinner layer of nitrogen ice, the origin of which is still unclear to scientists, but is probably related to Sputnik Planitia.

An oblique impact

"The elongated shape of Sputnik Planitia strongly suggests that the impact was not a direct head-on collision but rather an oblique one," points out Dr. Martin Jutzi of the University of Bern, who initiated the study. So the team, like several others around the world, used their Smoothed Particle Hydrodynamics (SPH) simulation software to digitally recreate such impacts, varying both the

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composition of Pluto and its impactor, as well as the velocity and angle of the impactor. These simulations confirmed the scientists' suspicions about the oblique angle of impact and determined the composition of the impactor.

"Pluto's core is so cold that the rocks remained very hard and did not melt despite the heat of the impact, and thanks to the angle of impact and the low velocity, the core of the impactor did not sink into Pluto's core, but remained intact as a splat on it," explains Harry Ballantyne. "Somewhere beneath Sputnik is the remnant core of another massive body, that Pluto never quite digested," adds co-author Erik Asphaug from the University of Arizona. This core strength and relatively low velocity were key to the success of these simulations: lower strength would result in a very symmetrical leftover surface feature that does not look like the teardrop shape observed by New Horizons. "We are used to thinking of planetary collisions as incredibly intense events where you can ignore the details except for things like energy, momentum and density. But in the distant Solar System, velocities are so much slower, and solid ice is strong, so you have to be much more precise in your calculations. That's where the fun starts," says Erik Asphaug. The two teams have a long record of collaborations together, exploring since 2011 already the idea of planetary "splats" to explain, for instance, features on the far side of the Moon. After our moon and Pluto, the University of Bern team plans to explore similar scenarios for other outer Solar System bodies such as the Pluto-like dwarf planet Haumea.

No subsurface ocean on Pluto

The current study sheds new light on Pluto's internal structure as well. In fact, a giant impact like the one simulated is much more likely to have occurred very early in Pluto's history. However, this poses a problem: a giant depression like Sputnik Planitia is expected to slowly move towards the pole of the dwarf planet over time due to the laws of physics, since it has a mass deficit. Yet it is paradoxically near the equator. The previous theorized explanation was that Pluto, like several other planetary bodies in the outer Solar System, has a subsurface liquid water ocean. According to this previous explanation, Pluto's icy crust would be thinner in the Sputnik Planitia region, causing the ocean to bulge there, and since liquid water is denser than ice, you would end up with a mass surplus that induces migration toward the equator.

However, the new study offers an alternative perspective. "In our simulations, all of Pluto's primordial mantle is excavated by the impact, and as the impactor's core material splats onto Pluto's core, it creates a local mass excess that can explain the migration toward the equator without a subsurface ocean, or at most a very thin one," explains Martin Jutzi. Dr. Adeene Denton from the University of Arizona, also co-author of the study, is currently conducting a new research project to estimate the speed of this migration. "This novel and inventine origin for Pluto's heart-shaped feature may lead to a better understanding of Pluto's origin," she concludes.

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Bernese space exploration: With the world's elite since the first moon landing

When the second man, "Buzz" Aldrin, stepped out of the lunar module on July 21, 1969, the first task he did was to set up the Bernese Solar Wind Composition experiment (SWC) also known as the "solar wind sail" by planting it in the ground of the moon, even before the American flag. This experiment, which was planned, built and the results analyzed by Prof. Dr. Johannes Geiss and his team from the Physics Institute of the University of Bern, was the first great highlight in the history of Bernese space exploration.

Ever since Bernese space exploration has been among the world's elite, and the University of Bern has been participating in space missions of the major space organizations, such as ESA, NASA, and JAXA. With CHEOPS the University of Bern shares responsibility with ESA for a whole mission. In addition, Bernese researchers are among the world leaders when it comes to models and simulations of the formation and development of planets.

The successful work of the Department of Space Research and Planetary Sciences (WP) from the Physics Institute of the University of Bern was consolidated by the foundation of a university competence center, the Center for Space and Habitability (CSH). The Swiss National Fund also awarded the University of Bern the National Center of Competence in Research (NCCR) PlanetS, which it manages together with the University of Geneva.