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ASTROBIOLOGY

Fascinating Plumes

Saturn's moon Enceladus has complex, life-friendly chemistry

ENCELADUS, a 500-kilometer-wide moon of Saturn, has been a top target in the hunt for extraterrestrial life for nearly two decades. In 2005, shortly after arriving in orbit around the ringed planet, the joint NASA–European Space Agency (ESA) Cassini mission found plumes of water spraying up from Enceladus's south pole—clinching evidence that the moon harbored a liquid-water ocean underneath its bright-white icy crust. Astrobiologists have become ever more enthralled by Enceladus as further studies of the plumes' ice grains have revealed multiple molecular building blocks of life blasting out from the hidden ocean.

Now scientists revisiting data from Cassini, which ended its mission to Saturn in 2017, have spied even more tantalizing ingredients in the plumes: suites of complex organic molecules that, on Earth, are involved in the chemistry associated with even bigger compounds considered essential for biology. The discovery, published in *Nature Astronomy*, bolsters the case for follow-up missions to search for signs of life within this enigmatic moon.

Its remoteness from Earth isn't the only thing that has let Enceladus keep so many secrets for so long. The Cassini orbiter wasn't really designed for deep scrutiny of a single, specific object in Saturn's system, says Nozair Khawaja, a planetary scientist at the Free University of Berlin, who led the *Nature Astronomy* study. Cassini launched nearly 30 years ago, back when Enceladus's subsurface ocean and south polar plumes were unknown. Repurposing its vintage kit for in-depth astrobiology was difficult—not least because of how hard the resulting data were to work with.

One problem was the relatively low resolution available from a mass spectrometer on Cassini called the Cosmic Dust Analyzer (CDA), which parsed the chemical composition of puffs of dust

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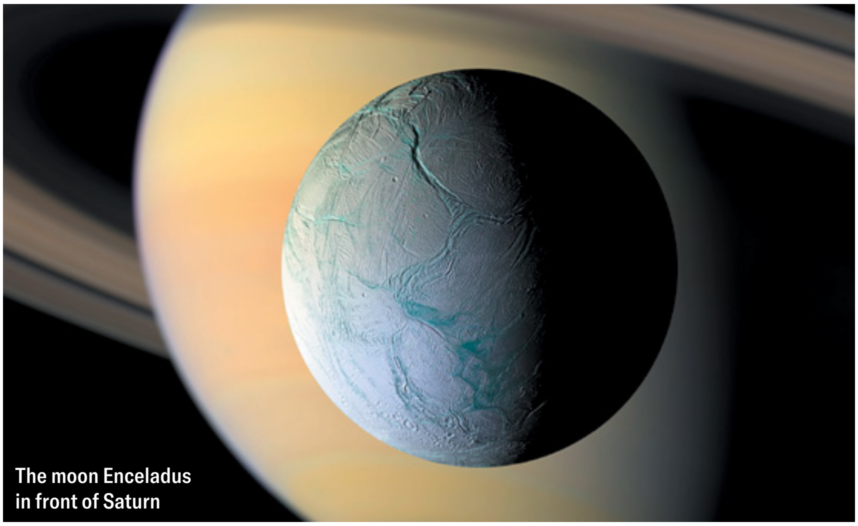
Artist's depiction of Cassini sampling plumes from the subsurface ocean of Saturn's icy moon Enceladus

NASA's Goddard Space Flight Center


The moon Enceladus in front of Saturn

NASA's Goddard Space Flight Center

from ice grains striking its detectors each time the spacecraft swooped through a plume. The plumes proved so thick with material, Khawaja says, that the CDA would be overwhelmed during Cassini's Enceladus flybys. Scientists could clearly see that ordinary water molecules made up most of the collected material—nearly 98 percent, according to Khawaja. Piecing together the nature of the remaining 2 percent, however, required many carefully choreographed flybys and tweaks to the CDA's operations across several years. The flyby that eventually hit a bull's-eye was a maneuver on October 9, 2008, code-named E5, which combined higher-than-average speed—nearly 18 kilometers per second (km/s), about 6 km/s faster than other flybys—and a fortuitously timed eruption from Enceladus just minutes beforehand.

"The impact speed was higher, and at such high speeds water molecules shatter. They don't survive. But other species such as organics remain," Khawaja explains. And the freshly ejected material had not been altered or degraded by cosmic radiation.

Some of the co-authors of the recent study published a paper in 2011 analyzing the E5 flyby results after years of painstaking data analysis, noting organic molecules but unable to tell what they were. And now, based on exhaustive experiments examining how differences in the ice grains' impact speeds affected the CDA data, the researchers think they've tracked down most of what was within the plume, with major implications for the moon's possibility of hosting life.

"I think it makes a lot of sense that it would take diligence and patience to fully understand the CDA data. I applaud them for taking such care in their analyses," says Shannon MacKenzie, a planetary scientist at the Johns Hopkins University Applied Physics Laboratory, who wasn't involved in the study.

The team's work revealed that the plumes contain many familiar molecules, including several massive and complex chemical compounds Cassini previously detected in the torus of ice and dust Enceladus releases into orbit around Saturn. Their presence in the freshly ejected plumes, Khawaja argues, confirms they all originated in Enceladus's subsurface ocean. Most exciting, the study also revealed new, never-before-seen compounds lurking in the plume, sourced from somewhere within the moon.

"In these fresh grains, we've got molecules such as esters and ethers, which were carrying oxygen in themselves and had double bonds," Khawaja says. His team also detected compounds in which oxygen and nitrogen were probably combined. "We suspect these are sort of intermediates to make further, complex organics, maybe potentially organics that are biologically relevant," he adds. Certainty is elusive because the organic molecules collected by CDA were shattered into multiple tiny fragments; researchers are still figuring out how to piece them back together.

"This work shows that some of the fragments are indeed derived from quite large and complex organic compounds," says Kevin Hand, a planetary scientist and director of the Ocean Worlds Lab at NASA's Jet Propulsion Laboratory, who was not involved in the study. "But maybe those compounds originated from even larger compounds. What exactly would we find if we dove into the ocean below? Are the compounds reported here just the tip of the astrobiological iceberg?"

Khawaja already has ideas about what follow-up missions might find with better, state-of-the-art instruments. The newly revealed cocktail of compounds, he says, could feed into a "network of reactions" to create pyrimidines—a class of molecules necessary for the formation of DNA. (Here on Earth DNA is what leads to fish, lions, humans ... and all life as we know it.) This network of reactions could yield lipids, too—molecules that can arrange themselves into cell membranes. Even so, Khawaja notes, "we don't have a clue about any actual biological relevance yet."

For now the team is developing an advanced computer model of the entire Enceladus subsurface system to map the probable sources and interactions among the moon's chemical compounds. There's also some room left for discovery in the Cassini data: "There are still certain spectral types that I see and don't understand," Khawaja says.

Most of the hope for near-term definitive answers ultimately lies with a mission still on the drawing board at ESA. Such a mission would most likely include an orbiter far more advanced than Cassini, with a lander as a possible addition. (Hand notes that an orbiter alone could be enough, given the plumes' fresh supply of material: "Why risk landing when Enceladus is handing out free samples?")

Regardless of how we investigate it, Enceladus remains one of the most alluring destinations in the search for extraterrestrial life. “Water, energy and the right chemicals—all three keystones of habitability are there,” Khawaja says. And if future studies fail to find life, he argues, the implications will still be enormous. “If it’s *not* there despite those three keystones, it will mean that life needs something more.” —*Jacek Krywko*

ANIMAL BEHAVIOR

Discerning Dogs

Some dogs can sort toys by function like human children do

ARYA, A SIX-YEAR-OLD border collie in Italy, can learn a new toy’s name with just one or two mentions. Her owners say she even knows words for her favorite foods; when pizza is on the menu, the word has to be whispered. Arya’s gift made her a natural subject for research showing that some dogs with unusually large vocabularies can go beyond simply memorizing terms.

For the new study, published in *Current Biology*, owners of 10 talented dogs—mostly border collies—taught them words for objects in two categories: tug toys, called “pulls,” and fetch toys, called “throws.” All toys were different in size, shape and color so appearance could not guide learning.

After four weeks of training, brand-new toys with a variety of designs were introduced. This time the dogs only experienced each toy’s function, either tugging or fetching, during play; they were not taught words for any of them. After a week of play, when asked to fetch a pull or a throw, the seven dogs that completed all experimental phases chose the right toy about two thirds of the time—well above the 12.5 percent expected for selections by chance. “These gifted

Border collie Arya

Simone Avezza