SPECIAL FEATURE

Cosmology Astrophysics Origin of life Astrobiology

A welcome mat

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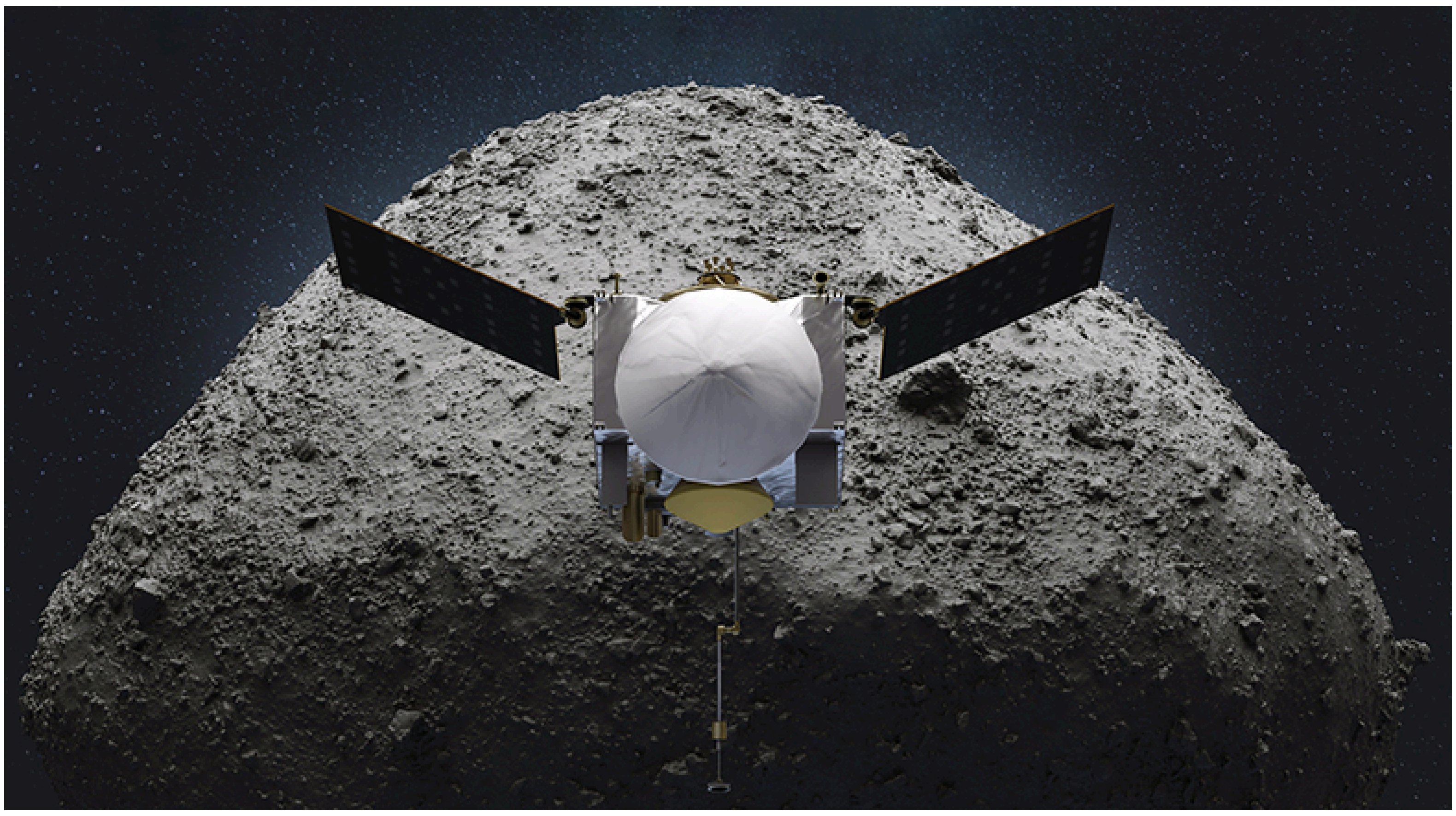
from *Shaastra* :: vol 04 issue 03 :: Apr 2025

APR 2025



Scientists have been studying samples collected by the NASA spacecraft OSIRIS-REx from the near-Earth asteroid Bennu.

Microbial mats may throw light on the chances of life on other planets. Findings from an exciting new study.

Two researchers have found what may be a sure-shot way of looking for microbial life in extraterrestrial environments. Their mathematical study on reproduction and ecology — which, they stress, are key features of life — directly predicts a structure widely seen in other forms of life.

Microbial mats, a few millimetres or centimetres thick, consist of neatly segregated, vertical layers of different bacteria usually found in oceans, lakes, and coastal lagoons. These bacteria require varying amounts of sunlight and oxygen to survive and are often coloured green, red, orange, purple, and brown. Akshit Goyal, Simons Young Researcher at the International Centre for Theoretical Sciences, Tata Institute of Fundamental Research, Bengaluru, and Mikhail Tikhonov, Assistant Professor in the Department of Physics at Washington University in St Louis, suggest that these features in microbial mats are key to life found anywhere in the universe. Their study (*go.nature.com/4c8Xbq2*) may help astrobiologists hunt for these signatures in samples carried by present and future spacecraft to near-Earth asteroids.

due to microbes called cyanobacteria in the Earth's ocean, the atmosphere was bombarded with oxygen for about 200 million years — a short burst of geological time. This bombardment caused changes in the climate and altered the course of life on the planet.

Cyanobacteria were the earliest to form oxygen photosynthesis, the process of using sunlight, water, and carbon dioxide to produce usable energy and output oxygen. They are now found across the globe in different environments because of their great ability to adapt: not just in soil, arid deserts, rocks and caves, Antarctica rocks, freshwater, and oceans, they also thrive in hot springs, where other forms of life find it difficult to survive. Some reside in stromatolites — layered, rock-like structures built of sediments trapped by cyanobacteria. They also dot the top layer of microbial mats.

Swanandee Nulkar, a microbiology researcher in the Department of Circular Economy at Brandenburgische Technische Universität Cottbus-Senftenberg, Germany, works with thin films of these bacteria. They get stuck to one another and are often found glued to a surface or floating on it. She says that although they look like Aladdin's carpet, the biofilms can be serious health hazards. They survive in hospital environments, on uncleaned toilet seats, and develop genetic resistance to antibiotics. They are "almost like single-celled organisms with a brain of their own", Nulkar says. The new study might have answers why.

BIOSIGNATURES

In September 2020, a group of astronomers from Cardiff University claimed to have detected 'phosphine', a rare molecule, in the Venusian atmosphere (*go.nature.com/4j4OWxt*). Since phosphine is created only by biological processes on Earth, it was thought to have been produced by microbial life in the highly acidic clouds of Earth's neighbouring planet. The claim led to intense debates among scientists about the study's methods, and consensus hasn't yet emerged on whether Venus's clouds indeed harbour microorganisms.

Although the controversy has led to plans for future Venusian missions, it stems from assuming that biological processes on Earth replicate on Venus, thus creating phosphine, a potential 'biosignature'. The study by Goyal and Tikhonov, however, claims to sidestep this problem. They have looked for 'agnostic' biosignatures, or signs of life independent of the detailed chemical and biological processes. In a sense, they have focused on the physical processes of life.

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AGNOSTIC BIOSIGNATURES

To begin with, Goyal and Tikhonov assumed that life didn't exist alone or just as one species. Their motivation stemmed from an observation of life on Earth: "Wherever we find life on Earth, we see not only one living species or organism, but a biodiverse ecosystem with several species," Goyal says. Even in hydrothermal vents, many species coexist despite the

Next, they assumed a feature of life often taken for granted: the reproduction of individual species. Taken together with ecology, they wrote down the maths — and out came energy-ordered layering, as seen in microbial mats. "When we started working on it," Goyal says, "we realised that it was actually pretty easy to get stratification!" They concluded the stratification itself was an agnostic biosignature.

In an environment with limited resources, the most successful species dominate the most energetic resource. In microbial mats, these species are the cyanobacteria, which form the top layer, hogging all the sunlight. They are followed by anaerobic bacteria, which can use chemical energy to survive, for example, from sulfates. Other bacteria below them can survive by breaking down organic matter. The mathematical model exactly reproduces this behaviour.

The model equations do not specify which resources get used up in which layers. Any resources are possible as long as the amount of energy extracted from the processes decreases with each layer. "Our model suggests this to be a pretty robust result that is agnostic to chemical details," Goyal says.

Not everyone agrees. Shreya Pramanik, a postdoctoral researcher at Oregon Health and Science University, Portland, believes the authors have considered the simplest form of interactions — "antagonism". Different microorganisms exhibit symbiotic behaviour, leading to a win-win situation for all. "A more complex ecology will have other interactions as well, such as cooperation and predation. The model presented in the manuscript is very basic," Pramanik says. Goyal clarifies that the duo considered beneficial interactions, too. "Species that eat a resource can produce by-products that serve as food for others — a phenomenon called 'cross-feeding'. We found that even with beneficial interactions, you get robust energy-ordered stratification," he says.

Pramanik points out that the duo's finding aligns with the *idea* that the diversity of life forms arises out of mutations and natural selection. For example, in hydrothermal vents, different forms of life coexist, and each form evolves at the molecular level, adding to the diversity. This molecular diversity then influences the ecological relationship. In a way, then, even the simplest life forms can develop a feedback loop in which diversity leads to collective survival, which leads to diversity.

SAMPLES FROM MISSIONS

In October 2020, the National Aeronautics and Space Administration (NASA) spacecraft OSIRIS-REx (Origins, Spectral Interpretation, Resource Identification and Security-Regolith Explorer) landed on a crater of the near-Earth asteroid Bennu, which it had been orbiting, mapping, and studying for close to two years. It dug its arm onto the asteroid's surface, threw up tonnes of debris, and collected roughly a quarter of a kilogram of it. In September 2023, a capsule from the spacecraft carrying the sample landed on Earth. Scientists who investigate the possibility of life outside Earth have been studying these samples. In January 2025, scientists said (*go.nature.com/425Llmn*) they had found 14 of the 20 amino acids that terrestrial life on Earth uses to make proteins and all five nucleobases in DNA and RNA: adenine, cytosine, guanine, thymine, and uracil.

While the findings are not evidence of life, they increase the chances of life on other planets and moons in the solar system. Moreover, they suggest the ingredients of life itself could have been brought to Earth by asteroids. The spacecraft is now on course to study another near-Earth asteroid, Apophis, which will closely approach Earth in April 2029 — the largest object to approach Earth at about 30,000 kilometres. Now renamed OSIRIS-APEX (OSIRIS-APophis EXplorer), it will similarly dig out samples on Apophis.

The paper by Goyal and Tikhonov suggests that to look for assured signs of life on such missions, astrobiologists need to look for the layered carpet patterns found in microbial mats. "This *idea* is... our central contribution," Goyal says. However, it's not yet clear what astrobiologists should be looking for. "Others smarter than us can think of whether — and how — this [idea] can be made more concrete."

***Debdutta Paul** is a Bengaluru-based science journalist.*

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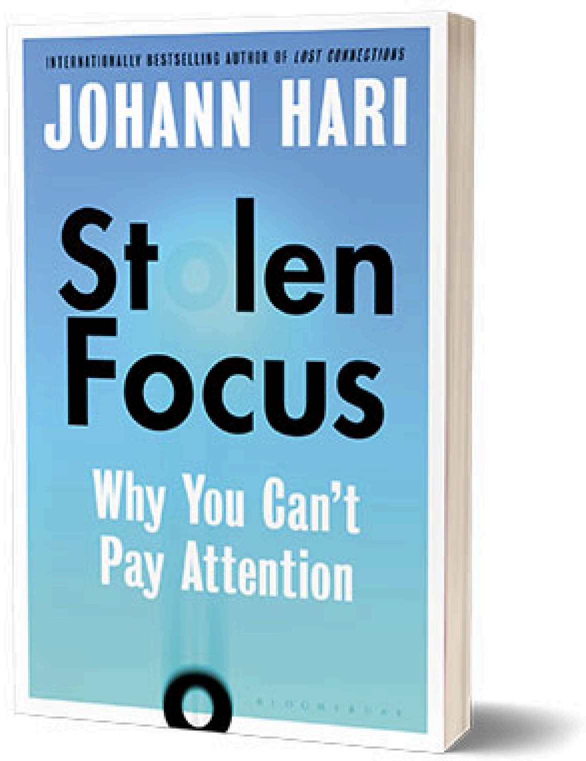

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