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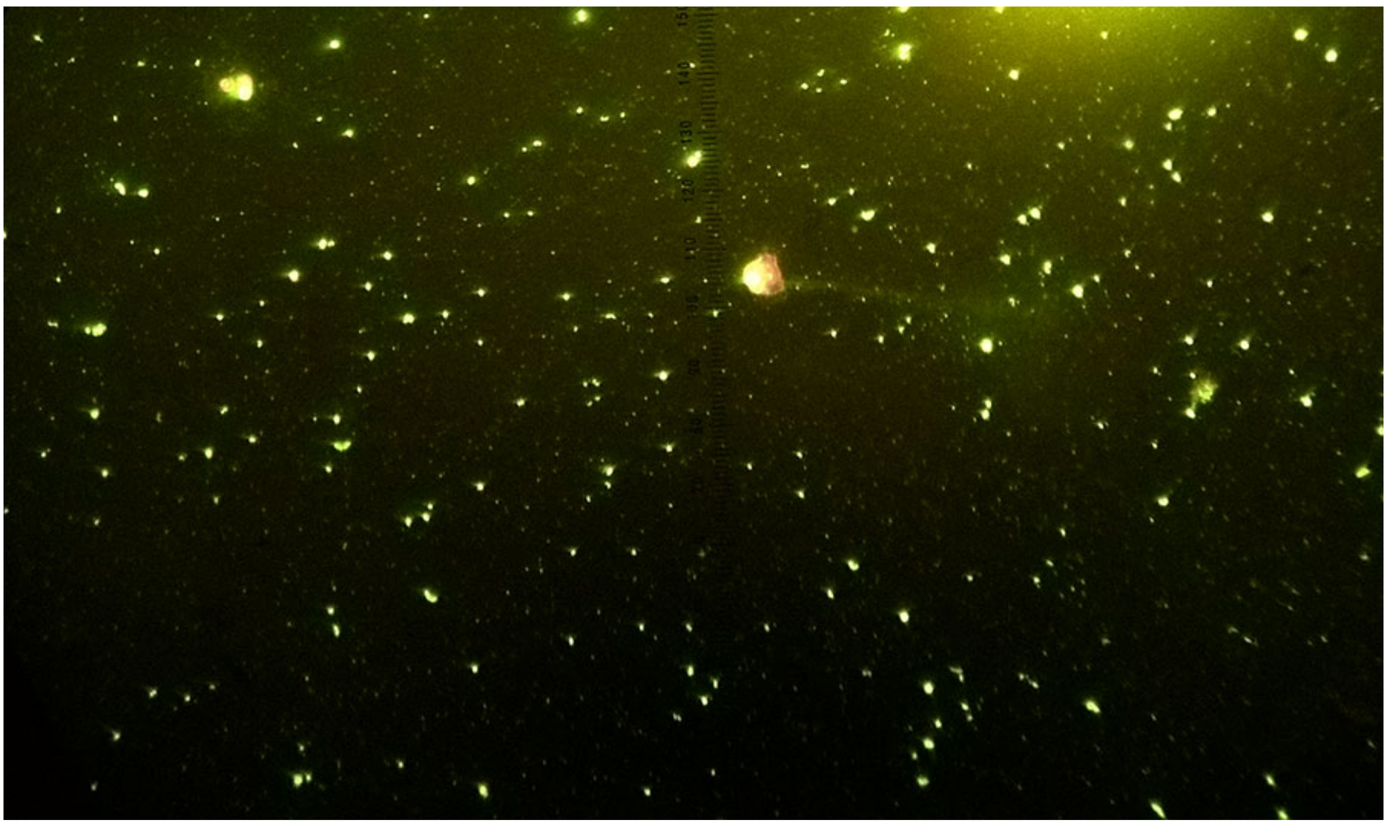
How Viruses Secretly Control the Planet

Bacteria help drive Earth's chemical cycles and climate. Viruses drive the bacteria.



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EARTH (/EARTH)

Tuesday, January 14, 2020

Nala Rogers, Staff Writer

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(Inside Science) -- Viruses control their hosts like puppets -- and in the process, they may play important roles in Earth's climate.

The hosts in this case aren't people or animals: They are bacteria. A growing body of research is revealing how viruses manipulate what bacteria eat and how they guide the chemical reactions that sustain life. When those changes happen to a lot of bacteria, the cumulative effects could potentially shape the composition and behavior of Earth's oceans, soil and air.

"We think that viruses have this huge impact that we just don't know about," said Gary Trubl, a soil virus ecologist at Lawrence Livermore National Laboratory in California. "They can actually impact the environment."

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Tiny masters of the ocean

Viruses are basically genetic material packed in a protein shell. To reproduce, they attach to a living cell and inject their genetic material. Some viruses then linger in the cell, often stitching their own DNA into that of the host and being copied along with the host DNA when the cell divides. At some point in a typical viral life cycle, the virus hijacks the cell's machinery to build new viruses, eventually causing the cell to burst and spill its infectious contents.

It's debatable whether viruses are alive, but if they are, they are the most abundant organisms on the planet. Most are so small it would take 55 million of them to cover the period at the end of this sentence, according to a review (https://www.nature.com/articles/s41564-018-0166-y) by Mya Breitbart and colleagues at the University of South Florida. But if you strung all the viruses in Earth's oceans together end to end, they could span the distance to Mars and back 12 trillion times.

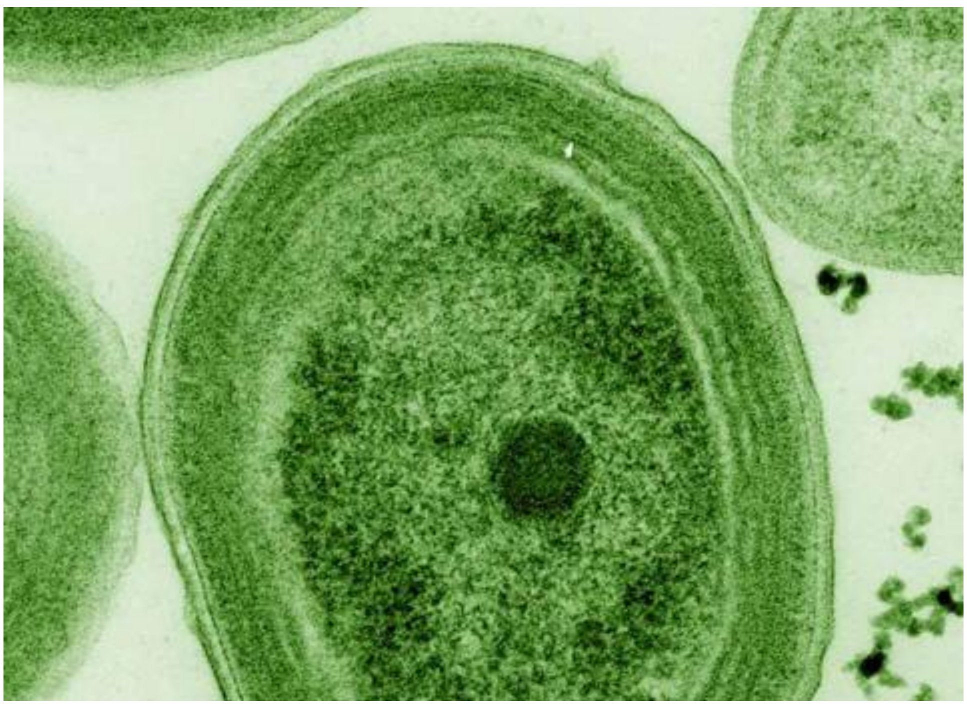
The vast majority of viruses infect bacteria.

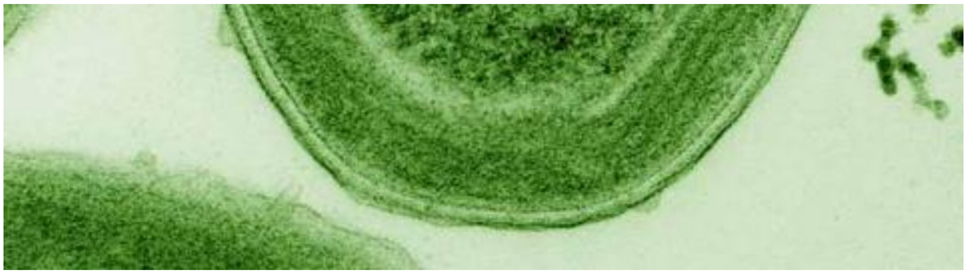
"If you go swimming in the ocean, that's about 200 million viruses per every mouthful of seawater. And almost all of those are going to be infecting the 20 million bacteria in that same mouthful of seawater," said Jennifer Brum, an oceanographer at Louisiana State University in Baton Rouge.

Viral infections are a ubiquitous part of bacterial life. This is a big deal, since bacteria recycle and transform the chemicals we eat and breathe. When viruses kill bacteria, they release nutrients back into the environment. Recently, scientists have been finding that viruses also change what bacteria do while they're alive.

"We live in a bacteria-driven world," said Martha Clokie, a microbiologist at the University of Leicester in the U.K. "Those bacteria are endlessly being subtly manipulated by viruses."

In 2003, Clokie and colleagues at the University of Warwick identified a key photosynthesis gene (https://www.nature.com/articles/424741a) called psbA in viruses that infect cyanobacteria in the ocean. Like plants, cyanobacteria use photosynthesis to transform sunlight into usable energy, releasing oxygen as a byproduct. Follow-up work by the Warwick team and other labs in the U.S. and Israel showed how the viral psbA gene allows photosynthesis to continue after a cell is infected, even though the bacteria's own photosynthesis genes are shut down. In fact, infected cells can photosynthesize even faster than uninfected cells in bright sunlight, according to recent work (https://www.nature.com/articles/s41396-017-0043-3) by Richard Puxty and colleagues at the University of Warwick.





Cyanobacteria like the Prochlorococcus cell pictured above are frequently infected with viruses that manipulate their photosynthesis.

Media credits: *Credits: Luke Thompson from Chisholm Lab and Nikki Watson from Whitehead, MIT via Wikimedia Commons (https://commons.wikimedia.org/wiki/File:Prochlorococcus_marinus_(cropped).jpg)*

Cyanobacteria are thought to produce one-quarter of all the oxygen in the atmosphere. Researchers have estimated that half of these bacteria are infected with viruses at any given time, although that number is highly uncertain. In essence, said Clokie, this could mean that one out of every eight breaths you take is made possible by a virus.

You might think all this virus-driven photosynthesis is good news for the climate, since photosynthesis typically pulls carbon dioxide out of the air and water. But Puxty and his colleagues have found that viruses in cyanobacteria suppress the steps of photosynthesis that bind up carbon dioxide into organic matter. That could mean that researchers have overestimated the power of ocean bacteria to clean up carbon dioxide, said Puxty.

Since the discovery of viral psbA, researchers have found dozens of other genes in ocean viruses that are similar to metabolic genes in bacteria. They have not yet examined how viruses use most of these genes, but they have guesses. For example, some of the genes look like they might help bacteria digest carbohydrates and fats (https://www.ncbi.nlm.nih.gov/pubmed/24200126), while others are likely to help bacteria collect scarce nutrients such as phosphate (https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5083919/).

Of course, viruses don't do all this to be nice, said Brum. They do it to make more viruses. But some viruses can linger in their hosts for a long time before they begin producing new viruses. In the meantime, a virus needs its host alive, so the interests of the parasite and its victim may be temporarily aligned.

"A cell that has a virus like that, when it's just living under not very good conditions, will replicate faster ... It will flourish," said Clokie. "But then it's got this molecular time bomb inside it."

From soils to gut mucus

Most of the evidence of viral puppeteers comes from the ocean, but scientists are starting to find the same thing on land.

In two (https://www.nature.com/articles/s41564-018-0190-y) 2018 studies (https://msystems.asm.org/content/msys/3/5/e00076-18.full.pdf), researchers found genes for breaking down plant carbohydrates in viruses living in thawing permafrost soils in Sweden. That could mean that the viruses are helping their hosts digest carbohydrates such as hemicellulose and starch.

But strangely, the carbohydrates the viral genes targeted are too large to fit inside most bacteria, said Joanne Emerson, a soil viral ecologist at the University of California, Davis and first author of one of the studies. It's doubtful whether bacteria could handle such large carbs even if they had the genes to break them down.

In an alternative scenario, the enzymes for breaking down unwieldy carbs might build up inside bacteria while they're infected. When the bacteria burst, they would release the enzymes along with all the new viruses. The enzymes would then break down carbs in the environment. The broken-down carbs would provide food for new bacterial hosts infected with the virus's progeny -- a sort of viral version of parents providing for their offspring. This idea of viral parental care is still only speculation, noted Emerson.

Researchers Robert Jones and Moira Hough prepare to collect soil samples in Sweden as part of the IsoGenie (https://isogenie.osu.edu/) project in 2014. The object in Hough's hands is the bit for a permafrost corer -- a device that spins like a drill to cut cylinders from frozen earth.

Media credits: *Credits: Gary Trubl*

Regardless of where the carbs are broken down, some of the simple sugars produced by this process will likely find their way into the wider environment, where many types of microbes can use them.

"It's like they're prepping meals for other organisms," said Trubl, who worked on both studies.

In an unpublished study from Matthew Sullivan and Virginia Rich's labs at Ohio State University in Columbus, scientists have found viral genes for breaking down carbohydrates in numerous environments, including soils, oceans, lakes, human guts, and cow rumens (organs where bacteria help cows digest their food).

For instance, many viruses from aquatic environments have a gene for breaking down alginate, which is produced by algae. And in the human gut, there are viral genes for breaking down starch -- a common carb in human food -- and mucin, which makes up the mucus lining our digestive tracts.

It's not clear yet how viruses use all these genes, said Lindsey Solden, a microbiologist at Ohio State who presented the preliminary findings (https://agu.confex.com/agu/fm19/meetingapp.cgi/Paper/500179) at the American Geophysical Union meeting in San Francisco last month. In some cases, viruses might speed up bacteria's own digestion processes; in other cases, they might give bacteria the power to use new food sources that they couldn't digest on their own.

For example, an uninfected bacterium might just pass through the human gut. But once a virus gave it genes for digesting mucus and starch, it might stay and become part of the person's microbiome.

Breaking complex carbohydrates into simple ones is the first step in the metabolic processes that produce carbon dioxide and methane, both greenhouse gases that cause climate change. The implications could be huge.

"We don't really know the role that viruses are playing in the global carbon cycle, but there is evidence that they are playing a very important role," said Solden.

For example, if viruses are enabling bacteria in a cow's rumen to use the cow's mucus as food, that could increase the amount of methane the cow belches out, said Solden. Similarly, viruses in the soil could be contributing to greenhouse gas emissions by helping decomposers break down dead plant material. Indeed, when Solden analyzed genetic data from soils, she found viral genes for breaking down two especially persistent plant carbohydrates, called xyloglucan and arabinogalactan, that most microbes can't digest.

Of course, whatever role viruses play in the climate, they have been doing it for millions of years, noted Brum. It's not as though they are going to suddenly wreck Earth's climate now that scientists have discovered them.

But human-caused climate change could disrupt the intricate balance between bacteria and viruses, changing how much carbon is released or taken up in ways we can't yet predict. Warmer temperatures and more acidic oceans will likely favor some types of viruses over others and influence how long (https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4231975/) viruses remain in their hosts before killing them, said Clokie.

"We have predictions on how things are going to change," said Brum. "Now we're finding more and more that we're going to have to include viruses within those predictive models to increase our ability to understand what's going to happen in the future."

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Nala Rogers is a staff writer and editor at Inside Science, where she covers the Earth and Creature beats. She has a bachelor's degree in biology from the University of Utah and a graduate certificate in science communication from U.C. Santa Cruz. Before joining Inside Science, she wrote for diverse outlets including *Science*, *Nature*, the *San Jose Mercury News*, and *Scientific American*. In her spare time she likes to explore wilderness.

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Santanu Chacraverti • 9 months ago

Remarkable! This could be just tip of the iceberg and one wonders how far we can and will learn about the role of viruses in the history of this planet. On a different note, one wonders whether virological experimentation with creation of new virus strains might not inadvertently result in ecological 'disasters'.

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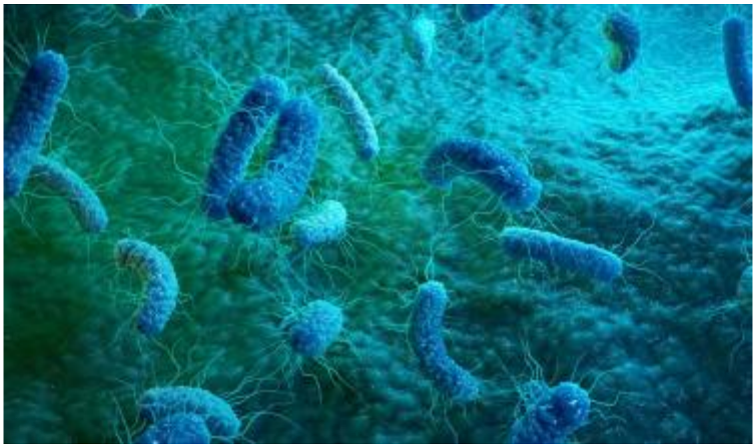

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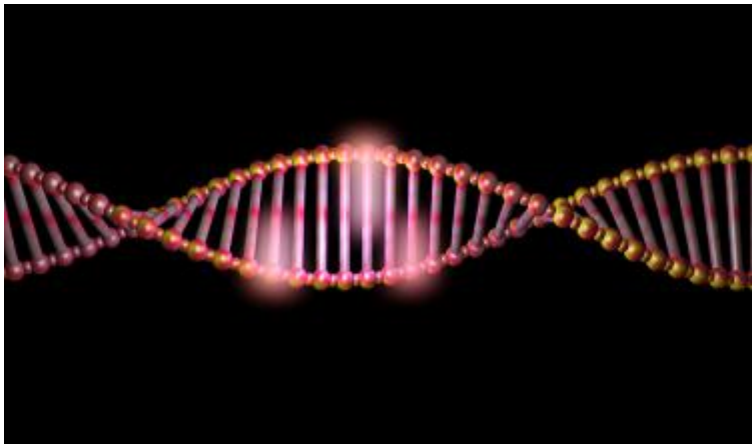

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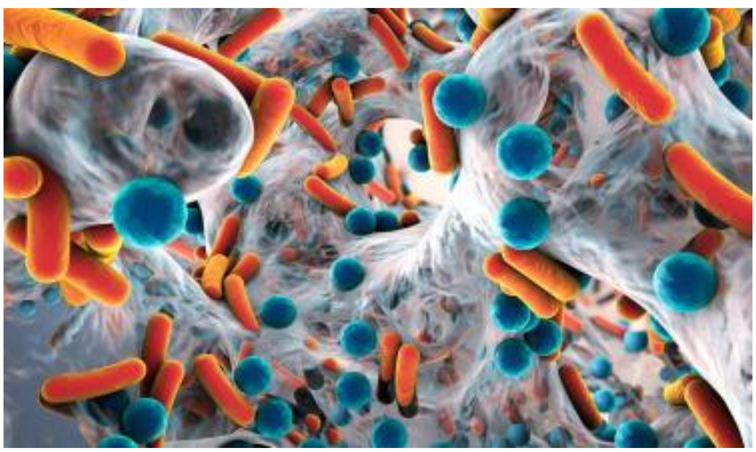

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