Life on Earth uses water as a solvent. What are some other options for life as we don't know it?

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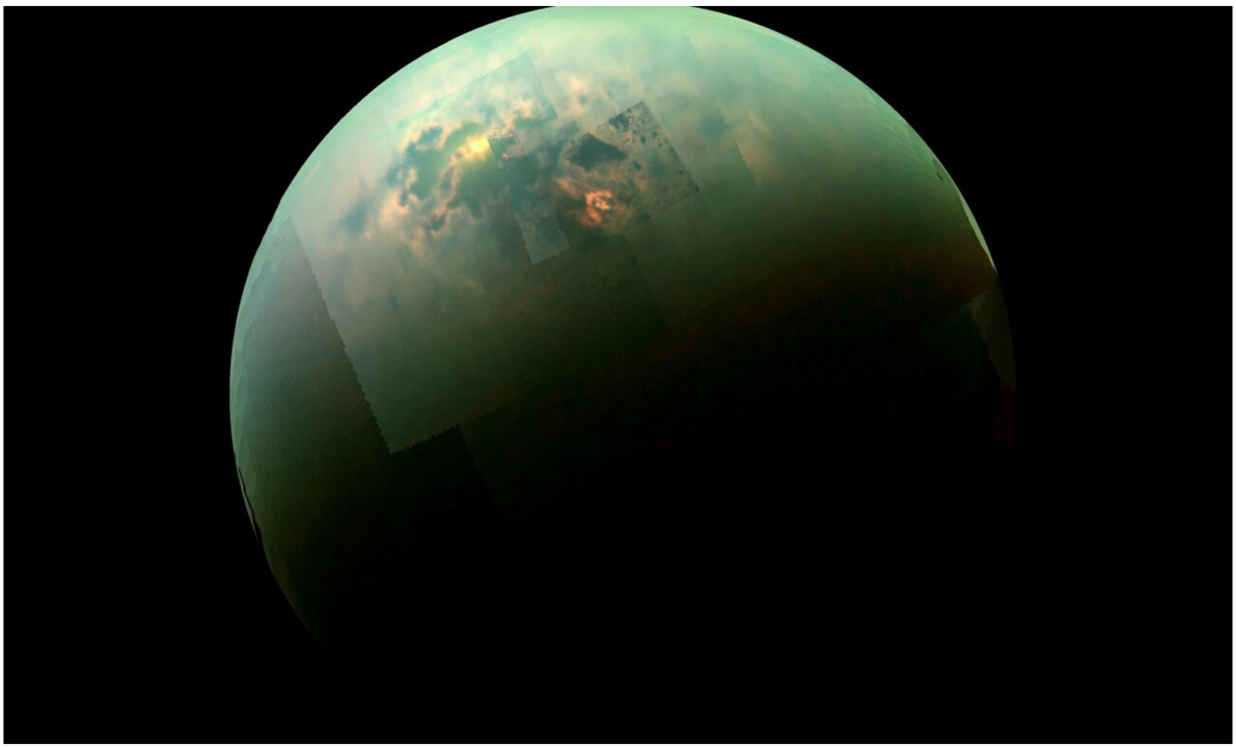

A near-infrared view of Titan showing its glinting seas. Credit: NASA/JPL-Caltech/University of Arizona/University of Idaho

There is a vast menagerie of potentially habitable worlds in the cosmos, which means the universe could be home to a diversity of life beyond what we can imagine. Creatures built on silicon rather than carbon, or organisms that breathe hydrogen instead of oxygen. But regardless of how strange and wondrous alien life may be, it is still governed by the same chemistry as life on Earth, and that means it needs a chemical solvent.

On Earth that solvent is water (H_2O). Water dissolves some molecules into solution, giving organisms access to a range of materials. Since it is a liquid, water also makes it easy for complex molecules to mix together and interact. Terrestrial life isn't possible without the solvent and fluid properties of water, and since water is a common molecule in the universe, its central role for life is not surprising. But are there other common molecules that could serve as the solvent of life? Could alien life arise on distant worlds without the need for water? That's the question studied in a recent article posted to the *arXiv* preprint server.

The authors begin with four general conditions for life-friendly solvents: They must dissolve some molecules but not all; they must be able to play a role in the metabolism of living things; a wide range of complex organic molecules must be able to survive in the solvent; and it must commonly exist on certain rocky worlds for billions of years.

Of all the known common solvents, only water clearly satisfies all four conditions. Ammonia (NH_3) satisfies the first three, but is unlikely to meet the fourth condition because it breaks down readily when exposed to ultraviolet light, and wherever ammonia is likely to survive water is likely as well. So while ammonia can play a role in life on other worlds, it isn't likely to be the main solvent. There are two molecules, however, that come pretty close to water.

The first is concentrated sulfuric acid (H_2SO_4). Although it's extremely dangerous to life on Earth, sulfuric acid satisfies three main conditions. What's not known is whether a diverse range of organic molecules can exist within it. Like water, it can provide ions for the exchange of electric charge, and it can participate in the interactions of certain compounds such as aromatic molecules. But there is one molecule that comes even closer to the usefulness and abundance of water: carbon dioxide (CO_2).

Carbon dioxide is quite common. The atmospheres of both Mars and Venus are composed mostly of CO_2, and it is likely that most rocky exoplanets are rich in carbon dioxide. It isn't a solvent in its gaseous state, so life on warm planets such as Earth would rely upon it. But more distant exoplanets such as a cold Venus might. Liquid CO_2 is geologically stable and tolerates a wide range of organic molecules.

What isn't known is whether its solvent properties are suitable for complex metabolism. CO_2 is a very benign solvent, so it may not stir the chemical pot enough for life to arise within it. But since it plays well with so many types of molecules, it might work in collaboration with other molecules to become a foundation for life. The authors conclude this is a topic worth further study.

On one level this work confirms what we've already known, that water is the most abundant and useful solvent for life. But it also raises interesting questions. Other common molecules come close, and they might work together to form a home for alien life.

The seas of Titan, for example, are rich in hydrocarbons and other complex organic molecules. Cold exoplanet moons similar to Titan could have oceans of CO_2, NH_3, and H_2O, each capable of serving part of the role that water does on Earth. There is still much we don't understand about cryogenic chemistry on cold exoplanets. So while the waters of life are likely in the cosmos, the seas of life on some worlds could be much more exotic.

More information: William Bains et al, Alternative solvents for life: framework for evaluation, current status and future research, *arXiv* (2024). DOI: 10.48550/arxiv.2401.07296

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