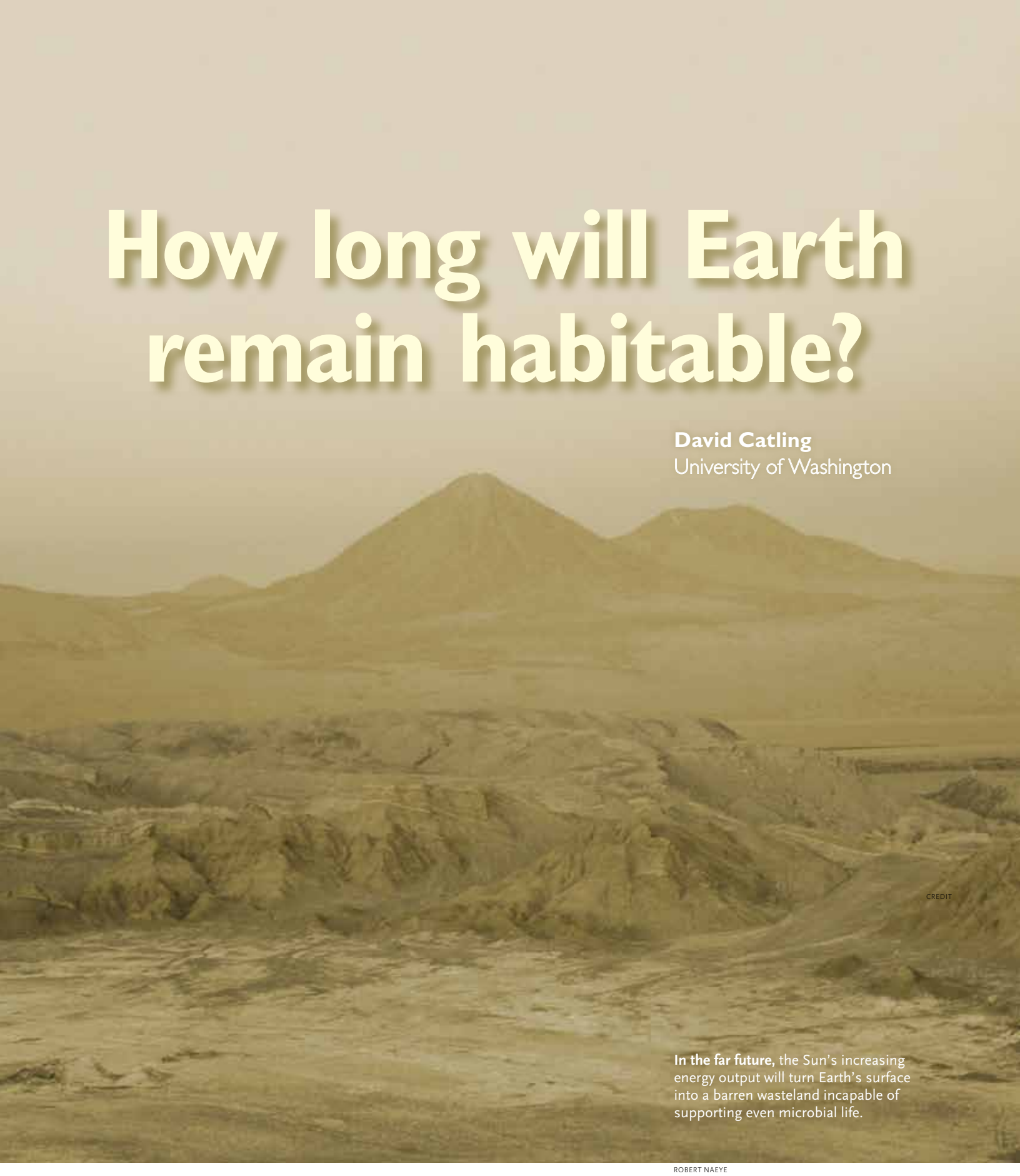
How long will Earth remain habitable?

David Catling
University of Washington



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In the far future, the Sun's increasing energy output will turn Earth's surface into a barren wasteland incapable of supporting even microbial life.

ROBERT NAEYE

David Catling studies the coevolution of planetary surfaces and atmospheres. He is the author of "*Astrobiology: A Very Short Introduction*" Oxford University Press (2013).

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Benjamin Franklin wrote that "nothing can be said to be certain, except death and taxes." Although we can make no predictions about taxation in a few billion years, we can be sure that Earth will become uninhabitable. If we leave any descendants, they will have long moved to a new planet. There are several ways that Earth's habitability will end. The most definite is the gradual brightening of the Sun, which will bake our planet into a scorching desert. But life on Earth faces other challenges before then.

The motion of Earth's tectonic plates is driven by geothermal heat, which is declining because the radioactive decay inside Earth that supplies that heat is diminishing. Plate tectonics could halt in as little as a half-billion years. Mountains will stop rising as erosion levels the land. Eroded material will flow into the ocean, so seawater will flood flattened continents. Land life will drown under a global ocean. By disturbing the nutrient flow that once came from rivers, most marine life might also go extinct.

Another fate that might befall Earth is too little atmospheric carbon dioxide. The Sun brightens roughly 10% every billion years and this rate is slowly accelerating. In about a half-billion years, the hotter climate will produce more rainfall and faster reactions of carbon dioxide in rainwater with minerals on the continents. The byproducts of these reactions are washed by rivers to the ocean and end up as limestone sediments on the seafloor. So as the Sun slowly brightens, carbon dioxide is sequestered into limestone. Some 600 to 800 million years from now, atmospheric carbon dioxide concentrations should fall below 10 parts per million, a threshold where plants can no longer photosynthesize. This process might wipe out plants and the animals that depend on them.

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Perhaps evolution will favor new plant species that adapt to ever-lower levels of carbon dioxide, extending the biosphere's lifespan. In fact, such evolution has happened before. Between 32 and 25 million years ago, some plants evolved the capability to concentrate carbon dioxide inside their cells.

But an extended biosphere will eventually experience sweltering heat and diminishing amounts of water on Earth's surface. Today, Earth is cool enough that most water vapor condenses into clouds below the stratosphere, where it remains safe from the ravages of solar ultraviolet light. In about a billion years from now, vigorous evaporation under a brighter Sun will waft great quantities of water vapor high into the atmosphere. There, ultraviolet light will break apart water molecules into hydrogen and oxygen atoms. The light hydrogen will escape into space and heavier oxygen will react with other gases or substances on the ground.

After another billion years, much of the planet will be a salty desert, with increasingly sparse lakes and seas. A further couple of billion years will see all remaining water enter the air, producing a greenhouse warming strong enough to melt rock. Thus, long before the Sun expands into a red giant some 7.5 billion years from now (see page XX), Earth will lose its oceans.

So, no matter what biological innovations evolve in the future, Earth's long-term fate is sealed. About 4 billion years from now, Earth's surface will be bereft of plants, animals, and even microbes. It will resemble the surface of Venus — a hellish, arid inferno. That's the way the world ends.

In fact, in the next few decades, we're likely to see hints of such calamitous fates by examining the spectra of Earth-sized worlds around other stars of various ages.