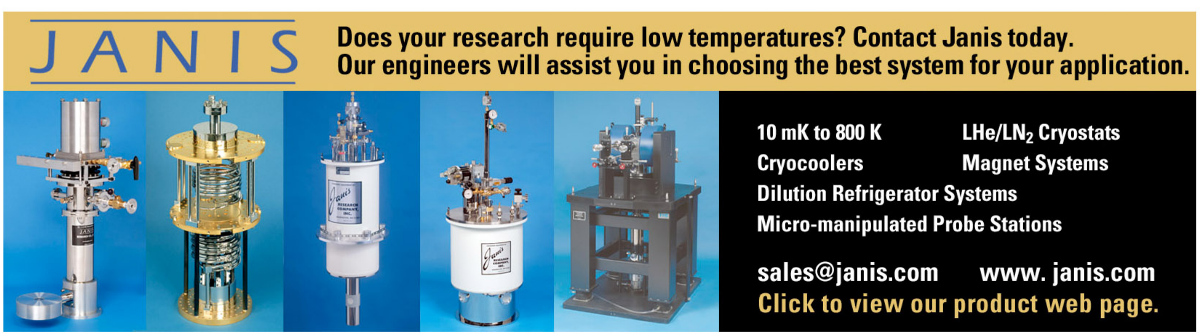
Commentary: The habitability mantra: Hunting the Snark

David J. Stevenson

Citation: Physics Today **71**, 11, 10 (2018); doi: 10.1063/PT.3.4054
View online: https://doi.org/10.1063/PT.3.4054
View Table of Contents: http://physicstoday.scitation.org/toc/pto/71/11
Published by the American Institute of Physics



Commentary

The habitability mantra: Hunting the Snark

Just the place for a Snark! I have said it twice:
That alone should encourage the crew.
Just the place for a Snark! I have said it thrice:
What I tell you three times is true.

—Lewis Carroll,
The Hunting of the Snark

The origin of life and the existence of extraterrestrial life are among the most important scientific puzzles of our time. Humans have embarked on a great quest, the discovery of extraterrestrial life: We are seeking the Snark. The work of characterizing celestial bodies within our solar system and beyond contributes toward solving the puzzle, and future astronomical observations of exoplanets are also essential. However, in promoting those efforts or the choice of targets, excessive emphasis on habitability is bad science policy: It presumes a greater understanding of the concept than we currently possess, and it may fail to recognize the extraordinary diversity of planetary environments.

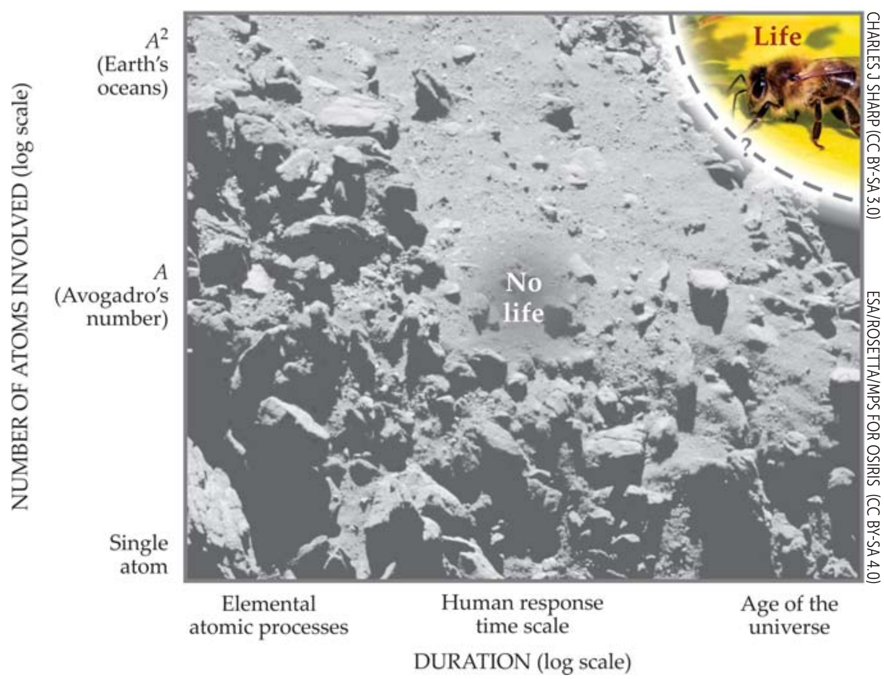
Unlike the original Sanskrit definition of "mantra" as a sacred text or passage, today's common Western definition, according to the Oxford English Dictionary, is "a constantly or monotonously repeated phrase or sentence." In planetary science and in many venues where exoplanets are discussed, that is an apt description of how "habitability" is used. The word figures prominently in the NASA planning documents that justify choices of future missions and observations. It motivates the endless drumbeat of reports about water on Mars. It drives the newspapers' front-page stories about the most recent discovery of a planet in or near the habitable zone of its parent star and considered suitable because it is "Earth-like." We assume that Earth-like is a virtue. The problem lies in our anthropocentric perspective.

As Charles Cockell discussed (Physics Today, March 2017, page 42), we believe that the rules and processes governing life are universal. However, we have only one known expression of that universality so far. We have a remarkably successful theory, firmly grounded in observations and molecular biology, of the evolution of life on Earth. Even so, the desirable conditions for initiating life are not understood beyond the obvious need for disequilibrium—that is, available free energy. Geobiology and the study of early Earth guide our thinking on evolutionary process and environmental conditions, but their applicability to the rest of the universe is not clear. There are no generally accepted guidelines for the time scales, volumes, or surfaces that are needed to start life.[1] The delineation of that ignorance is shown in the figure.

We don't know how the origin of life scales. Does the probability of occurrence double if we double the suitable volume, or the surface area, or time, or . . . ? Is it instead like nucleation theory, in which certain critical conditions must be satisfied? Homogeneous nucleation theory—which describes, for example, the formation of a snowflake in a supercooled cloud of water vapor—predicts that the change in state is primarily determined by the degree of supercooling and is insensitive to the volume or time scale.

The richness of the periodic table is universal; all relevant elements exist everywhere to a greater or lesser degree, though not necessarily in the phase, abundance, combination, or oxidation state that we have deemed necessary based on terrestrial experience. Inferring constraints based on the particular pathways that were in play on Earth is a danger to our quest elsewhere. The huge amount of literature on the habitability question should never imply that we have a deep understanding of it.

Arguably, our search does not require a precise understanding of what we seek.



THE NUMBER OF ATOMS AVAILABLE and the time they have to interact are two of the many variables relevant to the origin of life. Life is not so easily initiated that it readily leaves a signature in meteorites coming from parent bodies exposed to water for millions of years. Hence the suggested but highly uncertain boundary between life and nonlife. This figure is intended to demonstrate our ignorance, not to assert understanding.

When James Cook sailed the Pacific, part of his quest was for something that does not exist—the Great Southern Continent, thought to be needed to keep Earth from tipping over. But Cook did find lots of interesting stuff anyway. For example, he found that the language of the Maori in New Zealand is similar to that of the Easter Islanders, nearly 7000 kilometers away. He also made magnetic field measurements that were subsequently of great importance in establishing how Earth's magnetic field changes over time. The key, then, is to make sure that science policy permits discovery for the sake of discovery and not just for finding Earth-like planets, which we have prejudged to be of greatest interest.

The most important things found in planetary exploration were the surprises, not the unimaginative preconceptions that sold the missions. When resources are limited—in the case of the persistently future *James Webb Space Telescope*, for example—will the choices of missions have sufficient flexibility that we will find what we are not looking for? For a scientifically healthy enterprise, what is needed most is flexibility of thinking. The instrumentation is often capable of finding what we are not looking for, but the right instrumentation is not enough. The exoplanets we found first were the pulsar planets, followed by the hot Jupiters; neither were expected. We could have found the second kind sooner if we had been more open-minded about their possible existence. Will we make similar errors with extraterrestrial life?

The so-called habitable zone is perhaps the most distressing example of limited imagination. Certainly, all planets are hot inside, and all planets except those too close to their star can contain regions that permit liquid water, which is usually thought to be desirable for life. Most of the liquid water in our solar system resides in the Jupiter system and beyond, far outside what's been put forward as the Sun's habitable zone. All the major planets—Jupiter, Saturn, Uranus, and Neptune—have liquid water in the form of droplets in extensive clouds. Plausibly, the hypothesized Planet Nine has liquid water as well. Europa and Enceladus have oceans beneath relatively thin, icy shells. Many other bodies have oceans beneath surface ice: Ganymede, Callisto, and Titan; possibly Mimas, Triton, and Pluto; and perhaps once Ceres. The list is probably incomplete.

Much closer to home, Mars receives much attention precisely because it is somewhat Earth-like. Discovering evidence of past or present life on Mars would be a huge event in the history of humankind, but it might also strengthen our prejudices about habitability. Even with Mars, one has to wonder whether we are looking in the right places.

The thousands of exoplanets discovered by the Kepler mission already contain hints to challenge our prejudices. So-called super-Earths are common, but most are unlikely to have suitable surface conditions for life. More-distant, superficially

CONTACT PHYSICS TODAY

Letters and commentary are encouraged and should be sent by email to ptletters@aip.org (using your surname as the Subject line), or by standard mail to Letters, PHYSICS TODAY, American Center for Physics, One Physics Ellipse, College Park, MD 20740-3842. Please include your name, work affiliation, mailing address, email address, and daytime phone number on your letter and attachments. You can also contact us online at http://contact.physicstoday.org. We reserve the right to edit submissions.

colder planets of roughly Earth mass can retain a hydrogen atmospheric blanket that allows for liquid water; they could even be interstellar planets.[2]

The habitable zone, as usually defined, does have one obvious advantage in our exoplanetary observations. Earth-mass planets in that Goldilocks zone may have atmospheres sufficiently thin that they allow observation of the surface or at least yield clues as to what is below. Earth has a naked ocean, potentially observable from afar. It also has ample usable energy, in the form of sunlight, although one should never confuse supply with sufficiency—we do not know the minimum needed.

Let us be clear in our thinking: Do we choose to obsess over the habitable zone by the same reasoning that a drunkard looks for his car keys under the street lamp—because that is the only place he can see? Or is our thinking so anthropocentric that Earth-like planets matter most and are what the public will support with tax dollars? We cannot be sure that they are the most abundant habitations. And they are not necessarily easier to observe. When visiting a city far from home, do you immediately seek out the restaurant that provides the food most like what you usually eat? Do we know the right place to find a Snark?

References

1. For an attempt to quantify the origin of life, see C. Scharf, L. Cronin, *Proc. Natl. Acad. Sci. USA* **113**, 8127 (2016). For a discussion of how life on Earth constrains probability, see D. S. Spiegel, E. L. Turner, *Proc. Natl. Acad. Sci. USA* **109**, 395 (2012).
2. D. J. Stevenson, *Nature* **400**, 32 (1999).

David J. Stevenson
(djs@caltech.edu)
California Institute of Technology
Pasadena

LETTERS

Human rights and international collaboration

Charles Day's editorial "Physics and human rights" (PHYSICS TODAY, March 2018, page 8) raises an important question of whether we should limit collaboration with scientists from countries that violate their citizens' human rights. My own experience of living in the Soviet Union supports the editor's viewpoint that collaboration is almost always virtuous.

In the 1970s and early 1980s, Soviet researchers were rarely allowed to travel to international conferences abroad—even when that travel was fully paid for by the event organizers. We were often not allowed to submit papers for publication in international journals. I myself was summoned by the KGB and threatened with jail time for sending my mathematical papers abroad. Even access to international journals held in Soviet libraries was often limited. For example, several issues of the *Notices of the American Mathematical Society* were not available to us without special KGB permission, because in addition to mathematics they also discussed violations of scientists' human rights worldwide. Those issues never made it to the mailboxes of individual subscribers like me, and the ones delivered to the libraries were placed in special restricted-access sections.

After I complained to the American Mathematical Society (AMS) about missing issues, it started sending them to me by registered mail with return receipt, so I was probably the only person in the Soviet Union—and definitely the only one in St Petersburg—who received those forbidden issues. Of course, I gladly shared them with my colleagues.

Although the forbidden issues included pieces about how the Soviet Union often violated the human rights of scientists, the proposed responses to punish the leadership shocked many of us in the Soviet science community. Several AMS contributing writers suggested decreasing international collaboration, in particular expelling all Soviet scientists from the AMS and ceasing to send us their publications. So on the one hand, the KGB was stealing some of our publications, and on the other hand, our own colleagues were now proposing, in effect, further oppression by depriving us of the publications altogether.