FORUM: Astrobiology

Frontier or fiction

Astrobiology, the study of life in the Universe, is sometimes criticized as being a fashionable label with which to rebrand existing research fields. Its practitioners, however, argue that the discipline provides a broad framework for developing a better understanding of the frontiers of biology. A biologist and a planetary scientist offer their views.

THE TOPIC IN BRIEF

- Space-exploration programmes in the 1960s powered a new branch of biology called exobiology, which was focused on the search for life beyond Earth.
- Today, the term exobiology has been almost abandoned, to be replaced by a broader one, astrobiology — the study of the origin, evolution, distribution and future of life in the Universe[1].
- However, the nature of astrobiology as a distinct scientific discipline has been challenged because of the lack of proof for extraterrestrial life.
- Also, astrobiology is sometimes criticized as being a buzzword added to certain research topics in fields such as planetary science or biology — for example, in the study of microbes known as extremophiles, which live under extreme conditions.

Maintaining the plausible

ANTONIO LAZCANO

Stimulated by controversies[2] that arose over the evidence for extraterrestrial life in the Martian meteorite ALH 81004 in the mid-1990s, NASA reorganized its programmes on exobiology and planetary science as part of an attempt to integrate its research on life sciences into its space-exploration efforts. Thus was born astrobiology, an all-encompassing effort that was expanded to include the study of extremophiles, the occurrence of planets and their habitability beyond our Solar System, and research on the origin and evolution of life on Earth, among other disciplines[3]. But can a funding programme be transformed into a new science?

The astrobiology programme has indeed supported such studies, and has created jobs for young researchers, endorsed the teaching of evolutionary biology, and promoted major efforts in outreach following NASA's generous tradition of sharing its scientific results for free. The creation of the NASA Astrobiology Institute[1] was followed by the launch of specialized journals and scientific societies, university courses, graduate programmes and books, as well as by a handful of centres and networks of varying scope and uneven academic standards in countries other than the United States. The commitment of such efforts to understanding evolutionary perspectives is a major accomplishment, but I feel that many of them tend to place far too much weight on a handful of loose analogies between extremophilic microbes and the potential habitability of other worlds in our Solar System.

In the absence of unambiguous proof for its existence, almost nothing can be said about extraterrestrial life about which the opposite is not also true. The scarcity of evidence gives considerable latitude, and, in certain circles, astrobiology has become a resounding but meaningless catchword in the competition for grant money. It has been argued that the potential discovery of a terrestrial 'shadow biosphere' — that is, organisms that have an alternative chemical composition to that of all known organisms — would imply that life has appeared more than once on our planet and therefore that it could also have developed in other worlds.

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In spite of the fanfare[4] that advertised the existence of 'arsenic-based DNA' in a microbe isolated from a saline lake in California[5], mere distilled water and additional laboratory controls have washed away the speculation about such alien biochemistries[6,7]. And some of the attempts by other researchers to extrapolate to other parts of the Universe the ability of microbes to adapt to extreme environments may be due more to the struggle for funding than to the desire to study habitable planets.

The search for life beyond Earth is a legitimate scientific question and an alluring intellectual endeavour that can best be served by keeping a healthy distance from science-fiction scenarios and from the theological musings that somewhat surprisingly find their way into astrobiology meetings. Depending on who you speak to, astrobiology seems to include everything from the chemical composition of the interstellar medium to the origin and evolution of intelligence, society and technology — as if the Universe is following an inevitable upward linear path leading from the Big Bang to the appearance of life and civilizations capable of communication.

Neither the formation of planets nor the origin of life is seen today as the result of inscrutable events; rather, they are considered as natural outcomes of evolutionary processes. However, this does not mean that such outcomes are inevitable, and it is still to be shown that life exists — or has existed — in places other than Earth (Fig. 1). The lack of evidence should not inhibit us in the slightest, but unless we are bound by the highest academic standards and critical attitudes, astrobiological discussions will become nothing more than empty speculation laced with a formidable disregard for scientific plausibility.

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The last great experiment

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Of the four basic sciences — physics, chemistry, geology and biology — only one has yet to prove its functionality beyond Earth. In the centuries since Galileo, we have come to learn that the laws of physics, and the

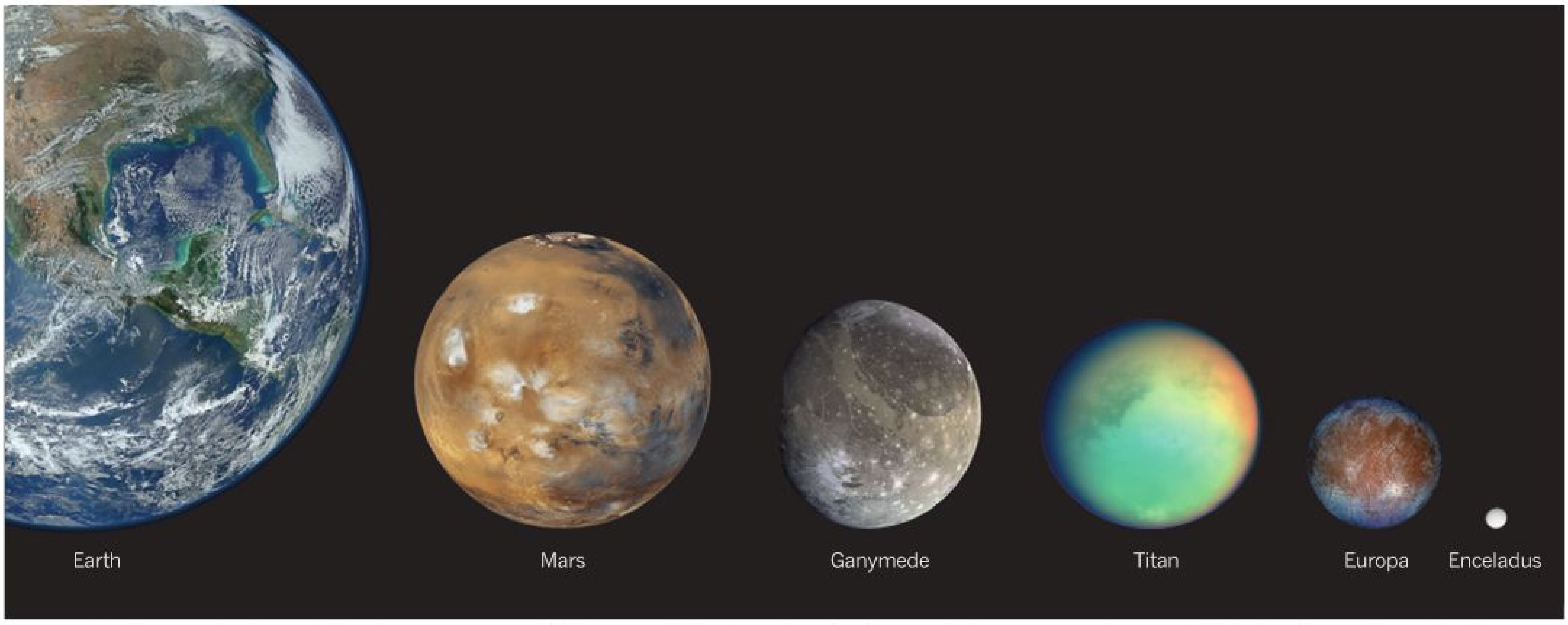

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Figure 1 | Life around us? Searching for extraterrestrial life is one of the aims of astrobiology, and there are several potentially habitable worlds in the Solar System, in addition to Earth. Two of Jupiter's moons (Ganymede and Europa) and two of Saturn's moons (Titan and Enceladus) harbour liquid-water oceans. And Mars probably had vast liquid-water environments during much of its early history.

principles of chemistry and of geology, work beyond our planet. Yet when it comes to this bizarre phenomenon known as life, we have yet to make that leap. The interdisciplinary field of astrobiology seeks to address that goal through the exploration of other worlds and of the limits of life on Earth.

A common misconception is that astrobiology is equivalent to the search for life elsewhere. Some people have even gone so far as to say that it is a science without a subject because we don't yet have any evidence for extraterrestrial life[8,9]. But that is a flawed argument that has been put to rest on several occasions (see, for example, ref. 10). Many experiments in science target hypothetical particles or objects; biology is simply handicapped by the fact that first principles and mathematics provide limited predictive power. In fact, the search for life beyond Earth is just one subset of astrobiology. As Knoll *et al.* have written[11]: "astrobiology can be thought of as the application of geobiological principles to the study of planets and moons beyond the Earth."

The heavily debated detection of methane on Mars serves as a useful example[12]. Because methane is rapidly destroyed by ultraviolet light from the Sun, the alleged presence of this molecule in Mars's atmosphere would necessitate an active source from geological or biological processes. Astronomers, chemists, geologists and biologists have all weighed in to address the issue from different perspectives and have worked together in an effort to triangulate on the major strengths and weaknesses of the data and models. Considerable support for that interdisciplinary work comes from NASA's Astrobiology Institute. This summer, the Mars Science Laboratory (MSL; a new NASA mission to explore the red planet) may help to resolve this debate, and the astrobiology community will be able to put the MSL results into context in part owing to our understanding of the geochemical and biological processes that generate methane here on Earth.

Some have argued that we know so little about life on Earth and its origin that we should focus our limited resources on these challenges[9]. Sixty years ago I might have been mildly sympathetic to this viewpoint, but now I think it's fair to say that our mapping of the tree of life on Earth begs the question of whether other trees exist. The analogy in chemistry would be as if, after creating the first periodic table in the 1860s, Mendeleev and others had decided not to search for more elements, even though the gaps in the table provided a guide for where to look. Life on Earth serves as a guide for identifying potentially habitable environments elsewhere. Yes, there is still much to learn about the specifics of terrestrial organisms, but our understanding of life as a phenomenon and of biology as a science will be greatly advanced by finding a second, separate origin that can help to put what we observe here on Earth in context.

"If funding permits, within the next few decades we will know the answer to whether or not life exists elsewhere in our Solar System."

And we now know where to go to conduct this great experiment. The vast, global subsurface liquid-water ocean of Jupiter's moon Europa[13] is arguably the best place to search for extant life in the Solar System. Furthermore, Europa's great distance from Earth nearly ensures that the two worlds have not seeded each other. Any life on Europa would thus represent a second, independent origin, even if it happened to converge on the chemistry based on DNA, RNA and proteins found in Earth's organisms.

If funding permits, within the next few decades we will know the answer to whether or not life exists elsewhere in our Solar System. We are perhaps just two or three missions away from having received enough data back from several potentially habitable worlds (Fig. 1) to know whether or not life has ever taken hold as a widespread process on other planets or moons. The combined cost of such missions would be comparable to that of the Large Hadron Collider, which has just revealed evidence for the Higgs boson, completing one of the other last great experiments of our era. It's time for biology's great experiment. It's time to learn whether we live in a biological Universe or one in which life on Earth is a singularity. ■

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1. http://astrobiology.nasa.gov/nai
2. Darling, D. *Life Everywhere: The Maverick Science of Astrobiology* (Basic, 2001).
3. Dick, S. J. & Strick, J. E. *The Living Universe: NASA and the Development of Astrobiology* (Rutgers Univ. Press, 2004).
4. http://blogs.discovermagazine.com/loom/category/arsenic-life/
5. Wolfe-Simon, F. *et al. Science* **332,** 1163–1166 (2011).
6. Reaves, M. L., Sinha, S., Rabinowitz, J. D., Kruglyak, L. & Redfield, R. J. *Science* **337,** 470–473 (2012).
7. Erb, T. J., Kiefer, P., Hattendorf, B., Günther, D. & Vorholt, J. A. *Science* **337,** 467–470 (2012).
8. Simpson, G. G. *Science* **143,** 769–775 (1964).
9. Bada, J. L. *Science* **307,** 46 (2005).
10. Chyba, C. F. *Science* **308,** 495–496 (2005).
11. Knoll, A. H., Canfield, D. E. & Konhauser, K. O. in *Fundamentals of Geobiology* 1–4 (Wiley–Blackwell, 2012).
12. Kerr, R. A. *Science* **336,** 1500–1503 (2012).
13. Kivelson, M. G. *et al. Science* **289,** 1340–1343 (2000).