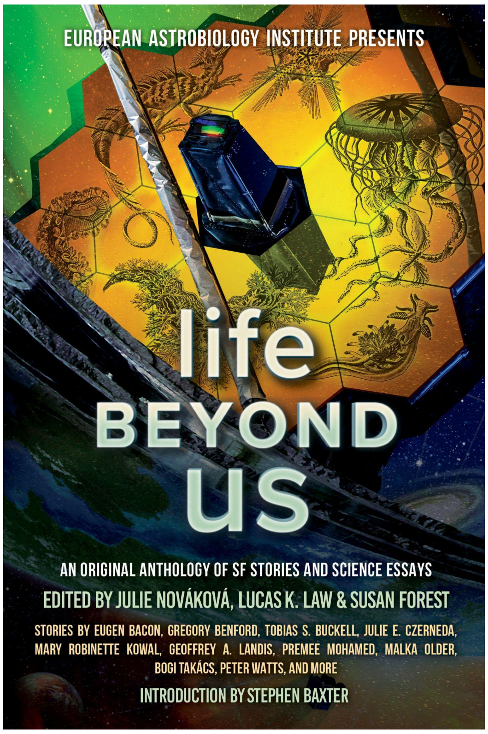
Life Beyond Us

Resources for Educators

If we ever find life beyond Earth, how are we going to know it? Could it be related to ours? And what good is it *for*, all those resources going into sending probes to space, researching extreme microbes in the most hellish places on our planet or running around a spacecraft-asembly cleanroom with swabs and sample tubes?

These are all relevant questions for all of humanity, most of all for the youngest generations, for prospective scientists or policy-makers, and the people forming their views of science, technology, their significance and social impacts.



This file contains openly released and gradually updated and augmented materials for educators who might be asking themselves these questions - and who would like to present them to their students. These resources accompany *Life Beyond Us*, an anthology of 27 science fiction stories centered around astrobiology, each paired with a popular science essay tackling the topic present in the preceding story (such as planetary protection, habitability of water worlds, spectroscopy, evolution, interspecies communication…). The book has been published by Laksa Media Groups in cooperation with the European Astrobiology Institute (EAI), and edited by Julie Nováková, Lucas K. Law and Susan Forest. You can find it here.

The book itself is commercially distributed, but if you are a librarian or educator wishing to obtain the book for your students and cannot go through the commercial channels, please drop us a note at julie.novakova at natur.cuni.cz and we'll try to help. Most of the materials will be possible to use without the book; while the discussion prompts and exercises work better after reading the corresponding story and its companion essay (and some, where the students are for instance asked what they'd do in the shoes of a character, would be difficult to do without knowledge of the story, as well as exercises asking to recall and think about a piece of information from the essay), there will always be a brief summary of the topic present here, so that the materials can at least partly be used as a standalone resource. If you plan on using the book *and* these resources, read the story *before* reading the corresponding resources, so that you avoid potential spoilers and enjoy the stories better.

We will be gradually adding more and more chapters to this brochure. So far, it contains classroom (or science club, etc.) exercises related to the first story and essay in the book and to the important topic of planetary protection. You can look forward to more in the coming months.

The discussion prompts and activity suggestions are divided into two levels: high school and undergraduate. However, we consider it prudent to point out that since science education and proficiency in working with academic resources can differ vastly between schools (and countries) and individually, educators should decide by their own experience rather than this general suggestion. Also, while we believe that none of the stories in any way contain material unsuitable for high-schoolers, this view may differ in some schools. If using these educational materials together with the book, do read the stories first to take this into consideration.

Finally, besides adding more of these resources, we are going to semi-regularly update the materials to reflect the current level of knowledge if a new important paper is published, new mission data arrives, etc. If you find something that's out of date or incorrect, please do let us know at julie.novakova at natur.cuni.cz. This is a collaborative effort and we'll be very happy to hear from you! We'll also gladly hear your feedback from using these materials so that we can continue to refine them.

Without further ado: Let us embark on a journey toward life beyond us, and toward knowledge relevant to us right here, right now.

Julie Nováková,

European Astrobiology Institute, October 5, 2023

www.europeanastrobiology.eu

TOPIC: PLANETARY PROTECTION

To be on Mars, or not to be on Mars? That is the question.

Story: Eric Choi: "Hemlock on Mars"
Essay: Giovanni Poggiali: "Planetary Protection: Best Practices for the Safety of Humankind (and all those Aliens out there)"

In Eric's story, SOCRATES space mission operations manager Ted Berenson is faced with a grave dilemma: In the clean room where the mission now going to Mars had been assembled, extremely resistant bacteria were found - bacteria that could potentially survive on Mars. The spacecraft is likely clean - but can they afford to take the risk that it is contaminated by these microbes? SOCRATES is supposed to revisit one of the life-seeking experiments flown to Mars on the Vikings in the 1970s, but with a modern level of knowledge and technology. Contamination by Earth microbes could compromise the scientific results of the mission, but more importantly might threaten indigenous Martian life - *IF* there is any. With so many unknowns, how should experts decide whether to go on with the mission, even if the contamination risk is found to be low? Is there a truly "right" decision to make?
The story depicts the reality of space mission operations, sterilization procedures and decision making down to tiny details. Giovanni's essay then introduces the issue of invasive (= alien) species on Earth, such as rabbits in Australia, and then summarizes the question of planetary protection (contamination avoidance) since the advent of the Space Age until the present-day.

Left: *Viking* in the oven, AKA planetary protection in practice. The *Viking* rovers were thoroughly baked in order to sterilize them. Unfortunately, the same can't be done with modern space probes, which wouldn't survive the process. Image credit: NASA

High school level

Discussion prompts

1. **In Ted's place, would you have done the same as he? Do you consider his decision right (why, or why not)?**
[There is no clear right answer. Ted aborted the mission for good reasons: he feared that Mars could be contaminated by Earth microbes once and for all; even if the likelihood of that wasn't great, the potential impact was. But perhaps the risk really was low enough, and now he stopped in its tracks a mission that could have contributed to our knowledge of whether there is life on Mars. Or perhaps Mars has *already* been contaminated either by earlier missions or material from meteorites of Earth origin. On a personal level, we can see what events prompted Ted to decide this way, but on a professional level, he went completely outside the decision-making chain.]

2. **Do you think a mission to Mars with a human crew is good from the point of view of planetary protection? What, generally, might be the advantages and disadvantages of sending humans to Mars?**
[Short answer: No; planetary protection-wise, humans on Mars are a nightmare, since we are walking bags of microbes and can't be sterilized, and no airlock and spacesuit sterilization can ever be perfect. But humans are flexible and they are generalists who could do the same work a present-day robotic rover does in a year easily in a week or less. On the other hand, humans are difficult and expensive to get to Mars: they require air, food, water, radiation protection… Multiple space agencies and private companies have plans to land humans on Mars in the coming decades, but so far those plans have not been well developed or budgeted. To conclude, a human crew, would have both advantages and disadvantages, and it's tricky to pinpoint the moment when the advantages would be greater, especially as robots are getting faster and smarter and if you emphasize planetary protection.]

Activities

1. **Find out some examples of invasive species** on Earth in Giovanni Poggiali's essay. Discuss in class some of the invasive species in your region and their impacts on local ecology. Discuss how past human activities caused the spread of invasive species and look for modern examples in the whole planet.

2. **Try to think of a system for monitoring certain invasive species** (e.g. the hemlock plant) in your area. Would it involve citizen science - e.g. local people getting involved and posting pictures of the plants with GPS coordinates? Do you think you could track the spread of the species? What existing initiatives in this vein can you find? Elaborate possible non-invasive solutions to limit the spread of invasive species.
   [A list of some of the European citizen science projects can be found here: https://easin.jrc.ec.europa.eu/easin/CitizenScience/Projects]

3. **Image potential extraterrestrial life forms and the best ways to detect them.** From microbes to more complex living beings, we could expect the galaxy to be populated by different extraterrestrial life forms. Of course, on Mars, only very simple forms could exist nowadays. What would be the best way to identify them and how to protect ourselves? Discuss within the class and with the teacher. [First, it would be useful to go through what existing or future probes like Perseverance or Rosalind Franklin can do, and review what the Viking probes did. The students can compare the different approaches.]

Above: Hemlock, or *Conium maculatum*, is a poisonous and environmentally highly disruptive invasive species. Image credit: Michael Kesl

University undergraduate level

Discussion prompts

Have a look at the high-school level prompts; the same can be used with university students who can dive deeper into these questions and present more developed opinions. There's also one extra prompt:

1. **Do you consider SOCRATES to be a good mission proposal? How would you go on searching for extant life on Mars? Where would you go (generally, no need for specifics), and how would you try to find it (ie. what kind of instruments, in general terms)?**
   [Again, there are no clear-cut answers. In general, going to one of the suspected recently active regions, where hydrothermal vents might still exist, would be advisable - liquid water at relatively shallow depths underneath the surface would be a great place to look. Regions with recent geological signs of surface water activity - although that is very old from the perspective of living beings - and with spectral signatures of minerals associated with water and life on Earth would also be a good place. While the suspected lakes under the south polar cap might contain water suitable for life, despite its likely very high salt content, we have no way of getting there in the near future.
   As to the method, experiments looking for active metabolism - like on the Vikings or SOCRATES - are one possibility. Another is looking for biomolecules: things like proteins, sugars, lipids, nucleic acids… A good review of such biomolecules and ways to detect them, in this case in returned Mars samples, can be found in Meneghin et al. (2022). We can take the approach of looking for specific biosignatures known from Earth, or for general, agnostic biosignatures. Both approaches have their benefits and pitfalls that could be further discussed among students.]

Activities

1. **Go through the paper "Clean room microbiome complexity impacts planetary protection bioburden" (Hendricksen et al. 2021, in *Microbiome*) with students. Discuss together:**
   a. How does the paper tie with Eric Choi's story?
   b. Do you think that the currently used methods for cleanroom bioburden assessment are sufficient? What do the authors of the paper think?
   c. What are the implications for planetary protection in general? Is Mars likely already irrevocably contaminated despite our efforts?

2. **Divide students into several groups and assign each a general method of life detection** - experiments for detecting metabolism, microphotography, infrared spectroscopy, Raman spectroscopy… Let each group list the basic pros and cons of their assigned method, and what place they think it would be good for (again, the paper Meneghin et al. (2022) and related works may come in useful here).
   [To answer this in detail would require an essay in itself; put simply, each method is more or less suited for different types of life and/or environment and/or type of evidence. In many cases, they are complementary. Few would produce strong evidence for life without being backed up by other methods. Putative microfossils could just be products of abiotic processes, and they are hard enough to reliably recognize in old rocks on Earth. And while some chemical tracers would point strongly at life, we are unlikely to find intact biomolecules such as DNA or its analog, proteins… Even if extant life were present on Mars, we are more likely to encounter broken fragments altered by radiation and other local conditions. However, if we find suspected microfossils *and* complex chemistry detectable by independent spectroscopic instruments *and* evidence of past habitable conditions, we'll have a strong case for the life hypothesis and for further investigation. Metabolism detection experiments, such as on the *Vikings*, are a rather special case; while other methods are relatively universal, these would be best deployed in places where liquid water is suspected to be present near the surface and where, consequently, life could potentially flourish in depths where we can venture.]

3. **Divide students into two groups and have them argue *for* or *against* more stringent planetary protection.** A scientific argument that took place on the pages of *Nature Geophysics* in 2013 can serve as an inspiration for the debate:

   Fairén, A. G., & Schulze-Makuch, D. (2013). The overprotection of Mars. Nature Geoscience, 6(7), 510-511.

   Conley, C. A., & Rummel, J. D. (2013). Appropriate protection of Mars. Nature Geoscience, 6(8), 587-588.

   [*Pro planetary protection*: We have no way of knowing if Mars has ever been contaminated by Earth life, be it in ancient past via meteorite exchange (lithopanspermia), or in the recent past by our spacecraft, and so we should take steps to keep the probability to a bare minimum if we don't want to risk potentially destabilizing, even wiping out potential local ecosystems, or "just" muddling up our scientific research (in some cases, distinguishing between local life and contamination might not be easy) and losing opportunities for pure knowledge as well as potential biotechnological and other applications. (Counterargument: We are losing potential for more active and widespread research as we tiptoe and wait, and eventually humans are going to land on Mars and contaminate it despite our best efforts with airlocks and disinfectants. We must send spacecraft *especially* to the "special regions" if we want to discover potential life before that.)

Against planetary protection: Mars and Earth have exchanged so much material via meteorite impacts throughout their whole history that if Earth life could survive on Mars, it must already be there. Moreover, planetary protection measures severely limit the kinds of research they supposedly protect. (Counterargument: If so, there is no telling when the last viable exchange occurred, and studying Earth-origin life adapted to Mars for millions or perhaps hundreds of million years could lead to amazing discoveries - and protection from present-day contamination should be all the more stringent, because in this case, it would be difficult to reliably distinguish ancient-past "contaminants" from present-day contaminants from our spacecraft - both would possess the same evolutionary origins, the same genetic code and basic metabolic pathways… We should send spacecraft to the special regions, yes, but only after extremely careful - if expensive - decontamination steps!)]

Planetary protection is an area that merges science, technology and ethics, like so many other issues in the present-day world. Interdisciplinary competences are essential, so don't be afraid to look at the issue from different angles!

This guide was written by Julie Nováková and reviewed by Eric Choi and Giovanni Poggiali. Any errors potentially found in it are on Julie. If you find any or have any suggestions for additions and improvements, please do not hesitate to contact her at julie.novakova at natur.cuni.cz. Thank you.