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Protecting planets beyond Earth

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Since the 1950s the international scientific community has debated the necessity of protecting the solar system, including Earth, from interplanetary biological and organic contamination. In fact, the notion of avoiding "harmful contamination" of celestial bodies was formally integrated into space policy in 1967, when the United Nations Outer Space Treaty came into force. For planetary bodies such as Mars, Europa, and Enceladus, the rationale for those efforts is primarily scientific, as contamination by Earth life could dramatically interfere with the search for extraterrestrial life. For Earth's biosphere, the reasons are more tangible: Biological or chemical agents returned from explored planetary bodies might deleteriously affect humans, animals, and plants.

Currently the term "planetary protection" is used to describe the practice of preventing, or at least minimizing, "forward" and "backward" contamination in the solar system. Forward contamination refers to the biological contamination of solar-system bodies by Earth life as a result of robotic or crewed exploration. Backward contamination is the contamination of Earth as a result of spacecraft and extraterrestrial samples that are returned to us. To date, exploratory missions have brought back samples only from the Moon, two asteroids, a comet, and the solar wind—environments that have little if any likelihood of harboring life. However, there is tremendous international interest in returning samples from Mars, Europa, and Enceladus and organizations such as NASA, the European Space Agency (ESA), and the Japan Aerospace Exploration Agency (JAXA) are devising safe protocols for the return of extraterrestrial samples.

Resilient life

Microorganisms such as bacteria, archaea, and fungi that have the ability to survive or perhaps even thrive in harsh environments can affect the search for life. On Earth, certain microorganisms tolerate extreme conditions such as high radiation, concentrated salts, hot or cold temperatures, high or low pressures, high acidity, low abundances of water, and the absence of light. Strikingly, those extreme settings mimic conditions in many of the environments found on planetary bodies in our solar system.

The Martian subsurface, for instance, includes abundant permafrost and ice. In comparison, Arctic permafrost and Antarctic ices on Earth contain trace veins and films of liquid water that harbor active microbial life. The icy moons Europa and Enceladus have interior oceans whose chemical and physical properties may be similar to those of Earth's oceans, where life is abundant. In the clouds of Venus, temperatures and pressures are similar to those found on Earth, and the acidic properties of the water droplets in the clouds are perhaps not so different from the acidic hot springs found in Yellowstone National Park, where microbial life abounds.

Biological contamination

On Earth, we've learned that mitigating the spread of invasive species is paramount to watershed, soil, and human health management. For instance, all across the US last summer, boats and water-related equipment got inspected for zebra mussels, faucet snails, and Eurasian watermilfoil, since those species, when left unchecked, harm swimmers, decimate local waterfowl populations, and outcompete native aquatic plants, respectively. Many countries and US states banned felt-soled waders because those "fisherman's boots" are linked to the spread of didymo, a diatom that harms aquatic populations. And we effectively keep many bacterial and viral infections at bay with proper hygiene and cleanliness.

Such practices serve as a proof of principle for planetary protection. When conducted over long periods, they also serve as conservation efforts, which ensure that generations of people will enjoy the recreational, economic, and scientific benefits of Earth's resources.

Planetary protection for Mars

According to NASA, a defining strategy of Mars exploration is to seek signs of life. So far, an international bevy of spacecraft has orbited around, landed on, and roved the planet as part of missions to systematically study the geology, atmosphere, habitability, and chemistry of Mars (see the article by Ashwin Vasavada, Physics Today, March 2017, page 34). By necessity, those missions were spread out over decades because of the time and costs associated with interplanetary travel.

All those spacecraft were built on Earth, where microorganisms are abundant. Consequently, the multistep exploration strategy could inadvertently bring Earth microbial life to Mars. In turn, contamination of promising study sites could compromise current and future science efforts and, in particular, obscure any findings that support the presence of life.

To avoid those issues, well-developed planetary protection guidelines—exemplars for thoughtful policymaking—mandate that missions to Mars maintain high cleanliness standards during spacecraft assembly and storage. In support of that goal, spacecraft are assembled in clean rooms, such as the one shown in the figure, where strict controls are placed on the amounts

ONE OF THE LARGEST CLEAN ROOMS IN THE WORLD is at NASA's Jet Propulsion Laboratory in California. The specially clothed technicians here are working on the Mars *Curiosity* rover. (Photo courtesy of Yvette Cendes.)

of dust, aerosols, and other particulates in the air; humidity; atmospheric composition; and clothes people wear. Moreover, those facilities are routinely cleaned with chemical agents that remove biological and nonbiological particles from surfaces and floors.

That cleaning fluid was delicious!

Despite the robust cleaning procedures, microbes find a way to survive. Molecular genetics shows that the clean rooms harbor a small but diverse microbiome (a collection of microorganisms) and that the abundances and taxonomic profiles of the microbes change during the different phases of spacecraft assembly. To help explain that observation, my research team has shown that the cleaning agents used during assembly may be biodegraded into carbon or energy sources—food—or into noncleaner components by members of the spacecraft microbiome.

To deal with the persistent microbiome, technicians don't just clean spacecraft, they sterilize them. Treatments include exposures to dry heat, hydrogen peroxide vapor, gamma radiation, high-pressure steam, and low-temperature plasmas. Typically, sterilization (or bioburden reduction) is required for missions that are focused on life detection and habitability. For Mars missions, special care is given to components—wheels, drills, scoops, and other sampling-system elements—that may contact the planet.

Bioburden reduction has been implemented on several spacecraft, including the *Curiosity*, *Opportunity*, *Spirit*, and upcoming Mars 2020 rovers; the *InSight* and *Phoenix* landers; and, most extensively, the Viking landers. After sterilization to prevent recontamination from transport or any subsequent assembly, test, launch, or operational procedures, the spacecraft are wrapped and appropriately stored. During the entire assembly process, technicians sample, characterize, and store microorganisms from the clean rooms and spacecraft, so that the scientific community may know what was carried to Mars.

After launch, planetary scientists protect Mars through trajectory biasing. During the cruise phase between Earth and Mars, the spacecraft, with its unsterilized propellant tanks and aeroshell (the casing that protects the craft during reentry), is aimed away from Mars to prevent a crash landing. Once in firm control, the spacecraft is then steered back toward Mars.

Debating points

The selection of landing sites and areas of study on Mars are also key components of planetary protection. Among the topics of vigorous debate are the science payoff, contamination probabilities, and operational feasibility. Special Regions, areas of Mars where Earth life may replicate, are the subject of particularly lively discussions regarding whether the requirements for Mars exploration are too restrictive or not restrictive enough. Further, the prospect of crewed missions to Mars demands reassessment of bioburden restrictions, development of new sampling strategies, and careful consideration of human health needs.

Indeed, the questions regarding the purposes of planetary protection, degree of required protection, and length of conservation efforts—should they extend over years or decades?—continue to be relevant to the space-science community. Today that community includes not only Mars scientists from ever more nations but commercial space enterprises, such as private mining operations and space tourism. In the new chapter about to be written, should commercial claims be regarded as equal to the needs of science? Or should the questions of how life originated and whether we are alone remain as the driving forces behind space exploration?

In this exciting future, we will need a balanced approach of streamlined regulations that promote smart resource and recreational management. At the same time, we must empower scientific study, as finding life elsewhere will monumentally affect global society.

Additional resources

▶ R. Mogul et al., "Metabolism and biodegradation of spacecraft cleaning reagents by strains of spacecraft-associated *Acinetobacter*," *Astrobiology* (2018), doi:10.1089/ast.2017.1814.

▶ NASA Office of Planetary Protection, https://planetaryprotection.nasa.gov/documents.

▶ NASA, "Mars Exploration Program and Missions, Overview," https://mars.nasa.gov/programmissions/overview.

▶ NASA, "Solar System and Beyond Overview," www.nasa.gov/topics/solarsystem/overview/index.html. PT