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TO THE STARS AND BACK AGAIN

Catalina Casillas (http://berkeleysciencereview.com/author/bsr_magazine_upload/) features (http://berkeleysciencereview.com/category/magazine/features-magazine/)
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Thousands of miles away from home you notice the first sign that something is wrong. Tingling pain on the skin near your rib cage gives way to unreachable itching under your suit. Ignoring the initial symptoms results in sensitivity to light and eventually chills, distracting you from your daily work of system maintenance, observation, and strength training.

The itching begins to burn, and as you float to the nearest mirror and lift the hem of your shirt, you see it—a blistering red rash spreading over one side of your abdomen. You think back to last week's intense ride through the atmosphere, how you entered and then left the orbit of the Earth, before finally being engulfed by the darkness of space. You were warned about the space sickness and fatigue, the aches and pains of space travel, but now your body is fighting a full-fledged infection. A simple blood test will reveal that the ***varicella zoster*** ***(http://en.wikipedia.org/wiki/Varicella_zoster_virus)*** virus that has been lying dormant inside you since you first contracted chickenpox as a child is now active. And of all places, here, in space.

Sustaining life in hostile environments

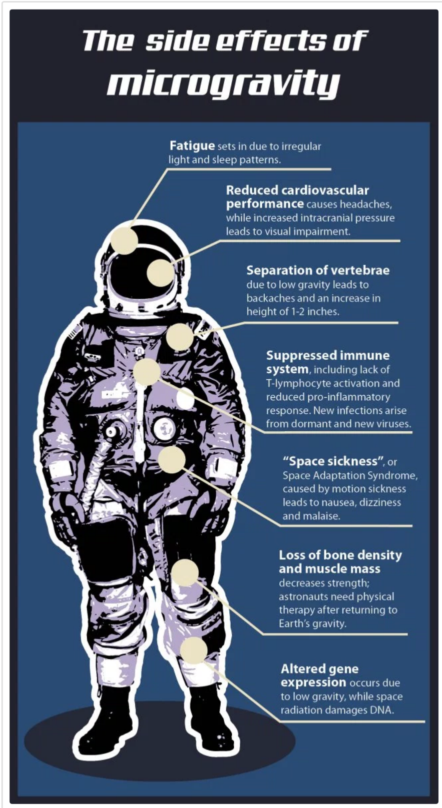
Aboard a highly sophisticated piece of machinery like a NASA-engineered rocket or the International Space Station, an astronaut's body is the most unpredictable instrument. Over the course of billions of years, terrestrial organisms have specifically adapted to life on Earth. Your body relies on Earth's environment to maintain homeostasis, and changes outside of the atmosphere can wreak havoc on everything from organ system functions to cellular activities. While each part of a spaceship has a distinct number of known parts with known functions, a living organism, composed of esoteric cellular and molecular components, is infinitely more complex. Unlike the many machines on board the ship, the structure and function of your body cannot be redesigned to be operational in space.

Space travel has many debilitating effects on the human body, but the most surprising and least understood are its effects on the immune system. Immune cells struggle to communicate with each other to launch a proper defense against infection in space, leaving the body susceptible to pathogenic microbes. During the 1960s and 1970s, more than half of the astronauts who served in the **Apollo space program (http://www.nasa.gov/mission_pages/apollo/missions/)** developed a bacterial or viral infection while in space. Infamously, Apollo VII resulted in **three miserable astronauts (http://news.discovery.com/space/history-of-space/near-mutiny-on-apollo-7-cold-stempers-marred-mission-131023.htm)** orbiting the Earth for 11 days suffering from the common cold. Skin infections, urinary tract infections, and instances of both new and dormant viral infections have also been reported. Scientists suspect that microgravity, or the absence of gravity, is the culprit behind these phenomena.

Another potential source of catastrophe is radiation. Beyond Earth's electromagnetic field, cosmic radiation emitted by stellar objects like stars, supernovae, and black holes becomes more powerful. The radiation itself is a constant stream of tiny, high-speed particles that can tear through molecules, including those that make up your cells. Living outside the protective shield of Earth increases exposure to harmful particles and leaves you—particularly your fragile DNA double helix—vulnerable to cancer-causing atomic damage. Pair that with the lesser-known microscopic effects of weightlessness, which include changes in cell shape and genetic output, and the ramifications of space travel become incredibly complicated.

Health, science, and the final frontier

Dr. Janice Pluth, **principal investigator at Lawrence Berkeley Laboratory (http://www2.lbl.gov/lsd/People_&_Organization/Scientific_Staff_Directory/Pluth_Lab.html)**, emphasizes that cosmic radiation is very different than the radiation you're exposed to on Earth. It is a continuous bombardment of particles that deposit their energy along destructive paths through your cells. On the ground, Pluth's team of scientists studies the effects of simulated space radiation on different types of mammalian cells. The potential for cosmic radiation and microgravity to exert harmful effects on development and reproduction—possibly the most foreboding incompatibility of life and space travel—is a new focus for the Pluth lab. Now Pluth and her team are preparing to gain new insights by literally launching their research out of the atmosphere.



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Design: Jo Downes, Astronaut: Jonny-Doomsday

Pluth's project is a component of NASA's **Fundamental Space Biology (http://www.nasa.gov/directorates/heo/slpsra/20120810-space-biology.html)** program, which funds research focused on the underlying biological processes of microbial, plant, and animal life in the space environment. Her goal is to understand how exposure to space radiation and microgravity affects developing organs, and whether that exposure has any effect on subsequent reproduction. To accomplish this, Pluth must send her mice to the **International Space Station (https://www.nasa.gov/mission_pages/station/main/index.html)** (ISS) to see how their bodies adapt to space. The Pluth lab will use the growth of the mammary gland as a model for development. Once a launch date is set, a group of mice will be sent to the ISS and exposed to space conditions four weeks after birth, while their mammary glands are still developing. After different times of exposure, biological samples will be collected and sent back to Earth.

Changes to the immune system due to microgravity and other environmental abnormalities in space may be particularly disastrous for the mammary gland, given that the growth of the mammary ducts is stimulated by the immune system. The effects of space on development will be examined by visualizing the ductal branching structure of the gland. The number of mammary stem cells, responsible for producing the cells that comprise the organ, will also be evaluated for any changes.

A second aim of the study is to evaluate the long-term effects of space exposure. This includes bringing mice back to Earth alive and evaluating their ability to re-adapt to life on our home planet. The ability of these mice to reproduce on Earth, as well as the health of their offspring, will be analyzed. Also of interest are the descendants of these pioneering rodents. Space travel may change the molecular tags attached to DNA, and these changes may be passed down to offspring. By studying each mouse's progeny, Pluth will investigate to what extent this epigenetic effect can be transferred through the generations.

To determine whether there is genetic susceptibility to space radiation, two strains of mice will be sent on the mission. One strain was selected for its increased sensitivity to radiation here on Earth, while the other strain is more resistant to its effects. It is possible that the mouse strain that is more resilient to radiation on Earth will fare better in space. Studying mice with different genetic backgrounds may reveal genetic traits that will help predict whether some people are better suited for space travel than others.

However, while this study brings scientists closer to understanding the consequences of space radiation on your body, the ISS still receives some protection from Earth's electromagnetic shield. This means that the results are a conservative estimate of the true destructive power of cosmic radiation. In reality, surviving and propagating outside the protective shell of Earth's atmosphere may be much more difficult.

Studying the galaxy

Surviving the trip through space is a daunting task, but it is only part of the quest. Any successful journey requires that the traveler have some knowledge about their destination. What will the weather be like? What kind of terrain will be encountered? Will you be the only life form present? As we prepare to leave Earth, basic knowledge of the galaxy will be vital to a fruitful mission. Collecting and analyzing information about the space environment is a primary focus of the **Space Sciences Laboratory (http://www.ssl.berkeley.edu/)** (SSL) and the Department of Astronomy at UC Berkeley. In these organizations, teams of scientists are studying the fundamentals of stars, planets, and the forces that shape and change them.

Since its inception in the 1960s, the SSL has expanded to include a broad range of space and planetary sciences. The NASA-funded laboratory has had dozens of projects that range from studying the impacts of the sun on Earth and other planets to listening for distant electromagnetic signals that may have come from extraterrestrial civilizations. However, a major focus of the lab is to understand how planets work, how they interact with the space environment around them, and how they evolve over time. To find answers, researchers at the SSL, such as senior scientist **Dr. Greg Delory (http://sprg.ssl.berkeley.edu/~gdelory/)**, design and build tools to measure a variety of phenomena such as radiation, electromagnetic fields, and infrared wavelengths. The ingenuity of these researchers is put to the test when the instruments are sent into orbit and beyond to gather valuable information that is then interpreted back on Earth.

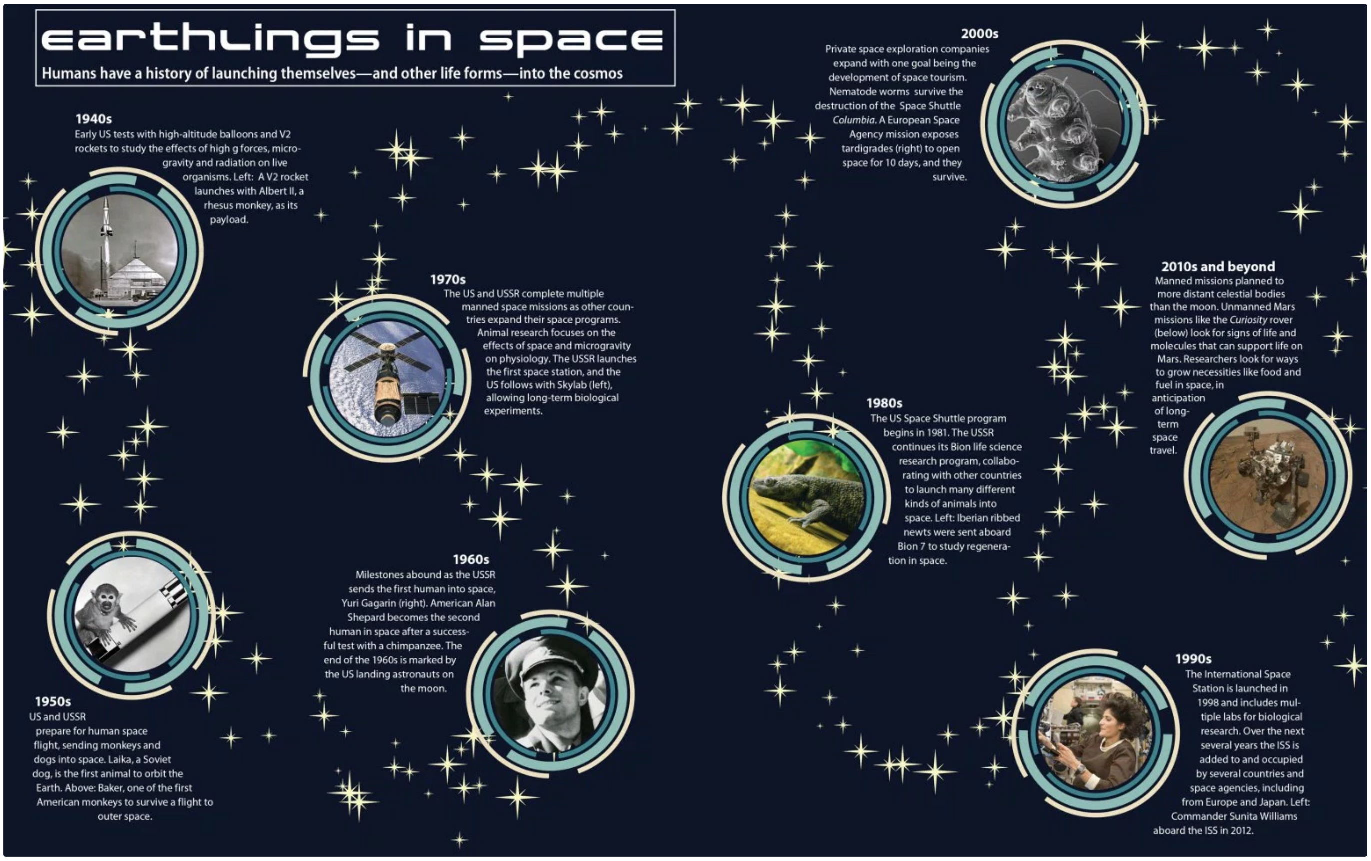
One of the lab's major projects involves solving a planetary mystery right next door. Our neighbor, Mars, is a cold and uninviting desert with a thin atmosphere, but within that dry landscape lie clues to its past. Geological studies have revealed that Mars was once wet and warm, and was protected by a much thicker atmosphere. Piecing together Mars' history from the information we have now, we know that drastic changes have occurred to Mars' climate in the past. The causes behind the dramatic transformations are unknown, and discovering the roots of the causes will help us understand how and why planets change.

To help solve the puzzle, the **Mars Atmosphere and Volatile Evolution (http://www.nasa.gov/mission_pages/maven/main/index.html)** project, or MAVEN, was created by scientists at UC Berkeley and the University of Colorado. MAVEN, which was launched in 2013, is a spacecraft that is currently orbiting Mars and recording a multitude of information about Mars' upper atmosphere. The sensors aboard the MAVEN spacecraft can measure the magnetic fields, solar winds, and cosmic particles that surround Mars. Scientists will use this information to study the interaction between Mars' "near space environment" and its atmosphere. The goal of this research is to understand the processes that have influenced the evolution of Mars' climate over time, and as Delory notes, this may tell us something about the evolution of our own atmosphere and climate.

Looking past the planets of our own solar system, **Dr. Geoffrey Marcy (http://astro.berkeley.edu/faculty-profile/geoff-marcy)**, of the astronomy department at UC Berkeley, is searching for planets that share some of the special characteristics of our own planet. In 2009 the **Kepler spacecraft (http://kepler.nasa.gov/)** was sent to wander through the Milky Way on a mission to discover Earth-like planets. What sets Kepler apart from past projects is that it is able to find Earth-sized planets within the so-called habitable zone of their sun. These planets, termed "Goldilocks planets" because they are neither too hot nor too cold, can potentially harbor the liquid water that is required for life.

Kepler records a picture of a particular field of stars every 30 minutes, and measures the brightness of each star. Periodic dimming of a star is an indication of a planet passing in front of it during its orbit. The images of stars recorded by Kepler are analyzed by a team at NASA Ames Research Center. As leaders of the NASA Kepler mission, Marcy and his students analyzed the Kepler data to determine how common Earth-sized planets are in the Milky Way, and whether they possess rocky terrain like Earth. To date, there are a few dozen planets within our galaxy that are similar in size to our own and possess a climate hospitable to life. The implications of this work are large—for the first time in our history we know that our unique planet is only one of many like it, and the possibility of other civilizations in the distance has become more tangible.

The identified planets are too far from Earth for humans to physically visit, but Marcy hopes for the next best thing: acquiring the technology and the funding to send spacecraft, with instruments similar to those being built by the SSL, to these planets. These space expeditions could send back pictures and information about the Earth-like planets and their solar systems, and may reveal what is lingering in the dust of the Milky Way.



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Timeline design: Jo Downes; V2: Smithsonian; Baker: US army; Yuri Gagarin: Fyodor Nosov; Skylab: Sunita Williams, Curiosity: NASA; Newt: Pengo; Tardigrade: ESA

Engineering our way through space

While it is illuminating to send robotic probes into the depths of space, the goal of sending a human through the cosmos requires many more steps of engineering and technical achievement. Understanding the biological implications of space flight and studying our future destinations are stepping stones toward the goal of human space travel, but the gritty details of what it takes to physically send and sustain humans in space are not inconsequential.

Propelling a rocket out of Earth's atmosphere requires a tremendous amount of fuel and supporting structures. In fact, close to only 1 percent of the total mass sent into space is the payload of the trip, be it humans or cargo. How could a space mission be efficiently stocked and supplied in such a way as to ensure the health and safety of space travelers?

Dr. Amor Menezes (http://genomics.lbl.gov/~amenezes/), a postdoctoral researcher in the Arkin Lab of the bioengineering department at UC Berkeley, is focused on finding practical solutions to these problems. Menezes, along with Arkin and their collaborators from the NASA Ames Research Center, have analyzed the cost-effectiveness of using biological techniques to supply a space mission and compared them to traditional non-biological techniques. The Arkin lab is proposing the use of microorganisms to generate supplies like food, pharmaceuticals, and biopolymers for 3D printing. The team is also exploring ways in which microbes could produce fuel for spacecraft (see "**Taking our (bacterial) cultures into space (http://berkeleysciencereview.com/article/taking-our-bacterial-cultures-into-space/)**").

The on-demand production of supplies can be realized by using various types of bacteria for the job, including cyanobacteria. Cyanobacteria are unique among bacteria because they are capable of producing their own energy through the same type of photosynthesis performed by plants. There are thousands of different species of cyanobacteria that can survive on many different terrains on Earth, from fresh and salt water to dry soil and rocks; this versatility may be useful on space missions. Valuable products can be collected from these cyanobacteria by exploiting either natural or engineered biological processes.

An obvious necessity for space travelers embarking on a journey through space is food. Currently, NASA launches wet food to its astronauts; however, an attractive alternative involves either shipping or producing nutritious dry biomass as a food source. Spirulina, made from two species of cyanobacteria, is an alternative food source that is sustainable and practical. Although the thought of eating cyanobacteria might not seem palatable, spirulina has historically been consumed by the people of Central America and is widely consumed as a supplement today. Spirulina contains all of the essential amino acids required for building muscle as well as many other essential vitamins and minerals, making it a realistic source of nutrition.

Additionally, with the realization that our immune systems can go awry in space, a steady supply of medicine to treat symptoms becomes essential. Unfortunately, many pharmaceuticals are sensitive to radiation and expire much more quickly in space than on Earth. This makes the ability to manufacture them as needed, in small batches, exceedingly valuable. Menezes believes that a realistic solution involves using synthetic biology to produce acetaminophen, more commonly known as Tylenol. Acetaminophen is used as a pain reliever and fever reducer, and is used to treat most symptoms of infection. Synthetic biology work by UC Berkeley **Professor Chris Anderson (http://andersonlab.qb3.berkeley.edu/#/)** that aims to produce acetaminophen in *E. coli* could be modified for use in cyanobacteria in space. This will provide a way for space travelers to produce the common panacea when they are so far from the convenience of a pharmacy.

Most of the biological processes required to produce these materials are natural, but they can be enhanced through bioengineering. Some biomanufacturing processes that require multiple steps can be made more efficient by coupling all pathways into one organism. The organisms themselves can be engineered for efficient nutrient recycling, reducing the need to ship nutrients and growth media to grow them. Another exciting possibility is to engineer spirulina to have different textures and flavors, making the experience of consuming it for months or years at a time more satisfying.

Although this technology is not ready for use, the field's advancements are encouraging. Menezes believes that these biological production methods are highly competitive with non-biological methods, some of which have been developed for hundreds of years. The real question is whether these microorganisms can generate the products efficiently in space conditions. Many trials and years of testing are required before astronauts and other space travelers can take advantage of these biological techniques.

Our place among the stars

Space radiation and microgravity prove to be formidable adversaries, and the task of engineering a space mission remains one of the biggest obstacles we have ever faced. As scientists examine the costs of space travel, it raises the inevitable question: Why put ourselves through this challenge?

"I don't think the human race will survive the next 1,000 years, unless we spread into space. There are too many accidents that can befall life on a single planet. But I'm an optimist. We will reach out to the stars." **Stephen Hawking (http://www.hawking.org.uk/)**, renowned cosmologist, has expressed his concerns about the growing list of dangers that threaten life on Earth. Pollution, consumption of our planet's resources, and catastrophes that continue to contaminate our world, such as the Fukushima nuclear power plant disaster and the BP oil spill in the Gulf of Mexico, will have tangible consequences on the quality of life on Earth. Taking into consideration the devastation of pandemic viruses and disease, and the growing tension between nations holding nuclear weapons, makes the future look bleak.

The **Doomsday Clock (http://thebulletin.org/timeline)**, an allegory that represents how close humanity is to global devastation, continues to tick closer to the symbolic end of times—midnight. The symbolic clock was established in 1947 by the Bulletin of the Atomic Scientists, a publication that works to inform the public about nuclear policies and issues. Since then, members of the Science and Security Board have maintained the clock, updating the "time" throughout the years based on the global threats we face. At the beginning of 2015 the clock was placed three minutes away from midnight. For those who believe that human ingenuity will be a saving force for Earth's creatures, the development of efficient space travel may be vital in a possibly desolate future.

The ability to reach into and beyond our solar system may also propel us into a new golden age of exploration. These technological advances may focus our interest in the cosmos, opening our eyes and minds to a broader universal truth. Perhaps as we take a step back and view ourselves within the larger context of the universe, arbitrary borders will no longer matter and petty disputes will fade away. As a species, we can pursue the answers to questions we've asked since the dawn of civilization and expand the treasure trove of human knowledge. With a growing understanding of the cosmos and our place in it, eventually we may be ready to ask new questions that will push the limits of human technology and civilization.

For many these efforts may seem trivial and frivolous, but for those who dream of planets and solar systems beyond our own, reaching them is the next logical step. Humanity has a long road ahead—successful long-range space travel is decades, if not centuries, away—but the progress we are making is continuous and comprehensive. Identifying how space travel affects our bodies will enable us to protect ourselves against the perils we will face. Learning about our future destinations and understanding basic cosmological events will prepare us for the obstacles that may lie ahead of us. Developing new technologies that will nourish and sustain us on our voyage will ensure our success. With the ingenuity and hard work of scientists at UC Berkeley and around the world, we will eventually see humanity, a highly-evolved bipedal life form from Earth, travel across the cosmos.

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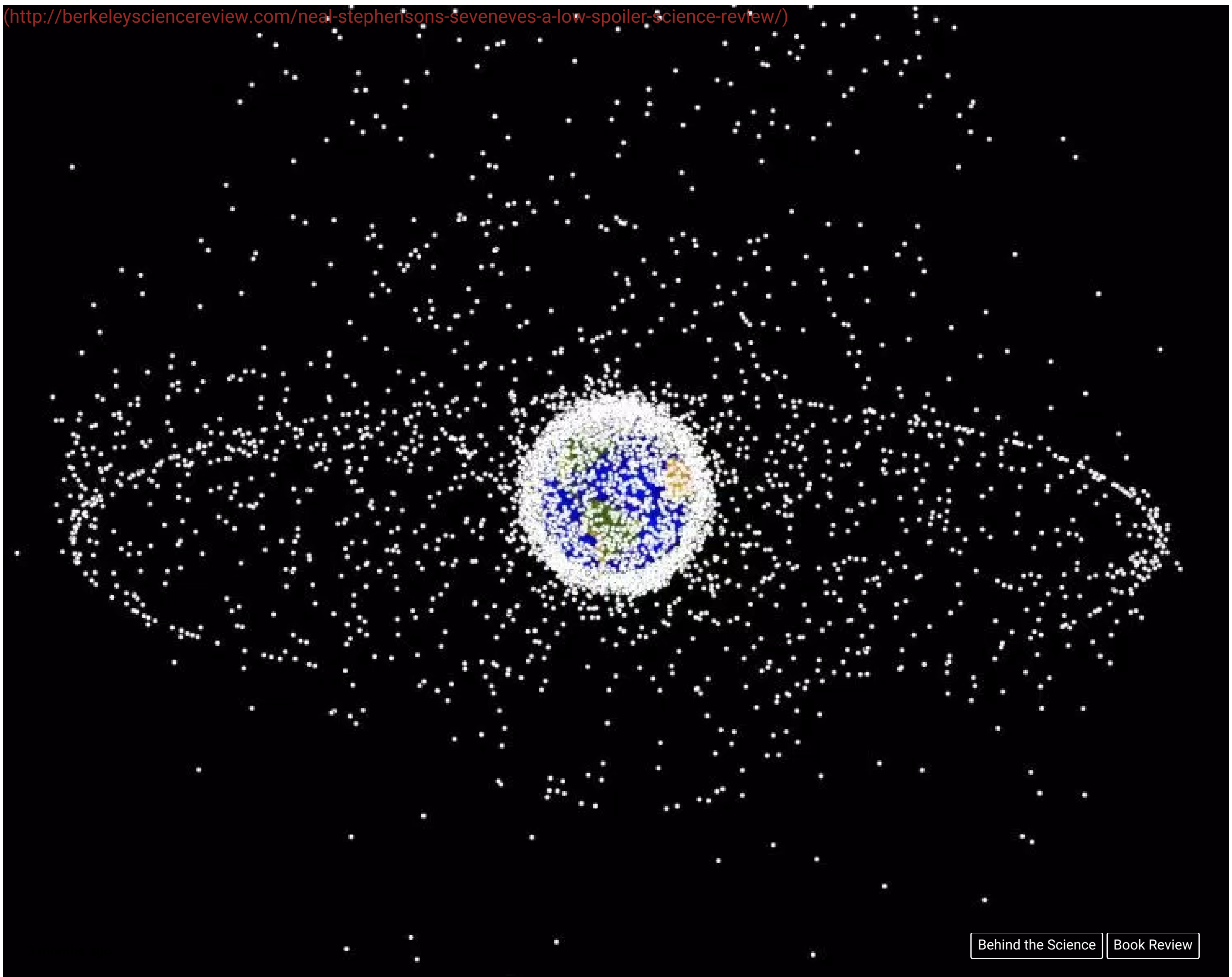

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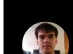 (http://berkeley :encereview.com/author/dfreeman/)

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