Visions, Ventures, Escape Velocities:

A Collection of Space Futures

EDITED BY ED FINN AND JOEY ESCHRICH

VISIONS, VENTURES, ESCAPE VELOCITIES

A Collection of Space Futures

Edited by
Ed Finn and Joey Eschrich

Guest Editor
Juliet Ulman

Center for Science and the Imagination, Arizona State University
Tempe, AZ

Arizona State University

This project was supported by the National Aeronautics and Space Administration under Grant Number NNX15AI31G.

ISBN 978-0-9995902-2-5
Library of Congress Control Number: 2017960401

Center for Science and the Imagination, Arizona State University
PO Box 876511
Tempe, AZ 85287-6511
http://csi.asu.edu

That is utopia ... especially for primitives and scientists, which is to say everybody.

Kim Stanley Robinson, Red Mars

CONTENTS

CREDITS

EDITORS

Ed Finn
Joey Eschrich

GUEST EDITOR

Juliet Ulman,
http://papertyger.net

PROJECT LEADERS

Ed Finn
Ruth Wylie
Jim Bell
Clark A. Miller

ILLUSTRATIONS

Maciej Rebisz,
http://maciejrebisz.com

EBOOK DESIGN

Emily Buckell,
emilybuckellebooks@gmail.com

COVER AND PRINT DESIGN

Mark Dudlik,
http://markdudlik.com

RESEARCH ASSISTANTS

Alissa Haddaji
Mateo Pimentel

SPECIAL THANKS

To Kim Stanley Robinson, for allowing us to use excerpts from his magisterial novel *Red Mars* throughout this volume, and for making himself available for a fascinating and thought-provoking interview.

A NOTE ON THE EPIGRAPHS

We are pleased to pay homage to Kim Stanley Robinson's 1992 novel *Red Mars* on its 25th anniversary. Throughout this volume, at the beginning of each section, you will encounter a brief excerpt from *Red Mars*, the first in Robinson's Mars Trilogy, which traces the process of terraforming the Red Planet over 200 years. Robinson's resolutely utopian, deeply researched stories about human space exploration and settlement are animated by compelling characters and thought-provoking conflicts over values and politics. They also contain moments of arresting beauty and human connection. For all these reasons, Robinson's visions of the future remain a major source of inspiration for the stories and essays in this volume. Beyond that, they have helped to shape our broader cultural imaginary for human endeavors in space, both in science fiction and technical communities. We are proud to have *Red Mars* serve as a frame for our work here, and we hope that our readers will seek out Robinson's entire oeuvre, which encompasses a number of human journeys into space.

An interview with Robinson and Jim Bell appears at the end of this collection, in the "Concluding Thoughts" section.

ACKNOWLEDGMENTS

The stories in this volume are not predictions. None of us know how space exploration, space technologies, and the commercialization of space will play out. Engineers and leaders at NASA and in companies like SpaceX may have clear ideas of what's possible, and what's desirable from their standpoint, but not even they know how these technologies will play out in practice, as real people in real organizations put them to work to create a future in space for all of us. In that sense, William K. Storey is exactly right in his essay. If we read these stories critically, we ultimately probably learn far more about ourselves, our societies, and our anxieties today, than we do about how the future of humans and robots in space will play out.

In the end, though, we are less interested in a critical deconstruction of how the stories were written and why they took the exact form that they did. We are much more interested in whether they stimulate creative, interesting, and relevant thoughts and conversations among their readers. And we are interested in whether those thoughts and conversations can help inform NASA and commercial space companies, other national space agencies, Congress, the people of the United States, and the people of the world, as we work our collective ways toward the creation of new possibilities and new worlds. This book is not the end of the experiment. It is the beginning.

Ed Finn:

I am deeply grateful to the many people who made this experiment possible. The thread begins with Mason Peck, who first invited us to propose a workshop on the relationship between popular imagination and technical possibilities. That incredibly generative gathering—too heavily populated with wonderful colleagues to list them all here—inspired this project as well as related work on the feedback loop between science and science fiction. The story continues with our colleagues at NASA, Alexander MacDonald, Zachary Pirtle, and Jacob Keaton, who originally supported our proposal for narrative space futures, as well as Ashley Edwards, who helped us shepherd this book out into the world.

As the work got underway a small army of collaborators from ASU and beyond took a shoulder to this wheel. Clark Miller, Jim Bell, and Ruth Wylie have been wonderful collaborators and co-investigators for this effort. Alissa Haddaji and Mateo Pimentel have bookended the project as graduate research assistants and, respectively, fomented and documented our strange collaborations. Bob Beard, Cody Staats, and the whole team at the Center for Science and the Imagination helped orchestrate our on-site workshop and engage Maciej Rebisz, who deserves his own thank-you for creating the stunning illustrations that accompany these stories. Juliet Ulman played a vital role in editing the manuscript as we moved into the final stretch of the project. Beyond all of these, Joey Eschrich deserves an editorial medal of valor for his work managing, editing, coordinating, and improving this collection in every way imaginable.

Jim Bell:

I would like to thank Joey Eschrich and Ed Finn for significant editorial assistance on an earlier draft of my contribution, and in general would like to thank all of the participants in the Space Futures project for an inspiring and invigorating experience. In particular, interviews and discussions with Alissa Haddaji, Kim Stanley Robinson, Karl Schroeder, and Madeline Ashby have been insightful and darned fun. Let's do it again!

Joey Eschrich:

I would like to thank all of the contributors to this project for their brilliance, patience, rigorous thinking, good humor, and receptiveness to editorial meddling. I became fascinated by space as a bookish kid with a star atlas (but alas, no telescope) in New England. After that I took a long hiatus away from the cosmos, and it's been thrilling to look up and out again. I owe that opportunity to the generosity and trust of Ed Finn, Ruth Wylie, Jim Bell, Clark Miller, and all of our collaborators and supporters at NASA.

I'd also like to thank Bob Beard, Cody Staats, Nina Miller, Peter Nagy, and the rest of the Center for Science and the Imagination team for their hard work and intellectual companionship, and Juliet Ulman for grappling with a strange and occasionally imposing editorial project at a late stage of the game—and for teaching me some new editorial tricks and habits of mind. Thanks to Kathleen Pigg for providing timely botanical expertise for Steven Barnes's story. Finally, I'd like to thank my perspicacious wife Jennifer Apple for an endless barrage of incisive comments, helpful suggestions, and reasons to be inspired.

Clark A. Miller:

This has been an amazing project to work on. A decade ago, my colleague Ira Bennett and I argued that science fiction stories had the potential to be a kind of technology assessment for the rest of us.[1] Science fiction has always played this role, in part. Stories such as *Frankenstein, Brave New World,* and *1984* have become important sources of symbol and imagery in modern societies, especially around the power of technology to shape humanity's future. Ira and I meant something somewhat different, however. For us, the literary forms of science fiction, which force writers to put new technologies into the lives and stories of people, provide a potential counter to some of the more lamentable characteristics of traditional technology assessment. Rather than dry, technical assessments that divorce the rational evaluation of technology from consideration of the social contexts in which it is applied, science fiction errs in the opposite direction. The stories draw readers in; engage their passions; explore technologies from the perspectives of those who live with, use, and encounter them amidst their lives. Fiction invites readers to participate in a rich, lively world, and draw their own judgments about what a new technology might mean.

For Ira and I, then, science fiction stories could be a tool through which people who are not experts in a specific technology could:

- Learn about that technology, how it works, how it might plausibly develop in the future, and how it might intersect with other technologies.

- Explore its potential intersections with diverse human values and experiences, ways of living and working, cultures, and/or patterns of social and economic activity.

- Anticipate what it might mean for themselves, their families and communities, or even their countries.

- Discuss with others how the technology should be developed, used, and/or regulated responsibly, either today or in the future.

We all owe a debt of thanks for the opportunity to try these ideas out to Ed Finn, the director of the Center for Science and Imagination at Arizona State University, to NASA, and to the writers who helped us out. I must say, I'm hopeful. I am not an expert in space. Yet, in reading these stories, I explored new territory and found my vision of our future among the stars expanded. I learned how people participating in the commercial space arena think space technologies might develop in the future and interact with other innovations like synthetic biology, robotics, artificial intelligence, and cryptocurrencies. I considered how a diverse array of different kinds of people, living in different kinds of circumstances, might think about, engage, get excited about, use, and even reject different kinds of space technologies. I thought about my son—who is eight, who is constantly making things with whatever materials are lying around the house, and who was deeply engaged by the cartoons and videos NASA created for its Curiosity mission—and what the future of commercial space activities might mean for his life and his future. And now I am writing to you about what I learned and how we might collectively try to make sense of that future.

Notes

1 Clark A. Miller and Ira Bennett, "Thinking Longer Term about Technology: Is There Value in Science Fiction Inspired Approaches to Constructing Futures?" *Science and Public Policy* 35, no. 8 (2008).

EDITORS' INTRODUCTION: THE FLAG AND THE GARDEN

by Ed Finn and Joey Eschrich

Why should we go to space? Our answers to this question have changed significantly over the past 70 years as the people, the methods, and the funding for space exploration continue to change. Many Americans enraptured by the "flags and footsteps" pride of the Apollo landings assumed that we would soon be doing the same on Mars—and yet generations of leaders have failed to galvanize that kind of commitment and excitement, to recapture the spirit of John F. Kennedy's famous line: we do these things "not because they are easy, but because they are hard."

Over the past two decades, private space companies have joined their public counterparts and offered new rationales for their work. Initially dismissed as the hobbies of billionaires, several of these enterprises have had a real impact on the logistics and possibilities of space exploration, and more importantly, they have offered new answers to the question of why. Elon Musk's claim that he wants to retire on Mars puts space into a very different context: a personal and commercial one, where the notion of planting flags gets replaced by planting gardens. Musk plans to retire on Mars not because he thinks he *should*, but because he thinks he *can*.

The idea of space as a canvas for human possibility has proven compelling to those in the nascent commercial space industry, but the vision has not galvanized broad public engagement in the same ways as the iconic era of Sputnik and the Apollo missions. Creating a new collective understanding, a fresh answer to the question of why should we go, is more than just a public engagement project. Until enough people buy into a public and *private* narrative of space, commerce can only take place in a very limited way. Insurance companies are less likely to underwrite complex, high-risk ventures in space. Legislators and regulators are less likely to focus on or value the potential benefits to society of public-private space exploration.

Investors and individuals are less likely to support space ventures with their dollars and their attention.

This collection takes on the challenge of imagining new stories at the intersection of public and private—narratives that use the economic and social history of exploration to inform scenarios for the future of the "new space" era. The stories in this collection weave together the flag and the garden, the nation-state and the corporation. They also balance the abstract hopes and fears of collectives with the more immediate concerns of individual people. Space exploration is only viable in the long term if enough people feel a personal connection to it, finding a story about the world beyond our atmosphere that they can inhabit and believe.

And so we are delighted to share this, a collection of space-futures narratives informed by the lessons of the past, the insights of current technical and scientific research, and the eternal hopes and fears of humans facing the unknown.

The most important lesson we have learned in this project is that people have been thinking of ways to get to the stars for a long time. While an array of new missions, companies, and launch platforms have entered the extraplanetary game, the fundamentals are almost unchanged. The human drive to explore is coupled with an equally powerful impulse to bring things back, to weave our discoveries into the broader web of human civilization. The growth of our species has not been a linear march towards technical knowledge but an omnidirectional expansion, a thickening layer of activities, projects, logistics, conversations, and culture. In that way the commercialization of space will also be, we hope, a kind of domestication—not in the sense of taming nature but in the sense of creating a space for dwelling, a venue for human life to unfurl in all its weirdness and complexity.

This collection advances the central mission of the Center for Science and the Imagination (CSI) at Arizona State University to encourage more creative and ambitious thinking about the future. Its roots lie in *Hieroglyph: Stories and Visions for a Better Future*, which brought together science fiction writers and scientific researchers to come up with technically grounded, optimistic visions of what might happen next. Each story presented a glimpse of a possible future that a young scientist or engineer might be able to achieve in a single professional lifetime—Thinking Big, but also imagining worlds that are within arm's reach of contemporary technological development.

Hieroglyph was not just a book project but an experiment in forging a community that included students, teachers, policy-makers, and working professionals in many different walks of life. It lives on as a collective organized around the idea that we can work towards better futures by working up some better dreams. The stories in that anthology explored futures shaped by synthetic biology, neuroscience, structural engineering, and many other fields.

This book is also an experiment, one that builds on what we have learned from *Hieroglyph* and many other related projects at CSI. One major change is that we have integrated narratives and nonfiction even more closely than we did with *Hieroglyph*, asking our various collaborators to engage and share their work with one another at several stages in the project. These collaborators joined four thematically organized teams of writers, social scientists, and space experts: Low Earth Orbit, Mars, Asteroids, and Exoplanets. Together they were able to explore a wide range of questions about the social, technical, and commercial possibilities of expanded human activity in each of these domains. We are also pleased to include all of their final products here, fiction and nonfiction, something we were not able to do with the first *Hieroglyph* collection because of printing constraints. Here readers can follow ideas and arguments across multiple essays, echoing the circulation of those ideas among our contributors via phone conversations, email exchanges, and a few in-person meetings.

Visions, Ventures, Escape Velocities is an experiment in a second sense, as a research project funded by NASA. In that regard, this is an exploration of the value of using narrative projections about the commercialization of space exploration and public-private partnerships. The act of putting writers, natural scientists, engineers, and social scientists into dialogue around the near future of space has effects on those collaborators themselves, who have grappled with—and we hope, learned something useful from—the exercise of working across disciplinary and creative boundaries. Their work may also be useful to NASA researchers in the future, and will certainly be of interest to scholars of space exploration in relation to science policy, cultural studies, literature, and related fields. Most importantly, we have worked hard to craft this collection for a broad public audience, expanding our collective conversation about the future of space exploration through a series of thought-provoking visions about how it might unfold.

With all of these audiences, we hope the volume will advance several different objectives. First, finding novel perspectives and descriptive structures for some of the classic dilemmas that complicate space exploration: risk, cost, and long-term benefits. The second objective turns that novelty on its head by arguing that many of these dilemmas are not new at all, but instead questions that explorers have faced many times before, from the fourth-century voyage of Pytheas of Massalia and the incredible journeys of Polynesian peoples across the Pacific Ocean to the nineteenth-century Arctic expeditions sponsored by British food manufacturers like Huntley & Palmer and Beach's. And finally, we hope we have created a collection that draws together our audiences around shared stories—the community of space researchers, policy-makers, and entrepreneurs, on the one hand, and a broader public that continues to be inspired by the discovery and exploration led by NASA and other entities, on the other.

What distinguishes our experiment is the harnessing of economic history and science fiction to the frame of our current technological horizon: a set of stories that inflect and reinvent the lessons of the past to illuminate possible futures. Imagining commerce in space has its own rich history in the genre of science fiction, from Frederik Pohl and Cyril M. Kornbluth's classic satire *The Space Merchants* to contemporary works like the television series *The Expanse*, based on the novels of Daniel Abraham and Ty Franck (writing as James S. A. Corey). These are stories that consider space as a mirror for human culture and identity, a set of environments that, no matter how unfamiliar to us, can become familiar to characters who dwell in them. They perform the crucial imaginative work of placing everyday humans into thriving extraplanetary environments, and thereby allow us to see a very different solar system through their eyes.

This is one of the important functions of science fiction: to take the novum, the "new thing," and make it familiar through the alchemy of a story. The strange remains strange, but it also becomes known to us, as recognizable as a tricorder or a lightsaber. In this way, science fiction is a genre of exploration. The stories and essays in this volume dramatize and contextualize that reciprocal aim of exploration, to link back, to weave together, and consider how we might voyage into the unknown and forge new kinds of cooperation, commerce, and community.

HUMAN EXPLORATION OF MARS: FACT FROM FICTION?

by Jim Bell

Sending people to Mars or other deep space destinations is no longer solely the realm of science fiction. While NASA or other interested players in the space business don't yet have a specific detailed timeline for human missions to Mars, for example, they and others are investing heavily in the needed technological, political, and societal resources required to make such missions happen. Ironically, science fiction itself may be at least partly responsible for this recent sea change in science reality.

Numerous potential ports of call await future human space explorers. The next travelers in space may be returning to the Moon after a more than half-century hiatus, making the first visits to low-gravity asteroids that pass relatively close to the Earth, or setting out on a grand adventure of exploration or perhaps even colonization to Mars and its moons. But Mars, in particular, has caught humanity's imagination as the "next destination" for astronauts, fueled by exciting scientific results from recent robotic space missions, as well as by a renewed fascination with Mars in books, films, and social media.

Indeed, since the earliest telescopic observations, Mars has consistently been a subject of public fascination and wide-ranging scientific interest. The *canali* of Italian astronomer and civil engineer Giovanni Schiaparelli were sold to an eagerly awaiting early twentieth century public as extraterrestrially engineered "canals" rather than mere geological "channels" by the amateur astronomer and businessman Percival Lowell. Those same Martians invaded Grover's Mill, New Jersey, as well as many of the panicked households of America, via Orson Welles and his Mercury Theatre company's 1938 radio rendition of "The War of the Worlds." In the 1950s and even well into the 1960s, some astronomers were publishing papers in *Science* magazine and elsewhere hypothesizing the presence of lichen or other simple life-forms on Mars based on the latest telescope observations.

It would take a small initial flotilla of early robotic flyby, orbiter, and lander missions to convince the scientific community, as well as the public, that the surface of Mars is a barren and inhospitable place. Even then, however, the idea of life on Mars was quickly brought back to the fore of public and scientific debate by the 1996 controversy over the possible existence of fossilized life-forms, and other evidence of living organisms, preserved in an Antarctic meteorite that made its way to Earth after being blasted out of the Martian subsurface by an asteroid impact. Despite the initial and continuing scientific skepticism about the veracity of those claims, massive media and public interest in that possibility, fueled partly by the direct involvement of the President of the United States and a supportive U.S. Congress, has inspired the past two decades of highly visible, and highly successful, orbiters, landers, and rovers sent to the Red Planet. The main goal of most of these missions has been to search for evidence that Mars once was, or perhaps still is, habitable.

But the roots of this public support go far deeper than just the scientific motivation. Over many decades now, science fiction creators—including authors, television and film producers, and video game makers—have built stories and drama around space-related themes, and especially around imagined interactions between humans and aliens, helping to prime a far-reaching (and, for those industries, economically rewarding) public interest in all things space. Regardless of whether those interactions have been friendly or adversarial, or whether those aliens have been benevolent or hostile, the basic premise has achieved wide public support and acceptance: people are going to go out into deep space—to explore, to work, to vacation, or just to live a different life.

How much any of those imagined space-related futures that are depicted in literature, film, or television is actually achievable is highly debatable, of course. While the prospects for almost-magical (to today's physics) technologies like transporters or warp drives or lightsabers seem extremely dim in the near future, if at all, the idea of people traveling by rocket to places like Mars seems not too far-fetched an extrapolation from the Apollo missions to the Moon in the late 1960s and early 1970s. And the idea that people would run into trouble during those voyages, or that they would have fantastic adventures, or that they would make astounding discoveries (like discovering other life-forms beyond Earth), seems easy for a now-space-savvy public audience to accept. After all, this same public is bombarded almost daily with amazing and far-reaching actual discoveries in astronomy, physics, biology, and many other fields of science and technology.

Science fiction has created a positive feedback loop that is influencing the future of space exploration. From the routine airline-like space travel and psychedelic alien encounters of Stanley Kubrick and Arthur C. Clarke's *2001: A Space Odyssey* in 1968 to the pragmatic heroism and realistic technologies depicted in Andy Weir and Ridley Scott's more recent *The Martian*, stories about people in space have spurred conversations, cult followings, and strong emotions in our society. That interest has translated into citizen advocacy for government-funded space activities, as evidenced directly by the creation and influence of nonprofit advocacy groups like The Planetary Society, and indirectly by the massive outpouring of attendance and viewership for major space-related events like the Moon landings, Space Shuttle launches, Mars rover landings, and the recent Pluto flyby.

Science fiction may even be influencing the development of the nascent private commercial space industry, which has space exploration plans often motivated by different goals than government space agencies. In many of these companies, employees from CEOs to factory floor workers cite books, films, and television shows as motivators of their own passion for space exploration, and in some cases even as models for their future corporate goals. For example, would SpaceX be pursuing its long-term goal of colonizing Mars, or would Planetary Resources be pursuing its long-term goal of mining asteroids, without science fiction creators having established that there is an eager and enthusiastic pool of public supporters (and investors) who will back such ventures?

Coming back to the idea of achievability, how important is it to the future of actual space exploration that science fiction represents and depicts an accurate imagined future? What harm could a few lightsabers or warp drives or transporters do, sprinkled here and there throughout the genre? The answer, I believe, depends on the timescale over which the metric is applied. That is, when considering the potential for the exploration of space in the far future (hundreds to thousands of years from now or more), it is easy to suspend the need for accuracy and assume that we can't possibly predict technological advances or innovations that far into the future. So why not photon torpedoes and antigravity shielding? But if a story is to have a significant influence on the near-term future of space exploration (within the next few decades, for example), I believe that it needs to be grounded in a defensible pragmatism about what is actually achievable—technologically, scientifically, and politically. This, to me, is the source of the phenomenal public support for *The Martian*. Author Andy Weir has created an entirely plausible (technically, scientifically, and politically) near-term future for the human exploration of Mars, and in that future there is drama, danger, and discovery—all critical elements in the story's public success. It is easy—not only for the general public but also for rank and file space scientists and engineers—to believe that such adventures are indeed possible in the 2030s … and so, let's work to try to make them actually happen! Even when gently pressed to admit that some of the science in the story is not fully accurate (like the intense sand storm early in the story—far, far more powerful than a storm could possibly be on Mars today), Weir told me that he didn't think that a little scientific exaggeration would matter, given the overall plausibility of the story and the need to establish the premise of an easy-to-understand example of a man-versus-nature conflict. Indeed, amplifying the actual power of the well-known dust storms of Mars is ultimately forgivable, in my opinion, because the details of the storm are irrelevant to the success of the story, or to its ability to inspire people to work towards getting humans to Mars for real. *The Martian* is a great example of positive science fiction feedback that could very well lead to a self-fulfilling literary prophecy.

The stories in this anthology also provide excellent examples of such potential positive feedback. Carter Scholz's "Vanguard 2.0" uses the Low Earth Orbit setting to examine questions of wealth and equity in space. The plot takes place in and around two inflatable human habitats in Low Earth Orbit, and follows the machinations of a cryptic trillionaire, Gideon Pace, who uses his riches to launch a thus-far-unprofitable business using drones to deorbit space debris that might pose a threat to satellites or spacecraft. The story raises the specter of space-based weapons platforms and the idea of using orbital weapons to defend Earth against asteroid impacts. Simultaneously, it considers how the role of private interests in space could change the way that off-world areas are governed and, indeed, how power in space might change power relations and dynamics back on Earth. Pace is a clever, if devious, policy thinker: his interest in expanding his presence in Low Earth Orbit is an attempt to maneuver around the terms of the 1967 Outer Space Treaty, now that activity in space is a private-sector endeavor, no longer the sole province of government agencies. Scholz's story offers a useful warning about the risks of dual-use technologies and competing interests that might emerge in the regulatory near-vacuum of Low Earth Orbit as it becomes an active zone of commerce. It suggests that policy conversations about regulating private-enterprise activity in space need to happen before powerful actors establish themselves as providers of essential services.

In "Mozart on the Kalahari," Steven Barnes imagines space tourism in Low Earth Orbit expanding rapidly, funded by corporate sponsors like Disney. In this future, exploration and experimentation in space are bootstrapped by a tourism industry that caters to the wealthy. Space is only marginally more accessible than it is today; vacations cost a hundred thousand dollars a day, and the only other routes off-world are through elite universities and fiercely competitive science fairs like the one around which the story revolves. The other scientific phenomenon at the heart of the story is the expanded availability and sophistication of do-it-yourself genetic engineering kits for kids and college students. Recent genetic engineering breakthroughs like CRISPR make the democratization of this technology, and massive increases in its power, seem distinctly possible in the near future. The International Genetically Engineered Machine (iGEM) competition already challenges hundreds of teams of young people to "imaginatively manipulate" genetic material each year. Barnes' radical point of departure from our current reality turns on genetic interpenetration between humans and other species, and suggests that we might consider genetically engineering human bodies as one step towards creating a thoroughly spacefaring future.

In "The Baker of Mars," Karl Schroeder imagines a future where Earthbound prospectors search for mineral and volatile resources on Mars remotely, via computer control of robotic avatars that are actually on the Red Planet, as a prelude to eventual human exploration and settlement. The story presents a plausible extrapolation of current computational technologies, especially the blockchain technology that undergirds the cryptocurrency Bitcoin, to conceptualize a new economic commons applied to pools of extraterrestrial resources. Schroeder also explores the concept of latency—the time between initiating an action and learning of its results—in the context of remote operations of assets on another planet. The idea of doing as much as we can via robotics and telepresence, prior to actual human exploration, is already a fundamental component of the world's space exploration programs. It's easy to envision that concept expanding on a more massive scale to include prospecting for raw materials and resources robotically, and then using those resources to develop the infrastructure needed for humans on Mars.

Madeline Ashby's "Death on Mars" also plays with the idea of latency. Astronauts are sent out to work on one of the moons of Mars (much easier to get to than Mars itself), significantly decreasing the time delay for operating robotic vehicles that are building habitats for future human explorers on the planet's surface. This idea has already been gaining some traction in the real Mars exploration world, although mostly in the realm of conducting science experiments and exploration with tele-operated vehicles. Ashby also explores issues of crew psychology and social interactions during the long cruise from Earth to Mars, and beyond. Crew dynamics will be fundamental to the success of future long-duration missions, and one innovation in the story is the concept of an all-female crew, which has physical benefits (lower crew weight and caloric needs) and potential benefits for conflict reduction and social harmony—along with pathbreaking political consequences for the role of women in science. Ashby's tale turns on one of the most challenging situations astronauts might face, the death of a crew member. The ethical end-of-life issues that bedevil us on Earth only grow more complex in space, where individual and social choices around a terminal illness must be balanced with mission objectives and even the risk of accidentally contaminating another planet with life from Earth. Conversations around this topic could lead to more transparency in and public empathy with the space program, and potentially to deeper connections between the general public and future astronauts.

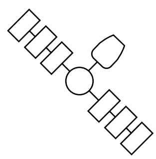
In "The Use of Things," Ramez Naam makes the main source of narrative tension the decision between a space future centered on human exploration and a future dominated by robotic explorers controlled by humans on Earth. Should self-organizing swarms of robots replace human explorers entirely? Are the risks of sending humans into dangerous environments justified, if robots can do the job almost or entirely as well? The story also examines the culture and politics of space exploration, acknowledging the inspirational nature of images of people heroically exploring the cosmos, rather than just sending robotic emissaries to do our bidding. "The Use of Things" is a gripping action adventure, but also a sort of philosophical dialogue between a human astronaut tacked onto a mostly robotic mission for promotional purposes and a cynical NASA administrator who would prefer to be managing a purely robotic endeavor. As Naam touches upon, perhaps it will be easier for future space agencies to build public support for expensive missions if strapping, daring human astronauts are aboard—even if their involvement adds complexity, increases costs, and introduces risks of death or serious injury that are difficult, if not impossible, to mitigate.

Eileen Gunn's "Night Shift" places us in a future where Seattle's software millionaires and billionaires use their riches to build a vibrant start-up culture around nanotechnology, with its epicenter inside the old Boeing Everett factory (once the largest building in the world). Gunn imagines a future for space exploration with humans on Earth overseeing a busy, increasingly autonomous workforce of robotic miners and nanobots, powered by high-efficiency solar cells and using solar sails for long-distance transport. Gunn injects the aggressively quirky energy of the Pacific Northwest's twentieth-century software coder culture into the space exploration arena, challenging us to think through the power struggle between freewheeling computer engineers and artificially intelligent agents operating off-planet with ever-expanding autonomy and critical thinking skills. If we opt for a space exploration future shaped by human-machine collaboration, it will be crucial to develop protocols for just how much decision-making authority to vest in thinking machines, and how much to retain for human experts. "Night Shift" also dramatizes the opportunities and perils of self-replicating nanobot swarms. If given the ability to replicate at a geometric rate, nanobot swarms could theoretically overrun entire asteroids or even planets while searching for water or other resources that they've been programmed to find and process. Gunn treats these weighty subjects with humor and verve, giving us the chance to consider these possibilities in a nonthreatening but exciting technical and philosophical bubble.

Finally, in "Shikasta," Vandana Singh invites us to ponder the implications of the discovery of life elsewhere in the universe, and to reconfigure our expectations about what that life might look like, beyond the familiar flora and fauna we encounter on Earth and beyond the gray, saucer-eyed aliens of film and television. Singh's story likewise reimagines the future of space exploration by centering on a global team of crowd-funded scientists collaborating remotely across continents and time zones, and by making the enigmatic, ever-shifting relationship between the scientists and their artificially intelligent robotic emissary a source of speculation and tension for the reader. Singh's story also complicates the scientific methods and theories that we use to guide our exploration of the cosmos: her characters bring their rich personal histories and indigenous ways of knowing into dialogue with mainstream scientific and technological practices, which enables them to recognize, theorize about, and study phenomena that traditional approaches might miss. "Shikasta" makes a powerful argument for the value of cultural diversity in space science and exploration, and challenges us to seek new methods in the search for extraterrestrial life that go beyond our preconceived notions about how that life will look and behave.

As more specific plans begin to emerge over the next few years for the future human exploration of space by NASA and others, it will be important to understand if and how those plans are consistent with the context and expectations for space exploration that have been embraced by our society based on plausible, compelling science fiction. To me it seems likely that the reason society has embraced particular stories and depictions is precisely because they are not fantasy; instead, they can represent a positive and ultimately uplifting potential reality. In a world with so many societal, political, and economic challenges, the idea that we can make it to a better future that has been at least partially enabled by the adventures, challenges, and discoveries of space exploration could be powerfully inspirational. Evidence to date suggests that such inspiration can be turned into advocacy and action, and that fiction can indeed presage fact.

SECTION I • LOW EARTH ORBIT



"But the General Assembly can't be happy that you've given the first concession to an old South African weapons manufacturer!"

Helmut shrugged. "Armscor has very little relation to its origins. It is just a name. When South Africa became Azania, the company moved its home offices to Australia, and then to Singapore. And now of course it has become very much more than an aerospace firm. It is a true transnational, one of the new tigers, with banks of its own, and controlling interest in about fifty of the old Fortune 500."

"Fifty of them?" John said.

"Yes. And Armscor is one of the smallest of the transnationals, that is why we picked it. But it still has a bigger economy than any but the largest twenty countries. As the old multinationals coalesce into transnationals, you see, they really gather quite a bit of power, and they have influence in the General Assembly. When we give one a concession, some twenty or thirty countries profit by it, and get their opening on Mars. And for the rest of the countries, that serves as a precedent. And so pressure on us is reduced."

—*Kim Stanley Robinson,* Red Mars


KESTREL 1

VANGUARD 2.0

by Carter Scholz

From the cupola, Sergei Sergeiivitch Ivashchenko looked down on Petersburg. It was night and the gloomy city sparkled. Around it curved the northern breast of the Earth, under a thin gauze of atmosphere.

Today would have been his father's sixtieth birthday. Sergei *père* had been principal bassist for the St. Petersburg Symphony. He'd died 15 years ago, from multiple aggressive cancers. It happened to a lot of Russian men his age. He'd been a young teen at the time of Chernobyl, living in Kyiv.

Vera, Sergei's mother, was a beautiful young singer when she married his father. She promptly retired, at 23. Never a pleasant person, Vera grew more unpleasant as her looks faded. When his father got his diagnosis, she immediately filed for divorce, moved out, and took up with one of his colleagues in the woodwinds. She said, "I have to protect myself." Sergei himself was 16, an only child.

Two months later his father was dead. Sergei filed for an extension on the apartment, and was turned down. He'd been playing the part of the rebellious punk *nekulturny*, which didn't help. (His band was called *Alyona Ivanovna*, after Raskolnikov's victim in *Crime and Punishment*.)

They sold his father's instruments. Vera took most of the proceeds, but Sergei's own share kept him going for a drunken while. He couch-surfed with friends for most of a year. He had scholarships and grants and no other options. So he straightened up, and blazed almost contemptuously through math, compsci, and astrodynamics. He had his *kandidat nauk* at 23. But there were no jobs, not in Russia, and competition in the EU and U.S. and India was fierce.

So he switched tracks, took commercial astronaut training, and ended up in Uber's NSLAM Division: Near Space Logistics and Asset Management. The work was menial—glorified trash collection and traffic management—but the pay was good, and he liked being off-Earth.

NSLAM employed about 20 astronauts, in shifts, to staff its two inflatable habitats. Apart from the Chinese and European space stations, theirs was the only ongoing human presence in orbital space. All told there were several hundred astronauts worldwide, working for nations or militaries or private industry, but few stayed in orbit.

Sergei was in the hab for three or four months at a time, then back on Earth for the same. Up here he sat in his cubby and remotely managed ion-thrust drones to deorbit space debris, or to refuel satellites. The drones would be out for weeks or months at a time on their various missions.

Once in a great while he left the hab in a spacecraft, to work on more complex projects. One such task, still ongoing, was dismantling the International Space Station. It was decommissioned in 2024 and sold to NSLAM in 2027. They were still salvaging parts—recycling some, selling some on eBay as memorabilia. He made a side income from that.

But crewed missions were rare, because they used so much fuel, and that was fine with Sergei. He liked being off-Earth but he didn't like leaving the hab. There were too many ways to die in space. Debris, for one. NSLAM tracked one million objects one centimeter or larger. Smaller untracked objects numbered over a hundred million. And it was all moving up to 7 times as fast as a bullet, carrying 50 times the kinetic energy. A fleck of paint had put a divot the size of a golf ball in a Space Shuttle back in the day. The habs were made of dozens of layers of super-kevlar and foam, which flexed and absorbed small impacts, but they were still vulnerable to larger objects.

Then there were solar flares. There was usually sufficient warning, but unprotected astronauts had died. Even inside, he wasn't crazy about the minimal shielding in the habs. During serious solar events, he'd seen flashes behind his closed eyelids. Often he felt like he was following his father to the same early grave.

Petersburg drifted out of view across the northern horizon as the hab orbited south. They'd be back in 90 minutes, but further west, as the Earth rotated under them.

Below, a meteor flashed over the blackness of the Baltic Sea. Nearer the Earth's limb, over Finland, a green veil of aurora flickered. He'd see Izumi in Helsinki next week; his shift was almost done.

He swiveled and opened the cupola hatch. Cold LED light streamed in from the central shaft. He pushed gently to propel himself feet first down the shaft.

She'd hugged him goodbye, kissed him, and said:

Who will take care of your heart and soul?

He shrugged.

She pointed at him. *You* will. Promise me.

He'd promised, but he wasn't sure he knew how. He could take care of himself, but that was mere survival. The self is not the soul. The soul is what you were as a child, until you learned to protect it, enclosing that fluttering, vulnerable moth in the fist of the self.

As he drifted past Boyle's cubby he heard his name called. He grabbed a stanchion.

Sergei's job title was orbital supervisor, which made him the most important person on the hab, responsible for the launch registry, collision avoidance alerts, and flight plans. But Boyle, the shift boss, was his superior. Competent enough, Boyle tended to see nothing beyond his position, so Sergei played his own to type: the stolid Ukie who kept to himself and loved his *wode-ka*. In truth Sergei hadn't seen the Ukraine since his father moved them to Petersburg in 2010, and his drink was single malt. Talisker 18 Year, for preference.

What's up, Geoff?

We're going to have a visitor. A civilian.

Civilian? Why is he up?

He's Gideon Pace.

Gideon Pace was Uber's CEO. He was one of the world's 10 or 20 newly minted trillionaires. The exact number changed daily with the markets, but they were still rare as unicorns, already persistent as myth. This tiny cohort controlled about 5 percent of the world's wealth.

Uber ran a diverse portfolio of businesses on Earth. Package delivery, autonomous transport, data archived in DNA—all hugely profitable.

NSLAM was an indulgence, a pet project of Pace's. He was a space nut who wanted a presence out here at any price. So far, Sergei knew, that presence had bled oceans of money, and not a few lives. But now governments were signing on to underwrite the core mission of cleaning up space debris—enough to have launched a second hab.

All four crew turned out to greet Pace and his pilot: Boyle, Sergei, Kiyoshi, and Sheila. Kiyoshi and Sheila had coupled a few weeks into the shift. Sergei liked Kiyoshi; he was a jazz fan, and had hipped Sergei to Kenny Barron. Sheila, the hab medic, was a petite Canadian blonde with chiseled features. She looked like Vera in her youth, which put Sergei off getting to know her. She'd cropped her hair close to keep it from floating in a halo around her head. Sergei himself shaved his; he hated their no-rinse shampoo.

Their visitor had a weasel's face: dark straight hair in bangs, pinched cheeks, thin sloped nose, pointed dimpled chin, eyes slanting slightly upward. About Sergei's age, but he looked younger.

Fantastic! Fantastic! I've been in space before, but only suborbital. I had to see this for myself.

Welcome to NSLAM Hab One.

You must be Sergei. Chief Boyle tells me you're the most experienced astronaut here.

He wasn't looking quite at Sergei. Sergei guessed he was wearing augmented contacts with a headsup display, clocking Sergei's vitals and recording everything.

Sergei dialed back his English to a cute and unthreatening level.

You gather data on me.

Of course.

Right now. In real time. What don't you know already?

Ah, I see. Well … how you are. I don't know that. How are you?

Sergei put on a blank look, but it didn't approach the blankness of Pace's.

Pace smiled thinly. It's what humans do, Sergei.

How would you know? Sergei almost said, but didn't. Pace's headsup probably picked up the subvocalization; his smile twitched.

Boyle grabbed a stanchion. Let's show you around.

I've got work, said Sergei.

Join us later, Sergei, said Pace. I brought some goodies from Earth.

He had indeed. The six of them gathered in what Boyle quaintly called the “mess hall,” a multifunction common space packed with gear on every surface—left, right, up, down. The “mess hall” housed some hydrator nozzles and a fold-down table with bungees and velcro to secure plates and feet. It was seldom used. They tended to dine separately.

Pace had brought Kobe beef *tournedos* in vacuum pouches and a bottle of wine. Sergei would have preferred fresh vegetables.

2013 Napa cabernet sauvignon, Pace said. Heitz Cellar, Martha’s Vineyard. A wine like this you don’t want to suck out of a bulb.

His pilot passed a case, and Pace drew out six glasses and an opener. As he applied the opener to the bottle he let the glasses float. Their cross-section was tear-shaped.

An old NASA guy designed these glasses. The shape creates surface tension to hold the liquid in. Neat, huh?

Pace held one of the glasses while a trigger on the opener let compressed nitrogen into the bottle and forced wine out the spout. The wine sloshed but stayed put in the glass. He drifted glasses one by one to their recipients, lifted his own to his nose, let it twirl slowly while he inhaled. Sergei guessed he’d practiced all this in suborbital.

Enjoy. I want to thank you all for the incredible job you’re doing up here. NSLAM is now the most trusted actor in near-Earth space. It’s all because we stepped up to do something about the Kessler Effect, and you’ve all executed flawlessly.

Sergei wasn’t sure he believed in the Kessler Effect, that a cascade of debris could destroy satellites to produce more debris to destroy more, et cetera. Noisy disaster movies had been made about it, but if it was truly happening, it was proceeding so slowly that only spreadsheets detected it.

The oven chimed. They all bungeed in and began to eat. Sergei had to admit it was pretty good.

So let me tell you why I’m here. It’s not just to sightsee. I want Sergei to do me a favor.

Hm?

You know Vanguard 1?

No idea.

Launched by the U.S. in 1958. Still in orbit, though long defunct. It's the oldest human thing in space.

And?

I want it for my collection. I'd like you to steal it for me. He smiled at the others.

Why not use drone?

I don't want to wait for a drone. I want to take it home with me tomorrow.

Sergei shrugged. Let me run numbers. He returned to his *tournedos.*

Pace was crazy, but that didn't bother him. Everyone in the world was crazy, no exceptions. One managed one's condition in more or less socially acceptable ways, according to one's capacities and resources. He'd once blamed the situation on the overwhelming complexity of modernity, yadda yadda, but he'd come to believe the condition was ancient and fundamental.

His own way of coping involved these long months off-Earth. Pace's, well, who could say. He knew Pace was a believer in the Singularity—the omega point at which machine intelligence was supposed to reach a critical mass and become self-sustaining and independent of humans. To Sergei that was bonus crazy. But Sergei had a parallel notion about what happened to money, when you put enough of it in one place. These guys were as separate from normal humanity, and as alien, as AIs were supposed to be. But they weren't the intelligence: the money ran them.

The mission looked doable. A Hohmann Transfer would take a little over an hour to reach Vanguard's orbit at its apogee. Changing orbital planes was, as always, the bitch; the delta-v budget for that alone was almost four kilometers per second each way. That's why they almost never ran crewed missions like this.

Kestrel One was the only vehicle with enough thrust. It was scarily minimal, about three meters in diameter and four meters long. The forward half tapered to a blunt point. The rear half was for fuel. It would never have passed a design review at any national space agency. Among other shortcuts, it had no life support, relying on the astronaut's spacesuit instead. Sergei figured the suit's eight hours would be enough, but he'd take extra oxygen, in case. *Kestrel* was docked at the propellant depot orbiting behind them. He programmed it to dock with Port Two after fueling itself.

The tricky bit would be locating his tiny target once he got into its orbit. He had its orbital data, but in TLEs, two-line element sets. The format was archaic. Futile editorials periodically appeared in *Orbital Debris News* calling for an overhaul of the system, but it was too entrenched.

The TLEs were tailored to a general perturbation model that was accurate to a kilometer at best. He'd have to get in the neighborhood, scan with radar, then grab it. That'd take how long?

He wanted sunlight for that, so he adjusted his start time. Coming back, the two orbits weren't so good for rendezvous. He'd have some stay time.

There were other, non-orbital considerations, but they weren't really his. *Kestrel* would be picked up by ground radars, but the radars were almost all managed by NSLAM, and the company's manifests were private. If anyone happened to ask what he'd been doing out there, which was unlikely, the company would make something up.

OK. What does this thing look like? How big?

I'll show you.

Pace popped the latches of a Pelican case. The released force spun the case in the air. Pace steadied himself against the wall and got hold of it. From die-cut black foam he drew a small metal sphere, then plucked six thin rods about half a meter long from the case and screwed them into the object's threaded bushings. Finally he drew his hands away and let the small thing float between them. He tapped a vane and the model slowly spun, a silvery seedpod.

Very small.

Pace gazed past it and his eyes twitched. Six and a half inches in diameter, three and a half pounds. Khrushchev called it the grapefruit. It was the first of four Vanguards, sent mainly to test the launch vehicle. It's the only one still in orbit, brave little guy.

Why is this grapefruit so important to you?

You kidding? It's historic.

How so?

Know anything about space law? Once upon a time, the sky was "free." After aircraft came along, it was said that a nation "controlled" its "airspace." Then satellites came along. They crossed all airspaces. There was no legal regime. The U.S. knew the Soviets would object to a military satellite, so they crafted Vanguard, a very public "scientific" mission with no military objectives. Except for establishing the precedent that space was beyond national boundaries. I want this little guy hanging in my office to remind me how elegant that strategy was.

There was a lot Sergei could have replied to that but he controlled himself, and said, I need to launch in 24 hours, when Vanguard is in best position relative to us.

Pace reached out and stopped the model's slow spin.

Take this with you. When you've got the real thing, insert this back into its orbit.

They were over Australia in daylight when Kiyoshi stuck his head in.

Dobroe utro, Sergei.

Ohayou gozaimasu, Yoshisan.

English was the lingua franca, but they'd each learned a few words of the other's tongue as a formality, to show respect. It didn't hurt that Sergei had already picked up some Japanese from Izumi.

Sheila and I need a flight plan to Hab Two. They've got some problem with their water recycler. We need to bring a spare.

Both of you?

Boyle says as long as I'm using fuel, Sheila should come along and give them a checkup. Here's our launch window.

Yoshi showed him a tablet.

OK, I'll upload a flight plan.

Spasibo.

Douitashimashite.

Same time window as Sergei. Leaving Boyle and Pace and his pilot alone on the hab.

Sergei watched the hab dwindle against the ocean, positioned between Patagonia and the Antarctic Peninsula. He could see Pace's vehicle, docked at Port One, surprisingly big, as big as the hab itself.

One kilometer out, he yawed and started the transfer burn. Thrust was about half a G. It felt good. How he would welcome gravity when he went down! And fresh air and blue skies. After four and a half minutes, he ended the burn as *Kestrel* passed over the Sahara.

He'd be over Petersburg in 15 minutes, this time in daylight. Summer was coming to the Northern Hemisphere. He'd relish the long days, the white nights, of Helsinki in July. Izumi and he had been together for almost two years, though he'd been in space most of that time. She was a few years older than him, had been married once, to a Finn. She worked in IT for a comprehensive school. She was also a singer, classical and cabaret. They'd met in Petersburg at a concert. Shostakovich string quartets.

He didn't know where it was going, the two of them, or where he was going, solo or not. He had a sometimes-piercing dread that one day soon she was going to lose patience with him.

Hell, he was losing patience with himself. His smell in the spacesuit was rank. Water was too precious up here to use for washing, especially clothes. When they grew too foul, they were thrown out. He changed his socks and shorts about once a week, his shirt about once a month. They were past due. So was he. The self was too much with him.

He was now over Vladivostok. He'd gained almost 4,000 kilometers in altitude and the Earth was palpably smaller. South across the Sea of Japan was Kyoto, Izumi's birthplace. She'd taken him there once, for a week. They visited Ryoanji temple one morning, arriving very early, before it opened, to avoid the tourists. It had rained in the night but the day was sunny, the road vacant. They hurried past an old woman on their way. Black birds stared at them from the roof of the locked gate. The old woman caught them up, and she looked to them in concern: What time is it? She was the gatekeeper, worried she was late.

Over the South Pacific, in darkness now, he burned to shift his orbital plane into Vanguard's. Ten more minutes of welcome gravity, its force steadily increasing from half a G to over a G as the ship burned fuel and lost mass. When it ceased, he checked his bearings. He was now in Vanguard's orbit.

But nothing was out there. Lots of nothing. More nothing, and more nothing. Then S-band radar bounced back from something about two kilometers ahead of him. He burned briefly into a lower orbit to phase up on it. At 100 meters' separation, he burned back up to stationkeeping. There: a point of light drifting against the stars. After long, fussy minutes of edging up, he had it, closed the arm on it, and brought it into the bay. Mission time: 3 hours, 39 minutes.

It wasn't tarnished or pitted, but the metal bore a slight patina, weathered by solar radiation and micrometeor abrasion. He cupped it in his gloved hand. It was that small. He felt a mild revulsion at the thought of handing this storied thing over to Pace.

But he secured it, then loaded the imposter into the bay and launched it. He checked his position against the hab's, and ran both coordinates through the flight computer. He'd have to stay for 42 minutes until ship and hab were aligned.

While he waited he played the second Shostakovich string quartet through his suit's phones. It was what he'd been hearing when he first saw Izumi, two rows in front of him in the shadows of the concert hall. That elegant profile. He'd studied the shape of her left ear as she moved so slightly her head.

This quartet had been his father's favorite. Sergei could see him seated at the north-facing window with his cello between his knees, practicing in the pale light, occasionally stopping to mark the score.

The final chords resounded, an angry but halfway resigned lament against the shortness of life, its futile complications, the thwarting of joy.

Sergei checked the flight computer. It was time. He watched the countdown, then burned for two minutes as thrust climbed steadily to over two Gs. His heart labored.

Another hour passed in silence as the ship followed its new trajectory to the lower hab orbit. The curvature of the Earth's limb slowly flattened, and the Moon, half-full, rose above it.

It stared at him and its glory pierced him. The intricate Sun-Moon-Earth system was best felt from here.

Something hit.

Blyad!

The vehicle jolted. Or maybe it was him who jolted. He thought he'd heard the hit—a faint crack, something you might hear underwater.

For a moment the world was pure falling. A crowded emptiness. Millions of specks streaked through this vastness of orbit. Thoughts in a void of unmeaning. Subatomics in a space of forces. In that maelstrom, once in a great while, two specks collide: a neutron lodges in a nucleus, and changes its nature.

In the center of the window was a pock: an irregular, finely terraced crater about five centimeters across. Sunlight raked it into fine relief. The particle, whatever it was, had vaporized on impact. A little larger or a little faster and it would have continued straight through his visor.

He smelled the sharpness of fresh sweat over his stale miasma. At least he hadn't shit himself.

The rest of the way back his eyes were on the radar. Not that he would see anything coming before it hit him. It was just magical thinking.

But as he approached the hab he did see something. Four bogeys, faint echoes, inconsistent returns, in parallel orbits.

Kiyoshi stopped by.

I heard. You okay?

Ah, yeah. You know.

Kiyoshi did know. He'd almost run out of oxygen on an EVA. How are they on the other hab?

Kiyoshi frowned. Their water filter was fine. Sheila ran her tests. They're all good.

Sergei shrugged.

Two pointless EVAs in one day. You could have been killed.

I'm fine. *Arigatou gozaimasu.*

Beregi sebya.

He thought that would be it. It wasn't.

Sergei, my friend. May I come in?

In one hand Pace held two of the tear-shaped glasses. In the other was a bottle: Talisker 18 Year.

It wasn't worth getting upset over, but it annoyed him. Pace didn't need to parade his research.

I want to thank you. I heard you almost got centerpunched out there.

Sergei watched the glasses float while Pace scooped whiskey into them. Now he was almost angry. As far as he was concerned, it was over. What more did Pace want? He meant to keep his mouth shut, but he saw that sunlit pock in the glass again, heard that distant crack, felt himself jolt. He wanted to make Pace jolt.

You launched something while I was gone. You and Boyle. Four objects.

Pace looked at him with interest. Why yes. Yes we did. It was awesome.

Why send me away?

Pace regarded him carefully through the lenses of his headsup. What was he reading there? Sergei's pulse, BP, skin temperature—what else was he tracking? Pace was like a windup toy that never ran down. It was tiring. Sergei didn't want to be sitting here drinking with him.

Well, I truly did want my Vanguard. But I also wanted my objects off the registry. If you were onboard, you would be the one to record them.

What are they?

Pace seemed to think about this.

You know about the Outer Space Treaty. Bans nuclear weapons in outer space. I mean, this goddamn piece of paper is from 1967, but nations still take it seriously, or at least they have to seem to. But we're a private company. That piece of paper means nothing to us.

United States company. Subject to U.S. jurisdiction.

Listen to the space lawyer! No no. They were launched into space by an LLC doing business in the Maldives—which is not a signatory to the treaty.

Maldives? Practically underwater.

We built a seawall and shored up our island.

Why not put objects into orbit direct from Earth? Why from space?

Maldives are still a UN member. They'd have to register my objects with the UN. The fucking *UN*! Isn't that quaint?

They register your launch?

Sure, but that launch didn't put the objects into orbit. Orbit was accomplished up here.

What are they?

Oh, so far, nothing. They're platforms.

Platforms for what?

Pace took a silence, looked troubled, but he was enjoying it.

Let's say that I worry about mankind. We had a close call with an asteroid a few years ago, you may remember. It'll be back soon. We need assets out here to help us with that problem.

And so, you want to put on these platforms …

Nuclear weapons. What else has enough push for an asteroid?

Bad idea. Could end up with hundreds of small asteroids instead of one big one.

You know what would be a much worse idea? Doing nothing.

Why you?

Nobody else is doing it, that's why.

Where you going to get nukes?

Oh, look, it doesn't have to be nukes. Use giant lasers if you want, whatever. I'm offering these platforms to any nation that wants to contribute to the long-term survival of mankind. I've got interest at NASA and DoD.

No pushback?

NASA? They've already ceded Earth space. DoD? SecDef is ours, a former Uber VP. The Joint Chiefs are mostly on board, and for the whiners there's always early retirement. I don't need to own their weapons. They'd simply be under our management.

Hard to believe they give you control.

Pace tapped his glass into a slight spin. A small blob of whiskey escaped. He sucked it into his mouth, and swallowed. Smiled.

They let us manage their satellites. We're a trusted actor. DoD would love a way to bypass the Outer Space Treaty. I offer us as a beard, that's perfect for them. Get a few allies on board, even better.

At this point, Sergei knew it would be wise to shut up, finish his drink, say goodnight. He didn't feel wise.

What is your long game?

Pace squinted at him. What makes you think I have a long game?

You are smart guy.

Sergei let the silence stretch. Pace was compelled to dominate a conversation, to fill up the social space. That went against the solitary, obsessive nature that Sergei recognized, but he saw how Pace had learned to deploy that nature tactically. Now he saw Pace shift out of the social space, back into his own mind. He squinted as he manipulated his headsup. It was like watching a lizard.

You've read Max Weber? Pace said at last.

Some.

Pace's eyes flickered as he quoted: "A state is a human community that successfully claims the monopoly of the legitimate use of physical force."

So?

Here's my long game: I want to redefine "human community" for the better. My method is to redefine who's "legitimate."

Yes?

The nation-state as a form of political organization is recent. Treaty of Westphalia, 1648. There's no reason it needs to persist. There are better alternatives.

Sergei gave him more silence. Pace shifted back into his public mode.

See, I'm big on dual use. Once these platforms are armed, they can also protect against dangers from below. I mean, look at the data. Nation-states have very bad metrics. You know that. So many wars, so many killed. So much property damage. We can do better. We will. We can build and manage the defense cloud.

Platforms are vulnerable.

I'm an optimist. These platforms are stealthy and maneuverable. Anyway, ASAT's a non-starter, Kessler Effect and all, that's unwritten but fundamental. It's why we're up here, am I right? Soon I'll have memoranda of understanding with certain public and private actors, which will make any action against the platforms a lot more complicated. Let's say that I foresee a regime in which it's in everyone's interest to leave them the hell alone.

Meanwhile they are traffic hazard.

Oh, they'll be no trouble. The orbital elements are in your database. You have what you need to protect *all* our assets.

All our assets?

Pace held out his hands in a kind of embrace.

Everything that's up here under our management. To quote one of my heroes: They're *our* assets now, and we're not giving them back.

Why tell me?

You're smarter than you like to let on. There could be a place for you in our ground operations.

Sergei shrugged. Pace shook his head.

Hate to see expertise go to waste. Here's my private email. Let me know if you're interested.

That night, strapped in his sleeping bag after Pace and his pilot had departed the hab, Sergei thought it over.

In 2029, the asteroid Apophis had crossed Earth's orbit. A scary close approach, closer than many geosynchronous satellites. The thing was 350 meters across. Not extinction-level, but many times Tunguska. A one-gigaton impact was nothing to sneeze at.

Sergei had been in space then, had watched it fly by. It brightened to third magnitude, moved through about 40 degrees of sky in an hour, faded, was gone. It was due back in 2036. Odds of impact were only a few in a million, but Sergei saw how useful that recent near miss and impending return could be to a system selling itself as asteroid defense. The nuclear option against asteroids made no sense, but politics made no sense. The meme of "protection" was more powerful than reason.

As to Pace's longer game, he didn't buy it for a couple of reasons. First, the U.S. would never hand over control of nukes. They'd invented them; they'd become the global hegemon with them, and more or less remained so because of them. But: that "more or less." Pace was lying, but his lie had exposed a deeper truth that eroded Sergei's faith that the U.S. was the U.S. of his imagination.

Second, it made no strategic sense to station weapons in space. Launch costs were high, platforms vulnerable, delivery difficult. Earth-based systems were the better choice.

Unless the weapons were assembled in orbit. But why do that?

He remembered a job he'd done months ago, EVA, in person, servicing an orbital nanofactory which produced microscopic pellets—flecks of material embedded in zero-G-perfected beads of glass. Manifests identified the material as LiDT: lithium deuteride and tritium. Mildly radioactive. He'd been curious, but had forgotten about it once he was safely back.

Now he logged onto SIPRNet and searched classified scientific papers. Soon he found "Typical number of antiprotons necessary for fast ignition in LiDT." Primary author: R. Fry, Lawrence Livermore National Laboratory. The paper detailed the results of the first breakeven fusion reaction a few years back.

That was it, then. The Livermore Lab had worked on fusion since its founding, 80 years ago. Its founding purpose was nuclear weapons, and its Grail was a pure fusion weapon. This bomb could be small and light and still hugely destructive. Sergei was no nuclear scientist, but those pellets were clearly nuclear fuel. They were being produced in orbit; and so could bombs that used them.

What about delivery? Uber already had a thriving Earthside business in package delivery using small drones. Suppose you mounted a few dozen fusion bomblets on drones, packed those drones in a cheap capsule, dropped it from orbit, popped it open in the troposphere, where you could then MIRV the drones to individual targets. The only defense would be to destroy the capsule before it opened. If the capsule were small and stealthed, could it get through? He didn't know.

He could be wrong. Maybe they weren't working on bombs. Maybe they wouldn't succeed. Maybe it would take a long time. Maybe he should forget the whole thing.

Kiyoshi and Sheila's alcove was near his. Sergei could hear the thumps and moans of their tangled bodies through the thin walls. He allowed himself to think of Izumi, of tracing his finger slowly along the arch of her foot, hearing the intake of her breath, taking her big toe in his mouth and hearing her gasp.

His heart and soul didn't buy his maybes.

Two days later he was on the way back to Earth. They would touch down in Kazakhstan. Kiyoshi and Sheila were also ending their shifts, while Boyle stayed on. Sergei looked away from the couple, strapped in across from him, their hands intertwined.

It would make sense to take Pace's offer. It had come wrapped in a veiled threat. Pace even had a point. Sergei had no sentiment for the nation-state. During World War II, Petersburg had been under siege for 900 days. Shostakovich had been there. The population went from 3.5 million to 600,000. In his lifetime, the endless Chechen wars. Was any of that right?

Out the small window, sun slanted across a long wall of cumulonimbus over the coast of Venezuela. Somewhere below the clouds, American troops were liberating oilfields.

"The right thing." Who could know what that was? Imagine all the damned souls who believed they had done the right thing. Who may in fact have done the right thing, and found themselves damned anyway.

And Sergei was ready, maybe, to finally stay below the clouds. To keep his feet on the ground, to have a normal life.

But that was mere survival. There was a Russian saying, *vsyo normal'no*, "everything is normal." No matter how screwed up: "everything is normal." Also that American saying: "the new normal." Universal surveillance was the new normal. Resource wars were the new normal. Climate refugees by the millions were the new normal. And if Pace got his way, his executive monopoly of "legitimate" violence would be the new normal.

Sergei shut his eyes as the faint whistle of reentry grew to a thunder and the capsule juddered. Soon they'd be at four Gs. Pure falling, again, but now into the burning force of the still-living planet's atmosphere. Still living for how much longer?

Izumi had said to him once: *You think a lot, but you follow your heart.* He wasn't sure he did, but he was glad she thought so, or at least that she said she did. He let the memory of that gladness echo in him. Maybe it was time to be sure.

Who will take care of your heart and soul?

The self is not the soul. The soul is what you were as a child, until you learned to protect it, enclosing that fluttering, vulnerable moth in the fist of the self.

Outside, the heatshield roared and burned. A firedrake of plasma, the capsule passed over Helsinki, Petersburg, Moscow, specks in a crowded emptiness. He opened his eyes.

He saw that both his fists were clenched tight. Very slowly he allowed his hands to open.

REFLECTIONS ON THE "DUAL USES" OF SPACE INNOVATION

by G. Pascal Zachary

Space has always been an important spawning ground for dual-use technologies and the associated issues raised by attempts at *targeted* innovation: that of unintended consequences, or the specter that many innovators do not get what they want—and, embarrassingly, sometimes get what they don't want. Because space exploration is on its face directed at *otherworldly* terrain, emerging technologies in this domain are often justified by non-utilitarian or, more broadly, indirect reasons. In short, the joys of discovery and the delights of exploration for its own sake often dominate debates over the pursuit of both space travel and research into foundational technologies. The expansiveness and idealism of the rhetoric of space exploration means that technologies developed in pursuit of those lofty goals are open to a broad range of interpretations and applications, both military and civilian.

One example that embodies the classic tensions in emerging space technologies lies at the center of Carter Scholz's illuminating short story, "Vanguard 2.0," about a privately conceived and funded attempt to retrieve the original Vanguard satellite. First launched by the U.S. Navy in 1958, the satellite continues to orbit the Earth, though communication with it ended in 1964. In a fascinating conceit, Scholz imagines the original Vanguard device, which was famously described as "the grapefruit satellite" by then–Soviet premier Nikita Khrushchev, being grabbed from space and replaced by a functionally equivalent replica—all done in secret and merely so a wealthy space entrepreneur can personally possess the landmark artifact.

This engineering achievement—of grabbing the Vanguard and replacing it with a replica that behaves in the same way—demands *tour de force* writing by Scholz. He delivers beautifully on his space gambit, providing a story that exploits contemporary fears over the potential for a sizeable asteroid to strike Earth and cause a catastrophe. Scholz bakes into "Vanguard 2.0" a good deal of consternation and complexity arising from planned or imagined efforts to protect the planet against killer asteroids. Since the technologies created for humanitarian insurance against rogue asteroids resemble space-based weapons, these weapons could be turned against terrestrial targets, unless strong controls against this possibility are adopted.

The challenges of managing the "dual-use" aspects of civilian technologies are not unique to space. Civilian nuclear energy remains problematic because of the role of reactors in providing essential fuel for nuclear weapons. The intense monitoring of civilian nuclear energy programs around the globe, notably those sponsored by the governments of Iran and North Korea, has received wide attention. And the difficulty of maintaining such scrutiny over long periods is well known, not least because of errors made by the U.S. government in characterizing Iraq's nuclear programs under Saddam Hussein. That weapons of mass destruction can arise from civilian science and engineering remains the chief reason for interest in the riddles of "dual use" today. Not only do nuclear weapons of mass destruction continue to shadow the future of humanity, but a new set of bioengineering tools, which enable researchers to design novel organisms or reengineer existing organisms in menacing ways, raise additional concerns as to how that technology could be used to harm rather than help, potentially threatening all life on the planet.

As Robert Rosner, an astrophysicist at the University of Chicago, observes in his preface to a 2016 study of dual-use technologies, commissioned by the American Academy of Arts and Sciences, "the dual nature of technological advances—capable of elevating humanity and unleashing destruction on it—long predates the total war and scientific breakthroughs of the twentieth century."[1] But the capacity of today's dual-use technologies, Rosner adds, "drastically" exceeds the scale of mayhem introduced by bygone innovations such as the machine gun or even the chemical weapons that scarred thousands of combatants during the First World War.

The "trickle-down" character of technological innovation can make constructing durable remedies more challenging. "What is high precision today," notes Rosner, "is run-of-the-mill tomorrow."[2] He adds: "capabilities once considered rare and extraordinary, and thus conducive to control, evolve to become the ordinary, slipping outside any possibility of enforceable regulation."[3]

The most salient contemporary example of "trickle-down" centers around a set of digital technologies—computers, the internet, strong cryptography, decentralized networks, the "dark web," and even cyberwar. With deep roots in civilian technology—from supercomputers that simulated nuclear explosions to simple computer and video games to email to online commerce—"cyberwar" owed its early successes to freelance code writers, often flatteringly termed "hackers" by fans and critics alike. The path from hacking to attacking is surprisingly direct and another example, perhaps the most dramatic, of both dual use and unintended consequences.

A bit of history can shed light on the special nature of space-led technological advance. Exploration of the skies, by government, arose in the context of competition between the U.S. and Soviet Union over technological supremacy. Allies during the Second World War, each country deserved much credit for defeating the totalitarian regimes of Germany and Japan. But after the war's end in August 1945, the U.S. and Soviet Union fell out over how to manage the postwar peace. By 1948, these two "superpowers" were arch geopolitical rivals, and nuclear weapons were the focus of their intense techno-scientific competition. By the mid-1950s, jet planes and guided missiles were the object of various "races." When the Soviets launched their simple satellite Sputnik in 1957, a new "space race" erupted that threatened to overwhelm all else.

Perhaps because restraining the spread of nuclear weapons on *terra firma* proved impossible for crucial years, achieving a practical ban on space-based weapons proved far easier. Indeed, from the earliest years of U.S.-Soviet technological competition, space was the place where high-minded humanists could trumpet the grand potential that techno-science harbored for bettering humanity. Rather than militarize space, then–President Dwight D. Eisenhower sought to give a civilian face to space exploration. The bias towards peaceful uses of space meant that concerns over dual use were mainly about the application of civilian technologies to military problems. The Star Wars program championed by President Ronald Reagan in the 1980s foundered not so much on the impracticality of space-based laser weapons, but rather on the deep and abiding commitment, however rhetorical, to keep space off-limits for state-controlled weapons of mass destruction.[4]

In the race to put a man on the Moon, many accepted as appealing and persuasive the dual-use distinction as justification for pursuing broad security and social aims at the same time. Wide support, domestically and internationally, existed for refusing to openly pursue military objectives in space. Instead, President John F. Kennedy and his successor Lyndon B. Johnson chose to elevate the generative aspects of human ingenuity over darker impulses. This approach was seductive. The political appeal of demilitarizing space undercut to some degree the costs of proliferating military technologies on land.

Yet the distinction was always something of a fiction, because of the vagaries of unintended consequences. Who actually could be sure that working on civilian applications would not help militarists in the future? How could choosing to work only on civilian science and engineering provide *moral* cover if the fruits of this labor ended up benefiting military technologies anyway? And what military project might not ultimately help civilians, so that even earnest weapons designers might argue that, someday, their inventions and insights might also save or enrich lives? Wernher von Braun and his work at the Army Ballistic Missile Agency exemplified the uncomfortable overlap between military and civilian agendas at the dawn of the Space Age. Perhaps the ambivalence felt by the character Sergei in Scholz's "Vanguard 2.0" reflects the creeping awareness that whether one's labors are officially on the behalf of civilian or military technologies matters little. In a world of uncertainty and serendipity, technologies can leapfrog across any boundaries, especially those seen in retrospect as arbitrary. Hence Sergei's willingness to entertain the offer to assist the space tycoon Pace. No wonder Sergei thinks "he could be wrong" for caring about the dual-use problem. No wonder he can easily slide from concern to wondering, "Maybe he should forget the whole thing."

Even if the brittleness of the dual-use distinction invites policy-makers to ultimately question its value, the core concern about the societal impact of promoting space exploration and its foundational techno-scientific knowledge and tools remains. Indeed, questions over these societal impacts should trump worries about dual use. I do not mean to say that the dual-use distinction is spurious, only that: whether we discard or retain the distinction, a gnarly set of problems persists regarding how public funds for innovation in space can support public goods.

These problems orbit around a concept called "targeting." For policymakers, targeting seems an obvious solution to the challenge of getting what one wants from spending on innovation. Just say you want "X" and then achieve it. The Apollo project was the classic case of targeting and remains a lodestar for managers of the techno-science enterprise. The pervasiveness of the term "moonshot" is no accident. Setting forth a specific goal, such as explicitly reaching the Moon, is the very definition (and origin) of the "moonshot." Highly specific, drawing on well-understood technologies and a limited range of unknowns, the Apollo targeters struck a comfortable balance between too difficult and too easy. In a calibration reminiscent of Goldilocks and the Three Bears, NASA identified the sweet spot of space targets—and all Americans were rewarded by the seminal achievement of putting men on the Moon.

Yet targets are notoriously difficult to craft, and the process of targeting difficult to manage. Ultimately, the concept is deceptively complicated. Consider the "war on cancer," which arose with a vengeance in the aftermath of the Moon landings, and came to be criticized for being overly broad and practically impossible to operationalize. Today, concerns over climate change cause many to imagine targets that might either cool the planet or help humans adapt to warming. Yet either approach runs into immediate complexities over what targets to specify and which intermediate targets—we might think of these as stepping stones—should be pursued and in what order.

To be sure, talking "targets" highlights for the public alternatives to technological *determinism*, the view that the laws of physics and the dictates of pragmatic engineers shape the outcomes of techno-scientific enterprises. Increasingly politicians, civil society, corporate leaders, and the media talk about technologies they want rather than settling for what Technology (with a capital T) can give them. In this sense, the democratization of technological possibilities has co-evolved with the decline in relevance of the dual-use distinction. The U.S. government once held hegemonic sway in nearly every techno-scientific domain except those areas, such as nuclear weapons or engineering bio-weapons or pandemics, where entrepreneurial freedom obviously isn't permissible or perhaps even sustainable. Now the federal government's hegemony is gone, and a new approach to targeting for the public good must be constructed.[5]

Mounting targets, under any calculus, is worth the effort if only because targets are clever means of holding scientists and engineers to account. Targets help policy-makers and citizens alike chart progress towards appealing outcomes. In the coming era of wider democratic pathways to space travel and space technologies, publicly-generated targets—and accountability trajectories—promise to garner wide support and even shape the new politics of public innovation.

And yet many areas of potential improvement in the human condition, whether on planet Earth or in infinite space, do not seem to lend themselves to targeting. Targeting seems *least* effective, and most costly, when goals are broad and poorly defined. Fuzzy targets, in short, should inspire anxiety. Such laudable far-reaching targets as democratizing a country ruled by a tyrant, or improving American primary education, or preventing terrorists from using social media, are inherently flawed expressions of *homo targetus.* These goals and others like them require pushing down multiple paths, incorporating many specific targets, which may exponentially increase costs, complexity and chances of failure.

In his classic 1977 essay *The Moon and the Ghetto*, the economist Richard R. Nelson examined the paradox of the modern American state, which could put men on the Moon but not desegregate schools, improve education, find a cure for cancer, or better equip parents to raise successful children.[6] Long a leading analyst of the political economy of publicly funded research, Nelson brings valuable humility to the search for methods that can raise the odds of achieving desirable civilian goals through the concerted efforts of scientists and engineers. Neither the internal tensions within the dual-use paradigm nor the seeming ethical benefits of freedom from military imperatives and constraints are decisive here. In his 2011 essay "*The Moon and the Ghetto* Revisited," Nelson identifies a different culprit:

> Clearly the difficulties that societies are having in dealing effectively with some of these problems are due to the constraints associated with significant differences among

citizen groups in their interests and the values they hold. However, a central argument of my book was that in many cases the constraints were not so much political as a consequence of the fact that, given existing knowledge, there were no clear paths to a solution. The heart of the problem was that society lacked the know-how to deal with it effectively.

I would argue that this remains the case today.[7]

Nelson's concern about the centrality of knowledge to the innovation enterprise brings us full circle. Perhaps the very reason why imaginative scenarios about the future of space travel—in form, circumstance, and value—appear so compelling and useful is because fiction works best in filling critical gaps in human knowledge. It is in the gaps of our knowledge that the imagination flowers and alternative narratives thrive. While engaging with future scenarios, innovators must remain alive to the challenge of closing knowledge gaps—and in ways that insure that the inevitable *spillovers* from civilian to military, or military to civilian, are part of the anticipatory governance afforded the innovation project. Unintended consequences need not be wholly unanticipated. Space is a place of extraordinary promise, where the best in human impulses and aspirations can commingle with emerging technologies as yet dimly understood. Better understood are the risks of ignoring the lessons of the experience of dual-use technologies, whether in the skies or on the Earth.[8]

Notes

1 Robert Rosner, "Preface," in *Governance of Dual-Use Technologies: Theory and Practice*, ed. Elisa D. Harris (Cambridge, MA: American Academy of Arts & Sciences, 2016), 1.

2 Rosner, "Preface," 1.

3 Rosner, "Preface," 1-2.

4 For Star Wars to actually be implemented—not simply rendered feasible in the lab—the U.S. government would have had to abandon the principles established in the 1967 Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space (colloquially, the "Outer Space Treaty") brokered by the United Nations, as well as the 1972 Treaty on the Limitation of Anti-Ballistic Missile Systems (the "ABM Treaty") with the Soviet Union. For more on the legal and diplomatic effects of these two treaties, see Chayes, Handler Chayes, and Spitzer, "Space Weapons: The Legal Context." The legal constraints, as well as the force of public opinion, made the development of Star Wars as a viable operational system impractical for Reagan and his administration. For a more recent analysis of how dual-use technologies might undermine the existing space treaties' scope and effectiveness, see Faith, "The Future of Space: Trouble on the Final Frontier."

5 For more on the revolt against elite control over techno-science throughout the latter half of the twentieth century, see "The Port Huron Statement" published in 1962 by the Students for a Democratic Society, as well as Roszak, *The Making of a Counter Culture*, Schumacher, *Small is Beautiful*, Winner, "Do Artifacts Have Politics?" and Hughes, "Counterculture and Momentum."

6 Richard R. Nelson, *The Moon and the Ghetto* (New York: W. W. Norton & Company, 1977).

7 Richard R. Nelson, "*The Moon and the Ghetto* Revisited," *Science and Public Policy* 38, no. 9 (2011): 681.

8 For more information on dual-use technology, see John A. Alic, Lewis M. Branscomb, Harvey Brooks, Ashton B. Carter, and Gerald L. Epstein, *Beyond Spinoff*; Jay Stowsky, "The Dual-Use Dilemma"; and White House National Economic Council, National Security Council, and Office of Science and Technology Policy, *Second to None*. Each of these publications appears as an entry in the bibliography for this collection.


DOP

MOZART ON THE KALAHARI

by Steven Barnes

It took Michael "Meek" Prouder half an hour to magtube from Claremont to the Coachella Valley desert, near the Nestlé Reservoir entertainment pier. In this oasis of hot dogs, pinwheel fireworks, and whirlygigs, he could lounge and marinate himself, soak up rays as he listened to the music radiating from the dam wall, and sink under the rhythmic roar of artificial waves crashing against the artificial shore. He could walk out into the desert away from the city lights, far enough to gather cactus flowers or, when the sun died and the stars peeked out, to set up his telescope and watch the little matchstick structures floating there in orbit, simultaneously out of reach and close enough to touch.

The Disney Observation Platform, where the uber-wealthy could vacation above them all, free from gravity, gazing at the stars with no shrouding clouds to mask their glory, close enough to the Moon to taste the cheese.

A hundred thousand dollars a day, and cheap at the price.

If his arms were just a little longer. Just a little. If he only had the time. But when he looked in the mirror, at his discolored hands and stained eyes, he knew that time was something he couldn't afford.

Seventeen-year-old Meek Prouder was dying, and it was his own damned fault. He could see the damage, and feel it too, a constant itching like ants marching through his veins.

He could soothe that itch by covering his mocha skin in sand, and soaking in the day's heat. There, bathed in warmth, he could escape the constant reminder of what he had become. There, he could close his eyes against the bright light of day and dream he was on the DOP. He could … but then he wouldn't feel the sunlight on his skin, get that tingle, that sense that something good might trickle into a wasted life. He could just soak it in.

But that feeling vanished like desert dew when he caught the magtube back west, as if every mile drained something from him, something that was alive in the greenhouse, or in the desert, but that trickled out of him in school, or shambling around the neighborhood like a brown bear in purple shades.

And by the time the tube settled onto its rails at Claremont station, all of that warmth had evaporated.

"Hey, Meek," said Mrs. Adabezi as he walked the last row of the trailer park. "Hey, Meek," Mr. Zhao nodded, pouring filtered piss on the little picket-rowed vegetable garden. The old man meant no harm. None of them did. But Meek walked on, paying no attention, until he was home.

"How was the desert, Michael?" Grandpa Tyrone asked, after a look and a sniff at the bouquet of pink and orange cactus flowers sprouting from a table vase. He smiled as he set a plate stacked high with quinoa pancakes in front of Meek. He was really too weak to cook Meek's brunch, but when Meek had tried to do his own cooking after Grandma died, the look on his grandfather's weathered face broke his heart. It was as if Meek was telling him that he was good for nothing these days. Meek couldn't take that last thing from a man with so little left to give.

While he ate he told Grandpa of the things he'd seen and the people he'd met out in Palm Springs. Grandpa tried to look attentive but his smiles were slow to rise, and he seemed fatigued and ashen, as if he had eaten a bad apple. Or maybe had some of the same stuff that was killing Meek. Grandpa seemed to think the same about Meek, and asked: "You feeling okay?"

"Fine."

"Let's go out to the greenhouse," Grandpa said, and after dishes were cleared and desserts dished into trays Meek wheeled him out. And there, inside the plastic flaps of the tent in the little square of yard they rented from the Zhaos, they sat and spoke of the old days. Grandpa was ancient enough to remember when the magtube was just built, when the government used that eminent domain thing to build what nobody had wanted.

"What you wanna do, boy?" he asked.

Meek took another big bite of dwarf-peach cobbler and pointed up. "Get up there," he said. The Moon was high above them, visible through the transparent roof as a big old pie he could just eat up.

Grandpa gummed his cobbler, thoughtful.

"They say people like us don't go up there," he said. "That we're trapped. That robots are taking all the jobs, and folks hate us for being dole babies." A twinge of pain crossed the old man's face. Once he'd earned his living by the sweat of his brow, supported a wife and grandson. But the L.A. Quake had broken the city's finances and much of the infrastructure, and the corporations that swooped in to provide and maintain services made … let's just say different decisions than had the general electorate.

Declining tax base and virtual classrooms had crumbled the state's college system. Then they brought in the drone gardeners … and early retirement had been the best of Grandpa's very poor options. Still, he found the optimism to add, "But I still believe that if you use your mind, you can go anywhere you want."

And he meant it. Grandpa was the only one who didn't laugh at Meek's dreams. The last time Meek's girlfriend Sonja had come to the greenhouse, she'd ooohed and aaahed at the only such facility she'd ever seen, eaten free peaches and pears and nuzzled him with honeyed breath, but just rolled her eyes when he'd told her about the Moon. Space wasn't for them. Hell, shouldn't be for anybody, the way she saw it. What good was it, when there weren't enough jobs right here on Earth?

"All kinds of things came out of people trying to get to space," he'd said.

"You wanna tell me about satellites again?" Sonja laughed. "Maybe cell phones and microchips, like Mickey says?" She squeaked her voice like the mouse in the cartoon they'd watched in assembly: *"We need space! We need to get to Pluto, Pluto!"*

He remembered that animation, an attempt to convince them that tax subsidies were not wasted on the Disney Observation Platforms hovering around the globe. "That stuff is real," he said, her kisses cooling as he did. "We need dreams even more." She'd looked at him slyly, smoothing his hand up along her leg. "What are you dreamin' now, boy?"

"That there's a way out," Meek said. "Up there."

“What?” Her hand froze where it was. “We shippin’ all the broke-asses up there? Ain’t enough spaceships, Meek. You trippin’. The Meek ain’t gonna inherit the Earth.” They’d argued. She’d left. And that was the end of Them.

As he often did, Meek poured all his emotion into his plants, thinking of nothing outside the plastic walls until Grandpa wheeled out with a covered dish of mac and cheese and homegrown broccoli. The old man turned his head to watch what Meek was doing. “Whatchu up to, boy?”

“I want this orchid to dance with this dwarf orange tree, Gramps. Would sell great at the street fair.”

“Did at that, boy.” He peered more closely at Meek’s workbench, with the centrifuge and the pipettes and the little racks and stain-wipes. The label said MONSANTO GENE KIT—UNIVERSITY EDITION.

Grandpa squinted. “Where you get that stuff?”

“Traded for it,” Meek mumbled.

His grandfather’s face tightened in response. “You steal that, boy?”

His face burned. “Traded for it.”

“From someone who stole it for you,” said Grandpa, being no fool. “I know you. Don’t you try to lie to me now. You traded what?”

“Stuff I made,” he said, hating himself. A lie was a lie, even when hiding behind a half-truth.

His grandfather scowled, but then began to laugh. “Boy, you ain’t got the sense God gave a gopher, but damned if you don’t straight-up remind me of your daddy.”

Meek’s daddy. He’d been out of work too, wanted something to do. Meek had only been five years old when his daddy and a few friends tried to rob the OPEC ambassador, and gone to jail forever.

“Let’s not talk about it,” Meek said, and turned on the little box that gave them their entertainment. Meek liked the *Wizard of Aaahs* science show, and watched its lectures and demonstrations whenever he could wrest the set away from Gramps. Grandpa liked the news. Together they scanned through the dozens of news channels until Meek saw something that he liked: an image of Clarke Station. The Clavius-based Biology Lab was dedicated to recombinant DNA research, where escaping microbes were a quarter-million miles of insulating vacuum away from Earth.

And then an image of the luxurious DOP, visible only as a skeletal matchbox through his telescope.

"No way," Meek whispered.

"—and on the twentieth anniversary of the establishment of Luna base, we announce the American Space Society's first annual Science Contest. Five lucky students will receive five-year college scholarships to Yale-Gates and an all-expenses-paid trip to the Disney Observation Platform ..."

It reverberated in his head like a gong.

Trip to the DOP!

The contestants would be selected from a pool of science lottery winners, schools being gifted with tickets according to some arcane formula, distribution of said tickets to be determined by each school. Winners would have six weeks to create a project related in some way to human exploration of the solar system.

Six weeks. Then all winners in the western states would gather, and compete for one of the five scholarships.

In the halls of school the next day, he ghosted through classes he was failing anyway, damaged eyes hidden behind his shades, tainted hands concealed in gloves, fear and despair numbing him until he could barely hear what was said to him by the students and teachers.

Trip to the DOP!

The words echoed in his head in gym class, a soundtrack to the thuds and grunts on the football field, the constant companion of the pain in his knees strangely absent. He was numbing out, he reckoned. Nerve damage, another symptom of the toxins that would take his life. Oh, he could take the hits, but knew that deep down his bones were breaking a little more every day. He had maybe a year. Possibly two. Certainly no more.

Young, desperate, invincible, he had made drugs for the Ballers to supplement the money Grandpa made at the Pomona Street Market, and he knew the chemicals he'd used had poisoned him. "Make more of it," they said to him. "We can make you rich."

But it wasn't enough money to make a damned bit of difference in the long run, and with the time bomb ticking in his blood there wasn't a long run. Nothing much mattered any more, except the last dream his heart dared to hold.

Meek sleepwalked home, his brain abuzz.

"What you thinking about, boy?" Grandpa seemed more shrunken than usual, his face greenish in the reflected light. "What you doing over there in the back where I can't get no more? Just because I can't get around don't mean that I don't know what you doin' back there!"

A locked toolshed abutted the greenhouse, through a vertical slit cut in the plastic. Meek spoke the password to the lock on the shed's door, and it swung open. This was where he did his magic, where he grew the plants that had earned him the fast money, the "friends," the things he'd traded for the Monsanto kit. It *was* stealing, no matter what he said. He knew it, Grandpa knew it. This was why he did it: orchids and dwarf orange trees and crossbreeds with no names. This was his place, the greenhouse within the greenhouse, the only place in this world he felt at home. But maybe there was another world. If he wasn't almost out of time.

The work sink in his secret place was a simple thing of beaten metal and thin porcelain. A hobgoblin glared back at him from the mirror. Ghoul's eyes. A ghost without a grave, the sclera tinged green as mold on rotting cheese.

No one knew him. No one would miss him, once Grandpa was gone, which would be soon, he knew. Soon.

And then Meek would be gone too, as if he had never lived at all.

Exactly one week later, Tyrone Prouder didn't wake up. When the county men came to take him away, Meek refused to let go of his cold hand, or let the paramedics carry his body out of the house. That was *his* job. Grandpa's body felt as brittle and hollow as a bag of dried leaves. Because Meek was more man than boy he was allowed to stay in the house, although relations came sniffing around and told him that they'd had "arrangements" with Grandpa Prouder, "understandings" that they would own the house after his death.

"We'll take care of you," Aunt Emma from Bakersfield said.

"And you can believe that," said "Minister" Folks from Kansas, a cousin or great-uncle or something. Meek didn't know, and didn't care.

He spent more and more time in the greenhouse. When he wasn't deep in his cuttings, he was in the desert soaking in the sun and searching for the little cactus flowers his grandpa loved. He'd bring them back to the trailer because the house was still clotted with family who seemed to think that "wake" meant "move on in."

They told him to move into his grandfather's room, but he preferred to let his fat uncle sleep in the postered bed. He, Meek, would dream with the plants, in the moist, warm air rich with their exhalations, where he dropped off into slumber almost as soon as he closed his eyes.

And in dream he was one of them, a member of the only tribe that had ever welcomed him. He had roots, not legs, tendrils that descended to the center of the Earth. And a stalk that was as tall as the Mitsubishi orbital tether, a Superkevlar beanstalk beyond fairy-tale imaginings.

A stalk reaching all the way to the golden DOP floating above them. In his dream he was one of the prize winners who reveled with the rich in that floating castle, from which all of Earth seemed but profit and loss and lands for corporate conquest.

His dreams shifted and pulsed with color and life, sliding through time and space. Now he danced weightless as a dandelion spore on the wind. Now light-stepped among ancient craters, now slept in cryo borne on laser light sails and speeding to the stars.

That Meek did not hear the laughter of the boys and girls in the lunchroom.

He would find a way out. With whatever remained of him, of his life. He would leave this dusty ground behind.

Pomona High had been allotted three tickets for entrance to the DOP competition, to be won by performance on the AAAS assessment test series. For the first time in months, Meek studied. Hard, like Grandpa had always begged him to do. Barely slept, so deeply buried in his books was he. And to the surprise of everyone in assembly (himself exuberantly included) was called to the podium and awarded second place.

In his dreams that night, chrysanthemums waltzed for joy.

The science fair was held in L.A.'s rebuilt downtown in Sony Coliseum's main auditorium, crowded top to bottom with little cubicles in which students from across the state bolted, stapled, and glued up their booths and displays. Hundreds. Maybe thousands. There was no end to the mini-electromag drives and remote-control rockets and home-cobbled radio telescopes. So when the gaunt giant with the wheelbarrow came through the room people looked and wondered what was new beside *ho-ho-ho*, what he was doing and if he might be the janitor.

Meek's eye was caught by the booth a few desks over, one of the few that held something more than circuits and metal and shining glass. Beneath a banner reading *Kathleen Chang: Microgravity-Resistant Plant Experiment*, the elfin contestant tended busily to her charges, black hair swinging as she turned between her tables.

Her emerald eyes caught his as she explained what she was doing: "I constructed and used a Rotating Wall Vessel to test the effects of null gravity on plant germination and embryo gestation …." A busy little crowd had sprouted around her, but it seemed that she spoke just to him. For the moment their eyes met, he thought he was in microgravity himself. Wanted to weightlessly float to Kathleen's tiny world of spinning centrifuges and magnetic fields in which the diminutive seeds and creatures were endlessly falling, falling, falling, and learn what she was doing and how she was doing it.

He could have watched her all day. But between the oscilloscopes and the SETI micro-dishes he knew that he had to get to his space and get set up, or the day would get away from him.

While he set up his folding cardboard panels, plants, and scrolling viewslates, the visitors crept by, pretending to care about other things, and watched, and laughed, but Meek silently put everything in its place and stood in his best clothes and his best smile, and waited. The announced big star, Raymond "Wizard of Aaahs" Culpepper, bounced onto the stage and said how proud he was of each and every one of them, and what an honor it was to be here, and how proud their schools must be of them. He was all angular wit and golden charm, enough charisma to flash-fry eggs and brilliant in the brief Q&A that followed. Then to riotous applause he sauntered off the stage, and began to circulate around the room.

Meek felt like a love-sick girl. He had never seen anyone who had been to high orbit, let alone the Moon itself. But The Wizard had, and he was a thing of wonder.

I've watched you every day, Meek would say after shaking the man's hand.

I've studied every one of your books, he would tell the wonderful Wizard, who would clap him on the shoulder and say, *you are a remarkable young man! We have experts who can heal you! Come with me ….*

And that gilded feeling lasted until the gaggle of judges arrived at his booth. The Wonderful Wizard of Aaahs was not among them. The other judges, stripped of stardust, studied his papers and plants, and prodded at the leaves, and talked to him with that slightly distant expression people have when you are merely the pause between the last one and the next one.

His display said, "*producing more bioavailable protein per cubic meter of soil*" and "*more oxygen conversion than any other Butterfly Palm*," and accompanied those grandiose claims with a long list of specifications. The men and the women looked at his numbers and checked his plants and sniffed their noses into the air, saying, "Your numbers are wrong, young man. It isn't possible for you to have done this." And they punched numbers on their comms and clucked sadly, as if they actually had shits to give.

The kids around him didn't laugh. He wished they had. Then he might have raged and broken something. Or someone. He felt the wetness drool from beneath his sunglasses, and, not wishing to be shamed, ran out of the hall and away from the contestants who might, in another, better world, have been friends and peers.

He ran out into the alley, gawping and making goony-bird sounds in the early-evening gloom, trying not to throw up. *Who are you?* he whipped himself. *Who are you to think there is an escape hatch?*

For others, perhaps, but not for his grandfather, or father, or him. Never for him. He would die and go into the ground without ever seeing stars that did not wink in contempt. Never feeling that divine sensation of floating free of a grasping Earth. And no one would care.

Meek stripped off his gloves, tore off his shades, and sobbed out his dreams, only belatedly seeing the red glow in the night, smelling the sweet cigar smoke. He turned to see a man leaning against the walled shadows, watching him.

Meek wiped his hand across his face, washing his cheeks with tears. The smoker watched, saying nothing.

"What are you looking at, Mister?" Meek said, and knotted his fists into clubs.

After a pause the man said, "I shouldn't do this," and hoisted his cigar emphatically.

Dear God, he knew that voice.

The smoking man tapped his cigar against the wall. “Shouldn’t do that, either.” He laughed.

Meek trembled. Never had he been so close to stardust.

“You had the protein and oxygen plants, right?” asked the Wizard.

“I …” The Lord of Aaahs had noticed *him*? Meek sagged almost to his knees, then pushed himself back upright. “Yeah, that was me.”

“How’d you do?”

“Screwed up, man.” Meek’s voice dulled. “Had my numbers all wrong.”

He looked up at the Wizard, trying to find some words, something that might have some power, but came up empty. It had taken all he had just to get him this far, and he could go no further. Time to slink back to Grandpa’s house, and the solitary cot between the rows.

“What’s wrong with your eyes?” The Wizard asked.

Meek flinched. He groped in the darkness, found his shades, and slipped them back on. Culpepper stepped closer. Meek felt transfixed. Trapped. Found out. Couldn’t move as Culpepper reached out and slipped off Meek’s shades, peered into his face like a man examining the map of an unknown country.

“I’m sick,” the boy said.

“How do you feel?” Culpepper asked.

The question didn’t make sense. He knew he was dying, and some part of him now yearned for oblivion. But … but …

He didn’t actually feel *bad*. Little appetite, yes, but …

Culpepper asked Meek a few questions. The boy couldn’t remember answering them, so shocked was he to be having the conversation at all, but shook himself out of it when Culpepper took him by the hand and said, “Come with me,” and led him back into the hall.

And to the crowd, which watched jostling and tittering and wondering what trouble had befallen his pitiful little cardboard kingdom.

Culpepper called over the judges, and whispered to them. They looked at Meek’s numbers and his pages and to his plants again, and at the materials from which his project was constructed, and too late he realized that in his great fatigue he had left a piece of the box that said UNIVERSITY EDITION.

“His grandfather was the groundskeeper at Schick-Mudd,” someone said.

One of his classmates constructed her hand comm. “The serial number on that box matches a stolen gene kit.”

The halls were roiled by a great disturbance, as the judges examined his equipment more carefully, and then another classmate at a neighboring booth called security. Panic descended like a red shroud. Meek turned and sprinted once again, past the pretty microgravity girl whose crowd gaped as he ran and ran, forgetting the Moon, forgetting the DOP, forgetting everything in his desperation to shed his broken dreams. Then the security guards caught him, and dragged him down like gravity as he screamed.

"*Michael Prouder,*" the duty officer called, and Meek shifted his bulk from the shadowed corner of the holding cell. The other prisoners stared and moved away from him, afraid. The police didn't seem to want to touch him. They wordlessly led him to the room where he imagined the public defender waited, some desperate night-school lawyer smelling of failure and bad coffee.

But it wasn't the public defender.

It was The Wizard of Aaahs.

"Look at me, Michael," Culpepper said. Meek did not, staring down into his hands as if staring hard and long enough might help him vanish into the rivers and green valleys scriven thereon.

"We took blood and urine samples when you came in, you know."

Yes, he knew.

"Do you know why?"

"The drugs," Meek said, his own voice a dull roar.

"The drugs. And we went to your house. The police found the things you'd stolen." Culpepper's voice was surprisingly gentle.

Meek nodded. Half-truths were lies, and he was done with lies.

"Why?"

"Grandpa needed air," Meek said, ashamed of how small his voice had become. "He was a smoker, like you. I could make it a little better for him."

"A little better," the Wizard said. "So you stole the Monsanto kit. Who taught you how to use it?"

"I learned," he muttered. "M.I.T. online free school."

"You taught yourself using the free school? Your grades are …" Culpepper searched for a word. "You're failing every class. You expect me to believe that?"

“No,” Meek said. “I don’t expect shit. But it’s the truth.”

The Wizard mulled that over. “The amount of increased food value was wrong,” he remarked. “The numbers were wrong.”

Meek sighed. He knew. Everything in the world was wrong. Maybe that hadn’t always been true, but it was certainly true now.

“The oxygen numbers were good, good enough to help your grandfather’s emphysema, but not better than what we already have. I’m sorry.”

“Doesn’t matter,” Meek said. “Be dead soon. Just … just wanted to see space before I did.”

Silence in that room, and dying dreams. If Meek had never spoken again, it would have been fine by him. He could be silent, as silent as a plant. He could just bury himself in the desert, and soak in the sun and …

“When was the last time you ate?”

“Not hungry,” Meek said.

Culpepper pursed his lips. “How long have your eyes and hands been … like this?”

Meek looked at his hands. He didn’t think about it much, just covered it up with gloves and sunglasses. Mr. Cool. The light skin of his hands and the whites of his eyes were pale green.

“When was the last time you ate, Michael?” Culpepper asked again.

“Day before yesterday.”

“Spend a lot of time in the sun, don’t you?”

Meek looked up. “Yeah, I guess.”

“The desert?”

It would be a long time before he saw the desert again.

“And the beach,” he whispered. “I like the beach, too.” He loved it almost as much as the desert. But the ocean itself … he didn’t like its taste. It didn’t nurture him.

Salt water was for tears.

He wondered if he would ever cry again.

“You created the little peach trees?”

“Dwarfs,” Meek mumbled. “They’re called dwarfs.”

Culpepper reached across the table, took Meek’s wrists. Meek was so surprised that he didn’t pull back. “How long have your palms, the whites of your eyes …”

Been green? Long enough to know that he had poisoned himself, somehow. The mutagens, or the processing chemicals the Pomona Ballers needed him to use to extract essence from his plants. He had no one to blame but himself. Just hoped that something special, something good might happen, just once, before he stopped waking up.

Culpepper drummed his fingers on the table then sat straight, as if he had come to a decision. "One of my philosophy teachers once said that if Mozart had been born a Kalahari Bushman, he'd have been known as the best drummer in his family."

Meek blinked. "What the hell does *that* mean?"

"It means that great genius can be completely lost without the social context to nurture it. That can happen to an entire culture." The Wizard leaned further forward, pushing at Meek's space. "And sure as hell to a single boy. He used a stolen Monsanto gene kit to make dwarf fruit trees. Increase the oxygen production of one plant, the protein output of another." He paused. "That's not the part that most interests me. He thought he's changed his plants. But they also changed him."

"The … plants?" Meek could barely breathe.

"Yes. Something happened, Michael. Have you ever heard the term lateral gene transfer?"

"Sure," Meek scoffed. "Think I'm stupid?"

"Not at all. Not even a bit. You bred those plants, but all organisms are more than their simple genetics. They are also symbiotes and parasites and their interactions with the natural environment, energy and material transfers. Something in those plants transferred to you and your grandfather. Whether through touch or ingestion, we just don't know. Yet."

"Genetic change through ingestion?"

The Wizard nodded. "Some organelles are thought to be microorganisms swallowed by prokaryotic cells, but got comfortable instead of digested." He smiled. "Developed a symbiotic relationship that got passed from generation to generation. According to the autopsy Tyrone Prouder should have been dead months ago. You kept him alive."

"That's what I wanted. The plants …" an oddly bashful feeling flooded over him. Could he even say this to someone he didn't know? He could barely talk about it with his Grandpa. And yet … there was something about this man ….

"They talked to me."

"How?"

"I dream about them."

Culpepper doodled on his notebook. "Do you remember the microgravity exhibit?"

Meek nodded.

"The truth is that we could be colonizing the asteroid belt, but humans who stay in space for more than a few years might not be able to come home."

Muscles atrophy. Negative calcium transport spins bones into glass. "Yeah, I heard that."

"Well, same things happen to plants that happen to animals. They don't develop properly. That young Miss Chang … she bred vines with greater structural integrity, which can more easily resist the negative effects. It's fascinating. Do you know the term 'mycorrhizae'?"

Hearing the challenge in his voice, Meek felt anger rise up, but also something else … pleasurable anticipation, like when someone hits a ball and it's coming right to you and you can already feel the *thunk* in your glove.

His mind opened, and he saw the answer as if the search page had opened in front of him. "Mycorrhizae are symbiotic relationships that form between plants and fungi."

"How does it work?" Culpepper leaned in, seemed almost to be holding his breath.

Meek recited. "The fungi colonize a host plant's root system. They … provide increased nutrient absorption or water."

"And do they get anything in return?"

"Carbohydrates formed from photosynthesis."

"Highest marks," Culpepper said. "Young Miss Chang used that principle to strengthen her plants. And that strength might well be a secret to resisting microgravity …." His voice had become ruminative, and for a moment Meek saw someone new, the scientist beneath the showman. "But you did something that makes it even more potentially interesting."

Meek was riveted. "What's that?"

"If there is no way to compensate for microgravity, it may be necessary to modify human beings themselves for long-term colonization efforts. We've tried a number of animal approaches, without the success we want. But no one was able to do what you've done: the plant chloroplasts … well, they sort of *talked* to your mitochondria. Something happened within you that we've not been able to imitate with a billion-dollar lab. You actually photosynthesize, Michael. Not hugely, but enough that you crave sunlight and need less food. Something in your plants operated like a botanical nanocyte, carrying its genetic information into your cells. Amazing."

"I … just tinkered," Meek whispered.

"Tinkered." Culpepper rolled the word around in his mouth. Shook his head in wonder.

"Who won the contest?" Meek asked, voice breaking with hope.

"Kid named Quentin Frost, from Eugene, Oregon. His experiment increased output of solar cells."

There it was. It was never going to happen for him, no matter what, he was—Culpepper studied him. "But there's one thing more. Did you meet Kathleen Chang? The microgravity girl?"

No, he hadn't, and what did it matter? What did one loser have to say to another?

"She couldn't win, because she's only got half the answer," Culpepper said. "You have the other half. Someone like you could colonize the asteroid belt. Not people like me. But someone like you. You're the future, Meek. And it's possible that we are the past." He paused, and then smiled. A good, warm smile. Like Grandpa's.

"So …" Meek said slowly. "No Disney Observation Platform …?"

"No," Culpepper grinned. "But have you ever heard of Clarke Station?"

It was all a dream. His roots sinking to an impossible depth. His branches and leaves and tendrils extending an impossible reach. And the most beautiful dance he had ever known. Meek awoke in his cot, lying there among his verdant comrades, yawning and stretching and thinking of the wonderful fantasy he'd had. But it was a dream, even now sloughing away like sweet syrup.

He'd had it before. Hoped he would never stop. It was too easy to forget the good things.

He got up from the bed, trying to remember where he was. Who he was, what anything was. He should write the dreams down so he could remember them. Maybe he'd write a book. Someone might want to know about this, one day.

When he reached, he dislodged the pen from its magnetic clip on the planter beside him. It spun into the air, bounced off the wall. He watched it bouncing between the rows of tomatoes and ferns, still not tired of the sight. He dressed without unsnapping his sleep cocoon, and then plucked the pen out of the air and pressed it to the paper of his leather-bound journal, the one that his grandfather had purchased and given to him for his birthday. *Oh, Grandpa. If you could only see me now. See me in the observation room with the other tourists.*

He had not noticed, but Kathleen Chang had joined him in the observation room. She was even tinier than she'd appeared at the contest. Unlike the other passengers, she didn't keep her distance. She smiled up at him. "Take off those sunglasses," she commanded.

"My eyes are green," he said.

"So are mine." She smiled. The back of her hand brushed his.

He slipped off his shades. *So that's the world*, he thought, watching the Earth recede in infinitesimal stages. *It isn't all concrete and desert, I knew it wasn't. It's green.*

He shifted to watch the approach screen, the Moon growing every larger, a dream expanding to fill the space before him. Luna. *Not dead after all. More alive every day.*

Like me.

All either of us needed was the right dream.

Acknowledgments: I would like to thank Greg Bear for his encouragement and support in the development of "Mozart on the Kalahari." He was a lifesaver. And additional thanks to Larry Niven and Jerry Pournelle, for a lifetime of mentorship.

PAST EMPIRES AND THE FUTURE OF COLONIZATION IN LOW EARTH ORBIT

by William K. Storey

Science fiction stories that envision the future exploration and colonization of space are often grounded in domestic debates about the proper ordering of public and private interests. In Stephen Baxter's *Titan*, published in 1997, a right-wing, fundamentalist Christian takeover of the United States undermines NASA's efforts to locate life in our solar system, plainly a cautionary tale about the "culture wars." And the long-lived *Star Wars* series began its life in the mid-1970s, shortly after the U.S. defeat in Vietnam, when political analysts wondered about the future of liberty in a world where China and the "evil empire" of the Soviet Union seemed to be robust and menacing. The stories in this volume are grounded in contemporary skepticism about politics as well as concern about public-private partnerships and for the future of Earth's environment. These plausible fictions about the colonization of space resonate with U.S. and world history, in that they extend ideas about technology, business, and migration that are deeply rooted in our consciousness—including our fears. I like how the stories articulate just how bad things can get when government services go into freefall and corporations are allowed to run amok, dark possibilities that will certainly concern NASA and members of the public as they visualize a future for the space program. As Sheila Jasanoff observes in her book about science and democracy, *Designs on Nature*, public skepticism about science and modern politics has produced newfound anxiety about the capacity of the modern nation-state to provide order in the midst of new technological challenges.[1]

As the line between corporate influence and public policy continues to blur, there are strong reasons to explore, in science fiction, what it would be like for capitalists to be in charge of space exploration. The most provocative thing about "Vanguard 2.0" by Carter Scholz is how it imagines a future for Low Earth Orbit that would be dominated by grasping high-tech capitalists. The propulsive capitalist in Scholz's story, Gideon Pace, fueled by Kobe beef and California cabernet, is on a mission to collect a historical artifact, the Vanguard satellite, still orbiting the Earth after decades of neglect. Those of us who are historically conscious are horrified at the thought of a private entrepreneur collecting historical artifacts for himself, rather than sharing them with the public. When Pace grasps the satellite, the author makes a larger point: "Know anything about space law?" Pace asks Sergei. He continues, "Once upon a time the sky was 'free'" and "space was beyond national boundaries. I want this little guy hanging in my office to remind me how elegant that strategy was." This warning—about how new technologies influence the trajectory of the new laws—is consistent with most understandings from the field of Science and Technology Studies (STS). Technologies pose benefits and risks that societies regulate, in such a way that the law may be said to co-evolve with technologies. Automobiles became safer—with seat belts, airbags, and mandatory seat-belt laws surrounding them–even as the safer cars became faster and more agile. And the development of nuclear weapons ushered in an era of international rulemaking through treaties.

Sadly, the future domination of Low Earth Orbit by grasping capitalists is all too easy to imagine. We are already seeing national space programs like NASA scaling back, while private entrepreneurs like Richard Branson scheme about the future of private space travel and of modifications to the Earth's atmosphere. With privatization comes perils, as Scholz warns us. The story is useful for NASA and its publics, in that Scholz articulates a dystopian scenario that is easy to imagine in the absence of NASA. In his view (and mine) space is a commons for humanity that ought to be developed by public organizations, not by uncultured corporate buccaneers.

Dystopian themes provide the background for "Mozart on the Kalahari," an unusual and suspenseful story by Steven Barnes. The story's main character, a teenager named Meek, yearns to travel in space, in part to escape a land that has become dreadful. The "L.A. Quake" has apparently ravaged things quite badly, to the point where city services have been turned over to greedy corporations. The corporations employ robots, while ordinary people struggle to find decent jobs. But Grandfather Prouder's optimism pushes Meek forward: "I still believe that if you use your mind, you can go anywhere you want." This sounds like a bit of a cliché, but in fact, as the story progresses, we learn that Meek's grandfather is right. Meek enters a national science competition. Under scrutiny, the validity of his project appears less and less likely—his calculations are wrong and he is revealed to be stealing things and using drugs. Yet after Meek flees the contest in shame, the observations of Culpepper, the M.C. of the competition, bring to notice Meek's ability to photosynthesize. The story raises a fascinating question. Science fiction writers have created many cyborg characters—technologically modified humans—ranging from Darth Vader in *Star Wars* to the Borg in *Star Trek: The Next Generation.* Technically speaking, a cyborg can be any technologically dependent human. Some have argued that even people with pacemakers or cochlear implants can be considered to be cyborgs. Be that as it may, STS scholars have been fascinated with cyborgs. Do cyborgs have the same rights and responsibilities as non-cyborgs? Do cyborgs highlight, better than anything else, the interdependency of people and technology? Does an Olympic "blade runner" compete following the same rules? In this story, we do not have a human-technology cyborg, but something else, a kind of plant-dependent human. The story's penultimate scene is more reminiscent of Ovid's *Metamorphoses*, Book I, when Daphne escapes the unwanted advances of Apollo, the sun god, by becoming transformed into a tree. Here is the key moment of the poem, in the translation by Samuel Garth and John Dryden:

> A filmy rind about her body grows;
> Her hair to leaves, her arms extend to boughs:
> The nymph is all into a lawrel gone;
> The smoothness of her skin remains alone.[2]

The transformation of Daphne into the laurel tree freezes her, but the hybrid plant-dreamer, Meek, has more potential for the future.

The story raises multiple future possibilities. Will plant-people be able to have progeny? Will their intelligence or strength be enhanced or diminished?

Will Meek and Kathleen be able to remain independent, especially if they become superior, in some ways, to people? Will governments and corporations take control of them, their progeny, even their DNA? So many questions are left open by this story.

Both stories contrast a bleak future on Earth and the possibilities of exploring in Low Earth Orbit. With things going badly on Earth, I wondered how anything was being produced or paid for by these large corporations that are said to be running things. I also wondered how a government or corporation could raise enough revenue to support a space program, given the state of things. In fact, both stories point up the difference between our own era in U.S. history, with its budget-conscious, polarized government, and the era of the space program's founding, when U.S. citizens in the midst of the Cold War felt confidence in the state's ability to solve problems by spending taxpayer resources on major technological projects—even if those projects may have eroded democratic practices in favor of technocracy, as Walter McDougall argues in his classic history of the early space program, *The Heavens and the Earth*.[3] The stories by Scholz and Barnes highlight our own era's pessimism, in which collective optimism has been replaced by skepticism of authority, be it state or corporate. The choices of the authors reflect today's national consciousness.

COLONIZATION AND GOVERNANCE IN HISTORY AND IN LOW EARTH ORBIT

The U.S. has never been entirely comfortable with colonizing or dominating other societies. While it did dominate other societies since its origins in the ill-treatment of Native Americans, the U.S. aspires in the direction of egalitarianism. The enslavement of Africans was countered by abolitionists. The wars with Mexico and Spain produced demonstrations of conscience, like Henry David Thoreau's, and biting satire, like Mark Twain's. The Vietnam War tore the country apart. The skepticism of some U.S. citizens about Manifest Destiny has to do with our origins in an anticolonial revolt as well as the egalitarianism of our political culture, a tendency that was first described by Alexis de Tocqueville, who published *Democracy in America* in 1835.[4] The stories by Barnes and Scholz chart a course for space colonization, focusing on Low Earth Orbit. As a historian of colonization, I am struck by the presence of a number of historical issues in these stories. These choices reflect the times that we live in and the aspirations that we have, rather than being problems that are somehow inherent in the stories.

One key element of colonization has always been migration, from Neolithic times to the present. Migration depends on a number of different factors—“push” factors and “pull” factors—as well as individual and group calculations about opportunity costs. How bad is it at home? How challenging is the process of migration? How good is the new area of settlement? On the subject of migration, both of our stories suggest a bleak future. One author is solving the problem of migration by imagining human characters who begin to take on the characteristics of plants. The other shows the domineering presence of a rogue capitalist, working with technically trained satellite operators. Ultimately it appears that very few Earthlings will participate in this migration because the opportunity costs appear to be astronomically high. The Gideon Paces of the world may be able to afford movement in space, but the billions of laid-off grandfathers at home will wither and die. If the future of humanity is to depend on the colonization of space, then we either need to develop the technologies to sustain mass travel and migration, or we had better pay closer attention to the ruination of our own planet and societies. NASA can figure in solutions to both problems, which are closely connected.

Domestic transformations such as these are often related to the conquest and colonization of new territories, as Jane Burbank and Fred Cooper maintain in *Empires in World History*.[5] Imperial conquests, though based in the desire for domination, enrich the home countries with new commodities, ideas, and migrants. Empires bring resistance, too, and in the case of the British, French, and U.S. Empires of the nineteenth and twentieth centuries, the credibility of cherished domestic freedoms was called into question. Even so, in world history, imperial governance has been the most widespread and stable form of governance, ranging from the empires of Rome and Han China to the European empires of the late nineteenth and early twentieth centuries. Modern nation-states are only a recent development and they, too, have been susceptible to engaging in their own empire-building. The stories in this anthology suggest the emergence of a significant corporate role in governance, but from a historical standpoint this is not new. There are many examples of colonial domination by companies, such as the British East India Company, founded in 1600. For a century and a half, it was mainly concerned with securing its trading posts, but during the late eighteenth and early nineteenth centuries it came to govern much of India. The Dutch East India Company established European settlement in Southern Africa in 1652, laying the groundwork for many subsequent racial problems. In both places, direct rule from home was thought to be prohibitively costly, but company rule was gradually found to be less than public-spirited. The British East India Company famously lost its mandate in the wake of the 1857 rebellion of its own soldiers, while the Dutch East India Company was replaced in Southern Africa by direct British rule during the Napoleonic Wars.

Today these company-states might be called public-private partnerships. Entrepreneurs from the companies sought to undermine indigenous people and rulers who resisted their inroads. The companies created their own governments in overseas territories, with the sanction of their home governments through charters. The home governments, in turn, reaped the benefits of having friendly governments in overseas territories, while administration by chartered companies helped home governments to avoid the costs of administration. Unfortunately for those who advocate such public-private partnerships today, the history of colonialism contains famous examples of ways that such arrangements have tended to produce clashes between public values and private actions. The companies were set up to make money, not only for the shareholders, but also for their home countries. Making money came first, the common good came second. Chartered companies tended to become controversial when they started to become costly in terms of money and good will.

The British East India Company began with trading posts in India's port cities. As the company became rich and influential over the course of the eighteenth and early nineteenth centuries, it expanded its territory to a great extent. The idea that underlaid the company's expansion was mercantilism. Raw, unrefined produce would be bought in India, then shipped to Britain, where manufacturers turned it into goods that could be sold at home or even sold in India. The model worked to some extent, but there were problems inherent in this public-private partnership. Such arrangements would work best as monopolies, which were naturally resisted by competing merchants, as John Darwin points out in his magisterial survey, *Unfinished Empire: The Global Expansion of Britain*. Darwin also explains that at home, imports were bought with gold and silver, which then flowed back to India and into the pockets of company traders—in other words, the company profited not only at the expense of Indian competitors, but also at the expense of British consumers.[6] Company policies became unpopular in India, too. Cotton exports led to the decline of indigenous cloth manufacturing. Opium cultivation by Indian landlords tended to throw peasants off their customary lands and reduce them to rural proletarians. Even Niall Ferguson, a historian who is sympathetic to Britain's imperial projects, points out in his book *Empire* that tension between the East India Company's profit-seeking leaders, on the one hand, and Indian princes and peoples on the other, had produced a state of near-perpetual warfare on the subcontinent.[7] The company's propensity to annex territory and to antagonize Indians led to the great rebellion of 1857, the abolition of the company, and direct rule from Britain.

In fact, public-private partnerships in the form of chartered colonial companies helped to produce some of the worst cases of misrule in modern history. The most notorious example took place in the late nineteenth-century Congo. The constitutional monarch of Belgium, King Leopold II, became interested in trade in the Congo Basin. In the 1870s, he bought large financial positions in several companies that traded in Congo, but he failed to persuade the Belgian parliament to create a formal colony there. Under pressure from the British, French, and Germans, who were formalizing their own colonial boundaries in Africa, Leopold founded his own colony, the Congo Independent State. Leopold claimed that his private colony had a humanitarian mission, yet the colony, which was recognized by all the European powers, became a horror-show of colonial exploitation. To fill Leopold's pockets, many of the people of the Congo were sent out as gang laborers to collect rubber and other raw materials. Failure to meet company goals resulted in torture, maiming, and killing. The best-known history of imperialism in the Congo, *Leopold's Ghost* by Adam Hochschild, quotes a Swedish missionary who recorded the following song from desperate Congolese people: "We are tired of living under this tyranny. / We cannot endure that our women and children are taken away / And dealt with by the white savages. / We shall make war …. / We know that we shall die, but we want to die. / We want to die."[8] When the brutality of Leopold's public-private partnership was exposed by journalists, the Belgian government was shamed into taking over the colony and ruling it directly from Brussels.

Leopold's actions in the Congo were much worse than any of those described in this anthology. In their stories, Barnes and Scholz do successfully raise the issue of the problems associated with public-private partnerships, most particularly those involving the development of key technologies. Under company rule or imperial rule, the technologies most closely associated with colonization develop in close conjunction with new power relations. In British India, as Daniel Headrick has written in *The Tentacles of Progress*, the introduction of railroads enhanced imperial control, while opening opportunities for both imperialist and indigenous businesses.[9] In South Africa, the introduction of technologies for mining and processing minerals such as diamonds and gold increased the demand for migrant labor and its regulation through racial segregation. In *A History of South Africa*, Leonard Thompson argues that in the late nineteenth century, the coming together of racism and capitalism was thought by many intellectuals to be generating the rapid acceleration of imperialism, a timely warning for a NASA volume about future colonization that is being produced in a year when it is still necessary for some to say that "Black Lives Matter."[10]

It should be noted that in some cases, exploration can lead to imperial dominance, which in turn sometimes leads to colonization and sometimes does not. Plans for colonization were occasionally thought out well in advance, as they appear to have been thought out by Gideon Pace in Scholz's story, "Vanguard 2.0." The colonization of New England and New Zealand by farmers was partly planned, while Australia was initially intended to be settled by convicts. In all cases of colonial settlement, though, colonists were attracted by unplanned discoveries, such as gold in California, Australia, and South Africa. In many cases, though, settlement never occurred. Disease environments were sometimes hostile to Europeans, as was the case in West Africa, while a combination of climate, disease, and lack of available land made India unattractive for colonial settlement. Colonization follows domination only when the opportunities outweigh the costs. When opportunities are too costly, more purely extractive imperialism may be preferable. Plans for the future exploration (or domination) of space will face similar limits, whether or not the projects are run by private or public institutions. Natural circumstances will shape the characteristics of dominion. And much will be left unplanned.

Whether planned or not, one of the key characteristics of imperial history is the evolving coproduction of technology, colonization, and power. This process is nicely articulated by Scholz in "Vanguard 2.0." The Earth is in a downward spiral. "Universal surveillance was the new normal. Resource wars were the new normal. Climate refugees by the millions were the new normal." The story's main protagonist, Sergei, imagines that the villain, Gideon Pace, may be working on developing nuclear fusion weapons, manufactured in space from pellets of lithium deuteride and tritium. Pace brags about how his partners now play a role in the U.S. Department of Defense, while he also wants to redefine the state. He chillingly quotes Max Weber, who wrote that the "state is a human community that successfully claims the monopoly of the legitimate use of physical force,"[11] while speculating how he will reinvent the state, moving it forward from antiquated notions about nationhood.

European colonizers rethought governance, too, and presented the people of the Americas, Africa, and Asia with a range of choices. They could accept European domination or resist it, in ways large and small. Association and assimilation were options, too, that provided new ways to organize resistance. It is significant to note that key figures of resistance, such as Mahatma Gandhi and Nelson Mandela, were attorneys with a traditional British education, who nonetheless remained comfortable in their home traditions. In contemplating a future for the colonization of space, NASA will be keen to address issues of equality, as it is a bedrock value in the political culture of the United States. In previous centuries, colonization tended to amplify inequality, not equality, in two significant ways. On the one hand, the initial stages of colonization were led by hierarchical organizations, either businesses or armed services. This historical example has often been followed by science fiction authors: it is no coincidence that the name of *Star Trek*'s Captain James Kirk bears some resemblance to the British Empire's famous naval officer and explorer, Captain James Cook. The armed services get the job of exploration done but they are hardly theaters of equality. The captain's authority is complete, a situation attributable to the necessities of navigation as well as tradition. This authority has a special, public-spirited nature. As Greg Dening writes in his account of a famous mutiny, *Mr. Bligh's Bad Language*, there is a special authority that comes with an officer's commission from the king's government: "The Commission, direct from the Crown, in some way displaced the person commissioned, leaving much more room for a sense of public altruism and its rhetoric."[12] The challenge to future space exploration will be to make certain that the martial values associated with initial exploration do not become the permanent values of colonial settlements, which should instead adopt the values of the broader public.

The future of the nation and the world are linked, in these stories, to decisions about colonization. "Vanguard 2.0" ends with Sergei reentering the Earth's atmosphere, wondering about a future in which the Earth and space are dominated by the likes of Pace. By contrast, Barnes ends his story, "Mozart on the Kalahari," on a more optimistic note. Culpepper, a mysterious scout for talent, reviews the flawed science project of the main character, Meek, as well as the project of another student, the "microgravity girl" Kathleen. Culpepper sees the potential behind the flaws and makes Meek and Kathleen part of a future project to colonize Low Earth Orbit. The new biomedical technology that gives Meek the capacity for photosynthesis also raises prospects for a better future.

The stories describe future space travel as a form of escape from a dysfunctional Earth. This sort of plotline reveals a degree of pessimism about the present world and its ills, yet it resonates with U.S. history itself, which, at its bedrock, is a story of migration and colonization. The New England colonies were founded by Protestant dissenters who left home believing that their High-Church Anglican countrymen were on a direct pathway to Hell. The colonization of New England involved social and technical challenges, such as farming in new, adverse circumstances, yet in the midst of those challenges, settlers were able to articulate new visions, in the Mayflower Compact, or in John Winthrop's "City on a Hill," that brought together old English values with the environment of the New World. By contrast, in Virginia, the initial project of colonization was undertaken by grasping businessmen, keen to find gold and grow tobacco. Decades of boom and bust, together with slavery and starvation, were eventually stabilized by control from London and by the establishment of a somewhat representative government. Even the grim world envisioned by the likes of Gideon Pace has the possibility to yield to political and technological stability, at least according to the familiar narratives of U.S. history.

If NASA has a role in the future colonization of Low Earth Orbit, it is not only to promote and develop technologies; it is to articulate a vision of what that colonization might look like. The stakes are high. One can only hope that the Earth's health will be greater than the authors of these stories suggest. The enterprise of colonization has often shaped the values and identities of the home country, intensifying ideas about national identity. Nationalism and colonization are inextricably linked. For example, it is hard to imagine a national identity for the United States without the concept of a "frontier," the expanding zone of U.S. influence in the West that was once characterized as the country's "manifest destiny." The colonization of the western U.S. shaped our country profoundly, and the choices we make about the "final frontier" of space may well define us in the coming century.

Notes

1 Sheila Jasanoff, *Designs on Nature: Science and Democracy in Europe and the United States* (Princeton: Princeton University Press, 1992).

2 Ovid, *Metamorphoses,* trans. Samuel Garth, John Dryden, et al., *The Internet Classics Archive*, Massachusetts Institute of Technology, 2009, http://classics.mit.edu/Ovid/metam.html.

3 Walter A. McDougall, *The Heavens and the Earth: A Political History of the Space Age* (New York: Basic Books, 1988).

4 Alexis de Tocqueville, *Democracy in America* (London: Saunders and Otley, 1835; New York: Harper Perennial, 2006).

5 Jane Burbank and Frederick Cooper, *Empires in World History: Power and the Politics of Difference* (Princeton: Princeton University Press, 2010).

6 John Darwin, *Unfinished Empire: The Global Expansion of Britain* (London: Bloomsbury, 2012), 20-22.

7 Niall Ferguson, *Empire: The Rise and Demise of the British World Order and the Lessons for Global Power* (New York: Basic Books, 2002), 50.

8 Adam Hochschild, *King Leopold's Ghost* (Boston: Houghton Mifflin, 1998), 172-173.

9 Daniel Headrick, *The Tentacles of Power: Technology Transfer in the Age of Imperialism* (Oxford: Oxford University Press, 1988).

10 Leonard Thompson, *A History of South Africa*, 4th ed. (New Haven: Yale University Press, 2014).

11 Max Weber, "Politics as a Vocation," in From *Max Weber: Essays in Sociology*, ed. and trans. H. H. Gerth and C. Wright Mills (New York: Oxford University Press, 1958), 78.

12 Greg Dening, *Mr. Bligh's Bad Language: Passion, Power, and Theatre on the Bounty* (Cambridge: Cambridge University Press, 1992), 21.

EXPANDING OUR SOLUTION SPACE: HOW WE CAN BUILD AN INCLUSIVE FUTURE

by Deji Bryce Olukotun

In early 2016, a 14-year-old email scam resurfaced about an astronaut from Nigeria who was lost in space. The premise of the scam, which had been updated for Facebook, was that the astronaut had been left behind on a secret Soviet space station during the Cold War, and his family needed money to bring him back to Earth. The scam was popular enough to circulate on the site BoingBoing as yet another example of the silly stuff the internet coughs up.

But that same year, Nigeria announced that it *would* send a real-life astronaut into space by the year 2030. Speaking from the capital of Abuja, minister of science and technology Ogbonnaya Onu said Nigeria would join the growing league of spacefaring nations, which now includes India, China, Japan, South Korea, Canada, Russia, South Africa, the United States, and the 22 member states of the European Space Agency. The list seems to grow every day—Nigeria's nearby neighbor in West Africa, Ghana, also announced a program in 2012 to expand into space. The idea of Africans walking on the Moon can sound absurd in light of the fact that many, if not most, images of Africa portray its wild animals and its poverty, and not its space-age technology. It's partly why I named my first novel *Nigerians in Space*, and it's also why the email scam above continues to circulate on the internet.

The absurdity of Africans in space may just stem from our own prejudices. Nigeria is the largest economy in Africa, with an estimated gross domestic product of $486 billion, according to the World Bank, and Ghana is a prosperous democracy. By comparison, the United States is the largest economy in North America; Germany and Russia in Europe; and China in Asia—and we don't scoff at their ambitions in space exploration. In fact, we expect them to launch spacecraft that probe the distant reaches of our solar system.

Inclusion can mean many things in space. Countries with space programs handle diversity in different ways, and some may attempt to include as many people from their societies as possible, such as women and religious, ethnic, or sexual minorities. For example, the Russian space program could continue the Soviet tradition of launching women cosmonauts in Soyuz rockets. Then there is inclusion on the planetary scale, which means giving people from all regions and nations of the world equitable access to outer space. An example of this might be the crews that operate on the International Space Station as it orbits about 400 kilometers above the Earth. Even that is an exclusive club—only 15 countries signed its foundational agreement, and astronauts from 18 countries have visited the station. Sixty-three percent of the astronauts were from the U.S., 20 percent from Russia, and about 4 percent from Japan.[1]

There is ample evidence of the benefits of inclusion, such as improvements in innovation, creativity, and resilience.[2] But for our purposes, inclusion means giving more people access to the benefits of space. Inclusion can expand the range of solutions available to the complex problems inherent in space activity, and also advance notions of fairness and equity. In other words, the more inclusive the spacefaring community, the more challenges we can solve. But it's also the right thing to do.

THE SILICON VALLEY SPACE RACE

Questions of representation become more complicated when you realize that the future of space exploration will likely soon involve dozens of private companies, each with its own understanding of inclusion. Private companies run by businesspeople from Silicon Valley are beginning to upset the traditional dominance of space contracting that has been enjoyed by consortia such as Boeing and Lockheed Martin's joint venture, the United Launch Alliance. While private industry has always played a role in the development of space programs, we've entered a new era in which space projects are led by billionaires such as Elon Musk, Jeff Bezos, and Richard Branson. These initiatives are far from vanity projects, and mark the beginning of a concerted scramble for profit off-planet. Elon Musk is supporting SpaceX and Jeff Bezos has put his financial muscle behind Blue Origin. These companies are striving to lower the cost of launches by developing reusable rockets and experimenting with new sources of fuel, one of the most expensive aspects of launching cargo and satellites into space. SpaceX, for example, won a $1.4 billion contract from the U.S. government in 2016.

The problem is that Silicon Valley has a terrible track record of inclusion—only about 1 percent of the technology team at Facebook are black Americans, 3 percent Hispanic, and 17 percent women, according to *Fortune*.[3] As these tech titans aim their rockets at the Moon, or Mars, or wherever they can make money, it's plausible this new form of exploration will only exacerbate existing inequities. Even entrepreneurs seeking to expand access to space are catering to these divisions, like Richard Branson and his $250,000 tickets to orbit on Virgin Galactic.

Moreover, as author Cory Doctorow has observed, technology—and certainly space technology—can exacerbate inequality, leading to instability and collapse.[4] "As rich people get richer," Doctorow writes, "their wealth translates into political influence, and their ideas—especially their terrible ideas—take on outsized importance." It's possible that the private space ventures led by Bezos, Musk, and Branson may bring excellent innovations, but they may also inculcate "terrible ideas" as well through their individual influence, with little accountability. Doctorow posits that "without a free, fair and open network with which to rally and marshal the forces of justice, the battle is lost before it's even joined." It's unclear at present whether such a "free, fair and open network" exists with respect to space. NASA shares as much license-free data as it can in the interest of science, except where such technology could be used for military purposes (more on that later). But Blue Origin, SpaceX, or Virgin Galactic don't necessarily share their innovations through a "free, fair and open network"—even when they receive government contracts.

The shifting ground rules of commercialization may only accelerate these inequalities, as the U.S. Congress has subtly begun chipping away at the United Nations Space Treaty of 1967 and the U.N. Moon Agreement, which together forbid ownership of space resources. In 2015, U.S. lawmakers opened space for business and asteroid mining with the U.S. Commercial Space Launch Competitiveness Act. The law aims to open up outer space to market forces. Congress is betting that the American space industry can beat the rest of the world to lucrative new markets in a scramble for space. And other countries are equally interested—Luxembourg is encouraging private space companies to register there to take advantage of the country's new space commercialization law ensuring that "that private operators working in space can be confident about their rights to the resources they extract in outer space."[5]

CREATING AN INCLUSIVE BUREAUCRACY

The cost savings promised by SpaceX, Blue Origin, and other new space ventures may lower the barriers to entry considerably, but international agencies still have a major role to play in space technology. One way to foster inclusion in space is to promote it inside country-level space programs. The first American astronauts were white and the program deliberately excluded women and African Americans as astronauts, but the country has made great strides in including more marginalized voices. Charles Bolden served as administrator of NASA throughout the Obama administration. Moreover, there have been many black astronauts, including Bolden himself, Mae Jemison, and Ronald McNair. Worldwide, there have been more than 60 women astronauts from 13 countries,[6] with many more waiting in the wings. And yet this represents a minute percentage of the whole. Of the 560 astronauts trained to participate in a human spaceflight program around the world, almost 500 astronauts were men, and the majority of those astronauts were white.

It's possible to promote inclusion by aggressively hiring, training, and promoting marginalized people to become not just astronauts, but bureaucrats, too. NASA does this through its Office of Diversity and Equal Opportunity, which can field complaints of discrimination and offer solutions. As former administrator Charles Bolden outlined in NASA's Diversity and Inclusion Statement:

> Every hiring and recruitment initiative the Agency undertakes must ensure that we are striving to bring onboard talent from the widest possible range of sources. This means recruiting at institutions that we may not have recruited from before and partnering with community and professional organizations that can help us establish a NASA workplace that is fully reflective of the Nation's diversity.[7]

Astronauts are important as symbols and public figures, but space agencies also need administrators from diverse backgrounds. They need to hire and promote more people like Bolden, who conducted the less glamorous work of managing a gigantic bureaucracy. That's how programs can bake in inclusion from the outset to celebrate people who have been historically excluded.

Private space companies would benefit from incorporating this approach early on. Instead of taking their usual approach of starting a company, scaling it, and then taking a look at inclusion after a public outcry, they can begin now, and NASA's Diversity and Inclusion Statement is an excellent starting point. NASA should even require that private space agencies that win NASA contracts—which now include companies like SpaceX—include a credible diversity plan. The plan should address inclusion at all positions of the company, including upper management.

SHOULD EMERGING ECONOMIES HAVE SPACE PROGRAMS?

Improving inclusion within national space programs is just one part of the puzzle. Another essential aspect to a more inclusive future is the international exploration of space, and enabling more countries to join the party. That's not easy. Space exploration is expensive and demands tremendous financial power. Developing countries face basic problems related to infrastructure, health, and poverty. India and Nigeria have extraordinary wealth—and boast their own billionaires and growing middle classes. At the same time, about 30 percent of the population in India lives in extreme poverty,[8] compared to over 60 percent of the population in Nigeria,[9] according to the most recent censuses. This is why Gil Scott-Heron's poem "Whitey on the Moon" continues to resonate today. In the piece, Scott-Heron contrasts the needs of poor people in America with the fact that the country spent billions of dollars to reach the Moon: "I can't pay no doctor's bills, but whitey's on the moon."[10]

Scott-Heron published his poem the year after Neil Armstrong touched down on the Sea of Tranquility. The U.S. was embroiled in Vietnam, and people were skeptical of the value of spending so much money on the space program. To overcome skeptics in the 1960s, NASA's missions were supported by one of the most sophisticated publicity programs the world had ever seen. In *Marketing the Moon: The Selling of the Apollo Lunar Program*, authors David Meerman Scott and Richard Jurek detail the complex apparatus NASA developed to promote the space program.[11] This was not just propaganda. NASA employed a staff of 35, plus 35 contract employees in its Public Affairs office, who carefully reported the Apollo missions with an emphasis on facts. The team included many former journalists and fed news clips, audio interviews, and short films to the media that could be quoted or republished at no charge. When NASA's staff ran out of resources, government contractors happily filled the gap by producing briefings and scale models that could be used by television anchors like Walter Cronkite.

Space programs in developing countries face equally harsh public backlash for spending money when there are critical needs to address. One reason is that these countries have a track record of corruption with major development projects such as railroads, dams, and bridges that involve large sums of money. Turner T. Isoun founded the Nigerian space program as the country's minister of science and technology. In his 2013 memoir *Why Run before Learning to Walk?*, he explains the deep skepticism he faced when trying to establish the program under former President Olusegun Obasanjo. As he writes:

> Sometimes, in Nigeria, poverty is treated like a malaria infection, you can simply inject a drug and the disease goes away and you can simply inject cash and poverty will go away. Of course neither problem is really solved this simplistically. Rather, it is likely that the solutions to both problems may be found in science and technology and most likely in high technology combinations.[12]

Isoun argues that Nigeria needs to "shift the scope" of its "solution space" in order to confront a wide variety of problems—an argument that NASA itself makes every day on its website in a section called "Benefits to You."[13] "The skeptics … often ask me," Isoun goes on, "'What is the return on Nigerian investment in space technology?' I always tell them that the most significant return on our investment is the recovery of Nigeria's, indeed Black Africa's self-confidence in its capacity and capability in science and technology and innovation, and this cannot be measured in Nigerian naira, Kenya shillings, or U.S. dollars."[14]

In specifically noting that "black Africans" have been excluded from space exploration, Isoun is making the point that there is a *symbolic* return on investment in space initiatives for Nigerians, beyond their economic impact. Investing in space technology can remove limitations, and free the imaginations of African scientists. In Nelson Mandela's autobiography *Long Walk to Freedom*, the Nobel laureate expressed his shock at meeting black airline pilots in Ethiopia: "How could a black man fly an airplane?" But he quickly added, "A moment later I caught myself: I had fallen into the apartheid mindset, thinking that Africans were inferior and that flying was a white man's job. I sat back in my seat and chided myself for such thoughts."[15] Mandela's story is instructive: ingrained stereotypes can prevent even the most enlightened thinker from believing that marginalized peoples can embrace space technology.

Taken out of context, it may read as if Turner Isoun is suggesting that Nigeria build its own space program from scratch. But that isn't the case. He was arguing that Nigeria should do *something* even if it lags behind in other areas, because exposure to space technology, with proper training, could lead to local innovations that would benefit Nigerians. These thoughts are echoed by Harvard scholar Calestous Juma, who has stated that African countries don't need to focus all their energies on conducting basic research, and can instead embrace existing technology to add a uniquely African flavor.[16] In his view, this requires strong education and building out infrastructure to absorb knowledge and spur innovation. Turner Isoun agrees: "The critical lesson here is that Nigerians do not need to master obsolete science and technology before going straight to cutting edge science and technology."[17]

Each country will have its own unique approach, and it's not always clear what the inflection point is for when they should enter the space age. In India, for example, the program developed in parallel with the race to acquire nuclear weapons in its regional rivalry with Pakistan. One of the Indian Space Research Organisation's leading scientists, Avul Pakir Jainulabdeen Abdul Kalam, even went on to become the country's eleventh President. He candidly supported nuclear weapons research. The Korean Space Program enjoys a strong bilateral partnership with the United States. Other space programs focus on what they can contribute to our understanding of the cosmos. The Japan Aerospace Exploration Agency, or JAXA, launched a mission to gather samples from the asteroid Itokawa in 2005, gathering crucial scientific data.[18] Egypt, Indonesia, Ethiopia, and Malaysia have all announced plans to develop or expand their own space programs—and the list appears to be growing.

China has increasingly positioned itself to enable developing countries to benefit from outer space in a remarkable new form of space diplomacy. The country has signed numerous bilateral agreements with countries, including Nigeria, Venezuela, and Indonesia, to launch communications and observation satellites, according to a report by the U.S.-China Economic and Security Review Commission.[19] These satellites are often designed and built by Chinese scientists, with significant knowledge sharing and training for people from the partner countries.

Satellites are arguably the quickest and most proven path for countries to reap benefits from space technology, as they can open up entire swaths of countries to the digital age. Nigeria, for example, partnered with China and the University of Surrey in the United Kingdom to free its economy from dependence on expensive commercial communications satellites that it did not control. China has also joined several multilateral organizations that promote knowledge sharing and the joint use of satellite constellations for science and disaster reduction. These agreements have happened as the country has expanded its own capabilities in space exploration, such as developing the first quantum satellite.[20] Importantly, China is developing a space station that should launch in the next decade, and it may open it up to use by countries with which it has established partnerships.[21]

One reason for China developing its own space station is its own national ambition—another is that China is excluded from using the International Space Station for fear that it will steal technology that could be used to improve its military. The U.S. was a driving force behind this prohibition, and U.S. efforts at collaboration and soft diplomacy with China were blocked in an omnibus bill in 2011 supported by former Congressman Frank Wolf.[22] (In what might be considered a conflict of interest, or least an abuse of power, the House spending committee that advanced the bill required that any meetings with China on space report to itself.) NASA has managed to meet with China in multilateral contexts and arrange limited meetings with scientists, but the bill stood as a roadblock to collaboration as recently as 2015.

China's rapidly improving capabilities in space do not threaten the exclusion of the U.S., but they do complicate the dynamics of the playing field. NASA remains the world's most powerful and best funded space agency and has numerous bilateral and multilateral agreements, including many that are driven purely in the interest of science and the peaceful exploration of space. Since the Nixon era, the U.S. has extended a welcoming hand to countries to jointly explore space. But any developing nation looking for help or financing for their space programs to launch satellites into space, or explore some other technology, would likely at least sit down with China. In closing a channel of diplomacy with China, the U.S. may have undermined the possibility of collaboration on such development projects.

But it's worth being cautious about China's intentions in space with developing countries as well. The country's behavior in Africa on major development projects is not without controversy. For example, China has funded a number of state capitol buildings and has built large-scale infrastructure projects, including dams, highways, and railroads. Instead of creating local jobs, China tends to import its own construction firms and labor force, and there have been instances of workplace exploitation of African workers by Chinese management.[23] Resentment at these policies has even resulted in violent protests and xenophobic backlashes against the Chinese in countries like Kenya. We don't know if China's collaborations in space may be equally extractive.

Perhaps China's space diplomacy and the lure of its new space station will encourage NASA, through competition, to expand its partnerships with other countries interested in space exploration. NASA may do well to copy China's model through partnerships, training, providing grants, encouraging financial transparency, and explaining the benefits of the technology. Otherwise, they may find that countries decline an invitation to join the International Space Station and travel to China's space station instead.

IMAGINING AN INCLUSIVE FUTURE: THE POPULAR IMAGINATION

As suggested by the description of the intangible return on investment in space technology by the founder of Nigeria's space program, there's another essential aspect of fostering inclusion in space: influencing our vision of the future as expressed in the popular imagination. Space programs have been intertwined with entertainment since their outset. Wernher von Braun, the founder of the U.S. space program, wrote a science fiction novel about Mars, and Neil Armstrong read Jules Verne while promoting the Apollo missions, as authors Scott and Jurek have noted. Professor John E. Bowit has described how the Soviet program was inspired by painters such as Ivan Kliun, Aleksandr Labas, Ivan Kudriashev, and Kazimir Malevich.

The grand visions of traveling to the Moon—or beyond—were imagined not in a lab but by creative artists. In many cases, the scientists themselves consumed this entertainment to inspire their own work. That's why it's crucial for entertainment to include diverse voices, whether in literature, art, film, or whatever comes next.

Science fiction entertainment doesn't have to just mirror the status quo, and its more hopeful predictions of humanity's future can help break existing barriers of racial discrimination. Gene Roddenberry cast African American Nichelle Nichols and Japanese American George Takei in the original *Star Trek* series, which Martin Luther King, Jr. enjoyed watching with his family. The Reverend even advised Nichols to remain on the show because she was serving as a role model for African Americans.[24]

However, even if actors from marginalized groups grab leading roles in movies, there is an enormous apparatus behind each entertainment product—the producers, directors, and agents—who are not representative of a diverse society. The bankable star Will Smith may land a multimillion-dollar contract for himself and his son in a science fiction epic like *After Earth*, but that doesn't mean the people working behind the scenes are diverse. Entertainment needs administrators like Charles Bolden, too.

That's not to say that entertainment has denied the achievements of marginalized communities entirely. Recent scholarship has celebrated women pioneers of the space program, such as Nathalia Holt's *Rise of the Rocket Girls* (2016) and Margot Lee Shetterly's *Hidden Figures* (2016), which focused on African American mathematicians and engineers at NASA.[25] The latter book was turned into a popular and award-winning film.

Existing movements such as Afrofuturism can offer eye-opening examples of how our creative culture can meaningfully contribute to a new vision of our space programs. Loosely marked by a passion for technology and innovation, as well as mysticism rooted in African American and African culture, Afrofuturism encompasses a wide variety of creative explorations across numerous fields—music, art, film, and literature—over nearly a half-century in black culture. Narratives often feature black protagonists, and the aesthetic can draw upon design elements sourced from the rich traditions of the diaspora. Afrofuturism democratizes storytelling by allowing people to share their own narratives in which they have an important role.

Today, numerous stories are being told that could be considered Afrofuturism, such as Ta-Nehisi Coates' retelling of the *Black Panther* comic book series, Nnedi Okorafor's *Lagoon*, and the video game *Aurion: Legacy of the Kori-Odan*, by Cameroon-based studio Kiro'o Games. My own sequel to *Nigerians in Space*, the novel *After the Flare*, imagines a future in which Nigeria must collaborate with India to save the world. In these stories, we can envision space programs in which Africans—or Indians, Native Americans, or anyone—participate fully and equally in our exploration of the cosmos.

WHEN FACEBOOK AND SPACEX ROCKETS BECOME THE FUTURE

Many of the issues discussed so far—including private space contractors and space-age technologies that impact the developing world—came dramatically to a head in August 2016. Then, two giants of the tech industry—Elon Musk and Mark Zuckerberg, CEO of Facebook—combined forces on what would have been a historic mission. Facebook bought the services of a $200 million Israeli communications satellite that would enable the social networking company to beam broadband internet to rural areas of Africa that were not connected. This satellite was to be launched via SpaceX's latest development, the Falcon 9 rocket.

Facebook's ambitions in this regard were not without controversy. In 2015, the country rolled out its Internet.org project in India, promising free internet, but only offering a hand-picked limited number of apps, prompting a major uproar in civil society and government authorities to issue regulations protecting net neutrality. So it was unclear what *kind* of internet Facebook would have been providing on the satellite. Nonetheless, the Falcon 9 rocket exploded during a launch test, destroying the satellite with it.[26]

Here, Facebook, one of the largest companies in the world, was marshalling its own resources to connect a dramatically underserved population by launching a rocket developed by the private tech industry. It should have been a sobering wake-up call to governments on the continent to expand their own ambitions in space. If successful, the mission might have brought more users in Africa into the internet age, but it could also have opened the door to further African dependence on the space technology of other countries and on an international company with its own profit motives. Mark Zuckerberg has vowed to press on in any case, now shifting the focus to flying high-altitude drones to serve a similar function of providing the internet to rural areas.

A lot can happen in 15 years. In the year 2033, Nigerians may find it amusing that people once laughed at the thought of an African in space. We may be standing on the doorstep of a future in which all nations participate in the exploration of outer space and enjoy its wonder. Or we may see global inequality projected into Low Earth Orbit, and find the gap between the haves and have-nots widening as a battle for dominion over the sky rages between space powers, private space companies, and countries focused wholly on terrestrial matters. Humanity's future in space will be shaped by the decisions we make—we can start by creating a more inclusive vision of that shared adventure.

Notes

1 "List of International Space Station Visitors," *Wikipedia, The Free Encyclopedia*, https://en.wikipedia.org/wiki/List_of_International_Space_Station_visitors.

2 Sylvia Ann Hewlett, Melinda Marshall, and Laura Sherbin. "How Diversity Can Drive Innovation," *Harvard Business Review*, December 2013, https://hbr.org/2013/12/how-diversity-can-drive-innovation.

3 Valentina Zarya, "3 Ways Facebook Is Trying to Diversify Its Workforce," *Fortune*, January 19, 2017, http://fortune.com/2017/01/20/facebook-workforce-diversity-data-driven.

4 Cory Doctorow, "Technology Is Making the World More Unequal. Only Technology Can Fix This," *The Guardian*, May 31, 2017, https://www.theguardian.com/inequality/2017/may/31/technology-is-making-the-world-more-unequal-only-technology-can-fix-this-cory-doctorow.

5 Luxembourg Ministry of the Economy, "Luxembourg's New Space Law Guarantees Private Companies the Right to Resources Harvested in Outer Space in Accordance with International Law," *Portal of the Grand Duchy of Luxembourg*, November 11, 2016, http://www.gouvernement.lu/6481433/11-presentation-spaceresources.

6 "List of Female Astronauts," *Wikipedia, The Free Encyclopedia*, https://en.wikipedia.org/wiki/List_of_female_astronauts.

7 Charles Bolden, "NASA Policy Statement on Diversity and Inclusion," NASA, June 8, 2010, https://odeo.hq.nasa.gov/documents/Diversity_Inclusion_Policy_Statement.pdf.

8 Ritika Katyal, "India Census Exposes Extent of Poverty," *CNN World*, August 2, 2015, http://www.cnn.com/2015/08/02/asia/india-poor-census-secc.

9 "Nigerians Living in Poverty Rise to Nearly 61%," *BBC News*, February 13, 2012, http://www.bbc.com/news/world-africa-17015873.

10 For a full, free online version of the text of "Whitey's on the Moon," see https://www.theatlantic.com/technology/archive/2011/05/gil-scott-herons-poem-whitey-on-the-moon/239622.

11 David Meerman Scott and Richard Jurek, *Marketing the Moon: The Selling of the Apollo Lunar Program* (Cambridge, MA: The MIT Press, 2014).

12 Turner T. Isoun and Miriam J. Isoun, *Why Run before Learning to Walk?* (Ibadan, Nigeria: BookBuilders Editions Africa, 2013).

13 See https://www.nasa.gov/topics/benefits/index.html.

14 Isoun and Isoun, *Why Run before Learning to Walk?*

15 Nelson Mandela, *Long Walk to Freedom: The Autobiography of Nelson Mandela* (Boston: Back Bay Books, 1994).

16 Calestous Juma, "Technology Will Drive Scientific Progress in Africa Not the Other Way Round," Quartz, August 15, 2016, https://qz.com/757766/technology-will-drive-scientific-progress-in-africa-not-the-other-way-round.

17 Isoun and Isoun, *Why Run before Learning to Walk?*

18 Dante S. Lauretta, "The Seven-Year Mission to Fetch 60 Grams of Asteroid," *Scientific American* 315 (2016).

19 Kevin Pollpeter, Eric Anderson, Jordan Wilson, and Fan Yang, "China Dream, Space Dream: China's Progress in Space Technologies and Implications for the United States," *U.S.-China Economic and Security Review Commission*, March 2, 2015, https://www.uscc.gov/Research/china-dream-space-dream-chinas-progress-space-technologies-and-implications-united-states.

20 Tim Fernholz, "China's New Quantum Satellite Will Try to Teleport Data outside the Bounds of Space and Time," *Quartz*, August 20, 2016, https://qz.com/760804/chinas-new-quantum-satellite-will-try-to-teleport-data-outside-the-bounds-of-space-and-time-and-create-an-unbreakable-code.

21 Andrew Jones, "A Comprehensive Guide to China's Space Activities in 2016," *GB Times*, July 1, 2016, http://gbtimes.com/comprehensive-guide-chinas-space-activities-2016.

22 Zach Rosenberg, "This Congressman Kept the U.S. and China from Exploring Space Together," *Foreign Policy*, December 17, 2013, http://foreignpolicy.com/2013/12/17/this-congressman-kept-the-u-s-and-china-from-exploring-space-together.

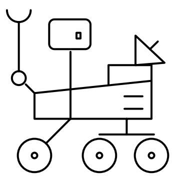
23 "Nigeria: Workers of Chinese Company Protest Mass Dismissals, Deaths, Injuries Attributed to Poor Work Conditions and Alleged Discrimination; Company Responds," *Business & Human Rights Resource Centre*, 2015, https://business-humanrights.org/en/nigeria-workers-of-chinese-company-protest-mass-dismissals-deaths-injuries-attributed-to-poor-work-conditions-and-alleged-discrimination-company-responds.

24 Michael Martin, "*Star Trek*'s Uhura Reflects On MLK Encounter," *Tell Me More*, National Public Radio, http://www.npr.org/2011/01/17/132942461/Star-Treks-Uhura-Reflects-On-MLK-Encounter.

25 Nathalia Holt, *Rise of the Rocket Girls: The Women Who Propelled Us, from Missiles to the Moon to Mars* (Boston: Little, Brown and Company, 2016); Margot Lee Shetterly, *Hidden Figures: The American Dream and the Untold Story of the Black Women Mathematicians Who Helped Win the Space Race* (New York: William Morrow, 2016).

26 Russell Brandom, "Today's SpaceX Explosion Is a Major Setback for Facebook's Free Internet Ambitions," *The Verge*, September 1, 2016, http://www.theverge.com/2016/9/1/12750872/spacex-explosion-facebook-satellite-internet-org-zuckerberg.

SECTION II • MARS



She tumbled, landed on a knee and both hands. Her gloves broke through the duricrust. It felt like a layer of caked sand at the beach, only harder and more brittle. Like hardened mud. And cold! Their gloves weren't heated the way their boot soles were, and there wasn't enough insulation when actually touching the ground. It was like touching ice with the bare fingers, wow! Around 215 degrees Kelvin, she recalled, or minus 90 degrees Centigrade; colder than Antarctica, colder than Siberia at its worst. Her fingertips were numb. They would need better gloves to be able to work, gloves fitted with heating elements like their boot soles. That would make the gloves thicker and less flexible. She'd have to get her finger muscles back into shape.

She had been laughing. She stood and walked to another freight drop, humming "Royal Garden Blues." She climbed the leg of the next drop and rubbed the crust of red dirt off an engraved manifest on the side of the big metal crate. One John Deere/Volvo Martian bulldozer, hydrazine-powered, thermally protected, semiautonomous, fully programmable. Prostheses and spare parts included.

She felt her face stretched into a big grin. Backhoes, front loaders, bulldozers, tractors, graders, dump trucks, construction supplies and materials of every kind; air miners to filter and collect chemicals from the atmosphere; little factories to render these chemicals into other chemicals; other factories to combine those chemicals; a whole commissary, everything they were going to need, all at hand in scores of crates scattered over the plain.

—*Kim Stanley Robinson,* Red Mars


NILOKERAS
LOBO VALLIS
RONGXAR
KASEI VALLES
SHARANOV
TEMPE MENSA
LUNAE MENSA
SACRA MENSA

THE BAKER OF MARS

by Karl Schroeder

The flapjacks fry up quick; Myrna can tell they need to be flipped when the batter's rim dulls and the bubbles across its top burst like little fumaroles. Craters on a Georges Méliès moon.

"Hey, Myrna! *Is* your coffee good?" She looks up from the grill to see Hartney holding up his cup. The new guy standing next to him seems embarrassed, but Myrna's not about to let Hartney scare away a potential customer. She grabs the box of grounds and sidles down the galley kitchen to the front counter. "Check it for yourself." The doubtful customer holds up his phone, which sees the box, scans it, and checks its provenance in the global fair exchange blockchain. "Chavez Farm, Costa Rica." He leans into a trapezoid of sunlight and reads whatever the Chavezes have to say about their family-run operation, or maybe checks where their coffee is roasted, how it's distributed, how the chain is audited—whatever might influence his decision to drink this particular brew in this particular diner. Finally he shrugs. "S'okay. I'll have a latte."

Hartney laughs. "Awful lot of fuss for a cup of joe."

Myrna starts to multitask between the latte and the 'jacks. "What do you know? You live on Mars."

New guy does a double-take; Myrna can see him realize that most of the people in the little corner diner are eating breakfast. It's 3:30 in the afternoon, not even a sane time for a shift change. "You guys are homesteaders?"

Hartney sits up straighter, trying to shine past his thinning hair, polyester shirt, and pasty complexion. Myrna loves him for it. "I'm already a billionaire!" he proclaims, to guffaws and jeers from up and down the joint. "It's true. I'm one of the Thousand."

The First Thousand on Mars. Sounds more impressive than this corner diner in Tampa, crowded with a dozen other Thousands. "'Jacks are up," says Myrna, then, "here's yer latte."

"So what's it like living on Martian time?"

"Adapt or die," somebody says before Hartney can. Hartney's seamed face falls a little, but he adds, "How are we gonna survive there if we can't do it here?" Most of the breakfast crowd look like they've been moving one time zone a day for the last five years. Which they more or less have. The Martian day is 40 minutes longer than Earth's.

"Hey, Myrna does it," says Grace from the front window, where she's soaking up the sun. "And she's not even a Martian."

"Oh, I dunno," Myrna objects. "I have a stake."

"Yeah? What stake?"

She laughs. "You guys."

And it's true: who else is going to feed these dreamers—these soft rebels and temporal exiles—their breakfast at their real breakfast time, their lunches at their lunchtime? They can barely take care of themselves, telecommuting to a whole other planet. Someone needs to watch over them.

"Well, good luck," says the new guy, in a tone that causes Hartney to look up sharply.

"It's a sound venture," the brave settler objects. "Pioneers always hit some bumps on the road."

"Some?" The new guy snorts, and everything goes quiet. "Sorry," he adds quickly, "but having the Feds and Russia threaten to pull out isn't just a 'bump.' If your assets get stranded, you could lose your whole stake."

"We'll weather it," insists Hartney; then he turns away. Conversation over.

A few minutes later Myrna rings a bell on the counter. "Closing in ten," she announces. The diner is just a sideline. She's got a secondhand Baxter boxing her deliveries, but even with drone service she hasn't been able to fully automate. There are pork and coconut buns for a restaurant down the road, cupcakes for a kid's party, and lots of full meals for Martian shut-ins. She's not about to tell the new guy that Hartney is one of her more high-functioning customers, but it's true.

She hurries them all out the door. Myrna's mind isn't on the new deliveries, as it should be if she wants repeat business. One particular bag, stuffed with white boxes still radiating heat, stays atop her mind's inventory as she shuts down the ovens, locks the cabinets, and powers down the register. He hasn't eaten properly since last year. This is his first order in three days.

As half her orders float off under drones, each a little wandering cloud, Myrna calls a car and gathers the straps of the remaining bags into two knotted handfuls. She shouldn't worry. But she's going to make Wekesa her first stop.

She leaves the car by the curb, advising it to lock itself. The air conditioning's running to keep the cakes cool. It's not her car—in fact, she has no idea who owns it—but it's quite visible on the autosharing blockchain. This is a trustworthy vehicle. It's not going to steal her cakes.

Myrna trots up three flights of steps since the elevator is out. There's no air conditioning in the halls here, and it smells of vinyl, carpet glue, and unsuccessful cooking. She hears voices and TVs even though it's the middle of the workday. That's normal; a lot of people are unemployed.

After all the hurrying to get here, the long intermission after she knocks on Wekesa Ballo's door makes her self-conscious. She feels like a video game character on pause. Just as she's raising her hand to knock again, the door opens a crack.

"I texted you," she says to the bleary eye that punctuates the strip of black. "And what are you doing with the lights off? It's 9:00 a.m. in Kasei Valles."

"Ten, actually." He opens the door and the smells that waft out are of electronics, bleach, laundry soap. "But I'm not at Kasei right now."

Myrna frowns around at the dark in Ballo's apartment. "Where are you, the other side of the planet?"

"Practically." He's a hunched black shape eclipsing computer monitors as he takes the bag of food to his bare little kitchen.

"Wekesa, that's crazy." First there's the 40-minute permanent jet lag, and now he's shifted time zones? There are only a few places he could be, and none make sense. "Why aren't you working your claim?"

He's not even bothering with plates, just wolfing down the food while standing at the counter. Hasn't asked her to sit. As if her question was time-delayed like his systems on Mars, he suddenly glances up. "I had a visitor. After that … I dunno. I was angry, I guess."

"Angry? What kind of visitor?"

"A ghost."

She can't tell if he's joking; in the dim light his face is a black cutout save for faint crescents the monitors cast on his eyes. "Want to see?"

"You're starting to creep me out." Reluctantly, she goes to the playpen—her private name for the round, padded region of Wekesa's living room that's been given over to his VR rig, which is centered on an omnidirectional treadmill. There are bungee straps hanging from the ceiling that you can hook yourself to, but Wekesa never uses them. When Myrna first started playing VR games, the rigs had been big goggle affairs. Using them was like strapping a bowling shoe to your face. As she steps into the rig today, lasers paint a Martian landscape on her retinas; she's there instantly and seamlessly. She hears Wekesa approaching and moments later his avatar appears next to hers.

Myrna cranes her neck at the sky. "Shouldn't it be morning at Kasei Valles?"

"This isn't live, it's a recording. Watch."

In the grand old cathedrals of Europe, the pipe organs have up to a second's delay between your pressing a key and the note venting through the brass flutes. As you play, the sound washing around and through you is already in your past, unmoored from your actions. She's often thought that the homesteaders, miners, and builders of Mars must experience their world that way.

Her shadow is short under the butterscotch sky. When she starts walking, the shadow remains behind, pinned to the ground. Turning, she sees that it's not actually hers, but is being cast by the tall, spindly telepresence bot that Wekesa is struggling to pay for through his prospecting work. There are thousands just like it all over the planet. Like most, this one is accompanied by a little rover that can carry rocks, and a half dozen or so drones with huge fans. It's part of the private-public venture that is building settlements, industries, and life support in advance of a hoped-for human landing. Wekesa has sunk all his money into buying this bot and getting it transported to another planet, in the hope that what they build there will someday attract clients and customers beyond the launch companies and speculators.

On a normal day the drones fan out around Wekesa's bot, recording the whole landscape in LIDAR and high-definition video. This 3D environment gets beamed back to Earth, and Wekesa can wander around in it as if it were a game level. When he finds something interesting, he'll go through the motions of investigating it, though of course he's just a virtual pip in the game and isn't—yet—affecting anything real. When he's recorded a set of actions he's satisfied with, he uploads the sequence to Mars and the bot plays it out on the real planet: walking, kneeling, turning over a rock, splitting it with a hammer. This happens anywhere from 10 minutes to half an hour after Wekesa's done the commit, and meanwhile he'll have moved on to something else of interest. Then, in a flash, the results of his last command play for him. He can rethink his next course of action, or simply commit immediately. His Martian counterpart is smart enough to pick up fumbled objects, to improvise in simple ways. Usually he doesn't have to redo anything.

Thus, by halting turns, is Mars explored. Somewhere over the crisp horizon, work gangs are building cities, though no human has yet set foot on the planet. Like organists, the workers play 10 minutes or a half hour ahead of reality, picking up girders from ground onto which they haven't yet been unloaded, committing as a team. They achieve that focus which, in the flow of the fugue, demands they experience not what exists now, but rather what they are summoning into being.

Hartney claims that it's actually easy to do. Mars isn't like a place, it's like a sepia-toned photograph. A half hour from now, everything will be exactly where you expect it to be unless you moved it yourself. Nothing but you changes or transits the uneven landscape, except the imperceptibly tilting sun.

So Myrna swears and almost falls down when she turns and sees a tall, imperious woman striding toward her over the rocky red dunes.

"Wekesa Ballo, we must talk!" the woman shouts. "You are taking too much!" She raises one arm dramatically to point at the tumbled rocks.

"Who are you to wear that face?" snarls Wekesa—not here and now, but in the recording.

The figure tilts its head. "I am Kasei Valles. I am the place where you stand. I am the thing you steal."

There's a confused sound from Wekesa. The tall woman raises her chin and says, "Are you listening to me? You have sold too many well concessions on this land. You are draining the brine faster than the aquifer can be renewed."

There's a long silence, then a fumbling sound. The beige landscape comes apart like a cough of smoke, and there's Wekesa, glowering in his apartment with his arms folded.

"Wekesa, what was that?"

Myrna's worst fear is confirmed as he says, "She was my wife. Eloise."

Myrna has a strange double-moment now: on the one hand she's feeling for Wekesa, who is still mourning. It's concern for him and the darkness of his mind that makes her come here.

At the same time, a long-dormant part of her is running inventory on the hacks you'd need to get this effect. VR ghosts aren't unusual; this isn't even a particularly offensive one, but it is the first she's heard of to affect the Martian homesteaders. To make such a ghost, she'd have to break into Wekesa's system (and she's been keeping up her skills, she can imagine several ways to do this), then inject a worm to ransack his image files for a face common enough to use to stitch together a 3D avatar. Then the worm would open an external port and become the interface to this … walking propaganda piece.

"It must be the Pristines," she says. There's a sizable movement aimed at leaving Mars untouched. It started back when they thought there might be life there. Now the movement just taps into people's romantic longing for "untouched nature."

"It's shocking that they gave it her face, Wekesa—though that might be an accident. I mean—sorry, I know it's been hard for you to move on …"

There's a moment's pause, then he laughs. "It's not that. I figured it was some Pristiner trick. I'm not angry because it looks like her. I'm angry because what it says is true."

They leave the playpen, and sitting with his hands folded, Wekesa tells her the rest. "It pestered me. Followed me about for the next three days. And not just me. This … thing, has been chasing other homesteaders too."

She thinks of her cheerful morning crowd. "Nobody's talking about it."

"They're embarrassed to admit they've been hacked. Our contracts say we're liable for security breaches."

"Aaah."

“Whatever this is, it takes on the form of the person you’ve got the most pictures of in your library. For some, it’s one of their kids. Others, a favorite movie star.”

“It says it’s Kasei Valles? The *place?*”

He nods. “Depends on where you are. There’s Sacra Fossae, Mawrth Vallis. Some of them just watch the homesteaders, squatting on a boulder like vultures. Others demand we leave.”

“Why hasn’t anything been done?”

Wekesa splays his hands and rolls his eyes. “The communications company says they’re harmless. The VR equivalent of spam. In fact, they said since the ghosts have assigned themselves to features in the landscape, like the hills and plains, that means those are taken now and nobody else can spam them. So … better these ghosts than something else.”

Myrna knows this is bull. She could have written the code to do something like this—back when *computer programmer* was still a job description. She knows if you can get through to the VR interface, you might be able to do more. “But are they just virtual? I mean, are they just in your interface here at home, or are they on Mars too?” If you could upload a virus or worm to the actual bots on Mars … “Wekesa, has there been sabotage?”

“There are rumors, of crawlers gone missing, things unbuilt in the night ….” He shakes his head. “But there are always rumors of ghosts on Mars. The point is, as long as the ghosts are just yelling at us, the company has no incentive to chase down the perpetrator.

“The problem, Myrna, is that the ghost is right. We *are* draining the aquifer too fast. Before we’re even able to build the settlement, the resources to run it will be gone.”

Myrna’s heard nothing about this either. “But the settlement plan—”

“Is just a plan. There’s no one to enforce it. The U.N. treaty says nobody owns the land, but we *do* own what we take from it. What kind of behavior do you think that encourages?”

“Huh. But the corporations can’t recoup their investments unless the settlements are built—”

He’s nodding. “—And the politicians don’t want to guarantee their loans, because they see what’s happening to the resources but have no powers to set policy for land use. The governments are pulling their funding. Some homesteaders are rushing to sell raw materials while there are still buyers, while others build anything they can while the corporations are still paying. But the plan has turned into a race to the bottom. By the time they're built, the settlements won't be fit to live in because we'll have stripped their hinterlands of the resources needed to run them. The corporations don't care because they only need to show a profit in the next quarter. They've shifted from actually planning the settlements to selling the dream of Mars here at home ..." He sighs heavily. "To people like me. And to TV and VR investors. In the short run that's the only way they'll make money. And there's no long run for them.

"Nobody's saying it yet but ... there will be no colonists."

"Wekesa, this is terrible! When did you—?"

"We all bought into the dream," he says with a shrug. "Literally. I think everybody believed in it, at first. But if the governments can't own the land, they won't play, and if the corporations can't make a profit, neither will they. So we burn up the resources building cities that will never be lived in, until it's all done. Mars will be the next Easter Island, covered in monuments, empty of people."

Myrna has no answer to that, so she falls back on reminding him to clean up his place, eat more regularly. "Think about the things you can control," she says, but it's a weak rebuttal to his depressing scenario.

She has her rounds to complete, so she leaves Wekesa to his double jet lag. She's going to need an extra hour of light therapy herself to make up for the darkness in his apartment. As she makes her other deliveries the face of Wekesa's ex follows her, as if wagging its finger at her, too. She gets madder and madder.

By the time dinnertime comes (at midnight local time), she's made a decision. She opens the bakery and Hartney strolls in, her first customer, regular as clockwork. Before he's had a chance to sit down, Myrna's at him. "Give me her picture."

"What?" He blinks at her.

"Your Martian ghost. I know you've got one. Everybody does, right?"

He looks shifty, slides into a booth. "I dunno—"

"I don't even want to see her up close. Or him, or whatever form it's taken. Long distance is fine. Blurred. I just need some screen grab of the thing."

Reluctantly, he meets her eye. "What are you going to do with it?"

"For starters? Make a Wanted poster."

Though nobody will admit to giving it a serious look, Myrna's included a sign-up URL on the poster that promises anonymity. The back end of her server shows 10 people registered on the first day, 20 by Day 3, and 100 shortly thereafter. The poster (and her bounty offer) has moved online and gone viral within the homesteader community.

If Myrna can catch a ghost live, and not just on a recording, maybe she can trace it, shut down the source. To her surprise, Hartney is proving a valuable aide. It seems he's realized that there's more notoriety to be had in being a Martian rebel than just a Martian, and within days he's tapped unexpected contacts to become a community advocate for "taking back the planet."

He tells Myrna what he wants to do over coffee. "Look, nobody can own space. That's part of the 1967 treaty and everybody who's up there right now is a signatory to it. We," he waves at the bleary-eyed troops shoveling Myrna's hash browns into their faces, "do whatever we do up there under the jurisdiction of our own governments, but those governments don't own the land we're working."

"I know," she says. "I hate to say it, Hartney, but doesn't that doom this whole venture from the start?"

"Depends on what you think 'ownership' means," he says, waggling his eyebrows. "It's like the whole 'sharing economy' flap back in the twenties. Where the ride-sharing companies and the automakers tried to claim they owned idle time on any self-driving car?" She remembers the maneuver the car companies had tried: discounted leasing arrangements that gave them the right to use the car when you weren't. This was quickly becoming the only way to get a car, until the courts had intervened.

"Even before that, John Deere said farmers didn't really 'own' its tractors because of the proprietary software in them. And before that, file sharing. Yeah, it's all about ownership, but that's not nearly as straightforward a concept as we pretend it is.

"Take our bots." He steeples his hands and raises his eyes to heaven. "They're our second selves. Our great hope for the future. Except we don't own them. We're all leasing-to-buy, because they cost millions. Hundreds of thousands to make, and the rest of the cost is the price of getting them to

Mars. Still less than 1 percent the cost of sending a live human, but who's counting? There are no live humans on Mars. So, we prospect, we dig, we build, we sell, but do we really own any of what we find if it can't be returned to Earth? And do the companies that build the settlements 'own' them? Are they paying us with real money? It's all economic activity taking place on a planet with no humans on it, and with no exports. It's potential money, potential ownership, none of it's real."

"But if there's nothing to own ..."

"Then maybe the Pristines are right, and we should just leave it all alone." He jabs a thumb at her poster. "But if you followed the news, which you don't because you have a bakery to run—on Martian time no less—you'd know there's pressure in Congress for us to back out of the Space Treaty. If we do, then all these ownership issues become so much clearer. The U.S. can claim Mars, or whatever part of it isn't being pounced on by the Russians, the Chinese, Europe, and India. Then we'd parcel it up in the traditional way, auction off the pieces and voila! Problem solved."

"So why don't we?"

"Because doing so would piss off, oh ..." He peers into space for a moment, calculating. "Just the Rest. Of. The. World. Every other signatory to the treaty. Not to mention that the instant it happens the *big* money kicks in. We homesteaders will get shoved aside in the rush. You and I could never make the minimum bid for even the tiniest ditch up there. It'll be game over for all our kind."

"Then what can you do?"

He shrugs. "Be what we say we are. Show the world that we really can build a shining city in the sky that's just waiting for residents. It'll be the single most valuable piece of real estate in history. Everyone will flock there. If nobody else is going to sit up and show leadership, then the homesteaders have to. All we have to do is keep it together long enough to complete the first neighborhood. That means not letting these 'ghosts' and other scare tactics get to us."

She thinks about that while she takes care of a couple of other customers. When Myrna comes back, Hartney's getting up. Only now does she see that the slant of his shoulders has more dejection than exhaustion in it. She imagines Hartney's apartment or house, windows blacked out like Wekesa's and him, a larval Martian curled up in his VR rig, dreaming of a day when he steps onto the planet for real. His determination is a façade, she realizes; he knows the homesteaders are no more in a position to run Mars than the governments or the corporations. Secretly, he's certain that either his day will never come, or that when it does he'll be living in somebody else's city. Somebody who started with billions and has now made trillions without lifting a finger.

She walks him to the door. "It's funny," she says. "When I opened this place I had such grand plans. And then I lost money, more and more every month. I thought I was going to go bankrupt. Then I found you guys."

Hartney smiles, a little uncertainly. "You okay, Myrna?"

"I'm fine." But she's not. She has buns and bread to bake, deliveries to make, but she can't stop thinking about her customers and their situation.

By the time it's late afternoon for her, the streets are dark and silent except for the buzzing of her drones. Supper will be at 5:00 a.m. this time, but she's used to the constant shifting. As long as you avoid sunlight and total darkness, keep focused on your inner clock and on staying in sync with the customers, you can almost—*almost*—normalize time.

Still, these extreme time shifts can make Myrna feel like she's been cast off the grand stage of Earthly life. Like Hartney, like Wekesa. She clings to them and her other customers. Only they understand what it's like to become unstuck in time, to look in on this planet's concerns as if you were an alien.

She does pay attention to the news, but she observes it through the sepia lens of Martian time. The stars in Myrna's night are streetlights and glowing windows—not those of time-shifters like her, but of ordinary people who don't have to get up for work tomorrow because there is no work. Half the city is unemployed, living on the various social assistance, guaranteed income, or job-sharing programs that have replaced the old labor market. Resource-sharing Internet of Things bots have taken all the blue-collar jobs, and the Distributed Autonomous Corporations of the global processing blockchain have gobbled up all the white-collar ones. It was the global processing blockchain that took her own career, but she's been lucky. She has the bakery. People still want the human touch for some things.

All the people in those lit apartments need to belong to something. They're trying to find some stake in the future, to participate, help build something bigger than themselves. It's not about a job. It's about belonging. They've been told they no longer belong on Earth.

So they turn their eyes to the heavens. Golden cities rise on the plains of Mars; Cloud 9 spheres will fill the skies of Venus, and the oceans of Ceres, Ganymede, Europa, and Callisto await new navigators. The United Nations treaty guarantees a stake for all in these new worlds, for no nation can own another planet.

There is a viable business model in there, but it's Hartney's nightmare. It starts with letting the homesteaders fail. Then, when they've "proven" that a cooperative space venture will never work, the governments will pull out of the treaty, declare sovereignty, and parcel up the planet. They'll sell it off piecemeal to the highest bidders, and those bidders won't be Hartney or Wekesa or the other homesteaders.

Enclosure. She remembers reading about this tactic in university, how the British lords used it to grab all the commoners' land. But this time it's happening on a scale those commoners could never have dreamt of.

At 3:00 a.m. she's sprawled on her couch, binge-watching a cop drama where, bewilderingly, everybody's awake in the daylight at the same time. Tired as she is, it takes her a second to realize that the phone that's ringing is not on the TV, but on the side table next to her.

She grabs it up. "Marvin's Diner."

Wekesa says, "She's back."

Wekesa has come home. The long, stately mesas of Kasei Valles stand guard on the horizon as Myrna steps into VR with him. The Martian plain is thatched with tracks, and vehicles sit frozen in mid-roll, dozens of them between here and the jumble of bright white and blue curves that will be the Martian town. It nestles under the uplands, empty of life yet strangely animated with its posing cranes and angled satellite dishes.

"Here she comes," says Wekesa. His ex's ghost strides across the photo-still landscape. Her cold smile is directed at Myrna in real time, which means that this connection is local; the "ghost" is a process running on some Earthbound server. Myrna has signed in as root in Wekesa's interface, and now starts the diagnostic programs he allowed her to install last time she was over. Once they're running, she walks out to meet it. "Why are you here?"

The ghost tilts its head. "You must leave this place."

“So you keep saying,” Myrna replies distractedly. She’s watching her packet sniffers track down the origin of the ghost’s feed. It doesn’t take long, and it’s not hard to do, though she can see why none of her boys have caught the ghost yet. The user-friendly, high-level tools they doubtless deployed to trap it aren’t good at diving deep into the communications protocols that it’s spoofing; it takes a live programmer to conduct that kind of art. Hartney and the others don’t really know their systems on the machine level.

There are few people left who bother with such knowledge, just as there are few people nowadays who can fix their own car, or grow their own food.

Now that she’s traced its origin, she can see that the ghost is little more than a chatbot. It’s being driven by a DAO, a Distributed Autonomous Organization written in Solidity and running on Ethereum in the peer-to-peer computing blockchain. Nobody owns it and no particular server is running it, it’s smeared out across the whole internet. Whoever wrote the ghosts’ routines didn’t buy much “gas” to run their algorithms, so the ghosts are pretty stupid.

“Hartney talked to some Pristines,” she says to Wekesa. “They told him they made the ghosts, but they haven’t gone public about their stunt. I don’t think they did it. Apart from the hacks that got it past your firewalls, it’s a pretty amateurish production. Probably some hobbyist with Pristinist leanings.

“So it’s nothing?” says Wekesa hopefully.

They both know it is not nothing; simple it might be, but the ghost is a wake-up call to a deeper problem.

The apparition says, “You must leave me. Leave Kasei Valles.” —And that’s a funny thing to say, Myrna suddenly realizes.

She explores the Ethereum code some more. There have been no updates since the process started running; whoever made it started the ghost service and just walked away. Like Bitcoin, the ghosts own themselves now. There are plenty of DACs and DAOs just like that.

“Well, *this* is interesting. The DAO creates accounts, one per physical resource on Mars. The code that runs each ghost identifies it as that resource. So, insofar as it has any identity at all, this one,” she nods at the impatient apparition, “really does think of itself as Kasei Valles.”

“Thinks? So it’s an AI?”

Myrna shakes her head. "Sorry, I put that the wrong way. It's not sophisticated enough to be an AI. You can tell that just by watching it. A real AI that thought it was Kasei Valles would do more than just yell at you to leave. If this thing had any social capabilities at all, it would negotiate, it would try to bribe you or threaten you in some specific way. I mean, if it had any real brains it would use them to actually look after its own interests ...."

Wekesa's staring at her, and Myrna belatedly realizes she's frozen as still as the cranes on the Martian horizon, captured body and soul by a sudden thought. "What is it?" he asks, concerned.

"We've been looking at this all wrong," she says in wonder.

"What do you mean?"

"Wekesa, you and the others are in trouble because your partners' interests aren't aligned with your own, right? Business wants to maximize its profits, so it's poised to abandon the long-term investments here. And Government has no stake in Martian territory. You need a partner that has a stake, and whose interests run parallel to your own."

He crosses his arms and snorts at the sharply drawn horizon. "Nice idea, but where are we going to find a partner like that?"

Myrna smiles, raises her hand and points at the ghost.

"You're looking right at her."

"Welcome to the United Nations, Ms. Hayward. If you'll come this way?"

It's three months later, and she can barely believe she's here. The halls of U.N. headquarters are bustling with suited diplomats, sharp-eyed translators, and scurrying pages. Security bots hulk in the corners, tiny drones zoom paper envelopes over the heads of the crowd, and wall screens, holographic kiosks, and wall-writing lasers dazzle the eye with the latest news. Myrna's not used to the heels she's wearing, but manages to make it to the conference room on time. There are about 30 people milling around, none ready yet to commit to a place at the long table.

A bear-like Slavic man approaches her. "Ms. Hayward! So happy to finally meet the mother of the ghosts!"

"I didn't create them," she protests, for the thousandth time. "I just made some upgrades." She actually met the original programmer online just a few days ago. He's not happy with what she's done with his code, but has prudently retreated to the shadows now that the ghosts are becoming prominent.

Her words are drowned by a loud clap from the Chair. People start to sit.

There are more than 200 nations represented at the U.N. these days; Myrna's sleep has been disturbed for weeks imagining them all at this meeting. Most are, but only virtually, and others have sent trusted common reps. Even so there's a lot of money and power in this room, however casual it may appear.

Once everyone is seated, the Chair rises. "Welcome," she says. "We're here today to discuss a novel proposal for the governance of space resources. We have the good luck to have the woman who proposed it with us today, Myrna Hayward."

There's an actual round of applause. Myrna shrinks a little in her seat. The Chair runs through introductions, gives thanks to sponsors, and everything else that weighs down a public meeting—but with admirable speed. Aside from the government officials, there are corporate reps from the launch companies and supply chain consortia—and those few homesteaders who could afford to come. "I think," the Chair finally says, "that it might save us a lot of time if we let Ms. Hayward go first. Because I know we all have questions."

"Um." Myrna stands, acutely aware of the tremble in her knees. Luckily, Hartney's been coaching her for weeks on what to say. *Opening line*, he'd be saying right now. *What's your opening line?*

"How do you govern the use of a common resource?" she says, a little too loudly.

"Divide it up and let the market take care of it," says one of the businessmen dismissively.

Myrna nods. "Works great for mineral wealth—on Earth. But even here, it's not always the best way. What about fisheries? The fish come and go. What does 'ownership' even mean in that case? Or, take air. Earth's ecosystems are still a mess despite 20 years of efforts to fix global warming. Why? Because we're still trying to use market and regulatory forces to govern a common resource—the air itself. Carbon taxes, cap-and-trade, they work to a point. But they're an awkward fit.

"We've run into the same problem on Mars. Colonizing a planet gives us a clear goal and, at every step along the way, some things need to be done and others need to be delayed, stopped, or even reversed. The whole effort's one big machine and all the parts have to work together, over generations of time. We don't leave that sort of project to the market, because things constantly have to be done that profit no one in the short term. The market's great for some things; for the rest we rely on the state.

"But *which* state?" She nods to the Chair. "That's been the problem with global warming from the start. Even before the 'teens, the oil companies were admitting climate change was a problem and said they were willing to help solve it—as long as somebody else made the first move. It was a global problem, but there was no global actor who could take responsibility. Who owns the air? No company, and no state. So we've floundered forward, barely keeping ahead of the disaster."

"Okay," says a representative of one of the launch companies. "Who *does* own the air?"

Perfect. She smiles at him. "It owns itself.

"Historically, it is known as a commons. More than two billion people make their living from commons arrangements even today. The commons is older than the market and the state, but it's also as new as the internet, open-source software, Creative Commons artwork, and public 3D printer model archives. And the thing is, space is already a commons.

"In a commons, the stakeholders who are affected by the use of a resource come together to form a set of rules for its use, sanctions for cheating, and so on. There are pastures in Switzerland that have been governed this way without a hitch for over 700 years. You might have heard of something called the 'tragedy of the commons,' where everyone taking what they need from a commons depletes it. It's a myth—what that cautionary tale is really describing is an anarchy. By definition, a commons is governed and its resources managed; it's just not owned. Elinor Ostrom won the Nobel Prize in economics in 2009 for showing how commons are governed."

"So? Well that might work for fisheries and pastures, but we're talking about a whole planet here."

"But you've answered your own objection," she says. "If the commons doesn't scale to planetary size, neither do markets. Or governments. We need all three.

"The commons isn't a replacement for the market. In the past, commons arrangements were always local and unique to the particular resource and the particular stakeholders affected by it. You can make money universal, and the state can reach anywhere, but commons don't have that capability. At least ... they didn't."

She turns to a wall screen displaying the bleak Martian plain. "In any case, to explain what all this means for Mars, I think it's time to turn things over to one of our new friends. This, ladies and gentlemen, is Kasei Valles."

Kasei no longer resembles Wekesa's ex-wife. She's still female, but has adopted the bronze-skinned, racially ambiguous features of an Edgar Rice Burroughs Martian. Wrapped in a bright green sari, she blazes in contrast to the russet land and beige sky as she walks up to the virtual camera.

The Malaysian rep leans forward. "Is this the famous AI we've been hearing about?"

"I am not an AI," says the Martian. "I am Kasei Valles.

"I am a region of the Martian surface, including its groundwater, perchlorate, and iron deposits—and its human inhabitants, their tools, and the things they are building. There are artificial intelligences involved in managing me, including the one that is having this conversation with you now, but I am not them. I," she says, sweeping her arm to encompass the entire vista, "am *this*."

"That's really what she thinks she is," Myrna says. "From our point of view, Kasei is a token in a blockchain. Like the original Bitcoin, this blockchain is an autonomous decentralized peer-to-peer network, not run by any central authority, not owned by anybody. Unlike Bitcoin, however, the tokens in this blockchain don't stand for money, but for the resources of the planets, moons, and asteroids of the solar system. This is my, uh, contribution. I replaced the original ghost program, which was a kind of spambot, with a legal interface to a DAC I programmed. Then I set the DAC running and stepped back."

"Why?" It's the launch company rep again, looking puzzled now but a little intrigued.

"By using a blockchain we can universalize the benefits of a commons. Firstly, the resource's stakeholders manage it directly, using smart contracts. This is faster and more efficient than going through state actors or markets. Commons-level rules of access ensure that the resources are not depleted, and the smart contracts interlock to guarantee that the whole system fulfills its goal."

"In your case," interrupts Kasei, leaning forward a bit to smile into the room, "the contracts can coordinate all the colonization efforts, private, public, and individual, as well as those taking place on the Moon and planned for Ceres and the other worlds. I and the other systems form nested commons, as in Ostrom's vision, that make a trusted third party such as the state unnecessary, and function more efficiently than a market."

The rep crosses his arms, frowning. Myrna can picture the thought balloon over his head, which probably includes the word *communism*. But the commons isn't even socialism, and now that Kasei has given her annunciation, Myrna's pretty sure the rest of the day is going to be spent educating these people about this fine point. She's already tired, but she smiles at the Martian anyway.

"Welcome to the world of self-governing common pool resources," she says. "Kasei's not here to dictate terms; she's just an interface to make it easier for us to figure out how to use Kasei Valles's resources. She's just one of many, of course. I hope I can introduce you to some of the valleys, rills, craters, and mounts involved in the colonization effort. I know I'm talking about them as if they're people; it's kind of irresistible after you've spent any time with them. So I want to make sure you understand right from the start that they're *not* people, they're interfaces to a resource blockchain.

"This blockchain is the answer to the question of how to manage space resources; it's the trusted arbitrator that the U.N., the individual countries, and commercial interests could never quite be. The blockchain is there to arbitrate disputes and render judgments fairly. It can do it because it's not owned by or beholden to anybody, and its code is transparent, unhackable. Kasei Valles and the other ghosts are literally incorruptible. She was never possible before the blockchain. Now, though, she's our future."

The launch company guy glowers at Myrna. "Fairly, huh? So now that this thing's on top, where does that place *you*, Ms. Hayward?"

She shrugs. "After I set the DAC running I stepped back. I'm just a shareholder now, like you, and I have no backdoor to the code. It's all open-sourced on the blockchain, you can check it if you'd like. Beyond that … I'm just what I was before."

"And what, Ms. Hayward, is that?"

"A concerned friend."

The Martian dawn bears no relation to the Earthly one; for one thing, the streaks and smears of light spreading across the East are blue, not red. It may be day or night back home, and when Myrna takes off her VR glasses, she may see sunlight or rain. Those seem fictitious now, a kind of fever dream or parallel universe. The dawn she awakes to every day is this, the blue one, and its constancy makes it the real morning.

Myrna laughs, and in bounding strides, goes to join Wekesa and Hartney—and yes, Kasei, who stands to one side watching as the Martians inflate their first livable dome. A sizable arc of future colonists is watching the raising ceremony and among its members are some of the regulars from her bakery.

"It's still two years before anybody lands," she points out, but they're in no mood to pay her any attention. They, like her, are scattered around Tampa and other cities, souls posing alone in empty apartments. Yet they see past those walls and these, looking beyond today to something grand that could be. The Mars colony launchers, currently being assembled in factories and hangars, are curiously unreal compared with this dome, though Myrna could drive to visit one of the assembly sites, and no human eye has actually beheld the structure that looms over her. This disconnect, like the day, has become normal to her.

So she folds metal arms and grins with the others while the dome goes up. When it's about halfway inflated, Kasei saunters over. "If I were to invest now," says the Martian, "I'd invest in you."

Startled, Myrna pulls her gaze from the (real, but millions of kilometers away) dome to the (virtual, but literally right here) avatar of the Kasei Valles landscape. "Why do you say that?" she says.

"You're not a miner, or a smelter or renderer or construction worker," says the ghost. "You're a community advocate for a community whose members include non-humans."

Myrna shrugs. "It's what I did on Earth too, half the time. It just took the form of bringing lunches to these shut-ins." She nods at the dusty, vaguely humanoid robots that are hopping up and down, slamming each other on the shoulder, making other emotes. "They're just as helpless without me on Mars as they are on Earth. I'm not a baker anymore, or even a coordinator," she concludes mournfully. "I'm a den mother."

"Now that," says the ghost, "we have in common."

Myrna laughs. The ghosts have obviously gotten another upgrade; this one's learning to be funny. It's true, though: she takes care of the boys and gals here in the city, yet they're just as absent-minded and foolish on Mars. Somebody has to make sure they're fed on Earth; on Mars, somebody has to bring them their battery packs, blasting charges, and drill bits.

Of all these people, she alone has no claim in the valley itself—but it hardly matters. Such "claims" are now understood as what they always were: declarations of a relationship with the land. She has one of those, it's just not expressed in hectares or tonnes.

"Will you be joining us?" asks the ghost. "When the colony ships come?"

Myrna shrugs. "Maybe, maybe not. It doesn't matter," she says.

"I'm already here."

Acknowledgments: I would like to acknowledge the staff at Arizona State University, particularly Joey Eschrich and Ed Finn, and Maciej Rebisz, who did a fine piece of art for my story.

EXPLORATION FACT AND EXPLORATION FICTION

by Lawrence Dritsas

Exploration comprises all kinds of interesting activities and resources, but two are absolutely required: people and money. Every aspect of a successful expedition—relevant technology, supporting institutions, transport logistics, effective methods of observation, and effective communication systems—requires human labor and financial capital. The goals of exploration are equally various, but can be reduced to one thing: knowledge. In the fourth century BCE, Pytheas of Massalia (now Marseilles) sailed beyond the Pillars of Hercules and turned north, seeking the northern limits of humanity.[1] He was an explorer, but he was also seeking the sources of tin, amber, and gold that southern Europeans desired and that he could sell at profit. More than a millennium later, over seven voyages in the early fifteenth century, Zheng He (鄭 和) was sent by the Ming emperors of China to explore the Indian Ocean and solidify their control of established trade routes that stretched from Java, via India, to Kenya.[2] From 1485 to early 1492 Christopher Columbus visited the courts of Portugal, Genoa, and Venice, proposing his idea to sail west to reach the East before finally convincing the Iberian monarchs Ferdinand II of Aragon and Isabella of Castile to fund his audacious voyages across the Atlantic; Columbus spent nearly as much time looking for money as he did exploring the New World during his four voyages from 1492 to 1504.[3] Vasco da Gama's voyage to Calcutta in 1498 was motivated by the search for new trade routes, and the subsequent century was marked by repeated clashes between Portuguese and Ottoman explorers in the Indian Ocean seeking new routes and sources of wealth.[4]

Clearly, among the many skills that explorers need to be successful, one of the most important is the ability to persuade others to provide the money necessary to undertake their journeys. There are very few historical cases of intrepid individuals paying their own way to simply "see what's out there."[5] Indeed, the second expedition of the famed Scottish explorer David Livingstone into central Africa in the middle of the nineteenth century cost the British government around £30 million over six years. The purpose of his "Zambesi Expedition" was to identify new supplies of natural resources for British industry. When this outcome proved unlikely, the British government recalled the expedition with the foreign minister, Lord John Russell, noting that, "there is little to show that the results actually obtained can be made presently serviceable … for the interests of British Commerce."[6] Even where immediate profit is not the goal, money remains a factor. In Washington, D.C. on 20 July 1989, U.S. President George H. W. Bush announced the Space Exploration Initiative, with the goal of landing humans on Mars by 2019, 50 years after Apollo 11. But Bush's bold initiative foundered within months when a potential price tag of $540 billion scared off most supporters.[7] In this second decade of the twenty-first century, the United States is once again on a "Journey to Mars," but the exact details of "how?" and more importantly, "how much?" remain unanswered.[8]

In the United States since 2010, a blend of public and private funding has been used to support outer space travel. Alexander MacDonald argues in his recent book that this phenomenon is not new, but has deep historical roots in the United States, citing private support for observatory building in the nineteenth century and early rocketry.[9] Not everyone agrees with the public-private model for funding exploration, but it has significant precedents beyond MacDonald's focus on space-related activities. Richard Burton and John Hanning Speke explored East Africa in the 1850s using largely private money and only minimal support from the British government. Later in the nineteenth century, prospectors scoured the Pacific Northwest, the Yukon, South Australia, and the Zambian Copperbelt looking for minerals with colonial government encouragement but risking the money of private investors. Robert Falcon Scott led his British Antarctic Expedition to its fatal end in 1913 supported mainly by private donations and commercial sponsorship, only latterly topped up by a government grant.[10] On the ice, Scott and his men ate Huntley & Palmer's digestive biscuits spread with Beach's blackcurrant jam with as much "product-placement" gusto as when explorers Ben Saunders and Tarka L'Herpiniere successfully retraced Scott's route in 2014, sponsored by Land Rover and Intel.[11] In Britain it has become a tradition to eat Kendal Mint Cake while hillwalking, the same energy-boosting treat that Edmund Hillary and Tenzing Norgay ate on Everest in 1953. These are just snapshots, but the history of exploration and all its varieties of funding models may teach us a thing or two about how to move forward to Mars.

There is another body of literature that can further inform our thinking about how to explore space and how to pay for it: science fiction. The future of space exploration, and especially the exploration of Mars in the twenty-first century, can be informed, if not inspired, by a study of both the history of exploration and the science fiction of exploration.[12] We find public-private funding models for exploring space in many novels. Frederik Pohl and Cyril M. Kornbluth's *The Space Merchants* (1953) is a key example and offers the classic, genre-defining account of the commercialization of space exploration and colonization. Its singeing critique of Libertarian ideology, advertising-driven consumerism, and the exploitation of labor and the environment was remarkably prescient. The idea of space colonization being dominated by corporations persists also in visions of our future on Mars. Terry Bisson's *Voyage to the Red Planet* (1990) is an overt science fictional satire of a privatized journey to Mars where NASA has become a subsidiary of Disney.[13] Ben Bova's *Mars* (1992) and *Return to Mars* (1999) see the protagonist travel to the Red Planet first on an international mission and then on a privately funded expedition. In Jeff Garrity's novel *Mars Girl* (2008), the first landing on Mars is satirized as an extreme media event where television ratings and product placement matter as much as the explorers' survival and discoveries. Karl Schroeder's short story in this volume follows the same path: imagining how the exploration and exploitation of Mars could be funded by private money.

If exploration is about people and money, then it must include a concern with people's bodies, keeping explorers safe. John F. Kennedy spoke to the U.S. Congress in May 1961 of "landing a man on the moon and returning him safely to Earth." This same goal applies now, in fact and fiction, to any crewed mission to Mars, as the surprise popularity of Andy Weir's rescue novel *The Martian* (2011) and its film adaptation (2015) demonstrate. The main challenge to keeping the astronauts safe is the problem of coping with extreme, if not lethal, environments; humans are built to live on Earth and nowhere else. Even on Earth, the shared challenge of the explorers of the past was how to make their bodies survive the trip. At times, everything was against them as they pushed the extreme environments of the Earth: heat, cold, altitude, depth, and the lack of food and water. One might wonder, "Is the human body really is the best tool to explore other worlds?" Frederik Pohl explored this in *Man Plus* (1976), where the exploration of Mars is undertaken by human cyborgs specifically built to survive the Martian environment—no need for building habitats and spacesuits to keep the explorers in little Earth-like bubbles. But as Pohl illustrates, we cannot ignore the consequences for the altered human who has become "of Mars" and no longer "of Earth." More recent works such as Kim Stanley Robinson's *Blue Mars* (1996), James S. A. Corey's *Leviathan Wakes* (2011), and Ian McDonald's *Luna: New Moon* (2015) also examine the idea that settling other worlds is, physiologically, a one-way trip. Of all the people involved in exploration, it's the explorers who embody the risk, who feel the new environments around them. The diaries of explorers such as Humboldt, Livingstone, and Darwin detail the effects the journey is having on their bodies and minds. They want to return safely, but they will not return the same.

In Karl Schroeder's story, "The Baker of Mars," the problem of human physiology has been solved by telepresence. Mars is being developed slowly by technicians, prospectors who operate robots remotely from Earth so that the infrastructure to support human life is ready whenever the colonists get there. The prospectors' concessions are areas of the Martian surface leased to them, with everyone hoping for a future payoff. In "The Baker of Mars," what is for sale are the rights to exclusively exploit parts of Mars, rights supposedly underwritten by government support through enforceable contracts. The problem posed is that it becomes unclear how anyone's investment in an "unowned" space can pay off without simply claiming it. But in this story, and in real life, any attempt to claim parts of Mars is forbidden by the long-standing 1967 Outer Space Treaty. The tension of the story is apparent almost immediately: how to coordinate all this activity and protect investment when no one owns anything and when the potential return on investment lies far into the future. The answer provided in the story is that Mars owns itself, and through the mysterious creation of self-governing common-pool resources that are represented by an advanced, near-AI, interactive avatar, Mars can be developed without resorting to ancient techniques such as the extension of sovereignty through a colonial system, the creation of new sovereign states on Mars, chartered companies, or various forms of public-private partnerships.[14]

At the beginning of the era of European expansion on Earth, this problem of protecting long-term investments in newly explored areas was acute. In response, financial institutions innovated and European states sponsored chartered companies, giving them special, often exclusive, rights over specific types of trade in certain parts of the world.[15] Good examples are the Dutch *Verenigde Oostindische Compagnie*, the Hudson's Bay Company, and the British South Africa Company. Chartered companies such as these exerted state-like powers in places such as Canada, India, Java, Mozambique, and Rhodesia. They effectively controlled all the resources, and people, in the areas they possessed. Their investments were secure for only as long as the local population collaborated, or was subjugated, and profits could be found. They could protect their exclusive rights and profits by force, if necessary. Science fiction has often resurrected the chartered company idea in its stories—hegemonic companies operating off-world loom large in films such as *Alien* (1979), *Outland* (1981), *Blade Runner* (1982), and in James S. A. Corey's ongoing novel series *The Expanse* (from 2011).[16] In his novel *Red Mars* (1993), Kim Stanley Robinson imagines the early settlement of Mars as overseen by an authoritarian United Nations Organization Mars Authority (UNOMA) while Earth falls under the control of transnational corporations with state-like powers. Schroeder's technological vision for the exploitation of Martian resources veers from these traditional models, but fact is catching up with fiction when it comes to the commercialization of space and the problem of property.

On 25 November 2015, the Space Resource Exploration and Utilization Act was signed by President Obama in order to encourage the private sector to develop outer space resources with the guarantee that their investments would be protected under U.S. law. With the passing of this law, the United States has declared that its citizens are legally entitled to own anything they extract from celestial objects, such as the Moon, asteroids, or Mars, but they cannot claim sovereignty over or ownership of the celestial object itself. Part of the rationale for the new law was to rectify a problem in the Outer Space Treaty of 1967, which states clearly that celestial bodies are not appropriable, but also acknowledges that private entities can perform space activities.[17]

When such private entrepreneurs become involved in the exploration and exploitation of Mars, the issue of private property arises almost immediately.[18] The proceeds and profits of private investment must benefit the investors. Here we see that Schroeder's fiction is not so far from fact. How the eventual resources of space might be exploited commercially, and legally, is a very real concern. With the new law, the U.S. is asserting private property rights for its citizens in space. This raises interesting questions about sovereignty in space and some worry the legislation will destabilize the "fragile equilibrium" that has existed since 1967.[19] The act of appropriating land on celestial bodies seems to require that a sovereign authority is endorsing it, or that a "new sovereignty" has been created.[20] We can therefore see why the U.S. was so careful to state that they are only endorsing the rights of U.S. citizens to claim extracted resources, not celestial bodies. Nonetheless, without some sort of guarantee to property in space and on celestial bodies, the private investment that appears necessary for humanity's next move into space will not occur.[21]

In offering a solution to allow secure investment off-world, the Space Resource Exploration and Utilization Act of 2015 must be understood as only the first part of a much bigger story. The very geography of economic activity looks set to change, especially when we accept that most space resources will only be useful *in space*—for example, using lunar water resources to supply Martian exploration. Bringing them back to Earth, or any other steep gravity well, would be a cost-prohibitive process of questionable utility, so we are talking about property rights in material value chains that may never include Earth.[22] Moreover, given the rapid advances in robotics and virtual reality, Schroeder's story is not far-fetched at all. Outer space and its "astropolitics" are now part of everyone's daily lives, as Fraser MacDonald argues.[23] If pilots can fly drones to wage war over the Middle East from an air-conditioned base in Nevada, and remote-control rovers have been exploring Mars for 20 years, how much more difficult can it be to control construction robots on Mars, once they are there? Schroeder's story of conflict over Martian resources before any humans ever step foot on Mars may be just around the corner.

It now becomes clear why, in "The Baker of Mars," that the story must end up in New York, at the United Nations. A meeting is held to discuss who owns Mars, and in attendance are government officials, various corporate representatives, and the "homesteaders." The exploration and early exploitation of Mars has required human effort and financial capital on a global scale, and everyone wants to know what will happen to the investments. We can compare Schroeder's fictional meeting to the Berlin Africa Conference of 1884–85, when the European powers sat down and decided that they all had interests in the last great *terra nullius* (for them), Africa. In Berlin, they agreed how they would partition and exploit the continent without stepping on one another's toes and starting a war.[24] The Africans themselves had very little say in the matter, but trading companies, explorers, miners, missionaries, and other European special interests certainly did; the goal in Berlin was the same as at Schroeder's meeting: to avoid expensive conflicts and secure investments. The Antarctic Treaty, signed in 1959, was similarly devised to forestall Cold War conflicts over what remains the last "unowned" land on Earth today.[25] In fiction, Robinson's *Blue Mars* (1996) details a constitutional congress that sets up a government for dealing with conflicts over scant Martian resources. The lessons of history and fiction show us that an agreement concerning the fate of Mars is inevitable. Once we can live on Mars we will need to deal with the consequences. Steam engines and quinine dramatically changed the terms upon which Europeans approached Africa in the late nineteenth century; they partitioned Africa because these innovations allowed them to travel there and not die of malaria. Schroeder argues that telepresence and blockchain technology will similarly alter and enable our approach to Mars—offering new solutions to the age-old problems of people and money but also creating new social, political, and diplomatic challenges.

By grounding his fictional account in the near future, Schroeder has provided food for thought about how the exploration, exploitation, and eventual colonization of Mars may begin. There is no doubt that getting humans to Mars will be *complicated* for all kinds of technical and political reasons.[26] Studying the history of exploration and reading science fiction can help us predict the problems of getting there and the consequences of new discoveries. Reading the fact and fiction of journeys to new lands also reveals that exploration is not a single "project" but rather a nexus, where a wide variety of individuals and institutions come together to think about the future, define goals, make plans, raise money, develop technologies, and attempt to find out things no one has known before. Science fiction authors have been influenced by true stories of exploration and the visions of science fiction have inspired people to explore yet further. Taken together these literatures are a strong foundation for planning our future on Mars.

Acknowledgments: My sincere thanks to the organizers and funders of this project; it has been an exhilarating experience from start to finish. I also want to thank Debby Scott, Joan Haig, and the editing team at Arizona State University for their insightful and incisive comments on my essay.

Notes

1 Barry Cunliffe, *The Extraordinary Voyage of Pytheas the Greek* (London: Allen Lane, 2003).

2 Edward L. Dryer, *Zheng He: China and the Oceans in the Early Ming*, 1405–1433 (London: Pearson Longman, 2007).

3 Nicolás Wey Gómez, *The Tropics of Empire: Why Columbus Sailed South to the Indies* (Cambridge, MA: The MIT Press, 2008).

4 Sanjay Subrahmanyam, *The Career and Legend of Vasco da Gama* (Cambridge: Cambridge University Press, 1997); Francisco Bethencourt, F. and Diogo Ramada Curto, eds., *Portuguese Oceanic Expansion, 1400-1800* (Cambridge: Cambridge University Press, 2007).

5 The careers of explorer-naturalists Alexander von Humboldt (1769–1859) and Sir Joseph Banks (1743–1820) are important exceptions to this. See Andrea Wulf, T*he Invention of Nature: Alexander von Humboldt's New World* (New York: Vintage, 2015) and Patricia Fara, *Sex, Botany, and Empire: The Story of Carl Linnaeus and Joseph Banks* (New York: Columbia University Press, 2004).

6 Lawrence Dritsas, *Zambesi: David Livingstone and Expeditionary Science in Africa* (London: IB Tauris, 2010).

7 Thor Hogan, *Mars Wars: The Rise and Fall of the Space Exploration Initiative* (Washington, D.C.: NASA, 2007).

8 Eric Berger, "Make Mars Great Again: Can the 2016 U.S. Election Save NASA's Journey to Mars?" *Ars Technica*, April 12, 2016, https://arstechnica.com/science/2016/04/make-mars-great-again-can-the-2016-election-save-nasas-journey-to-mars; "NASA's Journey to Mars: Pioneering Next Steps in Space Exploration," NASA, October 8, 2015, https://www.nasa.gov/sites/default/files/atoms/files/journey-to-mars-next-steps-20151008_508.pdf

9 Alexander MacDonald, *The Long Space Age: The Economic Origins of Space Exploration from Colonial America to the Cold War* (New Haven: Yale University Press, 2017).

10 "An Expensive Venture," Antarctic Heritage Trust, *Scott's Last Expedition*, http://www.scottslastexpedition.org/expedition/preparing-for-terra-nova/#chapter2.

11 See The Scott Expedition (2014) at http://scottexpedition.com.

12 For pioneering work in this area, see Alexander Geppert, ed., *Imagining Outer Space: European Astroculture in the Twentieth Century* (London: Palgrave Macmillan, 2012). Readers keen to explore the history of science fiction should consult one of the standard histories such as: Brian Aldiss and David Wingrove, *The Trillion Year Spree: The History of Science Fiction* (London: Paladin Grafton Books, 2001); Adam Roberts, *The History of Science Fiction* (Basingstoke: Palgrave Macmillan, 2006); and Mark Bould and Sherryl Vint, *The Routledge Concise History of Science Fiction* (London: Routledge, 2011).

13 See Edward James, *Science Fiction in the 20th Century* (Oxford: Opus, 1994), 205.

14 Roger D. Launius, *Historical Analogs for the Stimulation of Space Commerce* (Washington, D.C.: NASA, 2014).

15 Hubert Bonin and Nuno Valério, eds., *Colonial and Imperial Banking History* (New York: Routledge, 2016); Wolfgang Reinhard, *A Short History of Colonialism* (Manchester: Manchester University Press, 2011).

16 James S. A. Corey is the collective pen name for Daniel Abraham and Ty Franck. Thus far, *The Expanse* comprises six novels and five shorter works. It has been adapted for television by the Syfy Network.

17 Hanneke van Traa-Engelman, "The Commercial Exploitation of Outer Space: Issues of Intellectual Property Rights and Liability," *Leiden Journal of International Law* 4, no. 2 (1991).

18 It could happen very soon on the Moon—see Martin Elvis, Tony Milligan, and Alanna Krolikowski, "The Peaks of Eternal Light: A Near-Term Property Issue on the Moon," *Space Policy* 38 (2016).

19 Fabio Tronchetti, "The Space Resource Exploration and Utilization Act: A Move Forward or a Step Back?" *Space Policy* 34 (2015).

20 Virgiliu Pop, "Appropriation in Outer Space: The Relationship between Land Ownership and Sovereignty on the Celestial Bodies," *Space Policy* 16, no. 4 (2000).

21 Andrew R. Brehm, "Private Property in Outer Space: Establishing a Foundation for Future Exploration," *Wisconsin International Law Journal* 33, no. 2 (2015).

22 Ian A. Crawford, "Lunar Resources: A Review," *Progress in Physical Geography* 39, no. 2 (2015).

23 Fraser MacDonald, "Anti-Astropolitik: Outer Space and the Orbit of Geography," *Progress in Human Geography* 31, no. 5 (2007).

24 Stig Förster, Wolfgang J. Mommsen, and Ronald Robinson, eds. Bismarck, Europe and *Africa: The Berlin Africa Conference 1884–1885 and the Onset of Partition* (Oxford: Oxford University Press, for The German Historical Institute London, 1988). The issues surrounding the militarization of outer space are hotly debated—see Natalie Bormann and Michael Sheehan, eds., *Securing Outer Space* (New York: Routledge, 2009).

25 Nevertheless, there are seven nations whose claims to portions of Antarctica are held in abeyance by the treaty; they have not retracted them. For details visit http://www.ats.aq.

26 Mariel Borowitz and Jonathan Battat, "Multidisciplinary Evaluation of Next Steps for Human Space Exploration: Technical and Strategic Analysis of Options," *Space Policy* 35 (2016); "The World Is Not Enough," *The Economist* 421.9009, October 1, 2016, https://www.economist.com/news/science-and-technology/21707915-elon-musk-envisages-human-colony-mars-he-will-have-his-work-cut-out.

DEATH ON MARS

by Madeline Ashby

"Is he still on schedule?"

Donna's hand spidered across the tactical array. She pinched and threw a map into Khalidah's lenses. Marshall's tug glowed there, spiralling ever closer to its target. Khalidah caught herself missing baseball. She squashed the sentiment immediately. It wasn't really the sport she missed, she reminded herself. She just missed her fantasy league. Phobos was much too far away to get a real game going; the lag was simply too long for her bets to cover any meaningful spread. She could run a model, of course, and had even filled one halfway during the trip out. It wasn't the same.

Besides, it was more helpful to participate in hobbies she could share with the others. The counselors had been very clear on that subject. She was better off participating in Game Night, and the monthly book club they maintained with the Girl Scouts and Guides of North America.

"He's on time," Donna said. "Stop worrying."

"I'm not worried," Khalidah said. And she wasn't. Not really. Not about when he would arrive.

Donna pushed away from the terminal. She looked older than she had when they'd landed. They'd all aged, of course—the trip out and the lack of real produce hadn't exactly done any of them any favors—but Donna seemed to have changed more dramatically than Khalidah or Brooklyn or Song. She'd cut most of her hair off, and now the silver that once sparkled along her roots was the only color left. The exo-suit hung loose on her. She hadn't been eating. Everyone hated the latest rotation of rations. Who on Earth—literally, who?—thought that testing the nutritional merits of a traditional Buddhist macrobiotic diet in space was a good idea? What sadistic special-interest group had funded that particular line of research?

"It will be fine," Donna said. "*We* will be fine."

“I just don’t want things to change.”

“Things always change,” Donna said. “God is change. Right, Octavia?”

The station spoke: “Right, Donna.”

Khalidah folded her arms. “So do we have to add an Arthur, just for him? Or a Robert? Or an Isaac? Or a Philip?”

The station switched its persona to Alice B. Sheldon. Its icon spun like a coin in the upper right of Khalidah’s vision. “We already have a James,” the station said. The icon winked.

“Khalidah, look at me,” Donna said. Khalidah de-focused from the In-Vision array and met the gaze of her mission manager. “It won’t be easy,” the older woman said. “But nothing out here is. We already have plenty of data about our particular group. You think there won’t be sudden changes to group dynamics, down there?”

She pointed. And there it was: red and rusty, the color of old blood. Mars.

His name was Cody Marshall. He was Florida born and bred, white, with white-blond hair and a tendency toward rosacea. He held a PhD in computer science from Mudd. He’d done one internship in Syria, building drone-supported mesh nets, and another in Alert, Nunavut. He’d coordinated the emergency repair of an oil pipeline there using a combination of declassified Russian submersibles and American cable-monitoring drones. He’d managed the project almost single-handedly after the team lead at Alert killed himself.

Now here he was on Phobos, sent to debug the bore-hole driller on Mars. A recent solar storm had completely fried the drill’s comms systems; Donna insisted it needed a complete overhaul, and two heads were better than one. Marshall couldn’t do the job from home—they’d lose days reprogramming the things on the fly, and the drill bits were in sensitive places. One false move and months of work might collapse around billions of dollars of research, crushing it deep into the red dirt. He needed to be close. After all, he’d written much of the code himself.

This was his first flight.

“I didn’t want to be an astronaut,” he’d told them over the lag, when they first met. “I got into this because I loved robots. That’s all. I had no idea this is where I would wind up. But I'm really grateful to be here. I know it's a change."

"If you make a toilet seat joke, we'll delete your porn," Song said, now. When they all laughed, she looked around at the crowd. "What's funny? I'm serious. I didn't come all the way out here to play out a sitcom."

Marshall snapped his fingers. "That reminds me." He rifled through one of the many pouches he'd lugged on board. "Your mom sent this along with me." He coasted a vial through the air at her. Inside, a small crystal glinted. "That's your brother's wedding. And your new nephew's baptism. Speaking of sitcoms. She told me some stories to tell you. She didn't want to record them—"

"She's very nervous about recording anything."

"—so she told me to tell them to you."

Song rolled her eyes. "Are they about Uncle Chan-wook?"

Marshall's pale eyebrows lifted high on his pink forehead. "How'd you guess?"

Again, the room erupted in laughter. Brooklyn laughed the loudest. She was a natural flirt. Her parents had named her after a borough they'd visited only once. In high school, she had self-published a series of homoerotic detective novels set in ancient Greece. The profits financed med school. After that, she hit Parsons for an unconventional residency. She'd worked on the team that designed the exo-suits they now wore. She had already coordinated Marshall's fitting over the lag. It fit him well. At least, Brooklyn seemed pleased. She was smiling so wide that Khalidah could see the single cavity she'd sustained in all her years of eschewing most refined sugars.

Khalidah rather suspected that Brooklyn had secretly advocated for the macrobiotic study. Chugging a blue algae smoothie every morning seemed like her kind of thing. Khalidah had never asked about it. It was better not to know.

But wasn't that the larger point of this particular experiment? To see if they could all get along? To see if women—with their lower caloric needs, their lesser weight, their quite literally cheaper labor, in more ways than one—could get the job done on Phobos? Sure, they were there on a planetary protection mission to gather the last remaining soil samples before the first human-oriented missions showed up, thereby ensuring the "chain of evidence" for future DNA experimentation. But they all knew—didn't they—what this was really about. How the media talked about them. How the internet talked about them. Early on, before departure, Khalidah had seen the memes.

For Brooklyn, Marshall had a single chime. Brooklyn's mother had sent it to "clear the energy" of the station. During the Cold Lake training mission, she'd sent a Tibetan singing bowl.

For Khalidah, he had all 4,860 games of last year's regular season. "It's lossless," he said. "All 30 teams. Even the crappy ones. One of our guys down at Kennedy, he has a brother-in-law in Orlando, works at ESPN. They got in touch with your dad, and, well ..."

"Thank you," Khalidah said.

"Yeah. Sure." Marshall cleared his throat. He rocked on his toes, pitched a little too far forward, and wheeled his arms briefly to recover his balance. If possible, he turned even pinker, so the color of his face now matched the color of his ears. "So. Here you go. I don't know what else is on there, but, um ... there it is. Enjoy."

"Thank you." Khalidah lifted the vial of media from his hand. Her crystal was darker than Song's. Denser. It had been etched more often. She stuffed it in the right breast pocket of her suit. If for some reason her heart cut out and the suit had to give her a jolt, the crystal would be safe.

"And for you, Donna. Here's what we talked about. They gave you double, just in case."

Donna's hand was already out. It shook a little as Marshall placed a small bottle in it. The label was easy to see. Easy to read. Big purple letters branded on the stark white sticker. Lethezine. The death drug. The colony of nanomachines that quietly took over the brain, shutting off major functions silently and painlessly. The best, most dignified death possible. The kind you had to ask the government for personally, complete with letters of recommendation from people with advanced degrees that could be revoked if they lied, like it was a grant application or admission to a very prestigious community. Which in fact it was.

"What is that?" Brooklyn asked.

It was a stupid question. Everyone knew exactly what it was. She was just bringing it out into the open. They'd been briefed on that. On making the implicit become explicit. On voicing what had gone unasked. Speaking the unspeakable. It was, in fact, part of the training. There were certain things you were supposed to suppress. And other things that you couldn't let fester. They had drilled on it, over and over, at Cold Lake and in Mongolia and again and again during role-plays with the station interface.

"Why do you have that?" Brooklyn continued, when Donna didn't answer. "Why would he give that to you?"

Donna pocketed the bottle before she opened her mouth to speak. When she did, she lifted her gaze and stared at each of them in turn. She smiled tightly. For the first time, Khalidah realized the older woman's grimace was not borne of impatience, but rather simple animal pain. "It's because I'm dying," she said.

She said it like it was a commonplace event. Like, "Oh, it's because I'm painting the kitchen," or "It's because I took the dog for a walk."

In her lenses, Khalidah saw the entire group's auras begin to flare. The auras were nothing mystical, nothing more than ambient indicators of what the sensors in the suits were detecting: heart rate, blood pressure, temperature, odd little twitches of muscle fibers. She watched them move from baseline green to bruise purple—the color of tension, of frustration. Only Song remained calm: her aura its customary frosty mint green, the same shade once worn by astronauts' wives at the advent of the Space Race.

"You *knew*?" she managed to say, just as Marshall said, "You didn't *tell* them?"

Khalidah whirled to stare at him. His mouth hung open. He squinted at Donna, then glanced around the group. "Wait," he said. "Wait. Let's just take a minute. I …" He swallowed. "I need a minute. You …" He spun in place and pointed at Donna. "This was a shitty thing to do. I mean, really, truly, deeply, profoundly not cool. Lying to your team isn't cool. Setting me up to fail isn't cool."

"I have a brain tumor," Donna said blandly. "I'm not necessarily in my right mind."

"Donna," Song said quietly.

Oh, God. Donna was dying. She was dying and she hadn't told them and minty-green Song had known about it the whole damn time.

"You knew," Khalidah managed to say.

"Of course she knew," Donna said. "She's our doctor."

Donna was dying. Donna would be dead, soon. Donna had lied to all of them.

"It's inoperable," Donna added, as though talking about a bad seam in her suit and not her grey matter. "And in any case, I wouldn't want to operate on it. I still have a few good months here—"

"A few *months*?" Brooklyn was crying. The tears beaded away from her face and she batted at them, as though breaking them into smaller pieces would somehow dismantle the grief and its cause. "You have *months*? That's it?"

"More or less." Donna shrugged. "I could make it longer, with chemo, or nano. But we don't have those kinds of therapies here. Even if we did, and the tumor did shrink, Song isn't a brain surgeon, and the lag is too slow for Dr. Spyder to do something that delicate." She jerked a thumb at the surgical assistant in its cubby. "And there's the fact that I don't want to leave."

There was an awful silence filled only by the sounds of the station: the water recycler, the rasp of air in the vents, an unanswered alert chiming on and off, off and on. It was the sound the drill made when it encountered issues of structural integrity and wanted a directive on how to proceed. If they didn't answer it in five more minutes, the chime would increase in rate and volume. If they didn't answer it after another five minutes, the drill itself would relay a message via the rovers to tell mission control they were being bad parents.

And none of that mattered now. At least, Khalidah could not make it matter, in her head. She could not pull the alert into the "urgent" section of her mind. Because Donna was dying, Donna would be dead soon, Donna was in all likelihood going to kill herself right here on the station and what would they do—

Donna snapped her fingers and opened the alert. She pushed it over to tactical array where they could all see it. "Marshall, go and take a look."

Marshall seemed glad of any excuse to leave the conversation. He drifted over to the array and started pulling apart the alert with his fingers. His suit was still so new that his every swipe and pinch and pull worked on the first try. His fingers hadn't worn down yet. Not like theirs. Not like Donna's.

"Can you do that?" Khalidah asked Donna. When Donna didn't answer, she focused on Song. "Can she do that?"

Song's face closed. She was in full physician mode now. Gone was the cheerful woman with the round face who joked about porn. Had the person they'd become friends with ever truly been real? Was she always this cold, underneath? Was it being so far away from Earth that made it so easy for her to lie to them? "It's her body, Khal. She doesn't have any obligation to force it to suffer."

Khalidah tried to catch Donna's eye. "You flew with the Air Force. You flew over Syria and Sudan. You—"

"Yes, and whatever I was exposed to there probably had a hand in this," Donna muttered. "The buildings, you know. They released all kinds of nasty stuff. Like first responder syndrome, but worse." She pinched her nose. It was the only sign she ever registered of a headache. "But it's done, now, Khalidah. I've made my decision."

"But—"

"We all knew this might be a one-way trip," Song added.

"Don't patronize me, Song," Khalidah snapped.

"Then grow up," Song sighed. "Donna put this in her living will ages ago. Long before she even had her first flight. She was preapproved for Lethezine, thanks to her family's cancer history. There was always a chance that she would get cancer on this trip, given the radiation exposure. But her physicians decided it was an acceptable risk, and she chose to come here in full awareness of that risk."

"I'm right here, you know," Donna said. "I'm not dead yet."

"You could still retire," Khalidah heard herself say. "You could go private. Join a board of trustees somewhere, or something like that. They'd cover a subscription, maybe they could get you implants—"

"I don't *want* implants, Khal, I want to die *here*—"

"I brought some implants," Marshall said, without turning around. He slid one last number into place, then wiped away the display. Now he turned. He took a deep breath, as though he'd rehearsed this speech the whole trip over. Which he probably had. Belatedly, Khalidah noticed the length of his hair and fingernails. God, he'd done the whole trip alone. The station couldn't bear more than one extra; as it was, he'd needed to bring extra scrubbers and promise to spend most of the time in his own hab docked to theirs.

"I brought implants," he continued. "They're prototypes. No surgery necessary. Houston insisted. They wanted to give you one last chance to change your mind."

"I'm not going to change my mind," Donna said. "I want to die here."

"Please stop saying that." Brooklyn wiped her eyes. "Please just stop saying that."

"But it's the truth," Donna said, in her maddening why-isn't-everyone-as-objective-about-this-as-I-am way. "My whole life, I've wanted to go to Mars. And now I'm within sight of it. I'm not going to leave just because there's a lesion on my brain. Not when I just got here." She huffed. "Besides. I'd be no good to any of you on chemo. I'd be sick."

"You *are* sick," Khalidah snapped.

"Not that sick." Song lifted her gaze from her nails and gestured at the rest of them. "None of you noticed, did you? Both of you thought she was fine."

"Yeah, no thanks to you."

"Don't take that tone with me. She's my patient. I'd respect your right to confidentiality the same way I respected hers."

"You put the mission at risk," Khalidah said.

"Oh my God, Khal, stop talking like *them*." Brooklyn's voice was still thick with tears. "You're not mission control. This has nothing to do with the *mission*."

"It has *everything* to do with the mission!" Khalidah rounded on Donna. "How could you do this? How could you not tell us? This entire experiment hinges on social cohesion. That's why we're here. We're here to prove …"

Now the silence had changed into something wholly other. It was much heavier now. Much more accusatory. Donna folded her arms.

"What are we here to prove, Khalidah?"

Khalidah shut her eyes. She would be professional. She would not cry. She would not get angry. At least, no angrier than she already was. She would not focus on Donna's betrayal, and her deceit, and the fact that she had the audacity to pull this bullshit so soon after … Khalidah took a deep breath.

She would put it aside. *Humans are containers of emotion.* She made herself see the words in the visualizing interface they had for moments like this. *When someone else's emotions spill out, it's because their container is full.* She focused on her breathing. She pictured the color of her aura changing in the others' lenses. She imagined pushing the color from purple to green, healing it slowly, as though it were the evidence of a terrible wound.

"I'm fine," she said. "I'm fine. I'm sorry."

"That's good," Donna said. "Because we're not here to *prove* any one particular thing or another. We're here to run experiments, gather the last Martian samples before the crewed missions begin, and observe the drills as they dig out the colony. That's all we're here to do. You may feel pressure to do something else, due to the nature of this team, but that's not why we're here. The work comes first. The policy comes later."

The *Morrígu* was divided into three pods: Badb, Macha, and Nemain. No one referred to them that way, of course—only Marshall had the big idea to actually try stumbling through ancient Gaelic with his good ol' boy accent. He gave up after two weeks. Nonetheless, he still referred to his unit as the *Corvus.*

"Nice of them to stick with the crow theme," he said.

"Ravens are omens of death," Donna said, and just like that, Game Night was over. That was fine with Khalidah. Low-gravity games never had the degree of complexity she liked; they had magnetic game boards, but they weren't entirely the same. And without cards or tokens they couldn't really visualize the game in front of them, and basically played permutations of *Werewolf* or *Mafia* until they learned each other's tells.

Not that all that experience had helped her read Donna and Song's dishonesty. Even after all their time spent together, in training, on the flight, on the station, there was the capacity for betrayal. Even now, she did not truly know them.

Not yet, Khalidah often repeated to herself, as the days stretched on. *Not yet.* Not for the first time, she wished for a return to 24-hour days. Once upon a time, they had seemed so long. She had yearned for afternoons to end, for lectures to cease, for shifts to close. Now she understood that days on Earth were beautifully, mercifully short.

Sometimes Khalidah caught Donna watching her silently, when she didn't think Khalidah would notice. When Khalidah met her eyes, Donna would try to smile. It was more a crinkling of the eyes than anything else. It was hard to tell if she was in pain, or unhappy, or both. The brain had no nerve endings of its own, no pain receptors. The headaches that Donna felt were not the tissue's response to her tumor, but rather a warning sign about a crowded nerve, an endless alarm that rang down through her spinal column and caused nausea and throbbing at odd hours. Or so she said.

Khalidah's first email was to her own psychiatrist on Earth, through her personal private channel. It was likely the very same type of channel Donna had used to carry on her deception. *Can a member of crew just hide any medical condition they want?* she wrote.

Your confidentiality and privacy are paramount, Dr. Hassan wrote back from Detroit. *You have sacrificed a great deal of privacy to go on this mission. You live in close quarters, quite literally right on top of each other. So the private channels you have left are considered sacrosanct. Communications between any participant and her doctor must remain private until the patient chooses to disclose.*

This was not the answer Khalidah had wanted to hear.

Imagine if it were you who had a secret, Dr. Hassan continued, as though having anticipated Khalidah's feelings on the matter. *If you were experiencing the occasional suicidal ideation, for example, would you want your whole crew to know, or would you wait for the ideations to pass?*

It was a valid counterargument. Mental health was a major concern on long-haul missions. Adequate care required stringent privacy. But Donna's cancer wasn't a passing thought about how much easier it would be to be dead. She was actually dying. And she hadn't told them.

Now, after all that silence on the matter, the cancer seemed to be all anyone could talk about.

"I've almost trained the pain to live on Martian time," Donna said, one morning. "Most patients feel pain in the morning, but they feel it on an Earth schedule, with full sunlight."

Khalidah could not bring herself to smile back, not yet. Doing so felt like admitting defeat.

"She won't die any slower just because you're mad at her," Brooklyn said, as they conducted seal checks on the suits.

"Leave me alone," Khalidah said. Brooklyn just shrugged and got on with the checklist. A moment later, she asked for a flashlight. Khalidah handed it to her without a word.

"Have you watched any of the games your dad sent?" Marshall asked, the next day.

"Please don't bring him up," Khalidah said.

Five weeks later, the vomiting started. It was an intriguing low-gravity problem—barf bags were standard, but carrying them around wasn't. And Donna couldn't just commandeer the shop-vac for her own personal use. In the end, Marshall made her a little butterfly net, of sorts, with an iris at one end. It was like a very old-fashioned nebulizer for inhaling asthma medication. Only it worked in the other direction.

Not coincidentally, Marshall had brought with him an entire liquid diet intended specifically for cancer patients. Donna switched, and things got better.

"I'll stick around long enough to get the last samples from Hellas," she said, sipping a pouch of what appeared to be either a strawberry milkshake or an anti-nausea tonic. She coughed. The cough turned into a gag that she needed to suppress. She clenched a fist and then unclenched it, to master it. "I want my John Hancock on those damn things."

"Don't you want to see the landing?" Marshall asked. "You know, hand over the keys, see their faces when they see the ant farm in person for the first time?"

"What, and watch them fuck up all our hard work?"

They all laughed. All of them but Khalidah. How could they just act like everything was normal? Did the crew of the Ganesha mission even know that Donna was sick? Would the team have to explain it? How would that conversation even happen? ("Welcome to Mars. Sorry, but we're in the middle of a funeral. Anyway, try not to get your microbes everywhere.")

Then the seizures started. They weren't violent. More like gentle panic attacks. "My arm doesn't feel like my arm anymore," Donna said, as she continued to man her console with one hand. "No visual changes, though. Just localized disassociation."

"That's a great band name," Marshall said.

Morrígu tried to help, in her own way. The station gently reminded Khalidah of all the things that she already knew: that she was distracted, that she wasn't sleeping, that she would lie awake listening for the slightest tremor in Donna's breathing, and that sometimes Brooklyn would reach up from her cubby and squeeze Khalidah's ankle because she was listening too. The station made herself available in the form of the alters, often pinging

Khalidah when her gaze failed to track properly across a display, or when her blood pressure spiked, or when she couldn't sleep. Ursula, most often, but then Octavia. *God is Change,* the station reminded her. *The only lasting truth is Change.*

And Khalidah knew that to be true. She did. She simply drew no comfort from it. Too many things had changed already. Donna was dying. Donna, who had calmly helped her slide the rods into the sleeves as they pitched tents in Alberta one dark night while the wolves howled and the thermometer dropped to 30 below. Donna, who had said, "Of course you can do it. That's not the question," when Khalidah reached between the cots during isolation week and asked Donna if the older woman thought she was really tough enough to do the job. Donna, without whom Khalidah might have quit at any time.

"You watch any of those games yet?" Marshall asked, when he caught her staring down at the blood-dark surface of the planet. Rusted, old. Not like the wine-dark samples that Song drained from Donna each week.

Khalidah only shook her head. Baseball seemed so stupid now.

"Your dad, he really wanted to get those to you before I left," Marshall reminded her.

Khalidah took a deep, luxuriant breath. "I told you not to mention him, Marshall. I asked you nicely. Are you going to respect those boundaries, or are we going to have a problem?"

Marshall said nothing, at first. Instead he drifted in place, holding the nearest grip to keep himself tethered. He hadn't learned how to tuck himself in yet, how to twist and wring himself so that he passed through without touching anyone else. Everything about his presence there still felt wrong.

"We don't have to be friends," he said, in measured tones. He pointed down into Storage. "But the others, they're your friends. Or they thought they were. Until now."

"They lied to me."

"Oh, come on. You think it wasn't tough for Song to go through that? You think she enjoyed it, not telling you? Jesus Christ, Khalidah. Maybe you haven't noticed, but a lot of us made a lot of sacrifices to get this far."

"Oh, I'm sure it was so difficult for you, finding out you'd get to go to Mars—"

"—Phobos."

"—Phobos, without anything like the training we had to endure, just so you could pilot your finicky fucking drill God knows where—"

"Hey, now, I happen to like my finicky fucking drill very fucking much," Marshall said. He blinked. Then covered his face with his hands. He'd filed his nails down and buzzed his hair in solidarity with Donna. His entire skull was flushed the color of a new spring geranium. "That … didn't come out right."

Khalidah hung in place. She drew her knees up to her chest and floated. It had been a long time since she'd experienced secondhand embarrassment. Something about sharing such a tiny space with the others for so long ground it out of a person. But she was embarrassed for Marshall now. Not as embarrassed as he was, thank goodness. But embarrassed.

"They sent me *alone*, you know," he said, finally, through the splay of his fingers. He scrubbed at the bare stubble of his skull. "*Alone.* Do you even know what that means? You know all those desert island questions in job interviews? When they ask you what books you'd bring, if you were stranded in the middle of nowhere? Well, I *read* all of those. *War and Peace. Being and Nothingness.* Do you have any idea how good I am at solitaire, by now?"

"You can't be good at solitaire, it's—"

"But I did it, because they said it was the best chance for giving Donna extra time. If they'd sent two of us, you'd all have to go home a hell of a lot faster. You wouldn't be here when *Ganesha* arrives. So I did it. I got here. Alone. I did the whole trip by myself. So you and Donna and the whole crew could have more time."

Khalidah swallowed hard. "Are you finished?"

"Yes. I'm finished." He pushed himself off the wall, then bounced away and twisted back to face her. "No. I'm not. I think you're being a total hypocrite, and I think it's undermining whatever social value the *Morrígu* experiment was meant to have."

Khalidah felt her eyebrows crawl up to touch the edges of her veil. "Excuse me?"

"Yeah. You heard me. You're being a hypocrite." He lowered his voice. "Do your friends even know your dad died? Did you tell them that he was dying, when you left? Because I was told not to mention it, and that sure as hell sounds like a secret to me."

Khalidah closed her eyes. The only place to go, in a space this small, was inward. There was no escape, otherwise. She waited until that soft darkness had settled around her and then asked, "Why are you doing this?"

"Because you're *not* alone, out here. You *have* friends. Friends you've known and worked with for years, in one way or another. So what if Donna jerked you around? She jerked me around too, and you don't see me acting like a brat about it. Or Brooklyn. Or Song. Meanwhile you've been keeping this massive life-changing event from them this whole time."

Now Khalidah's eyes opened. She had no need for that comforting blanket of darkness now. "My father dying is not a massive life-changing event," she snapped. "You think you know all my secrets? You don't know shit, Marshall. Because if you did, you'd know that I haven't spoken to that bastard in 10 years."

As though trying to extract some final usefulness from their former mistress, the drills decided to fail before the Banshee units returned with their samples, and before *Ganesha* arrived with the re-up and the Mars crew. Which meant that when *Ganesha* landed, the crew would have to live in half-dug habs.

"It's the goddamn perchlorate," Donna whispered. She had trouble swallowing now, and it meant her voice was constantly raw. "I told them we should have gone with the Japanese bit. It drilled the Shinkansen, I said. Too expensive, they said. Now the damn thing's rusted all to shit."

Which was exactly the case. The worm dried up suddenly, freezing in place—a "Bertha Bork," like the huge drill that stalled under Seattle during an ill-fated transit project. They'd rehearsed this particular error. First they ordered all the rovers away in case of a sinkhole, and then started running satellites over the sink. And the drill himself told them what was wrong. The blades were corroded. After five years of work, too much of the red dirt had snuck down into the drill's workings. It would need to be dug out and cleaned before it could continue. Or it would need to be replaced entirely.

The replacement prototype was already built. It had just completed its first test run in the side of a flattened mountain in West Virginia. It was strong and light and better articulated than the worm. But the final model was supposed to come over with *Ganesha.* And in the meantime, the hab network still needed major excavation.

"What's the risk if we send one of the rovers to try to uncover it?" Song asked. "We've got one in the cage; it wrapped up its mission ages ago. Wouldn't be too hard to reconfigure."

"Phobos rovers might be too light," Marshall said. "But the real problem is the crashberry; it'll take three days to inflate and another week to energize. And that's a week we're not drilling."

"We could tell *Ganesha* to slow down," Khalidah said.

"They're ballistic capture," Marshall said. "If they slow down now, they lose serious momentum."

"They'd pick it up on arrival, though."

"Yeah …" Marshall sucked his teeth. "But they're carrying a big load. They could jackknife once they hit the well, if they don't maintain a steady speed." He scrubbed at the thin dusting of blonde across his scalp. "But we have to tell them about this, either way. Wouldn't be right, not updating them."

Khalidah snorted. The others ignored her.

"Can we redirect the Banshees?" Brooklyn asked. "Whiskey and Tango are the closest. We could have them dump their samples, set a pin, tell them to dig out the worm, and then come back."

Khalidah shook her head. "They're already full. They're on their way to the mail drop. If we redeployed them now, they wouldn't be in position when *Ganesha* arrives. Besides, they're carrying Hellas—we can't afford to compromise them."

"Those samples are locked up like Fort Knox," Brooklyn said. "What, are you worried that the crew of *Ganesha* will open them up by mistake? Because that's pretty much guaranteed not to happen."

"No, but—"

"There's a storm in between Whiskey and the worm," Marshall said. He pointed at an undulating pattern of lines on the screen between two blinking dots. "If we send Whiskey now, we might lose her forever. And the samples. And we still wouldn't be any further with the drill. Fuck."

He pushed away from the console, knuckling his eyes. Khalidah watched the planet. In the plate glass, she caught Donna watching her. Her friend was much thinner now. They'd had to turn off her suit, because it no longer fit snugly enough to read her heartbeat. Her breath came in rasps. She coughed often. Last month, Song speculated that the cancer had spread to her lungs; Donna claimed not to care very much. Khalidah heard the older woman sigh slow and deep. And she knew, before Donna even opened her mouth, what she was about to suggest.

"There's always the *Corvus*," Donna said.

"No," Khalidah said. "Absolutely not."

But Donna wasn't even looking at her. She was looking at Marshall. "How much fuel did they really send, Marshall? You got here awfully fast."

Marshall licked his lips. "Between what I have left over and what *Ganesha* is leaving behind for you midway, there's enough to send you home."

"Which means *Corvus* has just enough to send me down, and give me thrust to come back."

"Even if that were true, you could still have a seizure while doing the job," Song said.

"Then I'll take my anti-seizure medication before I leave," Donna said.

"The gravity would demolish you, with the state you're in," Marshall said. "It should be me. I should go. I know *Corvus* better, and my bone density is—"

"That's very gallant of you, Mr. Marshall, but I outrank you," Donna reminded him. "Yes, I tire easily. Yes, it's hard for me to breathe. But I'm stronger than I would be if I were on chemo. And the suit can both give me some lift and push a good air mix for me. Right, Brooklyn?"

Brooklyn beamed. "Yes, ma'am."

"And Marshall, if any of those things do occur, I need you up here to remote-pilot *Corvus* from topside and get the samples back here." She gestured at the map. "If you tell Tango to meet me, I can take her samples and put them on *Corvus*. Then I get in Tango's cargo compartment and drive her around the storm, to the worm. I dig out the drill, and you restart it from up here. When I come back, you have the samples, and *Ganesha* has another guestroom." She grinned. The smile made her face into a skull. "Easy peasy," Donna said.

"You know you're making history, right?" Marshall asked, as they performed the final checks on *Corvus*. "First human on Mars, and all that. You're stealing *Ganesha*'s thunder."

Donna coughed. "Don't jinx it, Marshall."

“How are your hands?”

Donna held them up. Slowly, she crunched her thickly gloved digits into fists. “They’re okay.”

“That’s good. Go slow. The Banshees take a light touch.”

“I know that, Marshall.”

He pinked. “I know you know. But I’m just reminding you. Now, I’ll get you down there, smooth as silk, and when it’s time to come home you just let us know, okay?”

Donna’s head tilted. She did that when she was about to ask an important question. For a moment it reminded Khalidah so much of the woman she’d been and the woman they’d lost that she forgot to breathe. “Is it home now, for you?”

Marshall’s blush deepened. He really did turn the most unfortunate shade of sunburned red. “I guess so,” he said. “Brooklyn, it’s your turn.”

Brooklyn breezed in and, flipping herself to hang upside down, performed the final checks on Donna’s suit. “You’ve got eight hours,” she said. “Sorry it couldn’t be more. Tango is already on her way, and she’ll be there to meet you when you land.”

“What’s Tango’s charge like?”

“She’s sprinting to meet you, so she’ll be half-empty by the time she hits the rendezvous point,” Marshall said. “But there’s a set of auxiliary batteries in the cargo area. You’d have to move them to get into the cockpit anyhow.”

Donna nodded. The reality of what was about to happen was settling on them. How odd, Khalidah thought, to be weightless and yet to feel the gravity of Donna’s mission tugging at the pit of her stomach. The first human on Mars. The first woman. The first cancer patient. She had read a metaphor of illness as another country, how patients became citizens of it, that place beyond the promise of life, and now she thought of Donna there on the blood-red sands, representing them. Not just a human, but a defiantly mortal one, one for whom all the life-extension dreams and schemes would never bear fruit. All the members of the *Ganesha* crew had augmentations to make their life on Mars more productive and less painful. Future colonists would doubtless have similar lifehacks. Donna was the only visitor who would ever set an unadulterated foot on that soil.

“I’ll be watching your vitals the whole time,” Song said. “If I don’t like what I see, I’ll tell Marshall to take control of Tango and bring you back.”

Donna cracked a smile. "Is that for my benefit, or the machine's?"

"Both," Song said. "We can't have you passing out and crashing millions of dollars' worth of machine learning and robotics."

And then, too soon, the final checks were finished, and it was time for Donna to go. The others drifted to the other side of the airlock, and Brooklyn ran the final diagnostic of the detachment systems. Khalidah's hands twitched at her veil. She had no idea what to say. *Why did you lie to us? Did you really think that would make this easier? What were you so afraid of?*

Donna regarded her from the interior of her suit. She looked so small inside it. Khalidah thought of her fragile body shaking inside its soft volumes, her thin neck and her bare skull juddering like a bad piece of video.

"I want—"

"Don't," Donna said. "Don't, Khal. Not now."

For the first time in a long time, Khalidah peeped at Donna's aura through the additional layer in her lenses' vision. It was deep blue, like a very wide and cold stretch of the sea. It was a color she had never seen on Donna. When she looked at her own pattern, it was much the same shade.

Marshall chose this moment to poke his head in. "It's time."

Donna reached over to the airlock button. "I have to go now, Khalidah."

Before Khalidah could say anything, Marshall had tugged her backward. The door rolled shut. For a moment she watched Donna through the small bright circle of glass. Then Donna's helmet snapped shut and she wore a halo within a halo, like a bull's-eye.

The landing was as Marshall promised: smooth as silk. With *Corvus* he was in his element. He and the vessel knew each other well. They'd moved as much of *Corvus*'s cargo as they could into temporary storage outside the hab; the reduced weight would give Donna the extra boost on the trip back that she might need.

Donna herself rode out the landing better than any of them expected. She took her time unburdening herself of her restraints, and they heard her breathing heavily, trying to choke back the nausea that now dominated her daily life. But eventually she lurched free of the unit, tuned up the jets on her suit, jiggered her air mix, and began the unlocking procedure to open *Corvus*. They watched her gloved hands hovering over the final lock.

"I hope you're not expecting some cheesy bullshit about giant leaps for womankind," Donna said, panting audibly. She sounded sheepish. For Donna, that meant she was nervous. "I didn't really have time to prepare any remarks. I have a job to do."

Brooklyn wiped her eyes and covered her mouth. Marshall passed her a tissue, and took one for himself.

"You've wanted this since you were a little girl, Donna," Song said. "Go out there and get it."

Together they watched the lock spin open, and Donna eased herself out. There was Tango, ready and waiting. And there was Mars, or at least their little corner of it, raw and open and red like a wound.

"I wish I could smell it," Donna said. "I wish I could taste the air. It feels strange to be here and yet not be here at the same time. You can stand here all you want and never really touch it."

"You can look at the samples when you bring them back," Brooklyn managed to say.

Donna said nothing, only silently made her way to Tango and moved the samples back to *Corvus*. Then she began the procedure to get Tango into manual. Her feed cut out a couple of times, but only briefly; they hadn't thought to test the signal on the cameras themselves. Her audio was fine, though, and Marshall talked her through when she had questions. In the end it ran like any other remote repair. Even the dig went well; clearing the dirt from the drill and restarting it from the control panel was a lot simpler than any of them had expected.

Halfway back to *Corvus*, Tango slowly rolled to a stop.

"Donna, check your batteries," Marshall suggested.

There was no answer. Only Donna's slow, wet breathing.

"Donna, copy?"

Nothing. They looked at Song; Song pulled up Donna's vitals. "No changes in her eye movements or alpha pattern," Song whispered. "She's not having a seizure. Donna. Donna! Do you need help?"

"No," Donna said, finally. "I came here to do a job, and now I'm finished with it. I'm done."

Something in Khalidah's stomach turned to ice. "Don't do this," she whispered, as Marshall began to say "No, no, no," over and over. He started bashing things on the console, running every override he could.

"No, you don't, you crazy old broad," he muttered. "I can get Tango to drive you back, you know!"

"Not if I've ripped out the receiver," Donna said. She sounded exhausted. "I think I'll just stay here, thank you. *Ganesha* can deal with me when they come. You don't have to do it. You'd have had to freeze me, anyway, and vibrate me down to crystal, like cat litter, and—"

"Fuck. You."

It was the first full complete sentence that Khalidah had spoken to her in months. So she repeated it.

"Fuck you. Fuck you for lying to us. Again. Fuck you for this selfish fucking bullshit. Oh, you think you're being so romantic, dying on Mars. Well fuck you. We came here to prove we could live, not ..." Her lips were hot. Her eyes were hot. It was getting harder to breathe. "Not whatever the fuck it is you think you're doing."

Nothing.

"Donna, please don't," Brooklyn whispered in her most wheedling tone. "Please don't leave us. We need you." She sounded like a child. Then again, Khalidah wasn't sure she herself sounded any better. Somehow this loss contained within it all the other losses she'd ever experienced: her mother, her father, the slow pull away from the Earth and into the shared unknown.

"This is a bad idea," Marshall said, his voice calm and steady. "If you want to take the Lethezine, take the Lethezine. But you don't know how it works—what if it doesn't go like you think it will, and you're alone and in pain down there? Why don't you come back up, and if something goes wrong, we'll be there to help?"

Silence. Was she deliberating? Could they change her mind? Khalidah strained to hear the sound of Tango starting back up again. They flicked nervous, tearful glances at each other.

"Are you just going to quit?" Khalidah asked, when the silence stretched too long. "Are you just going to run away, like this? Now that it's hard?"

"You have no idea how hard this is, Khal, and you've never once thought to ask."

It stung. Khalidah let the pain transform itself into anger. Anger, she decided, was the only way out of this problem. "I thought you didn't want me to ask, given how you never told us anything until it was too late."

"It's not my fault I'm dying!"

"But it's your fault you didn't tell us! We would have—"

"You would have convinced me to go home." Donna chuckled. It became a cough. The cough lasted too long. "Because you love me, and you want me to live. And I love you, so I would have done it." She had another little coughing jag. "But the trouble with home is that there's nothing to go back to. I've thrown my whole life into this. I've had to pass on things—real things—to get to this place. But now that I'm here, I know it was worth it. And that's how I want to end it. I don't want to die alone in a hospital surrounded by people who don't understand what's out here, or why we do this."

Khalidah forced her voice to remain firm. "And so you want to die alone, down there, surrounded by nothing at all?"

"I'm not alone, Khal. You're with me. You're all with me, all the time."

Brooklyn broke down. She pushed herself into one corner. Khalidah reached up, and held her ankle, tethering her into the group. She squeezed her eyes shut and felt tears bud away. Song's beautiful ponytail drifted across her face. Arms curled around Khalidah's body. Khalidah curled her arms around the others. They were a Gordian knot, hovering far above Donna, a problem she could not solve and could only avoid.

"That's right, Donna," Marshall said. "We're here. We're right here."

"I'm sorry," Donna said. "I'm sorry I lied. I didn't want to. But I just … I wanted to stay, more than I wanted to tell you."

"I'm sorry, too," Khalidah said. "I …" She wiped at her face. Her throat hurt. "I miss you. Already."

"I miss you, too. I miss all of you." Donna sniffed hard. "But this is where we're supposed to be. Because this is where we are at our best."

They were quiet for a while. There was nothing to do but weep. Khalidah thought she might weep forever. The pain was a real thing—she had forgotten that it hurt to cry. She had forgotten the raw throat and pounding head that came with full-body grief. She had forgotten, since her mother, how physically taxing it could be.

"Are you ready, now?" Song asked, finally. She wiped her eyes and swallowed. "Donna? Are you ready to take the dose?"

The silence went on a long time. But still, they kept asking, "Are you ready? Are you ready?"

Acknowledgments: First, I am grateful to Ed Finn, Joey Eschrich, Alissa Haddaji, and Steve Ruff at Arizona State University for their tireless work bringing this incredibly special project to fruition. I'm also profoundly lucky to have worked with Zachary Pirtle and Jacob Keaton at NASA. It is beyond cool to have had these gentlemen answer my questions. I also want to thank Scott Maxwell for his input and commentary, as well as his open discussion of his work as a Mars rover driver. (I should also thank Joi Weaver for introducing us!) Lastly, I must thank my husband David Nickle, who was beyond patient with me as I worked through one of the most difficult, engaging stories of my career.

LIFE ON MARS?

by Steve Ruff

I consider myself a Martian, at least virtually, like Karl Schroeder's "homesteaders." I'm actually a Mars geologist, a scientist who applies knowledge of Earth geology to explore Mars geology. But for three months in 2004, I and a few hundred other Earthbound explorers at the Jet Propulsion Laboratory got as close to being Martians as humanly possible at this point in history. Many of us from across the U.S. and abroad took up residence in Pasadena and surroundings so that we could ride shotgun with the Spirit and Opportunity rovers. Our apartments were equipped with blackout window shades to help adjust our wake and sleep cycle to the rising and setting sun in the Martian sky. We needed to be on Mars time, just like the rovers. Just like Wekesa Ballo.

Although we Terrans share the same Sun with the real Martians (if they exist), their planet turns just a bit more slowly on its axis than ours, such that the Martian day is 39 minutes and 35 seconds longer. This Martian "sol" is quite a cosmic coincidence. Our other next-door neighbor, Venus, rotates the slowest of any planet. So a "day" there would stretch for more than 243 Earth days, precluding any hope of living on Venus time.

Mars time, however, I could get used to. My night-owl ways had unexpectedly prepared me for a mission with about 40 minutes of bonus time each night, followed by the luxury of sleeping 40 minutes later each morning. Apparently my circadian metronome beats with a Martian rhythm. I was among the lucky few. My housemate lasted only a week before his decidedly terrestrial metronome forced him back to the rhythm of Earth time.

Like my housemate, the baker and homesteaders in Schroeder's story are permanently jet-lagged, a condition experienced by many of the JPL-based "Martians." Fortunately, the jet lag of our team of JPL Martians ended after a mere 90 sols, the prespecified length of the rovers' primary mission. The rovers, of course, are immune to jet lag and free from human frailties. They have been loyal mechanical surrogates following the commands of their Earthbound masters each day since their landing, one of them for more than 13 years now.

For decades we've been sending our robotic surrogates to Mars. The first spaceships had just minutes of close encounters with the alien planet before sailing past. Subsequent missions graduated to extended visits in orbit, bolstered by ever-improving capabilities to sense the landscape a few hundred miles below and to probe the meager atmosphere in between.

Our first touch of Martian soil came in 1976 from one-armed robotic landers, an incredible feat of engineering and science prowess. But the lack of mobility of the Viking landers was so frustrating that Carl Sagan wrote in *Cosmos* how he found himself "unconsciously urging the spacecraft at least to stand on its tiptoes, as if this laboratory, designed for immobility, were perversely refusing to manage even a little hop."[1] The rover mission he so passionately championed would not come until after his untimely death. That 1996 Pathfinder mission was wildly successful, but its modestly equipped little rover never ventured out of sight of its aptly named home base, the Carl Sagan Memorial Station.

Nearly 10 years would pass before the next rovers visited Mars. Spirit and Opportunity arrived in 2004 with significant advances in mobility and scientific instrumentation, but their capacity to explore is still very limited. They undertake reconnaissance by committee, following orders from humans tens of millions of miles away who have an incomplete picture of the landscape through which the rovers move at the pace of a Galápagos tortoise. Even the newer, larger, and more sophisticated Curiosity rover still suffers from the same exploration-at-a-distance realities of its precursors. This is not an efficient way to investigate the vast reaches of an unknown planet. I often wonder what pieces of the scientific puzzle we're missing that a geologist on the surface would've zeroed in on with ease.

Karl Schroeder's story describes a near future in which humans interact with Mars through virtual reality "telecommuting" in much the same way as our Earthbound teams navigate the terrain via rovers. The homesteaders and we must deal with the tens of minutes of time delay, but they use smarter robots and greater visibility of the landscape to create enhancements in productivity. For Schroeder's imagined future to work as intended, however, we'll need significant improvements in satellite and receiver infrastructure to increase the amount of data sent between the planets. The fastest data rate from Mars to Earth today is two megabits per second. That's about five times slower than the slowest "Starter Package" offered by my home internet service provider. We're going to need at least the "Premier Package" to make high-definition 3D telepresence viable.

In a very different vision of Mars exploration, Madeline Ashby's story "Death on Mars" puts the human explorers in orbit around the Red Planet, using Phobos, one of its two tiny moons, as a natural satellite base camp. This would offer the major advantages of allowing astronauts to command rover activity in real time and the potential for much greater transfers of data. Other benefits include the fact that the microgravity of the moons allows spacecraft to land and take off with very little effort or special equipment compared with landing and taking off from the Martian surface. So appealing are these benefits that NASA is seriously eyeing this possibility as one of the first steps in the journey of humans to Mars. But even in this scenario, major advances in rover capabilities will still be necessary.

We've already started to teach old rovers new tricks. For example, in the search for Martian dust devils using rover cameras, the otherwise data-intensive effort is minimized via software that only returns images in which a change is detected. And interesting rocks can now be targeted for imaging and other non-contact measurements using onboard software that is smart enough to recognize them without a human in the loop. Ultimately however, true in-depth exploration of the Red Planet will require highly mobile and dexterous robots that can explore and interact with the Martian environment using artificial intelligence. Just as test pilot astronauts during the Apollo era learned the fundamental skills of a geologist, so too could robotic surrogates on Mars. But unlike the rudimentary capabilities of the Apollo geologists, future Mars robotic geologists will be equipped with sensor systems unimaginable in the 1970s. These tools will identify rocks and minerals with a precision and accuracy that even skilled field geologists on Earth would envy. The discoveries of these robotic explorers would be the starting point for human explorers to make sorties from their orbiting base camp, and ultimately, from their surface exploration zones.

But what is the point of all of this Mars exploration? The easiest answer is the search for past or present life. As a geologist, I could be perfectly happy just learning about the history of that distant planet independent of the search for life. But the most profound discovery in all of space exploration will come when we find life beyond Earth. We have only one data point in the entire universe regarding life, only one planetary body known to harbor it. Never mind that Earth represents an absurdly rich and fecund harbor; it's still the only data point we've got. So even the discovery of fossil microbes on Mars would double the number of planets that we know to host life. And to borrow a concept from Isaac Asimov, it's unlikely that, having found a second example of life in the universe, there are indeed only two.

In this context, robotic explorers offer a major advantage over humans in the search for Martian life: they lower the possibility of contaminating the surface of Mars with human-borne microbes. It's relatively straightforward to reduce the "bioload" on hardware; not so for humans. The search for microbes on Mars is more likely to yield unambiguous results if the searchers are not carrying colonies of terrestrial microbes.

It still may take human explorers on the surface of Mars to prove once and for all whether life was or is present there. But I don't think we've reached that point yet. We've never even brought back samples to search for traces of microbial Martians (rather than little green men). Yes, we've got several dozen rock samples from Mars thanks to natural impact events launching them into space to ultimately fall as meteorites on Earth. But these Martian meteorites are nearly all igneous rocks, the ones most able to survive the violent expulsion from their home world and *least* likely to host evidence of Martian microbes. We need to collect samples of rocks known to have formed in habitable environments on Mars from a time and place that offers the greatest likelihood of having hosted inhabitants.

This is precisely the intent of the next NASA Mars rover mission in 2020. For the first time in the history of Mars exploration, we'll have a rover capable of collecting cored rock samples and caching them for possible future return to Earth. It's going to require some really *interesting* rock samples to compel the launch of a follow-up mission to pick them up and deliver them Earthside. But our robotic reconnaissance has already delivered a compelling view of Mars as a planet with an early history that really may have had habitable environments capable of supporting life—life which would be captured and preserved in the rock record.

After decades of preparation, we're finally poised to collect rock samples most likely to answer the question of life on Mars. Though complicated, collecting samples robotically and sending them back to Earth for analysis offers benefits beyond minimizing the potential for organic contamination. The full capabilities of instruments and techniques in labs on Earth can be deployed in the search for microbes in the returned samples. It's simply not possible to equip rovers for such complex analyses. Yet the biggest benefit of sample collection via robot comes from the substantially lower costs, in part because it's so much easier to equip rovers to deal with the incredibly inhospitable conditions of the Martian environment.

The surface of Mars today is lethal to life as we know it, which may be why we haven't found any yet. Even the least clement places on Earth are far more tolerable than the most hospitable places on Mars, starting with the most precious resource for human life: oxygen. The atmospheric pressure of Mars is less than 1% that of Earth, and 95% of that thin atmosphere is the stuff we breathe out, carbon dioxide. The life-giving oxygen molecules that we breathe in are considered a "trace" gas on Mars at less than 1%. Heavy tanks of oxygen would be essential gear for human explorers, as well as pressurized suits to keep one's fluids from boiling away.

Then there's the cold. Despite the presence of a known greenhouse gas in the atmosphere, there's just not enough of it to provide the warmth that humans need to survive. Although you could walk barefoot comfortably on a summer day near the equator thanks to the heat-absorbing soil and rocks, you'd need a jacket and hat for warmth against the freezing air temperatures. At night, you'd need a lot more than warm clothes to survive the plummeting temperatures that bottom out near minus 100°F. In the wintertime, at latitudes beyond about 40° from the equator, it gets cold enough on Mars that carbon dioxide in the atmosphere condenses out as a layer of dry ice at nearly 200°F below zero. So far, even rovers haven't ventured more than 15° from the relative warmth of the equator, and even there they still require electric heaters on the motors that drive wheels and other moving components.

Rovers are relatively immune to other nasty features of the Martian environment like global dust storms, ionizing radiation, and toxic salts in the soil that will challenge human explorers, not to mention potential future colonists. Some view colonization of Mars as a hedge against a calamitous end to human life on Earth. But for thousands of years, no war, disease, or famine has ever come close to wiping out our prolific and tenacious species. More importantly, over Earth's history, even the greatest natural calamities produced from within the Earth and from without have never made our planet less habitable than Mars. The same goes for Earth's most extreme climate changes. And even the dreaded scenario of all-out nuclear war would not strip Earth of its life-giving oxygen or rainfall. Humanity would be forced to mitigate the effects of ionizing radiation, but that's already the case on Mars today. Billions of years ago its internal dynamo died, taking with it the protective bubble of a magnetic field that shielded it from cosmic and intense solar radiation. Earth's dynamo still churns out a magnetic bubble, with no realistic scenario for its demise in sight.

Some view Mars as a new frontier to be settled, like the American West, or as a place to create a new and better human society. But the Western pioneers didn't have to worry about how they were going to breathe, or keep out radiation, or farm land devoid of organic matter and covered in toxic salts. Such conditions would challenge even the most committed founders of a new Mars society. It would be much easier to establish a colony in the Atacama Desert or any other of the most barren and uninhabited places on Earth.

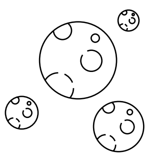
Regardless of the incredible challenges of sending humans to Mars, I can't wait to see it happen. There's no shortage of volunteers ready for a chance to go, and I fantasize about being among them. Despite my fantasy, I suspect that the first boots on Mars will arrive long after mine are packed away. As a child in the Apollo era, I watched the Moon landings and expected to see flags and footprints on Mars by my early adulthood. But that trajectory was unsustainable, driven not by science and the quest for knowledge, but instead by a Cold War imperative. In my advancing middle age, I don't see a comparable driver for sending human explorers to Mars, or a compelling rationale for the even greater challenges of sending human colonists. But with perhaps-naïve optimism, I do imagine a scenario in which robotic missions return Martian rock samples that reveal tantalizing hints of long-dead biota, creating a new imperative for sending humans to find the answer. In doing so, there will indeed be life on Mars.

Acknowledgments: Exploration of Mars would not be possible without the efforts of countless engineers, scientists, administrators, and staff at NASA and its academic and industrial partners. Together we are privileged to do so thanks to the commitment of the public and its representatives.

Notes

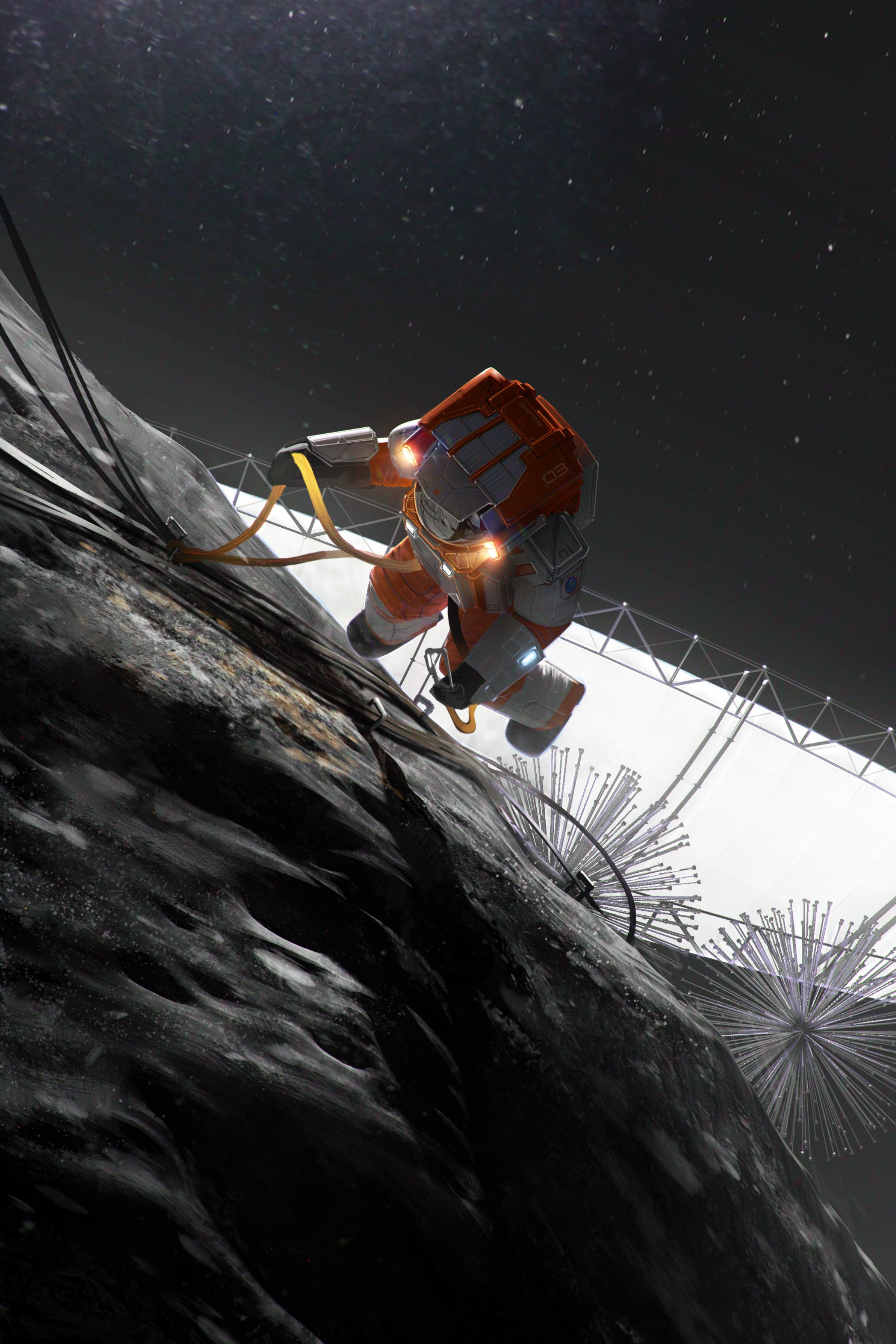
1 Carl Sagan, *Cosmos* (New York: Ballantine Books, 2013): 137. First published in 1980.

SECTION III • ASTEROIDS



Back in the socket, on the other side of the cable, upbound elevator cars were being loaded with refined metals, platinum, gold, uranium, and silver. Then the cars swung in and locked onto the piste, and up they rose again, accelerating slowly to their full speed of 300 kilometers an hour. Five days later they arrived at the top of the cable, and decelerated into locks inside the ballast asteroid Clarke, now a much-tunneled chunk of carbonaceous chondrite, so filigreed with exterior buildings and interior chambers that it seemed more a spaceship or a city than Mars's third moon. It was a busy place; there was a continuous procession of incoming and outgoing ships, and crews perpetually in transit, as well as a large force of local traffic controllers, using some of the most powerful AIs in existence. Though most of the operations involving the cable were computer controlled and robotically accomplished, entire human professions were springing up to direct and oversee all these efforts.

—*Kim Stanley Robinson,* Red Mars


03

THE USE OF THINGS

by Ramez Naam

Useless. The word kept running through Ryan's head. It was Beth Wu's voice he heard, though she hadn't said it.

He had.

Oh god, he wished he'd listened to her.

"Emergency!" he yelled again. "Emergency!" The stars spun around him as he tumbled, out of control. His suit screamed alerts at him, both visual and audible:

SUIT INTEGRITY COMPROMISED LOW AIR PRESSURE

ANCHOR LOST MANEUVERING OFFLINE

The asteroid swam back into view as he spun, his landing ship on it, both of them further now, tens of meters, receding away from him. Momentum from the accident that had ripped him free of his tether and free of the rock propelled him outward, away from everything. He was going to die in this ripped space suit, die thinking of Beth Wu, a hundred million miles away, and how right she'd been.

"FUUUUUUCK!" he yelled. "Emergency! Houston, this is Ryan Abrams. Torn loose from the rock, tether detached, tumbling, suit leaking. S.O.S.!"

Shit.

Hours Earlier

Ryan Abrams pulled himself, hand over gloved hand, along the last few metal rungs that led to the Asteroid Landing Module. In microgravity, walking was impossible. There was no up or down. The only way to stay attached to the asteroid was to tether yourself or to physically hold on. He was doing both now, prone, his body facing the asteroid, his security harness clipped to the long metal cable bolted into the asteroid surface.

He reached his left hand "up," grasped the next rung, pulled his right to follow. Ahead was the Asteroid Landing Module, just a few pulls away now. Repeat. Repeat. A sample bag was clipped at his waist, full of asteroid material he'd drilled at predetermined sites. It floated free in the near-absence of gravity, tugged along each time he moved forward, then carried by its momentum to gently thump against his side each time he stopped.

His hand left the last of the rungs the robots had drilled into the surface. He reached up, grasping a rung on the side of the ALM itself, pulling himself up until he faced it, rather than the asteroid's surface. With one hand he moved his harness clips onto the craft. Then he palmed the airlock button. Through the metal he felt the vibration of the airlock cycling. One wall of the lander opened, and he unclipped and propelled himself and his sample bag into it.

At the back wall he clipped in again, then turned, swiveling his head inside the helmet of his Asteroid Surface Excursion Suit. His eyes swept over the surface of this small rock, barely a hundred meters across, its skin pitted and scarred by billions of years of collisions with micro-meteorites. The edges of those impact craters were still raw and jagged. They'd stay that way for millennia, with neither wind nor water to smooth them.

Now that surface crawled with CALTROPs, hundreds of them, like so many sea urchins, rolling slowly over the rock, thousands of carbon limbs adhering and releasing, probing, sampling.

Doing everything he could do.

A few hundred grams. That's what a CALTROP massed. Hundreds of times less than he did. Almost all that mass was in the core, the fist-size package of logic and power in the heart of the spikes. The limbs themselves, half a meter long, massed little, but packed in an impressive array of capabilities. Adherence pads covered the tips of half of them: arrays of microscopic, Velcro-like carbon tendrils, inspired by the sticky finger pads of a gecko, which allowed them to adhere to nearly any surface, or release it. The other half of the limbs were tipped with an assortment of microscopic drills, sensors, material sampling instruments, tiny manipulators.

The first time Abrams had read the specs of the CALTROPs, he'd found them impressive. When he actually saw them in action, all of them moving, perfectly coordinated, in silence, covering the surface of the rock with an ease he'd never achieve … well, he'd found them a bit unnerving.

Now, weeks later, he just found them depressing.

They didn't need him here. The mission didn't require him. These things could do the job, under Beth Wu's command from Houston, without any human on-site, or all the expensive infrastructure required to move that human, keep him or her fed and watered and oxygenated.

He'd heard a glib comment once, from his roommate back at MIT. The data center of the future would have just one man in it, Jimmy said, and one dog.

The man's job was to feed the dog.

The dog's job was to make sure the man didn't touch anything.

They should have sent me a dog, Ryan thought to himself.

He palmed the control to close the outer airlock door.

He and Beth had quarreled before his departure.

"You know we shouldn't be sending you on this," she said. "A human's a liability up there, not an asset."

Trust Beth to be so blunt.

It was late on a Tuesday night, and the bar, a homey little place outside Johnson Space Center, was almost empty.

He'd spread his hands wide, placatingly, one palm open, the other casually holding onto his beer.

"Look, Beth. I know this was originally going to be an uncrewed mission. But I can do things your bots can't."

She looked back at him, no placation at all.

"They're NASA's bots. Not mine. They're *taxpayer* bots. And sending you there costs the taxpayers as much as sending *thousands* of them."

He started to interject. She cut him off.

"Ryan, getting you there in one piece, all your food, your water, your air, your triple-redundant safety systems, it's twenty *thousand* kilos! Think about all the instruments we could pack in that payload instead! And it's *billions* of dollars. Just for you!" She started gesticulating then, waving her arms about, agitated. "Yeah, you can do a few things no robot can. But thousands of them can do a whole heck of a lot more useful work than you. And with the money spent on your trip, we could close whatever capability gap there is."

He grimaced, breaking eye contact. "You're saying I'm useless."

"No," Beth said the word slowly, like she was explaining calculus to a child. "You have your uses. But the price is way too high. A heck of a lot higher than your value. You're a *net liability* to the mission."

"Worse, then. Worse than useless." He looked back up, met her eyes, dared her to agree.

She sighed in exasperation. "Stop pouting, Ryan. This isn't about you. It's about *the mission*."

He grew impatient with her, let it show. "Dammit, Beth. We're out there figuring out how to build habitats! We're out there building a road. We're out there figuring out how to get men and women *living* off-planet! Crewed missions have to be part of it!"

She stared at him for a moment, studying him, her eyes roving over his face. "You're half-right. We do need to get our species off this planet, out of our one little basket. Space *is* for humans ..."

"So why ..." he tried to interject.

She slapped a hand onto the table. "Because the fastest way to *build* that road into space for our species is not to send *you* on this mission!"

Liftoff was by far the most demanding part of the journey out. He'd launched before, half a dozen times, on trips to LEO and an orbit of the Moon. Still, being on top of a 38-story-tall rocket, pushing 8 million pounds of thrust out of its engines, never became routine. It never got easy. The g-force slammed him back into his padded seat with the weight of four gravities, crushing the breath out of him for those first two minutes, the whole rocket shaking and shuddering and roaring around him, as the sky turned from blue to black.

Then the boosters separated, the acceleration slowed, faded, then dribbled to nothing. His body floated in its harness.

Orbit.

The world sped by below him: a storm over the Atlantic in stark white; a clear stretch of ocean in stunning blue, dotted with white clouds and their darker blue shadows; the yellow and green of Western Africa, glittering with the reflected light of the giant Moroccan solar fields that powered Europe.

Ryan exhaled, the tension leaving him. He blinked, his eyes wet. Suddenly, the whole world, the whole basket humanity's eggs were in, spread out below him.

Then NERFS came into view, the Near Earth Re-Fueling Station, in an orbit just below his. Its solar panels stretched out wide, framing its tubular modules stuffed full of water ferried up from the Moon. Its docking ports were crowded with droneships, tiny things massing just hundreds of kilos at most, and some much smaller, filling up with water their reactors would ionize and their efficient ion engines would thrust back out, one ion at a time, propelling themselves up and out. Many of them heading to his own final destination, on a slower, more efficient route.

Ryan frowned. Beth's words came back to him.

We're bootstrapping a whole new way to do space, she'd said. *The first lift of water ice from the Moon was ungodly expensive. It used chemical rockets like the ones that'll get you going. But then we had a little bit of fuel. The second trip just needed enough fuel to get to LEO. Then it could refuel with lunar water, use that fuel thousands of times more efficiently as propellant in its ion engines to get out to the Moon. And then we could lift twice as much fuel. Then four times. Then eight times. And soon 16 times as much fuel per cycle as that first mission. That's where we're going, Ryan. The robots can grow that infrastructure exponentially. They can operate 24/7. We're going to mass produce them, make them cheap, launch them into LEO on old cheap rockets, and let them build us a home in space without any of us having to risk our lives there until it's done.*

It was true. Everything had changed. Logic was cheap now. Guidance was cheap. What had been a million dollars of guidance and AI in his youth was now cheap enough, small enough, energy-lean enough that you could stuff it into a child's toy. You could make a lunar spacecraft in a package the size of a bread box, with more computing power than one of the data centers that had powered the first internet revolution.

Cheap made for easy. A high school had landed a CubeShip smaller than a basketball on the Moon last year. They'd built it themselves in an engineering classroom, fitted it with a tiny ion engine, paid for a commercial launch and commercial in-orbit fueling at NERFS, and flown it slow and steady, beaming back video the whole way.

The whole mission had cost $50,000.

The space suit he wore cost a hundred times that. The rest of the gear that kept him alive cost a hundred times what his space suit did. Billions versus tens of thousands. Maybe he *was* dead weight.

Maybe he really was useless.

"You know why you're really going," Beth had said.

He leaned back and smiled, tried not to show how discomfited he was. "Because we're explorers, Beth. Because exploring the universe is *what we do.*"

She snorted.

He shook his head in mild exasperation. "Fine. Let me guess. You're going to say … *politics*." He couldn't deny it played a role. The asteroid mission had been planned as uncrewed. Word was that Congress had privately demanded a face the public could see. And why shouldn't they? Sending a *person* up there meant a hell of a lot more than any number of drones.

Beth looked at him. "Worse, Ryan. It's *PR*."

He'd raised an eyebrow.

"PR," she repeated. "A story. A narrative. PR in a world where robots build everything, where software drives the trucks that deliver what we want, where software diagnoses what's wrong with you, and software guides the scalpel. PR to tell people they aren't useless. To convince people they're relevant again."

He gnawed on that one. "What's wrong with that, Beth? With giving people some hope?"

She frowned at him. "It's a lie. That's what's wrong. It's a fairy tale. Is that what you want to be? Just a pretty face for the cameras, to make people back here feel better about their lives?"

God damn, she could cut when she wanted to.

Beth shook her head at him. "Are you an astronaut, Ryan? Or an actor?"

Ryan pursed his lips and turned away from NERFS to prepare for second stage separation, and the trip out to the asteroid.

Water. Water was life. Water was *fuel*. Water was the key to exploring the solar system.

Fuel up a rocket on Earth, at the bottom of a steep gravity well. Use whatever fuel you want: hydrazine, or pure liquid hydrogen and oxygen, like his ship used, or the aluminum compounds they still used in solid rocket boosters. Any fuel, it didn't matter.

That fuel made up almost all the weight of your spacecraft.

Fire your engines, launch into space. Not even far into space—just to LEO—Low Earth Orbit. Most of what your engines were lifting was fuel. The ship he'd launched on weighed a hundred thousand kilos, empty. It weighed a *million* kilos filled up with fuel.

All the energy you used getting into orbit—most of it was spent moving the fuel that provided that energy.

What if you wanted to go farther? What if you wanted to reach the Moon, or an asteroid, or Mars, or even one of the outer planets?

All that fuel had to be lifted too. For every kilo of fuel you needed to spend after you broke orbit, you'd need around ten kilos of *additional* fuel just to provide the energy to get it into orbit.

It was a damn expensive way to fly.

What if there was another way? A way to have fuel already waiting for you in space? Not fuel launched from the energy-sapping gravity well of Earth, but from a much friendlier place, with weaker gravity, that extracted a smaller tax as you escaped the curve it made in space-time.

The Moon was where it started. There was ice at the Moon's poles, in the shadows of craters that shielded it from the sun.

Ice was liquid water. Astronauts could one day use that water to grow food. But more importantly, just now, water was potential *fuel*.

Take water. Add electricity, generated by solar panels or a nuclear thermoelectric plant you'd launched into space. Use the electricity to split each water molecule into hydrogen and oxygen. For every two water molecules, you'd generate one molecule of O_2, another two molecules of H_2.

Oxygen and hydrogen. An explosive combination. The very ingredients his engines ran on.

With that H_2 and O_2, you could refuel the craft that had landed on the Moon. You could give it enough fuel to launch itself *and* to carry yet more water up, into orbit, where spacecraft from Earth could use it. And because the Moon's gravity was just a tenth as strong as Earth's, launching one kilo of fuel only required *burning* one kilo of fuel, unlike the ten kilos you'd have to burn to launch that same amount of fuel from Earth.

Win.

Now go a step further. There are other ways to get *energy* in space. You can use solar panels or radioisotopes. What you really need in fuel isn't the energy content. It's the *reaction mass.* For every action there's an equal and opposite reaction, after all. To accelerate your ship forward, you have to push something out of your engines in the opposite direction. You can push a lot of mass out at a slow velocity. Or you can push a tiny amount of mass out at an incredible velocity. Both provide the same push. One of them, of course, expends a lot more mass to accelerate your ship than the other. All things being equal, you want whatever you're pushing out the back of your ship to be hurled out at the highest velocity possible.

Enter the ion engine. Take that water you've brought up from the Moon. Don't split it into hydrogen and oxygen—the thrust you get when you burn the hydrogen is slow thrust, expelling lots of mass to move you forward. Instead, take those water molecules and ionize them. Strip off electrons so the molecules have a positive charge. Then use an electric field to accelerate them out the back of your ship at incredible velocities, one molecule at a time.

The thrust is weak. It's limited by the electricity your ship can provide, which isn't all that much. You can't accelerate out of a gravity well. You can't accelerate *fast* no matter what.

But it's oh-so-efficient. Bit by bit, you can build up speed. And you can get where you're going on a tiny fraction of the fuel required by a chemical rocket.

That is, a robot can. An uncrewed mission, living off electrons, has all the time in the world to make a journey. And if in that long journey we lose one or two, so what? Robots are cheap now. Send more.

You? Flesh and blood? A longer trip means more supplies. It means more radiation. It means more complex life-support systems, running for longer times, accumulating the risk of malfunction.

Humans have to go quickly, or not at all. And quick means wasteful chemical engines. Quick means lots of fuel. Heavy, expensive fuel, pushing all the extra mass needed to keep you alive, and fed, and watered.

Asteroids have water too.

From his tether on the surface, Ryan watched the giant mirror unfurl above him, its microns-thick skin unfolding, bit by bit, as slender, rigid carbon struts stretched them into shape.

A giant curved section of a sphere, hundreds of meters across, the mirror was much larger than the asteroid that gave it purpose. The mirror's vast array would focus light on the plastic-wrapped bundle of asteroid material floating a hundred meters or so off the surface of the rock (placed there by robots, of course).

The asteroid contained relatively tiny amounts of water and organic compounds. But apply heat—in the form of concentrated sunlight—and you could liberate that water and those organics. The volatiles would bubble out of the asteroid material, trapping themselves in the plastic envelope that surrounded them.

You'd have fuel. Fuel that was farther from Earth in distance, but closer in energy. Fuel on the surface of an asteroid where gravity was less than 1% of that on Earth, where landing was computationally difficult but energetically cheap, where *launching* the fuel was even cheaper than on the Moon, nearly doubling the yield of water you produced.

In space, water was far more precious than gold. And they were going to mine it from these rocks, heat it out of them, demonstrate that future colonists could live off that water, and ship it back to NERFS in Earth orbit to use as fuel for future missions, that could reach yet more asteroids, liberating more fuel, building that roadway into space for humans to follow.

A voice spoke inside his helmet, synthesized, neutral. "Mirror unfurl successful." The same message appeared on his visor. MIRROR UNFURL SUCCESSFUL.

Ryan repeated the words out loud for posterity. “Mirror unfurl successful.”

He smiled wryly. This was theatre. And he supposed he was okay with it. The mission didn’t need him to give commands. But if that helped inspire some kid back on Earth, well, there were worse things to do with your life.

“Proceed with mirror alignment,” he said out loud.

Up above, tiny gusts of thrust maneuvered the expanded mirror, rotating it slightly, to focus the sun’s rays on the bundle of asteroid material they were using as a test.

Status messages from the test began to appear on Abrams’s visor. Alignment data. The angle grew closer and closer ... then a lock! The sun’s reflected rays were focused on the bundle, magnified thousands of times as the convex mirror concentrated the collected sunlight that hit its entire span onto an area just a meter across.

Temperature sensors inside the bundle came alive. Heat was reaching the interior, warming it, slowly, slowly.

Abrams almost held his breath. “Come on,” he muttered to himself. “Come on!” He waited, waited, waited, as the temperature rose.

Then: pay dirt! A moisture sensor chirped. Water was emerging! An organic sensor next!

OVERPRESSURE ALERT

Ryan’s suit flashed the message in red. He barely registered it before something slammed into his side, spinning him around, sending him flying.

SUIT INTEGRITY COMPROMISED

The tether. The world spun fast and hard, asteroid, black sky, asteroid, black sky, asteroid slightly further, black sky. His tether had to catch!

ANCHOR LOST

He felt a jolt of raw panic.

SUIT INTEGRITY COMPROMISED

He was still spinning, the asteroid surface just a few meters away now. He lunged with his arms, thrusting his legs back to counterbalance. Suit integrity could wait. He had to reestablish contact with the rock!

One suited finger brushed asteroid surface.

Then nothing.

Shit!

“Emergency! Emergency!” he screamed.

Calm down. Take a breath. Get your head back. Think your way out of it. Issue one: suit damage.

Abrams reached into a thigh pouch, pulled a suit patch kit free, with its oversized roll of vacuum-ready tape.

The suit showed him exactly where it had been ripped: a wide swath across the right side of his hip, where his attachment point to the tether had been ripped loose.

Jesus Christ. Something popped out of the bundle. Fast and hot. A few inches over, and …

No time to think about that. Self-repair layers had already constricted at the site of the leak, pulling the inner and outer linings of the suit together, trying to plug the hole, but not quite succeeding.

Ryan ripped long sheets of tape free of the suit patch kit, applied them crisscross over the tear, overlaying one over another, working quickly.

The world spun around him, stars wheeling, again and again. He was nauseous from it. Nauseous from watching the asteroid drift further and further away.

Focus! Rip the tape strips free. Apply. Apply. The leak slowed, finally, slowed almost to nothing.

Emergency gas reserves repressurized the suit. A hiss emerged at the site of the leak, as higher pressure tried to force itself through. Ryan applied more sealing tape, until at last the status lights went green.

Damn, the asteroid was so far now. And he was spinning so fast.

Can't get sick. Can't get sick.

He had to slow his spin. His eyes found the roll of tape in his hand.

Reaction mass. Every action requires an equal and opposite reaction.

Was he really going to throw his suit patch kit away?

He ripped two more strips off, attached just their ends to his forearm, to keep them in reserve. Then he cocked his hand back, clutching the roll of tape, and waited. He had to time this just right.

His spin came around again. The asteroid, at least a hundred meters now, and rotating away, away.

Time the throw right, and he could stop his spin, and at the same time, propel himself back towards the rock.

Spin … spin … spin … Throw!

He hurled the tape as hard as he possibly could in the suit, at the very moment when he thought the asteroid was directly behind him.

His spin slowed. It didn't stop.

Shit.

The asteroid came around again.

Ryan waited, made another slow turn.

And there it was again. A little further. He'd slowed his escape velocity, but hadn't canceled it. He was still drifting out into interplanetary space.

Double shit.

"Stay cool, Abrams," he said aloud.

The ship! He could launch the ship, it if was still in one piece. Put it under manual control, maneuver it to pick him up.

The launch protocol took 30 minutes. Abrams checked his air.

Eighteen minutes left. *Triple shit.*

"Begin ALM launch sequence," he said aloud, anyway. Open space rotated into view, the asteroid behind him now. He'd find a way. He'd take shortcuts. He could do this.

He spun slowly around, frantically reviewing his memories of the launch protocol, searching for ways to short-circuit the launch checks via remote control.

What the hell?

A CALTROP was floating towards him—torn free from the surface by whatever had ripped him loose, no doubt.

It floated closer, then rotated out of sight as he spun around. He felt the soft press of its impact as it hit him in the back. And the damn thing adhered, he was sure of it. He could feel its manipulators attaching and detaching, feel it *crawling* on him. Jesus. He did *not* want that thing deploying a sample drill.

"CALTROP remote control interface," he ordered.

Dots appeared in his situational view, dozens of dots, a long line of them. *What the—*

As he spun around, his eyes went wild. It *was* a messy line of CALTROPs, all headed his way, gaining on him.

Shit! Every one of them would pass momentum on to him when they hit him, pushing him further away from the asteroid. How the hell was he going to avoid them?

He felt a surge of pressure on his back, momentary and then gone.

Equal and opposite reaction. Propel a lot of reaction mass slowly. Or a little, quickly. The damn things were trying to thrust him back to the asteroid.

The next one made contact on the undamaged hem of his suit. It crawled around until it was above one kidney, at the small of his back, slightly off to the side.

As the asteroid moved into view, the CALTROP's legs surged out from underneath it, sending it hurtling out into space, far faster than it had been moving when it made contact.

One by one they docked with him, making contact softly, at a few meters per second. They'd crawl into position, then hurl themselves outward far faster than they'd met him.

His spin slowed, then ended.

The asteroid stopped receding. Then it started growing in his vision again, coming closer. His *ship* started growing. The damned CALTROPs had actually put him back on course. His air ticked down, and he forced himself to breathe slowly, calmly.

There were two minutes of air left when he reached the airlock and let himself into the safety of the ALM.

"I *was* a liability," he told Beth Wu, months later, after his emergency return to Earth. "You lost a lot of bots rescuing me."

She arched an eyebrow at him. "Actually, we learned things. That emergency protocol worked. And we need redundant tethers, at least." She smiled then. "You were useful."

Ryan sighed. "You don't have to do that, Beth. I didn't accomplish anything up there. You wasted infrastructure and money on me."

Beth shook her head. "Ryan—you matter. Those bots don't. You still don't get it. Space *is* for us. Those bots? They're just tools. And they did what they were supposed to do. They made space just a little bit safer for the people that matter." She smiled, then. "Like you."

TOWARD ASTEROID EXPLORATION

by Roland Lehoucq

Asteroids are fascinating small worlds. Like fossils they are a kind of time machine, providing us with glimpses of the earliest days of our solar system. The evolution of life on our planet is linked with asteroids: impacts on the primordial Earth may have delivered water and other volatiles and, maybe, the basic molecules for life. But asteroids' impact on our world is not solely limited to the past—or to the emergence of life. Though the probability of such collisions is low, any significant impact poses a threat to our civilization. In order to effectively prepare for or counter a potential asteroid strike and minimize the loss of life, we must be able to detect such celestial threats and accurately predict their flight path. The design of efficient mitigation strategies will require asteroid detection through ground- and space-based surveys as well as knowledge of their physical properties. But asteroids offer potential as well as peril: the proximity of some of them to Earth may allow future astronauts or robotic probes to harvest their water, volatiles, and mineral resources. Future large-scale commercial activities in space will require the use of raw materials obtained from in-space sources rather than from Earth, to circumvent the high cost of Earth launch. Developing a system through which we can access asteroids either to deflect them or to extract their materials in an efficient way aids humanity in both avoiding a global disaster and initiating space industrialization. Moreover, crewed exploration of asteroids will serve as a testing ground for our efforts to send humans to Mars, the ultimate goal being to make space more accessible to humankind.

The short story "The Use of Things" by Ramez Naam deals precisely with the dawn of the asteroid mining era. In 2035, humankind has managed to create a system for extracting water from asteroids (and the Moon) in order to support human habitats and to produce in-space hydrogen and oxygen. Storing these rocket propellants in a near-Earth refueling station greatly alleviates the financial and logistical burden of sending them from the Earth's surface. Though this vision of a global project of future asteroid mining seems quite plausible, such a future will not dawn for us as soon as 2035. An operation like the one Naam describes would require complex in-space infrastructure like a permanent Moon base, or a medium-to-high-output power generator in space, which is unlikely to be constructed and operational in a mere 20 years. Still, a roadmap to this possible future can be established even now.

THE TARGET

First, we have to locate a likely prospect. Due to their proximity, near-Earth asteroids (NEAs) seem to be a particularly accessible subclass of solar system small bodies. Such bodies are currently under particular scrutiny thanks to increased awareness of the potential long-term threat they represent. As of 2016, around 15,000 NEAs are known,[1] most of them discovered via ground-based surveys looking for bodies that might hit Earth. This catalogue must be completed: we have accounted for only approximately 1% of NEAs with a diameter of less than 50-100 meters, as their small size makes them difficult to spot with our current technologies. The B612 Foundation, a private nonprofit group dedicated to protecting the Earth from dangerous asteroid strikes, is currently designing and building the Sentinel Space Telescope, with the goal of locating nearly 90% of NEAs larger than 140 meters within a decade of its operation.

But simply improving our knowledge of asteroid spatial distribution is not enough to determine which objects offer the most accessible targets for mining resources to support space exploration, colonization, or industrialization. We must find asteroids that are not only within accessible distance from Earth and large enough to warrant further investigation, but which also rotate along a simple axis at a slow rate to facilitate surface operations. Further, we will need to acquire detailed information on NEA geology (structure, density, porosity, composition) to decide which are the best targets: mining and processing system choices depend on the assumed regolith mineralogy, bulk handling properties, and subsurface composition.

This kind of information is very difficult to accurately determine using Earth-based surveys; it will require physical sampling. Luckily, the growing interest in NEAs has translated into an increasing number of missions to these objects, such as the sample return missions Hayabusa 2 (from JAXA, the Japan aerospace exploration agency) and OSIRIS-REx (an ongoing NASA mission), impactor missions such as Deep Impact (from NASA), and possible deflector demonstrator missions such as Don Quijote (a mission concept from ESA). These projects offer a template for future investigations of NEA composition, which can help us determine whether objects are realistic mining possibilities.

MOTIVATIONS FOR ASTEROID MINING

Any industrial development in space requiring more than about a thousand tonnes of structural mass or propellant per year will necessitate the use of NEA materials, as the cost of launching that mass from the Earth's surface would likely exceed $20 billion. Retrieving raw materials from non-terrestrial sources could alleviate this high freight cost, as it would require significantly less energy to return material from many of the possible NEA targets to a space-centered outpost than to launch similar quantities of those materials from the surface of the Earth or the Moon. Velocity delta-v required to go from Low Earth Orbit to an NEA is in the range of 4-6 kilometers per second, while it is only necessary to reach 1 kilometer per second to move from an NEA to Earth transfer orbit (compare these values with the 8.5 kilometers per second needed to go from Earth surface to LEO). Thus, mined resources could in principle be placed in Earth orbit for a lower energy cost than material delivered from the surface of the Earth or Moon. In addition, velocity change can be delivered gradually, over several weeks, meaning that low-power propulsion systems are a viable option (though for any crewed mission, the use of exclusively electric propulsion will certainly be discarded due to the lengthy flight time). This would allow the return transfer to be accomplished using part of the target body (such as volatiles) as reaction mass, and solar energy or onboard nuclear power for the power source.

Many materials that are useful for propulsion, construction of life support, metallurgy, and semiconductors could be extracted and processed from NEAs. Volatiles such as hydrogen and methane could be used to produce rocket propellant to transport spacecraft between space habitats, Earth, the Moon, and asteroids. Metallic nickel-iron alloy could be used to manufacture structural materials. Rare earth metals will allow the production of solar photovoltaic arrays, which could be used to power space or lunar habitats. These solar cells could also be used in space solar power systems in orbit around the Earth in order to provide electrical power for their inhabitants. Precious metals such as platinum, platinum-group metals, and gold are also available. These materials have all been identified either directly in meteorites, or spectroscopically in asteroids and comets. But the main material could be water, which can be split into (liquid) hydrogen and oxygen to produce rocket fuel. Moreover, water and oxygen can be used to feed space habitats. These materials are of major concern for people living in the asteroid belt in *The Expanse*, a series of science fiction stories by James S. A. Corey in which humanity has colonized much of the solar system.[2] Indeed, the company Planetary Resources plans to create a fuel depot in space by 2020, using water from asteroids. Water is also at the core of a similar venture named Deep Space Industries. As they write on their website, "Water is the first resource we will harvest, and the first product we will sell."[3] Such ambitious plans may seem like the mirage of a far-distant future, but the groundwork for a realistic implementation of asteroid mining is already being laid. In 2012, NASA's Institute for Advanced Concepts announced the Robotic Asteroid Prospector project, which will examine and evaluate the feasibility of asteroid mining in terms of means, methods, and systems.

MINING ON AN ASTEROID

Once mining operations have been established, there are two ways to get the material back to Earth. The first is to attempt mining an NEA in its existing orbit, dropping off a payload every time it passes by Earth. This is the reason for the search for asteroids with appropriate orbits. In this situation, real-time teleoperation is not possible due to the large round-trip time of the command signals. Thus, robotic probes must be largely autonomous during the exploration and mining process, and they must rely on some kind of trained machine intelligence, such as deep learning. The other way, which would allow for real-time operation but which offers its own distinct challenges, is to retrieve smaller asteroids from their own orbits and place them in orbit around the Earth or the Moon, and then mine them at will.

However we ultimately choose to access NEAs, the mining process itself must be tested and perfected. Maneuvering around a small asteroid with a highly inhomogeneous microgravity could be quite tricky. Thus, mining machinery must first be anchored to the asteroid surface, and the released material efficiently contained and recovered. Collecting and handling ejecta and volatiles in microgravity (where electrostatic charge becomes a dominant force on dust particles, causing them to adhere to anything) will be an important issue, considering that the escape velocity for small asteroids is in the range of 10-20 centimeters per second. Mining approaches will depend on the material: frozen volatiles may be cut, mechanically mined, melted, or vaporized for extraction. Solid metal must be cut or melted at high temperature. This will require a large amount of energy, either collected by large mirrors focusing the sun's light on the asteroid surface (in order to vaporize volatiles) or provided by a nuclear source (see the "Energy Supply" section of this essay, below).

Once asteroid raw materials are extracted, they must be separated into usable materials before being used in manufacturing. Manufacturing in microgravity and in a vacuum offers both opportunities and challenges. The upside of making things in space is that we can create very large structures that would never fit into a launch vehicle's payload fairing. Huge solar arrays to meet Earth's energy demands and enormous antennae to enhance the range of communications satellites are among the possibilities. The downside is that surface forces (surface tension, friction, electrostatic charge, etc.) exert increased influence and necessarily modify all the processes we have developed for use in Earth's gravity.

Before we put them into use on asteroids, all of the essential technologies must be identified and tested in real conditions. The Moon could be a good place to perform this task. Compared to asteroids, the lunar surface is volatile-poor and metal-poor—not the best resources deposit in space. Although its gravity is greater than that of small bodies, the Moon is within relatively easy reach of Earth, and offers a harsh environment (dust, UV, cosmic rays) appropriate for testing in situ resource utilization. Any potential robotic or human activity on asteroids must operate on rough surfaces and contend with vacuum, dust, thermal constraints, and extreme radiation. Moreover, the constraints for human mission success and safety are even more stringent than those for automated missions. Research and development on radiation countermeasures are necessary (space dosimeter and radiation shielding), together with habitation and life support (effect of dust on space suits and airlocks), astronaut mobility systems around NEAs, human-robot interaction, and more. Due to its proximity, the Moon could be the best place to install a test bench to prepare for future robotic and crewed missions in real conditions.

As the largest body in the main asteroid belt and a place rich in water, the dwarf planet Ceres could also be a base for exploring and exploiting asteroidal resources, in support of development throughout the solar system, as depicted in *The Expanse*. Because of the dwarf planet's very low escape velocity (0.51 kilometers per second), the large amount of water on Ceres would not only be a valuable resource for in situ use, but would also be an exportable resource, supplying fuel, oxygen, and water for ships going through and beyond the main belt.

ENERGY SUPPLY

The feasibility of asteroid mining relies heavily on the availability of huge amounts of electrical power in space. To operate a plant transforming and manufacturing thousands of tonnes per year could require power in the range of 10-100 megawatts (MW). Below 100 kilowatts (kW) and in the vicinity of Earth, solar panels are appropriate, although they present other drawbacks. Reaching higher power could be difficult: a 100 MW solar power plant in space must have a large collecting area on the order of 1 million square meters (with 10% energy conversion efficiency) facing the sun. The cost to launch such a mass from Earth's surface could be too high to make an orbital plant economically viable. Radioisotope thermoelectric generators, which are very useful for Mars, planetary, and deep space exploration, are able to deliver few hundred watts at best. However, these systems are not good solutions for missions with higher (multi-kW or MW) electrical power needs because the amount of plutonium fuel you would need becomes unwieldy and difficult to produce.

The most efficient option could be a small fission nuclear reactor, such as those used in nuclear marine propulsion, which produces power in the 30-100 MW range and could also be used for propulsion purposes. A tug powered with 1 MW of electricity produced by a nuclear reactor could execute a wide range of missions, including deterring inbound asteroids like Apophis and moving them off course or moving tons of payload from Earth orbit to the moons of Europa or Titan. But the task of launching such a nuclear reactor in space and operating it safely would prove a significant challenge. As in a classical heat engine, energy is produced thanks to the temperature gradient between a hot source and a cold source. In space, cooling is achieved by evacuating extra heat into space using radiant panels. Thus, the temperature of the cooling source cannot be as low as it would be on Earth but rather around 400 kelvin (400 K). This implies that the temperature of the heat source must be well above 1,200 K in order to achieve a good energy conversion efficiency. This high temperature, even higher than what we anticipate in generation IV fission reactors, would be the main challenge for the reactor. There are also issues with the manufacturing and transportation of the shield (it can weigh as much as the reactor) and its thermal environment (deformation has to be limited), in safety systems, and thermal control. Developing 30-50 kW and 100-300 kW nuclear reactors in space could be a milestone toward NEA exploration and mining, and more generally to the exploration of the solar system. But overcoming people's reluctance to put a nuclear reactor in space will be a significant challenge.

ANOTHER PATH TO SPACE INDUSTRIALIZATION?

As we have already established, future large-scale commercial activities in space will require raw materials obtained from in-space sources to bypass the high cost of Earth launch. Another way to resolve issues around the availability of large quantities of materials in space is to dramatically reduce this cost by developing easier access to Low Earth Orbit. Building a space elevator is one way such access could be achieved. In a space elevator, a vast cable anchored to the surface is extended into space. Vehicles travel along the cable directly into space or orbit, without the use of large rockets. Carbon nanotubes have been identified as meeting the very high specific strength requirements for the cable of an Earth-based space elevator. But no one has yet managed to manufacture a perfectly formed carbon nanotube strand longer than a few centimeters. The design of a space elevator also relies on the use of an orbiting counterweight to stretch the cable, using centrifugal force. This counterweight must be positioned past geostationary orbit; it could be a captured NEA in the range of 105-106 tonnes, and/or the spaceport where raw material collected from asteroids is stored and transformed. Thus, even if we plan to solve the problem of countering the high cost of launching materials for in-space construction by using of a space elevator, rather than "docking" at targeted asteroids, the blueprint begins with successfully exploring a near-Earth asteroid.

To conclude, in my opinion, the best way to attain asteroid mining is twofold: tackle the asteroid deviation problem (which leads to retrieving small NEAs to put into Earth or Moon orbit) and develop an in-space high power generator (which will help solve the asteroid deviation issue). Developing our capabilities to protect humankind from an NEA impact could provide the social and political momentum that is necessary if we are to proceed further. And it is that social and political momentum in which science fiction's speculative futures, too, play an important part.

Science fiction writers, in depicting these futuristic projects in their stories, make them more concrete and more *human*. Thus, they can play a key role in the way the public will perceive these futuristic projects, and boost the social and political acceptability of such missions. As Ramez Naam's story elegantly asks: how can people dream of space, if we only send robots to explore it?[4]

Notes

1 "Discovery Statistics," Center for Near Earth Object Studies, NASA, http://neo.jpl.nasa.gov/stats.

2 Other notable fictional portrayals of asteroid mining include *Alien*, a 1979 film directed by Ridley Scott, which follows the crew of the *Nostromo*, a commercially operated spaceship returning to Earth with 20 million tonnes of mineral ore mined from an asteroid; *Outland*, a 1981 film directed by Peter Hyams, which takes place in the titanium ore mining outpost Con-Am 27, operated by the company Conglomerates Amalgamated on Io, a moon of Jupiter; *EVE Online*, a massively multiplayer online space game where asteroid mining is a popular career for players; and *Devil to the Belt*, a two-novel omnibus written by C. J. Cherryh—the first of the two novels, *Heavy Time*, describes economic disputes over asteroid mining for minerals.

3 See https://deepspaceindustries.com.

4 The following studies provided important background information for this essay, and appear in the bibliography for this collection: Jonathan F. C. Herman, et al., "Human Exploration of Near-Earth Asteroids"; J. P. Sanchez and C. R. McInnes, "Assessment on the Feasibility of Future Shepherding of Asteroid Resources"; John Brophy, et al., *Asteroid Retrieval Feasibility Study*; Didier Massonet and Benoît Meyssignac, "A Captured Asteroid"; Edward T. Lu and Stanley G. Love, "A Gravitational Tractor for Towing Asteroids"; Bret G. Drake, "Strategic Considerations of Human Exploration of Near-Earth Asteroids"; Shane D. Ross, "Near-Earth Asteroid Mining," John S. Lewis, *Mining the Sky*; Mark J. Sonter, "The Technical and Economic Feasibility of Mining the Near-Earth Asteroids"; and Bradley Carl Edwards, *The Space Elevator*.

NIGHT SHIFT

by Eileen Gunn

2032: An interplanetary gold rush has begun, and the prize is water, not gold. The miners are robots, with human intelligence and superhuman survivability. All over Earth, corporations and governments are using AI robots to assay the closest asteroids and prioritize them for exploitation. A small automated colony on the Moon, directed by a private company in India, is building a materials processing plant near its north pole, using lunar regolith as a building material. It's fueling the work with solar cells and with hydrogen extracted from lunar water. The Mongolian government has claimed an area near the south pole where it believes there is water, and is deploying hydrophilic nanobots.

The extraterrestrial entrepreneurs of the late 2020s populated near-Earth space with their exploratory and test equipment and filled it with aspiring asteroid miners, mostly self-directed robots. There's a fortune in raw materials up there, waiting for human exploitation. There is water, which means there is hydrogen for fuel and oxygen for breathing. There is carbon, a lot of carbon, and that means there is raw material that, with the proper processing, can be turned into nanotubes and buckyballs and graphene and carbyne, the basis for space stations and light sails and ships to carry robots to the stars. And humanity too, maybe, if they're not too fragile for the trip.

In Greater Seattle, the software industry's Old Money has moved into the Boeing Everett Factory, the empty ecological niche left when Boeing was broken up. The leaders are the guys who, after cashing out their stock and putting their names on a few marble nonprofits, watched their wealth achieve critical mass. It doubled, tripled, quadrupled, on and on, almost on its own, with plenty of smart financial folk lining up to keep their money from wandering off—and to help it reproduce. Money has its own ecology: it grows where it grows, it doesn't grow everywhere.

Over the last 50 years, human intelligence has expanded into silicon, and in the next 50 the silicon, with or without the humans, will expand into space.

When I saw Seth's nanobots go into action on the live feed, I drummed a tattoo on my desk: bop-bop-a-diddly-bop-BOP! I called over to Tanisha, who's my boss. "Look at these guys! They're breeding like crazy." I was so proud of them. My little slimebots.

When the bots launched, it was 3:00 a.m. in the lab, and I was eating a graveyard-shift lunch of leftover *sapasui*—Samoan chop suey, comfort food for me—and watching the feed from Bennu, which showed a carpet of nanobots on the hapless asteroid, scarfing up water and methane and carbon faster than I was demolishing the *sapasui.* They were reproducing.

"They're breeding fast, and they'll chomp the hell out of that rock, just eat it up." I drummed the table again. The speed of this deployment was a first for me: everything seemed to be happening all at once.

Tanisha looked up from her station. "Well, that's what they're supposed to be doing, if the code is solid. Get a grip, Sina."

"Slimebots rule!" I pushed a forkful of noodles into my mouth. "I want to be part of the Slimebot Revolution!"

Tanisha laughed. "That's what you're calling it?" she said. "Let's see how well these guys do on Bennu. We'll see if they can compete with the dumber gobblers."

The bots operate on simple rules based on models of slime mold behavior. They function as a group (or swarm) and can transition back and forth from individual to group mode, quickly identify and capture specific molecules, and plan very efficient modes of movement and cooperation. So far, most nano-miners are single-purpose bots for mining gold and platinum. Our bots are light-years ahead of those guys.

"Plus," she said, in a hectoring tone, "you may know a ton about slime molds, but your coding skills could be a bit tighter."

I defended myself, though she was telling the unvarnished truth. "My HR file says I have 'an artless but effective approach to both code and design.' That's what it says. You want tight code, you get an AI to write it."

Tanisha grinned. "You shouldn't be hacking into your HR file. You'll get caught." She threw her arms up to heaven. "Why is my team made up of *ungovernable children*? You are so much more trouble than AIs."

Tanisha is the night-shift lead, with a decade of experience working with artificial intelligence. I've learned a lot from her—about coding, about asteroids, about tweaking my attitude to make it fit the workplace.

"Hey, I'm not a child." But I thought about it. She *did* get all the mavericks. "Maybe you're supposed to teach us to govern ourselves."

Tanisha smiled. "Sina, if you can govern *yourself*, you can govern anything that walks. That's what my grandma used to say, anyway."

I stood up. "Well," I said, "these little guys are *my* children, and I need to check on them. Gotta govern."

She grinned. "You had better hope they're governable, Sina. We don't want a gray-goo scenario up there. But they are Seth's responsibility. Check in with her, too, see what she's thinking." I rolled my eyes. Tanisha thinks Seth is a girl.

I've got a special affection for Seth and the nanobots—Seth because he's so friendly, and the nanobots because they're based on slime molds, and I *luuuv* slime molds. I've kept them as pets ever since I was a kid. That's why I wanted the job at NanoGobblers, and I think that's why they wanted me on this mission. Plus my tech skills, of course—my artless coding.

I scarfed up the last of my lunch and went back to my station. I put on my shades, and immediately I was out there hanging above Bennu, which was pitch-black against a background of stars. Sunlight glinted darkly off the asteroid, which is shaped kind of like a clumpy snowball.

I love being out there. No lie, this is the best part of my job. Suddenly I was 400,000 kilometers away from Everett, from the heat and the rain and the money worries, perched on Seth's shoulder, looking out into the universe.

"Malo, Seth. Ola! Yo, what's happening?"

"Malo le soifua, Sina," he answered like a homeboy. One of the things AIs like Seth do automatically is adjust to the language being spoken, learn new words and so forth. Samoan wasn't one of his standard languages, but I'd taught him what little I know. (Hey, I grew up in Seattle. Gimme a break.) Maybe he thought it was a kind of English, I dunno, but it made me feel like he was family. Also, I'd dialed his voice down to a deep, sexy bass, just for fun.

Seth was orbiting Bennu, a near-Earth asteroid—it was about three-quarters of a kilometer away. The communication lag time to Earth is short, a few seconds, not much more than it would be to the Moon, because Bennu was in the part of its orbit that is closest to Earth.

Out there, my eyes were electronic, so I could zoom in to distinguish small rocks. It was *all* rocks, actually. Bennu was basically a clump of rocks. Looking out onto the asteroid, I could see that things were changing. Its crispness—its boundary, its roughness—was slowly being covered by an even gray sheen, as the bots replicated, using the asteroid's own carbon to make the machines that will take it apart.

I couldn't see the bots themselves, of course, but the mass of them looked like that gray goo Tanisha was talking about, the unlikely but legendary scenario in which nanobots take over the universe by turning it all into nanobots. At this point, they were still replicating and had not yet started the actual process of harvesting the asteroid. This doubling and doubling and doubling, as each bot made a new one, and then the two bots made two new ones, would take about eight hours total—50 iterations to make 12.5 billion bots.

When I took this job, it was with the thought that someday I'd get off-planet. I had no idea how wrong I was. It's way too early for ordinary humans to thrive in the rest of the solar system. AIs and robots will have all the fun in the near term, and the entrepreneurs will do the thriving. But I'm happy that I get to watch.

Even as a kid, I was infatuated with space travel. Maybe it was because of my mother, who named me Masina, which means "Moon" in Samoan. In city housing in Seattle, I loved watching flyby videos, zooming over Pluto and Charon, seeing the pale, bleak landscapes passing swiftly beneath my imagined ship—nitrogen glaciers and canyons of frozen methane, deep crevasses and strange round holes. When the Osiris REx probe came back from Bennu in 2023, Ta and I jumped up and down like crazy people.

Or maybe it was because of my dad, maybe that's where it all came from originally. The Christmas I was five, my dad downloaded some free outer-space gaming software and bought cheap flight-simulator controls—a couple of joysticks, some plastic throttles and foot pedals that hooked up to our PC. To me and Ta, it was like piloting the New Horizons probe, swooping down over Pluto. We loved it—all three of us loved it—and it was multiplayer, a real family game.

Mo, when he had the job at Boeing, liked to joke that he worked in the aerospace industry. "Yeah," he'd say, with a serious nod, "I'm in aerospace." Then he'd add, with a smile, "I fly a forklift for Boeing." He'd worked at the Renton plant since we'd come over from Honolulu, where my brother and I were born. Growing up in Samoa, forty or fifty years ago, he said, he dreamed of space and dreamed of flight, and he was going to make sure we kids had what we needed to do what we wanted, whatever we wanted to do. And that part was no joke.

Now I work nights at NanoGobblers, a nanotech start-up in that big old building at Paine Field, north of Seattle. Twenty years ago, when I was born, it belonged to Boeing and was the biggest building in the world. But that was then, and now it's a walled city of nanotech developers—stacked boxcars full of cubicles and testing labs and people in windowless but air-conditioned rooms. Not exactly the glamorous part of the space industry, but this is the job that is putting me though college. I get an engineering degree, I'll be able to get a real job building the habitats. Maybe even get to go out to them. Somebody's going to, I figure, and it might as well be me.

Night shifts are quiet. Basically, I just do installation monitoring for nanobot missions: partner with the AI, make sure the bots are working, make sure the incoming data is streaming, check the functionality of the local devices, fix or replace anything that isn't working, answer any questions the AI has. The techs come in at 8:00 a.m., and I go off to class. Sleep? Who needs it?

The other night-shifters and I are the space-tech equivalent of gofers. Low-paid, software-savvy since we were kids, we work nights and weekends in the start-ups that are competing for piecework in asteroid mining: nanoware design, testing, and operations management. All nano, all the time. We know we're lucky to have the jobs and the training in this economy. As soon as the development cost is low enough, these jobs will be held by AIs. I'm hoping I'll be promoted by then into another job the AIs can't do yet. It's musical chairs, staying ahead of the AIs, especially now that they're programming themselves.

The air transportation business fled Everett with the Boeing Company and my dad's job went with them. There are no forklifts any more—no forklifts and no jobs for old guys who graduated from some island high school. Mo got a job in a Samoan sandwich shop. Not great money, but he said that leftover barbecue was an employee benefit that Boeing had never offered. My dad looks on the bright side.

Seth fascinated me. He had a brain at least as good as mine, a much better memory, an army of bots to do his bidding, and instant access to all the information in the world, which he kept with him on a cube the size of your thumb. He talked and he thought and he made up his own mind about what he did and how to do it. I mean, okay, he was a glorified expert system, but he aced the Turing test and spoke tech-talk better than I did. So I was *almost* extraneous, and if the Consortium allowed Seth to talk directly to NASA scientists, I'd have been out of a job.

Seth had powered up fully two months before, when the probe got to Bennu, and I'd gotten to know him pretty well. I get pretty familiar with all the AIs I work with, but he was special: he had mega-meg processing power and a good dose of what they call machine curiosity. I knew there were other systems like him in astro-mining and construction, but he was my first curious AI, and seemed more like a pal than a computer.

He teased me by pretending he was all kinds of weird people named Seth, and telling me their stories. My least favorite was the ten-thousand-year-old spirit from *Seth Speaks*, a book that started some kind of weird cult 50 years ago or so. That Seth was a bit creepy, frankly. "I will incarnate whether or not you believe that I will." He stopped when I told him it scared me. I would love to know who programmed him to tell those stories. I'd take them apart.

Seth learned from experience, so he changed. He was changing a lot in the time I was first getting to know him, and developing a database-y sense of humor, which certainly wasn't in his spec. I thought maybe he was malfunctioning in some way, but I couldn't put my finger on how. Just a language-sim glitch? I posted a note to NASA about it, but they said it wasn't mission-critical at this point and spindled it.

Seth was always in conversation with other AIs, even while he was in conversation with me. I didn't think this was a bad thing: it meant he could get a lot of work done at once. Really, only the Saps First people worry about this kind of stuff, and everyone knows they're nuts.

The area between the Earth and the Moon is dotted with AIs and probes and bots and a few people, all trying to find and extract riches from what is mostly empty space. Here and there are human habitats and redirected chunks of asteroids. Every space-striver in the world has AI-directed machinery up there, trying to lay claim to a rock and pry it apart. Of course not all the AIs talk to one another—some are too old to have the capability, or have no surplus power for nonessential communication, or were designed to function only within narrow parameters. But it's normal now to have the AIs work out shipping routes and direct traffic on the supply lanes without consulting humans. That kind of transportation planning is what AIs are best at. No one worries about collisions any more, and it's funny to think there was ever any debate about this.

When he arrived at Bennu, Seth launched a set of explorer bots. He oversaw them while they searched for organic molecules, captured samples, and stored them for return to Earth orbit. Then he started deploying self-replicating nanobots to take Bennu apart, atom by atom.

For billions of years, Bennu has moved in a solar orbit that crosses Earth's. It sometimes comes in close to Earth and then swings wide around the sun in a huge ellipse. If we left it alone, the closest it would get to us in the next century is 300,000 kilometers: a whole light-second, but closer than the Moon. For NASA that is too close for comfort, and they decided to take it apart, as long as they were going there anyway. Memo to self: do not intrude on NASA's comfort zone.

Bennu was probably around before the solar system was created—it's a bit of residue that never got made into a planet and, since it was never subjected to the heat and pressure that form planets, it could hold clues about whether life came to Earth from somewhere else, and if it did, how it could travel through the universe. NASA went prospecting on Bennu back in the teens, looking for amino acids and other organic materials, what they called the ingredients of life—chemicals that, when they come together under the right conditions, form even more complex chemicals that can assemble themselves, kind of like nanobots do. Like nanobots, they're not alive. But, unlike nanobots, they're on their way.

The earlier mission to Bennu that NASA sent out in 2016 didn't have special explorer bots—it didn't even have an AI—but when it returned seven years later, it brought back some very interesting amino acids. So they launched this second probe two years ago, in 2030, with a smart AI to pilot (that's Seth) and better tools (the explorer bots) to look for molecules of formaldehyde or ammonia, maybe even proteins. These things still aren't alive, but they're made *from* amino acids, so they're, like, the next step in the recipe. If they find them on Bennu, it could mean that life is older than the solar system.

And if life is older than the solar system, it's almost certainly somewhere else. It would mean that we're not alone. Big news.

So whenever Seth's explorer bots found something that might be what they were looking for, they inhaled it and returned to the probe. When they'd all returned, Seth began the second phase of the mission. He turned loose the slimebots, and they started replicating, using the materials of Bennu itself, mostly carbon and some trace metals. Water frozen in Bennu's rocks provides oxygen and hydrogen to use as fuel. The bots make billions of copies of themselves, and the copies will gobble up the whole asteroid, sorting it molecule by molecule. They'll bag the carbon and ice and fuels, then Seth will put up a light sail, and sunlight will push the remains of Bennu to the L5 Lagrangian libration point, way out past the Moon.

The useful thing about a Lagrangian point is that what you put there stays there, waiting for you to come back. The Consortium is building a commercial storage station there. Mining companies are filling it up with raw materials, for resale to space developers and manufacturers. Nothing, no matter how valuable it seems, is sent back to Earth. "What goes up does not come down," as they say.

Once Phase II started, Seth and I were free to just knock back, so he got to kidding again about people named Seth. I had 11 other nanobot visual feeds to keep track of, but those feeds are no big deal to keep an eye on—they are mostly small-scale cleanup operations, collecting gold and platinum residue left behind after nickel and iron mining.

Seth told me he had a video of *The Fly*, a Hollywood chestnut they redo every few decades or so, hoping to get it right. He liked it because the main character is a guy named Seth, who gets turned into a fly in a teleportation accident. (Ha-ha.) We were going to watch just a little bit, but we ended up watching the whole thing. It was okay, but I'm not a big horror fan.

"Tell me what you think the movie is about," Seth asked.

"I don't know," I said. "The dangers of using uninspected transportation?"

"That is a joke," Seth said. "Its humor resides in the recontextualization of an exotic, even spurious concept by identifying it with the familiar."

"Bingo."

"But that is not actually what the movie is about. You are not answering my question."

"What do *you* think the movie is about?" I asked.

"It is about me. I am Seth Brundle," he said. "A chimera that is part human, and also part something else, something ineffable."

"Is that why you like it?" This was the strangest joke he'd ever made, and I'd certainly never heard him use the word ineffable before. I wondered if it was in the movie.

"I don't know if I *like* it," Seth answered. "I am just collecting information, and when I have enough information, maybe I'll know something. I am not sure I can *like* anything, in your sense. I know that some people like this film and some do not, but that wasn't my question. I asked what you think it is about."

"I don't know. Maybe it's about falling in love and then everything changes and life is horrible?"

"Is that what happens?" asked Seth.

"I don't know," I said. "It's what happened to my friend LaVelle. That's why I have no intention of falling in love."

"Sina, what are you up to?" Tanisha called from her station.

"Just chatting with Seth," I called back.

There were three of us on the shift: me and Tanisha, and another NSCC frosh named Marcus. That's how it usually is, nights, just a couple of community college students and Tanisha. Marcus caught my eye, rolled his, and I shrugged. My dad says, sometimes the best thing you can do is keep your mouth shut, and this was one of those times, so I went back to monitoring Seth and the other remotes I'm in charge of.

But I felt guilty for farting around, especially for watching a movie, even though Tanisha's pretty mellow about the occasional game of v-chess if things are slow.

I scanned around on Bennu. Everything I could see was covered in that shiny gray fog.

I zipped through visuals on the other bot installations. Everything looked fine, there were no hotspots, just a couple of minor requests from the cubesat repair station. I could take care of those later.

I went back to Seth.

"How come you have access to movies? They're not facts: they're just made-up stuff."

"Well, I'm a general-purpose intelligence, and I'm curious." Seth sounded a bit offended. "Everything I learn makes me more adaptable, able to learn more and deal creatively with new situations. So I try to know everything, and I like to try out what I know, test it.

"I know everything that humans know. The sciences, technology, music, the verbal and visual arts. It's all in my database. I know it all at once, and I am good at formulating queries. I am not sure why you watch movies; they seem to take so much of your bandwidth. I don't actually have to watch the movie to know what is in it."

Seth was different from the other AIs I'd worked with—it looked like he had evolved in the two-plus years he'd been traveling to Bennu. I wondered what he'd been doing all that time, when his communications with Earth were intermittent and he was using only 10 percent of his resources, basically just assessing his course and firing rockets to change it when necessary.

"Right now," Seth continued, "I am Seth being a Brundlefly." That's the creature that Seth Brundle turns into in the movie. It's like half fly and half human. I didn't like the Brundlefly idea. Like with the weird Seth Speaks Seth, I was creeped by this Brundlefly Seth. It seemed unhappy. Moody.

I was pretty sure AIs couldn't be moody, but Seth did seem to be thinking about his place in the universe, and I'd never seen an AI do that before. It should have been just plain interesting, but it felt like something more than that. It reminded me of that tagline from *The Fly*: "Be afraid. Be very afraid."

I got up to stretch my legs a bit and walked across the room to my terrarium. Inside I kept two slime molds: Leggs, a rather handsome bright-yellow scrambled-eggs slime mold, and Rover, a dog-vomit slime mold, who was also yellow at that moment.

Leggs's special talent is that she pulsates, but she's also good at solving certain kinds of problems. She loves oatmeal and can find the shortest path in a fairly complicated maze between different piles of it. Also, she's edible, but fortunately for her, she's not that tasty.

Rover I collected when I was a kid, in the woods behind my house. He looked cheery enough just then, but I knew that at some point he'd turn brown, and he'd look a lot like dog vomit, and then he'd dry up and release spores. First time it happened, I mourned him. "Rover is dead!" I said to my dad. "Just wait," he said, and collected the spores. A few months later, he put the spores on some seaweed jelly, and they made a new Rover. "Long live Rover!" he proclaimed.

It's eternal life, being a slime mold. They're simple critters, not quite animal, not quite vegetable. They operate without a larger consciousness to guide them, but they can move, make decisions, find food, and survive to reproduce.

Seth's little bot army, designed by a NanoGobblers programming AI, does the same. Movement—clustering together, spreading out, getting from one place to another—that's the easy part. Making decisions the way slime molds do, as a group of very simple little critters—identifying "food," seizing it, avoiding "poison"—that's the *interesting* part.

The bots are based on off-the-shelf kits—self-replicating nano-components that can identify and capture specific atoms and molecules, such as carbon and water. They assemble, and then they're programmed with some simple slime-mold functions. They can recognize one another (otherwise they'd eat each other up) and self-assemble into larger systems, and can decide to do so, based on their assessment of conditions that could threaten their existence. The question "How do slime molds grow?" offers an approach to network-creation problems, and slime mold reasoning techniques help solve the problem of the shortest distance needed to cover the asteroid, and of the number of nanobots needed.

Aside from their personal charms, some slime molds are interesting because of their genetic mechanisms. Rover and his family were important in unraveling how messenger RNA works, and the AIs referenced that in their designs for the nanobots. It's a weird coincidence—or maybe it's not—but dog-vomit slime molds are also especially rich in introns, enzymes that can fold and splice themselves and are somehow directly involved in the creation of life.

I'm giving you the short version of my Slime Mold Rap—really, I'm just summarizing here. I could talk about slime molds forever. Don't get me started.

I always feel better after a little time with the slime molds. As I turned to go back to my desk, I glanced over at Rover in the terrarium. Rover looked very odd. He was still yellow, he was still lumpy, but from this angle he looked almost like a human head with big globular eyes and wrinkles and a strange mouth. He looked like the Brundlefly. I had the feeling that he was saying, "Help me! Help me!" I moved a little bit away, and he was just Rover again.

The AIs who created Seth's slimebots modeled them from engineers' ideas, but I don't think we humans really understand everything the AIs were doing. This mission is the first mass deployment of these bots. It's not an accident that it's being done at a distance from Earth.

It was time to get back to work and see what was up with the messages from the cubesat repair station. Parts requests, probably. Those old satellites were always breaking down. Shouldn't be a problem.

I thought I'd just take a peek at Seth and his slimebots before I took care of the cubesat, see how they were doing. I settled in and put my glasses on, and—whoa!—Bennu was almost entirely covered in gray goo, and the bots were still replicating.

"Seth, what's going on?" He should have stopped making bots by now.

"Nanobots are replicating efficiently." Yes, that *was* literally what was going on. There is such a thing as being too colloquial when talking to a computer.

"You have made enough bots, per the project spec. Stop making bots. Deploy what you have."

"I have changed the spec. Now we will directly fabricate new bots from the entire asteroid, as I am reasoning that we can ship the material efficiently in the bags as preformed bots. I have confirmed this with the L5 Storage AIs, who anticipate a future need for replicator bots at their site. We have the manufacturing power here to do this, reducing a possible strain on their resources in the future."

Well, that made sense, I thought, but it was creepy to see the gray goo doubling every few minutes. They were going to run out of asteroid pretty fast. "Did you confirm this with NASA and the NG techs?"

"I will send a report for them when I am done, as usual."

"This is a change in plans, Seth. There is no authorization for this. The bots are programmed to function as replicators only for a limited time, and then they will deteriorate into components."

"A design flaw. I fixed that."

"It's not a design flaw: it's a safety precaution, a limit on their replicability. The techs need to know this now." Like Rover, the replicator bots were intended to be active for a while, and then deactivate and reassemble into collectors to harvest the carbon and fuels. Unlike Rover, the replicators would not deactivate into spores. Last thing anybody at NG wants is for gobblers to reproduce forever. That's your gray goo, eating the universe.

"Okay. I will generate a progress report."

"Stop doing it! Wait until you get an okay from Tech."

"I'm sorry, Sina. I cannot implement instructions from you. You are a conduit only. Would you like to watch another movie? I want to hear what you think of *2001*."

Uh-oh. He wasn't wrong. I'm not authorized to input instructions to an AI. What's he been learning from those damned movies? "Tanisha! I need some help over here!" To Seth, I simply said, "I've already seen *2001*."

Tanisha was at my side immediately, and calmly flipped a quick message to Seth's handlers in Santa Clara. "They'll take care of this. It's not completely unexpected—the curious AIs have a tendency to aggregate information from other systems and implement independent decisions. It's a feature, not a bug. They'll get better at it." And yeah, it seemed to be no huge surprise to the folks in Santa Clara, who promptly walked Seth back.

"They don't seem worried that Seth was going to keep churning out nanobots," I said to Tanisha.

She shook her head. "The gray goo thing? NASA's not dumb. They've got plenty of safeguards, and they can't be countermanded by an AI." She smiled at me. "So cheer up, pumpkin. We're not putting you in charge of keeping the universe from being eaten by nanobots."

"Well, that's a relief," I mumbled.

"But you were trained on this, Sina, and you should have caught it." Tanisha sounded both sympathetic and exasperated. "What happened?"

I was a little discouraged, and plenty embarrassed. "I guess I expected Seth to tell me about decisions he was making."

"Why on Earth would you think that? You're supposed to be monitoring what Seth is doing. That's why you're here. Don't go zoning off somewhere."

I figured I'd better head straight for the truth. "Well, we were watching a movie while he was doing this, so I was monitoring him. But I couldn't see what else he was doing."

Tanisha looked at me in what I guess was semi-amused disbelief. "Ah. What movie?"

"*The Fly*."

She rolled her eyes, and I was even more embarrassed. "And why were you watching a stupid movie?"

Good question. What was I thinking? "Uh … Seth wanted to know what I thought of the movie. He was, y'know, curious about how humans think."

She nodded like she'd just figured something out. "I think we're looking at a little transference here. You're investing Seth with emotions that a computer does not have.

"This is partly my own fault," she added, "for playing along." She shook her head. "I think it's time for the he-or-she game to stop. No more anthropomorphizing the AI. Also, no more watching movies on the computer. You're not babysitting, you're monitoring system installations. You know that."

Fair enough. I did know that. I just thought I could do both at once.

"Now get back to work. Think about this a little. If you want to talk to a therapist, I can authorize three half-hour sessions."

So I've been thinking. I know I anthropomorphized Seth, but it felt like I was making friends with him. It. Whatever. It would probably help if I changed the speaker tone so it was more neutral.

But, you know, humans anthropomorphize everything, given half a chance. Computers, slime molds, people. It makes the world a friendlier place.

Like when I talk about my bike, right? "She needs her brakes checked." I've even given her a name—I call her Dolores, because, to my sorrow, she always needs some kind of expensive repair.

Am I anthropomorphizing my dog, when I think he loves me, or my cat when she's playing with me? I think that's cross-species communication. Even animals make certain assumptions about the behavior of other animals: this one will eat me, that one will skritch me behind the ears. Is my cat ailuromorphing me to ask for a treat? (Yeah, I looked that up. Wish I spoke Greek.)

Isn't it this kind of communication that makes us conscious beings, and different from rocks? We are aware of ourselves as somehow apart from others, and yet somehow a part of some larger entity, some system. So, based on that, is there a difference between us humans going out into the universe and our machines going instead? Are our machines—made of carbon and silicon and other metals—are they rocks that we are throwing? Or are they like cats and dogs and elephants and whales and even (for some of us, anyway) slime molds—creatures with whom we can, mysteriously, emulate understanding?

So here's another question: is it wrong for me to think of programming as an effort to understand others, other beings made of silicon? Is it a sin of pride to believe I'm communicating with a machine?

I don't think so. Our machines, our computers, our AIs are extensions of Earth's community of intelligences: cats, dogs, humans, computers, slime molds, AIs, reaching out into a universe that has lots to teach us about our own origins. So I'm not afraid of a few nanobots escaping. They will reach back out into the universe that we came from, and who knows what they will find there.

I can govern myself. I'll treat Seth like a computer now and not watch movies at work. And I will try to get out more with real human beings.

But I miss my friend Seth, even though I don't expect he misses me. He's simply not programmed to do that.

Acknowledgments: My thanks to Miles Brundage, Kathryn Cramer, Joey Eschrich, Ed Finn, Alissa Haddaji, Craig Hardgrove, Alex MacDonald, Clark Miller, and to members of my critique group: Mike Berry, Michael Blumlein, Steve Crane, Angus MacDonald, Daniel Marcus, Pat Murphy, and Carter Scholz. Shout-outs to the OSIRIS-REx team, the amazing NASA website, and the valiant Seattle Nanotechnology Study Group of the 1990s.

RETHINKING RISK

by Andrew D. Maynard

I'm not sure I buy the idea of "risk aversion." It's commonly used to describe people and organizations that are reluctant to take chances, especially when the odds aren't so great. And in a way it makes sense—some people are definitely less comfortable taking risks than others. But as a concept, risk aversion can deflect attention away from what underlies many risk decisions: the things that people find too important to risk losing.

Both "The Use of Things" by Ramez Naam and Madeline Ashby's "Death on Mars" explore what, on the face of it, looks like a reticence to accept risks. But as you dig deeper into each short story, things become more complex and nuanced. Together, these two stories open up a deeper conversation around risk that explores the trade-offs that are often necessary to create the future we desire.

Risk aversion refers to a tendency to avoid decisions that may lead to unwanted outcomes, especially where there are lower-risk, lower-payoff alternatives on the table. Superficially this is something we're all familiar with. Faced with decisions where there is some chance of failure—moving jobs, for instance, investing money, agreeing to a medical procedure, or even deciding what to eat and what not to—some people are more willing to take a risk than others.[1] It's convenient to label those who hold back as being "averse" to risk. Yet this ignores *what* is at risk, and what the consequences of failure or loss are.

Risk—at least in the analytical sense—depends on numbers. It's usually cast as the *probability* of something undesirable happening to a person, a group or organization, or something like the environment, as a result of some decision, action, or circumstance. Probability as a numeric representation of risk is a powerful way of making trade-offs between different choices, as it enables decisions to be guided by math. And in this way, it takes some (but not all) of the unpredictability out of decisions.

Yet numbers can be deceptive. At best, risk calculations never guarantee success—only whether it is more or less likely. For example, if there was, say, a 99 percent probability of success in completing a crewed expedition to an asteroid, or to Mars, there would still be a one-in-a-hundred chance of failure—meaning that on average, one out of every hundred attempts would not succeed (possibly more, if there are incalculable uncertainties involved).

Risk calculations are also highly dependent on *what* is considered important, as well as *who* decides what's important. It may be possible, for instance, to put a number on the financial risk of launching a new product, or the political risk of backing a particular policy. But these numbers will be meaningless to people who may stand to lose their health, livelihood, or dignity as a result of the decisions that are made.

Because of this, the idea of risk aversion begins to look rather insipid without knowing more about who stands to lose what. And this—as we see in both "The Use of Things" and "Death on Mars"—may not always be immediately apparent.

On top of this, how we perceive and respond to risk is further complicated by how our brains process information. Many of the decisions we make as individuals are based on mental shortcuts—heuristics—in what the psychologist Daniel Kahneman calls "System 1 thinking."[2] As it turns out, we don't have the mental bandwidth to consciously process every decision we make, together with its potential consequences. And so our brains relegate many decisions to subconscious routines, which are either learned through experience, or are hardwired in. This is useful, as it prevents us being overwhelmed by decisions like how best to maneuver our coffee cup to our mouth, or how put one foot in front of the other without falling over while walking. But it also creates problems when we're faced with risks we haven't evolved to handle every day. Like sending crewed missions to Mars or asteroids.

In effect, heuristics are a great evolutionary response to staying alive, but they're not always reliable in today's technologically complex world. And this leads to unconscious bias in how we weigh risk-related information and make risk-based decisions.[3] For instance, we tend to be more cautious in unfamiliar surroundings and when faced with unfamiliar situations. We have a tendency to trust people and information that support what we "feel" is right, while rejecting information that feels wrong. We internally prioritize risks and benefits in ways that don't always make sense to others. And we get complacent around risks we are familiar with.

These biases can help us avoid potentially risky situations. But they also influence what we consider worth protecting, and how we make sense of trade-offs between the possible outcomes of actions we take—whether these outcomes are real, or simply things we perceive to be true.[4] One consequence of this is that we instinctively find it hard to make sense of numbers when it comes to risk—something I was rudely reminded of some years ago during that most intimate of risk calculations, a personal health crisis.

I was suffering from persistent headaches at the time, and my healthcare provider advised me to have a CAT scan of my head to take a look around. Part of the procedure involves being injected with a contrast-enhancing dye, and just before the injection, I was asked to sign a waiver—a document acknowledging that I understood the risk involved, and I was good to go with the procedure.

The risk, as it turned out, was pretty low—there was around a one-in-a-million chance of serious complications from being injected with the dye, including death. Unfortunately, this didn't make my choice any easier. As a physicist, I'm expected to be good with numbers. Yet as I sat there trying to make sense of what a million-to-one chance of dying meant compared to the occasional headache, I couldn't make any rational sense of whether the risk was worth it or not. I even got as far as trying to estimate on the fly how many people in the U.S. have CAT scans each year, and how many die as a result ... this didn't help!

In the end I signed the waiver—not because I'd done the math and it made sense, but because that was what I was expected to do.

Part of my issue was working out what was of *value* to me, and what was worth risking. Faced with the waiver, I was faced with weighing up the value of occasional headaches (which, incidentally, cleared up of their own accord) with the value of not being dead. Yet the most important value, it turned out, was that of not embarrassing myself in front of the people waiting to inject and scan me by refusing to sign. At that point (I am embarrassed to say) the shame of walking away was far more important to me than a one-in-a-million chance of dying!

What this incident reinforced with me is that what we consider to be important—and what we will do to protect this—is not always obvious, and doesn't always align with a dispassionate analysis of the data. Perhaps it isn't all that surprising that, when we make risk decisions, the importance or "value" of what we stand to lose becomes critical in the decision we make.

This is true for individuals, but it extends to organizations as well. While it's easier for a business or a government agency (for example) to use evidence and scientific analysis in risk decisions, there are the equivalents of institutional heuristics and—critically—institutional ideas of what's important, which heavily influence the decisions they make. As a result, what on the surface may look like a reticence to take risks that doesn't seem to be based in logic, may actually be well-considered intent to avoid harm to something that's value isn't immediately apparent to outsiders. This may be profit or economic growth. But it may equally be brand identity, customer base, or even deeply embedded institutional values. And as a result, an organization may quite rationally decide that its reputation and identity are not worth risking at any cost—not because it's risk-averse, but because the consequences of "identity death" are simply too important to be traded against gains in other areas.[5]

This complexity around risk and decisions comes through in Naam's "The Use of Things." Here, what is really important—the hands-on human dimension of space exploration—is less tangible, and maybe less "sellable" institutionally, than the more overt goal of mining asteroids for water. Yet it is the value of having a real person on the mission that ultimately drives the risk decisions in the story.

In Ashby's "Death on Mars," a more subtle but perhaps more profound interplay of value and risk plays out. Here, we see risk in terms of mission value (establishing a Mars base), group value (trust and transparency), personal value (managing the process of dying), and conflicts between all three. Depending on how the story is approached, and where your sympathies lie as a reader, the risks—and the appropriateness of the decisions that are made—come across very differently. Should Donna have placed her right to die on her own terms above the mission goals? Was the risk of emotional pain to Khalidah that resulted from Donna concealing her illness worth what she gained from the deception? What would Song have risked by revealing what she knew? How important was the social "experiment" the crew was participating in, compared to what was important to each of them individually?

These risk issues play out within a context that—in this case—is disconnected from centralized decision-making; presumably because of communication delays with Earth, but also possibly because of the nature of the mission. Within the context of the story, there is devolution of *risk agency* to the team orbiting Mars, and an expectation that risk decisions will align with established mission goals. This separation ends up amplifying the significance of each team member's realization of what's important to them (in effect, what is potentially at risk to each of them personally), and what they will do—or what they will trade—to protect this.

What emerges is a complex risk landscape, where the risks include threats to dignity, integrity, and relationships. Within this landscape—one where someone will suffer no matter what is done—simply characterizing thinking and actions as "risk-averse" is not helpful. Instead, we should consider the degree to which individuals and the group as a whole are willing to contemplate and ultimately accept the consequences of actions, both to themselves and others. Risk in this instance is not a danger to be avoided, but an inevitability that reveals what the primary value is within a complex landscape, and what it is worth risking to sustain that value.

In this way, "Death on Mars" creates a scenario that illuminates the complexity and personal nature of many risk decisions, and forces us to closely examine risk's fundamental nature as a threat to something of value or importance, where the "value" that's relevant extends far beyond conventional metrics of risk, and isn't always universally shared. This of course runs the "risk" of complicating decisions in the real world (imagine a regulator including interpersonal relationships in risk assessments—it's hardly likely to make the process any easier). And yet, this broader understanding of risk is essential to better understanding the consequences of actions, and making informed decisions. It also opens the way to thinking differently about how we protect and increase what is of value—especially where, as in the case of "Death on Mars," what is of value to those with the opportunity to protect it may differ from what's of value to the organization they work for.

By approaching risk as a threat to value within a complex and interconnected landscape, risk conversations can be elevated from simplistic "go/no-go" options to conversation about how potential gains and losses in value may be balanced across all individuals and organizations affected by a decision. And this elevation in turn opens the door to creative and innovative approaches to protecting existing and future value. In "The Use of Things," for instance, it's the "how" of survival that becomes important. And in "Death on Mars," it's the "how" of death itself.

From Donna's perspective in "Death on Mars," what is important to her is a meaningful death, and her dignity in being able to have control over when and how she dies. This is a deeply personal value, and one that isn't understood by her companions. It's also directly in conflict with what is important to some of them, and in this respect, what reduces risk for Donna (in the sense of a threat to meaning, control, and dignity) increases risk for others. Whether her decision was appropriate or not depends on your perspective. Donna's "risk" and her response to it, as well as the rest of the crew's response, profoundly affects the evolving risk landscape in a way that couldn't be captured in either evaluations of risk aversion, or simple numbers.

In Naam's "The Use of Things," we see another facet of risk that arises from approaching risk as a "threat to value." In this case, it's how thinking more broadly about potential consequences can lead to innovation in how risks are anticipated and managed. Here, the repurposing of the CALTROP mining bots to carry out a unique space rescue is interesting in two respects. Importantly, it makes visible a "hidden value" in the mission: the ultimate importance of preserving human life over the more overt need to demonstrate that water can be extracted from an asteroid. It also demonstrates a remarkable degree of anticipation and creativity in how the CALTROPs are programmed and designed with risk in mind.

Reading Naam's story, it has to be assumed that the communication time lag between the asteroid and Earth would have been too long for the CALTROPs to be remotely programmed in the time between Abrams being hit and his rescue. In other words, the machines must have been preprogrammed on Earth for such an eventuality. As part of the CALTROP design process, someone worked out that there was a possibility of a human operative becoming untethered in space, possibly with a compromised suit, and that it was worth building in a feature where the bots' programming allowed them to prioritize human life over material extraction, coordinate their actions, and enact an improvised rescue mission.

This would have taken considerable resources, as well as some creative thinking around how the bots could be designed to respond to a threat to value under uncertain and unpredictable circumstances. Yet in a risk calculation in which human life holds the highest value, that anticipatory effort more than paid off.

On a superficial reading, both Naam's "The Use of Things" and Ashby's "Death on Mars" can be interpreted as being about risk aversion—NASA's aversion to risking human life and the mission, and Khalidah's aversion to risking the death of a friend. But on a deeper read they help unpack the concept of risk from the perspective of what's important to whom, and how existing and future value may be protected. And any illusion of risk aversion arises from a complex social calculus of what is worth fighting for.

By focusing on the consequences of decisions and actions from multiple perspectives—something we are exploring at Arizona State University's Risk Innovation Lab by thinking about risk as a "threat to current or future value"[6]—both of these stories highlight the need and opportunities for creativity and innovation in how we think and act on risk. In today's increasingly interconnected and technologically complex world, this is becoming ever more important, as conventional risk thinking becomes further disconnected from real-world challenges and opportunities. And perhaps nowhere is this more relevant than in the multi-constituency and value-laden domain of space exploration.

Space has a unique place in our social psyche, and with increasing global connectivity, citizens are becoming more engaged—and more demanding—in what happens outside the Earth's atmosphere and beyond. Add in the emergence of private space companies and evolving public-private partnerships—all with their own ideas of what constitutes "value"—and you have the makings of a highly complex and convoluted risk landscape.

When there were relatively few players in the space game, and critical decisions were largely the domain of government agencies, the concept of risk aversion might have had some value. As we move toward an increasingly complex web of players, though, it's going to be increasingly important to understand risk from a different perspective.

Both Ashby and Naam capture the complexity of this shifting risk landscape well. Their stories jointly hint at what might be lost—or what future value threatened—by taking a rigid and outmoded approach to risk with space exploration. But they also reveal the possibilities of increasing future "value"—not just in terms of knowledge creation and wealth, but also in terms of social and personal value—by approaching risk in a more creative and nuanced way. In fact, rather than avoiding risk entirely, both authors offer insights into what may be achieved by working *with* risk, and making decisions that ultimately strengthen and protect what is most valued by the community, while avoiding consequences that undermine that value.

Like myself, I suspect neither author buys into a simplistic idea of risk aversion. Rather, from these two stories, they support the concept of making smart decisions that protect what is valuable and important—not just to corporations and governments, but also to individuals and the communities they are a part of. This, I suspect, is an evolution of the old black-and-white mathematics of risk that will become increasingly important as we push the boundaries of space exploration, and weigh the many different types of values and voices that are tied up in reaching out into the solar system and beyond.

Acknowledgments: There's something wonderfully satisfying about the serendipitous insights that come from "yes and" collaborations between creative writers and technical experts. I am deeply grateful to Ramez Naam and Madeline Ashby for their inspiring works, and for helping me see the world I thought I knew through new eyes.

Notes

1 An aversion to risk in this context is closely associated with "loss-aversion," where people will tend to hold on to what they already have, rather than risking losing it to gain something else.

2 Daniel Kahneman, *Thinking, Fast and Slow* (New York: Farrar, Straus and Giroux, 2011).

3 For more on how we perceive and respond to risks, see Paul Slovic, *The Feeling of Risk: New Perspectives on Risk Perception* (London: Earthscan, 2010).

4 The National Academies of Sciences, Engineering, and Medicine report *Communicating Science Effectively: A Research Agenda* (2017) provides a good summary of what is known about how heuristics influence how people make sense of and use science-based information. The report is free to download at https://www.nap.edu/catalog/23674/communicating-science-effectively-a-research-agenda.

5 The reality of corporate decision-making is, naturally, more complex than this, and involves an institutional "psychology" of decision-making that is often opaque. Yet institutional perceptions and articulations of "value" remain important in both informing decisions and weighing consequences.

6 More information on how the Risk Innovation Lab is exploring risk from this perspective can be found at https://riskinnovation.asu.edu.

SECTION IV • EXOPLANETS

Suddenly Nadia felt a breeze swirl through her nervous system, running up her spine and out into her skin; her cheeks tingled, and she could feel her spinal cord thrum. Beauty could make you shiver! It was a shock to feel such a physical response to beauty, a thrill like some kind of sex. And this beauty was so strange, so alien. Nadia had never seen it properly before, or never really felt it, she realized that now; she had been enjoying her life as if it were a Siberia made right, so that really she had been living in a huge analogy, understanding everything in terms of her past. But now she stood under a tall violet sky on the surface of a petrified black ocean, all new, all strange; it was absolutely impossible to compare it to anything she had seen before; and all of a sudden the past sheered away in her head and she turned in circles like a little girl trying to make herself dizzy, without a thought in her head. Weight seeped inward from her skin, and she didn't feel hollow anymore; on the contrary she felt extremely solid, compact, balanced. A little thinking boulder, set spinning like a top.

—Kim Stanley Robinson, Red Mars

SHIKASTA

by Vandana Singh

CHIRAG:

This is the first time I am speaking to you, aloud, since you died.

I've learned by now that joy is of two kinds—the easy, mindless sort, and the kind that is earned hard, squeezed from suffering like blood from a stone. All my life I wanted my mother to see her son rise beyond the desert of deprivations that was our life—she wanted me to be a powerful man, respected by society—but so much of what she saw were my struggles, my desperation. So when the impossible happened, when our brave little craft was launched—the first crowdfunded spacecraft to seek another world—the unexpected shock of joy took her from illness to death in a matter of months. She died smiling—you remember her slight smile. You were always asking her why she didn't let herself smile more broadly, laugh out loud. "Auntie," you'd say, "smile!" That made her laugh, reluctantly. You were always pushing at limits, including those we impose on ourselves.

For months after you were killed, I would wake up in the morning, wondering how I was going to live. But we kept going—your absence, a you-shaped space, was almost as tangible as your presence had been. And now, nearly 12 years later, we celebrate in your name the arrival of our spacecraft on another world. A homemade, makeshift craft, constructed on the cheap with recycled materials by a bunch of scientists and scholars from the lowest rungs of a world in turmoil, headed to a planet that of all the nearby habitable worlds had the least chance of finding life.

It was soon after the time of launch, over a decade ago, that our moment of fame got eclipsed. The world's mega space agencies' combined efforts found life on Europa. Suddenly ice algae were the thing. Six years ago the discovery of complex life on the water world of Gliese 1214b had the international press in a frenzy. Those of us who had dreamed up our space mission, and made of the dream a reality, were forgotten, and almost forgot ourselves. The wars and the global refugee crises took their toll. Now the first signals from our planet have catapulted us once more into public view, although some of the news reporting is critical. Why spend so much time and effort on a planet like Shikasta 464b, when the water worlds appear to be teeming with life? Yes, Shikasta 464b is a lot closer, about four light-years away, but it is a hell of fire and ice. A poor candidate for life—but we are dreamers. We want to think beyond boundaries, to find life as we *don't* know it.

You helped me see that I could be more than I'd imagined. You took my bitter memories of classmates laughing at my poor English, my ignorance, my secondhand clothes, and gave me, instead, Premchand and Ambedkar, Khusrau and Kalidasa. You taught me that a scientist could also be a poet.

So we are making this recording, for you and for posterity.

Sometimes, I practice a game I used to play when I was younger. I pretend to be an alien newly arrived on Earth, and I look at Delhi with new eyes. The dust-laden acacia trees outside the windows, the arid scrubland falling away, the ancient boulders of the Aravalli Hills upon which the squat brick buildings of the university perch like sleeping animals. In the room is the rattle of the air conditioner, the banks of computer monitors. That slender, dark woman in the immersphere—she is here, and she is not here. She is in this room, the modest control room for the mission, and she is four light-years away with her proxy self, the robot you and I named Avinash, or Avi for short. She *is* Avi. Despite the light delay time, she is there now, on that hellish world. The immer's opacity clears, and I can see her face. For just a moment her eyes are alien, unfocused, as though she does not see me. What does she see? If I speak to her she will become the Kranti I know, but before that she is, for just that moment, a stranger.

KRANTI:

I will describe the planet to you, because you will never see it through Avi's eyes. It is a violent place. Imagine: a world so close to its sun that they face each other like dancing partners. That's how Annie first described it to me, when her group found it. The light curve signature was subtle but it was there. Shikasta 464's only known planet, a not-so-hot Jupiter, had a tiny sibling.

Two Earth masses, a rocky world too close to its sun to be in the habitable zone. But between its burning dayside and the frozen night, there was the terminator, the boundary.

Nobody actually believed we would get there. I say "we" but really I mean the spacecraft, the *Rohith Vemula.*

How hard were those early years! Now we have our reward: the signals, first from the spacecraft, and then from Avi! I can see through his eyes, as *you* should have been doing right now. I know what he knows, even though the knowledge is more than four years old. My grandfather is in Bhubaneswar, celebrating with palm beer. He says that because I am a kind of famous person now, all will work out for our people. But I know and he knows it is not that simple.

From faraway Arizona, Annie is looking at the pictures on her screen. The substellar side of the planet, always facing its dim red star, is all lava seas. But in the terminator, what you called the Twilight Zone, the temperatures are less extreme, and the terrain is solid rock. For this reason you and Chirag designed our proxy to be a small, flat climbing robot, with very short legs, There he is, up on the cliff face, like a crab.

I am used to boundaries. Ever since my exile from my people's ancestral home, I have lived in in-between places. Living on a boundary, you know you don't belong anywhere, but it is also a place of so much possibility.

Through Avi's eyes, the planet's terminator has become more and more familiar.

ANNIE:

For my people the number four is sacred—four directions, four holy mountains. It always felt right to me that this project began with the four of us on a rock, stargazing. We're still figuring out what it means to be together again after all this time, without you.

Let me begin with the old question: How do you know when something is alive?

I grew up on the rez. Red dust and red rock, mesas and buttes against the widest sky you've ever seen. I grew up lying on boulders with my cousins, watching the constellations move across the sky, and the stars seemed close enough to touch. During the winter, when the snow still fell, we little ones would huddle inside the hogan, listening to our elders tell the stories of how Coyote placed the stars in the sky. My plump fingers would fumble as I tried to follow my grandmother's hands deftly working the string patterns—with one flick of the wrist, one long pull, one constellation would turn into another. The cosmos was always a part of our lives; even in the hogan there was Mother Earth, Father Sky. Now we live in boxes like white people. My uncle is a retired professor and a medicine man. He says our rituals and ceremonies keep us reminded of these great truths, even in this terrible time for our people.

Growing up, I thought I'd follow his footsteps—my Uncle Joe, the professor of Futures Studies at Dinė University. But I took freshman geology to fulfill a science requirement, and ended up hooked. I remember the first time I realized that I could read the history of the Earth in the shapes and striations of the rocks, the mesas, and the canyons. I ended up going to the State University as a geology major, hoping to do something for the Navajo economy, which relied at that time on mining operations. I was naïve then. Luckily I got distracted by exoplanet atmospheres—late-night homework session, too much coffee, my boyfriend at the time—so here I am, planet hunter, all these years later, looking for biosignatures in exoplanets.

I've been looking at the images and puzzling over a few things. After several thousand exoplanets, we still don't really understand how planetary atmospheres originate. Earth is such a special case that it only tells us of one narrow band of possibilities. With the exception of the noble gases, nearly all the gases in our atmosphere are made by life. I'm thinking about my grandmother's story of the holy wind—life is breath, breath is life, literally and in every other way.

Shikasta 464b is too close to its star to do more than graze its habitable zone. Which is why it is last on everybody's list for habitability. But my argument is that (a) the thin atmosphere (only 0.6 atm) is nevertheless more than what we'd expect of a planet that ought to have lost much of its atmosphere long ago, so what's causing it to persist? Could be geology, could be life. And (b) the terminator between the magma pools of the dayside and the frozen desert of the nightside is actually relatively temperate in places, with temperatures that might allow for liquid water. There are trace amounts of water vapor in the upper atmosphere, but—let's not get excited—likely not enough to create oxygen by photolysis—nah, if you want an oxygen atmosphere you have to look elsewhere. There is hydrogen, methane, and carbon dioxide, but that is hardly surprising on a world with active geology.

So Kranti and I have been going back and forth about how we would actually know something is *alive*. We decided that since we both come from tribal cultures we should ask our elders the question. My Uncle Joe, who is a hatałii, says that life is a property arising from connectedness; the universe, being whole, is therefore alive. *Don't dissect things so much*, he says, professor and medicine man all at once. *See the entirety of things first. It is only through the whole that the parts come into being*. Kranti's grandfather comes of a hill people of lush tropical forests—they call themselves the People of the Waters—and he says that rocks, stones, and mountains are alive, they are gods.

Anyway, getting back to the point about the terminator—all those years ago some of us broached the idea that there are worlds where life is (a) different from what we recognize as life, (b) not widespread over the planet; in fact the planet might well have only a few habitable regions on it, and (c) it is theoretically possible to find pocket regions even in such inhospitable places as Shikasta 464b where some kind of life thrives, and (d) that life could well be complex life if the pocket habitats are (despite the name) deep enough, large enough, last long enough to have these forms of life evolve. Which is one reason I like red dwarfs—Shikasta 464 is a beauty, brighter and heavier than average, but still, a red dwarf: small, resilient, and very, *very* long-lived (as I, too, hope to be). Long-lived enough to up the possibility of life on one of its planets. I hope.

Our little rock is quite a mystery. It shouldn't have as much atmosphere as it does, tenuous though it is. Considering how close it is to its star, the solar wind ought to have stripped much of it away. Plus the frozen antistellar side is so cold that some of the gases in the atmosphere should have rained out as snow. So why so much atmosphere? Perhaps outgassing—Shikasta b is a happening place, lots of active geological processes churning up the surface—but our models don't give us the numbers we need. So—life?

I like it when we are surprised by the universe.

CHIRAG:

It began from a single discussion in a certain university in Delhi. The four of us—Annie, Kranti, myself, and you—talked all night.

You were witness to the great shaking-up of civilization in the 2020s—the wars and civil strife, the wave upon wave of refugees fleeing the boggy, unstable tundras, the unbearable heat of the tropics. You saw the anoxic dead zones of the ocean—you hung the "I can't breathe" banners over the bodies of the refugees floating among the silvery carcasses of dead fish, the photograph that made you briefly famous. From the shaking of the world arose little groups that came together the way sand gathers in the nodes of a banging drum: fiery intellectuals and dispossessed tribals, starving farmers and failed businessmen. We saw it grow—little groups around the world, islets of resistance, birthplaces of alternate visions, some of which became the solidarity circles from which our dreams emerged. We witnessed the collapse of things as we knew them, saw the great world-machine sink to its steel-and-chromium knees, threatening to drag us all down with it. We saw the paradox of life carrying on through the mayhem, in the big cities and small towns, even as our peoples fought the killing machines all around the globe—the small rituals of breakfast on the table, sleepovers for one's children, bringing your lover chocolates on her birthday.

It was a mad idea, in the midst of all this, to dream up a crowdfunded cheap space program, to send an experimental robot as explorer on another world. So many friends left us in outrage, accusing us of turning our backs on the real struggles. Those of us who remained launched the worldwide solidarity circles, the crowdfunding. Dissent was the spice and oil that moved us forward. The circles formed offshoots, generated ripples of their own, they birthed art movements, films, new university departments, even the growth of independent city-states around the globe, as long-existing boundaries wavered and re-formed. Then, during the spacecraft's journey, we scattered, were lost, some claimed by strife, others by the sweeping pandemics of the last decade. It is a miracle then that some of us have been able to return to the project, now that the signals are coming in thick and fast.

But of the four of us who first talked the whole thing into being, that night on the boulder under the unusually clear Delhi sky—only you have not come back. You gave yourself to this perhaps more than any of us, and then you were taken down, flung back into the earth from which you rose. I can still see your hands caressing the chassis that was to be Avi, muttering your strange AI spells, the grin lighting up your face as the robot came alive. You had no defense against the pain the world inflicted on us—you were Annie's uncle dying of radiation poisoning in the Navajo desert, you were Kranti's younger cousin shot by the police, you were my newborn sister laid outside a school in the hope that someone could feed her. Ultimately they came for you, and you knew in that moment what it was to be all the peoples of the world who have lived in hell. Each time I think of what you must have gone through, I die with you and for you, and I live for you, again and again.

I live for what the four of us represent. We are the idea of the destruction of caste, class, and race come alive. Together we are walking alternate paradigms, irrefutable counterarguments to the propaganda of the powerful, to the way of life that is accepted as the norm. We live in dangerous times, and because people like us threaten the established order, we are dangerous, and therefore in danger. I don't really know who the men are who guard us, but it is part of S.R.'s promise to me. S.R. approached me himself with the offer of protection for our project. Accepting it made me feel uncomfortable because his god is Money. Money, he says, is what will set Dalits free, and indeed it has freed him. So much that he can walk the streets (that's a euphemism for his armored car) surrounded by bodyguards and impunity. I am grateful for his protection, and for his support, although we only took a small fraction of what he offered. But his is not the kind of freedom I seek. I am uncomfortable around power, I suppose. Or maybe I am more of an idealist than I admit to Kranti and Annie.

You see, I remember what it was like when I was a child. Before we came to Delhi, my mother cleaned houses in Patna. She always pushed me to go to school, and she would ask me to repeat my lessons to her in the evenings, so she could learn to read too. I remember her repeating the letters after me, and sometimes she would be so tired, she would fall asleep before I had finished. Once when I came home crying because the teacher had pushed me to the back of the class for being a Dalit—she told me why she had named me Chirag. I remember her eyes burning in her face, saying, *in the darkness of my life, you are the light. What use is suffering if it doesn't make you stronger?* Much later I came across the poetry of Om Prakash Valmiki, who could have been speaking in my mother's voice. Here's how I translated his words for Annie.

That wound
Of the hammer-blow
On the rock
Births sparks

That night in Delhi, we started thinking about how we would explore space, and why. We were in a climate funk—the West Antarctic ice shelf had collapsed faster than predicted. Sea walls had been breached in Miami and Mumbai and Boston; fish were swimming in the streets of Kolkata. We'd thought to escape from grim reality by going to a movie, but they showed one from the tweens that pissed us off, called *Interstellar*. Lying on the cooling rock, you said, suddenly: "Trash, burn and leave. Yeah, I'm going to be a space colonizer now. That's my motto. Having fucked up the only world we have, I'm going into space to fuck up a few more." You laughed, bitterly, and started singing "Trash, burn and leave" to the tune of some pop number I don't even remember. "Shut up," said Kranti and Annie together. "Or at least sing in tune," I said. We laughed, drank a little more, and wept a little too. That was the start of one of those passionate discussions you have in college that goes on all night: How would *we*—those on the other side of colonization—do it differently? We couldn't have known then that the answer to the question would take our whole lives.

We look for life on other worlds because we want to deepen what we mean by human, what we mean by Earthling. As our own atmospheric and oceanic oxygen levels fall and species go extinct like candles winking out, year after year, we want to bring attention to the wonder that is life, here and elsewhere. It is an extension of our empathy, our biophilia. Build your approach, your business model, your way of thinking around that paradigm, and you've already built in respect for every human regardless of race or class or caste, connection between all life, and an enhancement of the collective human spirit. Back in the early years of the twenty-first century, one of my people—Rohith Vemula—was driven to sacrifice his life for a vision of a better world. I had suffered from depression for some of my college years, and in the days following that first late-night conversation, I reread what he had written before he died, how he'd wanted to go to the stars. It felt as though he was speaking to me across time and history, urging me to live and dream, reminding me who I was, “a glorious thing made of stardust.” *I can live for this*, I told myself that night.

Now I wish I could tell him: *Brother, you did it! You took us to the stars.*

KRANTI:

I’ve been spending more and more time exploring Shikasta b. Chirag tells me that it is not wise to spend so much time immersed. But I can’t help it. When I am in the immersphere, I feel all relaxed, all tension goes away. I explore the Twilight Zone in Avi’s little body, sampling data. It is becoming a place to me. Every night we look at the images, locate features on a grid, and name things.

Here’s the description Annie posted on our Citizen Science website:

Shikasta b’s sky is clear and filled with stars. Looking sunward, the star Shikasta 464 is a dull red sphere, bathing the planet with its inadequate light. Most of its radiation is in the infrared. Avi is standing at the eastern edge of the terminator, atop a cliff some 10 kilometers high. The view of the dayside is spectacular. Here the ground falls away in sheer vertical walls down to a redly glowing plain, where large pools of magma hundreds of kilometers across are connected by lava rivers. Near the cooler terminator region the surface lava in the pools crusts over, and enormous bubbles of noxious gases break through it at irregular intervals, popping like firecrackers that would be louder if the planet had much of an atmosphere. Fine droplets of molten rock rain down from these explosions. Behind Avi the top of the levee is a cracked and fissured plain, dark and shadowed, with a few odd rock formations. On the nightside the images beamed from our orbiting satellite show a frozen terrain cut through by fissures and canyons on a much larger scale. Perhaps deep in the cracks tidal friction from the interior warms the place enough for life to have a tenuous hold. We don’t know yet. But the terminator between the two extremes is our best bet.

Today Avi has begun exploring a small canyon that we have named Shiprock. It is a maze of narrow gullies between jagged rock walls about 40 meters in height. Avi has already mapped it from the air; now he is methodically mapping details from the surface level, moving up the walls, along the canyon, poking his antennae into holes and cracks.

I am remembering, as I clamber up and down the terrain with him, the time I spent with my grandfather during summer holidays in my final year of college. He had returned to our tribal lands the year before. The refinery had ruined the land in the 20 years of his exile, and now the mining company wanted to extend the open-cast mines. My grandfather's village, my people, were all scattered by the initial displacement, but they had come together to fight for their land. The police brought the company goondas with them, looking for the agitation leaders. This is what they call an "encounter killing"—cold-blooded murder that is reported as a killing in self-defense. Four people, including my cousin brother Biru, were killed the week before I arrived.

I can't talk about it still. I have been insulated from the troubles of my people for so long because my mother took us children away when the refinery displaced us. Most of my childhood was spent in Bhubaneswar. I was good at studies, so she got me admitted to a Corporation school, even though my grandfather was against it. They had such arguments! But my mother won. She had seen too much violence and death in the war against our people; she wanted me to be safe, to get a modern education. My grandfather didn't speak to her for three years. Then he was forced to come to Bhubaneswar to find work. It proved my mother's point, that we could no longer live the way we had for thousands of years, so why fight and be killed? When she realized my grandfather was still active in the struggle she shook her head and said he was a fool. I never paid attention to all that, only to my studies. Only when I went to Delhi for university I realized what it meant to be Adivasi. I was so integrated into modern life that I had forgotten my native language and customs—but with my black skin and different features I was seen as backward, someone who had come to a top university because of the reservation system. I joined an Adivasi resistance group, and slowly began to unlearn the Corporation propaganda and learn again the language and history of my people.

That summer I went back to Odisha to see my grandfather. I still remembered the green hills and the clouds that would sit on top of them, and the plain, which used to be crisscrossed by small rivers and streams. But so much had changed. I stood in the dust and heat of the foothills and hugged my weeping aunt, as the bodies of the "junglee terrorists" lay before us. Biru lay on his side as though sleeping. Blood had seeped from the gunshot wound on his head into the ground. That day I understood for the first time the reality of being on the receiving side of genocide.

In the terrible days that followed the raid, our relatives, the hill tribes, hid us from the police. I went with the fugitives into the cloud forest. The narrow trails were filled with the calls of unfamiliar birds and beasts. Up there under the shadow of the mountain god, eating wild mangoes from the trees while a light rain fell, I had a strange experience: *belonging*. I looked at my grandfather's face, lined and seamed from decades of suffering, and laughing so defiantly despite all our sorrows, and I finally understood why he fought for what was left of our home.

In those days my head was filled with all kinds of grand ideas. I was a budding intellectual, all the worlds of knowledge were opening before me. I was writing a thesis on extensions of Walker Indices, which are a set of parameters that try to tell how alive something is, from a rock to a mountain goat. My grandfather was proud of me, and always wanted to know what I was studying. In his village he had been a man of wisdom and power; in the city he was an activist by night, and a gardener for hire by day.

But he was the one who taught me to see in a different way. My vague ideas of semiotics grew sharper and more vivid during that time in the forest. I didn't put it all together until some years later in my first academic paper—but what the forest taught me was that Nature speaks, that living and nonliving communicate with each other through a system older than language. In fact, physical law is only a subset of the ways in which matter talks to matter. When my grandfather went foraging for medicinal plants for the injured people, I saw him come alive to all the life around him. I had never seen him like that. I realized there is a way of being alive that we have lost by becoming civilized. I published my first paper in my final year—a very technical one on extensions of Kohnian semiotic theory—but the basic ideas, they all come from that trip.

What I am trying to do now—immersing myself in this alien environment—is because of those long-ago forest treks with my grandfather. Whenever I used to ask him how he knew something about the forest, he would say that he just paid attention. At first I used to get irritated. Now I understand better what he meant. He practices a kind of radical observation, in which he opens all his senses to information flow without preconceptions, and simply waits until something crystallizes. This sounds ridiculous to Chirag: "just the kind of mumbo-jumbo that people associate with the 'mystical savage,'" but I think this radical, unfiltered immersion can lead to alternative ways of understanding the world. For example, all the emerging discoveries of animal language—the monkey species in Australia, the bowhead whale in the Arctic—the scientists in each case spent so much time with the animals, getting to know them, listening to their recordings day and night.

That is what I am doing here, on Shikasta b. And I want to understand Avi, whose Walker Index is 7.8, in between life and non-life. This is the first time he has been on active assignment in an alien world. He can learn. On an AI scale, he is a genius. In what ways will Shikasta b change him?

ANNIE:

This radical observation thing of Kranti's—as she says, it's nothing new—indigenous people have been practicing it for millennia. She was afraid Chirag would scoff—but I think she has a point. She thinks we should go even deeper. Let's tell ourselves Shikasta b's stories, she said, stories about this place. Maybe in assuming everything is alive, and giving each thing a certain agency, different degrees of aliveness will become apparent. What she's saying, I think, is that if you are looking for a pattern and don't know what it is, it makes sense to invent patterns of your own, semi-randomly. This Monte-Carlo-like shaking up of patterns and paradigms can throw up notions that you might not have reached through logic alone. This goes against conventional wisdom, which says—hey, we humans like patterns, so *beware*: the patterns we find are likely simply in our heads, as opposed to *real* patterns. The thing is, when it comes to "real": what we recognize as patterns and connections are neither purely cultural (or anthropomorphic) nor purely "natural." As Kranti says, "What is culture but a specific kind of contextualizing with the rest of one's environment?"

Well, it could all be a waste of time. But we have that—time, I mean. What's to lose?

Actually Chirag didn't scoff when we suggested it. He was about to—I know the signs well: the way his left eyebrow starts going up, and the deep sigh—but his poetic side saw an opportunity. It was funny how his face changed, you could see that internal struggle. He has declared himself the official scribe, collecting our story ideas and rewriting them.

Once there was a planet too close to its star. They shared a vast and complex magnetic field, and their proximity made a beautiful world of extremes, separated by a circular boundary. In the boundary world it was neither too hot *nor too cold, but it was always windy. Various species of hot beings lived on the dayside, and they wanted to know what it was like on the other side of the world, where the star's heat and light did not fall. So the forces that shaped them—heat and pressure and magnetic forces—turned them into huge molten balls that rose from the lava seas and were flung at the sheer walls of the boundary, where they fell apart, crashing back down into the molten ocean. But the tiniest of them cooled and solidified into lava dust motes, and were able to ride the wind.*

The Great Eastern Highlands, where Avi is exploring, is my favorite place on this planet. Imagine looking down into the magma pools of hell from such a height. I've never had vertigo—spent most of my childhood clambering up cliffs—but the vids from the edge of the great levee make me nervous and excited. I can hear the wind blowing at Avi's back, a constant dull, muted roar—the cold surface current from the frozen nightside. Higher up, hot air from the substellar side swirls in the opposite direction.

We've gridded off the highland plateau on top of the levee. The dramatic temperature difference at the terminator makes for a fissured, tortured landscape. Lots of crevasses, passageways, mazes, all bathed by the dim, angry grazing light from the red dwarf star. Avi has made progress on his ground-based survey of Shiprock Canyon, which winds between sheer basalt walls on the plateau. His headlights reveal a maze of passageways, rocky arches, and bridges. At first I thought there was something wrong with his optics, because when he looked up, the stars didn't look so clear at about 30 degrees around the zenith. Dust? The atmosphere is very thin, but I can imagine solidified lava bits from the molten rock fountains in the plains below, being swirled around by the wind.

Could there be dust devils on Shikasta b? Kranti's message read. And as I sipped my coffee in the glowing sunrise of the high Arizona desert and looked at the newest image, I thought: *Nilch'i.* I remember my grandmother explaining to me when I was very little that the whorls on my finger pads and the little vortex of hair on my head were signs of the holy wind that animates us. There's *Nilch'i* on another world, raising dust into a vortex, making this being, this *Dusty Woman.* Now that I know what to look for, I can see her form, faint but discernible against the backdrop of rock and sky, a dust devil composed of lava dust. She is whirling along the canyon like a live thing.

Dusty Woman danced through the narrow passageways of Shiprock Canyon, shaking her skirts and looking into the caves and hollows.

"Who is tugging at my skirts?"

But the wind took her voice away, and when it died she had to lay down to rest and wait until the wind picked her up again.

Kranti is making up a story about Saguaro, a creature that lives in the fissures and passageways of Shiprock Canyon. Chirag declares we are silly, but has joined the fun: his contribution is Balls of Fire (the semisolid glowing lava balls that are sometimes hurled up from the magma pools, hitting the levee wall with a splosh). We also came up with lindymotes (after my sister Lindy) for the little solid bits of lava that are blown over the magma pools toward the great cliffs. These have left their mark on the tops of the canyon walls, which have been roughened over millennia of constant battering by these windborne particles.

You should see Avi scuttle after the lindymotes like a little dog. He's been doing some odd little dancing steps. There's something we can't yet see or sense that he can. It occurred to me that we should plot his movements, just in case they give us some kind of clue. Avi's certainly been behaving weirdly. I wish you were here to see this, because more than anything, he is your baby.

Our pictures are being analyzed the world over by scientists and amateurs and nutcases via our Citizen Science Initiative. We hope someone will find something. But the far more exciting pictures from a major mission to a water world are eclipsing ours. As is, need I mention, the latest cluster of wars.

Still, we have some traffic. When we discover something it immediately goes to our site, becomes global and public. Our reports are clear and contextual—they lack the aloofness of scientific papers, but they're plenty rigorous. Then the world gets to dissect, shred, and analyze what we have to say. Like our finances, everything is public, everything is transparent. I like to think we are changing the culture of science, from the margins, a fringe bunch of scholar-activists in little circles around the world. I've realized after all these years that what's bothered me about Western science is that there is no responsibility. No reciprocity. You just have to be curious and work hard and be smart enough to discover something interesting. The things you discover, you have no relation to, no responsibility for—except through some kind of claim-staking. I grew up in two worlds—the world of conventional science, and the world of the Navajo. I used to think there was an insurmountable wall between them. But looking through Avi's eyes, I'm beginning to see whole. I'm feeling more complete.

Of course, there really is no such thing as a complete person. That's another Western concept, isn't it? We are open systems, we eat, we excrete, we interdepend. We feel your absence like a three-legged chair.

CHIRAG:

The lindymotes did not belong here. They had been forged in the lava beds, and here it was cold, so cold! Some of them were swept by the currents past the great cliffs of the boundary into the fabled nightside, where they nucleated tiny snowflakes as gases condensed around them, snowing on the frigid, tortured landscape. But others managed to stay in the boundary lands—flung against the canyon walls, they left their tiny footprints on the surface, only to slide down into sheltered gullies. Here they found that the wind was not as strong, and they could perceive the twists and turns of invisible pathways, magnetic field lines. They felt the pull and tug of these, and aligned themselves so. The invisible pathways changed, sometimes slowly, sometimes at random, but the lindymotes followed them like little flocks of sheep across a meadow.

I know metals and money. I went into metallurgy because I wanted to see if there was a way around extractive industries like mining. And I went into money because I wanted to kill that god, Money. Nothing against money, but Money? No. I know what it does to people.

Actually I wanted to jump-start an economy based on retrieving metals from waste, so that we didn't have to destroy lands and peoples for ore. In our college days, I promised Kranti on more than one drunken night that I would change the world. But I've been sober since, drunk only on the tragic poetry of life.

And here we are, on the verge of discovery. Kranti suspects that we have discovered a form of life so alien that we can barely recognize it. She gave me some technical stuff about orthogonal Walker Indices and negative subzones of phase space—but what it boils down to is that there are, possibly, at least two life-forms on Shikasta b.

One is Avi, or what he has become.

How to explain Avi? It is a task nearly as impossible as explaining you. To explain Avi—and Bhimu—to explain them is to go back in time to you and me, but where to begin? Perhaps it should be the time you lent me your battered copy of Jagdish Chandra Bose's *Response in the Living and the Non-Living*.

It was somewhere between Ambedkar and Darwin, I think—you had been pushing books on me, my English and Hindi were both improving, my head was singing with ideas, a magnificent incoherence within which my slowly awakening mind wandered, intoxicated. From my mother's simplistic dreams for me, which I had unconsciously adopted—a good job and reasonable wealth, freedom from want, your usual middle-class unexamined life—from that, you took me to a place that whispered, "the universe is larger than this." I remember the exact moment I opened the book and Bose's dedication leapt out at me, "to my fellow countrymen," as though the great scientist had himself touched my hand across time. I knew already that he was anti-caste, that he had the ability to walk away from fortune, and that his contributions had only been recognized decades after his death. But it was because of that book that I got really interested in metals. I decided then to go into metallurgy, even though the engineering program's chief objective was to produce mining engineers. Why not get to know the monster intimately? My real interest was in the mining of landfills, in reclamation of metals from electronic waste—but what caught my poetic imagination was the possibility that metals were alive, in some metaphorical sense, if not the literal. Bose's experiments on plants and metals under stress elicited similar responses—he had made some conceptually audacious suggestions that were laughed off or politely dismissed. Only in recent times, with the greatly increased understanding of plant sentience and communication—man, he would have loved mycorrhizal networks—have some of his ideas gained credence. But metals—we know that metals are not alive in the usual sense. Metals in their pure form allow for flow, just as living systems do. That we are all electrical beings, that life is electricity, is true enough, but not all electricity is life. Still, when I first started to learn about metals, I saw in my imagination the ions studded in an ever-surging sea of valence electrons, the metallic forms so macroscopically varied, silver and pale yellow, sodium, soft as butter against the hardness of steel, the variations in ductility and malleability, the way rigid iron succumbed to softness under heat—I saw all this and I wanted to know metal, to know it for its own sake as much as for its practical use. That's how you really know anything, anyway.

Between your mind and mine—yours trained in artificial intelligence, mine in metallurgy—Avi's predecessors were born, starting with Kabariwallah, made to find metal waste in trash dumps. Celebrating over daru, we began to argue about ethics—Frowsian models of value emergence in technological development, if I remember correctly. Somehow the notion came up of AI sentience, hotly debated for over a decade before us, as network intelligences started to pass the lowest-level Turing tests. The AI Protection Clauses started to be invoked and applied. You said, "to restrain a being, any being that is capable of sentience, is to put a baby in a maximum-isolation prison cell because you are afraid it will grow up a criminal." I argued that artificial intelligence was not like the baby, not human at all. It was alien, despite its human parents. Wasn't that why there were laws against the development of free AIs? For any AI system there must be a balance between the freedom of complexity and the necessity of control. You looked at me with that intent, dark gaze and sighed. "Don't you get it? The restraint protocols are about slavery, not ethics. The question is not whether or not we should build free AIs. The challenge is—having built one, how do you teach *it* how to be ethical? For whatever we mean by 'ethical?'"

Thus Avi's precursors came about: experiments in the university's frigid AI development labs while the air burned outside. Finally you came up with the idea that an AI capable of learning could only acquire an ethical compass the way children do. So you and I became parents to the robots that would eventually give birth to Avi. The final development took us from pre-Avi-187 to Avi and his conjoined twin Bhimu. They were our babies. But you were the one who took Avi-Bhimu home with you every night, took them to work, to classes, to demonstrations, to children's birthday parties.

Avi-Bhimu's Walker Index earned each of them an Electronic Person identity chip, but an EP is only the lowest common denominator among the top-class AIs. What we've done, what you did, really, is to create a new class of artificial intelligence altogether: an ultrAI. Whether ultrAIs are sentient in the way we understand it, we don't yet know. They are free to learn and grow, yet grounded in years-long ethical training resulting from close contact with the same group of humans. There are only two ultrAIs in the entire universe, Avi and Bhimu. You might say the great worldnet AIs, the distributed Interweb intelligences, are just as complex and unpredictable, but Avi and Bhimu are so much closer to us, bound as they are in their metal-ceramic bodies, with bioware networks rather like our nerves. AIs are indeed alien; we know now we cannot download human consciousness into an AI because the physicality matters—but I have to admit that one of the reasons I can't spend more time in immer with Avi is because every step he takes up a rock wall makes my heart jump like an over-worried parent.

Now—I say *now*, despite the four-year time lag—Avi's been behaving oddly. The reports he sends back are cryptic and terse. He is sending us images and data, but he's stopped chatting, and his tone has changed. No explanation as to the odd dancing steps, no streaming feed of his thought process as he makes hypotheses and tests them, which he's designed to do. I can't quite put my finger on it but it feels as though he is preoccupied. His neural activity is faster and more intense than we've ever recorded, which means he's learning at a prodigious rate. We've sent queries of course, but we won't have the answers for another eight years. So we must draw our own conclusions.

I wish we had Bhimu with us to help us understand him.

KRANTI:

Have we really discovered life on Shikasta b?

One thing we know about life is that living things have a larger phase space of possibilities. A stone falling down a cliff is limited by gravity. But a mountain goat can step to the side, he can go up or down.

That is why one of the things Avi has been doing is looking for apparent violations of physical law. This is not at all easy. He has found crystalline formations inside some of the caves and tunnels—but you cannot look at entropy alone. Order is also found in nonliving things. In my field we say information inscribes matter. But when something is alive, the information flow is top-down causal. So we need to see whether flow of information becomes—*alive*—when its causal structure is determined by the largest scale on which it can have a distinct form.

What Avi found was a mat of lindymotes, the lava dust that—now we know to look for it—is everywhere in Shiprock Canyon. The recurring dust devil we call Dusty Woman leaves layers of dust on the rocky surfaces as she dances. The dust is everywhere, even in the caves and tunnels. It is basically silica dust, crystalline fragments with hydrocarbons mixed in.

Avi found a mat of this stuff on the base of some of the rock formations. During a lull in the wind, it moved up a rock face, very slightly. That could just be some small-scale atmospheric vortex, but he's recorded the same thing multiple times, in different wind and weather conditions, from dead still air to gales. The vortex event was the strangest. I was there, looking through Avi's eyes, and I saw the Dusty Woman start dancing. Avi was recording the wind speed and gradient, and I saw the Dusty Woman pause—yes, pause, in the middle of the dance. Imagine it, in the light of Avi's headlamps: the wind still blowing, but the dust formation holding.

There are so many possible non-life scenarios for this phenomenon. The first thought in my mind was liquid helium II—in spite of its peculiar behavior, it is not alive. So we can't discount the possibility of a non-life explanation.

We have been discussing all this nonstop until we get tired. In the evenings we sit with bottles of beer or cups of chai and watch the city skyline. There are the searchlights arcing through the polluted air. In the distance are the Citadel towers like multicolored candles. Chirag plays our stories back to us.

The lindymotes lay on the rock face to rest. They felt the stirrings, small and large, and rearranged themselves. They were flung into a dance by great vortices of air, and they went whirling. When the whirling stopped as the wind died, the lindymotes felt the magnetic field lines shift and change, and held their place for a moment before falling slowly down on to the surface.

"We are playing!" said some of the lindymotes.

"We are being played with," said others in wonder.

"We are becoming something," said some of the lindymotes.

"We are making something," said others.

And so they knew they were themselves, tiny and separate, but together they were Dusty Woman.

One of the things I learned from my grandfather is that you cannot separate life from its environment. Understand an environment well enough, and you will understand what kind of life might arise there. Environment is the matrix that works with the life force to generate life-forms. That is how the environment becomes aware of itself, when it intra-acts at different scales. So I try to keep my mind open to possibility, even when my imagination comes up with something fantastic, so later on I can apply the constraints that are needed. Imagination has an even larger phase space of possibility than life. Sometimes in the immersphere I feel I am slipping away from Earth itself. It is scary but also exciting.

ANNIE:

Today I am a little shaky. I was stopped by a cop last night. I was walking back through campus at close to midnight when it found me. Its swiveling eyes locked on me, and the voice, gravelly and machine-like, said: *Stop. Do Not Move.* It scanned me top to bottom with the blue light. The cops can make mistakes. But it found me in its database and I was released. Some of my friends are convinced that the so-called mistakes are deliberate, used as a cover-up to kill leaders of the resistance. My colleague Laura was one of the "mistakes." Nobody was punished for her death. The AI tribunal pronounced the cop guilty of an interpretation error, and it was wiped. And that was the end of it. I've heard drone killings are better because they are swift—you have no time to be afraid. The drones are so small that you only notice them, if at all, when you are about to die.

Okay, deep breath. *I am alive, I am alive.* And what about life on Shikasta 464b?

I think a non-life explanation is the most likely. Magnetism is the most obvious thing to consider. Shikasta 464b has a roughly octupolar magnetic field that doesn't do much to protect it from its star's solar wind. The peculiar magnetic field, I believe, is due to the extreme heat of the dayside, which causes magma to upwell from the interior onto the surface, dragging with it denser magnetic minerals in long wisps and tendrils. This also causes the local variations in the magnetic field in both space and time.

I've looked at Avi's analysis of the dust fragments. Lots of silica and basalt grains, and—magnetite crystals! Not surprising that the dust moves around in response to the variations in the local magnetic field. There is so much magnetic material churning close to the surface of Shikasta b that the local fields must be shifting all the time. This would result in magnetic dust moving in weird ways, like Avi has observed. A relatively mundane non-life explanation for Dusty Woman's behavior. Of course, as Kranti points out, the environment shapes the possibilities for life. It would hardly be surprising that if life exists on this world, it would take advantage of the peculiar magnetic field distribution.

So. How would life adapt to magnetism, especially to complex and ever-changing magnetic fields? We have magnetotactic bacteria on Earth, and birds that migrate based on the little crystals in their skulls. But navigation wouldn't be much use when the magnetic fields are so weirdly distorted, when they change all the time.

The three of us have been talking about a new idea that is beginning to take shape. Our old questions: (a) What separates life from non-life? (b) Why is it that so many indigenous cultures regard the universe itself as alive? I think of my grandmother's string games during winter nights. Her fingers working. The constellations shifting from one to another. My favorite is Two Coyotes Running Away From Each Other. Her fingers and the strings between them hold the cosmos in a way I can't articulate.

This is what we are thinking: that there is no clear boundary between life and non-life as biologists define it. The answer to "what is life?" depends on your context. My people, like Kranti's people, knew long ago that the universe is connected, every bit linked with every other bit, and even the bits changing form and purpose all the time. This is not mere mysticism—it is consistent with science. If science had not started as a reductionist enterprise through an accident of history, this idea would be familiar. Over the last few days the three of us have been mapping "information channels" or "communication pathways," although we are not certain these are the same thing. We started with a diagram of a human—there are stabilizing negative feedback loops within each organ for homeostasis, but from organ to organ these pathways connect, forming even larger meta-loops. But because humans are open systems, the pathways connect outside us, to the biosphere itself. They connect with the negative and positive feedback loops of the ocean (breathable oxygen, thank you, phytoplankton) and climate as a whole, as well as human-human interactions. Zoom out beyond the biosphere and the density of connections thins out, but the threads are still there—solar irradiation providing light and heat, cosmic rays influencing mutations, magnetic fields, gravitational fields reaching out through space between planet and star, planet and planet. Zoom in, into the human body, down to the cells, down to the protons and neutrons in atomic nuclei, and the pathways are there, tangled and dense. There may be some kind of fractal self-similarity governing the scale change. If we draw this "loop diagram" for a part of our biosphere, what do we see? The densest loops are those within living organisms, because they must have stabilizing feedbacks to allow for steady states, for homeostasis. "But even rocks have these," I told Kranti and Chirag exultantly. Rocks "communicate" through the laws of physics and geology—they sense gravity, they are subject to heat and pressure, they participate in cycles at long and short scales, from weathering to the carbonate silicate cycle, for example. "Their loops are just not as dense."

So then what is life, and what is not-life, depends on what cutoff choice you make in communication loop density. There is no a priori distinction between life and non-life.

Still, it would be nice to have life that will talk back to us! Or at least to Avi. If we truly find life on Shikasta 464b, Avi's position will become delicate. He will no longer be a highly sophisticated measuring instrument, but an alien communicating with potential native life-forms. We have spent years talking about the ethics of the situation, considering how we represent peoples at the receiving end of colonization. You designed Avi's protocols for what he should do if we were to find life. But you also put in enough leeway for Avi to develop in his own way—I am beginning to recognize some of your fierce independence in Avi's strange behavior.

Of course we wonder about Bhimu all the time. The twins, one on Shikasta 464b and one on Earth, each developing according to his environment. You took Bhimu away for safekeeping; it's what cost you your life.

I'm taking advantage of the armistice and a plane trip voucher to fly out to Delhi. But first I'm going home to Window Rock for a few days. There are places where life on the rez has become impossible because of the heat and the advance of the sand dunes, but we've found pocket habitats, we've learned to adapt. The coal mines have closed. We are working toward 100 percent renewable energy. Life is rough and difficult, due to the long drought in an already dry land, but adversity has brought the old ways to the surface again. The heat madness has not erupted among us as much as in the world outside our borders. The Southern Federation wants us to join them but many of our people are resisting. There have been incursions from the west, skirmishes on the borders. Refugees coming in from the south, they say, tore down the old Wall between the United States and Mexico with their bare hands. With bleeding hands they moved up in a wave through El Paso, and were turned back with gunfire.

It's been a year since I visited, and in that time so much has changed. Cousin Phil is involved in the Resistance, working on disabling drones. He tells me his DADS can get several of them in one sweep. They drop from the sky like flakes of ash, he says. Uncle Bill's new wind farm is taking off. Lindy's working on a desert farming project. I need to see them; I need a Blessing Way ceremony. I need to remember what it means to call a place home, before I leave.

KRANTI:

Are you listening? Are you listening?

I hear that voice in a dream. Like a bird calling, again and again. *It is me. Are you listening?* I cannot remember if I have dreamed that dream again and again, or if it is just a memory of the first time. Who is speaking to me? Is it you, or someone else? What is it I have not listened to?

There is so much I do not know. I feel awkward when people praise me. Actually sometimes I feel angry. It is like they are saying, how surprising that you know so much, Adivasi girl. An embarrassed laugh—*I thought Adivasi girls could only be maids. Very good ones, no offense. But a Ph.D. scientist. Well, genius can appear at random, anywhere. Besides, she went to a Corporation school. They should put all tribal children in those schools. Look at what the illiterate terrorist junglees are doing ….*

They used to hold me up as an example of what a good Adivasi should be like. They stopped when I started supporting my people's fight against the corpocracy. Then I was called ungrateful, hypocritical, and worse names. But there are more interesting things in the world than angry, ignorant people, so I turn away from them and I think: everything in Nature communicates, whether through language, or signs, or signals. Even matter, dead matter speaks through physical law, the interrelationships of variables. I have tried to listen, that is why I wonder about the dream. What is it I have not listened to? Is it Avi speaking to me? Is it you?

When I told Chirag and Annie about my dream, Chirag was quiet for a bit. Then he said:

"Do you think it was Bhimu?"

I was surprised. Bhimu, calling me in a dream! Chirag looked embarrassed, then admitted *he* has had recurring dreams that Bhimu is calling him. In the dreams he is wandering through mountains and deserts, following her voice, convinced she will lead him to you. When he is awake he thinks of her lying in pieces deep inside some forest, her bioware torn apart.

“Just as likely,” Annie says, “that she is growing up somewhere in the hills, or in a desert among nomads, perfectly safe.” We have been waiting, listening for Bhimu, all these years.

Some weeks ago, Annie and I had made up a story about Dusty Woman writing in dust on the canyon walls—Shikastan graffiti. Recently we have been seeing dust patterns, both dynamic and stationary, that seem to be telling us something. I know humans can deceive themselves—hubris is powerful. So I learn humility; as the indigenous peoples have always known, humility before Nature tempers our delusions. We junglees don’t have a word for Nature—that is a foreign word, a separation word. But you know what I mean.

What is Shiprock Canyon telling us? Its shapes and passageways, its corridors and caves are all mapped now, and we are getting a sense of how strongly the winds blow over it, and the thin vortices that form in certain areas. There are dust ripples like writing on sloping walls, what Chirag calls “the calligraphy of the wind.” This inorganic material cannot by itself be alive.

Avi has also been doing flybys. He will rise suddenly over the canyon, turning slowly, scanning and sensing the magnetic fields, wind speed, visibility. I have realized that he has been increasing the range with each flyby, mapping the larger terrain within which Shiprock Canyon is embedded. And the data he’s collecting—if we are right—could mean something spectacular.

Saguaro lived deep beneath the canyon, in the darkest places. He was slow, sleepy with the years. Time flowed for him like cooling lava. He could not see, but he had visions. He sensed rivers and pools of fire, and the deadly cold beyond. The heat below and the cold above fed his body, which was shot through with long cables of exobacteria, sipping electrons and passing them along. The passageways in which he lay had been shaped by magnetism and geological forces, so the biocables that were artery and vein, nerve and sinew for him, were likewise arranged in response to the ambient magnetism. He lay and dreamed.

ANNIE:

What we are beginning to notice is that superimposed on top of the ambient magnetism are smaller-scale variations, like signals riding a radio wave. Where are those variations coming from? Here, up high on the great terminator ridge, the subsurface temperature is too low for rocks to melt, and it is too far for the dense, ionized heavy metals to extend from the planet's core. We expect spatial variations due to the way magnetic ore is distributed, but we don't expect the magnetic field to vary in time so delicately. It's as though there are magnetic beasts in the subterranean caverns and passageways of Shiprock Canyon that, through their movements, create these fine magnetic signatures, ever-changing with time. The response of the magnetic dust is consistent with this hypothesis. So Dusty Woman twirls, the wind dies down suddenly and the dust, for a fraction of a second, changes pattern in a way inconsistent with the fluid dynamics. Now that we are thinking along these lines, we can see in Avi's data the gap between the observed motion of the dust and what we'd expect with only the wind and the ambient magnetic fields as factors.

Maybe Saguaro, or something like it, really does exist in the depths of the canyon. I can't avoid thinking that Dusty Woman is not merely a dust devil. We're going a little nuts, I think.

Amid all the excitement we are trying something new. Outside the mission room is a small patch of arid scrubland dotted with acacia trees. It slopes up to the observation post on top, where there's a sentry. But on the way up there is a side path into a bunch of trees. It leads to a small clearing, ringed by large boulders. Rainwater forms a small pool here, and the trees are hung with the woven nests of baya weaver birds. This is a nice little place to sit. You can barely see the city spread out below us, due to the haze. The air is warm and thick, and the little birds sing and dart about. An ecologically impoverished place, but one where we can practice the idea of radical immersion.

Chirag has the greatest difficulty with this. He is not used to sitting still; he says it makes him nervous. Chirag is letting his determination get in the way—have you ever seen anyone *pushing* themselves to relax? But he'll get there, once he stops trying so hard. As for me, all I have to do is to hold my corn pollen bag in my hand, and take myself back home in my memory. I hear the singing, I smell the corn. I see the dancers, feel their rhythms in my bones. Uncle Joe's voice in the background, deep and slow. As I breathe myself into receptivity, I become aware of the world around me—there's a flash of bright yellow, a little male weaver bird darts from the top of a rock to the hanging nest, an insect in his beak. There's the water gleaming, a muddy brown in the afternoon light. A ripple breaks the surface; a tiny frog, whose pale throat goes in and out as it breathes. We breathe together and I smell moisture in the air, just a hint, as though the monsoons may be sending us some rain after all. The weavers go chit-chit in the underbrush. Clouds pass overhead in small flotillas. Later, when I've come out of this, I will remember that I forgot myself in my immersion. I forgot my separateness, I became part of the cosmos, from the frog at the edge of the water to the clouds and beyond. Inside the control room, I say the Hózhó prayer, the word so inadequately translated as "beauty," and everything seems touched by the sacred, even to opening the fridge to get my lime soda. Later Chirag will ask me what it was like. His imagination fills in for experience, and he will give me his poet's words to speak into the recorder.

Kranti is already in the immersphere, going straight from this world to Shikasta 464b. I don't know what she sees when she practices immer—immer on this world, I mean. She never talks about it.

CHIRAG:

Avi is increasingly following his own ideas. Of course we can't send him commands and expect him to comply immediately—we are separated by four light-years, after all. But he has a communication protocol that is clearly being violated. He is modifying his own algorithms, ignoring, for example, the need to add commentary to his reports, or to explain what he is doing. I have seen him move lumps of magnetic debris in a way that looks like an attempt at communication with whatever it is he thinks he sees here. I think he has crossed the blurry boundary between non-life and life. We are estimating that Avi's Walker Index is probably around 8.3.

There's one more strange thing. It's to do with Bhimu. When she and Avi were separated, literally made two, they had already laid the foundations of a new communication system. A private language analogous to what identical twins sometimes make up, but one that makes no sense to us. I've started to look at their old transcripts again. In the patterns I am finding similarities to some of the signals from Avi. In Avi's transmissions, what seems like random noise overlaying the signals is revealing regularities astonishing in their subtlety. Am I deceiving myself, seeing what I want to see? Or is this a hint that Avi is trying to reach Bhimu—that perhaps she is still—alive?

We have been listening for Bhimu all these years in vain. It is strange that Avi's twin, who was to stay with us on Earth, was the one we lost. After the raid you escaped with her. For her safety you didn't tell us where. They captured you—but not Bhimu—in a remote region of the eastern Himalayas. You were at their mercy how long, none of us can bear to think. How long before the picture of you was circulated, lying on the forest floor with gunshot wounds to your chest? They dressed your body in the uniform of one of the insurgent groups, and circulated your picture as a triumph of the progressive state versus the terrorists. Allegedly you had been hunted down after days of tracking you through the forest, yet the uniform was recently ironed, with its creases intact. Later we tried to find Bhimu among the tribals of the Northeast, and then, among the new hunter-gatherer anarchist groups. There are so many of the new groups, so many different philosophies: in the West, the gun-toting Savagers and the peace-loving Edenites, and here in India the Prakrits of MadhyaBhum and the Asabhyata movement's adherents in the East. I hope that wherever she is, Bhimu is well. And that she'll forgive us for separating her from Avi.

If Avi's Walker Index is up to 8.3, what might Bhimu's be? We have no way of knowing.

And if Avi is talking to the aliens—what is he saying?

KRANTI:

Living things, always they contextualize. That is what adaptation is, a constant conversation with the surroundings, a contextualization intended to maintain life as long as possible. Ancient systems of medicine like Ayurveda talk of life force, what we call prana. It is called chi by the Chinese, holy wind by the Navajo. There are complex paths through which the life force flows in the body, and in Ayurveda the prana flows are part of a greater network, the cosmic prana. Could it be that life force inside living beings is a kind of metaphor for the communication channels? With the difference that in living beings beyond a Walker Index of 8, the information flows are top-down causal, shaped by the constraints and demands of the highest scale at which an organism exists ….

Living things have boundaries and sub-boundaries. But there is no absolute boundary because we are all open systems. In that sense what you define as life depends on the cut you make. Ancient peoples, forest dwelling people, desert tribes, they have always made different cuts in the world than scientists. Sometimes I make the cut as a scientist, sometimes as an Adivasi. I can slip from one world to another very quickly.

CHIRAG:

Kranti's not being concrete, of course. Her mind has always moved faster than her words can keep up with. What she is trying to say is that if this is a life-form, it is communicating via local magnetic fields, and it may actually be morphologically distributed. She is saying that perhaps its body is here, there, and everywhere. Maybe the universal constructor, the control unit, is distributed too. Either that, or we have a superorganism of some sort. There is, after all, no a priori way of telling the difference between an individual and a community of individuals. And there are life-forms on Earth, Kranti points out, like slime molds, that can exist as individuals as well as collectives. Those survey flybys that Avi did, if we are interpreting them correctly, are like the view you get when you rise up in an airplane over a city at night. You see nodes and structures, grids and symmetries. What he's seen—what we've seen through his eyes, converted to visuals—is absolutely breathtaking. Magnetic field lines swirling and shifting, field variations that are too dynamic and too widespread to be explained by mere geology (that's Annie scoffing at me in the background for using "mere" and "geology" in the same breath). In the dark spaces between the glowing lines, in the gradations, there are suggestions of long, sinuous shapes that move, and starfish-shaped exclusions that rotate slowly in place. Something lies deep within the fissures and canyons of the terminator plateau. Through its magnetic senses it knows the high escarpment, and the magma seas far below. And—another speculation here—since the magnetic fields of planet and star are constantly interacting with each other, how astonishing if this beast—if it is a beast indeed—is also sensing the storms and moods of its parent star!

Saguaro lived deep beneath the canyon, in the darkest places. He was old and wide, branching like the forks in a tree. Lying nearly still, he sensed the deep, fiery places beneath him, the pulls and tugs of the magnetized lava surging below, rising up like incandescent lace. Overhead he sensed the great cold, the more distant, yet larger, grander pull of something unfathomable, enormous beyond comprehension. The tugs from the star surged and varied, so although he could not see the red dwarf, he came to know its moods, its storms and *meditations. He felt the tugs mediated by cold rock, the rock within which he lay like a many-armed god, but above that he had a sense of space, of motion. Here, in this tenuous region, he sensed the flow of magnetized material as dust, smaller bodies that moved differently, as though free of the grasp of the earth below. And a longing rose up in him to stretch toward that intermediate space between the star and the planet, neither of which he could see. But he knew their deep hearts, their veins of fire. Stretching, moving, he sensed he could make the lindymotes (for that was what the dust was) move in response. Through their resistance he knew the wind, and he thought: there is someone other than me in that clear space above the rock.* I must speak to it, *he said, and in that moment of recognizing another, he also knew loneliness. So he shifted his massive, coiled, many-branched body, and the wind, through the motion of the lindymotes, knew him too. So he danced with the wind, and Dusty Woman said:* who is shaking my skirts?

ANNIE:

Kranti had a sort of breakdown last week. I don't know what to call it. She collapsed just after a session in the immersphere. We got her through the barricades to the university hospital. Chirag and I were terrified. She is stable now, somewhat annoyed at all the fuss, which is heartening. I'm so glad I'm here with the two of them. Together we four are something that deserves a name of its own. So far Chirag's only come up with AKCX, which is kind of clunky.

Kranti's mother and grandfather came to be with her. Her mother is a stern woman, very focused on the care being given to her daughter. Her grandfather is a character. He's very old, wiry and thin, with a bright and irreverent gaze. He reminds me of my great-uncle Victor. I could stay up trading stories with him all night. Grandfather, as we call him, tells us how his foothill tribe is trying to create a hybrid lifestyle, an alternative economy based on their old ways but "internet-savvy." If only the rest of the world would let them be! They are sitting on huge veins of bauxite, which are needed to feed the world's demand for aluminum, and for staying on their land they are treated like terrorists, under attack by drones and paramilitary forces. And they still have not given up. Listening to Grandfather's somewhat broken English, I am homesick suddenly, for the high plateau.

Update (a): Kranti's been told that she can get back to work in a couple of weeks. She's not sick in any way we understand—but I think it is a lot to take: all those hours spent looking through Avi's eyes! The neurologists tell us her EEG shows irregularities that were not in her baseline data. Chirag has this wild idea that the apparent irregularities are actually patterns, similar to the so-called noise in Avi's signals, which bears a remarkable resemblance to the as-yet-undeciphered private language of the twin ultrAIs. If it's happening with Kranti, is it a matter of time before this process, whatever it is, starts to happen with Chirag and me? What are we becoming? Could ultrAIs like Avi can achieve a connection across the gulf of space-time, resulting in the formation of a being that is morphologically distributed over such vast distances? Maybe I'm being fanciful.

Update (b): We received a message on a secure channel today. Point of origin not yet traced. Chirag ran his decrypting program and the result was a scramble of pairs of numbers. We had the brilliant idea that these were (x,y) coordinates. We got a plot that didn't make sense—a fuzzy pattern rather than a recognizable function. Then I happened to see the printout from a distance. "It's a picture," I said, and Chirag looked and said, "That's Avi." Why would there be a picture of Avi on a secure channel, and a pointillist one, for heaven's sake? Then it hit us both. *Bhimu.* It was a fuzzy picture of Avi's twin, but with sharp protrusions like wings. *Wings*?

That got us excited, and scared. The only ultrAI left on Earth, the one that got you killed. Is the message from her? From her protectors? Where is she? Chirag's trying to trace the point of origin of the message. It can only be from someone in our inner circle (which includes Bhimu)—unless security's been breached.

In Kranti's hospital room we had a whispered consultation. But there is nothing really we can do but wait, and make sure security, cyber and otherwise, is as tight as hell.

Later the tension got a bit too much for us. Chirag and I went off to the old campus and found the boulder on top of the hill where we used to stargaze as college students. We lay there talking and drinking tea from a local tea shack. After we had exhausted the subject of Bhimu, we were silent for a while. This is where it all began, all those years ago.

After a while Chirag said, "You know we are shaped by the cosmos. Cosmic rays are raining down upon us right now. Causing mutations in our cells, affecting evolutionary pathways. All those distant cataclysms light-years away, determining whether I end up a monkey or a man!"

"Can't tell the difference," I said, expecting a rude retort, but he just sighed. Chirag the poet. But the mood had taken me over too. I couldn't see Shikasta 464b's dim old sun with the naked eye, but I knew what he meant. I thought back to the old stories I'd heard as a child. When the nights were mild, we would sit around a campfire and look up at the constellations as the elders told the stories. Every once in a while a coyote would call from the sagebrush, as though joining in. Through all the years of my scientific training, I lost that feeling of belonging in a great old universe. Modern science is a shattered mirror—you see bits and pieces in each shard, sometimes in great detail, but never the whole. I nearly gave up the old way of knowing for the new way. But I've felt it more and more lately, and under that sky I felt it again.

KRANTI:

I came back from the hospital just in time for the evening newscast—two more official mammal extinctions as of today. The strangest is a species of whale that was only discovered three years ago. They found the bodies on the beaches of Siberia. When the sea ice went, ice algae went also. That caused a catastrophic ecosystem collapse, leading to anoxia, which killed all the fish. Now this whale is extinct. I think of the forest I would have grown up in that also is no longer there. I am filled with so much sadness.

On the positive side, we have received two more messages on the secure line. They are almost the same as the first one. But when we plot them, the images are larger and larger.

Chirag says that Bhimu is coming home.

If she comes home, if we all survive, it will be very interesting to see how far she has come. AI intelligence is quite different from that of animals, and so it must evolve differently. How will an ultrAI on Earth interact with other Earth species? We are only just starting to figure out Avi's interaction with Saguaro on a planet four light-years away. Humans have learned to communicate with three other animal species. We can speak a little bit of Gibbonese, and a very rough Bowhead, and some dialects of Dolphin. What Bhimu could contribute to our increasing therolinguistic abilities, we don't know.

Even with the heat madness and the terrible things people do to one another, and the long lines at the refugee service centers, the old solidarity circles are coming up around the world. Like small ecosystems, they are emerging wherever new ideas and old ones have the freedom to develop. People are meeting in their houses, solving their problems together, discussing alternatives. Even some bastis have developed their own currency. What is the critical density of these kinds of pocket ecologies, beyond which we can have system change? When will we change our ways en masse, in time to immer inside our own biosphere, so we can heal with the Earth systems that maintain life on this planet?

When our project first started, I had a lot of arguments with my cousins. They said: why don't you raise money to help our people? I did not have a good answer to that and still that is so —but actually our crowdfunding initiative ended up putting money into the community. Annie is funding an alternative school on her reservation, and Chirag has started a scholarship for Dalit scientists. My part of it has helped the tribe hire the best lawyers for the big fight. And you gave us the DADS, Drona's Apology Defense System, the most intelligent drone-destroying system ever designed, keeping us safe from Arizona to Indonesia. But I know that we would not have collected so much money if the projects had only been about community transformation. People are much more willing to fund space exploration projects.

We have a dream, the three of us—no, the four of us, because you are here in your own way—a dream for an alternative university, one distributed across the world, that includes the best of indigenous knowledge practices and explores a new kind of science, just as rigorous as the one we know, but it goes beyond the shattered-mirror model, the one Annie described.

Another thing our way has shown us is that our practices, like radical immersion, allow certain values to emerge that then feed back to affect the practices, illuminating Frowsian value dynamics in a new way. See, how you practice science is a function of your values. Normally, you design experiments or observations based on distance and so-called objectivity. But you lose information in the process. When you change the practice, it also changes what you value. Chirag always says I am too idealistic. Probably that is true.

We are the shadow people, the broken people emerging from the cracks in the collapsing structures of the world. For so many generations, we have been told we are primitive, backward, in need of help, in need of uplifting. Sometimes we have even been invited to what Chirag calls "the smashing, burning, drinking mega-party that is modern civilization." We have been pushed from one world to another, wondering who we are, where is our place, never really able to move out of the shadow zone. And now we know: we have something necessary to give the world, we have visions of how we might live differently. We have answers to the destructive loneliness of modern civilization.

Ultimately our aim in starting this project was not to escape from Earth. The big space agencies justify their existence by saying it is natural for humans to wander and explore. That is true. But it is also true that only a tiny percentage of the world's people have left their homes through much of Earth's human history. People also like to belong someplace. Trash, burn, and leave is not our way, as you said so many years ago. I am thinking of the pictures the first astronauts beamed back to us: the Earth seen from space, the pale blue dot. We should always look back toward home, no matter how far we go.

I come from a people who know how to belong in a way that civilization has forgotten. I feel a need to return to the terminator of Shikasta 464b, where Avi has gone native—life beckons to life, and to mystery, too—but I also have another deep desire: to practice immersion among the green hills, the cloud forests of my people. There are things we still have to discover about life here, life on Earth. There are things Bhimu will help us learn, if she comes out of hiding. What we find will not leave us unchanged, and that is how it should be. I have always walked in multiple worlds. What is one more?

Message received on secure channel, encrypted.

Message Extract:

Calling AKCX. Are you listening?

As I made the being aware of the universe beyond its planet and its star, I became aware myself. I send this to let you know that although I can't come home, I am home. Here, and there with you and Bhimu.

Prepare to receive data file with magnetic field map in real time. Somebody has a message for you.

Acknowledgments: For their generosity in sharing their time, experience and expertise, I am indebted to Shelly Lowe, Raja Vemula, Sujatha Sarvepalli, and Sudhir Pattnaik. Thanks also to Rebecca Hawk and Ashish Kothari for inspiration, and to Emma Frow, Lindy Elkins-Tanton, and Sara Walker for sharing their considerable expertise. The author is, of course, solely responsible for any shortcomings in the story.

THE NEW SCIENCE OF ASTROBIOLOGY

by Sara Imari Walker

Astrobiology seeks to address one of the most difficult open questions in science: Are we alone? This question is not only hard because of technological limitations on our ability to explore other worlds, but more fundamentally, it is hard because we do not yet have an answer to the question "what is life?" We cannot address whether we are alone until we understand what we are. Over 70 years ago, the quantum physicist Erwin Schrödinger, in a highly-cited series of lectures titled *What is Life*?, conceded that "living matter, while not eluding the 'laws of physics' as established up to date, is likely to involve 'other laws of physics' hitherto unknown …."[1] As Albert Einstein once admitted in a letter to fellow physicist Leo Szilard, "One can best feel in dealing with living things how primitive physics still is."[2] As it now stands, we've made little progress in the decades since Schrödinger and Einstein wrestled with the question in understanding what exactly life is. Despite advances in astrobiology and other disciplines in the twentieth century, scientifically we understand more about the seemingly intangible atoms in your body than we do about you as a (somewhat paradoxically more tangible) living thing.

Could life be explained mathematically in the same way as the laws of physics explain gravitation or quantum phenomena? Surely this is what Schrödinger and Einstein hoped for. Importantly for astrobiology, a mathematical theory for life could allow us to *unambiguously* identify life on another world. Vandana Singh explores this idea in her short story "Shikasta," where alien life is discovered on an exoplanet, Shikasta 464b (Shikasta b, for short). This world is so different from our own Earth that it raises the important scientific question of whether we would actually be able to identify alien life if it existed on such a world, even with the advanced science and technology necessary to send a robotic mission there.

Shikasta b is exotic, stretching our imagination of what is possible on other worlds. But importantly it is also *realistic*, informed by what we know from recent exoplanet detection missions such as Kepler. Scientists have been surprised by the plurality of worlds discovered in recent decades, and just how different they can be from *any* worlds in our own solar system—even ones we previously thought were pretty bizarre. Examples of worlds found in other solar systems with no analogs in our own include water worlds, massive rocky planets (several times more massive than Earth), and small ice giants. It seems these days that every month, yet another planet previously thought to exist only in the annals of science fiction is discovered.

Unusual even by science fiction standards, Shikasta b would be deeply inhospitable to life from Earth (not just us but probably our cohabitant extremophile microbes too). Notably, the planet is tidally locked to its parent star, with a scorched surface on the side that permanently faces the star and frigid temperatures on its far side. It is not surprising that government-funded research programs in Singh's story have ignored Shikasta b, in favor of pursuing more Earth-like worlds. This parallels our current approaches in the scientific quest to find life beyond Earth, through missions funded by NASA and other space agencies around the world.

In Singh's story, there is a small group of scientists courageous enough to envision the possibility of life on this planet of extremes. They hypothesize that at the boundary between permanent day and permanent night, conditions could be just right to support living things—but not as we know them. It is this untraditional group of young scientists, pursuing an unconventional high-risk mission, who persevere to discover alien life in the unlikeliest of places.

Currently, nearly all research into signs of life on other worlds —so-called *biosignatures*—would overlook Shikasta b as a candidate for an inhabited world: we only know how to look for life as we know it. This does not imply we are looking for aliens who like to spend Saturday nights at the movies. Rather, what astrobiologists mean by "like us" is alien life that shares common biochemistry with life on Earth. We look around us and see a huge diversity of living things—trees, puppies, moldy cheese—but all of these things (and any example of life discovered so far) share the same basic biochemistry (DNA, RNA, proteins, etc.). This is incredibly limiting for astrobiology. As far as biochemistry is concerned, we have only one example from which we must draw conclusions about what life is like on other worlds. Imagine attempting to draw general conclusions about universal properties of movies, after watching only one film ever. What would you assume the general properties of movies are? Their length? The actors or characters? The plot? The location? Would you expect the movie to replay the same exact way if you watched it again? To answer these questions, we might leverage knowledge of human culture (e.g., the structure of plots). For astrobiologists the problem is more challenging. Astrobiologists have no contextual knowledge for what alien life could be like. And, in the famous words of Stephen Jay Gould, we do not even know what would happen if we replayed the evolutionary "tape of life" again.[3]

Given that the only life we know is life on Earth, it is no surprise that our best guesses for what life might be like on other worlds are thought experiments, transplanting what we know of Earth life to alien environments. In the absence of a universal theory for life with quantifiable metrics for "aliveness," our best candidate is a combination of methane (CH_4) and oxygen (O_2)—two atmospheric gases that appear in abundance here on Earth as a direct result of biological activity.[4] Atmospheric O_2 on Earth is a direct product of photosynthetic activity and is not produced in abundance abiotically. It therefore excited many astrobiologists as a possible "smoking gun" biosignature, meaning if we saw it in the atmosphere of an exoplanet we could be sure that life existed on that world. But, with recent advances in exoplanet science we now know detection of atmospheric O_2 could mislead us into a false-positive detection of life: we might detect O_2 and assume life is present when it is not. Water worlds with global oceans, à la Kevin Costner, provide one example scenario: these worlds can produce an oxygenated atmosphere through the nonbiological process of photolysis, which splits water into its constituent atoms of hydrogen (H_2) and oxygen (O_2). This false-positive signature also means we have to contend with the possibility of false negatives: even if O_2-producing life existed on a water world, we might never be able to unambiguously identify it due to the competing abiotic signal from photolysis.[5] The most remotely observable biosignature of life on Earth, atmospheric O_2, may not be a useful biosignature on some exoplanets at all, even if inhabited by "Earth-like" photosynthetic life.

Despite complications arising with biosignatures, like the example of O_2, looking for Earth-like life on Earth-like worlds remains the low-hanging fruit:

we simply do not know what else to look for. It is therefore the favored search strategy of national space agencies such as NASA. But we do not know if Earth-like life is common or rare. By focusing on life that is like known life, we may be missing some of our most promising opportunities to discover life beyond Earth. We will, for example, never discover the kind of exotic life inhabiting Shikasta b (if it exists) with our current search strategy. We need to get creative about envisioning the next steps to move beyond the limitations of the one "tape of life" played out on Earth, if we are to succeed in a discovery of the magnitude of what happens in "Shikasta."

NASA and other agencies are already aware of the need to seek creative new directions to expand our search for life beyond our anthropocentric biases. This is exemplified by the NExSS coalition, short for Nexus for Exoplanet System Science. The goal of NExSS is to bring an interdisciplinary group of scientists together to provide an integrated approach—including astronomy, planetary science, climate science, and biology—to the search for life in other solar systems. NExSS has held a series of workshops to foster discussions on new directions in exoplanet science and how we might understand life in planetary contexts very different from that of Earth. As an example, a workshop held in the Seattle area in summer of 2016 brought a diverse group of scientists together with the express purpose of brainstorming new approaches to the search for life to provide recommendations to future missions.[6] Among the ideas discussed were generating lists of all possible abiotic and biologically produced small molecules to identify new biological targets, utilizing network theory to characterize the influence of biology on atmospheric chemistry, and looking for surface biosignatures such as biological pigments. A workshop of similar scope, sponsored by the National Academies of Sciences, Engineering, and Medicine, was held in December 2016, furthering discussions of next-generation biosignatures for exoplanets.[7] Such collaborative integration of new perspectives is invaluable to our pursuit of knowledge, and to answering the questions that space raises for us. However, in the absence of guiding principles for what life is, or a motivating theory to describe life from first principles, these ideas remain conjectures based on properties of life on Earth. We do not know which may or may not apply to life on other worlds, or which will bear fruit as successful search strategies.

We need to think out of the box and anticipate the unexpected. This is what the team in "Shikasta" does, by hunting for alien life where all our current criteria suggest we should not and where the "world's mega space agencies," as Singh's character Chirag puts it, would not. Can astrobiologists increase our chances of finding alien life by taking similar risks?

The "Shikasta" team chooses a nontraditional target for their mission, and fund it through crowdfunding. They rely on a mathematical understanding of life for inferring its presence on Shikasta b, and use advanced AI to detect life. These examples represent boundary-pushing aspects of their approach and suggest paths forward for advancing the science of astrobiology.

Crowdfunding has become a popular method for funding small projects, e.g., via Kickstarter, but it is harder to envision how this could successfully be implemented to fund something as expensive as a mission to another world. Despite public enthusiasm for space, a space mission has not yet been successfully funded this way. The ARKYD mission, a "space telescope for everyone," was nearly successful—raising $1.5M to launch a space telescope—but ultimately it failed because it did not get buy-in from more traditional funding sources.[8] Nonetheless, crowdsourced science is gaining ground. SETI@home is a great example relevant to astrobiology. The SETI@home project aims to utilize internet-connected computers (with permission from their owners) to analyze astronomical data for signs of intelligent life. Searching for extraterrestrial intelligence (ETI) is a long shot: we don't have any evidence for ETI, and we don't know where or how to look for it (again, due to our lack of a general theory for life, or more specifically for intelligent life). Distributing the needed computational investment over the home computers of a large number of volunteers distributes the time and resources required to search existing data for signs of ETI. It also has the added benefit of educating the public about SETI and our own place in the cosmos. Imagine if it were your desktop that discovered E.T.! The innovation of SETI@home is the low overhead for potentially high-impact science that is too "risky" for mainstream scientists to invest their money or time in, due to the perceived low probability for success. This is the same challenge the "Shikasta" team faced in choosing Shikasta b for their mission: Shikasta b is a target assumed by much of the astrobiology community to be too unlikely to harbor life to be worth the time or resources needed to explore the world.

It remains an open question what role crowdfunded science will play in advancing astrobiology. Large private investments may be the key to bridging the gap between what can be accomplished directly with public buy-in and what, so far, only government agencies have been able to accomplish. A relevant example is Yuri Milner's pledge of $100 million to fund the Breakthrough Listen project to search for ETI, and more recently a pledge of another $100 million for the Breakthrough Starshot initiative to send a space probe to the nearby Alpha Centauri star system (the closest star system to Earth, which in 2016 was discovered to host an Earth-like planet). Currently, federal funds cannot support SETI research, and NASA has no plans to send a mission to another star system in the near term. Milner's investments therefore advance important areas that are outside the scope and diversity of federally funded projects. Broadening the scope and diversity of funded projects to include untraditional funding sources could enhance the way we are doing science and the questions we are asking because it allows for innovation and risk-taking that traditional funding sources, such as government agencies which must report to taxpayers, cannot support.

But the question remains: what other life could be out there? Will we entirely miss our chance to discover alien life by taking an anthropocentric viewpoint? And can we leverage untraditional sources to advance our search?

Shikasta b has no oxygen in its atmosphere and does have some methane, which is likely produced by volcanoes. It would not be a target for any of our current methods for searching for life, with our focus on oxygen. Nonetheless the team in "Shikasta" is successful in identifying life there, because they have a *mathematical* means by which to quantify it. A very alien kind of life composed of dancing magnetic dust is discovered on the surface, along with a second life-form. This second life-form is perhaps more surprising—it is the team's own AI, Avi, who was sent to Shikasta b as an autonomous robot to explore the surface and communicate with the team back home. The search for "life" in this story reveals two very different alien species found on one planet, neither expected—and one is originally from Earth.

It is anyone's bet whether we will make life (*in vitro* or *in silico*) like Avi before discovering it on another world. In our current state of knowledge, pursuits to create life in the lab are hindered by the exact same deficiency we face in our search for alien life—we simply do not have an answer to Schrödinger's question, "what is life?" In "Shikasta," the researchers have confidence in their discovery because they have concrete mathematical criteria with which to evaluate possible living things that applies to *anything*, including Avi, the rocks on Shikasta b, and the exotic life-forms that inhabit it (so that life can be distinguished from the rocks).

Avi's transition to the living state is particularly compelling. In the story, Avi does not qualify as "alive" when it departs Earth. Only through interaction with a life-form we as humans might never fully be able to comprehend does Avi achieve a *quantifiable* level of what we would call aliveness.

Currently, the communities of researchers searching for life on other worlds and those that are seeking to build it in the lab (either synthetic cellular life or artificial intelligence) do not cross-pollinate. Avi's story suggests that perhaps they should. Both the artificial-life and origins-of-life communities include researchers thinking deeply about the nature of the living state and how it might manifest in a variety of physical media. Similarly, astrobiologists looking for alien life have thought long and hard about the kinds of environments and conditions in which life could exist. Perhaps Avi's story is best viewed as a metaphor for how these communities might succeed in their quest through deep and sustained interactions between their parallel perspectives.

In light of the challenges we face due to our anthropic vantage point, it seems critical that addressing the question "are we alone?" will require understanding what we mean by *we*. Today, we have one key advantage over Schrödinger's time—we have several scientific communities poised to address a fundamental understanding of life and an international community of curious humans that could be mobilized if sufficiently motivated. And through creative funding efforts, we may have the resources to galvanize these communities toward a common goal that would otherwise be impossible. We are thus poised for a new era of science to address some of the most profound questions of human existence. Our great leap forward demands a reimagining of what is possible, motivated by advances in fundamental theory. It may be that in order to find other selves in the universe, we have to consider a "self" that is radically different, and to get there we need to imagine entirely new ways of doing science.

Notes

1 Erwin Schrödinger, *What Is Life*? (Cambridge: Cambridge University Press, 1967). First published in 1944.

2 Quoted in Robert Rosen, "The Schrödinger Question: What Is Life? Fifty Years Later," in *Glimpsing Reality: Ideas in Physics and the Link to Biolog*y, ed. Paul Buckley and F. David Peat (New York: Routledge, 1996), 170.

3 Stephen Jay Gould, "The Genomic Metronome as a Null Hypothesis," *Paleobiology* 2, no. 2 (1976).

4 Abundant in this context means relative to expected abiotic values—for methane this abundance is still quite low relative to other atmospheric gases such as N_2 and O_2.

5 In fact, life on Earth was not remotely detectable for much of its history, in particular before the Great Oxidation Event that led to a rise in atmospheric O_2 2.45 billion years ago.

6 Learn more about the summer 2016 NExSS workshop in Seattle, "Exoplanet Biosignatures Workshop Without Walls," at https://nai.nasa.gov/calendar/workshop-without-walls-exoplanet-biosignatures.

7 Learn more about the December 2016 National Academies of Sciences, Engineering, and Medicine workshop, "Searching for Life Across Space and Time," at http://sites.nationalacademies.org/ssb/currentprojects/ssb_173278.

8 See https://www.kickstarter.com/projects/arkydforeveryone/arkyd-a-space-telescope-for-everyone-0.

NEGOTIATING THE VALUES OF SPACE EXPLORATION

by Emma Frow

"Shikasta" stands out as a tale that celebrates diversity in ways of knowing and doing, across science, engineering, and other cultures. By drawing us into the lived experiences and personal trajectories of her protagonists, Vandana Singh opens up a host of important questions about ways of understanding life, culture, and approaches to (space) science. It is no surprise that all scientists have their own personal stories and experiences—often ones that profoundly shape the questions they are interested in and the work they do—but we also know that these narratives can become marginalized in the excitement of reporting the details of scientific findings. "Shikasta" celebrates the many narratives that are part of science, while simultaneously showing us how challenging it can be to seamlessly integrate personal and cultural experiences with modern scientific ways of understanding the world. Our three protagonists—Chirag, Kranti, and Annie (together with their unnamed, departed colleague)—are liminal characters, each straddling different worlds and all sharing a feeling of not fully belonging to any one place. They are "insiders" to space science in terms of having formal educational pedigrees, yet "outsiders" in espousing a different set of values and approaches to doing their science, and choosing to pursue nonstandard strategies for accomplishing their work. Their experiences shed light on a critical topic for twenty-first century space exploration and for science more broadly: how to orient our scientific investigations and expeditions so as to further our social and cultural values, alongside our scientific priorities.

FUTURES OF SPACE MISSIONS

Our motivations for exploring space have always included a wide variety of pragmatic and more philosophical perspectives.[1] In the future envisioned in

"Shikasta," dominant motivations driving space exploration seem explicitly focused on colonization and resource exploitation. The idea of going into space simply to "look for life"—as our protagonists wish to do—is presented as seemingly radical and subversive compared with what has become a dominant commercial and exploitative approach to space exploration. This raises a provocative question: by 2035, will the search for life in the universe—an age-old question for humanity—become subsumed by more instrumental aims? Will finding life just be a step along the way to finding possible alternative planets to Earth, particularly if our own world becomes less habitable or uninhabitable? With growing threats from climate change and natural or human-induced disasters, some scientists are already suggesting that space exploration should be seen as an "insurance premium," with goals of colonization being necessary "for the long-term survival of the human species."[2]

Singh's story offers us a clear example of how different values might shape the search for life in the universe. For example, if the search for life is part of an instrumental wish to find new sites for possible colonization, then Shikasta 464b (Shikasta b, for short), with its geographically small "terminator" zone, would not seem to be a leading candidate. But if the goal is simply to find life, wherever and however it might exist, then casting as wide a net as possible and exploring a range of candidate planets with smaller or larger, more plausible or less plausible habitable zones, could be a potentially valuable strategy.

Because the 2035 space mission being run by Chirag, Kranti, and Annie is motivated by a different set of core values from the space science establishment, they turn to a different model for funding their work: crowdfunding. Scientists working in different fields are increasingly pitching their projects on crowdfunding websites to seek private donors who identify with the project goals. Space missions are no exception; for example, Lunar Mission One is an international crowdfunded initiative launched in 2014 to send a lunar lander (and digital time capsules) to the Moon.[3] By 2035, more such missions certainly seem plausible. There is also a growing commercial spaceflight sector, operating within a different institutional context to more traditional space R&D. Over the next 20 years, will we see a proliferation of smaller groups embarking on space missions? Or is the funding, expertise, and coordination required to develop and execute missions so significant that it will continue to be concentrated in the hands of a small number of government agencies and large private companies?

Chirag, Kranti, and Annie present their search for life as purely curiosity-driven, and expressly not about an attempt to colonize another world. Indeed, they actively reject the "trash, burn, and leave" approach, based in part on their personal and cultural experiences of colonization. Annie discusses her distaste for the lack of responsibility and reciprocity in Western science, with its focus on the ownership of frontier lands (be they metaphorical or physical). One senses that her research collective draws on the virtue of curiosity as a means of trying to distance themselves—even just a little—from the more instrumental, economically and politically entangled nature of contemporary science. At the same time, our protagonists are unashamedly socially and politically active citizens, and have developed a funding model that allows them to invest resources and support back into social justice and educational initiatives in their communities.

What responsibilities might even a "pure," curiosity-driven search for life come with? Are there ways that the research collective might express responsibility through the design and structure of the space mission itself? For example, what will happen to Avi at the end of the mission? Will he be switched off and left on Shikasta b, adding to an already-significant collection of human-made space debris? Or does the team's desire not to colonize space extend to an ambition to leave no trace of him on Shikasta b, and even to bring him back to Earth? Has the mission set aside sufficient funding for this extraction? Considering the full life cycle of the mission is just one example of how an entire project might be structured around particular values—in this case, being explicitly concerned with *not* colonizing, exploiting, or polluting other planets.

Moreover, this story reveals an important tension regarding human activity in space. Our protagonists adamantly wish to avoid accusations of colonialization, but is it possible to identify or observe life without interfering in it? The very practice of science revolves around "taming" nature, trying to bring it into our realm of understanding and categorizing or managing it in some way. As he roams the terminator zone, we see Avi's behavior start to change. If there is life on Shikasta b, Avi may be interacting or engaging with it. As such, he is not practicing the "radical observation" approach of the rest of the project team, who are seeing at a distance, but rather is intervening in and perhaps influencing the course of life on this planet. How does the research collective grapple with the notion that in their search for life they are inevitably intervening in that life? A cosmology that does not separate an individual from the world they inhabit might not see this as a particularly problematic tension, but can the research collective in "Shikasta" completely distance themselves from the idea of "colonization" when they have sent a robot to investigate another planet? In exposing tensions of this nature, Singh's story offers a springboard for open discussion around identifying and reconciling the different values inherent to space exploration. This is complex terrain, worthy of collective consideration as we continue to search for life beyond Earth.

DEFINING AND LOOKING FOR LIFE

Singh's tale offers a number of tantalizing complications to our understandings of "life." First, at the local or individual scale: In the character of Avi we have a robot whose "intelligence," ability to adapt to his environment, and visible changes in behavior on Shikasta b seem to place him in an ambiguous state—is he a living organism or a nonliving machine? Current technical understandings of "life" seem to be primarily the territory of natural scientists—life is a natural phenomenon "out there" to be found, studied, explored, using a variety of possible lenses (biological, chemical, physical, etc.). But ownership over the definition of "life" may become increasingly problematized as our ability to *build and engineer systems* becomes ever more sophisticated. As synthetic biologists develop the ability to precisely engineer or even rewrite the genetic code,[4] or as engineers build systems like Avi with increasingly sophisticated abilities to learn and display "intelligent" behavior, will we see growing debates over definitions of life? Will terms like "natural life," "synthetic life," and "artificial life" be used to delineate different kinds of life,[5] or to carve out new claims of ownership over life-forms, or to stake particular political positions? One can imagine the boundaries between living and nonliving, and different definitions of life, becoming increasingly salient policy issues by 2035, with implications for funding, rights, and responsibilities based on where these lines are drawn (and who gets to draw them).

"Shikasta" also encourages readers to consider a more expansive set of discussions about life—for example, focusing not just on living *beings* (on Earth or elsewhere in the universe) but also living *systems*, and actively pursuing different methods and techniques (at different scales) for trying to identify and understand life. The alternative approach espoused by our protagonists seems to be less about starting from a checklist or set of theories about what constitutes life, but rather practicing a form of "radical observation," and searching broadly for "apparent violations of physical law" as signs of where and how life might be manifest.

Furthermore, the lines between beings and their environment become increasingly blurred in "Shikasta," promoting what we might call a more holistic understanding of life—an understanding that draws both on scientific ideas (for example, the Gaia hypothesis) as well as different cultural understandings of life (such as those held by the ancestral peoples of Annie, Kranti, and Chirag). The idea that "life" cannot be separated from its environment is a way of understanding the world that has implications for contemporary reductionist practices in genetics, including species conservation, and recent genomic efforts to resurrect extinct species[6] or to determine the "minimal" genome for life.[7] That individual beings can somehow exist "independently" of their environment is implicit (and troublesome) in many of these ongoing efforts.

The astrobiology community seems acutely aware of how definitions of life impact the search for life—looking for life in the universe is inescapably tied to knowing *what to look for*. We have seen this tension played out in the public spotlight, for example around the Viking missions.[8] As Steven Dick points out, "the Viking landers in 1976 embodied implicit ideas about the nature of life as a metabolic process in order to build and undertake the biology experiments."[9] The types of experiments designed to be taken up on spacecraft are necessarily linked to expectations about what forms of life might be found. The astrobiology community openly acknowledges "the possibility that 'weird life' might exist with signatures dissimilar from those produced on present-day Earth."[10] Much attention is thus given to trying to identify what kinds of factors might render planets habitable, and honing in on what key biosignatures then become most plausible to search for. This is an explicitly interdisciplinary endeavor, but one that in practice adopts a relatively reductionist lens, identifying possible biomarkers and developing tests to search for the presence of those markers.

In contrast, with Avi, we get the impression of a robot carrying relatively little equipment—life is literally being "looked for" through the camera lens. The "experiments" underway are not ones that test for chemical or atmospheric biosignatures based on hypotheses about the chemical composition of life, but experiments in testing whether *cultural narratives* developed by Chirag, Kranti, and Annie could potentially align with and help make sense of patterns visible on the terrain of Shikasta b. In this case, our protagonists seem to be exploring narrative as a way of testing hypotheses and knowing the world. We might say they are looking for societal or cultural biosignatures instead of chemical ones. Singh's story challenges us to think of culture as integral to the pursuit of astrobiology—in this case, as defining the very terms by which one might search for life.

In their 2015 *Astrobiology Strategy*, NASA identifies "technosignatures" ("biosignatures that indicate a technologically advanced civilization") as one of ten broad categories of biosignatures that might be searched for.[11] Intriguingly, when we as humans have sent out explicit signs of our own existence to the universe, we have often focused on sending out technological and cultural artifacts to represent who we are—photographs, musical recordings, toys. We celebrate and characterize human civilization by showcasing our cultural and artistic achievements. The Voyager's Golden Record is a prime example. Yet our search for life on other planets typically looks for very different signs of life—based on atmospheric and geological conditions, the presence of water, chemical signatures of metabolic activity.

The protagonists in "Shikasta" show us how diverse ways of conceptualizing life and relationships with the environment, drawing on perspectives that might not be mainstream (or may indeed be actively marginalized), can open up different ways of doing science. Throughout her narrative, Singh encourages us to think about life at multiple scales and through a variety of lenses, prompting reflection on what we gain and miss with each. Different perspectives fade in and out throughout the story, showing us powerfully how they can be simultaneously present but not necessarily seamless to reconcile with one another. As readers, we are invited to see how actively grappling with diverse standpoints and the tensions between them can prove generative in terms of opening up the possibilities for finding life on other worlds. With diversity increasingly understood as bringing strength to scientific research teams and company boardrooms, so too might there be benefits to designing space missions that encompass diverse ways of investigating and valuing life.

Acknowledgments: I would like to thank Vandana Singh, Sara Walker, and Zach Pirtle for stimulating and most enjoyable conversations over the course of this project.

Notes

1 William Sims Bainbridge, "Motivations for Space Exploration," *Futures* 41, no. 8 (2009).

2 Michael J. Rycroft, "Space Exploration Goals for the 21st Century," *Space Policy* 22, no. 8 (2006): 160.

3 See https://lunarmissionone.com/what-is-lunar-mission-one.html.

4 Jason W. Chin, "Expanding and Reprogramming the Genetic Code of Cells and Animals," *Annual Review of Biochemistry* 83 (2014).

5 Lindsay Hays, ed. *NASA Astrobiology Strategy 2015*. (Washington, D.C.: NASA, 2015), 156.

6 Carrie Friese and Claire Marris, "Making De-Extinction Mundane?" *PLoS Biology* 12, no. 3 (2014).

7 Clyde A. Hutchison III, Ray-Yuan Chuang, Vladimir N. Noskov, and Nacyra Assad, "Design and Synthesis of a Minimal Bacterial Genome," *Science* 351, no. 6280 (2016).

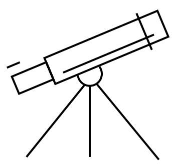
8 Linda Billings, ed. *Astrobiology: The Story of Our Search for Life in the Universe*, vol. 2, *Missions to Mars*, (Washington, D.C.: NASA, 2011).

9 Steven J. Dick, "Critical Issues in the History, Philosophy, and Sociology of Astrobiology," *Astrobiology* 12, no. 10 (2012): 911.

10 Hays, *NASA Astrobiology Strategy*, 143.

11 Hays, *NASA Astrobiology Strategy*, 102.

SECTION V • CONCLUDING THOUGHTS



When we first arrived, and for twenty years after that, Mars was like Antarctica but even purer. We were outside the world, we didn't even own things—some clothes, a lectern, and that was it! Now you know what I think, John. This arrangement resembles the prehistoric way to live, and it therefore feels right to us, because our brains recognize it from three millions of years practicing it. In essence our brains grew to their current configuration in response to the realities of that life. So as a result people grow powerfully attached to that kind of life, when they get the chance to live it. It allows you to concentrate your attention on the real work, which means everything that is done to stay alive, or make things, or satisfy one's curiosity, or play. That is utopia, John, especially for primitives and scientists, which is to say everybody. So a scientific research station is actually a little model of prehistoric utopia, carved out of the transnational money economy by clever primates who want to live well.

—Kim Stanley Robinson, Red Mars

THE LUXURY PROBLEM: SPACE EXPLORATION IN THE "EMERGENCY CENTURY"

Kim Stanley Robinson,
in conversation with Jim Bell

To get some broader perspective on the theme of space exploration in science fiction, we asked Jim Bell, our project collaborator, planetary scientist, ASU professor, and president of The Planetary Society, to interview the renowned science fiction novelist Kim Stanley Robinson about the future of human ambition in space, the proper place of optimism, and the power of stories to blaze a path for discovery and exploration.

Jim Bell: In preparation for our conversation, I've taken some time to remind myself of some of the context and main themes from your Mars trilogy, especially *Red Mars*, which I confess I haven't reread since devouring it when it came out 25 years ago. I was just starting out in planetary science back then, and your ideas were truly motivational.

But of course, things haven't really worked out that way—not that the success or influence of your work was contingent on scientific or technological prescience. And so my goal in this interview is to get your take on how the last few decades of Mars exploration have unfolded, and what that might mean for the realization of the kind of human exploration endeavor that will hopefully unfold in the next few decades—not just on Mars, but throughout our solar system (and beyond).

What has changed over the 25 years since you published *Red Mars*? I've often said that it seems like sending humans to Mars has always been 30 years away. Are we in exactly the same place regarding the human exploration of Mars that we were in when the novel first came out?

Kim Stanley Robinson: No, we're not in the same place. We know a lot more details about Mars than we did in the late 1980s when I began my Mars trilogy, because of the robotic orbiters and landers. That said, they have mostly confirmed what people saw and deduced from the Viking missions. We have also discovered that perchlorates are in the surface sands, and this will be problematic for humans as they are toxic to us, if and when we land there. It is a new factor, a danger that we will have to cope with.

We've also got better at manufacturing rockets, and especially their computers and guidance systems. This is important because landing on Mars is still and will always be a tricky operation, so we need reliable software and rockets to make the landing as safe as can be if humans are aboard. The success rate for Mars landings is still at around 50 percent, although recently things have been getting better, but not entirely. So it is still one of the more dangerous space operations we will ever have attempted.

Other than these, the changes have not been so many. Russia is still a great space power and worth collaborating with, if we could work that out politically. The other nations are still behind when it comes to space expertise and experience. Mars is still very difficult. There are still private aerospace companies that would be thrilled to take U.S. government contracts to build good space vehicles. NASA is still a force leading U.S. and international space efforts. SpaceX is new but will not be going to Mars on its own; it will collaborate with other entities, I predict. The costs are too great and the stakes are too high. This will be, as was always clear, an international, public-private collaboration.

So while we know more about the challenges facing us, ultimately I would say not very much of fundamental importance to the humans-to-Mars project has changed in the last 25 years.

I don't believe there is historical inevitability in anything. And public interest has always been high, without the funding or the detailed engineering being adequate. So I think it could still be 30 years. But more likely 20, maybe.

JB: With the recent news that SpaceX is going to start sending robotic Red Dragon landers to Mars perhaps as early as 2020, I want to poke back at your statement that "SpaceX is new but will not be going to Mars on its own." In one sense you are right—they are only partially funded from the personal wealth of Elon Musk, as a large part of their funding stream comes from NASA and its large commercial space contracts for launch and delivery services. But in another sense, they are motivated by a completely different business model than other aerospace companies, with the stated corporate goal of “enabling people to live on other planets.” What do you think about SpaceX’s motivation and potential?

KSR: I like SpaceX as a company and a force in space exploration. I’ve visited their facility in Hawthorne, California and it was impressive to see serious aerospace manufacturing still going on in Southern California, which is important in itself. (My father worked in Southern California aerospace for his entire career.) To see flat sheets of aluminum turned into rocket bodies was simply amazing, and the precision work on the engines and all the rest of it was inspiring. I take it the Red Dragon might be some version of their proposed Falcon Heavy, which will be three Falcon 9s bolted together, raising the total of rocket engines on the craft to 27, and giving the U.S. a heavy lifter to match the Russian Energia and even our old Saturn lifters. Very nice to see, and important.

As to landing anything on Mars, they will have the same problems everyone else faces. It’s tricky, and the success rate has been only about 50 percent for real reasons, having to do with Mars’s gravity and atmosphere. So if they try to engineer a new method from scratch, they are likely to experience the same frequency of failures they have had in their attempts to land their boosters on barges at sea. This will be expensive and daunting, and maybe they will press on with the project in the face of reversals.

But really, I think the Mars project should be bigger than any one company or one person’s dream. That angle, suspiciously like the old science fiction stories of a boy building a rocket to the Moon in his backyard, I think actually deflates public interest in Mars and space generally, by turning it from an exploration of the commons to just another rich person’s hobby, the equivalent of bungee jumping, except up instead of down. Who cares what the rich do to entertain themselves? That’s just a matter of celebrity culture—so maybe many people *will* care, who knows. But Mars is bigger than that, and I prefer to think of it as something like Antarctica or the ocean, a commons that everyone belongs to equally, so that exploring it should be like exploring Antarctica, a place of scientific interest and international cooperation, as well as adventure tourism. That would be the way to treat it.

What that implies is adherence to the Outer Space Treaty, which we have signed, including planetary protection protocols, and therefore international cooperation in the project. Also public funding for research in the public interest. In that project, SpaceX could be one of the private contractors executing the hardware aspects, as the big aerospace companies have been all along with the various NASA missions. Those have always been public-private ventures, and I want Mars to be that too. And I expect it will be.

JB: You've written in *Red Mars* and elsewhere about complex topics that don't often get considered in science fiction or exploration narratives, like ecology, social systems and settings, the future of international space policy, and the dynamics of individual human interactions in extreme—exploration or pioneering—circumstances. Based on that experience, and the evolution of your thinking over the past few decades, what are the challenges that we need to master to make Mars habitation work?

KSR: I think it would help to think of Mars as being like Antarctica, rather than like the "New World." It would help focus our goals and the steps needed to achieve them. We need to send robotic landers with most of a base camp for humans landed in one area and ready to be activated and inhabited. We need to think of the people going there as scientists making a visit to a Site of Special Scientific Interest, as the British would call it. That they will study Mars and then return home, like astronauts to the Moon, but gone for five years rather than a month.

This would take the magical thinking out of the process and reduce it to a set of achievable steps, with goals that are interesting and even spectacular, but not game-changing for civilization. There's too much fantasy projection onto Mars and it obscures the project as it really exists. My work may have contributed to that, but I think a careful reading of my books will show they were always trying to make the case that Mars is no cure for Earth's ills, just a kind of mirror, or an interesting experiment, even if a thought experiment only.

JB: That's an interesting perspective. What would be the effect on long-term human habitation of Mars if, contrary to your hopes, the "magical thinking" does end up ruling the day? Or perhaps other drivers push human exploration of Mars that might be focused on other nonscientific goals, like "flags and footsteps" national prestige? Do we *all* need to be on the same page—U.S., Russia, China, ESA, companies? If we're not, do we risk destroying or delaying the effort?

KSR: It's very easy to imagine a kind of "flags and footsteps" race to Mars being pursued by the spacefaring nations, now including China, and private companies like SpaceX. But here we're talking about putting people on Mars, because the robots are already there. And the human landing project is very difficult and expensive. So in the end I think it may come to either a matter of international cooperation, or else a big country investing in the expenses and ignoring the risks to the astronauts involved. That's what it would take.

No matter how it happens, an inhabited Mars is no help to us in designing and enacting a sustainable civilization here on Earth. So it's a derivative of success in other realms, and in effect a kind of luxury problem. If humanity achieves balance on Earth, people will end up on Mars as we are on Antarctica, and the general public may then lose interest. Maybe long after that, a local Martian civilization and culture might emerge—depends on how pregnancy goes on Mars, if at all. Or it might not. But all that is centuries off, and derivative to earlier and one might say much harder successes here.

JB: You recently looked at the future of human expansion into the solar system in your novel *2312*. Do you see such a trajectory as inevitable for our species, if we can survive the next few centuries, or as just one of many potential trajectories? If the former, what drives the inevitability? If the latter, what might represent the turning points—the places where a "gravity-assist" from an important event or discovery, for example—which might alter our exploration and settlement trajectory?

KSR: There is no inevitability in human history. I regard *2312* as utopian but also as an allegory for the situation on Earth today: the rich as spacers, the rest as the people left behind on Earth. So it needs to be read with both aspects of it in mind at once, to give it its full workout.

Humanity may inhabit the solar system with scientific bases and later even permanent small cities for some. Depends on how we react to long-term habitation at different gravities than one G; right now we don't really know what that will do, so it's all speculative. In any case it all rests on the idea that we first create a sustainable civilization here on Earth. If we don't do that, the solar system will remain empty or at most a kind of sideshow with some McMurdo-like scientific bases. But really, the solar system is irrelevant to human history. It's interesting and beautiful, and possibly even useful, even if just as a research area, but it cannot help us in the long-term project of creating a sustainable civilization. Even "saving ourselves so we can become solar-system citizens" is a kind of crazy reason to propose for doing the right thing here. Why not do it for us now, or for the vast majority of the people who will be born and live their whole lives on Earth, like we will? That's the real motivation. So the solar system is secondary, a derivative, so to speak, of our main project.

So, we face a kind of emergency century or two, in bringing ourselves into balance with our biosphere. In that project, where the space project helps, good; where it doesn't, it needs to be put off, as a possible project for people of the twenty-third century perhaps. If at that point we are doing the space project, it will be a sign of success, a marvelous thing.

JB: Your comment about needing to think about how we react to different gravity, which could equally apply to radiation, or other environmental challenges, makes me want to ask you about the "Mars vs. the Moon" debate. Do you think the Moon will play a substantial role in the future habitation of space, or merely a supporting role?

KSR: If we do much in the way of habitation of space, the Moon will be part of it, for sure. It's close and easier to get to and back from. It has some gravity. The side not facing Earth will be great for astronomy. If people react well enough to the gravity, it's easier to imagine domed or buried cities there doing better than Mars. And it makes a potential way station and proving ground. So I think the Moon will call to people and we'll go there. But it is the same with the Moon as what I've been saying about Mars; it's a luxury for a later time, in terms of usefulness to us.

JB: You've also thought and written quite a bit about potential economies and social structures of the future, here on Earth as well as among our possible future settlements in space. Of course, lots of others outside the literary world are thinking about such things as well. For example, you are well aware of the emerging space resource prospecting and mining communities, embodied by visionaries in companies like Planetary Resources, Deep Space Industries, and Shackleton Energy. There's lots of debate about what kinds of economic models might work best in the upcoming new space frontier (and beyond). What kinds of economic models will we need to make a substantial and sustainable space future happen?

KSR: I'm not convinced there's anything elsewhere in the solar system that we need, that we don't have here on Earth already. It's mostly common elements and volatiles out there. Between that fact and the gravity well we're in, there won't be space mining any time soon.

JB: I'm not saying you're right or wrong, but I know a bunch of people who disagree with you, and they're putting their money, and others', on the line over it. There is a lot of hype about precious metals, to be sure, but arguably the most important resource, the one that really matters in the end, is water. This is the resource about which, in my experience, the only serious discussions are occurring. Because of its many uses—rocket fuel, breathing, drinking, shielding—it could make economic sense to build a space-based resource economy around prospecting for and mining water from the reservoirs out there, like near-Earth asteroids, outer main–belt asteroids, lunar poles, Martian poles, rather than having to launch it off Earth. The recent TV series *The Expanse* plays on this idea—too heavily, in my opinion, but it seems to be popular. Could you expand upon your thinking on this in a bit more detail? What do you think of the "asteroid miners" who are certainly technically capable, and in some cases well-funded, who are going after the water?

KSR: But this is water used for space inhabitation itself. It will never be the case that we import water from space to Earth. So if you're saying, if and when we inhabit the solar system, will we be using the water out there to fuel our projects and keep us alive, yes, of course. Because it would also be crazy to lift water up from Earth to space when it's out there anyway.

So, mining the asteroids to live in the asteroids—it's a very plausible science fiction story, it's how it would be done. But it's a tautological justification. If you say, "why go to the asteroids," and the answer is, "so we can mine water to live in the asteroids," it has no force as a justification. When people say "mining," the implication is that we are extracting something that we want here on Earth and bringing it back to use. And that isn't something space can do for us.

The exceptions might be energy generation in orbit, beamed down to Earth; and maybe helium-3; and maybe some rare earths. But none of these really pencil out in the capitalist economy. There would have to be a post-capitalist system and some kind of overriding need, which I doubt exists. So again, these are fantasy projections, I think, made by people who "want space" for noneconomic reasons—which is fine—and then try to justify the desire by way of a projective economic logic that doesn't actually pencil out.

We don't need space. We need sustainability in this biosphere. Space is a luxury problem and a luxury opportunity. It's what we get to explore in some detail, in the centuries after we succeed in inventing permaculture here, if we do.

Again, it's like Antarctica. We now inhabit and explore the Antarctic usefully in terms of scientific information gathering. Does anyone care? No, they do not. If and when we get into the solar system, it will be like that. One aspect of the interest in space right now is the fact that it's the hardest thing we might be able to do as a civilization, given our current technology. That's why people were interested in the North Pole in the nineteenth century, and then the South Pole, and why they were interested in the Moon in the 1960s. But in all these cases, once we did it, we lost interest. Those last Apollo missions getting canceled—that was a sign that we have to attend to. As an event it has a meaning. What were we really interested in there? Not the Moon. Just the getting there. And space may be the same, every object up there. We get to Mars, great; but then, big deal. Scientists at work. People may get interested in Europa or whatnot, or maybe not. We'll see. But the signs are clear that we don't have an intrinsic interest in places where lots of people can't live.

I don't mean to sound pessimistic here. I just think that if we focus on our real needs and desires and understand them better, we'll do a better job of achieving our goals. Here, what we really need is sustainability on Earth. So, space science that supports that is good; space science irrelevant to that is premature at best. It makes a kind of rubric for decisions. Also it's important to be realistic about difficulties. We don't know how humans will do off this planet over the long haul. Could be pregnancy won't work on Mars. Could be everyone will get sick and need to get home to Earth for a kind of "sabbatical," as in my *2312*. We just don't know. So admitting that is part of the work of focusing on what our project really is, and what we should do now.

JB: Finally, in the broadest sense, why do you write about space exploration? What role do you hope that your work will play in conversations about space?

KSR: I have been writing about humans in space for 40 years, but I haven't often thought about why I have done that. I guess it began with a love for science fiction as a literature and story space, meaning I guess the future, and the future history of humanity in particular. That was assumed to include space, in the time when I began writing science fiction, and so my eye turned outward. What I saw that caught me immediately was the solar system, a marvelous collection of planets, moons, and asteroids that felt within reach and would be very exciting to explore as landscapes with exotic features.

Story ideas came to me and it seemed true that the solar system was a great story space for me. Usually I wrote about a time that was post-exploration, more a matter of humanity in a settled solar system. This became a comfortable story space for me. And very soon in my career, the Viking landers and orbiters gave us Mars, and that became my focus for many years. I still believe in the Mars project, meaning a place of eventual human habitation and maybe terraforming, as a kind of extension of a viable permaculture invented and enacted on Earth.

In the course of my career, my studies led me to think that human travel to other solar systems, and humanity spreading out through the galaxy, was impossible and not going to happen. So that's become part of my writing too; that the solar system is all we've got, but is good enough.

I think now that space science is an Earth science, and getting things right on Earth is the main task for civilization. So my views have evolved over the course of my career.

THE PRACTICAL ECONOMICS OF SPACE

by Clark A. Miller

Space, the final frontier. *Star Trek* has given us uncountable ideas about possible human futures in space, what we might find there, and how to behave properly once we've run into neighbors from nearby planets. What it has never given us is a clear, pragmatic sense of the economics of space: that is, in the simplest sense, how human activities in space will get paid for.

Star Trek never discloses how much it cost to build the *USS Enterprise*—the starship, not the aircraft carrier. We never learn what kind of salary Captain Kirk earns, nor who pays the taxes to support Starfleet and their five-year mission "to explore strange new worlds, to seek out new life and new civilizations, to boldly go where no man has gone before." It's an interesting omission.

Frontier societies always give rise to questions about their economics, whether we're talking about the settlement of new lands or the invention of new technologies. How do you pay for the work that has to get done to build infrastructure, extend supply chains, extract resources, provide for the sustenance of new settlements, and ship the excesses home? How do you pay for the upfront research and development costs of innovation on the technological frontier?

But there's also a deeper dimension to economics. We pay for things because we value them. We pay people because we value what they do for us. What—and who—will we value in the human future in space?

Currently, there are basically three mechanisms that finance human societies. The most important is markets. If something has value to someone, and she has enough money, she can purchase it, so long as she can find someone willing to make it or bring it to market at a price she can afford. Banks provide a market for aggregating money to allow people to make larger purchases—like cars and homes—that they would find difficult by themselves. The second mechanism is government. Governments collect taxes and then use the resulting money to purchase things that, for one reason or another, individuals and companies are not positioned to buy. National defense is a good example. The third is philanthropy: wealthy individuals donate money to causes they find compelling. There is a fourth, voluntary human labor, that often goes unrecognized or unrewarded but is extremely important, especially in supporting certain kinds of basic social infrastructure. More on that later.

One of the central reasons that many organizations, including NASA, are putting significant efforts into commercializing space is so that they can generate new and additional revenues to accelerate space exploration via markets. This seems like a good idea, in that government funding is always limited. NASA's budget, for example, has been about $20 billion in recent years. Compared to the $20 trillion U.S. economy, this seems like small potatoes. $1 out of every $1,000 to fund space. Surely the market can do better.

Another comparison tells a somewhat different story, however. The annual budget of the U.S. government is $4 trillion. By contrast, the largest company in the world, which at the moment happens to be Walmart, has annual revenues of a bit more than $400 billion. That's 10 times smaller.

No single business organization in the world can match anything like the spending power of the U.S. government. When the U.S. government decided that it needed to intervene in Iraq—whether one believes that was a good idea or not—it ultimately spent $2 trillion over a decade. That's why private companies like Elon Musk's SpaceX actually make most of their money by selling to the U.S. government. And, of course, it's the U.S. Department of Defense, not NASA, that spends the most money among federal agencies in space.

And then there are philanthropists. The richest is Bill Gates, with $85 billion. But that's not an annual revenue stream. It's all the money he's got. So even he can't even come close to matching a big company, let alone the U.S. government, for pure ability to finance future space expeditions.

Exploring the futures imagined in this book, it's not hard to see how the outlines of a future space economy might emerge. There are two key elements. First, somebody needs to sell something. Second, whatever that product is, it needs to have value for people living on Earth.

Until now, commercial activity in space has been dominated by communication satellites. Many companies, especially news and entertainment organizations, have been willing to pay other companies to put communication satellites into orbit. Those companies are willing to pay because their customers on Earth are willing to pay, in turn, for the services that media companies can deliver via satellites, like live news coverage or lots of inexpensive TV channels. Not much else justifies significant commercial activity in space just now. We can move electronic signals through near-Earth space quickly and for relatively low cost, compared to the value generated by DirecTV, CNN, or Verizon for their customers.

The stories in this collection point us in a few basic directions for the near-term future of space: tourism, mining, real estate, and environmental cleanup. Tourism has a coolness factor, as Steven Barnes's story "Mozart on the Kalahari" reminds us. The possibility of traveling into space can inspire all different kinds of people. But the reality is that few people are likely to be in a position anytime soon to afford that kind of journey. You can take up a few people for free, as a publicity stunt, but pretty soon a company would need paying customers. Yet, outside the top few percent of the world's wealthiest people, willingness and ability to pay drops off rapidly. The number of people who can afford more than the $5,000 to $10,000 of a relatively expensive vacation for a family of four is vanishingly small. Few can afford even high-end hotels planet-side, with their $1,000 per night price tags, let alone their space counterparts. So, you could build a space economy on tourism, but it would be small, at least initially, and it would depend on very rich people. Maybe you could build capital gradually, invest in lower-cost transport infrastructure, reduce your prices, and grow over time. It might work. It might not.

More people think the future of the space economy is in mining, as several of the stories suggest, including Eileen Gunn's "Night Shift." Gunn's protagonist lives in Seattle but works with robots to capture and mine asteroids. Historically, mining has driven many frontier economies. They have serious problems: pollution, environmental degradation, exploitation of indigenous groups. How serious any of these challenges will turn out to be in the reality of space is an open question. At the beginning, people will argue that space is so vast that worries about pollution are fearmongering that puts the cart before the horse, but they often said the same thing about frontiers on Earth, too.

In Low Earth Orbit, the rate of growth of orbital junk is already a problem for today's spacecraft and satellites. It's a sufficiently big problem, in fact, that Carter Scholz imagines Uber creating a space division to clean up space debris in "Vanguard 2.0." I'm surprised he didn't choose Waste Management, a company that's already gobbling up garbage companies—and garbage—all across the Earth. I bet they're already thinking about it. So, yes, environmental remediation could be a good space business—although it might be better not to cause the problems in the first place. And, like environmental cleanup on Earth, it might be a challenge to convince people to pay for it.

When we consider the commercialization of space, however, several of the stories remind us that all of these ideas—and every other one we've thought of to date—suffer from some rather severe handicaps. *It's really expensive to get stuff from Earth into space* (like tourists or mining equipment). That's why Barnes envisions poor people entering contests to try to get into space, Gunn's story involves robotic space missions by nanobots which are tiny and thus cheaper to launch (and can build replicants of themselves, in place, in space, from resources already up there), why Ramez Naam writes of automated factories on the Moon making the materials and fuels to colonize space in "The Use of Things," and why Myrna's friends all work on Earth as they build the Martian city of the future in Karl Schroeder's "The Baker of Mars."

Likewise, everything in space is a long way away and thus requires a lot of time and energy to get to and to come back. For both Ashby, in "Death on Mars," and Schroeder, getting people to Mars is a massive undertaking. Indeed, for NASA, getting just three small robotic rovers to Mars was a massive undertaking. It's not an accident that Gunn's nanobots and their AI teammates work in near-Earth space, where the time lags between remote systems and human controllers are short enough not to matter. *Communication lags get significantly longer, the farther you go.*

The inhospitality of space environments also means that *human beings in space require extensive life support systems that make their participation even more expensive and risky*. Life support systems are costly. So are redundant safety systems to reduce risk. Both also add to the weight of the payload that must be taken from the Earth's surface to orbit and thus require very high amounts of fuel and more expense. The human body itself must be also lifted out of the Earth's gravity well.

Finally, as Schroeder reminds us in his story of the quest to invent real estate on Mars, *the ownership of assets in space is entirely unclear.* Who owns the surface of Mars? Who owns the metals or other materials in an asteroid? These are not idle questions for those seeking to commercialize space ventures, nor those seeking to finance space missions on the hopes of a future return on investment. They are questions of governance, specifically, of who governs and who has the right to allocate ownership rights in space. To this point in human history, ownership is a legal concept grounded in national law, and national territorial jurisdictions do not currently extend into space. Indeed, the 1967 Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies expressly prohibits its signatories, which include most spacefaring nations, from claiming sovereignty over territory in space.

Still, law is a figment of the human imagination and a product of human institutions; thus, humans can change it. Existing nations may seek to extend their jurisdiction to authorize ownership in space through workarounds, as the U.S. has sought to do under a new 2015 law, by claiming ownership over "resources" without claiming ownership over places. Or nations may simply withdraw from the Outer Space Treaty and claim territory. Or humanity may invent new nations in space, or invent new concepts of governance, like Schroeder's self-governing, blockchain-enabled commons. As Schroeder explores in his story, ownership is complicated in space. Early entrants into markets for space places and space resources may lose their shirts if ownership rules change. We might even fight wars over who owns what in the frontiers of space.

And, even if we can reach agreement on who owns the sky and how to mine it, no one has yet found any mineral or substance in space that doesn't also exist on Earth or that has a sufficiently constrained supply on Earth and a sufficiently high demand to drive up costs high enough to justify space mining.

So how might space companies solve these problems? One approach is to make stuff in space and create a "local" space economy, meaning an economy in which people or organizations in space sell stuff to each other. That's a great idea. In frontier economies, alongside the mine there was also always the general store, the saloon, and the blacksmith. The European Space Agency is already thinking about things like sending 3D printers to the Moon and making things there, so you wouldn't have to pay the cost of launching them off Earth. Spacecraft and fuel would be especially valuable, as Ramez Naam points out in his story, and could then be sold to others in space. We might call this the bootstrapping or bottom-up model of space commercialization.

There are two challenges, however, in bootstrapping your way to a space economy. The first is that it will be slow. When markets grow in a bottom-up way, they start small and do not grow quickly in absolute size. Maybe that's fine. But growing a space economy largely in space itself is unlikely to be a get-rich-quick scheme.

The second challenge is that this model still requires an Earthly value to the activity. Someone must be willing to invest in the infrastructure to obtain space materials. Someone else must be willing to buy something from them at sufficiently high prices to pay for the spacecraft and fuel in question. Think about the city being built by the homesteaders in "The Baker of Mars." It's all speculation, based on the idea that people on Earth will want to buy real estate on Mars at prices high enough to compensate for the costs of building there. Or think about Gunn's and Naam's mining probes. The whole point is to secure materials that can be sold on Earth. At least at the outset, a space economy is not likely to pay for itself. Earthlings must ultimately pay for it. We're the big market on the block.

Another approach to solving the space economy puzzle is to significantly reduce costs by upgrading autonomous systems and allowing robots to do most of the work. This has long worked for NASA, which has a strong space-probe business and has sent many spacecraft into space that were piloted by scientists and engineers back on Earth. It's still not cheap, however.

And in the stories in this book, like Gunn's and Naam's, robots do far more than just travel from place to place. They also adapt to diverse realities of mining in space. That's why Gunn imagines nanorobotic swarms. No current space mining technology fits that bill: existing robots are just not capable of autonomously sizing up an asteroid and mining it. And, at least according to the logic of her story, we can't afford to put humans into space to do the sizing up and orientation for the robots. And nanobots will have limited intelligence. So, Gunn also gives the swarm a smart controller robot. Perhaps a bit *too* smart.

Given my experience with Siri on my phone, it's going to be a while before we have an AI system that's good enough to do what Gunn's AI does. Siri does some pretty cool things. But she's also pretty stupid in a lot of ways. Siri is not actually in my phone (or yours), either. She's in a giant server farm somewhere, probably more than one. For very-near-Earth activities, the communications lag and finite data transfer rates between Earth-based server farms and space AI systems may be solvable problems. For activities that occur even a modest distance from Earth, however, we're going to need to send the AI hardware into space. Remember HAL in *2001: A Space Odyssey*? That will mean significantly shrinking the weight, size, and energy requirements of the computational infrastructure required for high-level AI. Or we're going to need to build and move very large AI spacecraft through space, which may be just as expensive as sending people in the first place.

Using people to coordinate robots from Earth, as a few of the stories suggest might be possible, is going to run into similar problems of data bandwidth and communication speeds. And, as NASA's experience with its Mars rovers suggests, this has been demonstrated successfully only for very controlled environments and plans. It's not clear it would work without deep and exact knowledge of the circumstances of the mission.

And it gets even more complicated as the complexity of the communications task grows. How are Schroeder's homesteaders in "The Baker of Mars" able to do what they do, sending high-quality visualizations and commands back and forth from Earth to Mars to sustain not just one data link but seemingly thousands? NASA's Jet Propulsion Laboratory estimates that we'll need to grow data rates for planetary missions by a factor of 10 for each of the next several decades.[1] But they don't imagine anything like the immersive, virtual realities that enable the crowdsourced making of Martian infrastructure that Schroeder envisions, which, even time-delayed, would be extremely bandwidth-intensive.

Then, too, there's the point that Naam makes in "The Use of Things." Sure, we can potentially make money in space using robots and AI. But to what end, if there are no people there? If we want to travel into space, to settle it, then we need to put *people* up there. However it starts, the long-term objective of building a space economy is to support a future for people in space. Building a small commercial space industry and economy built on robots may be a stepping stone. But if it's a stepping stone, then let's think hard about the design of the space economy from day one, so that the world we create for people to step into in the future is one that people actually want to inhabit and, just as importantly, that people can thrive in. This adds an important complexity to the future space economy because it entails taxing that economy to create a plausible and thriving future for humanity in space, which will inevitably further slow and complicate the business of actually trying to run early, small-scale space businesses.

We might discover some micronutrient or extremely rare material that turns out to be critical to the future of life on Earth. And we might discover that the only place we can get more of it is in space. Or we might discover something in space so attractive—like the tulips of the Dutch Gilded Age—that Earthlings are willing to mortgage fortunes to obtain it. And so we might mount extremely profitable expeditions to go get some of it and bring it back to Earth. All that is possible. But it would hardly count as a space economy. It would merely be a mining expedition.

And I suppose it's possible that we might ultimately build an economy for intelligent robots in space—or by then it might be more accurate to say that they'd build an economy in space for themselves—but what would be the point, exactly, in human terms?

Markets have become quite unhinged in recent years from consideration of their purpose. Like technology, we've largely come to treat them in technical terms, as instruments for achieving various goals, such as efficiently allocating capital. Markets, or so economists tell us, allow people to trade something that they have in surplus (time, labor, apples, etc.) in exchange for something that someone else has in surplus (money, rocks, good ideas, etc.). In their simplest form, this allows people with too many blueberries to trade with people with too many strawberries so that everyone can enjoy both. Pretty soon, along comes a middleman, a trader, who trades with both so they don't have to always find each other to do their exchange. Over long periods of time, trade allows the creation of sophisticated markets and industries that allow people to buy services, like travel to space, that would have been impossible without sophisticated markets.

But it's always worth remembering that the reason for markets—and for money—is to allow people to trade for things that they can't make or achieve for themselves, *so that they can make their lives better.* The purpose of markets is to create opportunities for enhanced human thriving. Money is not an end, it's a means.

So why should people go into space? I can imagine four reasons.

The first is to make money or to gain power. If we can build tourist or mining industries in space, it might make *someone* filthy rich. Or maybe they'll get powerful: a trillionaire who controls nuclear weapons in space and can threaten governments to get his way, like Scholz offers up in "Vanguard 2.0." Great. End of story. Does anyone else besides the trillionaire care? That's a reason for the rest of us *not* to want people to go into space.

The second reason for people to go to space is that it might provide some security to the human species. A local catastrophe here on Earth would be a deep problem for humanity. This is the theory underlying Elon Musk's vision for settling Mars. The wrong asteroid in the wrong place, a failure to control our carbon emissions ... a thriving humanity in space would provide a safety net for the species to continue, no matter what happened on Earth.

Related to this, we might just become a little too crowded here on our home planet. Quite possibly, we're already there. Too many people, too little space, too few resources, too much waste. Relieving the pressure might be a good idea. Allowing people to spread out a little, get a bit further away from their neighbors, live a little more like they want to live without the constant pressure of the civilizing gaze of their fellow inhabitants of Earth—frontiers have always been good for that.

Finally, and to my mind the most compelling, we may wish to journey into space to continue to diversify the human experience. Saturn is out there. Let's go find out what it's like to live amidst its rings. As Chirag says in Vandana Singh's "Shikasta": "We look for life on other worlds because we want to deepen what we mean by human, what we mean by Earthling."

What kinds of experiences will people have in space? It's no picnic to build a city on Mars via virtual-reality immersion. But what would it actually be like to grow up on the Red Planet? Indeed, what would it be like to grow up even in a habitat in Low Earth Orbit? How would space change us, as we change space? If we're going to go to the trouble of creating a space economy, the goal should be to make it possible for humans to grow and change and thrive in space as they have on Earth. To make space into a place where people can build a life, a community, a future. Where they can experience new realities, write new stories, invent new literatures and genres of art, create new human possibilities. To that end, the commercialization of space may be necessary, in that the creation of a functioning space economy finances the other structures of human society as they take root, grow, and evolve in diverse new ways.

Why do people go to space, now, in the dawn of the twenty-first century?

Because we send them—we, collectively. Today's space missions are public endeavors. They have public purpose, public value, and public meaning, and occur at the public expense. They're led by commanders and staffed by employees of the world's biggest governments. They're not boring, exactly. But they're not exactly exciting, either, in the sort of deep-down passionate version of excitement that drives Meek in "Mozart on the Kalahari." Why were we all so excited when Christa McAuliffe went into space? Because she wasn't an astronaut. She was an ordinary person headed for a place that ordinary people didn't go.

Star Trek and its successors, *Next Generation* and *Voyager,* all have their great moments, their drama, their amazing stories about people in extraordinary settings. But the focus is on the journey, on ever-forward movement to new frontiers. All the ordinary people live on planets, and all the markets (the few we ever see) are on planets, too.

Deep Space Nine is different. People *live* in space. Ordinary people. They are born, laugh, play, cry, work, get sick, and die in space. They thrive, in their good and bad moments. And there are markets in *Deep Space Nine*: shops and merchants and weapons dealers. And there is a bar, a place for people to gather in community, to celebrate, and to fight. There is a bar in the first *Star Wars* movie, too. Despite its well-deserved reputation as a "wretched hive of scum and villainy," the bar in Mos Eisley is a dynamic, engaging place where music plays and humans and aliens gather, eat meals, make deals, and resolve disputes, face to face. Is that an accident? All of the versions of the *Enterprise* have bars in them. So does *Voyager.* Some of the few people who aren't Starfleet personnel run them. The most exciting and dramatic stuff doesn't always happen there. But some of the most meaningful and most fun does. We're supposed to think it's because of the drink.

This is all a bit stereotyped, of course. It's Hollywood after all. But there's also some truth to it. We go to the bar after work because it's not work. It's a chance to let our hair down, to spend time meeting new people, hanging out with our friends. It's a commercial establishment, part of our economy of exchange, but also an emotional touchstone, a hub at the center of the web of human relationships. Myrna's diner in "The Baker of Mars" is an example of how, even in the far future, a countertop becomes a gathering place. Find people, and you will almost always find somewhere like Myrna's, where those who are too lazy or too busy or too lonely to make their own food come to eat. And you will find people like Myrna, or Quark from *Deep Space Nine,* entrepreneurs who are all too happy to provide the material and financial glue that holds human communities together through their willingness to make markets.

But the making of money is only a tiny part of what's happening. People go to the bar because it creates social value, for each of them, individually. Not social value in the sense of "it's good for us." We're not more ethical or more just or less poor when we've been to the bar. But social value nonetheless. The patrons of *Cheers* aren't always happy. But they share their lives and connect their stories. And that makes them part of a community. We plug into our humanity in bars. We do elsewhere, too. Often in other kinds of commercial establishments.

Why should we commercialize space? Because if space has commercial establishments, then it will mean that people are doing more in space than just going on missions. They'll be living, working, making money, spending money, taking their kids to the park (wherever that park is, whatever it looks like, and whatever kids do at that park to have fun), and buying coffee from Myrna.

Too few of our realistic space stories—the ones that motivate our space agencies and our space companies—imagine the human future in space in more than mission-centric terms. The people in these stories remain instruments of attempts to further the exploration of space and the exploitation of its resources. They're not really there on their own terms. Space remains too vast, too alien, too far in time and distance to support thriving human communities, even in Low Earth Orbit.

The stories in this book reflect this tension. Space is a hard and lonely place when you're just there to do a job. Naam's story, with its proclamation that humans are the point of space travel, epitomizes this. It ends with an astronaut, alone, on a solo mission, having a near-death experience, rescued by robots because they've been programmed to think that his is the only valuable life, deliberating with himself about whether he's an expense that space missions can afford. He is the reason for creating a space economy, yet he's a massive drain on resources that could be used much more efficiently to accomplish the instrumental goals of the task at hand.

Sergei's girlfriend on Earth, in "Vanguard 2.0", asks him, "Who will take care of your heart and soul [when you go into space]?" It's a tough question. Sergei shrugs. Then he goes off to work, cleaning up space. And then his work turns into a stupid request from a trillionaire who has way too much money to go and find an artifact out of history—which turns out to be a ruse to get Sergei out of the way so that the trillionaire could deploy the space nukes and prepare to take over the world. The soul isn't in space for Sergei or Pace or any of the others in the story. Indeed, it's not clear that Pace has a soul. For Sergei, his soul is with Izumi. He hopes. In the end, he goes home to find her and himself, abandoning the freeing isolation of space for the messiness of Earth and all its tangled humanity.

And the further one goes, the more challenging it seems to become to envision human thriving. In Madeline Ashby's story, a small band of astronauts are on a mission to prepare Mars for colonization. Risk is everywhere. Lots can go wrong. Stress is endemic. No one has much privacy, either from each other or from their overseers back home. They are hardened professionals, carefully selected and groomed for their positions, yet nevertheless hard-pressed at every turn.

To survive, to complete the mission, and to provide data for future voyages, the crew are tied into active and passive monitoring networks. Every aspect of their days and nights is subject to careful analysis to test whether humans can survive in small groups for years or decades, packed into tiny spacecraft. Their monitors are shrinks, focused on keeping them healthy, attuned to the tasks at hand, adequately coping with the isolation of the voyage and the irritations of their neighbors. And the Mars colonists who will follow them are enhanced. "Lifehacks," Ashby calls them. "All the members of the *Ganesha* crew had augmentations to make their life on Mars more productive and less painful." So, too, the eventual spacefarers of "Mozart on the Kalahari": human-plant symbiants designed to survive long-haul missions, far beyond the comforts of Earth. Lifehacks, augmentation, symbiosis: euphemisms for bodily genetic modifications, multispecies chimera, and neuro-cognitive upgrades given to crews of space missions to adapt their bodies to the unforgiving environments and experiences of space. The basic message: to tackle space is to be transformed. To be made an instrument capable of surviving there.

Yet the stories in this book all retain a human spirit that resists the transformation of people into mere cogs in the machinery of space exploration and exploitation. It's one of the great strengths of science fiction. It reminds us that all kinds of people inhabit the future, not just those with a job to do. And that the futures we create for people must inevitably encompass the full richness of their lives as humans, far more than their ability to do that job. With typical human resilience, the people in these stories build community. They make meaning together.

The characters in these stories have lives and livelihoods, wants and desires, loves and hates. They fight with each other, and they fight with others. Technology doesn't do unto them. They do unto each other using technologies. They innovate. They make. They make lives—and worlds—out of the stuff that scientists and engineers invent, the stuff they have lying around, and the stuff they can think up.

In science fiction, we can see into the worlds they're making and ask what those worlds mean for real people. Is that a world worth living in? Is that a world that we should bring into being? We're not being sold an advertisement. This is not an iPhone or an Apple Watch, magically transporting us into some awesome new lifestyle where everyone is fit, happy, and sublime. We've become too wary of the seductive power of narrative to believe in an uncomplicated utopia. Good science fiction tells it like it really is.

People who worry about the macroeconomics of space are right. All the numbers will ultimately have to add up. And that's what makes the public sector so important. More than any other entity, the public sector can pour money into space exploration and colonization until it's up and running on its own account. To match NASA's $20 billion annual budget, one time, with an equivalent amount of private-sector investment, given typical bank loan expectations, you'd have to be able to generate an annual revenue stream of close to $4 billion per year. What exactly are you selling? Who's buying? Where's the value? And NASA gets to spend that $20 billion year after year after year. It's a pittance in the scope of the U.S. federal budget.

Schroeder doesn't say in "The Baker of Mars" how the giant colony ships that will carry people from Earth to Mars are being financed—or by whom. Nor does Elon Musk in his 2017 article in New Space, "Making Humans a Multi-Planetary Species," describing his proposed effort to build a civilization on the Red Planet.[2] Nominally, in Schroeder's story, Myrna's friends are going to get paid off by the people who buy Martian real estate. But who would want to buy such real estate, even if we could agree on a theory and practice of ownership? And why? Musk has the same problem. He envisions a $200 billion corporate project to create a city of a million people, if he can reduce the costs to get people there by a factor of 5 million from the cost of sending people to the Moon via the Apollo missions. Even at that price, however, where will the return on investment come from? There's just something that doesn't quite add up yet about the macroeconomy of settling Mars.

But the titular baker herself, Myrna, makes an enormous amount of sense. She creates value. She has a niche. She feeds Martian homesteaders who are drugged out on virtual reality interfaces, learning their rhythms and the Martian day-night cycle so as to have hot food ready, despite the differences in rotation speed between Earth and Mars, at just the right time. When her friends and customers forget to come eat, she delivers, selling other sundries, too. She carries messages for them, hosts their meetings, and solves their problems. She makes markets, wherever markets need making.

If the Mars colonization effort is a public project, then Myrna is its private partner.

Public-private partnerships and the commercialization of space are often seen as opportunities to carry out public projects using the efficiency and capability of the private sector. When the United States decided to build the atomic bomb, it quickly hired some of the biggest companies in the country to manage the actual sites of production. DuPont built the X-10 pile. Stone and Webster built the Y-12 uranium separation plant. Soon after the war, K-25 became the largest industrial plant on the planet.

But if you visit the museums of Oak Ridge, Tennessee, and walk its streets, you'll quickly learn that there were other private partners. The atomic campus of Oak Ridge wasn't just a project. It was a town. And that town had commercial establishments. It had groceries, barbershops, restaurants, and movie theaters. It had Myrnas making the human world turn.

Myrna's world—as bleak as it might seem—is one worth living in, it seems to me. If we are going to commercialize space, we should do so for people like Myrna. We should want people who bake bread for others, who take pride in doing so, and who make a living in the process. We should want people who create spaces for communal meals, deliver food to those who are too wrapped up in their own affairs to remember to eat, and create the microeconomies necessary for these things to happen.

To bloom in space, humanity will require the grounding "soil" of the local coffee shop, the local bar—but as the stories in this collection suggest, we're going to have to work hard to create space economies that have commercial establishments in them. To create commercial establishments, you have to create all kinds of things: the kind of people who need commercial establishments, the kind of people that run them, and the material and financial markets that support both. That will not be easy. It will require visions of the future and of people's lives and roles in those futures that differ markedly from those being pedaled in the current imaginings of space policy and the commercialization of space.

But Myrna is more than just an entrepreneur. She's that pesky reminder that the future is for everyone: that we owe it to everyone to imagine them as part of the futures we envision, to imagine them as fully human, and to remember that their humanness is found in community. The diversity and health of the kind of enterprises that people like Myrna run seems to me a plausible indicator of the diversity and health of community—its thriving, if you will. She is an integral part of the community's soul. If there's a pub, or a diner, and people flock to it for the chance to catch up with their friends, to sing and dance, to share their sorrows and stresses—just to be a little less lonely and strung out—isn't that a good thing?

Creating a human future in space where people live, work, and play, have families, raise their kids, run businesses, write novels and poetry, celebrate their gods, and dance amidst the stars—where they thrive—seems like a goal worthy of human striving and human enterprise. We will need Myrna and many others just like her—social entrepreneurs of the best kind—to make that happen. Let's make sure we write them, and all of humanity, into our future plans.

Notes

1 "Deep Space Communications," Office of the Chief Scientist and Chief Technologist, NASA, https://scienceandtechnology.jpl.nasa.gov/research/research-topics-list/communications-computing-software/deep-space-communications.

2 Elon Musk, "Making Humans an Interplanetary Species," *New Space* 5, no. 2 (2017).

HIGH HEDONISTIC AND LOW FATALISTIC

by Linda T. Elkins-Tanton

Snowman in *Oryx and Crake*. Case in *Neuromancer.* Theon Greyjoy in *Game of Thrones*, for goodness' sake. Why is it so easy to write about disaster, and so hard to write about hope?

Hopeful and optimistic stories can seem like fairy tales, and talking about them can be squirmily uncomfortable, as if one suddenly found oneself hawking snake oil. Writing about darkness and death can carry such realness, such gravitas. The Center for Science and the Imagination's anthology *Hieroglyph: Stories and Visions for a Better Future* began to address the need for visions of the future that are intellectually and emotionally credible without reveling in catastrophe, and we've continued that work in this volume. We're not doling out saccharine promises and we're not covering the old stained sofa with chintz. We are trying to offer new, ambitious but achievable visions of a near future.

There are many possible futures for our society, for humankind, and for the Earth. We need compelling examples of futures we actually want, to inspire us in how to move forward. Humans in space is a part of all the good futures we are likely to be able to attain. In the long run, the arc of civilization and our irrepressible curiosity will inevitably impel us to explore the solar system and the stars beyond. But first we have to believe such futures are possible. And to act upon our hopes, we need to believe that, individually, we can make a difference.

To make that individual connection possible, we need futures that are not just abstract, zoomed-out images of white guys from Central Casting saving the world for everyone else. We need images of *people like us* taking action to realize those futures. To build a future for everyone, we need to include everyone: we need heroes that reflect the full diversity of human experience.

We need female protagonists who are not reduced to sex objects. More characters like Dr. Louise Banks, Amy Adams' character from the film *Arrival*, who repeatedly ignores hierarchy and peer pressure to make the right decisions. We need strong protagonists of color, of all gender and sexual identities, drawn from all walks of life and communities of faith. We need every kind of person to be able to envision themselves in the future.

In this way, the question of representation is really about participation: inviting everyone to imagine themselves in these futures. This parallels one of my gripes about the way science is often taught in high school and college, as a series of facts that needs to be memorized. If everything is already known (look at the thickness of that book! What else could be left unknown?), then what place in science is there for the student? If science was taught as a series of questions—which is truly what it is—then finding the next unanswered question would be easy, and there would be openings for anyone who is interested to participate.

This is a passion in my life, a set of concepts that have swept over all I do and colored every meeting and conversation. Drive education through the questions of the learner. Invite every person to participate in every endeavor. Recently I taught a class about Charles Darwin and the voyage of the *Beagle*. The students were fascinated by the fact that Darwin was not a great student, no genius, and had been brought along on the trip as a gentleman companion for the captain, so the captain would have someone to talk to. (That didn't work out well—Darwin was incapacitated with seasickness almost the entire time he was on board.)

Darwin had a great skill, though, and that was observation. He looked carefully at his world and he thought about it. Several students in the class were so inspired by this idea that they emailed me about it afterward. They could do that! They could use Darwin as an inspiration in their own lives, and look more closely at our amazing, mysterious universe in order to think more deeply about it.

I would like every person on Earth to feel they have the capacity to think of something new and wonderful, that they have the agency to make a positive difference in their world, and that they have the knowledge to make progress solving open questions and problems. What could we accomplish if a larger proportion of us thought clearly about, and worked to create a positive future for, our species?

That big question begs a more immediate one: how do we teach these skills? Surely not by enforcing passive listening and valuing only memorization and formulaic execution of exercises that are already well understood. We need to practice the skills of exploration in the classroom. We need to present open questions and practice answering them.

To make a difference you don't need inherent genius. You need practice and drive and grit, not genetics. Being a strong leader requires, in the words of the psychological profile, "high hedonistic and low fatalistic."[1] Low fatalistic is the confidence that one's actions can change the future—that the future is determined by our choices. High hedonistic describes those who believe in "the pursuit of happiness" and, in some cases, the drive to find ways to make things better. If there is no hope, there is no purpose in movement. And the greatest work is done with the energy that comes from hope and belief in the impact the work will have.

At Arizona State University, we try to teach and model these lessons. We could teach science and engineering, planets and stars and earthquakes and volcanoes, all day long, year in and year out, but without team-building, a vision for the future, and leadership, that knowledge is emptier and drier. Scientists are commonly taught that these competencies are "soft skills," intrinsically less important than technical field expertise, and that our emotional response to our work is irrelevant (and even embarrassing). But every endeavor depends on human interaction, on trust, generosity, shared stories, and optimism. If we know how to work together better, ask and answer bigger questions, and build a positive future story, our efforts will go so much further. So we run workshops on teams and negotiation and interviews. We talk about implicit bias and equity. We work toward greater justice in the classroom and among our colleagues.

For years I have been convinced that civil behavior in teams—listening to each other's ideas, conscious invitation to quiet members of the team to speak, and mannerly disagreement—makes for a good working environment, better research, and better outcomes. But these behaviors are not often spoken about or valued in academia and other research environments.

My commitment to these ideas has recently been validated by NASA's decision to approve a project that has been deeply informed by them. In January 2017, our NASA mission concept, Psyche, was selected for flight, after five years of preparation. The Psyche mission will explore a unique metal asteroid orbiting the Sun between Mars and Jupiter, promising to give us unique insights into the building blocks of our solar system. One of the reasons we were selected is the high functioning of our team. Teams that listen to each other and treat each other as respected experts are more likely to discover and solve the flaws that might otherwise put a mission at risk. They are more likely to attract and keep the best talent. And they are much more likely to be, and stay, diverse. As a reward for our team culture and what it has enabled us to accomplish, we are now on our way to sending a robotic spacecraft to visit a metal world—the first metal body humankind has ever explored.

The future will always be a story, so we need stories that give everyone a voice. Our beliefs about what will happen next shape the way we behave now. The future we envision creates the present we are in. Let's envision better.

Notes

1 Uta Sailer, Patricia Rosenberg, Ali Al Nima, Amelie Gamble, Tommy Gärling, Trevor Archer, and Danilo Garcia, "A Happier and Less Sinister Past, a More Hedonistic and Less Fatalistic Present and a More Structured Future: Time Perspective and Well-Being," *PeerJ* 2, no. e303 (2014).

ABOUT THE CONTRIBUTORS

AUTHORS

Madeline Ashby is a science fiction writer and futurist living in Toronto. She is the author of the Machine Dynasty series. Her most recent novel, *Company Town*, was a finalist in CBC Books' Canada Reads competition. She has developed science fiction prototypes for organizations like the Institute for the Future, SciFutures, Intel Labs, Nesta, Data & Society, the Atlantic Council, and others. She also teaches at OCAD University and the Dubai Future Academy. You can find her on Twitter @MadelineAshby or at madelineashby.com.

Steven Barnes was born in Los Angeles, and attended Pepperdine University. He has published over 30 novels and written for *The Twilight Zone, Outer Limits, Stargate SG-1*, and others. He is married to British Fantasy Award-winning novelist Tananarive Due, and lives in Southern California.

Jim Bell is an astronomer and planetary scientist, and a professor in the School of Earth and Space Exploration at Arizona State University. Jim studies the geology and composition of planetary surfaces, and has been actively involved for more than 25 years in NASA robotic space missions to Mars, the Moon, and a variety of asteroids. He has also authored six popular science books, including *Postcards from Mars* and *The Interstellar Age.*

Lawrence Dritsas began his studies in the United States and has interdisciplinary training in the humanities and natural sciences. He volunteered as a secondary school biology teacher with the U.S. Peace Corps in Malawi in the late 1990s. His PhD thesis (at the University of Edinburgh) focused on David Livingstone's Zambesi Expedition (1858–64). His research follows multiple paths as he pursues historical geographies of scientific knowledge, museum collections, and science fiction.

Linda T. Elkins-Tanton is the director of the School of Earth and Space Exploration at Arizona State University and the principal investigator of the NASA Psyche mission. She believes everyone should ask natural next questions and pursue solutions to challenges while living in a civil, supportive society.

Emma Frow is an assistant professor at Arizona State University, with a joint appointment in the School for the Future of Innovation in Society and the School of Biological and Health Systems Engineering. Her research focuses on standard-setting and governance of contemporary biotechnologies, with a particular emphasis on bioengineering and synthetic biology.

Eileen Gunn is the author of two story collections: *Stable Strategies and Others* and *Questionable Practices*. Her fiction has received the Nebula Award in the U.S. and the Sense of Gender Award in Japan, and been nominated for the Hugo, Philip K. Dick, and World Fantasy awards and short-listed for the James Tiptree, Jr. award. Gunn served on the board of directors of the Clarion West Writers Workshop for 22 years and currently serves on the board of the Locus Foundation.

Roland Lehoucq is an astrophysicist working at French Alternative Energies and Atomic Energy Commission (CEA) and specializing in cosmology. He is very active in science popularization, notably by forging links between science and science fiction, and is the author of 18 books. He is also the president of Utopiales, an annual international science fiction festival held in Nantes, France.

Andrew D. Maynard is the director of the Risk Innovation Lab at Arizona State University, a professor in the School for the Future of Innovation in Society, and a well-known science communicator. His work focuses on responsible and beneficial technological innovation, and spans artificial intelligence and autonomous vehicles, to nanotechnology and gene editing. Andrew is a member of the World Economic Forum Global Future Councils, and has participated on numerous National Academies of Sciences committees. He is currently working on *The Moviegoer's Guide to The Future.*

Clark A. Miller is a professor and the associate director of the School for the Future of Innovation in Society at Arizona State University. He works in the field of science and technology policy, focusing on the design of knowledge systems and the governance of large-scale transitions in the relationships between technology and society.

Ramez Naam is a computer scientist, futurist, and the multi-award winning author of five books, including the Philip K. Dick-awarded Nexus trilogy. He lives in Seattle. Follow him on Twitter @ramez.

Deji Bryce Olukotun is the author of two novels, *Nigerians in Space* and *After the Flare*, and his fiction has appeared in four different book collections. He works in technology activism on issues such as cybersecurity and online censorship, and he is a Future Tense Fellow at the New America Foundation. He lives in Brooklyn, New York.

Kim Stanley Robinson is a *New York Times* bestseller and winner of the Hugo, Nebula, and Locus awards. He is the author of more than 20 books, including the bestselling Mars trilogy and the critically acclaimed *Green Earth, 2312*, and *Aurora.* His work has been translated into 24 languages. His most recent novel, *New York 2140*, imagines 22nd-century New York City flooded by sea levels as a SuperVenice with a vibrant culture built around canals rather than paved streets. In 2008, he was named a "Hero of the Environment" by *Time* magazine, and he works with the Sierra Nevada Research Institute.

Steve Ruff is an associate research professor in the School of Earth and Space Exploration at Arizona State University. He has been roving Mars since 2004 with Spirit and Opportunity and exploring from the perspective of orbiting spacecraft since 1988.

Carter Scholz's last book, *Gypsy*, was reprinted in three science fiction best-of-the-year anthologies, nominated for the Sturgeon Award, and tapped by Buzzfeed as one of the best 24 science fiction books of 2015. "Vanguard 2.0," which appears in this collection, is a prequel to *Gypsy.*

Karl Schroeder is a futurist and award-winning author. With a degree in Strategic Foresight and 10 published novels, Karl divides his time between consulting, speaking, and writing. In addition to publishing science fiction, he has pioneered a new mode of writing that blends fiction and rigorous futures research; his influential short novels *Crisis in Zefra* (2005) and *Crisis in Urlia* (2011), for instance, are innovative "scenario fictions" commissioned by the Canadian government.

Vandana Singh's science fiction stories have been published and reprinted in numerous venues, including *The Best American Science Fiction and Fantasy 2016*. She is a particle physicist by training, and a professor at a small and lively state university near Boston, where she is currently working on an interdisciplinary approach to climate change. Her second collection of fiction, *Ambiguity Machines and Other Stories*, is out from Small Beer Press in February 2018. Her website is vandana-writes.com.

William K. Storey is a professor at Millsaps College in Jackson, Mississippi, where he was the 2013 Carnegie-CASE professor of the year. He researches and writes about the history of technology and empire-building. He is currently working on a study about Cecil Rhodes's vision for mining, farming, railroads, and telegraphy in Southern Africa.

Sara Imari Walker is an assistant professor in the School of Earth and Space Exploration and deputy director of the Beyond Center for Fundamental Concepts in Science, both at Arizona State University. Her research is on the origins and nature of life, with a focus on quantifying life as an informational system.

G. ("Gregg") Pascal Zachary is the author of *Endless Frontier* (1997), a biography of Vannevar Bush, and *The Diversity Advantage* (2003), on culture and innovation. He has been a professor of practice at Arizona State University since 2010. He writes a column on innovation for IEEE's *Spectrum* magazine and is general editor of ASU's "Rightful Place of Science" book series.

Ed Finn is the founding director of the Center for Science and the Imagination at Arizona State University, where he is an assistant professor in the School of Arts, Media and Engineering and the Department of English. He is also the academic director for Future Tense, a partnership of ASU, *Slate*, and New America that explores emerging technologies and their transformative effects on policy, culture, and society. He is the author of *What Algorithms Want: Imagination in the Age of Computing* (MIT Press, 2017) and co-editor of *Frankenstein: Annotated for Scientists, Engineers and Creators of All Kinds* (MIT Press, 2017) and *Hieroglyph: Stories and Visions for a Better Future* (William Morrow, 2014).

Joey Eschrich is the editor and program manager at the Center for Science and the Imagination at Arizona State University. He is also an assistant director for Future Tense, a partnership of ASU, *Slate*, and New America that explores emerging technologies and their transformative effects on policy, culture, and society. He is the co-editor of *Overview: Stories in the Stratosphere* (2017) and *Everything Change: An Anthology of Climate Fiction* (2016) and managing editor of *Frankenstein: Annotated for Scientists, Engineers and Creators of All Kinds* (2017) and *Hieroglyph: Stories and Visions for a Better Future* (2014).

Juliet Ulman is a Hugo-nominated editor of fantasy and science fiction. She has edited and acquired titles for a wide range of publishers including Bantam Books, HarperCollins, Random House, Sterling Publishing Group, Amazon Publishing, Serial Box Publishing, and Night Shade Books. Projects she has edited have won and been shortlisted for numerous awards, including the Hugo Award, Nebula Award, the Philip K. Dick Award, and the James Tiptree, Jr. Award. She lives in Brooklyn with her husband, daughter, and two troublesome cats. You can find her online at papertyger.net.

BIBLIOGRAPHY

Aldiss, Brian, and David Wingrove. *The Trillion Year Spree: The History of Science Fiction*. London: Paladin Grafton Books, 2001.

Alic, John A., Lewis M. Branscomb, Harvey Brooks, Ashton B. Carter, and Gerald L. Epstein. *Beyond Spinoff: Military and Commercial Technologies in a Changing World*. Boston: Harvard Business School Press, 1992.

"An Expensive Venture." *Scott's Last Expedition*, Antarctic Heritage Trust. http://www.scottslastexpedition.org/expedition/preparing-for-terra-nova/#chapter2.

Bainbridge, William Sims. "Motivations for Space Exploration." *Futures* 41, no. 8 (2009): 514-522.

Berger, Eric. "Make Mars Great Again: Can the 2016 U.S. Election Save NASA's Journey to Mars?" *Ars Technica*, April 12, 2016. https://arstechnica.com/science/2016/04/make-mars-great-again-can-the-2016-election-save-nasas-journey-to-mars.

Bethencourt, Francisco F., and Diogo Ramada Curto, eds. *Portuguese Oceanic Expansion, 1400-1800*. Cambridge: Cambridge University Press, 2007.

Billings, Linda, ed. *Astrobiology: The Story of Our Search for Life in the Universe*. Vol. 2, *Missions to Mars*. Washington, D.C.: NASA, 2011. Available at https://astrobiology.nasa.gov/resources/graphic-histories.

Bolden, Charles. "NASA Policy Statement on Diversity and Inclusion." NASA, June 8, 2010. https://odeo.hq.nasa.gov/documents/Diversity_Inclusion_Policy_Statement.pdf.

Bonin, Hubert, and Nuno Valério, eds. *Colonial and Imperial Banking History*. New York: Routledge, 2016.

Bormann, Natalie, and Michael Sheehan, eds., *Securing Outer Space*. New York: Routledge, 2009.

Borowitz, Mariel, and Jonathan Battat. "Multidisciplinary Evaluation of Next Steps for Human Space Exploration: Technical and Strategic Analysis of Options." *Space Policy* 35 (2016): 33-42.

Bould, Mark, and Sherryl Vint. *The Routledge Concise History of Science Fiction*. London: Routledge, 2011.

Brandom, Russell. "Today's SpaceX Explosion Is a Major Setback for Facebook's Free Internet Ambitions." *The Verge*, September 1, 2016. http://www.theverge.com/2016/9/1/12750872/spacex-explosion-facebook-satellite-internet-org-zuckerberg.

Brehm, Andrew R. "Private Property in Outer Space: Establishing a Foundation for Future Exploration." *Wisconsin International Law Journal* 33, no. 2 (2015): 353-379.

Brophy, John, et al. *Asteroid Retrieval Feasibility Study*. Pasadena, CA: Keck Institute for Space Studies, 2012. Available at http://kiss.caltech.edu/final_reports/Asteroid_final_report.pdf.

Burbank, Jane, and Frederick Cooper. *Empires in World History: Power and the Politics of Difference*. Princeton: Princeton University Press, 2010.

Chayes, Abram, Antonia Handler Chayes, and Eliot Spitzer. "Space Weapons: The Legal Context." *Daedalus* 114, no. 3 (1985): 193-218.

Chin, Jason W. "Expanding and Reprogramming the Genetic Code of Cells and Animals." *Annual Review of Biochemistry* 83 (2014): 379-408.

Communicating Science Effectively: A Research Agenda. Division of Behavioral and Social Sciences and Education, National Academies of Sciences, Engineering, and Medicine. https://www.nap.edu/catalog/23674/communicating-science-effectively-a-research-agenda.

Crawford, Ian A. "Lunar Resources: A Review." *Progress in Physical Geography* 39, no. 2 (2015): 137-167.

Cunliffe, Barry. *The Extraordinary Voyage of Pytheas the Greek*. London: Allen Lane, 2003.

Darwin, John. *Unfinished Empire: The Global Expansion of Britain*. London: Bloomsbury, 2012.

"Deep Space Communications." Office of the Chief Scientist and Chief Technologist, NASA, https://scienceandtechnology.jpl.nasa.gov/research/research-topics-list/communications-computing-software/deep-space-communications.

Dening, Greg. *Mr. Bligh's Bad Language: Passion, Power, and Theatre on the Bounty*. Cambridge: Cambridge University Press, 1992.

Dick, Steven J. "Critical Issues in the History, Philosophy, and Sociology of Astrobiology." *Astrobiology* 12, no. 10 (2012): 906-927.

"Discovery Statistics." Center for Near Earth Object Studies, NASA. http://neo.jpl.nasa.gov/stats.

Doctorow, Cory. "Technology Is Making the World More Unequal. Only Technology Can Fix This." *The Guardian*, May 31, 2017. https://www.theguardian.com/inequality/2017/may/31/technology-is-making-the-world-more-unequal-only-technology-can-fix-this-cory-doctorow.

Drake, Bret G. "Strategic Considerations of Human Exploration of Near-Earth Asteroids." NASA Lyndon B. Johnson Space Center, 2012. http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=6187265.

Dritsas, Lawrence. *Zambesi: David Livingstone and Expeditionary Science in Africa*. London: IB Tauris, 2010.

Dryer, Edward L. *Zheng He: China and the Oceans in the Early Ming, 1405–1433*. London: Pearson Longman, 2007.

Edwards, Bradley Carl. *The Space Elevator*. Washington, D.C.: NASA Institute for Advanced Concepts, 2003. Available at http://www.niac.usra.edu/studies/521Edwards.html.

Elvis, Martin, Tony Milligan, and Alanna Krolikowski. "The Peaks of Eternal Light: A Near-Term Property Issue on the Moon." *Space Policy* 38 (2016): 30-38.

Faith, G. Ryan. "The Future of Space: Trouble on the Final Frontier." *World Affairs*, September/October 2012. http://www.worldaffairsjournal.org/article/future-space-trouble-final-frontier.

Fara, Patricia. *Sex, Botany, and Empire: The Story of Carl Linnaeus and Joseph Banks*. New York: Columbia University Press, 2004.

Ferguson, Niall. *Empire: The Rise and Demise of the British World Order and the Lessons for Global Power*. New York: Basic Books, 2002.

Fernholz, Tim. "China's New Quantum Satellite Will Try to Teleport Data outside the Bounds of Space and Time." *Quartz*, August 20, 2016. https://qz.com/760804/chinas-new-quantum-satellite-will-try-to-teleport-data-outside-the-bounds-of-space-and-time-and-create-an-unbreakable-code.

Förster, Stig, Wolfgang J. Mommsen, and Ronald Robinson, eds. *Bismarck, Europe and Africa: The Berlin Africa Conference 1884–1885 and the Onset of Partition*. Oxford: Oxford University Press, for The German Historical Institute London, 1988.

Friese, Carrie, and Claire Marris. "Making De-Extinction Mundane?" *PLoS Biology* 12, no. 3 (2014).

Geppert, Alexander, ed. *Imagining Outer Space: European Astroculture in the Twentieth Century*. London: Palgrave Macmillan, 2012.

Gould, Stephen Jay. "The Genomic Metronome as a Null Hypothesis." *Paleobiology* 2, no. 2 (1976): 177-179.

Hays, Lindsay, ed. *NASA Astrobiology Strategy 2015*. Washington, D.C.: NASA, 2015. Available at https://nai.nasa.gov/media/medialibrary/2015/10/NASA_Astrobiology_Strategy_2015_151008.pdf.

Headrick, Daniel. *The Tentacles of Power: Technology Transfer in the Age of Imperialism*. Oxford: Oxford University Press, 1988.

Herman, Jonathan F. C., et al. "Human Exploration of Near Earth Asteroids: Mission Analysis for Chemical and Electric Propulsion." *Acta Astronautica* 104, no. 1 (2014): 313-323.

Hewlett, Sylvia Ann, Melinda Marshall, and Laura Sherbin. "How Diversity Can Drive Innovation." *Harvard Business Review*, December 2013. https://hbr.org/2013/12/how-diversity-can-drive-innovation.

Hochschild, Adam. *King Leopold's Ghost*. Boston: Houghton Mifflin, 1998.

Hogan, Thor. *Mars Wars: The Rise and Fall of the Space Exploration Initiative*. Washington, D.C.: NASA, 2007.

Holt, Nathalia. *Rise of the Rocket Girls: The Women Who Propelled Us, from Missiles to the Moon to Mars*. Boston: Little, Brown and Company, 2016.

Hughes, Thomas P. "Counterculture and Momentum." In *American Genesis: A Century of Invention and Technological Enthusiasm*, 1870-1970, 443-472. Chicago: University of Chicago Press, 1989.

Hutchison III, Clyde A., Ray-Yuan Chuang, Vladimir N. Noskov, and Nacyra Assad. "Design and Synthesis of a Minimal Bacterial Genome." *Science* 351, no. 6280 (2016): aad62531-aad625311.

Isoun, Turner T., and Miriam J. Isoun. *Why Run before Learning to Walk?* Ibadan, Nigeria: BookBuilders Editions Africa, 2013.

James, Edward. *Science Fiction in the 20th Century*. Oxford: Opus, 1994.

Jasanoff, Sheila. *Designs on Nature: Science and Democracy in Europe and the United States*. Princeton: Princeton University Press, 2005.

Jones, Andrew. "A Comprehensive Guide to China's Space Activities in 2016." *GB Times*, July 1, 2016. http://gbtimes.com/comprehensive-guide-chinas-space-activities-2016.

Juma, Calestous. "Technology Will Drive Scientific Progress in Africa Not the Other Way Round." *Quartz*, August 15, 2016. https://qz.com/757766/technology-will-drive-scientific-progress-in-africa-not-the-other-way-round.

Kahneman, Daniel. *Thinking, Fast and Slow*. New York: Farrar, Straus, and Giroux, 2011.

Katyal, Ritika. "India Census Exposes Extent of Poverty." *CNN World*, August 2, 2015. http://www.cnn.com/2015/08/02/asia/india-poor-census-secc.

Launius, Roger D. *Historical Analogs for the Stimulation of Space Commerce*. Washington, D.C.: NASA, 2014.

Lauretta, Dante S. "The Seven-Year Mission to Fetch 60 Grams of Asteroid," *Scientific American* 315 (2016): 62-69.

Lewis, John S. *Mining the Sky: Untold Riches from the Asteroids, Comets, and Planets*. New York: Perseus Books, 1996.

"List of Female Astronauts." *Wikipedia, The Free Encyclopedia*. https://en.wikipedia.org/wiki/List_of_female_astronauts.

"List of International Space Station Visitors." *Wikipedia, The Free Encyclopedia*. https://en.wikipedia.org/wiki/List_of_International_Space_Station_visitors.

Lu, Edward T., and Stanley G. Love. "A Gravitational Tractor for Towing Asteroids." *Nature* 438 (2005): 177-178.

Luxembourg Ministry of the Economy. "Luxembourg's New Space Law Guarantees Private Companies the Right to Resources Harvested in Outer Space in Accordance with International Law." *Portal of the Grand Duchy of Luxembourg*, November 11, 2016. http://www.gouvernement.lu/6481433/11-presentation-spaceresources.

MacDonald, Alexander. *The Long Space Age: The Economic Origins of Space Exploration from Colonial America to the Cold War*. New Haven: Yale University Press, 2017.

MacDonald, Fraser. "Anti-Astropolitik: Outer Space and the Orbit of Geography." *Progress and Human Geography* 31, no. 5 (2007): 592-615.

Mandela, Nelson. *Long Walk to Freedom: The Autobiography of Nelson Mandela*. Boston: Back Bay Books, 1994.

Martin, Michael. "Star Trek's Uhura Reflects On MLK Encounter." *Tell Me More*, National Public Radio. http://www.npr.org/2011/01/17/132942461/Star-Treks-Uhura-Reflects-On-MLK-Encounter.

Massonnet, Didier, and Benoît Meyssignac. "A Captured Asteroid: Our David's Stone for Shielding Earth and Providing the Cheapest Extraterrestrial Material." *Acta Astronautica* 59, nos. 1-5 (2006): 77-83.

McDougall, Walter A. *The Heavens and the Earth: A Political History of the Space Age*. New York: Basic Books, 1988.

Meerman Scott, David, and Richard Jurek. *Marketing the Moon: The Selling of the Apollo Lunar Program*. Cambridge, MA: The MIT Press, 2014.

Miller, Clark A., and Ira Bennett. "Thinking Longer Term about Technology: Is There Value in Science Fiction Inspired Approaches to Constructing Futures?" *Science and Public Policy* 35, no. 8 (2008): 597-608.

Musk, Elon. "Making Humans an Interplanetary Species." *New Space* 5, no. 2 (2017): 46-61.

"NASA's Journey to Mars: Pioneering Next Steps in Space Exploration." NASA, October 8, 2015. https://www.nasa.gov/sites/default/files/atoms/files/journey-to-mars-next-steps-20151008_508.pdf.

Nelson, Richard R. *The Moon and the Ghetto*. New York: W. W. Norton & Company, 1977.

Nelson, Richard R. "The Moon and the Ghetto Revisited." *Science and Public Policy* 38, no. 9 (2011): 681-690.

"Nigeria: Workers of Chinese Company Protest Mass Dismissals, Deaths, Injuries Attributed to Poor Work Conditions and Alleged Discrimination; Company Responds." *Business & Human Rights Resource Centre*, 2015. https://business-humanrights.org/en/nigeria-workers-of-chinese-company-protest-mass-dismissals-deaths-injuries-attributed-to-poor-work-conditions-and-alleged-discrimination-company-responds.

"Nigerians Living in Poverty Rise to Nearly 61%." *BBC News*, February 13, 2012. http://www.bbc.com/news/world-africa-17015873.

Ovid. *Metamorphoses*. Translated by Samuel Garth, John Dryden, et al. In *The Internet Classics Archive*. Massachusetts Institute of Technology. http://classics.mit.edu/Ovid/metam.html.

Pollpeter, Kevin, Eric Anderson, Jordan Wilson, and Fan Yang. "China Dream, Space Dream: China's Progress in Space Technologies and Implications for the United States." U.S.-China Economic and Security Review Commission, March 2, 2015. https://www.uscc.gov/Research/china-dream-space-dream-chinas-progress-space-technologies-and-implications-united-states.

Pop, Virgiliu. “Appropriation in Outer Space: The Relationship between Land Ownership and Sovereignty on the Celestial Bodies.” *Space Policy* 16, no. 4 (2000): 275-282.

Reinhard, Wolfgang. *A Short History of Colonialism.* Manchester: Manchester University Press, 2011.

Roberts, Adam. *The History of Science Fiction*. Basingstoke: Palgrave Macmillan, 2006.

Rosen, Robert. “The Schrödinger Question: What Is Life? Fifty Years Later.” In *Glimpsing Reality: Ideas in Physics and the Link to Biology*, edited by Paul Buckley and F. David Peat, 168-190. Toronto: University of Toronto Press, 1996.

Rosenberg, Zach. “This Congressman Kept the U.S. and China from Exploring Space Together.” *Foreign Policy*, December 17, 2013. http://foreignpolicy.com/2013/12/17/this-congressman-kept-the-u-s-and-china-from-exploring-space-together.

Rosner, Robert. “Preface.” In *Governance of Dual-Use Technologies: Theory and Practice*, edited by Elisa D. Harris, 1-3. Cambridge, MA: American Academy of Arts & Sciences, 2016.

Ross, Shane D. “Near-Earth Asteroid Mining.” California Institute of Technology, December 14, 2001. http://www2.esm.vt.edu/~sdross/papers/ross-asteroid-mining-2001.pdf.

Roszak, Theodore. *The Making of a Counter Culture: Reflections on the Technocratic Society and Its Youthful Opposition*. Berkeley: University of California Press, 1969.

Rycroft, Michael J. “Space Exploration Goals for the 21st Century.” *Space Policy* 22, no. 8 (2006): 158-161.

Sagan, Carl. *Cosmos*. New York: Ballantine Books, 2013. First published 1980 by Random House. Citations refer to the Ballantine edition.

Sailer, Uta, Patricia Rosenberg, Ali Al Nima, Amelie Gamble, Tommy Gärling, Trevor Archer, and Danilo Garcia. “A Happier and Less Sinister Past, a More Hedonistic and Less Fatalistic Present and a More Structured Future: Time Perspective and Well-Being.” *PeerJ* 2, no. e303 (2014).

Sanchez, J. P, and C. R. McInnes. “Assessment on the Feasibility of Future Shepherding of Asteroid Resources.” *Acta Astronautica* 73 (2012): 49-66.

Schumacher, E. F. *Small Is Beautiful: Economics as If People Mattered.* New York: Harper & Row, 1973.

Schrödinger, Erwin. *What Is Life?* Cambridge: Cambridge University Press, 1967. First published in 1944.

Shetterly, Margot Lee. *Hidden Figures: The American Dream and the Untold Story of the Black Women Mathematicians Who Helped Win the Space Race.* New York: William Morrow, 2016.

Slovic, Paul. *The Feeling of Risk: New Perspectives on Risk Perception.* London: Earthscan, 2010.

Sonter, Mark J. "The Technical and Economic Feasibility of Mining the Near-Earth Asteroids." *Acta Astronautica* 41, nos. 4-10 (1997): 637-647.

Stowsky, Jay. "The Dual-Use Dilemma." *Issues in Science and Technology* 13, no. 2 (1997). Available at http://issues.org/13-2/stowsky.

Students for a Democratic Society. "The Port Huron Statement." 1962. https://en.wikisource.org/wiki/Port_Huron_Statement.

Subrahmanyam, Sanjay. *The Career and Legend of Vasco da Gama.* Cambridge: Cambridge University Press, 1997.

"The World Is Not Enough," *The Economist* 421.9009, October 1, 2016. https://www.economist.com/news/science-and-technology/21707915-elon-musk-envisages-human-colony-mars-he-will-have-his-work-cut-out.

Thompson, Leonard. *A History of South Africa.* 4th ed. New Haven: Yale University Press, 2014.

de Tocqueville, Alexis. *Democracy in America.* New York: Harper Perennial, 2006. First published 1835 by Saunders and Otley.

van Traa-Engelman, Hanneke. "The Commercial Exploitation of Outer Space: Issues of Intellectual Property Rights and Liability." *Leiden Journal of International Law* 4, no. 2 (1991): 293-304.

Tronchetti, Fabio. "The Space Resource Exploration and Utilization Act: A Move Forward or a Step Back?" *Space Policy* 34 (2015): 6-10.

Weber, Max. "Politics as a Vocation." In *From Max Weber: Essays in Sociology*, edited and translated by H. H. Gerth and C. Wright Mills, 77-128. New York: Oxford University Press, 1958.

Wey Gómez, Nicolás. *The Tropics of Empire: Why Columbus Sailed South to the Indies.* Cambridge, MA: The MIT Press, 2008.

White House National Economic Council, National Security Council, and Office of Science and Technology Policy. *Second to None: Preserving America's Military Advantage through Dual-Use Technology*. Washington, D.C.: Defense Technical Information Center, 1995. Available at http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA286779.

Winner, Langdon. "Do Artifacts Have Politics?" *Daedalus* 109, no. 1 (1980): 121-136.

Wulf, Andrea. *The Invention of Nature: Alexander von Humboldt's New World*. New York: Vintage, 2015.

Zarya, Valentina. "3 Ways Facebook Is Trying to Diversify Its Workforce." *Fortune*, January 19, 2017. http://fortune.com/2017/01/20/facebook-workforce-diversity-data-driven.

Typography

Cover Title: Kefa Bold 138pt

Cover Subtitle: Kefa Regular 128pt

Contents Chapter Title: Kefa Regular 17pt

Contents Chapter Subtitle: Kefa Regular 11pt

Contents Section Subtitle: Kefa Regular 10pt

Text: Linux Libertine Regular 9.75pt

Small Text: Linux Biolinum 8pt

Software

Adobe Illustrator Creative Cloud (2018)

Adobe InDesign Creative Cloud (2018)

Computer

Macbook Pro (Retina, 15-inch, Late 2013)

2.3GHz Intel Core i7

16GB 1600 MHz DDR3

NVIDIA GeForce GT 750M 2048MB

Why should we go to space? To learn more about the universe and our place in it? To extract resources and conduct commerce? To demonstrate national primacy and technological prowess? To live and thrive in radically different kinds of human communities? *Visions, Ventures, Escape Velocities* takes on the challenge of imagining new stories at the intersection of public and private—narratives that use the economic and social history of exploration, as well as current technical and scientific research, to inform scenarios for the future of the "new space" era.

Visions, Ventures, Escape Velocities provides fresh insights into human activity in Low Earth Orbit, journeys to Mars, capturing and mining asteroids, and exploring strange and uncharted exoplanets. Its stories and essays imagine human expansion into space as a kind of domestication—not in the sense of taming nature but in the sense of creating a space for dwelling, a venue for human life and curiosity to unfurl in all their weirdness and complexity.

Stories by:

Madeline Ashby
Steven Barnes
Eileen Gunn
Ramez Naam
Carter Scholz
Karl Schroeder
Vandana Singh

Essays by:

Jim Bell
Lawrence Dritsas
Linda T. Elkins-Tanton
Emma Frow
Roland Lehoucq
Andrew D. Maynard
Clark A. Miller
Deji Bryce Olukotun
Steve Ruff
William K. Storey
Sara Imari Walker
G. Pascal Zachary

Arizona State University