Martian Migration

Policy Report on Science, Society, and Sustainability

Duke Project on Going to Mars

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Center on Risk in SCIENCE & SOCIETY

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BASS CONNECTIONS

Martian Migration

Policy Report on Science, Society, and Sustainability

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Decisions on Complex Interdisciplinary Problems of Health and Environmental Risk

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This report, accompanied by the website (www.ourmartian.world), was prepared by a team of student and faculty researchers over the summer of 2021, based on the work by our Bass Connections team at Duke University during the full 2020-21 academic year. The report reflects the work of all members of our team, composed of both students and faculty. The full team is listed in this report under "Our Project Team." We also list and give many thanks to the several expert Guest Speakers who helped inform our project.

Thanks to Chase Hamilton for leading and serving as our Project Manager during the academic year, and for serving as a remote consultant for the production of the report and website during the summer. Thanks to Somia Youssef for then serving as the Project Coordinator of the team members working to prepare the report and website over the summer. Thanks to Joanna Feaster for serving as a graphic designer, technical expert, and editor for the report. Thanks to Donald Pepka, Adam Doll, and Jeremy Yu for serving as primary editors of the report. Thanks to Christopher Kilner for serving as the lead website developer. Thanks to Jenny (Changhe) Chen, Joanna Feaster, Angel Heredia, Lelia Jennings, Chunxin Tang, and Logan Taylor for serving as website developers.

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THE MARTIAN MIGRATION

TIMELINE

PRESENT DAY

ESTABLISH SAFE TRAVEL

OPTIMIZE SPACE HEALTH

DEVELOP COMMERCIAL VENTURES

FUND INDUSTRIES

CONSTRUCT MARTIAN EQUALITY

COORDINATE INTER-STATE POLICIES

MARTIAN SETTLEMENT

Preface

A new space era towards Mars is well underway. Countries and corporations are planning and sending missions to explore, study, and possibly settle on Mars. Much of the focus to date has been on the science and engineering needed to get to Mars and study it. But there are further challenges ahead. Our project team came together to examine the urgent social, cultural, economic, legal, health, and environmental issues facing the possible future—perhaps quite near future—settlement of Mars. The possibility of a "Martian migration" served as the focal point of our year-long project to explore the range of risks, rewards, and rules involved in such an ambitious endeavor. We began from the premise that these issues warrant study and deliberation before any such settlement arrives on Mars.

This report is a compilation of our team's research on several (not all) of the important issues facing a sustainable Martian settlement. This report does not present a singular viewpoint, but is rather a composition of multiple perspectives approaching various issues from different angles. Each chapter may take a different perspective. This report is neither exhaustive nor comprehensive, given the complexity of research needed to grasp the set of risks, rewards and decisions posed by Martian migration. Through this report and our accompanying website, we hope to add to public discourse and to participate in the ongoing debates relevant to humanity's efforts to go to Mars.

This report may be of value to several audiences. For policymakers, it evaluates regulations and institutions that may be relevant—or needed—for successfully migrating to, and living on, Mars. For researchers, it offers a framework for the scope and direction of investigating the most pressing issues raised by human settlement on Mars. And for us all, it seeks to inform the nascent public discourse on whether and how to settle Mars by contributing our perspective as a diverse, multidisciplinary set of students, faculty, and experts affiliated with the Duke Initiative for Science and Society and its Center on Risk, under the sponsorship of the Bass Connections program at Duke University.

Our project on Going to Mars: Science, Society and Sustainability in the 2020-21 academic year was one of the "DeCIPHER" projects (Decisions on Complex Interdisciplinary Problems of Health and Environmental Risk)—a series of Bass Connections projects at Duke University, organized by the

Duke Center on Risk and designed to improve the holistic understanding of risks and decisions faced in complex problems through multidisciplinary analysis. Bass Connections is a university-wide program at Duke that sponsors innovative collaborative research projects on real-world challenges as year-long courses (see https://bassconnections.duke.edu); each Bass Connections project team is both horizontally integrated (multidisciplinary across schools and departments) and vertically integrated (involving faculty working together with graduate, professional, and undergraduate students). Because our project occurred during the 2020-21 academic year during the COVID-19 pandemic, our team met each week online, a format that posed its own challenges but also enabled us to connect across space and time zones, and may even have simulated some of what interactions would be like for future settlers on Mars. Perhaps some of our team members or readers will themselves be among those settlers.

Executive Summary

Concrete investments towards the new Martian era features a range of public and private actors. In 2021, missions by the national governments of the United States, China, and the United Arab Emirates have successfully delivered orbiters, rovers, and other equipment to explore Mars, and other countries may follow. Companies such as Virgin Galactic, Blue Origin, and SpaceX are competing to access and develop outer space. Ambitious visions—from commercial space tourism in low Earth orbit, to the industrial mining of valuable elements beyond Earth, to the establishment of self-sustaining settlements on Mars and beyond—fuel activity in space. The possibility that a "Martian migration" may be attempted in the near future stimulated our team to investigate what kinds of social, cultural, economic, legal, health and environmental arrangements would be needed if humans go to Mars to stay.

Our team project has produced several student-authored research papers, which appear as the main chapters of this report. In this executive summary, we highlight four central points. First, the challenge of settling Mars is not only scientific and technical (though those are clearly crucial, and they imply key conditions and limitations for any settlement), but also social. Study and deliberation are needed on the social, cultural, legal, and political arrangements for successful human and environmental sustainability on Mars (and its interactions with Earth). Second, the range of these issues involved in a Martian migration is multidisciplinary, requiring ongoing collaboration among diverse subject-matter experts, generalists, and scholars from across the sciences, social sciences, law, policy, and arts and humanities. Third, institutions seeking the success of humans migrating to Mars ought to foster such multidisciplinary collaboration by engaging a diverse range of expert and non-expert involvement and overcoming barriers that often stand in the way of effective collaboration, given differences in the cultures of knowledge acquisition, communication and deliberation. If humanity is to settle Mars, we must face basic questions of organizing a new society. We must learn from our history on Earth to do better at social organization in a new world, while addressing the novel risks and rewards we would encounter there. Fourth, even if humans never go to Mars, studying how we would do so can offer a useful thought experiment and exercise in shared deliberation for how we could improve our evolving and imperfect social institutions on Earth.

The chapters that follow, drawn from our team's student-led research, propose the following recommendations:

A Multi-Agency Regulatory Framework to Prevent Interplanetary Contamination

Considering the prospect of interplanetary travel, this chapter identifies and addresses potential risks associated with "backward contamination," defined as the risk of extraterrestrial life forms brought back to Earth by outer space missions, with potentially catastrophic outcomes. To mitigate the risk of backward contamination, the international scientific body COSPAR has developed planetary protection protocols since at least the 1960s, and NASA has implemented a comprehensive planetary protection policy for its space missions. However, NASA may not have all the appropriate regulatory authority to apply its planetary protection policy to private space missions (nor to other countries). Moreover, the risks of backward contamination implicate fields of expertise beyond the spacecraft and crew, including the study of extreme biology, disease pathogens, and ecological disturbance. To address key gaps in NASA's authority and expertise, this chapter proposes a regulatory framework that involves multiple agencies.

Recommendation:

- To supplement NASA's authority to apply planetary protection policies to public and private space missions, new regulatory oversight should be allocated among the FAA, USDA, CDC, DHS, and NSC, in the manner detailed in chapter 1.1.

Ultrasound Based Autonomous Systems can Mitigate Medical Risk on Deep Space Missions

This chapter discusses the utility of automated ultrasound collection and diagnosis for the list of key human medical conditions that NASA has identified based on likelihood and potential severity for long duration crewed space missions. Medical conditions that could either be diagnosed or used to rule out related conditions with ultrasound were selected based on feedback from an expert clinician. The chapter assesses the utility of gathering automated ultrasound images for diagnosing these conditions based on findings in the literature.

While ultrasound diagnosis has currently been automated for few conditions and existing autonomous collection systems can only collect images for limited areas of the body while requiring significant clinician oversight, further development of autonomous ultrasound systems could aid space crew members in diagnosing medical conditions on long duration space missions. Autonomous ultrasound could be a first line diagnostic to aid in medical decision-making before Earth-based experts could help in interpretation. This could be critical to allocate medical resources effectively, reduce requisite medical training, and effectively address conditions identified during the mission for human health and mission success.

Recommendation:

- To further develop autonomous ultrasound systems, as they could aid human space crew in diagnosing medical conditions on long duration space missions. Using autonomous ultrasound systems on space missions as a first line diagnostic could aid medical decision-making before Earth-based experts can assist.

Promoting Commercial Investment On Mars: Extending International Arbitration To Conflicts in Space

This chapter discusses conflict resolution regarding international investments in space. It discusses existing frameworks for international arbitration of commercial and investment disputes, and examines the risks of investments made in space. It suggests that current international arbitration is unlikely to resolve major commercial disputes due to unresolved issues related to the territorial nexus requirement, the dual-use nature of space technology, encroaching protectionism in the name of national security, and reemergent great power competition. In light of these issues, the chapter suggests that public-private partnerships provide a path forward to promote commercial investment in space and reduce risk until a comprehensive multilateral agreement is attained.

Recommendation:

- To pursue public-private partnerships as a mechanism for resolving disputes arising in international investment in space, given persistent problems related to Bilateral Investment Treaties, the territorial nexus requirement, the dual-use nature of space technology, encroaching protectionism in the name of national security, and reemergent great power competition.

Analysis of Commercial Funding Strategies for the Settlement of Mars

This chapter examines the potential for commercial activity on Mars. How profitable could a private mission to Mars be without the capital partnership of a government or other subsidiary sources unrelated to Mars? Even when considering all income streams both directly and indirectly related to the exploration and settlement of Mars, it is highly unlikely that settlement of Mars would generate significant revenue in the short term. Thus, this chapter argues that public-private partnerships will play a key role in reaching Mars because they allow government actors to more efficiently meet their political goals regarding space exploration while providing commercial actors with a stable source of revenue.

Recommendation:

- To pursue public-private partnerships as the best and most stable source of revenue from Mars-related operations in the near-term, because all other directly and indirectly related income streams are unlikely to generate profit in the near-future.

Systems for Resource Equality in Martian Society from Foundation to Independence

This chapter proposes systems of governance, labor relations, and sustainability in the spirit of promoting the rights and equality of crew members, future settlers, and eventual citizens on Mars. With respect to governance, the chapter proposes that a "Mars Treaty" (among states on Earth) modelled after the Antarctic Treaty would promote international cooperation. However, for later stages of Martian development and self-determination, the chapter recommends that this Mars Treaty allow for representation of those living on Mars, in order to facilitate the long-term development of democratic institutions. To safeguard workers, and resource equality broadly, the chapter recommends that labor unions as an institution be protected for workers on Mars. During stages of Martian development, there could be risks that corporations and governments might infringe upon the rights of Martian workers if such protections are not in place and enforced. To ensure the sustainability of early missions to Mars and then later Martian societies, we recommend substantial material reusability, waste clean-up and containment, and the anticipatory institutionalization of sustainable practices.

Recommendations:

- To model a "Mars Treaty" after the Antarctic Treaty to help to promote international cooperation on Mars. Such a model should also provide flexibility, allowing for future revisions to the Mars Treaty to facilitate the eventual development of democratic institutions on Mars.
- To protect the right to organize labor unions for workers on Mars in order to safeguard their liberty to advocate for themselves and to promote resource equality on Mars.
- To promote substantial material reusability, waste clean-up and containment, and rules and norms of behavior that promote sustainability as necessary for a long-term settlement on Mars.

Inter-State Cooperation on Mars: Institutional Incentives for Collaboration

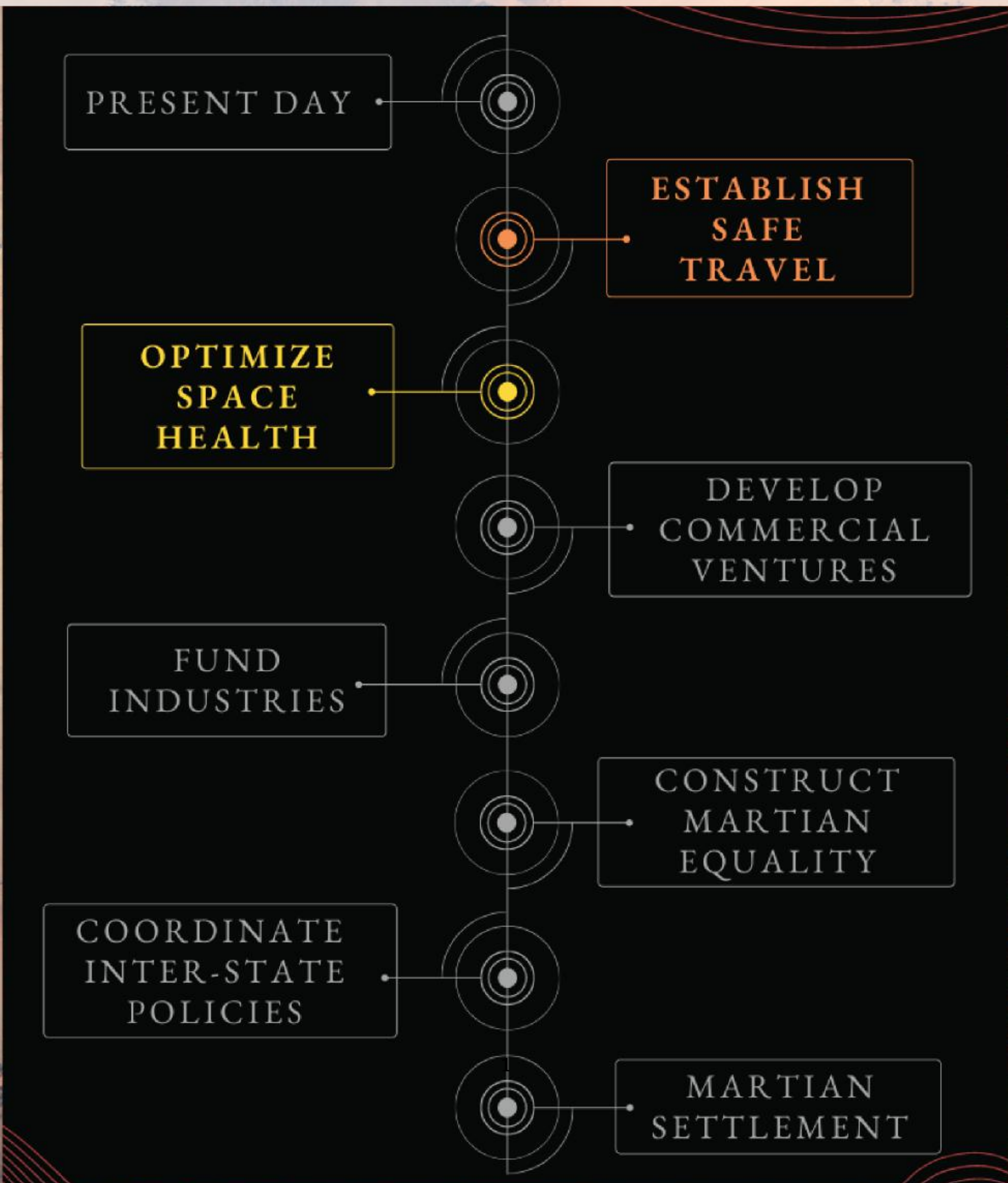
An absence of collaborative frameworks in the development and settlement of Mars could lead to inter-state conflict. This chapter provides a set of recommendations for future international agreements related to space and Mars exploration in order to facilitate collaboration. The chapter argues that such treaties should include dispute resolution provisions that optimize efficiency and security. To address negotiation challenges, treaties should integrate the preferences of domestic actors (within countries, and on Mars). To increase accountability, treaties should highlight the reputational impacts of space exploration and emphasize regional collaboration. Treaties should also include collaborative technical and financial assistance from more powerful states to smaller states. Finally, the chapter argues, treaties should embed a commitment to transparency on behalf of all parties to reduce miscommunication, increase mutual trust, and enable more efficient dispute resolution.

Recommendations:

- To facilitate international collaboration for the purpose of settling Mars, states should:
    - Explore multiple options for conflict resolution in a way that optimizes the efficiency and security of all parties involved;
    - Highlight the reputational impacts of achievements in space exploration;
    - Emphasize collaboration and hold actors accountable; and
    - Embed a commitment to transparency on behalf of all parties, to reduce miscommunication, build mutual trust, and enable more effective dispute resolution.

1

Space Travel



A Multi-Agency Regulatory Framework to Prevent Interplanetary Contamination[1]

Shu Boboila[2]

Abstract

In considering the prospect of interplanetary travel, this chapter identifies and addresses potential risks associated with backward contamination, broadly defined as the propagation of extraterrestrial life forms brought back to Earth by outer space missions, which could result in potentially catastrophic outcomes. To mitigate the risk of backward contamination, the National Aeronautics and Space Administration (NASA) has implemented a comprehensive planetary protection policy for its space missions. However, NASA does not have the appropriate regulatory authority to apply its planetary protection policy to private space missions. To address this gap in NASA's authority, this chapter proposes an alternative regulatory framework that accommodates multiple agencies. Similar to the Coordinated Framework for Regulating Biotechnology, Congress should grant multiple agencies, including the Federal Aviation Administration (FAA), Centers for Disease Control and Prevention (CDC), and United States Department of Agriculture (USDA), the authority to impose planetary protection requirements on private space activities. NASA should also cooperate with other government agencies, space scientists, and private parties to provide updated guidance on risk regulations with regards to backward contamination. The updated policies should reflect recent advances in our knowledge about potential extraterrestrial life, the prevention and containment of infectious agents, the protection of individual rights, and the incentivization of private initiatives. Altogether, a regulatory framework could provide a safer avenue for interplanetary travel and exploration within our solar system and beyond.

[1] Thanks to Adam Doll, Joanna Feaster, Donald Pepka, Somia Youssef, Jeremy Yu, Jonathan Wiener, and Jory Weintraub for providing feedback on and editing this chapter.

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I. Introduction

In response to the earliest developments in space exploration, the U.S. federal government established the National Aeronautics and Space Administration (NASA) in 1958 to conduct civilian space programs.[3] In 1969, NASA achieved a milestone with its Apollo 11 mission which sent astronauts to the Moon and returned them safely back to Earth. Subsequently, more states joined the race for space exploration. Currently, 72 states have space programs and 14 states have the ability to launch spacecraft.[4]

In 1967, the United States, the United Kingdom, and the Soviet Union signed The Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies (commonly known as the "Outer Space Treaty of 1967").[5, 6] The treaty aims to ensure peaceful space exploration and has since been the basis of international space law.[7] Currently, 110 states have signed the treaty, including all the major space-faring states.[8] The Outer Space Treaty (OST) emphasizes important responsibilities during space missions, including the prevention of "backward contamination."[9]

Backward contamination refers to the possibility that extraterrestrial life could be brought back to Earth by outer space missions. These foreign life forms could potentially infest and propagate on Earth, posing a host of unknown risks.[10] This could cause events that are catastrophic to humans and

[3] NASA. The birth of NASA. March 28, 2008. https://www.nasa.gov/exploration/whyweexplore/Why_We_29.html (accessed on May 10, 2021)
[4] Wikipedia. List of government space agencies. https://en.wikipedia.org/wiki/List_of_government_space_agencies (accessed on May 10, 2021)
[5] Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies, Jan. 27, 1967, 18 U.S.T. 2410, 610 U.N.T.S. 205 [hereinafter Outer Space Treaty].
[6] U.S. Department of State. Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies. https://2009-2017.state.gov/t/isn/5181.htm (accessed on May 10, 2021)
[7] Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies, Jan. 27, 1967, 18 U.S.T. 2410, 610 U.N.T.S. 205 [hereinafter Outer Space Treaty].
[8] United Nations Office for Outer Space Affairs. Status of International Agreements relating to Activities in Outer Space. https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/status/index.html (accessed on May 10, 2021)
[9] *See* Outer Space Treaty, *supra* note 6, at Art. IX.
[10] Profitiliotis G, Loizidou M. Planetary Protection Issues of Private Endeavors in Research, Exploration, and Human Access to Space: An Environmental Economics Approach to Backward Contamination. *Space Policy.* (2019) 50; 101332.

other life forms on Earth, such as pandemic diseases or significant climate change.[11, 12] According to Article IX of the OST, "… States parties to the Treaty shall pursue studies of outer space, including the moon and other celestial bodies, and conduct exploration of them so as to avoid their harmful contamination and also adverse changes in the environment of the Earth resulting from the introduction of extraterrestrial matter and, where necessary, shall adopt appropriate measures for this purpose."[13] An international scientific committee, the Committee on Space Research (COSPAR), has been updating regulatory guidelines to prevent backward contamination since its establishment in 1958.[14, 15] NASA also has its own planetary protection policy, which is generally consistent with COSPAR guidelines.[16]

The backward contamination risk is of particular concern in the case of return missions from Mars, especially missions seeking to bring back samples of Martian soil, because scientific evidence suggests that extraterrestrial life is relatively more likely to be found on Mars than other planets in the Solar System.[17] For this reason, NASA categorizes any return missions from Mars as the highest category (Category V) restricted Earth return.[18] All NASA sponsored Mars missions, including both robotic sample returns and human crewed returns, would be subject to the restricted Earth return standard. Excluded from this standard are private space missions, whose regulations currently fall outside of NASA's formal authority.

New concerns over the regulation of backward contamination raised by the advent of private space missions are now at the forefront of debates seeking to mitigate risks of backward contamination both by public and private actors. Within the past decade, private companies have developed the

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[11] *Id.*
[12] Wiener JB. The tragedy of the uncommons: on the politics of apocalypse. *Global Policy.* (2016) 7; 67e80.
[13] Outer Space Treaty, *supra* note 6, at Art. IX.
[14] The Committee on Space Research. https://cosparhq.cnes.fr/about/ (accessed on May 10, 2021)
[15] The National Academies of Sciences, Engineering and Medicine (NASEM) is the U.S. representative in the COSPAR. The Committee on Space Research. https://cosparhq.cnes.fr/about/members/ (accessed on May 10, 2021).
[16] *See* NASA. NASA Updates Planetary Protection Policies for Moon to Mars Missions. https://www.nasa.gov/feature/nasa-updates-planetary-protection-policies-for-robotic-and-human-missions-to-earth-s-moon (accessed on May 10, 2021).
[17] Joseph RG, Dass RS, Cantasano N, *et al.* Evidence of life on Mars? Journal of Astrobiology and Space Science Review. (2019) 1; pp. 40-81.
[18] Rummel JD. Planetary Protection in Planetary Exploration Missions. *Planetary Astrobiology.* (2020)

capability to transport crew members and deliver cargo to the International Space Station in Low Earth Orbit.[19, 20] SpaceX is also developing a long-duration cargo and passenger spacecraft named "Starship," with the aim of sending its astronauts to Mars by 2026.[21] Other private companies, including Virgin Galactic and Blue Origin, have started space tourism in Low Earth Orbit.[22] Moreover, if the voyage to Mars becomes shorter and safer in the future, private companies may promote space tourism to Mars.[23] Congress has welcomed participation from private entities as a way to promote the development of a human presence in space, effectively reducing much of NASA's operating costs.[24, 25] In 2015, Congress passed the U.S. Commercial Space Launch Competitiveness Act (USCSLA), which grants U.S. citizens engaged in commercial space activities the right to "possess, own, transport, use, and sell the asteroid resource or space resource obtained in accordance with applicable law."[26,27] The Act also states, in rather ambiguous terms, that such rights should be "free from harmful interference."[28]

It is unclear where and how to regulate the backward contamination risks of private entities' future Mars missions. Article VI of the OST affirms that States are responsible for the space activities of their private corporations.[29] However, NASA is not a regulatory agency, so it does not have the

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[19] SpaceX to launch astronauts – and a new era of private human spaceflight. *Nature News.* (2020) May 26. https://www.nature.com/articles/d41586-020-01554-8 (accessed on May 10, 2021)

[20] NASA. NASA's SpaceX Crew-1 Astronauts Headed to International Space Station. November 15, 2020. https://www.nasa.gov/press-release/nasa-s-spacex-crew-1-astronauts-headed-to-international-space-station/ (accessed on May 10, 2021)

[21] Patel NV, *supra* note 23.

[22] Space tourism: How SpaceX, Virgin Galactic, Blue Origin, Axiom compete in the growing space tourism market. https://www.cnbc.com/2020/09/26/space-tourism-how-spacex-virgin-galactic-blue-origin-axiom-compete.html; Jeff Bezos launches into space on Blue Origin's 1st astronaut flight. https://www.space.com/jeff-bezos-blue-origin-first-astronaut-launch; Richard Branson's trip to space is about convincing others to come along. https://www.vox.com/recode/22570789/richard-branson-elon-musk-jeff-bezos-spacex-blue-origin-virgin-galactic.

[23] Drake N. The future of Spaceflight – from orbital vacations to humans on Mars. https://www.nationalgeographic.com/science/space/space-exploration/future-spaceflight/ (accessed on May 10, 2021)

[24] *See* House Hearing, 114th Congress 2d session. Committee on Science, Space and Technology. The commercial space launch industry: small satellite opportunities and challenges. April 19, 2016.

[25] *See* House Hearing, 116th Congress 1st session. Committee on Science, Space and Technology. The commercial space landscape: innovation, market and policy. July 29, 2019.

[26] 51 U.S.C. §51303 (Supp. III 2015) (section entitled "Asteroid Resource and Space Resource Rights").

[27] U.S. Commercial Space Launch Competitiveness Act of 2015, Pub. L. No. 114-90 (codified at 51 U.S.C. §§51301-51303 (Supp. III 2015)).

[28] 51 U.S.C. §51302(a)(3) (Supp. III 2015).

[29] *See* Outer Space Treaty, *supra* note 6, at Art. VI.

authority to impose its planetary protection policy on private parties.[30] Congress has not explicitly delegated the regulatory authority to any federal agency.

This chapter focuses on the regulatory gap concerning potential backward contamination by private entities' future exploration and usage of Mars. Part II explains why Congress should prioritize efforts to mitigate the risk of backward contamination by private entities whose actions are currently excluded from the existing regulatory framework. Part III discusses NASA's planetary protection policy guidelines for its Mars missions. Part IV examines different federal agencies which may have authority to regulate sub-issues related to planetary protection. Part V analyzes a multi-agency framework for regulating biotechnology, in order to extrapolate from lessons about multi-agency collaboration learned there to be applied to the regulation of backward contamination. Part VI proposes a multi-agency framework for coordinating the regulation of missions to and from Mars to mitigate risks of backward contamination.

II. Prioritizing risk management of backward contamination

Despite the many potential benefits of Mars exploration, we need to first assess and manage the associated risks. The environment on Mars is very harsh, but life forms still may be able to survive there. The Martian atmosphere is roughly one hundred times thinner than Earth's atmosphere, which results in high levels of solar radiation reaching the Martian surface.[31] The Martian atmosphere consists of 95% carbon dioxide and 3% nitrogen.[32] Surface temperatures at Mars' equator fluctuate dramatically between 20° Celsius during the day and −80° Celsius at night.[33] The fluctuations are even greater elsewhere on the planet. Nevertheless, the NASA Phoenix Rover found ice on the surface at the poles, as well as high-energy oxidants at several locations, which suggests that the existence of life forms on the

[30] Uhran B, Conley C, Spry A. Updating Planetary Protection Considerations and Policies for Mars Sample Return. Space Policy. (2019) 49; 101322.
[31] Rapparport M, Corbally C. Program planning for a Mars hardship post: social, psychological and spiritual services. *The human factor in a mission to Mars.* (2019); 35-58.
[32] *Id.*
[33] *Id.*

planet is possible.[34,35] Giant slabs of ice have also been found underneath Mars' soil.[36] Research shows that certain extremophiles from Earth, which are radiation resistant and can survive in low temperatures, are theoretically able to survive and proliferate in the harsh Martian environment.[37] NASA scientists recently recovered a fungus from the Norris Geyser Basin, a highly acidic and toxic pool in Yellowstone National Park, which contained two new types of bacteria within it that would be able to survive on Mars.[38]

Patterns of human migration are typically associated with the spread of diseases. The well-known Columbian exchange is a good example, since European settlers not only brought new technologies, languages, foods, animals, and plants to the Americas, but also carried diseases that devastated the Indigenous populations.[39] Because the local populations had not developed immunity from the foreign contaminants brought by European settlers, it is estimated that diseases such as smallpox, measles, typhus, and cholera wiped out more than 85% of the Indigenous population within the first 100 years of European arrival in their territories.[40] It is worth noting that contamination goes both ways; in fact, the settlers introduced syphilis back to Europe.[41]

Terrestrial microbes have significantly altered the Earth's atmosphere, so the potential proliferation of extraterrestrial microbes could also lead to climate change.[42] The atmosphere consisted primarily of nitrogen until the Great Oxidation Event 2.7 billion years ago, in which the rapid growth of photosynthesizing cyanobacteria gradually oxidized the atmosphere.[43, 44] Although the composition

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[34] SSB. An astrobiology strategy for the search for life in the Universe. (2019). National Academics. Washington D.C.
[35] Rummel JD, *supra,* note 19.
[36] Choi CQ. Gigantic Ice Slab Found on Mars Just Below the Planet's Surface. September 15, 2015. https://www.space.com/30502-mars-giant-ice-sheet-discovery-mro.html (accessed on May 10, 2021).
[37] Mastascusa V, Romano I, Donato PD, *et al.* Extremophiles Survival to Simulated Space Conditions: an Astrobiology Model Study. *Origins of life and evolution of biosphere.* (2014) 44; 231-237.
[38] NASA. NASA Discovers Two New Types of Bacterial Life Inside a Fungus. (Jun. 1, 2020) https://www.nasa.gov/feature/ames/new-bacterial-life-inside-fungus (accessed on May 10, 2021)
[39] Nunn N, Qian N. The Columbian Exchange: A History of Disease, Food, and Ideas. *Journal of Economic Perspectives (2010)* 24 (2): 163-88.
[40] *Id.*
[41] *Id.*
[42] Hayes JM. Evolution of Earth atmosphere. https://www.britannica.com/topic/evolution-of-the-atmosphere-1703862 (accessed on December 11, 2020)
[43] *Id.*
[44] *Id.*

of Earth's atmosphere appears to be stable now, scientists have warned that a loss of biodiversity and changes due to microorganism activity could lead to significant climate change that pose a range of threats to human flourishing on Earth.[45] If it is discovered that Martian life forms exist and may be brought back to Earth unintentionally during Mars missions, the spread of extraterrestrial contaminants might generate catastrophic outcomes on Earth. Because such microorganisms are adapted to harsher conditions on Mars, they may have adaptations that would allow them to outcompete life forms that have not acquired similar resilience. This could lead to disastrous pandemics or irreversible alterations to climate conditions on Earth.

In recent years, NASA has successfully landed five rovers on Mars to study the surface and search for life on the Red Planet.[46] The most recent rover, Perseverance, landed on Mars in February 18, 2021, with the goal to look for signs of past or present life and to assess the possibility of crewed missions to Mars.[47] Together with another rover sent by the European Space Agency, Perseverance is set to bring Martian samples back to Earth in 2031.[48]

Due to Mars' relatively close proximity to Earth and the wealth of potential resources it provides, the Red Planet presents unique business opportunities as well as the possibility for human migration, exploration, and settlement. The potential of extraterrestrial mining is one such exciting business opportunity. As of today, precious elements such as gold, cobalt, and platinum are exclusively mined on Earth's crust.[49] As these raw mineral resources become increasingly scarce on our planet, public and private sector entities have explored the possibility of extracting them from extraterrestrial bodies, such as comets, asteroids, or other planets.[50] Scientists suggest that the strong gravitational force on Earth pulled mineral elements to the core of the planet in its early formation more than four

[45] Cavicchioli R, Ripplo WJ, Timmis KN, *et al.* Scientists' warning to humanity: microorganisms and climate change. *Nature Reviews Microbiology.* (2019) 17; 569-586.
[46] NASA. Mars Exploration Rovers. https://mars.nasa.gov/mars-exploration/missions/mars-exploration-rovers/ (accessed on May 10, 2021).
[47] NASA. Mars 2020 Perseverance Rover. https://mars.nasa.gov/mars2020/ (accessed on May 10, 2021).
[48] NASA. Concepts for Mars Sample Return. https://mars.nasa.gov/mars-exploration/missions/mars-sample-return/ (accessed on May 10, 2021).
[49] Elvis M. Prospecting Asteroid Resources. *Asteroids.* (2013) pp. 81-129.
[50] *Id.*

billion years ago.[51] Mars and other minable bodies are all smaller than Earth and have weaker gravity; therefore their minerals and rare metals may have remained closer to the surface, making them more accessible.[52] Since the costs of space travel are decreasing, space mining may become an economically feasible business in the near future.[53] If human settlement on Mars becomes possible, it is likely that the cost of mining there may be further reduced.

The number of Mars missions sponsored by both NASA and private companies is likely to increase dramatically in the near future. Consequently, the chance of accidentally bringing back harmful extraterrestrial life forms will surge. Appropriate planetary protection policies must be put in place to mitigate backward contamination risks before any Earth-return missions from Mars occur.

III. NASA planetary protection policy to mitigate backward contamination risks

NASA has always implemented appropriate planetary protection policies on its own space missions. Prior to the 1969 Apollo 11 mission, due to the concern that extraterrestrial life forms might be brought back during the lunar return mission, NASA issued the extraterrestrial exposure rule in the Federal Register, codified as 14 C.F.R. §1211.[54] This regulation gave NASA the authority to quarantine anyone who was extraterrestrially exposed at the Manned Spacecraft center.[55] "Extraterrestrially exposed" was defined as "... the state or condition of any person, property, animal or other form of life or matter whatever who or which has (1) Touched directly or come within the atmospheric envelope of any other celestial body; or (2) Touched directly or been in close proximity (or been exposed indirectly to) any person, property, animal or other form of life or matter who or which has been extraterrestrially exposed by virtue of subparagraph (1) of this paragraph."[56] For Apollo missions 11, 12, 13, and 14, procedures were put in place to quarantine astronauts, the spacecraft, and

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[51] Brenan JM, McDonough WF. Core formation and metal–silicate fractionation of osmium and iridium from gold. *Nature Geoscience. (2009)* ***2****(11); pp. 798–801.*
[52] Elvis M, *supra,* note 50.
[53] Reaven E. The United States Commercial Space Launch Competitiveness Act: The Creation of Private Space Property Rights and The Omission of The Right To Freedom From Harmful Interference. Washington University Law Review. (2016) 94; 233.
[54] Extraterrestrial Exposure, 56 Fed. Reg. 19,259 (Apr. 26, 1991) (removing and reserving 14 C.F.R. §1211.100.08).
[55] *Id.*
[56] *Id.*

all materials originating on the moon.[57] The Apollo astronauts were quarantined for 21 days at the Lunar Receiving Laboratory in Building 37 of the Manned Spacecraft Center in Houston, TX.[58] However, due to technical difficulties and concerns about the astronauts' discomfort, NASA opened the spacecraft as it floated on the sea, letting the astronauts out before transferring them and the empty spacecraft to the quarantine facility.[59] Several scholars have criticized the brief opening and closing of the spacecraft in this incident, as it could have potentially introduced harmful extraterrestrial materials to the atmosphere.[60] Carl Sagan remarked in a report that "Maybe it's sure to 99 percent that Apollo 11 will not bring back lunar organisms, but even that one percent of uncertainty is too large to be complacent about."[61] In the 1990s, NASA formally withdrew the extraterrestrial exposure rule, because scientific evidence gained from lunar missions showed that the lunar samples do not contain anything hazardous or alive, and NASA had moved away from crewed space exploration.[62]

However, Mars-return missions in the near future pose much greater risks of backward contamination than other extraterrestrial-return missions because of the possibility of life on Mars. Mistakes, such as accidentally opening the capsule, should not be replicated. NASA has been actively developing planetary protection policies and imposing planetary protection requirements on its own space missions to Mars. Most of NASA's planetary protection studies are conducted by its planetary protection office. In 2019, NASA established a Planetary Protection Independent Review Board (PPIRB) in response to a report (hereinafter referred to as "the 2018 report") by the Space Studies Board (SSB) of the National Academies of Sciences, Engineering and Medicine (NASEM) and a

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[57] Space Center Houston. Apollo mission quarantine procedures. March 24, 2020. https://spacecenter.org/apollo-mission-quarantine-procedures/ (accessed on May 10, 2021)

[58] *Id.*

[59] Ken Kremer. Apollo 11 Splashdown 45 Years Ago on July 24, 1969 Concludes First Moon Mission – Gallery. July 24, 2014. https://www.universetoday.com/113428/apollo-11-splashdown-45-years-ago-on-july-24-1969-concludes-1st-moon-landing-mission-gallery/ (accessed on May 10, 2021).

[60] Space: Is the Earth Safe From Lunar Contamination? Times Magazine. June 13, 1969. http://content.time.com/time/magazine/article/0,9171,942095,00.html (accessed on May 10, 2021)

[61] *Id.*

[62] Victoria Sutton. Planetary Protection and Regulating Human Health: A Risk that is Not Zero. 19 Hous. J. Health L. & Policy. (2019)

recommendation by the NASA Advisory Council (NAC).[63] PPIRB reviewed NASA's contemporary planetary protection policies and published a report ("the 2019 report") recommending areas where NASA should update its policies.[64] The NASEM then assessed the 2019 report and responded in 2020 ("the 2020 report").[65] The reports made several recommendations regarding future Mars missions sponsored by NASA or private entities. All three reports recommended that Congress should designate authority to the appropriate agency to oversee private parties' space missions.

IV. Multiple agencies may have the authority to regulate planetary protection-related issues

Despite the extensive planetary protection policy that NASA and NASEM observe, they are not regulatory agencies. In the past, NASA used contracts or other agreements to compel non-NASA parties to comply with its planetary protection policy.[66] It also had a formal procedure whereby non-NASA missions needed to demonstrate compliance with the COSPAR Planetary Protection Policy if they sought support from NASA (including hardware, services, data, funding, etc.) (NPD8020.12D (section 2.2.2)).[67] However, in the past decade or so, private companies have carried out space missions without NASA's sponsorship. NASA and NASEM cannot impose their policy on private-sponsored Mars missions. Several agencies may have the authority to regulate specific issues of

[63] The National Academy of Sciences, Engineering, Medicine. Review and Assessment of Planetary Protection Policy Development Processes. (2018) https://spacescience.arc.nasa.gov/wp-content/uploads/2018/11/ReviewAssessmentPlanetaryProtectionPolicyDevelopmentProcesses.pdf (accessed on May 10, 2021)
[64] NASA Planetary Protection Independent Review Board. Report to NASA. (2019) https://www.nasa.gov/sites/default/files/atoms/files/planetary_protection_board_report_20191018.pdf (accessed on May 10, 2021)
[65] National Academy of Science, Engineering and Medicine. Assessment of NASA's Planetary Protection Independent Review Board (2020). https://www.nap.edu/catalog/25773/assessment-of-the-report-of-nasas-planetary-protection-independent-review-board (accessed on May 10, 2021)
[66] Id.
[67] NASA NPD8020.12D: Planetary Protection Provisions for Robotic Extraterrestrial Missions. (Effective date: April 20, 2011; expiration date: August 20, 2021) https://nodis3.gsfc.nasa.gov/displayDir.cfm?t=NPR&c=8020&s=12D (accessed on May 10, 2021).

planetary protection policy, including the Federal Aviation Administration (FAA), the Centers for Disease Control (CDC) and the United States Department of Agriculture (USDA).

The FAA has the legal authority to review payloads, approve launches of spacecraft in the U.S., and oversee their re-entry into Earth's atmosphere.[68] The FAA may consult with other agencies to determine if the proposed payload would affect public health, the United States' national security and foreign policy interests, or other international considerations.[69] However, in reviewing private parties' lunar missions, the FAA concluded that it might need additional authority in order to ensure full compliance with Article IV of the OST.[70] Therefore, it is unclear whether the FAA authority covers review and approval of planetary protection policies.

The CDC may have authority to quarantine astronauts returning from outer space. Under the federal statute 42 U.S.C. §264(a), the Department of Health and Human Services (DHHS), headed by the Surgeon General, can quarantine individuals who have been infected or potentially exposed to an infectious disease.[71] This federal statute has been invoked by the federal government during outbreaks of infectious diseases, including the Ebola outbreak in West Africa and the COVID-19 pandemic.[72, 73] In response to the COVID-19 pandemic, federal and state governments imposed mandatory 2-week quarantines for anyone returning to the U.S. from an area with high risk of infection and anyone traveling across state lines from high-risk regions, even if they were asymptomatic.[74] The DHHS may also need additional authority, however, because it is unclear whether 42 U.S.C. §264 extends to the quarantine of individuals who were potentially exposed to extraterrestrial life forms while in outer space. The Surgeon General is authorized to "make and enforce such regulations as in his judgment are necessary to prevent the introduction, transmission, or spread of *communicable diseases from foreign*

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[68] *See* 51 U.S.C. §50904
[69] 14 C.F.R. §415.
[70] *See e.g.* Laura Brown. Fact Sheet – Moon Express Payload Review Determination. (Aug. 3, 2016) https://www.faa.gov/news/fact_sheets/news_story.cfm?newsId=20595 (accessed on May 10, 2021).
[71] 42 U.S.C. §264(a) (2018).
[72] Ulrich MR, Mariner WK. Quarantine and the federal role in epidemics. SMU Law Review. (2018) 71; 391.
[73] *See* White House Press. Letter from President Donald J. Trump on Emergency Determination under the Stafford Act. (2020)
https://www.whitehouse.gov/briefings-statements/letter-president-donald-j-trump-emergency-determination-stafford-act/
[74] Florey K. Covid-19 and Domestic Travel Restrictions. Notre Dame Law Review. (2020) 96; Reflection 1.

countries into the States or possessions, or *from one State or possession into any other State or possession.*"[75] Returning from outer space is not explicitly included in the language of returning from foreign countries or traveling from one state to another. Moreover, it is unclear whether life forms or hazardous materials from Mars would cause "communicable diseases." In addition, if the threat of microorganisms were not to human health from "communicable diseases" but rather threats to Earth's climate, it is not clear that section 264 would provide any authority to regulate.

For Mars sample return missions, the USDA may have the authority and expertise to regulate non-native species entering the United States. The USDA is responsible for quarantining specific non-native plant and animal species imported into the U.S., with the purpose of controlling the spread of pests or diseases. For example, the Plant Quarantine Act of 1912, which was consolidated into the Plant Protection Act of 2000, gave the Animal and Plant Health Inspection Service (APHIS) the authority to regulate and quarantine imported plants that may carry pests and diseases across state lines or into various disease outbreak regions in the U.S.[76] The Animal Health Protection Act, enacted in 2001, gave the Secretary of Agriculture the authority to restrict the importation and further movement of sick animals within the U.S., and to order the destruction of sick animals for the purpose of disease control.[77] However, it is unclear whether federal regulations for quarantine of non-native species imported from foreign countries are applicable to the quarantine of extraterrestrial samples. The Plant Protection Act gave the APHIS the authority to inspect, hold, quarantine, and destroy any "plant pest, (or) noxious weeds" that are "moving into the United States, or through the United States, or interstate."[78, 79] Moreover, "plant pest" and "noxious weeds" are defined in the statute as agents that can cause damage or disease to crops, plants, livestock or poultry.[80] Because the potential hazard of Martian

[75] 42 U.S.C. §264(a).
[76] Plant Quarantine Act of 1912, 7 U.S.C. §§151-167, repealed by Plant Protection Act of 2000, Pub. L. 106-224, 7 U.S.C. §§7701-7772 (2000).
[77] 7 U.S.C. §8308.
[78] 7 U.S.C. §§7701-7772.
[79] It is unclear whether reentering the United States from outer space without crossing a border is "moving into the United States.
[80] *Id.* at §7702.

samples is unknown, they may not be classified as plant pests or noxious weeds. New regulations that specifically address contamination risks of outer space samples are needed.

In addition, policymakers may need to consider whether quarantining or treating samples retrieved from Mars by private entities constitutes regulatory taking under the Fifth Amendment Taking Clause. The Fifth Amendment to the U.S. Constitution provides that private property may not "be taken for public use, without just compensation."[81] In most cases, whether a regulation that results in infringement on private property rights by the government constitutes a regulatory taking depends on the specific facts of the case. The U.S. Supreme Court has set a three-factor test to determine regulatory taking: (1) "the economic impact of the regulation on the claimant"; (2) "the extent to which the regulation has interfered with distinct investment-backed expectations"; and (3) "the character of the governmental action."[82] The USCSLA grants private entities the property rights to "possess, own, transport, use, and sell the asteroid resource or space resource obtained in accordance with applicable law."[83] Whether quarantine regulations for Martian samples constitute regulatory taking will likely depend on several factors, including how long the government agency plans to keep the samples and whether the samples require additional sterilization treatments which imply significant decreases to their economic value. Because Martian samples might be worth millions of dollars, the stakes are high for anyone in possession of these rare samples. If the *Penn Central Transportation Co. v. New York City* three-factor test is satisfied, how much would the government need to compensate the private parties? This would be an important consideration for enacting policy.

Other agencies may play a secondary supporting role in the implementation of planetary protection policy. The Department of Homeland Security (DHS) may have the authority to oversee transportation of returned samples and astronauts to quarantine centers.[84] The Occupational Safety and Health Administration (OSHA) may be responsible for evaluating the working conditions for scientists and staff in the designated quarantine centers and biosafety laboratories.[85] Under the

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[81] U.S. Const. amend V.
[82] *Penn Central Transportation Co. v. New York City*, 438 U.S. 104 (1978).
[83] USCSLA, *supra* note 28.
[84] Uhran B, *supra* note 31.
[85] *See* The Occupational Safety and Health Act of 1970. 29 U.S.C. §651 et esq.

National Environmental Policy Act (NEPA), the Environmental Protection Agency (EPA) has the authority to require other federal agencies to prepare an analysis prior to making decisions that may significantly affect the environment.[86] Since Martian samples may, for example, cause significant climate change, the EPA may require the relevant agency to submit environmental risk assessments prior to releasing Martian samples from biosafety locations.

The White House National Space Council (NSC) may have the authority to oversee different agencies' space policies. The predecessor of NSC, the White House National Aeronautics and Space Council, was created together with NASA under the 1958 National Aeronautics and Space Act.[87] Its primary responsibility was to coordinate between NASA, which conducts civil space activities, and the Department of Defence (DOD), which is responsible for space activities regarding national security.[88] The first Council was soon abolished by President Nixon in 1973.[89] In the late 1980s, Congress recreated the NSC under Title V of the 1989 NASA Authorization Act in response to the lack of transparency in space policymaking.[90] The President has the discretion to decide whether or not to have a space council, and if they choose to have it, the NASA Authorization Act requires the Vice President to lead the council.[91] The NSC in the White House was not re-established until 2017 by President Donald Trump and Vice President Mike Pence. The administration has since been much more active in issuing space policies, and it appears that the Biden Administration will continue the activities of the previous White House NSC.[92]

V. Multi-agency coordination framework

As discussed, the jurisdiction of regulating backward contamination may fall upon multiple agencies. Congress in the past had delegated the authority to regulate complex private activities to

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[86] 42 U.S.C. §4321 et seq.
[87] *See* Historical and revision notes, 51 U.S.C. §201(e) (Pub. L. 111-314) .
[88] Macia Smith. Biden to Keep White House National Space Council. SpacePolicyOnline.com. (Mar. 30, 2021) https://spacepolicyonline.com/news/biden-to-keep-white-house-national-space-council/ (accessed on May 9, 2021).
[89] *Id.*
[90] 51 U.S.C. §20111 (Pub. L. 100-685).
[91] *Id.*
[92] Smith, *supra* note 96.

multiple agencies, with each agency in charge of different aspects of the regulation. Scholars have supported multi-agency-based coordination frameworks because they have a number of advantages.[93] Multi-agency coordination can minimize redundant or inconsistent regulatory requirements from different entities.[94] Moreover, it promotes exchange of ideas and the pooling of specialized expertise to tackle unique and particular issues. Finally, individual agencies can review each other and provide a quality check for other agencies' risk assessment methods. In turn, broader viewpoints may arise, and the risk of narrow agency "group-thinking" will be diminished. The key to creating an efficient multi-agency regulatory framework is to ensure that each agency has independence, while the assessment of risk and the regulations across different agencies are consistent.[95] As an example of effective multi-agency coordination, this chapter will discuss the framework for biotechnology regulation, first implemented in 1986 and updated in 2017.

Biotechnology experienced rapid development in the 1980s. The first U.S. patent for gene cloning was granted in 1980, for a method of insulin production from genetically modified (GM) bacteria. In the same year, the first genetically engineered vaccine was approved by the FDA for the hepatitis B virus. In 1983, the first genetically modified bacteria were approved for release into the environment. These bacteria helped potato plants withstand low temperatures. At the time, public concerns were raised as to whether genetically engineered products were safe for human health and the environment in the long run. In response, the Reagan Administration formed an interagency working group under the White House Cabinet Council on Natural Resources and the Environment in 1984. The group intended to create a coordinated interagency framework to address the need for regulation that maintained health and environmental safety while promoting biotechnology. The Coordinated Framework for Regulating Biotechnology was finalized in 1986.

Before 1986, three federal agencies—the United States Food and Drug Administration (FDA), the USDA, and the EPA—were already authorized to regulate products manufactured by traditional

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[93] *See* John D. Graham, Jonathan Wiener, Cass Sunstein. Chapter 13, Risk vs. Risk: Tradeoffs in Protecting the Health and Environment. (1995). ISBN-10: 0674773071; *See also,* Alejandro Camacho. Reorganizing Government: A Functional and Dimensional Framework. (2019).
[94] *Id.*
[95] *Id.*

genetic manipulation techniques.[96] The new, finalized framework built on the pre-existing laws and assigned the primary responsibility of regulating genetically engineered products to these three agencies due to their prior expertise in regulating genetically manipulated products.[97] The FDA would regulate Genetically Modified (GM) food and drugs for humans. The USDA would be responsible for regulating GM plants, animals, and animal drugs manipulated through biotechnology. The EPA would be in charge of the safe release of GM products into the environment. Under the new framework, the three primary agencies would cooperate in an integrated and consistent fashion. Other relevant agencies could play supporting roles or offer voluntary reviews of the regulatory process. The rationale for a coordinated framework was thus to utilize existing legal authority and regulatory programs to govern the development of new technology in an efficient and timely manner.[98, 99] Biotechnology is a fast-evolving industry, much like the space sector. The agencies may need to share relevant scientific information to better understand and regulate new products. To the extent that this is possible, the primary responsibility to regulate GM products lies with one agency to avoid redundant regulatory requirements. The following table illustrates the agencies' jurisdiction in regulating GM products, detailing each agency's authority and responsibility.

[96] Office of Science and Technology Policy (OSTP). Coordinated framework for the regulation of biotechnology. (1986). Fed Reg 49:50856–50907
[97] *Id.*
[98] *Id.*
[99] Concerns over bureaucratic inefficiency still need to be further explored and considered.

Subject	Responsible Agencies
Food additives	FDA*, USDA
Human drugs medical devices, biologics	FDA
Animal drugs	FDA
Animal biologics	FDA
Plants and animals	USDA*, EPA
Pesticides released into the environment	EPA*, USDA
Other uses (microorganisms) • Intergeneric combination • Intrageneric combination • Pathogenic source organism • Agricultural use • Non-Agricultural • Non-Pathogenic source organism	 EPA*, USDA USDA EPA*, USDA EPA reports
Federally funded GM research	Funding agency
Non-federally funded FM research: • Food, drugs, medical devices, biologics • Plants, animals, animal biologics • Pesticides, microorganisms • Other uses(microorganisms) released into the environment • Intergeneric combination • Intrageneric combination • Pathogenic source organism • Non-pathogenic source organism	 FDA*, NIH voluntary review USDA*, S&E voluntary review EPA*, S&E voluntary review EPA*, USDA, S&E voluntary review USDA, EPA (if non-agricultural) EPA report

Table 1: Agency jurisdiction in regulating different types of GM products. Adapted from Chart I & Chart II of the Coordinated Framework of Regulating Biotechnology (1986). * Lead agency

Under the Public Health Service Act and the Federal Food, Drug, and Cosmetic Act, the FDA has the authority to regulate food and drug products regardless of how they are manufactured.[100, 101] The FDA had prior experience and an existing regulatory system for assessing product safety and effectiveness. Accordingly, the FDA concluded that existing procedures would also apply to GM products manufactured with new technology.[102] No new regulations would be needed.

Before 1986, the USDA already had the authority to regulate products that may pose a risk to agricultural plants and animal health, under the Animal Health Protection Act (AHPA)[103] and the

[100] 42 U.S.C. ch. 6A §201 et esq. (Pub.L. 78-410).
[101] 21 U.S.C. ch. 9 §301 et esq.
[102] OSTP, *supra* note 110.
[103] 7 U.S.C. §8308.

Plant Protection Act (PPA).[104] The USDA has regulatory oversight over veterinary biologics under the Virus-Serum-Toxin Act (VSTA).[105] In response to the expanded authority granted by the Coordinated Framework, the USDA published new rules to regulate GM products that are modified by new types of biotechnology.[106] Broadly, the new rules state that the USDA is authorized to regulate GM organisms if there is reason to believe that they are plant pests or pose risks to animal health. One example would be if the donor, vector agent, or recipient organism were a member of a group of organisms known to contain plant pests. The USDA also published detailed companion documents detailing research guidance for non-federally funded GM products.[107] These documents recommend standards of safety closely aligned to the National Institutes of Health (NIH) standards for academic and industrial research laboratories.[108]

Before 1986, the EPA was responsible for regulating pesticides and other new biotechnology which might pose harm to the environment, under the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA),[109] section 408 of the Federal Food, Drug and Cosmetic Act (FFDCA),[110] and the Toxic Substances Control Act (TSCA).[111] Under the new framework, the EPA announced new policies for addressing GM microbial products that are under TSCA authority and for reviewing GM products with particular emphasis on small-scale field testing.[112] These new rules included updated interpretation of the new chemical premanufacture notification provisions (PMN) for "new" GM microorganisms, pathogenic microorganisms and nonindigenous microorganisms, additional reporting rules for other microorganisms prior to their release to environment, and changes in exemptions. The EPA also posted detailed explanations of which particular microorganisms are subject to regulatory review prior to release to the environment.[113]

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[104] 7 U.S.C. §§7701-7772.
[105] 21 U.S.C. §§151-158.
[106] OSTP, *supra* note 110.
[107] *Id.*
[108] *Id.*
[109] 7 U.S.C. ch 6 §136 et esq.
[110] 21 U.S.C. §301 et seq.
[111] 15 U.S.C. §§2601-2629.
[112] OSTP, *supra* note 110.
[113] *Id.*

The NIH, an agency within the Department of Health and Human Services, leads the federally funded research programs designed to improve human health.[114] The NIH funds basic research on biotechnology and has published guidelines on how to conduct proper research with genetic modification technology. Compliance with relevant guidelines is required for all NIH funded programs. Additional FDA approval is required for certain experiments such as gene therapy, even if they are funded by the NIH.[115] However, the NIH is not a regulatory agency and therefore cannot impose its policy on non-federally funded programs. The FDA and USDA are the lead agencies authorized to regulate non-federally funded research on GM products, and they have their own guidelines for GM research, which closely follow the NIH guideline.[116] Each lead agency may ask scientific advisory committees at NIH to provide expert reviews on specific experiments that require agency approval.

The Occupational Safety and Health Administration (OSHA) plays a supporting role in the biotechnology regulation framework. Under the Occupational Safety and Health Act of 1970, OSHA is responsible for protecting the safety and health of employees who work in the field of biotechnology.[117] After assessing risk, OSHA published a notice in the Federal Registrar stating that existing regulations on employee working conditions were adequate and no specific regulation was needed for workers in the field of biotechnology.[118]

In the next 30 years after the implementation of the 1986 coordinated framework for regulating biotechnology, there were significant scientific advances.[119] Genetic engineering techniques have expanded. The initially described categories of GM products are no longer appropriate for assigning responsibility to specific agencies.[120] Often, a new GM product may fall into multiple categories and thus be subjected to multiple agency reviews. In 2015, the Obama Administration issued a memorandum urging the agencies to update the Coordinated Framework and clarify their

[114] National Institutes of Health (NIH). https://www.nih.gov/ (accessed on May 10, 2021).
[115] OSTP, *supra* note 110.
[116] *Id.*
[117] 29 U.S.C. §651 et esq.
[118] OSHA, 50 FR 14468. Federal Register Notice of 1984.
[119] McCammon, *supra* note 108.
[120] *Id.*

responsibility.[121] The Office of Science and Technology Policy (OSTP) within the White House led the effort to identify agency roles that needed to be updated.[122] The OSTP also commissioned expert analysis of the future landscape of biotechnology products to ensure that the updated framework would remain appropriate for a longer period. Each agency published their finalized version of the 2017 Update to the Coordinated Framework for the Regulation of Biotechnology.[123] Together, the update clarifies agency responsibilities, provides a framework for effective interagency coordination, and offers several case studies to guide product developers in the biotechnology industry. Overall, the update remains faithful to the prior legal regulatory framework and maintains a risk-aware approach of balancing potential benefits of new technology with the potential risk of new technology.[124]

VI. Proposing a new framework

The gap in the regulation of space activities by private entities raises increasing concerns. The 2018, 2019, and 2020 reports on updating NASA's planetary protection guidelines all recommend that Congress should grant authority to the appropriate agency to oversee the activities of private actors in space as soon as possible.[125] Clear guidance would help the industry prepare for procedural compliance to planetary protection policies seeking to mitigate the risk of backward contamination.[126] In July 2020, the Trump Administration established a Planetary Protection Interagency Work Group.[127] The group consists of nearly twenty federal agencies, including NASA, FAA, USDA, CDC, DHS, EPA, the

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[121] OSTP. National strategy for modernizing the regulatory system for biotechnology products. (Sep. 26, 2016). https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/biotech_national_strategy_final.pdf (accessed on May 10, 2021)

[122] *Id.*

[123] White House. Increasing the Transparency, Coordination, and Predictability of the Biotechnology Regulatory System. (Jan. 4, 2017) https://obamawhitehouse.archives.gov/blog/2017/01/04/increasing-transparency-coordination-and-predictability-biotechnology-regulatory (accessed on May 10, 2021).

[124] McCammon, *supra* note 108.

[125] *See* NASEM, *supra* note 72; *See* NASA PPIRB, *supra* note 73; *See also,* NASEM, *supra* note 74.

[126] *Id.*

[127] Meghan Bartels. Planetary protection needs more than just NASA, White House plan says. (Jan. 4, 2021). https://www.space.com/white-house-unveils-planetary-protection-plan (accessed on May 10, 2021).

Federal Bureau of Investigation (FBI), and the Federal Emergency Management Agency (FEMA). The Biden Administration may continue the efforts to address this gap in the near future.[128]

As discussed in Part IV, similar to GM product regulation, multiple agencies (e.g. the FAA, CDC, and USDA) may already have experience and existing authority to regulate subsets of issues regarding backward contamination risk. Therefore, a multi-agency coordinated framework is proposed in this report to oversee both NASA and private parties' missions to Mars (Table 2). The FAA, CDC and USDA would be lead agencies depending on the type of mission, and other agencies would provide supporting roles.

Mission Type	**Agency**
Launch Permit • Microbial reduction/sterilization • Planetary Protection Plan	FAA*
Robotic Sample Return • Building secure biosafety labs • Sample transfer to biosafety lab • Sample treatment and monitoring • Sample release	USDA*
Crewed Return • Astronaut transfer to quarantine centers • Disinfection of astronaut personal items • Astronaut monitoring	CDC* • DHS • CDC • CDC
Research Missions • Federally funded • Non-federally funded • Robotic sample return • Crewed return	 • Funding agency • FAA, USDA (NASA voluntary review) • FAA, CDC (NASA voluntary review)
Executive Branch Oversight	NSC

Table 2: Proposed multi-agency framework for regulating Mars return missions

The aims for the coordinated framework are to minimize redundant agency reviews, utilize existing regulatory regimes and improve regulatory efficiency. Thus, to the extent possible, each leading agency should have independent roles in the agency review process. In accord with their new granted authority, the agencies may adapt an existing policy or enact new policies regarding Mars samples or astronaut returns.

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[128] *Id.*

The FAA is already responsible for issuing space operator launch and reentry permits. In the new framework, this chapter proposes to grant the FAA additional authority to review missions' microbial reduction plan before launch and to ensure that the missions observe a planetary protection plan which is in compliance with other agencies' guidelines.

The USDA would be the lead agency to oversee Mars sample return missions. It already has procedures for regulating the importation of non-native species into the United States. The agency may be able to assess whether its current regulations apply to samples from outer space. New provisions may be needed to redefine "non-native" species and to handle "new" unknown microorganisms.

The CDC is an appropriate agency to oversee quarantine procedures for returning astronauts. In the past, it has collaborated with NASA on the Apollo missions to help develop quarantine guidelines. To extend the quarantine requirement to private party astronauts, the CDC may need additional authority to quarantine anyone exposed to extraterrestrial environments. The CDC could make use of existing regulations for quarantine of individuals returning to the U.S. after potential exposure to infectious diseases.

In addition, the USDA and CDC should work with DHS to set up guidelines for transporting samples and astronauts to the designated biosafety laboratories and quarantine centers. OSHA may be responsible for ensuring that working conditions in these facilities do not pose health risks to the scientists. When the samples are removed from the laboratory, the EPA may require an environmental release risk assessment from the USDA.

The White House NSC could be assigned the authority to oversee the coordination among agencies. Since its creation, the NSC has been assigned the roles of facilitating interagency work to develop space policies.[129] Under the Trump Administration, the Council members include the representatives of all the space related agencies in the executive branch, including the Departments of State, Defense, Commerce, Transportation, Energy, and Homeland Security, NASA, National Intelligence, the Office of Management and Budget, the Office of Science and Technology Policy, and

[129] Smith, *supra* note 96.

Assistants to the President for National Security Affairs, Economic Policy, and Domestic Policy.[130] The NSC would be the most appropriate agency to oversee the coordinated framework of planetary protection policy, given their expertise.

Even though NASA is not a regulatory agency, it employs scientists with expertise in multiple areas of space research. Similar to NIH's role of oversight in biotechnology research regulation, NASA should play an important role in updating the Mars regulatory policy. The FAA, USDA and CDC regulations would all benefit from NASA guidelines.

Moreover, NASA should regularly update its planetary protection policy because space exploration is developing rapidly. NASA could adopt the concept of adaptive regulation, where regulations are dynamic and frequently updated to reflect developments in the relevant fields as they become available.[131, 132] A more cautious planetary protection policy may be appropriate at the beginning because much is still unknown about backward contamination risks associated with missions from Mars. As scientists learn more about Mars from future missions, policymakers will have a better idea of the appropriate quarantine requirements and can adapt their regulations accordingly. NASA should form a committee with relevant agencies, scientists and private entities in relevant fields in order to develop a clear and up-to-date planetary protection policy. Most importantly, NASA should include private party stakeholders in the policy making process. Private space companies have been rapidly advancing technologies for space exploration. Inclusion of private parties in the policy development process will ensure that the quarantine guidelines would meet the private entities' expectations and would not become counterproductive to the aims of these missions. Finally, mitigating backward contamination risk requires collective action. Robotic or crewed Mars space missions by any state would impose such risks and collective action problems are likely to arise. As of January 2018, very few states have included planetary protection provisions in their national space law

[130] *Id.*
[131] Bennear L, Wiener JB. Built to Learn: From Static to Adaptive Environmental Policy, in A Better Planet. (Esty DC, ed., Yale Univ. Press 2019).
[132] Wiener JB, *supra* note 61.

and many of these provisions are vague and potentially unhelpful.[133] This could be explained by the fact that not many states have planned return missions from Mars in the near future. A regulatory framework that effectively addresses risks associated with backward contamination, especially for private space missions, may be more urgent for the U.S. government due to their near-term plans to oversee travel to and from Mars. NASA should continue to work with COSPAR and provide updated planetary protection policy guidelines for all space-faring states as it becomes relevant to their purposes in space.

VII. Conclusion

With proper regulations in place by the appropriate authority, the risks associated with backward contamination have a better chance of being mitigated or effectively prevented. To fully embrace the opportunities and advantages of interplanetary travel, regulatory collaboration, as recommended in this report, would likely address the gap in the existing regulatory framework, thus mitigating the risk of catastrophic events resulting from hazardous materials brought to Earth from outer space.

[133] Gustavo Boccardo. UPDATE: Planetary Protection Obligations of States Pursuant to the Space Treaties and with Special Emphasis on National Legislations Provisions. *Hauser Global Law Program.* https://www.nyulawglobal.org/globalex/Planetary_Protection_Obligations_States1.html (accessed on May 10, 2021).

Ultrasound Based Autonomous Systems can Mitigate Medical Risk on Deep Space Missions[1]

Adam Doll[2] and Siobhan Oca[3]

Abstract

When considering the various medical conditions NASA is preparing to encounter in a long duration space mission to Mars, they must assess the value of sending various personnel and decide which aspects of training could be most helpful [1]. It is generally understood that ultrasound (US) would be useful [2,3], although the scale of risk reduction from sending ultrasound diagnostics to space on long duration space missions has received only limited analysis. This chapter discusses the specific utility of automated US diagnostics for conditions predefined by NASA as likely to occur [4]. Increasing specialization in medicine raises barriers for astronauts with generalist expertise seeking to deliver adequate medical care [5,6]. An automated system that offsets some of the clinical training currently required to collect and analyze US images could aid astronauts in diagnosing medical conditions quickly while using limited resources that are critical to survival in space.

Autonomous ultrasound image collection and analysis were explored separately for these conditions enumerated by NASA. Recommendations were based on timing of onset and duration of conditions, efficacy and utility of diagnosis for ultrasound, and training capability that could be offloaded to an autonomous system versus crew expertise requirements for launch. Of the list of conditions from NASA, 20 were identified by clinical experts as at least partially diagnosable by ultrasound, where US could either diagnose the condition itself or rule out other conditions with similar symptoms. The efficacy of this diagnosis for clinicians in recent literature was explored separately for each condition. Autonomous systems are generally trained with data from clinician-identified images; this makes autonomous systems, at best, as good as the clinician data used to train them. This, along with current research of autonomous US diagnosis of a few particular conditions, generated the data to help select the conditions potentially diagnosable by ultrasound to direct support for technological innovation in autonomous detection. For the separate issue of collection, autonomous US systems currently can only collect images for limited areas of the body and also require significant clinician oversight. Supporting applied research in this field in addition to improving technological innovation in autonomous diagnosis could further offload medical training and standardize images collected, a current shortcoming of ultrasound scans today.

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I. Introduction

NASA currently trains clinical and nonclinical personnel to collect ultrasound (US) images on the ISS. Still, most US analysis is done on the ground as collection of US images is primarily for research purposes and there are limited clinical personnel at the ISS at any one time [7]. Additionally, there are limited accidents or time sensitive clinical issues that would require clinical analysis of ultrasound images [8]. However, as space missions take longer and access to medical resources is further limited, on-board clinical analysis of US images could be helpful. Additional medical personnel could help offset certain medical risks, but would require many additional resources (and increase the weight of the spacecraft) and would likely have specialized, and therefore limited, medical knowledge. For instance, radiologists trained specifically in US image analysis could be helpful to analyze scans, but would not be as useful as emergency medicine clinicians at quickly assessing and treating patients. Internists could be most effective at managing a disease long-term. Generally, the diseases discussed in this chapter could be initially evaluated by a variety of clinicians, given appropriate training before launch. However, offloading training to autonomous systems can improve crew members' training and preparedness for the other critical aspects of deep space missions.

This chapter assumes the medical supply of the ISS for the long duration Mars mission profile (though it is expected for such a mission to have even less) with key medical personnel (such as those described above) available on Earth for a consultation with a maximum time delay of 44 minutes round trip [9]. An autonomous ultrasound collection system could be most useful in collecting consistent images (possibly a smaller subset compared to a clinician with limited training) for autonomous or Earth evaluation. Additionally, for conditions where a time delay of one hour is critical in disease progression, autonomous diagnosis could help astronauts make appropriate initial decisions for resource allocation and astronaut health. To fully diagnose and treat the diseases outlined by NASA [4], ultrasound would be just one of many necessary tools. Other diagnostics, medicines, and procedures would all be necessary. To this end, ultrasound's largest benefit may not be how it diagnoses key conditions that can be treated, but rules out conditions that would require more or less of the mission's limited medical supplies, such as antibiotics.

II. Methods

NASA has defined key medical conditions that they are preparing for on long duration space missions [4]. These conditions were selected based on their likelihood of occurrence and potential severity. This helps to identify which medical supplies are necessary and should be brought on long duration space missions. Starting with this predefined condition list, conditions that could be diagnosed with ultrasound were selected based on feedback from a clinician [10]. The conditions for which US couldn't diagnose directly but could still rule out related conditions were also selected, as shown in Figure 1.

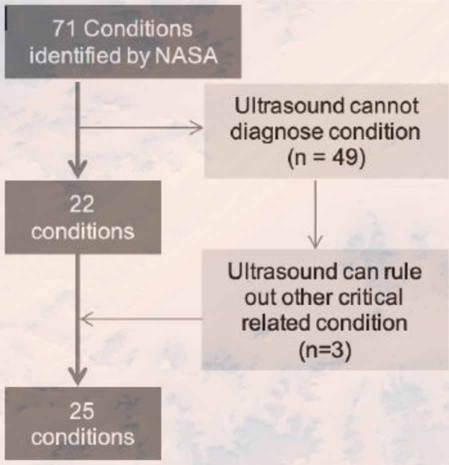

Figure 1: Medical conditions were downselected from the initial set identified by NASA.

From the remaining 25 conditions, the advantages of using autonomous US collection and diagnosis were explored separately. An expert clinician and researcher [10] was consulted to understand the utility of ultrasound gathered images for diagnosing these conditions on a scale of low-medium-high. A literature review was then performed to understand the state-of-the-art diagnostic capability of ultrasound and autonomous US for efficacy. To identify the benefits of autonomous collection, a separate literature review of gathering ultrasound images autonomously in different regions of the body was performed as well.

III. Results

From NASA documentation and clinical experts [4,10], Figure 2 was constructed to show the 25 selected conditions and how effective ultrasound would be in diagnosing these conditions or ruling out other related critical conditions that NASA expects to see on a mission to Mars.

Condition	Expected chance of occurrence on mission from NASA simulation	Can US rule out/ diagnose?	Is US used as first line of diagnosis?	Benefit of diagnosing with US in <1 hour	Can US rule out condition that shares symptoms with this disease?	If yes, name of rule out condition
Urinary Tract Infection	0.02924	No	No		Yes	Nephrolithiasis
Nephrolithiasis	0.01691	Yes	Yes	High	Yes	Abdominal Aortic Aneurysm
Eye Infection	0.00892	No			Yes	Detached Retina
Small Bowel Obstruction	0.00623	Yes	No	Medium	Yes	Abdominal Aortic Aneurysm
Wrist Fracture	0.00492	Yes	No	Low	Yes	Tendinitis
Angina/ Myocardial Infarction	0.00333	Yes	No	High	Yes	
Appendicitis	0.00319	Yes	No	High	Yes	Abdominal Aortic Aneurysm
Neck Sprain/Strain	0.00277	No			Yes	Neck Fracture
Atrial Fibrillation/ Atrial Flutter	0.00268	Yes	No	Medium		
Traumatic	0.00193	Yes	No	High		

Hypovolemic Shock						
Acute Cholecystitis/ Biliary Colic	0.00115	Yes	Yes	Low	Yes	
Skin Infection	0.00112	Yes	No	Low	Yes	Abscess
Retinal Detachment	0.001	Yes	Yes	Medium		
Gastroenteritis	0.00064	Yes	No	Low	Yes	Abdominal Aortic Aneurysm
Acute Pancreatitis	0.00062	Yes	No		Yes	Abdominal Aortic Aneurysm
Hip/ Proximal Femur Fracture	0.00062	Yes	No			
Abdominal Wall Hernia	0.00049	Yes	No			
Chest Injury	0.00024	Yes	No			
Hip Strain/Sprain	0.00022	Yes	No		Yes	Hip Fracture
Abdominal Injury	0.0002	Yes	No			
Shoulder Dislocation	0.00014	Yes	No			
Elbow Strain/Sprain	0.0001	Yes	No			
Cardiogenic Shock secondary to myocardial infarction	0.00008	Yes	Yes			
Finger Dislocation	0.00008	Yes	No			

Eye Penetration (Foreign Body)	0.00006	Yes	No			

Figure 2: Selected conditions based on the risks defined by NASA with their expected incidence based on a simulation of a mission profile of a 4-person crew for 923 days with 401 days of extravehicular activity [4]. The percentage chance of a condition occurring on a mission refers to the condition reaching a severity to warrant consideration of evacuation criteria. Additionally, the utility of ultrasound in diagnosing each condition or related conditions is described.

From the literature review performed to evaluate the state-of-the-art diagnostic capability of ultrasound, quantitative efficacy for each disease is shown in Figure 3. Where studies were too small (n<20) or quantitative efficacy data could not be found, a qualitative description of their current utility is given.

Condition	**Sensitivity**	**Specificity**	**Accuracy**
Urinary Tract Infection [11]	US used to differentiate from nephrolithiasis		
Nephrolithiasis [12]	40%	84%	78%
Eye Infection [10]	US used to differentiate from eye penetration		
Small Bowel Obstruction [13]	98%	93%	
Wrist Fracture [14]	50-92%	92%	
Angina/ Myocardial Infarction	No specific quantitative study, but US commonly accepted as critical tool for diagnosis		
Appendicitis [15]	84%	96%	92%
Neck Sprain/Strain [10]	US used to differentiate from neck fracture		
Atrial Fibrillation/ Atrial Flutter [10]	US used to differentiate from other heart abnormalities		
Traumatic Hypovolemic Shock [16]	100%		

Acute Cholecystitis/ Biliary Colic [17]	94%	78%	
Skin Infection [18]	98%	69%	
Retinal Detachment [19]	97%	92%	93%
Gastroenteritis [20]	US key for diagnosis and differentiating from Abdominal Aortic Aneurysm (99% accuracy)		
Acute Pancreatitis [21]	82%	89%	
Hip/ Proximal Femur Fracture [22,23]	83%	93%	
Abdominal Wall Hernia [24]	86%	97%	
Chest Injury [25]	67-100%	98-99%	
Hip Strain/Sprain [10]	US used to differentiate from hip fracture		
Abdominal Injury [26]	US used frequently in diagnosing different abdominal injuries and diseases		
Shoulder Dislocation [27]	100%	100%	
Elbow Strain/Sprain [28]	64-100%	36-100%	
Cardiogenic Shock Secondary to Myocardial Infarction [29]	US is key diagnostic tool to see if this will progress after myocardial infarction		
Finger Dislocation [30]	90%	98%	
Eye Penetration (Foreign Body)	No specific quantitative study, but US commonly accepted as critical tool for diagnosis		

Figure 3: Diagnostic capability of ultrasound with clinician collection and analysis.

Autonomous analysis of ultrasound images is limited by clinician experience and technique more than other imaging modalities because the orientation of the probe and the collection procedure can vary significantly between clinicians. For example, there are multiple machine learning algorithms used just to identify the view of US images of the heart [31]. Still, there is early work in automated disease detection in US imaging, particularly in cancer detection [32,33]. From the conditions most critical to NASA, only myocardial infarction (99% sensitivity, specificity and accuracy) [34] and nephrolithiasis (86% accuracy to differentiate between renal diseases) have been automated.

From the literature review performed to understand the state-of-the-art autonomous ultrasound collection, it was found that there are very limited cases of fully autonomous US collection on the human body without significant trained oversight or teleoperation. Outside of examples in liver collection [35], peripheral vasculature [36], and adaptive stiffness models [37], most autonomous US systems tend to focus on image processing and needle insertion. Even with systems that focus on US image collection, they tend to be ineffective, based on tissue phantoms with limited geometry and surface area [35,36,37].

IV. Discussion

Autonomous collection and diagnosis of ultrasound images could aid astronauts in diagnosing conditions on long duration space missions. This could be critical to allocate medical resources effectively, reduce requisite medical training, and effectively address conditions identified during the long duration space mission for astronaut health and mission success. Autonomous US could be a first line diagnostic to aid in medical decision making, before Earth-based experts could help in interpretation.

The time delay of information between Earth and Mars, along with the limited bandwidth capacity, makes autonomous collection of US images a potentially life-saving tool. As clinicians can collect inconsistent images and may need to select between many to send back for analysis, the most beneficial aspect of autonomous collection might be the ability to select only a few images that are needed for diagnosis. This system would reduce the medical risks of time delay and resource misallocation. The exact risk reduction is hard to estimate without empirical data on the incidence of resource misallocation or the efficacy of faster diagnosis.

For most autonomous identifications of disease, machine learning methods utilize training and testing images that have been pre-identified by expert clinicians. This means that these autonomous systems could never have a higher efficacy than human clinicians, but could come as close as possible to the people who label the training and testing images. The current efficacy of US interpretation by humans is described in Figure 3.

Select autonomous ultrasound based detection systems have already shown promise in detecting renal diseases [38] and myocardial infarction [34], considering only the condition list provided by NASA. The limit in autonomous US image disease recognition is in part due to the variety of images that are collected by clinicians based on the orientation of the probe and clinical expertise [39,40]. If testing, training, and real-time collected images were collected more systematically and consistently, such as by a robotic system, it might be easier for a machine learning algorithm to utilize specific features in determining a diagnosis.

For the autonomous collection of ultrasound images, there are currently few systems that can complete this task effectively. Even so, it would be a worthwhile investment for NASA to use its robotic expertise to develop robotic capability to collect US images, as this would reduce the medical training required for mission success. Autonomous systems also collect more standardized images, which would have benefits if an automated image processing system for diagnosis is also used. Additionally, as commercial robotic arms have developed in accuracy and safety [41], using different end effectors for different use cases around the future spaceship could be useful for many tasks, medical or otherwise.

Other options to offset the risks of the specified medical conditions include bringing additional supplies and/or additional personnel with specialized medical expertise. These would cost precious weight, especially considering the long journey, and therefore were not considered in this analysis. Additionally, many medical conditions were unrelated to ultrasound or other medical diagnostics, but could be affected by other environmental considerations, such as extra barriers for radiation exposure. Furthermore, the implications of human robotic interaction were not fully explored. Although teleoperation is unlikely to be effective with the significant time delays and limited bandwidth accompanying such a mission, these autonomous systems could use the limited clinical training of onboard astronauts to aid in the collection and interpretation of the ultrasound images. For example, a color-coded system could be employed to help define unequivocal cases; then in the instance of edge cases, the system could highlight the image features explaining how it generated its decision and suggest further clinical insight from Earth as necessary. Additionally, critical safeguards would need to be in place and clear edges of the workspace defined for autonomous collection of ultrasound images to be safe and effective.

V. Future Work

Machine learning depends on large amounts of feature-rich data to develop an effective algorithm. Human spaceflight, especially a Mars mission, is limited in this regard because of the lack of data sets currently available. Since these algorithms require significant data and examples to be effective, collecting diagnostic data on deep space missions, in conjunction with current efforts on the ISS, could help develop detection algorithms that are specialized for space.

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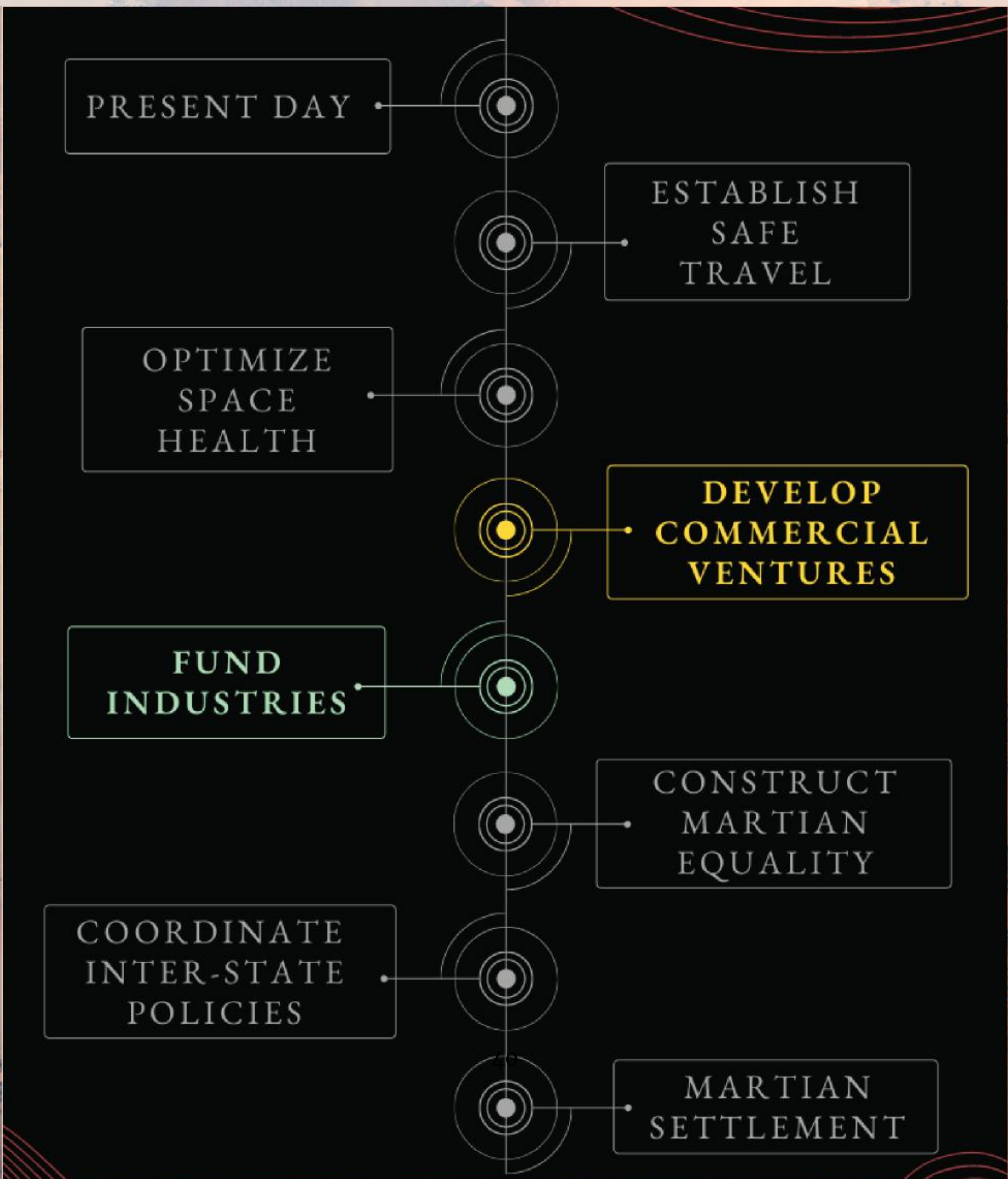
Economies of Mars



Promoting Commercial Investment On Mars: Extending International Arbitration To Conflicts in Space[1]

Clare Holtzman and Sam Schrader

Abstract

The proliferation of commercial space activity will likely intensify competition between the most powerful actors, increasing the likelihood of conflict in space. Without a clear mechanism for conflict resolution in space, international investment efforts in space and on Mars will be at greater risk. Existing international arbitration agreements (Bilateral Investment Treaties, or BITs) offer a valid mechanism. However, most BITs require that a covered investment be located in the territory of the host state. As of now, it seems unlikely that investors will be able to recover under BITs for investments they make in space, where states are not considered to be in possession of territory. In some circumstances, however, the recent ruling in CC/Devas v. India offers a key precedent for resolving this issue. Still, international arbitration is unlikely to resolve major commercial disputes because of unresolved issues related to the territorial nexus requirement, the dual-use nature of space technology, encroaching protectionism in the name of national security, and reemergent great power competition. In light of these challenges, we will examine alternative proposals to promote commercial activity in space, concluding that public-private partnerships offer a promising path forward.

[1] Thanks to Adam Doll, Joanna Feaster, Donald Pepka, Somia Youssef, Jeremy Yu, Jonathan Wiener, and Charles (Chase) Hamilton for providing feedback on and editing this chapter.

I. Introduction

Property rights, and a reliable mechanism for resolving disputes over property rights and contracts, are essential to economic growth over time.[2] In space, activity in both public and private investments is rising. However, the status of property rights and what dispute resolution mechanisms might be available and effective remains uncertain. Investing in space entails great risk[3] and as of now there are few mechanisms investors can rely on to protect their investment interests. Property rights in space are currently ill-defined—arguably non-existent—and legislation intending to convey them, such as the U.S. Commercial Space Launch Competitiveness Act, has caused significant international controversy.[4] Even if property rights in space were more clearly defined, a significant gap in the realm of dispute resolution persists. The dispute resolution mechanism most likely to fill this gap is international arbitration because it has already been successfully employed to resolve high-stakes commercial satellite disputes in space. While international arbitration may function well in some commercial disputes, the utility of such methods will be limited by emerging great power competition[5] and consequent national security concerns over technology.

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[2] *See* Acemoglu, Johnson & Robinson, Institutions As a Fundamental Cause of Long-Run Growth, in Handbook of Economic Growth, Volume IA (Philippe Aghion and Steven N. Durlauf, eds., 2005) (noting that "economic institutions encouraging economic growth emerge when political institutions allocate power to groups with interests in broad-based property rights enforcement"); *see also* Furubotn and Pejovich, Property Rights and Economic Theory: A Survey of Recent Literature, 10 Journal of Economic Literature no.4 1137, at 1139—40 (1972) (explaining why property rights are essential for the optimal use of assets); *see also* David Collins, Efficient Allocation of Real Property Rights on the Planet Mars, B.U. J. Sci. & Tech. L. no. 14:201, at 218–19 (2008) (linking a stable legal regime that offers bounded plots of land to early arrivers on Mars). A deeper discussion of property rights in space is beyond the scope of the chapter.

[3] *E.g.*, Clive Cookson, 'Huge Risk' of space junk collisions as satellite launches intensify, experts warn, Financial Times (Apr. 20, 2021) (satellites to improve global internet access have the side effect of contributing to potentially catastrophic space debris).

[4] Pub. L. No. 114-90 (2015) ("A United States citizen engaged in commercial recovery of an asteroid resource or a space resource under this chapter shall be entitled to any asteroid resource or space resource obtained, including to possess, own, transport, use, and sell the asteroid resource or space resource obtained in accordance with applicable law, including the international obligations of the United States."). The language of the statute, conferring property rights in space objects to private citizens, arguably conflicts with Article II of the Outer Space Treaty (OST) which proclaims that "outer space . . . is not subject to national appropriation by claim of sovereignty, by means of use or occupation, or by any other means." *Infra* note 7. For a discussion on the legal controversy between the OST and the CLSCA *see* P.J. Blount and Christian J. Robison, One Small Step: The Impact of the U.S. Commercial Space Launch Act of 2015 on the Exploitation of Resources in Outer Space, N.C. J. of Law & Tech., no. 2 at 160 (2016).

[5] Great power competition is defined as the struggle over which specific state(s) have asymmetrical power to set international standards.

In 2019, the private space sector made $366 billion in revenue, 95% of which consisted of space-to-Earth functions like satellites for telecommunications, the Internet, and national security infrastructure.[6] Therefore, protecting international investment in space is already a significant issue that threatens to become more complex as the nature of international investment shifts from space infrastructure to the settlement of Mars. While some of the disputes that may arise in this arena will be between commercial entities, states will also likely be party to disputes, given that the government comprises the vast majority of the market for private commercial space enterprises.[7] Furthermore, Articles VI and VII of the Outer Space Treaty (OST) implicate states in the extraterrestrial commercial activity of their citizens.[8] This chapter outlines the application of international arbitration for protecting investment on Mars and recommends public-private partnerships as the best measure to mitigate the national security limitations and negative externalities inherent in extending international arbitration to space.

II. Extending Existing Commercial Dispute Resolution to Space and Mars

International arbitration can provide a suitable default mechanism for resolving some investment disputes, and thus pave the way for a peaceful, stable, and predictable environment conducive to the commercial development of space. But if the national interests of a major space power are materially impinged by a commercial dispute, the matter will likely need to be solved at the diplomatic level. Such a dispute might occur, for instance, over proprietary dual-use technologies that the National Aeronautics and Space Administration (NASA) helped create in partnership with the private sector. This section outlines the application of international arbitration to commercial and investor-state disputes, noting the shortcomings of relying on these mechanisms alone without additional diplomatic interference or military interventions.

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[6] Matt Weinzierl and Mehak Sarang, The Commercial Space Age is Here, Harv. Bus. Rev. (Feb. 12, 2021).
[7] Id. (NASA and SpaceX launch agreements).
[8] Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (passed by the U.N. General Assembly in 1966) ("The activities of non-governmental entities in outer space, including the moon and other celestial bodies, shall require authorization and continuing supervision by the appropriate State Party to the Treaty").

The Convention on the Recognition and Enforcement of Foreign Arbitral Awards was signed in 1958 by over 150 states.[9] This landmark treaty established the legal foundation for enforcing foreign arbitration awards from another signatory country.[10] Signatories to the Convention widely adhere to the UN Commission on International Trade Law's (UNICTRAL) 1976 *Arbitration Rules,*[11] which constitute "a comprehensive set of procedural rules which parties can rely on or even adopt for the conduct of an arbitral procedure arising out of commercial disputes."[12] Since then, UNICTRAL has attempted to increase consistency across the arbitration laws of signatory states by publishing Model Laws on "all stages of an arbitral process . . . from the initiation of an arbitration and the composition of the arbitral tribunal, to the recognition and enforcement of an arbitral award."[13]

International arbitration arises in both the investor-state context and the commercial context. In the investor-state arena, international arbitration takes the form of a mechanism called Investor State Dispute Resolution (ISDS). Currently, the United States has over fifty ISDS provisions in bilateral investment treaties (BITs) with other states.[14] And more broadly, since the 1960s "nearly 3,200 trade and investment agreements among 180 states have included investment provisions, and the vast majority of these agreements have included some form of ISDS."[15] These mechanisms protect investors from one party from interference with investments they make in the territory of another party.[16] Specifically, ISDS was traditionally utilized to prevent states from expropriating an investment once it becomes profitable.[17]

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[9] Contracting States, N.Y. ARB. CONVENTION, http://www.newyorkconvention.org/countries.
[10] United Nations, The New York Convention, art. III. (1958), http://www.newyorkconvention.org/11165/web/files/original/1/5/15432.pdf
[11] UNCITRAL Arbitration Rules, UNITED NATIONS COMMISSION ON INTERNATIONAL TRADE LAW, http://www.uncitral.org/uncitral/en/uncitral_texts/arbitration/2010Arbitration_rules.html
[12] George Khoukaz, ADR That is Out of This World: A Regime for the Resolution of Outer-Space Disputes, Journal of Dispute Resolution 265, at 278 (2018).
[13] Id.
[14] The Facts on Investor-State Dispute Settlement, Office of the United States Trade Representative (2014), https://ustr.gov/about-us/policy-offices/press-office/blog/2014/March/Facts-Investor-State%20Dispute-Settlement-Safeguarding-Public-Interest-Protecting-Investors.
[15] Id.
[16] Id.
[17] Id.

ISDS balances protecting investors with preserving a state's ability to fend off abuses and its regulatory rights as a sovereign.[18] Historically, the local courts of the host state resolved investor-state disputes, but developed states pushed for international arbitration, due to the increasing prevalence of expropriations, perceived power imbalances, and a concern that the host country's court system would not adjudicate investor claims fairly.[19] Since governments capture the vast majority of the private commercial space market,[20] international arbitration offers a medium of conflict resolution between private entities and sovereign governments. The mechanisms of ISDS are generally the subject of bilateral investment treaties (BIT).

However, there are significant barriers to the use of ISDS under current frameworks. ISDS mechanisms require that an investor has made a covered investment within the territory of the host state.[21] But these mechanisms do not thus far include outer space within the definition of "territory of a host state."[22, 23] This may be in part due to the ambiguity around property rights and the bar against an exercise of sovereignty in space in the OST.[24] Under the OST, space "is not subject to national appropriation by claim of sovereignty, by means of use or occupation, or by any other means."[25] Whether this article is a complete bar to the procurement of materials in space or is simply meant to stop a state from claiming a planet remains unclear. Additionally, states "bear international responsibility for national activities in outer space," including by private parties, and for making sure such activities conform with the OST.[26] As noted previously, recent international controversy has arisen in relation to the U.S.'s 2015 Commercial Space Law Competitiveness Act, which

[18] Khoukaz, supra note 11.
[19] Id.
[20] Weinzierl, supra note 5.
[21] Stephan w. Schill et al., *Oceans and Space: New Frontiers in Investment Protection?*, Journal of World Investment and Trade, 775, 766 (2018).
[22] Peter Malanczuk, *Investment Protection of Commercial Activities in Space: Treaties, Contracts, Licenses, Insurance, Arbitration*, Journal of World Investment and Trade 951, 980 (2018).
[23] For more on cross-contamination, see Shu Boboila. "A Multi-Agency Regulatory Framework to Prevent Interplanetary Contamination."
[24] OST Article II
[25] Id.
[26] Id.

simultaneously authorized property rights over space resources claimed by commercial entities, while disclaiming any kind of national appropriation.[27]

While the United States has argued that the claiming of space resources should be regarded similarly to fishing in international waters, there are noteworthy distinctions between the two cases.[28, 29] The United Nations Convention on the Law of the Sea (UNCLOS), outlines rules for fishing in international waters,[30] but the OST does not contain any equivalent provisions for the procurement of space resources. The rules set out in UNCLOS also long predate the OST; an earlier treaty, the 1958 Convention on the High Seas, explicitly states that it was codifying existing principles of international law.[31] Therefore, at the time of the OST, the idea that a resource could be extracted from a place where no state could claim sovereignty was already a common idea. And yet, rather than incorporating this concept into the OST, as it had been in the Convention on the High Seas and UNCLOS, the OST instead contains only a bar on national appropriation, including through acts like use or occupation.[32]

Even if the United States' interpretation of the OST were accepted, this would not settle the issue of the territorial nexus. Given that a state cannot make a claim of sovereignty over territories in outer space, any investment made into, for instance, building a hotel on Mars would not be considered to fall under a BIT given that Mars cannot be any state's territory. If a state were to claim or interfere with such an investment, it seems unlikely that an investor could recover under a BIT since the territorial nexus would be lacking. However, a state could be in violation of the OST, since the state would in effect be appropriating the investment. Unfortunately, a private party would likely be unable to recover under the OST, given that the obligations are between states and it lacks any form of dispute settlement mechanism.

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[27] Commercial Space Law Competitiveness Act (2015); Couch, Jordan L. "You Can't Take the Sky from Me." American Bar Association. accessed April 29, 2021.
https://www.americanbar.org/groups/young_lawyers/publications/tyl/topics/space-law/you-cant-take-sky-me/.

[28] Couch, Jordan L. "You Can't Take the Sky from Me." American Bar Association. accessed April 29, 2021.
https://www.americanbar.org/groups/young_lawyers/publications/tyl/topics/space-law/you-cant-take-sky-me/.

[29] For more on international fishing laws, see: Holtzman, Nouri, and Saligram. "Inter-State Cooperation on Mars: Institutional Incentives for Collaboration."

[30] United Nations Convention on the Law of the Sea, Article 87.

[31] Convention on the High Seas, Preamble, Article 2.

[32] OST, Article 2; Convention on the High Seas, Preamble, Article 2; United Nations Convention on the Law of the Sea, Article 87.

Despite the uncertainty created by the ISDS mechanism, international arbitration has had some successful application to space disputes involving space objects originating from Earth, like satellites. Satellites are the most common reason for dispute in the context of space investment.[33] States regularly enter contracts with private entities to manufacture satellites, provide broadband services, and manage satellite orbits to keep a nation's designated orbit under the International Telecommunication Union's (ITU) "move it or lose it" policy. Per rules of the ITU, a rulemaking agency of the UN, a nation-state may lose its assigned orbital slot after three years of not using it.[34]

One example of the successful application of ISDS to investments in space involves the recent dispute between Avanti Communications and the government of Indonesia.[35] Indonesia leased a satellite from Avanti to fill the lapse in time that would have occurred since Indonesia's last satellite malfunctioned and their next one was due in over three years.[36] Since Indonesia stopped payments at $12 million, with about $17 million outstanding, Avanti sued to obtain the balance and interest on its initial $30 million contract.[37] The arbitrator awarded Avanti $20.075 million because Indonesia's argument that Avanti's Artemis satellite was no longer fulfilling its purpose was without merit and irrelevant to the contract.[38]

Another recent arbitration ruling establishes the jurisdiction of ISDS where the foreign space company or basis of investment was in the host country. As noted previously, a limitation to extending international arbitration to space is that most BITs require an "investment" in the "territory" of the host state."[39] But in the matter of CC/Devas v. India, the arbitrator did not apply strict territoriality requirements, considering instead whether the foreign company or the geographical basis of its investment is in the host state. In this case, the Mauritius-based company Devas entered into an agreement with the commercial wing of India's space agency, Antrix, to license a satellite spectrum for

[33] Jan Frohloff, Arbitration in space disputes, Oxford Arbitration Journal 309, at 318 (2018).
[34] Id.
[35] Id. at 316.
[36] Id.
[37] Id.
[38] Id.
[39] *Supra* note 11.

high-speed internet.[40] Soon after, negative media coverage and public criticism of the deal made Antrix back out of the contract, purportedly based on concerns raised by India's powerful Cabinet Committee on Security.[41] The tribunal weighed whether the purported national security concerns, which were vaguely disclosed, were legitimate or merely a pretext for obtaining a negotiating advantage with Devas. Since the BIT did allow an exception for essential security interests, the tribunal held India responsible for "expropriating" forty percent of the investor's investment.[42] This case posed a new issue because it centered on investment in a satellite located in shared territory, which the tribunal's analysis resolved by assuming that the physical location of the space object (e.g., satellite) is wherever the basis of the investment is located. Because the OST incentivizes states to issue licenses or otherwise supervise the launch of objects from its territory into space, states therefore have jurisdiction over their launched objects as it relates to their BIT.[43]

III. The Limits of Investment Arbitration in the Age of Dual-Use Technology and Great Power Competition

Traditional criticisms of ISDS center around the tribunal usurping the authority of the state to regulate or interpret an agreement. In essence, they enable multinational corporations to block host governments from regulating harms they cause. Other concerns involve the alleged bias and lack of independence of arbitrators favoring investors, limited oversight or recourse to ensure the veracity of tribunal rulings, and rising costs for resolving investment disputes.[44] If these patterns continue on Mars, there might be an erosion of trust in ISDS institutions among less developed states and accusations that the great space powers are engaged in selfishly hoarding space resources. This could

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[40] *Supra* note 11.
[41] Id.
[42] Id.
[43] If a state owns the spacecraft they launch, it follows that the state maintains ownership over the craft if it lands on another planet. The OST is less clear, however, on whether a state may claim samples of Martian rock dug up by a spacecraft it owns. The practice of NASA's Martian rovers over prior years is consistent with the United States' narrow interpretation of the OST's constraints on property rights.
[44] Stephan W. Schill, Reforming Investor-State Dispute Settlement (ISDS): Conceptual Framework and Options for the Way Forward, E15 Task Force on Investment Policy (2015), https://pure.uva.nl/ws/files/2512304/163092_E15_Investment_Schill_FINAL.pdf.

lead to a vicious cycle where less developed states are dissuaded from partaking in the commercial development of space as a host state to a company like SpaceX because adequate protections are not afforded under existing BITs.

Great power competition among leading space powers poses the greatest risk to commercial dispute resolution and development in space. The trend is intensifying, given recent lunar space station proposals of the U.S., China, and Russia.[45] Although emerging great power competition is multifaceted, the national interests of these powers are ever likelier to collide in the commercial space realm given the greater willingness of nation-states to use national security as a pretext for defending economic and other interests.

Nation-states are compelled to invoke national security exceptions more often than commercial activity because the most advanced technology is often used in service of a space program.[46] For instance, the technology behind civilian use missions like NASA's Mars Opportunity rover is "dual-use" because the technology often has both civilian and military applications. Even technology as basic to the digital world as semiconductors, which power all manner of consumer and military electronic devices, are considered "dual-use" and their supply chain is presently severely affected by U.S. national security sanctions.[47] Since so much of modern technology is dual-use, especially the technology used in a national space program which has direct and immediate military applications, there is a powerful disincentive toward any meaningful cooperation with the space program of any nation-state designated as a strategic competitor.[48] In fact, the dual-use technology enabling spaceflight implicates numerous export controls, namely the U.S.'s Export Administration

[45] Matthew Bodner, Russia and China unveil plans for joint lunar space station as Moscow drifts away from NASA, NBC News (published Mar. 11 2021).
[46] *See generally* Roger Handberg, Societal Impact of Spaceflight, Ch. 18 "Dual-Use as Unintended Policy Driver: The American Bubble" at 353 ((discussing the positive externalities to come of research and development during the U.S. Space Age), https://history.nasa.gov/sp4801-chapter18.pdf.
[47] Eun-Young Jeong and Dan Strumpf, Why the Chip Shortage Is So Hard to Overcome, The Wall Street Journal (published Apr. 19, 2021) (progressive American sanctions on Chinese buyers of micro-processing chips, namely Huawei, deliberately exacerbated an existing supply crunch).
[48] J. Benton Heath, Trade and Security Among the Ruins, Duke J. Comparative & Int'l L. 223 (2020).

Regulations (EAR).[49] The Wolf Amendment also notably restricts bilateral cooperation between NASA and China in the interest of national security.[50]

If space distills and projects the twenty-first century geopolitical contest emerging on Earth, the costs and uncertainties to commercial actors of any state in space will rise. Already on Earth, when the World Trade Organization (WTO) and bilateral forums both failed to resolve trade disputes between the United States and China, a damaging and costly tariff war ensued, causing disruption to technology supply chains.[51] That is just one of many strategic flashpoints between the world's three major space powers; with the U.S. Space Force already in motion, it is easy to imagine strategic and military conflicts spilling into the upper atmosphere. For stability in space, one alternative to a hegemonic power, akin to the U.S. Navy's protection of global shipping lanes, is a negotiated multilateral understanding about commercial property rights and dispute resolution.

One conception of international property rights in space seeks to manage the existential threat of space debris.[52] This "polycentric governance solution" entails both state and private actors sharing collective responsibility for managing orbital debris "in a way similar to how [many] actors manage large-scale irrigation projects and water rights in some emerging economies."[53] However, this type of cooperation works best when actors have the "ability to monitor and discipline actions," and outer-space lacks that circumstance with only a few states possessing limited surveillance infrastructure.[54]

Some individual states, like the United States, are already asserting the right of private companies to mine and profit from property in space.[55] In order to earn the support of developing states for a new regime of private commercial space property, however, distributional issues must be accounted for. If corporations and their shareholders in developed states stand to profit exclusively

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[49] 15 C.F.R. § 730–774.
[50] Hannah Kohler, "The Eagle and the Hare: U.S.-Chinese Relations, the Wolf Amendment, and the Future of International Cooperation in Space," Georgetown Law Journal 103, no. 4 (April 2015): 1135-[iii]
[51] Ryan Hass and Abraham Denmark, More pain than gain: How the US-China trade war hurt America, Brookings (published Aug. 7, 2020).
[52] Weinzierl, *infra* note 39.
[53] Id. at 187.
[54] Id.
[55] Id. at 189 (referring to the CLSLCA and Luxembourg's similar law on property rights in space).

from the exploitation of space, there will likely be political pressure back on Earth to share the riches with humankind. One solution could be a flat tax on all space revenues in exchange for granting a corporation a license to own, operate, and acquire new property in space. The tax would then go to a UN assistance program for poorer states.

Another promising idea for facilitating commercial dispute resolution is the International Institute for the Unification of Private Law (Unidroit) draft Protocol on Space Assets.[56] This idea proposes an international registry of assets in space. The theory is that lenders would be able to perfect security interests in identifiable space assets, in turn reassuring lenders and driving down the cost of capital for risky commercial space projects. However, private companies likely possess too few assets in outer space to adequately reassure private lenders to provide the billions of dollars needed for long-term space projects. Furthermore, Unidroit would first necessitate the "international harmonization of the rules governing investment" in space projects because their financing sources are varied.[57] This could lead to a global alternative dispute resolution (ADR) regime where investor-state conflicts are first addressed diplomatically or through mediation, and, if that fails, then through a standardized arbitration process (instead of a custom process negotiated bilaterally) based on the UNCITRAL's Arbitral Rules.[58] Although that might be an optimal commercial dispute resolution mechanism, the process to arrive there would be long and arduous considering the dwindling areas of agreement among major space powers.[59] Nonetheless, policymakers are encouraged to consider all of the preceding proposals to supplement international arbitration in protecting international investment on Mars.

[56] Paul B. Larsen & Juergen A. Heilbock, Unidroit Project on Security Interests: How the Project Affects Space Objects, 64 J. AIR L. & COM. 703, 706 (1999).
[57] Christopher Daniel Johnson, FINANCING FOR COMMERCIAL SPACE – ASSET-BACKED FINANCING, INTERNATIONAL SPACE LAW, AND THE UNIDROIT DRAFT PROTOCOL ON SPACE ASSETS, Int'l Inst. Of Air & Space Law (2010).
[58] *Supra* note 10.
[59] Id. at 39 (remarking that a solution under international law might be more expedient).

IV. How Public-Private Partnerships May Aid the Near-Term Commercial Development of Space

International arbitration is theoretically limited and largely untested in its application to potential space conflicts, and the proposed multilateral solutions are politically difficult to accomplish in the foreseeable future. Consequently, private investors wishing to explore space will need a lot of capital and some mechanism to ensure the security of their investments.[60] Public-private partnerships (PPPs) offer a way to achieve both, until a more comprehensive multilateral agreement is attained. The theoretical benefit of a PPP is to harness the innovation of private enterprise with the financial power of the government to spread out loss and fund research and development (R&D) projects with low probability of success, high fixed investment, and high reward (with potential civilian externalities) if it succeeds. According to Price Waterhouse Cooper, additional benefits to public-private partnerships include reduced cost (at scale), speed, risk-sharing, and long-term maintenance.[61]

For these reasons, public-private partnerships have a long track record in China, although the regulatory frameworks governing them remain opaque.[62] Although Beijing only formally allowed private investment in commercial space companies in 2014, there has been over $1 billion in private investment since then.[63]

Recently in America, with the encouragement of the Obama Administration, 35 states have now passed legislation legalizing PPPs as a corporate-government hybrid form in designated industries.[64] And the U.S. federal government has a long and controversial history of informal PPPs with defense contractors.[65] There is also the likelihood that the U.S. military's Space Force will share many vendors with NASA, enhancing the incentive for the U.S. government to seek control over more

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[60] For more on public-private partnerships, see Patel and Yu, "Analysis of Commercial Funding Strategies for the Settlement of Mars."
[61] Public-private partnerships in the US: The state of the market and the road ahead, Price Waterhouse Cooper (Nov. 2016)
[62] Ke Y., et al, Public Private Partnerships in China: Where to from Here, Organization, Technology & Management in Construction: An international Journal, no. 6, 1156–1162.
[63] Tanner Brown, Opinion: Private sector is no longer a bit payer in China's big space plans, MarketWatch (published Jan. 7, 2020).
[64] Id.
[65] Matthew Weinzierl, Space, the Final Economic Frontier, J. of Econ. Perspectives, no. 2, 173 at 180 (2018) (describing the advantage NASA contractors like Boeing received from the "cost-plus" contract).

key space industry players through a more formal PPP form. This form mitigates the national security risks posed by dual-use commercial space technologies by expanding government oversight over the process and fruits of research and development. In the case of the U.S., having direct authority and oversight over corporations which own key technologies would allow the government to streamline Committee on Foreign Investment in the United States (CFIUS) reviews and enforcement of export controls in the space sector. And with better knowledge of emerging space technologies, the U.S. government would be able to keep the lists of space technologies subject to export controls and investment screening up to date. In return for sacrificing some rights of ownership over the technology it helped develop (and a percentage of commercial profits derived from it), private industry would receive the military protection of the U.S. Space Force to enforce America's conception of private property rights on Mars to the exclusion of other states and private actors.[66] Although this form of American PPP raises glaring distributional issues, it would seem an attractive option to prospective private asteroid miners who have developed the requisite technology with NASA and need stable legal assurances of property rights and protection, backed by the U.S. federal government and its Space Force, to secure capital.[67]

Perhaps with that end in mind, NASA has recently begun soliciting partners through its 'Tipping Point' program, which seeks to partner with companies developing pioneering space technology, exemplifying the 'civil-military' fusion of dual use technologies.[68] Through Tipping Point, NASA offers its resources and expertise in exchange for "a negotiated industry contribution" of at least 25% of program costs, "shepherding the development of critical space technologies while also saving the agency, and American taxpayers, money."[69] NASA's other PPP initiative is the "Announcement of Collaboration Opportunity" (ACO), which is so early-stage that it lacks an official name.[70] This PPP initiative appears aimed at smaller companies nurturing potential for emerging, next-generation space

[66] *See* CSLCA, *supra* note 2.
[67] Weinzierl, *supra* note 51 at 189 (observing that many predict asteroid mining will serve as the initial revenue driver to finance further space developments like a Martian settlement).
[68] NASA, Space Tech Public-Private Partnerships (accessed Apr. 24, 2021), https://www.nasa.gov/directorates/spacetech/solicitations/tipping_points.
[69] Id.
[70] Id.

technologies. As such, NASA's terms for the ACO are vague: NASA provides expertise, facilities, hardware and software at no cost in return for being able to use any proprietary technology for its ends. NASA is actively developing both of these PPP initiatives. Since the modern space technology that would power NASA's Mars missions and the Space Force will very likely spawn terrestrial commercial applications, the incentive exists for PPPs to form and the National Intelligence Council predicts that several will in the near future.[71]

[71] The National Intelligence Council's four-year Global Trends report lists among likely medium-term future scenarios a global renaissance of democracies powered by "rapid technological advancements fostered by public-private partnerships in the United States and other democratic societies . . .". *See* National Intelligence Council, Global Trends 2040, at 4 (published Mar. 2021), https://www.dni.gov/files/ODNI/documents/assessments/GlobalTrends_2040.pdf.

Analysis of Commercial Funding Strategies for the Settlement of Mars[1]

Shivam Patel[2] and Jeremy Yu

Abstract

With current technological capabilities, it is highly unlikely that there can be a sustainable private enterprise with its business ventures exclusively oriented towards Mars. The costs for a crewed mission aiming to settle Mars is expected to far exceed any potential economic profit that can be generated. If space technology can advance far enough where interplanetary travel is cost effective, then the potential of Mars resource extraction can make a private space enterprise possibly profitable. Public-private partnerships potentially open the opportunity for a commercial organization to profit by traveling to Mars.

[1] Thanks to Adam Doll, Joanna Feaster, Donald Pepka, Somia Youssef, Tyler Felgenhauer, Dan Buckland, and Spencer Kaplan for providing feedback on and editing this chapter.
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I. Introduction

“I would like to die on Mars. Just not on impact.”

—Elon Musk

This chapter focuses on potential opportunities to earn capital on a mission to Mars to determine if a commercial mission could be profitable. The chapter will evaluate the claim that a completely private mission to Mars is profitable and possible without the capital partnership of a government or other subsidiary operations that are not Mars-related. The scope of “Mars-related operations” includes all business practices that are in direct connection to a crewed mission to Mars. Though many companies that work in the field of aeronautics also have business practices in other domains, it is still important to focus strictly on Mars-related profits for the sake of this chapter’s evaluation. Similarly, to study the potential for private entities to independently venture beyond Earth today, it is necessary to distinguish gains from partnerships between the public and private spheres from exclusively privately earned profit.. These assumptions will help narrow the scope of the chapter to evaluate the commercial viability of a private mission to Mars that does not rely on government support.

We have restricted our examination to income streams related to the settlement and exploration of Mars. This includes practices directly arising from the settlement of Mars, such as the extraction of physical resources or tourism by private individuals, as well as derivative revenue from services and technologies that would be developed in the process of settling Mars. Even with all these different avenues considered, we find that settlement of Mars is unlikely to generate significant revenue, especially in the short-term. Therefore, we argue that public-private partnerships will play a key role in reaching Mars because they allow government actors to more efficiently meet their political goals regarding space exploration while providing commercial actors with a stable source of revenue.

II. Cost Estimate of a Crewed Mars Mission

While current estimates for the cost of landing people on Mars vary widely, this section examines the existing literature to develop a sense of how much one can reasonably expect a Mars mission to cost.

Perhaps the most high-profile private attempt to land humans on Mars was the Dutch Mars One project. The project, which sought to establish the first Mars settlement by the year 2025, estimated that it would cost around $6 billion. While Mars One argued that their comparatively low costs were due to them only attempting a one-way mission, their $6 billion estimate was widely criticized by experts for being unrealistically optimistic. One study, conducted by a team of PhD students at MIT, found the Mars One plan to be completely infeasible.[3] They found that the cost of just sending the supplies needed for the initial settlement would cost around $4.5 billion. Furthermore, the cost of resupplying a Mars settlement would balloon exponentially. They found that the cumulative cost to grow and sustain Mars One's proposed settlement would exceed $100 billion.[4]

Indeed, Mars One ended up failing spectacularly. The mission was never attempted and the company ended up bankrupt in 2019.[5] Luckily, there are other, more realistic estimates of the cost of a human mission to Mars that this chapter explores. In October of 2015, NASA published their "Journey to Mars" program which outlined the agency's plan for Mars exploration and sustained human settlement.[6] The stated goal of the program is to "extend human presence deeper into the solar system and to the surface of Mars." To do this, the Journey to Mars program breaks down the process of reaching Mars into three steps. First is the "Earth Reliant" phase which focuses on conducting research on the International Space Station to build the systems necessary for long-term space travel. Second is the "Proving Ground" where NASA will validate and advance capabilities for Mars

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[3] Do, Sydney, Andrew Owens, Koki Ho, Samuel Schreiner, Olivier de Weck. "An independent assessment of the technical feasibility of the Mars One mission plan – Updated analysis." *Acta Astronautica* 120. (2013): 192-228,

[4] Ibid

[5] O'Callaghan, Jonathan. "Goodbye Mars One, The Fake Mission To Mars That Fooled The World." Forbes. February 12, 2020. https://www.forbes.com/sites/jonathanocallaghan/2019/02/11/goodbye-mars-one-the-fake-mission-to-mars-that-fooled-the-world/?sh=7fe158982af5

[6] "NASA's Journey to Mars - Pioneering Next Steps in Space Exploration." NASA. February 3, 2015. https://www.nasa.gov/sites/default/files/atoms/files/journey-to-mars-next-steps-20151008_508.pdf

exploration. Finally, the "Earth Independent" stage is where attempts at long-term settlement of Mars would begin in earnest.

While the agency has not produced any official cost estimates for the program, several estimations by NASA employees and government research reports exist. Brent Sherwood, manager of mission formulation at NASA's Jet Propulsion Laboratory, estimated that a crewed mission to Mars would cost around $100 billion over thirty to forty years.[7] A comprehensive report authored by the National Research Council argued that in order to achieve a landing by 2050, the pathway to Mars would need to cost less than $220 billion in order for the project to be justifiable for the federal government.[8] For context, the International Space Station required $100 billion to build and costs roughly $4 billion in maintenance every year, with the vast majority of the cost (i.e. 83% of it) falling on the United States.[9,10]

However, it is important to note that it is highly possible that we will see massive reductions in the costs of space enterprise arising from technological innovations in reusable space launch technology, propulsion technology, life support systems, etc. As an example, the advent of SpaceX's Falcon 9 and Falcon Heavy rockets have dramatically decreased the cost of launching material into space because they can be reused.[11] SpaceX advertises a cost of $2,720 per kilogram to launch into Low Earth Orbit (LEO). For comparison, NASA's Space Shuttle cost $54,500 per kilogram.[12] In the future, SpaceX's Starship could reduce costs even further. Musk plans for Starship to cost as little as $10 per kilogram to launch to LEO and as little as $20 to $30 per kilogram for lunar payloads.[13]

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[7] Wall, Mike. "Should NASA Ditch Manned Missions to Mars?" Space.com. 2013. https://www.space.com/16918-nasa-mars-human-spaceflight-goals.html

[8] National Research Council. *Pathways to Exploration: Rationales and Approaches for a U.S. Program of Human Space Exploration*. Washington, DC: The National Academies Press. 2014 https://doi.org/10.17226/18801.

[9] McKie, Robin "Twenty years of the International Space Station – but was it worth it?" The Guardian. October 25, 2020. https://www.theguardian.com/science/2020/oct/25/twenty-years-of-the-international-space-station-but-was-it-worth-it

[10] National Research Council. Pathways to Exploration: Rationales and Approaches for a U.S. Program of Human Space Exploration. 2014

[11] Sheetz, Michael. "Elon Musk touts low cost to insure SpaceX rockets as edge over competitors" CNBC. April 16, 2020. https://www.cnbc.com/2020/04/16/elon-musk-spacex-falcon-9-rocket-over-a-million-dollars-less-to-insure.html

[12] Jones, Harry. "The Recent Large Reduction in Space Launch Cost" 48th International Conference on Environmental Systems. July 8, 2018. https://ntrs.nasa.gov/citations/20200001093

[13] Zafar, Ramish. "SpaceX Could Bring Starship Launch Costs Down To $10/kg Believes Musk" *WCCFTech*. May 8, 2020. https://wccftech.com/spacex-launch-costs-down-musk/

At present, it is difficult to accurately predict how much landing humans on Mars would cost because of this rate of technological advancement. As the report from the National Research Council Notes, many of the capabilities needed for successful settlement of Mars have not been actualized, making realistic budget calculations difficult. The National Research Council, for their part, used margins of 50% for development efforts and 25% for production and operations to formulate their cost estimates. Furthermore, their cost analysis was based on historical NASA acquisition patterns, derived from past examples like the Apollo missions or the launching of the ISS. They stipulate that costs could be reduced through "extensive use of broadly applicable commercial products and practices."[14] As SpaceX's ability to slash launch costs with their Falcon rockets demonstrates, this sort of technological innovation that brings down costs is likely to continue. Regardless, one thing is clear: reaching Mars will not be cheap.

III. Space Tourism

One of the most prominent potential uses of space is the possibility of space tourism, a system in which people pay a ticket price to venture into space or to Mars. One of the most prominent players in this industry is Virgin Galactic. Founded in 2004 by Richard Branson, Virgin Galactic has been attempting to develop commercial spacecraft in order to provide suborbital flights for space tourists. However, they have faced a number of difficulties and setbacks in their attempts to make commercial space tourism a reality. Their development of a viable commercial spacecraft has been beset by major delays, the biggest of these being a catastrophic crash in 2014 that killed one of the craft's pilots.[15] It

[14] National Research Council. Pathways to Exploration: Rationales and Approaches for a U.S. Program of Human Space Exploration. 2014

[15] "Virgin Galactic spacecraft crash kills pilot" BBC. November 1, 2014. https://www.bbc.com/news/world-us-canada-29857182

was not until 2018 that Virgin Galactic was successfully able to reach LEO.[16] However, in 2021 both Virgin Galactic and Blue Origin were able to successfully launch crewed missions into space.[17, 18]

Aside from engineering difficulties, one of the major problems the company struggles with is bringing in a consistent source of revenue. While Virgin Galactic was initially able to sell around 600 tickets at prices between $200,000 and $250,000, they struggle to "generate significant revenue" by their own admission, only bringing in $238,000 of revenue in 2020.[19,20] However, the company remains optimistic that they will soon be able to leverage revenue from commercial space flights for tourists. Virgin Galactic CEO Michael Colglazier told investors that he sees each spaceport generating $1 billion in revenue every year with each spaceport handling 400 flights. This works out to roughly $400,000 a ticket.[21]

Furthermore, Virgin Galactic faces competition with Blue Origin, which has similar plans to bring tourists into space. Blue Origin has been routinely testing their Blue Shepard rockets with plans for its first crewed launch on July 20, 2021.[22] Tentatively, tickets aboard Blue Origin are expected to cost at minimum $200,000 and up to $300,000. As the industry matures, competition between firms like Virgin Galactic and Blue Origin is likely to drive down ticket prices and reduce profit margins.

In addition to sales of tickets, companies like Virgin Galactic and Blue Origin are also looking at other potential streams of revenue. Virgin Galactic says that their spaceflight system is also targeted

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[16] "Branson's Virgin Galactic reaches edge of space." *BBC*. December 13, 2018. https://www.bbc.com/news/business-46550862

[17] "Richard Branson's trip to space is about convincing others to come along." *Vox.* Jul 11, 2021. https://www.vox.com/recode/22570789/richard-branson-elon-musk-jeff-bezos-spacex-blue-origin-virgin-galactic.

[18] "Jeff Bezos launches into space on Blue Origin's 1st astronaut flight." *Space.com*. https://www.space.com/jeff-bezos-blue-origin-first-astronaut-launch.

[19] Sheetz, Michael. "Virgin Galactic delays next spaceflight test to May, with commercial service launch pushed to 2022." CNBC. February 25, 2020. https://www.cnbc.com/2021/02/25/virgin-galactic-spce-earnings-q4-2020.html

[20] "VIRGIN GALACTIC ANNOUNCES FOURTH QUARTER AND FULL YEAR 2020 FINANCIAL RESULTS" Virgin Galactic. Feb 25. 2021. https://investors.virgingalactic.com/news/news-details/2021/Virgin-Galactic-Announces-Fourth-Quarter-and-Full-Year-2020-Financial-Results/default.aspx

[21] Sheetz, Michael. "Virgin Galactic says each spaceport it launches from is a $1 billion annual revenue opportunity." November 6 , 2020. https://www.cnbc.com/2020/11/06/virgin-galactic-each-spaceport-is-1-billion-annual-revenue-opportunity.html

[22] Sheetz, Michael. "Jeff Bezos' Blue Origin to launch first space tourism passengers on July 20 and auction off a seat." CNBC. May 5, 2021. https://www.cnbc.com/2021/05/05/jeff-bezos-blue-origin-space-tourism-flight-launches-july-20.html

at those looking to conduct microgravity research or for the training of professional astronauts.[23] Virgin Galactic, in fact, signed a contract with the Italian government to allow researchers to conduct experiments in space using Virgin Galactic's spaceflight systems.

In the context of a Mars mission, the sale of tickets to individuals becomes more complicated given the massively increased cost- and time-scales of reaching Mars, as opposed to brief 90-minute space flights offered by Virgin Galactic or Blue Origin. While Elon Musk optimistically predicts that ticket price to Mars could reach as low as $500 or $100 thousand, relying solely on ticket sales to finance a mission to Mars is likely infeasible.[24] Current models for space tourism already exclusively target the ultra-wealthy who are able to afford spending hundreds of thousands of dollars on a brief space flight. The higher costs of Mars tourism would be restricted to an even smaller pool of ultra-high net worth individuals with an extreme affinity for space travel. This lack of demand may not justify the costs of managing a Mars tourism business.

Furthermore, the possibility of tourism to a functioning Mars colony would only be possible after a relatively large, independent settlement is established on Mars—a prospect that is likely decades out. In fact, any sort of leisure tourism to Mars would require such a significant settlement to have not only the infrastructure to support tourists, but to return them to Earth—an aspiration that may not be realized until years, if not decades, after such a settlement is formed in the first place.[25] Even then, it would still require a months long journey only to reach a largely barren, inhospitable planet. As it currently stands, widely accessible space tourism to LEO is still likely years out. As Virgin Galactic demonstrates, the profitability of such a venture also remains to be seen. Given that the viability of LEO tourism is still an open question, any sort of "tourism" to Mars would likely be impossible for years after initial settlement.

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[23] “”Fourth Quarter and Full Year 2020 Investor Update.” Virgin Galactic. February, 25, 2021. https://s24.q4cdn.com/816362521/files/doc_presentations/Virgin-Galactic-Q4-FY-2020-Earnings-Presentation-2.25.21.pdf

[24] Wall, Mike. “Tickets to Mars Will Eventually Cost Less Than $500,000, Elon Musk Says” Space.com 2018. https://www.space.com/elon-musk-spacex-mars-mission-price.html

[25] China plans to send a crewed mission to Mars by 2023. For more, see: https://www.reuters.com/business/aerospace-defense/china-plans-its-first-crewed-mission-mars-2033-2021-06-24/&sa=D&source=editors&ust=1626293718318000&usg=AOvVaw1uo33OLpAJHi3iRr9mYHya.

IV. Media and Product Revenue

The holistic review of the potential sources of income for a mission to Mars encompasses the profit that is obtained before a ship even leaves the ground. It is estimated that close to 600 million people watched the Apollo 11 mission in 1969.[26] It was also estimated that broadcast news networks paid upwards of $11 to $12 million to conduct the broadcast over one and a half days.[27] That is close to $80 million in today's dollars, taking inflation into account. The Apollo 11 mission holds the record for the most viewers ever for a space launch. However, it may be fair to assume that the number of people watching a mission to Mars launch will be greater. A smaller, less spectacular, joint NASA-SpaceX launch was able to gather 10.3 million viewers to watch at one time.[28] The first ever human mission to Mars is sure to draw in an even larger crowd.

Furthermore, since 1969 the Earth's population has significantly grown and, with the advent of the Internet, the accessibility of viewing a space launch has grown, too. As of 2016, there are nearly 3.4 billion internet users.[29] The Superbowl and its revenue can be used as a possible estimation of revenue for a broadcast of this magnitude. In 2019, CBS—which broadcasted the Apollo 11 mission—generated $336 million from ad revenues for the Superbowl.[30]

Additionally, with 21st century technology, a Mars space launch can generate passive income. Unlike the Apollo 11 launch, a modern day Mars launch has access to online video platforms like Youtube. Indeed, the Perseverance rover landing on Mars has accrued 22 million views on Youtube so far.[31] Since the writing of this chapter, NASA boasts over 9 million subscribers on Youtube and Space X has close to 6 million.[32] A platform like Youtube presents the opportunity to post monetized videos

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[26] CNN Editorial Research. "First Moon Landing Fast Facts." CNN. Cable News Network, July 10, 2020. https://www.cnn.com/2013/09/15/us/moon-landing-fast-facts/index.html.
[27] Ibid
[28] Wall, Mike. "SpaceX's 1st Astronaut Launch Was NASA's Most-Watched Online Event Ever." Space.com. Space, June 2, 2020. https://www.space.com/nasa-spacex-astronaut-launch-viewer-record.html.
[29] Roser, Max, Hannah Ritchie, and Esteban Ortiz-Ospina. "Internet." Our World in Data, July 14, 2015. https://ourworldindata.org/internet.
[30] Adgate, Brad. "What You Should Know About Super Bowl LIV Advertising And Broadcast." Forbes. Forbes Magazine, January 30, 2020. https://www.forbes.com/sites/bradadgate/2020/01/27/super-bowl-liv-fun-facts/?sh=3989734e718e.
[31] NASA. "Watch NASA's Perseverance Rover Land on Mars!" https://www.youtube.com/watch?v=gm0b_ijaYMQ&t=7s. July 14, 2021.
[32] See the NASA and SpaceX YouTube channels: https://www.youtube.com/channel/UCLA_DiR1FfKNvjuUpBHmylQ; https://www.youtube.com/user/spacexchannel.

of a Mars launch to accumulate revenue. The profit that is collected from Youtube will vary, based on the types of ads and number of viewers. The exact amount received is unclear, but it is worth noting that the income received from Youtube can be a supplemental source of revenue. People may watch and rewatch videos, and each view results in a small amount of revenue generated. Therefore, even after the launch of the ship, uploading videos to this platform might generate revenue for the enterprise.

One of the more out of the box ideas for producing revenue from a mission to Mars was Mars One's plan to create a 24/7 reality television out of their Mars colonists. This plan faced no shortage of ethical criticism and did not come to fruition.[33] However, the possibility of Mars entertainment television that is broadcast back to Earth could present a legitimate source of revenue. While a 24/7 reality TV show might be excessively intrusive, a documentary about the first settlers on Mars and the journey would likely be extremely popular. In the long term, Mars might even develop unique sports that take advantage of the planet's lower force of gravity.

A modern-day Mars space launch as noted can generate income from media outlets and streaming, but it can also generate income from merchandise. NASA shirts and memorabilia are commonly sold and the NASA logo is in the public domain.While NASA holds certain restrictions around its insignia, private companies are free to use it on their merchandise as long as they are approved.[34] However, we can look at companies like SpaceX and see that they have a full website of countless merchandise that can be sold.[35] They sell an assortment of items on the website, from clothes to backpacks. Unfortunately, we do not have access to data on the amount sold; therefore, it is difficult to calculate the potential revenue that can be earned through this channel.

The total amount earned from pre-launch avenues can be a major source of capital in funding a mission to Mars. The versatility and diversity of media and product income helps provide a platform for building a robust portfolio. By conducting analyses of consumer data and customer surveys, a

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[33] Erik Seedhouse. *Mars One: The Ultimate Reality TV Show?* Berlin: Springer, 2016.
[34] Dunbar, Brian. "NASA Regulations for Merchandising Requests." NASA. NASA, November 15, 2005. https://www.nasa.gov/centers/ames/multimedia/merchandising.html.
[35] "Official SpaceX Store." SpaceX Store. accessed May 1, 2021. https://shop.spacex.com/.

better evaluation of merchandise and media revenues can be made. Furthermore, the media and products are an element to a much bigger portfolio of sources of revenue in a crewed-mission of Mars.

V. Extractable Martian Resources

Studies of the Martian environment reveal the solar system's largest volcano—Olympus Mons; the area may hold enormous deposits of nickel, copper, chromium, and other mineral resources.[36] In addition to the volcanic resources on Mars, there are also valuable ores and minerals from impact craters. An estimation of the value of North America's craters—which, like Martian craters, contain valuable extraterrestrial ores—was determined to be $5 billion annually.[37] There are an estimated 43,000 impact craters present on Mars. Any estimations of the value of Martian craters has yet to be confirmed because there still have not been any Martian samples analyzed on Earth. However, if they are similar to Earth's impact craters, then the potential revenue is certainly great.

Beyond just minerals and ores, Mars is also home to other deposits of resources that are not found as commonly on Earth. Deuterium (an isotope of hydrogen) is much more abundant on Mars relative to Earth and is used in developing fusion reactors.[38] The payout for deuterium is $10,000 per kilogram — while nowhere near the price of gold, it is still worth more than 10 times the value of silver.[39] Furthermore, the price of deuterium may rise, along with an incentive to capture it from Mars. The steep cost of transport may keep the price high despite supplies of it increasing. And as countries begin transitioning away from fossil fuels, and if fusion energy becomes a viable form of nuclear energy, the demand for deuterium may rise. If nuclear fusion becomes feasible, it presents the lucrative possibility of quadrupling the current energy production capacity of nuclear fission.[40]

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[36] West, Michael D. and Jonathan D. A. Clarke. "Potential Martian Mineral Resources: Mechanisms and Terrestrial Analogues." *Planetary and Space Science* 58, no. 4 (2010): 574-582.
[37] Grieve, R. A., and V. L. Masaitis. "The Economic Potential of Terrestrial Impact Craters." *International Geology Review*36, no. 2 (1994): 105–51. https://doi.org/10.1080/00206819409465452.
[38] Zubrin, Robert. "The Case for Colonizing Mars." National Space Society, August 1996. https://space.nss.org/the-case-for-colonizing-mars-by-robert-zubrin/.
[39] Ibid
[40] "Advantages of Fusion." Iter. https://www.iter.org/sci/Fusion.

However, there are great cost barriers associated with any operation attempting to bring Martian materials back to Earth. For one, the cost of payloads is extremely high. Transporting a payload to Mars using Spacex's Falcon Heavy rockets costs $5,357 per kilogram, significantly less expensive than previous launch costs but expensive nonetheless.[41] Furthermore, this does not account for the cost and energy requirements of actually extracting the resources and bringing them back from Mars. NASA and the European Space Agency's plan to return a one kilogram sample from Mars is estimated to cost around $7 billion and take over ten years.[42] If technology can reach a point where the costs can be reduced, then the potential for a profitable mining and resource extraction enterprise could be achievable. But as it currently stands, the upfront costs of such an operation likely outweighs the value of whatever resources could be extracted from Mars.

Despite the shortcomings of resource extraction methods as a source of income, there is a small potential for commercial profit. A popular form of wedding rings are meteorite rings. Many of these rings sell for thousands of dollars. A Martian meteorite ring that is custom made is currently on sale for $29,000.[43] This opens the possibility of bringing small amounts of Martian rock or minerals back to the Earth and fitting them for potential use in rare space jewelry. The scarcity of these minerals is what gives them their value on Earth. Since the technological capabilities of bringing back large amounts of Martian resources is not currently possible, their scarcity can be used as an advantage. However, the market of Mars jewelry is not widely tested, though investment into consumer surveys might help to develop a wiser estimation of its value. There is not enough data to make a clear estimation for the amount of money that can be generated by Martian jewelry. From the aforementioned sources of revenue, there currently does not seem to be a significant amount of profit that can be extracted. A more practical use of these materials, with the current technological limitations, would be scientific research.

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[41] Fickling, David. "We're Never Going to Mine the Asteroid Belt." Bloomberg. December 21, 2020. https://www.bloomberg.com/opinion/articles/2020-12-21/space-mining-on-asteroids-is-never-going-to-happen

[42] Froust, Jeff. "NASA and ESA outline cost of Mars sample return." Spacenews. July 29, 2020. https://spacenews.com/nasa-and-esa-outline-cost-of-mars-sample-return/

[43] "Meteorite Engagement Ring from Mars: Custom Engagement Rings." Abby Sparks Jewelry, April 15, 2020. https://www.abbysparks.com/custom-jewelry/the-black-beauty-yellow-gold-diamond-engagement-ring/.

Until there is technology capable of lessening the cost of interplanetary commerce, Martian resource extraction is not possible. The value of the minerals and other resources on Mars and the asteroids near Mars can surpass $1 trillion.[44] However, there are challenges that make interspace commerce extremely expensive. In addition to the high cost of sending a single payload, launch windows to Mars are infrequent. The orbits of Earth and Mars only line up every couple years for sufficiently efficient travel distances, using current rocket technology. Therefore, interspace commerce with Mars' resources with current technologies is unreliable and not yet profitable.

VI. Intellectual Property and the Provision of New Services

In addition to the export of material goods like rare minerals or deuterium, the settlement of Mars presents significant opportunities to make money off of technological and intellectual developments that may arise out of these ventures generating content for various industries. Innovations in life support, agriculture, in-situ resource utilization, energy, radiation shielding, and the many other capabilities necessary to sustain a Mars colony are likely to have financially lucrative applications on Earth.[45] One example of this can be seen in Solar Electric Propulsion systems which are already used in many commercial satellites.[46] Improvements in Solar Electric Propulsion for the purposes of supporting a Mars mission are also of interest to companies launching commercial satellites, who could increase the operational life cycle of their satellites.[47]

Scholar Robert Zubrin also argues that Martian settlers might be able to sustain themselves off the export of intellectual property. Zubrin draws an analogy to the settlement of the Americas, arguing that an extreme shortage of labor would drive a technological culture on Mars that could produce inventions that they could sell back to Earth.[48] Detractors argue that relying heavily on intellectual property faces large political risks. At the moment, it is unclear how IP law would be enforced on an

[44] Wong, Andrew. "Space Mining Could Become a Real Thing - and It Could Be Worth Trillions." CNBC. CNBC, May 15, 2018. https://www.cnbc.com/2018/05/15/mining-asteroids-could-be-worth-trillions-of-dollars.html.
[45] Carberry, Chris and Rick Zucker. "Is there a business case for Mars?" The Space Review. October 10, 2016. https://www.thespacereview.com/article/3080/1
[46] "Solar Electric Propulsion" NASA Glenn Research Center. accessed May 2, 2021. https://www1.grc.nasa.gov/space/sep/
[47] Ibid
[48] Zubrin, Robert. "The Economic Viability of Mars Colonization" http://www.aleph.se/Trans/Tech/Space/mars.html

inter-planetary scale and what recourse Mars settlers could have if people on Earth did not respect their copyrights.

VII. Public-Private Partnerships

This chapter has so far focused on ways to generate revenue from private actors (tourism and media revenue) or from industrial ventures like extracting resources or collecting royalties on intellectual property. We argue that these private revenue streams alone are insufficient for funding a private mission to Mars. However, one avenue of funding that is becoming increasingly common in LEO spaceflight that has not been explored is that of public-private partnerships (PPP). Put simply, a PPP is a type of long-term contractual relationship between the government and one or more private actors.[49]

NASA has already been contracting a variety of private partners to develop the requisite technologies for LEO, lunar, and Mars-based operations for years.[50] One of the biggest and robust partnerships between NASA and the private sector can be seen in the operations of the ISS. Launched in 2005, the effort to transition from a wholly government-owned and operated cargo delivery system to the ISS to one primarily operated by the private sector is called the Commercial Orbital Transportation Services (COTS).[51] This program paved the way for the development of SpaceX's Falcon 9 and Orbital's Antares launch vehicles.[52]

One of the biggest successes of the COTS program was the tremendous cost savings it delivered. In 2010, NASA conducted a study to compare what it cost SpaceX and Orbital to develop their launch vehicles compared to what it would have cost NASA to develop comparable technology. The study found that NASA estimates for such a project would amount to almost $4 billion while the

[49] "Recommendation of the Council on Principles forPublic Governance of Public-Private Partnerships." OECD. May 2012. https://www.oecd.org/governance/budgeting/PPP-Recommendation.pdf
[50] "NASA Announces Partners to Advance 'Tipping Point' Technologies for the Moon, Mars." NASA. October 14, 2020. https://www.nasa.gov/directorates/spacetech/solicitations/tipping_points
[51] "Commercial Orbital Transportation Services (COTS)" NASA. accessed May 2, 2021.https://www.nasa.gov/commercial-orbital-transportation-services-cots
[52] Miller, Charles, Alan Whilhite, Dave Cheuvront, Rob Kelso, Howard McCurdy, Edgar Zapata. "Economic Assessment and Systems Analysis of an Evolvable Lunar Architecture that Leverages Commercial Space Capabilities and Public-Private-Partnerships." NextGen Space LLC. July 13, 2015.

reported cost to SpaceX was $443 million, accounting for a cost savings of almost 89%.[53] Based on this experience, it is reasonable to assume that the continued utilization of PPP may significantly reduce the cost of reaching Mars.

PPPs are able to solve major problems for both the government and private actors when it comes to space exploration. The U.S. government has an interest in continuing to invest in human spaceflight for a variety of reasons. One 2009 National Research Council report argued that the U.S. civil space program has been "integral to achieve goals significant to the nation." They cite a variety of reasons, from national security to providing clean energy to improving the U.S.'s international standing.[54] Private actors are, in turn, able to provide services cheaper than the government and have security knowing that there is a paycheck waiting for them once they deliver.

Despite these advantages, PPPs do carry significant disadvantages and risks. Some of the biggest, especially in a long-term project like Mars exploration or settlement, are political risks from shifting political administrations. As new Congresses and Presidents are elected, new space policies are promulgated. This instability would likely dissuade investors from entering into such a long-term and risky contract with the U.S. Government to reach and/or settle Mars. Furthermore, collaboration with the government would not change the underlying reality that successfully settling or even landing a crewed mission on Mars would be incredibly risky and difficult financially and technologically.

To address these challenges, one paper discussing the settlement of the Moon suggests the development of an "International Lunar Authority" to mitigate the business risks associated with PPP acquisition strategies. Drawing on examples like CERN, the transnational European nuclear research organization, they argue that developing a transnational lunar authority to manage settling the Moon could mitigate many of the risks inherent to PPP.[55] A similar authority may prove similarly effective for Mars settlement by bringing together international actors and providing a stable, long-term mandate.

In spite of these challenges, our research suggests that PPP will likely be one of the few viable ways for commercial actors to earn profit on the road to Mars settlement. As we have discussed, most

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[53] Ibid.

[54] National Research Council, *America's Future in Space: Aligning The Civil Space Program With National Needs, The National Academies Press*, Washington, D.C., 2009, p. 59.

[55] Ibid.

of the traditional propositions for making money from settling Mars are impractical, uncertain, or require massive time horizons. At present, one of the major sources of revenue for companies like SpaceX or Blue Origin is executing government contracts, demonstrating the value of PPP in LEO or lunar spaceflight. In fact, in April of 2021, NASA announced that it had awarded SpaceX a $2.89 billion dollar contract to land astronauts on the Moon as a part of the Artemis program,[56] showcasing how PPP will likely become a bigger part of NASA's overall strategy.

VIII. Conclusion

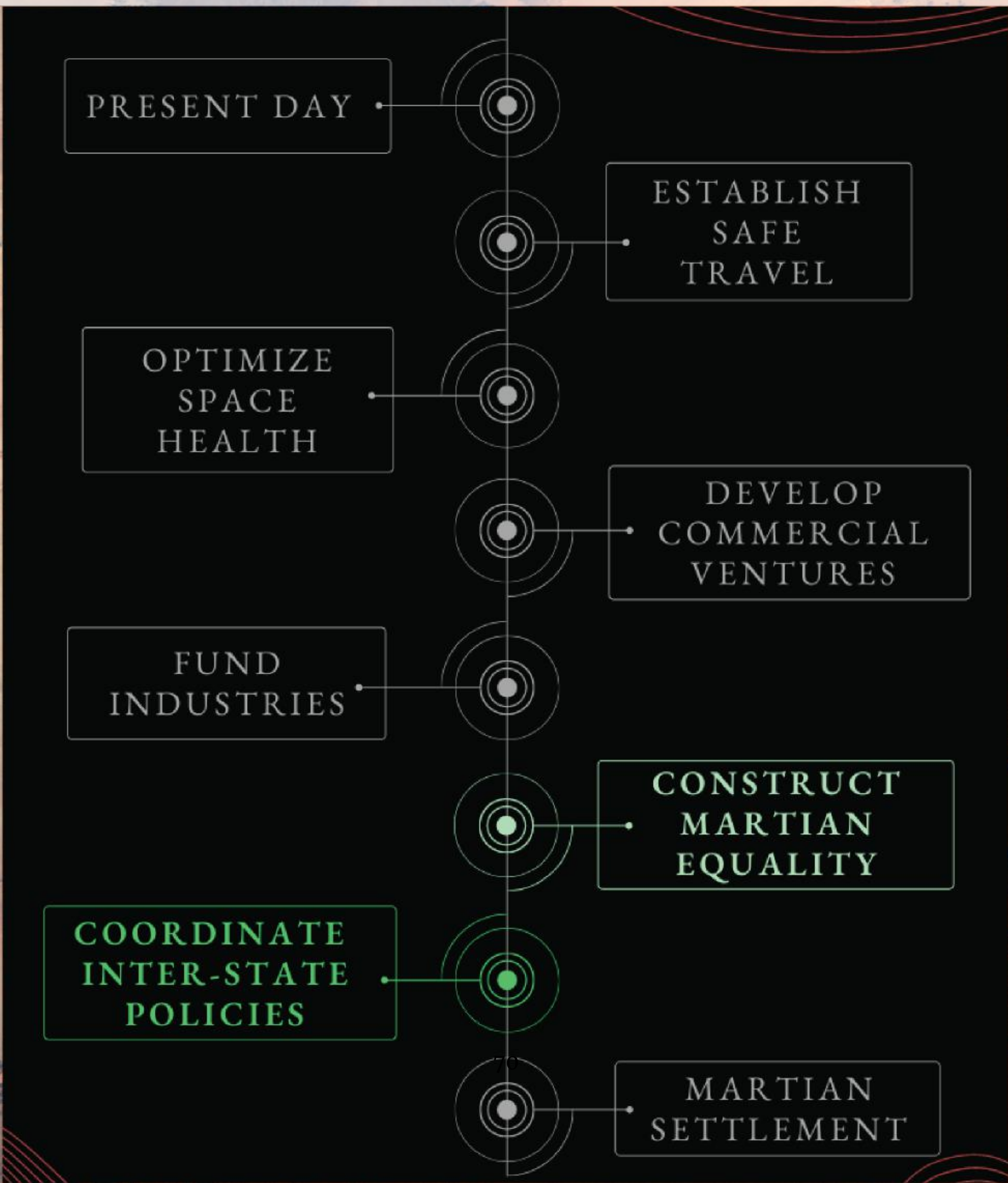
This chapter has examined the costs of a crewed mission and eventual settlement of Mars as well as several avenues from which profit could be generated from a Mars settlement. We argue that the high investment required for any kind of Mars mission would heavily outweigh any revenue that could be generated for years, if not decades. However, if technological advances continue to reduce the cost of interplanetary travel, the prospects of space tourism, resource extraction, and intellectual property exports could eventually lead to Mars settlement that is self-sufficient or even profitable.

Our research considers both private and public-private avenues for funding a Mars mission. We have not considered non-traditional funding schemes, such as crowdfunding. At present, any serious attempt to put humans on Mars would require substantive investment by the government through the form of public-private partnerships. Ultimately, it is worth considering if a profitability case for Mars is even required. For almost all of human existence, people have explored not for logical, profit-driven reasons, but simply out of a desire to explore. While a mission to Mars may not yet be commercially viable in the short term, it is possible that investors may choose to back the project for reasons other than the generation of profit. When considering a task so monumental and emotional as settling Mars, using a traditional profit driven framework may not be the most useful. As our research finds, settling Mars is likely of limited economic value, especially in the short run. There are many good reasons to explore and settle Mars, but the profit incentive may ultimately not be one.

[56] "As Artemis Moves Forward, NASA Picks SpaceX to Land Next Americans on Moon" NASA. April 16, 2021. https://www.nasa.gov/press-release/as-artemis-moves-forward-nasa-picks-spacex-to-land-next-americans-on-moon

3

Martian Governance



Systems for Resource Equality in Martian Society from Foundation to Independence[1]

Patrick Wilson,[2] Donald Pepka,[3] and Savannah Artusi[4]

Abstract

To explore ways of reducing injustice in a new, Martian society, this chapter proposes systems of governance, organized labor, and sustainability that would promote the rights of crew members, future settlers, and eventual citizens on Mars. We presume that Martian exploration will occur in three stages: Foundation, when people first arrive on Mars; Settlement, when residents on Mars still rely on support from Earth; and Independence, when Mars has developed a self-sustaining society.

Governance: During the Foundation phase, a "Mars Treaty" modelled after the Antarctic treaty would promote international cooperation. In the Settlement Phase, the Mars Treaty could be modified to include Martian representation in decision-making. Once Mars reaches the Independence phase, possibilities for representative democratic systems are explored.

Labor: Across all stages of development on Mars, organized labor is a tool for promoting equality. In the Foundation stage, crew members may have substantial leverage to protect equality and their labor rights. However, because the risk of inequality and the threat of effective anti-union policies are greater in the Settlement stage, labor unions are more important and more in need of formal protection. It is difficult to make projections about the Independence stage, but labor unions could remain a force for equality on Mars then, as they currently are on Earth.

Resource Sustainability: To protect space travel to Mars in the long-term, cleanup and regulation of Low Earth Orbit satellite debris is needed during the Foundation stage. En route to Mars, most spaceship materials should be reusable and meet multiple needs, which will reduce in-flight waste production. Upon arrival, missions to Mars must have policies in place to contain any waste materials and to clean up those that have already been left on the surface. In the Settlement stage, the viability of Martian society will heavily depend on Earth's ability to control and mitigate the effects of climate change to protect the resources being exported to Mars. Once Mars reaches the Independence Stage, it must enact laws to ensure the sustainable use of its resources—including those that may seem abundant on the planet, like water—to avoid the shortages experienced on Earth.

[1] Thanks to Adam Doll, Joanna Feaster, Somia Youssef, Jeremy Yu, Charles (Chase) Hamilton, and Spencer Kaplan for providing feedback on and editing this chapter.

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I. Introduction

Space has long captured the imagination of science fiction and popular media, enabling people to envision a better future. As the prospect of a Martian society becomes more realistic, the opportunity to realize that vision is presented to humanity. Establishing a presence on Mars sets the stage for interplanetary expansion, securing humanity's ability to live long and, ideally, prosper. However, this is not guaranteed. Without advanced planning and international cooperation, systems that generated inequality and suffering on Earth could be replicated on Mars. To reduce the risk of perpetuating those structural inequalities, this chapter proposes systems of governance, organized labor, and sustainability that would promote the fair distribution of resources on Mars.

For the sake of this discussion, we assume that Martian development will likely occur in three major stages, each with different challenges associated with resource inequality. First, during the Foundation stage, humanity is just beginning to set foot on Mars and establish bases and outposts. Mars bases will be owned and operated by terrestrial states or corporations. Crew members will live on Mars for brief periods of time and may need to be replaced regularly, due to radiation or other medical concerns.[5] Next, Mars will enter the Settlement stage. People will live permanently on Mars, raising children there, and contributing to a Martian society. Terrestrial interests may still directly own and govern these settlements but, as settlements become more complex, it may be possible for multiple entities to have a presence on the same settlement, such as a space tourism business on board a state-owned settlement. Finally, once Martian settlements are fully self-sufficient and separate from terrestrial control, they will reach the Independence stage. These newly independent Martian settlements might still engage in trade and other relations with Earth but would be entirely self-governed by Martians. For this chapter, it is assumed that a human presence on Mars will happen eventually, but we recognize that this may not actually happen and that there are many barriers to a long-term, self-sustaining human presence on Mars. Indeed, despite the predictions about the future that this chapter makes, it is impossible to be certain that Mars exploration will develop as we expect.

[5] Scoles, "Break Radiation Rules."

The choice to go to Mars presents the opportunity to plan ahead, to think differently about the systems that have developed on Earth, and to be intentional about preventing systemic inequality. In this chapter, we analyze systems of governance, organized labor, and sustainability that would promote the rights of crew members, settlers, and citizens on Mars. These rights include economic justice, protection of civil liberties, and equitable access to basic resources—including food, water, shelter, and breathable air—and the guarantee of these rights for future generations. In this chapter we will propose systems and address issues that may arise in order to ensure these rights throughout the stages of Martian development.

II. Governance on Mars

If humanity populates Mars, we will bring along our systems of governance. Ultimately, we establish governance and regulatory bodies that guide human behavior in every frontier we explore.[6] As with other frontiers, the best form, function, and structure of such a government for Mars is widely debated. The only thing humanity can know for certain, built upon our wealth of historical knowledge, is that the government for Mars will change over time.

Foundation

Because states are no longer the only space-faring entities, governments and private companies will likely collaborate on early systems of governance on Mars during the Foundation stage.[7,8] An option for governance during this phase would begin with a treaty signed by as many United Nations participants as possible—preferably all of them. While difficult to arrange, such a treaty would likely have the least dissent and longest lifespan of any international plans during this phase. First the structure and benefits of this hypothetical treaty will be discussed, followed by the shortcomings and challenges associated with such a venture.

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[6] Cohen, "Inevitability of Law," 1.
[7] Griggs, "Get to Mars."
[8] Etherington, "NASA taps for Mars."

This treaty would either replace the Outer Space treaty or build upon it, dictating the general rules to be followed during the Foundation stage, concerning in part the commercialization of Mars or the entire solar system. This treaty could perhaps be modelled after the Antarctic treaty. The Antarctic Treaty is remarkably simple and effective, spelling out how signatories should treat the continent as a place of peace and scientific research. In fourteen articles, the Treaty sets out a number of rules, from prohibiting military bases and weapons testing, to guaranteeing scientific free access and setting up international cooperation in science, to settling territorial disputes.[9] There are many specific components of the Antarctic Treaty that would fit well into a hypothetical Mars Treaty. First, such a Treaty should mimic the core mechanism of the Antarctic Treaty, allowing for new signatories to accede, as well as replicate the ability for modifications to be made to the document. Pairing the ability to make changes to the treaty with the Antarctic Treaty's dispute settlement procedure and annual Consultative Meetings would allow for some shared rules and responsibilities across Mars while still allowing states to govern their own bases. The annual Consultative Meetings would also serve the purpose of being where changes would be voted upon, and any conflicts resolved. Additionally, the Mars Treaty should have the same military and nuclear explosion prohibitions to keep Mars peaceful and safe. Finally, a Mars Treaty could include a bill of rights for Martian settlers, helping to safeguard human rights on the planet. This bill of rights should be modelled after the Universal Declaration of Human Rights and should include fundamental rights to not only civil and political liberties but economic, social, and cultural rights as well.[10]

Although this hypothetical treaty would form a complete framework for government on Mars, there are problems that may stem from such a treaty. Chief among them is the weakness of enforceability. Any state could decide to ignore the treaty and break any number of critical agreements. Additionally, commercial activity is almost guaranteed to be a driving force in Mars development, unlike in Antarctica, and thus will bring a host of untested situations.[11] Companies could break the treaty without their state's permission or knowledge, motivated by increasing profit. While the

[9] BAS, "The Antarctic Treaty Explained."
[10] UN, "Universal Declaration Human Rights."
[11] Persson, "Citizens of Mars Ltd.," 123.

Antarctica Treaty allows for inspection by observers of all stations, ships, and equipment in Antarctica to ensure compliance, that is likely an impossibility for Mars. In addition to the difficulty and expense in sending observers to Mars, adding such a clause to the Mars Treaty might sink its signing.

Another major flaw is arranging the initial signing of the Mars Treaty. States are almost guaranteed to disagree on the specifics, and negotiations could come to a standstill over any number of issues within the treaty; everything from guaranteeing scientific free access to prohibiting military presence could be the straw that breaks the camel's back. Stronger enforcement measures to address the problems previously discussed would likely only further strangle negotiations, and it is unclear if this hypothetical Mars treaty could ever get signed in today's geopolitical environment.[12]

Ultimately, having a Mars Treaty to manage the growing spread of bases across Mars would be ideal, but may be difficult to achieve. It would lead to some centralized regulations while still leaving the bulk of governance to the Earth states driving the development of Mars. This Mars Treaty would be sufficient to ensure peace and cooperation throughout the Foundation phase, only becoming outdated as the Settlement stage begins and progresses.

Settlement

As the decades go by, Mars will become the permanent home of some humans and will enter the Settlement stage. The companies and states of Earth that built the first bases will likely still be relevant, but as permanent settlers begin to grow in numbers, changes to the initial treaty structure will need to occur to allow for them to have a say in how they are governed. Local governments at each base could be established to manage the people living there and maintain their rights, but larger scale governments—up to one covering the entirety of Mars—are possible. The goal for these changes is to facilitate a peaceful transition from the Foundation phase, keeping terrestrial governments involved in a way that promotes autonomy for Martian settlers.

The model we propose for this phase consists of two parts: the formation of elected planetary representatives and the consent of the governed among the settlers. Democracy—which we broadly

[12] Lawson, "Ratifying International Agreements Difficult."

define as majority rule—is chosen for this model to equip settlers with equal decision-making capacities.[13] This would require extensive revisions to the Mars Treaty, setting up an election structure that allows settlers from across Mars to elect representatives to send to the annual meeting regarding the Mars Treaty. Those annual meetings would now have a Martian voice at the table, someone who is involved in any further changes to the treaty. Additionally, in this model, the governance of bases would begin to involve the settlers, although it would still be based on the terrestrial legal systems they originated from. This likely would involve elections for local leaders to both manage the bases and uphold the rights of their fellow Martians.

Some problems with such a system exist. This system would lead to a diverse number of local governance systems and laws, perhaps causing discord between bases with different national backgrounds.[14] Additionally, as the number of laws and regulations increase naturally with the increased population, it becomes increasingly likely the planetary elected body would fail to properly represent all on the planet and anger a particular base. Finally, such a drastic change to the initial Mars Treaty is likely to face some resistance from Earth states and corporations, who would lose power. Getting these changes approved may prove impossible.

Despite these problems, this system of elected planetary representation and integrated local elections is one of the best for the Settlement phase. It allows for an easy transition from the Foundation phase with modifications to the initial Mars Treaty, and keeps terrestrial governments involved while allowing Martian settlers to have autonomy. This process also secures the rights of settlers through continued use of the modified treaty's bill of rights and with local and planetary representatives to uphold it.

Independence

Finally, Mars could become self-sufficient, truly an independent world. This would likely be centuries into the future, when Mars produces food and resources sufficient for all settlers.[15] This phase

[13] This chapter models its proposed governance structure on the United States.
[14] Karim, "Clash of Ignorance," 17.
[15] Cannon, "Feeding People on Mars," 246.

is the most unpredictable from the present, but should likely result in a new state, or possibly several states, on Mars that interact with the states of Earth as their own entities.[16]

The structure in this phase is a full-fledged government, so the system we will explore will be what form that planetary government takes. A good option for securing the rights of the Martian people would be a representative democracy for regulations on the planetary scale, with most day-to-day governance and regulation occurring through local governance from various forms of elected government. However, many other forms of democracy could work while preserving the rights of Martians.

The transition from the modified Mars Treaty in the Settlement phase to this hypothetical planetary government will be difficult. Earth states are unlikely to want to relinquish their hold on Mars and could fight the swap to sovereignty. Assuming the Mars Treaty was modified during the Settlement phase to allow for planetary representation, that representative body will likely be those pushing for Independence. Once Mars is self-sustaining with the means to produce all of the resources it needs for survival, the representative body can begin the Independence push and the final phase of humanity on Mars will be at hand.

III. Organized Labor on Mars

Within each stage of development on Mars, there is a risk of resource inequality among settlers. Here, resource inequality refers to both economic inequality, such as income or wealth inequality, and an inequality in access to basic resources necessary for survival, such as food, water, and oxygen. For a number of reasons that shall be discussed, regulation is necessary to mitigate this inequality. Reducing or mitigating resource inequality is a complicated task, with many facets and multiple potential approaches. One such approach may involve the structure of the economy itself; a centralized, socialist economy could directly ensure equality. However, this section shall assume a capitalist Martian economy and will propose one potential approach for regulating inequality in such a scenario: organized labor.

[16] Eveleth, "Mars should be independent."

On Earth, labor unions function as vital institutions for reducing economic inequality.[17] They provide workers a mechanism for collectively organizing themselves and negotiating with their employer on various conditions of employment. Collective bargaining, combined with various enforcement tactics such as striking, enables labor unions to regulate firms, both directly and indirectly.[18] Moreover, unions have a history of advocating for economic equality for more than just workers at a particular firm, but for workers of other firms and low-income individuals.[19] While a variety of factors today render unions in the U.S. weak, they previously were a tremendous force for reducing overall income inequality.[20] Altogether, it is not unreasonable to suppose that a Martian union could serve the crucial function of regulating the risk of resource inequality among settlers on Mars, especially during later stages of development.

This section hopes to open a discussion into the applicability of organized labor to society on Mars. Further research is necessary into both the advantages and disadvantages of extraterrestrial unionization.

Foundation

At this stage, when bases on Mars are most unstable, state or corporate actors have the greatest incentive to regulate any source of risk threatening a mission's success. Early settlers will be under a variety of psychological pressures which threaten the integrity of a mission to Mars, including interpersonal or group conflict.[21] Such conflict can arise as a result of mental health problems or other stressors in space or on Mars.[22] However, substantial resource inequality can also result in conflict between unequal groups.[23] The magnitude of this conflict depends both on the magnitude of the inequality and on the presence of other stressors; interpersonal conflict might interfere with cohesion

[17] Brady, Baker, and Finnigan, "When Unionization Disappears," 875; McNicholas, Shierholz, and Poydock, "Union Workers," 7.
[18] Western and Rosenfeld, "Unions, Norms, and Wage Inequality," 517.
[19] Currarino, "The Politics of 'More,'" 26; Brueggemann, "Role of Organized Labor," 1034-1035.
[20] Western and Rosenfeld, "Unions, Norms, and Wage Inequality," 532-533.
[21] Kanas, "Psychosocial Issues," 104.
[22] Tachibana, "Hobbesian Qualm," 29.
[23] Dutta, Madden, and Mishra, "Group Inequality and Conflict," 274.

and mission objectives or even threaten the mission's existence, if severe enough.[24] Though, the risk of mutual destruction from severe conflict may itself serve as a deterrent to all workers on a base. In any case, there may be a need—and an incentive for mission planners—to ensure an equal distribution of vital resources (food, water, and oxygen) for early missions; failing to do so could be inefficient or even disastrous. There may still be the possibility of wage inequality among crew members, but at this stage crew members will likely be motivated by different objectives than wealth or even economic security. So long as they are paid sufficiently, wage inequality might not concern workers much; previous missions in space have been successful despite such apparent inequalities.[25]

Labor unions at this stage thus might not be needed for addressing inequality in resources but could still serve other important functions. For instance, they could address the risk of over-working crew members. Any early mission to Mars will face a significant time constraint. Within this finite window of time, states or corporations will want to conduct as much research as possible—even if it may mean working crew members to exhaustion. Certainly, due to the extreme environment on Mars, crew members will need to work for a greater proportion of time. Yet this overworking itself can be a psychological stressor.[26] Of course, the need to protect crew members' psychological health provides a countervailing incentive here. Even so, during the National Aeronautics and Space Administration's (NASA) Skylab mission, astronauts felt exhausted and overworked, and—deliberately or inadvertently—successfully protested their labor conditions.[27] Their strike cost NASA millions of dollars—demonstrating the immense leverage they possessed while in space (once they returned to Earth, however, NASA never sent them to space again).[28] In fact, even for round-trip missions, Martian crew members likely will exceed radiation exposure limits and will not return to Mars a second time regardless of any actions they take, providing them even greater leverage than the Skylab astronauts.[29] Thus, an organized protest among crew members could be an effective means of ensuring they have a say in their labor conditions.

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[24] Kanas, "Psychosocial Issues," 114.
[25] Simmons, "Apollo 11 Astronauts."
[26] Kanas, "Psychosocial Issues," 104.
[27] Giaimo, "'Space Strike' in 1973."
[28] Hiltzik, "NASA Astronauts Staged a Strike."
[29] Scoles, "Break Radiation Rules."

Even on Mars, workers should have a voice in how they labor. Whether this will be achieved through unregulated organized protests which may be costly to employers, or through some fair, legal mechanism as exists in states around the world, is yet to be seen. It should be clarified, though, that at this stage of development, organized labor on Mars or in space would not quite resemble terrestrial labor unions. There would be a small number of workers in space, and they would both live and work together—there would be no need for a formal "union" to assemble an organized protest. The astronauts at Skylab had no such union.[30] Rather, they organized in an informal kind of directly democratic union, rather than a more traditional representatively democratic union.

Settlement

As settlements become more complex and profitable, the risk of resource inequality rises. Assuming long-term survival and reproduction on Mars becomes possible, greater numbers of settlers might live out their lives and raise children on Mars. This, in turn, could open the door to both social stratification and structural, intergenerational inequality. Once a settlement begins producing profits, the possibility for inequality arises. The incentive to maximize profit could lead to a separation of the settlers into two classes: the more elite "technocrats," specialists in science, engineering, or medicine, and the lower "laborers," performing less specialized yet still essential tasks for the settlement, such as maintenance or tourism services. Because the Martian environment emphasizes the necessity of all workers, the disparity between these classes may not be great, but it is still entirely possible for the lower class to be paid smaller wages as their employer tries to make profits.[31] Moreover, because owners of the settlements will need to provide and pay for life support for all workers onboard, the cost of basic necessities may be factored into wages.[32] Thus, as employers try to minimize the wages they pay, they may also try to minimize the basic resources they provide to workers—and this minimization would likely be unequal. The lower class might be forced to ration food and water and survive on lower oxygen levels. In a 2015 essay, author Adam H. Stevens imagines a similar vision of an extraterrestrial

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[30] Hiltzik, "NASA Astronauts Staged a Strike."
[31] Cain, "Economic Development of Space Colonies," 91.
[32] Cain, "Economic Development of Space Colonies," 86.

society, in which workers are obligated to purchase their oxygen supply.[33] In such a society, there could exist inequalities as well based on genetic proclivity to efficient oxygen consumption; an individual born with stronger lungs might be able to survive on less oxygen, therefore saving money and getting ahead.

With that said, it is worth recalling that, in the earlier Foundation stage, the risk of conflict arising from inequality posed a potentially existential risk to the mission, and thereby provided an incentive to mitigate resource inequality. Perhaps this will be the case in the Settlement stage as well; however, the risk calculus is unclear. After all, inequality does not guarantee conflict. The risk of conflict (especially violent conflict) itself dissuades groups from engaging in behaviors that might threaten their own well-being.[34] It is not certain to what extent a Martian settlement must be egalitarian to survive. Therefore, settlement governments may or may not choose to address resource inequality on their own.

If inequality is indeed allowed to persist on a Martian settlement, labor unions could play a role in advocating for change. Since terrestrial interests would still be governing settlements, workers would have similar advantages in distance and labor value as in the Foundation stage. Living together would also make organizing easier. Though, unlike in the Foundation stage, the larger quantity of workers may necessitate a more formal, representatively democratic union, rather than a simpler direct union. If the lower class, whatever form that takes, becomes discontent with their treatment, they might organize strikes or protests of some kind and engage in collective bargaining. They could demand reform from the settlement's governing body, extending beyond work conditions. Many anti-union tactics that exist on Earth might not affect workers as much on Mars. Namely, because there may not be much excess labor in space, and due to long distances between terrestrial replacements, it may be difficult to simply fire and replace disobedient workers, especially given their more essential status on a fragile Martian settlement.[35]

[33] Stevens, "The Price of Air," 57.
[34] Dutta, Madden, and Mishra, "Group Inequality and Conflict," 262.
[35] Cain, "Economic Development of Space Colonies," 92.

Even so, any Martian union will have to surmount a variety of old and new anti-union policies that governing entities may have at their disposal. The upper class on Mars might be unsympathetic or even opposed to unionization efforts, providing an on-planet opponent to organizing. Governing entities might use surveillance to monitor organizer and worker activities. To preempt the desire to unionize, governments might only send workers who are biased against unionization, or whose beliefs conform with those of the state. Such selective decisions are already made regarding ability-status.[36] Education in a settlement might be given an anti-union bias and, as happens on Earth, anti-union propaganda could abound. Perhaps most dangerous of all is control over the supply of oxygen and other vital resources—such power could be an extreme deterrent to any attempt to resist authority.

Independence

If a settlement becomes independent, it will no longer need labor unions to protect workers from terrestrial policies. Instead, Martian settlers would be able to determine their own government. At this point, it seems difficult to say if such a settlement would even choose to remain capitalist in nature. If not, labor unions might be irrelevant. If so, it still remains challenging to project the specifics of how that settlement's economy would function. If there are terrestrial corporations present in an independent settlement, workers might have leverage similar to the Foundation stage, since that employer would not necessarily be able to influence the settlement at large. However, there may also be a desire for labor unions to regulate Martian firms. It is difficult to project what specific challenges such unions might face, but if Martian unions at this stage resemble terrestrial unions, then the challenges they face may be similar to those unions deal with on Earth. Regardless, it is most crucial for this stage that there already exist some precedent of unionization; if unions are effective during the Settlement stage, they may be able to carry their institutional power here, and continue to advocate for rights and equality for Martian workers into the future.

[36] Wells-Jensen, Miele, and Bohney, "An Alternate Vision for Colonization," 51.

IV. Sustainability on Mars

Although the definition of sustainability is often debated, it is here defined as the ability to develop and maintain competency throughout a long-term system in a way that is affordable, meets the needs of present and future generations, and preserves key functionality of the natural environment.[37] So far, space sustainability has been focused on Low Earth Orbit (LEO), which will be discussed here briefly as well. However, exploration of Mars during the Foundation phase and the subsequent Settlement and Independence phases require consideration of even more aspects of sustainability.

Foundation

Sustainability figures prominently in three aspects of the Foundation process: departure from Earth through LEO, the journey to Mars, and early uncrewed landings. Human landings on and occupation of Mars will be discussed in the Settlement section below.

Sustainability in Low Earth Orbit

Despite the wide recognition of sustainability and its importance, space flight is already facing a significant threat from the unsustainable production of space debris. Thus far, there have been approximately 200 satellite collisions in LEO, creating a minefield of over 100 million small pieces and thousands of larger chunks of debris traveling at 17,000 miles per hour in the most important and congested of Earth's orbits.[38] Collisions with space debris are expected to increase even without an increase in space traffic, and the expected increase in space traffic will only exacerbate this threat.[39] These collisions threaten life on Earth and travel to Mars in many ways, as LEO satellites provide internet and other communications services on which Earth residents and future space missions depend. Given the current state of LEO, mitigation techniques for new missions will not be sufficient to prevent debris accumulation and its catastrophic consequences.[40] Instead, there is a need for satellite

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[37] Cooke, "Deep Space Exploration Sustainability"; Newman and Williamson, "Reframing Space Sustainability Debate," 31.
[38] Freeland and Handmer, "Space Law: Space Debris"; Liou and Johnson, "Orbiting Space Debris Risks," 340; Taverney, "Proliferated LEO: Risk, Necessary."
[39] Bastida Virgili et al., "Space Sustainability: Satellite Risks," 154.
[40] Liou and Johnson, "Orbiting Space Debris Risks," 340

owners to remove their debris or for an independent remediation effort (perhaps modeled after the United States' Superfund program for toxic waste cleanup)[41] as well as an international agreement or entity to regulate space debris.[42]

Related to the threat of devastating collisions for debris and satellites already in LEO, the proliferation of such debris presents another significant risk: Kessler Syndrome.[43] Proposed in 1978 by NASA Scientist Donald J. Kessler, this theory states that at a certain point the number of objects in LEO will reach a critical mass and initiate a chain reaction of collisions, creating so much space junk that travel into space would become impossible.[44] If this were to happen, all space missions would have to be suspended, at least until technology was developed to address the problem, if not indefinitely. This would severely impact Mars exploration since only spacecraft that were already above LEO would be operable and nothing would be able to return to Earth safely.

Sustainability En Route to Mars

Leaving Earth, the next source of unsustainable waste production during the Foundation phase would be the spaceships transporting crew members and future settlers. In 2018, NASA estimated that each astronaut produced 115 pounds of trash per month in space.[45] If that production rate were applied to a trip to Mars, and assuming a travel time of seven months (about 213 days), each crew member would produce approximately 804 pounds of trash during the voyage. Currently, most waste produced in space is disposed of the old fashioned way—tied up in a trash bag—and either brought back to Earth or burned up in the atmosphere upon reentry.[46] Of course, this would not be an option for Mars-bound ships unless they were to carry the waste back on the return trip to Earth, which would present serious storage and safety concerns (and which would add another 804 pounds

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[41] Taverney, "Proliferated LEO: Risk, Necessary."
[42] Crowther, "Space for Future Generations," 1242. For a discussion of the legal and policy implications of active space debris removal, see Way and Josef, "Active Debris Removal."
[43] For more on the effects of Kessler Syndrome, see: Holtzman, Nouri, and Saligram. "Inter-State Cooperation on Mars: Institutional Incentives for Collaboration."
[44] Thompson, "The Kessler Syndrome."
[45] Herridge, "Waste Handling in Microgravity."
[46] Herridge, "Waste Handling in Microgravity."

per person, bringing the total waste for each crew member to 1,608 pounds, not including any waste produced upon arrival to Mars). Clearly, maintaining current terrestrial systems of sustainability and waste management would be untenable for long-term space travel or Martian settlements. Ejecting the trash into space would not be a feasible option either: the technology necessary for high-velocity ejection would be prohibitively heavy, large, or expensive, and low-velocity ejection could lead to waste collected on or colliding with the exterior of the spacecraft.[47]

During the Foundation phase of Mars exploration, the inability to fully resupply spaceships on Mars will further necessitate sustainable and resource-efficient systems.[48] One option would be to send initial supply missions to establish a well-stocked base on Mars; however, this would be extremely time- and resource-intensive. For comparison, it took over thirty space shuttle missions to fully establish the International Space Station (ISS),[49] which did not involve the complicating factors of a seven-month travel time to the destination, a landing on another planet with a hostile environment, and a communications delay that would inhibit timely support from Earth. Thus, it is likely that fully self-sustaining spaceships will be necessary, at least in the early days of Mars exploration.

As of 2012, NASA stated that such potential missions to Mars—with surface time of either less than thirty or more than 500 days—would "significantly exceed our demonstrated capability to sustain life in space without direct support from Earth."[50] NASA has identified three key aspects of a habitation system that would be needed to accommodate missions to Mars: packaging and materials that can be reused or repurposed; engineering and medical technologies that could care for the crew without the need to interface with Earth; and techniques for addressing the psychological challenges of sustained confinement and isolation.[51] Ideally, the system would also be able to extract and use substances from Mars (the sustainability issues associated with on-planet resource extraction are discussed in the Independence section below).[52]

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[47] Linne et al., "Long Mission Waste Management," 7.
[48] Makower, "NASA Sustainability."
[49] Makower, "NASA Sustainability."
[50] Olson, "Sustainable Human Space Exploration," 17.
[51] Olson, 27.
[52] Olson, 31.

The goal of repurposing materials is the most applicable to space sustainability. Currently, the ISS is able to convert 90% of the water (sweat and urine) and 42% of the oxygen produced onboard into potable water and breathable air for crew members, but it still requires regular resupplies of other materials.[53] One technology in development that could address this issue is the ability to split water into hydrogen and oxygen, which could provide fuel and air for a spaceship without the need for a flammable or hazardous substance.[54] NASA is still working to address the trash problem through reusable materials and is seeking proposals for waste disposal ideas.[55] Previous design ideas include a heat melt compactor, which compacts trash and extracts water in the process, and "trash to gas" technologies, which turn trash into methane gas for use as rocket propellant.[56]

Sustainability on the Surface

Early arrivals to Mars have already begun to create their own sustainability concern: litter. For example, the 2012 landing of the Curiosity Rover on Mars's surface has already created a collection of debris (Figure 1).[57] Missions to the Moon have left behind over 400,000 pounds of human materials, including two golf balls, a feather, and twelve pairs of boots.[58] The increased difficulty of returning materials from Mars makes it likely that the amount of waste left on Mars will continue to increase and potentially surpass that found on the Moon. Given the lack of clear property rights and regulations on Mars, it is unlikely that this waste is technically considered "litter" at this point (and, if it was, NASA has a 0-1 record for paying its littering fines)[59] but it represents a troubling beginning to humankind's presence on Mars.

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[53] McSweeney, "Zero Gravity Recycling."
[54] McSweeney, "Zero Gravity Recycling."
[55] Gohd, "NASA's Astronaut Trash Problem."
[56] Gohd, "NASA's Astronaut Trash Problem."
[57] Gonzalez, "Curiosity Rover Space Litter."
[58] Garber, "Trash on the Moon."
[59] Greene, "NASA's Unpaid Littering Ticket."

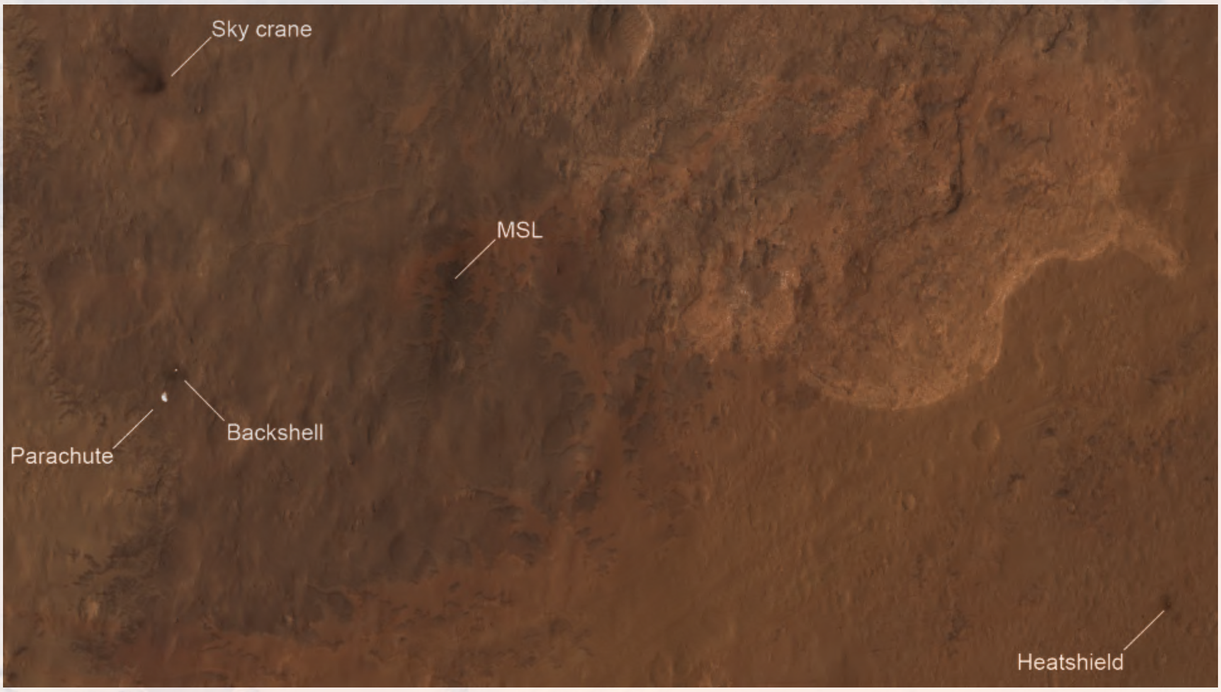

Figure 1. Debris from the Curiosity Rover's crash landing on Mars in 2012 are already littering the surface of Mars.[60]

On Earth, plastic has only been around for about 100 years, yet it has already become one of the planet's most pressing environmental issues.[61] Over 450 tons of plastic are produced each year, some of which will take over 400 years to decompose naturally.[62] Although the decomposition rate on Mars is unknown, the long lifespan of plastics indicates that this is not a problem that will easily be resolved with time. If SpaceX is able to launch the first humans to Mars in 2024 or 2026 as desired,[63] the remnants of Curiosity and other missions to Mars will surely be there awaiting the new arrivals.

It is unknown what harm the debris littering Mars might cause, but given the threats that plastics, and especially microplastics, pose to life on Earth, the deposition of waste on Mars could threaten any life that may exist on the planet by leaching toxic chemicals when exposed to Mars'

[60] Gonzalez, "Curiosity Rover Space Litter."
[61] Parker, "Plastic Pollution Crisis Explained."
[62] Parker, "Plastic Pollution Crisis Explained."
[63] Wall, "SpaceX 2024 Launch Possible."

radiation.[64] Already, debris left behind by Curiosity has complicated the study of Mars by leaving behind what appeared to be a shred of plastic, requiring additional efforts and surveillance of the material to confirm it was not native Martian material.[65] The presence of uncontrollable debris on the surface could also threaten the safety of future habitats and crew members on Mars.

While this debris does not appear to be a priority for NASA—so far, no retrieval or cleanup initiatives have been announced—inspiration for such initiatives can be taken from Earth efforts. For example, the Barber Sand Man is a walk-behind machine that uses a vibrating screen to sift debris out of beach sand and soil, which could be used to collect debris from the sand-covered Martian surface.[66] Additionally, preventing debris deposition in future landings can reduce the threat of waste accumulation and its consequences.

Settlement

During the second phase of Mars development, surface settlements are created but are still heavily reliant on Earth for survival. Elon Musk, CEO of SpaceX, has proposed sending 1,000 spaceships—each containing 100 passengers and costing about $2 million to launch—over the course of twenty years to establish a self-sustaining city on Mars.[67] Realistically, recognizing that space travel and settlement does not occur in a vacuum, the Settlement phase will involve unique sustainability challenges, such as ensuring the continued viability of Earth supplies, that may take longer to address in a safe and equitable manner.

Given the complexities of the voyage from Earth, the development of a fully self-sustaining Martian society (discussed in the Independence section below) would likely be the most efficient use of the planet. However, even according to SpaceX's ambitious goals, this would take at least twenty years of regular missions to Mars, and more typical projections estimate it will take closer to 100 years.[68] In

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[64] For a discussion of the threats plastics pose to human health, see Hand, "Danger of Plastics"; Cox et al., "Human Consumption of Microplastics." For a discussion of the threat waste on Mars poses to the search for human life there, see Weintraub, "Colonizing and Contaminating Mars."
[65] NASA, "Curiosity Rover Benign Plastic."
[66] Schmaltz et al., "Plastic Pollution Technology Solutions," 9.
[67] Reisinger, "Elon Musk 1,000 Spaceships."
[68] Osborne, "SpaceX City on Mars."

the meantime, Mars will continue to depend on Earth for provision of key materials, ideas, and settlers. But what happens if Earth itself becomes unreliable?

Earth is already severely threatened by climate change, with high-end projections estimating a 4.7°–8.6°F warming for 2081–2100 compared to 1986–2005.[69] This timeline means that significant warming would likely occur before Mars becomes fully self-sustaining, which means that climate change could heavily impact many of the key resources that would be needed from Earth. For example, under higher-end warming scenarios, if there is no change to current water resources management, chronic, long-duration drought is expected (with very high confidence) by the end of this century.[70] Although we observe water ice on Mars, the exact amount may not be sufficient for Martian settlers, who would still require water supplies from Earth.

Climate change—in the form of drought, warming, and increased CO_2 concentrations—would also reduce the nutritional value, yields, and pest resistance of crops.[71] Providing sufficient nutrition for crew members with limited storage is already a significant challenge for long-term space travel,[72] and these changes to crops due to climate change would only make this more difficult. A related issue is the threat from climate change to seeds that could be sent to Mars to aid in agricultural development. Norway's Global Seed Vault (also known as the Doomsday Vault) is a repository for seeds that could be used as a last resort if other seed supplies on Earth were compromised. But in 2017, even this perceived stronghold was threatened by climate change when its permafrost protection unexpectedly began to melt and threatened to flood the vault.[73] Seed vigor is already reduced during spaceflight,[74] so threats to high-quality seed banks due to unexpected changes on Earth could be devastating for the development of agriculture on Mars.

The continued availability of Earth resources is essential to the settlement of Mars. Climate change and other threats to that availability must be addressed and mitigated to ensure that Martian settlements will have the opportunity to develop and become self-sustaining. Proposals for combating

[69] Wuebbles et al., "Climate Science Special Report," 133.
[70] Wuebbles et al., 11.
[71] EPA, "Climate Impacts on Agriculture."
[72] See Cahill and Hardiman, "Space Travel Nutritional Challenges."
[73] Carr, "Climate Change Threatens Vault."
[74] Chandler et al., "Spaceflight Effects on Seeds," 8.

climate change are outside the scope of this chapter but have been thoroughly addressed elsewhere.[75] However, the relevance of these issues for the viability of Martian exploration is not often recognized and should be included in any discussion of settlement sustainability.

Independence

Sustainable use of resources may be a prerequisite for successful exploration and settlement of Mars. "Everything that you use and you create on Mars is so valuable. You simply can't afford a pollution stream, you can't afford a waste stream at all. Everything will absolutely be recycled...at least in the beginning," said Stephen Petranek, author of *How We'll Live on Mars*.[76] But what happens after the beginning? Once a self-sustaining, independent society is established on Mars, it will need to address many of the same issues of sustainable resource management that Earth is facing right now. While this may not seem to be the case—for example, Mars has large polar ice caps[77]—a mistaken belief in the abundance of natural resources is part of what motivated the overconsumption that has led to Earth's current state of crisis.[78] Strategies implemented on Earth and on spaceships can inform sustainability efforts on Mars, for example, to prevent water overuse. In the same way, techniques developed to optimize sustainability during space travel and within Martian society could also be applied to help address related problems on Earth.

Likely because of the abundance of hydrogen-based materials from which water can be extracted, sustainable use of such resources on Mars is not always considered. For example, a 2016 NASA study on in-situ water resource extraction featured no discussion on sustainability other than one line recognizing the need to "[h]ave additional discussions of planetary protection concerns."[79] This indicates that such concerns were not fully integrated into the plans for water extraction technologies. For example, because of their low water density, proposed techniques for in-situ resource utilization (ISRU) of hydrated minerals "would necessitate mining and processing in large quantities to

[75] See, for example: NASA, "Responding to Climate Change"; Wuebbles et al., "Climate Science Special Report."
[76] Lackey, "Will Humans Trash Mars?"
[77] Starr and Muscatello, "Mars in situ resource utilization," 6.
[78] Sheehan, "Competing Visions of Sustainability."
[79] Abbud-Madrid et al., "Mars Water In-Situ Utilization," 86

produce sufficient amounts of water."[80] These aspects of ISRU techniques are only addressed from the perspective of mission efficiency, without consideration of long-term sustainability and resource management. In fact, a stated benefit of efficient ISRU techniques is that it would decrease reliance on strict water recycling.[81]

Nevertheless, some recycling and sustainable techniques may still be the most efficient option (or the only option) for a long-term Martian civilization. While short-term missions to Mars can rely on food supplies from Earth, a self-sustaining society cannot. Therefore, agriculture will need to be established on Mars, as these plant systems could provide microbial recycling of wastewater while also supplying oxygen and a nutrient source.[82] As efficient water recycling systems are developed for use on Mars and best water management practices are developed on Earth,[83] the hope is that these will provide the bases for a sustainable water system in a long-term Martian civilization.

To ensure and require development of such a system, sustainable and equitable water use regulations should be implemented at the international and organization levels that could be later incorporated into the laws of an independent Martian society. One proposed option, a prior appropriation water rights regime—the system used during westward expansion in the United States—would provide the same perverse incentives on Mars: to arrive quickly and make "beneficial use" of as much water as possible, which rewards haste but not sustainability[84] and does not account for the inherent right to water of future Martian citizens (if such a right is recognized). Instead, the principle of Equitable and Reasonable Utilization, which is endorsed by the United Nations,[85] should be used to guide development of Martian water resources law and promote sustainable and equitable access.[86] According to this principle, civilizations that have ready access to a water resource should use that resource in a reasonable way that does not unfairly impact other civilizations that depend on the

[80] Starr and Muscatello, "Mars in situ resource utilization," 8.
[81] Starr and Muscatello, 9.
[82] Garland, "Microbial functions in space," 518.
[83] See, for example, Maddaus et al., "Future of Water Conservation."
[84] Larson, "Who Uses Mars Water?"
[85] UN, "Equitable and Reasonable Utilisation," 1.
[86] For an example applying the principles of Equitable Utilization to create an equitable water management system, see Wohlwend, "Allocation of Water Rights."

same resource. Applying this principle to Mars would require citizens and other organizations to avoid contaminating or overusing shared water resources.

V. Conclusion

Mars has the potential to extend humanity's reach beyond Earth. The choices we make now could allow for a just and sustainable society on Mars that supports the rights of its citizens through fair governance, organized labor, and resource use. This chapter explores some of the systems that could make this possible by assuming a three-stage model of Martian development. Imagining a society on Mars that is truly equal is a complicated topic that touches on many crucial issues of human rights and justice. Future work should further explore other aspects of Martian society, such as racial equality and gender dynamics. Even the systems discussed in this chapter could be further explored, but this chapter takes an important first step in initiating conversations focused on equality in Martian society.

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Inter-State Cooperation on Mars: Institutional Incentives for Collaboration[1]

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Abstract

Opening Mars as a new frontier could easily incite inter-state conflict. States share mutual interests in the settlement and development of Mars, but without collaborative frameworks, the incentives to defect from inter-state collaboration could dominate the Martian political landscape, spurring conflict instead of collaboration. One such issue is competition over the control and consumption of scarce resources critical for survival such as oxygen and water. Another is a race to the bottom in planetary protection standards, which would increase the likelihood of both forward and backward contamination. A similar issue is the emergence of conditions described as the Kessler Syndrome, which details the near impossibility of launching spacecraft from Earth due to the formation of a "debris belt."

Human migration to Mars for the purpose of long-term settlement is highly likely to become militarized and weaponized, further intensifying geopolitical conflicts that already exist and introducing additional sources of conflict as new disputes emerge. Conflict will likely center on property rights disputes and concerns over distributions of power between the various actors, given the range of conflicting claims, motives, and purposes involved in a heretofore unventured terrain. While not all conflict is avoidable or preventable, the development of social norms that incentivize peaceful and productive cooperation is necessary should a successful Martian settlement flourish.

To regulate the behavior of individuals and groups going to Mars such that the possibility of perpetuating or aggravating conflict beyond Earth is reduced as much as possible, the burden of costs and risks of violating agreements such as the Outer Space Treaty (OST) ought to be shared by the various actors involved. The social and political institutions facilitating cooperative dynamics on Mars will likely emerge over time through adaptive processes as living conditions change. The self-preservation and eventual self-determination of a permanent Martian settlement will be the product of a collaborative effort between decision makers on Earth and Mars. Early migrants aiming to settle Mars will soon discover which practices are most and least sustainable for the efficient allocation and consumption of resources, favoring a pragmatist approach that accounts for the particular conditions in the harsh Martian climate.

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I. Introduction

Outer space is no longer a "new frontier." However, Mars is certainly a new frontier that powerful actors have their eyes fixed upon, whether they be states or private entities. It is entirely possible, given both the adverse conditions and relevant history, that human efforts to migrate to and settle on Mars could induce conflict. Competition for resources, lack of formal legal regulation, and potential weaponization of space at large could easily devolve into conflict between spacefaring nations. This chapter seeks to understand how those conflicts might arise and through what collaborative frameworks it could be averted, including investigations of multilateral organizations, bilateral trade agreements, and international dispute settlement bodies as sources of solutions.

II. Potential Sources of Conflict on Mars

While states share mutual and common interests in the settlement and development of Mars, without the implementation of cooperative frameworks, individual incentives to defect from the "Greater Good" could come to dominate the Martian political landscape. It is these individual incentives that, when left unchecked, could lead to inter-state conflict and other outcomes that are detrimental to the prosperity of humanity both on Mars and on Earth. This section outlines several scenarios in which the absence of a collaborative framework could lead to the outbreak of inter-state conflict. This section outlines factors that could lead to conflict on Mars, such as the overuse and deterioration of common resources, a race to the bottom on planetary protection standards, orbital debris and Kessler Syndrome, and the militarization and weaponization of space.

Overuse and Deterioration of Common Pool Resources on Mars

One aspect of Martian settlement that could lead to the outbreak of conflict on Mars is the severe shortage of common pool resources necessary for sustaining human life. Scientists have yet to discover a planet within our reach that is better suited for human life than Earth. Earth's supplies of vital resources necessary for supporting life (such as water, oxygen, food, and sunlight, among others) are abundant relative to those of Mars. While Earth's atmosphere is 21% oxygen, Mars' atmosphere consists of only 0.13% oxygen, meaning that the resource vital to sustaining human life exists only in trace amounts on the Red Planet.[3] While nearly three quarters of the Earth is covered with water, the only water visible on Mars' surface is frozen at the planets' poles, and though scientists suspect that there is water present below Mars' surface, it is unclear how much water exists below surface-level, if any.[4] This makes the allocation and distribution of these resources become much more of a pressing concern on Mars, where the majority of the environment is hostile to life.

Because the availability of resources such as oxygen and water on Mars is limited, competition between space-faring nations over the control and consumption of these resources could conceivably ensue. Seeing as these resources are both scarce and rivalrous, it is in each individual party's rational best interest to acquire as many resources as possible as quickly as possible. Prioritizing short-term private utility over the long-term sustainability of the resource, the scarce and rivalrous nature of resources on Mars could potentially set off a consumption and hoarding frenzy, known generally as the Tragedy of the Commons, that would likely lead to the significant deterioration of these shared resources and, ultimately, their collapse.[5] Both the scarcity of natural resources and ecological degradation are two phenomena that political science literature suggests are common sources of conflict, suggesting that the scarcity of natural resources on Mars, along with environmental degradation resulting from a Tragedy of the Commons, could themselves become sources of conflict.[6] In such a scenario, it could be a more efficient use of a states' resources to subvert or even attack their adversaries' space-faring infrastructure as opposed to competing with one another to gather and consume resources as quickly as possible. Such a conflict, though prompted by circumstances on Mars, would have significant implications for both Mars and Earth, as the most important elements of

[3] "U.S. Standard Atmosphere, 1976," n.d., 241.; Heather B. Franz et al., "Initial SAM Calibration Gas Experiments on Mars: Quadrupole Mass Spectrometer Results and Implications," *Planetary and Space Science* 138 (April 1, 2017): 44–54, https://doi.org/10.1016/j.pss.2017.01.014.

[4] Michael Carr, *Water on Mars* (Oxford University Press, 1996).

[5] Garrett Hardin, "The Tragedy of the Commons | Science," *American Association for the Advancement of Science* 162, no. 3859 (1968): 1243–48.

[6] Thomas F. Homer-Dixon, "Environmental Scarcities and Violent Conflict: Evidence from Cases," *International Security* 19, no. 1 (1994): 5–40, https://doi.org/10.2307/2539147.; Philippe Le Billon, "The Political Ecology of War: Natural Resources and Armed Conflicts," *Political Geography* 20 (June 1, 2001): 561–84, https://doi.org/10.1016/S0962-6298(01)00015-4.

space-faring infrastructure, and thus the most important targets of such attacks, lie not on Mars but on Earth. Therefore, if states are unable to come to an agreement as to how Martian resources will be treated, shared, and distributed, a conflict could ensue that would likely expand beyond the Martian theater.

Race to the Bottom in Planetary Protection Standards

Another issue that could potentially arise in the process of settlement and lead to inter-state conflict is a "race to the bottom" in planetary protection standards between states. This race to the bottom is a phenomenon in which political entities cut regulations in order to attract or retain economic activity. In the same way that producers in a perfectly competitive market can increase their output by lowering their price, nations can increase the size of their registries by lowering their regulatory standard.[7] For example, in the maritime logistics industry, a vessel is subject to the law of the nation in which it is registered and documented (i.e. its "flag state").[8] While most registries are open only to vessels of their own nation, others are open to foreign-owned ships, giving the owners of merchant vessels the ability to pick and choose which registry to register their ship under and, accordingly, which set of laws to follow. As a result, much of the global fleet of merchant ships flies "flags of convenience" and are registered in open registries that allow them to follow less restrictive labor laws and environmental regulations; for example, about 8,600 ships fly the Panamanian flag, which has an open registry, as opposed to the 3,400 that fly the U.S. flag and the 3,700 that fly the Chinese flag.[9]

With the sizable role that corporations are beginning to play in the space exploration industry, a similar race to the bottom could be witnessed in planetary protection standards—a phenomenon that could seriously jeopardize the scientific integrity of Martian exploration. Because spacecraft are largely subject to the laws of their flag state in the same way that maritime vessels are, it is in executives' best

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[7] Thomas Oatley, *International Political Economy* (New York, NY: Routledge, 2019).

[8] Arnd Bernaerts, *Bernaerts' Guide to the 1982 United Nations Convention on the Law of the Sea : Including the Text of the UN Convention and Final Act* (Fairplay Publications Ltd, 1988).

[9] "Why so Many Shipowners Find Panama's Flag Convenient," *BBC News*, August 5, 2014, sec. Latin America & Caribbean, https://www.bbc.com/news/world-latin-america-28558480."

interest to subject themselves to the most cost-effective or least restrictive set of laws, which would likely take the form of lower planetary protection standards, among other regulations.

If states race to lower their planetary protection standards in order to attract commerce and investment, the likelihood of both forward and backward contamination could rise significantly. This development could incite a domino effect that culminates in inter-state conflict. The scientific exploration of Mars, particularly the search for life on Mars, is among the strongest motivations underlying states' efforts to establish permanent presences on the Red Planet. If, however, a state were to lower their planetary protection standards such that vessels belonging to said state or flying said state's flag were not required to sterilize their equipment before making the voyage to Mars, a situation could arise in which an Earthly extremophile (a hardy microbe capable of living under extreme conditions) is introduced to the Martian environment. Such a development could render the search for life on Mars moot, as the introduction of Earthly extremophiles to Mars "would jeopardize the chance to detect life forms indigenous to Mars."[10] The thwarting or even rendering moot of the incredibly expensive scientific efforts of one nation by another could conceivably lead to a serious dispute or even conflict.

Along with forward contamination, backward contamination as a result of low planetary protection standards could also easily lead to the outbreak of inter-state conflict.[11] Were a state to bring a Martian microbe to Earth, the range of possible outcomes varies so widely that it is challenging to predict or even conceive of what such an introduction would ultimately result in. As the Space Studies Board of the National Research Council concluded in 1997, "contamination of Earth by putative Mars microorganisms is unlikely to pose a risk of significant ecological impact or other significant harmful effects. The risk is not zero, however."[12] No matter how unlikely the prospect may seem, the reality is that backward contamination as a result of Martian exploration could indeed have "significant

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[10] Gerda Horneck, "The Microbial Case for Mars and Its Implication for Human Expeditions to Mars," *Acta Astronautica* 63 (October 1, 2008): 1015–24, https://doi.org/10.1016/j.actaastro.2007.12.002.

[11] For more on backward contamination, see Shu Boboila. "A Multi-Agency Regulatory Framework to Prevent Interplanetary Contamination."

[12] National Research Council, *Mars Sample Return: Issues and Recommendations* (Washington, DC: The National Academic Press, 1997), https://doi.org/10.17226/5563.

ecological impact or other significant harmful effects," effects that literature suggests has and could once again in the future serve as a source of conflict.[13]

Orbital Debris and Kessler Syndrome

The third problem that could potentially lead to the outbreak of conflict as a result of Martian settlement is the various effects of orbital debris on satellites and spacecraft in Low Earth Orbit.[14] Satellites in Earth orbit play a key role in global telecommunications infrastructure, facilitating much of the exponential increase in connectivity that we have witnessed in the past 20 to 30 years. In the development of a Martian settlement, satellites will play a similarly important role, facilitating not only communication between Earth and Mars but also the use of remote-controlled robotic systems such as rovers and other instruments. Due to the vast distance between Earth and Mars (~180 million miles), resupply missions and voyages of other natures between the two planets will likely be infrequent—barring any major advances in rocket propulsion technologies. This means that communications infrastructure, such as satellites and NASA's Deep Space Network, will be of truly vital importance to any Martian settlement by serving as a lifeline between the crew and Earth.

While the orbital collision of satellites is an admittedly rare occurrence, it is a phenomenon that is steadily increasing in frequency, particularly as Earth orbit becomes more and more crowded with new satellites and new space debris.[15] Despite the advancements that have been made in states' situational awareness capabilities, the possibility remains that a satellite could be destroyed in an unattributable orbital collision where it is unclear whether the collision was simply a random occurrence or an adversarial stealth offensive.[16] If such a collision were to destroy a satellite in Earth

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[13] National Research Council.; Michael Renner, Mario Pianta, and Cinzia Franchi, "International Conflict and Environmental Degradation," in Raimo Väyrynen and International Social Science Council, eds., *New Directions in Conflict Theory: Conflict Resolution and Conflict Transformation* (London; Newbury Park, Calif.: Sage Publications, 1991).
[14] For more on the effects of Kessler Syndrome, see Wilson, Pepka, and Artusi. "Systems for Resource Equality in Martian Society from Foundation to Independence." 16.
[15] "ESA - About Space Debris," accessed April 30, 2021, https://www.esa.int/Safety_Security/Space_Debris/About_space_debris.
[16] "Will Space Debris Be Responsible for World War III?," spacedaily.com, accessed April 30, 2021, http://www.spacedaily.com/reports/Will_Space_Debris_be_Responsible_for_World_War_III_999.html.

orbit vital to supporting a state's interests on Mars, what was in truth a random occurrence could be mistaken for an act of war, a development that would clearly incite inter-state conflict.

However, the destruction of a satellite as a result of an unattributable orbital collision is only one way in which satellites in Earth orbit could bring about considerable conflict. Originally described by NASA scientist Donald Kessler in 1978, Kessler Syndrome depicts a situation in which, as a result of the formation of a "debris belt," the launching of spacecraft from Earth could be made extremely difficult if not altogether impossible.[17] Without effective cooperation and collaboration among space-faring states, the development of a debris belt surrounding Earth could lead to considerable inter-state conflict and could jeopardize the existence of Martian settlements before they are even established. In the scenario that Kessler describes, in which collision breakup has significantly limited the amount of navigable space in Earth orbit, the scarce nature of this navigable space could spur competition over its access, similar to the ways in which access over key waterways have been sources of conflict on Earth.[18] In such a scenario, this limited navigable space is the only way in which individual states can support and protect their interests in outer-space, such as a Martian settlement. As a result, in order to secure their interests in space, conflict over this limited and rivalrous navigable space could ensue. Thus, a situation in which space-faring states are forced to compete for access to navigable space could easily escalate into intense, state-to-state conflict.

Militarization, Weaponization, and Nuclear Armament

The final potential source of conflict we examine is the militarization and weaponization of Martian assets as a result of their massive monetary, scientific, and strategic value to their respective states. There is a great deal of debate surrounding the price of establishing a Martian settlement. According to Elon Musk, sending 12 people to Mars could cost as much $120 billion, or about $10 billion per person; another figure puts nine voyages to and from Mars at a total cost of a whopping

[17] "Collision Frequency of Artificial Satellites: The Creation of a Debris Belt - Kessler - 1978 - Journal of Geophysical Research: Space Physics - Wiley Online Library," accessed April 30, 2021, https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/JA083iA06p02637.

[18] Hans Petter Wollebaek Toset, Nils Petter Gleditsch, and Havard Hegre, "Shared Rivers and Interstate Conflict - PRIO," *Political Geography* 19, no. 8 (2000): 971–96.

$1.5 trillion, or $166 billion per voyage.[19, 20] While there is no consensus surrounding an exact figure of what a Martian settlement would cost, there is clearly general agreement that establishing a Martian settlement will be among the most capital-intensive investments in history.

If individual, space-faring nations are left to establish Martian settlements on their own, the investment of time, money, and labor will be of such magnitude that these settlements simply cannot be left unprotected and without defenses. In other words, the sheer size of the investment required to establish a Martian settlement could ultimately necessitate its defense, meaning that without any cooperative or collaborative framework, Martian settlements could potentially be militarized and weaponized. This weaponization would not only increase the likelihood of the outbreak of conflict but also render Mars as a whole less efficient, as resources that could have been directed towards research and development or infrastructure would now be funneled into weaponry.

Even if the militarization and weaponization of individual Martian settlements fails to materialize, the increased investment in Mars as a strategic resource will, at a minimum, lead to increased military investment in space, something that is already beginning to take shape. In recent years, several states have begun to seriously increase their interest in space as a potential theater of conflict, with some even establishing entirely new branches of their armed forces in preparation. The most notable example of this phenomenon came in December of 2019, in which the United States established the United States Space Force as a branch of its armed services with the explicit purpose of "protect[ing] U.S. and allied interests in space" and of "deter[ring] and defeat[ing] aggression."[21] In July of 2019, France, under the direction of President Emmanuel Macron, announced the creation of a space command within the French Air Force and subsequently officially renaming its air force the

[19] April Glaser, "Elon Musk Will Need One Million Mars Colonists to Get the Ticket Price down to $200,000," Vox, September 27, 2016, https://www.vox.com/2016/9/27/13081488/elon-musk-spacex-mars-colony-space-travel-funding-rocket-nasa.; Glenn Smith and Paul Spudi, "Op-Ed | Mars for Only $1.5 Trillion," SpaceNews, March 8, 2015, https://spacenews.com/op-ed-mars-for-only-1-5-trillion/.

[20] For more on the costs of Mars settlement, see Patel and Yu, "Analysis of Commercial Funding Strategies for the Settlement of Mars." 3.

[21] United States Space Force, "United States Space Force Mission," accessed April 30, 2021, https://www.spaceforce.mil/About-Us/About-Space-Force/Mission/.

"French Air and Space Force."[22] As nations continue to invest further into the exploration and settlement of Mars, the value of their strategic interests in space will only grow, interests that must be defended either on-site via weaponization or doctrinally on Earth. In either case, the increased investment in space defense that endeavors such as the settlement of Mars will continue to necessitate could render inter-state conflict over Mars all the more destructive.

III. Multilateral Dispute Settlement and Avoidance in Space

As discussed in the previous section, the settlement of Mars risks being the source of many inter-state disputes.[23] While, as will be discussed in this section, a state of complex interdependence in space can promote conflict avoidance, it is likely that that might not be enough to prevent future disputes.[24] This is because the settlement of Mars envisioned by Elon Musk arguably presents a situation that is not in perfect conformity with complex interdependence, as the Arctic or even outer space largely have been until now.[25] Up until now, space exploration has largely been dominated by governments.[26] But now, with the Elon Musks of the world eyeing space exploration and the settlement of Mars, a private variable will be introduced that could increase the likelihood of conflicts as discussed in section one and perhaps risks violating the Outer Space Treaty.[27]

Therefore, in addition to the existing frameworks, a combination of dispute resolution systems, soft law, and new agreements accounting for the private developments will be necessary both for preventing future conflicts as well as resolving them when they occur. In this section, first complex interdependence will be outlined and applied to Mars, followed by a brief discussion of how this theory

[22] Nicholas Wu, "French President Emmanuel Macron Announces Creation of French Space Force," USA TODAY, accessed April 30, 2021, https://www.usatoday.com/story/news/world/2019/07/13/french-space-force-macron-announces-creation-space-force-command/1723998001/.

[23] See Section One.

[24] Michael Byers, "Arctic Security and Outer Space," *Scandinavian Journal of Military Studies* 3, no. 1 (November 13, 2020): 183–96, https://doi.org/10.31374/sjms.56.

[25] SpaceX, "Mars and Beyond," SpaceX, accessed April 30, 2021, https://www.spacex.com/human-spaceflight/mars/.; Byers, "Arctic Security and Outer Space."

[26] Ally Levine, "New Space," Reuters, accessed April 30, 2021, https://graphics.reuters.com/SPACE-EXPLORATION-NEW-SPACE/0100B03R062/index.html.

[27] Jordan Couch, "You Can't Take the Sky from Me," accessed April 30, 2021, https://www.americanbar.org/groups/young_lawyers/publications/tyl/topics/space-law/you-cant-take-sky-me/.

cannot fully account for the settlement of Mars. Finally, this section will explain how multilateral systems can fill in the gaps left by a system of complex interdependence.

Complex interdependence is "an ideal type of international system, deliberately constructed to contrast with a 'realist' ideal type."[28] According to Byers, the theory of complex interdependence was developed by earlier theorists to explain the reciprocal interactions between states not accounted for by realist theories.[29] This is because complex interdependence explains interactions where security is not the primary goal, states are not the only significant actors, and force is not the dominant tool.[30] Thus, its defining characteristics are described by Byers as "an absence of hierarchy among issues, the presence of transgovernmental and transnational channels of contact, and the near irrelevance of military force."[31]

In applying complex interdependence to the Arctic and outer space, Byers outlines in his scholarship how international behavior in these contexts is primarily characterized by cooperation and these international interactions are largely kept separate from other international issues.[32] As Byers explains, this is largely because the remoteness and extreme conditions of the Arctic and space lead to high risks and costs of operating within these areas.[33] Thus, international cooperation shares the burden of these risks and costs amongst multiple parties, reinforcing and encouraging cooperation.[34] As Byers notes, "Arctic and Space-faring states engage in risk management through international law-making."[35] He also describes how while both the Arctic and space are militarized, meaning the regions are used "for the transportation of personnel and weapons as well as the placement of

[28] Byers, "Arctic Security and Outer Space." Quoting Robert Keohane and Joseph Nye, Power and Interdependence, 4th ed. (Boston: Longman, 2012), p. 265.
[29] Byers.
[30] Byers.
[31] Byers.
[32] Michael Byers, "Cold, Dark, and Dangerous: International Cooperation in the Arctic and Space," *Polar Record* 55, no. 1 (January 2019): 32–47, https://doi.org/10.1017/S0032247419000160.Byers, "Arctic Security and Outer Space."; Byers, Michael, "Arctic Security and Outer Space," Scandinavian Journal of Military Studies, 2020, https://sjms.nu/articles/10.31374/sjms.56/.
[33] Byers, "Cold, Dark, and Dangerous."
[34] Byers.
[35] Byers.

supporting equipment," they are not weaponized given that weapons are not actually placed within these spaces.[36] The avoidance of weaponization also lowers costs and the risk of conflict.[37]

What is remarkable about both of these areas is that political conflicts between states involved in space and the Arctic have not caused a significant disruption in cooperation.[38] For instance, when Russia annexed Crimea, communication channels and search and rescue programs continued in the Arctic, the ISS continued to operate largely as usual, and in fact new avenues for cooperation emerged between Russia and other states in the realm of natural hazards in and resulting from space.[39]

Complex interdependence is applicable to Mars given that it is remote with extreme conditions, just as outer space at large, leading to high risks and costs associated with its settlement. Therefore, the settlement of Mars will similarly require international cooperation to share costs and risks. But while international behavior on Mars largely fits into the framework of complex interdependence contemplated by Byers, a divergence occurs when private activities are accounted for. However, this does not necessarily differ from the situation in the Arctic or outer space at large. In fact, recent tensions related to the Arctic have been caused by the commercial possibilities there, such as oil and shipping routes.[40]

The prospect of private investment in space has recently resulted in international tensions in light of legislation by the United States.[41] The 2015 Commercial Space Law Competitiveness Act provided commercial entities with "ownership rights over natural resources mined in outer space."[42] This act arguably violates the Outer Space Treaty of 1967 (OST), which states that outer space "is not subject to national appropriation by claim of sovereignty, by means of use or occupation, or by any

[36] Byers.
[37] Byers.
[38] Byers.
[39] Byers.
[40] Duxbury, "The 5 Most Important Races for the Arctic," POLITICO, January 1, 2020, https://www.politico.eu/article/5-races-for-the-arctic-trade-resources-supremacy-tourism-salvation/.
[41] Couch, "You Can't Take the Sky from Me.".
[42] Couch.

other means."[43] Given that, under space law, the actions of a nation are attributed to a state, any act of use or appropriation by a commercial entity are also acts of the state itself.[44]

However, the United States has argued that commercial activities like mining in outer space should be treated similarly to fishing in international waters.[45] The difference here is that while the United Nations Convention on the Law of the Sea specifically sets out rules for fishing in international waters, the OST does not.[46] A prior treaty in 1958, the Convention on the High Seas, also set out rules for fishing in international waters, which were meant to codify existing rules of international law.[47] Therefore, concepts of utilizing resources in international shared spaces long predated the OST. But instead of providing for rules similar to those related to the Law of the Sea, the OST instead seems to contain a blanket prohibition on similar resource utilization. Specifically, the OST bars use[48] or occupation.[49] Thus, it seems that the OST truly does prohibit the commercial use of shared spaces.

Mining resources in space is consumption and the literal availment of the resource, so it would constitute "use" under the OST. Additionally, the settlement of Mars would be using the land by similarly availing oneself. However, settlements on Mars might not meet the Black's Law Dictionary definition if no such settlements were exclusive, but rather were open to anyone. Without the right to exclude though, the settlement of Mars might lose some of its profitability. For instance, if Elon Musk

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[43] "The Outer Space Treaty, Article 2" accessed April 30, 2021, http://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/introouterspacetreaty.html.
[44] "The Outer Space Treaty, Article 6."
[45] Couch, "You Can't Take the Sky from Me."
[46] United Nations Convention on the Law of the Sea, Article 87.
[47] Convention on the High Seas, Preamble, Article 2.
[48] According to Black's Law Dictionary, "use" can be defined as "[t]o make use of or to employ something." For more, see: "What Is USE? Definition of USE (Black's Law Dictionary)," accessed April 30, 2021, https://thelawdictionary.org/use/. Alternatively, Merriam-Webster defines "use" as "to put into action or service: avail oneself of" or "to expend or consume by putting to use." Merriam-Webster. "Definition of USE," accessed April 30, 2021, https://www.merriam-webster.com/dictionary/use."Use."
[49] Occupation is defined by the Black's Law Dictionary as "[p]ossession; control; tenure; use [or] where a person exercises physical control over land [meaning] . . . the power of entering into and staying there [and] . . . excluding all other persons . . . from the use of it." Black's Law Dictionary, "What Is OCCUPATION? Definition of OCCUPATION (Black's Law Dictionary)," accessed April 30, 2021, https://thelawdictionary.org/occupation/. Merriam Webster Dictionary defines it as "the possession, use, or settlement of land." Merriam-Webster. "Definition of OCCUPATION," accessed April 30, 2021, https://www.merriam-webster.com/dictionary/occupation.

built a hotel on Mars for tourists, theoretically other companies could come and use that hotel free of charge—otherwise they would be excluded.

Given the increased interest in commercial activities in space, and on Mars in particular, without resolution on the international permissibility of such activities, conflicts are likely to arise. Additionally, even if a multilateral instrument sufficiently provided for commercial activity such as Elon Musk's space settlements, disputes are likely inevitable, varying from questions of whose state can invest where, tragedies of the commons issues of overuse, or even criminal matters between citizens of different states. And while multilateral instruments will be necessary to fully answer these questions, treaty making is a notoriously slow process, particularly in this arena; one of the more recent attempts, the 1979 Moon Treaty, was largely a failure given its inability to attract signatories.[50]

Thus, in tandem with any attempts at multilateral treaty making (and even after successful multilateral treaty making) other mechanisms will be necessary to prevent and navigate conflicts. These mechanisms will include soft law and dispute settlement mechanisms.[51] However, even the use of conflict resolution mechanisms without multilateral agreements could be difficult depending on the states involved. The OST does not actually provide for any form of dispute settlement and therefore looking to alternatives is necessary.[52] One of the outside mechanisms scholars have pointed to as the most likely choice is the International Court of Justice (ICJ).[53] However, the ICJ only has compulsory jurisdiction over parties to the ICJ Statute or parties to treaties with a provision providing for ICJ jurisdiction.[54] Therefore, without an ICJ declaration or a treaty whose subject matter is directly relevant to the conflict, the ICJ has no jurisdiction over outer space disputes. It is notable here that the

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[50] Steven Freeland, "The Role of ?Soft Law? In Public International Law and Its Relevance to the International Legal Regulation of Outer Space," in *Soft Law in Outer Space*, vol. Volume 102, 0 vols., Studien Zu Politik Und Verwaltung, Volume 102 (Böhlau Verlag, 2012), 9–30, https://doi.org/10.7767/boehlau.9783205791850.9.; Michael Listner, "The Space Review: The Moon Treaty: Failed International Law or Waiting in the Shadows?," October 24, 2011, https://www.thespacereview.com/article/1954/1.

[51] George Paul Sloup, "Peaceful Resolution of Outer Space Conflicts through the International Court of Justice: The Line of Least Resistance" 20, no. 3 (1971): 82.

[52] Sloup.

[53] Sloup.

[54] "Statute of the Court | International Court of Justice, Article 36" accessed April 30, 2021, https://www.icj-cij.org/en/statute.

United States is not a party to the ICJ, and therefore no dispute settlement over the OST and the recent U.S. legislation could be initiated at the ICJ without the consent of the United States.[55]

Thus, absent new multilateral agreements or circumstances where conflicts are between parties that are both subject to a compulsory dispute settlement mechanism, alternatives will be necessary. Such alternatives for conflict avoidance and dispute resolution could include soft law or bilateral mechanisms, as will be discussed in the next section.[56]

IV. Bilateral Trade Agreements: A Model for Solutions

Traditional space relations between civilian space actors are evolving to include new institutional entities which require new mechanisms of collaboration that accommodate new actors and their rapidly expanding scientific and technological capabilities.[57] One of the most common institutional mechanisms to incentivize cooperation are treaties, which are often multilateral in nature.[58] However, international dispute resolution—as it relates to Mars and space—does pose a few key issues.

The first major problem with international dispute resolution is treaty non-compliance. There are three main causes for non-compliance: ambiguity and indeterminacy of treaties, capacity limitations of states, and uncontrollable social or economic changes.[59] Moreover, states on the receiving end of non-compliance may choose to retaliate against the defector, which risks the breakdown of future cooperation. A second major issue with international dispute resolution involves the negotiation of the treaties themselves.[60] Negotiation requires the management of inherent tensions between creating and distributing value, balancing empathy and assertiveness, and balancing principals

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[55] "United Nations Treaty Collection," accessed April 30, 2021, https://treaties.un.org/Pages/ViewDetails.aspx?src=TREATY&mtdsg_no=I-4&chapter=1&clang=_en.
[56] Freeland, "The Role Of ?"
[57] Nicolas Peter, "The Changing Geopolitics of Space Activities," *Space Policy* 22, no. 2 (May 1, 2006): 100–109, https://doi.org/10.1016/j.spacepol.2006.02.007.
[58] Karolina M. Milewicz and Duncan Snidal, "Cooperation by Treaty: The Role of Multilateral Powers," *International Organization* 70, no. 4 (2016): 823–44.
[59] George W. Downs, David M. Rocke, and Peter N. Barsoom, "Is the Good News about Compliance Good News about Cooperation?," *International Organization* 50, no. 3 (1996): 379–406..
[60] Robert Mnookin, "Strategic Barriers to Dispute Resolution: A Comparison of Bilateral and Multilateral Negotiations on JSTOR," *Journal of Institutional and Theoretical Economics (JITE)* 159, no. 1 (2003): 199–220.

and agents.[61] Parties are often tempted to use hard-bargaining tactics, which is a rational action for self-interested actors.[62] However, if treaty formation is approached solely from the lens of self-interest, it is highly unlikely that efficient outcomes will be achieved. Bilateral *trade* agreements specifically provide certain solutions for this self-interested actor issue; the incentive structures present in trade agreements, as opposed to general bilateral agreements, emphasize mutual gains that encourage cooperation over defection and hard bargaining. We therefore argue that the framework of dispute resolution present in most bilateral trade agreements (BITs) might provide solutions for some of the common issues and conflicts that might arise on Mars as discussed in the first section of the chapter.[63] Moreover, the structure of dispute resolution mechanisms presented in BITs can work in concert with multilateral treaty making to prevent and navigate conflicts. This is particularly salient to conflict resolution and collaboration on Mars, as the OST does not actually provide for any form of dispute settlement.

Any discussion of bilateral agreements in space is incomplete without mention of the Artemis Accords. The Accords are a set of guidelines surrounding the Artemis Program, an international effort spearheaded by NASA to send crewed missions to the Moon.[64] Though multiple countries have signed the Accords, they are being implemented through bilateral agreements that delineate responsibilities and other legal provisions. The bilateral aspect of the agreement will allow partnering countries to hold each other accountable in complying with the accords and encouraging future cooperation.[65] NASA representatives have described the Accords as a tool to "help to avoid conflict in space and on Earth by strengthening mutual understanding and reducing misperceptions [through] transparency, public registration, [and] deconflicting operations."[66]

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[61] Mnookin.

[62] Mnookin.

[63] For more on Bilateral Trade Agreements, see Holtzman and Schrader, "Promoting Commercial Investment On Mars: Extending International Arbitration To Conflicts in Space."

[64] Sean Potter, "NASA, International Partners Advance Cooperation with Artemis Accords," Text, NASA, October 13, 2020, http://www.nasa.gov/press-release/nasa-international-partners-advance-cooperation-with-first-signings-of-artemis-accords.

[65] It is worth noting that Russia and China are highly critical of the Artemis Accords. Boley and Byers. "U.S. policy puts the safe development of space at risk." https://science.sciencemag.org/content/370/6513/174.

[66] Potter.

As the previous section noted, soft law and other mechanisms can provide short-term solutions to any issues that may arise, filling the gaps left by the long negotiation and formation processes of multilateral mechanisms. Bilateral trade agreements can provide certain insights into multi-party international treaties and conflicts with a focus on longer-term institutional mechanisms for avoiding conflict. The Artemis Accords are an important foundation for the future of space cooperation, but examining political economy literature on bilateral trade agreements can provide even more potential solutions. Looking at BITs allows us to isolate conflict resolution mechanisms that might be harder to unpack within the framework of multilateral agreements. For example, Pareto-efficiency in a multilateral negotiation requires unanimity, which is difficult to achieve under normal circumstances, let alone when it comes to the tenuous domain of space.[67] Naturally, the unanimity rule creates the strategic risk of holdout problems, which would likely be incredibly costly in the time-sensitive context of space missions. Given the time delay that accompanies most space missions, decisions need to be made with utmost efficiency to guarantee mission success—especially if those decisions involve life-or-death situations, such as negotiations between various national settlements on Mars. That is a situation in which the conditions elicited by unanimity rule could easily devolve into a prisoner's dilemma or collective action problem. In another example, if holdout problems do occur, they could exacerbate Kessler syndrome, encourage weaponization of space, or incite a race to the bottom; operating under the assumption that unanimity rule is the only way to make decisions could easily lead to many of the prisoner's dilemma and collective action problems discussed in the first section. Therefore, while they may not map entirely onto potential multilateral disputes in space, BITs provide solutions that could be applied on a case-by-case basis.

The literature on bilateral trade agreements elucidates two major areas of exploration relevant to our discussion of international space disputes: arbitration best-practices and optimal conditions for compliance. Looking first at arbitration, Allee and Peinhardt (2014) find that treaties that allow third parties to resolve disputes can raise ex-post costs of compliance; having both state parties pre-consent to international arbitration speeds up the dispute resolution process. Given the plethora of available

[67] Mnookin, "Strategic Barriers to Dispute Resolution: A Comparison of Bilateral and Multilateral Negotiations on JSTOR."

arbitration venues, it is tempting to leave arbitration processes unspecified in the treaty itself and decide which one to use as the need arises—which happens more often than expected, especially within economic agreements that do not wish to commit themselves to one version of a constantly-changing environment.[68] After all, such venues include diverse options such as domestic courts in the host state, standing bodies, regional arbitration centers, and international arbitration through institutions like the World Trade Organization's dispute settlement mechanism.[69] Some of these venues are more institutionalized than others, which is why many treaties choose ad hoc options, or options where the parties involved do not pre-select an institution of arbitration.

However, BITs are susceptible to global power dynamics and have an inherent asymmetry built into them, as do many other cross-national agreements. Under ad hoc arbitration, weaker states have to balance against stronger ones that are likely to exert their influence while also navigating various aspects of the dispute such as choice of law, rules for selecting arbitrators, objection, compensation, and award procurement.[70] The delay in dispute resolution decreases both procedural efficiency and security. Given the time-sensitive and risk-averse nature of space exploration and collaboration, any hindrance in efficiency and security can be life-threatening to international collaboration. Additionally, changing dispute conditions are endemic to the unpredictable nature of space. Therefore, the best way to protect against security and efficiency risks in such an environment is to include pre-consent clauses that select an institution of arbitration, multiple options for enforcement, and the ability to utilize institutionalized arbitration venues.[71] With these three mechanisms embedded in space agreements, disputes can be resolved in a targeted and efficient fashion. Moreover, including pre-consent causes that specify arbitration venues avoids the unanimity issues discussed earlier, making this structure ideal for bilateral or multilateral agreements.

Another major area of focus within international disputes is the optimal conditions for treaty compliance. Treaty compliance is relevant to space for a multitude of reasons: compliance is necessary

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[68] Todd Allee and Clint Peinhardt, "Evaluating Three Explanations for the Design of Bilateral Investment Treaties Symposium: The Regime for International Investment - Foreign Direct Investment, Bilateral Investment Treaties, and Trade Agreements," *World Politics* 66, no. 1 (2014): 47–87."
[69] Allee and Peinhardt.
[70] Allee and Peinhardt.
[71] Allee and Peinhardt.

for sustainable institution building (as discussed in the previous section), and is also crucial to avoiding issues such as a race to the bottom or appropriation of resources (as discussed in the first section). A high rate of compliance often results from states formulating treaties that require them to do little more than they already would have.[72] Treaties are endogenous strategies—states will rarely spend lots of time negotiating agreements that they think will be continuously violated by the other party.[73] Treaty negotiation can also be used as a delay tactic, where states draw out negotiations to buy time for activities that the other party would disapprove of. In either case, states will rarely comply with treaties that require them to put in exorbitant amounts of effort, particularly when the treaty works towards a common good susceptible to free rider problems, such as scientific discovery from Mars missions.[74] This would also prove true in a space environment where time is a constraint and lengthy negotiations can lead to increased security risks. Therefore, it is essential that all parties involved in space agreements feel that their goals can be met with a feasible plan of action. Otherwise, compliance will likely be hard to enforce and sustain.

Simmons (2000) finds that reputational concerns also explain patterns of compliance. Governments interested in efficiency gains from international transactions will establish credibility through commitment and compliance to relevant treaties. The issue of reputation may be key to understanding compliance in space-related treaties. Space activities traditionally confer a high political profile, and space science is an established area of cooperation between spacefaring nations.[75] Regardless of the fact that more nations are entering space endeavors, these two features remain constant; reputation is inherent to space exploration and it is essential to creating the credibility that fosters cooperation. A reputation for credible commitment to treaties and negotiations, as well as fair arbitration, will incentivize trust and cooperation between states in areas where progress is costly and heavily resource-dependent, as space exploration is. Given the high costs of space exploration, multiple nations have updated their defense strategies and space-facing positions to emphasize collaboration and

[72] Downs, Rocke, and Barsoom, "Is the Good News about Compliance Good News about Cooperation?""
[73] Downs, Rocke, and Barsoom.
[74] Downs, Rocke, and Barsoom.
[75] Peter, "The Changing Geopolitics of Space Activities."

the sharing of space-related information and intelligence.[76] In the same vein, there has been a recent emergence of regional space coalitions such as the European Space Agency (ESA), Asia-Pacific Space Cooperation Organization (APSCO), and Asia-Pacific Regional Space Agency Forum (APRSAF) to encourage regional cooperation on space initiatives.[77] Given that governments are generally positively influenced by the choices of others in their region, treaty compliance and enforcement measures that are taken on by these regional coalitions may be more likely to call upon the reputation of their members to encourage compliant behavior. Additionally, these regional coalitions can balance against the collective action problems that often arise from treaties that seek to establish a common good by emphasizing the concerns that accompany non-compliance (including security, mission failure, and the survival of relevant space actors).

The literature on BITs and compliance provides a few core takeaways for space-related inter-state dispute settlement. Firstly, states should strive to integrate preferences of domestic actors within the country into the treaties.[78] The inclusion of domestic and international perspectives will likely address the negotiation challenges discussed earlier, specifically the issues of creating and distributing value and balancing principals and agents; domestic actors do have an important bearing on states' foreign policy, so the creation of value, even at the international level, will need to involve their perspectives. Furthermore, if there are opportunities to include prominent domestic voices, it would help reduce the impact of power asymmetries as the key needs of both parties will be represented to create a fairer and more balanced agreement. In terms of the agreement structure itself, we recommend the inclusion of pre-consent clauses, multiple options for enforcement, and the ability to utilize institutionalized arbitration venues to ensure efficient and equitable dispute resolution without compromising the security of any party involved. In order to induce compliance and maintain cooperation, treaties should stress the reputational impacts of space exploration and emphasize regional collaboration to increase accountability. One powerful reputational impact of space

[76] Makena Young, "Why Cooperation Is Still Possible in a More Militarized Space," World Politics Review, September 22, 2020, https://www.worldpoliticsreview.com/articles/29076/why-cooperation-is-still-possible-in-a-more-militarized-space.
[77] Saadia Pekkanen, "China, Japan, and the Governance of Space: Prospects for Competition and Cooperation | International Relations of the Asia-Pacific | Oxford Academic," *International Relations of the Asia-Pacific* 21, no. 1 (January 2021): 37–64, https://doi.org/10.1093/irap/lcaa007.
[78] Allee and Peinhardt, "Evaluating Three Explanations for the Design of Bilateral Investment Treaties Symposium."

exploration that treaties can draw on is the effects of the Space Race between the U.S. and Russia. The prestige conferred to both states as a result of their activities during the Space Race is still relevant to endeavors today, and could be leveraged as a powerful example for states looking to enter the space domain. Additionally, the inclusion of technical and financial assistance from the more powerful states will indicate to smaller states a good faith intention to collaborate in the space domain and reinforce the idea that space is a resource of common exploration and knowledge rather than one reserved only for great powers. In the same vein, treaties that embed a commitment to increased transparency will likely be able to solve disputes with less hassle because of decreased miscommunication and the implicit exchange of mutual trust that accompanies transparency.

Commitment to a space treaty does not have to come at the expense of one state over the other. There is a way for all parties involved, however many there may be, to further their own space-related interests while also collaborating effectively. As long as the treaties stress the importance of compliance, equitable and secure arbitration, and transparency, the choice to collaborate is not only possible but actually incentivized over conflict.

V. Conclusion

Opening Mars as a new frontier could easily incite inter-state conflict. In this chapter, we have examined the possible ways in which this conflict could arise, including competition for and deterioration of shared resources, a race to the bottom on planetary protection standards, issues with orbital debris and Kessler Syndrome, and the weaponization of space. Moreover, the recent introduction of a private variable into space exploration could increase the likelihood of conflicts and risk violating the Outer Space Treaty. In understanding how this conflict could be averted, we have turned to pre-existing multilateral structures in isolated and difficult conditions such as the Arctic, as well as bilateral trade agreements and the foundations set by the Artemis Accords. Moving forward, if space exploration endeavors could share the burden of the risks and costs present in the remote and extreme conditions of Mars, cooperation could be reinforced and encouraged. Additionally, our research indicates that the frameworks for dispute settlement and compliance present in bilateral trade agreements would translate well to the tenuous and unpredictable domain of space exploration. As humans look to settle on Mars, the agreements that guide their efforts should stress the importance of treaty compliance and transparency to global security and provide opportunities for equitable and secure arbitration. Though conflict can easily arise in such an environment, calculated choices around collaboration in exploration can create long-term patterns of stability.

Abbreviations

Abbreviation	Definition
ACO	Announcement of Collaboration Opportunity
ADR	Alternative Dispute Resolution
APHIS	Animal and Plant Health Inspection Service
APRSAF	Asia-Pacific Regional Space Agency Forum
APSCO	Asia-Pacific Space Cooperation Organization
BITs	Bilateral Investment Treaties
CDC	Center for Disease Control
CERN	European Council for Nuclear Research
CFIUS	Committee on Foreign Investment in the United States
COSPAR	Committee on Space Research
COTS	Commercial Orbital Transportation Services
CSLCA	U.S. Commercial Space Launch Competitiveness Act
DeCIPHER	Decisions on Complex Interdisciplinary Problems of Health and Environmental Risk
DHS	Department of Homeland Security (U.S.)
DOD	Department of Defense (U.S.)
EAR	U.S. Export Administration Regulation
EPA	Environmental Protection Agency (U.S.)
ESA	European Space Agency
FAA	Federal Aviation Administration
FEMA	Federal Emergency Management Agency (U.S.)
FBI	Federal Bureau of Investigation (U.S.)
FFDCA	Federal Food, Drug and Cosmetic Act (U.S.)
FIFRA	Federal Insecticide, Fungicide and Rodenticide Act (U.S.)
GM	Genetically Modified
ICJ	International Court of Justice
JPL	Jet Propulsion Laboratory
LEO	Low Earth Orbit
ISDS	Investor State Dispute Resolution
ISRU	In-Situ Resource Utilization
ISS	International Space Station
ITU	International Telecommunication Union
NAC	NASA Advisory Council
NASA	National Aeronautics and Space Administration
NASEM	National Academies of Sciences, Engineering and Medicine
NEPA	National Environmental Policy Act
NIH	National Institutes of Health (U.S.)
NSC	White House (U.S.) National Space Council
OSHA	Occupational Safety and Health Administration
OST	Outer Space Treaty
PMN	Premanufacture Notification
PPA	Plant Protection Act
PPIRB	Planetary Protection Independent Review Board
PPP	Public-Private-Partnership
SSB	Space Studies Board
TSCA	Toxic Substances Control Act
UN	United Nations

Abbreviation	Definition
UNCLOS	United Nations Convention on the Law of the Sea
UNCITRAL	United Nations Commission on International Trade Law
US	Ultrasound
U.S.	United States (of America)
USA	United States of America
USCSLC	U. S. Commercial Space Launch Competitiveness Act
USDA	United States Department of Agriculture
VSTA	Virus-Serum-Toxin Act
WTO	World Trade Organization

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