Interplanetary Risk Regulation

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Abstract

Space exploration promises new opportunities but also new risks. After centuries of national settlements and international conflicts on Earth, and the Cold War era of two great power states racing to the Moon, today we see a rapidly proliferating arena of actors, both governmental and non-governmental, undertaking bold new ventures off-Earth while posing an array of new risks. These multiple activities, actors, and risks raise the prospects of regulatory gaps, costs, conflicts, and complexities that warrant reconsideration and renovation of legacy legal regimes such as the international space law agreements. New approaches are needed, beyond current national and international law, beyond global governance. We suggest that interplanetary risks warrant new institutions for risk regulation at the interplanetary scale. We discuss several examples, recognizing that interplanetary risks may be difficult to foresee. Some interplanetary risks may arise in the future, such as if settlements on other planets entail the need to manage interplanetary relations. Some interplanetary risks are already arising today, such as space debris, space weather, planetary protection against harmful contamination, planetary defense against asteroids, conflict among spacefaring actors, and potentially settling and terraforming other planets (whether to conduct scientific research, exploit space mining, or hedge against risks to life on Earth). These interplanetary risks pose potential tragedies of the commons, tragedies of complexity, and tragedies of the uncommons, in turn challenging regulatory institutions to manage collective action, risk-risk tradeoffs, and extreme catastrophic/existential risks. Optimal interplanetary risk regulation can learn from experience in terrestrial risk regulation, including by designing for adaptive policy learning. Beyond national and international law on Earth, the new space era will need interplanetary risk regulation.

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I. INTRODUCTION

Humans have always dealt with risk, surviving from early evolution to the present by assessing and managing possible scenarios and their consequences.[1] Over time, there have been considerable changes in the types of risks humans face and the approaches to assessing and managing them.[2] Today, risks such as climate change have reached the planetary scale.[3] As humanity begins to expand its presence beyond the Earth in pursuit of new opportunities, we face a new arena of risks—"interplanetary risks," both present and future, such as interplanetary contamination, asteroid impacts, and conflicts across multiple celestial bodies—which demand new approaches to risk assessment and risk management.[4] If we are to live long and prosper in a multiplanetary future,[5] our institutions for risk regulation must update and adapt to address interplanetary risks. Current laws and institutions for what Earthlings call "outer space"—the set of rules that have come to be known as "space law," made at the international and national levels on Earth[6]—represent valuable, arguably essential, but only initial, terrestrial

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1 PETER BERNSTEIN, AGAINST THE GODS: THE REMARKABLE STORY OF RISK (1996); HOWARD MARGOLIS, DEALING WITH RISK (1996).

2 *See* ORTWIN RENN, RISK GOVERNANCE: COPING WITH UNCERTAINTY IN A COMPLEX WORLD (2008); Jonathan B. Wiener, *Learning to Manage the Multirisk World*, 40 RISK ANALYSIS 2137 (2020). Risk can be understood as the combination of the likelihood (or probability) and consequence (severity or magnitude of impact) of an adverse outcome, including related attributes such as timing, uncertainty, and distribution.

3 Recent surveys of multiple global risks include WORLD ECON. F., GLOBAL RISKS REPORT 2025 (Jan. 15, 2025); UNITED NATIONS, GLOBAL RISKS REPORT (forthcoming 2025).

4 In addition to potential negative "interplanetary risks," there are also potential positive "interplanetary opportunities" for benefits such as scientific investigation (including the search for alien life), resource extraction, and settlement off-Earth. Negative interplanetary risks include scenarios that diminish the likelihood or value of interplanetary opportunities, such as where contamination of a celestial body spoils a possible search for alien life, or asteroid impacts harm off-Earth settlements. In turn, positive interplanetary opportunities can involve the avoidance or mitigation of negative risks, such as if a self-sufficient off-Earth settlement enables human resilience to potential catastrophes on Earth. Interplanetary risk regulation offers a framework for both reducing negative risks and promoting beneficial opportunities relating to interplanetary activities.

5 *See* Xiao-Shan Yap & Rakhyun Kim, *Towards Earth-Space Governance in a Multi-Planetary Era*, 16 EARTH SYS. GOVERNANCE 100173 (2023). A "multiplanetary future" can involve, but does not necessitate, humans settling on multiple planets; it can also involve human activities from Earth interacting with multiple celestial bodies, such as mining asteroids or the Moon, establishing space station habitats, or sending remotely piloted or autonomous robotic probes or rovers to other planets. *See infra* note 33.

6 The principal international agreement is the 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), 610 U.N.T.S. 205 [hereinafter Outer Space Treaty or OST], https://perma.cc/G3U7-VZ7M. For learned studies of current "space law," see generally FRANS VON DER DUNK, ADVANCED INTRODUCTION TO SPACE LAW (2020); STEVE MIRMINA & CARYN SCHENEWERK,

steppingstones toward the coming frontier of "interplanetary law."[7] In this Essay, we propose that the insights of risk regulation should be brought to bear on emerging risks in and beyond current space law and policy, toward a future domain of "interplanetary risk regulation" and "interplanetary law."[8]

INTERNATIONAL SPACE LAW AND SPACE LAWS OF THE UNITED STATES (2022); MICHAEL BYERS & AARON BOLEY, WHO OWNS OUTER SPACE? INTERNATIONAL LAW, ASTROPHYSICS AND THE SUSTAINABLE DEVELOPMENT OF SPACE (2023); FRANCIS LYALL & PAUL LARSEN, SPACE LAW: A TREATISE (3rd ed. 2024).

7 Perhaps because human activity beyond the Earth is a relatively recent development, "space law" remains an extraordinarily broad subject, including activities on the Earth (such as rules for transactions involving space technologies), around the Earth (such as rules for satellite operations and debris in Earth orbit), and in the "outer space" or "void" between celestial bodies (such as rules for navigation or communications), as well as actual or potential rules for planetary and "interplanetary" activities (such as rules for mining and returning materials from asteroids and planets to the Earth). On this traditional use of the term "space," the Earth is treated as central and all other celestial bodies (such as planets and moons) are presumed to have more in common with each other and with the void between and beyond them, than they have in common with the Earth—hence they are lumped together under the singular term "[outer] space" which actually refers to everything else in the universe besides Earth. In our view, this use of the term "space" will soon become antiquated, as activities involving celestial bodies other than the Earth proliferate and gain significance. The physical, biological, and environmental context of each celestial body is likely to emerge as an important frame of reference for activities there, distinct from the "space" between the Earth and other celestial bodies and beyond. Eventually, human settlements off-Earth may arise, and some human beings may be born on other celestial bodies and never traverse the void of "space" to live off-Earth (i.e., on another planet). If so, the phrase "space law" might eventually change in meaning, coming to refer to rules for activities in the void between celestial bodies and beyond, while "planetary/global law" (such as "Earth law," "Mars law," etc.) would refer to "intraplanetary" rules within or on a celestial body, and "interplanetary law" would refer to rules for relations among multiple celestial bodies, akin to the way that "international law" currently refers to relations among multiple national legal systems. Hence, we propose the terms "interplanetary law" and "interplanetary regulation" to address present and future interplanetary risks.

8 Our search for the term "interplanetary law" found only a few uses. *See, e.g.*, Myres McDougal & Leon Lipson, *Perspectives for a Law of Outer Space*, 52 AM. J. INT'L L. 407, 421 (1958) (discussing "interplanetary interdependence," citing Edgar Danier, *Les Voyages Interplanétaires et le Droit*, 15 REV. GÉN DE L'AIR 422, 425 (1952)); Aldo Armando Cocca, *Contributions of Space and Interplanetary Law to Juridical Science*, 28 J. AIR L. & COM. 351 (1962); AJ Link, *Galactic Accessibility: An Introduction to Interplanetary Human Rights Law Through Crip Legal Theory*, 42 N. ILL. U. L. REV. 345 (2022). Another legal reference to "interplanetary," although more focused on internal laws within new settlements, is CHARLES S. COCKELL, INTERPLANETARY LIBERTY: BUILDING FREE SOCIETIES IN THE COSMOS (2022). One of our favorite uses of "interplanetary law" is the title of a Chuck Jones cartoon, featuring attorney Daffy Duck cross-examining Marvin the Martian in a courtroom regarding the destruction of the Earth, with the Hon. Yosemite Sam as the presiding judge. *See* Chuck Jones, *Interplanetary Law* (Cartoon), https://perma.cc/X87Z-YVBQ. Invocations of the "interplanetary" domain more generally include discussions by the British Interplanetary Society (https://perma.cc/YGS5-UY6L) and the Arizona State University (ASU) Interplanetary Initiative (https://perma.cc/GJ2D-UDKK).

By "interplanetary risks," we mean risks involving multiple celestial bodies, including planets, moons, asteroids, comets, meteoroids, and stars.[9] Other risks from space activities primarily affect a single planet, such as the Earth, including space debris in Earth orbit, the effects of rocket launches on Earth's land, water and atmosphere, and the potential placement of weapons in Earth orbit—though each of these may also affect outer space exploration from Earth. Some risks would primarily affect another, single celestial body, such as the local effects of mining on an asteroid or Mars.[10] While all of these issues are important (and are interconnected with the risks we address in this Essay), here we focus on issues relating to multiple celestial bodies, presenting new and distinctive "interplanetary risks" (some already in view today) that would benefit from the insights of risk analysis and new institutions for risk management.

Unlike the Cold War era of two great power states racing to the Moon, today, a rapidly proliferating arena of actors, both governmental and non-governmental, are undertaking an array of bold new ventures in space and on different celestial bodies. These multiple actors, activities, and risks raise the prospects of regulatory gaps, conflicts, and complexities that warrant reconsideration and renovation of legacy legal regimes. Interplanetary law may seem a distant prospect, but interplanetary risks are already in view, including planetary protection against harmful contamination and planetary defense against asteroids; and in the (near?) future we may face new risks regarding armed conflict among spacefaring actors, and mining, settling and terraforming other planets and celestial bodies. These interplanetary risks pose potential tragedies of complexity,[11] tragedies of the

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9 The term "celestial bodies" is used in the Outer Space Treaty and subsequent space-related treaties. While not defined therein, the term is generally understood to refer to bodies of mass outside Earth's atmosphere. Legal debates sometimes consider whether all sizes of objects down to specks of dust are "celestial bodies," and whether the term includes only "natural" objects or also constructed objects such as space stations. *See, e.g.*, David Epstein, *Protecting the Cosmos: Defining Celestial Bodies in the Outer Space Treaty*, 15 SPACE & DEF. 35, 47–55 (2024) (discussing the legal scope of "celestial bodies" in the Outer Space Treaty). To address "interplanetary risks," what matters about "celestial bodies" is that they punctuate the otherwise near empty void of space and implicate various interests—and risks—in the ways that they and their uses relate to inhabitants, to other such bodies, and to interactions among them.

10 To the extent that mining on Mars is undertaken by Earth-originated (or off-Mars-originated) robots, materials, or people, or could affect Earth (or other celestial bodies), this activity could meet our definition of "interplanetary" and could be subject to interplanetary risk regulation.

11 *See generally* GUIDO CALABRESI & PHILIP BOBBITT, TRAGIC CHOICES (1978); JOHN D. GRAHAM & JONATHAN B. WIENER, EDS., RISK VS. RISK (1995); Bernardo Mueller, *Why Public Policies Fail: Policymaking Under Complexity*, 21 ECONOMIA 311, 311 (2020).

commons,[12] and tragedies of the uncommons[13]—each in turn challenging regulatory institutions to manage risk-risk tradeoffs, collective action problems, and extreme catastrophic/existential risks.[14] Regulatory design needs to address these interplanetary risks intelligently, without unduly impeding beneficial space activities.

A sensible framework for carefully assessing and managing interplanetary risks is needed. Space actors on Earth have articulated different—and often competing—visions of humanity's future in space, including those that prioritize the commercial extraction of space resources to benefit people on Earth, the settlement of other planets (in part to increase humanity's resilience against catastrophes), and the preservation of celestial bodies for scientific investigation, future generations, and indigenous ecology. These visions imply and sometimes explicitly assert views on what a regulatory regime (or regimes) should do. Advocacy for increased regulatory oversight of space activities points to risks on Earth, in space, and on other celestial bodies. Advocacy for relaxed regulatory oversight warns that over-regulation will slow progress towards the desirable goals and opportunities of space activities. In this Essay, we propose not more or less regulation, but a more sensible and structured approach to interplanetary risk regulation that considers the wide array of risks, opportunities, values, and stakeholders in interplanetary activities.

Section II frames interplanetary risk regulation as a new arena of governance that involves the development of rules and institutions tailored to emerging space activities. Section III applies lessons learned from risk analysis (on Earth) to lay the foundations for interplanetary risk regulation. Section IV explores two currently emerging interplanetary risks in more detail—planetary protection against contamination and planetary defense against asteroids—to examine the ways such risks are not adequately managed under the current regime of national, international, and global law and policy on Earth. Section V concludes with recommendations for a sensible approach to interplanetary risk regulation.

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12 *See generally* Garrett Hardin, *The Tragedy of the Commons*, 162 SCIENCE 1243 (1968). For lessons on commons governance drawn from insights about space, see, e.g., Marco A. Janssen & Xiao-Shan Yap, *Governing Outer Space as a Commons is Critical for Addressing Commons on Earth*, 18 INT'L J. COMMONS 32 (2024).

13 *See* Jonathan B. Wiener, *The Tragedy of the Uncommons*, 7 GLOB. POL'Y 67 (2016).

14 *See* Charles (Chase) Hamilton, *Space and Existential Risk: The Need for Global Coordination and Caution in Space Development*, 21 DUKE L. & TECH. REV. 1 (2022) (arguing that space development under the current space law regime potentially increases the risk of human extinction, in part due to collective action problems). In addition to extreme negative risks, interplanetary risk regulation should also consider potential extreme benefits or opportunities, such as whether space settlements can help hedge against catastrophic risks to Earth. *See* Arden Rowell, *Regulating Best-Case Scenarios*, 50 ENV'T L. 1105, 1135 (2021) (examining regulation considering potential extreme benefits, including successful space settlements as an example); *see infra* note 49 (discussing the pros and cons of space settlements as a hedging strategy against catastrophe on Earth).

II. FRAMING INTERPLANETARY RISK REGULATION

The development of interplanetary risk regulation can be viewed as part of the ongoing human project of enhancing systems of governance to address and accommodate social, environmental, political, economic, and technological change over time. In early human history, immediate risks of predation and food scarcity dominated daily life and forced humans to undertake risk assessment and risk management, developed through trial and error and diffused through shared community learning, to survive and prosper.[15] The emergence of agriculture and civilizations brought new systemic risks involving nutrition, disease, resource depletion, pollution, and armed conflicts, which in turn were met with developing systems of governance (some more successful than others).[16] As the world has become increasingly interconnected through trade, travel, and communication, so too have risks and human responses to them become more interconnected and interdependent.[17] Interconnectedness has at least three dimensions: first, faster and wider propagation of risks across transboundary networks (so far, around the Earth), such as the global spread of pathogens, pollution, terrorism, financial crashes, and information technologies (including AI); second, more complex and extended ripple effects of policy responses to address these risks, because each policy intervention itself operates in a web of interconnectedness, so that reducing one risk may also affect multiple other risks; and third, greater diffusion of information, learning and lessons from experience and policy variation around the world (so far, the Earth), helping to respond to these risks by revising and improving policy interventions.[18] Today, we live in a highly interconnected world, on all three dimensions: multiple simultaneous risks spreading from local to global; a complicated array of national laws and regulations as well as international law and global institutions with multi-risk effects; and a race to learn how best to assess and manage emerging risks. As humans go to space, extending interconnectedness beyond the Earth,[19] we can foresee an ever-broadening arena

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15 *See generally* BERNSTEIN, *supra* note 1.

16 For popular accounts, see YUVAL NOAH HARARI, SAPIENS: A BRIEF HISTORY OF HUMANKIND (2011); ANDREW H. KNOLL, A BRIEF HISTORY OF EARTH 195–230 (2021). To be sure, human societies were complex at every stage and scale, and social evolution is not linear in obligatory stages but is marked by many experiments and variations. *See generally* DAVID GRAEBER & DAVID WENGROW, THE DAWN OF EVERYTHING: A NEW HISTORY OF HUMANITY (2021).

17 Jonathan B. Wiener, *Risk Regulation and Governance Institutions*, *in* RISK AND REGULATORY POLICY 151 (2010).

18 *See* Wiener, *supra* note 2.

19 Interconnectedness may take on a different character or degree when dealing with interplanetary relationships compared to those on a single planet like Earth. Whereas environmental and other impacts on Earth can be felt across national borders, even across oceans, the distances between planets and the presence of an unforgiving vacuum between them may limit their interconnections.

of risk governance—from local, to national, to international, to planetary, to interplanetary.

Human activities are already multiplanetary. Our spacecraft have visited every planet in our Solar System, flying by many and landing robotic probes on some. Physical contact has been made with multiple asteroids and comets, and litigation has arisen over claims to their ownership.[20] Plans to land new missions on the Moon and Mars are now underway, with some pursuing human settlement. That our sphere of influence has already expanded to celestial bodies beyond the Earth means that we are already assessing and managing at least some risks relating to these interplanetary activities. The rapid technological change of the last half-century that is enabling these activities shows no signs of slowing down. It may not be long, on historical and geological time frames, before humanity and terrestrial life become multiplanetary inhabitants.

In an even more significantly multiplanetary future,[21] interplanetary risk regulation would be a key part of broader institutions of "interplanetary law and governance," thus building upon—and going beyond—"international" law and international relations (among the nations on Earth), the "global" governance of the people of Earth (through global law),[22] and the "planetary" (Earth considered holistically),[23] to reach the "interplanetary" scale. That future may seem far off, but humans may soon visit, establish bases, and even settle on the Moon, Mars,

See Arden Rowell, *"Improving" Outer Space*, *in* THE PHILOSOPHY OF OUTER SPACE (Mirko Daniel Garasic & Marcello di Paola eds., 2024). Nonetheless, some interconnections may come from the physical movement of people or objects or energy, or the digital flow of information, between planets. And where there is interconnection, its risks may depend on the sometimes radically different contexts of each celestial body, as demonstrated by the potential risks of interplanetary contamination, discussed *infra* page 15–16 (Part IV-A).

20 *See, e.g.*, Nemitz v. United States, No. CV-N030599-HDM (RAM), 2004 WL3167042 at 1 (D. Nev. Apr. 26, 2004), *aff 'd sub nom.* Nemitz v. Nat'l Aeronautics & Space Admin., 126 F. App'x 343 (9th Cir. 2005).

21 *See* Yap & Kim, *supra* note 5.

22 *See* Benedict Kingsbury et al., *Foreword: Global Governance as Administration – National and Transnational Approaches to Global Administrative Law*, 68 L. & CONTEMP. PROBS. 1 (2005); Jonathan B. Wiener, *Global Environmental Regulation: Instrument Choice in Legal Context*, 108 YALE L. J. 677 (1999).

23 *See* JONATHAN BLAKE & NILS GILMAN, CHILDREN OF A MODEST STAR: PLANETARY THINKING FOR AN AGE OF CRISES (2024); Nils Gilman & Jonathan Blake, *Governing for the Planet*, AEON (July 16, 2024), https://perma.cc/85Y8-9BJA; *see also* Dipesh Chakrabarty, *The Planet: An Emergent Humanist Category*, 46 CRITICAL INQUIRY 1, 5 (2019). Blake and Gilman argue that a "planetary" view of governance would go beyond the "international" and the "global" to provide a more effective framework (than nation-state interactions through international law and globalization) to tackle planetary-scale issues facing the Earth, while they also favor multi-level governance for smaller-scale and national-scale problems. BLAKE & GILMAN, *supra*, at 107. Relatedly, Elinor Ostrom advocated "polycentric" governance. *See* Elinor Ostrom, *Beyond Markets and States: Polycentric Governance of Complex Economic Systems*, 100 AM. ECON. REV. 641 (2010); Elinor Ostrom, *Polycentric Systems for Coping with Collective Action and Global Environmental Change*, 20 GLOB. ENV'T CHANGE 550–57 (2010); Elinor Ostrom, *Nested Externalities and Polycentric Institutions: Must We Wait for Global Solutions to Climate Change Before Taking Actions at Other Scales?* 49 ECON. THEORY 353–69 (2012).

asteroids, and elsewhere—only 60 (or a few more) years after humans first set foot on the Moon. That would be a short time in the history of humanity and a tiny instant in the history of life on Earth.[24] These spacefaring pioneers (or exploiters or conquerors) may be state or non-state actors, just as past exploration and colonization on Earth was often led by private corporations.[25] Relations among Earth and these new worlds, and among these other worlds (with or without involving Earth), will be interplanetary relations and will require some form of interplanetary law and governance. Conflicts may arise both across planets and within planets. There will be questions regarding how to use and respect the ecologies of new worlds.[26] Even if other planets are currently uninhabited,

24 If humans have been on Earth for millions of years, if the era of global colonization by European powers is about five centuries old (though other settlements and empires occurred earlier), and if public international law is at least four centuries old (from, e.g., the Treaty of Westphalia in 1648 C.E.), then by comparison it would be a relatively brief interval if the first human landing on our Moon in 1969 C.E. were followed by an era of multiplanetary settlements and interplanetary relations in the coming century or the next. The time between now and then offers a valuable period to prepare for risk management on this new interplanetary scale (as a polycentric complement to local, national, international and global/planetary law on Earth. *See supra* note 23.).

This timeline also illustrates our suggestion, *supra* note 7, that the Earth-centric orientation of "space law" (centered on Earth, and addressing everything else in the universe in one category) will become antiquated and need to evolve into a more multi-planetary stance and structure of "interplanetary law" as humans begin to settle or encounter off-Earth polities, and as interplanetary relations develop. This evolution from "space law" to "interplanetary law" will build on the Copernican and Darwinian "decentering" of perspectives, from Earth-centric to Heliocentric, and from anthropocentric to evolutionary. *See* BLAKE & GILMAN, *supra* note 23, at 75. Indeed, the OST, *supra* note 6, Art. I, declares the "exploration and use of outer space" to be "the province of all mankind"—a claim that was likely meant in 1967 to be egalitarian in its inclusion of all nations on Earth (not only the spacefaring great powers), but that could soon seem, in an interplanetary future, to assert that Earth is claiming all other planets as "the province of all mankind" in a project of Earth-centric and anthropocentric (not to mention gendered) space colonialism. By analogy, imagine—or indeed recall—European great powers agreeing among themselves that the exploration and use of the "New World" (i.e. the other continents on Earth) would be "the province of Europe"—a doctrine of alleged discovery that has cast a long shadow on American law, see Johnson v. M'Intosh, 21 U.S. (8 Wheat.) 543, 572–84, 588–90 (1823) (recounting the European doctrine of "discovery" of America, and characterizing it as "conquest" based on "pompous claims"); City of Sherrill v. Oneida Indian Nation of N.Y., 544 U.S. 197, 203 n.1 (2005) ("Under the 'doctrine of discovery' … 'fee title to the lands occupied by Indians when the colonists arrived became vested in the sovereign—first the discovering European nation and later the original States and the United States'.") (citations omitted), and that is only now being revisited and unwound some 500 years later. *See* Bill Chappell, *The Vatican repudiates 'Doctrine of Discovery,' which was used to justify colonialism*, NATIONAL PUBLIC RADIO (Mar. 30, 2023), https://perma.cc/EC9J-NYHX. In a multi-planetary future, casting all of "space" as "the province of [hu]mankind" through an international legal instrument may seem similarly presumptuous.

25 *See* PHILIP J. STERN, EMPIRE, INCORPORATED (2023); Matt Weinzierl & Mehak Sarang, *The Commercial Space Age Is Here*, HARV. BUS. REV. (Feb. 12, 2021), https://perma.cc/QZP2-N67D.

26 *See* ERIKA NESVOLD, OFF-EARTH: ETHICAL QUESTIONS AND QUANDARIES FOR LIVING IN OUTER SPACE 93–112 (2023); MARY-JANE RUBENSTEIN, ASTROTOPIA: THE DANGEROUS RELIGION OF THE

successive waves of Earthling settlements, as in the past on Earth, may lead to conflicts among them, such as if rival powers seek the same location.[27] Myriad risks may threaten the survival and success of these multiplanetary populations, be they human, other terrestrial life forms brought abroad, robotic, or truly indigenous life encountered off Earth. It is not too early to think ahead now, before risks arise and settlements are claimed, to scenarios for the potential coming era of interplanetary law and the design of interplanetary risk regulation.

The need for interplanetary foresight is made especially acute by the growing disagreements over the direction of space law and governance. The Outer Space Treaty, which has over 100 State parties, extends international law from Earth to space and celestial bodies, while providing that space is "not subject to national appropriation by claim of sovereignty, use or occupation . . . ."[28] But nations are engaged in significant disputes about the scope of that provision, such as whether it permits States to occupy (and potentially exclude others from occupying or utilizing) portions of land on celestial bodies for periods of time,[29] or whether it permits nations to allow private companies to set up (exclusive) mining operations, extract resources from celestial bodies, and sell them (on Earth or in situ) for profit.[30] Meanwhile, although the Outer Space Treaty provides for national government supervision of non-governmental actors in space,[31] one major private space company's Terms of Service declare that for services provided on Mars or in transit to Mars, "the parties recognize Mars as a free planet and that

CORPORATE SPACE RACE 119–53 (2022); Peter Singer & Agata Sagan*, Should We Protect Space Because Doing so Will Benefit Humans, or is There Some Intrinsic Value in Preserving Places Beyond Our Own Planet?* NEW STATESMAN (June 13, 2012), https://perma.cc/83X2-ND4P; Robert D. Pinson, *Ethical Considerations for Terraforming Mars*, 32 ENV'T L. REP. 11333–41 (2002).

27 It may be hasty to assume that dispossession of Native or Indigenous Peoples cannot happen on currently unpopulated planets, because multiple waves of settlers from Earth could entail later arriving settlers encountering the progeny of prior settlers, who have by then become the Indigenous population of the planet and may then welcome, or resist and exclude, or be subjugated by, the later arriving colonists.

28 OST, *supra* note 6, Art. II.

29 As potentially envisioned by the Artemis Accords, Principles for Cooperation in the Civil Exploration and Use of the Moon, Mars, Comets, and Asteroids for Peaceful Purposes, Oct. 13, 2020, NASA, perma.cc/7V8L-EQ2J (providing in Section 11 for "deconfliction" by establishing exclusive national "safety zones," ostensibly temporary).

30 *See* Charles (Chase) Hamilton, *Legal Controversies in Commercial Space Resource Extraction*, FED. LAW. 54 (2024); US Commercial Space Launch Competitiveness Act of 2015, sections 402–403, codified at 51 U.S.C. 51303 (conferring on U.S. citizens a set of private rights to space resources). Other countries have also adopted such laws, including Luxembourg, Japan, and U.A.E., drawing attention to the possibility that first-movers could establish a monopoly or concentrated power over valuable space resources. *See* Morgan DePagter, *"Who Dares, Wins:" How Property Rights in Space Could be Dictated by the Countries Willing to Make the First Move*, 1 CHI. J. INT'L L. ONLINE (2022); Tyler Conte, *Property Rules for Martian Resources: How the SPACE Act of 2015 Increases the Likelihood of a Single Entity Controlling Access to Mars*, 84 J. AIR L. & COM. 187 (2019).

31 OST, *supra* note 6, Art. VI.

no Earth-based government has authority or sovereignty over Martian activities. Accordingly, Disputes will be settled through self-governing principles, established in good faith, at the time of Martian settlement."[32] The future envisioned by these Terms of Service suggests the possibility of legally independent settlements, each with potentially different legal and governance systems, across multiple celestial bodies. Such a scenario implies a potential role for laws and institutions that go beyond the "international" and the "planetary," toward the "interplanetary," as well as plural legal systems within each planet.

In this Essay, we suggest the coming need for "interplanetary" scale governance to address interplanetary risks, requiring potentially novel institutions and governance authorities.[33] Current approaches to such risks are largely extensions of local, national, or international regimes—all grounded in the histories and polities of Earth, which may have partial but limited usefulness for dealing with new problems involving interplanetary space.[34] Addressing interplanetary risks using instruments grounded in national and international law presents a scale mismatch.[35]

Moreover, interplanetary risks are not just future conjectures—we already face some of them today. Below we discuss the risks of interplanetary contamination and asteroid collisions. Interplanetary risk regulation is thus already

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32 Starlink Terms of Service, Article 11, https://perma.cc/XG2Q-JAR7.

33 Thinking through interplanetary governance is timely today because human activities are already multiplanetary, and humans may soon settle off Earth. At least in concept, some authors have imagined that there may (very) eventually be even broader approaches to governance beyond "interplanetary"—including, potentially, "solar system," "interstellar," and even "galactic." *See, e.g.*, FRANK HERBERT, DUNE (1965) (envisioning a multiplanetary system of governance across a galaxy, with interconnected economics, politics, religion, trade, transport, and ecology of critical materials). Another dimension could be across "physical" and "virtual," with the development of advanced artificial intelligence, and perhaps human-machine integration or transhumanism via the uploading of human psyches into digital form—possibly enabling much more distant space travel than physical human bodies can attain. *See* MARTIN REES, ON THE FUTURE: PROSPECTS FOR HUMANITY 153, 178 (2018); DONALD GOLDSMITH & MARTIN REES, THE END OF ASTRONAUTS: WHY ROBOTS ARE THE FUTURE OF EXPLORATION (2022).

34 *See generally* Yap & Kim, *supra* note 5 (advocating a framework of Earth-space governance). The current body of "space law," including the OST and related international treaties, soft law guidelines, national laws, and non-governmental arrangements, *supra* note 6, can be seen as a "regime complex" described in Karen J. Alter & Kal Raustiala, *The Rise of International Regime Complexity*, 14 ANN. SOC. SCI. 329 (2018); Karen J. Alter, *The Promise and Perils of Theorizing International Regime Complexity in an Evolving World*, 17 REV. INT'L ORGS. 375 (2022); or a "hybrid institutional complex" (including non-state actors and arrangements) described in Kenneth W. Abbott & Benjamin Faude, *Hybrid Institutional Complexes in Global Governance,* 17 REV. INT'L ORGS. 263 (2022). To this institutional complexity, we add the need to address the interplanetary scale and its novel risks.

35 *See* Graeme S. Cumming et al., *Scale Mismatches in Social-Ecological Systems: Causes, Consequences, and Solutions*, 11 ECOLOGY & SOC'Y 14 (2006); D.W. Cash et al., *Scale and Cross-Scale Dynamics: Governance and Information in a Multilevel World*, 11 ECOLOGY AND SOCIETY no.8 (2006). On the general problem of mismatch in regulatory design, see STEPHEN G. BREYER, REGULATION AND ITS REFORM (1982).

important, interesting, and an opportunity for adaptive learning, because it poses immediate challenges for risks and opportunities we face today (when we inhabit only the Earth), while also implicating humanity's potential future activities and opportunities off-Earth if we explore and settle other celestial bodies.

III. RISK ASSESSMENT AND MANAGEMENT FOR THE INTERPLANETARY

As long as we do not know the future, risk is an unavoidable feature of living in an uncertain world. Risk regulation involves both risk assessment and risk management. Risk assessment involves identifying and estimating the probability (likelihood) and consequence (severity or magnitude of impacts) of risks, as well as other key attributes such as timing, distributional incidence, and uncertainty. Risk management involves deciding what to do about the risk, including how stringently to set standards, and what type of policy instrument to employ. Risk assessment and risk management are critical components of governance systems designed to address potential hazards and opportunities in areas such as health, safety, environment, finance, and security. They provide a structured approach to evaluating risks and responses.

Institutionally, risk is typically assessed and managed through combinations of private and state actors (and multiple agencies or ministries of the state, at several scales of governance). Private actors, such as individuals and companies, can be well-suited to address risks with localized (internalized) effects, or where low transaction costs enable efficient bargains, socially beneficial markets, and innovation. But leaving the responsibility for risk assessment and management to private actors alone is problematic if market failures mean that private and social objectives diverge, such as from important externalities, high transaction costs, collective action problems, information gaps, and inequities. State actors can better address many risks in circumstances that are not adequately addressed by private actors, including by collecting information, funding public goods, and issuing regulations to internalize and reduce externalities,[36] but states can also face potential dysfunctions including misallocation of resources, unintended side effects, and internal motivations insulated from public demand signals.[37] Identifying and implementing an appropriate balance between public and private responsibilities is an essential feature for any system of regulatory governance, entailing considerations involving the structure of government, modes of

36 DAVID MOSS, WHEN ALL ELSE FAILS: GOVERNMENT AS THE ULTIMATE RISK MANAGER 1 (2002).

37 CHARLES WOLF, MARKETS OR GOVERNMENTS: CHOOSING BETWEEN IMPERFECT ALTERNATIVES 44 (1988). The problem of interplanetary externalities warranting interplanetary risk regulation can be analogized to the problem of interjurisdictional externalities on Earth warranting higher-scale (federal or international) risk regulation. *See* Richard L. Revesz, *Federalism and Interstate Environmental Externalities*, 144 U. PA. L. REV. 2341 (1996).

interaction between public and private entities, policy analysis tools, and the specific policies adopted.

These familiar features of risk regulation on Earth may be replicated and amplified in space. Article VI of the Outer Space Treaty, which requires that states provide "authorization and continuing supervision" for nonstate actors' activities in space,[38] necessitates state involvement to some degree but allows each state to govern private activities as it sees fit. Both states (governments) and non-state actors (private/commercial) are already active in space, with bold plans to go to the Moon, build space stations, visit and possibly settle on Mars, explore moons of Jupiter and Saturn, study asteroids for possible mineral extraction, and more. These activities offer enormous opportunities but may also pose significant risks, including to the Earth, to the spacefaring actors and their passengers, workers, and customers, and to other planets, moons, and other celestial bodies. In this Essay, we focus on a set of interplanetary risks which illustrate the multidisciplinary kinds of expertise needed to understand, assess and manage these risks. Some of these risks are already identified but remain complex and uncertain; others will become manifest as space activities reach farther. In addition, space activities may face multiple layers of governance institutions and stakeholders, from the local to the national to the international, the global, and the interplanetary.

One significant challenge for regulatory governance is the fragmentation among regulatory bodies and the risks or activity areas for which each is responsible. Fragmented institutions may excel in their specialized areas of expertise, but can also suffer gaps or overlaps in responsibilities. Fragmentation can lead to siloed approaches that neglect interconnected risks in complex systems.[39] Historically, regulatory approaches to risk often focus only on one target risk at a time (such as by a single government agency acting to address its bounded mission).[40] By contrast, a risk-risk or multi-risk framework aims to understand and manage the tradeoffs among risks (including target risks, co-benefits, and countervailing risks), overcoming neglect or "disregard" of impacts and of adversely affected groups,[41] and seeking "risk-superior" policies that reduce multiple risks in concert.[42]

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38 OST, *supra* note 6, Art. VI.

39 *See* GRAHAM & WIENER, *supra* note 11.

40 *Id.*; J. Liu et al., *Systems Integration For Global Sustainability*, 347 SCI. 963 (2015); *see generally* Robert Baldwin, *Regulatory Excellence and Lucidity*, *in* CARY COGLIANESE, ED., ACHIEVING REGULATORY EXCELLENCE (2017); Paul T. Anastas & Julie B. Zimmerman, *Environmental Protection Through Systems Design, Decision-making, and Thinking*, *in* DANIEL C. ESTY, ED., A BETTER PLANET (2019).

41 *See* Jonathan B. Wiener, *Disregard and Due Regard*, 29 N.Y.U. ENV'T L. J. 437 (2021); Richard B. Stewart, *Remedying Disregard in Global Regulatory Governance*, 108 AM. J. INT'L L. 211 (2014).

42 *See* GRAHAM & WIENER, *supra* note 11; Wiener, *supra* note 2.

Risks, uncertainties, and risk-risk tradeoffs are likely to afflict interplanetary activities and regulations. All of the extremely diverse hazards and benefits that are addressed by risk regulations on Earth have at least in common that they involve just one planet, with a relatively similar or at least familiar set of environmental conditions (gravity, temperature, air pressure, atmospheric composition, liquid water, etc.). In a multiplanetary world, humans will need new methods to assess the risks on planets and other celestial bodies with heterogeneous environmental and geologic conditions, each differing in significant, fundamental ways from the Earth and from each other (while some areas on each celestial body can vary significantly from other areas on that same body, as on the Earth).[43] Over time, the number and types of stakeholders and government agencies involved in each activity or area may also vary significantly. Policies to reduce target risks may encounter unexpected side effects, in part due to the differing conditions across planets and other celestial bodies. Evaluating interplanetary risks or activities based only on a predefined target risk may be frustrated by these side effects and the wide diversity of contexts in which the activities are occurring or the consequences are felt. Psychological heuristics and biases that lead decision makers to focus on (or neglect) a risk may yield unexpected mismatches with conditions, processes, and risks on different celestial bodies, especially across great distances in space and time.[44] A holistic approach to interplanetary risk regulation—one that likely expands the bounds of current risk-risk frameworks—will be difficult but necessary for addressing risks on and across different celestial bodies.

Of particular importance for interplanetary activities and regulation are extreme catastrophic risks. These ultra-low likelihood but existential-impact risks are often misperceived and mismanaged for at least three reasons: they have not occurred frequently enough for humans to have learned to react, assess, and manage them, yielding an "unavailability" heuristic; their magnitude is so large that they may yield numbing "compassion fade"; and their magnitude is so large and destructive of institutions that private actors may be under-deterred by the prospect of ex post sanctions applied after a catastrophe, such as civil or criminal liability, which may not be credible ex ante.[45] Risks such as global pandemics, large-scale nuclear war, and large asteroid collisions can threaten civilization, potentially reaching the degree of "existential risks" that threaten the existence of

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43 *See* Rowell, *supra* note 19.

44 *See* ARDEN ROWELL & KENWORTHY BILZ, THE PSYCHOLOGY OF ENVIRONMENTAL LAW 31–62 (2021) (discussing heuristics and biases affecting terrestrial environmental policy).

45 *See* Wiener, *supra* note 13.

human life or all life on Earth.[46] Such catastrophic/existential risks may require different regulatory approaches than more familiar risks, because learning by iterative trial and error is seriously suboptimal when the error could be existential (ending all future life—and precluding further learning). Thus extreme catastrophic/existential risks pose the strongest case for foresight and precaution, while still involving potential risk-risk (catastrophe-catastrophe) tradeoffs of policy responses.[47] To the extent that interplanetary risk regulation would address activities that are both novel and interplanetary in scale (and may carry a heightened possibility of catastrophic risk, across celestial bodies and potentially affecting vast numbers of stakeholders), its risk assessment and management strategies will need to account for extreme catastrophic risks.

On the other hand, interplanetary activities also carry the potential for extreme upsides—"wonders"—which are similarly often misperceived and mismanaged in policy.[48] One of the motivations for establishing self-sustaining off-Earth settlements is hedging against the risk of catastrophes that may be existential if humanity is all based on one celestial body, as it is now on Earth.[49] Meanwhile, the resources that could be extracted from even a handful of asteroids could be worth enormous economic value that could be used to dramatically improve lives on Earth or elsewhere.[50] These significant opportunities are subject to many of the same (and some different) psychological heuristics as catastrophic risks that make it easy to misjudge their likelihood, and it is not straightforward to compare the high-magnitude scenarios with other more routine risks/opportunities.[51] Interplanetary risk regulation must be equipped to sensibly handle tradeoffs between multiple wonders (such as where different off-Earth settlement locations carry different potential opportunities for citizens to flourish), as well as between wonders and catastrophes (such as where mining

46 *See* Jason Matheny, *Reducing the Risk of Human Extinction*, 27 RISK ANALYSIS 1335–44 (2007); Nick Bostrom, *Existential Risk Prevention as Global Priority*, 4 GLOB. POL'Y 15 (2013); RICHARD A. POSNER, CATASTROPHE: RISK AND RESPONSE 1–5 (2004); TOBY ORD, THE PRECIPICE (2020).

47 *See* Wiener, *supra* note 13; CASS R. SUNSTEIN, AVERTING CATASTROPHE 48–49 (2021).

48 *See* Rowell, *supra* note 14.

49 For a critical examination of this motivation, see Hamilton, *supra* note 14, at 36–39. The multiplanetary hedging strategy may be thwarted if the catastrophic risk affecting Earth also affects the other planet, or if the off-Earth settlement still depends on resupply from Earth. Having an off-Earth settlement also might influence the probability of risk-taking on Earth, such as increasing risk-taking through moral hazard or decreasing risk-taking through greater appreciation of Earth's fragility. *See* Seth D. Baum, David C. Denkenberger & Jacob Haqq-Misra, *Isolated Refuges for Surviving Global Catastrophes*, 72 FUTURES 45–56 (2015).

50 Shriya Yarlagadda, *Economics and the Stars: The Future of Asteroid Mining and the Global Economy*, HARV. INT'L REV. (Apr. 8, 2022); *see also* Hamilton, *supra* note 14, at 53–54 (arguing that asteroid mining may cause economic disruption or risky economic acceleration).

51 *See* Rowell, *Regulating Best-Case Scenarios*, *supra* note 14.

bountiful asteroids also raises the risk that an asteroid is caused to collide with the Earth or another populated planet).

In addition, risk regulation involves some mechanism for enforcement or compliance assurance, which poses difficulties in the vast domain of space beyond the Earth. The distances between celestial bodies often involve vast scales that make it costly or impossible to monitor activities from afar and to deploy law enforcement from Earth. Although Article II of the Outer Space Treaty limits states from asserting sovereignty over celestial bodies in outer space, Article VI provides that each national government has jurisdiction to authorize and supervise its own private actors in space.[52] States can pursue ex post remedies against other states for alleged violations of international law after they have occurred, or for liability for damages caused by space activities,[53] but ex post remedies may not be credible at the international (let alone the interplanetary) scale, especially for extreme catastrophic risks that could destroy the necessary institutions, so that the ex ante influence of such ex post remedies for interplanetary risks may be inadequate.[54] Attempts to enforce interplanetary rules may be met with resistance by local inhabitants of celestial bodies who may not share the same sense of identity as or fondness for the rule-making and enforcing body on different distant planet.[55] Interplanetary risk regulation may need to incorporate or accommodate new jurisdictional models (perhaps local adjudication and enforcement, and even local lawmaking) and advanced technologies for surveillance and enforcement (perhaps employing AI), while both addressing interplanetary externalities and maintaining legitimacy in the eyes of the governed.

In sum, the lessons from risk regulation scholarship to date indicate some ways to begin to craft an effective framework for interplanetary risk regulation, including developing institutions to match the interplanetary scale, carefully assessing and managing interplanetary risks, adopting a comprehensive multi-risk approach to identifying and addressing risk-risk tradeoffs, and incorporating careful consideration and management of extreme catastrophic risks and extreme potential upside scenarios. In practice, interplanetary law will need to respond to the characteristics that distinguish the interplanetary from the national, international, and planetary, including the heterogeneity across planets, the distances between celestial bodies, and the risks that may interconnect them.

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52 OST, *supra* note 6, Art. II, Art. VI.

53 Convention on International Liability for Damage Caused by Space Objects, Mar. 29, 1972, 24 U.S.T. 2389.

54 *See* Wiener, *supra* note 13.

55 *See* Hamilton, *supra* note 14, at 39 (discussing the difficulty of surveillance and enforcement, and related conflict risks, in the potential development of a space diaspora).

IV. ANALYZING TWO NEAR-TERM INTERPLANETARY RISKS

In this section we examine more closely two of the interplanetary risks that are already in view today—microbial contamination and asteroid collisions—and the current and future approaches to regulation of these risks.

A. Planetary Protection Against Contamination

"Planetary protection" refers to measures to prevent harmful biological contamination of a planet or other celestial body. The Outer Space Treaty (OST), in Article IX, calls on parties to "avoid harmful contamination" of other celestial bodies, known as "forward contamination" from the Earth to other celestial bodies; and it calls on parties to avoid "adverse changes in the environment of the Earth resulting from the introduction of extraterrestrial matter," known as "back contamination" from other celestial bodies to the Earth.[56]

This two-way treatment of planetary protection, forward and back, addresses missions heading in two general directions: away from the Earth and coming back to the Earth. In the future, if humans (or our robots) visit and establish bases, camps, or settlements on multiple planets, moons, and asteroids, then in a multiplanetary setting, additional routes will travel not only from/to Earth but also across and among other planets, moons and asteroids—and movements of biological contamination could occur along these routes among these bodies, beyond Earth. Hence the two-way Earth-centered treatment of "forward" and "back" contamination needs to be expanded to a multiplanetary approach to "interplanetary contamination."

1. Risk assessment of interplanetary contamination

As space missions increase, forward contamination of other planets seems relatively more likely than back contamination, because life is so plentiful on Earth, and because adequately sterilizing or otherwise preventing Earth-originating missions from bringing life along is so difficult—on robotic missions, and especially on human crewed missions (which would introduce not only humans but also human microbiomes, food cultivation, and waste disposal). The adverse consequences of forward contamination could include (i) compromising the search for life off the Earth, if life that we detect on another planet was actually brought from the Earth (a false positive finding that we are not alone); and (ii) damaging the ecosystems of other planets. These risks are not merely hypothetical; for example, the Apollo missions to the Moon from 1969-1973 left behind

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56 OST, *supra* note 6, Art IX.

numerous bags of human waste,[57] and when the Beresheet mission crashed on the Moon in 2019, it spilled a secret sample of tardigrades (hardy microscopic "water bears" which might remain dormant and possibly revive in the future).[58]

Back contamination seems relatively less likely, because we are unsure whether any life exists off the Earth, but is still possible. (The Perseverance rover is searching for life on Mars right now, presumably for fossil evidence of past life on ancient Mars, but conceivably finding dormant life or biologically active materials—questions to be studied in eventual Mars Sample Returns.) Back-contamination presents one type of extreme catastrophic risk, for which the probability may be very low, but the consequence may be catastrophic or existential to life on Earth—such as if extraterrestrial microbes were virulent human pathogens, or if they caused global ecological disruption. Microbes are thought to have changed the Earth's atmosphere in the past, such as by adding oxygen—though on long time scales.[59] In the 1960s, the Apollo 11 mission to the Moon sparked a debate over the risks of back contamination; public health agencies and key scientists pressed NASA to create a quarantine for the returning astronauts—which NASA eventually did.[60] The returning Apollo 11 astronauts donned Biological Isolation Garments before exiting their spacecraft, and were isolated first in the Mobile Quarantine Facility and then in the Lunar Receiving Laboratory (LRL) for several weeks.[61] But the quarantine was breached before that, upon the capsule's splashdown in the ocean, when the recovery team opened the capsule's hatch to get the astronauts out from the rough seas and rising interior temperatures, thereby releasing the capsule's interior air into the Earth's environment.[62] This decision reflected the priority put on the three identified (and celebrated) individual humans, over the low-probability but potentially

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57 Megan Garber, *The Trash We've Left on the Moon: The lunar surface is strewn with more than 100 manmade items, from bags of urine to monumental plaques*, THE ATL. (Dec. 19, 2012), https://perma.cc/2ERH-UAFZ; Brian Resnick, *Apollo astronauts left their poop on the moon. We gotta go back for that shit. What 50-year-old dirty diapers can teach us about the potential origins of life on Earth,* VOX (July 12, 2019), https://perma.cc/9TG8-SAPR.

58 Daniel Oberhaus, *A Crashed Israeli Lunar Lander Spilled Tardigrades on the Moon*, WIRED (Aug. 5, 2019), https://perma.cc/B95W-NZCN.

59 *See* KNOLL, *supra* note 16, at 101–11.

60 *See* Kent Carter, *Moon Rocks and Moon Germs: A History of NASA's Lunar Receiving Laboratory*, 33 PROLOGUE 233–50 (2001); *Space: Is the Earth Safe From Lunar Contamination?*, TIME (June 13, 1969), https://perma.cc/383F-4PGG (quoting Carl Sagan: "Maybe it's sure to 99% that Apollo 11 will not bring back lunar organisms, but even that 1 percent of uncertainty is too large to be complacent about.").

61 *See* Carter, *supra* note 60; John Uri, *Building on a Mission: The Lunar Receiving Laboratory*, NASA JOHNSON SPACE CTR. (Oct. 13, 2021), https://perma.cc/A6MH-4BV5.

62 *See* Carter, *supra* note 60; Dagomar Degroot, *One Small Step for Man, One Giant Leap for Moon Microbes? Interpretations of Risk and the Limits of Quarantine in NASA's Apollo Program*, 114 ISIS 272 (Jun. 2023).

catastrophic risk posed by potential Moon microbes to the Earth.[63] Today, the prospect of Mars Sample Returns (MSR) has sparked a new debate over planetary protection against back contamination.[64] Missions and sample returns from other planets and moons may pose further contamination risk scenarios.

The risks of interplanetary contamination are likely to vary across planets and moons, as the probabilities of encountering life vary across potential habitats. Some moons and planets may be barren; others may hold greater potential for harboring life. The international Committee on Space Research (COSPAR) issues Planetary Protection Policies, which include a five-level scale of contamination risk assessment, with designations for restricted or unrestricted missions and returns.[65] Sources of uncertainty in these risk assessments include that there may be habitats on some planets that are difficult to observe (e.g., in caves and shaded areas), and that there may be forms of life on other planets that are so different from Earth life that we are not yet sure how to recognize them.[66]

In addition to varying probabilities of life on different celestial bodies, there may also be varying consequences of bringing life from one celestial body to another. The OST refers not to avoiding all contamination, but "harmful contamination" and "adverse changes."[67] Interplanetary risk assessment needs methods to define what qualifies as "harmful" and "adverse" and to foresee the likely severity of these consequences. For example, human or robotic explorers

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63 *See* Degroot, *supra* note 62; Wiener, *supra* note 13.

64 *See* Bhavya Lal & Jeff Trauberman, *Mars Is Coming to Earth: It's Time to Take a Close Look at the US Planetary Protection Policy*, ISSUES SCI. & TECH. (Aug. 4, 2020), https://perma.cc/YKV6-697Y; Donna Shalala and Susan Brooks, *Is the U.S. ready for extraterrestrials? Not if They're Microbes. How to Defend Earth from Space Bugs*, HOUS. CHRON. (Apr. 11, 2024), https://perma.cc/9G7D-2Q85. NASA has postponed the MSR missions into the 2030s due to high costs, both in the Biden and Trump administrations, with the latter's budget proposing to cancel NASA's MSR entirely until human crews can go to Mars (at greater expense and with greater risks of forward contamination—implying that the first MSR may be brought back by China, Europe, or private actors). *See* Leonard David & Lee Billings, *NASA Spent Billions to Bring Rocks Back from Mars. Trump Wants to Leave Them There,* SCI. AM. (May 8, 2025), https://perma.cc/CB99-AZP5. If any actor undertakes MSR, appropriate planetary protection measures to prevent possible back contamination will be essential.

65 *See Policy on Planetary Protection*, COSPAR (June 3, 2021), https://perma.cc/7TNY-WWVW; Thomas Cheney et al., *Planetary Protection in the New Space Era: Science and Governance*, 7 FRONTIERS ASTRONOMY & SPACE SCI. (2020); Athena Coustenis et al., *Planetary Protection: An International Concern and Responsibility*, 10 FRONTIERS ASTRONOMY & SPACE SCIS. (2023)=; *COSPAR Updates Planetary Protection Policy for Lunar Missions*, NASA (Aug. 31, 2021), https://perma.cc/ERS9-GAU3. COSPAR relies on scientists from governmental and non-governmental research centers, typically in major spacefaring countries, see John D. Rummel & Linda Billings, *Issues in Planetary Protection: Policy, Protocol and Implementation,* 20 SPACE POL'Y 49, 50 (2004), a group of experts that is broadening as illustrated by the numerous and nationally diverse co-authors of Coustenis et al., *supra*.

66 *See* Daniel Oberhaus, *Will We Recognize Life on Mars When We See It?*, WIRED (July 9, 2020), https://perma.cc/2Y9J-ZYAZ; Mohamed Noor, *Thinking Outside Earth's Box: How Might Heredity and Evolution Differ on Other Worlds*, 15 EVOLUTION: EDUC. & OUTREACH 13 (2022).

67 OST, *supra* note 6, Art. IX.

carrying Earth microbes and treading on local soil microbes (a form of forward contamination) may harm local ecology and may compromise the search for life off Earth; bringing back contamination to Earth, though less likely, could be catastrophic. What is "harmful" for one planet, such as two degrees Celsius global average surface temperature change on the Earth, may be negligible—or even beneficial—on another planet.[68] And even if an interplanetary yardstick for "harm" could be established, it may be difficult to predict how life would interact with an entirely different planet once relocated from its original ecosystem. On Earth, "invasive species" sometimes, but not always, pose risks of harmful or adverse consequences in new habitats.[69] Risk regulation will need to adapt methods of human and ecological risk assessment to evaluate the impacts (harmful or beneficial) of novel life forms coming from or to outer space.

As we explore more planets, moons, and asteroids, and if we eventually establish larger installations such as scientific bases, mining camps, military bases, or settlements, we will likely make trips among celestial bodies that do not always involve starting or stopping on Earth. These trips will pose risks of cross-contamination from one planet or moon to another. Our multiplanetary missions may make us vectors of interplanetary contamination, like insects spreading vector-borne diseases across national borders on Earth—or human colonists and conquistadors bringing animals and pathogens to new settlements on Earth. Future space missions and settlements will need protection against contamination not only from Earth but also from other planets. We will need an approach to "interplanetary contamination" that is broader than forward/back contamination from/to the Earth, and we will need "interplanetary risk regulation" of harmful contamination.

2. Risk management of interplanetary contamination

Interplanetary risk regulation, building up from current risk regulation of forward/back contamination, will need good methods of risk management—guidelines for decision making and policy design. The COSPAR Planetary Protection Policies are a start; they will need to be updated and elaborated as we learn more about potential life off Earth, and as we visit and settle asteroids, moons and planets.[70] The COSPAR policies' restrictions may need to be more

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68 *See* Rowell, *supra* note 19.

69 *See* ANDREW P. ROBINSON ET AL., EDS., INVASIVE SPECIES: RISK ASSESSMENT AND MANAGEMENT (2017); Mark C. Andersen et al., *Risk Assessment for Invasive Species*, 24 RISK ANALYSIS 787–93 (2004).

70 *See infra* note 80 (discussing adaptive learning). The COSPAR policies are soft law, see Cheney et al., *supra* note 65, which may be less binding on states and may not govern non-state (private) actors unless implemented in national law, but can also be more flexible in updating over time and in gaining participation including by non-state actors. *See* Kenneth W. Abbott & Duncan Snidal, *Pathways to International Cooperation*, *in* THE IMPACT OF INTERNATIONAL LAW ON INTERNATIONAL

stringent, or more nuanced, as we learn more about the probabilities of life off Earth, the types of such life, the health and ecological impacts of contamination, the benefits of decoding novel genomes and perhaps cultivating novel life, and other aspects.

Regulatory gaps in the current regime will need to be addressed. Before reaching the interplanetary scale, there are already gaps at the planetary or global (international law) scale, and at the national scale, on Earth. At the international scale, the text of OST Article IX does not define "contamination," nor "harmful," nor "adverse." These key terms need analytic criteria to bolster the COSPAR policies and national policies. Further, other key terms in Article IX—"due regard" and "appropriate measures"—could be interpreted, as in US national law, to entail reasonable precautions whose benefits justify their costs.[71] But Article IX calls for "due regard" only to the "interests of other State Parties" to the treaty,[72] which could be expanded to cover due regard for impacts on non-state populations and on other planets.

In addition, by addressing the two scenarios of contamination brought to other celestial bodies, and adverse changes to Earth from the introduction of extraterrestrial matter, Article IX may not address an intermediate scenario: life brought from Earth to space, mutated or altered in space, and then returned to Earth with adverse impacts. This scenario seems more likely than returning back contamination from other planets, because the likelihood of life from Earth traveling in a spacecraft seems far higher than the likelihood of finding life on another planet; on the other hand, it may be difficult to assess the consequences of such space-altered Earth life upon its return to Earth. Perhaps Article IX could be interpreted broadly, such that "extraterrestrial matter" covers terrestrial biota after being altered in space. (And note that "extraterrestrial matter" may already cover non-biological threats to Earth, such as chemical or radiological hazards.) For example, the Russian space station Mir experienced unexpected fungal growth on windows (including on the outside of the spacecraft), electronic equipment, and the crew's food and water, which were later identified as Aspergillus and Penicillium species inadvertently brought from Earth via the bodies of the human astronauts.[73] The fungi had adapted to become resistant to radiation, surviving

COOPERATION 50, 70–71 (Eyal Benvenisti & Moshe Hirsch eds., 2004); Setsuko Aoki, *The Function of 'Soft Law' in the Development of International Space Law, in* SOFT LAW IN OUTER SPACE: THE FUNCTION OF NON-BINDING NORMS IN INTERNATIONAL SPACE LAW 57, 84–85 (Irmgard Marboe ed., 2012).

71 *See* Wiener, *supra* note 41; Stewart, *supra* note 41; US v. Carroll Towing, 159 F.2d 169 (2d Cir. 1947) (introducing Learned Hand's rule for reasonable precautions against risks).

72 OST, *supra* note 6, Art. IX.

73 K. Makimura et al., *Fungal flora on board the Mir-Space Station, identification by morphological features and ribosomal DNA sequences*, 45 MICROBIOLOGY & IMMUNOLOGY 357 (2001).

doses that would kill a human.[74] These or other adaptations could have unexpected, potentially harmful (or possibly beneficial) effects on Earth.

COSPAR's policies may help address these questions about the reach of OST Article IX. So far, COSPAR has succeeded in developing planetary protection policies that have safeguarded the Earth from back contamination. But as noted above, COSPAR policies are soft law guides, not binding treaty law. And OST Article IX does not provide penalties for noncompliance. Moreover, as spacefaring activities are now expanding rapidly among many more actors, including private/commercial actors, there may be more chance of noncompliance, error, or neglect, and more need for global rules to prevent contamination at the interplanetary scale.

COSPAR Planetary Protection Policies depend on implementation by national regulatory bodies. But not all countries have well-developed national planetary protection policies. As the number of spacefaring countries has grown significantly in recent years, there is a need to track and update these countries' national planetary protection policies. UNOOSA has a program to help develop "space law for new space actors," which may be valuable in this effort if it addresses planetary protection against contamination. The tardigrades spilled on the Moon illustrate the difficulty of coordinating national planetary protection policies to prevent forward contamination.[75]

In addition, the array of private/commercial space actors has multiplied in recent years, yet national governments may not all be supervising these non-state actors with regard to planetary protection.[76] OST Article VI says that national governments (state parties) bear "international responsibility" for their "non-governmental entities," and it calls for these national governments to exercise "authorization and continuing supervision" of these non-governmental entities.[77]

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74 Sharmila Kuthunur, *Fungi creepily infiltrates space stations—but scientists aren't scared. They're excited*, SPACE.COM (Sept. 26, 2023), https://perma.cc/T3RK-Q7TG.

75 *See* Loren Grush, *Why stowaway creatures on the Moon confound international space law: Who gets to decide what gets blasted into space?* THE VERGE (Aug. 16, 2019), https://perma.cc/7MQ9-F7LW; Kathryn Gundersen, *Beyond the Tardigrades Affair: Planetary Protection, COSPAR, and the Future of Private Space Regulation*, 53 N.Y.U. J. INT'L L. & POL. 871 (2021). The US (NASA), Europe (ESA), and Japan (JAXA), among others, have adopted planetary protection policies for their national space agencies, but even these may not cover private space actors. *See* Cheney et al., *supra* note 65.

76 *See* Kelsey Eyanson, *Billionaires Eclipse NASA: The Next Space Race over National Regulation*, 60 HOUS. L. REV. 1181 (2023).

77 *See* OST, *supra* note 6, Art. VI. This provision in OST Article VI was evidently a Cold War compromise between the USA and USSR, the only two spacefaring powers at the time (1967), because the USSR favored only government space missions, whereas the USA wanted to allow private/commercial space missions, which the USSR agreed to allow only if subject to national authorization and continuing supervision. *See* Letter from John P. Holdren, Director, Office of Science and Technology Policy (OSTP) to Chairmen Thune and Smith on Space Mission Authorization 3 (Apr. 4, 2016) (available at https://perma.cc/VG82-ST6C).

These terms are not defined in the treaty. Whether national governments actually undertake such "continuing supervision" of private/commercial space activities is unclear. For example, the United States, the largest spacefaring country (with many private/commercial actors such as SpaceX, the largest rocket launching company, and its subsidiary Starlink, the largest satellite network in Earth orbit), has gaps in its regulatory regime for planetary protection and private/commercial space activities. U.S. NASA has a Planetary Protection Officer and detailed planetary protection policies, which it recently updated to take a more risk-based approach.[78] But NASA does not regulate private actors or other government agencies (unless it puts conditions in its contracts as a payload customer). The Federal Aviation Administration (FAA) in the U.S. Department of Transportation (DOT) has the statutory authority to grant or deny launch and reentry permits,[79] but focuses mainly on avoiding collision risks, and may not have the in-house expertise or policy focus to adopt planetary protection policies for microbiological contamination risks. Although the FAA has issued guidance under which it can prospectively assess the risks of in-space activities before it grants or denies a launch permit,[80] during the in-space period between launch and reentry, the FAA says it does not generally undertake "continuing supervision" of space missions—at least those with human crews—citing Congressional restrictions on FAA's supervisory role.[81]

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78 *NASA Releases New Planetary Protection Standard* (Aug. 31, 2022), https://perma.cc/ZG85-AGGL; J. Nick Benardini, Elaine Seasly & J. Andy Spry, *Updates in NASA Policy and Practice in Planetary Protection,* IEEE AEROSPACE CONFERENCE (2023).

79 *See* 51 U.S.C. §§ 50901–50905.

80 *See* FAA, ADVISORY CIRCULAR (AC) 450.31-1, APPLYING FOR FAA DETERMINATION ON POLICY OR PAYLOAD REVIEWS (2023), https://perma.cc/74SY-KVHK; *see also* NAT'L ACADS. SCI., ENG'G & MED., *The Private Sector and Planetary Protection Policy Development, in* REVIEW AND ASSESSMENT OF PLANETARY PROTECTION POLICY DEVELOPMENT PROCESS 85–89 (2018), https://perma.cc/224M-JX9J.

81 FAA's website stated: "Human space flight is changing. What once was an exclusive government-led activity is now open to commercial space operators and private individuals. The FAA's safety oversight responsibilities are designed to protect the safety of the public on the ground and others using the National Airspace System. Congress has both given and restricted the FAA's authority. The FAA issues commercial space licenses, verifies launch or reentry vehicles meant to carry humans operate as intended and provides regulation of flight crew qualifications and training. The FAA also performs safety inspections and safely integrates commercial space operations into the National Airspace System. However, Congress has limited the FAA's authority in specific ways. Under federal law, the FAA is prohibited from regulating the safety of individuals on board. This legislative 'moratorium,' originally established in 2004, and extended multiple times by Congress, will now expire January 1, 2028." *Human Space Flight*, FAA (updated Jan. 8, 2025) (italics added), https://perma.cc/2Q5Z-ZWS8.

In September 2024, the FAA responded to an inquiry asking whether the US government "supervises" private human crewed space activities, such as the Polaris Dawn first-ever private extra-vehicular activity (EVA) ("spacewalk"). "'No,' said the Federal Aviation Agency by email to

Debate is ongoing over whether oversight of private/commercial space activities should be assigned to the Department of Commerce (DOC) rather than DOT.[82] It remains to be seen how DOC would address planetary protection policies and the expert risk analysis of interplanetary contamination. Further, because interplanetary contamination by any space actor could affect the entire planet, attention should also be given to how other key spacefaring governments, such as China, Europe (and its European Space Agency (ESA)), Japan (JAXA), India, UAE, Israel, and others, oversee their governmental and non-governmental entities regarding planetary protection against contamination risks.

Planetary protection against harmful contamination raises all three types of "tragedy" discussed above, and poses challenges for the development of planetary, and then interplanetary, risk regulation. First, it raises a "tragedy of complexity," with uncertainties in the scientific knowledge of life off the Earth, and multiple interconnected risks. The multiplicity of interconnected risks means both that risk assessment must address the joint effects of simultaneous exposures, and that policies to prevent one risk may also affect other risks. Such "risk-risk tradeoffs" could arise, for example, if efforts to settle other planets—in order to hedge against the risk of catastrophe on Earth and ensure the survival of human/terrestrial life on another planet—could also yield harmful interplanetary contamination (as could other space activities such as scientific research missions, space tourism, and space mining).

Second, planetary protection raises a "tragedy of the commons," because multiple actors (both states and non-state entities), each with incentives to go to space, could each cause harm to all by contaminating other worlds or the Earth.

Al Jazeera. 'Under federal law, the FAA is prohibited from issuing regulations for commercial human spaceflight occupant safety.' This blunt reply is no accident. It is longstanding US policy. For 20 years, the US Congress has limited its aviation regulator's oversight, placing a moratorium on making rules for private human space endeavors. The moratorium has been extended multiple times and will now expire in 2025. Instead, the FAA only certifies the rocket and the spacecraft, ensuring, mostly, that they are safe for those back on Earth. 'The FAA has no regulatory oversight for the activities of the Polaris Dawn mission,' the agency said." Colin Baker, *SpaceX Polaris Dawn spacewalk: Is the US breaking a 50-year-old space law?*, AL JAZEERA (Sept. 12, 2024), https://perma.cc/LC2R-GKBX. The Polaris Dawn mission in September 2024 was led by entrepreneur Jared Isaacman—who was later nominated in January 2025 to head NASA.

82 *See* Kevin O'Connell et al., *Practical applications of a space mission authorization framework*, SPACE NEWS (Apr. 11, 2023), https://perma.cc/8VQS-N3FF (comparing approaches for a new mission authorization framework); Dale Skran & Dave Huntsman, *Should the FAA regulate all space activities?* SPACE NEWS (June 10, 2023), https://perma.cc/V569-HFFR (advocating DOC oversight of "in-space" activities, from Earth orbits to bases on Mars, while retaining FAA oversight of launches from Earth and reentries to Earth); WHITE HOUSE, UNITED STATES NOVEL SPACE ACTIVITIES AUTHORIZATION AND SUPERVISION FRAMEWORK (2023) (proposing shared authority between DOT/FAA and DOC); Theresa Hitchens, *White House plan for 'novel' space activities faces industry, Hill skepticism*, BREAKING DEF. (Nov. 29, 2023), https://perma.cc/JBV5-VUMX; U.S. GAO, COMMERCIAL SPACE TRANSPORTATION: FAA'S OVERSIGHT OF HUMAN SPACEFLIGHT (Feb. 2024), https://perma.cc/62R6-XVPY.

With widely shared benefits of planetary protection—indeed global benefits on Earth, and interplanetary benefits beyond Earth—but local costs to each actor to implement planetary protection policies, there can be incentives to free ride, yielding collectively suboptimal precaution.[83] Any one actor can cause contamination that harms all (on or off Earth). Collective cooperation is needed but difficult.

Third, planetary protection raises a "tragedy of the uncommons," in which three key characteristics tend toward misperception and mismanagement of extreme catastrophic risk: (i) the extremely rare (ultra-low probability) scenario lies outside most human experience and thus fails to trigger the "availability heuristic" that often spurs action on episodically experienced salient risks; (ii) the catastrophic or existential magnitude of the impact fosters mass numbing (compassion fade) that yields inaction; and (iii) the catastrophic magnitude of the impact leads to underdeterrence of actors whose assets would be wiped out and of actors who anticipate ex ante that ex post remedies (e.g. civil liability, insurance, criminal sanctions) would be inactive after the global catastrophe destroys relevant institutions.[84]

These three types of tragedies warrant expert analysis and careful institutional design. Interplanetary risk regulation needs to reduce overall risk, accounting for multiple risk-risk tradeoffs, while designing policies that are cost-effective and avoid inhibiting beneficial space activities. The need for planetary protection against harmful contamination, both forward and back, is already present today. As spacefaring expands, these policies will need to be upgraded from the international/global/planetary to the interplanetary and updated in light of new knowledge and changing conditions, incorporating learning into the risk regulatory system.[85] Adaptive policy learning is particularly valuable where

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83 While no one country has an incentive to carry the entire burden of planetary protection, each country may have an incentive to invest to some degree because of the potential risks to its own population (for back contamination) and the risks to its interests on other planets (for forward contamination). However, individual incentives, especially when met by individual risk mitigation efforts, do not guarantee sufficient collective precaution. Even international organizations such as COSPAR rely significantly on the participation of its members which include national scientific institutions who have sometimes shared but sometimes differing interests.

84 *See* Wiener, *supra* note 13.

85 On adaptive learning in regulatory systems, see Wiener, *supra* note 2; Lori S. Bennear & Jonathan B. Wiener, *Built to Learn: From Static to Adaptive Environmental Policy*, *in* DANIEL C. ESTY, ED., A BETTER PLANET: FORTY BIG IDEAS FOR A SUSTAINABLE FUTURE (2019); Wendy Wagner et al., *Dynamic Rulemaking*, 92 N.Y.U. L. REV. 182 (2017); Justin R. Pidot, *Governance and Uncertainty*, 37 CARDOZO L. REV. 112 (2015); Robin Craig & J.B. Ruhl, *Designing Administrative Law for Adaptive Management*, 67 VAND. L. REV. 1 (2014); Gary E. Marchant, *Addressing the Pacing Problem, in* THE GROWING GAP BETWEEN EMERGING TECHNOLOGIES AND LEGAL-ETHICAL OVERSIGHT: THE PACING PROBLEM 199–205 (Gary E. Marchant et al., eds., 2011); Lawrence E. McCray et al., *Planned Adaptation in Risk Regulation*, 77 TECH. FORECASTING & SOC. CHANGE 951 (2010); Daniel A. Farber, *Environmental Protection as a Learning Experience*, 27 LOY. L.A. L. REV. 791 (1994).

uncertainties are significant because scientific knowledge and new technologies are developing rapidly. As space activities grow and evolve toward the interplanetary scale, adaptive learning can help risk regulation keep up with the pace of change.[86]

B. Planetary Defense against Asteroids

"Planetary defense" refers to strategies and actions aimed at protecting Earth from the potential impact of Near-Earth Objects ("NEOs") such as asteroids and comets.[87] These efforts may prevent a global catastrophe on Earth. Planetary defense can also be understood as a crucial domain of interplanetary risk regulation—to protect Earth and other planets as well, such as if humans settle off-Earth. The potential impacts of a large asteroid include a range of consequences from minor to catastrophic, depending on the size, velocity, composition, and angle of incidence of the object and the planet it strikes.[88] On Earth, asteroids have been responsible for injuries to humans and damages to their structures (as in the 2013 Chelyabinsk event which caused 1500 injuries and $33 million in property damage), destruction of local ecosystems (as in the 1908 Tunguska event, which flattened and burned about eighty million trees in an 830 square mile forest), and global mass extinction events (as in the Chicxulub impact about 66 million years ago, which caused an approximate 75% global species loss, including the demise of the non-avian dinosaurs).[89] To assess and manage these risks on the Earth, the concept of planetary defense—including plans for the detection and potential deflection of NEOs—has emerged and gained traction among policymakers in the last three decades. Notably, NASA's "Double Asteroid Redirect Test" (DART) in 2022 was the first mission to test deflecting an asteroid—a remarkable experiment in shielding the Earth from future catastrophic asteroid risks.[90] ESA's Hera mission, launched in 2024, is underway to further study the effects of DART, and China is preparing to conduct its own

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86 *See* Brett Loubert et al., "Rockets and Regulation: Injecting Agility into US Space Industry Oversight," DELOITTE (July 15, 2024), https://perma.cc/SV9M-LG9N (advocating "agile regulation" to address the "pacing problem" of technological change outpacing risk regulation, including via soft law guidelines). For planetary protection against contamination, a new set of soft law guidelines may be forthcoming from the new ASTM committee on Planetary Protection, announced Sept. 2024, to be chaired by NASA astrobiologist Dr. Betsy Pugel. *See New ASTM Space Simulation Subcommittee Addresses Planetary Protection*, ASTM (last accessed Apr. 27, 2025) https://perma.cc/KP2U-SRBX.

87 *See* IRMGARD MARBOE, ED., LEGAL ASPECTS OF PLANETARY DEFENCE (2021).

88 *See* J.C. Reinhardt et al., *Asteroid Risk Assessment: A Probabilistic Approach*, 36 RISK ANALYSIS 244 (2016).

89 *See* David Kring, *Understanding the K-T Boundary*, LUNAR & PLANETARY INST., https://perma.cc/38XG-FQKP (last accessed May 13, 2025).

90 *See* NASA, *Planetary Defense: Double Asteroid Redirection Test (DART)*, https://perma.cc/JRU4-94A7 (last accessed May 13, 2025).

asteroid deflection mission.[91] Research and investment in the detection, risk assessment, and deflection of NEOs occurs on local, national, and international scales, but there is no collective global or planet-scale decision-making body for planetary defense against asteroids and other NEOs.[92]

1. The need for an interplanetary approach to planetary defense

From an interplanetary perspective, the concept of planetary defense can be broadened beyond the Earth to include the prevention of harmful collision impacts between celestial bodies. Which impacts we deem "harmful" will depend on the interests relating to the celestial bodies involved. On populated celestial bodies, which currently include only Earth, but which may eventually come to include human settlements on the Moon, Mars, and elsewhere, the risks of impact include the loss of human life and property. Damage from asteroids can also occur away from the Earth wherever there is infrastructure supporting space activities, such as orbiting space stations. There is also the possibility of damage to non-human life, which currently is only known to exist on the Earth, but which may also exist elsewhere (and the search for which may be frustrated by interplanetary collisions). Asteroids can cause other environmental changes on celestial bodies, such as the creation of impact craters and ejecta blankets or the release of large amounts of heat and gases that can alter the climate.[93] One other obvious but perhaps underemphasized environmental change includes the destruction of the asteroid, which might have otherwise been a valuable source of scientific knowledge or resources in space. On the other hand, the environmental changes from asteroid impacts could be seen as a benefit on some celestial bodies, such as where they make the climate more tolerable for humans, cause a source of rare minerals to become readily available for extraction on the surface of a planet,

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91 Robert Lea, *China plans to deflect an asteroid by 2030 to showcase Earth protection skills*, SPACE.COM (July 11, 2024), https://perma.cc/2VDE-E9DB.

92 *See* Alyse Beauchemin et al., *Assessing International Cooperation for Planetary Defense: A Comparative Analysis of Space Policy Frameworks* (Int'l Astronautical Fed'n Conference Paper, Oct. 2024). The International Asteroid Warning Network (IAWN) and the Space Mission Planning Advisory Group (SMPAG) are international organizations addressing issues related to NEOs whose establishment was recommended by the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS) and endorsed by the UN General Assembly. Participation in IAWN and SMPAG is voluntary and reflects interests in asteroids and other NEOs by national space programs, observatories, and astronomers around the world. *See* CHRISTOPHER JOHNSON, SECURITY, POLICY AND LEGAL CHALLENGES OF PLANETARY DEFENSE, SECURE WORLD FOUNDATION 5–8 (2023) (discussing entities involved in planetary defense). *See also* Abbott & Snidal, *supra* note 70 (discussing the role of soft law in advancing international cooperation, such as through the voluntary participation in international fora).

93 Asteroid impacts on ancient Mars are thought to have released large quantities of hydrogen into the atmosphere, raising the temperature of the planet and allowing for the flow of liquid water. *See* Kathryn Steakley et al., *Impact induced H_2-rich climates on early Mars explored with a global climate model*, 394 ICARUS 115401 (2023).

deliver materials vital to life such as water (as is thought to have occurred on the early Earth),[94] or result in the destruction of an inconvenient or otherwise hazardous asteroid in orbit.

Because collisions between celestial bodies involve potentially destructive consequences (as well as some potential opportunities), and as we visit or settle other planets, planetary defense should be viewed from a multiplanetary perspective. This view suggests several planetary defense activities that should fall within the scope of interplanetary risk regulation:

- The early detection and ongoing monitoring of potentially hazardous objects and their trajectories using ground- or space-based telescopes or radar systems ("detection");
- The evaluation of the likelihood of an impact and the severity of potential consequences ("impact assessment"); and
- The development, evaluation and deployment of methods to prevent or reduce impact risk, such as through deflection (to prevent collision, e.g., by nudging the object to a different trajectory or velocity), disruption, evacuation, or resilience in case of an impact ("responses").

While these activities have largely to date been the domain of scientific research, policy judgments about risk are inescapable when making decisions about whether and how to pursue planetary defense.[95] Properly scaled and sensible interplanetary risk regulation can play an important role in this process. Regulatory oversight is needed to manage the risks associated with detection, impact assessment, and response to potential interplanetary collisions.[96]

For example, institutional fragmentation in approaches to planetary defense may pose risk-risk tradeoffs. A larger and more diverse set of actors involved in the detection of potentially hazardous objects may help reduce the probability that a dangerous object might go undetected (due to shortcomings in any one actor's methods or assumptions). Indeed, the detection of NEOs has been largely effective, in part through the crowdsourcing of knowledge between astronomers and space agencies around the world, with information made widely available in public registries through the International Asteroid Warning Network (IAWN).[97]

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94 *See* Adam R. Sarafian et al., *Angrite meteorites record the onset and flux of water to the inner solar system*, 212 GEOCHIMICA ET COSMOCHIMICA ACTA 156 (2017).

95 JOHNSON, *supra* note 92, at 7; *see also* MARBOE, *supra* note 87.

96 *See* Michael B. Gerrard & Anna W. Barber, *Asteroids and Comets: U.S. and International Law and the Lowest-Probability, Highest Consequence Risk*, 6 N.Y.U. ENV'T. L. J. 4–49 (1997).

97 *See International Asteroid Warning Network*, INT'L ASTEROID WARNING NETWORK https://perma.cc/JCP7-QD9A (last accessed May 13, 2025); UN Committee on the Peaceful Uses of Outer Space, Scientific and Technical Subcommittee, Status report by the International Asteroid Warning Network (IAWN) and the Space Mission Planning Advisory Group (SMPAG),

But more diverse early warnings, some of which may later be revised or rescinded as additional observational data are shared to refine projections, may lead to public skepticism of such warnings. And there is no guarantee that actors will share the results of their observations or assessments.

Additionally, the detection, assessment, and responses to hazardous NEOs involve public goods dilemmas that challenge terrestrial approaches to risk assessment and management. While a group of people on a planet would benefit if some of the members contributed to the common good of planetary defense, individual actors may be incentivized to free ride on the contributions of others. The situation is complicated further by the fact that in most cases, not all actors will be equally situated with respect to impact risks—geographically larger political units are physically more likely to be the location of an asteroid impact and therefore may have stronger incentives to address these risks. Planets also face differing levels of risk—Mars, for example, is more vulnerable to asteroids (due to its thinner atmosphere and closer proximity to the asteroid belt) than the Earth.[98] Hence if we settle on Mars, our planetary defense will need to be multi-planetary. In cases where the risks from impact are planet-wide, population size or relative capabilities of subgroups may be strong influences on incentives and bargaining positions that frustrate collective action. In some cases, if a single large and capable actor has sufficient incentive to protect itself (including for risk reduction and prestige), that may be enough to motivate it to protect the entire planet despite free riding by others. The DART mission by NASA (and European space agencies) may reflect such incentives for leadership in asteroid deflection.

Responses to potential asteroid impacts face coordination difficulties, potential conflicts and risk-risk tradeoffs, especially as the set of actors grows larger and more diverse. One actor's attempt to deflect an asteroid may be complicated or rendered unsuccessful by another's, or may shift risks from one to another.[99] The plan for an asteroid redirection may involve a gradual change of the asteroid's trajectory, which could change the risk corridor of its arrival on the surface of the planet. If so, redirection would temporarily increase the risk to some

A/AC.105/C.1/2017/CRP (2017). Scientists continue to improve asteroid detection methods. *See, e.g.*, Maryann Benny Fernandes et al., *Measuring the Distances to Asteroids from One Observatory in One Night with Upcoming All-Sky Telescopes* (draft Feb. 19, 2025), https://perma.cc/W8SS-DWN9.

98 Yufan Fane Zhou et al*., Martians (Mars2020, TIANwen and so on) would see more potentially hazardous asteroids than Earthlings,* 532 MONTHLY NOTICES ROYAL ASTRONOMICAL SOC'Y L7 (2024). Recent studies of seismic data from NASA's InSight lander found higher rates of asteroid impacts on Mars than had been estimated from crater observations, *see* Géraldine Zenhäusern, et al., *An estimate of the impact rate on Mars from statistics of very-high-frequency marsquakes*, 8 NATURE ASTRONOMY 1138–47 (2024).

99 While the U.N.-endorsed Space Mission Planning Advisory Group (SMPAG) can recommend coordinated mitigation measures, participation in this group is voluntary and none of its decisions or recommendations constitute binding obligations or mandatory actions of any of its members, who are also free to act independently. JOHNSON, *supra* note 92, at 7.

populations in order to eventually eliminate the risk for the entire planet, but these temporary shifts in risk may be met with resistance by those who perceive the risks being foisted upon them. Similarly, one celestial body's redirection mission to shield itself may cause an asteroid to shift to a trajectory intersecting with another celestial body (a phenomenon which may already be set to occur on a smaller scale, as debris from NASA's DART mission could come to Earth and Mars within a decade).[100]

Interplanetary risk regulation must also consider the risk-risk tradeoffs from the dual-use character of asteroid redirection technology. The same technologies and techniques that can be used to deflect an asteroid away from a collision trajectory could also be used to redirect an asteroid into a collision trajectory.[101] Malevolent, irresponsible, or unlucky actors wielding asteroid redirection technologies (or seeking to steer an asteroid into a favorable orbit for mining or other resource use) might cause asteroid impacts to occur where they otherwise would not have, potentially on timescales much shorter than the average intervals between natural impact catastrophes.[102] The core mechanism for asteroid redirection is change in velocity (or "delta-v"), which is a function of the mass of the object, time, and energy. Where an asteroid is not currently on a collision course but could be shifted onto one with a relatively low delta-v (either intentionally, or unintentionally because of mining or other activities), there is a risk that space actors could cause the asteroid to strike the planet. This suggests that there may be a need to take measures to reduce the risk of human-caused impacts between celestial bodies, which could include:

- Slowing the development of sufficiently precise methods of redirecting asteroids;
- Preventing the proliferation of technology, including information, necessary to redirect asteroids;
- Restricting the universe of space actors and increasing surveillance and enforcement capabilities;
- Developing closely-guarded countermeasures (including the ability to overcome counter-countermeasures) to asteroids being directed into impact trajectories; and

100 Eloy Peña-Asensio et al., *Delivery of DART Impact Ejecta to Mars and Earth: Opportunity for Meteor Observations*, 5 PLANETARY SCI. J. 206, 206 (2024).

101 Carl Sagan & Steven Ostro, *Dangers of Asteroid Deflection*, 368 NATURE 501, 501 (1994); Alan Harris et al., *The Deflection Dilemma: Use vs. Misuse of Technologies for Avoiding Interplanetary Collision Hazards, in* HAZARDS DUE TO COMETS AND ASTEROIDS 1145 (ed. Gehrels & Matthews, 1994); Jakub Drmola & Miroslav Mareš, *Revisiting the Deflection Dilemma*, 56 ASTRONOMY & GEOPHYSICS 15, 15 (2015); Hamilton, *supra* note 14, at 28–31.

102 Hamilton, *supra* note 14, at 28–31.

- Reducing the incentives, and increasing the disincentives, for actors to engage in activities that could either accidentally or intentionally redirect asteroids into impact trajectories.

Each of these policy choices—including any decision not to address these risks through policymaking—will likely involve risk-risk tradeoffs. While generally slowing or reducing the capabilities of asteroid redirection would limit the abilities of actors to cause new asteroid strikes, it would also expose people and planets to greater risks from extant impact trajectories by limiting the speed or effectiveness of deflection missions. It would also limit the abilities of actors to engage in potentially beneficial types of asteroid redirections, such as to steer asteroids into manageable orbits for scientific investigation or resource extraction. Attempting to restrict the proliferation of asteroid redirection technology or space actors may be costly, difficult given the simplicity of the techniques (which include kinetic impactors which are little more than heavy spacecraft, as in the DART mission), and unpopular especially among non-spacefaring actors who, perhaps in some cases correctly, may believe that the parties initially in control of the deflection technology do not adequately represent their interests. Countermeasures to potential impacts could in other contexts become counter-countermeasures that prevent actors from deflecting asteroids from impact trajectories.

2. Institutions for planetary defense

Management of planetary defense risks by individual private actors and states alike suffers from tragedies of complexity, commons, and uncommons, with the collective action and coordination problems described above. The current regime of international law is not sufficient to ameliorate these difficulties and may in its current form exacerbate some of the risks. The DART mission illustrated the potential for a pioneering actor to deflect an asteroid for the benefit of planet Earth, but it also indicated the potential for unilateral action by one spacefaring power rather than global cooperation or consultation. The growing set of spacefaring actors, and the growing set of planets with settlements or other valued activities warranting planetary defense, seem likely to increase the risks from (errant) asteroid redirection efforts. A 2020 report by the members of an ad-hoc working group on legal issues for the Space Mission Planning Advisory Group (SMPAG), facilitated by the U.N., recommended that state parties to the Outer Space Treaty should share the information they have on impact assessments that predict an asteroid impact threat to Earth; but there is no obligation to collect or share such information.[103] Furthermore, if such information were to indicate a high impact risk, there is no obligation to assist other states in the deflection of an

103 LINE DRUBE ET AL., PLANETARY DEFENCE: LEGAL OVERVIEW AND ASSESSMENT, REPORT BY THE SPACE MISSION PLANNING ADVISORY GROUP (SMPAG) AD-HOC WORKING GROUP ON LEGAL ISSUES TO SMPAG (2020).

asteroid. If a state attempts to deflect an asteroid but fails to completely divert it (or errs by redirecting it toward a planet), the state would be liable on an absolute basis (regardless of fault) for damages from the asteroid that occurred on the Earth, and on the basis of fault for damages in space.[104] This liability may discourage reckless redirection efforts, but it may also be a disincentive for individual states to undertake planetary defense missions, especially on behalf of another state (let alone for another planet entirely). And the differentiation between liability for damages on Earth (absolute) versus in space (fault) may become a mismatch as we explore or settle other planets where asteroid impacts are risky and sound planetary defense is also needed.

Furthermore, the development and use of nuclear explosive devices as a potential means of deflecting or disrupting asteroids would be restricted by the Limited Test Ban Treaty (which prohibits any nuclear explosion in outer space regardless of its purpose),[105] by the Outer Space Treaty (which prohibits stationing nuclear weapons in orbit, in space, or on celestial bodies),[106] and by the global nuclear nonproliferation regime (which limits the transfer of hardware, software, and technology relating to these items). While the U.N. Security Council has extraordinary power to supersede these rules of international law, a decision would require the votes of nine out of fifteen members and no opposing vote by any one of the permanent five members.[107]

All of these considerations suggest that planetary defense—including of other vulnerable celestial bodies we may settle, such as Mars—may require forms of risk regulation managed by cooperative interplanetary institutions that do not yet exist. Such institutions could be empowered to:

- Coordinate and/or carry out the detection and assessment of potentially harmful impacts of a collision to any celestial body (in cooperation with existing detection efforts such as the IAWN, potentially extended to other planets as well);
- Evaluate missions involving movable celestial bodies (such as steering an asteroid for mining) to identify potential risks of redirection that could result in impact with another celestial body;

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104 *See* Convention on International Liability for Damage Caused by Space Objects, *supra* note 53.

105 Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and Under Water, Aug. 5, 1963, 480 U.N.T.S. 43, 14 U.S.T. 1313.

106 OST, *supra* note 6, Art. IV.

107 *See* David Koplow, *Planetary Defense: The Nuclear Option Against Asteroids*, ARMS CONTROL TODAY (April 2024), https://perma.cc/2XVM-JSYN; *see also* David Koplow, E*xoatmospheric Plowshares: Using a Nuclear Explosive Device for Planetary Defense Against an Incoming Asteroid*, 23 UCLA J. INT'L L. & FOREIGN AFFS. 76–158 (2019); James A. Green, *Planetary Defense: Near-Earth Objects, Nuclear Weapons, and International Law*, 42 HASTINGS INT'L & COMP. L. REV. 1–71 (2019).

- Coordinate and/or carry out responses to potentially harmful impact threats to any celestial body (such as deflecting asteroids from a new settlement on Mars); and
- Regulate the development, production, transfer, and use of asteroid deflection technologies to reduce the risk-risk tradeoff of human-caused impacts.

Planetary defense will likely take on an increasing importance over time as asteroids and meteors continue to present a chance of harmful impact, including to celestial bodies which are not yet populated with humans but are deemed worth defending (such as because of the presence of remote communications infrastructure or robotic mining missions). Planetary defense raises the three potential tragedies—of complexity, of the commons, and of the uncommons—warranting expert analysis and institutions for well-informed cooperative decision making. The potential for catastrophic impacts, the dual-use nature of redirection technology, and the difficulty in unilaterally assessing and managing these risk-risk tradeoffs, suggest the need for interplanetary risk regulation beyond current international law.

V. CONCLUSION: TOWARD INTERPLANETARY RISK REGULATION

Humanity is poised to significantly expand its influence beyond the Earth to the Moon, Mars, and other celestial bodies. This presents promising opportunities, but also significant risks, including some far off and some we are already facing today, such as interplanetary contamination, asteroid impacts, and conflicts on Earth and beyond. We suggest that just as prior risks of expanding scales of activity have been met with commensurately broadening scales of institutional adaptation—from individual, to local, to national, to international, to global, to planetary—so too humanity needs interplanetary risk regulation to manage new interplanetary risks. Both to protect the Earth, and to protect interests on and interactions among other planets and celestial bodies, well-designed interplanetary risk regulation will be essential.

As with each stage of governance, interplanetary risk regulation will need to coexist with, and supplement, other polycentric forms of governance that remain well-tailored to addressing their own scales of risks. Advancing "interplanetary law" to address interplanetary concerns does not presume that each planet would be governed by a single monolithic planetary law and world government. National laws (and international agreements) are likely to remain preeminent for governance on Earth. And if we settle other planets, such as Mars, there may likewise be differing legal systems for different settlements (perhaps via national governments' "continuing supervision" from Earth, or new "self-governing" polities on Mars), and multi-settlement cooperative agreements—akin to differing national laws and international agreements on Earth. This prospect of interplanetary legal pluralism underscores the emerging need for interplanetary law to manage interplanetary relations and interactions. Seeking to address interplanetary risks using only more narrowly-scaled instruments would pose a scale mismatch, leaving these risks insufficiently assessed and poorly managed—with perhaps catastrophic impacts both on Earth and on other planets.

We are not suggesting that the wheel needs to be entirely reinvented (though transportation on other planets may go beyond wheels, and new legal approaches may also be needed for new planets). Nor are we suggesting that interplanetary rules and interplanetary institutions must be launched immediately or all at once. Interplanetary risks will initially continue, as they are now, to be addressed by Earth-based institutions of various scales—but improvements are needed, as we have discussed here, to strengthen collective protection of the Earth against interplanetary risks from contamination and asteroids. The Outer Space Treaty seeks to address several key interplanetary risks, such as harmful contamination and conflict over celestial bodies. Additional relevant institutions include the United Nations (including COPUOS and UNOOSA), international scientific organizations (such as COSPAR and IAWN), and national regulators and space agencies. New institutions may need to be added to address newly emerging risks.

Today, these institutions can and should leverage the insights of risk regulation to better assess and manage these and other interplanetary risks at the scales at which they are capable. For example, the United States-led Artemis Accords, a series of bilateral diplomatic arrangements, do not address interplanetary contamination or many other interplanetary risks (likely in keeping with their focus on going to the Moon); if the Artemis Accords become a platform for activities beyond the Moon, they would need to add provisions on planetary protection or biosafety, on asteroid defense, and more.

Over time, as humanity's activities reach further to multiple celestial bodies at great distances, with significant heterogeneity, and with potential tragedies of complexity, commons, and uncommons, the need for new institutions tailored to effectively address these interplanetary risks will grow. As with other forms of regulatory development, this process will likely be adaptive, iteratively improving with new science, technology, social conditions, and policy learning. And this broader scale of governance will need to coexist with, and supplement, other forms of governance that remain well-tailored to addressing their own scales of risks. As humanity takes its steps toward the stars, its success and survival will depend on intelligent interplanetary risk regulation.