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Opening Outer Space: Safety and Stability Through Open Standards and Open Source

Alex Li

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Alex S. Li*

"It will not be we who reach Alpha Centauri and other nearby stars. It will be a species very like us, but with more of our strengths, and fewer of our weaknesses . . . more confident, farseeing, capable and prudent[.]"[1] – Carl Sagan

ABSTRACT

With both commercial and governmental activities heating up in Outer Space, the need to maintain a safe and stable environment for all types of human activities grows. While current international laws for this sector seek to reduce risks by encouraging cooperation among different entities, these legal regimes have several shortcomings that limit their effectiveness. With Outer Space becoming more populated, other solutions that can improve the safety and long-term availability of this sector must be implemented. This Article attempts to address this need by encouraging the application of open standards with open source components for certain critical Outer Space technologies. Specifically, this Article argues that these tools can incentivize the widespread standardization of critical life-saving technologies that can make Outer Space safer and more viable for all.

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* In-house counsel by day, Outer Space blogger at #TheSpaceBar® (www.thespacebar.space) by night. 2014–2015 law clerk to the Honorable Robert E. Bacharach of the U.S. Court of Appeals for the Tenth Circuit; Gunderson Dettmer, Latham, and PwC alumnus. UC Berkeley School of Law, J.D., Order of the Coif, 2014; Duke University, B.S.E., 2009. I am extremely grateful to the talented editors of the Penn State Law Review for their diligent hard work. Thank you to the Gunderson Dettmer IP team—especially Colin Chapman, Shu Hu, Julie Mahoney, Brendan McCarthy, and Tom Villeneuve—for teaching me the legal side of open source and the Teradata open source team—especially Aliya Ashraf, Kirk Johnsen, and Mark Kackstetter—for keeping me up-to-date on the latest open source news. I would also like to give a warm shout out to my parents for all their support throughout the years. And to everyone who has cosmic dreams, thank you for sharing this galaxy with me.

1. CARL SAGAN, PALE BLUE DOT: A VISION OF THE HUMAN FUTURE IN SPACE 329 (1994).

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INTRODUCTION

In the quest to fulfill Sagan's prophecy, human activities in Outer Space have continued unabatedly since Sputnik 1's fateful flight on October 4, 1957.[2] Once the exclusive realm of governmental agencies, Outer Space is now becoming a popular playground for commercial

2. *See Sputnik 1, Earth's First Artificial Satellite in Photos*, SPACE (Oct. 4, 2020), https://bit.ly/3ByPO8Y (noting that Sputnik 1, "the world's first artificial satellite," officially kicked off the "dawn of the Space Age").

entities as well.[3] As private enterprises increasingly cast their gaze upon the stars, the rise of space commercialization has led to a significant increase in the number of launches and satellites in or near Earth's orbits.[4] In fact, commercial companies will launch more objects to Outer Space in the next few years than humanity has in the first sixty-year history of the Space Age.[5] This explosion in activities will likely transform Outer Space into the next trillion-dollar market.[6] The environment will be brimming with a myriad of opportunities: from space tourism to space mining, from satellite coordination to launch operations, from supply ships to space stations; the list goes on.

With activities heating up in both near and far space, the need for coordination among all space-faring entities grows. Declaring that Outer Space is the common heritage and province of humanity, the United Nations mandates that Outer Space activities must be conducted in a mutually respectful manner.[7] Hence, all governmental entities and commercial enterprises need to ensure that their space-based objects and/or activities in Outer Space do not interfere with or cause harm to those of others. While Outer Space is expansive, the immediate area surrounding Earth is finite. To maintain safety and stability, several international organizations have been tasked and intergovernmental accords have been executed to facilitate cooperation and coordination in this sector. For instance, the International Telecommunication Union, an agency of the United Nations, is responsible for the allocation and assignment of satellites in the space-limited Geosynchronous Equatorial Orbit.[8]

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3. *See* Michael Sheetz & Magdalena Petrova, *Why in the Next Decade Companies Will Launch Thousands More Satellites than in All of History*, CNBC (Dec. 15, 2019, 9:01 AM), https://cnb.cx/34Sy8t2.

4. *See* Arjun Kharpal, *Space Companies Are Racing to Beam Web Access to the Entire Planet. But 'Space Junk' Is a Big Worry*, CNBC (Feb. 16, 2020, 11:38 PM), https://cnb.cx/3H4w26B (noting that "ITU's role in facilitating the coordination of satellites remains increasingly important"); *see also* Alex S. Li, *Spinning in Outer Space: Common Orbits and Prominent Locations Around Earth*, #THESPACEBAR (Apr. 21, 2019), https://bit.ly/3s4BxON (noting there are three types of orbits around Earth: low Earth orbits, medium Earth orbits, and high Earth orbits; Low Earth orbit tends to be a "common destination for many satellites providing data communications").

5. *See* Sheetz & Petrova, *supra* note 3.

6. *See* Michael Sheetz, *An Investor's Guide to Space, Wall Street's Next Trillion-Dollar Industry*, CNBC (Dec. 13, 2019, 11:33 AM), https://cnb.cx/3sBA8Of (indicating that Outer Space "will become a multitrillion-dollar economy in the next ten to twenty years").

7. *See* Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies art. 9, Jan. 27, 1967, 18 U.S.T. 2410, 610 U.N.T.S. 205 [hereinafter Outer Space Treaty].

8. The Geosynchronous Equatorial Orbit ("GEO") is an important, but space-limited, orbit around Earth. The rotational velocity of an object in GEO is very similar to Earth's rotational period. Therefore, an object in GEO appears stationary as both it and the earth

While the regulation of Outer Space activities by these organizations will always play an important role in preserving safety and long-term availability of this space, given the increased traffic, this is no longer enough. Projections in early January 2022 indicate that there are about 7,840 satellites in Outer Space, of which around 5,100 are still functioning.[9] While this is already a large number, it still pales in comparison to the total number of objects orbiting around Earth: 36,500 objects greater than ten centimeters, one million objects that are between one centimeter to ten centimeters, and 130 million objects between one millimeter to one centimeter.[10] With some of these objects likely already abandoned by their owners, the chances of triggering the Kessler Syndrome—a series of cascading collisions that would render an area of Outer Space unsafe for human activities[11]—increases. Although efforts are underway to eliminate existing space junk,[12] this is mainly a reactive approach. While guidelines have been promulgated to prospectively address end-of-life operations for satellites,[13] it is hard to police such clean-up efforts that will only occur decades after the objects are placed in orbit; it might very well be the case that the entity responsible for an object may no longer be in existence by the time these safety maneuvers need to be performed. Hence, international frameworks and mandates are not enough to completely ensure the safety and long-term availability of Outer Space for human activities. Therefore, rather than relying solely on mere rules and regulations, more pragmatic solutions in the form of practical

"moves" at the same rate. This enables a receiver on Earth to have constant line-of-sight/communication with the object. But, because satellites' signals can interfere with each other, it makes GEO even more space constrained than a typical finite orbit. Thus, international organizations are needed to regulate the use of this important orbit. *See Sharing the Sky – ITU's Role in Managing Satellite and Orbit Spectrum Resources*, INT'L TELECOMM. UNION, https://bit.ly/3BfstJw (last visited Feb. 12, 2022) (noting that "ITU's role in facilitating the coordination of satellites remains increasingly important"); *see also* Alex S. Li, *The International Telecommunications Union: Orbital Parking Enforcement*, #THESPACEBAR (July 16, 2017), https://bit.ly/3GFhVo0.

9. *See Space Debris by the Numbers*, EUR. SPACE AGENCY SPACE DEBRIS OFF. (Jan. 5, 2022), https://bit.ly/3sAk5jF.

10. *See id.*

11. *See* Alex S. Li, *Up in the Air: Turning Space Debris into Opportunities*, #THESPACEBAR (Aug. 13, 2017), https://bit.ly/3Lr1SxI.

12. *See id.*

13. *See* Christopher D. Johnson, *Legal and Regulatory Considerations of Small Satellite Projects*, *in* SMALL SATELLITE PROGRAM GUIDE ch. 5, 29–30 (Wiley Larson et al. eds., 2014) (ebook), https://bit.ly/3rMfvj3 (explaining "Inter-Agency Debris Coordination Committee . . . formulated a set of technical and precise guidelines to address [end-of-life issues]"); *see also* David M. Livingston, *Broadcast 3655 Mark Sundahl and T.L. Masson*, THE SPACE SHOW, at 39:43 (March 7, 2021), https://bit.ly/3uMPK4e ("[T]here is no binding law about . . . . not creating space debris or forcing operators to remove their inactive satellites.").

technologies and tools must be implemented to actively mitigate dangers in Outer Space.

For instance, space debris management systems developed by both public agencies and private companies can augment legal enforcement.[14] These solutions can track trajectories and run predictive analysis, thereby proactively preventing possible collisions.[15] However, for these systems to have the greatest impact on Outer Space safety and stability, standardization of critical Outer Space technologies will be the key to their success. Through greater use of standardization, more data can be onboarded onto, and tools developed against, a common framework. This can lead to the creation of a comprehensive technological ecosystem that can streamline the analysis and collection of critical information. The resulting foundation can empower scientists, engineers, and researchers around the globe to quickly and proactively identify and resolve issues that might destabilize Outer Space.

This Article argues that the widespread adoption of open standards and open source components can promote safety and encourage collaboration in Outer Space. This framework could achieve these results by incentivizing Outer Space-related entities to build, improve, and use more standardized techniques and protocols. The resulting consistency will facilitate its participants to rely on a common body of knowledge for certain essential—potentially life-saving—technologies. This will better equip operators in Outer Space to assist one another in the event of an emergency. In turn, these efforts will reduce risks to safety in and improve stability of a region that is naturally inhospitable to human life.

Part I begins by providing an overview of how prominent Outer Space legal frameworks have sought to encourage cooperation and collaboration in this environment. This Part also explains the shortcomings of these legal regimes in achieving these goals. Part II illustrates how the use of open standards in Outer Space could address these weaknesses, thereby helping to preserve safety and stability. Part III explores the role open source components can play in this arena and how open source-

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14. *See* EUR. SPACE AGENCY, *ESA Makes Space Debris Software Available Online*, SPACEREF (June 25, 2014), https://bit.ly/3h1wjfT (noting the European Space Agency's creation of a new platform that will allow experts "to perform risk assessment and analysis of debris mitigation actions . . . ."); Michael Sheetz, *Space Debris Tracker LeoLabs Raises $65 Million as Satellites Launch to Orbit at Unprecedented Rate*, CNBC (June 3, 2021, 9:02 AM), https://cnb.cx/3oYC5mL (contributing the success of LeoLabs business to the fact that "low Earth orbit is now a commercial economy").

15. *See* Mark Pontin, *Beyond Gravity: The Complex Quest to Take out Our Orbital Trash*, ARS TECHNICA (May 27, 2014, 6:00 PM), https://bit.ly/3p5k1aL (indicating that one of the first steps in resolving the orbital debris issue is to answer the "following questions: What are the different categories of threat posed by orbital debris? How much time do we have and what should we prioritize? And what potential debris removal technologies might we have in our toolbox?").

capable licenses have been implemented for Outer Space technologies. Part III then proposes several other types of open source-capable licenses that can be used and demonstrates how such licenses will not stifle commercial developments but rather encourage more innovations. Given humanity's current level of operations in Outer Space, Part IV then suggests several focus areas where open standards and open source components will have the greatest immediate and long-term impact in promoting safety in and longevity of human activities for this environment. With more pervasive use of open standards and open source components, it is this Article's hope that the international community will engage in more cooperation and collaboration in Outer Space—thereby ensuring humanity's final frontier remains safe and accessible for all.

I. PROMOTING SAFETY AND STABILITY THROUGH LEGAL FRAMEWORKS

Recognizing that Outer Space is infinitesimally large and inhospitable to human life, the need to maintain safe and stable operations in this domain is of paramount importance. To effectuate these goals, themes such as cooperation and mutual assistance pervade through many Outer Space-related treaties and frameworks. Starting with the foundational United Nations treaties on Outer Space, this Part first explores how several international agreements have attempted to ensure Outer Space remains a safe and stable environment. Then, this Part introduces several issues that have hamstrung existing legal regimes' ability to fully achieve these goals. In subsequent Parts, this Article discusses how these issues can be solved using open standards and open source.

A. *United Nations Treaties on Outer Space*

On October 4, 1957, the Space Race between the Soviet Union and United States made its visible debut with Sputnik 1's successful launch.[16] With broad public exposure, Outer Space accomplishments had strategic value for both sides. Hence, both countries eagerly and heavily devoted resources to their space programs.[17] As the Cold War heated up between the United States and the Soviet Union, many worried that the conflict might spill over into Outer Space. Attempting to avoid catastrophic results

16. *See* Michelle Cadoree Bradley, *Sputnik and the Space Race: 1957 and Beyond*, LIBR. OF CONG. (July 10, 2019), https://bit.ly/3sAB9X0.

17. *See* Maddie Davis, *The Space Race*, UNIV. VA. MILLER CTR., https://bit.ly/3GL2E58 (last visited Feb. 12, 2022) ("National leaders from both countries recognized the opportunity of space exploration from a political perspective and began heavily funding missions.").

with deadly consequences,[18] the international community negotiated and passed a series of treaties to govern activities in Outer Space. In chronological order, they are:

1. The Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space,[19] commonly known as the Outer Space Treaty of 1967;

2. Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space,[20] commonly known as the Rescue Agreement of 1968;

3. Convention on International Liability for Damage Caused by Space Objects,[21] commonly known as the Space Liability Convention of 1972;

4. Convention on Registration of Objects Launched into Outer Space,[22] commonly known as the Registration Convention of 1975; and

5. Agreement Governing the Activities of States on the Moon and Other Celestial Bodies,[23] commonly known as the Moon Treaty of 1979.

These international agreements, more commonly known as the "five United Nations treaties on Outer Space,"[24] became the first set of laws focusing directly on Outer Space. Of these five treaties, four have been ratified—all except the Moon Treaty of 1979—with the Outer Space Treaty of 1967 becoming the bedrock of legal doctrine regarding Outer

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18. *See* Loren Grush, *How an International Treaty Signed 50 Years Ago Became the Backbone for Space Law*, THE VERGE (Jan. 27, 2017, 11:14 AM), https://bit.ly/3KReeyY [hereinafter Grush, *Backbone for Space Law*] ("Both the US and the Soviet Union wanted to prevent the expansion of the nuclear arms race into a completely new territory.").

19. Outer Space Treaty, *supra* note 7.

20. Agreement On the Rescue of Astronauts, the Return of Astronauts and Return of Objects Launched Into Outer Space, Apr. 22, 1968, 19 U.S.T. 7570, 672 U.N.T.S. 119 [hereinafter Rescue Agreement].

21. Convention On the International Liability For Damage Caused By Space Objects Mar. 29, 1972, 24 U.S.T. 2389, 961 U.N.T.S. 187 [hereinafter Space Liability Convention].

22. Convention On the Registration Of Objects Launched Into Outer Space, Jan. 14, 1975, 28 U.S.T. 695, 1023 U.N.T.S. 15 [hereinafter Registration Convention].

23. Agreement Governing the Activities Of States On the Moon And Other Celestial Bodies, Dec. 18, 1979, 1363 U.N.T.S. 3 [hereinafter Moon Treaty].

24. U.N. OFF. FOR OUTER SPACE AFFS., SPACE LAW TREATIES AND PRINCIPLES, U.N. DOC. ST/SPACE/61/Rev.2 (2017), https://bit.ly/3G51hxF [hereinafter U.N. SPACE LAW TREATIES AND PRINCIPLES].

Space.[25] While each of these agreements have a different purpose, all five treaties attempt to promote safety through provisions focusing on mutual assistance and cooperation.

The first of the five treaties, the Outer Space Treaty, states the need for cooperative activities in its preamble, noting that these agreements are intended to "contribute to broad international co-operation in the scientific as well as the legal aspects of the exploration and use of outer space for peaceful purposes . . . ."[26] Emphasizing this principle, the agreement further dictates that all nations shall have the freedom to explore Outer Space and encourages cooperation in any such endeavors.[27] Furthermore, the agreement also calls for mutual aid among all nations by mandating an obligation to assist and a duty to rescue.[28]

Through these provisions, the Outer Space Treaty firmly establishes the principles of cooperation and mutual assistance. One of the primary reasons underlying the creation of these principles is to maintain safety in and ensure the long-term availability of Outer Space.[29] Without an eye toward these principles, it is very possible that Outer Space may become a zone of deadly hazards. Through cooperation, the possibility of armed conflicts can be reduced. Through mutual assistance, survivability can be increased. Hence, these provisions are key to maintaining stability, reducing safety risks, and promoting viability of human activities in Outer Space.

Subsequent United Nations treaties also emphasize these goals. For instance, the Rescue Agreement elaborates on the Outer Space Treaty's mutual assistance provisions by detailing procedures that States should take in response to any distress in Outer Space.[30] This treaty also seeks to preserve stability in Outer Space by encouraging nations to cooperate in the identification and elimination of hazardous conditions. Specifically, the Rescue Agreement notes that if a country "has reason to believe that a

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25. *See* Grush, *Backbone for Space Law*, *supra* note 18.

26. Outer Space Treaty, *supra* note 7 ("Reaffirming the importance of international cooperation in the field of activities in the peaceful exploration and use of outer space . . . .").

27. *See id.* art. I, ¶ 1.

28. *Id.* art. V, ¶ 1.

29. *See* U.N. OFF. FOR OUTER SPACE AFFS., COMM. ON THE PEACEFUL USES OF OUTER SPACE: GUIDELINES FOR THE LONG-TERM SUSTAINABILITY OF OUTER SPACE ACTIVITIES, at 2, U.N. DOC. A/AC.105/2018/CRP.20 (June 27, 2018) ("The long-term sustainability of outer space activities is defined as the ability to maintain the conduct of space activities indefinitely into the future in a manner that realizes the objectives of equitable access to the benefits of the exploration and use of outer space for peaceful purposes . . . . This is consistent with, and supports, the objectives of the [Outer Space Treaty], as such objectives are integrally associated with a commitment to conducting space activities in a manner that addresses the basic need to ensure that the environment in outer space remains suitable for exploration and use by current and future generations.").

30. *See* Rescue Agreement, *supra* note 20, art. IV.

space object or its component parts discovered . . . is of a hazardous or deleterious nature[, it] may . . . notify the launching authority [for such component, who] shall immediately take effective steps . . . to eliminate possible danger of harm."[31] By creating cooperative methods that can mitigate dangerous circumstances, the Rescue Agreement also addresses the goal of making Outer Space safer for all.

The theme of mutual assistance also makes an appearance in the Space Liability Convention. Although this agreement largely deals with the apportionment of liabilities among parties to an incident, it prioritizes the mitigation and remediation of events leading to the harm. As an example, this convention implores nations to work together to provide aid and support to any country that might be suffering harm from a catastrophic or serious Outer Space incident.[32] Recognizing that such activities might create an appearance of liability, the treaty explicitly indicates that mitigation efforts shall not affect the eventual apportionment of fault.[33] No doubt the drafters included this Good Samaritan-esque provision to prioritize the elimination of dangers that might impact Outer Space's long-term availability for human activities over all other considerations.

Further, for nations to successfully cooperate with and assist one another in Outer Space, they must be able to easily identify the country of origin for any spacefaring object. The United Nations ratified the Registration Convention with this goal in mind. This treaty established a catalog of objects in Outer Space that are updated and kept by the United Nations.[34] Under this convention, when a party realizes that an object might be in distress, that State can use the database to quickly identify and communicate with the nation responsible for the object. While this registry is essential for maintaining order in Outer Space, it is also notable for another reason: setting up the first open standard related to spacefaring operations.[35] In creating this repository, the drafters of the Registration Convention dictated a specific set of information that a country must submit for its Outer Space objects,[36] thereby instituting the first uniform standard for Outer Space objects. Additionally, by allowing for "full and open access" to the database,[37] the treaty ensures that this data is always publicly available. Hence, the Registration Convention also set a

31. *Id.* art. V, ¶ 4.
32. *See* Space Liability Convention, *supra* note 21, art. XXI.
33. *See id.*
34. *See* Registration Convention, *supra* note 22, pmbl.
35. *See infra* Section II.B.
36. *See* Registration Convention, *supra* note 22, art. IV (noting the type of information that a country must submit to the registry).
37. *Id.* art. III, ¶ 2.

pathbreaking precedent that open standards can be a valuable tool in fostering mutual assistance and cooperation in Outer Space.

Finally, the Moon Treaty—the last of the five United Nations treaties related to Outer Space—tries to extend the principles of cooperation and mutual assistance to activity on the Moon.[38] But, this agreement also goes a step further in dictating that all facilities, materials, and equipment on the Moon are a part of the human collective and must be freely accessible and available to all.[39] It mandates that all parties must be as transparent as possible regarding their lunar activities and must publicly disclose the results of any mission.[40] Additionally, in the event of life-threatening emergencies, the Moon Treaty authorizes the use of any nation's property in resolving such distress.[41] Finally, to ensure cooperation on the Moon, the treaty provides a form of open access audit rights as a policing mechanism.[42] To this end, the agreement states that any nation can inspect any other party's "space vehicles, equipment, facilities, stations and installations on the moon" to ensure compliance with the provisions of the Moon Treaty.[43] While these extensive requirements could promote safety and security in Outer Space, their intrusive nature might have contributed to the Moon Treaty's lack of international support.[44] Because most space-faring nations (including the United States, Russia/Soviet Union, China, Japan, and several members of the European Space Agency) have not ratified, signed, or acceded to the Moon Treaty,[45] the agreement does not have widespread practical effect.

Although many see the Moon Treaty as a failed agreement because of the general lack of adoption among countries with Outer Space programs, its provisions demonstrate the drafters' concern for maintaining the stability and availability of Outer Space for all human activities. Given that these authors also drafted the other four major treaties for Outer Space,[46] it suggests that all seminal laws on Outer

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38. *See* Moon Treaty, *supra* note 23, art. 4, ¶ 2 ("States Parties shall be guided by the principle of co-operation and mutual assistance in all their activities concerning the exploration and use of the moon.").

39. *See* Alex S. Li, *Ruling Outer Space: Defining the Boundary and Determining Jurisdictional Authority*, 73 OKLA. L. REV. 711, 722 (2021) [hereinafter *Ruling Outer Space*].

40. *See* Moon Treaty, *supra* note 23, art. 5, ¶ 1.

41. *See id.* art. 12, ¶ 3.

42. *See id.* art. 15.

43. *See id.* art. 15, ¶ 1.

44. *See* Michael Listner, *The Moon Treaty: Failed International Law or Waiting in the Shadows?*, SPACE REV. (Oct. 24, 2011), https://bit.ly/3GegmNx.

45. *See* U.N. OFF. FOR OUTER SPACE AFFS., STATUS OF INTERNATIONAL AGREEMENTS RELATING TO ACTIVITIES IN OUTER SPACE, at 1, U.N. DOC. A/AC.105/C.2/2021/CRP.10 (Jan. 2020), https://bit.ly/3rdVrGa.

46. *See* U.N. SPACE LAW TREATIES AND PRINCIPLES, *supra* note 24 ("The Committee has concluded five international treaties[.]").

Space implicitly view cooperation and mutual assistance as key elements in ensuring the safety and availability of this region. In addition, several of these agreements, such as the Rescue Agreement and the Registration Convention, make clear that information-sharing is also a critical component in achieving these goals. Thus, these international agreements have laid the groundwork for incentivizing the development of a common knowledge foundation and provide support for a movement toward standardization of critical Outer Space technologies.

With the United Nations treaties on Outer Space forming the legal foundation for this environment, many subsequent international agreements have extended upon these treaties' principles. Section B discusses one of these subsequent international accords: the agreement that laid the ground rules for the International Space Station.

B. International Space Station Intergovernmental Agreement

Apart from the United Nations treaties on Outer Space, the governing agreements for the International Space Station ("ISS") form another major legal framework for this environment. As the first long-term multinational space station, the ISS has been serving as a pioneer symbol of international cooperation ever since its launch in 1998.[47] Jointly operated by United States' National Aeronautics and Space Administration ("NASA"), Russia's Roscosmos State Corporation for Space Activities, the European Space Agency, Canadian Space Agency, and Japan Aerospace Exploration Agency, the ISS is governed by several international accords.[48] Of these, the International Space Station Intergovernmental Agreement ("IGA")[49] forms the base layer of ISS's legal framework.[50] With ISS's operations being heavily dependent on mutual assistance and cooperation among its participants, the IGA explicitly references these themes to ensure the space station's success and safety.[51]

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47. *See Space Station Exemplifies Cooperation*, TIMES REC. NEWS (Nov. 8, 2015), https://bit.ly/3fSMEmv.

48. *See International Space Station Legal Framework*, EUR. SPACE AGENCY, https://bit.ly/3r6tSid (last visited June 29, 2021).

49. Agreement Among the Government of Canada, Governments of Member States of the European Space Agency, the Government of Japan, the Government of the Russian Federation, and the Government of the United States of America Concerning Cooperation on the Civil International Space Station, Jan. 29, 1998, S. TREATY DOC. NO. 01-52, T.I.A.S. No. 12, 927 [hereinafter IGA].

50. *See International Space Station Legal Framework*, *supra* note 48.

51. *See, e.g.*, IGA, *supra* note 49, pmbl. ("Convinced that working together on the [ISS] will further expand cooperation through the establishment of a long-term and mutually beneficial relationship, and will further promote cooperation in the exploration and peaceful use of outer space."); art. 15, ¶ 2 ("Recognizing the importance of [ISS]

The IGA incorporates many of the guiding principles of the United Nations treaties on Outer Space into the ISS's legal framework. In fact, the IGA explicitly provides that the ISS "shall be developed, operated, and utilized in accordance with international law, including the Outer Space Treaty, the Rescue Agreement, the Liability Convention, and the Registration Convention."[52] Reiterating several of these treaties' themes, the IGA emphasizes the importance of mutual assistance and cooperation among ISS partners.[53] These types of cooperative activities even extend into the financial realm where the agreement removes potential tariff obligations that might result from national export and import laws.[54] Each ISS partner is also mandated to "expeditiously" provide mutual assistance in the form of "technical data and goods" in the event such information is necessary for any party to accomplish its ISS obligations.[55] Through these IGA provisions, all ISS participants are fully committed to cooperate in information sharing and cost optimization activities that will ensure the safe and smooth operations of the ISS.

With the ISS made up of many independently partner-manufactured components, the IGA also focuses on preventing potential compatibility issues. The agreement requires its members to first inform and consult all other ISS partners before designing, developing, or constructing an ISS element.[56] In addition, when a country's technical data and software are "necessary for interface, integration or safety purposes," the country must transfer these components with minimal restrictions.[57] If an ISS partner is contemplating changes that could have a significant impact on the ISS's maneuvering operations, that nation can only make those alterations after consultations with other ISS participants.[58] Rather than the passive aspirational language found in the United Nations treaties, these detailed IGA provisions take on a more active role in promoting cooperation and mutual assistance.

New ISS elements include requirements such as group consultations that will not only promote interoperability but also ensure that every ISS

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cooperation . . . ."); art. 22, ¶ 4 ("Each Partner State shall . . . afford the other Partners assistance in connection with alleged misconduct on orbit.").

52. *Id.* art. 2, ¶ 1.

53. *Id.* art. 23, ¶ 1.

54. *See id.* art. 18, ¶ 3 ("Each Partner State shall grant permission for duty-free importation and exportation to and from its territory of goods and software which are necessary for [the ISS].").

55. *Id.* art. 19, ¶ 1.

56. *See id.* art. 8 ("[E]ach Partner . . . shall interact with the other Partners, through their Cooperating Agencies, to reach solutions on design and development of their respective elements.").

57. *See id.* art. 19, ¶ 3.

58. *See id.* art. 23, ¶ 3.

member will be familiar with all aspects of the space station, including components for which a partner might not be primarily responsible. The background gained through these collaborative workshops will make each ISS participant more adept at addressing emergencies that might arise anywhere on or near the ISS. Thus, the IGA takes the cooperative themes introduced in the United Nations treaties and sharpens them into more practical tools that can reduce risks in Outer Space.

With the ISS, through its IGA, successfully using cooperation and collaboration as means of ensuring safety and stability of human activities in Outer Space, other multinational projects have also adapted this stance. Section C explores one of these more recent international initiatives: the Artemis Accords.

C. *The Artemis Accords*

Recent Outer Space-related international initiatives have continued to focus on cooperative behavior. But these new agreements have also introduced interoperability and the development of technology standards as new means of preserving safety and long-term viability of human activities in Outer Space. One example is the Artemis Accords.[59] Developed by NASA, the Artemis Accords is envisioned as a new framework to guide twenty-first century deep space exploration, assistance, and cooperation among different nations.[60] This international agreement is seen as an answer to the failed Moon Treaty.[61] While ostentatiously setting up guidelines for civilian activities on the Moon, the accords' principles could be extended to all regions of Outer Space.[62]

Similar to the IGA, the Artemis Accords explicitly affirms its alignment with many of the fundamental concepts introduced in the United Nations treaties on Outer Space.[63] For instance, the themes of mutual assistance and cooperation are readily apparent in several of the agreement's provisions; this framework decrees that its members must comply with the Rescue Agreement's duties of rescue and mutual

59. *See* NASA, 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), https://go.nasa.gov/3gmEzXz [hereinafter ARTEMIS ACCORDS].

60. *See* Alex S. Li, *The Artemis Accords: Moonwalking to More Giant Leaps*, #THESPACEBAR (Aug. 17, 2020), https://bit.ly/3uqcw1M (noting that the Artemis Accords attempts to set "up rules of the road that will enable nations to work together" for deep space exploration to destinations such as the Moon).

61. *See Ruling Outer Space*, *supra* note 39, at 711.

62. *See* ARTEMIS ACCORDS, *supra* note 59, § 1 ("These activities may take place on the Moon, Mars, comets, and asteroids, including their surfaces and subsurfaces, as well as in orbit of the Moon or Mars, in the Lagrangian points for the Earth-Moon system, and in transit between these celestial bodies and locations.").

63. *See id.* pmbl. (envisioning the Artemis Accords "to implement the provisions of the Outer Space Treaty and other relevant international instruments").

assistance.[64] On cooperation, the agreement dictates that its partners must ensure that their use of Outer Space does not harmfully interfere with any other country's activities in this environment.[65] The accords also promote active use of communication channels through provisions mandating proper notice and facilitating coordination among all affected members.[66]

In addition, similar to the open database concept introduced in the Registration Convention,[67] the agreement encourages public disclosure of scientific knowledge on "a good-faith basis."[68] Such sharing will be done in a cooperative yet protective manner.[69] While the commitment is limited to government-backed public projects,[70] it could incentivize cooperation in Outer Space research. Because activities in this space are still very limited, any analysis and findings will be extremely valuable to the international scientific community. This is especially important to researchers living in countries that do not budget for an Outer Space program. Examining this data, these scientists will be able to participate in Outer Space research and come up with innovative technologies that could reduce risks. Hence, by democratizing access to this region, the Artemis Accords can make Outer Space safer and more stable for all.

Following the IGA's footsteps, the Artemis Accords also promotes interoperability as a way of building further cooperation in Outer Space. In fact, this agreement devotes an entire section to interoperability.[71] These accords emphasize the importance of interoperable technology "and common exploration infrastructure and standards" in "enhanc[ing] space-based exploration, scientific discovery, and commercial utilization."[72] Thus, the Artemis Accords encourages all of its partners to adopt existing and create new interoperability standards for space-based infrastructure.[73] This stance on promoting standardization is not misplaced. Interoperability can have a powerful effect in ensuring successful cooperation and mutual assistance in Outer Space—an environment that is unforgiving for human life. Having standardized infrastructure and mechanisms for critical Outer Space technologies will enable all nations to better assist and aid one another in the event of distress. This is crucial

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64. *Id.* § 6.

65. *See id.* § 11, ¶ 4 (noting that countries must "refrain from any intentional actions that may create harmful interference").

66. *See id.* § 11 ¶¶ 5, 7.

67. *See supra* Section I.A.

68. ARTEMIS ACCORDS, *supra* note 59, § 4, ¶ 2.

69. *Id.* § 8, ¶ 1.

70. *See id.* § 8, ¶ 3 ("The commitment to openly share scientific data is not intended to apply to private sector operations[.]").

71. *See id.* § 5.

72. *Id.*

73. *See id.*

for maintaining safety in Outer Space—especially on long-durational missions—where explorers will become more reliant on one another rather than waiting for any time-delayed assistance from Earth.

D. Legal Frameworks' Shortcomings in Maintaining Safety and Stability

Through provisions on cooperation and mutual assistance, prominent Outer Space-related international agreements can play a significant role in promoting the safety and longevity of human activities in this sector. However, this is not enough. Because of (1) external geopolitical tensions, (2) intranational policy changes, and (3) adoptions of different standards of measurement, these international agreements might be limited in their ability to comprehensively maintain safety and security in Outer Space.

1. External Geopolitical Tensions

Geopolitical tensions among competing space-faring nations can limit the practical applicability of these international agreements. If certain governing documents bar a major space-faring nation from working with other countries in Outer Space, universal consensus and cooperation is difficult to achieve. Additionally, a cooperative framework is only effective if all parties it seeks to govern fully respect the agreement's provisions and unconditionally accede to its authority. Without a fully collaborative and comprehensive exchange of ideas and scientific results, differing and incompatible technology standards might develop. Worse yet, different blocs of countries might actively create differentiating technology standards to prevent attacks and hacks by rivals. These competitive factors can impede the ability of countries to assist one another in the event of an emergency.

Unfortunately, the current reality in Outer Space is that geopolitical factors bar some States from working with other States. For instance, under the Wolf Amendment, the United States is essentially forbidden from partnering with China on any Outer Space activities.[74] This makes cooperation between the countries difficult, if not impossible. Because of this geopolitical obstacle, it is unlikely that China will ever be a signatory to the Artemis Accords. Hence, the accords' aspiration to create interoperable standards for Outer Space technologies is unlikely to achieve universal adoption. Thus, the effectiveness of this international framework is diminished.

Furthermore, if geopolitical conflicts arise among partners to an international agreement, the treaty's usefulness may become limited. In

74. *See* Jeff Foust, *Defanging the Wolf Amendment*, SPACE REV. (June 3, 2019), https://bit.ly/3KLS0l1.

2022, tensions between the United States and Russia increased because of the Ukrainian conflict.[75] As a result, Russian officials made saber-rattling statements that created concerns for the safety of the ISS, to which NASA and Roscomos are integral partners.[76] With Roscomos responsible for ISS's propulsion, the lack of Russian support for the space station could lead to dangerous results.[77] Although the IGA mandates collaboration and cooperation,[78] its partners essentially comply on a good-faith basis. As a result, the IGA—and other Outer Space-related treaties—could be rendered powerless in times of increased hostilities on Earth.[79] Thus, geopolitical tensions can have a strong effect in limiting certain agreements' practical authority in preserving safety and stability among all space-faring nations.

2. Intranational Policy Changes

Maintaining the long-term viability and safety of human activities in Outer Space through international frameworks can also be adversely affected by changing intranational policies. All national governments are susceptible to regime changes. As new administrations come into power, governing coalitions change, or heads of states succeed, national priorities might shift. A nation's new government may have policies that are radically different from those of the previous one. Hence, it is entirely possible that a State that has previously acceded to an international agreement might disavow its continued involvement and refuse to uphold its treaty obligations.[80] Changes in national governments can also hinder progress in certain cooperative activities. With a new administration installing its own personnel in key leadership positions and transitioning out the old regime's team members, projects and goals in support of

75. *See* Rebecca Heilweil, *The International Space Station Isn't Above Global Politics*, VOX (Mar. 4, 2022), https://bit.ly/3toKSRC (noting that the head of Roscomos indicated "on a state-controlled Russian television show that if the US continued to be 'hostile,' Roscosmos would rescind its support for the space station").

76. *See id.*

77. *See id.* (noting that if the ISS were to fall to Earth, certain heavy components will not break up in the atmosphere and "could hit structures or kill people").

78. *See supra* Section I.B.

79. *See* Heilweil, *supra* note 75 ("[T]hese ongoing tensions are a clear sign that the state of international collaboration in space is rapidly changing, and becoming much more sensitive to politics here on Earth.").

80. For instance, nations have exited Outer Space-adjacent multinational treaties and contemplated exiting existing projects in Outer Space. *See* Bill Chappell, *Trump Administration Confirms U.S. Is Leaving Open Skies Surveillance Treaty*, NPR (May 21, 2020, 4:42 PM), https://n.pr/3H73Hwr (noting the Trump administration's intent to exit a "34-nation agreement" that has been in effect since 2002 which allows one another to fly aircraft over each other's territory); *see also* Olga Dobrovidova, *Russia Mulls Withdrawing from the International Space Station After 2024*, SCI. (Apr. 20, 2021), https://bit.ly/3I2N9qF (indicating Russia might leave the ISS partnership).

international obligations might experience fits and spurts, leading to stagnation in such efforts.

A recent example of this issue can be found after the 2020 elections in the United States. In 2018, a new United States space policy, Space Policy Directive-3, was launched that called for the development of an open architecture space situational awareness data repository ("OADR").[81] As part of a cooperative international data sharing effort, the OADR was envisioned to improve Outer Space traffic management by acting as a centralized repository of information on space objects.[82] This would assist with early warnings and notifications of potential collisions in Outer Space.[83] Yet since the presidential transition, progress on the OADR has stalled.[84] The lack of movement on this significant Outer Space cooperative activity can be attributed to the departure of the previous president's leadership team.[85] Thus, even if international agreements call for further cooperation and all countries agree to these goals, changing administrations might still impact these treaties' effectiveness.

3. Different Standards of Measurement

The use of different standards of measurement can also detract from any international framework's goal of promoting safety and stability in Outer Space. While most of the world utilizes the metric system, there are a few imperial-system holdouts, including one prominent space-faring nation: the United States.[86] Although a minor inconvenience, it can still have an outsized impact on cooperative activities. Even if parties agree to cooperate, it is hard for an international agreement to practically and successfully implement a uniform measurement system. For instance, while NASA has "officially" adopted the metric system,[87] there are still several major components and certain missions that rely on imperial measurements.[88] This has led NASA to officially admit that while the "use

81. *See* Memorandum on Space Policy Directive-3, National Space Traffic Management Policy, 83 Fed. Reg. 28,969 (June 18, 2018).

82. *See* Jeff Foust, *Data Sharing Seen as Critical to Future of Space Situational Awareness*, SPACENEWS (Sept. 20, 2019), https://bit.ly/3KTMNEH.

83. *See id.*

84. *See* Anthony Colangelo, *T+193: Marcia Smith, SpacePolicyOnline.com*, MAIN ENGINE CUT OFF, at 15:27 (July 9, 2021), https://bit.ly/3ud50qJ ("And it's a shame because . . . with a tiny amount of money . . . they actually were making a lot of progress.").

85. *See id.* at 15:05 ("[T]he air has all gone out of the balloon since the administration changed. And a lot of the people who were there in the office of space commerce were political appointees or they were there on term appointments that have now expired . . . .").

86. *See* Katharina Buchholz, *Only Three Countries in the World (Officially) Still Use the Imperial System*, STATISTA (June 6, 2019), https://bit.ly/3AIlpEO.

87. *See NASA Finally Goes Metric*, SPACE.COM (Jan. 8, 2007), https://bit.ly/3KVvJOq.

88. *See* Paul Marks, *NASA Criticized for Sticking to Imperial Units*, NEWSCIENTIST (June 22, 2009), https://bit.ly/3KW2Txz.

of [the metric system] in the U.S. is increasing, aerospace is recognized as one area where adoption will be difficult, due to the long-standing use of the U.S.-based 'inch-pound' system for aircraft."[89] This difficulty can be partly attributed to national pride and partly to an attitude of 'why fix something that is not broken.'[90] Hence, human inertia might drive against the successful implementation of any standard-of-measurement mandates in an international agreement.

While rules and regulations ensuring the use of conversion tables could resolve the differences in measurement units, forgetfulness and carelessness could still lead to disasters in Outer Space. Back in late summer of 1999, NASA lost one of its Mars orbiters primarily because of a failure to convert imperial measurements to metric units.[91] With the mistake coming at the end of a ten-month journey for the spacecraft, this $125 million loss greatly stung and led to a significant black eye for NASA.[92] Even though the contract explicitly dictated that NASA's contractor for the orbiter would convert its measurements to metrics, this provision was not followed and no one caught the error.[93] As old habits die hard, even if there is an agreement on what measurement to use, engineers accustomed to different standards might fail to follow the proper procedures. Combating such mindsets, an international framework's ability to reduce safety and stability risks in Outer Space can be hampered by differences in measurement systems.

Because of international geopolitical tensions, changes in intranational policies, and different customs of measurement, international frameworks can be limited in their effectiveness in preserving safety and stability of human activities in Outer Space. Hence, other solutions are needed to supplement and incentivize cooperative activities that could reduce these risks. Part II continues by exploring one solution: encouraging the widespread adoption of open standards for critical Outer Space technologies.

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89. OFF. CHIEF ENG'R, NASA, INTERNATIONAL SYSTEM OF UNITS – THE METRIC MEASUREMENT SYSTEM (Oct. 10, 2014), https://go.nasa.gov/3ALHPVR.

90. *See generally* Benjamin Plackett, *Why Doesn't the US Use the Metric System?*, LIVESCIENCE (Aug. 15, 2020), https://bit.ly/3obrGny (indicating that United States' "political stability" prevents a measurement system change because that "requires quite a bit of turmoil for disrupters to take advantage of" especially when such change has been "deemed to be voluntary instead of mandatory"). *Cf.* Jo Craven McGinty, *Will the U.S. Ever Go Metric? It Already Has, Sort of*, WALL ST. J. (Aug. 6, 2021) (noting that the country is slowly moving toward a metric system, but it might take "seven or more generations, if ever" before fully converting).

91. *See* Ajay Harish, *When NASA Lost a Spacecraft Due to a Metric Math Mistake*, SIMSCALE (Jan. 26, 2021), https://bit.ly/3g94EZZ [hereinafter *Metric Mistake*].

92. *See* Kathy Sawyer, *Mystery of Orbiter Crash Solved*, WASH. POST (Oct. 1, 1999), https://wapo.st/3gasVPt.

93. *See Metric Mistake*, *supra* note 91.

II. OPEN STANDARDS FOR OUTER SPACE

With international frameworks alone being not enough to minimize risks in Outer Space, other methods are needed to maintain safety and stability. One solution could be the adoption of open standards for critical Outer Space technologies. This Part begins by providing a brief overview on technology standards and their benefits. Then, it will explore open standards in depth. Finally, it will explain how the use of open standards in Outer Space can assist international frameworks in ensuring the safety and viability of human activities in this environment.

A. Standards in General

With so many interconnected technologies and systems, the world we live in is governed by many standards. A standard is simply "a document that provides requirements, specifications, guidelines, or characteristics that can be used consistently to ensure that materials, products, processes, and services are fit for their purpose."[94] Standards are designed to ensure different items can sync, function, and connect with one another. They do this by essentially forming a common language that enables different components to communicate with one another. Hence, as long as a component follows the rules laid out by a standard, this component will be able to seamlessly participate in the technical ecosystem governed by such standard.

Standards can be beneficial for the user, the component, and the ecosystem. For the user, standards can be a source of convenience. If all the components a user picks are on the same standard, that user no longer needs to spend time determining whether the components could "talk" with one another. For the product, standards can act as a common foundation. The product's creators can focus on developing the product's features without having to exert effort in harmonizing the product's interconnective functions. For the ecosystem, standards can help drive adoption. As long as the underlying standard is used by many popular hardware and software parts, the ecosystem can thrive and flourish.

Standards come in one of two forms: proprietary or open.[95] Developed, controlled, and owned by a private entity or a small group of entities, proprietary standards are generally licensed out to the world with specific restrictions.[96] Because the success of proprietary standards is highly dependent on how much effort and resources their owners put in,

94. *ISO Standards*, INST. OF ENV'T SCI. & TECH., https://bit.ly/3ulb9RJ (last visited July 9, 2021).

95. *See Standards*, BCC, https://bbc.in/34u7J4j (last visited July 19, 2021).

96. *See id.*

these standards tend to be well-supported and maintained.[97] However, proprietary standards are typically used as a revenue generator; thus, their owners tend to create a monopolistic and closely controlled environment, leading them to "lock-in" their users by making it hard to transfer components out.[98]

Meanwhile, open standards are made available for public use without any expectations of profits.[99] They are generally developed in transparent and collaborative processes that are open to all.[100] Not driven by revenue, open standard communities focus primarily on improvements to the protocol to make open standards more efficient and continuously usable as technologies evolve.

Because open standards are designed to both create interoperability among different components and allow free and open use by all, their widespread adoption can encourage cooperative and collaborative behavior. Section B provides a more detailed examination of open standards.

B. *Overview of Open Standards*

Aside from being publicly available, open standards are defined by several key characteristics.[101] First, any interested individual or entity should be able to participate in an open standard's development and adoption.[102] During this process, all interested parties' ideas should be given due consideration and care should be taken to prevent any one group from dominating the discussion.[103] Second, if an open standard requires the use of any intellectual property rights, those rights should be available for licensing on nondiscriminatory terms with reasonable restrictions and fees.[104] Third, because an open standard seeks to encourage technological advancement in an unbiased way, the standard should be written with sufficient detail so that all products and/or services in the marketplace can

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97. *See* Paul Zubrinich et al., *Proprietary vs. Open Standards*, 4IP COUNCIL, at 7 (Nov. 2018), https://bit.ly/3scK80h.

98. *See id.*

99. *See Definition of "Open Standards,"* INT'L TELECOMM. UNION, https://bit.ly/3IZ4sJh (last visited July 9, 2021) ("'Open Standards' are standards made available to the general public and are developed (or approved) and maintained via a collaborative and consensus driven process."); *see also What are Open Standards?*, OPENSOURCE.COM, https://red.ht/3AXDCyc (last visited July 9, 2021) ("But the high-level overview shows how open standards must be *openly created* and easy to adopt without restrictions or for use or royalties expectations.") (emphasis in original).

100. *See id.*

101. *See Definition of "Open Standards," supra* note 99 ("'Open Standards' facilitate interoperability and data exchange among different products or services and are intended for widespread adoption.").

102. *See id.*

103. *See id.*

104. *See id.*

successfully implement the standard.[105] Finally, each open standard should have the backing of a neutral and trusted organization—ensuring that the standard is continually refined as new innovations develop in the standard's field.[106]

The use of open standards brings with it many advantages. First and foremost, because of their public nature, open standards can lead to the development of broad and neutral specifications for interoperability.[107] Second, with open standards harmonizing fundamental protocols, companies that make subcomponents or provide subcontracting services on one platform in the ecosystem should be able to easily port their products or services to another in the same ecosystem, preventing technology capture or monopolistic behaviors.[108] Finally, with open standards relying on the community for development and maintenance, technical support is no longer dependent on the survival of a specific organization; troubleshooting efforts can be crowdsourced because the knowledge is publicly available. Hence, unlike proprietary standards, open standards ensure that products and services will not be locked into a specific type of technology or held at the whim of a particular commercial entity. This can encourage more participants to enter the market and come up with the best products and/or services for the ecosystem, leading to better choices for the customer and the industry.[109]

However, open standards do have some disadvantages. Because they are created and developed through a collaborative process that any interested party can participate in, it can be hard to reach a consensus.[110] Additionally, with a passive group in charge of developing an open standard, the organization may not always have the resources needed to actively enforce compliance.[111] Furthermore, without strong marketing backing from a commercial entity, an open standard's success is largely dependent on it gaining 'viral traction.'[112] Thus, if its creators are too focused on niche and highly technical aspects, they might create an open standard that the general public might not use or understand.[113] All of these

105. *See id.*
106. *See id.*
107. *See* IEEE Standards, *5 Reasons Open Standards are Essential to Application Development*, OPEN STAND (June 18, 2014), https://bit.ly/3IZrP5j.
108. *See id.*
109. *See id.*
110. *See* Brian Kelly & Marieke Guy, *Addressing the Limitations of Open Standards*, MUSEUMS & THE WEB 2007: PROC. (Mar. 1, 2007), https://bit.ly/3shX8lc (noting some open standards have been "plagued by disagreements over governance and the roadmap for future developments").
111. *See id.*
112. *See id.*
113. *See id.*

issues could limit the effectiveness of an open standard, causing it to become obsolete.

But against this backdrop, open standards have led to the development of many highly successful products and services that are now considered essential to everyday life. One clear example is the Internet. As the Internet Society notes, "[t]he Internet is fundamentally based on the existence of open, non-proprietary standards. These standards are key to allowing devices, services, and applications to work together across a wide and dispersed network of networks."[114] Here, it is worth noting that because each open standard should be specific enough to address a particular issue, complex services can be governed by a multitude of open standards. For instance, the Internet itself is regulated by thousands of open standards.[115]

While open standards might appear to be antagonistic toward revenue-generating activities, they are not incompatible with proprietary products and services. In fact, open standards can create new commercial opportunities. For instance, the now burgeoning and highly profitable field of software-as-a-service ("SaaS") came about because of the rise of the Internet,[116] which itself is highly dependent on open standards. Hence, open standards can lay the foundation needed for the creation and development of a new field or technology paradigm. As the next section demonstrates, this characteristic makes open standards perfect for use in Outer Space.

C. Applying Open Standards to Outer Space

By promoting neutral and publicly accessible technical protocols, open standards can encourage the development of interoperable technologies. The widespread adoption of these technologies across the world could lead to a virtuous cycle in which these standards gain additional popularity from newcomers to the field. Hence, if open standards are used more pervasively in Outer Space, this could lead to technologies becoming more unified. By working off the same foundation, participants in Outer Space will be better able to cooperate with and provide mutual assistance to one another. In this way, the use of open standards represents a companion solution that can mitigate the three main

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114. *Open Internet Standards Chapter Toolkit*, INTERNET SOC'Y, https://bit.ly/3sbIAnm (last visited July 21, 2021).

115. *See Official Internet Protocol Standards*, RFC ED., https://bit.ly/3ASKsoV (last visited July 21, 2021).

116. *See* Victoria Fryer, *The History of SaaS: From Emerging Technology to Ubiquity*, BIGCOM., https://bit.ly/347ZP0V (last visited July 21, 2021) ("SaaS platforms make software available to users over the internet, usually for a monthly subscription fee.").

weaknesses in international agreements' ability to maintain safety and stability.[117]

Unlike international treaties, open standards are not affected by geopolitical tensions because they are designed to be forum neutral. As one of their key characteristics, open standards must ensure that they do not lock users into a specific type of technology or implement processes that are favorable to one particular group over another.[118] If an open standard incorporates a restrictive component or process, it fails one of its essential elements and can no longer be considered an open standard. Thus, open standard communities will veer away from any technology, process, or procedure that would seek to discriminate. Therefore, if open standards underlie critical Outer Space technologies and protocols, it will prevent unilateral use restrictions.

Additionally, once an open standard is developed, all technologies will be developed according to the standard's specifications. Even if there was disagreement, and a technology creator refuses to comply with the open standard for subsequent updates, the standard can continue to work. The rest of the community can simply design an update or replace the technology with one that is compatible with the standard. Thus, the lack of future compliance by one will not hold up the overall open standard's continued use or development. These characteristics of open standards would help to bypass the geopolitical issues that hinder international agreements' ability to foster universal cooperation in Outer Space.

Additionally, open standards are not as susceptible to intranational policy changes as international agreements are. With an emphasis on consensus and a view toward long-term use, the development of any new open standard can take time. Compromises must be made, and implementations must be fully vetted to ensure that their functionalities live up to their purpose.[119] This means that once an open standard is established, the likelihood of a dramatic policy change is rare. With all parties on an open standard's governing council having equal standing, any change that represents a significant departure from the original purpose will likely be blocked. Thus, an open standard can withstand the type of whipsaw intragroup policy changes that can impact the

117. *See supra* Section I.D.

118. *See ITI Views on Open Standards and Open Source Software*, INFO. TECH. INDUS. COUNCIL, at 2, https://bit.ly/3s8bZ1q (last visited July 22, 2021) ("Open standards are technology neutral.").

119. *See What Are Open Standards?*, OPENSOURCE, https://red.ht/3gcaQk8 (last visited July 9, 2021) ("[Open] standards encourage multiple implementations and tend to enter a market with some maturity and competition. Standards and specifications don't change quickly, so they are developed with expectation that they'll need to last for longer periods of time.").

effectiveness of international agreements. This enables an open standard to remain relevant for a long period of time.

With the standard of measurement set during their formation, open standards are less vulnerable to measurement system errors. Before an open standard is finalized, its measurement settings must be determined. So, while an international agreement might punt on this issue because of a lack of universal support, an open standard cannot bypass this problem; the measurement system must be finalized before the standard can be implemented. With engineers personally involved in a standard's development process, only a measurement system that everyone is comfortable with will receive consensus. This could reduce critical conversion mistakes. Once a system of measurement is written into the open standard, it will be promulgated by all parties using the standard. In the unlikely event that an open standard was to change its measurement settings once the new system is adopted, the old criteria will no longer be relevant. Hence, unlike international agreements, open standards will be less likely to suffer from misalignments and mistakes in measurement settings.

Addressing the shortcomings of various international agreements, open standards can establish a uniform set of technologies that can help to promote cooperative behaviors. Because mutual cooperation can significantly reduce risks, applying open standards to critical Outer Space technologies can bring about a more stable and viable environment for human activities. But to optimize this risk reduction, these open standards should focus on the incorporation of open source components. The next Part explores why open source components also have a critical role to play in maintaining safety and stability in Outer Space.

III. OPEN SOURCE IN OUTER SPACE

While open standards can encourage cooperation—and thereby ensure safety and stability in Outer Space—this strategy can be further optimized if these standards rely primarily on open source components. This Part starts by exploring how open source components can bolster efforts to maintain safety and stability in Outer Space. Then, it focuses on an instance of an open source-like license developed for Outer Space and the challenges it has faced. This Part continues by introducing several alternative open source-capable licenses that can be applied to Outer Space components. Finally, it concludes by demonstrating how the broad use of open source components can incentivize, rather than inhibit, further technological advancements that can make the region safer and more stable for all.

A. Open Source as a Companion to Open Standards

While putting certain Outer Space technologies and protocols on open standards can encourage cooperative behavior, this effect might be limited if such standards mainly contain proprietary components. In these cases, the components could still be subject to changing licensing terms at the whim of their owners, limiting the open standard's widespread adoption. However, open source components do not have these concerns. With features that can preserve the long-term viability and public accessibility of the technologies that they support, open source components can contribute to the goal of creating a safe and stable Outer Space for human activities.

Although "open standards" and "open source" both seek to promote "interoperability, innovation, and choice," they each have different uses and characteristics.[120] While an open standard is designed so that its components can seamlessly interoperate with one another, an open source license ensures that the licensed components are freely available for use, modification, and distribution.[121] So although the two can work together, they can also be mutually exclusive; an open standard does not have to utilize any open source components and an open source component might not be designed for open standards.[122]

With open standards helping to encourage more cooperation in Outer Space, the inclusion of open source components can further this goal. When utilized as an open standard's backbone, open source components can prevent the standard from being captured by proprietary technologies. This alleviates the risk that an open standard's components might become unavailable because of a license change or a shift in strategic vision of a component's owner. Having open source components at the heart of an open standard will enable proprietary technologies to be easily phased out or replaced if they become too restrictive. Furthermore, the details of an open source component are publicly accessible. Open access to such information would be advantageous if a critical open source component were to fail. When this occurs, engineers across the world (and in Outer Space) can all collectively analyze the failure and assist with the component's repair. If this component was a part of a critical life support protocol, the additional brainpower could mean the difference between life or death. For these purposes, open standards in Outer Space should seek to incorporate open source components whenever possible.

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120. *See* Guy Martin, *A Revival at the Intersection of Open Source and Open Standards*, TECHCRUNCH (June 9, 2021, 1:45 PM), https://tcrn.ch/33YTDbt.

121. *See id.*

122. *See* Larry Seltzer, *Open Source vs. Open Standards: Know the Difference*, HEWLETT PACKARD ENTER. (Mar. 26, 2018), https://bit.ly/3oeXsjt.

Reducing reliance on proprietary components can also be significantly important in Outer Space where technology needs to last longer. Because of the cost to escape Earth's gravity,[123] Outer Space-based components tend to be in use for prolonged periods of time. Hence, any device designed and built for Outer Space will usually undergo many repairs to extend its usable life. Yet if the apparatuses were dependent on many proprietary parts, the equipment's useful life could be overly reliant on its creators' survival. If any of these enterprises go out of business and no other company can replace the failed components, then the overall instrument can become permanently inoperable.[124] If such gadgets were needed to maintain the well-being of a spacecraft's personnel in an emergency, inoperability would significantly increase the risks to safety.

In this case, policy makers will be left with a Morton's Fork: either attempt to come up with a new design that can replace the defunct device or send the personnel back to Earth earlier than expected. Furthermore, if these mission specialists were involved in a long-term mission far away from Earth, a decision to send these personnel back early might not be feasible and everyone would have to accept a permanent increase in the mission's risk profile. The use of open source components can go a long way in eliminating this concern. Because open source components' designs are publicly disclosed, it will be possible to manufacture a replacement that can be sent up and delivered to the spacecraft; in the meantime, the spaceship crew may also be able to fashion a temporary solution as a stop-gap measure. Hence, the substitution of proprietary parts with their open source counterparts can help to maintain the long-term viability of many Outer Space technologies, and in turn make the environment safer for operations.

Thus, the use of open source components can help to further promote cooperative behavior in Outer Space and make it safer and more stable for human activities. Because of these features, it is no surprise that policymakers have tried to develop and use open source-like licenses for these technologies. The next section explores one example: the NASA Open Source Agreement.

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123. *See* Alex S. Li, *Defying Gravity: Taming the Rocket Equation*, #THESPACEBAR (Apr. 8, 2020), https://bit.ly/344I16G.

124. *See* William J. Broad, *For Parts, NASA Boldly Goes . . . on eBay*, N.Y. TIMES (May 12, 2002), https://nyti.ms/3JAT4ng (noting that in order to keep the Space Shuttle flying, NASA resorted to "trolling the Internet—including Yahoo and eBay—to find replacement parts" that no one makes anymore).

B. NASA Open Source Agreement

As a public agency, NASA has a mandate to broadly promulgate any of its Outer Space discoveries.[125] To achieve this goal, NASA has demonstrated a commitment to open source.[126] This arrangement also benefits NASA because its open source technologies can then be commercialized and freely improved through crowdsourcing efforts.[127] Thus, the space agency created the NASA Open Source Agreement ("NOSA"),[128] an open source license designed for Outer Space technologies. Though, because of controversies surrounding some of its licensing language, NOSA has not yet been widely adopted.

NOSA has many licensing characteristics common to most open source licenses. As long as a user complies with the license's copyright notice and attribution requirements,[129] the user can use, distribute, reproduce, modify, redistribute, and display the underlying NOSA-licensed technology without any monetary payments.[130] As a feature common to open source licenses, NOSA explicitly disclaims any warranty and liability as to the underlying technology.[131] However, NOSA's copyright notice requirement is very different from that of a typical open source license. While most open source licenses presume the underlying technology is entitled to copyright protection, NOSA is typically used for U.S. government work—which cannot be copyrighted in the United States.[132] To address this issue, the license indicates that when it comes to government work, the notice requirement only needs to state: "No copyright is claimed in the United States under Title 17, U.S. Code. All Other Rights Reserved."[133] With this language, the license safeguards itself from any invalidity challenges stemming from copyright violations.

125. *See, e.g.*, National and Commercial Space Programs, Pub. L. No. 111-314, § 20163, 124 Stat. 3328, 3355 (2010) ("[M]ake all results of the program authorized by this subchapter available to the appropriate regulatory agencies and provide for the widest practicable dissemination of such results.").

126. *See, e.g.*, SEAN HERRON, NASA, OPEN SOURCE SUMMIT 2011 (Nov. 20, 2012), https://go.nasa.gov/3ue2TTt ("On March 29 & 30, NASA will host its first Open Source Summit . . . to discuss the challenges with the existing open source policy framework, and propose modifications that would make it easier for NASA to develop, release, and use open source software.").

127. *Id.*

128. *See* NASA, NASA OPEN SOURCE AGREEMENT VERSION 1.3, https://go.nasa.gov/3gciVFq (last visited Feb. 13, 2022) [hereinafter NASA OPEN SOURCE AGREEMENT 1.3].

129. *See id.* § 3.

130. *See id.* § 2.

131. *See id.* § 4.

132. *See U.S. Government Works*, USA GOV. (Oct. 25, 2021), https://bit.ly/3obIB9H ("Most U.S. government creative works such as writing or images are copyright-free.").

133. *See* NASA OPEN SOURCE AGREEMENT 1.3, *supra* note 128, § 3(B).

While several Outer Space projects have been licensed under NOSA,[134] the use of this license is not without controversy. Specifically, there is a debate whether NOSA is a genuine open source license. This issue centers around its language in Section 3(G) where the license states: "Each Contributor represents that . . . its Modification is believed to be Contributor's original creation . . . ."[135] The Free Software Foundation expresses concern with this language because it would disallow a user from contributing—to a NOSA-licensed project—any modification that is not personally developed by the user.[136] Hence, the foundation recommends against the use of this license and urges the public to "please write to NASA and call for the use of a truly free software license."[137] In addition, others have dismissed NOSA because of its registration requirement. These critics believe that NOSA's mandate, which requires that they must register with the owner of a NOSA-licensed technology before use or modification, is an outdated tracking requirement that violates modern free and open source licensing principles.[138]

Because of these criticisms, NOSA's adoption as a mainstream open source license for Outer Space technologies is limited. However, with a universe of open source-capable licenses available, there are several others that can serve as replacements. The next section will explore a few licenses that could be implemented for components that are a part of open standards for Outer Space technologies and protocols.

C. *Open Source-Capable Licenses for Outer Space*

Because of the aforementioned objections, NOSA might not be the best license for open sourcing critical Outer Space components. But there are several alternative open source-capable licenses that could be used. Before elaborating on three of these licenses, it is worth noting that this Article uses the term "open source-capable" license to differentiate it from a pure "open source" license. While an open source-capable license can act as an open source license as long as certain conditions are met, some might not consider it a true open source license given these prerequisites. Thus, pure open source licenses are a subtype of open source-capable

134. *See, e.g.*, NASA, CERTWARE, https://bit.ly/3KWzmDJ (last visited Aug. 4, 2021); NASA, OPENVSP, https://bit.ly/3uhymEq (last visited Aug. 4, 2021); NASA WORLDWIND, ABOUT, https://go.nasa.gov/3rdxqiw (last visited Aug. 4, 2021).

135. NASA OPEN SOURCE AGREEMENT 1.3, *supra* note 128, § 3(G).

136. *See Various Licenses and Comments About Them*, FREE SOFTWARE FOUND., https://bit.ly/33gbo5t (last visited Aug. 4, 2021).

137. *Id.*

138. *See* Ross A. Beyer et al., *No to NOSA, Yes to Mainstream Licenses* 2 (Jan. 22, 2018) (research paper, National Academies of Sciences Engineering Medicine), https://bit.ly/3IYIYfD.

licenses, and not the other way around.[139] However, because the conditions are designed solely to incentivize these licenses' adoption for Outer Space purposes, the use of these open source-capable licenses should avoid the controversies that surrounded NOSA and gain support for adoption in Outer Space.

In this Section, three types of open source-capable licenses are detailed for Outer Space use. They are: (1) traditional open source licenses, (2) time-delayed open source-capable licenses, and (3) field-limited open source-capable licenses.

1. Traditional Open Source Licenses

The first type of open source-capable license that can be adopted for Outer Space is an obvious choice: the traditional open source license. For software, examples of this type of license include the 3-Clause BSD,[140] the Apache license,[141] or the MIT license.[142] For hardware, they can be the CERN Open Hardware License,[143] the Solderpad Hardware License,[144] or the TARP Open Hardware License.[145] These licenses all allow for permissive and unrestrictive use of the underlying component for any purpose as long as the notice and attribution requirements are followed: When distributing any licensed component, the user must include the license file for the component as a notice and properly attribute any applicable copyrights.

Because of their traditional nature, these open source licenses have been broadly used and are well-understood by many engineers, developers, and programmers. With hardly any restrictions, these licenses are seen as the gold standard within the open source community. Furthermore, these licenses do not create intellectual property problems for people working in for-profit enterprises. Under more complex open source licenses, the user of the licensed component not only needs to make the licensed component—and any modifications to it—fully and freely available, but also needs to do the same for the entire end-product

139. *See infra* Sections III.C.2, III.C.3.

140. *The 3-Clause BSD License*, OPEN SOURCE INITIATIVE, https://bit.ly/3g6WtgZ (last visited Aug. 9, 2021).

141. *Apache License, Version 2.0*, OPEN SOURCE INITIATIVE, https://bit.ly/3s9wsDm (last visited Aug. 9, 2021).

142. *The MIT License*, OPEN SOURCE INITIATIVE, https://bit.ly/3ARlNBb (last visited Aug. 9, 2021).

143. *CERN Open Hardware License Version 2 – Permissive*, OPEN HARDWARE REPOSITORY, https://bit.ly/3oN5eBp (last visited Aug. 9, 2021).

144. *Solderpad Hardware license v2.1*, SOLDERPAD, https://bit.ly/3HqwH3h (last visited Aug. 9, 2021).

145. *The TAPR Open Hardware License*, TOMORROW'S HAM RADIO TECH. TODAY, https://bit.ly/3IY77D8 (last visited Aug. 9, 2021).

containing such licensed component as well.[146] In these cases, any proprietary materials combined with the licensed parts will also become open sourced, creating a commercialization concern that is known as a "viral" or strong copyleft issue.[147] In contrast, traditional open source licenses eliminate this concern by only mandating these type of licensing terms on the open sourced component—and any modifications to it—but not on the final combined work.[148] With this permissive nature, traditional open source licenses are favored by both commercial entities and individual developers. Thus, any open standards containing components under these licenses should not have issues in gaining popular acceptance.

2. Time-Delayed Open Source-Capable Licenses

Another type of license that can be used for Outer Space-related technologies is a time-delayed open source-capable license. Under this license, for an initial period of time, the underlying component can only be used freely for non-commercial or developmental purposes. Once this period expires, the license automatically converts into a traditional open source license with all restrictions eliminated. One example is the Business Source License.[149] It is worth noting that these purpose-related restrictions, although temporary, prevent a time-delayed open source-capable license from being categorized as a 'true' open source license. Its restrictive initial period makes this license violate one of the main principles of an open source license: no use restrictions.[150]

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146. *See Open Source Licenses: Types and Comparison*, SNYK, https://bit.ly/3rlqqjv (last visited Feb. 21, 2022) (indicating certain open source licenses, such as the GPL, mandate their users to distribute the end application and "all of its source code under the same license").

147. *See* Craig Mundie, *Speech Transcript—Craig Mundie, The New York University Stern School of Business*, MICROSOFT (May 3, 2001), https://bit.ly/3K1lSFR ("This viral aspect of the GPL poses a threat to the intellectual property of any organization making use of it. It also fundamentally undermines the independent commercial software sector because it effectively makes it impossible to distribute software on a basis where recipients pay for the product rather than just the cost of distribution."); *see generally* Michael J. Cavaretta, *Open Source Issues in Mergers & Acquisitions*, MORSE (Jan. 6, 2015), https://bit.ly/3GptLTc ("In other words, strong copyleft licenses cause an entire proprietary work which incorporates or is based on OSS to itself become OSS. For this reason, strong copyleft licenses are often referred to as 'viral' licenses which have a 'tainting' effect on proprietary software products if they incorporate OSS.").

148. *See Open Source Licenses: Types and Comparison*, SNYK, *supra* note 146 (noting that the BSD, MIT, and Apache licenses are all "permissive open source licenses").

149. *See Business Source License 1.1*, MARIADB, https://bit.ly/3J39UL6 (last visited Aug. 10, 2021) ("Effective on the Change Date, or the fourth anniversary of the first publicly available distribution of a specific version of the licensed Work under this License, whichever comes first, the Licensor hereby grants you rights under the terms of the Change License, and the rights granted in the paragraph above terminate.").

150. *See The Open Source Definition (Annotated)*, OPEN SOURCE INITIATIVE, https://bit.ly/3sirMLg (last visited Aug. 10, 2021) (stating "[t]he license shall not restrict

Because technological innovations related to Outer Space still require a tremendous amount of human and financial capital, companies might not be willing to conduct research and development in this field if they cannot profit from such efforts. But to advance the field and open up new opportunities, certain baseline technologies need to be publicly available. The time-delayed open source-capable license can strike a perfect balance between these competing needs.

By putting a temporary restriction on how certain enabling technologies can be freely used, this license enables companies who came up with the critical technology to have an exclusive revenue-generation period, thereby enabling companies to recoup their expenditures and gain a healthy profit margin. Once this exclusivity wears off, the technology will become publicly available for any use without restrictions. By lowering the barrier to entry, this could encourage additional enterprises to enter and build on top of the protocols, developing the next set of innovations for the field. In this way, the time-delayed open source-capable license is essentially acting as a patent, helping to encourage investment in the field in the short run while preventing technology capture in the long run. Thus, time-delayed open source-capable licenses could be a perfect tool for use in open standards for critical Outer Space technologies.

3. Field-Limited Open Source-Capable Licenses

Finally, a field-limited open source-capable license can also be well-suited for integration into open standards for Outer Space. Under this license, licensing rights to the underlying component will only be free if such component is used in a specific field. Many traditional open source licenses can be adopted for this purpose. For instance, the Apache license can be field-restricted by revising the license grant in sections two and three[151] to add in the phrase 'and solely as applied to Outer Space-related

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any party from selling or giving away the software as a component of an aggregate software distribution").

151. *See Apache License, Version 2.0*, OPEN SOURCE INITIATIVE, https://bit.ly/3L8hJRF (last visited Aug. 9, 2021).

Specifically: Section 2 would be modified to read "Subject to terms and conditions of this License *and solely as applied to Outer Space-related technologies*, each Contributor hereby grants to You a perpetual, worldwide, non-exclusive, no-charge, royalty-free, irrevocable copyright license to reproduce, prepare Derivative Works of, publicly display, publicly perform, sublicense, and distribute the Work and such Derivative Works in Source or Object form." (Revisions emphasized).

The first sentence of Section 3 would be modified to read, "Subject to the terms and conditions of this License *and solely as applied to Outer Space-related technologies*, each Contributor hereby grants to You a perpetual, worldwide, non-exclusive, no-charge, royalty-free, irrevocable (except as stated in this section) patent license to make, have made, use, offer to sell, sell, import, and otherwise transfer the Work, where such license technologies.' But because of this addition, similar to time-delayed open source-capable licenses,[152] a field-limited open source-capable license will not be accepted as a 'true' open source license. Specifically, it would violate the general rule that all open source licenses cannot discriminate against any "fields of endeavor."[153]

However, a field-limited open source-capable license has certain advantages when applied to Outer Space technologies. Much like the time-delayed open source-capable license, it strikes a balance between promoting innovation and protecting investment. Further, the field-limited open source-capable license is perfect for a company that is not focused on Outer Space yet develops a technology that could have a critical impact for the industry. If this enterprise wants to contribute to humanity's advancement in Outer Space, then it can use this license to ensure that its technology will be freely available for Outer Space use while maintaining its commercial rights in all other fields. Unlike the use of a time-delayed open source-capable license, the use of a field-limited open source-capable license is not dependent on any temporal elements. Thus, this license is perfect for non-space companies to promote their contributions that might have serendipitous Outer Space applications. While the organization might lose some revenue related to Outer Space use, the goodwill generated from free publicity might make up for the loss. Thus, field-limited open source-capable licenses could also play an important role in Outer Space.

But the use of open source components does raise a significant question: apart from potentially generating goodwill, why would a company with a proven technology that it can profit from ever decide to open source this component? Additionally, some might argue that the excessive use of open source components might stunt future investments in the field because of a lack of a rate of return. The next section will assuage these concerns.

D. *Technological Advancements Through Open Source*

The pervasive use of open source components might lead some to worry about the negative implications it might have on technological advancements. But by making foundational and enabling technologies freely available, the use of open source components could create more

applies only to those patent claims licensable by such Contributor that are necessarily infringed by their Contribution(s) alone or by combination of their Contribution(s) with the Work to which such Contribution(s) was submitted." (Revisions emphasized).

152. *See supra* Section III.C.2.

153. *See The Open Source Definition (Annotated)*, *supra* note 150 ("The license must not restrict anyone from making use of the program in a specific field of endeavor. For example, it may not restrict the program from being used in a business, or from being used for genetic research.").

opportunities for commercialization and growth. In turn, this could lead to more innovations that make Outer Space safer and more stable for human activities.

Open source started as a protest movement against companies that were unreasonably profiting from their proprietary software that—while once was revolutionary—had become outdated or inefficient.[154] But over time, the movement became a successful business model on its own. By democratizing software development, the open source movement enabled greater participation and empowered small projects to gain popularity.[155] With the ability to freely modify, use, and distribute the resulting software, many open source projects saw developers flock in to make improvements and discover new use cases.[156] These 'network effects' encouraged the software industry to grow as a whole, leading to its omnipotent reach in modern society.[157]

Similar to how open source code revolutionized the software industry, the incorporation of more open source components in critical Outer Space technologies could incentivize additional entities to enter this sector. With free and public access to these foundational technologies, collaboration among scientists, engineers, and developers will likely increase. Bringing together the brightest minds around the globe, these brainstorming sessions could finetune and improve these technologies, making them more efficient, practical, and/or durable for use in Outer Space. This acceleration in innovation can enlarge humanity's capabilities in resolving challenges identified in the known galaxy as well as exploring further into the unknown universe. As new enterprises form and participate in this growing market, additional discoveries could be uncovered that lead to more sophisticated inventions. As subsequent technologies also become open sourced through this iterative process, the virtuous cycle of innovation continues. Hence, the use of open source components can

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154. *See* Mike Volpi, *How Open-source Software Took Over the World*, TECHCRUNCH (Jan. 12, 2019, 12:00 PM), https://tcrn.ch/3root60 ("The original open-source projects were not really businesses, they were revolutions against the unfair profits that closed-source software companies were reaping.").

155. *See id.* ("[O]pen-source software permeates itself through the true experts, and makes the selection process much more grassroots than it has ever been historically. The developers basically vote with their feet. This is in stark contrast to how software has traditionally been sold.").

156. *See id.* ("[I]t is adopted by the developers who appreciate the software more because they can see it and use it themselves rather than being subject to it based on executive decisions.").

157. *See* Alex Engler, *How Open-Source Software Shapes AI Policy*, BROOKINGS INST. (Aug. 10, 2021), https://brook.gs/3JpIHCw ("Much attention has been paid to training and retaining AI talent, but making AI easier to use, which open-source code does, may have a similarly significant impact in enabling economic growth.").

significantly advance Outer Space developments by encouraging broader levels of participation.

Furthermore, for-profit enterprises might license parts of their technology under open source licenses to increase the market for their products and/or services. Although counterintuitive, when companies make some of their proprietary components freely available, they expand their sales opportunities. Here, open source components can act as an "evaluation agreement" for an enterprise.[158] As evaluators become intrigued by these components and want to unlock more functionalities, the corporation can turn them into paying customers.[159] Thus, open source materials can act as a Costco sampler, enticing the customer to buy the sampled product.[160] Additionally, the open source model offers companies another avenue for revenue; companies could open source certain components but offer product support on a paid subscription basis.[161] While they might not generate profit from the products themselves, these enterprises can receive consistent income from servicing their open sourced devices.

Open sourcing certain "infrastructure" components can also grow key markets needed for future expansion. For instance, automobile makers are typically zealous about their technologies and will refuse to share proprietary information with their competitors.[162] However, in designing and creating hydrogen and fuel cell vehicles, engineers from different automotive companies have been eager to share knowledge.[163] This collaboration ensures that the supporting infrastructure for these next-generation automobiles is optimally standardized and regulated.[164] Through these efforts to essentially open source and standardize components such as fuel pumps so that all vehicles can refuel at any hydrogen fuel station, the automobile industry laid the foundation needed to create a new thriving commercial market. This same concept can be

158. *See #125 Is This a Tragedy of the Commons? Antitrust Law and Open-Source Licensing*, OUR CURIOUS AMALGAM, at 13:20 (July 26, 2021), https://bit.ly/3rIE9kS ("It serves as a kind of proxy for an evaluation agreement.").

159. *Id.*

160. *See* Joe Pinsker, *The Psychology Behind Costco's Free Samples*, THE ATLANTIC (Oct. 1, 2014), https://bit.ly/34XVayE ("When we compare it to other in-store mediums . . . in-store product demonstration has the highest [sales] lift . . . .").

161. *See* Volpi, *supra* note 154 ("The first entrepreneurial ventures attempted to capitalize on this adoption by offering 'enterprise-grade' support subscriptions for these software distributions.").

162. *See* Physics Girl, *The Truth About Driving a Hydrogen Car*, YOUTUBE, at 11:51 (Aug. 9, 2021), https://bit.ly/34D5M5V ("Normally in the automotive industry, it's very competitive.").

163. *See id.* at 11:53.

164. *See id.* at 11:58.

applied to Outer Space with open source components laying the groundwork for future revenue opportunities.[165]

For these reasons, the use of open source in Outer Space can drive, rather than hinder, innovation. Additionally, companies might be willing to open source their technologies in order to increase market size. By adopting open standards that primarily contain open source components, cooperation in Outer Space can be further encouraged with scientists, lawyers, and entrepreneurs all incentivized to participate. Their collective efforts could lead to new technologies as well as techniques that will make Outer Space safer and preserve its long-term viability. But, given that humanity's current activities in Outer Space are still in their nascency, there are certain priority research and development areas that are critical for maturing and expanding opportunities in this space. Part IV of this Article will describe these technological areas where open standards along with their open source components will have the greatest and most immediate impact in reducing risks to safety in this environment.

IV. IMMEDIATE OUTER SPACE FOCUS AREAS FOR OPEN STANDARDS AND OPEN SOURCE

As commercial opportunities increase in Outer Space, open standards and open source are starting to gain a foothold in this universe as well.[166] Yet, given the current state of development, there are several Outer Space technology areas where the use of open standards and open source can have an immediate impact in preserving safety and stability of human activities. Specifically, standardizations of technologies and techniques in the fields of (1) life support systems, (2) docking mechanisms, and (3) in-space refueling infrastructure can rapidly lead to more cooperative and collaborative activities that will make Outer Space safer and more viable for all.

A. *Life Support Systems*

For all its wonder, Outer Space is inherently dangerous and not naturally suitable for human life. Hence, one of the first critical areas that would benefit from standardization is life support technologies. If open standards for life support systems are widely adopted, survival rates in the event of an emergency will likely increase. By assembling life support systems on open standards and open source components, a crew in distress can avail themselves to the brightest minds around the world in creating a

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165. *See, e.g.*, discussion *infra* Section IV.C.

166. *See* Jaouhari Youssef, *To Space and Beyond with Open Source*, OPENSOURCE.COM (Oct. 19, 2019), https://red.ht/3IpE4YY (listing several open source related Outer Space projects).

rescue plan. With the information on their life support mechanisms publicly available, people across the globe can study the technology, diagnose the issue, and devise a solution to save the crew. The accessibility of such information can also bring benefits in non-emergency situations. With scientists and engineers able to perform more expansive research into life support systems, impromptu and organic collaborations about the technology are likely to occur. These joint projects can lead to modifications and enhancements to these life support systems, improving their reliability or strengthening their durability. This will not only reduce risks to safety but can also pave the way for deep space explorations with more robust crew-oriented systems.

Life support protocols designed around open standards will also prevent country-specific proprietary technologies from hindering rescue efforts. With all participants having a common framework for these systems, a vessel in distress can rely on any nearby spacecrafts—even that of a different country—for assistance. Interoperable life support systems mean that critical parts that are failing or have failed can be more easily replaced by spare components from another spacecraft. As humanity ventures deeper into Outer Space, in-space assistance from nearby spacecrafts will become even more important. In these circumstances, reliance on Earth might be infeasible with two-way communications and supply runs becoming impractical. Thus, it is highly possible that nearby, foreign space crews will be in the best position to render immediate assistance, further effectuating the Rescue Agreement.[167] With open standards ensuring that all life support systems are based on the same protocols, crews from different nations can work together in these life-or-death situations. Advantageously, open standards and open source can lay the foundation for humanity to put aside its differences and focus on its commonalities. Hence, applying open standards with open source components to life support systems can promote cooperative behaviors and make Outer Space safer for all.

B. Docking Mechanisms

To facilitate rescues in Outer Space, another technological area that open standards and open source should focus on is docking mechanisms. As a recent pandemic has shown, while virtual meetings can sustain human relationships, they cannot fully replicate face-to-face meetings.[168]

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167. *See* discussion *supra* Section I.A.

168. *See* Robert Hooijberg & Michael D. Watkins, *When Do We Really need Face-to-Face Interactions?*, HARV. BUS. R. (Jan. 4, 2021), https://bit.ly/3GL5HdA ("Face-to-face experiences inherently have the potential to generate and sustain focus. When we are physically together, it is more difficult to give in to all kinds of distractions. Group

Likewise, efforts in maintaining safety in Outer Space can benefit tremendously from in-space, face-to-face discussions among personnel from different countries. These meetings—no matter how brief—can have symbolic and practical effects, especially among rivals. For instance, amid the Cold War, the Soviet Union and the United States conducted the Apollo-Soyuz Test Project.[169] Not only was it a trial run for testing how an Outer Space rescue can be conducted with different technologies, it also represented the first multinational Outer Space mission.[170] Under this project, the United States' manned capsule, Apollo, successfully docked with the Soviet Union's manned capsule, Soyuz, and enabled citizens of different countries to physically meet in Outer Space for the very first time.[171] The literal out-of-this-world handshake between an astronaut and a cosmonaut brought a ray of hope for many across the globe; it served as "'a spark or a foot in the door that started better communications'" between two countries that were constantly on the brink of war.[172] Aside from the mission's symbolic nature, this episode proved that personnel from different nations, who are occupying the same region in Outer Space, could have face-to-face discussions to resolve differences. Through these real-time meetings, coordination can be organized, and tensions can be alleviated. Hence, the ability for different spacecrafts to dock with one another could lead to a safer environment for all.

Having uniform docking procedures can facilitate more of these Outer Space meetings. By standardizing docking mechanisms, open standards and open source can remove any country-specific or proprietary technologies that might hinder cooperative activities. While the Apollo-Soyuz Test Project proved that two completely different manned spacecrafts could dock with each other, it was only accomplished through the design, construction, and launch of a specialized docking module.[173] If the technologies had been too different or undisclosable state secrets were involved, this symbolic handshake might not have ever occurred. Open standards along with open source components can eliminate these obstacles by ensuring all spacecrafts can dock with one another without having to design, build, or launch a new component.

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dynamics operate much more effectively to reinforce focus in face-to-face interaction: It is easier for our colleagues to keep us focused and we all keep each other on task.").

169. *See* Sarah Loff, *Apollo-Soyuz Test Project Overview*, NASA (Aug. 3, 2017), https://go.nasa.gov/3IDgcRC.

170. *See id.*

171. *See id.*

172. Jim Wilson, *Apollo-Soyuz: An Orbital Partnership Begins*, NASA (Aug. 7, 2017), https://go.nasa.gov/3H0KJID.

173. *See* Charles Redmond, *The Flight of Apollo-Soyuz*, NASA (Oct. 22, 2004), https://go.nasa.gov/3qZ0VEw ("The Docking Module was designed jointly by the United States and Soviet Union, and built in the United States. Its purpose was to enable a docking between the dissimilar Soyuz spacecraft and the U.S. Apollo.").

Common docking mechanisms also become significantly important for crews on long-durational missions where the nearest human contact might not be compatriots but fellow Outer Space travelers from other countries. If an emergency rescue is necessary in these circumstances, those nearby crews will be in the best position to provide aid. However, if the docking systems are incompatible, it will be difficult for these rescuers to assist in-person even if they have the knowledge or the components needed to physically fix an issue onboard the vehicle in distress. Additionally, should there be a need for evacuation, the nearby spacecrafts will not be able to retrieve the crew in distress without exposing their own interior cabin to the vacuum of Outer Space, thereby increasing risk to their own safety. With compatible docking systems, these worries can be reduced and/or eliminated. Nearby space crews will only need to focus on the actual rescue efforts, which could already be daunting. In these circumstances, having standardized docking mechanisms and technologies will assist in such efforts and might be the difference between life or death.

C. *In-Space Refueling Infrastructure*

As explorers venture into deep space, another critical technology that will benefit from open standards and open source components is in-space refueling infrastructure. While in-space refueling is still more of a conceptual idea than one ready for implementation, funding has been pouring into this field.[174] If in-space refueling becomes a reality, it will enable scientists, designers, and engineers to better adapt to the tyranny of the rocket equation and empower humans to extend their grasps farther outwards.[175] Fuel depots can be placed in different orbits with miniature rockets servicing each with reserve fuel from Earth. Rockets and spacecrafts, once launched, can stay in Outer Space and be reused for subsequent missions. With the fuel savings,[176] each spacecraft will have

174. *See* Eric Berger, *NASA Makes a Significant Investment in On-Orbit Spacecraft Refueling*, ARS TECHNICA (Oct. 14, 2020), https://bit.ly/3G0r7D2 ("NASA has reached an agreement with 14 US companies to develop technologies that will enable future modes of exploration in space and on the surface of the Moon. NASA says the value of these awards for 'Tipping Point' technologies is more than $370 million.").

175. *See* Alex S. Li, *Defying Gravity: Taming the Rocket Equation*, #THESPACEBAR (Apr. 8, 2020), https://bit.ly/3rTOppn; *see also #237 – The Expanse*, INTERPLANETARY PODCAST, at 16:43 (May 16, 2021), https://bit.ly/3ihMRkq ("You need fuel and you need the stuff to chuck out the back and therefore if you are carrying that, you need to then have fuel to carry that, and then you need to have fuel that carries that. So something like Saturn V weighed three thousand tons on the launchpad to get fifty tons to the Moon, so barely one and a half percent of the mass of the original rocket is actually usable mass.").

176. *See id.* ("[M]ost of the delta-v needed to reach a certain point in Outer Space is expended to escape Earth's gravitational pull. For instance, while it takes 9.3 to 10 km/s to

more room to devote to substantive payloads, such as instrumentations and supplies. With their structural integrity no longer weakened by the stress and strain of multiple launches,[177] spacecrafts can also last longer. These factors will lead to longer missions in larger and more durable vessels. With Outer Space becoming more accessible for pioneers to spread out and independently explore, the risk of hostile conflicts over nearby resource-rich environments can be reduced. Less competition could also mean more collaboration, making Outer Space safer and more stable for all.

Because this subindustry is critical for unlocking farther regions of Outer Space, having a uniform in-space refueling infrastructure will be of paramount importance. With the in-space refueling industry still in its conceptual and prototype stage, this is the perfect time to incorporate open standards and open source components to streamline the technology as it develops. Through standardization, open standards and open source components can reduce dependencies on any proprietary parts. This will incentivize the international community to pick and choose the protocols and technologies that will lead to the safest and most efficient in-space refueling infrastructure. Very much like the fuel network for automobiles on Earth, this unifying infrastructure can ensure that all spacecrafts will be capable of being refueled from any space-based fuel depot. The resulting consistency will ensure safer operations with all Outer Space-based personnel trained on the same procedures. As a standardized, in-space refueling system gains efficiency through mass adoption, other ancillary refueling and 'road-side' services such as emergency assistance or maintenance and support can also develop. The rise of these cooperative activities would expand humanity's footprint in Outer Space. This could lead to other improvements that can set the stage for humanity's expansive quest to explore and chart the unknown regions of the galaxy.

V. TO ALPHA CENTUARI AND OTHER NEARBY STARS

With both commercial and governmental activities heating up in Outer Space, the need to maintain a safe and stable environment for human activities grows. While current Outer Space international laws seek to reduce risks by encouraging cooperation among different entities, these legal regimes' various shortcomings limit their effectiveness. With Outer Space becoming more populated, other solutions that can improve safety and long-term availability must be implemented.

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escape Earth's gravity, it would only take an additional 10.2 km/s to get from Low Earth Orbit to Mars.").

177. *See* Tom Benson, *Dynamic Pressure*, NASA (May 13, 2021), https://go.nasa.gov/3Ayger5 ("The Max Q condition is a design constraint on full scale rockets.").

This Article addresses this need by encouraging the application of open standards with open source components for certain critical Outer Space technologies. Specifically, these tools can incentivize the widespread standardization of critical technologies that can make Outer Space safer and more viable for all. With stability ensured and more opportunities created, more participants will enter Outer Space and make extraordinary discoveries that will further advance humanity. As the universe becomes more accessible, we will also likely become more cognizant of the fact that our differences are infinitesimally small compared to our commonalities. So, while the use of open standards and open source components can preserve safety and stability for human activities in Outer Space, it could also unite humanity to fulfill Sagan's prophecy for the better version of us to become an interstellar species.