KEEP MARS CLEAN: THE NEED FOR SPACE POLICY TO AVOID PLANETARY SPACE DEBRIS

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Space debris mitigation guidelines such as ISO 24113 of 2019[1] *and the Space Debris Mitigation Guidelines of the U.N. Committee on the Peaceful Uses of Outer Space*[2] *have recently been put in place to coordinate efforts to protect the future of space flight around Earth. However, Earth is not the only planet at risk. The current global interest in Mars puts the Red Planet's orbital environment at risk of becoming another space debris zone. This three-part article explores the costly dangers of planetary debris, highlights the gaps in current mitigation policy, and suggests preliminary ideas for future planetary debris mitigation guidelines. To conclude, this article calls for the extension of current national and international space debris mitigation guidelines to include planetary bodies beyond Earth.*

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[1] *ISO 24113:2019 Space Systems—Space Debris Mitigation Requirements*, INT'L STAND. ORG., https://www.iso.org/standard/72383.html (last visited Apr. 7, 2020) [hereinafter *ISO Requirements*].

[2] Comm. on the Peaceful Uses of Outer Space, Space Debris Mitigation Guidelines, U.N. Doc. ST/SPACE/49 (2010) [hereinafter COPUOS Guidelines].

I. INTRODUCTION

Humans have always dreamed of going to the Moon. Once this was accomplished in 1969, Mars did not seem so far away. Recent advancements in technology have brought Mars even closer with a possible manned mission as early as the 2030s.[3] However, the dream of maintaining a sustainable relationship with Mars is far from realized. In fact, the dream of Martian colonization is in jeopardy. Due to the lack of standardized operating and decommissioning policies for Martian satellites, Mars's orbital environment is at risk of being polluted with space debris.

This article presents several arguments to support new space debris mitigation guidelines for Martian missions. These arguments are then followed by an analysis of current policies and guidelines used by space agencies and international organizations, which demonstrate a lack of protection for the Martian space environment. Finally, this article makes preliminary recommendations for possible operating and decommissioning policies that could be adopted by the Inter-Agency Space Debris Coordination Committee (IADC),[4] other space debris mitigation organizations, and space agencies.

II. LOGICAL REASONING

a. Our History Shows the Challenges in Coordinating Debris Mitigation

With more than 22,000 trackable objects and 128 million undetectable objects in orbit, Earth's space debris has become a major and expensive headache.[5] Some experts fear that continued mission operations without mitigation standards or active debris removal will cause the debris density to increase and eventually lead to an unpredictable cascade of collisions, commonly called the Kessler Syndrome.[6] After this point, the debris would be so dispersed and minuscule that

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[3] NAT'L AERONAUTICS & SPACE ADMIN., NATIONAL SPACE EXPLORATION CAMPAIGN REPORT 17–18 (2019), available at https://www.nasa.gov/sites/default/files/atoms/files/nationalspaceexplorationcampaign.pdf; *but see* Jeff Foust, *Independent Report Concludes 2033 Human Mars Mission is Not Feasible,* SPACE NEWS (Apr. 18, 2019), https://spacenews.com/independent-report-concludes-2033-human-mars-mission-is-not-feasible/ (citing generally IDA SCI. & TECH. POLICY INST., EVALUATION OF A HUMAN MISSION TO MARS BY 2033 (2019)).

[4] IADC is an "international forum of national and international space agencies." Part of its efforts include "worldwide technical/scientific coordination of activities related to space debris in Earth orbit issues and provid[ing] technical recommendations." Alberto Tuozzi, *The Inter-Agency Space Debris Coordination Committee: An Overview of IDAC's Annual Activities*, INT'L COMM. ON GLOBAL NAVIGATION SATELLITE SYSTEMS (ICG), http://www.unoosa.org/documents/pdf/icg/2018/icg13/wgs/wgs_23.pdf (last visited Apr. 8, 2020).

[5] *See Space Debris by the Numbers*, EUR. SPACE AGENCY, https://www.esa.int/Our_Activities/Space_Safety/Space_Debris/Space_debris_by_the_numbers (last updated Jan. 2019).

[6] This phenomenon is first attributed to scientist Don Kessler, who posited that "random collisions between objects large enough to catalogue would produce a hazard to spacecraft from small debris that is greater than the natural meteoroid environment" Donald Kessler, *The Kessler Syndrome as*

Earth's orbital environment would sandblast and destroy satellites, and Earth's orbits would no longer be able to sustain spacecraft.[7]

Although the exact economic impact of space debris is unknown, some experts estimate that the immediate destruction due to a single collision could total up to "$30 million, with an additional $200 million in damages to all currently existing space assets."[8] Such collision events could threaten a growing multibillion-dollar industry: global satellite revenue in 2018 totaled $277.4 billion, with the wider space economy—including human spaceflight and interplanetary missions—amounting to $360 billion.[9] As more private companies enter the market, the space economy will expand to new sectors such as space tourism (projected to be a $3 billion market by 2030[10]), high speed travel ("In a decade . . . an annual market of at least $20 billion"),[11] and internet services (SpaceX's new Starlink program "could be valued at a little over $30 billion").[12] Space debris places each of these growing sectors at significant risk.

Despite this danger, coordinating efforts to reduce debris creation is complex and slow. The recent U.N. debris mitigation guidelines were the result of a protracted process which started in 1994 and only recently resulted in the General Assembly's approval in 2007.[13] The challenge of building consensus to allow for accountability and enforcement through international resolutions has left many organizations to individually decide how to reduce their own space debris footprint.[14]

Discussed by Donald J. Kessler, UNIV. OF WESTERN ONTARIO: METEOR PHYSICS GROUP (Mar. 8, 2009), http://aquarid.physics.uwo.ca/kessler/KesSym.html.

[7] *See* Steve Olson, *The Danger of Space Junk*, THE ATLANTIC (Jul. 1998), https://www.theatlantic.com/magazine/archive/1998/07/the-danger-of-space-junk/306691/ (highlighting the dangers posed by Kessler's theory to space objects).

[8] Alexander William Salter, Space Debris: A Law and Economics Analysis of the Orbital Commons 4 (Sep. 2015) (Mercatus Center Working Paper), available at https://www.mercatus.org/system/files/Salter-Space-Debris.pdf.

[9] *2019 State of the Satellite Industry Report – Two Page Summary*, SATELLITE INDUSTRY ASSOCIATION, https://sia.org/news-resources/state-of-the-satellite-industry-report/ (last visited Apr. 19, 2020).

[10] Michael Sheetz, *Super Fast Travel Using Outer Space Could be $20 Billion Market, Disrupting Airliners, UBS Predicts,* CNBC (Mar. 18, 2019, 2:50 PM), https://www.cnbc.com/2019/03/18/ubs-space-travel-and-space-tourism-a-23-billion-business-in-a-decade.html.

[11] *Id.*

[12] Trefis Team, *SpaceX's Satellite Internet Service Could Warrant a $30 Billion Valuation,* FORBES (Oct. 11, 2019, 8:57 AM), https://www.forbes.com/sites/greatspeculations/2019/10/11/spacexs-satellite-internet-service-could-warrant-a-30-billion-valuation/#7a06ca581ff8.

[13] COPUOS Guidelines, *supra* note 2, at iii–iv.

[14] The United Nations Office for Outer Space Affairs (OOSA) maintains a compendium for the various national and international debris mitigation standards. *See* U.N. OFF. FOR OUTER SPACE AFF., COMPENDIUM OF SPACE DEBRIS MITIGATION STANDARDS ADOPTED BY STATES AND INTERNATIONAL ORGANIZATIONS (Feb. 25, 2019), https://www.unoosa.org/documents/pdf/spacelaw/sd/Space_Debris_Compendium_COPUOS_25_Feb_2019p.pdf [hereinafter U.N. OOSA COMPENDIUM].

These space agencies and inter-agency organizations, such as the IADC[15] and the European Space Agency (ESA),[16] have adopted their own unique space debris guidelines and compliance procedures. While many of these guidelines share the same intent and approach, requirements vary from group to group.[17]

For example, the U.S.'s National Aeronautics and Space Administration (NASA) missions undergo several rounds of review before launch and continuous monitoring throughout the life of the spacecraft to ensure compliance with the U.S. Government Space Debris Mitigation Standard Practices.[18] NASA assigns roles and responsibilities to specific persons within a mission project to assess, verify, and report compliance.[19] As a result, any NASA mission must plan for and pass minimum requirements before launch.[20]

However, strict compliance with mitigation guidelines is not universal. The Indian Space Research Organization (ISRO) is a member of IADC and has agreed to abide by IADC's Space Debris Mitigation Guidelines,[21] which emphasize limiting in-orbit explosions and avoiding intentional destruction as mechanisms to reduce debris formation.[22] IADC's policies are similar to NASA's, but on March 27, 2019, India launched a rocket and shot down one of its own satellites in orbit.[23] This missile test created 270 pieces of debris, a number that is likely to grow as the debris field spreads.[24] The Indian missile test followed in the footsteps of IADC colleague China, who in 2007 launched its own missile to remove its aging weather satellite Fengyun-1C.[25] The impact "created an estimated 3,400 pieces of debris

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[15] *See* INTER-AGENCY SPACE DEBRIS COORDINATION COMM., IADC SPACE DEBRIS MITIGATION GUIDELINES, REVISION 1, (2007), available at https://www.unoosa.org/documents/pdf/spacelaw/sd/IADC-2002-01-IADC-Space_Debris-Guidelines-Revision1.pdf [hereinafter IADC GUIDELINES].

[16] *Mitigating Space Debris Generation,* EUR. SPACE AGENCY, https://www.esa.int/Safety_Security/Space_Debris/Mitigating_space_debris_generation (last visited Apr. 8, 2020).

[17] *See* V. Lukjashchenko et al., *The Status of Russian Debris Mitigation Standard, in* PROCEEDINGS OF THE THIRD EUROPEAN CONFERENCE ON SPACE DEBRIS (Huguette Sawaya-Lacoste ed., 2001) (comparing debris mitigation standards of various national space agencies), available at https://conference.sdo.esoc.esa.int/proceedings/sdc3/paper/9/SDC3-paper9.pdf.

[18] *See e.g.*, *Complying With OD Mitigation Requirements,* NAT'L AERONAUTICS & SPACE ADMIN. (June 26, 2018), https://sma.nasa.gov/news/articles/newsitem/2018/06/26/complying-with-od-mitigation-requirements.

[19] NAT'L AERONAUTICS & SPACE ADMIN., NPR 8715.6B, PROCEDURAL REQUIREMENTS FOR LIMITING ORBITAL DEBRIS AND EVALUATING THE METEOROID AND ORBITAL DEBRIS ENVIRONMENTS (2017) [hereinafter NASA PROCEDURAL REQUIREMENTS].

[20] *Id.* at 3.1.1–3.4.3.

[21] *See* IADC GUIDELINES, *supra* note 15, at 3.

[22] *Id.* at 8–9.

[23] Jeffrey Gettleman & Hari Kumar, *India Shot Down a Satellite, Modi Says, Shifting Balance of Power in Asia*, N.Y. TIMES (Mar. 27, 2019), https://www.nytimes.com/2019/03/27/world/asia/india-weather-satellite-missle.html.

[24] *Id.*

[25] Leonard David, *China's Anti-Satellite Test: Worrisome Debris Cloud Circles Earth*, SPACE.COM (Feb. 2, 2007), https://www.space.com/3415-china-anti-satellite-test-worrisome-debris-cloud-circles-earth.html.

that will be around for several decades before decaying" into Earth's atmosphere.[26] However, despite the extensive debris formation, India and China have faced minimal repercussions for their actions. The international community's inability to enforce compliance with the IADC guidelines allowed both countries to proceed with harmful high-debris-yielding missions without fear of reprisal.[27]

As these examples show, international coordination and enforcement of space debris mitigation policies is challenging, especially when countries, space agencies, and private companies have already developed their own standard practices through domestic processes. The formation of groups such as IADC helps facilitate international cooperation, but its 1993 inauguration came more than 30 years after mankind first began placing objects into space. By then, space agencies such as NASA had already formed their first space debris mitigation policies and the problem of Earth-centered space debris was already long underway. As the space industry looks to Mars, the international space community has an opportunity to implement space debris mitigation guidelines before the Martian debris density rises. Now is the time to start the long process to coordinate global efforts and set standards that guide international activities around Mars.

b. Tracking Martian Satellites is Hard, but Tracking Martian Debris is Almost Impossible

In addition to avoiding the same mistakes we have made on Earth, we have an interest in preventing Martian space debris formation to protect future missions. Martian satellites and debris cannot be tracked and located in the same way as Earth-based satellites and debris, and this disparity calls for new guidelines to establish corresponding procedures.

Earth-centered satellites are tracked using a network of ground-based receivers that listen for carrier signals sent by functioning satellites.[28] Even though these carrier signals are encoded, "[T]he direction and speed of [the] spacecraft [can be] measured using the Doppler shift of the signal."[29] As a result, "When a spacecraft sends a signal to Earth, any radio antenna belonging to any country that's

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[26] Saadia Pekkanen, *Why Space Debris Cleanup Might be a National Security Threat*, THE CONVERSATION (Nov. 13, 2018, 6:46 AM), https://theconversation.com/why-space-debris-cleanup-might-be-a-national-security-threat-105816.

[27] Anti-satellite testing is not a new phenomenon, and India and China are not the first countries to perform anti-satellite tests in Earth's orbital environment. In 1985, the United States destroyed its Solwind satellite with an anti-satellite test, creating several pieces of debris. Paul Glenshaw, *The First Space Ace,* AIR & SPACE MAG. (Apr. 2018), https://www.airspacemag.com/military-aviation/first-space-ace-180968349/. This test was performed before international space debris mitigation guidelines were in place. The U.S. still practices anti-satellite capabilities, with a recent test in 2008 destroying an out-of-control intelligence satellite. Ajey Lee, *The Implications of India's ASAT Test*, THE SPACE REV. (Apr. 1, 2019), https://www.thespacereview.com/article/3686/1.

[28] *NASA Space Communications and Navigation: Supporting Exploration,* NAT'L AERONAUTICS & SPACE ADMIN. (Dec. 6, 2018) https://www.nasa.gov/directorates/heo/scan/explore.

[29] Emily Lakdawalla, *Tracking Spacecraft from Earth*, THE PLANETARY SOC'Y (Dec. 2, 2008), http://www.planetary.org/blogs/emily-lakdawalla/2008/1757.html.

pointed in the right direction can at least pick up the carrier signal, which allows them to pinpoint the spacecraft's location and speed in the sky."[30] The right to monitor spacecraft this way is provided by Article X of the U.N. Outer Space Treaty, which protects the "opportunity to observe the flight of space objects."[31]

Given a satellite's position and speed, a country can predict a satellite's future position, based on solar activity and atmospheric drag.[32] Networks of ground-based radars and other sensors, known as space surveillance systems, can verify these future positions. Currently, the U.S., Russia, Japan, France, Germany, and India operate state-run networks, while some commercial companies operate private networks.[33] With each satellite's new position, space agencies update models of Earth's orbital environment and recalculate collision probabilities.[34]

Since any country can track and monitor Earth-based satellites, any country can create its own models of Earth's orbital environment and predict collisions. Space agencies are able to independently track, monitor, and verify the positions of these spacecraft because every country may access each other's satellite's positions through receiver tracking, which provides each country with sufficient information to form its own space surveillance system. As a result, the physics and laws pertaining to Earth-based satellite tracking have limited impact on inter-agency information sharing of the positions of their satellites around Earth.

Mars brings new limitations to satellite tracking. Space agencies track their Martian satellites with Earth-based radio receivers that are supersensitive to unique frequencies.[35] These unique receivers form communication networks known as deep space networks.[36] For example, NASA communicates with its Martian spacecraft using a three-part antenna network called the NASA Deep Space Network,[37] which is similar to the networks run independently by ESA, India, and China.[38]

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[30] *Id.*

[31] Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (Outer Space Treaty) art. 10, Jan. 27, 1967, 18 U.S.T. 2410, 610 U.N.T.S. 205 [hereinafter Outer Space Treaty].

[32] NAT'L RESEARCH COUNCIL, ORBITAL DEBRIS: A TECHNICAL ASSESSMENT 36 (1995) [hereinafter NAT'L RESEARCH COUNCIL ASSESSMENT].

[33] BHAVYA LAL ET AL., SCIENCE & TECH. POLICY INST., GLOBAL TRENDS IN SPACE SITUATIONAL AWARENESS (SSA) AND SPACE TRAFFIC MANAGEMENT (STM) 32–33 (2018), available at https://www.ida.org/-/media/feature/publications/g/gl/global-trends-in-space-situational-awareness-ssa-and-space-traffic-management-stm/d-9074.ashx.

[34] *See* NAT'L RESEARCH COUNCIL ASSESSMENT, *supra* note 32, at 31.

[35] *Communications with Earth*, NASA: MARS EXPLORATION PROGRAM https://mars.nasa.gov/msl/mission/communications/ (last visited Apr. 19, 2020).

[36] *Id.*

[37] *Deep Space Network*, CALIFORNIA INSTITUTE OF TECHNOLOGY JET PROPULSION LAB, https://deepspace.jpl.nasa.gov/about/ (last visited Apr. 8, 2020).

[38] *See ESA Tracking Network*, EUR. SPACE AGENCY, https://www.esa.int/About_Us/ESOC/ESOC_history/ESA_tracking_network (last visited Apr. 8, 2020); *ISRO Telemetry, Tracking and Command Network (ISTRAC)*, INDIAN SPACE RES. ORG.,

These networks are capable of receiving low-strength signals from distant spacecraft,[39] and sometimes work together to receive communications from across the solar system.[40]

Trans-national cooperation makes tracking Martian satellites easier, but when nations fail to coordinate, space agencies may find it difficult to obtain the complete dataset of operational satellites necessary to accurately model Mars's orbital environment. These models are essential for predicting and avoiding in-orbit satellite collisions. Therefore, space agencies must coordinate and share their spacecraft positions in order to accurately predict and avoid collisions with other countries' spacecraft.

Avoiding collisions will be more important than ever as eyes turn to other celestial bodies. Many space agencies and private organizations have joined NASA in the mission to explore Mars, and with renewed public attention, new Martian satellites are on the horizon.[41] In turn, the Martian orbital space has become more populated.[42] This congestion leads to a dangerously familiar problem—collisions leading to space debris formation.

Collisions generate debris, in turn increasing the risk of future collisions. On Earth, countries monitor the orbital environment and try to predict when these collisions are most probable. But errors in orbital models, uncertainty in satellite position estimates, and false positives in collision warnings reduce the reliability and efficiency of our prediction systems.[43] It is common that models maintained by different agencies predict different collision warnings and yield little consensus about the current space-traffic situation.[44] The task to predict and prevent collisions becomes even more complicated around Mars, due to limited information on the locations of satellites and debris. As a result, operators cannot avoid collisions with confidence, risking a conjunction which would create more debris and further complicate satellite navigation around Mars.

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https://www.isro.gov.in/about-isro/isro-telemetry-tracking-and-command-network-istrac (last visited Apr. 8, 2020) *China Satellite Launch and Tracking Control General (CLTC),* NUCLEAR THREAT INITIATIVE https://www.nti.org/learn/facilities/124/ (last updated Jan. 31, 2013).

[39] Nola Taylor Redd, *NASA's Deep Space Network: How Spacecraft Phone Home*, SPACE.COM (Feb. 2, 2018), https://www.space.com/39578-deep-space-network.html.

[40] *Big Dishes Band Together,* EUR. SPACE AGENCY (Aug. 25, 2017), http://www.esa.int/Enabling_Support/Operations/Estrack/Big_dishes_band_together.

[41] *See The Global Exploration Roadmap*, INT'L SPACE EXPLORATION COORDINATION GROUP (Jan. 2018), https://www.nasa.gov/sites/default/files/atoms/files/ger_2018_small_mobile.pdf.

[42] Elizabeth Howell, *A Brief History of Mars Missions*, SPACE.COM (Apr. 8, 2019), https://www.space.com/13558-historic-mars-missions.html.

[43] R.L. Wang et al., Thinking Problems of the Present Collision Warning Work by Analyzing the Intersection Between Cosmos 2251 and Iridium 33, *in* PROCEEDINGS OF THE SIXTH EUROPEAN CONFERENCE ON SPACE DEBRIS (L. Ouwehand ed., 2013), available at https://conference.sdo.esoc.esa.int/proceedings/sdc6/paper/45/SDC6-paper45.pdf.

[44] *See id.*

NASA has already seen the danger of congested skies and Martian satellite collisions. On January 3, 2015, NASA's satellite monitoring system "calculated that the Mars Atmosphere and Volatile Evolution satellite (MAVEN) and the Mars Reconnaissance Orbiter would come within about two miles of each other—far too close for comfort."[45] As a result, NASA has devoted new efforts to "set[ting] its tracking procedures before the skies get too crowded."[46]

Unfortunately, Martian debris is impossible to detect with our current technology and, therefore, is difficult to avoid. On Earth, a worldwide network of telescopes and radar tracks Earth-based space debris greater than 10 centimeters.[47] Once located, the position of each piece of debris is cataloged and monitored by several entities, such as NASA or the U.S. Department of Defense.[48] This system does not work for Mars. Our Earth-based networks, which track debris within tens of thousands of miles of Earth,[49] are not designed to detect debris around Mars, which is millions of miles away from Earth.[50] In addition, these ground-based, debris-tracking systems and debris catalogues do not exist on Mars and will continue to be absent until the required network of telescopes and radars can be installed and managed. In the meantime, there is no way of tracking Martian space debris with our current technology and thus no way of maneuvering our spacecraft to avoid collisions with existing debris.

Since collisions with Martian debris are largely unavoidable, it is important to prevent debris formation with appropriate guidelines. Despite operational guidelines to prevent in-orbit collisions, space debris can still form. Space debris can form from accidental explosions and in-orbit part release, among other causes.[51] As a result, operation guidelines that explain how to communicate satellite positions need to be coupled with guidelines that mitigate these other unintentional sources of debris formation. Guidelines that only work to prevent collisions will not be enough.

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[45] Danny Lewis, *Here's How NASA is Keeping The Satellites Around Mars From Running Into Each Other,* SMITHSONIAN MAG. (May 6, 2015), https://www.smithsonianmag.com/smart-news/mars-drawing-crowd-satellites-180955183/.

[46] *Id.*

[47] *See* NAT'L RESEARCH COUNCIL ASSESSMENT, *supra* note 32, at 34; *About Space Debris*, EUR. SPACE AGENCY, https://www.esa.int/Safety_Security/Space_Debris/About_space_debris (last visited Apr. 19, 2020).

[48] *See id.* (the U.S. Space Surveillance Network, under U.S. Strategic Command within the U.S. Department of Defense, currently catalogs about 23,000 tracked objects in orbit).

[49] "Most orbital debris reside within 1,250 miles of Earth's surface." *Frequently Asked Question: Orbital Debris*, NASA, https://www.nasa.gov/news/debris_faq.html (last visited May 9, 2020).

[50] Throughout its orbit, Mars is on average 140 million miles away from Earth. However, a Mars mission would likely occur when the two planets are closer. The closest recorded distance between the two planets was 34.8 million miles. *See* Tim Sharp, *How Far Away is Mars*, SPACE.COM (Dec. 15, 2017), https://www.space.com/16875-how-far-away-is-mars.html.

[51] *About Space Debris*, EUR. SPACE AGENCY, *supra* note 47.

c. Current Debris Removal and Decommissioning Practices Would Not Work on Mars

Since collisions perpetuate debris formation, the only way to break the path toward the Kessler Syndrome may be to clean up existing debris and remove the most dangerous pieces from orbit.[52] Yet, cleaning orbits is not an easy or cheap task. On Earth, several ideas have been proposed to actively remove space debris, including large ground-based lasers[53] and expanding foam-based systems.[54] Each idea, however, comes with its own complexities and immense expense. The company Astroscale, which aims to reduce the cost of space debris cleanup, estimates that removing one piece of space debris could cost between $100 and $500 million.[55]

However, everything is more expensive and complex on Mars. Missions like ESA's giant net may double in price since the net-like spacecraft has to leave Earth's gravity to travel to Mars, which requires a larger rocket with more fuel.[56]

To illustrate the difference in cost, one can compare the price per kilogram to send a payload into low Earth, geostationary transfer, and Martian orbit using a SpaceX Falcon 9 rocket.[57] The Falcon 9 can send one kilogram of payload to low Earth orbit for $2,719, to geostationary transfer orbit for $7,469, and to Mars for $15,422.[58] Due to the increased travel time and the amount of fuel per kilogram, before even considering other potential costs, Martian missions may cost significantly more than their Earth-centered counterparts.

Furthermore, during the months of space travel, the spacecraft is exposed to space's harsh environment and solar radiation, which may damage components

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52 *See* Kessler, *supra* note 6.

53 Emerging Technology from the arXiv, *NASA Studies Laser for Removing Space Junk*, MIT TECH. REV. (Mar. 14, 2011), https://www.technologyreview.com/s/423302/nasa-studies-laser-for-removing-space-junk/.

54 "The core idea is to develop a platform able to realize a foam ball around a target debris that enlarges its area-to-mass ratio such that the atmospheric drag can exert a significant influence to decelerate the debris." M. Andrenucci et al., *Active Removal of Space Debris: Expanding Foam Application for Active Debris Removal*, EUR. SPACE AGENCY (Feb. 21, 2011), https://www.esa.int/gsp/ACT/doc/ARI/ARI%20Study%20Report/ACT-RPT-MAD-ARI-10-6411-Pisa-Active_Removal_of_Space_Debris-Foam.pdf.

55 Saheli Roy Choudhury, *Space Junk is a Big Problem and It's Going to Get Worse,* CNBC (Sept. 18, 2018, 4:51 AM), https://www.cnbc.com/2018/09/18/wef-tianjin-space-junk-is-a-big-problem-and-its-going-to-get-worse.html.

56 *See* Brian Koberlein, *Why It Takes A Big Rocket to Reach Mars*, FORBES (Oct. 11, 2016, 10:00 AM), https://www.forbes.com/sites/briankoberlein/2016/10/11/why-it-takes-a-big-rocket-to-reach-mars/.

57 *Falcon 9*, SPACEX, https://www.spacex.com/falcon9 (last visited Apr. 19, 2020).

58 *Id.* The prices per kilogram for each orbit were based on the standard price, $62 million USD, as advertised by SpaceX for a standard Falcon 9 in April 2020. *Capabilities & Services*, SPACEX, https://www.spacex.com/about/capabilities (last visited Apr. 19, 2020).

onboard.[59] This exposure continues even when the spacecraft reaches its destination, because, unlike Earth, Mars lacks a magnetic field to protect satellites.[60] Therefore, the risk of mission failure is potentially higher for Martian missions than Earth-based ones, creating a higher risk of loss of investment. It is entirely possible that a mission to clean up Martian space debris could end with the spacecraft on the wrong trajectory and lost in space, along with potentially millions of dollars and years of development. As a result, it is easy to see why companies and governments would be reluctant to invest in Martian cleanup missions.

We could avoid the expense of cleaning up Mars if we take care of the Martian orbital environment now. The Martian environment is still clean and, if we act soon, we can protect Mars's orbits and avoid repeating the same mistakes we made on Earth—waiting more than 30 years to begin implementing space debris mitigation policies.

One potential solution is to establish international guidelines regarding decommissioning standards before the Martian environment becomes crowded. Orbital congestion limits the number of potential options to prevent space debris formation because satellites have to be configured for specific decommissioning and operation practices before they leave Earth's surface.[61] Once they have reached Mars, it may be too late to change decommissioning strategies—if there was even one planned for the satellite in the first place. Since there are no international agreements requiring a decommissioning strategy,[62] it is possible that a Martian mission is planned and launched without any intent of deorbiting at the end of the spacecraft's lifetime. As a result, Martian orbits may be filled with numerous spacecraft with a variety of decommissioning strategies, including no strategy to deorbit. Satellites that lack a deorbiting strategy contribute to space debris formation. Likewise, spacecraft with a variety of uncoordinated decommissioning strategies could lead to satellite collisions and unnecessary debris formation.

Yet, it is not enough to only implement a decommissioning strategy; we must consider the strategy's efficacy. For Mars, atmospheric entry may not be an effective strategy since the Martian atmosphere is composed of different gases and is less dense than Earth's atmosphere.[63] As a result, some common materials found

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[59] Miria M. Finckenor & Kim K. de Groh, *A Researcher's Guide to: Space Environmental Effects*, NAT'L AERONAUTICS & SPACE ADMIN. (Jul. 6, 2016), https://www.nasa.gov/sites/default/files/files/NP-2015-03-015-JSC_Space_Environment-ISS-Mini-Book-2015-508.pdf.

[60] Sarah Frazier, *Real Martians: How to Protect Astronauts from Space Radiation on Mars*, NAT'L AERONAUTICS & SPACE ADMIN. (Sep. 30, 2015), https://www.nasa.gov/feature/goddard/real-martians-how-to-protect-astronauts-from-space-radiation-on-mars (last updated Aug. 6, 2017).

[61] *See, e.g.*, *United States of America Space Debris Mitigation Standards*, UNITED NATIONS OFF. FOR OUTER SPACE AFF. (Sep. 2015), https://www.unoosa.org/documents/pdf/spacelaw/sd/United_States_of_America.pdf (U.S. agencies' policies regarding orbital debris and disposal).

[62] *See Space Law Treaties and Principles,* UNITED NATIONS OFF. FOR OUTER SPACE AFF., https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties.html (last visited May 9, 2020).

[63] Garry Hunt, *Mars: the Outstanding Physical Problems*, NEW SCIENTIST, June 24, 1976, at 712.

on spacecraft may not disintegrate upon entry like they do on Earth.[64] If these defunct spacecraft make it to Mars's surface, it will leave an impact mark, changing the geology of the Martian surface.

In addition, forming graveyard orbits may be counterproductive. Graveyarding is the practice of moving satellites at the end of their operational life to non-operational orbits to avoid future collisions.[65] Graveyard orbits are used on Earth for a small number of spacecraft, namely those that are in orbits so high that they require less fuel to ascend to a graveyard orbit than descend to reenter the atmosphere.[66] This strategy works on Earth because the majority of spacecraft launched on Earth are destined for lower orbits, meaning they will never cross paths with buried satellites.[67] The only exceptions are the few satellites escaping Earth's gravity, which will cross this higher orbit region on their way to other solar system destinations.

However, on Mars, all satellites come from higher orbits and slow down to enter lower orbits, some of which enter the atmosphere to land on the surface. Every satellite launched from Earth destined for Mars may cross a high-altitude graveyard orbit. As a result, the risk of a mission failure due to a collision with a buried satellite in the graveyard orbit may be higher on Mars than on Earth, especially as the graveyard satellite density increases with the number of Martian missions. Therefore, graveyarding might not be an effective nor suitable decommissioning strategy because it does not reduce the risk of debris formation around Mars.

Another idea for decommissioning is to escape Mars's gravity, sending the spacecraft into the solar system. This strategy has already been used for satellites close to Earth. "In 2013, ESA's astronomy satellites Planck and Herschel, which were in a Lagrange-point orbit,[68] were injected into orbits around the Sun after their missions were completed in order to avoid creating a collision threat or reentry hazard."[69] Satellites in high orbits around Mars may be able to perform similar maneuvers to place themselves in Sun-centered orbits, especially since Mars's gravity is weaker than Earth's pull.[70] However, this maneuver is not cheap. It requires a

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[64] *Five Things to Know About InSight's Mars Landing,* NAT'L AERONAUTICS & SPACE ADMIN. (Oct. 31, 2018), https://mars.nasa.gov/news/8382/five-things-to-know-about-insights-mars-landing/.
[65] *Graveyard Orbits and the Satellite Afterlife*, NAT'L. OCEANIC & ATMOSPHERIC ADMIN. (Oct. 31, 2016), https://www.nesdis.noaa.gov/content/graveyard-orbits-and-satellite-afterlife.
[66] *Id.*
[67] *Three Classes of Orbit*, NAT'L AERONAUTICS & SPACE ADMIN. https://earthobservatory.nasa.gov/features/OrbitsCatalog/page2.php. (last visited Apr. 19, 2020) ("Most scientific satellites and many weather satellites are in a nearly circular, low Earth orbit.").
[68] "A Lagrange point is a location in space where the combined gravitational forces of two large bodies, such as Earth and the sun or Earth and the moon, equal the centrifugal force felt by a much smaller third body. The interaction of the forces creates a point of equilibrium where a spacecraft may be 'parked' to make observations." Elizabeth Howell, *Lagrange Points: Parking Places in Space,* SPACE.COM (Aug. 22, 2017), https://www.space.com/30302-lagrange-points.html.
[69] *Mitigating Space Debris Generation,* EUR. SPACE AGENCY, *supra* note 16.
[70] *See* Matt Williams, *How Strong is the Gravity on Mars*, PHYS.ORG (Dec. 11, 2014), https://phys.org/news/2014-12-strong-gravity-mars.html.

significant amount of additional fuel to propel the spacecraft out of Mars's gravity.[71] As a result, the weight and the cost of the spacecraft increases.

In addition, Martian escape may not be a realistic decommissioning strategy for low Martian orbiters. These low orbiters need more fuel than high-altitude orbiters to eject themselves out of Mars's gravity due to their initial low altitude.[72] Low orbiters have to first accelerate to the same speed as the high orbiters and then continue to accelerate to escape Mars's gravity.[73] This acceleration to adequate escape velocity requires additional fuel, which increases the low orbiter's weight and cost.[74] As we've seen before, additional spacecraft weight calls for more launch fuel when the mission leaves Earth's surface—fuel to launch the fuel. Consequently, low Martian orbiters may be limited to expensive, powerful launch vehicles capable of carrying them to outer space. A more affordable option for low Martian orbiters may be to deorbit through Mars's atmosphere, which has its own set of limitations mentioned earlier.

We must determine which decommissioning practices are most effective for Martian missions in order to better protect the planet from space debris formation and to ensure the safety of future missions. Many of the strategies used on Earth would cause problems if done elsewhere without modifications to fit the new environment and could be cost prohibitive. We are at the beginning of our exploration of Mars, and there are many more missions to come with human colonization on the horizon. It would be a shame if we surround Mars with dangerous yet entirely avoidable debris and limit the future of our Martian exploration.

III. Legal Analysis

After recognizing the danger of Earth-centered space debris, the international community came together to put in place several laws and guidelines to protect Earth and mitigate debris formation. However, our space debris mitigation policies have clear gaps in applicability when it comes to Mars, even among the most experienced space agencies and international regulatory bodies.

a. Current Space Debris Guidelines are Insufficient at Preventing Martian Debris

United Nations (U.N.) member states are encouraged to voluntarily follow the U.N.'s guidelines, including those on space law—namely, the nonbinding Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of

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[71] Tom Clarke, How Feasible is a Mission to Settle Mars?, Channel 4 News (Feb. 17, 2015), https://www.channel4.com/news/by/tom-clarke/blogs/feasible-mission-settle-mars.
[72] *See id.*
[73] *See id.*
[74] Shelley Canright, *Escape Velocity: Fun and Games*, Nat'l Aeronautics & Space Admin. (Apr. 10, 2009), https://www.nasa.gov/audience/foreducators/k-4/features/F_Escape_Velocity.html.

Outer Space.[75] While these guidelines have accelerated international cooperation on reducing Earth-centered space debris, they do not protect other planetary bodies. In fact, the guidelines specifically define space debris "as all man-made objects, including fragments and elements thereof, in Earth orbit or re-entering the atmosphere, that are non-functional."[76] Given this definition of space debris, the guidelines' application statement below is limited to Earth-centered space debris:

> Member States and international organizations should voluntarily take measures, through national mechanisms or through their own applicable mechanisms, to ensure that these guidelines are implemented, to the greatest extent feasible, through space debris mitigation practices and procedures.[77]

The U.N. Space Debris Mitigation Guidelines is the only General Assembly-endorsed document pertaining to space debris mitigation.[78] Since planetary space debris mitigation is not within the scope of these guidelines, there are no U.N.-led and generally accepted international guidelines for space debris mitigation around other planets like Mars, and thus, member states are not expected to implement planetary space debris mitigation policies, such as standardizing operations and decommissioning practices for planetary satellites, and most do not.[79] At the highest level of international cooperation, there is no official and collective consideration for Mars's space debris future.

The U.N. is not the only international organization lacking planetary space debris mitigation policies. IADC's guidelines "are applicable to mission planning and the design and operation of spacecraft and orbital stages that will be injected into Earth orbit."[80] Similarly, the International Organization for Standardization (ISO) standard 24113 applies space debris mitigation requirements to "all elements of unmanned systems launched into, or passing through, near-Earth space, including launch vehicle orbital stages, operating spacecraft and any objects released as part of normal operations or disposal actions."[81] In both cases, the space debris mitigation guidelines only apply to Earth-centered debris and fail to protect against debris formation around other planets.

The lack of planetary protection also extends to space agencies. ESA does not explicitly state that its policies are bound to Earth-centered operations, but the

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75 G.A. Res. 62/217, International Cooperation in the Peaceful Uses of Outer Space, at 27–28 (Dec. 22, 2007).
76 COPUOS Guidelines, *supra* note 2, at 1.
77 *Id.* at 2.
78 *See id.* at iii.
79 *See id.* at 2–3. Of the 92 member states of the U.N. Committee on the Peaceful Uses of Outer Space, only 30 have created national debris mitigation standards. *See generally*, U.N. OOSA COMPENDIUM, *supra* note 14.
80 IADC GUIDELINES, *supra* note 15, at 5.
81 *ISO Requirements*, *supra* note 1.

scope of ESA's former Requirements on Space Debris Mitigation for ESA Projects is limited to Earth's atmosphere:

> The Requirements on Space Debris Mitigation for ESA Projects define a minimum set of requirements for the limitation of space debris, in particular in the LEO and GEO protected areas, and a minimum set of risk reduction measures in the case of re-entries of space-systems or their components into the Earth's atmosphere.[82]

ESA has since adopted the European Cooperation for Space Standardization's (ECSS) standard as the agency's standard for technical requirements on space debris mitigation.[83] The ECSS standard is itself based upon the 2019 edition of ISO 24113 "Space Systems – Space Debris Mitigation Requirements."[84] Since ISO's space debris mitigation policies only apply to Earth-centered space operations,[85] the ECSS standard and likewise ESA's space debris policy only apply to Earth-centered operations. Similarly, India, China, and Russia's national space agencies use IADC's Earth-focused space debris mitigation policy as the basis for their respective debris mitigation policies.[86]

NASA is a notable exception among major space agencies. The applicability of NASA's Procedural Requirement (NPR) for limiting orbital debris extends to both Earth-centered and other planetary activities:

> In addition to limiting generation of debris in all Earth orbits, NASA also desires to limit the generation of debris in other orbits where debris might pose a hazard to future spacecraft. Section 3 applies to Earth, Moon, or Mars or in the vicinity of Sun-Earth or Earth-Moon Lagrange Points. All missions traveling beyond Earth orbit must comply with NASA's Planetary Protection policy and requirements as described in NPD 8020.7 and NPR 8020.12. In the event of conflicts between this document and Planetary Protection requirements, the Planetary Protection requirements will take precedence.[87]

Based on a plain reading of the document, this NPR only protects orbits around these aforementioned locations, and as such, unnamed planets, space bodies, and orbits around those space bodies are not covered.

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[82] *Requirements on Space Debris Mitigation for ESA Projects*, EUR. SPACE AGENCY, http://emits.sso.esa.int/emits-doc/ESTEC/AD4RequirementsSpaceDebrisMitigationESA_Projects.pdf (last visited Apr. 19, 2020).
[83] *Mitigating Space Debris Generation,* EUR. SPACE AGENCY, *supra* note 16.
[84] *ECSS-U-AS-10C Rev. 1 - Adoption Notice of ISO 24113: Space Systems - Space Debris Mitigation Requirements*, EUR. COOPERATION FOR SPACE STANDARDIZATION (Dec. 3, 2019), https://ecss.nl/standard/ecss-u-as-10c-adoption-notice-of-iso-24113-space-systems-space-debris-mitigation-requirements-2/.
[85] *ISO Requirements*, *supra* note 1.
[86] Comm. on the Peaceful Uses of Outer Space, Rep. of the Int'l Interdisciplinary Cong. on Space Debris on its Forty-Eighth Session, U.N. Doc. A/AC.105/C.1/2011/CRP.14, at 30–32 (Feb. 3, 2011).
[87] NASA PROCEDURAL REQUIREMENTS, *supra* note 19, at P.2(C).

Nonetheless, NASA's protection of the Moon, Mars, and other non-Earth locations is unique among space agencies. NPR 8715.6B, Chapter 3.3 requires missions "around the Earth, Moon, or Mars or in the vicinity of Sun-Earth or Earth-Moon Lagrange Points" to "implement operational measures identified in the EOMP [End of Mission Plan] to limit the generation of orbital debris from and safely dispose of the spacecraft."[88] Furthermore, project managers for missions that "will fly around the Moon or Mars or in the vicinity of Sun-Earth or Earth-Moon Lagrange Points" are required to provide data which will "allow other spacecraft operators to evaluate conjunction assessments based on the most accurate data possible."[89]

Requiring operators to review and establish a plan to decommission a spacecraft addresses the need to remove spacecraft from orbit and proactively prevent space debris formation around Mars. By requiring a decommissioning plan, engineers can design end-of-life systems that include high reliability as a design specification. For example, if engineers choose to deorbit the spacecraft by reentering Mars's atmosphere, they can allocate space for deorbiting fuel, choose materials that will disintegrate during reentry, and ensure that the spacecraft goes through extensive sterilization. Spacecraft sterilization will reduce the risk of infecting the Martian surface with microbes that may exist on debris that survives reentry, in accordance to the U.N.'s Planetary Protection requirements.[90] In addition, providing data to help evaluate conjunction assessments allows NASA to accurately predict the location of its satellites and prevent collisions between them. As mentioned above, preventing in-orbit collisions is one of the main ways to prevent space debris formation.

Future guidelines to mitigate space debris formation must be implemented at a higher organizational level than individual space agencies in order to facilitate international data-sharing of satellite positions. The U.N. and other international organizations, like IADC and ISO, cultivate international cooperation and structure information flow. The U.N. Register of Objects Launched into Outer Space is an example of how international organizations facilitate data-sharing and establish international cooperation.[91] Since 1976, "States and international intergovernmental organizations that agree to abide by the Convention [on Registration of Objects Launched into Outer Space] are required to establish their own national registries

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[88] *Id.* at 3.3.1(a).
[89] *Id.* at 3.3.3(b).
[90] *Planetary Protection*, EUR. SPACE AGENCY, https://www.esa.int/Science_Exploration/Human_and_Robotic_Exploration/Exploration/ExoMars/Planetary_protection (last visited Apr. 7, 2020).
[91] *See, e.g.*, *United Nations Register of Objects Launched into Outer Space*, UNITED NATIONS OFF. FOR OUTER SPACE AFF., http://www.unoosa.org/oosa/en/spaceobjectregister/index.html (last updated Apr. 16, 2020).

and provide information on their space objects to the Secretary-General for inclusion in the United Nations Register."[92] This convention not only encourages countries to cooperate, but it has also supported information sharing for each country's space objects.[93] Neither task is easy to accomplish, especially given the sensitive nature of military spacecraft data and the independent sovereignty of each country.[94] However, the U.N. was able to accomplish both tasks by using its position as a facilitator of international agreement where countries can hold each other accountable.

International organizations can promote cooperation by facilitating satellite position sharing to ensure universal participation and by adopting planetary operation and decommissioning guidelines. Standards like NASA's NPR 8715.6B, adapted and implemented on a global scale, will encourage international cooperation to mitigate planetary space debris while a country-to-country or agency-to-agency basis may be ineffective and inflame political tensions.

b. Current International Treaties are Insufficient at Preventing Martian Debris

i. Free Use of Outer Space

The Outer Space Treaty, the foundational space law treaty, states in Article I:

> Outer space, including the Moon and other celestial bodies, shall be free for exploration and use by all States without discrimination of any kind, on the basis of equality and in accordance with international law, and there shall be free access to all areas of celestial bodies.[95]

The freedom of exploration resulting from Article I should, in theory, protect planets from man-made space debris since space debris threatens the safety of future missions to explore and therefore infringes upon other countries' right to explore.[96] However, companies and space agencies alike continue to pollute Earth's orbital environment with minimal or no consequences. One problem with current international law lies in trying to pinpoint when the space debris density would become too thick to allow continued safe space exploration, and thereafter apportioning fault for why safe travel is no longer possible. If every nation active in space contributes to space debris, then who is at fault? Is it the nation who put the last bit of

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[92] *Id.*

[93] *See Space Treaty Implementation*, UNITED NATIONS OFF. FOR OUTER SPACE AFF., https://www.unoosa.org/oosa/en/treatyimplementation/index.html (last visited Apr. 20, 2020).

[94] *See* David Axe*, When it Comes to War in Space, U.S. Has the Edge,* REUTERS (Aug. 10, 2015), http://blogs.reuters.com/great-debate/2015/08/09/the-u-s-military-is-preparing-for-the-real-star-wars/ (discussing the "New Cold" war in space and potential for weaponizing spacecraft).

[95] Outer Space Treaty, *supra* note 31, at art. 1.

[96] *See* Choudhury, *supra* note 55 ("[Space debris] accumulation in Earth's orbit has become a hindrance and can endanger future missions to the moon or Mars").

space debris that tipped the scales from safe to dangerous exploration, or is it every nation who came before and contributed to the current space debris density?

The lack of definitive rules surrounding space debris allows nations to continue creating space debris, despite Article I of the Outer Space Treaty, with little concern for the consequences of their actions. Therefore, new guidelines are needed to protect other planets from space debris in order to prevent this lack of due regard from extending further.

ii. Liability Convention

The Liability Convention, a second foundational space law treaty, puts in place international laws that also appear to protect against planetary space debris. Article III states:

> In the event of damage being caused elsewhere than on the surface of the earth to a space object of one launching State or to persons or property on board such a space object by a space object of another launching State, the latter shall be liable only if the damage is due to its fault or the fault of persons for whom it is responsible.[97]

Based upon this, it seems that launching countries would be compelled to take actions to prevent space debris formation around any planet to avoid an injured country from invoking the Liability Convention and thereby incurring liability for damage done to other states' spacecraft.

However, due to the challenges in tracing debris, the Liability Convention ineffectively disincentives companies and space agencies from creating Earth-centered space debris.[98] For example, the majority of debris are fragments less than ten centimeters in size that orbit undetected,[99] and these pieces may be too small for systems to track their location.[100] Without the ability to track the location of debris, a satellite operator would then not be able to tell if that debris caused damage to the satellite or if the satellite was simply malfunctioning. Likewise, space agencies may be unable to detect if small debris change orbital course or impact a satellite, which then limits countries' ability to detect collisions with those small debris. Because of these causation and proof limitations, it would presumably be difficult to bring a damages claim under the Liability Convention.

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[97] Convention on International Liability for Damage Caused by Space Objects (Liability Convention) art. 3, Mar. 29, 1972, 24 U.S.T. 2389, 961 U.N.T.S. 187.
[98] *See* NAT'L RESEARCH COUNCIL ASSESSMENT, *supra* note 32, at 186 ("[T]he [L]iability [C]onvention assigns liability based on ownership of the objects involved, but the origin of the vast majority of debris objects that are not cataloged cannot be determined").
[99] *Space Debris by the Numbers*, EUR. SPACE AGENCY, *supra* note 5.
[100] *About Space Debris*, EUR. SPACE AGENCY, *supra* note 47.

In addition, it is difficult to determine whose debris would be responsible without knowing the debris' location. Debris ownership is based on location because the positions of those particles can be traced back to a single source, and thus an owner. For minuscule debris, however, space agencies can only estimate regions as possible origination locations.[101] If two estimated regions associated with two different countries overlap, then it would be impossible to tell who owned the piece of debris that collided with a third-party satellite. As a result, we often cannot determine with certainty whose undetectable debris is liable for damage done to a spacecraft because of overlapping estimated regions and an inability to decisively locate small debris.

Since the systems necessary to track space debris are not currently in place on Mars,[102] we are currently unable to distinguish one country's debris from another's. For example, if several satellites exploded in Martian orbit independent of one another, it would be impossible to decisively locate the debris and determine who owns which piece. Debris fields could be predicted, but the debris may eventually intermix, which might cause further collisions and make it even harder to identify ownership. If any of the debris collides and damages a functioning satellite, the origin country of the damaged satellite may bring a claim for compensation.[103] However, which country would it bring the claim against? How can you tell whose debris committed the fault if you cannot track and catalogue the debris?

In practice, many space agencies release bolts, covers, and various other parts into orbit as a spacecraft progresses through its mission.[104] A space agency could estimate the orbital location of their released parts, but this estimate will not be able to predict the probability of conjunction with other spacecraft with high certainty, especially as the number of Martian spacecraft increases. If damage is done, an estimated part location may overlap with another agency's estimated part location, and it would be impossible to determine with certainty who is at fault.

The inability to track and catalogue debris on Mars makes the Liability Convention ineffective to persuade space agencies and companies to take actions to mitigate space debris formation away from Earth. However, international guidelines that proactively prevent the creation of space debris, such as standardizing satellite tracking, sharing orbital position, and decommissioning, could provide necessary protection to other planets.

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[101] *See* NAT'L RESEARCH COUNCIL ASSESSMENT, *supra* note 32, at 34 ("[T]he commonly reported minimum trackable size has been 10 cm in diameter.").
[102] See *supra* Part III(2).
[103] Luke Punnakanta, Note, *Space Torts: Applying Nuisance and Negligence to Orbital Debris*, 86 S. CAL. L. REV 163, 177 (2012).
[104] *Id.* at 165–66.

IV. POTENTIAL GUIDELINES

After exploring the rationale supporting new guidelines for preventing orbital debris on Mars, we should consider what those new guidelines should be; NASA's NPR 8715.6B provides a helpful starting place. My first proposal is to extend current space agency and international organization space debris mitigation guidelines to include other planetary bodies, specifically Mars. This extension can be accomplished by modifying the applicability or scope of these policies. For example, current guidelines implemented by NASA, ESA, and Roscosmos already require Earth-centric spacecraft to deplete their stored energy before decommissioning.[105] An extension of these guidelines to include spacecraft headed to other planets would help mitigate in-orbit explosion risks and provide basic protection against rapid debris formation.

Likewise, policies that require missions to justify their use of released parts in-orbit could be extended to apply to missions headed to other planets. Many space agencies already have systems in place to review and revise mission plans.[106] It would not be burdensome to include debris mitigation reviews for missions targeting key planetary bodies. This process of justifying in-orbit part releases may find unnecessary or avoidable releases and encourage mission engineers to find alternative solutions. In effect, missions operate more contentious of space debris formation, and minimize the number of parts released into orbit.

a. Decommissioning Strategies

Some of the current guidelines will require adjustment to fit the challenges of operating around Mars. Decommissioning strategies used around Earth may not be as effective around Mars. As a result, international space debris organizations need to allocate resources to determine acceptable decommissioning strategies for Mars and the conditions under which a particular strategy should be used. These conditions could include a satellite's composition, operating altitude, and reliability.

Martian decommissioning policies could specify which materials should not be used to build satellites that decommission via atmospheric entry. As previously mentioned, Mars has a thinner atmosphere than Earth and therefore atmospheric reentry may not be an acceptable decommissioning strategy for materials capable of surviving entry.[107]

Some decommissioning strategies could be better suited for satellites at certain altitudes. Planetary gravity escape may be best suited for high-altitude satellites

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[105] Int'l Acad. Astronautics, *Position Paper Space Debris Mitigation: Implementing Zero Debris Creation Zones*, at 5, ESA SP-1301 (Oct. 15, 2005), available at http://www.esa.int/esapub/sp/sp1301/sp1301.pdf.
[106] *See id.* at 55.
[107] *See supra* Part III(3).

while atmospheric entry is better for low-altitude spacecraft. High-altitude graveyarding may not be a suitable strategy, given that Martian satellites reach the planet from Earth, entering high orbits and slowing down to reach lower orbits. As a result, operational satellites may cross paths with a high-altitude graveyard. One potential solution is to form a low-altitude graveyard. Satellites orbiting Mars at higher altitudes than the graveyard orbit would never cross paths with dead spacecraft. Only satellites intending to operate lower than the graveyard or enter Martian atmosphere have the potential to encounter debris in the graveyard. This risk could be mitigated if a graveyard orbit that least interferes with preferable entry trajectories is chosen. Martian decommissioning policies could recommend what altitudes and inclinations define suitable graveyard orbits.

In addition, policies should mandate decommissioning by a certain deadline. Around Earth, NASA, ESA, and the German and Japanese national space agencies have adopted requirements for low Earth orbit (LEO) satellites to deorbit within 25 years of completing their missions (commonly referred to as the "25 Year Rule").[108] Martian decommissioning policies should include a similar timeline requirement to ensure room is made for future satellites in a timely manner. The limit may be adjusted to fit the needs and capabilities of Martian satellites.

Once space debris organizations have an idea of what decommissioning strategy to use and a potential deadline, they must ensure that satellites are able to perform decommissioning maneuvers. The journey to Mars takes between 150 to 300 days, during which time a satellite is exposed to harsh conditions.[109] Since it is not uncommon for components to fail during this travel, policies should recommend minimum levels of equipment redundancy so that Martian satellites can overcome any potential component failure and still decommission successfully.

In addition, decommissioning policies should still permit adaptability to suit mission needs. Martian decommissioning policies may require several implementations to account for different missions and operating environments. Each mission can weigh its decommissioning options—including atmospheric entry, graveyarding, and planetary gravity escape—choose one, and prove to an overseeing body that their choice complies with debris mitigation policies. This strategy is already

[108] J.C. Liou, Chief Scientist for Orbital Debris, National Aeronautics and Space Administration, *Orbital Debris Briefing,* NAT'L AERONAUTICS & SPACE ADMIN. (Dec. 2017), available at https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20170011662.pdf.

[109] *See* Fraser Cain, *How Long Does it Take to Get to Mars?*, UNIVERSE TODAY (May 9, 2013), https://www.universetoday.com/14841/how-long-does-it-take-to-get-to-mars/; Jennifer Chu, *Space Weather's Effects on Satellites*, MIT NEWS (Sep. 17, 2013), http://news.mit.edu/2013/space-weather-effects-on-satellites-0917.

used by many space agencies, including NASA[110] and ESA,[111] to review a mission's compliance with space debris mitigation policies. These reviews could be extended to consider decommissioning strategies for satellites operating around other planets, including Mars. While what constitutes best practices on Mars needs to be determined and will vary from what constitutes best practices on Earth, extending the current guidelines will initiate this conversation.

b. Satellite Position Sharing

Finally, guidelines will have to be created to standardize and encourage satellite position sharing. Martian satellite operators require full situational awareness when operating around Mars. To achieve this transparency, stakeholders should come together to form an international database which stores Martian satellite position information. International space debris organizations can maintain this database and set policies that incentivize countries and space agencies to share their satellite positions. A space agency could upload a current position of their satellite, allowing other agencies to download the data and update their orbital models. In return, other agencies could upload their satellite positions and inform others of the location of their satellites. This sharing of information will help operators make more informed decisions and better avoid collisions with operational satellites.

Policies that structure this satellite position sharing database will have to address the flow of communication between countries. Questions that should shape these guidelines include:

1. How frequently will agencies be updated on the positions of spacecraft around other planetary bodies? What type of information on a satellite's orbits will be shared?
2. What type of procedure would ensure that other agencies are notified of trajectory or altitude adjustment maneuvers?
3. If an agency detects a collision, who will be responsible for notifying other agencies of conjunction probabilities?

Countries should notify one another of satellite maneuvers through this database platform in a timely manner, so that others may have time to update their models and adjust their satellites or planned maneuvers accordingly. Planned maneuvers should be shared with the international database a few days before implementation. This early warning would give others time to confirm that the maneuver would not result in a collision with another satellite and allow for operators to make adjustments. Maneuvers, like atmospheric entry burns, can change a satellite's altitude

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[110] NAT'L AERONAUTICS & SPACE ADMIN., NASA-Handbook 8719.14, HANDBOOK FOR LIMITING ORBITAL DEBRIS (2008), available at https://explorers.larc.nasa.gov/APMIDEX2016/MO/pdf_files/NHBK871914.pdf.

[111] *Active Debris Removal*, EUR. SPACE AGENCY, https://www.esa.int/Safety_Security/Space_Debris/Active_debris_removal (last visited Apr. 20, 2020).

and cross the paths of other satellites. It may be best to schedule these maneuvers so that other maneuvers and orbiting satellites do not interfere.

In addition, space agencies should confirm the status of satellites after a maneuver. This update can be done by uploading a new satellite position to the international database. Agencies should disclose full information on a satellite's position around another planet, such as the seven elements needed to define an orbit, known as the Kepler elements.[112] With this clearly-defined position, other satellite operators can understand this new location, which may be different than the planned location, and adjust accordingly.

Finally, agencies should notify each other immediately of collision probabilities. The international database could house each agencies' collision probabilities in addition to the positions of satellites. With this open information source, agencies can be immediately warned when others believe a collision is probable and also verify the warning with predictions from other agencies. Conjunction analysis around Mars could reach a new level of confidence with this shared information source and new potential to verify predictions.

V. CONCLUSION

We have a duty to protect planets from human-made space debris for the benefit of science, exploration, and mankind. Unlike Earth, Mars has a chance to have a clean orbit, which would pave the way for long-term, sustainable Martian exploration. In fact, Martian colonization depends upon our ability to mitigate Martian space debris formation. Adopting new guidelines to protect Mars and other planets may be a small change to Earth-based activities, but for future missions it makes all the difference. We can accomplish this task by extending current guidelines to include missions headed to other planets and implementing a small number of specification requirements for those planets. It is time to call upon both national and international stakeholders to begin the process of policy change to protect planets from space debris formation through revised guidelines.

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[112] *Keplerian Elements Tutorial,* RADIO AMATEUR SATELLITE CORP., https://www.amsat.org/keplerian-elements-tutorial/ (last visited Apr. 20, 2020).