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Roundtable Outcomes Report

Space Sustainability

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University of Colorado Law School

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In Gratitude

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1

[1] Image credit: Peter Tenhula

Contents

I. Introduction

On June 28, 2024, Silicon Flatirons convened a roundtable discussion titled "Space Sustainability." The day-long event asked a diverse group to explore issues related to the sustainability of space as a resource for mankind.

The Space Sustainability Roundtable highlighted an uncomfortable insight. Space commercialization activities are increasing at – quite literally – exponential growth rates. Yet space law and policy today is ill-equipped to answer many crucial, pressing questions. Rapid growth in the space industry puts several values about use of resources in conflict. In an ideal world, information collection and thoughtful analysis would produce smart policy. In reality, regulatory efforts are stymied by uncertainty about international treaties, patchwork jurisdiction over space matters by administrative bodies in the United States, and challenges arising from the dual commercial and military uses of space systems. International and domestic space regulation, as described in this report, is surprisingly underdeveloped at a time when many issues demand attention.

In theory, space is infinite. In practice, it is not. The technical and physical limitations of the environment necessarily funnel space missions into a handful of orbital regimes and spectrum bands. As barriers to entry continue to fall, the competition for these limited resources increases congestion and the risk of interference. The advent of cheap and repeatable space launch provides a major first-mover advantage to commercial operators intending to capitalize on proliferated "mega constellations" (i.e., networks consisting of many satellites launched by the same provider, often in low earth orbit) or other emerging space-based applications. The economies of scale are a boon to the entrants' business cases. But these uses may unreasonably burden other stakeholder groups. To proceed blindly without intelligent operational regulations could limit, and even foreclose, the continued use of space for other valuable activities. The global community should weigh tradeoffs about how to use space resources. This is necessary to develop protections to anticipate and prevent pernicious effects and, moreover, develop policies that serve the public good.

NASA defines space sustainability as "the ability to maintain the conduct of space activities indefinitely into the future in a manner that is safe, peaceful, and responsible to meet the needs of the present generations while preserving the outer space environment for future activities and limiting harm to terrestrial life."[2] To achieve this vision, policy-makers and the relevant stakeholder communities (e.g., defense, science, industry, …) must develop mechanisms to arbitrate the conflicts associated with multiple, perhaps conflicting, uses of space. This means engaging in difficult conversations about resource management and enforcement, as well as confronting the current shortcomings of established regulatory schemes.

The Silicon Flatirons Center, by hosting the Space Sustainability Roundtable, brought together private voices, academics, public interest representatives, policy makers, and

[2] *NASA's Space Sustainability Strategy, Volume 1: Earth Orbit*, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (Mar. 23, 2024), https://www.nasa.gov/wp-content/uploads/2024/04/nasa-space-sustainability-strategy-march-20-2024-tagged3.pdf

government agencies to have a true shoulder-to-shoulder conversation addressing the sustainability of operations, and the conflict between scientific missions and advancing technologies. The event counted engineers, technologists, lawyers, and business voices among its participants – enhancing the depth of discussion to cover the various disparate interests in the space environment.

Key Findings and Recommendations

The roundtable identified multiple issues that should be considered in a future conference, with the intent being to inform stakeholders and regulators on both the necessity for standards and regulation and the potential consequences of failing to act. These issues include:

- **Integrating Economists**
  - How can the scientific community leverage resource economists to articulate the value of astronomy?
- **Reforming Space Governance**
  - What are the immediate next steps required, and which is the correct agency, to develop a centralized and trustworthy space domain awareness capability?
  - What role should multilateral organizations including UN agencies play in coordinating international space governance?
  - What reforms are necessary to update the current space governance models?
  - What does it mean to write "technology-neutral" policy? Have we seen this work in other industries? Are there risks of being too ambiguous that may lead to loopholes or issues of insufficient notice?
  - Considering communication barriers between nations, what is the best approach to addressing differing cultural interpretations of international treaties and regulations to acquire a broad and consistent understanding?
- **Space Sustainability**
  - What enforcement regime is desired for regulating space sustainability, should this be a sovereign capability or an international framework? What fora exist or should be established to resolve and arbitrate conflicting uses of space?
  - How can incentivizing industry be balanced with resisting agency capture? Are penalties or rewards more efficient at promoting sustainability goals? What does industry "want" from federal regulators
- **Striking the Balance Among Diverse Space Activities**
  - How can the international space community agree upon the appropriate tradeoff between space activities that appear mutually exclusive? For example, the increasing the number of satellites in low earth orbit improves communications to the detriment of quiet skies for radio astronomy.
  - What type of regulatory benefits should these spectrum licenses entail? Is a bond program appropriate to ensure safety of flight? What would it take to operationalize the NSF's NRDZ efforts within a regulatory agency?

- **Space Safety**
  - What is the carrying capacity of space, and at what point does overcrowding become detrimental to scientific and commercial satellites?
  - What is the role of emerging technologies in improving space safety and managing the increasing density of satellites in orbit.
  - What is the potential for commercial opportunities in space object tracking and measurement and how could third-party databases improve collision avoidance and space traffic management? How can third-party entities take a more significant role in space object collision avoidance, and what infrastructure and investments are required to make this feasible?
- **Environmental Impacts**
  - What environmental impact do space launches have on the stratosphere and mesosphere, and how can these impacts be mitigated? What new technologies or innovations could reduce the environmental impact of space launches?
- **Best Practices and Standards**
  - Can updating satellite licensing protocols to include maneuverability and safety standards account for emerging risks in higher orbits? How should licensing requirements evolve for satellites?
  - What barriers exist to establishing shared best practices and common operational standards?
- **Enforcement**
  - Where is the appropriate starting point for measuring damages in space, both in terms of responsibility and measurement methodology?
  - In the interest of increased accountability, what are the specific detriments of current monitoring practices of space activities, and how can the international community move forward with adequate monitoring?

The roundtable addressed four main topic areas, each of which is discussed in a separate section of the report: Resolving Interference with Scientific Applications; Space Resource Management; Licensing and Regulation for Future Technologies; and Enforcement in Space. The report steps through each topic area and notes key findings and recommendations, summarized above, that will serve as the basis for a future conference. Ultimately, the goal is to provide decision makers and industry leaders with actionable insight to help shape future space policy efforts.

II. Session 1: Resolving Interference with Scientific Applications

Framer – Albin Gasiewski

Albin "Al" Gasiewski, Ph.D., Professor of Electrical and Computer Engineering at the University of Colorado at Boulder kicked off the first session by framing the discussion and emphasizing that both the space and spectrum environments are shared resources. Sharing such resources is difficult. Sharing access to a resource that is scarce is even more challenging. Add in a diverse, and often adverse, group of stakeholders and the task becomes prodigious. Unfortunately, when it comes to space, sharing a scarce resource is the operational reality. When discussing space resource utilization, Al employed the public well metaphor: many townspeople relying on water from a single source. Place no restrictions on the well and risk too many people accessing the well with no regard for their neighbors. Conflicts emerge and the resource becomes overused and thus "poisoned." Manage or restrict access to the resource, limit the resource, and earn enmity. But at bottom, the goal is to avoid poisoning this public resource for future generations. This same goal applies to space access and utilization, and this section focuses specifically on protecting important scientific applications like optical and radio astronomy and remote sensing.

Not long ago we had no man-made objects in orbit. Few people beyond the scientific and military communities would have looked skyward with any sense of how important those orbits would become. Then the First Space Race kicked off with the successful launch of Sputnik, and the world took notice. The advancements in technology that followed would enable previously inconceivable global communications and Earth observation. These new satellites were launched at a critical time in the development of our global society. For the first time, countries could attempt to preserve stability by observing other sovereigns – massive amounts of newly available information affected the behavior of global actors. The importance of space during the Cold War indicated a new era where modern innovations could impact the natural and political environment in significant ways.

The goal is to avoid poisoning this public resource for future generations.

With the newfound appreciation for space as a domain in which to project power, more interested parties (primarily nation-state actors) began to enter the field. Fast forward to the modern age and the global community is challenged with managing the congestion problem to prevent space from devolving into a tragedy of the commons. Problems of the commons arise in situations where unrestricted access to a resource incentivizes overconsumption due to the lack of any guarantees that other users will not do the same. Actors then enter a perverse economic race to the bottom as they behave individually rational in the short term (squeezing as much value out of the resource as possible) yet collectively disastrous in the long run (completely exhausting the resource). Merely knowing the risks is insufficient to combat the tragedy of the commons. Rather, stakeholders must strive to overcome collective action

challenges and work to manage the situation as a common pooled resource controlled by community norms or external regulations. In the space context, poisoning of the public well by overutilization can occur either by physical collisions or by radio frequency interference (RFI).

For physical conjunctions – the risk of two satellites crashing into each other – the doomsday scenario involves the intrinsic problem of managing space traffic in a highly congested domain. Eventually, when certain orbits are nearing their true carrying capacity, one debris-generating collision could lead to a domino effect of similar collisions, ultimately making the orbit – and possibly nearby orbits - unusable and potentially impassable. This phenomenon is known as the Kessler Syndrome. It was only recently that stakeholders began advocating for the use of sustainable practices for launch and disposal operations. For most of our common history, defunct space objects and spent hardware were permitted to remain in orbit. Some of those old rocket bodies have led to the exact type of collision that the community would hope to prevent, with many reports of old Russian communications satellites making the news recently due to their impact on the International Space Station after being used as targets for anti-satellite missile testing.[3]

Just as important, but perhaps underappreciated by the public, is the impact that the proliferation of satellites has on the radio frequency (RF) spectrum. Harmful interference occurs when a receiver becomes saturated with other signals it was not intended to hear. When this happens to a satellite in orbit, or to a radio telescope on Earth, users are unable to receive the necessary data. Space assets offer zero value if we cannot communicate with them. Consequently, regulating the RF spectrum becomes incredibly important as we continue to launch more and more objects lest we function-kill our space capabilities. The data generated by space platforms has utility beyond the borders of the few countries from which they are launched. As the spacefaring community works to draft regulations and policy, it must remember that developed countries are not the only stakeholders – all parties can benefit from space exploitation and deserve their fair share of space.

If the space environment was not challenging enough, there exists the looming issue of *how* to regulate it. Since the value of space for the global community was already widely accepted, the roundtable's discussion focused on the mechanisms necessary to preserve that value. The participants' opening discussion recommended: (1) simple access restrictions for both the physical and spectral environments; (2) the need to communicate the value proposition for scientific missions; and (3) the need to understand the relative costs and benefits between domestic and international regulation. The aim for each of these lines of effort was clear: avoid poisoning the public well.

[3] Idrees Ali & Steve Gorman, *Russian Anti-satellite Missile Test Endangers Space Station Crew – NASA*, REUTERS (Nov. 16, 2021, 8:45 AM MST), https://www.reuters.com/world/us-military-reports-debris-generating-event-outer-space-2021-11-15/.

Framer – Chris Anderson

Chris Anderson, Ph.D., P.E., stepped to the podium to put a finer point on the future coexistence issues that are implicated by the "coming tidal wave of spectrum demand." Chris is the Theory Division Chief at the National Telecommunications Information Administration's (NTIA) Institute for Telecommunication Sciences (ITS) where he specializes in wireless communications, propagation measurements and modeling, and software-defined radio technology. He is also one of the co-organizers of the National Science Foundation's (NSF) funded National Radio Dynamic Zone (NRDZ) workshop series effort to explore expanding dynamic spectrum sharing technologies to maximize the use of RF spectrum.

[There is] a coming tidal wave of spectrum demand.

Chris began his comments by noting that all current projections, though estimates, forecast a near-exponential spike in demand for space access, platforms, and capabilities. Excepting specific allocations for space-to-Earth communications, historical spectrum use in support of these missions was non-allocated (operators did not require licenses for use), but the changing environment demanded a new solution. Today, there are rules in place to ensure operators are "staying in their lane" with respect to radio frequency bands. When seeking licenses, the regulator assigns each platform a given portion of the RF spectrum in which they can operate, effective only in the orbital slot defined in their license. To use the regulatory terms, an "allocation" reserves a portion of the RF spectrum for a particular use, for example broadcast television. An "assignment" is an operating license granted to a specific entity to utilize a portion of that allocation, subject to certain restrictions. This management framework helps mitigate the risks of harmful interference, but again, innovations and expansion may demand additional problem-solving. Service overlaps and congestion are inevitable in highly desirable spectrum bands and orbits, especially for remote sensing and communications missions.

Though much attention is being paid to the current efforts to expand terrestrial mobile broadband connectivity via satellites (known as Supplemental Coverage from Space, or SCS), we must not overlook the importance of such legacy applications like weather monitoring, remote sensing, optical astronomy, and radio astronomy. Each of these services provides critical value, by the generation of data that, through analysis, becomes actionable information. What is difficult, however, is quantifying this value in monetary terms and defining why the data matters in cases where the societal benefit may be difficult to establish. The community has an even harder task to quantify the impact of *inaccurate* and *untimely* data – the main risks associated with a congested environment. Without the necessary value proposition, stakeholders encounter headwinds when advocating for traditionally non-economic missions, though their impact on day-to-day life may be immense.

Chris then went deeper into the technical challenge of RFI. He reminded the participants that harmful interference is inherently a receiver sensitivity issue. Scientific missions experience perturbations from other signal sources primarily because, out of necessity, the receivers must be able to hear very, very (very) quiet signals. As a result, out-of-band emissions (OOBE) – those emissions inadvertently propagating through

the receiver's band – frustrate the radio telescope's ability to collect unadulterated data. The SCS effort, mentioned above, is but one example of many demonstrating how orbital radiators impact science. Because these telescopes are several orders of magnitude more sensitive than other systems, they have an inherently different technological posture than the "active" community. By "active," we mean those systems that transmit radio signals. In contrast, radio telescopes are large "passive" sensors, designed to listen rather than transmit. Active transceivers typically involve more resilient designs, using filters or internal amplifiers to limit the impact of harmful interference. Unfortunately, the nature of the scientific work forecloses the use of similar technologies in the radio astronomy context. By adding filters to a radio telescope, scientists would blind themselves to much of the data they are searching for.

Though the risk to these missions have been communicated, to date, many promises of non-interference have gone unfulfilled. Though many orbital operators work to minimize scientific impact, interference from satellites remains a significant concern. Chris highlighted trust as a key issue. Any success in resolving tensions among stakeholders begins from a place of trust and respect. Resource management in space, implicating both orbital parking spots and spectrum operating licenses, is handled by various national and international organizations (see Section 3 of this report). One of these entities, the World Radiocommunication Conferences (WRC), is planning many agenda items on the subject of trust in management for its 2027 event. Specifically, the gathering community will confront RFI protections for radio observatories as well as ideate on the new frameworks proposed for SCS and emerging mobile service applications. Though it is encouraging to see these issues make the agenda, much work remains to be done before the community develops credible solutions. Recall the risk highlighted by Al Gasiewski: myopic regulations and conduct could poison the public well for good.

To date, many promises of non-interference have gone unfulfilled.

Discussion

Resolving RF Interference with Scientific Applications ("Loud Skies")

Roundtable participants confronted the issue of how to effectively manage increasing spectrum demand in space and how the increase in satellite numbers in all orbits will heighten the risk of harmful interference. For the purposes of this report, this issue will be termed the "loud skies" problem as a nod to the increased amount of noise in the ambient RF environment as the number of transmitters increases. Identified by a participant earlier, but now explicitly discussed as a group, was the clear need to measure and articulate the economic value of remote sensing and radio astronomy. As a non-commercial use of spectrum, resource economists must be engaged to help define the societal value of these efforts in terms that capture the benefits beyond bottom-line dollars. From this starting point, discourse among stakeholders may begin on firmer footing, each party understanding the relative value of missions in the trade space.

[T]he current lack of a common definition for "spectrum efficiency" hampers progress.

This, unfortunately, is missing from today's conversations; science is often neglected in deference to commercial applications. Defining mission value in economic terms enables parties to outline what the art of the possible is for sharing regimes that leverage new and emerging technologies. Understanding opportunity costs enables the stakeholder community to make decisions about competing or adverse spectrum uses. Additionally, the current lack of a common definition for "spectrum efficiency" hampers progress. Balanced argument rests on a shared understanding of the services and technical rules that should be prioritized – so far, these conversations are siloed in the commercial context rather than including scientific applications.

Scientific representatives are usually not involved in discussions on sharing. One participant compared their struggle to that of being trapped inside of a house in which the only means of observing the universe are the windows. Due to the proliferation of satellites and their signal pollution, these "windows" are being covered up one-by-one, limiting the ability of future scientists to conduct research. This then begs the question, what is the value of preserving these windows? Many attendees agreed that more stewardship and education on behalf of radio astronomy is required since the primary sensitivity issues manifest in two distinct ways. First, there is the well-known issue of polluting the spectrum with undesired signals and spoiling the data. And second, there is the issue of causing hardware damage to these systems because of high-energy radiation. Heightened receiver sensitivity means it does not take much to damage internal components. There may be avenues available to improve the durability and resiliency of these sensors, but they demand significant resource investments to achieve. As such, the community hopes policy and regulatory measures can fill the gap.

Potential Solutions to the Loud Skies Issue

Throughout the discussion, many options emerged as potential permanent or temporary solutions. Perhaps the most ambitious suggestion from a participant was to locate sensitive scientific missions like radio astronomy off-planet. This would see the sensors placed in areas like the shielded zone of the moon (SZM) and the LaGrange points. Though attractive due to the quiet spectrum environment, challenges arise in terms of technical architecture and costs. Additionally, though ideal today, there is no telling how congested these non-terrestrial locations may become in the future as the space economy expands. Regardless, there is true merit in exploring these options further to define the system requirements necessary to achieve the desired ends. At the very least, the conversation around non-terrestrial sensor sites would further engage stakeholders to address the issue of resolving interference with scientific applications.

The next concrete option, though an interim step in many ways, is no less important: define objective measures of spectrum value in space. One participant offered two satellite systems that could serve as useful case studies. First, there are the weather monitoring constellations that provide real-time data and constant global observation to feed forecasts. These platforms inform such critical decisions as coastal evacuation and recovery planning for hurricanes. They also enable us to accurately predict weather five to seven days in advance. The economic impact of losing this data could be shocking to not only industry, but society as a whole. Second, there are the

constellations that monitor the atmosphere in support of climate change mitigation. Because even a perfect sensor produces imperfect data in a degraded environment, it is imperative that we limit harmful interference from perturbing these missions. These space-based sensors, tasked with monitoring atmospheric temperatures, could potentially lead to a $10 billion impact for every 10 millikelvin temperature inaccuracy. If that figure is valid, the need to protect these systems becomes very apparent. But only through economic valuation does the scope of the problem become apparent to every stakeholder.

The economic impact of losing this data could be shocking to not only industry, but society as a whole.

Finally, the last option centered on grounding the entirety of the spectrum demand problem in the Coase Theorem, in terms of transaction costs. Under this framework, the goal is to maximize economic output rather than to minimize harmful interference. In space, the two main options are command-and-control and market forces. In a command-and-control system, the Government dictates how entities may use portions of the RF spectrum, including where and when. Under market forces, however, the use of these bands is essentially unrestricted, and the Government takes a more hands-off approach. The idea being that market participants will default to the use that is most economically prosperous and offers the most utility for consumers. There are positives and negatives about both that will need to be appropriately weighed prior to implementation of either. For example, a market approach allows for flexibility, enabling the rapid adoption of new technologies by allowing for low-friction transactions. However, traditionally non-economic uses like astronomy may be marginalized due to the lack of revenue generation. Situations like this highlight the value that a command-and-control model brings to the table, protecting these missions despite the relatively low economic benefits.

Challenges Associated with Loud Skies Solutions

Every opportunity worth exploring has challenges. Most notably are the challenges that we cannot yet fully appreciate due to imperfect information. As an example, as scientific data becomes more difficult to acquire and consequently less voluminous, the need for a large expert workforce will wane. Jobs will be lost, and employees let go. It is currently unknown what impact such an exodus may have on the pace of scientific advancement or the communities these discoveries benefit. Another unknown is whether the spectrum management model currently employed by the Federal Communications Commission (FCC) is appropriate for the space environment. For now, the community works within this existing framework, but it remains an open question whether the aspects of the space environment that make it uniquely challenging technologically will pose similar issues when attempting to regulate RF. Note, the FCC's authority, although broad, does not provide a guaranteed global framework. Foreign actors, either nation-states or private companies, are not required to respect the Commission's rules unless they are attempting to access U.S. markets and therefore directly seeking a license.

Deeper questions exist around coordination in general. What makes organizing the space environment in such a way as to limit harmful interference so difficult? A few key

reasons were offered by the participants. First, the ability to coordinate requires the ability to resource the coordination effort. Absent appropriate funding, many actors cannot afford to take their seat at the table, and one cannot be a good coordination partner if they are unable to participate in the conversation.

Second, the "aggregate interference" we are seeing emanate from large constellations is unprecedented. Aggregate interference refers to the combined effects of multiple radiators acting throughout the environment – harmless on their own but potentially devastating when taken together. This problem reaches beyond the typical licensing focus on resolving interference between operators in a given frequency band and encompasses the effects in adjacent bands that may occur even if an operator is in compliance with license requirements. Think of the classic cocktail party analogy. Even if we are all speaking quietly at first, because the room eventually becomes crowded, we all end up screaming at our conversation partner just to cut through the noise. The same problem occurs in orbit. Even if every satellite is abiding by its spectrum license, the sheer number of active radiators can result in the noise floor going way up.

[T]he "aggregate interference" we are seeing emanate from proliferated mega constellations is unprecedented.

Third, the International Telecommunications Union (ITU) regulations are in some instances treated as guidelines rather than enforceable operating requirements. The ITU is chartered as a multinational platform to broker international agreements and standards, not to levy enforceable regulations. As such, compliance issues continuously spring up in the geosynchronous region of Earth's orbit. Under the ITU's policy, operators may drift out of their assigned parking spot for certain operational reasons – no penalty will result, other than potentially the absence of international recognition and interference protection for the related radiofrequency operations. Note, however, that this is not uniformly the case for licenses granted under national authority, such as the FCC's. In the United States, satellite operators may face enforcement actions for operations outside their assigned parking spots. These penalties range from monetary fines to license revocation.

Resolving Optical Interference with Scientific Applications ("Dark Skies")

With these bright skies comes a dark future for optical astronomy and, potentially, the human spirit.

With proliferated constellations comes a concomitant increase in orbital light pollution. With these bright skies comes a dark future for optical astronomy and, potentially, the human spirit. In this report, the term "Dark Skies" captures the optical counterpoint to the spectrum management "Loud Skies" issue. The same way an abundance of satellites firing off radio waves pollutes the spectrum environment, numerous satellites in the sky, reflecting the sun's rays, creates bright objects in Earth's orbit that disrupts many terrestrial stakeholders. As mentioned previously, the number of operational satellites is increasing at an exponential rate. Observation of SpaceX's recent Starlink deployments illustrates the light pollution issue. Just after dusk, the sun illuminates these satellites while the observer is shielded in Earth's shadow. From this vantage point, the satellites appear as bright spots streaking across the night sky. Unfortunately, optical astronomy sites need "dark sky" conditions to effectively collect their scientific data. See Figure 1 for an example of what the spoiled data looks like from the scientists' perspective.[4] The challenge to reduce visibility of a spacecraft is relatively new to satellite manufacturing technology. The silver lining to it all, is that U.S. LEO constellation operators are taking steps to address reflectivity concerns. The satellite industry has pursued and trialed several initial design modifications and operational approaches with some success in mitigating the effects. The international community should draw approaches from government, industry, and academic stakeholders that are

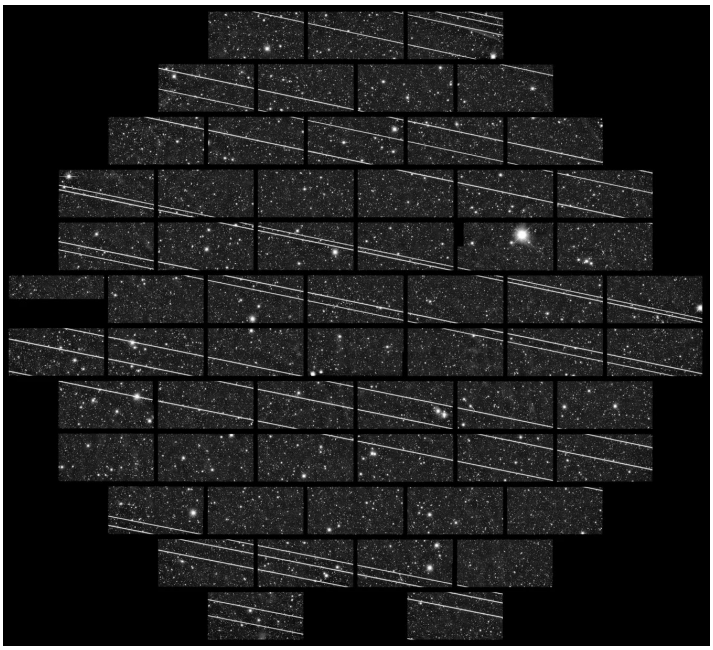

Figure 1, Example of how satellites transiting an optical astronomy sensor's field of view can impact data collection. Source: Tololo Inter-American Observatory in Chile (November 2019); Emily Zhang, SpaceX's Dark Satellites Are Still Too Bright for Astronomers, SCIENTIFIC AMERICAN (Sept. 10, 2020).

[4] Emily Zhang, *SpaceX's Dark Satellites Are Still Too Bright for Astronomers*, SCIENTIFIC AMERICAN (Sept. 10, 2020), https://www.scientificamerican.com/article/spacexs-dark-satellites-are-still-too-bright-for-astronomers/.

appropriate, evidence-based, and aligned with existing practices and requirements. Investment and research and development continues to pursue various possible solutions.

As the demand for space capabilities drives more entrants to the market, there is no guarantee that other stakeholders will act in such a collaborative manner. That is why it is so vital that we engage in multi-stakeholder conversation today, to avoid additional friction tomorrow. Collectively, responsible space actors maximize long-term benefits for consumers while preserving the ability to conduct scientific missions. If, instead, parties choose to enter this new space age from an adversarial position, we could face the complete exhaustion of terrestrial astronomy of any kind in a few short decades. Furthermore, there are very real concerns regarding our human connection to the night sky. Soon, truly dark night skies may disappear entirely in certain parts of the world. Many cultures have strong bonds to these dark skies; often their creation stories involve the heavens in ways that only are meaningful if the stars are visible. As such, the roundtable participants observed the need to involve these Indigenous populations in the conversation. And when indigenous representatives are unavailable, cultural anthropologists could serve as representatives of non-western values involving the night sky.

Potential Solutions to the Dark Skies Issue

Within the spacefaring community, the "Dark Skies" problem has, until recently, received less attention than the issues around "Loud Skies." It follows then that many of the suggested options for resolving these issues begin with establishing the means and the mechanisms to bring the stakeholder community together. Many roundtable participants suggested that the situation could improve if the U.S. government took a more active role to engage industry more consistently. Citing successes when mandatory coordination is incorporated as an element of the licensing requirements, they suggested establishing relationships early in the design lifecycle. Few would disagree that these efforts would benefit both the regulator and the regulated, but dissonance arises when attempting to assign responsibility to a single agency. Which government entity has the resources or necessary congressional directives to satisfy this request? None of the current agencies regulating the various pieces of the space enterprise seem positioned to take on the whole body of work. But without a conduit for these conversations, the community will miss an opportunity to enhance capacity building by familiarizing the group with specific efforts and by facilitating access to common tools.

Collectively, responsible space actors maximize long-term benefits for consumers while preserving the ability to conduct scientific missions.

Many roundtable participants suggested that the situation could improve if the U.S. Government took a more active role to engage industry more consistently.

Coming off the back of this suggestion, many in the room suggested that the Dark Skies problems could largely be overcome by the U.S. taking a more overt leadership

role. Specifically, many speakers noted that the most benefit would come in the areas of enforcement protocols and establishing norms. To some degree it may already be occurring, but the idea is that whatever standard the U.S. sets, the international community will follow. But is this sort of unilateral sovereign regulation preferable to an international regime? The risks may be numerous, but two stood out at the roundtable. First, those parties who do not like the U.S. regulations could seek licenses in countries with more favorable policies. Sidestepping rules in this manner would, in theory, be more difficult within an international framework. Second, and a tally in the sovereign column, current international bodies like the United Nations strictly focus on nation-state actors, with "free agents" often overlooked. Could this risk be alleviated by familiarizing responsible nations with their obligations under the Outer Space Treaty (OST)?[5] That treaty, signed in 1967 set forth basic standards of conduct and expectation for how signatories would act in space. Notably, the OST assigns liability conventions for mishaps, requires satellite registration (attributed to a sovereign nation), and disallows territorial claims over celestial bodies.

Challenges Associated with Dark Skies Solutions

When the conversation shifted to defining the challenges, one issue quickly captured the room's attention: the lack of adequate metrology to effectively measure the problem. One participant succinctly framed the issue by explaining that we cannot manage what we do not understand, and we cannot understand what we do not measure. Currently, data is lacking at the scale necessary to provide actionable information to operators. This includes ephemeris data (orbital propagation information) and even spectrum usage statistics. No single entity exists within the community that is responsible for providing data or volunteering to take the lead. An example cited by this same participant pointed to how many repeat offenders consistently drift out of their designated ITU slots in geostationary Earth orbit (GEO) because they know the feedback loop is not sufficient to hold them accountable for the transgression. To increase transparency in this area, it was suggested that these monitoring tools, when implemented, be made available to the public. This would enhance trust among the wider stakeholder community while putting bad actors under additional scrutiny in hopes of modulating disfavored behavior.

The next portion of the discussion refocused on challenges with international regulation. First, because the ITU is not an enforcement body, its authority is limited to assisting coordination efforts among parties. The ITU cannot enforce its guidelines in strong terms, which may make it reluctant to assign blame or liability. Additionally, many of the space treaties that inform the ITU's policies have gone unratified and therefore lack the bite of truly binding agreements. Second, there is the issue of government inaction – though only mentioned briefly. The criticism here centered on the U.S.'s calls for all parties to be good stewards of the space environment yet itself resisting calls for accountability. Again, this point goes to the current lack of uniformity and transparency around space sustainability. And third, there exists a catch twenty-two when regulating space sustainability: implementing strict access controls and

[5] 2222 (XXI). Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies, UNITED NATIONS OFFICE FOR OUTER SPACE AFFAIRS, https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/outerspacetreaty.html.

regulatory regimes undermines the common resource framework (the public well) that has been adopted by many. Common resources are inherently first-come-first-served, but that may change if the regulators enhance restrictions. The balancing act will be difficult, but it remains to be seen if the space environment requires an entirely novel regulatory structure or if the organizations drafting policy can strike the right mix.

[T]here exists a catch twenty-two when regulating space sustainability: implementing strict access controls and regulatory regimes undermines the common resource framework (the public well) that has been adopted by many.

Key Findings and Recommendations

The roundtable participants covered a lot of ground during this session. What follows is a summary of the key findings as well as topic recommendations for an upcoming conference:

- **Articulate the Value of Scientific Missions**
  - Specifically in support of resolving interference with scientific applications, there is a clear need to define for the global community the value of missions like optical and radio astronomy.
- **Objectively Measure the Space Environment (Physical and Spectrum)**
  - Some participants noted that much work needs to be done to measure the spectrum environment's true usage and to monitor objects currently in orbit. The community must work to objectively model orbital carrying capacity, forecast time to exhaustion, and identify technology developments that enhance capacity, craft regulations to control the progression.
  - Other participants noted that Space is a finite resource—even though space is substantial, operators need to use it efficiently, especially in LEO. The best near-term solution to maximizing efficiency in LEO is to develop and employ best practices, such as tight orbital tolerances and technologies/operating practices that increase operational safety, while also encouraging prudent, technical work on orbital capacity and ways to optimize constellation designs for sustainability and efficiency.
- **Right-sizing Regulatory Frameworks**
  - There is a need to understand the appropriate amount of regulation required to ensure that an international commons like space is well-managed, yet not overly restrictive. How can we ensure space safety and sustainability in order to maximize the benefits of space?
- **The Nuts and Bolts of Enforcement**
  - Regulation and policy mean little without an enforcement mechanism. There is a need to identify the correct organizational structure to develop and execute an enforcement regime.
  - Building on these findings, a future conference should include topics and discussions around the following questions:

- **Integrating Economists**
    - How can the scientific community leverage resource economists to articulate the value of astronomy and remote sensing?
- **Building Trust through Widely Available Domain Information**
    - What are the immediate next steps required, and which is the correct agency, to develop a centralized and trustworthy space domain awareness capability?
- **Resolving Sovereign and International Authorities**
    - What enforcement regime is most appropriate for regulating space sustainability? Should this be a sovereign capability or an international framework? What fora exist or should be established to resolve and arbitrate conflicting uses of space?

III. Session 2 – Space Resource Management

Background

Earlier this year, the National Aeronautics and Space Administration (NASA) unveiled a new strategy outlining its approach to responsible and sustainable operations in Earth's orbit.[6] The first of four volumes focuses on the Agency's efforts to address the growing space sustainability challenges to NASA's mission arising from the rapidly evolving space environment. The strategy highlights the critical importance of Space Situational Awareness, Debris Mitigation, and Space Traffic Coordination to ensure the long-term and equitable use of space. Space operations' increasing congestion and complexity reduce conjunction predictability and disrupt scientific missions. Given the absence of a unified framework for addressing sustainability, there is a pressing need for global collaboration to enhance model capabilities, improve transparency, and clearly define roles and responsibilities among stakeholders.

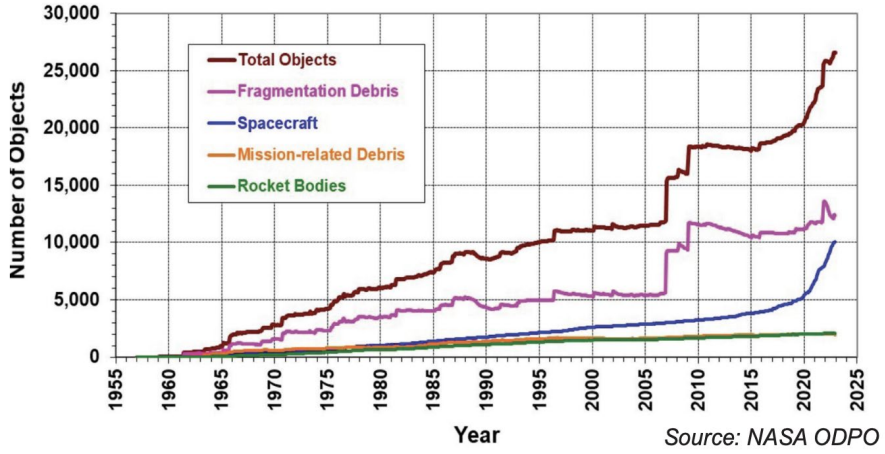

Figure 2: The figure illustrates the number of debris objects in space that are currently being tracked. NASA estimates that approximately 100 million small pieces of debris are not tracked or avoided by spacecraft, yet they are large enough to damage or destroy them.

The roundtable's second session, focused on space resource management, was kicked off by Siamek Hesar of Kayhan Space Corp and Daniel Baker of the Laboratory for Atmospheric and Space Physics (LASP) at the University of Colorado Boulder. This session explored the policies and regulations necessary to manage space as a shared resource, and addressed critical issues such as orbital slot management, satellite end-of-life disposal, risk mitigation, debris management, indemnification, and more.

[6] National Aeronautics and Space Administration, NASA's Space Sustainability Strategy; Volume 1: Earth's Orbit 1-13 (2024), https://www.nasa.gov/wp-content/uploads/2024/04/nasa-space-sustainability-strategy-march-20-2024-tagged3.pdf?emrc=9a7020.

Framer – Siamek Hesar

Siamek Hesar is the co-founder and CEO of Kayhan Space, a company that focuses on space domain awareness (SDA). Siamek offered a unique perspective on space sustainability based on his extensive industry experience. He shared his insights on space infrastructure, commercial space industry growth, and challenges faced by satellite operators.

Siamek emphasized the critical importance of viewing space as a vital infrastructure. He highlighted how spaceflight safety and collision avoidance are integral components that underpin a $1 trillion industry, including communications, air travel, agriculture, and national defense. He underscored the staggering impact a disruption in space services could have, noting, for example, that if the Global Positioning System (GPS) were to fail, it would result in a financial loss of approximately $1 billion per day.[7] Siamek stated that space is no longer an obscure thing that is out there, out of reach, that individuals do not have to deal with. Every person with a cell phone has a connection to space.

The commercial space industry is expanding rapidly. Siamek pointed to the exponential growth within the space industry, predicting the deployment of at least 100,000 additional satellites over the next decade. This surge is driven by companies which have reduced launch costs, thereby allowing more entities to deploy assets into space. He noted that the Starship launch vehicle is expected to reduce costs even further, leading to a further increase in space activity.

Satellite operators face significant challenges in managing the increasingly crowded orbital environment. For example, a constellation of 100 satellites can generate around 60,000 collision alerts per week. Large operators can automate some processes, but smaller operators struggle with the complexity of managing potential conjunctions. Siamek stressed the importance of communication among engineers from different organizations to address these challenges. However, he noted that not all operators are willing to cooperate, citing China as an example which often fails to communicate or coordinate with other operators. This lack of collaboration poses a significant risk to the safety and sustainability of space operations.

Additionally, Siamek emphasized that managing the risk of collisions between operational satellites is far more complex than just avoiding debris. Conjunctions, or potential collisions, between satellites are increasing as more satellites are packed into critical orbital altitudes. The risk of collisions grows as a growing number of operators are attempting to deploy their satellites in the same operationally and economically relevant orbital regimes.

A critical issue is the absence of globally agreed-upon standards for managing conjunctions. As he described, today's operators rely on informal communication, such as phone calls or email exchanges, to coordinate maneuvers, which is unsustainable.

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[7] O'Connor, A.C., Et Al., Economic Benefits of the Global Positioning System (GPS) (2019), https://www.nist.gov/system/files/documents/2020/02/06/gps_finalreport618.pdf.

Currently, this coordination is limited to U.S., European, Australian, and Japanese operators. The lack of engagement with Chinese operators, who also plan to deploy large constellations, presents an additional challenge.

Siemek concluded his framing remarks by underscoring that global leadership and cooperation are essential to developing standards and regulations for space sustainability. Without involving all spacefaring nations, solutions to the growing challenges of space operations may remain elusive.

Framer – Daniel Baker

Daniel Baker is the Director of the Laboratory for Atmospheric and Space Physics (LASP) at the University of Colorado Boulder. Dan's presentation focused on the broad scope of challenges, including orbital debris, space traffic congestion, and the exploitation of space resources, while emphasizing the need for regulation and enforcement. Dan outlined that the growing accumulation of debris in Earth's orbit poses a severe threat to future operations, and increased activity in space, with more satellites and missions, is causing congestion, making space management more complex.

Without proper regulations, activities such as resource extraction, energy harvesting, and manufacturing in space could lead to irreversible damage to space environments, including Earth's orbit, the Moon, and Mars. Dan cautioned that unregulated industrialization could forever change these celestial environments.

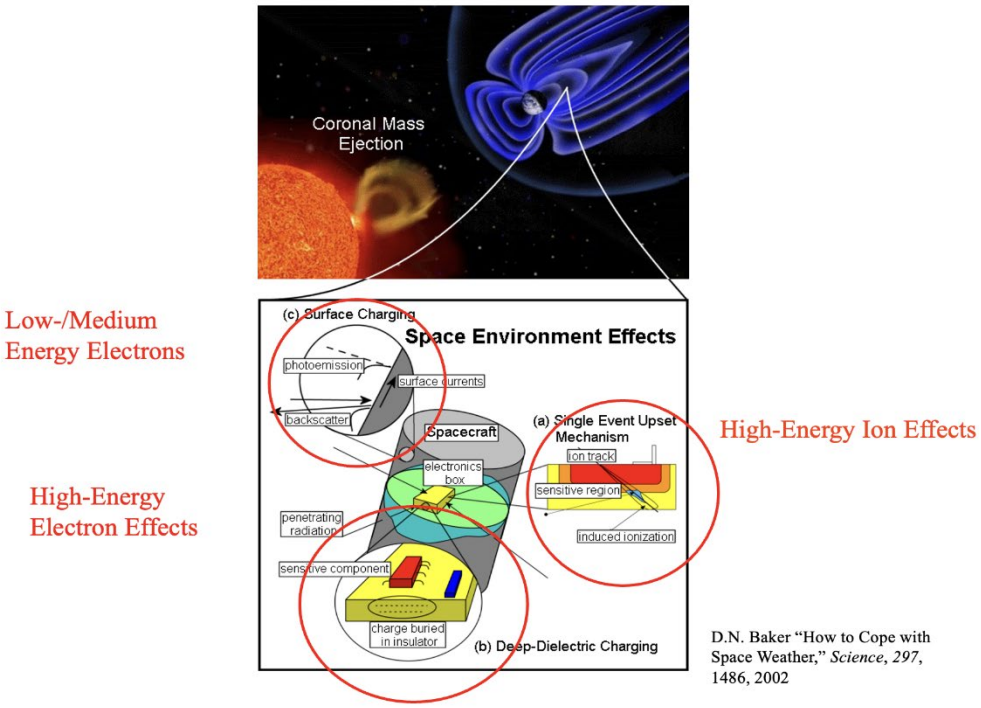

Figure 3: Solutions to orbital debris and space resource management could be applied that are similar to how engineers have made progress in mitigating the effects of space weather on satellites.

Drawing on his experience in space science, Baker noted that significant progress has been made in dealing with space weather, such as solar energetic particles and cosmic rays. Engineers have successfully designed systems that mitigate the impact of these challenges. He suggests that similar engineering solutions can be applied to sustainability issues, such as orbital debris and space resource management.

Using an analogy from the movie The Day the Earth Stood Still,[8] Dan suggested that objective, impartial enforcement is needed to ensure the responsible use of space. He concludes by calling for collective action, transcending the interests of individual entities, to safeguard space for future generations.

Figure 4: In The Day the Earth Stood Still, the robot GORT is an impartial enforcer of intergalactic law.

Discussion

Following Siamek's and Dan's presentations, participants engaged in a discussion, raising concerns and addressing critical issues surrounding space resource management.

Governance Challenges

Space governance presents numerous challenges, from managing spectrum allocation to addressing orbital pollution and preventing collisions. The exploitation of celestial bodies adds further complexity to these issues. Effective governance in space requires real-time communication, especially when issuing conjunction warnings to avoid potential collisions. Although space is recognized as an international domain akin to the law of the sea, current governance structures are inadequate in addressing the growing risks, such as collisions and determining fault among operators – an issue explored in a later session. Politics often interferes with spaceflight safety, as evidenced by China's reluctance to cooperate with other nations on conjunction management. This highlights the need to depoliticize space safety efforts. However, national sovereignty remains a significant barrier to achieving comprehensive international cooperation.[9] A potential solution could involve empowering a neutral, passionate country like Brazil to take a leadership role in space governance, facilitating more effective collaboration without compromising the sovereignty of other nations.

One participant, building on ideas from the previous session about the limited access to space ("access to the well"), proposed categorizing space governance issues into distinct "buckets." These might include areas where U.S. leadership could play a key role in driving solutions, issues requiring international collaboration, and situations where *participant* leadership is needed. The speaker also raised several questions: Can governance issues be grouped into categories when they have widespread impact?

[8] Twentieth Century Fox, 1951.
[9] See the Registration Convention under the Outer Space Treaty as an example of current sovereign entanglement. G.A. Res. 3235 (XXIX) (Nov. 12, 1974).

Can multi-stakeholder areas, where industry and governments collaborate, drive progress when incentives align? And in multilateral contexts, where interests of global governments and other space participants may diverge, how should those be addressed? Lastly, they questioned whether U.S. leadership helps or hinders in these scenarios.

Following those comments, another participant providing an operator's perspective on space situational awareness (SSA)[10] and collision avoidance and expressed support for the efforts of the Office of Space Commerce within the U.S. Department of Commerce to leverage commercial services for SSA. However, they voiced concerns about the slow progress, noting that Phase I of these efforts may take up to five years, which creates challenges for relying solely on this system. They pointed out that while the Department of Defense (DOD) provides valuable services, it struggles with real-time conjunction warnings due to outdated mechanisms. As a result, much of the responsibility falls on satellite operators to ensure safe operations, coordinate with prominent constellations, and establish operator agreements, including with NASA. Coordination with smaller or isolated operators remains difficult and lacks clear mechanisms.

The participant stressed the need for real-time, two-way communication between the U.S. and other nations, particularly when collisions involve countries like China. They emphasized that spaceflight safety should not be politicized and urged the U.S. government to develop real-time SSA coordination mechanisms to improve safety and communication across international borders.

Figure 5: The Department of Defense uses multiple sensors to track space-based objects and predict potential collisions.

[10] *Space situational awareness* is the knowledge and characterization of space objects and their operational environment to facilitate decisions that support safe, stable, and sustainable space activities. In 2023, U.S. Representatives Beyer (VA) and Norcross (NJ), reintroduced the Space Situational Awareness Transition Act that would establish a civil SSA capability under the Department of Commerce and provide new congressional oversight to support spaceflight safety and space sustainability. There has been no congressional action on this bill since introduction. Space Situational Awareness Transition Act, H.R. 5431, 118th Cong. (2023).

The participant also stated that the U.S. lacks strong leadership in developing best practices and a bottom-up approach to SSA due to the absence of a cohesive government strategy. They suggest that perhaps the White House could lead such efforts, emphasizing the need for collaboration between industry and government to create a unified voice for bilateral and multilateral discussions. The speaker also highlighted that a new international regulatory treaty is unlikely, especially with countries like China, Russia, and Iran. Instead, they advocate for a practical focus on best practices, as legally binding international agreements will be difficult to achieve. The goal is for all operators to agree on and follow the same practices.

In response to the comments on SSA, another participant suggested using the International Committee on Global Navigation Satellite Systems (ICG) under the UN as a potential model for developing a common approach to SSA efforts. The ICG, which brings together users and providers of Global Navigation Satellite Systems (GNSS), has successfully adopted a technical, bottom-up approach, removing policy elements and establishing best practices for coordination. The speaker proposed that this model could be applied to SSA on an international level.

In addition to communication challenges, one participant emphasized the critical role of cultural competence in international communication. They pointed out that cultural differences can affect satellite operations and must be considered for effective global collaboration. They argued that establishing a coordinated system for managing traffic is essential as space becomes increasingly congested, and sovereign nations cannot operate independently in orbit.

Reflecting on their experience, one of the participants noted parallels between space and maritime law. They highlighted that space, like the sea, is a domain governed by international law, mainly through the OST. However, governance issues in space are complex and multifaceted, covering areas like spectrum management, collision avoidance, and resource exploitation. Drawing from the Law of the Sea, the speaker emphasized the intricate, layered regulations that govern different parts of the ocean, including resource management and jurisdictional boundaries. They suggested that space governance could benefit from a similarly sophisticated approach, as the Law of the Sea has evolved over centuries to address challenges in what was once a global commons. The speaker also critiqued how current space governance is stuck in outdated notions of state sovereignty and suggests that space requires new, forward-thinking solutions. They pointed to historical examples, like post-World War II treaties and the Helsinki Accords, as models for fostering cooperation among global powers. They advocated for more pragmatic, technocratic coordination, particularly around collision avoidance, and suggested that space governance could evolve, similar to how maritime law developed through gradual compromises and technological advances.

The role of the U.S. in space governance was a topic that was heavily debated. U.S. leadership could be pivotal in establishing international norms and regulations, but this leadership must be carefully balanced to avoid alienating other nations. A participant stated that the U.S. lacks strong leadership in developing best practices and a bottom-up approach to SSA due to the absence of a cohesive government strategy. They suggest that perhaps the White House could lead such efforts, emphasizing the need for collaboration between industry and government to create a unified voice for bilateral and multilateral discussions.

One of the participants expressed dissatisfaction with the ITU's lack of expertise and emphasized the need for the U.S. to select a suitable organization and commit to it. They rejected the idea of a UN or non-UN body enforcing regulations, as countries are unlikely to relinquish sovereignty. The participant criticized the Artemis Accords[11] for missing an opportunity to address space sustainability and suggested that the U.S. leadership was lacking. They believe that the U.S. should support other countries, especially developing ones like Brazil, that are passionate about space issues and are willing to take on leadership roles. They proposed that the U.S. might be more effective in a supportive role rather than taking the lead.

The complexities of managing space governance across various U.S. agencies, such as the DOD and the Department of Homeland Security (DHS), further complicates the issue, especially considering how Congress oversees these efforts. One of the participants noted that space is unique because it is the only domain where both commercial and military activities coexist. Unlike other domains, where military conflicts or exercises can lead to the closure of commercial activities (e.g., air traffic or maritime routes), space does not have such mechanisms. Satellites cannot be easily redirected or stopped, which complicates the situation. The participant highlighted that the U.S., China, and Russia all view space as a warfighting domain, making international discussions and coordination challenging due to the high stakes involved with military assets in space.

Industry Best Practices

Participants next discussed the development and implementation of best practices and regulatory frameworks. Various government and industry groups, like the Space Safety Coalition and the European Space Agency (ESA)[12], are working on developing best practices. One of the participants discussed the lack of U.S. leadership in creating a cohesive, bottom-up approach for these practices and emphasized the need for a whole-of-government strategy. They debated that best practices can eventually lead to more concrete regulations, particularly in the areas of satellite maneuverability and data sharing.

Another speaker criticized best practices. The best practices that the industry has come up with are things already being done or easily achievable and do not address more challenging issues. They argue that creating an international organization with significant private-sector involvement could be more effective. The participant expressed skepticism about the effectiveness of current international organizations like the Committee on the Peaceful Uses of Outer Space (COPUOS) and the ITU and emphasized the importance of meaningful private sector engagement.

Another concern raised was the issue of carrying capacity, referring to the threshold at which the number of satellites and space activities can be sustained without causing irreparable harm. For example, NASA scientists have struggled to collect data due to

[11] https://www.nasa.gov/artemis-accords/
[12] In May, the European Space Agency (ESA) announced that 12 countries signed the Zero Debris Charter. The ESA developed the Charter in response to its member states' call for a "zero debris" approach to its mission, aiming to achieve no net addition of debris in orbit by 2030. European Space Agency, Zero Debris Charter (2024), https://esoc.esa.int/sites/default/files/Zero_Debris_Charter_EN.pdf.

frequent satellite maneuvers needed to avoid space debris, highlighting the negative consequences of reaching this threshold. One participant noted that to have a concrete number for carrying capacity, a clear understanding of the capabilities of each satellite is required. Currently, challenges exist in developing necessary algorithms, identifying suitable analogies, and determining the relevant concepts for such a calculation.[13]

Overall, the discussion reflects ongoing debates about the relative merits of managing space operations via best practices versus formal regulations. It also underscores the need for incentive structures, which are currently lacking, and effective international and national leadership.

Environmental Issues

Concerns were raised about the impact of space activities on the Earth's atmosphere. One participant highlighted the environmental consequences of space travel on Earth's atmosphere from rocket launches and satellite deorbits. The ascent and descent of spacecraft introduce water vapor and nitrous compounds into the stratosphere, altering the mesosphere with metals like aluminum and iron. The long-term effects of these changes, especially with the potential for frequent launches, could disrupt the atmosphere, raising questions about the number of launches Earth's atmosphere can tolerate.

Another speaker highlighted the problem of current space systems being single use, leading to space debris. They argue that every satellite launched ends up as junk, as they are neither reusable nor recyclable. To address this, the participant advocated for in-space manufacturing and resource utilization, emphasizing that humanity cannot continue to transport everything from Earth to space indefinitely. They suggested that a shift towards a circular space economy, where satellites are reusable and recyclable, would reduce the number of satellites and mitigate the growing issue of space debris.

Another participant offered insights on space resource management from an environmental law perspective. They emphasized the need to differentiate between various types of commons issues, such as spectrum congestion and orbital debris quality, and how these distinctions could inform different governance strategies. The participant discussed potential regulatory approaches. These included command-and-control standards, performance-based standards, and strategies based on carrying capacity, where ambient levels of resources are used to monitor and manage multiple users. They highlighted the limitations of the Coase theorem in contexts like air quality, where many users make the bargaining difficult, and equity concerns arise, suggesting that setting ambient resource levels might be a better approach for space. They also

[13] See Moriba Jah, *Two Ideas to help FCC Curb Orbital Debris*, Aerospace America (July/August 2024), https://aerospaceamerica.aiaa.org/departments/two-ideas-to-help-fcc-curb-orbital-debris/. Jah argues that the FCC should go beyond the "100 object-years metric" and adopt more comprehensive measures, such as orbital carrying capacity and space traffic footprint, to more effectively evaluate and mitigate risks related to space debris and satellite collisions.

brought up the issue of "cradle to grave" resource management, referencing U.S. laws on waste management[14] as applicable to one-time-use satellites.

The participant also touched on valuation difficulties, referencing environmentalists' initial concerns of being able to put an economic value on human life and how economists ultimately succeeded in doing so through benefit-cost analyses. Today, every Clean Air Act regulation that reduces particulate matter is benefit-cost justified because human lives are saved. A similar valuation can be done for space resources. The participant also discussed that Indigenous peoples have rights to traditional resources. If we want to honor these commitments, it's essential to address what role Indigenous people play in managing space resources.

Key Findings and Recommendations

Several actionable strategies are necessary to guide future efforts to address the growing challenges of space resource management and sustainability. These actions focus on improving governance frameworks, promoting international cooperation, and fostering responsible space activities. From strengthening U.S. leadership and revising best practices to addressing environmental impacts and respecting Indigenous rights, these initiatives aim to create a more sustainable and equitable approach to space operations. Below are key recommendations to advance global space governance and ensure the long-term viability of space activities.

- **U.S. Leadership and Whole-of-Government Strategy**
  - The U.S. government should take a more active role in developing and promoting best practices for space operations, emphasizing a cohesive, bottom-up approach. A whole-of-government strategy should be designed to address critical areas like satellite maneuverability, data sharing, and debris mitigation.
- **Reevaluation of Best-Practices**
  - Revise and expand current industry best practices to tackle more complex challenges in space governance, including space debris management and satellite coordination.
- **Promote Real-Time Communication Systems**
  - Invest in enhancing real-time, two-way communication systems for space situational awareness to foster international collaboration and prevent collisions, particularly with countries like China. Expedite the deployment of commercial SSA services to reduce dependence on outdated government systems.
- **Research on Orbital Carrying Capacity**
  - Prioritize research to determine space's carrying capacity by focusing on satellite capabilities, analogous scenarios, and algorithm development to prevent space congestion. Foster collaboration between governments, space agencies, and industry to establish clear carrying capacity metrics and guidelines for satellite operations. One near-term solution to maximizing efficiency in LEO is to develop and

[14] The Resource Conservation and Recovery Act (RCRA) authorizes the EPA to control hazardous waste. *See* 42 U.S.C. § 6901 (1976).

employ best practices, such as tight orbital tolerances and technologies and operating practices that increase operational safety, while also encouraging prudent, technical work on orbital capacity and ways to optimize constellation designs for sustainability and efficiency.

- **Incentive Structures and International Cooperation**
  - Develop incentive structures encouraging private sector adoption of best practices and cooperation in space governance. Foster meaningful international cooperation, ensuring that national and global leadership work in tandem to address space sustainability issues.
- **Indigenous Rights**
  - Address the role of Indigenous peoples in space resource management, ensuring that their rights are respected in developing space law and policy.

Looking ahead, below is a list of potential topics for future conferences:

- **Space Governance**
  - What reforms are necessary to update the current space governance models?
  - What role should multilateral organizations like the UN play in coordinating international space governance?
- **Space Safety**
  - What is the carrying capacity of space, and at what point does overcrowding become detrimental to scientific and commercial satellites?
  - What is the role of emerging technologies in improving space safety and managing the increasing density of satellites in orbit.
  - What is the potential for commercial opportunities in space object tracking and measurement and how third-party databases could improve collision avoidance and space traffic management. How can third-party entities take a more significant role in space object collision avoidance, and what infrastructure and investments are required to make this feasible?
- **Environmental Impacts**
  - What environmental impact do space launches and satellite re-entries have on the stratosphere and mesosphere, and how can these impacts be mitigated? What new technologies or innovations could reduce the environmental impact of space activities?
- **Best Practices and Standards**
  - Can updating satellite licensing protocols to include maneuverability and safety standards account for emerging risks in higher orbits? How should licensing requirements evolve for satellites?
  - What barriers exist to establishing shared best practices and common operational standards?

IV. Session 3: Licensing and Regulation for Future Technologies

Framer – Jonathan Bair

Jonathan Bair is an associate at Wilkinson Barker Knauer, a Washington, D.C. law firm, who focuses his practice on the complex regulatory issues in both the terrestrial and space telecommunication industries. He brings valuable experience to the roundtable, with a background in the development of applications for satellites and Earth stations as well as pleadings before the FCC. His comments centered on the challenges associated with future-proofing regulatory regimes to novel space technologies and their applications. Jonathan advocated for a flexible regulatory framework for emerging technologies, and highlighted that regulators often struggle to keep pace with rapid technological advancements, leading to a lag in effective governance.

To address this issue, Jonathan emphasized the need for clear policies, goals, and priorities to ensure space sustainability. He noted space sustainability's multi-faceted nature, involving issues such as orbital debris, traffic coordination, RF interference, and space weather. He posited that future regulatory frameworks could only manage these issues if they are open, inclusive, and transparent. To achieve these ends, Jonathan emphasized the need to include diverse stakeholders from industry, government, academia, and more. The perspectives these groups bring to the decision-making process lead to comprehensive understanding and inclusion of critical issues. Furthermore, he stressed the importance of objective, evidence-based regulations. In concert, these hard regulatory expectations, as defined by diverse parties, can help overcome governance lag in the face of technological advancement.

Jonathan articulated five guiding principles that may assist space regulators: (1) articulate clear policies, goals, and priorities; (2) encourage broad participation and transparency; (3) implement technology-neutral regulations; (4) no rule should be set in stone; and (5) allow for multiple modes of regulation. Beginning with the need for explicit messaging, he offered that all regulations should be grounded in well-defined objectives that specifically address the various aspects of space sustainability mentioned above. There should be no guesswork on behalf of the regulated parties. The expectations around space sustainability should be clear, agreed-upon, and achievable. These expectations then should be easily translated into responsible space operations. Next, to encourage participation and transparency, Jonathan explained that, through the decision-making process, the community should aim to build a body of common knowledge by maximizing information sharing across both formal and informal channels. This effort dovetails nicely with his commentary around openness and inclusion—success in one area begets success in the other. The reasons behind each decision should be rooted in objective criteria and clearly explainable.

The expectations around space sustainability should be clear, agreed-upon, and achievable.

Regulators are "not always well-placed to look over the horizon" and predict the next hit technology.

Jonathan then moved on to his third principle: to maintain adaptability, regulations should focus on the *uses* of technologies rather than the technologies themselves. Functional performance requirements and the associated objective metrics are then able to evolve with future technological changes without committing the regulator to any one solution. Finally, to ensure that the rules do not become gold-plated, the community needs to remain open to revision, when necessary, without slowing down the technological advancements. No rule should be set in stone, and regulators may need to get creative with their approach by offering "things like the experimental authorizations or special temporary authorizations." Regarding his fifth principle, multiple regulatory regimes, Jonathan cited the idea of using "best practices" to inform traditional regulation. He offered that by "looking at what satellite industry operators and others are doing in order to create best practices and standards," regulators can develop starting points and assess feasibility of formalizing those practices. "[T]he government is not able to do everything." As a result, there is room for other stakeholders to step into the gap and provide first-look assessments of new topics and issues as they arise.

In closing, Jonathan cautioned the roundtable about the risks of stifling innovation through ex-ante regulations – those rules that prematurely restrict technologies. Regulators are "not always well-placed to look over the horizon" and predict the next hit technology. As such, a balanced approach would ensure that emerging technologies are responsibly managed while not choking development. Performance-based regulations better promote innovation since they are not tied to potentially outdated technologies nor commit the regulator to specific technological solutions. Before stepping away from the podium, he hammered home the need for open, inclusive, and adaptable regulatory regimes to meet the space industry's rapid advancement head on.

Framer – Jennifer Warren

In response to Jonathan Bair's comments, Jennifer Warren discussed the regulatory and licensing environment in the U.S. Positioned well to speak with authority on the issue, Jennifer is the Vice President of Civil & Regulatory Affairs (C&RA) for Lockheed Martin Corporation. She has experience representing Lockheed Martin programs while interfacing with the executive branch, independent agencies, and various intergovernmental bodies. Her regulatory portfolio includes spectrum governance, 5G, commercial space, crewed and uncrewed aviation, ocean minerals, and emerging technologies. With her comments, Jennifer intended to expand on the adaptable regulatory framework principles Jonathan opened with. But, diverging slightly from the topics, she pointed out that many of the typical economic drivers that incentivize industry behavior are missing in the space sustainability context.

She first highlighted maneuverability–the ability of satellites to flexibly relocate on orbit – as a perfect case study into current regulatory shortcomings. Though essential for space sustainability, maneuverability requirements are not typically part of private-sector business or funding plans. Jennifer offered that regulators should provide

financial incentives to encourage operators to adopt those practices which are important yet are unattractive due to the minimal return on investment. If not financial incentives, she suggested providing soft mandates or offers of preferential treatment for systems that meet specific performance criteria. She noted the World Economic Forum's space sustainability ratings program as an example of incentivizing satellite operators to achieve higher sustainability standards than they would otherwise.[15] While thinking through these issues, national regulators, including those in the U.S., must consider the broader implications of their leadership in space sustainability. Jennifer argued that those national leaders have a duty to set high standards. She stressed that industry is communicating a demand signal for a framework that recognizes and rewards sustainability efforts, and regulators would do well to listen. Approaching regulation from a commerce-centric perspective may lead to the greatest response from industry, either as it relates to general governance or specifically to future technologies.

Many of the typical economic drivers that incentivize industry behavior are missing in the space sustainability context.

Jennifer noted, however, the delicate balance between regulating for sustainability without giving up our national competitive advantages. Multiple administrative agencies, including NASA, the National Oceanic and Atmospheric Administration (NOAA), and FCC, will play key roles the effort to craft smart regulations without limiting future development. To remain flexible in the face of disruptive technologies, constant revision and adaptability must be the foundational principles upon which all regulatory schemes are built. Because the space industry is inherently global, operators from industry and academia have the flexibility to choose their regulatory forums. If certain domestic standards become overly restrictive, stakeholders may leave the U.S. for friendlier regulatory environments. The U.S. has "leadership to lose" in this regard. She explained that by prioritizing adaptability and iteration, especially concerning environmental policies, the U.S. can remain a leader in space. This approach allows stakeholders to respond to new knowledge without running afoul of ossified rules.

Jeniffer next reached back to the analogy of the communal well used earlier: *everyone benefits from space sustainability, even if not directly involved*. She pointed to Bangladesh's participation in NASA's Artemis program as an example of space sustainability's global impact. Though not as active as some other spacefaring nations, Bangladesh is just as invested as any other party in preserving the environment for future use. Again, this reality shows the importance of involving diverse stakeholders in regulatory discussions to achieve space sustainability goals. As many space applications move beyond traditional Earth-oriented technologies, global engagement can lead to widely accepted standards of conduct. These norms will be crucial as the community embraces advanced space activities like debris removal, refueling, manufacturing in space, and bioengineering. These activities require a broader regulatory approach than the community has seen to date. In conclusion, Jennifer offered that to manage the coming change, regulators should bias their policies

[15] *The Rating*, SPACE SUSTAINABILITY RATING, https://spacesustainabilityrating.org/the-rating/ (last visited Oct. 4, 2024).

towards enabling industry innovation while still preserving the space environment. However, this is no simple task.

Space Sustainability Regulatory Organizations

Before diving into the heart of the roundtable discussion, it is helpful to first outline the major organizations dealing space sustainability today. Many organizations are working to combat these issues today. What remains troublesome, however, is the lack of resources and the tension between domestic and international regulators – to say nothing of the commercial industry partners who are playing an increasingly more significant role. Traditional regulatory schemes must evolve to accommodate emerging space technologies and operational concepts.

The United Nations (UN)

To begin with the international organizations, there are two main players: The UN's Committee on the Peaceful Use of Outer Space (COPUOS) and the International Telecommunications Union (ITU). To address the dark skies issues discussed above, COPUOS is in the design and operational phases of reflectivity mitigation efforts for these mega constellations – data and findings forthcoming. Working alongside COPUOS on this matter is the International Astronomical Union's (IAU) Centre for the Protection of the Dark and Quiet Sky from Satellite Constellation Interference (CPS). The IAU CPS, in contravention of traditional management approaches, takes a bottom-up approach to norm development and best practices. The goal is to share best practices across the scientific and commercial communities to preserve scientific missions well into the future. Some participants were critical of COPUOUS, however, noting "decades of inaction" regarding space debris mitigation guidelines. Though the guidelines are now in place, they came along well after other organizations had spoken on the subject. COPUOS is also looking beyond Earth's orbit, and recently sponsored a conference on Moon, Mars, and Beyond.[16]

The International Telecommunications Union (ITU)

Lunar planning is "radically outpacing ethical thinking."

The next major international actor is the ITU. Beyond managing the orbital parking slots and spectrum databases, the ITU also convenes the WRC every three to four years to update the radio regulations, as necessary. Gathering the international community in this way allows for key dialogue in developing areas – recently the WRC has turned attention to the moon. One roundtable participant noted that lunar planning is "radically outpacing ethical thinking." Touted as one of the most successful international organizations out there, participants noted that space operators are incentivized to participate by the promise of protections from harmful interference. Such protections secure stakeholder investments and financing.

[16] https://www.unoosa.org/oosa/en/ourwork/moon-mars-and-beyond/sustainable-lunar-activities-conference-2024.html

Cooperation is guaranteed by each operator's own self-interest in preserving their mission.

Though regulating celestial bodies is new territory, it is encouraging to see the ITU attempting to confront these challenges, especially as it relates to the fairness and equity of impacts their regulations may have. The cislunar environment may present fantastic opportunities for some capable nations while stranding developing countries due to unfavorable regulatory rules. It is important to acknowledge this reality in the policy drafting stage. Then, there are the questions about whether the current terrestrial framework is applicable in the lunar environment. On this point, a participant highlighted the need to leverage commercial technologies in this new domain. Additionally, they acknowledged the difficult tradeoff between studying the necessary technology and simply moving fast to operationalize technologies and "learn as we go." What sort of opportunities might expire if we collectively *keep* staring at the problem prior to implementation? The moon and its orbit are receiving more and more attention on the international stage, and the ITU seems to be the organization at the center of the conversation with respect to radiofrequency use.

The National Science Foundation (NSF)

The NSF is the organization that is advocating for the protection of key scientific missions. Currently, the NSF resolves harmful interference with radio astronomy sites, whether the source is terrestrial or in orbit. Additionally, the NSF works to protect remote sensing and Earth observation platforms from the same. Underpinning both missions is the NSF's desire to build trust and relationships among the various stakeholder communities to better inform policy decisions.

The National Aeronautics and Space Administration (NASA)

The primary focus of NASA are those communications and navigations spectrum bands that support human spaceflight and other critical operations. Recognizing that without these bands functioning properly all satellites turn into space junk, NASA advocates for policies that balance commercial and scientific goals. This is apparent in their internal policy directives, but some participants called for the agency to become more vocal during interagency discussions. NASA may soon be forced into a leadership role as the demand for adjacent band usage continues to increase the risk of international interference. As the de facto operational expert in many of these areas, NASA's example is one that other stakeholders are likely to follow. With increased congestion, downlinking NASA data is becoming more difficult, and technologies like mobile broadband Supplemental Coverage from Space may interfere with the agency's planned lunar command and control architecture. As congestion increases, NASA will be compelled to engage with other stakeholders lest they lose mission capability altogether. The Artemis Accords' "non-binding principles" of responsible space behavior, have been a success for NASA. At the time of the roundtable, 43 nations had signed on, with more seemingly joining every month. These standards, as developed by NASA, can lead to customary international law (or even a treaty). The benefits seen by this effort demonstrate the importance of potentially retaining multiple regulatory regimes. Domestic regulators can let organizations like NASA take

the first cut at governing new technologies, and then sweep in later to formalize the standards after they are fully ventilated by the community.

The Federal Communications Commission (FCC)

The FCC is the leading domestic space regulator because of its role in licensing radio spectrum. Almost all satellites require spectrum access to function. As the licensing authority for those wishing to operate signals from satellites in U.S. markets, the FCC offers various license types, each with their own procedures. There are generic operational licenses that permit companies to operate their satellites and access uniquely assigned portions of the RF spectrum. There are experimental licenses, used for novel technologies and services. There is the amateur radio licensing process that is reserved for non-commercial and hobbyist use, and sometimes used by university-affiliated missions– only a small number of satellites leverage this option. Then there are grants of Special Temporary Authority (STA), which as one participant remarked, may be intended for short-term fixes but can become long-term solutions. Underpinning each license type are the FCC's service and technical rules which define the operational requirements that accompany each license. The FCC serves as the conduit between the domestic industry and the ITU. Licensees incorporate basic basic RF usage information into a draft ITU filing which the FCC then reviews and submits on the company's behalf. This review is intended to ensure that all information is accurate and sufficient to complete ITU review.

The FCC has implicitly become the leading regulator since all satellites require spectrum access to function.

As the primary organization dealing with these companies, the FCC is on the frontlines of dealing with the challenges around mega constellations. And the advent of low-cost access to space means that this is no longer a "10-year-out" problem, but a today problem, as one participant stated. The government may be criticized as being slow to grasp the nature of these challenges, but many mature satellite operators appreciate the risks to their business case. Because of this recognition, many owner-operators have begun investing substantial amounts of money in research and development to future-proof their systems in anticipation of forthcoming regulation. Though expensive, many companies are already seeing tangible returns on investment in these areas.

The FCC also serves as the conduit between the other agencies like NSF and NASA. The FCC, though engaged today, still has work to go with the NSF to understand and quantify the potential impact to scientific missions from large constellations. Additionally, there is a dearth of research being done to study the spectrum environment more holistically. Together with the NSF, the FCC should assess the true spectrum carrying capacity for orbital assets to establish efficiency goals that will inform necessary standards and technical requirements applicable to both receivers and transmitters. The Commission also should engage with NASA to address any operational concerns around ongoing human spaceflight missions and the future cis-lunar architecture. As noted previously, solutions must be grounded in trust to succeed. Routine engagement and intentional relationship building are the first steps required to cultivate that trust.

Discussion

As the open discussion began, the initial focus was on Jennifer's framing comments around the space sustainability ratings. With respect to that effort specifically, and incentive programs more broadly, one participant noted the success of modern seatbelts as a corollary. He explained that, though merely a "recommendation" when he was a child, mandatory seatbelt wear is now broadly accepted. The speaker suggested that similar measures could be taken to make SSA technologies universally adopted to support sustainability goals. Incentives would play a crucial role in encouraging safe and responsible space operations, of which domain knowledge is a part.

Additionally, the concept of maritime flags of convenience has an equivalence in the space environment. This is the theory that operators register their craft in a certain nation to take advantage of favorable regulations. This speaker argued that there is a real need for research in this area, to catalogue who is doing this in space today and identify all launching states for each space object. The FCC is grappling with the challenge of companies seeking jurisdictions with lesser regulations. But such regulator-shopping leads to international siloes where certain nations split the ITU filing and registration functions or lack a space regulator altogether. The need for standardization becomes clear when the existing systems are confronted with novel space applications. The community will certainly struggle with finding solutions if there is no consensus over who "owns" the international registration responsibility. Because the answer to this question feeds into the liability calculus should an accident occur, getting this right today is vitally important.

The FCC is grappling with the challenge of companies seeking jurisdictions with lesser regulations.

This same speaker also pushed back on Jennifer's comments regarding the potential for the U.S. to lose its competitive edge due to overregulation. Essentially, he characterized these comments[17] as mere fodder for lobbyists, intended at urging regulators to preserve the status quo within industry. While the space community worries that stringent sustainability requirements could undermine competitive advantages, the speaker pointed to existing structures as successful examples of industries addressing similar issues. Notably, the Internet Corporation for Assigned Names and Numbers (ICANN) model could be adopted for space governance. ICANN is a not-for-profit organization that represents industry interests and developed methods for dealing with enterprise issues and scarcity problems (Internet Protocol (IP) Addresses being one). Under this framework, "you have supporting organizations who are experts in their respective fields feeding into someone who's looking at the larger picture." Recognizing the difficulty associated with creating something new, the speakers agreed that adapting an existing model is likely the best course for the space industry. Organizations like the United Nations Office for Outer Space Affairs (UNOOSA) and the ITU are already essential to the evolving space landscape, especially given the improbability of a new treaty. The community might be best

[17] Paraphrased by the speaker as, "The U.S. is going to be left behind. People are going to run laps around us."

served by identifying how these entities could serve a role like ICANN in preparing the industry to internalize novel technologies.

The participants noted the evolving end-of-life (EoL) standards for space objects to emphasize the challenges with new regulations. EoL occurs when, after running out of fuel or satisfying its mission objectives, a satellite either must move to a graveyard orbit or re-enter the atmosphere to burn up. Though routine in the U.S., these practices are new on the international stage, and compliance is critical for foreign systems seeking market access in the U.S. Critics, and some participants, argue that U.S. regulations for satellite orbit management are among the worst, often leading businesses to engage with the U.S. only when absolutely necessary. By mixing government and industry interests within a single regulatory entity, the participants noted that much of this friction could be resolved. Ofcom, the privatized telecommunications regulator in the United Kingdom[18], could serve as another example of how a bifurcated approach to governance balances government oversight privatization. Open-source tools also play a role in ensuring that stakeholders remain accountable to the relevant standards. These same entities could facilitate widespread dissemination of trusted tools to enhance space domain awareness and, as a result, affirm the community's commitment to sustainable practices.

Critics, and some participants, argue that U.S. regulations for satellite orbit management are among the worst.

On the topic of new technologies, one participant wanted to give credit to the FCC. He noted that a colleague of his, who works with space startups, routinely "approaches the FCC with new ideas all the time for future systems and licensing," and the FCC "has been a great partner for many of those companies." Even in the instances where those companies seek other regulatory jurisdictions, "no matter what, they have to come back to the United States because it is the largest economy in the world where they want to demonstrate their capability to the US government." Participants credited the FCC's Space Bureau for its focus on attracting new technologies. The Bureau was noted as being very flexible with novel technologies and attempting to shorten licensing timelines – often it takes upwards of "12 months for your license to be approved." The U.S. has the economic and regulatory clout to capitalize on novel space technologies, and now it is simply a matter of being very intentional on crafting the regulators' approach. This means agreeing upon a structure that is amenable to both public and private interests and prioritizes tech-neutral standards. Additionally, incentives for research and development as well as achieving sustainability standards will be valuable if the U.S. is to remain a leader in the field. Based on the discussion, a bifurcated regulatory structure like that of ICANN or Ofcom, should be seriously considered as a potential space governance model.

[18] *What is Ofcom?*, OFCOM (June 24, 2010), https://www.ofcom.org.uk/about-ofcom/what-we-do/what-is-ofcom/ ("Our duties come from Parliament…We are independent, and funded by fees paid to us by the companies we regulate.").

In concluding this part of the discussion, one astute participant cautioned the group that success requires constant, self-critical evaluation. The speaker's concerns stemmed from the assumptions supporting the current spectrum regulatory framework, and she questioned whether it may actually hinder the introduction of innovative technologies to the market. These assumptions rely on economic principles to drive the most valuable uses to the fore. The participant noted the reliance on spectrum auctions, and whether reliance on this method may create disincentives for investment in new technologies. The participant highlighted the potential negative impact on U.S. leadership due to blind commitment to existing regulatory paradigms. Recursive self-monitoring – constantly evaluating if regulators are making good decisions – will be required if the community is to capitalize on emerging markets like In-Space Assembly and Manufacturing (ISAM). The need to reevaluate, and possibly adapt, the regulatory approach to foster technological growth and maintain competitiveness was emphasized.

Participants credited the FCC's Space Bureau for its focus on attracting new technologies.

Examples From Other Regulatory Models and Use-Cases

The next phase of the discussion involved the aspects of existing regulatory structures that have worked well. At a high-level, the comments can be organized as five unique case studies, offering descriptions of the various complexities and the relevance to space regulation.

Supplemental Coverage from Space (SCS)

The mobile broadband community has exerted effort to access additional spectrum for SCS by allocating spectrum from existing satellite operators to terrestrial companies. This is an important case study because it illustrates the FCC's current spectrum management framework. Portions of the RF spectrum are assigned to specific uses and are notoriously difficult to reassign. One participant argued that the current table of allocations may impede growth because it is proscriptive with respect to technology. "I think one thing that's just important to keep in mind is that we probably don't want spectrum allocations that are specific to a technology." What was seen as valuable, however, was keeping the allocations bucketed at a high-level, differentiating amongst the "very large concepts of fixed satellite service, mobile satellite service, mobile service that can encompass a great many different technologies." Because these characterizations are based on function rather than technology, they fit the guiding principles Jonathan Bair laid out at the beginning of the section.

Informal Collaboration

Since space licensees enjoy no exclusive use, informal collaboration is a hallmark of the space industry. That fact, paired with the U.S.'s lack of formally delegated supervisory authority over space, means stakeholders "collaborate more informally than probably any other industry." Though this may work today, one commenter argued that is sends the wrong message internationally. Especially when regulating new space applications, it is important to consider optics when deciding what

regulatory structure is appropriate. Since supervisory authority is integral to achieving sustainability objectives, this participant cautioned that the U.S. is at risk simply by not identifying a responsible domestic regulator.

The FCC's Starlink Decision

A notable case is the FCC's recent Starlink decision, which underscored the need for dynamic regulatory approaches to accommodate evolving technologies. In March, the FCC denied Starlink's (SpaceX) application for more MSS spectrum[19]. Despite it being unused, the FCC cited the "plans filed" as a reason for foreclosing Starlink's request. One participant noted that is a serious opportunity cost that the community suffers if large companies continue to horde spectrum, to the detriment of new entrants and evolving technologies. In response, another participant stated that this issue led to the possibility of time-based incentives that would grant new entrants non-exclusive spectrum rights and would sunset the legacy protections for fallow allocations. This plan, if implemented, would signal to industry a meaningful shift in the regulatory environment–a shift that prioritizes productive use and incentivizes innovation and speed.

Low Earth Orbit (LEO) Interference Rulemakings

The FCC's NGSO interference rulemakings have emphasized risk-informed interference assessments. The speaker who brought this up noted that this method was intended to mitigate conflicts and ensure harmonious operations but did so based on risk ratings. This was a shift from the traditional approach of prioritizing licensees based on the date of issuance. Such an approach, they offered, reflects a growing trend towards using data-driven decisions in the regulatory processes and should be a model for how to adopt novel technologies. If anything, it serves as proof that regulators are able to internalize something "that is abstract in a way and then craft … policy that sort of implements something similar." Tying back in with the earlier discussion, however, the quality of data ingested will have a direct impact on the quality of the risk ratings and resulting policies. This is yet another argument for a robust and open SDA capability.

Spectrum Sandboxes

A participant followed the LEO discussion by citing the concept of spectrum sandboxes that is emerging at the national level. He argued that this effort represents a progressive step towards fostering innovation by "allowing light licensing regimes to be applied for innovative services." In a sense, the industry is incentivized to innovate because of the relatively relaxed regulatory constraints afforded to new applications. The speaker highlighted Europe's work in this

Spectrum sandboxes represent a progressive step towards fostering innovation by "allowing light licensing regimes to be applied for innovative services."

[19] https://arstechnica.com/tech-policy/2024/03/starlink-mobile-plans-hit-snag-as-fcc-dismisses-spacex-spectrum-application/

area as well, and how those regulators strip the license requirements down to the simplest constituent parts: "you get a temporal license, you get a bandwidth license, you get a power license." As a parting shot, another participant mentioned the NSF's NRDZ, which is essentially "a high functioning spectrum sandbox that's got some additional features like automated spectrum management." These light licensing regimes provide a flexible environment for testing and deploying new technologies and could serve as a bridge between the existing framework and the future tech-neutral structure.

The value and need for adaptive regulatory frameworks is evident based on the above examples. Certainly domestically, and arguably internationally, the FCC plays the largest role in steering the community through its work issuing licenses and setting performance requirements. As an extension of this leadership, the FCC will also likely have the most clout to set trends regarding the adoption of disruptive space technologies. It is imperative then that the licensing and rulemaking processes remain iterative and informed by risk assessments. These tenets are essential for balancing technological innovation with regulatory oversight.

Key findings and Recommendations

The roundtable conversation can be distilled into the following summary of key findings as well as recommendations for future conference topics:

- **Regulators should focus on technology-neutral policies**
    - What sort of performance requirements are necessary to ensure governance is aimed at the *uses* of technology in space rather than the technology itself? What is the appropriate or most pressing starting point? Maneuverability, communications resilience, location transponders, launch?
- **Incentives are required to for industry to pursue sustainable technologies and practices**
    - What is the best incentive scheme? Financial, soft mandates, preferential treatment?
- **Open, transparent, and diverse decision-making processes are required**
    - Diverse perspectives early in the regulatory lifecycle ensure critical issues are driven out. What must exist for these conversations to occur?
- **Regulators should seriously consider adopting a bifurcated governance model**
    - Look to organizations like ICANN and Ofcom as potential examples of hybrid regulation. Could this work for the space environment? If so, should it be adopted on the domestic or international level?

To make these findings actionable, a future conference should include topics and discussions around the following questions:

- **Drafting Resilience: How to Write Future-proof Rules**
    - What does it mean to write "technology-neutral" policy? Have we seen this work in other industries? Are there risks of being too ambiguous that may lead to loopholes or issues of insufficient notice?

- **Carrots and Sticks: Incentivizing Space Sustainability**
    - How can incentivizing industry be balanced with resisting agency capture? Are penalties or rewards more efficient at promoting sustainability goals? What does industry "want" from federal regulators?
- **Bifurcation or Bust: Pros and Cons of Public-private Governance**
    - How would industry partners be selected to join the organization? Which government agency would be responsible for overseeing the stand-up? Would this entity be responsible for all regulations, or simply specific parts of the environment?
- **Orbital Playground: Spectrum Sandboxes and their Role in Regulating Innovation**
    - What type of regulatory benefits should these licenses entail? Is a bond program appropriate to ensure safety of flight? What would it take to operationalize the NSF's NRDZ efforts within a regulatory agency?

V. Session 4: Enforcement in Space

Framer – Milton "Skip" Smith

As the roundtable moved on to the Enforcement in Space portion of the discussion, Milton "Skip" Smith from Greenberg Traurig outlined some of the key issues. First and foremost, Skip stated how there is not much enforcement in space other than a loose regulatory framework. Diving into the international legal framework, the Outer Space Treaty of 1967 (OST) got the ball rolling for regulating space activity. Most notably, Articles I and III mandated that space activities must be in accordance with international law. This international treaty was followed by the Liability Convention of 1971, which imposed absolute liability for damage caused by space objects to the surface of the Earth or to aircrafts in flight. Additionally, the Convention imposed fault liability for damage caused elsewhere. This, noted Skip, is problematic as there is not a sufficient means to prove "fault" without adequate rules. Skip beautifully analogized this issue to that of red lights in city streets–there are no "red lights" in space, so there is no fault for running them. This regulatory void has led to an environment where contractual obligations "fill in the gap." Thus, the most effective management regime currently addressing issues in space, such as debris mitigation and management of the "orbital highway," are contracts that contain these particular mandates.

There are no "red lights" in space, so there is no fault for running them.

Skip highlighted a number of policies and guidelines that set the international stage. COPUOS developed Long-Term Sustainability Guidelines in Space, promoting sustainability through encouraging transparency, cooperation, and preservation. The Space Safety Coalition (SSC) Best Practices offers recommendations for the mitigation of space debris and safe operations in space. The ITU Radiocommunication Sector allocates spectrum in space for efficient communications. Lastly, the Inter-Agency Space Debris Coordination Committee (IADC) has developed further guidelines for the mitigation of space debris. The common feature of these guidelines, recommendations, and regulations, however, is that they are rarely, if ever, enforced.

Turning to the United States, Skip outlined the domestic legal framework, which includes the enforcement branch of the FCC and its issuance of fines and orders for space communications and activities. Skip provided the roundtable with examples of enforcement measures, including Swarm Technologies receiving a $900,000 civil penalty for an unauthorized deployment of satellites. Additionally, DISH received a $150,000 civil penalty for disposing of their Echostar 7 satellite at 122 kilometers above the geostationary orbit, which fell short of their 300-kilometer minimum distance in the license issued by the FCC. The corresponding consent decrees, however, are subject to negotiations and compliance agreements. In the absence of a negotiated penalty, enforcement may take years to bring to fruition due to legal requirements that result in reliance on the DOJ bringing suit in federal court. These examples illustrate the potential for lack of consistency, timeliness, proportionality,

predictability, and capacity for enforcement, which can contribute to the overall lack of deterrence in the current enforcement regime.

Framer – Jonathan Skinner-Thompson

Jonathan Skinner-Thompson, a professor of law at the University of Colorado, responded to Skip's framing of the issues by offering helpful environmental law perspective. He began by asking what the goals of international enforcement should be. Should the community be striving for 100% compliance? Are exceptions and waivers that take different requirements into consideration appropriate? Furthermore, Professor Skinner-Thompson noted that there has been a shift away from binding targets in environmental law and instead a greater interest in capacity building and finance. But this, he mentions, begs the question of which players should be involved? Is there a need for all the "big players"? Or are these goals best addressed by a particular selection of international leaders?

Turning to the domestic enforcement environment, Jonathan mentioned a popular study[20], rooted in social psychology and enforcement theory, suggesting that a strong enforcement regime can theoretically result in 95% compliance across the industry. In the study, it was found that 20% of actors will comply voluntarily with any new standard. Additionally, 5% will always try to get around or avoid this new standard, and the remaining 75% will comply *if* they know that the 5% that break the law will be caught and punished. Therefore, the potential of a 95% compliance is predicated upon showing the entire community that enforcement will be taken seriously. This study highlights the problems first introduced by Skip: the few examples the community has witnessed of regulatory bodies following through with enforcing standards falling short of what would be a sufficient enforcement regime that consistently metes out timely punishment.

Lastly, Jonathan offered the EPA's principles for enforcement. The following are the most applicable to enforcement in space:

1. **Designing Effective Requirements**. Any regulation governing activity in space must be clear, balance stringency with feasibility, and promote compliance.
2. **Monitoring**. This is a big issue in any enforcement regime, and the vastness of space requires a multi-pronged approach that requires more analysis. What are the benefits of audits compared to inspections? What of self-monitoring and record-keeping versus citizen monitoring? What roles should citizens, communities, and non-regulated entities take in monitoring?
3. **Measuring and Managing Performance**. How can we measure performance, given different environmental, cultural, and sustainability expectations?
4. **Next-Gen Compliance**. The five interconnected components designed to improve compliance are 1) designing regulations that are easier to implement;

[20] C Bowles, *Promises to Keep: My Years in the Public Services, 1941-1969 (1971)*, quoted in D Zaelke, D Kaniaru and E Kruzikova (eds) Making Law Work: Environmental Compliance and Sustainable Development Vol 1 (2005)

2) using advanced detection technologies; 3) electronic reporting; 4) expanding transparency; and 5) use of innovative analytics and enforcement and voluntary disclosure.

Nobody will agree to standards that they don't think they can meet.

Broadly, Professor Skinner-Thompson's remarks provide a great starting point for how the international community can move forward with an effective enforcement regime. By introducing a multitude of questions, the remarks highlight the necessity for international cooperation, standardization, and broad participation.

Discussion

Registration Obstacles

With the issues nicely framed by Skip and a thought-provoking response by Jonathan, the table was now set to begin the discussion. The first comment outlined the obstacles to space registration. The participant asked what the lag was between putting satellites in orbit and registration through UNOOSA? They noted that, on average, it took Spain several years to register their satellites, while China waits until it has a fleet of several hundred satellites in orbit, then registers them all simultaneously. This, of course, causes disruption in the international community in how companies and governments track and traverse their objects in orbit. However, the participant stated that measuring the difference in registration tactics among the diverse nations allows the space community to attain a deeper understanding of how countries interpret these rules. This highlights another baseline question to add to Jonathan's list that must be answered before addressing how to move forward with enforcement: cultural interpretations vary greatly among the participating nations, so how can the community address this variation to achieve uniformity?

This comment echoed throughout the discussion with multiple participants offering their thoughts and opinions on the issue of registration. One participant stated how, overall, registration is a nightmare. Speaking to the original mention of registration, this participant stated how part of the reason for this nightmare is cultural—different nations have conflicting interpretations of registration requirements. Later, Skip re-entered the conversation by adding fodder to the nightmare comment. He stated that it is a mistake to read too much into the information accessible from the UN or Department of State (DOS) regarding registration. Doing so reveals that there is no obligation to update satellites and that participating actors only need to provide information about the general function of the satellite. Therefore, it is clear that the ultimate goal for registration should be to create an environment where registering objects put into orbit occurs as soon as practicable with as much information regarding their activity, purpose, function, and trajectory as possible.

The Importance of Measurement in Enforcing Regulations

It was conceded by all participants that among the most important starting points for enforcing regulations is measurement. However, this portion of the discussion reached somewhat of a stalemate with the questions of *how* regulating bodies should measure

and frame the problems. One participant made a statement that resonated with everyone. Specifically, he said that you cannot enforce something that is not managed; cannot manage something that is not known; and cannot know something that is not measured.

You cannot enforce what you don't manage, cannot manage what you don't know, cannot know what you don't measure.

By measurement, the participants specifically mentioned the importance of space object registration under UNOOSA, which was met with more comments regarding the inadequacy of the current registration regime mentioned before. Additionally, measuring the carrying capacity of space is necessary in order to create any workable regime. This included the recognition of third-party managers in the measurement of space objects, which includes the priority of operators contributing to external databases.[21] However, among the most important measurement considerations is the understanding of how different countries and cultures interpret regulations. Specifically, it is necessary to ensure that the words of our regulations are meeting the intent behind them through the subjective lenses of nations outside the U.S.

This portion of the discussion was closed off with a participant's comment that mostly addressed the inadequacy in the ITU treaty. It was agreed upon that the ITU treaty is not enforceable because there are simply no corresponding punishments. If we are going to have rules, we must enforce them. Because there are no "punishments" connected with the rules, there are many rules that the community should get rid of. Currently, space sustainability rules are highly subjective, which is a problem derivative of the lack of measurement noted above. Any rules for the international community should be clear and well-written. Achieving clarity, however, is predicated upon a measurement of cultural interpretations so as to understand how to tailor words to meet their intent across the community.

Tied with the notion of measurement playing a crucial role in writing regulations is its equal importance in understanding the damages occurring in space. All participants recognized that the damages in space encompass the physical and radio realms, and that the whole world must be on the same page with respect to this framework. The onset of increased commercialization has brought about cheaper methods of sending satellites to space. Single-use plastics, although cheap to develop and deploy, will eventually rain down into the atmosphere, implicating increased environment pollution and safety concerns. However, the participants recognized that the radio environment is *at least* as important as the resource of physical space. The rationale for this conclusion is that if you cannot communicate in space, then you have lost the use of it.

A few participants noted how the atmospheric impact of reentry can be significant, particularly for radio astronomers. Unfortunately, there is not enough data to come up with an enforceable standard. One participant noted that NOAA had once begun

[21] With regard to spectrum coordination, it was beneficial to offload coordination in the terrestrial network so that parties are not responsible for coordinating spectrum with other operators. It is much easier to place that responsibility on a third party, such as the FCC, and have that spectrum coordinator manage that resource alone. Additionally, participants during this portion of the discussion mentioned websites, such as space-track.org, which act as another third-party manager in the measurement of space activities.

studying the effects of satellite impact on the atmosphere, but this effort was soon abandoned. Thus, measurement of damages to the atmosphere, as it pertains to both radio astronomy and the health of the environment, must be completed. Lastly, a determination of appropriate tradeoffs is needed to satisfy all involved parties. One participant closed the discussion by offering a potential starting point for this effort, arguing that defining a proper method for measuring atmospheric impact is necessary.

Broadly, the importance of measurement in enforcing regulations cannot be understated. This notion was raised many times throughout the roundtable's discussion, with the undeniable fact that defining a starting point to measurement requires further discussion. However, the participants' comments can be distilled to the following ideas for moving forward:

1. Measuring cultural interpretations through continued cooperation and conversation among participating nations.
2. The continued measurement of the carrying capacity of space with a corresponding support of third-party managers.
3. Measuring the impact of physical and radio pollution after articulating a proper method of measurement.

Uniformity and Purposeful Penalties

Regarding the penalties themselves, a participant brought up the two examples raised by Skip in his background discussion of the enforcement framework. The FCC's monetary civil penalties on DISH and Swarm Technologies are an uncommon response to a common practice. Specifically, this participant mentioned that there are *several* cases that do not conform to regulation and licensing requirements that never reach the stage of imposing a monetary penalty. This notion was further emphasized by another participant when describing the sheer number of violations to space treaties and regulations that never see a fine or any form of strict action. The FCC attempted to respond to this frustrating issue by proposing a performance bond regime for end-of-life disposal. This, was not favored by industry, and the idea has not been implemented.

If you are going to have rules, enforce them. If you don't enforce them, do away with them.

However, the discussion surrounding civil penalties to companies like Swarm Technologies and DISH Network continued among the various participants and thus warrants further consideration. The circumstances surrounding Swarm's penalty provide an example the direction in which the enforcement regime needs to be going. Swarm sent multiple unauthorized satellites into orbit. What followed was a hefty monetary penalty of $900,000. This fine is substantial for a startup such as Swarm Technologies and ultimately heightened awareness surrounding the importance of regulatory compliance. Swarm continued to operate and receive approval for their subsequent launches. Although debated, it was of general consensus that the circumstances surrounding Swarm's infractions and subsequent penalty provide a good example of an enforcement regime correcting a deficiency so as to prevent further infractions.

Unfortunately, it is probable that the same cannot be said for DISH Network, especially considering the company's size. DISH's infraction arose through a disposal of a satellite at *less than half* the required distance from Earth articulated in their license. Given the significance of space debris, this begs the question of whether DISH's $150,000 penalty was proportionate to their actions.

The argument can go both ways. The roundtable participants were not advocating for an enforcement regime where one infraction puts a company at risk for bankruptcy. A fine of $150,000 *could* be enough to encourage a company like DISH to take greater precautions in their disposal of satellites. However, this belief is slightly curtailed when considering the fact that DISH's annual revenue exceeds $16 *billion*. Therefore, is a fine of $150,000 *actually* effective at changing inadequate behavior?

Regardless of the effectiveness of DISH's $150,000 penalty, it was generally agreed upon among the participants that consent decrees increase the likelihood that fines are actually collected. This is crucial. As mentioned, a recurring issue recognized by multiple participants is the lack of accountability. It is often that activities in space break regulation without any consequences. However, civil penalties like consent decrees offer a potential remedy. In addition, it was noted that purely focusing on monetary penalties can result in overlooking other typical aspects of consent decrees, in particular the compliance plans that focus on steps to avoid repetition of the undesired behavior.

Taking Action

Among the final comments made between participants was how to move forward with an enforcement regime. Many countries, including the U.S., cannot decide who is supposed to be in charge. As for the U.S.'s role, one participant mentioned the human problem with power sharing. It is common for committees and regulatory agencies to get upset that certain powers are being taken away from their authority to regulate space activities, describing their bickering as "chaos." Order is needed, particularly for the U.S., which is among the world's leaders when it comes to space activity.

> *Space is a warfighting domain, and it is the only place where we have war, peace, and commercial operations going on at the same time.*

Additionally, since the U.S. DOD has begun openly calling space a warfighting domain, the risk of satellite hacking has become extremely worrisome due to the military's dependence on space as a resource. Although it has not happened yet, one participant mentioned their certainty that, at some point, countries will begin targeting other countries' satellites. This carries a multitude of implications that would lead to a poisoning of the well for everyone. Thus, this must be addressed immediately.

Lastly, a list of questions was offered by one participant, beginning with the question of who is to pay for these enforcement measures? There is a need to quantify the burden of an object remaining in orbit so the community is capable of valuing the price of its removal. Additionally, many questions were left unanswered at this roundtable, including:

1. When is an object considered "abandoned" in space?
2. Who is the owner of the debris, and are they willing to give away their rights?
3. Who has liability if removal goes wrong?
4. Who has the right to remove existing debris?

All in all, the pressure to take action grows as the days go on. The idea of space being used as a weapon carries with it the weight of responsibility for international leaders to decisively take enforcement actions. However, shedding barriers between cultures and the desire to have the final word in regulating and enforcing is necessary to have any beneficial conversation.

Key Findings and Recommendations

The participants provided the roundtable with several crucial questions, comments, and recommendations on how to move forward with enforcement in space. Below is a short summary of their key findings:

- **Goals Must Be Established**
  - Laying the groundwork for establishing a strong enforcement regime begins with articulating the goals of the international space community.
- **Current Measurement Practices are Insufficient**
  - Measuring activity in space is of equal importance to articulating the goals of the international space community. However, current methodologies are insufficient, leading to inadequate enforcement, limited cooperation, and a restricted understanding of negative externalities of space activities.
- **Cross-Cultural Misinterpretation Injures Uniformity in Registration and Compliance**
  - Understanding conflicting cultural interpretations in treaties and established registration standards is crucial to achieving consistency among the various actors.
- **Accountability is Severely Insufficient**
  - Accountability for infractions in space activities is extremely insufficient, resulting in a multitude of actors going against their licenses, international treaties, and regulations without seeing any form of repercussion.

Following from the participants' key findings is a list of important recommendations for further discussion at an upcoming conference:

- **Appropriate Space Activity Tradeoff**
  - How can the international space community agree upon the appropriate tradeoff between space activities that are mutually exclusive? This includes the implication of increasing the number of satellites in orbit to improve space communications at the detriment of clear skies for radio astronomy.

- **Measuring Damages in Space**
  - Where is the appropriate starting point for measuring damages in space, both in terms of responsibility and methodology?
- **Measuring Activity in Space**
  - What is the best approach to measuring activity in space? Are third-party managers a sufficient resource to rely upon?
- **Cross-Culture Interpretations**
  - Considering communication barriers between nations, what is the best approach to addressing differing cultural interpretations of international treaties and regulations to acquire a broader and more consistent understanding?
- **Monitoring and Accountability**
  - In the interest of increased accountability, what are the specific detriments of current monitoring practices of space activities, and how can the international community move forward with adequate monitoring?

VI. Conclusion

The roundtable clearly revealed the need for more standards and regulations regarding the sustainability of space as a common resource. The lack of regulations puts space assets, terrestrial assets (radio telescopes), and various scientific enterprises at risk. However, while many (most?) stakeholders agree on the need for community standards and regulations, no entity is standing up to lead the effort. And it is unclear as to whether all stakeholders will ever agree to standards and regulations that negatively affect their self-interests.

That said, the consensus was that the community needs to move forward with discussions to preserve the *public well* that is space.

VII. Participants

Christopher Anderson – National Telecommunications and Information Administration

Jonathan Bair – Wilkinson Barker Knauer

Daniel Baker – University of Colorado Boulder

Brad Bernthal – University of Colorado Boulder

Matthew Burns – Cairn Engineering

Amber Charlesworth – Amazon Project Kuiper

Phil Erickson – MIT Haystack Observatory

Al Gasiewski – University of Colorado Boulder

Kevin Gifford – University of Colorado Boulder

Keith Gremban – University of Colorado Boulder

Dale Hatfield – University of Colorado Boulder

Siamak Hesar- Kayhan Space

Moriba Jah – University of Texas Austin

Kelsey Johnson – University of Virginia

Karl Kensinger – Federal Communications Commission

Vivek Krishnamurthy – University of Colorado Boulder

Jennifer A. Manner – National Telecommunications and Information Administration

Lynna McGrath – National Aeronautics and Space Administration

Ed Perlmutter – Holland and Knight

David Redl – Saltpoint Strategies

David Reed – University of Colorado Boulder

Zach Rosenbaum – DLA Piper

Jonathan Skinner-Thompson – University of Colorado Boulder

Milton "Skip" Smith – Greenberg Traurig

David St. John-Larkin – Perkins COIE

Peter Tenhula – University of Colorado Boulder

Stefan Tschimben – University of Colorado Boulder

Jennifer Warren – Lockheed Martin

VIII. Acronyms

COPUOS	Committee on the Peaceful Uses of Outer Space
CPS	Centre for the Protection of the Dark and Quiet Sky from Satellite Constellation Interference
DHS	Department of Homeland Security
DOD	Department of Defense
DOJ	Department of Justice
DOS	Department of State
EoL	End-of-Life
EPA	Environmental Protection Agency
ESA	European Space Agency
FCC	Federal Communications Commission
GEO	Geostationary Earth Orbit
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
IADC	Inter-Agency Space Debris Coordination Committee
IAU	International Astronomical Union
ICANN	Internet Corporation for Assigned Names and Numbers
ICG	International Committee on Global Navigation Satellite Systems
IP	Internet Protocol
ITU	International Telecommunications Union
LASP	Laboratory for Atmospheric and Space Physics
LEO	Low Earth Orbit
MSS	Mobile-Satellite Services
NASA	National Aeronautics and Space Administration
NGSO	Non-Geostationary Satellite Orbit
NOAA	National Oceanic and Atmospheric Administration
NRDZ	National Radio Dynamic Zone
NSF	National Science Foundation
NTIA	National Telecommunications and Information Administration

OOBE	Out-of-band emissions
OST	Outer Space Treaty
RF	Radio Frequency
RFI	Radio Frequency Interference
SCS	Supplemental Coverage from Space
SDA	Space Domain Awareness
SSA	Space Situational Awareness
SSC	Space Safety Coalition
SZM	Shielded Zone of the Moon
UN	United Nations
UNOOSA	United Nations Office for Outer Space Affairs
WRC	World Radiocommunication Conferences

IX. About Silicon Flatirons Center

Mission

Silicon Flatirons' mission is to elevate the debate surrounding technology policy issues; support and enable entrepreneurship in the technology community; and inspire, prepare, and place students in these important areas. Learn more at siliconflatirons.org/about-us/.

Spectrum Policy Initiative

Spectrum policy dictates how, where, and when wireless services can be delivered to devices—and it has deep ramifications for the economy, scientific development, national security, personal enjoyment, and more. Since 2005, Silicon Flatirons has explored the intersection of policy and engineering in the heavily regulated and rapidly changing wireless services industry.

Silicon Flatirons convenes stakeholders and provides law and engineering students with a foundational understanding of spectrum policy. The Spectrum Policy Initiative engages a wide range of wireless industry professionals, radio engineering professionals, and spectrum policymakers from Colorado, Washington, D.C., and across the country.

Learn more about the Spectrum Policy Initiative and other Silicon Flatirons Initiatives at siliconflatirons.org/initiatives/.

Our Team

For more information about center leadership, faculty, staff, fellows, and advisory board, visit siliconflatirons.org/about-us/our-team/.

Our Supporters

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We promote thought leadership and intellectually honest discourse not only in our events, but in publications from our team, our roundtables, and scholars presenting at our conferences. See more at siliconflatirons.org/publications/.