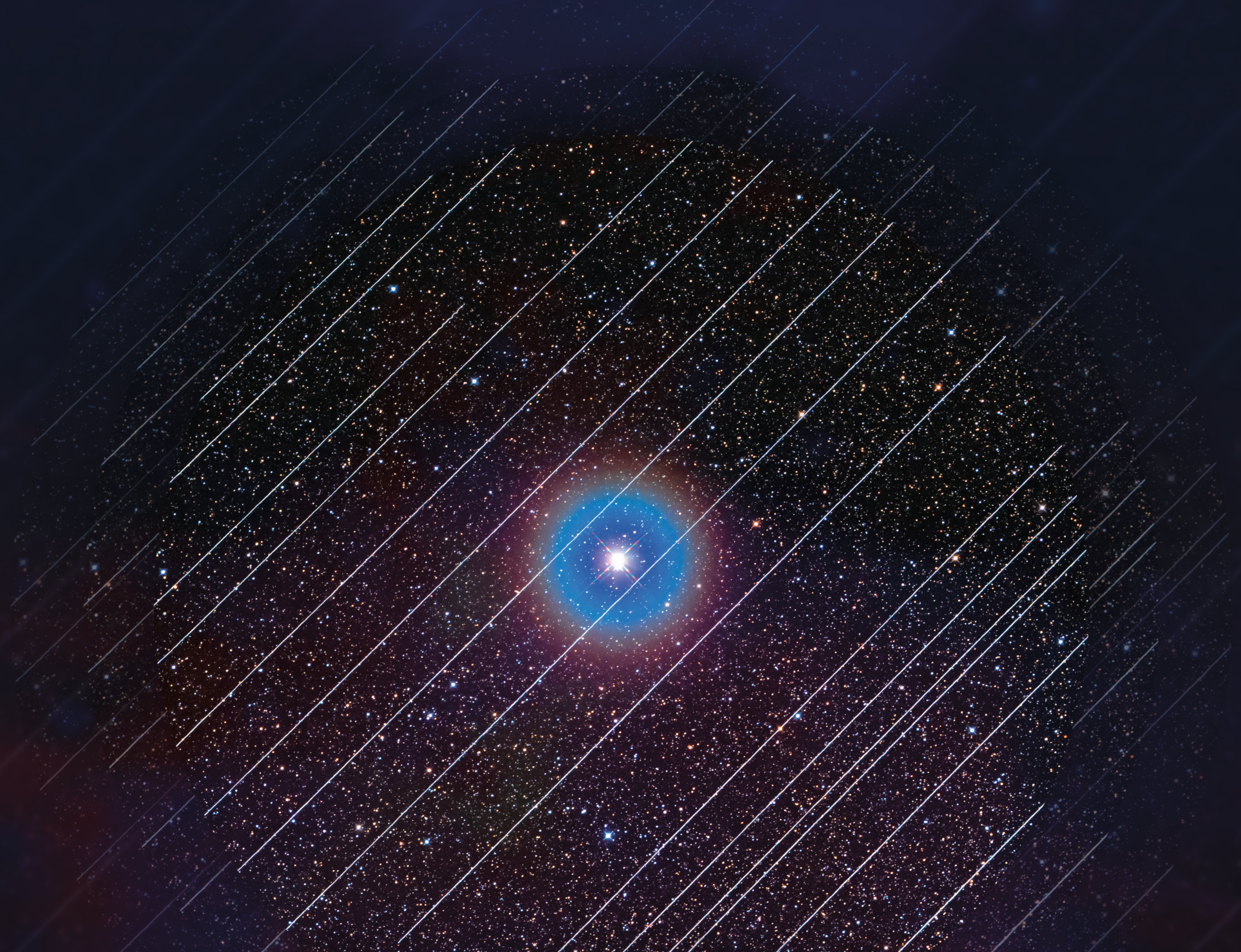

# SATCON2

## Policy Working Group Report

NOIR Lab AURA AAS

# SATCON2 Policy Working Group Report

## Contributors and Discussants


| | | | |
|---|---|---|---|
| Richard | Green | University of Arizona/Steward Observatory; Chair | USA |
| Lori | Allen | NSF's NOIRLab | USA |
| Lauren | Andrade | University of Mississippi/Air & Space Law | USA |
| Jurgen | Bohnlein | OneWeb Airbus | USA |
| Aaron | Boley | University of British Columbia | CA |
| Patricia | Cooper | Satellite Industry Advisor | USA |
| Mat | Dunn | SpaceX | USA |
| Andrew | Falle | Outer Space Institute | CA |
| John | Grunsfeld | NASA ret. | USA |
| Michelle | Hanlon | University of Mississippi/Air & Space Law | USA |
| Ruskin | Hartley | International Dark-Sky Assoc. | USA |
| Chris | Hofer | Amazon/Kuiper | USA |
| Ram | Jakhu | McGill U/Space Law | CA |
| Gerry | Jansson | Telesat | USA |
| Therese | Jones | Satellite Industry Association | USA |
| Doug | Knox | SpaceX | USA |
| Kelsie | Krafton | American Astronomical Society | USA |
| Harvey | Liszt | NRAO | USA |
| Nishith | Mishra | McGill U/Space Law | CA |
| Charles | Mudd | Mudd Law | USA |
| Joel | Parriott | American Astronomical Society | USA |
| Erica | Rosenberg | NRDC Consultant | USA |
| Phil | Puxley | AURA | USA |
| Vikram | Raval | AST&Science | USA |
| Giuliana | Rotola | Moon Village Association | DE |
| Ray | Sedwick | AST&Science | USA |
| Andrew | Simon-Butler | Outer Space Institute | CA |
| Joshua | Smith | University of Mississippi/Air & Space Law | USA |
| Maurizio | Vanotti | OneWeb | UK |
| Connie | Walker | NSF's NOIRLab; SATCON2 Co-Chair | USA |
| Andrew | Williams | European Southern Obs. | DE |


We are grateful for the constructive comments of Mark Mulholland and Dianne Poster from their perspective of the Office of Space Commerce.

## Table of Contents

# 1. Executive Summary

This report is part of a collection of Working Group Reports from the SATCON2 Conference.

The charge to the SATCON2 Policy Working Group was to review existing national policies and legislative frameworks. With the SATCON1 recommendations as context, the group was charged to assess policy options to serve the diverse requirements of astronomy, the satellite industry, and other communities.

## 1.1. International Law and Treaties

The international shared use of "outer space" has a heritage in the international approach to Antarctica. The Antarctic Treaty articulates three core principles: peaceful use, scientific exploration, and protection of certain identified components of the Antarctic environment. The last two principles provide policy support to the need to protect Earth's dark skies. And all three principles are mirrored in the 1967 Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (the "Outer Space Treaty", hereinafter the OST), elaborated within the United Nations (UN) Committee on the Peaceful Uses of Outer Space (COPUOS). The OST is a legally binding instrument for the States that have signed and ratified it (110 ratifications and 23 signatures to date). The foundational principle of the OST and related UN space treaties, namely the freedom of exploration and use of space, has been recognized as customary international law, binding all States.[1] The last sentence of Article I states that "[t]here shall be freedom of scientific investigation in outer space" and that "States shall facilitate and encourage international co-operation in such investigation." This aspect is exceptionally relevant to mitigating the impact that satellite constellations may have on astronomy, which could be partially mitigated with a continuous exchange of information and data. Article IX of the OST suggests that the US and other parties to the OST have an obligation to implement activities in space with "due regard" to the corresponding interests of other States in respect of potential light pollution created by satellite constellations. This language could also be used to encourage other States to adopt licensing conditions that will lessen the impact of satellite constellations on astronomy — anywhere in the world -— to the greatest degree practicable.

1 https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/status/index.html

Another of the most relevant limitations to the activities of States and other actors in the exploration and use of outer space can be found in Article II of the OST, which establishes that "Outer space, including the Moon and other celestial bodies, is not subject to national appropriation by claim of sovereignty, by means of use or occupation, or by any other means." The conditions for a safe, stable and sustainable environment should not ignore considerations regarding the impact that space activities, albeit coordinated, can have on ground-based activities and should not overlook the application of fundamental principles of international law for the development of exploration and use of space, such as the non-appropriation principle, correlated with freedom of access, principles of fairness and regard for the interests of other actors. A change would therefore be necessary at the international level to ensure that the first-come, first-served allocation practices for non-geostationary orbits are gradually replaced with more equitable procedures capable of responding to the emerging needs prompted by the spread of satellite constellations.

The legal principles contained in Article VI of the OST, namely (a) State responsibility for national space activities, including those pursued by nongovernmental entities; and (b) authorization and continuing supervision of such activities by a State, provide two important safeguards for the conduct of space activities by non-governmental entities of a State. The US position has always been that private agencies would not be free to engage in space programs without governmental permission and continuing governmental supervision. Evidence of current and potential interference to astronomy is being submitted by the American Astronomical Society (AAS) and other stakeholders, so the obligation of the US government to maintain "continuing supervision" could be interpreted, at the very least, as demanding a thorough inspection into this matter and further consideration of appropriate measures to safeguard its own interests as well as those of all its actors, governmental and non-governmental entities alike. In the event of transboundary impact/harm/damage (present as well as future), it is recognized that the US maintains the view that States will not necessarily be responsible for the liability of private entities/actors; however, Article VI of the OST suggests that this position cannot be taken in respect of space activities. A **good starting point would be to conduct due diligence concerning the activities of commercial satellite operators, specifically as regards the impact of in-orbit operation of such activities.**

Astronomy plays an integral role in planetary defense, a core mission of COPUOS. Thus, as a policy consideration, planetary defense considerations support the inclusion, as a condition of licensing, of an obligation to reduce the impact (if any) of satellite constellations on telescopes used for planetary defense to the greatest degree practicable. Altogether, we do not expect large constellations to prevent planetary defense from operating. Rather, they could under certain conditions cause delays in the identification of objects, which could have widespread ramifications if an object is on an Earth-impact trajectory. This will further affect responses by numerous US government agencies and could delay an internationally coordinated response.

The Working Group considered whether planetary protection policy (PPP) might provide considerations for the impacts of satellite constellations on astronomy. The motivation is that satellite constellations have the potential to contaminate the night sky and cause harm to astronomical observations, as well as enjoyment of the night sky. As astronomy is one of the foremost ways we study and explore space and is advanced by multiple agencies within States, activities that "*would cause potentially harmful interference* *with activities of other States Parties in the peaceful exploration and use of outer space*," in the language of OST Article IX, are intended to be subject to international consultations.

## 1.2. US National Law

A variety of existing local, state and national regulations and laws, coupled with the policy rationales for those measures, support the inclusion, as a condition of licensing commercial satellites and in particular satellite constellations, of an obligation to reduce the detrimental effect of such satellites on astronomy to the greatest degree possible.

In the US, a growing number of federal, state and local ordinances and regulations are being implemented to address the threats posed by light pollution. The main thrust of these efforts is to address the persistent light pollution generated by terrestrial lighting fixtures and:

- the consequential effect on wildlife;
- the aesthetic impact on recreational viewing of the night sky;
- related energy consumption; and
- in some cases, the effect on astronomy.

These regulations and ordinances are localized, deal with persistent lighting fixtures and generally cover light visible to the naked eye. Conversely, satellite constellations generate diffuse or reflected light that is generally visible to the naked eye in dark skies only temporarily, post-launch and prior to orbit raise. Additionally, the cumulative effect of all satellites and debris results in an overall brightening of the sky that, while not detectable by the naked eye, may be observed with astronomical instruments. However, the goal — to preserve the environment for astronomy — remains the same and only the means to achieve the goal will differ. Nineteen US states, plus Washington, DC and Puerto Rico have enacted laws to address light pollution. Many localities are referring to the principle-based outdoor lighting model ordinance of the International Dark-Sky Association and the Illumination Engineering Society in establishing their regulatory frameworks.

Federal agencies are now also taking affirmative steps to protect the sky at night from light pollution. The federal system of protected lands has grown, and agencies have come to recognize that a naturally dark, star-filled sky is an intrinsic part and a critical aspect of the park or wilderness experience. While the focus of the federal system is on the visual experience of visitors, the fact must be recognized that light pollution that can ruin aesthetic experiences will also be ruinous to astronomy. Certainly, to those who benefit from astronomical research — which, it may be argued, is nearly everyone — utilitarian concerns may be considered to be vastly more important than scenic. Consequently, an effort to protect the beauty of the skies can, by inference, be considered to require the protection of the astronomical value of the skies.

Directly relevant as the basis for federal agency protection of full natural landscapes, including the dark night sky, are The Antiquities Act of 1906 establishing National Monuments, The Organic Act of 1916 creating the National Park Service (which now has a Natural Sounds and Night Skies Division), and the Wilderness Act of 1964 with a system now including 803 wilderness areas. The three most recent declarations of National Monuments contained specific reference to the value of pristine night skies.

There are several precedents in Federal regulation and agency policy implementation for protecting dark and quiet skies. 51 USC 50911 explicitly prohibits space-based advertising visible to the naked eye. Congress authorized NASA in 2005 to conduct sensitive surveys in service of planetary defense against near-Earth asteroids. The very fact that light pollution may have an effect on planetary defense supports the need to include as a condition of licensing an obligation to reduce the impact of satellite constellations on astronomy to the greatest degree possible. A National Radio Quiet Zone (RQZ) in West Virginia is established by federal statute. Although it is protected from radio interference only by stationary sources, the principle of having a sensitive zone meriting special protection is valuable.

The National Space Traffic Management (STM) Policy articulates the principles for a safe, stable and sustainable operational space environment. The US National Oceanic and Atmospheric Administration (NOAA) and Federal Aviation Administration (FAA) have recently revised their policies to take these STM principles into account, as did the US Federal Communications Commission (FCC) as part of their licensing considerations. There are three implications for licensing requirements. One is the precedent that these agencies can and do consider at least one aspect of in-orbit operations as a condition of licensing. Another is that aggregate effects can and should be taken into account, relevant to the cumulative impact of all orbital material in brightening the diffuse sky glow. The third is that the FCC can pursue regulations that address perceived issues of the space environment without invoking or relying explicitly on environmental statutes like the National Environmental Policy Act of 1969 (NEPA).

## 1.3. Considerations Regarding Orbit as Environment

Article III of the OST makes clear that States must carry out activities in outer space in accordance with international law. The effect of this concept was articulated in the the 2018 Guidelines for the Long-Term Sustainability of Outer Space Activities (LTSG) which indicate that States should build upon principles of international law "*when developing and conducting their national activities in outer space*." In particular, the LTSG recommends that in drafting national legislation, States should address to the extent practicable risks to the environment associated with in-orbit operating and support the idea of minimizing the impacts of human activity on the outer space environment.

The LTSG can be interpreted as requiring, as part of the licensing process, due diligence in respect of potential environmental harm — or the preparation of an environmental impact statement (EIS). A 2018 report prepared by the Secretary General of the UN concluded that the "prevention principle" — the prevention of transboundary harm to the environment — is a well-established rule of customary international law. The UN report further concluded that the prevention principle creates a duty to undertake an Environmental Impact Assessment (EIA) prior to engaging in activities which pose a risk of transboundary harm.

The concept of prevention of transboundary damage suggests that States have a responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States or areas beyond the limits of natural jurisdiction. While the US has stated its position that a State is not in general liable for transboundary harm caused by private entities, this precept cannot apply to space activities given the OST Article VI construct which makes States responsible for the private activities of their nationals in space.

As established by SATCON1, large satellite constellations create an environmental impact due to the light pollution generated as a result of the reflectivity factor of the spacecraft. If one accepts the prevention principle as a rule of Customary International Law, adding the OST Article VIII statement that space objects remain within the jurisdiction and control of the State Party who launched it, then it can be surmised that States must work to assure their nationals reduce the potential environmental impact of their in orbit activities.

US law also considers the effect of human activity on the natural environment. NEPA was enacted in recognition, by the US Congress, of the "*profound impact of [hu]man's activity on the interrelations of all components of the natural environment*". Within NEPA, the Council on Environmental Quality (CEQ) was created to review all government programs in light of national environmental policy. All federal agencies must consult with the CEQ and complete EISs in respect of any actions that will have a significant effect on the environment.

However, certain definitions used within US environmental policy are unclear, including the definition of "human environment." While the term suggests a narrow concept of the environment, namely as it directly affects humans, the definition itself places no limits on the concept of natural or physical environment, leaving open the argument that, the use of the word "human" aside, NEPA is intended to cover all of Earth, its orbital environment and all other celestial bodies.

Within these strictures, it is recognized that the FAA construes NEPA and the CEQ Implementing Regulations broadly and indicates, among other things, that it recognizes light emissions as possibly in the environmental impact category. The FCC, which licenses satellite constellations, does not consider its licensing activities to require EISs.

We note that the processes inherent in the application of NEPA address a concern articulated in the Community Engagement report. Consultation is required with impacted stakeholders, which could be extended to indigenous communities with respect to their cultural relationship with natural dark skies. That process could then satisfy some expectations of the UN Declaration on the Rights of Indigenous Peoples (UNDRIP). We also note that the practical production of a full EIS can be a costly and time-consuming endeavor, of concern to industry in a highly competitive environment.

## 1.4. Industry Perspective

Within the SATCON2 Policy Working Group, the Industry Subgroup brought together industry representatives, astronomers and others to explore the feasibility of recommendations for implementation and where appropriate, to consider how best to advance and refine them. The Industry Subgroup included discussants from SpaceX, Amazon/Kuiper, OneWeb and OneWeb/Airbus, Telesat, AST&Science, and the Satellite Industry Association. The context was to ensure that satellite operators with a sense of a corporate responsibility had access to sufficient insight to astronomical concerns, analytical tools and testing, and cross-industry collaboration for information sharing on mitigation techniques to develop satellite systems mindful of their effect on astronomy. The conclusions do not represent official corporate policy, but rather the continuation of needed technical discussion between industry and the astronomical/dark sky community. They are also an expression of industry intent to be responsive to the technical recommendations of SATCON1 to the extent that solutions are possible and practical, and to generate broader awareness of the impact of their operations on observations and practices dependent on a traditional dark sky.

The Industry Subgroup concluded that satellite operators were more likely to adopt voluntary practices or mitigation tools if they engaged with astronomers early in their project cycle, before spacecraft designs were finalized and when modifications to architectures, spacecraft design or operations could be introduced at less cost or schedule impact. Further, the group concluded that more work was required to ensure that analytical tools, test facilities and observational data are widely available to satellite operators, and are cost-effective, so that their adoption does not disrupt either budgets or schedule for their project.

Building on SATCON1 and the primary concern of brightness, the Industry Subgroup recommends that astronomers continue to develop a hierarchy of additional characteristics of spacecraft, operations and/or altitude for satellites/constellation systems that would indicate to owner/operators either that they have a low/no concern from a reflection perspective, or that they have a high level of concern. These may include key characteristics that exclude/capture a constellation, such as the altitude, number of satellites, design of satellites, and the satellites' shape, surface or materials used. Astronomers should perform the same exercise on the recommendations that apply to them.

The Industry Subgroup also explored the possibility of recommending designs, materials and operations to limit impact on astronomy from cubesats and smaller satellites for remote sensing or Earth imaging. Commercial communications are being launched in larger numbers in the near term and typically weigh more than even the new generation of commercial remote sensing satellites, and should certainly remain the primary for technical work and stakeholder outreach. However, little technical work has been undertaken on the impact of cubesats and commercial remote sensing satellites, and deployments of both types of satellites are growing rapidly. Developing clear and early guidance would improve awareness and voluntary adoption of techniques among operators of these additional types of satellites that could lessen the impact on astronomy. All projects should be given guidance to minimize reflectivity. All satellite projects should be encouraged to minimize nadir-facing specular surfaces and maintain robust orbital attitude control to minimize flares and glints.

Given that each proposed satellite constellation to date features distinct spacecraft designs, orbital architecture and business model, the assessment of visibility, potential to disrupt optical observation and potential for effective mitigation approaches at pre-deployment phases are best assessed in a customized way, constellation by constellation. A centralized hub for communicating such evaluations would help reduce confusion and speed the process for assessing mitigation strategies. The International Astronomical Union (IAU) has taken the lead in establishing a "Centre for the Protection of the Dark Sky from Satellite Constellation Interference." It is recommended that operators, as a first step, share and publish their experience and lessons learnt across the community, in order to build understanding of mitigation design techniques and foster innovation in new concepts.

Industry R&D efforts can be focused on the most impactful problems if guided by the development of an “impact metric” to depict the relative effect of satellite visibility on various astronomy fields, not just the types of telescopes or observations, but also their frequency or proliferation. While this may be a problematic value judgement for the astronomy community to adopt broadly, it could be considered on a constellation-by-constellation basis as part of the SatHub concept discussed elsewhere in the SATCON2 workshop.

Ideally, modeling and testing for impacts on astronomy would become routine for satellite constellations, and all satellite operators would interject into the design phase a step to model their spacecraft to predict accurately the likely visibility well before designs are set and any test articles are fabricated. Further, prior to deployment, any demonstration satellites would ideally be subjected to ground testing, as well as the kind of systematic observation measurements of brightness once launched. While testing for reflection and albedo during the development stage is a worthwhile goal, these are relatively new engineering protocols. Given the newer nature of this consideration, additional experience and development are needed to allow for a mature capability to the point where willing satellite operators can readily access reliable and cost effective testing tools.

Satellites deorbiting as part of their end of life (EOL), a requirement for space safety, present several complications for astronomy. For mature constellations that require continuous replacement and EOL maneuvers of satellites, the deorbiting satellites could lead to a non-negligible addition to the bright satellite population. This is expected to be more acute for long deorbiting timescales, even when adhering to the 25-year rule. Moreover, satellites that are passively deorbiting are expected to tumble, which will cause variations in satellite brightness, with the possibility of bright transients. Such variations have the potential to cause significantly greater data loss than those under active control meeting the recommended brightness limit. On-orbit aging of satellites, whether active or defunct, could further lead to changes in satellite brightness or variability. For these reasons, satellite operators should deorbit their satellites as soon as practicable upon satellites reaching their end of mission, consistent with the US government’s Orbital Debris Mitigation Standard Practices (ODMSP) 4-1(a).

Because the technical and practical inquiry into mitigation techniques is still at an early stage, the Industry Subgroup endorses an outcome-driven focus for any mitigation recommendations and guidelines, rather than overly prescriptive language that stipulates a specific technology or technique. The community should continue its work to establish data-driven, well-defined standards and requirements based on continued research, modeling, and analytical efforts, and promote meeting these desired performance-based outcomes. With such dynamism and iteration in mitigation techniques and ongoing work to evaluate their effectiveness, recommendations should incentivize further innovation and leave room for variations in mitigation approaches that may be suitable for different types of constellations and operators.

# 2. Introduction

Both the SATCON1 and the subsequent Dark and Quiet Skies Workshops identified various recommendations for operators of satellite constellations to consider in order to mitigate their impact on optical astronomy. An emphasis of the SATCON2 Workshop was on paths to implementation of the technical recommendations of SATCON1.

The charge to the SATCON2 Policy Working Group was to review existing national policies and legislative frameworks. With the SATCON1 recommendations as context, the group was charged to assess policy options to serve the diverse requirements of astronomy, the satellite industry, and other communities.

To address these charges, the Working Group focused on three specific areas and structured the work through three subgroups with overlapping membership: international law and policy; US national law and policy; and industry perspective. All three focused their attention on the current playing field, whether in law, policy, or practice, of satellites' effects on ground-based astronomy.

## 2.1. Industry Subgroup

Within the SATCON2 Policy Working Group, the Industry Subgroup brought together industry representatives, astronomers and others to explore the feasibility of these earlier recommendations for implementation and, where appropriate, to consider how best to advance and refine them. The Industry Subgroup included discussants from SpaceX, Amazon/Kuiper, OneWeb and OneWeb/Airbus, Telesat, AST&Science, and the Satellite Industry Association. Co-conveners were Chris Hofer of Amazon/Kuiper and Patricia Cooper, an industry advisor. The subgroup set out to identify viable tools that willing satellite owner/operators can readily use to evaluate, test, mitigate and field spacecraft in a manner that limits impact on ground-based optical astronomy.

The context was to ensure that satellite operators with a sense of a corporate responsibility had access to sufficient insight to astronomical concerns, analytical tools and testing, and cross-industry collaboration for information sharing on mitigation techniques to develop satellite systems mindful of their effect on astronomy. The conclusions do not represent official corporate policy, but rather the continuation of needed technical discussion between industry and the astronomical/dark sky community. They are also an expression of industry intent to be responsive to the technical recommendations of SATCON1 to the extent that solutions are possible and practical, and to generate broader awareness of the impact of their operations on observations and practices dependent on a traditional dark sky.

The Industry Subgroup noted that since SATCON1 took place in 2020 considerable progress has been made to raise awareness within the communications satellite sector that large constellations of satellites can have adverse impacts on astronomical discovery. Active outreach and engagement by the AAS, the Satellite Industry Association, the National Science Foundation (NSF), the IAU, along with regular discussions at conferences and frequent coverage in trade press and even mass media have improved the likelihood that new satellite operators in the US will consider their impact on astronomical observation when developing a new satellite system. In addition to SpaceX's active engagement over the past two years, others currently deploying or planning satellite broadband constellations are now participating in policy and technical discussions, including Amazon's Kuiper, OneWeb, and others. Further work remains to engage other newer satellite operators and those proposing constellations for purposes other than communications and broadband.

## 2.2. International Subgroup

The goal of the authors within the International Law and Policy Subgroup was to:

- identify how international obligations are implemented by US regulatory and policy mechanisms, with specific regard to international space law and international environmental law;
- identify any gaps; and
- suggest where the implementations could be strengthened.

The Convener was Giuliana Rotola, with Vice-Convener Andrew Williams, both of the European Southern Observatory. The members sought a few case studies of space and environmental regulations in other countries to provide supportive comparisons to the US case. There are, at present, no international/multilateral/bilateral agreements or formal understandings of any kind addressing the issue of interference with astronomy. This issue did not emerge until large constellations began deploying into low Earth orbit (LEO). The findings of the authors are preliminary and will be further developed.

## 2.3. US National Subgroup

The goal of the US National Subgroup was solely to make the policy case for including as a condition of licensing an obligation to reduce detrimental effects[2] of satellite constellations on astronomy to the

2 We note that 40 CFR § 1508.8; 48 USC §§4321 ***et. seq.*** define the term "effects" to include:

Direct effects, which are caused by the action and occur at the same time and place.

Indirect effects, which are caused by the action and are later in time or farther removed in distance, but are still reasonably foreseeable. Indirect effects may include growth inducing effects and other effects related to induced changes in the pattern of land use, population density or growth rate, and related effects on air and water and other natural systems, including ecosystems.

Effects and impacts as used in these regulations are synonymous. Effects includes ecological (such as the effects on natural resources and on the components, structures, and functioning of affected ecosystems), aesthetic, historic, cultural, economic, social, or health, whether direct, greatest degree practicable. The Convener was Michelle Hanlon, co-Director of the Center for Air and Space Law at the University of Mississippi School of Law, with Vice-Convener Joshua Smith, JD, LLM candidate in Air and Space Law at the University of Mississippi. The subgroup considered the FAA and the FCC to be the two agencies most likely to administer such licenses.

The subgroup focused narrowly on the impacts on astronomy of increased light pollution as generated by:

the increase in artificial light caused by the sheer volume of satellites which redirect sunlight, adding to the diffuse natural glow of the night sky;

reflectivity issues of the individual satellites; and the increase in visual disruption due to the sheer volume of space objects.

The US National Subgroup found a growing recognition of the detrimental effect of light pollution both as an aesthetic matter and specifically as it interferes with astronomy, as evidenced by the implementation of local, state and national ordinances, laws and regulations.

Rationale for the implementation of licensing conditions can also be found in relation to the role astronomy plays in respect of planetary defense, to the extent any detrimental effect is found.

The US National Subgroup made note of the concern that unilateral licensing conditions may cause satellite operators to seek licenses in jurisdictions without such constraints and found that national responsibilities imposed by international treaties may be used to counter this concern. Members also acknowledged that the US is a very attractive market for telecommunications, a benefit which may offer a counterbalance against costs related to an elevated regulatory burden.

The US National Subgroup also considered STM and RQZs as possible models for the development of licensing conditions.

With respect to each policy rationale, a balance must be achieved. The effect and the level of impact reduction must be weighed against the use of satellite constellations to provide broadband to unserved areas of the world providing important life-saving and educational opportunities where they previously did not exist and where other infrastructure possibilities are too impractical to pursue or would be worse for the environment. Moreover, satellites in general are also integral to national security and planetary defense measures.

The US National Subgroup approached its analysis from three different angles:

1. focusing on how satellite constellations are impacting the terrestrial human environment.
2. conceptualizing LEO as part of the human environment; and
3. embracing the perception that LEO is an environment that needs to be protected.

The US National Subgroup did not reach consensus with respect to points two and three.

---

indirect, or cumulative. Effects may also include those resulting from actions which may have both beneficial and detrimental effects, even if on balance the agency believes that the effect will be beneficial.

## 2.4. Full Policy Working Group

This paper combines the findings of each of the subgroups. The full considerations of each subgroup are contained in the subsequent sections. We also note that there are two outstanding issues that are beyond the current remit but will require consideration:

1 the reality that there currently exists no national or international regulation of on-orbit activities of any kind beyond the OST restriction on the placement of weapons and the general concepts of due regard, harmful contamination, and harmful interference; and
2 the need to aggregate impact and the application of such aggregation in an equitable manner across industry and sovereign States.[3]

In the Policy Working Group's positive engagement among satellite industry representatives, legal/policy scholars and astronomers, no consensus was reached regarding the standards and requirements that might be imposed as part of the licensing conditions. The Policy Working Group takes note of the industry perspective that:

1 such conditions should ultimately be data-driven, well-defined standards and requirements based on continued research, modeling and analytical efforts to better inform and understand this new research area, and encourage operators to share data with the astronomy community;
2 licensing requirements should focus on general design approaches, strategies and performance-based metrics that enable operators to innovate with different mitigation strategies and should not rely on specific, overly-prescriptive mitigations; and
3 over-zealous regulations could result in satellite systems obtaining licenses outside of the US, creating a situation where the US has even less control over constellation impacts.

The structure of the report is as follows: Section II offers a global perspective on efforts and current legal regimes that could be used to mitigate the effects of orbital light pollution; Section III looks specifically at the US laws and policies within its jurisdictional territory regarding light pollution, generally, and how they might be applied to light pollution in orbit; Section IV introduces the industry perspective as prepared by the Industry Subgroup; Section V offers considerations regarding the consideration of orbit as environment; Section VI identifies some key concerns raised in the policy analysis; and Section VII articulates the industry perspective on the challenges of mitigating impacts.

3 *See* Friends of the Earth, Inc. v. US Army Corps of Engineers, 109 F.Supp.2d 30,43 (D.D.C. 2000) ("*the significant cumulative impacts of the multiple casino projects along the coast that the Court has discussed above warrant the preparation of an EIS*"). Here, the court noted that the goal of examining the cumulative impacts of a project is to prevent an actor from engaging in an activity that has a minimal impact on the environment but, when combined with the activity of other actors, results in a significant impact on the environment. ***Id.***

# 3. International Law and Treaties

## 3.1. Antarctic Treaty

By the 1940s, seven countries had made territorial claims in Antarctica.[4] Another five countries operated in Antarctica without making territorial claims.[5] Moreover, these five countries disregarded the territorial claims made by other countries.[6] Eventually, the US realized that continuing territorial claims could lead to problems and, in 1947, issued a policy statement advocating international action and agreement to address the Antarctic territorial problem.[7] In 1959, the US convened the Antarctic Conference that included the countries maintaining operations or claims in Antarctica.[8] At the Conference, the participating countries adopted the Antarctic Treaty.[9]

The Antarctic Treaty contains fourteen articles.[10] Arguably, the underlying principle of the Treaty establishes Antarctica as a region to be used for peaceful purposes.[11] To that end, the Treaty prohibits any claims of sovereignty (though it allowed claims existing at the time of the Treaty's coming into force to remain) and militarization. Indeed, it specifically prohibits military bases or fortifications. It also prohibits nuclear explosions, testing, and waste within the region.[12]

Two additional principles emerge from the Antarctic Treaty. With respect to science endeavors, Articles II and III of the Antarctic Treaty protect the freedom of scientific investigation in Antarctica (Article II) and require cooperation and transparency between State Parties in their scientific research (Article III). Indeed, the Treaty makes clear that scientific observations and results from Antarctica shall be exchanged and made freely available. Article IX reaffirms these concepts and the importance of "*scientific*

---

4 Jonathan Blum, ***The Deep Freeze: Torts, Choice of Law, and The Antarctic Treaty Regime***, 8 Emory Int'l L. Rev. 667, 670 (1994); Ottavio Quirico, ***Climate Change, Regionalism, and Universalism: Elegy For The Arctic and The Antarctic?,*** 35 Am. U. Int'l L. Rev. 487, 491 (2020). The countries making territorial claims were Argentina, Australia, Chile, France, Norway, New Zealand, and Great Britain (United Kingdom).

5 These were Belgium, Japan, South Africa, the Soviet Union, and the United States.

6 Colin Diehl, ***Antarctica: An International Laboratory***, 18 B.C. Envtl. Aff. L. Rev. 423, 433.

7 Blum, ***supra*** note 3, at 671.

8 Quirico, ***supra*** note 3, at 492.

9 ***Id.*** Following ratification, it required member states to ensure their activities did not violate the Treaty and encouraged them to implement measures consistent therewith.

10 Antarctic Treaty, Dec. 1, 1959, 12 UST. 794, 402 U.N.T.S. 71 [hereinafter Antarctic Treaty].

11 Articles I and V of the Antarctic Treaty make clear that Antarctica shall be used solely for peaceful purposes and that State Parties shall not place or test nuclear weapons in the region.

12 Antarctic Treaty, art. V.

*cooperation*," "*scientific research*" and "*scientific expeditions*" in Antarctica. Additionally, Article IX introduced an environmental component to the Treaty. Specifically, it required further discussion on the "*preservation and conservation of living resources in Antarctica*."[13]

In essence, the Antarctic Treaty articulates three core principles: peaceful use, scientific exploration, and protection of certain identified components of the environment in Antarctica. Though the Treaty discusses the first two principles more thoroughly and explicitly, the third principle nonetheless clearly emerges — if only as an invitation for further discussion. Each of these three principles contributes to the OST that followed less than a decade later. As articulated below, the last two principles provide policy support to the need to protect Earth's dark skies.

## 3.2. The Outer Space Treaty: Freedom of Exploration and Use, and Limitations

Indeed, the principles of the Antarctic Treaty connect to those of the OST, elaborated within the United Nations Committee on the Peaceful Uses of Outer Space ("COPUOS"), and which entered into force in 1967.[14] The OST is a legal instrument that is binding on the States that have signed and ratified it (110 ratifications and 23 signatures to date[15]), with the foundational principles of the OST and related UN space treaties regarded as customary international law, binding *all* States[16].

Additional international developments moved the international community toward a space treaty. After the launch of the first artificial satellite in 1957, the international community and, more specifically, the United Nations recognized a need to establish regulations regarding space activities.[17] In 1961, as the joint initiative of the US and the former Soviet Union, the United Nations established COPUOS. The United Nations tasked COPUOS with establishing regulations for the peaceful uses, scientific exploration, and protection of space and celestial bodies.[18] COPUOS directed its Legal Subcommittee to consider and enact rules that would be harmonious between the actors of the international community that intended to use space. The same year, the United Nations General Assembly adopted Resolution 1721 relating to the peaceful uses of outer space.

In 1962, following comments from Soviet Chairman Kruschev, US President Kennedy proposed cooperation with the former Soviet Union on space science which led to agreement on four specific projects. Both countries also expressed their intentions "*not to station in outer space any objects carrying nuclear weapons or other kinds of weapons of mass destruction*."[19] The next year, the United Nations General Assembly adopted Resolution 1884 on the Question of General and Complete Disarmament that specifically acknowledged the expressions of the US and Soviet Union as well as calling upon all States to

13 *Id.*, art. IX.
14 Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies, Jan. 27, 1967, 18 UST. 2410, 610 U.N.T.S. 205 [hereinafter Outer Space Treaty].
15 "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 Disarmament Affairs https://treaties.unoda.org/t/outer_space.
16 Jakhu, Ram S. and Freeland, Steven, The Relationship Between the Outer Space Treaty and Customary International Law (2016). http://dx.doi.org/10.2139/ssrn.3397145.
17 Chairman, Legal Subcommittee of the Committee on the Peaceful Uses of Outer Space (COPUOS), ***Treaty On Principles Governing The Activities Of States In The Exploration And Use Of Outer Space, Including The Moon And Other Celestial Bodies***, at 1, (2008).
18 *Id.*
19 G.A. Res. 1884 (XVII), Question of General and Complete Disarmament (Oct. 17, 1963).

do the same. The United Nations General Assembly also adopted Resolution 1962 on the Legal Principles Governing the Activities of States in the Exploration and Use of Outer Space.[20]

Subsequently, in 1966, US President Johnson announced the need for a treaty relating to the exploration of space and proposed that international discussions begin to facilitate that purpose.[21] In doing so, he proposed six elements to be included:

> (1) freedom of exploration, (2) prohibition of claims of sovereignty, (3) freedom of scientific investigation and international cooperation, (4) studies to avoid harmful contamination, (5) mutual assistance among astronauts in case of need, and (6) a ban on the stationing of weapons of mass destruction, weapons tests and military maneuvers on celestial bodies.[22]

These elements echo the Antarctic Treaty principles of peaceful purposes,[23] scientific exploration, and matters related to the environment.[24]

In fact, congressional testimony supporting adoption of the treaty that followed President Johnson's directive clearly indicates that the Antarctic Treaty served as a foundation for the OST.[25] US Ambassador Arthur J. Goldberg made clear that the authors of the provisions focused on arms control, prohibitions on military fortifications, maneuvers, and weapons on celestial bodies, and the use of celestial bodies only for peaceful purposes drew from the corresponding provisions of the Antarctic Treaty.[26] A review of the relevant articles in the treaties further demonstrates this connection.[27] Specifically, Article IV of the OST correlates directly to Article I of the Antarctic Treaty in articulating that each respective area shall not be militarized and shall only be used for scientific and peaceful purposes.[28]

Further, Ambassador Goldberg stated that the provisions for "*freedom of scientific investigation in outer space*," "*international co-operation in such investigation*"[29] and the ability to use military in such investigations originate from the Antarctic Treaty. [30]

Article I of the OST establishes which activities are allowed in space, affirming the freedoms of exploration and use of outer space, the freedom of access to all the areas of celestial bodies, and the freedom of scientific investigation in outer space. Astronomical observations and satellite constellations constitute two legitimate ways of exploring and using outer space. However, coordination mechanisms are required to limit the impact and negative consequences caused by the interference between the two activities.

---

20 Chairman, Legal Subcommittee of the Committee on the Peaceful Uses of Outer Space (COPUOS), ***Treaty On Principles Governing The Activities Of States In The Exploration And Use Of Outer Space, Including The Moon And Other Celestial Bodies***, at 2 (2008).

21 ***Id.*** at 151.

22 ***Id.***

23 In his United States Senate testimony in favor of the Outer Space Treaty, then-NASA Administrator James Webb indicated that the drafters adopted a principle first articulated in the National Aeronautics and Space Act of 1958. ***Treaty on Outer Space: Hearings Before the Committee on Foreign Relations United States Senate***, 90th Cong. 157-158 (1967) (Referring to National Aeronautics and Space Act of 1958, P. L. No. 85-568, 72 Stat. 426-438, § 102).

24 See ***supra*** and generally Antarctic Treaty art. 1, 2, and 4, Dec. 1, 1959, 12 UST. 794, 402 U.N.T.S. 71.

25 90th Cong., ***supra*** note 1, at 80 (testimony of Deputy Secretary of Defense Cyrus R. Vance).

26 ***Id.*** at 149, 153.

27 Not surprisingly, the procedural provisions in the OST reflect nearly verbatim those of the Antarctic Treaty. Outer Space Treaty, art. 13–17; Antarctic Treaty, 11–14.

28 Outer Space Treaty, art. I; Antarctic Treaty, art. 4.

29 Outer Space Treaty, art. 1.

30 90th Cong., ***supra*** note 21 at 53, 154.

The scope of the following analysis is to verify whether the US national space legislation and policies meet the obligations deriving from the treaty mentioned above or whether the relevant provisions need further implementation. As stated in Article I:

> *The exploration and use of outer space, including the Moon and other celestial bodies, shall be carried out for the province and in the interests of all countries, irrespective of their degree of economic or scientific development, and shall be the province of all (human)kind. Outer space, including the Moon and other celestial bodies, shall be free for exploration and use by all States without discrimination of any kind, on a basis of equality and in accordance with international law, and there shall be free access to all areas of celestial bodies. There shall be freedom of scientific investigation in outer space, including the Moon and other celestial bodies, and States shall facilitate and encourage international cooperation in such investigation.*[31]

The fundamental freedoms recalled by Article I are not absolute but subject also to the freedoms of other actors, whether their activities are ground-[32] or space-based. Indeed, the first limitations indicated by Article I are that such activities must take place for the benefit and in the interests of all countries. These must also happen on the basis of equality and in accordance with international law.[33] Such consideration is recalled in Article III of the OST, which affirms the applicability of international law, including the Charter of the United Nations, to the activities of exploration and use of outer space.[34]

The last sentence of Article I states that "*[t]here shall be freedom of scientific investigation in outer space*" and that "*States shall facilitate and encourage international co-operation in such investigation.*"[35] This aspect is exceptionally relevant to mitigating the impact that satellite constellations may have on astronomy, which could be partially mitigated with a continuous exchange of information and data.

Further, Article XI of the OST and Article III of the Antarctic Treaty detail international scientific cooperation in reporting experiments and respecting the research of other countries.[36]

Finally, with respect to the principle relating to matters of the environment, Article IX of both the Antarctic Treaty and the OST articulate their respective concerns.[37] The Antarctic Treaty focuses on the "*preservation and conversation of living resources in Antarctica*." Within the OST, Article IX requires States Parties to conduct exploration of celestial bodies in a manner such as to avoid their contamination as well as to avoid adverse changes in Earth's environment, albeit through the introduction of extraterrestrial material.

---

31 Outer Space Treaty, art. I.

32 Ground-based activities can be considered "space activities" when they are supporting a space activity in-orbit, or directly associated with it. [Citation for explanatory footnote?]

33 Cologne Commentary on Space Law # (Stephan Hobe, Bernhard Schmidt-Tedd, Kai-Uwe Schrogl eds., 2009). [need pin cite-Art I]

34 Outer Space Treaty, art. III.

35 This principle recalls the similar dictate of the earlier Antarctic Treaty of 1959, which revolves around the same direction. It states that "*Freedom of scientific investigation in Antarctica and cooperation toward that end… shall continue….*" The Antarctic Treaty also goes beyond this statement, affirming that in addition to the original signatories, the participation in the Treaty is limited to actors who can demonstrate their scientific interest in Antarctica by carrying out meaningful scientific research. This principle could not similarly be applied to space, given the freedom of access established in Article I OST. However, both treaties support research and science concepts and cooperation, emphasizing how collaboration, the exchange of data, observations, and results are essential for scientific development. ***See Antarctic Treaty System***, SCAR, https://www.scar.org/policy/antarctic-treaty-system/ (last accessed Aug. 21, 2021).

36 Outer Space Treaty, art. XI; Antarctic Treaty, art. 3.

37 Outer Space Treaty, art. IX; Antarctic Treaty art. 9.

It is noteworthy that unlike the Antarctic Treaty, the OST recognizes in Article I the importance of both "*exploration*" and "*use*" of outer space for peaceful purposes. Throughout the treaty, the word "exploration" is tied to the word "use" of space. The treaty is specifically designed to balance scientific research with other benefits to be derived from the "use" of space.

### 3.2.1. Article IX of the Outer Space Treaty

The environmental protection arising from Article IX of the OST deserves a bit more focused attention. Article IX states in relevant part:

> *In the exploration and use of outer space, … States Parties to the Treaty … shall* ***conduct all their activities in outer space,…with due regard to the corresponding interests of all other States Parties to the Treaty****. States Parties to the Treaty shall pursue studies of outer space, including the Moon and other celestial bodies, and conduct exploration of them so as to avoid their harmful contamination … If a State Party to the Treaty has reason to believe that an activity or experiment planned by it or its nationals in outer space, … would cause potentially harmful interference with activities of other States Parties in the peaceful exploration and use of outer space … it shall undertake appropriate international consultations before proceeding with any such activity or experiment….* [38]

At the outset, States Parties to the OST must: 1) "*conduct* ***all*** *their activities* [whether by government agencies or non-governmental entities][39] *in outer space with due regard to the corresponding interests of all other States Parties to the Treaty*;"[40] and 2) presumably avoid harmful interference with the activities of another.

Per the Permanent Court of Arbitration,

> *… the ordinary meaning of "due regard" calls for the [first State] to have such regard for the rights of [the second State] as is called for by the circumstances and by the nature of those rights. The Tribunal declines to find in this formulation any universal rule of conduct. The Convention does not impose a uniform obligation to avoid any impairment of [the second State's] rights; nor does it uniformly permit the [first State] to proceed as it wishes, merely noting such rights. Rather, the extent of the regard required by the Convention will depend upon the nature of the rights held by [the second State], their importance, the extent of the anticipated impairment, the nature and importance of the activities contemplated by the [first State], and the availability of alternative approaches.*[41]

This language suggests that the US and other States Parties to the OST have an obligation to consider the corresponding interests of other States in respect of potential light pollution created by satellite constellations. This language could also be used to encourage other States to adopt licensing conditions

---

38 *Id*. (emphasis added).
39 Outer Space Treaty, art. VI (emphasis added). Article VI of the OST expressly states that each State shall be responsible for its national activities whether "***carried on by governmental agencies or by non-governmental entities***." ***Id.*** at art. VI.
40 Outer Space Treaty, art. IX.
41 In the Matter of the South China Sea Arbitration (Republic of the Philippines v People's Republic of China), para. 742 (12 July 2016) ***citing*** Chagos Marine Protected Area Arbitration (Mauritius v United Kingdom), para. 519 (18 March 2015).

that will lessen the impact of satellite constellations on astronomy — anywhere in the world — to the greatest degree possible.

Additionally, Article IX of the OST compels States Parties to at least engage in a consultation prior to causing harmful interference with the activities of another. Again, this provision can be read to indicate that the US and other States Parties to the OST have an obligation to consider the corresponding interests of other States in respect of potential light pollution created by satellite constellations. This language could also be used to encourage all States to adopt licensing conditions that will lessen the impact of satellite constellations on astronomy — anywhere in the world — to the greatest degree possible.

### 3.2.2. Article II and the Non-Appropriation Principle

Another of the most relevant limitations to the activities of States and other actors in the exploration and use of outer space can be found in Article II OST, which establishes "***Outer space, including the Moon and other celestial bodies, is not subject to national appropriation by claim of sovereignty, by means of use or occupation, or by any other means.***"[42]

The term "*national*" recalls what is subsequently stated in Article VI of the OST regarding the international responsibility of States for national activities, and therefore can be interpreted to impose on them an obligation to verify that such appropriation activities do not take place by their own national actors or by the organizations to which they belong.[43]

In the current interpretation, no use or occupation of outer space could, in fact, constitute appropriation of outer space since it refers only to a limited part of it.[44] However, there are two considerations to make: the first is that although legitimate, these uses of space and partial occupations must always be read also in the light of the other provisions of the treaty, and therefore must, in any case, occur according to principles of fairness and having regard to the interest of the other actors. Secondly, satellite constellations raise new questions about the possibility of using large portions of outer space, whose access, use, and scientific investigation are hindered to other stakeholders, including the astronomy community.

Indeed, the current allocation practices for orbital slots and frequency spectrum in the low orbital region, including the FCC assigning procedures, are based on a "first come, first served" principle, which in the long term could cause the exclusion of some space actors and an appropriation of orbital planes by satellite constellation operators while the satellites in those constellations remain in orbit.

The US Space Policy Directive (SPD) 3, published in June 2018 and concerning STM, refers to the volume of space used by large constellations, promoting best practices for improving strategies for STM, and favoring the coordination of satellite operators:[45]

---

42 Outer Space Treaty, art. II (emphasis added).
43 Cologne Commentary on Space Law, ***supra*** note 30, at #. [Need pin cite – art II]
44 *Id.*
45 Space Policy Directive-3 of June 18, 2018, 83 Fed. Reg. 28969 (Jun. 21, 2018).

> *The United States should explore strategies that will lead to the establishment of common global best practices, including:*
> *A common process addressing the volume of space used by a large constellation, particularly in close proximity to an existing constellation;*
> *A common process by which individual spacecraft may transit volumes used by existing satellites or constellations; and*
> *A set of best practices for the owner-operators of utilized volumes to minimize the long-term effects of constellation operations on the space environment (including the proper disposal of satellites, reliability standards, and effective collision avoidance).*[46]

However, improving coordination between in-orbit activities does not necessarily mitigate harmful interference with ground-based astronomical activities.

One potential way to address the management of satellite constellation volume is to limit orbital slots. Other common processes could be established that also include other actors, including ground-based astronomy, such as providing public data about spacecraft trajectories. Purely technical solutions, such as better orbit determination, may only displace the problem, or from the astronomer's point of view, make the problem worse, as more satellites might safely occupy a given volume.

It was noted that SPD 3 considers the promotion of best practices within the context of national interests.

> *Given the significance of space activities, the United States considers the continued unfettered access to and freedom to operate in space of vital interest to advance the security, economic prosperity, and scientific knowledge of the Nation.*[47]

To that end, SDP 3 itself promotes principles that encourage the safe and sustainable operation of the outer space environment, affirming:

> *Safety, stability, and operational sustainability are foundational to space activities, including commercial, civil, and national security activities. It is a shared interest and responsibility of all spacefaring nations to create the conditions for a safe, stable, and operationally sustainable space environment.*[48]

The conditions for a safe, stable and sustainable environment, however, should not ignore considerations regarding the impact that space activities, albeit coordinated, can have on ground-based activities and should not overlook the application of fundamental international principles of law for the development of exploration and use of space, such as the non-appropriation principle mentioned earlier, correlated with freedom of access, principles of fairness and regard for the interests of other actors.

---

46 *Id.*
47 *Id.*
48 *Id.*

### 3.2.3. Article VI and the Obligation to Maintain "Continuing Supervision" over National Space Activities

Historically noted as a core compromise to achieve fruition,[49] the legal principles contained in Article VI of the OST,[50] namely (a) international responsibility for national space activities; and (b) authorization and continuing supervision of such activities by a State, provide two important safeguards for the conduct of space activities by non-governmental entities of a State. The US position has always been that private agencies would not be free to engage in space programs without governmental permission and continuing governmental supervision.[51] And indeed, the US has the most robust space regulatory framework in the world.

For the purposes of this report, the obligation of the US government to maintain "continuing supervision" over the space activities of its private actors assumes prime importance. In the view of the authors of this paper, such an obligation entails the attention of the US government in ascertaining the impact of in-orbit operational phases of commercial satellites of large-scale constellations.

At this juncture, the authors of this paper note with appreciation all actions (legislative, policy, directives, and implementation) of the US government in pursuance to its overall objective of safe and sustainable use of outer space by authorizing and licensing the space activities of its private actors,[52] including its efforts to sustain the conduct of EIAs for its space activities:

- § Council on Environment Quality, Executive Order of the President – Regulations for Implementing the Procedural Provisions of the National Environmental Policy Act, 40 CFR Parts 1500 – 1508;
- § NASA's Project Review Model based on NASA NPR 8580.1A – Implementing the National Environmental Policy Act and Executive Order 12114 (please also see Appendix I at the end of this document); and
- § FAA Order 1050.1F, Paragraphs 3-1.2 (15), and 3-1.3 (2).

However, it is also equally important to note that while the National Aeronautics and Space Administration (NASA) — a US governmental entity, and thus outside the scope of regulation under Article VI of the OST — conducts separate assessments pertaining to the environmental impact of its activities (governmental projects, defense applications, etc.). The FAA conducts similar assessments

---

49 ***See generally,*** Comm. on the Peaceful Uses of Outer Space, Summary Record of the Twenty-Second Meeting, 4–5, U.N. Doc. A/AC.105/C.2/SR.22 (April 26, 1963); ***see also***, Letter from the Permanent Representatives of the Union of the Soviet Socialist Republics and the United States of America, U.N. Doc. A/5482 (Aug. 22, 1963).

50 Outer Space Treaty, art. VI ("***States Parties to the Treaty shall bear international responsibility for national activities in outer space, including the moon and other celestial bodies, whether such activities are carried on by governmental agencies or by non-governmental entities, and for assuring that national activities are carried out in conformity with the provisions set forth in the present Treaty. The activities of non-governmental entities in outer space, including the moon and other celestial bodies, shall require authorization and continuing supervision by the appropriate State Party to the Treaty***.")

***51*** Comm. on the Peaceful Uses of Outer Space, Summary Record of the Twenty-Second Meeting, U.N. Doc. A/AC.105/C.2/SR.20 (27 June 1963) at 12: "***The sixth principle in the United States draft declaration dealt with international responsibility. It was recognized that in some instances a governmental authority might choose to license a private firm to carry out activities in space. Such private agencies would not be free to engage in space programmes without governmental permission and continuing governmental supervision. The principle of national responsibility for national space activities was embodied in the United States Communication Satellite Act of 1962***"; ***see also***, Comm. on the Peaceful Uses of Outer Space Verbatim Record of the Thirtieth Meeting, 4-5, U.N. Doc. A/AC.105/PV.30 (Dec. 8, 1964).

52 ***See e.g.***, 51 USC § 50906 (2010). In the US, the Commercial Space Launch Act of 1984 (CSLA) authorized the FAA to license the launch and re-entry of expendable and reusable vehicles, as well as the operation of a launch or re-entry site by a US citizen irrespective of whether the launch site is within or without the US.

pertaining to (i) issuance of a commercial space launch site operator license; (ii) launch licenses; and (iii) experimental permits to support activities requiring the construction of a new commercial space launch site on undeveloped land. A gap, identified by the authors, is the requirement to conduct an EIA of space activities of commercial entities (which entities satisfy, for the US government, the international responsibility criterion under Article VI of the OST[53]) pertaining to their on-orbit operations in the outer space environment.

Moreover, authors of this paper note that it is not particularly relevant here to discuss and debate the terminology ("environmental impact assessment" or "impact of human activities in Earth environment as well as the outer space environment") as it is being sufficiently covered in other sections of the entire report and also being presented as different options for the US government to pick and choose as per its policy initiative and requirements.[54] It is also important to note here that the manner in which national laws implement a State's international obligation relating to authorization and continuing supervision does not in any way affect the nature of that obligation under international law.[55]

The LTSG provides, in Guideline A.3 (supervise national space activities), the need for States to supervise the space activities of its non-governmental entities, and to (a) develop specific procedures and requirements to address safety and reliability of outer space activities *during all phases of a mission life cycle;* (b) assess all risks to the long-term sustainability of outer space activities associated with the space activities conducted by [an] entity, in *all phases of the mission life cycle*, and take steps to mitigate such risks to the extent feasible.[56]

Evidence of current and potential interference to astronomy is being submitted by the AAS and other stakeholders, so the obligation of the US government to maintain "continuing supervision" could be interpreted, at the very least, as demanding a thorough inspection into this matter and further consideration of appropriate measures to safeguard its own interests as well as those of all its actors, governmental and non-governmental entities alike. As discussed in relevant sections below, a good starting point would be to conduct due diligence into the activities of commercial satellite operators, and specifically regarding the impact of in-orbit operation of such activities.

53 Outer Space Treaty, art. VI ("*States Parties to the Treaty shall bear international responsibility for national activities in outer space, including the moon and other celestial bodies, whether such activities are carried on by governmental agencies or by non-governmental entities, and for assuring that national activities are carried out in conformity with the provisions set forth in the present Treaty. The activities of non-governmental entities in outer space, including the moon and other celestial bodies, shall require authorization and continuing supervision by the appropriate State Party to the Treaty*.")

54 *See* G.A. Res. 68/74, para. 4 (Dec. 16, 2013) ("*The conditions for authorization should be consistent with the international obligations of States, in particular under the United Nations treaties on outer space, and with other relevant instruments, and may reflect the national security and foreign policy interests of States; the conditions for authorization should help to ascertain that space activities are carried out in a safe manner and to minimize risks to persons, the environment or property and that those activities do not lead to harmful interference with other space activities; such conditions could also relate to the experience, expertise and technical qualifications of the applicant and could include safety and technical standards that are in line, in particular, with the Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space.*")

55 *See* Vienna Convention on the Law of Treaties, art. 27, May 23, 1969 1155 U.N.T.S. 331; ***see also***, 51 USC § 60122 (wherein the regulations governing the licensing of private remote sensing systems in the US note that the "***responsibility falls to the [US] Government with respect to the activities in outer space of private entities subject to US jurisdiction***", and such responsibility is fulfilled through issuing and enforcing licenses for the "*operations of such systems*").

56 Comm. on the Peaceful Uses of Outer Space, Guidelines for the Long-term Sustainability of Outer Space Activities, Guideline A.3, paras 2(b-c), U.N. Doc. A/AC/105/2018/CRP.20 (emphasis added.) [hereinafter LTSG]

## 3.3. Equitable Access to Orbital Resources

A change would likewise be necessary at the international level to ensure that the first-come, first-served allocation practices are gradually replaced with more equitable procedures capable of responding to the emerging needs prompted by the spread of satellite constellations.

As mentioned above, current allocation practices for orbital slots in non-geosynchronous orbits are solely based on coordinated allocation mechanisms, which respond to the needs of efficiency in orbit distributions, but not to equitable interests. There is, however, no formalized allocation procedure for non-geostationary satellites. Rather, there are only International Telecommunications Union (ITU) requirements to coordinate around certain frequencies.[57]

On the other hand, considerations of equitable access are considered for allocating radio frequency spectrum and orbital slots in geostationary orbit (GSO), as provided by article 44 of the Constitution of the ITU, which states:

> *1 Member States shall endeavor to limit the number of frequencies and the spectrum used to the minimum essential to provide in a satisfactory manner the necessary services. To that end, they shall endeavor to apply the latest technical advances as soon as possible.*
>
> *In using frequency bands for radio services, Member States shall bear in mind that radio frequencies and any associated orbits, including the geostationary-satellite orbit, are limited natural resources and that they must be used rationally, efficiently and economically, in conformity with the provisions of the Radio Regulations, so that countries or groups of countries may have equitable access to those orbits and frequencies, taking into account the special needs of the developing countries and the geographical situation of particular countries.*

The recognition of GSO's limited nature and the consequent determination to establish a system that guarantees the allocation and use of this resource rationally, efficiently and economically, and based on the principle of equity, occurs during the World Administrative Radio Conference for Space Telecommunications, held in Geneva in 1971. The final acts of the Conference, at Resolution No. Spa2-1, affirm:[58]

> *The World Administrative Radio Conference for Space Telecommunications (Geneva, 1971),*
>
> - *considering that all countries have equal rights in the use of both the radio frequencies allocated to various space radiocommunication services and the geostationary satellite orbit for these services;*
> - *taking into account that the radio frequency spectrum and the geostationary satellite orbit are limited natural resources and should be most effectively and economically used;*
> - *having in mind that the use of the allocated frequency bands and fixed positions in the geostationary satellite orbit by individual countries or groups of countries can*

57 *See Non-geostationary satellite systems*, ITU, https://www.itu.int/en/mediacentre/backgrounders/Pages/Non-geostationary-satellite-systems.aspx (last accessed Aug. 17, 2021).
58 ITU, Finals Acts of the World Administrative Radio Conference for Space Telecommunications 311-12 (1971).

*start at various dates depending on requirements and readiness of technical facilities of countries;*

Resolves

1 ... that the registration with the I.T.U. of frequency assignments for space radiocommunication services and their use should not provide any permanent priority for any individual country or groups of countries and should not create an obstacle to the establishment of space systems by other countries;
2 that, accordingly, a country or a group of countries having registered with the I.T.U. frequencies for their space radiocommunication services should take all practicable measures to realize the possibility of the use of new space systems by other countries or groups of countries so desiring;
3 that the provisions contained in paragraphs 1 and 2 of this Resolution should be taken into account by the administrations and the permanent organs of the Union.

These considerations indeed find their basis in the immediately preceding ratification of the OST in 1967, to guarantee the respect of the fundamental freedoms recalled, in particular by Article I, and the relative limitations, such as the prohibition of national appropriation established in Article II, and to ensure that the exploration and use of outer space are effectively provinces of all humankind and that equal benefits and rights are granted to all countries, regardless of their level of economic and technological development.[59]

The current assignment procedures in the GSO, which do not allow the permanent assignment of orbital positions, are in any case due to the physical characteristics of this orbit, which is spatially limited and offers an optimal position for certain services, basically communication services, characteristics that cannot always be found in different orbits, such as LEO. However, the emergence of mega-constellations of satellites could call these considerations into question, given the progressively higher number of objects in orbit, their permanence, and the consequent inaccessibility to the same resources in an equitable manner by other actors, including the astronomy community.

## 3.4. Astronomy and Planetary Defense

Astronomy plays an integral role in planetary defense. Thus, as a policy consideration, planetary defense considerations support the inclusion, as a condition of licensing, of an obligation to reduce the impact (if any) of satellite constellations on telescopes used for planetary defense to the greatest degree possible.

Planetary defense involves the detection and characterization of Near-Earth Objects (NEOs) and, if needed, the mitigation or management of Earth impacts. While a NEO making impact is functionally in line with a traditional natural disaster, it is rhetorically linked to an act of war.[60]

---

59 Matteo Cappella, ***The principle of equitable access in the age of mega-constellations**, in* # Legal Aspects Around Satellite Constellations (Annette Froelich ed., 2019).
60 Andrea Harrington, ***National and International Security in Space: International Law Implications of Space Force and Planetary Defense,*** 48 Ga. J. Int'l. Comp. L. 767, 770 (2020).

Large satellite constellations may impact the effectiveness of planetary defense, which relies on astronomy as one of its principal tools. As discussed in the US policy section below, such interference has broad implications for public policy and disaster management.

International coordination for planetary defense is through the United Nations Office of Outer Space Affairs (UNOOSA). Upon the recommendation of the COPUOS, two collaborative bodies were established to strengthen international cooperation on NEO studies: the Space Mission Planning Advisory Group (SMPAG) and the International Asteroid Warning Network (IAWN).

SMPAG is an advisory group composed of space agencies from Member States. As UNOOSA explains:

> *[SMPAG's] responsibilities include laying out the framework, timeline and options for initiating and executing response activities, informing the civil-defense community about the nature of impact disasters and incorporating that community into the overall mitigation planning process through an impact disaster planning advisory group.*[61]

Two things should be kept in mind: SMPAG is advisory only and does not have any decision-making authority; and SMPAG does not have direct industry involvement, and the roles of industry and NewSpace on planetary defense efforts are not internationally coordinated.

The second forum for international cooperation on planetary defense is IAWN, which is a:

> *virtual network linking together the institutions performing functions such as discovering, monitoring and physically characterizing the potentially hazardous near-Earth object population and maintaining an internationally recognized clearing house for the receipt, acknowledgment and processing of all near-Earth object observations.*[62]

Participation in the IAWN network is open to applicants, requiring a signed commitment to IAWN's charter and Statement of Intent. The IAWN Steering Committee decides whether to admit the applicant as a member. As a result of this process, IAWN network participation ranges from amateur astronomers, to major observatories and national space agencies.[63] IAWN's role is one of information sharing and cooperation, but again it does not have decision-making authority.

Fostering international cooperation and maintaining efficient ways to promote information sharing is of general importance to the international community, as demonstrated by UN General Assembly Resolution 73/91:

> *[The General Assembly] reiterates the importance of information-sharing in discovering, monitoring and physically characterizing potentially hazardous near-Earth objects to ensure that all countries, in particular developing countries with limited capacity for predicting and mitigating a near-Earth object impact, are aware of potential threats, emphasizes the need for capacity-building for effective emergency response and disaster management in the event of a near-Earth object impact, and notes with satisfaction the work carried out by the International Asteroid Warning Network and the Space Mission Planning Advisory Group to*

---

61 ***SMPAG,*** UNOOSA, https://www.unoosa.org/oosa/en/ourwork/topics/neos/smpag.html (last accessed Aug. 21, 2021).
62 *IAWN*, UNOOSA, https://www.unoosa.org/oosa/en/ourwork/topics/neos/iawn.html (last accessed Aug. 21, 2021).
63 *Id.*

*strengthen international cooperation to mitigate the potential threat posed by near-Earth objects, with the support of the Office, serving as the permanent secretariat of the Advisory Group" (paragraph 10).*[64]

Nonetheless, despite a general view of the importance of planetary defense, there is a lack of international policy. Decision making is ultimately a national matter. Thus, as discussed in the US policy section, the 2018 US National NEO Preparedness Strategy and Action Plan (AP) Goal 1: Enhance NEO Detection, Tracking, and Characterization Capabilities will be directly affected. Mistaking a satellite as an NEO is not the concern. Rather, it is the loss of detection efficiency as a direct result of data loss. A way to think about the effects of data loss is, instead, a loss of time. As the AP explains:

*Early detection and characterization of hazardous NEOs increases the time available to make decisions and take effective mitigating action, and it is the first priority for planetary defense.*[65]

Indeed, a persistent theme that arises from the planetary defense tabletop exercises, held every two years, is the need for observational follow up after the discovery of a potential impactor. Through the participation of multiple IAWN members, some inefficiencies in data collection can be tolerated. However, the initial discovery of a *hazardous* impactor could be delayed.

There could also be issues with "precoveries," i.e., an often-used technique that relies on searching through archival data for the object, which had previously missed detection. Such lack of detections will be common for faint objects, and precoveries rely on having information about where the object should be, within some uncertainty. The object might not even be noticeable in a single image, relying instead on combining multiple images to obtain sufficient signal relative to the noise. If large fractions of archival data cannot be searched for faint objects, then this important component of planetary defense could be partially compromised.

Altogether, we do not expect mega-constellations to prevent planetary defense from operating. Rather, it will cause delays in the identification of objects, under certain conditions, which may have widespread ramifications if an object is on an Earth-impact trajectory. This will further affect responses by numerous US government agencies and could delay an internationally coordinated response.

## 3.5. Astronomy, Planetary Protection, and the Contamination of the Night Sky

The authors considered whether PPP might provide considerations for the impacts of satellite constellations on astronomy. The motivation is that satellite constellations have the potential to contaminate the night sky and cause harm to astronomical observations, as well as the enjoyment of

64 G.A. Res. 73/91, International Co-operation in the Peaceful Uses of Outer Space (Dec. 18, 2018); ***see also*** Comm. on the Peaceful Uses of Outer Space, Report of the Scientific and Technical Subcommittee on its fifty-fourth session (Jan. 10–Feb. 10, 2017).
65 https://www.nasa.gov/sites/default/files/atoms/files/ostp-neo-strategy-action-plan-jun18.pdf

the night sky. As PPP seeks to protect Earth from "*harmful contamination*" due to space activities, it is instructive to examine whether PPP might be applied in this context.[66]

PPP was developed to address the potential for spaceflight and space exploration missions to contaminate the Moon and other celestial bodies, compromising future missions. It was also developed to address concerns over the introduction of potentially dangerous extraterrestrial matter to Earth. The Committee on Space Research (COSPAR) is the primary international forum for developing international PPP, and its policy is written to guide compliance with Article IX of the OST; namely,

> *States Parties to the Treaty shall pursue studies of outer space, including the moon and other celestial bodies, and conduct exploration of them so as to avoid their harmful contamination and also adverse changes in the environment of the Earth resulting from the introduction of extraterrestrial matter and, where necessary, shall adopt appropriate measures for this purpose.*[67]

The most recent COSPAR PPP was updated and approved in 2017.[68] The preamble of the PPP notes that:

> *COSPAR maintains and promulgates this planetary protection policy for the reference of spacefaring nations, both as an international standard on procedures to avoid organic-constituent and biological contamination in space exploration, and to provide accepted guidelines in this area to guide compliance with the wording of this UN Space Treaty and other relevant international agreements.*[69]

What the above makes clear is that while COSPAR PPP is concerned with "*harmful contamination*," it does so in the context of introducing extraterrestrial materials to Earth or contaminating celestial bodies with organic material from Earth. With this scope, COSPAR PPP is not inherently intended to protect Earth from other forms of harmful contamination resulting from space exploration.

COSPAR PPP itself sets forth guidelines, and it is the responsibility of States to establish their own PPP requirements. In December 2020 the US released its National Strategy for Planetary Protection (US NSPP)[70] which is intended to address, in part, the 2020 National Space Policy call "[to develop] *national and international planetary protection guidelines, working with scientific and commercial partners, for the appropriate protection of planetary bodies and Earth from harmful biological contamination*."[71]

The US NSPP states that:

> *The practice of planetary protection is grounded in the premise that life may exist beyond the Earth's biosphere. Should life exist elsewhere in the universe, measures to avoid the introduction of external contaminants are necessary in order to protect life on Earth and*

---

66 G. Kminek, C. Conley, V. Hipkin, H. Yano, ***COSPAR's Planetary Protection Policy*** (2017), ***available at*** https://cosparhq.cnes.fr/assets/uploads/2019/12/PPPolicyDecember-2017.pdf.
67 Outer Space Treaty, art. IX.
68 G. Kminek, C. Conley, V. Hipkin, H. Yano, ***COSPAR's Planetary Protection Policy*** (2017), ***available at*** https://cosparhq.cnes.fr/assets/uploads/2019/12/PPPolicyDecember-2017.pdf.
69 G. Kminek, C. Conley, V. Hipkin, H. Yano, ***COSPAR's Planetary Protection Policy*** (2017), ***available at*** https://cosparhq.cnes.fr/assets/uploads/2019/12/PPPolicyDecember-2017.pdf.
70 Nat'l Space Council, ***National Strategy for Planetary Protection*** (2020).
71 President Donald Trump, National Space Policy, Dec. 9, 2020, ***available at*** https://www.space.commerce.gov/policy/national-space-policy/ (last accessed Aug. 21, 2021) [hereinafter US National Space Policy 2020].

*ensure the validity of any scientific study related to such a discovery. In essence, planetary protection refers to the policies and practices related to two aspects of space exploration. First, planetary protection aims to protect future scientific investigations by limiting the forward biological contamination of other celestial bodies by terrestrial lifeforms. Second, planetary protection aims to protect Earth's biosphere by preventing the backward biological contamination of Earth by returning spacecraft and their payloads.*[72]

Again, we see that the emphasis of PPP as written is on biological contamination through the introduction of organic material and is not intended to protect Earth from other forms of harmful contamination.

However, it must be kept in mind that PPP, including COSPAR PPP and the US NSPP, is policy that is intended to augment Article IX of the OST:

*States Parties to the Treaty shall pursue studies of outer space, including the moon and other celestial bodies, and conduct exploration of them so as to avoid their harmful contamination and also adverse changes in the environment of the Earth resulting from the introduction of extraterrestrial matter and, where necessary, shall adopt appropriate measures for this purpose.*[73]

Here, we see the reference to adverse changes in the environment of Earth resulting from "*the introduction of extraterrestrial matter.*" This is consistent with PPP. In contrast, "*harmful contamination*" is not so clearly defined and requires further clarification. With this in mind, PPP results from only one interpretation of "*harmful contamination*." This phrasing is also used to describe how we should "*pursue studies of outer space*" and "*conduct exploration*." Article IX continues:

*If a State Party to the Treaty has reason to believe that an activity or experiment planned by it or its nationals in outer space, including the moon and other celestial bodies, would cause potentially harmful interference with activities of other States Parties in the peaceful exploration and use of outer space, including the moon and other celestial bodies, it shall undertake appropriate international consultations before proceeding with any such activity or experiment. A State Party to the Treaty which has reason to believe that an activity or experiment planned by another State Party in outer space, including the moon and other celestial bodies, would cause potentially harmful interference with activities in the peaceful exploration and use of outer space, including the moon and other celestial bodies, may request consultation concerning the activity or experiment.*[74]

As astronomy is one of the foremost ways we study and explore space and is advanced by multiple agencies within States, activities that "*would cause potentially harmful interference with activities* [of other States Parties] *in the peaceful exploration and use of outer space*" are intended to be subject to international consultations.

72 Nat'l Space Council, ***supra*** note 68, at 2.
73 This is text from article IX OST
74 Article IX again OST

Finally, as described in the US policy section of this document, Article IX clearly implies that the environments of space and the Moon and other celestial bodies are intended to have some protections. Thus, it can be suggested that States Parties to the Treaty are obligated to avoid harming environments beyond Earth, including orbital environments.

## 3.6. IDA/IES Model Lighting Ordinance Limits Light Pollution

The International Dark-Sky Association (IDA) and the Illuminating Engineering Society (IES) created the Five Principles for Responsible Outdoor Lighting Practices[75] which offer principles for safe outdoor lighting that limits light pollution.

In 2011 the IDA and the IES drafted a Model Lighting Ordinance (MLO).[76] The MLO was drafted in response to the growing number of states passing light pollution regulations that had little cohesion, making it difficult to assess the success of the laws. The MLO seeks to help municipalities reduce light pollution through the development of lighting standards to reduce glare, light trespass and skyglow. The MLO implements lighting zones to allow governments to adjust the stringency of lighting regulations. In summary, the zones are:

1 LZ0: no ambient light. To include natural areas where there should be no human-created lighting, e.g., rural areas, parks, wildlife preserves, etc.
2 LZ1: low ambient lighting. Lighting is permitted for safety but should not be continuous, e.g., rural or agricultural areas, sparsely populated, wildlife preserves in populated areas, business parks.
3 LZ2: moderate ambient lighting. Lighting is permitted for safety but should not be continuous, e.g., neighborhoods, businesses, churches, schools, industrial areas.
4 LZ3: moderately high ambient lighting. Lighting is often uniform or continuous as desired for safety, security or convenience, e.g., business zones, heavy industrial areas.
5 LZ4: high ambient lighting. Lighting is considered necessary and is mostly continuous or uniform, e.g., high-intensity business/industrial.

The MLO includes a Backlight, Uplight, and Glare classification to create light shielding standards.[77] The MLO also suggests that it is best implemented as an "overlay zoning" ordinance so that it may be implemented into existing land-using zoning ordinances.

---

75 IDA, ***Light to Protect the Night*** (2020) ***available at*** https://www.darksky.org/wp-content/uploads/2020/06/Light-to-Protect-the-Night-IDA-and-IES.pdf
76 ***Joint IDA-IES Model Lighting Ordinance*** 1,6 (2011) ***available at*** https://www.darksky.org/our-work/lighting/public-policy/mlo/
77 ***Id.*** at 3.

# 4. US National Law

In the United States, a growing number of federal, state and local ordinances and regulations are being implemented to address the threats posed by light pollution. The main thrust of these efforts is to address the persistent light pollution generated by terrestrial lighting fixtures and:

- the consequential effect on wildlife;
- the aesthetic impact on recreational viewing of the night sky;
- related energy consumption; and
- in some cases, the effect on astronomy.

These regulations and ordinances are localized, deal with persistent lighting fixtures and generally cover light visible to the naked eye. Conversely, satellite constellations generate diffuse or reflected light that is generally visible to the naked eye only temporarily, post-launch and prior to orbit raise. Additionally, the cumulative effect of all satellites and debris results in an overall brightening of the sky that, while not detectable by the naked eye, may be observed with astronomical instruments.

However, the goal — to preserve the environment for astronomy — remains the same and only the means to achieve the goal will differ.

## 4.1. Astronomy Protected from Light Pollution by Local and State Laws

Nineteen US states, plus Washington DC and Puerto Rico, have enacted laws to address light pollution.[78] The stated legislative purposes include energy reduction, preservation of aesthetics and the protection of science. Most state regulations are narrowly limited to outdoor lighting on the grounds of state buildings or public roadways. They commonly require one or more of the following:

1 The shielding of light fixtures to make light eliminate downward rather than upward/outward.
2 Low-glare or low-wattage lighting

78 *See* Appendix I for a complete list.

3 Timing regulations, for example, lighting only on for a certain amount of time.
4 The adoption of IES[79] guidelines.

Some states regulate light pollution through zoning codes. There are 27 dark skies parks and preserves located in twelve states (primarily in the western United States).

Some states specifically identify astronomical interests, as described below.

### 4.1.1. Arizona

The urtext for protection of astronomical sites came first from the City of Flagstaff in 1958 and the City of Tucson and surrounding Pima County in 1973. Those updated codes have remained model ordinances for the rest of the world. They prescribe control of spectral output and limits on total outdoor light per area per legal parcel dependent on distance from the observatories.[80]

The City of Flagstaff was designated by the IDA as the world's first Dark Sky Community. The City of Tucson / Pima County's code articulates the modern purpose:

> *The purpose of this code is to preserve the relationship of the residents of the City of Tucson, Arizona and Pima County, Arizona to their unique desert environment through protection of access to the dark night sky. Intended outcomes include continuing support of astronomical activity and minimizing wasted energy, while not compromising the safety, security, and well being of persons engaged in outdoor night time activities. It is the intent of this code to control the obtrusive aspects of excessive and careless outdoor lighting usage while preserving, protecting, and enhancing the lawful nighttime use and enjoyment of any and all property. It is recognized that developed portions of properties may be required to be unlit, covered, or have reduced lighting levels in order to allow enough lumens in the lighted areas to achieve light levels in accordance with nationally recognized recommended practices.*[81]

### 4.1.2. Hawai'i

Act 185 (2015) established the Dark Skies Protection Advisory Committee, comprising 13 members tasked with identifying and evaluating light pollution-related issues. The Committee's 2020 report essentially stated that they needed more time to complete the task. Interestingly, Hawai'i places the bulk of its lighting regulations in Title 13 Chapter 201 (Department of Business, Economic Development, and Tourism). At the county level, Hawai'i County on the Big Island has stringent lighting ordinances designed to protect the many observatories on Maunakea. The ordinances divide lighting into three categories (Class I, II, III) from least to most essential.[82]

---

79 *See* subsection II.B below.
80 City of Flagstaff Division 10-50.70: Outdoor Lighting Standards; 2012 City of Tucson / Pima County Outdoor Lighting Code
81 Pima County Ordinance 2012-14 Exhibit A: https://webcms.pima.gov/UserFiles/Servers/Server_6/File/Government/Development%20Services/Building/OLC.pdf.
82 Haw. County Code § 14-50 (2017).

### 4.1.3. New Mexico

The Night Sky Protection Act regulates outdoor night lighting "*to preserve and enhance the state's dark sky while promoting safety, conserving energy and preserving the environment for astronomy*".[83]

### 4.1.4. Texas

Regulation of outdoor lighting (both mandatory and permissive) "*must be designed to protect against the use of outdoor lighting in a way that interferes with scientific astronomical research of the observatory or military and training activities of the military installation, base, or camp.*"[84]

### 4.1.5. Puerto Rico

The Light Pollution Prevention and Control Program, administered by the Puerto Rico Environmental Quality Board, is intended to "*prevent and control light pollution from night skies for the enjoyment of all our inhabitants, the benefit of scientific research, astronomy…[to] promote darkness to be able to appreciate the light of the stars…*"[85]

## 4.2. Astronomy Protected from Light Pollution at Federal Level

### 4.2.1. Protecting Aesthetics Implies Need to Protect Astronomy

The Federal Government has a long history of recognizing and protecting natural landscapes for their scenic value. In 1872 the United States Congress and President Grant designated Yellowstone as the first National Park and the first conservation area of its kind in the world. In establishing the park, the legislation declared that the area would be preserved "*for the benefit and enjoyment of all people.*"[86] The act provided for "*all timber, mineral deposits, natural curiosities, or wonders within said park, and their retention in their natural condition.*"[87]

Over the intervening years, the federal system of protected lands has grown, and agencies have come to recognize that a naturally dark, star-filled sky is an intrinsic part and critical aspect of the park or wilderness experience. While the focus of the federal system is on the visual experience of visitors, the fact must be recognized that light pollution that can ruin aesthetic experiences will also be ruinous to astronomy. Certainly, to those who benefit from astronomical research — which, it may be argued, is nearly everyone — utilitarian concerns may be considered to be vastly more important than scenic.

83 NM Stat § 74-12-2 (2019).
84 Tex. Local Government Code § 240.032(c)
85 PR Laws 1 § 8032 (2019) (translated from Spanish).
86 We want to acknowledge that in setting Yellowstone aside as a National Park, the Government forcibly removed the Tribes who had called the landscape home. The National Park Service was founded on the myth of the American wilderness as a place untouched by people. The reality is that the landscape had been populated for at least 15,000 years by Native peoples. ***See*** David Treuer, ***Return the National Parks to the Tribes,*** Atlantic, https://www.theatlantic.com/magazine/archive/2021/05/return-the-national-parks-to-the-tribes/618395/ (May 2021).
87 An Act Establishing Yellowstone National Park, 17 Stat. 32 (1872).

Consequently, an effort to protect the beauty of the skies can, by inference, be considered to require the protection of the astronomical value of the skies.

In any event, federal agencies are now taking affirmative steps to protect the sky at night from light pollution.

#### 4.2.1.1. The Antiquities Act of 1906

In 1906 the Antiquities Act was enacted.[88] This authorized the President of the United States to "*declare by public proclamation historic landmarks, historic and prehistoric structures, and other objects of historic or scientific interest that are situated upon the lands owned or controlled by the Government of the United States to be national monuments…*"[89] Bear Lodge Butte, also known as Devils Tower, was established as the first National Monument. Since then, 200 have been created, 69 of which have now been incorporated into the National Parks system or other protected lands systems.

While this Act does not mention light pollution or the protection of dark skies, it lays an early foundation for the preservation of sites of scientific interest and also introduces the need to balance protection with and assure that protection "*be confined to the smallest area compatible with proper care and management of*"[90] the area to be protected.

#### 4.2.1.2. The Organic Act of 1916

By 1916 the Department of the Interior was overseeing 14 national parks, 21 national monuments, and the Hot Springs and Casa Grande Ruin reservations, but it lacked a unified organization to manage them. This changed with the creation of The National Park Service (NPS) through the Organic Act of 1916.[91] The Act directs the NPS to:

> *…conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations.*[92]

Today, the National Park System comprises more than 400 areas covering more than 84 million acres in 50 States, the District of Columbia, American Samoa, Guam, Puerto Rico, Saipan, and the Virgin Islands.

#### 4.2.1.3. The Natural Sounds and Night Skies Division

The Natural Sounds and Night Skies Division[93] was established within the NPS. Its goal is to support units across the NPS system in the stewardship of natural sounds and night skies. It recognizes that the soundscape, alongside the quality of the nighttime environment, is an intrinsic part of the scenery and ecosystem of Park units.

---

88 American Antiquities Act of 1906, 16 USC. § 431-433.
89 *Id.* at § 431.
90 *Id.*
91 Organic Act of 1916, 16 USC. § 1 ***et. seq.***
92 *Id.* at § 1.
93 *Natural Sounds and Night Skies Division*, NPS, https://www.nps.gov/orgs/1050/index.htm (last accessed Aug. 27, 2021).

The division recognizes the night sky as a natural resource, a cultural resource, and an economic resource.[94] Since 2001 the Division has measured and inventoried night sky conditions in approximately 100 parks. Maintaining the dark night sky above many national park units is a high priority for the NPS. Their policy is to preserve, to the greatest extent possible, the natural night sky of parks, which are natural resources and values that exist in the absence of human-caused light.[95]

### 4.2.1.4. Lightscape Management

The 2006 NPS Management Policies include the following language:

> *The Service will preserve, to the greatest extent possible, the natural lightscapes of parks, which are natural resources and values that exist in the absence of human-caused light….The stars, planets, and earth's moon that are visible during clear nights influence humans and many other species of animals, such as birds that navigate by the stars or prey animals that reduce their activities during moonlit nights.*
>
> …
>
> *The Service will … shield the use of artificial lighting where necessary to prevent the disruption of the night sky …* [96]

Over the past decade, many National Park units have taken steps to invest in new infrastructure to reduce the impact of artificial light at night to protect the environment and enhance the visitor's appreciation of the park at night. Night sky programming is one of the most popular interpretive programs in many parks.

Moreover, many National Park units are now recognized as International Dark Sky Parks, and many more are pursuing designation

### 4.2.1.5. The Wilderness Act of 1964

In September 1964, the Wilderness Act was signed into law by President Lyndon Johnson.[97] The Act defines wilderness as:

> *A wilderness, in contrast with those areas where man and his own works dominate the landscape, is hereby recognized as an area where the earth and its community of life are untrammeled by man, where man himself is a visitor who does not remain.*[98]

The National Wilderness Preservation System now includes 803 Wilderness Areas protecting 450,691 square kilometers of federal lands. In 2020 the Boundary Waters Canoe Area Wilderness in Superior National Forest was designated as an International Dark Sky Sanctuary in recognition of its exceptional starry skies.[99]

---

94 ***Night Sky Resources***, NPS, https://www.nps.gov/subjects/nightskies/resources.htm (last accessed Aug. 27, 2021).
95 ***Managing Lightscapes,*** NPS, https://www.nps.gov/subjects/nightskies/management.htm (last accessed Aug. 27, 2021).
96 NPS, ***Lightscape Management,*** Management Policies 1, 57 (2006).
97 Wilderness Act, 16 USC. § 1131-1136 (1964).
98 ***Id.*** at § 1131(c).
99 Kate Legner, ***Superior's wilderness area world-recognized for its starry sky,*** USDA Forest Service, https://www.fs.usda.gov/features/superiors-wilderness-area-world-recognized-its-starry-night-sky (Sept. 16, 2020).

### 4.2.1.6. Recent National Monuments

In 2016 President Obama established National Monuments at Bears Ears in Utah, Katahdin Woods and Waters in Maine, and Castle Mountains in California/Nevada.[100] All three proclamations were issued under the authority of the Antiquities Act. They are noteworthy as they show how our understanding of "*special landscapes that need protecting*" now extends to the pristine dark night sky overhead.

- The star-filled nights and natural quiet of the Bears Ears area transport visitors to an earlier eon. Against an absolutely black night sky, our galaxy and others more distant leap into view. As one of the most intact and least roaded areas in the contiguous United States, Bears Ears has that rare and arresting quality of deafening silence.
- The remoteness of the Castle Mountains area offers visitors the chance to experience the solitude of the desert and its increasingly rare natural soundscapes and dark night skies.
- Since the glaciers retreated 12,000 years ago, these waterways and associated resources — the scenery, geology, flora and fauna, night skies, and more — have attracted people to this area. Native Americans still cherish these resources.
- Katahdin Woods and Waters's daytime scenery is awe-inspiring, from the breadth of its mountain-studded landscape, to the channels of its free-flowing streams with their rapids, falls, and quiet water, to its vantages for viewing the Mount Katahdin massif, the "greatest mountain." The area's night skies rival this experience, glittering with stars and planets and occasional displays of the aurora borealis, in this area of the country known for its dark sky.

## 4.2.2. Preventing New Sources of Interference with Astronomy (51 USC 50911)

Section 50911 of Article 51 of the US Code (51 USC 50911) prohibits "*the launch of a payload containing any material to be used for the purposes of obtrusive space advertising*."[101] In adopting this measure, which is discussed in the House of Representatives conference report on the NASA Authorization Act of 2000, the conferees indicate that they "*are seeking to preserve a view of the sky that humanity has enjoyed since the beginning of human existence. Moreover, this section will help prevent new sources of interference with astronomy.*"[102]

The conferees note that obtrusive space advertising is defined as "*advertising in outer space that is capable of being recognized by a human being on the surface of the Earth without the aid of a telescope or other technological device*,"[103] i.e., that which is recognizable to the human eye.

100 *See* Dana Varinsky, Here's every piece of land Obama has put under protection during his presidency, Business Insider (Dec. 30, 2016), https://www.businessinsider.com/every-piece-of-land-obama-has-protected-2016-12.
101 51 USC. § 50911(a).
102 H.R. Rep. No. 106-843, at 35 (Conf. Rep.).
103 *Id.*

# 4.3. Policy Rationales from Other US Laws to Protect Astronomy

## 4.3.1. Planetary Defense Efforts by the US and National Security

Planetary defense is considered a national security interest of the US. First, planetary defense may be understood as a national security interest purely on the basis that an asteroid plummeting toward Earth is nearly guaranteed to cause incredible and likely irreparable damage. Second, maintaining systems that identify exoatmospheric planetary threats like asteroids or other NEOs is an interest aligned with existing national security goals.

Thus, light pollution which impairs the functionality of a telescope tasked with any aspect of planetary defense could impact national security. This concern is particularly broad given the multi-functional nature of most telescopes.

The consideration of national security interests requires balance. National security interests are supported by both satellite systems and astronomy. With respect to planetary defense in particular, the potential effect of light pollution on planetary defense telescopes is an important factor that must be taken into consideration. The very fact that light pollution may have an effect on planetary defense supports the need to include as a condition of licensing an obligation to reduce the impact of satellite constellations on astronomy to the greatest degree possible. Such conditions should be measured to take into account specific research with respect to the effects of light pollution on planetary defense telescopes.

The 2005 Authorization Act required NASA to enact the NEO Observation Program to locate, track, and characterize at least 90% of predicted NEOs of 140 meters or larger.[104]

Planetary defense activities in the US are coordinated through the NASA Planetary Defense Coordination Office (PDCO), which works closely with the Jet Propulsion Lab's Center for Near Earth Object Studies and the Federal Emergency Management Agency (FEMA). The PDCO is also responsible for updating the AP.[105] The AP makes clear that NEOs are an issue addressed by multiple agencies:

> *The Strategy and Action Plan builds on efforts by the National Aeronautics and Space Administration (NASA), Department of Homeland Security (DHS), and Department of Energy (DOE) to detect and characterize the NEO population and to prevent and respond to NEO impacts on Earth.*[106]

The reasoning behind the vast number of agencies involved is succinctly explained by the AP:

---

104 NASA Authorization Act of 2005, Pub. L. No. 109-155 § 321.
105 Interagency Working Group for Detecting and Mitigating the Impact of Earth-Bound Near-Earth Objects, ***National Near-Earth Object Preparedness Strategy and Action Plan*** (2018), ***available at*** https://www.nasa.gov/sites/default/files/atoms/files/ostp-neo-strategy-action-plan-jun18.pdf.
106 ibid.

*NEO impacts pose a significant and complex risk to both human life and critical infrastructure, and have the potential to cause substantial and possibly even unparalleled economic and environmental harm.*[107]

Indeed, even the uncertainty of an impact could have major socio-economic consequences[108] beyond the scope of any single agency.

Recognizing the global implications of planetary defense, the AP elevates international cooperation to be one of its five goals:

*Goal 4: Increase International Cooperation on NEO Preparation: Agencies will work to inform and develop international support for addressing global NEO impact risks. International engagement and cooperation will help the Nation to prepare more effectively for a potential NEO impact.*[109]

which is aligned with US National Space Policy's guidelines, specifying that the Administrator of NASA shall:

*Develop options, in collaboration with other agencies, and international partners, for planetary defense actions both on Earth and in space to mitigate the potential effects of a predicted near Earth object impact or trajectory.*[110]

Among other things, PDCO:

- Provides early detection of potentially hazardous objects (PHOs) — the subset of NEOs whose orbits predict they will come within 5 million miles of Earth's orbit, and which are large enough (30 to 50 meters) to cause significant damage on Earth;
- Tracks and characterizes PHOs and issues warnings of the possible effects of potential impacts;
- Studies strategies and technologies for mitigating PHO impacts; and
- Plays a lead role in coordinating US government planning for response to an actual impact threat.[111]

The PDCO is charged with warning the government, the media, and the public of any PHOs and disclosing their potential for impact. In the event that a PHO poses greater than a 1% threat over 50 years, the PDCO must notify the government.[112]

In June 2021 NASA approved the continued development of the NEO Surveyor, an infrared telescope designed to help "hunt" NEOs.

107 ibid.
108 Rudolf Albrecht, ***Towards Plans for Mitigating Possible Socio-Economic Effects due to a Physical Impact of an Asteroid on*** Earth, 7th IAA Planetary Defense Conference (Apr. 29, 2021).
109 Interagency Working Group for Detecting and Mitigating the Impact of Earth-Bound Near-Earth Objects, ***National Near-Earth Object Preparedness Strategy and Action Plan*** (2018), ***available at*** https://www.nasa.gov/sites/default/files/atoms/files/ostp-neo-strategy-action-plan-jun18.pdf.
110 US National Space Policy 2020, 24.
111 ***Planetary Defense Coordination Office,*** NASA, https://www.nasa.gov/planetarydefense/overview (last accessed June 16, 2021).
112 ***Planetary Defense Coordination Office,*** NASA, https://www.nasa.gov/planetarydefense/overview (last accessed June 16, 2021).

NASA's efforts to coordinate planetary defense strategies are primarily through the SMPAG and the IAWN, both of which international bodies were established in response to a 2013 UN COPUOS call for a recommendation to develop an international response to NEO threats.[113] The Planetary Impact Emergency Response Working Group (PIERWG) was established in 2015 in partnership with FEMA to aid federal agencies in preparing for the possibility of future NEO collisions with Earth.[114]

#### 4.3.1.1. Telescopes Detect and Track NEOs

The Center for Near Earth Object Studies (CNEOS) computes the orbit paths of NEOs based on position data provided by the IAU's Minor Planet Center, the official repository of NEO observational data. The NEO Wide-field Infrared Survey Explorer (NEOWISE) spacecraft uses the Wide-field Infrared Survey Explorer telescope to survey NEOs. Wide-field telescopes are used to identify objects moving in the sky.

The Asteroid Terrestrial-impact Last Alert System (ATLAS) is an early-warning system funded by NASA and developed at the University of Hawai'i, comprising two telescopes on Mauna Loa and Haleakala. It is intended to provide one day's warning of a 30-kiloton (equivalent TNT) "town killer," one week's warning of a 5-megaton "city killer," and three week's warning of a 100-megaton "county killer."[115]

#### 4.3.1.2. Telescopes Characterize NEOs

Follow-up telescopes are used to examine NEOs once identified to determine size, shape, orbit, etc. They include:

- Spacewatch
- Astronomical Research Institute
- Las Cumbres Observatory
- Magdalena Ridge Observatory
- Mission Accessible Near-Earth Objects Survey (MANOS)
- Infrared Telescope Facility (IRTF)
- NOIRLab large-aperture telescopes: Gemini, WIYN, Blanco, SOAR

#### 4.3.1.3. Telescopes Integral to Early Detection

The AP identified the need to "[e]*xercise, evaluate, and continually improve modeling and analysis capabilities*."[116] As such, NASA has participated in five tabletop exercises at Planetary Defense Conferences, in 2013, 2015, 2017, 2019, and 2021, and has additionally engaged in three joint exercises with FEMA, in 2013, 2014, and 2016.

---

113 A/RES/68/75 (Dec. 11, 2013).

114 *Planetary Impact Emergency Response Working Group (PIERWG) Charter*, FEMA 1 (2015).

115 *Asteroid Terrestrial-impact Last Alert System,* Atlas, https://atlas.fallingstar.com/home.php (last accessed Aug. 17, 2021).

116 Nat'l Sci. & Tech. Council Interagency Working Group for Detecting & Mitigating the Impact of Earth-bound and Near-Earth Objects, *National Near-Earth Object Preparedness Strategy and Action Plan* 1, 15 (June 2018).

Detailed in Appendix II are the scenarios and findings of the most recent exercise, at the 2021 Planetary Defense Conference.

The CNEOS develops fictional impact scenarios to help identify the effectiveness of current planetary defense capabilities and to identify where they need to be improved. The 2021 Scenario was analyzed at the 7th International Academy of Astronautics (IAA) Planetary Defense Conference in April, hosted by UNOOSA and the European Space Agency (ESA).[117]

Crucially, participants observed that had more sensitive detection systems been in place in 2014, the asteroid named 2021 PDC would have been detected seven years prior to potential impact rather than six months. This conclusion emphasizes the importance of precoveries in assessing impact probabilities.

## 4.4. Outer Space Treaty and US Law

The lineage of the principles under the OST in the US arguably began with the enactment of the National Aeronautics and Space Act of 1958 that stated "*it is the policy of the United States that activities in space should be devoted to peaceful purposes for the benefit of all humankind*."[118] The Antarctic Treaty followed in 1959 with a similar purpose and, as will be demonstrated below, it served as the foundation for the OST.[119]

The United States of America has signed and ratified the OST and is therefore legally bound by its provisions. The US has also signed and ratified the following treaties concerning international space activities[120]:

- Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space (ARRA, 1968)[121];
- Convention on International Liability for Damage Caused by Space Objects (LIAB, 1972)[122];
- Convention on Registration of Objects Launched into Outer Space (REG, 1975)[123].

### 4.4.1. Space Traffic Management

The US recognizes the need to protect the "space environment." It is noteworthy that the US Government makes a distinction between the "space environment" and the "human environment" or "natural environment."

117 *See* Appendix II for an outline of the Conference activities.
118 National Aeronautics and Space Act of 1958, P. L. No. 85-568, 72 Stat. 426-438, § 102.
119 Antarctic Treaty, 1.
120 UNOOSA, Status of International Agreements Relating to Activities in Outer Space as at 1 January 2020, ***available at*** https://www.unoosa.org/documents/pdf/spacelaw/treatystatus/TreatiesStatus-2020E.pdf.
121 Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space*,* 19 December 1967, 672 U.N.T.S. 119, 19 UST 7570, TIAS No 6599, 7 ILM 151 (entered into force 3 December 1968).
122 Convention on International Liability for Damage Caused by Space Objects, 29 March 1972, 961 U.N.T.S. 187, 24 UST 2389, 10 ILM 965 (1971) (entered into force 1 September 1972).
123 Convention on Registration of Objects Launched into Outer Space, 12 November 1974, 28 UST 695, 1023 U.N.T.S. 15 (entered into force 15 September 1976).

Nevertheless, Space Policy Directive-3 which articulated the United States' National Space Traffic Management Policy, [124] stressed the importance of the space environment:

> *Our society now depends on space technologies and space-based capabilities for communications, navigation, weather forecasting, and much more. Given the significance of space activities, the United States considers the continued unfettered access to and freedom to operate in space of vital interest to advance the security, economic prosperity, and scientific knowledge of the Nation.*[125]

The principles established in the National Space Traffic Management Policy include:

> *(a) Safety, stability, and operational sustainability are foundational to space activities, including commercial, civil, and national security activities. It is a shared interest and responsibility of all spacefaring nations to create the conditions for a safe, stable, and operationally sustainable space environment.*
> *(b) Timely and actionable SSA data and STM services are essential to space activities. Consistent with national security constraints, basic US Government-derived SSA data and basic STM services should be available free of direct user fees.*
> *(c) Orbital debris presents a growing threat to space operations. Debris mitigation guidelines, standards, and policies should be revised periodically, enforced domestically, and adopted internationally to mitigate the operational effects of orbital debris.*
> *(d) A STM framework consisting of best practices, technical guidelines, safety standards, behavioral norms, pre-launch risk assessments, and on-orbit collision avoidance services is essential to preserve the space operational environment.*[126]

Generally, the first principle articulates a basis for protecting the space environment for all actors and persons reliant upon it. The second principle correlates with the recommendations of SATCON1 for timely telemetry and ephemeris data.[127] With respect to the latter two principles, the FCC recently promulgated regulations imposing obligations on space station operators with respect to space debris.[128] These regulations follow the efforts of the FAA and NOAA to update their regulations with respect to space operations.

This underscores that the FCC can pursue regulations that address perceived issues without invoking or relying on statutes like NEPA. Indeed, to the extent that relevant, data-driven standards are developed relating to astronomy mitigations (and benefits) from satellite constellations, the FCC can impose conditions as part of its license for a US authorized system.

However, this again raises challenges associated with operator "forum shopping," since US license requirements are asymmetric, in that they do not apply to foreign-licensed systems. Without addressing

---

124 National Space Traffic Management Policy, 83 Fed. Reg. 28969 (Jun. 21, 2018). This expanded upon the National Space Policy articulated in 2010 that committed to policies and guidelines that influenced space traffic through international cooperation and self-accountability.
125 *Id.*
126 *Id.*
127 SATCON1, C (Positional Accuracy), pp. 20-21; Recommendations 9 and 10, p. 22.
128 "Report and Order and Further Notice of Proposed Rulemaking," In the Matter of Mitigation of Orbital Debris in the New Space Age – IB Docket No. 18-313 ("18-313 Report and Order") (April 24, 2020); see also Office of Safety and Mission Assurance, Process for Limiting Orbital Debris, NASA, https://standards.nasa.gov/standard/nasa/nasa-std-871914. Additional final regulations should be forthcoming in 2021.

this regulatory asymmetry, the likely result of additional conditions would be that operators will not license in the US, creating even less US oversight. This could, perhaps, be countered should the US be willing to assert Article IX "due regard" and "harmful interference" objections to the activities of other States or their nationals.[129]

## 4.5. Radio Quiet Zones

RQZs are limited to specific geographies and allow the benefits of technology outside the zones. A brief summary is offered here to continue the discussion of how a balance may be struck between the critical services people can receive from satellite services and the impact of those services on astronomy.

The first RQZ, the US National Radio Quiet Zone (NRQZ) was established in 1958 and is administered jointly by the National Radio Astronomy Observatory (NRAO) in Green Bank, West Virginia in conjunction with the FCC. The NRAO also represents the National Security Agency listening station in Sugar Grove, West Virginia. The NRQZ has an area of 13,100 square miles and a population of 600,000 people. That's comparatively large and well inhabited for a RQZ. Like other RQZs around the world the NRQZ is governed by laws in the national code.[130]

Briefly put, the NRQZ imposes a requirement on the operation of all fixed licensed transmitters (but only those) to meet power level requirements as their emissions would be or are received at a reference point near the primary focus of the Green Bank Telescope (well above ground level). If they do not meet the power levels, the NRAO can protest to the FCC which generally upholds the NRAO's view.  The vast majority of transmitters are well outside the area where they might interfere and are approved almost pro forma; a relative few must be adjusted to meet the rules and a very few wind up being rejected. The transmitters that are most likely to be allowed to operate with strong NRAO objections are those of government agencies like the US Department of Agriculture.

Transmitters that are not intended to operate at fixed locations inside the NRQZ, or in some cases at modestly changeable fixed locations within certain well-defined geographic areas of the NRQZ, are not affected. Transmitters on boats, planes, trains, or satellites are not governed by NRQZ rules per se. The FCC has ignored NRQZ rules in some rulings, for instance the so-called TV White Space Devices that provide broadband internet by operating in unused UHF TV channels. Potential interference from unintentional radiators like sawmills, gospel revivals and power lines is regulated by West Virginia state laws. The NRQZ rules are waived in cases of emergencies like floods when power transmission lines are loosely strung all over the site.

Worldwide, RQZs function somewhat like the US NRQZ, but with their own particular wrinkles. Not all regulate transmitters at all frequencies. One or two limit air traffic over the RQZ.[131] RQZs have no regulatory recognition by the ITU Radiocommunications Sector (ITU-R), but rather a general awareness.

The uses and limitations of RQZs were discussed in the Radio Astronomy Working Group Report that can be found on the IAU website https://iau.org/news/announcements/detail/ann21002/.

129 Outer Space Treaty, art. IX.
130 47 CFR 1.924(a); ***see also*** Paulette Woody, ***National Radio Quiet Zone***, NRAO, https://science.nrao.edu/facilities/gbt/interference-protection/nrqz (last accessed Aug. 17, 2021).
131 The operation of the wider set of world RQZ is described by the ITU-R. ITU-R, ***Characteristics of radio quiet zones***, RA.2259 (2012) (a new version will be published later this year).

# 5. Considerations Regarding Orbit as an Environment

## 5.1. The Outer Space Treaty and International Environmental Law

Article III of the OST[132] prescribes that:

> *States Parties to the Treaty shall carry on activities in the exploration and use of outer space, including the Moon and other celestial bodies, in accordance with international law, including the Charter of the United Nations, in the interest of maintaining international peace and security and promoting international co-operation and understanding.*[133]

In the interest of understanding the specific applicability of international law provisions to the body of international space laws, we refer to the introductory section of the LTSG, which at Paragraph 7 states:

> *In this regard, the guidelines also reiterate the principles contained in article III of the Outer Space Treaty that the activities of States in the exploration and use of outer space shall be carried out in accordance with international law, including the Charter of the United Nations. Accordingly, States should build on these principles when developing and conducting their national activities in outer space.*[134]

Moreover, from the US perspective, the National Space Policy of the United States of America (9 December 2020), in its relevant portion, recognizes:

> *Preserving the Space Environment to Enhance the Long-term Sustainability of Space Activities Preserve the Space Environment.*

132 *Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies*, 27 January 1967, 610 U.N.T.S. 205, (entered into force 10 October 1967) [*Outer Space Treaty*], Art III.

133 *Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies*, 27 January 1967, 610 U.N.T.S. 205, (entered into force 10 October 1967) [*Outer Space Treaty*], Art III.

134 UN COPUOS Sustainability Guidelines, pp. 2, para. 7.

*To preserve the space environment for responsible, peaceful, and safe use, and with a focus on minimizing space debris the United States shall: Continue leading the development and adoption of international and industry standards and policies, such as the Guidelines for the Long-term Sustainability of Outer Space Activities and the Space Debris Mitigation Guidelines of the United Nations Committee on the Peaceful Uses of Outer Space . . .*[135]

From a combined reading, it could be noted here that the LTSG and the provisions contained therein are intended/designed to expand the scope of Article III of the OST by inducting newer elements of consideration for national space legislations, policies, guidelines, etc. Thus, for the purpose of this report, we now turn to the enabling (applicable) provision(s) contained in the LTSG:

*Guideline A.2*
*Consider a number of elements when developing, revising or amending, as necessary, national regulatory frameworks for outer space activities*
*. . .*
*2. In developing, revising or amending, as necessary, national regulatory frameworks, States and international intergovernmental organizations should:*
*. . .*
*(a) Consider the provisions of General Assembly resolution 68/74, on recommendations on national legislation relevant to the peaceful exploration and use of outer space;*
*. . .*
*(c) Address, to the extent practicable, risks to people, property, public health and the environment associated with the launch, in-orbit operation and re-entry of space objects;*
*. . .*
*(d) Promote regulations and policies that support the idea of minimizing the impacts of human activities on Earth as well as on the outer space environment. They are encouraged to plan their activities based on the Sustainable Development Goals, their main national requirements and international considerations for the sustainability of space and the Earth;*
*. . .*
*(g) Weigh the costs, benefits, disadvantages and risks of a range of alternatives and ensure that such measures have a clear purpose and are implementable and practicable in terms of the technical, legal and management capacities of the State imposing the regulation. Regulations should also be efficient in terms of limiting the cost for compliance (e.g., in terms of money, time or risk) compared with feasible alternatives;*[136]

In turn, the applicable provisions of General Assembly resolution 68/74 contain the following points for our additional consideration; it: (a) observes that appropriate action at the national level is needed in view of the increasing participation of non-governmental entities in space activities; (b) notes the need for consistency and predictability with regard to the authorization and supervision of space activities and the need for a practical regulatory system for the involvement of non-governmental entities to provide further incentives for enacting regulatory frameworks at the national level; and (c) recommends, *inter alia*, the following elements for consideration by States when enacting regulatory frameworks for

135 US National Space Policy 2020, 14..
136 UN COPUOS Sustainability Guidelines, Guideline A.2, para. 2.

national space activities: (i) scope of space activities targeted by national regulatory frameworks may include, amongst other things, operation and control of space objects in orbit, (ii) States might employ specific procedures for the licensing and/or for the authorization of different kinds of space activities, and (iii) the conditions for authorization should help to ascertain that space activities are carried out in a safe manner and to minimize risks to persons, the environment or property.[137]

Here follows a more detailed description of the LTSG.

### 5.1.1. The Long-Term Sustainability Guidelines

The LTSG are a set of 21 voluntary guidelines grounded in the ideas, *inter alia*, that states remain committed to peaceful uses of outer space, pursue space use and exploration in sustainable ways, cooperate internationally to address natural and human-caused hazards, and develop national and international safety frameworks for space use and exploration.

The background text accompanying the LTSG makes clear that the guidelines were developed with the ongoing development of space in mind, including mega-constellations:

> *The Earth's orbital space environment constitutes a finite resource that is being used by an increasing number of States, international intergovernmental organizations and non-governmental entities. The proliferation of space debris, the increasing complexity of space operations, the emergence of large constellations and the increased risks of collision and interference with the operation of space objects may affect the long-term sustainability of space activities. Addressing these developments and risks requires international cooperation by States and international intergovernmental organizations to avoid harm to the space environment and the safety of space operations.*[138]

The background continues to note that the sustainable development of space is not something that can be achieved by the actions of any single State. Rather, it requires international cooperation, as the text explains:

> *International cooperation is required to implement the guidelines effectively, to monitor their impact and effectiveness and to ensure that, as space activities evolve, they continue to reflect the most current state of knowledge of pertinent factors influencing the long-term sustainability of outer space activities, particularly with regard to the identification of factors that influence the nature and magnitude of risks associated with various aspects of space activities or that may give rise to potentially hazardous situations and developments in the space environment.*[139]

As previously discussed, the development of mega-constellations and the prospects of the proliferation of space debris stand to impact space exploration by having adverse effects on astronomy, which is one of the foremost ways that humanity explores space. This is through direct interference with optical and radio observations, as well as indirect interference by potentially changing the sky brightness.

137 G.A. Res. 68/74, Recommendation on national legislation relevant to the peaceful exploration and use of outer space (Dec. 16, 2013).
138 UN COPUOS Sustainability Guidelines, pp. 1, para. 1.
139 *Id.* at pp. 4, para. 21.

The development of mega-constellations further has environmental impacts, including the potential for direct and indirect impacts on the climate and stratospheric ozone. The "*most current state of knowledge of pertinent factors*" influencing the development of space is changing rapidly along with our understanding of "*risks associated with various aspects of space activities*."[140] In light of this, Guideline A.2 has several relevant paragraphs, as mentioned above.

Regarding A.2, 2(c), space launch and satellite re-entry activity may reach sufficient levels to require further study.[141] Paragraph A.2, 2(d) has implications for light pollution (direct and diffuse), as it limits humanity's ability to explore space. Together, these paragraphs, along with the risks discussed herein, suggest that EIAs should be conducted by States, through their national mechanisms, when granting licenses to mega-constellation companies and that the categorical exclusions (CEs) used by the FCC do not meet the US government's (non-binding) commitments to the LTSG.

Paragraph A.2, 2(g) further suggests that the current use of CEs is inadequate:

> *Weigh the costs, benefits, disadvantages and risks of a range of alternatives and ensure that such measures have a clear purpose and are implementable and practicable in terms of the technical, legal and management capacities of the State imposing the regulation. Regulations should also be efficient in terms of limiting the cost for compliance (e.g., in terms of money, time or risk) compared with feasible alternatives;*[142]

An EIA would include a cost-benefit analysis and a risk assessment. These guidelines together are also consistent with the Rio Declaration on Environment and Development (the Rio Declaration) Principles 15, 16, and 17 (discussed in 5.1.7) through the promotion of identifying risks through EIAs and implementing "cost-effective" measures.

It may also be important to consider Guideline D.1, 2, and 4:

> *Promote and support research into and the development of ways to support sustainable exploration and use of outer space*
> *(...)*
> *2. In their conduct of space activities for the peaceful exploration and use of outer space, including celestial bodies, States and international intergovernmental organizations should take into account, with reference to the outcome document of the United Nations Conference on Sustainable Development (General Assembly resolution 66/288, annex), the social, economic and environmental dimensions of sustainable development on Earth.*
> *4. States and international intergovernmental organizations should consider appropriate safety measures to protect the Earth and the space environment from harmful contamination, taking advantage of existing measures, practices and guidelines that may apply to those activities, and developing new measures as appropriate.*[143]

Paragraph D.1, 2 promotes States to include "*social, economic, and environmental dimensions*" into their "*conduct of space activities*", with direct reference to the annex of resolution 66/288, which among

140 *Id.* at pp. 4, para. 20.
141 *Id.* at Guideline A.2.
142 *Id.* at Guideline A.2, 2(g).
143 *Id.* at Guideline D.1, 2, 4.

other things reaffirms a commitment to the Rio Declaration. This guideline can thus be interpreted to include the effects of light pollution on activities on Earth, as well as direct and indirect consequences of environmental changes.

Paragraph D.1, 4 may also be of interest, as it encourages States to consider "*appropriate safety measures to protect the Earth and the space environment from harmful contamination*". Whether this implies protections for astronomy does depend on whether harmful contamination includes light pollution and the visible (and radio) alteration of the night sky.

> From a cursory reading of the above, the following finer/subtle points emerge for consideration of the authors' Study Report:
>
> - § Apart from the environmental impact (on the "human environment") of launch and re-entry of space objects, newer and increasingly well-defined risks associated with "in-orbit" operation of space activities is now becoming a vital element for consideration while assessing the overall impact of space activities in the outer space environment;
> - § Regulations and policies regarding safe conduct of space activities may not only target the assessment of impact of such activities on the "human environment", but also may include the outer space environment; and
> - § Weigh the costs, benefits, disadvantages and risks of a range of alternatives and ensure that such measures have a clear purpose and are implementable and practicable.

### 5.1.2. Impact of On-Orbit Operations in Outer Space as Distinguished from the Environmental Impact of Launch and Re-entry of Launch Vehicles; Legal Policy and Support

At this juncture and for this part of the report, the authors, again, note with appreciation all actions (legislative, policy, directives, and implementation) of the US government in pursuance of its overall objective of the safe and sustainable use of outer space (please see the introduction to Section 5.1.1 above). The Working Groupalso wishes to reiterate its earlier concerns about the potential lacunae or "missing links" with respect to the urgent and immediate necessity of conducting due diligence or EIAs with respect to the "on-orbit" operations of commercial satellites of private constellations.

Principally drawing on our observations in Section 5.1.1., this section provides additional policy and legal support for the requirement to conduct due diligence based on international law, including well established and recognized principles of international environment law.

Please see again LTSG A.2 – Para 2 (a), (c), and (d) read with recommendations contained in UN General Assembly Resolution 68/74. In the LTSG, the use of the words "*in-orbit operation*" in Para 2(c) and the words "*minimizing the impacts of human activities on Earth as well as on the outer space environment*" in Para 2(d) are critical to the discussions above.

An authentic and conclusive UN Report by the Secretary General of the UN entitled *Gaps in international environmental law and environment-related instruments: towards a global pact for the environment*[144] was published on 30 November 2018 (hereinafter the SG Report) in response to General Assembly resolution 72/277 entitled *Towards a Global Pact for the Environment*, in which the General Assembly requested the Secretary General to submit, at its seventy-third session in 2018, a technical and evidence-based report that identifies and assesses possible gaps in international environmental law and environment-related instruments with a view to strengthening their implementation.

After a review and analysis of the corpus of international environmental law and environment-related instruments as well as the governance structure and implementation of international environmental law[145], it concludes the following on the prevention principle:

> *Since it first appeared in the 1938 Trail Smelter arbitration, the prevention of transboundary harm has been framed as a principle in foundational instruments of international environmental law, United Nations instruments, regional instruments, texts drafted by civil society and the decisions of the International Court of Justice. This principle is intrinsic to a core preference in international law for preventing environmental harm rather than compensating for harm that has already occurred. <u>The prevention principle is well established as a rule of customary international law</u>, supported by relevant practice in many environmental treaties and major codification initiatives. <u>In practice, this principle is also related to due diligence obligations, particularly the duty to undertake an environmental impact assessment prior to engaging in activities which pose a potential risk of transboundary harm</u>.*[146]

The SG Report also notes, in its preambular portion, that: (a) there is no single overarching normative framework that sets out what might be characterized as the rules and principles of general application in international environmental law …; (b) international environmental law is piecemeal and reactive; (c) the structure of international environmental governance is characterized by institutional fragmentation and a heterogeneous set of actors.

Owing to the piecemeal nature of environmental law , even under the prevention principle, three different regimes appear to have emerged: (a) prevention of transboundary damage; (b) prevention of transboundary harm; and (c) prevention of transboundary environmental impact.

144 Report of the Secretary General, Gaps in international environmental law and environment-related instruments: towards a global pact for the environment, U.N. Doc. A/73/419 (Nov. 30, 2018).
145 *Id.* at 1. Although the primary purpose of this Report was to reveal gaps and deficiencies at multiple levels, this Report analyzes all relevant principles of international environmental law and confirms its findings on different levels based on an evidence based modality.
146 *Id.* at 7. (emphasis added)

### 5.1.2.1. Prevention of Transboundary Damage

This specific principle pertains to transboundary damage and is essentially captured in certain foundational instruments of international environment law[147] and decisions of the International Court of Justice.[148]

It requires the highest standard of care, and the corresponding obligation of due diligence, as there is State responsibility affixed with this principle. To state the exact principle:

> *States have, in accordance with the Charter of the United Nations and the principles of international law, the sovereign right to exploit their own resources pursuant to their own environmental and developmental policies, and the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction.*[149]

The relevant US policy position/stance is reflected in the International Law Commission (ILC). As regards liability for transboundary damage, it is relevant to note that the US position (as captured by the Second Report of the International Law Commission[150]) on the subject is as follows:

> *The United States did not believe that "under customary international law, States are generally liable for significant transboundary harm caused by private entities acting on their territory or subject to their jurisdiction or control". It added that, "from a policy point of view, a good argument exists that the best way to minimize such harm is to place liability on the person or entity that causes such harm, rather than on the State.*[151]

However, in the domain of space activities, and given the nature of legal obligations contained in the space law treaties pertaining to state liability and responsibility, any potential liability has been drafted to be placed on States Parties (and not on its private entities); and thus, in cases of non-compliance, the US government may not be able to resort and defend this earlier position.

Please also see again, the SG Report and the excerpt quoted above which, in its relevant portions, states "*This principle is intrinsic to a core preference in international law for preventing environmental harm rather than compensating for harm that has already occurred.*"[152]

---

147 See Declaration of the United Nations Conference on the Human Environment (Stockholm Declaration), Principle 21; Rio Declaration on Environment and Development, principle 2, June 13, 1992, 31 ILM 874 [hereinafter Rio Declaration]; World Charter for Nature (WCN), art. 21(d).

148 Pulp Mills on the River Uruguay (Argentina v. Uruguay), Judgment, I.C.J. Reports 2010, pp. 14, para. 10 (The Court points out that the principle of prevention, as a customary rule, has its origins in the due diligence that is required of a State in its territory); (Corfu Channel (United Kingdom v. Albania), Merits, Judgment, I.C.J. Reports 1949, p. 22 (It is "***every State's obligation not to allow knowingly its territory to be used for acts contrary to the rights of other States***"); Legality of the Threat or Use of Nuclear Weapons, Advisory Opinion, I.C.J. Reports 1996 (I), p. 242, para. 29 (A State is thus obliged to use all the means at its disposal in order to avoid activities which take place in its territory, or in any area under its jurisdiction, causing significant damage to the environment of another State. This Court has established that this obligation "***is now part of the corpus of international law relating to the environment***").

149 Rio Declaration, principle 2.

150 International Law Commission, Second report on international liability for injurious consequences arising out of acts not prohibited by international law (prevention of transboundary damage from hazardous activities), pp. 17, U.N. Doc. A/CN.4/501 (May 5, 1999.

151 ***See*** U.N. Doc. A/CN.4/481, para. 24; ***see also***, U.N. Doc. A/C.6/51/SR.39, at para. 31-33.

152 Report of the Secretary General, Gaps in international environmental law and environment-related instruments: towards a global pact for the environment, U.N. Doc. A/73/419 (Nov. 30, 2018).

### 5.1.2.2. Prevention of Transboundary Harm

The draft Articles on Prevention of transboundary harm from hazardous activities, as published by the International Law Association and as recommended by the UN General Assembly, through its Resolution 62/68 entitled *Consideration of prevention of transboundary harm from hazardous activities and allocation of loss in the case of such harm,*[153] contain the following considerations.

*Article 2(a) states:*

> *Risk of causing significant transboundary harm includes risks taking the form of a high probability of causing significant transboundary harm and a low probability of causing disastrous transboundary harm.*[154]

Given this definition, these articles offer a mid-way between (a) "transboundary damage" (for which there is State responsibility, or in certain cases, state liability, i.e., it requires the highest standard of care); and (b) "transboundary environmental impact" (for which the only obligation is of due diligence, potentially in the form of an EIA (see discussions in the next subsection) but it does not obligate a State to act on the due diligence of the EIA Report — it leaves it at the State's discretion, i.e., the lowest standard of care is required).

Article 3 (Prevention) states:

> *The State of origin shall take all appropriate measures to prevent significant transboundary harm or at any event to minimize the risk thereof.*[155]

Article 5 (Implementation) states:

> *States concerned shall take the necessary legislative, administrative or other action including the establishment of suitable monitoring mechanisms to implement the provisions of the present articles.*[156]

### 5.1.2.3. Prevention of Transboundary Environmental Impact

The essence of this is primarily captured in the Convention on Environmental Impact Assessment in a Transboundary Context (the Espoo Convention)[157]. The US has signed but not ratified this Convention.

The prevention principle captured in this Convention requires the lowest standard of care, with a view to preventing, reducing and controlling significant adverse transboundary environmental impact from proposed activities (Article 2(1)), and recommends conducting an EIA prior to a proposed activity (Article 2(3)).

---

153 G.A. Res. 62/68, Consideration of prevention of transboundary harm from hazardous activities and allocation of loss in the case of such harm (Dec. 6, 2007)
154 https://digitallibrary.un.org/record/613193?ln=en
155 https://digitallibrary.un.org/record/613193?ln=en
156 https://digitallibrary.un.org/record/613193?ln=en
157 Convention on Environmental Impact Assessment in a Transboundary Context, 1989 U.N.T.S. 309, Feb. 25, 1991 [hereinafter Espoo Convention] https://unece.org/DAM/env/eia/documents/Espoo10years/english10years.pdf.

The Convention provides the following definitions:

> *"Proposed activity" means any activity or any major change to an activity subject to a decision of a competent authority in accordance with an applicable national procedure; and*
> *"Transboundary impact" means any impact, not exclusively of a global nature, within an area under the jurisdiction of a Party caused by a proposed activity the physical origin of which is situated wholly or in part within the area under the jurisdiction of another Party.*[158]

Technicalities in the Convention: Certain activities stated in Appendix 1 are automatically deemed to cause significant transboundary impact. However, it is important to note here that the principles of this Convention are not only applicable to a "proposed activity" (as contained in Appendix 1), but is subject to all such "proposed activities" that may cause a significant transboundary environmental impact.

### 5.1.3. International Policy Analysis

The AAS, through its SATCON1 Report, states and affirms, with sufficient evidence and via a thorough scientific approach, that environmental impact/harm/damage (or, at the very least, environmental impact) is caused by light pollution resulting from the reflectivity of the satellites of mega-constellations.

Having discussed the three sub-categories under which the "prevention principle" has been applied in practice, the authors wish to note that the prevention principle per se is part and parcel of customary international law. The obligation to conduct due diligence is a natural and relevant outcome of this.

The authors commend the efforts of the US in pursuing EIAs of launch and re-entry of all space vehicles as well as of governmental and defense projects undertaken by NASA. The Working Group however, wishes to reiterate that there is a key missing link such that no due diligence is currently being conducted for the in-orbit operation of commercial satellites of private entities.

The Working Group wishes to draw attention to Article VIII of the OST[159] which postulates that space objects are within the jurisdiction and control of the State Party on whose registry it is carried. Thus, despite the fact that these satellites are operating in orbit, they continue to remain within the jurisdiction of the US. Any pollution (as is being alleged) generated by them would directly attract the customary international principle of the duty to undertake prevention and a corresponding obligation to conduct a due diligence at the very minimum.

If, in this regard, the US wishes to pursue a policy based or regulatory framework to fill the current gap, the authors request that it pay attention to the LTSG, which in Guideline A.2 states:

> *Consider a number of elements when developing, revising or amending, as necessary, national regulatory frameworks for outer space activities … 2. In developing, revising*

158 Convention on Environmental Impact Assessment in a Transboundary Context, 1989 U.N.T.S. 309, Feb. 25, 1991 [hereinafter Espoo Convention] https://unece.org/DAM/env/eia/documents/Espoo10years/english10years.pdf.

159 Outer Space Treaty, art. VIII ( "*A State Party to the Treaty on whose registry an object launched into outer space is carried shall retain jurisdiction and control over such object, and over any personnel thereof, while in outer space or on a celestial body. Ownership of objects launched into outer space, including objects landed or constructed on a celestial body, and of their component parts, is not affected by their presence in outer space or on a celestial body or by their return to the Earth. Such objects or component parts found beyond the limits of the State Party to the Treaty on whose registry they are carried shall be returned to that State Party, which shall, upon request, furnish identifying data prior to their return.*").

*or amending, as necessary, national regulatory frameworks, States and international intergovernmental organizations should:*

*. . .*

*(h) Encourage advisory input from affected national entities during the process of developing regulatory frameworks governing space activities to avoid unintended consequences of regulation that might be more restrictive than necessary or that conflicts with other legal obligations;*[160]

Affected national entities, in this instance, would include the concerns being raised by the AAS.

With the above in mind, the authors urge the US government to consider the following proposal, which may help to avoid any State responsibility or liability. Prevention should be a preferred policy because compensation in the case of harm often cannot restore the situation prevailing prior to the event or accident. Discharge of the duty of prevention or due diligence is all the more required as knowledge regarding the operation of hazardous activities, the materials used and the process of managing them and the risks involved is steadily growing. And thus, for the in-orbit operation phases of commercial satellites, due diligence may be conducted keeping in view the following tier-system or classification:

160 UN COPUOS Sustainability Guidelines, Guideline A.2.

*Table 1. Prevention principle" and corresponding obligations*

| **Influence[161] of satellites** | **Application of principle** | **Standard of care required to be observed** | **Corresponding obligations** | **Additional remarks** |
|---|---|---|---|---|
| Low | Prevention of transboundary <u>environmental impact</u> | A cumulative impact analysis of the total satellite population in orbit by all States is desirable. | Obligation to only conduct due diligence or EIA prior to the undertaking of a "proposed activity" or if there is a major change to any existing activity. Obligation to act on the EIA Report is left to the discretion of individual States. | Support: Espoo Convention;<br>US has signed but not ratified this convention. |
| Medium | Prevention of transboundary <u>harm</u> | Includes risks taking the form of a high probability of causing significant transboundary harm and a low probability of causing disastrous transboundary harm | In addition to conduct of due diligence, States are asked to take the necessary legislative, administrative or other action including the establishment of suitable monitoring mechanisms. | Support:<br>The draft Articles on Prevention of transboundary harm from hazardous activities, as published by the International Law Association and as recommended by the UN General Assembly, through its Resolution 62/68 entitled *Consideration of prevention of transboundary harm from hazardous activities and allocation of loss in the case of such harm*[162]<br>Owing to the nature of space activities, the obligations would be very difficult to implement after an incident or activity. Thus, it may be prudent to combine this with a precautionary approach |

161 "Influence" generally refers to the cumulative effect of all satellites, with individual satellite characteristics also considered.
162 G.A. Res. 62/68, Consideration of prevention of transboundary harm from hazardous activities and allocation of loss in the case of such harm, Annex (Dec. 6, 2007)

| | | | | |
|---|---|---|---|---|
| High | Prevention of transboundary damage | Highest degree of care<br><br>State responsibility/ liability affixed for damage caused. | US position on this: "*The United States did not believe that under customary international law, States are generally liable for significant transboundary harm caused by private entities acting on their territory or subject to their jurisdiction or contro*l". It added that, "*from a policy point of view, a good argument exists that the best way to minimize such harm is to place liability on the person or entity that causes such harm, rather than on the State.*"[163] | Support: Foundational environmental treaties and conventions; ICJ cases, etc.<br>Please note that in the field of space activities, the US position would be automatically negated due to application of Article VI of the Outer Space Treaty |

The first column of the above table lists descriptors for the tier-system, addressing the effect that the satellite population has on the environment or other activities. In the present context, those activities are ground-based astronomy, including stargazing for cultural practices or night sky enjoyment. The authors purposefully do not define the technical thresholds for those categories, which should include a number of factors such as satellite numbers at different altitudes, the total on-orbit cross section of satellites, and the risk of proliferating debris. The descriptors are intended to have the following broad meanings:

- Low — Observing the sky is occasionally affected by the satellite population. There is only a minor disruption of activities. However, the growth of the satellite population could lead to a noticeable change in the sky. Conducting a cumulative impact analysis is desirable prior to approving additional satellites. SATCON1 astronomy impact category: "Negligible".
- Medium — Observing the sky is regularly affected by the satellite population. Some activities have large disruptions. Further growth could have severe impacts on sky use. SATCON1 astronomy impact category: "Significant but tolerable".
- High — Observing the sky is regularly and in at least some cases severely affected by the satellite population. Effects might include substantial data loss, major interference with stargazing, or inability to conduct some science programs. SATCON1 astronomy impact category: "Extreme".

It is the view of some members of the International Policy Subgroup that the current situation of on-orbit interference with astronomy and viewing the sky is between the Low and Medium categories above, with

163 *See* U.N. Doc. A/CN.4/481, para. 24; ***see also***, U.N. Doc. A/C.6/51/SR.39, at para. 31-33.

concern for a rapid transition to Medium. The members stress that carefully considered metrics needs to be developed to assess the current situation properly.

Moreover, recent trends, opinions of States, and related industry practices also show an increasing need to pay attention to EIAs for space activities during their operational phase in the "outer space environment" as distinguished from the impact of such activities only on the "human environment" on Earth.

Thus, the new LTSG guidelines stress the words: minimizing the impacts of human activities on Earth *as well as on the outer space environment*. And thus, the authors urge the US to consider a holistic approach to the conduct of EIAs for in-orbit operations of commercial satellites with a view to ascertaining both (a) the impact on the human environment; and (b) the impact on the outer space environment. From a policy perspective, the procedure could be to ascertain all impacts of the in-orbit operation of commercial satellites, their rocket bodies, and their debris while they are in the orbital space. As the concerns of the AAS (as discussed in the preceding section) are concerns raised by "affected national entities", their concerns would automatically find redressal if this policy approach is pursued.

<u>Legal/policy support:</u>

- § LTSG A.2 (2)(d) recommends promotion of regulations and policies that support the idea of minimizing the impacts of human activities on Earth <u>as well as on the outer space environment;</u>
- § UN General Assembly Resolution 68/74, noting the need to maintain the sustainable use of outer space, in particular by mitigating space debris, and to ensure the safety of space activities and minimize the potential harm to the [outer space] environment;
- § UN General Assembly Resolution 73/91 entitled *International cooperation in the peaceful use of outer space*, wherein the General Assembly expresses its deep concern "*about the fragility of the space environment and the challenges to the long-term sustainability of outer space activities, in particular the impact of space debris, which is an issue of concern to all nations*";
- § To a certain extent, the US already considers aspects of the space environment, as contained in the Space Policy Directive – 3, wherein Section 2(a), (b) and Section 3 treats the "*space environment*" as a separate environment (albeit in the context of Space Situational Awareness (SSA) and STM activities).
- § NPR 8715.6B defines responsibilities and requirements to ensure that NASA and its partners, providers, and contractors consider the preservation of the near-Earth space environment and the space environment beyond Earth's orbit.

## 5.1.4. Precautionary Principle

The precaution proposed to be considered by the US is (a) consider a Cumulative Impact Analysis of all satellites in orbit, and (b) consider enacting measures and policies deemed to be a tier above the current category as given in Table 1 above.

With respect to the precautionary principle (PP), which will be addressed further below, the SG Report[164] also notes:

> *12. This principle stipulates that States are required to adopt a precautionary approach when taking decisions or in regard to potential omissions which may harm the environment. Such a duty remains intact irrespective of the absence of scientific certainty as to the existence or extent of such risk. While the principle as formulated in Principle 15 of the Rio Declaration reflects other critical principles, such as the effective implementation of international environmental law, the legal basis of precaution as a principle is a matter of some controversy and debate. However, the exercise of precaution in this respect is expressed in other foundational instruments of international environmental law, regional instruments, texts drafted by civil society and rulings of the International Tribunal for the Law of the Sea.*[165]

With respect to the application of this principle, although well-defined, the authors note that its implementation and state practice is not yet enough to categorize it as a customary principle of international law. The authors recognize that it would wholly be the prerogative of the US to consider and adopt this principle as regards the conduct of EIAs for in-orbit operations.

### 5.1.4.1. Preliminary Discussion

The PP is an approach that encourages preventative measures to be taken in the event that the full consequences of a hazardous activity are yet to be scientifically determined. Essentially, "...*where there is the potential for serious or irreversible harm to the ecosystem or human health, anticipatory measures should be taken to prevent such harm; furthermore, uncertainty as to the likelihood or extent of the harm should not result in the postponement of cost-effective measures to avoid it*."[166] It is important to stress that the PP does motivate scientific inquiry into the potential consequences of hazardous activities. As a result, if scientific inquiry determines that an action initially prevented by the PP can be carried out safely with the implementation of proper measures, protections may be lifted, and the activity can move forward. However, as will be explored later in this section, there has been pushback from the US government in suggesting that the PP does not, in their view, promote a science-based approach; yet overlap between the US approach and the PP is present in that both seek to achieve the similar goal of exercising precaution and scientific investigation with regard to activities that present unknown hazards.

The PP was first incorporated into German law regulating air pollution in the 1970s as *Vorsorgeprinzip* — the translation of which is essentially the "foresight principle".[167] Since the 1980s it has emerged as a widely cited concept in both international treaties and national legislation focusing on human health, safety, and the environment. However, the adoption of the PP varies in degree and interpretation, owing to the lack of a universal consensus on its definition.[168]

164 Report of the Secretary General, Gaps in international environmental law and environment-related instruments: towards a global pact for the environment, U.N. Doc. A/73/419 (Nov. 30, 2018).
165 *Id.* at 8.
166 Theresa McClenaghan, ***Precautionary Principle, in*** # Encyclopedia of Quality of Life and Well-Being Research (Alex Michalos ed., 2014). [need pin cite]
167 Timothy O'Riordan and Andrew Jordan, ***The Precautionary Principle in Contemporary Environmental Politics***, 4 Environmental Values 191, 193 (1995).
168 McClenaghan, ***supra*** note 157 at #.

Many international environmental instruments have included iterations of the PP in text to emphasize the precaution as a means of preserving human health and the environment. The Vienna Convention for the Protection of the Ozone layer (VCPOL)[169], adopted in 1985, was the first international treaty to explicitly emphasize the concept, with Article 2(1) of the Convention reading:

> *The Parties shall take appropriate measures in accordance with the provisions of this Convention and of those protocols in force to which they are party to protect human health and the environment against adverse effects resulting or likely to result from human activities which modify or are likely to modify the ozone layer.*[170]

Article 2(b) of VCPOL again reiterates the PP:

> *Adopt appropriate legislative or administrative measures and co-operate in harmonizing appropriate policies to control, limit, reduce or prevent human activities under their jurisdiction or control should it be found that these activities have or are likely to have adverse effects resulting from modification or likely modification of the ozone layer.*[171]

The 1987 Montreal Protocol on Substances that Deplete the Ozone Layer (the Montreal Protocol),[172] which built on the obligations in VCPOL, further compelled states to take precautionary measures when dealing with substances that deplete the ozone layer. Although a comprehensive scientific understanding of ozone-depleting substances had not been established, the Montreal Protocol obligated states to phase out the use of certain chemicals and products and was ultimately successful in doing so — thereby allowing the ozone layer to recover.[173]

The 1992 Earth Summit in Rio De Janeiro marked a significant rise in the inclusion of the PP within international legal instruments. The resulting documents included the Rio Declaration,[174] the United Nations Framework Convention on Climate Change (UNFCCC),[175]and the Convention on Biological Diversity (CBD),[176] all of which embody the PP. Principle 15 of the Rio Declaration is the most widely cited example of the PP in international legal instruments, offering a robust definition that includes the core attributes of the PP:

> *Principle 15: In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation.*[177]

The UNFCCC, a monumental step in addressing global climate change that would later lead to the Kyoto protocol and the Paris Agreement, included a principle obligating states to prioritize human health in the case of scientific uncertainty in Article 3(3).

---

169 Vienna Convention for the Protection of the Ozone Layer, Mar. 22, 1985, 1513 U.N.T.S. 293 [hereinafter VCPOL].
170 ***Vienna Convention for the Protection of the Ozone Layer online Handbook***, United Nations Environment Programme Ozone Secretariat, https://ozone.unep.org/treaties/vienna-convention (last accessed Aug. 21, 2021).
171 Vienna Convention for the Protection of the Ozone Layer, Mar. 22, 1985, 1513 U.N.T.S. 293.
172 Montreal Protocol on Substances that Deplete the Ozone Layer, 1522 U.N.T.S. 3, Sept. 16, 1987 [hereinafter Montreal Protocol]
173 Guus Velders et. al., *The Importance of the Montreal Protocol in Protecting* Climate, 104 PNAS 4814 (2007).
174 Rio Declaration on Environment and Development, June 13, 1992, 31 ILM 874.
175 United Nations Framework Convention on Climate Change, May 9, 1992, 1771 U.N.T.S. 107.
176 Convention on Biological Diversity, June 5, 1992, 1760 U.N.T.S. 79 [hereinafter UNFCC].
177 Rio Declaration, principle 15.

*The Parties should take precautionary measures to anticipate, prevent or minimize the causes of climate change and mitigate its adverse effects. Where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing such measures, taking into account that policies and measures to deal with climate change should be cost-effective so as to ensure global benefits at the lowest possible cost. To achieve this, such policies and measures should take into account different socio-economic contexts, be comprehensive, cover all relevant sources, sinks and reservoirs of greenhouse gases and adaptation, and comprise all economic sectors. Efforts to address climate change may be carried out cooperatively by interested Parties.*[178]

Lastly, the CBD included a reference to the PP in its preamble:

*Noting also that where there is a threat of significant reduction or loss of biological diversity, lack of full scientific certainty should not be used as a reason for postponing measures to avoid or minimize such a threat.*[179]

However, having said that, the authors wish to direct the attention of concerned policy-makers towards the positions stated in US policy documents:

§ National Space Policy of the United States of America (09 December 2020), page 5:

*"Create a safe, stable, secure, and sustainable environment for space activities, in collaboration with industry and international partners, through the development and promotion of responsible behaviors …"*

§ National Space Policy of the United States of America (09 December 2020), page 15:

*"Regularly assess existing guidelines for non-government activities in or beyond Earth orbit, and maintain a timely and responsive regulatory environment for licensing those activities, consistent with United States law and international obligations;"*

§ Report No. IG-21-011, 27 January 2021: NASA's Efforts to Mitigate the Risks posed by orbital debris, Conclusion:

*"Protecting the expanding space environment is critical since the services billions of people rely on daily such as weather forecasting, telecommunications, and global positioning systems require a stable space environment."*

### 5.1.5. Atmospheric Pollution and Relevant International Environmental Law

The effects of satellites on the environment cannot be considered in isolation. Rather, there are cumulative effects due to actions by multiple actors in various States. These effects can have a negative impact on the environment, human activities, and on all satellite operations. They also might not be

178 UNFCC, art. 3(3).
179 Convention on Biological Diversity, June 5, 1992, 1760 U.N.T.S. 79.

recognized if a system of satellites is evaluated independently of other systems or, worse yet, only single satellites are considered. In the following discussion, the authors focus the discussion on two aspects of this cumulative effect problem as it pertains to mega-constellations, namely light pollution and atmospheric pollution, as the latter can affect ground-based astronomy in non-trivial ways. In regard to developing a regulatory framework addressing light pollution, governments might, for example, consider:

1 How bright is an individual satellite (which combines phase, albedo, and reflecting area)?
2 How many satellites are there in a constellation?
3 What duration of the night are the satellites visible, for the time of year and latitude of the observer?
4 What is the diffuse brightness due to all material in orbit, for the time of year and latitude of the observer?

The brightness of an individual satellite may or may not be important. For example, the International Space Station can be brighter than Venus, but because it is a single object it is generally not a problem for stargazing or astronomical measurements. In contrast, the over 1600 Starlink satellites currently in orbit are notable for the combination of their brightness and their numbers. With the prospects of between ten and a hundred times more satellites of potentially comparable brightness, or brighter, the problem of light pollution is potentially significant for the amount of diffuse light. In this way, regulating, say, a single satellite's brightness might only address one part of the problem.

Air pollution provides another example on how cumulative effects can be overlooked by focusing on single satellites. The real effects might only be understood by considering the collective action of all operators over decade timescales, taking into account material placed into the upper atmosphere due to rocket launches as well as satellite re-entries. Information available to scientists and policy makers will be incomplete at first, even if potential issues are identifiable now. Again, there might not be a single metric that we can use to understand the full effects either, owing to secondary effects. For example, climate impacts could alter global atmospheric circulation, which in turn could alter weather patterns.

As described below, there are numerous instances of national and international law, as well as international guidelines, that are built on the concept of the PP. This is done to avoid activities that might cause serious or irreversible harm to people and the environment. Because it calls for action (or restraint) before a full understanding of a development can be made, it is sometimes viewed as an unscientific approach to development[180]. However, making cautious policy decisions in the face of scientific uncertainty is not the same as making decisions based on conjecture. Indeed, the precautionary principle is rooted in the scientific process, as McClenaghan[181] explains:

> *Since there must be a basis on which to conclude that a threat of harm is serious and perhaps irreversible, the precautionary principle is truly science based. The more good science we have, the better our precautionary decision making can be. In other words, as more evidence is compiled, we might conclude that the harm in question either is not serious or irreversible or can be prevented through appropriate actions. Or we may conclude that there is less*

180 McClenaghan, ***supra*** note 157, at #.
181 *Id.*

*uncertainty or doubt about the potential harm that may be caused or alternatively that we cannot reasonably reduce the uncertainty and precaution must be maintained. (Once we have a great deal of certainty, we no longer need to apply the precautionary principle per se; our other decision-making criteria are relevant to determine what course of action is indicated).*[182]

One way that there can be meaningful environmental assessment in the face of scientific uncertainty is to consider whether proposed or ongoing human activities will, directly or indirectly, introduce rates of change in an environment that are comparable to or exceed natural rates or whether the development will introduce new damaging materials to an environment.

Current development of LEO has the potential to interfere with its future development, an antithesis to sustainable development.[183] This interference, as discussed above, includes the de facto exclusion of other actors from orbital slots, the increased conjunction assessment burden and corresponding maneuvers, and delays in launches.[184] Specific to astronomy, unsustainable practices in space may already be causing a change in the nighttime brightness of the sky due to light reflected off space debris.[185] These changes will not be noticeable at this time by stargazers, but may become measurable at dark sites when conducting any form of deep (long integration) imaging. Further proliferation of space debris and the widespread construction of mega-constellations is thus not just an operational concern for satellite activities, but a concern for the sky brightness. The overall effect will depend on the total reflecting area that is placed in orbit, including debris that will arise from any type of on-orbit fragmentation event from collisions, battery and fuel explosions, or meteoroid impacts. Understanding the scope of this problem requires evaluating the cumulative effects.

Another area of concern is the deposition of materials into the upper atmosphere well above natural rates. One example is the placement of soot, alumina, and ozone-depleting substances in the stratosphere by rockets.[186] Soot and alumina have climate implications by altering Earth's radiative balance, while alumina, chlorine, and radicals destroy ozone. Such ozone depletion has been measured directly in the wake of some rockets.[187] The rocket launches needed to support mega-constellations are a concern for altering Earth's climate and ozone layer. Note that $CO_2$ emission from rockets is of little to no concern at this time (although we should be mindful that this could change), and the evaluation of climate impacts based solely on $CO_2$ emissions misses the largest effects of rockets on Earth's atmosphere.

Along with direct climate and ozone implications, however, are secondary effects, such as changes to global atmospheric circulation and the formation of mesospheric clouds. The latter has direct

---

182 *Id.*
183 Report of the World Commission on Environment and Development: Our Common Future (1987).
184 e.g., The Future of Security in Space: A Thirty-Year US Strategy, 2021, C.G. Starling et al., Atlantic Council Strategy Paper Series, https://www.atlanticcouncil.org/content-series/atlantic-council-strategy-paper-series/the-future-of-security-in-space/
185 M. Kocifaj, et. al., ***The proliferation of space objects is a rapidly increasing source of artificial night sky brightness***, 504 MNRAS, L40, L44 (2021).
186 Martin Ross & James Vedda, ***The Policy and Science of Rocket Emissions,*** Aerospace Corp. (2018), ***available at*** https://aerospace.org/sites/default/files/2018-05/RocketEmissions_0.pdf.
187 M.N. Ross et al, ***Observation of stratospheric ozone depletion associated with Delta II rocket emissions***,

27 Geophysical Research Letters 22209, 2209-2212 (2000).

implications for astronomical observations, and such mesospheric cloud cover is already thought to be influenced by space traffic.[188]

Yet another area of concern is the deposition of material into the atmosphere due to satellite and rocket body reentries[189]. Each day, meteoroids deliver 54 tons of material to Earth[190], most of which is deposited in Earth's mesosphere. Satellite operations of large constellations are proposing system recycling approximately every five years. If one considers as an example the 42,000 satellites under consideration by the FCC for Starlink, the average satellite reentry from this constellation alone would be 23 satellites per day. For satellite masses of 260 kg (empty), this amounts to about 6 tonnes per day. At face value, one might see this human activity as having only a 10% effect compared with meteoroids. However, meteoroids and satellites have vastly different compositions. For example, satellites are mostly aluminum, while meteoroids are only about 1% aluminum by weight[191]. Thus, anthropogenic deposition of aluminum is poised to exceed that of meteoroids by a factor of ten. Other elements may also exhibit high levels of anthropogenic placement into the environment.

As seen with the rocket launch studies discussed above, high-altitude aluminum introduces multiple concerns, including albedo changes to Earth and ozone depletion as the material sinks into the stratosphere. The full composition of satellites may have further effects that cannot be identified until there is a registry of satellite composition by mass fraction (empty and wet). As an example, the sodium contained within meteoroids, which is only about 0.5% of their composition by weight, produces a sodium layer in the mesosphere. That layer leads to a component of "airglow", contributing to sky brightness in some observing bands.[192]

### 5.1.6. The Rio Declaration

The Rio Declaration[193] consists of 27 principles adopted during the 1992 United Nations on Environment and Development, the so-called Earth Summit. While the Declaration is non-binding, it lays out several important ideas concerning the environment. All nations present at the Summit accepted the Declaration without change[194]. The first principle emphasizes that the scope is centred on concerns for humanity:

> *Human beings are at the centre of concerns for sustainable development. They are entitled to a healthy and productive life in harmony with nature.*[195]

Principle 2 acknowledges the right of states to exploit their own resources, but also declares that states have a responsibility not to "*cause damage to the environment of other States or of areas beyond the limits of national jurisdiction*". In full,

---

188 David E. Siskind et al., ***Recent observations of high mass density polar mesospheric clouds: A link to space traffic***, 40 Geophysical Research Letters 2813, 2813-2817 (2013).
189 Aaron Boley & Michael Byers, ***Satellite mega-constellations create risks in Low Earth Orbit, the atmosphere and on Earth***, 11 Sci. Rep. 10641 (2021).
190 Gerhard Drolshagen et al., ***Mass accumulation of earth from interplanetary dust, meteoroids, asteroids and comet***, 143 Planetary Space & Sci. 21, 21-27 (2017).
191 Katharina Lodders, ***Solar system abundances of the elements***, in Principles and Perspectives in Cosmochemistry (Aruna Goswami and B. Eswar Reddy eds., 2008).
192 F. Patat, ***UBVRI night sky brightness during sunspot maximum at ESO-Paranal***, 400 Astronomy & Astrophysics 1183, 1183-1198 (2002).
193 U.N. Doc. A/CONF.151/26 (Vol I) (Aug. 12, 1992).
194 G.A. Res. 47/190 (Mar. 16, 1993).
195 Rio principle 1

*States have, in accordance with the Charter of the United Nations and the principles of international law, the sovereign right to exploit their own resources pursuant to their own environmental and developmental policies, and the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction.*[196]

Principle 3 goes on to define sustainable development, using language similar to that used in the Brundtland Report[197] and emphasizing that the development must be done in ways that do not prevent future generations from also developing an area:

*The right to development must be fulfilled so as to equitably meet developmental and environmental needs of present and future generations.*[198]

Having defined sustainable development, the Declaration sees environmental protection as inseparable from the development process:

*In order to achieve sustainable development, environmental protection shall constitute an integral part of the development process and cannot be considered in isolation from it.*[199]

While many of the principles contain text relevant to this discussion, it is important to highlight principle 15, which is a statement of the PP, namely:

*In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation.*[200]

This principle highlights the situation we now face with the construction of satellite mega-constellations. Multiple risks have been identified, some of which are serious (as discussed above) and require further study. The lack of certainty must not be used to dismiss such concerns.

Principles 16 and 17 are also relevant. They are, in turn:

*National authorities should endeavour to promote the internalization of environmental costs and the use of economic instruments, taking into account the approach that the polluter should, in principle, bear the cost of pollution, with due regard to the public interest and without distorting international trade and investment*

and

*Environmental impact assessment, as a national instrument, shall be undertaken for proposed activities that are likely to have a significant adverse impact on the environment and are subject to a decision of a competent national authority.*[201]

196 Rio principle 2
197 Report of the World Commission on Environment and Development: Our Common Future (1987).
198 Rio principle 3
199 Rio principle 4
200 Rio principle 15
201 Rio principles 16 and 17

Damage to the night sky, the atmosphere, and Earth's orbital environment through the use and occupation of satellites are examples of negative externalities that licensing States impose on the global population. As principle 16 explains, these externalities should be internalized and the "*polluter should, in principle, bear the cost of pollution*". Moreover, principle 17 gives States a responsibility to ensure that an environmental assessment is carried out for activities "*that are likely to have a significant impact on the environment*". This must be read with principle 15 as well, again stressing that scientific uncertainty cannot be used as an argument to ignore potentially serious adverse effects.

The US joined over 170 other nations in adopting these non-binding principles. However, the US did note several reservations[202]. Of the principles listed above, only principle 3 was offered an explicit note:

> *The United States does not, by joining consensus on the Rio Declaration, change its long-standing opposition to the so-called 'right to development'. Development is not a right. On the contrary, development is a goal we all hold, which depends for its realization in large part on the promotion and protection of the human rights set out in the Universal Declaration of Human Rights.*
> *The United States understands and accepts the thrust of principle 3 to be that economic development goals and objectives must be pursued in such a way that the development and environmental needs of present and future generations are taken into account. The United States cannot agree to, and would disassociate itself from, any interpretation of principle 3 that accepts a 'right to development', or otherwise goes beyond that understanding.*[203]

Thus, while the US government rejected the idea that development is a right, it accepted the idea of sustainable development and that the needs of future generations must be "*taken into account*" when pursuing "*economic development goals and objectives*".

Nonetheless, as emphasized above, the Rio Declaration is non-binding and its principles are open to interpretation by each State. To look at potentially relevant binding international law, we turn toward the 1979 Convention on Long-Range Transboundary Air Pollution (LRTAP), the 1985 VCPOL, and the 1987 Montreal Protocol on Substances that Deplete the Ozone Layer.

### 5.1.7. The Convention on Long-Range Transboundary Air Pollution

The preamble of LRTAP states that the parties agreed to the convention, including the United States,

> *<u>Considering</u> the pertinent provisions of the Declaration of the United Nations Conference on the Human Environment, and in particular principle 21, which expresses the common conviction that States have, in accordance with the Charter of the United Nations and the principles of international law, the sovereign right to exploit their own resources pursuant to their own environmental policies, and the responsibility* ***to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction*** *[emphasis added],*

202 Report of the United Nations Conference on Environment and Development, Rio de Janeiro (June 3-14 1992) (Vol. 2).
203 Id.

> *Affirming their willingness to reinforce active international co-operation to develop appropriate national policies and by means of exchange of information, consultation, research and monitoring, the co-ordinate national action for combating air pollution including long-range transboundary air pollution.*[204]

In the Convention, the term "*'Air Pollution' means the introduction by man, directly or indirectly, of substances or energy into the air resulting in deleterious effects of such a nature as to endanger human health, harm living resources and ecosystems and material property and impair or interfere with amenities and other legitimate uses of the environment, and 'air pollutants' shall be construed accordingly*;"

As discussed above, the combination of rocket launches and satellite re-entries is a principal source of upper atmosphere air pollution and is expected to become more severe. The LRTAP continues under its "Fundamental Principles":

> *Article 2: The Contracting Parties, taking due account of the facts and problems involved, are determined to protect man and his environment against air pollution and shall endeavour to limit and, as far as possible, gradually reduce and prevent air pollution including long-range transboundary air pollution.*
> *Article 3: The Contracting Parties, within the framework of the present Convention, shall by means of exchanges of information, consultation, research and monitoring, develop without undue delay policies and strategies which shall serve as a means of combating the discharge of air pollutants, taking into account efforts already made at national and international levels.*[205]

Together, these articles suggest that the US government should "*develop without undue delay policies and strategies*" that would address the cumulative atmospheric effects of the launch and re-entry of satellites operated by entities under its jurisdiction, as per Article VI of the OST. In understanding whether the US government considers the deposition of harmful substances into the upper atmosphere as "air pollution", it should be noted that Title VI of the US Clean Air Act[206] specifically addresses pollution in the context of stratospheric ozone protection, with reference to the VCPOL and the corresponding 1987 Montreal Protocol[207].

### 5.1.7.1. The Vienna Convention on the Protection of the Ozone Layer and the Montreal Protocol

The preamble[208] of the VCPOL affirms that states party to the treaty have a:

> *responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction.*[209]

Under the VCPOL, the US government has a general obligation:

204 Convention on Long-range Transboundary Air Pollution. Geneva, Nov. 13, 1989, 1302 U.N.T.S. 217.
205 Id.
206 Clean Air Act Title VI - Stratospheric Ozone Protection, 42 USC. § 7671 *et. seq.*
207 Montreal Protocol.
208 VCPOL, preamble.
209 Id.

1 The Parties shall take appropriate measures in accordance with the provisions of this Convention and of those protocols in force to which they are party to protect human health and the environment against adverse effects resulting or likely to result from human activities which modify or are likely to modify the ozone layer.

2 To this end the Parties shall, in accordance with the means at their disposal and their capabilities:

a) Co-operate by means of systematic observations, research and information exchange in order to better understand and assess the effects of human activities on the ozone layer and the effects on human health and the environment from modification of the ozone layer;

b) Adopt appropriate legislative or administrative measures and co-operate in harmonizing appropriate policies to control, limit, reduce or prevent human activities under their jurisdiction or control should it be found that these activities have or are likely to have adverse effects resulting from modification or likely modification of the ozone layer...[210]

Given the potential of the construction and maintenance of satellite mega-constellations to contribute to ozone loss, appropriate measures may be required by all parties to the agreement to limit the impact of the cumulative effects of satellites on the atmosphere, including the ozone layer. We note that Section 11 of VCPOL focuses on dispute resolution, should there be a disagreement between parties to the agreemen regarding the interpretation or application of the Convention. Thus, should parties find that some governments are approving the construction of mega-constellations without taking appropriate measures to limit adverse effects resulting from changes or likely changes to the ozone layer, then those governments may be subject to the execution of that dispute resolution.

This “Settlement of disputes” provision at Article 11 enables parties in significant disagreement regarding their VCPOL obligations to first mutually seek a resolution through negotiation (Article 11(1)) or mediation (Article 11(2)). This provision does, though, also contain at Article 11(3) a robust compulsory dispute settlement mechanism, involving either formal arbitration or submission of the dispute to the International Court of Justice for adjudication. Only five of the 197 States Parties (Andorra, Finland, the Netherlands, Norway and Sweden) have accepted this compulsory dispute settlement procedure,[211] which accordingly is not applicable to the US.

The remaining 192 States Parties, including the US, are, however, alternatively subject to Article 11(4)-(5), where those parties not accepting the compulsory dispute settlement mechanism can instead be required to participate in a formal “conciliation commission” at the request of one party to a dispute under VCPOL. This is a final option should negotiation or mediation under Article 11(1)-(2) prove unsuccessful or inappropriate. Such a conciliation commission shall be composed of an equal number of members chosen by each party in dispute and a chair jointly selected by these appointed members. The power of the commission enables it to “*render a final and recommendatory award, which the parties shall consider in good faith*.” Article 11(4)-(5) accordingly offers a powerful, albeit very rarely used, diplomatic tool as it can be used to compel a party (such as the US) into a formalized dispute resolution process, where a final decision and award is publicly delivered by a commission of appointed experts,

210 VCPOL
211 *Id.*

even though this decision and award is ultimately only recommendatory and non-enforceable. The mere existence of this conciliation commission as an obligatory institutional process within VCPOL can, however, positively influence the behavior of States Parties, via a wish to avoid the negative publicity and diplomatic fallout resulting from such a commission process being potentially initiated against it.

The Montreal Protocol is also of interest as it provides a forum for identifying new threats to the ozone layer's stability. Even secondary effects that can lead to ozone loss can be considered, as the United Nations Environment Programme Ozone Secretariat explains[212]:

> *The parties to the Protocol meet once a year to make decisions aimed at ensuring the successful implementation of the agreement. These include adjusting or amending the Protocol, which has been done six times since its creation. The most recent amendment, the Kigali Amendment, called for the phase-down of hydrofluorocarbons (HFCs) in 2016. These HFCs were used as replacements for a batch of ozone-depleting substances eliminated by the original Montreal Protocol. Although they do not deplete the ozone layer, they are known to be powerful greenhouse gases and, thus, contributors to climate change.*[213]

While much of this is connected with atmospheric pollution rather than light pollution only, there may be considerable overlap in the steps necessary to limit both.

## 5.2. US and European Union Adoption of the Precautionary Principle in Domestic Legislation

Although the US rejects the Precautionary Principle (PP) as it is interpreted in international law and subsequent EU legislation, the US arguably operates with at least as much or, in some cases, more precaution than EU states regarding activities posing risks to human health and the environment.[214]For example, the Treaty on European Union: the environmental portion of the treaty includes the PP and has been adopted in the domestic legislation of many European countries:

> *Community policy on the environment shall aim at a high level of protection taking into account the diversity of situations in the various regions of the Community. It shall be based on the precautionary principle and on the principles that preventive action should be taken, that environmental damage should, as a priority, be rectified at the source and the polluter should pay. Environmental protection requirements must be integrated into the definition and implementation of other Community policies.*[215]

Very little work has been done by the US government to implement the PP into domestic environmental law as it has been interpreted in international legal instruments. The US government rejects the idea that the PP — as it appears in international instruments — encourages science-based assessment in its determination of when an activity may result in serious harm to human health and the environment,

212 *Montreal Protocol on Substances that Deplete the Ozone Layer online Handbook*, United Nations Environment Programme Ozone Secretariat, https://ozone.unep.org/treaties/montreal-protocol (last accessed 26 June 2021).
213 Id.
214 Joakim Zander, The Application of the Precautionary Principle in Practice: Comparative Dimensions 267-326 (2010).
215 Treaty on European Union, art. 130r(2) Feb. 7, 1992 [hereinafter Maastricht Treaty].

and that such an approach stifles progress. A Statement by the US Chamber of Commerce highlights the obscure position that the US has adopted:

> *The regulatory implications of the precautionary principle are substantial. For instance, the precautionary principle holds that since the existence and extent of global warming and climate change are not known, one should assume the worst, and immediately restrict the use of carbon-based fuels. However the nature and extent of key environmental, health, and safety concerns require careful scientific and technical analysis. That is why the US Chamber has long supported the use of sound science, cost-benefit analysis, and risk assessment when assessing a particular regulatory issue.*[216]

Alternatively, the US has adopted a precautionary approach which calls for science-based risk assessment and a cost-benefit analysis, but differs in that it aims to never prevent an activity from moving forward when the risks are not fully understood. Only if hard scientific evidence exemplifies that the activity is, or would be, detrimental to human health and/or the environment would the activity then be stopped. The US approach instead subjects riskier activity to more stringent regulatory scrutiny. As the US Chamber of Commerce states:

> *The US Chamber of Commerce supports a science-based approach to risk management where risk is assessed based on scientifically sound and technically rigorous analysis. Under this approach, regulatory actions are justified where there are legitimate, scientifically ascertainable risks to human health, safety, or the environment. That is, the greater the risk, the greater the degree of regulatory scrutiny. This standard has served the nation well, and has led to astounding breakthroughs in the fields of science, health care, medicine, biotechnology, agriculture, and many other fields…*[217]

Examples of the precautionary approach adopted in US environmental legislation are found in the following Acts:[218]

- The Occupational Safety and Health Act of 1970[219]
- The 1977 Clean Air Act[220]
- The 1975 Toxic Substances Act[221]

---

216 *Precautionary Principle*, US Chamber of Commerce, https://www.uschamber.com/precautionary-principle (last accessed Jul 1, 2021).
217 *Id.*
218 For a full list of US Legislation and Executive Orders that contain a precautionary approach, ***see*** Zander, ***supra*** note 192, at xxx-xxxii.
219 29 USC. §651 ***et seq.*** (1970).
220 42 USC. § ch. 85.
221 Pub. L. No. 94-469 (Oct. 11, 1967).

# 5.3. US Environmental Law

## 5.3.1. NEPA

Any consideration by the US of modern regulation of the natural environment and the effects of human activity upon it must include a discussion of NEPA, enacted in 1970.[222] Through NEPA, the US articulated its national environmental policy:[223]

> *to use all practicable means and measures to foster and promote the general welfare, create and maintain conditions under which man and nature can exist in productive harmony, and fulfill the social, economic, and other requirements of present and future generations of Americans.*[224]

This declaration followed Congress's recognition of the "*profound impact of* [hu]*man's activity on the interrelations of all components of the natural environment*."[225] Congress further articulated the "*responsibility of the Federal Government to use all practicable means, consistent with other essential considerations of national policy, to improve and coordinate Federal plans, functions, programs and resources to the end to that the Nation may:*

> ***(1)*** *fulfill the responsibilities of each generation as trustee of the environment for succeeding generations;*
> ***(2)*** *assure for all Americans safe, healthful, productive, and esthetically and culturally pleasing surroundings;*
> ***(3)*** *attain the widest range of beneficial uses of the environment without degradation, risk to health or safety, or other undesirable and unintended consequences;*
> ***(4)*** *preserve important historic, cultural, and natural aspects of our national heritage, and maintain, wherever possible, an environment which supports diversity and variety of individual choice."*[226]

Within NEPA, Congress also created the CEQ to "*review and appraise the various programs and activities of the Federal Government in*" light of the national environmental policy.[227] Indeed, NEPA sought "*to ensure Federal agencies consider the environmental impacts of their actions in the decision-making process*."[228] Subsequently, the CEQ promulgated regulations to establish parameters for agencies when they adopt their own NEPA implementing procedures in light of their own specific operations. In adopting their NEPA procedures, agencies must consult with the CEQ. When taking a major federal action (e.g., licensing), federal agencies must complete EISs for actions that will have a significant effect on the environment; when a proposed action may have a significant effect or "*when the significance of the effects is unknown*," the agency must prepare an environmental assessment.[229] When actions do not have an effect on the

222 42 USC. § 4321, ***et seq.*** (1970).
223 For this reason, any argument or discussion relating to the United States' environmental policy must begin with NEPA.
224 ***Id.***; 40 C.F.R. § 1500.1 (1978).
225 42 USC. § 4331 (1970).
226 ***Id.*** at § 4331(b).
227 40 C.F.R. § 4344(3) (1978).
228 40 C.F.R. § 1500.1 (1978).
229 40 C.F.R. § 1501.5 (1978).

environment either individually or cumulatively, the agency may categorically exclude the action from NEPA review (unless certain circumstances are present).[230]

Nevertheless, certain definitions within the US's own national environmental policy are unclear. For example, an agreed definition on the limits of Earth's environment within its broader regulatory regime remains somewhat elusive.

CEQ Implementing Regulations provide a definition for "human environment":

> ***§ 1508.14 Human environment.***[231]
>
> *Human environment shall be interpreted comprehensively to include the natural and physical environment and the relationship of people with that environment. (See the definition of "effects" (§ 1508.8).) This means that economic or social effects are not intended by themselves to require preparation of an environmental impact statement. When an environmental impact statement is prepared and economic or social and natural or physical environmental effects are interrelated, then the environmental impact statement will discuss all of these effects on the human environment.*[232]

Despite the nomenclature "*human*" environment, the definition provided in the CEQ Implementing Regulations includes the entire "*natural and physical environment*" as well as the "*relationship of people with that environment*."[233]

Some of the authors maintain that the absence of any limitations on the "*natural and physical environment*" suggests that the term includes Earth and its orbital environment. The debate then moves to the farthest extent of Earth's environment — whether it includes the moon, and whether it even includes the greatest distances touched by human artifacts such as planetary probes.

The CEQ Implementing Regulations further define "effects" as:

> **§ 1508.8 Effects.**
> *Effects include:*
> **(a)** *Direct effects, which are caused by the action and occur at the same time and place.*
> **(b)** *Indirect effects, which are caused by the action and are later in time or farther removed in distance, but are still reasonably foreseeable. Indirect effects may include growth inducing effects and other effects related to induced changes in the pattern of land use, population density or growth rate, and related effects on air and water and other natural systems, including ecosystems.*
> *Effects and impacts as used in these regulations are synonymous. Effects includes ecological (such as the effects on natural resources and on the components, structures, and functioning of affected ecosystems), aesthetic, historic, cultural, economic, social, or health, whether direct, indirect, or cumulative. Effects may also include those resulting from actions which*

---

230 *Id.*
231 Although NEPA discussed "environment" and "natural environment," the CEQ Implementing Regulations use the term "human environment" for the title of the definition.
232 40 CFR § 1508.14.
233 *Id.*

*may have both beneficial and detrimental effects, even if on balance the agency believes that the effect will be beneficial.*[234]

While these implementing regulations contain some of the same terms as those in NEPA, they do not explicitly convey the same imperative and scope presumably intended under NEPA.[235] This definitional discrepancy has arguably led to more limited interpretations of "environment" and "effects" by certain federal agencies.

Each of the federal agencies must ensure that its activities comply with NEPA and the CEQ Implementing Regulations; because NEPA is a federal obligation, licensees must comply with agency NEPA procedures if due diligence is delegated to them to ensure agency compliance.. With respect to commercial satellite operations within Earth's orbital environment, two primary agencies whose actions trigger NEPA compliance include the FAA (e.g., permitting launch and re-entry of satellites) and the FCC (e.g., licensing satellite radio frequency operations).

### 5.3.2. FAA Interpretation

In adopting its NEPA procedures for its operations, the FAA has construed CEQ Implementing Regulations broadly. In 2015, the FAA updated and published its Order for Environmental Impacts: Policies and Procedures as Order 1050.1F (Order).[236] In the 132-page Order, the FAA indicates several environmental impact categories that *may* be relevant to FAA actions under NEPA.

Not surprisingly, areas of potential applicable relevance identified by the FAA as environmental impact categories include: air quality; climate change; hazardous materials, solid waste, and pollution prevention; as well as historical, architectural, archeological, and cultural resources.[237] With respect to satellites, the alumina introduced into the atmosphere clearly could invoke the first three categories listed. Light pollution could fall under pollution or the latter category of cultural resources.

Interestingly, the FAA also identifies visual effects, light emissions, and visual resources/visual character as a possible environmental impact category.[238] Indeed, the FAA recognizes that light emissions can "affect the visual character of the area…including the importance, uniqueness, and aesthetic value of the affected visual resources."[239] With respect to light emissions, the factors to consider include:

*[t]he degree to which the action would have the potential to . . . [c]reate annoyance or interfere with normal activities from light emissions; and . . . [a]ffect the visual character of the area due to the light emissions, including the importance, uniqueness, and aesthetic value of the affected visual resources.*[240]

---

234 40 CFR § 1508.8.
235 See discussion of NEPA ***supra***.
236 US Dep't. of Transp., Fed. Aviation Admin., Order 1050.1F, Environmental Impacts: Policies and Procedures (2015). FAA Order 1050.1D became effective December 1, 1983 and was cancelled on June 8, 2004. FAA Order 1050.1E became effective March 20, 2004, was amended March 20, 2006, and was cancelled on July 16, 2015. This Order mentions light emissions and visual impacts as an environmental impact category.
237 These all should be explored further.
238 FAA 1050.1F, at 4-1, 4-10.
239 FAA Order 1050.1F, at 4-10.
240 FAA Order 1050.1F at 4-10 (Though, the "FAA has not established a significant threshold for Light Emissions.").

With respect to visual resources/visual character, the FAA considers:

> *[t]he extent the action would have the potential to: . . . [a]ffect the nature of the visual character of the area, including the importance, uniqueness, and aesthetic value of the affected visual resources; . . . [c]ontrast with the visual resources and/or visual character in the study area; and . . . [b]lock or obstruct the views of visual resources, including whether these resources would still be viewable from other locations.*[241]

Of course, the FAA determined that certain light emissions and visual effects associated with aviation operations would fall within one or more categorical exclusions. For example, the FAA excludes certain lighting for operations and safety.[242] However, the analysis under this exclusion would still be subject to the assessment of "extraordinary circumstances."[243]

At the same time, the FAA considers noise to be a significant environmental consideration. In fact, it represents that "[n]*oise is often the predominant aviation environmental concern of the public*."[244] Not surprisingly then, a number of statutes and regulations have been enacted and promulgated, respectively, related to noise and noise-compatible land-uses.[245] With respect to the FAA, it established the Day Night Average Level metric for noise analysis in conjunction with decibel levels.[246] The FAA also provides substantial guidance in preparing appropriate reports of such analyses for purposes of complying with NEPA.[247] Depending on planned aircraft and land uses, different criterion levels and metrics may apply.[248] For example (and perhaps most commonly), it delineates specific altitude ranges for noise analysis depending on arrival and departures at airports. It also recognizes that special sensitivities exist "*with respect to certain resources such as national parks*."[249] The applicable decibel levels can further be applied depending on the size of the aircraft and the surrounding land use.

With respect to noise alone, the FAA provides numerous resources and tools to consider the applicable environmental impacts.[250] The Desk Reference accompanying the Order includes 21 pages focused specifically on "*Noise and Noise-Compatible Land Use*." Moreover, the FAA also licenses an Aviation Environmental Design Tool (AEDT) for aviation stakeholders that provides information on the specific environmental impacts of "*fuel consumption, emissions, noise, and air quality consequences*" and

---

241 *Id.* (though, the "FAA has not established a significant threshold for Visual Resources/Visual Character.").

242 FAA Order 1050.1F at 5-8—5-9 (5-6.3 Categorial Exclusions for Equipment and Instrumentation);

243 *Id.*

244 1050.1F Desk Reference (v2) (February 2020).

245 Airport and Airway Improvement Act of 1982, 49 USC § 47101 et seq. (authorizes funding for noise mitigation and noise compatibility planning and projects. Establishes requirements related to noise-compatible land use); Airport Noise and Capacity Act of 1990, 49 USC. §§ 47521-47534 §§ 106(g), 47523-47527 (establishes requirements regarding airport noise and access restrictions for Stage 2 and 3 aircraft); Aviation Safety and Noise Abatement Act of 1979, 49 USC. § 47501 et seq. (directs the FAA to establish a single system for measuring noise and determining the exposure of people to noise); Prohibition on Operating Certain Aircraft Weighing 75,000 Pounds or Less Not Complying with Stage 3 Noise Levels (Section 506 of the FAA Modernization and Reform Act of 2012), 49 USC. §§ 47534 (a person may not operate a civil subsonic jet airplane with a maximum weight of 75,000 pounds or less unless the aircraft complies with stage 3 noise levels); The Control and Abatement of Aircraft Noise and Sonic Boom Act of 1968, 49 USC. § 44715 (authorizes the FAA to prescribe standards for the measurement of aircraft noise and establish regulations to abate noise); The Noise Control Act of 1972, 42 USC. §§ 4901-4918 (amends the Control and Abatement of Aircraft Noise Sonic Boom Act of 1968 to add consideration of the protection of public health and welfare and to add the EPA to the rulemaking process for aircraft noise and sonic boom standards).

246 *Id.* at 11-2.

247 *See generally* 1050.1F Desk Reference (v2) (February 2020).

248 *See generally* 14 CFR § 36, et seq.

249 1050.1F Desk Reference (v2) (February 2020) at 11-1. This could very easily parallel the concerns of solar reflectivity affecting resources associated with dark sky areas.

250 *Airport Noise*, FAA, https://www.faa.gov/airports/environmental/airport_noise/ (last accessed Aug. 17, 2021).

"*facilitates environmental review activities required under NEPA by consolidating the modeling of these environmental impacts in a single tool*."[251]

### 5.3.3. FCC Interpretation

In contrast to the FAA's and other agencies' NEPA procedures, the FCC's rules implementing NEPA at 47 CFR § 1.1307 construed the CEQ Implementing Regulations narrowly. Rather than identifying classes of actions that are categorically excluded, the FCC categorically excludes most of its actions but for those that fall within a limited set of circumstances, including facilities that affect historic resources or endangered species, or exceed Radio Frequency (RF) exposure limits. The relevant portions for satellites of Section 1.1307 focus on human exposure to RF from FCC-authorized facilities.[252] In explaining the scope of § 1.1307, the FCC stated:

> *Based upon the Commission's experience, we have determined that the telecommunications industry does not generally raise environmental concerns. The comments filed in this proceeding support the Commission's determination. Thus, we have categorically excluded most Commission actions from environmental processing requirements.*[253]

It further stated that:

> *The Commission has reduced to three general areas the types of actions that may have a significant environmental impact to include cases in which facilities: (1) will be located in sensitive areas (e.g. wildlife preserves); (2) will involve high intensity lighting in residential areas; and/or (3) will expose workers or the general public to levels of radiofrequency radiation which would exceed the applicable health and safety standards set forth in § 1.1307(b) of our rules.*[254]

Despite the FCC's oversight and authorization of satellite operations, § 1.1307 makes no reference to satellites or the orbital space surrounding Earth in which the satellites will operate.[255] And, the regulation has not been significantly amended since 1986.[256]

The FCC delegates the initial determination of whether a facility is categorically excluded to the applicant. Hence, FCC satellite license application forms inquire whether the facility would have a "*significant environmental impact*" as defined by 47 CFR §1.1307.[257]Considering the FCC's interpretation of the CEQ regulations and the dearth of guidance to applicants on the due diligence required to answer this question, it should not be surprising that satellite license applicants have routinely indicated that their operations will not have a significant environmental impact under § 1.1307 so that no environmental assessment is required. It is worth noting that no-one seems to have raised potentially significant effects with the FCC with regard to any satellites authorized before 2020. However, it must also be noted that the

---

251 *Aviation Environmental Design Tool,* FAA, https://aedt.faa.gov/ (last accessed Aug. 17, 2021).
252 47 C. F. R. § 1.1307 (1990).
253 Environmental Rules in Response to New Regulations Issued by the Council on Environmental Quality, 51 Fed. Reg. 14999 (Apr. 22, 1986) (to be codified at 41 C.F.R. pts. 1, 21, 63, 90, 94).
254 *Id.*
255 47 C. F. R. § 1.1307 (1990).
256 *Id*.
257 Application for Satellite Space Station Authorizations, FCC 312 Main Form (November 15, 2016).

satellite environment has changed significantly in the last year. Whereas in 2019 3600 satellites — both operational and defunct — were in orbit, that number has increased to 7500. This presents an ongoing and increasing challenge.

Based on the foregoing, some authors of this paper suggested that the FCC should be encouraged to interpret its NEPA obligations to include satellite operations above the Earth's surface[258] and maintained that the FCC can implement this interpretation by amending § 1.1307[259] to include:

(a) Commission actions with respect to satellite operations may significantly affect the environment and thus require the preparation of EAs or may require further Commission environmental processing where:[260]
    (1) Satellite operations may affect scientific investigations of space including, but not limited to, optical, radio, and infrared astronomy;
    (2) Satellite operations may affect aesthetic or cultural use of the night sky; or,
    (3) Satellites will contain elements or materials that could affect chemical composition of the atmosphere.

The proposed (c)(1) could be more explicit by adding that the visual effects of satellites would fall within its scope.

Additionally, some authors of this paper indicated that the FCC should provide satellite stakeholders with comprehensive and thorough resources to analyze the relevant environmental impacts. The resources provided by the FAA for aviation stakeholders can serve as an initial model. In particular, the FAA resources dedicated to assessing noise as an environmental concern should be quite instructive. Also, similar to the AEDT provided by the FAA and the NASA Debris Assessment Software, the FCC could develop and license software for satellite stakeholders to use in assessing satellite effects on astronomy in terms of radio, infrared, and optical interference. Many of these resources could be provided independent of any regulatory amendments.

Some authors of this paper pointed out that requiring EIAs or EISs for satellite licensing in the US could result in satellite operators abandoning the US licensing system. In counterpoint, access to the US market is likely to be viewed as attractive. It was suggested that the FCC already requires — as conditions placed on US licensees — protection for radio astronomy, for example, emphasizing that the application of NEPA is not a prerequisite to US government oversight of satellite systems. Indeed, the FCC has recognized the need to mitigate astronomy impacts in its most recent orders relating to constellations without invoking the NEPA requirement of preparing an EIA.[261]

Moreover, some authors to this paper raised questions about how "*aesthetic or cultural use*" will be defined, what standards will be used and who arbitrates the applicability of those standards.

---

258 We do not need to assess whether the CEQ misinterpreted NEPA or the FCC misinterpreted CEQ regulations; CEQ approved FCC NEPA regulations. .

259 Further, the existing (c) would become (d), (d) would become (e), and (e) would become (f).

260 For reference, the language of 1.1307(a) states:

Commission actions with respect to the following types of facilities may significantly affect the environment and thus require the preparation of EAs by the applicant (see §§ 1.1308 and 1.1311) and may require further Commission environmental processing (***see*** §§ 1.1314, 1.1315 and 1.1317):

261 FCC Order 21-48, https://docs.fcc.gov/public/attachments/FCC-21-48A1.pdf.

Finally, as for amending 47 C. F. R. § 1.1307 by adding the suggested point (c)(3), it was noted that this language is extremely overbroad without some defined limits, as all satellites contain such elements.

Potential conditions for licensing to mitigate the impact on astronomy for either FAA or FCC may be found in Appendix III.

### 5.3.4. CEQ Clarification

Given the FCC's narrow interpretation of CEQ Implementing Regulations, some authors of this paper suggested that the CEQ could also facilitate a broader interpretation by clarifying its own regulations. To begin with, it could amend (subject to comment) the title of the § 1508.14 definition from "*Natural environment*" to "Human environment."[262] It also could amend (subject to comment) its regulations to clarify the scope of the environment and effect on it. Specifically, the CEQ could amend 40 CFR § 1508.14 to read:

> **§ 1508.14 Human environment.**[263]
>
> *Human environment shall be interpreted comprehensively to include the natural and physical environment,* **including Earth's orbital space,** *and the relationship of people with that environment. (See the definition of "effects" (§ 1508.8).) This means that economic or social effects are not intended by themselves to require preparation of an environmental impact statement. When an environmental impact statement is prepared and economic or social and natural or physical environmental effects are interrelated, then the environmental impact statement will discuss all of these effects on the human environment.*

Some authors of this paper disagree with this proposed change as it was stated that it would have far reaching effects that would go well beyond the goal of this paper. The view was also expressed that it would fundamentally reset major areas of US policy and law, and likely result in a major degradation of US space capabilities while new regulatory structures were established to implement this language. The concern was raised that this change will upend US policy distinguishing between the Earth environment and the space environment with unpredictable consequences.

Some authors of this paper also suggested that the CEQ could amend § 1508.8 to read:

> *§ 1508.8 Effects* include:
>
> **(a)** *Direct effects, which are caused by the action and occur at the same time and place.*
> **(b)** *Indirect effects, which are caused by the action and are later in time or farther removed in distance, but are still reasonably foreseeable. Indirect effects may include growth inducing effects and other effects related to induced changes in the pattern of land use, population*

262 Within the International policy section, this report proposes an alternative that, rather than working with existing definitions, suggests adding a definition within the environmental regulatory regime expressly and specifically focused on the "outer space environment." The international policy alternative does not necessarily conflict with the proposals to amend existing regulations and, in fact, could complement them. In any case, we collectively seek to provide as many options to for effectuating the same goal as possible.

263 The CEQ could also amend the title of the definition to be "natural environment" rather than "human environment," however, the definition itself does include the "natural and physical environment." 40 C. F. R. § 1508.14 (1978)

*density or growth rate, and related effects on air and water and other natural systems, including ecosystems.*

*Effects and impacts as used in these regulations are synonymous. Effects includes ecological (such as the effects on natural resources and on the components, structures, and functioning of affected ecosystems), aesthetic,* **astronomical (such as the effects on human enjoyment of the observable dark sky, optical astronomy, radio astronomy, and space debris),** *historic, cultural, economic, social, or health, whether direct, indirect, or cumulative. Effects may also include those resulting from actions which may have both beneficial and detrimental effects, even if on balance the agency believes that the effect will be beneficial.*

It was indicated that these minor amendments would be consistent with the scope of NEPA and ensure that every agency properly includes more than the surface of Earth within the scope of its environmental jurisdiction.

However, concern was raised that the "effects on human enjoyment" is a highly subjective standard that would be easily abused.

## 5.4. Model from FCC Space Debris Regulations

Recently, the FCC implemented updated regulations focused on mitigating space debris. Notably, these efforts do not rely on NEPA or any other fundamental changes to US law.

This update to satellite regulations follows a general effort (concerted or separate) to update the space regulatory regime. For example, in 2020 NOAA published its final rules overhauling the licensing of private remote sensing space systems.[264] Similarly, the FAA implemented new launch and reentry regulations through its Office of Commercial Space Transportation.[265] Consequently, regulations promulgated to mitigate adverse effects of satellites in Earth's orbit would be consistent with an overall objective to update the US space regulatory regime, again without the need to rely upon NEPA.

In doing so, the recent and current efforts of the FCC to adopt and implement regulations to mitigate orbital debris can provide a model through which to propose regulations relating to satellites and their interference in astronomy.

Some authors of this paper suggested that the recommendations from SATCON1 can be adopted into regulatory form as indicated in Appendix II hereof.

Some authors of this paper indicated their opinion that this approach is flawed and requires additional consideration. These members suggested that this path incorrectly assumes the FCC has some expertise in which satellite technologies best mitigate reflectivity and can realistically assess whether an operator is using the best approach given its system. These members also noted that, assuming the FCC is even the best agency to make this assessment, a better approach may be to have the FCC check to see

264 "Licensing of Private Remote Sensing Space Systems," 15 CFR § 690 (85 Federal Register 98, pp. 30790-30815) (published May 20, 2020, effective July 20, 2020).
265 "Streamlined Launch and Reentry License Requirements," 14 CFR 401, et seq. (85 Fed. Reg. 79566-79740 (published December 10, 2020, effective Mar. 10, 2021).

whether the satellites meet a data-derived standard prepared by experts, rather than a subjective assessment. The concern was raised that this approach is limited to current technology and would disincentivize the development of new technologies. Finally, some authors of this paper were concerned that this approach also fails to properly account for or balance against the critical services satellites can provide to people on the ground.

## 5.5. NASA and Planetary Protection

Planetary protection broadly encompasses the protection of Earth and other celestial bodies from cross-contamination.[266] Its origins date back to the beginning of international space exploration and research in the 1950s.[267] In fact, the International Council for Scientific Unions (now the International Science Council) issued a committee report in 1958 that contained a "Code of Conduct" for planetary protection and recommended that COSPAR[268] address such matters. The international policy section of this document discusses COSPAR and other international components in more detail.

Within the US, NASA has implemented a PPP.[269] The foundation for NASA's PPP arises from its interpretation of Article IX of the OST.[270] To implement the policy, NASA established an Office of Planetary Protection within its Office of Safety and Mission Assurance. Some authors of this paper noted that although focus is on "*the scientific study of chemical evolution and the origins of life in the solar system*," an argument can be made that its broader philosophical basis "*promotes the responsible exploration of the solar system by implementing and developing efforts that protect the science, explored environments and Earth*."[271]

The implementation of this policy resulted in the publication of several documents. Most recently, these include Planetary Protection Categorization for Robotic and Crewed Missions to Earth's Moon[272] and Biological Planetary Protection for Human Missions to Mars.[273] Previously, NASA issued several iterations of 8020.7 Biological Contamination Control for Outbound and Inbound Planetary Spacecraft[274] which cites principles from COSPAR as the foundation for PPP.[275] Further, NASA's Planetary Protection

266 Planetary protection differs from planetary defense that focuses on protecting Earth from collision with space debris and celestial bodies.

267 Office of Safety and Mission Assurance, ***Planetary Protection***, NASA, https://sma.nasa.gov/sma-disciplines/planetary-protection (last accessed Aug. 21, 2021).

268 COSPAR, https://cosparhq.cnes.fr/ (last accessed Jun. 22, 2021).

269 There does not appear to be any specific regulation or statute directed to planetary protection by that term.

270 Off. Safety & Mission Assurance, Nat'l Aeronautics and Space Admin., NID 8715.128, Planetary Protection Categorization for Robotic and Crewed Missions to the Earth's Moon (2020).

271 Office of Safety and Mission Assurance, ***Planetary Protection***, NASA, https://sma.nasa.gov/sma-disciplines/planetary-protection (last accessed Aug. 21, 2021).

272 The following interpretative language could be used elsewhere:

*In this directive, all mandatory actions (i.e., requirements) are denoted by statements containing the term "shall." The term "may" denotes a discretionary privilege or permission, "can" denotes statements of possibility or capability, "should" denotes a good practice and is recommended, but not required, "will" denotes expected outcome, and "are/is" denotes descriptive material*.

Off. Safety & Mission Assurance, Nat'l Aeronautics and Space Admin., NID 8715.128, Planetary Protection Categorization for Robotic and Crewed Missions to the Earth's Moon (2020) at 2.

273 Off. Safety & Mission Assurance, Nat'l Aeronautics and Space Admin., NID 8715.129, Biological Planetary Protection for Human Missions to Mars (2020).

274 Off. Safety & Mission Assurance, Nat'l Aeronautics and Space Admin., NPD 8020.7G, Biological Contamination Control for Outbound and Inbound Planetary Spacecraft (2020).

275 *Id.*; Comm. on Space Rsch. [COSPAR], ***The COSPAR Panel on Planetary Protection Role, Structure, and Activities*** (2019), ***available at*** COSPAR https://cosparhq.cnes.fr/assets/uploads/2019/07/PPP_SRT-Article_Role-Structure_Aug-2019.pdf.

Provisions for Robotic Extraterrestrial Missions that became effective on 20 April 2011 will expire absent extension on 1 August 2021.[276]

It is argued by some authors of this paper that the focus on preventing contamination — i.e., protecting the environment — of celestial bodies under Article IX of the OST extends beyond the surface and orbits of Earth.[277] Moreover, NASA's implementation of Article IX's planetary protection principles reflects this interpretation by the US. Consequently, Earth's orbit and space activities therein clearly fall within the jurisdiction of Article IX and both its interpretation and implementation by the US. Combined with Article IX's requirement that States Parties conduct activities in space "*with due regard to the corresponding interests of all other States Parties to the Treaty*" and potential remedies for instances where harmful interference in the activities of others may occur, these policies support regulation of satellite activity that adversely affects Earth's environment and the activities of other actors in and related to space.[278]

That said, definitional hurdles were acknowledged. As has recently been stated:

> *Article IX is very broad in its terms and encompasses not just the concepts of due regard for, and the prevention of, harmful interference with activities of other states but also the inherent value in the preservation of natural celestial environments from harmful contamination. Nevertheless, there is no international consensus on the definitions of "harmful contamination" or "interference." Nor have the interests of other states that shall be given due regard been identified, other than avoidance of harmful contamination. However, the COSPAR PPP represents a consensus that, at a minimum, harmful contamination includes the introduction of biological matter from the Earth into at least certain celestial environments.*[279]

Based on the foregoing, some authors of this paper suggest that planetary protection can and should be used as a basis to support efforts to reduce the detrimental effects of satellite constellations on astronomy. Primarily, it was suggested that it should be presented as an example of how the international community and national actors implement obligations under the OST.[280]

Additionally, planetary protection furthers a general policy of protecting aspects of the space environment (albeit focused on contamination). And, on this point, it is argued by some members, planetary protection inherently demonstrates that our concept of environment and the regulation of human effects on the environment extends beyond the surface of Earth.[281] Consequently, the regulation of human activity on the natural environment above the surface of Earth and into its orbital environment remains consistent with existing US PPP.

---

276 Off. Safety & Mission Assurance, Nat'l Aeronautics and Space Admin., NPR 8020.12D, Planetary Protection Provisions for Robotic ExtraterrestrialvMissions (2011).
277 Outer Space Treaty, art. 9.
278 ***See*** the discussion at Section III.B.3 above.
279 Leslie Tennen, ***The Role of COSPAR for Space Security and Planetary Protection***, Handbook of Space Security, (Jul. 3, 2020), https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7990663/.
280 See the discussion at Section III.B.3 above.
281 NASA actually refers to terrestrial missions as "***Earth-orbital***." 2020 Moon Directive, p. 2 P.2.c. Thus, we should be careful in using terrestrial to define merely that on the Earth's surface to avoid confusion on the terms. But, more importantly, NASA interprets Earth's terrestrial space as including its orbital space thereby lending support to the NEPA-CEQ-FCC interpretation of environment extending out this far. This should be further explored.

## 5.6. FCC Categorical Exclusion

The FCC has implemented a Categorical Exclusion with respect to telecommunications activities but for those that fall into limited circumstances. It was pointed out that in *Foundation on Economic Trends v. Heckler* the court understood that federal agencies might attempt to avoid performing environmental reviews under NEPA by arguing that certain actions involving new technology have unknown environmental impacts, making them unreviewable.[282]

To combat this line of reasoning, the court pointed to the Council's requirement for an EIS when "*the possible effects on the human environment are highly uncertain or involve unique or unknown risks*." The court concluded with an excerpt from the opinion of *Scientists' Institute for Public Information v. Atomic Energy Commission*,[283] in which that court stated that it "*must reject any attempt by agencies to shirk their responsibilities under NEPA by labeling any and all discussion of future environmental effects as 'crystal ball inquiry'*."

282 756 F.2d 143, 147 (D.C. Cir. 1985).
283 481 F.2d 1079, 1092 (D.C. Cir. 1973).

# 6. Conclusions

## 6.1. Preliminary conclusions

This section is intended to be a very brief summary of the suggestions already made by the International and US Policy subgroups.

- If the US wishes to adopt or amend/revise any legislative provisions concerning the conduct of EIAs for the in-orbit operation of commercial satellites, it should pay attention to the provisions contained in the LTSG, and specifically Guideline A.2 as indicated in Section 5.1.2.
- The US may wish to consider the adoption of a due diligence mechanism (see Table 1 for details) for the in-orbit operation phases of large-scale commercial satellite constellations. In the event of transboundary impact/harm/damage (present as well as future), the US may not be able to take its previous views regarding the liability of a private entity/actor. This is due to the application of Article VI of the OST, where a State remains responsible for all its national space activities, and there is an obligation to continually supervise such activities.
- The US government may wish to include the outer space environment as an additional domain for protection and conduct of environmental impact assessments. A similar approach has been followed internationally through the Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques (ENMOD), 1977. Within the national policy section, this report proposes amending existing CEQ definitions to expressly include Earth's orbital space and specific astronomical effects. The Working Group members are of the view that the alternative(s) provided here in this section of the Report do not conflict with the one's provided in the national policy section, and in fact complement each other. In any case, we collectively seek to provide as many options for effectuating the same goal as possible.
- The US may wish to adopt a precautionary approach owing to technical and policy considerations.
- The US may wish to adopt a precautionary approach in the face of scientific uncertainty considering whether human activities proposed or underway will introduce, directly or indirectly, rates of change in an environment that are comparable or superior to natural ones or whether they will introduce new potentially harmful materials into an environment, such as the atmosphere.

To conclude the above considerations, this Working Group notes an important and relevant excerpt contained in the LTSG:

> *20. International cooperation is required to implement the guidelines effectively, to monitor their impact and effectiveness, and to ensure that, as space activities evolve, they continue to reflect the most current state of knowledge of pertinent factors influencing the long-term sustainability of outer space activities, particularly with regard to the identification of factors that influence the nature and magnitude of risks associated with various aspects of space activities or that may give rise to potentially hazardous situations and developments in the space environment.*[284]

It also notes, with humility and concern, the following excerpt from the judgment of the International Court of Justice, in Gabčíkovo-Nagymaros Project (Hungary/Slovakia), Judgment, I.C.J. Reports 1997, p. 7, para. 140:

*Throughout the ages, mankind has, for economic and other reasons, constantly interfered with nature. In the past, this was often done without consideration of the effects upon the environment. Owing to new scientific insights and to a growing awareness of the risks for mankind - for present and future generations - of pursuit of such interventions at an unconsidered and unabated pace, new norms and standards have been developed, set forth in a great number of instruments during the last two decades. Such new norms have to be taken into consideration, and such new standards given proper weight, not only when States contemplate new activities but also when continuing with activities begun in the past. This need to reconcile economic development with protection of the environment is aptly expressed in the concept of sustainable development.*

## 6.2. Cultural Considerations

The Community Engagement Working Group is conducting extensive outreach with diverse communities, including indigenous peoples. Indigineous peoples in particular have sought recognition throughout history, yet throughout history their rights have been violated. Indeed, emerging bodies of work view current narratives of space exploration as parallel to the historic colonization that negatively impacts indigenous peoples, and how the commercial exploitation of space acts to further colonization.[285]

This section identifies some of the relevant International Frameworks that include human rights, culture, and the rights of indigenous peoples.

The first critical document is the United Nations Universal Declaration of Human Rights, adopted in 1948[286]. In 2007 UNDRIP was adopted by the General Assembly[287]. This was the culmination of work that had begun in earnest in 1985 when a working group was established.

---

284 UN COPUOS Sustainability Guidelines, pp. 4, para. 20.
285 Hilding Neilson & E.E. Ćirković, ***Indigenous rights, peoples, and space exploration: A response to the Canadian Space Agency (CSA) Consulting Canadians on a framework for future space exploration activities*** (2021) ***available at*** arXiv:2104.07118
286 G.A. Res. 217 A (III), Universal Declaration of Human Rights (Dec. 10, 1948).
287 G.A. Res. 61/295, United Nations Declaration on the Rights of Indigenous Peoples (Sept. 13, 2007).

*Article 8:*

> *1. Indigenous peoples and individuals have the right not to be subjected to forced assimilation or destruction of their culture.*
> *(a) Any action which has the aim or effect of depriving them of their integrity as distinct peoples, or of their cultural values or ethnic identities;*
> *(b) Any action which has the aim or effect off dispossessing them of their lands, territories or resources;*

*Article 18:*

> *Indigenous peoples have the right to participate in decision-making in matters which would affect their rights, through representatives chosen by themselves in accordance with their own procedures, as well as to maintain and develop their own indigenous decision-making institutions.*

Consultations to address the needs of indigenous communities also emerge as one of the most critical and important points of this Declaration, as stated in Article 19:

> *States shall consult and cooperate in good faith with the indigenous peoples concerned through their own representative institutions in order to obtain their free, prior and informed consent before adopting and implementing legislative or administrative measures that may affect them.*

*And Article 32(2) has:*

> *States shall consult and cooperate in good faith with the indigenous peoples concerned through their own representative institutions in order to obtain their free and informed consent prior to the approval of any project affecting their lands or territories and other resources, particularly in connection with the development, utilization or exploitation of mineral, water or other resources.*

In 2003 the UN Educational, Scientific and Cultural Organization (UNESCO) created an Astronomy and World Heritage Thematic Initiative as a means for states to evaluate and recognize this specific heritage. The guidelines start out[288]:

> *The sky, our common and universal heritage, forms an integral part of the total environment that is perceived by mankind. Including the interpretation of the sky as a theme in World Heritage is a logical step towards taking into consideration the relationship between mankind and its environment. This step is necessary for the recognition and safeguarding of cultural properties and of cultural or natural landscapes that transcribe the relationship between mankind and the sky.*

In 2007 the participants of the International Conference in Defence of the Quality of the Night Sky, jointly with representatives of UNESCO, the UN World Tourism Organization, the IAU, and other international agencies, adopted the Starlight Declaration:

288 *Astronomy and World Heritage Thematic Initiative*, UNESCO, https://whc.unesco.org/en/astronomy/ (last accessed Aug, 21, 2021).

*a. An unpolluted night sky that allows the enjoyment and contemplation of the firmament should be considered an inalienable right equivalent to all other socio-cultural and environmental rights. Hence the progressive degradation of the night sky must be regarded as a fundamental loss.*

In a 2020 US Supreme Court ruling in *McGirt v Oklahoma*, Judge Gorsuch wrote that "… *the magnitude of a legal wrong is no reason to perpetuate it. …"* He warns against arguments that the consequences will be:

*drastic precisely because they depart from . . . more than a century [of] settled understanding. ... In reaching our conclusion about what the law demands of us today, we do not pretend to foretell the future and we proceed well aware of the potential for cost and conflict around jurisdictional boundaries, especially ones that have gone unappreciated for so long. But it is unclear why pessimism should rule the day. … As a result, many of the arguments before us today follow a sadly familiar pattern. Yes, promises were made, but the price of keeping them has become too great, so now we should just cast a blind eye. We reject that thinking.*[289]

## 6.3. Emerging Policy Gaps

### 6.3.1. The lack of considerations for light pollution due to on-orbit infrastructure

In these analyses, the Working Group sought to determine whether existing international or national laws and policies offer protections of the sky from human-made forms of interference, predominantly visible light. As discussed, the VCPOL, LRTAP, Rio Declaration, and LTSG provide mechanisms for addressing pollution of the atmosphere. The Working Group finds that this includes pollution by space launches and material reentries, with national mechanisms in place, even if inadequately executed, for conducting EIAs.

Protections of the orbital environment are less clear. For example, the US Space Policy Directive 3 issues guidelines for the STM of Earth orbit, but this is in the context of operational, security, and economic concerns, with appropriate standards still lacking in most ways. The LTSG go further, in this regard, to describe outer space as an environment that needs to be developed in a way that allows future generations to also develop space. In other words, the LTSG propose that space, including Earth orbit, is an environment worth preserving.

The concept of space as an environment is enshrined in Article IX of the OST, which is the basis of PPPs. Such policies seek to protect Earth from harmful contamination by extraterrestrial materials, as well as to protect environments beyond Earth from contamination by human exploration. Thus, there are environments beyond traditionally regarded human environments that are worth protecting (see further discussions in the US policy section analysis).

289 140 S.Ct. 2452, 2480 (2020).

Moreover, according to Article IX of the OST, activities by a State Party to the Treaty that may cause "*potentially harmful interference with activities of other States Parties*" in their use or exploration of outer space have a duty to conduct international consultations. The Working Group takes the position that astronomy is a form, if not the oldest form, of space exploration. Thus, States Parties to the Treaty that place or have their entities place infrastructure into orbit that cause interference with ground-based astronomy might not be meeting their commitments to Article IX of the OST without conducting international consultations. The Working Group found Article IX to be the piece of international law that is closest to providing protections of the night sky. However, invoking the OST may have limited effect, as there is not a clear internationally accepted meaning of "harm" in this context.

Ultimately, the Working Group finds that protections of the night sky from objects in orbit are lacking in national and international laws, representing a major policy gap. The US policy analysis section came to a similar conclusion. This gap has been able to persist because of a lack of need prior to entering an era of multiple, large-number satellite constellations. Concerns that range from preserving the night sky for future generations, to ensuring non-interference with space exploration by ground-based astronomy, to limiting the diffuse emission that could be produced by satellites and debris make it salient for national and international lawmakers to fill this gap. Such new policy can use Article IX of the OST as its foundation, similar to PPP, appropriately supported by the LTSG.

It may also be possible for the US government to make progress on this policy gap by

(1) Broadening the concept of "human environment" to include, in the short term, Earth orbit and the Moon, and our interactions with them;
(2) Expanding the definition of "effects" or "harm" to explicitly include interference with astronomy, wherever caused;
(3) Considering outer space to be an additional domain for protection and requiring the conduct of due diligence and the completion of EIAs, with a view to assess the effects of on-orbit light pollution and other emerging issues that are specifically applicable to this new domain; or,
(4) Developing new policies that address orbital light pollution.

We note that in the use of LEO and the regulation of Non-Geostationary Orbits (NGSOs) there are conflicting mandates, priorities, and review processes that need resolving. These include planetary defense, astronomical research, privatization of access to space, pursuit of broadband infrastructure and environmental protection. Mitigating the impacts on astronomical research and agency missions requires a whole-of-government approach.

## 6.4. The multiple actor problem

The US government, through national policies, could make major contributions toward addressing on-orbit light pollution and other environmental impacts, such as air pollution, resulting from the placement, use, maintenance, and decommissioning of orbital infrastructure, including large-number satellite constellations. The Working Group notes that the US is not the only launching state for so-called mega-constellations[290], and thus progress toward reducing environmental impacts could be limited by other launching states should they not also require their entities to adopt emerging standards and best practices.

The Working Group is pleased that "*Canada, Japan and the United States therefore propose to inscribe a single-issue item on 'General Exchange of Views regarding Satellite System Effects upon Terrestrial-Based Astronomy' at the fifty-ninth session of the Scientific and Technical Subcommittee in 2022*".[291] Although the proposal was not ultimately accepted by the Sub-Committee and moved forward, there is an evident interest in discussing such critical topics in a multilateral context. The Working Group encourages the US to engage, through multilateral fora, with all states seeking to place or who might seek to place large constellations into orbit. The Working Group further urges the US to seriously consider the output from SATCON2 and the 21 October 2021 IAU Dark and Quiet Skies workshop, as well as additional complementary reports submitted to other states,[292] in the proposed multilateral discussions at the fifty-ninth session of the UN COPUOS Scientific and Technical Subcommittee (STSC).

By taking a leadership position in implementing new policies for on-orbit environmental impacts, including light pollution, the US government can influence other State actors positively and engage them in an internationally constructive approach. To that end, the US government should support discussions of the interference of on-orbit infrastructure on astronomy, as well as other environmental impacts, in multilateral fora. This might include discussions within a subcommittee at UN COPUOS leading to a UN General Assembly resolution or through an ad hoc process. The Working Group notes the recent single-issue item A/AC.105/C.1/2021/CRP.24, which states

> *1. At the current session of Scientific and Technical Subcommittee, the issue of the impact of new satellite constellations has been a topic for discussion. This discussion included a presentation of the results of an online workshop organized by the United Nations Office for Outer Space Affairs and Spain, jointly with the International Astronomical Union (IAU) on the topic of 'Dark and Quiet Skies for Science and Society', which took place on 5–9 October, 2020. This workshop was convened pursuant to the agreement reached by the Committee on the Peaceful Uses of Outer Space at its sixtieth session that the Office for Outer Space Affairs and IAU would jointly organize a workshop/conference on the general topic of light pollution. 1 Based on the results of this work, Chile, Ethiopia, Jordan, Slovakia, Spain and IAU submitted a series of recommendations in A/AC.105/C.1/2021/CRP.17. Although the delegations of Canada, Japan and the United States cannot support all recommendations presented in that conference room paper at this time, the fulsome consideration of this topic is supported.*[293]

290 Examples include OneWeb (UK) and StarNet/GW (China)
291 U.N. Doc. A/AC.105/C.1/2021/CRP.24 (Apr. 27, 2021).
292 *See e.g.* Boley & Lawler, *supra* note 178.
293 U.N. Doc. A/AC.105/C.1/2021/CRP.24 (Apr. 27, 2021).

# 7. Industry Perspective

The Industry Subgroup used as its starting point the premise that satellite companies are predisposed toward good stewardship of space and operations that support space sustainability. Whether prompted by a commitment to space in general or a more pragmatic interest in protecting their investment in their various space-based interests, satellite companies have committed resources to improving space safety and innovated to improve reusability and reduce orbital debris. The Industry Subgroup considered the practicalities of the SATCON1 recommendations and mitigations from the perspective of a willing operator — whether analytical models could reliably predict the impact on astronomy from their spacecraft and systems, whether testing approaches prior to launch were available, affordable and accurate, how quickly observational feedback was needed to inject any alterations into ongoing plans, and whether operators could readily verify the relative success of any mitigations.

The Industry Subgroup concluded that satellite operators were more likely to adopt voluntary practices or mitigation tools if they engaged with astronomers early in their project cycle, before spacecraft designs were finalized and when modifications to architectures, spacecraft design or operations could be introduced at less cost or schedule impact. Further, the subgroup concluded that more work was required to ensure that analytical tools, test facilities and observational data are widely available to satellite operators, and are cost-effective, so that their adoption does not disrupt either budgets or schedule for their project.

The Industry Subgroup noted throughout that the work of analyzing the impact of diverse constellation architectures and spacecraft designs on the myriad astronomy scientific undertakings was still a relatively new practice, and that considerable ongoing work continues to analyze, test, innovate and observe the intersection of constellations and astronomical observation. With further inquiry and new case studies from new and diverse constellations, it seems likely that recommendations for operators will continue to emerge on the nature of satellite impact, innovations on additional mitigation approaches for both the satellite and astronomy operations, and the means to encourage voluntary steps that will allow both satellite development and astronomical discovery.

The scope of the Industry Subgroup was focused on the effects for ground-based optical astronomy primarily because this intersection has featured the most mature analysis to date and because the deployment of communications constellations has been rapid and on a large scale. Other individual spacecraft or constellations of satellites intended for other non-communications purposes, such as Earth imaging, weather, and asset tracking, among others, are being deployed and may also prove to impact optical astronomy activities, depending on their spacecraft design, altitude or operations. Similarly, SATCON1 and subsequent work with Dark & Quiet Skies have identified additional astronomy-related activities that may be affected by visibility from satellite constellations and merit review by the satellite industry when considering the impact from satellite constellations. Industry efforts to reduce harmful effects for astronomy could be better focused and potentially more effective with some characterization of the relative priorities of the astronomy activities identified.

For the purposes of SATCON2, the Industry Subgroup did not discuss the following items:

- Radio astronomy. Although the emergence of large constellations is a concern to radio astronomy, there is no direct spectrum sharing in the most common frequency bands for the largest constellations. Coordination and mitigation for out-of-band emissions from satellite constellations operating in frequency bands adjacent to radio astronomy frequency bands is addressed with the existing practice within the ITU and national spectrum regulation. Satellite issues of concern to radio astronomy are also being addressed in the Dark and Quiet Skies Workshops.
- Space safety topics like STM, satellite collision avoidance, end-of-life orbital disposal of satellites. While these aspects of constellation operations are of high interest to astronomers, they are well addressed in other fora.

## 7.1. Promoting Awareness and Industry Engagement with Astronomy

SATCON1 encouraged close collaboration between the satellite and astronomy communities and urged efforts to raise awareness across both communities at their intersections. Considerable work has been undertaken toward these dual goals of collaboration and awareness of the SATCON1 report and its findings.

**Promoting SATCON1**. Following the technical workshop from 29 June to 2 July 2020, the SATCON1 working groups produced and publicized the work in various fora. The SATCON1 white paper became available online in August 2020 and the AAS held a press conference on the report and launched a follow-up advocacy campaign to raise awareness on the issue generally. This included the AAS Public Policy Department (PPD) successfully advocating that NSF include the issue of satellite constellations in their authorization being drafted for the US. The report has since been published in the Bulletin of the AAS and NOIRLab also released a simultaneous announcement of the report. Dr. Tony Tyson of Vera C. Rubin Observatory and Dr Joel Parriott, Director of the AAS PPD, co-authored a companion article for *Science* magazine entitled Dark Skies and Bright Satellites. Members of the AAS group working on satellite constellations contributed to a *Nature Astronomy* paper on satellite constellations that was published on 6 November as part of a special edition on small satellites. Members of the AAS group working on satellite constellations contributed presentations at the Astronomical Society of the Pacific (ASP) meeting on satellite constellations in December 2020. The AAS PPD reached out to engineering societies to collaborate on raising awareness in January 2021.

**Subsequent workshops**. The AAS PPD also participated in the Dark and Quiet Skies Workshop in October 2020. The workshop was divided into working groups on the sub-disciplines of optical astronomy, radio astronomy, dark sky sites, light effects on the bio-environment, and the impact of satellite constellations on astronomy, both radio and optical. The AAS PPD joined the Recommendations group within the Satellite Constellations Working Group. Astronomers, operators, and space lawyers worked together to draft recommendations aimed toward international policy using the results in the report produced from the SATCON1 workshop. The SATCON2 workshop was announced and advertised by the AAS in May 2021. The AAS Committee on Astronomy and Public Policy and Committee on Light Pollution, Radio Interference, Space Debris co-hosted a town hall at the AAS 238 summer meeting on Astro2020 Advocacy, Satellite Constellations, and More! in June 2021.

**US government outreach**. To educate government decision makers on the findings of SATCON1, the AAS held an informational briefing with staff from Congressional offices and a meeting with the US communications regulatory authority, the FCC. The interagency Astronomy and Astrophysics Advisory Committee also discussed the SATCON1 report at their meeting in September 2020. The AAS group working on satellite constellations presented information on satellite constellations to the National Academies' Board on Physics and Astronomy. The AAS PPD discussed options for authorizing NSF to address satellite constellations with Congressional staffers in April 2021. Following the November 2020 US Presidential elections, the AAS PPD met with the Biden transition team for NSF to discuss concerns about the threat that satellite constellations pose for ground-based observation. The AAS PPD also wrote letters to the incoming Biden-Harris transition team and included a section on the need to preserve our dark and quiet skies.

**Satellite industry outreach**. The AAS has also continued to engage directly with the satellite industry to broaden awareness of the potential impact of satellite visibility on astronomy, deepen technical dialogue with the astronomy community and encourage voluntary adoption of the recommendations developed in SATCON1. Voluntary collaboration is a particularly urgent aspect of protecting astronomical observation in the immediate and near term, while national and international decisionmakers become more educated about the issue and contemplate legal or regulatory requirements for satellite operators to consider astronomy in their design and deployment. Enlisting members of the satellite community is essential, given the number and pace of satellite constellations being planned, fielded and operated, contrasted with the expected lead time for any new requirements-based approach to be agreed upon, adopted and implemented by any given individual nation or internationally.

The AAS and the Satellite Industry Association (SIA), the leading US satellite trade organization, teamed up to host an October 2020 informational webinar on astronomers’ concerns about satellite constellations and the technical recommendations of the SATCON1 Report. The AAS group working on satellite constellations hosted a special session at the AAS 237 winter meeting on Astronomy and Satellite Constellations with a panel that included astronomers, SpaceX, OneWeb and Amazon. The AAS group working on satellite constellations also continued to meet with SpaceX directly to discuss observations of VisorSat, the first of which had been launched around the time of SATCON1 with multiple subsequent spacecraft deployed.

The AAS and SIA plan to continue their partnership for informational webinars and and the two associations plan to continue doing so in the future. The AAS also intends to contact other industry associations to help disseminate information across the space and satellite sector. The AAS and SIA will additionally try to partner with external organizations to organize events that will bring major international commercial satellite stakeholders to the table to further disseminate recommendations on satellite brightness and encourage the participation of international governments and regulators.

**Public comments**. The AAS also relied on the work of SATCON1 to become a more active participant in public consultations relating to satellite constellations and their impact on astronomy. In January 2021 the AAS PPD filed reply comments in the FCC docket considering a modification to allow SpaceX's Starlink constellation to fly lower, thanking Viasat for calling attention to the impacts of satellite constellations on astronomy and offering corrections to technical assumptions in Viasat's comments. The FCC quoted the AAS's comments about the benefits of lower altitudes in its Report and Order granting Starlink's modification, and included a condition that SpaceX consider impacts to astronomy as part of their deliberations, a landmark decision. The AAS PPD and the IAU's US National Committee joined forces to write a letter to the US Department of State urging them to endorse moving forward the Dark and Quiet Skies Conference Room Paper at the April meeting of the Long Term Space Sustainability sub-committee of COPUOS.

## 7.2. Future Plans and Next Steps

**Rating system**. The AAS is evaluating a rating system that can recognize companies who go to great lengths to mitigate the impacts of their satellite constellations on astronomical observations. To this end, the AAS have created a checklist for industry participants to use to measure mitigation strategies, with higher recognition standing given as satellite operators employ more of the identified mitigation steps. This is part of the AAS's approach of emphasizing a collaborative role with industry, while also pursuing an evidence-based advocacy strategy to ensure the various workshop report recommendations are implemented.

## 7.3. Identifying Key Satellite Characteristics that Affect Reflectivity

SATCON1 identified various operational, design and architecture mitigations for constellation operators to consider in mitigating their effect on astronomy. SATCON2 recommends identifying those key characteristics of a spacecraft or constellation that trigger heightened concern for ground-based optical astronomical observation.

The primary concern remains reflected sunlight from satellites. Using determinations from the Rubin Observatory system, an instantaneous brightness limit is defined for individual satellites. Satellites appearing brighter than this limit are expected to degrade substantially the data quality from astronomical observations. It is highly desirable to remain below that limit for all phases of a mission's lifetime. A key aspect of staying below these reflected brightness limits is avoiding bright glints from specular surfaces. Reliable attitude control is a crucial capability to limit periodic glints, in that an out-of-control or tumbling satellite is much more likely to generate glints and therefore less likely to remain within the brightness limits.

Beyond brightness, the Industry Subgroup discussed the value of creating a hierarchy of features that could aid new satellite operators in understanding whether and to what extent their proposed constellation is likely to impact ground-based optical astronomy, and to correlate their efforts at mitigation accordingly. Similarly, a construct to identify the constellation projects that create elevated concern will ensure that astronomy resources can be put to best use in analyzing and observing proposed satellite projects that are most likely to harm optical observation.

**Recommendation**. Building on SATCON1 and the primary concern of brightness, the Industry Subgroup recommends that astronomers continue to develop a hierarchy of additional characteristics of spacecraft, operations and/or altitude for satellites/constellation systems that would either indicate to owner/operators that they have a low/no concern from a reflection perspective, or that they have a high level of concern. These may include key characteristics that exclude/capture a constellation, such as Altitude, Number of satellites, Design of satellites, and the satellites' shape, surface or materials used. Astronomers should perform the same exercise on the recommendations that apply to them.

## 7.4. Establishing Criteria for Smaller Satellites

The Industry Subgroup also explored the possibility of recommending designs, materials and operations to limit impact on astronomy from cubesats and smaller satellites for remote sensing or Earth imaging. Commercial communications are being launched in larger numbers in the near term and typically weigh more than even the new generation of commercial remote sensing satellites, and should certainly remain the primary for technical work and stakeholder outreach. However, little technical work has been undertaken on the impact of cubesats and commercial remote sensing satellites, and deployments of both types of satellites are growing rapidly. Developing clear and early guidance would improve awareness and voluntary adoption of techniques among these additional types of satellites that could lessen the impact on astronomy.

**Cubesats**. The Industry Subgroup discussed the value of defining characteristics that could reasonably predict whether a cubesat would have higher or lower expected levels of brightness. The vast majority of cubesats right now are fainter than the desired cutoff and, as seen in the chart below, they are not yet a major contributor to bright sky objects. Most cubesats operate between 500 km and 700 km orbital altitude, with many at quickly decaying altitudes; it is unclear whether regulators like the FCC will impose regulations to limit their operating altitude.

Although only 200 cubesats are being launched per year, this number is expected to increase as space becomes ever more accessible and affordable. At current predicted deployment rates, cubesats are not expected to contribute substantially to overall light pollution for at least several generations of satellites. However, little study has been undertaken to date on those cubesats that are noticeably more visible and why the brighter ones are bright. Further study here could confirm which designs, materials and operational characteristics are less likely to be visible and add to the impact on astronomy.

The Industry Subgroup found it particularly important to provide recommendations for cubesats to voluntarily adopt, because the community proposing, designing and fielding cubesats may be more difficult to reach out to and to regulate. While there are commercial cubesat constellations, these satellites are largely faint. Many cubesats are academic or research-based and one-off projects, which have less access or ability to test or model their satellites in the same way as envisioned for the commercial industry. There may also be less willingness to impose stricter regulations on academic cubesats and chilling space research, as seen in the national and international resistance to regulating cubesats at an orbital debris level. Cubesats are also more likely to be outside of the jurisdiction of US FCC regulations, operating solely on approvals from their home country or launching state. In contrast, commercial satellites are often motivated to provide services in the US marketplace and therefore seek FCC licensing approval to win US market access. Very high-level best practices that are easily implementable, as well as any open source brightness modeling tools, will be critical to outreach and voluntary implementation across the diverse ranks of cubesat projects.

**Commercial remote sensing**. Satellites have been increasingly employed to detect and monitor the physical characteristics of an area by measuring its reflected and emitted radiation at a distance. Current and planned constellations envision hundreds of satellites weighing up to 30 kg and smaller constellations with dozens of satellites around 100 kg. Existing and planned commercial remote sensing constellations are distributed internationally., as shown in the picture below (SIA The community, with State of the Satellite Industry Report, 2021). Most remote sensing satellites will orbit in the 400–500 km range; many do not feature propulsion, so will decay rapidly. Most of the commercial remote sensing satellites in the ~ 30–kg range are below the desired brightness threshold, but further consideration should be given to any new consideration for constellations of hundreds of satellites of this mass class. Heavier commercial remote sensing satellites are likely above the desired brightness threshold of 7th magnitude, but given the low total number of these larger satellites on-orbit, these may be best considered in their cumulative impact.

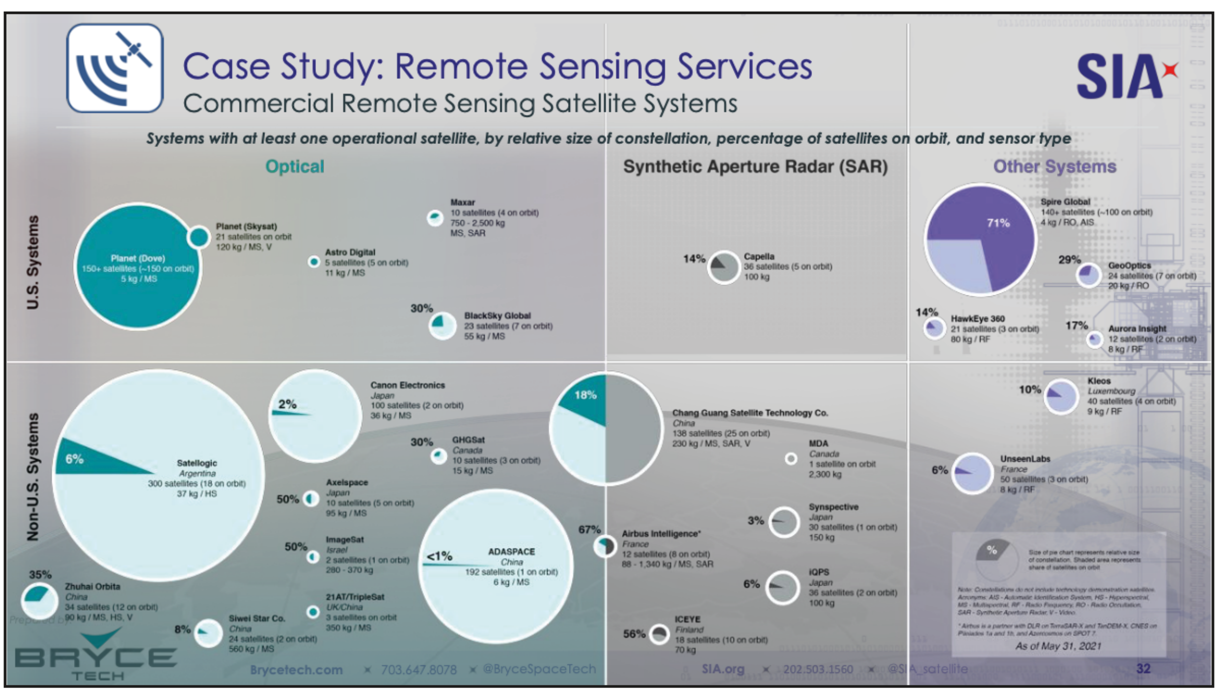


*Figure 7.1. A case study for remote sensing services. (SIA)*

The Industry Subgroup explored the usefulness of converting the kilogram-based definition that the FCC uses to define small satellites into a formulation scaling to surface area and reflectivity to evaluate altitude and numbers of satellites in constellations as a lower threshold. The first interpretation of this exploration, as depicted in Figure 7.1, is that there is a tail of the distribution of observed mean brightness at any mass that well exceeds the desired brightness limit. This suggests that all projects should be given guidance to minimize reflectivity. Additionally, there is a bigger fractional tail of maximum brightness, attributable to glints and flares off specular surfaces. This indicates that all satellite projects should be encouraged to minimize nadir-facing specular surfaces and maintain robust orbital attitude control.

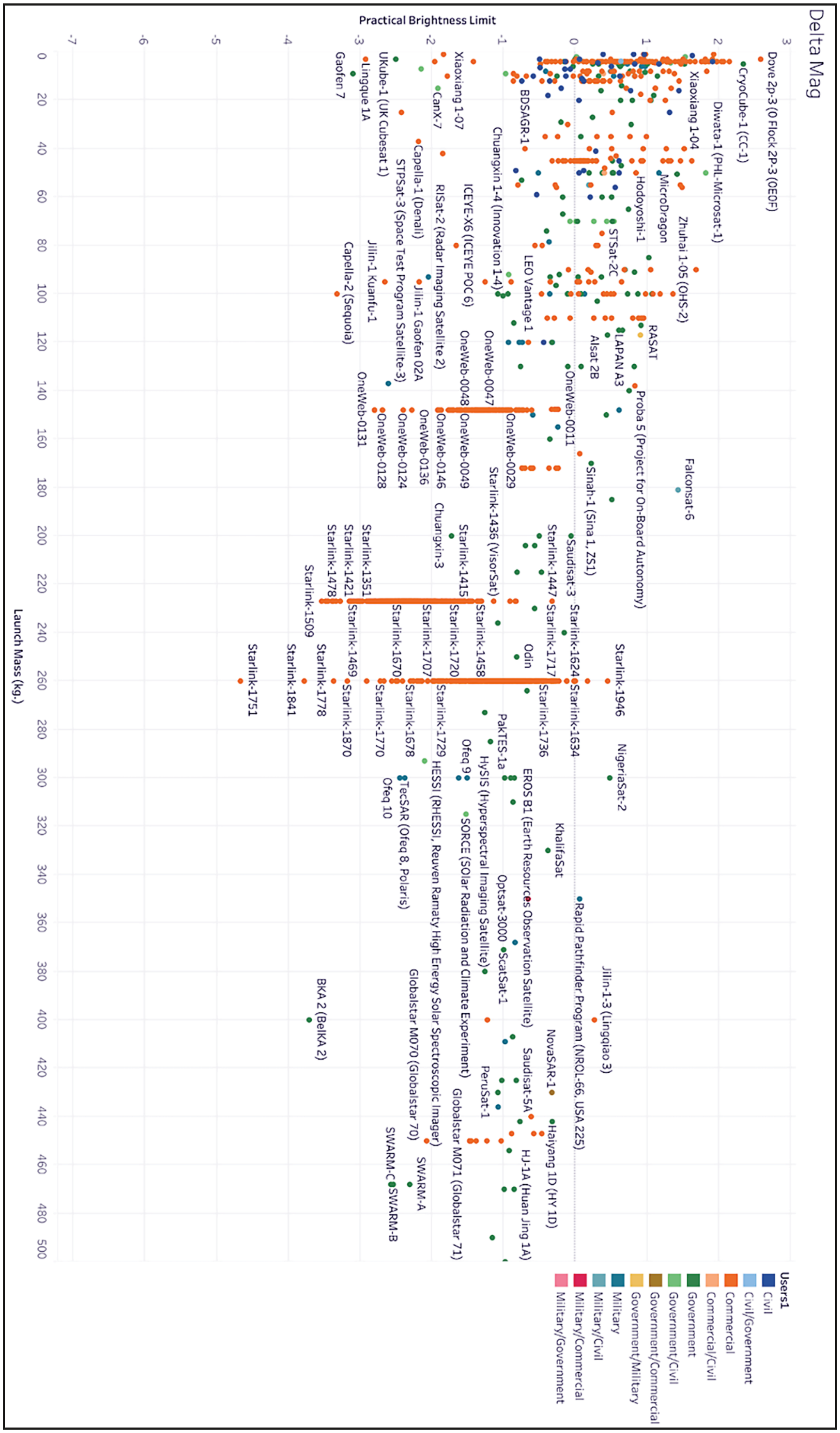


*Figure 2.. Brightness in reflected sunlight compared to satellite mass. The Y-axis is the difference in astronomical magnitudes between the brightness of the satellite as observed through a clear bandpass at its orbital height vs. the V magnitude limit as recommended in SATCON1 to stay below a data-damaging threshold. (Negative values are too bright.) The X-axis is the*

*launch mass of each satellite. Magnitude data are from the Russian MMT database (http://mmt9.ru/satellites/) and the Union of Concerned Scientists Satellite database (https://www.ucsusa.org/resources/satellite-database). The easily readable interactive chart can be found at: https://tabsoft.co/3ABZoqG.*

## 7.5. Collaboration Tools

### 7.5.1. IAU Centre

One important goal is to have a clear landing spot for continuing interaction of industry with the astronomical community.Given that each proposed satellite constellation to date features distinct spacecraft designs, orbital architecture and business model, the assessment of visibility, potential to disrupt optical observation and potential for effective mitigation approaches at pre-deployment phases are best assessed in a customized way, constellation by constellation. A centralized hub for communicating such evaluations would help reduce confusion and speed the process for assessing mitigation strategies. The IAU has taken the lead in establishing a Centre for the Protection of the Dark and Quiet Sky from Satellite Constellation Interference. The IAU call for proposals is at: https://www.iau.org/news/announcements/detail/ann21039. A successful centralized operation will require full time staff, and thus significant ongoing funding.

While the IAU is establishing a collaborative center intended to benefit astronomers and satellite operators alike from anywhere in the world, the AAS will remain a conduit for discussion, partnerships with US industry, and a major advocate for appropriate policies and oversight in the US and internationally. The AAS will work with the IAU on a strategy to help secure funding for the Centre. Once the IAU Centre is established, the AAS will act as an advocate for it and will continue communicating broadly with industry on behalf of the astronomical community, and guiding relevant spacecraft designers, manufacturers, and operators to the resources at the Centre and elsewhere (e.g., standards/testing capabilities at the National Institute of Standards and Technology (NIST) for US companies).

The IAU Centre will foster the development of tools and procedures that can mitigate the impact of satellite constellations on optical astronomy and will work with the space companies and industries to discuss and converge on mitigations. The overall situation has been thoroughly analyzed in the report of the online Workshop on Dark and Quiet Skies for Science and Society, which contains a number of recommendations for possible mitigation actions.

The focus is on mitigating optical interference from satellites and the goal is enabling the recommendations of the Dark and Quiet Skies Conference Room Paper. It is expected that the IAU Centre will be hosted by an existing institute or organization of excellence, or a partnership thereof, with proven experience in international cooperation.

The mission of the IAU Centre can be summarized as follows:

- Work together in partnership to coordinate the observation and measurement of the optical interference caused by satellite constellations.

- Establish contacts with the space companies and industries involved in the construction and deployment of LEO satellites and eventually with their national regulation authorities, in order to discuss and converge on relevant mitigation measures.
- Foster and coordinate the study and testing of hardware solutions aimed at reducing reflected sunlight by the satellites as well as thermal emissions from the satellite surfaces.
- Interface with space agencies in order to get access to accurate and up-to-date orbital parameters of all LEO satellites.
- Work together in partnership to coordinate the development of “smart” scheduling and/or detector operation software as well as specific artifact removal algorithms and distribute them.
- Provide suggestions for possible international regulations governing LEO satellites to the IAU Officers, in support of their pursuing the matter at the COPUOS level.
- Maintain regular contact on matters of common interest with the other IAU Offices.
- Create and maintain a dedicated set of web pages under iau.org for disseminating information about the protection of the dark sky from satellite interference.
- Organize thematic workshops (online and/or in person) as needed.
- Support the mitigation of interference caused by satellite constellations to radio astronomy as formulated in the Dark & Quiet Skies Workshop report and seek coordination of possible common actions with radio spectrum managers where appropriate.

The AAS will publish a checklist of mitigation strategies. This will be used to assess individual companies’ efforts to mitigate impacts to astronomy. The more boxes a company can check, the higher their rating. The AAS will then issue an annual award for the highest rated companies, commending/ endorsing their efforts.

New companies can go to a new organization like the IAU Centre as a port of entry and start engaging.

### 7.5.2. Sharing Industry best practices and experiences

There are multiple advantages for industry to be enabled to share best practices while they develop effective techniques to mitigate the impact of satellites on ground-based observations.

- Many spacecraft designs and satellite constellation systems are highly customized and vary significantly in the nature of their mission (communications, imagery, tracking, Positioning Navigation and Timing (PNT)), space safety approach, and business approach.
- Still, it is instructive to share techniques tested and fielded across the satellite community to advance more rapidly an understanding of effective mitigation tools.
- Operational constellations and industry manufacturers are in a unique position and have the opportunity to introduce lessons learnt from previous experience into the design of future constellations.

- SpaceX's work with Starlink (the initial DarkSat demo in January 2020, and over 1200 VisorSats deployed in 2020–21, plus almost a year of experience employing post-launch orientation rolls) provides an early canon of mitigation techniques.
- OneWeb applied some changes to their Gen1 spacecraft design to mitigate the predicted satellite brightness in the design phase, but this was prior to the observation of the actual level of brightness on Gen1 satellites. OneWeb is working with astronomers now to verify the actual level of brightness and is considering painting certain on-board antennas with a dark coating, if needed. OneWeb expects to include further mitigations in their next-generation spacecraft design.
- **Recommendation**. Operators are recommended, asa first step, to share and publish their experience and lessons learnt across the community, in order to build understanding in mitigation design techniques and foster innovation in new concepts.
- SpaceX documentation/publication of mitigation efforts to date (DarkSat, VisorSat, Operational roll, early TLE provision, other) https://www.spacex.com/updates/starlink-update-04-28-2020/index.html
- Collaborative paper with SpaceX / Vera Rubin Observatory discussing the impacts of different numbers of satellites, orbital characteristics, brightness magnitudes, etc. Includes data from DarkSat. https://arxiv.org/pdf/2006.12417.pdf
- Paper from National Astronomical Observatory of Japan, discussing DarkSat measurements: https://iopscience.iop.org/article/10.3847/1538-4357/abc695

Internationally, the Industry Subgroup noted the importance of engaging more actively with nations that have either licensed or directly invested in satellite constellations, but have not yet participated in the various US, European or international fora or technical discussions that focus on the intersection of constellations and astronomy. For example, China's Guowang satellite constellation of 13,000 broadband and 5G satellites has the potential to contribute substantially to light pollution, and early engagement with scientists and engineers from China will be critical to collaboration and adoption of best practices on mitigation.

## 7.6. Mitigation Goals

The SATCON1 and Dark & Quiet Skies efforts set targets for the reduction of the visible brightness of the satellites as seen from the ground, by both naked-eye observers of the night sky and ground-based optical telescopes. Reach the fainter of these in all phases of a constellation:

- Naked eye visibility: $V = 7.0$ mag (Broad-band visible light filter, centered on 550 nm).
  Or
- $V = 7.0 + 2.5 \log10 (r_{orbit}/550 \text{ km})$, equivalent to $44 \times (550/r_{orbit})$ watts steradian$^{-1}$, where $r_{orbit}$ is the altitude of the satellite orbit in km.

If met, that brightness limit would render constellations effectively invisible to the unaided eye once in orbit, addressing the naked eye observation concerns, including potential cultural impact.

The reference goals following, based on the SATCON1 recommendations, have been articulated by the International Dark-Sky Association for constellations at https://www.darksky.org/satellite-megaconstellations-and-the-night-sky/. Corresponding consideration should be given to minimize apparent brightness during mission phases of orbit-raise and de-orbit as much as practicable, to address the same visual concerns.

> IDA's **five principles** to preserve the quiet enjoyment of the night sky and protect the general public from the impacts of mega-constellations:
>
> 1. **Stewardship** of the night sky is a shared responsibility that requires participation and consultation with all stakeholders.
> 2. The **cumulative impact on night sky brightness** attributed to satellites does not exceed 10 percent above natural background levels.
> 3. **Maintained satellite brightness** is below the threshold for detection by the unaided eye.
> 4. **Satellite visibility** is an unusual occurrence.
> 5. **Launch schedules and orbital parameters** are publicly available in advance.

Provided glints and flares are avoided, meeting the limit defined above would reduce the impact to below the threshold defined in SATCON1 for wide-field, large aperture telescopes, such as Rubin Observatory.

## 7.7. Open Issues from Industry Discussants

1. Should there be different targets based on different wavelengths? Some relevant information is contained in the analysis of the impact on Rubin Observatory by Tyson et al. (2020, Astronomical Journal, 160, 226). These limits depend on the sensitivity of the Rubin Observatory system, including filters and detector. For the limits for calibratable cross-talk corresponding to $V = 7$ mag at 550 km, in the LSST bandpass system, the other band limits are $u \sim 5.5$ mag; $r \sim 7$ mag; $i \sim 6.5$ mag; $z \sim 6.8$ mag; and $y \sim 6.5$ mag. Note that these are not equivalent to a wavelength-independent reflection of the solar spectrum. Visual reference for filter bandpasses are found at https://www.lsst.org/scientists/keynumbers.
2. Note that other potential impacts exist, but are not currently prioritized on account of their level of development being too low to provide actionable guidance to satellite owner/operators.
3. Interference with infrared observations (this issue is discussed in the NSF JASON report https://www.nsf.gov/news/special_reports/jasonreportconstellations/).
4. Interference with low-solar-elongation observations for near-Earth asteroid searches, with potential impacts on planetary defense (see US and International Policy Group Papers for policy considerations).
5. Interference with high-cadence occultation surveys due to unlit satellites passing in front of stars and momentarily blocking light.
6. Interference with high-cadence time domain astronomy through optical flashes of otherwise low-brightness satellites and debris.
7. Aggregate effect vs an individual effect.

## 7.8. Aggregate Impact

Discussion was held of an eventual cumulative effect of visibility that could create an overall lighter night sky, reducing ability to make observations. This concern is developed in a peer-reviewed publication based on numerical modeling, by Kocifaj et al. (2021, MNRAS Lett, 504, L40). Using plausible assumptions, they show that scattered sunlight from all current LEO satellites and space debris may already have brightened the diffuse natural sky glow by 10%. Measurements to test for this change in absolute level on a large angular scale are challenging and have yet to be made or examined in archival data.

A parallel exists in spectrum rules for Non-Geostationary Systems by establishing both individual limits of power (Equivalent Power Flux Density or EPFD) for each individual constellation, but also an aggregate EPFD limit to protect higher-orbiting geostationary satellites operating in the same frequency band. This is conceptually interesting, but an arbitrary number of assumed systems (3.5) and no practical testing of this undermine its value as a template for brightness.

Regarding the aggregate-effect vs the individual-effect, there is not sufficient evidence or study of this problem to characterize it properly or recommend an arbitrary number that, unsupported by any empirical testing, would undermine its value and meaning. However, the modeling formalism is now in place, and can be subjected to variation of assumptions and parameters as well as observational validation. Although further simulations are needed for impacts on data analysis for specific investigations, it is generally true that streaks from individual satellites impact finite areas of images, while increased diffuse sky glow requires increased exposure time for all images.

## 7.9. Impact Metric

In reviewing the recommendations for satellite operators made in SATCON1 and subsequent papers, the Industry Subgroup noted certain internal tensions among the recommendations, with some that are mutually exclusive and others setting up trade-offs on their relative impact to astronomy from a preferred system architecture or spacecraft design. For example, SATCON1 sets a clear priority on constellations flying at lower altitudes, in order to reduce the time that the spacecraft are moving across the field of view of the observer on the ground. Another SATCON1 recommendation prefers reducing the overall number of satellites even though, in general, constellations operating at lower altitudes require more spacecraft to yield comparable geographic coverage and throughput. Similar tensions have been identified in the recommendation to darken satellite services to reduce reflection, which may in turn elevate the thermal footprint so as to cause disturbances for infrared astronomical observations.

Spacecraft design changes and satellite system mitigations all tend to feature some sort of trade-off in performance, reliability or attitude control, or spectral efficiency or data rates. Well-intentioned satellite operators will need further guidance from astronomers on how to weigh these trade-offs and avert the potential for unintended consequences on other fields of astronomy. We note that the SatHub discussed elsewhere in the SATCON2 exercise may be a productive venue to evaluate the relative tradeoffs for a given constellation between internally-conflicted technology or mitigation solutions.

Similarly, not all mitigations will have the same usefulness across the astronomy community, and the satellite industry would benefit from deeper insights into the relative impacts and priorities, and which astronomy activities merit concentrated efforts to address. This sort of “impact metric” could consider which mitigations would yield the widest possible benefit across the astronomy field, as well as those more specialized activities that have limited alternative workarounds available to date.

For example, it has been useful for the satellite community to have as a target the general agreement from the astronomy community that reaching a brightness of 7 magnitude is of the highest priority, because meeting this target would relieve concerns both about naked-eye visibility and loss of the night sky for unaided observation, and also appears to provide the minimum mitigation needed for most professional optical telescopes. It is less clear, however, what astronomers would characterize as the next highest priority target to achieve. Further delineation of the remaining astronomical targets within a subtler hierarchy could better guide industry in its ongoing assessment of mitigations.

Beyond the types of telescopes and astronomical observations, industry research and experimentation could be better applied with further astronomy community guidance as to which of the various concerns and/or stakeholder groups would have the largest or most beneficial impact if solved. While the majority of study to date has focused on Rubin Observatory as a wide-field observatory most impacted by constellations, there are relatively few such wide-field telescopes to date, and it is unclear how many (if any) other observatories are affected as non-linearly. Other mitigations may be of use to the large inventory of narrow-field telescopes.

Industry R&D efforts can be focused on most impactful problems if guided with the development of an impact metric to depict the relative effect of satellite visibility on various astronomy fields, and not just the types of telescopes or observations, but also their frequency or proliferation. While this may be a problematic value judgement for the astronomy community to adopt broadly, it could be considered on a constellation-by-constellation basis as part of the SatHub concept discussed elsewhere in the SATCON2 workshop.

## 7.10. Mitigation Approaches

While other aspects of SATCON2 evaluate approaches that would compel satellite constellation operators to consider and address their effect on astronomy through regulatory or legal means, the Industry Subgroup focused on the resources and recommendations that could be reasonably adopted by those satellite owner/operators that are committed to voluntarily limiting their impact on astronomy. The Industry Subgroup’s focus was to inform and enable satellite operators and manufacturers of the tools and techniques they can voluntarily employ to minimize their potential impact on astronomy. This section explores the resources available to, or necessary for, satellite stakeholders to voluntarily assess and, if necessary, mitigate the visibility of proposed satellites as seen from the ground.

An initial list of recommended performance metrics and mitigation techniques was provided in the AAS document from SATCON1, Impact of Satellite Constellations on Optical Astronomy and Recommendations toward Mitigations, while the effectiveness of these techniques is being evaluated and discussed elsewhere in the current work of SATCON2.

Many of the initial mitigation techniques rested on SpaceX's pioneering work with Starlink, including the initial DarkSat demonstration satellite launched in January 2020 and the initial test VisorSat from May 2020 and subsequent production-version VisorSat models. With over 1000 VisorSats deployed in 2020–21 and over a year of experience employing post-launch orientation rolls for Starlink, there is a reasonably rich early canon to consider these initial mitigation techniques.

OneWeb also has applied some changes to their Gen1 spacecraft design to mitigate the predicted satellite brightness in the design phase. However, these were undertaken prior to the observation of the actual level of brightness of Gen1 satellites in orbit. OneWeb has commenced work with astronomers to verify the observed level of brightness and persistence in view, and is considering painting certain on-board antennas for its remaining Gen-1 satellites with a dark coating, if needed. OneWeb expects to include further mitigations in their next-generation spacecraft design.

With the recent proliferation of constellations, and with extensive analytical work and collaborative commitment from the astronomy and industry communities, a critical opportunity presents itself now for visibility to be taken into account in the early stages of project development, spacecraft design and constellation architecture.

Operational constellations and industry manufacturers are in a unique position to introduce lessons learned from previous experience to improve the design of future constellations and eventual upgrades to those constellations now being deployed. It will be instructive to share techniques tested and fielded across the satellite community to more rapidly advance this nascent field of engineering and analysis. To the extent possible, satellite operators are encouraged to share and publish their experience and lessons learned across the community, in order to build understanding of effective mitigation design techniques and foster innovation in new concepts.

Not all mitigation techniques will be satisfactorily effective, nor will each technique suit each proposed constellation. Whereas satellite systems in decades past tended to be produced by a small number of spacecraft manufacturing companies, today's small satellites and constellations come from a far more diffuse source of manufacturers and their designs are highly customized. Further, constellations and small satellites vary significantly by the nature of their business approach or mission, whether for broadband communications, Earth imagery, tracking, or navigation. The most suitable, cost-effective and available mitigation techniques will certainly depend on the specific spacecraft design and orbital characteristics.

## 7.11. Pre–Launch Analytical Resources

The challenge of accurately predicting the visibility of a spacecraft prior to launch is a novel one for spacecraft designers, and one not previously a part of the routine test and design practice of the commercial satellite industry. However, pre-launch modeling and testing are arguably the least disruptive and most effective ways to prevent inadvertently pronounced visibility that is harmful to astronomy.

The most effective time to avert harmful brightness is in the design phase of the spacecraft and when the constellation architecture is still in development. It is expected that many satellite constellation operators, particularly those who commission the design and production of satellites from a third-party manufacturer will be limited in their ability to halt production lines mid-stream for modifications to mitigate visibility, and will potentially be deterred by the prospect of added costs from retooling designs and disrupting production lines as well as cascading project delays and eventual time to market effects.

Ideally, modeling and testing for impacts to astronomy would become routine for satellite constellations, and all satellite operators would interject into the design phase a step to model their spacecraft to accurately predict the likely visibility well before designs are set and any test articles are fabricated. Further, prior to deployment, any demonstration satellites ideally would be subjected to ground testing, as well as the kind of systematic observation measurements of brightness once launched as is contemplated elsewhere in SATCON2.

While testing for reflection and albedo during the development stage is a worthwhile goal, these are relatively new engineering protocols. Given the newer nature of this consideration, additional experience and development are needed to allow for a mature capability to the point where willing satellite operators can readily access reliable and cost effective testing tools.

Material level optical property testing should be considered in the design cycle of the spacecraft. It is feasible to conduct ground optical testing for specific material samples using the limited existing databases which provide optical properties for various materials. However, these databases do not appear to be comprehensive in nature. This potentially useful predictive tool requires further exploration of appropriate testing parameters to obtain accurate material properties for a more complete range of materials commonplace in spacecraft manufacturing.

Traditional optical modeling remains quite complex and challenging to implement, given the lack of experience and background in using these capabilities in this way. Further analysis on approaches and capabilities should be developed in order to simplify the problem and enable operators to incorporate this potential preventative step into their design cycle.

Modelling by using Bi-directional Reflectance Distribution Function (BRDF) testing in the laboratory is a promising step in the development phase to forecast the expected brightness level. BRDF testing could be introduced through a process similar to the Thermal Balance and Vibrations test used to correlate thermal and finite element models of a satellite during the environmental test campaign. The Industry Subgroup inquiry concluded that full satellite-level optical property testing is not currently feasible, given the limited facilities and complication with this type of integrated test. In order to reach a point where such testing is accessible, cost-effective and ultimately routine for satellite operators, further inquiry will be required to refine and mature the analytical techniques needed to predict brightness levels reliably, and also to evaluate the technical requirements and expected costs of BRDF test set-ups.

## 7.12. Post–Launch Mitigation Techniques and Analytical Resources

### 7.12.1. Transparent Location Data after Deployment

As noted in both SATCON1 and discussed in SATCON2, astronomers seek more readily available, more extensive information on satellite positions in order to permit many telescopes to apply scheduling tools to avoid the impact of constellations on observation images. The owner/operators are encouraged to provide and make publicly available high-accuracy data on the predicted locations of individual satellites (or ephemerides). In general, satellite operators are willing to share accurate, timely orbit position information in whatever format the government and industry eventually agree on, noting that access to these data needs to be reasonably controlled. This drive coincides with a broader desire within the space and satellite community to improve collision avoidance and enhance space safety by collecting and sharing more detailed and readily accessible ephemerides and covariance data, as well as early assignment of two-line element identifiers (TLEs). Sharing of such information is still uneven across various satellite owners, with several governments encouraging more transparency and new data sharing tools.

To a certain extent, the requirements of astronomers exceed the level of detail being considered for space safety purposes, such as proposals to utilize a new standard format for ephemerides beyond TLEs to include covariances and other useful information. The Industry Subgroup noted that there are limitations within the existing system to capturing ephemeris data at more frequent intervals and with finer specificity. At this time, the current system is not set up to share this level of data, although there is great interest in the US and internationally in upgrading capabilities to permit improved information collection and sharing. The Observations Working Group of SATCON2 is considering these.

To incentivize further refinement of the systems now in place, the Industry Subgroup noted that it would be helpful to understand just how widely such information could be used for astronomy, including what representation of telescopes could or would reasonably employ scheduling. It is unclear how many observatories have available software or are inclined to employ scheduling techniques for avoidance should such data be made available. If it is clear that the higher frequency interval of data or its specificity would be of high potential use to widespread telescopes, this could elevate the priority and prompt new resources to work on the enhancement of data systems for the unique requirements of astronomy.

### 7.12.2. End of Life Deorbit

The US government's ODMSP were updated in 2019 to accommodate the changing near-Earth space environment. As the preamble explains: "*While the original ODMSP adequately protected the space environment at the time, the* [US government] *recognizes that it is in the interest of all nations to minimize new debris and mitigate effects of existing debris. This fact, along with increasing numbers of space* *missions, highlights the need to update the ODMSP and to establish standards that can inform development of international practices*".[294]

Of particular importance, the new ODMSP state that "[t]*he new standard practices established in the update include the preferred disposal options for immediate removal of structures from the near-Earth space environment*." Specifically, standard 4-1(a) lists the preferred options as follows:

*Direct reentry or heliocentric, Earth-escape: Maneuver to remove the structure from Earth orbit at the end of mission into (1) a reentry trajectory or (2) a heliocentric, Earth-escape orbit. These are the preferred disposal options. (…)*

Standard 4-2(b) lists a second option, which is restating the well-known 25-year rule:

*Atmospheric reentry: Leave the structure in an orbit in which, using conservative projections for solar activity, atmospheric drag will limit the lifetime to as short as practicable but no more than 25 years after completion of mission. If drag enhancement devices are to be used to reduce the orbit lifetime, it should be demonstrated that such devices will significantly reduce the area-time product of the system or will not cause spacecraft or large debris to fragment if a collision occurs while the system is decaying from orbit. (…)*

While these standards are written with space environmental stability in mind, they have implications for astronomy.

Satellites deorbiting as part of their EOL, a requirement for space safety, present several complications for astronomy. For mature constellations that require the continuous replacement and EOL maneuvers of satellites, the deorbiting satellites could lead to a non-negligible addition to the bright satellite population. This is expected to be more acute for long deorbiting timescales, even when adhering to the 25-year rule. Moreover, satellites that are passively deorbiting are expected to tumble, which will cause variations in satellite brightness, with the possibility of bright transients. Such variations have the potential to cause significantly greater data loss than those under active control meeting the recommended brightness limit. On-orbit aging of satellites, whether active or defunct, could further lead to changes in satellite brightness or variability.

**For these reasons, satellite operators should deorbit their satellites as soon as practicable upon satellites reaching their end of mission, consistent with ODMSP 4-1(a).**

Adherence to ODSMP 4-1(a) presumes spacecraft of concern will feature propulsion capabilities adequate to accelerate natural deorbiting. Other methods exist to decrease the natural deorbiting timescale, such as drag enhancement (e.g., drag sails). Such devices necessarily increase the cross section of the satellite, which has the potential to substantially increase its brightness or variability, even for small satellites.

**For this reason, satellite operators who use drag enhancement technology should, in addition to the considerations presented in ODMSP 4-1(b), demonstrate that the use of such technology adheres to best practices for astronomical impact reduction.**

294 United States Government. Orbital Debris Mitigation Standard Practices. November (2019). https://orbitaldebris.jsc.nasa.gov/library/usg_orbital_debris_mitigation_standard_practices_november_2019.pdf

In particular, because many small satellites do not have propulsion, such systems may require ongoing evaluation and monitoring to understand correlations, if present, between the likelihood of a satellite having an astronomical impact and its satellite type, deorbiting method and characteristics, and altitude.

## 7.13. Ongoing Mitigation Iteration

The Industry Subgroup noted throughout its discussions that it is a relatively new field of technical work to analyze the impact of diverse constellation architectures and spacecraft designs on the myriad astronomy scientific undertakings. This intersection between satellite constellations and astronomy is prompting a new field of engineering that is cycling rapidly with iteration in new mitigation approaches. While not all techniques are destined to prove effective, this is a dynamic area of inquiry that is rapidly deepening understanding of how to lessen the impact of satellite constellations on astronomy.

For the satellite industry, it is nascent engineering work to conceive, test and field mitigation techniques to reduce visibility on communications satellites operating in LEOs. To date, only SpaceX's experimentation on the Starlink DarkSat test satellite and considerable deployments of the now ubiquitous VisorSat design and operational roll techniques have been well studied to date. With growing participation from OneWeb, Amazon Kuiper and Telesat's Lightspeed, and work to engage spacecraft manufacturers and proponents of new constellations from other countries, there is further voluntary work toward innovations in spacecraft designs and operational adjustments with astronomy in mind. Ongoing work by SpaceX and now other systems will yield new iterative mitigation approaches that may better suit different types of spacecraft and varying constellation designs. This diversity of approach should be encouraged, as new iterations will benefit both new constellations that are currently in the planning phase and future generations of spacecraft to upgrade existing constellations.

The considerable efforts of the astronomy community to analyze and observe the intersection of constellations and astronomical observation are also providing new and valuable insights to the efficacy of early mitigations and prompting concepts for alternate mitigation approaches.

**Recommendation.** Because the technical and practical inquiry into mitigation techniques is still at an early stage, the Industry Subgroup endorses an outcome-driven focus for any mitigation recommendations and guidelines, rather than overly prescriptive language that stipulates a specific technology or technique. The community should continue its work to establish data-driven, well-defined standards and requirements based on continued research, modeling, and analytical efforts, and promote meeting these desired performance-based outcomes. With such dynamism and iteration in mitigation techniques and ongoing work to evaluate their effectiveness, recommendations should incentivize further innovation and leave room for variations in mitigation approaches that may be suitable for different types of constellations and operators.

# Appendix I — State Lighting Regulations

*Table 2. State Lighting Regulations*

| State | Statute | Summary[295] |
|---|---|---|
| Arizona | Ariz. Rev. Stat. Ann. §§49-1101 *et seq.* (2020) | Outdoor light fixtures must be fully or partially shielded.<br>● Exempt are:<br>○ Incandescent fixtures of 150 watts or less or other light sources of 70 watts or less;<br>○ Emergency and construction lights;<br>○ Airport lighting.<br>● Nonconforming light fixtures are allowed as long as they are extinguished by automatic shutoff between midnight and sunrise.<br>Towns, cities, and municipalities may have more stringent regulation. |
| Arkansas | Ark. Stat. Ann. §§8-14-101 *et seq.* (2019)<br>Short Title: Shielded Outdoor Lighting Act | Stated purpose: conserve energy and preserve environment.<br>Outdoor lighting fixtures installed using public funds must be shielded *unless* a municipality determines doing so would be cost prohibitive.<br>● Analysis must include cost of fixtures and projected energy cost of operation.<br>Electric public utilities must offer a shielded lighting option to customers. |
| Colorado | Colo. Rev. Stat. §§24-82-901 *et seq.* (2018) | Any new outdoor lighting fixture installed after 1 July 2002 by or on behalf of the state must meet the following requirements:<br>● Fixtures with a greater output than 3200 lumens must be full cutoff luminaires.<br>● Fixtures only emit as much light as is necessary for the intended purpose.<br>● For roadway lighting, it must be shown that the intended purpose *could not* be achieved by other means (ie., reflective markers, warning signs, etc.)<br>● Environmental/energy costs and glare reduction measures must be considered.<br>Subject to exemptions/exceptions. |

295 Luminaire and lighting fixture are used interchangeably. Some statutes define these elements individually, some do not. Generally, a luminaire refers to the lighting unit itself and the lighting fixture refers to any fixed or moveable equipment used to install the luminaire (ie., a streetlight pole).

| | | |
|---|---|---|
| Connecticut | Conn. Gen. Stat. §13a-110a (2019) | State funds may not be used to install or replace a permanent outdoor light fixture on a roadway unless:<br>• It is designed to maximize energy efficiency and minimize light pollution/glare/trespass;<br>• It only emits as much light as is necessary for its intended purpose;<br>• Any fixture with a greater output than 1800 lumens is a full cutoff luminaire; and<br>• It can be shown that the intended purpose *could not* be achieved by other means (ie., reflective markers, warning signs, etc.) |
| | Conn. Gen. Stat. §4b-16 (2019) | State funds may not be used to install or replace a permanent outdoor light fixture on the grounds of any state building unless:<br>• It is designed to maximize energy efficiency and minimize light pollution/glare/trespass;<br>• It only emits as much light as is necessary for its intended purpose; and<br>• Any fixtures with a greater output than 1800 lumens is a full cutoff luminaire. |
| Delaware | Del. Code Ann. Tit. 7, §§7101a *et seq.* (2021) | State funds may not be used to install or replace a permanent outdoor light fixture unless:<br>• It is designed to maximize energy efficiency and minimize light pollution/glare/trespass;<br>• It only emits as much light as is necessary for its intended purpose; and<br>• Any fixture with a greater output than 1800 lumens is a full cutoff luminaire.<br>For roadway lighting, it must be shown that the intended purpose *could not* be achieved by other means (ie., reflective markers, warning signs, etc.). |
| Florida | Fla. Stat. §161.163 (2020) | Model lighting ordinance to guide municipalities in enacting policies to protect sea turtles when hatching. |
| Hawai‘i | HRS § 201-8.5 (2019) | Establishes standards for outdoor lighting:<br>• Outdoor lighting emitting more than 3000 lumens must be fully shielded.<br>• Where lighting is not required to be shielded, it still must meet criteria outlined. |

| | | |
|---|---|---|
| | 2017 Haw. Sess. Law, Act 185 | Establishes a Dark Skies Protection Advisory Committee, comprised of 13 members to evaluate issues relating to light pollution reduction, energy conservation, value associated with dark night skies, protection of endangered species and astronomical efforts, etc.<br>In December 2020 the Committee provided a report to the legislature identifying several issues for further exploration including the replacement of streetlights in Maui with LED lights. However, the Committee stated that it was not yet prepared to produce a full report. |
| Maine | Maine Stat. 5 § 1769 *et. seq.* (2011) | State funds may not be used to install or replace a permanent outdoor light fixture unless:<br>• Any fixtures with a greater output than 1800 lumens is a full cutoff luminaire;<br>• It only emits as much light as is necessary for its intended purpose; and<br>• Consideration is given to minimizing glare and light trespass.<br>Exceptions/exemptions may apply. |
| Maryland | Md. State Finance & Procurement Code Ann. §14-412 (2018) | State funds may not be used to install or replace a permanent outdoor light fixture unless:<br>• It is designed to maximize energy efficiency and minimize light pollution/glare/trespass;<br>• It only emits as much light as is necessary for its intended purpose; and<br>• Any fixture with a greater output than 1800 lumens is a restricted uplight luminaire. |
| Michigan | Mich. Comp. Laws § 324.75101 *et. seq.* (2021) | Designates specific areas as dark sky preserves and limits the installation of lighting in these areas unless required for safety or the reasonable use and enjoyment of the preserve. When lighting is installed it must be fully shielded and directed downward. |
| Minnesota | Minn. Stat. §16B.328 (2020) | Instructs the commissioner of administration to develop a model ordinance governing outdoor lighting with the intent of reducing light pollution. The model ordinance is intended to be utilized by cities, counties, and towns.<br>Prohibits the use of state funds to install or replace an outdoor lighting fixture unless:<br>• It is designed to maximize energy efficiency and minimize light pollution/glare/trespass;<br>• It only emits as much light as is necessary for its intended purpose; and<br>• Any fixture with a greater output than 1800 lumens is a full cutoff luminaire.<br>For roadway lighting, it must be shown that the intended purpose *could not* be achieved by other means (ie., reflective markers, warning signs, etc.). |

| | | |
|---|---|---|
| New Hampshire | N.H. Rev. Stat. Ann. §§9-E:1 *et seq.* (2020) | State funds may not be used to install or replace a permanent outdoor light fixture unless:<br>• It is designed to maximize energy efficiency and minimize light pollution/glare/trespass;<br>• It only emits as much light as is recommended for the intended purpose as outlined by the IES or FHA; and<br>• Any fixture with a greater output than 1800 lumens is a fully shielded fixture.<br>Encourages municipalities to enact local ordinances to conserve energy, minimize light pollution, and preserve dark skies. |
| New Mexico | N.M. Stat. Ann. §§74-12-1 *et seq.* Short Title: Night Sky Protection Act | All outdoor lighting fixtures must be shielded except incandescent fixtures of 150 watts or less or other sources of 70 watts or less. No outdoor recreational facilities may use lighting after 11:00pm with fines for violation. |
| New York | N.Y. Public Buildings Law §143 | State funds may not be used to install or replace a permanent outdoor light fixture or to pay for the operating cost of such fixtures unless:<br>• For roadway or parking lot lighting, the fixture is fully shielded;<br>• For building-mounted fixtures, the fixture is fully shielded if it is greater than 3000 lumens<br>• Façade lighting is shielded; and<br>• For ornamental roadway lighting, the fixture is not greater than 700 lumens above the horizontal plane.<br>Exemptions:<br>• Temporary emergency lighting<br>• Lighting for athletic playing areas (however, fixtures must minimize upward lighting and glare as much as possible)<br>• If a safety or security arises, as determined by the state<br>• For replacement of a previous outdoor fixture<br>• Lighting for tunnels and underpasses<br>• If the cost of implementing compliant fixtures is prohibitive |
| Oregon | Or. Rev. Stat. §455.573 (2019) | Public buildings constructed on or after 1 January 2010 or that have fixtures installed or replaced must use shielded lighting fixtures to the greatest extent possible.<br>Municipalities may require more stringent regulations, and may also waive the above requirement if the building is of a historic nature or for other reasons. |

<table>
<tr><td>Rhode Island</td><td>R.I. Gen. Laws §§42-136-1 et seq. (2020)<br>Short Title: Outdoor Lighting Control Act</td><td>Mandates new or replacement permanent outdoor lighting fixtures by or for a state agency to meet the following requirements:<ul><li>Must consider maximizing energy efficiency and minimizing light pollution.</li><li>New or replacement fixture permits no more than 2% of the total lumens in the zone of 90–180 degrees if the total output is more than 3200 lumens.</li><li>Only emits as much light as is necessary for its intended purpose.</li></ul>For roadway lighting, it must be shown that the intended purpose could not be achieved by other means (ie., reflective markers, warning signs, etc.).</td></tr>
<tr><td>Texas</td><td>Tex. Local Government Code §§240.031 et seq. (2019)</td><td>Instructs commissioners court of a county located within 57 miles of a major astronomical observatory at the McDonald Observatory to adopt orders regulating the installation and use of outdoor lighting. Permits commissioners of court within 5 miles of a major astronomical observatory at the George or Stephen F. Austin State Observatory to adopt orders regulating the installation and use of outdoor lighting at the request of the director of the observatories. Permits commissioners of court to adopt orders regulating the installation and use of outdoor lighting at the request of a military installation, base, or camp commanding officer.</td></tr>
<tr><td></td><td>Tex. Health and Safety Code §§425.001 et seq. (2020)</td><td>Prohibits the use of state funds to install or replace an outdoor lighting fixture unless:<ul><li>It is designed to maximize energy efficiency and minimize light pollution/glare/trespass;</li><li>It only emits as much light as is necessary for its intended purpose; and</li><li>Any fixture with a greater output than 1800 lumens is a full cutoff luminaire.</li></ul>For roadway lighting, it must be shown that the intended purpose could not be achieved by other means (ie., reflective markers, warning signs, etc.)</td></tr>
<tr><td>Virginia</td><td>Va. Code §2.2-1111 (2016)</td><td>Requires that the state only procure shielded outdoor light fixtures and provides waivers for this requirement if the Division determines there is a bona fide reason to do so.</td></tr>
<tr><td>Wyoming</td><td>Wyo. Stat. §37-16-202</td><td>Mandates that electric utilities offer tariffs for utility-provided outdoor lighting that provide an option for customers to choose a lighting fixture designed to minimize illuminating unintended areas and maintain dark skies.</td></tr>
<tr><td>District of Columbia</td><td>D.C. Code Ann. §§8-1776.01 et seq. (2019)</td><td>The Smart Lighting Study Act of 2009 instructed the Department of Energy and Environment to submit a report recommending strategies and standards for optimal lighting methods, taking into account public safety, energy efficiency, cost efficiency, effects on environmental health, and aesthetics. This must include an analysis of IDA and IES standards.</td></tr>
</table>

| | | |
|---|---|---|
| Puerto Rico | P.R. Code §§8031 *et seq.* (2019) Short Title: Program for the Control and Prevention of Light Pollution) | The Environmental Quality Board will approve regulations. Regulates light fixtures installed on private properties:<br>• Colored and decorative lights must have automatic on/off switches.<br>• Lighting systems used for security or to light walkways must use low-pressure sodium emission sources.<br>• Certain lighting systems must be turned off between 11pm and dawn.<br>Makes 1 August Light Pollution Awareness Day |

# Appendix II — 2021 Planetary Defense Conference Hypothetical Asteroid Impact Scenario

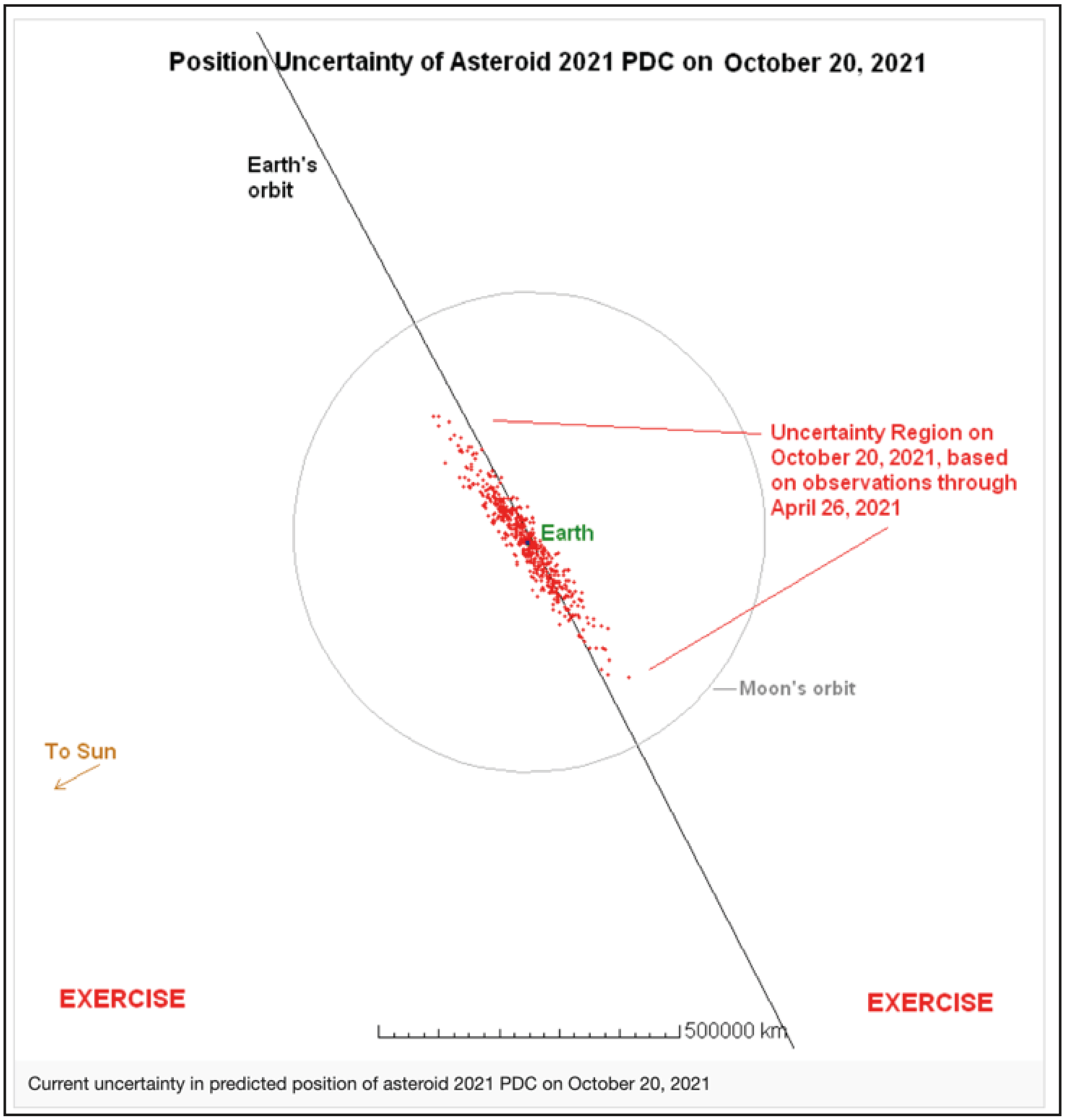


*Figure AII.1. Input to Multi-agency exercise for potential asteroid impact.*

- Asteroid 2021 PDC is discovered by Pan-STARRS and named by the Minor Planet Center on 19 April 2021.

- 20 April 2021: JPL's Sentry impact monitoring system and ESA's CLOMON system identify potential impact dates.
    - Both systems predict possible impact on 20 October 2021 — a short time frame but low probability (1 in 2500).
- Pre-Conference Details
    - Size of 2021 PDC is uncertain: estimated to be ~ 120 meters but could be anywhere between 35 and 700 meters.
    - 2021 PDC continues to approach Earth for 3 weeks but wouldn't be detected on radar until October when it became much closer to impact.
    - As of 26 April — the date of the conference — the probability of impact has reached 5%.
- Over the course of 3 days, participants assessed the data and drafted a briefing detailing the mission options.[296]
    - Day 1 (Setting: 26 April 2021)
    - Day 2 (Setting: 2 May 2021)
        - Newly processed data from Pan-STARRS collected in 2014 shows that 2021 PDC could have been identified up to 7 years earlier. Using these data, astronomers determine that there is 100% certainty that 2021 PDC will make impact in either Europe or north Africa.
    - Day 3 (Setting: 30 June 2021)
        - Shrink impact zone to Czech Republic, Austria, Slovenia, and Croatia.
        - Size remains uncertain but NASA NEOWISE satellite narrows parameters to 35–500 meters.
    - Day 4 (Setting 14 October 2021)
    - Identified likely location of impact as Czech Republic near Germany/Austria border, ~ 300 km.
    - 2021 PDC is close enough that Goldstone System Radar can detect it and determine its size and characteristics.
    - 2021 PDC is smaller than expected, lessening the region of impact.
    - Commence discussions on evacuation of region.

296 https://cneos.jpl.nasa.gov/pd/cs/pdc21/pdc21_day2_briefing2.pdf

# Appendix III — SATCON1 “Regulations”

The following are suggested conditions of licensing for launch and/or operations of a satellite constellation to mitigate the impacts on astronomy.

47 CFR--PART 25

§25.114 Applications for space station authorizations.

(d) The following information in narrative form shall be contained in each application, except space station applications filed pursuant to § 25.122 or § 25.123:

* * * * *

(19) A description of the design and operational strategies that will be used to mitigate interference with Earth surface-based optical and radio observation of space, including the following information:

(i) A statement detailing the manner in which the space station operator has assessed and limited the amount of reflected sunlight occurring during normal operations, with reflected sunlight ideally slowly varying with orbital phase as recorded by high etendue (effective area × field of view), large-aperture ground-based telescopes to be fainter than 7.0 $V_{mag}$ +2.5 × log($_{rorbit}$ / 550 km), equivalent to 44 × (550 km / $r_{orbit}$) watts/steradian.

(A) The statement must include the extent to which the satellite operator considered:

(1) Satellite darkening;

(2) Sun shielding; and,

(3) Avoiding non-rigid specular materials on the nadir face of the satellites to reduce false transients.[297]

(B) Where applicable, this statement must include a reflected sunlight mitigation disclosure for any separate deployment devices, distinct from the space station launch vehicle, that may become a source of reflected sunlight;[298]

(ii) A statement that the space station operator has assessed and limited the probability that the space station(s) will become a source of specular reflection (flares) in the direction of observatories. Space station operators must make their best effort to avoid such flares. However, if such flares will occur, accurate timing information from ground-based observing must be required to enable observatories an opportunity for planned avoidance. The statement must indicate whether this probability for an individual space station is 0.01 (1 in 100) or less, and indicate the means by which such calculation

297 SATCON1 4.
298 SATCON1 Recommendation 5.

has been obtained;[299]

(iii) A statement detailing the manner in which the space station operator has assessed and limited reflected light on the ground track by adjusting space station attitudes. The statement should indicate when and how the space station operator has the capability to adjust its space station attitudes.[300]

(iv) A statement that the space station operator has assessed and planned satellite proximity configuration to facilitate pointing avoidance by observatories, with the understanding that this can be most readily achieved if the immediate post-launch satellite formation is configured as tightly as possible consistent with safety and orbital debris mitigation requirements such that the orbit raise affords rapid passage of the train through a given pointing area;[301]

(v) A statement detailing the manner in which the space station operator shall ensure observatories obtain the information needed for pointing avoidance, with specific reference to the provision of updated positional information or processed telemetry;

(vi) A statement whether the satellite operator has engaged in any efforts to support coordinated efforts for optical observations of constellation space stations in LEO, to characterize both slowly and rapidly varying reflectivity and the effectiveness of experimental mitigations.[302]

(vii) A statement whether the satellite operator has engaged in any efforts to support a comprehensive satellite constellation observing network with uniform observing and data reduction protocols for feedback to operators and astronomical programs.[303]

(viii) For operators of space station constellations, a statement that the space station operator has assessed the ability to limit the number of space stations to the minimum number of units needed for bandwidth and coverage requirements and maintain their operational orbits below 600km to mitigate adverse effects on Earth surface-based optical and radio observation of space. Where the space station operator has not implemented such limits on units or orbit altitude, the space station operator shall explain in sufficient detail the calculations and needs that support such decision.

(ix) For operators of space station constellations, a statement that the space station operator has implemented measures to ensure ongoing provision of ephemerides information for all constellation space stations in a public database to sufficient accuracy.

(A) For purpose of this requirement, sufficient accuracy shall mean information that enables the transit of any unit across the field during the exposure interval to be predicted:

(1) To be predicted within 12 hours in advance of the observation, to an accuracy of 10 seconds in time, as well as the position of the track to within 12

299 SATCON1 Recommendation 6.
300 *Id.*
301 SATCON1 Recommendation 7.
302 SATCON1 Recommendation 8.
303 Id.

arcminutes in the cross-track direction and 12 arcminutes in position angle;[304] and,

(2) For a given position on the sky and given start and end times for an exposure, can be predicted within 12 hours in advance of the observation to an accuracy of 2 seconds in time and the position of the track to 6 arcminutes in the cross-track direction and 6 arcminutes in position angle.[305]

(x) For operators of space stations in LEO orbit, a statement that the space station operator has performed adequate laboratory Bi-directional Reflectance Distribution Function (BRDF) measurements and a reflectance simulation analysis as part of the satellite design and development phase.[306]

(xii) For non-US-licensed space stations, the requirement to describe the design and operational strategies to minimize Earth surface-based optical and radio observation of space can be satisfied by demonstrating that mitigation plans for the space station(s) for which US market access is requested are subject to direct and effective regulatory oversight by the national licensing authority.

§25.122 Applications for streamlined small space station authorization.

* * * * *

(c) Applicants filing for authorization under the streamlined procedure described in this section must include with their applications certifications that the following criteria will be met for all space stations to be operated under the license:

* * * * *

(15) The space station(s) will operate only in non-geostationary orbit;

(i) A statement detailing the manner in which the space station operator has assessed and limited the amount of reflected sunlight occurring during normal operations, with reflected sunlight ideally slowly varying with orbital phase as recorded by high etendue (effective area × field of view), large-aperture ground-based telescopes to be fainter than 7.0 $V_{mag}$ +2.5 × log($r_{orbit}$ / 550 km), equivalent to 44 × (550 km / $r_{orbit}$) watts/steradian.

(A) The statement must include the extent to which the satellite operator considered:

(1) Satellite darkening;

(2) Sun shielding; and,

(3) Avoiding non-rigid specular materials on the nadir face of the satellites to reduce false transients.[307]

(B) Where applicable, this statement must include a reflected sunlight mitigation disclosure for any separate deployment devices, distinct from the space

304 SATCON1, C.1.
305 Id.
306 SATCON1 Recommendation 4.
307 SATCON1 4.

station launch vehicle, that may become a source of reflected sunlight;[308]

(ii) A statement that the space station operator has assessed and limited the probability that the space station(s) will become a source of specular reflection (flares) in the direction of observatories. Space station operators must make their best effort to avoid such flares. However, if such flares will occur, accurate timing information from ground-based observing must be required to enable observatories an opportunity for planned avoidance. The statement must indicate whether this probability for an individual space station is 0.01 (1 in 100) or less, and indicate the means by which such calculation has been obtained;[309]

(iii) A statement detailing the manner in which the space station operator has assessed and limited reflected light on the ground track by adjusting space station attitudes. The statement should indicate when and how the space station operator has the capability to adjust its space station attitudes.[310]

(iv) A statement that the space station operator has assessed and planned satellite proximity configuration to facilitate pointing avoidance by observatories, with the understanding that this can be most readily achieved if the immediate post-launch satellite formation is configured as tightly as possible consistent with safety and orbital debris mitigation requirements such that the orbit raise affords rapid passage of the train through a given pointing area;[311]

(v) A statement detailing the manner in which the space station operator shall ensure observatories obtain the information needed for pointing avoidance, with specific reference to the provision of updated positional information or processed telemetry;

(vi) A statement whether the satellite operator has engaged in any efforts to support coordinated efforts for optical observations of constellation space stations in LEO, to characterize both slowly and rapidly varying reflectivity and the effectiveness of experimental mitigations.[312]

(vii) A statement whether the satellite operator has engaged in any efforts to support a comprehensive satellite constellation observing network with uniform observing and data reduction protocols for feedback to operators and astronomical programs.[313]

(x) A statement that the space station operator has performed adequate laboratory Bi-directional Reflectance Distribution Function (BRDF) measurements and a reflectance simulation analysis as part of the satellite design and development phase.[314]

---

308 SATCON1 Recommendation 5.
309 SATCON1 Recommendation 6.
310 *Id.*
311 SATCON1 Recommendation 7.
312 SATCON1 Recommendation 8.
313 Id.
314 SATCON1 Recommendation 4.

# Acronyms & Abbreviations

| Acronym/ abbreviation | Meaning | First appears on page |
|---|---|---|
| | | |
| **OBSERVATIONS chapter** | | |
| AO | adaptive optics | 27 |
| BRDF | Bidirectional Reflectance Distribution Function | 20 |
| COPUOS | (UN) Committee on the Peaceful Uses of Outer Space | 18 |
| D&QS Report | Dark & Quiet Skies Report | 3 |
| EIRP | effective isotropic radiated power | 20 |
| FCC | Federal Communications Commission | 18 |
| IAU | International Astronomical Union | 3 |
| ITU | International Telecommunications Union | 18 |
| LEO | low-Earth orbit | 1 |
| LEOsat | LEO satellite | 1 |
| NIR | near-infrared | 2 |
| OEM | orbit ephemeris message | 19 |
| OMM | Orbit Mean-elements Message | 24 |
| STK | Systems Tool Kit | 26 |
| TLE | two-line element | 2 |
| WCS | World Coordinate System | 9 |
| | | |
| **ALGORITHMS chapter** | | |
| 18SPCS | US Space Force 18th Space Control Sqn. | 20 |
| API | applications programming interface | 13 |
| BRDF | bidirectional reflectance distribution function | 17 |
| CADC | Canadian Astronomy Data Centre | 12 |
| ESA | European Space Agency | 12 |
| GNSS | Global Navigation Satellite System | 22 |
| GPU | Graphics Processing UNit | 17 |
| ICRS | International Celestial Reference System | 6 |
| ILRS | International Laser Ranging Service | 20 |
| ITC | International Telecommunications Corporation | 22 |

| | | |
|---|---|---|
| IVOA | International Virtual Observatory Alliance | 5 |
| JSON | software protocol | 17 |
| LEO | low-Earth orbit | 3 |
| TAP | Table Access Protocol | 17 |
| TLE | two-line element | 19 |
| WCS | World Coordinate System | 6 |
| ITRF | International Terrestrial Reference Frame | 20 |
| CCSDS | Consultative Committee for Space Data Systems | 22 |
| | | |
| **COMMUNITY ENGAGEMENT chapter** | | |
| AAS | American Astronomical Society | 6 |
| AAVSO | American Association of Variable Star Observers | 21 |
| IPS | International Planetarium Society | 40 |
| LEO | low-Earth orbit | 2 |
| LIPS | Live Interactive Planetarium Symposium | 39 |
| NEPA | National Environmental Policy Act | 5 |
| OST | Outer Space Treaty | 5 |
| UNOOSA | UN Office of Outer Space Affairs | 43 |
| FCC | Federal Communications Commission | 44 |
| IAU | International Astronomical Union | 6 |
| EO | Earth Observation | 47 |
| | | |
| **POLICY Chapter** | | |
| AAS | American Astronomical Society | 5 |
| AP | National NEO Preparedness Strategy and Action Plan | 28 |
| ATLAS | Asteroid Terrestrial-impact Last Alert System | 41 |
| BRDF | Bi-directional Reflectance Distribution Function | 102 |
| CBD | Convention on Biological Diversity | 60 |
| CE | Categorical Exclusion | 48 |
| CEQ | Council on Environmental Quality | 8 |
| CNEOS | Center for Near Earth Object Studies | 41 |
| COPUOS | (UN) Committee on the Peaceful Uses of Outer Space | 4 |
| COSPAR | Committee On Space Research | 29 |
| CSLA | Commercial Space Launch Act | 23 |

| | | |
|---|---|---|
| EIA | Environmental Impact Assessment | 48 |
| EOL | end of life | 10 |
| EPFD | Equivalent Power Flux Density | 99 |
| FAA | Federal Aviation Administration | 7 |
| FCC | Federal Communications Commission | 7 |
| FEMA | Federal Emergancy Management Agency | 39 |
| GSO | geostationary orbit | 25 |
| IAA | International Academy of Astronautics | 42 |
| IAU | International Astronomical Union | 9 |
| IAWN | International Asteroid Warning Network | 27 |
| IDA | International Dark Sky Association | 31 |
| IES | Illuminating Engineering Society | 31 |
| IRTF | Infrared Telescope Facility | 41 |
| ITU | International Telecommunications Union | 25 |
| LEO | low-Earth orbit | 12 |
| LRTAP | Convention on Long-Range Transboundary Air Pollution | 66 |
| LTSG | Guidelines for the Long-Term Sustainability lof Outer Space Activities | 7 |
| MANOS | Mission Accessible Near-Earth Objects Survey | 41 |
| MLO | Model Lighting Ordinance | 31 |
| NASA | National Aeronautics and Space Administration | 23 |
| NEO | near-Earth object | 27 |
| NEOWISE | NEO Wide-field Infrared Survey Explorer | 41 |
| NEPA | National Environmental Policy Act | 7 |
| NOAA | National Oceanic & Atmospheric Administration | 7 |
| NPS | National Park Service | 36 |
| NRAO | National Radio Astronomy Observatory | 44 |
| NRQZ | US National Radio Quiet Zone | 44 |
| NSF | National Science Foundation | 11 |
| ODMSP | Orbital Debris Mitigation Standard Practices | 10 |
| OST | Outer Space Treaty | 4 |
| PDCO | [NASA] Planetary Defense Coordination Office | 39 |
| PIERWG | Planetary Impact Emergency Response Working Group | 40 |
| PP | precautionary principle | 58 |

| | | |
|---|---|---|
| PPD | (AAS) Public Policy Department | 90 |
| PPP | planetary protection policy | 3 |
| RQZ | Radio Quiet Zone | 7 |
| SIA | Satellite Industry Association | 91 |
| SMPAG | Space Mission Planning Advisory Group | 27 |
| SPD | Space Policy Directive | 21 |
| STM | space traffic management | 7 |
| TLE | two-line element | 103 |
| UN | United Nations | 4 |
| UNDRIP | UN Declaration on the Rights of Indigenous Peoples | 8 |
| UNESCO | United Nations Educational, Scientific and Cultural Organization | 85 |
| UNFCCC | UN Framework Convention on Climate Change | 60 |
| UNOOSA | UN Office of Outer Space Affairs | 27 |
| US NSPP | National Strategy for Planetary Protection | 30 |
| VCPOL | Vienna Convention for the Protection of the Ozone Layer | 59 |