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The Negative Impacts of Light Pollution Caused by Satellite Mega-Constellations on the Environment and the Approach of International Space Law to the Issue

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Abstract: This study examines the environmental impacts of light pollution caused by satellite mega-constellations and the approach of international space law to this issue. The research analyses the technical impacts of satellite constellations on astronomical observations, wildlife, and cultural heritage from a technical perspective. The study demonstrates that satellite-reflected light significantly affects both professional and amateur astronomical observations, disrupts natural behaviour patterns of migratory birds and sea turtles, and threatens traditional celestial practices of indigenous communities. Within the framework of international law, the study presents solution proposals in light of the environmental protection provisions of the 1967 Outer Space Treaty and fundamental environmental law principles established in international court decisions. The research concludes that states must conduct environmental impact assessments for space activities, establish minimum environmental standards to eliminate light pollution caused by satellite constellations, and promote international cooperation through UNOOSA to address these challenges. The study emphasizes the importance of balancing technological advancement with environmental preservation and cultural heritage protection.
Keywords: Light pollution, Satellite mega-constellations, Space law

I. INTRODUCTION

It has been observed that discussions regarding the negative impacts of satellite mega-constellations, which are placed in Earth's orbit by the satellite sector for various purposes, have begun to emerge. The International Astronomical Union (IAU) defines satellite mega-constellations as “a series of satellites of similar type and function, designed to operate in similar, complementary orbits under shared control for a common purpose” [1]. Satellite mega-constellations are typically deployed in Low Earth Orbit (LEO) to provide communication services in areas where such services are inadequate or nonexistent. The satellite flares, which occur due to the reflection of sunlight by these satellites, can be seen with the naked eye from the Earth's surface. The rapid increase in the number of satellites raises concerns about the threat to dark and radio-quiet skies, as expressed by the IAU. In fact, in a statement published on June 3, 2019, the IAU officially brought this issue to the attention of the international public, highlighting the negative effects on humanity and nocturnal wildlife, and encouraging researchers to conduct studies on the threats posed by satellite flares to the Earth's environment [2]. Similarly, the publication of research reports by various international organizations on this issue underscores its significance. This study will address the technical damages caused by satellite flares to the Earth's environment, examine the approach of international space law to this issue, and present some recommendations.

II. TECHNICAL EXPLANATION OF THE NEGATIVE EFFECTS OF LIGHT POLLUTION CAUSED BY SATELLITE MEGA-CONSTELLATIONS

The rapid proliferation of satellite mega-constellations in low Earth orbit (LEO) presents unprecedented challenges for astronomy, wildlife, and cultural heritage. While smallsats and satellite mega-constellations can be viewed as innovative disruptions to the traditional satellite industry, they also contribute significantly to orbital congestion and threaten the traditional societal and scientific values of dark and quiet skies [3]. Currently, mega-constellations like SpaceX's Starlink operate over 6764 satellites simultaneously, with plans for dramatic expansion [4].

The environmental and scientific impacts of these mega-constellations manifest in two primary ways: First, the satellites illuminate the night sky with unnatural light, making both professional and recreational astronomical observations increasingly difficult. Studies have shown that still an important portion of astronomical images are disrupted by satellite trails, even after attempts to reduce satellite visibility [5]. This light pollution poses particular challenges for sensitive instruments like the Vera C. Rubin Observatory's Legacy Survey of Space and Time (LSST), described as "the widest, fastest, and deepest view of the night sky ever observed" [6]. Second, radio frequency interference (RFI) from these constellations adds obtrusive "noise" to sensitive astronomical measurements in the radio portion of the electromagnetic spectrum [7]. This interference can either contaminate signals from celestial sources or be mistakenly identified as celestial signals themselves [8]. The scale of this challenge is set to increase dramatically, as scientists predict the growing commercial space sector will add more than 100,000 satellites to Earth's orbit by the end of the decade [9]. This expansion occurs against a backdrop of existing concerns about space debris, with trackable space debris already exceeding 35,000 objects [10]. While these mega-constellations aim to provide valuable services like global internet connectivity, their deployment raises fundamental questions about balancing technological progress with environmental and scientific preservation. The International Dark Sky Association (IDA) notes that dark skies are increasingly recognized as a limited natural resource requiring protection, similar to clean air and water [11]. This recognition has led to increased international attention, exemplified by recent joint efforts between the United Nations Office of Outer Space Affairs (UNOOSA) and International Astronomical Union (IAU) on "Dark and Quiet Skies for Science and Society" [12].

This study examines the complex interplay between satellite mega-constellations and dark sky preservation, analyzing current regulatory frameworks, environmental impacts, and potential mitigation strategies. The analysis draws on established legal precedents, scientific research, and ethical considerations to propose balanced approaches for preserving both technological advancement and our natural night sky heritage.

A. Impact of Constellations on Astronomy and Scientific Research

The impact of satellite mega-constellations on astronomical research represents one of the most significant challenges facing modern observational astronomy. These impacts manifest across multiple wavelengths and observing techniques, affecting both ground-based and space-based astronomy in unprecedented ways [13].

1) Classification of Adverse Effects on Astronomy and Scientific Research

a) Ground-Based Optical Astronomy Impacts

The most immediate and visible impact occurs in optical astronomy. When SpaceX launched its first 60 Starlink satellites in May 2019, astronomers worldwide reported significant disruptions to their observations. Initial studies revealed that 15-20% of twilight observations at the Zwicky Transient Facility were impacted by satellite trails [14]. These bright streaks not only contaminate scientific images but can also saturate sensitive astronomical detectors, potentially causing permanent damage to expensive equipment [15].

The Vera C. Rubin Observatory, representing a $473 million investment in next-generation astronomy, faces particular challenges. This facility's Legacy Survey of Space and Time (LSST) project, designed to create the most comprehensive astronomical survey ever conducted, is especially vulnerable due to its wide field of view and sensitive detectors [16]. Studies indicate that:

- Up to 30% of all LSST exposures could be affected by satellite trails during twilight hours [17].
- Each satellite trail can affect up to 0.01% of a detector's pixels, leading to significant data loss in long-exposure images [18].
- The observatory's ability to detect near-Earth asteroids, crucial for planetary defense, could be compromised by satellite interference [17].

b) Radio Astronomy Interference

Beyond optical impacts, satellite mega-constellations pose significant challenges for radio astronomy. Modern radio telescopes are designed to detect extremely faint signals from distant celestial objects, making them particularly susceptible to interference from satellite communications [7]. Specific concerns include:

- Direct interference from satellite downlink transmissions
- Out-of-band emissions affecting protected radio astronomy bands
- Cumulative effects of multiple satellites operating simultaneously [20]

The Square Kilometre Array (SKA), currently under construction and set to be the world's largest radio telescope, faces particular challenges from these constellations. Studies indicate that satellite transmissions could exceed harmful interference thresholds by several orders of magnitude [19].

c) Impact on Specific Research Areas

Several critical research areas face particular challenges:

- Time-Domain Astronomy: Studies of transient phenomena like supernovae and gravitational wave events require immediate observation capabilities, which can be compromised by satellite interference [13].
- Wide-Field Surveys: Large-scale astronomical surveys, crucial for understanding dark energy and cosmic structure, are particularly vulnerable due to their broad field of view [20].
- Near-Earth Object Detection: Programs designed to identify potentially hazardous asteroids face increased difficulty in distinguishing between satellites and actual astronomical objects [15].

2) Mitigations Efforts and Their Limitations to Reduce the Negative Effects of Constellations on Astronomy and Scientific Research:

While satellite operators have implemented various mitigation strategies, including:

- DarkSat coating to reduce reflectivity
- VisorSat technology to block sunlight
- Operational altitude adjustments

These efforts have shown limited success, with satellites remaining visible to both professional and amateur astronomers [14]. The International Astronomical Union notes that even with these measures, the cumulative effect of thousands of satellites poses an unprecedented challenge to ground-based astronomy [21].

B. Environmental and Wildlife Impacts o Satellite Mega-Constellations

The environmental impacts of satellite mega-constellations extend far beyond astronomical concerns, creating complex and often understudied effects on various ecosystems and wildlife behaviors that have evolved under natural darkness conditions [22]. The artificial brightening of the night sky through these constellations poses significant challenges to numerous species that depend on natural darkness for their survival and behavioral patterns.

Navigation and migration represent one of the most critical areas impacted by satellite-based light pollution. Many bird species, particularly the North American Indigo Bunting and European Robin, utilize star patterns for navigation, especially in situations where magnetic field readings prove unreliable [23]. Scientific studies have demonstrated that migratory birds can become disoriented by artificial light sources, potentially leading to collision events and disrupted migration patterns [24]. This vulnerability is particularly pronounced among nocturnal migrants, who rely heavily on celestial cues during their long-distance journeys [25].

Marine ecosystems face similar challenges, with sea turtle hatchlings particularly affected. These creatures rely on the reflection of moonlight and starlight on water surfaces for orientation [26]. The presence of artificial light sources, including bright satellites, can disorient hatchlings, leading them away from the ocean and significantly increasing mortality rates [27]. Additionally, marine plankton exhibit vertical migration patterns based on natural light levels, which artificial lighting can severely disrupt [28].

Perhaps most surprisingly, insects demonstrate remarkable abilities to navigate by celestial bodies. The South African dung beetle has been scientifically proven to navigate using the Milky Way, despite its relatively poor eyesight [29]. This discovery suggests that stellar navigation might be more widespread in the insect world than previously understood. The implications of satellite interference with these natural navigation systems could be far-reaching, as many species may possess similar abilities that have yet to be documented [30]. The introduction of artificial light from satellite mega-constellations creates cascade effects throughout ecosystems. These impacts manifest in altered predator-prey relationships, disrupted breeding patterns, and changes in natural photoperiods affecting plant life [31]. Studies indicate that artificial light can affect plant flowering times and growth patterns, while also disrupting pollinator behavior and consequently impacting plant reproduction [32].

The cumulative environmental effects of satellite mega-constellations, combined with other forms of light pollution, create complex environmental challenges. Satellite albedo (reflectivity) contributes to sky brightness, potentially impacting atmospheric chemistry and upper atmosphere composition [33]. Furthermore, artificial light creates barriers for nocturnal species movement, making natural dark sky corridors increasingly rare and potentially compromising ecosystem connectivity [34].

Current understanding of these environmental impacts faces several limitations. The relatively recent nature of mega-constellations means long-term effects are not yet fully understood, and baseline data for many species' responses to artificial light is lacking [35]. Additionally, there are significant challenges in measuring and quantifying specific impacts on wildlife, as well as isolating satellite-based light pollution from other sources [31].

C. Cultural and Heritage Impacts of Satellite Mega-Constellations

The proliferation of satellite mega-constellations presents significant challenges to cultural heritage, particularly affecting indigenous astronomical practices and traditional knowledge systems that have been maintained for millennia. These impacts extend beyond mere visibility issues, touching upon fundamental aspects of cultural identity, traditional practices, and indigenous rights [36].

Indigenous astronomical knowledge systems represent sophisticated understanding of celestial phenomena that have been developed and refined over thousands of years. Aboriginal Australians, for instance, have developed complex systems that use stars for navigation, food economics, weather forecasting, and seasonal change prediction. These celestial references also serve crucial roles in social structure organization and act as powerful mnemonics for preserving and transmitting cultural knowledge across generations [36]. The increasing presence of artificial satellites threatens these traditional practices by altering the very sky maps that indigenous peoples have relied upon for countless generations.

The Torres Strait Islander peoples provide a compelling example of how celestial knowledge integrates with daily life and cultural practices. Their traditional calendar system, based on stellar positions and movements, determines crucial activities such as planting times, hunting seasons, and ceremonial occasions [36]. The interference with clear night sky observation directly impacts their ability to maintain these traditional practices and pass this knowledge to future generations. This disruption represents not merely an inconvenience but a fundamental threat to cultural continuity and traditional ways of life [36].

The impact on cultural heritage extends beyond indigenous communities to affect various traditional practices worldwide. Many cultures have developed sophisticated astronomical traditions that inform agricultural practices, navigation systems, and spiritual beliefs. For instance, Polynesian wayfinders have historically relied on detailed stellar navigation techniques for ocean voyaging, a practice that becomes increasingly challenging with the proliferation of artificial satellites [37].

The interference with indigenous celestial observation has been noted by scholars as a contemporary instance of colonial expansion, albeit in a new frontier. This perspective emphasizes how satellite mega-constellations, despite their global benefits, can perpetuate historical patterns of technological advancement at the expense of indigenous rights and cultural practices [36]. The situation raises important questions about environmental justice and the equitable distribution of technological benefits versus cultural costs.

Traditional knowledge systems often incorporate complex understanding of environmental relationships that modern science is only beginning to appreciate. These systems frequently integrate astronomical observations with ecological knowledge, creating sophisticated calendars that guide sustainable resource management practices. The disruption of these observation-based systems can have cascading effects on traditional environmental management practices and cultural continuity.

The international legal framework has begun to recognize the importance of protecting cultural heritage rights, including those related to astronomical knowledge. The United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP) specifically acknowledges indigenous peoples' rights to maintain and protect their cultural heritage, though the application of these principles to satellite mega-constellations remains unclear [12]. Some scholars argue that the current regulatory framework inadequately addresses the cultural heritage impacts of satellite proliferation [38].

Efforts to mitigate these cultural impacts face significant challenges. While some satellite operators have implemented measures to reduce satellite visibility, these efforts primarily focus on professional astronomical observations rather than cultural heritage concerns [21]. The development of effective mitigation strategies requires meaningful consultation with affected communities and recognition of traditional knowledge systems as valid and valuable ways of understanding the night sky [36].

III. LEGAL RECOMMENDATIONS AGAINST LIGHT POLLUTION CAUSED BY SATELLITE FLARES WITHIN THE FRAMEWORK OF INTERNATIONAL SPACE REGULATIONS

It is evident that states take measures to protect the environment through regulations made under their national laws. However, in the case of environmental issues that transcend national borders, such as the high seas, Antarctica, and outer space, the protection of the environment falls under the purview of international law [39,40]. The objective of environmental protection is addressed in international treaties and customary rules.

Additionally, decisions made by international organizations that establish flexible rules of international law regarding protected environmental areas include regulations on this matter. Furthermore, fundamental principles of environmental law are expressed in international judicial decisions related to environmental law.

This section of our study aims to examine the issue of light pollution caused by satellite flares as an environmental law problem within the framework of international legal sources.

A. Identification of Fundamental Principles of Environmental Law in International Court Decisions

It can be observed that fundamental principles of international environmental law have been identified in certain international court decisions. One notable case is the Trail Smelter case [41]. In the ruling of the Arbitration Tribunal regarding this case, the existence of a rule stating that a state must not cause harm to neighbouring states due to activities within its territory was recognized for the first time in international law [41]. Additionally, this ruling references the principle of cooperation, which is one of the fundamental principles of environmental law. Under this principle, it is emphasized that states must resolve transboundary environmental issues through cooperation [40,42]. Another case where fundamental principles of environmental law were identified is the Corfu Channel case before the International Court of Justice [43]. The ruling in this case states that states are under an obligation not to allow actions and activities that knowingly violate the rights of other states [39,40,42]. In the ruling of the Arbitration Tribunal in the Lake Lanoux case [44], it was accepted as a principle that a state would be held responsible if transboundary waters entering its territory were polluted by a neighbouring state [40]. In the Nuclear Tests case between New Zealand and France in 1995 [45], the International Court of Justice recognized that states are under an obligation to conduct environmental impact assessments based on a widely accepted international practice before carrying out nuclear tests. In the Gabcikovo-Nagymaros case [40,46], it was observed that environmental impact assessments for transboundary activities affecting the environment have become part of international law. In fact, this environmental impact assessment is defined as a process that encompasses all stages of a project, not just the preliminary phases, and is considered a concept that states are obliged to comply with under customary law [47].

B. Examination of Light Pollution Caused by Satellite Flares in International Space Treaties

In addition to the fundamental principles of environmental law identified in international court decisions, this section will examine the international legal rules regulating states' activities in outer space, particularly in relation to the protection of the environment, as part of our main argument. The fundamental normative structure of space law is based on five key international treaties. The process of regulating space law through international treaties—corpus juris spatialis internationalis—began with the United Nations General Assembly resolution 1962 (XVIII) titled "Legal Principles Governing the Activities of States in the Exploration and Use of Outer Space," adopted on December 13, 1963. The fundamental space law treaties currently in force, prepared by the Committee on the Peaceful Uses of Outer Space (COPUOS) and adopted by the UN General Assembly, are the Outer Space Treaty of 1967 [48], the Rescue and Return Agreement of 1968 [49], the Liability Convention of 1972 [50], the Registration Convention of 1976 [51], and the Moon Agreement of 1979 [52,53]. Within these fundamental treaties of space law, there are both direct and indirect provisions regarding the protection of the environment during space activities. It is observed that the regulations relevant to the issue of light pollution caused by satellite flares are found in the Outer Space Treaty of 1967 [54]. Indeed, although indirectly, the Rescue and Return Agreement of 1968, the Liability Convention of 1972, and the Registration Convention of 1976 do not contain direct provisions regarding environmental protection [55]. The Moon Agreement of 1979, however, includes provisions concerning the protection of the environment in the context of lunar exploration and use. Specifically, Article 7(1) of the Moon Agreement states: "In exploring and using the moon, States Parties shall take measures to prevent the disruption of the existing balance of its environment whether by introducing adverse changes in that environment, by its harmful contamination through the introduction of extra-environmental matter or otherwise. States Parties shall also take measures to avoid harmfully affecting the environment of the earth through the introduction of extraterrestrial matter or otherwise." As can be understood from this provision, since the Moon Agreement regulates the protection of the environment in the context of activities related to the use and exploration of the Moon, the provisions of the Agreement do not include regulations concerning the issue of satellite flares.

The Outer Space Treaty, adopted based on the UN General Assembly resolution 1962 (XVIII) titled "Declaration of Legal Principles Governing the Activities of States in the Exploration and Use of Outer Space," which was unanimously accepted by the United Nations General Assembly on December 13, 1963, establishes the fundamental rules for space activities [56]. Article 1 of the Outer Space Treaty outlines the following fundamental principles for the exploration and use of outer space, including the Moon and other celestial bodies:

1) Activities in the exploration and use of outer space, including the Moon and other celestial bodies, shall be conducted for the benefit and in the interest of all countries, without discrimination [57].
2) Outer space, including the Moon and other celestial bodies, shall be open to exploration and use by all states on the basis of equality and in accordance with international law; states shall have access to all parts of celestial bodies.
3) Scientific investigations in outer space, including the Moon and other celestial bodies, shall be free. States are under an obligation to facilitate and promote international cooperation in these investigations.

Article 1 of the Outer Space Treaty establishes the necessity for states to conduct their exploration, use, and scientific research activities in outer space, including the Moon and other celestial bodies, in compliance with the rules established by international law and with regard to the benefit and interests of humanity. In this context, it is evident that states are under an obligation to act in accordance with the fundamental principles of environmental protection adopted in international court decisions and to ensure environmental sustainability as required by the interests of all humanity [58].

In parallel with the provisions of Article 1 of the Outer Space Treaty, Article 3 also imposes an indirect obligation on states conducting activities in outer space regarding environmental protection. According to this article, “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 cooperation and understanding.” This provision expresses the necessity for states to conduct their exploration, use, and related activities in outer space in accordance with the UN Charter and international law. As in Article 1 of the Treaty, it is reiterated that states must observe the fundamental principles of environmental protection established by international law in their activities in outer space [55].

Today, it is observed that space activities are predominantly carried out by private enterprises rather than states. The international responsibility of states for the activities conducted by private enterprises is regulated in Article 6 of the Outer Space Treaty, which allows and continuously supervises these activities [56]. Within this framework, states that grant permission to private enterprises to conduct space activities in accordance with their national legislation and continuously supervise these activities must also incorporate the standards of their obligations regarding environmental protection derived from international law into their national laws.

In the second sentence of Article 9 of the Outer Space Treaty, a specific obligation regarding environmental protection is imposed on states conducting activities in outer space. According to this provision, “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.” This provision imposes a general obligation on states to protect the space environment while also requiring them to conduct their activities in a manner that prevents adverse changes resulting from the introduction of extra-terrestrial matter to Earth and to take appropriate measures when necessary. The determination of the content of the appropriate measures to be taken by states conducting activities in outer space is left to their discretion [38,55].

IV. CONCLUSIONS

The proliferation of satellite mega-constellations represents one of the most significant anthropogenic alterations to our night sky, creating unprecedented challenges that span scientific, environmental, and cultural domains. The evidence presented throughout this study demonstrates the complex and interconnected nature of these impacts, requiring immediate attention and comprehensive solutions. The astronomical community faces substantial challenges from these satellite mega-constellations, with studies showing significant disruption to both professional and amateur observations. The documented interference with up to 20% of twilight observations at major facilities represents not merely an inconvenience, but a fundamental threat to our ability to conduct crucial astronomical research. The Vera C. Rubin Observatory's experience particularly highlights how even the most advanced astronomical facilities cannot fully mitigate these impacts, potentially compromising our ability to detect near-Earth objects and study transient celestial phenomena. Environmental impacts present equally pressing concerns, as emerging research reveals the complex ways in which artificial satellite brightness affects wildlife behaviour and ecosystem functions. The documented effects on species ranging from migratory birds to marine life demonstrate the far-reaching consequences of satellite-based light pollution. The South African dung beetle's ability to navigate by starlight serves as a compelling example of how celestial observation capabilities exist throughout the natural world, suggesting that the full scope of impacts on wildlife may be far greater than currently understood. The cultural heritage implications of satellite mega-constellations are particularly profound. Indigenous communities worldwide have developed sophisticated astronomical knowledge systems over millennia, using celestial observations for navigation, resource management, and cultural practices. The disruption of these traditional practices represents not merely a loss of cultural heritage but threatens the very transmission of knowledge that has sustained communities for generations.

Current mitigation efforts, while representing important first steps, have proven insufficient to fully address these challenges. Despite technological improvements such as darkening treatments and operational adjustments, satellites remain visible to both professional instruments and the naked eye. The cumulative effect of thousands of satellites, even with reduced brightness, continues to alter humanity's relationship with the night sky in unprecedented ways.

Looking forward, the trajectory of satellite mega-constellation deployment suggests these challenges will only intensify. With projections indicating the potential for over 100,000 satellites in orbit by the end of the decade, the urgency of addressing these impacts cannot be overstated. The scientific community's ability to conduct crucial research, wildlife's capacity to maintain natural behaviors, and indigenous peoples' right to maintain cultural practices all hang in the balance.

The path forward requires a fundamental reconsideration of how we value and protect the night sky as a shared natural and cultural resource. While the benefits of global connectivity are significant, they must be weighed against the collective costs to scientific discovery, environmental health, and cultural heritage. The night sky, as humanity's common heritage, demands protection that balances technological advancement with preservation of the natural environment and cultural traditions that have sustained human civilization throughout its history.

The concerns raised in this technical analysis highlight the necessity of addressing the issue of light pollution caused by team satellites, which harms the Earth's environment, through the rules of international law. In accordance with the fundamental environmental principles identified in the decisions of international judicial bodies regarding environmental protection, as well as the provisions of the 1967 Outer Space Treaty, which is the fundamental treaty of space law and contains provisions directly related to environmental protection, specifically Articles 1, 3, 6, and 9, states operating in space through team satellites must act in the interest and benefit of humanity and comply with the treaty and customary rules of international law concerning the environment.

In this context, states must establish minimum environmental standards to eliminate light pollution caused by team satellites when granting permission for space activities under their national laws and while continuously monitoring those engaged in such activities. The evaluation of the environmental impacts of activities conducted with team satellites in the space area allocated to humanity by the Outer Space Treaty should be given a legal basis in national laws. The environmental impact assessments obtained should be shared through necessary international initiatives under the coordination of UNOOSA, in line with the principle of international cooperation, to allow for broader consultation among states regarding the activity.

REFERENCES

[1] International Astronomical Union, "Satellite Constellations," iau.org, Dec. 2024. [Online]. Available: https://www.iau.org/public/themes/satellite-constellations/#n2

[2] International Astronomical Union, "IAU Statement on Satellite Constellations," iau.org. [Online]. Available: https://www.iau.org/news/announcements/detail/ann19035/

[3] J. Hecht, "Will Satellites Cripple Ground-Based Astronomy?," Optics & Photonics News, vol. 26, pp. 28-35, May 2021.

[4] E. Howell, "Starlink satellites: Facts, tracking and impact on astronomy," Space.com, Oct. 2023. [Online]. Available: https://www.space.com/spacex-starlink-satellites.html

[5] A. Witze, "Astronomers push for global debate on giant satellite swarms," Nature, Jul. 2021. [Online]. Available: https://www.nature.com/articles/d41586-021-01954-4

[6] Vera C. Rubin Observatory, "The Legacy Survey of Space and Time (LSST)," SLAC National Accelerator Laboratory, Tech. Rep., Sep. 2020.

[7] F. Di Vruno et al., "Unintended electromagnetic radiation from Starlink satellites detected with LOFAR between 110 and 188 MHz," Astronomy & Astrophysics, vol. 676, pp. A75:3-4, 2023.

[8] D. Grigg et al., "Detection of intended and unintended emissions from Starlink satellites in the SKA-Low frequency range," Astronomy & Astrophysics, vol. 678, p. L6, 2023.

[9] European Space Agency, "ESA's Annual Space Environment Report," ESA Space Debris Office, Tech. Rep., pp. 15-17, 2023.

[10] NASA Orbital Debris Program Office, "Orbital Debris Quarterly News," vol. 27, no. 4, pp. 2-3, 2023.

[11] International Dark-Sky Association, "Satellite mega-constellations and Their Impact on Dark Skies: A Position Statement," IDA Tech. Rep. 2023-01, pp. 4-6, 2023.

[12] United Nations Office for Outer Space Affairs & International Astronomical Union, "Dark and Quiet Skies for Science and Society II," UN/IAU Tech. Rep., pp. 8-12, 2023.

[13] O. R. Hainaut and A. P. Williams, "Impact of satellite mega-constellations on astronomical observations with ESO telescopes," Astronomy & Astrophysics, vol. 636, pp. A121:3-5, 2020.

[14] P. Mroz et al., "Impact of the Starlink Satellites on the Zwicky Transient Facility Survey," The Astrophysical Journal Letters, vol. 924, no. 2, pp. L30-L33, 2022.

[15] J. C. McDowell, "The Low Earth Orbit Satellite Population and Impacts of the SpaceX Starlink Constellation," Nature Astronomy, vol. 7, no. 1, pp. 14-18, 2023.

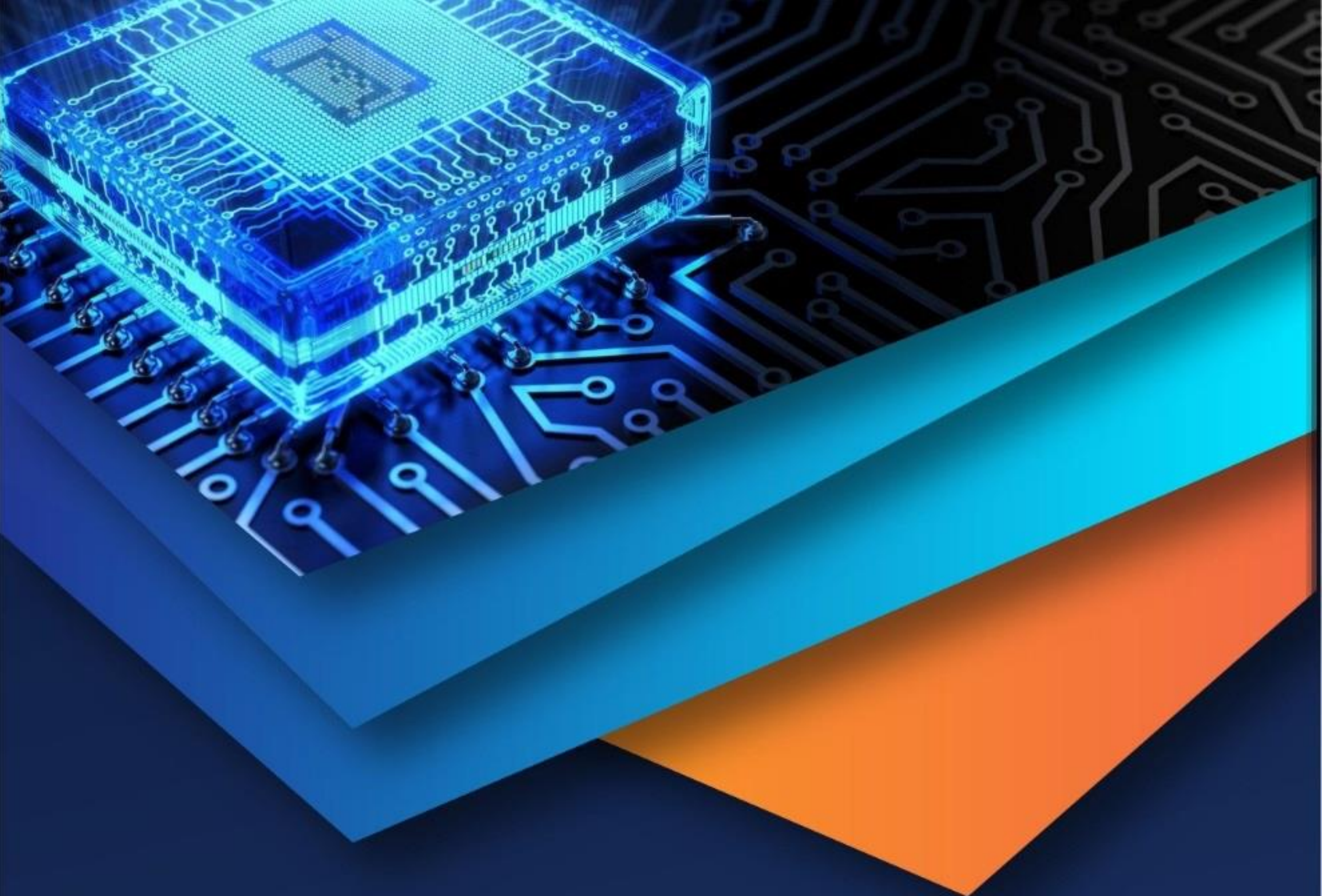
[16] National Science Foundation, "Vera C. Rubin Observatory Construction Update and Science Impact Assessment," NSF Tech. Rep. 2023-01, pp. 12-15, 2023.

[17] S. Greenstreet et al., "The Impact of Satellite mega-constellations on Rubin Observatory's Legacy Survey of Space and Time (LSST)," in Proc. AAS/Division of Dynamical Astronomy Meeting, vol. 55, 2024, pp. 1-3.

[18] C. G. Bassa et al., "Analytical simulations of the effect of satellite mega-constellations on optical and near-infrared observations," Astronomy & Astrophysics, vol. 657, pp. A159:5-8, 2022.

[19] SKA Observatory, "Impact of Satellite mega-constellations on the Square Kilometre Array," SKA Tech. Rep., 2023. [Online]. Available: https://www.skao.int/en/news/198/skao-needs-corrective-measures-satellite-mega-constellation-operators-minimise-impact-its

[20] American Astronomical Society, "SATCON 1: Report on the Impact of Satellite mega-constellations on Astronomy," AAS Tech. Rep., 2020. [Online]. Available: https://aas.org/sites/default/files/2020-08/SATCON1-Report.pdf
[21] International Astronomical Union, "IAU Statement on Satellite mega-constellations," IAU Tech. Rep., p. 1, 2020.
[22] K. J. Gaston, T. W. Davies, S. L. Nedelec, and L. A. Holt, "Impacts of artificial light at night on biological timings," Annual Review of Ecology, Evolution, and Systematics, vol. 48, pp. 49-68, 2017.
[23] H. Poot et al., "Green light for nocturnally migrating birds," Ecology and Society, vol. 13, no. 2, p. 47, 2008.
[24] J. R. Conklin, N. R. Senner, P. F. Battley, and T. Piersma, "Extreme migration and the individual quality spectrum," J. Avian Biol., vol. 48, pp. 19-36, 2017.
[25] S. A. Cabrera-Cruz, J. A. Smolinsky, and J. J. Buler, "Light pollution is greatest within migration passage areas for nocturnally-migrating birds around the world," Sci. Rep., vol. 8, p. 3261, 2018.
[26] B. E. Witherington and R. E. Martin, "Understanding, Assessing, and Resolving Light-Pollution Problems on Sea Turtle Nesting Beaches," Florida Marine Research Institute, Tech. Rep. TR-2, 2014.
[27] E. Silva et al., "Light pollution affects nesting behavior of loggerhead turtles and predation risk of nests and hatchlings," J. Photochem. Photobiol. B, vol. 173, pp. 240-249, 2017.
[28] J. Berge et al., "Artificial light during the polar night disrupts Arctic fish and zooplankton behaviour down to 200 m depth," Commun. Biol., vol. 3, p. 102, 2020.
[29] M. Dacke, E. Baird, M. Byrne, C. H. Scholtz, and E. J. Warrant, "Dung Beetles Use the Milky Way for Orientation," Current Biology, vol. 23, no. 4, pp. 298-300, 2013.
[30] E. Gkanias et al., "Celestial compass sensor mimics the insect eye for navigation under cloudy and occluded skies," Commun. Eng., vol. 2, p. 82, 2023.
[31] T. Longcore and C. Rich, "Ecological and organismic effects of light pollution," in eLS: Citable Reviews in the Life Sciences, 2016.
[32] E. Knop et al., "Artificial light at night as a new threat to pollination," Nature, vol. 548, pp. 206-209, 2017.
[33] S. Perkins, "Albedo is a simple concept that plays complicated roles in climate and astronomy," Proc. Natl. Acad. Sci., vol. 116, no. 51, pp. 25369-25371, Dec. 2019.
[34] DarkSky, "Effects of light pollution on wildlife and ecosystems," International Dark-Sky Association, Dec. 2024. [Online]. Available: https://darksky.org/resources/what-is-light-pollution/effects/wildlife-ecosystems/
[35] F. Hölker et al., "Light pollution of freshwater ecosystems: principles, ecological impacts and remedies," Phil. Trans. R. Soc. B, vol. 378, p. 20220360, 2023.
[36] D. W. Hamacher, K. D. Napoli, and B. Mott, "Whitening the Sky: light pollution as a form of cultural genocide," arXiv: Popular Physics, 2020.
[37] K. Martins, "Polynesian Navigation & Settlement of the Pacific," World History Encyclopedia, Aug. 2020. [Online]. Available: https://www.worldhistory.org/article/1586/polynesian-navigation--settlement-of-the-pacific/
[38] A. Venkatesan et al., "SATCON2: Community Engagement Working Group Report," in Proc. SATCON2 Workshop, Jul. 2021. [Online]. Available: https://baas.aas.org/pub/enwrps6k
[39] M. N. Shaw, Uluslararası Hukuk, (Translation.: Yücel Acer, İbrahim Kaya, M. Turgut Demirtepe, G. Engin Şimşek) 8th ed. Ankara: Tüba Yayınları, 2017, pp. 611-612.
[40] H. Pazarcı, Uluslararası Hukuk Dersleri, vol. 2. Ankara: Yetkin Yayıncılık, 2021, p. 438.
[41] "Trail Smelter Case (United States v. Canada)," Reports of International Arbitral Awards, vol. 3, pp. 1905-1982, 1938.
[42] Ş. Güneş, Uluslararası Hukuk Açısından Çevresel Etki Değerlendirmesi. Ankara: Siyasal Kitabevi, 2007, p. 113.
[43] "Corfu Channel Case (United Kingdom v. Albania)," ICJ Reports, p. 244, 1949.
[44] "Lake Lanoux Arbitration (France v. Spain)," Reports of International Arbitral Awards, vol. 12, p. 281, 1957.
[45] "Nuclear Tests Case (New Zealand v. France)," ICJ Reports, p. 106, 1995.
[46] "Case Concerning the Gabčíkovo-Nagymaros Project (Hungary/Slovakia)," ICJ Reports, p. 88, 1997.
[47] United Nations, "Declaration of Legal Principles Governing the Activities of States in the Exploration and Use of Outer Space," UN General Assembly Resolution 1962 (XVIII), Dec. 1963.
[48] United Nations, "Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies," Oct. 1967.
[49] United Nations, "Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space," Dec. 1968.
[50] United Nations, "Convention on International Liability for Damage Caused by Space Objects," Dec. 1968.
[51] United Nations, "Convention on Registration of Objects Launched into Outer Space," Sep. 1976.
[52] United Nations, "Agreement Governing the Activities of States on the Moon and Other Celestial Bodies," Jul. 1984.
[53] S. Bektaş, Uluslararası Hukukta Uzaya Fırlatılan Araçların Tescili. Ankara: Yetkin Yayınları, 2023, pp. 41-42.
[54] A. Akyol, Uluslararası Hukukta Takım Uydular. Ankara: Yetkin Yayınları, 2024, p. 108.
[55] L. Viikari, The Environmental Element in Space Law. Leiden: Martinus Nijhoff Publishers, 2007, pp. 59-62.
[56] F. von der Dunk, "International space law," in Handbook of Space Law, F. Von Der Dunk and F. Tronchetti, Eds. Cheltenham: Edward Elgar Publishing, 2015, p. 49.
[57] T. Tarhanlı, Uydular Aracılığıyla Yer Doğal Kaynaklarının Uzaktan Algılanması ve Uluslararası Hukuk. İstanbul: Edebiyat Fakültesi Basımevi, 1991, pp. 25-34.
[58] I. H. Ph. Diederiks-Verschoor and V. Kopal, An Introduction to Space Law. Netherlands: Wolters Kluwer, 2008, pp. 25-27.



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