aerospace

MDPI

Article

Assessing the Principle of Equitable Access versus Non-Appropriation in the Era of Mega-Constellations

Kuan Yang * and Sandra Amongin

School of Law, Beijing Institute of Technology, Beijing 100081, China; aaroscar@gmail.com
* Correspondence: kuanyang@bit.edu.cn

Abstract: In the 21st century, mega-constellations and interconnected satellite constellations deployed at various orbital altitudes, such as LEO, MEO, and GEO, with low Earth orbits (LEOs) being the most commonly used, have emerged as a trend, aiming to enhance the productivity and reduce the costs in space service delivery. The UNOOSA has noted the uncertainty in the exact number of satellites but conducted simulations based on a substantial sample, projecting a significant increase from the 2075 satellites recorded in orbit in 2018. This surge in the launch of mega-constellations poses profound challenges to existing international space laws, originally formulated with limited consideration for private space actors, who are increasingly engaging in space activities, particularly with the cost-effective utilization of mega-constellations. This study critically analyzes the compatibility of mega-constellations with the current international space laws by examining the applicability of mega-constellations concerning equitable access and the non-appropriation principle, addressing their potential occupation of substantial orbital spaces during activities, and analyzing whether the acquisition of orbital slot licenses violates these two principles. Following an in-depth analysis, this study proposes recommendations to amend the existing laws, aiming to resolve ambiguities and address emerging challenges. Recognizing the time-consuming process of amending international space laws, this study suggests practical recommendations for supplementary rules of the road, prompting reflection on the potential obsolescence of the current international space laws in the face of evolving space activities.

Keywords: mega-constellations; international space law; equitable access; non-appropriation

Citation: Yang, K.; Amongin, S. Assessing the Principle of Equitable Access versus Non-Appropriation in the Era of Mega-Constellations. *Aerospace* **2024**, *11*, 842. https://doi.org/10.3390/aerospace11100842

Academic Editor: Paolo Tortora

Received: 22 August 2024
Revised: 19 September 2024
Accepted: 5 October 2024
Published: 12 October 2024

1. Introduction

The rapid development and deployment of mega-constellations, consisting of numerous small satellites operating in a low Earth orbit (LEO), have significantly transformed the landscape of space activities. In 2018, the UNOOSA recorded 2075 satellites in orbit, which, based on projections and simulations, is expected to increase. By 2021, the number of satellites, both active and defunct, had increased by over 50% in just two years, reaching approximately 5000 satellites. This number has since increased, reaching, by the end of 2023, an estimated 11,330 satellites [1]. Companies like SpaceX, OneWeb, Amazon, and Telesat are leading this trend, with SpaceX intending to add 11,000 more satellites to its Starlink mega-constellation, having already filed for permission for an additional 30,000 satellites [2]. This surge in satellite deployment is driven by the need to provide global broadband internet coverage and other communication services, leveraging the advantages of smaller, more cost-effective satellites over traditional, larger ones.

However, the proliferation of mega-constellations presents significant legal and regulatory challenges. The current international legal framework, primarily governed by the Outer Space Treaty and other related agreements, is struggling to keep pace with the rapid advancements in satellite technology and the sheer volume of satellites being launched. For instance, the Outer Space Treaty is not detailed regarding regulations or punishments in the event of violation and has ambiguous terminology, such as outer space, national

appropriation, debris, space object, harmful contamination, and interference, among others. These are not clearly defined and there is no agreed upon definition, thus rendering it futile in addressing issues such as liability for collisions, space debris management, and the potential for orbital slot monopolization [3–6]. The lack of binding international rules on satellite design and operation exacerbates these challenges, necessitating a coordinated global effort to develop new regulations and norms. As the number of satellites in orbit increases, with projections indicating tens of thousands more in the coming years, the international community, while acknowledging the work conducted so far, must urgently address these legal and regulatory gaps to ensure the sustainable and equitable use of outer space [2,4].

Furthermore, due to the rapid rise of mega-constellations, there is a need test their applicability against two of the key principles described in the Outer Space Treaty: the principle of equitable access and the principle of non-appropriation. These principles play a key role in the development of outer space in that, regarding equitable access, the rising number of satellites—in this case, mega-constellations—raises questions regarding equitable access through the distribution of orbital slots, as well as the possible domination of space, hindering equitable access to it. Secondly, regarding the principle of non-appropriation, questions have been raised regarding whether the occupation of substantial orbits constitutes appropriation. This paper therefore explores the challenges posed by mega-constellations within the context of the international space law framework by examining their intersection, with the aim of paving the way for the equitable and sustainable use of outer space.

The subsequent sections are organized as follows: Section 2 introduces the legal status of mega-constellations under international space law; Section 3 addresses the legal challenges posed by mega-constellations to the existing international space law regime; Section 4 analyzes the applicability of mega-constellations in light of the principles of equitable access and non-appropriation; Section 5 proposes both policy and technical recommendations regarding the issues discussed; and Section 6 presents the conclusions.

2. Legal Status of Mega-Constellations under International Space Law

2.1. International Treaties and Principles Governing Mega-Constellations

The legal status of mega-constellations is currently an evolving and contentious issue in international space law [7]. Through the United Nations Committee On Peaceful Uses of Outer Space [8], five space treaties have been molded over time by the application of domestic policies and regulations as a result of the obligation placed upon states by Article 6 of the Outer Space Treaty. The 1967 Outer Space Treaty [9], also referred to as the Constitution of Outer Space [10,11], provides the basic framework on international space law, as well as the basic principles pertaining to the conduct of space activities. However, it does not specifically address the unique challenges posed by mega-constellations consisting of thousands of satellites. These treaties were drafted in the 1960s–1970s, when only a handful of large, individual satellites were being launched. As a result, there are significant gaps and ambiguities in how existing space law applies to mega-constellations.

During its early stages, in order to ensure uniformity and align with norms and standards promoting responsible behavior, the Outer Space Treaty required all space actors to comply with international laws through a number of principles. These included the freedom of exploration and use of outer space; carrying out space activities for the benefit of all mankind; the principle of the non-appropriation of outer space and of celestial bodies by states; the de-weaponization of outer space while encouraging the use of outer space for peaceful purposes; authorization and supervision; liability for outer space activities, which is further detailed in the Liability Convention [12]; cooperation and mutual respect, as well as international cooperation, as enunciated in the Rescue Agreement [13]; and the registration of launched objects catered for in the Registration Convention [14]. An example of this uniformity can be seen in the application of the UNCLOS in Article 87 to cater for the principle of freedom of the high seas and Article 89 to cater for the principle of non-appropriation, among others. It can be said that, because of the similarities that these

two possess, outer space law development could benefit from experience gained in the law of the sea.

As a result, based on the freedom to use and explore outer space, both public and private entities utilize space for commercial purposes, making satellite ownership overly commercialized, particularly in the areas of communication and navigation, as well as space travel [15] and mining, despite there being no actual international consensus on whether space mining is part of the freedom to use and explore outer space. This has, of course, been subject to controversy in the field of environmental protection, sustainability, and conservation [16]. Furthermore, despite its far-reaching positive purpose of holding space in trust for future space expeditions and protecting space from exploitation by individual states and corporations, the declaration of the use and exploration of space as the province of mankind has faced criticism due to being imperialistic and lacking [17]. This is based on the argument that the present politico-legal regimes and their philosophical grounding are imperialistic [18]. The current trends show tremendous growth towards the privatization and commercialization of space activities [19], including the emergence of mega-constellations. These trends have also led to an increase in the amount of space debris, despite the numerous normative regulations available on an international scale, such as the Space Debris Mitigation Guidelines, as well as on a regional scale, such as Europe's Zero Debris Charter, among others.

2.2. International Telecommunications Union in Regulating Mega-Constellations

Mega-constellations also fall within the scope of the activities of the International Telecommunications Union (ITU) [20], since it manages space telecommunications through the equitable and rational distribution of terrestrial frequencies and specific applications for geostationary orbit. As one of the UN's specialized agencies responsible for issues that concern information and communication technologies, it coordinates the shared global use of the radio spectrum, promotes international cooperation in assigning satellite orbits, aims to improve the telecommunication infrastructure in the developing world, and assists in the development and coordination of worldwide technical standards. It also recognizes the sovereign right of each state to regulate its telecommunications. The ITU's regulatory framework aims to promote equitable access to these resources, which is particularly important given the rapid increase in the number of satellites being launched into low Earth orbits (LEOs) by companies like SpaceX, OneWeb, and Amazon [2,5], as well as the GuoWang (SatNet) mega-constellation [21,22]. The ITU has faced some legal and regulatory challenges, such as the following.

2.2.1. Frequency and Orbital Slot Allocation

The ITU's role in assigning frequencies and orbital slots is critical to preventing conflicts and ensuring that all countries have fair access to space resources. Previously, there has been an issue related to radio frequency spectrum warehousing, which tended to reflect the inaccurate deployment of non-geostationary satellite systems (NGSO) in the Master International Frequency Register. In response, the ITU adopted a milestone-based regulatory approach, requiring operators to demonstrate progress in deploying their satellites to retain their frequency assignments [5,23]. This deployment has been categorized as 10% deployment within two years from the end of the current period to enter into use, 50% within five years, and complete deployment within seven years. This approach helps to manage the risk of "paper satellites" [24], where companies file for more slots than they intend to use, potentially blocking other operators. This has created an issue regarding the warehousing of orbital slots and frequencies, especially if the operator has planned to launch numerous satellites [25]. Secondly, the ITU has also adopted Resolution 219 for the responsible utilization of radio frequency spectra, with international cooperation at its core [26].

Therefore, regarding frequency allocations, the ITU does not license spectra and is rather general in nature. Through the World Radio Communication Conferences (WRC)

and Regional Radio Communication Conferences (RRC) texts, it leaves the regulation of specific matters to the discretion of each member state, as long as they adhere to the ITU rules, as well as international law. This can be controversial, especially when deciding how much of the spectrum is allocated to each applicant. An example of a national regulator is the USA FCC, whose responsibilities include assigning spectrum licenses and ensuring competitive innovation and efficient communications services. Significantly, the USA FCC mandates that internet service providers deploy and run at least 50% of their constellation within six years of approval; otherwise, they risk losing their permission and their allotted spectrum. Then, by nine years, the entire constellation must be fully deployed [27].

Against this background, it is clear that radio frequencies and orbital positions are absolutely necessary tools for satellite communications. This is simply because, without them, satellites' functionality would be hindered, triggering the interference of radio frequencies, which in turn reduces the quality of communications, leading to harmful interference. The term "harmful interference" refers to the unwanted energy that arises from one or more emissions, radiations, or inductions during reception in a radio communication system. This unwanted energy can cause performance degradation, misinterpretation, or the loss of information that could have been obtained had the unwanted energy not been present [28]. Thus, because the need for telecommunications (for satellites and radio frequencies) is crucial, its expansion is significantly determined by the availability of radio frequencies and orbital positions.

In order to carry out the international notification, coordination, and registration of radio frequencies and orbital positions, two methods are normally used. The first is the "first come, first served" method, which ensures international protection against harmful interference through the proper coordination of assignments within the ITU and registration with the ITU if international protection against harmful interference is desired, or if the assignment will be used for international services or if it is a precaution against harmful interference from the use of a new assignment [28]. The second method is "a priori planning", which is essentially used to ensure equitable access to radio frequencies and orbital positions. The World Radio Communications Conferences demonstrate that Article 44.2 of the ITU Constitution [20] introduced the idea of equity and equitable access with regard to the use or sharing of radio frequencies and orbital positions.

However, it has only been used in conjunction with a small number of allotment plans. These include, among other aspects, the provision and related frequency allotment plan for the aviation mobile service in the bands allotted solely to that service, the frequency allotment plan for the aviation mobile service, and related information [28]. Because of the rarity of such plans, new challenges arise in accessing appropriate radio frequencies due to increasing privatization, competition, globalization, and the abuse of ITU regulatory processes.

Communication is substantial in operating a constellation because of the frequent need to communicate with the ground team and because satellites are designed for real time, thus requiring continuous communication. Because of this, questions about radio frequency spectrum partitioning have arisen, since an overcrowded radio frequency spectrum may cause physical interference with adjacent radio frequency signals, making space traffic management a critical issue [29,30]. The regulatory aspects of space traffic management are inadequately covered because of the emphasis on acquiring any available orbital slots. This is because interferences that affect other operators that may be approaching a target orbit or de-orbiting at the end of a satellite's life are not given sufficient consideration. With the increase in the number of satellites and constellations, many interferences may occur, like the interference of Earth observation and overcrowding, among others.

2.2.2. Compliance with International Law

The ITU's regulations must align with broader international space law principles, such as those outlined in the Outer Space Treaty. The ITU's role in promoting international

cooperation and equitable access helps to ensure that mega-constellations do not violate these principles by monopolizing orbital slots or frequencies.

While the ITU coordinates international standards, it also recognizes the sovereign right of each state to regulate its telecommunications. This dual responsibility can create challenges, as national regulators may prioritize their own interests, potentially leading to conflicts with the ITU's goal of equitable resource distribution. For instance, the US Federal Communications Commission (FCC) assigns orbital shells on a first-come, first-served basis, which can lead to the de facto appropriation of these orbits, contrary to the Outer Space Treaty [2,5].

2.2.3. Application of Military Satellites within ITU Framework

The ITU framework involves the licensing and allocation of radio frequencies, which applies to both civilian and military satellites, regardless of whether they are dual use or not [31]. Furthermore, ITU radio regulations are internationally binding for all ITU member states. This has been emphasized by the ITU's Report on Satellite Regulation in Developing Countries [32]. As a result, even if Article 48 of the ITU Constitution allows member states to retain their freedom regarding military radio installations, they are bound to abide by the principles and provisions of the ITU Constitution and are encouraged to observe the provisions of the ITU Administrative Regulations concerning the types of emission and the frequencies to be used [33].

In summary, the ITU's role is fundamental to the legal status of mega-constellations. By managing the allocation of radio frequencies and satellite orbits, the ITU helps to mitigate the risks of interference and ensures compliance with international space law principles. However, the rapid growth of mega-constellations and the varying priorities of national regulators present ongoing challenges that require coordinated international efforts in order to be addressed effectively [2,4,5,34–36].

3. Legal Challenges Posed by Mega-Constellations to Existing International Space Law Regime

The launch and utilization of mega-constellations has highlighted several deficiencies within the current international space law framework, presenting challenges that the existing legal regime has yet to effectively address. Notably, the mechanisms established to prevent interference have proven inadequate, as evidenced by reports of astronomical interference, collisions, and the proliferation of space debris. Moreover, there are concerns about the potential violation of environmental sustainability laws. Presently, there are no stringent international rules governing how operators manage constellations in orbit, despite the rapid expansion of mega-constellations.

3.1. Astronomical Interference and Space Debris

Mega-constellations have exacerbated issues of astronomical interference and space debris. The current measures to mitigate these problems are insufficient. According to Johnson (2020) [36], the sheer number of satellites increases the likelihood of interference with astronomical observations and contributes significantly to the space debris problem, posing risks to both existing and future space operations. This makes establishing liability and causation for collision damage very complex, especially for knock-on collisions involving debris. There are no clear international rules on satellite design and operation standards to determine negligence.

The issue of space debris presents a significant challenge to the current international space law regime. While the Liability Convention attempts to address space debris by defining a "space object" to include component parts and launch vehicles, its application reveals substantial gaps. Notably, the definition of "space object" does not explicitly encompass non-functional debris, leading to ambiguity about the responsibility for such debris. The exclusion of "useless" space debris from the definition limits the Convention's effectiveness in managing the debris problem. Moreover, unidentifiable space debris,

which cannot be traced back to a specific space object or launching state, poses a major legal challenge. The Liability Convention's framework does not address the responsibility for such debris, necessitating amendments to the current conventions to tackle these issues effectively. It should also be noted, while calls have been made for the ICJ to provide advisory opinions on orbital light and spectrum pollution, the same should be implemented regarding the determination of responsibility when dealing with debris.

The increasing number of satellites, particularly with the advent of mega-constellations, exacerbates the space debris problem. The rapid deployment of satellites into low Earth orbits (LEOs) by companies like SpaceX and OneWeb significantly heightens the risk of collisions, potentially triggering a "collisional cascading process" or the Kessler syndrome [37]. This scenario, where the density of objects in LEO increases to a point where collisions generate more debris, further increases the likelihood of additional collisions, posing a severe threat to both current and future space operations.

Furthermore, the failure rate of satellites, especially the cheaper models used in mega-constellations, contributes to the growing debris issue [38]. Even a 5% failure rate in a constellation of 100 satellites results in five new pieces of debris, which can significantly impact the fragile space environment. This is particularly concerning given that Article 9 of the Outer Space Treaty mandates the prevention of the harmful contamination of the space environment. The principles of due regard and cooperation, although not explicitly defined, underscore the importance of international collaboration and mutual respect but also address the aspect of discretion, which has led to controversial interpretation by member states regarding whether their activities qualify for the application of these provisions. Bourbonniere and Lee (2019) argue that such cooperation is vital in addressing the collective challenges posed by the increasing commercialization and privatization of space activities [39]. However, the existing legal framework is insufficient to effectively manage and reduce the risks associated with the rising amount of space debris.

3.2. Environmental Sustainability

Article 3 of the Outer Space Treaty states that space activities should be carried out in accordance with international law; this Article is all-inclusive and thus has no limitations regarding which international laws apply [40]. Therefore, environmental sustainability laws, although often flaunted in the pursuit of the rapid deployment of mega-constellations, do apply in this instance. Under the Outer Space Treaty's principle of "due regard" for others' interests, states may be required to conduct environmental impact assessments before approving mega-constellations. However, this is not an explicit requirement. Furthermore, despite the 1992 Rio Declaration's [39,41] emphasis on sustainable development, the space industry lacks rigorous environmental regulations, leading to potential long-term ecological impacts. Recent studies highlight the urgent need for comprehensive environmental standards specific to space activities (Pelton and Madry, 2019) [41,42].

The proliferation of space activities, especially the deployment of mega-constellations, raises significant concerns regarding environmental sustainability. While the Liability Convention addresses physical damage, it falls short in considering the environmental harm caused by space debris. Space debris, essentially a form of pollution, threatens the space environment since there is a possibility of increased space pollution from combustion by-products, which is accumulated in space and can alter the chemical composition of the near-Earth atmosphere, leading to contamination. Furthermore, space debris also leads to the Kessler syndrome, impacting future space activities, which necessitates a more comprehensive approach to include environmental damage within the legal framework.

The environmental impact of increased space launches is multifaceted.

Firstly, the reentry of space debris poses risks of environmental contamination through the release of nitrogen oxides, which, based on a study by Robert et al. (2022), can contaminate the environment [43], including soil and water [44,45]. Secondly, biological contamination cannot be ruled out, as the introduction of terrestrial microorganisms into outer space or the return of extraterrestrial materials to Earth can have unforeseen consequences,

such as posing a significant risk of contamination during space missions from terrestrial microorganisms in spacecraft [46]. There are also risks of biological contamination from the return of extraterrestrial materials, as found in a study by Rummel et al. (2011) [47], and forward contamination during lunar missions, as it could compromise life detection missions [48], underlining the necessity for tight precautions to prevent contamination [49].

Moreover, the potential loss of scientific evidence about the solar system due to increased space debris also undermines the scientific value of outer space in the sense that space debris collisions with spacecraft or instruments like probes, landers, or telescopes [50] used to study the solar system could cause damage. The same applies to the exploration of the solar system, which would be hazardous in the face of space debris [51]. Furthermore, solar phenomena observations like the Maunder minimum and the grand minimum, which are believed to have an influence on the amount of debris, may be difficult to study as a result of this debris. Therefore, the study by Greenly (2023) [44] emphasizes the need to address the environmental impacts of space activities, including the reduction of space debris [48], and NASA (2020) [52] has highlighted the importance of preserving the scientific integrity of space missions by minimizing contamination and ensuring the accuracy of the data collected [53].

Furthermore, the multinational nature of commercial space activities complicates the enforcement of environmental laws, since ownership transfers and the involvement of multiple jurisdictions make it challenging to establish and enforce environmental regulations effectively. For instance, a study by Lihua et al. (2019) noted that the involvement of multiple jurisdictions and ownership transfers make it challenging to establish and enforce environmental regulations effectively [54], and a study by Dempsey (2016) found that national laws governing commercial space activities are often inadequate or unclear, leading to the lack of effective enforcement of environmental regulations [49,55].

In conclusion, the environmental impacts can trigger these two principles in the sense that, if not meticulously handled, they could create inequalities among nations, especially by widening the gap between well-established space-faring nations and the up-and-coming ones.

3.3. The Issue of Space Traffic Management

3.3.1. Space Situational Awareness and Space Traffic Management

The ITU orbital allocations divide spacecraft into two categories: geostationary (GSO) and non-geostationary (NGSO). The International Telecommunication Union currently coordinates GSO, and, because of the limited and distinctive nature of these positions within GSO, coordination has always been considered essential. Current statistics reveal that there are only 1800 orbital slots in GSO, which is well organized when compared to other orbits [56]. Because of the increased use of other orbits closer to Earth, like LEO, it has been suggested that they may soon need coordination, although this is not currently performed, especially since satellites in LEO do not have a fixed location. The ITU and WRC have engaged in efforts through discussions and proposals to develop frameworks for coordination amidst the growing number of constellations [57,58]. During the World Radio Communication Conference (WRC-23), a proposal to review the equivalent power flux density (EPFD) limits was approved in order to address the unfavorable limits placed on LEO users, especially in spectrum utilization [59,60]. With this in mind, users at GSO are assigned an orbital slot that is as small as a three-dimensional box in which to work. Due to this, these slots differ from the multi-orbital planes of several satellites that constellations use, also referred to as orbital "shells", which essentially encircle the entire planet. The organized GSO region is very different from that of the low Earth orbit (LEO) and medium Earth orbit (MEO), where regulations governing the use and governance of these regions are not very specific, the congestion and collision risks are constantly rising, and satellites owned by numerous users and for a variety of purposes are periodically transiting around the planet. The National Telecommunications and Information Administration (NTIA) and the Federal Communications Commission (FCC), two national frequency administrators that oversee government and commercial frequencies, respectively, license operators in

accordance with how they understand their responsibilities under the space law. No problems with constellations have arisen during the license giving process.

On the one hand, the argument that satellite constellations' use of LEO is legal because it is essentially the same as their use of GSO could be upheld, since the utilization of pre-coordinated subsections of space is granted to individual actors in each region by a national administrator or through a national administrator by an international regulatory body (ITU). This is essentially the same as using orbital slots in GSO; placing spacecraft into a low Earth orbit (LEO) or higher does not imply possession, ownership, or occupation. This is because states have been using GSO slots for many years without ever being accused of misusing GSO. Other space actors in the space domain recognize the users' rights to utilize GSO, and they have never claimed to be appropriating it.

On the other hand, it could be argued that although allocation does not come with ownership rights to the outer space area, it grants lifetime exclusive rights to an operator based on its satellite life. Moreover, because the operators keep refiling for the slot and replacing old satellites with new ones, they are typically keeping these orbital slots indefinitely. This is not a clear-cut occupation or appropriation, because spacecraft in a low Earth orbit (LEO) are actually moving through space and are not stationary, whereas GSO locations are relatively stable—for example, they are subject to space weather and other perturbations and require station keeping. Additionally, other users will be able to use these orbits thanks to space situational awareness (SSA) and space traffic management (STM), and aspects of one user's use will not prevent the use of others. To reiterate (Johnson 2020), constellation operators do not intend to hold, or occupy, these orbits exclusively [36].

Space law applies strict liability whereby the intention of the space actor or not would constitute appropriation. However, even if one were to argue intention as a prerequisite for appropriation, no such intention can be found in the operators of global constellations, which raises the question of the applicability of Article 2 of the Outer Space Treaty and how orbital slots can be successfully distributed given the nomadic nature of spacecraft in LEO or MEO. This all serves to prove how ungoverned the LEO is compared to the GSO. Moreover, it should be noted that the fact that there is no complaint about something does not make it right or legal.

3.3.2. Dispute Resolution Mechanisms within the ITU Framework

Because the ITU lacks a compulsory international dispute resolution system for the resolution of interference complaints, these interferences continue. Article 56 of the ITU Constitution addresses dispute resolution and stipulates that member states may negotiate a settlement through diplomatic channels, follow the procedures outlined in various treaties concluded between them for dispute settlement, or use any other method that is mutually agreed upon to resolve disputes in the interpretation or application of the ITU Constitution, the Convention [30], or the Administrative Regulations (including the Radio Regulations governing space communications). Any member state subject to a dispute may resort to arbitration in line with the arbitration procedure as defined in Article 41 of the ITU Convention if none of the aforementioned means of settlement are chosen.

The Optional Protocol on the Compulsory Settlement of Disputes relating to the ITU Regulatory Regime [61] satisfies Article 41 of the ITU Convention for member states. The provisions mentioned herein and in the Optional Protocol have never been used, thereby resolving all harmful interference issues according to Article 15 of the ITU Radio Regulations. Under this provision, a case of harmful interference is resolved exclusively through bilateral negotiations between the concerned administrations under the obligation of good will and mutual assistance in the application of the ITU regime provisions. All stations, regardless of their intended use, must be set up and run so as to avoid detrimentally interfering with other members' communications that also involve a radio service and that comply with radio regulations [20]. Moreover, it is prohibited for any station to transmit superfluous signals or unnecessary signals, and transmitting stations are only allowed to radiate as much power as is necessary to ensure an adequate service [28]. Despite the above,

there is still a risk of frequency jamming, particularly for national and international security, because it is viewed as hostile or a warlike act. The fact that frequency jamming has been linked to both military and commercial satellites [62] further demonstrates the ITU's lack of authority to enforce its rules, regulations, or procedures or to impose punishment on military satellites unless they provide nonmilitary services; however, they are bound by ITU regulations. This means that, while the voluntary compliance strategy has proven successful over the years, the deterrent component of a law is conspicuously absent. With the rise of numerous mega-constellations, it is highly doubtful whether the voluntary compliance quality will be effective given the increased competition for the already scarce resources.

Therefore, for purposes of addressing this issue, the ICJ, as well as the permanent court of arbitration's optional rules for the arbitration of disputes relating to outer space activities, can be employed.

3.3.3. Flags of Convenience under the Space Traffic Management Issue

The registration of a foreign-owned vessel under easy and advantageous conditions for the entity registering the vessel is known as a "flag of convenience" in maritime practice and law [63]. This practice is usually for the purpose of reducing operating costs and avoiding "burdensome regulations". In 2009, when measured in terms of total tonnage, numerous worldwide merchant ships were registered under flags of convenience, with the Panamanian, Liberian, and Marshall Islands flags accounting for nearly 40 percent of the global fleet [64]. Because of the lax regulations, poor or minimal oversight, and poor record keeping in the flag of convenience states, this practice has been criticized for creating an environment for criminal activities, poor working conditions, failed environmental protection, and safety concerns [65], among others. Examples include the Torrey canyon situation in 1968, the Amoco Cadiz situation in 1978, the Exxon Valdez situation in 1989, the Scandinavian star situation in 1990, and the sea empress situation in 1996 [66]. The Deepwater Horizon oil rig explosion in the Gulf of Mexico in 2010—which occurred while flying the Marshall Islands' flag of convenience—was dubbed the greatest environmental disaster in American history and is a more recent occurrence.

As with maritime law, space objects operating under the Outer Space Law (Treaty) are governed by the laws of the country of registration [9,14,67], because the launching state is the state of registry. As one of the Outer Space Treaty's objectives, this discourages space actors from engaging in excessively risky activities [68]. Because of this, the registering state cum launching state is responsible and liable for activities pertaining to the registered activities [68]. The relevant Articles 6 and 7 of the Outer Space Treaty confer responsibility and liability to state parties for their activities in outer space, including activities carried out by national non-governmental entities [69]. The Liability Convention [12] is more detailed and supplements Article 7 of the Outer Space Treaty regarding the determination of liability for damage caused by space objects [70]. It integrates a framework under Article 9 to settle liability claims. It states that "a claim for compensation for damage must be presented to a launching State through a diplomatic channel or through the Secretary General of the United Nations" [12]. Moreover, a claims commission may be established by either party involved if they do not reach a settlement within one year of notification. The claims commission therefore decides the merits of the claim and determines the amount of compensation payable, if any. The decision of the commission is final and binding upon the agreement of the parties; otherwise, the commission should render a final and recommendatory award, which the parties should consider in good faith [12]. This shows that the Liability Convention is deficient, since its decision can only be final and binding if the parties are in agreement, thus diminishing the decision to the status of an advisory award in all other cases [71]. Secondly, only one case has been filed under the Liability Convention, namely the Cosmos case [72], which, in the end, was settled diplomatically. This does not show much regard for said convention in terms of dispute settlement.

International law is consensual by nature, meaning that states are not obligated to adhere to laws that they have not clearly consented to. Therefore, the Outer Space Treaty and the Registration Convention provide a framework whereby national laws can be applied to space objects based on state registry [67,68,73], which is similar to the flags of convenience under the law of the sea. Nonetheless, some states may be motivated to relax their regulations, especially since enforcement mechanisms are not robust, enabling flags of convenience scenarios where space actors choose a launching state with lax standards. This may in turn devalue patent protections, especially if space actors opt to register in countries where patents are not filed.

Projections indicated that flags of convenience would not be an immediate problem [67]; however, with the current technological trends, it can be stated that space companies do in fact have the freedom to establish themselves and launch spacecraft from any country on Earth. This is clearly a major challenge because it is rendering the outer space patent system ineffective in protecting outer space inventions.

The dangers of flags of convenience have been explored in regard to maritime activities; however, it is also imperative that the dangers that they pose to outer space are addressed. On 20 March 2012, the head of the US Federal Aviation Administration forecast that space tourism would become a one-billion-dollar industry within the next ten years. We are clearly within the ten-year prediction, and a 2019 report estimated space tourism with both suborbital and orbital levels at a potential market value of three billion dollars by 2030. Therefore, even if Mathew Klein initially believed that the flags of convenience would not be a problem due to the infancy of the space industry [67], state shipping registries frequently lack the resources or will to monitor the safety and conditions of ships. Similar outcomes may occur in space, since the rapid development of space technologies and the resulting commercial space industry could create a competitive environment that poses a threat to both the environment and space tourists [74], such as space debris and environmental degradation.

Space debris can potentially increase in the Earth's orbit if the flags of convenience states do not follow the Space Debris Mitigation Guidelines, such as limiting spent rocket break-ups, deorbiting vessels at the end of their useful lives, and moving them to graveyards in orbit [75]. With space travel becoming a common occurrence, debris will increase, including operational and fragmented debris, which is, of course, a danger to other users. As it accumulates, the probability of inter-debris collisions will greatly increase, increasing the likelihood of the Kessler syndrome [76] as inter-debris collisions will be uncontrollable once they start, encasing the Earth in an impenetrable cloud of broken debris and making space travel all but impossible [77,78].

Therefore, because the right to take part in space activities, whether governmental or nongovernmental, is provided for by the Outer Space Treaty [9], all states, including flags of convenience, can enjoy this right. Now, with the popularity of mega-constellations, it is expected that flags of convenience will become a major trend, especially in developing countries, which feel that they are missing out on space resources due to their inability to take part.

3.4. Transfer of Satellite Ownership in Orbit

Currently, the transfer of satellite ownership in orbit is a common practice as compared to the initial days of space exploration, since it was not considered essential at the time [79], especially as few states were interested and had the capability to carry out space activities. Numerous explanations arise as to the development of the in-orbit ownership transfer trend, and some of these are as follows. The public procurement schemes have been faced with change, leading to public–private partnerships (PPP) [80,81], which essentially involve privatization, outsourcing a private company to fulfil a particular service, which can be an on-orbit service to change the functionality of a satellite, assets sales between private firms, or even bankruptcy proceeding outcomes like the iridium LLC [82]. Furthermore, private

entities can also be called upon to deliver space objects in orbit, like the turnkey satellite systems, as an additional option to providing on-ground deliveries [83].

The major space treaties make no mention of the concept of the transfer of ownership. The Outer Space Treaty [9] mentions ownership in a way that neither seems to allow for transfer nor results in any change with regard to an existing treaty. It states that the "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 Earth" [9]. This, however, does not restrict the transfer of ownership; rather, because of the restriction of a launching state being a state of registry, it creates complications in application. Despite the fact that the concept of ownership is interestingly absent from the Liability Convention [12], Rescue Agreement [13], and Registration Convention [14], the Moon Agreement [84] merely echoes the Outer Space Treaty: "the ownership of space vehicles, equipment, facilities, stations and installations shall not be affected by their presence on the moon". The ITU Trinity Treaty documents (the ITU Constitution [20], Convention [30], and Radio Regulations [28]) also provide legal instruments that are indispensable for space activities to protect against radio frequency interference but make no mention of or reference to the concept of ownership or the transfer of ownership. The UNDROIT Space Assets Protocol of 2012 [85] is the only relevant international treaty linked to space and ownership issues, primarily from a private international law perspective. It addresses, among others, the ownership of satellites, but it is not yet in force, with only four signatories—Burkina Faso, Germany, Saudi Arabia, and Zimbabwe. Thus, there is no legal basis upon which the concept of ownership can be argued, especially with space treaties relevant to satellite communications. It is therefore important that the protocol is discussed to clear any uncertainties, followed by encouraging states to ratify it.

When an in-orbit transfer occurs between states or other entities that are covered by Article 6 of the Outer Space Treaty, or when the acquiring party does not meet the definition of a "launching state" as defined by the Liability Convention and Registration Convention, the implications of the transfer become more complicated. This, therefore, requires an innate understanding of what is legally and factually possible in the exercise of sufficient jurisdiction and control in order to effectively transfer the ownership of satellites in orbit. From a legal perspective, the right to exercise jurisdiction and control is retained by the states on whose register [14] the space object is carried [9]. However, only a launching state can be a state of registry, and, regarding interstate agreements on the exercise of jurisdiction and control of a space object, the status of a launching state is required [14]. Thus, even if it will not be able to use it, the transferring state (launching state) will continue to be the state of registry and maintain de jure power and jurisdiction over the transferred space object. Because of this de jure jurisdiction and control, the transferring state will still be liable for any harm that the space object causes [12], even if the recipient state has de facto control over it, despite not having registration rights or being held liable for damages caused by the space object. Therefore, even if, at the time of the drafting of the space conventions, there was a very limited number of space actors (states), the space conventions did not and still do not deter the transfer or purchase of space objects in orbit [81]. They do create inconsistencies between the legal and factual/actual status of a space object and the consequences therein, since this transfer of ownership is more to the acquiring state's advantage. As explained previously, states are held responsible for all national activities and are required to exercise legal control in the form of the obligation to authorize and continuously supervise these national activities normally by way of licensing [86]. Therefore, based on this background, if the satellite is transferred, there will be issues with licensing or the continued applicability of the original license, whether it is an international transfer or not.

The Outer Space Treaty requires comprehensive compliance by virtue of Article 3; therefore, the control of a satellite requires conformity with other rules of space treaties, including the ITU regime on the allocation, allotment, and assignment of orbital frequencies

and slots. Therefore, regardless of whether the space object is owned, controlled, or operated by a third party, states are internationally liable for space objects for which they qualify as the launching state, according to the Liability Convention. Because of this, a transfer of ownership in orbit may raise concerns about the applicability of the license-handling liabilities. In the case of international transfers, the jurisdiction of the launching state would have to cover damages caused by the transferred object under the Liability Convention. This is because of the nature of state liability, i.e., once a launching state, always a launching state, and it is always liable. The same is true for registration-related concerns, as they stem from the same launch. A state may exercise quasi-territorial jurisdiction over a satellite based on the same launching state criteria. However, in the event of an international transfer, the acquiring state may not be able to register the space object because it is not the launching state. In summary, there is a higher likelihood of complete system disruption when the private ownership of a satellite in orbit translates into private control, giving rise to questions of jurisdiction and control, which, as has been noted, have not been legally addressed by the standing space treaties. This is especially important now, with the increased commercialization of space and the sheer number of satellites launched per constellation.

The challenges discussed herein, despite some having been present earlier (before the rise in mega-constellations), have been magnified by the introduction of mega-constellations, especially given the fact that the governance policy for mega-constellations has been found to be lacking, especially with regard to legally binding, unambiguous definitions and also the limited regulation of private entities. This has been seen to escalate and undermine state sovereignty and also question the idea of global governance.

While some non-binding guidelines exist, there is an urgent need for new international regulations and norms to be developed to specifically address the challenges of mega-constellations and ensure the sustainable and equitable use of outer space. Proposals include creating new regulatory bodies, developing satellite design standards, and clarifying liability and environmental assessment rules. However, achieving a global consensus will be difficult given the competing interests involved.

In summary, the legal status of mega-constellations is currently highly uncertain and unresolved under existing space law frameworks. Significant international cooperation and new binding regulations will likely be required to manage their impacts and implications going forward. Against this background, the next section will assess the applicability of mega-constellations under the principles of equitable access and non-appropriation, as the core principles in this study.

4. Assessing Applicability of Mega-Constellations in Light of Principles of Equitable Access and Non-Appropriation

4.1. Principle of Equitable Access

4.1.1. Legal Framework and Significance of Equitable Access Principle

The principle of equitable access is predicated on the idea that all states, whether or not they are space-faring, have the ability to access space and the spectrum required for communication with satellites without interfering with or receiving harmful interference from others [9]. This idea particularly pertains to the processes used to assign orbital slots and spectra for the geosynchronous orbit belt, which has been used for broadcasting since the 1960s, upheld by the International Telecommunications Union Convention [30] and the Outer Space Treaty, among others.

Although there are several significant problems, the low Earth orbit (LEO) launch of many constellations of small satellites seems promising. Even though low Earth orbit (LEO) spacecraft are only in orbit for a restricted period, what are the implications of having such an overwhelming presence in LEO, where numerous orbital planes are occupied by spacecraft with numerous satellites and other potential users of these orbits are limited in trying to share them? Currently, the appropriation of space—whether void space or celestial bodies—is forbidden by international law. However, this core principle conflicts

with the broad freedom to enter, explore, and use space, especially regarding national innovations in industrial space capabilities. These rights, principles, and obligations will therefore be explored with regard to mega-constellations.

The concern for non-space-faring states emerged after the ITU began allocating orbital slots and spectra based on the first-come first-served principle. The World Administrative Radio Conference Delegates stressed every nation's right to access, simply because of the limited nature of the spectrum and GSO as natural resources. This concern was addressed under Article 33 of the Union's Convention [30].

Despite the good intentions of this provision, it led to debates on the enforceability of the principle stated therein. An example is the Bogota Declaration [87], which saw eight equatorial countries declaring sovereignty over the GSO belt directly above their national territory, which is a clear violation of the Outer Space Treaty, as will be discussed in the following. A compromise was reached to redefine the allocation process for GSOs [88].

All states are free to enter, use, and explore outer space, including the moon and other celestial bodies, according to Article 1 of the Outer Space Treaty. All other requirements and prohibitions, however, are weighed against this fundamental principle of space law.

The wording in Article 1 essentially speaks for itself. States are free to access and explore space without first obtaining permission from any other state, international organization, or other body of authority, as stated in Paragraph 2 of Article 1. Initially, the freedom of states to independently explore space was not a given but, rather, a privilege that was agreed upon by the member states of the United Nations. This right to unilaterally access space was implicitly accepted by the world community when the USSR launched Sputnik-1, and it was further codified in a statement of principles adopted by the UN in the early 1960s [89]. This right was finally made clear and explicit under binding international law with the Outer Space Treaty.

It is also worth noting that Paragraph 1 refers to outer space as the "province of all mankind", rather than merely outer space. It further requires that this exploration and use be by all states, "without discrimination of any kind on the basis of equality and in accordance with international law. . .". However, when a single private company controls such a large percentage of space, their use discriminates against other potential users and impedes their ability to access, investigate, and utilize space. In other words, this implies that other space players will not be able to use specific orbits that these space actors predominantly possess, use, or occupy due to their actions. The reason for this is that, since it would be risky to try and share the specific orbit, forcing them to choose other altitudes or orbits, no other operator would dare to use those specific orbits where hundreds of satellites are already operating as part of a constellation.

4.1.2. Application of Equitable Access Principle to Mega-Constellations

Firstly, since it prevents other parties from using space, the widespread occupation of specific orbits fundamentally negates the intent behind Article 1 of the Outer Space Treaty. Consequently, even though a state may grant licenses to one of its corporations for the launch and operation of satellites to this degree, this does not imply that the activities of the corporation in space, an area outside its national borders, are entirely compliant with the requirements of international law. Therefore, national approvals do not provide any such assurances.

Furthermore, based on a comparison between the proposed constellations in 1996 and the current proposed constellation estimates [90], it is clear that the numbers have risen dramatically and are still increasing. This leads to the question of how operators will be able to avoid interference with GSO satellites, especially in relation to launching smallsats and cubesats in large batches, increasing the possibility of unlicensed launches or transmissions [90], which, of course, risk interference, which violates equitable access.

The World Administrative Radio Conference Delegates emphasized the right of every nation to access space due to the limited nature of spectra and geostationary Earth orbits (GEO) as natural resources [91]. However, concerns arose [87], leading to debates on the

enforceability of this principle [88]. This led to the ever-present realization that the res communis of outer space is fictitious, thus pushing for the Bogota Declaration in 1976. This is because the developing countries feared that no space would be left for them in which to launch geostationary satellites in the future due to orbital congestion. To put this into perspective, in 2019, there were two thousand active satellites in orbit around the Earth [92] and thirty-four thousand objects larger than ten centimeters in size. This shows orbit monopoly and questions the equitable use of the outer space, since, among other discussed issues, mega-constellations raise the risk of orbital congestion, which could hamper space missions in the future.

Secondly, this has further been reinforced by the issue of the encroachment of rights, where satellite constellations have been seen to have grave effects on the astronomy industry as these unprecedented launches have endangered ground-based astronomical instrumentation [93]. The metallic, reflective surfaces of satellites have been reported to reflect light rays, which prevents ground-based equipment like telescopes from determining the movement of celestial bodies or other cosmological behavior; together with the emitted radio signals from satellites, this all obstructs astronomical research [93].

Therefore, due to Article 1 of the Outer Space Treaty, everyone is free to explore and thus reserve the right to conduct research on space. It is also clear that there are unlimited rights regarding the number of satellites launched into space. This creates an important dynamic because, ultimately, one of the parties will be hindered in the exercise of their rights, because there is currently no law or legislation that deals with the issue of the encroachment of rights. The obligation under Article 9 against harmful interference and the equitable access rights under Article 1 of the Outer Space Treaty offer no recourse or solution in the event that these rights are violated, especially with the mega-constellation trend.

The principle of equitable access, enshrined in the International Telecommunications Union Convention and the Outer Space Treaty, assumes that all states, whether space-faring or not, should have equal opportunities to access space and communicate via satellites without interference. This principle primarily pertains to the allocation of orbital slots and spectrum procedures for geosynchronous orbits, where broadcasting activities have been conducted since the 1960s.

Therefore, even if international law currently prohibits the appropriation of outer space, aligning with the principle that space exploration should be open to all nations, the rise of mega-constellations challenges the balance between rights, principles, and obligations in space law.

In conclusion, firstly, the Outer Space Treaty defines outer space as the "province of all mankind", aiming to ensure equitable access to and use of space for all nations. However, mega-constellations challenge this principle by disproportionately occupying valuable orbital slots, thereby restricting access for other space actors and potentially interfering with their space operations. National authorizations for satellite launches often do not align with international obligations, leading to the situation where the increasing number of mega-constellations exacerbates concerns about orbital congestion and equitable access.

Secondly, the historical apprehensions articulated in the Bogota Declaration reflect ongoing fears among developing nations regarding their ability to access outer space amidst growing orbital congestion. With thousands of active satellites and tens of thousands of sizable debris objects already in orbit, the deployment of mega-constellations significantly heightens the risk of congestion, which could impede future space missions and compromise the sustainable use of outer space.

Furthermore, the expansion of mega-constellations poses substantial threats to the astronomy community. The reflective surfaces of numerous satellites hinder ground-based astronomical observations and interfere with radio signals, thereby obstructing essential astronomical research. Despite the existing freedom to explore and utilize outer space, the absence of specific legal frameworks addressing the encroachment of rights presents significant challenges. The Outer Space Treaty's provisions regarding no harmful interference and equitable access fail to provide clear remedies for the issues arising from

the proliferation of mega-constellations. Consequently, there is a pressing need for updated international regulations to balance the rights and interests of all space users, ensuring that outer space remains a shared and accessible domain for the benefit of all of humanity.

4.2. Principle of Non-Appropriation

4.2.1. Legal Interpretation and Application of Non-Appropriation Principle

The Outer Space Treaty forbids national appropriation in its second article. This demonstrates that the utilization of space for national purposes is not acceptable. This even persisted in the early United Nations talks on space exploration [8,94]. This principle was also reiterated in 1963, in a draft precursor to the binding Outer Space Treaty.

States are effectively prohibited from lawfully appropriating outer space, including void space and celestial bodies, as a form of alien territory that is ready for annexation and occupation [95]. From a historical standpoint, a state could lawfully expand its territory by unilateral sovereign claims. However, tensions between space states would undoubtedly arise from such a rush to claim territory on, for example, the moon. Therefore, it was preferable to agree that no state could or would be able to directly and permanently possess space, including orbits and celestial bodies. Beyond this comprehension, the article's intricacies are somewhat unclear, particularly with regard to how it should be applied to specific tasks and how it relates to current and upcoming space missions. It enumerates the ways in which national appropriation can be accomplished, including claims of sovereignty, use, occupation, and any other method, concluding that space is not subject to national appropriation. Stated differently, there is no legal or acceptable way to justify the national appropriation of space. At the end of the list, "by any other means" is used to indicate that the article is not all-inclusive and to close any potential gaps. Therefore, it is used cautiously to emphasize that no state may claim sovereignty over space and that no state may ever bring it under its sovereign jurisdiction. Consequently, based on this reasoning, a state cannot appropriate space or regions of space, such as spots on celestial bodies, specific trajectories, or orbits, since any action taken would not be considered authorized appropriation.

4.2.2. Application of Non-Appropriation Principle to Mega-Constellations

The initial consideration in this investigation is whether private actors—whether commercial or authorized by the national government—are unlawfully claiming or possessing vast areas of low Earth orbit. For instance, as of June 2024, there were 19 planned constellations, 547,267 planned satellites, 8 constellations with at least one launched satellite, 6786 launched satellites in all constellations, and 5880 launched satellites in constellation operational shells [96].

Do these large constellations represent the illegal appropriation or ownership of specific areas of space?

On the one hand, Article 2 of the Outer Space Treaty indicates that it is against international law to appropriate any part of outer space, including void space or celestial bodies. The appropriation or ownership of space or parts of it cannot be justified by any means or methods of possession. The aforementioned constellations appear to have a disproportionate amount of control over certain orbits due to their deployment of several satellites to occupy orbital planes, which, in a way, prevents others from accessing these planes, thus appropriating these orbits [36]. With the affirmation that orbits closer to Earth are unique and that, when any actor uses these orbits to the extent that these proposed constellations will, it means that other space actors cannot. Access to outer space is unlimited in the sense that anyone with the technological means to launch space objects can explore space [36]. The Starlink satellites exclusively occupy three orbits: the 550 km, 570 km, and 540 km orbits [36,97,98]. This essentially means that SpaceX will be the only user and occupier of these orbits going forward, at least until its satellites are removed. As such, SpaceX will be the only occupant, and, since possession is a physical act, SpaceX seems to be the rightful owner of these orbits.

Secondly, this is particularly unacceptable and a violation of space rules, since the space actors—in this example, SpaceX and other mega-constellation operators—are acting without any genuine international dialogue or agreement. Therefore, the LEO is essentially ungoverned in comparison to the GSO regime, which is managed by the ITU and other national frequency administrators. It appears that SpaceX and other actors are trying to take advantage of this loophole to claim entire portions of LEO for themselves, all before any international agreement, consensus, or even discussion is achieved [99]. This results in a purely first-come, first-served situation, which creates a unilateralism or colonialism scenario.

Since a state is accountable for the actions of a non-governmental organization under international space law, it must approve, oversee, and guarantee the ongoing observance of international law by its non-governmental organizations. Therefore, non-governmental commercial organizations like SpaceX, OneWeb, and others are subject to the same appropriation prohibitions as states under Article 2. Nevertheless, SpaceX will be the only occupant and hence the lawful owner of the 550 km, 1100 km, 1130 km, 1275 km, and 1325 km heights above our planet, or whichever orbits they ultimately occupy, thanks to the launch and use of the Starlink constellation. The other large constellation operators are in a similar scenario. While the altitudes chosen for the Starlink constellation are technologically desirable for their purposes, it also means that any spacecraft not deorbited from these regions may remain there for decades or possibly longer. This underscores the significance of these altitudes, as malfunctioning spacecraft in orbits lower than 500 km will re-enter the Earth's atmosphere in a few months or years [100]. If a comparison is made, the duration of time that the mega-constellation altitudes threaten is far less than the 15-year increments in which rights for orbital slots are granted at GSO. The argument that this occupation reaches the level of appropriation of these orbits is further supported by these extended periods of time at the specified mega-constellation heights.

Article 9 of the Outer Space Treaty supports this violation of the non-appropriation principle by these gigantic constellations. It is necessary for the utilization and exploration of space that states "shall be guided by the principle of cooperation and mutual assistance and shall conduct all their activities in outer space. . .with due regard to the corresponding interests of other States. . .". Thus, it is difficult to see how this placement of massive constellations demonstrates any form of respect for the comparable interests of others. Their unilateral transgressions of the goals of space law standards are further supported by this disregard.

In summary, these massive constellations effectively monopolize entire orbital areas, thereby preventing other actors from sharing such domains. This has been implemented without international discussion or consensus [99], which is unacceptable for a domain that is outside of state sovereignty and that no state may hold. Governments are forbidden from appropriating space, and they will eventually be in charge of this decision. Unlike GSO, they were able to occupy these areas for extraordinarily extended periods thanks to their authority to travel there, demonstrating appropriation. As shown, these constellations severely restrict other actors' ability to use certain areas, interfering with their freedom to explore and utilize space. Ultimately, as stated in Article 9 of the Outer Space Treaty, this heedless desire demonstrates complete disregard for the comparable rights of others. In light of this, these massive constellations represent the illegal appropriation of specific space regions, independent of any formal or official claim to the contrary made by an accountable or approving authority.

On the other hand, a counterargument claiming that the deployment and operation of these massive constellations is in complete compliance with the regulations governing space travel could legitimately lead to a different decision. These constellations do not represent any unlawful appropriation of the orbits that they utilize; rather, they simply represent the freedom to explore and use space. The right to unrestricted access to and use of space is established under Article 1 of the Outer Space Treaty. Regardless of where the spacecraft is traveling or how many satellites it contains, preventing an actor from deploying one

would constitute a violation of their right to explore and use outer space freely. In addition, space actors do not require authorization from any other state in order to access or explore space. Although the drafters of the outer space law did not specifically mention it, this use of space by constellations in low Earth orbits actually satisfies their goals for the use of space [101]. The preface to the Outer Space Treaty outlines the goals and subject matter of the agreement, which includes a desire to contribute to international cooperation, which will in turn culminate in mutual understanding and strengthen mutual friendships towards progress in the exploration and use of outer space for peaceful purposes. These goals can be used to interpret the treaty's operative articles, which discuss how humanity has explored and used space as inspiration. It is also easy to see how these constellations currently provide the services that the treaty's drafters intended, especially since these activities are a result of international cooperation.

Consequently, rather than being interpreted restrictively and concentrating primarily on the possible drawbacks of constellations, the articles of the Outer Space Treaty should be interpreted permissively, allowing constellations.

It has also been argued that, since orbits and frequencies constitute res communis, they are not "property" in the legal sense because they are finite communal resources that are objectionable to appropriation. However, while orbital positioning is protected by space law and international communications law, it does not apply to the first-come, first-served concept that applies to orbital placement, which is the de facto appropriation of orbits and frequencies by industrialized countries [102]. This, of course, does not favor developing countries in a sense that they are not able to participate in this "space grabbing" and thus does not include appropriation, since it is based on a traditional system of the distribution of access rights. The regime of res communis of outer space does not therefore meet the demand and needs of developing countries or even consider the possibilities for their future access to geostationary orbits, as well as the associated radio frequencies granted [103]. Of course, the WRC-19 made decisions to address this issue; however, some limitations regarding equitable access were identified since the identified spectrum for IMT/5G would overlap with the planned satellite spectrum for ultra-high-throughput satellite systems [104]. The ongoing challenges, like the increased demand for spectrum and the disproportionate accommodation of developing countries' needs, call for new rules or necessary amendments to ensure that a balance is struck and that all states enjoy the privilege of res communis of outer space, as well as a review of the res communis principle.

Basing on the argument herein, it is clear that even if the international space law seeks the benefit of humankind, it is insufficient given the argued controversy between the principle of equitable access and the principle of non-appropriation. Furthermore, more mega-constellations have been launched into outer space, and the only control mechanism in place is one based on good conduct. What will happen when one space actor is not on their best behavior? This will of course increase the risk of tragic events given the fact that there is no stable means of dealing with space debris. Moreover, even if space actors do not recognize orbital slots as appropriation, this is inadvertently the case, given the fact that space actors renew their licenses, meaning that they use these slots for decades.

It is therefore clear that mega-constellations are legally applicable under international space law, although the risks of interference are increased. It is also clear that the international space legal framework, although working towards addressing these issues, is not prepared to deal with them given how long it takes for international law amendments to be made. The launch and use of mega-constellations have brought to light the loopholes within international space law and thus the challenges that it has not yet been able to aptly solve. The measures put in place to ensure non-interference have proven to be ineffective, as indicated by the reports on astronomical interference [93], collisions, and space junk/debris. There is also a possible violation of environmental sustainability laws. There are currently no strict international rules that regulate or dictate how constellation operators should operate constellations in orbit, especially with the rapid rise in the use of mega-constellations [92]. For instance, the issue of flags of convenience states for launching,

the transfer of satellite ownership in orbit, the issue of the acquisition of radio frequencies proportionate to the number of slots and filings, the issue of equitability, and the international regulations on space traffic management pose challenges. These do not have adequate regulations and thus challenge the current international space law regime.

5. Proposed Solutions and Policy Recommendations

5.1. Policy Recommendations

5.1.1. Enhancing State Supervision and Authorization for Space Activities through National and International Obligations

According to the Outer Space Treaty, a commercial operator's operations must be governed, approved, and overseen by the state that launched the satellite and has jurisdiction and control over this spacecraft. In other words, both international obligations and national regulations require service providers to obtain permission or authorization from relevant governments to operate within their jurisdictions to ensure spectrum management while also fulfilling international obligations. Furthermore, as a result of technological advancements and massive constellations, states are gradually losing their ability to fully exercise their sovereign right to control activities by being forced to respond to the conduct of for-profit corporations operating within their borders. For instance, the Aeolus incident [105] highlights the urgent need for laws or policies to guide states on the procedures to take during these interactions. Therefore, urging states to ratify international laws on space would give the current international law regime the backing to regulate space actors, since it is already on a national level.

5.1.2. Clarifying Legal Definitions and Governance of Mega-Constellations

Secondly, because there is no definitive, legally binding definition of mega-constellations, the concept is legally ambiguous; this calls for discussions in order to clarify what mega-constellations are, as well as limitations on their operation, in order to close the gap that the lack of governance has created and that mega-constellation operators are taking advantage of.

Furthermore, it is necessary to clarify the parameters of space objects to cater for space debris, as well as the liability for damage incurred in the event of claims.

5.1.3. Modernizing Spectrum Policies for Equitable Access

Regarding spectrum policy sharing, spectrum policies ought to be modernized to allow for spectrum sharing. National agencies like the NTIA therefore need to coordinate the spectrum needs given the fact that more individual agencies are working on individual spectrum priorities.

Furthermore, in order to avoid the issue of warehousing radio frequencies, the United Nations Specialized Agency for Satellite Radio Spectrum recently updated its regulatory framework [106] to deal with this issue independently. Through this, a balance will be struck between the prevention of spectrum warehousing, the proper functioning of coordination mechanisms, and operational requirements for the deployment of NGSO systems. The flexible timelines and objective criteria will also regulate the phases of deployment of the satellites.

5.2. Recommendations on Space Traffic Management

5.2.1. Establishing an Independent International Monitoring System

At present, there is no impartial worldwide monitoring mechanism in place, which would be necessary to address interference as a whole. The only national monitoring stations that are part of the current international monitoring system are those that have been nominated by administrations in correspondence with the ITU Secretary General. Furthermore, these stations are monitored by an administration or by authorization granted by the appropriate administration, a public or private enterprise, a common monitoring service established by two or more countries, or an international organization, even though Article 16 of the ITU Radio Regulations encourages administrations to continue develop-

ing their monitoring facilities. This demonstrates a lack of autonomy, and independence prevents the availability of unbiased information that is necessary for the impartial resolution of conflicts involving any detrimental intervention. There should be a mechanism of independent international monitoring developed.

5.2.2. Developing International Law for Space Flight

Furthermore, there is no basic international law or order governing space flight, since there has been no international consensus on how this can be achieved. It is suggested that this governance can be classified into space resources, occupation, and income transfer to avoid the disordered state that they are currently in. Thus, with reference being made to international aviation governance, this problem can be solved to ensure controlled space flight, just as aviation has been controlled under the auspices of the International Civil Aviation Organization [107].

5.2.3. Strengthening ITU's Role in Space Traffic Management

Firstly, to address the issue of harmful interference and enhance the monitoring capabilities, a new resolution was proposed on the strengthening of the role of the ITU with regard to transparency and confidence-building measures in outer space activities [108]. The European Common Position provides the ITU with the ability to monitor and measure detrimental interferences affecting satellite systems using an independent network of monitoring control stations, irrespective of any data supplied by a complaining state. This could prove useful, especially with the increased number of satellites being launched, in terms of the accountability of all space actors, as well as granting autonomy to the ITU to record, regulate, and enforce international laws.

Secondly, the ITU could amend its trinity laws to make the license requirements more limited and stringent as a deterrent regarding the rise of unprepared space actors to ensure that, in the event of a failure to fulfill these requirements, satellites are not launched, as well as a follow-up process when the constellations are deployed.

Thirdly, to address the problem of congestion, the International Telecommunication Union (ITU) should manage the utilization of both orbital allocations and slots at the Earth's geostationary orbit (GEO), which is located 35,786 km above the equator, and exploitable sections of the electromagnetic spectrum. The goal of ITU coordination is to promote the economical, equitable, efficient, and sensible use of these resources. Actors must coordinate to make use of both usable areas of the spectrum and orbital locations, which are considered restricted resources. This is carried out on a "first-come, first-served" basis. This, however, does not preclude the needs of potential future users. Thus, striking a balance between current and future users will be challenging, but it will also guarantee that no state or other space actor will be able to rush to claim orbital or spectrum resources.

Finally, the ITU could also adopt the method of limiting the number of satellites launched per constellation in such a way that, if the constellation is launched for communication purposes and there are about three or more applications for the same purpose, the ITU could encourage collaborations between these parties, potentially assigning each party a number of satellites under the same constellation. To ensure success, the ITU could categorize the constellations into classes of relevance to avoid unnecessary applications and an upsurge in constellations. This could make way for the more productive cooperation and development of all collaborating parties.

5.3. Demystifying Controversy between Principles of Equitable Access and Non-Appropriation

5.3.1. Ensuring Equitable Access through Coordinated Efforts

In order to ensure equitable access for all states, the ITU RR 2016, after the WRC 2015, provided a measure stating that all filings for orbital slots must be accompanied by coordinated efforts considering the potential stakeholders' activities actively or passively impacted by the proposed satellite [28]. These coordinated efforts ensure that the satellite operator takes measures to refrain from causing radio interference to other satellites in

orbit [109] for a period of up to seven years [28]. These measures, although pledged to cater to the radio astronomy needs of astronomers, have proven insufficient due to the prevalent congestion in both the LEO and MEO, causing major interference and thus inhibiting equitable access [110]. Therefore, in addition to the filling and coordinated efforts, it is recommended that the ITU reduce the number of satellite constellations and satellites in LEO and MEO equitably.

5.3.2. Defining and Enforcing Limitations for Equitable Outer Space Access

The issue can also be dealt with based on the principle of equitable access by placing a limit on the number of orbital slots per satellite based on a minimum requirement, to ensure that operators efficiently operate the satellite constellation. The ITU can also factor in the operator's ability to perform mitigation measures to lower the interference rates—for instance, SpaceX's introduction of a "darksat" prototype—to curb astronomical interferences.

Every right, therefore, has a limitation, and, in order to fully enjoy outer space equitably, these limitations must be clearly delineated to avoid misunderstandings and to also ensure equitable access for all. Thus, by enforcing these measures, it is ensured that mega-constellation operators have access to outer space, as well as other actors, while also ensuring that the appropriation of outer space is not condoned by the granting of licenses and approval for specific amounts of time and employing the milestone-based approach to avoid the warehousing of orbital slots.

5.3.3. Enhancing Compliance through Non-Coercive Tools

These solutions and recommendations are more focused on the drafting, amendment, and passing of new laws, policies, or standards in order to cater to both the anticipated and unanticipated fallout of the use of mega-constellations, especially on a large scale. Therefore, for issues regarding the lack of proper enforcement mechanisms, and based on the solutions and recommendations given herein, a few specialized legal approaches can be employed, especially since there is a nexus between international space law, the rules of road or soft laws, and compliance. From a managerial point of view, states like the United States of America and China could comply with rules in the regulatory space law regime out of self-interest and, through this, they can easily respond to non-coercive tools like reporting and monitoring. Therefore, with this approach, especially for international space institutions, a focal point is created to maximize compliance, thus reducing the likelihood of defection. In this regard, the enforcement power needs to be placed in an automatic, autonomous administrative structure whose enforcement authority is set out in clear, unambiguous terms [111]. This enforcement could be in the form of the revocation or suspension of licenses or the imposition of fines, among others.

5.3.4. Enhancing Regulation of Private Space Actors

It is suggested that a single international regulatory body be established to regulate private actors or that the current space laws be modified to account for this omission, because the enforcement mechanism of the space law regime on private space actors is likewise deficient [112]. Domestic laws could also be strengthened by promoting firmer and more uniform standards, as well as creating more avenues of recourse when private actors cause harm, although it is important to note that some states will not be motivated or incentivized to increase regulation, since this may hinder the launch statistics of these particular States.

6. Conclusions

As the deployment of mega-constellations accelerates, ensuring equal access and non-interference in outer space becomes increasingly important. The growing number of satellites and mega-constellations occupying crucial orbits calls into question the fundamental ideals stated in the Outer Space Treaty, such as the "province of all mankind" and

the prohibition on appropriating space. To resolve these concerns, space actors must accelerate the legislative process and establish strong, nonpolitical solutions through UNGA resolutions, supplemented by multilateral agreements, as well alternative governance models such as adaptive forums, communication networks, and collaborative governance frameworks that reflect the global nature of these issues. To prevent mega-constellations from posing a substantial threat to space safety and sustainability, strict legislation and severe penalties for infractions are required.

Given the current and dynamic nature of this topic, extensive research and analysis are required. Future research should focus on global space governance, the long-term sustainability of space operations, and the imposition of sanctions or limits on operators to ensure compliance. By doing so, we can reap the benefits of mega-constellations while mitigating the potential negative consequences, promoting the more balanced and equitable usage of outer space. This approach will not only protect the interests of all space-faring nations, but will also ensure that outer space remains viable for future generations.

Author Contributions: Methodology, K.Y.; supervision, K.Y.; writing—original draft, K.Y. and S.A.; writing—reviewing and editing, K.Y. and S.A. All authors have read and agreed to the published version of the manuscript.

Funding: This research is funded by the National Social Science Foundation of China, for the research projects "International Regulation of Large Constellations and China's Response" (grant number 20CFX078) and "Research on Strengthening the Construction of Space Safety System in the New Era" (grant number 23&ZD137).

Data Availability Statement: The data used to support the findings of this study are available from the corresponding author upon reasonable request.

Acknowledgments: The authors greatly appreciate the insightful and constructive comments and suggestions from the anonymous reviewers.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Andy How Many Satellites Are Orbiting the Earth in 2023? Pixalytics. Available online: https://www.pixalytics.com/satellites-orbiting-earth-2023/ (accessed on 10 September 2024).
2. Boley, A.C.; Byers, M. Satellite mega-constellations create risks in Low Earth Orbit, the atmosphere and on Earth. *Sci. Rep.* **2021**, *11*, 10642. [CrossRef] [PubMed]
3. Grotch, S.E. Mega-Constellations: Disrupting the Space Legal Order. *Emory Int'l L. Rev.* **2022**, *37*, 101. Available online: https://heinonline.org/HOL/LandingPage?handle=hein.journals/emint37&div=7&id=&page= (accessed on 17 July 2024).
4. Jha, A.J.D.; Manti, N.P.; Carlo, A.; Zarkan, L.C.; Breda, P. Safeguarding the final frontier: Analyzing the legal and technical challenges to mega-constellations. *J. Space Saf. Eng.* **2022**, *9*, 636–643. Available online: https://www.sciencedirect.com/science/article/abs/pii/S2468896722001057 (accessed on 17 July 2024). [CrossRef]
5. Byers, M.; Boley, A. Mega-Constellations and International Law. In *Who Owns Outer Space?* Cambridge University Press: Cambridge, UK, 2023. Available online: https://www.cambridge.org/core/books/who-owns-outer-space/megaconstellations-and-international-law/B7453D99235EB7C62A29C9191087F612 (accessed on 18 July 2024).
6. Douglas Ligor Reduce Friction in Space by Amending the 1967 Outer Space Treaty. War on the Rocks. Available online: https://warontherocks.com/2022/08/stabilize-friction-points-in-space-by-amending-the-1967-outer-space-treaty/ (accessed on 10 September 2024).
7. Martin, A.-S.; Freeland, S.R. From One to Many: "Mega" (Constellation) Challenges to the Legal Framework for Outer Space. *Ann. Air Space Law* **2021**, *46*, 131–176. Available online: https://heinonline.org/HOL/P?h=hein.crasl/nairspl4646{\&}i=159 (accessed on 18 July 2024).
8. International Cooperation in the Peaceful Uses of Outer Space 1959. Available online: http://www.oosa.unvienna.org/oosa/COPUOS/copuos.html (accessed on 11 November 2023).
9. Treaty on principles governing the activities of States in the exploration and use of outer space, Including the moon and other celestial bodies. *Int. Leg. Mater.* **1967**, *6*, 386–390. [CrossRef]
10. Wessel, B. The Rule of Law in Outer Space: The Effects of Treaties and Nonbinding Agreements on International Space Law. *Hastings Int'l Comp. L. Rev.* **2012**, *35*, 289.

11. Von der Dunk, F.G. The origins of authorization: Article VI of the outer space treaty and international space law. Space Cyber Telecommun. *Law Program Fac. Publ.* **2011**, *69*, 1–20. Available online: https://digitalcommons.unl.edu/spacelaw/69?utm_source=digitalcommons.unl.edu%2Fspacelaw%2F69&utm_medium=PDF&utm_campaign=PDFCoverPages (accessed on 21 August 2024).
12. Schmalenbach, K. Convention on International Liability for Damage Caused by Space Objects. In *Corporate Liability for Transboundary Environmental Harm*; Springer International Publishing: Cham, Switzerland, 2023; pp. 523–536. [CrossRef]
13. Marboe, I. Agreement on the Rescue and Return of Astronauts and Objects Launched into Outer Space. In *Oxford Research Encyclopedia of Planetary Science*; Oxford University Press: Oxford, UK, 2019. [CrossRef]
14. Cocca, A.A. Convention on Registration of Objects Launched into Outer Space. *Int. Leg. Mater.* **2023**, 255–267. [CrossRef]
15. Steven, F. Up, Up and . . . Back: The Emergence of Space Tourism and Its Impact on the International Law of Outer Space. *Chic. J. Int. Law* **2005**, *6*, 1–22. Available online: https://chicagounbound.uchicago.edu/cjil/vol6/iss1/4 (accessed on 9 July 2024).
16. Rummel, J.D. Planetary exploration in the time of astrobiology: Protecting against biological contamination. *Proc. Natl. Acad. Sci. USA* **2001**, *98*, 2128–2131. [CrossRef]
17. Haris Durrani Is Spaceflight Colonialism? 2019. Available online: https://www.thenation.com/article/archive/apollo-space-lunar-rockets-colonialism/ (accessed on 22 December 2020).
18. Alan Marshall development and imperialism in space. *Space Policy* **1995**, *11*, 41–52. Available online: http://www.sciencedirect.com/science/article/pii/026596469593233B (accessed on 6 August 2024). [CrossRef]
19. Freeland, S.; Jakhu, R. Article II. In *Cologne Commentary on Space Law: V. 1, Outer Space Treaty*; Carl Heymanns: Cologne, Germany, 2009; Volume 1, pp. 44–63.
20. Kanevskaia, O. Constitution of the International Telecommunication Union. *Int. Leg. Mater.* **2016**, *135*, 1–66. Available online: http://opil.ouplaw.com/view/10.1093/law-oxio/e135.013.1/law-oxio-e135?rskey=MVcULk&result=7&prd=OXIO (accessed on 9 July 2024).
21. The State Council. China's New Mega-Constellation Marks Milestone in Satellite Internet. Available online: https://english.www.gov.cn/news/202408/09/content_WS66b55ad9c6d0868f4e8e9cf8.html (accessed on 9 August 2024).
22. Jones, A. China to Launch First Satellites for Megaconstellation in August. *Space News*. 27 June 2024. Available online: https://spacenews.com/china-to-launch-first-satellites-for-megaconstellation-in-august/ (accessed on 9 August 2024).
23. ITU News ITU Members Agree to New Milestones for Non-Geostationary Satellite Deployment. The UN Agency for Digital Technologies. Available online: https://www.itu.int/hub/2020/01/itu-members-agree-to-new-milestones-for-non-geostationary-satellite-deployment/#:~:text=The%20milestone%2Dbased%20approach%20will,radio%2Dfrequency%20bands%20and%20services (accessed on 10 September 2024).
24. Galeriu, I.-D. "Paper Satellites" and the Free Use of Outer Space. Globalex. Available online: https://www.nyulawglobal.org/globalex/paper_satellites_free_use_outer_space1.html (accessed on 10 September 2024).
25. Henry, C. ITU wants mega constellations to meet tougher launch milestones. *Space News*, 9 May 2019.
26. WRC. ITU Radiocommunication Assembly Sets Agenda for Development of IMT-2030 for 6G and Sustainable Use of Spectrum and Orbital Resources. Available online: https://www.itu.int/en/mediacentre/Pages/PR-2023-11-17-RA23-closing-ceremony.aspx#:~:text=in%20accordance%20with%20Resolution%20219,resources%20used%20by%20space%20services (accessed on 10 September 2024).
27. Henry, C. FCC Approves SpaceX, Telesat, LeoSat and Kepler Internet Constellations. *Space News*. 23 November 2018. Available online: https://spacenews.com/fcc-approves-spacex-telesat-leosat-and-kepler-internet-constellations/ (accessed on 18 July 2023).
28. International Telecommunication Union. Radio Regulations Articles. In *International Legal Materials*; 2012; Available online: https://search.itu.int/history/HistoryDigitalCollectionDocLibrary/1.41.48.en.101.pdf (accessed on 21 August 2024).
29. Nag, S.; Murakami, D.; Marker, N.; Lifson, M.; Kopardekar, P. Prototyping Operational Autonomy for Space Traffic Management. *Acta Astronaut.* **2021**, *180*, 489–506. [CrossRef]
30. *ITU Convention of the International Telecommunication Union*; United Nations: Geneva, Switzerland, 1994.
31. Brobst, J.A. Role of the International Telecommunication Union in Regulating Space Activities. In *International Space Law in the New Space Era: Principles and Challenges*; Bhat, B.S., Ukey, D., Variath, A., Eds.; Oxford University Press: Oxford, UK, 2024. [CrossRef]
32. ITU. *"Report on Satellite Regulation in Developing Countries" TU-D Study Group 1, 3rd Study Period (2002–2006)*; Question 17/1; International Telecommunications Union: Geneva, Switzerland, 2004; Available online: https://www.itu.int/itudoc/itu-d/question/studygr1/q17-1-ii.pdf (accessed on 18 August 2024).
33. WRC-19. *Clarification on the Implementation of Article 48 of the ITU Constitution by the Radiocommunication Bureau*; International Telecommunications Union: Sharm el-Sheikh, Egypt, 2019.
34. Putro, Y.M.; Andriani, P.; Salsabila, G.; Al Asyari, H. Satellite Mega Constellations: Conflict Between Freedom of Exploration and Unsustainable Outer Space Activities. *Brawijaya Law J.* **2023**, *10*, 89–105. Available online: https://lawjournal.ub.ac.id/index.php/law/article/view/1073 (accessed on 15 March 2024). [CrossRef]
35. Abashidze, A.; Chernykh, I.; Mednikova, M. Satellite constellations: International legal and technical aspects. *Acta Astronaut.* **2022**, *196*, 176–185. [CrossRef]
36. Johnson, C.D. The Legal Status of MegaLEO Constellations and Concerns About Appropriation of Large Swaths of Earth Orbit. In *Handbook of Small Satellites*; Springer International Publishing: Cham, Switzerland, 2020; pp. 1–22.

37. Drmola, J.; Hubik, T. Kessler syndrome: System dynamics model. *Space Policy* **2018**, *44–45*, 29–39. [CrossRef]
38. Sánchez, A.H.; Soares, T.; Wolahan, A. Reliability aspects of mega-constellation satellites and their impact on the space debris environment. In Proceedings of the 2017 Annual Reliability and Maintainability Symposium (RAMS), Orlando, FL, USA, 23–26 January 2017; pp. 1–5.
39. Bourbonniere, M.; Lee, R.J. *Reforming International Space Law: Balancing Commercial and Public Interests*; Oxford University Press: Oxford, UK, 2019.
40. Hoe, L.I.; Umar, R.; Kamarudin, M.K.A. Article III of the 1967 Outer Space Treaty: A Critical Analysis. *Int. J. Acad. Res. Bus. Soc. Sci.* **2018**, *8*, 326–338. [CrossRef]
41. Francis, T. Rio Declaration on environment and development. *Glob. Environ. Politics Pers. Planet* **2016**, 117–120. [CrossRef]
42. Pelton, J.N.; Madry, S. Retrofitting and Redesigning of Conventional Launch Systems for Small Satellites. In *Handbook of Small Satellites: Technology, Design, Manufacture, Applications, Economics and Regulation*; Springer International Publishing: Cham, Switzerland, 2020; pp. 403–422.
43. Robert, G.; Ryan, E.A.; Marais, C.J. Balhatchet, Impact of Rocket Launch and Space Debris Air Pollutant Emissions on Stratospheric Ozone and Global Climate. *Earth's Future* **2022**, *10*, e2021EF002612. [CrossRef]
44. Safdie, S. Could a Rocket Launch Really Become "Green" and Sustainable? Available online: https://greenly.earth/en-us/blog/ecology-news/could-a-rocket-launch-really-become-green-and-sustainable (accessed on 10 July 2024).
45. Byers, M.; Byers, C. Toxic splash: Russian rocket stages dropped in Arctic waters raise health, environmental and legal concerns. *Polar Rec.* **2017**, *53*, 580–591. [CrossRef]
46. Rettberg, P.; Antunes, A.; Brucato, J.; Cabezas, P.; Collins, G.; Haddaji, A.; Kminek, G.; Leuko, S.; McKenna-Lawlor, S.; Moissl-Eichinger, C.; et al. Biological Contamination Prevention for Outer Solar System Moons of Astrobiological Interest: What Do We Need to Know? *Astrobiology* **2019**, *19*, 951–974. [CrossRef] [PubMed]
47. Rummel, R.; Yi, W.; Stummer, C. GOCE gravitational gradiometry. *J. Geod.* **2011**, *85*, 777–790. [CrossRef]
48. Glavin, D.P.; Dworkin, J.P.; Lupisella, M.; Kminek, G.; Rummel, J.D. Biological contamination studies of lunar landing sites: Implications for future planetary protection and life detection on the Moon and Mars. *Int. J. Astrobiol.* **2004**, *3*, 265–271. [CrossRef]
49. Carter, S.M. Biological Threats and Growth in Space. In *Cyber-Human Systems, Space Technologies And Threats*; Nichols, R.K., Carter, C.M., Diebold, C., Drew, J., Farcot, M., Hood, J.P., Jackson, M.J., Johnson, P., Joseph, S., Khan, S., et al., Eds.; New Prairie Press: Manhattan, NY, USA, 2023; Available online: https://kstatelibraries.pressbooks.pub/cyberhumansystems/chapter/9-biological-threats-and-growth-in-space-sincavage/ (accessed on 10 July 2024).
50. Ashruf, A.M.; Bhaskar, A.; Pant, T.K. Deciphering Solar Cycle Influence on Long-Term Orbital Deterioration of Space Debris in LEO and MEO orbits 2024. Available online: https://arxiv.org/abs/2405.08837 (accessed on 11 August 2024).
51. Olivieri, L.; Giacomuzzo, C.; Lopresti, S.; Francesconi, A. Research at the University of Padova in the Field of Space Debris Impacts against Satellites: An Overview of Activities in the Last 10 Years. *Appl. Sci.* **2023**, *13*, 3874. [CrossRef]
52. Barbier, L. *NASA Guidelines for Promoting Scientific and Research Integrity (No. HQ-E-DAA-TN61012)*; National Aeronautics and Space Administration Office of the Chief Scientist: Washington, DC, USA, 2018.
53. Planetary Protection Research. Astrobiology at NASA. Available online: https://astrobiology.nasa.gov/research/astrobiology-at-nasa/planetary-protection-research/ (accessed on 10 July 2024).
54. Lihua, W.U.; Tianshu, M.A.; Yuanchao, B.I.A.N.; Sijia, L.I.; Zhaoqiang, Y.I. Improvement of regional environmental quality: Government environmental governance and public participation. *Sci. Total Environ.* **2020**, *717*, 137265. [CrossRef]
55. Dempsey, P.S. National laws governing commercial space activities: Legislation, regulation, & enforcement. *J. Space Saf. Eng.* **2014**, *1*, 44–60. [CrossRef]
56. Roberts, L.D. A Lost Connection: Geostationary Satellite Networks and the International Telecommunication Union. *Berkeley Technol. Law J.* **2000**, *15*, 1095–1144. Available online: www.jstor.org/stable/24115686 (accessed on 27 February 2021).
57. Zhang, J.; Cai, Y.; Xue, C.; Xue, Z.; Cai, H. LEO Mega Constellations: Review of Development, Impact, Surveillance, and Governance. *Space Sci. Technol.* **2022**, *2022*, 9865174. [CrossRef]
58. ITU Sharing the Sky—ITU's Role in Managing Satellite and Orbit Spectrum Resources. Available online: https://www.itu.int/en/plenipotentiary/2014/newsroom/Pages/backgrounders.aspx (accessed on 11 August 2024).
59. Marklund, A. WRC-23: Satellite Is Key for the Future of Radiocommunications. *SES*. 2024. Available online: https://www.ses.com/blog/wrc-23-satellite-key-future-radiocommunications (accessed on 11 September 2024).
60. Rainbow, J. Satellite industry at odds over proposed power limit review ahead of WRC-23. *Space News*. 9 November 2023. Available online: https://spacenews.com/satellite-industry-at-odds-over-proposed-power-limit-review-ahead-of-wrc-23/ (accessed on 11 September 2024).
61. Optional Protocol to the Vienna Convention on Diplomatic Relations, Concerning the Compulsory Settlement of Disputes, UN Treaty Series. 1964, Volume 500, p. 241. Available online: https://treaties.un.org/doc/Treaties/1964/06/19640624%2010-27%20PM/Ch_III_5p.pdf (accessed on 11 July 2024).
62. Butsch, F. GPS and GLONASS radio interference in Germany. In Proceedings of the ION GPS, Kansas City, MO, USA, 16–19 September 1997; pp. 1427–1436.
63. Boczek, B.A. Flags of Convenience: An International Legal Study. *Int. J.* **1963**, *18*, 558. [CrossRef]
64. UNCTAD. *Review of Maritime Transport*; UN: Geneva, Switzerland, December 2013; pp. 35–65. [CrossRef]

65. Edwin Anderson, I.H. The Nationality of Ships and Flags of Convenience: Economics, Politics, and Alternatives. *Tul. Mar. L. J.* **1997**, *21*, 139–170.
66. Gold, E. Learning from Disaster: Lessons in Regulatory Enforcement in the Maritime Sector. *Rev. Eur. Community Int'l Envtl. L.* **1999**, *8*, 16–20. [CrossRef]
67. Kleiman, M.J. Patent Rights and Flags of Convenience in Outer Space. *Air Space Lawyer* **2011**, *23*, 4–7. Available online: http://www.thespacereview.com/article/1772/1 (accessed on 10 December 2023).
68. Lyall, F.; Larsen, P.B. Space Law: A Treatise. Ashgate Publishing Limited: Farnham, UK, 2009; pp. 469–470.
69. Gabrynowicz, J.I. One Half Century and Counting: The Evolution of U.S. National Space Law and Three Long-Term Emerging Issues. *Harv. L. Pol'y Rev.* **2010**, *4*, 405–426.
70. Tan, D. Towards a New Regime for the Protection of Outer Space as the "Province of All Mankind". *Yale J. Int'l L.* **2000**, *25*, 145–194.
71. Goh, G.M. *Dispute Settlement in International Space Law: A Multi-Door Courthouse for Outer Space*; Study Space Law; Leiden University: Leiden, the Netherlands, 2007; pp. 365–401. Available online: https://scholarlypublications.universiteitleiden.nl/access/item%3A2932757/view (accessed on 14 August 2024).
72. Bryan Schwartz; Mark L Berlin After the Fall: An Analysis of Canadian Legal Claims for Damage Caused by Cosmos 954. *McGill Law J.* **1982**, *27*, 676. Available online: https://lawjournal.mcgill.ca/article/after-the-fall-an-analysis-of-canadian-legal-claims-for-damage-caused-by-cosmos-954/ (accessed on 11 August 2024).
73. OECD. *SPACE 2030: Tackling Society's Challenges*; OECD Publishing: Paris, France, 2005. [CrossRef]
74. Özçayir, Z. Flags of Convenience and the Need for International Cooperation. *Int. Marit. Law* **2000**, *7*, 111–117.
75. United Nations Office for Outer Space Affairs. *UNOOSA Space Debris Mitigation Guidelines for the Committee on the Peaceful Uses of Outer Space, UN*; United Nations Office for Outer Space Affairs: Vienna, Austria, 2018; pp. 89–93. [CrossRef]
76. Kessler, D.J.; Johnson, N.L.; Liou, J.C.; Matney, M. The Kessler Syndrome: Implications to Future Space Operations (AAS 10-016). *Adv. Astronaut. Sci.* **2010**, *137*, 2010.
77. Sundahl, M.J. Unidentified Orbital Debris: The Case for a Market-Share Liability Regime. *Hastings Int'l Comp. L. Rev.* **2000**, *24*, 125.
78. Kaineg, S. The Growing Problem of Space Debris. *Hastings Envt'l L.J.* **2019**, *26*, 277. Available online: https://repository.uchastings.edu/hastings_environmental_law_journal/vol26/iss2/5 (accessed on 14 July 2024).
79. von der Dunk, F. Transfer of ownership in orbit: From fiction to problem. In *Ownership of Satellites*; Nomos Verlagsgesellschaft mbH & Co. KG.: Baden-Baden, Germany, 2017; pp. 27–44.
80. Undseth, M.; Jolly, C.; Olivari, M. *Evolving Public Private Relations in the Space Sector Lessons Learned for the Post-COVID-19 Era*; OECD Science, Technology and Industry Policy Papers, No. 114; OECD Publishing: Paris, France, 2021.
81. Rausser, G.; Choi, E.; Bayen, A. Public–private partnerships in fostering outer space innovations. *Proc. Natl. Acad. Sci. USA* **2023**, *120*, e2222013120. [CrossRef]
82. IN RE: IRIDIUM OPERATING LLC, Iridium Capital Corp., Iridium IP LLC, Iridium LLC, Iridium Roaming LLC, Iridium (Potomac) LLC, and Iridium Promotions, Inc., Debtors. Motorola, Inc., Appellant, v. Official Committee of Unsecured Creditors and JPMorgan Chase Bank, N.A., Appellees. 2007. Available online: https://caselaw.findlaw.com/court/us-2nd-circuit/1193131.html (accessed on 14 July 2024).
83. Coykendall, J.; Hardin, K.; Brady, A.; Hussain, A. Riding the Exponential Growth in Space. *Deloitte Insights*. 22 March 2023. Available online: https://www2.deloitte.com/us/en/insights/industry/aerospace-defense/future-of-space-economy.html (accessed on 14 July 2024).
84. United Nations. *Agreement Governing the Activities of States on the Moon and Other Celestial Bodies*; United Nations: San Francisco, CA, USA, 2018; pp. 30–39. [CrossRef]
85. Sgrosso, G.C. Last comments on the text of the draft Protocol to the Convention on International Interests in Mobile Equipment on Matters Specific to Space Assets (hereafter Space Assets Protocol). In Proceedings of the International Astronautical Congress, IAC, Naples, Italy, 1–5 October 2012; pp. 11529–11537.
86. Dunk, F.G. von der International Space Law. In *Handbook of Space Law*; von der Dunk, F.G., Ed.; Edward Elgar Publishing Ltd.: Cheltenham, UK, 2015; pp. 29–126.
87. Heads of Delegations, E.N. *Declaration of the First Meeting of Equatorial Countries (Bogotá Declaration)*; UNGA: Vienna, Austria, 1977.
88. Allison, A.L. *The ITU and Managing Satellite Orbital and Spectrum Resources in the 21st Century*; Springer International Publishing: Cham, Switzerland, 2014. Available online: https://link.springer.com/book/10.1007/978-3-319-05314-1 (accessed on 11 July 2024).
89. Noyes, J.E. The Common Heritage of Mankind: Past, Present, and Future. *Denv. J. Int'l L. Pol'y* **2011**, *447*, 2011–2012.
90. Potter, B. *The Growing Specter of LEO/GEO Interference*; 32nd Annual AIAA/USU Conference on Small Satellites, Digital Commons. 2018. Available online: https://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=4133&context=smallsat (accessed on 10 July 2024).
91. ITU World Administrative Radio Conference on the use of the geostationary-satellite orbit and the planning of the space services utilizing it (2nd session) (Geneva, 1988). *Int. Leg. Mater.* **1988**. Available online: http://handle.itu.int/11.1004/020.1000/4.119 (accessed on 10 July 2024).
92. Kessler Syndrome. Wikipedia. 2024. Available online: https://en.wikipedia.org/wiki/Kessler_syndrome (accessed on 14 July 2024).

93. Gallozzi, S.; Scardia, M.; Maris, M. Concerns about Ground Based Astronomical Observations: A Step to Safeguard the Astronomical Sky. ArXiv: Instrumentation and Methods for Astrophysics 2020. pp. 4–11. Available online: https://www.semanticscholar.org/paper/Concerns-about-ground-based-astronomical-a-step-to-Gallozzi-Scardia/91e8b7b0e836be58dca2b919139f1ccf67c8f15d (accessed on 14 July 2024).
94. United Nations. Statement on International cooperation in the peaceful uses of outer space. *Chin. J. Int. Law* **2007**, *6*, 507–509. [CrossRef]
95. Robinson, G.S. Red Space Law. *Technol Rev.* **1977**, *80*, 58–64. [CrossRef]
96. McDowell, J. Jonathan's Space Report. Available online: https://planet4589.org (accessed on 12 August 2024).
97. Antal, J. The Battle for Low Earth Orbit and the Stratosphere. European Security and Defence. Available online: https://euro-sd.com/2023/12/articles/34976/the-battle-for-low-earth-orbit-and-the-stratosphere/ (accessed on 12 August 2024).
98. Grossman, L. Half of All Active Satellites are Now from SpaceX. Here's Why That May be a Problem. Science News. Available online: https://www.sciencenews.org/article/satellites-spacex-problem-space-pollution (accessed on 12 August 2024).
99. Venkatesan, A.; Lowenthal, J.; Prem, P.; Vidaurri, M. The impact of satellite constellations on space as an ancestral global commons. *Nat. Astron.* **2020**, *4*, 1043–1048. [CrossRef]
100. Guido, P. Debris Mitigation in LEO Orbits: Performance Analysis and Comparison of Different Deorbit Systems. 2014. Available online: http://goo.gl/f6Ukl5 (accessed on 11 July 2024).
101. Dembling, P.G.; Arons, D.M. The Evolution of the Outer Space Treaty. In *Space Law*; Lyall, F., Larsen, P.B., Eds.; Ashgate: Farnham, UK, 2007; pp. 151–188. Available online: https://digitalcommons.unl.edu/spacelawdocs/3 (accessed on 11 July 2024).
102. Altholz, E.D. WARC 1985: The Effects of an Equitable Access Regime on Satellite Telecommunications Services. *Univ. Chic. Leg. Forum* **1986**, *1986*, 10. Available online: http://chicagounbound.uchicago.edu/uclf/vol1986/iss1/10 (accessed on 11 July 2024).
103. Galloway, J.F. The Current Status of the Controversy Over the Geostationary Orbit. In Proceedings of the 21st Colloquium on the Law of Outer Space, Dubrovnik, Yugoslavia, 1–8 October 1978; p. 22.
104. AsiaSat Decisions Made at WRC-19 Support Satellite's Continued Access to Essential Radio Spectrum for Future Applications. *AsiaSat*. 2019. Available online: https://www.asiasat.com/news/blog/decisions-made-wrc-19-support-satellites-continued-access-essential-radio-spectrum-future (accessed on 12 August 2024).
105. Markelov, G.N. Plume impingement analysis for Aeolus spacecraft and gas/surface interaction models. *J. Spacecr. Rocket.* **2007**, *44*, 607–618. [CrossRef]
106. World Radiocommunication Conference 2019. Available online: https://www.itu.int/en/ITU-R/study-groups/rcpm/Pages/wrc-19-studies.aspx (accessed on 14 July 2024).
107. Huang, J. The Development of International Air Law under the Auspices of ICAO. In Proceedings of the Civil Aviation Legal Advisers Forum, Singapore, 16–17 May 2019.
108. UNGA. *UNGA Resolution on Reducing Space Threats through Norms, Rules and Principles of Responsible Behaviours*; 76th Sess., Suppl. No. 49; UNGA: New York, NY, USA, 2021.
109. Cappella, M. The Principle of Equitable Access in the age of Mega-constellations. In *Legal Aspects Around Satellite Constellations 15*; Froehlich, A., Ed.; Springer: Berlin/Heidelberg, Germany, 2019; pp. 11–23.
110. Stelmakh, O.S. Global Space Governance for Ensuring Responsible Use of Outer Space, Its Sustainability and Environmental Security: Legal Perspective. In Proceedings of the International Astronautical Congress, IAC, Jerusalem, Israel, 12–16 October 2015; Volume 15, pp. 12245–12247.
111. Glickman, S.K. Enforcement Mechanisms of the Law of the Sea Treaty. *Suffolk Transnat'l L.J.* **1977**, *1*, 1. Available online: https://heinonline.org/HOL/License (accessed on 12 December 2023).
112. Christol, C.Q. An Introduction to Space Law. *Space Policy* **2000**, *16*, 229. [CrossRef]