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A Sky Full of Stars, Constellations, Satellites and More! Legal Issues for a 'Dark' Sky

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Abstract
An ever-increasing number of actors, including private entities, are conducting space activities that involve the launch of spacecraft into orbit. The 'miniaturisation' of technology has meant that this now includes the launch of large constellations of small satellites. Notwithstanding their commercial benefits, the deployment of large numbers of objects into Low Earth Orbit raises concerns for elements of the international space community specifically concerned with the protection of the 'dark' skies. Large constellation programmes and space debris reflect sunlight into astronomical telescopes or cross their field of view, in many instances degrading certain astronomical observations which would otherwise support our capacity to understand the universe, enable deep-space navigation and exploration and provide early warning detection of near-Earth objects. The various differing interests at stake represent challenges in the application of international environmental law as well as for the current space legal framework, especially for the preservation of the space environment and the long-term sustainability of space activities. Considering the congested space environment and the need to preserve the 'dark' skies for astronomical observation, establishing space traffic management rules and standards is of particular importance.

Keywords
astronomy, large constellations, mega-constellations, environment, sustainability, international law, space law
space traffic management

1. Introduction – Preservation of the Night Skies: New Concerns for the Space Community

Astronomical observations are particularly relevant for our understanding of the universe. The dark skies[1] represent a window towards an 'unknown' world, allowing us to observe planets and stars.[2] The night sky offers a rich display to fortunate viewers, but over the last few decades its viewing quality has been increasingly diminished as a result of encroaching

1. 'Dark Skies' means 'places where the darkness of the night sky is relatively free of interference from artificial light': <https://www.solar-eye.com/blog-lighting-for-dark-skies-the-ultimate-guide-to-dark-sky-friendly-lighting/> accessed 27 November 2023. Unless otherwise stated, all URLs were last accessed on this date.
2. Ciara Finnegan, 'Indigenous Interests in Outer Space: Addressing the Conflict of Increasing Satellite Numbers with Indigenous Astronomy Practices' (2022) 11 *Laws* 2, 26 <https://doi.org/10.3390/laws11020026>.

ground-based light pollution.[3] A new threat is now also emerging: the large number of satellites being introduced into Low Earth Orbits (LEOs). As many as 100,000 additional satellites – and perhaps even more – could be placed into these orbits in the coming decade.

These large constellation satellite systems play a range of important roles, including the enabling of global communications networks. Within the new dynamic of space activities, particularly in an increasingly globalised and digitised world where the demand for fast and affordable internet and communications is rapidly growing, satellite mega-constellations[4] are becoming an attractive choice. Private commercial companies such as SpaceX and Amazon have developed projects such as Starlink[5] and Kuiper[6] respectively, which seek to offer low-latency, high-speed broadband internet connectivity to all corners of the globe. Nevertheless, as a counterpoint to these benefits, the deployment of tens of thousands of satellites could potentially lead to the over-population of Non-Geostationary Orbits, as these and other companies and countries[7] are planning to increase the number of the existing satellites within the next decade, potentially to a staggering degree.[8]

In some areas, these satellites can disrupt astronomy because of their sheer number, their brightness, and their ubiquitous radio emissions.[9] In particular, they can affect measurements that require twilight observation, such as searches for (potentially) Earth-threatening asteroids. The proliferation of LEO satellites entails the potential to negatively impact the (once) pristine view of the natural night sky and consequently to hamper ground-based astronomical observations, resulting in considerable financial losses and scientific miscalculations in the methodical observation of the night sky.

Mega-constellations and space debris[10] represent significant issues, as the number of objects in space rises at an exponential rate. There are realistic fears that this trend will have

3. Report of the United Nations/Spain/International Astronomical Union Conference on Dark and Quiet Skies for Science and Society (5 November 2021) UN Doc A/AC.105/1255; Summary of discussions on dark and quiet skies for science and society (6 December 2021) UN Doc A/AC.105/1257.
4. In this article, the terms 'large constellations' and 'mega-constellations' are used interchangeably. Both expressions refer in a broad sense to constellations consisting of several hundreds or even thousands of satellites orbiting Earth, primarily in Low Earth Orbit.
5. Starlink website, Astronomy Discussion with National Academy of Sciences (28 April 2020) <www.spacex.com/updates/#starlink-update-04-28-2020>.
6. Amazon website, 'Amazon makes historic launch investment to advance Project Kuiper' (5 April 2022) <www.aboutamazon.com/news/innovation-at-amazon/amazon-makes-historic-launch-investment-to-advance-project-kuiper>.
7. Andrew Jones, 'China is developing plans for a 13000 satellite megaconstellation' *SpaceNews* (21 April 2021) <https://spacenews.com/china-is-developing-plans-for-a-13000-satellite-communications-megaconstellation/>; see also Andrew Jones, 'China's megaconstellation project established satellite cluster in Chongqing' *SpaceNews* (12 January 2022) <https://spacenews.com/chinas-megaconstellation-project-establishes-satellite-cluster-in-chongqing/>.
8. This will also raise issues relating to the availability of sufficient radio spectra for these constellations to operate without causing unacceptable harmful interference to other systems. Whilst this is not the focus of this article, it is a very important challenge that also will need to be addressed: see eg SpaceWatch.Global, 'Rwanda Files at ITU for Nearly 330 000 satellites' (October 2021) <https://spacewatch.global/2021/10/rwanda-files-at-itu-for-nearly-330000-satellites/>.
9. See International Academy of Astronautics (IAA), the International Astronautical Federation (IAF) and the International Institute of Space Law (IISL), Cooperative initiative to develop comprehensive approaches and proposals for Space Traffic Management, 17 September 2022, 9–10 <https://iaaspace.org/wp-content/uploads/iaa/Communication/stm-mou.pdf >.
10. For a detailed discussion of the challenges associated with the proliferation of space debris, see Martha Mejia-Kaiser, 'Space Law and Hazardous Space Debris' (January 2020) *Oxford Research Encyclopedia* <https://oxfordre.com/planetaryscience/view/10.1093/acrefore/9780190647926.001.0001/acrefore-9780190647926-e-70>; Steven Freeland, 'Space Debris: A Major Challenge for the Future of Humanity' (July 2021) ILA Reporter <https://ilareporter.org.au/2021/07/space-debris-a-major-challenge-for-the-future-of-humanity-steven-freeland/>; European Space Agency, *The current state of space debris* (12 October 2020) <https://www.esa.int/Space_Safety/Space_Debris/The_current_state_of_space_debris>.

a negative impact on astronomical observation, the safety of space operations, and the long-term sustainability of space activities.

A first point to consider is whether astronomy can be considered as a space activity in order to understand whether the norms included in the United Nations Space Treaties and other relevant legal instruments can, indeed, be applied to astronomical observation.[11] On the one hand, the 'physical' exploration of space is conducted by human spaceflight and robotic space probes; on the other, ground-based astronomy is an important way to conduct space exploration by observation from Earth.

During the UNISPACE+50 Conference in 2018,[12] the importance of increasing our knowledge of outer space for the benefit of humankind was underscored, including through enhanced access to astronomy and space science data. It is within this perspective that the protection of the dark skies has, in 2022, been added as a new single agenda item entitled 'General exchange of views on dark and quiet skies for science and society' at the Scientific and Technical Subcommittee (STC) of the United Nations Committee for the Peaceful Uses of Outer Space (COPUOS).[13] Several COPUOS Member States have underlined the fact that astronomical observations were an essential aspect of space activities and should be protected from interference, because space and Earth-based installations give to the space community the ability to understand the universe and observe stars and other planets, thus enabling deep-space navigation and exploration, as well as providing early warning detection of near-Earth objects.[14]

A working paper[15] sponsored by Chile, Slovakia, Spain, the International Astronomical Union, the European Southern Observatory and the Square Kilometre Array Observatory was presented and accepted by the COPUOS STC in February 2022. The paper encourages the international community to protect global astronomical observation capabilities from disruptive and harmful artificial interference. In February 2023, during the meeting of the STC, some delegations also proposed the creation of an Expert Group 'with the task of promoting awareness, providing guidance, and enabling communication and cooperation between Member States and stakeholders regarding the impact of the satellite constellations on astronomy […]'.[16] With this perspective in mind, there is a clear view among many that astronomical observations represent an essential tool for the conduct of space activities. In this regard, some States have already established national policies and introduced regulatory regimes that address light pollution in order to protect astronomy from artificial light.[17]

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11. Gabriel Lafferanderie, 'Space Law Relevant to Astronomy', Selected Papers on Space Science Education, Remote Sensing, and Small Satellites. Seminars of the United Nations Programme on Space Applications (1997) (A/AC.105/650) Vol 8, United Nations, New York 75, 76–79.
12. UNGA Resolution, Fiftieth anniversary of the first United Nations Conference on the Exploration and Peaceful Uses of Outer Space: space as a driver of sustainable development (26 October 2018) A/RES/73/6 <https://www.unoosa.org/res/oosadoc/data/resolutions/2021/general_assembly_76th_session/ares763_html/A_RES_76_3_E.pdf>.
13. Report of the Scientific and Technical Subcommittee of COPUOS on its fifty-ninth session (23 February 2022) UN Doc. A/AC.105/1258, para. 16 <https://www.unoosa.org/oosa/en/ourwork/copuos/stsc/2022/index.html>.
14. ibid para 267.
15. COPUOS, Working Paper prepared by Chile, Slovakia, Spain, the International Astronomical Union, the European Southern Observatory and the Square Kilometre Array Observatory, Protection of Dark and Quiet Skies (24 December 2021) UN Doc A/AC.105/C.1/L.396 <https://www.unoosa.org/res/oosadoc/data/documents/2022/aac_105c_1l/aac_105c_1l_396_0_html/AC105_C1_L396E.pdf>.
16. COPUOS, Conference Room Paper on the Protection of Dark and Quiet Skies for science and society (15 February 2023) A/AC.105/C.1/2023/CRP/18/Rev.1, para 8 <https://www.unoosa.org/res/oosadoc/data/documents/2023/aac_105c_12023crp/aac_105c_12023crp_18rev_1_0_html/AC105_C1_2023_CRP18Rev01E.pdf>.
17. National Capital Authority, Australia, 'Outdoor Lighting Policy' (August 2012) <https://www.nca.gov.au/sites/default/files/publication-documents/1021_NCA-Lighting-Policy.pdf>. The Australian policy makes reference to

The increasing trend towards deployment of large constellations of small satellites highlights a number of challenges for the current legal framework for space activities,[18] including the protection of the dark skies and concerns regarding the space environment, as well as how to reconcile the free access to and use of outer space with the activities of other States and private entities.[19] These and other concerns will require a determination of practical and appropriate standards or rules, also with respect to environmental impact assessment and space traffic management.

This paper addresses the key elements of international environmental law applicable to space activities, in particular mega-constellations, with a view to protect the 'dark' skies. In addition, it focuses on the necessity of conciliating the main principles of the Outer Space Treaty with the various activities conducted in outer space and on Earth. With this in mind, the authors conclude that it is important to development norms to regulate the traffic in orbit in order to limit the risk of interference between activities and to allow actors to conduct their activities in a safe and secure manner.

This paper therefore provides a more detailed analysis than most previous commentaries of the interaction between the principles of international law applicable to the protection of the space environment, taking into account new space activities and the need to establish rules to regulate space traffic. It examines the challenges that arise regarding the problems of light pollution (2), the increasing use of large constellations of small satellites (3), and the complexities required to develop practical and effective space traffic management systems that will help with the future management of these diverse but interrelated issues (4). This 'holistic' approach is necessary if we are to find appropriate solutions to the increasing complexities associated with the myriad space activities now and into the future.

2. 'Light Pollution' of the Space Environment and Astronomical Observations: Legal Insights

2.1 Key Elements of International Environmental Law: 'Applicable' to the Sustainable Use of Outer Space?

Article III of the 1967 Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies (Outer Space

'light pollution' that affects astronomy (p 21); South Africa, Astronomy Geographic Advantage Act No.21 of 2007, 24 April 2009 (Gazette 32163 of 24 April 2009) <https://www.gov.za/sites/default/files/gcis_document/201409/gg31157nn666apg1-30.pdf>. The South African Act provides for the preservation and protection of areas that are uniquely suited for optical and radio astronomy.

18. See Aaron C Boley and Michael Byers, 'Satellite Mega-Constellations Create Risks in Low Earth Orbit, the Atmosphere and on Earth' (2021) 11 *Scientific Research* 10642 <https://www.nature.com/articles/s41598-021-89909-7>; Steven Freeland, 'Legal Issues Related to the Future Advent of Small Satellite Constellations' in Joseph Pelton (ed), *Handbook of Small Satellites* (Springer 2020) ch 23 <https://doi.org/10.1007/978-3-030-20707-6_73-1>; Christopher D Johnson, 'The Legal Status of Mega LEO Constellations and Concerns about Appropriation of Large Swaths of Earth Orbit' in Joseph Pelton (ed), *Handbook of Small Satellites* (Springer 2020) ch 78 <https://doi.org/10.1007/978-3-030-20707-6_95-1>; Andrew Williams and Giuliana Rotola, 'Bringing Policy Coherence to Satellite Constellation Mitigations for Space Debris and Astronomy' in T Flohrer, S Lemmens and F Schmitz (eds), *Proceedings of the 8th European Conference on Space Debris* (Darmstadt 2021) 1–10 <https://conference.sdo.esoc.esa.int/proceedings/sdc8/paper/208/SDC8-paper208.pdf>; Neta Palkovitz, *Regulating a Revolution – Small Satellites and the Law of Outer Space* (Wolters Kluwer 2019); Alberto Rueda Carazo, 'Mega-Constellations: Legal Aspects' in Anja Nakarada Pecujilic and Matteo Tugnoli (eds), *Promoting Productive Cooperation Between Space Lawyers and Engineers* (IGI Global 2019) 141, 142–154.

19. Alistair Rieu-Clarke, 'The Duty to Take Appropriate Measures to Prevent Significant Transboundary Harm and Private Companies: Insights from Transboundary Hydropower Projects' (2020) 20 *International Environmental Agreements: Politics, Law and Economics* 667, 668–682.

Treaty)[20] requires that activities related to the exploration and use of outer space are to be carried out in accordance with international law. It follows that, as a starting point, certain principles of international environmental law *might* have some application to space activities; however, the extent of application can only be assessed within the context of the unique legal paradigm of space.[21]

In other words, some principles of international environmental law might be of relevance for space activities and be applicable to the space environment, although it will be necessary to take into consideration the specific legal and other characteristics of outer space rather than simply employing a 'copy-paste' approach.[22] We seek here to identify the most relevant environmental law principles that might be applicable for the preservation of the space environment, in particular by taking into account the challenges of mega-constellations, space debris and astronomy observations.

The genesis of contemporary international environmental law can be traced back to the 1972 Stockholm Declaration on the Human Environment,[23] and the 1992 Rio Declaration on Environment and Development.[24]

Principle 21 of the Stockholm Declaration and Principle 2 of the Rio Declaration assert that States have the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States,[25] or to areas beyond national jurisdiction (ABNJ), which include the high seas and outer space. By its legal characterisation, outer space is an area beyond national jurisdiction and thus encompassed by this principle, which some argue represents a norm of customary law,[26] and thus may likely also apply to the space environment.

Based on this principle, the duty of control and due diligence in the conduct of space activities, as part of the more general duty of environmental prevention,[27] was implicitly rec-

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20. Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies (Outer Space Treaty), London/Moscow/Washington, 27 January 1967, 610 UNTS 205, in force 10 October 1967.
21. Sandeepa Bhat, 'Application of Environmental Law Principles for the Protection of the Outer Space Environment: a Feasibility Study' (2014) XXXIX *Annals of Air & Space Law* 323, 324–354.
22. Anne-Sophie Martin and Steven Freeland, 'Back to the Moon and Beyond: Strengthening the Legal Framework for Protection of the Space Environment' (2021) 46(3) *Air & Space Law* 415, 420–446 <https://doi.org/10.54648/aila2021023>.
23. United Nations Conference on the Human Environment (5–12 June 1972) UN Doc. A/CONF.48/14/Rev.1, Stockholm <https://www.un.org/en/conferences/environment/stockholm1972>.
24. Rio Declaration on Environment and Development (Rio Declaration), 31 *ILM* 874 (12 August 1992) UN Doc. A/CONF.151/26 (Vol. I), Annex I: <https://www.un.org/en/development/desa/population/migration/generalassembly/docs/globalcompact/A_CONF.151_26_Vol.I_Declaration.pdf>.
25. This concept dates back to the *Trail Smelter Arbitration*, Reports of International Arbitral Awards, Trail smelter case (United States, Canada), 16 April 1938 and 11 March 1941, Vol III, 1905–1982. The Trail Smelter dispute was a transboundary pollution case involving the Federal Governments of both Canada and the United States, which eventually contributed to establishing the 'no-harm principle' within the environmental law of transboundary pollution. Smoke from the smelter caused damage to forests and crops in the surrounding area and also across the Canada-US border in Washington. The smoke from the smelter distressed residents, resulting in complaints to the Consolidated Mining and Smelting Company (COMINCO) and demands for compensation. Also relevant is the *Corfu Channel Case*, Judgment of 9 April 1949, ICJ Reports 1949, 4.
26. Pierre-Marie Dupuy, Ginevra Le Moli and Jorge E. Viñuales, 'Customary International Law and the Environment' (December 2018) *C-EENRG Working Papers* 2018-2, 2, 12–22 <https://www.ceenrg.landecon.cam.ac.uk/system/files/documents/CEENRG_WP_19_CustomaryInternationalLawandtheEnvironment.pdf>; Foo Kim Boon, 'The Rio Declaration and its Influence on International Environmental Law' (1992) *Singapore Journal of Legal Studies* 347, 348–364.
27. Malgosia Fitzmaurice, 'A Few Reflections on Space Responsibility or Liability for Environmental Harm' (8 March 2023) *EJIL:Talk!* <https://www.ejiltalk.org/a-few-reflections-on-state-responsibility-or-liability-for-environmental-harm/>: '[…] international environmental law obligations are obligations of prevention. However,

ognised by the words of the International Court of Justice (ICJ) in its 1996 Advisory Opinion on the Legality of the Threat or Use of Nuclear Weapons:[28] 'the existence of a general obligation of States to ensure that activities within their jurisdiction and control respect the environment of other States or of areas beyond national jurisdiction is now part of the corpus of international law relating to the environment'.[29]

Furthermore, in the 1997 *Gabcikovo-Nagymaros* case,[30] the ICJ noted that 'in principle, States are under the obligation to ensure that activities within their jurisdiction and control do not cause damage as well as to respect the environment of other States or of areas beyond their jurisdiction and control'.[31] This so-called 'prohibition of the causation of transboundary harm' may have acquired customary character and may also have relevance for space activities,[32] as well as the protection of astronomical observations.

In connection with its statement on environmental protection being an essential interest of States, the ICJ further emphasised 'the great significance that it attaches to respect for the environment' of areas beyond national control.[33] The 'no-harm rule', which many consider to be a principle of customary international law,[34] requires State to avoid, limit and mitigate the risk of environmental damage to other States.[35] The principle of preventing transboundary harm, set out in the International Law Commission's (ILC) Draft Articles on the Prevention of Transboundary Harm from Hazardous Activities,[36] might arguably also have some application to satellite constellation-related activities. These activities are permitted by international law (Article 1 of the Draft Articles) and must be authorised by an appropriate State under Article VI of the Outer Space Treaty. In addition, they are conducted under the jurisdiction and control of a State (Article 2 of the Draft Articles). In this regard, the State of registration of a mega-constellation will have jurisdiction and control over the relevant satellites according to Article VIII of the Outer Space Treaty.[37] Accordingly, all necessary steps

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the relationship between due diligence and the obligations of prevention of transboundary harm is very complex and still unresolved […]'; *see also* Jorge E. Viñuales, 'Due Diligence in International Environmental Law: A Fine-grained Cartography' in Heike Krieger, Anne Peters and Leonhard Kreuzer (eds), *Due diligence in the international legal order* (Oxford University Press 2021) 111, 112–128 <https://doi.org/10.1093/oso/9780198869900.003.0007>; Nicolas de Sadeleer, *Environmental Principles: from Political Slogans to Legal Rules* (Oxford University Press 2020) 151–187.

28. *Legality of the Threat or Use of Nuclear Weapons*, Advisory Opinion, ICJ Reports 1996, 226.
29. ibid para. 27.
30. *Gabcikovo-Nagymaros Project* (Hungary v Slovakia) Judgment, ICJ Reports 1997, 7.
31. ibid para 53.
32. Stephan Hobe, *Space Law* (Nomos 2019) 115.
33. *Gabcikovo-Nagymaros Project* (n 30) para 53.
34. Patricia Birnie, Alan Boyle and Catherine Redgwell, *International Law and the Environment* (4th ed, Oxford University Press 2021) 159–163; Mara Tignino and Christian Bréthaut, 'The Role of International Case Law in Implementing the Obligation Not to Cause Significant Harm' (2020) 20 *International Environmental Agreements: Politics, Law and Economics* 631, 633–648; see also United Nations Environment Programme, No-Harm Rule: <https://leap.unep.org/en/knowledge/glossary/no-harm-rule>.
35. Marte Jervan, 'The Prohibition of Transboundary Environmental Harm. An Analysis of the Contribution of the International Court of Justice to the Development of the No-Harm Rule' (2014) *PluriCourts Research Paper* No 14-17, 16–119; Ian Brownlie, *Principles of Public International Law* (7th ed, Oxford University Press 2008) 275–285.
36. Draft articles on Prevention of Transboundary Harm from Hazardous Activities, 2001, Text adopted by the Commission at its fifty-third session, in 2001, and submitted to the General Assembly as a part of the Commission's report covering the work of that session (Draft Articles), *Official Records of the General Assembly*, Fifty-sixth Session, Supplement No 10 (A/56/10) <https://legal.un.org/ilc/texts/instruments/english/draft_articles/9_7_2001.pdf>. Note that these are *draft* articles and not binding except to the extent that any of them are regarded as representing customary international law.
37. Of course, in practical terms, it becomes more complicated when multiple States are the State of Registry over different satellites within the constellation, although the principle still remains applicable: see UN, Registration of large constellations and mega-constellations (2 February 2022) UN Doc A/AC.105/C.2/L.322

should be taken to prevent or mitigate damage (Article 3 of the Draft Articles). This provision brings to mind the principle of due regard in space law and Article IX of the Outer Space Treaty, which requires that: '… States Parties […] shall conduct all their activities in outer space […] with due regard to the corresponding interests of all other States […]' and shall 'pursue studies of outer space […] and conduct exploration […] so as to avoid their harmful contamination […]' or 'cause potentially harmful interference with activities of other States'.

Furthermore, Principle 19 of the Rio Declaration specifies that: 'States shall provide prior and timely notification and relevant information to potentially affected States on activities that may have a significant adverse transboundary environmental effect and shall consult with those States at an early stage and in good faith'.[38] It refers to a system of notification, which is important to avoid harmful contamination of the environment.

This notion is also envisaged in Article IX of the Outer Space Treaty, which deals with the concept that States shall, when conducting space exploration, avoid 'harmful contamination' of outer space as well as 'adverse changes to the environment of Earth'. Moreover, Article IX provides that State shall adopt appropriate measures and, in particular, shall undertake appropriate international consultations before proceeding with any such activity. These elements are further developed in part 3.

Principle 19 of the Rio Declaration specifically requires a State to notify and consult other States both before and after carrying out any environmentally harmful activities. Such 'environmental consultation' clauses are more specific compared to the general terms under Article IX providing for 'international consultation'.[39] The concept of 'notification' should be detailed with respect to the space environment in order to establish more reliable and appropriate thresholds for its conservation.

When addressing satellite constellation issues, the precautionary principle, set out in Principle 15 of the Rio Declaration, is of possible relevance. The concept implies that, even if the extent of a (environmental) threat is unknown, it is still crucial to take action to eliminate it.[40] The precautionary principle is the counterpart of the more conventional principle of prevention.[41] 'Prevention' refers to the averting of environmental damage at source through appropriate corrective measures at an early stage.[42]

<https://www.unoosa.org/res/oosadoc/data/documents/2022/aac_105c_2l/aac_105c_2l_322_0_html/AC105_C2_L322E.pdf>; Alexander Soucek, 'Legal and Practical Considerations of Registering Constellations and Space Debris', IISL/ECSL Symposium, 4 April 2016, UNCOPUOS, Vienna, Austria: <https://www.unoosa.org/documents/pdf/copuos/lsc/2016/symp-01.pdf>. As a practical example, we refer to the QB50 Project, an international network of 50 cubesats for multi-points, in-situ measurements in the lower thermosphere and re-entry research, which was launched in 2017: <https://cordis.europa.eu/project/id/284427/reporting>.

38. Rio Declaration (n 24) Principle 19.
39. Gordon Chung, 'The Emergence of Environmental Protection Clauses in the Outer Space treaty: A Lesson from the Rio Principles', in Annette Froehlich (ed), *A Fresh View on the Outer Space Treaty* (Springer 2018) 1, 2–13 <https://doi.org/10.1007/978-3-319-70434-0_1>.
40. For a relatively early example of the precautionary principle as codified into an international treaty framework, see International Convention for the Regulation of Whaling, adopted 2 December 1946, Washington, DC, in force 10 November 1948, 161 UNTS 72, Article IV (1), which provides as follows: 'The Commission may either in collaboration with or through independent agencies of the Contracting Governments or other public or private agencies, establishments, or organizations, or independently a) encourage, recommend, or if necessary, organize studies and investigations relating to whales and whaling; b) collect and analyze statistical information concerning the current condition and trend of the whale stocks and the effects of whaling activities thereon; c) study, appraise, and disseminate information concerning methods of maintaining and increasing the populations of whale stocks'.
41. See generally Leslie-Anne Duvic-Paoli, *The Prevention Principle in International Environmental Law* (Cambridge University Press 2018).
42. European Environment Agency, *Prevention Principle* <https://www.eea.europa.eu/help/glossary/eea-glossary/prevention-principle>.

Realising the fragility and vulnerability of the space environment,[43] as well as the uncertainties associated with the increasing transition to satellite operations through the deployment of satellite constellations, the precautionary principle might potentially be applicable to provide appropriate action and standards for the protection of the space environment.[44]

Certain impacts of large constellations of small satellites on the space environment, and various negative consequences they may have on space activities of other States or entities, including astronomy, are already well documented.[45] The principles of precaution and prevention are both intended to replace *ex post facto* corrective measures, which are by definition introduced only when the ecological damage has *already occurred*, in order to remove or reduce its effects.

Given that the use of such constellations will continue to grow exponentially, we consider it prudent to explore *pre-emptive* possibilities and adopt measures to reduce the future consequences of mega-constellations on other important activities, including astronomy.

An additional principle of possible relevance may be the 'concept of common but differentiated responsibilities' (CBDR)[46] contained in Principle 7 of the Rio Declaration, which provides that: 'in view of the different contributions to global environmental degradation, States have common but differentiated responsibilities'.

This concept is closely related to the notion of sustainable development, which seeks to balance environmental protection and economic development.[47] It considers that, although all countries have a responsibility for the development of society, including tackling particular (environmental) problems, each has a range of different tools at its disposal.

The Stockholm Declaration points out that: 'the applicability of standards which are valid for the most advanced countries […] may be inappropriate and of unwarranted social cost for […] developing countries'.[48] The CBDR approach is intended to take these distinctions into account when targets and benchmarks are applied to global development programmes.

This principle could potentially be of significance in terms of feasible measures to mitigate and remediate space junk[49] that could conceivably cause interference to astronomical observations.[50] Indeed, some COPUOS State members have argued that: 'States most responsible for the creation of space debris and the States having the capability to take action on space

43. International cooperation in the peaceful uses of outer space (9 December 2015) UNGA Res 70/82 <https://www.unoosa.org/res/oosadoc/data/resolutions/2015/general_assembly_70th_session/ares7082_html/A_RES_70_082E.pdf>.
44. Olavo de O Bittencourt Neto, 'Preserving the Outer Space Environment: the "Precautionary Principle" Approach to Space Debris' (2013) *IISL Eleven Journal* 341, 342–351; Paul B Larsen, 'Application of the Precautionary Principle to the Moon' (2006) 71(2) *Journal of Air Law and Commerce* 295 <https://scholar.smu.edu/cgi/viewcontent.cgi?article=1104&context=jalc>.
45. Giacomo Curzi, Dario Modenini and Paolo Tortora, 'Large Constellations of Small Satellites: A Survey of Near Future Challenges and Missions' (2020) 7(9) *Aerospace* 133, 134–151 <https://doi.org/10.3390/aerospace7090133>.
46. This principle is also enshrined in Article 3(1) of the 1992 United Nations Framework Convention on Climate Change, New York, 9 May 1992, in force 21 March 1994, 1771 UNTS 107.
47. Ellen Hey and Sophia Paulini, 'Common but Differentiated Responsibilities', *Max Planck Encyclopedia of International Law* (October 2021) <https://opil.ouplaw.com/display/10.1093/law:epil/9780199231690/law-9780199231690-e1568>.
48. Stockholm Declaration (n 23) Principle 23.
49. Peter Stubbe, *State Accountability for Space Debris: A Legal Study of Responsibility for Polluting the Space Environment and Liability for Damage Caused by Space Debris* (Brill 2017); Jinyuan Su, 'Control Over Activities Harmful to the Environment' in Ram S Jakhu and Paul S Dempsey (eds), *Routledge Handbook of Space Law* (Routledge 2017) 73, 76–80.
50. Dylan McNally and Richard H Rast, 'The Effect of Spacecraft and Space Debris on Astronomical Observation' (1999) 23 *Advances in Space Research* 255–258.

debris mitigation should make a greater contribution to space debris mitigation efforts than other States'.[51]

Newer States that have more recently started to undertake space activities face the challenges associated with the environmental degradation of space for which they are not responsible, but nevertheless from which they (like others) are nonetheless potentially adversely affected. One possibility is that those States that have generated space debris make efforts to clean up outer space, through active debris removal and other appropriate means.[52]

This is, however, a seductive and overly simplistic conclusion. For one thing, the issue remains to determine which State is responsible for causing which and what level of space debris. In addition, the technology to remove space debris largely remains with developed States. More generally, it is by no means clear as to how to 'encourage' those responsible States to actually undertake such activities without providing financial (and other) incentives, as opposed to a 'stick' approach.

Furthermore, concerning the deployment of mega-constellations, it is usually clear which States and operators conduct the activity and, while these have historically predominantly been spacefaring nations, the Rwandan application[53] referred to earlier illustrates that the range of space 'actors' is continually expanding, and easy identification may not always be entirely straightforward. With this in mind, the CBDR principle is highly complex and, in practical terms, may seem inappropriate or not feasible for application to the case of proliferating space debris.

Another element of terrestrial environmental law and sustainable development is the 'polluter pays principle' – the idea that the person or organisation that causes pollution should pay for the damage it causes (or perhaps for the 'right' to cause such damage).[54] Principle 16 of the Rio Declaration stresses that: 'National authorities should endeavour to promote the internalization of environmental costs and the use of economic instruments, taking into account the approach that the polluter should, in principle, bear the cost of pollution, with due regard to the public interest and without distorting international trade and investment.'

In the case of mega-constellations, it will often be relatively easy to identify the launching State(s) and the owner(s) of the constellation; however, it becomes more complicated when space debris is generated. It is difficult, although not always entirely impossible,[55] to ascertain the 'original' polluter in the case of space debris – particularly if there are multiple owner/operators of different satellites within a particular constellation, and thus to prove that a

51. COPUOS, Report of the Scientific and Technical Subcommittee on its fifty-third session (9 March 2016) UN Doc A/AC.105/1109, para 239 <https://www.unoosa.org/oosa/oosadoc/data/documents/2016/aac.105/aac.1051109_0.html>. Already in 2016, some delegations during the COPUOS STC expressed the view that 'space debris had been created through past space operations by countries with advanced space capabilities, and that those states should help new entrants in space activities to mitigate space debris by providing scientific, technological and financial support […]'.
52. Nicol Svarovska, 'Common but Differentiated Responsibilities for Space Debris Removal' (2021) 19(1) *Astropolitics* 1, 2–17 <https://doi.org/10.1080/14777622.2021.2000322>.
53. Jeff Foust, 'Satellite operators criticize "extreme" megaconstellation fillings', *Space News* (14 December 2021) <https://spacenews.com/satellite-operators-criticize-extreme-megaconstellation-filings/>.
54. European Court of Auditors, 'The Polluter Pays Principle: inconsistent application across EU environmental policies and actions', *Special Report* (12/2021) 6–14 <https://www.eca.europa.eu/Lists/ECADocuments/SR21_12/SR_polluter_pays_principle_EN.pdf>; Peter Stubbe, *State Accountability for Space Debris: A Legal Study of Responsibility for Polluting the Space Environment and Liability for Damage Caused by Space Debris* (Brill 2018) 124; Michael Byers and Aaron Boley, 'Opinion: How Elon Musk can help save astronomy' *Los Angeles Times* (13 December 2019) <https://www.latimes.com/opinion/story/2019-12-13/spacex-elon-musk-starlink-satellites>.
55. Andrew Jones, 'China's Space Station Maneuvered to Avoid Starlink Satellites', *SpaceNews* (28 December 2021) <https://spacenews.com/chinas-space-station-maneuvered-to-avoid-starlink-satellites/>.

specific space object has caused damage to another space object and the space environment. Naturally, this becomes even more difficult if the damage is caused long after the generation of the debris in the first place.

Lastly, the principle of sustainable use is of particular relevance in the case of space activities, including with respect to the use of LEO.[56] This principle advocates the utilisation of any resource in such a way as to prevent their extinction, as well as the idea of intergenerational equity,[57] making resources available to all. Accordingly, it requires that resources should be used in a controlled manner.[58]

The application of this principle to outer space is highly valuable in a number of respects, especially in relation to mega-constellation programmes and space debris mitigation and remediation measures. Within this context, the issue of space traffic management is closely connected with the sustainable use of outer space and that, without the development of an effective system of space traffic management through regulation and monitoring, the use of outer space by future generations cannot be assured.[59]

The principles of environmental law considered here can potentially be adapted to the protection of the space environment from the effects of space debris, the growing number of satellites being launched into 'popular' orbits and the adverse impacts on astronomy and associated activities from increasing light pollution. In saying this, however, it bears repeating that a clear determination of the extent to which any of these principles may apply (if at all) to the unique environment of space is not straightforward and must be carefully considered by stakeholders in the adoption of mitigating measures as well as in the development of associated best practices and standards.

2.2 Articles I and IX of the Outer Space Treaty: Free Access to and Use of Outer Space and 'Due Regard'

Principle 2 of the 1963 Declaration of Legal Principles Governing the Activities of States in the Exploration and Use of Outer Space[60] stipulates that 'outer space and celestial bodies are free for exploration and use by all States on a basis of equality and in accordance with international law'. This principle in part reflects the terms of Article I of the Outer Space Treaty, which provides that:

> the exploration and use of outer space, including the Moon and other celestial bodies, shall be carried out for the benefit and in the interests of all countries […]. Outer space, including the

56. Elena Cirkovic, 'The Next Generation of International Law: Space, Ice, and the Cosmolegal Proposal' (2021) 22 *German Law Journal* 147, 148–167; Minna Palmroth and others, 'Towards Sustainable Use of Space: Economic, Technological and Legal Perspectives' (2021) 57 *Space Policy* 101428 <https://doi.org/10.1016/j.spacepol.2021.101428>.
57. Note in this regard that Article 4 (1) of the Moon Agreement makes express reference to 'the interests of present and future generations': Agreement governing the Activities of States on the Moon and Other Celestial Bodies (Moon Agreement), New York, 5 December 1979, in force 11 July 1984, 1363 UNTS 3.
58. In this respect, it is pertinent to note that Article 11(7) of the Moon Agreement provides: 'The main purposes of the international regime to be established shall include (a) the orderly and safe development of the natural resources of the Moon; (b) the rational management of those resources; (c) the expansion of opportunities in the use of those resources; (d) an equitable sharing by all States Parties in the benefits derived from those resources, whereby the interests and needs of the developing countries, as well as the efforts of those countries which have contributed either directly or indirectly to the expansion of the Moon, shall be given special consideration.'
59. COPUOS, Report of the Legal Subcommittee on its sixtieth session (24 June 2021) UN+ Doc A/AC.105/1243, para 197 <https://documents-dds-ny.un.org/doc/UNDOC/GEN/V21/047/17/PDF/V2104717.pdf?OpenElement >.
60. Declaration of Legal Principles Governing the Activities of States in the Exploration and Use of Outer Space (13 December 1963) UNGA Res 1962 (XVIII) <https://www.unoosa.org/pdf/gares/ARES_18_1962E.pdf>.

> Moon and other celestial bodies, shall be free for exploration and use by all States without discrimination of any kind, on a basis of equality and in accordance with international law, and there shall be free access to all areas of celestial bodies. There shall be freedom of scientific investigation in outer space […]

As noted, the exploration of space can be carried out by astronomers with telescopes, while its physical exploration is conducted by human spaceflight and robotic (and other) space probes. Article I of the Outer Space Treaty can arguably be interpreted so as to implicitly include ground-based astronomy, which may help us to understand how different needs, and the freedoms of exploration and use of outer space, can best be balanced.

Astronomical observations represent an important methodology for accessing, exploring and using outer space. However, the deployment of large constellations of small satellites could have negative consequences for States and others engaged in astronomy as a space exploration activity. Hence, an appropriate coordination and balance must be found between astronomical observation and satellite activities that, at the same time, might allow for economic and developmental benefits for States and operators to accrue, while not unduly interfering with other equally important space activities.[61]

Article I must be reconciled with Article IX of the Outer Space Treaty, which demonstrates that the exploration and use of space is not completely unfettered – such activities must be undertaken within important behavioural requirements. In other words, the principle of freedom of exploration and use of outer space must also take account of, *inter alia*, the imperative to preserve the space environment.

The concept of cooperation, mutual assistance, avoiding harmful interference, and consultations – essential elements within the terms of Article IX – had been previously articulated in Principle 6 of the 1963 Declaration of Legal Principles referred to above.

Article IX requires that, in the exploration and use of outer space, States Parties to the Treaty shall be guided by 'the principle of cooperation and mutual assistance' and shall conduct their activities 'with due regard to the corresponding interests of all other' States Parties. In addition, they shall 'pursue studies of outer space' and conduct their activities so as to avoid 'harmful contamination' of the space environment.

The final element of the provision requires States to engage in 'appropriate international consultations' if they have reason to believe that their proposed space activity would cause 'potentially harmful interference' to the activities of other States, and also gives the opportunity for other States to request such consultations regarding planned activities by another State if they have reason to believe that those activities will have such a potential impact. This appears relevant in the case of the (potential) impact of mega-constellations on astronomy observation and, if this is the case, would require that consultations be conducted between the parties involved in appropriate circumstances.

As noted, in certain respects, Article IX represents a limit to the freedom of exploration and use of outer space. States are required to consider whether and how the exercise of their own rights and freedoms impact on the space activities of other nations. Thus, space activities carried out by a given State should reflect not only its own interests but take account of the 'corresponding' interests and rights of the other States Parties to the Outer Space Treaty.[62]

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61. Connie Walker and Piero Benvenuti (eds), 'Dark and Quiet Skies II for Science and Society' (2022) *Working Group Reports* 83–91 <https://doi.org/10.5281/zenodo.5874725 >.
62. Neta Palkovitz, 'Exploring the Boundaries of Free Exploration and Use of Outer Space – Article IX and the Principle of Due Regard, Some Contemporary Considerations' (2014) 57 *Proceedings of the Colloquium on the Law of Outer Space* 93–105.

In addition, Article IX refers to the principle of 'due regard',[63] which implies that States, and private entities authorised by their respective State, should carry on space activities with a certain standard of care, attention, or observance. This idea of due regard is also referred to (albeit in a very different context) in the 1982 United Nations Convention on the Law of the Sea (UNCLOS) in Article 87(2), which states: 'These freedoms [of the high seas] shall be exercised by all States with due regard for the interests of other States in their exercise of the freedom of the high seas, and also with due regard for the rights under this Convention with respect to activities in the Area'.[64]

Both the high seas and outer space are, as noted, regarded at law as being beyond national jurisdiction and are often thought of as belonging to the category of *res communes omnium*[65] which, while prohibiting national appropriation, recognises the right to use and exploit these areas and their resources with due diligence, by taking into account the interests and rights of other States when they conduct activities in those areas. Article IX appears to introduce an objective 'due diligence' concept within the particular circumstances. Due diligence typically requires the taking of all reasonable and appropriate measures that might be expected in order to examine and evaluate the risks that may affect a specific situation, so as to appropriately address them.

As noted, Article IX also deals with the notion of 'harmful contamination'. The provision implies that any contamination which would result in harm to another State's programmes is to be avoided. However, Article IX does not specify under what circumstances it would be necessary to adopt appropriate measures, or indeed which measures would in fact be appropriate. Nevertheless, one can argue that the obligation to take all appropriate measures to prevent harm, or to minimise the risk, would apply to existing as well as 'possible future' activities that might involve such a risk.

Article IX deals as well with mechanisms of consultation with regard to the avoidance of potentially harmful interference in outer space. As noted, a State (or its nationals) that plans an activity or experiment has the obligation, before proceeding, to undertake appropriate international consultations with other States Parties if it has reason to believe that such activity or experiment would cause potentially harmful interference to the activities of those other States in the peaceful exploration and use of outer space.[66]

In this context, one could argue that operators should, in appropriate circumstances, be required to enter into consultations with the relevant astronomers before deploying a mega-constellation programme (assuming that their reasonable investigations would enable them to be made aware of those astronomical activities).[67] Such consultations

63. John D Rhummel, '"Due Regard" in Space Activities: Avoiding Harmful Contamination in the Exploration and Use of Outer Space' in M Tanveer Ahmad, J Su (eds), *New Space Commercialisation and the Law* (McGill University 2017) 153, 154–158.
64. See also Article 3(d) of the Convention on International Civil Aviation (Chicago Convention), Chicago, 7 December 1944, in force 4 April 1947, 15 UNTS 295: 'The contracting States undertake, when issuing regulations for their state aircraft, that they will have due regard for the safety of navigation of civil aircraft'.
65. Martin Svec, 'Outer Space, an Area Recognised as *Res Communis Omnium*: Limits of National Space Mining Law' (2022) 60 *Space Policy* <https://doi.org/10.1016/j.spacepol.2021.101473>.
66. Sergio Marchisio, 'Article IX', in Stephan Hobe, Bernhard Schmidt-Tedd and Kai-Uwe Schrogl (eds), *Cologne Commentary on Space Law: Volume I, Outer Space Treaty* (Carl Heymanns Verlag 2009) 169, 179–180.
67. See National Science Foundation and SpaceX Astronomy Coordination Agreement, reported here: National Science Foundation, 'NSF statement on NSF and SpaceX Astronomy Coordination Agreement' *NSF News* (10 January 2023) <https://new.nsf.gov/news/statement-nsf-astronomy-coordination-agreement>. This agreement applies only to the US observatories and concerns only one of the many satellite constellations in development; but it is encouraging that such an agreement can be reached between a major commercial company and a science funding agency. There appears to be a willingness to find innovative solutions and the release of substantial details of SpaceX's technologies.

should be undertaken at an international level given the environmental and technical issues raised.

In addition, a State potentially affected by an activity to be conducted by another State may request that the latter enter into consultations regarding that specific mission/activity. In this regard at least, consultation could be viewed in part as an element in a more effective environmental protection regime for outer space.[68] However, it should be noted that, in relevant circumstances, the proposed activity might have already been authorised by an appropriate State (as required by Article VI of the Outer Space Treaty) and conducted by a private entity, while the activities of amateur astronomers do not require such authorisation.[69] Coordination and information sharing is therefore a paramount requirement.

To sum up these observations, States Parties to the Outer Space Treaty have to: (1) conduct their space activities with due regard to the corresponding interests of all other States Parties to the Treaty; (2) carry out their activities in outer space in a way that avoids harmful interference with the missions of others; and (3) engage in international consultations when necessary and required. Moreover, it can be argued that Article IX could, in appropriate circumstances, apply with respect to terrestrial activities such as ground-based astronomy that are potentially affected by mega-constellations and other activities conducted in outer space. That said, this provision has never been applied to cover such a contingency.

Nevertheless, even if Article IX provides some relevance for safeguarding the space environment,[70] it lacks precision,[71] in particular concerning the terms 'appropriate measures' and 'harmful contamination', and also with regard to the scope of its application.

3. Large Constellations and Orbital Sustainability: An Imperative to Conduct an Environmental Impact Assessment?

3.1 Environmental Impact Assessment in Areas Beyond National Jurisdiction: the Case of the High Seas

Principle 17 of the Rio Declaration emphasises that: 'Environmental impact assessment, as a national instrument, shall be undertaken for proposed activities that are likely to have a significant adverse impact on the environment and are subject to a decision of a competent national authority'.

While the Rio Declaration is a non-binding instrument,[72] many countries have included environmental impact assessment (EIA) requirements within their national environmental law frameworks.[73] International obligations to carry out EIAs also exist in relation to activi-

68. Marchisio (n 66) 179–180.
69. Astronomical activity can be carried out by public institutions, as well as by amateur astronomers in the private sphere.
70. Stephan Hobe, *Space Law* (Nomos 2019) 108–109.
71. Tanja Masson-Zwaan and Mahulena Hofmann, *Introduction to Space Law* (Wolters Kluwer 2019) 122.
72. That said, some of the principles are generally regarded as representing customary international law. For example, see Dupuy, Le Moli and Viñuales (n 26) 8–11; Philippe Sands, Jacquelline Peel, Adriana Fabra and Ruth MacKenzie, *Principles of International Environmental Law* (Cambridge University Press 2018) 41.
73. Richard K Morgan, 'Environmental Impact Assessment: The State of the Art' (2012) 30(1) *Impact Assessment & Project Appraisal* 5, 6–14 <https://doi.org/10.1080/14615517.2012.661557>; Lotta Viikari, 'Environmental Impact Assessment and Space Activities' (2004) 34(11) *Advances in Space Research.* <https://doi.org/10.1016/j.asr.2004.01.016>. See also International Institute for Sustainable Development, 'EIA Timeline' <https://www.iisd.org/learning/eia/eia-essentials/timeline/>. The notion of an EIA within national legislative frameworks is not a new concept. For example, Canada introduced EIA legislation in 1973, Australia in 1974, France in 1976, Costa Rica in 1982, and Italy in 1986.

ties that take place in areas beyond national jurisdiction.[74] Such obligations can be identified in the 1991 Protocol to the Antarctic Treaty on Environmental Protection,[75] and the 1982 UNCLOS.[76] In the 1997 *Gabcikovo-Nagymaros* case, the ICJ held that there was a duty to conduct EIAs before proceeding with serious transboundary projects.[77]

The starting point for an EIA is the idea that the impact of (potentially) environmentally harmful projects should be analysed *before* the authorisation of the project, in order to be able to take an appropriate decision given all possible (reasonably foreseeable, identifiable and measurable) impacts of that project.[78] In this sense, an EIA is in some ways a practical application of the precautionary principle in order to as much as possible prevent environmental harm, since it is necessary to understand the environmental impacts of a project as early as possible. A precautionary approach is desirable where the long-term effects are little known, and those effects will also emerge cumulatively with other ongoing changes in large-scale ecosystems.

If one considers general State practice in relation to the high seas, scientists continue to make important discoveries about marine depths in locations that are ABNJ, which are in most cases distant places that support life throughout the global oceans and are home to some of its most fascinating and valuable species. With new and emerging activities threatening the health of these ecosystems, safeguarding their biodiversity is increasingly important.

To ensure that they do not upset the fragile and interconnected marine environment,[79] the conduct of high seas activities and any associated impacts must be fully understood and carefully managed, and an EIA is a significantly important tool in this effort.[80]

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74. William R Kramer, 'Extraterrestrial Environmental Impact Assessment – A Foreseeable Prerequisite for Wise Decisions Regarding Outer Space Exploration, Research and Development' (2014) 30 *Space Policy* 215, 217–222 <https://doi.org/10.1016/j.spacepol.2014.07.001>; Vito De Lucia and Viviana Iavicoli, 'From Outer Space to Ocean Depths: the 'Spacecraft Cemetery' and the Protection of the Marine Environment in Areas Beyond National Jurisdiction' (2019) 49(2) *California Western International Law Journal* 345, 346–389 <https://scholarlycommons.law.cwsl.edu/cwilj/vol49/iss2/4>.
75. Protocol on Environmental Protection to the Antarctic Treaty, Madrid, 4 October 1991, in force 14 January 1998, 2941 UNTS, 30 ILM 1455; see also Donald R Rothwell, 'Polar Environmental Protection and International Law: the 1991 Antarctic Protocol' (2000) 11(3) *European Journal of International Law* 591, 592–614 <https://doi.org/10.1093/ejil/11.3.591>.
76. United Nations Convention on the Law of the Sea (UNCLOS), Montego Bay, 10 December 1982, in force 16 November 1994, 1833 UNTS 3, 21 ILM 1261.
77. *Gabcikovo-Nagymaros Project* (n 30) 7; see also Erika L Preiss, 'The International Obligation to Conduct an Environmental Impact Assessment: the ICJ Case Concerning the Gabcikovo-Nagymaros Project' (1999) 7(3) *New York University Environmental Law Journal*, 307, 308–351.
78. European Commission, 'Environmental Impact Assessment of Projects', 2017, 84 <https://ec.europa.eu/environment/eia/pdf/EIA_guidance_Screening_final.pdf>; Articles 2 and 3 of Directive 2014/52/EU of the European Parliament and of the Council of 16 April 2014 amending Directive 2011/92/EU on the assessment of the effects of certain public and private projects on the environment [2014] OJ L124/1. Article 206 UNCLOS requires an assessment of 'the potential effects of such activities on the marine environment …'; Article 1(vi) of the Espoo Convention refers to the 'national procedure for evaluating the likely impact of a proposed activity on the environment'. See Convention on Environmental Impact Assessment in a Transboundary Context (Espoo Convention), Espoo, 25 February 1991, in force 10 September 1997.
79. See Article 145 of the UNCLOS (n 76), Protection of the marine environment. See also Agreement relating to the Implementation of Part XI of the United Nations Convention on the Law of the Sea of 10 December 1982, New York, 16 November 1994, in force 16 November 1994 (provisionally) and 28 July 1996 (definitely), 1836 UNTS 3, 33 ILM 1309.
80. Tomohiko Fukushima, 'The Role of Science for Environmental Impact Evaluation Resulting from Ocean Mining' in Myron H Nordquist, John N Moore and Ronan Long (eds), *The Marine Environment and United Nations Sustainable Development Goal 14* (Brill 2018) 251, 252–262; Laura Pineschi, 'The Duty of Environmental Impact Assessment in the First ITLOS Chamber's Advisory Opinion: Towards the Supremacy of the General Rule to Protect and Preserve the Marine Environment as a Common Value?' in Nerina Boschiero, Tullio Scovazzi, Cesare Pitea and Chiara Ragni (eds), *International Courts and the Development of International Law: Essays in Honour*

EIAs allow policymakers to identify the potential effects of proposed projects, explore alternative solutions, and determine ways to prevent, mitigate and control environmental harm.

United Nations General Assembly Resolution 69/292 underlines the fact that States should commit to developing an: 'international legally binding instrument … on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction'.[81] After years of discussions by States at the United Nations, the final text of the instrument ('Agreement under the United Nations Convention on the Law of the Sea on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction' (BBNJ))[82] contains provisions addressing the issues relating to EIAs.

UNCLOS establishes the mandate of the International Seabed Authority (ISA) to: 'organise and control activities in the Area, particularly with a view to administering the resources of the Area.' 'The Area' refers to the seabed beyond the 200 nautical mile limits of national jurisdiction. UNCLOS requires that the ISA manage potential mineral-related activities of the Area for the benefit of humankind as a whole – where both the Area and its resources are considered 'the common heritage of [hu]mankind'.[83]

Central to the mission of the ISA is the 'effective protection of the marine environment' and management that allows development of the Area's resources to contribute 'to agreed international objectives and principles, including the Sustainable Development Goals (SDGs)'.[84] While the ISA does not govern seabed mining within any nations' exclusive economic zones (EEZs), deep-water mineral extraction is also being pursued in these areas. Management here is likely to reflect the progression of what might be developed and implemented by the ISA. The evolution of this is being carefully watched.

The ISA is currently developing regulations for commercial-scale deep-seabed mining: 'The Mining Code'. This relates to both exploration and exploitation of minerals.[85] These regulations are necessary in order to meet the mandate of the ISA to protect the marine environment.

In 2019, the ISA began to hold consultations on a series of draft 'Standards and Guidelines'[86] which set out how impact assessment of deep-sea mining projects should be undertaken, in particular for EIAs. The documents are a component of the Mining Code (exploration and exploitation) and are intended to operationalise the exploitation regula-

of Tullio Treves (Springer 2013) 425, 426–439; Gwénaëlle Le Gurun, 'EIA and the International Seabed Authority' in Kees Bastmeijer and Timo Koivurova (eds), *Theory and Practice of Environmental Impact Assessment* (Brill 2008) 221, 222–263.

81. Development of an international legally binding instrument under the United Nations Convention on the Law of the Sea on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction (19 June 2015) UNGA Res 69/292, para 1.
82. Agreement under the United Nations Convention on the Law of the Sea on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction (A/CONF.232/2023/4) 19 June 2023.
83. UNCLOS (n 76) Article 136: 'The Area and its resources are the common heritage of mankind'.
84. Strategic Plan of the International Seabed Authority for the period 2019–2013, Annex (ISBA/24/A/10) 26 July 2018, para 7.
85. As regards the exploitation of space resources, there is also a governance process underway at the COPUOS. In 2022, consensus has been reached within the Legal Subcommittee regarding the detailed 5-year Workplan of the recently established (2021) Working Group on Legal Aspects of Space Resource Activities; see UN Doc A/AC/C.2/2022/SRA/L.1 (5 April 2022). One of the possible outcomes from the Working Group may be the preparation of a set of principles for the exploration, exploitation and utilisation of space resources.
86. International Seabed Authority, 'The Mining Code: Standards and Guidelines' <https://www.isa.org.jm/the-mining-code/standards-and-guidelines/>; see Draft regulations on exploitation of mineral resources in the Area (22 March 2019) ISA Doc ISBA/25/C/WP.1; Report of the Chair of the Legal and Technical Commission on the Work of the Commission at the second part of its twenty-fifth session (11 July 2019) ISA Doc ISBA/25/C/19/Add.1, part IV.

tions and outline the process and criteria by which projects will be appraised for acceptability and granted permission.

These standards aim to ensure that EIAs for activities in the Area are designed with a view to protecting and conserving the marine environment; to anticipate and avoid or minimise harmful the environmental effects of exploitation activities; and to ensure that environmental considerations are expressly addressed and incorporated into the ISA decision-making process.

While application by analogy is not appropriate, certainly some of these elements could be take into consideration within the context of deployment of mega-constellations and its impact on astronomy, perhaps in terms of a 'Space Code', comprised of appropriate standards and guidelines. Moreover, one idea is that the Secretariat of COPUOS, the United Nations Office for Outer Space Affairs (UNOOSA), could be given a mandate related to the preservation of the space environment, given the impacts that mega-constellations and space debris have on environment and other space activities.

3.2 A Sustainable Impact Assessment for Space Activities

The concept of an EIA is not a well-established tool in the international law of outer space. However, the negative effects of some space activities are well known, including the potential 'overcrowding' through a proliferation of mega-constellations and the creation of space debris on the space environment, both of which also have consequences for astronomy.

This gives rise to the question as to whether there exists an obligation on (authorising) States to conduct EIAs on potential space activities,[87] including possibly a strategic environmental assessment (SEA)[88] and a sustainability impact assessment (SIA), in order to minimise light pollution and protect the dark and quiet skies before such authorisation.

An SIA could be particularly relevant for space activities in that it may increase awareness of the potential for developing more sustainable policies, strategies and action plans.[89] As regards large constellations of small satellites and their impact on astronomy, performing an SIA would be a major refinement to an EIA and would, for instance, cover the key elements of the 2019 Guidelines for the Long-Term Sustainability of Space Activities (LTS Guidelines).[90] This might include the implementation of policies that support the objectives of minimising the impacts of human activities on Earth as well as on the outer space environment (Guideline A.2), and the adoption of appropriate safety measures to protect the Earth and the space environment from harmful contamination (Guidelines A.4 and D.1).

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87. Masson-Zwaan and Hofmann (n 71) 129. See NASA and the 1970 National Environmental Policy Act (NEPA) <https://www.nasa.gov/emd/nepa/>; see also Article 4 'Conditions de délivrance des autorisations' of the French Law, Loi n° 2008-518 du 3 juin 2008 relative aux opérations spatiales; Article 8 of the Belgian Law of 17 September 2005 on the Activities of Launching, Flight Operation or Guidance of Space Objects; Division 2 'Launch facility licences' Australian Space (Launches and Returns) Act 2018.
88. SEA 'consists of a range of analytical and participatory approaches that aim to integrate environmental considerations into policies, plans and programmes and evaluate the inter-linkages with economic and social considerations': OECD, 'Applying Strategic Environmental Assessment' (2006) 17 <https://doi.org/10.1787/9789264026582-en>.
89. OECD, 'Guidance on Sustainability Impact Assessment' (2010) <https://www.oecd.org/greengrowth/48305527.pdf>.
90. COPUOS, Guidelines for the Long-term Sustainability of Outer Space Activities, (2019) UN Doc. A/74/20, Annex II. See in particular Guidelines A.2, C.4, D.1 and D.2. <https://www.unoosa.org/res/oosadoc/data/documents/2018/aac_1052018crp/aac_1052018crp_20_0_html/AC105_2018_CRP20E.pdf>.

An SIA could be required of private entities[91] and contractors as a pre-condition to obtaining a licence from the appropriate State. They would have to comply with any standards and rules encompassed in the assessment along with any other conditions included with the licence approval.

4. Considerations for Space Traffic Management Systems to Protect the Dark Skies

4.1 Developing and Implementing a Set of Technical and Regulatory Provisions to Promote Safe Access to Outer Space

As noted, the number of satellites in orbit, and particularly in LEO, continues to increase, and the instances of close approaches requiring coordination between operators are growing.[92] In this context of ever-expanding space activities, it is becoming an imperative to devise appropriate and effective rules for Space Traffic Management (STM).[93]

According to the International Academy of Astronautics (IAA), STM represents: 'the set of technical and regulatory provisions for promoting safe access into outer space operations in outer space, and return from outer space to Earth free from physical or radio-frequency interference'.[94] With the advent of numerous non-governmental entities into the realm of space activities, the positioning of mega-constellations, the increase of space debris,[95] and the growing number of launch vehicles, appropriate 'rules of the road' are necessary in order to ensure the safety and security of space operations and to preserve the long-term sustainability of space activities.[96]

Space Traffic Management is most likely relevant throughout all elements of a typical mission – during the launch, in-orbit operation and re-entry phases. The United Nations

91. The United Kingdom recently released its 'Space Sustainability Plan' for industry. Currently in its initial stages, the sustainability push involves working alongside industry and academia to develop standards for satellite licensing, launches, and the sustainable development of space. The government will also review the regulatory framework, including exploring ways of lowering insurance costs for sustainable missions; see 'Government announces package of new measures to drive space sustainability', Gov.UK (23 June 2022): 'UK industry will work in partnership with government to develop a new Space Sustainability Standard, which will incentivise companies to adopt best practice'; <https://www.gov.uk/government/news/government-announces-package-of-new-measures-to-drive-space-sustainability>.
92. In December 2021, China lodged a *Note verbale*, on the basis of Article V of the Outer Space Treaty, raising issues allegedly raised by the movement of specific Starlink Satellites: see Jon Henley, 'China berates US after "close encounters" with Elon Musk satellites' *The Guardian* (28 December 2021) <https://www.theguardian.com/science/2021/dec/28/china-complains-to-un-after-space-station-is-forced-to-move-to-avoid-starlink-satellites>; see *Note verbale* dated 3 December 2021 from the Permanent Mission of China to the United Nations (Vienna) addressed to the Secretary-General (2021) UN Doc A/AC.105/1262.
93. Anne-Sophie Martin and Steven Freeland, 'From One to Many: "Many" (Constellation) Challenges to the Legal Framework for Outer Space' (2021) 46 *Annals of Air and Space Law* 131, 162–169.
94. Corinne Jorgeson, Petr Lala and Kai-Uwe Schrogl, 'Cosmic Study on Space Traffic Management' (The International Academy of Astronautics (IAA), June 2006) <https://www.black-holes.eu/resources/IAA_spacetraffic-management.pdf>.
95. Katherine Tangalakis-Lippert, 'The International Space Station swerved to avoid colliding with shrapnel from a Russian anti-satellite missile test' *Business Insider India* (20 June 2022) <https://www.businessinsider.in/science/space/news/the-international-space-station-swerved-to-avoid-colliding-with-shrapnel-from-a-russian-anti-satellite-missile-test/articleshow/92324913.cms>; see also Statement released by NASA about the avoidance manoeuvre: Mark Garcia, 'Life Science, Debris Avoidance Manoeuvre Takes Place on Station' *NASA Blogs* (16 June 2022) <https://blogs.nasa.gov/spacestation/2022/06/16/life-science-debris-avoidance-maneuver-takes-place-on-station/>.
96. Kai-Uwe Schrogl, Corinne Jorgenson, Jana Robinson and Alexander Soucek, *Space Traffic Management –Towards a roadmap for implementation* (IAA 2018) 107–119.

Space Treaties provide for some significant frameworks relevant for the future establishment of a more comprehensive STM regime, such as the registration of space objects, and requirements for notification and consultations. A comprehensive STM system should also relate to the terms of Article IX of the Outer Space Treaty, which (as noted above) provides an obligation on all States Parties to pay due regard to the corresponding interests of other States Parties and to act so as to avoid potential harmful interference to the activities carried out by other States in outer space.

Notwithstanding this, the provisions of the United Nations Space Treaties alone are not sufficiently comprehensive to meet the challenges of new space activities without additional augmentation.[97] The myriad issues raised by the increasing proliferation of mega-constellations and of orbital space debris highlight even more the impacts for astronomical observations, thus meaning that an effective STM system becomes ever more urgent.

The issue of STM was added as a new single item to the agenda of the Legal Subcommittee of COPUOS in 2016 under the title 'General exchange of views on the legal aspects of space traffic management',[98] but no concrete results have as yet been formulated. However, some relevant elements are present in 'soft law' documents, such as the 2019 LTS Guidelines, which provide practical approaches for pre-launch conjunction assessment and the promotion of collection, sharing and dissemination of space debris monitoring information. There is a necessity to disseminate such data also with astronomical requirements.

Some crucial elements of STM can also be identified within national space legislation, policy, regulations and licensing regimes.[99] Nevertheless, these national frameworks deal primarily with issues related to the preservation of the space environment, the mitigation of space debris, and safe launches. In addition, States like Australia and South Africa are, as noted above, now adopting policies and strategies that include issues relating to astronomy and the preservation of space environment.[100]

The way forward for effective STM necessitates technical coordination and cooperation between the relevant actors involved. Developing an STM system capable of effectively and comprehensively managing launches, in-orbit operations, and re-entries will require practical adherence to important principles of cooperation, mutual assistance, due regard, the duty to consult, and notification.

A probable first step is to incorporate these rules into national space regulations and licensing regimes.[101] Another option is to develop an informative platform within the

97. ESPI, 'Towards a European Approach to Space Traffic Management' (January 2020) 10 <https://www.espi.or.at/wp-content/uploads/2022/06/ESPI-Public-Report-71-Towards-a-European-Approach-to-Space-Traffic-Management-Full-Report.pdf>.

98. COPUOS, Report of the Legal Subcommittee on its fifty-fifth session (27 April 2016) UN Doc A/AC.105/1113 <https://www.unoosa.org/oosa/oosadoc/data/documents/2016/aac.105/aac.1051113_0.html>.

99. See eg White House, 'Space Policy Directive-3, National Space Traffic Management Policy' (18 June 2018) <https://trumpwhitehouse.archives.gov/presidential-actions/space-policy-directive-3-national-space-traffic-management-policy/>.

100. Australia: the 2012 Outdoor Lighting Policy (n 17); South Africa: the 2007 Astronomy Geographic Advantage Act No.21 (n 17); Slovenia: the 2007 Law on limit values for light pollution of the environment; UK: the 2012 National Planning Policy Framework; France: the 2018 Decree relating to the prevention, reduction and limitation of light pollution, the 2012 Decree on the outdoor advertising, signs and signposting; Germany: the 1974 Law on the protection against harmful environmental effects from air pollution, noise, vibrations and similar processes; Spain: the 1988 Law on Protection of the Astronomical Quality of the Observatories of the Institute of Astrophysics of the Canary Islands; New Zealand: the 1991 Resource Management Act. Legal frameworks related to light pollution have progressively been developed under national regulations. Some are more general and deal with general environmental laws.

101. Rafael Moro-Aguilar and Steve A Mirmina, 'Space Traffic Management and Space Situational Awareness' in Jakhu and Dempsey (n 49) 180, 193–195.

United Nations as a mechanism for integrating the efforts of States, international intergovernmental organisations, spacecraft operators and specialised national and international non-governmental organisations in the collection, systematisation and provision for general use and analysis of information on objects and events in outer space.[102]

In 2021, during the sixtieth session of the COPUOS Legal Subcommittee session and the fifty-eighth session of the COPUOS Scientific and Technical Subcommittee, the impact of large satellite constellations on radioastronomy and optical astronomy was underscored, as well as the necessity to identify STM standards that would generate mutual benefits. This was important in particular in view of the increasingly complex and congested space environment resulting from the growing number of objects in outer space, the diversity of actors in outer space and the increased number of space activities, which each pose a challenge to the safety and sustainability of space activities.[103]

In that connection, there were calls to keep dark and quiet skies for science and society,[104] in particular regarding non-geostationary orbit satellites.[105]

Space Traffic Management could be considered with a view to developing and implementing a set of technical and regulatory provisions to promote safe access to outer space, the safety of operations in outer space, and safe return from outer space, free from physical or radio frequency interference. Hence, both legal and technical aspects of STM should be developed. The international community must strive towards a legally binding instrument for STM negotiated under the aegis of the United Nations, and both private and public stakeholders should be included in the development of any related strategies and regulatory frameworks.[106]

The growing use and development of large constellations of small satellites, if anything adds to this imperative to implement comprehensive STM measures.[107] The increasing deployment of satellite constellations will lead to Earth's orbits becoming more crowded in the coming years.

Space Traffic Management encompasses safety issues that require international coordination and harmonised rules. In June 2022, European Ministers responsible for space adopted a set of conclusions related to STM.[108] The conclusions strengthen the EU's common position on STM and underline the necessity of sharing capacities, information and best practices amongst Member States in order to address strategic and competitiveness challenges in space. The Ministers underscored the importance of strengthening EU space surveillance and tracking capabilities, and of coordinating legislation and standardisation of governance requirements.

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102. COPUOS, Further ideas on a set of goals of achieving the Vienna Consensus on Space Security and the need for thorough reflection on the modalities of addressing the tangled issues associated with space traffic management and the justifiability of intense expectations of early decisions in this area (7 June 2016) UNDocA/AC.105/2016/CRP.13<https://www.unoosa.org/res/oosadoc/data/documents/2016/aac_1052016crp/aac_1052016crp_13_0_html/AC105_2016_CRP13E.pdf>.
103. COPUOS, Report of the Legal Subcommittee on its sixtieth session (n 59); Report of the Committee on the Peaceful Uses of Outer Space on its sixty-fourth session (21 October 2021) UNGA Doc A/76/20, para 196 <https://www.unoosa.org/res/oosadoc/data/documents/2021/a/a7620_0_html/A_76_20E.pdf>.
104. COPUOS, Recommendations to keep Dark and Quiet Skies for Science and Society (19 April 2021) UN Doc A/AC.105/C.1/2021/CRP.17 < https://noirlab.edu/public/media/archives/techdocs/pdf/techdoc022.pdf>.
105. COPUOS, Report of the Legal Subcommittee on its sixtieth session (n 59) para 210.
106. COPUOS, Report of the Committee on the Peaceful Uses of Outer Space on its sixty-fourth session (n 103) para 198.
107. COPUOS, Report of the Scientific and Technical Subcommittee on its fifty-ninth session (n 13) para 122.
108. Council of the European Union, EU approach to space traffic management – Council conclusions (10 June 2022) (ESPACE 69, CFSP/PESC 756, CSDP/PSDC 351, TRANS 372) <https://www.consilium.europa.eu/media/56974/st10071-en22.pdf>.

As large constellations of satellites pose a heightened risk for the safety and sustainability of space activities, in particular with regard to the mitigation of space debris, and present challenges for astronomical observation, a comprehensive STM system could enhance the safe and sustainable conduct of space activities.[109] There is a need to manage the orbital environment with appropriate standards and best practices for the maintenance and stability of the satellite industry, and also to pay proper account to the importance of astronomical observations for humanity.

4.2 Radio-Quiet Skies: STM and ITU Coordination

By the 2030s, if one adopts a 'business-as-usual' case, more than 5,000 satellites could potentially be sighted above the horizon at any given moment in the case of a typical mid-latitude observatory.[110] Of those, thousands could be illuminated, and thus affect all-optical wide-field images obtained at twilight, perhaps with the exception of those taken by the smallest optical telescopes.[111]

Large constellations of satellites also pose a challenge to radio astronomy.[112] Though certain narrow frequency bands are protected by the International Telecommunication Union (ITU), and some telescopes are located in protected radio-quiet zones,[113] the sheer number of new satellites will result in thousands of additional radio transmitters moving rapidly across the sky. These are bound to affect measurements made by highly sensitive radio telescopes. With this in mind, the establishment of STM rules will need to be carefully coordinated with ITU requirements.[114]

5. The Way Ahead – A Long and Winding Road

The impacts on astronomy from satellite constellations are one concern amongst many in this 'NewSpace' era. The large numbers of satellites planned for LEO give rise to significant additional risks arising from the heightened proliferation of space debris, increasing the difficulty to safely operate satellites in LEO, and generally to introduce a global approach to STM. These issues raise a number of secondary questions of governance and regulation in terms of liability for harmful interference and damage, and more broadly key questions about how to treat LEO as a regulated environment and deal with transboundary impacts.

Space activities are guided by the general provisions of the United Nations Space Treaties. However, astronomical observations are increasingly 'competing' with other space activities,

109. Report of the Committee on the Peaceful Uses of Outer Space on its sixty-second session (12–21 June 2019) UN Doc A/74/20, para 241 <https://www.unoosa.org/oosa/oosadoc/data/documents/2019/a/a7420_0.html>.
110. European Southern Observatory (ESO), 'ESO and international partners petition UN for the protection of the Earth's dark and quiet skies' (7 February 2022) <https://www.eso.org/public/announcements/ann22001/>.
111. ibid.
112. The Impacts of Large Constellations of Satellites, Report by JASON for the National Science Foundation (JSR-20-2H), November 2020, 49–70 <https://www.nsf.gov/news/special_reports/jasonreportconstellations/JSR-20-2H_The_Impacts_of_Large_Constellations_of_Satellites_508.pdf>.
113. International Telecommunication Union, 'Safeguarding radio astronomy on the Moon' *ITU News* (25 May 2022) <https://www.itu.int/hub/2022/05/moon-based-radio-astronomy-spectrum/>.
114. COPUOS, Scientific and Technical Subcommittee on its fifty-ninth session, Draft Report: Examination of the physical nature and technical attributes of the geostationary orbit and its utilization and applications, including in the field of space communications, as well as other questions relating to developments in space communications, taking particular account of the needs and interests of developing countries, without prejudice to the role of International Telecommunication Union (16 February 2022) UN Doc A/AC.105/C.1/L.394/Add.7, paras 18 and 19 <https://www.unoosa.org/res/oosadoc/data/documents/2022/aac_105c_1l/aac_105c_1l_394add_7_0_html/AC105_C1_L394Add07E.pdf>.

especially expanding commercial activities, for use of frequencies. There is now a need to balance different interests: free access, free exploration and preservation of the space environment.

We believe that the time is approaching to devise a set of principles based on Article I of the Outer Space Treaty to reinforce the 'benefit of (hu)mankind' concept by safeguarding the scientific interests of space astronomy in a combined effort by the United Nations, International Telecommunication Union and International Astronomical Union[115]; as well as on Article IX and the principle of due regard and to avoid harmful interference with activities of other States.

That said, Article IX was never intended to be a primarily environmentally centred provision and consequently it does not establish comprehensive and rigorous environmental standards to effectively govern ever-increasing (and environmentally harmful) space activities. Therefore, the current space legal regime must be supplemented by concepts that perhaps may be derived and adapted from international environmental law.

It is certainly the case that ground- and space-based astronomical research constitute an instrumental part of space exploration. There is a necessity to raise awareness of the harm created by the uncontrolled expansion of artificial light at night and their consequences on astronomical observations. Consequently, the space community must recognise and act upon the need to adopt mitigating measures as a preliminary steps, and then (voluntary) best practices and guidelines for satellite constellation operators and consider the implementation of a regime requiring an EIA and SIA before authorisation and licensing.

While space debris represents a significant concern in terms of STM, it is important to note that its 'contribution' to the brightness of the sky is (currently) still orders of magnitude less than ground-originated light pollution. The mega-constellation satellites themselves do not significantly contribute to the diffuse sky background – provided they remain in one piece and are not pulverised by collisions. It is therefore critical to avoid collisions among satellite constellations, not only because of the disastrous effects that would have in orbit, but also to avoid additional sky brightness pollution issues.

Further collaboration will be necessary between the satellite industry and astronomers regarding the development of best practice and guidelines, which may include modifying orbital altitudes, voluntary changes to satellite design, the provision of telemetry information for astronomical observations, and the modification of satellite orientation to minimise the reflected light produced by satellites. These notions should be included in satellite design and development.[116] Best practices might inevitably involve a compromise between the needs of the astronomical community and orbital operators.

The implications for astronomy and dark and quiet skies are that, at the current time, there is little recourse to address real and potential harm and to prevent additional adverse consequences in the future, other than through direct interaction with willing space operators and appealing to government funding agencies and regulators. There is thus a clear need for better global coordination, policies, and laws for dark skies protection, but also for radio-quiet skies. A failure to address these issues through a coordinated and holistic approach to the management of space activities will likely have very significant consequences for the way we are able to utilise space for the benefit of humanity. Indeed, this relates also to the need to understand the fragility of the space environment and how important it will be to carry

115. See International Astronomical Union <https://www.iau.org/static/publications/uncopuos-stsc-crp-8jan2021.pdf>.
116. Report of the Scientific and Technical Subcommittee on its fifty-ninth session (n 13) para 272.

out space activities in a manner that best supports, or at least does not unduly threaten, the long-term sustainability of space and space activities.

Clearly, we are really just at the beginning of these discussions and there is much work to be done to find the appropriate balance for a sustainable path forward. We hope that the interrelationships borne out in this paper will help to contribute to the considerations that we must have now and into the future.