Technology and the Unique Challenges of Applying Law to the Realm of Outer Space and Space Activities

F.G. von der Dunk*

Abstract

For better or worse, technology at heart is—except to the extent that artificial intelligence fundamentally becomes involved—not so much a creator as a facilitator and enhancer of human acts, actions and activities, allowing them to become more effective, less costly, or sometimes even just merely feasible. Perhaps nowhere that is more pertinent then when it comes to human activities in outer space, which are still overwhelmingly conducted remotely and hence crucially dependent on technology. Given that "the law" has always been geared to address humans and their acts, actions, and activities, this gives rise to a rather special approach to maintaining and further developing a legal regime for outer space. The present Article intends to address and assess some of the most pertinent aspects of the unique body of space law from precisely this perspective, to shed some light on how "the law" would, could, and/or should handle relevant human endeavours in or with regard to outer space, in particular in the context of legal responsibilities and liabilities.

* Dr. Frans G. von der Dunk is the Harvey & Susan Perlman Alumni/Othmer Professor of Space Law at the University of Nebraska-Lincoln College of Law's unique Program in Space, Cyber and National Security Law, as well as the Director of Black Holes B.V., a leading space law and policy consultancy based in The Netherlands.

Table of Contents

I. Introductory Remarks: Technology and 'The Law' 57

II. The Law, the Delimitation of Outer Space as a Realm, and the Role of Technology 59

III. The Law, Space Activities, the Exercise of Jurisdiction and the Role of Technology 62

IV. The Law and the Role of Technology in Space Activities in Determining its Substance 65

V. The Law, Responsibilities and Liabilities for Space Activities and the Role of Technology 68

VI. Concluding Remarks 72

I. INTRODUCTORY REMARKS: TECHNOLOGY AND 'THE LAW'

Outer space and the human engagement in space activities, which took off in earnest with the launch of Sputnik I by the Soviet Union in 1957, has always been viewed as a realm of human activity where high-key technology has played a comprehensive and fundamental role, perhaps even more so than in any other "geographical" area where humanity has become active.[1] This is, for a major part, the consequence of the strange and deadly physical nature of space and the distances and dangers which have to be overcome in order to allow humans to even just get there and undertake activities of interest and importance.

From a legal perspective outer space has turned out to be a rather special environment as well. It refers to an area where the application of individual territorial sovereignty of states, that classic bedrock concept of public international law, is fundamentally denied,[2] but where those same states are uniquely, directly, and comprehensively responsible,[3] and liable[4] for activities of private sector entities somehow operating under their respective control.

In the context of law addressing outer space and space activities, this paper presents an effort to investigate the complex role of technology in the human space endeavour: to what extent and how has that role, quasi-omnipresent as it were, driven, or is it *vice versa* impacted by the development of legal norms and principles guiding such human endeavour?

---

1 The cyber realm, where high-key technology is actually omnipresent, should essentially be defined not as a "geographical" but as a virtual realm, where humans cannot "physically" enter.

2 *Cf.* the seminal clause of Art. II, Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies, *adopted* Dec. 5, 1979, 18 U.S.T. 2410, 610 U.N.T.S. 205 [hereinafter Outer Space Treaty], which provides: "Outer space, including the Moon and other celestial bodies, is not subject to national appropriation by claim of sovereignty, by means of use or occupation, or by any other means." *See also*, F.G. von der Dunk, *International space law*, in HANDBOOK OF SPACE LAW, 55–60 (F.G. von der Dunk & F. Tronchetti eds., 2015); S.R. Freeland & R. Jakhu, *Article II*, in COLOGNE COMMENTARY ON SPACE LAW Vol. I 48–55 (S. Hobe, B. Schmidt-Tedd & K.U. Schrogl eds., 2009).

3 *Cf.* Art. VI, providing in relevant part: "States Parties to the Treaty shall bear international responsibility for national activities in outer space, including the Moon and other celestial bodies, whether such activities are carried on by governmental agencies or by non-governmental entities, and for assuring that national activities are carried out in conformity with the provisions set forth in the present Treaty." *See also* von der Dunk, *supra* note 2, at 46; M. Gerhard, *Article VI*, in COLOGNE COMMENTARY ON SPACE LAW Vol I 111–22 (Stephan Hobe, et al. eds., 2009).

4 *Cf.* Art. VII, providing: "Each State Party to the Treaty that launches or procures the launching of an object into outer space, including the Moon and other celestial bodies, and each State Party from whose territory or facility an object is launched, is internationally liable for damage to another State Party to the Treaty or to its natural or juridical persons by such object or its component parts on the Earth, in air space or in outer space, including the Moon and other celestial bodies." *See further*, von der Dunk, *supra* note 2, at 46; A. Kerrest & L.J. Smith, *Article VII*, *in* COLOGNE COMMENTARY ON SPACE LAW Vol. I, 134–39 (Stephan Hobe, et al. ed., 2009).

As a starting point it should be pointed out that, for better or worse, generally speaking so far technology has not been so much replacing humans as a creator but rather served as a facilitator and enhancer of human acts, actions, and activities, allowing them to become more effective, less costly or often even just merely feasible.[5] Transportation technology allows humans to move faster and with less effort than when they would have to run, communication technology allows humans to communicate more information and over longer distances than when they would have to shout, and engineering technology allows humans to construct for instance better buildings more efficiently than if they would have to build everything by hand. This should also be the point of departure for discussions specifically focused on outer space and space law.

So far, it always was a matter of humans using or engaging with technology and hence (at least in principle) in control of the acts, actions, or activities resulting from such use and engagement. To that extent technology indeed is not a "creator" in a meaningful sense. Also, and for the same reason, technology is essentially "amoral" in that it can be used for good, for bad, or for anything in between. One can use transportation technology to escape murder or, by contrast, to go and murder someone; one can use communication technology to spread peace and understanding or, alternatively, hatred and filth; and one can use engineering technology to either keep people warm and safe or to incarcerate and torture them—each and every time it is the humans using technology which determine such usage.

That humans are the ultimate determinators of how technology is put to use is also crucial when it comes to the law as a social mechanism for creating some measure of justice and fairness as well as stability and foreseeability in human society. Law has always addressed humans by allocating rights and imposing obligations upon them, normally in first instance regardless of whatever technology they may use. This also applies where such humans operate through legal fictions such as states, intergovernmental organizations, associations, and commercial companies: rights allocated to any of those are ultimately invoked by the individual humans in charge of them—Presidents, Secretaries-General, Chairpersons, and CEOs—and those individuals are, in turn, also supposed to ensure that any of those comply with relevant obligations.

In other words: so far, humans, not technology, are the creators as far as the law is concerned. Only with the current developments concerning artificial intelligence (AI) is this fundamental paradigm about to change, as increasingly higher levels of AI make it increasingly unclear (read doubtful) whether

---

5 *Cf.*, *e.g.*, definitions of "technology" as "the use of scientific knowledge to solve practical problems" (*Technology*, BRITANNICA.COM, https://perma.cc/A6L4-2URS (last accessed Mar. 25, 2025), "the application of scientific knowledge to the practical aims of human life" (*Technology*, DICTIONARY.COM, https://perma.cc/YG62-SQCF (last accessed Mar. 25, 2025), or "the application of conceptual knowledge to achieve practical goals" (*Technology*, WIKIPEDIA, https://perma.cc/449Q-7RX9 (last accessed Mar. 25, 2025).

humans are (still) the ultimate decision-makers as to such acts, actions, and activities, or whether technology would truly become a creator in and of itself.

Outer space and human endeavours in that realm would, because of their unique nature, present an environment particularly conducive to the use of AI, although it is probably fair to say that even in that environment the use of advanced AI is in its early stages.[6] Still, given the near-comprehensive absence of humans out there and the indispensable involvement of complex technologies in space activities from the beginning of the Space Age, the law developed in that context has from the very beginning dealt with such indispensability, which raises another crucial question of whether it would for that reason also be more easily adaptable to any future fundamental AI usage as well.

When analysing how the law has come to address the realm of outer space and relevant human activities, one should start realizing that both the key terms here—"outer space" and "space activities"—are already subject to considerable discussions as to how they should properly be defined for legal purposes, where technology has then played a main role.

At this stage, it is submitted that the intricate relationship between "law" and "technology" in the context of outer space and human acts, actions and activities of all sorts involving that realm has substantially arisen in at least four major and illustrative contexts: (1) the delineation, read effectively delimitation, of outer space as a realm subject to law; (2) the high-level approach to legally addressing human acts, actions and activities in that particular realm; (3) some key areas where technology drives the actual substance of such law; and (4) the particular case of accountability, read in particular liability, for space activities notably also of the private sector and their consequences.

II. THE LAW, THE DELIMITATION OF OUTER SPACE AS A REALM, AND THE ROLE OF TECHNOLOGY

First, as to the concept of "outer space." Following the inherent logic of that realm being the subject first and foremost of international law,[7] states have always had a strong incentive to establish clearly where relevant rules of relevant international treaties and customary international law[8] apply. With

---

6 That, of course, partially depends on the definition of "(advanced) AI": if preprogrammed computers would qualify as such, clearly AI would already be of crucial importance for most space activities today; if, however, "advanced" would refer to "self-learning" or even "self-deciding", it would seem current applications thereof in outer space would be extremely rare, if indeed operative at all. Equally clear however, of course, this is rather likely to change within the near future.

7 *See, e.g.*, von der Dunk, *supra* note 2, 29–32.

8 Note the reference to "a. international conventions, whether general or particular, establishing rules expressly recognized by the contesting states; b. international custom, as evidence of a general practice accepted as law" of Art. 38, Statute of the International Court of Justice, San Francisco, June 26, 1945, entered into force Oct. 24, 1945; 156 U.N.T.S. 77; U.S.T.S. 993; 59

respect to outer space this is important in particular given the traditional and universally acknowledged sovereignty of individual states over the airspaces above their territory[9] which is diametrically opposed to the legal status of outer space as being "not subject to national appropriation by claim of sovereignty, by means of use or occupation, or by any other means."[10]

However, while few would deny that "outer space" somehow refers to a "geographical realm" somewhere above/beyond the airspaces of this world, there is no international consensus on where, that is at which particular altitude, that realm begins relative to the Earth—or even, that it is desirable and feasible to determine a particular attitude in the first place. This discussion has inevitably involved a discussion on relevant technologies, as lawmakers and lawyers would instinctively tend to look for guidance from that perspective as for the appropriate boundary between airspaces and outer space.

Not accidentally, this had been also the case historically with the discussion on the two-dimensional delimitation of the territorial waters. The original idea was to equate, for obviously practical as well as logical purposes, those waters to the areas that the coastal state could actually "control," basically by means of military power. After all, if you can exercise full military control over a certain area, you can substantively both impose and enforce 'the law' there, as well as *vice versa* be logically and justifiably held responsible and liable for what happens there. From early on, therefore, a so-called "cannon-shot rule" was applied in this context: territorial seas were supposed to extend as far as the military technology available to a particular country allowed a cannon on the edge of the water to shoot.

However, both the continuous evolution of artillery technology and the uneven availability thereof as between more and less developed countries gradually caused the politico-legal feasibility and legitimacy of this rule to erode. Originally, it had been translated customarily into a 3-nautical-mile maximum breadth of the territorial seas, which was still left unchallenged (but also unconfirmed) by the 1958 Convention on the Territorial Sea and the Contiguous Zone.[11] But the resulting idiosyncrasies, inequalities, and general confusion ultimately became untenable, and the 1982 U.N. Convention on the Law of the Sea finally arrived—without any regard for technologies, military or otherwise—at a compromise of a maximum breadth of the territorial seas of

---

Stat. 1031; U.K.T.S. 1946 No. 67; A.T.S. 1945 No. 1; generally acknowledged to reflect the two main sources of public international law.

9 *See, e.g.*, Art. 1, Convention on International Civil Aviation, Chicago, Dec. 7, 1944, entered into force Apr. 4, 1947; 15 U.N.T.S. 295; T.I.A.S. 1591; 61 Stat. 1180; Cmd. 6614; U.K.T.S. 1953 No. 8; A.T.S. 1957 No. 5; ICAO Doc. 7300: "The contracting States recognize that every State has complete and exclusive sovereignty over the airspace above its territory."

10 Outer Space Treaty, *supra* note 2, Art. II.

11 Convention on the Territorial Sea and the Contiguous Zone, Geneva, entered into force Sept. 10, 1964; 516 U.N.T.S. 205; T.I.A.S. 5639; U.K.T.S. 1965 No. 3; Cmd. 584; A.T.S. 1963 No. 12.

12 nautical miles[12] which as of today presents the universally acknowledged legal rule.

In the context of the three-dimensional realm of outer space, it was much clearer already from the beginning that technology would fall short of being able to determine a boundary generating widespread acceptance. To start with, while most countries could afford cannons of at least reasonable efficiency and range back in the day, the differences in available relevant technology among nations in the context of outer space were of a different magnitude. More fundamentally, however, how does one define "control" in the enormous, ultimately infinite realm at issue: by means of the technology of controlling space objects by radio waves? By the technological capability to actually hit space objects kinetically? By the possibility to detect space objects, identify them and hold the appropriate entities legally and politically accountable for them?

Where the concept of military technology and the resulting control consequently did not make much sense as a boundary-determining criterion pretty much from the start, lawmakers and lawyers started to look more broadly at the science and scientists to provide them with guidance on a logical scientific—read: determined by physics—boundary between airspaces and outer space.

However, while at first glance outer space might be viewed as a realm where, contrary to airspace, air molecules for all practical purposes were absent, there is no single altitude at which "air," as it were, suddenly gives way to "vacuum;" there is a gliding scale of ever less air molecules the higher one goes. Thus, as it turned out, the range of boundary altitudes suggested by scientists ran from a few thousand metres ("high up on Mount Everest there are not enough air molecules for average humans to breathe normally") to hundreds of thousands of miles (deep into an area where the presence of air molecules had long become so scarce as to be irrelevant, yet a distance at which the impact—read: gravity pull—of the Earth would still be felt)—which was not very helpful either.[13]

Ultimately, therefore, when neither technology nor more broadly science at large could come up with a generally acceptable boundary, it had become clear that politico-legal discussions would have to solve this issue.

Currently, however, the most that could be said with any degree of authority is that some consensus seems to be building to consider the altitude of 100 km above the Earth's surface as presenting the most likely boundary

---

12 *See* Art. 3, United Nations Convention on the Law of the Sea, Montego Bay, entered into force Nov. 16, 1994; 1833 U.N.T.S. 3 & 1835 U.N.T.S. 261; U.K.T.S. 1999 No. 81; Cmnd. 8941; A.T.S. 1994 No. 31; 21 ILM 1261 (1982); S. Treaty Doc. No. 103-39. Note that, in order to address the still existing wide variety of interests of states in certain amounts of control over parts of interantional waters, the Convention also introduced such new concepts as "contiguous zones" and "Exclusive Economic Zones".

13 *See generally* THOMAS GANGALE, HOW HIGH THE SKY? (2019), who, for over more than 600 pages, analyzed dozens of efforts to establish a meaningful lower boundary of outer space.

between the realms of airspace and outer space—more than a handful of countries as of today refer to such an altitude in national legal documents, a few international legal documents do so likewise, and then there is the private suborbital space tourism industry which—so far without many official challenges—claims to make their clients 'astronauts' by briefly bringing them above that altitude and back.[14]

That is, however where "technology" finally not only fails to help arriving at a delimitation of outer space but is actually used at least by the largest space power as an argument to not arrive at an agreement on such a delimitation. Even the two theories most often referenced in this discussion—the "lowest-perigee rule" and the so-called "Von Kármán-line"[15]—continuously failed to arrive at unequivocal and undisputable specific altitudes, which allowed the United States to make the official argument that it would be inopportune to arrive at any particular altitude as ongoing developments in technology might risk that such an altitude would sooner or later become confusing and/or problematic.[16]

In short: at the end of the day technology has played a surprisingly limited role in determining the most fundamental concept underlying any discussion of "space law": what exactly does "outer space" refer to with a view to legal discussions? Notwithstanding its key role in making the Space Age happen in practice as its "facilitator" and "enhancer," or even—potentially—as a "creator", in this context technology has not substantially contributed to allowing the law to deal with the consequences.

III. THE LAW, SPACE ACTIVITIES, THE EXERCISE OF JURISDICTION AND THE ROLE OF TECHNOLOGY

Second, as to the concept of "space activities." Accepting for the time being that there is a geographical realm labelled "outer space" which begins at an altitude somewhere between say 50 and 150 km altitude above the Earth's

---

14 For more extended analyses, *see* von der Dunk, *supra* note 2, at 60–72; F.G. VON DER DUNK, ADVANCED INTRODUCTION TO SPACE LAW 100, fn. 371 (2020).

15 The "lowest-perigee rule" assumes that there is an altitude below which it is impossible for a space object to continue an orbit around the Earth, whereas the "Von Kármán-line" assumes there is an altitude above which it is impossible for an aircraft to make use of the upward lifting force of air molecules due to their lack of density. GANGALE, *supra* note 13, as well as in his *The Non Karman Line: An Urban Legend of the Space Age*, 41 J. OF SPACE L. 151 (2017), ff., thoroughly dismantled the relevance of both rules by comparing them with actual practice and orbital physics, including the fact that Theodore von Kármán himself never referenced a single altitude for delimitation purposes, and references to his imaginary "line" as a consequence differed considerably as to actual altitudes quoted. *See also* von der Dunk, *supra* note 2, 62–67.

16 *See, e.g.*, the statement of the U.S. delegate to the COPUOS Legal Sub-Committee, Unedited Transcript of its 644th Mtg., Apr. 4, 2011, COPUOS/LEGAL/T.644, at 2, as quoted by V. Nase, *Delimitation and the Suborbital Passenger: Time to End Prevarication*, 77 J. OF AIR L. & COM. 747, 754 (2012).

surface,[17] "space activities" for the sake of the law would then logically refer to "activities in the realm of outer space."

Immediately, however, a next conundrum arises here—where, crucially, the issue of technology comes in. Namely: what precisely constitutes an activity in outer space, given that by far the largest number of activities which one would normally label space activities are remote-controlled, with a human somewhere on Earth pushing a button or pulling a switch resulting in a launch vehicle changing course in outer space or a geostationary satellite switching broadcasting frequencies? Strictly speaking, the activity is the action of the human in the ground control station, but its overwhelming relevance lies in what then happens in outer space as a result.

Somehow, one should include the latter, the effects in outer space resulting from the button-pushing or switch-pulling, in the concept of "activity" if the discussion on the application of law to space activities is to make any sense—or at least is not to be confined to the, still relatively rare, activities conducted by humans themselves present in that realm.

This also has crucial ramifications in the legal context. Addressing human activities by way of the law, namely, standard-wise—though largely unconsciously—assumes a "unity of location:"when a human activity becomes the subject of a legal discussion, the actor(s), the activity itself and its (intended) target(s) usually find themselves in the same geographical area legally speaking. It is, consequently, not usually of great import how the applicable domestic law is exactly phrased. It may be phrased as imposing obligations upon humans (namely not to conduct certain activities harmful to someone else for violations of which that human could be brought to justice), it may be phrased as defining a legal prohibition of certain activities harmful to others (for violations of which the actor could then be brought to justice), or it may be phrased as offering victims of certain harmful activities (or in case of criminal law the state) opportunities to see justice being done. All three constitutive elements of the activity at issue—the actor, the activity properly speaking, and the target/victim—usually are "present" in the same legal realm (read, in the international context, in one country or another) which consequently will apply its jurisdiction to address, legislatively, adjudicatively, and executively, those scenarios as considered appropriate.[18]

Space activities, however, are overwhelmingly of the remote-controlled kind, where the technology of radio-frequency transmitters and receivers allows the humans pushing the buttons and pulling the switches to achieve the

---

17 It may be noted that the theories on delimitation which carry at least substantial support as well as making most sense usually focus on altitudes in this range, including the "lowest-perigee" rule and the "Von Kármán-line" (*see supra* note 15): few people would seriously claim that activities up till at least 50 km could still be labeled "space activities" whereas conversely few people would seriously claim that activities above at most 150 km should *not* be so labeled.

18 Traditionally, the discipline of private international law has dealt with the—relatively rare—cases where the unity of location was not present; ref. classic law school examples of someone shooting someone else across a national border or disputes involving contracts involving the law of various states at the same time.

desired results in outer space. Consequently, the unity of location is overwhelmingly absent as well: the human actor would be in some country or other on Earth (hence within that state's jurisdiction), the activity-proper would (depending upon the precise definition thereof) at least as to its major results play out in the realm of outer space which, as per Article II of the Outer Space Treaty,[19] fundamentally does not constitute part of any state, while the results in turn might well fundamentally impact many humans or other legal persons back down again on Earth—possibly or even likely in countries different from the one(s) where the activity originated.

In other words: for the purpose of addressing space activities by law in order to promote the desired levels of justice and fairness respectively stability and foreseeability, the scoping of jurisdiction of individual States takes centre stage, noting furthermore that States are held internationally responsible and liable also for relevant sets of private activities[20]—while at the same time they need to address or even target in a properly prominent manner the relevant use of technology involved in making all those activities a reality.

States can use both territorial jurisdiction and nationality-based jurisdiction[21] to address the humans pushing the buttons and pulling the switches on their territory, thereby effectively legally controlling the results of such button-pushing and switch-pulling in outer space. They cannot, however, enunciate laws prohibiting or conditioning the latter as such—as that would run counter to the foundational provision of Article II of the Outer Space Treaty as mentioned above—except as for their own nationals operating in outer space. And while they can (at least in principle) legally apply jurisdiction again regarding the targets (victims) of space activities and provide them with rights to obtain redress; when the persons or entities accountable for the button-pushing or switch-pulling find themselves in other countries the actual possibility of applying relevant law is limited once again to their own nationals.

Partly to augment the toolbox for states to legally control activities in outer space given this overwhelming dependence on remote-control technology, international space law itself has added a third legal tool for states to exercise jurisdiction: Article VIII of the Outer Space Treaty, as further elaborated by the Registration Convention,[22] allows states to extend their

---

19 Famously, Outer Space Treaty,*supra* note 2, Art. II provides: "Outer space, including the Moon and other celestial bodies, is not subject to national appropriation by claim of sovereignty, by means of use or occupation, or by any other means." *See also* von der Dunk, *supra* note 2, at 55–60; Freeland & Jakhu, *supra* note 2*,* at 44–63.

20 *See* Outer Space Treaty, Arts. VI & VII, as quoted in *supra* notes 3 & 4.

21 The rights of states to exercise legislative, adjudicative, and executive jurisdiction over both everything occurring within national territory and all activities conducted nationals are universally accepted, even if as for the latter the exercise of adjudicative and executive jurisdiction may require the application of such concepts as extradition if the targeted nationals happen to be present in another state—in deference to the territorial sovereignty of that state.

22 Convention on Registration of Objects Launched into Outer Space, New York, Jan. 14, 1975, entered into force Sept.15, 1976, 1023 U.N.T.S. 15, T.I.A.S. 8480, 28 U.S.T. 695, U.K.T.S. 1978 No. 70, Cmnd. 6256; A.T.S. 1986 No. 5, 14 ILM 43 (1975).

jurisdiction, as it were on a quasi-territorial basis, to space objects which they respectively registered as well as "any personnel thereof."[23] The net effect of this tool however, ironically, remains largely confined to crewed space operations, where non-crewed, read remote-controlled space operations, can be handled legally much more effectively and sensibly using the territorial jurisdiction of the relevant state *vis-à-vis* the operators on the ground.

In short: while technology has turned out to be an indispensable element as "facilitator," "enhancer" or even—potentially—as "creator" of space activities, it has by that token indeed here exerted a distinct impact on how space law would (have to) be developed to achieve the ultimate goals of justice, fairness, stability, and foreseeability in relevant human acts, actions, and activities—all the while however continuing to hold the relevant humans or the legal fictions behind which they operate ultimately accountable for them.

IV. THE LAW AND THE ROLE OF TECHNOLOGY IN SPACE ACTIVITIES IN DETERMINING ITS SUBSTANCE

Third, the foremost technological aspect of space activities addressed by the current body of space law concerns the inescapable need for all of those to use radio transmissions. This applies almost by definition to all non-crewed remote-controlled space operations, but to a considerable extent also to crewed space missions, given that the astronauts involved are in need of regular communication with ground control to optimize their operations and activities.

While indeed this technological aspect has become the topic of major international regulations, for historical reasons, those had developed not as part of the classic body of the *corpus juris spatialis internationalis*, read the four treaties developed in the bosom of the United Nations in the second half of the sixties and the first half of the seventies considered to provide the backbone of all international space law,[24] but in a different context and hence not always semi-automatically coordinated with the former.

---

23 Outer Space Treaty, *supra* note 2, Art. VIII; the reference to "personnel" of the space object at issue actually extends that jurisdiction beyond the 'quasi-territory' of crewed space objects to humans engaged in Extra-Vehicular Activities (EVAs) such as space walks or lunar excursions. *See also* B. Schmidt-Tedd & S. Mick, *Article VIII*, *in* COLOGNE COMMENTARY ON SPACE LAW Vol. I 156–63 (Stephan Hobe et al. eds., 2009).

24 Outer Space Treaty,*supra* note 2; Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space, Apr. 22, 1968, entered into force Dec. 3, 1968, 672 U.N.T.S. 119, T.I.A.S. 6599. 19 U.S.T. 7570. U.K.T.S. 1969 No. 56, Cmnd. 3786 A.T.S. 1986 No. 8, 7 ILM 151 (1968); Convention on International Liability for Damage Caused by Space Objects, Mar. 29, 1972, entered into force Sept. 1, 1972, 961 U.N.T.S. 187, T.I.A.S. 7762, 24 U.S.T. 2389, U.K.T.S. 1974 No. 16, Cmnd. 5068, A.T.S. 1975 No. 5, 10 ILM 965 (1971); 1975 Registration Convention, *supra* note 22. *See also* von der Dunk, *supra* note 2, at 49–99. Many authors also include a fifth international treaty in the concept of the *corpus juris spatialis internationalis*, Agreement Governing the Activities of States on the Moon and Other Celestial Bodies, New York, 18 December 1979, entered into force July 11, 1984; 1363 U.N.T.S. 3, A.T.S. 1986 No. 14, 18 ILM 1434 (1979), but given its rather poor level of

Already since the late nineteenth century, the international aspects of the use of radio waves for communication purposes had been taken care of as much as politically and practically feasible by an intergovernmental organization especially established for the purpose: the International Telecommunication Union (ITU).[25] Within the context of the ITU, its member states (comprising almost all sovereign nations in the world) have agreed to abide by an extended set of rules and obligations intended to facilitate international radio communications, *inter alia* by setting up an elaborate system of coordinating the use of international frequencies to limit radio interference as much as possible.[26]

For instance, radio frequencies were declared "limited natural resources" to be "used rationally, efficiently and economically, in conformity with the provisions of the Radio Regulations,"[27] ITU member states "shall endeavour to limit the number of frequencies and the spectrum used to the minimum essential to provide in a satisfactory manner the necessary services" and "to apply the latest technical advances as soon as possible,"[28] and radio stations, "whatever their purpose, must be established and operated in such a manner as not to cause harmful interference to the radio services or communications" of other duly authorized users.[29]

More specifically, the use of radio frequencies by any nation or operators (to be) authorized by them with intentional or unintentional cross-border effects was to be coordinated according to a two-step alternatively three-step approach, which can be summarized as follows.

The first step of "allocation," the term of art referring to the "reservation" at the international level of frequency bands to categories of services using radio waves,[30] followed a specification, over time more and more elaborate, of different types of services—currently amounting to a list of forty-two.[31] This step is taken care of by the collective of ITU member states at the quadrennial World Radio Conferences (WRCs), each time agreeing—following immensely complex preparations and negotiations—on revisions of

---

adherence especially among leading spacefaring nations its importance is fairly limited from the perspective of (international) *lex lata*.

25 Originally established in 1865 as the International Telegraph Union, the ITU is currently legally and institutionally underpinned by the \Constitution of the International Telecommunication Union, Dec. 22, 1992, entered into force July 1, 1994, 1825 U.N.T.S. 1, U.K.T.S. 1996 No. 24, Cm. 2539, A.T.S. 1994 No. 28, Final Acts of the Additional Plenipotentiary Conference, 1992 (1993), at 1, 71;;both amended a few times since 1992; as well as the ITU Radio Regulations, amended every four years – most recently in 2024.

26 *See, e.g.*, von der Dunk, *supra* note 2, at 460–75.

27 ITU Constitution *supra* note 25, art. 44(2).

28 *Id.* art. 44(1).

29 *Id.* art. 45(1).

30 *See also id.* art. 1(16).

31 *See* Constitution of the International Telecommunication Union, Geneva, Dec. 22, 1992, entered into force July 1, 1994; 1825 U.N.T.S. 1, U.K.T.S. 1996 No. 24; Cm. 2539, art. 1(19)–(60).

existing and incorporation of new allocations according to the generally perceived needs of the world community for certain services relative to others.

In order to allow for as much flexibility as possible in serving the needs and interests of the sovereign member states and their operators, this very complex system for interference-avoidance furthermore allows for differences between three global ITU regions or even between individual (groups of) member states, as well as for a differentiation between primary and secondary allocations.

The result of such negotiations culminating in the WRCs is laid down in the Table of Frequency Allocations, incorporated in the Radio Regulations.[32] The Table of Frequency Allocations itself encompasses all frequencies practically useful for telecommunication purposes, currently running from 8.3 kHz to 275 GHz,[33] subdivided into a large number of frequency bands bookended by specific frequencies.

The second step of 'allotment' refers to the 'reservation' of specific frequencies to States for the purpose of specific telecommunication services intended to be provided.[34] This part of the process of arranging the international use of the radio frequency spectrum has a continuous character: in order to realize allotment in a manner not interfering with other lawful international usage of the frequency spectrum within the ITU framework, each time such interference-free access to a frequency or set of frequencies was requested by a state an extended coordination process entered into operation. This essentially allowed other states with prior rights to protest if they expected harmful interference to result from the proposed newcomer. Ultimately, a frequency or set of frequencies was to be arrived at not giving rise to any such concerns (as long as valid).

If the radio frequencies thus allotted were to be used by state operators themselves, effectively the third step of "assignment" automatically followed (which is why many clauses in the ITU documents already refer to assignment straight away): the specific frequencies at issue were now reserved to specific operators for purposes of the services these intended to provide.[35]

If, however, the actual intended operator would be an intergovernmental organization or a private operator, neither of which enjoyed the independent competence under the ITU regime to request 'allotment' of frequencies themselves, this third step of 'assignment' meant that the state to which the frequencies were formally allotted would in turn formally permit that operator to use them. In the case of an intergovernmental organization, that would normally be the host state of that organization; in the case of a private operator, it would (usually) be the state under whose (territorial) jurisdiction that operator fell. Assigned frequencies would then be included in the Master

---

32 *Id.* art. 5.53–5.565.

33 *Id.* The bands below 8.3 kHz are not allocated, and so are those between 275 and 3000 GHz.

34 *See id* art. 1(17).

35 *See id* art. 1(18).

International Frequency Register, and by that token henceforth enjoy legal protection against interference by others.

In short: while the key technology indispensable for (almost) all space activities has been addressed by a well-weathered and very sophisticated (and as a consequence often rather burdensome) specific legal regime, and the ITU and COPUOS have since the beginning of the Space Age been fairly effective in ensuring that the former would not unnecessarily conflict with the *corpus juris spatialis internationalis* and *vice versa*, this same technology has (still) not been treated very much as a "creator:" ultimately, the operators respectively the states supervising them continue to be held accountable for the proper use of the relevant technologies in the international context.

V. THE LAW, RESPONSIBILITIES AND LIABILITIES FOR SPACE ACTIVITIES AND THE ROLE OF TECHNOLOGY

The fact that, in spite of the key role of highly advanced technology in space activities, so far operators and/or their states remain accountable brings the analysis, finally, to the fourth context to be discussed here: the core issues of responsibility and liability and how they take, in the context of outer space and space law, the key roles of technology into consideration. A few points merit consideration from this perspective.

First, as referred to before, the space law responsibility regime as per Article VI of the Outer Space Treaty provides for a unique level of direct and full responsibility of states for activities notably also if undertaken by private actors, as long as they qualify as "national activities" of the state in question.[36] The original assumption behind this regime, deviating from general public international law where states can only be held internationally responsible for private acts vicariously,[37] certainly had a lot to do with the assumption back in the day that only states (and only a few ones at that) would have the technology available to undertake any activity in outer space and the means available to reasonably limit the risks involved. Also, by that token the clause requiring "authorization and continuing supervision by the appropriate State"[38] of any private activities—*if* non-state actors would become engaged in such space activities—would allow the technologically superior public entities to

---

36 Outer Space Treaty, *supra* note 2, Art. VI. Over time, "national activities" have become generally assumed to refer to both activities conducted from national territory and activities conducted by national citizens or juridical persons such as companies with the nationality of the State concerned, and arguably also to space activities involving ships, aircraft or other space objects registered by the State concerned. *See, e.g.*, G.A. Res. 68/74, Recommendations on national legislation relevant to the peaceful exploration and use of outer space (Dec. 16, 2013); and State practice overwhelmingly reflecting this approach; *cf.* F.G. von der Dunk, *Scoping National Space Law: The True Meaning of 'National Activities in Outer Space' of Article VI of the Outer Space Treaty*, *in* PROCEEDINGS OF THE INTERNATIONAL INSTITUTE OF SPACE LAW 227–37 (2020).

37 *Cf.* Art. 2(a), also in much more detail *see* Responsibility of States for Internationally Wrongful Acts 2001, UN Doc. A/56/10(2001), arts. 4–11.

38 Outer Space Treaty, *supra* note 2, Art. VI.

effectively control any such activities by presumably less technologically savvy private ones.

Ironically but dangerously, with the relatively recent development of major private space operators in particular in the U.S. and their ability, financially and otherwise, to almost monopolize the best brains in the business, one may now seriously start to question whether this assumption is still appropriate. Would the authorities (continue to) be able to command sufficient technological know-how and expertise to make fundamental decisions as to whether specific operators are qualified to safely and soundly undertake their intended space operations?

At least, the legal approach currently still prevailing has given rise to more and more countries drafting national space laws—with the U.S. body of national space law still being by far the most extended and elaborate—to ensure that private sector space activities are properly addressed and the risks of technologies involved.[39] All of them include regimes of authorization (even if often under other names such as "licenses," "approvals," "permits" or "permissions"[40]) of private sector space operations, and prominently include within those authorization regimes conditions related to the safe use of technology.

In other words, compliance with the general principles of international space law relating to its "global commons" status and resulting obligations to limit accidents, interference and harmful contamination[41] focuses on safety through technology, as per national regimes trying to ensure only those with the required high levels of technological expertise would be admitted into the space arena so as to minimize violations of such obligations and principles. Also the national regimes for actually monitoring[42] such authorized (as well as unauthorized) space activities by others than the state actors themselves will consequently focus on the technological means of remotely controlling space activities and then controlling the quality and sufficiency of those remote-controlling capabilities.

In addition, the major space powers—where space also is a crucial element of national security (and in the case of major European space powers partly also of common EU-wide security)—have also put in place major control regimes with regard to sensitive high-key dual-use technology wherever their export from national (respectively EU) territory could give rise

---

39 *See generally*, I. Marboe, *National space law*, in HANDBOOK OF SPACE LAW, *supra* note 2, at 127–204.

40 The key point here is that all of those concepts amount to a state granting a private entity the official and formalized right to undertake certain activities subject to certain conditions and obligations.

41 *Cf.* Outer Space Treaty, *supra* note 2, Arts. I, II, IX. .

42 Note that Outer Space Treaty, *supra* note 2, Art. VI, also "require[s] (…) continuing supervision by the appropriate State Party to the Treaty" of space activities conducted by non-governmental entities once qualifying as "national."

to security risks. Most visible—since most transparent—here are the U.S. and EU regimes.

The former takes a two-pronged approach. On the one hand, launch systems and all components and key technologies involved were now included in the U.S. Munitions List (USML),[43] which under the Arms Export Control Act[44] was subject to the jurisdiction of the U.S. Department of State, as further implemented by the (in)famous International Traffic in Arms Regulations (ITARs) which controlled the export of such systems, components and technologies to anywhere outside the U.S. where their presence might result in security threats.[45] On the other hand, a more or less parallel system as per the U.S. Commerce Control List (CCL),[46] which falls within the jurisdiction of the U.S. Department of Commerce and was ruled by the Export Administration Act,[47] dealt with the export of all sensitive dual-use items for which an export authorization was required under the Export Administration Regulations (EARs).

The latter meanwhile has been able to establish, over and above the national technology export controls of the major (Western) European powers such as France, Germany, and Italy, a level of harmonization of these regimes at least when it comes to all but the most sensitive technologies. By that token currently a 2021 Regulation[48] provides for, among others, a common EU list of dual-use items along the lines of the MTCR[49] and Wassenaar Arrangement[50] Lists, specific control measures to be introduced by exporters and provisions setting up a network of competent authorities supporting the exchange of information and the consistent implementation and enforcement of controls throughout the European Union.[51]

Second, as also briefly referred to before, the closely related space law liability regime as per Article VII of the Outer Space Treaty and its further elaboration by way of the Liability Convention echoed the same accountability of States for private space activities—in this case, specifically for those causing damage—and thus resulting in almost all national space laws hitherto

---

43 United States Munitions List (USML), 22 C.F.R. 121.

44 Arms Export Control Act of 1976, 22 U.S.C. 2751.

45 *See, e.g.*, P.L. Meredith & S.P. Fleming, *U.S. Space Technology Exports: The Current Political Climate*, 27 J. OF SPACE L. 40, 41 (1999).

46 Commerce Control List (CCL), 15 C.F.R. 774.

47 Export Administration Act of 1979, 50 U.S.C. §§ 4601–23; regularly amended since.

48 Regulation of the European Parliament and of the Council setting up a Union regime for the control of exports, brokering, technical assistance, transit and transfer of dual-use items, (EU) 2021/821, of 20 May 2021; OJ L 206/1 (2021); last amended by Commission Delegated Regulation, (EU) 2023/996, of 23 February 2023; OJ L 138/1 (2023).

49 *See* Agreement on Guidelines for the Transfer of Equipment and Technology Related to Missiles, Apr. 16, 1987; 26 ILM 599 (1987).

50 *See* Wassenaar Arrangement on Export Controls for Conventional Arms and Dual-Use Goods and Technologies, Dec. 19, 1995, effective July 12, 1996.

51 *See also* F. Tronchetti, *Legal aspects of the military uses of outer space*, *in* HANDBOOK OF SPACE LAW 369–77 (F.G. von der Dunk & F. Tronchetti eds., 2015) .

enunciated addressing such liability questions as well, in addition to reinforcing their focus on imposing safety-related, read technology-related, conditions as part of the authorization process on intended space operators.

The definition of the liable entity for damage caused by space objects, after all, referred to "(i) A State which launches or procures the launching of a space object; (ii) A State from whose territory or facility a space object is launched", in other words: to one or more states qualifying as launching states.[52] Which means, in turn, that whatever the private role in manufacturing, ownership, operation or benefits might be, it does not give rise to liability of any private entities involved at the international level, so that the individual states which would be held liable as launching states would be strongly incentivized to include obligations of reimbursement of the state by the accountable private operator.[53]

Then, under the international space law liability regime, liability for damage caused "on the surface of the Earth or to aircraft in flight" was conceptualized in a fairly straightforward manner as "absolute:" the mere evidence of damage and identification of the launching state as per the above, within the scope of application of the Liability Convention to "international" occurrences of damage, sufficed for a principled right to be compensated.[54]

This absoluteness also was at least for a major part the result of an understanding that victims and victim states might not have the technology available to determine specific causes for the causation of damage as would have been a prerequisite for any successful claim under fault or other forms of non-absolute liability—as well as of a conception of space activities generally being at least akin to "ultra-hazardous activities," meaning that the technologies involved were often "on the edge" of the capabilities of even the most advanced states.

Conversely, those considerations did not play a similar role when it came to liability for damage "elsewhere than on the surface of the Earth to a space object of one launching State or to persons or property on board such a space object by a space object of another launching State", in which case the extent of fault of the operator of the damage-causing space object would determine

---

52 Liability Convention, *supra* note 24, art. I(c); *See also* L.J. Smith & A. Kerrest de Rozavel, *Article I (Definitions)*, *in* COLOGNE COMMENTARY ON SPACE LAW Vol. II 107–09 (Stephan Hobe et al. eds., 2013).

53 In the United States for instance, this has given rise to a fairly flexible yet complex system of obligatory third-party liability acceptance and insurance resting upon the licensed operator imposing certain limits on the amounts involved which also translates into limits of the obligation to make sure the U.S. government is compensated for any international third-party liability claims pursuant to this international regime; *see* 51 U.S.C. 509 § 50914.

54 Liability Convention, *supra* note 24, art. II. *See also* L.J. Smith & A. Kerrest de Rozavel, *Article II (Absolute Liability)*, *in* COLOGNE COMMENTARY ON SPACE LAW Vol. II 117–18, 125–26 (Stephan Hobe et al. eds., 2013). Only under specific circumstances could the absolute character of this liability become mitigated; *see* Liability Convention, *supra* note 24, art. VI(1).

the extent of its liability.[55] The principled equality of the two parties involved in any hypothetical collision-in-space, in terms in particular of technology, legitimized this approach, as deviating fundamentally from the absolute liability-approach for damage caused on Earth or to aircraft in flight.

Unfortunately, the absence of any further definition of "fault" in this context[56] makes it difficult to assess to what extent technology is part of the analysis here. There are no specific standards of technology that would or at least might give rise to a conclusion that an operator cannot be held "at fault" since using state-of-the-art technology as much as can reasonably be expected.

In short, while technology is unequivocally crucial in complying with international space law in such realms as safety and liability and with such national export control laws as protecting national security, currently those same bodies of law still address technology not so much as a "creator" of space activities but indeed as a "facilitator" and "enhancer"—without much wriggle room, both responsibility for those activities and liability for damage caused by them is still squarely laid at the doorstep of humans and their legal fictions such as states and "non-governmental entities,"[57] almost regardless of what particular technology is used.

VI. CONCLUDING REMARKS

At this point it thus remains very much an open question whether, once technology would indeed become much more of a "creator" of space activities due to the evolution of more advanced versions of AI, space law would be up to the task of appropriately addressing those activities for the benefit of justice, fairness, stability, and foreseeability. So far the purportedly limited use of advanced AI has not yet required such a paradigm change in the approaches to attributability—the baseline for establishing responsibilities and liabilities also in the context of outer space and space activities—but as indicated, that might soon change. Relatively simple concepts such as "(national) activities (in outer space)" for which the actor, be it a state or a "non-governmental entit[y],"[58] can be held accountable directly through international space law respectively through domestic law implementing such international obligations, and "launching State(s)" which will be held accountable for "(damage caused by) its space object"[59], may no longer be adequate to play their intended roles in this respect.

---

55 *Id.* art. III; *see also* L.J. Smith & A. Kerrest de Rozavel, *Article III (Fault Liability)*, *in* COLOGNE COMMENTARY ON SPACE LAW 132, 132–34 (Stephan Hobe et al. eds., 2013).

56 *See, e.g.*, F.G. von der Dunk, *Too-Close Encounters of the Third-Party Kind: Will the Liability Convention Stand the Test of the Cosmos 2251-Iridium 33 Collision?*, *in* PROCEEDINGS OF THE INTERNATIONAL INSTITUTE OF SPACE LAW 199–209 (AIAA)(2010).

57 *Cf.* Outer Space Treaty, *supra* note 2, Art. VI.

58 *Id.* art. VI.

59 Liability Convention, *supra* note 24, art. II; *cf. id.* art. III.