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AUTONOMOUS SPACE OBJECTS AND INTERNATIONAL SPACE LAW: NAVIGATING THE LIABILITY GAP

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Abstract

The introduction of advanced new technologies is transforming the space industry. Artificial intelligence is offering unprecedented possibilities for space-related activities because it enables space objects to gain autonomy. The increasing autonomy level of space objects does not come without legal implications. The lack of human control challenges existing liability frameworks. This paper reviews the provisions of the Outer Space Treaty and the Liability Convention as the main legal documents introducing the legal grounds for attributing liability in case of damages caused by autonomous space objects. Looking at the limitations of these legal frameworks in what concerns the attribution of liability, this paper identifies the conditions that could cause a liability gap. The amendment of the Liability Convention, the concept of "international responsibility" introduced by Article VI of the Outer Space Treaty and several international law principles are analysed as potential solutions for preventing the liability gap and mitigating the risks posed by autonomous space objects.

Keywords *:artificial intelligence, autonomous space object, liability, responsibility, Liability Convention, Outer Space Treaty*

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I. INTRODUCTION

Ever since Gagarin entered space, and a little later, Armstrong set foot on the moon, governments spent large amounts of money on space-related activities. On a yearly basis, the global space economy is estimated by the Space Foundation, an organization actively advocating on behalf of the global space community, and by the Satellite Industry Association, engaged in advocating on behalf of the commercial satellite industry of United States (US). According to these two sources, the global space economy is gradually increasing. In 2018, the worth of the global space economy was estimated at $360 billion (according to the Space Foundation) and approximately $415 billion (according to the Satellite Industry Association).[1]

The increasing investments in the space industry also come from the pri-

[1] "ESPI Yearbook 2019: Space Policies, Issues and Trends," European Space Policy Institute, https://espi.or.at/?view=article&id=468:espi-yearbook-2019&catid=29.

vate sector, the so-called "New Space", with major players such as SpaceX and Blue Origin. This new phenomenon includes the emerging trends from the space private business, which aims to engage in space-related activities independently from governments. New entrants in the space industry usually fall in one of two categories: the first is existing large companies, such as Google or Facebook, interested in diversifying their portfolio and creating a symbiosis between their current business activities and space applications and the second is new space companies: start-ups.[2] In terms of space budgets allocated by the private space sector, the last decade showed a significant increase in investments. Over the last 15 years, the total investment in space-related start-up ventures amounts to $13.3 billion and more than 80 new space companies have been set up.[3]

In addition to being the new actors, New Space also includes innovative industrial approaches, specifically in what concerns advanced new technologies. Space-related technologies contributed to the growth of the private sector and by developing innovative technologies will continue to do so in the near future, as indicated by Jet Propulsion Laboratory (JPL), a global leader in planetary exploration and space-based astronomy that supports the missions of National Aeronautics and Space Administration (NASA). Regarding these innovative technologies, developing autonomous systems is a top priority.[4] Autonomous systems are equipped with artificial intelligence (AI) capabilities and function without human intervention.

The introduction of autonomous systems in space activities does not come without legal implications, especially in what concerns issues of liability. As far as we know there are no cases yet requiring the application of space law in the context of damages caused by an AI system. However, if we look at the evolution of AI systems in other industries, such as the self-driving cars industry, many incidents already occurred.[5] We believe we should anticipate future incidents involving autonomous space objects and consider a framework for liability regimes, in order to avoid situations in which liability cannot be attributed, in other words: a liability gap. Therefore, this paper analyses whether existing legal frameworks dealing with liability for damages caused by space objects are capable of dealing with incidents caused by AI, specifi-

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[2] *Ibid.*

[3] Alessandra Vernile, *The Rise of Private Actors in the Space Sector* (Springer International Publishing, 2018), 2.

[4] *Strategic Technologies: Science and Technology*, Jet Propulsion Laboratory (California Institute of Technology, 2019), 2.

[5] "Self-Driving Car Statistics for 2021: Policy Advice," accessed February 14, 2021, https://policyadvice.net/insurance/insights/self-driving-car-statistics/.

cally, by autonomous space objects.

II. ARTIFICIAL INTELLIGENCE FOR SPACE ACTIVITIES

Defining AI is no easy task. The concept itself is broad and different approaches have proposed different definitions.[6] Despite the increased interest in AI by academia, industry and public institutions, there is no standard definition of AI systems. Mostly, AI is described by reference to the historical evolution of this concept, its corresponding evolution of capabilities, and the use of technology that performs tasks requiring human intelligence.[7]

A. THE CONCEPT OF ARTIFICIAL INTELLIGENCE

In this paper, the definition of AI draws on the European Commission's reports, the expert groups appointed by the European Commission and by the European Parliament. In accordance with the opinion of the Independent High-Level Expert Group on Artificial Intelligence, AI systems aim to realize a goal, by acting in the physical or digital dimension by perceiving their environment through data acquisition, interpreting the collected structured or unstructured data, reasoning on the knowledge, or processing the information, derived from this data and deciding on the best action(s) to take to achieve the given goal.[8] Pursuant to European Parliament's Committee on Legal Affairs, in some cases, AI systems can adapt their behaviour by analysing how the environment is affected by their previous actions.[9] In a different position paper, the European Commission states that AI refers to systems that display intelligent behaviour by analysing their environment and taking appropriate action to achieve specific goals with some degree of autonomy.[10]

AI is already used in various fields, such as healthcare, transport, finance,

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[6] Virginia Dignum, "What Is Artificial Intelligence?" in *Responsible Artificial Intelligence: How to Develop and Use AI in a Responsible Way*, Virginia Dignum, ed. (Cham: Springer International Publishing, 2019), 9–34.

[7] Sofia Samoli et.al, "AI Watch: Defining Artificial Intelligence," (Luxembourg: Publications Office of the European Union, 2020).

[8] European Commission, "A Definition of Artificial Intelligence: Main Capabilities and Scientific Disciplines," in *Independent High-Level Expert Group on Artificial Intelligence set up by the European Commission*, 8 April 2019.

[9] Nathalie Nevejans, *European Civil Law Rules in Robotics* (Brussels: European Parliament, 2016).

[10] "Communication from the Commission to the European Parliament, the European Council, the European Economic and Social Committee and the Committee of the Regions, Coordinated Plan on Artificial Intelligence," European Commission Brussels, 7 December 2018, https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52018DC0795&from=EN.

personnel recruitment etc.[11] AI systems can be descriptive, they tell you what happened; diagnostic, they tell you why something happened or predictive as they forecast what will (statistically probably) happen; and prescriptive in the sense of being capable of performing actual decision making and implementation.[12]

The process of making decisions and taking actions of AI systems is enabled by the fact that the system is fed with a relevant set of data or uses appropriate sensors, for example, cameras or microphones, enabling the system to collect the data required for achieving the goal for which it was designed.[13] Subsequently, the collected data are interpreted and the system takes a decision, which may be translated into either pursuing an action or not. If it decides to act, this decision will be executed through the system's physical or software actuators.[14]

Depending on the type of the AI system, the final decision is made either by humans or autonomously, sometimes with some degree of human control. AI systems can make decisions and improve their capabilities without human intervention but depending on the available data. The process in which possible new actions are considered through an analysis of desired outcomes based on previous failure or success is known as machine learning (ML).[15] The inspiration for this comes from the neural networks of the human brain. As a general classification, there are two main categories of ML: supervised and unsupervised. Supervised ML relies on algorithms, which have been trained to calculate outcomes based on examples, i.e. the AI system was "trained" with examples of sets of input and corresponding output data previously identified as correct.[16] For unsupervised learning, algorithms are not trained, do not receive instructions identifying which data sets are correct and, therefore, will

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[11] "What Is Artificial Intelligence and How Is It Used?" *News European Parliament*, 9 April 2020, https://www.europarl.europa.eu/news/en/headlines/society/20200827STO85804/what-is-artificial-intelligence-and-how-is-it-used.

[12] Humberto Farias, "Machine Learning vs. Predictive Analytics: What's the Difference?" *Concepta*, 10 October 2017, accessed 11 February 2021, https://www.conceptatech.com/blog/machine-learning-vs-predictive-analytics-what-is-the-difference.

[13] Basheer Qolomany, et. al., "Leveraging Machine Learning and Big Data for Smart Buildings: A Comprehensive Survey," *IEEE Access* 7, (2019): 90316–90356.

[14] "How Artificial Intelligence Works," European Parliament Think Tank, 14 March 2019, accessed 14 February 2021, https://www.europarl.europa.eu/thinktank/en/document.html?reference=EPRS_BRI(2019)634420.

[15] "Machine Learning: What It Is and Why It Matters," SAS, accessed 14 February 2021, https://www.sas.com/en_us/insights/analytics/machine-learning.html.

[16] Stuart Russell and Peter Norvig, *Artificial Intelligence: A Modern Approach (Third edition)* (Harlow: Pearson, 2014), 695.

search independently for relevant data sets required for achieving their goal.[17]

In the space industry, one area in which the applications of AI are currently being investigated is in satellite operations; in particular, to support the operations of large satellite constellations, such as positioning, communication and end-of-life management. In addition, it is becoming more common to find ML systems analysing the huge amount of data that comes from each space mission.[18]

B. PRACTICAL APPLICATIONS OF ARTIFICIAL INTELLIGENCE FOR SPACE ACTIVITIES

Using AI for space-related activities enable space objects to gain autonomy. This offers a series of advantages, such as spacecraft being capable to rapidly assess and react to events and changing environments, thus increasing the reliability and productivity of missions.[19] In the absence of AI capabilities, spacecraft cannot determine their own operational status and make decisions on their own. In space missions dependent on the ground segment, many human experts are required, making such missions cumbersome and time-consuming. Sometimes, it may take days before the data are processed, decisions are made, and uploaded commands reach the spacecraft.[20] According to the European Space Agency (ESA) the AI disruption is emphasised by its convergence with other transformative technologies such as IoT, cloud computing and blockchain, which are transforming entire industry verticals such as automotive, healthcare, transport and banking. For example, the emergence of self-driving cars, is made possible today due to the convergence and integration of technologies such as IoT, cloud computing and AI. Will a similar disruption occur in the space sector? Will AI be the key to unlock the potential of the new streams of Earth Observation (EO) data coming online to better understand changes on Earth? Will satellite hardware become a commodity focusing on the AI-powered software enabling autonomy and remote upgrade, as is happening with Tesla cars? In this context, one of the key challenges for the EO community is to be able to exploit the full power of AI in collaboration with new players in the ecosystem including ICT companies, start-ups and

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[17] "Big Data, Artificial Intelligence, Machine Learning and Data Protection," Information Commissioner's Office, 2017, https://ico.org.uk/media/for-organisations/documents/2013559/big-data-ai-ml-and-data-protection.pdf.

[18] European Space Agency, "Robots in Space," accessed 12 February 2021, https://www.esa.int/Enabling_Support/Preparing_for_the_Future/Discovery_and_Preparation/Robots_in_space2

[19] *Ibid.*

[20] Daniela Girimonte and Dario Izzo, "Artificial Intelligence for Space Applications," in *Intelligent Computing Everywhere*, Alfons J. Schuster, ed. (London: Springer London, 2007), 235-253.

data and EO scientists.[21]

There is a growing necessity for processing the extensive amount of data generated by the new generation of satellites, such as the Copernicus programme's data.[22] Moreover, the success of future deep space missions (e.g., travelling to Mars) will be dependent on various types of AI applications.[23] Also, by enabling onboard decision-making, AI technologies support spacecraft in detecting events. Using AI maybe even access to dynamic environments, such as comets, will become feasible.[24]

AI is also used to monitor the operation of satellites by watching the patterns of other satellites, planets, and space debris and carrying out corrective actions if needed. Such monitoring capabilities are used, for example, by SpaceX for avoiding collision of satellites with other objects.[25] Another recent example relates to space station operations. The Crew Interactive Mobile Companion (CIMON) is the world's first flying autonomous astronaut assistant featuring AI,[26] introduced on the International Space Station in 2018. CIMON enables fully voice-controlled access to documents and media, and it can conveniently navigate through operating and repair instructions and procedures for experiments and equipment.[27] In terms of planetary exploration, AI is used to navigate on-site conditions that are still too dangerous for humans. The rover Perseverance was launched by US for navigating on Mars.[28] The technology behind it is similar to the one used by self-driving vehicles, however, with the major difference, that this rover has to navigate more complicated terrain, which is analysed by the computer vision systems installed in the rover as it moves. If a terrain problem is encountered, the AI system takes

[21] Pierre-Philippe Mathieu, Sveinung Loekken, et. al., "Towards a European AI for Earth Observation Research & Innovation Agenda," in *Workshop at ESA Φ-lab* (European Space Agency, 2018), 1-20, https://blogs.esa.int/philab/files/2018/07/Towards-a-European-AI-for-Earth-Observation-Research-Innovation-Agenda-.pdf.

[22] *Ibid.*

[23] European Space Agency, "Robots in Space."

[24] Steve Chien, et. al., "The Future of AI in Space," *IEEE Intelligent Systems* 21, no. 4 (July 1, 2006): 64–69.

[25] Ron Schmelzer, "How is AI Helping to Commercialize Space?" *Forbes*, 21 March 2020, accessed February 12, 2021, https://www.forbes.com/sites/cognitiveworld/2020/03/21/how-is-ai-helping-to-commercialize-space.

[26] "Astronaut Assistant CIMON-2 Is on its way to the International Space Station," Airbus, accessed 12 February 2021, https://www.airbus.com/newsroom/press-releases/en/2019/12/astronaut-assistant-cimon2-is-on-its-way-to-the-international-space-station.html.

[27] "Floating Robot Cimon sent to International Space Station," *BBC News*, 29 June 2018, accessed February 12, 2021, https://www.bbc.com/news/technology-44655675.

[28] Daniel Oberhaus, "How NASA Built a Self-driving Car for Its Next Mars Mission," *Wired*, 21 July 2020, accessed February 12, 2021, https://www.wired.com/story/how-nasa-built-a-self-driving-car-for-its-next-mars-mission/.

a decision and changes the course of the rover in order to avoid it.[29] AI is also used for space sustainability, i.e. for removing space junk. ESA plans to launch the world's first debris-removing space mission, ClearSpace-1, which will use an AI-powered camera to find the debris. Its robotic arms will then grab the object and drag it back to the atmosphere in order to burn it up.[30] Another approach in using AI for space sustainability includes collision avoidance manoeuvres using ML techniques.[31] This collision avoidance system, currently under development by ESA, will automatically assess the risk and likelihood of in-space collisions, improve the decision making process on whether or not a manoeuvre is needed, and may even send the orders to at-risk satellites to get out of the way.[32]

These examples of how AI can be used in space are paving the way for a higher autonomy level of this technology, which will be required to achieve other important milestones in space-related activities, for example reaching out to neighbouring solar systems, as Alpha Centauri. This would imply the traversing of a distance of over four light-years. Upon arrival, the spacecraft would need to operate independently for years, even decades, exploring multiple planets in the solar system. This ambition is not far from becoming a reality, given recent precedents: for example, in 2017, an autonomous spacecraft completed almost a dozen years of nearly continuous operations of Earth observation, using both onboard and ground-based AI.[33]

III. SPACE LAW LIABILITY REGIMES UNDER THE UN INTERNATIONAL TREATIES

The space treaties form the core of the whole space legal system concluded within the framework of the United Nations, by the Committee on the Peaceful Uses of Outer Space. Out of these, the Outer Space Treaty[34] and the

[29] "NASA's Mars Rover Drivers Need Your Help," *Jet Propulsion Laboratory*, 12 June 2020, accessed February 12, 2021, https://www.jpl.nasa.gov/news/nasas-mars-rover-drivers-need-your-help/.

[30] Thomas Macaulay, "AI to Help World's First Removal of Space Debris," *Neural*, 30 October 2020, accessed 12 February 2021, https://thenextweb.com/neural/2020/10/30/ai-to-help-worlds-first-removal-of-space-debris.

[31] Audrey Berquand and Deep Bandivadekar, "Five Ways Artificial Intelligence Can Help Space Exploration," *The Conversation*, 25 January 2021, accessed February 12, 2021, http://theconversation.com/five-ways-artificial-intelligence-can-help-space-exploration-153664.

[32] "Automating Collision Avoidance," European Space Agency, accessed February 12, 2021, https://www.esa.int/Safety_Security/Space_Debris/Automating_collision_avoidance.

[33] Steve Chien and Kiri L. Wagstaff, "Robotic Space Exploration Agents," in *Science Robotics* 2, no. 7 (2017): 1-2.

[34] Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer

Liability Convention[35] provide the legal grounds for attributing liability in case of damage caused by space objects. Article VII of the Outer Space Treaty sets forth the principle of international liability of the launching state for damage caused by its space object. However, several key-issues remained unaddressed, such as: what qualifies as damage, what type of liability regime is applicable or what procedure should be followed in case damage occurs.[36] Given these issues, the Liability Convention's purpose was to elaborate on Article VII of the Outer Space Treaty and to establish a detailed liability regime.

The characteristics of the Liability Convention together with the corresponding provisions of the Outer Space Treaty are discussed below.

A. LIABILITY VERSUS RESPONSIBILITY

First of all, a distinction needs to be made between two concepts of accountability, liability and responsibility, which are used in the same convention in an outer space context:

1. Article VI of the Outer Space Treaty provides that states shall bear "international responsibility" for national activities in outer space,
2. Article VII of the same Treaty refers to "international liability" to be attributed to a state that launches or procures the launching of an object into outer space, in case damage is caused to another state or to its natural or juridical persons by such object or its component parts.

The Liability Convention details the provisions of Article VII of the Outer Space Treaty differentiating between absolute and fault-based liability, depending on the location of the damages. Neither "liability" nor "responsibility" has been defined in the UN International Treaties. The term "liability" is used to establish the launching state's liability for damage caused by space objects, while the term "responsibility" has been used to mandate international responsibility by the appropriate state party for national activities in outer space.[37] From this it may be concluded that "liabilities" are mentioned when we are dealing with legal consequences, mostly in terms of damages, arising from a particular behaviour. On the opposite side, it seems that when we speak of responsibilities, we are dealing primarily with obligations imposed on people and institutions who are supposed to carry out certain activities

Space, Including the Moon and Other Celestial Bodies, 610 U.N.T.S. 205 [Outer Space Treaty].

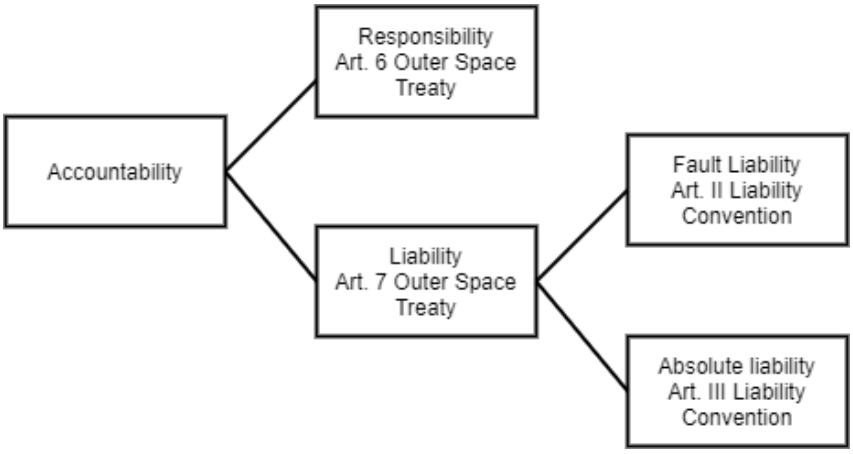
[35] United Nations Convention on the International Liability for damage caused by space objects, opened for signature on 29 March 1972, 961 UNTS 13810 (entered into force September 1972).

[36] Fabio Tronchetti, *Fundamentals of Space Law and Policy* (New York: Springer, 2013), 72.

[37] Bin Cheng, "International Responsibility and Liability for Launch Activities," *Air and Space Law* 20, no. 6 (December 1, 1995): 297-310.

or are accountable in given situations though not necessarily in the form of compensation for damages. Therefore, it appears that to some extent the two concepts are interrelated.[38]

An in-depth analysis of the potential confusion between the two concepts of accountability is beyond the purpose of this paper.[39] However, given the challenges posed by the rapid introduction of advanced AI systems in space-related activities and the risks related to attributing liability under the Liability Convention, it is worth mentioning that there is no fundamental reason why the more general concept of state responsibility could not be used also for obtaining compensation for damage in cases where the liability concept may not offer this possibility. Thus, at least in theory, a state that is the victim of damage caused by an unlawful act might choose to seek compensation for such injuries not from the state technically liable under Article VII of the



Outer Space Treaty and the corresponding Articles II and III of the Liability Convention, but from the state technically responsible under Article VI of the Outer Space Treaty.[40]

Figure 1. Accountability Concepts under Core International Space Law

B. ABSOLUTE AND FAULT-BASED LIABILITY

Under the Liability Convention, liability is by definition attributed only

[38] Stephen Gorove, "Liability in Space Law: An Overview Space Law," *Annals of Air and Space Law* 8, (1983): 373–380.

[39] See for this issue in detail, Frans von der Dunk "Liability versus Responsibility in Space Law: Misconception or Misconstruction?" in *Proceedings of the Thirty-Fourth Colloquium on the Law of Outer Space,* 1992, 363–371.

[40] Frans von der Dunk, "International Space Law," in *Handbook of Space Law*, Frans von der Dunk and Fabio Fonchetti, eds. (Cheltenham, United Kingdom: Edward Elgar Publishing), 50.

to states, specifically to "launching states", which include: (i) a state which launches or procures the launching of a space object or (ii) a state from whose territory or facility a space object is launched.[41] The Convention distinguishes between the liability of states related to damage caused by its space object on the surface of the Earth or to aircraft in flight, which is absolute[42] and to damage caused not on the surface of the Earth.[43] For the latter type of damage the state can be held liable only if the damage is due to its fault or the fault of persons for whom it is responsible. Thus, the geographical location of the damage is a fundamental criterium[44] for attributing liability, i.e., on the surface of the Earth or elsewhere.

1. Absolute Liability

The reason behind the Liability Convention's introduction of absolute liability is the fact that space activities create an extraordinary risk to persons and property with the supplementary inconvenience of the difficulty of establishing the proof of fault in the case of an accident caused by a space object. In order to protect victims, the burden of proof was therefore put on the launching state, since it supposedly benefits from the activity which caused the damage. It is also important to note that it is not a general principle of international law that states can be held absolutely liable, but rather an exceptional situation. As a rule, the establishment of fault is required before liability can be attributed.[45] Thus, it can be argued that the Liability Convention has created a new situation which so far has not been reproduced by any other international treaty.[46]

2. Fault Liability

The reason behind the introduction of a fault liability regime is that, in space, all parties in the position to operate a space object are assumed to be acting on an equal footing, to have the technology to provide the proof of the fault, and in any case to have assumed the risks of conducting these activities: none of them should be a "privileged victim".[47]

The notion of "fault", or more precisely, the interpretation of this notion, received a lot of attention in the legal doctrine because the Liability Convention does not define the term. The Convention also fails to refer to a duty of

[41] Frans von der Dunk, *Advanced Introduction to Space Law* (Cheltenham, United Kingdom: Edward Elgar Publishing, 2020), 49.
[42] Liability Convention, art II.
[43] liability Convention, art III.
[44] Valérie Kayser, *Launching Space Objects: Issues of Liability and Future Prospects* (Dordrecht: Springer, 2001), 50.
[45] *Ibid.*
[46] von der Dunk and Tronchetti, *Handbook of Space Law*, 89.
[47] Valérie Kayser, *Launching Space Objects*, 51.

care in outer space, the breach of which would constitute fault.[48] As a general rule, fault can only be asserted when the act violates duty of care or standard of conduct. The Convention does not provide a clear obligation to act or to abstain from acting, making it difficult to implement this notion in practice.[49] Some legal scholars referred to Black's Law Dictionary in an attempt to define fault as "an error or defect of judgement or of conduct; any deviation from prudence or duty resulting from inattention (…); the intentional or negligent failure to maintain some standard of conduct when the failure results in harm to another person".[50] As such, "fault liability" can then be defined as implying a certain degree of blameworthiness, or, alternatively, a type of liability in which the plaintiff must prove that the defendant's conduct was either negligent or intentional.[51] Other legal scholars considered that the Liability Convention did not explicitly resolve certain details on purpose, for instance defining "fault", in order to avoid a too specific approach. If the negotiations of the Liability Convention had moved in that direction most likely the Liability Convention would have never been agreed upon. Fortunately, it was possible to agree on a formal process for the resolution of disputes, therefore, some of the lacunae in the Convention can be resolved through the use of this process. Thus, it may, for example, be possible to obtain the required understanding of the meaning of "fault," if necessary.[52]

IV. AUTONOMOUS SPACE OBJECTS AND CHALLENGES POSED TO SPACE LAW LIABILITY REGIMES

In the near future, most likely human intervention will still be required beyond the initial programming of the AI system, which would entail that states remain liable for national space activities and space objects equipped with AI capabilities. However, the hypothetical case when a state deploys in space a fully autonomous space object raises important questions due to the removal

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[48] Marc S. Firestone, "Problems in the Resolution of Disputes Concerning Damage Caused in Outer Space," *Tulane Law Review : Devoted to the Civil Law, Comparative Law and Codification*, 1985.

[49] Yun Zhao, "The 1972 Liability Convention: Time for Revision?" *Space Policy* 20, no. 2 (May 1, 2004): 117–22, https://doi.org/10.1016/j.spacepol.2004.02.008.

[50] Frans 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?," *Space, Cyber, and Telecommunications Law Program Faculty Publications*, January 1, 2010, https://digitalcommons.unl.edu/spacelaw/28.

[51] *Ibid.*

[52] Carl Q. Christol, ""International Liability for Damage Caused by Space Objects", *American Journal Of International Law* 74, no. 2 (1980): 346-371, doi:10.2307/2201505.

of human judgment from the equation.[53] In case of incidents involving autonomous space objects, significant liability issues may arise in the event of, for example, collisions or destructions. Therefore, the use of AI in space-related activities require revisiting the traditional concepts of liability under the Outer Space Treaty and the Liability Convention.

A. THE NOTION OF "SPACE OBJECT"

A first step in the process of attributing liability would require investigating if the provisions of the UN International Treaties are sufficient to deal resolve any claims arising out of incidents involving autonomous space objects. The Liability Convention does not provide a clear definition for the term "space objects". It only mentions that "the term space object includes component parts of a space object as well as its launch vehicle and parts thereof".[54]

Taking into consideration the limited technologies available when the Convention was drafted, the underlying assumption may have been that a launch constituted a vertical departure from a land-based launch facility aimed at entering outer space using rocket engines. The technological developments challenge the existing notion of "launch vehicle" and consequently, the entire notion of "space object". New technologies already started to facilitate air launches[55] and, more recently, autonomous air launches.[56] In this context, the definition of a "space object" should be interpreted as including any man-made object which is attempted to be physically brought into outer space.[57] Moreover, any piece of hardware used in a launch together with all other pieces collectively constitute a space object, and states cannot choose what does, or does not, make up the object for the purposes of this legal definition.[58] Based on this interpretation, the term "space object" would also need to include any AI software and any technical features enabling autonomy of a space object.

Autonomous space objects require extra attention also in what concerns

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[53] Anne-Sophie Martin and Steven Freeland, "The Advent of Artificial Intelligence in Space Activities: New Legal Challenges," *Space Policy* 55 (February 1, 2021): 101408, https://doi.org/10.1016/j.spacepol.2020.101408.

[54] Liability Convention, art I (b).

[55] von der Dunk and Tronchetti, *Handbook of Space Law*, 86.

[56] Eric Berger, "Meet Ravn X—A fully autonomous, air-launched rocket for small satellites," Ars Technica, accessed 20 December 2020, https://arstechnica.com/science/2020/12/meet-ravn-x-a-fully-autonomous-air-launched-rocket-for-small-satellites/.

[57] Vladimir Kopal, "Some Remarks on Issues Relating to Legal Definitions of Space Objects, Space Debris and Astronaut," in *Proceedings of the 37th on the Law of Outer Space* (1994), 99.

[58] Stephan Hobe, *Cologne Commentary on Space Law / Vol. 2, Rescue Agreement, Liability Convention, Registration Convention, Moon Agreement.* (Köln: Heymann, 2013), 34.

registration requirements under the UN Registration Convention.[59] Registration of space objects is an indispensable means for administering good care of space objects relating directly to legal issues such as jurisdiction and control over space objects.[60] The Registration Convention provides that when a space object is launched into Earth orbit or beyond, the launching State shall register the space object by means of an entry in an appropriate registry which it shall maintain; where there are two or more launching States in respect of any such space object, they shall jointly determine which one of them shall register the object.[61] The Registration Convention also provides that each State of registry shall furnish to the Secretary-General of the United Nations, as soon as practicable, the following information concerning each space object carried on its registry: name of launching State or States; an appropriate designator of the space object or its registration number; date and territory or location of launch; basic orbital parameters; general function of the space object.[62] Given the specific capabilities of autonomous space objects, some authors recommend taking in consideration the possibility of developing a 'special' registry that specifies the unique features of spacecraft having on board AI capabilities.[63] It is also duly noted that this suggestion will require additional investigations to see whether, and if so how, this should be implemented.[64]

B. THE NOTION OF "GROSS-NEGLIGENCE"

In what concerns the absolute liability described under Article II of the Liability Convention, we do not envisage any particular difficulties in relation to attributing this type of liability. States are to be held absolutely liable for the damages caused by their space objects on the surface of the Earth irrespective of their autonomous capabilities. The situation is more complicated in case of the exoneration procedure described under Article VI of the Liability Convention: "exoneration from absolute liability shall be granted to the extent that a launching State establishes that the damage has resulted either wholly or partially from gross negligence or from an act or omission done with intent to cause damage on the part of a claimant State or of natural or juridical persons it represents". The provisions of this article relate to the exoneration of liability for damages caused by the claimant state's own gross negligence subject

[59] United Nations Convention on Registration of Objects Launched into Outer Space, Nov. 12, 1975, 28 U.S.T. 695, 1023 U.N.T.S. 15. [Registration Convention]

[60] Yoon Lee, "Registration of Space Objects: ESA Member States' Practice," *Space Policy* 22, no. 1 (February 1, 2006): 42–51, https://doi.org/10.1016/j.spacepol.2005.11.007.

[61] Registration Convention, art. II

[62] Registration Convention, art. IV

[63] Martin and Freeland, "The Advent of Artificial Intelligence in Space Activities"

[64] *Ibid.*

that the launching state had not violated international law and the international UN treaties.[65]

The Liability Convention does not provide for a definition of "gross negligence" and no indication was made for attributing negligent conduct to others or for the allocation of a principal's vicarious liability for an agent or employee.[66] In the absence of clear criteria applicable to gross negligence, it may prove difficult to apply them in practice. According to the Cambridge Dictionary, gross negligence is being defined as a serious lack of care or attention towards a person or thing that another person is responsible for.[67] The analysis of this definition reveals that the concept is related to the mental element of an act or omission, it is a product of human thought, it is associated to an action or omission part of a human activity. The concept is being challenged in case of a damage resulting wholly or partially from an act or omission of an autonomous space object deployed or controlled by a claimant state. Depending on the autonomy level of the space object, invoking exoneration of liability based on the concept of gross negligence may not be applicable in case of space objects equipped with AI capabilities,[68] because it no longer involves a human activity.

C. THE NOTIONS OF "FAULT" AND "PERSON"

The fault-based liability regime introduced by Article III of the Liability Convention also raises similar problems in what concerns its applicability to potential incidents involving autonomous space objects. The absence of a definition concerning the notion of "fault" or clear criteria for assessing fault may cause difficulties in practice.[69] The same applies to the notion of "persons", which was not defined. The notion "person", as it is used Article III generally refers to an entity which is subject to legal rights and duties such as a natural or juridical person. The law considers artificial entities like corporations, partnerships, joint ventures, and trusts to be "persons" as they are subject to legal rights and duties. Additionally, in certain instances, the law recognizes and imposes legal rights and duties on certain inanimate objects like ships, land, and goods which results in such inanimate objects being subject to adjudica-

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[65] Liability Convention, art. VI (2)

[66] Christol, "International Liability for Damage Caused by Space Objects".

[67] "Gross Negligence," Cambridge Dictionary, accessed 20 December 2020, https://dictionary.cambridge.org/dictionary/english/gross-negligence.

[68] George Anthony Gal, Cristiana Santos, Lucien Rapp, Réka Markovich, Leendert van der Torre, "Artificial intelligence in space," available at https://www.researchgate.net/publication/342377395_Artificial_intelligence_in_space.

[69] See Supra 3.2, II

tive jurisdiction as well as being subject to a judgment rendered against it.[70]

Related to the case of autonomous space objects, i.e., space objects equipped with AI capabilities, the discussions surrounding the possibility of granting legal personality to AI systems received a lot of attention in academic literature. In general, the analysis concerns the question of whether or not one can argue that an AI system possesses the necessary capabilities to be considered full moral and legal persons.[71] The topic was also discussed by one of the expert groups of the European Commission, part of the legislative train schedule related to the future of AI governance. Even if only formulated as a recommendation, the report includes a straightforward message concerning this topic, indicating that there is currently no need to give a legal personality to emerging digital technologies, such as AI. This is because harm caused by even fully autonomous technologies can generally be reduced to risks attributable to natural persons or existing categories of legal persons, and where this is not the case, new laws directed at individuals are a better response than creating a new category of legal person.[72]

Given the above, it may be concluded that, since fault liability under Article III of the Liability Convention is premised on the fault of a State or the faults of persons, a decision by an autonomous space object will, in all likelihood, not be the "fault of persons".[73] This may cause difficulties in attributing liability based on the fault-based regime under the Liability Convention, thus potentially leading to a liability gap.

V. PROPOSED SOLUTIONS FOR MITIGATING LIABILITY GAPS

Several solutions can be proposed for mitigating the challenges posed by the autonomous space objects to the liability regimes. Even if they have not been tested in practice yet, these proposals are mentioned here for the purpose of avoiding situations in which liability cannot be attributed, in other words a liability gap.

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[70] *Ibid.*

[71] David J. Gunkel, "The Other Question: Can and Should Robots Have Rights?," *Ethics and Information Technology* 20, no. 2 (2017): pp. 87-99, https://doi.org/10.1007/s10676-017-9442-4.

[72] Publications Office of the European Union, "Liability for Artificial Intelligence and other Emerging Digital Technologies." (Publications Office of the European Union, November 27, 2019), http://op.europa.eu/en/publication-detail/-/publication/1c5e30be-1197-11ea-8c1f-01aa75ed71a1/language-en/format-PDF.

[73] George Anthony Gal et al., "Artificial Intelligence in Space."

A. INTERNATIONAL RESPONSIBILITY UNDER THE OUTER SPACE TREATY

The Outer Space Treaty and the Liability Convention do not expressly provide that the Liability Convention should serve as the sole remedy for seeking compensation for damages caused by space objects. Thus, there is no reason why the more general concept of state responsibility could not be used as an alternative for obtaining compensation for damage in cases where the liability concept does not offer a solution.[74]

The difficulty in applying this solution is related to the grounds based on which liability and responsibility are attributed. A state is responsible for "national activities" in outer space under Article VI of the Outer Space Treaty, while a state is liable pursuant to its capacity as a "launching state" under Article VII of the Outer Space Treaty and the corresponding Articles II and III under the Liability Convention.

The challenges triggered by the intersection of these legal provisions may be more visible in the following example: a telecommunications satellite that was launched by state X is then sold, while in orbit, to a private operator of state Y. State Y was not involved in the launch, therefore it cannot be categorised as a 'launching State' of the satellite. If the satellite caused damage compensable under the Liability Convention, the original launching state, i.e., state X, would have remained liable even if it no longer exercised any jurisdiction and control over the satellite. The liability of state X would have been attributed in accordance with Article VII of the Outer Space Treaty and the corresponding Article II or III of the Liability Convention, depending on geographical location of the damage. In the legal doctrine, this was described as "once a launching state, always a liable one",[75] meaning that the qualification of a state as a launching state is directly connected with the attribution of liability. At the same time, under Article VI of the Outer Space Treaty, state Y could also be held responsible, but this time, based on the national activity of that state in the outer space.

The overlap between Article VI and Article VII of the Outer Space Treaty stands in the way of an effective framework for dealing with incidents resulting in damages caused by space-related activities. Until such overlap is resolved in a formal manner (e.g., by an authoritative document with the necessary legal force), the confusion remains.

Despite the outlined potential difficulties, Article VI of the Outer Space

[74] von der Dunk and Tronchetti, "International Space Law," 51 – 52.
[75] *Ibid*.

Treaty offers a theoretical possibility for obtaining compensation in case of damages caused by space objects, which should be taken into account as an alternative to the liability gap caused by the insufficient clarity of the liability regimes introduced by the Liability Convention.

B. AMENDMENTS TO THE LIABILITY CONVENTION

The developments of autonomous technologies, together with ample resources in outer space, provide a strong incentive for more challenging space activities. Space activities are becoming significantly more complex than at the time when the Liability Convention was drafted.[76] During the negotiations for the Liability Convention, the parties involved acknowledged that it may eventually prove desirable to have a separate additional treaty when the presence of human beings in space becomes frequent and numerous.[77] Given that the circumstances present at the moment of its adoption have changed, it might be the time to have a second look at the provisions of the Liability Convention.

The analysis of Article II and Article III of the Liability Convention revealed that attributing liability for damages caused by autonomous space objects may be hindered by the lack of clarity in what concerns the fundamental concepts included in the Liability Convention (more specifically: negligence and intention) and the basis for attributing liability. The optimal solution for mitigating these challenges would be an amendment of the Liability Convention.

However, the process of amending the Liability Convention may prove to be extremely complicated. The initial drafting and negotiation of the Liability Convention required an extended period of time. The entire process was initiated in 1962, while the final version of the Convention was made available in 1971 and it proved to be the result of one of the most difficult treaty negotiations since 1945.[78] Establishing this regime encountered difficulties due to the very different approach of the states on various aspects to be included in the text of the Convention, such as: the determination of the applicable law, in particular to deal with the amount of damages, the question of whether or not a limit should be placed on liability incurred under the Convention, the method for settlement of disputes and the character of the decision rendered, and the status of international organizations with regard to the Convention.[79]

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[76] Zhao, "The 1972 Liability Convention".

[77] Herbert Reis, "Some Reflections on the Liability Convention for Outer Space," *Journal of Space Law* 6, no. 2 (1978): 125–28.

[78] *Ibid.*

[79] Valérie Kayser, *Launching Space Objects*, 33.

The discussion surrounding potential amendments of the Liability Convention have been taken place ever since its enactment. However, because of the political situation (Cold War) during the drafting period, scholars tend to be satisfied with the achievements made.[80]

One of the pressing needs requiring special attention is the definition of the "space object", due to the practical difficulties raised by the current provisions of the Liability Convention, as already outlined under Section 4.1 above. The definition of "damages" would also require a more detailed approach. Currently, the Liability Convention only provides for the availability of damages, without further clarification concerning direct and indirect damages. Consequently, direct damages should be compensated, but indirect damage still constitute a gray area for the Convention. [81] Another important amendment to the Liability Convention could refer to the notion of "fault". By including a definition of this notion, the Convention would anticipate any future debates concerning the attribution of the fault-liability system in case of damage caused by an autonomous space object. Another essential amendment could refer to the intersections between the provisions of the Outer Space Treaty, more specifically Article VI and VII and those of the Liability Convention, Articles II and III. The Liability Convention could expressly state that the Convention itself represents the sole remedy to be used for dealing with compensation for damages caused by space objects, with the explicit exclusion of Article VI of the Outer Space Treaty as an option for a remedy. Such an amendment would lay the grounds for a transparent and efficient mechanism for attributing liability and seeking compensation for damages caused by space-related activities.

In what concerns the legal basis for initiating a potential amendment, there seems to be agreement between space lawyers, who are of the opinion that potential amendments can be initiated in accordance with article 25 of the Liability Convention, which states that any State Party to this Convention may propose amendments to this Convention. Amendments shall enter into force for each State Party to the Convention accepting the amendments upon their acceptance by a majority of the States Parties to the Convention and thereafter for each remaining State Party to the Convention on the date of acceptance by it.[82]

Nevertheless, until either an official amendment process is initiated, or an equally authoritative decision of an international court or tribunal would rule in a given dispute providing clarification of the liability regimes, the existing

[80] Zhao, "The 1972 Liability Convention".
[81] *Ibid.*
[82] Edward R. Finch, "Outer Space Liability: Past, Present and Future," *The International Lawyer* 14, no. 1 (1980): 123–127.

provisions of the Liability Convention remain effective.

C. APPLYING PRINCIPLES OF INTERNATIONAL LAW

In any legal system, there is the possibility of gaps and silences.[83] Therefore, assuming that neither the Liability Convention nor the Outer Space Treaty can offer a solution for obtaining compensation in case of damages caused by space objects and that the amendment of the Liability Convention does not represent an efficient solution, then, states can make use of general principles of international law.

For example, the principles from several international law cases concerning fault standards and due diligence obligations can be applied to space-related activities, in an attempt to identify solutions for attributing fault-based liability. The due diligence obligations of a state were defined in the International Court of Justice's (ICJ) decision Corfu Channel.[84] According to this decision, states are obliged not to knowingly allow their territory to be used for acts contrary to the rights of other States.[85] Under this due diligence obligation, the relevant fault standard is so-called 'constructive knowledge',[86] meaning that a state is expected to be aware of certain important activities being developed on its territory. In this specific case, Albania did not necessarily know of the presence of mines in its territorial waters but it 'should have known'.

Applying this obligation in the outer space context would mean that, by virtue of a launching state's control over its activities, it is presumed that a state will have constructive knowledge about the circumstances surrounding the operation of the space object, including, for example, the possibility of its collision with another space object.[87] As such, irrespective of the potentially unforeseeable behaviour of a space object equipped with AI capabilities, launching states can be expected to know about the circumstances relevant to their active space objects' operation. In particular, a launching state should be

[83] Prosper Weil, "The Court Cannot Conclude Definitively . . . Non Liquet Revisited Chapter 1: Questions of Theory," *Columbia Journal of Transnational Law* 36, no. Issues 1 & 2 (1998): 109–119.

[84] International Court of Justice, "Latest Developments | Corfu Channel (United Kingdom of Great Britain and Northern Ireland v. Albania) | International Court of Justice," accessed February 14, 2021, https://www.icj-cij.org/en/case/1.

[85] William W. Bishop, J. G. Guerrero, and E. Hambro, "The Corfu Channel Case (Merits)," *American Journal of International Law* 43, no. 3 (July 1949): 558–89, https://doi.org/10.2307/2193658.

[86] Frauke Renz, *State responsibility and new trends in the privatization of warfare* (Edward Elgar Publishing Limited 2020), 86

[87] Joel A Dennerley, "State Liability for Space Object Collisions: The Proper Interpretation of 'Fault' for the Purposes of International Space Law," *European Journal of International Law* 29, no. 1 (May 8, 2018): 281–301, https://doi.org/10.1093/ejil/chy003.

aware of the risk that it takes by launching an autonomous space object. This knowingly taking a risk would then be the justification for assigning liability to that state should the risk materialise in the sense that the autonomous object causes damage.

In a distinct case concerning Application of the Convention on the Prevention and Punishment of the Crime of Genocide (Bosnia and Herzegovina v. Serbia and Montenegro)[88] the ICJ extended the application of due diligence under the Corfu Channel case. This means that the due diligence obligation is not exclusively connected to a state's control over its territory. The due diligence obligation also covers elements under a state's jurisdiction and control that it has power over or has the capacity to influence.[89] In an outer space context, the space objects' launch and operation are presumed to be activities that launching states have control over. This suggests that the best-efforts obligation of due diligence to prevent acts, such as causing space object collisions, that would cause damage to another state is a duty incumbent on launching states.[90]

The launching state's responsibility also applies in cases where it is not the state itself that is involved in the launching, but a New Space private party – as there is not yet in the Treaties a provision to hold a private company liable for damages caused in space.

VI. CONCLUSION

In recent years, the space industry has been revolutionised. Increasing budgets laid the grounds for technological advancements. Space objects launched by states and private actors are becoming increasingly sophisticated given their AI capabilities. The autonomy of space objects has become a priority for states as well as for private actors. Autonomous space objects are used, among others, to monitor the operation of satellites and climate change, are implemented in space stations operations as virtual assistants for astronauts and they support exploration on planets, where on-site conditions are still too dangerous for humans. Moreover, there is an increasing number of situations in which human control over a space object is no longer economically or practically feasible.

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[88] International Court of Justice, "Latest Developments: Application of the Convention on the Prevention and Punishment of the Crime of Genocide (Bosnia and Herzegovina v. Serbia and Montenegro)," accessed February 14, 2021, https://www.icj-cij.org/en/case/91.

[89] Dennerley, "State Liability for Space Object Collisions," 281.

[90] *Ibid.*

The introduction of AI systems in space-related activities does not come without legal implications, especially regarding liability matters. Autonomous space objects may display unforeseeable behaviour by being capable of taking decisions on their own, thus challenging the existing liability frameworks, under the Liability Convention. The optimal solution for mitigating such challenges would be the amendment of the Liability Convention for addressing the latest technological advancements. However, the process of amending the Liability Convention may prove to be extremely complicated. The negotiation process prior to the entering into force of the Convention took a long time due to conflicting interests of the parties involved. Initiating an amendment process for the Liability Convention should take in consideration these potential drawbacks. When the Liability Convention is unable to offer a solution for attributing liability, there is no fundamental reason why the general responsibility framework, as provided by the Article VI, under the Outer Space Treaty could not be invoked. A potential solution for situations in which the Liability Convention is unable to offer a solution would be applying principles of international law, as an alternative fall-back mechanism.

Initiating legal discussions related to the potential damages caused by autonomous space objects is required in order to avoid situations where liability cannot be attributed: a liability gap. Mapping the legal framework in advance is preferable to a post-factum intervention, in which scenario an incident would have occurred already.

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