Navigating the Legal Complexities of Artificial Intelligence in Outer Space

Governing 'Autonomous Collision Avoidance Systems' Through a European Lens: A Small Step or Giant Leap Forward?

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List of abbreviations

- ACAS – autonomous collision avoidance system
- AI – Artificial Intelligence
- AI Liability Directive – Proposal for a Directive of the European Parliament and of the Council on adapting non-contractual civil liability rules to artificial intelligence (AI Liability Directive)
- AIA - AI Act - Council Regulation (EU) 2024/1689 of 13 June 2024 laying down harmonised rules on artificial intelligence (Artificial Intelligence Act) [2024] OJ L168/9 Regulation (EU) 2024/… of the European Parliament and of the Council of … laying down harmonised rules on artificial intelligence (Artificial Intelligence Act)
- CAM – Collision Avoidance Manoeuvre
- CDMs – Collision Warning Data
- Commission – European Commission
- COPUOS - United Nations Committee on the Peaceful Uses of Outer Space
- Council – European Council
- Discovery & Preparation - The Discovery & Preparation team, part of the Future Preparation and Strategic Studies Office within the Directorate of Technical and Quality Management of the European Space Agency.
- DL – deep learning
- ESA – European Space Agency
- ESPI – European Space Policy Institute
- EU – European Union
- EUSL – EU Space Law
- FCC - Federal Communications Commission
- GA Res - UN General Assembly Resolution
- GDPR – Regulation (Eu) 2016/679 of the European Parliament and of the Council of 27 April 2016 on the protection of natural persons with regard to the processing of personal data and on the free movement of such data, and repealing Directive 95/46/EC (General Data Protection Regulation)
- GEO - Geostationary Orbit

- ISS – International Space Station
- Launching State - any State party to the Outer Space Treaty or the Liability Convention that launches or procures the launching of an object into outer space
- LEO – Low Earth Orbit
- LoT – Internet of Things
- MEO – Medium Earth Orbit
- Mitigation Guidelines – Space Debris Mitigation Guidelines from the Committee on the Peaceful Uses of Outer Space
- ML – machine learning
- NASA - National Aeronautics and Space Administration
- Outer Space Treaty (OST) - Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies
- Parliament – European Parliament
- Product Liability Directive – Proposal for a Directive of the European Parliament and of the Council on liability for defective products
- RAI – Responsible Artificial Intelligence
- SpaceX – Space Exploration Holdings, LLC
- TWAIL – Third World Approach to International Law
- UN – United Nations
- UNOOSA – United Nations Office for Outer Space Affairs

1. Introduction

1.1 Background and problem statement

Elon Musk, founder of SpaceX, once said: “There’s a silly notion that failure’s not an option at NASA. A failure is an option here. If things are not failing, you are not innovating enough”.[1] While the essence of this inspirational quote might be true in a business and development context, it is not inherently applicable in the context of outer space. ‘A failure’ in a space-related activity could ultimately lead to destructive consequences, including accidents involving human spaceflights, disturbances in communication networks, environmental contamination, and terrestrial damage.[2] In a world where the commercialization of space is intensifying, it is increasingly important to regulate the behaviour of commercial actors to limit such ‘failures’.

In October 2023, a ground-breaking settlement related to our densely populated space took place.[3] The United States Federal Communications Commission (FCC) imposed a civil penalty of $150,000 on a commercial actor operating in space.[4] The satellite television company Dish Network was found guilty of inadequately fuelling its satellite *Echostar-7*,[5] making it impossible to move the non-operational satellite into a ‘graveyard’ orbit far from Earth specifically meant for such disposals.[6] Instead, the satellite was left close to the numerous telecommunications satellites and space debris. This debris is defined as consisting of non-functional, man-made objects floating

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1 Jennifer Reingold, ‘Hondas in Space’ (FastCompany, 2 January 2005) <https://www.fastcompany.com/52065/hondas-space> accessed 25 November 2023.

2 ‘The Cost of Catastrophe: Assessing the Impact of Accidents on the Space Economy’ (New Space Economy, 22 June 2023) <https://newspaceeconomy.ca/2023/04/06/the-cost-of-catastrophe-assessing-the-impact-of-accidents-on-the-space-economy/> accessed 23 March 2024.

3 Ian Mundell, 'The Ecosystem: space debris rules are an opportunity for tech start-ups' (ScienceBusiness, 24 October 2023) <https://sciencebusiness.net/news/aerospace/ecosystem-space-debris-rules-are-opportunity-tech-start-ups> accessed 29 October 2023.

4 In the Matter of DISH Operating L.L.C., Consent Decree (Federal Communications Commission, DA 23-888, 2 October 2023)

5 ‘FCC Takes First Space Debris Enforcement Action’ (FCC News, 2 October 2023) <https://docs.fcc.gov/public/attachments/DOC-397412A1.pdf> accessed 25 November 2023 and Jackie Wattles, 'Space debris investigation results in fine and an ‘admission of liability’ by satellite TV company' (CNN, 2 October 2023) <https://edition.cnn.com/2023/10/02/world/space-debris-fine-dish-fcc-scn/index.html> accessed 29 October 2023

6 European Space Agency, ‘End-of-life disposal of satellites’ (January 2015) <https://www.esa.int/Enabling_Support/Preparing_for_the_Future/Discovery_and_Preparation/End-of-life_disposal_of_satellites> accessed 24 November 2023.

around in space and it originates from launching activities, explosions, and collisions.[7] *Echostar-7* also moved relatively close to the International Space Station (ISS), which serves as a home for astronauts and an exceptionally important laboratory for research.[8] Due to Dish Network's (lack of) action, the risk of collision in space increased, and therefore posed major safety concerns. FCC's investigation led to an 'admission of liability' for a private company, which results in the first space debris enforcement action by a federal regulator.[9]

Over the last years, the number of (near) collisions has considerably increased, so (multi)national public space organizations have been burdened with this higher risk of collision.[10] In 2019, the European Space Agency (ESA) had to perform a, largely manual, manoeuvre to avoid the risk of its Earth science satellites colliding with a SpaceX satellite, as a part of the Starlink constellation.[11] For the ESA, this was an unprecedented event, as it had never before been required to manoeuvre to prevent a collision with a broadband megaconstellation, a group of satellites that provide broadband internet worldwide.[12] A similar incident occurred in 2021 when the China's Tiangong space station had to move away from the Starlink constellation.[13] Such ad hoc manoeuvres are not only often performed by governmental space entities, but also by private actors themselves. SpaceX was forced to preventively move its satellites over 50,000 times in the course of four years.[14] The beforementioned events and statistics illustrate the urgency of the high collision risk.

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[7] Frans G. von der Dunk, *Advanced Introduction to Space Law* (Edward Elgar Publishing 2020) para 2.6 and European Space Agency, 'FAQ Frequently asked questions' (April 2021) <https://www.esa.int/Space_Safety/Space_Debris/FAQ_Frequently_asked_questions> accessed 3 November 2023.

[8] 'International Space Station' (Woods Hole Oceanographic Institution) <https://www2.whoi.edu/site/seafloortospacestation/international-space-station/> accessed 25 November 2023.

[9] Jackie Wattles, 'Space debris investigation results in fine and an 'admission of liability' by satellite TV company' (CNN, 2 October 2023) <https://edition.cnn.com/2023/10/02/world/space-debris-fine-dish-fcc-scn/index.html> accessed 29 October 2023.

[10] Jeff Foust, 'ESA spacecraft dodges potential collision with Starlink satellite' (SpaceNews, 2 September 2019) <https://spacenews.com/esa-spacecraft-dodges-potential-collision-with-starlink-satellite/> accessed 3 November 2023.

[11] European Space Agency, 'ESA spacecraft dodges large constellation' (3 September 2019) <https://www.esa.int/Space_Safety/ESA_spacecraft_dodges_large_constellation> accessed 3 November 2023.

[12] Jeff Foust, 'ESA spacecraft dodges potential collision with Starlink satellite' (SpaceNews, 2 September 2019) <https://spacenews.com/esa-spacecraft-dodges-potential-collision-with-starlink-satellite/> accessed 3 November 2023.

[13] Loren Grush, 'China Complains to UN After Maneuvering its Space Station Away from SpaceX Starlink Satellites' (The Verge, 28 December 2021) <https://www.theverge.com/2021/12/28/22857035/china-spacex-starlink-tianhe-space-station-satellites-collisions> accessed 3 November 2023.

[14] Tereza Pultarova, 'SpaceX Starlink satellites had to make 25,000 collision-avoidance maneuvers in just 6 months — and it will only get worse' (Space.com, 6 July 2023) <https://www.space.com/starlink-satellite-conjunction-increase-threatens-space-sustainability> accessed 3 November 2023.

The privatization of the satellite industry began in the early 2000s.[15] The commercial investments and the innovative methods introduced by key players led to the so-called "New Space" economy.[16] One result of private actors operating in space is the increased use of artificial intelligence (AI). AI systems have been present in space technologies for some time, but more recently there is a growing dependence on autonomous systems powered solely by AI and machine learning technologies.[17] For instance, SpaceX uses autonomous collision avoidance systems (ACASs) to keep the Starlink satellites away from other space-objects, without any human intervention.[18] This is an indispensable technology as it is becoming too burdensome to manually avoid collisions.[19]

However, the rise in non-state space activities and the use of autonomous systems have raised legal questions concerning responsibility and liability in case of an incident. The existing space law framework, formulated in the 1960s and 1970s, was drafted with an emphasis on conflict prevention without regard for the impact of the New Space Era and modern-day advanced technology.[21] The framework consists primarily of five United Nations treaties and conventions, which have been complemented by resolutions, principles, and guidelines over the years. The most relevant laws for liability are the Outer Space Treaty (OST) of 1967 and the Liability Convention of 1972.[22] Generally, they determine responsibility and liability for states for the activities of their

[15] Christina Isnardi, 'Problems with Enforcing International Space Law of Private Actors' (2020) 58(2) Columbia Journal of Transnational Law 6.
[16] Ioana Bratu, Arno R. Lodder and Tina van der Linden, 'Autonomous Space Objects and International Space Law: Navigating the Liability Gap' (2021) 18 Indonesian Journal of International Law 423, 424.
[17] Klemens Katterbauer, 'AI will impact outer space financing and its legal implications' (LinkedIn, 1 July 2023) <https://www.linkedin.com/pulse/ai-impact-outer-space-financing-its-legal-dr-klemens-katterbauer/> accessed 7 January 2023
[18] Tereza Pultarova, 'SpaceX Starlink satellites responsible for over half of close encounters in orbit, scientist says' (Space.com, 20 August 2021) <https://www.space.com/spacex-starlink-satellite-collision-alerts-on-the-rise> accessed 3 November 2023.
[19] Irina F Stroe and others, 'Autonomous Collision Avoidance System' (Paper presented at the 8th European Conference on Space Debris 2021) 8(1) 1.
[21] Thomas Graham, Kathiravan Thangavel, and Anne-Sophie Martin, 'New Challenges for International Space Law: Artificial Intelligence and Liability' (Paper presented at the 17th International Conference on Space Operations, Dubai, United Arab Emirates, 6-10 March 2023) 3 and
Ugo Pagallo, Eleonora Bassi, and Massimo Durante, 'The Normative Challenges of AI in Outer Space: Law, Ethics, and the Realignment of Terrestrial Standards' (2023) 36(2) Philosophy & Technology.
[22] Ioana Bratu and Steven Freeland, 'Artificial Intelligence, Space Liability and Regulation for the Future: A Transcontinental Analysis of National Space Laws' (Paper presented at the 73rd International Astronautical Congress (IAC), Paris, France, 18-22 September 2022) 4 and
Thomas Graham, Kathiravan Thangavel, and Anne-Sophie Martin, 'New Challenges for International Space Law: Artificial Intelligence and Liability' (Paper presented at the 17th International Conference on Space Operations, Dubai, United Arab Emirates, 6-10 March 2023) 3.

national private actors. Nonetheless, there are some legal uncertainties when applying the framework to private operations, for example due to a lack of coherent definitions.[23] The framework also currently lacks specific regulatory measures addressing liability for damages caused by AI systems. This results in an evident gap in the international regulation of liability for modern-day space object collisions.[30]

This issue can potentially also be addressed by another regulatory framework. Currently, the European Union is the regulatory front runner in the field of AI and liability, developing legislation that could offer clearer guidance to the beforementioned liability questions.[31] The relevant (upcoming) EU laws include the AI Act[32], the proposed AI Liability Directive[33], and the revised Product Liability Directive[34]. These laws do not (yet) specifically mention AI in the context of space or the use of privately-owned ACASs. Nevertheless, it is interesting to evaluate the applicability of the regulatory approaches presented in the beforementioned EU laws. These include the risk-based approach, the fault-based liability regime, and the product liability regime. This raises the question of whether the EU approach to AI and liability governance can effectively bridge the existing AI liability gap in outer space to regulate future incidents. If this current approach is inadequate, European legislators could consider this, for example during the legislative process of the new initiative for an EU Space Law.[35]

1.2 Research question and sub-questions

The main research question of this thesis is: *Should the existing legal framework be enhanced to better allocate liability for damages attributable to private autonomous collision avoidance systems (ACASs) in outer space, and if so, what can be the role of EU legislation?*

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[23] Joel A. Dennerley, 'State Liability for Space Object Collisions: The Proper Interpretation of 'Fault' for the Purposes of International Space Law' (2018) 29 The European Journal of International Law 281-301

[30] ibid.

[31] Ioana Bratu and Steven Freeland, 'Artificial Intelligence, Space Liability and Regulation for the Future: A Transcontinental Analysis of National Space Laws' (Paper presented at the 73rd International Astronautical Congress (IAC), Paris, France, 18-22 September 2022) 10.

[32] Council Regulation (EU) 2024/1689 of 13 June 2024 laying down harmonised rules on artificial intelligence (Artificial Intelligence Act) [2024] OJ L168/9

[33] Proposal for a Directive of the European Parliament and of the Council on Adapting Non-Contractual Civil Liability Rules to Artificial Intelligence (AI Liability Directive). COM(2022) 496 final. (European Commission 2022)

[34] Proposal of the European Commission for a Directive of the European Parliament and of the Council on Liability for Defective Products. COM(2022) 495 final. European Commission (European Commission 2022)

[35] 'Targeted consultation on EU Space Law' (European Commission) <https://defence-industry-space.ec.europa.eu/public-consultations/targeted-consultation-eu-space-law_en> accessed 25 November 2023.

To answer this question, the following three sub-questions will be answered beforehand:

i. *Why and how has AI been integrated into space applications and what are the potential implications?*
ii. *How is liability allocation regulated within international space law and European AI and liability legislation and to what extent is that applicable to collisions attributable to ACASs?*
iii. *Which regulatory measures can be taken to better govern the risks posed by privately-owned ACASs in space?*

1.3 Literature review

It is apparent that over the years, the legal concerns of scholars regarding space law have evolved, influenced by the privatization of space and technological advancements. Pagallo et al. distinguished these concerns into four classes of legal issues.[36] Their first class entails a more general debate about space law, focusing on the interplay between international and domestic space law, as well as public international law. The legal issues related to this first class concern the unclarities and ambiguities in (international) space law, particularly for the concepts of 'fault' and 'liability'.[37] This uncertainty has become particularly problematic with the increased involvement of private actors in space, which represents the second class of legal problems.[38]

The third class concerns the issues revolving around the introduction of AI to space half-way 2010s. There is an evident consensus in academic literature regarding the benefits of deploying AI systems in space, which has become indispensable. For example, Stroe and colleagues express that the growth in space debris and mega-constellations leads to an unavoidable stream of collision warnings, subsequently making it too challenging to manually handle collision avoidance decisions.[47] AI could potentially help to solve that problem. Though, despite its

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[36] Ugo Pagallo, Eleonora Bassi, and Massimo Durante, 'The Normative Challenges of AI in Outer Space: Law, Ethics, and the Realignment of Terrestrial Standards' (2023) 36(2) Philosophy & Technology 1.
[37] ibid 5
[38] Paul B. Larsen, 'Commercial Operator Liability in the New Space Era' (2019) 113 AJIL Unbound 109-113
[47] Irina F Stroe and others, 'Autonomous Collision Avoidance System' (Paper presented at the 8th European Conference on Space Debris 2021) 8(1) 1.

potential benefits, there are concerns about the legal implications of AI's complexities, such as opacity, autonomy, and unpredictability, and problems like malfunctions and biased data.[48]

However, uniqueness of AI in space does not merely depend on the possible complexities of AI, but also on the specific nature of outer space. Thus, the fourth class revolves around the specific legal challenges of the space domain.[49] These are distinctive and more pressing due to the unique nature and important features of this domain.[50] Pagallo et al. believe that the use of AI in this domain boosts existing space technology and the space economy, such as the role of private actors and the world's growing dependency on space services.[51] To accommodate the boost of these space developments, a new set of legal standards needs to be implemented. There is a unanimous call for more regulation since scholars agree that the existing notions of responsibility and liability do not appropriately cover private actors using autonomous technologies.[52] However, experts present different approaches on how to address AI space liability.

Graham and colleagues suggest adding a binding protocol to the current Liability Convention in order to define requirements such as 'fault'.[53] Another suggestion is the introduction international law principles to the OST. However, the authors are doubtful about a solution in the near future, since international politics are lacking the willpower and harmony. Therefore, they are in favour of a 'bottom-up' approach to regulate AI in space. International guidelines and standards could start to provide more clarification, which could later form the basis of binding multilateral documents.[54]

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[48] HLEG, 'Liability for Artificial Intelligence and Other Emerging Technologies' (European Commission's Group of Experts on Liability and New Technologies, 2019) < https://op.europa.eu/en/publication-detail/-/publication/1c5e30be-1197-11ea-8c1f-01aa75ed71a1/language-en> accessed 28 October 2023.
[49] Ugo Pagallo, Eleonora Bassi, and Massimo Durante, 'The Normative Challenges of AI in Outer Space: Law, Ethics, and the Realignment of Terrestrial Standards' (2023) 36(2) Philosophy & Technology 18.
[50] George Anthony Gal, Cristiana Santos, Lucien Rapp, Réka Markovich, and Leendert van der Torre, 'Artificial Intelligence in Space' (2020) Cornell University 2.
[51] Ugo Pagallo, Eleonora Bassi, and Massimo Durante, 'The Normative Challenges of AI in Outer Space: Law, Ethics, and the Realignment of Terrestrial Standards' (2023) 36(2) Philosophy & Technology 2.
[52] Eve Massingham and Dale Stephens, 'Autonomous Systems, Private Actors, Outer Space and War: Lessons for Addressing Accountability Concerns in Uncertain Legal Environments' (2022) 23(2) Melbourne Journal of International Law and
Thomas Graham, Kathiravan Thangavel, and Anne-Sophie Martin, 'New Challenges for International Space Law: Artificial Intelligence and Liability' (Paper presented at the 17th International Conference on Space Operations, Dubai, United Arab Emirates, 6-10 March 2023) 3.
[53] Thomas Graham, Kathiravan Thangavel, and Anne-Sophie Martin, 'New Challenges for International Space Law: Artificial Intelligence and Liability' (Paper presented at the 17th International Conference on Space Operations, Dubai, United Arab Emirates, 6-10 March 2023) 3-4.
[54] ibid 10.

Pagallo et al. also emphasize the important role that standards can play to point out what is distinct to the set of legal issues created by AI systems in space activities. In their opinion the standards could be sui generis, or stricter or potentially more flexible standards for AI in space. Furthermore, they introduce the "principle of equality" between standards for humans and for robots.[55] This entails that existing human standards should be adequate as a benchmark for AI systems in space. The authors provide an example concerning healthcare during space operations. During a space operation, the expected performance of an artificial doctor should align with a human doctor on Earth. Therefore, they suggest an equal protection under the law, so individuals affected by AI systems enjoy the same rules and safeguards.

Bratu takes it a step further as she introduces a more comprehensive approach, namely a holistic integrated approach. She suggests measures at different regulatory levels.[56] This would entail supplementing the existing Liability Convention and a non-binding 'rules of the road' approach at international level.[57] Or at national level, the implementation of provisions on liability in space. She also expressed that national space laws must be aligned with the AI Act (AIA) and AI Liability Directive.[58] Graham and Thangavel similarly suggest that the AI Act is relevant in the space context and believe that space laws should be aligned with the principles of the Act.[59] Experts believe that "the Brussels Effect" is likely to manifest in specific elements of the AIA .[60] This phenomenon describes how EU legislation can influence the regulations of other jurisdictions, thereby playing an important role in shaping global standards.[61] A noteworthy example of the Brussels Effect is the international impact of the GDPR.

While legal experts agree that international space law is currently lacking comprehensive regulatory measures addressing AI liability in space, they propose different types of approaches to tackle the problem. Moreover, there is no definitive answer whether EU legislation on AI liability

[55] Ugo Pagallo, Eleonora Bassi, and Massimo Durante, 'The Normative Challenges of AI in Outer Space: Law, Ethics, and the Realignment of Terrestrial Standards' (2023) 36(2) Philosophy & Technology 17.
[56] Ioana Bratu and Steven Freeland, 'Artificial Intelligence, Space Liability and Regulation for the Future: A Transcontinental Analysis of National Space Laws' (Paper presented at the 73rd International Astronautical Congress (IAC), Paris, France, 18-22 September 2022) 10.
[57] ibid.
[58] ibid.
[59] Thomas Graham and Kathiravan Thangavel, 'Artificial Intelligence in Space: An Analysis of Responsible AI Principles for the Space Domain' (Paper presented at the 74th International Astronautical Congress (IAC), Baku, Azerbaijan, 2-6 October 2023) 9.
[60] Charlotte Siegmann and Markus Anderljung, *The Brussels Effect and Artificial Intelligence: How EU regulation will impact the global AI market* (Centre for the Governance of AI 2022) 5.
[61] ibid.

is applicable in the first place and whether it would sufficiently address the regulatory gap of liability with the commercial use of AI. There is, for example, a lack of clarity regarding the classification of future AI systems in space according to the AIA .[62] In short, existing literature does not present an explicit answer whether EU legislation could be just 'a small step' in bridging the AI liability gap, or 'a giant step' forward.

1.4 Methodology

In addressing the question whether and how EU legislation regulates responsibility and liability allocation for damages caused by private AI-driven ACASs in space, the doctrinal legal research methodology is appropriate. This thesis is fundamentally legal, which makes this methodology suitable. To understand the discussed laws and to attempt to solve the legal problem, a few steps are taken following the doctrinal methodology. First, relevant facts are gathered. Next, the legal issues are identified, followed by an analysis of these issues to find the relevant laws. After that, background materials provide knowledge and context, leading to discovery of the significant primary materials including legislation. Then, the issues are synthesized in context, resulting to the ability to form a tentative conclusion.[63]

First, this research will dive more into the historical and technological development of the space industry and ACASs by using mostly secondary sources. The focus will lie on the progress AI is making in relation to legal issues. Thus, this part of the research needs a socio-technical approach to learn how AI technology intersects with the societal implications and needs, creating a clear context. Subsequently, primary and secondary sources are used to interpret and compare international and domestic legislation to be able to research the regulatory coverage of the laws in relation to the AI liability gap. The research will delve into international space law, particularly the Outer Space Treaty and the Liability Convention, including interpretive documents. Policy papers, books, academic articles, reports, interviews and seminar sessions help to synthesize the issues in the context. The applicability of legislation is analysed by delving deeper into the legal consequences for ACAS.

[62] Thomas Graham, Kathiravan Thangavel, and Anne-Sophie Martin, 'New Challenges for International Space Law: Artificial Intelligence and Liability' (Paper presented at the 17th International Conference on Space Operations, Dubai, United Arab Emirates, 6-10 March 2023) 6.
[63] Terry Hutchinson and Nigel Duncan, 'Defining and Describing What We Do: Doctrinal Legal Research' (2012) 17(1) Deakin Law Review 83, 106

Furthermore, the AIA, proposed AI Liability Directive, the revised Product Liability Directive will be analysed for their applicability. Again, the beforementioned sources will be utilized. Finally, the significance of this thesis lies in finding a solution to the AI liability gap in space due to the private use of ACASs, so a regulatory approach will be suggested for this to form a tentative conclusion.

1.5 Outline of the chapters

The research in this thesis is divided into chapters that align with the sub-questions posed. Chapter 2 explores the effect of the New Space Era on AI, the necessary use of AI in space, and the issues and risks associated to ACASs. Chapter 3 presents a detailed examination of international space laws and relevant EU laws, their applicability and their effectiveness in addressing the new liability challenges in the context of privately-owned ACASs. Chapter 4 evaluates what regulatory steps can be taken to provide answers to the old and new legal questions. This includes an analysis whether and how the EU's perspective on AI liability regulation adds value. This research is concluded with an answer to the main research question.

2. AI Technologies in Outer Space

The presence of AI-driven applications in outer space, once deemed unimaginable, has now become indispensable. To understand this transformative shift and the legal challenges it could pose, it is valuable to comprehend the concept of AI and its evolution (2.1), before elaborating why and how it was introduced to the space industry (2.2). Additionally, it is important to provide an overview of the AI applications deployed in space (2.3), with a specific focus on the potential benefits and risks of ACASs (2.4). In this way, a conclusion can be made concerning the potential issues of ACASs (2.5). This chapter leads to an answer to the first sub-question: *Why and how has AI been integrated into space applications and what are the potential implications?*

2.1 The Concept of Artificial Intelligence

The EU AI Act defines an AI system in Article 3(1):

> *'AI system' means a machine-based system that is designed to operate with varying levels of autonomy and that may exhibit adaptiveness after deployment, and that, for explicit or implicit objectives, infers, from the input it receives, how to generate outputs such as predictions, content, recommendations, or decisions that can influence physical or virtual environments.*[65]

But how does this translate into practice?

Throughout the years, diverse lexicon and interpretations related to AI have been circulating. The accurate terminology is dependent on the perspective as the concept of AI and AI's capabilities have evolved. To illustrate, experts have been writing about *intelligence* versus *rationality*[66], *reasoning* versus *learning*[67], *knowledge-based* versus *data-based*[68], *symbolic* versus

[65] Council Regulation (EU) 2024/1689 of 13 June 2024 laying down harmonised rules on artificial intelligence (Artificial Intelligence Act) [2024] OJ L168/9

[66] European Commission, "A Definition of Artificial Intelligence: Main Capabilities and Scientific Disciplines" (Independent High-Level Expert Group on Artificial Intelligence set up by the European Commission, 8 April 2019) 1-2.

[67] ibid 3.

[68] Rembrandt Devillé, Nico Sergeyssels and Catherine Middag, *Artificial Intelligence and The Law* (Cambridge University Press 2021) para 1.

numeric[69] and *traditional* versus *generative*[70] and *narrow* versus *general*[71]. To properly comprehend the concept of AI, it is essential to briefly conceptualize the different aspects and sub-techniques of AI.

An AI system, meaning any AI-based component existing as software or integrated in hardware[72], has the ability to 'mimic' human intelligence.[73] A common misperception is that an AI-driven system is truly intelligent while in fact AI produces intelligent results without actual intelligence.[74] Hence, experts prefer the notion of *rationality* over *intelligence*, meaning that AI systems perceive the situation, reason and process the information, and then take action – with a certain level of autonomy – to adapt the environment.[75] Such rational *reasoning* is also known as the *knowledge-based* approach, which was the first prevailing method in AI research and is now considered a simple approach.[76] Current AI techniques have an additional ability: the *learning* capability, enabling a system to reason and change its behaviour to achieve the best course of action.[77] This modern-day category of AI includes, amongst others, machine learning (ML), neural networks and deep learning (DL). By employing such techniques, more can be realized than by an individual, due to the capacity to handle large amounts of input data. This has become especially relevant due to the extensive generation of data by the Internet of Things (IoT).[78] In addition, the

[69] Stan Franklin, ch. "History, motivations, and core themes." In: Keith Frankish, William M. Ramsey, *The Cambridge Handbook of Artificial Intelligence* (Cambridge University Press 2014) 15-33.
[70] Bernard Marr, "The Difference Between Generative AI And Traditional AI: An Easy Explanation For Anyone" (Forbes, 24 July 2023) <https://www.forbes.com/sites/bernardmarr/2023/07/24/the-difference-between-generative-ai-and-traditional-ai-an-easy-explanation-for-anyone/?sh=712ee760508a> accessed 15 February 2024.
[71] European Commission, "A Definition of Artificial Intelligence: Main Capabilities and Scientific Disciplines" (Independent High-Level Expert Group on Artificial Intelligence set up by the European Commission, 8 April 2019) 5.
[72] Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions on Artificial Intelligence for Europe, Brussels, 25.4.2018 COM(2018) 237 final. 1.
[73] European Space Agency, "Artificial Intelligence in Space" (Last updated 3 August 2023) <https://www.esa.int/Enabling_Support/Preparing_for_the_Future/Discovery_and_Preparation/Artificial_intelligence_in_space> accessed 19 February 2024.
[74] Harry Surden, "Artificial intelligence and law: An overview" 35 Georgia State University Law Review (2019) 1305-1337.
[75] European Commission, "A Definition of Artificial Intelligence: Main Capabilities and Scientific Disciplines" (Independent High-Level Expert Group on Artificial Intelligence set up by the European Commission, 8 April 2019)
[76] Rembrandt Devillé, Nico Sergeyssels and Catherine Middag, *Artificial Intelligence and The Law* (Cambridge University Press 2021) para 3.1.
[77] European Commission, "A Definition of Artificial Intelligence: Main Capabilities and Scientific Disciplines" (Independent High-Level Expert Group on Artificial Intelligence set up by the European Commission, 8 April 2019).
[78] Rembrandt Devillé, Nico Sergeyssels and Catherine Middag, *Artificial Intelligence and The Law* (Cambridge University Press 2021) para 1.

considerable amounts of data serve the AI learning techniques for training, or *data-driven* learning. Some ML approaches adopt algorithms that are based on the concept of neural networks, which are computer models inspired by the human brain that identify patterns and relationships in sets of data.[79] DL, as a sub-technique within ML, is the most common approach to neural networks which developers use to train a model.[80] Multi-layered artificial neural networks are employed, leading to more accurate predictions as errors are eliminated through each layer.[81]

A relatively new and advanced subset of AI and DL is *generative* AI (GenAI).[82] As opposed to *traditional* AI which uses mostly *numeric* data and produces decisions and predictions, GenAI is capable of generating new and unique data based on a set of probabilities resembling the original input data.[83] Up until now, the world only knows *narrow* AI systems that can perform one or a few specific task(s) in a few domains.[84] While the futuristic and hypothetical *general* AI would imply intelligence in all domains.

2.2 "New Space" and AI

The space industry has experienced a transformation since the early 2000s due to the privatization of the industry.[85] This shift gained significant momentum following the Columbia space shuttle tragedy in 2003, which claimed the lives of all seven crew members. As this was one of the most impactful incidents in the history of space exploration, the US space shuttle program was suspended. This in combination with budget reductions and slow advances in military-based technologies, led NASA to envision a future with a more substantial role for commercial actors in

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79 European Commission, "A Definition of Artificial Intelligence: Main Capabilities and Scientific Disciplines" (Independent High-Level Expert Group on Artificial Intelligence set up by the European Commission, 8 April 2019) 4.
80 ibid.
81 Tom Taulli, *Generative AI: How Chatgpt and Other Ai Tools Will Revolutionize Business* (Apress 2023) 67.
82 Akshay Kulkarni , Adarsha Shivananda , Anoosh Kulkarni , Dilip Gudivada, *Applied Generative AI for Beginners* (Apress 2023) 3
83 Tom Taulli, *Generative AI: How Chatgpt and Other Ai Tools Will Revolutionize Business* (Apress 2023) 67.
84 Rembrandt Devillé, Nico Sergeyssels and Catherine Middag, *Artificial Intelligence and The Law* (Cambridge University Press 2021) para 5.2
85 Christina Isnardi, 'Problems with Enforcing International Space Law of Private Actors' (2020) 58(2) Columbia Journal of Transnational Law 6.

activities in Earth orbit.[86] Following that, governments induced a race to commercialize space by publicly investing in private actors, resulting in the so-called "New Space" economy.[87]

Large existing companies, such as Google, entered the market to invest in a mutually beneficial synergy between their commercial operations and space applications.[88] New giants arose in the first years of the 2000s which resulted into a 'billionaire space race', primarily between Blue Origin, Virgin Galactic / Virgin Orbit and SpaceX.[89] In the mid-2010s, an enormous rise in venture capital investments, a form of funding typically directed towards smaller companies, led to the establishment of many space start-ups[90], with an investment peak in 2021 for space start-ups.[91] All these new actors, funded largely by public procurement and private investments, have been introducing novel space applications.[92] Research has proven that the investments led to the substantial development of space technology.[93]

One significant innovation introduced to space by private actors, is AI technology. While the presence of AI in space has become indispensable, this advancement was still a mere dream a few years back. The possible replication of human intelligence, with the ability to interpret the world as it interacts, to understand how it works and to act in unforeseen situations that require

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86 Christina Isnardi, 'Problems with Enforcing International Space Law of Private Actors' (2020) 58(2) Columbia Journal of Transnational Law 5 and
National Aeronautics and Space Administration, 'The Vision for Space Exploration' (Report, February 2004) 17 <https://www.nasa.gov/pdf/55583main_vision_space_exploration2.pdf> accessed 15 February 2024.
87 "ESPI The Rise of Private Actors in the Space Sector" (European Space Policy Institute, July 2017) <https://www.espi.or.at/wp-content/uploads/2022/06/ESPI-report-The-rise-of-private-actors-Executive-Summary-1.pdf> 1
88 Ioana Bratu, Arno R. Lodder and Tina van der Linden, 'Autonomous Space Objects and International Space Law: Navigating the Liability Gap' (2021) 18 Indonesian Journal of International Law 423, 424.
89 Jackie Wattles, 'Which Billionaire is Winning the Space Race? It Depends' (CNN Business, 20 July 2021) <https://edition.cnn.com/2021/07/14/tech/jeff-bezos-richard-branson-elon-musk-space-race-scn/index.html> accessed 16 February 2024.
90 "ESPI Yearbook 2019: Space Policies, Issues and Trends" (European Space Policy Institute, 2019) <https://www.espi.or.at/reports/space-policies-issues-and-trends-in-2009-2010/> and
Maksim Malyy, Zeljko Tekic and Alessandro Golkar, 'What drives technology innovation in New Space? A preliminary analysis of Venture Capital investments in Earth Observation startups' (2019) 7 EEE Geoscience and Remote Sensing Magazine 59, 65.
91 Chris Metinko, "Space Tech Funding Comes Back Down To Earth" (Crunchbase News 20 July 2023) <https://news.crunchbase.com/venture/space-tech-funding-drops-spacex-relativity/> accessed 21 February 2024.
92 "ESPI The Rise of Private Actors in the Space Sector" (European Space Policy Institute, July 2017) <https://www.espi.or.at/wp-content/uploads/2022/06/ESPI-report-The-rise-of-private-actors-Executive-Summary-1.pdf> 1-2
93 Maksim Malyy, Zeljko Tekic and Alessandro Golkar, 'What drives technology innovation in New Space? A preliminary analysis of Venture Capital investments in Earth Observation startups' (2019) 7 EEE Geoscience and Remote Sensing Magazine 59, 65.

flexibility, was still unimaginable.[94] Advancing AI became an utmost priority.[95] Thus, investments were made both in autonomous and semi-autonomous machinery. This is of great importance to the space sector since autonomous systems have proven to effectively and swiftly resolve issues that arise in space, without having to wait for a human interference.[96]

2.3 AI Technologies Deployed in Space-Related Activities

AI was first used in space exploration in 1998 with the launch of NASA's Deep Space 1 probe spacecraft, which used an algorithm to autonomously plan activities and detect failures on board.[97] This event was possible due to NASA's early focus on AI research.[98] In the year 2000, ESA's Discovery & Preparation also made efforts to automate constellations, involving initiatives such as facilitating autonomous navigation.[99] Moreover, in the early 2000s, the Earth Observing-1 (EO-1) satellite, launched by NASA, combined AI and Earth observation for the first time. Its autonomous system could react to selected Earth-based events demonstrating AI's capability for real-time decision-making.[100] After these earlier applications of AI, more advanced systems have made a revolutionary impact on the industry. AI advancement can now be found in (satellite) data processing; space exploration, mission planning; navigation; astronaut assistance; atmospheric monitoring; terrestrial analyzation; material design and simulation and space debris management.[101]

[94] Munevar, Gonzalo, 'Humankind in Outer Space International Journal of Technology, Knowledge and Society' (2008) 4 Champaign 17, 20.
[95] Strategic Technologies: Science and Technology, Jet Propulsion Laboratory (California Institute of Technology, 2019), 2.
[96] Larysa Soroka and Kseniia Kurkova, 'Artificial Intelligence and Space Technologies: Legal, Ethical and Technological Issues' (2019) 3 Advanced Space Law 131, 134.
[97] Matthew Williams and Martin Braddock, 'AI Case Studies: Potential for Human Health, Space Exploration and Colonisation and a Proposed Superimposition of the Kubler-Ross Change Curve on the Hype Cycle' (2019) 8(1) Studia Humana 3, 11.
[98] Steve Chien, Dennis DeCoste, Richard Doyle, and Paul Stolorz, 'Making an Impact, Artificial Intelligence at the Jet Propulsion Laboratory' (1997) 18 AI Magazine 103, 104
[99] European Space Agency, "Artificial Intelligence in Space" (Last updated 3 August 2023) <https://www.esa.int/Enabling_Support/Preparing_for_the_Future/Discovery_and_Preparation/Artificial_intelligence_in_space> accessed 19 February 2024.
[100] Elizabeth M. Middleton et al., 'The Earth Observing One (EO-1) Satellite Mission: Over a Decade in Space' (2013) 6 IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 243, 251
[101] Thomas Graham, Kathiravan Thangavel, and Anne-Sophie Martin, 'New Challenges for International Space Law: Artificial Intelligence and Liability' (Paper presented at the 17th International Conference on Space Operations, Dubai, United Arab Emirates, 6-10 March 2023) 1 and
Ioana Bratu and Steven Freeland, 'Artificial Intelligence, Space Liability and Regulation for the Future: A Transcontinental Analysis of National Space Laws' (Paper presented at the 73rd International Astronautical Congress (IAC), Paris, France, 18-22 September 2022) 1-2.

To begin, ML techniques provided possibilities for data analysis for space exploration. These techniques have enabled the analysis of vast amounts of data collected. Consequently, the identification of patterns that would normally be impossible to find can lead to new discoveries. NASA and Google collaborated to train AI algorithms to effectively analyse a mission's data which has resulted in the discovery of two new exoplanets outside our own solar system.[102] Also, deep space missions to remote areas in space (e.g. to the Moon or Mars) have become more feasible, extending humanity's reach to areas that are too far and complex.[103] A famous example is NASA's 2020 Perseverance rover which navigates on Mars and is equipped with AI technology similar to that found in self-driving cars.[104] The surroundings on Mars are complex, so the rover's AI system became essential to autonomously make a decision when encountering a terrain challenge, eliminating interruptions resulting from communication relay times.[105] Still, a team on Earth is involved in controlling the rover.

The use of ML and DL techniques for Earth observation and atmospheric monitoring purposes has also proven its great relevance for (climate) research, environmental protection, and disaster management. Image recognition of space-related imageries can be achieved with DL technique, either via supervised learning (e.g. providing photos of the Moon and Earth as input data until it can effectively identify both) or via unsupervised learning, where the artificial network finds structure by itself.[107] Interestingly, scientists have even shown that data from Earth is no longer required to train a ML model to analyse aerial images. In 2023, for the first time, they successfully trained a model in space, eliminating the need for ground-based training and the delays between data acquisition and responsive actions.[108]

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[102] European Space Agency, "Artificial Intelligence in Space" (Last updated 3 August 2023) <https://www.esa.int/Enabling_Support/Preparing_for_the_Future/Discovery_and_Preparation/Artificial_intelligence_in_space> accessed 19 February 2024.
[103] Linda Jaeck, "Challenges and Opportunities of AI in Outer Space" (16 January 2022) <https://www.internetjustsociety.org/cosmonaut/challenges-and-opportunities-of-ai-in-outer-space> accessed 18 February 2024.
[104] Daniel Oberhaus, "How NASA Built a Self-driving Car for Its Next Mars Mission" (Wired, 21 July 2020) <https://www.wired.com/story/how-nasa-built-a-self-driving-car-for-its-next-mars-mission/> accessed 19 February 2024.
[105] "NASA's Mars Rover Drivers Need Your Help" (Jet Propulsion Laboratory 12 June 2020) <https://www.jpl.nasa.gov/news/nasas-mars-rover-drivers-need-your-help/> accessed 19 February 2024.
[107] European Space Agency, "Artificial Intelligence in Space" (Last updated 3 August 2023) <https://www.esa.int/Enabling_Support/Preparing_for_the_Future/Discovery_and_Preparation/Artificial_intelligence_in_space> accessed 19 February 2024.
[108] "Researchers successfully train a machine learning model in outer space for the first time" (University of Oxford, 28 July 2023) <https://www.ox.ac.uk/news/2023-07-28-researchers-successfully-train-machine-learning-model-outer-space-first-time> accessed 21 February 2024.

Furthermore, new methods in autonomous navigation have been introduced, which is important for space traffic management. SpaceX's rockets are equipped with an autopilot system to autonomously navigate to the International Space Station (ISS) and its famous Falcon 9 rocket is making use of ML and real-time computer vision for landing.[109] ESA's Hera mission planned for 2024 will demonstrate the use of AI for autonomous navigation towards an asteroid, also mirroring self-driving technology.[110]

SpaceX, Blue Origin, and Rocket Lab are now even using GenAI to generate new data, like more realistic simulations, to find more effective solutions.[111] Such AI simulations can, for example, replicate the interactions between spacecraft component, enabling engineers to test designs virtually before manufacturing it.

However, the focus of this research relates to the effect of AI on space debris management. Both national space agencies and private actors utilize AI for space debris detection, avoidance, and removal. ML and DL models are being used for the detection, classification and monitoring of satellites and space debris. The localisation of debris and satellites, makes avoidance and removal possible. Furthermore, the ESA is invested in debris removal and space sustainability. It's Clearspace-1 mission, planned for launch in 2026, represents the first effort to actively remove space debris from orbit.[113] Clearspace-1 will employ an AI-powered camera to detect the debris and robotic arms to retrieve it.[114]

2.4 Autonomous Collision Avoidance Systems (ACASs)

As previously discussed, the development of ACASs is on the agenda for ESA, NASA, and key private actors. But what has been the incentive to introduce ACASs to space? A short answer would be 'necessity', due to the growing danger of space debris and the increasing number

[109] Poulomi Chatterjee, "How SpaceX is using AI to advance its ambitions" (Analytics India Magazine, 18 April 2022) <https://analyticsindiamag.com/how-spacex-is-using-ai-to-advance-its-ambitions/> accessed 19 February 2024.
[110] European Space Agency, "Artificial Intelligence in Space" (Last updated 3 August 2023) <https://www.esa.int/Enabling_Support/Preparing_for_the_Future/Discovery_and_Preparation/Artificial_intelligence_in_space> accessed 19 February 2024.
[111] Jean Koïvogui, 'AI, Generative AI, and their Impact on NewSpace Development' (16 August 2023) <https://www.linkedin.com/pulse/ai-generative-impact-newspace-development-jean-koïvogui/> accessed 21 February 2024.
[113] European Space Agency, " Clearspace-1" <https://www.esa.int/Space_Safety/ClearSpace-1> accessed 19 February 2024.
[114] Ioana Bratu, Arno R. Lodder and Tina van der Linden, 'Autonomous Space Objects and International Space Law: Navigating the Liability Gap' (2021) 18 Indonesian Journal of International Law 423, 429.

of satellite constellations. The density of satellites, especially in Low Earth Orbit, has been requiring frequent collision avoidance manoeuvres (CAMs) by satellite operators to prevent crashes.[116] Without any form of autonomous CAM technology, a detailed risk analysis must be made for each manual manoeuvre. Many satellite operators, for example at NASA, need to take action when the risk of collision surpasses a 1 in 10,000 threshold, requiring a lot from the operators.[117] These necessary actions also require fuel. It has become too challenging to manually control all satellites and perform manoeuvres, making human control no longer feasible.[118] Therefore, autonomous systems in satellites could be the solution.

2.4.1 Technical overview

An ACAS is based on ML techniques to predict the path of debris, and primarily aims its application for (future) large constellations in the Low Earth Orbit (LEO), Medium Earth Orbit (MEO) and Geostationary Orbit (GEO) (See Fig. 2.1).[119]

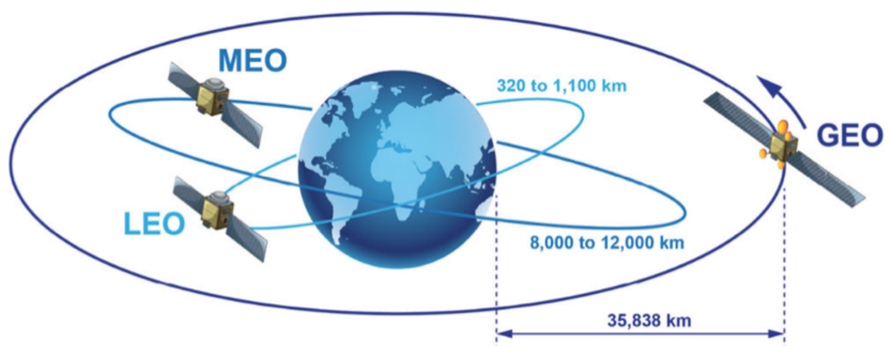

Figure 2.1: Difference between LEO, GEO and MEO satellites
Source: Grupo Arbulo, 21 September 2022

According to Stroe and colleagues the software of ACASs can be divided into four operational stages (see Fig. 2.2):

[116] Europeans Space Agency, "Automating collision avoidance" (22 October 2019) <https://www.esa.int/Space_Safety/Space_Debris/Automating_collision_avoidance> accessed 16 February 2024.
[117] Victor Heaulme, 'Decoding Space Waste: Awareness, Concern, Action' (Cutter.com, 28 February 2024) <https://www.cutter.com/article/decoding-space-waste-awareness-concern-action> accessed 12 July 2024.
[118] Irina F Stroe and others, 'Autonomous Collision Avoidance System' (Paper presented at the 8th European Conference on Space Debris 2021) 8(1) 1.
[119] ibid.

1) Data Initialisation: first the system loads historical collision warning data (CDMs). These CDMs are saved in the software's database to be able to use it in the next step.

2) ML Training: the CDMs are used to train the machine learning models. These models learn to predict how the position and movement of space objects could change.

3) Data Ingestion: in case of a new CDM, which will be added to the database, the CDM is correlated with the other CDMs to identify series of CDMs that refer to the same collision warning event.

4.) CAM Decision-making: finally, the software can autonomously decide whether a CAM is required. It also suggests which CAM should be made by predicting how critical the situation is and considering what manoeuvres are possible within the operational limits.[120]

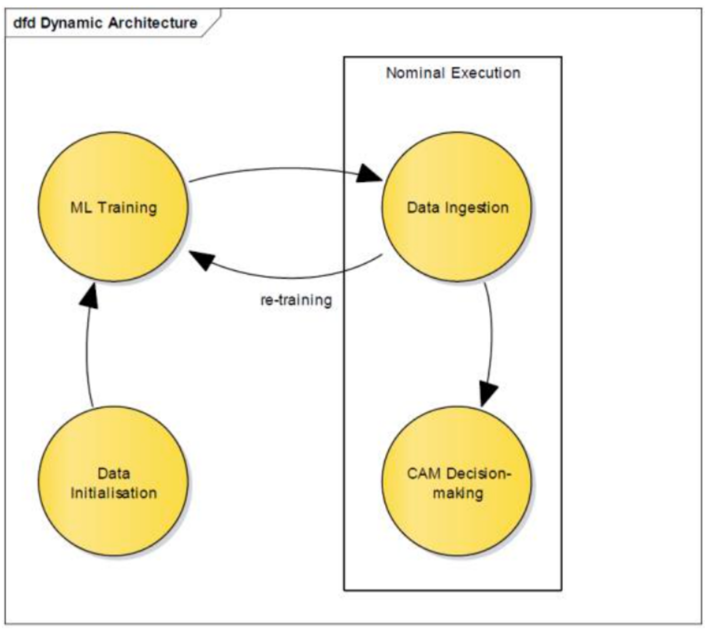

Figure 2.2: Four stages of operation in ACASs

Source: Paper presented at the 8th European Conference on Space Debris 2021

2.4.2 Issues and risks

Despite the advantages, critics believe that systems like ACASs are not always accurate. The possible repercussions of a malfunction could be harmful. To illustrate, one of the immediate consequences of an accidental collision in space would be an increase in space debris. A rise in the levels of space debris intensifies the risk of further collisions, leading to a cascade of debris.

[120] ibid 2.

This phenomenon is known as ‘the Kessler Effect’ or ‘the Kessler Syndrome’, a ‘simple’ chain with an increasing likelihood of subsequent collisions.[122] Collisions are detrimental to human safety, property and infrastructure, the environment, and the economy.[123] It can jeopardize the safety of astronauts or even other humans since the space tourism industry is uprising.[124] The award-winning film "Gravity", portrayed the dangers of a severe collision for astronauts and space infrastructures.[125] If satellites were to collide and lose their function, the consequences on Earth could range from unpleasant (e.g. temporary internet disruptions or long-term 5G connectivity issues) to rigorous (e.g. disaster response delay or banking and government security systems crashing).[126] A more futuristic possible concern could be the crash of self-driving vehicles that rely on satellite connectivity.

Naturally, collisions and the subsequent implications can also occur when humans are in full control and other types of technologies are used. Systems and technologies in space are always at the risk of malfunctioning. However, the specific legal risks associated with AI systems make them worthy of separate consideration. These legal challenges arise due to the specific characteristics of AI, such as autonomy, opacity, unpredictability, complexity, adaptability, and data-drivenness.[127] Generally, these features can impact the application of responsibility and liability, but the effect is dependent on the framework, such as criminal law, tort law and of course space law.[128] So what are these challenges in the context of space?

While autonomy reduces the need for continuous human monitoring, it also limits the opportunity for immediate human intervention when necessary. This can be problematic when encountering an unexpected situation, such as changing velocity of an object, cyber-attacks, or

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[122] European Space Agency, 'The Kessler Effect and how to stop it' <https://www.esa.int/Enabling_Support/Space_Engineering_Technology/The_Kessler_Effect_and_how_to_stop_it> accessed 3 November 2023.

[123] Thomas Graham, Kathiravan Thangavel, and Anne-Sophie Martin, 'New Challenges for International Space Law: Artificial Intelligence and Liability' (Paper presented at the 17th International Conference on Space Operations, Dubai, United Arab Emirates, 6-10 March 2023) 2

[124] Eve Massingham and Dale Stephens, 'Autonomous Systems, Private Actors, Outer Space and War: Lessons for Addressing Accountability Concerns in Uncertain Legal Environments' (2022) 23(2) Melbourne Journal of International Law 6

[125] *Gravity* (Warner Bros. Pictures. 2013)

[126] Global Future Council on Space Technologies, 'Six Ways Space Technologies Benefit Life on Earth' (Briefing Papers, World Economic Forum, September 2020) 7

[127] HLEG, 'Liability for Artificial Intelligence and Other Emerging Technologies' (European Commission’s Group of Experts on Liability and New Technologies, 2019) <https://op.europa.eu/en/publication-detail/-/publication/1c5e30be-1197-11ea-8c1f-01aa75ed71a1/language-en> accessed 28 October 2023.

[128] Ugo Pagallo, Eleonora Bassi, and Massimo Durante, 'The Normative Challenges of AI in Outer Space: Law, Ethics, and the Realignment of Terrestrial Standards' (2023) 36(2) Philosophy & Technology 8.

unforeseen environmental conditions. Due to the autonomous nature and the minimal human involvement, AI systems do not have the legal capacity to hold rights or duties. It has been debated whether autonomous systems should have a legal personhood status.[129] Nonetheless, these systems lack human qualities and assets to pay damages making them unqualified to act as a defendant in liability cases.[130] Therefore, the question raises who can be held liable.

Moreover, due to the opacity of these systems, controllers often experience difficulties to understand and predict AI behaviour, undermining the trustworthiness of such systems. This inability to anticipate or comprehend AI decisions in real-time can lead to risks. It is questionable whether operators of the systems can be liable for unforeseen and unpredictable AI-driven actions. The inherent "black-box" nature of AI adds complexity. Additionally, even with good understanding of an AI system, its capacity to adapt requires continuous effort to monitor and manage these changes, again prompting the question whether it is humanly possible to do this, especially for space applications.

Another challenge of AI's characteristics is the need for large, accurate data sets to create precise models and patterns. Data collected to make estimations for space traffic management and collision avoidance results from ground-based and space-based technologies.[131] Ground-based monitoring is limited by atmospheric conditions and the coverage from the Earth's surface, making it hard to detect small debris threatening satellites. Space-based monitoring can overcome these limitations. However, they also require advanced image processing to detect objects. Unfortunately, satellite data is not always available or of poor quality, which leads to simulated databases instead of accurate ones.[132] Therefore, ACASs initiate manoeuvres based on realistic yet uncertain data simulations.

2.5 Conclusion

Why and how has AI been integrated into space applications? The space industry has developed enormously as investments and the rise of private actors led to technological

[129] Gerhard Wagner, 'Robot, Inc.: Personhood for Autonomous Systems?' (2020) 88(2) Fordham Law Review 201.
[130] Nynke E. Vellinga, 'Challenges Posed by Autonomous Systems to Liability Regimes: Finding a Balance' in Andrej Zwitter and Oskar Gstrein (eds), *Handbook on the Politics and Governance of Big Data and Artificial Intelligence* (1st edn, 2023) 456-475, 461.
[131] Susmitha Patnala and Adam Abdin, 'Spacecraft Collision Avoidance: Data Management, Risk Assessment, Decision Planning Models and Algorithms' in Agostino Cortesi (ed) *Space Data Management* (Springer 2024) 8.
[132] ibid 25

advancement. Autonomy became a top priority, but autonomous decision-making could potentially lead to undesirable consequences, such as unpredictable collisions, impacting our satellite-dependent world. Therefore, we could speak of a disruption of AI in outer space since the introduction of AI technology reinforced the existing legal questions and *created new potential implications*. In general, autonomy, opacity, unpredictability, complexity, adaptability, and data-drivenness of autonomous systems create new challenges for establishing responsibility and liability. This is an increasingly relevant issue since the investments in the space sector are expected to rise and an upcoming space race to commercialize space is predicted.[133] Thus, these unprecedented challenges should be addressed.

[133] Kevin J. Martin, "America's New Space Race: Who Will Be First to Commercialize Space?" (MagellanTV, 11 February 2024) <https://www.magellantv.com/articles/americas-new-space-race-who-will-be-first-to-commercialize-space> accessed 22 February 2024

3. International Space Law and European Legislation

Establishing accountability is essential in any hazardous situation, such as in space. However, when humans are 'out of the loop,' existing liability frameworks face challenges, raising the question of who can be held responsible for decisions made by autonomous systems. To assess this, the concepts of responsibility and liability require some clarification (3.1). This chapter continues to examine these concepts within international space law (3.2) and national space law (3.3). Considering that space law, on its own, overlooks the use of modern AI technologies, this research also requires a technology law perspective. The latter can be achieved through the lens of EU laws and proposals, as the EU is the evident leader in the field of AI governance (3.4) and product liability (3.5). Ultimately, this chapter provides an answer to the second sub-question (3.7): *How is liability allocation regulated within international space law and European AI and liability legislation and to what extent is that applicable to collisions attributable to ACASs?*

3.1 Responsibility versus Liability

First, a distinction can be made between moral and legal responsibility. Moral responsibility relates to an expected level of care and civility, mainly encompassing ethical obligations that individuals have towards others when carrying out certain tasks.[134] One can be accountable without having to pay compensation for damages. In the context of ACASs, moral responsibility could imply that engineers designing these systems should carefully assess the risks of their design choices, which relates to forward-looking responsibilities.[135] Additionally, moral responsibility can also involve accountability for earlier events, making it also backward looking. Legal responsibility is related to a more retrospective approach as it concerns the accountability for events that have already occurred which creates legal consequences. Legal responsibility typically leads to legal liability which is enforceable, so compensation for damages is possible.

When addressing damages resulting from collisions caused by autonomous systems, we refer to non-contractual liability. In general, the key elements of non-contractual liability are 1) an act, 2) fault: intention and negligence, 3) damage, 4) causation (causal link between the conduct

[134] Ioana Bratu, Arno R. Lodder and Tina van der Linden, ‘Autonomous Space Objects and International Space Law: Navigating the Liability Gap’ (2021) 18 Indonesian Journal of International Law 423, 430.
[135] John Zerilli, John Danaher, James Maclaurin, Colin Gavaghan, Alistair Knott, Joy Liddicoat, Merel Noorman, *A Citizen’s Guide to Artificial Intelligence* (The MIT Press 2021) 62

and damage), and 5) damage.[136] These aspects depend on the type of liability, namely for strict and absolute liability, as opposed to fault liability, there is no need to establish fault or negligence because the emphasis lies on the protection of the victim impacted by the act. Under strict liability, the victim only needs to demonstrate that the acts led to their harm.[137] In respect to this causality condition, exceptions such as *force majeure* exist. In contrast, no reasonable defence is accepted when absolute liability applies.[138] This liability type is imposed when there are hazardous risks to public safety or the environment, regardless of possible precautionary measures taken. But how are all these concepts applied in space law?

3.2 International space legislation

In general, numerous laws can be applicable to activities in space, including legislation that does not take unique 'space-characteristics' into consideration. Therefore, the classification "space law" refers to any legal or regulatory framework that significantly affects, whether implicitly or indirectly, a space activity or application.[139] This includes international laws that do not exclusively focus on space activities but are by some means relevant, e.g. military law, and laws relevant to one category of space activities, but that is not the specific focus, e.g. international property rights. Additionally, national laws are part of "space law".

[136] Cees van Dam, European Tort Law (Oxford University Press 2013) para 105-3
[137] John Zerilli, John Danaher, James Maclaurin, Colin Gavaghan, Alistair Knott, Joy Liddicoat, Merel Noorman, *A Citizen's Guide to Artificial Intelligence* (The MIT Press 2021) 66
[138] Andrea Capurso, Paolo Marzioli, Michela Boscia, 'Questions of fault liability: A case study analysis of in-orbit collisions with debris' (2023) 10 Journal of Space Safety Engineering 439, 442
[139] Frans G. von der Dunk, *Advanced Introduction to Space Law* (Edward Elgar Publishing 2020) para 1.1

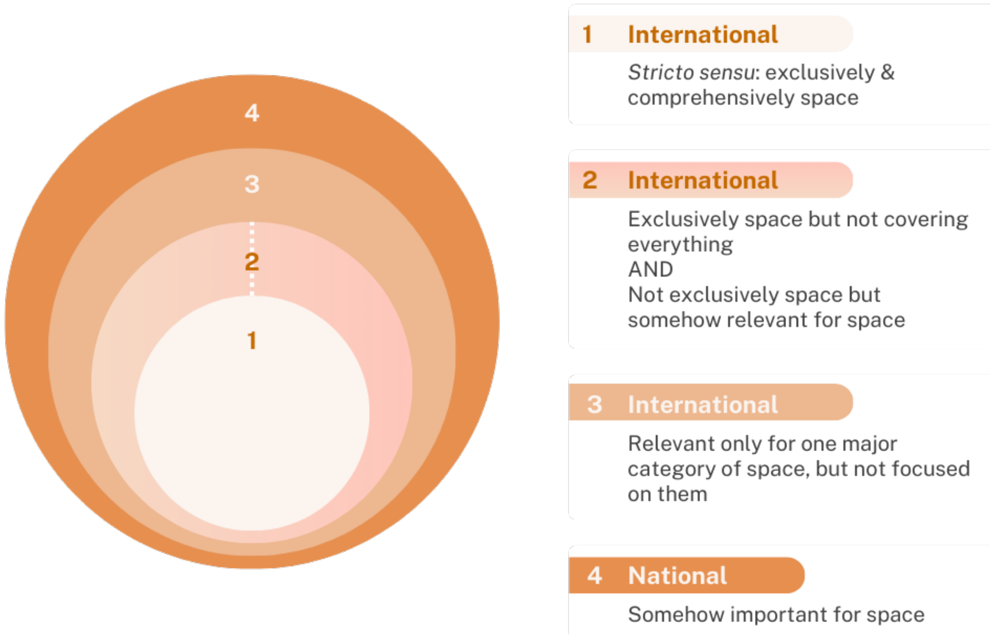

Figure 3.1: Structure of space law

Source: Based on figure 1.1 in Advanced Introduction to Space Law, Frans von der Dunk

The core of the framework, being space law *stricto sensu*, exclusively and comprehensively focusses on space activities, consists of four UN treaties and conventions.[140] These are the Outer Space Treaty 1967, the Rescue Agreement 1968, the Liability Convention 1972, the Registration Convention 1975. The Moon Agreement 1979 is partially considered part of this core since it does not primarily address all space activities. The framework has been complemented by resolutions, principles, and guidelines. In the research of space debris and liability, the OST, the Liability Convention and the Space Debris Mitigation Guidelines are primarily relevant. The other treaties fall outside the scope.

The applicability of the international space law framework depends on whether the issue at hand relates to the domain of space rather than Earth or airspace. A specific boundary between outer space and our atmosphere has not been universally defined. Yet it depends on the thinness of the air, and it is set to be not higher than 100 km above sea level, also referred to as the Kármán line.[141] Essentially, airspace and outer space are distinguished based on their differentiating legal

[140] ibid para 1.4
[141] Daniel C. Patton, 'Managing Space as Global Commons' (Paper presented at the 74th International Astronautical Congress (IAC), Baku, Azerbaijan, 2-6 October 2023) 4.

status. Whereas airspace falls under the sovereignty of subjacent states.[142] An exception is the airspace above the high seas and Antarctica, as these regions and the air above them are 'global commons', just like outer space.[143] Since the global commons are outside the exclusive jurisdiction of individual states, space is governed by the regime of freedom. Therefore, international and collective governance is required for the global commons.

3.2.1 Outer Space Treaty (OST) and Liability Convention

Article VI of the OST, concerning 'state responsibility', decides that states are responsible for national space activities, including those conducted by private actors operating in their jurisdiction.[144] States must authorize and continuously oversee these private sector activities. Article VII of the same treaty establishes 'international liability' for states to other states. So, the launching State is liable for damage caused by their space objects.[145]

The Liability Convention expands the 'international liability' of the OST, by establishing two types of liability: absolute in Article II and fault-based in Article III.[146] It distinguishes damages on Earth or to aircrafts, which results in absolute liability, from those occurring elsewhere, which leads to fault-based liability.[147] Absolute liability provides legal certainty when 'normal victims' face the challenges of proving fault, which is crucial in situations with high risks to individuals. However, the burden of prove is less onerous in space-related situations, as parties that are capable to operate a space object can reasonably be expected to have the ability to prove fault. Moreover, the absolute liability of Article II of the Convention can be exonerated and changed into fault-based liability.[148] A launching state can be exonerated from liability when, and

[142] Agus Pramono, 'Air Sovereignity and No-fly Zones' (2016) 1(1) Diponegoro Law Review 99, 104
[143] Markus Gunneflo, 'TWAIL for Outer Space: Space Law Negotiations at the UN 1958-63' (Kickoff seminar: A Legal History of the Global Commons, Faculty Club Tilburg, Tilburg, 16 May 2024)
[144] Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (adopted 19 December 1966, entered into force 10 October 1967) 610 UNTS 205 (OST) art 6.
[145] ibid art 7
[146] Convention on International Liability for Damage Caused by Space Objects (opened for signature 29 March 1972, entered into force 1 September 1972) 961 UNTS 187 (Liability Convention) art 2, 3.
[147] Ioana Bratu and Steven Freeland, 'Artificial Intelligence, Space Liability and Regulation for the Future: A Transcontinental Analysis of National Space Laws' (Paper presented at the 73rd International Astronautical Congress (IAC), Paris, France, 18-22 September 2022) 4
[148] Frans G. von der Dunk, 'Lability versus Responsibility in Space Law: Misconception or Liability versus Responsibility in Space Law: Misconception or Misconstruction?' (1992) Proceedings of the Thirty-fourth Colloquium on the Law of Outer Space 363, 366

to the extent that, it can prove the damage was entirely or partially caused by the gross negligence, or intentional acts or omissions, of the claimant state or their national actors.[149]

3.2.1.1 Lack of definitions

The Liability Convention has been criticized for the interpretation of liability due to the lack of definitions, like ‘fault’, “gross negligence”, ‘launching state’ and “cause”[150], despite the attempt to clarify some definitions in the Registration Convention.[151] As discussed in Chapter 1, this uncertainty in scope created the first category of legal issues in space. The vagueness did not improve with the rise of private actor.[152] Several challenges within the framework of international space law are: states bear the responsibility of overseeing private companies since they can be held accountable for their actions; the presence of private actors in space may result in increased third-party interventions (see an example below); and the relationship between the ambiguous “launching state” and their “national activities”[153] generates uncertainties. Scholars, for example, question which state should be held liable for damages caused by private companies that are incorporated in one country but launch from another.[154]

An interesting example by author Kehrer concerning third party interventions under the Liability Convention, is when a satellite launched by Country A is manipulated by a third party (e.g. a private actor or cybercriminal) and then crashes into a satellite from Country B, which consequently causes damage on Earth in Country C.[155] Since this relates to damage on Earth, absolute liability is applicable. Therefore, liability is not dependent on ‘fault’, but on the causal link between the damage and the act.

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149 Convention on International Liability for Damage Caused by Space Objects (opened for signature 29 March 1972, entered into force 1 September 1972) 961 UNTS 187 (Liability Convention) art 6.

150 Joel A. Dennerley, ‘State Liability for Space Object Collisions: The Proper Interpretation of ‘Fault’ for the Purposes of International Space Law’ (2018) 29 The European Journal of International Law 281-301

151 Convention on Registration of Objects Launched into Outer Space, opened for signature 14 January 1975, 1023 UNTS 15020 (entered into force 15 September 1976) art 1.

152 Ugo Pagallo, Eleonora Bassi, and Massimo Durante, 'The Normative Challenges of AI in Outer Space: Law, Ethics, and the Realignment of Terrestrial Standards' (2023) 36(2) Philosophy & Technology 5.

153 Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (adopted 19 December 1966, entered into force 10 October 1967) 610 UNTS 205 (OST) art 6.

154 Ugo Pagallo, Eleonora Bassi, and Massimo Durante, 'The Normative Challenges of AI in Outer Space: Law, Ethics, and the Realignment of Terrestrial Standards' (2023) 36(2) Philosophy & Technology 5.

155 Trevor Kehrer, ‘Closing the Liability Loophole: The Liability Convention and the Future of Conflict in Space’ Chicago Journal of International Law, section II

Kehrer claims that Country B is likely to be held liable and Country A not. Country B's liability is based on the direct causal link between the crash of its satellite from and the damage on Earth, even though it can demonstrate that it had no control over the crash. Exoneration within absolute liability is only possible when Country B can prove the gross negligence of the claimant state, Country C. However, Country C did not intentionally act or failed to act in this situation, making such a claim very difficult. Furthermore, the author states that Country A is not likely to be held responsible since the harm was not due to any 'fault' of this country. However, establishing 'fault' is not necessary in this context. Kehrer also notes that it might be possible that Country A's satellite is seen as the cause of the harm on Earth, depending on the meaning of 'cause' in the Liability Convention. This is a crucial point since the interpretation of 'causality' is very relevant. There are several causal links, but due to a lack of a clear definition, it is unclear whether direct causation prevails indirect causation.

This example demonstrates the exoneration possibility for absolute liability was implemented without considering private actors. Based on the Liability Convention it is only possible to hold a state responsible in case of 'gross negligence', not a private party. So, Kehrer argues that the third party that manipulated the satellite cannot be held liable under the Convention.[156] Something he did not consider in this example is the responsibility of the state in which the manipulating private actor is incorporated or the state of the cybercriminal's nationality.

The terminology problem and the lack of enforcement mechanisms, make it difficult to enforce international space law on private actors, laying the basis for an AI liability gap.[158]

3.2.1.2 Case law?

Examples of the application of international space law in case law is scarce. In the 1978 case of *U.S.S.R v. Canada*, a dispute arose when a Soviet space object, the satellite Cosmos 954 equipped with a nuclear reactor, re-entered Earth's atmosphere.[159] Consequently, debris was spread over a large area in Canada, leading to damages such as nuclear contamination. According to the Liability Convention, the Soviet Union (U.S.S.R), as the 'launching state' of the Cosmos 954, has

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[156] ibid.
[158] Christina Isnardi, 'Problems with Enforcing International Space Law of Private Actors' (2020) 58(2) Columbia Journal of Transnational Law 25.
[159] Canada's Statement of Claim, Claim against the Union of Soviet Socialist Republics for Damage Caused by Soviet Cosmos 954 (23 January 1979) annexed to a note from Mark MacGuigan, Secretary of State for External Affairs, to Soviet Ambassador Alexander N. Yakovlev, (1979) 18 ILM 899.

an absolute liability to pay compensation to Canada for the damages. So, liability could be assigned regardless of fault or negligence as the occurrence of damage was more relevant than the actions of the U.S.S.R.

Due to scarcity of case law in space, the interpretation of aviation law could be interesting. For example, in *Boyle v. United Technologies Corporation* of 1988, it was determined that private contractors working for the military could not be held liable for design flaws if they comply with federal requirements.[160] This could suggest that private space companies might also be protected under similar circumstances. After this proceeding, claims against private contractors became significantly harder to win, as manufacturers could not be held liable when their designs were approved by the government.

3.2.2 Applicability of international space law to ACASs

As mentioned before, the UN space treaties do not directly address AI systems in space. The Liability Convention establishes absolute liability for states when damages caused by their space objects on Earth, regardless of the objects' autonomy.

3.2.2.1 "Fault" and autonomy in space?

The Liability Convention currently fails to define 'fault' effectively, as the definition relates to 'causation' which also lacks a clear definition and there is no standard of care for space activities.[161] Generally, certain intentional or negligent conduct determines fault liability, suggesting a thought element. This sparks a debate concerning legal personhood for AI systems, as discussed as one of the issues and risks related to the characteristics of AI in Chapter 2.[162] An expert group of the Commission clearly communicates that there is no immediate necessity to assign legal personhood to emerging digital technologies like AI.[163] The rationale provided is that damages caused by fully autonomous technologies can usually be linked to risks associated with

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[160] *Boyle v United Technologies Corporation* 487 US 500 (1988).

[161] Andrea Capurso, Paolo Marziolo, and Michela Boscia, 'Questions of fault liability: A case study analysis of in-orbit collisions with debris' (2023) 10 Journal of Space Engineering 439-446, 439.

[162] Nynke E. Vellinga, 'Challenges Posed by Autonomous Systems to Liability Regimes: Finding a Balance' in Andrej Zwitter and Oskar Gstrein (eds), *Handbook on the Politics and Governance of Big Data and Artificial Intelligence* (1st edn, 2023) 456-475, 465.

[163] Publications Office of the European Union, 'Liability for Artificial Intelligence and other Emerging Digital Technologies' (Publications Office of the European Union, 2019) <http://op.europa.eu/en/publication-detail/-/publication/1c5e30be-1197-11ea-8c1f-01aa75ed71a1/language-en/format-PDF> accessed 22 May 2024

natural persons or legal entities. However, the difficulties in the context of space are not considered in this rationale. The Commission suggests considering new laws targeting individuals in cases where this is not possible, since this is more effective than establishing a new category of legal person.

Thus, in the absence of clear criteria for 'fault', it is difficult to determine fault-based liability for incidents in space when an advanced AI system decides independently. This situation could reveal a significant gap in liability coverage.[164]

3.2.2.2 ACAS as a "space object"?

One of the uncertainties in assessing the AI liability gap is whether the UN space treaties adequately address and resolve claims arising from incidents with autonomous "space objects". The definition of a "space object" in the Liability Convention incorporates "component parts of a space object as well as its launch vehicle and parts thereof".[165] Early debates assumed that this definition only includes the 'component parts' and a 'launch vehicle' which launches from a land-based facility, but technological advancements, such as air and autonomous launches, challenge this definition.[166] These scholarly debates have also shown that the object is commonly interpreted to be physical and tangible[167], as well as man-made[168]. The latter is in line with the definition provided in the EU Space Regulation on space programs.[169]

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164 Ioana Bratu and Steven Freeland, 'Artificial Intelligence, Space Liability and Regulation for the Future: A Transcontinental Analysis of National Space Laws' (Paper presented at the 73rd International Astronautical Congress (IAC), Paris, France, 18-22 September 2022) 9

165 Convention on International Liability for Damage Caused by Space Objects (opened for signature 29 March 1972, entered into force 1 September 1972) 961 UNTS 187 (Liability Convention) art 1.

166 Ioana Bratu, Arno R. Lodder and Tina van der Linden, 'Autonomous Space Objects and International Space Law: Navigating the Liability Gap' (2021) 18 Indonesian Journal of International Law 423, 434.

167 Stephan Hobe, *Cologne commentary on space law / Vol.2, Rescue agreement, liability convention, registration convention, moon agreement* (Heymann 2013) and
Carl Q. Christol, 'International Liability for Damage Caused by Space Objects' (1980) 74 American Journal of International Law 346 and
Stephen Gorove, 'Toward a Clarification of the Term Space Object—An International Legal and Policy Imperative' (1993) 21 Journal of Space Law 11, 25

168 Vladimir Kopal, 'Some Remarks on Issues Relating to Legal Definitions of Space Objects, Space Debris and Astronaut' (1994) American Institute of Aeronautics 99

169 Regulation (EU) 2021/696 of the European Parliament and of the Council of 28 April 2021 establishing the Union Space Programme and the European Union Agency for the Space Programme and repealing Regulations (EU) No 912/2010, (EU) No 1285/2013 and (EU) No 377/2014 and Decision No 541/2014/EU [2021] OJ L 170/69, Art.2(2)

The first uncertainty in the question whether AI systems can be considered a "space object", concerns AI's intangible nature. Traditionally, intangibles, such as satellite signals, fall outside the scope. However, it is generally accepted that the Liability Convention was drafted with the intention to facilitate a fair and adequate compensation mechanism for victims[170], meaning that the concept should be interpreted broadly. The Convention itself even sets forth that it is important to have international rules so victims receive full compensation promptly.[171] Following that line of thought, ACASs as intangibles, could be considered a space object when it results in damage to 'innocent victims'[172]. This conclusion is not visible in any binding laws.

Another issue is the interpretation of the ambiguous "component parts" since it has not been explained or illustrated in the Convention. It can be suggested that these 'parts' are integral to the extent that the removal of the parts would affect the *physical construction* of the whole object,[173] result in incomplete. Therefore, when evaluating it based on other reliable sources, it would not be possible to remove such parts without *substantial damage*.[174] On the one hand, we can say that the physical structure of a satellite will not substantially change or be impaired when an ACAS is removed from the satellite. On the other hand, the vague terminology could imply that the mere extraction of such a component part would affect the *optimal functionality* of the entire space object. Currently, due to the high levels of debris, operating without an ACAS will have a detrimental effect on the functionality of the satellite. Thus, it is reasonable to conclude that a satellite lacking an ACAS as a "component part" would not be capable of *performing its function*[175] over a longer period.

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[170] Joseph A. Burke, 'Convention on International Liability for Damage Caused by Space Objects: Definition and Determination of Damages After the Cosmos 954 Incident' (1984) 8 Fordham International Law Journal 255, 257 and
Ioana Bratu, 'Blaming Galileo: Liability for Damage Caused by GNSS Enabled Autonomous Systems' (Paper presented at the 72nd International Astronautical Congress (IAC), Dubai, United Arab Emirates, 25-29 October 2021) 6
[171] Convention on International Liability for Damage Caused by Space Objects (opened for signature 29 March 1972, entered into force 1 September 1972) 961 UNTS 187 (Liability Convention) Annex.
[172] Joseph A. Burke, 'Convention on International Liability for Damage Caused by Space Objects: Definition and Determination of Damages After the Cosmos 954 Incident' (1984) 8 Fordham International Law Journal 255, 257
[173] Thomas Graham, Kathiravan Thangavel, and Anne-Sophie Martin, 'New Challenges for International Space Law: Artificial Intelligence and Liability' (Paper presented at the 17th International Conference on Space Operations, Dubai, United Arab Emirates, 6-10 March 2023) 4.
[174] 'Legal Definition of 'component part' (Merriam-Webster) <https://www.merriam-webster.com/legal/component+part> accessed 19 May 2024
[175] 'Component Definition & Legal Meaning', The Law Dictionary https://thelawdictionary.org/component/ accessed on 19 May 2024

If an ACAS installed on a satellite would be considered a space object, the launching state from where the object with the ACAS was launched, could be held liable for any damages it causes.[176] Liability would imply that states must oversee all AI-supported space objects, exercise due diligence and take measures to prevent systems like ACASs to cause damage, potentially leading to opposition and the hinder of innovation.

3.2.2.3 "Gross negligence" and autonomy in space?

The autonomy of an ACAS creates additional challenges for the exoneration process. This defence against absolute liability requires proving 'gross negligence' on the part of the claimant state or the private actor it represents.[177] Due to the lack of a definition in the Liability Convention and no legal precedence found in this research, the criteria to establish this for AI systems in space is unclear.[178] Arguments have been made that ESA acted in gross negligence in the Case of EnviSat, due to reckless behaviour, but ESA has not been held liable yet.[179]

Generally, gross negligence suggests intent, conscious recklessness, or foreseeable consequence, indicating a mental thought element, not an artificial machine decision process.[180] The absence of human involvement in the decision-making process and the opacity of such an artificial decision process, makes it difficult to apply gross negligence. This issue relates to the third class of problems representing the use of AI in space.

Instead, accountability shifts to the design, testing, and deployment phases. If an ACAS is not thoroughly tested and operates without human supervision, gross negligence can be argued. Additionally, human intention is involved when delegating important decisions to complex autonomous systems, creating a foreseeable harm. Furthermore, an ACAS could be used as a human instrument to execute an intentional act or omission, for example when a country plans an

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[176] Thomas Graham, Kathiravan Thangavel, and Anne-Sophie Martin, 'New Challenges for International Space Law: Artificial Intelligence and Liability' (Paper presented at the 17th International Conference on Space Operations, Dubai, United Arab Emirates, 6-10 March 2023) 4.
[177] Convention on International Liability for Damage Caused by Space Objects (opened for signature 29 March 1972, entered into force 1 September 1972) 961 UNTS 187 (Liability Convention) art 6.
[178] Ioana Bratu and Steven Freeland, 'Artificial Intelligence, Space Liability and Regulation for the Future: A Transcontinental Analysis of National Space Laws' (Paper presented at the 73rd International Astronautical Congress (IAC), Paris, France, 18-22 September 2022) 9
[179] Tom Segert, 'Who is liable for ESA satellites?' (LinkedIn, 12 November 2021) <https://www.linkedin.com/pulse/who-liable-esa-satellites-tom-segert/> accessed 14 July 2024.
[180] George Anthony Gal, Cristiana Santos, Lucien Rapp, Réka Markovich, and Leendert van der Torre, 'Artificial Intelligence in Space' (2020) Cornwell University 10.

attack. So, gross negligence can in fact be present when using ACAS. But what complicates the liability allocation, is the fact that there are typically more actors involved in the development and utilization of an ACAS next to the claimant state or the actor it represents.

Thus, for an exoneration to be possible in the case of a collision, the defendant must prove that the damage could be wholly or partially attributed to the ACAS of the claimant state, and that a certain party involved in the process acted with gross negligence. This is cumbersome to prove because the defendant, who bears the burden of proof, does not have detailed knowledge of which actor contributed to the development and utilization of the ACAS that eventually resulted in the damage. Under the principles of international space law, this burden of proof is high in such situation. In general, the position of the party trying to prove that an autonomous system caused an incident in space should be improved to ensure fairness. The burden would be reduced if the defendant only needs to demonstrate that the ACAS of the claimant contributed to the incident.

3.3 National space legislation

Even though international space law does not explicitly require states to implement national space laws, holding launching states jointly and severally liable for any damage creates an intrinsic motivation to mitigate risks and set up national laws to regulate private actors. Through domestic laws, states can exercise control over their private actors, for example through rules on liability, licensing, and insurances.[183]

In 2013, the United Nations General Assembly adopted the 'Recommendations on national legislation relevant to the peaceful exploration and use of outer space', which emphasizes that nations must ensure space activities are authorized by a competent authority through licenses. Authorization can also be withdrawn in case of specific conditions. These conditions should align with standards in the UN treaties and ensure the safe conduct of space operations, minimizing the

[183] Jean-Claude Vecchiatto and Jalal El Ahdab, 'Navigating the Legal Cosmos of Space Disputes: Sources of Space Law and Core Principles' (Global Arbitration Review, 30 April 2024) <https://globalarbitrationreview.com/guide/the-guide-aviation-and-space-disputes/first-edition/article/navigating-the-legal-cosmos-of-space-disputes-sources-of-space-law-and-core-principles> accessed 13 July 2024

risks.[184] It includes the adherence to safety and technical standards consistent with the Mitigation Guidelines, which was created to offer direction for safe and responsible space operations.[185]

The recommendations also address potential liabilities by explaining methods for seeking recourse from space object operators or owners through national law. This often involves insurance agreements to cover costs from damages caused by their space objects, which protects the launching state.[186] For instance, French law mandates that private actors obtain insurance, allowing the state to recover compensation when it is held liable under international space law. Well-organized domestic laws, therefore, reduce the liability gap for private actors as they ultimately bear the financial responsibility. Nevertheless, limitations are likely to still be present, for example when private actors can demonstrate they comply with federal requirements, like in the case of *Boyle*.[187] Or, when national laws do not specifically regulate the use of AI in space. The UN recommendations do not offer advice or guidance on this yet.

3.4 Technology Law from the Perspective of the EU Legislator

During the last years, various EU bodies developed non-binding initiatives to identify solutions for the potential risks posed by AI systems. The Parliament recommended future regulations on AI systems and liability[189], the Council called for the adoption of common AI rules[190] and the Commission became active in formulating AI initiatives[191]. In 2020, the Parliament requested ethical principles for the development and deployment of AI and a civil liability regime, using a risk-based approach[193]. In 2021, actual results emerged with the landmark proposal of the AI Act, the first binding horizontal regulation on AI. In September 2022 both the AI Liability

[184] 'Key elements of National Space Law' (UNODC e-Learning platform) <https://elearningunodc.org/local/cohorts/loginUNOOSA.php> accessed 23 April 2024
[185] Committee on the Peaceful Uses of Outer Space, Space Debris Mitigation Guidelines (United Nations Office for Outer Space Affairs 2010).
[186] 'Key elements of National Space Law' (UNODC e-Learning platform) <https://elearningunodc.org/local/cohorts/loginUNOOSA.php> accessed 23 April 2024
[187] *Boyle v United Technologies Corporation* 487 US 500 (1988).
[189] Resolution 2015/2103(INL) with Recommendations to the Commission on Civil Law Rules on Robotics (European Parliament 2017)
[190] Tambiama Madiega, 'Briefing EU Legislation in Progress, Artificial intelligence act' (European Parliamentary Research Service, March 2024) 2
[191] Building a European Data Economy COM(2017) 9 final (European Commission 2017)
[193] Andrea Bertolini, 'Artificial Intelligence and Civil Liability' (Policy Department for Citizens' Rights and Constitutional Affairs Directorate-General for Internal Policies, July 2020).

Directive and the new Product Liability Directive were proposed[195]. A political agreement on the draft AIA was reached in December 2023[196], then the Parliament adopted the AIA on the 13th of March 2024 and the final version of the AIA was published in the Official Journal on the 12th of July 2024.

3.4.1 AI Act (AIA)

The AIA, which is a form of product safety law, applies a risk-based classification, categorizing AI systems as prohibited, high-risk or limited risk. A risk-based approach to regulation is advantageous when targeting emerging technological risks, since it avoids rules and procedures that do not align with actual threats, ensuring efficient regulatory efforts and reducing unnecessary costs and burdens.[197]

The first risk category establishes which systems are prohibited under Article 5, because of the potential to cause unacceptable risks. The repercussions of using such AI systems include endangering fundamental rights, manipulating behaviour, targeting vulnerable groups based on age or disability, facilitating discrimination by authorities, and allowing real-time distant biometric identification by law enforcement.[198] The second category, laid down in Article 6, introduces high-risk AI systems, which are associated with significant dangers related to specific products and sectors. Therefore, Article 6 refers to Annexes I and III with legislation related to these products and sectors, such as toys and aviation.[199] High-risk systems must adhere to a series of requirements. The last category, in Article 7, concerns the systems that interact with humans resulting in limited risks, e.g. chatbots and content manipulating systems, like deepfakes.[200] These systems are subject only to minor transparency requirements.

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[195] Proposal for a Directive of the European Parliament and of the Council on Adapting Non-Contractual Civil Liability Rules to Artificial Intelligence (AI Liability Directive). COM(2022) 496 final. (European Commission 2022) and
Proposal of the European Commission for a Directive of the European Parliament and of the Council on Liability for Defective Products. COM(2022) 495 final. European Commission (European Commission 2022)
[196] Tambiama Madiega, 'Briefing EU Legislation in Progress, Artificial intelligence act' (European Parliamentary Research Service, March 2024) 1
[197] OECD Regulatory Policy Outlook 2021, Chapter 6
[198] Council Regulation (EU) 2024/1689 of 13 June 2024 laying down harmonised rules on artificial intelligence (Artificial Intelligence Act) [2024] OJ L168/9 Art 5.
[199] ibid Annex I and III
[200] ibid Art 7 and Recital 43

3.4.1.1 Applicability of the AI ACT to ACASs

The applicability of the AIA should always be assessed by considering the relevant jurisdiction, as well as the specific AI application. To begin with jurisdiction, Graham et al. note that space-based AI systems typically operate across several jurisdictions, which would mean that the AIA could apply to most of them.[201] One key aspect of the AIA is the extraterritorial scope, laid down in Article 2, which also imposes significant obligations on companies outside the EU.[202] Therefore, providers of AI products situated outside the EU cannot avoid the new rules when they introduce the products into the EU market, make their products available here or supply the AI product within the EU market. The Act also applies when the producers are making the outputs produced by their AI product available in the EU.

However, from a critical point of view, it can be questioned whether the AIA can have effect on ACASs in space as a 'global commons', which is not owned by any single state and falls under international law. It is debatable whether the AIA's scope extends to such a territory governed by international law. The AIA is not designed as an international law and large (space) states, such as the US and China do not have such established AI regulations yet.[204] Nevertheless, the current rule is that the jurisdiction and applicable law for space activities is determined by the launching state. This would imply that the AIA only regulates the use of AI systems in space when the launching state is a Member State or ESA itself. When ESA causes damage, it bears responsibility and liability for its activities, but the Member States which are party to the Liability Convention, share this liability jointly and severally.[205] There is an internal administrative system to deal with the legal consequences and the apportionment of liability.

Furthermore, the applicability also relates to the application. Space applications or ACASs are not explicitly mentioned within the risk categories. ACASs cannot be classified as prohibited, as they do not pose unacceptable risks, nor as limited risk systems, which is more pertinent to

[201] Thomas Graham, Kathiravan Thangavel, and Anne-Sophie Martin, 'New Challenges for International Space Law: Artificial Intelligence and Liability' (Paper presented at the 17th International Conference on Space Operations, Dubai, United Arab Emirates, 6-10 March 2023) 8
[202] Council Regulation (EU) 2024/1689 of 13 June 2024 laying down harmonised rules on artificial intelligence (Artificial Intelligence Act) [2024] OJ L168/9 Art 2
[204] Pavlo Kryvenko, 'Cosmic Transformation: AI is Revolutionizing Outer Space' (New Geopolitics, 20 May 2024) < https://www.newgeopolitics.org/2024/05/20/cosmic-transformation-ai-is-revolutionizing-outer-space/> accessed 13 July 2024
[205] Jessica, 'What is a "launcing state"' (ESA Blogs, 13 June 2017) <https://blogs.esa.int/cleanspace/2017/06/13/what-is-a-launching-state/> accessed 14 July 2024.

systems like chatbots. There have been suggestions that some space applications could be designated as high-risk, depending on their specific application.[207]

According to Article 6(1), an AI system is considered high-risk when fulfilling two conditions. First, the AI system must be intended for use as a safety component of a product, or as the product itself covered by the Union harmonisation legislation listed in Annex I.[208] In general, ACASs are designed to ensure safety in different contexts, such as automotive, aviation, maritime and space. Section B of Annex I lists several types of products in which ACASs are used, such as vehicles and aircrafts. It is evident that space is not among the areas mentioned in this Annex. Thus, ACASs in general could be considered to fall under the high-risk category of Article 6(1), except for the deployment in space. This reasoning could be explained by the fact that the AIA cannot refer to any existing Union legislation on AI systems in space, or by the fact that it has limited sovereignty to include this since space is a global common.

Article 6(2) of the AIA covers another category of high-risk AI systems which are listed in Annex III. One of the listed areas might be applicable to ACASs, namely the area of critical infrastructure. One example described is an AI system intended to be used as safety components in the management and operation of critical digital infrastructure.[209] ACASs are crucial to the infrastructure in space, as collisions can lead to the malfunction of satellites resulting in possible internet disruptions and security systems crashes.[210] However, a significant exception to the high-risk category arises when an AI system enhances results of activities previously performed by humans, which is the case for ACASs that surpass the capabilities of manual manoeuvres, consequently rendering the AIA inapplicable to the use of ACASs in space. Thus, the obligations of the high-risk category do not apply.

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[207] Ioana Bratu, 'A first critical analysis of the European approach to damage caused by artificial intelligence enabled by global navigation satellite systems. A bridge to nowhere or a cloud with a silver lining?' (2023) 37 International Review of Law, Computers & Technology 147, 151 and
Thomas Graham, Kathiravan Thangavel, and Anne-Sophie Martin, 'New Challenges for International Space Law: Artificial Intelligence and Liability' (Paper presented at the 17th International Conference on Space Operations, Dubai, United Arab Emirates, 6-10 March 2023) 6

[208] Council Regulation (EU) 2024/1689 of 13 June 2024 laying down harmonised rules on artificial intelligence (Artificial Intelligence Act) [2024] OJ L168/9 Art. 6(1), Annex I.

[209] ibid Article 6(2), Annex III

[210] Global Future Council on Space Technologies, 'Six Ways Space Technologies Benefit Life on Earth' (Briefing Papers, World Economic Forum, September 2020) 7

The regulatory framework governing the risks and accountability in case of damages caused by AI systems does not end with the AIA, since it is supplemented with the AI Liability Directive and the revised Product Liability Directive.[217]

3.4.2 AI Liability Directive

The proposed AI Liability Directive addresses claims for harm caused by using AI through the modification of non-contractual civil liability rules to fit the specific characteristics of AI. Typically, in fault-based liability claims, the victim is required to identify the liable parties, and to provide a detailed explanation of the fault, damage, and causality. These difficulties for victims to claim compensation can potentially undermine their right to access justice.[219]

The new rules introduce safeguards like allowing courts to presume the causality if the fault seems likely, while also still enabling defendants to challenge this presumption.[220] Causality can be presumed when three conditions are met: 1) non-compliance with a duty of care, 2) the fault influenced the output produced by (the failure of) the AI system, and 3) the output resulted in the damage.[221] Another safeguard is the simplification of the burden of proof by ensuring that potential claimants have access to information.[222] This can help them identify liable parties and understand the incidents. These measures aim to address the liability gap by improving the feasibility and effectiveness of filing a claim, creating more trust in AI.[223]

3.4.2.1 Applicability of the AI Liability Directive to ACASs

The presumption of causality is especially significant in the context of space. It is not merely enough to tackle the legal issues arising from the complexities of AI, it is especially helpful

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[217] Ioana Bratu, 'A first critical analysis of the European approach to damage caused by artificial intelligence enabled by global navigation satellite systems. A bridge to nowhere or a cloud with a silver lining?' (2023) 37 International Review of Law, Computers & Technology 147, 153

[219] 'Questions & Answers: AI Liability Directive', (European Commission, 28 September 2022) <https://ec.europa.eu/commission/presscorner/detail/en/qanda_22_5793> accessed 20 April 2024

[220] ibid.

[221] Proposal for a Directive of the European Parliament and of the Council on adapting non-contractual civil liability rules to artificial intelligence (AI Liability Directive) Art 4.

[222] Ioana Bratu, 'A first critical analysis of the European approach to damage caused by artificial intelligence enabled by global navigation satellite systems. A bridge to nowhere or a cloud with a silver lining?' (2023) 37 International Review of Law, Computers & Technology 147, 154

[223] Ioana Bratu, 'A first critical analysis of the European approach to damage caused by artificial intelligence enabled by global navigation satellite systems. A bridge to nowhere or a cloud with a silver lining?' (2023) 37 International Review of Law, Computers & Technology 147, 155

in the context of space, since proving and explaining the link between fault and damage is very difficult in such a complicated and unknown territory, even for experts of space companies. Therefore, access to evidence concerning the incident in space is also very important. These developments in AI liability legislation are worthy steps towards more clarity, better access to justice and potentially bridging the liability gap. However, these measures have been criticized due to the absence of a procedure defined in the proposed Directive that outlines the court's authority to demand the release of evidence, which should be provided in a simple enough manner.[224] It is still unclear whether in practise the evidence release will noticeably strengthen the position of the claimant suffering from damages caused by an ACAS. Nevertheless, if a clear procedure is used, it seems that the application of the AI Liability Directive could make liability claims more accessible which is beneficial to the AI liability gap in space.

The AI Liability Directive aligns with the AIA by using the same definitions and maintaining the classification of high-risk systems as opposed to other types of systems. The Directive applies to all damage caused by AI systems, regardless of whether they are identified as high-risk under the AIA. Thus, the outcome of the risk-assessment of ACASs under the AIA does not influence the Directive' applicability. This Directive also aligns with the new Product Liability Directive, since they both introduce similar mechanisms, like the right to evidence disclosure, and use comparable terminology.[225]

3.5 Revised Product Liability Directive and ACASs

The proposal presents new measures concerning liability for products like digital services and software, including AI systems, to address the challenges posed by digital transformation.[226] The proposed revision offers some clarity on the inclusion of intangibles in the traditional definition of 'products', by using a broader definition, namely: 'all movables, even if integrated into another movable or into an immovable'. According to this definition, AI systems fall within

[224] ibid 154-155
[225] 'Questions & Answers: AI Liability Directive', (European Commission, 28 September 2022) <https://ec.europa.eu/commission/presscorner/detail/en/qanda_22_5793> accessed 20 April 2024
[226] Stefano De Luca, 'Briefing EU Legislation in Progress, New Product Liability Directive' (European Parliamentary Research Service, December 2023) 1

the scope of this definition.[227] This amendment expands the definition of "component" to explicitly include "embedded software."[228] Thus, Article 7 extends liability to manufacturers of defective 'components', which now explicitly includes embedded software.[229]

When applying this to space, an ACAS as a type of integrated software, can be seen as a component of a satellite, meaning the revision of this article could mean a clarification of the term 'component parts' in the Liability Convention. Another change is the exclusion of liability of a manufacturer of a defective component when the defect originates from the product design, rather than the component design, and/or when the defect occurred due to instructions given to the component manufacturer by the product manufacturer.[230]

This is a good development, providing additional alternatives for pursuing compensation, thus safeguarding the interests of victims. In essence, this could mean that a possible claimant has the right to claim compensation from the manufacturer of the satellite, the value-added service provider (so the provider of data upon which the ACASs rely), and the signal provider (as a jointly defendant).[231] However, in practise, these possibilities might lead to difficulties. It remains important whether the AI product can be considered under the control of the producer, since Article 6(1)(c) establishes a liability exemption. This could protect producers when a product learns by itself. This serves as a safeguard for producers based on the idea of limited control and ability to anticipate. Consequently, it is essential to ascertain if the product's learning capabilities are within the producer's control, even after deploying it.[233]

Other interesting points are Article 8 concerning the disclosure of evidence and Article 9 on the burden of proof.[234] Article 8 introduces a 'presumption of defect', so when a manufacturer

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[227] Ioana Bratu, 'A first critical analysis of the European approach to damage caused by artificial intelligence enabled by global navigation satellite systems. A bridge to nowhere or a cloud with a silver lining?' (2023) 37 International Review of Law, Computers & Technology 147, 158

[228] Louise Freeman, Bithia Large and Tom Cusworth, 'EU Legislative Update on the New Product Liability Directive' (Inside Privacy, 12 October 2023) <https://www.insideprivacy.com/artificial-intelligence/eu-legislative-update-on-the-new-product-liability-directive/> accessed 15 March 2024.

[229] Proposal of the European Commission for a Directive of the European Parliament and of the Council on Liability for Defective Products. COM(2022) 495 final. European Commission (European Commission 2022) art 7.

[230] Louise Freeman, Bithia Large and Tom Cusworth, 'EU Legislative Update on the New Product Liability Directive' (Inside Privacy, 12 October 2023) <https://www.insideprivacy.com/artificial-intelligence/eu-legislative-update-on-the-new-product-liability-directive/> accessed 15 March 2024.

[231] Ioana Bratu, 'A first critical analysis of the European approach to damage caused by artificial intelligence enabled by global navigation satellite systems. A bridge to nowhere or a cloud with a silver lining?' (2023) 37 International Review of Law, Computers & Technology 147, 159

[233] ibid.

[234] Proposal of the European Commission for a Directive of the European Parliament and of the Council on Liability for Defective Products. COM(2022) 495 final. European Commission (European Commission 2022) art 8, 9.

fails to provide relevant evidence, it will result in a rebuttable presumption of defect. This is quite similar to the presumption of causality of the AI Liability Directive.[235] Article 9(4) also simplifies things for claimants in complex situations who must prove a product's defect or causal link to the damage. Then, they are merely required to show the likelihood that the product was defective or caused the damage. This could lead to a ‘presumption of dangerousness’ when dealing with complex AI systems such as ACASs.[236]

3.6 Conclusion

How is liability allocation regulated within international space law and European AI and liability legislation and to what extent is that applicable to collisions attributable to ACASs?

International space law provides a basis for liability allocation by assigning the liability to the state from which a space object is launched, irrespective of the involvement of AI systems. But the ambiguities leave much room for interpretation. However, clear domestic laws concerning licensing and insurances, reduce the liability gap for private actors. ACASs could potentially fall under the high-risk category of the AIA, but not the ACAS deployed in space. The AI Liability Directive and Product Liability Directive make liability claims more accessible for victims which is beneficial for AI liability gap.

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[235] Ioana Bratu, 'A first critical analysis of the European approach to damage caused by artificial intelligence enabled by global navigation satellite systems. A bridge to nowhere or a cloud with a silver lining?' (2023) 37 International Review of Law, Computers & Technology 147, 160

[236] ‘The EU’s new Product Liability Directive (from a German perspective)’ (Clyde&CO, 4 April 2024) <https://www.clydeco.com/en/insights/2024/04/the-eu-s-new-product-liability-directive> accessed 23 May 2024.

4. Regulatory Approach to the AI Liability Gap

First, it is important to identify the actual objective of the need for better AI governance in space, by looking at the interconnected concepts of the 'what' (4.1), 'why' (4.2), and 'how' (4.3) of AI regulation. This research will dive into the 'how' by considering several legal solutions concerning international guidance on definitions and EU legislation. This chapter will end with an answer to the final sub-question: *Which regulatory measures can be taken to better govern the risks posed by privately-owned ACASs in space?* (4.4).

4.1 'What' is the object of regulation?

Legal scholar Lodder has identified three aspects relevant to understanding the 'what' in the regulation of AI: added value of the technology, the human factor, and the need for logical explanations and oversight.[241] ACASs are of added value due to the major space debris problem. The technology surpasses the limitations of humans. Several authors stress that such an interaction between human judgment and algorithmic decision-making is fundamental for determining the "principle of equality". Thus, the regulatory norms of liability should not be stricter for ACASs than for humans, while also maintaining the recognition of the fundamental differences in the way they learn.[242] Lodder also emphasizes the need for explanations and oversight for accountability.[243] While, the AI liability Directive requires detailed explanations of system development and training, this does not fully resolve the problem of unclear outcomes.

Important to note in the context of 'what' the object of regulation entails, is technological neutrality.[244] According to this, rules should neither be overly specific nor too abstract and the focus should lie on the actions and consequences of ACASs rather than its definition.[245] Regulating the consequences of AI ties directly into understanding the reasons behind ('Why') the necessity

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[241] Arno R. Lodder, Zachary Cooper, 'Do algorithms need to be regulated, and if so, what algorithms?' in A. Savin, and J. Trzaskowski (eds.), *Research Handbook on EU Internet Law* (2 ed., Edward Elgar Publishing Ltd 2023) 80-93

[242] Ugo Pagallo, Eleonora Bassi, and Massimo Durante, 'The Normative Challenges of AI in Outer Space: Law, Ethics, and the Realignment of Terrestrial Standards' (2023) 36(2) Philosophy & Technology 17.

[243] Arno R. Lodder, Zachary Cooper, 'Do algorithms need to be regulated, and if so, what algorithms?' in A. Savin, and J. Trzaskowski (eds.), *Research Handbook on EU Internet Law* (2 ed., Edward Elgar Publishing Ltd 2023) 80-93

[244] ibid.

[245] Bryan Casey & Mark A. Lemley, 'You Might Be a Robot' (2020) 105 Cornell Law Review 287-362

of a regulatory approach. Thus, formulating a clear definition should not be a part of the efforts to bridge the liability gap of this research.

4.2 'Why' is there a need for regulation?

But what is the objective behind regulating ACASs ('Why')? Given the potential for AI to facilitate certain space activities, such as collision avoidance, regulatory frameworks must be enhanced to nurture innovation and economic growth while ensuring safety and accountability. The EU priorities that are relevant in the context of advanced space technologies are: well-being of citizens, security and justice, economic growth, environmental, scientific, and technological progress, and sustainable development of the Earth.[246] Naturally, these are also very relevant for the regulation of AI liability. The use of unregulated technologies could potentially lead to global tensions when liability questions are left unanswered in cases of severe incidents.

Essentially, regulation should not only aim to mitigate AI risks in space technologies, but also to optimize the benefits by leaving room for its potential positive change. Regulation is necessary to achieve this balance and control AI advancements in space responsibly and ethically.

4.3 'How' should it be regulated?

Scholars lack a unified perspective on 'how' AI systems in space should be regulated. At the same time, less effective ways to regulate are clear. For example, proposals for a new binding space treaty aimed at governing current issues like AI in space have been suggested.[248] Experts are sceptical as there has been limited international political interest for this.[249] This international disagreement can be illustrated by the recent failure to pass a first-ever resolution on Arms Race in space.[250] Non-binding principles and mitigation guidelines have proven to be not sufficient to ensure the right conduct, as the problem of debris is only growing.

[246] 'Aims and values' <https://european-union.europa.eu/principles-countries-history/principles-and-values/aims-and-values_en> accessed 22 May 2024
[248] Larysa Soroka and Kseniia Kurkova, 'Artificial Intelligence and Space Technologies: Legal, Ethical and Technological Issues' (2019) 3 Advanced Space Law 131, 134.
[249] Thomas Graham, Kathiravan Thangavel, and Anne-Sophie Martin, 'New Challenges for International Space Law: Artificial Intelligence and Liability' (Paper presented at the 17th International Conference on Space Operations, Dubai, United Arab Emirates, 6-10 March 2023) 3.
[250] United Nations, 'Security Council Fails to Adopt First-Ever Resolution on Arms Race in Outer Space, Due to Negative Vote by Russian Federation' (Meetings Coverage and Press Releases, 2024) <https://press.un.org/en/2024/sc15678.doc.htm> accessed 23 May 2024

Furthermore, self-regulation by private actors focused on Responsible Artificial Intelligence (RAI), would seem like an ideal approach. RAI refers to the design, development, and deployment of AI systems in a 'responsible' way, intending to create reliable, transparent, accountable AI.[251] Unfortunately, this would not work in practise with major space tech companies. It is highly probable that they aim to escape regulation by showing they have created their own standards, which will likely lack transparency, oversight, and enforcement mechanisms. Private companies would prioritize profits over RAI and ethical considerations, resulting in minimal changes which are misleadingly marketed as significant. This results in a similar situation as the greenwashing wave.

But what approach is effective? Since there are several legal issues at various regulatory levels, as indicated in this research, a holistic integrated approach across these multiple levels is recommended, as argued by Bratu. This section will explore practical solutions, such as the formulation of definitions and concrete ideas for guidance and (new) laws.

4.3.1 Definitions international space law inspired by EU law

Chapter 3 has shown that problems like ambiguities in terminology and the lack of enforcement mechanisms, make it difficult to enforce international space law on private actors.[252] Therefore, a good regulatory move would be to define key liability terms. The most important concepts to define are: ‘fault’, ‘space object’ and ‘cause’. As experts have argued, these definitions could be added to the Liability Convention or another type of binding protocol. Alternatively, clarified definitions could also be integrated to soft law guidance documents. For all these definitions it is important to adapt national space laws as well.

4.3.1.1 ‘Fault’

Next to intentional acts, the definition of 'fault' should also include a lack of due diligence, where states fail to prevent foreseeable harm caused by their space objects.[253] This is inspired by

[251] Thomas Graham and Kathiravan Thangavel, ‘Artificial Intelligence in Space: An Analysis of Responsible AI Principles for the Space Domain’ (Paper presented at the 74th International Astronautical Congress (IAC), Baku, Azerbaijan, 2-6 October 2023) 2
[252] Christina Isnardi, ‘Problems with Enforcing International Space Law of Private Actors’ (2020) 58(2) Columbia Journal of Transnational Law 25.
[253] Joel A. Dennerley, ‘State Liability for Space Object Collisions: The Proper Interpretation of ‘Fault’ for the Purposes of International Space Law’ (2018) 29 The European Journal of International Law 281-301, 293

general international law. The definition should describe a high threshold of due diligence to eliminate uncertainties concerning the scope of liability when states have not performed due diligence sufficiently. The best approach is to align the concept of 'fault' in space law with the interpretations of 'fault' in the AI Liability Directive, which focuses more on a breach of duty of care and establishes some standards of care. The new definition should also correspond to 'fault' in the revised Product Liability Directive, which relates to non-compliance with mandatory safety requirements and the failure to ensure product safety during its entire lifecycle, which includes software updates.[254]

For ACASs, this broader definition would mean that the damages caused can still be linked to risks associated with natural persons or legal entities, such as the developers of the systems. Manufacturers are forced to ensure high safety standards during the entire operation of an ACAS.

4.3.1.2 'Space object'

Whether ACASs can be considered as component parts or not, is determinative relevant for liability allocation and compensation. Thus, it is crucial that the definition will be broadened or clarified to align with the current advancements in space technology.[256] The term should encompass any man-made object aimed for space, including all hardware and software facilitating its autonomy. Inspiration can be sought through Article 7 of the New Product Liability Directive, which includes "embedded software" to the scope of 'component'. ACASs have proven to be essential to the functionality of satellites, which should also be reflected in the definition. An ACAS as a component, qualifying as a space object, clarifies the presence of liability.

Furthermore, the Registration Convention obligates the registration of space objects, including their jurisdiction and control issues within a registry.[257] A special registry for AI-enabled space objects to address their unique features and complexities would be a helpful step towards the classification and clarification of AI systems as space objects.

[254] Ioana Bratu, 'A first critical analysis of the European approach to damage caused by artificial intelligence enabled by global navigation satellite systems. A bridge to nowhere or a cloud with a silver lining?' (2023) 37 International Review of Law, Computers & Technology 147, 151
[256] Ioana Bratu, Arno R. Lodder and Tina van der Linden, 'Autonomous Space Objects and International Space Law: Navigating the Liability Gap' (2021) 18 Indonesian Journal of International Law 423, 434.
[257] ibid 435.

4.3.1.3 'Cause'

As was illustrated with an example, it is unclear if only direct causation can lead to a successful claim under the Liability Convention, or also when damage is caused indirectly. It is recommendable to determine this depending on the specific circumstances based on reasonableness and fairness.

Furthermore, according to the Liability Convention, the fault liability regime applies when an ACAS would malfunction and damage another satellite. When the 'presumption of causality' incorporated in the AI Liability Directive is applied, it would resemble absolute liability more, since the burden of proof is put on the launching state. This puts victims in a stronger legal position. However, the presumption could also create unfair scenarios for defendants, due to other factors such as manoeuvrability, information flow, third-party space situational information providers, and space weather.[259] A presumption that works for AI applications on Earth, is not necessarily an effective protection method in space.

It is suspected that the Liability Convention prevails the AI Liability Directive in terms of the presumption of causality, for incidents in space, given that this is governed by international law. However, existing laws and literature do not offer a definitive answer to this issue. This research suggests that the applicability of the AI Liability Directive is the most suitable option, as the presumption of causality aligns with the primary aim to protect the victim. Nevertheless, EU legislators should provide their interpretation on this.

4.3.2 EU Technology Law

AI regulation within the EU is advanced. As discussed in Chapter 3, ACASs in space do not fall under the high-risk category of the AIA. Nevertheless, the EU could lead the way in the process of drafting international AI principles, that could also apply to space. This role is suitable since the legislative process behind the AIA aligns with the process of international space law within the COPUOS, for example with respect to the consultation methods.[261] Scholars anticipate that the "Brussels Effect" will likely manifest in certain aspects, so the AIA could have a

[259] Interview with Yiron Sun, Research and Teaching Fellow, NYU (Online, 12 July 2024)
[261] Thomas Graham, Kathiravan Thangavel, and Anne-Sophie Martin, 'New Challenges for International Space Law: Artificial Intelligence and Liability' (Paper presented at the 17th International Conference on Space Operations, Dubai, United Arab Emirates, 6-10 March 2023) 3.

significant international impact in the governance of AI (liability).[262] It is interesting to see whether the Brussels Effect could shape global AI standards.

4.3.3 EU Space Law (EUSL) Initiative

In the State of the Union of 2023, the key priorities for 2024 included an initiative for an EU Space Law (EUSL) [264]. This initiative aims to harmonize rules concerning safety, resilience, and sustainability of space activities, while it wants to eliminate barriers across the single market caused by the heterogeneity or lack of national space law.[265] A new coherent legal framework will guarantee more legal certainty and the competitiveness of the EU industry in an international trade context.

The EUSL will primarily focus on three objectives with corresponding pillars. The first concrete goal is to ensure a safe satellite traffic that tackles the increasing risk of collisions and damages by space debris, which is connected to the EUSL safety pillar. The Commission states that one of the key measures concerns CAMs.[266] Secondly, the initiative focusses on the protection of the European and national space infrastructures and assets against harmful threats due to the rise of technological/cyber risks, which falls under the resilience pillar aligning with the new NIS2 Directive concerning cybersecurity. The final sustainability pillar aims to address the long-term sustainability of space operations, fostering climate-neutral space activities.

The details of the practical implementation of these objectives and pillars are still unclear. Unfortunately, the legislative proposal, which was supposed to be adopted by the Commission in the first trimester of 2024, has been postponed until the new European Commission is in place.[267]

Different models of extraterritoriality could be employed for this initiative, one of which is extended extraterritoriality.[268] In this most extreme case, the initiative could affect private actors like SpaceX by denying spectrum licenses for Starlink's uplink and downlink operations. Uplink, the process of sending data to satellites, and downlink, the process of receiving data from satellites,

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[262] Charlotte Siegmann and Markus Anderljung, *The Brussels Effect and Artificial Intelligence: How EU regulation will impact the global AI market* (Centre for the Governance of AI 2022) 5.
[264] President von der Leyen's letter of intent (State of the Union, 13 September 2023)
[265] 'Targeted consultation on EU Space Law' (The European Commission) <https://defence-industry-space.ec.europa.eu/consultations-0/targeted-consultation-eu-space-law_en> accessed 14 March 2024
[266] Ibid.
[267] Interview with Dimitra Stefoudi, PhD candidate, Faculty of Law, Universiteit Leiden (Online, 17 April 2024)
[268] Interview with Yiron Sun, Research and Teaching Fellow, NYU (Online, 12 July 2024)

are critical for such satellite internet services. Therefore, without these licenses, SpaceX would be unable to operate Starlink within the EU market. This is interesting for EU legislators to consider while drafting the law.

4.3.4 International guidance for States

COPUOS can draft guidelines, as it did with the Mitigation Guidelines and the Principles of the use of nuclear power in space of 1992.[274] Potentially, these new guidelines can be called the 'Principles on the use of AI in Outer Space'. Even though, non-binding guidelines do not stimulate private actors in the long term, the recommendations of the General Assembly illustrated that it could facilitate states with the best practises (discussed in Chapter 3). New guidelines focused on AI applications in space, could be beneficial for insurance agreements and setting technical standards.

While strict liability would be the easiest method receive compensation, insurance and compensation funds are essential in managing the economic risks for states and the developers and deployers of ACASs.[275] This is necessary to encourage innovation while ensuring that private actors can pay for the damages.

Technical standards are highly prevalent in the space field and often create a framework of order through contractual agreements, or voluntary adoption in institutional cooperation.[276] International guidance helps to form universally applicable standards.

4.4 Conclusion

When answering *Which regulatory measures can be taken to better govern the risks posed by privately-owned ACASs in space?* the 'what', 'why' and 'how' helped to delineate the answer. To address the multifaceted legal challenges identified, a comprehensive and integrated regulatory approach across different levels is essential.

[274] 'Key elements of National Space Law' (UNODC e-Learning platform) <https://elearningunodc.org/local/cohorts/loginUNOOSA.php> accessed 23 April 2024

[275] Nynke E. Vellinga, 'Challenges Posed by Autonomous Systems to Liability Regimes: Finding a Balance' in Andrej Zwitter and Oskar Gstrein (eds), *Handbook on the Politics and Governance of Big Data and Artificial Intelligence* (1st edn, 2023) 456-475, 469.

[276] Interview with Yiron Sun, Research and Teaching Fellow, NYU (Online, 12 July 2024)

To ensure better enforcement, the definitions of terms such as 'fault', 'space objects' and ‘cause’ must be clearly established, while EU laws and proposals serve as a valuable inspiration for this. Furthermore, the application of 'presumption of causality' as seen in the AI Liability Directive is recommended. The initiative for an EU Space Law signals the significance of collision avoidance measures and it holds significant potential to take another step towards bridging the AI liability gap in space. Together with international guidance on AI, insurance provisions and technical standards, this approach can form a balanced, clear, and forward-thinking regulatory framework.

5. Conclusion

The use of AI in space is transforming the way we understand, explore, and engage with the universe, while both safety on Earth and in space should be ensured. In the dynamic realm of the space industry, private actors are dedicated to integrating increasingly more AI technologies into their space activities, for example autonomous collision avoidance systems in their satellites. Their role is crucial in avoiding other space objects to guarantee more safety by minimizing human errors. While experts, national space organizations and private companies are optimistic that these systems will significantly reduce the risk of collisions in space, careful consideration is required to possible negative consequences. *What are these potential implications?* Space has faced numerous legal challenges over time. Uncertainties were created due to the lack of definitions. These challenges were followed by the legal issues associated with the privatization of space activities and the integration of AI into space activities. The inherent features of AI such as autonomy, opacity, unpredictability, complexity, adaptability, and data-drivenness create distinct and pressing challenges in the context of space, which should be addressed.

To what extent does this occur in the existing legal framework? International space law is focused on state responsibility and liability and the framework is currently too ambiguous to claim that damages caused by privately-owned ACASs are sufficiently regulated. Moreover, for the risk assessment of ACASs according to the AIA, both jurisdiction and application were evaluated. This assessment was focused on the high-risk category of Article 6 and Annexes I and III. The research concluded that ACASs do not fall under the high-risk category, so the AIA does not apply to its use in space. Thus, international space law and the AIA do not specifically address liability for autonomous systems in space, highlighting a notable AI liability gap for damages caused by ACASs. *The existing legal framework should therefore be enhanced to better allocate liability for damages attributable to private ACASs in outer space.*

But *what can be the role of EU legislation* in this*?* On a positive note, the AI Liability Directive, and the revised Product Liability Directive, are not dependent on the categorization under the AIA, so the laws can still address liability when ACASs are deployed. Furthermore, the 'presumption of causality' under the AI Liability Directive and its interplay with the Liability Convention presents an intriguing legal connection. This approach presumes causality between the fault of a defendant and the damage, which is necessary due to the complex nature of AI technologies, where proving causation can be too cumbersome. This research suggests that the applicability of the AI Liability Directive is the most suitable option in such situations, as the ‘presumption of causality’ aligns with the primary aim of space liability law in general, which is the protection of the victim. The ‘presumption of defect’ of the revised Product Liability Directive also strengthens the position of the claimant concerning the burden of proof and in case the defendant fails to disclose relevant evidence. Victims can also pursue legal action against different parties involved in the development and deployment of ACASs. The measures taken in EU legislation to protect a victim in liability cases where they suffered damages attributable to complex AI systems, provides a lot of guidance for the liability allocation in case of ACASs in space.

EU legislation can play another significant role. The initiative for an EU Space Law shows the relevance of collision avoidance, safety, and sustainability in space. If this initiative follows the legislative trajectory of recent EU laws, it holds significant potential to advance efforts towards bridging the AI liability gap in space. This initiative presents an ideal opportunity for EU legislators to clarify some of the limitation of this research, namely: the applicability of EU laws to space applications considering space is a ‘global common’, the extraterritorial scope of the AIA, and the precedence of the AI Liability Directive over the Liability Convention concerning the presumption of causality. Although, this research established that the AIA does not apply to ACASs, the EU could use its position at the forefront of drafting technology and liability legislation to have influence on global AI standards applicable to ACASs in space. Existing and upcoming EU technology and liability laws provide interesting insights, for example for the broader definitions of terms such as 'fault', 'space objects', and 'cause', which are more aligned with contemporary technologies. These must be clearly established in international agreements, using EU legislation as a valuable inspiration.

In addition to EU legislation, there are further *regulatory measures that can be taken to better govern the risks posed by privately-owned ACASs in space.* A multi-dimensional regulatory approach is likely to bridge the AI liability gap for these systems. Establishing a special registry for AI-enabled space objects to address their unique features and complexities would be a relevant step. When combined with international guidelines on insurance provisions and technical standards, concerning AI, these measures create a balanced, clear, and forward-thinking regulatory approach. For instance, a national obligation for private space actors to have an insurance, already reduces the liability gap for private actors, since states can recover compensation when they are held liable.

In conclusion, *the existing legal framework should be enhanced to better allocate liability for damages attributable to private autonomous collision avoidance systems (ACASs) in outer space,* by considering EU technology and liability laws as a source of inspiration. These EU laws hold promising potential to take ‘a giant step’ towards bridging the AI liability gap in outer space, mostly due to the level of innovation and contemporary relevance, rather than being directly applicable to the liability allocation for damages caused by *all* privately-owned ACASs in space. Thus, additional (practical) measures remain to be relevant.

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