From the Legal Vacuum to Autonomous ASAT (Anti-Satellite Weapons): Challenges for International Cooperation and Peace in Outer Space

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The rise of autonomous weapons and space technologies is reshaping global security, raising challenges for strategic stability, disarmament, and orbital sustainability. The integration of artificial intelligence into satellite weapon systems exemplifies the militarization of space, where conflicts may extend beyond Earth with systemic security implications. This study introduces the category of Autonomous Anti-Satellite Weapons (Autonomous ASAT) as evidence of international legal gaps: the absence of binding norms enables space to emerge as a frontier of autonomous warfare. Satellites, central to surveillance, targeting, and communication, illustrate the "dual-use" nature of space technologies, while existing instruments, such as the 1967 Outer Space Treaty, prove inadequate to regulate defense experimentation. The analysis reviews limits of current international law and explores soft- and hard-law proposals to prevent armed conflict in orbit, reduce debris, and manage environmental risks. It outlines pathways for a multilayered regulatory framework promoting transparency, shared security, and international cooperation. Balancing innovation with governance is essential to preserving the peaceful use of autonomous systems for humanity.

Keynotes: Autonomous Weapons, Outer Space Security, International Law, Dual Use Technologies

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Introduction

Despite the fact that, to date, no recorded cases are known in which a Nation has concretely employed an Anti-Satellite Weapon (ASAT) against an object in orbit belonging to another State (O'Meara, 2025; Bingen et al., 2023), the growing strategic importance of satellites in military operations and the management of critical infrastructures makes these orbital assets vulnerable and highly attractive in conflict scenarios.

Satellites, in fact, constitute the beating heart of communications, strategic surveillance, navigation and the collection of meteorological and environmental data: it is therefore understandable that many space powers have invested, and continue to do so, in the development of technologies capable of neutralizing such resources. The tests conducted in recent years, together with the official statements accompanying the development of offensive and defensive capabilities in space, demonstrate how the use of ASAT weapons (capable of disabling or destroying civilian, commercial, and military satellites) is no longer a remote possibility but rather a concrete threat of global scope.

Anti-satellite weapons have become a constant feature in discussions among States and International organizations regarding outer space security. An exemplary case is that highlighted in the European Union's statement at the United Nations Conference on Disarmament in 2023, in which the Russian test of a direct-ascent ASAT missile conducted in 2021 (Völkerrechtsblog, 2021) was described as a "*strong reminder*" of the need to strengthen the normative framework regulating space activities. The absence of specific binding norms on the limitation or prohibition of such weapon systems has made space a new terrain of strategic and legal ambiguity.

In this context, some scholars (Swope et al., 2024) have argued for defining all space countermeasure capabilities as "weapons," emphasizing their aggressive function and their ultimate purpose of denying the operational use of satellites to legitimate users. Space countermeasures today represent, in fact, a complex and technologically advanced set of instruments developed to interfere with the operational integrity or functionality of satellite systems and related infrastructures. Such capabilities are divided into physical and non-physical forms and manifest through both kinetic and non-kinetic effects, depending on the nature of the intervention (Hoxha, 2023).

ASATs constitute one of the most relevant expressions of this category: systems specifically designed to neutralize or destroy satellites in orbit, with the objective of denying an adversary access to essential strategic resources, such as communication networks, global positioning systems, and observation and surveillance capabilities (Czajkowski, 2024).

A first fundamental distinction concerns Kinetic physical ASATs, which include, on the one hand, missiles launched from the ground, known as direct-ascent ASATs, and, on the other, co-orbital systems, i.e., platforms positioned in space, designed to approach the target and perform impact or damaging maneuvers. Attack methods in these cases vary: they range from simple mechanical impact to the use of robotic arms, guided projectiles, or chemical agents (Czajkowski, 2021; Pobjie and Ortega, 2024). Particular concern is raised by so-called "*inspector*" or "*servicing*" satellites, whose declared use for peaceful purposes can easily be reconverted for hostile ends. States such as the United States, Russia, China, and India have already demonstrated such capabilities, as evidenced by the 2021 Russian test that destroyed the Cosmos 1408 satellite, generating an enormous amount of orbital debris (United States Space Command, 2020).

A second category concerns Non-kinetic physical ASATs: these systems do not require direct contact with the target but employ forms of directed energy to produce destructive effects. Among the most significant examples are high-powered lasers, capable of temporarily or permanently blinding satellite optical sensors; high-intensity microwaves, able to compromise sensitive electronic circuits; and, finally, nuclear detonations in orbit, whose electromagnetic pulses (EMPs) could affect numerous devices simultaneously. Such weapons can be operated from terrestrial, naval, aerial, or space-based platforms (Pobjie and Ortega, 2024).

The third domain concerns electronic technologies, such as *jamming systems*, which block or degrade communications between satellites and ground stations, or *spoofing* techniques (lit. "deception"), which transmit misleading signals to manipulate navigation or data processing. Finally, there are cyberattacks aimed at infiltrating on-board computer systems, compromising sensitive data, or assuming partial or total control of entire satellites, with either temporary and reversible or permanent and irreversible effects (Czajkowski, 2024).

ASATs, based on this classification, are thus divided into two operational families: Co-orbital weapons, striking from nearby orbits, and Direct-ascent weapons, launched from the Earth's surface toward an orbital target. Both can be employed through a plurality of vectors and techniques: direct impact, close detonation of conventional or nuclear warheads, or high-density energy beams.

These instruments constitute the most aggressive and destabilizing dimension of the contemporary space arsenal and, therefore, in an orbital environment increasingly congested, interdependent, and crucial for civilian life, the introduction of destructive capabilities risks undermining collective security, strategic stability, and the reliability of global infrastructures. Technical terminology, often the subject of debate, in reality reflects an analytical and normative necessity: to understand the function, modalities of use, and systemic implications of each capability, so as to develop a coherent and updated legal regime.

An additional level of complexity opens with the introduction, still experimental, of Autonomous ASAT systems. The question of how far such technologies may operate without direct human control, both in the engagement and offensive phases and according to the principles of "*human on the loop*" and "*human in the loop*" (Frau, 2024), and with what legal, ethical, and strategic implications, remains largely unresolved. It is also legitimate to ask whether this will lead to an acceleration of the arms race in space.

In this respect, there is also a lack of in-depth studies on the geopolitical repercussions of introducing autonomous weapons into space, particularly concerning new strategic balances, the possibility of automated escalation of conflicts, and the erosion of deterrence and multilateral control mechanisms, which – due to industrial, experimental, and defense-related secrecy – prevent a thorough exploration of the real operational capabilities of these technologies in extreme environments such as outer space, where communication delays, physical isolation and decision-making autonomy pose unique challenges (Silverstein et al., 2020).

It is precisely for this reason that the absence of a clear and shared international normative framework governing the use of weapons (especially those of autonomous nature) in space generates legal uncertainty and accountability gaps (Frau, 2024). Added to this is the absence of systematic reflections on the consequences of possible autonomous actions carried out by such systems: who bears legal responsibility, or in other words, who is accountable for a decision-making error made in orbit by an algorithm? Which standards should be applied to assess proportionality or necessity in an extraterrestrial scenario?

It is precisely within this *framework*, specifically of a normative character, that this study identifies its basis of investigation: the absence of binding norms has fostered the uncontrolled development of space technologies, among them autonomous ASAT weapons, with the risk of crystallizing logics of deterrence and dominance rather than promoting cooperation and shared security.

The growing attention to orbital security has also been confirmed by the observations addressed by States to the Secretary-General of the United Nations (UNSG, 2025), which highlight at least five areas of concern requiring urgent attention (First, 2022).

The first concerns the uncontrolled increase of space debris (Esquivel & Molnar, 2018), namely any artificial object placed in orbit around Earth that has ceased to have a useful function, which, depending on the orbit, can persist for hundreds of years (or even longer) and is therefore considered one of the main threats to the long-term sustainability of space activities: for this reason, States agree on the need to prevent the deliberate generation of persistent debris, which can remain in orbit for decades or centuries and compromise safe access to space (United, 2022; Byers & Boley, 2023).

The second concern relates to the proliferation of Kinetic ASAT technologies, directly responsible for the fragmentation of satellites and the creation of new collision threats. These systems exacerbate the risk of cascading events, such as the so-called "Kessler syndrome" (Williams & Shearer, 2011; Harrison, 2020; Hoxha, 2023), in which the destruction of a satellite generates debris that in turn collides with other objects, exponentially multiplying the damage (United States Space Command, 2020).

Added to this is the third source of instability: the use of Non-kinetic technologies, such as electronic warfare or cyberattacks, which can interfere with the functionalities of active satellites without causing physical damage, but with potentially catastrophic effects on communications, navigation systems, and other essential services (Traynor, 2007; Libicki, 2009; Pobjie & Ortega, 2024; Weeden & Samson, 2024).

The fourth problematic area concerns *dual-use* space systems (Ortega and Samson, 2023; Alioti, 2024), namely all those space objects originally designed for legitimate or beneficial purposes – such as orbital debris removal or in-orbit support to other satellites – but which at the same time carry an intrinsic potential to be repurposed for hostile ends, particularly to damage or interfere with other space objects (Ortega & Samson, 2023). Platforms designed for civilian purposes but easily convertible for military uses (such as orbital inspection or maintenance vehicles) raise issues of transparency and mutual trust among States. This technological ambiguity contributes to fueling strategic competition and hinders any attempt at multilateral cooperation.

Finally, emphasis has been placed on the risk of long-term effects, both direct and indirect, on the space environment and on terrestrial infrastructures dependent on it. Satellites are increasingly interconnected with energy networks, global communications, transportation, and even emergency management. The damage to even a single satellite can therefore produce systemic consequences[1].

In light of the technological advent of Anti-satellite weapons and their autonomous versions, this contribution aims to offer a critical and updated analysis of the normative landscape relating to such capabilities, assessing the resilience of the current legal framework and identifying its main gaps: the objective is to provide insights for a more coherent and forward-looking international regulation, capable of addressing the future implications of operational autonomy and of ensuring a use of outer space that is peaceful, responsible, and sustainable.

[1] With regard to international norms on the limitation of hostile uses of environmental modification technologies, the *Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques*(ENMOD), adopted on May 18, 1977 (31 U.S.T. 333; 1108 U.N.T.S. 151), prohibits States Parties – under Article I – from employing such techniques for destructive, damaging, or injurious purposes, whenever they have widespread, long-lasting, or severe effects. This prohibition is expressly extended to outer space under Article II, thereby including the space environment among the contexts of application of the norm.

Evolutions of Space Treaties

From the earliest phases of the space age, the issue of security has been a constant concern for the international community, well before it became central in contemporary strategic debates. The launch of Sputnik I by the Soviet Union in 1957 not only inaugurated space exploration but also immediately highlighted the military potential of space launch vehicles, implicitly demonstrating the capability of the first Soviet intercontinental ballistic missiles (ICBMs) and signaling the possibility of projecting military competition beyond Earth's atmosphere (Maogoto & Freeland, 2007; Maogoto & Freeland, 2008). The event also introduced the uncontested principle of freedom of access to and passage through outer space, later consolidated in customary international law (Grego, 2012).

Shortly thereafter, several States began developing capabilities against space threats and dangers, such as the United States, which in 1958 conducted nuclear explosion tests in space and in 1959 tested the "Bold Orion" program, aimed at verifying the capability of ballistic missiles to hit satellites, as demonstrated by the approach to the Explorer I satellite (see also "Operation Fishbowl," 1962, USA). At the same time, in 1963, the Soviet Union began developing co-orbital ASAT systems, designed to approach and, if necessary, neutralize satellites from orbit (Grego, 2012). The prospect that geopolitical tensions could extend into this new domain led the United Nations General Assembly to reaffirm the need to prevent the militarization of space (UNGA, Res. 1348 (XIII), 1958).

These concerns led to the creation of the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS), which played a crucial role in drafting the Outer Space Treaty (OST), adopted in 1967. The OST is based on principles such as the freedom of exploration and use of space "in the interest and for the benefit of all countries" (OST, Art. 1), expressly prohibiting any military activity on the Moon and other celestial bodies (OST, Art. 4). In this perspective, the treaty also assumes an arms control function, prohibiting the placement of nuclear weapons or weapons of mass destruction in orbit or on celestial bodies (OST, Art. 4) (Lyall & Larsen, 2018).

In response to the proven effects of nuclear explosions in space (Hoerlin, 1976), the 1963 Partial Nuclear Test Ban Treaty (PTBT) banned such tests in space and underwater, providing a concrete basis for the OST, though it remains a treaty based on general statements, lacking binding enforcement mechanisms. Its principles were later developed in specific treaties on liability, registration of space objects, and humanitarian cooperation. The principle of non-contamination was translated into non-binding guidelines for limiting orbital space debris and ensuring long-term sustainability, promoted by COPUOS and adopted by the General Assembly. These instruments, however, did not fill the gaps of the OST regarding the control of conventional weapons in space, allowing the development and testing of ASAT weapons both from Earth and in orbit (Weeden & Samson, 2021).

The risk of a new arms race in space not only threatens orbital assets but also poses a potential danger to terrestrial stability, in contradiction with the peaceful vocation of space law. Already in 1978, during the General Assembly's special session on disarmament, States recognized the need for new negotiations to prevent the extension of armed competition into space (United, 1980). From this need arose the concept of PAROS (Prevention of an Arms Race in Outer Space), formalized with the first two resolutions in 1981 (Silverstein et al., 2020).

In this context, sharp divergences emerged between the normative visions promoted by major military and space powers. For instance, the Russian Federation and the People's Republic of China consider the OST and the UN Charter legally insufficient and argue for a new

binding treaty explicitly banning the deployment of weapons in space: a proposal formalized in the "Prevention of the Placement of Weapons in Outer Space and the Threat or Use of Force against Outer Space Objects" (PPWT), presented in 2008 and updated in 2014.

Conversely, many NATO countries and allies are more inclined to promote Transparency and confidence-building measures (TCBMs) for space security (Robinson, 2011), considering the existing legal framework sufficient and showing reluctance to accept new legally binding obligations that could limit their defense and deterrence capabilities (Johnson, 2014). In this spirit, the European Union presented a proposal for an International Code of Conduct (ICoC) in 2008, revised in 2014 after multilateral consultations. However, the code, developed outside the UN context and without US support following its withdrawal in 2015, received mixed reactions, both in terms of content and method (West, 2021a). The lack of consensus, compounded by the US withdrawal of support in 2015, ultimately undermined the initiative.

In parallel, the UN initiated two processes of Groups of Governmental Experts (GGEs) to explore both normative solutions and non-binding cooperative approaches. The 2013 GGE recommended a series of TCBMs, including prior notification of space activities and information exchange. A second GGE, convened between 2018 and 2019, aimed to define a possible legally binding instrument but failed to produce a consensual report. However, it highlighted some significant convergences: recognition of the applicability of international treaty and customary law to space, the need for non-discriminatory access, and the necessity of not hindering the technological and economic development of States.

PAROS-related issues continue to be addressed in the First Committee of the General Assembly: in 2021, five thematic resolutions were adopted (GA Res. 76/22; 76/23; 76/230; 76/55; 76/231), reflecting growing polarization among States. Particularly significant is Resolution 76/231, inspired by the UK's proposal no. 75/36, which calls for the development of norms of responsible behavior in space. Its broad support (164 votes in favor) demonstrates the shared urgency to address emerging threats in the space domain and the collective aspiration to build an effective and sustainable multilateral framework (West, 2021b).

In today's context, the outer space, while formally designated as a domain for peaceful use, increasingly emerges as an arena of growing strategic and geopolitical relevance, where behind the official rhetoric of cooperation and non-armament lies a reality marked by intensifying technological and military competition among major space powers. This tension does not represent an anomaly but rather the projection of terrestrial conflict dynamics into space: space thus becomes an extension of the global arena of confrontation, serving power projection and the defense of national interests.

The obsolescence and indeterminacy of current legal instruments, in particular the 1967 Outer Space Treaty and the lack of effective mechanisms of implementation, monitoring, and verification, have thus created a regulatory vacuum that has encouraged the experimentation and development of advanced orbital technologies. Among these, Autonomous ASAT systems represent one of the most emblematic products: systems that, in the absence of clear regulatory constraints, can integrate automatic engagement capabilities and operate outside any direct human control. The lack of an updated legal framework has, in fact, normalized a context of strategic deregulation, in which technological competition is encouraged rather than contained.

The universal appeal to the "*peaceful use*" of space, therefore, takes on an ambiguous value, often serving to legitimize dual-use activities – civilian in form but susceptible to military application. This ambiguity reflects the tension between the need for shared regulation and States' fear of compromising their technological sovereignty. In a context of mutual distrust, even measures ostensibly aimed at stability, such as Transparency and Confidence-Building

Measures, may be perceived as tools for information gathering or surveillance, further fueling mistrust among actors (Rajagopalan, 2022).

Added to this is the structural difficulty of building a truly multilateral space governance: divergences in UN negotiations and the multiplication of non-binding political resolutions reveal a fragmented normative framework, in which geopolitical positioning logics prevail over the concrete will to achieve a shared regulatory consensus.

In summary, the space dimension today constitutes a crossroads of strategic interests, emerging technologies, and normative fragilities: while cooperation and peace remain necessary to guide international discourse, they cannot conceal the profound underlying tensions. It is for this reason that launching a multilateral process aimed at defining an integrated normative corpus, capable of combining hard law and soft law instruments, and limiting the proliferation of space weapons, while promoting transparency and long-term sustainability of space activities, becomes even more urgent.

Possible forward steps

In innovative and dynamic fields such as outer space, norms assume an even more significant role: the legal principles of "*due regard*" and non-contamination, for example, inspired the guidelines on space debris mitigation (United, 1967), while non-binding resolutions guided the emergence of virtuous behavior. In this sense, space norms can be understood as forms of "*soft law*," capable of shaping conduct even in the absence of formal obligations (UNIDIR, 2013).

Their development takes place through multilateral processes, but also through unilateral initiatives that can have a significant impact, such as the ASAT moratoria of the 1980s or unilateral political declarations on the use of weapons in space (West & Ortega, 2022). Furthermore, the establishment of common norms can foster mutual trust among States and create the conditions for future measures of disarmament or conflict prevention. The promotion of new norms, based on shared values and compatible with existing law, is considered fundamental to achieving the objectives of PAROS and ensuring a safe, sustainable, and inclusive space order (West & Ortega, 2022).

From this perspective, the definition and consolidation of norms, whether in the form of soft law or hard law, are essential instruments to prevent an escalation in outer space toward a war of an autonomous nature, outside direct human control, and to preserve the peaceful, sustainable, and collective character of the space environment.

Space, in fact, also stands out for its capacity to generate unprecedented forms of collaboration: suffice it to consider the continuation of joint missions, such as operations aboard the International Space Station (ISS), which continue to involve actors such as the United States, Europe, and Russia, even in moments of strong geopolitical confrontation. This paradox highlights the ambivalent character of outer space: at the same time an arena of strategic confrontation and a laboratory of multilateral cooperation.

In this respect, an essential prerequisite could be constituted by widespread adherence to existing international legal instruments, both customary and treaty-based: universal ratification and full implementation of the OST and its related instruments would strengthen the existing normative architecture, promoting a common language among space actors.

Such adherence must then be accompanied by reinforced transparency practices, including prior notification of orbital maneuvers, regular exchange of information, and the adoption of shared Space Situational Awareness (SSA) systems, elements that decisively contribute to reducing tensions and preventing unintended incidents or escalation.

In parallel, the issue of the use of anti-satellite weapons, especially autonomous ones, must be decisively addressed: the prohibition of destructive tests and intentionally harmful activities in the orbital environment should constitute a shared principle. The elaboration of preventive measures for crisis management (such as the establishment of direct communication channels and multilateral consultation procedures) would further contribute to building mutual trust and stabilizing the strategic space context.

For these measures to be truly effective, a structural reform of the current legal regime is necessary, starting with a revision of the OST and providing mechanisms of normative adaptability capable of responding to rapid technological evolution, establishing permanent forums for monitoring, updating, and intergovernmental dialogue. Such reform should be articulated along three fundamental lines.

First, the introduction of a generalized obligation to conduct environmental impact assessments for ASAT missile launches in extra-jurisdictional areas, when there is a risk of significant harm to space, would constitute an important alignment with the consolidated principles of international environmental law, including due diligence, prevention, and responsibility. In the event of damage, the principle of "the polluter pays" should be applied, holding the State responsible for repair and mitigation costs (Völkerrechtsblog, 2021).

Second, the reuse or recycling of obsolete but still functional satellites should be encouraged, avoiding their destruction and promoting, through an international supervisory committee, a circular economy in space: this strategy, besides enhancing the existing orbital heritage, would reduce the risk of space saturation and the dreaded Kessler syndrome (Völkerrechtsblog, 2021).

Finally, operational standards on debris mitigation must be made binding, and the provisions of the 1972 Liability Convention clarified to facilitate attribution of fault. In this framework, the establishment of a Space Damage Compensation Fund, modeled on funds for hazardous terrestrial activities, would represent an important instrument of solidarity and cooperation among States, especially in cases where the origin of debris is not immediately identifiable (UN, 2017; Buana Rumiartha, 2022).

In parallel with normative instruments, concrete technological solutions must be promoted: initiatives already underway, such as those of the United Kingdom and the Russian Federation for the development of debris removal technologies, indicate a promising direction; the urgency of such interventions is dictated by the irreversible nature of many orbital damages: if not addressed promptly, debris risks definitively compromising access to space for future generations (Committee, 2017).

Conclusions

The interweaving between autonomous weapons and space technologies represents one of the deepest ruptures in the traditional architecture of international security. The idea that space could be not only a technical vector for terrestrial warfare but a potential autonomous theater of automated hostilities raises political, legal, and ethical questions that challenge existing conceptual structures. In particular, the coupling of artificial intelligence and low Earth orbits, such as ASAT technologies and their autonomous versions, outlines a scenario in which the deployment of force and responsibility tends to escape the classical logic of deterrence and human political control.

In light of what has emerged, the adoption of an integrated strategic perspective (that simultaneously considers the military, technological, and normative implications of autonomous warfare in space) is indispensable today.

In this context, it is no longer sufficient to invoke the "peaceful use of space" as a foundational principle: it is necessary to question at the international level the actual normative scope in light of current technologies that make extensive use of dual-use capabilities and potentially lethal systems without direct supervision. The ambiguous nature of many of these orbital experiments raises, in fact, profound issues of accountability, transparency, and legitimacy, especially when integrated into an ecosystem of algorithmic warfare.

The emergence of Autonomous anti-satellite weapons is not an anomaly but the predictable outcome of a fragile regulatory context, in which normative inertia has left room for military innovation. This imbalance between technological advancement and legal control not only undermines collective security but risks institutionalizing a competitive dynamic that is difficult to reverse.

Policy choices can no longer be limited to fragmented or reactive interventions: they require systemic vision and anticipatory capacity. In this sense, it is essential to promote multi-level governance that combines binding legal measures with shared technical standards, verifiable transparency regimes, and multilateral operational protocols. The construction of a liability regime for automated orbital operations, the inclusion of the space dimension in strategic arms control frameworks, and the codification of operational limits for lethal autonomy constitute medium-term priorities.

From this perspective, the lack of binding legal instruments and the fragmentation of multilateral consensus expose the international system to a silent but structural drift toward the normalization of force in space. It is no longer a matter of preventing a remote possibility, but of intervening in an ongoing process, accelerated by the race for operational autonomy and the multiplication of non-state and commercial actors in the space domain.

Finally, a more radical question imposes itself: what idea of security do we intend to project into space? Security based on dominance and algorithmic deterrence, or security built on the principle of shared vulnerability, transparency, and co-regulation? It is in this question, more than in immediate solutions, that the maturity of the international community is measured in the face of the new post-terrestrial condition of war, thus imposing a double responsibility: on the one hand, to relaunch a critical reflection on the content and limits of jus ad bellum and international humanitarian law applied to space and automation; on the other, to imagine new institutions, new legal languages, and new models of cooperation capable of addressing the growing complexity of the space environment.

Through the concertation of diplomacy, law, and innovation, it will be possible to prevent space from becoming a normatively vacant and strategically destabilized domain: the goal cannot be only to govern technology, but to orient it toward a political and institutional configuration compatible with peace, collective security, and the common interest of humanity. At present, the stakes are not only the orbital order but the very possibility of conceiving a space future that is not inevitably conflictual.

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